# A catalogue of 58 candidate stellar anomalies from Gaia and public time-domain surveys: long dimmings, microlensing-like brightenings, slow changes and possible dark companions

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**Abstract**

Most stars vary in brightness in ways that are well understood, but a few do something rare: they dim for weeks to years and recover, as Boyajian's star, $\epsilon$ Aurigae and stars eclipsed by dusty discs have done, or they brighten once, symmetrically, as a background star does when a foreground object passes in front of it and acts as a gravitational lens. Large public time-domain surveys now record the light of hundreds of millions of stars over many years, which makes systematic searches for such events possible. We present 58 candidates found by searching the third data release of the European Space Agency's Gaia mission (Gaia DR3), the light curves of the Zwicky Transient Facility (ZTF) and old photographic sky-survey plates, and by examining every candidate in other public data: ASAS-SN, Pan-STARRS1, SkyMapper, the Dark Energy Camera, TESS and WISE. Thirty-seven are stars that were steady for years, dimmed for weeks to about a year by between 4 and 70 per cent of their light and recovered; for most of them the likeliest cause is dust passing in front of the star. One star has been fading for a decade, one dipped for about twelve years, three brightened (one for five months, two over decades), and four brightened once as microlensing predicts, in Gaia data, without being in Gaia's published list of microlensing events. One is a star-like spot on two photographic plates of 1955 that no later image shows, and eleven are stars whose Gaia orbits imply unseen companions, of about 1.5 to 4.7 solar masses where the mass is constrained. We checked each against blends, crowding, instrumental and scanning-law artefacts, known variable stars and the literature. For each we give an estimated probability that it is a real, previously unrecorded case of the kind described; the estimates range from 1 to 60 per cent (median 30 per cent) and sum to about 16, and none has been reviewed by outside experts. One dimming, candidate 58, turned out to have been published already by Tzanidakis et al. (2025). We found no earlier report of the others, and none of the 58 has been confirmed by new observations; spectroscopy and new photometry would test them. For every candidate we give its identifiers, position, dates, a sky image with the star marked, its light curve, before-and-after survey images where they exist, and a plain account of the evidence.

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# 1 Introduction

Almost every star varies in brightness at some level. Pulsations, rotating starspots, eclipses by companion stars, flares, accretion and the irregular variability of young stars account for nearly all the variable stars that surveys find, and each leaves a recognisable signature in a light curve (Eyer et al. 2023; Rimoldini et al. 2023). Starspots change a quiet dwarf's light by a few per cent, cyclically and with a rotation period (Strassmeier 2009); young stars with dusty discs dim irregularly, often deeply, as clumps of their own disc pass across the line of sight (Herbst et al. 1994; Cody et al. 2014; Ansdell et al. 2016); and R Coronae Borealis stars fade by many magnitudes when they eject clouds of soot (Clayton 1996).

A small number of stars have done something rarer. KIC 8462852, Boyajian's star, an ordinary F-type main-sequence star, showed irregular, aperiodic dips of up to about 20 per cent lasting between 5 and 80 days in the Kepler data (Boyajian et al. 2016), as well as a slow fading (Montet and Simon 2016), and the wavelength dependence of its dimming points to circumstellar dust (Meng et al. 2017). The giant $\epsilon$ Aurigae is eclipsed every 27 years for nearly two years by an opaque disc around its companion, which interferometry has imaged (Kloppenborg et al. 2010), and EE Cephei shows shorter eclipses of the same kind (Mikołajewski and Graczyk 1999). The young star J1407 was occulted for weeks by what appears to be a giant ring system around a companion (Mamajek et al. 2012); EPIC 204376071 underwent a single, deep and asymmetric occultation (Rappaport et al. 2019); the Sun-like star ASASSN-21qj dimmed after an infrared brightening that has been attributed to the debris of a collision between planets (Kenworthy et al. 2023); and the giants VVV-WIT-08 and Gaia17bpp faded deeply for months and for years respectively (Smith et al. 2021; Tzanidakis et al. 2023). Such events probe dust, discs and debris that no other method detects. Most were found by chance or by eye, and only recently have they been sought systematically: Tzanidakis et al. (2025) searched the ZTF light curves of 63 million FGK main-sequence stars and found 81 new "dipper" candidates whose dimmings last from days to years.

A second kind of rare event is gravitational microlensing: when a foreground star or a dark object passes almost exactly in front of a distant star, its gravity focuses the distant star's light, which brightens and fades once, smoothly, symmetrically and by the same factor in every colour (Paczyński 1986). Microlensing is expected and is monitored intensively towards the Galactic bulge and plane by dedicated surveys such as OGLE (Udalski et al. 2015; Mróz et al. 2020), but elsewhere in the sky events are found mainly by all-sky surveys. Gaia DR3 contains a catalogue of 363 microlensing events found in its photometry, 90 of them new (Wyrzykowski et al. 2023). A third kind of search uses Gaia's astrometry: a star that wobbles on the sky with a large orbit but no visible companion may orbit a neutron star or a black hole. Gaia DR3 published about eight hundred thousand solutions for non-single stars (Gaia Collaboration et al. 2023a; Halbwachs et al. 2023; Holl et al. 2023b), and dormant black holes and candidate neutron stars have been found among them (El-Badry et al. 2023b; El-Badry et al. 2023a; El-Badry et al. 2024b; Shahaf et al. 2023), together with many more candidates that turned out to be spurious orbits or luminous companions (El-Badry et al. 2024a); a third dormant black hole, Gaia BH3, was found in pre-release Gaia DR4 astrometry (Gaia Collaboration et al. 2024). Finally, a few searches have looked for star-like sources on old photographic plates that are missing from modern surveys (Villarroel et al. 2020; Solano et al. 2022).

Large public time-domain surveys make all these searches possible. Gaia DR3 provides 34 months of multi-epoch photometry for 10.5 million variable sources together with positions, parallaxes, colours and stellar parameters for 1.8 billion (Gaia Collaboration et al. 2016; Gaia Collaboration et al. 2023b; Eyer et al. 2023); ZTF has imaged the northern sky every few nights since 2018 (Bellm et al. 2019; Graham et al. 2019; Masci et al. 2019); ASAS-SN has observed the whole sky nightly since 2017 (Shappee et al. 2014; Kochanek et al. 2017; Hart et al. 2023); and Pan-STARRS1, SkyMapper, the Dark Energy Camera surveys, TESS and WISE add earlier epochs, other colours and the infrared (Chambers et al. 2016; Onken et al. 2024; Dey et al. 2019; Ricker et al. 2015; Wright et al. 2010; Mainzer et al. 2014). Because these data are public and overlap in time, a dimming found in one survey can often be confirmed or rejected in another.

This paper presents 58 candidates found in such a search: stars that dimmed, faded or brightened in unusual ways, four microlensing-like brightenings, one vanished plate source and eleven possible dark companions. None of them, as far as the catalogues and literature we could search show, has been recorded before as such,

with one exception, candidate 58, which Tzanidakis et al. (2025) had already published. We describe the data (Section 2) and the method, including how false positives were rejected, how the candidates were checked against the record, the independent re-examination of the strongest dark-companion candidates and how the probabilities were estimated (Section 3). Section 4 summarises the candidates in a table and figures, and Section 5 gives an entry for each, with its figures, a plain account of what changed and why it may matter, the checks made and the caveats. Section 6 discusses the limitations and how the candidates could be confirmed. The candidates are numbered 1 to 58 as on the public pages (Section 7).

# 2 Data

Table 1 lists the surveys and archives used. All the data are public; the searches and checks were made in late October and early November 2026 with the releases available then.

## 2.1 Gaia DR3

Gaia scans the whole sky repeatedly with two telescopes; DR3 covers the 34 months from 2014 July 25 to 2017 May 28 (Gaia Collaboration et al. 2016; Gaia Collaboration et al. 2023b). The median source has 40 to 44 field-of-view transits in each photometric band (Rimoldini et al. 2023). We used the main source table (positions, parallaxes, proper motions, mean photometry and its quality indicators, such as the renormalised unit weight error RUWE, the image-parameter indicators and the BP/RP flux excess; Lindegren et al. 2021; Riello et al. 2021); the variability summary statistics and the machine-learning classification of variable sources (Eyer et al. 2023; Rimoldini et al. 2023); the epoch photometry in $G$, $G_{\rm BP}$ and $G_{\rm RP}$, which was published only for sources classified as variable and a few other samples (Eyer et al. 2023); the two-body orbits of the non-single-star catalogue (Gaia Collaboration et al. 2023a; Halbwachs et al. 2023; Holl et al. 2023b); the binary masses table; and the astrophysical parameters of the GSP-Phot and FLAME modules (Creevey et al. 2023; Andrae et al. 2023). Distances were also taken from Bailer-Jones et al. (2021) and the StarHorse catalogue (Anders et al. 2022). Queries went to the ESA Gaia archive by its table access protocol (TAP), and epoch photometry for large samples to the Gaia@AIP mirror of the same tables. Every candidate's Gaia DR3 `source_id` was checked against the archive for this paper: all 57 exist, and the positions on the public pages agree with the archive positions (ICRS, epoch J2016.0) to better than 0.03 arcsec (Section 4.5).

## 2.2 ZTF

ZTF images the northern sky from the Palomar 48-inch Schmidt telescope with a 47 deg$^2$ camera, in $g$ and $r$ every few nights and in $i$ less often (Bellm et al. 2019; Dekany et al. 2020). Its public data releases contain light curves built from point-spread-function photometry of each exposure, separately for each field, detector quadrant and filter; the 24th release covers public $g$ and $r$ data from 2018 March 17 to 2025 October 22 (Masci et al. 2019). A star in the overlap of two ZTF fields falls on different detectors in each, which gives two nearly independent light curves. ZTF's alert system compares each new image with a reference image and issues an alert for every significant change at a position, with a machine-learned real-or-bogus score (Patterson et al. 2019; Duev et al. 2019); we read the alerts, their image cutouts and their light curves through the ALeRCE broker, whose machine-learned classifications we did not count as records (Förster et al. 2021; Sánchez-Sáez et al. 2021). Single ZTF exposures and information on the reference images were taken from IRSA.

## 2.3 ASAS-SN

ASAS-SN observes the whole sky every night with 14-cm telescopes at several sites, in $V$ until 2018 and in $g$ since 2017, to about $g \approx 18.5$ (Shappee et al. 2014; Kochanek et al. 2017). Its Sky Patrol v2 serves continuously updated light curves for about 111 million catalogued stars (Hart et al. 2023). ASAS-SN shares no equipment with ZTF and was the main independent check of the ZTF dimmings. Its light curves combine

**Table 1:** Data used in this study. Time spans are those of the data used here.

| Survey or archive | Bands | Time span | Use |
|---|---|---|---|
| Gaia DR3 (Gaia Collaboration et al. 2023b) | $G$, $G_{\rm BP}$, $G_{\rm RP}$ | 2014 Jul 25 – 2017 May 28 | source catalogue, variability summaries and classes, epoch photometry, non-single-star orbits, astrophysical parameters; ESA archive and Gaia@AIP mirror |
| ZTF (Bellm et al. 2019; Masci et al. 2019) | $g$, $r$, $i$ | 2018 Mar – 2025 Oct (light curves); alerts to 2026 | public light curves (IRSA), alerts and cutouts (ALeRCE), reference images and single exposures (IRSA) |
| ASAS-SN Sky Patrol v2 (Hart et al. 2023) | $V$, $g$ | 2012 – 2025 | light curves of candidates and comparison stars |
| Pan-STARRS1 (Chambers et al. 2016; Flewelling et al. 2020) | $grizy$ | 2009 – 2014 | single-exposure photometry, colour images (MAST) |
| DECam, Legacy Surveys, DECaPS2 (Flaugher et al. 2015; Dey et al. 2019; Saydjari et al. 2023) | $grizY$ | 2012 – 2019 | single-epoch images and photometry (NOIRLab Astro Data Archive), colour images |
| SkyMapper DR4 (Onken et al. 2024) | $uvgriz$ | 2014 – 2021 | per-image photometry (southern sky) |
| TESS (Ricker et al. 2015) | 600–1000 nm | 2018 – 2026 | full-frame images and light curves (MAST) |
| WISE, NEOWISE, unTimely, CatWISE2020 (Wright et al. 2010; Mainzer et al. 2014; Meisner et al. 2023; Marocco et al. 2021) | 3.4, 4.6 µm | 2010 – 2024 | single-exposure and coadded photometry (IRSA) |
| 2MASS, GALEX, IPHAS DR2 (Skrutskie et al. 2006; Martin et al. 2005; Barentsen et al. 2014) | $JHK_s$, FUV/NUV, H$\alpha$ | 1997 – 2013 | infrared excess, ultraviolet activity, H$\alpha$ emission |
| Digitized Sky Survey, USNO-B1.0 (Reid et al. 1991; Monet et al. 2003) | photographic | 1951 – 1999 | plate images and plate photometry |
| PTF, SDSS, LAMOST (Law et al. 2009; York et al. 2000; Cui et al. 2012) | optical | 2002 – 2014 | earlier photometry and archival spectra for a few candidates |
| Catalogues | – | to 2026 | SIMBAD, VSX, VizieR, Gaia alerts, TNS, literature (Section 3.7) |

several cameras, which can differ slightly in zero point, so changes were measured per camera and against comparison stars of similar brightness.

## 2.4 Other surveys

Pan-STARRS1 provides single exposures and stacks in $grizy$ from 2009 to 2014, the main record of the years before Gaia and ZTF (Chambers et al. 2016; Flewelling et al. 2020). Archived images from the Dark Energy Camera (DECam) on the Blanco telescope (Flaugher et al. 2015) were measured directly for candidates 1 and 3; the colour images of the DESI Legacy Imaging Surveys (Dey et al. 2019) and of the DECam Plane Survey DECaPS2 (Saydjari et al. 2023) were used for finder charts. SkyMapper DR4 (Onken et al. 2024;

Australian National University 2023) covers the southern sky from 2014 to 2021. TESS (Ricker et al. 2015) gives continuous photometry over 27-day sectors, used to test whether a star rotates and is spotted and, for candidates 25 and 32, to follow part of a dimming; light curves were measured from the full-frame images or taken from the TESS-SPOC, QLP and TGLC products (Caldwell et al. 2020b; Huang et al. 2020a; Huang et al. 2020b; Han and Brandt 2023b). WISE and NEOWISE observed the sky at 3.4 and 4.6 µm about every six months from 2010 to 2024 (Wright et al. 2010; Mainzer et al. 2011; Mainzer et al. 2014); we used their single exposures, the unTimely coadds of each visit (Meisner et al. 2023) and CatWISE2020 (Marocco et al. 2021). Infrared excess was tested with 2MASS (Skrutskie et al. 2006) and WISE (for candidate 1 also with the VISTA Hemisphere Survey, McMahon et al. 2013), ultraviolet activity with GALEX (Martin et al. 2005; Bianchi et al. 2017), and H$\alpha$ emission with IPHAS DR2 (Barentsen et al. 2014) and Gaia's low-resolution spectra. X-ray counterparts were sought in the 4XMM, 2SXPS and eRASS1 catalogues (Webb et al. 2020; Evans et al. 2020; Merloni et al. 2024) (Section 3.7), and for candidate 5 an XMM-Newton image of 2017 gave an upper limit. Photographic plates of the first and second Palomar Sky Surveys and the UK Schmidt surveys were used through the Digitized Sky Survey and the USNO-B1.0 catalogue (Reid et al. 1991; Monet et al. 2003). For a few candidates, earlier photometry came from the Palomar Transient Factory (Law et al. 2009) and SDSS (York et al. 2000), and archival spectra were sought in LAMOST (Cui et al. 2012) and SDSS (Abdurro'uf et al. 2022). Interstellar extinction was taken from the dust maps of Schlegel et al. (1998) and Schlafly and Finkbeiner (2011).

# 3 Methods

## 3.1 Overview

The search had four strands (Figure 1): a selection of Gaia DR3 light curves that dimmed or brightened for longer than Gaia's sampling interval, together with Gaia light curves showing smooth long-term trends; a search of ZTF light curves for stars that were steady for years and then dimmed for months; a screening of all Gaia DR3 orbits for companions too heavy to be ordinary stars of the observed brightness; and a pilot search for star-like sources on old photographic plates that are missing from modern surveys. Every candidate from these strands was then examined in the other public data that cover it, tested against the common look-alikes, checked against the published record and given an estimated probability. We describe each stage below as far as the records of the search allow; where those records give only a summary, we give only a summary.

## 3.2 Gaia light curves

**Selection.** The Gaia DR3 variability summary gives, for every source with epoch photometry, moments of its $G$ light curve: the number of accepted transits, the median, minimum and maximum magnitude, the skewness and the Abbe value $\mathcal{A}$, which is half the von Neumann ratio of the mean square successive difference to the variance (von Neumann 1941). A light curve that spends most of its time at one level and occasionally becomes fainter has a positive skewness of its magnitudes, and if those faint stretches last longer than the spacing of the measurements, successive points are correlated and $\mathcal{A}$ is small. We therefore selected, with at least 20 accepted $G$ transits, "dimmers" with skewness $> 1$, $\mathcal{A} < 0.6$ and a faintest point at least 0.25 mag below the median, and "brighteners" with skewness $< -1$, $\mathcal{A} < 0.6$ and a brightest point at least 0.3 mag above the median. Split into 60 ranges of `source_id` so that each query stayed within the archive's time limit, the selection returned 128,650 dimmers and 94,258 brighteners, joined with their source parameters and their Gaia variability class.

Most of these belong to classes whose behaviour is understood. Sources classified as active galactic nuclei, long-period variables or eclipsing binaries were removed, except for "AGN" with a parallax measured to better than five standard deviations (that is, probably stars), "long-period variables" bluer than $G_{\mathrm{BP}} - G_{\mathrm{RP}} = 1.8$ (bluer than typical long-period variables) and, among the dimmers, "eclipsing binaries" with $\mathcal{A} < 0.25$, whose faint stretches last too long for ordinary eclipses. This kept 8,060 dimmers, most of them classified as solar-like or other low-amplitude variables (3,995), young stellar objects (1,520) or RS CVn-type stars (885),

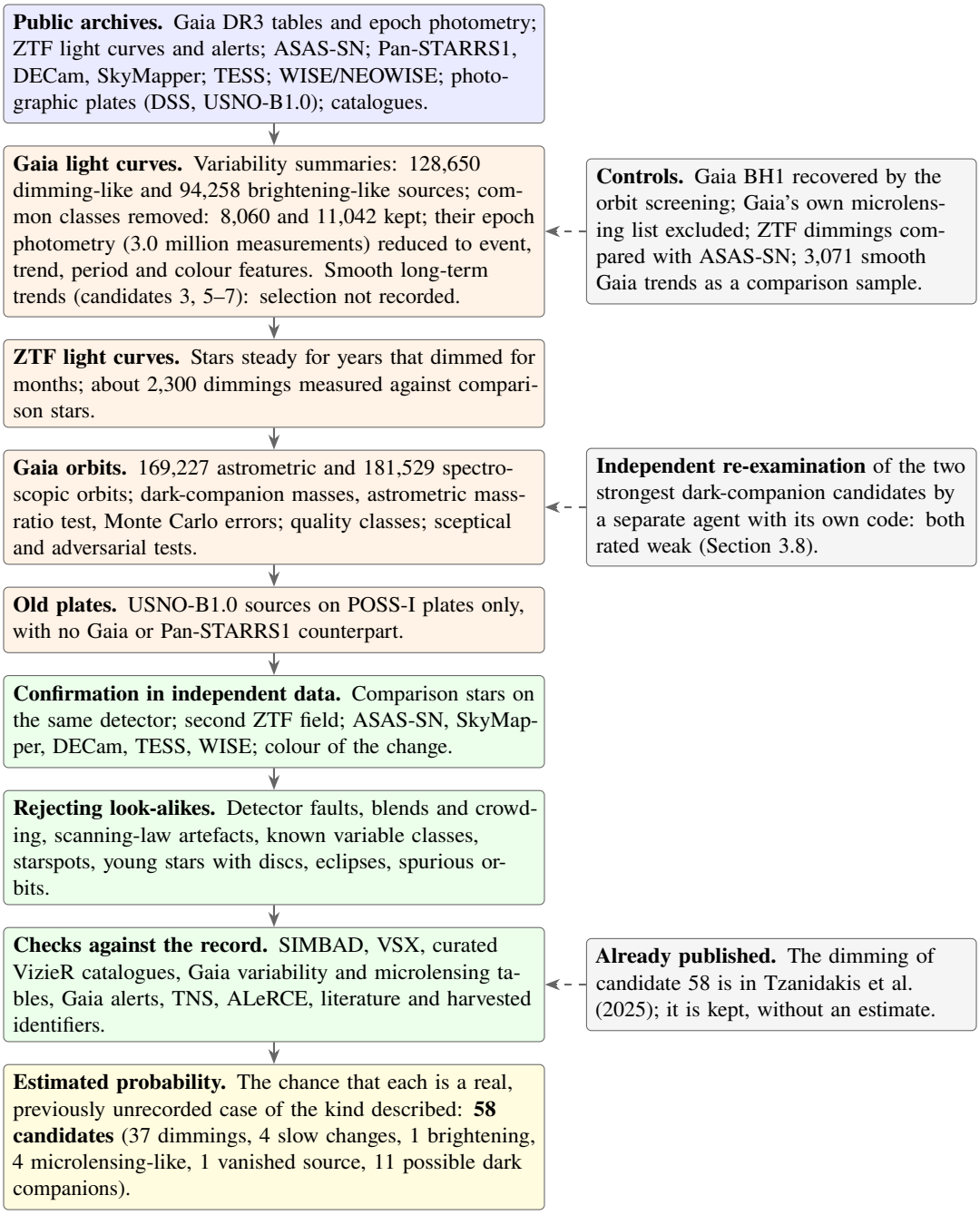



**Figure 1:** The method, from the public archives to the catalogue. Numbers are those of the search reported here. The four search strands are shown in orange; the side boxes give the controls, the independent re-examination (Section 3.8) and the one candidate found to be published already.

and 11,042 brighteners, among them 213 with the classifier label "microlensing". Their epoch photometry, 1,392,012 and 1,642,071 measurements in the three bands, was downloaded from the Gaia@AIP mirror.

**Light-curve features.** For each light curve the $G$ measurements were reduced to a set of features. For dimmers the baseline is the median of the brightest 60 per cent of the points and the noise the larger of their normalised median absolute deviation, the median photometric error and 0.003 mag; points fainter than the baseline by more than five times the noise, and by at least 0.05 mag, are flagged, and flagged points less than 20 days apart are grouped into events, each with its start, end, number of points and depth. Brighteners are treated in the same way with the faintest 60 per cent as the baseline. The features also include the fraction of flagged points that Gaia's own processing had rejected and the fraction of all points that it had marked as

noisy; the skewness and the von Neumann ratio $\eta$; the long-term trend, as the difference between the medians of the last and first thirds of the light curve and as a linear slope; the strongest period of a Lomb–Scargle periodogram between 0.05 and 1000 days (Lomb 1976; Scargle 1982) together with the phase coherence of the flagged points at that period, which identifies periodic dips such as eclipses; and the colour of the change, from $G_{\mathrm{BP}}$ and $G_{\mathrm{RP}}$ measurements matched to the same transits, as the slope of $G_{\mathrm{BP}} - G_{\mathrm{RP}}$ against $G$ and as the ratios of the $G_{\mathrm{BP}}$ and $G_{\mathrm{RP}}$ depths to the $G$ depth during an event. The candidates of this strand were chosen from light curves with long single events, smooth trends or large one-off brightenings, which were examined individually. The records keep the features and the light curves examined, but not a fixed formula by which they were ranked, so we do not give one.

**Candidates from this strand.** Candidates 1 and 2 are dimming events in Gaia's own photometry; both meet the dimmer selection above. The four microlensing-like candidates, 9 to 12, meet the brightener selection; they are brightenings that Gaia's classifier labelled "microlensing" but that are not among the 363 events of the Gaia DR3 microlensing catalogue (Wyrzykowski et al. 2023); for each, the shape was compared with the light curve of a point lens (Paczyński 1986) and the brightening was sought in SkyMapper, WISE and other data taken at the same time. Candidates 3, 5, 6 and 7 have smooth long-term trends in Gaia. None of them meets the selection above: candidate 3 fails the depth cut (its faintest point is 0.17 mag below its median), and candidates 5, 6 and 7 have a skewness in $G$ of only 0.95, 0.59 and 0.33 and also fail the depth cuts. The records do not describe how these four light curves were selected; the only sample of smooth Gaia trends they describe is the comparison sample of 3,071 stars measured later (Section 3.9). For them the behaviour before and after Gaia was reconstructed from Pan-STARRS1, ZTF, PTF, SDSS, DECam, SkyMapper, WISE and, for 5 and 7, photographic plates back to the 1950s, each measured against field stars of the same colour.

## 3.3 ZTF light curves

Thirty-five candidates (24 to 58) and the brightening of candidate 4 were found in ZTF light curves, of stars that were steady for years and then dimmed (or, for candidate 4, brightened) for weeks to months. The search measured about 2,300 such dimmings, but its records describe the initial selection of these stars only in outline, so we describe instead the measurements and checks that every candidate passed, which are recorded in detail on its public page and in its catalogue entry. The change was measured in each ZTF field, filter and detector separately, as the median offset from the star's normal level over the months of the event, and compared with the offsets over the same months of stars of similar colour and brightness on the same detector (typically dozens to hundreds of them). A dimming was accepted only if it was also seen on a second ZTF detector (where the star lies in the overlap of two fields) or by a second instrument (usually ASAS-SN, sometimes SkyMapper, TESS or DECam), and if ZTF's alerts, from difference images and independent of the light-curve photometry, recorded it with good real-or-bogus scores and positions centred on the star. The image cutouts of those alerts, a reference image made before the event, an image taken during it and their difference, are the "before and during" figures of most of these candidates. For candidates 52, 54 and 58 the second confirmation is weak or missing; they are kept and say so.

## 3.4 Gaia orbits

**Data and masses.** All 169,227 astrometric two-body orbits of Gaia DR3 (of the solution types Orbital, AstroSpectroSB1, OrbitalTargetedSearch and OrbitalAlternative, with their validated variants) and all 181,529 single-lined spectroscopic orbits (types SB1 and SB1C) were joined with the source table, the astrophysical parameters and the binary masses table. The mass of the visible star, $M_1$, was taken from the binary masses table where available, otherwise from FLAME and otherwise, for parallaxes better than five standard deviations, from the absolute magnitude through the main-sequence relation of Pecaut and Mamajek (2013). For astrometric orbits the photocentre semi-major axis $a_0$ follows from the Thiele–Innes elements, and with the parallax and period it gives the astrometric mass function; the mass $M_2$ a companion would need if it gave off no light then follows from $M_1$. The astrometric mass-ratio function (AMRF) of Shahaf et al. (2019) was

compared with the largest values that a single main-sequence companion or a close pair of main-sequence stars could give. For spectroscopic orbits the minimum companion mass follows from the mass function. Orbits passing a loose cut (for astrometric orbits a dark companion above one solar mass or an AMRF above the triple-system limit; for spectroscopic orbits a minimum companion mass above one solar mass or above $M_1$) were given uncertainties by drawing 4,000 samples: for astrometric orbits from the full covariance of each solution, reconstructed with the DPAC tool `nsstools`, and for spectroscopic orbits from the errors of the period, semi-amplitude and eccentricity, taken as independent. This gave 13,618 astrometric and 26,400 spectroscopic orbits.

**Selection.** After quality cuts (for astrometric orbits a parallax better than ten standard deviations, significance above 10, goodness of fit below 5, period below 1,500 days and almost no negative parallax samples; for spectroscopic orbits a semi-amplitude above 15 times its error, at least 15 good radial velocities, significance above 20, goodness of fit below 5 and period below 1,500 days), the selection classes were: astrometric neutron-star or black-hole companions (probability above 0.9 that the AMRF exceeds the triple-system limit computed for a main-sequence primary and above 0.5 that $M_2 > 1.4$ solar masses; 769 orbits, 620 of them not in lists of known objects), astrometric black-hole companions (probability above 0.5 that $M_2 > 3$; 176, of them 167 not known) and evolved primaries with heavier dark companions (36, 35 not known), and the corresponding spectroscopic classes (151, 401 and 5 orbits). The lists of known objects were 15,217 Gaia identifiers harvested from the sources of 65 recent papers on compact companions and the catalogues of Shahaf et al. (2023) and Gomel et al. (2023).

**Sceptical tests.** Each selected orbit was then tested for the known causes of spurious or misleading solutions: a position more than 1.25 mag above the dwarf sequence in the colour–magnitude diagram, a low surface gravity or an evolved FLAME stage (evolved or blended primaries); a BP/RP flux excess more than three standard deviations from normal, multiple-peak or asymmetric images, or a duplicated source (blends and close pairs); fewer than 12 visibility periods; a period longer than 1,000 days, within about a year, or near Gaia's 63-day precession period (scanning-law aliases; Holl et al. 2023a); an eccentricity above 0.8 or a poor fit; a spectral energy distribution classified as that of a binary; for astrometric orbits a significance below 10, a large flux ratio, an inconclusive mass posterior, a RUWE too small for the orbit, an unphysical companion mass above 30 solar masses, a near-circular orbit with a large mass (a known pattern of spurious solutions), or a RUWE above 15; and for spectroscopic orbits a temperature above 7,000 K, a poorly measured semi-amplitude, or a radial-velocity scatter inconsistent with the orbit. As a calibration, the black hole Gaia BH1 (El-Badry et al. 2023b) passes these tests, while Gaia BH2, whose primary is a giant (El-Badry et al. 2023a), is removed, a known loss of such systems. A second, adversarial script, written separately to reject candidates, recomputed $M_2$ with $M_1$ changed by ±30 per cent, applied the significance threshold of Halbwachs et al. (2023), compared $a_0$ with the wobble implied by RUWE and the predicted radial-velocity swing with Gaia's measured scatter, and looked for period aliases, bright neighbours within 5 arcsec, blended photometry, variability and extinction. It was written by the same agent as the selection, so it was not independent (Section 3.8). The shortlist that came out of these tests holds nine orbits not in the lists of known objects: three that passed every sceptical test (candidates 13, 21 and 22) and six that failed exactly one, a period longer than 1,000 days (17 and 18) or a position more than 1.25 but less than 2.5 mag above the dwarf sequence (16, 19, 20 and 23). The adversarial script then raised an objection to six of the nine: for 16 to 20 the companion falls below 1.4 solar masses if the visible star is 30 per cent lighter, and 22 fails the significance threshold of Halbwachs et al. (2023). Candidates 14 and 15 are giants whose orbits imply companions heavier than the giants themselves; they belong to the class of evolved primaries with heavier dark companions, fail the tests for evolved primaries and for periods longer than 1,000 days, and the records do not say how these two were chosen from that class.

## 3.5 Old photographic plates

The pilot search for vanishing sources followed the logic of Villarroel et al. (2020) in 16 random fields of 0.5 degree radius at Galactic latitudes above 30°: USNO-B1.0 sources detected on both the blue and the red

POSS-I plates and on no later plate; not in the 1.5-arcsec cross-match between USNO-B1.0 and Gaia DR3; with no Gaia source within 5 arcsec at either epoch after allowing for proper motion; consistent positions on the two plates; more than 90 arcsec from any star brighter than $G = 12$; not in groups of three or more such sources within 30 arcsec, as emulsion flaws often are; and with no Pan-STARRS1 detection within 5 arcsec. The pilot found 32 to 210 POSS-I-only sources per field and none that was shown to pass every cut, although the Pan-STARRS1 query failed for 29 of the sources that had passed the other cuts, and these were not tested further. Candidate 8 comes from a wider search of the same kind, whose records give only its summary: 21 sources were found on a POSS-I red plate and nowhere later, and candidate 8 is the one that also appears on the blue plate of the same night. The published list of vanishing sources of Solano et al. (2022) could not be retrieved for comparison.

## 3.6 Rejecting look-alikes

Almost every apparent dimming or brightening in survey data is something other than a new astrophysical event. Each candidate was tested against the following explanations, and kept only if none of them fits as well:

- **Calibration drifts and detector faults.** Comparison stars of similar colour and brightness on the same detector must stay steady, and a second detector or instrument must see the change. The search met exactly this false positive: one star's "dimming" was a fault on a single ZTF detector, although its comparison stars stayed flat and ZTF issued alerts; two other ZTF fields and ASAS-SN saw it steady on the same nights, its alerts had doubtful real-or-bogus scores and its difference image showed a red-and-blue smear rather than a clean dark spot. In a comparison of about 160 ZTF dimmings with ASAS-SN, every one of the 10 uncatalogued dimmings with good alerts that ASAS-SN could measure was seen by ASAS-SN too, and those ASAS-SN found flat had missing or doubtful alerts.
- **Blends and crowding.** Neighbours within a few arcseconds were listed from Gaia; alert positions must be centred on the star; Gaia's image-parameter and flux-excess indicators must be normal; and surveys with large pixels (ASAS-SN, TESS, WISE) were used only where a neighbour cannot dominate, as each entry states.
- **Scanning-law and processing artefacts in Gaia.** Gaia's own rejection and noise flags, agreement between its two telescopes and between transits taken hours apart, the behaviour of nearby sources on the same dates and the mean photometry of the earlier Gaia DR2 were checked; for orbits, periods near the precession period, one year and their harmonics were treated as suspect (Holl et al. 2023a).
- **Known kinds of variable star.** Common classes were removed at the start (Section 3.2), and every candidate was cross-matched with the variable-star catalogues (Section 3.7).
- **Starspots.** Spotted stars dim by similar amounts in blue and red light and rotate. The ratio of the change in $g$ to that in $r$ was compared with about 1.0 for an opaque body, 1.1 to 1.3 for spots and 1.40 for ordinary interstellar dust, for which the ratio of the change in $i$ to that in $r$ is 0.74 (the Pan-STARRS1 extinction coefficients of Schlafly and Finkbeiner 2011); a steeper ratio points to finer dust or to a hotter source of light that faded. WISE measurements at 3.4 µm during an event distinguish the cases further: an opaque body dims the infrared as much as visible light, spots about half as much and dust very little. Rotation was sought in each ZTF season and in TESS, and ultraviolet activity in GALEX.
- **Young stars with dusty discs.** Infrared excess in 2MASS, WISE and CatWISE, H$\alpha$ emission, membership of young clusters and groups (Hunt and Reffert 2023; Zari et al. 2018; Kounkel and Covey 2019), young-star catalogues (Marton et al. 2019), position relative to star-forming regions and height above the Galactic plane were checked.
- **Eclipses and pulsations.** Eclipses by stars are symmetric and repeat; pulsating giants are recognised by their colours, spectra and periods.

## 3.7 Checks against the record

A candidate counts as previously unrecorded if its event or system is not described as such in the literature or in any of the curated catalogues and alert streams searched. Gaia DR3's machine-generated tables list all 21 stars found in Gaia data, as variables, as orbits or with the label "microlensing", and ALeRCE gives machine-learned labels to the ZTF stars; such machine-generated entries were not counted as records. If they are counted, candidates 9 to 12 are the first independent confirmations of events that Gaia's classifier flagged, not new events. The checks were made by position and by identifier in SIMBAD (through its mirror at the Center for Astrophysics, because the Strasbourg site could not be reached; Wenger et al. 2000); in VSX, within 30 arcsec (Watson et al. 2006); in a curated list of VizieR catalogues within 5 arcsec (through the IDIA mirror; Ochsenbein et al. 2000): VSX, the GCVS (Samus' et al. 2017), the cross-match of Gaia DR3 with known variables (Gavras et al. 2023), the Gaia DR3 classification (Rimoldini et al. 2023) and microlensing catalogue (Wyrzykowski et al. 2023), the ZTF and Catalina periodic variables (Chen et al. 2020; Drake et al. 2014), the ATLAS variable stars (Heinze et al. 2018), SB9 (Pourbaix et al. 2004), the Washington Double Star catalogue (Mason et al. 2001), the 4XMM, 2SXPS and eRASS1 X-ray catalogues (Webb et al. 2020; Evans et al. 2020; Merloni et al. 2024), GALEX GUVcat (Bianchi et al. 2017), LAMOST and APOGEE DR17 (Abdurro'uf et al. 2022); in the index of about 27,000 Gaia Science Alerts from 2014 to 2025, within 3 arcsec (Hodgkin et al. 2021); in the Transient Name Server; in ZTF's alert archive; in the 81 dipper stars of Tzanidakis et al. (2025); and in the literature, by searching arXiv for each star's identifiers. For the dark-companion candidates, Gaia identifiers were also harvested from the source files of 65 recent papers. These searches are limited (Section 6): ADS full texts were not searched, and some catalogues could not be retrieved.

## 3.8 Independent re-examination

The two strongest dark-companion candidates, then rated promising (candidates 13 and 21), were re-examined independently by a separate agent, working in its own workspace with its own environment and scripts, which was instructed to act as a hostile referee and not to reuse the earlier code or conclusions. It re-read the Gaia DR3 data from the archive and found them consistent with the earlier values; propagated the full covariance of each orbit by Monte Carlo with 200,000 draws; applied the acceptance filters of Halbwachs et al. (2023) and the significance criterion of Holl et al. (2023b); re-estimated the mass of the visible star from its colour, absolute magnitude, metallicity and motion; tested whether luminous companions, including triples and quadruples of main-sequence stars, could produce the observed photocentre orbit; and searched SIMBAD, LAMOST, APOGEE, SDSS, Pan-STARRS1 and the web for spectra or prior records (its GALEX and VizieR queries failed). It found that candidate 13's solution, an alternative-pipeline orbit, fails the parallax-significance filter and has no radial velocities, and that its primary is probably a metal-poor star of 0.75 to 0.85 solar masses, which lowers the companion mass to about 1.5 (1.35 to 1.72) solar masses, so that a massive white dwarf is as possible as a neutron star; and that candidate 21's orbit has an efficiency of zero, Thiele–Innes elements each measured to only about two standard deviations and a significance of about 8 under non-linear error propagation instead of the catalogue's 36, the profile of a spurious solution. Both were downgraded to weak, candidate 13 being judged the only one of the two worth a radial-velocity check, and their probabilities (about 10 and 1 per cent) reflect that. No comparable independent re-examination is recorded for the other candidates. Their checks were the sceptical tests of Sections 3.6 and 3.7, made by the search itself, and their probabilities have not been reviewed by outside experts.

## 3.9 Probabilities

Each candidate was given an estimated probability that it is a real, previously unrecorded astrophysical event (for candidates 13 to 23, a system) of the kind described, and not an artefact, a blend or an object already known. The estimates are judgements that weigh the evidence of each case: how many independent instruments recorded the change, how well the comparison stars and the colour exclude instrumental and stellar explanations, whether the star shows signs of youth, activity or a companion, and whether a spectrum exists. They are meant to be calibrated in the sense that of all candidates given about 50 per cent, roughly half

should survive an independent expert check, but no such check has yet been made. For the microlensing-like candidates the estimate measures only whether each is a real, new lensing event, since microlensing itself is expected; for the dark-companion candidates it is low because spurious orbits, luminous companions and wrong primary masses are known to be far more common than dark companions (El-Badry et al. 2024a; El-Badry et al. 2024b).

Some estimates were lowered, or kept low, as evidence accumulated. Candidate 5's estimate, about 30 per cent, is held down mainly by the star's fast rotation, found in ZTF, which shows that it is magnetically active, and by a comparison sample: the same change between Pan-STARRS1 (2009–2014) and ZTF (2018–2025) was measured for 3,071 stars with smooth Gaia trends, 1,186 of them main-sequence dwarfs. Eighteen of the dwarfs changed by 0.45 mag or more; of the 17 whose light curves allow a rotation test, 13 rotate fast, and 6 of the 18 have a Gaia rotation period, against 16 per cent of all the dwarfs, so large slow changes seem to favour active, spotted stars (chance would produce this excess about once in 17 trials; with so few stars it is not proof). Among about 2,500 stars of the sample that Gaia flags as spotted or active, about 1 per cent changed by half a magnitude or more; candidate 5's change in green light (0.64 mag) exceeds that of any of the 290 Gaia rotators, and candidate 7's is the third largest. This is why candidates 3, 5, 6 and 7 have modest estimates. Candidate 43 was lowered from 35 to 30 per cent after a closer measurement of the uncertainty of its colour. The probabilities used throughout this paper are those of the public pages (Section 7).

## 3.10 Figures

The catalogue reproduces the published figures of each candidate. *Finder charts* show a patch of sky two arcminutes across, about a fifteenth of the Moon's width, from Pan-STARRS1, the Legacy Surveys or DECaPS2 (or, where no modern image covers the position well, a Digitized Sky Survey plate), with north up and east to the left; the star sits between two yellow ticks and the white bar is 30 arcsec long. On *light curves* the vertical axis is magnitude, drawn so that down means fainter, and each survey is compared with its own normal level, because the surveys use slightly different filters; purple (or orange) shading marks the event, and dates such as 2016.22 are decimal years. The *before-and-during* images of the ZTF dimmings show ZTF's reference image, an image taken during the event and their difference, in which only what changed remains (blue means fainter and red brighter); for candidate 24, whose deepest images have no stored cutouts, they are single 30-second exposures before, during and after the dimming beside a steady comparison star. *TESS* figures show the star in black at the bottom of each 27-day sector and comparison stars, each divided by the others, above it. The *orbit* figures of candidates 15 to 23 show the orbit Gaia fitted, the mass the companion would need for each assumed mass of the visible star, and the star's place in Gaia's colour–magnitude diagram. The bold title line of each finder chart and light curve gives the candidate's number and probability. The ZTF image figures of candidates 24, 25, 27, 33, 34, 36, 41, 44, 45 and 46 and the TESS figure of candidate 25 carried an earlier display number in their title line on the public pages; that number has been corrected here, and nothing else in the figures has been changed. For the printed version the published JPEG images were re-encoded at a lower quality and the largest finder charts and image strips slightly reduced, about 200 to 300 pixels per inch as printed.

**Figures made for this paper.** No light curve had been published for candidate 8 or for the seven companion candidates 15, 16, 17, 19, 20, 22 and 23, which lie too far south or are too bright for Pan-STARRS1 and ZTF. Their light curves were made for this paper from the original public data: for candidates 15, 16, 17, 19 and 22, ASAS-SN Sky Patrol v2 light curves of the star and of 11 or 12 comparison stars within 0.3° and 0.5 mag of it, each measured as the change from its camera's median; for 15, 16, 17, 22 and 23, SkyMapper DR4 per-image photometry without flags for saturation or truncation; for candidates 15, 16 and 17, NEOWISE single exposures averaged per visit, keeping unblended detections without artefact flags from frames not scored as poor and taken away from the South Atlantic Anomaly and the Moon (the infrared archive was unavailable when the data of the other four were sought); and TESS full-frame-image light curves (TESS-SPOC, QLP or TGLC) for candidates 19, 20, 22 and 23, which were found through the MAST interface of `astroquery` (Ginsburg et al. 2019). The ASAS-SN and SkyMapper data were matched to the Gaia DR3 position to within

0.2 arcsec. Candidate 20, at $G = 9.8$, saturates ASAS-SN and SkyMapper, so its light curve is from TESS alone, and no ASAS-SN light curve was obtained for candidate 23. For candidate 8 a brightness history was made from the 1955 plate photometry and the depths of the later surveys that imaged the position.

# 4 Results

## 4.1 Overview

Table 2 lists all 58 candidates with their Gaia DR3 identifiers, positions, magnitudes, types, events and estimated probabilities. Figure 2 shows how they divide by type: 37 dimming episodes of weeks to about a year (candidates 1, 2 and 24 to 58), one decade-long fading (3), one dip lasting about twelve years (6), one five-month brightening (4), two brightenings over decades (5 and 7), four microlensing-like brightenings (9 to 12), one vanished plate source (8) and eleven possible dark companions (13 to 23). The public pages group them as unexplained changes in brightness (candidates 1 to 8), possible new microlensing events (9 to 12), possible hidden companions (13 to 23) and stars that dimmed for months (24 to 58). The candidates range from $G = 9.8$ to 19.4.

**Table 2:** All 58 candidates. Positions are Gaia DR3 positions (ICRS, epoch J2016.0) in degrees, from the public pages and checked against the Gaia DR3 archive; *G* is the Gaia DR3 mean magnitude. *P* is the estimated probability, from the public pages, that the candidate is a real, previously unrecorded case of the kind described (for candidates 13–23, a system rather than an event); candidate 58 is already published (Tzanidakis et al. 2025) and has no estimate. The event column summarises the public pages: depths are changes in magnitude or in the fraction of the light, in the band given. Candidate numbers link to the catalogue entries.

| No. | Gaia DR3 source_id | RA | Dec | *G* | Type | Event: dates, timescale and depth | *P* |
|---|---|---|---|---|---|---|---|
| 1 | 6521694778536448640 | 357.49427 | -51.92332 | 19.36 | Dimming | faded by up to 0.5 mag in G (38 per cent) for about a year from 2016 Nov; brief 0.1 mag dip in 2018 Nov | 60% |
| 2 | 2212797391765189760 | 339.75244 | +66.91673 | 19.24 | Dimming | 0.33 mag fainter in G (26 per cent) from 2015 May to mid-Oct, after a two-month fade; normal again within 40 days | 35% |
| 3 | 4296242940002232704 | 291.36673 | +8.34015 | 15.53 | Slow fading | steady 2009–2013; fading since 2014, by 0.3–0.4 mag (25–30 per cent) by 2025 and still fading | 35% |
| 4 | 2196222627638729984 | 318.89815 | +63.08011 | 16.38 | Brightening | 0.19 mag brighter in g (about 19 per cent) from 2022 Jun to Nov, with a 1.24-day cycle while bright | 35% |
| 5 | 381248613189061632 | 9.67009 | +41.53879 | 17.30 | Slow brightening | steady 1983–2002; 0.6–0.7 mag brighter in g (60–90 per cent) over 2010–2020 | 30% |
| 6 | 4096419827121636736 | 275.11834 | -18.01907 | 16.56 | Dip (years) | faded by about 0.2 mag from 2010 to 2014, then brightened by about 0.5 mag until 2022 | 25% |
| 7 | 6908199778856910464 | 309.76240 | -5.83758 | 16.71 | Slow brightening | 0.5–0.9 mag fainter in blue-green light on every plate from 1951 to 1994 than today; still brightening | 15% |
| 8 | USNO-B1 1345-0235496 | 183.19213 | +44.57734 | – | Vanishing source | on both POSS-I plates of 1955 Feb 28 (red 18.1, blue 21.2 mag); in no later image | 3% |
| 9 | 4145977633638478336 | 272.16646 | -15.31958 | 16.04 | Microlensing-like | brightened once, by up to 0.46 mag (about 60 per cent), for about two months in early 2016 | 60% |
| 10 | 5620272814897694848 | 112.12679 | -20.68682 | 17.10 | Microlensing-like | brightened once, by 0.6 mag (70 per cent), peaking near 2015.15; normal by late 2015 | 55% |
| 11 | 4119926316171065984 | 266.73508 | -19.15256 | 17.58 | Microlensing-like | brightened once, by at least 0.83 mag (2.1 times), peaking near 2015.15 | 50% |
| 12 | 1861208444041823360 | 304.60954 | +29.40616 | 19.37 | Microlensing-like | brightened once, by 1.5 mag (four-fold), for a few weeks in 2016 (2016.16–2016.42) | 45% |
| 13 | 1121443762310292096 | 129.77669 | +70.16274 | 15.54 | Dark companion? | Gaia orbit, P = 530 d; unseen companion of about 1.5 solar masses (1.35–1.72) | 10% |
| 14 | 2018177545831527808 | 293.89075 | +20.85997 | 13.38 | Dark companion? | Gaia orbit, P = 1,032 d, eccentric; unseen companion of 4.3 solar masses (3.7–5.9) | 5% |
| 15 | 5238699738399933952 | 165.33933 | -65.92882 | 13.40 | Dark companion? | Gaia orbit, P = 1,009 d; unseen companion of about 3.3 solar masses (2.9–3.8) | 5% |
| 16 | 5351774995980250880 | 155.80550 | -57.44321 | 13.92 | Dark companion? | Gaia orbit, P = 678 d; unseen companion of about 1.6 solar masses (1.5–1.8) | 5% |
| 17 | 5556237944880786816 | 101.56835 | -44.07287 | 14.11 | Dark companion? | Gaia orbit, P = 1,237 d, e = 0.73; unseen companion of about 1.7 solar masses (1.5–2.0) | 4% |
| 18 | 5617846158373940096 | 110.31119 | -23.56349 | 13.78 | Dark companion? | Gaia orbit, P = 1,040 d; unseen companion of about 1.6 solar masses (1.5–1.8) | 4% |
| 19 | 3416706995764557568 | 83.46221 | +24.31705 | 11.82 | Dark companion? | Gaia orbit, P = 725 d, e = 0.58; companion of about 1.6 solar masses (1.4–1.7); known binary | 2% |

*Table 2 continued*

| No. | Gaia DR3 source_id | RA | Dec | *G* | Type | Event: dates, timescale and depth | *P* |
|---|---|---|---|---|---|---|---|
| 20 | 5664612407982550528 | 145.93223 | -21.75301 | 9.81 | Dark companion? | Gaia orbit, P = 958 d; companion of about 2.6 solar masses (1.7–5.9); known binary | 2% |
| 21 | 1334956997595864960 | 259.76536 | +34.27371 | 15.58 | Dark companion? | Gaia orbit (alternative solution), P = 753 d; companion of about 1.8 solar masses (1.6–2.3) | 1% |
| 22 | 5406907085973524224 | 151.00434 | -49.79403 | 14.53 | Dark companion? | Gaia orbit (alternative solution), P = 25 d; companion of about 4.7 solar masses (4.0–5.9) | 1% |
| 23 | 5329908767714982400 | 132.40037 | -45.93832 | 15.78 | Dark companion? | Gaia orbit (alternative solution), P = 705 d; companion mass unconstrained (2.6–117) | 1% |
| 24 | 3062085079575847296 | 113.41797 | -1.15380 | 17.00 | Dimming | lost 0.7–0.75 mag in r (about half its light) within a day, 2020 Nov 17–18; normal by 2021 Mar 17 | 60% |
| 25 | 1026501719229603584 | 144.03137 | +59.16899 | 17.99 | Dimming | dips every 4.8 d in 2020 Feb–Mar (up to 30 per cent); faint 2020 Sep–2021 Mar, up to 70 per cent in g | 55% |
| 26 | 2173085230811134208 | 325.17016 | +52.12885 | 13.90 | Dimming | about 9 per cent in g (0.10 mag) from 2021 Apr to spring 2022; 0.19 mag brighter at 4.6 microns | 50% |
| 27 | 2202439064530584320 | 329.64009 | +58.73070 | 13.72 | Dimming | faded from 2021 Apr; 13 per cent in g from 2021 Sep to end of Mar 2022; recovered within about a week | 45% |
| 28 | 69548890757086720 | 52.53906 | +25.66977 | 15.53 | Dimming | two steps: 0.04 mag in g from mid-2020, then 0.21–0.29 mag in 2021 Aug–Nov; normal from 2022 Jul | 45% |
| 29 | 3433284916692771840 | 93.59992 | +27.76124 | 14.10 | Dimming | slight fade from 2020; 0.14–0.15 mag in g in 2021 Jul–Dec; normal by 2022 Jul | 45% |
| 30 | 2881413844294611968 | 358.82898 | +38.76450 | 13.29 | Dimming | 0.15 mag in g in 2018 Dec (17 per cent on Dec 20); 2018 Nov–2019 Feb; weaker dips in two later winters | 40% |
| 31 | 199850192700779520 | 73.27141 | +38.87426 | 13.61 | Dimming | 0.08 mag in g but 0.03 in r, from 2020 Sep to 2021 Mar | 35% |
| 32 | 4268970443075403776 | 287.05406 | +3.29682 | 14.93 | Dimming | faded from 2022 May; 0.45–0.51 mag in g in late Jul 2022; has dimmed again every season since | 35% |
| 33 | 474224278503283328 | 57.05289 | +60.32597 | 18.76 | Dimming | faded from late Feb 2022; 0.57–0.76 mag in r (up to half its light) in 2022 Jul; normal by late Jan 2023 | 35% |
| 34 | 523729725131148672 | 14.70820 | +63.37671 | 17.33 | Dimming | 0.19–0.22 mag in r (0.28–0.33 in g) in 2020 Sep–Oct; about a year, normal by late May 2021 | 35% |
| 35 | 542101567988836224 | 42.12621 | +70.58989 | 16.95 | Dimming | about 15 per cent in r (up to a quarter in g) in 2022 Aug–Sep; normal from 2023 Feb; faint again from 2025 Aug | 35% |
| 36 | 281268169743000832 | 77.70638 | +58.80213 | 17.54 | Dimming | faded within a month in 2019 Aug; up to 30 per cent in g (2020 Apr 2); normal by 2020 Jul 15 | 35% |
| 37 | 2230583057497888512 | 335.43080 | +72.33084 | 17.36 | Dimming | from 2019 Sep 21; about a fifth in g by 2020 Jan; recovered within about five weeks after 2020 Apr 2 | 35% |

*Table 2 continued*

| No. | Gaia DR3 source_id | RA | Dec | *G* | Type | Event: dates, timescale and depth | *P* |
|---|---|---|---|---|---|---|---|
| 38 | 555998192372279808 | 53.27765 | +79.77970 | 13.95 | Dimming | about 0.04 mag in g from early 2022, 0.07 mag in 2023 Jul–Sep; close to normal in 2024 | 35% |
| 39 | 2274904749169663744 | 310.70327 | +71.31979 | 14.83 | Dimming | 0.04–0.06 mag in g from 2023 May; 0.063 mag in 2024 Feb–Mar; normal by 2024 Jun | 35% |
| 40 | 274442882597165440 | 70.82205 | +55.26868 | 15.57 | Dimming | about 0.10 mag in g from mid-Aug 2021; 0.23 mag on 2021 Oct 2; normal by 2022 Apr | 35% |
| 41 | 4160428240050322176 | 274.68837 | -7.08184 | 13.97 | Dimming | abrupt 6 per cent fade in g in 2021 Mar; up to 10 per cent in May; normal by mid-Aug 2021 | 30% |
| 42 | 3129286753527839104 | 101.71166 | +5.12660 | 15.85 | Dimming | up to about 9 per cent in g from 2018 Nov to 2019 Sep; normal from late Oct 2019 | 30% |
| 43 | 1861194257781817600 | 305.03506 | +29.27932 | 15.05 | Dimming | from the end of Mar 2021, up to about 10 per cent in g; normal by 2022 Apr 1 | 30% |
| 44 | 524272505912906240 | 14.48339 | +64.63949 | 17.47 | Dimming | three dimmings 2021–2023; 0.49–0.55 mag in r on 2021 May 31; steady since 2023 | 30% |
| 45 | 4158876141940382976 | 271.98114 | -8.34530 | 16.31 | Dimming | 14 per cent in r and 29 per cent in g in late Mar 2021; about a tenth until Sep; nearly normal by Nov 2021 | 30% |
| 46 | 4209854719371553152 | 294.11852 | -5.17622 | 17.55 | Dimming | two steps over five weeks from 2023 Jun 19; 44 per cent in g on Jul 26; normal by 2023 Nov 20 | 30% |
| 47 | 2064351502266362624 | 309.48111 | +39.04921 | 16.04 | Dimming | from late May 2022; about a sixth in g (a tenth in r) from Sep to Dec 2022; normal by 2023 Mar 29 | 30% |
| 48 | 4417400634468116864 | 231.76807 | +0.43141 | 14.98 | Dimming | from 2022 Aug; 0.07–0.09 mag in g in 2023 Apr–Aug; normal from spring 2024 | 30% |
| 49 | 4235833950054628096 | 301.77934 | -1.21691 | 15.60 | Dimming | from 2019 Apr; about 0.06 mag in g (0.035–0.04 in r) in 2019 Jun–Nov; normal by spring 2020 | 30% |
| 50 | 2285208410072626688 | 331.90027 | +79.68360 | 15.16 | Dimming | 0.07–0.10 mag in g in mid-Aug–early Sep 2019, within 2019 Jul–Dec; brief dip 2024 Apr 28–May 8 | 30% |
| 51 | 2012763683708712192 | 357.92259 | +61.82215 | 16.70 | Dimming | about a seventh in g but a fifteenth in r, 2020 Jul–Oct, within 2020 Jan–2021 Feb | 25% |
| 52 | 3415149842485194240 | 76.78700 | +21.69702 | 16.21 | Dimming | 0.21 mag in g and 0.10 in r in mid-2021, within late 2020–mid-2022 | 25% |
| 53 | 1943310596493970048 | 353.89101 | +48.43848 | 13.66 | Dimming | 0.06–0.08 mag in g from spring 2023 to early 2024, after a slight fade in 2022 | 25% |
| 54 | 61027606923915008 | 50.78965 | +20.61755 | 15.62 | Dimming | 0.08–0.12 mag in g in 2019 Sep–Oct (11 per cent on Oct 13); steady again from 2020 Feb | 25% |
| 55 | 1706330828131818240 | 260.88431 | +78.84802 | 14.09 | Dimming | 0.05–0.07 mag in g from about 2024 Jun 26 to mid-Aug; normal from early Sep 2024 | 25% |
| 56 | 2814851407508236160 | 345.48049 | +12.76838 | 15.31 | Dimming | faint from before 2018 May to mid-2019; 0.19 mag in g (16 per cent) on 2018 Dec 17 | 20% |

*Table 2 continued*

| No. | Gaia DR3 source_id | RA | Dec | *G* | Type | Event: dates, timescale and depth | *P* |
|---|---|---|---|---|---|---|---|
| 57 | 3106218759061394176 | 102.64724 | -2.30237 | 14.44 | Dimming | slow fade from 2021 Mar; 0.045–0.07 mag in 2022 Jan–May; normal by 2022 Aug–Sep | 10% |
| 58 | 972475707866911744 | 92.36076 | +53.20510 | 14.67 | Dimming | 0.17 mag in g (14 per cent) from 2021 Sep 10–17 to at least late Nov; already published | publ. |

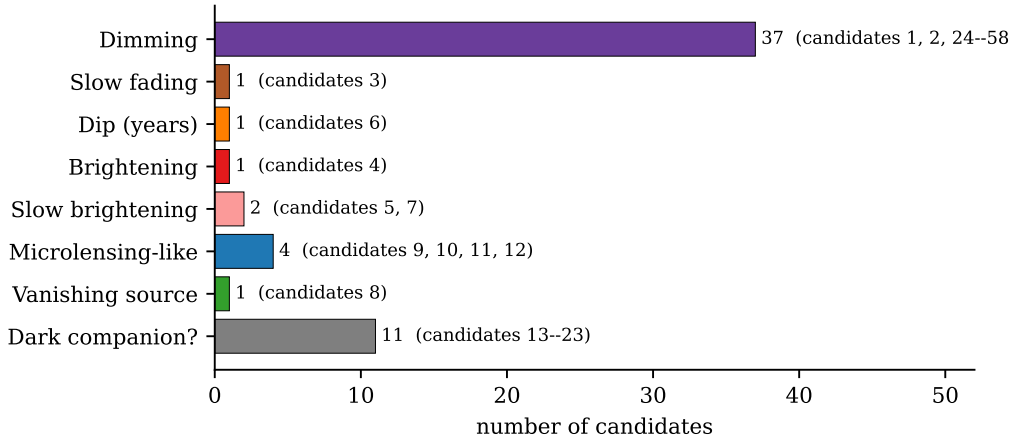



**Figure 2:** The 58 candidates by type of event. "Dark companion?" denotes the stars whose Gaia orbits imply an unseen companion.

## 4.2 Where the candidates are

Figure 3 shows the candidates in Galactic coordinates. Fifty-two of them lie north of declination −30°, where ZTF observes; the six southern ones are candidate 1 and five of the dark companions. Twenty-six lie within 5° of the Galactic plane and 33 within 10°: the plane holds most of the stars, and dust and young stars are concentrated there, which helps to explain both why dimmings are found there and why the young-star alternative is stronger for some of them (for example candidates 44, 33, 34 and 51 in the direction of the Perseus arm). Others lie far from the plane, where almost all stars are old: candidates 48 and 25, for example, are 44° above it, and candidate 1 is 63° below it.

## 4.3 Probabilities and timing

The 57 estimates range from 1 to 60 per cent, with a median of 30 per cent (Figure 4). Their sum, 16.3, would be the expected number of real, previously unrecorded cases among the 57 if the estimates were unbiased: about 12 among the 36 dimmings with estimates, 2 among the microlensing-like events and 0.4 among the dark companions. The highest estimates, about 60 per cent, belong to candidate 1, a red dwarf that faded by up to 38 per cent for about a year; candidate 24, an orange dwarf that lost half its light within a day; and candidate 9, the microlensing-like event with the most independent support. Next come candidate 10 and candidate 25 at about 55 per cent and candidate 11 and candidate 26 at about 50 per cent.

Figure 5 shows when the events happened. The Gaia candidates fall in Gaia's observing window and the ZTF dimmings between 2018 and 2025, with no strong clustering. Some dimmings nevertheless overlap closely in time. Candidates 26 and 27, 7° apart, and 43, 27 to 34° from both, dimmed over the same months of 2021 and 2022, and 27 and 43 began and ended within weeks of each other; candidates 41 and 45, 3.0° apart on the same ZTF field but on different detectors, were both faint from March to the late summer of 2021; candidates 36 and 37, 39° apart, both dimmed from August or September 2019 to the spring of 2020; candidates 30 and 56, about 29° apart, were both deepest in December 2018; and candidates 28, 52 and 58, within 20° of the Galactic anticentre in longitude (11 to 30° from it on the sky), were all deepest in the second half of 2021 with a similarly steep colour. In every case each star's own comparison stars stayed steady, and for most of them a second ZTF detector or ASAS-SN saw the dimming too. The start dates of 438 ZTF dimmings measured during the search spread evenly over 2020 to 2024, the late-2021 episodes fall on 15 detectors and 24 fields, steep-coloured dimmings are no more common in late 2021 than in other half-years, and with so many dimmings lasting months between 2018 and 2023, overlaps of this kind are expected by chance. A shared instrumental cause therefore seems unlikely, and no single cloud could cover stars so far apart, but the coincidences have not been explained.

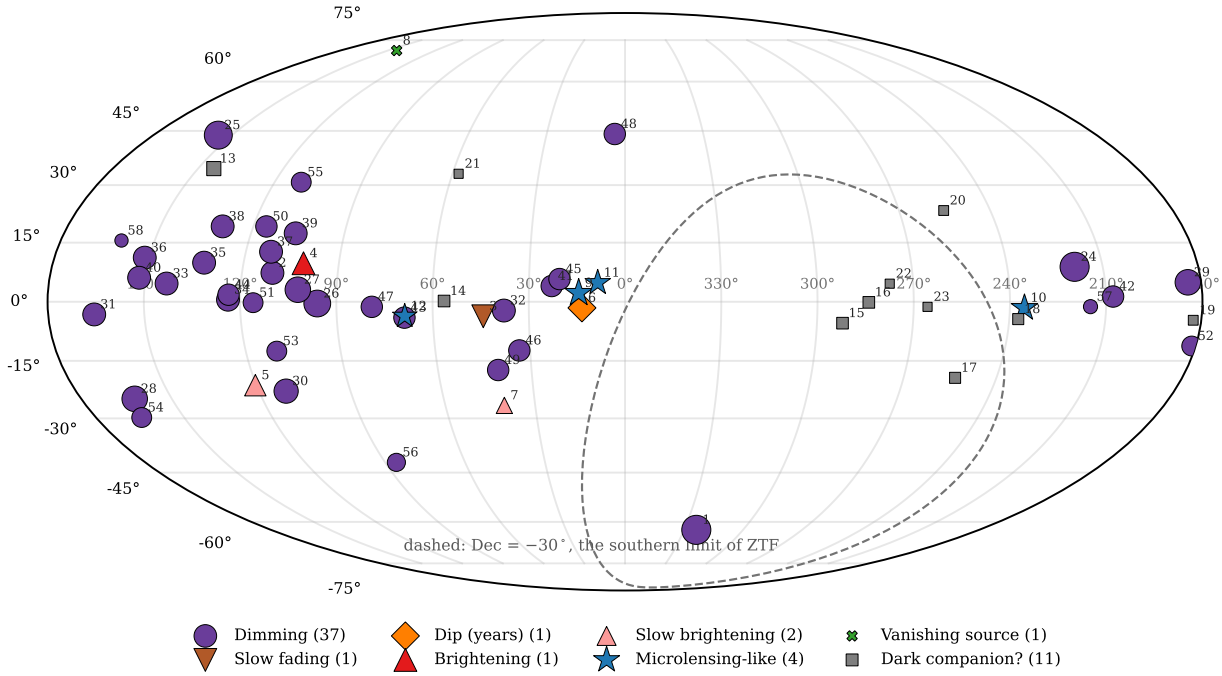



**Figure 3:** The candidates in Galactic coordinates (Mollweide projection, longitude increasing to the left, the Galactic centre at the middle). Symbols show the type; their size grows with the estimated probability; numbers are candidate numbers. The dashed curve is declination −30°, the southern limit of ZTF.

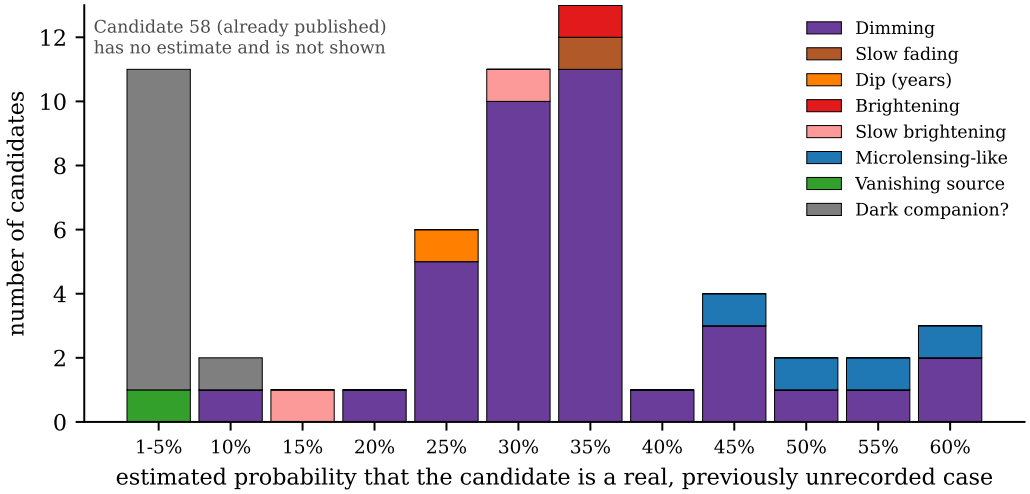



**Figure 4:** Distribution of the estimated probabilities, from the public pages, coloured by type. The first bin collects the estimates of 1 to 5 per cent.

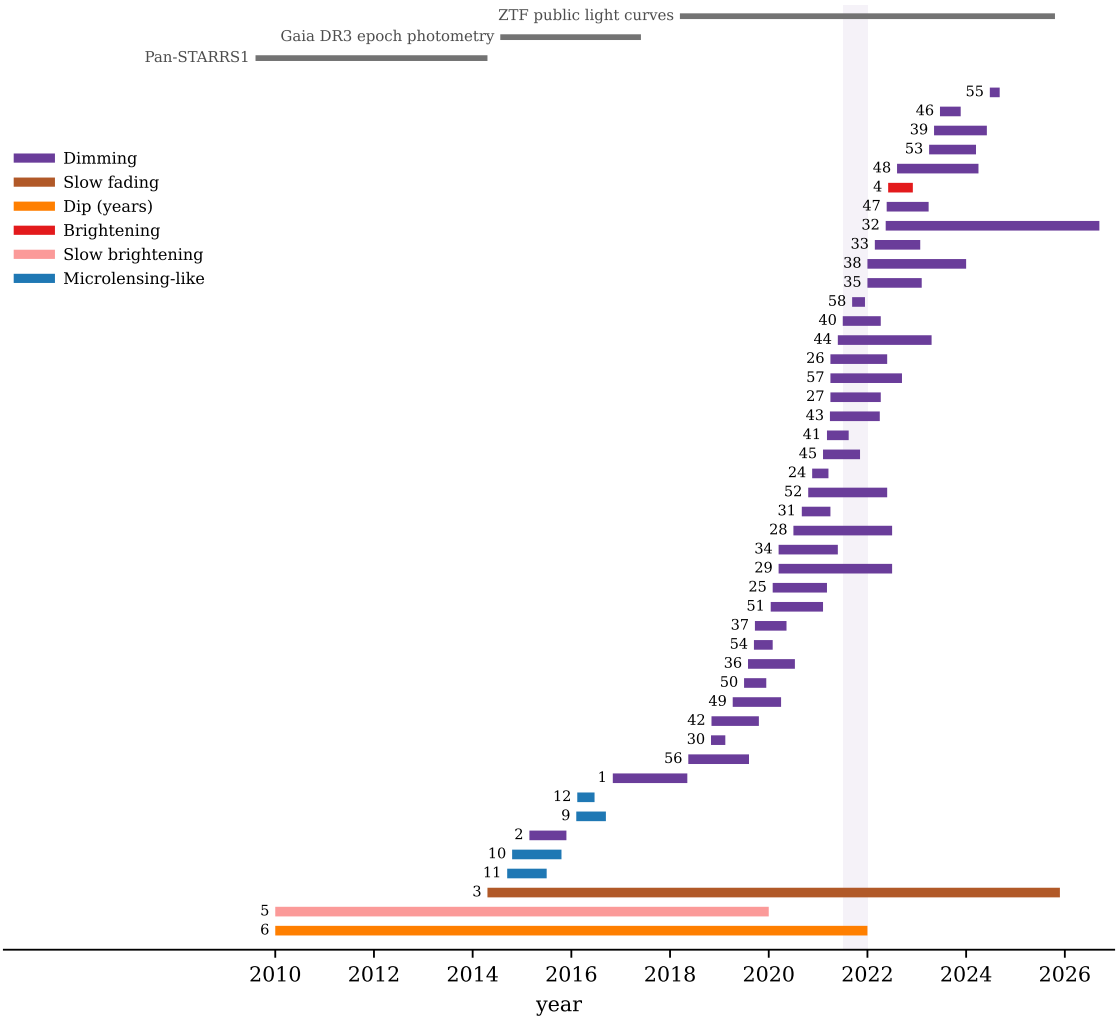



**Figure 5:** When the events happened, from the start to the end of each event as given in Table 2 (the plate source 8, the long-term brightening 7 and the dark companions are not shown). Grey bars at the top mark the main surveys; the shaded band marks the second half of 2021.

## 4.4 Confirmation, before-and-after images and the published candidate

Every dimming of candidates 24 to 58 was recorded by ZTF while comparison stars stayed steady; for most, a second ZTF detector or ASAS-SN saw it too, and for 24 and 45 SkyMapper did, and for 25 and 32 TESS followed part of the event. Before-and-after survey images exist for 39 candidates: the ZTF reference, event and difference images of candidates 4 and 25 to 58, single ZTF exposures of candidate 24 before, during and after its dimming, the DECam images of candidate 1 before, during and after its fading, and photographic and digital images of candidate 5 from 1989 to 2025, while candidate 8's plate cutouts show the spot on the 1955 plates and its absence later. For candidates 2, 3, 6, 7 and 9 to 12 no survey imaged the star both before and during its event, or the change is too small to see in an image; their entries say which.

Candidate 58's dimming, from September to at least late November 2021, is among the 81 dipper stars of Tzanidakis et al. (2025), who show the same dip in their appendix. The arXiv version of that paper lists most of its stars only in figures; the full list, with Gaia DR3 identifiers, is the machine-readable table of the journal version, which gives candidate 58 with its deepest dip on 2021 November 20. That table is not in VizieR, which is why catalogue look-ups missed it. It is kept because the checks made here were independent and agree that the dip is real, but it carries no estimate. None of the other candidates is among those 81 stars, although candidate 24 appears to meet their selection.

### 4.5 Checks of this paper against the public pages and the archive

For this paper, every candidate's Gaia DR3 `source_id` was queried in the Gaia archive. All 57 exist; their positions agree with those of the public pages to better than 0.03 arcsec, the rounding of the pages, and their mean $G$ magnitudes agree with the pages to within 0.06 mag (the pages round some to one decimal). The magnitudes in Table 2 and in the catalogue are the archive values. The probabilities are those of the public pages, character for character.

## 5 Catalogue of the candidates

Each entry begins with a summary: the star's identifier and type, its Gaia DR3 position, Galactic coordinates, distance and brightness, the event (or, for candidates 13 to 23, the claim) and the estimated probability. Then follow what changed (or what Gaia found), why it might matter (or why the estimate is low), the checks against the record, the reasons for the estimate and the caveats, all as on the public pages, and the figures: a sky image with the star marked, the light curve, and, where they exist, before-and-after images, TESS light curves and the orbit. Section 3.10 explains the conventions of the figures. Cross-references to other candidates are links.

## Candidate 1: A red dwarf that faded for about a year

| | |
|---|---|
| **Star** | Gaia DR3 6521694778536448640, a cool red dwarf (an M dwarf) |
| **Position** | RA 357.49427°, Dec −51.92332° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Phoenix |
| **Galactic** | $l = 323.77°$, $b = -62.65°$ |
| **Distance** | about 650 parsecs (2,100 light-years) |
| **Brightness** | Gaia $G = 19.36$; far too faint for the eye or a small telescope |
| **Event** | faded by up to 0.5 mag in G (38 per cent) for about a year from 2016 Nov; brief 0.1 mag dip in 2018 Nov |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 60% |

**What changed.** The star is a cool red dwarf in the southern constellation Phoenix, smaller and cooler than the Sun and far too faint to see by eye. Gaia measured it 99 times between 2014 and May 2017. It was steady until late 2016, apart from one slightly faint visit in February 2016. From November 2016 until Gaia's published measurements end, in May 2017, it was 0.1 to 0.5 magnitudes fainter than normal, which means 7 to 38 per cent less light, and the depth could change by up to 0.2 magnitudes within two or three days.

Two other telescopes saw the same fading. On 4 November 2016 the Dark Energy Camera in Chile recorded the star 0.105 ± 0.007 magnitudes fainter in its z filter, and 0.083 ± 0.015 magnitudes fainter in Y, than in earlier images (the number after ± is the uncertainty). An image from 3 October 2016 was normal, so the fading began within those four weeks. On 13 November 2016 SkyMapper, in Australia, found the star about 0.2 magnitudes fainter than in its own later measurements.

The recovery was uneven. On 12 August 2017 SkyMapper had the star only 0.03 to 0.06 magnitudes faint, but on 7 October 2017 it was 0.1 to 0.15 magnitudes faint again, in two filters. A Dark Energy Camera z image from 28 September 2017 also shows it about 0.11 magnitudes faint, although the star falls at the edge of the detector there, so that value is less reliable. On its own, each of these 2017 points is only a weak measurement. The star was back to normal by May 2018 in SkyMapper and by September 2018 in the Dark Energy Camera, and a SkyMapper image from June 2021 is normal too.

The star was also measured afresh on 15 usable deep SkyMapper images. They include six r-filter images from August and September 2017 and May 2018, most of which the SkyMapper catalogue had not measured. In SkyMapper's blurrier images the light of its bright companion star spills onto it, so that light is subtracted, using the light at the same distance from the companion in other directions. Where the catalogue also measured the star, the two sets of values agree to within 0.07 magnitudes. On average the new r points sit at the normal level, 0.04 ± 0.04 magnitudes fainter than expected from the Dark Energy Camera once the different filters are allowed for. They scatter more than their uncertainties, by about 0.4 magnitudes between nights 11 days apart. That could be flickering, but noise alone would produce as much scatter about once in 50 tries, so it does not count as significant.

There was also a second, shorter dip. A Dark Energy Camera image from 15 November 2018 shows the star 0.095 ± 0.007 magnitudes faint in the i filter, and the archive catalogue gives 0.093 for the same image. The value holds up whatever the size of the measuring window (0.089 to 0.099 across six sizes), and there are no bad pixels near the star. Twelve days later the star was nearly normal: 0.02 ± 0.01 magnitudes faint in r and 0.04 ± 0.03 in g. All 60 i-filter images from July, October and November 2019 are within 0.03 magnitudes of normal. Because this second dip rests on a single image, it is less certain than the main fading.

The colour of the fading is a clue. In Gaia the fading was about as deep in the red band as in the broad band (a ratio of 1.09 ± 0.11, where fine interstellar dust would give about 0.83). SkyMapper's near-infrared z filter, at 0.9 microns, showed about the same 0.2 magnitudes as Gaia and SkyMapper's i filter, in measurements a few days apart. From blue light to the near infrared, then, the fading was roughly grey. The preference for grey over fine dust is only a hint, at about 2.4 times the uncertainty, not a proof.

In the infrared the fading was much weaker. WISE measured the star at 3.4 microns twice during the fading, on 3 to 10 November 2016 and on 20 to 27 May 2017, using the combined image of each visit. Both times the star was only 0.05 ± 0.05 magnitudes fainter than in 2010 to 2016, while in visible and near-infrared

light it was about 0.2 magnitudes fainter. A grey fade would have shown about 0.2 magnitudes in WISE too, and that is ruled out at about three times the uncertainty. An opaque body covering part of the star would dim every colour equally, so the result points instead to a thin veil of dust. A standard light-scattering calculation puts the grains at a few tenths of a micron across, about 0.2 to 0.5 microns: bigger than most interstellar grains, which would redden the light, but small enough to let 3.4-micron light through. Grains of a micron or more would dim the infrared at least as much as visible light. A similar pattern, nearly the same in visible colours and weaker at 3.6 to 4.5 microns, was found in the slow fading of Boyajian's star and attributed to dust (Meng et al. 2017). The comparison is of colours only: Boyajian's star is hotter, and its slow fading was a few per cent, not 20 per cent.

**Why it might matter.** Red dwarfs do flare, brightening briefly, and they do have starspots, which cause small, regular wiggles in brightness. They do not normally fade by up to a third for a year. A long fading is usually caused by dust passing in front of the star, for example a dusty disc around an unseen companion. Young stars often do this, but this one is probably old: the system lies about 580 parsecs below the plane of the Milky Way, where young stars are rare, and it moves like an ordinary older disc star. Old red dwarfs are not expected to have dusty discs, and that is what makes the event unusual.

The red dwarf also appears to have a companion. A Sun-like star 14 arcseconds to the south, the bright star below the target on the finder chart, is at the same distance (parallaxes of 1.53 and 1.60 milliarcseconds) and moves the same way across the sky (the motions differ by 0.5 ± 0.2 milliarcseconds per year). It is about 175 times brighter, at Gaia G = 13.7. An unrelated star this close and this similar would turn up by chance only about once in a thousand fields like this one. Gaia's own analysis gives it a temperature of about 5,800 K, like the Sun, perhaps somewhat fewer heavy elements than the Sun (this is uncertain), and a speed along the line of sight of 13.4 ± 2.5 km/s. The two stars are at least 9,200 AU apart, about 300 times the Sun–Neptune distance. The pairing rests on statistics: there is no line-of-sight speed for the red dwarf to compare.

**Checks against the record.** SIMBAD, VSX (the variable-star index) and the Gaia alerts list show nothing known about the star apart from an entry derived from Gaia. Gaia's indicators of instrumental artefacts are normal, and other stars nearby did not fade on the same dates. Infrared colours from 2MASS, VHS and WISE are normal for a red dwarf, with no sign of warm dust, although cold or faint dust would not show. About 110 archived Dark Energy Camera images in five filters and 15 SkyMapper images were measured afresh, and 16 WISE visits from 2010 to 2020 were checked against hundreds of field stars of the same brightness. GALEX, in the ultraviolet, and eROSITA, in X-rays, do not detect the star, which is expected at this distance and says nothing either way.

**Why this estimate.** The fading itself is certainly real: Gaia, the Dark Energy Camera and SkyMapper all recorded it. Without a spectrum of the star, though, its cause remains open. The grey colour of the fading argues only weakly against starspots, and only the way the star moves argues that it is not a young star with a dusty disc.

**Caveats.** The main event is sparsely sampled, with about 30 measurements from three telescopes, and its depth varies from date to date. There is no spectrum. The 2018 dip rests on one image, and the autumn 2017 dip on three marginal measurements. No matching line-of-sight speed for the red dwarf confirms the companion. The infrared test assumes that the depth in visible light during each WISE visit matched the measurements just before and after it, but the depth could change by 0.2 magnitudes within days. WISE also reads the star about 0.1 magnitudes faint in 2019 and 2020, when the Dark Energy Camera saw it at its normal level. Each of those points is less than twice its uncertainty, so they are not taken as fading.

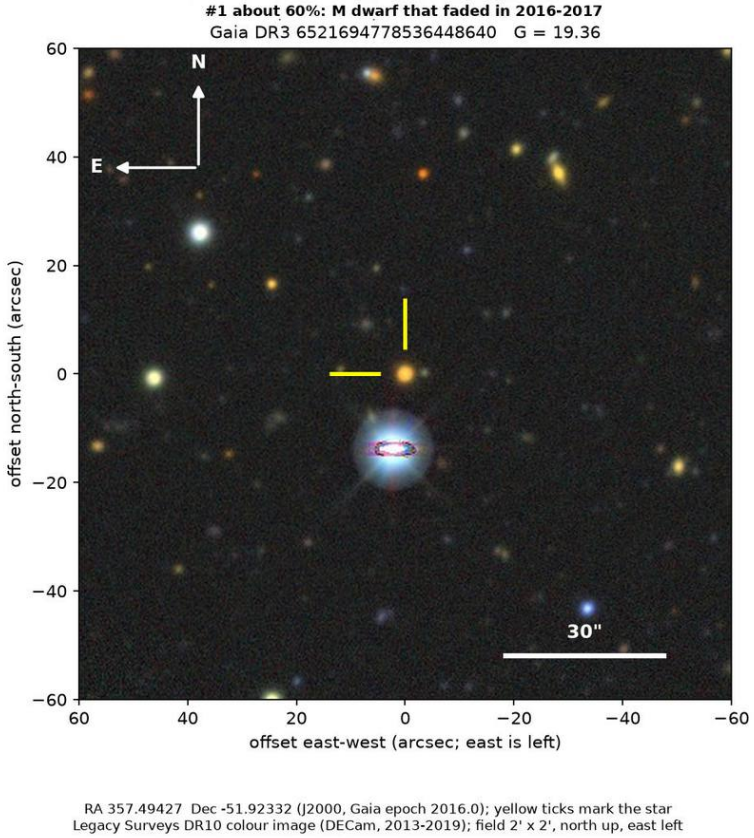



**Figure 6:** Candidate 1, sky image. Legacy Surveys DR10 colour image from the Dark Energy Camera, two arcminutes by two. The red dwarf is the orange dot between the yellow ticks, and the bright star below it is its proposed Sun-like companion. North is up, east is left, and the white bar is 30 arcseconds. Data: DESI Legacy Imaging Surveys (NOIRLab); ESA/Gaia/DPAC.

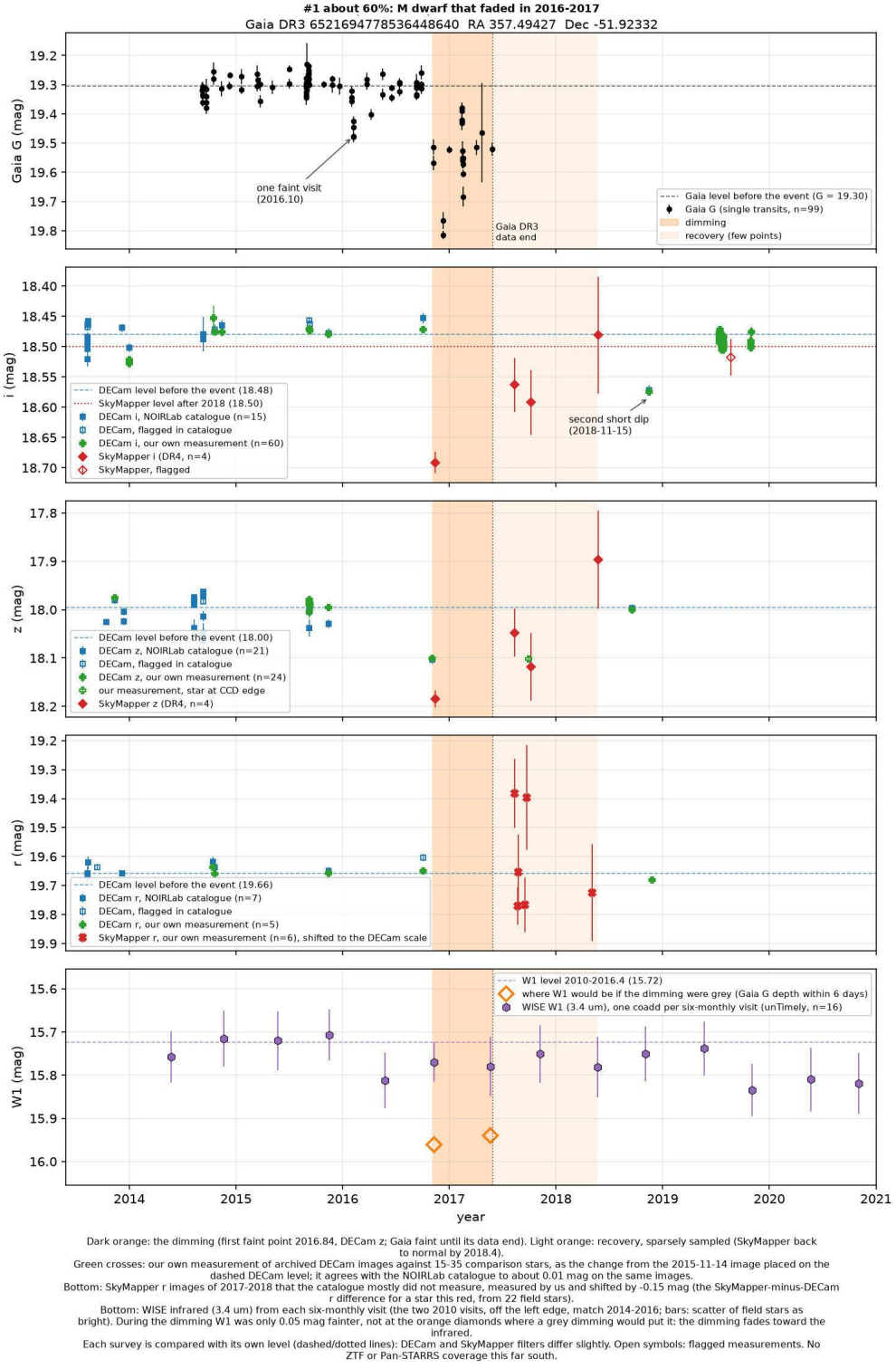



**Figure 7:** Candidate 1, light curve. Brightness from 2014 to 2021. Top: Gaia's broad G band. Below it: the i, z and r filters of the Dark Energy Camera and SkyMapper. Bottom: WISE at 3.4 microns. Blue squares are values from the NOIRLab catalogue. Green crosses are fresh measurements of archived Dark Energy Camera images; on images that the catalogue also measured, the two agree to about 0.01 magnitudes. Red diamonds are values from the SkyMapper catalogue, and red crosses are fresh SkyMapper r measurements from 2017 and 2018. Dark orange marks the dimming and light orange the poorly sampled recovery. The open orange diamonds show where the infrared points would be if the fading were grey, with the same fraction of light missing at every colour. Down means fainter. Data: DECam images from the NOIRLab Astro Data Archive; SkyMapper (ANU); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

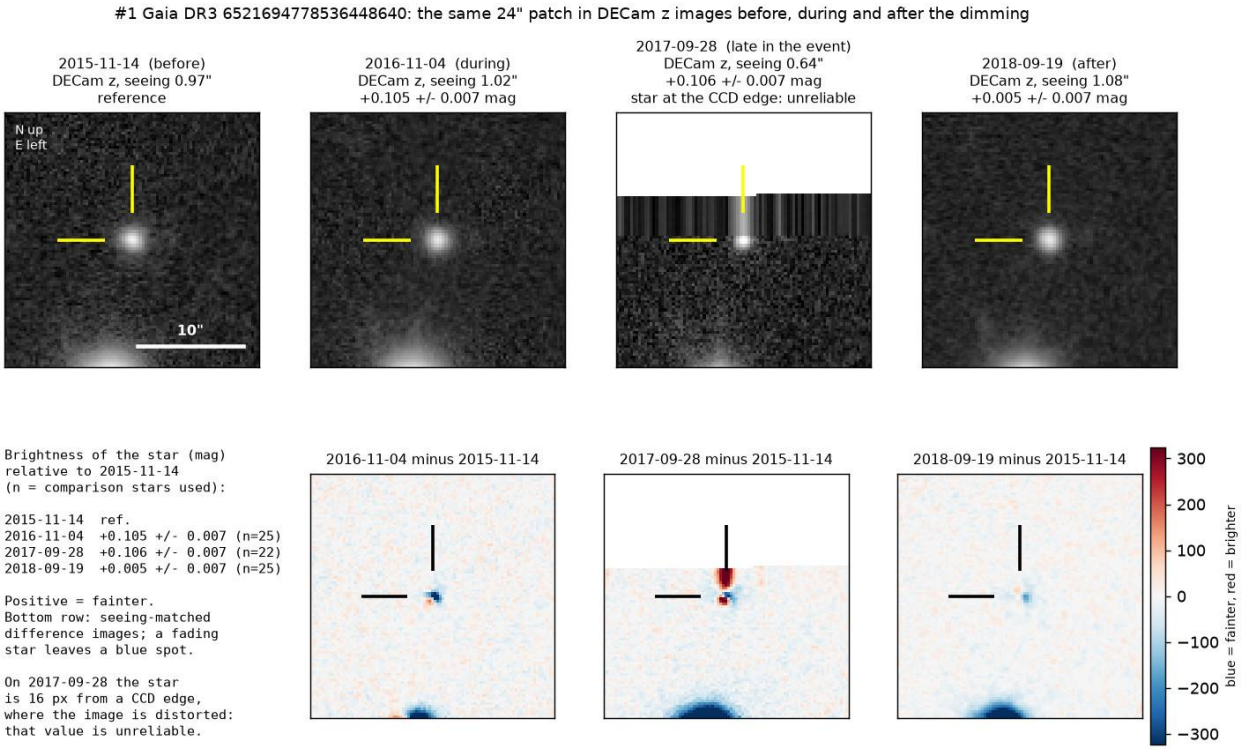



**Figure 8:** Candidate 1, DECam z-band images before, during and after. The same 24-arcsecond patch in single 90-second z images, all shown on one brightness scale. Compared with 14 November 2015, the star was 0.105 ± 0.007 magnitudes fainter on 4 November 2016, 0.106 ± 0.007 fainter on 28 September 2017, and normal (0.005 ± 0.007) on 19 September 2018. The 2017 value is less reliable, because the star falls 16 pixels from the edge of the detector, where the picture is distorted. The lower row subtracts the 2015 image, and a blue spot means fainter. A fade of about 10 per cent is real but too small to see by eye in the top row; the numbers and the blue spot in the 2016 difference image show it. Data: DECam images from the NOIRLab Astro Data Archive.

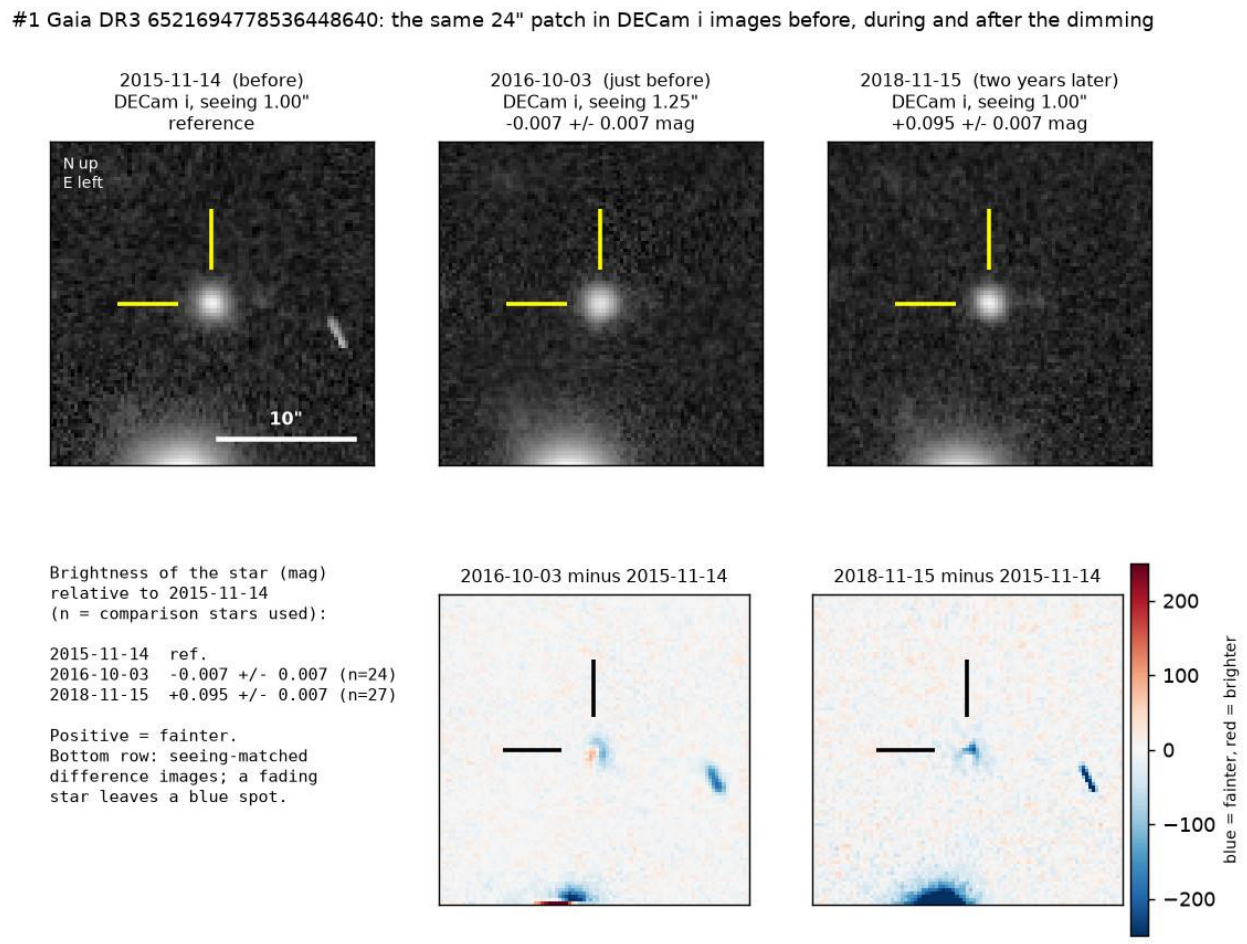



**Figure 9:** Candidate 1, DECam i-band images before and after. The same test in the i filter. The star was normal on 3 October 2016, just before the main fading (−0.007 ± 0.007 magnitudes relative to 14 November 2015), and 0.095 ± 0.007 magnitudes faint on 15 November 2018, during the second dip. Blue in the difference image means fainter. Data: DECam images from the NOIRLab Astro Data Archive.

## Candidate 2: A white dwarf that faded for eight months

| | |
|---|---|
| **Star** | Gaia DR3 2212797391765189760, a white dwarf |
| **Position** | RA 339.75244°, Dec +66.91673° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cepheus |
| **Galactic** | $l$ = 110.46°, $b$ = +7.31° |
| **Distance** | about 270 parsecs (880 light-years) |
| **Brightness** | Gaia $G$ = 19.24 |
| **Event** | 0.33 mag fainter in G (26 per cent) from 2015 May to mid-Oct, after a two-month fade; normal again within 40 days |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is a white dwarf in Cepheus: the burnt-out core of a Sun-like star, about the size of the Earth. Its Gaia colours fit a hydrogen atmosphere at about 12,000 K and a mass of about 0.7 times that of the Sun. Gaia measured it 35 times between 2014 and 2017. In early 2015 it faded smoothly over about two months, stayed 0.33 magnitudes fainter, or 26 per cent less light, from May to mid-October 2015, and was back to normal less than 40 days later. Before that it was steady in Pan-STARRS from 2010 to 2014, and afterwards it was steady in Gaia from 2016 to 2017 and in ZTF from 2018 to 2025.

As far as is known, no other survey observed the star during 2015, so there is no picture of it while it was faint. Pan-STARRS1 stopped routine imaging in 2014 and ZTF started in 2018, while the Dark Energy Camera and SkyMapper do not cover this part of the sky. The dip is covered by 10 Gaia measurements in 6 visits.

**Why it might matter.** White dwarfs almost never change brightness like this. A fading of a quarter of the light, nearly the same at all colours and lasting most of a year, could mean that a large dusty body or a cloud of debris passed in front of the star. Other explanations are not ruled out, and the strongest test, a second telescope seeing the same dip, is missing.

**Checks against the record.** SIMBAD, VSX (the variable-star index) and the Gaia alerts list show nothing known about the star. Gaia's artefact indicators are normal, there is no other Gaia source within 6 arcseconds, and Gaia's two telescopes agree to 0.01 magnitudes. Gaia's previous data release, processed separately and including data up to May 2016, has the star fainter on average by the amount the 2015 dip predicts. Nearby stars did not dip.

**Why this estimate.** Only Gaia observed the dip. An earlier Gaia data release only reprocesses the same observations, and no other measurement from 2015 exists, so an unrecognised instrumental artefact remains possible, even though every available test for artefacts came out clean.

**Caveats.** Only Gaia saw the event, so independent confirmation, the strongest test, is not available.

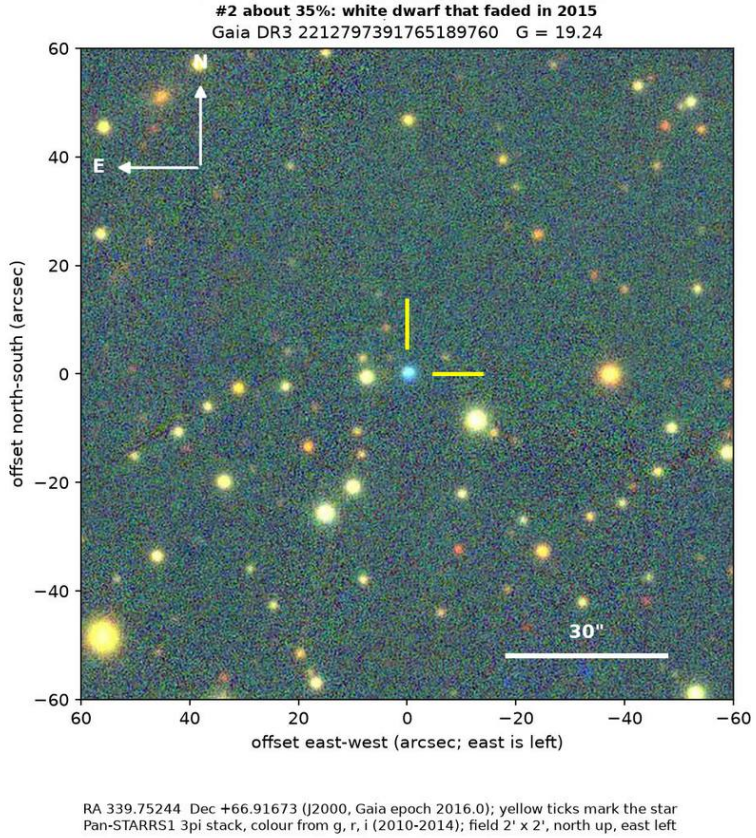



**Figure 10:** Candidate 2, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The white dwarf is the small blue dot between the yellow ticks. The yellow star 8 arcseconds to its east is unrelated. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

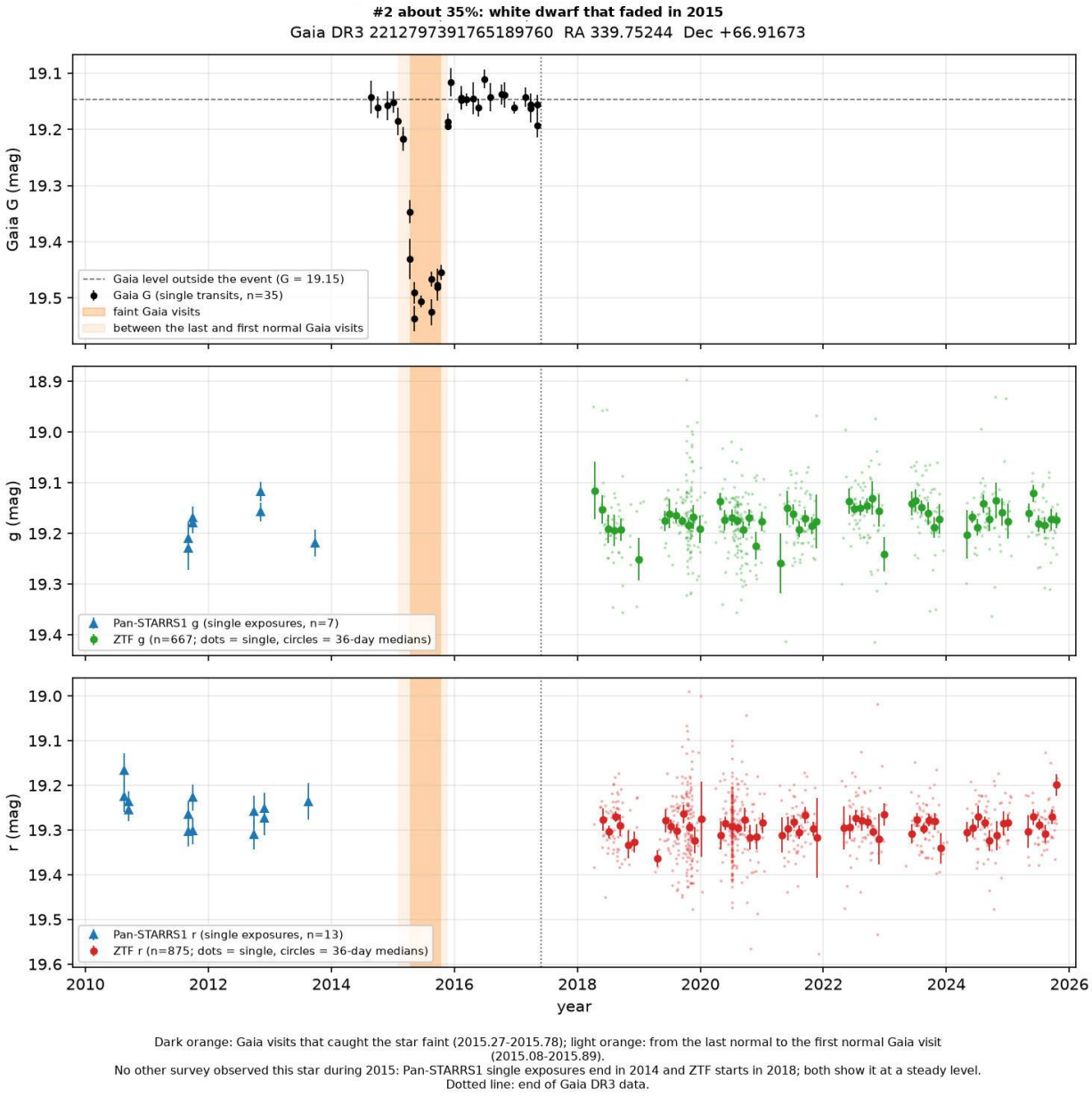



**Figure 11:** Candidate 2, light curve. Top: Gaia's broad G band, with the 2015 dip in orange. Middle: Pan-STARRS1 and ZTF in the g filter. Bottom: the same in the r filter. ZTF dots are single images and the circles are 36-day medians. Down means fainter. The middle and bottom panels have no points during the dip, because those surveys were not observing then. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

## Candidate 3: An orange dwarf in Aquila that has been fading for a decade

| | |
|---|---|
| **Star** | Gaia DR3 4296242940002232704, an orange K dwarf |
| **Position** | RA 291.36673°, Dec +8.34015° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Aquila, 3.7 degrees below the plane of the Milky Way |
| **Galactic** | $l = 44.25°$, $b = -3.68°$ |
| **Distance** | about 790 parsecs (2,600 light-years), uncertain by about 2 per cent |
| **Brightness** | Gaia $G = 15.53$ |
| **Event** | steady 2009–2013; fading since 2014, by 0.3–0.4 mag (25–30 per cent) by 2025 and still fading |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is an orange dwarf in Aquila, a little cooler and smaller than the Sun, about 790 parsecs (2,600 light-years) away. Its brightness for its distance places it on the main sequence: it is an ordinary hydrogen-burning star, neither young nor a giant. Pan-STARRS1 saw it at one steady level from mid-2009 to mid-2013, in 26 exposures in green and red light, all within 0.05 magnitudes of the average. Then it began to fade. The Dark Energy Camera caught the start: in mid-2014 the star was 0.07 magnitudes fainter in red light than in early 2013. From late 2014 to mid-2017 Gaia saw a steady fade of 0.07 magnitudes a year, slightly faster in blue light than in red. From 2018 to 2025 ZTF finds the star 0.2 to 0.45 magnitudes below the Pan-STARRS1 level. It recovered a little, by about 0.07 magnitudes, in 2019 to 2021, then faded further, and it was still fading in 2025. In the infrared, at 3.4 microns, the same pattern appears with a smaller amplitude. Compared with ten nearby stars of similar brightness and colour, the star is now about 0.4 magnitudes fainter in green light and 0.33 magnitudes fainter in red than it was in 2009 to 2013: about 25 to 30 per cent less light.

**Why it might matter.** This star is the mirror image of candidate 5 . Ordinary quiet dwarf stars do not fade by a third of their light over a decade. Magnetic activity cycles change such stars by a few hundredths of a magnitude, up to about 0.1, and the changes repeat. This star is quiet from night to night: ZTF's scatter is no larger than its measurement errors, the strongest periodic signal (1.38 days) is only 0.005 magnitudes, and when the data are analysed season by season, no period repeats more often than it does in nearby stars. Its Gaia spectrum shows no hydrogen-alpha emission. That leaves two explanations. One is dust moving into the line of sight. The infrared faded about 0.45 times as much as the red light, whereas ordinary interstellar dust would dim the infrared much less, so the grains would have to be large. The other is a change in the star itself. The colours also fit a cooler surface or more dark spots, but the surface would have to cool by about 300 K, or spots would have to spread over a large part of a star that shows neither hydrogen emission nor a rotational wobble. Passing dust is the simpler reading, although nothing shows the dust directly.

