



Constraints on Late-time Flaring from Luminous Fast Blue Optical Transients Using the Transiting Exoplanet Survey Satellite and the Zwicky Transient Facility

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Abstract

The luminous fast blue optical transient (LFBOT) AT2022tsd exhibited minutes-timescale optical flares in the tens of days following the initial transient event, likely due to a central engine—either an accreting black hole or a magnetar. In this paper, we use data from the Transiting Exoplanet Survey Satellite (TESS) and the Zwicky Transient Facility (ZTF) to constrain the occurrence of similar flares in the 12 (of 14) known LFBOTs that had observational coverage with TESS from tens to thousands of days after the transient’s initial emission. We find seven flare-like signals at the locations of four unique LFBOTs; all seven can likely be attributed to a solar system object (SSO) moving through the TESS aperture. Assuming all seven flares arise from SSOs, for the LFBOT AT2024qfm we rule out flaring with a similar timescale (40–65 days) and luminosity ($\nu L_\nu \sim 10^{43} \text{ erg s}^{-1}$) as in AT2022tsd, while for AT2022tsd itself we rule out flares between 380 and 430 days after the initial transient that were as luminous as the earlier flares. This observation suggests that the engine power in AT2022tsd declined or shut off on a timescale of hundreds of days. We also find that there is no late-time activity detectable in TESS thousands of days after the prototype LFBOT, AT2018cow. We discuss our constraints on the duty cycle of such flaring and then present estimates for the number of minutes-duration flares detectable with ongoing and upcoming high-cadence ($\ll 1$ day) wide-field surveys.

Unified Astronomy Thesaurus concepts: [Transient sources \(1851\)](#); [Sky surveys \(1464\)](#)

Materials only available in the [online version of record](#): [animations](#), [machine-readable table](#)

1. Introduction

All-sky optical surveys have led to the discovery of new classes of transients that rise and decay on timescales of a few days, compared to the tens of days associated with typical core-collapse supernovae (SNe; e.g., C. Inserra 2019). Of particular interest is the empirical class of luminous fast blue optical transients (LFBOTs), peaking at absolute magnitudes $-22 \leq M \leq -20$ (e.g., A. Y. Q. Ho et al. 2020; D. A. Perley et al. 2021; C. P. Gutiérrez et al. 2024). Unlike typical core-collapse SNe, LFBOTs exhibit luminous emission across the electromagnetic spectrum (e.g., R. Margutti et al. 2019). These transients bear marked similarities to engine-powered events such as gamma-ray bursts (GRBs; e.g., D. L. Coppejans et al. 2020) and tidal disruption events (D. Tsuna & W. Lu 2025), as well as to interaction-powered SNe (e.g., of Type Ibn; O. D. Fox & N. Smith 2019).

The first LFBOT to be discovered and identified as such, AT2018cow (S. J. Prentice et al. 2018), had an optical light curve that peaked within a few days and decayed to one-half of maximum light after ~ 3 days. AT2018cow also had a persistently blue color and fast ejecta ($v \sim 0.1c$; A. Y. Q. Ho et al. 2019; R. Margutti et al. 2019; D. A. Perley et al. 2019; A. J. Nayana & P. Chandra 2021). An estimate of the LFBOT¹² rate using the Zwicky Transient Facility (ZTF), a ground-based optical transient survey (E. C. Bellm et al. 2019; M. J. Graham et al. 2019; R. Dekany et al. 2020) suggests that these events are rare, being $\sim 0.001\%$ – 0.01% as common as nearby core-collapse SNe (D. A. Perley et al. 2026). As a result, only 14 have been discovered (see Table 1).

Numerous other transients have been found to be fast and blue, but their connections to LFBOTs are unclear because they were found in archival surveys and therefore have limited follow-up observations (e.g., M. R. Drout et al. 2014; I. Arcavi et al. 2016; M. Tanaka et al. 2016; M. Pursiainen et al. 2018). Alternatively, they have been spectroscopically classified as known types of core-collapse SNe, with light curves powered



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¹² In this paper, “LFBOT” refers to transients with optical light curves similar to AT2018cow (C. Sevilla et al. 2026).

Table 1
Information About All 14 Luminous Fast Blue Optical Transients Detected to Date and Observational Details with TESS

Identifier	Nickname	R.A. (HH:MM:SS.SS)	Decl. (DD:MM:SS.SS)	Discovery Epoch (BJD – 2457000)	<i>z</i>	TESS Sectors
CSS161010 [*]	...	04:58:34.00	−08:18:03.00	671.98366	0.033	[5, 32, 98, 109–110]
AT2018cow [*]	“Cow”	16:16:00.22	+22:16:04.91	1285.94556	0.014	[25, 51, 52, 78, 117]
AT2018lug [*]	“Koala”	02:00:15.19	+16:47:57.30	1373.91246	0.271	[42–43, 70, 71]
AT2020mrf ^c	...	15:47:54.16	+44:39:07.41	2015.87459	0.135	[23–24, 50–51, 77–78]
AT2020xnd ^d	“Camel”	22:20:02.03	−02:50:25.30	2134.67579	0.243	[42, 55, 92]
AT2022tsd ^e	“Tasmanian Devil”	03:20:10.86	+08:44:55.63	2829.97633	0.256	[4, 31, 42–44, 70–71]
AT2022abfc ^e	...	04:51:19.20	−26:58:41.60	2904.84850	0.212	[32, 98, 106–109]
AT2023fhn	“Finch”	10:08:03.82	+21:04:26.95	3044.70826	0.240	[21, 45–46, 48, 72]
AT2023hkw	“Hawk”	10:42:17.75	+52:29:19.33	3065.70049	0.343	[21, 48, 75]
AT2023vth	...	17:56:34.40	+08:02:37.32	3235.61473	0.075	[80, 118]
AT2024qfm	...	23:21:23.46	+11:56:32.04	3518.85066	0.227	[56, 83]
AT2024aehp	...	08:21:07.47	+28:44:22.30	3663.86281	0.172	[44–47, 71–72]
AT2024wpp	“Whippet”	02:42:05.50	−16:57:22.90	3579.87606	0.087	[4, 31, 97, 108]
AT2026dbl	“Dibbler”	09:01:17.37	+18:36:07.73	4085.85565	0.190 ^a	[44–46, 72]

Notes. Redshift values, coordinates, and discovery epochs are taken from published values in C. Sevilla et al. (2026) unless indicated otherwise. Some discovery epochs are taken from the Transient Name Server (TNS; A. Gal-Yam 2021). Barycentric corrections were made to the time of discovery (from ZTF, at Palomar Observatory), and then rewritten in the TESS Barycentric Julian Date (BJD) format: BJD – 2457000. Sources with * indicate that limits on flares (or detections in the case of AT2022tsd) were presented in A. Y. Q. Ho et al. (2023b), using data from ZTF and other surveys. TESS sectors (in the last column) written in bold indicate that those periods of observation occurred after the discovery epoch given in the fourth column. Italicized sectors indicate future observations that are part of TESS’s Cycle 9 observations, starting in 2026 September.

^a J. Wise et al. (2026) and Z. McGrath et al. (2026, in preparation).

by shock interaction (e.g., E. O. Ofek et al. 2010; A. Y. Q. Ho et al. 2023a). In contrast, the observational characteristics of LFBOTs, including their long-lived luminous X-ray and radio emission, suggest that they are powered at least in part by a central engine (A. Y. Q. Ho et al. 2019; R. Margutti et al. 2019; A. J. Nayana & P. Chandra 2021; J. S. Bright et al. 2022; Y. Yao et al. 2022; D. Matthews et al. 2023; G. Migliori et al. 2024). Further evidence for a central engine is the detection of a tentative (3.7σ) quasiperiodic oscillation in X-ray emission from AT2018cow (D. R. Pasham et al. 2021) and a luminous late-time UV source at the location of AT2018cow (N.-C. Sun et al. 2022; Y. Chen et al. 2023; A. Inkenhaag et al. 2025). However, recent modeling of AT2018cow (T. Govreen-Segal et al. 2026) has proposed that a shock propagating through an aspherical circumstellar medium (CSM) could also explain much of the observed early ($t < 40$ days) multiwavelength emission.

While the mechanism of AT2018cow’s emission remains debated, the unambiguous detection of late-time, persistent, rapid flaring from the LFBOT AT2022tsd (A. Y. Q. Ho et al. 2023b, hereafter H23), provided strong support for a central engine in at least some LFBOTs. The minutes-duration flares emitted from AT2022tsd tens of days after the initial transient radiated luminosities up to $\nu L_\nu \sim 10^{44} \text{ erg s}^{-1}$ (spherical equivalent). These observations enabled constraints on the radius of the flare-emitting region, which was found to be much smaller than the initial transient’s photospheric radius. To date, AT2022tsd is the only LFBOT for which such rapid, luminous, long-lasting flares have been detected. It remains unknown if this flaring behavior is universal among LFBOTs, or whether it occurs in other transient types. Searches for flaring in the LFBOT AT2024wpp (A. J. Nayana et al. 2025; M. Pursiainen et al. 2025; N. LeBaron et al. 2026; D. A. Perley et al. 2026) using the Large Array Survey Telescope (LAST; E. O. Ofek et al. 2023a) yielded nondetections (E. O. Ofek et al. 2025). One hypothesis for these nondetections is that the

flare emission is beamed, compared to the thermal, more isotropic emission from the initial transient.

Targeted searches for LFBOT flares require significant amounts of telescope time to achieve the necessary temporal resolution and coverage (the duty cycle is low), and are not a guaranteed success. Moreover, if a detection is made, the integration times of existing detectors may not be able to capture very short-timescale variability; variability between 30 s exposures was observed in AT2022tsd. The best (and often only) method to search for flares is using minutes-cadence wide-field surveys—such as the LAST (E. O. Ofek et al. 2023a, 2023b; S. Ben-Ami et al. 2023), the Argus Array (N. M. Law et al. 2022), and the Transiting Exoplanet Survey Satellite (TESS; G. R. Ricker et al. 2015). Days-cadence surveys such as ZTF, which has found most known LFBOTs, could identify single-epoch flux excesses in LFBOTs that imply a flaring state (H23).

Moreover, it is crucial to search for these flares using detectors sensitive to redder emission—H23 found that the flares from AT2022tsd had a $u-I$ color of 1.4, as opposed to its initial blue color. This observation, combined with a high brightness temperature ($\gtrsim 10^{10} \text{ K}$), suggests that these flares are nonthermal. TESS’s bandpass has a pivot wavelength similar to that of Cousins I but is twice as wide (G. R. Ricker et al. 2015), straddling the optical and near-infrared (600–1000 nm), making it an excellent tool to search for these flares.

