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Minutes-duration Optical Flares with Supernova Luminosities

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In recent years, certain luminous extragalactic optical transients have been observed to last only a few days¹. Their short observed duration implies a different powering mechanism from the most common luminous extragalactic transients (supernovae) whose timescale is weeks². Some short-duration transients, most notably AT2018cow³, display blue optical colours and bright radio and X-ray emission⁴. Several AT2018cow-like transients have shown hints of a long-lived embedded energy source⁵, such as X-ray variability^{6,7}, prolonged ultraviolet emission⁸, a tentative X-ray quasiperiodic oscillation^{9,10}, and large energies coupled to fast (but subrelativistic) radio-emitting ejecta^{11,12}. Here we report observations of minutes-duration optical flares in the aftermath of an AT2018cow-like transient, AT2022tsd (the “Tasmanian Devil”). The flares occur over a period of months, are highly energetic, and are likely nonthermal, implying that they arise from a near-relativistic outflow or jet. Our observations confirm that in some AT2018cow-like transients the embedded energy source is a compact object, either a magnetar or an accreting black hole.

32 In a 30 s exposure beginning at 11:21:22 on 2022 September 7 (UTC), the Zwicky Transient
33 Facility (ZTF; Methods section 16) detected a new optical transient (internal name ZTF22abftjko)
34 at $r = 20.36 \pm 0.23$ mag with the position right ascension $\alpha = 03^{\text{h}}20^{\text{m}}10^{\text{s}}.873$ and declination
35 $\delta = +08^{\circ}44'55''.739$ (J2000; uncertainty $0.009''$ from Methods section 16) as part of its public
36 two-day cadence all-sky survey. The transient was reported¹³ to the Transient Name Server by
37 the Automatic Learning for the Rapid Classification of Events (ALeRCE) Alert Broker¹⁴ and
38 designated AT2022tsd. Forced photometry on ZTF images (Methods section 16) revealed that
39 the light-curve evolution was faster than that of typical supernovae (Figure 1). The optical light
40 curve, and the implied high peak luminosity from a nearby ($1.4''$) catalogued galaxy (Methods
41 section 1, Figure 1), led AT2022tsd to be flagged as a transient of interest as part of ongoing efforts
42 to discover luminous and fast-evolving optical transients (Methods section 1).

43 We obtained two spectra of AT2022tsd with the Low Resolution Imaging Spectrometer
44 (LRIS) on the Keck I 10-m telescope (Extended Data Figure 1; Methods section 16), and measured¹⁵
45 a redshift of $z = 0.2564 \pm 0.0003$ (luminosity distance $D_L = 1.34$ Gpc assuming a Planck
46 cosmology¹⁶) of the nearby galaxy using prominent narrow host-galaxy emission lines (Methods
47 section 1). The optical properties — the fast light-curve evolution, the implied high peak luminosity
48 ($M_{\text{peak}} = -20.64 \pm 0.13$ at rest-frame wavelength 5086\AA ; Methods section 1), and the lack of
49 prominent spectroscopic features after the transient faded by 2–3 magnitudes — were unusual
50 for extragalactic transients but similar to AT2018cow, which motivated us to trigger additional
51 multiwavelength observations (Figure 2; Methods section 2). We detected luminous radio (decimeter¹⁷
52 to submillimeter) emission that peaked at hundreds of GHz for over a month in the rest frame
53 (Methods section 16; Extended Data Figure 3), as well as luminous ($> 10^{44}$ erg s⁻¹) and steadily
54 fading ($L_X \propto t^{-1.81 \pm 0.13}$ over nearly 300 days) 0.3–10 keV X-ray emission¹⁸ well described by a
55 power law with photon index $\Gamma \approx 2$ (Methods section 2, Methods section 16, Figure 2, Extended
56 Data Figure 2). Although we did not detect clear spectroscopic features from the transient itself,
57 the galaxy alignment is very unlikely to be a coincidence (Methods section 3), and we conclude
58 that the galaxy is the host of the transient. The multiwavelength properties of AT2022tsd are
59 most similar to those of AT2018cow-like transients (also referred to as luminous fast blue optical
60 transients or “LFBOTs”¹⁹), suggesting a common origin (Methods section 2).

61 In a photometric optical imaging sequence starting at 04:29:57 on 2022 December 15, 100 days
62 (observer frame) after the initial transient discovery, we detected²⁰ a flare at the position of AT2022tsd

63 across five three-minute Magellan/IMACS g -band images (Figure 3) that was nearly as bright as the
 64 original transient event: $\nu L_\nu \approx 10^{44} \text{ erg s}^{-1}$ (Figure 1, Figure 2). Forced photometry on ZTF and
 65 Pan-STARRS survey images (Methods section 16) at the position of the transient revealed previous
 66 flare detections, as early as 26 d (observer frame) after the initial transient discovery (Figure 2;
 67 Extended Data Figure 4). Following the IMACS flare detection, we obtained a total of 60 hr of
 68 optical observations of AT2022tsd on 20 different nights, using 13 different telescopes (Extended
 69 Data Table 1). The duration of each sequence ranged from 10 min to 4.5 hr. In total we detected
 70 at least 14 flares (Extended Data Figure 4). High-cadence ULTRASPEC observations (Methods
 71 section 16) revealed flux variations exceeding an order of magnitude on timescales shorter than
 72 20 s (rest frame; Figure 3), and complex temporal profiles that vary between flares (Extended Data
 73 Figure 4; Methods section 4). Two different Keck/LRIS observations revealed red flare colours
 74 (Extended Data Figure 4; Methods section 4): $u - I = 1.41 \pm 0.31 \text{ mag}$, or $\beta = -1.6 \pm 0.1$ where
 75 $f_\nu \propto \nu^\beta$ (corrected for Milky Way extinction but not corrected for host attenuation).

76 *Chandra* X-ray observations²¹ (Methods section 16) revealed X-ray variability on timescales
 77 of tens of minutes, but no clear high-amplitude flares. We detected one definitive optical flare
 78 during X-ray monitoring, but no X-ray flare counterpart was detected (Extended Data Figure 2).
 79 In addition, we find no clear periodicity between or within flares in either the optical or X-ray
 80 emission (Methods section 4, Extended Data Figure 5, Extended Data Figure 6). We did not
 81 identify any high-energy (gamma-ray burst; GRB) counterpart to either the initial LFBOT or the
 82 flares (Methods section 5), nor did we identify any similar optical flares in the aftermath of other
 83 LFBOTs (Methods section 6). In addition, optical observations of AT2022tsd prior to the first
 84 clear flare detection show no significant variability on timescales of minutes (Methods section 2),
 85 implying that there was a longer-duration transient underlying the flares, with a fade rate very
 86 similar to that of the LFBOT AT2020mrf⁷ (Figure 2).

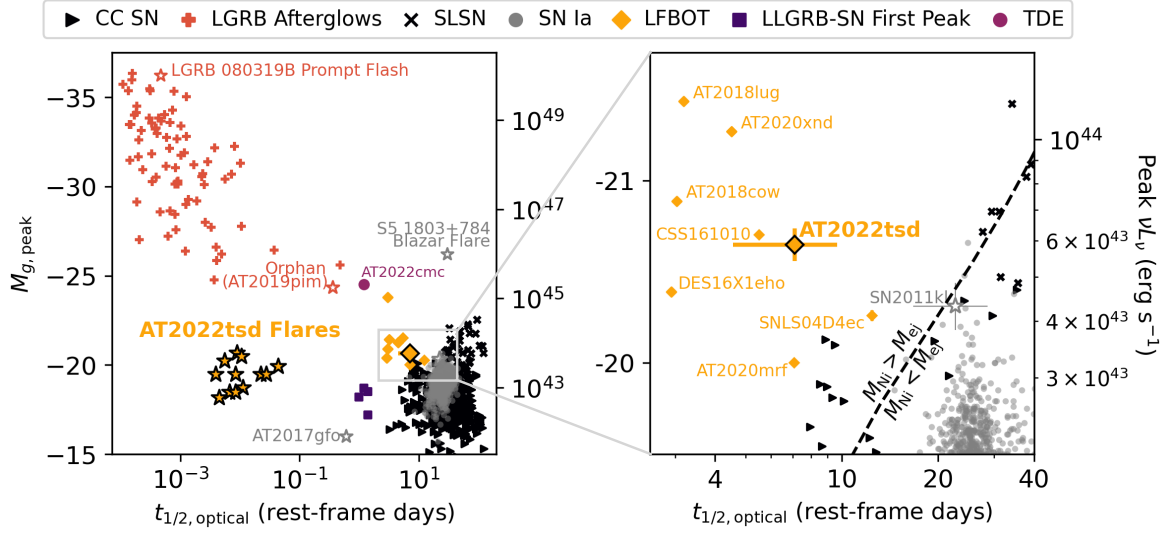
87 To our knowledge, this phenomenon — minute-timescale optical flares at supernova-like
 88 luminosities, with order-of-magnitude amplitude variations, persisting for 100 days — has no
 89 precedent in the literature. Supplementary Information Table 1 lists known classes of objects that
 90 exhibit large-amplitude (factor of $\gtrsim 10$ times the baseline flux level) flares. Previously observed
 91 flaring behaviour was either orders of magnitude less luminous, persisted for only a few minutes,
 92 had much longer durations, or was at much higher photon energies. The fact that these optical
 93 flares were observed in the aftermath of an extragalactic transient is even more unusual.