**Checks against the record.** SIMBAD lists nothing known about the star. The variable-star index lists it only because it copies Gaia's machine classification, and Gaia alerts, published variable-star lists and arXiv show nothing. Gaia's fit to the star's motion is that of a normal single star, and its images show no second peak. The three neighbours marked on the finder chart, 3 to 5 arcseconds away, are much more distant background stars, and Gaia sees them as steady. The fading is the same in two separate ZTF fields. Ninety-five per cent of the comparison stars changed by less than 0.08 magnitudes between Pan-STARRS1 and ZTF, and within ZTF the star's change since 2018 is larger than that of any of the 15 comparison stars.

**Why this estimate.** The fading is certainly real: Gaia, the Dark Energy Camera, ZTF and WISE all recorded it, and field stars of the same colour did not fade. But the steady level before it is known only for 2009 to 2013, the fading paused and partly reversed in 2019 to 2021, and there is no spectrum. The estimate is also modest because similar spotted dwarfs, including two with no measured rotation, drift by about as much, so the star's quietness is a weaker argument for dust than it might seem.

**Caveats.** No spectrum of the star exists in the archives that were checked. The steady level is known only for 2009 to 2013; older photographic plates were not examined. The partial recovery in 2019 to 2021 makes the shape less clean than that of candidate 5. The field is crowded: in WISE the neighbours make up about a third of the light, which has been allowed for. Gaia's classifier calls the star a spotted active star, a label probably driven by the slow trend itself. Among 425 similar dwarfs, ten changed by 0.45 magnitudes or more, and two of the three that, like this star, do not spin fast still changed. So the lack of rotation sets it apart less than it might seem.

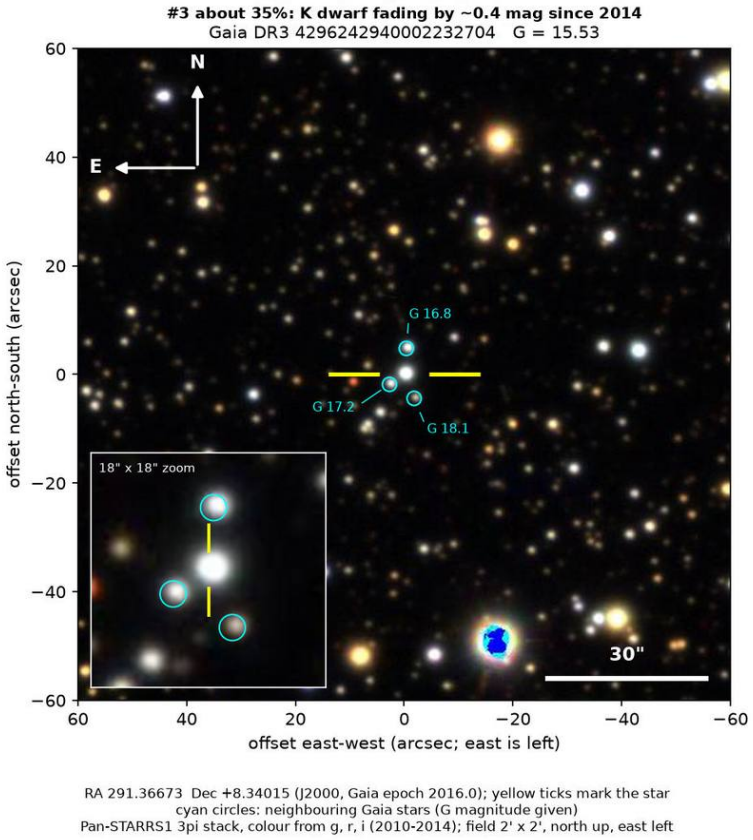



**Figure 12:** Candidate 3, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks. The cyan circles mark the three neighbouring stars, and the inset enlarges them. North is up, east is left, and the white bar is 30 arcseconds. Apart from two Dark Energy Camera visits that bracket the very start of the fading, no single survey imaged the star both before and during it, so there is no before-and-after picture. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

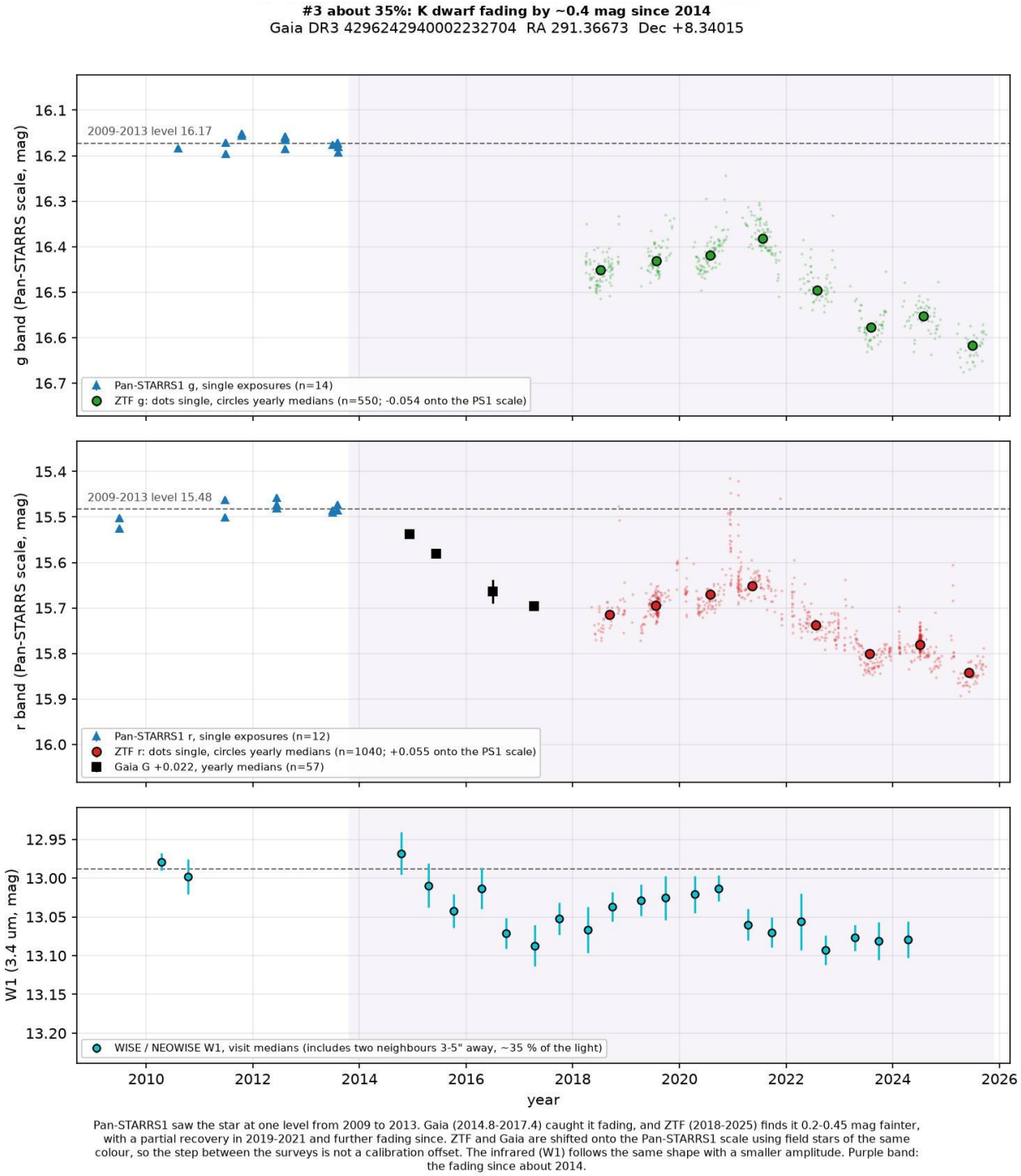



**Figure 13:** Candidate 3, light curve. Brightness from 2009 to 2025. Top: green light. Middle: red light. Bottom: WISE infrared at 3.4 microns, which includes light from the neighbouring stars. ZTF and Gaia are shifted onto the Pan-STARRS1 scale using field stars of the same colour, so the step between surveys is not a calibration offset. The dashed line is the 2009 to 2013 level, and purple marks the fading since about 2014. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 4: A hot star that brightened for five months

| | |
|---|---|
| **Star** | Gaia DR3 2196222627638729984, a hot A-type star |
| **Position** | RA 318.89815°, Dec +63.08011° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cepheus |
| **Galactic** | $l$ = 101.13°, $b$ = +9.76° |
| **Distance** | about 2,400 parsecs (7,800 light-years) |
| **Brightness** | Gaia $G$ = 16.38; far too faint for the eye |
| **Event** | 0.19 mag brighter in g (about 19 per cent) from 2022 Jun to Nov, with a 1.24-day cycle while bright |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is a hot white star of type A, about 7,700 K and roughly 300 million years old, some 2,400 parsecs away behind a thick layer of dust in Cepheus. ZTF saw it steady, within about 0.02 magnitudes, from 2018 to 2021. In June 2022 it began to brighten, reached 0.19 magnitudes brighter in green light and 0.13 in red light in September, about 19 per cent more light, and was back to normal by December. While it was bright, ZTF also caught it rising and falling every 1.24 days, by about a tenth of a magnitude in green light, which it does in no other year. TESS recorded the same cycle in September and October 2022, and a 1.52-day cycle in November, as the brightening faded.

**Why it might matter.** Stars of this kind do not usually brighten by a fifth for months. The light that was added is bluer than the star itself, as if it came from something hotter than about 10,000 K, and at 3.4 microns WISE saw almost no change in July 2022, when the star was 0.13 magnitudes brighter in red light. A gravitational lens would have brightened every colour by the same factor, so that is ruled out. A hot companion or a faint neighbour that flared, or a burst of activity on the star itself, could fit, but none is established. An unseen star within 0.4 arcseconds cannot be excluded, and if one is there it may be the source.

**Checks against the record.** No record of the brightening could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The brightening is real: ZTF recorded it on two of its detectors, flagged it 99 times and saw the star alone change while its neighbours stayed steady, and ASAS-SN, a separate network of small telescopes, saw it too. What it was is unclear. The added light was bluer than the star, it came with a 1.24-day cycle that NASA's TESS space telescope also recorded, and the infrared hardly changed, which rules out a gravitational lens. A faint unseen star very close to it may be what flared.

**Caveats.** The cause is unknown. ASAS-SN sees the star near its faint limit, so its support is noisy. Two faint Gaia neighbours lie close to the star, one of them only 1.4 arcseconds away, and an even closer unseen star cannot be excluded. There is no spectrum.

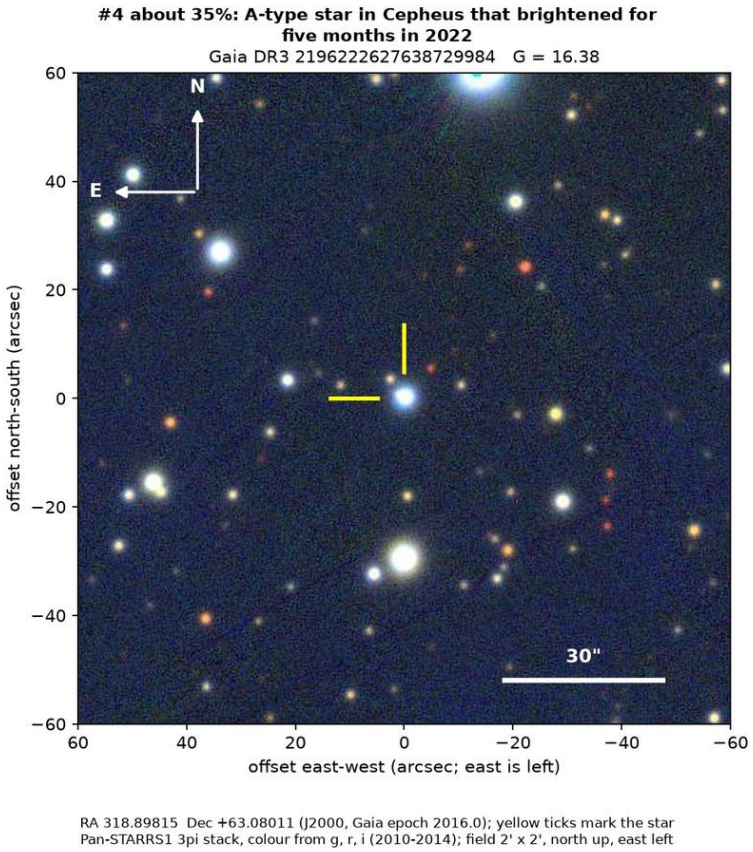



**Figure 14:** Candidate 4, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the one between the yellow ticks. A faint neighbour (G = 19.9) is the dot just to its upper left, and a second (G = 20.6), only 1.4 arcseconds away, merges with the star at this scale. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

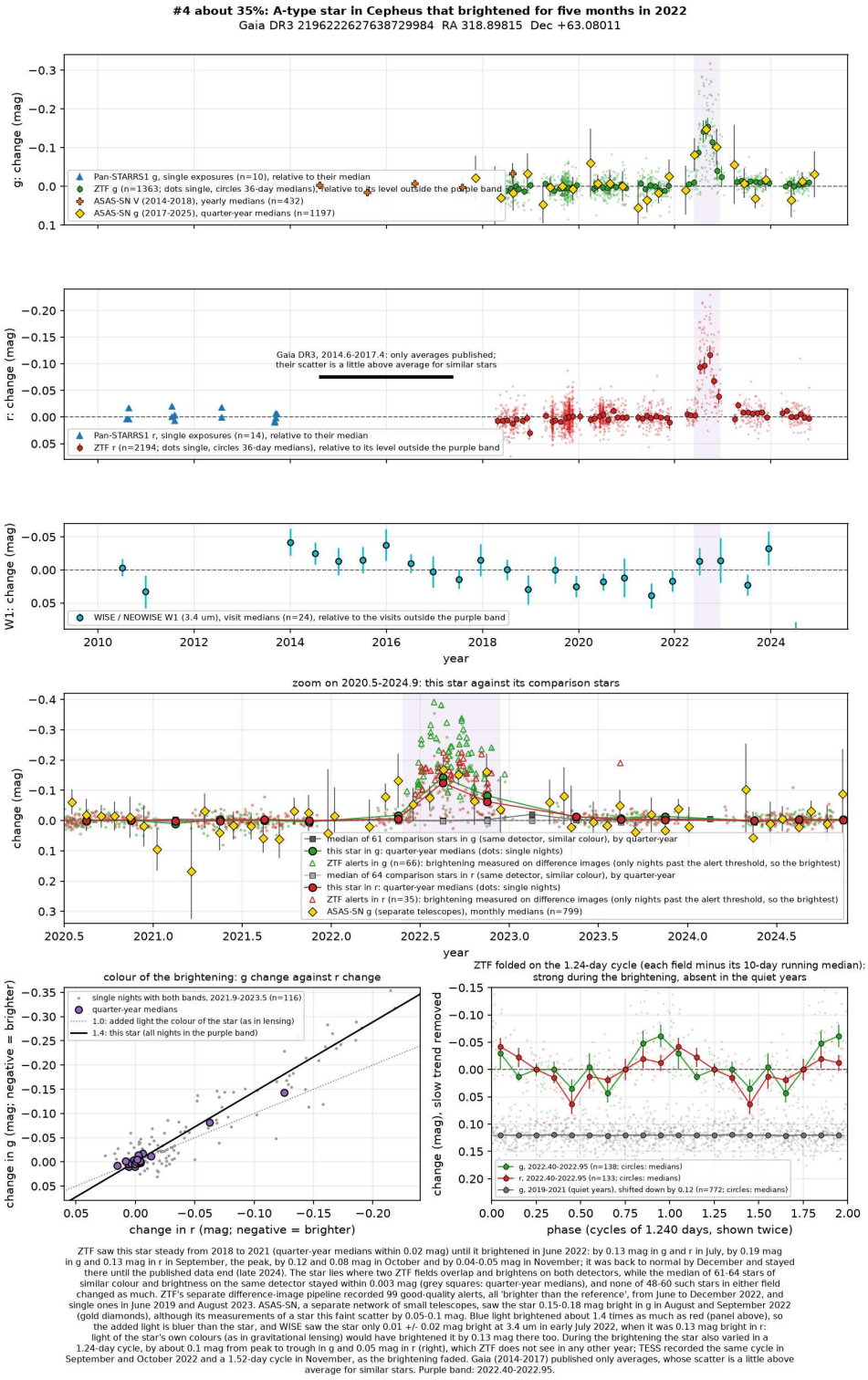



**Figure 15:** Candidate 4, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds are ASAS-SN, and a note marks the years of Gaia, which publishes only averages. Purple marks the brightening. Middle: a closer view of 2020 to 2024, with the star against its comparison stars and ZTF's alerts. Bottom left: the change in green against that in red. Bottom right: ZTF's measurements folded on the 1.24-day cycle, strong during the brightening and absent in the quiet years. Up means brighter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

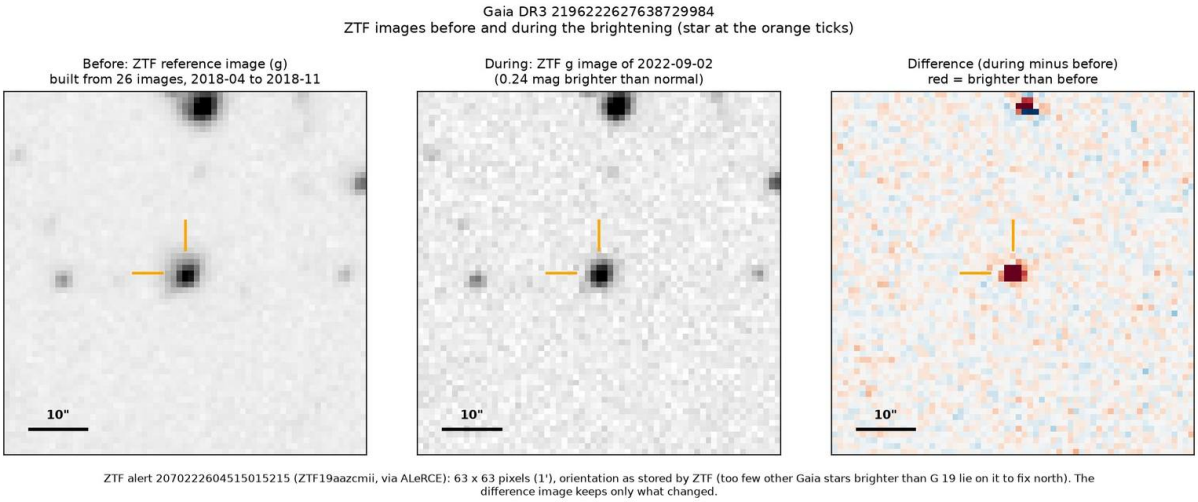



**Figure 16:** Candidate 4, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the brightening. Middle: an image taken during the brightening. Right: the difference between them, in which red means brighter; the star leaves a dark red spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

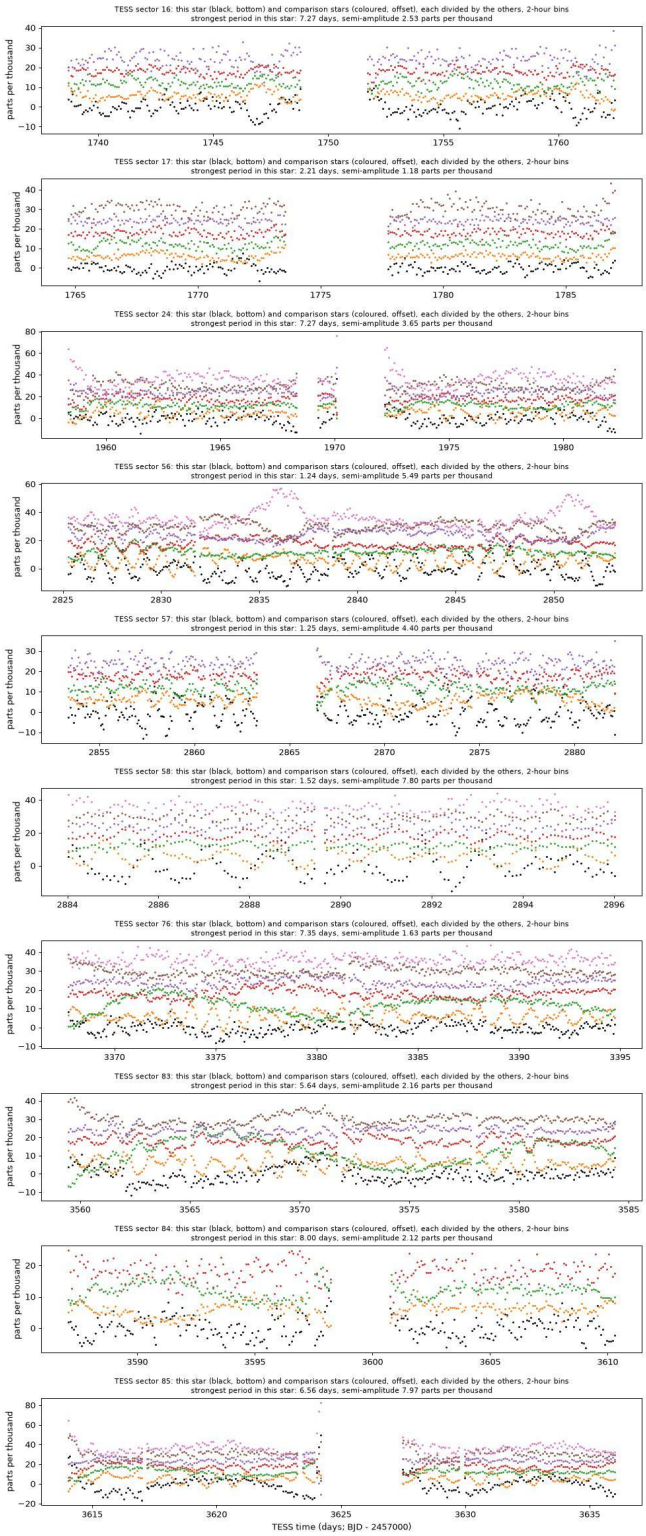



**Figure 17:** Candidate 4, TESS light curves. TESS light curves from sectors in 2019, 2020, 2022 and 2024, one panel per sector. The 1.24-day cycle shows in the panels for September and October 2022, during the brightening, and a 1.52-day cycle in November 2022. In each panel the star is in black at the bottom, below comparison stars on the same images, each divided by the others, averaged over two hours and offset for clarity. Data: TESS (NASA; MAST).

## Candidate 5: An orange dwarf that brightened for a decade

| | |
|---|---|
| **Star** | Gaia DR3 381248613189061632, an orange K dwarf |
| **Position** | RA 9.67009°, Dec +41.53879° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Andromeda, 0.8 degrees north-west of the Andromeda Galaxy; a foreground Milky Way star, not part of that galaxy |
| **Galactic** | $l = 120.37°$, $b = -21.27°$ |
| **Distance** | about 1.3 to 1.9 kiloparsecs (4,000 to 6,000 light-years), uncertain by about 20 per cent |
| **Brightness** | Gaia $G = 17.30$ |
| **Event** | steady 1983–2002; 0.6–0.7 mag brighter in g (60–90 per cent) over 2010–2020 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is an orange dwarf, a K star, cooler and smaller than the Sun, in the constellation Andromeda. It lies 0.8 degrees north-west of the centre of the Andromeda Galaxy, but it is a Milky Way star in front of that galaxy, not part of it. Gaia estimates a temperature of about 4,900 K and a low content of heavy elements, about a tenth of the Sun's. The star is about 1.3 to 1.9 kiloparsecs (4,000 to 6,000 light-years) away and 500 to 700 parsecs below the plane of the Milky Way, so it is probably old.

For at least 20 years it stayed at one faint level: photographic plates from 1983, 1989 and 1993, the 2MASS survey in 2000 and the Sloan survey in 2002 all agree. From about 2010 it brightened steadily, and four surveys followed the rise: Pan-STARRS1 from 2009 to 2014, the Palomar Transient Factory from 2010 to 2014, Gaia from 2014 to 2017 and ZTF from 2018 to 2025. By 2020 the star was 0.6 to 0.7 magnitudes brighter in green light and 0.5 to 0.7 magnitudes brighter in red light, which is 60 to 90 per cent more light. Since 2020 the rise has almost stopped, at about 0.01 magnitudes per year. In the infrared, at 3.4 microns, the star brightened by only about 0.2 magnitudes. The 1953 plates are less precise, and they disagree with each other: the blue plate shows the faint level, and the red plate a level between faint and bright.

**Why it might matter.** Ordinary, slowly spinning dwarf stars do not brighten by more than half a magnitude over a decade. Magnetic activity cycles change such stars by a few hundredths of a magnitude, up to about 0.1, and the change repeats. This change is several times larger and has gone one way only. Within each survey the star became bluer as it brightened, with blue light rising faster than red. From night to night it varies only slightly: by 0.001 to 0.006 magnitudes within a month in Gaia, and by about 0.02 in ZTF. Analysed one observing season at a time, however, the ZTF data from 2018 to 2025 show a small repeating wobble of about 2 per cent, larger in green than in red, as starspots produce. The same period comes back in 9 of 16 data sets, each covering one season in one colour, whereas none of 30 nearby stars of the same brightness, analysed in the same way, repeats a period in more than five. The period is most likely 1.19 days, but because ZTF observes once a night, 0.86 days and 6.1 days cannot be excluded. Any of these means that the star rotates fast, so it is magnetically active and spotted. An old K dwarf spins this fast only if a close companion keeps it spinning, so the star is probably a close binary.

That leaves two explanations. The first is dust clearing: a dusty cloud or disc that had dimmed the star for decades moved out of the line of sight. Ordinary interstellar dust would have changed the colours more than observed, but dust with a mixture of small and large grains fits. The second is a change in the star itself. The colours, and the small infrared change, also fit a hotter surface or fewer cool, dark spots. The star would have to be about 550 K hotter, 11 per cent, which means about 50 per cent more light, or to have lost dark spots covering half to nine tenths of its surface. Ordinary dwarf stars do neither in a decade. Fast-spinning, magnetically active dwarfs, often close binaries, are the exception: their average brightness drifts over decades as the spot cover changes. Against that reading, the star had a normal ultraviolet brightness in the 2000s, while it was still faint and its spots should have been at their strongest, and its Gaia spectrum shows no hydrogen-alpha emission, although that is a weak test at this brightness. It also rose one way for a decade after at least 20 years at one level, rather than going up and down.

A comparison with 425 similar dwarf stars makes a starspot cycle the likelier explanation. Ten of them changed by 0.45 magnitudes or more from Pan-STARRS1 to ZTF, and seven of those ten spin fast, this star

among them. Measured against field stars of the same colour, two fast-spinning dwarfs brightened by 0.3 to 0.4 magnitudes over those years, and two spotted active binaries by 0.6 to 0.8. On the same measure this star brightened by about 0.5 magnitudes. Dust is still favoured by the one-way rise after decades at one level and by the normal ultraviolet brightness while the star was faint, but nothing shows the dust directly.

**Checks against the record.** SIMBAD and VSX (the variable-star index) list nothing known about the star, and Gaia's variability summary assigns it no class. Gaia's fit to its motion on the sky is that of a normal single star (its single-star statistic, RUWE, is 1.02). There is no other Gaia source within 15 arcseconds, and no star moving with it within 2 arcminutes. Catalogues from ROSAT, XMM-Newton and Chandra for this part of the sky, and Swift ultraviolet catalogues, show nothing. An XMM-Newton image from 2017 does not detect the star, so it is not a strong X-ray source: the limit is below about $10^{30}$ erg/s. Its GALEX ultraviolet brightness is normal for an orange dwarf of this colour, compared with 238 similar stars, so there is no sign of strong activity or of a hot companion. Forty-one stars of similar brightness within 6 arcminutes do not show the trend in the Palomar Transient Factory data, so it is not a calibration drift. Measured directly against two steady neighbours in the same images, the star brightens by the same amount as in the survey catalogues.

**Why this estimate.** The decade-long rise is certainly real. But ZTF shows a small repeating wobble in brightness, most likely every 1.19 days, which marks the star as fast-spinning and magnetically active, probably a close binary. Other spotted active stars have changed by comparable amounts, so a giant starspot cycle is the likelier cause. What still favours dust is the one-way rise after decades at one level, and a normal ultraviolet brightness while the star was faint.

**Caveats.** LAMOST and the Sloan survey, the public archives checked for a spectrum, have none of this star, so its type and the cause of the change rest on Gaia's colours. The faint level before 2010 comes from photographic plates, precise to 0.05 to 0.12 magnitudes, and from one Sloan visit; an independent scan of the same plates agrees within the errors. The rotation period is uncertain (1.19, 0.86 or 6.1 days). A rare kind of variable star that behaves like this cannot be ruled out.

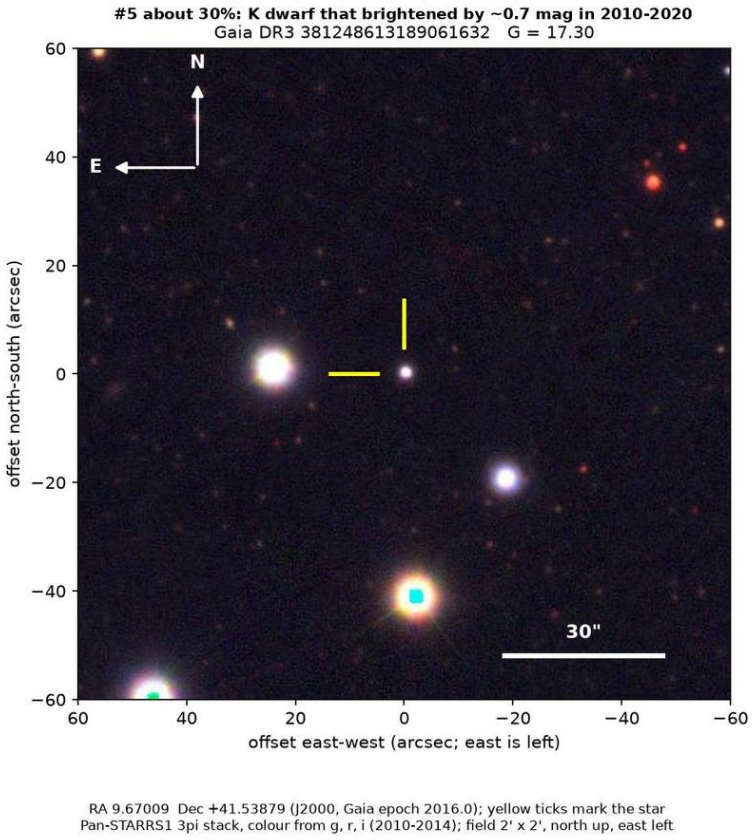



**Figure 18:** Candidate 5, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the small dot between the yellow ticks, and the brighter stars nearby are unrelated. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

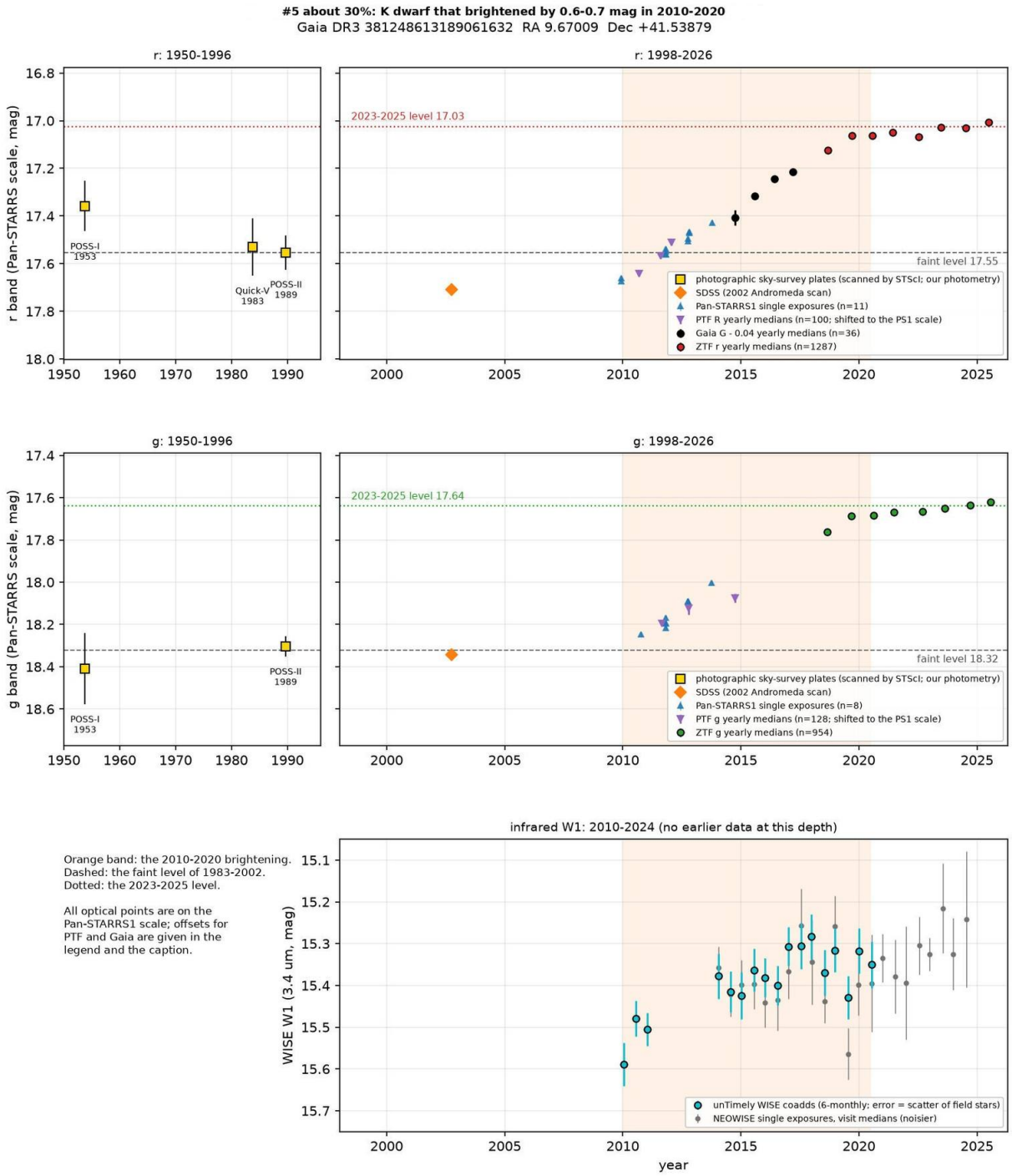



**Figure 19:** Candidate 5, light curve. Brightness from 1953 to 2025. Top row: red light. Middle row: green light. The left panels are photographic plates from 1953 to 1993, and the right panels digital surveys from 2002 to 2025. Bottom: WISE at 3.4 microns. Visible-light points are put on the Pan-STARRS1 scale using the overlap with Pan-STARRS1 and 53 nearby stars: Palomar Transient Factory points are shifted by +0.09 magnitudes in red and +0.05 in green, and Gaia's broad band by −0.04. The dashed line is the old faint level, the dotted line is the 2023 to 2025 level, and orange marks 2010 to 2020. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); Digitized Sky Survey (STScI); SDSS; PTF (Caltech/IPAC); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

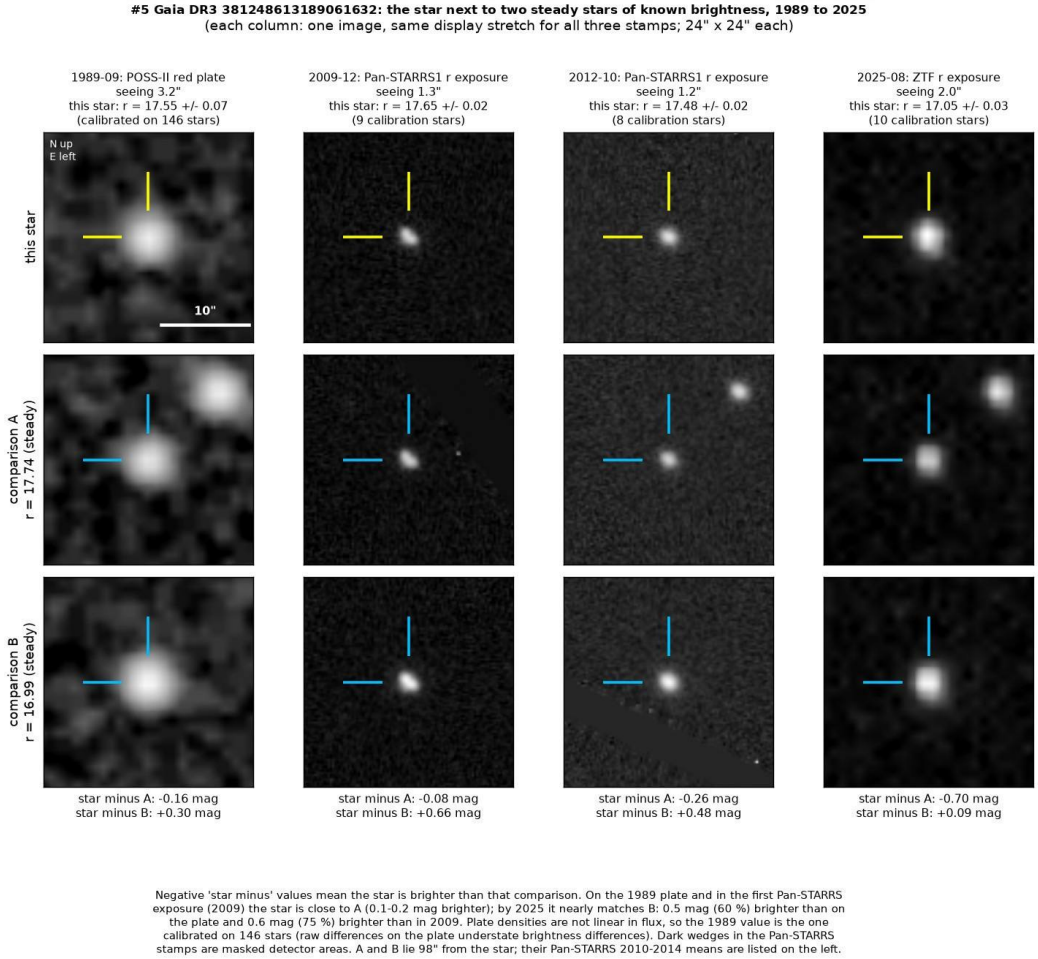



**Figure 20:** Candidate 5, before and after images, 1989 to 2025. The star beside two steady comparison stars, A at r = 17.74 and B at r = 16.99, on the 1989 red photographic plate, in Pan-STARRS1 r images from December 2009 and October 2012, and in a ZTF r image from August 2025. In 1989 and 2009 the star looks like the fainter star A; by 2025 it looks almost like the brighter star B. These are the images themselves, not difference images. A negative "star minus A" value on the figure means the star is brighter than A. Data: Pan-STARRS1 (STScI/MAST); Digitized Sky Survey (STScI); ZTF (Caltech/IPAC).

## Candidate 6: An orange dwarf near the Omega Nebula that dimmed and recovered

| | |
|---|---|
| **Star** | Gaia DR3 4096419827121636736, an orange K dwarf |
| **Position** | RA 275.11834°, Dec −18.01907° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Sagittarius, 1.8 degrees from the Omega Nebula |
| **Galactic** | $l = 13.43°$, $b = -1.55°$ |
| **Distance** | about 1.5 kiloparsecs (5,000 light-years), uncertain by about 10 per cent |
| **Brightness** | Gaia $G = 16.56$ |
| **Event** | faded by about 0.2 mag from 2010 to 2014, then brightened by about 0.5 mag until 2022 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 25% |

**What changed.** The star is an orange dwarf in Sagittarius, in the plane of the Milky Way, 1.8 degrees from the Omega Nebula, a region where stars are still forming. Gaia estimates its temperature at about 5,050 K. It is about 1.5 kiloparsecs (5,000 light-years) away, with an uncertainty of about 10 per cent, similar to the distance of the nebula, and it lies in a crowded field. Pan-STARRS1 saw it fade by about 0.2 magnitudes in green, red and near-infrared light from 2010 to 2014, or by 0.4 magnitudes in green if a single 2009 measurement is included. SkyMapper from 2014 to 2021, Gaia from late 2014 to mid-2017 and ZTF from 2018 to 2025 then followed a rise of about 0.5 magnitudes, which ended around 2022; the star has been flat since. Where the surveys overlap, they agree. The star is now about 0.1 magnitudes brighter than in the 2009 measurement and 0.2 to 0.35 magnitudes brighter than in 2010 to 2012.

**Why it might matter.** Ordinary quiet dwarf stars do not dim and recover by half a magnitude over a decade. This star is quiet from night to night: the ZTF scatter equals the measurement errors, and there is no rotation period. Its Gaia spectrum shows no hydrogen emission. The dimming was deeper in blue light than in red, as dust would cause, so a dusty cloud passing in front of the star is one explanation. The pattern can also be read as a slow brightening interrupted by a dip around 2014.

**Checks against the record.** SIMBAD lists nothing known about the star. The variable-star index lists it only because it copies Gaia's machine classification, and Gaia alerts, published variable-star lists and arXiv show nothing. Gaia's images show a single star, despite 15 fainter stars within 10 arcseconds; the three nearest are circled on the finder chart. About 30 nearby stars of similar brightness did not fade like this in Pan-STARRS1, and 22 did not change like this in ZTF.

**Why this estimate.** Four instruments recorded the change, and nearby stars rule out a drift in the surveys themselves. But the star may be young, and long dimmings by dust are a known behaviour of young stars. The fading half of the event rests on Pan-STARRS1 alone, and the star is now brighter than in 2010, so the dip may be only a pause in a slow rise. Slow changes of a few tenths of a magnitude are also common among similar dwarfs, often the spotted, fast-spinning ones. This star shows no rotation, which argues against that, but a rise and fall driven by magnetic activity cannot be ruled out.

**Caveats.** The star may be young, and long dimmings by dust are a known behaviour of young stars with dusty discs. It lies 0.7 magnitudes above the main sequence for its colour, which fits a young star or an unresolved binary, and it is at about the distance of the Omega Nebula's star-forming region. It shows no hydrogen emission, and the infrared images are too blended to test for warm dust. The fading half rests on Pan-STARRS1 alone: the three 2014 measurements come from one poor night and are each uncertain by 0.2 magnitudes, although SkyMapper confirms that level a month later. The level before 2009 is unknown. No spectrum of the star exists in the public archives that were checked. Gaia's classifier calls it a spotted active star, with a low score.

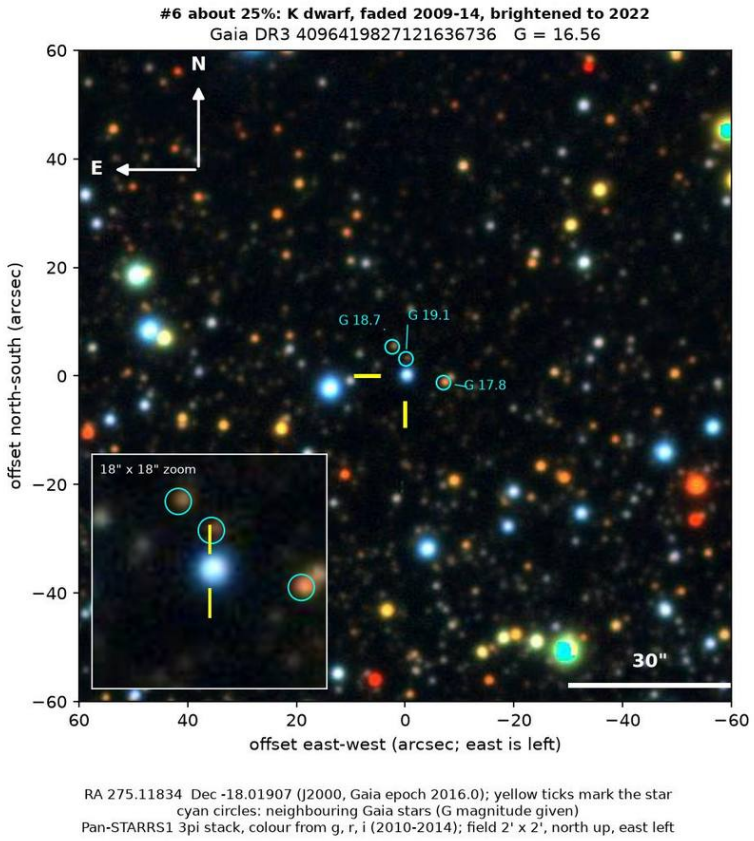



**Figure 21:** Candidate 6, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks. The cyan circles mark the three nearest fainter stars, and the inset enlarges them. The brighter blue star 14 arcseconds to the east is unrelated: Gaia puts it about four times farther away, and it moves differently. North is up, east is left, and the white bar is 30 arcseconds. No single survey imaged the star both near its faintest, in 2014, and at its 2009 or 2022 to 2025 level, so there is no before-and-after picture. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

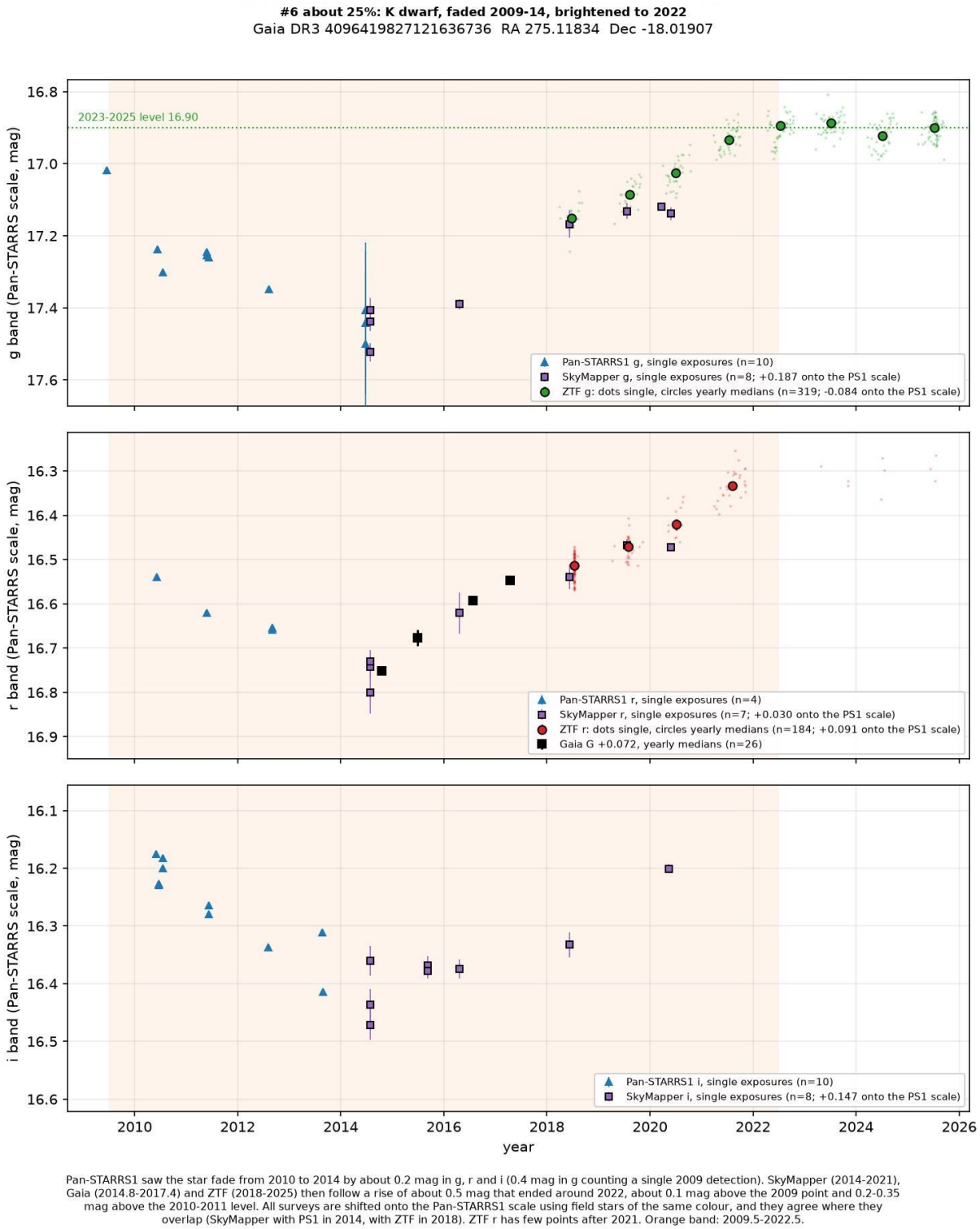



**Figure 22:** Candidate 6, light curve. Brightness from 2009 to 2025 in green, red and near-infrared light. Every survey is put on the Pan-STARRS1 scale using field stars of the same colour. The dotted line is the 2023 to 2025 level, and orange marks 2009.5 to 2022.5, that is, mid-2009 to mid-2022. The Pan-STARRS1 points with large error bars come from one poor night in 2014. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); SkyMapper (ANU); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

## Candidate 7: An orange dwarf in Aquarius, brighter today than on any photographic plate since 1951

| | |
|---|---|
| **Star** | Gaia DR3 6908199778856910464, an orange K dwarf |
| **Position** | RA 309.76240°, Dec −5.83758° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Aquarius, 27 degrees below the plane of the Milky Way |
| **Galactic** | $l = 40.30°$, $b = -26.55°$ |
| **Distance** | about 1.2 to 1.8 kiloparsecs (4,000 to 6,000 light-years); the two Gaia estimates differ by about 50 per cent |
| **Brightness** | Gaia $G = 16.71$ |
| **Event** | 0.5–0.9 mag fainter in blue-green light on every plate from 1951 to 1994 than today; still brightening |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 15% |

**What changed.** The star is an orange dwarf in Aquarius, 27 degrees below the plane of the Milky Way, in a region where most stars are old. Gaia estimates its temperature at about 5,300 K and finds a low content of heavy elements, about a tenth of the Sun's, though that is a rough figure for a star this faint. It is about 1.2 to 1.8 kiloparsecs (4,000 to 6,000 light-years) away and 500 to 800 parsecs below the Galactic plane, and no other Gaia star lies within 10 arcseconds. On every photographic plate from 1951 to 1994 the star is fainter than it is today: by 0.5 to 0.9 magnitudes in blue-green light, 0.5 to 0.65 in red light and 0.3 in the near infrared. Two separate measurements of each plate agree, except on the 1982 blue plate, where they differ by 0.2 magnitudes. From 2009 to 2014 Pan-STARRS1 sees the star brightening faster than any of 13 to 15 field stars measured in the same way. From late 2014 to mid-2017 Gaia sees a steep rise of 0.08 magnitudes a year, and SkyMapper agrees. From 2018 to 2025 ZTF sees a slight fade until 2021, followed by a further rise. Between the Pan-STARRS1 and ZTF measurements the star brightened by 0.36 magnitudes in green light and 0.33 in red, relative to 15 field stars of similar colour, which themselves changed by at most 0.05 magnitudes. Blue light changed more than red, and the infrared, at 3.4 microns, changed least, by about 0.1 magnitudes.

**Why it might matter.** A rise of almost a magnitude in blue-green light over 70 years is large for an ordinary dwarf star, and it is the same kind of change as in candidate 5 . The low estimate concerns the cause, not whether the star got brighter. Gaia's rotation analysis found that the star spins once every 3.9 days and carries large dark spots, so its brightness varies by about 0.05 magnitudes as they rotate in and out of view. ZTF's night-to-night scatter is 1.3 times what its measurement errors would predict, against 1.0 for field stars, and the hydrogen absorption line is slightly filled in, as in other spotted stars. If the star is as old as its low heavy-element content and its height below the plane suggest, then spinning this fast means it is most likely a close binary whose two stars are locked to each other's orbit. Such stars are known to drift by several tenths of a magnitude over decades as their magnetic activity waxes and wanes. In a comparison sample of stars that Gaia flags as spotted or active, a few per cent changed by half a magnitude or more over the past decade, and among 176 rotating stars detected by Gaia this star's change in green light is the third largest. The ZTF fade and the renewed rise also look more like a cycle than a one-way change.

**Checks against the record.** SIMBAD has only the Gaia entry, from Gaia's rotation catalogue, and the variable-star index only copies that result: type ROT, period 3.908 days. Gaia alerts, published variable-star lists, X-ray and ultraviolet catalogues, and arXiv show nothing. Two brighter stars 11 arcseconds away are unrelated, because their motions across the sky differ by more than 6 milliarcseconds a year. They do, however, sit inside the ring used to measure the plate background. Field stars with a similar bright neighbour show no offset, to within 0.05 magnitudes, and measuring the plates again with the neighbours masked makes the old-plate offsets 0.05 to 0.15 magnitudes smaller. Those masked values are the ones used here.

**Why this estimate.** The brightening is certainly real: two separate measurements of each photographic plate agree, and Pan-STARRS1, Gaia, SkyMapper and ZTF all see the rise when it is measured against field stars. But Gaia lists the star as a spotted rotator with a 3.9-day period, its hydrogen line is slightly filled in, and

ZTF sees extra night-to-night scatter, so it is an active star, probably a close binary. A long starspot cycle explains a change of this size more simply than dust does.

**Caveats.** A starspot cycle is the likelier explanation, and dust the less likely one. Each plate is good to about 0.1 magnitudes, there are only two plates per colour, and the two measurements disagree on the 1982 blue plate. In near-infrared light the star was already at its 2010 to 2014 level in 1994, so in red light most of the change may be recent. No spectrum of the star exists in the public archives that were checked. A change of half a magnitude is hard to see by eye on the plates, so there is no before-and-after picture.

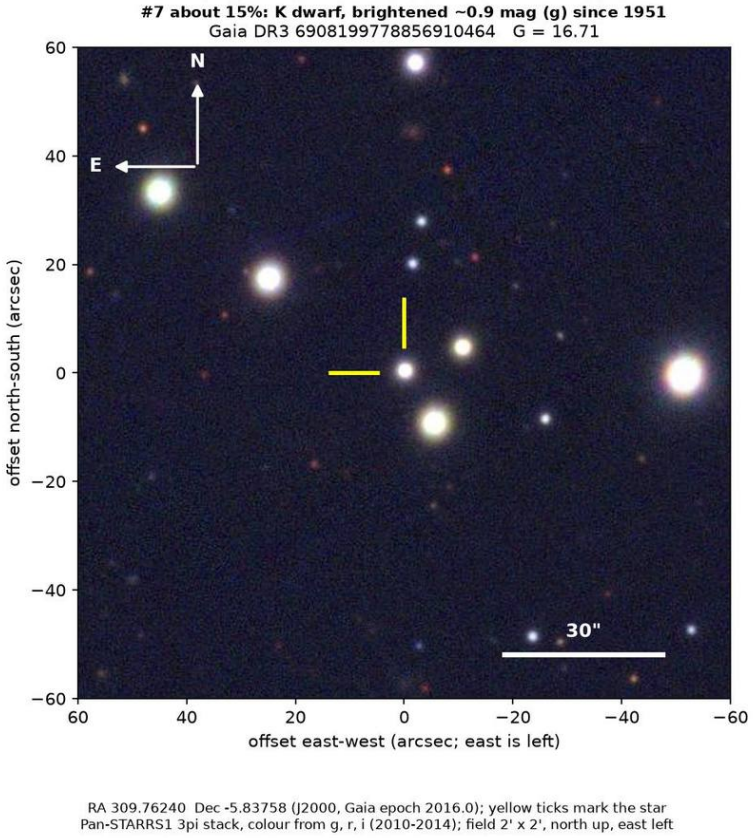



**Figure 23:** Candidate 7, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks. The bright star just below it to the right, to the south-west, is an unrelated neighbour. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

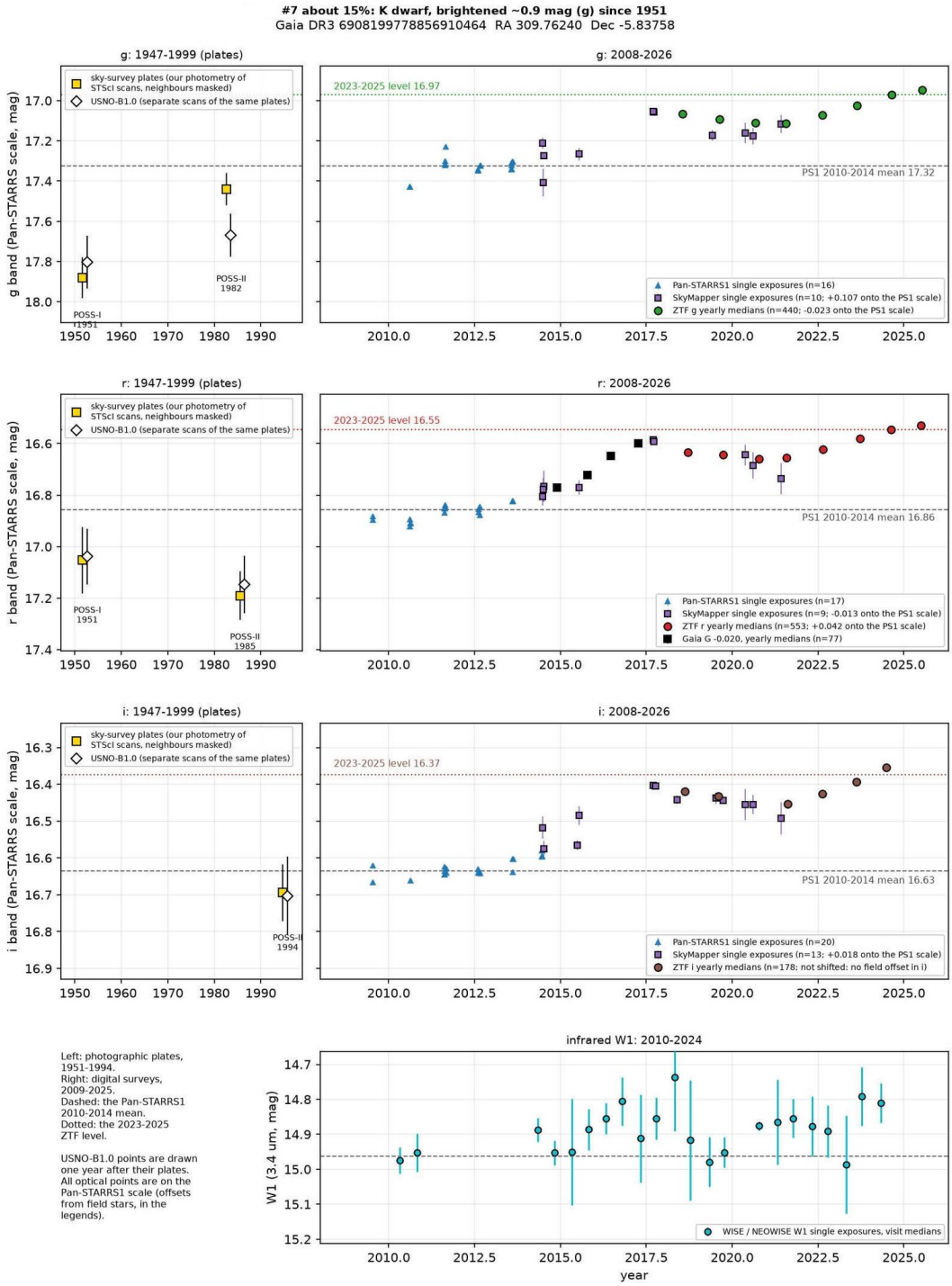



**Figure 24:** Candidate 7, light curve. Brightness in green, red and near-infrared light. Left: photographic plates from 1951 to 1994, measured with the neighbouring stars masked, alongside values from a second catalogue, which are plotted one year later for clarity. Right: Pan-STARRS1, SkyMapper, Gaia and ZTF from 2009 to 2025. Bottom: WISE at 3.4 microns from 2010 to 2024. Every survey is put on the Pan-STARRS1 scale using field stars of the same colour. The dashed line is the 2010 to 2014 mean, and the dotted line is the 2023 to 2025 level. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); Digitized Sky Survey (STScI); SkyMapper (ANU); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 8: A faint spot on 1955 plates that is no longer there

| | |
|---|---|
| **Source** | USNO-B1 1345-0235496, a source seen only on photographic plates from 1955; no Gaia star lies within 53 arcseconds |
| **Position** | RA 183.19213°, Dec +44.57734° (J2000) |
| **Where** | In Canes Venatici, far from the Milky Way |
| **Galactic** | $l$ = 144.38°, $b$ = +70.91° |
| **Distance** | unknown |
| **Brightness** | red magnitude 18.1 and blue magnitude 21.2 on the 1955 plates; nothing seen there since |
| **Event** | on both POSS-I plates of 1955 Feb 28 (red 18.1, blue 21.2 mag); in no later image |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded case of the kind described: about 3% |

**What changed.** In 1955 the Palomar Sky Survey photographed this patch of sky in blue and red light on the same night. Both plates show a faint, star-like spot at the same position, to within 1.4 arcseconds, with a red magnitude of about 18.1 and a blue magnitude of about 21.2. Nothing has been found there since: no star in Gaia, nothing in Pan-STARRS1 within 8 arcseconds, nothing in the Legacy Surveys, 2MASS or WISE within 3 arcseconds, and nothing on the later Palomar red plate or in the much deeper Legacy Surveys images. No known asteroid was there, a moving object would not have appeared at the same place on two plates taken at different times, and no fast-moving Gaia star passes through the spot.

**Why the estimate is low.** Light from the sky is always blurred at least as much as the stars on the same plate, but on the red plate the spot is 3.2 arcseconds across, sharper than every real star on it (3.8 to 6.3 arcseconds). That is how flaws in a photographic emulsion look. The blue detection is weak, 4.6 times the noise; a noise peak this strong at the same spot turns up for about one source in 170, so about one in eight searches of this size would turn up such a coincidence. If the spot was real, it would be one of the few known stars that seem to have vanished, which are interesting because a star should not simply disappear.

**Checks against the record.** The published list of vanishing sources of Solano et al. (2022) could not be checked, so this source may already be on it.

**Why this estimate.** The spot is on both photographic plates taken at Palomar on the night of 28 February 1955, one in red and one in blue light, at the same place, and nothing has been seen there since. But on the red plate it is sharper than every real star, which is what a flaw in the emulsion looks like, and on the blue plate it is barely above the noise, so the most likely explanation is a plate flaw that happened to fall where a noise peak was.

**Caveats.** The red image is sharper than any real star on the plate and the blue one is close to the noise, so a plate flaw is the likelier explanation. The list of vanishing sources of Solano et al. (2022) could not be checked.

**Figure note.** No light curve was published for this candidate; the brightness history in Figure 26 was made for this paper (Section 3.10).

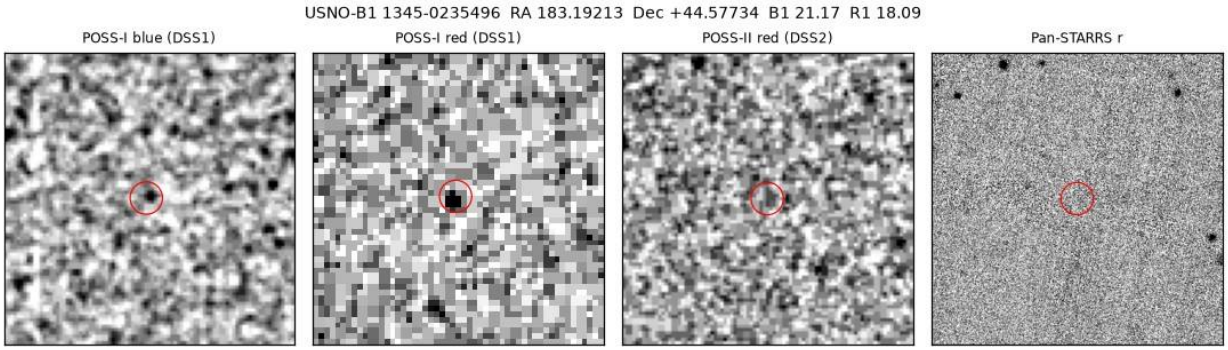



**Figure 25:** Candidate 8, sky images, 1955 to 2014. From left to right: the first Palomar Sky Survey blue and red plates of 1955 (Digitized Sky Survey 1), the second Palomar Sky Survey red plate (Digitized Sky Survey 2) and Pan-STARRS1 in red light (2010 to 2014). The spot is visible inside the circle on both 1955 plates and absent from the two later images. Dark means bright. Data: Pan-STARRS1 (STScI/MAST); Digitized Sky Survey (STScI).

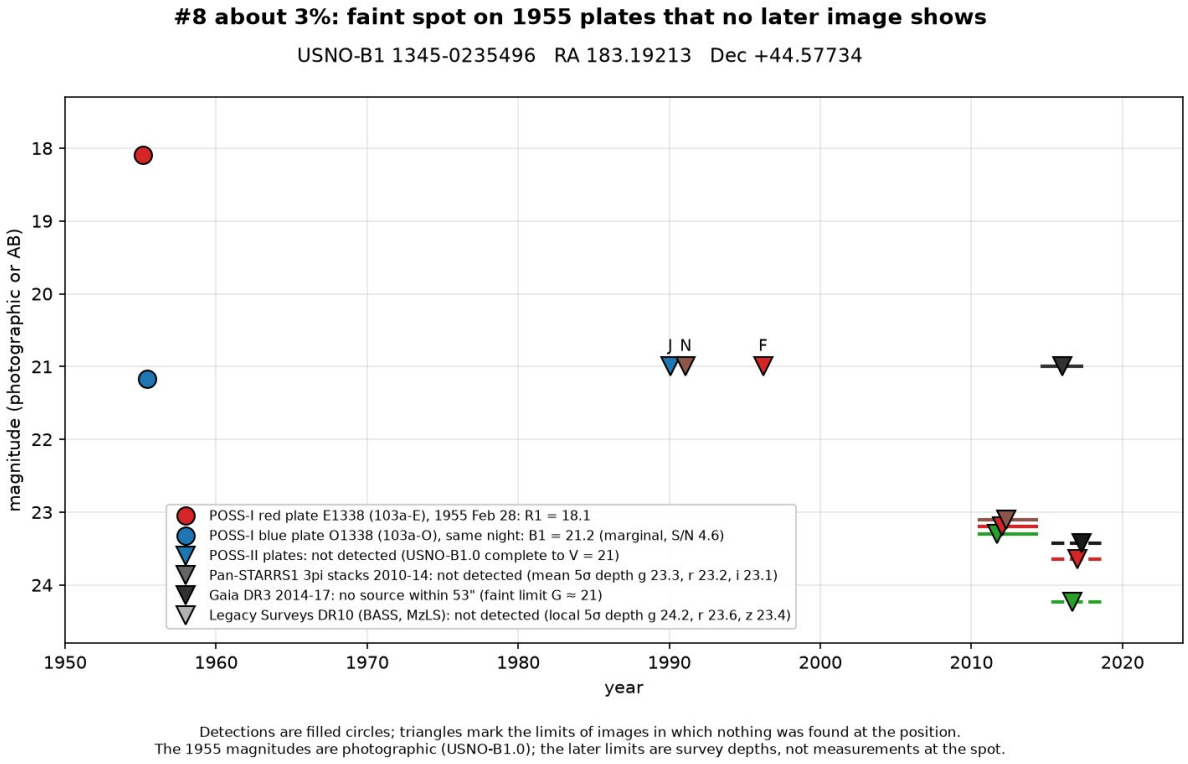



**Figure 26:** Candidate 8, brightness history made for this paper. Filled circles: the two detections on the POSS-I plates of 1955 February 28, with their USNO-B1.0 magnitudes (red 18.1 on plate E1338, blue 21.2 on plate O1338). Triangles: images in which nothing was found at the position, plotted at the depth of each: the POSS-II blue (IIIa-J, 1990 January 28), near-infrared (IV-N, 1991 February 2) and red (IIIa-F, 1996 March 16) plates at the USNO-B1.0 completeness limit, $V = 21$ (Monet et al. 2003); Gaia DR3 (2014–2017) at its faint limit, $G \approx 21$ (Gaia Collaboration et al. 2021); the Pan-STARRS1 $3\pi$ stacks (2009–2014) at their mean $5\sigma$ point-source depths, $g = 23.3$, $r = 23.2$, $i = 23.1$ (Chambers et al. 2016); and the Legacy Surveys DR10 images (BASS and MzLS) at the local $5\sigma$ point-source depths, $g = 24.2$, $r = 23.6$, $z = 23.4$, measured from the ten catalogued sources within 30 arcsec (none lies within 14 arcsec of the position). Plate dates are from the Digitized Sky Survey headers. The later points are survey depths, not measurements at the spot. Data: Digitized Sky Survey (STScI); Pan-STARRS1 (STScI/MAST); DESI Legacy Imaging Surveys (NOIRLab); ESA/Gaia/DPAC.

## Candidate 9: A star that brightened by 60% for about two months

| | |
|---|---|
| **Star** | Gaia DR3 4145977633638478336 |
| **Position** | RA 272.16646°, Dec −15.31958° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Serpens |
| **Galactic** | $l$ = 14.45°, $b$ = +2.22° |
| **Distance** | parallax 0.11 ± 0.05 milliarcseconds, so several thousand parsecs away |
| **Brightness** | Gaia $G$ = 16.04 |
| **Event** | brightened once, by up to 0.46 mag (about 60 per cent), for about two months in early 2016 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 60% |

**What changed.** This is a distant star in Serpens, in the direction of the inner Galaxy, 2.2 degrees above the mid-plane of the Milky Way and 14 degrees from the Galactic centre. Its parallax, Gaia's measure of distance, is 0.11 ± 0.05 milliarcseconds, which puts it several thousand parsecs away, in a crowded field. Gaia measured it 28 times between 2014 and 2017. It was steady except in early 2016, when it was 0.46 magnitudes brighter than normal at 2016.18, 0.36 at 2016.26 and 0.15 at 2016.32, and it was back to normal by 2016.7. In each of those visits the blue, green and red bands agree to within 0.05 magnitudes.

Two other telescopes caught the event. NEOWISE, at 2016.22, close to the peak, found the star 0.52 magnitudes brighter than normal at 3.4 microns and 0.56 magnitudes brighter at 4.6 microns. SkyMapper, at 2016.30, found it 0.19 to 0.23 magnitudes brighter in the r, i and z filters, when Gaia had it about 0.20 magnitudes brighter. NEOWISE observed the star twice a year from 2014 to 2024, and ZTF observed it from 2018 to 2025; neither saw anything else.

**Why it might matter.** Gravitational lensing brightens a star once, smoothly, and by the same factor at every wavelength. This star brightened by the same amount in eight bands, from blue light to 4.6 microns, by between 0.2 and 0.5 magnitudes depending on the date, and only once in ten years. Outbursts and flares, by contrast, change colour strongly, and no ordinary variable star is known to brighten like this. Gaia's classifier labelled it as microlensing.

**Checks against the record.** The event may be new. It is not in Gaia's published list of 363 microlensing events, it has no Gaia alert, and it has no entry in SIMBAD, VSX (the variable-star index) or the Transient Name Server. Nothing about it appears on arXiv either. It is not in the OGLE or KMTNet microlensing lists for 2014 to 2018, nor in OGLE's published list of events in the Galactic disc (Mróz et al. 2020). Microlensing is an expected kind of event, not an exotic one.

**Why this estimate.** Three instruments recorded the same brightening in eight bands, from blue light to the infrared, which makes this the strongest evidence for lensing among these candidates. But Gaia caught the event in only three visits, so its shape alone does not establish lensing, and the star lies in a sparsely observed OGLE field that lists no event.

**Caveats.** Gaia caught the event in only three visits, with five measurements, so the shape alone cannot prove lensing: a plain symmetric bump fits as well, and the lensing timescale, about 30 days, is only a rough estimate. The case rests on the colours agreeing and on three instruments seeing the same thing. The star sits 0.4 degrees from the centre of an OGLE field, BLG767, which was imaged 80 times over about three years; those images may or may not cover early 2016. Four faint stars, with G from 19.7 to 20.6, lie within 5 arcseconds, and a star of G = 17.4 lies 6.9 arcseconds away. WISE cannot separate them, but the infrared brightening matches Gaia's, so the change in light belongs to this star.

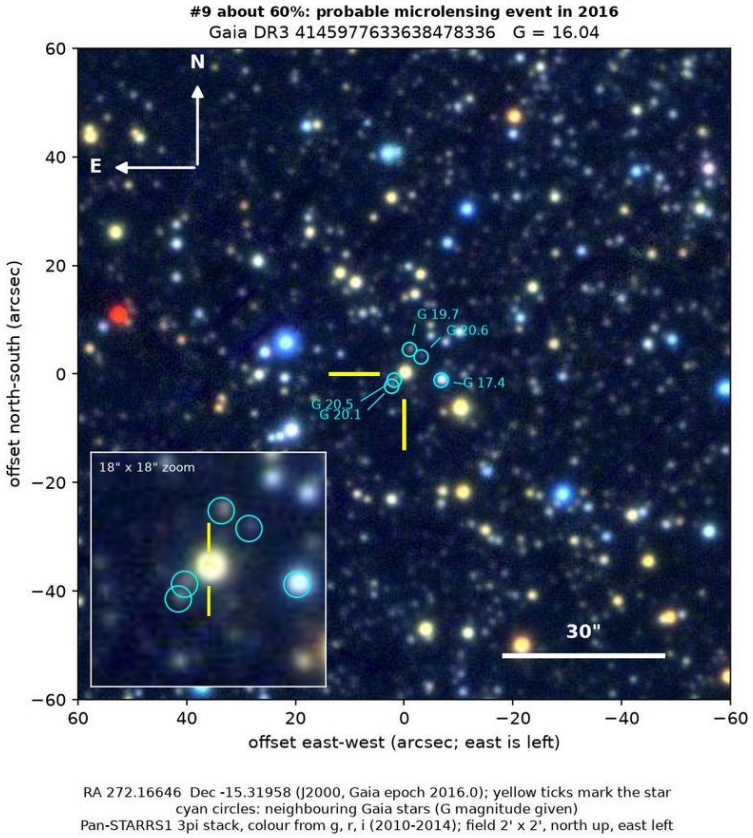



**Figure 27:** Candidate 9, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks, and the inset at lower left enlarges the central 18 by 18 arcseconds. North is up, east is left, and the white bar is 30 arcseconds. SkyMapper's image at 2016.30 caught the decline, when the star was about 20 per cent brighter than normal, a difference too small to see by eye, so there is no before-and-after picture. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

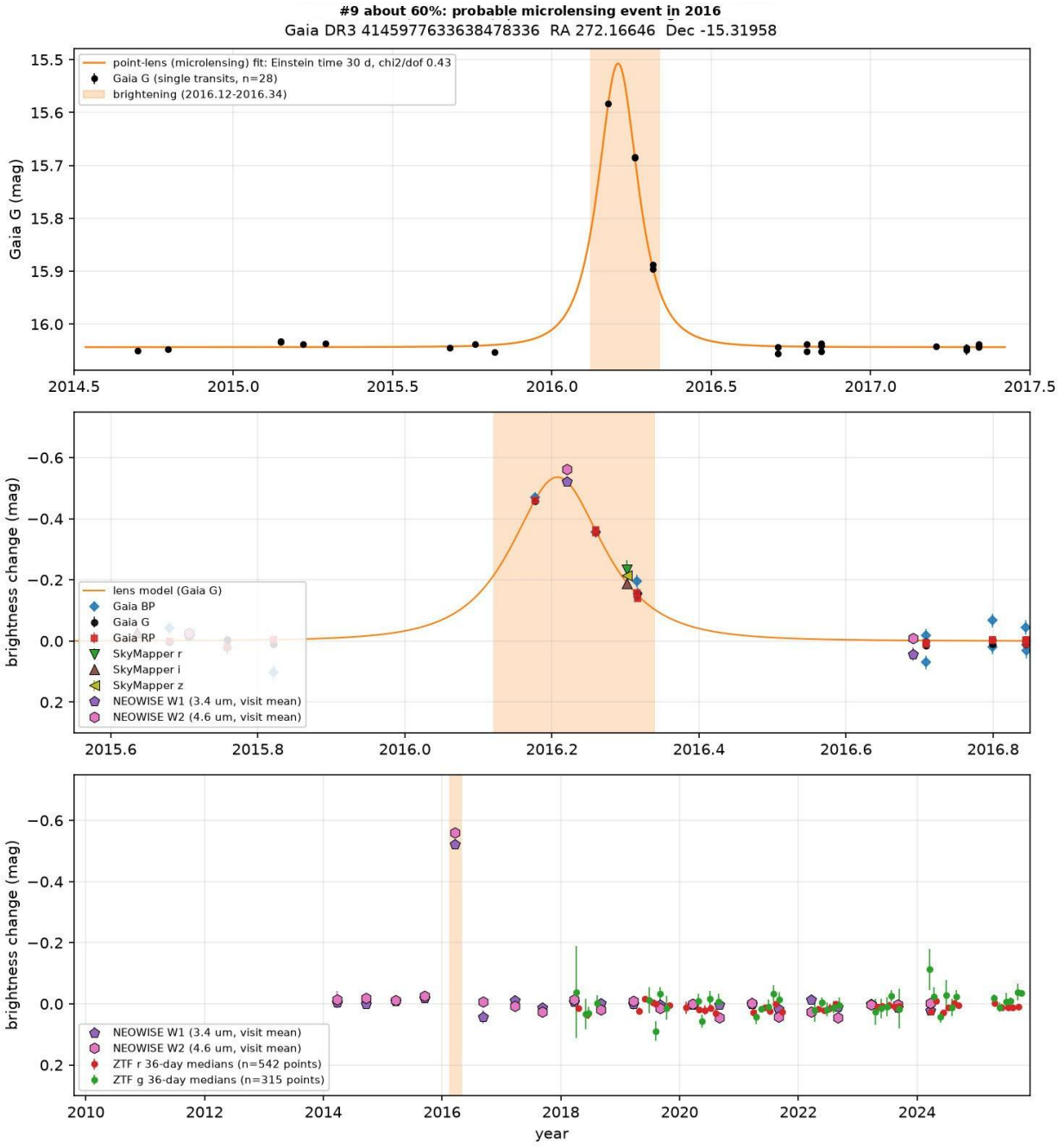



**Figure 28:** Candidate 9, light curve. Top: every Gaia G measurement, with the lensing model. Middle: the event in every band that caught it, from Gaia, SkyMapper and NEOWISE, each relative to its own normal level. Bottom: NEOWISE from 2014 to 2024 and ZTF from 2018 to 2025. Down means fainter, and orange marks the single brightening. Data: SkyMapper (ANU); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 10: A star that brightened by 70% for a few months

| | |
|---|---|
| **Star** | Gaia DR3 5620272814897694848; Gaia's fit to its colours suggests a hot star, about 8,100 K |
| **Position** | RA 112.12679°, Dec −20.68682° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Puppis |
| **Galactic** | $l = 235.47°$, $b = -1.55°$ |
| **Distance** | parallax 0.14 ± 0.06 milliarcseconds, so several thousand parsecs away, behind a lot of dust |
| **Brightness** | Gaia $G = 17.10$ |
| **Event** | brightened once, by 0.6 mag (70 per cent), peaking near 2015.15; normal by late 2015 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 55% |

**What changed.** This is a distant star in Puppis, 1.5 degrees below the mid-plane of the Milky Way and roughly opposite the Galactic centre. Its parallax, Gaia's measure of distance, is 0.14 ± 0.06 milliarcseconds, which puts it several thousand parsecs away, behind a lot of dust. Gaia's fit to its colours suggests a hot star, about 8,100 K. Gaia measured it 71 times between 2014 and 2017, and it was steady except at the start: it rose from late 2014, peaked around 2015.15 at 0.6 magnitudes brighter than normal (1.7 times the light), was nearly back to normal by mid-2015 and was fully back by late 2015.

Two other telescopes caught the same event. SkyMapper, in Australia, saw it on three nights around 2014.97, when the star was 0.06 to 0.20 magnitudes brighter, typically 0.14, in its r, i and z filters, and Gaia had it 0.16 magnitudes brighter. NEOWISE, an infrared satellite, saw it at 2015.27, when the star was 0.31 magnitudes brighter at 3.4 microns and 0.33 magnitudes brighter at 4.6 microns, and Gaia had it about 0.30 magnitudes brighter. WISE and NEOWISE observed the star in 2010 and twice a year from 2014 to 2024, and ZTF observed it from 2018 to 2025; neither saw anything else.

**Why it might matter.** A foreground star passing almost exactly in front of a distant star focuses its light, so the distant star brightens and fades once, smoothly, and by the same factor at every wavelength. Here the brightening was the same in Gaia's blue, green and red bands and in the infrared out to 4.6 microns. The standard lensing model fits the Gaia light curve better than a plain bump does, and the brightening happened only once in 15 years. Gaia's classifier labelled it as microlensing.

**Checks against the record.** The event may be new. It is not in Gaia's published list of 363 microlensing events, it has no Gaia alert, and it has no entry in SIMBAD, VSX (the variable-star index) or the Transient Name Server. Nothing about it appears on arXiv either. It is not in the bulge event lists of OGLE or KMTNet, nor in OGLE's published list of microlensing events in the Galactic disc (Mróz et al. 2020). Events towards this side of the Galaxy are rare, which is what would make this one valuable. Microlensing is an expected kind of event, not an exotic one.

**Why this estimate.** SkyMapper and NEOWISE independently recorded a brightening that was the same from visible light out to 4.6 microns, as lensing predicts. However, OGLE's survey of the Galactic disc covered this field without listing an event, and the lens parameters are not pinned down.

**Caveats.** The star lies inside an OGLE Galactic-disc field, GD1639, which was imaged 171 times from 2013 to 2019, yet OGLE did not list an event here. OGLE's selection cuts may have dropped it, or OGLE's own data may disagree; its measurements of this star are not available to check. The lensing model is poorly pinned down: it prefers a long timescale, about 300 days, with the lensed star providing only a small part of the light, a combination that is notoriously uncertain. Gaia's colour points scatter more than their stated errors. Hot stars with gas discs, called Be stars, also brighten for months, but their outbursts brighten the infrared much more than visible light, which is not what NEOWISE saw. Three faint stars, with Gaia G from 19.6 to 20.7, lie 3 to 7 arcseconds away, but they are too faint to cause a 70 per cent brightening.

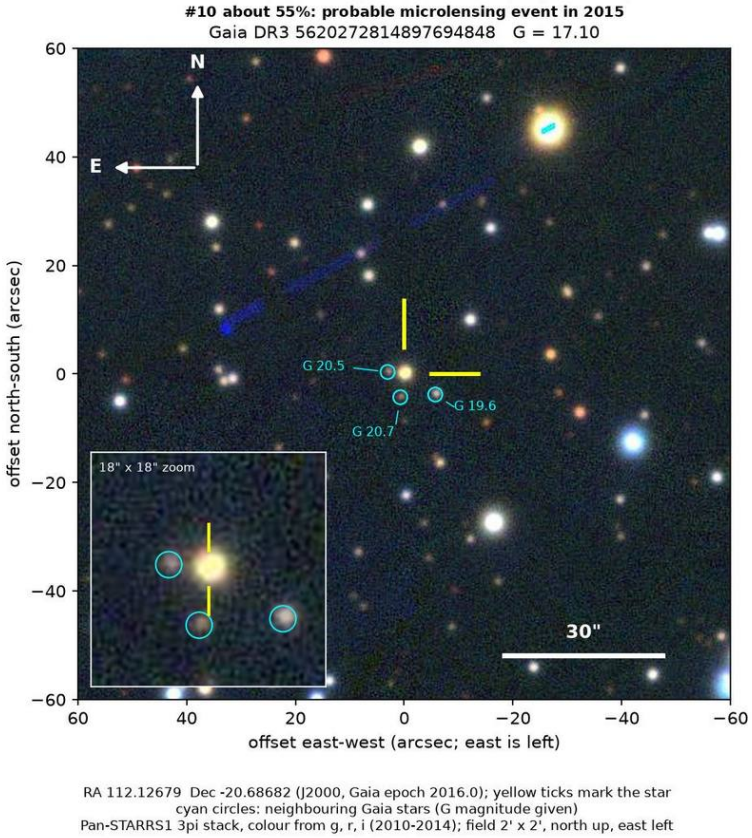



**Figure 29:** Candidate 10, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks, and the inset at lower left enlarges the central 18 by 18 arcseconds. North is up, east is left, and the white bar is 30 arcseconds. The only public images taken during the event are SkyMapper's, from around 2014.97 on the early rise, when the star was only 10 to 20 per cent brighter; that is too small to see by eye, so there is no before-and-after picture. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

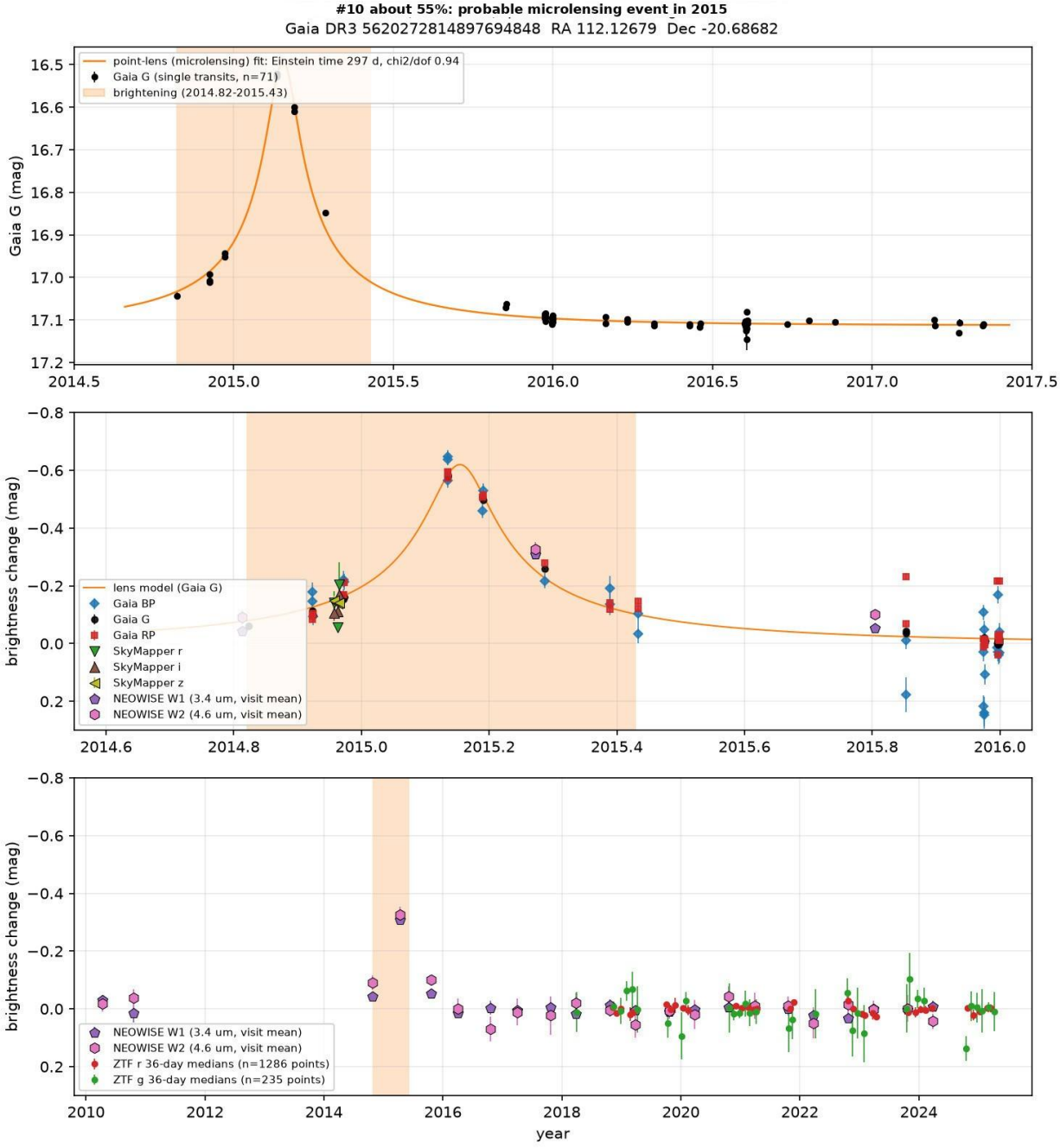



**Figure 30:** Candidate 10, light curve. Top: every Gaia G measurement, with the lensing model. Middle: the event in every band that caught it, from Gaia, SkyMapper and NEOWISE, each relative to its own normal level. Bottom: NEOWISE from 2010 to 2024 and ZTF from 2018 to 2025. Down means fainter, and orange marks the single brightening. Data: SkyMapper (ANU); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 11: A star in the direction of the Galactic bulge that brightened at least two-fold

| | |
|---|---|
| **Star** | Gaia DR3 4119926316171065984 |
| **Position** | RA 266.73508°, Dec −19.15256° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Sagittarius |
| **Galactic** | $l$ = 8.53°, $b$ = +4.81° |
| **Distance** | parallax too small to measure; the star is reddened by dust |
| **Brightness** | Gaia $G$ = 17.58 |
| **Event** | brightened once, by at least 0.83 mag (2.1 times), peaking near 2015.15 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 50% |

**What changed.** This is a star in Sagittarius, 4.8 degrees above the mid-plane of the Milky Way and about 10 degrees from the Galactic centre. It is far away, with a parallax too small to measure, and it is reddened by dust. The field is crowded: five other Gaia stars lie within 6 arcseconds. When Gaia's measurements began, in September 2014, the star was already 0.44 magnitudes brighter than normal. At 2015.15 it was 0.83 magnitudes brighter, 2.1 times the light. Then it faded: it was 0.55 magnitudes brighter at 2015.22 and 0.34 at 2015.29, and it was back to normal by mid-2015. It stayed steady until Gaia's published data end, at 2017.3, and ZTF saw nothing from 2018 to 2025. Gaia's blue, green and red bands brightened by the same amount. The peak itself fell in a gap between Gaia visits around the turn of 2014 and 2015, so the maximum brightness is unknown.

WISE cannot separate this star from a brighter neighbour 5.5 arcseconds away (Gaia G = 16.9, circled on the finder chart), so it measures the pair as one blurred source. Judging from where WISE places that blend, normally about 3.4 arcseconds from this star in the direction of the neighbour, this star gives about 40 per cent of its infrared light. WISE visited twice during the event, in September 2014 and March 2015. Both times the blended source was 0.18 to 0.26 magnitudes brighter than on every comparable visit from 2010 to 2020, visits that agree with one another to within 0.04 to 0.08 magnitudes, and the blend sat closer to this star, at 2.2 arcseconds. That is what should happen if this star brightened by the factor Gaia measured, and the lensing model predicts 0.19 to 0.24 magnitudes for the blend. Position alone would not be decisive, because one ordinary visit in 2019 also placed the source close to this star, but only the two visits during the event are both brighter and shifted.

**Why it might matter.** A foreground star passing almost exactly in front of a distant star focuses its light, so the distant star brightens and fades once, smoothly, and by the same factor in every colour. Here the standard lensing model fits all 53 Gaia measurements more closely than a plain bump does. The Gaia colours and the infrared agree, and nothing similar shows in WISE, Gaia or ZTF from 2010 to 2025. Gaia's classifier labelled it as microlensing.

**Checks against the record.** The event may be new. It is not in Gaia's published list of 363 microlensing events, it has no Gaia alert, and it has no entry in SIMBAD, VSX (the variable-star index) or the Transient Name Server. Nothing about it appears on arXiv either. The star lies outside the fields of the OGLE early-warning system, and KMTNet, which began full operations in 2016, did not list it. It is not in OGLE's list of events in the Galactic disc (Mróz et al. 2020), and it sits just outside OGLE's nearest disc fields. Microlensing is an expected kind of event, not an exotic one. One worry is that Gaia's brightness measurements rise and fall with one of Gaia's image-quality indicators, which in a field this crowded could mean a measurement artefact caused by the neighbours. A real brightening among close neighbours can produce the same correlation, however, and the WISE result shows that the change in light was real and came from this star's position.

**Why this estimate.** WISE recorded a brightening of the size that the lensing model predicts, and the infrared position shifted towards this star. But in this crowded field the size of that brightening depends on how the blended light is split between the star and its neighbour, and Gaia never observed the peak.

**Caveats.** The peak was not observed, so the maximum brightness and the lens parameters are uncertain. The size of the WISE brightening depends on how WISE splits the blend, and on one visit, in the 3.4-micron band in March 2015, it split the blend differently. No public optical survey imaged this field during the event: the NOIRLab Dark Energy Camera archive, SkyMapper and ZTF have no data from those months. WISE's images are too blurry, with a resolution of about 6 arcseconds, to show the star separately.

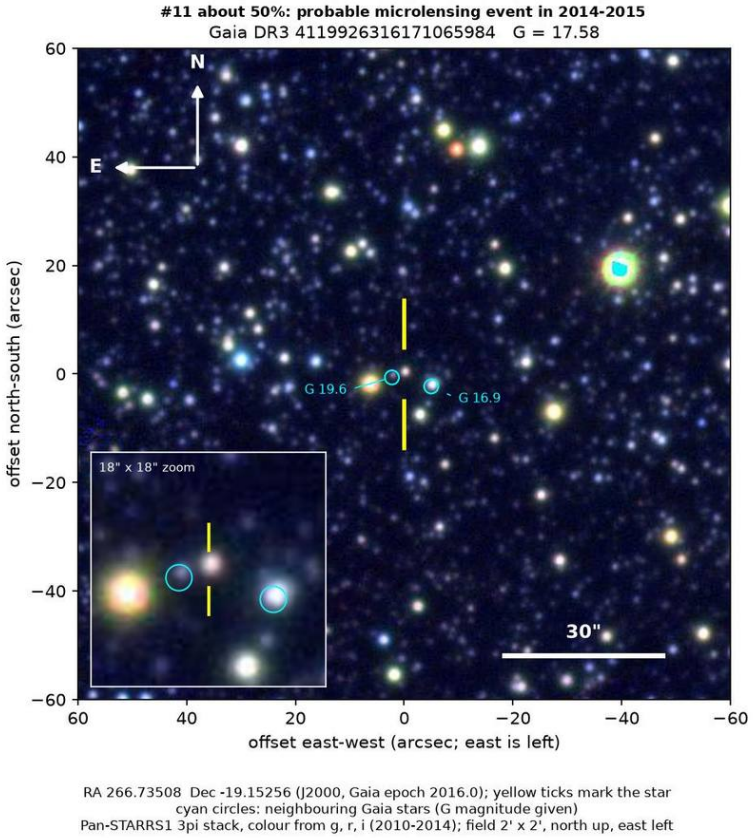
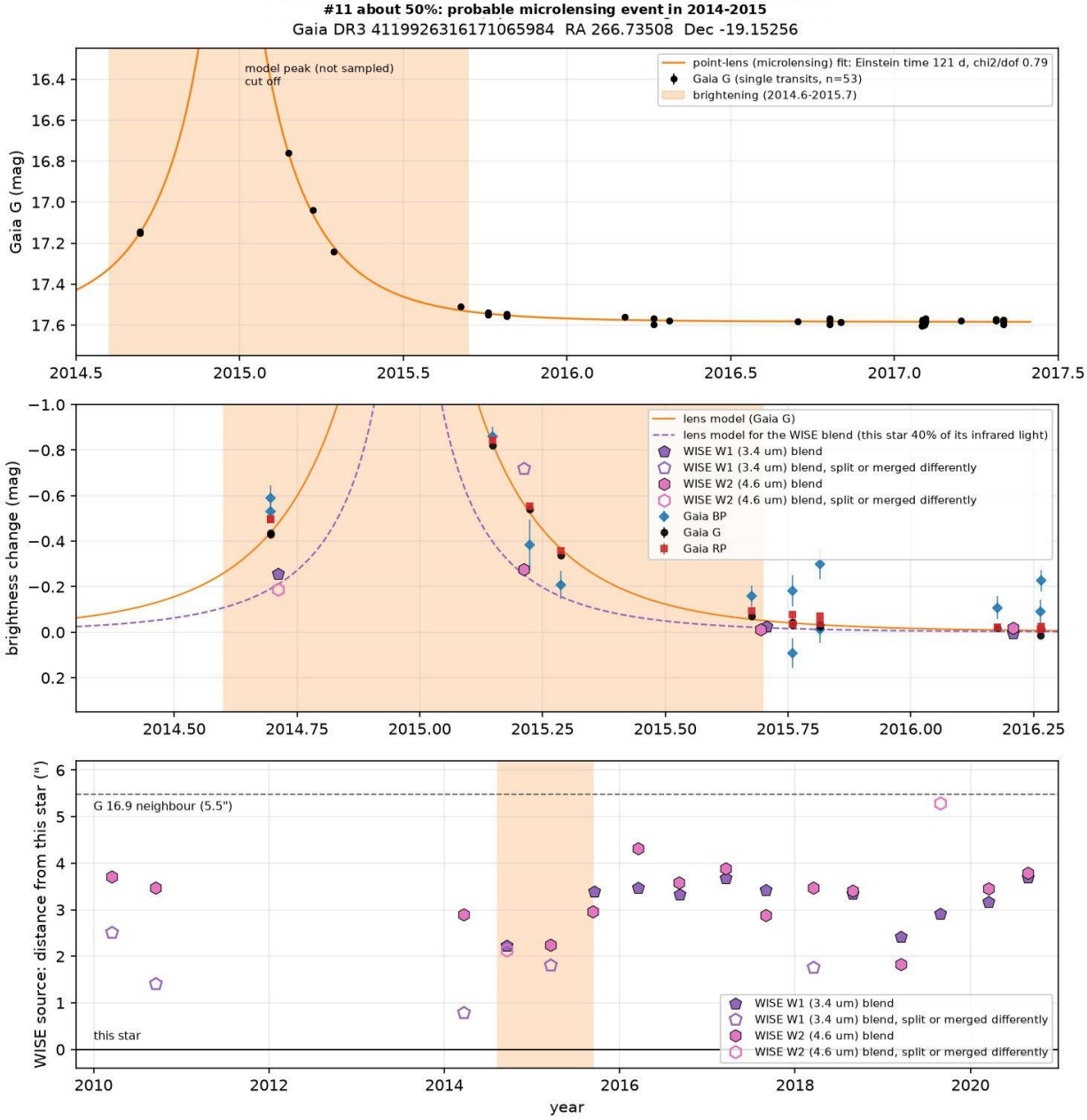



**Figure 31:** Candidate 11, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks, and the inset at lower left enlarges the central 18 by 18 arcseconds. The bright orange star 7 arcseconds to the left, that is, to the east, is a red giant (G = 14.9) that dominates the infrared light there. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Top: all Gaia DR3 G transits (2014.6-2017.4): one smooth brightening, flat otherwise; the peak (about 2014.98) fell between Gaia visits.
Middle: zoom on the event. Gaia BP, G and RP relative to their normal level, and WISE, which cannot separate this star from a G 16.9 star 5.5" away (this star gives about 40 % of the infrared light). WISE caught the blend brighter at both visits during the event, by the amount the lens model predicts for the blend (dashed).
Bottom: where WISE puts the blended source: usually 2.4-4.3" from this star, toward the neighbour. At the two event visits it was 2.2" away, on the near side, as expected if the extra light came from this star (one normal visit, 2019.2, was as close, so position alone is not decisive; only the event visits are both brighter and closer). Open symbols: visits where WISE split or merged the blend differently (not comparable). ZTF (2018-2025, not shown): no repeat.

**Figure 32:** Candidate 11, light curve. Top: every Gaia G measurement, with the lensing model; the model's unobserved peak is cut off, because Gaia did not visit at the maximum. Middle: a close-up of the event, with Gaia's three colours and the WISE blend at 3.4 and 4.6 microns, each relative to its own normal level. The dashed line is the lensing model's prediction for that blend. Bottom: where WISE places the blended source at each visit from 2010 to 2020. Down means fainter. Data: WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 12: A star that brightened four-fold for a few weeks

| | |
|---|---|
| **Star** | Gaia DR3 1861208444041823360 |
| **Position** | RA 304.60954°, Dec +29.40616° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cygnus, 3.6 degrees from the mid-plane of the Milky Way |
| **Galactic** | $l = 68.76°$, $b = -3.64°$ |
| **Distance** | parallax too small to measure; probably more than 2,000 parsecs away |
| **Brightness** | Gaia $G = 19.37$ |
| **Event** | brightened once, by 1.5 mag (four-fold), for a few weeks in 2016 (2016.16–2016.42) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 45% |

**What changed.** This is a faint star in Cygnus, 3.6 degrees from the mid-plane of the Milky Way. Its parallax, Gaia's measure of distance, is 0.09 ± 0.23 milliarcseconds, too small to measure, so the star is probably more than 2,000 parsecs away. Gaia measured it 59 times between 2014 and 2017. It was steady except in early 2016, when five visits caught it rising and falling: it was 0.5 magnitudes brighter than normal at 2016.16, 1.5 magnitudes brighter (four times the light) at 2016.22, 0.5 magnitudes brighter at 2016.32, almost normal at 2016.42 and normal by 2016.47. ZTF observed the star from 2018 to 2025, and it never did this again.

WISE happened to visit at 2016.35. Its single exposures showed the star 0.21 ± 0.11 magnitudes brighter than normal, only a weak detection. The deeper combined image of that visit gives 0.19 ± 0.03 magnitudes brighter, which is what the lensing model predicts, and it is the brightest of 16 visits from 2010 to 2020. Stars of the same brightness in this field vary by about 0.05 magnitudes from visit to visit, and only about 1 in 200 of their measurements is that bright. Still, one infrared point cannot show the shape of the event.

**Why it might matter.** When a foreground star, or a dark object, passes almost exactly in front of a distant star, its gravity focuses the distant star's light. The distant star then brightens and fades once, symmetrically, and by the same factor in every colour, and that is what this light curve looks like. The standard lensing model fits all 59 points, while a plain bump fits worse. The red and blue Gaia bands rise and fall together, and there is no repeat. Gaia's classifier also labelled it as microlensing.

**Checks against the record.** The event may be new. It is not in Gaia's published list of 363 microlensing events, it has no Gaia alert, and it has no entry in SIMBAD, VSX (the variable-star index) or the Transient Name Server. It lies far outside the fields of the OGLE and KMTNet microlensing surveys. Microlensing is an expected kind of event, not an exotic one, and the value of this event would be as one more lens towards the disc of the Milky Way.

**Why this estimate.** Five Gaia visits trace a clean lensing curve, but the only independent detection comes from a single WISE visit, and two close neighbours contaminate the colour and infrared measurements.

**Caveats.** Gaia is the only telescope that sampled the shape of the event. One other WISE visit, at 2020.35, reads 0.16 magnitudes fainter than normal, so the infrared measurements have occasional outliers. Two fainter stars, 2.7 and 2.8 arcseconds away, add light in Gaia's red and blue bands and in WISE, though they lie outside Gaia's measuring window for G. At 2016.16, two measurements taken 106 minutes apart disagree by 0.4 magnitudes in the red band but agree in G. No lensed star changes that fast, so that red point is a glitch, and the colour fits are less tidy than the G fit. The peak at 2016.22 is consistent in all three bands, and Gaia flagged none of the measurements during the brightening as bad or noisy. Gaia's earlier data release does not show the brightening in the star's average brightness, but the same is true of two events that OGLE confirmed, so that test does not work for an event this short and this bright.