In this paper, we use existing TESS and ZTF data to constrain the existence, timescale, duty cycle, and overall rates of late-time flaring in all the currently known LFBOTs. TESS’s survey strategy—repeating fields on years-long time-scales—also allows us to constrain the recurrence timescale, if any, of these flares. Our work sets limits on the occurrence of flares in 12 of 14 currently known LFBOTs. Section 2 discusses the TESS data (and our difference imaging approach) and the ZTF data used as part of our analysis. Section 3 presents our limits on the brightness of putative

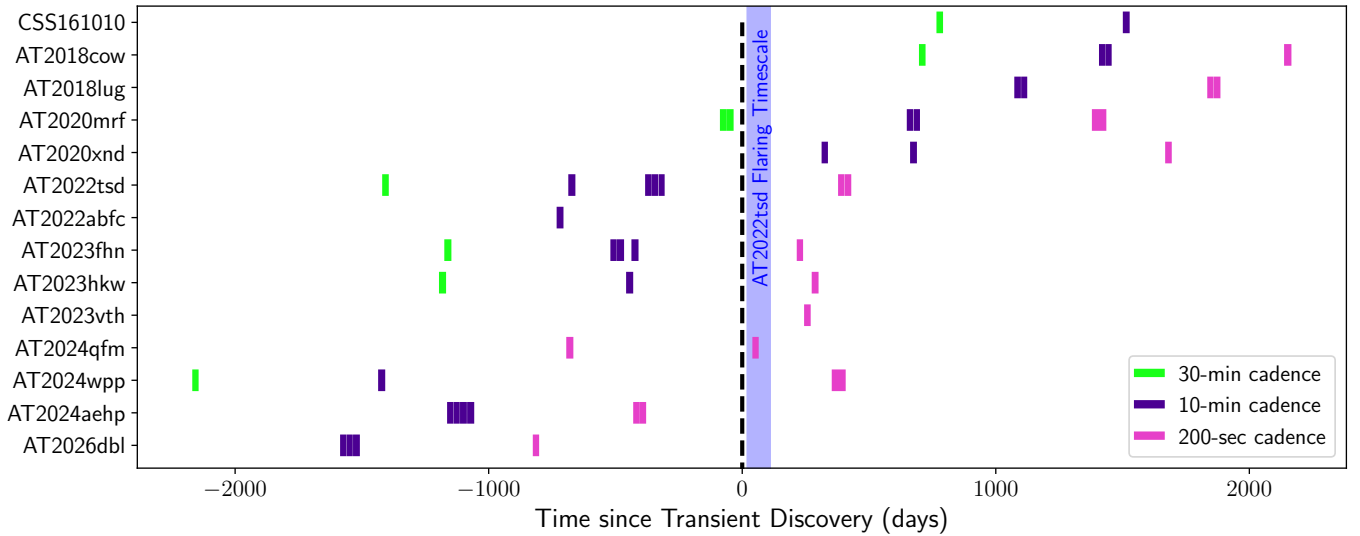


Figure 1. TESS observations of the 14 known LFBOTs compared to their discovery epochs (black dotted line). The different observational cadences (1800, 600, and 200 s) are shown in different colors (light green, purple, and pink, respectively). We highlight the limits on flaring in AT2024qfm obtained through TESS observations that occurred on the same timescale as the flaring in AT2022tsd. Two of the 14 LFBOTs (CSS161010 and AT2018cow) occurred prior to the start of TESS observations.

flares, and Section 4 estimates these flares’ duty cycle and evaluates our ability to discover them using ongoing and upcoming high-cadence (minutes–hours) wide-field surveys in ground and space.

2. Observations

2.1. TESS Data and Difference Imaging

The primary goal of TESS is to find transiting exoplanets around nearby stars (G. R. Ricker et al. 2015). However, its high cadence (hundreds of seconds) and large field of view (FOV; 2304 deg^2) make it amenable to studying short-timescale transient behavior. At the start of the TESS Mission (2018 July–2020 July), the observational cadence of TESS’s full-frame images (FFIs) was 1800 s. During Years 3–4 of the mission (2020 July–2022 September), the cadence was reduced to 600 s, and since Year 5 of the mission (2022 September–present), the FFI cadence has been 200 s. TESS’s observing strategy for the first several years of its mission was to cover over 85% of the sky every 2 yr by staring at a given FOV for roughly a month at a time. Figure 1 shows the times during which TESS observed each LFBOT, relative to its initial detection.

We extracted TESS light curves at the locations of the known LFBOTs (given in Table 1) for every observational sector in which TESS observed their positions. To do so, we performed forced photometry on difference images created from the calibrated FFIs output by the TESS Image Calibrator (TICA) pipeline (M. M. Fausnaugh et al. 2020). These difference images are constructed using ISIS (C. Alard & R. H. Lupton 1998). In short, each image was subtracted with respect to a reference image constructed from 20 low-background FFIs; systematic errors were fixed through the use of a spatially variable smoothing kernel that aimed to match the reference image to an individual FFI. Further details about the full difference imaging procedure can be found in M. M. Fausnaugh et al. (2021, 2023). We then performed forced point-spread function (PSF)-fitting photometry on these difference images. Light curves were flux calibrated by first

calculating the Vega zero-point in the TESS bandpass using the CALSPEC Vega model (R. C. Bohlin 2014). We found $T=0$ to correspond to a flux (F_ν) of 2583 Jy. We then calculated the TESS magnitude T using

$$T = -2.5 \log_{10} \left(\frac{N}{t \times 0.99 \times 0.8} \right) + 20.44, \quad (1)$$

and then converted this to physical flux (in Jy) using the expression $F_\nu = 2583 \text{ Jy} \times 10^{-T/2.5}$. Here, N represents the total observed counts from a source, 0.99 estimates the frame transfer efficiency, 0.8 is the cosmic-ray mitigation (CRM) factor, and 20.44 is the TESS zero-point corresponding to $1 \text{ e}^- \text{ s}^{-1}$. More details about this flux calibration technique, as well as TESS’s onboard cosmic-ray mitigation algorithm and its effects on short-timescale variability, can be found in R. Jayaraman et al. (2024), as well as the TESS Instrument Handbook.¹³ We convert TESS Vega magnitudes to AB magnitudes using a constant offset (calculated in R. Jayaraman et al. 2024): $T_{\text{AB}} = T_{\text{Vega}} + 0.3697$. The TESS light curves for all observations of LFBOT locations are given in Table 2.

An example late-time TESS light curve for an LFBOT is shown in Figure 2. This light curve demonstrates both a large source of false positives (solar system objects (SSOs) passing through the photometric aperture) and a large source of systematic error—scattered light. In particular, scattered light from the Earth and the Moon (when they are above the sunshade) leads to elevated, time-variable backgrounds, especially toward the end of an orbit. To mitigate the effect of scattered light on our analysis, the light curves were visually inspected to mask out periods of time with backgrounds arising from significant scattered light (see Figure 2). We note that background values are centered at zero in these light curves because they represent the local backgrounds in the difference image, after subtracting the reference image.

¹³ https://archive.stsci.edu/missions/teess/doc/TESS_Instrument_Handbook_v0.1.pdf

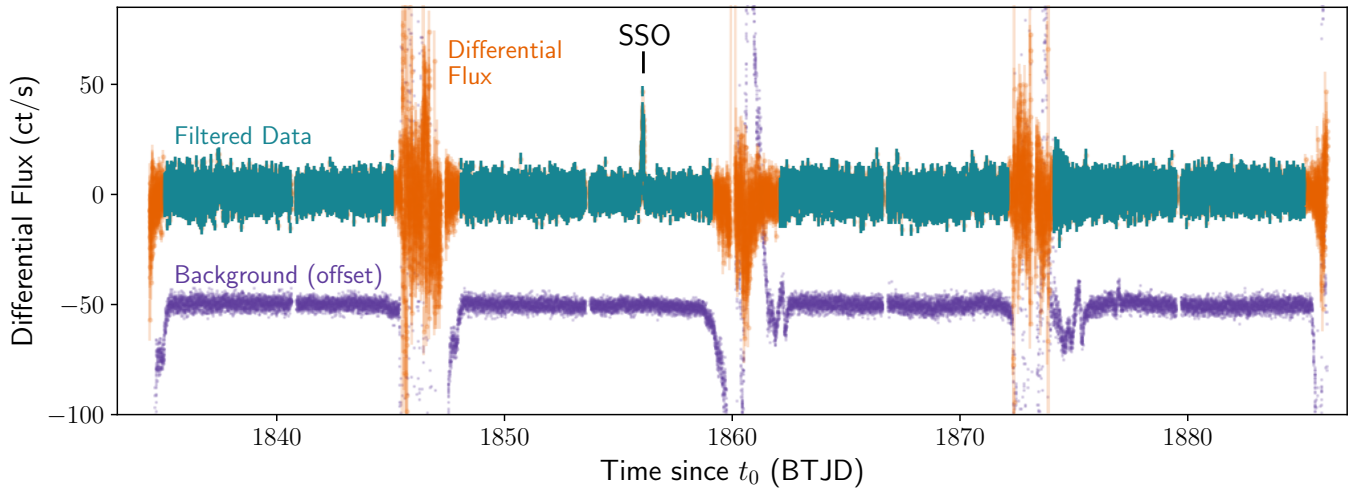


Figure 2. Light curve for AT2018lug from TESS Sectors 70 and 71 showing the differential flux (orange), the filtered data points used in our analysis (turquoise), and the backgrounds from scattered light (purple). The background is offset for clarity. The scattered light backgrounds peak toward the end of a given orbit (each sector is two TESS orbits). An SSO passing through the aperture is indicated; for further details, see Section 3.3 and Table 5. There is no evidence of flaring here.

Table 2
TESS Light Curves of the Luminous Fast Blue Optical Transients Analyzed in This Work

Sector	Identifier	Time (BJD – 2457000)	Photometry		Background		
			Differential Flux (counts s ⁻¹)	Uncertainty	Local	Model (counts s ⁻¹)	Residual
5	CSS161010	1438.01566	0.0527	1.0766	–11.5339	0.2296	1.280187
5	CSS161010	1438.03650	3.1743	1.0485	–12.3155	0.3522	0.390901
...	...	...	...	...	...	...	...

Note. The light curves are given for the full sector, for all sectors in which the LFBOT fell. We report the limiting magnitudes in Table 3 for flares and Table 4 for precursors. In this table, we include the time, differential flux, and background estimates from our photometric pipeline described in Section 2.1. The background estimate consists of three values: (1) local, measuring the local background; (2) model, encapsulating the potential systematic errors inherent in the background correction; and (3) residual, enumerating the remaining background in the photometric aperture after subtraction of the background (local + model) and measured flux. Further information about the background modeling can be found at <https://tess.mit.edu/public/tesstransients/pages/readme.html>. The light curve of AT2023hkw in Sector 21 suffered from severe scattered light, making the data unusable. As a result, it is not included in this table. All photometric flux values that are brighter than $T = 7.5$ have been removed, as these are epochs where the detector is saturated. Any background model with values of ± 0 should be ignored, as that corresponds to epochs of high scattered light, when the background estimation failed.

Table 2 is published in its entirety in the machine-readable format. A portion is shown here for guidance regarding its form and content.

(This table is available in its entirety in machine-readable form in the [online article](#).)

We corrected for extinction using the maps of E. F. Schlafly & D. P. Finkbeiner (2011). A_V values were obtained from the NASA Extragalactic Database extinction calculator (NED 2019) and were corrected using the prescription presented in R. Jayaraman et al. (2024), using $A_{\text{TESS}} \approx 0.6470A_V$. These values were used to correct the upper limits on flux and luminosity in Tables 3–4.

2.2. ZTF

To access photometry from ZTF, we use `Fritz`, an instance of `SkyPortal` (S. van der Walt et al. 2019; M. W. Coughlin et al. 2023), which allows us to download all photometry for a given target from ZTF, and perform forced photometry on the ZTF difference images (F. J. Masci et al. 2019, 2023). We performed forced photometry at the site of each of the six LFBOTs in Table 1 that were not already searched for flaring in H23 to collect all observations (including nondetections) until 2026 March 30. We then filtered the data to search for any detections hundreds of days after the initial detection of the transient (this epoch is henceforth referred to as t_0). For any detection, we inspected

the corresponding images to determine whether this was genuine. Further details are given in Section 3 and Appendix.

2.3. Other Photometry

`Fritz` also enables users to upload photometric and spectroscopic observations that were collected as part of follow-up efforts, as well as perform forced photometry on difference images from the Asteroid Terrestrial-impact Last Alert System (ATLAS; J. L. Tonry et al. 2018). We performed ATLAS forced photometry for all the LFBOTs to ensure maximal coverage, especially for epochs that were not observed by ZTF due to weather or other constraints. This functionality relies upon the online ATLAS forced photometry API, as described in K. W. Smith et al. (2020) and L. Shingles et al. (2021).