94 The fast variability timescale of the flares implies an emitting-region radius of $< (9 \times$
 95 $10^{11} \text{ cm})\Gamma^2$, where Γ is the Lorentz factor of the flare-emitting outflow, and a brightness temperature
 96 of $T_B > (2 \times 10^{10} \text{ K})\Gamma^{-4}$. The radius is similar to that inferred from late-time ($\Delta t \approx 10^3 \text{ d}$) UV
 97 observations of AT2018cow⁸, and (as in that case) is much smaller than the blackbody radius of the
 98 initial LFBOT (Methods section 8). The high brightness temperature, combined with the red flare
 99 colour, implies a nonthermal emission mechanism such as optically thin synchrotron radiation
 100 (Methods section 7). The flares are extremely energetic, with 10^{46} – 10^{47} erg in radiated energy
 101 alone per detected flare (not corrected for beaming; Extended Data Table 2). In addition, the
 102 radiated energy in X-rays during the flaring period exceeds 10^{50} erg. The timescales, the enormous
 103 energetics, the high brightness temperature, and the requirement of optically thin emission for the
 104 flares strongly implies that the flare-emitting outflow has at least near-relativistic ($v/c \gtrsim 0.6$)
 105 velocities (Methods section 7), which reduces the energetics requirements owing to beaming.
 106 However, we have no direct evidence for ultrarelativistic speeds, including a lack of associated
 107 detected prompt high-energy emission, a lack of detected variability at radio wavelengths (Methods
 108 section 16), and sub-relativistic speeds inferred from a basic equipartition analysis of the radio data
 109 (Methods section 9; Table 1).

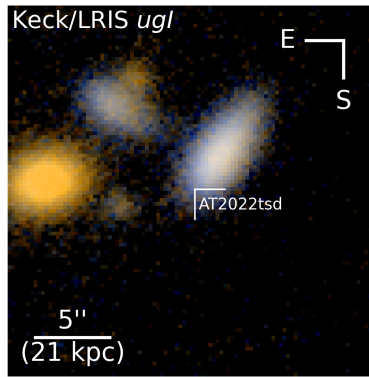
110 We conclude that the flares in AT2022tsd arose from a near-relativistic outflow that was
 111 powered by a compact object over a period of 100 days. For the compact object, a supermassive
 112 black hole is highly unlikely given the location of AT2022tsd 6 kpc from the nucleus of a star-forming
 113 galaxy (Figure 1, Methods section 10) and the rapid timescale of the initial LFBOT. The possible
 114 power sources for the outflow are therefore the rotational spindown of a newborn neutron star, or
 115 accretion onto a stellar- or intermediate-mass compact object. In the latter case, the compact object
 116 could be a newly formed stellar-mass black hole, or, if the process was tidal disruption followed
 117 by the formation of an accretion disk, a neutron star, stellar-mass black hole, or intermediate-mass
 118 black hole.

119 Several models have been proposed to explain LFBOTs¹⁹, and we consider three most likely
 120 in light of the newly discovered flares (Methods section 11): the collapse of a supergiant star^{5,28,29},
 121 the merger and tidal disruption of a Wolf-Rayet star by a compact object¹⁹, and the tidal disruption
 122 of a white dwarf by an intermediate-mass black hole^{28,30}. Accretion processes and jets from
 123 systems involving black holes are well known to produce fast and luminous flares, and explaining
 124 AT2022tsd as an analog of observed flares from supermassive black hole tidal disruption events

125 (TDEs) and blazars might be most natural for an intermediate-mass black hole owing to the flare
126 duration and time between flares (tens of minutes to hours). If AT2022tsd arose from a stellar-mass
127 black hole, the accretion rate would be highly super-Eddington ($10^5 L_{\text{Edd}}$ for a $10 M_{\odot}$ black hole
128 without relativistic or geometric beaming). Such a rate could be compatible with a merger and
129 tidal disruption scenario¹⁹, and establishing the existence and prevalence of such binary systems is
130 important for understanding the progenitors of merging gravitational-wave sources. Alternatively,
131 the high accretion rate could arise from the collapse of a supergiant star²⁹ and subsequent formation
132 of an accretion disk; the identification of these systems is a longstanding goal for understanding
133 the conditions that determine whether a star will explode, as well as the formation properties of
134 black holes. In either picture, the flares could be analogous to the emission observed in GRBs:
135 the timescales are not consistent with external shocks, but could potentially arise from internal
136 shocks. The lack of detected flares in other LFBOTs could be due to viewing angle: AT2018cow is
137 thought to have been observed close to the plane of the circumburst “disk” rather than face-on^{5,8},
138 and a more on-axis viewing angle for AT2022tsd could also help explain the significantly more
139 luminous X-ray emission (Figure 2).

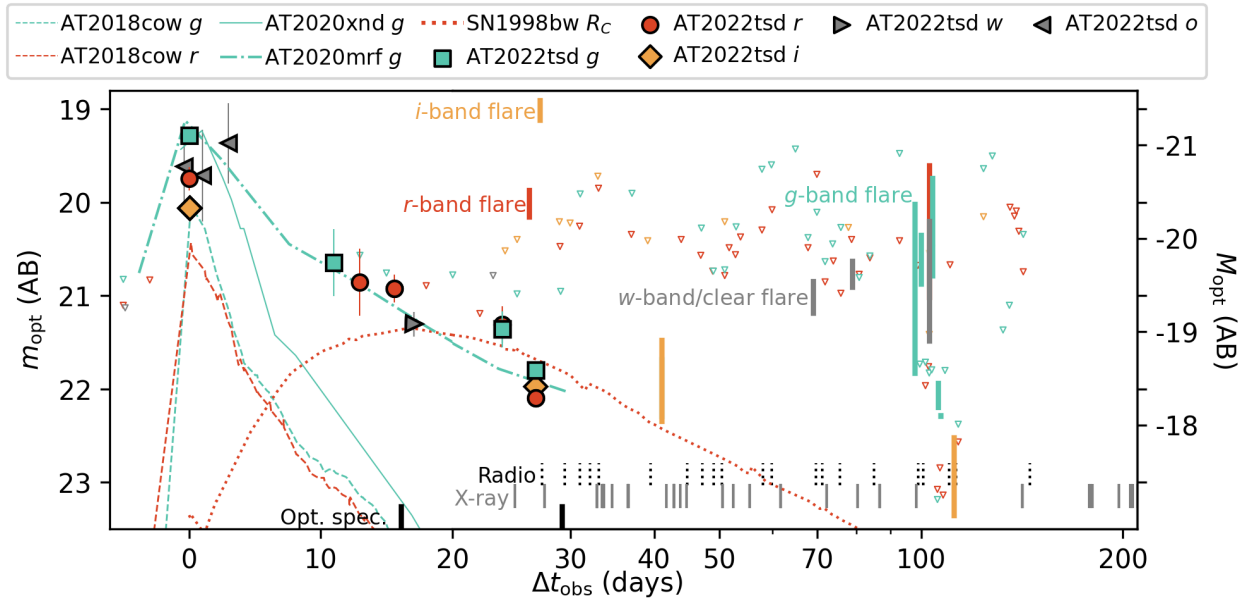


(a)

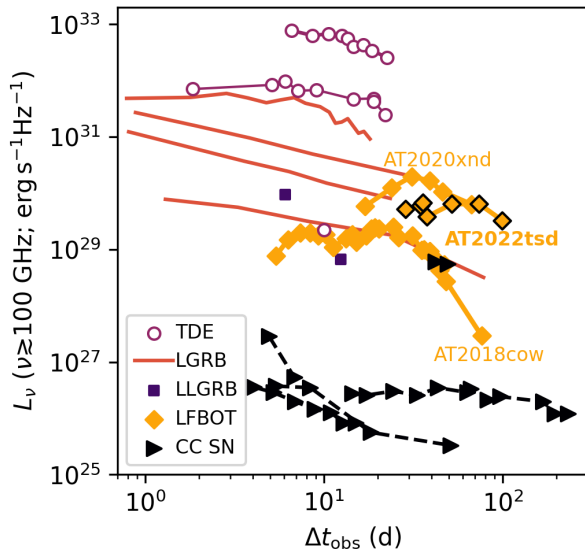


(b)