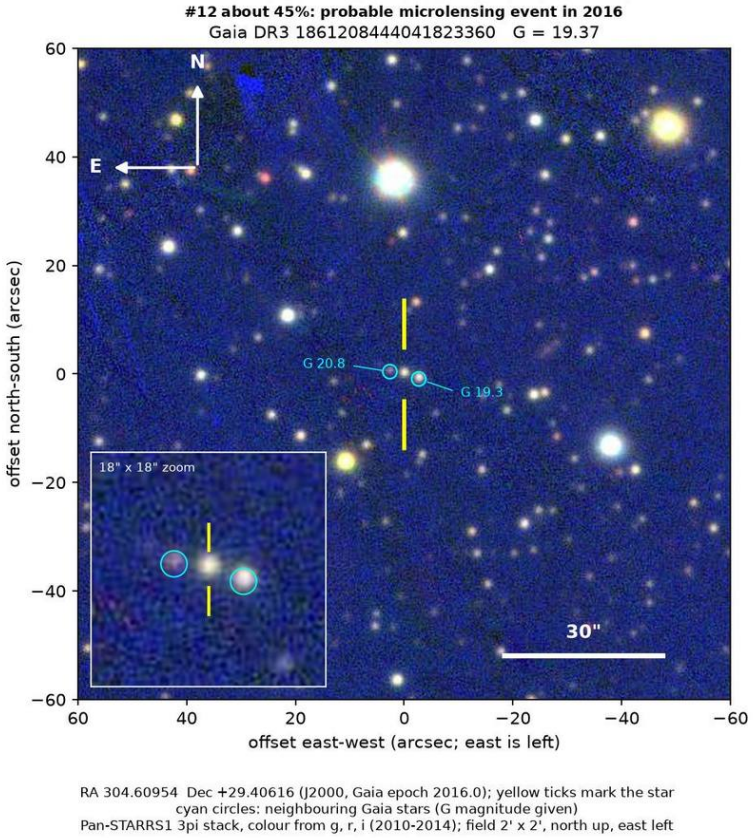



**Figure 33:** Candidate 12, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks, and the inset at lower left enlarges the central 18 by 18 arcseconds, showing the star and its two neighbours. North is up, east is left, and the white bar is 30 arcseconds. No public image from the NOIRLab archive, PTF, Pan-STARRS1 or ZTF was taken during the brightening; only Gaia and WISE were watching, so there is no before-and-after picture of the event. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

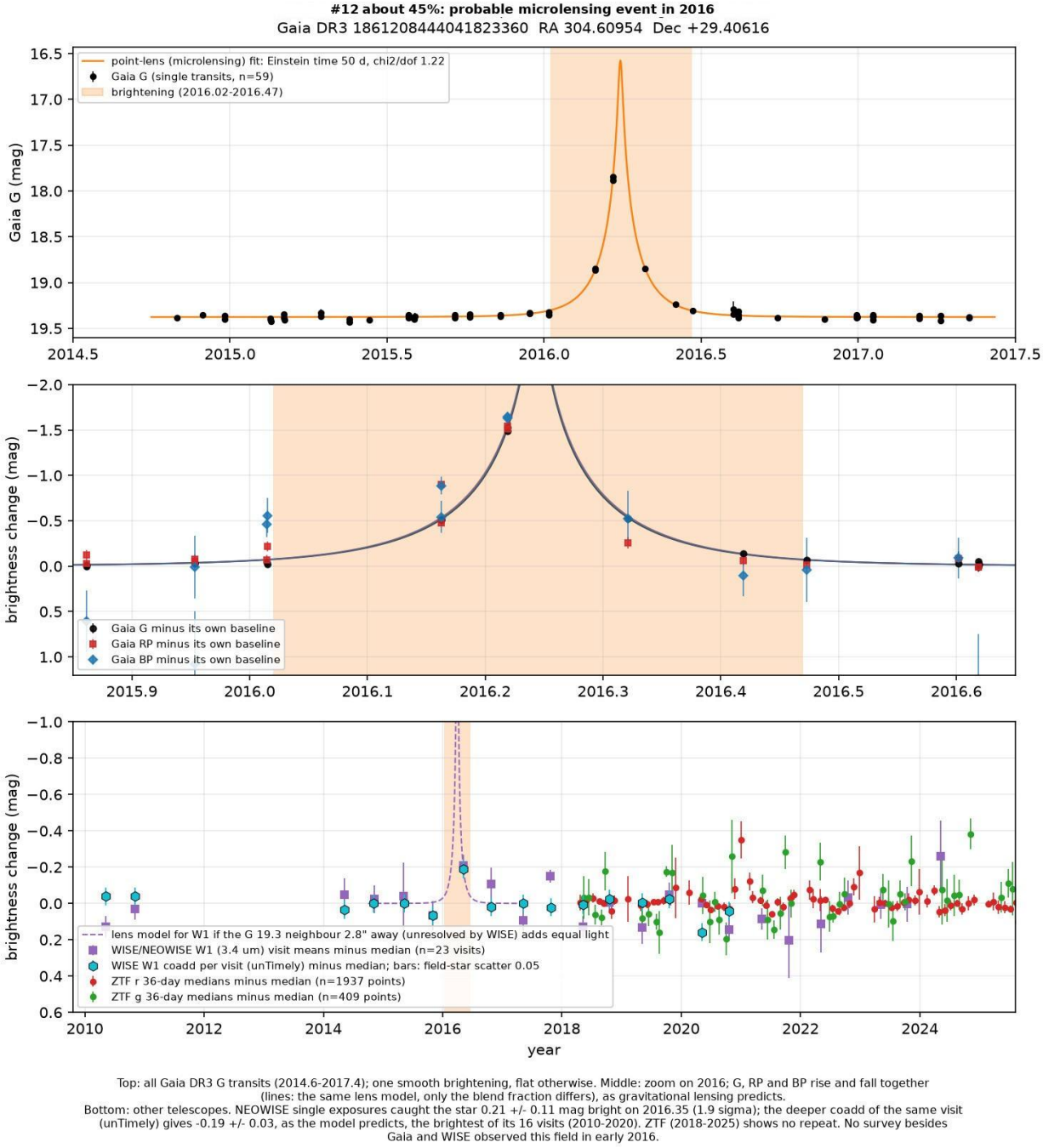



**Figure 34:** Candidate 12, light curve. Top: every Gaia G measurement, with the gravitational-lensing model drawn through them. Middle: a close-up of 2016, with Gaia's broad band and its red and blue bands. Bottom: WISE and NEOWISE infrared visits from 2010 to 2024, showing both the single exposures and, for 2010 to 2020, the deeper combined image of each visit, together with ZTF from 2018 to 2025. Each survey is shown relative to its own normal level. Down means fainter, and orange marks the brightening. Data: ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 13: A wobble that hints at a dark companion

| | |
|---|---|
| **Star** | Gaia DR3 1121443762310292096, a Sun-like star |
| **Position** | RA 129.77669°, Dec +70.16274° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Ursa Major |
| **Galactic** | $l$ = 144.46°, $b$ = +34.45° |
| **Distance** | about 1,500 parsecs (5,000 light-years) |
| **Brightness** | Gaia $G$ = 15.54 |
| **Claim** | Gaia orbit, P = 530 d; unseen companion of about 1.5 solar masses (1.35–1.72) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 10% |

**What Gaia found.** This is a Sun-like star in Ursa Major that moves in a small ellipse on the sky every 530 days, as if a companion were pulling it around. If the star has about 0.8 solar masses, the companion would have 1.35 to 1.72 solar masses and yet give off no light that Gaia can see. It could be a neutron star, a heavy white dwarf or a pair of white dwarfs. The steady light curve is consistent with a dark companion, since the brightness does not have to change for the wobble to be real.

**Why the estimate is low.** The orbit fails one of Gaia's recommended quality cuts: the parallax signal-to-noise ratio, the parallax divided by its uncertainty, is 23.7, and the cut requires 37.7. A mass near 1.5 times the Sun's cannot tell a neutron star from a heavy white dwarf, and there are no measurements of the star's speed along the line of sight to confirm the orbit.

**Why this estimate.** The orbit is one of Gaia's less reliable solutions: it fails the published filter on parallax quality, no measurements along the line of sight confirm it, and orbits of this kind are often spurious.

**Caveats.** The orbit does not pass Gaia's quality cut on the parallax, the mass does not say what the companion is, and no measurements along the line of sight confirm the orbit.

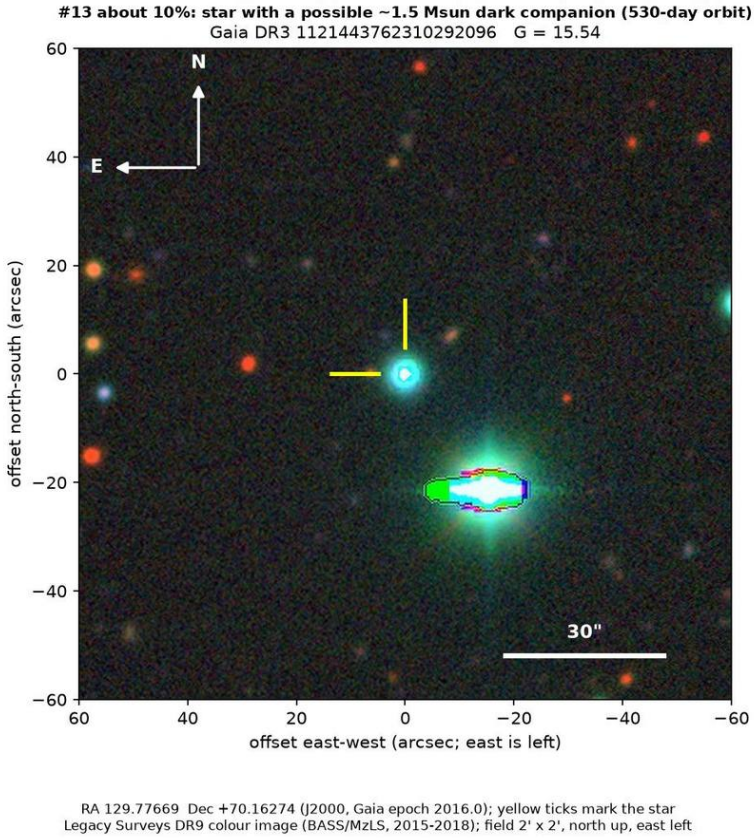



**Figure 35:** Candidate 13, sky image. Legacy Surveys DR9 colour image, two arcminutes by two. The star is bright enough to saturate the camera at its centre. The brighter star 25 arcseconds to the south-west, with the long artefact, is unrelated. North is up, east is left, and the white bar is 30 arcseconds. Data: DESI Legacy Imaging Surveys (NOIRLab); ESA/Gaia/DPAC.

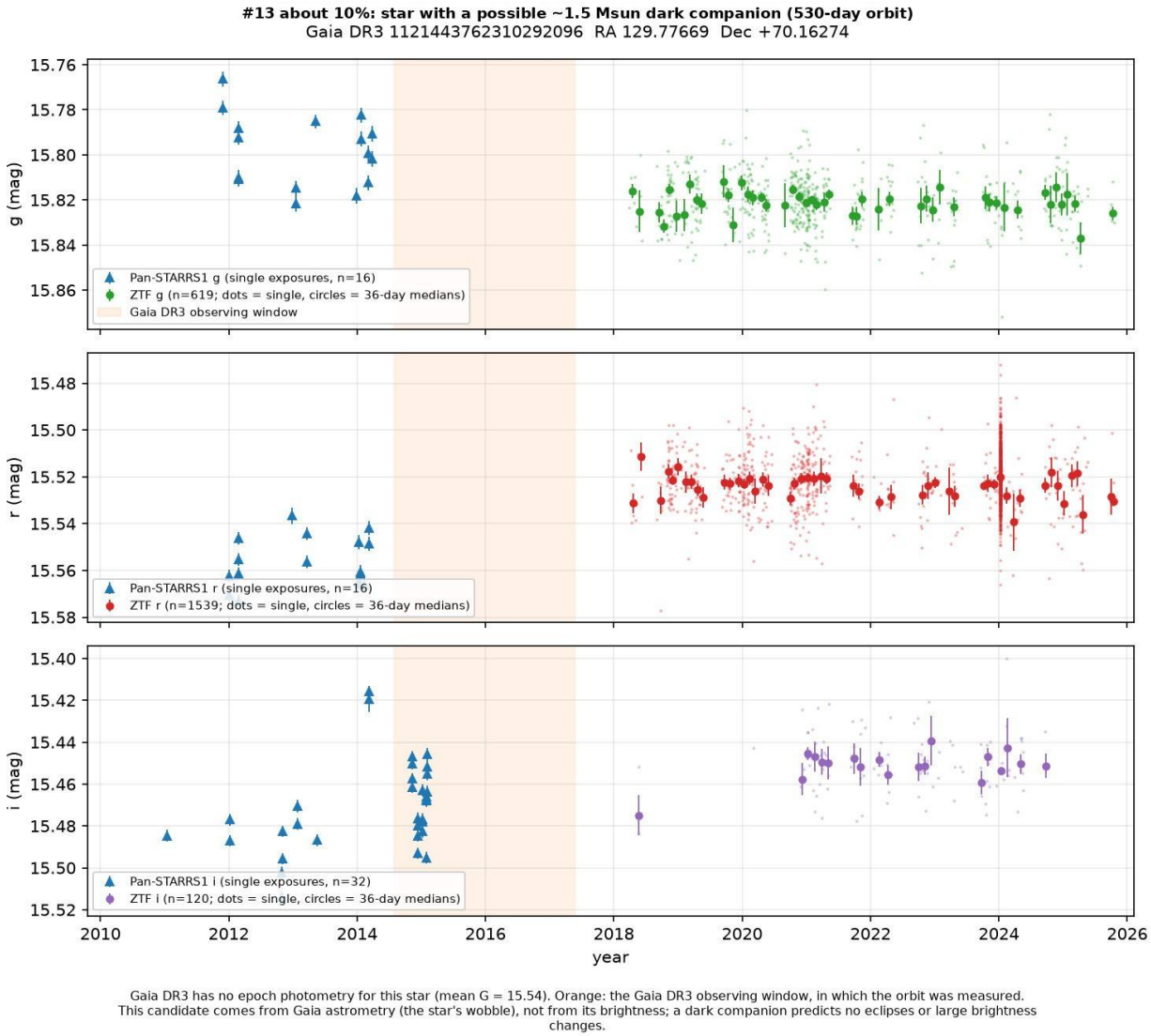



**Figure 36:** Candidate 13, light curve. Pan-STARRS1 from 2010 to 2014 and ZTF from 2018 to 2025, in the g, r and i filters. The star is steady to within a few hundredths of a magnitude, and the offsets between the two surveys come from their slightly different filters, not from a change in the star. Down means fainter. Gaia DR3 has published no visit-by-visit brightness measurements for this star. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

## Candidate 14: A giant star that may have a heavy, dark companion

| | |
|---|---|
| **Star** | Gaia DR3 2018177545831527808, a cool giant, about 4,600 K |
| **Position** | RA 293.89075°, Dec +20.85997° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Vulpecula, in the plane of the Milky Way |
| **Galactic** | $l$ = 56.41°, $b$ = +0.19° |
| **Distance** | roughly 2,900 parsecs, dimmed by about 2.4 magnitudes of interstellar dust |
| **Brightness** | Gaia $G$ = 13.38 |
| **Claim** | Gaia orbit, P = 1,032 d, eccentric; unseen companion of 4.3 solar masses (3.7–5.9) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 5% |

**What Gaia found.** This is a cool giant star in Vulpecula, in the plane of the Milky Way, with a temperature of about 4,600 K, dimmed by about 2.4 magnitudes of interstellar dust. The orbit Gaia measured on the sky has a period of 1,032 days and is quite eccentric. If the giant has the 3.5 solar masses that Gaia estimates, the companion has 4.3 solar masses, with a range of 3.7 to 5.9. An ordinary star of 4.3 solar masses would outshine the giant, so the companion would have to be dark. The light curve is steady where it can be trusted, and the candidate rests on the wobble, not on a change in brightness.

**Why the estimate is low.** The orbital period is as long as the whole Gaia DR3 data set, 1,038 days, so the size and shape of the orbit are poorly pinned down. The conclusion also depends on an uncertain mass for the giant: if the giant has about 6 solar masses, the companion could be an ordinary star.

**Why this estimate.** The fitted period is as long as the whole Gaia DR3 data set, so the orbit is poorly constrained, and the companion counts as dark only if the giant's uncertain mass is right. Several earlier claims of dark companions to giant stars were later explained by companions that are luminous or have been stripped of their outer layers.

**Caveats.** The orbit is barely covered by the data Gaia has published, and a heavier giant would allow the companion to be an ordinary star.

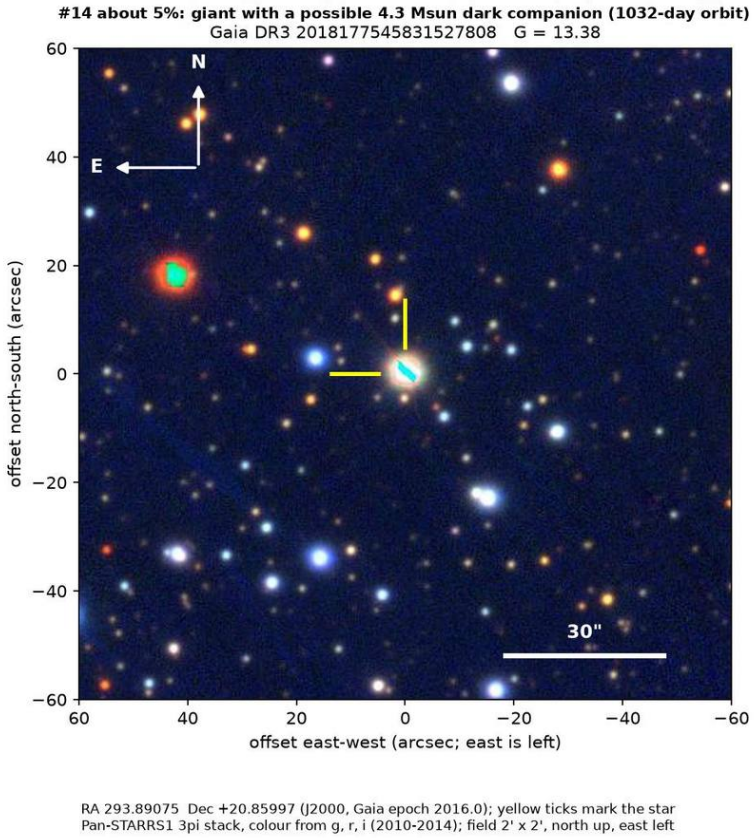



**Figure 37:** Candidate 14, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two, showing a crowded field. The star is saturated at its centre, and the cyan smudge there is an artefact of that saturation. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

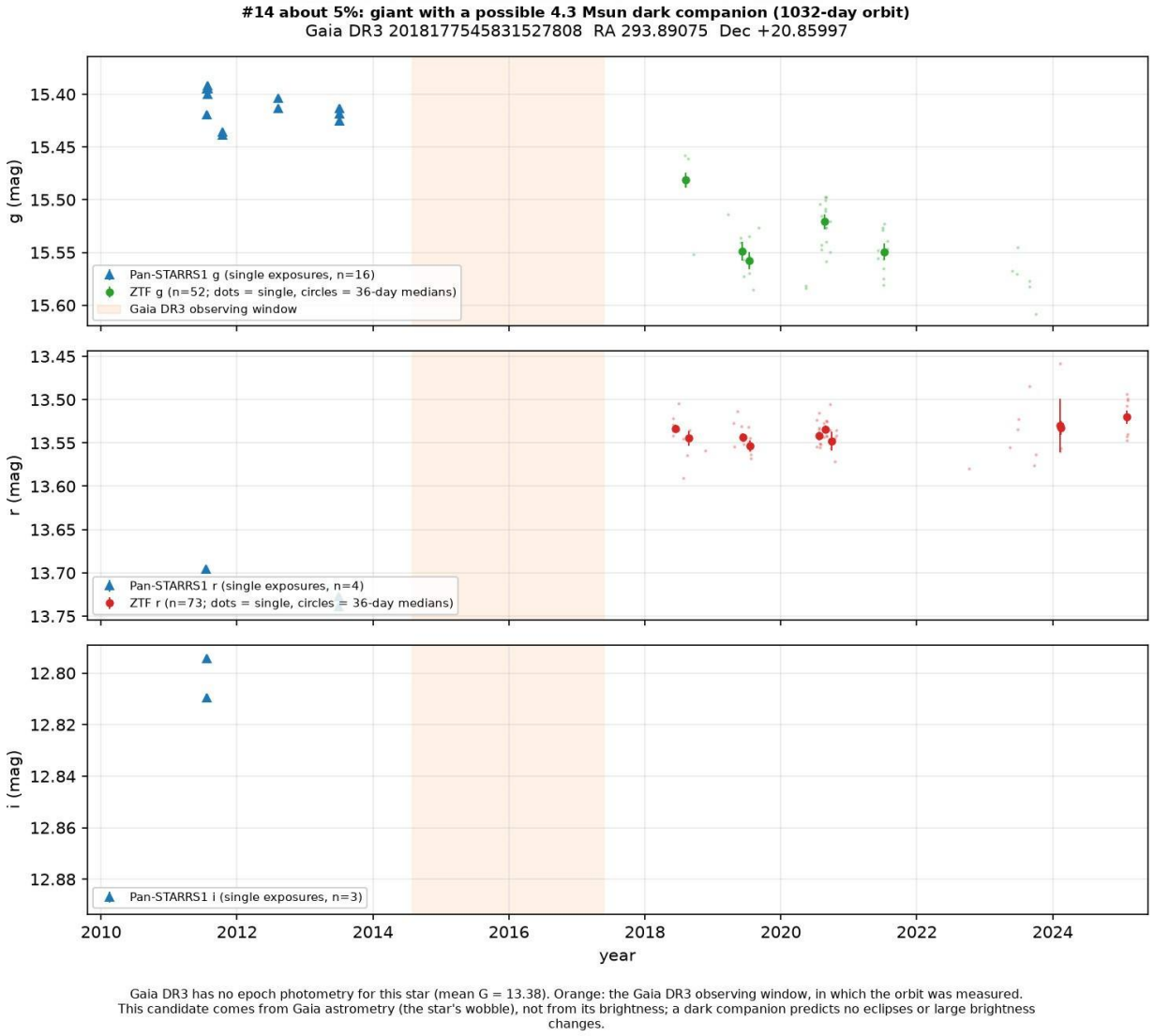



**Figure 38:** Candidate 14, light curve. Pan-STARRS1 from 2010 to 2014 and ZTF from 2018 to 2025. ZTF shows a steady star. The large offsets between Pan-STARRS1 and ZTF are not real changes: they come from the different filters, which matter because this star is very red, and from saturation in Pan-STARRS1. The orange band is the stretch of time Gaia used for the orbit, not a change in brightness. Down means fainter. Gaia DR3 has published no visit-by-visit brightness measurements for this star; this candidate comes from the wobble, not from the light curve. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

## Candidate 15: A giant whose wobble hints at a heavy dark companion

| | |
|---|---|
| **Star** | Gaia DR3 5238699738399933952, a yellow giant |
| **Position** | RA 165.33933°, Dec −65.92882° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Carina, in the southern Milky Way |
| **Galactic** | $l = 292.02°$, $b = -5.42°$ |
| **Distance** | about 3,000 parsecs (10,000 light-years) |
| **Brightness** | Gaia $G = 13.40$ |
| **Claim** | Gaia orbit, P = 1,009 d; unseen companion of about 3.3 solar masses (2.9–3.8) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 5% |

**What Gaia found.** This is a yellow giant, about 5,400 K, some 3,000 parsecs away in a crowded Milky Way field in Carina. Gaia found that it moves in a small ellipse on the sky every 1,009 days, seen almost edge-on. If the giant has its model mass of 2.5 solar masses, the companion has about 3.3 solar masses (2.9 to 3.8). An ordinary star that heavy would outshine the giant, so the companion would have to be dark, and at that mass it would be a black hole near the low end of the range black holes are known to have. The giant fills only a small part of the space available to it, so no gas is flowing between the two, and GALEX saw no ultraviolet light from a hot companion.

**Why the estimate is low.** The fitted period is about as long as the 1,038 days of Gaia's third data release, so the orbit is poorly constrained. The companion is only 0.6 to 0.8 solar masses heavier than the giant, which is within the uncertainty of the giant's model mass. Gaia has no measurements of the star's speed along the line of sight to confirm the orbit, and two ordinary stars in a close orbit around each other, together orbiting the giant, would produce the same wobble without being dark.

**Checks against the record.** No record of a dark companion for this star could be found. The star is too far south for Pan-STARRS1 and ZTF, so there is no light curve, and the claim rests on its motion, not its brightness.

**Why this estimate.** The orbit takes about as long as Gaia's published observations lasted, so it is poorly pinned down. The companion outweighs the giant by less than the uncertainty in the giant's own mass, there are no measurements of the star's speed along the line of sight to confirm the orbit, and a close pair of ordinary stars orbiting the giant would look the same.

**Caveats.** The orbit is as long as Gaia's observations, the masses overlap within their uncertainties, there are no measurements along the line of sight, and a triple system would look the same.

**Figure note.** No light curve was published for this candidate; the one in Figure 41 was made for this paper from public data (Section 3.10).

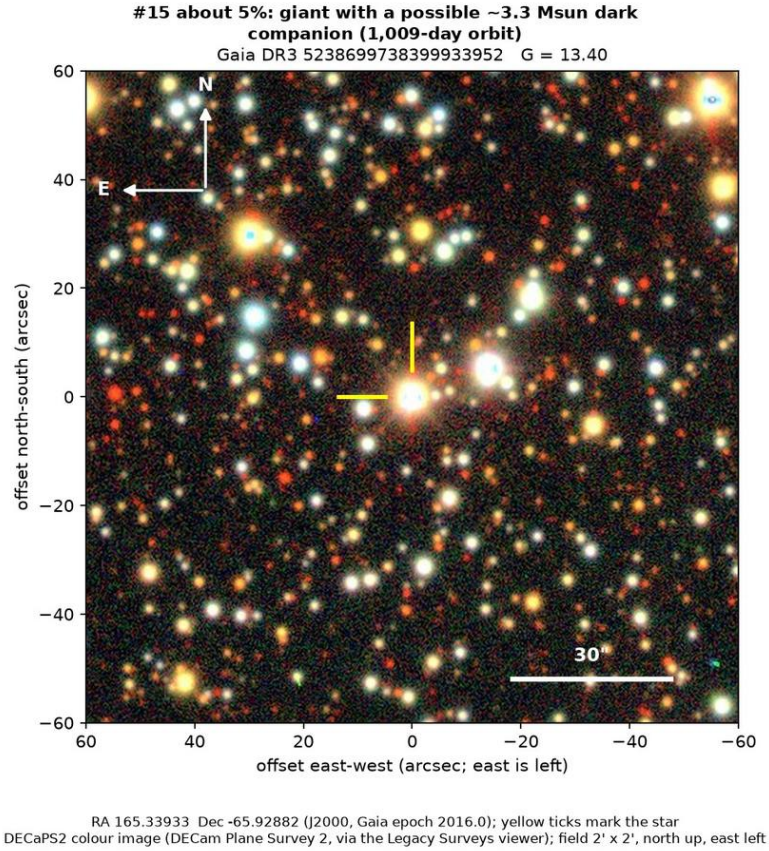



**Figure 39:** Candidate 15, sky image. DECaPS2 colour image (the DECam Plane Survey), two arcminutes by two, in a crowded Milky Way field. The star is between the yellow ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: DECaPS2 (NOIRLab); ESA/Gaia/DPAC.

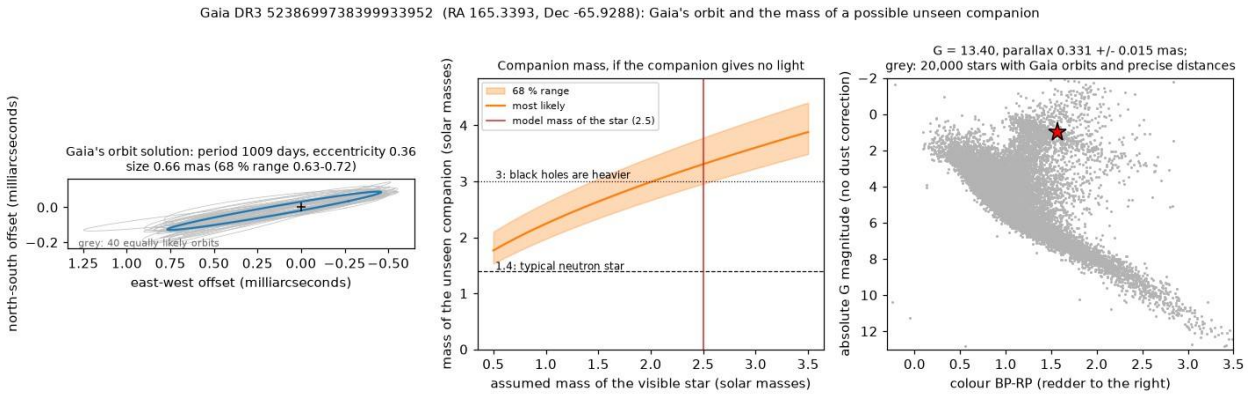



**Figure 40:** Candidate 15, Gaia orbit. Left: the orbit Gaia fitted, a 1,009-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

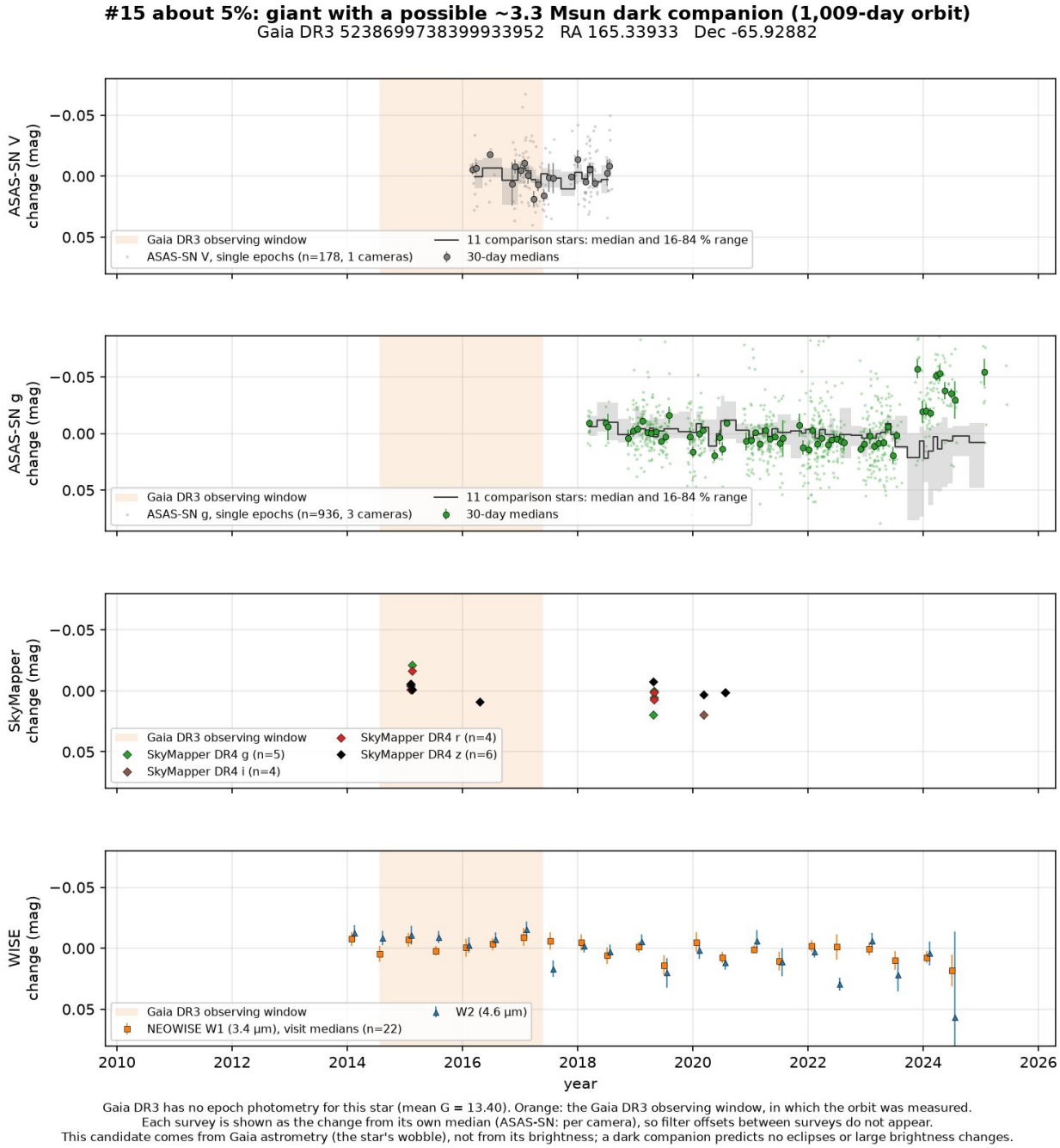



**Figure 41:** Candidate 15, light curve made for this paper from public data. Upper panels: ASAS-SN V (2016–2018; 178 good epochs from 1 camera; 30-day medians scatter by 0.009 mag, robust rms) and ASAS-SN g (2018–2025; 936 good epochs from 3 cameras; 30-day medians scatter by 0.009 mag, robust rms), each shown as the change from its camera's median; dots are single epochs and circles 30-day medians; the grey line and band are the median and 16–84% range of 11 comparison stars within 0.3° and 0.5 mag of the star. From late 2023 the star's ASAS-SN g measurements are 0.04 mag brighter than in 2018–2023, while the median of its comparison stars changed by +0.009 mag (positive values are fainter); seen by one survey only, the change is not interpreted here. SkyMapper DR4 panel: 19 unflagged measurements in g, r, i and z (2015–2020), each relative to its filter's median; robust scatter 0.007 mag. WISE panel: NEOWISE single exposures in W1 (3.4 microns) and W2 (4.6 microns), 444 after quality cuts, averaged in 22 visits (2014–2024) and shown as the change from their median; the visit medians scatter by 0.008 mag in W1 and 0.013 mag in W2, robust rms. The two NEOWISE visits after late 2023 show no such change in W1 (+0.012 mag relative to 2018–2023). The orange band marks the Gaia DR3 observing window (2014 July 25 to 2017 May 28), in which the orbit was measured. A dark companion predicts a steady star. Data: SkyMapper (ANU); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 16: An F star with the cleanest of these orbits

| | |
|---|---|
| **Star** | Gaia DR3 5351774995980250880, a slightly evolved F-type star |
| **Position** | RA 155.80550°, Dec −57.44321° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Carina, in the plane of the Milky Way |
| **Galactic** | $l = 284.01°$, $b = -0.12°$ |
| **Distance** | about 1,800 parsecs (5,800 light-years) |
| **Brightness** | Gaia $G = 13.92$ |
| **Claim** | Gaia orbit, P = 678 d; unseen companion of about 1.6 solar masses (1.5–1.8) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 5% |

**What Gaia found.** This is a slightly evolved yellow-white star of type F, about 6,500 K, some 1,800 parsecs away in the plane of the Milky Way. Gaia's main orbit-fitting method found a 678-day orbit, well inside its observing period and with good significance. If the star has about 1.6 solar masses, the companion has about 1.6 solar masses too (1.5 to 1.8) and yet gives off no visible light: it could be a neutron star or a heavy white dwarf.

**Why the estimate is low.** If the star is 30 per cent lighter than its model mass, the companion drops below 1.4 solar masses, where ordinary white dwarfs are common. The star sits 2.2 magnitudes above the main sequence in Gaia's colour–brightness diagram, so it is either evolved or a blend of two stars, and a blend would upset the mass estimate. A close pair of ordinary stars can mimic a dark companion of this mass, and there are no measurements of the star's speed along the line of sight.

**Checks against the record.** No record of a dark companion for this star could be found. The star is too far south for Pan-STARRS1 and ZTF, so there is no light curve.

**Why this estimate.** Of the nine Gaia orbits among candidates 15 to 23, this is the cleanest: it is well inside Gaia's observing period and strongly significant. But the star sits well above the main sequence, so it is either evolved or a blend of two stars, which would upset the mass estimate; if the star is 30 per cent lighter than modelled, the companion drops below 1.4 solar masses, and a close pair of ordinary stars could mimic it.

**Caveats.** The star's own mass is uncertain, it may be a blend of two stars, a close pair of ordinary stars could mimic the companion, and no measurements along the line of sight confirm the orbit.

**Figure note.** No light curve was published for this candidate; the one in Figure 44 was made for this paper from public data (Section 3.10).

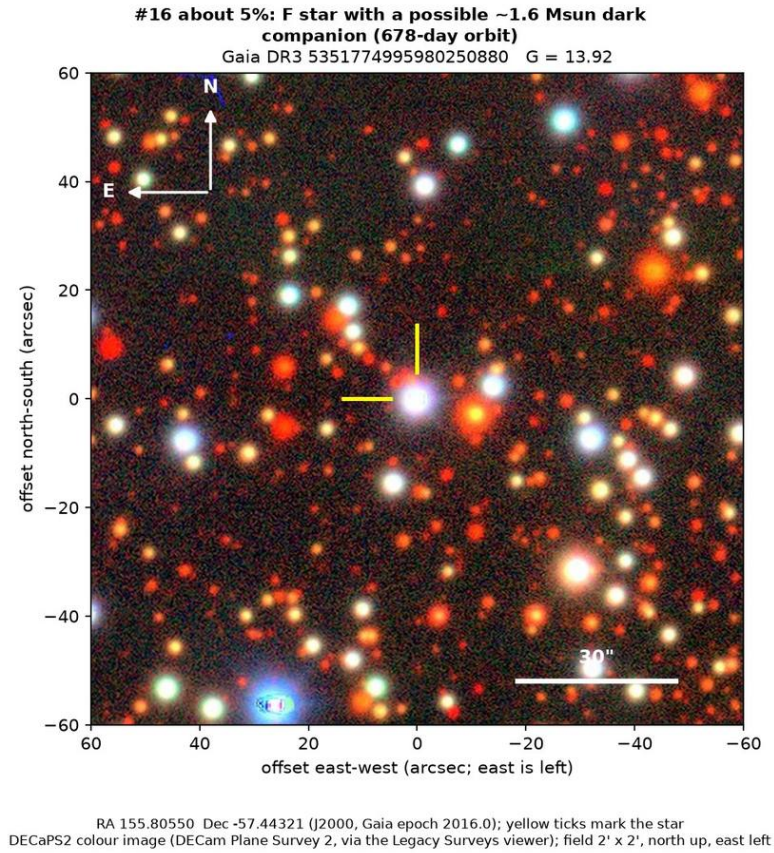



**Figure 42:** Candidate 16, sky image. DECaPS2 colour image (the DECam Plane Survey), two arcminutes by two. The star is between the yellow ticks; two much fainter Gaia stars lie 3.3 and 8.4 arcseconds away. North is up, east is left, and the white bar is 30 arcseconds. Data: DECaPS2 (NOIRLab); ESA/Gaia/DPAC.

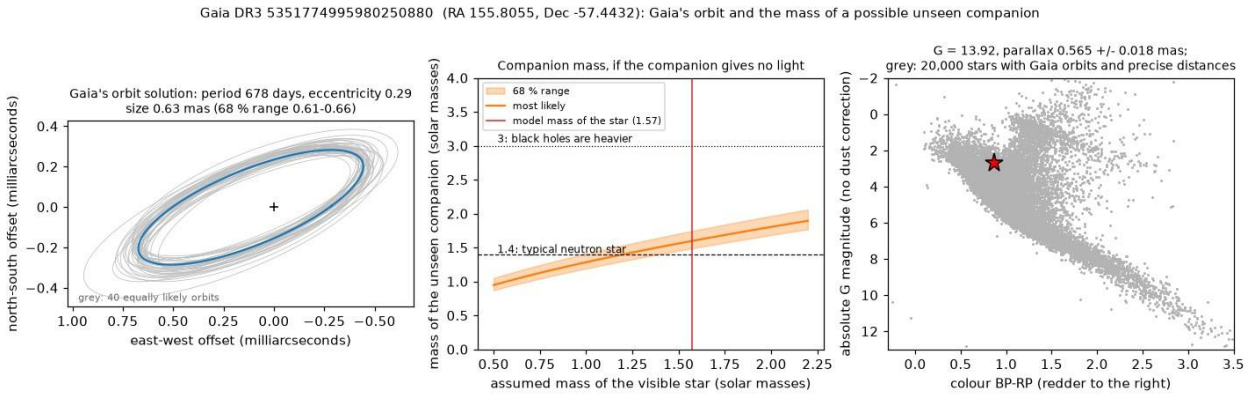



**Figure 43:** Candidate 16, Gaia orbit. Left: the orbit Gaia fitted, a 678-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

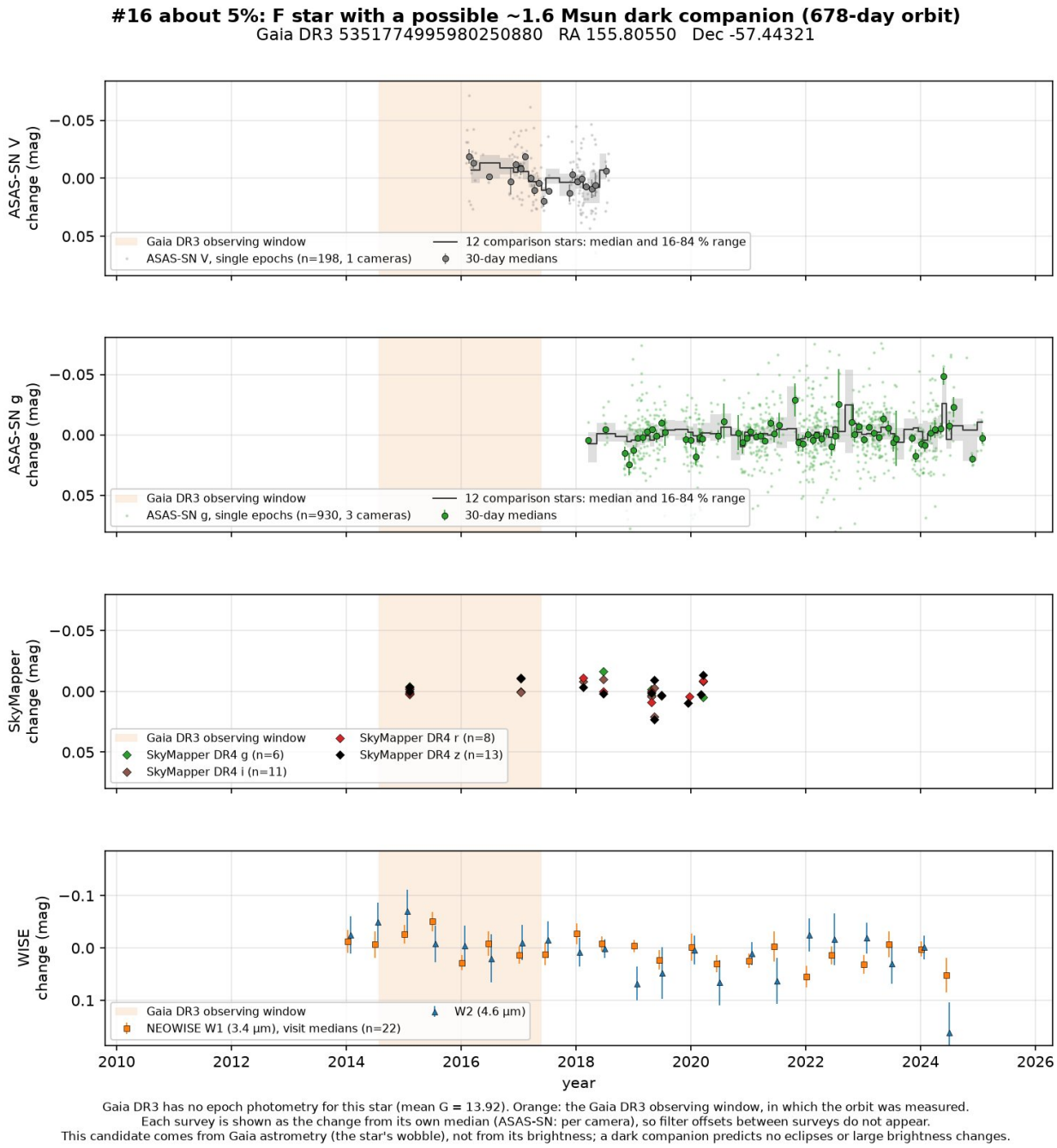



**Figure 44:** Candidate 16, light curve made for this paper from public data. Upper panels: ASAS-SN V (2016–2018; 198 good epochs from 1 camera; 30-day medians scatter by 0.011 mag, robust rms) and ASAS-SN g (2018–2025; 930 good epochs from 3 cameras; 30-day medians scatter by 0.006 mag, robust rms), each shown as the change from its camera's median; dots are single epochs and circles 30-day medians; the grey line and band are the median and 16–84% range of 12 comparison stars within 0.3° and 0.5 mag of the star. SkyMapper DR4 panel: 38 unflagged measurements in g, r, i and z (2015–2020), each relative to its filter's median; robust scatter 0.005 mag. WISE panel: NEOWISE single exposures in W1 (3.4 microns) and W2 (4.6 microns), 259 after quality cuts, averaged in 22 visits (2014–2024) and shown as the change from their median; the visit medians scatter by 0.020 mag in W1 and 0.029 mag in W2, robust rms. The orange band marks the Gaia DR3 observing window (2014 July 25 to 2017 May 28), in which the orbit was measured. A dark companion predicts a steady star. Data: SkyMapper (ANU); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 17: An F star on a long, elongated orbit

| | |
|---|---|
| **Star** | Gaia DR3 5556237944880786816, an F-type star |
| **Position** | RA 101.56835°, Dec −44.07287° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Puppis |
| **Galactic** | $l = 253.35°$, $b = -19.36°$ |
| **Distance** | about 1,400 parsecs (4,600 light-years) |
| **Brightness** | Gaia $G = 14.11$ |
| **Claim** | Gaia orbit, P = 1,237 d, e = 0.73; unseen companion of about 1.7 solar masses (1.5–2.0) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 4% |

**What Gaia found.** This is a yellow-white star of type F, about 6,300 K, some 1,400 parsecs away in Puppis. Gaia's main orbit-fitting method found a very elongated orbit (eccentricity 0.73) with a period of 1,237 days. If the star has about 1.2 solar masses, the companion has about 1.7 solar masses (1.5 to 2.0) and gives off no visible light: it could be a neutron star or a heavy white dwarf.

**Why the estimate is low.** The period is longer than the 1,038 days of Gaia's third data release, so the orbit is poorly constrained. If the star is 30 per cent lighter than its model mass, the companion drops below 1.4 solar masses. A close pair of ordinary stars, together orbiting the visible star, can mimic a dark companion of this mass, and there are no measurements of the star's speed along the line of sight.

**Checks against the record.** No record of a dark companion for this star could be found. The star is too far south for Pan-STARRS1 and ZTF, so there is no light curve.

**Why this estimate.** The orbit takes longer than Gaia's published observations lasted, so its period, shape and size are poorly constrained. A star 30 per cent lighter than modelled would bring the companion below 1.4 solar masses, a close pair of ordinary stars could mimic it, and no measurements along the line of sight confirm it.

**Caveats.** The orbit is longer than Gaia's observations, the companion's mass depends on the star's uncertain mass, a triple system would look the same, and no measurements along the line of sight confirm the orbit.

**Figure note.** No light curve was published for this candidate; the one in Figure 47 was made for this paper from public data (Section 3.10).

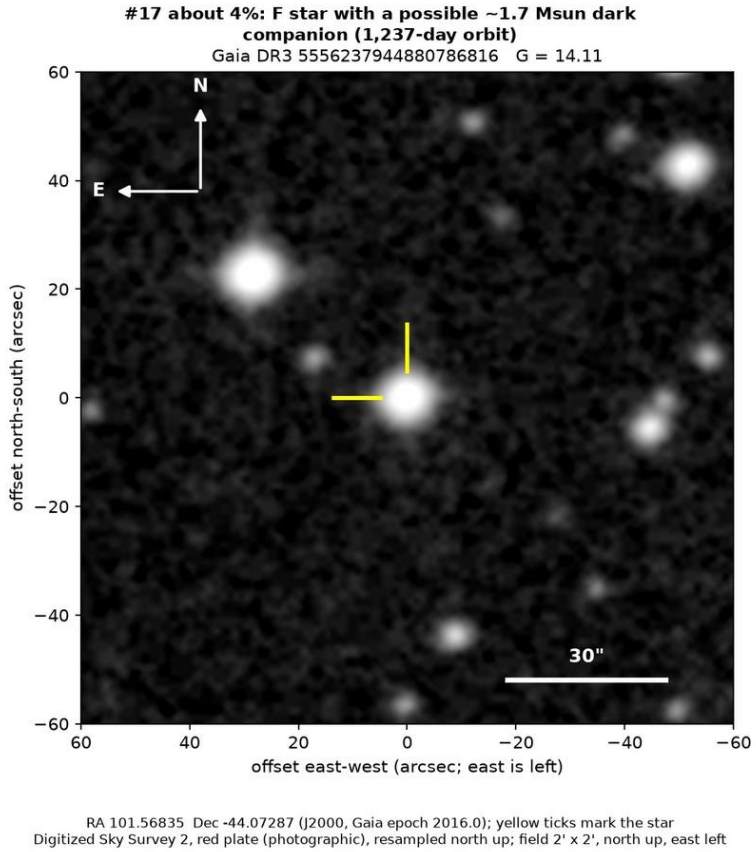



**Figure 45:** Candidate 17, sky image. Red photographic plate of the second Palomar-UK Schmidt sky survey (Digitized Sky Survey 2), two arcminutes by two, because no modern survey image covers this position well. The star is between the yellow ticks; the two brighter Gaia stars nearby are 28 arcseconds east and 23 north of it (G = 13.7) and 45 arcseconds west (G = 16.8). North is up, east is left, and the white bar is 30 arcseconds. Data: Digitized Sky Survey (STScI); ESA/Gaia/DPAC.

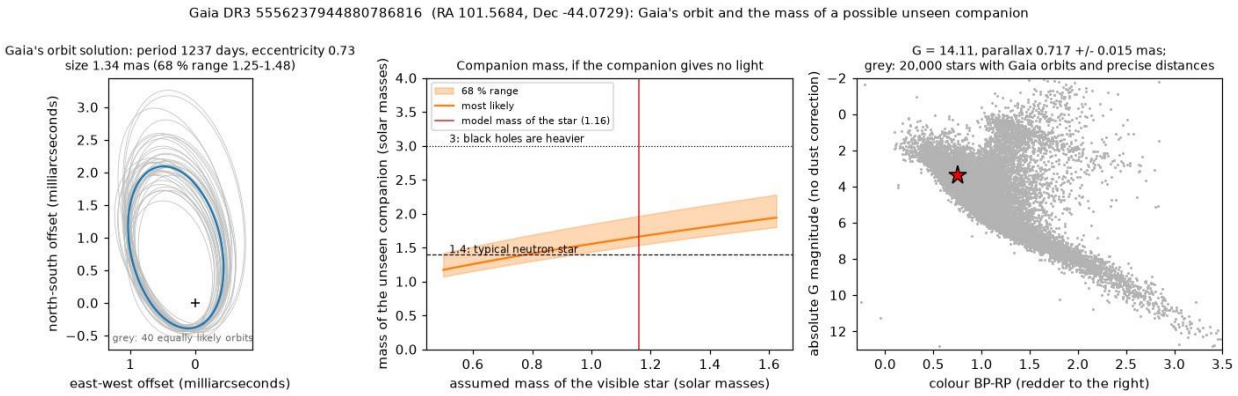



**Figure 46:** Candidate 17, Gaia orbit. Left: the orbit Gaia fitted, a 1,237-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

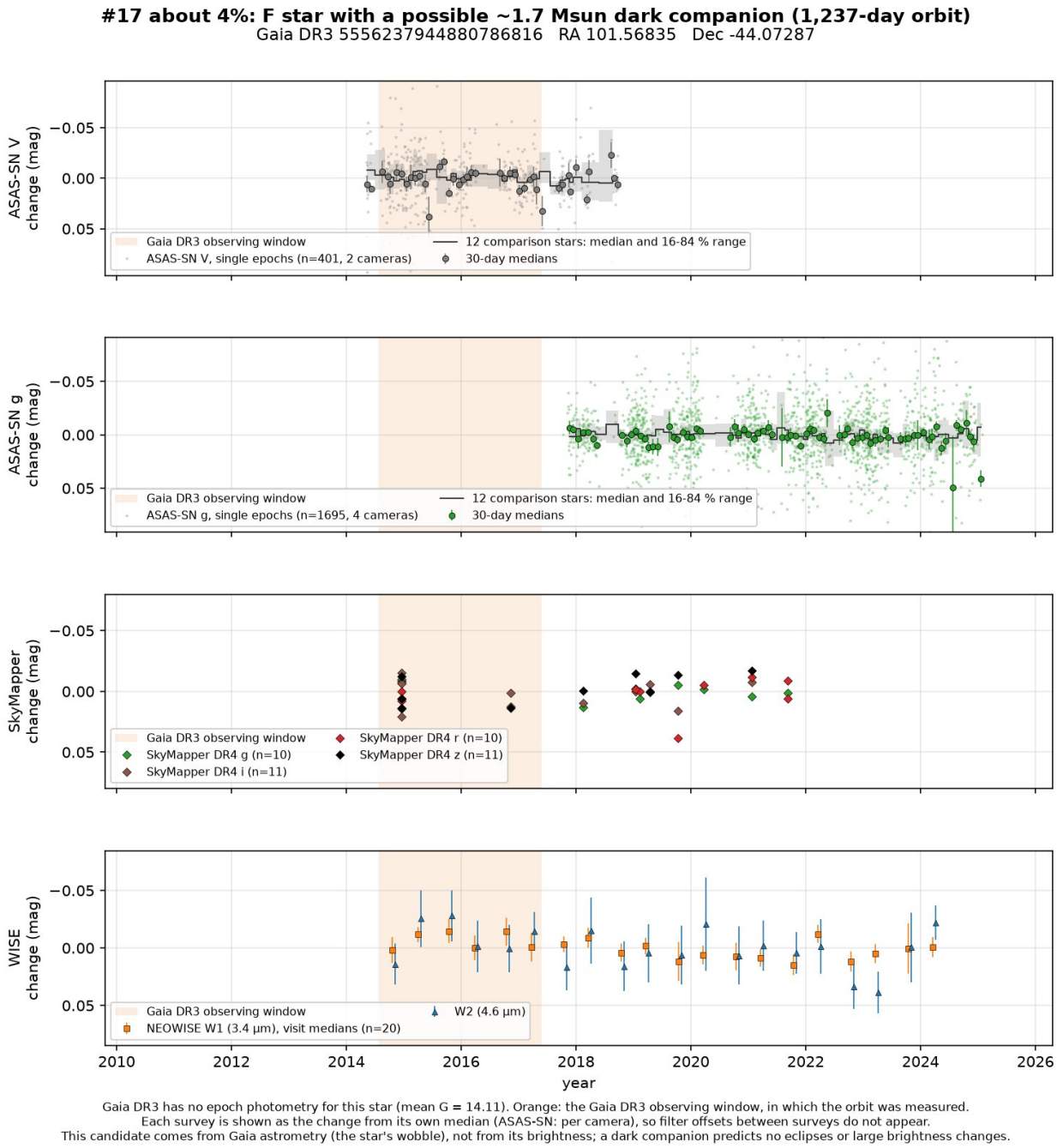



**Figure 47:** Candidate 17, light curve made for this paper from public data. Upper panels: ASAS-SN V (2014–2018; 401 good epochs from 2 cameras; 30-day medians scatter by 0.009 mag, robust rms) and ASAS-SN g (2017–2025; 1695 good epochs from 4 cameras; 30-day medians scatter by 0.005 mag, robust rms), each shown as the change from its camera's median; dots are single epochs and circles 30-day medians; the grey line and band are the median and 16–84% range of 12 comparison stars within 0.3° and 0.5 mag of the star. SkyMapper DR4 panel: 42 unflagged measurements in g, r, i and z (2014–2021), each relative to its filter's median; robust scatter 0.010 mag. WISE panel: NEOWISE single exposures in W1 (3.4 microns) and W2 (4.6 microns), 445 after quality cuts, averaged in 20 visits (2014–2024) and shown as the change from their median; the visit medians scatter by 0.010 mag in W1 and 0.021 mag in W2, robust rms. The orange band marks the Gaia DR3 observing window (2014 July 25 to 2017 May 28), in which the orbit was measured. A dark companion predicts a steady star. Data: SkyMapper (ANU); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

## Candidate 18: A hot star whose wobble hints at a dark companion

| | |
|---|---|
| **Star** | Gaia DR3 5617846158373940096, a hot A-type star |
| **Position** | RA 110.31119°, Dec −23.56349° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Canis Major |
| **Galactic** | $l = 237.21°$, $b = -4.39°$ |
| **Distance** | about 2,000 parsecs (6,500 light-years) |
| **Brightness** | Gaia $G = 13.78$ |
| **Claim** | Gaia orbit, P = 1,040 d; unseen companion of about 1.6 solar masses (1.5–1.8) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 4% |

**What Gaia found.** This is a hot white star of type A, about 9,800 K, seen through some dust about 2,000 parsecs away in Canis Major. Gaia's main orbit-fitting method found a 1,040-day orbit. If the star has about 1.8 solar masses, the companion has about 1.6 solar masses (1.5 to 1.8) and gives off no visible light: it could be a neutron star or a heavy white dwarf. The steady light curve is consistent with a dark companion.

**Why the estimate is low.** The period equals the length of Gaia's third data release, so the orbit is poorly pinned down. Two estimates of the star's mass disagree (1.8 and 2.4 solar masses), and if the star were 30 per cent lighter than the lower one, the companion would drop below 1.4 solar masses. A close pair of ordinary stars can mimic a dark companion of this mass, and there are no measurements of the star's speed along the line of sight. A faint eclipsing binary lies 3.3 arcseconds away, but at G = 19.9 it is far too faint to fake the orbit.

**Checks against the record.** No record of a dark companion for this star could be found.

**Why this estimate.** The orbit takes as long as Gaia's published observations lasted, so it is poorly pinned down. Estimates of the star's own mass disagree, so the companion's mass is uncertain, a close pair of ordinary stars could mimic it, and no measurements along the line of sight confirm it.

**Caveats.** The orbit is as long as Gaia's observations, the star's mass is uncertain, a close pair of ordinary stars could mimic the companion, and no measurements along the line of sight confirm the orbit.

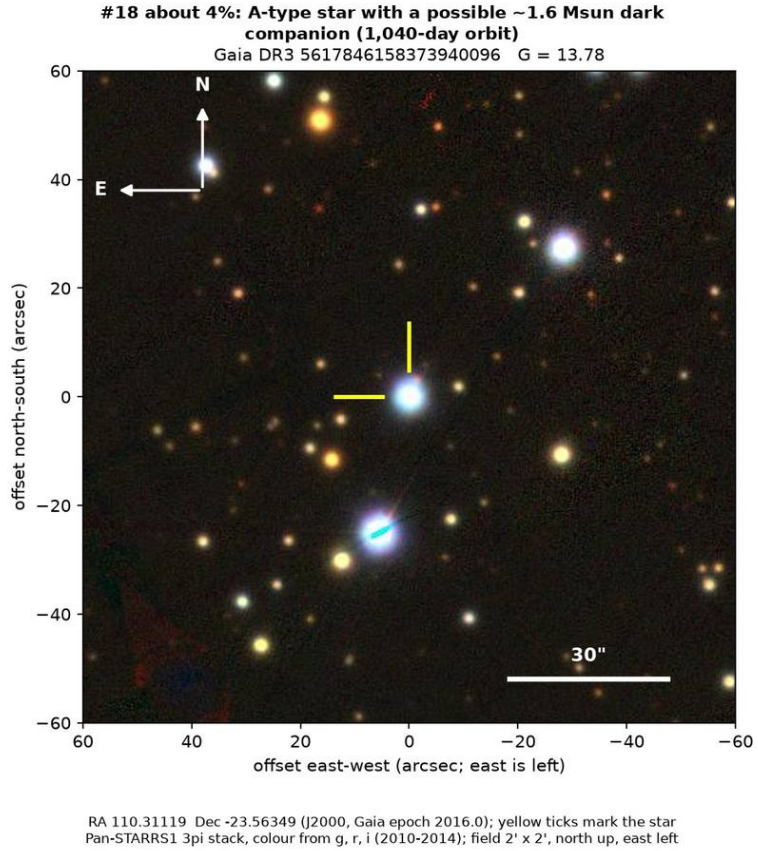



**Figure 48:** Candidate 18, sky image. Pan-STARRS1 colour image, two arcminutes by two. The star is between the yellow ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

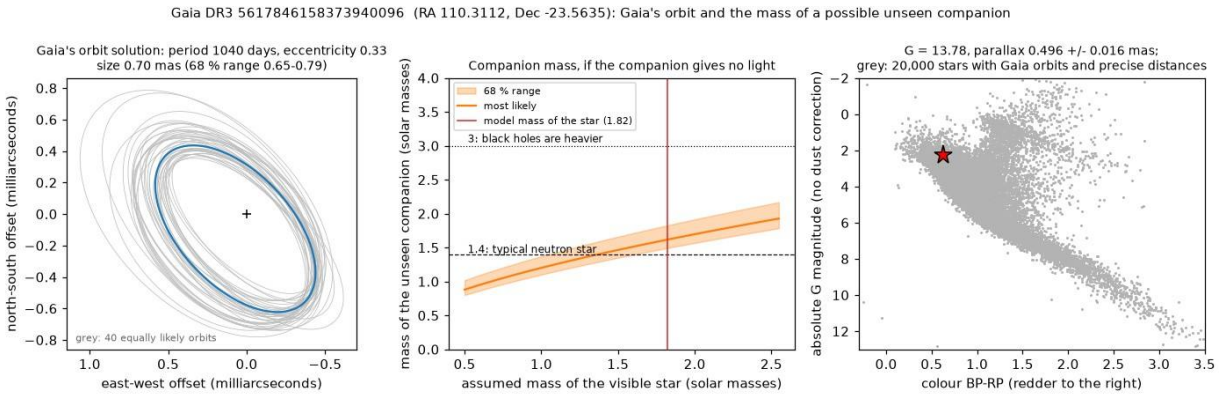



**Figure 49:** Candidate 18, Gaia orbit. Left: the orbit Gaia fitted, a 1,040-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

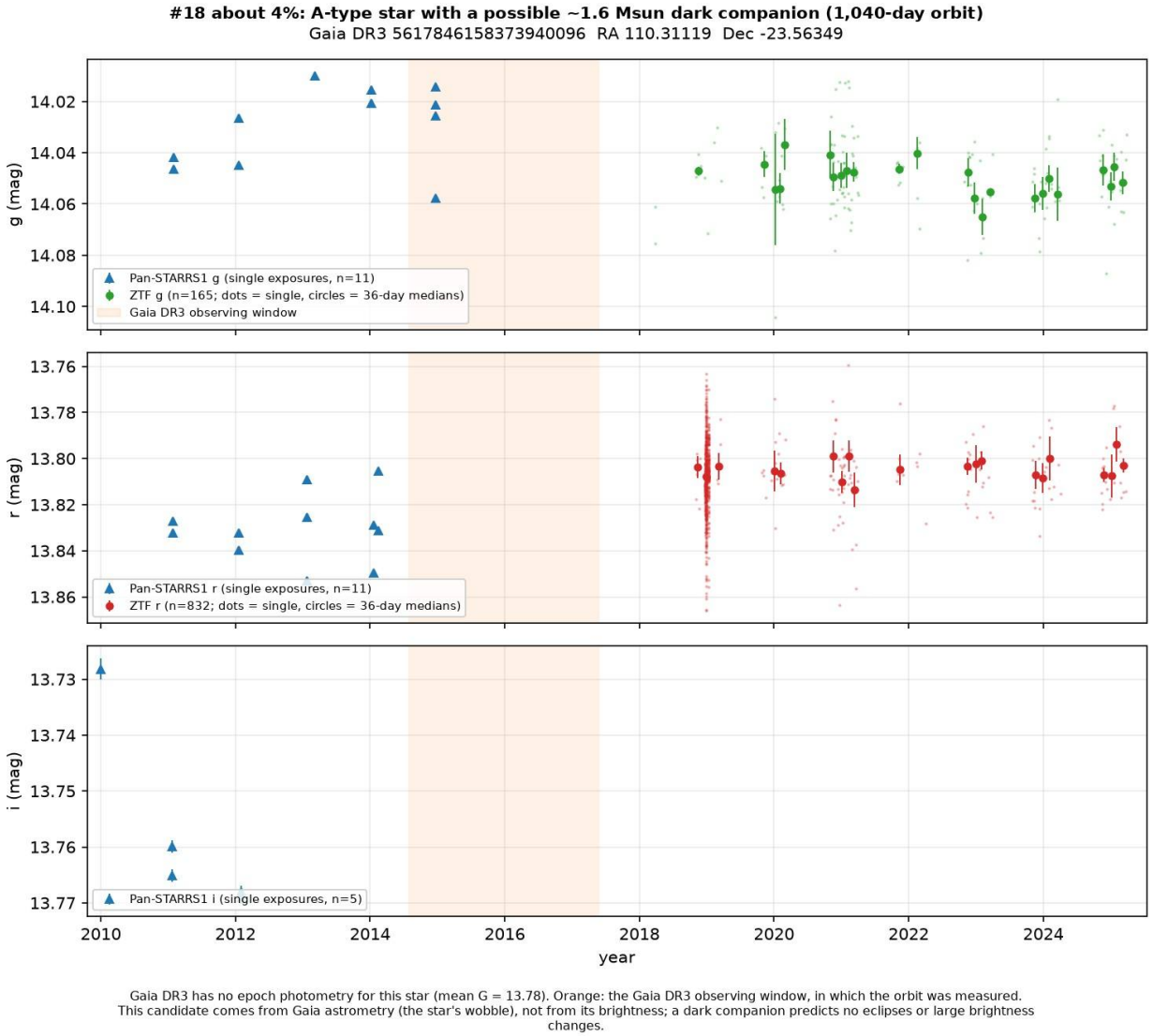



**Figure 50:** Candidate 18, light curve. Pan-STARRS1 from 2010 to 2014 and ZTF from 2018 to 2025, in the g, r and i filters. The orange band marks the years in which Gaia measured the orbit. A dark companion predicts a steady star, and the star is steady to within a few hundredths of a magnitude. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

## Candidate 19: A known binary with a doubtful heavy companion

| | |
|---|---|
| **Star** | Gaia DR3 3416706995764557568 (TYC 1848-703-1), an F-type star in a known binary |
| **Position** | RA 83.46221°, Dec +24.31705° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Taurus |
| **Galactic** | $l = 182.52°$, $b = -4.68°$ |
| **Distance** | about 330 parsecs (1,100 light-years) |
| **Brightness** | Gaia $G = 11.82$; too faint for the eye but easy in a small telescope |
| **Claim** | Gaia orbit, P = 725 d, e = 0.58; companion of about 1.6 solar masses (1.4–1.7); known binary |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 2% |

**What Gaia found.** This is a yellow-white star of type F, about 6,700 K, some 330 parsecs away in Taurus, already catalogued as a spectroscopic binary, a pair of stars betrayed by the shifting lines in their spectrum. Gaia combined the star's motion on the sky with its speeds along the line of sight into a 725-day orbit with eccentricity 0.58. If the star has about 1.3 solar masses, the companion has about 1.6 solar masses (1.4 to 1.7) and gives off no visible light.

**Why the estimate is low.** Over 13 visits Gaia measured the star's speed along the line of sight varying by only 14.7 kilometres per second, where this orbit with so heavy a companion predicts about 43. Sparse sampling of an elongated orbit can hide part of the swing, but not likely most of it. The star is also seen through about a magnitude of dust, which makes its own mass uncertain, and the binary itself is already recorded.

**Checks against the record.** The binary is known, but no record of a dark companion this heavy could be found. The star is too bright for Pan-STARRS1 and ZTF, which saturate on it, so there is no light curve.

**Why this estimate.** The star is already known to be a binary, and Gaia's own measurements of its speed along the line of sight swing by only about a third of what a companion this heavy would cause, so the companion's mass is probably overestimated.

**Caveats.** The star's measured speeds swing far less than the orbit predicts, its mass is uncertain because of dust, and the binary is already known.

**Figure note.** No light curve was published for this candidate; the one in Figure 53 was made for this paper from public data (Section 3.10).

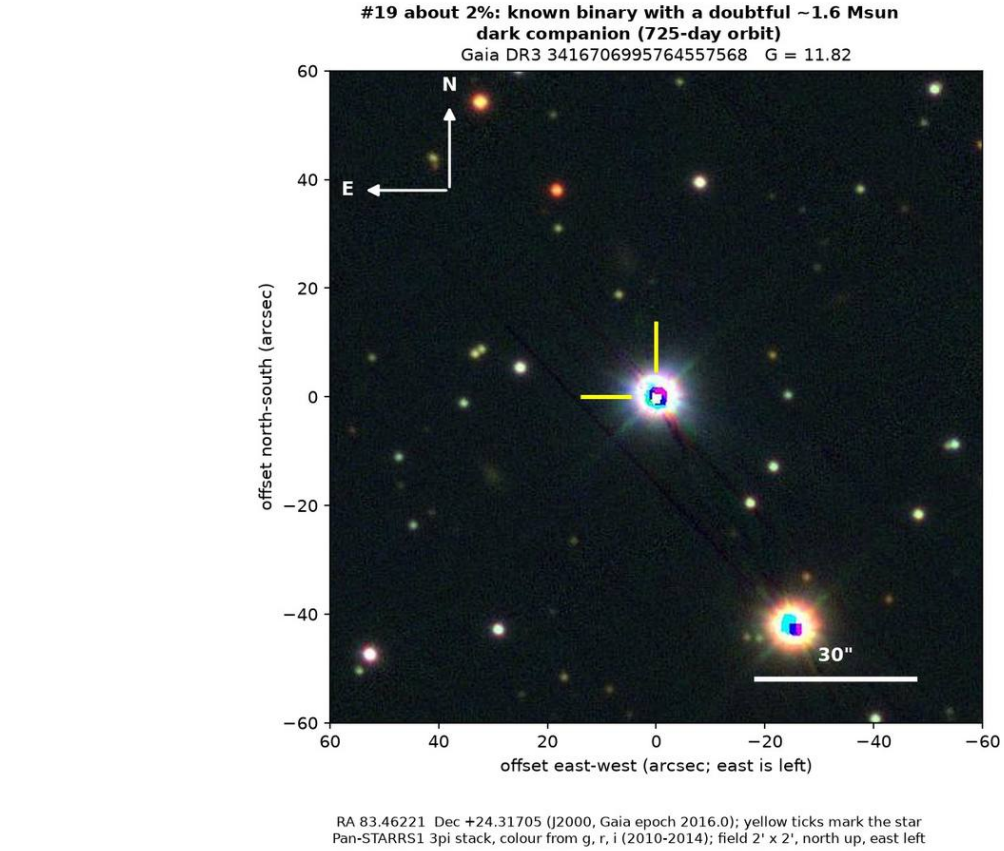



**Figure 51:** Candidate 19, sky image. Pan-STARRS1 colour image, two arcminutes by two. The star is between the yellow ticks; it is bright enough to saturate the image. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

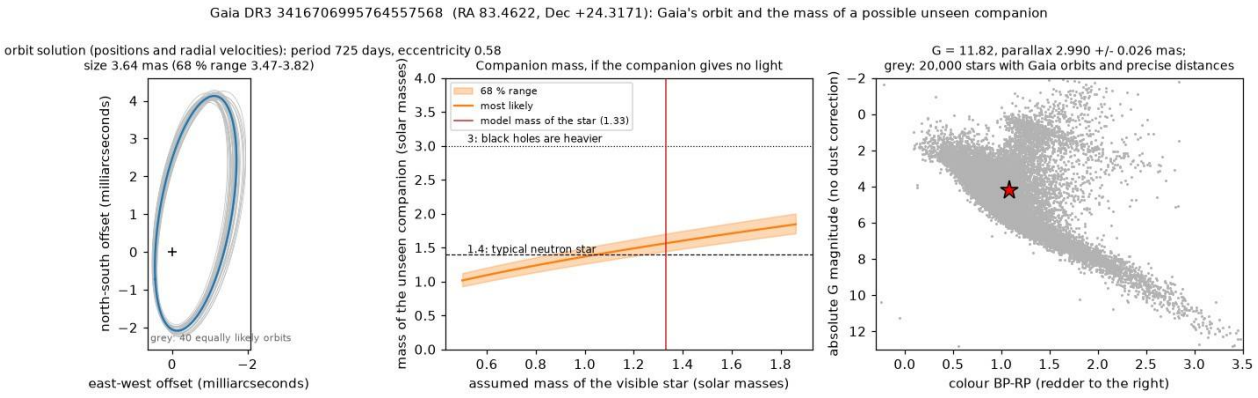



**Figure 52:** Candidate 19, Gaia orbit. Left: the orbit Gaia fitted, a 725-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

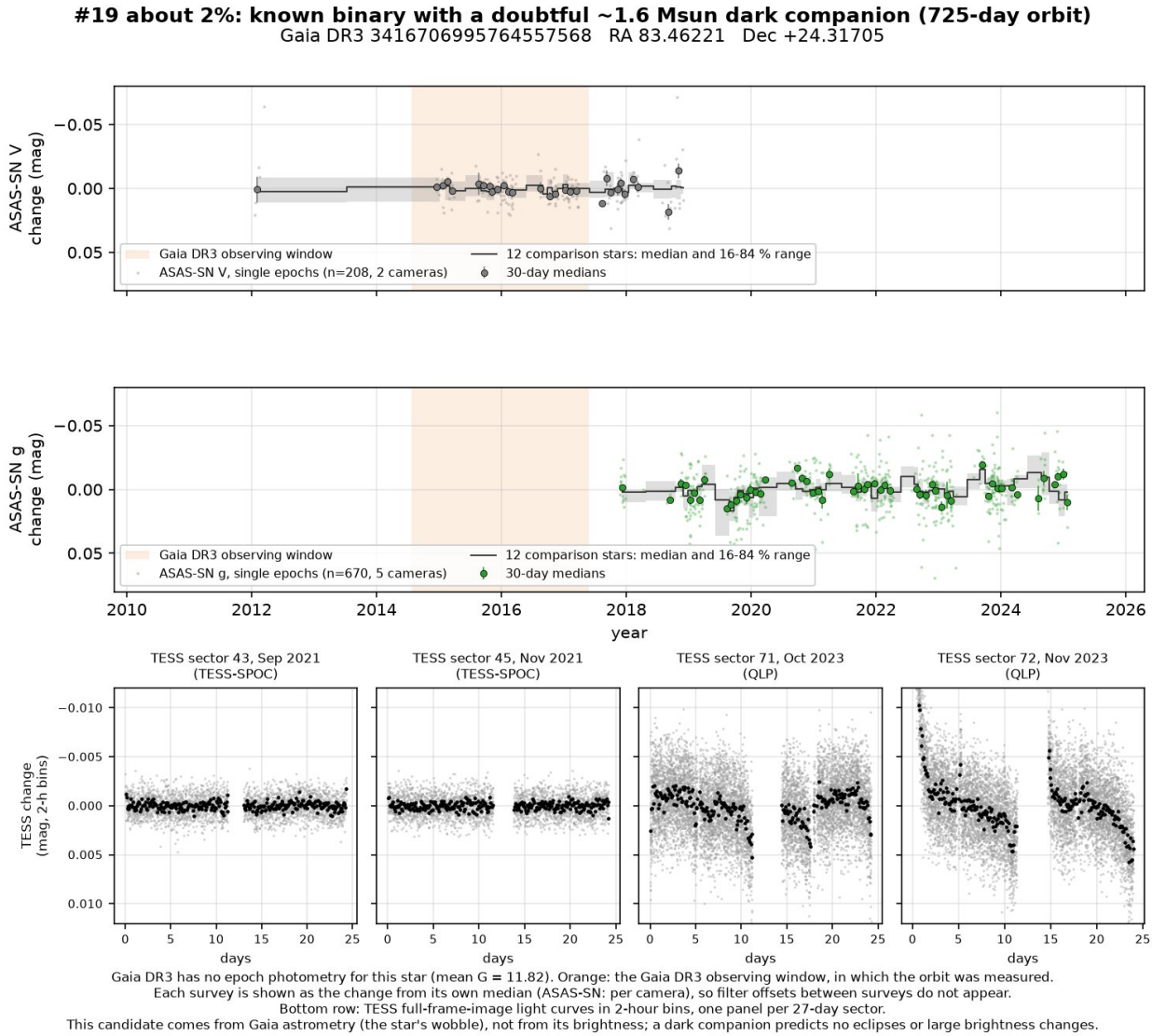



**Figure 53:** Candidate 19, light curve made for this paper from public data. Upper panels: ASAS-SN V (2012–2018; 208 good epochs from 2 cameras; 30-day medians scatter by 0.004 mag, robust rms) and ASAS-SN g (2017–2025; 670 good epochs from 5 cameras; 30-day medians scatter by 0.007 mag, robust rms), each shown as the change from its camera's median; dots are single epochs and circles 30-day medians; the grey line and band are the median and 16–84% range of 12 comparison stars within 0.3° and 0.5 mag of the star. Bottom row: TESS full-frame-image light curves in 2-hour bins (Ricker et al. 2015; Huang et al. 2020a; Huang et al. 2020b; Caldwell et al. 2020b), with the robust scatter of the bins: sector 43 (Sep 2021, TESS-SPOC, 0.4 mmag); sector 45 (Nov 2021, TESS-SPOC, 0.4 mmag); sector 71 (Oct 2023, QLP, 1.1 mmag); sector 72 (Nov 2023, QLP, 1.5 mmag). The orange band marks the Gaia DR3 observing window (2014 July 25 to 2017 May 28), in which the orbit was measured. A dark companion predicts a steady star. Data: ASAS-SN Sky Patrol; TESS (NASA; MAST); ESA/Gaia/DPAC.

## Candidate 20: A bright known binary whose companion is probably a hot star

| | |
|---|---|
| **Star** | Gaia DR3 5664612407982550528 (HD 84286), an A- or F-type star in a known binary |
| **Position** | RA 145.93223°, Dec −21.75301° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Hydra |
| **Galactic** | $l$ = 255.31°, $b$ = +23.30° |
| **Distance** | about 700 parsecs (2,300 light-years) |
| **Brightness** | Gaia $G$ = 9.81; visible in binoculars |
| **Claim** | Gaia orbit, P = 958 d; companion of about 2.6 solar masses (1.7–5.9); known binary |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 2% |

**What Gaia found.** This is a bright white star of type A or F, about 700 parsecs away in Hydra, catalogued as a spectroscopic binary, with five references in the SIMBAD database. Gaia combined its motion on the sky with its speeds along the line of sight into a nearly circular 958-day orbit. If the star has about 2.1 solar masses, the companion has about 2.6 solar masses (1.7 to 5.9) and gives off no visible light.

**Why the estimate is low.** The binary is long recorded. GALEX, NASA's ultraviolet space telescope, found the star brighter in far-ultraviolet light (magnitude 16.6) than a star of its type should be, which points to a hot companion that shines on its own. A hot white dwarf would fit the ultraviolet light, but it cannot weigh 1.7 to 5.9 solar masses. The companion's mass is poorly constrained in any case.

**Checks against the record.** The binary is known, but no record of a companion this heavy could be found. The star is far too bright for Pan-STARRS1 and ZTF, so there is no light curve.

**Why this estimate.** The binary has long been known, and the star gives off more far-ultraviolet light than a star of its type should, which points to a hot companion that shines on its own rather than a dark one. The companion's mass is also poorly constrained.

**Caveats.** The binary is already known, the ultraviolet light points to a hot companion that shines, and the companion's mass is poorly constrained.

**Figure note.** No light curve was published for this candidate; the one in Figure 56 was made for this paper from public data (Section 3.10).

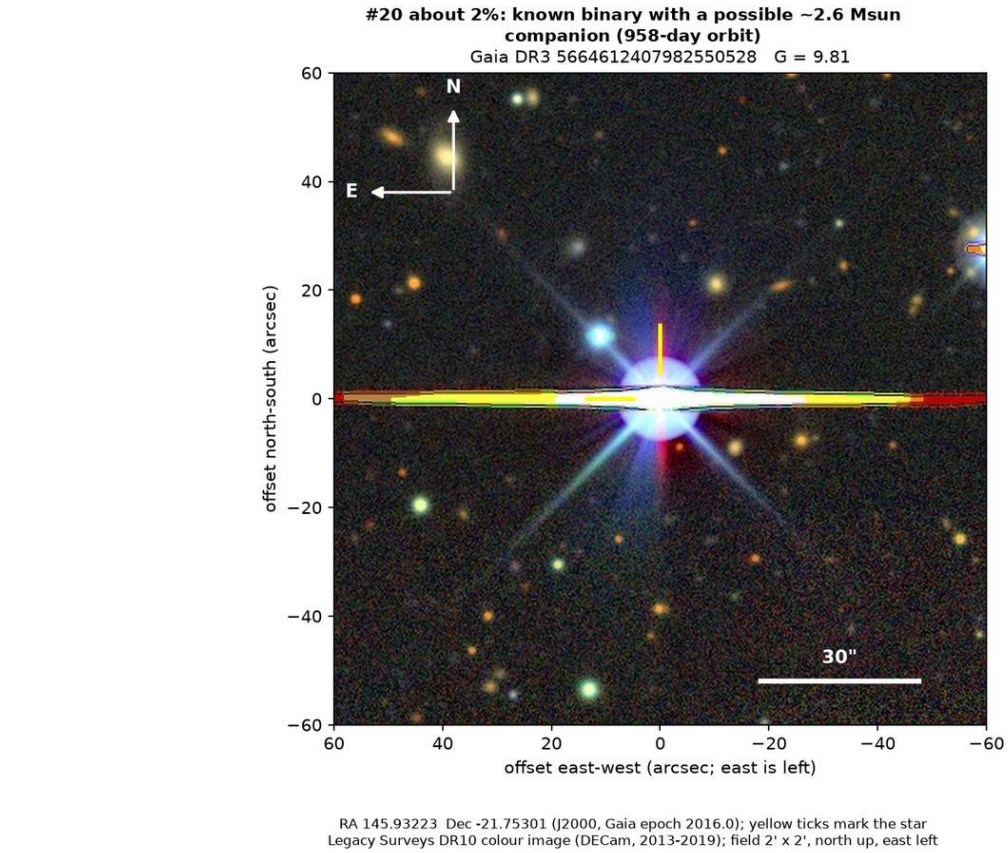



**Figure 54:** Candidate 20, sky image. Legacy Surveys DR10 colour image (DECam), two arcminutes by two. The star is between the yellow ticks; it is bright enough to saturate the image. North is up, east is left, and the white bar is 30 arcseconds. Data: DESI Legacy Imaging Surveys (NOIRLab); ESA/Gaia/DPAC.

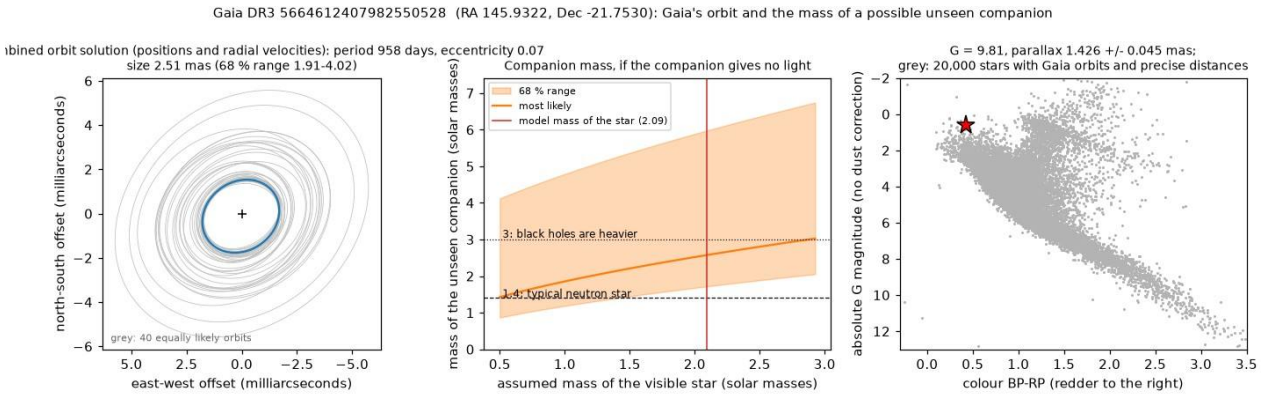



**Figure 55:** Candidate 20, Gaia orbit. Left: the orbit Gaia fitted, a 958-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

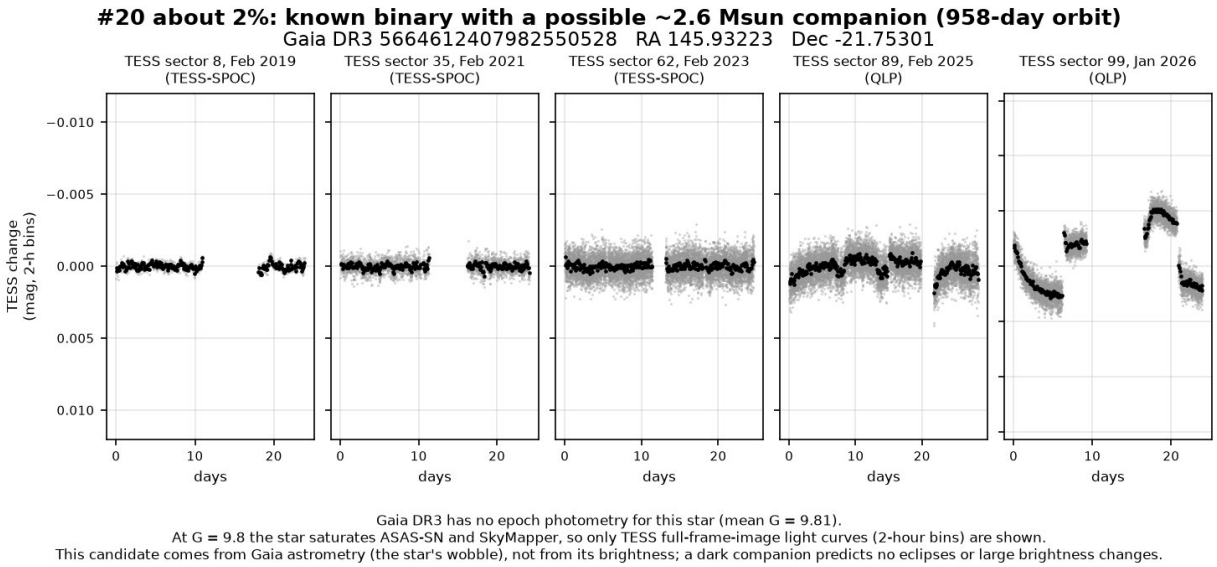



**Figure 56:** Candidate 20, light curve made for this paper from public data. TESS full-frame-image light curves in 2-hour bins, one panel per sector (Ricker et al. 2015; Huang et al. 2020a; Huang et al. 2020b; Caldwell et al. 2020b), with the robust scatter of the bins: sector 8 (Feb 2019, TESS-SPOC, 0.2 mmag); sector 35 (Feb 2021, TESS-SPOC, 0.2 mmag); sector 62 (Feb 2023, TESS-SPOC, 0.2 mmag); sector 89 (Feb 2025, QLP, 0.5 mmag); sector 99 (Jan 2026, QLP, 3.1 mmag). At $G = 9.8$ the star saturates ASAS-SN and SkyMapper, so only TESS is shown. A dark companion predicts a steady star. Data: TESS (NASA; MAST); ESA/Gaia/DPAC.

## Candidate 21: A Sun-like star with a doubtful wobble

| | |
|---|---|
| **Star** | Gaia DR3 1334956997595864960, a Sun-like star |
| **Position** | RA 259.76536°, Dec +34.27371° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Hercules |
| **Galactic** | $l$ = 57.87°, $b$ = +33.04° |
| **Distance** | about 1,100 parsecs (3,600 light-years) |
| **Brightness** | Gaia $G$ = 15.58 |
| **Claim** | Gaia orbit (alternative solution), P = 753 d; companion of about 1.8 solar masses (1.6–2.3) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 1% |

**What Gaia found.** This is a Sun-like star, about 5,600 K, some 1,100 parsecs away in Hercules. One of Gaia's alternative orbit-fitting methods found a 753-day wobble that, for a star of about one solar mass, implies a companion of about 1.8 solar masses (1.6 to 2.3) giving off no visible light. If the orbit were real, the companion would be a neutron star or a heavy white dwarf.

**Why the estimate is low.** Gaia's alternative orbit solutions are less reliable than its main ones and are left out of most published studies, and this one fails the published quality cuts. There are no measurements of the star's speed along the line of sight.

**Checks against the record.** No record of a dark companion for this star could be found.

**Why this estimate.** The orbit comes from Gaia's less reliable alternative orbit solutions, which most published studies leave out, and it fails the published quality cuts: the fit is degenerate, the orbit is only about eight times its uncertainty, and the parallax is too uncertain. No measurements along the line of sight confirm it.

**Caveats.** The orbit is a less reliable kind of Gaia solution and fails the published quality cuts, and no measurements along the line of sight confirm it.

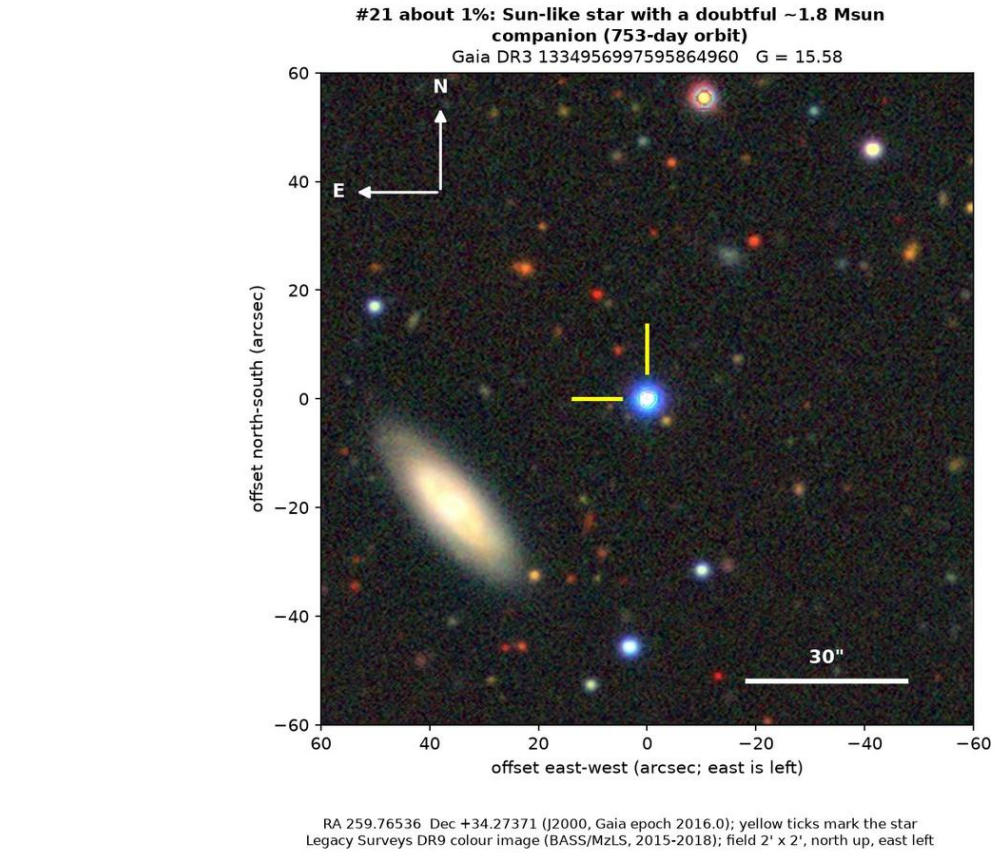



**Figure 57:** Candidate 21, sky image. Legacy Surveys DR9 colour image, two arcminutes by two. The star is between the yellow ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: DESI Legacy Imaging Surveys (NOIRLab); ESA/Gaia/DPAC.

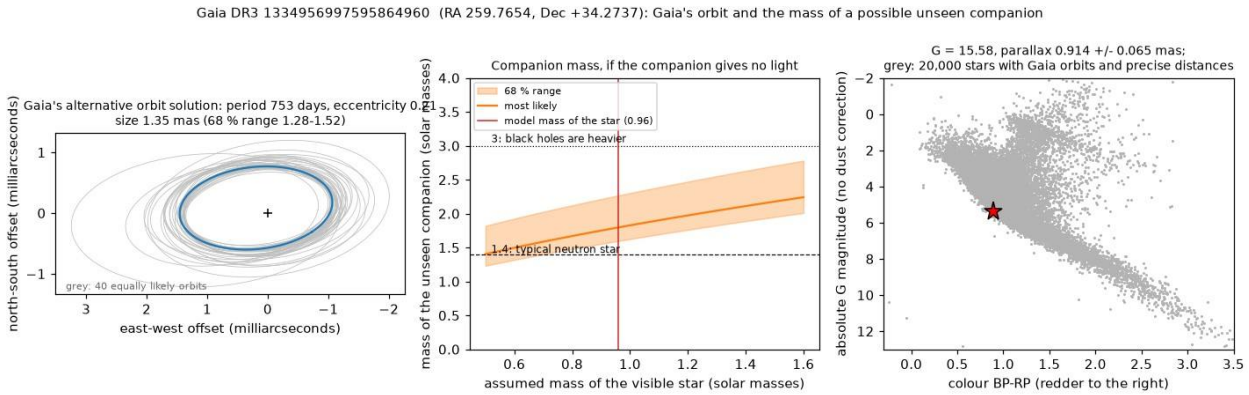



**Figure 58:** Candidate 21, Gaia orbit. Left: the orbit Gaia fitted, a 753-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

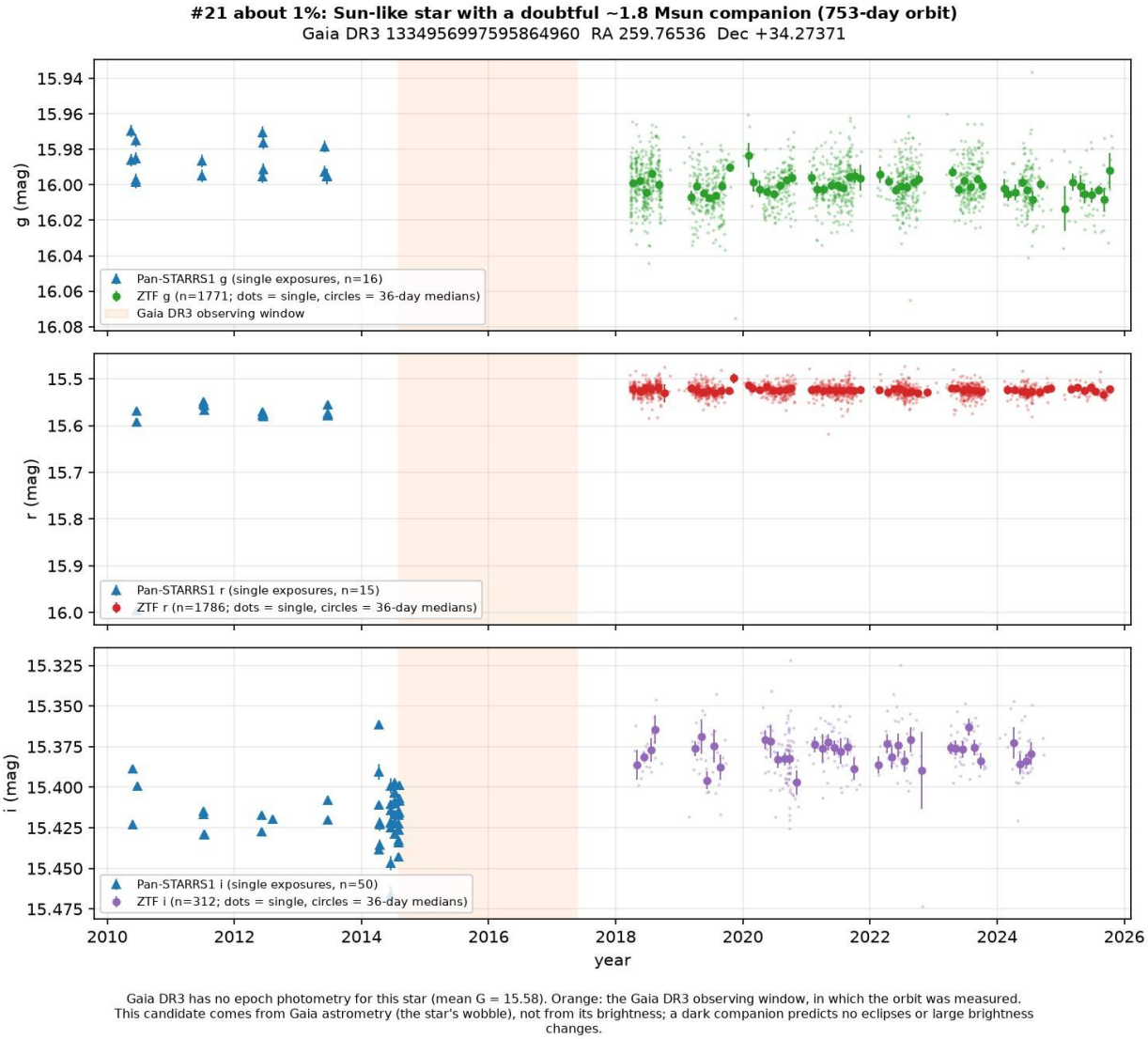



**Figure 59:** Candidate 21, light curve. Pan-STARRS1 from 2010 to 2014 and ZTF from 2018 to 2025, in the g, r and i filters. The orange band marks the years in which Gaia measured the orbit. A dark companion predicts a steady star, and the star is steady; the offsets between the two surveys come from their slightly different filters. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

## Candidate 22: A Sun-like star with a doubtful 25-day wobble

| | |
|---|---|
| **Star** | Gaia DR3 5406907085973524224, a Sun-like star |
| **Position** | RA 151.00434°, Dec −49.79403° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Vela |
| **Galactic** | $l$ = 277.33°, $b$ = +4.57° |
| **Distance** | about 610 parsecs (2,000 light-years) |
| **Brightness** | Gaia $G$ = 14.53 |
| **Claim** | Gaia orbit (alternative solution), P = 25 d; companion of about 4.7 solar masses (4.0–5.9) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 1% |

**What Gaia found.** This is a Sun-like star, about 5,500 K, some 610 parsecs away in Vela. One of Gaia's alternative orbit-fitting methods found a 25-day wobble that, for a star of about 0.9 solar masses, implies a companion of about 4.7 solar masses (4.0 to 5.9) giving off no visible light. If real, that would be a black hole in a tight orbit around an ordinary star.

**Why the estimate is low.** The solution fails the published significance cut that weeds out spurious short-period Gaia orbits (it reaches 20.7, where 31.6 is needed), it comes from Gaia's less reliable alternative solutions, and there are no measurements of the star's speed along the line of sight.

**Checks against the record.** No record of a dark companion for this star could be found. The star is too far south for Pan-STARRS1 and ZTF, so there is no light curve.

**Why this estimate.** A black hole in a tight orbit around an ordinary star would be a major find, but spurious short-period Gaia orbits are far more common. This one fails the published significance cut for such orbits, comes from Gaia's less reliable alternative solutions, and has no measurements along the line of sight to confirm it.

**Caveats.** The orbit fails the published significance cut, comes from a less reliable kind of Gaia solution, and no measurements along the line of sight confirm it.

**Figure note.** No light curve was published for this candidate; the one in Figure 62 was made for this paper from public data (Section 3.10).

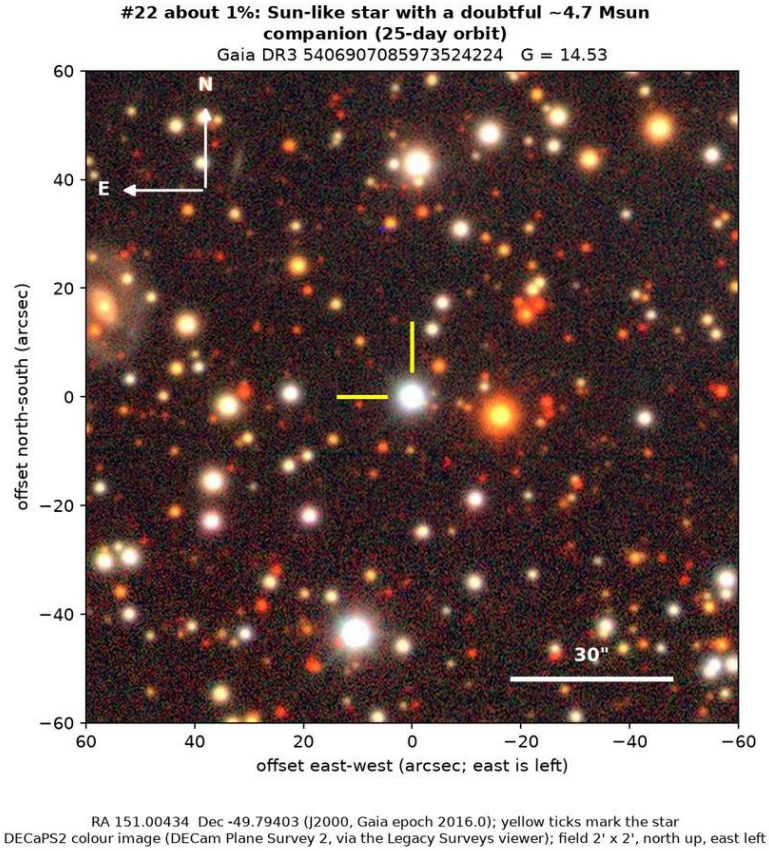



**Figure 60:** Candidate 22, sky image. DECaPS2 colour image (the DECam Plane Survey), two arcminutes by two. The star is between the yellow ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: DECaPS2 (NOIRLab); ESA/Gaia/DPAC.

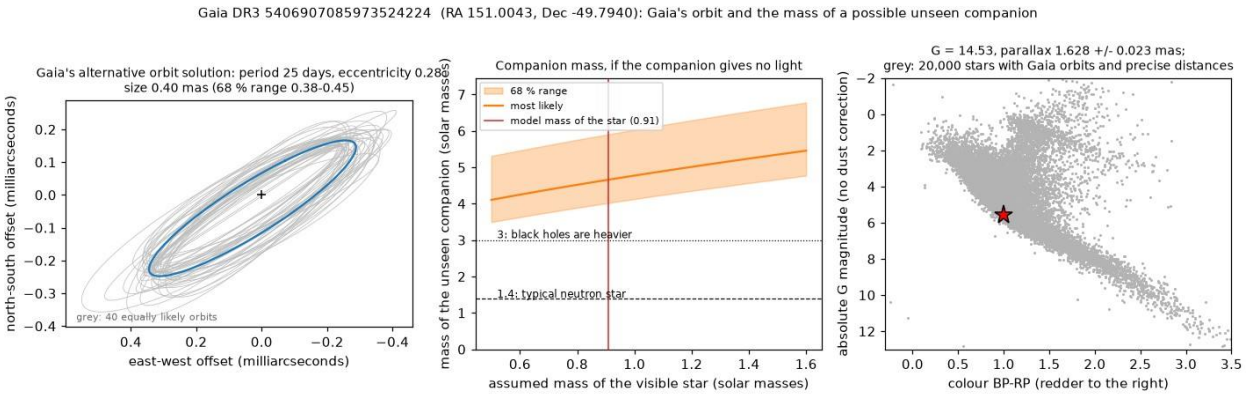



**Figure 61:** Candidate 22, Gaia orbit. Left: the orbit Gaia fitted, a 25-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

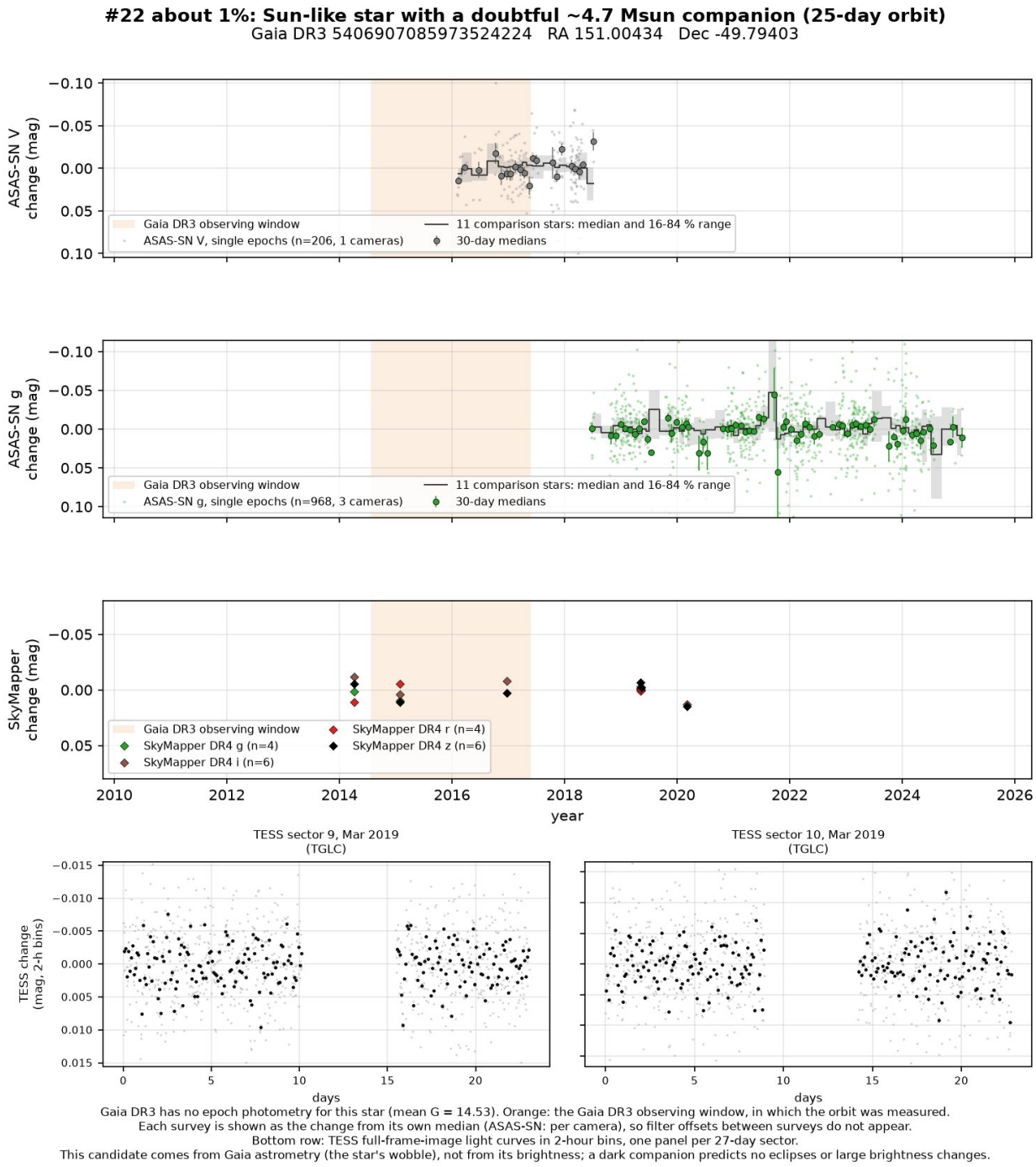



**Figure 62:** Candidate 22, light curve made for this paper from public data. Upper panels: ASAS-SN V (2016–2018; 206 good epochs from 1 camera; 30-day medians scatter by 0.009 mag, robust rms) and ASAS-SN g (2018–2025; 968 good epochs from 3 cameras; 30-day medians scatter by 0.009 mag, robust rms), each shown as the change from its camera's median; dots are single epochs and circles 30-day medians; the grey line and band are the median and 16–84% range of 11 comparison stars within 0.3° and 0.5 mag of the star. SkyMapper DR4 panel: 20 unflagged measurements in g, r, i and z (2014–2020), each relative to its filter's median; robust scatter 0.007 mag. Bottom row: TESS full-frame-image light curves in 2-hour bins (Ricker et al. 2015; Han and Brandt 2023b), with the robust scatter of the bins: sector 9 (Mar 2019, TGLC, 3.1 mmag); sector 10 (Mar 2019, TGLC, 3.3 mmag). The orange band marks the Gaia DR3 observing window (2014 July 25 to 2017 May 28), in which the orbit was measured. A dark companion predicts a steady star. Data: SkyMapper (ANU); ASAS-SN Sky Patrol; TESS (NASA; MAST); ESA/Gaia/DPAC.

## Candidate 23: A reddened star whose orbit does not fix the companion's mass

| | |
|---|---|
| **Star** | Gaia DR3 5329908767714982400, a star seen through thick dust |
| **Position** | RA 132.40037°, Dec −45.93832° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Vela, in the Milky Way |
| **Galactic** | $l = 265.69°$, $b = -1.29°$ |
| **Distance** | about 1,350 parsecs (4,400 light-years) |
| **Brightness** | Gaia $G = 15.78$ |
| **Claim** | Gaia orbit (alternative solution), P = 705 d; companion mass unconstrained (2.6–117) |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded system of the kind described: about 1% |

**What Gaia found.** This star is seen through thick dust, about 1.4 magnitudes of dimming in Gaia's G band, some 1,350 parsecs away in the Milky Way in Vela. One of Gaia's alternative orbit-fitting methods found a nearly circular 705-day wobble.