3. Results

An initial visual inspection of the available light curves from TESS and ZTF yielded seven detections of flux excesses that resembled flaring behavior, of which all seven were

Table 3Results of Our Searches for Luminous Fast Blue Optical Transient Flares in TESS That Occurred after the Transient, with Limiting Magnitudes and Upper Limits on the Luminosity (νL_ν)

Identifier	LFBOT Initial Peak νL_ν (erg s ⁻¹)	TESS Observation Details			200 s cadence limits		2 hr binned limits	
		Sector	Start Time	End Time	Magnitude T_{AB}	Luminosity (erg s ⁻¹)	Magnitude T_{AB}	Luminosity (erg s ⁻¹)
CSS161010	4.97×10^{43} (a)	5	$t_0 + 766.04$	$t_0 + 791.81$	18.89	$<1.04 \times 10^{42}$	19.37	$<6.69 \times 10^{41}$
		32	$t_0 + 1502.28$	$t_0 + 1528.25$	18.20	$<1.95 \times 10^{42}$	19.32	$<6.97 \times 10^{41}$
		98	$t_0 + 3322.02$	$t_0 + 3344.91$	17.45	$<3.91 \times 10^{42}$	19.31	$<7.04 \times 10^{41}$
		25	$t_0 + 697.72$	$t_0 + 723.34$	18.45	$<2.73 \times 10^{41}$	19.05	$<1.57 \times 10^{41}$
AT2018cow	4.29×10^{43} (b)	51–52	$t_0 + 1407.01$	$t_0 + 1457.14$	18.25	$<3.27 \times 10^{41}$	19.42	$<1.11 \times 10^{41}$
		78	$t_0 + 2148.33$	$t_0 + 2163.57$	17.57	$<6.17 \times 10^{41}$	19.79	$<7.93 \times 10^{40}$
AT2018lug	4.71×10^{43} (c)	42–43	$t_0 + 1073.79$	$t_0 + 1124.98$	18.16	$<1.84 \times 10^{44}$	19.46	$<5.54 \times 10^{43}$
		70–71	$t_0 + 1834.45$	$t_0 + 1886.06$	17.65	$<2.96 \times 10^{44}$	19.55	$<5.10 \times 10^{43}$
AT2020mrf	2.71×10^{43} (d)	50–51	$t_0 + 649.40$	$t_0 + 701.66$	18.30	$<3.45 \times 10^{43}$	19.54	$<1.10 \times 10^{43}$
		77–78	$t_0 + 1379.61$	$t_0 + 1433.64$	17.89	$<5.02 \times 10^{43}$	~19.5	$\lesssim 1 \times 10^{43}$ (e)
AT2020xnd	4.71×10^{43} (f)	42	$t_0 + 313.03$	$t_0 + 338.49$	18.02	$<1.63 \times 10^{44}$	18.71	$<8.68 \times 10^{43}$
		55	$t_0 + 662.44$	$t_0 + 689.60$	18.09	$<1.53 \times 10^{44}$	19.38	$<4.66 \times 10^{43}$
		92	$t_0 + 1669.33$	$t_0 + 1692.63$	17.41	$<2.88 \times 10^{44}$	19.52	$<4.12 \times 10^{43}$
AT2022tsd	6.81×10^{43} (g)	70–71	$t_0 + 379.03$	$t_0 + 429.53^g$	17.26	$<3.68 \times 10^{44}$	19.11	$<6.70 \times 10^{43}$
AT2022abfc	5.16×10^{43} (h)	98	$t_0 + 1083.65$	$t_0 + 1112.04$	17.94	$<1.29 \times 10^{44}$	20.39	$<1.37 \times 10^{43}$
AT2023fhn	1.08×10^{44} (h)	72	$t_0 + 215.47$	$t_0 + 240.88$	17.57	$<2.41 \times 10^{44}$	19.56	$<3.87 \times 10^{43}$
AT2023hkw	6.80×10^{43} (h)	75	$t_0 + 274.09$	$t_0 + 301.79$	17.89	$<4.06 \times 10^{44}$	19.89	$<6.48 \times 10^{43}$
AT2023vth	2.71×10^{43} (h)	80	$t_0 + 244.27$	$t_0 + 270.72$	17.18	$<2.72 \times 10^{43}$	18.77	$<6.30 \times 10^{42}$
AT2024qfm	5.66×10^{43} (h)	83	$t_0 + 40.58$	$t_0 + 65.53$	17.51	$<2.23 \times 10^{44}$	19.23	$<4.59 \times 10^{43}$
AT2024wpp	1.30×10^{44} (h)	97	$t_0 + 356.13$	$t_0 + 380.67$	17.66	$<2.42 \times 10^{43}$	19.79	$<3.40 \times 10^{42}$

Note. For contiguous sectors, we shifted the light curves to have a common baseline of zero and then analyzed them jointly. Sectors 1–26 had a cadence of 1800 s, Sectors 27–55 had a cadence of 600 s, and Sectors 56 onward have a cadence of 200 s. The reported magnitudes and luminosities are corrected for Galactic extinction, as described in Section 2.1. Notes and references: (a) C. P. Gutiérrez et al. (2024). (b) D. A. Perley et al. (2019). (c) A. Y. Q. Ho et al. (2020). (d) Y. Yao et al. (2022). (e) High backgrounds and rms scatter in this light curve affect this limit. (f) D. A. Perley et al. (2021). (g) TESS observations of AT2022tsd occurred ~300–350 days after the flaring seen by H23. (h) C. Sevilla et al. (2026).

Table 4

Constraints on Precursors from TESS Observations of the Luminous Fast Blue Optical Transients Prior to Their Initial Detections

LFBOT	Observation		Limits	
	Start	End	Native (10 ⁴³ erg s ⁻¹)	2 hr (10 ⁴³ erg s ⁻¹)
AT2020mrf ^a	$t_0 - 87.75$	$t_0 - 33.61$	2.35*	1.23
AT2022tsd	$t_0 - 382.28$	$t_0 - 305.53$	21.4†	5.95
AT2023fhn	$t_0 - 518.67$	$t_0 - 466.00$	13.4†	4.36
AT2024aehp	$t_0 - 1163.67$	$t_0 - 1056.92$	6.82†	2.10
AT2024aehp	$t_0 - 427.86$	$t_0 - 378.27$	11.27‡	1.53
AT2026dbl	$t_0 - 1585.35$	$t_0 - 1507.15$	7.51†	2.22

Notes. We only include LFBOTs that had ≥ 2 sectors of contiguous prior observations in TESS, a cut based on the duration of observed pre-SN outbursts. “Native” cadence means 1800 s (indicated with *), 600 s (indicated with †), or 200 s (indicated with ‡), depending on when the observations occurred.

^a AT2020mrf suffered from high backgrounds, so we only used a portion of the data that exhibited low scattered light as part of this analysis.

confirmed to be SSOs through inspection of the TESS images and comparisons with the Sky Body Tracker (SkyBoT) service (J. Berthier et al. 2006). Forced photometry with ATLAS revealed a single detection (with a 4.6σ significance) for AT2022abfc roughly 380 days after the first detection of the transient, though the raw difference image from ATLAS did not show clear evidence of a source. Further properties of this detection are discussed in the Appendix.

In addition, we also searched for any precursor emission at the locations of these transients in both TESS and ZTF, and found no evidence for any pre-LFBOT emission at any of these locations that was comparable to the peak luminosity of the transient. Our results, including upper limits on the luminosity of putative flares, are given in Tables 3–4. All magnitudes reported are in the AB system, and all calculations involving redshifts will assume a Planck18 cosmology as implemented in *astropy* (Planck Collaboration et al. 2020), with $H_0 = 67.66 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $\Omega_M = 0.31$.

3.1. Ruling Out Spurious Late-time Detections

Given the sheer number of photometric data points from TESS and ZTF since the discovery of these transients, there were several instances of formal 3σ detections of a source at the location of the transient. For each such detection, we evaluated the probability that such detections are caused by statistical fluctuations and inspected the difference images at that epoch (to search for point sources at that location).

For the statistical test, we assumed that the distribution of flux residuals is Gaussian (see Figure A1), and calculated the probability of at least one $>3\sigma$ detection occurring throughout the span of observations after the initial LFBOT. We then used binomial statistics to characterize the probability of observing at least one detection across the entire light curve, and found that none of these detections were statistically significant ($p > 0.05$). This analysis mirrors that in H23. Further details about our results for the individual LFBOTs can be found in Appendix. We also note that the rms scatter for TESS light curves increases considerably during times of high

background, yielding spurious detections. These were identified via visual inspection and comparison to the local background (details on background estimation can be found in Appendix A of M. M. Fausnaugh et al. 2023).

3.2. Limits on Precursors

The repeated visits of TESS to different fields of the sky allow us to search for precursors to all 14 known LFBOTs from thousands of days before the event to tens of days before the event. However, given that known examples of precursors (to SNe) can often last from tens to hundreds of days (e.g., E. O. Ofek et al. 2014; N. L. Strotjohann et al. 2015, 2021), we focused our search on those LFBOTs that had contiguous TESS observations prior to the initial transient (i.e., fell within the FOV during back-to-back sectors). This was the case for AT2020mrf, AT2022tsd, AT2023fhn, AT2024aehp, and AT2026dbl (see left half of Figure 1). Given that there may be evidence for significant mass loss prior to the LFBOT (e.g., C. Sevilla et al. 2026), precursors to these events could arise from a similar mechanism as those occurring prior to SNe (see, e.g., T. Matsumoto & B. D. Metzger 2022). However, the luminosities of SN precursors are often $\lesssim 10\%$ the luminosity of the eventual transient (e.g., E. O. Ofek et al. 2014), making them difficult to detect in surveys.

For the five LFBOTs mentioned above, we searched for precursors in TESS using the available contiguous sectors of data. We are able to rule out precursors that would have had a luminosity comparable to that of the original transient at its peak. Such luminous precursors are ruled out at several timescales—from tens of days before the transient (AT2020mrf) to thousands of days before the event (AT2026dbl). Details about the precursor limits for our LFBOTs are given in Table 4.

3.3. Other Photometric Features in TESS Light Curves

Due to TESS’s wide FOV and large plate scale ($21'' \text{ pixel}^{-1}$), there are several sources of false positives in any analysis of transients (see, e.g., B. B. Ogunwale et al. 2025; H. Roxburgh et al. 2025). In particular, the largest issue affecting our search for flaring in LFBOTs was the presence of SSOs passing near the on-sky location of the transient. The light curve of an SSO passing through the photometric aperture appears like a roughly symmetric Gaussian (e.g., H. Roxburgh et al. 2025), in contrast to stellar flares—which have a fast rise and a slower decay (M. N. Günther et al. 2020). The seven flare-like features in the light curves—which are confirmed SSOs—are shown in Figure 3. We fit Gaussians to these profiles; Table 5 gives their best-fit parameters.

To confirm that these peaks were caused by SSOs (and not by flares intrinsic to the LFBOT), we used TESS-cut (C. E. Brasseur et al. 2019) to download $410'' \times 410''$ ($20 \times 20 \text{ pixel}$) cutouts around the transient from 0.5 days before to 0.5 days after the best-fit peak time from Table 5. We used a custom aperture centered on the LFBOT’s location to extract a light curve (with *lightcurve*; Lightcurve Collaboration et al. 2018), and created a video tracking the measured flux in the aperture alongside the FFI cutout. Note that this light curve is different than the difference imaging light curve described in Section 2.1, in order to verify that the observed signal is visible no matter

what photometric pipeline is used. We also constructed a per-pixel rms map, which tracks the variability in each pixel across a given time span. This mirrors the transient detection approach used in G. Mo et al. (2023), and allows us to track the movement of an SSO through the image—it will show up as a “streak” that is considerably higher in flux than the background. For four of the seven cases given in Table 5, we found an object moving through the aperture constructed using *lightcurve*, as shown in Figure 4. For the other three cases, we did not see a clear signal in the calibrated FFIs. As a result, we constructed an rms map from the difference images and searched for evidence of SSOs therein. These three cases were found to have SSO “streaks” in the difference image rms maps, suggesting that the observed flares do not arise from the LFBOTs themselves. All the LFBOTs whose TESS light curves are shown in Figure 3–5 are at low ecliptic latitudes (see Table 5). Table 5 also shows the peak luminosity if this feature were a real flare associated with the LFBOT. The luminosities in Table 5 are a few times the peak luminosities of the original LFBOTs (enumerated in Table 3).

