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A Deep Dimming and Abrupt Recovery of a YSO Candidate in MonR2

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Abstract

We report on a nearly factor-of-ten fade and then re-brightening after several months of [CMD97]-1031, a candidate young stellar object. Through fitting of light curve data from ZTF and ATLAS, we find a dip amplitude >2.5 mag and duration 80–320 days. After the large dip, the source recovered to slightly fainter brightness and redder color.

1. Introduction

Young stars are ubiquitously variable objects (Joy 1945), attributed to physical processes occurring in their immediate circumstellar environment. Phenomena include accretion from a circumstellar disk, outflow in winds and jets, and the presence of hot and cool spots on the rotating stellar surface (Fischer et al. 2022). The brightness variations present a range in magnitudes and timescales.

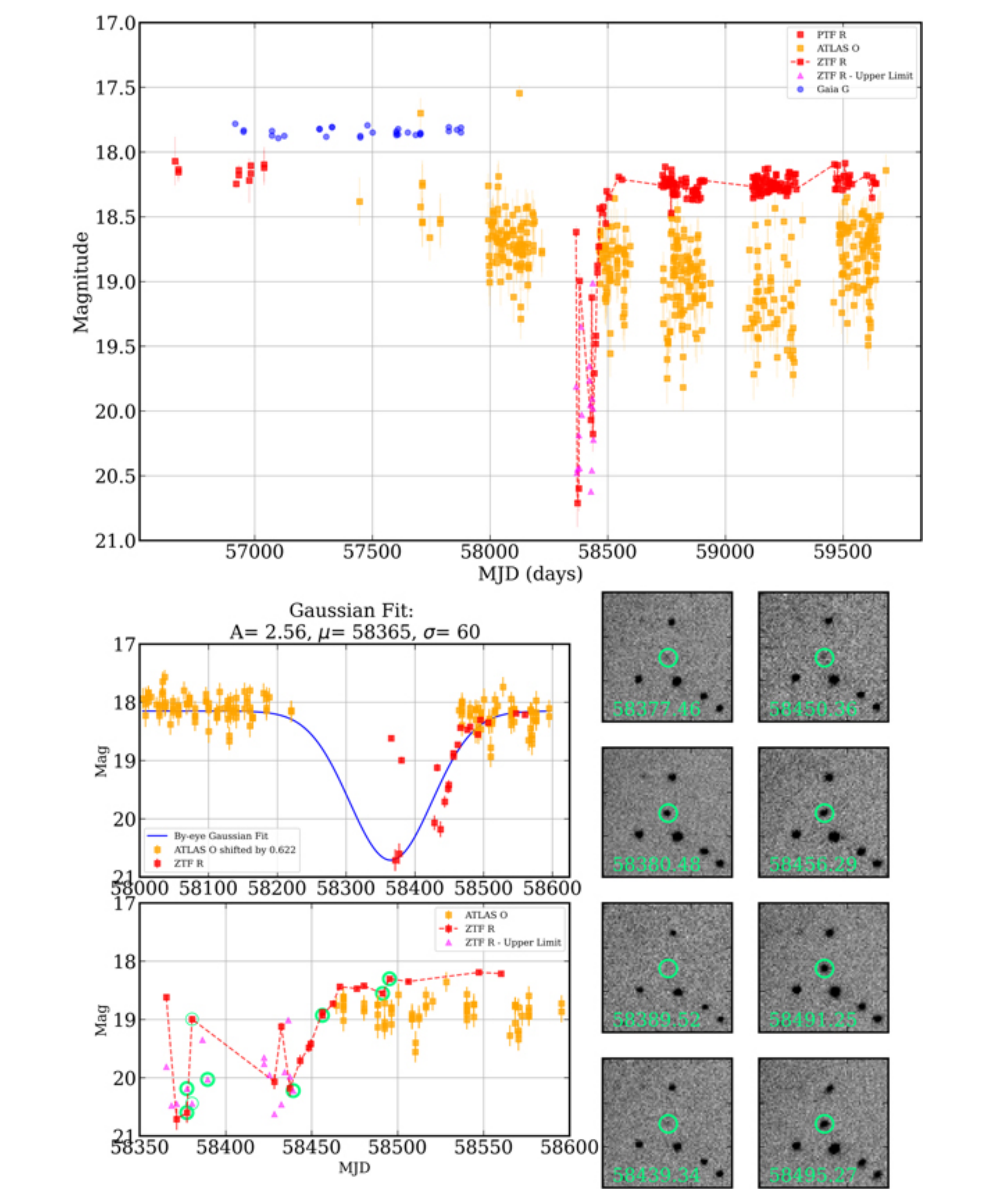
[CMD97]-1031 (Carpenter et al. 1997) is an optically-visible X-ray source (Nakajima et al. 2003) with saturated activity (Wang et al. 2020). It was classified based on its variability as a young stellar object (YSO) (Gaia Collaboration 2022), and has substantial near-infrared excess—indicating accretion—but only weak mid-infrared excess—indicating low dust levels. The source is located southeast of the main Mon R2 cluster, at 06:07:21.78–06:26:31.0 (J2000.). With distance 1050 pc and proper motions 2.56 ± 0.11 mas yr^{-1} in R.A. and 1.06 ± 0.11 mas yr^{-1} in decl. (Gaia DR3 3018461199827407488; Gaia Collaboration 2020), the source is a likely member of Mon R2.

While examining light curves for a large sample of candidate members of Mon R2, we found that [CMD97]-1031 had experienced a substantial dip in brightness. Here, we present optical light curves over a span of 8 yr, from 2014 to 2022, including data from multiple wide-field surveys, and we estimate the properties of this dip.