**Why the estimate is low.** The fit leaves the companion's mass open: its likely range extends from 2.6 to 117 solar masses, and the upper end is unphysical. The dust makes the star's own mass uncertain, the solution comes from Gaia's less reliable alternative solutions, and there are no measurements of the star's speed along the line of sight.

**Checks against the record.** No record of a dark companion for this star could be found. The star is too far south for Pan-STARRS1 and ZTF, so there is no light curve.

**Why this estimate.** The fit leaves the companion's mass almost entirely open, the dust in front of the star makes its own mass uncertain, the orbit comes from Gaia's less reliable alternative solutions, and no measurements along the line of sight confirm it.

**Caveats.** The companion's mass is unconstrained, the star's own mass is uncertain, the orbit is a less reliable kind of Gaia solution, and no measurements along the line of sight confirm it.

**Figure note.** No light curve was published for this candidate; the one in Figure 65 was made for this paper from public data (Section 3.10).

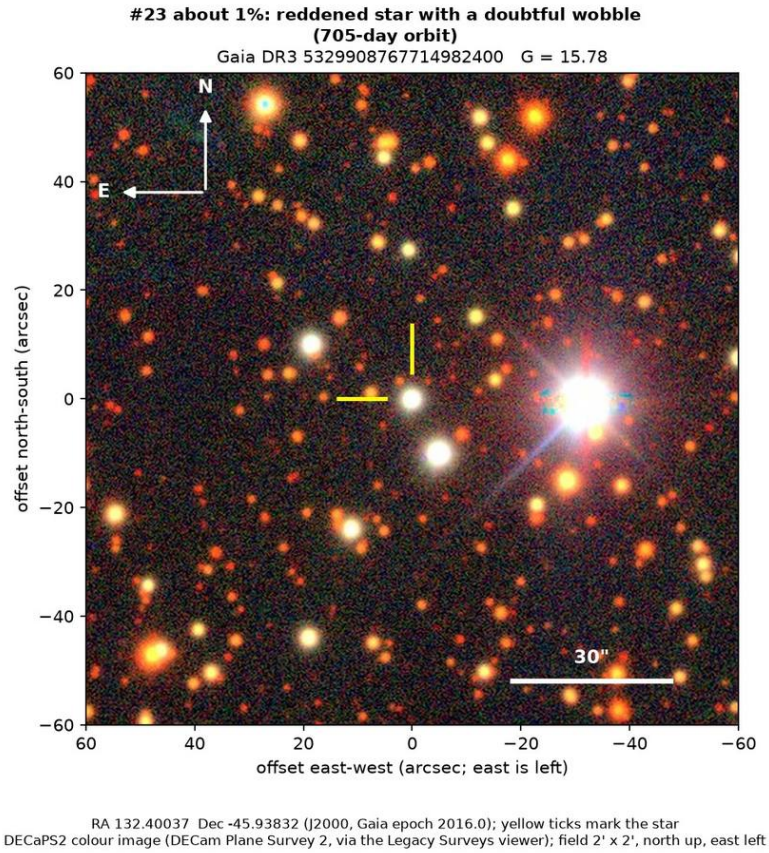



**Figure 63:** Candidate 23, sky image. DECaPS2 colour image (the DECam Plane Survey), two arcminutes by two. The star is between the yellow ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: DECaPS2 (NOIRLab); ESA/Gaia/DPAC.

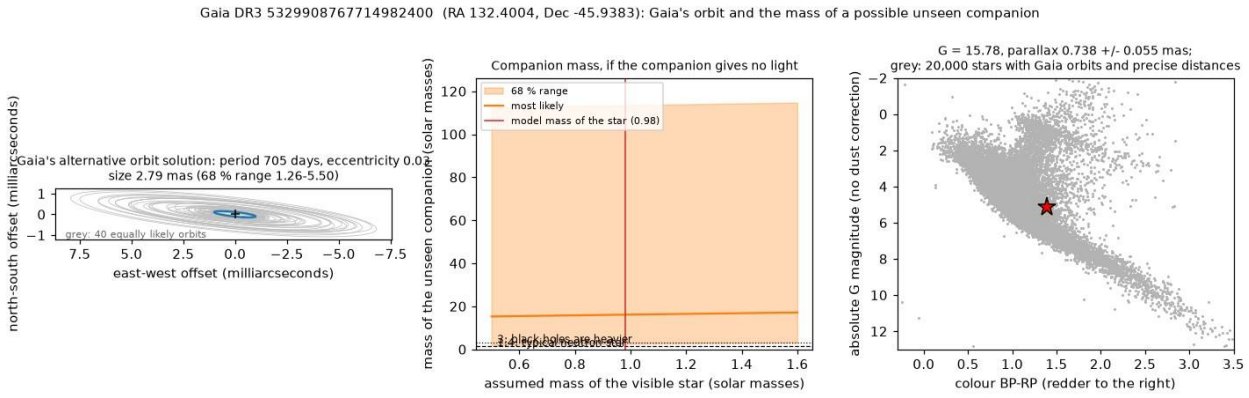



**Figure 64:** Candidate 23, Gaia orbit. Left: the orbit Gaia fitted, a 705-day ellipse traced on the sky, with grey orbits that fit about equally well. Middle: the companion's mass for each assumed mass of the visible star, if the companion gives off no light. Right: the star (red) in Gaia's diagram of colour against brightness, among stars with Gaia orbits and precise distances. Data: ESA/Gaia/DPAC.

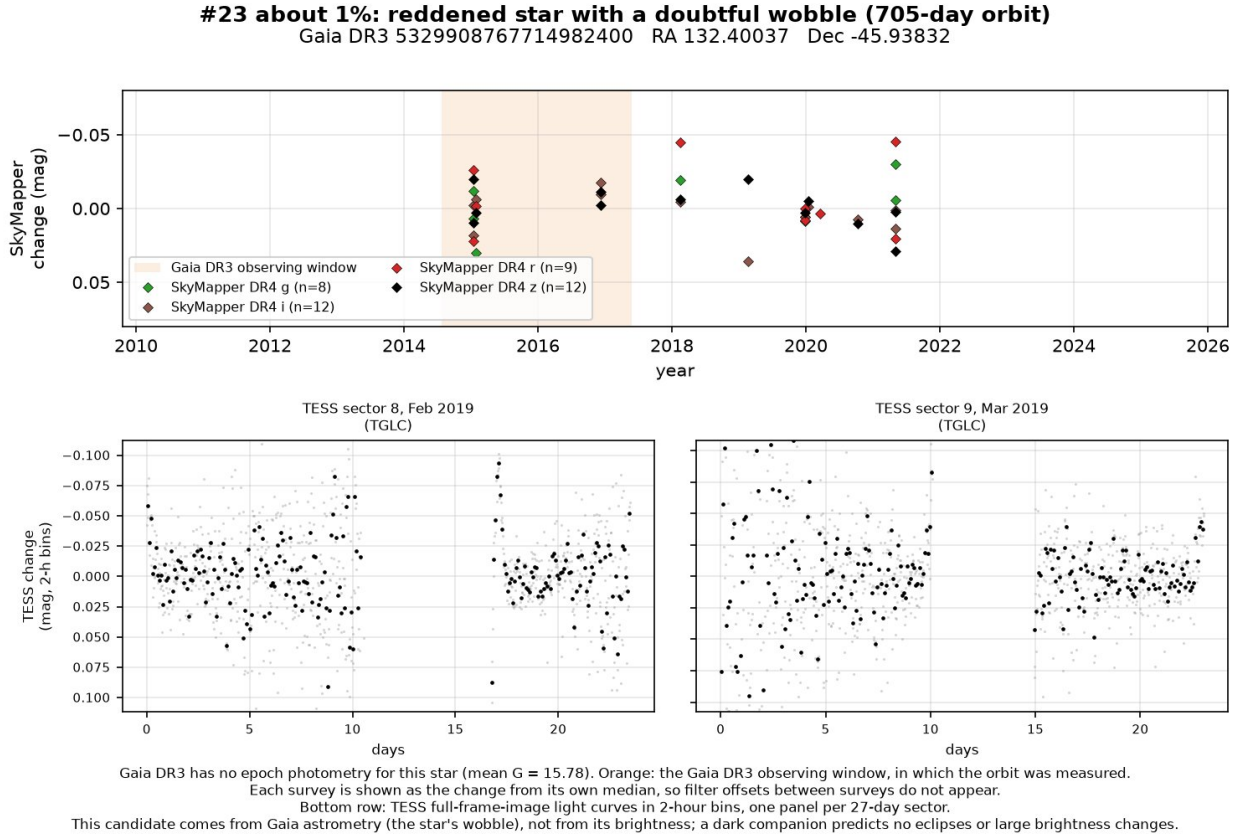



**Figure 65:** Candidate 23, light curve made for this paper from public data. SkyMapper DR4 panel: 41 unflagged measurements in g, r, i and z (2015–2021), each relative to its filter's median; robust scatter 0.013 mag. Bottom row: TESS full-frame-image light curves in 2-hour bins (Ricker et al. 2015; Han and Brandt 2023b), with the robust scatter of the bins: sector 8 (Feb 2019, TGLC, 22.4 mmag); sector 9 (Mar 2019, TGLC, 17.3 mmag). The excursions near the start of each orbit are typical scattered-light systematics for a star this faint; no dip deeper than about 5% appears. The orange band marks the Gaia DR3 observing window (2014 July 25 to 2017 May 28), in which the orbit was measured. A dark companion predicts a steady star. Data: SkyMapper (ANU); TESS (NASA; MAST); ESA/Gaia/DPAC.

## Candidate 24: An orange dwarf that lost half its light within a day

| | |
|---|---|
| **Star** | Gaia DR3 3062085079575847296, an orange K dwarf |
| **Position** | RA 113.41797°, Dec −1.15380° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Monoceros, 8.9 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 218.83°, $b$ = +8.85° |
| **Distance** | about 1,300 to 1,500 parsecs (4,200 to 4,900 light-years) |
| **Brightness** | Gaia $G$ = 17.00; far too faint for the eye or a small telescope |
| **Event** | lost 0.7–0.75 mag in r (about half its light) within a day, 2020 Nov 17–18; normal by 2021 Mar 17 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 60% |

**What changed.** The star is an ordinary orange (K-type) dwarf, somewhat smaller and cooler than the Sun, about 1,300 to 1,500 parsecs (4,200 to 4,900 light-years) away and steady for at least ten years. On 17 November 2020 ZTF found it normal; at 10:54 UTC on 18 November, less than 24 hours later, it was 0.7 to 0.75 magnitudes fainter in red light, having lost about half of its light. Through late November and December it stayed 0.4 to 0.7 magnitudes faint in green light, then recovered unevenly, back to normal by 17 March 2021.

It dimmed alike on two overlapping ZTF fields, and so on two detectors, while none of 65 comparison stars changed by more than 0.03 magnitudes. ZTF's alert system, which compares each new image with a reference image, recorded 49 good-quality alerts, all fainter than the reference and centred on the star. On 28 November SkyMapper found the star 0.61 magnitudes faint in near-infrared light, while about 150 other stars on its images stayed unchanged.

**Why it might matter.** A cloud of dust with a sharp front edge and a long, patchy tail is the likeliest cause. Green light dimmed 1.28 times as much as red, between an opaque body (1.0) and ordinary interstellar dust (1.40), which fits dust with grains somewhat larger than usual. To cover half the star within a day, the edge must have moved at 5 to 8 km/s or more, so four months of recovery mean a structure at least 55 to 80 million km long: perhaps a cloud like a comet's dust tail but vastly larger, or debris from a collision between planets or asteroids.

Starspots change a quiet orange dwarf's light by only a few per cent, and this star shows no rotation; an eclipse by another star would be symmetric, the star recovering as fast as it faded. Young stars are often dimmed by their own dusty discs, but this one gives off no extra infrared light, shows no hydrogen emission and lies 200 parsecs above the Milky Way's mid-plane, in no known cluster or young group. Two telescopes and steady comparison stars rule out an instrumental cause. A spectrum would settle the star's type and age.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, Gaia lists no variability, VSX (the variable-star index) has nothing within 30 arcseconds, and the star is in no other variable-star catalogue consulted. No transient report, Gaia alert or paper names it, and ZTF's alert system holds only machine-generated classifications. The star is not among the 81 dimming stars of Tzanidakis et al. (2025), although it appears to meet their selection.

**Why this estimate.** The dimming is certain: ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) and SkyMapper (a telescope in Australia) both recorded it, while comparison stars stayed steady. Starspots cannot halve a star's light within a day. The estimate is not higher because there is no spectrum, which could still reveal a young star or a companion; no infrared measurement was made during the dimming; and deep, one-off dimmings of ordinary dwarf stars are rare enough that an unrecognised kind of variability cannot be excluded.

**Caveats.** There is no spectrum. The star is too faint for ASAS-SN, a worldwide network of small telescopes, and SkyMapper caught the dimming on one night only. WISE, NASA's infrared space telescope, never

observed during it, so warm dust near the star is untested. Gaia's models disagree about the star's temperature and reddening, and its distance is uncertain by about 15 per cent.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

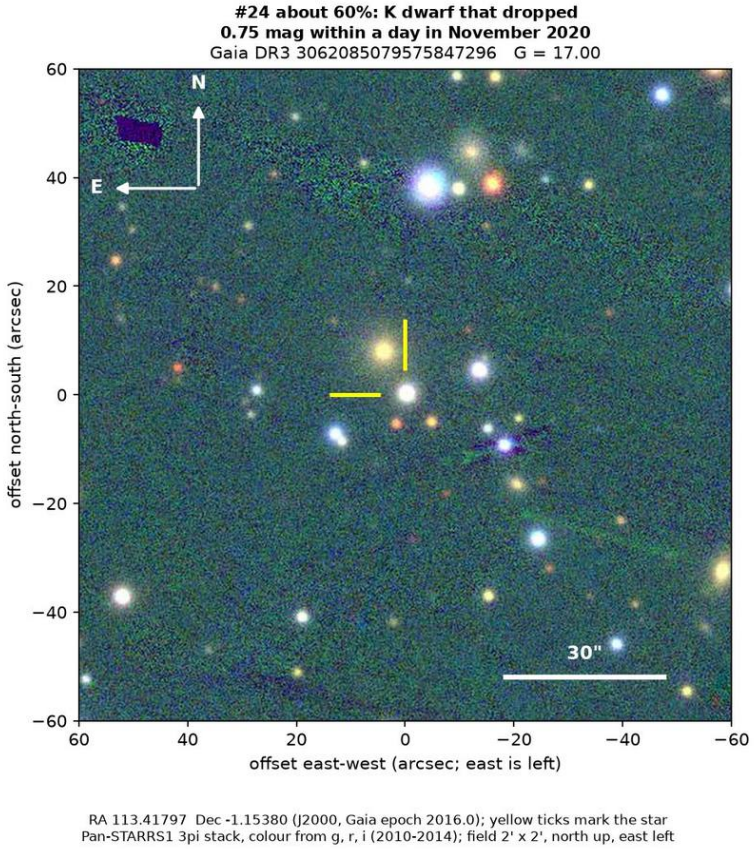
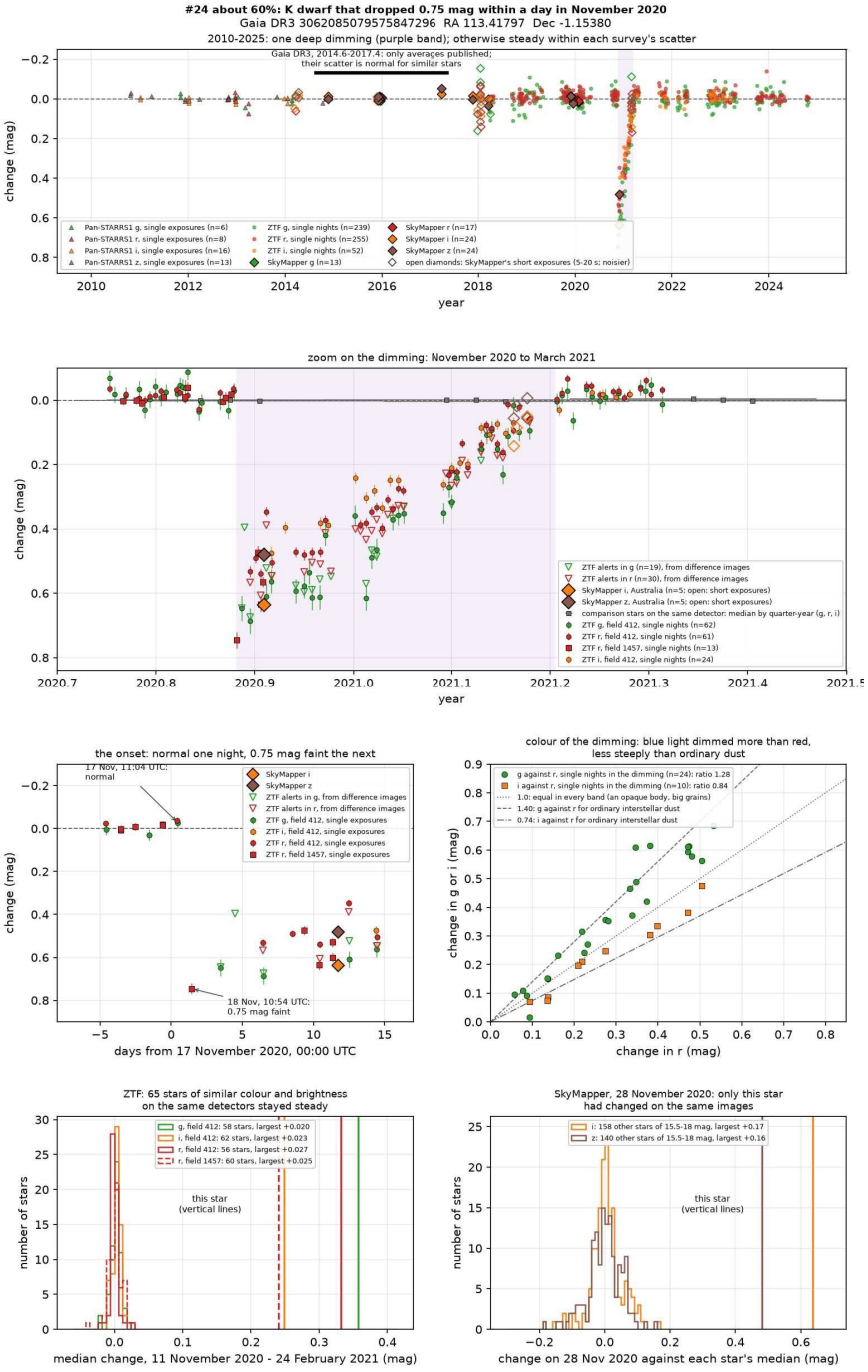



**Figure 66:** Candidate 24, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the white one between the yellow ticks. The fuzzy yellow patch just north-north-east of it is a background galaxy; two faint red stars lie 6 to 7 arcseconds to the south, and comparison star A 14 arcseconds to the west-north-west. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its level outside the dimming, ZTF saw this star steady from March 2018 to mid-November 2020 (single nights scatter by about 0.04 mag in g and 0.02 mag in r). On 17 November 2020 it was normal in g and r (last exposure 11:04 UTC); less than 24 hours later, at 10:54 UTC on 18 November, it was 0.75 mag fainter in r, the deepest point recorded. In late November and December it stayed 0.4-0.7 mag faint in g and 0.35-0.65 mag in r, changing by up to 0.2 mag from one night to the next; it then recovered unevenly, to 0.35-0.6 mag faint in g in January and 0.1-0.35 mag in February, and was back to normal by 17 March 2021. The star lies where two ZTF fields overlap: it dims in g, r and i in one and in r in the other (ZTF's i band began on 30 November), while none of 65 stars of similar colour and brightness on the same detectors changed by more than 0.03 mag (bottom left). ZTF's separate difference-image pipeline recorded 49 good-quality alerts from 20 November 2020 to 7 March 2021, all 'fainter than the reference' and centred on the star. SkyMapper, a separate telescope in Australia, imaged the star on 28 November 2020 and found it 0.61 mag faint in i and 0.48 mag faint in z, while about 150 other stars of similar brightness on the same two images were unchanged (bottom right); its images of 2014-2020 show the star at its normal level, and its short exposures of early March 2021 the end of the recovery. Blue light dimmed 1.28 times as much as red (68 % range 1.24-1.32) and the near-infrared i band 0.84 times as much (in SkyMapper, z dimmed 0.79 times as much as i), between an opaque body (1.0) and ordinary interstellar dust (1.40 and 0.74). Purple band: 18 November 2020 - 17 March 2021.

**Figure 67:** Candidate 24, light curve. Top: 2010 to 2025, from Pan-STARRS1 (a survey telescope in Hawaii), SkyMapper and ZTF; Gaia, the European Space Agency's star-mapping satellite, publishes only averages, so only its years are marked. Purple marks the dimming, from 18 November 2020 to 17 March 2021. Below: the dimming night by night; its onset; green (g) and near-infrared (i) dimming against red (r), with lines for an opaque body and ordinary dust; and the comparison stars of ZTF and SkyMapper. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); SkyMapper (ANU); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

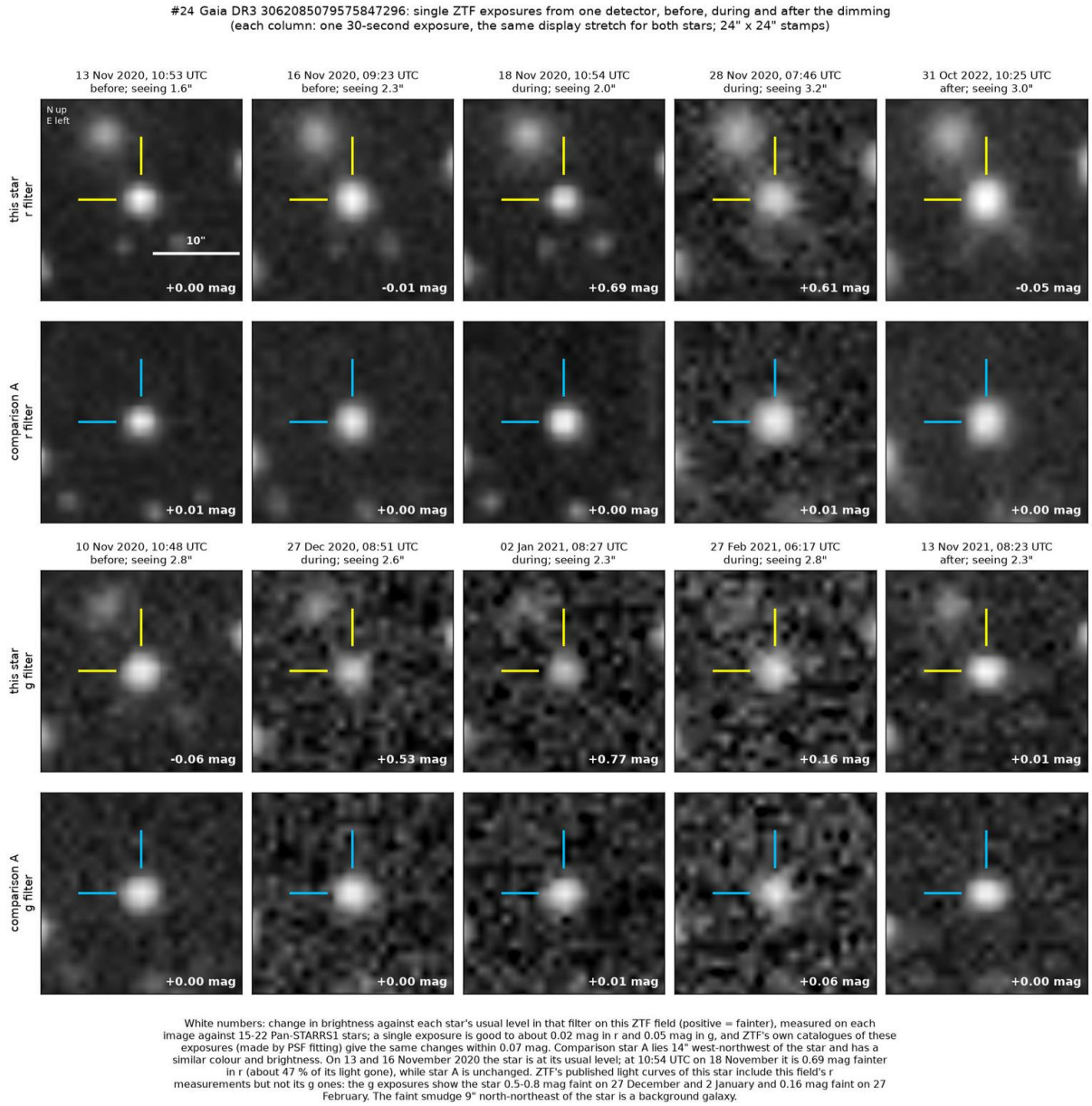



**Figure 68:** Candidate 24, before and during. Single 30-second ZTF exposures from one detector, 24 arcseconds across, north up and east left: the star at the yellow ticks and comparison star A at the blue ticks, both shown on the same brightness scale in each exposure. Upper two rows: red light before, during (18 and 28 November 2020) and after the dimming; lower two rows: green light, likewise. White numbers are changes in magnitudes, positive meaning fainter: on 18 November the star was 0.69 magnitudes fainter than usual, while star A was unchanged. Data: ZTF (Caltech/IPAC).

## Candidate 25: An orange dwarf that dipped every 4.8 days, then faded for months

| | |
|---|---|
| **Star** | Gaia DR3 1026501719229603584, an orange K dwarf |
| **Position** | RA 144.03137°, Dec +59.16899° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Ursa Major, 43.8 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 155.23°, $b$ = +43.77° |
| **Distance** | about 2,600 parsecs (8,500 light-years), with a range of 2,000 to 3,400 parsecs |
| **Brightness** | Gaia $G$ = 17.99; far too faint for the eye or a small telescope |
| **Event** | dips every 4.8 d in 2020 Feb–Mar (up to 30 per cent); faint 2020 Sep–2021 Mar, up to 70 per cent in g |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 55% |

**What changed.** The star is an orange (K-type) dwarf, a little smaller and cooler than the Sun, about 2,600 parsecs (8,500 light-years) away. Steady from 2010 to 2019, it dipped slightly in January 2020 and then six times between 4 February and 5 March, about every 4.8 days, each time for one to three nights and by up to 30 per cent in green light. TESS recorded the dip of 13 to 15 February as a drop of about 8 per cent lasting 2.5 days.

After its yearly gap in observations, the star was faint again on 29 September 2020 and stayed so until mid-February 2021, changing by up to 0.6 magnitudes from night to night; on 11 December it had lost 71 per cent of its green light. ZTF's alert system, which compares each new image with a reference image, recorded 87 good-quality alerts, all fainter than the reference and centred on the star. It dimmed again, slightly, in November 2025.

**Why it might matter.** Clouds of dust passing in front of the star are the likeliest cause. Green light dimmed 1.37 times as much as red, as through ordinary interstellar dust (1.40), and WISE, NASA's infrared space telescope, found the star no fainter at 3.4 microns mid-way through the deep episode; together these rule out an opaque body. Material orbiting every 4.8 days would lie about 8 million km from the star, where a compact body would cross it in about two and a half hours; the 2.5-day TESS dip needs material spread along about half the orbit, like a long dust tail.

Starspots change a quiet orange dwarf's light by only a few per cent, and an eclipse by another star would repeat with the same depth. The star resembles young stars dimmed by clumps in their own discs, but it lies about 1,800 parsecs above the Milky Way's plane, far from any star-forming region, moves fast and gives off no extra infrared light. Three detectors and a space telescope rule out an instrumental cause. A spectrum would settle the star's type and age and could reveal a companion.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, Gaia lists no variability, VSX (the variable-star index) has nothing within 30 arcseconds, and the star is in no other variable-star catalogue consulted, nor among the 81 dimming stars of Tzanidakis et al. (2025). No transient report, Gaia alert or paper names it, and ZTF's alert system holds only machine-generated classifications.

**Why this estimate.** The dimming is certain: ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) recorded it on three detectors while comparison stars stayed steady, and NASA's TESS space telescope caught one dip. The estimate is not higher because on about two dozen nights the star was also slightly brighter than usual, which passing dust cannot cause, so the star or a companion may vary too; because it is faint, so that only ZTF and TESS recorded the dimming; and because there is no spectrum.

**Caveats.** There is no spectrum, and the star is too faint for ASAS-SN, a worldwide network of small telescopes. Its brightenings of 2019 to 2021, by up to 0.23 magnitudes, are unexplained, and TESS's large pixels take in light from neighbouring stars, so its 8 per cent depth is a lower limit.

**Figure note.** The title line of the ZTF image figure and of the TESS figure carried an earlier display number on the public page; it has been corrected here.

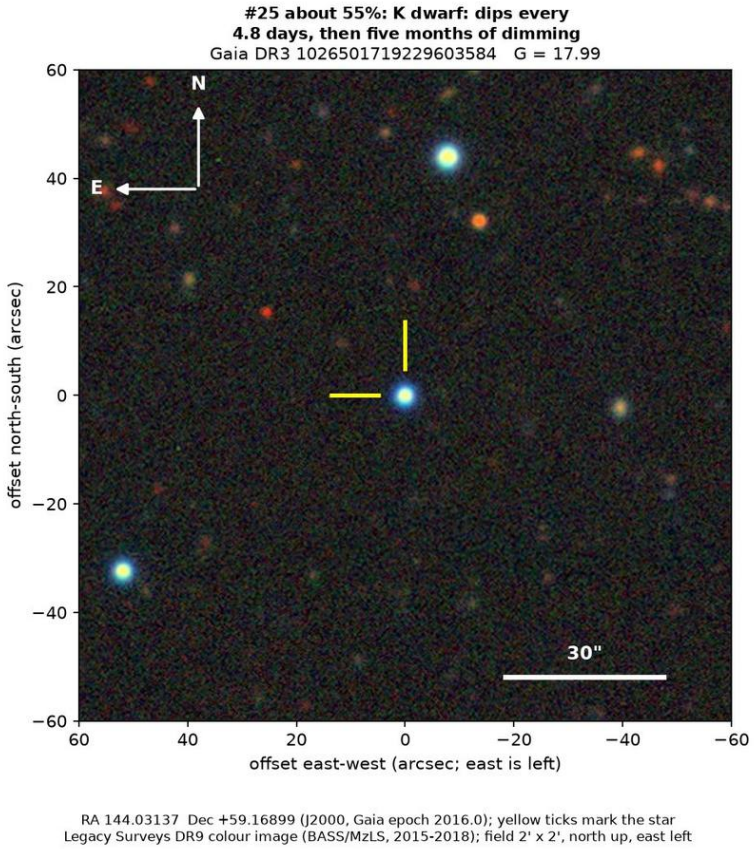
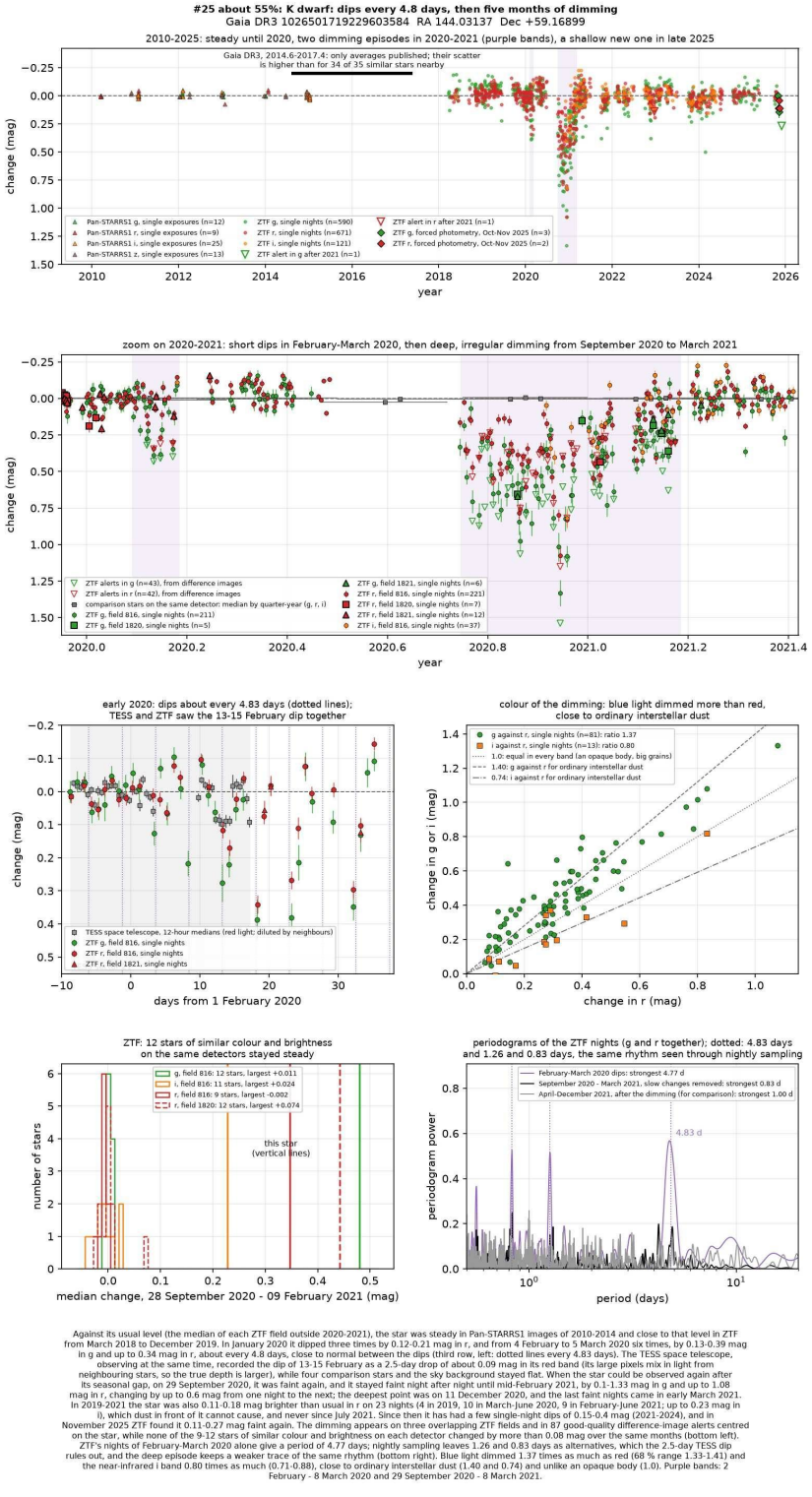



**Figure 69:** Candidate 25, sky image. Legacy Surveys colour image (Data Release 9, from BASS and MzLS, 2015 to 2018), two arcminutes by two. The star is the white one between the yellow ticks; nothing else seen by Gaia lies within 12 arcseconds, and the nearest bright star is 45 arcseconds to the north-north-west. North is up, east is left, and the white bar is 30 arcseconds. Data: DESI Legacy Imaging Surveys (NOIRLab); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside 2020-2021), the star was steady in Pan-STARRS1 images of 2010-2014 and close to that level in ZTF from March 2018 to December 2019. In January 2020 it dipped three times by 0.12-0.21 mag in r, and from 4 February to 5 March 2020 six times, by 0.13-0.39 mag in g and up to 0.34 mag in r, about every 4.8 days, close to normal between the dips (third row, left: dotted lines every 4.83 days). The TESS space telescope, observing at the same time, recorded the dip of 13-15 February as a 2.5-day drop of about 0.09 mag in its red band (its large pixels mix in light from neighbouring stars, so the true depth is larger), while four comparison stars and the sky background stayed flat. When the star could be observed again after its seasonal gap, on 29 September 2020, it was faint again, and it stayed faint night after night until mid-February 2021, by 0.1-1.33 mag in g and up to 1.08 mag in r, changing by up to 0.6 mag from one night to the next; the deepest point was on 11 December 2020, and the last faint nights came in early March 2021. In 2019-2021 the star was also 0.11-0.18 mag brighter than usual in r on 23 nights (4 in 2019, 10 in March-June 2020, 9 in February-June 2021; up to 0.23 mag in i), which dust in front of it cannot cause, and never since July 2021. Since then it has had a few single-night dips of 0.15-0.4 mag (2021-2024), and in November 2025 ZTF found it 0.11-0.27 mag faint again. The dimming appears on three overlapping ZTF fields and in 87 good-quality difference-image alerts centred on the star, while none of the 9-12 stars of similar colour and brightness on each detector changed by more than 0.08 mag over the same months (bottom left). ZTF's nights of February-March 2020 alone give a period of 4.77 days; nightly sampling leaves 1.26 and 0.83 days as alternatives, which the 2.5-day TESS dip rules out, and the deep episode keeps a weaker trace of the same rhythm (bottom right). Blue light dimmed 1.37 times as much as red (68 % range 1.33-1.41) and the near-infrared i band 0.80 times as much (0.71-0.88), close to ordinary interstellar dust (1.40 and 0.74) and unlike an opaque body (1.0). Purple bands: 2 February - 8 March 2020 and 29 September 2020 - 8 March 2021.

**Figure 70:** Candidate 25, light curve. Top: 2010 to 2025, from Pan-STARRS1 (a survey telescope in Hawaii) and ZTF; Gaia, the European Space Agency's star-mapping satellite, publishes only averages, so only its years are marked. Purple marks the two dimming episodes. Below: 2020 and early 2021; early 2020 with TESS and dotted lines every 4.83 days; the dimming in green (g) and near-infrared (i) light against red (r); the comparison stars; and tests for a repeating period. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); TESS (NASA; MAST); ESA/Gaia/DPAC.

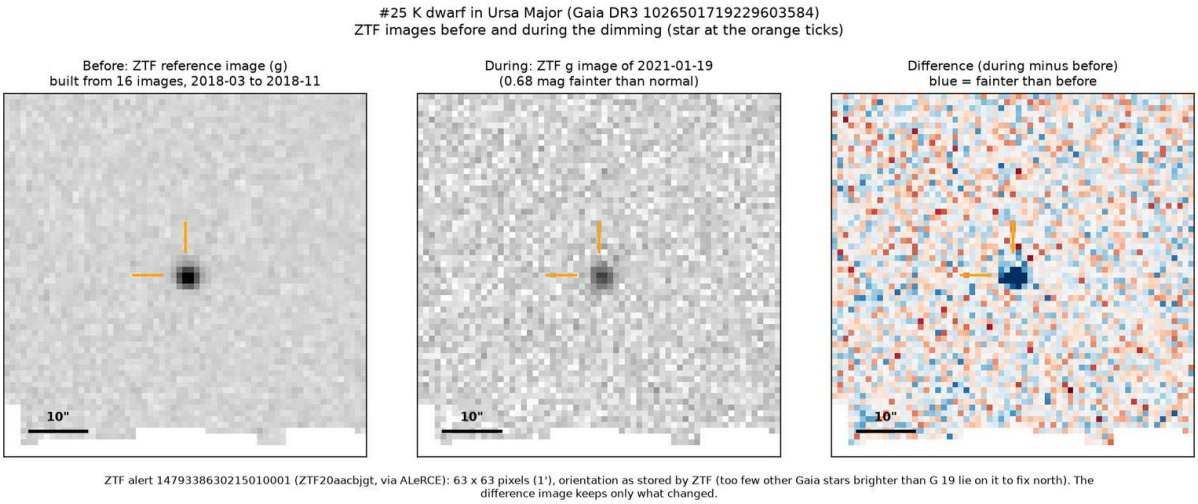



**Figure 71:** Candidate 25, before and during. ZTF alert cutouts in green light, one arcminute across, with the star at the orange ticks, shown as ZTF stores them, not north up: no other star on them is bright enough to fix the orientation. Left: the reference image, from 16 images of 2018. Middle: 19 January 2021, with the star 0.68 magnitudes fainter than normal. Right: the difference; blue means fainter. Data: ZTF (Caltech/IPAC).

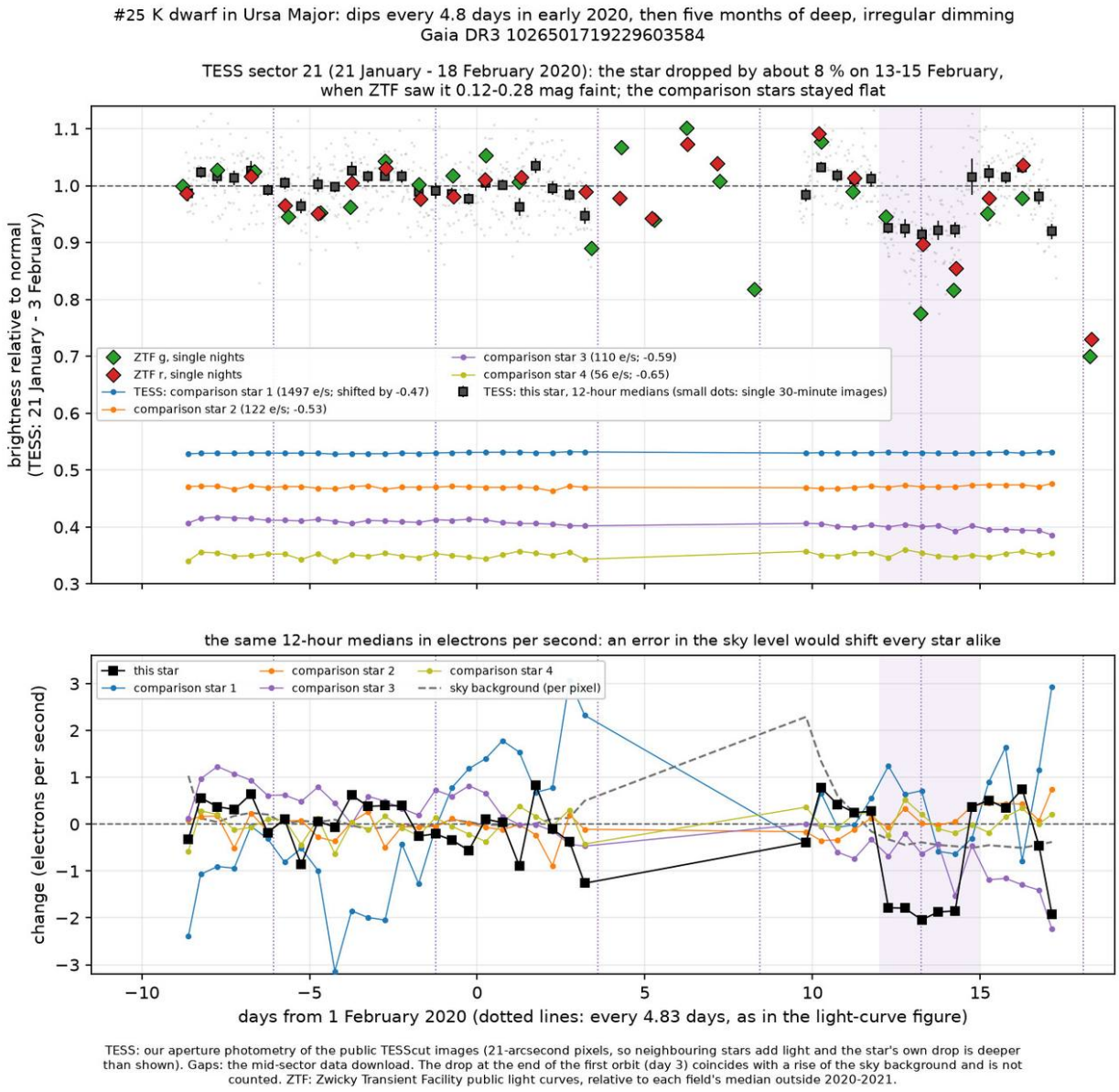



**Figure 72:** Candidate 25, TESS light curves. TESS, 21 January to 18 February 2020. Top: the star in 12-hour medians (black squares), ZTF's nights and four brighter comparison stars, shifted down. Bottom: the same medians in electrons per second, with the sky background: an error in the sky level would shift every star alike, but only this star dropped on 13 to 15 February (purple). Drops on 3 to 4 and 18 February coincide with sky changes and are not counted. Dotted lines are 4.83 days apart. Data: ZTF (Caltech/IPAC); TESS (NASA; MAST).

## Candidate 26: A hot star that dimmed for a year and brightened in the infrared

| | |
|---|---|
| **Star** | Gaia DR3 2173085230811134208, a hot A-type star |
| **Position** | RA 325.17016°, Dec +52.12885° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cygnus, 0.45 degrees south of the Milky Way's mid-plane |
| **Galactic** | $l = 95.93°$, $b = -0.45°$ |
| **Distance** | about 2,400 parsecs (8,000 light-years) |
| **Brightness** | Gaia $G = 13.90$; far too faint for the eye |
| **Event** | about 9 per cent in g (0.10 mag) from 2021 Apr to spring 2022; 0.19 mag brighter at 4.6 microns |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 50% |

**What changed.** This hot A-type star in Cygnus, about 2,400 parsecs (8,000 light-years) away, is roughly 100 times as luminous as the Sun and seen through a lot of interstellar dust. After at least six steady years it faded from April 2021, most deeply from October to December 2021, when it had lost about 9 per cent of its green light and 6 per cent of its red. By April to June 2022 it had nearly recovered.

During the dimming, none of 45 comparison stars on the same ZTF detector changed by more than 0.01 magnitudes in green light. ZTF's alert system, which compares each new image with a reference image, recorded 24 good-quality alerts, all fainter than the reference, and ASAS-SN's eight faintest well-observed months all fall inside the dimming. NEOWISE found the star 0.19 magnitudes brighter at 4.6 microns by November 2021 and back to normal only by June 2024, with no change at 3.4 microns.

**Why it might matter.** Dust close to the star is the likeliest cause. Green light dimmed about 1.5 times as much as red, like ordinary interstellar dust (1.4); an opaque body would dim all colours equally. Dust a few astronomical units out (one is the Earth–Sun distance), warmed by the star to 300 to 400 kelvin, brightens it far more at 4.6 microns than at 3.4, as seen. The glow means that the dust absorbed only about 0.3 to 1.5 per cent of the star's light, yet along the line of sight it blocked about 6 to 9 per cent, so it must be clumped or flattened.

A Be star, a hot star with a disc of gas, would also have brightened at 3.4 microns, and the spectra of Gaia, the European Space Agency's star-mapping satellite, show no emission; a young star with a dusty disc would have shown hot dust before the event. ASAS-SN and NEOWISE make an instrumental cause unlikely. A similar dimming and glow around the Sun-like star ASASSN-21qj was attributed to debris from colliding planets (Kenworthy et al. 2023). A spectrum would confirm the star's type and show whether it has the emission lines of a Be star.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or any other catalogue consulted, nor among the dimming stars of Tzanidakis et al. (2025), the nearest of which is 1.8 degrees away. No transient report, Gaia alert or paper names it, and ZTF's alert system holds only machine-generated classifications, none of them confident.

**Why this estimate.** The dimming is certainly real: ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) and ASAS-SN (a worldwide network of small telescopes) both recorded it, and a star this hot has no large starspots. NEOWISE, NASA's infrared space telescope, also saw it grow brighter at 4.6 microns, as dust warmed by the star would make it. The estimate is not higher because there is no spectrum, ZTF's light curves come from a single field, and an unrelated infrared source very close to the star cannot be fully excluded.

**Caveats.** There is no spectrum, and the star's type and reddening rest on Gaia's low-resolution spectra alone. Two other stars, candidate 27 and candidate 43 , dimmed over almost the same months, but they are far nearer, at 870 and 1,000 parsecs, so no single cloud could have dimmed all three; the coincidence is most likely chance. Several other stars that dimmed in the same survey data, among them candidate 57 and one

already published by Tzanidakis et al. (2025), were also faint in late 2021 and early 2022, but ASAS-SN and NEOWISE, which share no equipment with ZTF, recorded this one too.

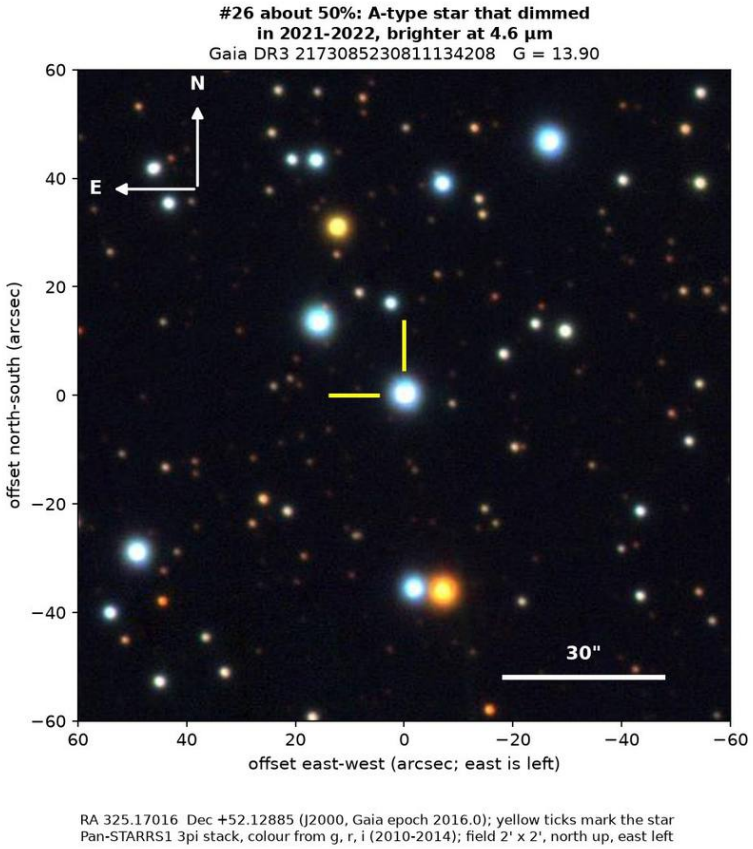



**Figure 73:** Candidate 26, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright white one between the yellow ticks. Its similar neighbour, 21 arcseconds to the north-east, is a nearer star, about 580 parsecs away, that varies slightly as it spins. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

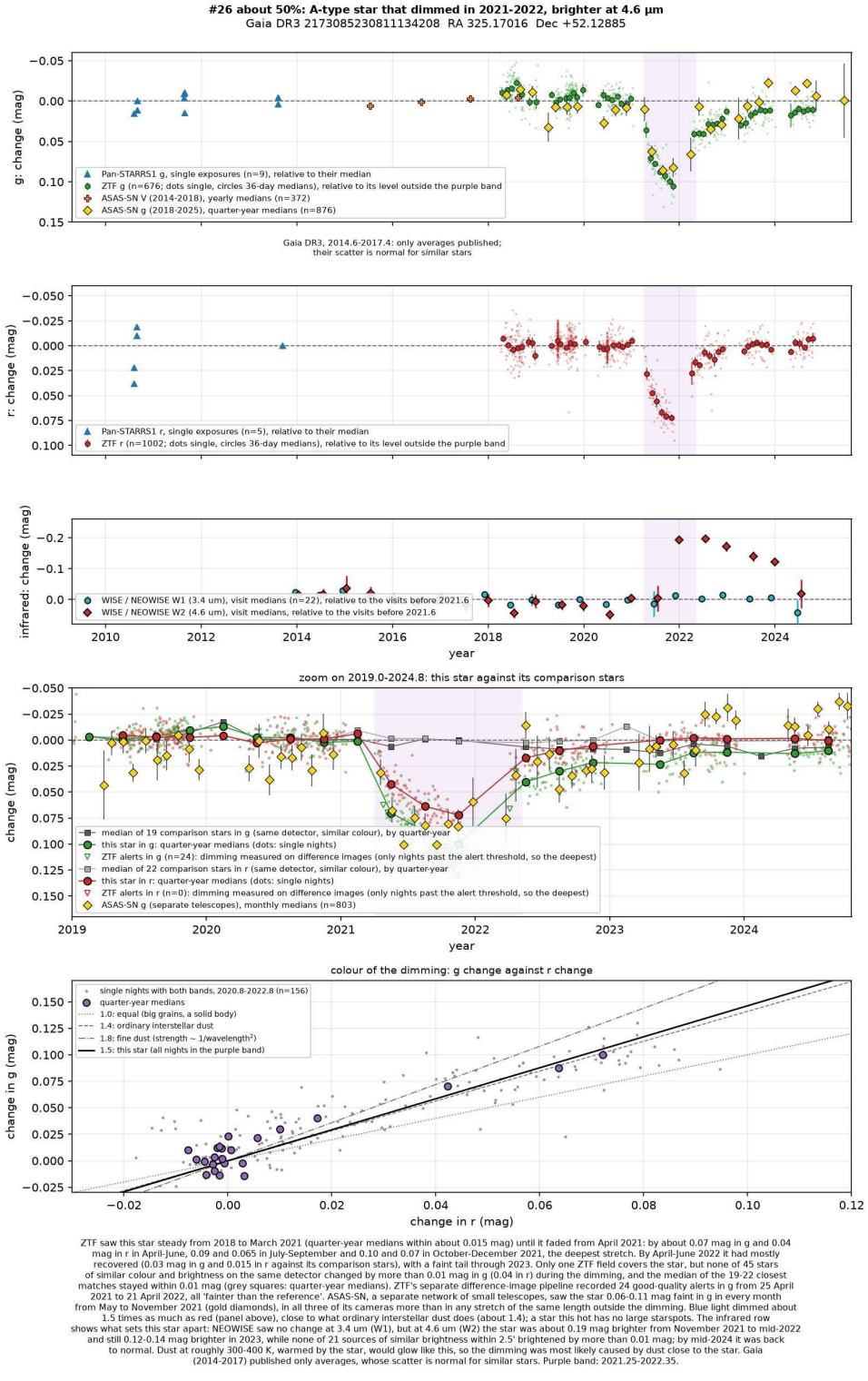



**Figure 74:** Candidate 26, light curve. Top three rows: 2010 to 2025 in green (g) and red (r) light, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF and ASAS-SN, and in the infrared from NEOWISE, at 3.4 microns (circles) and 4.6 microns (red diamonds). Purple marks the dimming. Middle: 2019 to 2024, with comparison stars, ZTF's alerts and ASAS-SN. Bottom: green dimming against red, with lines for an opaque body, ordinary dust and fine dust. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC).

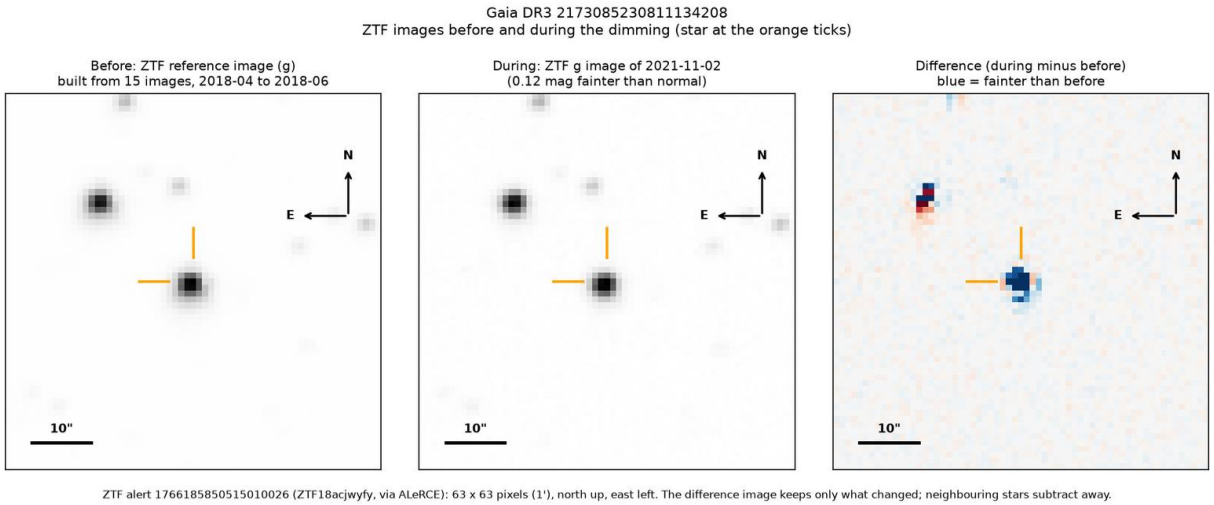



**Figure 75:** Candidate 26, before and during. ZTF alert cutouts in green light, one arcminute across, turned north up and east left, with the star at the orange ticks. Left: the reference image, from 15 images of April to June 2018. Middle: 2 November 2021, with the star 0.12 magnitudes fainter than normal. Right: the difference, in which blue means fainter; the variable to the north-east leaves a small red-and-blue pattern from imperfect subtraction. Data: ZTF (Caltech/IPAC).

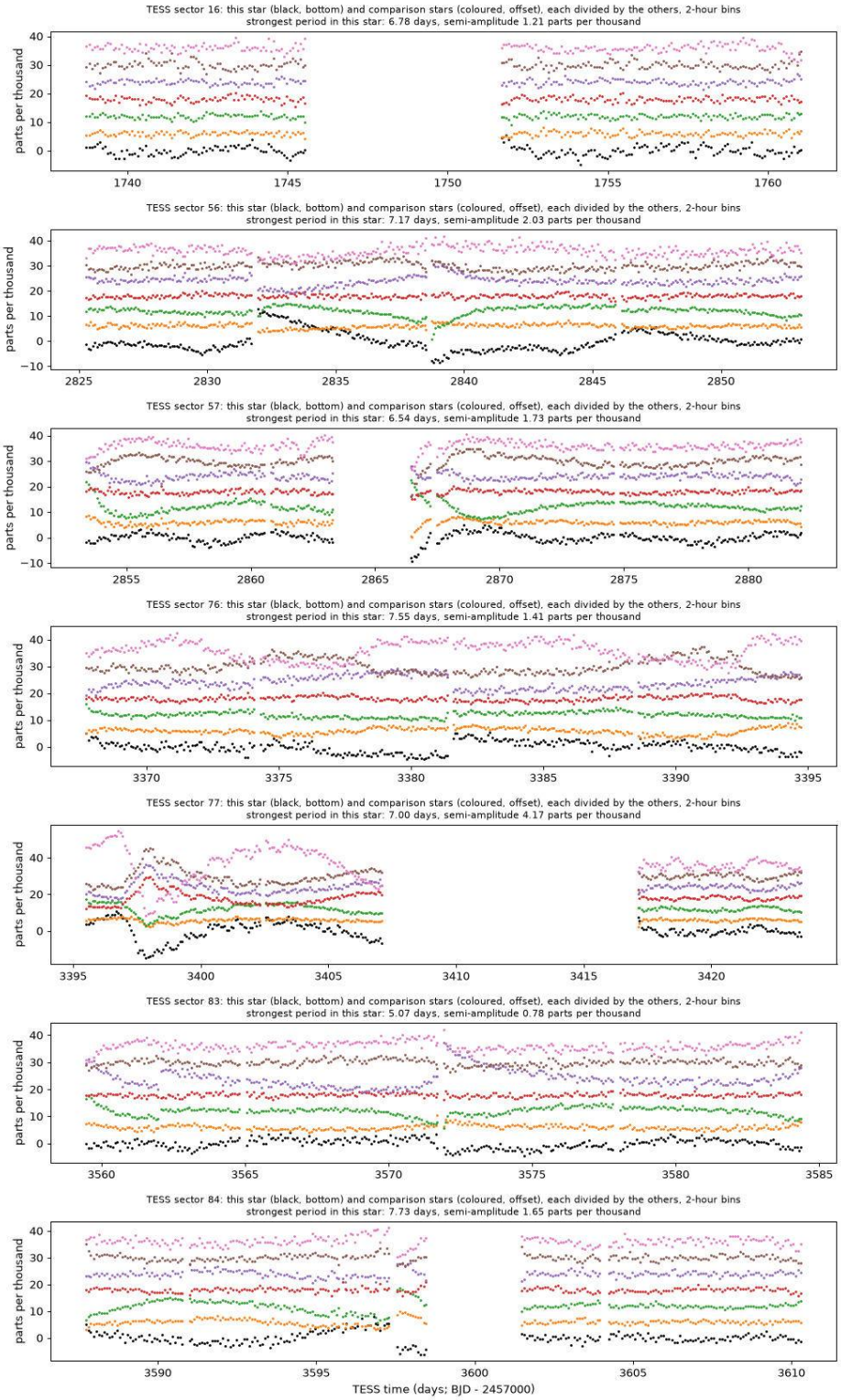



**Figure 76:** Candidate 26, TESS light curves. NASA's TESS space telescope in September to October 2019 and 2022, February to April 2024 and August to October 2024, all outside the dimming. This star is in black at the bottom, six comparison stars above it, each divided by the others. Its strongest signal, which moves from 5.1 to 7.7 days between panels, is comparable to theirs: slow drifts, not a stable period. TESS's large pixels also take in the variable 21 arcseconds away. Data: TESS (NASA; MAST).

## Candidate 27: A yellow subgiant that faded for a year, then recovered in a week

| | |
|---|---|
| **Star** | Gaia DR3 2202439064530584320, a reddened yellow subgiant |
| **Position** | RA 329.64009°, Dec +58.73070° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cepheus, 3.0 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 102.08°, $b$ = +3.04° |
| **Distance** | about 870 parsecs (2,800 light-years) |
| **Brightness** | Gaia $G$ = 13.72; far too faint for the eye |
| **Event** | faded from 2021 Apr; 13 per cent in g from 2021 Sep to end of Mar 2022; recovered within about a week |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 45% |

**What changed.** The star is a yellow subgiant in Cepheus, about 870 parsecs (2,800 light-years) away and seen through a lot of interstellar dust. It has used up the hydrogen in its core and swollen to about four and a half times the Sun's size. After at least six steady years it faded from April 2021, and from September 2021 to the end of March 2022 it stayed about 13 per cent fainter in green light and 8 per cent in red.

ZTF cannot observe the star from December to March, but ASAS-SN still found it about 0.15 magnitudes faint in the last week of March 2022; on 3 April ASAS-SN and on 7 April ZTF found it only 0.04 to 0.05 magnitudes faint, so most of the recovery took about a week. ZTF's alert system, which compares each new image with a reference image, recorded 57 good-quality alerts, all fainter than the reference and centred on the star, and ASAS-SN's eight faintest well-observed months all fall inside the dimming.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed about 1.7 times as much as red, between ordinary interstellar dust (about 1.4) and fine dust (1.8 to 2.2); starspots would give 1.1 to 1.3. Two NEOWISE visits during the dimming saw no change at 3.4 microns, which rules out an opaque body and argues strongly against spots. ZTF found no rotation in eight seasons, and the star's age, motion and lack of an infrared excess rule out a young star with a dusty disc.

The abrupt end points to a sharp-edged structure: if it was dust, its trailing edge crossed the star, about 6 million km across, within about a week, at 10 km/s or more, so the structure was at least one to two astronomical units long (one is the Earth–Sun distance). A dusty disc or cloud orbiting the star or an unseen companion would fit, as in the long eclipses of EE Cephei and epsilon Aurigae, and the dimming would then recur, perhaps after many years; an unusually compact clump of interstellar dust is also possible. A spectrum would settle the star's type and could reveal a companion.

**Checks against the record.** No record of the dimming could be found. SIMBAD lists the star only under its Gaia number, and VSX (the variable-star index) has only a generic entry, based on a slight flicker in Gaia's data of 2014 to 2017. The star is in no other variable-star catalogue consulted, nor among the dimming stars of Tzanidakis et al. (2025), and no transient report, Gaia alert or paper names it. ZTF's alert system holds only machine-generated classifications.

**Why this estimate.** The dimming is certainly real: ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) and ASAS-SN (a worldwide network of small telescopes) both recorded it. Its colour, unchanged infrared brightness and lack of rotation argue against starspots, and its motion shows that it is not a young star. The estimate is not higher because there is no spectrum, only ZTF measured the colour, the quick recovery rests on a few ASAS-SN nights, and what the dust is, and where it lies, remains open.

**Caveats.** There is no spectrum, so the star's temperature, size and reddening rest on Gaia's models. The colour comes from ZTF alone, and the speed of the recovery rests on a few ASAS-SN nights. Two other stars, candidate 26 and candidate 43 , dimmed over almost the same months, but they lie at 2,400 and 1,000 parsecs, so no single cloud could have dimmed all three; the comparison stars of all three stayed flat, which makes an instrumental cause unlikely, and the coincidence is most likely chance.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

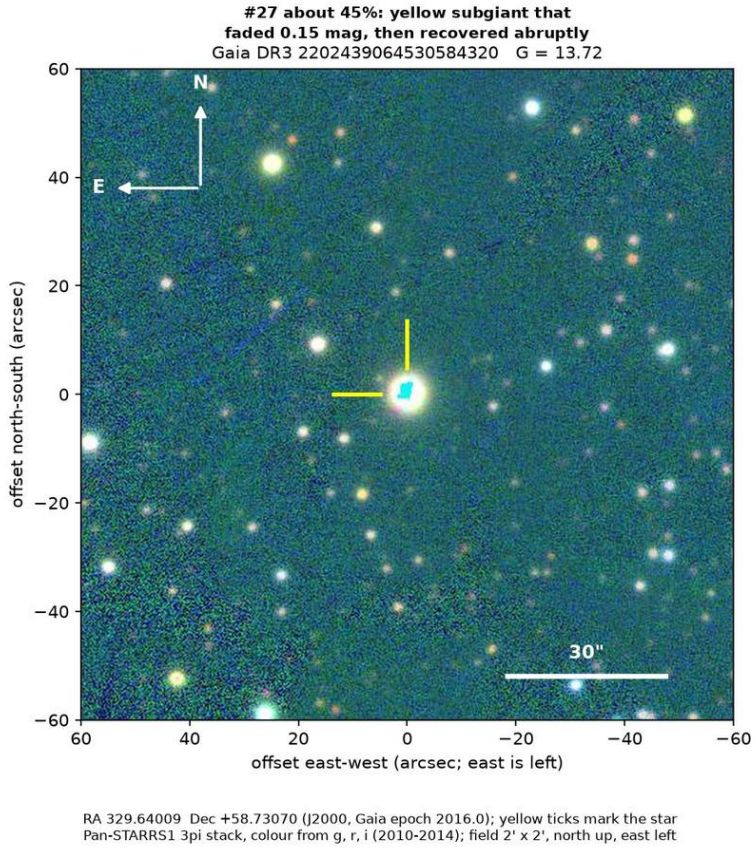



**Figure 77:** Candidate 27, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; its core is overexposed, which leaves a coloured patch at its centre. An eclipsing binary, two stars eclipsing each other as they orbit every 1.288 days, lies 18.8 arcseconds to the north-east. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

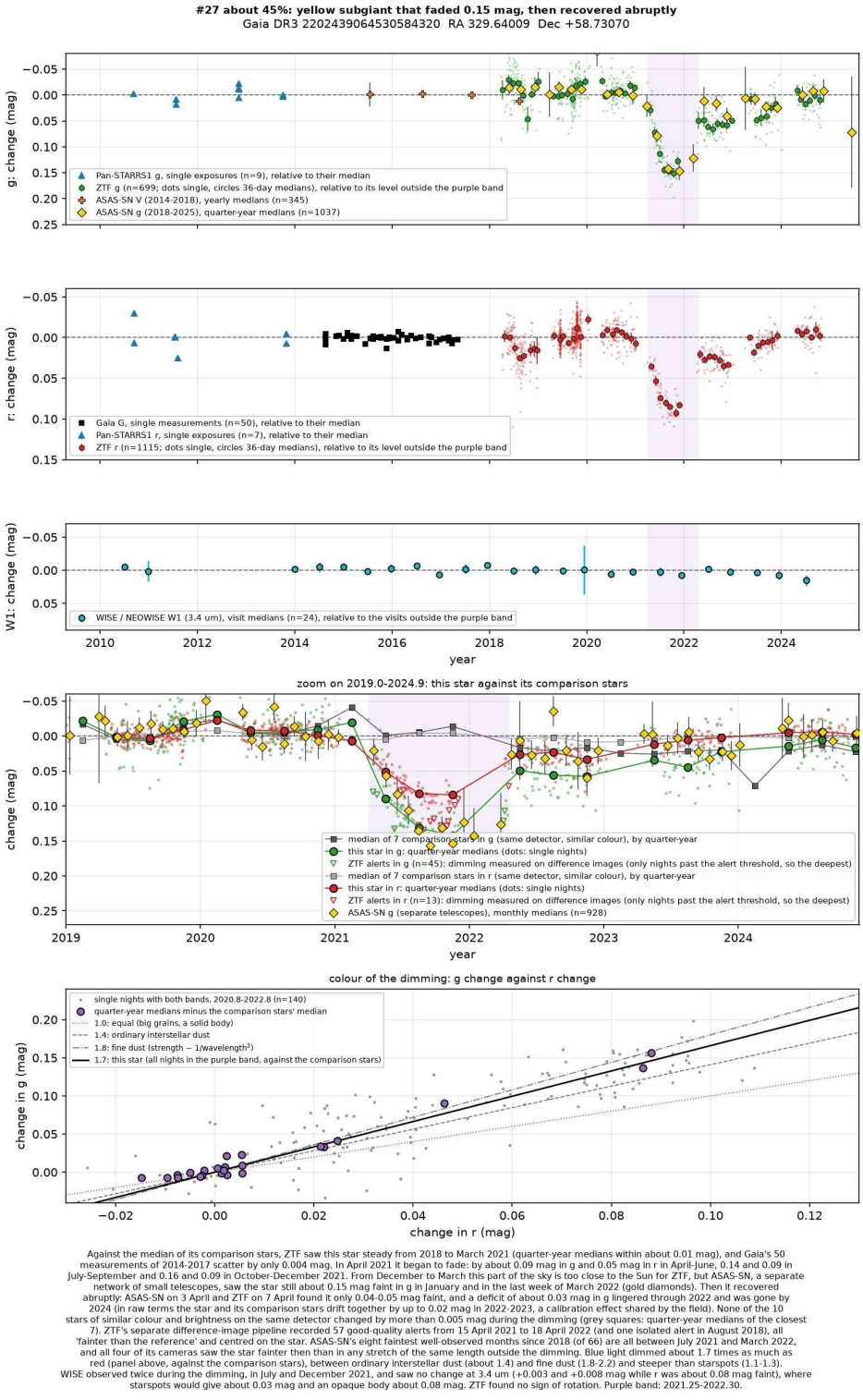



**Figure 78:** Candidate 27, light curve. Top three rows: 2010 to 2025 in green (g) light, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF and ASAS-SN; in red (r) light, adding as black squares the single measurements of Gaia, the European Space Agency's star-mapping satellite; and at 3.4 microns from WISE and NEOWISE, NASA's infrared space telescope. Purple marks the dimming. Middle: 2019 to 2024, with comparison stars, ZTF's alerts and ASAS-SN. Bottom: green dimming against red, with lines for an opaque body, ordinary dust and fine dust. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

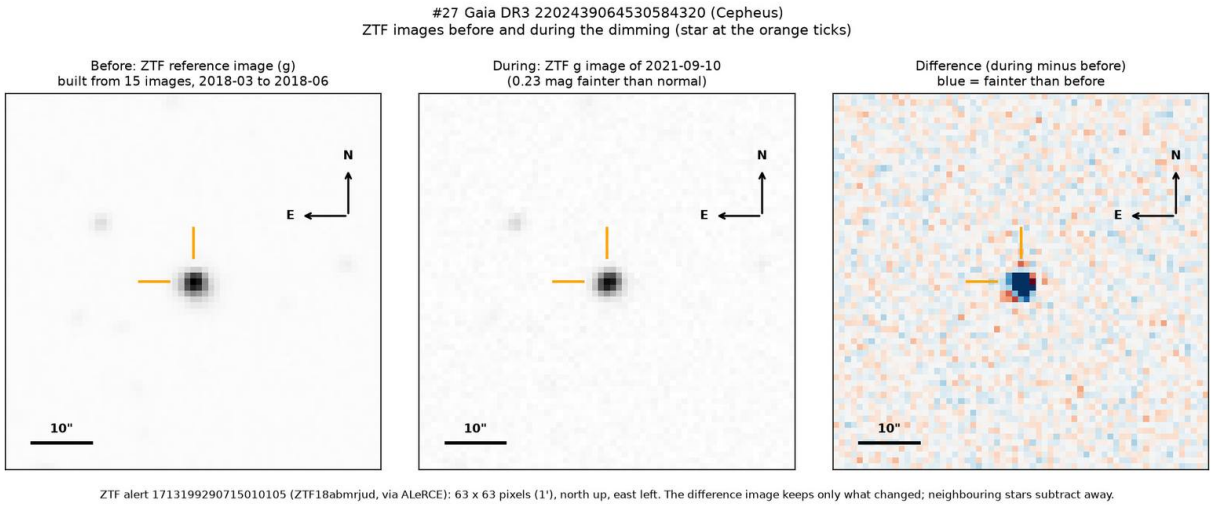



**Figure 79:** Candidate 27, before and during. ZTF alert cutouts in green light, one arcminute across, turned north up and east left, with the star at the orange ticks. Left: the reference image, from 15 images of March to June 2018. Middle: 10 September 2021, with the star 0.23 magnitudes fainter than normal. Right: the difference, in which blue means fainter; the neighbouring stars subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 28: A distant star that dimmed in two steps

| | |
|---|---|
| **Star** | Gaia DR3 69548890757086720, a yellow star beginning to swell into a subgiant |
| **Position** | RA 52.53906°, Dec +25.66977° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Taurus, 25 degrees below the Milky Way's mid-plane |
| **Galactic** | $l = 162.28°$, $b = -24.82°$ |
| **Distance** | uncertain: 1,800 parsecs from Gaia's model of its spectrum, about 4,000 from its parallax |
| **Brightness** | Gaia $G = 15.53$; far too faint for the eye |
| **Event** | two steps: 0.04 mag in g from mid-2020, then 0.21–0.29 mag in 2021 Aug–Nov; normal from 2022 Jul |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 45% |

**What changed.** The star is a yellow star of about 5,900 K that has begun to swell, seen through more dust than maps give for its line of sight, in Taurus about 4 degrees from the Pleiades (which are much closer and unrelated). ZTF saw it steady until spring 2020. By July 2020 it was 0.04 magnitudes fainter in green light, and it stayed slightly faint until spring 2021. From August to November 2021 it was 0.21 to 0.29 magnitudes fainter in green light, losing about 24 per cent of it at the deepest, in November. In February and March 2022 it was back at the first step's level, and from July 2022 it was normal. ZTF's alert system flagged it 59 times, every time fainter than the reference. ASAS-SN saw the same two steps and recovery, and its older record shows the star steady from 2012 to 2018.

**Why it might matter.** Blue light dimmed about 2.3 times as much as red light, and near-infrared light least. A solid body passing in front would dim all colours equally, ordinary interstellar dust gives 1.4 and starspots about 1.1 to 1.3, so a steeper ratio points to a cloud of very fine dust crossing the line of sight. A hot companion star that faded could also take away more blue light, but it would have to be hotter than about 11,000 K, and GALEX saw too little ultraviolet light for that. Dust clouds in front of ordinary, mature stars are rare, which is why such cases are worth following up.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is certain: ZTF recorded it on two of its detectors, and ASAS-SN, a separate network of small telescopes, saw both steps and the recovery while nearby stars stayed steady. Green light dimmed more than twice as much as red, the steepest ratio among many such dimmings checked, which fits very fine dust. The estimate is held down by the lack of a spectrum and by two disagreeing distances.

**Caveats.** Only ZTF measured the colour, the infrared measurements are too noisy to help, and TESS cannot separate the star from a brighter neighbour 35 arcseconds away. Several stars in the same part of the sky were faint in late 2021, but ASAS-SN, which shares no equipment with ZTF, saw this dimming too. There is no spectrum, and the two distances disagree.

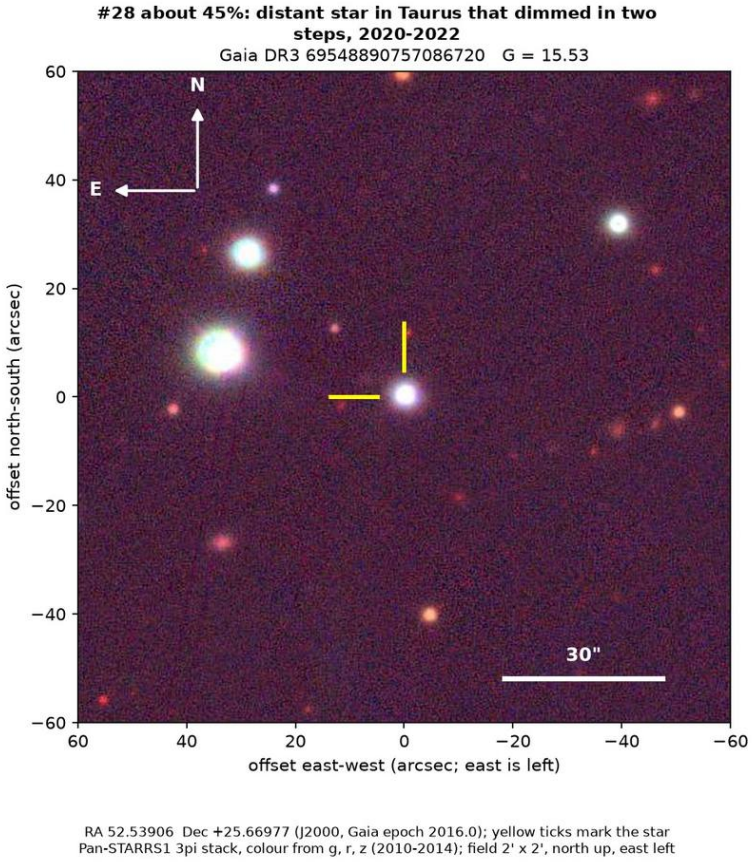



**Figure 80:** Candidate 28, sky image. Pan-STARRS1 colour image in the g, r and z filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; the bright star 35 arcseconds to the east shares its TESS pixels. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

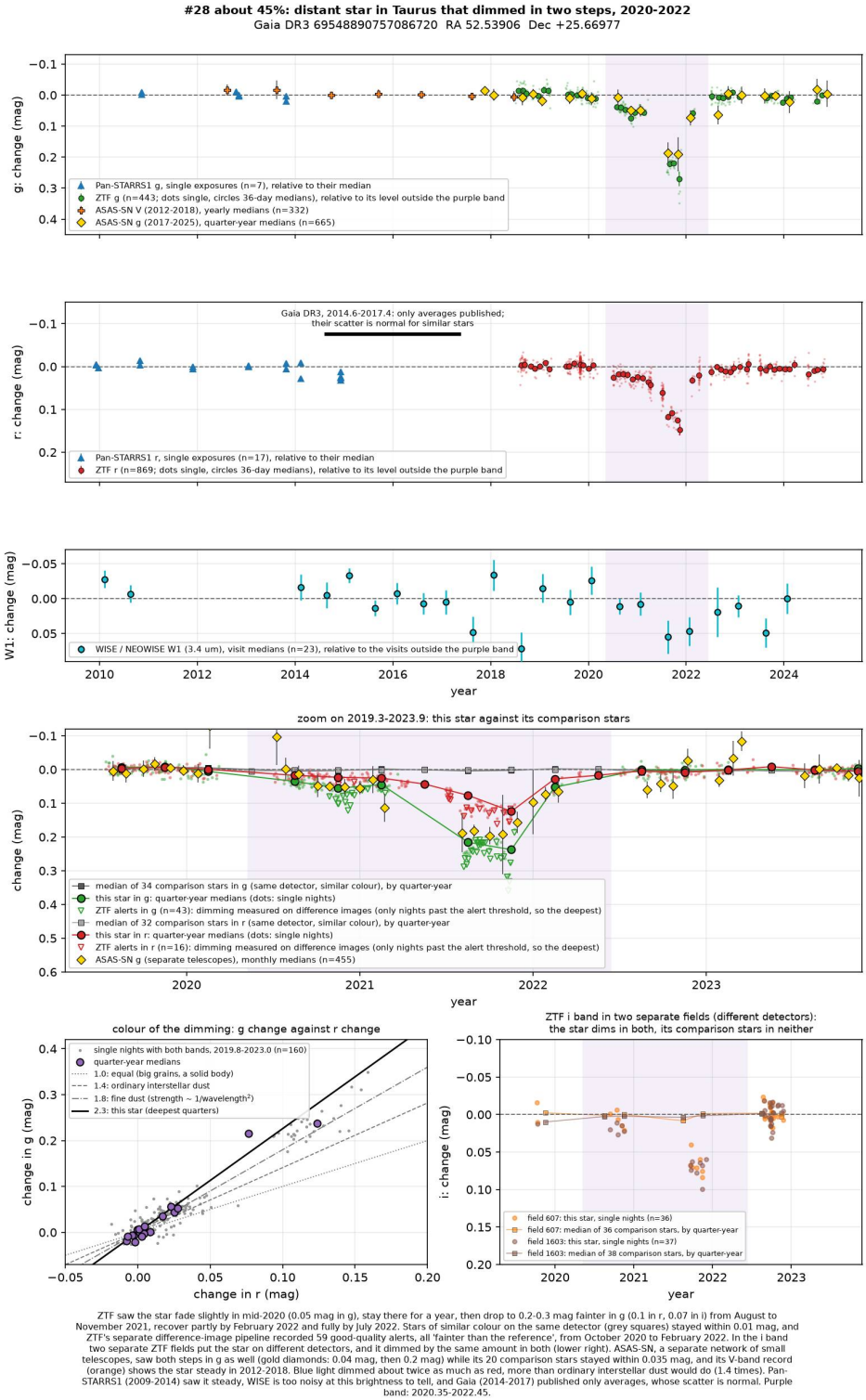



**Figure 81:** Candidate 28, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Bottom right: the star and its comparison stars on two separate ZTF fields, recorded by different detectors. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

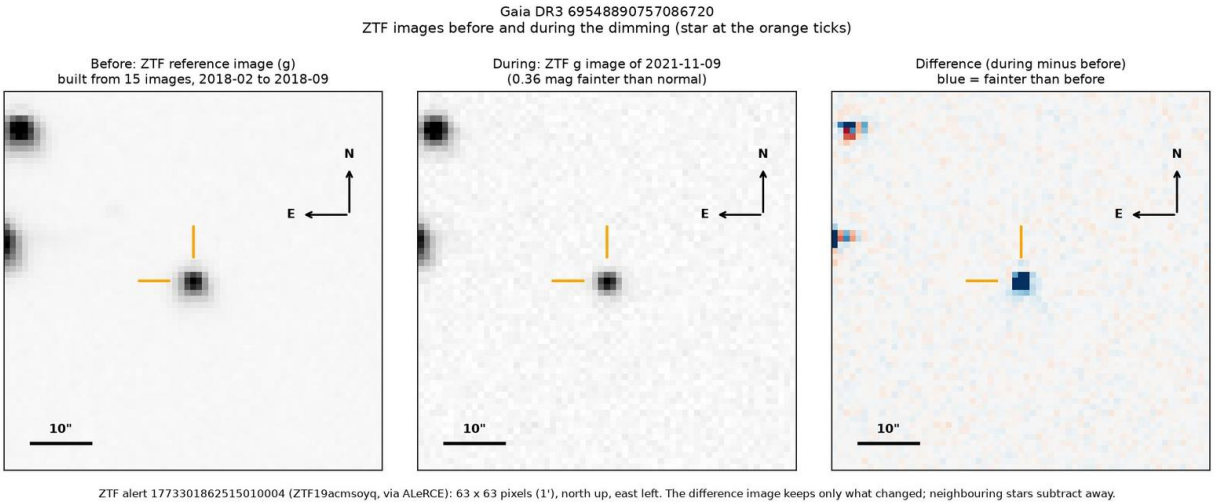



**Figure 82:** Candidate 28, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 29: An old Sun-like star that dimmed for a year

| | |
|---|---|
| **Star** | Gaia DR3 3433284916692771840, an old Sun-like star |
| **Position** | RA 93.59992°, Dec +27.76124° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Gemini |
| **Galactic** | $l$ = 184.17°, $b$ = +4.91° |
| **Distance** | about 670 parsecs (2,200 light-years) |
| **Brightness** | Gaia $G$ = 14.10; far too faint for the eye |
| **Event** | slight fade from 2020; 0.14–0.15 mag in g in 2021 Jul–Dec; normal by 2022 Jul |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 45% |

**What changed.** The star is an old Sun-like star, about 5,700 K and some 10 billion years old, about 670 parsecs away in Gemini. ZTF saw it steady in 2018 and 2019. It began to fade slightly in 2020, dimmed further in the first half of 2021 and from July to December 2021 was 0.14 to 0.15 magnitudes fainter in green light and 0.07 to 0.08 in red light, about 15 per cent less light. It recovered during 2022 and was back to normal by July. ZTF's alert system flagged it 53 times, every time fainter than the reference.

**Why it might matter.** Blue light dimmed about 1.8 to 2.0 times as much as red light, more than ordinary interstellar dust (1.4) or starspots (1.1 to 1.3) would cause and as very fine dust would. In late September 2021, near the deepest point, NEOWISE saw no change at 3.4 microns, which rules out a solid body passing in front (it would have dimmed the infrared as much) and argues against spots. TESS watched the star for two and a half months during the minimum and found no rotation. A cloud of fine dust passing in front of an old, quiet star is the likeliest explanation.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is certain: ZTF flagged it 53 times, and the eight faintest months that ASAS-SN, a separate network of small telescopes, has recorded since 2018 all fall inside it. Green light dimmed about twice as much as red, as behind fine dust; NEOWISE saw no change in the infrared, which rules out a solid body and argues against spots, and NASA's TESS space telescope found no rotation during the dimming. There is no recent spectrum.

**Caveats.** Only one ZTF field covers the star, and only ZTF measured the colour. A faint neighbour 1.85 arcseconds away is lost in its glare. The only spectrum, from the LAMOST survey, was taken in 2013, long before the dimming.

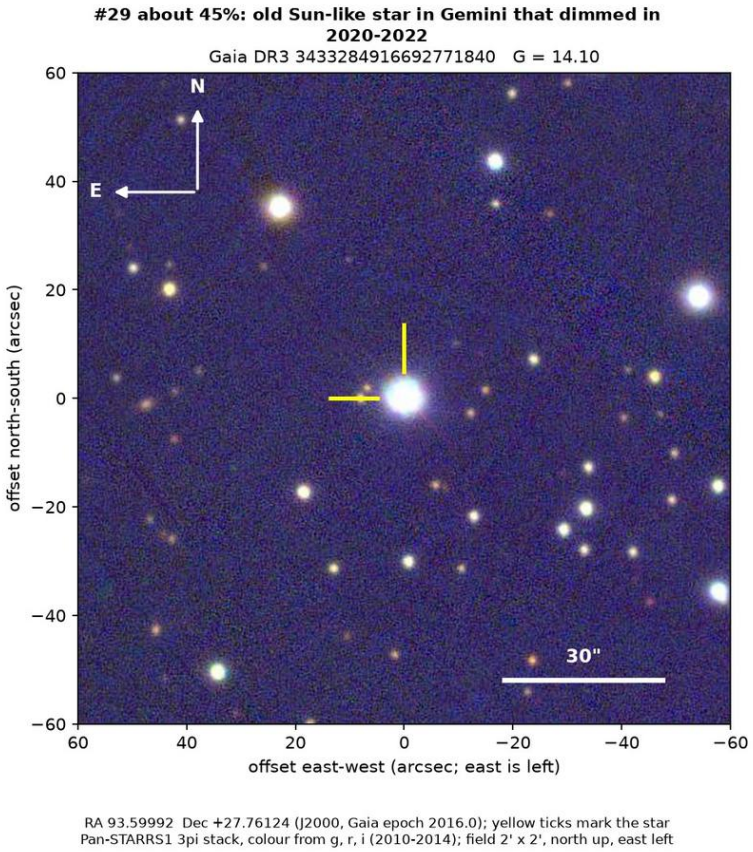



**Figure 83:** Candidate 29, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; a faint neighbour (G = 18.3) 1.85 arcseconds away is lost in its glare, and fainter ones 7 to 8 arcseconds to the east sit beside the left-hand tick. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

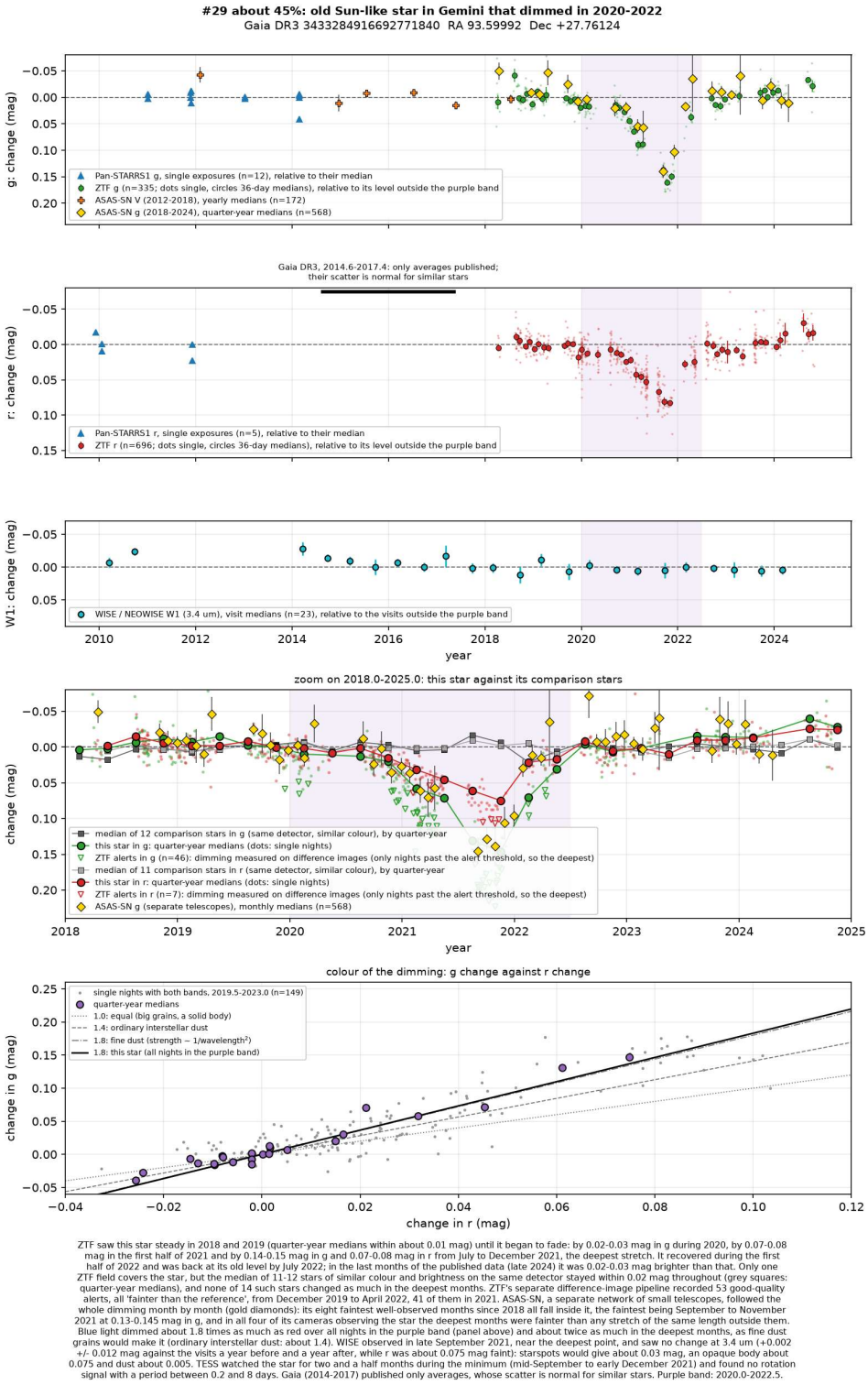



**Figure 84:** Candidate 29, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

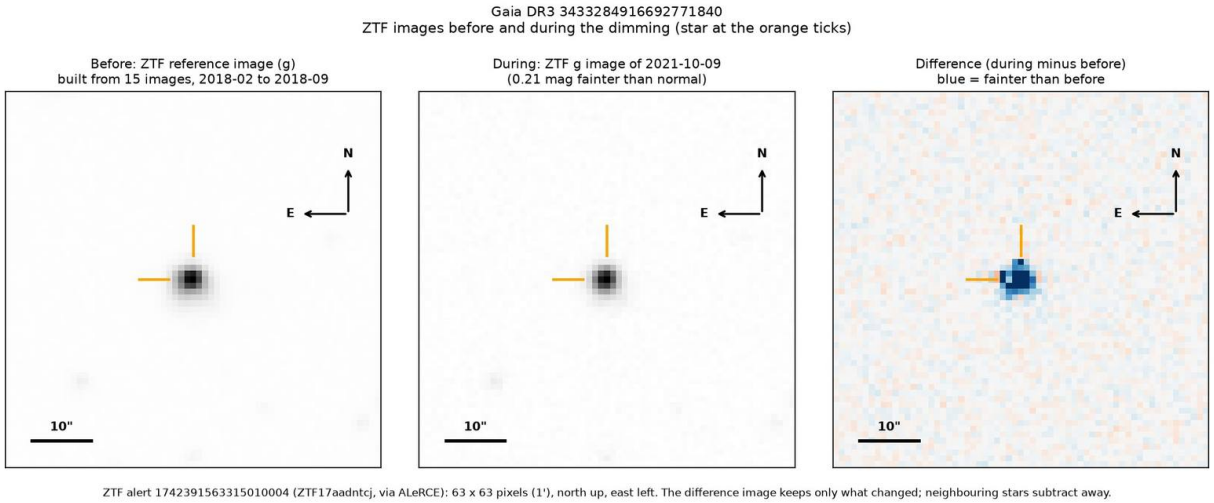



**Figure 85:** Candidate 29, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

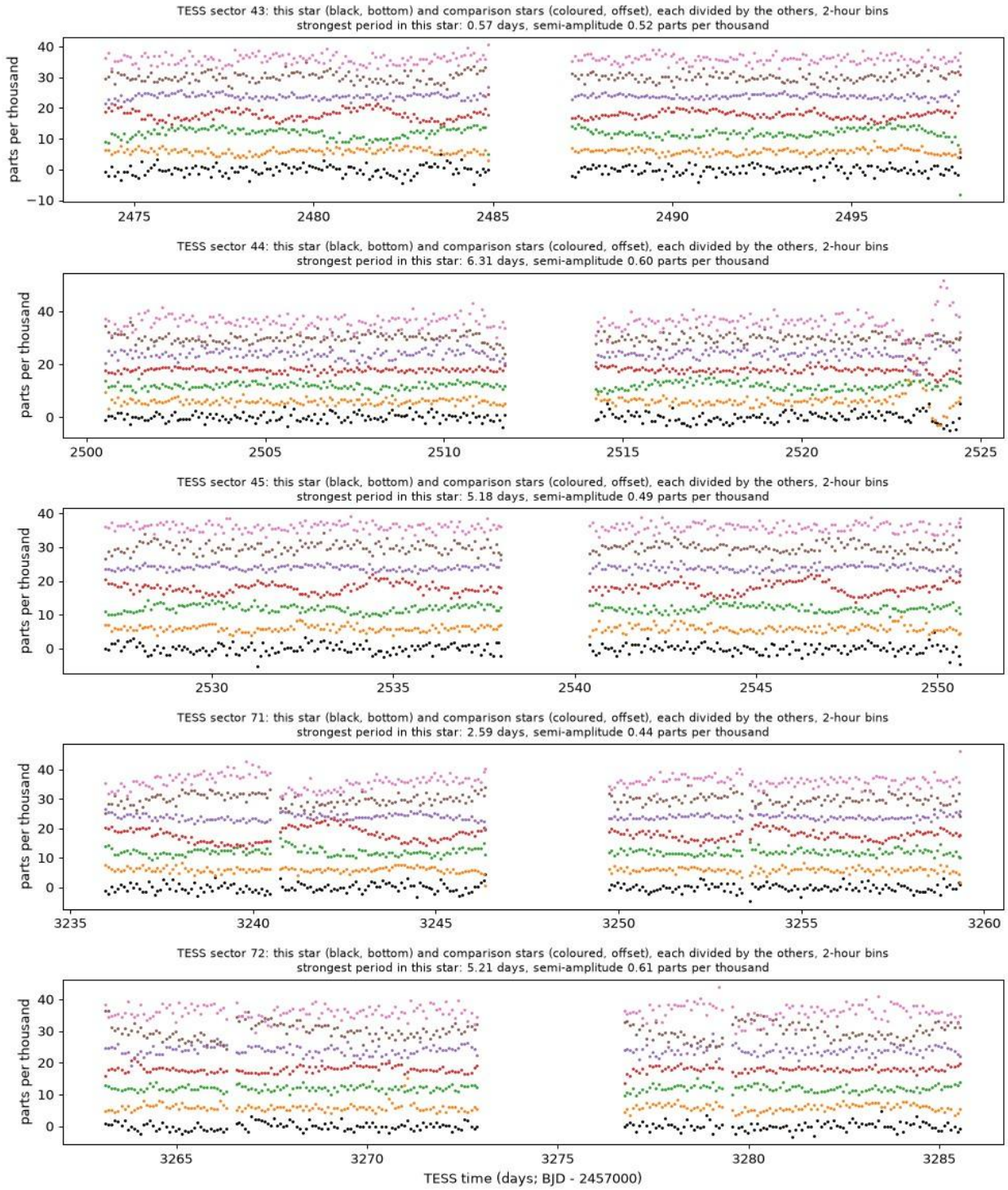



**Figure 86:** Candidate 29, TESS light curves. TESS light curves from five sectors: three from 16 September to 2 December 2021, in the deepest stretch of the dimming, and two from October to December 2023. No panel shows the steady wave of a spotted star. In each panel the star is in black at the bottom, below comparison stars on the same images, each divided by the others, averaged over two hours and offset for clarity. Data: TESS (NASA; MAST).

## Candidate 30: An old star that dimmed for three winters

| | |
|---|---|
| **Star** | Gaia DR3 2881413844294611968, an old subgiant of the Milky Way's thick disk |
| **Position** | RA 358.82898°, Dec +38.76450° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Andromeda |
| **Galactic** | $l = 111.10°$, $b = -22.81°$ |
| **Distance** | about 610 parsecs (2,000 light-years) |
| **Brightness** | Gaia $G = 13.29$; far too faint for the eye |
| **Event** | 0.15 mag in g in 2018 Dec (17 per cent on Dec 20); 2018 Nov–2019 Feb; weaker dips in two later winters |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 40% |

**What changed.** The star is an old subgiant, about 5,500 K, poorer in heavy elements than the Sun and about 11.5 billion years old, a member of the Milky Way's thick disk some 610 parsecs away in Andromeda. ZTF saw it steady from mid-2018 to late 2024 apart from one smooth dip: 0.04 magnitudes fainter in green light in November 2018, 0.15 in green and 0.08 in red in December, and back within 0.015 magnitudes by February 2019. At the deepest, on 20 December, it had lost 17 per cent of its green light. Smaller dimmings followed in the winters of 2020–21 and 2021–22. ZTF's alert system flagged it 16 times.

**Why it might matter.** WISE observed the star from 15 to 19 December 2018, near the deepest point, and saw no change at 3.4 microns, while red light was 0.06 to 0.08 magnitudes faint. Starspots would have dimmed the infrared by about 0.035 magnitudes and a solid body by about 0.07, so both are ruled out, while dust would dim it by only about 0.005. That makes dust the likeliest cause. Gaia's measurements of the star scatter more than those of a single star (its RUWE is 2.26), which hints at a companion.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is certain: ZTF recorded it on two of its detectors and ASAS-SN, a separate network of small telescopes, saw it too. NEOWISE observed the star at the deepest point and saw no change in the infrared, which rules out starspots and a solid body and fits dust. The estimate is held down by the possible companion that Gaia's measurements hint at, and by the lack of a spectrum.

**Caveats.** Blue light dimmed about 1.9 times as much as red over the whole dip but only 1.1 to 1.6 times on each ZTF field separately, so the colour on its own is not decisive. Gaia hints at an unseen companion, which could complicate the picture. There is no spectrum.

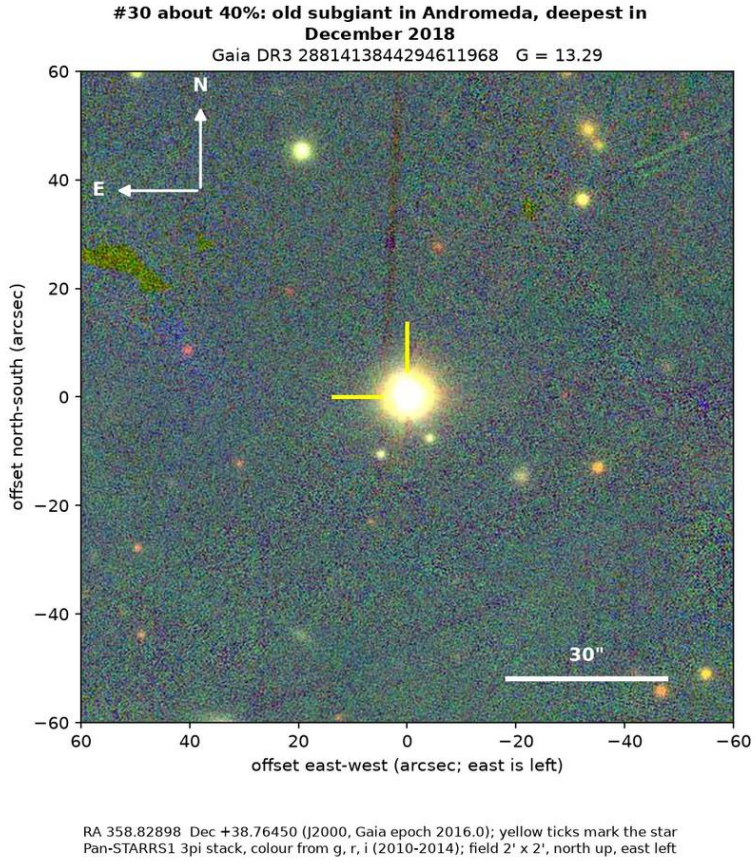



**Figure 87:** Candidate 30, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; the two faint dots just south of it are much fainter neighbours (G = 20.4 to 20.6). North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

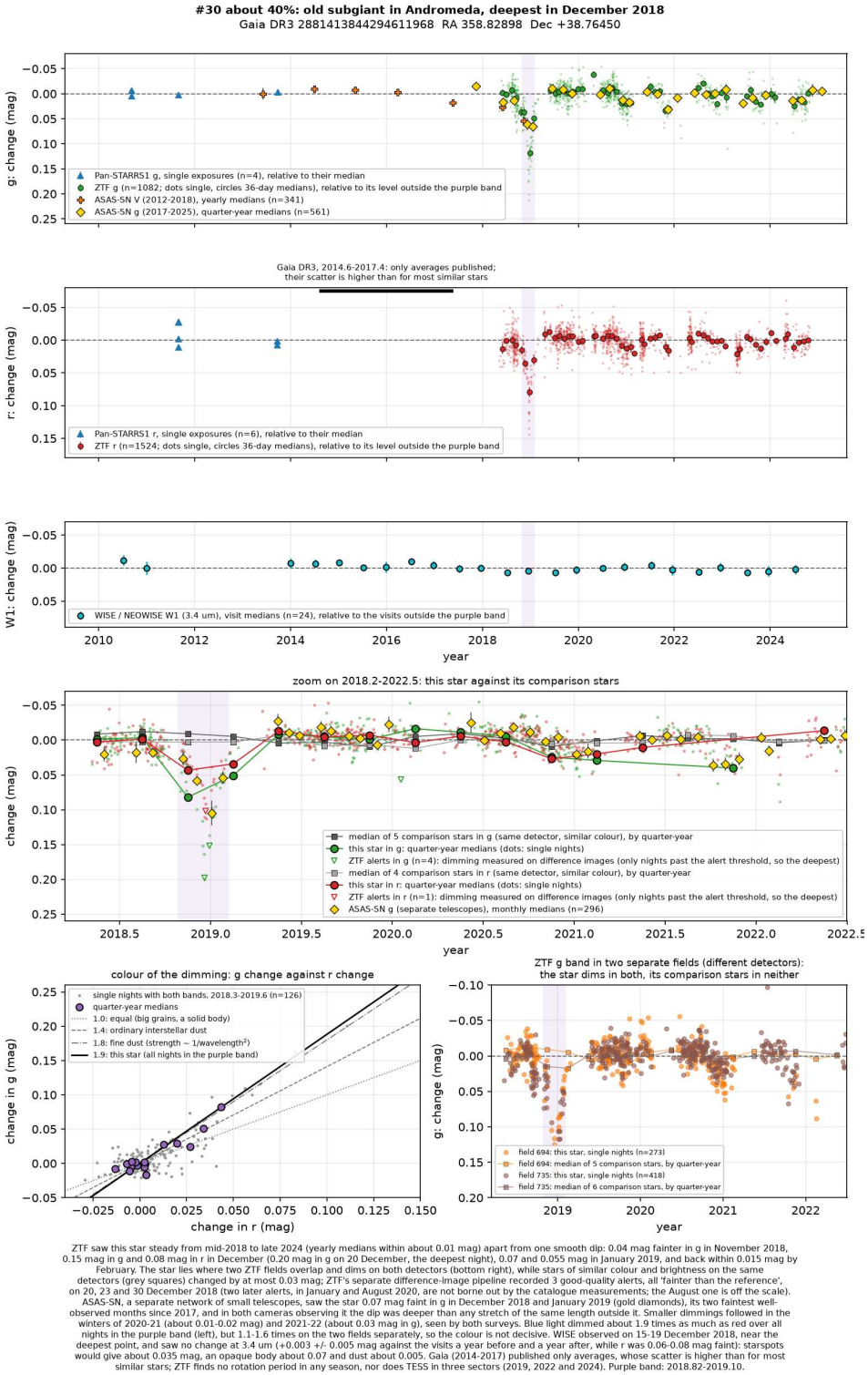



**Figure 88:** Candidate 30, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Bottom right: the star and its comparison stars on two separate ZTF fields, recorded by different detectors. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

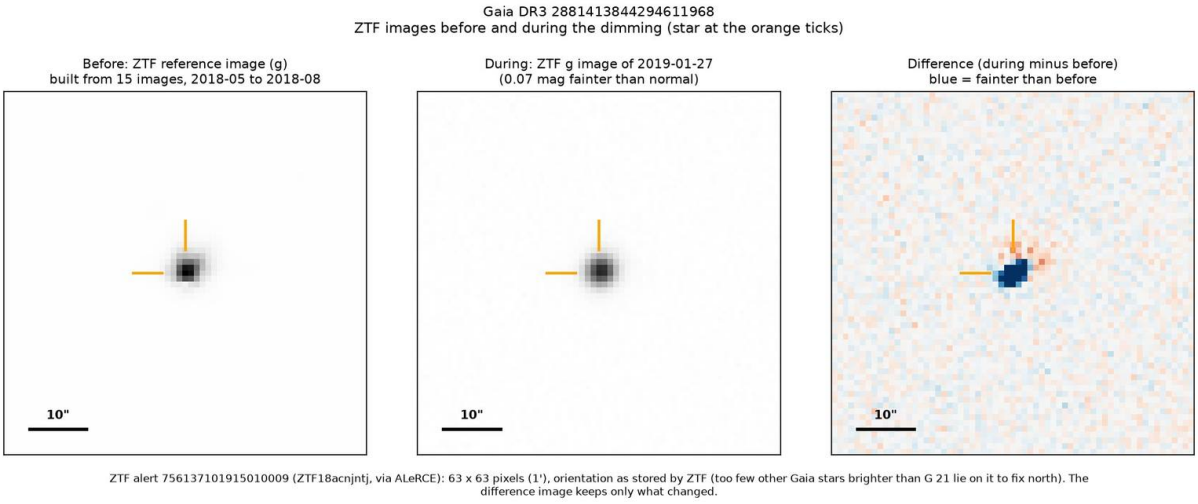



**Figure 89:** Candidate 30, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

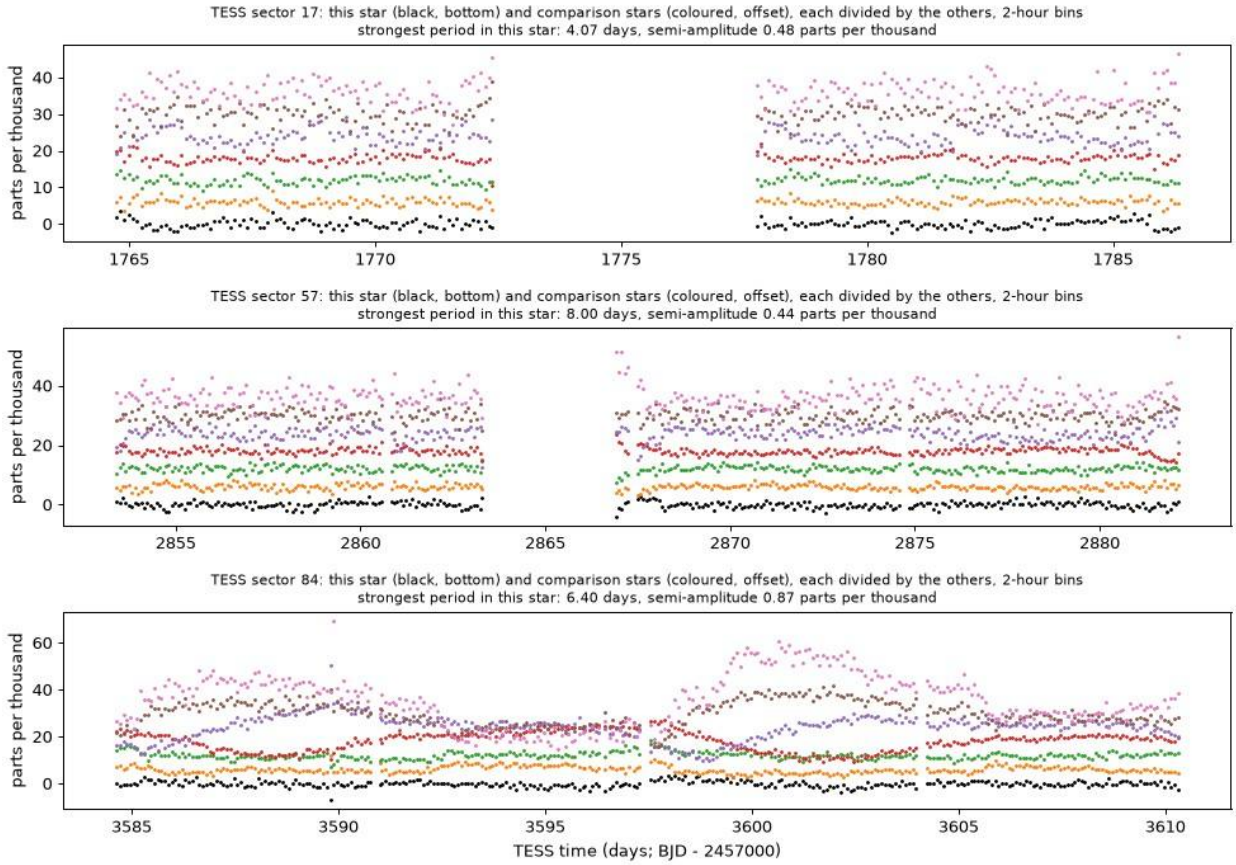



**Figure 90:** Candidate 30, TESS light curves. TESS light curves from three sectors, in 2019, 2022 and 2024, all outside the dimming. No panel shows the steady wave of a spotted star. In each panel the star is in black at the bottom, below comparison stars on the same images, each divided by the others, averaged over two hours and offset for clarity. Data: TESS (NASA; MAST).