To characterize the prevalence of false positives in TESS light curves close to the ecliptic, we selected 500 random times during the roughly 7 yr of TESS observations and queried the SkyBoT (J. Berthier et al. 2006) to see whether there was an asteroid passing within $80''$ of that location at that time. This cone search radius is appropriate, given that TESS’s large plate scale ($21'' \text{ pixel}^{-1}$) can lead to contamination from objects that other surveys, like ZTF, would consider “far away.” We repeated this experiment for the LFBOTs that had an ecliptic latitude between -10° and 10° (AT2018lug, AT2020xnd, AT2022tsd, AT2023fhn, and AT2024aehp) and found that there was between a 15% and 20% chance of any SSO passing through the aperture at any given time for each of these objects, with the likelihood going up the closer the transient was to the ecliptic plane. However, the number of bright ($V < 19$) SSOs passing close to the LFBOT target was much smaller, making up $\lesssim 10\%$ of SSO passages.¹⁴

To estimate the overall prevalence of detectable SSO signals, we make the simplifying assumption that SSO passages are a Poissonian process. We can put an upper limit on the probability of any asteroid passage as 0.2 (from our calculated rate) and a 95% lower limit (from N. Gehrels 1986, for $n = 1$) of 0.05. The probability of seeing at least one asteroid passing through the frame is given by $1 - e^{-\lambda t}$, where λ is the aforementioned rate, and t is the observing duration (~ 25 days). Since not all asteroids will produce a detectable signal in TESS, we assume that 10% of asteroids have $V \lesssim 19$ to determine which could affect the TESS photometry. Thus, the probability of seeing a detectable signal from a bright SSO in a 25 day long TESS observing sector is between 5% and 10%, for an observation near the ecliptic.

4. Discussion

4.1. Constraints on Flare Luminosity and Duty Cycle

Here, we constrain properties of flares from the observed LFBOTs using limits from TESS observations, making the assumption that all detected “flares” arise from SSOs rather than from the transient. All upper limits are given as one-sided

¹⁴ These bright SSOs are likely cataloged in the JPL Small-Body Database: https://ssd.jpl.nasa.gov/tools/sbdb_query.html.

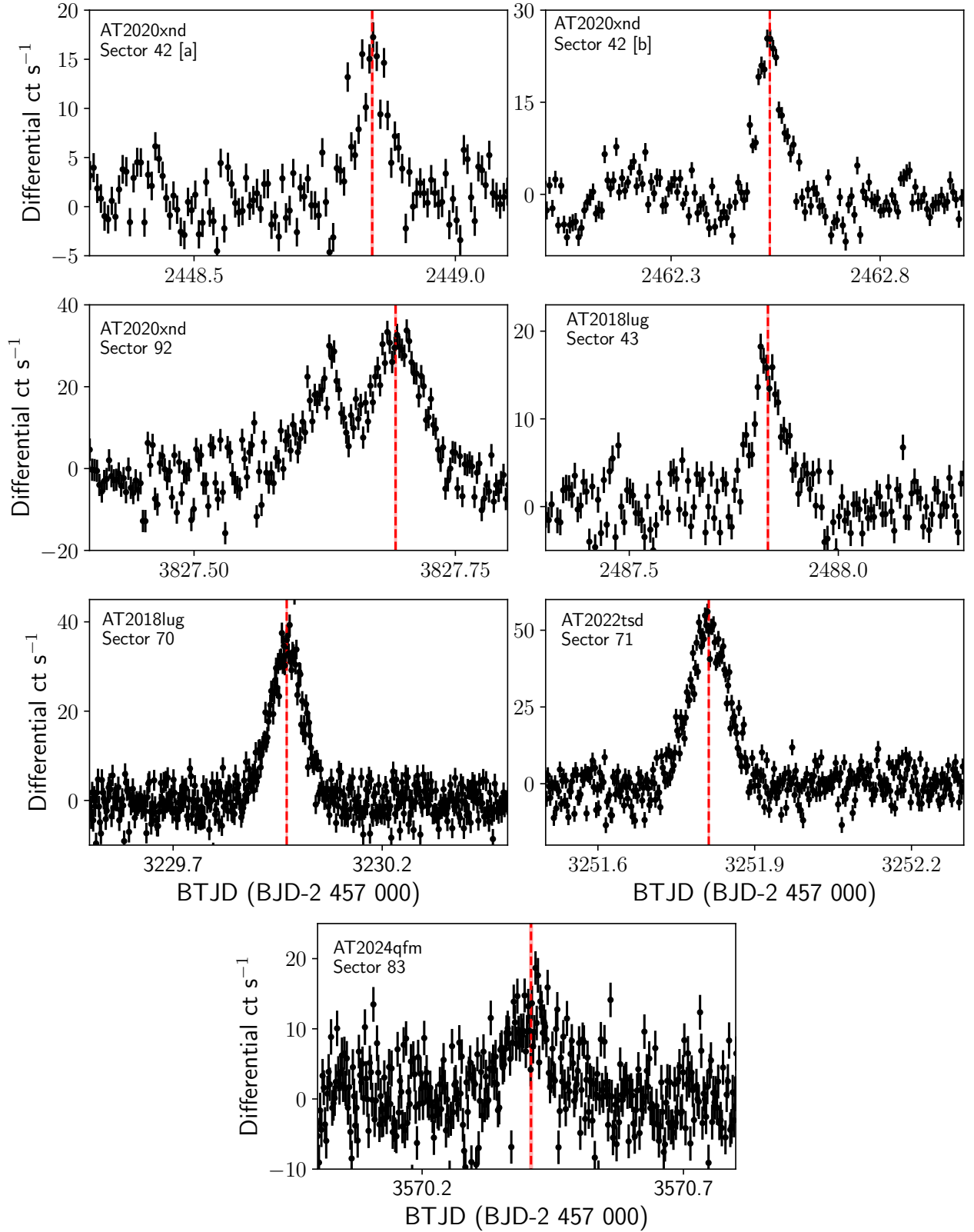


Figure 3. Flare-like features in TESS light curves. These all likely arise from SSOs (see Figures 4–5), which represent the largest source of false positives in the search for LFBOT flaring. These photometric features are best fit with Gaussians in order to distinguish them from stellar flares and rule this out as a possibility (see Table 5). Each panel has been annotated with the LFBOT and its corresponding TESS sector.

3σ upper limits, using Poisson statistics (N. Gehrels 1986)—this mirrors the analysis from H23, who assumed a Poisson distribution for the likelihood of detecting a flare in a given interval.

4.1.1. Until $t_0 + 100$ days

AT2022tsd flared from roughly 30–120 days after the initial transient (see Figure 2 in H23). The only transient for which

Table 5
Results of a Gaussian Fit to the Flare-like Profiles Seen in Each Light Curve

LFBOT	Ecliptic Latitude (DD:MM:SS.SS)	Sector	t_{peak} (BTJD)	Time since LFBOT (days)	FWHM (days)	νL_{ν} (erg s^{-1})
AT2020xnd	...	42	2448.8409(17)	$t_0 + 314.165$	0.071(2)	3.97×10^{44}
AT2020xnd	+07:01:49.00	42	2462.5361(8)	$t_0 + 327.860$	0.075(2)	5.77×10^{44}
AT2020xnd ^a	...	92	3827.6928(7)	$t_0 + 1693.017$	0.045(3)	1.41×10^{45}
AT2018lug	+04:16:02.78	43	2487.8316(16)	$t_0 + 1113.919$	0.090(4)	5.21×10^{44}
AT2018lug	...	70	3229.9716(6)	$t_0 + 1856.059$	0.093(2)	1.32×10^{45}
AT2022tsd	−09:18:47.31	71	3251.8121(5)	$t_0 + 421.836$	0.090(1)	1.41×10^{45}
AT2024qfm	+14:46:51.63	83	3570.4084(24)	$t_0 + 51.558$	0.103(7)	2.28×10^{44}

Notes. We report the LFBOT’s ecliptic latitude, peak time, FWHM, and the luminosity if the flare arose from that particular LFBOT. The peak luminosities—if these features are bona fide flares—are higher than the peak luminosity of the initial transient (from Table 3). AT2022tsd’s flares were comparably or less luminous than the peak of the initial transient and were also observed in a different bandpass (H23). Figures 4–5 show these targets’ light curves, as well as cutouts from the FFIs showing SSOs passing through the aperture.

^a This feature exhibits a double peak, but we fit it using a single Gaussian.

this period of time (relative to the initial detection) was observed in TESS was AT2024qfm ($t_0 + 40$ –65 days). Using the photometry from C. Sevilla et al. (2026), we calculate that AT2024qfm had a peak luminosity of $\nu L_{\nu} \approx 5.7 \times 10^{43} \text{ erg s}^{-1}$. Our results show that there are likely no flares with luminosities comparable to that of the original transient during the TESS observation, using the 2 hr binned flux limit; i.e., there is no evidence for excess flux (above typical backgrounds or rms scatter) during the TESS observation. At the 200 s native cadence, our limit rules out minutes-timescale flares that were $4\times$ as luminous as the peak of the original transient. Our constraint on the duty cycle from the unbinned light curve is <0.0073 (rate of $<0.011 \text{ hr}^{-1}$), and from the binned light curve, <0.022 .

For comparison, AT2022tsd had one detected flare during the 40–65 day window, at $\nu L_{\nu} \approx 5 \times 10^{42} \text{ erg s}^{-1}$ in Keck *I* band (which is slightly narrower than the TESS bandpass, but with a similar pivot wavelength). Such a flare would have been below TESS’s sensitivity at the distance of AT2024qfm (see Table 3).

4.1.2. From $t_0 + 100$ to 450 days

There are several LFBOTs, including AT2022tsd and a recent nearby one (AT2023vth), that were observed by TESS within roughly a year after their initial detections.

AT2022tsd. Our limit for minutes-timescale flaring using 50 days of continuous, 200 s cadence observations from TESS between $t_0 + 380$ and 430 days (corresponding to ~ 260 days after the last observed flares from H23) is $\nu L_{\nu} \approx 3.68 \times 10^{44} \text{ erg s}^{-1}$, which is roughly $5\times$ as luminous as the most luminous flare seen from AT2022tsd. For any flaring on timescales of up to 2 hr, we have a limit comparable to the brightest flare, of $6.7 \times 10^{43} \text{ erg s}^{-1}$. If we assume that AT2022tsd continued to flare identically to the observations reported in H23, with the brightest flare (in *i* band) reaching a peak luminosity of roughly $5 \times 10^{43} \text{ erg s}^{-1}$, TESS would likely not have detected these, even with a 2 hr bin. This weak constraint is partially due to the distance of AT2022tsd, which is the third-furthest LFBOT we know of. Such an energetic AT2022tsd-like flare could have been detected for an LFBOT with $z < 0.2$ (this would have had apparent AB magnitude of ~ 18.8 , which is easily detectable in a single 30 minute TESS [co-added] exposure, and marginally detectable in a 10 minute TESS exposure; see Section 4.3). Nevertheless, the

nondetection of any flux excess even in longer bins suggests that AT2022tsd’s flares might either have stopped or have become less luminous by the time TESS observed the field. This possibility is further discussed in Section 4.2.1.

Other LFBOTs. We do not find any evidence for flaring in the other LFBOTs at these intermediate times. For the more distant ($z > 0.1$) LFBOTs (AT2020xnd, AT2023fhn, and AT2023hkw), we find that there is no evidence for flaring comparable to the original transient’s luminosity on timescales of 2 hr or shorter. For minutes-duration flaring, our limits are above the original transient’s luminosity. We do note that the second flare observed from AT2022tsd (at roughly $t_0 + 28$ days) exhibited a luminosity that was comparable to, if not greater than, the peak luminosity of the early LFBOT light curve.

For the nearby ($z < 0.1$) LFBOTs (AT2023vth and AT2024wpp), our limits are considerably more stringent. At the native 200 s cadence, we can rule out flaring comparably as luminous as the original transient for AT2023vth, and flaring that is over $5\times$ as faint as the peak of AT2024wpp out to a year after the initial observation. Binning to 2 hr strengthens these limits (see Table 3). This last nondetection suggests either that the flaring turns off after a year (as was seen in AT2022tsd) or that there is another phenomenon at play (e.g., beaming) that has prevented us from observing flaring in other events apart from AT2022tsd (see Section 4.2 for further discussion). Our limits from TESS (for a 2 hr bin) are comparable to the limits for early time flaring from E. O. Ofek et al. (2025), of roughly $3 \times 10^{42} \text{ erg s}^{-1}$.