2. Data

We used optical photometry from Palomar Transient Factory (PTF; Law et al. 2009; Rau et al. 2009), its successor Zwicky Transient Facility (ZTF; Bellm et al. 2019; Graham et al. 2019), and Asteroid Terrestrial-impact Last Alert System (ATLAS; Heinze et al. 2018; Tonry et al. 2018). PTF and ZTF *r*-band ($\lambda_{\rm eff}$ = 6340 Å) data were obtained from PTF Third Public Data Release, spanning 2014 January to 2015 January, and ZTF Data Release 12, spanning 2018 March to 2022 May. In addition to measurements, we include limits at epochs on which images exist but no photometry is reported. From ATLAS, we used publicly available ATLAS-o (λ = 5600–8200 Å) and ATLAS-c (λ = 4200–6500 Å) data, initially restricting to flux signal-to-noise ratio >5 and sky brightness limit >17.5 mag. We also collected photometry from Gaia (Gaia Collaboration 2022).

Figure 1 shows the PTF/ZTF-r, ATLAS-o, and Gaia-G photometry in the top panel, with other panels highlighting the dip portion of the light curve. Also provided are images corresponding to individual measured or limiting magnitudes.



Zoom In Zoom Out Reset image size

Figure 1. Time Series Photometry and Images of [CMD97]-1031: Top—Lightcurve from Gaia G (blue squares), ATLAS *o*-band with SNR >5 (orange squares), PTF and ZTF *r*-band (red squares), and ZTF upper limits where image data exist but no photometry was calculated (magenta triangles). Lower Left—Two successive zooms of the lightcurve. Upper panel shows the ATLAS-o data shifted by −0.622 mag in order to match the median brightness with the ZTF-r data, and a Gaussian fit for the dip assuming that the fade starts immediately after an observing season, in the data gap. The resulting fit has amplitude of 2.56 mag, mean JD = 58365, and standard deviation of 60 days. Lower panel highlights the epochs (green circles) for which ZTF images are shown. Lower Right—ZTF images corresponding to 8 different dates, with MJD indicated.

Download figure: Standard image High-resolution image

3. Analysis

The median *r*-band magnitude is 18.26. The lightcurve of [CMD97]-1031 exhibits a clear deep fade that appears to have begun between observing seasons, but is well-measured in the recovery phase by ZTF. We performed a Gaussian fit (see Figure 1), considering measurements between MJD 58300 and 58700, and shifting ATLAS-o data by -0.622 mag to match the ATLAS and ZTF median magnitudes. The dip magnitude ranged from a lower bound of 1.75 mag to an upper bound of 2.56 mag, and the duration was between about 80 and perhaps up to 320 days. Within the deep fade, the star appears to blink up and down by at least 2 magnitudes on short timescales.

We can also compare the measured magnitudes before and after recovery from the dip. The star appears to have recovered from the dip to a fainter and redder brightness level.

We find a slight decrease in brightness for all photometric data sets after the dip recovery at MJD 58550. The PTF/ZTF median magnitude from MJD 56662.2 to 57040.2 was 18.14, while later from MJD 58506.2 to 59640.2 it was around 18.25, a difference of 0.11 magnitudes. For ATLAS-o, we similarly find that from MJD 56700 to 58350, the star had median magnitude (unshifted) of 18.68, while subsequently from MJD 58500 to 59700, the median magnitude is 18.93, a difference of 0.24 magnitude.

In addition to magnitude changes, the star color also appears to have changed. We calculated $c-o$ color as the difference median(c) − median(o), and the dispersion, $\sigma_{c-o} = \sqrt{\sigma_c^2(c) + \sigma^2(o)}$, where the σ's are the standard deviations of ATLAS data with SNR >3 for both the cyan and orange bands. Before the dip, $(c-o)_{\rm before} = 1.22 \pm 0.47$ mag, while after the dip, $(c-o)_{\rm after} = 0.76 \pm 0.45$ mag, resulting in a color difference of 0.46 mag.

4. Discussion/Conclusions

Although unusual, the long-lived (months) deep (>2.5 mag) fading behavior of [CMD97]-1031 is not unique. An analog among YSOs is [OSP2002]-BRC-31-1 (Findeisen et al. 2013). Other potentially similar examples include ASASSN-21qj[3] and ASASSN-21sa,[4] among others.

We note that the more common "dipper" category of stellar variability (Cody & Hillenbrand 2010) differs from the sources above in having typically much smaller amplitudes, and shorter, few-day durations. There are currently hundreds of cataloged stars with such dipper-type variability identified from space-based platforms (Capistrant et al. 2022; Cody et al. 2022). Longer-term fades like that in [CMD97]-1031, are probably similar to the dipper objects in that the presence of orbiting clouds of dusty material can, on occasion, pass through our line-of-sight to the star. But the relative angular size of the clouds must be much bigger, and the orbital radii much larger. Deep fading objects such as UX Ori and WW Vul type stars dim along reddening vectors then turn blueward due to dust scattering. Constraining the timescales, depths, and colors for fading and dipping stars can help us better understand dust in the circumstellar environments of young stars.

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Footnotes

3 https://asas-sn.osu.edu/sky-patrol/coordinate/044d7a1e-1073-4f3e-88c8-b18178ae4f34 at R.A., decl. = 123.847530, −38.989820.

4 https://asas-sn.osu.edu/sky-patrol/coordinate/7ac04d15-8f28-4725-b198-d37d865bc53b at R.A., decl. = 248.937958, −48.95119.