## Candidate 31: A yellow-white star that faded for about half a year

| | |
|---|---|
| **Star** | Gaia DR3 1998501927007795 20, a reddened yellow-white F-type star, probably a subgiant |
| **Position** | RA 73.27141°, Dec +38.87426° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Auriga, 3.2 degrees south of the Milky Way's mid-plane |
| **Galactic** | $l = 165.62°$, $b = -3.21°$ |
| **Distance** | about 1,100 parsecs (3,600 light-years) |
| **Brightness** | Gaia $G = 13.61$; far too faint for the eye |
| **Event** | 0.08 mag in g but 0.03 in r, from 2020 Sep to 2021 Mar |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is a yellow-white F-type star in Auriga, somewhat hotter than the Sun, about 1,100 parsecs (3,600 light-years) away and seen through a lot of interstellar dust. It is probably a subgiant, a star that has begun to evolve away from its long hydrogen-burning stage. Steady from 2018 to mid-2020, it faded by about 0.05 magnitudes in green light and 0.02 in red from September to November 2020, and by 0.08 and 0.03 from December to February; by April 2021 it was back to normal.

Only nine comparable stars lie on the same ZTF detector, but none of them faded, nor did any of 23 in a wider selection. ZTF's alert system, which compares each new image with a reference image, recorded 12 good-quality alerts, all fainter than the reference and centred on the star. ASAS-SN's seven faintest well-observed months are exactly September 2020 to March 2021, while the next faintest is only 0.012 magnitudes faint.

**Why it might matter.** The colour is the striking part: green light dimmed about 2.5 times as much as red. An opaque body would dim all colours equally, starspots on a star like this give about 1.1 to 1.3, ordinary interstellar dust 1.4 and fine dust 1.8 to 2.2, so this would need grains much smaller than ordinary interstellar ones. A star dimmed by up to 12 per cent by spots usually shows the wave of its rotation, but neither ZTF, in seven seasons, nor NASA's TESS space telescope, in four separate years, found one.

The star is quiet in the measurements of Gaia, the European Space Agency's star-mapping satellite, and an F-type subgiant has only a thin convective layer, which makes large spots unlikely. Its normal ultraviolet brightness in NASA's GALEX telescope argues against a fading hot companion, WISE shows no disc of warm dust around the star, and NEOWISE saw no change at 3.4 microns in February 2021, which disfavours an opaque body. The simplest explanation is a cloud of very fine dust drifting across the line of sight; if ZTF underestimated the dimming in red light, ordinary dust would fit better. A spectrum would settle the star's type.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or any other catalogue consulted, nor among the dimming stars of Tzanidakis et al. (2025), the nearest of which is 1.2 degrees away. No transient report, Gaia alert or paper names it, and ZTF's alert system holds only machine-generated classifications, none of them confident.

**Why this estimate.** The dimming is certainly real: ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) and ASAS-SN (a worldwide network of small telescopes) both recorded it. Its colour and the lack of any rotation argue against starspots. The estimate is not higher because the colour rests on ZTF alone and is steeper than even fine dust usually gives, so a problem with ZTF's red-light measurements of this fairly bright star cannot be excluded; because only one ZTF field covers it; and because there is no spectrum.

**Caveats.** There is no spectrum, and Gaia gives only a spectral class, so the star's temperature, size and reddening are uncertain. The colour comes from ZTF alone, and only one ZTF field, with few comparison

stars, covers the star. Five other stars that dimmed in the same survey data lie 16 to 22 degrees away in the same broad direction, one of them already published by Tzanidakis et al. (2025); all were faintest in the second half of 2021, about a year after this star, and three dimmed with a similarly steep colour. ASAS-SN recorded this star's dimming independently.

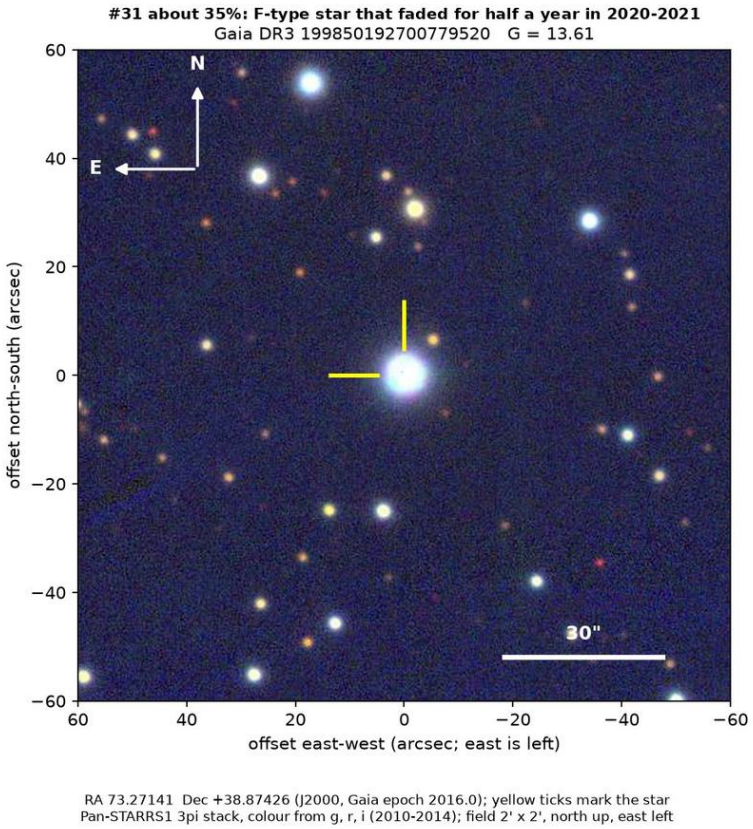



**Figure 91:** Candidate 31, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star, between the yellow ticks, is the brightest in the field. The faint orange dot 8 arcseconds to the north-west is the only star that Gaia sees within 25 arcseconds of it, with under 0.5 per cent of its light. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

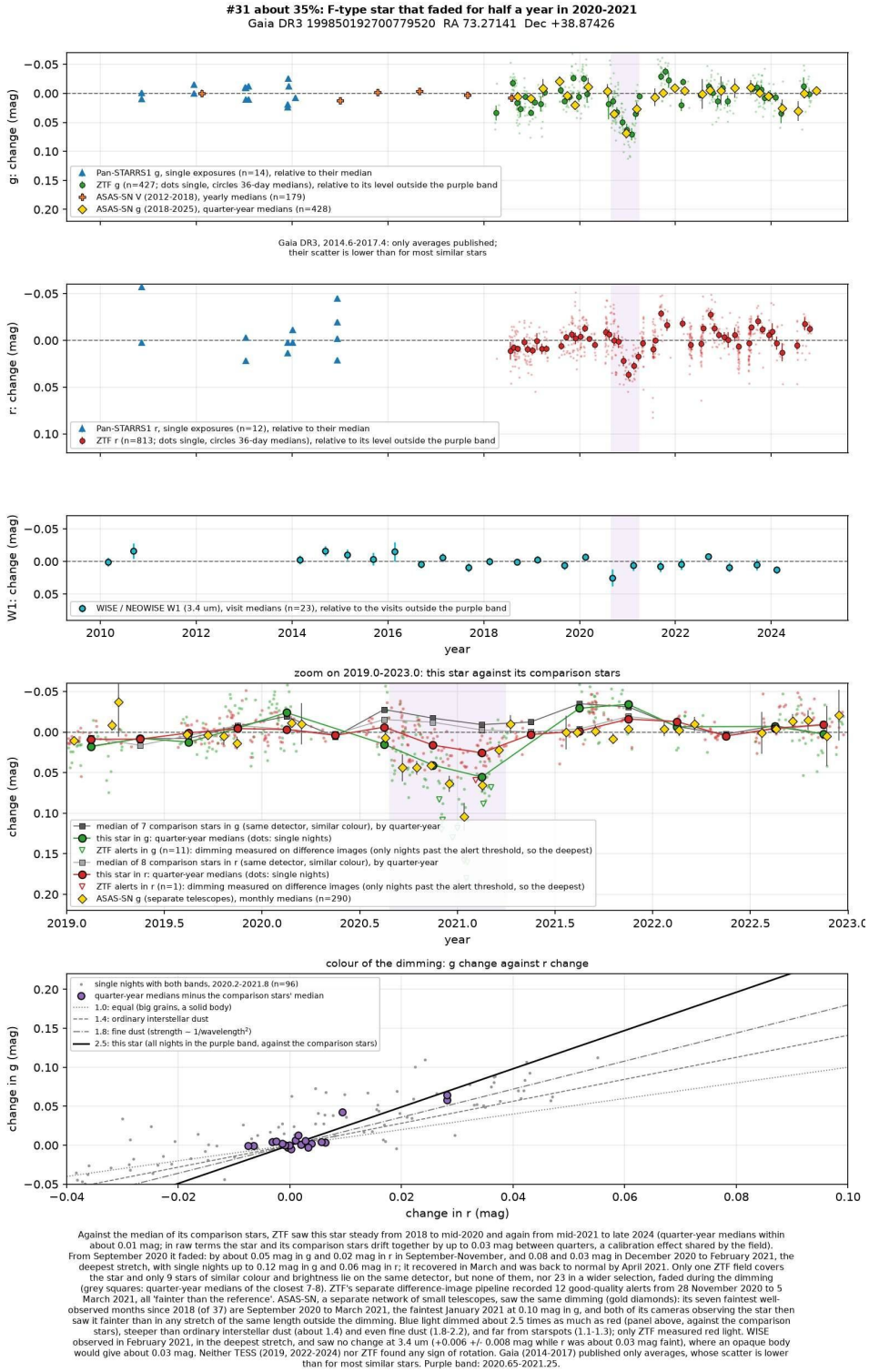



**Figure 92:** Candidate 31, light curve. Top three rows: 2010 to 2025 in green (g) light, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF and ASAS-SN; in red (r) light; and at 3.4 microns from WISE and NEOWISE, NASA's infrared space telescope. Purple marks the dimming. Middle: 2019 to 2022, with comparison stars, ZTF's alerts and ASAS-SN. Bottom: green dimming against red, with lines for an opaque body, ordinary dust and fine dust. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC).

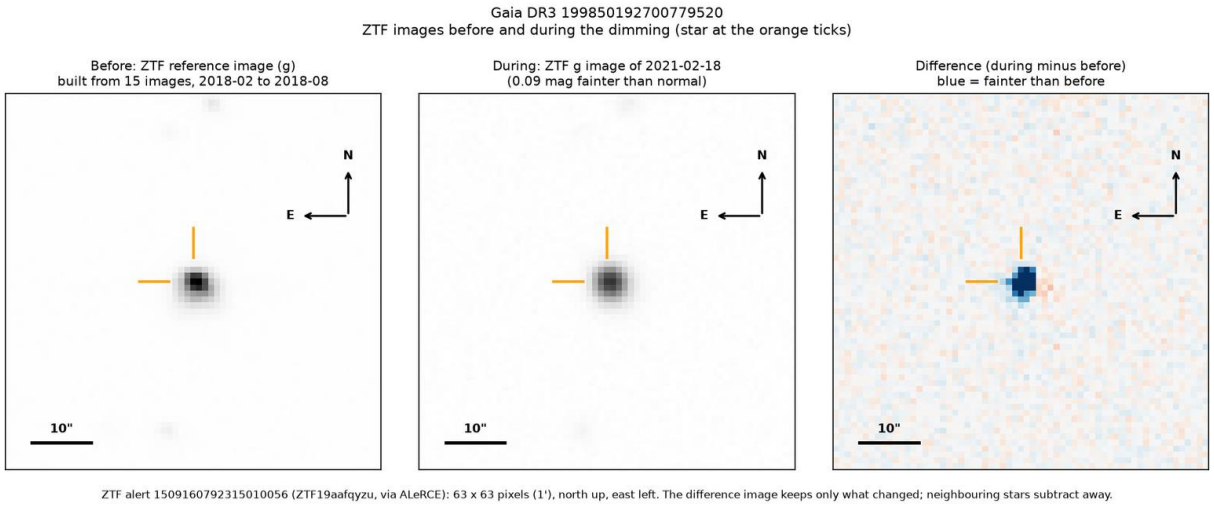



**Figure 93:** Candidate 31, before and during. ZTF alert cutouts in green light, one arcminute across, turned north up and east left, with the star at the orange ticks. Left: the reference image, from 15 images of February to August 2018. Middle: 18 February 2021, with the star 0.09 magnitudes fainter than normal. Right: the difference, in which blue means fainter. Data: ZTF (Caltech/IPAC).

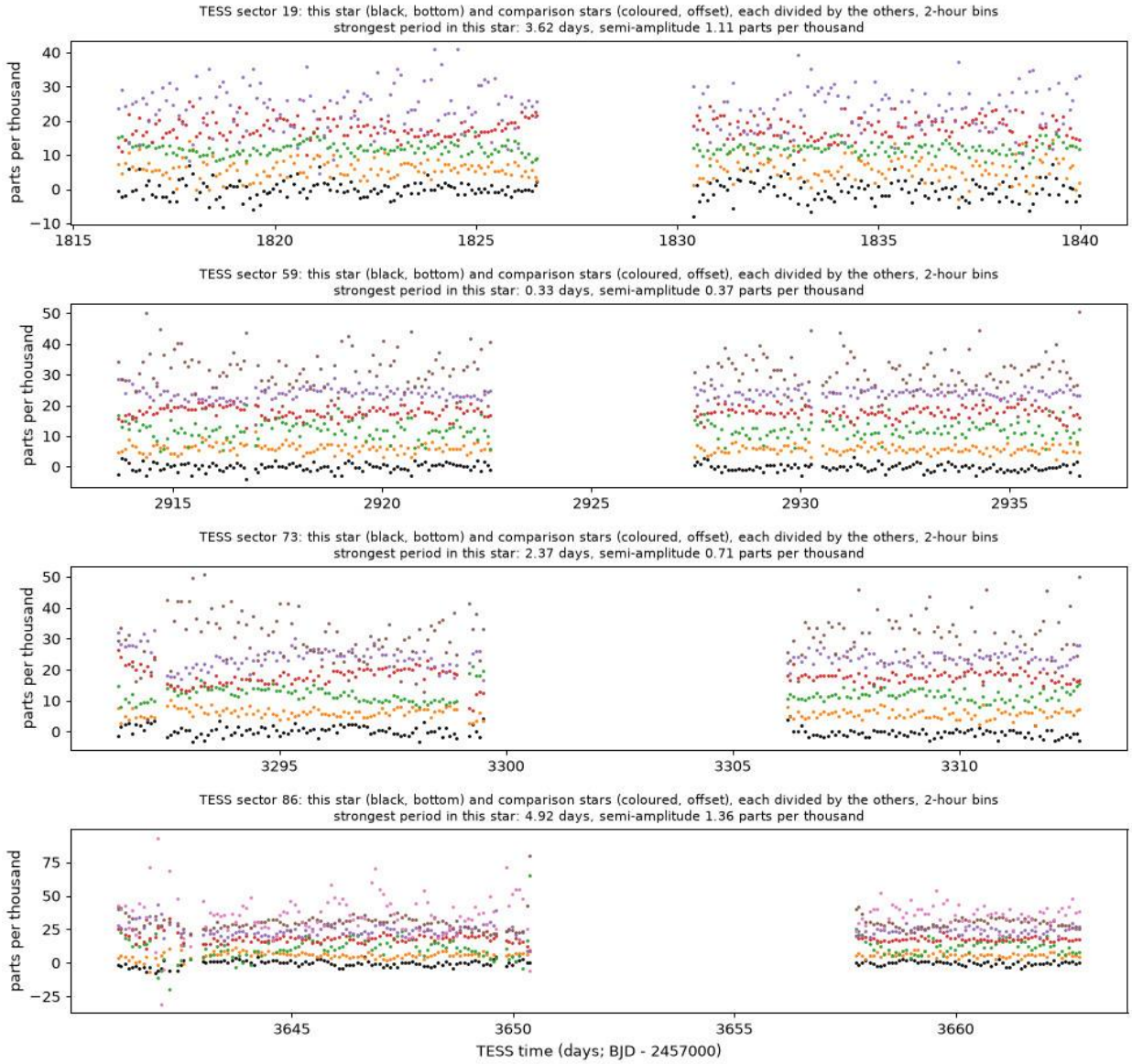



**Figure 94:** Candidate 31, TESS light curves. TESS in late November to December 2019, 2022 and 2024 and in December 2023, all outside the dimming. This star is in black at the bottom, with four to six comparison stars above it, each divided by the others. Its strongest signal in each stretch, 0.4 to 1.4 parts per thousand, is weaker every time than the strongest among the comparison stars, so there is no sign of rotation. Data: TESS (NASA; MAST).

## Candidate 32: A reddened giant that has been fading on and off since 2022

| | |
|---|---|
| **Star** | Gaia DR3 4268970443075403776, a reddened G-type giant |
| **Position** | RA 287.05406°, Dec +3.29682° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Aquila, 2.2 degrees south of the Milky Way's mid-plane |
| **Galactic** | $l = 37.78°$, $b = -2.22°$ |
| **Distance** | about 2,200 to 3,700 parsecs (7,000 to 12,000 light-years) |
| **Brightness** | Gaia $G = 14.93$; far too faint for the eye |
| **Event** | faded from 2022 May; 0.45–0.51 mag in g in late Jul 2022; has dimmed again every season since |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is a giant in Aquila, 10 to 16 times the Sun's size and reddened by thick Milky Way dust. ZTF found it steady from March 2018 to March 2022. In mid-May 2022 it faded by about 0.2 magnitudes within two weeks, and on 19 to 23 July it was 0.45 to 0.51 magnitudes faint in green light and 0.32 to 0.37 in red: it had lost more than a third of its green light.

It recovered about two-thirds of the way by late August, but has dimmed again in every season since, most deeply between April and July, and in September 2026 it was still 10 to 15 per cent faint. ZTF's alert system has flagged it as fainter 173 times since April 2022, ASAS-SN's ten faintest well-observed months since 2018 all fall in 2022 to 2024, and in late July 2022 TESS saw the star fade further and then begin to recover, in step with ZTF.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed 1.3 to 2 times as much as red, more than starspots on so cool a star would give (about 1.1 to 1.2), and two NEOWISE visits during the dimming saw no infrared change, which rules out an opaque body. Spectra from Gaia, the European Space Agency's star-mapping satellite, show an ordinary giant of about 5,000 K, too hot for the red giants that pulsate this much, and it lacks the warm dust of a young star. An eclipse by a companion star would be brief and repeat exactly. Dimmings repeated over more than four years suggest a large, uneven structure of dust, perhaps a disc around an unseen companion, as in epsilon Aurigae. A spectrum would settle what kind of star it is.

**Checks against the record.** No record of the dimming could be found. SIMBAD and VSX, the variable-star index, list nothing at the star's position, Gaia gives it no variability entry, and it is in no variable-star catalogue checked, nor among the 81 dimming stars of Tzanidakis et al. (2025). There is no transient report, Gaia alert or paper naming it. ALeRCE, which holds ZTF's alerts, has only machine-generated labels for it, such as "long-period variable", which describe the light curve's shape, not the kind of star.

**Why this estimate.** The dimming is certain: ZTF, a survey telescope at Palomar Observatory in California, recorded it while none of 57 similar stars on the same detector changed as much, and ASAS-SN, a worldwide network of small telescopes, and NASA's TESS space telescope saw it too. Its colour and the unchanged infrared light point to dust. The estimate is not higher because there is no spectrum, the star's distance is uncertain, the field is crowded, the latest dimmings rest on ZTF's alerts alone, and at its low end the colour approaches that of starspots.

**Caveats.** There is no spectrum, and Gaia's models disagree with its parallax on the star's distance and size. The colour rests on ZTF alone, and the infrared test on two visits. Since 2025 only ZTF's alerts follow the star, and they cannot show whether it recovered between them. ASAS-SN and TESS blend it with its neighbours.

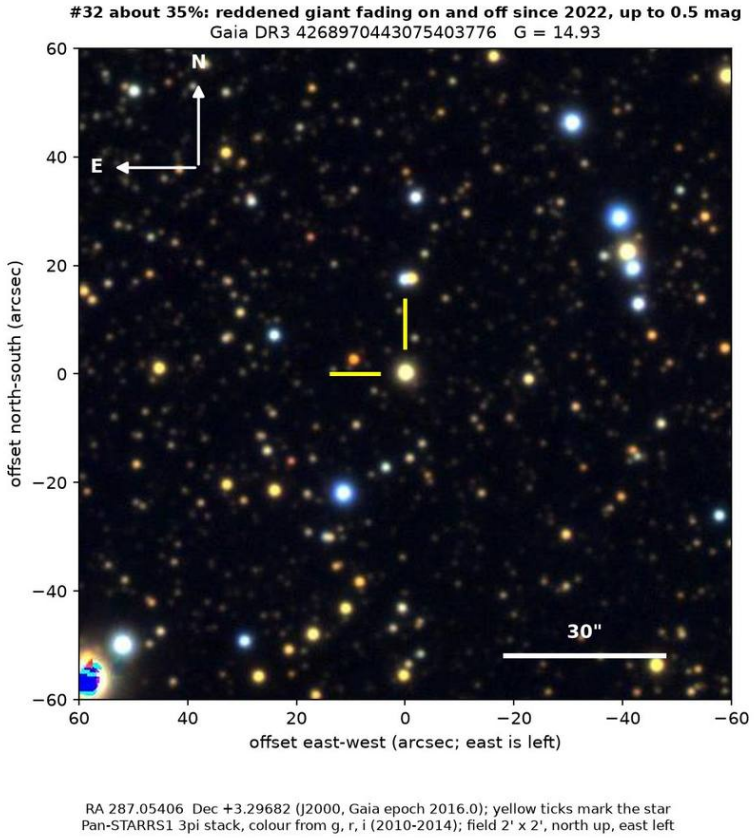



**Figure 95:** Candidate 32, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; the orange-red star 10 arcseconds east of it is a very red neighbour. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

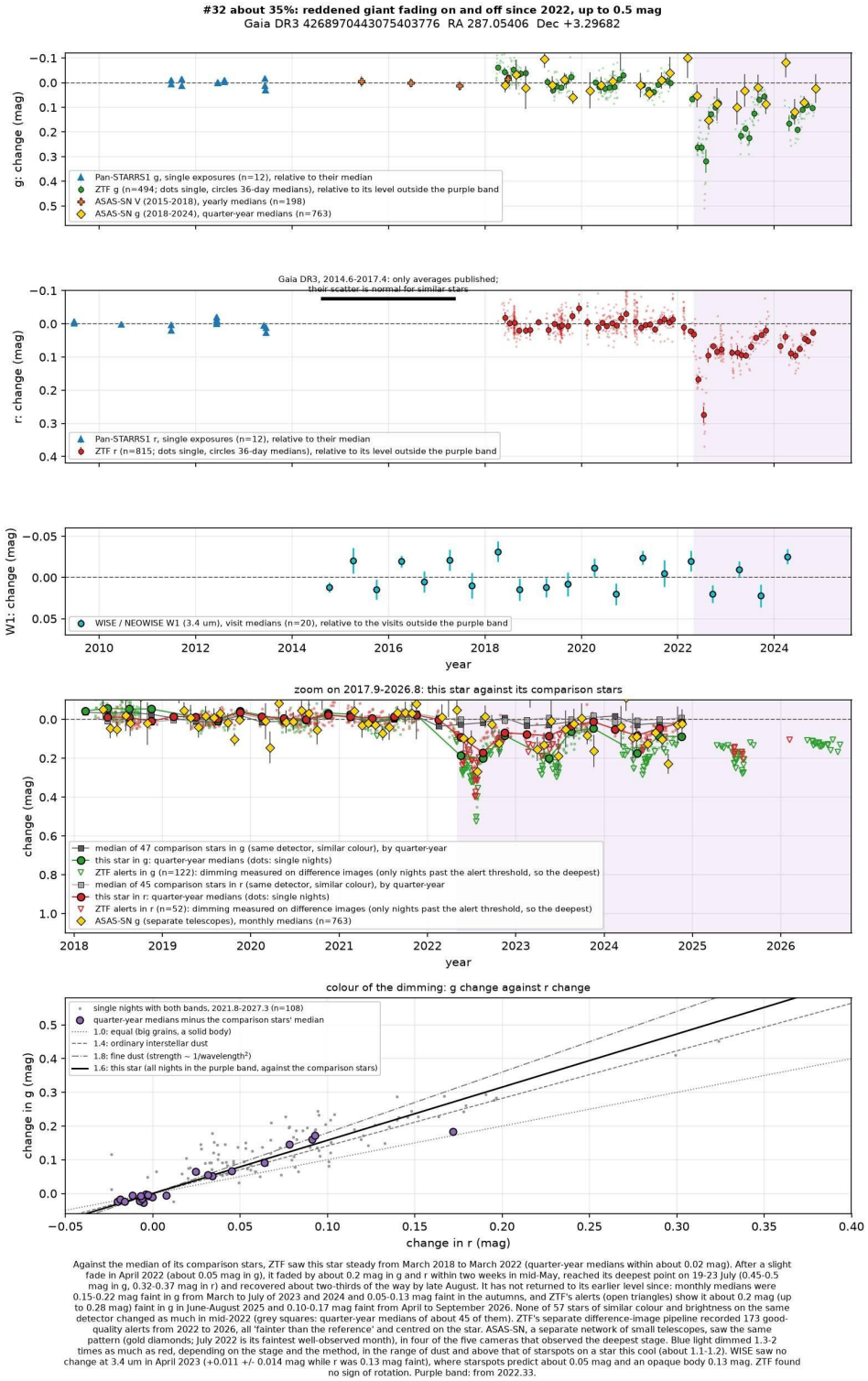



**Figure 96:** Candidate 32, light curve. Top three panels: green, red and 3.4-micron infrared light from 2009 to 2025, from Pan-STARRS1, a survey telescope in Hawaii, ZTF, ASAS-SN and NEOWISE, NASA's infrared space telescope. Middle: a zoom on 2018 to 2026, with comparison stars (grey squares), ZTF's alerts (open triangles) and ASAS-SN (gold diamonds). Bottom: green dimming against red, with lines for equal dimming, ordinary dust and fine dust. Purple marks the dimming. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC).

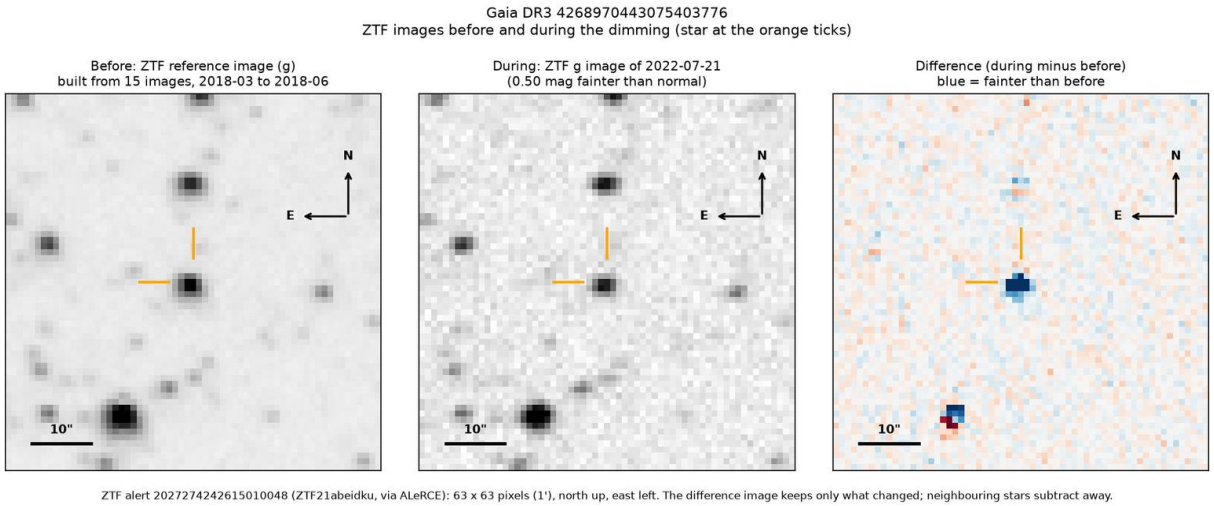



**Figure 97:** Candidate 32, before and during. ZTF images one arcminute across, north up and east left, with the star at the orange ticks. Left: the reference image in green light, built from 15 images taken from March to June 2018. Middle: 21 July 2022, when the star was 0.50 magnitudes fainter than normal. Right: their difference, in which blue means fainter; the neighbours subtract away. Data: ZTF (Caltech/IPAC).

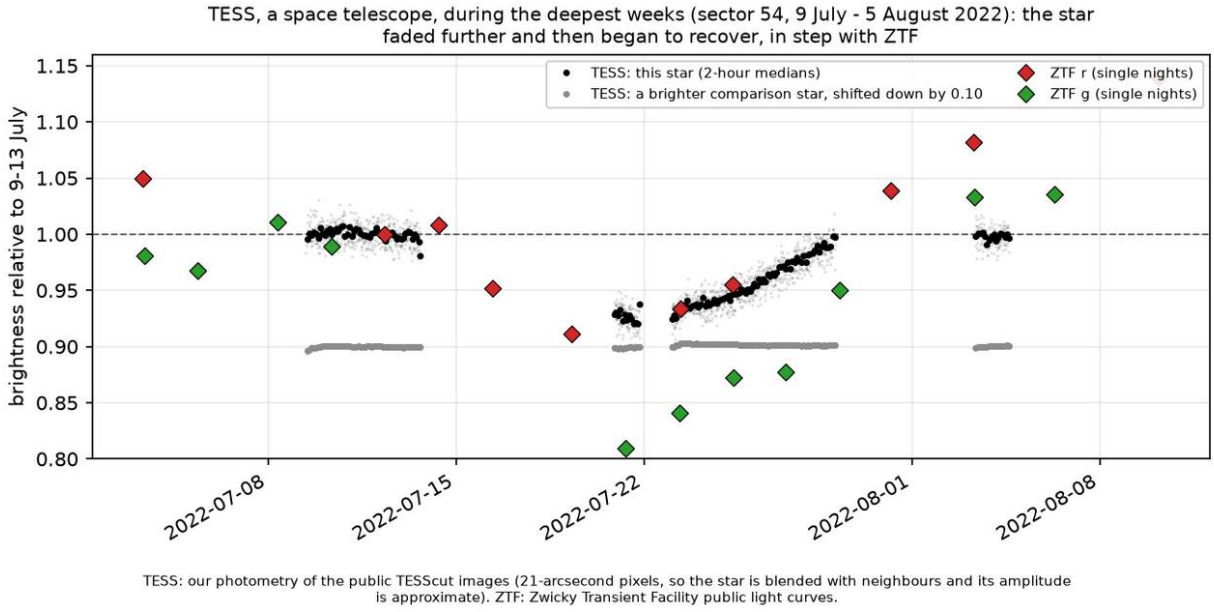



**Figure 98:** Candidate 32, TESS light curves. Brightness during the deepest weeks of the dimming, 9 July to 5 August 2022, relative to 9 to 13 July. Black: the star in TESS, as two-hour medians; grey: a brighter comparison star, shifted down by 0.1; diamonds: ZTF in red and green light. The star was about 7 per cent fainter on 21 to 23 July, then recovered in step with ZTF. TESS's 21-arcsecond pixels blend it with its neighbours, so the amplitudes are approximate. Data: ZTF (Caltech/IPAC); TESS (NASA; MAST).

## Candidate 33: A distant star that lost up to half of its light in 2022

| | |
|---|---|
| **Star** | Gaia DR3 474224278503283328, a Sun-like or slightly cooler star behind much dust (type uncertain) |
| **Position** | RA 57.05289°, Dec +60.32597° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Camelopardalis, 4.6 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 143.19°, $b$ = +4.60° |
| **Distance** | about 2,500 parsecs (8,000 light-years), within a range of 2,000 to 4,000 parsecs |
| **Brightness** | Gaia $G$ = 18.76; far too faint for the eye or a small telescope |
| **Event** | faded from late Feb 2022; 0.57–0.76 mag in r (up to half its light) in 2022 Jul; normal by late Jan 2023 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** This faint star in Camelopardalis lies about 2,500 parsecs (8,000 light-years) away and is most likely a Sun-like or slightly cooler star seen through much dust. Steady from 2010 to mid-2021 and very slightly faint for the next half-year, it began to fade in earnest in late February 2022, just before its yearly spell too low in the night sky to observe. When ZTF could see it again, on 5 to 13 July 2022, it was 0.57 to 0.76 magnitudes faint in red light and 0.52 to 0.94 in green: it had lost up to half of its red light and more than half of its green.

It then recovered slowly and unevenly, changing by up to 0.2 magnitudes from night to night, and was back to normal by late January 2023; it has not dimmed again up to September 2025. ZTF's alert system flagged the star as fainter 41 times from July to October 2022, always centred on the star rather than on its two brighter neighbours.

**Why it might matter.** Dust passing in front of the star is the likeliest cause: green light dimmed 1.68 times as much as red, more steeply than through ordinary interstellar dust (about 1.4), while an opaque body would dim all colours equally. Starspots change such a star by only a few per cent, an eclipse by another star lasts hours or days, not a year, and the two detectors rule out an instrumental fault. Young stars are often dimmed for months by their own dusty discs, and this one lies where they are common, but it shows no sign of warm dust close to it; cooler dust farther out cannot be tested. The dust might come from colliding planets or asteroids, or from a disc around an unseen companion. A spectrum would settle the star's type and could show signs of youth.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, VSX, the variable-star index, has nothing within 30 arcseconds, and Gaia, the European Space Agency's star-mapping satellite, lists no variability. The star is in no variable-star catalogue checked, nor among the 81 dimming stars that Tzanidakis et al. (2025) found in ZTF data of 2018 to 2023, and no transient report, Gaia alert or paper names it. ALeRCE, which holds ZTF's alerts, has only machine-generated labels for it.

**Why this estimate.** The dimming is certain: ZTF, a survey telescope at Palomar Observatory in California, recorded it on two detectors and in three filters, while none of 353 similar stars on the same detectors faded by more than 0.12 magnitudes. The estimate is not higher because only ZTF saw it; the main fade, and perhaps the deepest point, fell while the star was too low in the night sky to observe; its type and distance are uncertain; it lies where young stars with dusty discs are common; and there is no spectrum.

**Caveats.** There is no spectrum, and Gaia's models of the star contradict its parallax, the direct measure of distance, so its type and distance are uncertain. Only ZTF recorded the dimming, and the yearly gap hid how fast it faded and how deep it became. Cool dust far from the star cannot be tested, and its slight changes before and after the event are unexplained.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

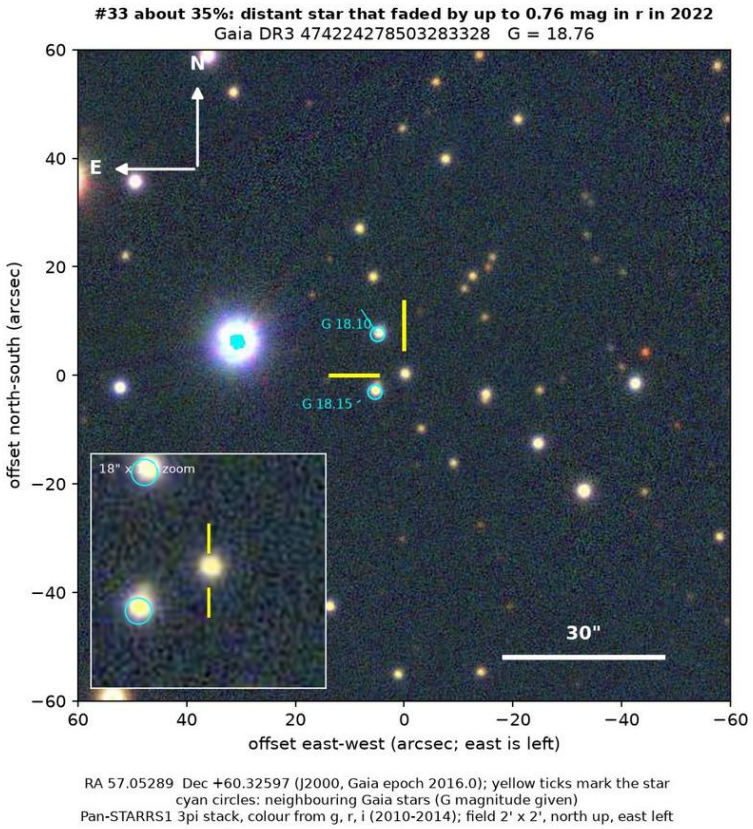
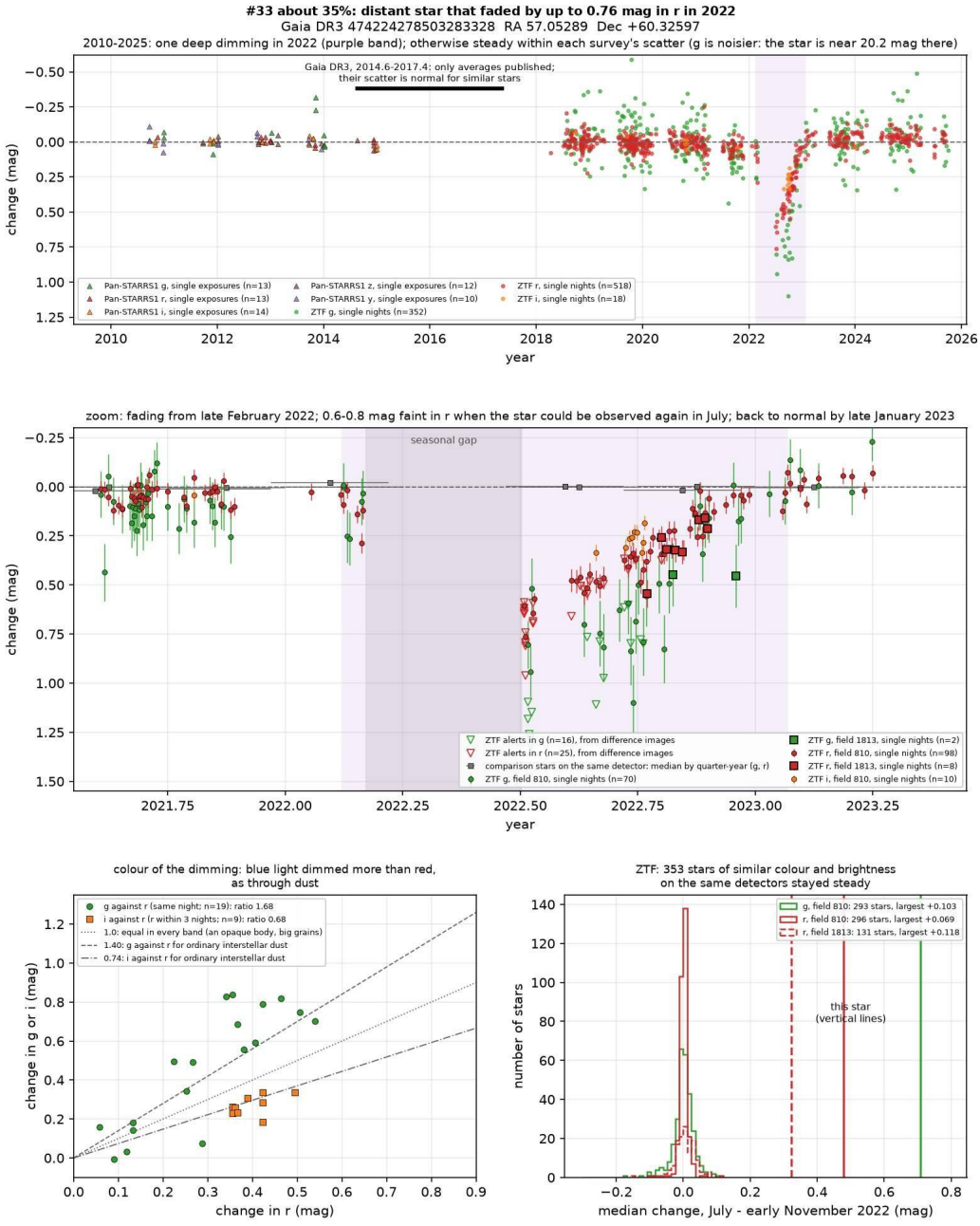



**Figure 99:** Candidate 33, sky image. Pan-STARRS1 colour image in the g, r and i filters, 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; cyan circles mark two slightly brighter neighbours, 6 arcseconds east-southeast and 9 northeast of it, and the inset enlarges the centre. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside 2022), the star was steady in Pan-STARRS1 images of 2010-2014 and in ZTF from April 2018 to mid-2021: single nights scatter by about 0.05 mag in r and 0.12 mag in g, where the star is near 20.2 mag. From July 2021 to January 2022 it was slightly faint, by about 0.04 mag in r and 0.1 mag in g on average, and in late February 2022 it began to fade, by 0.09-0.29 mag in r on four nights between 15 February and 2 March, shortly before its seasonal gap (grey band: the star then stands too low in the night sky for ZTF). When ZTF could observe it again, on 5-13 July 2022, it was 0.57-0.76 mag faint in r and 0.52-0.94 mag in g. It then recovered slowly and unevenly: 0.44-0.54 mag faint in r in August, 0.34-0.51 mag in September, 0.22-0.49 mag in October, 0.02-0.33 mag in November and 0.04-0.09 mag in December; it was back to normal by late January 2023 and has since been about 0.04 mag brighter in r than in 2018-2021, to the end of the record in September 2025. The star lies where two ZTF fields overlap: on the second (squares), where it falls on a different detector, it was 0.16-0.54 mag faint in r in October and November 2022. None of the 353 stars of similar colour and brightness on the same detectors faded by more than 0.12 mag from July to early November 2022 (bottom right), and the comparison stars' quarter-year medians stayed within 0.02 mag in g and 0.004 mag in r (grey squares). ZTF's separate difference-image pipeline recorded 41 good-quality alerts from 5 July to 20 October 2022, all 'fainter than the reference' and centred on the star (median offset 0.15"). Blue light dimmed 1.68 times as much as red (68 % range 1.53-1.83) and the near-infrared i band 0.68 times as much (0.64-0.71): more steeply than through ordinary interstellar dust (1.40 and 0.74), as through dust of smaller grains, and unlike an opaque body (1.0). Purple band: mid-February 2022 - late January 2023.

**Figure 100:** Candidate 33, light curve. Top: the whole record, 2010 to 2025, from Pan-STARRS1, a survey telescope in Hawaii, and ZTF. Middle: mid-2021 to mid-2023, with ZTF's two fields as circles and squares, its alerts as open triangles and comparison stars as grey squares; grey shading marks the yearly gap in observations. Bottom left: green and near-infrared dimming against red, with lines for an opaque body and ordinary dust. Bottom right: how much the comparison stars changed, with this star as vertical lines. Purple marks the dimming. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC).

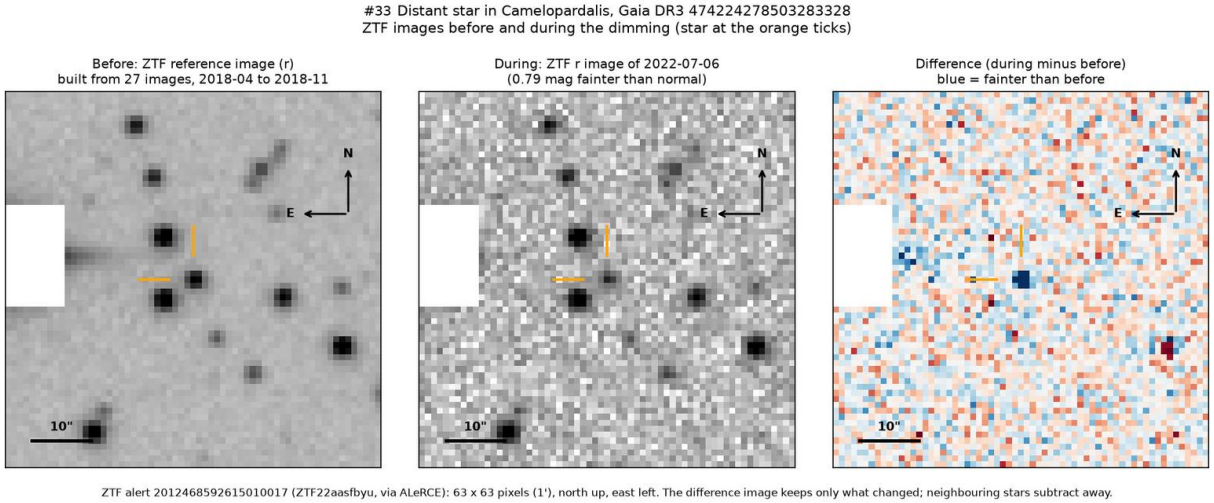



**Figure 101:** Candidate 33, before and during. ZTF images one arcminute across, north up and east left, with the star at the orange ticks. Left: the reference image in red light, from 27 images taken from April to November 2018. Middle: 6 July 2022, with the star 0.79 magnitudes fainter. Right: their difference, in which blue means fainter; both neighbours subtract away. The blank patch is beyond the detector's edge. Data: ZTF (Caltech/IPAC).

## Candidate 34: A Sun-like star that dimmed for about a year in 2020 and 2021

| | |
|---|---|
| **Star** | Gaia DR3 523729725131148672, a Sun-like star behind much interstellar dust |
| **Position** | RA 14.70820°, Dec +63.37671° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cassiopeia, 0.5 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 123.76°, $b$ = +0.52° |
| **Distance** | about 1,800 parsecs (5,800 light-years), within a range of 1,590 to 2,050 parsecs |
| **Brightness** | Gaia $G$ = 17.33; far too faint for the eye or a small telescope |
| **Event** | 0.19–0.22 mag in r (0.28–0.33 in g) in 2020 Sep–Oct; about a year, normal by late May 2021 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is much like the Sun and lies about 1,800 parsecs (5,800 light-years) away in Cassiopeia, in the plane of the Milky Way, behind much interstellar dust. It shone steadily from 2010 to early 2020. When ZTF could observe it again after its yearly gap, at the end of May 2020, it had lost about 11 per cent of its red light. In September and October it was 0.19 to 0.22 magnitudes faint in red light and 0.28 to 0.33 in green, and on single nights it had lost more than a fifth of its red light and about a third of its green. It then recovered slowly and was back to normal by late May 2021, apart from a faint tail of about 2 per cent until early 2022. ZTF's alert system flagged the star as fainter 149 times from June to December 2020, always centred on it.

**Why it might matter.** Dust passing in front of the star is the likeliest cause: green light dimmed 1.46 times as much as red, about as through ordinary interstellar dust, and two visits of WISE, NASA's infrared space telescope, found the infrared almost unchanged, while an opaque body would dim all colours equally. Young stars, often dimmed for months by their own dusty discs, are common in this direction, but this star shows neither warm dust nor hydrogen emission, and it moves about 40 km/s differently from the stars around it, like an older star of the Milky Way's disc. Starspots change a Sun-like star by a few per cent at most, and an eclipse by another star lasts hours or days. The dust might come from colliding planets or asteroids, or from a disc around an unseen companion. A spectrum would settle the star's type and age.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, VSX, the variable-star index, has nothing within 30 arcseconds, and Gaia, the European Space Agency's star-mapping satellite, lists no variability. It is in no variable-star, young-star or cluster catalogue checked, nor among the 81 dimming stars of Tzanidakis et al. (2025), and no transient report, Gaia alert or paper names it. ALeRCE, which holds ZTF's alerts, has only machine-generated labels for it, one of which calls the light curve young-star-like.

**Why this estimate.** The dimming is certain: ZTF, a survey telescope at Palomar Observatory in California, recorded it on two detectors, while hundreds of similar stars on the same detectors stayed steady. Its colour and the nearly unchanged infrared light point to dust. The estimate is not higher because only ZTF recorded it; its start fell while the star was too low in the night sky to observe; it lies where young stars with dusty discs are common, though it shows no sign of youth; two models of the star disagree; and there is no spectrum.

**Caveats.** There is no spectrum, and Gaia's model, a cooler orange star, conflicts with the distance from its parallax. Only ZTF recorded the dimming, and the yearly gap hid its start. Cool dust far from the star cannot be tested. The star lies 1.3 degrees from candidate 44 , which dimmed in 2021 to 2023 on the same ZTF fields; the two fall on different detectors and dimmed at different times, so a shared instrumental cause is unlikely, and they are too far apart in distance for one cloud to cover both.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

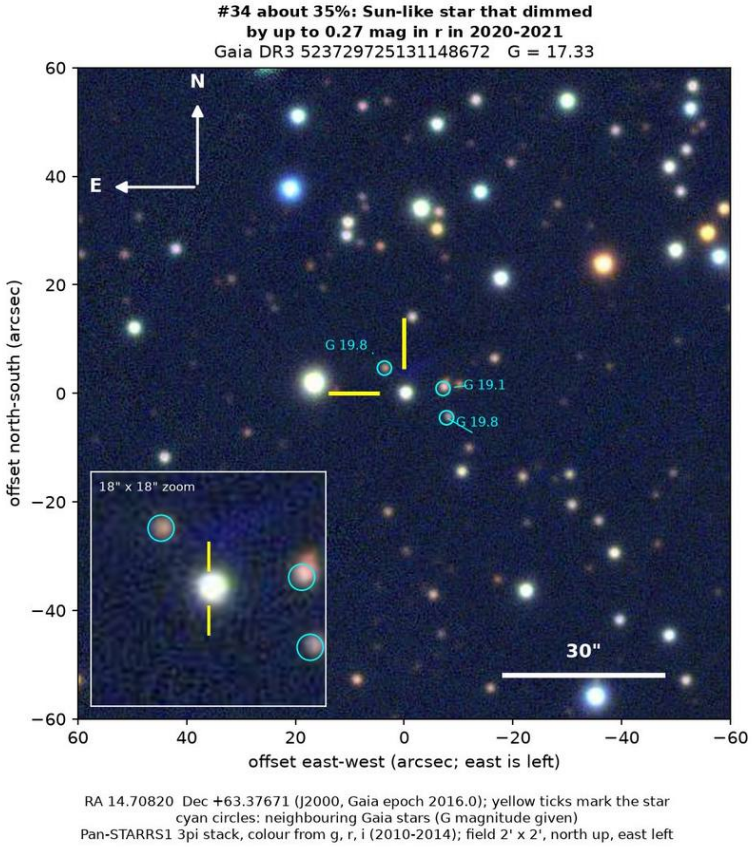
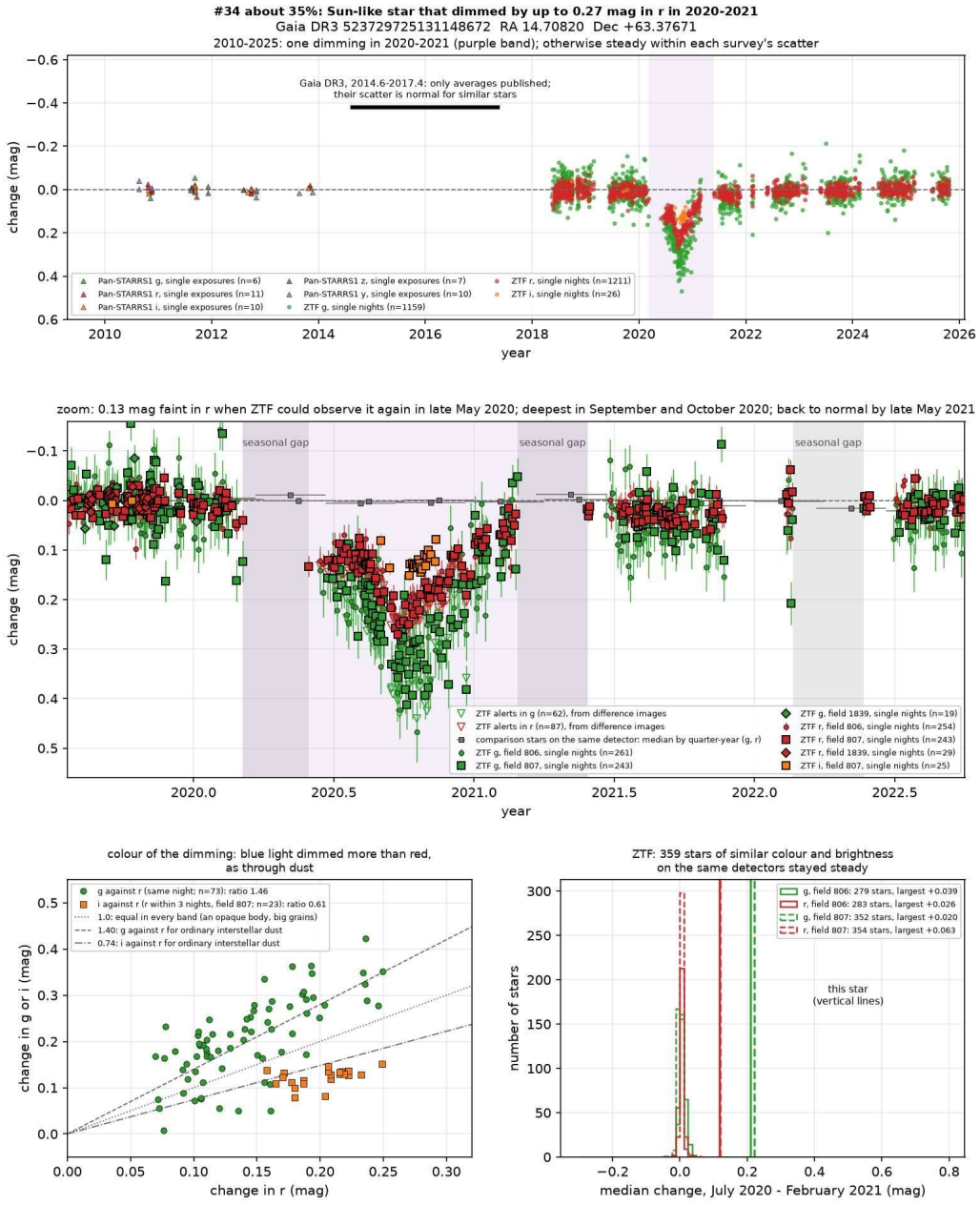



**Figure 102:** Candidate 34, sky image. Pan-STARRS1 colour image in the g, r and i filters, 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; cyan circles mark its three much fainter nearest neighbours, the bright star just east of the ticks lies 17 arcseconds away, and the inset enlarges the centre. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside March 2020 - March 2022), the star was steady in Pan-STARRS1 images of 2010-2013 and in ZTF from May 2018 to February 2020 (single measurements scatter by about 0.02 mag in r and 0.05 mag in g); on the last night before its seasonal gap (grey bands: the star then stands too low in the night sky for ZTF), 5 March 2020, it was 0.04 mag faint in r and 0.12 mag in g. When ZTF could observe it again, on 30 May 2020, it was 0.13 mag faint in r. It stayed 0.11-0.13 mag faint in r (0.14-0.21 mag in g) from June to August, dimmed further in September and October, to 0.19-0.22 mag in r (monthly medians; up to 0.27 mag in r on 23 September and 0.47 mag in g on 18 October), and then recovered slowly: 0.17 mag faint in r in November, 0.12 in December, 0.08-0.09 in January 2021 and 0.06-0.08 in February. On 28-31 May 2021 it was within 0.02 mag of normal; it then stayed very slightly faint (about 0.025 mag in r and 0.05 mag in g) until early 2022 and has been steady since, to October 2025. The dimming appears on both main ZTF fields (circles: field 806; squares: field 807), where the star falls on different detectors (diamonds: field 1839, which observed the star only before and after the dimming). None of the 279-354 stars of similar colour and brightness per field and filter on the same detectors changed by more than 0.063 mag from July 2020 to February 2021, when this star was 0.12 mag faint in r and 0.21-0.22 mag in g (bottom right), and the comparison stars' quarter-year medians stayed within 0.02 mag in g and 0.01 mag in r (grey squares). ZTF's separate difference-image pipeline recorded 149 good-quality alerts from 14 June to 21 December 2020, all 'fainter than the reference' and centred on the star (median offset 0.23"). Blue light dimmed 1.46 times as much as red on the same nights (68 % range 1.41-1.52; 1.53 on field 807), as through ordinary interstellar dust (1.40), and the near-infrared i band, measured on field 807, 0.61 times as much as red (0.59-0.63), more steeply than through ordinary dust (0.74); an opaque body would dim every band equally (1.0). Purple band: early March 2020 - late May 2021, as far as ZTF's observations bracket the dimming.

**Figure 103:** Candidate 34, light curve. Top: the whole record, 2010 to 2025, from Pan-STARRS1, a survey telescope in Hawaii, and ZTF. Middle: mid-2019 to late 2022, with ZTF's three fields as circles, squares and diamonds, its alerts as open triangles and comparison stars as grey squares; grey shading marks the yearly gaps in observations. Bottom left: green and near-infrared dimming against red, with lines for an opaque body and ordinary dust. Bottom right: how much the comparison stars changed, with this star as vertical lines. Purple marks the dimming. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC).

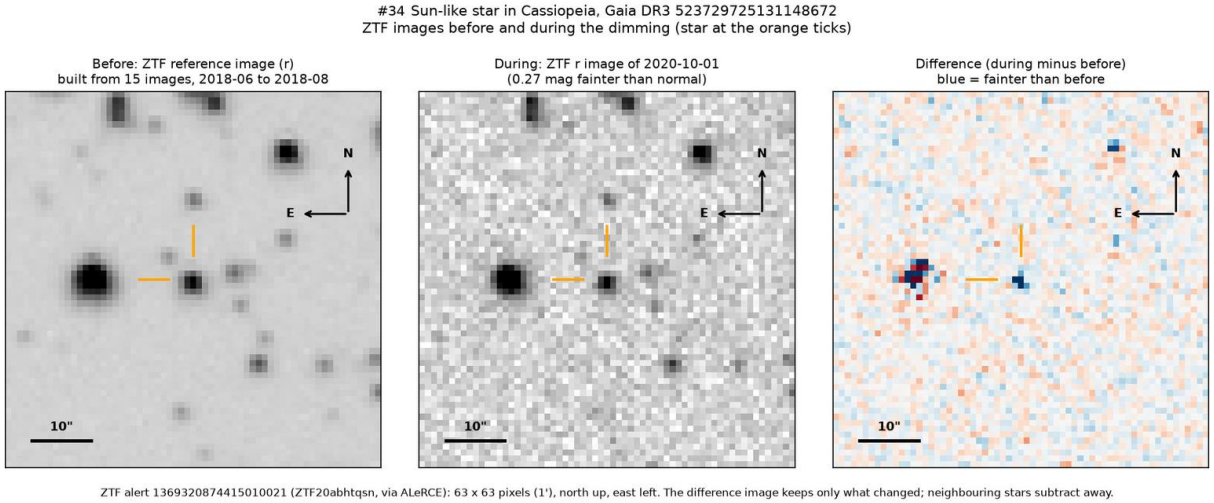



**Figure 104:** Candidate 34, before and during. ZTF images one arcminute across, north up and east left, with the star at the orange ticks. Left: the reference image in red light, from 15 images taken from June to August 2018. Middle: 1 October 2020, with the star 0.27 magnitudes fainter. Right: their difference, in which blue means fainter; the red-and-blue mark to the east is the bright neighbour, imperfectly subtracted, not a change in it. Data: ZTF (Caltech/IPAC).

## Candidate 35: An F-type star that dimmed for a year in 2022 and again from 2025

| | |
|---|---|
| **Star** | Gaia DR3 542101567988836224, a reddened F-type star |
| **Position** | RA 42.12621°, Dec +70.58989° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cassiopeia, 9.9 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 132.42°, $b$ = +9.91° |
| **Distance** | about 1,600 parsecs (5,200 light-years), within a range of 1,470 to 1,710 parsecs |
| **Brightness** | Gaia $G$ = 16.95; far too faint for the eye or a small telescope |
| **Event** | about 15 per cent in r (up to a quarter in g) in 2022 Aug–Sep; normal from 2023 Feb; faint again from 2025 Aug |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** This F-type star, somewhat hotter and larger than the Sun, lies about 1,600 parsecs (5,200 light-years) away in Cassiopeia, behind a thick layer of the Milky Way's dust. From 2018 to 2021 ZTF saw it fade slowly, losing about a tenth of its green light. After a break of almost three months in ZTF's observations, it was faint in February 2022, and it went on dimming until August and September, when it had lost about 15 per cent of its red light and up to a quarter of its green. It recovered from October and was back to normal by February 2023.

It then stayed steady for two years, but when ZTF could next observe it after its yearly gap, in August 2025, it was faint again, by about 5 per cent in red light and 8 to 12 per cent in green, and it was still faint in mid-December 2025. ZTF's alert system flagged the star as fainter 69 times in 2022 and 12 times from August to December 2025, always centred on it.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed 1.59 times as much as red, a little more steeply than through ordinary interstellar dust and far more than starspots on such a star would give, and a NEOWISE visit at the depth of the dimming found the infrared unchanged, which rules out an opaque body. An eclipse by another star lasts hours or days, not a year. Machine classifiers call the star possibly young, a label common in this dusty part of the sky, but it shows no warm dust or hydrogen emission and moves about 50 km/s differently from the stars around it, unlike most young stars. If the second dimming is the same material coming round again, it orbits the star every 3.1 to 3.7 years; but the star was at its brightest in 2018 and 2019, when an earlier passage was due, so the material would have to be new, perhaps dust from a recent collision. A spectrum would settle the star's type and age.

**Checks against the record.** No record of the dimmings could be found. SIMBAD has no entry for the star, VSX, the variable-star index, has nothing within 30 arcseconds, and Gaia, the European Space Agency's star-mapping satellite, lists no variability. It is in no variable-star, young-star or cluster catalogue checked, nor among the dimming stars of Tzanidakis et al. (2025), and no transient report, Gaia alert or paper names it. ALeRCE, which holds ZTF's alerts, has only machine-generated labels for it.

**Why this estimate.** The dimming of 2022 is almost certainly real: ZTF, a survey telescope at Palomar Observatory in California, recorded it on three detectors, while none of 51 similar stars on the same detector changed by more than 0.04 magnitudes. The estimate is not higher because only ZTF recorded the dimmings; both began while ZTF was not observing the star; the second had not ended when the published measurements stop and rests on a single detector; the star's slow fade of 2018 to 2021 is unexplained; and there is no spectrum.

**Caveats.** There is no spectrum, and Gaia's model of the star conflicts with the distance from its parallax. Only ZTF recorded the dimmings, both began while it was not observing the star, and the second had not ended when its published measurements stop, in October 2025; since the end of 2023 only one ZTF field covers the star. The slow fade of 2018 to 2021 is unexplained.

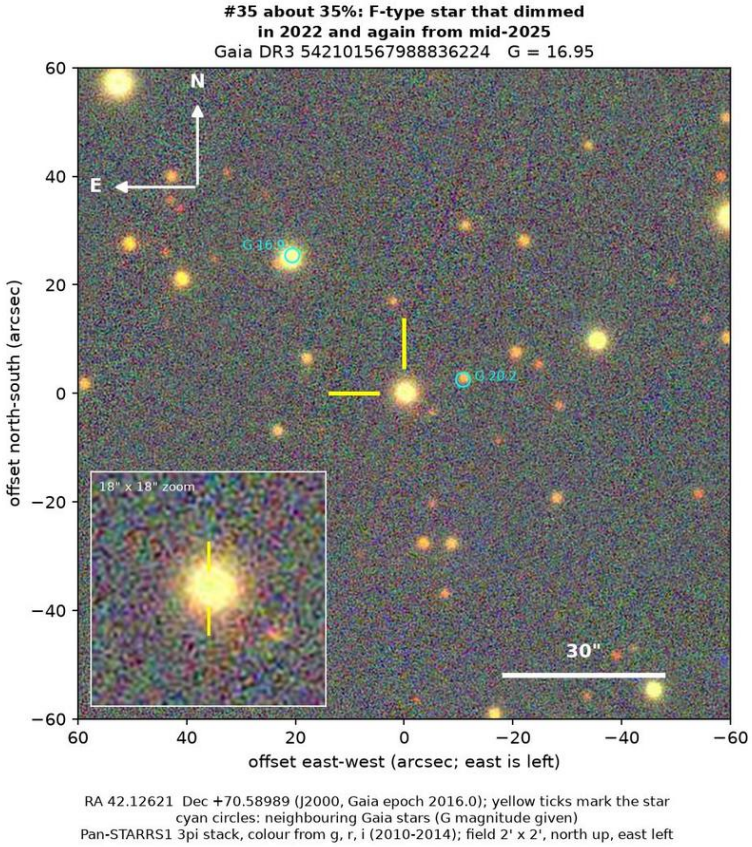
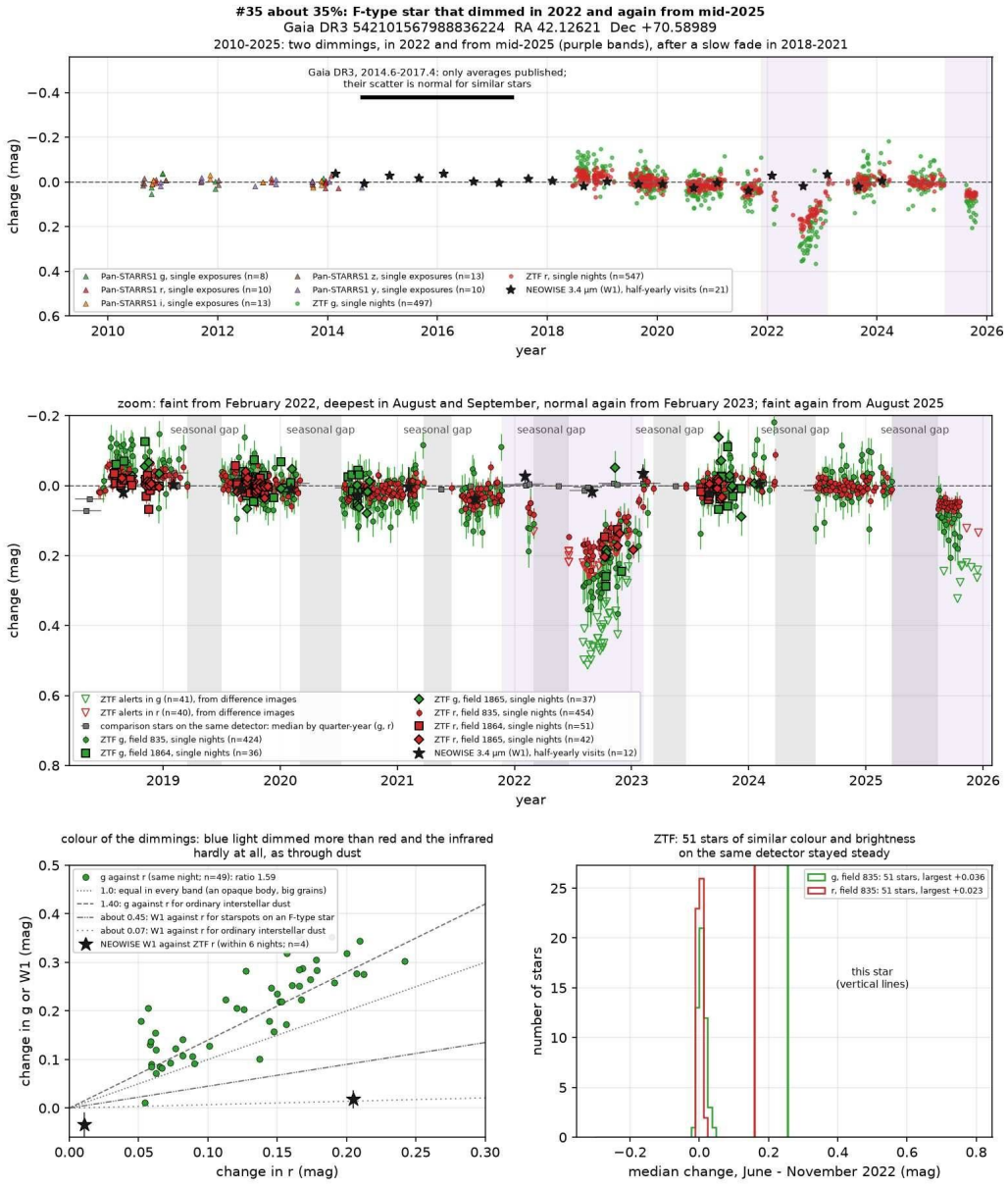



**Figure 105:** Candidate 35, sky image. Pan-STARRS1 colour image in the g, r and i filters, 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; cyan circles mark its much fainter nearest neighbour, 11 arcseconds west, and a much nearer star of similar brightness, 33 arcseconds northeast. The inset enlarges the centre. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside November 2021 - February 2023 and after March 2025), the star was steady in Pan-STARRS1 images of 2010-2014, and NEOWISE's half-yearly visits at 3.4 micrometres stayed within 0.04 mag of their median from 2014 to 2024. In ZTF it faded slowly from 2018 to 2021, by about 0.1 mag in g and 0.06 mag in r (yearly medians; single nights scatter by about 0.02 mag in r and 0.04 mag in g). After a break in ZTF's observations from 22 November 2021, it was 0.05-0.19 mag faint in g and 0.05-0.08 mag in r on 12 February - 2 March 2022, and it was deepest in August and September (monthly medians 0.28-0.29 mag in g and 0.17-0.19 mag in r; up to 0.24 mag in r on 26 August). It recovered from October (0.21 mag faint in g, 0.15 in r) to January 2023 (0.14 in g, 0.05 in r) and was normal from 8 February 2023. It then stayed steady until 23 March 2025, the last night before its seasonal gap (grey bands: the star then stands too low in the night sky for ZTF). When ZTF could observe it again, on 13 August 2025, it was faint again, by about 0.05 mag in r and 0.09–0.14 mag in g (monthly medians), to the end of ZTF's published record on 20 October 2025, and ZTF's alerts show it still faint in mid-December. The first dimming appears on three ZTF fields, where the star falls on different detectors (circles: field 835; squares: field 1864; diamonds: field 1865). None of the 51 stars of similar colour and brightness on the same detector of field 835 changed by more than 0.036 mag in g or 0.023 mag in r from June to November 2022, when this star was 0.26 mag faint in g and 0.16 mag in r (bottom right), and from July 2018 on the comparison stars' quarter-year medians stayed within 0.04 mag in g and 0.01 mag in r (grey squares); from August to October 2025, against 2023-2025, none changed by more than 0.031 mag in g or 0.014 mag in r, when this star was 0.10 mag faint in g and 0.05 mag in r. ZTF's separate difference-image pipeline recorded 69 good-quality alerts from 2 March to 23 December 2022 and 12 from 31 August to 18 December 2025, all 'fainter than the reference' and centred on the star (median offsets 0.21" and 0.50"); they imply deeper dimming, partly because ZTF's reference images were made in 2018 and 2019, when the star was slightly brighter. Blue light dimmed 1.59 times as much as red on the same nights (68 % range 1.53-1.66), somewhat more steeply than through ordinary interstellar dust (1.40), and unlike an opaque body (1.0). At 3.4 micrometres (NEOWISE W1) the star was within 0.02 mag of normal on 30 August 2022, when ZTF had it 0.21 mag faint in r: dust would give about 0.015 mag there, starspots about 0.09 mag and an opaque body 0.21 mag. Purple bands: 22 November 2021 - 8 February 2023 and from 23 March 2025, as far as ZTF's observations bracket the dimmings.

**Figure 106:** Candidate 35, light curve. Top: the whole record, 2010 to 2025, from Pan-STARRS1, a survey telescope in Hawaii, ZTF, and NEOWISE, NASA's infrared space telescope (black stars). Middle: mid-2018 to late 2025, with ZTF's three fields as circles, squares and diamonds, its alerts as open triangles and comparison stars as grey squares; grey shading marks the yearly gaps in observations. Bottom left: green and infrared dimming against red, with lines for an opaque body, ordinary dust and starspots. Bottom right: how much the comparison stars changed, with this star as vertical lines. Purple marks the two dimmings. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC).

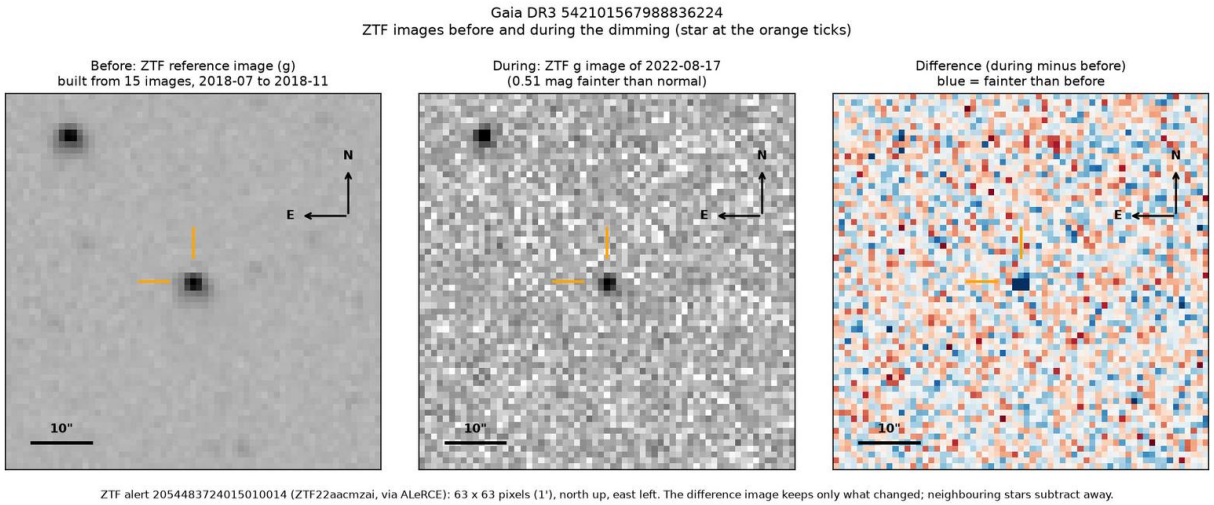



**Figure 107:** Candidate 35, before and during. ZTF images one arcminute across, north up and east left, with the star at the orange ticks. Left: the reference image in green light, from 15 images taken from July to November 2018. Middle: 17 August 2022, with the star 0.51 magnitudes fainter than in the reference, made when it was slightly brighter than usual. Right: their difference, in which blue means fainter. Data: ZTF (Caltech/IPAC).

## Candidate 36: A Sun-like star that faded in 2019 and stayed faint into 2020

| | |
|---|---|
| **Star** | Gaia DR3 2812681697430008 32, a Sun-like star, a little cooler and smaller than the Sun |
| **Position** | RA 77.70638°, Dec +58.80213° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Camelopardalis, 11.2 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 151.48°, $b$ = +11.19° |
| **Distance** | about 1,740 parsecs (5,700 light-years), within a range of 1,560 to 1,980 parsecs |
| **Brightness** | Gaia $G$ = 17.54; far too faint for the eye or a small telescope |
| **Event** | faded within a month in 2019 Aug; up to 30 per cent in g (2020 Apr 2); normal by 2020 Jul 15 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** This ordinary Sun-like star, a little cooler and smaller than the Sun, lies about 1,740 parsecs (5,700 light-years) away in Camelopardalis, behind a moderate layer of the Milky Way's dust. ZTF saw it steady from 2018 to April 2019 and still close to normal at the end of July 2019, after its yearly gap. Within about four weeks in August it then lost a quarter of its green light and about a tenth of its red light. It stayed faint through the autumn and winter, and on 2 April 2020, the last night before the next gap, it was as faint as at any time, down by 30 per cent in green light and 16 per cent in red. When ZTF could observe it again, on 15 July 2020, it was back to normal, and it has stayed steady since, to October 2025. ZTF's alert system flagged the star as fainter 56 times from August 2019 to April 2020, always centred on it, while its brighter neighbour 8 arcseconds away stayed steady.

**Why it might matter.** Fine dust passing in front of the star is the likeliest cause. Green light dimmed about twice as much as red: far more than starspots on a Sun-like star would give, and more steeply than through ordinary interstellar dust, a ratio that needs grains much smaller than average. Two infrared visits of WISE and NEOWISE during the dimming found almost no change, which rules out an opaque body. An eclipse by another star lasts hours or days, not eight months. The star shows no sign of youth: it has no warm dust around it and lies about 340 parsecs above the Milky Way's mid-plane, well above the layer where most young stars are found. Grains this fine are blown out of a planetary system within about an orbit, so dust orbiting the star would have to be fresh, perhaps from a recent collision. A spectrum would settle the star's type and age.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, VSX, the variable-star index, has nothing within 30 arcseconds, and Gaia lists no variability. It is in no variable-star, young-star or cluster catalogue checked, nor among the dimming stars of Tzanidakis et al. (2025), and no transient report, Gaia alert or paper names it. ALeRCE, which holds ZTF's alerts, has only machine-generated labels for it, such as "active galaxy", which the star's parallax rules out.

**Why this estimate.** The dimming is almost certainly real: ZTF, a survey telescope at Palomar Observatory in California, recorded it on two detectors, while the similar stars on the same detectors stayed steady, and its start was observed. The estimate is not higher because only ZTF recorded it; it ended while ZTF could not observe the star, after a last night on which it was as faint as at any time; its steep colour needs unusually fine dust; measurements by Gaia, the European Space Agency's star-mapping satellite, scatter more than for most similar stars; and there is no spectrum.

**Caveats.** There is no spectrum, and Gaia's model, a cooler orange star, conflicts with the distance from its parallax. Only ZTF recorded the dimming, although Gaia's next data release should show its first five months. Its end fell in the yearly gap, so how deep it became and how it recovered are unknown. A Sun-like star 39 degrees away, candidate 37 , dimmed over nearly the same months, but on different ZTF fields and detectors, and no single cloud could cover both, so the timing is most likely a coincidence.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

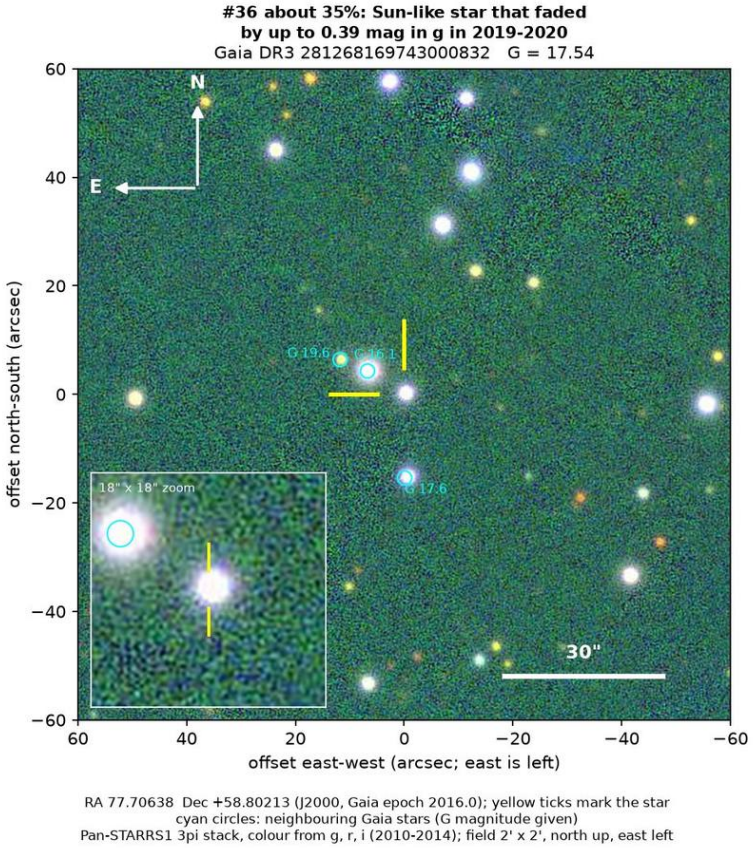
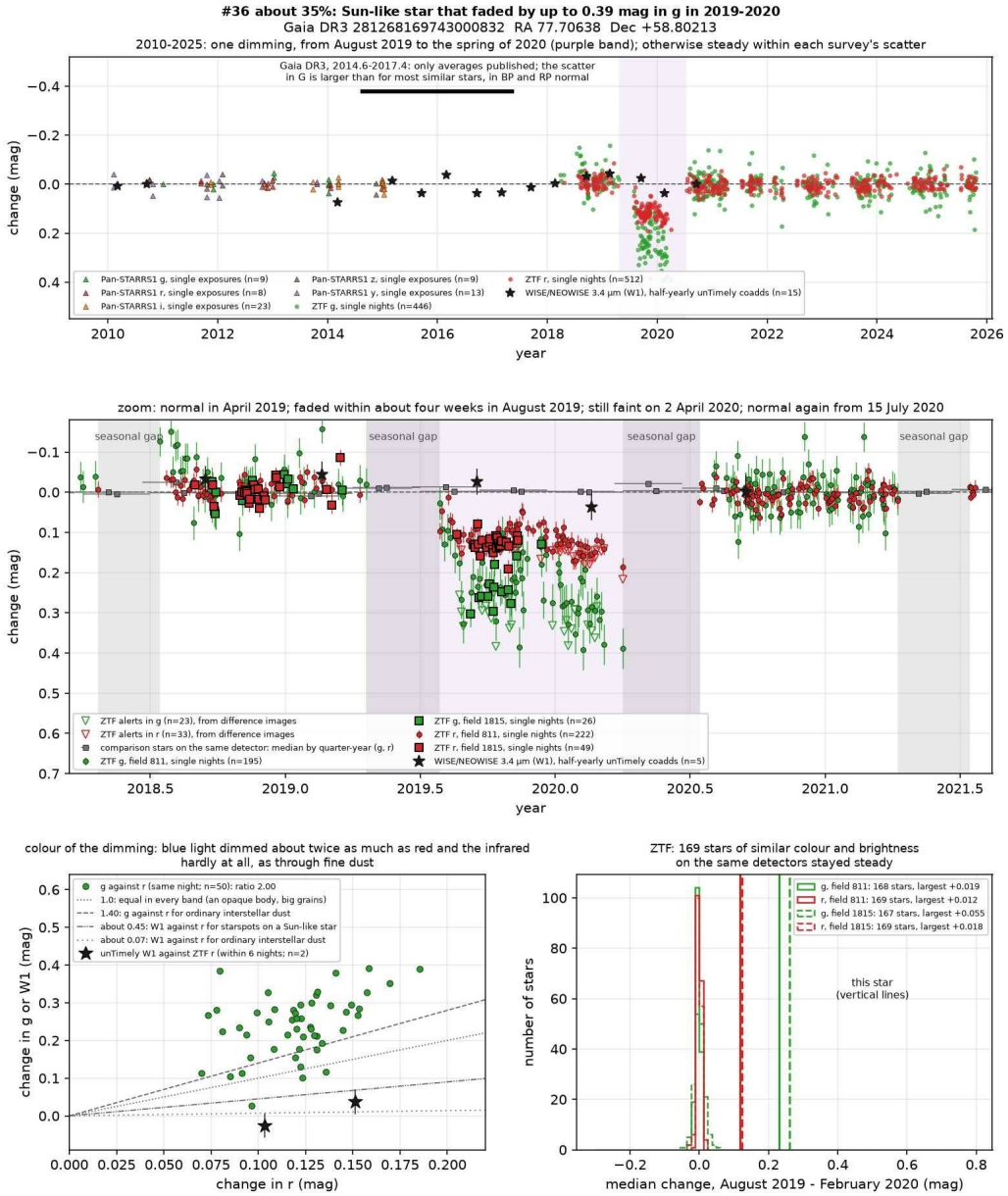



**Figure 108:** Candidate 36, sky image. Pan-STARRS1 colour image in the g, r and i filters, 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; cyan circles mark its three nearest neighbours: a brighter, more distant star 8 arcseconds northeast, a faint one 13 arcseconds northeast and one 15 arcseconds south. The inset enlarges the centre. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside August 2019 - July 2020), the star was steady in Pan-STARRS1 images of 2010-2015 (one g exposure, taken through about a magnitude of cloud, is left out), in the unTimely coadds of WISE and NEOWISE images at 3.4 micrometres from 2010 to 2019 (one epoch, September 2014, is left out because the catalogue split the star's light between two sources) and in ZTF from March 2018 to 21 April 2019, the last night before its seasonal gap (grey bands: the star then stands too low in the night sky for ZTF; single nights scatter by about 0.02 mag in r and 0.035 mag in g, and two nights in g in July 2018, with the star low in the sky, came out 0.13-0.15 mag bright). When ZTF could observe it again, it was close to normal in g on 29 July 2019 and then faded: 0.09-0.18 mag in g from 1 to 24 August, and 0.27-0.33 mag in g and 0.11-0.15 mag in r by 27-30 August. It stayed faint for the rest of the season (monthly medians 0.17-0.29 mag in g and 0.09-0.15 mag in r from September 2019 to February 2020), and on 2 April 2020, the last night before the next gap, it was as faint as on any earlier night (0.39 mag in g, 0.19 mag in r). When ZTF could observe it again, on 15 July 2020, it was back to normal, and it stayed steady to the end of ZTF's published record in October 2025. The dimming appears on two ZTF fields, where the star falls on different detectors (circles: field 811; squares: field 1815). None of the 168-169 stars of similar colour and brightness on the same detector of field 811 changed by more than 0.028 mag in g or 0.022 mag in r from August 2019 to February 2020, when this star was 0.23 mag faint in g and 0.12 mag in r (bottom right; on field 1815, none by more than 0.059 and 0.029 mag), and the comparison stars' quarter-year medians stayed within 0.035 mag in g and 0.011 mag in r (grey squares). ZTF's separate difference-image pipeline recorded 56 good-quality alerts from 24 August 2019 to 2 April 2020, all 'fainter than the reference' and centred on the star (median offset 0.19"). The star's brighter neighbour 8" away stayed steady. Blue light dimmed 2.0 times as much as red on the same nights (68 % range 1.91-2.09), more steeply than through ordinary interstellar dust (1.40) and unlike an opaque body (1.0), as through dust of grains smaller than ordinary. At 3.4 micrometres (W1) the star was within 0.04 mag of normal on 17 September 2019 and 19 February 2020, when ZTF had it 0.10 and 0.15 mag faint in r: dust would give about 0.01 mag there, starspots about 0.05-0.07 mag and an opaque body 0.10-0.15 mag. Purple band: 21 April 2019 - 15 July 2020, as far as ZTF's observations bracket the dimming.

**Figure 109:** Candidate 36, light curve. Top: the whole record, 2010 to 2025, from Pan-STARRS1, a survey telescope in Hawaii, ZTF, and WISE and NEOWISE, NASA's infrared space telescope (black stars). Middle: early 2018 to mid-2021, with ZTF's two fields as circles and squares, its alerts as open triangles and comparison stars as grey squares; grey shading marks the yearly gaps in observations. Bottom left: green and infrared dimming against red, with lines for an opaque body, ordinary dust and starspots. Bottom right: how much the comparison stars changed, with this star as vertical lines. Purple marks the dimming. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC).

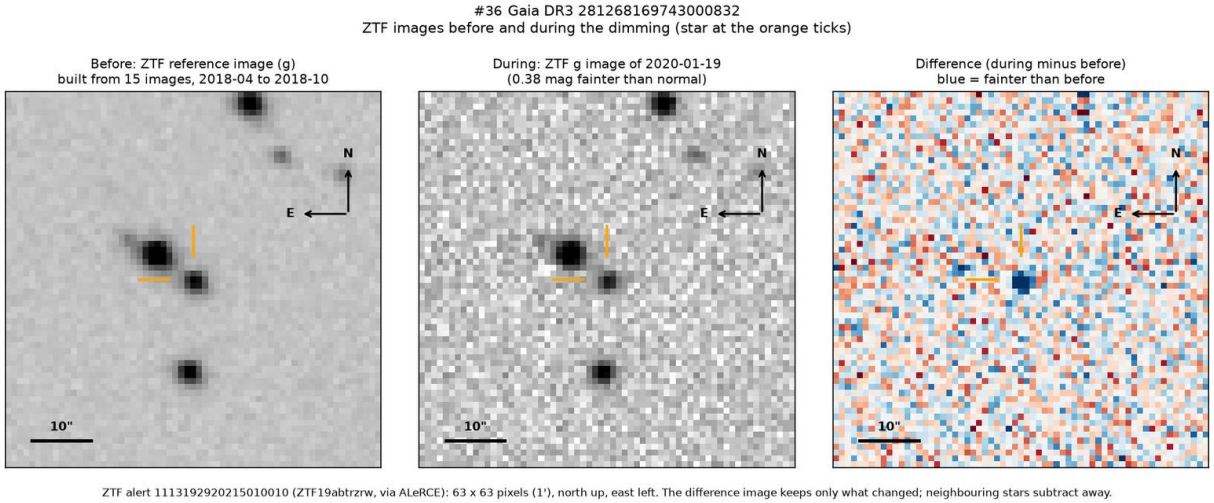



**Figure 110:** Candidate 36, before and during. ZTF images one arcminute across, north up and east left, with the star at the orange ticks. Left: the reference image in green light, from 15 images taken from April to October 2018. Middle: 19 January 2020, with the star 0.38 magnitudes fainter. Right: their difference, in which blue means fainter; the brighter neighbour subtracts away. Data: ZTF (Caltech/IPAC).

## Candidate 37: A Sun-like star that dimmed for eight months in 2019 and 2020

| | |
|---|---|
| **Star** | Gaia DR3 2230583057497888512, a Sun-like star (type about G0) |
| **Position** | RA 335.43080°, Dec +72.33084° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cepheus, 12.7 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 112.03°, $b$ = +12.71° |
| **Distance** | about 1,280 parsecs (4,200 light-years) |
| **Brightness** | Gaia $G$ = 17.36; far too faint for the eye or a small telescope |
| **Event** | from 2019 Sep 21; about a fifth in g by 2020 Jan; recovered within about five weeks after 2020 Apr 2 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is an ordinary Sun-like star in Cepheus, a little hotter than the Sun, about 1,280 parsecs (4,200 light-years) away behind a thick layer of the Milky Way's dust. ZTF saw it steady from March 2018 to August 2019. From 21 September 2019 it faded steadily, and by January 2020 it had lost about a fifth of its green light and a seventh of its red.

From late January to early April the star is too low in the night sky for ZTF. On 2 April 2020 it was still at least as faint, down by about a fifth in both colours. It then recovered within about five weeks, was close to normal from mid-May and has stayed steady since, to October 2025. ZTF's alert system, which compares each new image with a reference image, flagged the star 53 times as fainter, always centred on it.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed 1.48 times as much as red, close to the 1.40 of ordinary interstellar dust; an opaque body would dim all colours equally, and starspots would give about 1.1 to 1.2. During the dimming NEOWISE found the star at its usual brightness at 3.4 microns, which rules out an opaque body and argues strongly against spots, and ZTF found no sign of rotation. An eclipse by another star would last hours or days, not months, and the two detectors make an instrumental fault unlikely. The star lies in the direction of a region of young stars, but those catalogued there lie far in front of it, and it shows no other sign of youth. The cause could be debris from a collision between planets or asteroids, or a dusty disc around an unseen companion, as in epsilon Aurigae. A spectrum would settle the star's type and age.

**Checks against the record.** No record of the dimming could be found: SIMBAD has no entry for the star, Gaia DR3 lists no variability, and VSX (the variable-star index) and the other variable-star, young-star and cluster catalogues checked do not include it. It is not among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications.

**Why this estimate.** The dimming is almost certainly real: ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) recorded it on two overlapping fields, with the star on two different detectors, while similar stars stayed steady. Its colour and the unchanged infrared light fit dust. The estimate is not higher because only ZTF recorded it, and its deepest part may have fallen while the star was too low in the sky to observe; because a machine classifier calls its light curve a young star's and Gaia (the European Space Agency's star-mapping satellite) finds a weak hint of hydrogen emission; because Gaia's own model of the star disagrees with its parallax; and because there is no spectrum.

**Caveats.** There is no spectrum. Only ZTF recorded the dimming: the star is too far north for SkyMapper (a telescope in Australia) and too faint for ASAS-SN (a worldwide network of small telescopes) and NASA's TESS space telescope. Gaia's model of the star, a cooler K star 730 parsecs away, disagrees with the parallax. The timing matches that of candidate 36 , 39 degrees away on different ZTF fields, most likely by coincidence.

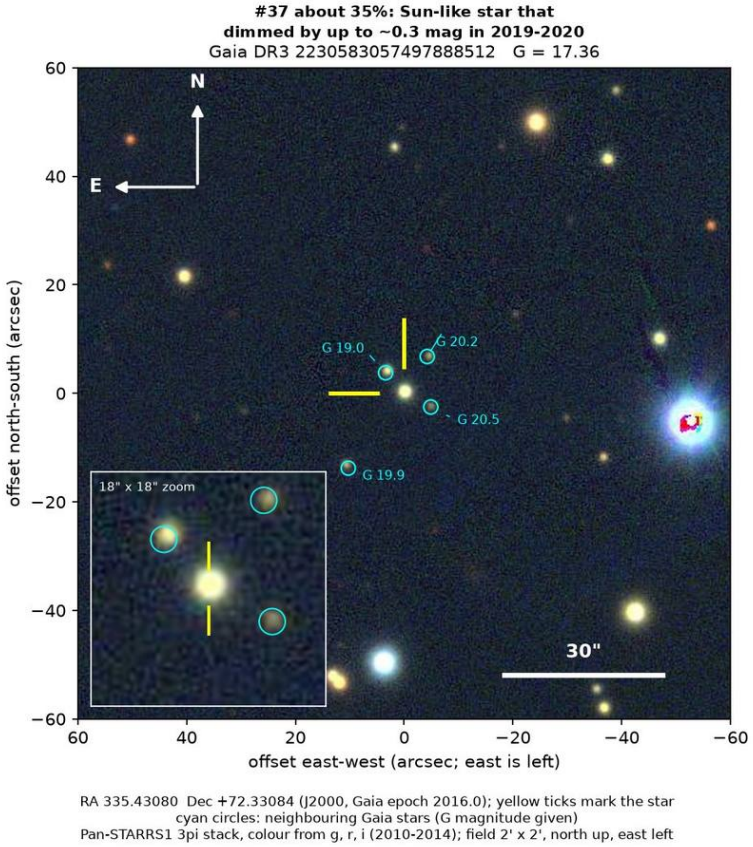
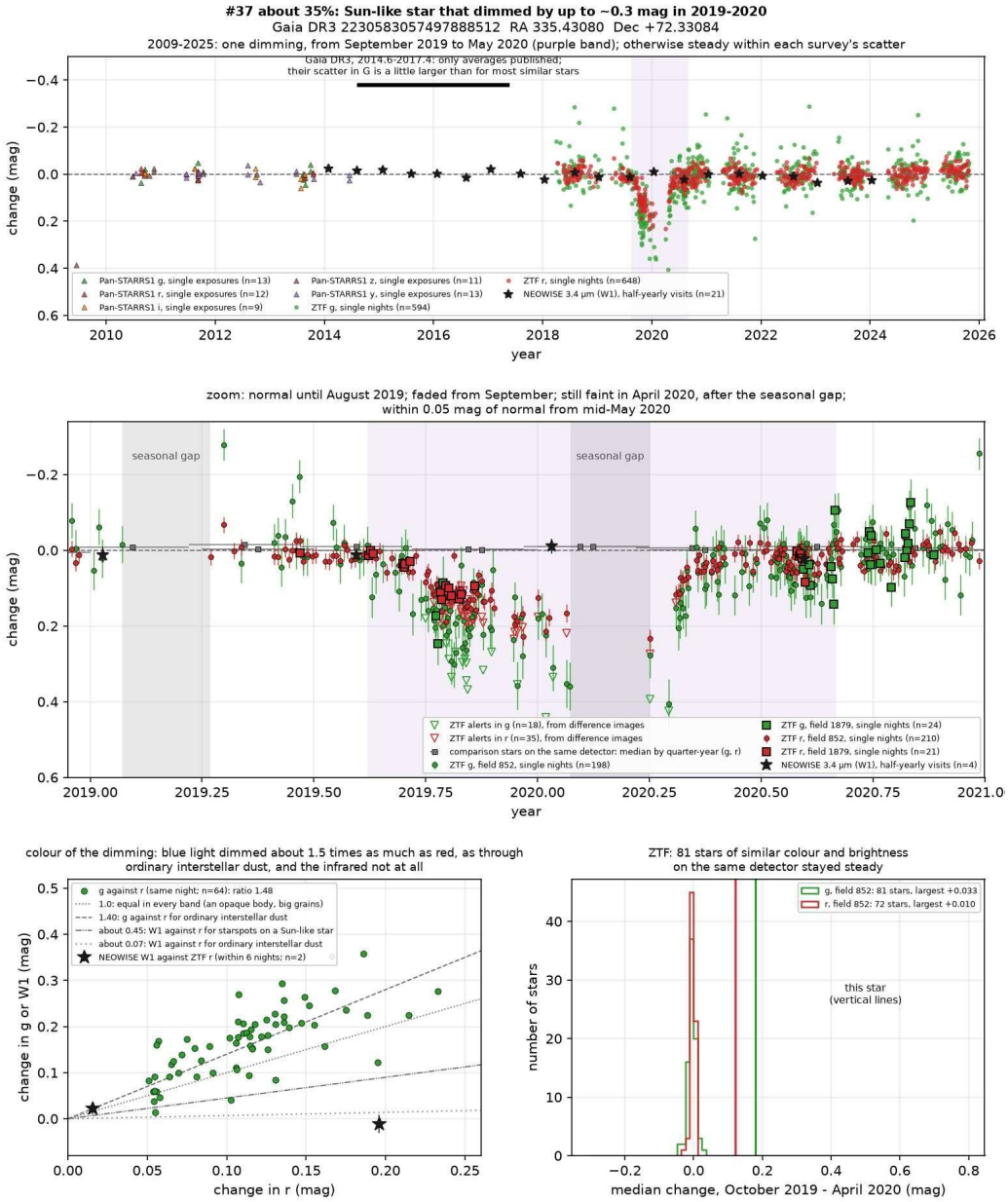



**Figure 111:** Candidate 37, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; cyan circles mark its four nearest neighbours, all fainter, and the closest, 5 arcseconds to the north-east, stayed steady. The inset enlarges the centre. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside 20 July 2019 - 1 October 2020), the star was steady in Pan-STARRS1 images of 2010-2014 (one z exposure, taken through about two magnitudes of cloud, is left out; a single z exposure of June 2009, from the survey's test period, came out 0.38 mag faint), in WISE and NEOWISE measurements at 3.4 micrometres from 2010 to 2019 and in ZTF from March 2018 to mid-August 2019 (single nights scatter by about 0.05 mag in g and 0.03 mag in r; in g about one night in twenty comes out 0.12-0.29 mag bright, while in r no night outside the dimming strays by more than 0.12 mag; grey bands: the star then stands too low in the night sky for ZTF). It was slightly faint on a few nights from late August (up to 0.06 mag in r), and from 21 September 2019 it faded steadily: monthly medians of 0.17, 0.20, 0.24 and 0.27 mag in g and 0.11, 0.13, 0.19 and 0.17 mag in r from October 2019 to January 2020. When ZTF could observe it again, on 2 April 2020, it was 0.28 mag faint in g and 0.23 mag in r, and on 17 April 0.41 mag in g (a single measurement); it then recovered within about four weeks, to within about 0.05 mag of normal from mid-May, and it was normal from September 2020 to the end of ZTF's published record in October 2025. The dimming appears on two ZTF fields, where the star falls on different detectors (circles: field 852; squares: field 1879, which observed it faint on 11 nights in October and November 2019). None of the 81 stars of similar colour and brightness on the same detector of field 852 changed by more than 0.044 mag in g, nor any of 72 by more than 0.028 mag in r, from October 2019 to April 2020, when this star was 0.18 mag faint in g and 0.12 mag in r (bottom right), and the comparison stars' quarter-year medians stayed within 0.011 mag of normal throughout the dimming (grey squares). ZTF's separate difference-image pipeline recorded 53 good-quality alerts from 2 October 2019 to 23 April 2020, all 'fainter than the reference' and centred on the star (median offset 0.19"). The star's neighbour 5" away (G = 19.0) stayed steady. Blue light dimmed 1.48 times as much as red on the same nights (68 % range 1.42-1.54), close to ordinary interstellar dust (1.40) and unlike an opaque body (1.0) or starspots on a Sun-like star (about 1.1-1.2). At 3.4 micrometres (W1) the star was not fainter than usual on 12 January 2020 (-0.01 +/- 0.02 mag), when ZTF had it 0.20 mag faint in r: dust would give about 0.01 mag there, starspots about 0.09 mag and an opaque body 0.20 mag. Purple band: 15 August 2019 - 1 September 2020, as far as ZTF's observations bracket the dimming.