4.1.3. Late Times: $t_0 + 450$ days and Beyond

There are several LFBOTs in our sample that have observations over a year to several years after the initial transient. We have demonstrated that AT2022tsd likely stops flaring with a comparable luminosity to the initial flares after roughly a year, and can extend this limit to other events. For the farther LFBOTs with late-time observations (AT2022abfc, AT2020mrfr, AT2018lug, and AT2020xnd), our upper limits on years-long timescales are within an order of magnitude of the initial luminosity. For the nearby LFBOTs with late-time observations (AT2018cow and CSS161010), we can constrain the luminosity of any potential extremely late-time flaring to be a few hundred times as faint as the initial transient, suggesting that they are not as active at late times after a

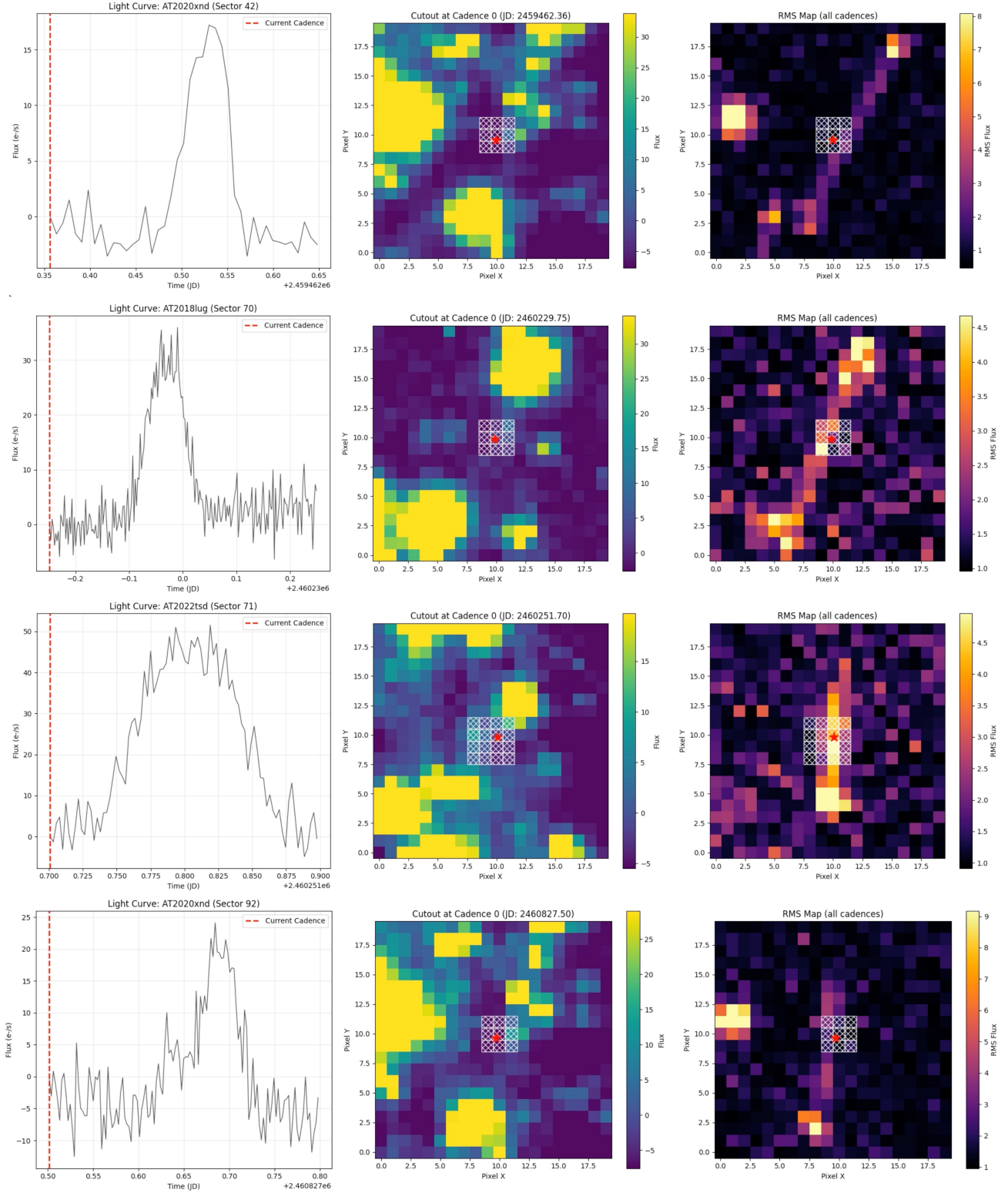


Figure 4. Screenshots of the vetting tool used to identify the passage of SSOs through a photometric aperture (shown as a white cross-hatched box) centered on the LFBOT location (indicated with a red star, roughly in the center of the field), for four of the seven LFBOTs with clear SSO signals. The dotted line on the left panel moves across the light curve, corresponding to the cadence of the FFI in the middle panel. The right panel is an rms map of simple difference images created for each cadence (relative to the first image in the series); streaks in this rms map also suggest that there is an object moving through the field during this time period. The cutouts and rms maps have a spatial scale of $410'' \times 410''$ (20×20 TESS pixels). An animated version of this figure for each of the LFBOTs in Table 5 is available in the online Journal. The animation proceeds through the complete time duration shown in the left panel light curve.

(An animation of this figure is available in the [online article](#).)

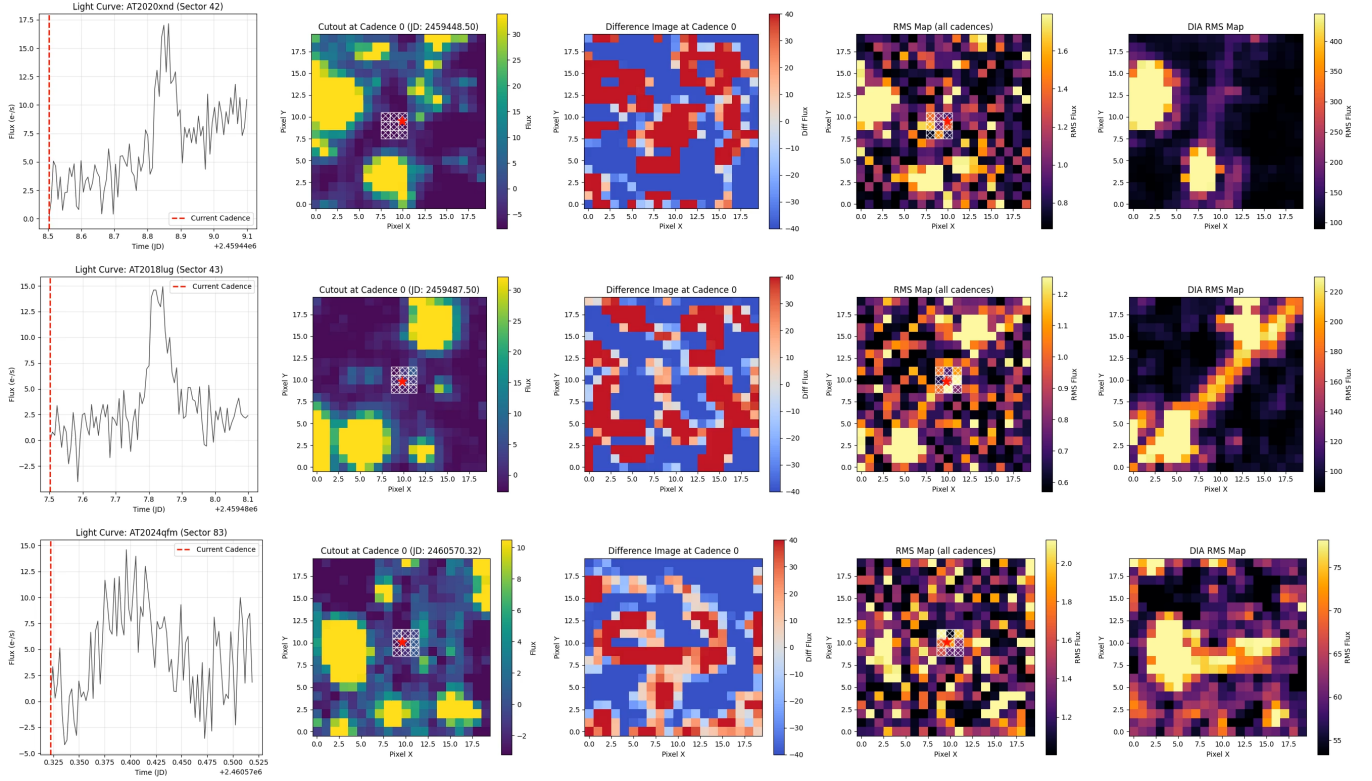


Figure 5. As Figure 4, but for LFBOTs without evidence for a source moving through the photometric aperture in our vetting tool. We inspected the ISIS difference images (third column; see Section 2.1) and constructed an rms map using these—there is a clear streak visible in these maps (right column). These SSO signals, on the whole, are of considerably lower amplitude than the corresponding signals in Figure 4. An animated version of this figure is available in the online Journal. The animation proceeds through the complete time duration shown in the left panel light curve. (An animation of this figure is available in the [online article](#).)

potentially stable accretion disk has formed (Y. Chen et al. 2023; A. Inkenhaag et al. 2025).

Our TESS observations of AT2018cow coincide with Hubble Space Telescope observations of this source, reported in N.-C. Sun et al. (2022). In the F814W bandpass (which overlaps much of the TESS bandpass), N.-C. Sun et al. (2022) report a detection of a source at the position of AT2018cow with a magnitude of 25.82 ± 0.19 (Vega). To within a small correction term (for Vega to AB conversion), this source is roughly $800\times$ fainter than the TESS detection limit. A. Inkenhaag et al. (2025) theorize that this source is powered by accretion, with a persistent luminosity that is roughly $1000\times$ fainter than the detection limit of TESS during this time.

4.1.4. Flaring Duty Cycle and Observability

Our observations suggest that there is a point at which the flaring “switches off” or becomes less luminous for AT2022tsd, and suggest that there is no evidence for flaring beyond 100 days in any of the other transients (as well as no flaring at early times in AT2024qfm). These results allow us to constrain the duty cycle of these flares when TESS was observing them. Our approach mirrors that of E. O. Ofek et al. (2025), and we use the formula $\Delta t/(60T_{\text{obs}})$ for the duty cycle. Here, Δt represents the timescale over which we expect the flares to be active, and T_{obs} represents the observation duration. Since the Poisson single-sided upper limit for a 3σ detection (99.8% confidence) is 6.6 (from N. Gehrels 1986), the upper limit on the duty cycle is $<6.6\Delta t/60T_{\text{obs}}$.

If we assume an average flaring duration of ~ 40 minutes (based on AT2022tsd) and an average TESS observation duration of 20–25 days, then the upper limit on the duty cycle is <0.007 – 0.01 during the times of observation. Relaxing the upper limit to 2σ yields a duty cycle of <0.003 – 0.004 . For continuous observations with two 25 day sectors (as was the case for AT2018cow, AT2018lug, AT2020mrf, and AT2022tsd), or the case of longer sectors (e.g., Sectors 97 and 98—the case for AT2024wpp, CS161010, and AT2022abfc), the T_{obs} increases to roughly 55 days. This larger T_{obs} strengthens the constraint on the duty cycle to $\lesssim 0.004$ (3σ), under the assumption that any flaring occurring in the transient would have been luminous enough for TESS to detect. The duty cycle limit and observation time are inversely related; these limits are reduced by factors of $1/N$ for longer observations, where N is the number of sectors during which the transient was observed. These upper limits are comparable to, if not more stringent than, the estimates for the duty cycle of the flaring of AT2022tsd (between 0.02 and 0.5; see Extended Data Table 3 in H23).

We simulated how AT2022tsd-like flaring would appear in TESS if an LFBOT were situated at $z = 0.08$, which is further than AT2018cow and CSS161010 but closer than AT2022tsd. These flares peak at $T_{\text{mag}} \sim 16.5$, with the substructure clearly resolved at TESS’s 200 s cadence (shown in Figure 6). While we do not yet have a robust constraint on the rate of late-time flaring in LFBOTs, we estimate the detection rates of these flares using current and upcoming facilities in Table 6. These calculations are further discussed in Section 4.4.