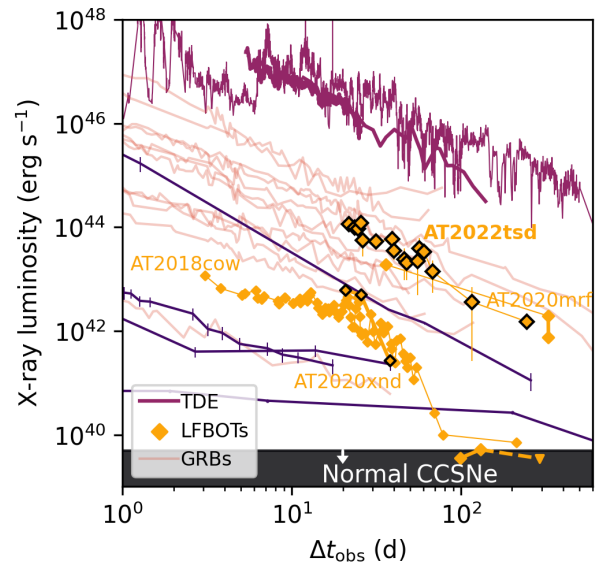
Figure 1: **AT2022tsd is a luminous fast blue optical transient showing flares with unprecedented timescales.** (a) Duration above half-maximum light ($t_{1/2}$) vs. peak absolute magnitude M (or peak luminosity νL_ν) of AT2022tsd, its flares, and other extragalactic optical transients. (b) Keck/LRIS false-colour $u/g/I$ image centred at the position of AT2022tsd, which is marked. See Methods section 12 for additional details and data sources.



(a)

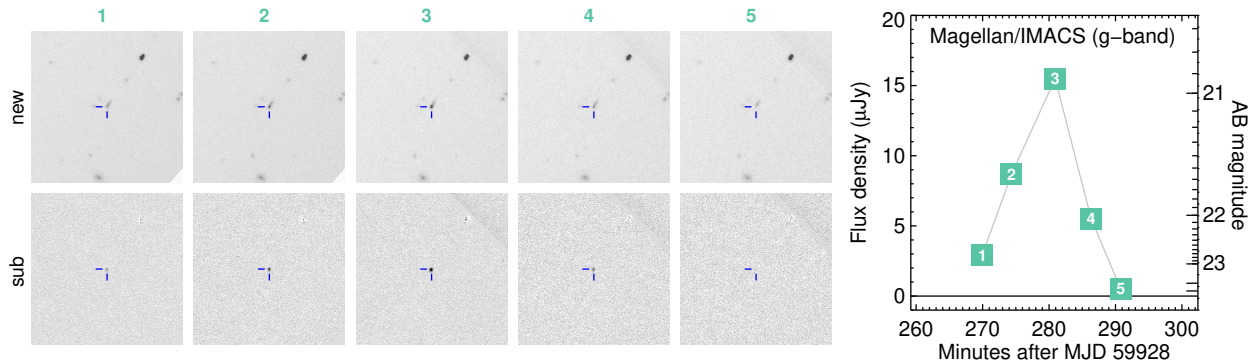


(b)

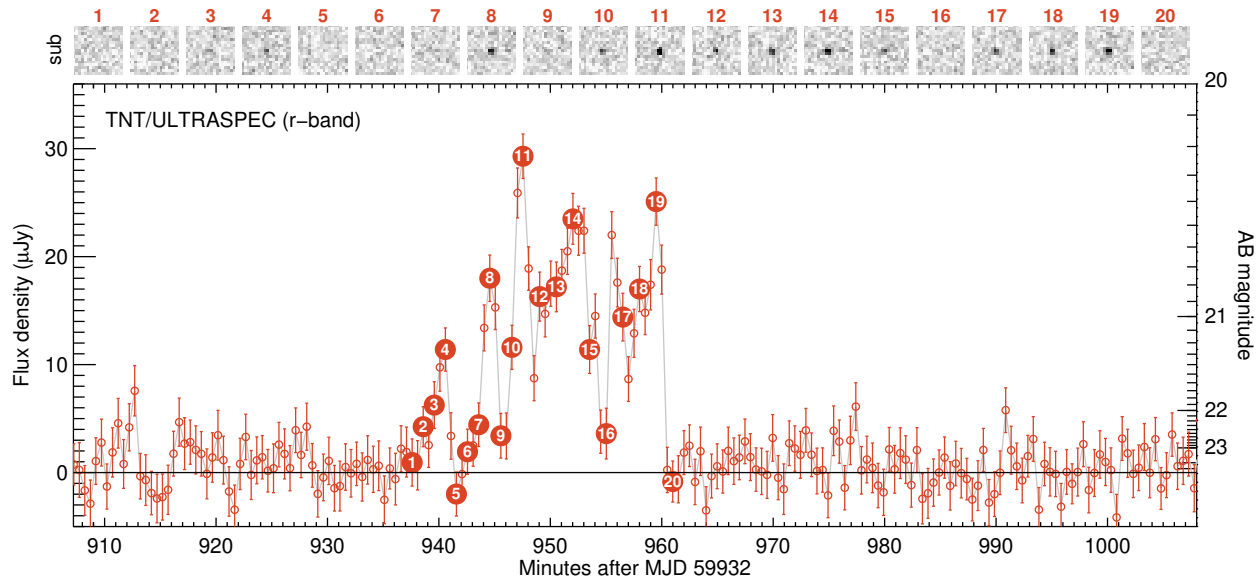


(c)

Figure 2: **The multiwavelength properties of AT2022tsd are most similar to those of transients in the literature dubbed luminous fast blue optical transients.** (a) Optical light curve of AT2022tsd compared to the luminous fast blue optical transients (LFBOTs) AT2018cow, AT2020xnd, and AT2020mrf, as well as the stripped-envelope SN1998bw (associated with GRB 980425). Vertical bars mark flares, open triangles represent upper limits, and lines along the bottom axis show epochs of radio and X-ray observations as well as optical spectroscopy. (b) Millimeter-wave light curve of AT2022tsd compared to different classes of extragalactic transients. (c) 0.3–10 keV X-ray light curve of AT2022tsd compared to different classes of extragalactic transients. Error bars are 1σ confidence intervals. See Methods section 13 for additional details and data sources.



(a) Flare detected by Magellan/IMACS on 2022 December 15. The cutouts show a $45''$ by $45''$ region.



(b) Flare detected by TNT/ULTRASPEC on 2022 December 19.

Figure 3: **Luminous flares from AT2022tsd lasting tens of minutes were clearly detected with variability timescales as short as 30 s.** (a) Science images (“new”), images with the host galaxy subtracted (“sub”), and the corresponding light curve of a flare detected by Magellan/IMACS at the position of AT2022tsd. IMACS observations consisted of five 3 min-duration exposures. (b) Same as (a) but for a flare detected by ULTRASPEC, which is mounted on the Thai National Telescope. ULTRASPEC observations consisted of 30 s-duration exposures with 15 msec of dead time between exposures. Error bars are 1σ confidence intervals.

Table 1: Summary of basic constraints from different emission components.