**Figure 112:** Candidate 37, light curve. Brightness from 2009 to 2025, each survey against its own normal level. Top: Pan-STARRS1 (a survey telescope in Hawaii), WISE and NEOWISE (NASA's infrared space telescope), shown as black stars, and ZTF; Gaia published only averages. Purple marks the dimming. Middle: 2019 and 2020, with circles and squares for the two ZTF fields, triangles for ZTF's alerts and grey squares for the comparison stars; grey bands mark when the star is too low in the sky. Bottom: the colour of the dimming, and the changes of the comparison stars. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

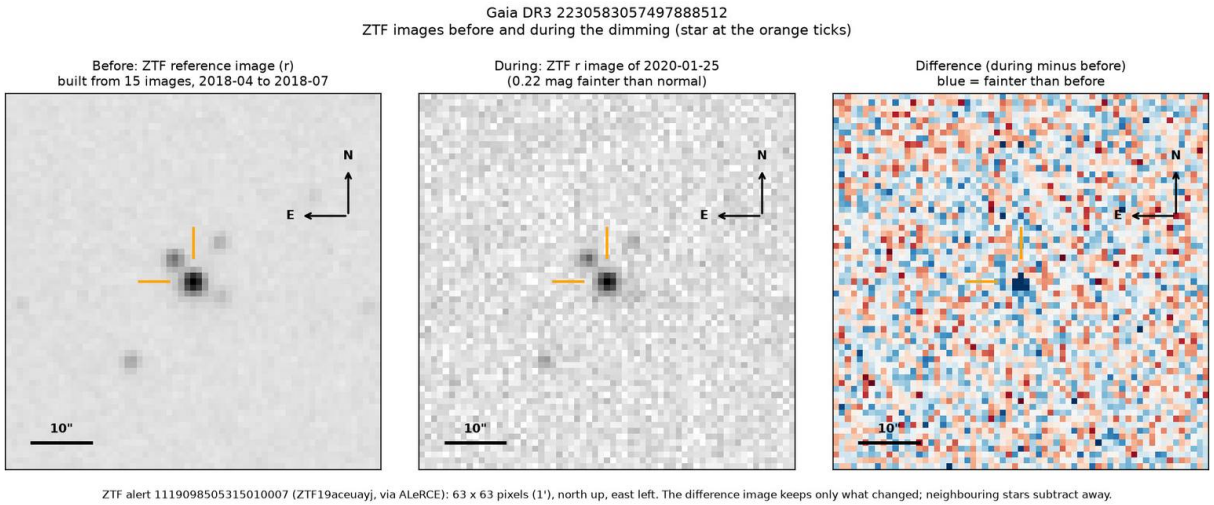



**Figure 113:** Candidate 37, before and during. Cutouts from a ZTF alert, one arcminute across, north up and east left. Left: the reference image in red light, from April to July 2018. Middle: 25 January 2020, when the star was 0.22 magnitudes fainter than normal. Right: their difference, in which blue means fainter; the star, at the orange ticks, leaves a dark blue spot while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 38: An old Sun-like star that was slightly faint for two years

| | |
|---|---|
| **Star** | Gaia DR3 555998192372279808, an old Sun-like star beginning to evolve off the main sequence |
| **Position** | RA 53.27765°, Dec +79.77970° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cepheus |
| **Galactic** | $l$ = 129.93°, $b$ = +19.18° |
| **Distance** | about 920 parsecs (3,000 light-years) |
| **Brightness** | Gaia $G$ = 13.95; far too faint for the eye |
| **Event** | about 0.04 mag in g from early 2022, 0.07 mag in 2023 Jul–Sep; close to normal in 2024 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is a Sun-like star, about 5,700 K and some 10 billion years old, that is beginning to leave the main sequence, about 920 parsecs away in Cepheus. ZTF saw it steady from 2018 to late 2021. From early 2022 it was about 0.04 magnitudes fainter in green light, and in July to September 2023 0.07 in green and 0.03 in red, about 7 per cent less light. It was close to normal again during 2024. ZTF's alert system flagged it 17 times, and ASAS-SN saw the same episode.

**Why it might matter.** Blue light dimmed about 1.7 times as much as red light, more than starspots usually give (1.1 to 1.3) and at least as much as ordinary interstellar dust. WISE, observing every six months, saw no clear change at 3.4 microns, so whatever dimmed the star blocked visible light more than infrared light, as dust does. TESS found no rotation in any of seven sectors, so the star does not look spotted. A thin dust cloud drifting slowly across an old star would fit.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is real: ZTF recorded it on two of its detectors and ASAS-SN, a separate network of small telescopes, saw it in all five of its cameras that watched the star. Green light dimmed more than red, and the infrared did not change, which rules out a solid body. But the dip is shallow, and spots or another slow cause are harder to exclude for a change this small.

**Caveats.** The dimming is shallow, only a few per cent for most of its length. The colour ratio differs between the two ZTF fields (1.5 and 2.0), and GALEX gives only a mild hint of ultraviolet light. There is no spectrum.

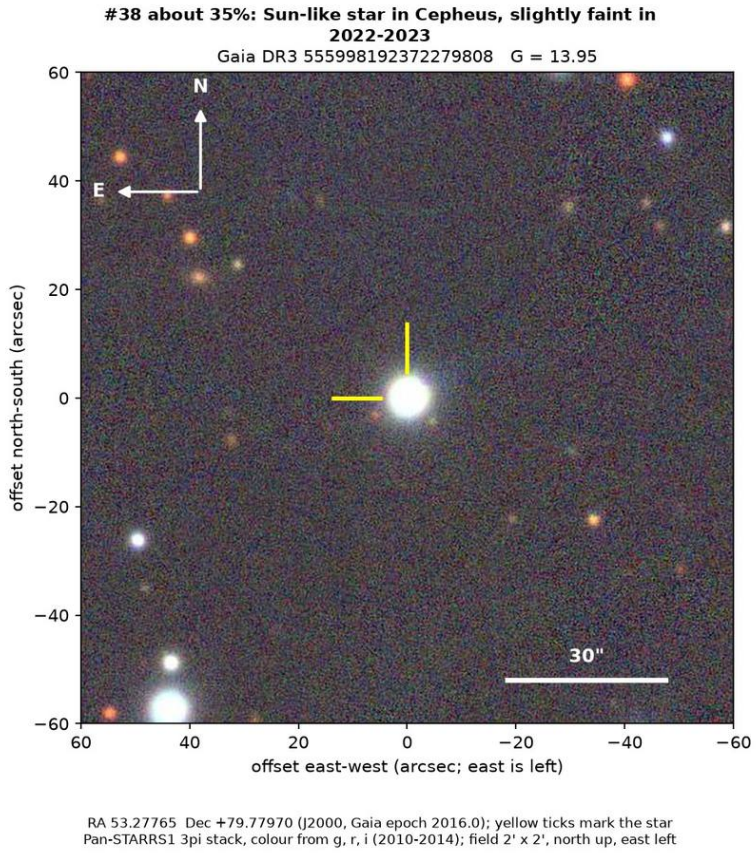



**Figure 114:** Candidate 38, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; the faint dots around it are 7 or more magnitudes fainter. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

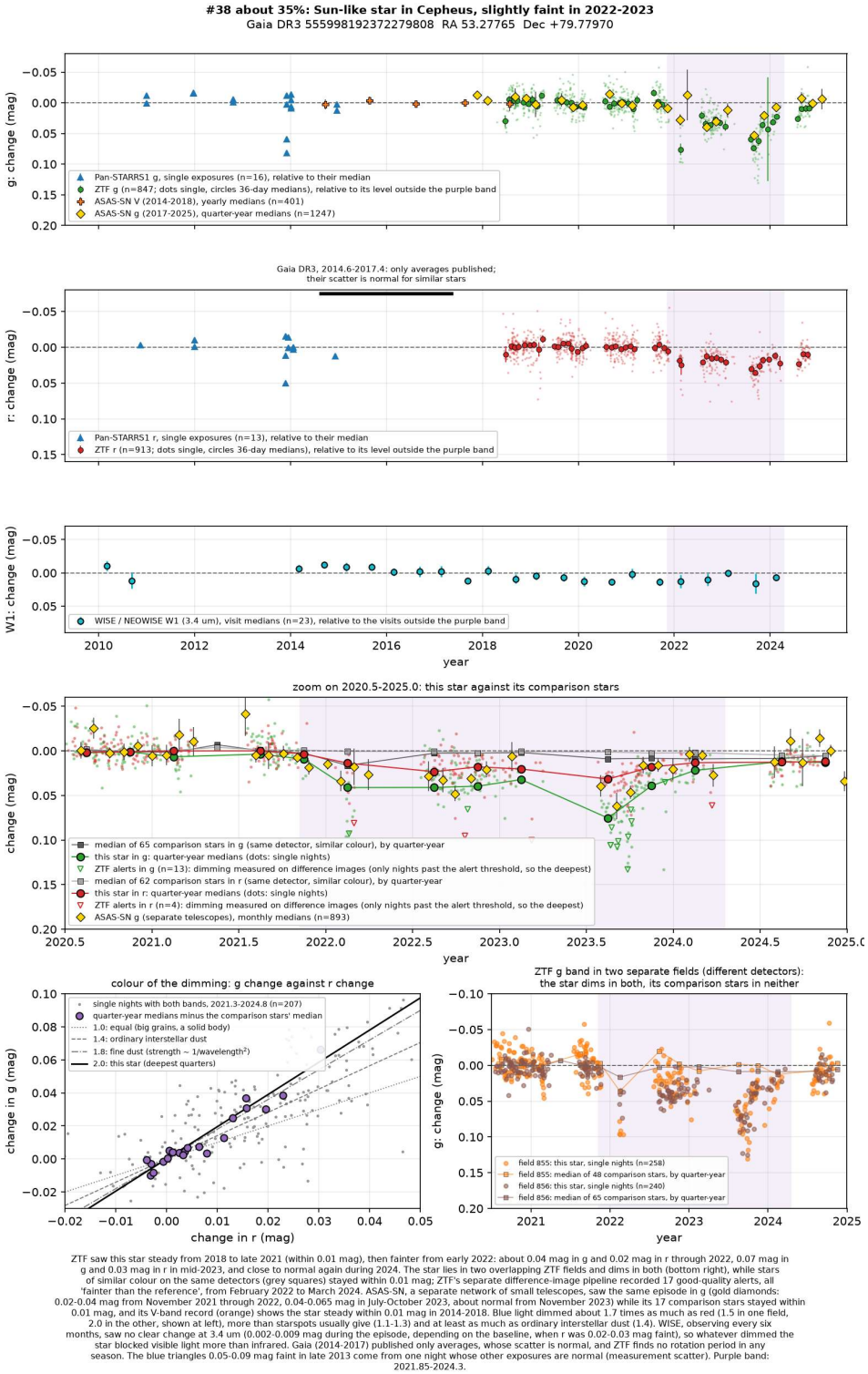



**Figure 115:** Candidate 38, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Bottom right: the star and its comparison stars on two separate ZTF fields, recorded by different detectors. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

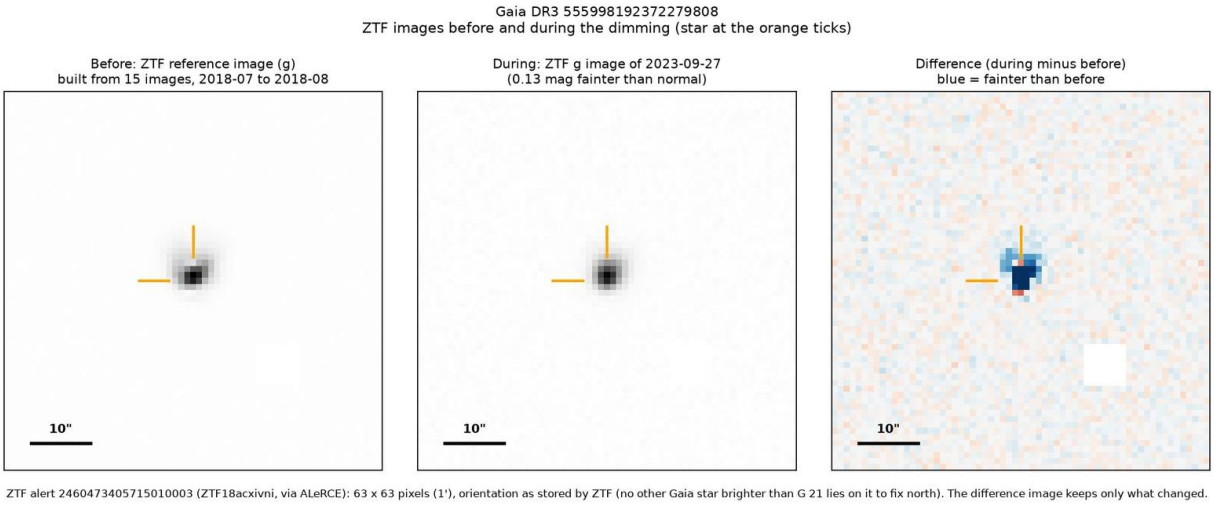



**Figure 116:** Candidate 38, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

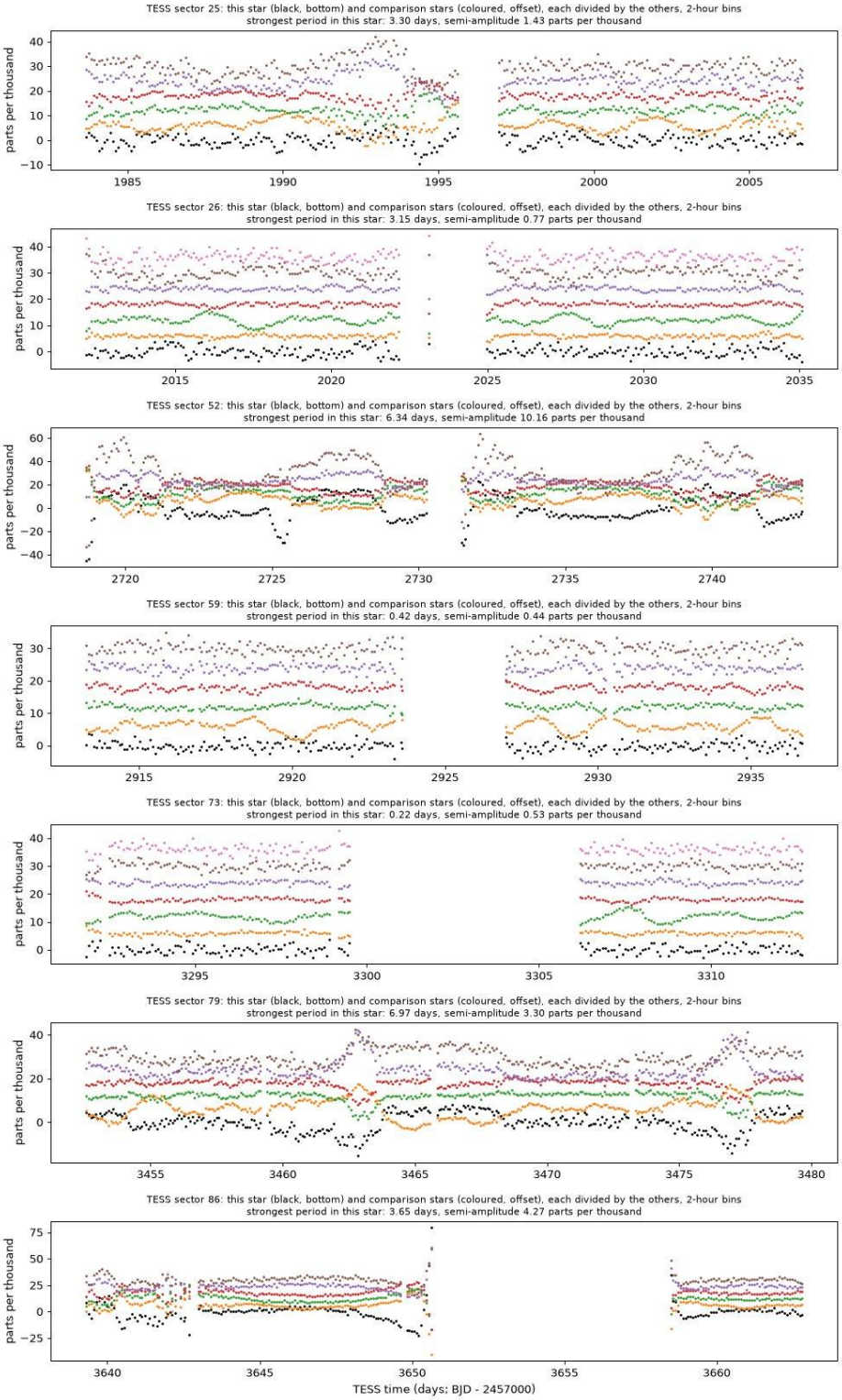



**Figure 117:** Candidate 38, TESS light curves. TESS light curves from seven sectors, in 2020, 2022, 2023 and 2024. No panel shows the steady wave of a spotted star. In each panel the star is in black at the bottom, below comparison stars on the same images, each divided by the others, averaged over two hours and offset for clarity. Data: TESS (NASA; MAST).

## Candidate 39: A Sun-like star that dimmed for a year

| | |
|---|---|
| **Star** | Gaia DR3 2274904749169663744, a Sun-like dwarf |
| **Position** | RA 310.70327°, Dec +71.31979° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cepheus |
| **Galactic** | $l$ = 105.67°, $b$ = +17.39° |
| **Distance** | about 810 parsecs (2,600 light-years) |
| **Brightness** | Gaia $G$ = 14.83; far too faint for the eye |
| **Event** | 0.04–0.06 mag in g from 2023 May; 0.063 mag in 2024 Feb–Mar; normal by 2024 Jun |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is a Sun-like dwarf, about 5,800 K and 6.7 billion years old, some 810 parsecs away in Cepheus. ZTF saw it steady from 2018 to early 2023. From May 2023 it dimmed by 0.04 to 0.06 magnitudes in green light, reached 0.063 in green and 0.033 in red in February and March 2024, about 6 per cent less light, and was back to normal by June 2024. ZTF's alert system flagged it 7 times, and ASAS-SN saw the star 0.03 to 0.07 magnitudes faint in green light in every month from June to December 2023.

**Why it might matter.** Blue light dimmed about twice as much as red light, more than ordinary interstellar dust (1.4) or starspots (1.1 to 1.3) would cause and as fine dust would. TESS watched the star in many sectors outside the dip and never saw the regular wave of a spotted star. WISE observed twice during the dip and saw the star at most a few thousandths of a magnitude fainter at 3.4 microns, too little to tell dust from spots at this depth.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is real: ZTF recorded it on two of its detectors and ASAS-SN, a separate network of small telescopes, saw it in each of its five cameras that observed the star. Green light dimmed about twice as much as red, as behind fine dust, and NASA's TESS space telescope found no sign that the star is spotted. The dip is shallow, the infrared cannot decide between spots and dust, and there is no spectrum.

**Caveats.** The dip is shallow, the colour ratio depends on how it is measured (1.6 to 2.3 on the two ZTF fields), and the infrared cannot decide between dust and spots. There is no spectrum.

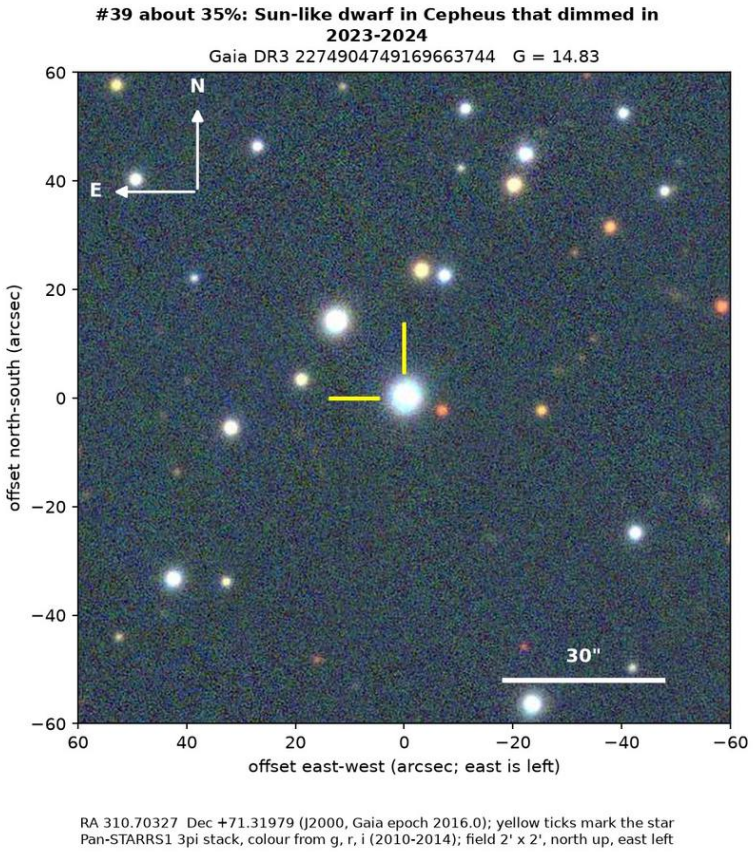
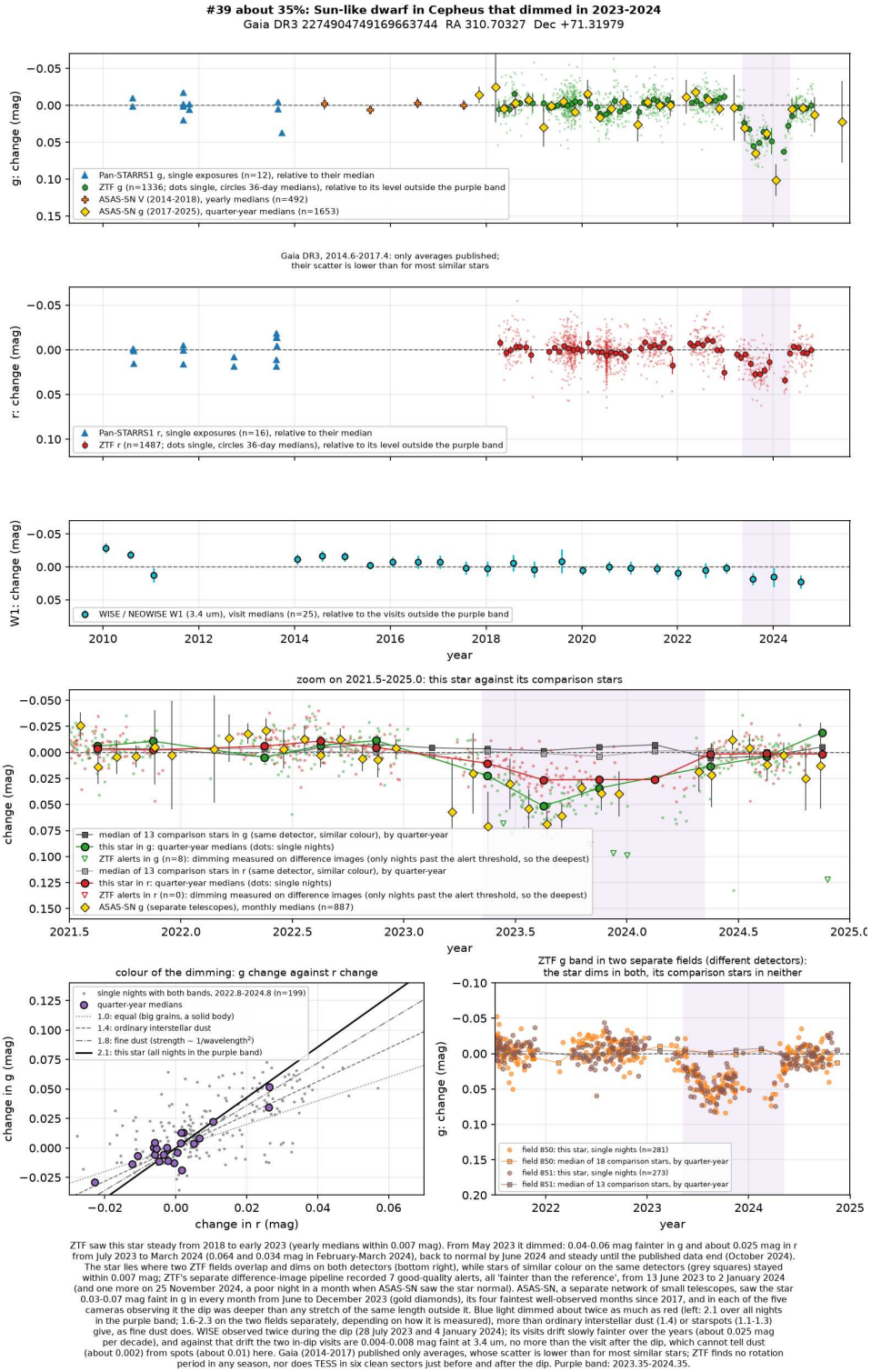



**Figure 118:** Candidate 39, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; a neighbour (G = 15.9) lies 19 arcseconds away. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




ZTF saw this star steady from 2018 to early 2023 (yearly medians within 0.007 mag). From May 2023 it dimmed: 0.04-0.06 mag fainter in g and about 0.025 mag in r from July 2023 to March 2024 (0.064 and 0.034 mag in February-March 2024), back to normal by June 2024 and steady until the published data end (October 2024). The star lies where two ZTF fields overlap and dims on both detectors (bottom right), while stars of similar colour on the same detectors (grey squares) stayed within 0.007 mag; ZTF's separate difference-image pipeline recorded 7 good-quality alerts, all 'fainter than the reference', from 13 June 2023 to 2 January 2024 (and one more on 25 November 2024, a poor night in a month when ASAS-SN saw the star normal). ASAS-SN, a separate network of small telescopes, saw the star 0.03-0.07 mag faint in g in every month from June to December 2023 (gold diamonds), its four faintest well-observed months since 2017, and in each of the five cameras observing it the dip was deeper than any stretch of the same length outside it. Blue light dimmed about twice as much as red (left: 2.1 over all nights in the purple band; 1.6-2.3 on the two fields separately, depending on how it is measured), more than ordinary interstellar dust (1.4) or starspots (1.1-1.3) give, as fine dust does. WISE observed twice during the dip (28 July 2023 and 4 January 2024); its visits drift slowly fainter over the years (about 0.025 mag per decade), and against that drift the two in-dip visits are 0.004-0.008 mag faint at 3.4 um, no more than the visit after the dip, which cannot tell dust (about 0.002) from spots (about 0.01) here. Gaia (2014-2017) published only averages, whose scatter is lower than for most similar stars; ZTF finds no rotation period in any season, nor does TESS in six clean sectors just before and after the dip. Purple band: 2023.35-2024.35.

**Figure 119:** Candidate 39, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Bottom right: the star and its comparison stars on two separate ZTF fields, recorded by different detectors. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

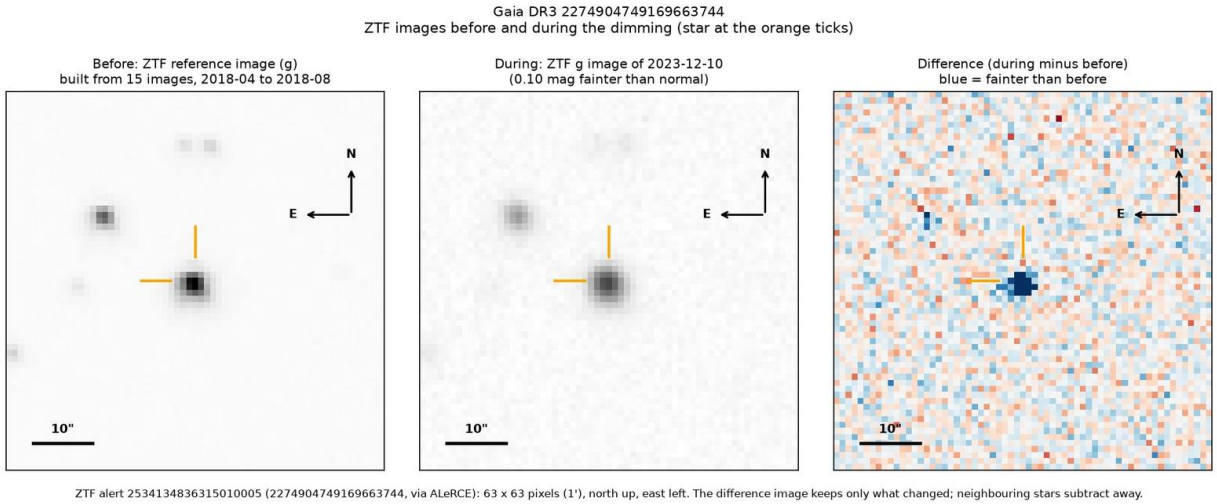



**Figure 120:** Candidate 39, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

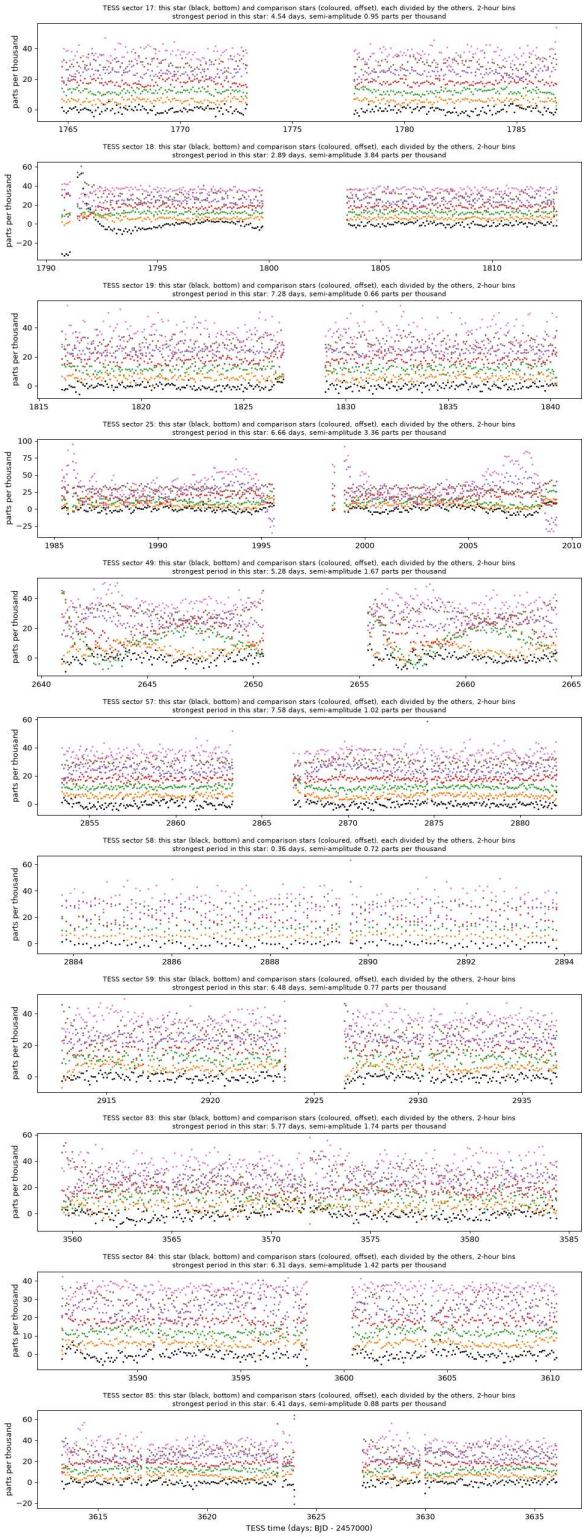



**Figure 121:** Candidate 39, TESS light curves. TESS light curves from sectors observed from 2019 to 2024, all outside the dimming. No panel shows the steady wave of a spotted star. In each panel the star is in black at the bottom, below comparison stars on the same images, each divided by the others, averaged over two hours and offset for clarity. Data: TESS (NASA; MAST).

## Candidate 40: An old Sun-like star that lost a fifth of its light

| | |
|---|---|
| **Star** | Gaia DR3 274442882597165440, an old Sun-like star |
| **Position** | RA 70.82205°, Dec +55.26868° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Camelopardalis |
| **Galactic** | $l$ = 151.99°, $b$ = +6.07° |
| **Distance** | 980 to 1,250 parsecs (3,200 to 4,100 light-years) |
| **Brightness** | Gaia $G$ = 15.57; far too faint for the eye |
| **Event** | about 0.10 mag in g from mid-Aug 2021; 0.23 mag on 2021 Oct 2; normal by 2022 Apr |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 35% |

**What changed.** The star is an old Sun-like star, about 5,500 K and some 11 billion years old, 980 to 1,250 parsecs away in Camelopardalis. ZTF saw it steady from 2018 to April 2021. It began to fade in mid-2021, and from mid-August to late September was about 0.10 magnitudes faint in green light, with a deeper dip for about a week at the end of September: on 2 October it was 0.23 magnitudes fainter in green light and 0.14 in red, a fifth of its green light gone. It then recovered slowly and was back to normal by April 2022.

**Why it might matter.** Blue light dimmed about 1.5 to 1.7 times as much as red light, as dust would make it. WISE observed the star on 10 September 2021, in the deepest stretch, and saw no change at 3.4 microns while red light was about 0.07 magnitudes faint; starspots would have dimmed the infrared by about 0.03 and a solid body by about 0.07, so both are disfavoured. A dust cloud passing in front of an old, quiet star is the likeliest explanation.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is certain: ZTF flagged it 26 times, and ASAS-SN, a separate network of small telescopes, saw five of its six faintest months since 2018 fall inside it. Green light dimmed more than red, as behind dust, and NEOWISE saw no change in the infrared, which argues against spots. Only one ZTF field covers the star, and there is no spectrum.

**Caveats.** Only one ZTF field covers the star, and only ZTF measured the colour. TESS did not observe during the dimming. There is no spectrum.

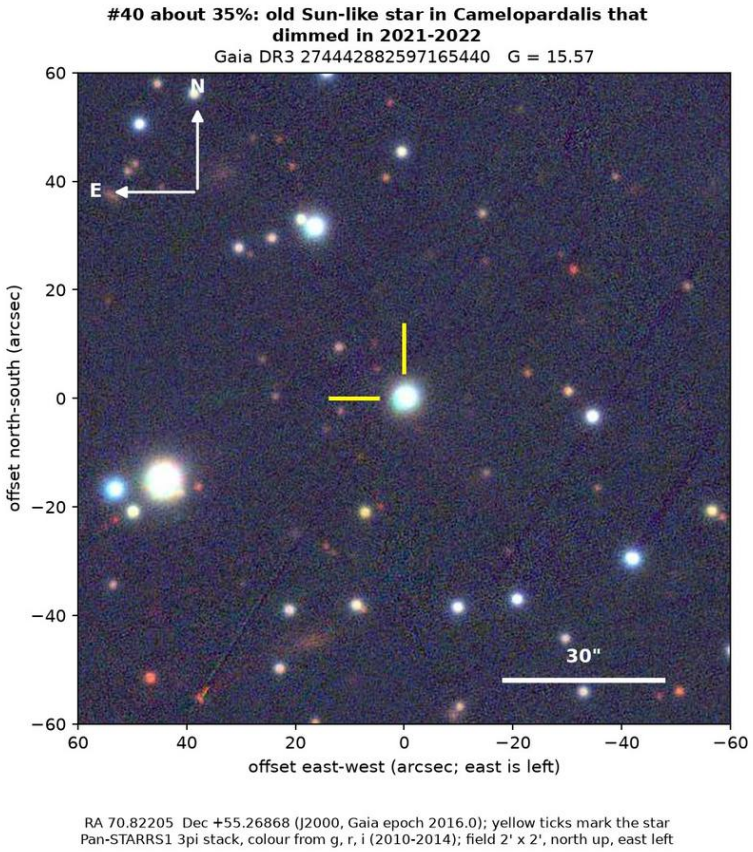



**Figure 122:** Candidate 40, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; its nearest Gaia neighbour (G = 20.5), 15 arcseconds to the north-east, is the faint reddish dot above and to the left of the ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

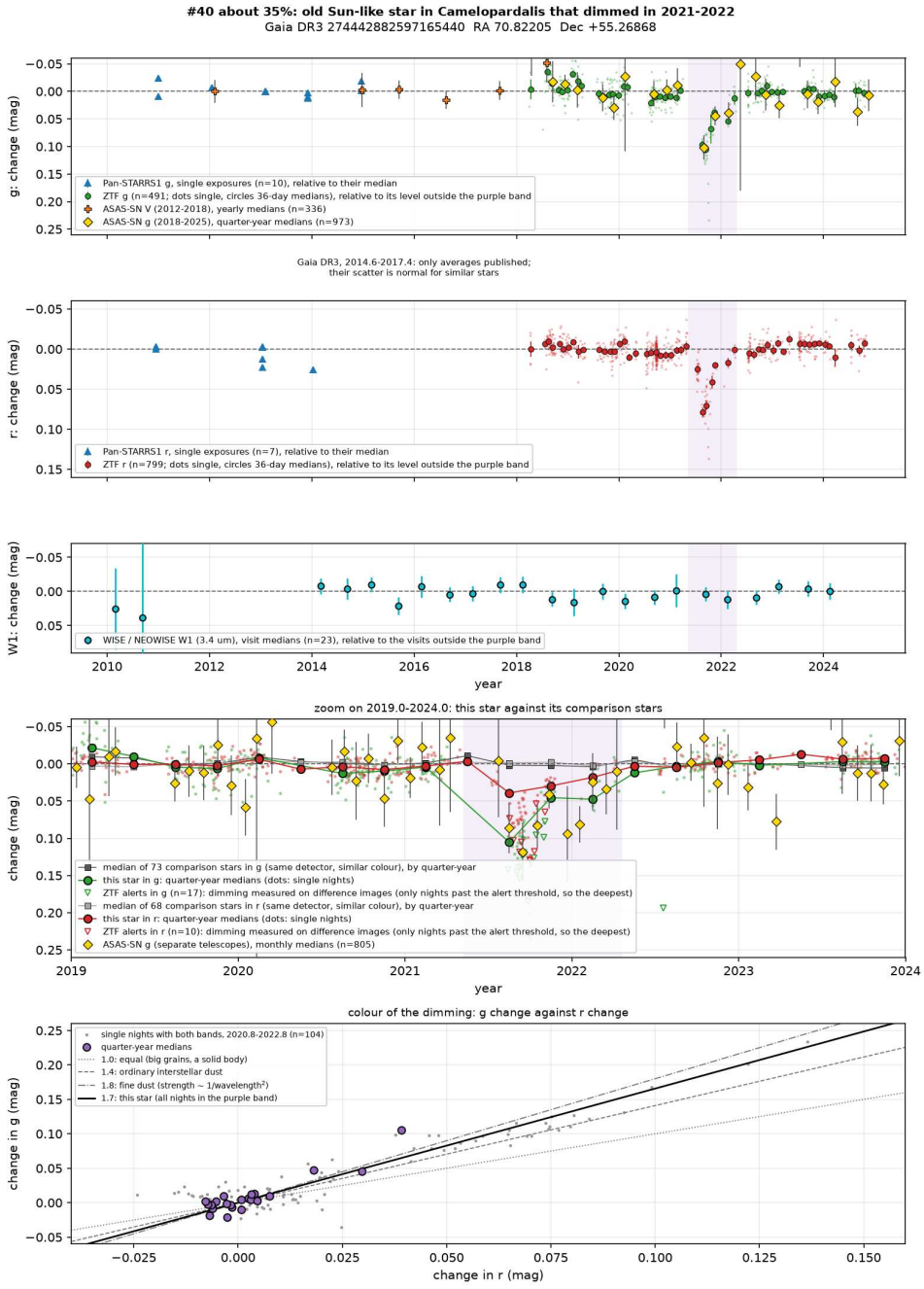



**Figure 123:** Candidate 40, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

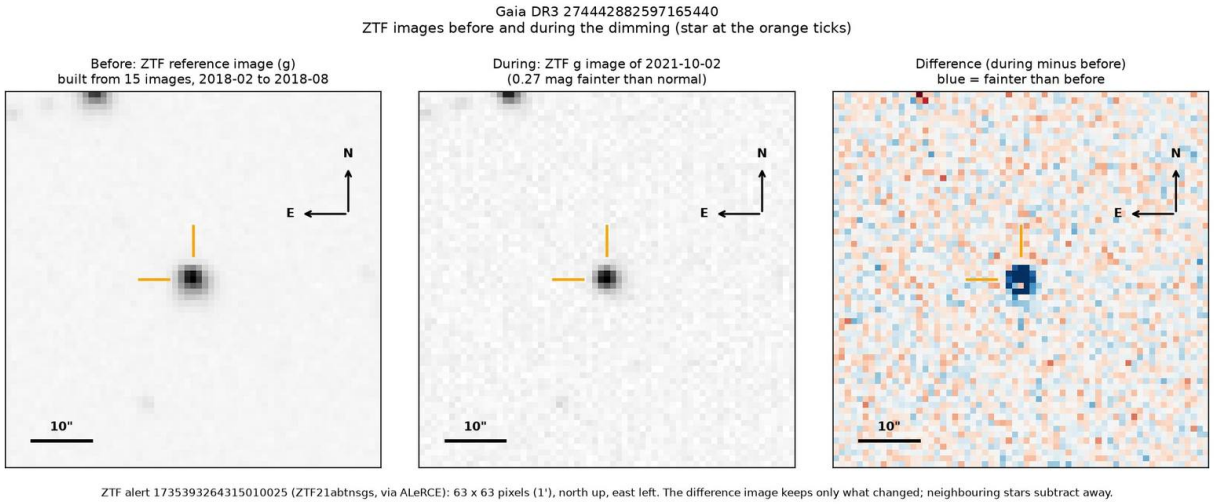



**Figure 124:** Candidate 40, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

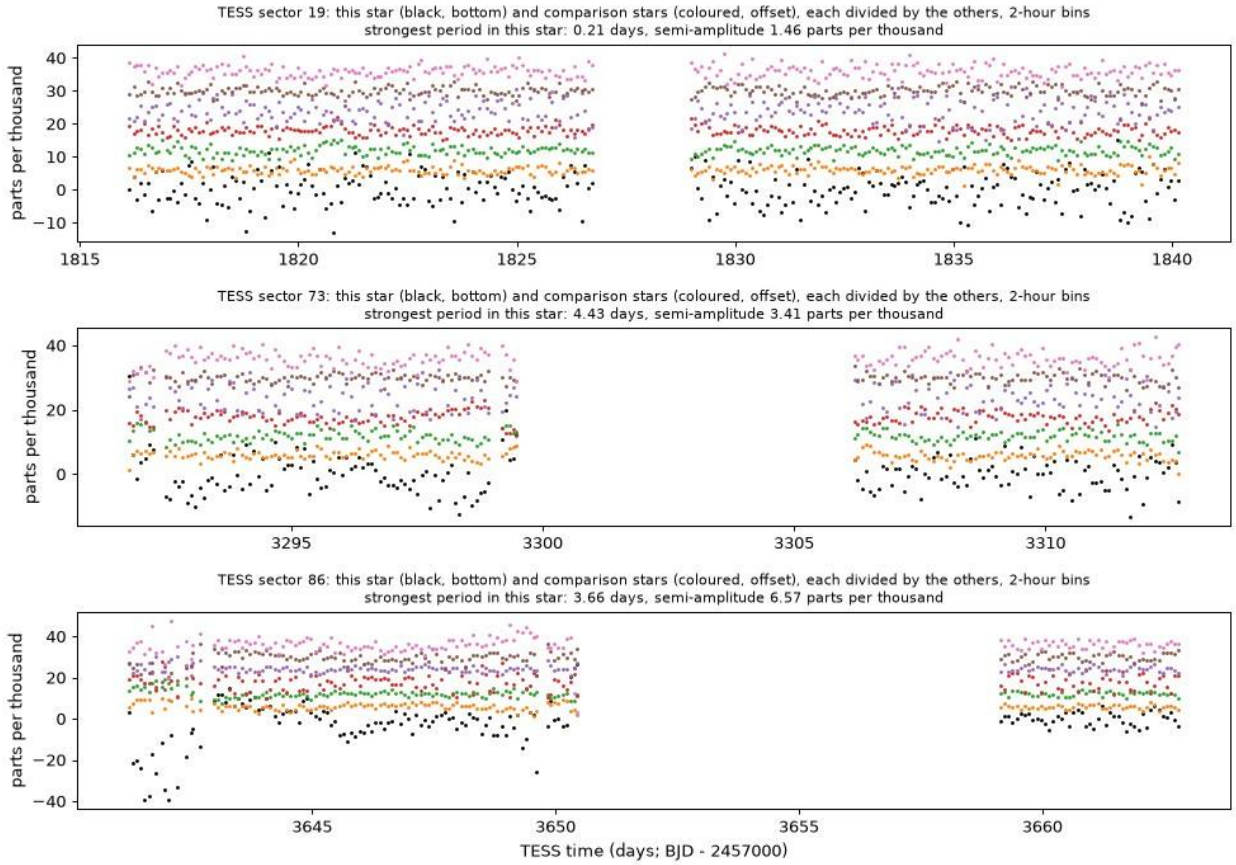



**Figure 125:** Candidate 40, TESS light curves. TESS light curves from three sectors, in November and December 2019, December 2023 to January 2024 and November and December 2024, all outside the dimming. No panel shows the steady wave of a spotted star. In each panel the star is in black at the bottom, below comparison stars on the same images, each divided by the others, averaged over two hours and offset for clarity. Data: TESS (NASA; MAST).

## Candidate 41: An old yellow star that faded abruptly in March 2021

| | |
|---|---|
| **Star** | Gaia DR3 4160428240050322176, an old yellow star of type G |
| **Position** | RA 274.68837°, Dec −7.08184° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Serpens (Serpens Cauda), 4.0 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 22.88°, $b$ = +3.97° |
| **Distance** | about 570 parsecs (1,850 light-years) |
| **Brightness** | Gaia $G$ = 13.97; far too faint for the eye |
| **Event** | abrupt 6 per cent fade in g in 2021 Mar; up to 10 per cent in May; normal by mid-Aug 2021 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is an old yellow star in Serpens, about 570 parsecs (1,850 light-years) away; Gaia finds it close to the Sun's temperature but larger, three times as luminous and about 7 billion years old. Earlier surveys from 2010 show nothing unusual, and ZTF, which measured it 1,077 times from 2018 to late 2024, found it within about 0.01 magnitudes of normal until early March 2021.

Then it faded abruptly. ZTF found it normal on 3 March 2021 and ASAS-SN had it about 0.10 magnitudes faint on 13 March: in March the star lost about 6 per cent of its green light, most of it within about ten days. In May, the deepest month, ZTF found it 0.11 magnitudes faint in green light and 0.05 in red. It recovered through June and July and was back to normal by mid-August 2021.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. For starspots to dim such a star by 11 per cent, a tenth of its face would have had to be covered, mostly within ten days, which is not seen in stars this old and inactive; its hydrogen-alpha line shows no magnetic activity, and neither ZTF nor NASA's TESS space telescope found any rotation. Green light dimmed 1.4 to 1.8 times as much as red, at or above the top of the range for starspots and in the range of dust. A young star with a dusty disc is ruled out by the star's age, motion and lack of infrared excess, and two surveys make an instrumental fault unlikely. The abrupt start points to a cloud with a sharp front edge, perhaps a dusty disc around the star or an unseen companion, as in epsilon Aurigae. A spectrum would settle what kind of star it is.

**Checks against the record.** No record of the dimming could be found: SIMBAD has no object within 10 arcseconds, Gaia DR3 gives the star no variability entry, and VSX (the variable-star index) lists only its two variable neighbours. It is not in the other variable-star catalogues checked or among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications.

**Why this estimate.** The dimming is certainly real: two independent surveys, ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) and ASAS-SN (a worldwide network of small telescopes), recorded it, including its abrupt start. The star is old and quiet and shows no sign of spinning, so large dark starspots are unlikely, and the colour of the dimming is closer to that of dust. The estimate is not higher because only ZTF measured the colour, which argues against starspots only mildly; because the glare of a bright neighbour spoils the infrared test; because only one ZTF field covers the star; and because there is no spectrum.

**Caveats.** There is no spectrum, so the star's type and age rest on Gaia's models. TESS did not observe during the dimming, and the abrupt start rests on a few measurements. Of several other stars that dimmed in the same survey data in 2021 and 2022, candidate 45 , 2.9 degrees away on the same ZTF field, dimmed over nearly the same months; but the two lie on different detectors, and no single cloud could have dimmed both.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

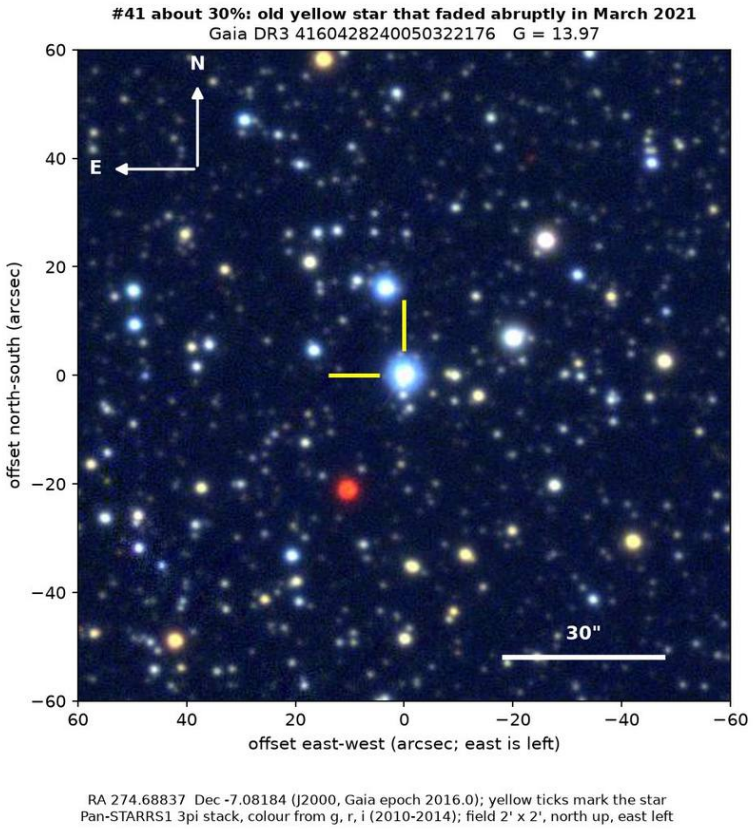



**Figure 126:** Candidate 41, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; the bright star just north of it is a variable with a 1.8-hour period, and the red star to the south-east a long-period variable. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

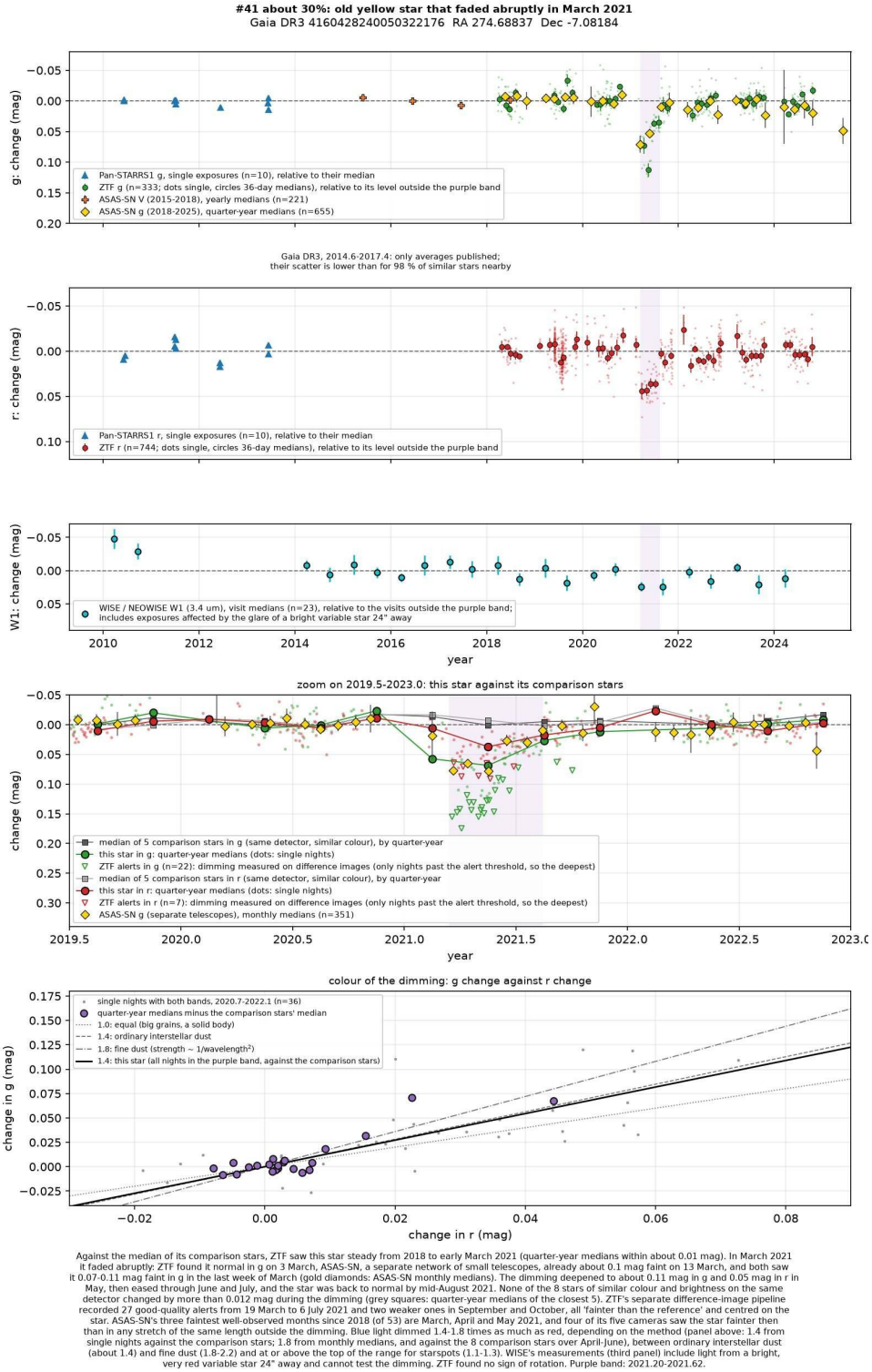



**Figure 127:** Candidate 41, light curve. Brightness from 2010 to 2025. Top three rows: green, red and infrared light against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, ASAS-SN (gold diamonds) and WISE and NEOWISE (NASA's infrared space telescope), whose values include glare from the red neighbour. Gaia (the European Space Agency's star-mapping satellite) published only averages. Purple marks the dimming. Middle: 2019 to 2023, with the comparison stars (grey squares), ZTF's alerts (triangles) and ASAS-SN's monthly values. Bottom: the colour of the dimming, against lines for grey dimming, ordinary dust and fine dust. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

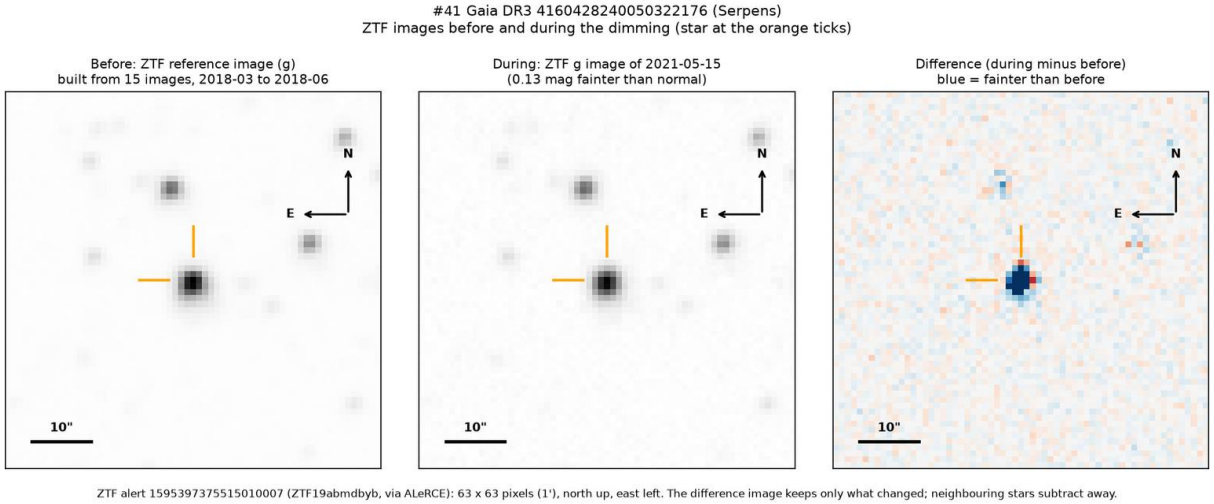



**Figure 128:** Candidate 41, before and during. Cutouts from a ZTF alert, one arcminute across, turned north up and east left. Left: the reference image in green light, from March to June 2018. Middle: 15 May 2021, when the star was 0.13 magnitudes fainter than normal. Right: their difference, in which blue means fainter; the star, at the orange ticks, leaves a dark blue spot while its neighbours subtract away, and the faint spot to the north is the 1.8-hour variable. Data: ZTF (Caltech/IPAC).

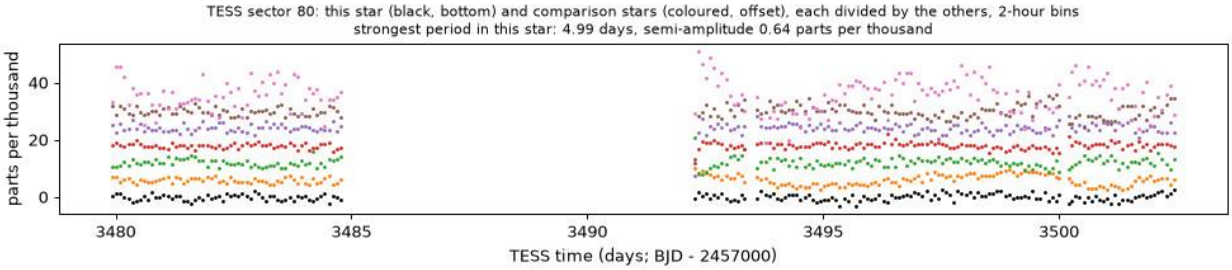



**Figure 129:** Candidate 41, TESS light curves. TESS in June and July 2024, three years after the dimming: this star (black, bottom) and comparison stars nearby (coloured, offset), each divided by the others, in two-hour bins. No rotation or other regular variation is visible in this star. Data: TESS (NASA; MAST).

## Candidate 42: A Sun-like star that faded for most of a year in 2018 and 2019

| | |
|---|---|
| **Star** | Gaia DR3 3129286753527839104, a Sun-like star of type G |
| **Position** | RA 101.71166°, Dec +5.12660° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Monoceros, 1.3 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 207.85°, $b$ = +1.32° |
| **Distance** | about 1,450 parsecs (4,700 light-years) |
| **Brightness** | Gaia $G$ = 15.85; far too faint for the eye or a small telescope |
| **Event** | up to about 9 per cent in g from 2018 Nov to 2019 Sep; normal from late Oct 2019 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is a Sun-like star in Monoceros, about 1,450 parsecs (4,700 light-years) away; Gaia's models give it nearly the Sun's temperature, size and luminosity, in the long, hydrogen-burning main part of its life. It was normal until the end of October 2018, and earlier surveys from 2010 to 2018 show nothing unusual. In November 2018 it began to fade, and January 2019 was the deepest month. From February to April the depth changed from week to week, between about 0 and 0.11 magnitudes in green light. From May to August the star is too close to the Sun for ZTF; in early September it was still faint, and it recovered over four to six weeks, staying normal from late October 2019. In all it lost up to about 9 per cent of its green light and 5 per cent of its red. Five of ASAS-SN's six faintest well-observed months fall in the dimming.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed 1.5 to 1.85 times as much as red, above the 1.1 to 1.3 of starspots and in the range of dust (1.4 for ordinary interstellar dust, 1.8 to 2.2 for fine dust). The star is also quiet: its hydrogen-alpha line and ultraviolet light show no magnetic activity, and ZTF found no rotation in six seasons, so spots dimming it by 6 to 10 per cent for most of a year would be very unusual. The star's place on the main sequence, its motion and its lack of infrared excess rule out a young star with a dusty disc; an eclipse by a companion star would be shorter and regular; and two ZTF fields and a second survey make an instrumental fault unlikely. The shape of the dimming points to an uneven cloud, larger than the star, perhaps a dusty disc around the star or an unseen companion, as in epsilon Aurigae. A spectrum would settle what kind of star it is.

**Checks against the record.** No record of the dimming could be found: SIMBAD has no object within 10 arcseconds, Gaia DR3 gives the star no variability entry, and VSX (the variable-star index) and the other variable-star catalogues checked do not include it. It is not among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications.

**Why this estimate.** The dimming is almost certainly real: ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) recorded it on two separate fields, on different detectors, and ASAS-SN (a worldwide network of small telescopes) also saw the star fainter in those months. The star is quiet and shows no rotation, and its green light dimmed more than its red, by more than starspots would cause, as dust does. The estimate is not higher because the star is faint for ASAS-SN and blended there with a neighbour, so that confirmation is noisy; because only ZTF measured the colour; because the single infrared visit during the dimming is too uncertain and NASA's TESS space telescope did not observe then; and because there is no spectrum.

**Caveats.** There is no spectrum, so the star's type and age rest on Gaia's models, and the colour comes from ZTF alone. From May to August 2019 only three ASAS-SN measurements cover the dimming. Several other stars that dimmed in the same survey data did so in 2018 and 2019, but all of them lie in other parts of the sky, on other ZTF fields.

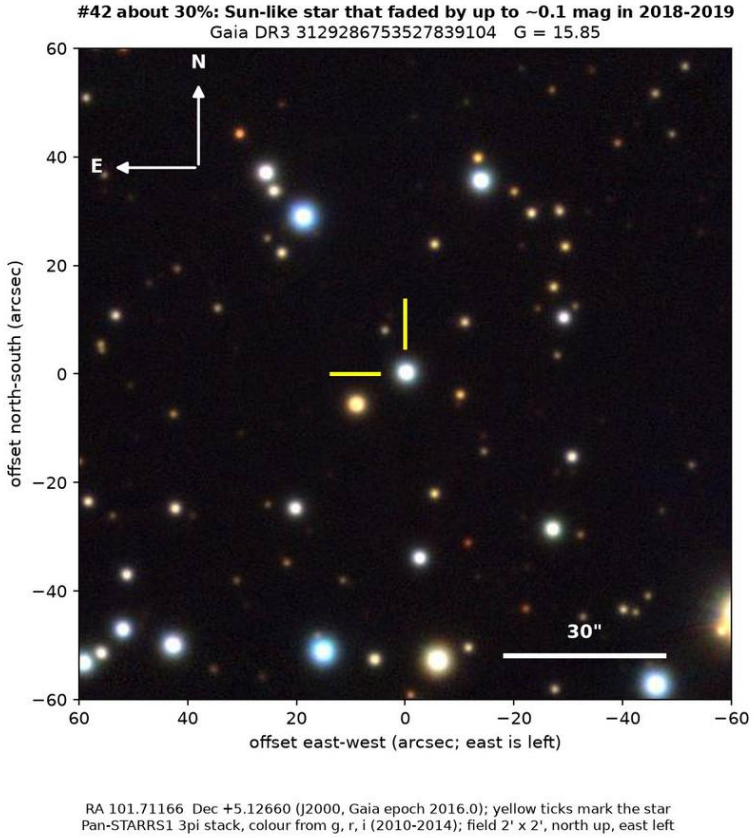



**Figure 130:** Candidate 42, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks. The orange star 11 arcseconds to the south-east is a redder, much more distant neighbour, separate in ZTF's images but blended with the star in ASAS-SN's. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

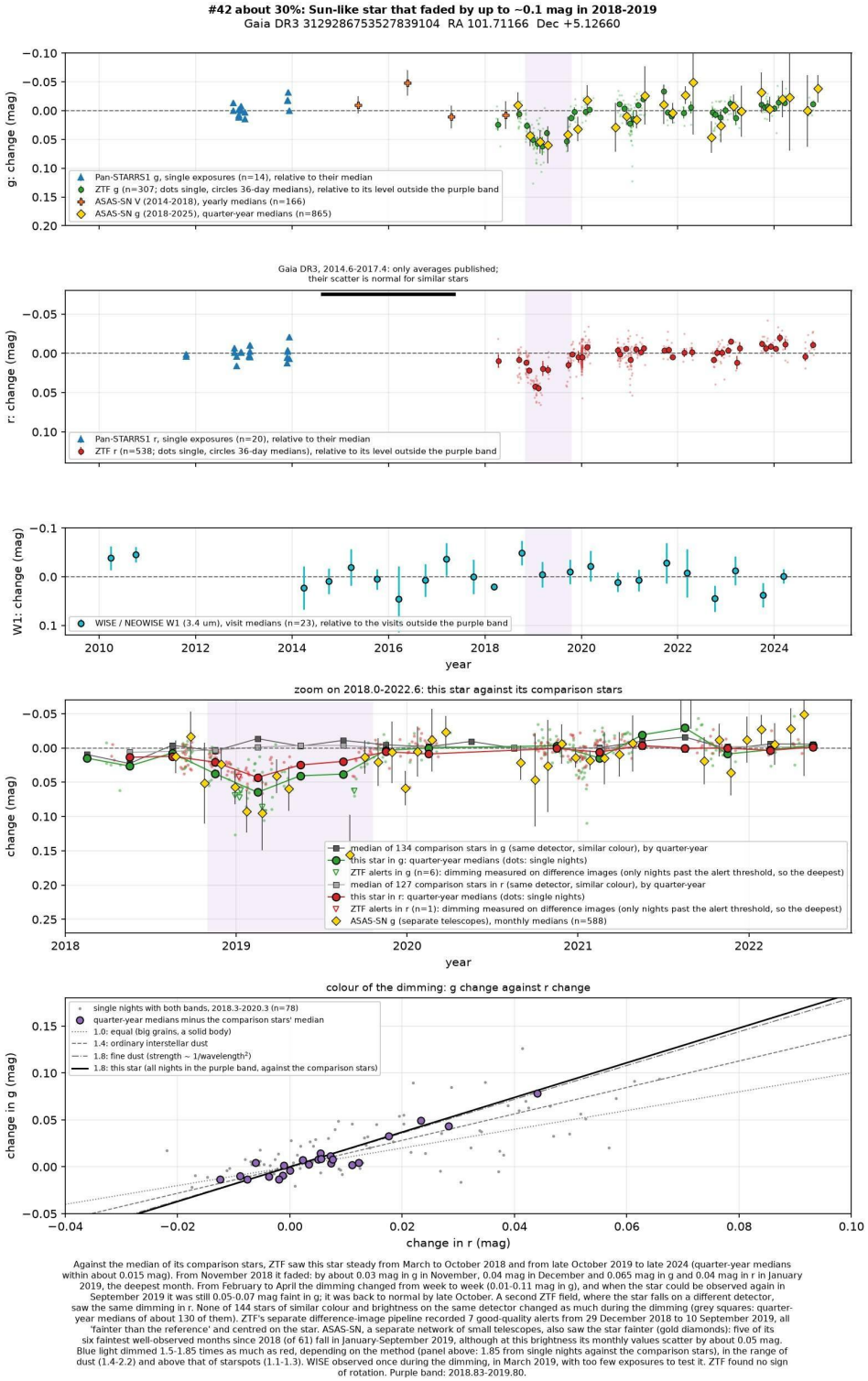



**Figure 131:** Candidate 42, light curve. Brightness from 2010 to 2025. Top three rows: green, red and infrared light against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, ASAS-SN (gold diamonds) and WISE and NEOWISE (NASA's infrared space telescope). Gaia (the European Space Agency's star-mapping satellite) published only averages. Purple marks the dimming. Middle: 2018 to mid-2022, with the comparison stars (grey squares), ZTF's alerts (triangles) and ASAS-SN's monthly values. Bottom: the colour of the dimming, against lines for grey dimming, ordinary dust and fine dust. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

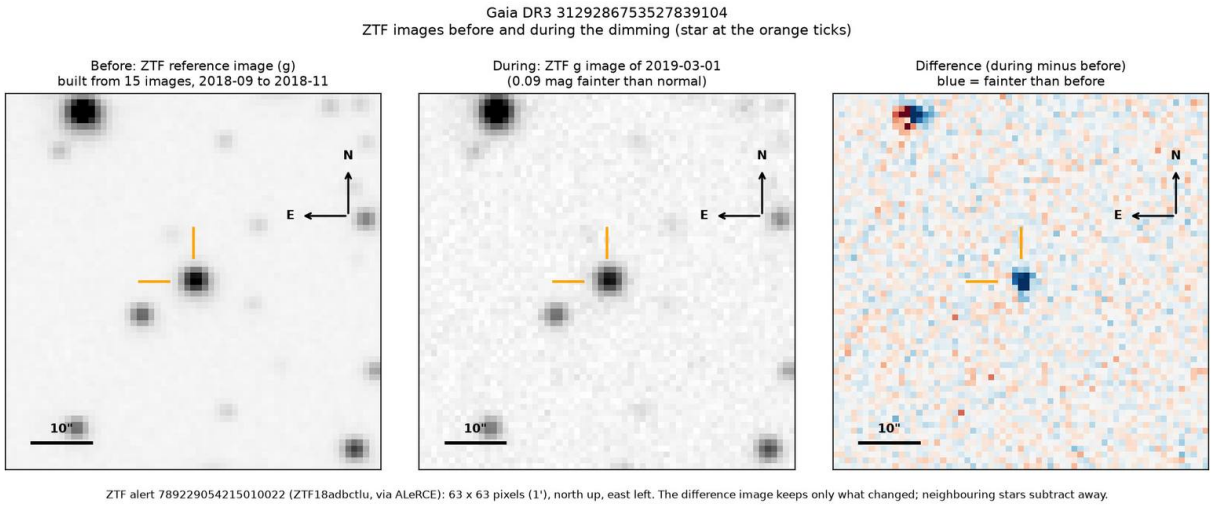



**Figure 132:** Candidate 42, before and during. Cutouts from a ZTF alert, one arcminute across, turned north up and east left. Left: the reference image in green light, from September to November 2018, before most of the dimming. Middle: 1 March 2019, when the star was 0.09 magnitudes fainter than normal. Right: their difference, in which blue means fainter; the star, at the orange ticks, leaves a dark blue spot while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 43: An old Sun-like star that faded for a year in 2021 and 2022

| | |
|---|---|
| **Star** | Gaia DR3 1861194257781817600, an old Sun-like star |
| **Position** | RA 305.03506°, Dec +29.27932° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Vulpecula, 4.0 degrees south of the Milky Way's mid-plane |
| **Galactic** | $l = 68.86°$, $b = -4.01°$ |
| **Distance** | about 1,000 parsecs (3,300 light-years) |
| **Brightness** | Gaia $G = 15.05$; far too faint for the eye or a small telescope |
| **Event** | from the end of Mar 2021, up to about 10 per cent in g; normal by 2022 Apr 1 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is an old Sun-like star in Vulpecula, about 1,000 parsecs (3,300 light-years) away; Gaia's models make it slightly hotter than the Sun, 40 per cent larger and some 8 billion years old. ZTF found it steady from 2018 until March 2021, apart from a slight fade of about 0.02 magnitudes in late 2020. It began to fade at the end of March 2021, and by August it had lost about 10 per cent of its green light and 6 per cent of its red. A short, deeper dip in mid-October took it 0.15 to 0.23 magnitudes below normal in both ZTF and ASAS-SN. It stayed 6 to 8 per cent faint until at least early March 2022 and recovered by 1 April, probably within a few days.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed about 1.7 times as much as red, between ordinary interstellar dust (1.4) and fine dust (1.8 to 2.2); starspots on a star like this would give 1.2 to 1.3. Old stars like this one spin slowly and are magnetically quiet, and their spots change their brightness by fractions of a per cent; this star's hydrogen-alpha line shows no activity, and neither ZTF, in eight seasons, nor TESS, during the dimming, saw any rotation. WISE saw no change at 3.4 microns during the dimming, which disfavours an opaque body but cannot exclude spots. The star's age, motion and lack of infrared excess rule out a young star with a dusty disc, and ASAS-SN makes an instrumental fault unlikely. The sharp end of the dimming suggests a dusty structure at least about 25 million km long, perhaps a disc around an unseen companion, as in epsilon Aurigae. A spectrum would settle what kind of star it is.

**Checks against the record.** No record of the dimming could be found: SIMBAD has no entry for the star, Gaia DR3 lists no variability, and VSX (the variable-star index) and the other variable-star catalogues checked do not include it. It is not among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications.

**Why this estimate.** The dimming is certainly real: two independent surveys recorded it, ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) and ASAS-SN (a worldwide network of small telescopes). Its colour, the star's age and quietness, and the lack of any rotation, even in NASA's TESS space telescope during the dimming, argue against starspots. The estimate is not higher because the dimming is shallow, so its colour is uncertain; because infrared measurements cannot tell dust from starspots; because only one ZTF field covers the star; because there is no spectrum; and because candidate 27 , 34 degrees away, faded and recovered on almost the same dates.

**Caveats.** There is no spectrum, so the star's type and age rest on Gaia's models, and the colour comes from ZTF alone. The dimming coincides with those of candidate 27 and of candidate 26 , 27 degrees away, but the three stars are 870 to 2,400 parsecs away and both surveys saw each of them dim, so neither a single cloud nor the surveys can explain it; the coincidence is most likely chance, but unexplained.

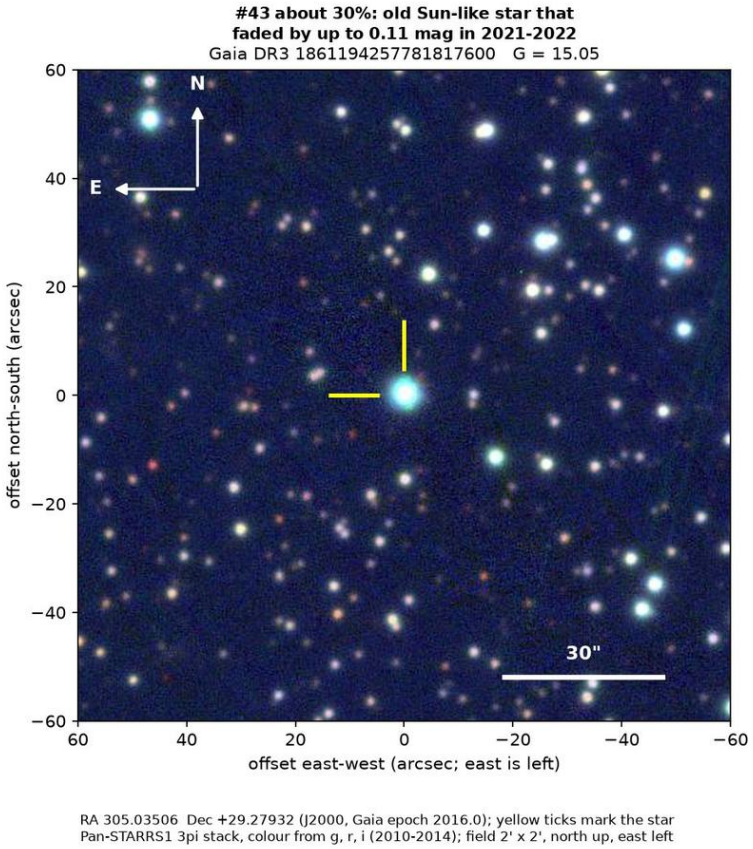



**Figure 133:** Candidate 43, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; Gaia lists no other star within 12 arcseconds, and its two brightest neighbours within 25 arcseconds are 20 and 22 arcseconds away. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

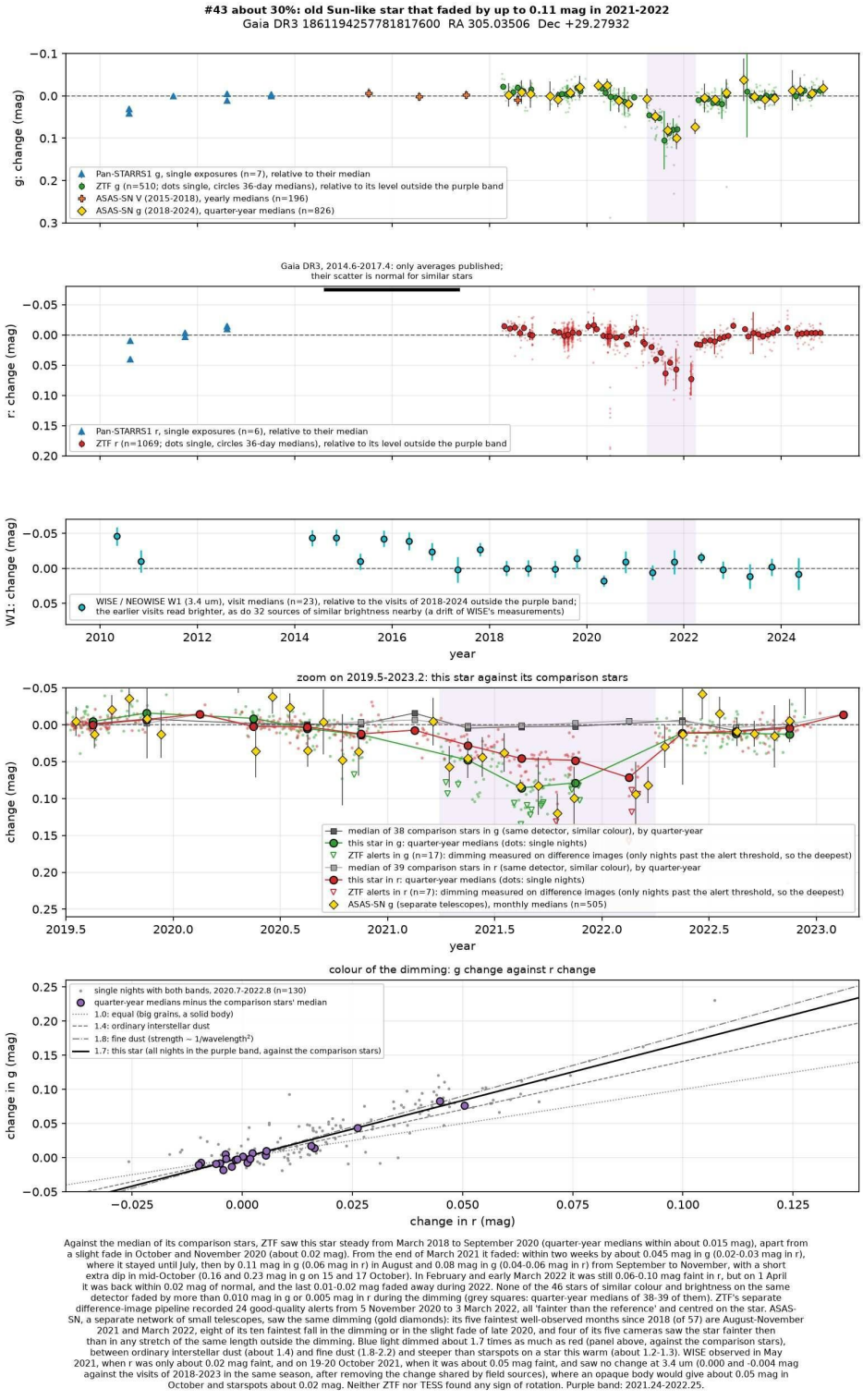



**Figure 134:** Candidate 43, light curve. Brightness from 2010 to 2025. Top three rows: green, red and infrared light against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, ASAS-SN (gold diamonds) and WISE and NEOWISE (NASA's infrared space telescope). Gaia (the European Space Agency's star-mapping satellite) published only averages. Purple marks the dimming. Middle: mid-2019 to early 2023, with the comparison stars (grey squares), ZTF's alerts (triangles) and ASAS-SN's monthly values. Bottom: the colour of the dimming, against lines for grey dimming, ordinary dust and fine dust. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

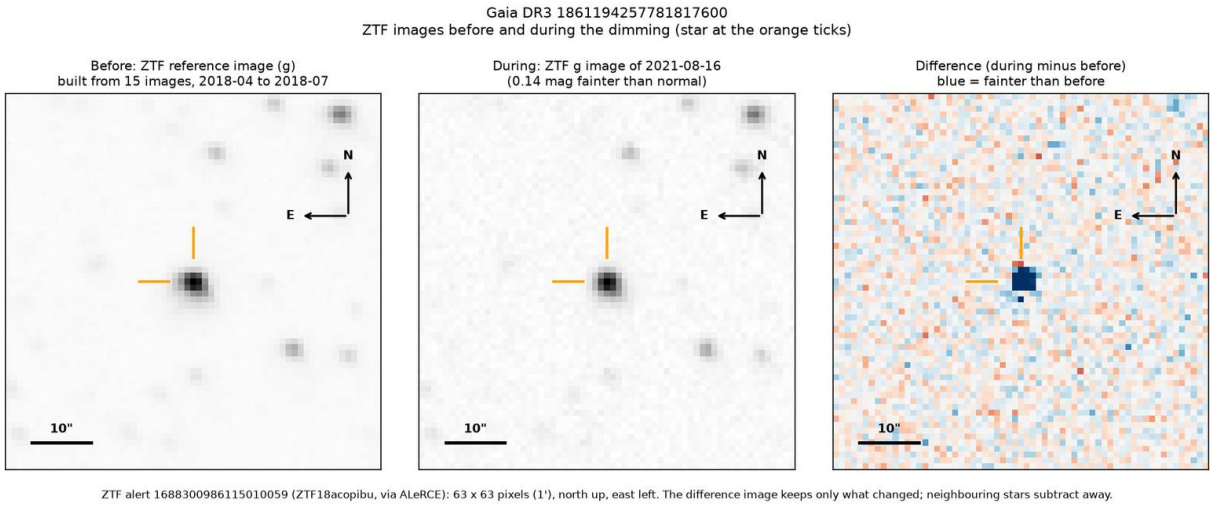



**Figure 135:** Candidate 43, before and during. Cutouts from a ZTF alert, one arcminute across, turned north up and east left. Left: the reference image in green light, from April to July 2018. Middle: 16 August 2021, when the star was 0.14 magnitudes fainter than normal. Right: their difference, in which blue means fainter; the star, at the orange ticks, leaves a dark blue spot while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

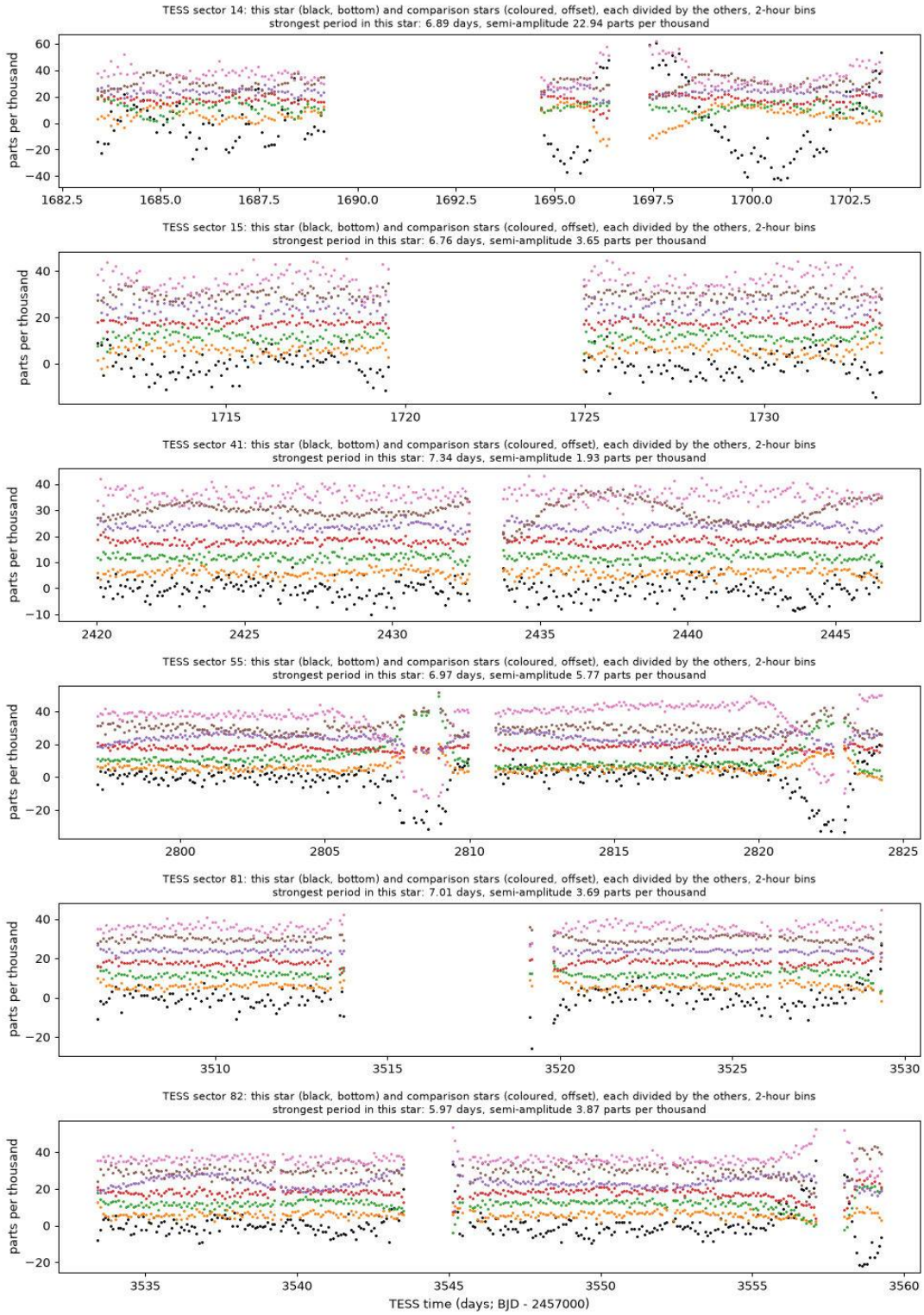



**Figure 136:** Candidate 43, TESS light curves. TESS, one panel per observing period of about 25 days: two in 2019, one in July and August 2021, during the dimming, one in 2022 and two in 2024. Each shows this star (black, bottom) and five comparison stars (coloured, offset), each divided by the others, in two-hour bins. The 2021 panel is flat; the dips in the first panel come from scattered light, since ZTF saw the star normal then. Data: TESS (NASA; MAST).

## Candidate 44: A distant A- or F-type star that dimmed three times in two years

| | |
|---|---|
| **Star** | Gaia DR3 524272505912906240, a distant A- or F-type star |
| **Position** | RA 14.48339°, Dec +64.63949° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cassiopeia, 1.8 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 123.63°, $b$ = +1.78° |
| **Distance** | about 2,500 to 3,400 parsecs (8,000 to 11,000 light-years) |
| **Brightness** | Gaia $G$ = 17.47; far too faint for the eye or a small telescope |
| **Event** | three dimmings 2021–2023; 0.49–0.55 mag in r on 2021 May 31; steady since 2023 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star, in Cassiopeia, lies about 2,500 to 3,400 parsecs (8,000 to 11,000 light-years) away, almost exactly in the plane of the Milky Way, behind a thick screen of dust. It is hotter and more massive than the Sun: an A-type star of about 8,500 K in Gaia's models, an F-type star of about 6,000 K in the StarHorse catalogue. It was steady from 2010 to late 2020.

When ZTF could observe it again after its yearly gap, in late May 2021, the star had lost about a fifth of its red light, and on 31 May, within a day, nearly two fifths. It stayed faint for the rest of 2021, slowly recovering, and was almost normal in late May 2022. It dimmed again from June to November 2022, by up to 0.24 magnitudes in red light and 0.37 in green, and a third time in late January and February 2023, by up to 0.19 magnitudes in red and 0.34 in green. Since late May 2023 it has been steady.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed 1.82 times as much as red, more than the 1.40 of ordinary interstellar dust, as expected for small grains. An opaque body would dim all colours equally, yet in August 2021 and 2022, while the star was faint, WISE (NASA's infrared space telescope) found it within 0.03 magnitudes of normal at 3.4 microns. Stars this hot rarely have large spots, an eclipse by another star lasts hours or days, not months, and three detectors leave no room for an instrumental fault. Young A-type stars dimmed by their own dusty discs, the main alternative, glow in the near-infrared and most show hydrogen emission; this one shows neither. The dust might come from a collision between planets or asteroids, or from a disc around an unseen companion, as in epsilon Aurigae. A spectrum would settle the star's type, age and distance.

**Checks against the record.** No record of the dimmings could be found: the star has no SIMBAD entry and no Gaia DR3 variability entry, VSX (the variable-star index) and the other variable-star, young-star and cluster catalogues checked do not include it, and it is not among the dimming stars of Tzanidakis et al. (2025). There is no Transient Name Server entry, Gaia alert or paper giving its Gaia number, and ZTF's alert system holds only machine-generated classifications.

**Why this estimate.** The dimmings are certain: ZTF (the Zwicky Transient Facility, a survey telescope at Palomar Observatory in California) recorded them on three different detectors while similar stars stayed steady, and their colour and the nearly unchanged infrared light fit dust. The estimate is not higher because young A-type stars, common in this part of the Milky Way, dim in just this way behind their own dusty discs; this star shows no sign of a disc close to it, but cooler dust farther out cannot be tested. Only ZTF recorded the dimmings, the starts of the two longer ones went unobserved, the star's type is uncertain, and there is no spectrum.

**Caveats.** There is no spectrum, so the star's type and distance are uncertain. Only ZTF recorded the dimmings: the star is too faint for ASAS-SN (a worldwide network of small telescopes), and NASA's TESS space telescope blends it with its neighbours. The deepest point recorded may not be the deepest reached, and a machine classifier calls the light curve a young star's.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

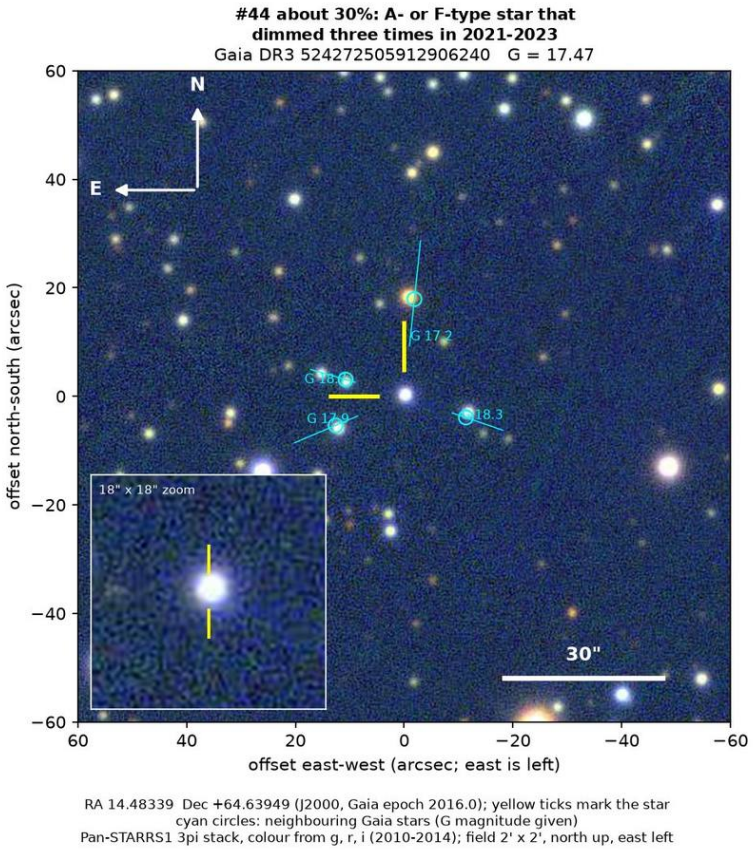
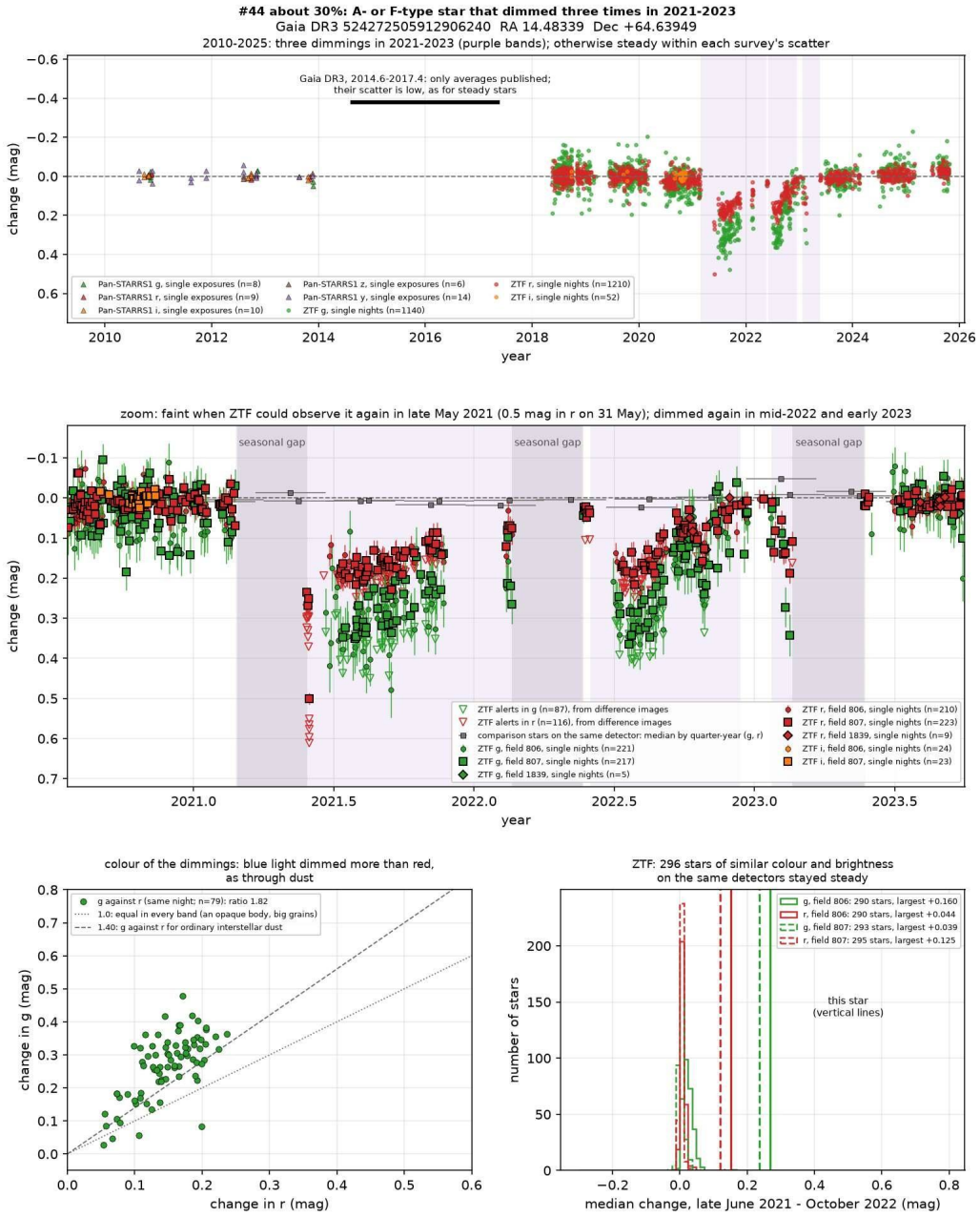



**Figure 137:** Candidate 44, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; cyan circles mark four neighbours 11 to 18 arcseconds away, among them a very red star to the north, which ZTF's images separate from the star. The inset enlarges the centre. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside 2021-2023), the star was steady in Pan-STARRS1 images of 2010-2014 and in ZTF from May 2018 to late 2020 (single measurements scatter by about 0.025 mag in r and 0.05 mag in g); from December 2020 to February 2021 it may have been very slightly faint (0.01-0.03 mag in r, 0.02-0.08 mag in g, depending on the field). When ZTF could observe it again after its seasonal gap (grey bands: the star then stands too low in the night sky for ZTF), on 28-30 May 2021, it was 0.22-0.29 mag faint in r, and on 31 May 0.49-0.55 mag in all five exposures. It stayed 0.09-0.23 mag faint in r (0.08-0.48 mag in g) for the rest of 2021 and was 0.03-0.15 mag faint in r in February 2022. In late May 2022 it was close to normal (0.02-0.05 mag faint in r), but by early July it had dimmed again, to 0.10-0.24 mag in r (0.18-0.37 mag in g) in July and August, and it recovered by mid-December. A third, shorter dimming followed in late January and February 2023 (up to 0.19 mag in r and 0.34 mag in g); from late May 2023 to October 2025 the star was steady again. The dimmings appear on three overlapping ZTF fields (circles: field 806; squares: field 807; diamonds: field 1839). Of the 296 stars of similar colour and brightness on the same detectors (bottom right), none dimmed as much as this star from late June 2021 to October 2022 in g, or in r on field 806; in r on field 807 one changed by 0.125 mag, as much as this star there (0.12 mag). The comparison stars' quarter-year medians stayed within 0.05 mag in g and 0.02 mag in r (grey squares). ZTF's separate difference-image pipeline recorded 203 good-quality alerts from 28 May 2021 to 19 February 2023, all 'fainter than the reference' and centred on the star (median offset 0.22"). Blue light dimmed 1.82 times as much as red on the same nights (68 % range 1.76-1.87): more steeply than through ordinary interstellar dust (1.40), as through dust of smaller grains, and unlike an opaque body (1.0). Purple bands: the three dimmings, as far as ZTF's observations bracket them.

**Figure 138:** Candidate 44, light curve. Brightness from 2010 to 2025, each survey against its own normal level. Top: Pan-STARRS1 (a survey telescope in Hawaii) and ZTF; Gaia (the European Space Agency's star-mapping satellite) published only averages. Purple marks the three dimmings. Middle: mid-2020 to late 2023, with circles, squares and diamonds for the three ZTF fields, triangles for ZTF's alerts and grey squares for the comparison stars; grey bands mark when the star is too low in the sky. Bottom: the colour of the dimmings and the changes of the comparison stars. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

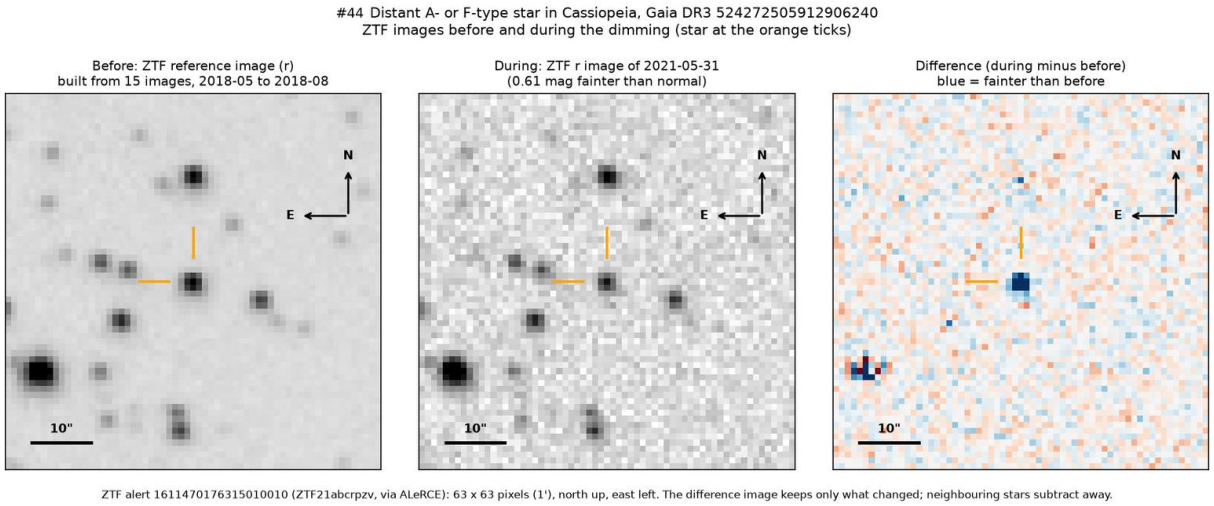



**Figure 139:** Candidate 44, before and during. Cutouts from one of ZTF's 203 alerts for the star, all centred on it, one arcminute across, north up and east left. Left: the reference image in red light, from May to August 2018. Middle: 31 May 2021, when the star was 0.61 magnitudes fainter than normal by the difference image's measure. Right: their difference, in which blue means fainter; the star, at the orange ticks, leaves a dark blue spot while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 45: A nearby orange dwarf that dimmed for most of 2021

| | |
|---|---|
| **Star** | Gaia DR3 4158876141940382976, an orange dwarf of spectral type K4 to K5 |
| **Position** | RA 271.98114°, Dec −8.34530° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Serpens (Serpens Cauda), 5.7 degrees north of the Milky Way's mid-plane |
| **Galactic** | $l$ = 20.49°, $b$ = +5.74° |
| **Distance** | about 330 parsecs (1,080 light-years) |
| **Brightness** | Gaia $G$ = 16.31; far too faint for the eye or a small telescope |
| **Event** | 14 per cent in r and 29 per cent in g in late Mar 2021; about a tenth until Sep; nearly normal by Nov 2021 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is an orange dwarf, smaller and cooler than the Sun, about 330 parsecs (1,080 light-years) away, seen through the dark dust clouds of the Aquila Rift. It was steady from 2010 until 11 November 2020, just before the Sun's glare hid it for the winter. When ZTF saw it again, in February 2021, it was slightly faint, and by late March it had lost about 14 per cent of its red light and up to 29 per cent of its green light. It stayed about a tenth fainter in red light until September and was nearly normal by November 2021, apart from a faint tail of about 3 per cent through 2022. ZTF's alert system, which compares each new image with a reference image, flagged it 45 times, and SkyMapper saw it faint on 21 August 2021.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed 1.53 times as much as red: ordinary interstellar dust gives about 1.40, starspots on a star this cool about 1.1 to 1.2, and an opaque body would dim all colours equally. The infrared light, measured twice by NEOWISE during the dimming, did not change, which rules out an opaque body and argues against spots. An eclipse by another star lasts hours or days, not months, and the comparison stars and SkyMapper make an instrumental fault unlikely.

The main alternative is a young star dimmed by dust of its own: the star lies in front of the star-forming clouds of Serpens and Aquila, and Gaia's spectra hint at weak hydrogen emission. But it moves 9 to 22 km/s differently from the young stars catalogued there, shows no warm dust and sits on the main sequence of ordinary stars, suggesting an age above about 50 million years. A spectrum would settle its type and age.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, Gaia lists no variability, and VSX, the variable-star index, has nothing within 30 arcseconds. It is in none of the variable-star, young-star or cluster catalogues consulted, and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is almost certainly real: the ZTF survey telescope at Palomar Observatory in California recorded it while 70 stars of similar colour and brightness on the same detector stayed steady, and SkyMapper, a telescope in Australia, caught the star faint too. Its colour fits dust. But only one ZTF detector covered the star, SkyMapper saw it on a single night, the start was hidden, the star shows weak hints of youth, and there is no spectrum.

**Caveats.** There is no spectrum, and SkyMapper's confirmation rests on a single night. The hints of youth leave room for a moderately young star with dust of its own. A star on another detector of the same ZTF field, candidate 41 , dimmed over nearly the same months; no single cloud could have dimmed both, so this is most likely chance, but a reason for caution.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

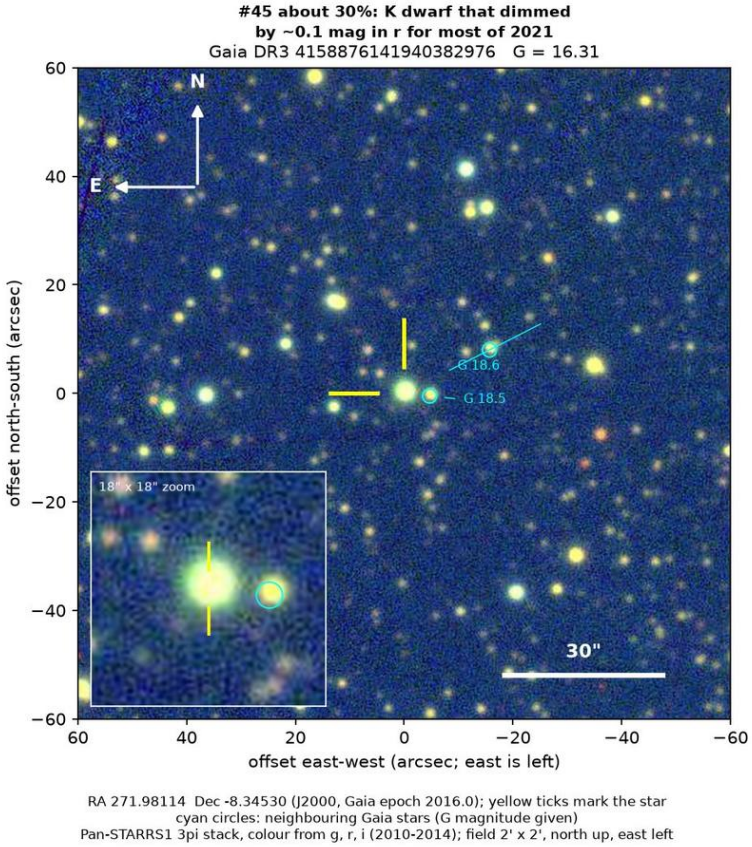
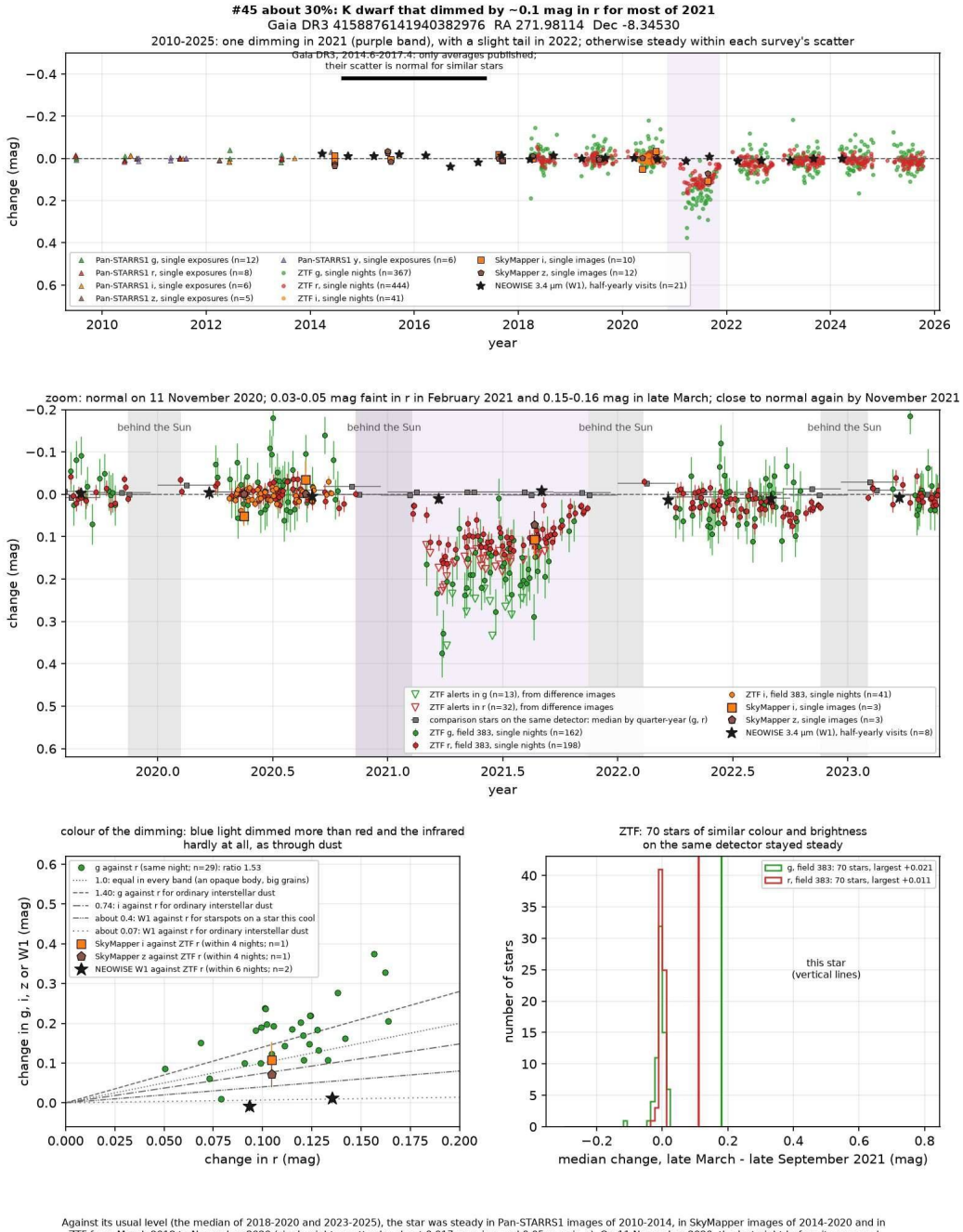



**Figure 140:** Candidate 45, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks. Cyan circles mark a distant background star (G = 18.5) 4.7 arcseconds to the west and a star of G = 18.6 about 18 arcseconds to the west-north-west, and the inset enlarges the centre. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of 2018-2020 and 2023-2025), the star was steady in Pan-STARRS1 images of 2010-2014, in SkyMapper images of 2014-2020 and in ZTF from March 2018 to November 2020 (single nights scatter by about 0.017 mag in r and 0.05 mag in g). On 11 November 2020, the last night before its seasonal gap (grey bands: the star is then too close to the Sun in the sky), it was normal; on 9-11 February 2021, when ZTF could observe it again, it was 0.03-0.05 mag faint in r, and by mid-March 0.11 mag. It was deepest in late March and early April (0.15-0.16 mag in r on 27 March - 4 April; 0.37 mag in g on 27 March), stayed 0.10-0.12 mag faint in r (monthly medians; 0.14-0.19 mag in g) from May to August and recovered from mid-September: 0.05 mag faint in r in October and 0.03 mag in November 2021. Through 2022 it stayed very slightly faint (about 0.03 mag in r and g); from 2023 to October 2025 it was steady again. One ZTF field covers the star (field 383, on one detector). None of the 70 stars of similar colour and brightness on the same detector changed by more than 0.021 mag from late March to late September 2021, when this star was 0.11 mag faint in r and 0.18 mag in g (bottom right), and the comparison stars' quarter-year medians stayed within 0.03 mag (grey squares). ZTF's separate difference-image pipeline recorded 45 good-quality alerts from 3 March to 7 September 2021, all 'fainter than the reference' and centred on the star (median offset 0.32"). SkyMapper, a separate telescope in Australia, imaged the star on 21 August 2021: against stars of similar brightness on the same images it was 0.11 +/- 0.045 mag faint in i and 0.07 +/- 0.033 mag in z, while ZTF had it 0.10 mag faint in r. Blue light dimmed 1.53 times as much as red on the same nights (68 % range 1.44-1.63), as through ordinary interstellar dust (1.40). At 3.4 micrometres (NEOWISE W1) the star stayed within 0.011 mag of normal in late March and early September 2021, when ZTF had it 0.13 and 0.09 mag faint in r: dust would give about 0.01 mag there, starspots about 0.04-0.05 mag and an opaque body 0.09-0.13 mag. Purple band: 11 November 2020 - 14 November 2021, as far as ZTF's observations bracket the main dimming.