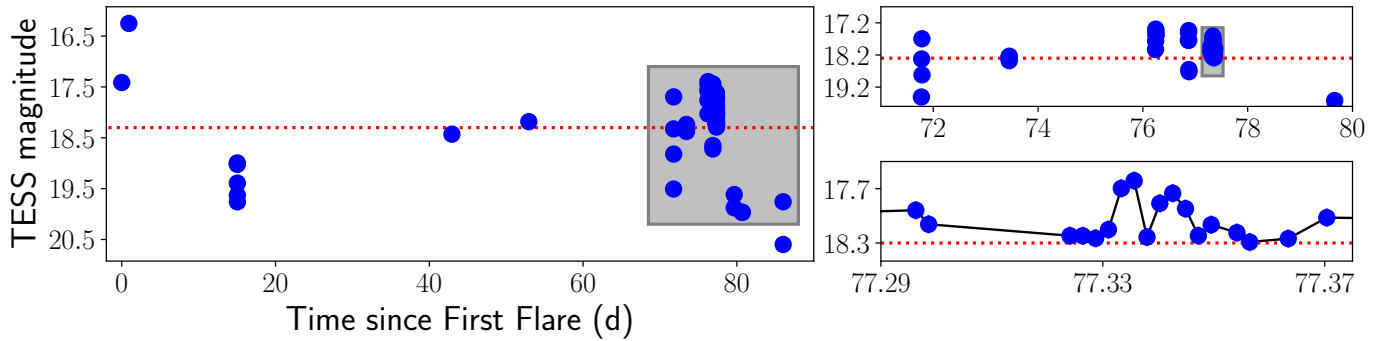


Figure 6. A simulated light curve of AT2022tsd-like flares in the TESS passband, situated at $z = 0.08$. TESS has the necessary temporal resolution to individually resolve several distinct flaring episodes, as shown in all three panels. The red dotted line in all panels represents the theoretical lower limit for TESS detections at the native cadence of 200 s (see Figure 7). However, only three known LFBOTs lie within this redshift—the first two discovered (CSS161010 and AT2018cow; see Table 1), and AT2023vth (C. Sevilla et al. 2026). Within this volume, there should be 0.2–2 LFBOTs per year, based on the rates from D. A. Perley et al. (2026). The k -correction used in this analysis assumes an underlying source spectral energy distribution (SED) of $F_\nu \propto \nu^{-1.6}$ (H23).

4.2. Physical Implications

Our nondetection of confirmed late-time flaring in any of the other LFBOTs (apart from AT2022tsd) across several time-scales has implications for the duration of central engine activity and the beaming of observed emission. We consider both hypotheses separately and characterize each one’s effects on flare detection.

4.2.1. Decline or “Shutoff” in Engine Power

First, our results suggest that the engine power declines or shuts off on a timescale of hundreds of days, given the nondetection of flaring after 100 days in AT2022tsd. The redshift of AT2022tsd and the sensitivity of our limits from TESS mean that we cannot constrain the rate at which the engine power declined. If the engine is fallback accretion from stellar collapse (e.g., E. Quataert & D. Kasen 2012; E. Quataert et al. 2019; A. A. Chrimes et al. 2026), the engine power drops precipitously after much of the mass is accreted. The relevant timescale for this phenomenon is the freefall time t_{ff} (E. Quataert & D. Kasen 2012):

$$t_{\text{ff}}(r) = \frac{\pi r^2}{(2GM)^{1/2}} \approx 702 \left(\frac{r}{10^{14} \text{ cm}} \right)^{3/2} \left(\frac{M(r)}{10 M_\odot} \right)^{-1/2} \text{ days}, \quad (2)$$

where r and M are the initial radius and the mass of the infalling material, respectively. Thus, in this scenario a timescale of hundreds of days would require an extended ($\sim 10^{14}$ cm) stellar progenitor, like a red supergiant.

The calculations in B. D. Metzger (2022) suggest that the luminosity available to power accretion by the central engine drops as roughly $t^{-2.1}$, as observed in light curves of AT2018cow and several other LFBOTs (see, e.g., Figure 1 in C. Sevilla et al. 2026).¹⁵ The flaring phenomenon may be related to transitions in accretion state, as suggested in G. Migliori et al. (2024) for AT2018cow in order to explain the late-time X-ray observations, though flaring was not detected in this event (despite intensive multiwavelength monitoring).

¹⁵ This power-law slope is seemingly not universal across all LFBOTs: N. LeBaron et al. (2026) find that the engine luminosity of AT2024wpp’s declined as $t^{-3.4}$ between $t_0 + 10$ and 30 days (see Figure 8 therein).

4.2.2. Beaming of the Flare Emission

The red color of the flares in AT2022tsd suggests that this emission is nonthermal (possibly of synchrotron origin); together with the high brightness temperature, this suggests it is somewhat beamed. This would require the observer to be on axis to observe these flares. H23 estimated the outflow opening angle of AT2022tsd to be roughly 30° based on the nondetection of flaring from the other six (at the time) known LFBOTs. From our constraints on the newer LFBOTs, we can constrain the beaming fraction f_b to be between $1/14$ and $1/6$, where the denominator is the number of LFBOTs we have detected so far (14 as of this work; six in H23). Since $f_b = 1 - \cos \theta$, where θ is the outflow opening angle, we find that a beamed outflow could be weakly collimated, with an estimated beaming angle of 5° – 30° . This uncertainty calculation uses the 90% confidence lower limit for Poisson statistics (from N. Gehrels 1986), 0.0513 for $n = 1$.

From this simple beaming angle calculation (which has a high uncertainty, given only one detection of LFBOT flaring, and also does not take into account any potential flare “shutoff” timescale), it appears that LFBOT outflows could be wider than those observed in GRBs (see, e.g., the jet opening angle distributions for long GRBs from A. Goldstein et al. 2016). The presence of a collimated outflow could also explain the asphericity observed in certain LFBOTs (e.g., J. R. Maund et al. 2023), and further support the hypothesis that while AT2018cow was well monitored, we were not observing it at an appropriate orientation (i.e., pole on) that would enable us to observe a launched jet and any concomitant late-time flaring. These results are consistent with inferences on the jet geometry from R. Margutti et al. (2019), who find that the radio observations of AT2018cow can be explained by either low-energy, highly collimated jets or high-energy, weakly collimated jets propagating into a wind medium with low mass-loss rates ($\dot{M} < 10^{-4} M_\odot \text{ yr}^{-1}$). As the ejecta decelerate, for an off-axis relativistic jet, we theoretically could observe a “jet-break-like” phenomenon (as seen in GRBs), though the late-time millimeter and radio observations of AT2024wpp are difficult to explain using such a model (A. J. Nayana et al. 2025).

4.3. TESS and Luminous Fast Blue Optical Transients

Our results demonstrate that, for a nearby LFBOT such as AT2018cow, CSS161010, or AT2023vth ($z \lesssim 0.08$) that

Table 6
Properties of Different High-cadence Surveys and Their Efficiencies in Detecting Late-time Flaring in Luminous Fast Blue Optical Transients

Survey	Exposure (s)	Cadence (minutes)	FOV (deg ²)	Limiting Magnitude	Maximum z	Volume (Gpc ³)	Rate (yr ⁻¹)
TESS	200	3.33	2304	18.2	0.08	0.007	5.5–54
LAST	20 ($\times 20$) ^a	$\lesssim 60$ ^b	355	21.0	0.19	0.015	0.5–5
ULTRASAT	300	5 ^c	204	22.5	0.23	0.014	6.9–69
Legacy Survey of Space and Time (LSST) Deep Drilling Fields (DDFs; r band)	30	$\lesssim 500$ ^d	9.6	24.7	0.80	0.10	0.9–8.6
Argus Array	60	1 ^e	8000	20.5	0.17	0.97	8–80

Notes. Further information about LAST can be found in E. O. Ofek et al. (2023a) and R. Konno et al. (2026); Vera C. Rubin (Rubin)/LSST in Ž. Ivezić et al. (2019); ULTRASAT in I. Sagiv et al. (2014) and Y. Shvartzvald et al. (2024); and the Argus Array in N. M. Law et al. (2022). The calculations in this table rely on the following assumptions: (a) the luminosity of each flare is 10^{43} erg s⁻¹ in r band, (b) the spectral index of these flares is $F_\nu \propto \nu^{-1.6}$ (as reported in H23), and (c) there are 100 episodes of flaring, each lasting ~ 25 minutes, occurring over 90 days (similar properties as AT2022tsd). If we assume that all LFBOTs flare in such a manner, then we can use the rate of 1–10 Gpc⁻³ yr⁻¹ (D. A. Perley et al. 2026) for the calculations of flaring detectability.

^a In the slow mode, LAST scans the sky in 20×20 s exposure visits; in the fast mode, the visits are reduced to 5×20 s exposures.

^b Based on the fast-cadence survey (see Figure 5 in E. O. Ofek et al. 2023a, which assumes 300 s exposures).

^c This is for the high-cadence survey (21 hr day⁻¹); the low-cadence survey (3 hr day⁻¹; 6800 deg²) will have a much lower detection rate.

^d It is anticipated that DDF fields will get $10\times$ as many visits as the Wide, Fast, Deep (WFD) survey fields, which will be observed every ~ 3 days. Further information about the WFD and DDF surveys can be found at survey-strategy.lsst.io.

^e Argus Array is a “drift scanning” survey, which tracks the sky as the Earth rotates.

exhibits flares with luminosities comparable to the original transient (approximately 10^{43} erg s⁻¹), TESS should be able to confidently detect them and capture temporal substructure, especially at its current 200 s cadence. If the flares in AT2022tsd were at the distance of AT2018cow, they would have a peak magnitude $T_{\text{mag}} \sim 12\text{--}15$ —comfortably detectable by TESS.

Assuming a fiducial limiting (AB) magnitude for TESS of ~ 18 at its 200 s cadence, and an LFBOT peak magnitude range of $-22 \leq M \leq -20$, TESS could detect the peaks of LFBOTs out to a luminosity distance of ~ 1 Gpc ($z \sim 0.2$) for the brightest events. However, a single detection (or several) at or around the LFBOT peak would not leverage TESS’s key advantage, its 200 s cadence. Realistically, TESS could provide a well-sampled light curve for an LFBOT within a few hundred megaparsecs ($z \lesssim 0.1$; see, e.g., Figure 6). TESS light curves could be binned to longer intervals (e.g., a few hours) to help characterize the rise to peak and the decay, expanding the horizon for LFBOT detectability, though this is contingent on the level of the background from scattered light due to earthshine and/or moonshine entering the TESS camera. High-cadence observations of the initial transient could also help us study its evolution on short timescales (minutes to hours).

While the duration of the most intense episode of flaring observed in H23 was roughly 40 minutes, we binned the light curves to 120 minutes in order to establish deeper limits (by a factor of $\sim 5\text{--}10$) than possible using the 200 s data alone. Even if the flare spanned two of these 120 min bins, the flux excess would have been detectable at a $3\sigma\text{--}5\sigma$ level, especially for the nearby LFBOTs. However, this binning approach obscures any substructure in a flare. This issue could be overcome for a nearby LFBOT by obtaining TESS short-cadence observations (at either 2 minutes or 20 s)¹⁶ in the months after the initial transient, though the likelihood of one

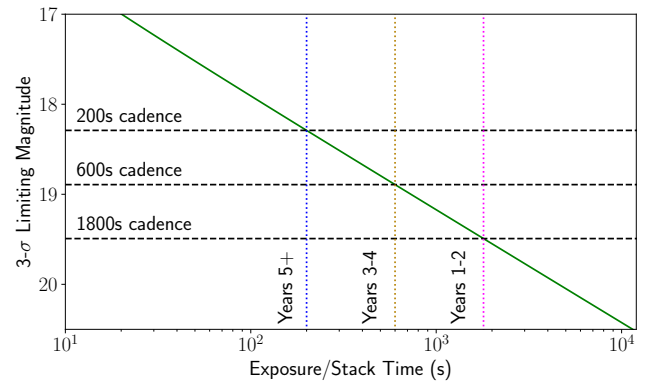


Figure 7. The theoretical TESS limiting magnitude as a function of exposure time (as calculated from the CCD equation) is shown in green, with the various observational cadences throughout the mission duration indicated. As inputs to the CCD equation, we assumed a dark current of zero, a fiducial quantum efficiency (QE) of 0.95, (this has been found to vary across the bandpass; see, e.g., Figures 9–10 in A. Krishnamurthy et al. 2019), a read noise of $10 e^- \text{ pixel}^{-1}$ (sources: Figure 4.5, Section 6.2, and Section 6.1 in the TESS Instrument Handbook, respectively, for the three values: https://archive.stsci.edu/files/live/sites/mast/files/home/missions-and-data/active-missions/teess/_documents/TESS_Instrument_Handbook_v0.1.pdf), an aperture size of 4 pixels, an effective exposure time of 160 s (20% of the subexposures are clipped due to onboard cosmic-ray mitigation, reducing the effective exposure time from the nominal cadence; see the Appendix of R. Jayaraman et al. 2024), and an average sky background of $100 e^- \text{ pixel}^{-1} \text{ s}^{-1}$. The sky background was empirically calculated using several FFIs from different sectors with low scattered light background.

happening as nearby as AT2018cow or CSS161010 is quite low.