Component	Property	Constraint
Prompt Optical	Photospheric radius	$(6.8 \pm 3.0) \times 10^{14}$ cm
–	Effective temperature	$(3.3 \pm 1.8) \times 10^3$ K
Optical Flares	Radiated energy	10^{46} – 10^{47} erg
–	Radius (light-crossing time)	$< (9 \times 10^{11}$ cm) Γ^2
–	Brightness temperature	$> (2 \times 10^{10}$ K) Γ^{-4}
–	Equipartition magnetic field strength	$(10^4$ G) $\Gamma^{-12/7}$
–	Equipartition energy	$(10^{43}$ G) $\Gamma^{18/7}$
–	Velocity	$\gtrsim 0.6c$
Radio	Shock radius (equipartition)	$\gtrsim 6 \times 10^{15}$ cm
–	Shock speed (average)	$\gtrsim 0.06c$
–	Magnetic field strength	$\lesssim 6$ G
–	Shock energy	$\lesssim 3 \times 10^{48}$ erg
–	Ambient density	$\lesssim 6 \times 10^5$ cm $^{-3}$
X-rays	Radiated energy	$> 10^{50}$ erg
Host Galaxy	Stellar mass	$\log(M/M_{\odot}) = 9.96^{+0.06}_{-0.09}$
–	Star-formation rate	$0.55^{+1.36}_{-0.19} M_{\odot} \text{ yr}^{-1}$

140 **References**

- 142 1. Drout, M. R., et al. Rapidly Evolving and Luminous Transients from Pan-STARRS1.
141 *Astrophys. J.*, **794**, 23 (2014).
143
- 144 2. Kasen, D. Unusual Supernovae and Alternative Power Sources. *Handbook of Supernovae*,
145 **939** (2017).
- 146 3. Prentice, S. J., et al. The Cow: Discovery of a Luminous, Hot, and Rapidly Evolving
147 Transient. *Astrophys. J. Lett.*, **865**, L3 (2018).
- 148 4. Ho, A. Y. Q., et al. A Search for Extragalactic Fast Blue Optical Transients in ZTF and the
149 Rate of AT2018cow-like Transients. *Astrophys. J.*, **949**, 120 (2023).
- 150 5. Margutti, R., et al. An Embedded X-Ray Source Shines through the Aspherical AT 2018cow:
151 Revealing the Inner Workings of the Most Luminous Fast-evolving Optical Transients.
152 *Astrophys. J.*, **872**, 18 (2019).
- 153 6. Rivera Sandoval, L. E., et al. X-ray Swift observations of SN 2018cow. *Mon. Not. R. Astron.*
154 *Soc.*, **480**, L146 (2018).
- 155 7. Yao, Y., et al. The X-Ray and Radio Loud Fast Blue Optical Transient AT2020mrf:
156 Implications for an Emerging Class of Engine-driven Massive Star Explosions. *Astrophys.*
157 *J.*, **934**, 104 (2022).
- 158 8. Chen, Y., et al. Late-Time HST Observations of AT 2018cow II: Evolution of a UV-Bright
159 Underlying Source 2-4 Years Post-Explosion. *arXiv e-prints*, arXiv:2303.03501 (2023).
- 160 9. Pasham, D. R., et al. Evidence for a compact object in the aftermath of the extragalactic
161 transient AT2018cow. *Nature Astronomy*, **6**, 249 (2021).
- 162 10. Zhang, W., et al. A Possible 250 s X-Ray Quasi-periodicity in the Fast Blue Optical Transient
163 AT2018cow. *Research in Astronomy and Astrophysics*, **22**, 125016 (2022).
- 164 11. Coppejans, D. L., et al. A Mildly Relativistic Outflow from the Energetic, Fast-rising Blue
165 Optical Transient CSS161010 in a Dwarf Galaxy. *Astrophys. J. Lett.*, **895**, L23 (2020).
- 166 12. Ho, A. Y. Q., et al. The Koala: A Fast Blue Optical Transient with Luminous Radio Emission
167 from a Starburst Dwarf Galaxy at $z = 0.27$. *Astrophys. J.*, **895**, 49 (2020).

- 168 13. Munoz-Arancibia, A., et al. ALeRCE/ZTF Transient Discovery Report for 2022-09-07.
169 *Transient Name Server Discovery Report*, **2022-2602**, 1 (2022).
- 170 14. Förster, F., et al. The Automatic Learning for the Rapid Classification of Events (ALeRCE)
171 Alert Broker. *"Astron. J."*, **161**, 242 (2021).
- 172 15. Ho, A. Y. Q., et al. Keck/LRIS Observations of AT2022tsd, a Fast-Rising Optical Transient
173 Coincident with a $z=0.256$ Galaxy. *Transient Name Server AstroNote*, **199**, 1 (2022).
- 174 16. Planck Collaboration, et al. Planck 2018 results. VI. Cosmological parameters. *Astron.*
175 *Astrophys.*, **641**, A6 (2020).
- 176 17. Ho, A. Y. Q., & Perley, D. A. VLA Ku-band Detection of AT2022tsd. *Transient Name Server*
177 *AstroNote*, **205**, 1 (2022).
- 178 18. Schulze, S., Ho, A. Y. Q., Perley, D. A., Yan, L., & Fremling, C. Swift X-ray Detection of
179 AT2022tsd. *Transient Name Server AstroNote*, **207**, 1 (2022).
- 180 19. Metzger, B. D. Luminous Fast Blue Optical Transients and Type Ibn/Icn SNe from
181 Wolf-Rayet/Black Hole Mergers. *Astrophys. J.*, **932**, 84 (2022).
- 182 20. Ho, A. Y. Q., et al. Discovery of Minute-timescale Optical Flares with Supernova-like
183 Luminosities at the Position of the Luminous Fast Blue Optical Transient AT2022tsd (the
184 "Tasmanian Devil"). *Transient Name Server AstroNote*, **267**, 1 (2022).
- 185 21. Matthews, D., et al. Chandra-NuSTAR Detection of X-ray Emission at the Location of FBOT
186 AT2022tsd. *Transient Name Server AstroNote*, **218**, 1 (2022).
- 187 22. Kumar, P., & Zhang, B. The physics of gamma-ray bursts & relativistic jets. *Phys. Reports*,
188 **561**, 1 (2015).
- 189 23. van Velzen, S., et al. Seventeen Tidal Disruption Events from the First Half of ZTF Survey
190 Observations: Entering a New Era of Population Studies. *Astrophys. J.*, **908**, 4 (2021).
- 191 24. Mangano, V., Burrows, D. N., Sbarufatti, B., & Cannizzo, J. K. The Definitive X-Ray Light
192 Curve of Swift J164449.3+573451. *Astrophys. J.*, **817**, 103 (2016).
- 193 25. Kasliwal, M. M., et al. GRB 070610: A Curious Galactic Transient. *Astrophys. J.*, **678**, 1127
194 (2008).

- 195 26. Castro-Tirado, A. J., et al. Flares from a candidate Galactic magnetar suggest a missing link
196 to dim isolated neutron stars. *Nature*, **455**, 506 (2008).
- 197 27. Stefanescu, A., et al. Very fast optical flaring from a possible new Galactic magnetar. *Nature*,
198 **455**, 503 (2008).
- 199 28. Perley, D. A., et al. The fast, luminous ultraviolet transient AT2018cow: extreme supernova,
200 or disruption of a star by an intermediate-mass black hole?. *Mon. Not. R. Astron. Soc.*, **484**,
201 1031 (2019).
- 202 29. Quataert, E., Lecoanet, D., & Coughlin, E. R. Black hole accretion discs and luminous
203 transients in failed supernovae from non-rotating supergiants. *Mon. Not. R. Astron. Soc.*, **485**,
204 L83 (2019).
- 205 30. Kuin, N. P. M., et al. Swift spectra of AT2018cow: a white dwarf tidal disruption event?.
206 *Mon. Not. R. Astron. Soc.*, **487**, 2505 (2019).

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412 **Correspondence** Correspondence and requests for materials should be addressed to Anna Y. Q. Ho (email:
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414 **Data Availability** The reduced optical photometric data of AT2022tsd are provided in Supplementary
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420 **Code Availability** The code and data used to perform the calculations and produce the figures for this
421 paper are available in a public Github repository.^a

^awww.github.com/annayqho/AT2022tsd

Methods

1 Identification of AT2022tsd and Redshift Measurement

Following the discovery of AT2018cow, we devised and implemented⁴ a filter to discover additional LFBOTs in the ZTF alert stream. Transients are filtered based on age, light-curve timescale (we require duration above half-maximum light $t_{1/2} \lesssim 12 \text{ d}^1$), and peak absolute magnitude (via the best-available host-galaxy redshift estimate).

AT2022tsd was first detected by ZTF (Methods section 16) on 2022 September 7^b as part of its public survey, which images the visible sky in the g and r bands every two nights. Owing to inclement weather and technical issues, the field was next observed on 2022 September 18; on this date, AT2022tsd was not detected with sufficiently high significance (5σ) for an alert to be generated. On 2022 September 22 ($\Delta t_{\text{obs}}^c = 15 \text{ d}$), forced photometry at the position of AT2022tsd recovered 3σ detections on September 18 and September 20, which revealed that the transient had faded by over a magnitude since discovery. In addition, AT2022tsd was noted to be $1.4''$ from a catalogued⁴⁶ galaxy in Pan-STARRS (Methods section 16; Figure 1; PSO J050.0451+08.7492; host-galaxy $g = 21.21 \pm 0.13 \text{ mag}$, $r = 20.93 \pm 0.05 \text{ mag}$). The galaxy’s photometric redshift⁴⁶ of $z_{\text{ph}} = 0.44 \pm 0.12$ implied a high peak luminosity (as described later in this section, the true redshift is $z = 0.2564$). The transient met our criteria for fast evolution ($t_{1/2, \text{rise}} < 4 \text{ d}$ and $t_{1/2, \text{fade}} = 5.1 \pm 0.6 \text{ d}$) and possible high peak luminosity, so we pursued follow-up spectroscopy.