**Figure 141:** Candidate 45, light curve. Top: brightness from 2010 to 2025 in Pan-STARRS1 (a survey telescope in Hawaii), SkyMapper, ZTF and NEOWISE (NASA's infrared space telescope; black stars), each against its own normal level; Gaia, the European Space Agency's star-mapping satellite, publishes only averages, so only its years are marked. Purple marks the dimming. Middle: mid-2019 to mid-2023, adding ZTF's alerts (open triangles) and the comparison stars' median (grey squares); grey bands mark when the star is too near the Sun. Bottom left: the change in other colours against that in red, with lines for an opaque body, ordinary dust and starspots. Bottom right: the changes of the 70 comparison stars, and this star's (vertical lines). Down means fainter. Data: Pan-STARRS1 (STScI/MAST); SkyMapper (ANU); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

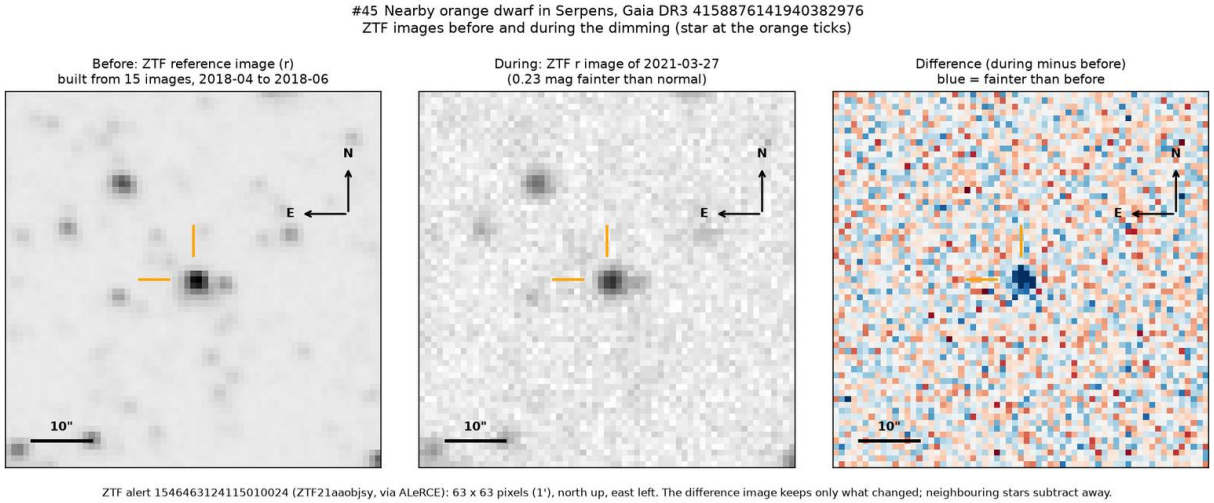



**Figure 142:** Candidate 45, before and during. Cutouts from one ZTF alert, one arcminute across, north up and east left; orange ticks mark the star. Left: the reference image in red light, made in 2018. Middle: the image of 27 March 2021, during the dimming, with the star 0.23 magnitudes fainter than in the reference image. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot. Data: ZTF (Caltech/IPAC).

## Candidate 46: A Sun-like star that dimmed for five months in 2023

| | |
|---|---|
| **Star** | Gaia DR3 4209854719371553152, a Sun-like star of spectral type about F8 to G0 |
| **Position** | RA 294.11852°, Dec −5.17622° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Aquila, 12.4 degrees south of the Milky Way's mid-plane |
| **Galactic** | $l = 33.42°$, $b = -12.37°$ |
| **Distance** | about 2,600 to 2,900 parsecs (8,400 to 9,400 light-years) |
| **Brightness** | Gaia $G = 17.55$; far too faint for the eye or a small telescope |
| **Event** | two steps over five weeks from 2023 Jun 19; 44 per cent in g on Jul 26; normal by 2023 Nov 20 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is Sun-like, probably a little hotter and larger than the Sun, about 2,600 to 2,900 parsecs (8,400 to 9,400 light-years) away and about 600 parsecs below the Milky Way's mid-plane. ZTF saw it steady from 2018 until 19 June 2023. It then faded in two steps over five weeks, and on 26 July it had lost 44 per cent of its green light; two nights earlier it had lost 29 per cent of its red light. Within five days it recovered most of the way, then slowly returned to normal by 20 November, and it has been steady since February 2024. ZTF's alert system, which compares each new image with a reference image, flagged it 26 times from July to September 2023.

**Why it might matter.** Fine dust passing in front of the star is the likeliest cause. Green light dimmed 1.67 times as much as red: ordinary interstellar dust gives about 1.40, starspots on a Sun-like star about 1.1 to 1.2, and an opaque body would dim all colours equally. Only grains smaller than average give so steep a colour. Spots on Sun-like stars that are no longer young rarely dim them by more than a few hundredths of a magnitude, an eclipse by another star lasts hours or days, not months, and the second detector argues against an instrumental fault.

The star shows no sign of youth: it lies far outside the thin layer of the Milky Way where young stars are found, has no warm dust, shows hydrogen in absorption in Gaia's spectra and moves about 50 km/s differently from the stars around it, as old stars often do. Such fine grains are blown out of a planetary system within about an orbit, so dust orbiting the star would have to be fresh, as from a recent collision. A spectrum would settle the star's type and distance.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, Gaia lists no variability, and VSX, the variable-star index, has nothing within 30 arcseconds. It is in no variable-star catalogue consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is almost certainly real: the ZTF survey telescope at Palomar Observatory in California recorded it in two colours and on two detectors, while 409 stars of similar colour and brightness on the main detector stayed steady in green light. Its start, deepest part and recovery were all observed, and the star shows no sign of youth. But only ZTF recorded it, one comparison star changed in red light, the star's type and distance are uncertain, and there is no spectrum.

**Caveats.** There is no spectrum, and no infrared measurement was made during the deep part of the dimming. Nearly all the measurements come from one ZTF detector, where one comparison star changed by 0.12 magnitudes in red light alone, so the red changes and the colour are less certain than the green. The parallax is measured to only about 28 per cent, and Gaia's own model of the star disagrees with it.

**Figure note.** The title line of the ZTF image figure carried an earlier display number on the public page; it has been corrected here.

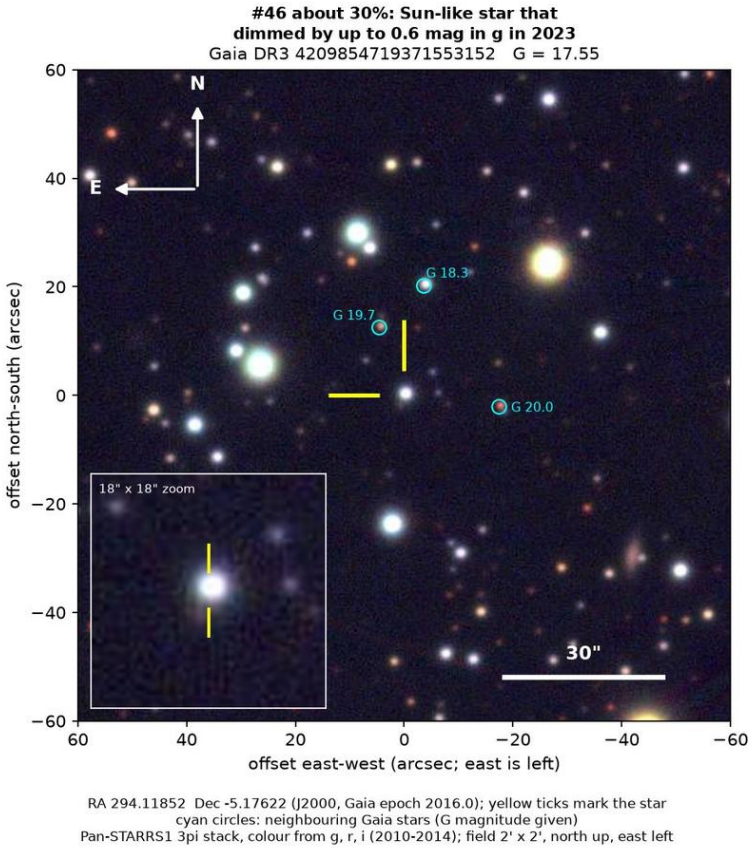
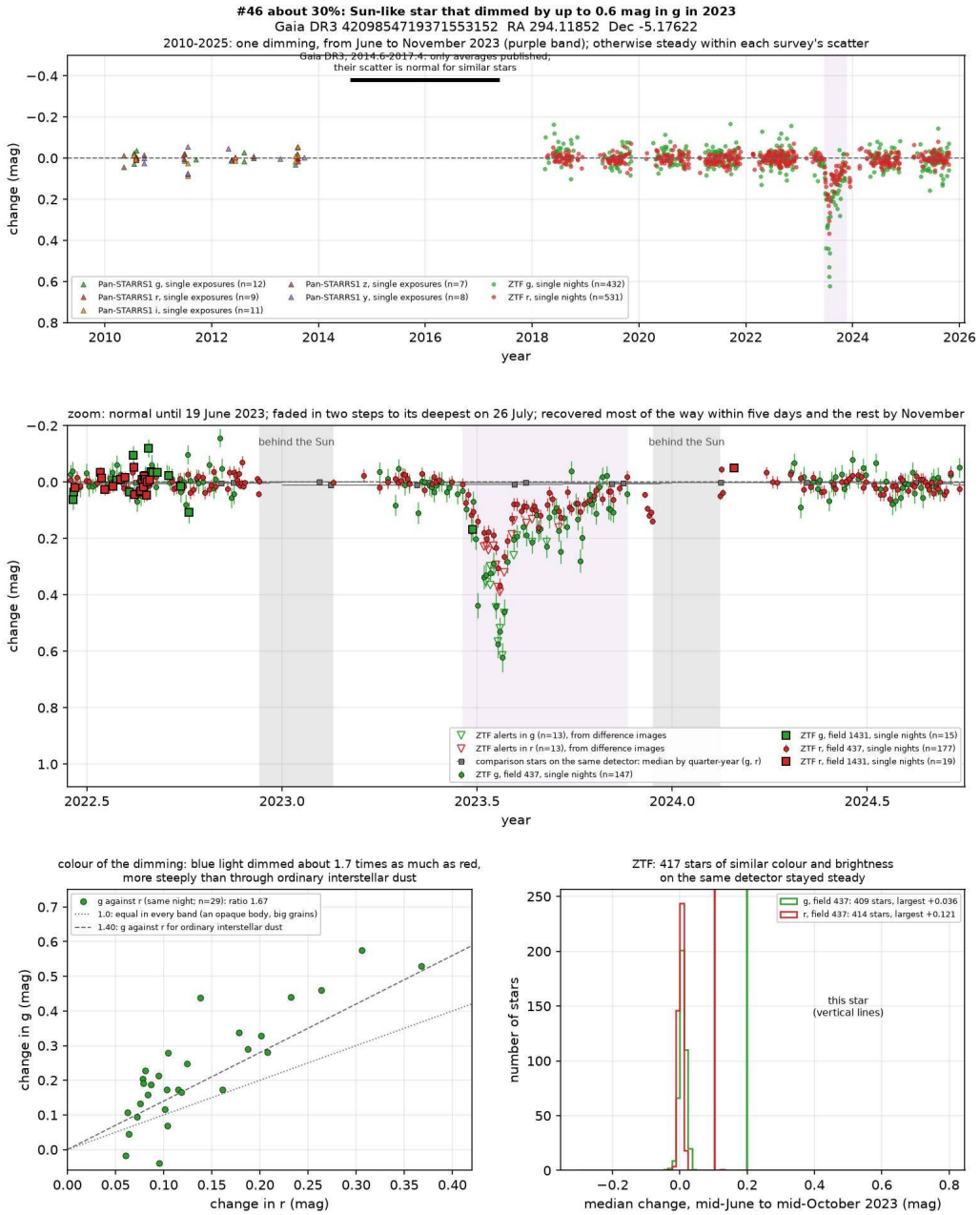



**Figure 143:** Candidate 46, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks. Cyan circles mark its three nearest neighbours in Gaia, 13 to 21 arcseconds away (G = 18.3 to 20.0); the inset enlarges the centre, with much fainter stars 6 to 10 arcseconds away. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside late May 2023 - early February 2024), the star was steady in Pan-STARRS1 images of 2010-2014 and in ZTF from March 2018 to 19 June 2023 (single nights scatter by about 0.04 mag in g and 0.02 mag in r; grey bands: the star is then too close to the Sun in the sky for ZTF). It then faded in two steps: to 0.29-0.44 mag in g and 0.14-0.23 mag in r from 3 to 20 July, and to its deepest on 22-26 July (0.53-0.62 mag in g, 0.31-0.37 mag in r). Within five days it recovered most of the way (0.28 mag in g on 31 July); it stayed 0.07-0.18 mag faint in g and 0.06-0.10 mag in r (monthly medians, August to October) and was close to normal on 20 November. On five nights in December, low in the evening sky, it was 0.04-0.14 mag faint in r, more than on such nights in other years, so a faint tail may have lasted into December; from February 2024 to October 2025 it was steady (three nights in g around the full moon of 7 September 2025 came out 0.10-0.13 mag faint while r stayed normal). Most measurements come from ZTF field 437 (circles); field 1431, where the star falls on a different detector (squares), observed it on one night of the dimming, 28 June 2023, and found it 0.17 mag faint in g, as field 437 did on 27 June. None of the 409 stars of similar colour and brightness on the same detector changed by more than 0.036 mag in g from mid-June to mid-October 2023, when this star was 0.20 mag faint in g (bottom right); in r, one of 414 changed by more than this star's 0.10 mag, but in r alone, and the comparison stars' quarter-year medians stayed within 0.02 mag in g and 0.01 mag in r (grey squares). ZTF's separate difference-image pipeline recorded 26 good-quality alerts from 9 July to 17 September 2023, all 'fainter than the reference' and centred on the star (median offset 0.12"). Blue light dimmed 1.67 times as much as red on the same nights (68 % range 1.56-1.78), more steeply than through ordinary interstellar dust (1.40) and unlike an opaque body (1.0), as through dust of grains smaller than ordinary. Purple band: 19 June - 20 November 2023, as far as ZTF's observations bracket the dimming.

**Figure 144:** Candidate 46, light curve. Top: brightness from 2010 to 2025 in Pan-STARRS1 (a survey telescope in Hawaii) and ZTF, each against its own normal level; Gaia, the European Space Agency's star-mapping satellite, publishes only averages, so only its years are marked. Purple marks the dimming. Middle: mid-2022 to late 2024, with circles for the main ZTF field and squares for the second, ZTF's alerts (open triangles) and the comparison stars' median (grey squares); grey bands mark when the star is too near the Sun. Bottom left: the change in green against that in red, with lines for an opaque body and ordinary dust. Bottom right: the changes of the comparison stars, and this star's (vertical lines). Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

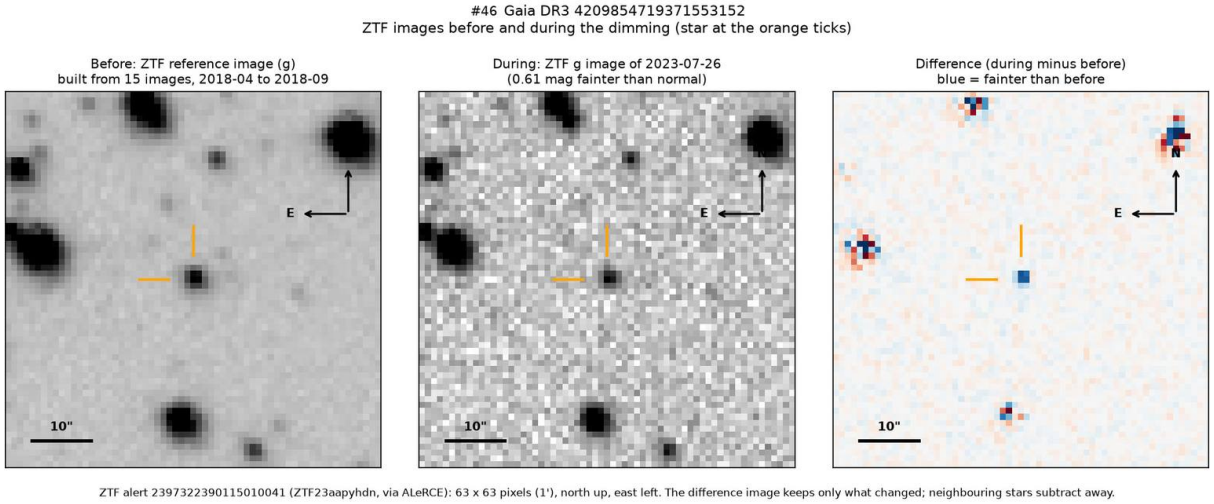



**Figure 145:** Candidate 46, before and during. Cutouts from one ZTF alert, one arcminute across, north up and east left; orange ticks mark the star. Left: the reference image in green light, made in 2018. Middle: the image of 26 July 2023, during the dimming, with the star 0.61 magnitudes fainter than in the reference image. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, and bright stars only small paired marks, from slight differences in sharpness. Data: ZTF (Caltech/IPAC).

## Candidate 47: A Sun-like star that dimmed slowly for seven to ten months

| | |
|---|---|
| **Star** | Gaia DR3 2064351502266362624, a Sun-like star of spectral type about G2 to G3 |
| **Position** | RA 309.48111°, Dec +39.04921° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cygnus, 1.3 degrees south of the Milky Way's mid-plane |
| **Galactic** | $l = 78.95°$, $b = -1.29°$ |
| **Distance** | about 910 parsecs (3,000 light-years) |
| **Brightness** | Gaia $G = 16.04$; far too faint for the eye or a small telescope |
| **Event** | from late May 2022; about a sixth in g (a tenth in r) from Sep to Dec 2022; normal by 2023 Mar 29 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is very much like the Sun in temperature and luminosity, about 910 parsecs (3,000 light-years) away, close to the mid-plane of the Milky Way. ZTF saw it steady from 2018 to mid-May 2022. From late May it faded slowly, and by September it had lost about a sixth of its green light and a tenth of its red light. It stayed about that faint until 24 December 2022, the last night before it stood too low in the night sky for ZTF; on 29 March 2023, when ZTF could observe it again, it was back to normal. ZTF's alert system, which compares each new image with a reference image, flagged it 28 times, and ASAS-SN had it about 0.13 magnitudes faint on average from August to December 2022.

**Why it might matter.** Dust passing in front of the star is the likeliest cause. Green light dimmed 1.40 times as much as red, and near-infrared light 0.73 times as much, close to the 1.40 and 0.74 of ordinary interstellar dust; an opaque body would dim all colours equally, and starspots on a Sun-like star give only about 1.1 to 1.2 for green against red. NEOWISE found the infrared light unchanged in October 2022, as dust would leave it, though a red source 6 arcseconds away, blended with the star in its images, weakens that test. An eclipse by another star lasts hours or days, not months, and two ZTF detectors and ASAS-SN make an instrumental fault unlikely.

The main alternative is a young star with a dusty disc: the star lies towards Cygnus X, a rich star-forming region; three young clusters lie at its own distance 1.0 to 1.7 degrees away; and a machine classifier labels its light curve as a young star's. But it moves 26 to 53 km/s differently from every cluster within 2 degrees, sits on the main sequence and shows no warm dust and no hydrogen emission. A good spectrum would settle its type and age.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, Gaia lists no variability, and VSX, the variable-star index, has nothing within 30 arcseconds. It is in none of the variable-star, young-star or cluster catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is almost certainly real: the ZTF survey telescope at Palomar Observatory in California recorded it in three filters and on two detectors while 35 stars of similar colour and brightness on the main detector stayed steady, and ASAS-SN, a worldwide network of small telescopes, saw it too. Its colour is that of ordinary interstellar dust. But the dimming is shallow, its end was not observed, the star lies towards the young stars of Cygnus X, and there is no usable spectrum.

**Caveats.** There is no usable spectrum: one taken by the LAMOST survey in 2014 has too little signal. How quickly the star recovered is unknown, and Gaia's own model of the star puts it at 770 parsecs, which the parallax excludes. Four other stars, candidate 32 , candidate 33 , candidate 35 and candidate 44 , also dimmed during 2022, but on other ZTF fields 41 to 65 degrees away, so a shared instrumental cause is unlikely.

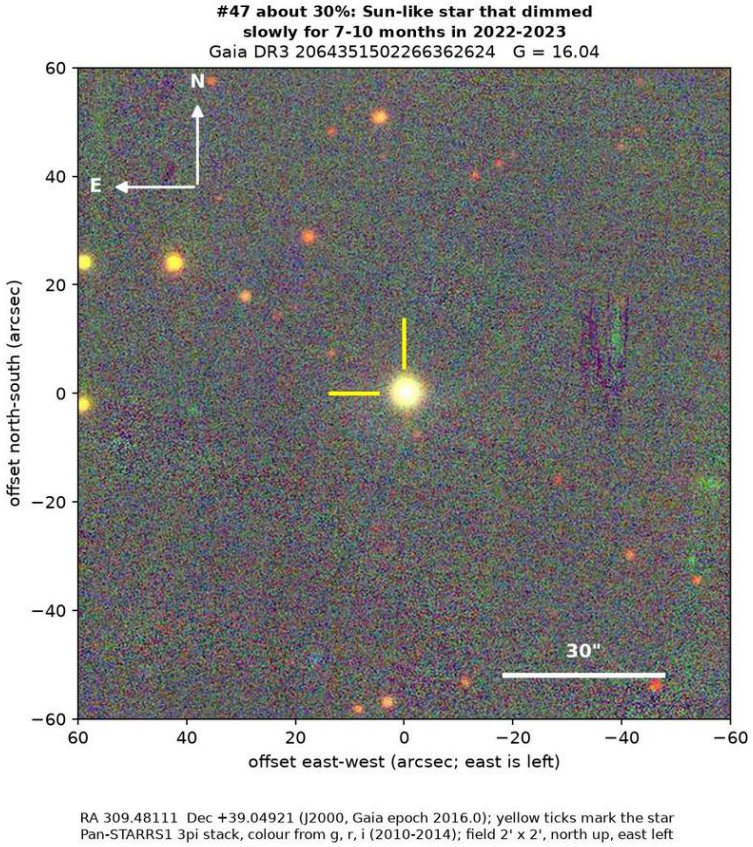



**Figure 146:** Candidate 47, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; Gaia lists no other star within 25 arcseconds of it. The faint red point about 7.5 arcseconds to the south-south-west is the outer of the red infrared sources just south of the star. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

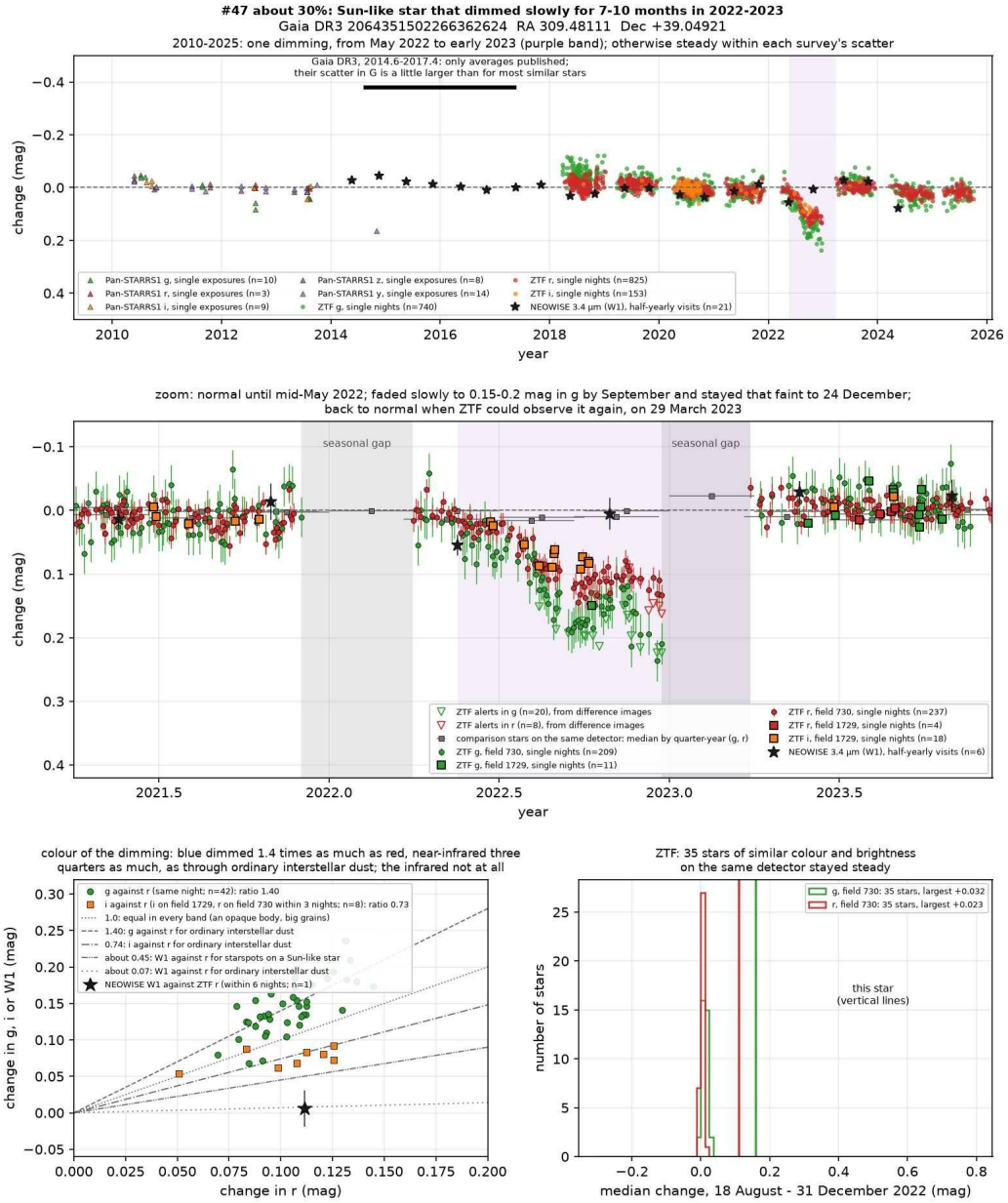



**Figure 147:** Candidate 47, light curve. Top: brightness from 2010 to 2025 in Pan-STARRS1 (a survey telescope in Hawaii), ZTF and NEOWISE (NASA's infrared space telescope; black stars), each against its own normal level; Gaia, the European Space Agency's star-mapping satellite, publishes only averages, so only its years are marked. Purple marks the dimming. Middle: April 2021 to December 2023, with circles for the main ZTF field and squares for the second, ZTF's alerts (open triangles) and the comparison stars' median (grey squares); grey bands mark when the star is too low in the night sky. Bottom left: the change in other colours against that in red, with lines for an opaque body, ordinary dust and starspots. Bottom right: the changes of the 35 comparison stars, and this star's (vertical lines). Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

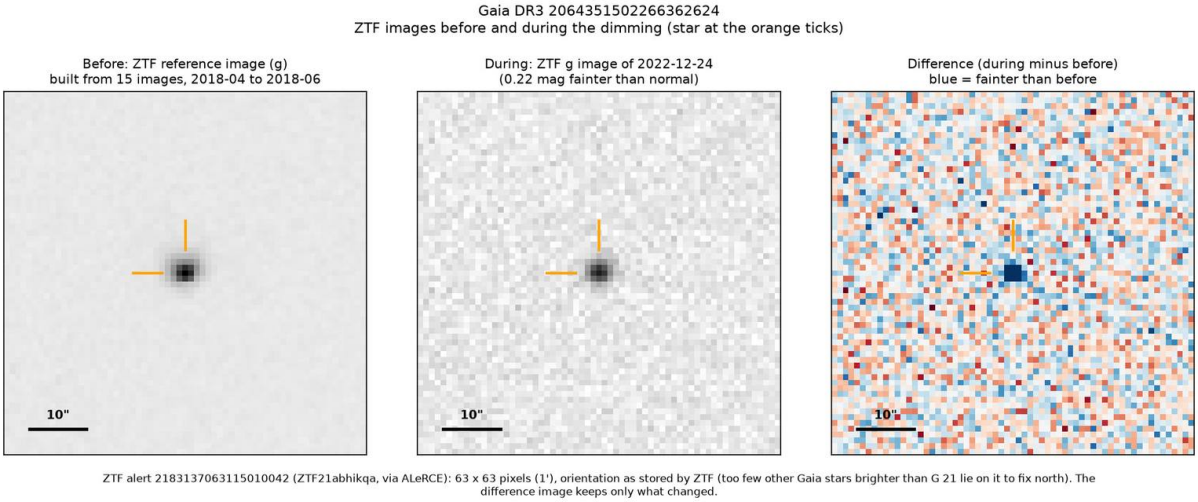



**Figure 148:** Candidate 47, before and during. Cutouts from one ZTF alert, one arcminute across, shown as ZTF stores them rather than north up, since too few other stars lie on them to fix the direction; orange ticks mark the star. Left: the reference image in green light, made in 2018. Middle: the image of 24 December 2022, during the dimming, with the star 0.22 magnitudes fainter than in the reference image. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot. Data: ZTF (Caltech/IPAC).

## Candidate 48: A quiet old star that dimmed for a year and a half

| | |
|---|---|
| **Star** | Gaia DR3 4417400634468116864, an old subgiant |
| **Position** | RA 231.76807°, Dec +0.43141° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Serpens, 44 degrees above the Milky Way's mid-plane |
| **Galactic** | $l = 3.93°$, $b = +44.10°$ |
| **Distance** | 1,300 to 1,700 parsecs (4,200 to 5,500 light-years) |
| **Brightness** | Gaia $G = 14.98$; far too faint for the eye |
| **Event** | from 2022 Aug; 0.07–0.09 mag in g in 2023 Apr–Aug; normal from spring 2024 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is a subgiant of about 5,250 K, somewhat poorer in heavy elements than the Sun and about 10 billion years old, 1,300 to 1,700 parsecs away and about a kiloparsec above the Milky Way's plane, where almost all stars are old. ZTF saw it steady to within 0.01 magnitudes until mid-2022. From August 2022 it faded slowly, and from April to August 2023 it was 0.07 to 0.09 magnitudes fainter in green light and 0.06 to 0.07 in red, about 8 per cent less light. The Sun then hid it until December; in January and February 2024 it was only slightly faint, and from spring 2024 it was normal. ASAS-SN saw the same dip in green light.

**Why it might matter.** Old stars far from the plane should be quiet, and Gaia sees this one as a single, well-behaved star with no infrared excess and no sign of a companion, so a dust cloud passing in front of it would be unusual. Blue light dimmed only about 1.2 times as much as red light, between a solid body (1.0) and ordinary interstellar dust (1.4); WISE, near the deepest point, saw the star about 0.03 magnitudes faint at 3.4 microns, which cannot tell the two apart. GALEX saw the star faint in ultraviolet light, as a quiet star should be, and ZTF found no rotation period in any season.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is real: ZTF flagged it 23 times and ASAS-SN, a separate network of small telescopes, saw the same dip while nearby stars stayed steady. But green and red light dimmed almost equally, which spots could also explain, the dip is shallow, the deepest part may have been missed while the Sun hid the star, and there is no spectrum.

**Caveats.** Only one ZTF field covers the star, and only ZTF measured the colour. The dip is shallow, its deepest part may have fallen in a gap, and its colour is within the range of starspots. There is no spectrum, and the two distance estimates disagree.

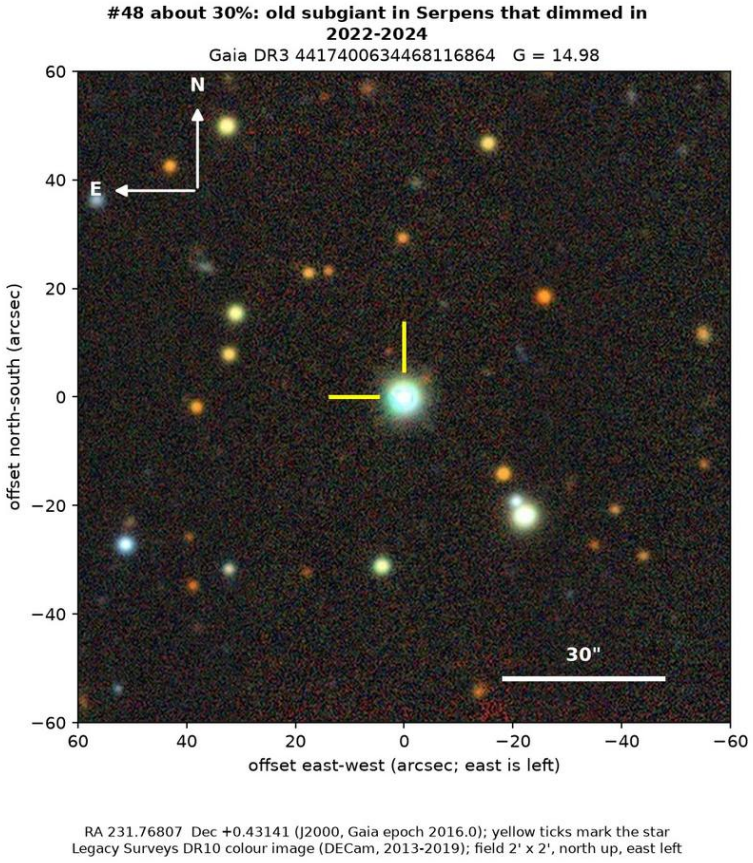



**Figure 149:** Candidate 48, sky image. Legacy Surveys DR10 colour image (DECam, 2013 to 2019), two arcminutes by two. The star is between the yellow ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: DESI Legacy Imaging Surveys (NOIRLab); ESA/Gaia/DPAC.

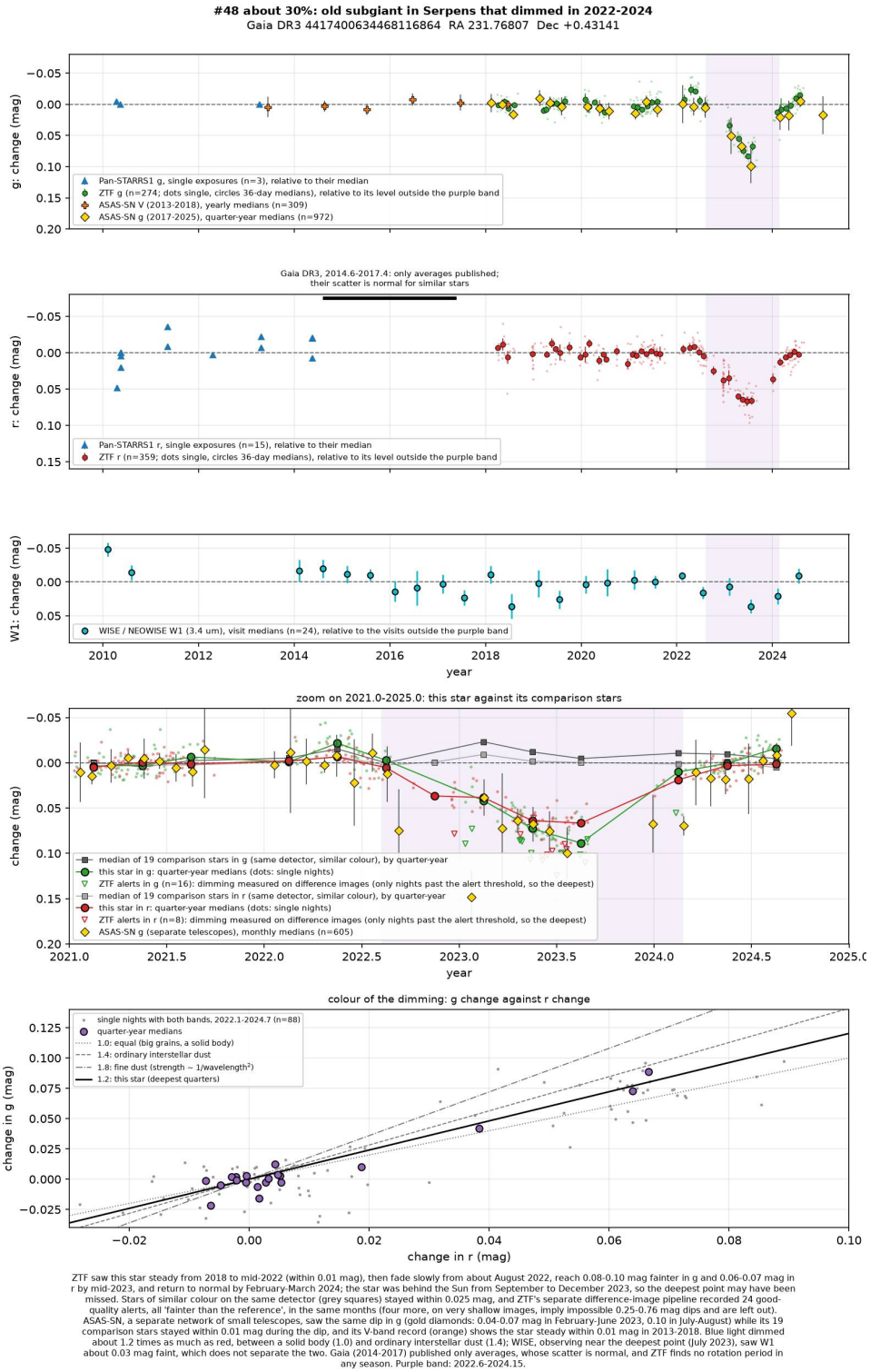



**Figure 150:** Candidate 48, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

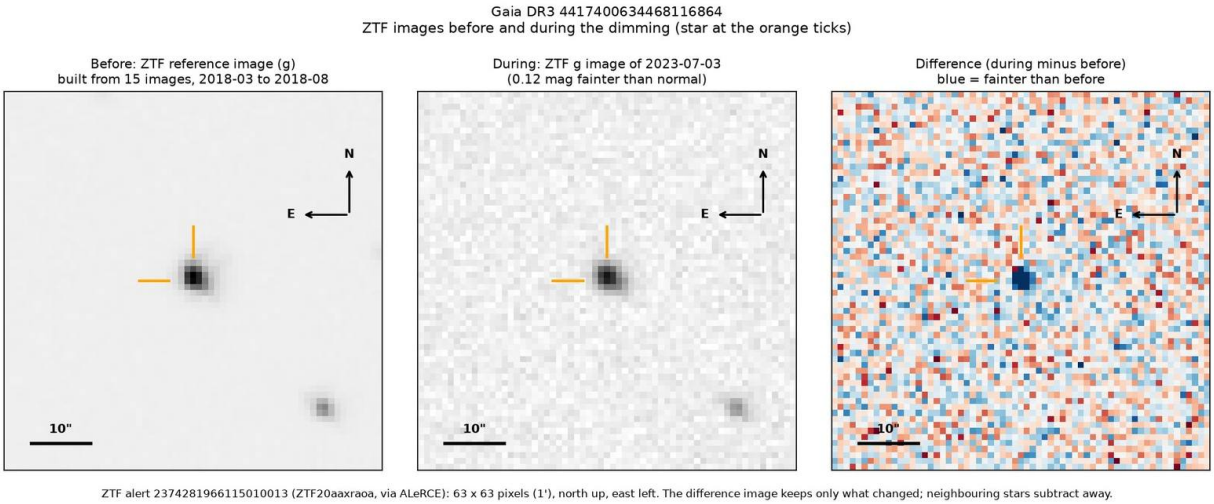



**Figure 151:** Candidate 48, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 49: A very old star that dimmed for most of 2019

| | |
|---|---|
| **Star** | Gaia DR3 4235833950054628096, a very old, metal-poor subgiant |
| **Position** | RA 301.77934°, Dec −1.21691° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Aquila |
| **Galactic** | $l = 40.69°$, $b = -17.35°$ |
| **Distance** | 1,500 to 1,900 parsecs (4,900 to 6,200 light-years) |
| **Brightness** | Gaia $G = 15.60$; far too faint for the eye |
| **Event** | from 2019 Apr; about 0.06 mag in g (0.035–0.04 in r) in 2019 Jun–Nov; normal by spring 2020 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is a subgiant of about 5,500 K with only about a twelfth of the Sun's share of heavy elements, about 13 billion years old, some 1,500 to 1,900 parsecs away in Aquila. ZTF saw it steady in 2018. It faded from April 2019 and from June to November was about 0.06 magnitudes fainter in green light and 0.035 to 0.04 in red, about 5 per cent less light. It recovered between December 2019 and March 2020 and was steady from April 2020 to 2024. ASAS-SN saw the dip in green light, 0.07 to 0.10 magnitudes, from April to November 2019, and its older record shows the star steady from 2014 to 2018.

**Why it might matter.** A star this old should be quiet, and ZTF found no rotation period in any season. Blue light dimmed about 1.6 times as much as red, more than ordinary interstellar dust (1.4) or starspots (1.1 to 1.3) usually give, which points to dust passing in front. WISE observed the star in April and October 2019 and saw no clear change, but that does not decide the colour in the infrared.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is real: ASAS-SN, a separate network of small telescopes, saw the same dip in all five of its cameras while nearby stars stayed steady, and ZTF flagged it six times. Green light dimmed more than red, as behind dust. But the dip is shallow, only one ZTF field covers the star, and the infrared cannot decide between dust and spots.

**Caveats.** The dip is shallow. Only one ZTF field covers the star, and only ZTF measured the colour. The infrared cannot decide between dust and spots, and there is no ultraviolet measurement. There is no spectrum.

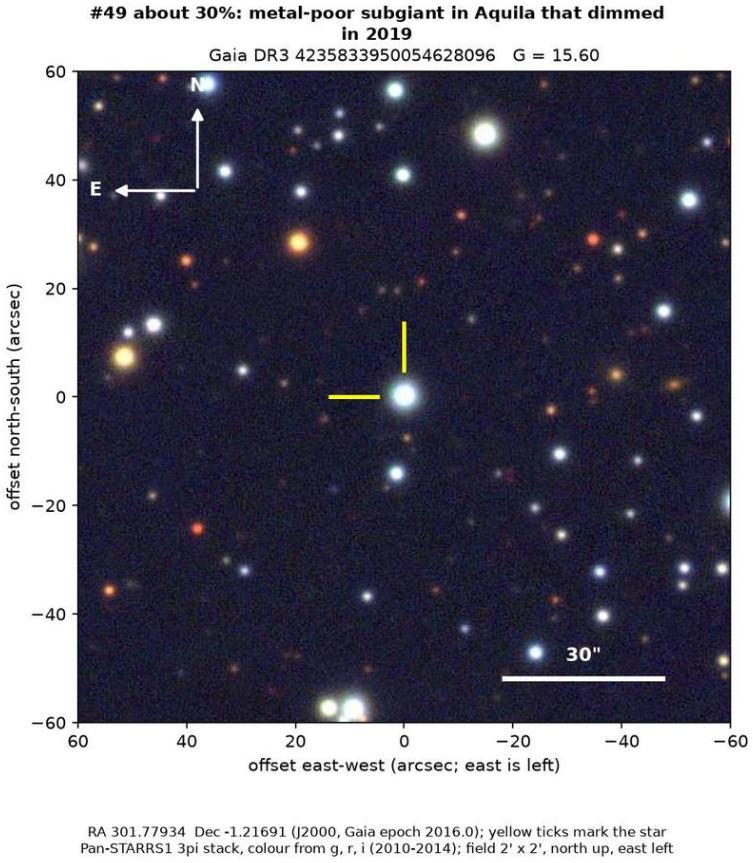



**Figure 152:** Candidate 49, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; the fainter star 15 arcseconds south of it is a neighbour (G = 17.8). North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

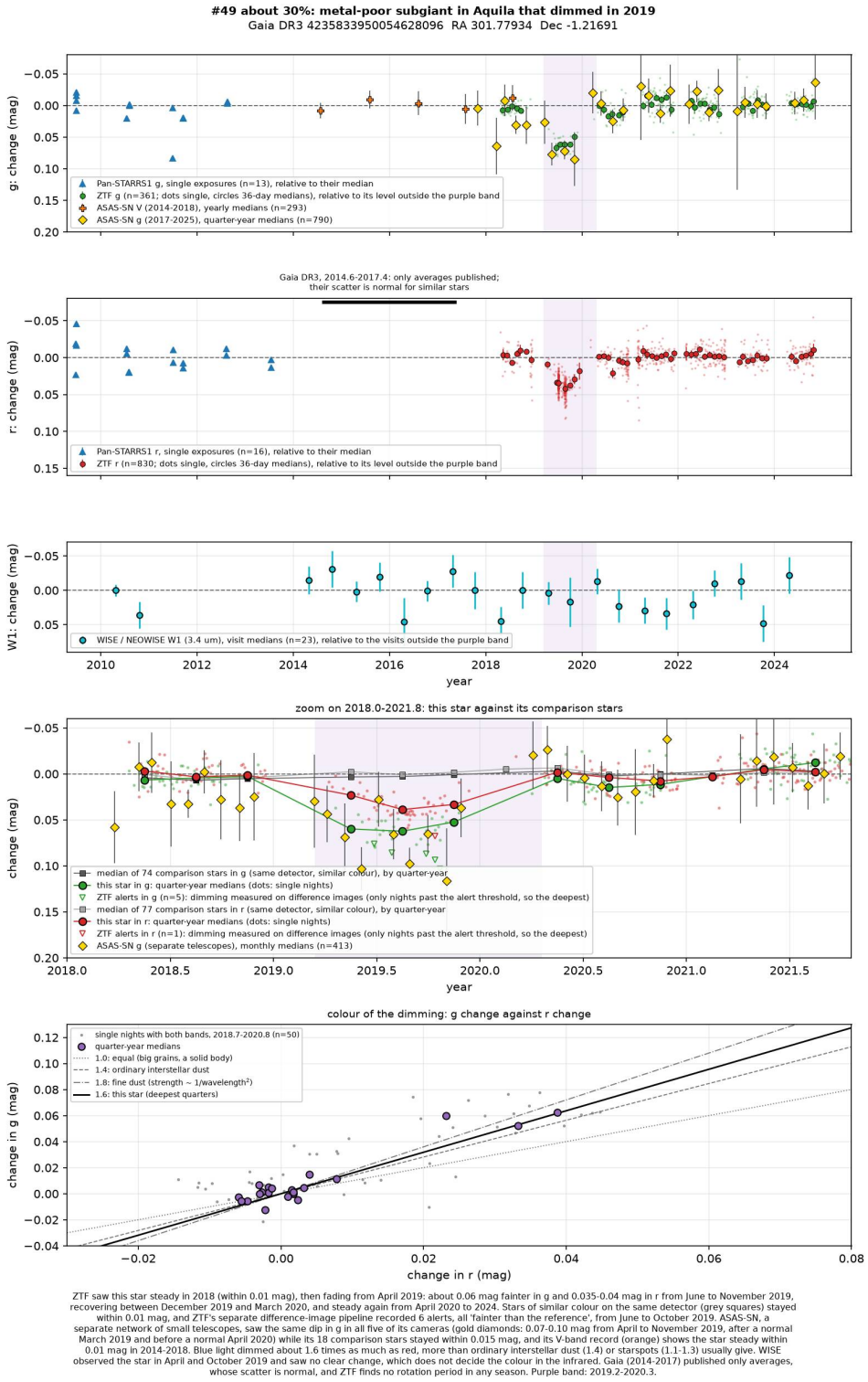



**Figure 153:** Candidate 49, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

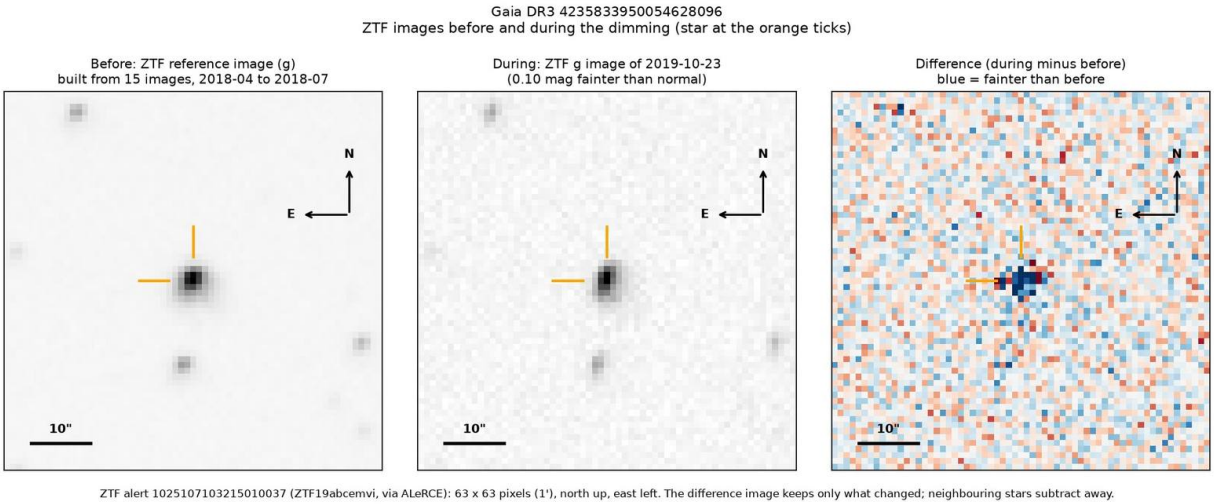



**Figure 154:** Candidate 49, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 50: A subgiant that dimmed for half a year

| | |
|---|---|
| **Star** | Gaia DR3 2285208410072626688, a subgiant |
| **Position** | RA 331.90027°, Dec +79.68360° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cepheus |
| **Galactic** | $l$ = 115.79°, $b$ = +19.16° |
| **Distance** | about 1,750 parsecs (5,700 light-years) |
| **Brightness** | Gaia $G$ = 15.16; far too faint for the eye |
| **Event** | 0.07–0.10 mag in g in mid-Aug–early Sep 2019, within 2019 Jul–Dec; brief dip 2024 Apr 28–May 8 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 30% |

**What changed.** The star is a subgiant of about 5,400 K, some 6 billion years old, about 1,750 parsecs away in Cepheus. ZTF saw it steady from 2020 to 2024, though 0.02 to 0.04 magnitudes brighter in 2018. From early July 2019 it dimmed, by 0.07 to 0.10 magnitudes in green light and 0.05 to 0.08 in red from mid-August to early September, about 9 per cent less light, and it was normal again by mid-December. ZTF's alert system flagged it 81 times, every few nights from June to December 2019. A second, shorter dip followed from 28 April to 8 May 2024, seen by one ZTF field only.

**Why it might matter.** Blue light dimmed about 1.3 to 1.65 times as much as red light, between starspots (1.1 to 1.3) and ordinary interstellar dust (1.4). WISE observed on 27 August 2019, at the deepest point, and saw only about 0.01 magnitudes of change at 3.4 microns while red light was 0.07 magnitudes faint: spots would have given about 0.03 and a solid body 0.07, so this favours dust, though only mildly. TESS shows no repeating period in any sector.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is certain: ZTF recorded it on two of its detectors and flagged it 81 times, and ASAS-SN, a separate network of small telescopes, saw it in each of its three cameras that observed the star. But green light dimmed only somewhat more than red, between starspots and ordinary dust, so the colour alone cannot tell them apart, and the star was slightly brighter in 2018 for reasons that are unclear.

**Caveats.** The colour alone cannot tell spots from dust, and the infrared favours dust only mildly. The star was slightly brighter in 2018 for reasons that are unclear, and the 2024 dip was seen on one ZTF field only. There is no spectrum.

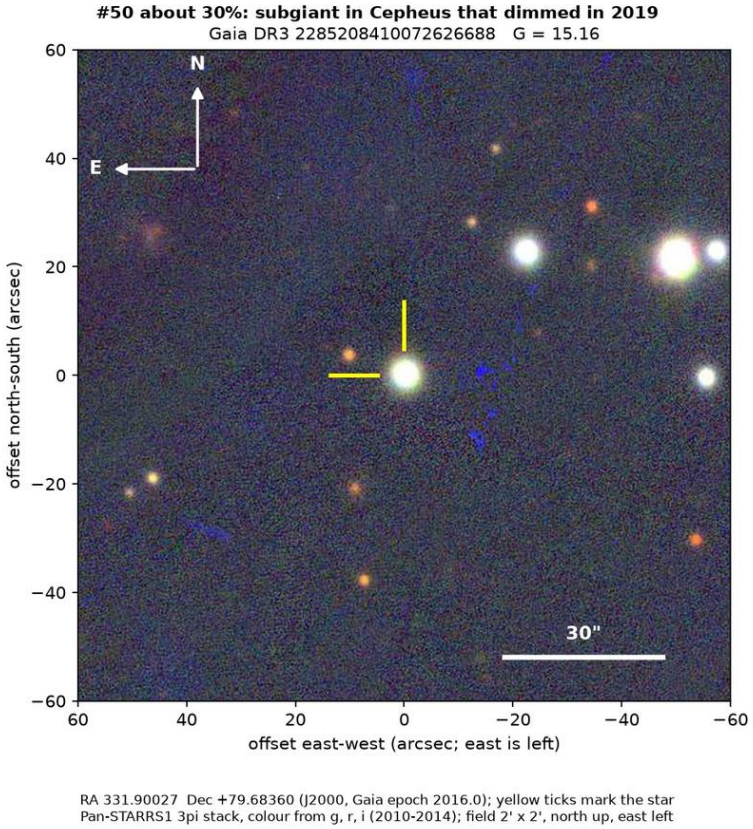



**Figure 155:** Candidate 50, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright white one between the yellow ticks; the faint red star 11 arcseconds to the east-north-east is a neighbour (G = 19.6), and the blue smudges to the west are artefacts of the image. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

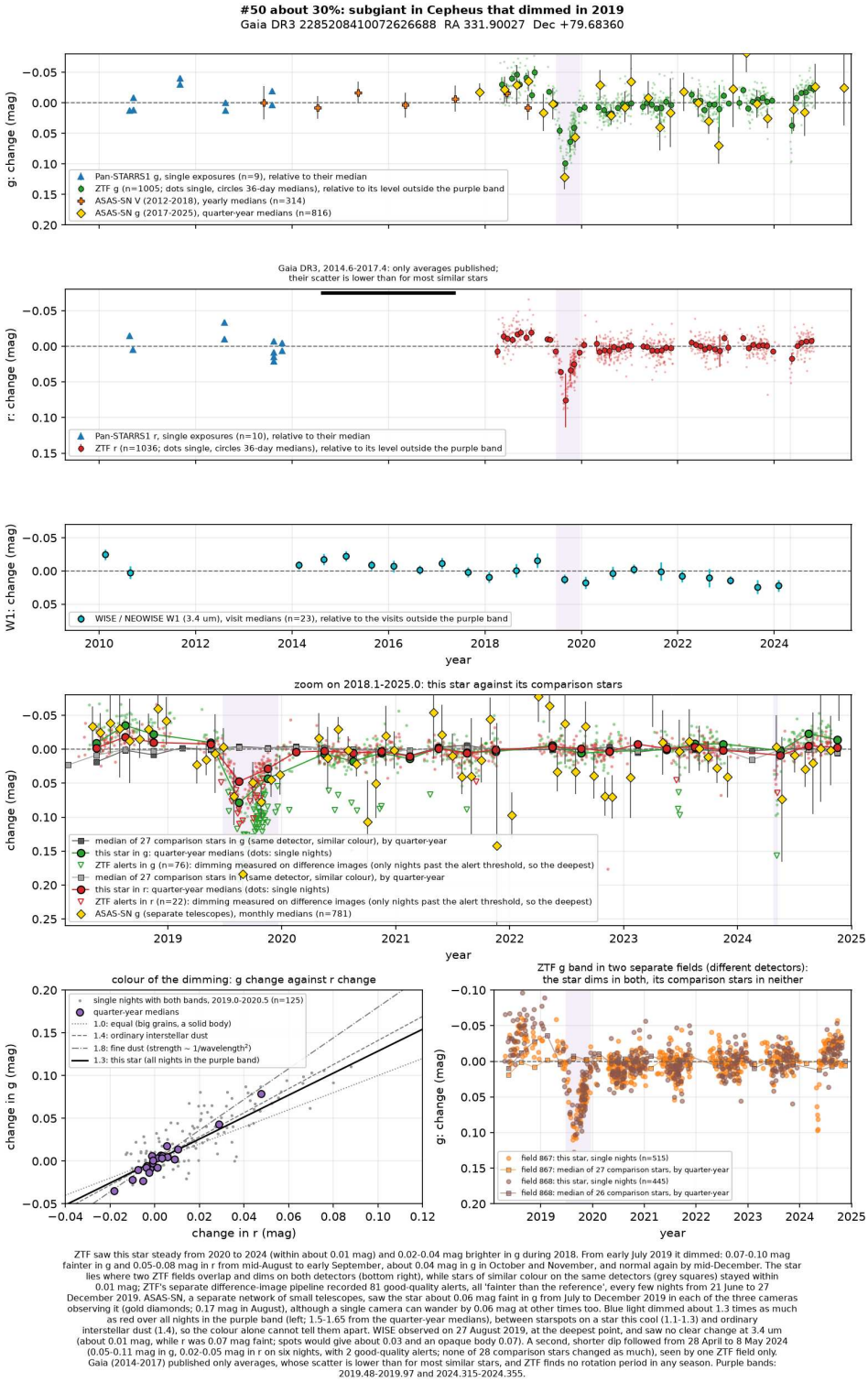



**Figure 156:** Candidate 50, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Bottom right: the star and its comparison stars on two separate ZTF fields, recorded by different detectors. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

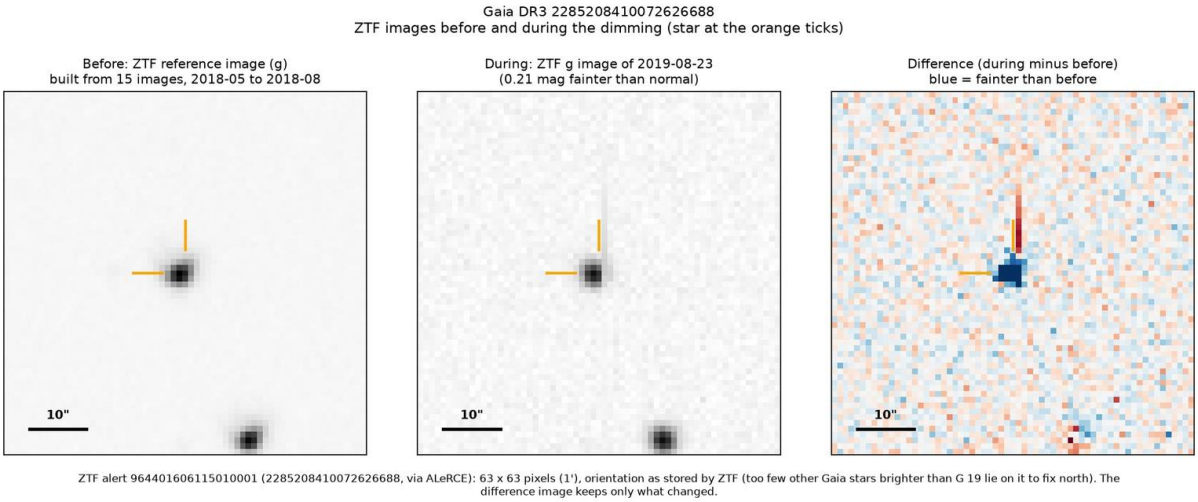



**Figure 157:** Candidate 50, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

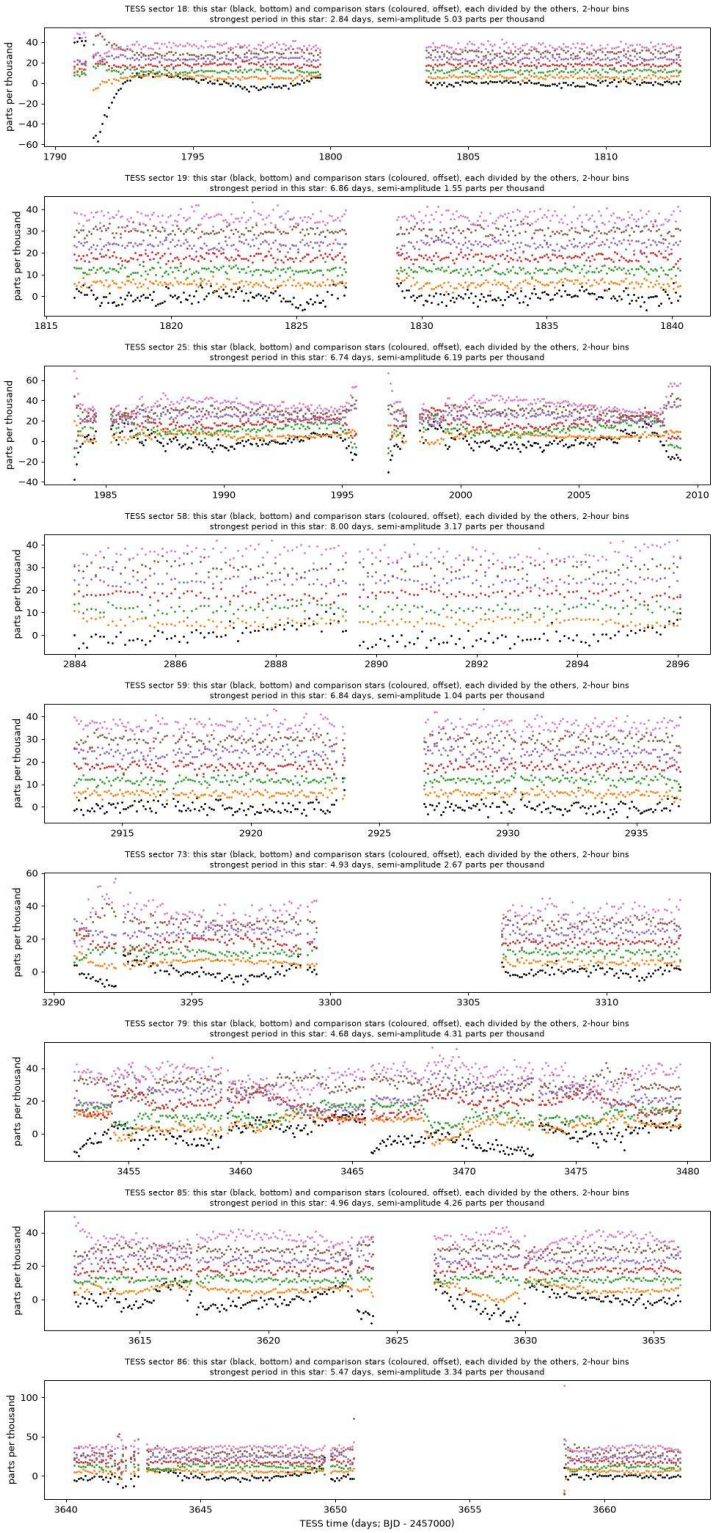



**Figure 158:** Candidate 50, TESS light curves. TESS light curves from nine sectors. The first two panels, from November and December 2019, were taken at the end of the dimming. No panel shows a repeating period. In each panel the star is in black at the bottom, below comparison stars on the same images, each divided by the others, averaged over two hours and offset for clarity. Data: TESS (NASA; MAST).

## Candidate 51: An F-type star that dimmed for a year, with an unusual colour

| | |
|---|---|
| **Star** | Gaia DR3 2012763683708712192, an F-type main-sequence star of spectral type about F3 |
| **Position** | RA 357.92259°, Dec +61.82215° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Cassiopeia, 0.24 degrees south of the Milky Way's mid-plane |
| **Galactic** | $l = 115.94°$, $b = -0.24°$ |
| **Distance** | about 2,700 parsecs (8,800 light-years) |
| **Brightness** | Gaia $G = 16.70$; far too faint for the eye or a small telescope |
| **Event** | about a seventh in g but a fifteenth in r, 2020 Jul–Oct, within 2020 Jan–2021 Feb |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 25% |

**What changed.** The star is an F-type star, hotter and more massive than the Sun and a few times as luminous, some 2,700 parsecs (8,800 light-years) away in the plane of the Milky Way, towards the Perseus spiral arm. ZTF saw it steady from 2018 to the end of 2019. From about January 2020 it faded slowly, and from July to October 2020 it had lost about a seventh of its green light but only about a fifteenth of its red light. It then recovered slowly and was back to normal by early February 2021, and it has stayed close to normal since. ZTF's alert system, which compares each new image with a reference image, flagged it 60 times in the second half of 2020, and at no other time.

**Why it might matter.** The colour is unusual. Green light dimmed 2.07 times as much as red, and near-infrared light only 0.50 times as much, whereas ordinary interstellar dust gives about 1.40 and 0.74, an opaque body would dim all colours equally, and starspots, weak on a star this hot, would dim green only a little more than red. It fits either dust with grains smaller than about a tenth of a micron, which starlight clears out within about an orbit, so the dust would have to be fresh, as from a recent collision; or a very hot companion or hot gas that faded or was hidden for a year. An eclipse by another star would last hours or days, not a year, and an instrumental fault, though unlikely, cannot be excluded entirely.

A young star, varying in a known way, is the main alternative: the star lies just outside the 20-million-year-old cluster King 12, at the same distance, and its hydrogen line in Gaia's spectra is weaker than expected, perhaps partly filled in by emission. But it moves about 8 km/s differently from King 12, whose stars share their motion to within one or two km/s, and shows no warm dust. A spectrum would show whether it is young, has hot gas or a disc, or has a hot companion.

**Checks against the record.** No record of the dimming could be found. SIMBAD has no entry for the star, Gaia lists no variability, and VSX, the variable-star index, has nothing within 30 arcseconds. It is in none of the variable-star, young-star or cluster catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is almost certainly real: the ZTF survey telescope at Palomar Observatory in California measured it on more than a hundred nights while 237 of the 238 stars of similar colour and brightness on the same detector stayed steady, and a second ZTF detector saw it in near-infrared light. Both its start and its end were observed. But only ZTF recorded it, its colour fits neither ordinary dust nor starspots nor an opaque body, the star may be young, and there is no spectrum.

**Caveats.** There is no spectrum, and no second survey confirms the dimming: ASAS-SN, a worldwide network of small telescopes, has no light curve of the star, and nearly all measurements by WISE, NASA's infrared space telescope, are contaminated by a brighter star. The star was again slightly faint in green light in the summers of 2022 and 2023. Seven stars on other ZTF fields, 8 to 103 degrees away, dimmed partly at the same time, most likely by chance: candidate 24 , candidate 25 , candidate 31 (another F-type star with a steep colour), candidate 34 , candidate 36 , candidate 37 and candidate 44 .

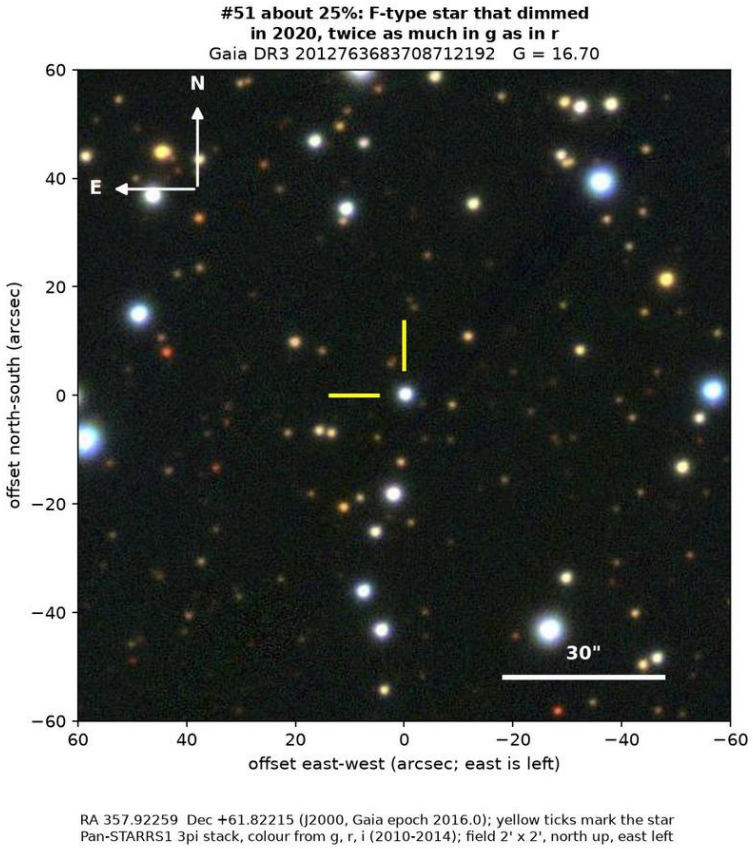
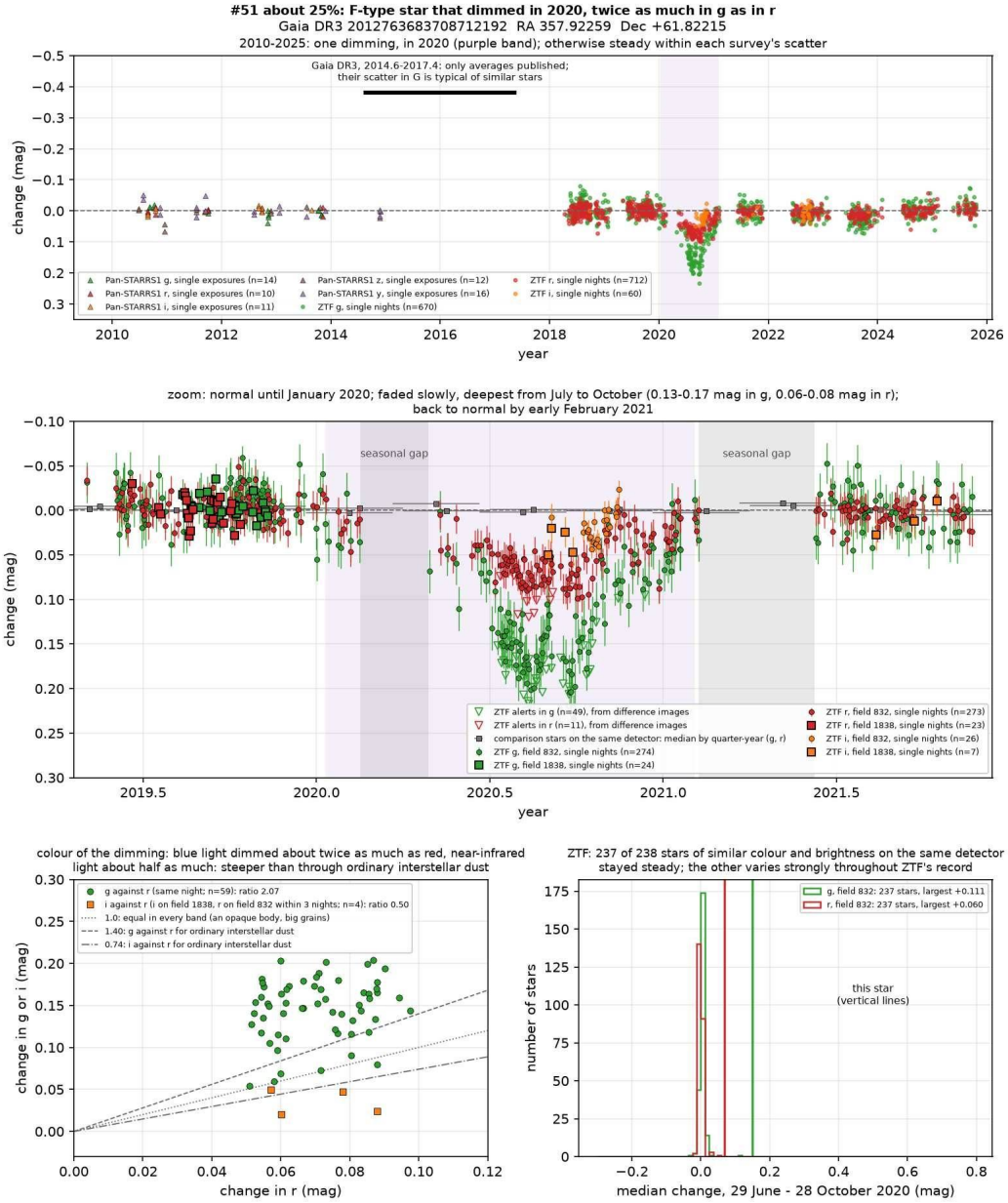



**Figure 159:** Candidate 51, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; Gaia's nearest neighbour to it is 6.2 arcseconds away and 4 magnitudes fainter. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




Against its usual level (the median of each ZTF field outside 1 January 2020 - 13 February 2021), the star was steady in Pan-STARRS1 images of 2010-2014 and in ZTF from April 2018 to December 2019 (single nights scatter by about 0.03 mag in g and 0.015 mag in r; grey bands: the star then stands too low in the night sky for ZTF). From about mid-January 2020 it faded slowly, with monthly medians of about 0.03 mag in g in January and February (0.01 mag in r), 0.05-0.07 mag in May and June (0.04 mag in r) and 0.14, 0.17, 0.17 and 0.13 mag in g from July to October (0.06, 0.08, 0.08 and 0.07 mag in r), with single nights down to 0.23 mag in g (28 September) and 0.10 mag in r. It then recovered slowly (0.08, 0.07 and 0.05 mag in g in November, December and January) and was back to normal on 3-7 February 2021, the last nights before the next seasonal gap. Since then it has stayed within about 0.04 mag of normal: in the summers of 2022 and 2023 it was slightly faint in g (by about 0.02 and 0.03-0.04 mag in monthly medians; about 0.01 mag in r), while the comparison stars stayed within 0.006 mag. Most measurements come from ZTF field 832 (circles); field 1838, where the star falls on a different detector (squares), observed it in the near-infrared i band on 4 nights in September 2020, when it was 0.036 mag faint; field 832's own i measurements of October and November 2020 (0.02-0.04 mag faint) are set against only two nights outside the dimming. Of the 238 stars of similar colour and brightness on the same detector of field 832, 237 changed by at most 0.026 mag in g and 0.029 mag in r from 29 June to 28 October 2020, when this star was 0.150 mag faint in g and 0.068 mag in r (bottom right); the other, 5.5 arcminutes away, varies irregularly throughout ZTF's record, at times by more than a magnitude. The comparison stars' quarter-year medians stayed within 0.014 mag of normal throughout (grey squares). ZTF's separate difference-image pipeline recorded 60 good-quality alerts from 10 July to 12 December 2020, all 'fainter than the reference' and centred on the star (median offset 0.26"). Blue light dimmed 2.07 times as much as red on the same nights (68 % range 2.00-2.14) and near-infrared i light 0.50 times as much as red (0.39-0.61, from field 1838), both steeper than through ordinary interstellar dust (1.40 and 0.74) and unlike an opaque body (1.0). Nearly all of WISE's infrared measurements of the star are flagged as contaminated by light from a brighter star, and none of the others was taken during the dimming. Purple band: 11 January 2020 - 3 February 2021, as far as ZTF's observations bracket the dimming.

**Figure 160:** Candidate 51, light curve. Top: brightness from 2010 to 2025 in Pan-STARRS1 (a survey telescope in Hawaii) and ZTF, each against its own normal level; Gaia, the European Space Agency's star-mapping satellite, publishes only averages, so only its years are marked. Purple marks the dimming. Middle: April 2019 to December 2021, with circles for the main ZTF field and squares for the second, ZTF's alerts (open triangles) and the comparison stars' median (grey squares); grey bands mark when the star is too low in the night sky. Bottom left: the change in green and near-infrared light against that in red, with lines for an opaque body and ordinary dust. Bottom right: the changes of the comparison stars, and this star's (vertical lines). Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ESA/Gaia/DPAC.

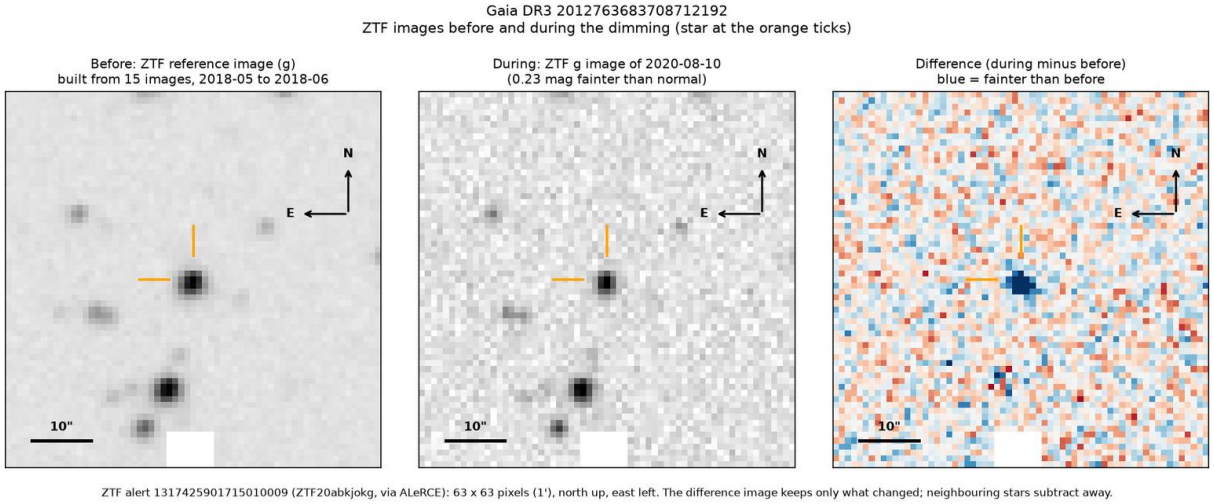



**Figure 161:** Candidate 51, before and during. Cutouts from one ZTF alert, one arcminute across, north up and east left; orange ticks mark the star. Left: the reference image in green light, made in 2018. Middle: the image of 10 August 2020, during the dimming, with the star 0.23 magnitudes fainter than in the reference image. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract cleanly. Data: ZTF (Caltech/IPAC).

## Candidate 52: An orange dwarf that dimmed smoothly for a year and a half

| | |
|---|---|
| **Star** | Gaia DR3 3415149842485194240, a dust-reddened orange (K-type) dwarf |
| **Position** | RA 76.78700°, Dec +21.69702° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Taurus, 11 degrees below the Milky Way's mid-plane |
| **Galactic** | $l = 181.24°$, $b = -11.24°$ |
| **Distance** | about 530 parsecs (1,700 light-years) |
| **Brightness** | Gaia $G = 16.21$; far too faint for the eye |
| **Event** | 0.21 mag in g and 0.10 in r in mid-2021, within late 2020–mid-2022 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 25% |

**What changed.** The star is an orange dwarf of about 5,000 K, about 530 parsecs away in Taurus, seen through a thick layer of interstellar dust that makes it look red. ZTF measured it about 840 times from 2018 to 2025. It was steady except from late 2020 to early 2022, when it faded gradually, reaching 0.21 magnitudes fainter in green light and 0.10 in red in mid-2021, 18 and 9 per cent of its light, and it was back to normal by mid-2022. Stars of similar colour on the same detector changed by less than 0.02 magnitudes. TESS watched it for 24 days in September and October 2021, near the deepest point, and saw no dips or eclipses: the dimming was smooth.

**Why it might matter.** Blue light dimmed about 2.2 times as much as red light. A solid body would dim all colours equally, ordinary interstellar dust gives 1.4 and spots or a cooler surface about 1.1 to 1.3, so the steep ratio fits a cloud of very fine dust crossing the line of sight. NEOWISE saw at most 0.02 to 0.03 magnitudes of fading at 3.4 microns, which also rules out a solid body. Averaged over July to December 2021, ASAS-SN found the star 0.11 magnitudes faint, in agreement with ZTF, but with an uncertainty of 0.05.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it. A machine label calls it a possible young star, but no person has classified it.

**Why this estimate.** ZTF recorded the dimming in green and red light and flagged it 75 times, and its difference images show a clean dark spot, but only one ZTF detector covers the star, and ASAS-SN, a separate network of small telescopes, sees it too close to its faint limit to give more than a hint. Green light dimmed about twice as much as red, as behind fine dust.

**Caveats.** Only one ZTF detector covers the star, and ASAS-SN's support is only a hint. The star is not perfectly quiet at other times, so it may be an active, spotted star. A young star dimmed by its own dusty disc would behave similarly, though this one shows no infrared excess. There is no spectrum.

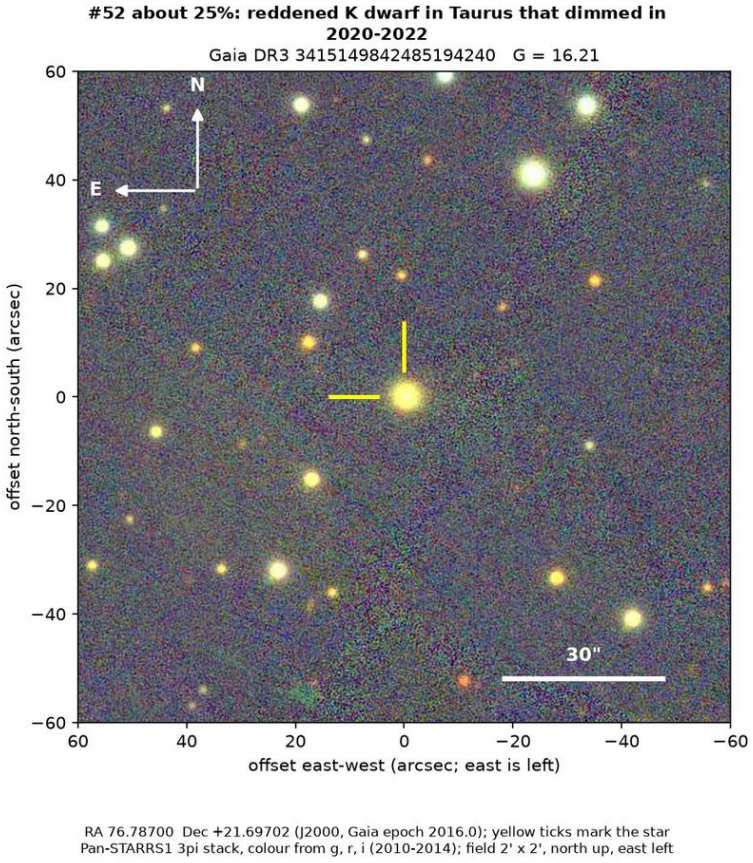



**Figure 162:** Candidate 52, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; no other star lies within 20 arcseconds. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

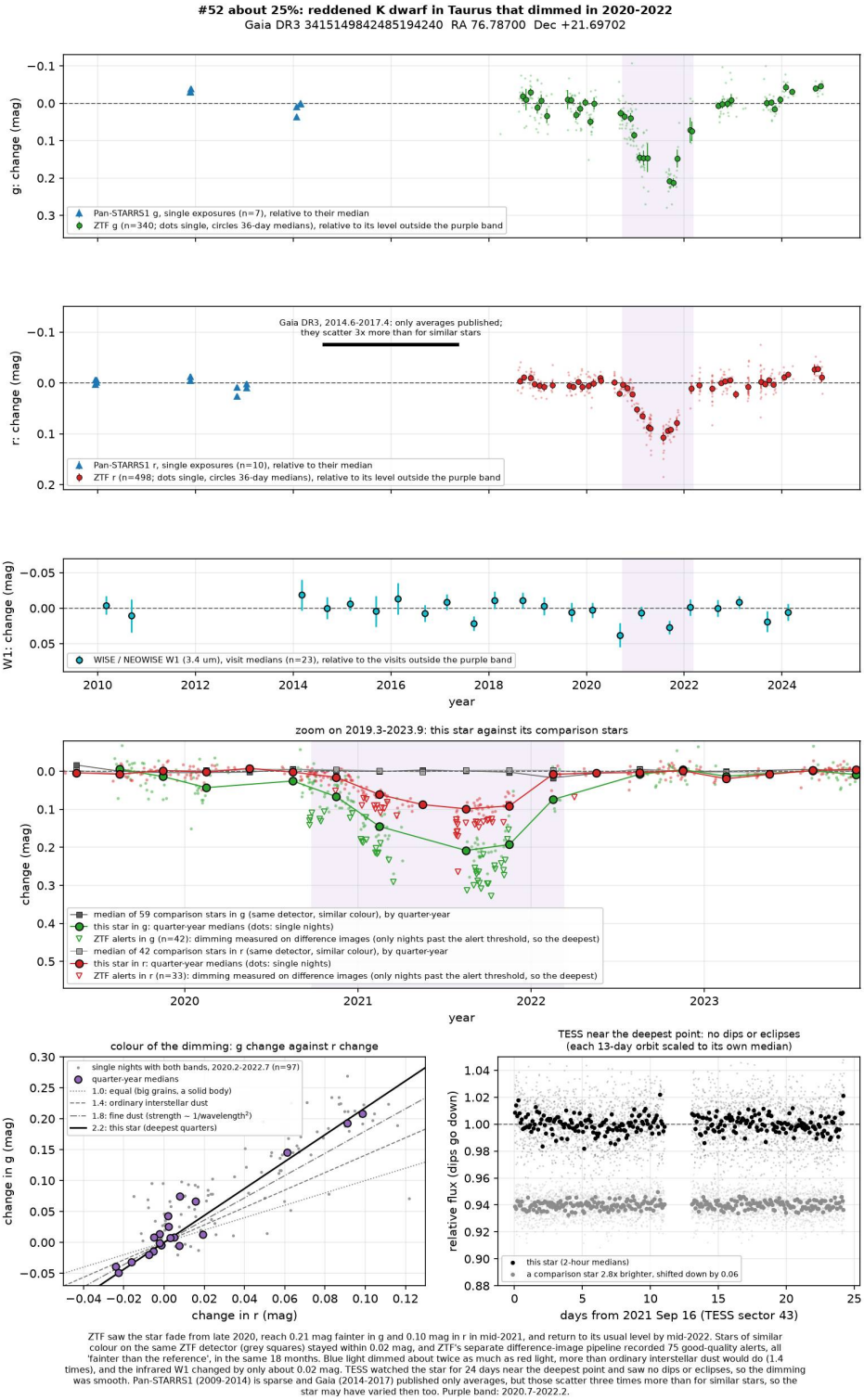



**Figure 163:** Candidate 52, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope), and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars and ZTF's alerts. Bottom left: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Bottom right: TESS near the deepest point (sector 43), the star and a brighter comparison star in 2-hour medians: no dips or eclipses. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); TESS (NASA; MAST); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

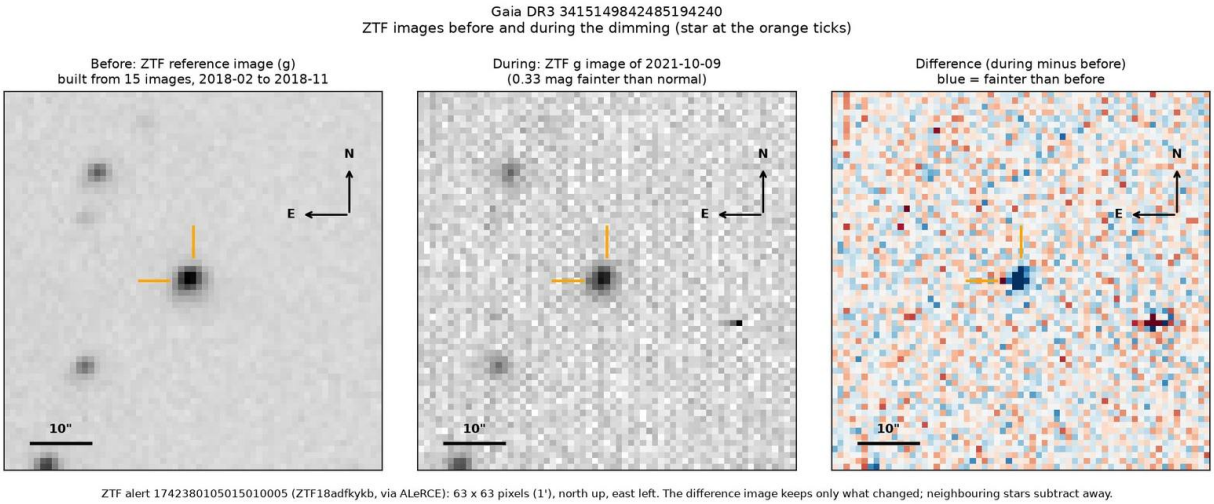



**Figure 164:** Candidate 52, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 53: A red giant that dimmed for a year

| | |
|---|---|
| **Star** | Gaia DR3 1943310596493970048, a red giant |
| **Position** | RA 353.89101°, Dec +48.43848° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Andromeda |
| **Galactic** | $l = 110.17°$, $b = -12.54°$ |
| **Distance** | 1,400 to 1,800 parsecs (4,600 to 5,900 light-years) |
| **Brightness** | Gaia $G = 13.66$; far too faint for the eye |
| **Event** | 0.06–0.08 mag in g from spring 2023 to early 2024, after a slight fade in 2022 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 25% |

**What changed.** The star is a red giant of about 4,800 K and about five times the Sun's radius, 1,400 to 1,800 parsecs away in Andromeda. ZTF saw it steady from 2018 to 2021, about 0.01 magnitudes faint in green light during 2022, and then 0.06 to 0.08 magnitudes fainter in green and 0.03 to 0.05 in red from spring 2023 to early 2024, about 7 per cent less light. It was back to normal by mid-2024. ASAS-SN saw the same dip from June to December 2023.

**Why it might matter.** Blue light dimmed about 1.7 times as much as red light, more than ordinary interstellar dust (1.4) or starspots (about 1.1 for a star this cool). WISE observed the star in July and December 2023, deep in the dip, and saw no change at 3.4 microns, which excludes a solid body and is less than starspots would give. Gaia's measurements of the star scatter more than those of a single star (its RUWE is 1.6), which suggests a companion, and dust in such a pair could pass in front of the giant.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it. One of them calls it a spotted binary of the RS Canum Venaticorum kind, with a probability of about one half.

**Why this estimate.** The dimming is real: ZTF flagged it 13 times, and ASAS-SN, a separate network of small telescopes, saw the same dip in two of its cameras. Green light dimmed more than red and the infrared did not change, which argues against starspots. But the star is a giant and probably has a companion, and a machine classification calls it a spotted binary.

**Caveats.** Only one ZTF field covers the star. Giants with companions are often spotted and active, and a machine classification labels it a spotted binary of the RS Canum Venaticorum kind. There is no spectrum.

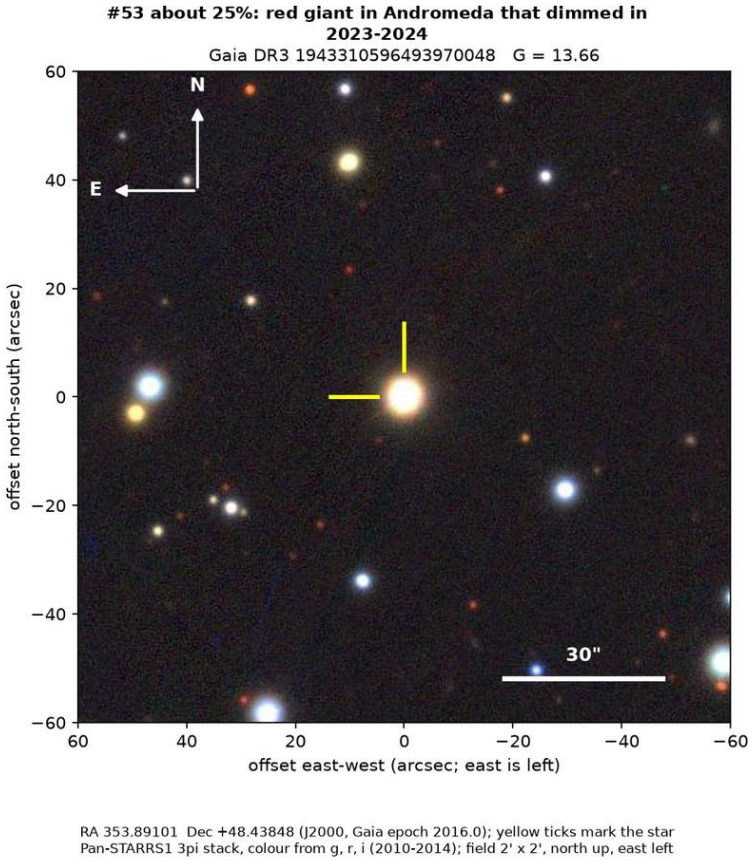



**Figure 165:** Candidate 53, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright orange one between the yellow ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

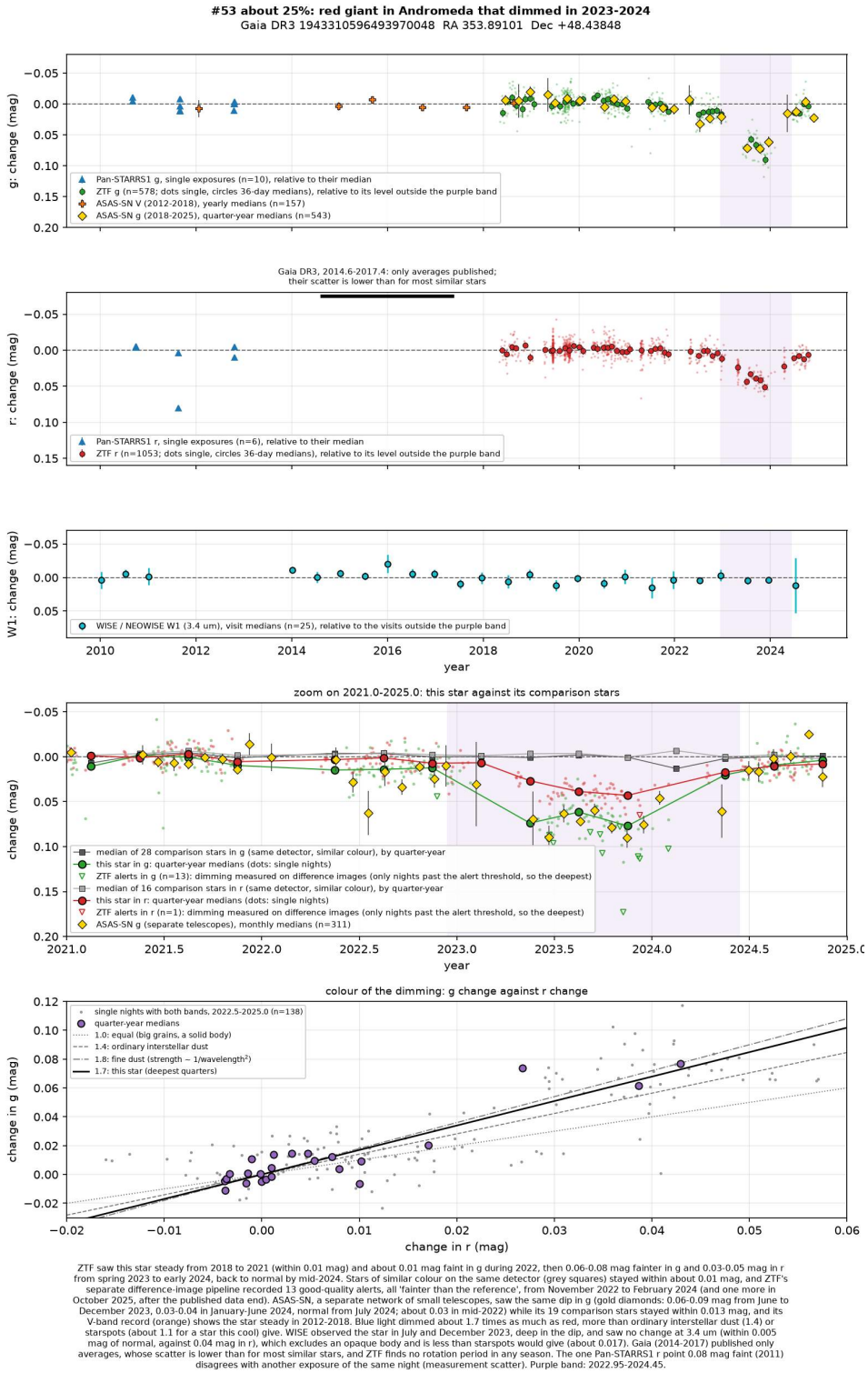



**Figure 166:** Candidate 53, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

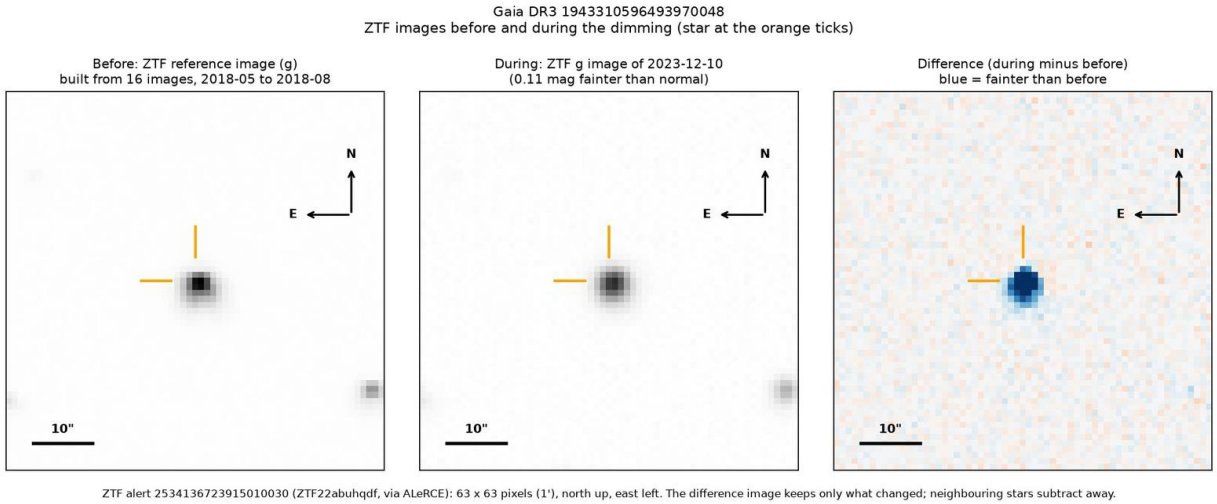



**Figure 167:** Candidate 53, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 54: A distant F star that dimmed for four months

| | |
|---|---|
| **Star** | Gaia DR3 61027606923915008, an F-type star |
| **Position** | RA 50.78965°, Dec +20.61755° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Aries |
| **Galactic** | $l = 164.44°$, $b = -29.77°$ |
| **Distance** | 2,000 to 2,400 parsecs (6,500 to 7,800 light-years) |
| **Brightness** | Gaia $G = 15.62$; far too faint for the eye |
| **Event** | 0.08–0.12 mag in g in 2019 Sep–Oct (11 per cent on Oct 13); steady again from 2020 Feb |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 25% |

**What changed.** The star is a yellow-white star of type F, about 6,400 K, some 2,000 to 2,400 parsecs away in Aries. ZTF saw it steady from 2018 to mid-2019. From mid-September 2019 it dimmed, by 0.08 to 0.12 magnitudes in green light and 0.03 to 0.08 in red until mid-October, about 0.05 magnitudes in November and 0.01 to 0.04 in December and January, and it was steady again from February 2020. On 13 October 2019, near the deepest point, it was 11 per cent fainter in green light. ASAS-SN saw it 0.11 magnitudes faint in October 2019 in all three cameras observing it.

**Why it might matter.** Blue light dimmed only about 1.15 times as much as red light, close to what a solid body or large dust grains would cause (1.0) and below ordinary interstellar dust (1.4); spots on a star this hot usually give about 1.2. So the colour cannot tell the causes apart. A dark object or a clump of coarse dust passing in front of the star would be the most interesting explanation.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** ZTF recorded the dimming in three filters and flagged it six times, and ASAS-SN, a separate network of small telescopes, saw the star faint in October 2019, but that support is weak because its measurements of this star scatter. Green and red light dimmed almost equally, which large dust grains, a solid body or spots could all explain, and WISE did not observe during the dip.

**Caveats.** Only one ZTF field covers the star, and ASAS-SN's support is weak: one other month of its record is also faint when ZTF saw the star normal. The colour does not separate large dust grains from spots, and there is no infrared measurement during the dip. There is no spectrum.