Figure 7 shows the theoretical 3σ detection limits for TESS as a function of exposure time for an assumed set of input values to the CCD equation

$$S/N = \frac{S_{\text{obj}} \cdot \sqrt{t} \cdot \text{QE}}{\sqrt{S_{\text{obj}} + n_{\text{pix}} \left(S_{\text{sky}} + \frac{S_{\text{dark}}}{\text{QE}} + \frac{R^2}{\text{QE} \cdot t} \right)}}, \quad (3)$$

where S_{obj} is the flux of the object (electrons per second), t is the effective exposure time, n_{pix} is the number of pixels in the

¹⁶ TESS obtains high-cadence observations of a 10×10 pixel region of the sky around $\sim 10,000$ (community-selected) targets at 2 minute cadence and ~ 3000 targets at 20 s cadence.

photometric aperture, S_{sky} is the sky background (also in electrons per second), S_{dark} is the dark current, and R is the read noise. The equation also relates the signal-to-noise ratio (S/N) to the QE. Note that at the flight temperatures of the TESS detectors (~ 200 K), dark current has been found to be negligible during lab testing (C. Thayer et al. 2016). Other input parameters are enumerated in the caption to Figure 7.

One other crucial consideration when studying short-time-scale phenomena with TESS is its onboard cosmic-ray mitigation algorithm, which clips roughly 20% of the exposures when it coadds subexposures to create the “final” FFI. For phenomena varying on timescales of a few seconds, this onboard technique could clip a large fraction of astrophysical flux from the source. This effect was investigated by R. Jayaraman et al. (2024), who found that in the worst cases, TESS’s onboard CRM could clip over 50% of the flux from a source varying on timescales of a few seconds. LFBOT flares were found (in H23) to vary on timescales of ~ 30 – 60 s, which could be clipped as part of TESS’s coaddition when it constructs the FFIs. This would thus lead to a systematic underestimate of the flux from a rapidly varying source. Contemporaneous observations from another observatory can help diagnose this issue; R. Jayaraman et al. (2024) found that flux estimates would need to be revised upward by 20%–25% for a more accurate value, when compared to high-energy prompt light curves for GRBs.

Rates. A. Y. Q. Ho et al. (2023a) initially calculated the volumetric rate of LFBOT events to be $70 \text{ yr}^{-1} \text{ Gpc}^{-3}$; this estimate was revised downward by D. A. Perley et al. (2026) to be between roughly 1 – $10 \text{ yr}^{-1} \text{ Gpc}^{-3}$, with the rate of bright AT2024wpp-like events being even lower—with an upper limit of $0.7 \text{ yr}^{-1} \text{ Gpc}^{-3}$. In a simplistic analysis (i.e., not accounting for extinction, assuming a 100% observing efficiency, and achieving full sky coverage from TESS every ~ 2 yr), we find that TESS, which covers $\sim 5\%$ of the sky every sector, should be able to detect the initial emission of up to one LFBOT per year. Such a detection has not yet been achieved, as there has not yet been an LFBOT (discovered by another survey) that has fallen within TESS’s FOV at that time. Untargeted searches (e.g., H. Roxburgh et al. 2025) in archival TESS images may yield such transients, as occurred during the Kepler mission for KSN 2015K (A. Rest et al. 2018), referred to at the time as a “fast-evolving luminous transient.” However, the rates for such untargeted discoveries are highly uncertain: Table 2 in H. Roxburgh et al. (2025) suggests that there are 1093 ± 1092 “FBOTs,” with peak absolute magnitudes from -16 to -22 ,¹⁷ which could be recovered from the first ~ 6 yr of TESS observations.

4.4. Luminous Fast Blue Optical Transient Flaring from High-cadence Surveys

We evaluate the ability of high-cadence (minutes to hours) surveys—LAST, ZTF, the LSST at Rubin, the Argus Array, and the upcoming ULTRASAT satellite—to detect late-time flaring in LFBOTs. We assume that the most luminous flares have a luminosity of $10^{43} \text{ erg s}^{-1}$ and use this value in the

calculations underlying Table 6. We convert this to a flux and calculate the redshift at which we could detect this flux; we correct the volume enclosed at this redshift for a given survey’s FOV to find the comoving volume probed, and apply the appropriate k-corrections. We assume that there are 100 flares, each lasting 25 minutes over a period of 90 days (H23 detected 12 flares from AT2022tsd, but there may have been more that were not observed). We also assume that the flare emission has an SED of $F_{\nu} \propto \nu^{-1.6}$, identical to AT2022tsd, and then calculate the probability of detecting a flare for a given survey cadence. For Argus Array specifically, given that it is not a slewing survey, but rather observes the sky as the Earth rotates, we take into account the accessible range of the sky and how long a source transits over Argus Array (i.e., remains visible at its decl.). We find that the highest rates of flare detections will arise from the Argus Array, ULTRASAT, and TESS.

In calculating the rates of flaring detectability shown in Table 6, we assume that every LFBOT flares like AT2022tsd and so adopt the LFBOT rate. In reality, we have shown that not every LFBOT is observed to flare in an AT2022tsd-like manner. If not every LFBOT flares, then the calculated rates should be scaled by the fraction of LFBOTs empirically observed to flare— $1/14$ in the most pessimistic case, based on this work and H23. This multiplicative factor could also account for beaming, i.e., where we are observing the majority of LFBOTs off axis, and only saw AT2022tsd on axis (and hence observed flaring). We also note that for LFBOTs flaring at higher redshifts, given the $F_{\nu} \propto \nu^{-1.6}$ dependence, much of the emission should be in the near-infrared, though this is a difficult band to observe with ground-based observatories, given the high sky backgrounds. We thus focus on *r*-band observations from ground-based surveys to capture flares from nearby LFBOTs in this analysis.

LAST. This survey telescope was already used to search for flares from AT2024wpp in E. O. Ofek et al. (2025) and will be fully operational by the end of 2026. A LAST “node” is comprised of 48 28 cm telescopes equipped with CMOS detectors that provide a total FOV of 355 deg^2 and a collecting area equivalent to a 1.9 m telescope. The 5σ limiting magnitude (from R. Konno et al. 2026) for the 20×20 s exposures is 20.6 ± 0.4 .

In our rate calculations, we assume LAST’s fast-cadence survey strategy (as discussed in E. O. Ofek et al. 2023a), which scans the sky up to eight times in a given night (in areas below an airmass of two). In this case, we obtain a rate of flare detection of 0.5 yr^{-1} . However, this number comes with caveats; in particular, LAST can be used for targeted follow-up of LFBOTs detected by other surveys in order to search for flares, as in E. O. Ofek et al. (2025). This will likely increase the rates of flaring that would be detected, or provide further, more stringent constraints on the timescale and luminosity of flaring in LFBOTs. It could also be used to search for flaring in other transients, as this is an unexplored regime.

ZTF. H23 set upper limits on flaring in six of the first seven LFBOTs discovered (not including AT2022tsd) using ZTF. For the remaining six LFBOTs, we do not find any detections consistent with flaring behavior (on minutes-duration timescales) in the months to years after the transient. ZTF’s uneven sampling and 1 day cadence observations make it difficult to calculate upper limits on a duty cycle, in contrast with the limits we are able to set using TESS (and those set with LAST

¹⁷ The rate of LFBOTs, i.e., AT2018cow-like transients, is likely a small fraction of this number. However, there are likely several LFBOTs in southern fields (inaccessible to ZTF) that could be identified through an untargeted search in TESS. The limiting magnitude for such a search is rather bright, though, with 50% of injected sources at 16th magnitude being recovered by the TESSELLATE detection pipeline (H. Roxburgh et al. 2025).

in E. O. Ofek et al. 2025). We discuss spurious ZTF detections at the locations of these transients in Appendix and calculate the chance occurrence probabilities of such detections.

Given ZTF’s observing strategy, it will be able to detect epochs at which flaring is occurring (as in H23), but cannot resolve the minutes-timescale duration of this behavior. Its ongoing nightly cadence survey in *gri* bands of the region of the sky overlapping Rubin’s footprint will help us detect any potential flux excesses (i.e., deviating from the typical LFBOT decay) that could herald flaring behavior. In addition, its higher cadence (compared to Rubin’s WFD survey) will allow a better constraint on the peak time of the initial LFBOT.

Rubin/LSST. While the cadence of Rubin/LSST’s WFD survey will be insufficient to study such flares, LFBOTs found in DDFs (spanning 70 deg^2) may be amenable to flare identification, given the subday cadence observations. However, these fields represent an extremely small portion of the overall LSST survey, and given the low (and highly uncertain) rate of LFBOTs, it is difficult to determine whether the DDF cadence and observations will yield any useful detections of LFBOTs or flaring. Our predictions in Table 6 suggest that the DDFs will yield, in an optimistic case, around nine LFBOT flares per year. However, the WFD will still be useful as a discovery engine for LFBOTs themselves—the 3 day cadence is enough to track their early evolution and help constrain the blackbody parameters. Moreover, the WFD will enable the identification of LFBOTs at higher redshifts, across cosmic time. Our preliminary estimates suggest that Rubin could detect tens of LFBOTs throughout its survey (though a far smaller number of flares). Complementary higher-cadence surveys whose FOVs overlap with Rubin (LAST and Argus Array) can then be used to search for flaring in these events.

Argus Array. The Argus Array (N. M. Law et al. 2022), an upcoming survey telescope with an FOV of 8000 deg^2 that will be able to image the sky at a 60 s cadence with a limiting magnitude of $\sim 20\text{--}20.5$, represents one of the highest-cadence ground-based transient surveys to date. Assuming flaring behavior comparable to that of AT2022tsd, Argus Array could detect up to 80 flares in a year—making it among the most promising surveys of the ones in Table 6. We do note that to resolve minutes-duration flares (rather than simply observe the peaks of several flaring episodes), the volume that Argus Array can probe reduces somewhat, and the rates that we estimate in Table 6 will reduce concomitantly. Regardless, it still retains its considerable advantages over other surveys with its large FOV and high cadence.

ULTRASAT. This satellite will conduct a survey of the sky at near-UV wavelengths (Y. Shvartzvald et al. 2024), with its high-cadence survey observing roughly 200 deg^2 near the ecliptic poles at a 300 s cadence for 6 months at a time. With a limiting magnitude of ~ 22.5 , this will be sensitive to both the initial blue emission of LFBOTs, as well as their flares (which are anticipated to be fainter at blue and UV wavelengths due to the steep SED observed in H23). While the 5 minute cadence will obscure some of the substructure in the flares, the spatial association with an LFBOT and contemporaneous observations planned using LAST¹⁸ (in a redder band) will allow us to rapidly characterize these flares and trigger other facilities to observe and monitor these events, perhaps at a higher cadence.

5. Conclusions

In this paper, we have presented TESS observations of LFBOTs to constrain the presence and incidence of late-time optical flaring in 12 of the 14 known such events. We detected seven flares in total from four unique LFBOTs. All of the seven were found to arise from SSOs passing through the photometric aperture.