On 2022 September 23, we obtained a spectrum of AT2022tsd using Keck/LRIS (Extended Data Figure 1; Methods section 16). AT2022tsd had $r \approx 21.5 \pm 0.2 \text{ mag}$ at the time, and the slit contained $\sim 20\%$ of the host-galaxy flux. In a 40 min exposure, we detected a blue continuum and a series of prominent host-galaxy emission lines at a consistent redshift. We fit a Gaussian independently to the following emission lines (wavelength given as rest wavelength in air): $\text{H}\alpha$ $\lambda 6562.819$, $\text{H}\beta$ $\lambda 4861.333$, $[\text{O II}]$ $\lambda\lambda 3726.032, 3728.815$, $[\text{O III}]$ $\lambda\lambda 4958.911, 5006.843$, $[\text{N II}]$ $\lambda\lambda 6548.050, 6583.460$, and $[\text{S II}]$ $\lambda\lambda 6716.44, 6730.81$. We measured the redshift by taking the average redshift from the independent fits. The uncertainty in the redshift is set by the small wavelength offset in the line positions between the two Keck spectra (Methods section 16). The result is $z = 0.2564 \pm 0.0003$. We did not detect any clear spectroscopic features from the transient

^bUTC dates are used throughout this paper.

^cAll epochs in this paper are given with respect to the first ZTF detection of AT2022tsd, which is also the observed peak of the optical light curve.

450 itself. Assuming the transient occurred in the galaxy (and the association is highly likely; Methods
 451 section 3), the implied peak absolute magnitude was $M_{\text{peak}} = -20.64 \pm 0.13$ at a rest wavelength
 452 of 5086 \AA , accounting for Milky Way extinction ($E_{B-V} = A_V/R_V = 0.27 \text{ mag}$, where $R_V =$
 453 3.1)^{48–50}. To calculate the absolute magnitude, we used the brightest r -band detection m_{peak} and
 454 the following equation,

$$M_{\text{peak}} = m_{\text{peak}} - 5 \log_{10} \left(\frac{D_L}{10 \text{ pc}} \right) + 2.5 \log_{10}(1 + z), \quad (1)$$

455 where D_L is the luminosity distance. The duration, absolute magnitude, and blue colours of
 456 AT2022tsd’s optical light curve characterise it as an LFBOT (Figure 1). In addition, the lack of
 457 prominent spectral features after the transient had faded by over 2 mag from peak argued against a
 458 traditional supernova origin (Methods section 2). Therefore, we triggered multiwavelength (X-ray
 459 through radio) follow-up observations (Methods section 2) and searched for associated high-energy
 460 emission (Methods section 5). Follow-up observations were coordinated using the SkyPortal^{51,52}
 461 platform.

462 2 Multiwavelength Properties of AT2022tsd Compared to Other Extragalactic Transients

463 AT2022tsd is only the third LFBOT (after AT2018cow^{3,28} and AT2020xnd⁵⁴) to receive intensive
 464 multiwavelength follow-up observations within the first month post-discovery. Three other LFBOTs
 465 (CSS161010¹¹, AT2018lug¹², and AT2020mrf⁷) received their first radio observations only 100 d
 466 post-discovery. MUSSES2020J⁵⁵ was discovered at $z = 1.063$, so follow-up opportunities were
 467 limited. Additional LFBOTs have been identified in archival searches of optical survey data, too
 468 late for follow-up observations, such as DES16X1eho⁵⁶ and SNLS04D4ec⁵⁷.

469 The peak luminosity ($M_{g,\text{pk}} = -20.64 \pm 0.13 \text{ mag}$), and blue peak colours ($g - r =$
 470 $-0.47 \pm 0.16 \text{ mag}$) of AT2022tsd’s optical light curve are similar to those of AT2018cow^{3,28} and
 471 AT2020xnd⁵⁴ (Figure 2). The rise rate is not well constrained ($t_{1/2,\text{rise}} < 4 \text{ d}$), but is consistent with
 472 what was observed for these two objects. The fade rate ($t_{1/2,\text{fade}} = 5.1 \pm 0.6 \text{ d}$, or $\sim 0.1 \text{ mag d}^{-1}$)
 473 is very similar to that of AT2020mrf⁷.

474 Following the Keck/LRIS spectrum on 2022 September 23 ($\Delta t_{\text{rest}} = 13 \text{ d}$ after peak; Methods
 475 section 1), we obtained a second 40 min Keck/LRIS spectrum on 2022 October 6 ($\Delta t_{\text{rest}} = 23 \text{ d}$
 476 after peak), when AT2022tsd had $r = 22.73 \pm 0.09 \text{ mag}$ (Extended Data Figure 1). The two Keck

477 spectra are characterised by a blue continuum down to $\sim 3000 \text{ \AA}$ in the rest frame, and we do not
 478 identify any clear features from the transient itself.^d A featureless blue continuum so long after
 479 peak light, when the light curve has faded by 2–3 mag, is unusual for extragalactic transients in
 480 general⁵⁸ but has been seen in other LFBOTs. For example, AT2018cow²⁸ exhibited a featureless
 481 continuum at $\Delta t = 8 \text{ d}$, a weak feature at 4850 \AA from $\Delta t = 9 \text{ d}$ to $\Delta t = 14 \text{ d}$ (attributed to He I
 482 $\lambda 4686$), and a variety of other lines appearing at 20–30 d.

483 The X-ray luminosity of AT2022tsd during the first observation at $\Delta t = 20 \text{ d}$ was $10^{44} \text{ erg s}^{-1}$,
 484 which is similar to that of AT2020mrf⁷ and long-duration gamma-ray burst (LGRB) afterglows; the
 485 luminosity is over an order of magnitude greater than that of AT2018cow^{5,6,53} or AT2020xnd^{59,60}
 486 (Figure 2). We fit the *Swift*/XRT and *Chandra*/ACIS detections of AT2022tsd to a power law using
 487 the `curve_fit` module in `scipy`, assuming a t_0 equal to the first ZTF detection. The best-fit
 488 power-law index (Extended Data Figure 2) is $\alpha = -1.81 \pm 0.13$, where $L_X \propto t^\alpha$. The X-ray
 489 light curve of AT2018cow also exhibited a power-law decline near this value^{5,53}, which is close
 490 to the t^{-2} power law expected for magnetar spindown or accretion under certain conditions¹⁹, and
 491 close to $t^{-5/3}$ power law expected for fallback accretion⁶¹. Binning the *Chandra* observations in
 492 time revealed variability at the 3σ level, with flux variations of factors of a few on timescales
 493 of tens of minutes (Extended Data Figure 2). Prolonged rapid X-ray variability was observed in
 494 AT2018cow^{5,6,53} and AT2020mrf⁷, and has also been seen in jetted TDEs^{62–64}. An independent
 495 analysis of the X-ray data⁶⁵ found similar values for the luminosity and the temporal power-law
 496 index under the assumption of a single power law.

497 Unlike the vast majority of extragalactic transients, the spectral energy distribution (SED)
 498 of the radio emission from AT2022tsd peaked at hundreds of GHz for months post-discovery
 499 (Extended Data Figure 3). To our knowledge, as shown in Figure 2, the only known extragalactic
 500 transients with similar behaviour are the LFBOTs AT2018cow⁵³ and AT2020xnd^{59,60}. In addition,
 501 the slope of AT2022tsd’s radio SED is significantly shallower than the $f_\nu \propto \nu^{5/2}$ expected from
 502 synchrotron self-absorption⁶⁶; the value is closer to $f_\nu \propto \nu^1$. A similarly shallow radio SED was
 503 observed in AT2018cow⁶⁷, and attributed to inhomogeneities in the emitting region or circumburst
 504 medium⁶⁷. The shallow spectrum and the persistent peak in the sub-mm bands are more similar to
 505 the emission from X-ray binaries (XRBs^{68–70}) and low-luminosity active galactic nuclei (AGNs)
 506 such as Sagittarius A*⁷¹ than from explosive transients such as supernovae⁷². In the XRB and AGN

^dDespite the lack of distinct transient features, in Methods section 3 we show that it is highly likely that the transient occurred in the galaxy and is not a foreground object.

507 contexts, the shallow mm-peaking SED is often interpreted as the superposition of self-absorbed
508 components along a continuously powered relativistic jet⁷³, which we discuss in more detail in
509 Methods section 11.