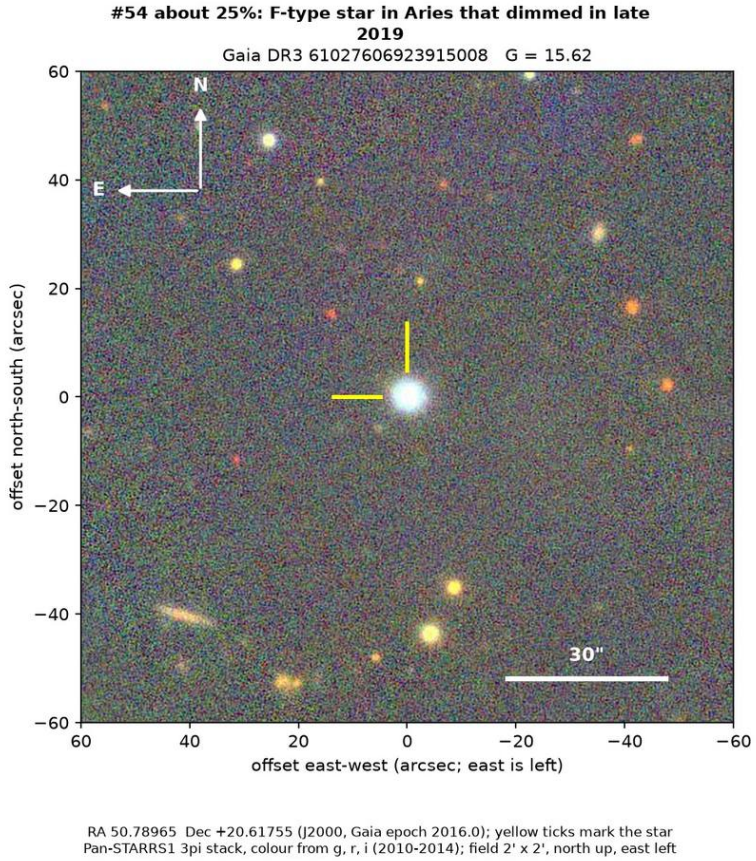



**Figure 168:** Candidate 54, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright white one between the yellow ticks; the very faint smudge about 7 arcseconds to its south-east is below Gaia's limit. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

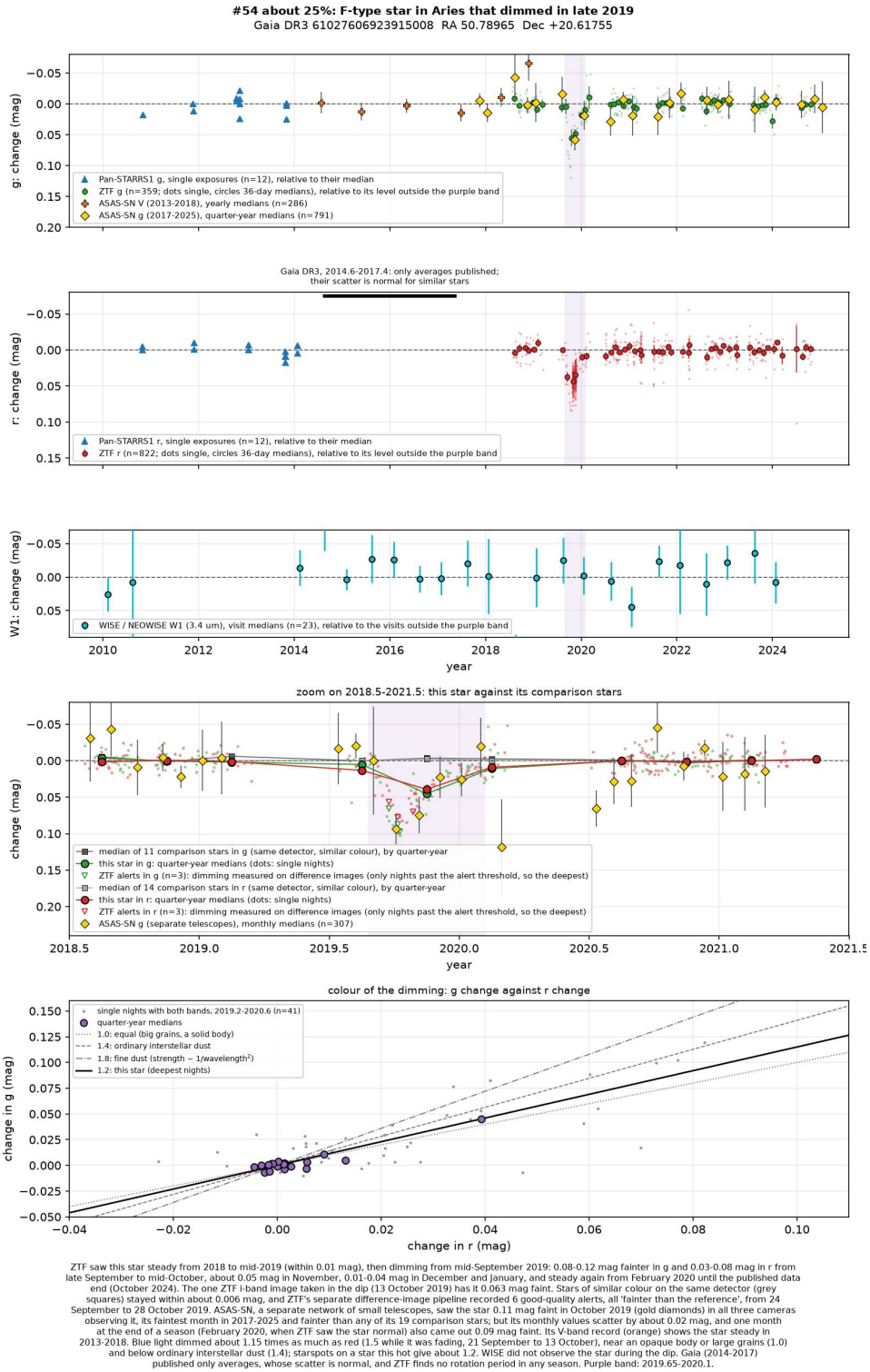



**Figure 169:** Candidate 54, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

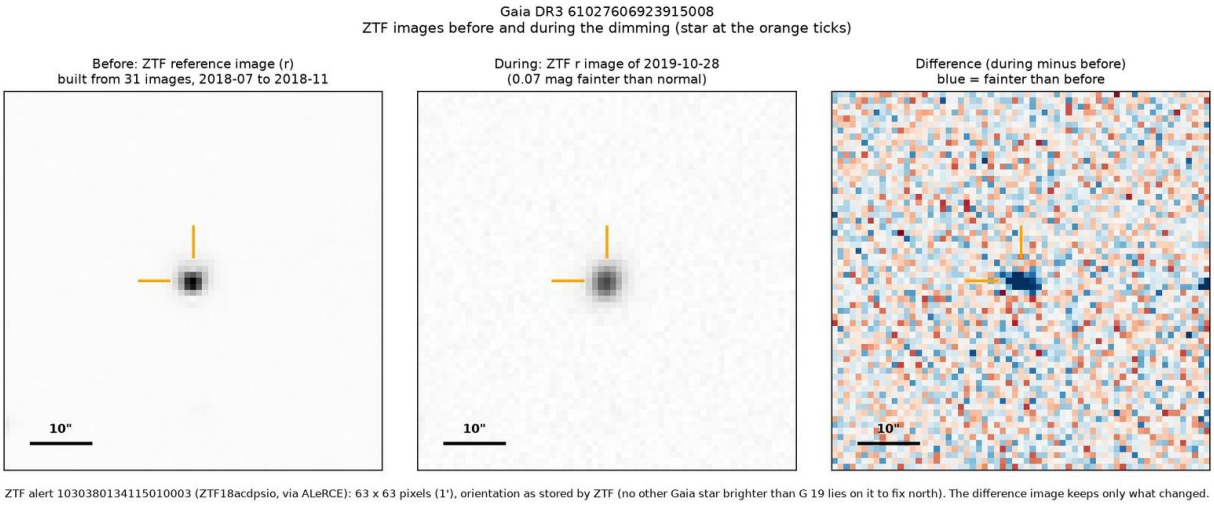



**Figure 170:** Candidate 54, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 55: A subgiant that dimmed for two months

| | |
|---|---|
| **Star** | Gaia DR3 1706330828131818240, a subgiant |
| **Position** | RA 260.88431°, Dec +78.84802° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Draco |
| **Galactic** | $l$ = 110.88°, $b$ = +30.78° |
| **Distance** | about 2,200 parsecs (7,200 light-years) |
| **Brightness** | Gaia $G$ = 14.09; far too faint for the eye |
| **Event** | 0.05–0.07 mag in g from about 2024 Jun 26 to mid-Aug; normal from early Sep 2024 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 25% |

**What changed.** The star is a subgiant of about 5,300 K, some 2 billion years old, about 2,200 parsecs away in Draco. ZTF saw it steady from 2018 to mid-2024. From about 26 June 2024 it was 0.05 to 0.07 magnitudes fainter in green light and 0.03 to 0.05 in red, about 6 per cent less light, until mid-August; it recovered over the next two weeks and was normal from early September. ASAS-SN saw it 0.05 magnitudes faint in July and 0.04 in August 2024.

**Why it might matter.** Blue light dimmed about 1.4 to 1.8 times as much as red light, at or above ordinary interstellar dust (1.4) and more than spots on a star this cool would give (1.1 to 1.2). TESS watched the star in twenty sectors and found no rotation, so it does not look spotted. Alerts in 2025 and early 2026 suggest it may have dimmed again, but those are not confirmed.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it.

**Why this estimate.** The dimming is real: ZTF recorded it on two of its detectors, and ASAS-SN, a separate network of small telescopes, saw it in three of its four cameras observing the star. Green light dimmed more than red, as behind dust, and NASA's TESS space telescope never saw the star spinning. But the dip is shallow and short, ZTF flagged it only twice, and there is no infrared measurement during it.

**Caveats.** The dip is shallow and short, ZTF flagged it only twice, and WISE did not observe during it. The later alerts that hint at a repeat are unconfirmed. There is no spectrum.

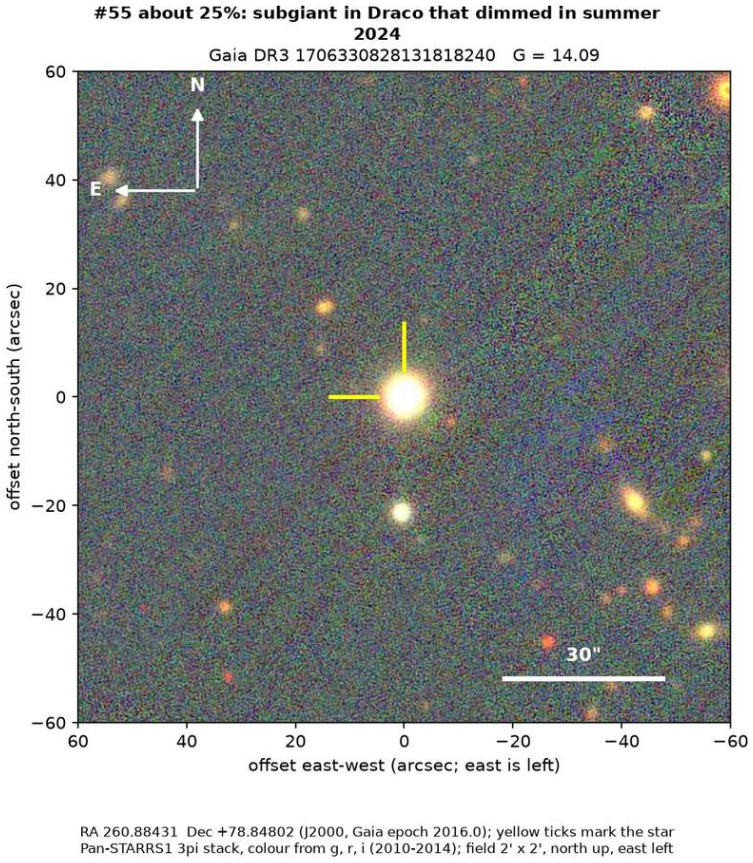
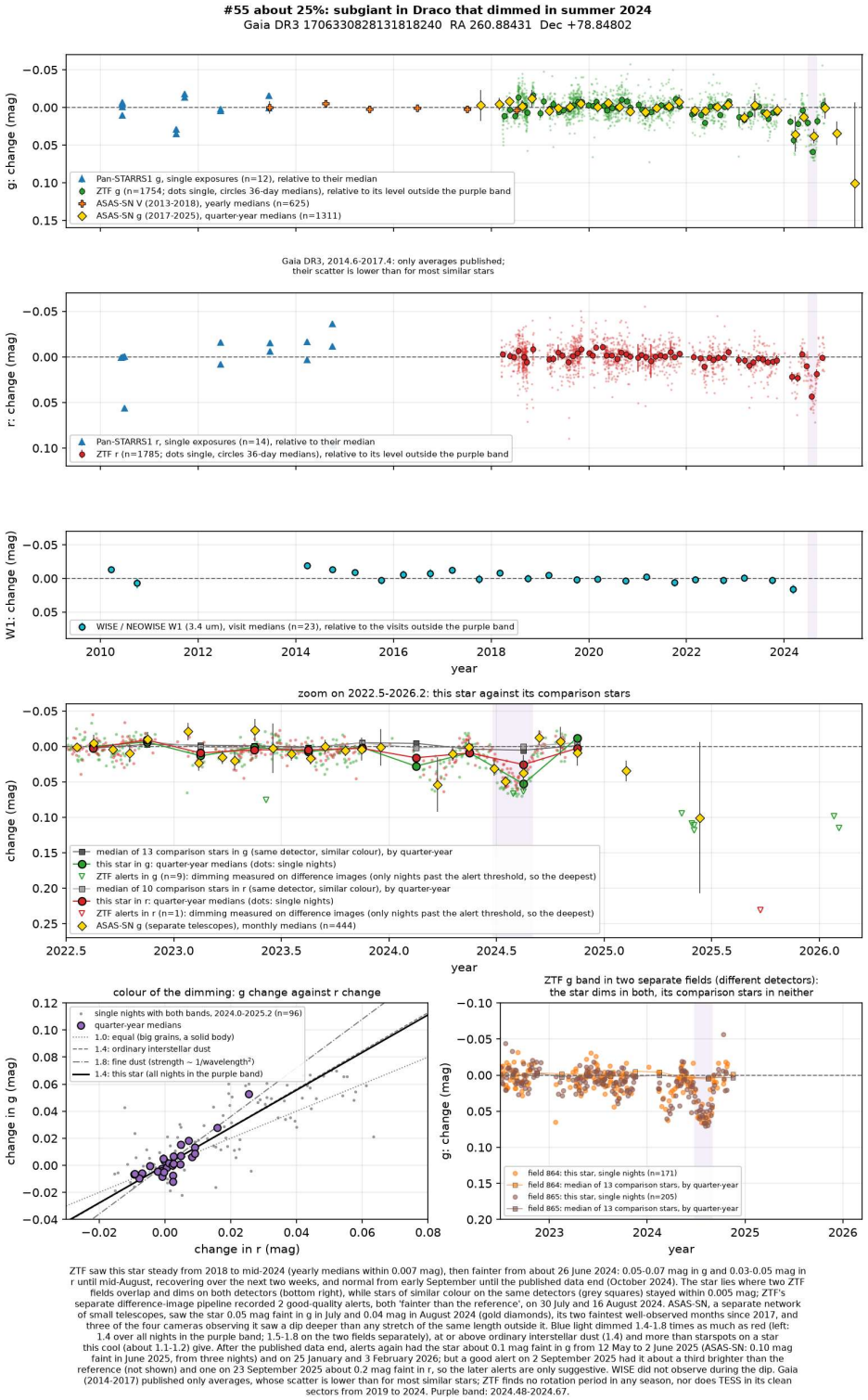



**Figure 171:** Candidate 55, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




ZTF saw this star steady from 2018 to mid-2024 (yearly medians within 0.007 mag), then fainter from about 26 June 2024: 0.05-0.07 mag in g and 0.03-0.05 mag in r until mid-August, recovering over the next two weeks, and normal from early September until the published data end (October 2024). The star lies where two ZTF fields overlap and dims on both detectors (bottom right), while stars of similar colour on the same detectors (grey squares) stayed within 0.005 mag; ZTF's separate difference-image pipeline recorded 2 good-quality alerts, both 'fainter than the reference', on 30 July and 16 August 2024. ASAS-SN, a separate network of small telescopes, saw the star 0.05 mag faint in g in July and 0.04 mag in August 2024 (gold diamonds), its two faintest well-observed months since 2017, and three of the four cameras observing it saw a dip deeper than any stretch of the same length outside it. Blue light dimmed 1.4-1.8 times as much as red (left: 1.4 over all nights in the purple band; 1.5-1.8 on the two fields separately), at or above ordinary interstellar dust (1.4) and more than starspots on a star this cool (about 1.1-1.2) give. After the published data end, alerts again had the star about 0.1 mag faint in g from 12 May to 2 June 2025 (ASAS-SN: 0.10 mag faint in June 2025, from three nights) and on 25 January and 3 February 2026; but a good alert on 2 September 2025 had it about a third brighter than the reference (not shown) and one on 23 September 2025 about 0.2 mag faint in r, so the later alerts are only suggestive. WISE did not observe during the dip. Gaia (2014-2017) published only averages, whose scatter is lower than for most similar stars; ZTF finds no rotation period in any season, nor does TESS in its clean sectors from 2019 to 2024. Purple band: 2024.48-2024.67.

**Figure 172:** Candidate 55, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Bottom right: the star and its comparison stars on two separate ZTF fields, recorded by different detectors. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

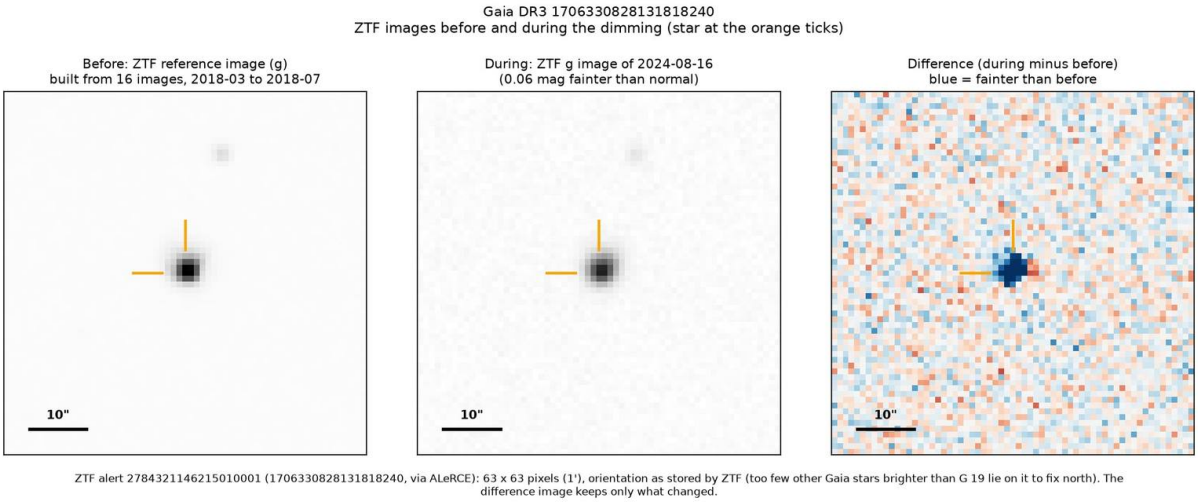



**Figure 173:** Candidate 55, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

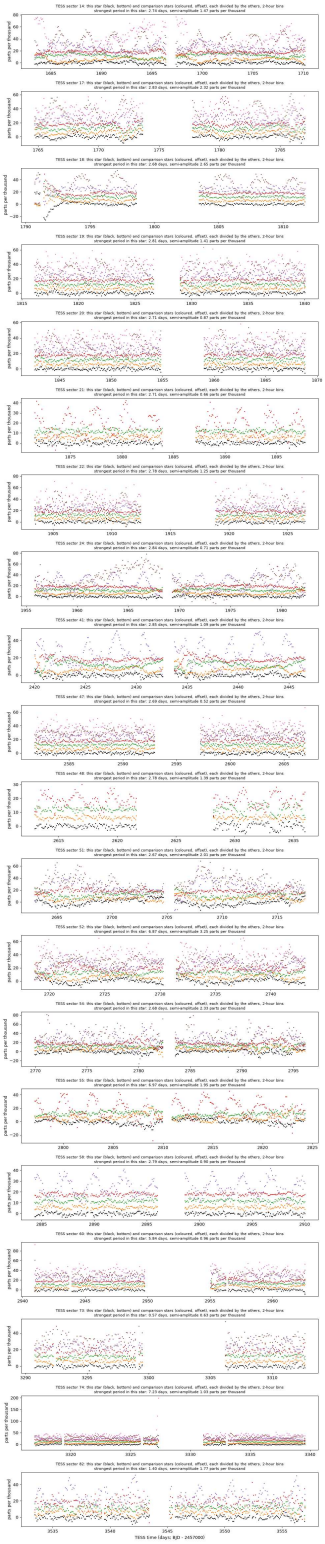


**Figure 174:** Candidate 55, TESS light curves. TESS light curves from twenty sectors, from 2019 to 2024; the last was taken during the recovery. The comparison star with a clear 2.77-day cycle is a different variable star; this star shows no rotation in any panel. In each panel the star is in black at the bottom, below comparison stars on the same images, each divided by the others, averaged over two hours and offset for clarity. Data: TESS (NASA; MAST).

## Candidate 56: A distant old star that was faint for a year

| | |
|---|---|
| **Star** | Gaia DR3 2814851407508236160, a distant, metal-poor subgiant |
| **Position** | RA 345.48049°, Dec +12.76838° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Pegasus |
| **Galactic** | $l = 85.77°$, $b = -42.07°$ |
| **Distance** | 2,200 to 2,900 parsecs (7,200 to 9,500 light-years) |
| **Brightness** | Gaia $G = 15.31$; far too faint for the eye |
| **Event** | faint from before 2018 May to mid-2019; 0.19 mag in g (16 per cent) on 2018 Dec 17 |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 20% |

**What changed.** The star is a subgiant poor in heavy elements, 2,200 to 2,900 parsecs away in Pegasus, in the Milky Way's thick disk or halo and near the direction of the MBM 53–55 dust clouds. ZTF found it already faint when it began observing in May 2018. It was faintest from November 2018 to January 2019, 0.19 magnitudes fainter in green light on 17 December 2018, about 16 per cent less light, faint again in June 2019, and steady from August 2019 to 2024. ASAS-SN saw it 0.14 magnitudes faint in December 2018.

**Why it might matter.** Blue light dimmed about 1.4 to 1.7 times as much as red light, which fits dust and is more than spots on a star this cool usually give. But WISE observed in November 2018 and saw the star 0.024 magnitudes faint at 3.4 microns, about what starspots would give and more than dust would (0.004), so the infrared leans towards spots. In May 2025 alerts showed the star faint again, but no other survey confirmed it.

**Checks against the record.** No record of the dimming could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it. One of them calls it a spotted binary of the RS Canum Venaticorum kind, with a probability of 0.90.

**Why this estimate.** The dimming is real: ZTF recorded it in three filters and ASAS-SN, a separate network of small telescopes, saw the star faintest in December 2018 too. But the infrared measurement made during the dimming leans towards starspots, a machine classification calls the star a spotted binary, and only one ZTF field covers it.

**Caveats.** The infrared leans towards starspots. Only one ZTF field covers the star, its beginning was missed, and there is no TESS or ultraviolet test. Candidate 30, about 29 degrees away, was also deepest in December 2018. There is no spectrum.

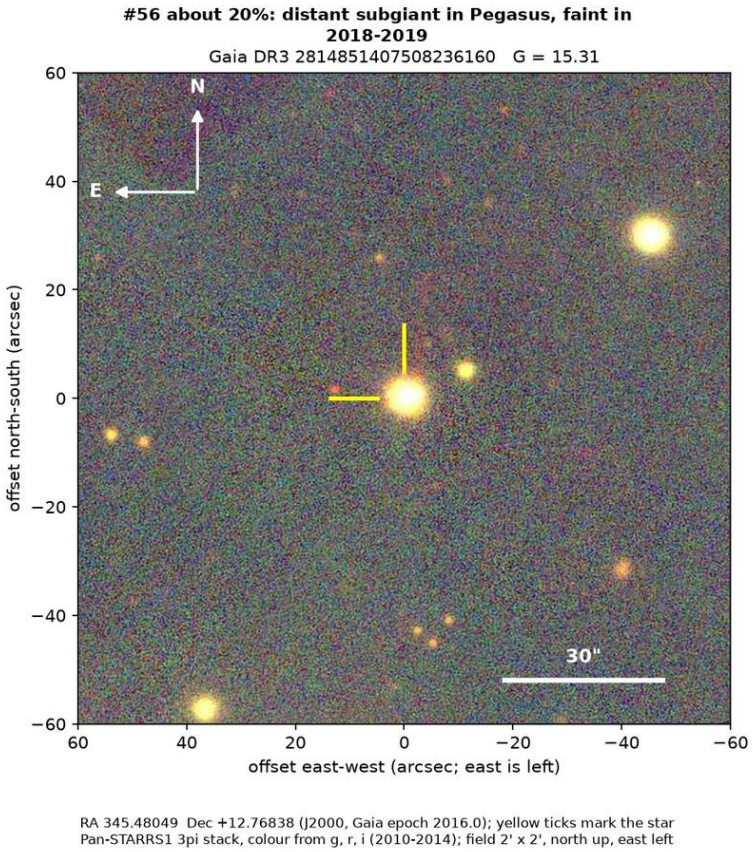
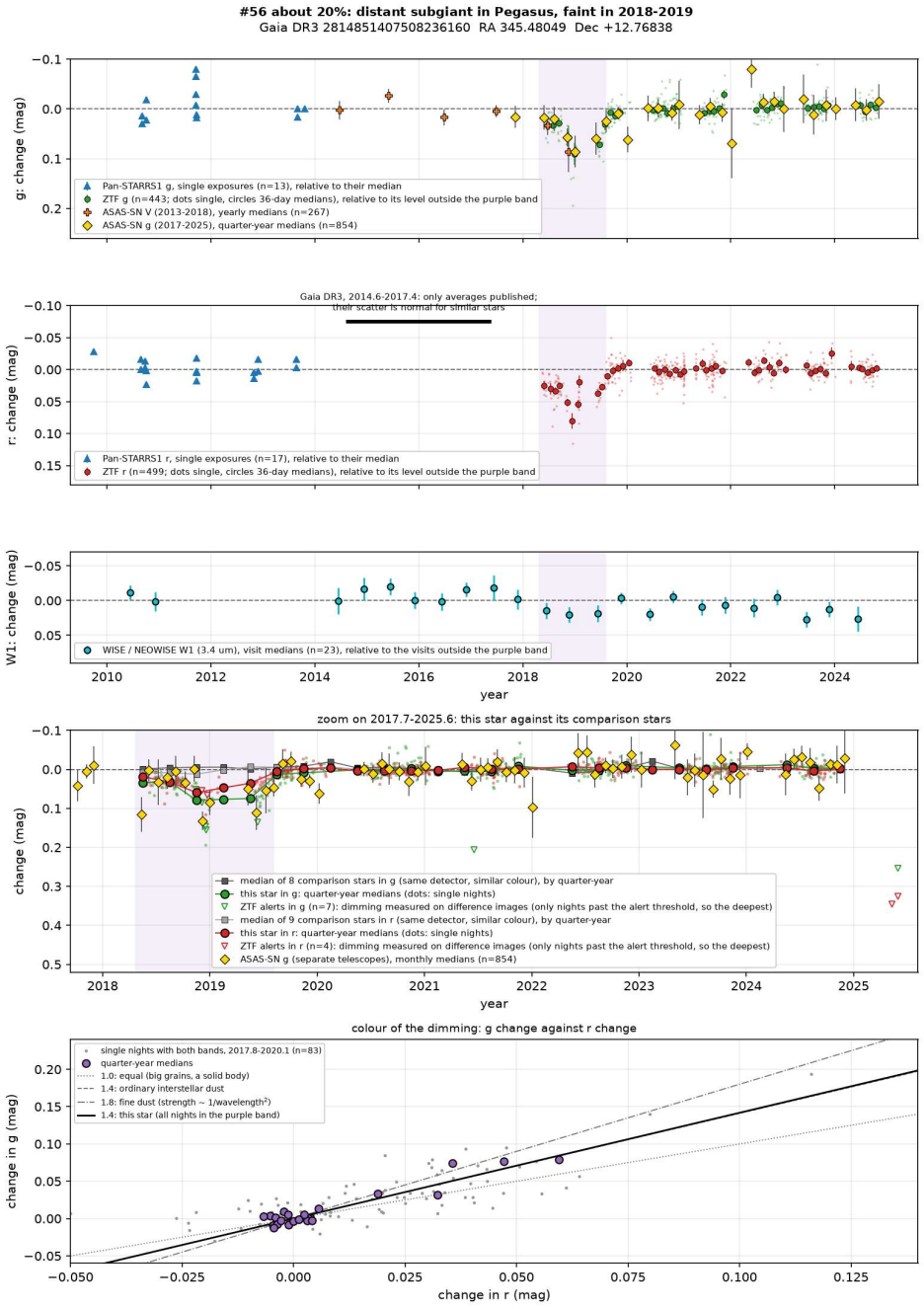



**Figure 175:** Candidate 56, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks; the fainter star 12 arcseconds to its west-north-west is a neighbour (G = 18.7). North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.




ZTF saw this star faint from the start of its observations (May 2018: about 0.03 mag in g and r) until mid-2019, most of all from November 2018 to January 2019 (0.14 mag in g and 0.08 mag in r in December 2018) and again in June 2019 (0.07 mag in g); from August 2019 until the published data end (October 2024) it was steady (yearly medians within 0.005 mag). Only one ZTF field covers it, but in all three filters: from November 2018 to mid-July 2019 the star was 0.075 mag faint in g, 0.043 in r and 0.026 in i, while 9-10 stars of similar colour and brightness on the same detector changed by at most 0.018 mag (grey squares: quarter-year medians of comparison stars). ZTF's separate difference-image pipeline recorded 7 good-quality alerts, all 'fainter than the reference', from 14 November 2018 to 13 June 2019; the last of them, and an eighth on 19 June 2021 (with r normal that night), come from g exposures that the catalogue flags as poor. ASAS-SN, a separate network of small telescopes, saw the star 0.14 mag faint in g in December 2018 (gold diamonds), its faintest well-observed month from 2017 to 2025, with June 2019 second, and in four of the five cameras observing it the dip was deeper than any stretch of the same length outside it, although its measurements of a star this faint scatter by about 0.05 mag; its V record has the star steady from 2014 to 2017 and 0.05 mag faint in 2018. Blue light dimmed about 1.4 times as much as red over all nights in the purple band (panel above) and 1.7 times from November 2018 to mid-July 2019, and red about 1.7 times as much as the near-infrared i band (few i nights): fine dust gives about 1.8 and 1.5, starspots on a star this hot about 1.2 and 1.2. WISE saw the star 0.024 +/- 0.011 mag faint at 3.4 um in November 2018 (r 0.05 mag faint), as starspots would (dust: about 0.004), and within 0.01 mag of normal in June 2018 and June 2019, between the two, so the infrared leans slightly towards spots. After the published data end, three good alerts had the star 0.25-0.35 mag faint in g and r in May 2025 (right edge of the zoom), which no other survey covered well. Gaia (2014-2017) published only averages, whose scatter is normal for similar stars, and ZTF finds no rotation period in any season. Purple band: 2018.3-2019.6.

**Figure 176:** Candidate 56, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars, ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

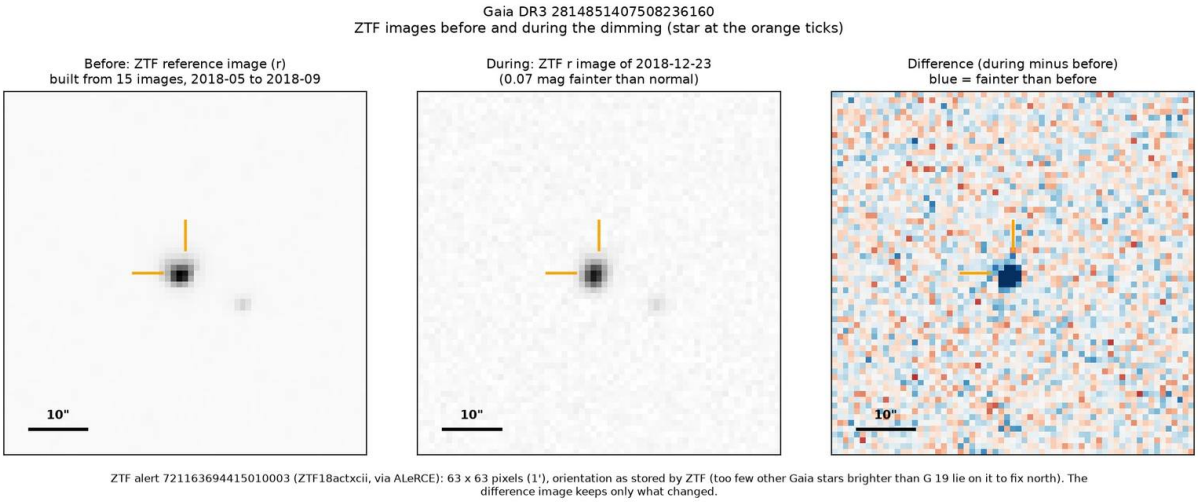



**Figure 177:** Candidate 56, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

## Candidate 57: A cool Sun-like dwarf that faded for about a year

| | |
|---|---|
| **Star** | Gaia DR3 3106218759061394176, a cool Sun-like dwarf of early K type |
| **Position** | RA 102.64724°, Dec −2.30237° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Monoceros, 1.2 degrees south of the Milky Way's mid-plane |
| **Galactic** | $l = 214.88°$, $b = -1.24°$ |
| **Distance** | about 700 parsecs (2,300 light-years) |
| **Brightness** | Gaia $G = 14.44$; far too faint for the eye |
| **Event** | slow fade from 2021 Mar; 0.045–0.07 mag in 2022 Jan–May; normal by 2022 Aug–Sep |
| **Assessment** | unconfirmed candidate; estimated probability of a real, previously unrecorded event of the kind described: about 10% |

**What changed.** The star is a cool Sun-like dwarf, a little smaller and cooler than the Sun, about 700 parsecs away near the plane of the Milky Way. ZTF saw it steady, within about 0.015 magnitudes, from 2018 to March 2021. It then faded slowly, and from January to May 2022 it was 0.045 to 0.07 magnitudes faint in green and red light, about 4 to 6 per cent less light. It was back to normal by August 2022 in ASAS-SN and by September in ZTF. ZTF's alert system, which compares each new image with a reference image, flagged it six times during the fade, and ASAS-SN's six faintest well-observed months since 2018 all fall inside it.

**Why it might matter.** Starspots are the likeliest cause. In the season just before the fade, ZTF found the star varying with a period of 7.46 days, in green and red light alike, and none of 12 similar stars nearby shows such a signal. A Sun-like dwarf that spins once every 7.5 days is either young or kept spinning by a close companion, and either way magnetically active; the spots of such stars grow and decay over months and years, changing their brightness by several per cent. Green light dimmed 1.0 to 1.2 times as much as red, as spots would make it, though large dust grains would too; ordinary interstellar dust gives 1.4.

Dust passing in front of the star could still explain the slow fade and quick recovery. NEOWISE saw no clear change at 3.4 microns in March 2022, which argues against an opaque body but cannot tell spots from dust. A spectrum would settle the question: strong emission in the calcium H and K lines, or lithium in the star's atmosphere, would confirm a young, active star.

**Checks against the record.** No record of the fade could be found. The star is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted, nor among the dimming stars of Tzanidakis et al. (2025), and there is no Transient Name Server entry, Gaia alert or paper giving its Gaia number. ZTF's alert system holds only machine-generated classifications for it. But a young spotted star that varies by a few per cent would be an ordinary find, not an anomaly.

**Why this estimate.** The fade is certainly real: the ZTF survey telescope at Palomar Observatory in California and ASAS-SN, a worldwide network of small telescopes, both recorded it while comparison stars stayed steady. But just before it, ZTF caught the star's light rising and falling every 7.5 days, and NASA's TESS space telescope found a similar period. A Sun-like dwarf that spins this fast is magnetically active, its starspots can dim it by a few per cent, and green and red light dimmed about equally, as spots make them do, so spots are the likelier cause.

**Caveats.** The rotation signal is clear in only one season, and the matching TESS signal is weak and blended with a bright giant. Only one ZTF field covers the star. Several other stars in the same broad part of the sky, one of them already published by Tzanidakis et al. (2025), were also faint in late 2021 and early 2022, but ASAS-SN, which shares no equipment with ZTF, saw this fade too. There is no spectrum.

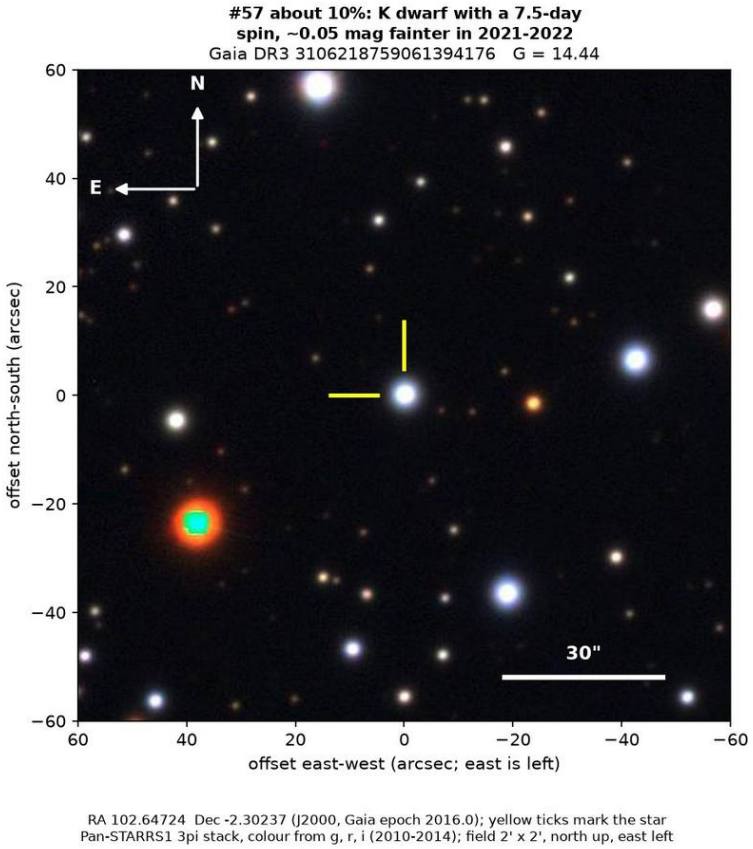



**Figure 178:** Candidate 57, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is the bright one between the yellow ticks. Its brightest close neighbours are the small orange star 24 arcseconds to the west (G = 16.8) and the bright, saturated orange giant 45 arcseconds to the south-east (G = 12.5). North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

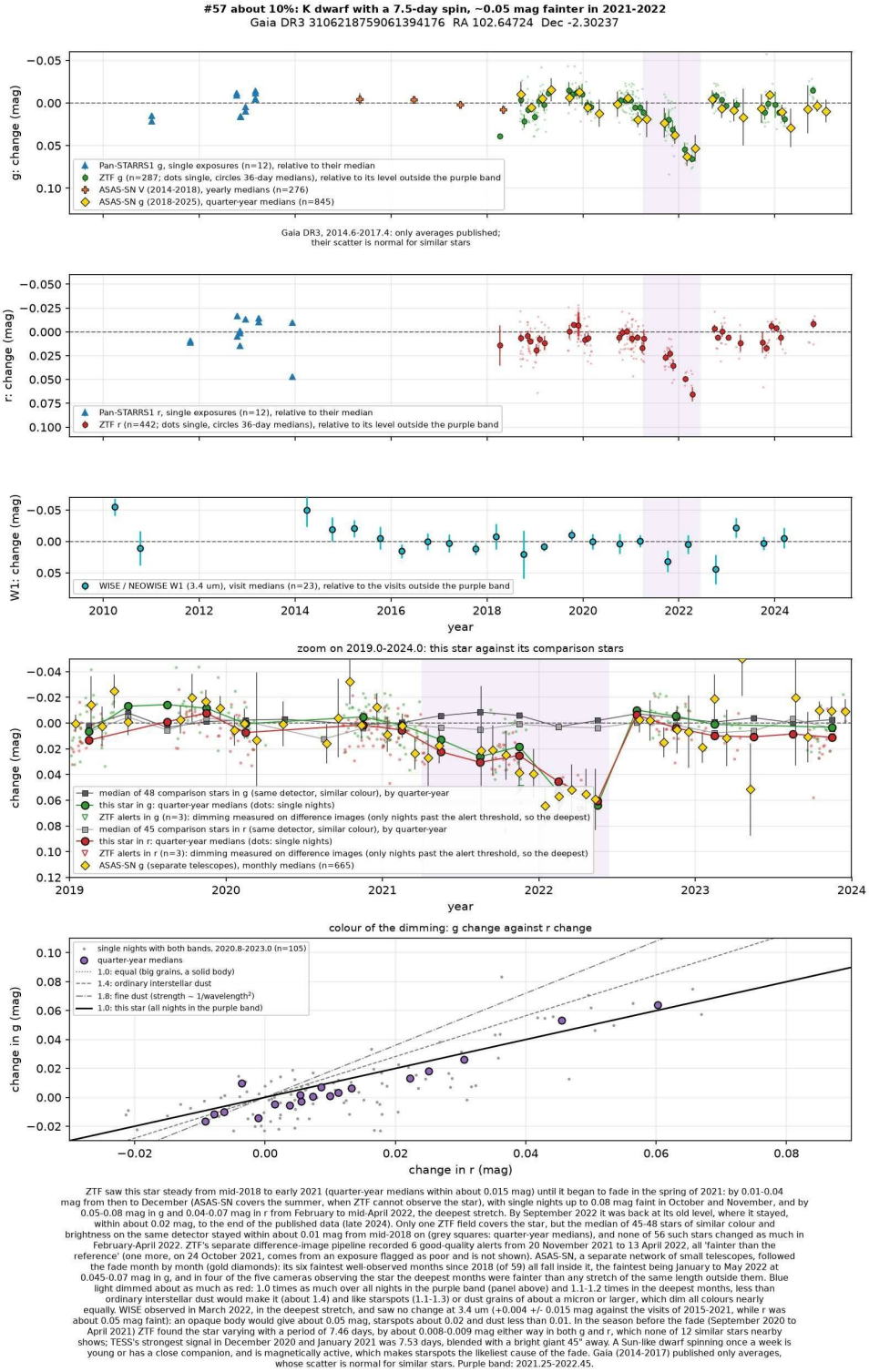



**Figure 179:** Candidate 57, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope); gold diamonds and orange crosses are ASAS-SN, and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the fade. Middle: 2019 to 2024, the star against its comparison stars, with ZTF's alerts and ASAS-SN's monthly medians. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); ASAS-SN Sky Patrol; WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

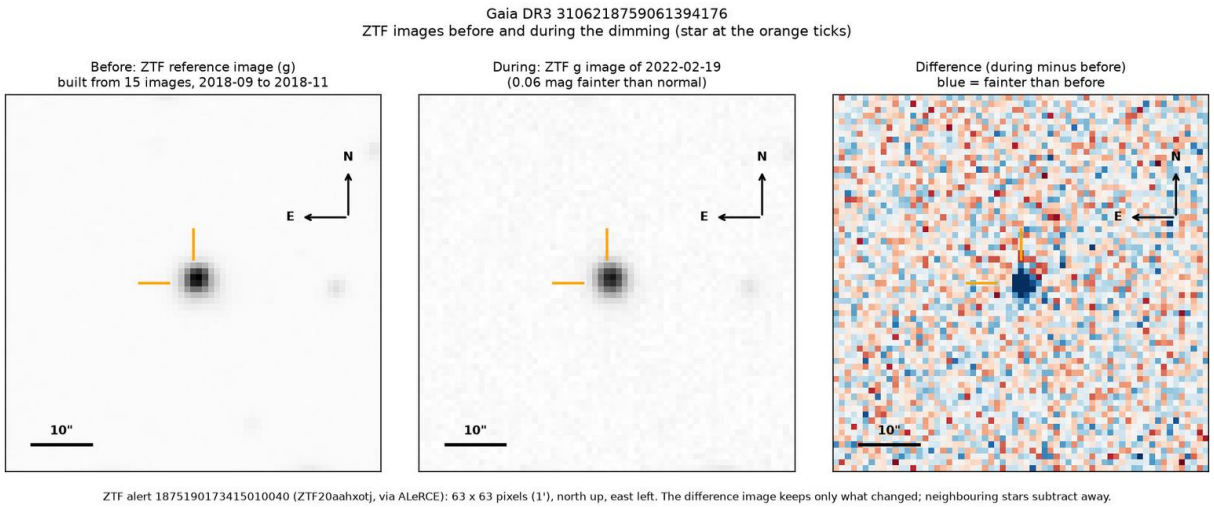



**Figure 180:** Candidate 57, before and during. Cutouts from one ZTF alert, one arcminute across, turned north up and east left; orange ticks mark the star. Left: the reference image in green light, made in 2018, long before the fade. Middle: the image of 19 February 2022, during the fade, with the star 0.06 magnitudes fainter than normal. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot. Data: ZTF (Caltech/IPAC).

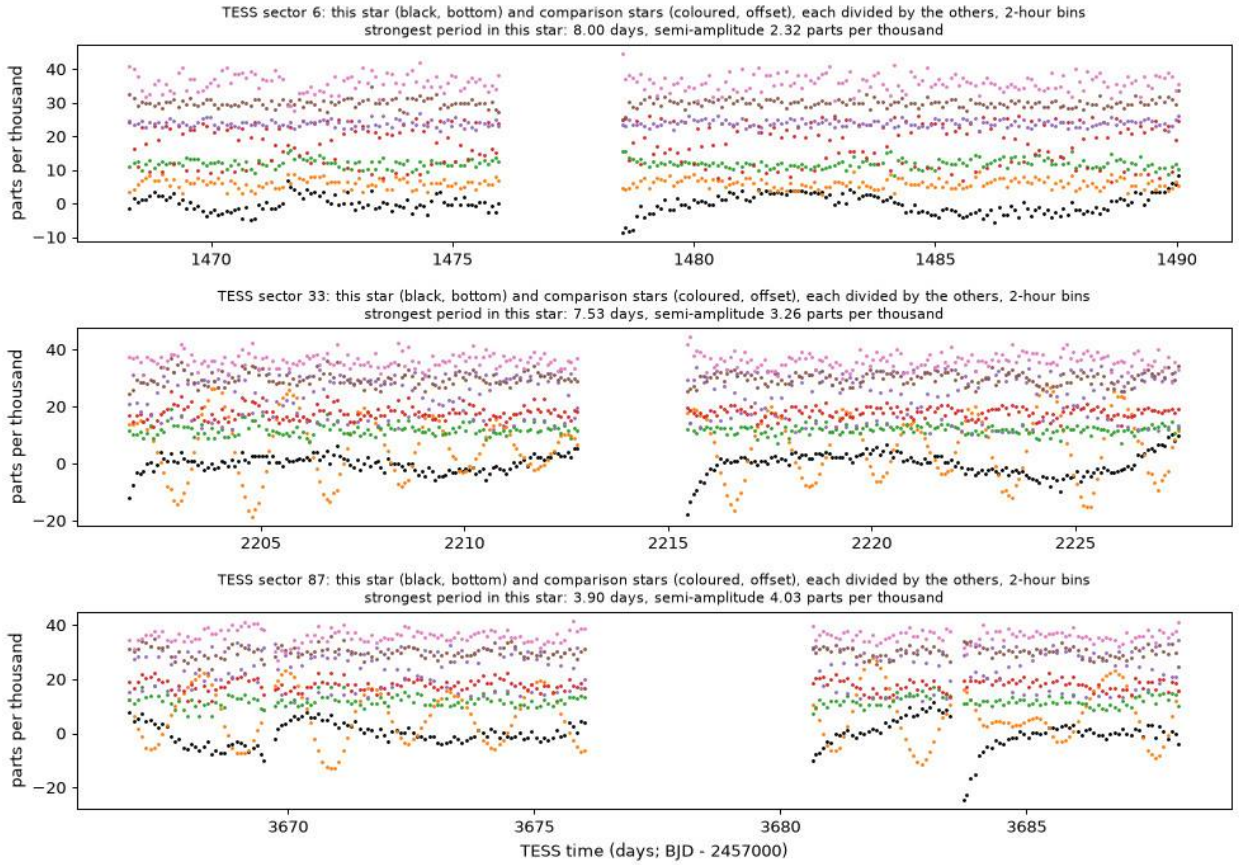



**Figure 181:** Candidate 57, TESS light curves. TESS light curves from three periods, all outside the fade: December 2018 to January 2019 (top), December 2020 to January 2021, three months before the fade began (middle), and December 2024 to January 2025 (bottom). The star is in black at the bottom of each, below six comparison stars, each divided by the others and offset for clarity; in the lower two panels one of them (orange) is an eclipsing binary with dips every 1.7 days. The star's strongest signal is 8.0 days at the top (the longest period tested), 7.53 days in the middle and 3.9 days at the bottom, each a few parts per thousand; the bright giant 45 arcseconds away shares its TESS pixels. Data: TESS (NASA; MAST).

## Candidate 58: A Sun-like star that dimmed for three months, already published

| | |
|---|---|
| **Star** | Gaia DR3 972475707866911744, a Sun-like star |
| **Position** | RA 92.36076°, Dec +53.20510° (Gaia DR3, ICRS, epoch J2016.0) |
| **Where** | In Auriga, 16 degrees above the Milky Way's mid-plane |
| **Galactic** | $l = 160.61°$, $b = +15.55°$ |
| **Distance** | about 860 parsecs (2,800 light-years) |
| **Brightness** | Gaia $G = 14.67$; far too faint for the eye |
| **Event** | 0.17 mag in g (14 per cent) from 2021 Sep 10–17 to at least late Nov; already published |
| **Assessment** | already published (Tzanidakis et al. 2025); no estimate |

**Why it is listed.** This dip is not new. Tzanidakis et al. (2025) include the star among 81 main-sequence stars with dips found in ZTF data and show the same late-2021 dip, so it carries no estimate. The checks described here were made independently and agree with the paper that the dip is real.

**What changed.** The star is very like the Sun, about 5,900 K, 1.04 times the Sun's mass and about 4.6 billion years old, some 860 parsecs away in Auriga. ZTF saw it steady until August 2021. Between 10 and 17 September 2021 it dropped to 0.17 magnitudes fainter in green light, 14 per cent of it, and 0.06 in red light, and it stayed faint until at least late November. ZTF took no data from early December to mid-January; when it looked again, the star was back to normal. Of 56 stars of similar colour on the same detector, none changed by more than 0.014 magnitudes, and ZTF's alert system flagged the star 13 times.

**Why it might matter.** Blue light dimmed about 2.2 times as much as red light. By luck, NEOWISE observed the star on 24 September 2021, in the middle of the dip, and found it exactly as bright at 3.4 microns as on its 22 other visits. A solid body or large dust grains would have dimmed the infrared too, by about 0.06 magnitudes, so they are ruled out, and the steep colour fits very fine dust crossing the line of sight.

**Checks against the record.** Apart from the paper of Tzanidakis et al. (2025), the dip is not in SIMBAD, VSX (the variable-star index), Gaia's variable-star lists or the other catalogues consulted. The paper gives the star's position only in a figure, which is why catalogue look-ups do not find it.

**Caveats.** The dip has already been published. Only one ZTF field covers the star, and no other survey watched it during the dip. A star of similar brightness 15 arcseconds away, unrelated to it, stayed steady on the same images.

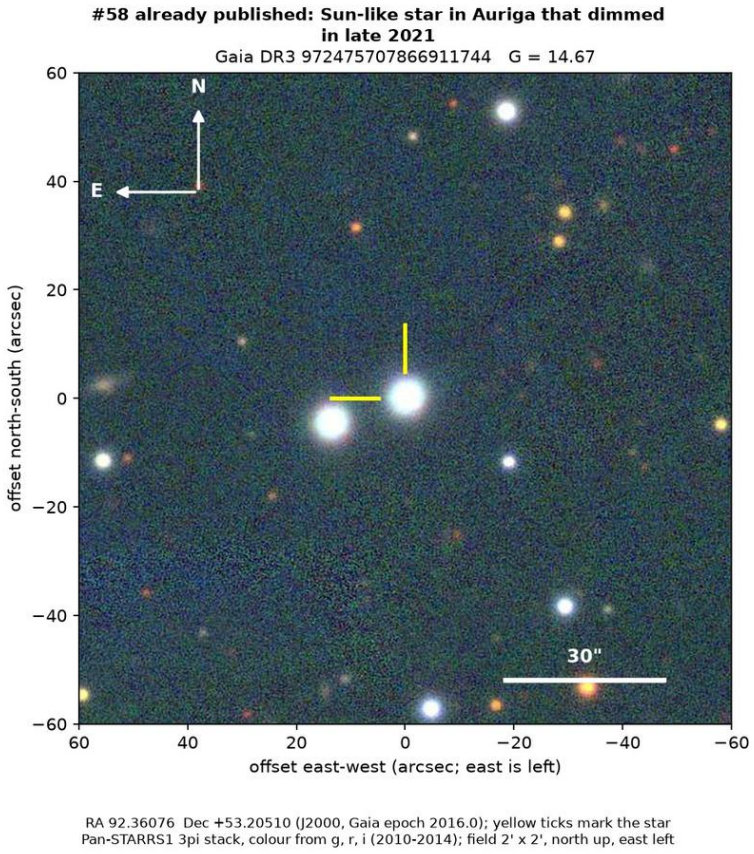



**Figure 182:** Candidate 58, sky image. Pan-STARRS1 colour image in the g, r and i filters, from 2010 to 2014, two arcminutes by two. The star is between the yellow ticks; the similar star just to its lower left is an unrelated background star. North is up, east is left, and the white bar is 30 arcseconds. Data: Pan-STARRS1 (STScI/MAST); ESA/Gaia/DPAC.

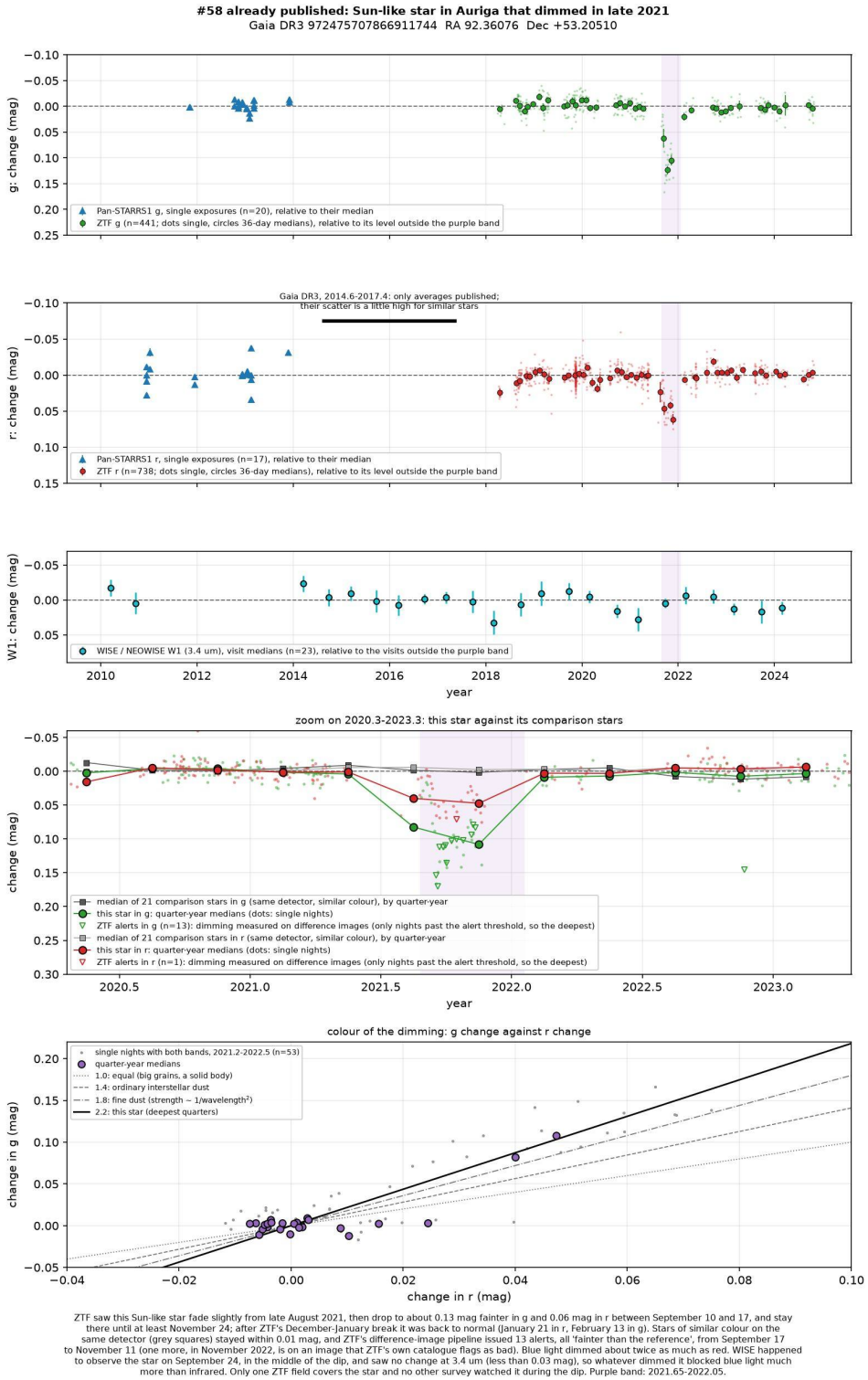



**Figure 183:** Candidate 58, light curve. Top three rows: brightness from 2010 to 2025 in green, red and infrared light, each against the star's normal level, from Pan-STARRS1 (a survey telescope in Hawaii), ZTF, and WISE and NEOWISE (NASA's infrared space telescope), and a note marks the years of Gaia, the European Space Agency's star-mapping satellite, which publishes only averages. Purple marks the dimming. Middle: a closer view, with the star against its comparison stars and ZTF's alerts. Bottom: the change in green against that in red, with lines for dimming equal in all colours, ordinary dust and fine dust; the solid line is this star's. Down means fainter. The note under the graphs sums up the measurements. Data: Pan-STARRS1 (STScI/MAST); ZTF (Caltech/IPAC); WISE/NEOWISE (NASA/JPL/IPAC); ESA/Gaia/DPAC.

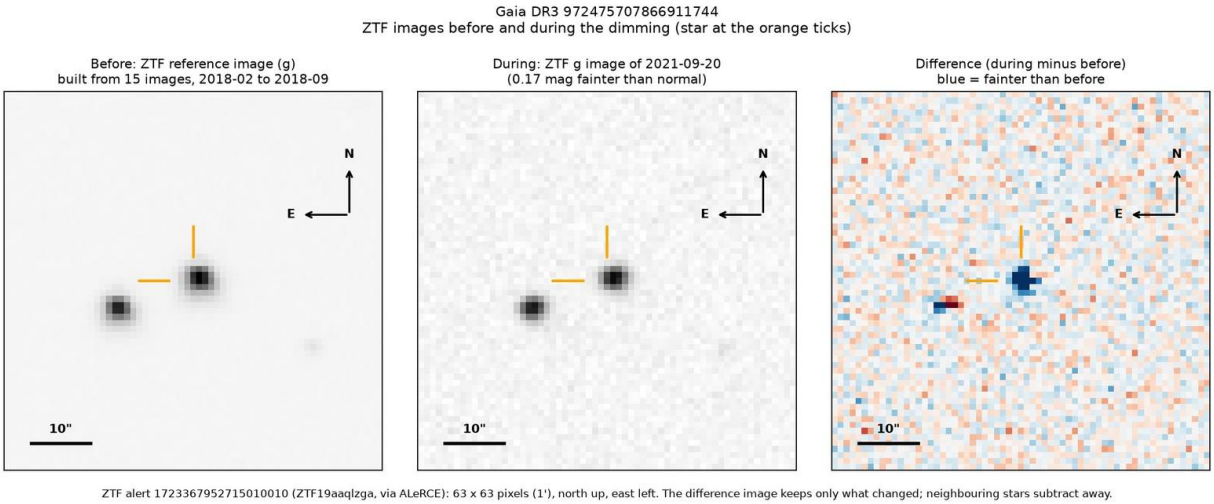



**Figure 184:** Candidate 58, before and during. Cutouts from one ZTF alert, one arcminute across; orange ticks mark the star. Left: the reference image, made in 2018 before the dimming. Middle: an image taken during the dimming. Right: the difference between them, in which blue means fainter; the star leaves a dark blue spot, while its neighbours subtract away. Data: ZTF (Caltech/IPAC).

# 6 Discussion

## 6.1 Why these are candidates and not discoveries

For most of the dimmings the change itself is not in doubt: two detectors or two instruments recorded it while comparison stars stayed steady. What is uncertain is its cause. Dust passing in front of an ordinary, mature star is the explanation that best fits most of them, from the colour of the dimming and the lack of signs of youth or activity, but spotted stars, young stars with discs of their own, faint companions that vary and unrecognised instrumental effects can produce similar light curves, and for a single star the tests made here favour one explanation over another only by a few standard deviations. None of the 57 unpublished candidates has a spectrum taken during or after its event, which is the main reason no estimate is higher. The microlensing-like events rest on Gaia's sparse sampling of a single brightening each; the dark companions rest on Gaia orbits that lack radial-velocity confirmation and that, in several cases, come from Gaia's less reliable alternative solutions or have periods as long as the data set; and the plate source most probably is an emulsion flaw.

## 6.2 Is each candidate really unrecorded?

We could search only public records, and several were incomplete: the Strasbourg services were unreachable during the search, so SIMBAD and VizieR were read through mirrors; ADS full texts were not searched; some catalogues, such as the vanishing sources of Solano et al. (2022), could not be retrieved; and papers whose source lists appear only in figures or in journal tables that are not in VizieR, as for Tzanidakis et al. (2025), escape catalogue look-ups, which is how candidate 58's publication was nearly missed. Machine-generated entries were not counted as records. The probabilities refer to whether each case is real and unrecorded; for candidates 9 to 12 they would be higher if Gaia's machine-generated classification were counted as a record.

## 6.3 How reliable are the probabilities?

The probabilities are careful judgements, not calibrated frequencies, and they have not been checked by outside experts. Their sum, about 16, would be the expected number of real, previously unrecorded cases among the 57 if the judgements were unbiased, but there is no independent sample of outcomes with which to test them. The one independent re-examination, of two dark-companion candidates, lowered both. The population comparison of Section 3.9 lowered the estimates of the slow changes. Follow-up of even a few candidates across the range of probabilities would show whether the estimates are too high or too low.

## 6.4 Completeness and biases

The catalogue is far from complete. The Gaia strand saw only the 34 months of DR3 and only sources that Gaia classified as variable; its dimming and brightening events came only from light curves that passed the skewness and Abbe cuts after common classes were removed, so dimmings of stars that Gaia's classifier assigned to those classes, including eclipsing binaries and long-period variables, were lost, and how its smooth trends were selected is not recorded. The ZTF strand covers only the sky north of declination $-30^\circ$ and the years since 2018, and it favours stars of $G \approx 13$ to 18 that ZTF measures well; its initial selection is described only in outline. The orbit screening inherits the selection of Gaia's non-single-star catalogue (El-Badry et al. 2024a), and its sceptical tests remove genuine companions of giants, as they removed Gaia BH2. The plate strand was a pilot. The catalogue should therefore not be used to estimate how often such events happen.

## 6.5 How the candidates could be confirmed

**Spectroscopy.** A spectrum of each dimming star would establish its type, age and activity (from its temperature and gravity, lithium, H$\alpha$ and calcium emission) and test for youth and for companions. During a future dimming, spectra could show absorption by gas in the occulting material. For the dark-companion

candidates, a few radial velocities over a year would test the Gaia orbits directly: a flat radial-velocity curve would reject a candidate, and the amplitude would fix the companion's minimum mass.

**Photometry.** Continued monitoring by ZTF, ASAS-SN, TESS and the Legacy Survey of Space and Time of the Vera C. Rubin Observatory would show whether any dimming repeats; a periodic repeat would point to an orbiting body. Simultaneous measurements in several colours and in the infrared during a dimming would separate dust from spots and opaque bodies better than the measurements available here. Gaia DR4, expected around the end of 2026 and based on 66 months of data, is to publish epoch photometry and astrometry for all sources; it should cover the recovery of candidate 1 and its second dip, extend the light curves of the Gaia candidates, and confirm, revise or drop the orbits of candidates 13 to 23. For the microlensing-like candidates, high-resolution imaging years after the event could separate the lens from the source. For candidate 8, a fresh scan or inspection of the original 1955 plates, or other plates of the same night, would show whether the spot is a flaw.

**Priorities.** Natural first targets are the candidates with the highest estimates and the clearest predictions: candidates 1 and 24 (spectra, and Gaia DR4 for 1), 25, 26 (whose infrared brightening suggests warm dust), 27, 28 and 29 among the dimmings; candidates 9 and 10 among the microlensing-like events; and candidate 13, the one of the two dark companions examined independently (Section 3.8) that was judged worth a radial-velocity check.

### 6.6 Honest uncertainty

No candidate in this catalogue has been confirmed by new observations, and apart from candidate 58, whose dip had already been published, we found no earlier report of any of them. For most of them the change in brightness or the Gaia measurement is well established, but whether it is a new astrophysical event of the kind described is a matter of probability, and on the evidence collected here most of the candidates probably have mundane explanations. We have tried to state for each one what the data show, how the alternatives were tested and what remains uncertain, so that each case can be checked against the original data and settled by new observations.

## 7 Data availability

The public pages that present the 58 candidates, with their pictures, plain-language explanations and probabilities, are at `https://paatai.github.io/vibe-projects/galaxy/`; the candidates are numbered 1 to 58 as in this paper. The LaTeX source of this paper, its figures, the tables from which its tables and statistics are generated (`data/candidates.json`, `data/events.csv`, `data/gaia_dr3.csv`) and the scripts that make the figures for this paper and check its references are distributed with the paper. All the data used are public and can be retrieved from the archives named in Section 2: the ESA Gaia archive (`https://gea.esac.esa.int/archive/`), IRSA (`https://irsa.ipac.caltech.edu`), MAST (`https://archive.stsci.edu`), the NOIRLab Astro Data Archive and Data Lab (`https://astroarchive.noirlab.edu`, `https://datalab.noirlab.edu`), ASAS-SN Sky Patrol (`http://asas-sn.ifa.hawaii.edu/skypatrol/`), SkyMapper (`https://skymapper.anu.edu.au`), the ALeRCE broker (`https://alerce.online`) and the CDS (`https://cds.unistra.fr`). Contact: `ivanishvili.paata@gmail.com`.

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This work made use of Astropy (`https://www.astropy.org`), a community-developed core Python package and an ecosystem of tools and resources for astronomy (Astropy Collaboration et al. 2013; Astropy Collaboration et al. 2018; Astropy Collaboration et al. 2022). It also made use of astroquery (Ginsburg et al. 2019), NumPy (Harris et al. 2020), SciPy (Virtanen et al. 2020), Matplotlib (Hunter 2007), pandas (McKinney 2010), PyVO (`https://github.com/astropy/pyvo`), the ASAS-SN Sky Patrol client `pyasassn` (Hart et al. 2023), the Gaia DPAC tool `nsstools` (`https://gitlab.obspm.fr/gaia/nsstools`) and Pillow.

# 8 Disclosure of AI assistance

The search described in this paper, the analysis of the data, the figures and much of the text were carried out with Grok Bot coordinating Cursor cloud agents, under the direction of the author. The author set the aims and rules of the search and reviewed and approved its results and the public descriptions of the candidates. The estimated probabilities were made in the same way and have not been reviewed by outside experts. The independent re-examination of two dark-companion candidates (Section 3.8) was carried out in the same way, by a separate agent instructed to act as a hostile referee and not to reuse the earlier code or conclusions. The light curves made for this paper, and the checks of its references, identifiers and acknowledgment statements, were also made with Cursor cloud agents. None of the candidates has yet been confirmed by new observations.

# References

Abdurro'uf, K. Accetta, C. Aerts, V. Silva Aguirre, R. Ahumada, N. Ajgaonkar, N. Filiz Ak, S. Alam, et al. (2022). "The Seventeenth Data Release of the Sloan Digital Sky Surveys: Complete Release of MaNGA, MaStar, and APOGEE-2 Data". In: *The Astrophysical Journal Supplement Series* 259, p. 35. DOI: 10.3847/1538-4365/ac4414.

Anders, F., A. Khalatyan, A. B. A. Queiroz, C. Chiappini, J. Ardèvol, L. Casamiquela, F. Figueras, Ó. Jiménez-Arranz, et al. (2022). "Photo-astrometric distances, extinctions, and astrophysical parameters for Gaia EDR3 stars brighter than $G = 18.5$". In: *Astronomy & Astrophysics* 658, A91. DOI: 10.1051/0004-6361/202142369.

Andrae, R., M. Fouesneau, R. Sordo, C. A. L. Bailer-Jones, T. E. Dharmawardena, J. Rybizki, F. De Angeli, H. E. P. Lindstrøm, et al. (2023). "Gaia Data Release 3. Analysis of the Gaia BP/RP spectra using the General Stellar Parameterizer from Photometry". In: *Astronomy & Astrophysics* 674, A27. DOI: 10.1051/0004-6361/202243462.

Ansdell, M., E. Gaidos, S. A. Rappaport, T. L. Jacobs, D. M. LaCourse, K. J. Jek, A. W. Mann, M. C. Wyatt, et al. (2016). "Young "Dipper" Stars in Upper Sco and $\rho$ Oph Observed by K2". In: *The Astrophysical Journal* 816, p. 69. DOI: 10.3847/0004-637X/816/2/69.

Astropy Collaboration, A. M. Price-Whelan, P. L. Lim, N. Earl, N. Starkman, L. Bradley, D. L. Shupe, A. A. Patil, et al. (2022). "The Astropy Project: Sustaining and Growing a Community-oriented Open-source Project and the Latest Major Release (v5.0) of the Core Package". In: *The Astrophysical Journal* 935, p. 167. DOI: 10.3847/1538-4357/ac7c74.

Astropy Collaboration, A. M. Price-Whelan, B. M. Sipőcz, H. M. Günther, P. L. Lim, S. M. Crawford, S. Conseil, D. L. Shupe, et al. (2018). "The Astropy Project: Building an Open-science Project and Status of the v2.0 Core Package". In: *The Astronomical Journal* 156, p. 123. DOI: 10.3847/1538-3881/aabc4f.

Astropy Collaboration, T. P. Robitaille, E. J. Tollerud, P. Greenfield, M. Droettboom, E. Bray, T. Aldcroft, M. Davis, et al. (2013). "Astropy: A community Python package for astronomy". In: *Astronomy & Astrophysics* 558, A33. DOI: 10.1051/0004-6361/201322068.

Australian National University (2023). *SkyMapper Southern Survey (SMSS) Data Release 4 (DR4)*. NCI Australia. DOI: 10.25914/5M47-S621.

El-Badry, K., C. Lam, B. Holl, J.-L. Halbwachs, H.-W. Rix, T. Mazeh, and S. Shahaf (2024a). "A generative model for Gaia astrometric orbit catalogs: selection functions for binary stars, giant planets, and compact object companions". In: *The Open Journal of Astrophysics* 7. DOI: 10.33232/001c.125461. arXiv: 2411.00088.

El-Badry, K., H.-W. Rix, Y. Cendes, A. C. Rodriguez, C. Conroy, E. Quataert, K. Hawkins, E. Zari, et al. (2023a). "A red giant orbiting a black hole". In: *Monthly Notices of the Royal Astronomical Society* 521, pp. 4323–4348. DOI: 10.1093/mnras/stad799.

El-Badry, K., H.-W. Rix, D. W. Latham, S. Shahaf, T. Mazeh, A. Bieryla, L. A. Buchhave, R. Andrae, et al. (2024b). "A population of neutron star candidates in wide orbits from Gaia astrometry". In: *The Open Journal of Astrophysics* 7. DOI: 10.33232/001c.121261. arXiv: 2405.00089.

El-Badry, K., H.-W. Rix, E. Quataert, A. W. Howard, H. Isaacson, J. Fuller, K. Hawkins, K. Breivik, et al. (2023b). "A Sun-like star orbiting a black hole". In: *Monthly Notices of the Royal Astronomical Society* 518, pp. 1057–1085. DOI: 10.1093/mnras/stac3140.

Bailer-Jones, C. A. L., J. Rybizki, M. Fouesneau, M. Demleitner, and R. Andrae (2021). "Estimating Distances from Parallaxes. V. Geometric and Photogeometric Distances to 1.47 Billion Stars in Gaia Early Data Release 3". In: *The Astronomical Journal* 161, p. 147. DOI: 10.3847/1538-3881/abd806.

Barentsen, G., H. J. Farnhill, J. E. Drew, E. A. González-Solares, R. Greimel, M. J. Irwin, B. Miszalski, C. Ruhland, et al. (2014). "The second data release of the INT Photometric H$\alpha$ Survey of the Northern Galactic Plane (IPHAS DR2)". In: *Monthly Notices of the Royal Astronomical Society* 444, pp. 3230–3257. DOI: 10.1093/mnras/stu1651.

Bellm, E. C., S. R. Kulkarni, M. J. Graham, R. Dekany, R. M. Smith, R. Riddle, F. J. Masci, G. Helou, et al. (2019). "The Zwicky Transient Facility: System Overview, Performance, and First Results". In: *Publications of the Astronomical Society of the Pacific* 131, p. 018002. DOI: 10.1088/1538-3873/aaecbe.

Bianchi, L., B. Shiao, and D. Thilker (2017). "Revised Catalog of GALEX Ultraviolet Sources. I. The All-Sky Survey: GUVcat_AIS". In: *The Astrophysical Journal Supplement Series* 230, p. 24. DOI: 10.3847/1538-4365/aa7053.

Boyajian, T. S., D. M. LaCourse, S. A. Rappaport, D. Fabrycky, D. A. Fischer, D. Gandolfi, G. M. Kennedy, H. Korhonen, et al. (2016). "Planet Hunters IX. KIC 8462852 – where's the flux?" In: *Monthly Notices of the Royal Astronomical Society* 457, pp. 3988–4004. DOI: 10.1093/mnras/stw218.

Caldwell, D. A., J. M. Jenkins, and E. B. Ting (2020a). *TESS Light Curves From Full Frame Images ("TESS-SPOC")*. STScI/MAST. DOI: 10.17909/t9-wpz1-8s54.

Caldwell, D. A., P. Tenenbaum, J. D. Twicken, J. M. Jenkins, E. Ting, J. C. Smith, C. Hedges, M. M. Fausnaugh, et al. (2020b). "TESS Science Processing Operations Center FFI Target List Products". In: *Research Notes of the American Astronomical Society* 4, p. 201. DOI: 10.3847/2515-5172/abc9b3.

Chambers, K. C., E. A. Magnier, N. Metcalfe, H. A. Flewelling, M. E. Huber, C. Z. Waters, L. Denneau, P. W. Draper, et al. (2016). *The Pan-STARRS1 Surveys*. arXiv: 1612.05560.

Chen, X., S. Wang, L. Deng, R. de Grijs, M. Yang, and H. Tian (2020). "The Zwicky Transient Facility Catalog of Periodic Variable Stars". In: *The Astrophysical Journal Supplement Series* 249, p. 18. DOI: 10.3847/1538-4365/ab9cae.

Clayton, G. C. (1996). "The R Coronae Borealis Stars". In: *Publications of the Astronomical Society of the Pacific* 108, pp. 225–241. DOI: 10.1086/133715.

Cody, A. M., J. Stauffer, A. Baglin, G. Micela, L. M. Rebull, E. Flaccomio, M. Morales-Calderón, S. Aigrain, et al. (2014). "CSI 2264: Simultaneous Optical and Infrared Light Curves of Young Disk-bearing Stars in NGC 2264 with CoRoT and Spitzer – Evidence for Multiple Origins of Variability". In: *The Astronomical Journal* 147, p. 82. DOI: 10.1088/0004-6256/147/4/82.

Creevey, O. L., R. Sordo, F. Pailler, Y. Frémat, U. Heiter, F. Thévenin, R. Andrae, M. Fouesneau, et al. (2023). "Gaia Data Release 3. Astrophysical parameters inference system (Apsis). I. Methods and content overview". In: *Astronomy & Astrophysics* 674, A26. DOI: 10.1051/0004-6361/202243688.

Cui, X.-Q., Y.-H. Zhao, Y.-Q. Chu, G.-P. Li, Q. Li, L.-P. Zhang, H.-J. Su, Z.-Q. Yao, et al. (2012). "The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST)". In: *Research in Astronomy and Astrophysics* 12, pp. 1197–1242. DOI: 10.1088/1674-4527/12/9/003.

Dekany, R., R. M. Smith, R. Riddle, M. Feeney, M. Porter, D. Hale, J. Zolkower, J. Belicki, et al. (2020). "The Zwicky Transient Facility: Observing System". In: *Publications of the Astronomical Society of the Pacific* 132, p. 038001. DOI: 10.1088/1538-3873/ab4ca2.

Dey, A., D. J. Schlegel, D. Lang, R. Blum, K. Burleigh, X. Fan, J. R. Findlay, D. Finkbeiner, et al. (2019). "Overview of the DESI Legacy Imaging Surveys". In: *The Astronomical Journal* 157, p. 168. DOI: 10.3847/1538-3881/ab089d.

Drake, A. J., M. J. Graham, S. G. Djorgovski, M. Catelan, A. A. Mahabal, G. Torrealba, D. García-Álvarez, C. Donalek, et al. (2014). "The Catalina Surveys Periodic Variable Star Catalog". In: *The Astrophysical Journal Supplement Series* 213, p. 9. DOI: 10.1088/0067-0049/213/1/9.

Drew, J. E., R. Greimel, M. J. Irwin, A. Aungwerojwit, M. J. Barlow, R. L. M. Corradi, J. J. Drake, B. T. Gänsicke, et al. (2005). "The INT Photometric H$\alpha$ Survey of the Northern Galactic Plane (IPHAS)".

In: *Monthly Notices of the Royal Astronomical Society* 362, pp. 753–776. DOI: 10.1111/j.1365-2966.2005.09330.x.

Duev, D. A., A. Mahabal, F. J. Masci, M. J. Graham, B. Rusholme, R. Walters, I. Karmarkar, S. Frederick, et al. (2019). "Real-bogus classification for the Zwicky Transient Facility using deep learning". In: *Monthly Notices of the Royal Astronomical Society* 489, pp. 3582–3590. DOI: 10.1093/mnras/stz2357.

Evans, P. A., K. L. Page, J. P. Osborne, A. P. Beardmore, R. Willingale, D. N. Burrows, J. A. Kennea, M. Perri, et al. (2020). "2SXPS: An Improved and Expanded Swift X-Ray Telescope Point-source Catalog". In: *The Astrophysical Journal Supplement Series* 247, p. 54. DOI: 10.3847/1538-4365/ab7db9.

Eyer, L., M. Audard, B. Holl, L. Rimoldini, M. I. Carnerero, G. Clementini, J. De Ridder, E. Distefano, et al. (2023). "Gaia Data Release 3. Summary of the variability processing and analysis". In: *Astronomy & Astrophysics* 674, A13. DOI: 10.1051/0004-6361/202244242.

Fitzpatrick, M. J., K. Olsen, F. Economou, E. B. Stobie, T. C. Beers, M. Dickinson, P. Norris, A. Saha, et al. (2014). "The NOAO Data Laboratory: a conceptual overview". In: *Observatory Operations: Strategies, Processes, and Systems V*. Vol. 9149. Proc. SPIE, 91491T. DOI: 10.1117/12.2057445.

Flaugher, B., H. T. Diehl, K. Honscheid, T. M. C. Abbott, O. Alvarez, R. Angstadt, J. T. Annis, M. Antonik, et al. (2015). "The Dark Energy Camera". In: *The Astronomical Journal* 150, p. 150. DOI: 10.1088/0004-6256/150/5/150.

Flewelling, H. A., E. A. Magnier, K. C. Chambers, J. N. Heasley, C. Holmberg, M. E. Huber, W. Sweeney, C. Z. Waters, et al. (2020). "The Pan-STARRS1 Database and Data Products". In: *The Astrophysical Journal Supplement Series* 251, p. 7. DOI: 10.3847/1538-4365/abb82d.

Förster, F., G. Cabrera-Vives, E. Castillo-Navarrete, P. A. Estévez, P. Sánchez-Sáez, J. Arredondo, F. E. Bauer, R. Carrasco-Davis, et al. (2021). "The Automatic Learning for the Rapid Classification of Events (ALeRCE) Alert Broker". In: *The Astronomical Journal* 161, p. 242. DOI: 10.3847/1538-3881/abe9bc.

Gaia Collaboration, F. Arenou, C. Babusiaux, M. A. Barstow, S. Faigler, A. Jorissen, P. Kervella, T. Mazeh, et al. (2023a). "Gaia Data Release 3. Stellar multiplicity, a teaser for the hidden treasure". In: *Astronomy & Astrophysics* 674, A34. DOI: 10.1051/0004-6361/202243782.

Gaia Collaboration, A. G. A. Brown, A. Vallenari, T. Prusti, J. H. J. de Bruijne, C. Babusiaux, M. Biermann, O. L. Creevey, et al. (2021). "Gaia Early Data Release 3. Summary of the contents and survey properties". In: *Astronomy & Astrophysics* 649, A1. DOI: 10.1051/0004-6361/202039657.

Gaia Collaboration, P. Panuzzo, T. Mazeh, F. Arenou, B. Holl, E. Caffau, A. Jorissen, C. Babusiaux, et al. (2024). "Discovery of a dormant 33 solar-mass black hole in pre-release Gaia astrometry". In: *Astronomy & Astrophysics* 686, p. L2. DOI: 10.1051/0004-6361/202449763.

Gaia Collaboration, T. Prusti, J. H. J. de Bruijne, A. G. A. Brown, A. Vallenari, C. Babusiaux, C. A. L. Bailer-Jones, U. Bastian, et al. (2016). "The Gaia mission". In: *Astronomy & Astrophysics* 595, A1. DOI: 10.1051/0004-6361/201629272.

Gaia Collaboration, A. Vallenari, A. G. A. Brown, T. Prusti, J. H. J. de Bruijne, F. Arenou, C. Babusiaux, M. Biermann, et al. (2023b). "Gaia Data Release 3. Summary of the content and survey properties". In: *Astronomy & Astrophysics* 674, A1. DOI: 10.1051/0004-6361/202243940.

Gavras, P., L. Rimoldini, K. Nienartowicz, G. Jevardat de Fombelle, B. Holl, P. Ábrahám, M. Audard, M. I. Carnerero, et al. (2023). "Gaia Data Release 3. Cross-match of Gaia sources with variable objects from the literature". In: *Astronomy & Astrophysics* 674, A22. DOI: 10.1051/0004-6361/202244367.

Ginsburg, A., B. M. Sipőcz, C. E. Brasseur, P. S. Cowperthwaite, M. W. Craig, C. Deil, J. Guillochon, G. Guzman, et al. (2019). "astroquery: An Astronomical Web-querying Package in Python". In: *The Astronomical Journal* 157, p. 98. DOI: 10.3847/1538-3881/aafc33.

Gomel, R., T. Mazeh, S. Faigler, D. Bashi, L. Eyer, L. Rimoldini, M. Audard, N. Mowlavi, et al. (2023). "Gaia Data Release 3. Ellipsoidal variables with possible black hole or neutron star secondaries". In: *Astronomy & Astrophysics* 674, A19. DOI: 10.1051/0004-6361/202243626.

Graham, M. J., S. R. Kulkarni, E. C. Bellm, S. M. Adams, C. Barbarino, N. Blagorodnova, D. Bodewits, B. Bolin, et al. (2019). "The Zwicky Transient Facility: Science Objectives". In: *Publications of the Astronomical Society of the Pacific* 131, p. 078001. DOI: 10.1088/1538-3873/ab006c.

Halbwachs, J.-L., D. Pourbaix, F. Arenou, L. Galluccio, P. Guillout, N. Bauchet, O. Marchal, G. Sadowski, et al. (2023). "Gaia Data Release 3. Astrometric binary star processing". In: *Astronomy & Astrophysics* 674, A9. DOI: 10.1051/0004-6361/202243969.

Han, T. and T. Brandt (2023a). *TESS-Gaia Light Curve ("TGLC")*. STScI/MAST. DOI: 10.17909/610m-9474.

Han, T. and T. D. Brandt (2023b). "TESS-Gaia Light Curve: A PSF-based TESS FFI Light-curve Product". In: *The Astronomical Journal* 165, p. 71. DOI: 10.3847/1538-3881/acaaa7.

Harris, C. R., K. J. Millman, S. J. van der Walt, R. Gommers, P. Virtanen, D. Cournapeau, E. Wieser, J. Taylor, et al. (2020). "Array programming with NumPy". In: *Nature* 585, pp. 357–362. DOI: 10.1038/s41586-020-2649-2.

Hart, K., B. J. Shappee, D. Hey, C. S. Kochanek, K. Z. Stanek, L. Lim, S. Dobbs, M. Tucker, et al. (2023). *ASAS-SN Sky Patrol V2.0*. arXiv: 2304.03791.

Heinze, A. N., J. L. Tonry, L. Denneau, H. Flewelling, B. Stalder, A. Rest, K. W. Smith, S. J. Smartt, et al. (2018). "A First Catalog of Variable Stars Measured by the Asteroid Terrestrial-impact Last Alert System (ATLAS)". In: *The Astronomical Journal* 156, p. 241. DOI: 10.3847/1538-3881/aae47f.

Herbst, W., D. K. Herbst, E. J. Grossman, and D. Weinstein (1994). "Catalogue of UBVRI photometry of T Tauri stars and analysis of the causes of their variability". In: *The Astronomical Journal* 108, pp. 1906–1923. DOI: 10.1086/117204.

Hodgkin, S. T., D. L. Harrison, E. Breedt, T. Wevers, G. Rixon, A. Delgado, A. Yoldas, Z. Kostrzewa-Rutkowska, et al. (2021). "Gaia Early Data Release 3. Gaia photometric science alerts". In: *Astronomy & Astrophysics* 652, A76. DOI: 10.1051/0004-6361/202140735.

Holl, B., C. Fabricius, J. Portell, L. Lindegren, P. Panuzzo, M. Bernet, J. Castañeda, G. Jevardat de Fombelle, et al. (2023a). "Gaia Data Release 3. Gaia scan-angle-dependent signals and spurious periods". In: *Astronomy & Astrophysics* 674, A25. DOI: 10.1051/0004-6361/202245353.

Holl, B., A. Sozzetti, J. Sahlmann, P. Giacobbe, D. Ségransan, N. Unger, J.-B. Delisle, D. Barbato, et al. (2023b). "Gaia Data Release 3. Astrometric orbit determination with Markov chain Monte Carlo and genetic algorithms: Systems with stellar, sub-stellar, and planetary mass companions". In: *Astronomy & Astrophysics* 674, A10. DOI: 10.1051/0004-6361/202244161.

Huang, C. X. (2020). *TESS Lightcurves From The MIT Quick-Look Pipeline ("QLP")*. STScI/MAST. DOI: 10.17909/t9-r086-e880.

Huang, C. X., A. Vanderburg, A. Pál, L. Sha, L. Yu, W. Fong, M. Fausnaugh, A. Shporer, et al. (2020a). "Photometry of 10 Million Stars from the First Two Years of TESS Full Frame Images: Part I". In: *Research Notes of the American Astronomical Society* 4, p. 204. DOI: 10.3847/2515-5172/abca2e.

Huang, C. X., A. Vanderburg, A. Pál, L. Sha, L. Yu, W. Fong, M. Fausnaugh, A. Shporer, et al. (2020b). "Photometry of 10 Million Stars from the First Two Years of TESS Full Frame Images: Part II". In: *Research Notes of the American Astronomical Society* 4, p. 206. DOI: 10.3847/2515-5172/abca2d.

Hunt, E. L. and S. Reffert (2023). "Improving the open cluster census. II. An all-sky cluster catalogue with Gaia DR3". In: *Astronomy & Astrophysics* 673, A114. DOI: 10.1051/0004-6361/202346285.

Hunter, J. D. (2007). "Matplotlib: A 2D Graphics Environment". In: *Computing in Science & Engineering* 9, pp. 90–95. DOI: 10.1109/MCSE.2007.55.

Kenworthy, M., S. Lock, G. Kennedy, R. van Capelleveen, E. Mamajek, L. Carone, F.-J. Hambsch, J. Masiero, et al. (2023). "A planetary collision afterglow and transit of the resultant debris cloud". In: *Nature* 622, pp. 251–254. DOI: 10.1038/s41586-023-06573-9.

Kloppenborg, B., R. Stencel, J. D. Monnier, G. Schaefer, M. Zhao, F. Baron, H. McAlister, T. ten Brummelaar, et al. (2010). "Infrared images of the transiting disk in the $\epsilon$ Aurigae system". In: *Nature* 464, pp. 870–872. DOI: 10.1038/nature08968.

Kochanek, C. S., B. J. Shappee, K. Z. Stanek, T. W.-S. Holoien, T. A. Thompson, J. L. Prieto, S. Dong, J. V. Shields, et al. (2017). "The All-Sky Automated Survey for Supernovae (ASAS-SN) Light Curve Server v1.0". In: *Publications of the Astronomical Society of the Pacific* 129, p. 104502. DOI: 10.1088/1538-3873/aa80d9.

Kounkel, M. and K. Covey (2019). "Untangling the Galaxy. I. Local Structure and Star Formation History of the Milky Way". In: *The Astronomical Journal* 158, p. 122. DOI: 10.3847/1538-3881/ab339a.

Law, N. M., S. R. Kulkarni, R. G. Dekany, E. O. Ofek, R. M. Quimby, P. E. Nugent, J. Surace, C. C. Grillmair, et al. (2009). "The Palomar Transient Factory: System Overview, Performance, and First Results". In: *Publications of the Astronomical Society of the Pacific* 121, pp. 1395–1408. DOI: 10.1086/648598.

Lindegren, L., S. A. Klioner, J. Hernández, A. Bombrun, M. Ramos-Lerate, H. Steidelmüller, U. Bastian, M. Biermann, et al. (2021). "Gaia Early Data Release 3. The astrometric solution". In: *Astronomy & Astrophysics* 649, A2. DOI: 10.1051/0004-6361/202039709.

Lomb, N. R. (1976). "Least-squares frequency analysis of unequally spaced data". In: *Astrophysics and Space Science* 39, pp. 447–462. DOI: 10.1007/BF00648343.

Mainzer, A., J. Bauer, R. M. Cutri, T. Grav, J. Masiero, R. Beck, P. Clarkson, T. Conrow, et al. (2014). "Initial Performance of the NEOWISE Reactivation Mission". In: *The Astrophysical Journal* 792, p. 30. DOI: 10.1088/0004-637X/792/1/30.

Mainzer, A., J. Bauer, T. Grav, J. Masiero, R. M. Cutri, J. Dailey, P. Eisenhardt, R. S. McMillan, et al. (2011). "Preliminary Results from NEOWISE: An Enhancement to the Wide-field Infrared Survey Explorer for Solar System Science". In: *The Astrophysical Journal* 731, p. 53. DOI: 10.1088/0004-637X/731/1/53.

Mamajek, E. E., A. C. Quillen, M. J. Pecaut, F. Moolekamp, E. L. Scott, M. A. Kenworthy, A. Collier Cameron, and N. R. Parley (2012). "Planetary Construction Zones in Occultation: Discovery of an Extrasolar Ring System Transiting a Young Sun-like Star and Future Prospects for Detecting Eclipses by Circumsecondary and Circumplanetary Disks". In: *The Astronomical Journal* 143, p. 72. DOI: 10.1088/0004-6256/143/3/72.

Marocco, F., P. R. M. Eisenhardt, J. W. Fowler, J. D. Kirkpatrick, A. M. Meisner, E. F. Schlafly, S. A. Stanford, N. Garcia, et al. (2021). "The CatWISE2020 Catalog". In: *The Astrophysical Journal Supplement Series* 253, p. 8. DOI: 10.3847/1538-4365/abd805.

Martin, D. C., J. Fanson, D. Schiminovich, P. Morrissey, P. G. Friedman, T. A. Barlow, T. Conrow, R. Grange, et al. (2005). "The Galaxy Evolution Explorer: A Space Ultraviolet Survey Mission". In: *The Astrophysical Journal Letters* 619, pp. L1–L6. DOI: 10.1086/426387.

Marton, G., P. Ábrahám, E. Szegedi-Elek, J. Varga, M. Kun, Á. Kóspál, E. Varga-Verebélyi, S. Hodgkin, et al. (2019). "Identification of Young Stellar Object candidates in the Gaia DR2 x AllWISE catalogue with machine-learning methods". In: *Monthly Notices of the Royal Astronomical Society* 487, pp. 2522–2537. DOI: 10.1093/mnras/stz1301.

Masci, F. J., R. R. Laher, B. Rusholme, D. L. Shupe, S. Groom, J. Surace, E. Jackson, S. Monkewitz, et al. (2019). "The Zwicky Transient Facility: Data Processing, Products, and Archive". In: *Publications of the Astronomical Society of the Pacific* 131, p. 018003. DOI: 10.1088/1538-3873/aae8ac.

Mason, B. D., G. L. Wycoff, W. I. Hartkopf, G. G. Douglass, and C. E. Worley (2001). "The 2001 US Naval Observatory Double Star CD-ROM. I. The Washington Double Star Catalog". In: *The Astronomical Journal* 122, pp. 3466–3471. DOI: 10.1086/323920.

McKinney, W. (2010). "Data Structures for Statistical Computing in Python". In: *Proceedings of the 9th Python in Science Conference*. Ed. by S. van der Walt and J. Millman, pp. 56–61. DOI: 10.25080/Majora-92bf1922-00a.

McMahon, R. G., M. Banerji, E. Gonzalez, S. E. Koposov, V. J. Bejar, N. Lodieu, R. Rebolo, and VHS Collaboration (2013). "First Scientific Results from the VISTA Hemisphere Survey (VHS)". In: *The Messenger* 154, pp. 35–37. ADS bibcode 2013Msngr.154...35M.

Meisner, A. M., D. Caselden, E. F. Schlafly, and F. Kiwy (2023). "unTimely: a Full-sky, Time-domain unWISE Catalog". In: *The Astronomical Journal* 165, p. 36. DOI: 10.3847/1538-3881/aca2ab.

Meng, H. Y. A., G. Rieke, F. Dubois, G. Kennedy, M. Marengo, M. Siegel, K. Su, N. Trueba, et al. (2017). "Extinction and the Dimming of KIC 8462852". In: *The Astrophysical Journal* 847, p. 131. DOI: 10.3847/1538-4357/aa899c.

Merloni, A., G. Lamer, T. Liu, M. E. Ramos-Ceja, H. Brunner, E. Bulbul, K. Dennerl, V. Doroshenko, et al. (2024). "The SRG/eROSITA all-sky survey. First X-ray catalogues and data release of the western Galactic hemisphere". In: *Astronomy & Astrophysics* 682, A34. DOI: 10.1051/0004-6361/202347165.

Mikołajewski, M. and D. Graczyk (1999). "Is the eclipsing variable EE Cep a cousin of $\epsilon$ Aur?" In: *Monthly Notices of the Royal Astronomical Society* 303, pp. 521–524. DOI: 10.1046/j.1365-8711.1999.02257.x.

Monet, D. G., S. E. Levine, B. Canzian, H. D. Ables, A. R. Bird, C. C. Dahn, H. H. Guetter, H. C. Harris, et al. (2003). "The USNO-B Catalog". In: *The Astronomical Journal* 125, pp. 984–993. DOI: 10.1086/345888.

Montet, B. T. and J. D. Simon (2016). "KIC 8462852 Faded throughout the Kepler Mission". In: *The Astrophysical Journal Letters* 830, p. L39. DOI: 10.3847/2041-8205/830/2/L39.

Mróz, P., A. Udalski, M. K. Szymański, I. Soszyński, P. Pietrukowicz, S. Kozłowski, J. Skowron, R. Poleski, et al. (2020). "Microlensing Optical Depth and Event Rate in the OGLE-IV Galactic Plane Fields". In: *The Astrophysical Journal Supplement Series* 249, p. 16. DOI: 10.3847/1538-4365/ab9366.

Nikutta, R., M. Fitzpatrick, A. Scott, and B. A. Weaver (2020). "Data Lab—A community science platform". In: *Astronomy and Computing* 33, p. 100411. DOI: 10.1016/j.ascom.2020.100411.

Ochsenbein, F. (1996). *The VizieR database of astronomical catalogues*. CDS, Centre de Données astronomiques de Strasbourg. DOI: 10.26093/cds/vizier.

Ochsenbein, F., P. Bauer, and J. Marcout (2000). "The VizieR database of astronomical catalogues". In: *Astronomy and Astrophysics Supplement Series* 143, pp. 23–32. DOI: 10.1051/aas:2000169.

Onken, C. A., C. Wolf, M. S. Bessell, S.-W. Chang, L. C. Luvaul, J. L. Tonry, M. C. White, and G. S. Da Costa (2024). "SkyMapper Southern Survey: Data Release 4". In: *Publications of the Astronomical Society of Australia* 41, e061. DOI: 10.1017/pasa.2024.53.

Paczyński, B. (1986). "Gravitational microlensing by the galactic halo". In: *The Astrophysical Journal* 304, pp. 1–5. DOI: 10.1086/164140.

Patterson, M. T., E. C. Bellm, B. Rusholme, F. J. Masci, M. Juric, K. S. Krughoff, V. Z. Golkhou, M. J. Graham, et al. (2019). "The Zwicky Transient Facility Alert Distribution System". In: *Publications of the Astronomical Society of the Pacific* 131, p. 018001. DOI: 10.1088/1538-3873/aae904.

Pecaut, M. J. and E. E. Mamajek (2013). "Intrinsic Colors, Temperatures, and Bolometric Corrections of Pre-main-sequence Stars". In: *The Astrophysical Journal Supplement Series* 208, p. 9. DOI: 10.1088/0067-0049/208/1/9.

Pourbaix, D., A. A. Tokovinin, A. H. Batten, F. C. Fekel, W. I. Hartkopf, H. Levato, N. I. Morrell, G. Torres, et al. (2004). "SB9: The ninth catalogue of spectroscopic binary orbits". In: *Astronomy & Astrophysics* 424, pp. 727–732. DOI: 10.1051/0004-6361:20041213.

Rappaport, S., G. Zhou, A. Vanderburg, A. Mann, M. H. Kristiansen, K. Oláh, T. L. Jacobs, E. Newton, et al. (2019). "Deep long asymmetric occultation in EPIC 204376071". In: *Monthly Notices of the Royal Astronomical Society* 485, pp. 2681–2693. DOI: 10.1093/mnras/stz537.

Reid, I. N., C. Brewer, R. J. Brucato, W. R. McKinley, A. Maury, D. Mendenhall, J. R. Mould, J. Mueller, et al. (1991). "The second Palomar Sky Survey". In: *Publications of the Astronomical Society of the Pacific* 103, pp. 661–674. DOI: 10.1086/132866.

Ricker, G. R., J. N. Winn, R. Vanderspek, D. W. Latham, G. Á. Bakos, J. L. Bean, Z. K. Berta-Thompson, T. M. Brown, et al. (2015). "Transiting Exoplanet Survey Satellite". In: *Journal of Astronomical Telescopes, Instruments, and Systems* 1, p. 014003. DOI: 10.1117/1.JATIS.1.1.014003.

Riello, M., F. De Angeli, D. W. Evans, P. Montegriffo, J. M. Carrasco, G. Busso, L. Palaversa, P. W. Burgess, et al. (2021). "Gaia Early Data Release 3. Photometric content and validation". In: *Astronomy & Astrophysics* 649, A3. DOI: 10.1051/0004-6361/202039587.

Rimoldini, L., B. Holl, P. Gavras, M. Audard, J. De Ridder, N. Mowlavi, K. Nienartowicz, G. Jevardat de Fombelle, et al. (2023). "Gaia Data Release 3. All-sky classification of 12.4 million variable sources into 25 classes". In: *Astronomy & Astrophysics* 674, A14. DOI: 10.1051/0004-6361/202245591.

Samus', N. N., E. V. Kazarovets, O. V. Durlevich, N. N. Kireeva, and E. N. Pastukhova (2017). "General catalogue of variable stars: Version GCVS 5.1". In: *Astronomy Reports* 61, pp. 80–88. DOI: 10.1134/S1063772917010085.

Sánchez-Sáez, P., I. Reyes, C. Valenzuela, F. Förster, S. Eyheramendy, F. Elorrieta, F. E. Bauer, G. Cabrera-Vives, et al. (2021). "Alert Classification for the ALeRCE Broker System: The Light Curve Classifier". In: *The Astronomical Journal* 161, p. 141. DOI: 10.3847/1538-3881/abd5c1.

Saydjari, A. K., E. F. Schlafly, D. Lang, A. M. Meisner, G. M. Green, C. Zucker, I. Zelko, J. S. Speagle, et al. (2023). "The Dark Energy Camera Plane Survey 2 (DECaPS2): More Sky, Less Bias, and Better Uncertainties". In: *The Astrophysical Journal Supplement Series* 264, p. 28. DOI: 10.3847/1538-4365/aca594.

Scargle, J. D. (1982). "Studies in astronomical time series analysis. II. Statistical aspects of spectral analysis of unevenly spaced data". In: *The Astrophysical Journal* 263, pp. 835–853. DOI: 10.1086/160554.

Schlafly, E. F. and D. P. Finkbeiner (2011). "Measuring Reddening with Sloan Digital Sky Survey Stellar Spectra and Recalibrating SFD". In: *The Astrophysical Journal* 737, p. 103. DOI: 10.1088/0004-637X/737/2/103.

Schlegel, D. J., D. P. Finkbeiner, and M. Davis (1998). "Maps of Dust Infrared Emission for Use in Estimation of Reddening and Cosmic Microwave Background Radiation Foregrounds". In: *The Astrophysical Journal* 500, pp. 525–553. DOI: 10.1086/305772.

Shahaf, S., D. Bashi, T. Mazeh, S. Faigler, F. Arenou, K. El-Badry, and H.-W. Rix (2023). "Triage of the Gaia DR3 astrometric orbits – I. A sample of binaries with probable compact companions". In: *Monthly Notices of the Royal Astronomical Society* 518, pp. 2991–3003. DOI: 10.1093/mnras/stac3290.

Shahaf, S., T. Mazeh, S. Faigler, and B. Holl (2019). "Triage of astrometric binaries – how to find triple systems and dormant black hole secondaries in the Gaia orbits". In: *Monthly Notices of the Royal Astronomical Society* 487, pp. 5610–5617. DOI: 10.1093/mnras/stz1636.

Shappee, B. J., J. L. Prieto, D. Grupe, C. S. Kochanek, K. Z. Stanek, G. De Rosa, S. Mathur, Y. Zu, et al. (2014). "The Man behind the Curtain: X-Rays Drive the UV through NIR Variability in the 2013 Active Galactic Nucleus Outburst in NGC 2617". In: *The Astrophysical Journal* 788, p. 48. DOI: 10.1088/0004-637X/788/1/48.

Skrutskie, M. F., R. M. Cutri, R. Stiening, M. D. Weinberg, S. Schneider, J. M. Carpenter, C. Beichman, R. Capps, et al. (2006). "The Two Micron All Sky Survey (2MASS)". In: *The Astronomical Journal* 131, pp. 1163–1183. DOI: 10.1086/498708.

Smith, L. C., S. E. Koposov, P. W. Lucas, J. L. Sanders, D. Minniti, A. Udalski, N. W. Evans, D. Aguado, et al. (2021). "VVV-WIT-08: the giant star that blinked". In: *Monthly Notices of the Royal Astronomical Society* 505, pp. 1992–2008. DOI: 10.1093/mnras/stab1211.

Solano, E., B. Villarroel, and C. Rodrigo (2022). "Discovering vanishing objects in POSS I red images using the Virtual Observatory". In: *Monthly Notices of the Royal Astronomical Society* 515, pp. 1380–1391. DOI: 10.1093/mnras/stac1552.

Strassmeier, K. G. (2009). "Starspots". In: *The Astronomy and Astrophysics Review* 17, pp. 251–308. DOI: 10.1007/s00159-009-0020-6.

Tzanidakis, A., J. R. A. Davenport, E. C. Bellm, and Y. Wang (2023). "Gaia17bpp: A Giant Star with the Deepest and Longest Known Dimming Event". In: *The Astrophysical Journal* 955, p. 69. DOI: 10.3847/1538-4357/aceda7.

Tzanidakis, A., J. R. A. Davenport, N. Caplar, E. C. Bellm, W. Beebe, D. Branton, S. Campos, A. J. Connolly, et al. (2025). "A Systematic Search for Main-sequence Dipper Stars Using the Zwicky Transient Facility". In: *The Astrophysical Journal* 991, p. 118. DOI: 10.3847/1538-4357/adf5bb. arXiv: 2508.03964.

Udalski, A., M. K. Szymański, and G. Szymański (2015). "OGLE-IV: Fourth Phase of the Optical Gravitational Lensing Experiment". In: *Acta Astronomica* 65, pp. 1–38. arXiv: 1504.05966.

Villarroel, B., J. Soodla, S. Comerón, L. Mattsson, K. Pelckmans, M. López-Corredoira, K. Krisciunas, E. Guerras, et al. (2020). "The Vanishing and Appearing Sources during a Century of Observations Project. I. USNO Objects Missing in Modern Sky Surveys and Follow-up Observations of a "Missing Star"". In: *The Astronomical Journal* 159, p. 8. DOI: 10.3847/1538-3881/ab570f.

Virtanen, P., R. Gommers, T. E. Oliphant, M. Haberland, T. Reddy, D. Cournapeau, E. Burovski, P. Peterson, et al. (2020). "SciPy 1.0: fundamental algorithms for scientific computing in Python". In: *Nature Methods* 17, pp. 261–272. DOI: 10.1038/s41592-019-0686-2.

von Neumann, J. (1941). "Distribution of the Ratio of the Mean Square Successive Difference to the Variance". In: *The Annals of Mathematical Statistics* 12, pp. 367–395. DOI: 10.1214/aoms/1177731677.

Watson, C. L., A. A. Henden, and A. Price (2006). "The International Variable Star Index (VSX)". In: *Society for Astronomical Sciences Annual Symposium*. Vol. 25, p. 47. ADS bibcode 2006SASS...25...47W.

Webb, N. A., M. Coriat, I. Traulsen, J. Ballet, C. Motch, F. J. Carrera, F. Koliopanos, J. Authier, et al. (2020). "The XMM-Newton serendipitous survey. IX. The fourth XMM-Newton serendipitous source catalogue". In: *Astronomy & Astrophysics* 641, A136. DOI: 10.1051/0004-6361/201937353.

Wenger, M., F. Ochsenbein, D. Egret, P. Dubois, F. Bonnarel, S. Borde, F. Genova, G. Jasniewicz, et al. (2000). "The SIMBAD astronomical database. The CDS reference database for astronomical objects". In: *Astronomy and Astrophysics Supplement Series* 143, pp. 9–22. DOI: 10.1051/aas:2000332.

Wright, E. L., P. R. M. Eisenhardt, A. K. Mainzer, M. E. Ressler, R. M. Cutri, T. Jarrett, J. D. Kirkpatrick, D. Padgett, et al. (2010). "The Wide-field Infrared Survey Explorer (WISE): Mission Description and Initial On-orbit Performance". In: *The Astronomical Journal* 140, pp. 1868–1881. DOI: 10.1088/0004-6256/140/6/1868.

Wyrzykowski, Ł., K. Kruszyńska, K. A. Rybicki, B. Holl, I. Lecœur-Taïbi, N. Mowlavi, K. Nienartowicz, G. Jevardat de Fombelle, et al. (2023). "Gaia Data Release 3. Microlensing events from all over the sky". In: *Astronomy & Astrophysics* 674, A23. DOI: 10.1051/0004-6361/202243756.

York, D. G., J. Adelman, J. E. Anderson Jr., S. F. Anderson, J. Annis, N. A. Bahcall, J. A. Bakken, R. Barkhouser, et al. (2000). "The Sloan Digital Sky Survey: Technical Summary". In: *The Astronomical Journal* 120, pp. 1579–1587. DOI: 10.1086/301513.

Zari, E., H. Hashemi, A. G. A. Brown, K. Jardine, and P. T. de Zeeuw (2018). "3D mapping of young stars in the solar neighbourhood with Gaia DR2". In: *Astronomy & Astrophysics* 620, A172. DOI: 10.1051/0004-6361/201834150.