On the timescales over which flaring was observed in AT2022tsd, we do not observe any confirmed flaring comparable to the original luminosity in the LFBOT AT2024qfm that clearly arises from the transient itself. For intermediate timescales (between 100–450 days after the initial transient), we can rule out flaring that is roughly 10 times as faint as the original event for two nearby LFBOTs ($z \lesssim 0.1$). At late timescales, beyond 450 days posttransient, we find no confirmed flaring in our sample, and can constrain the luminosity of such events in nearby LFBOTs to be hundreds of times fainter than the original transient. For LFBOTs with $z \gtrsim 0.1$, our constraints on the luminosity of any flaring are roughly comparable to the luminosity of the original event itself.

We hypothesize that our nondetection of flares in other LFBOTs could arise from one of two factors: (a) the phenomenon powering the flares (e.g., accretion) “shuts off” or declines ~ 100 days after the initial transient, or (b) the emission from the flares are beamed, requiring an on-axis observation for a detection. However, we also note that the flaring seen in AT2022tsd could be the exception rather than the norm, and a larger sample of LFBOTs (and further detections of flaring) is necessary to probe the rates, timescales, and durations of such flaring. Further observations of LFBOTs will also help determine whether they are all powered by a central engine, or if some of them could be powered by another mechanism—such as CSM interaction.

We also simulated the appearance of such flares in TESS data, and found that for a sufficiently nearby LFBOT (occurring once every few years), TESS would be able to provide a well-sampled light curve that can be studied for evidence of late-time flaring. Over the next several years, the LAST and ULTRASAT represent the best facilities with which to search for these late-time flares, given their relatively large FOVs and their high cadences. Interestingly, we also find that the Rubin/LSST DDFs could also represent promising avenues for LFBOT flare searches, given the subday cadence and depth. With LSST, we will also be able to track the evolution of LFBOTs (and their rates) across cosmic time, and gain a better understanding of their progenitors and underlying astrophysical processes.

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¹⁸ <https://www.weizmann.ac.il/ultrasat/science-mission/modes-of-operation/modes-of-operation>

Explorer Program. The TICA data utilized in this work (M. Fausnaugh 2021) were obtained from the MAST archive, which is hosted by the Space Telescope Science Institute (STScI). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5–26555.

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This research has made use of the NASA/IPAC Extragalactic Database’s extinction calculator (NASA/IPAC Extragalactic Database (NED)), which is funded by the National Aeronautics and Space Administration and operated by the California Institute of Technology. This research has also made use of the ZTF Image Service (IRSA 2022), which is hosted at the NASA/IPAC Infrared Science Archive.

Facilities: TESS, PO:1.2m, ATLAS, MAST, NED.

Software: `astropy` (Astropy Collaboration et al. 2013, 2018; Astropy Collaboration et al. 2022), `astroquery` (A. Ginsburg et al. 2019), `numpy` (C. R. Harris et al. 2020), `matplotlib` (J. D. Hunter 2007), `tess-point` (C. J. Burke et al. 2020), `lightkurve` (Lightkurve Collaboration et al. 2018), `scipy` (P. Virtanen et al. 2020), `synphot` (STScI Development Team 2018).

Appendix

Statistically Ruling Out Late-time Detections As Flares

Late-time ZTF detections were ruled out for the first six LFBOTs in our sample by H23. In this appendix, we rule out any detections as arising from flaring using the TESS data from all LFBOTs, as well as the ZTF data from the most recent six FBOTs in our sample. For a detection to be statistically significant, we impose the condition that it must have a chance occurrence probability of $<1\%$. None of the late-time detections that we find here have such a low probability of chance occurrence. Figure A1 shows example flux distributions from the TESS difference images for three of the most common kinds of light curves (featureless, with SSOs, or high levels of scattered light); in cases where scattered light was not present, we can use Gaussian statistics to estimate probabilities of spurious detections.

We also direct the reader to E. O. Ofek et al. (2025) for the details of a targeted search using the LAST to identify AT2022tsd-like flaring in AT2024wpp. Details about targeted, high-cadence follow-up of AT2026dbl will be presented in Z. McGrath et al. (2026, in preparation).

CSS161010. In TESS, there was one spurious detection in Sector 5, which has a probability of chance occurrence of roughly 79%. In Sector 32, there is one spurious detection; the

probability of such a detection is over 99%. There are no spurious late-time detections in Sector 98.

AT2018cow. In TESS, Sector 25 suffered from severe scattered light toward the end of each of the two orbits. As a result, there are several spurious detections where the background was difficult to model, and these detections during periods of high scattered light should be discounted. For Sectors 51–52, which also suffered from significant scattered light, a large fraction of the data were unusable. For the portion of the data that we did use, we saw three detections, which had a chance occurrence probability of roughly 85%. These were one-off points with elevated flux that occurred during times of elevated background. For Sector 78, there is one detection; this has a probability of chance occurrence of over 99% percent. As a result, none of these detections are likely real.

AT2018lug. In TESS Sectors 42–43, there are no spurious detections; the SSO moving through the aperture was discussed in Section 3. In Sectors 70–71, there are eight formal detections in over 17,000 photometric flux measurements; this has a chance of occurring of over 99%.

AT2020mrf. In TESS Sectors 50–51, there are three points with detections above the magnitude limit, though these correspond to epochs with a high level of background due to scattered light. The probability of chance occurrence of these detections is 98.5%, suggesting that they are not real. In Sectors 77–78, there are several spurious detections due to elevated background; there is no coherent signal in this light curve. In particular, the background begins to exhibit a periodic variation toward the end of the observation.

AT2020xnd. The Sector 42 measurements suffer from significant scattered light, as well as two SSOs passing through the aperture (see Section 3). There are only two spurious detections outside of these times, which would occur due to pure chance at an 82% probability. In Sector 55, there is a significant time-varying background, which could explain most of the spurious detections. In Sector 92, there are two detections, which could occur due to random chance with a probability of $>99\%$.

AT2022tsd. The TESS observations contain two points that are formal detections, apart from the SSO moving through the aperture (described in Section 3.3). There is a very high likelihood (nearly 100%), out of over 19,000 observations, that there could be two spurious detections. Additionally, these occur during regions of high background, which suggests they are spurious. From ZTF, there is one detection ($S/N = 3.3$) roughly 800 days after the last detection (at roughly MJD 60690), a few years after the last flares were observed. The probability of this happening due to pure chance is roughly 13%, suggesting that this is not real. Inspecting the ZTF image does not reveal evidence for a source there.

AT2022abfc. There are no late-time detections in ZTF, though there is a late-time detection in ATLAS photometry at MJD 60283.18512 (roughly $t_0 + 380$ days), with a significance of 4.6σ . While this detection is not obviously an artifact, it does not have a clear PSF-like shape; the ATLAS PSF is undersampled, so this detection being real is certainly a possibility. If real, the measured flux is $30 \pm 7 \mu\text{Jy}$; at this transient’s redshift of 0.212, this corresponds to a luminosity of $(1.9 \pm 0.5) \times 10^{43} \text{ erg s}^{-1}$. The original transient had a peak AB magnitude of 19.1 ± 0.1 in ATLAS, corresponding to a peak luminosity of $5.7 \times 10^{43} \text{ erg s}^{-1}$. If this were a bona fide flare from AT2022abfc, the luminosity would be comparable

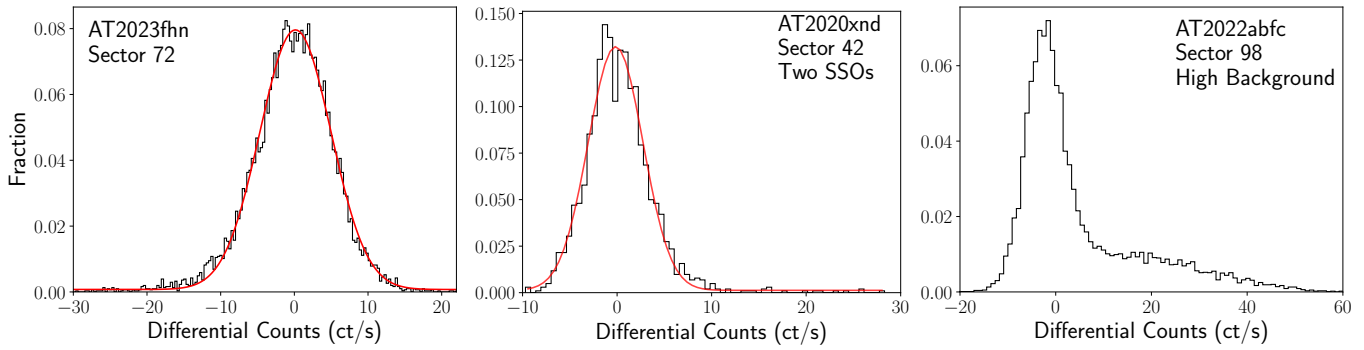


Figure A1. Flux distributions for three sample light curves from the ones we analyzed in our sample, with fits to Gaussians in two cases. Left: AT2023fhn shows a featureless light curve whose flux distribution can be well approximated by a Gaussian. Center: AT2020xnd had two SSOs pass through the aperture in Sector 42, which leads to outliers in the distribution from the excess flux; the rest of the distribution is well approximated by a Gaussian. Right: AT2022abfc’s Sector 98 light curve suffered from significant scattered light, leading to a skewed distribution that cannot be approximated using a Gaussian.

to those observed from AT2022tsd (H23). The last r -band ZTF upper limit is 19.05, 15 days prior, and the subsequent upper limit is 19.29, roughly 5 days later, making it difficult to determine if this detection is real. Moreover, publicly available Pan-STARRS1 photometry (K. C. Chambers et al. 2016) does not extend until this epoch.

In TESS observations from Sector 98, there are several spurious detections that are strongly correlated with regions of the light curve with elevated background, suggesting that these are not real.

AT2023fhn. We found a single detection in ZTF with an S/N of 3.1. Out of 453 images, the chance of exactly one image yielding such a detection is $\sim 28\%$. Inspection of the ZTF image at this epoch did not show evidence for a clear point source. There were no significant detections in TESS throughout the duration of the Sector 72 observations.

AT2023hkw. We found a single detection in ZTF with an S/N of 3.2. Out of 650 images, the chance of exactly one image yielding such a detection is roughly 28%, suggesting that this detection is spurious. Inspection of this ZTF image revealed significant contamination from satellite tracks (see, e.g., P. Mróz et al. 2022), one of which passed through the location of the transient at this image. In TESS, there is one formal detection out of 7681 photometric points, which has a chance probability of occurring of over 99%.

AT2023vth. We did not find any late-time detections from ZTF, although there was a late-time detection in ATLAS. We inspected the ATLAS difference image at this time using the online photometry service and found an artifact in the data, with a black strip running through the center of the image (through the location of the LFBOT)—making this likely a spurious detection. In TESS, there are several detections that occur during periods of high background; the temporal profile of these detections is correlated with the changes in background, suggesting these are systematic artifacts rather than real detections.

AT2024qfm. We found one late-time detection in ZTF with an S/N of 3.7 out of 217 images. There is an $\sim 2\%$ chance of this occurring purely via chance. We inspected the difference image at this position and found no evidence for a source. In addition, there is also an ATLAS detection at MJD 60540.43737, although inspection of the difference images reveals that this could arise from spurious photometry due to a black band running through the bottom of the image, almost through the location of the LFBOT. In TESS, there is one detection out of over 10,000

photometric points, which has a probability of chance occurrence of nearly 100%, suggesting that this detection is not real.

AT2024wpp. There are three detections in TESS Sector 97 out of a total of 9416 points, which has a probability of chance occurrence of almost 100%. This suggests that these detections are not real. There are no late-time detections after the last detection in ZTF.

AT2024aehp. There are no posttransient TESS data. There are also no detections from ZTF after the last detection by ZTF that is associated with the original transient.

AT2026dbl. We found one late-time detection in ZTF with an S/N of 3.3, out of 95 images. There is an $\sim 4.7\%$ chance of this occurring purely via chance, suggesting that this detection is spurious. There is no evidence for a source in the corresponding ZTF difference image at this position.

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