510 3 Flare Association and Extragalactic Origin

511 A hundred days after the discovery of the initial transient event (hereafter referred to as the
512 LFBOT), as part of routine follow-up observations to track the decay of the optical light curve, we
513 detected²⁰ a minute-timescale flare at the position of AT2022tsd across five 3 min Magellan/IMACS
514 *g*-band images (Figure 3, Extended Data Figure 4, Methods section 16). A retrospective search of
515 ZTF, Pan-STARRS, and Keck/LRIS data (Methods section 16) revealed additional flare detections
516 as early as $\Delta t_{\text{rest}} = 21$ d. We searched for detections prior to the LFBOT using ZTF and Pan-STARRS,
517 as might be expected if the flares arose from a foreground Galactic object. There were 190 images
518 obtained by Pan-STARRS going back 3000 days prior to the LFBOT, with no significant ($> 1.4\sigma$)
519 flux excess⁷⁴. There were 647 images obtained by ZTF going back 1600 days prior to the LFBOT,
520 with one image having a $> 3\sigma$ flux excess (3.2σ). The probability of finding at least one image
521 above 3σ in 647 images is 60% (from binomial statistics), so this is not statistically significant. By
522 contrast, of the 65 ZTF exposures obtained from JD 2,459,856.9 to JD 2,459,969.7 (all after the
523 LFBOT), three showed $> 3\sigma$ excesses (7.4σ , 10.1σ , and 3.5σ). The probability of finding at least
524 three images above 3σ in 65 images is 0.01%; the probability of finding at least two images above
525 5σ is 1.7×10^{-8} . Therefore, it is highly likely that the LFBOT, the multiwavelength (X-ray and
526 radio) emission, and the flares are all associated.

527 Given the lack of clear spectroscopic features from the transient itself (Methods section 2),
528 we considered whether the LFBOT, the multiwavelength emission, and flares could all arise from
529 a foreground source, i.e., whether the proximity to a $z = 0.2564$ galaxy could be a chance
530 alignment. We note that the Galactic latitude of AT2022tsd is 39.2° , that there is no counterpart
531 recorded in SIMBAD within $30''$, and that the closest *Gaia* DR3 object is $25''$ away. From our
532 imaging sequence, we estimate that any foreground counterpart would have to be $g \gtrsim 24$ mag. We
533 considered two classes of events that can resemble LFBOTs owing to their fast blue optical light
534 curves: classical novae and dwarf novae.

535 Classical novae can produce fast optical light curves and multiwavelength emission⁷⁵. However,
536 we find a classical nova unlikely for several reasons. First, the peak absolute magnitude of novae

537 (-5 mag to -10 mag⁷⁵) implies a distance of 1–10 Mpc for AT2022tsd, yet there is no nearby
 538 galaxy at this position. Second, novae typically show prominent spectral features of $H\alpha$ and other
 539 species after maximum optical light⁷⁵, but the LRIS spectra of AT2022tsd show no such features
 540 at $z \approx 0$ (Extended Data Figure 1). In addition, the optical to X-ray luminosity ratio of novae is
 541 generally $L_{\text{opt}}/L_X = 10^5\text{--}10^6$ (for > 1 keV X-rays, which typically become detectable one month
 542 post-eruption⁷⁵), whereas in AT2022tsd we observe $L_{\text{opt}}/L_X \lesssim 1$ (Supplementary Information
 543 Figure 2).

544 Dwarf novae, a subclass of cataclysmic variable (CV) outbursts, can also have fast day-timescale
 545 blue optical light curves; the optical light curve of AT2022tsd (while sparsely sampled) is similar
 546 to that of classified dwarf novae in ZTF’s Bright Transient Survey^{76,77}. The absolute magnitudes
 547 of dwarf novae in quiescence are in the range 8–14 mag for systems with outburst amplitudes of
 548 $\gtrsim 4$ mag⁷⁸, implying a distance to AT2022tsd of 1–20 kpc. At 0.6 kpc, the X-ray and 10 GHz
 549 radio luminosities of AT2022tsd would be 7×10^{30} erg s⁻¹ and 2×10^{16} erg s⁻¹ Hz⁻¹, respectively,
 550 which is in the observed range for dwarf novae^{79,80}. However, dwarf novae develop prominent
 551 spectroscopic features (particularly Balmer lines, He I, and He II) after peak light^{81,82}. By contrast,
 552 we do not see any features at the expected wavelengths of $H\alpha$ or He I (Extended Data Figure 1).
 553 Searching for He II $\lambda 4686$ is complicated by the redshifted [O II] line, which has a centroid of
 554 4683.5 Å in the first Keck spectrum and 4686.7 Å in the second Keck spectrum. As discussed in
 555 Methods section 16, the shift between the centroids is present in all features at the same level,
 556 so is likely due to different slit positions and orientations. In addition, we confirmed that the
 557 line-strength ratios are consistent between the two spectra. So, we conclude that we do not detect
 558 any contribution from He II at $z = 0$. Finally, to our knowledge there is no dwarf nova with X-ray
 559 emission that decays as a power law for so long after the optical outburst; outside the outburst
 560 itself, the X-ray luminosity is typically constant⁸³.

561 Another argument disfavouring a CV origin is that the optical flares we observe are very
 562 different from the minute-timescale “flickering” observed in CVs: CV flickering has much smaller
 563 amplitudes (a fraction of a magnitude⁸⁴) and a typical flare has blue colours consistent with a
 564 hot ($\sim 17,000$ K) blackbody⁸⁴. As a final check, we searched for minute-timescale variability
 565 using ZTF light curves of dwarf novae. We employed the ZTF Bright Transient Survey⁷⁶ Sample
 566 Explorer⁷⁷ to identify 182 CVs with peak apparent brightness fainter than 18 mag and that do not
 567 have bright quiescent counterparts. Note that BTS requires transients to have a Galactic latitude of
 568 at least 7° . For each object, we retrieved a forced-photometry light curve from the IPAC service

569 (Methods section 16), from March 2018 (the start of the survey) until the end of 2022. For each
570 CV, we searched each night of observations for pairs of subtractions in the same filter and based
571 on the same reference stack. To count as a flare, a pair of detections had to have a flux change
572 exceeding a factor of 10, and the flux difference had to be significant ($> 3\sigma$). We identified eight
573 candidate flares from six distinct objects. Visual inspection of the science images and difference
574 images revealed that the brightness variations were due to cosmic rays (two images; ZTF18abyxlas
575 and ZTF20acufmrl), a likely “ghost” (an artifact of internal reflection, with significant drift from
576 image to image; three images of ZTF18acbwkqu), and a streak (one image; ZTF19abljehr). An
577 additional image (of ZTF19abylcik) had a data-quality flag (`infobitssci`) and visual inspection
578 showed a positive residual at the location of a nearby star, in addition to a positive residual at the
579 location of the CV; the flag, together with the by-eye assessment of the subtraction, suggest that
580 this positive residual was also an artifact. The remaining object (ZTF18acxhfkq) had a bright
581 point-like counterpart in PS1, the light curve revealed highly significant negative flux values, and
582 visual inspection of the images showed a low significance for the positive residuals; thus, the
583 variability is not robust. Therefore, we find that among dwarf novae there is no precedent for
584 flaring with the timescale and amplitude seen in AT2022tsd.

585 We conclude that if AT2022tsd is a foreground source, it would be a highly exotic object,
586 and it would be unlikely for such an unusual stellar system to be aligned with a galaxy (Figure 1)
587 whose redshift implies LFBOT-like optical, X-ray, and radio luminosities. For a crude estimate
588 of the probability of chance alignment, we used the COSMOS photometric redshift catalogue⁸⁵
589 to estimate the density of galaxies brighter than 22 mag with $0.1 \leq z \leq 0.3$. We found that the
590 number density is $\sim 1000 \text{ deg}^{-2}$. A spatial offset of 6 kpc corresponds to $3''$ for $z = 0.1$, so for
591 each galaxy a transient would have to be within a 30-square-arcsecond region to be considered
592 aligned. For 1000 galaxies in a square-degree region, that gives a covering fraction of 0.002 in
593 which a transient could be considered aligned with a galaxy at the appropriate redshift. During the
594 second year of ZTF, 372 CV candidates were discovered⁷⁸, most of which were dwarf novae; we
595 estimate a rate of 400 per year in the $15,000 \text{ deg}^2$ of the ZTF public survey, or $0.02 \text{ deg}^{-2} \text{ yr}^{-1}$. So,
596 in a given year, the chance of detecting an uncatalogued dwarf nova aligned with a $z = 0.1\text{--}0.3$
597 galaxy is $\sim 4 \times 10^{-5}$; over the course of five years in ZTF, we estimate 2×10^{-4} . Assuming the
598 flaring in AT2022tsd occurs in 1/100 dwarf novae, we find 2×10^{-6} . So, we conclude that the most
599 likely explanation is that AT2022tsd is extragalactic.

