TESS Free-floating Planet Candidate Is Likely a Stellar Flare

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ABSTRACT

The discovery of a terrestrial-mass free-floating planet candidate in the light curve of the star TIC 107150013 observed by the Transiting Exoplanet Survey Satellite (TESS) has recently been announced. A short-duration (~0.5 day), low-amplitude (~0.06 mag) brightening in the TESS light curve was interpreted as a short-timescale gravitational microlensing event. However, the purported event occurred far from the Galactic center and the Galactic plane ($l \approx 239^\circ$, $b \approx -5^\circ$), on a relatively nearby (~3.2 kpc) star, making the microlensing interpretation unlikely. Here, we report the archival photometric observations of TIC 107150013 collected by the Optical Gravitational Lensing Experiment (OGLE) from 2018 through 2020. The archival OGLE light curve reveals periodic variability indicative of starspots on the surface of the star. The presence of starspots indicates magnetic activity of the star, which may also manifest as stellar flares. We interpret the brightening of TIC 107150013 seen in the TESS data as the stellar flare. We present similar flaring stars detected in the archival OGLE data, mimicking short-timescale, low-amplitude microlensing events. Such stars may be a source of non-negligible false positive detections in the planned space-based microlensing surveys.

Key words: *Gravitational microlensing* (672), *Free-floating planets* (549), *Stellar activity* (1580), *Starspots* (1572), *Stellar flares* (1603), *Flare stars* (540)

1. Introduction

High-cadence photometric observations by ground-based gravitational microlensing surveys have uncovered a population of short-timescale microlensing events (Mróz *et al.*, 2017; Gould *et al.*, 2022; Sumi *et al.*, 2023) that are interpreted as due to free-floating (or wide-orbit) planets. These studies indicate that free-floating planets are common (about 7^{+7}_{-5} objects more massive than $1M_{\oplus}$ per star) and that their mass function approximately scales as $dN/d \log M \propto M^{-1}$. We refer the readers to reviews by Zhu and Dong (2021) and Mróz and Poleski (2023) for an in-depth discussion of these results.

Microlensing events by terrestrial-mass objects are expected to have short Einstein timescales (usually a few hours) and small amplitudes due to finite-source effects, rendering them difficult to detect in ground-based data. Therefore, even though the population of free-floating planets seems to be large, only a handful of candidates have been detected by ground-based microlensing surveys in the past years.

The sensitivity to short-timescale microlensing events can be boosted with nearly continuous, high-cadence observations conducted from space. For example, the planned Nancy Grace Roman Space Telescope is expected to detect hundreds of short-timescale microlensing events due to free-floating planets as part of its Galactic Bulge Time Domain Survey (Johnson *et al.*, 2020; Sumi *et al.*, 2023). Similarly, the Earth 2.0 (ET) mission is estimated to find about 600 free-floating planets (Ge *et al.*, 2022). These missions were designed to observe dense stellar fields of the Galactic bulge at high cadence.

Kunimoto *et al.* (2024) reported the results of searching for short-duration microlensing events in the photometric data from one of the sectors (Sector 61) observed by the Transiting Exoplanet Survey Satellite (TESS). TESS observed a field of view $24^{\circ} \times 96^{\circ}$ wide for 27.4 days at a 200-second cadence. The analyzed data set contained 1.3 million stars as faint as T = 15 mag. Kunimoto *et al.* (2024) used the modified version of the BLS period search algorithm to select candidate microlensing events. They vetted all selected objects by checking the quality of the microlensing model fit, removing edge artifacts, asteroids, and repeating or asymmetric light curves.

Only one object, TIC 107150013, met all selection criteria and was considered to be a compelling microlensing event candidate. The brightening observed by TESS lasted about ~ 0.5 day and had a low amplitude (~ 0.06 mag). The best-fit microlensing model fitted to the light curve yielded the Einstein timescale $t_{\rm E} = 0.074 \pm 0.002$ days, and the angular Einstein radius $\theta_{\rm E} = 4.1^{+0.4}_{-0.5} \mu$ as, which are similar to those of other known free-floating planet candidates.