600 4 Flare Observational Characteristics

601 After the discovery of the Magellan/IMACS flare (Figure 3), we searched for additional flares with
602 13 different instruments (Extended Data Table 1). Here we summarise the observed properties of
603 the flares we detected, which are also listed in Extended Data Table 2. For each flare, we measured
604 the time interval in which 90% of the flux was detected (T_{90}). The value of T_{90} ranged from
605 ~ 10 min (the LT flare, and the small ULTRASPEC g -band flare prior to the large flaring episode;
606 Extended Data Figure 4) to 80 min (the large ULTRASPEC g -band flare; Extended Data Figure 4).

607 The observed optical flares (Figure 2, Extended Data Figure 4) exhibit a variety of morphologies.
608 The ULTRASPEC g -band flare (Extended Data Figure 4) showed a multihour flaring “episode”
609 with two prominent peaks superimposed on an exponential decline, as well as a short precursor
610 flare lasting just a few minutes. The ULTRASPEC r -band flare (Figure 3) was more erratic, with
611 an abrupt turnoff rather than an exponential decline. A Lomb-Scargle periodogram^{86,87} revealed
612 no significant periodicity in the ULTRASPEC light curves (Extended Data Figure 5), nor in the
613 X-ray observations (Extended Data Figure 6).

614 The ULTRASPEC r -band flare shows strong variability (Figure 3), with order-of-magnitude
615 changes in flux on timescales much shorter than the overall duration of the outburst. The time
616 to change by order unity, δt , is limited by the 30 s cadence of the observations. The ratio of
617 this variability time to the overall duration of the burst is therefore $\delta t/T < 2 \times 10^{-2}$. For the
618 ULTRASPEC g -band flare (Extended Data Figure 4), the time to change by a factor of order
619 unity is resolved by the individual observations, and is approximately a few minutes. We find
620 $\delta t/T < 4 \times 10^{-2}$.

621 From the Keck/LRIS observations (Extended Data Figure 4), we can measure the optical-flare
622 colour. The $g + I$ flare detection on 2022 October 19 gives $f_\nu \propto \nu^{-0.45 \pm 0.01}$ at the start of the
623 sequence, with a trend toward bluer colours over the next 20 min. The colour evolution may
624 be due to an increasing contribution from the underlying blue transient, rather than a colour
625 change inherent to the flare mechanism. The $u + I$ flare detection on 2022 December 29 gives
626 $f_\nu \propto \nu^{-1.6 \pm 0.1}$. There was only one clear detection in both bands during the $u + I$ sequence, so we
627 cannot draw conclusions about the colour evolution using the $u + I$ observations.

628 We have simultaneous X-ray and optical observations during one flare (Extended Data Figure
629 2). We detected an optical flare with LRIS at 10:10 on 2022-12-19, with significant emission

630 lasting for ~ 20 min. We have no constraint on the start time of the optical flare (the previous
631 optical observation ended three days prior). There is no obvious X-ray excess at the time of
632 observed optical peak. The average X-ray luminosity during this epoch is 10^{43} erg s $^{-1}$, while the
633 peak observed optical luminosity is $\sim 10^{42}$ erg s $^{-1}$. Adopting 10^{17} Hz for the X-ray frequency and
634 10^{14} Hz for the optical frequency, we rule out an optical to X-ray spectral index shallower than
635 $\beta = -4/3$ where $L_\nu = \nu^\beta$.

636 We estimated the flare duty cycle for different limiting-magnitude thresholds, assuming a
637 Poisson distribution for the likelihood of detecting a flare in any given time interval. We performed
638 the calculation using all images in the MJD range 59856.4–59942.4 (from the first to last flare
639 detection) except the PS1 w -band images, because the wide filter makes it difficult to convert
640 the measurement to a specific filter. We converted each detection to its estimated g -band value,
641 using the measured colour of the flares. For each threshold, Extended Data Table 3 gives the total
642 number of exposures above that threshold (the number of exposures in which a flare brighter than
643 the threshold could have been detected), the total exposure time of those exposures, and the fraction
644 of time in which a flare was detected.

645 To estimate the uncertainty in the duty cycle, we performed a simulation as follows. We
646 adopted a range of flare durations for each threshold (10–20 min for 21 mag, and 1 min to 3 hr for
647 22.5 mag and 24 mag), based on what we observed. For each choice of flare duration and average
648 flare frequency, we simulated 1000 sets of flare start times from one day prior to our earliest
649 detected flare to one day after our last detected flare. We calculated what the observed duty cycle
650 would have been, and discarded values of average flare frequency that resulted in $< 2.5\%$ of the
651 1000 trials being above or below our true observed value. As shown in Extended Data Table 3,
652 bright (< 21 mag) flares have a maximum allowed duty cycle of 10%. Constraints are weak for
653 fainter ($\gtrsim 24$ mag) flares owing to limited observations.

654 Finally, we searched for periodicity in the flare occurrence times. The longest continuously
655 observed interval without a flare detection was 3 hr (ULTRASPEC r -band; Extended Data Figure
656 4). The shortest continuously observed interval between two flares was also several hours (ULTRACAM
657 and KP84), or possibly half an hour if the two flares observed by ULTRASPEC in g were truly
658 distinct. We folded the optical observations by periods between 3 hr and 1 d, in 1 s steps. We did not
659 identify any clear period that aligned the flares, particularly taking into account our nondetections.
660 Several short periods (3.35 hr, 3.7 hr) aligned the flares to a 2 hr window, and slightly longer periods

661 (5.0 hr, 5.1 hr) to within a ~ 2.7 hr window.

662 **5 Limit on an Associated GRB**

663 We searched for a GRB counterpart in the 3.0 d between the last ZTF nondetection (4 Sep.; JD
664 2,459,826.9464) and the first ZTF detection of AT2022tsd. We did not identify any burst consistent
665 with the time and position of AT2022tsd in the GCN archive or the *Fermi* burst catalogue. Konus-Wind
666 was taking data throughout this interval, but detected no events consistent with the AT2022tsd
667 position. We adopt a 10 keV – 10 MeV fluence and peak flux threshold of $\text{few} \times 10^{-7}$ erg cm $^{-2}$ and
668 $\text{few} \times 10^{-7}$ erg cm $^{-2}$ s $^{-1}$, respectively (which correspond to the dimmer end of GRBs detected by
669 Konus-Wind in the waiting mode⁸⁸), giving upper limits of $E_{\gamma,\text{iso}} < \text{few} \times 10^{49}$ erg and $L_{\gamma,\text{iso}} < \text{few}$
670 $\times 10^{49}$ erg s $^{-1}$. These limits rule out an on-axis classical long-duration GRB, but not an off-axis or
671 low-luminosity GRB⁸⁹. In addition, these limits are for sources with typical GRB prompt emission
672 timescales; we cannot rule out an ultra-long duration GRB such as Swift J1644+57. We also
673 searched for GRBs consistent with the position of AT2022tsd between the first ZTF detection and
674 2023-04-27, but found no reliably associated bursts.

675 **6 Search for Flares in Other LFBOTs**

676 The discovery of flares in the aftermath of AT2022tsd (Methods section 3) raises the question of
677 whether there could have been flares associated with other LFBOTs. Over the years 2018–2022,
678 six LFBOTs were identified in addition to AT2022tsd: AT2018cow³, AT2018lug¹², AT2020xnd⁵⁴,
679 AT2021ahuo, AT2022abfc⁹⁰, and AT2020mrf⁷. We performed forced photometry on ZTF images
680 at the position of all six objects, with a start date of JD 2,458,194.5 (17 March 2018) and an
681 end date of JD 2,459,944.5 (31 December 2022), identifying no significant flares. However, for
682 most objects the nominal ZTF survey data cannot be used to rule out flaring with the duty cycle
683 of AT2022tsd. There were two tentative 3σ detections in the r band, 60 d after the discovery of
684 AT2021ahuo. However, with only two detections at low significance, it is difficult to determine if
685 they are true flares. AT2018cow was observed intensely by a variety of optical telescopes during
686 the 80 d post-discovery²⁸. At the distance of AT2018cow, the threshold of 24.0 mag for AT2022tsd
687 corresponds to a threshold of 17.4 mag for AT2018cow. We consider flares of duration 10 min and
688 1 hr. The 964 photometric points can be binned into 497 blocks of 10 min each, or 257 blocks
689 of 1 hr. We rule out flares as bright as 17.4 mag (corresponding to $M = -16.6$ mag) for all
690 images. We find an upper limit on the duty cycle of 10 min and 1 hr flares to be 0.7% and 1.4%,

691 respectively (95% confidence), lower than the 3% bound for the equivalent threshold in AT2022tsd.
 692 Therefore, we conclude that AT2018cow did not exhibit flaring behaviour with the same duty cycle
 693 as AT2022tsd.