All known microlensing events due to free-floating planets have occurred toward the dense regions of the Galactic bulge, where the probability of finding microlensing events is highest. On the contrary, the star TIC 107150013 is located at the Galactic coordinates $l = 239.1^{\circ}$, $b = -5.0^{\circ}$, at a distance of 3.19 ± 0.15 kpc (Kunimoto *et al.*, 2024). The probability of observing a microlensing event so far away from the Galactic center and the Galactic plane, on such a nearby star, is extremely low. Mróz *et al.* (2020) found that the microlensing event rate in the Galactic plane decreases exponentially with the increasing angular separation from the Galactic center $\Gamma \propto \exp(-|l|/l_0)$, where $l_0 = 31.5^{+4.2}_{-3.7}$ deg. At $l = -120.9^{\circ}$, the average event rate is approximately 0.6×10^{-7} yr⁻¹ star⁻¹, and is ~ 300 times lower than that toward the Galactic bulge. The estimated number of microlensing events in one TESS sector is approximately $0.6 \times 10^{-7} \times 1.3 \times 10^6 \times$ $27.4/365.25 \approx 0.006$, assuming 100% detection efficiency. The expected number of microlensing events is even lower because Mróz *et al.* (2020) calculated the event rate averaged over the latitude range $-7^{\circ} < b < 7^{\circ}$ and Γ is known to be decreasing with the increasing distance from the Galactic plane, the analyzed TESS star is relatively nearby, and events due to free-floating planets are expected to be far less frequent than those by stars. That makes the interpretation that TIC 107150013 showed a short-duration microlensing event very unlikely.



Fig. 1. Archival OGLE light curve of TIC 107150013 shows periodic variability due to starspots.

2. Archival OGLE Observations of TIC 107150013

TIC 107150013 was observed by the Optical Gravitational Lensing Experiment (OGLE; Udalski *et al.* 2015) as part of its Galaxy Variability Survey between October 2018 and March 2020. The OGLE survey uses the 1.3-m telescope located at Las Campanas Observatory, Chile. The analyzed star has an internal OGLE identifier GD2353.13.32. It was observed 145 times in the *I* band, with 25 s exposure time. The archival light curve of TIC 107150013 is presented in the upper panel of Figure 1.

The star shows periodic variability in the archival OGLE data with a period of $P = 42.37 \pm 0.22$ days (as measured using the algorithm presented by Schwarzenberg-Czerny 1996). The phase-folded light curves, separately for observing seasons 2018/2019 and 2019/2020, are shown in the lower panels of Figure 1. The observed variability may be explained by starspots (Iwanek *et al.*, 2019). The observed pe-

riod remains constant throughout OGLE light curve (and is the star's rotation period). However, the shape and amplitude of light variations change over time as the spot pattern changes. Both the rotation period and the amplitude of brightness variations in TIC 107150013 are typical for spotted stars (Iwanek *et al.*, 2019).

Even though the rotation period of the star is longer than the duration of TESS observations, a low-amplitude, long-timescale variability can be noticed in the predetrended TESS data, which are presented in Figure 2 of Kunimoto *et al.* (2024).



Fig. 2. Light curves of two flaring stars with symmetric flares from Iwanek et al. (2019).

3. Discussion

The presence of spots on the star's surface indicates that it is magnetically active. The stellar activity may also manifest in the form of flares (e.g., Iwanek *et al.*, 2019), which in cool stars are related to the sudden release of energy accumulated in the magnetic field. Whereas light curves of stellar flares are usually asymmetric (rapid brightening followed by a slower decline), flares may sometimes be deceivingly symmetric.

We analyzed the light curves of 79 flaring stars published by Iwanek *et al.* (2019) and found two objects with flares similar to that seen in TIC 107150013 (Figure 2). Two such flaring episodes occurred for the left panel object over the last 14 years of the OGLE monitoring and just one for the right panel star. In both cases, an additional periodic variability due to starspots is present in the data. Therefore, a natural explanation of the brightening observed in the light curve of TIC 107150013 is a stellar flare, not a short-timescale, low-amplitude microlensing event.

Flaring stars similar to TIC 107150013 may be a source of false positive detections in the planned space-based microlensing surveys (Roman, ET). The easiest method to distinguish them from genuine microlensing events would be to check

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the archival data for flares and periodic variability due to starspots. The contamination from flaring stars may be largest early in the missions, when the light curve archives may not be available. Another way of distinguishing flares from shorttimescale microlensing events would be multiband observations: flares are known to have larger amplitudes in the bluer passbands (e.g., Davenport *et al.*, 2012), while microlensing is achromatic.

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