694 We also performed forced photometry at the position of the LFBOT CSS161010¹¹ ($z =$
 695 0.033). We used the online Asteroid Terrestrial-impact Last Alert System (ATLAS; Methods
 696 section 16) forced-photometry service (Methods section 16) to identify 480 images within 600 d
 697 after the transient. There is no $\geq 5\sigma$ detection after the original transient. At the distance of
 698 CSS161010, the threshold for 24.0 mag for AT2022tsd corresponds to 19.2 mag. The number of
 699 images that are sufficiently sensitive, binned by hour, between 20 d and 100 d after the transient, is
 700 only 8. Therefore, we cannot exclude flaring with a duty cycle identical to that of AT2022tsd. ZTF
 701 forced photometry also did not identify any significant flares. A 4σ “detection” turned out upon
 702 visual inspection to arise from an image artifact (streak).

703 7 Physical Origin of AT2022tsd’s Flares

704 In this section, we use the observational characteristics of the AT2022tsd flares (Methods section 4)
 705 to set constraints on their physical origin.

706 The lowest frequency with clear detected variability is the optical band, so we use this to
 707 estimate the brightness temperature of the flares. From the ULTRASPEC r -band observations, the
 708 shortest timescale of variability we resolve is $\delta t_{\text{obs}} = 30$ s, setting a limit on the emission-region
 709 radius R of $R < \Gamma^2 c \delta t_{\text{obs}} \approx (9 \times 10^{11} \text{ cm}) \Gamma^2$, where Γ is the Lorentz factor of the outflow. The
 710 source angular radius is therefore $d\theta < 7 \times 10^{-5} \Gamma^2 \mu\text{as}$. Taking the intensity of the brightest
 711 ULTRASPEC flare detection (65 μJy in the rest frame), we find $T_B > I_\nu c^2 / (2k\nu^2) \approx 2 \times$
 712 $10^{10} \Gamma^{-4}$ K. For reasonable values of the Lorentz factor, the limiting blackbody temperature would
 713 result in very blue optical emission ($f_\nu \propto \nu^2$), yet all of the observed optical-flare colours are
 714 significantly redder. Therefore, we consider the emission more likely to be nonthermal. In addition,
 715 the value of $T_B = 2 \times 10^{10}$ K is very close to the equipartition brightness temperature limit⁹¹ of
 716 10^{11} K, suggesting that the outflow is at least close to relativistic.

717 Optically thin synchrotron radiation is a possible candidate for the nonthermal flare emission.
 718 The flux density from a population of synchrotron-emitting electrons in a power-law energy distribution
 719 $N(E)dE = \kappa E^{-p} dE$, where $N(E)dE$ is the number density of electrons in the energy interval E
 720 to $E + dE$ in units of $\text{cm}^{-3} \text{erg}^{-1}$, is⁹²

$$J(\nu) = 2.344 \times 10^{-37} a(p)(10^4 B)^{(p+1)/2} \kappa \left(\frac{1.253 \times 10^{37}}{\nu} \right)^{(p-1)/2} \text{ erg s}^{-1} \text{ cm}^{-3} \text{ Hz}^{-1}, \quad (2)$$

721 where B is the magnetic field strength and ν is the observed frequency. The optical depth to
 722 synchrotron self-absorption at a given frequency is $\tau_\nu = \chi_\nu R$, where R is the line-of-sight path
 723 length and the absorption coefficient χ_ν is

$$\chi_\nu = 3.354 \times 10^{-24} \kappa (10^4 B)^{(p+2)/2} (3.54 \times 10^{18})^p b(p) \nu^{-(p+4)/2} \text{ cm}^{-1}. \quad (3)$$

724 We assume $p = 2.5$, which corresponds to⁹² $a(p) = 0.359$ and $b(p) = 0.244$. Adopting the
 725 observed peak flux density of the Keck/LRIS $u + I$ flare, and the inferred size from the variability
 726 timescale $R = (1.8 \times 10^{12} \text{ cm}) \Gamma^2$, we find that the frequency at which the optical depth is unity
 727 (the synchrotron self-absorption frequency ν_{SSA}) is

$$\nu_{\text{SSA}} = (2 \times 10^{14} \text{ Hz}) \left(\frac{B}{\text{G}} \right)^{0.14} \Gamma^{-1.14}. \quad (4)$$

728 Therefore, given the observed characteristics of the AT2022tsd flares, the inferred synchrotron
 729 self-absorption frequency is very close to the optical band, consistent with our observation of
 730 optically thin emission. If the flares are synchrotron emission, we can estimate the equipartition
 731 energy U_{eq} and magnetic field strength B_{eq} . The latter is⁹³

$$B_{\text{eq}} = \left(\frac{8\pi A g(\alpha) L}{V} \right)^{2/7}, \quad (5)$$

732 where $A = 1.586 \times 10^{12}$ in cgs units, L is the luminosity, V is the volume of the synchrotron-emitting
 733 electrons, and $g(\alpha)$ is a function of the spectral index α (defined as $f_\nu \propto \nu^\alpha$) and frequency range
 734 (ν_1 to ν_2) for the power law:

$$g(\alpha) = \frac{2\alpha + 2}{2\alpha + 1} \left[\frac{\nu_2^{\alpha+1/2} - \nu_1^{\alpha+1/2}}{\nu_2^{\alpha+1} - \nu_1^{\alpha+1}} \right]. \quad (6)$$

735 From the Keck/LRIS flares we have $L = 10^{43} \text{ erg s}^{-1}$ and $\alpha = -1.6$. We assume that the
 736 power law extends from 10^{13} Hz to 10^{15} Hz . From the variability timescale, we have a radius
 737 of the synchrotron-emitting electron sphere of $(9 \times 10^{11} \text{ cm})\Gamma^2$. Taken together, we find $B_{\text{eq}} \approx$
 738 $(10^4 \text{ G})\Gamma^{-12/7}$, which is relatively insensitive to our choices of ν_1 , ν_2 , and α .

739 Next, we estimate the equipartition energy,

$$U_{\text{eq}} = 2 \frac{VB^2}{8\pi}. \quad (7)$$

740 We find $U_{\text{eq}} \approx (10^{43} \text{ erg})\Gamma^{18/7}$. Our estimated value of U_{eq} can be reconciled with the
 741 radiated flare energy in one of two ways: the flare-emitting outflow could be ultrarelativistic, or
 742 the electrons could be fast-cooling. Both scenarios are plausible; the observed spectral index
 743 ($f_\nu \propto \nu^{-1.6 \pm 0.1}$) is relatively steep, and the high B_{eq} implies a synchrotron cooling time that is
 744 much shorter than the dynamical time of the system.

745 Given the values above, we can estimate the Lorentz factor of the particles emitting in the
 746 optical band, γ_e . The characteristic frequency of those electrons ν_e is related to the gyrofrequency
 747 $\nu_g = q_e B / (2\pi m_e c)$ as $\nu_e = \gamma_e^2 \nu_g$. At 10^{15} Hz we find $\gamma_e \approx 10^2 \Gamma^{6/7}$.

748 Finally, we estimate the velocity of the flare-emitting outflow. Assuming that the kinetic
 749 energy of the outflow in AT2022tsd is on the order of the observed optical flare luminosity, we
 750 have $L_{\text{opt}} \approx 10^{44} \text{ erg s}^{-1} \approx \eta \dot{M} v^2$ (for the brightest flares), where \dot{M} and v are the mass-loss rate
 751 and velocity of the outflow (respectively), and η is the efficiency of converting kinetic energy to
 752 radiation. In this case, the observed nonthermal emission must arise from a radius that is larger
 753 than the Thomson scattering photosphere. In the observer frame, the optical depth to Thomson
 754 scattering is

$$\tau = n_e \sigma_T R, \quad (8)$$

755 where σ_T is the scattering cross-section, R is the depth into the outflow (assumed to be comparable
 756 to the radius of the outflow), and

$$n_e = \frac{\dot{M}}{4\pi m_p R^2 v}. \quad (9)$$

757 The quantity $\nu\sigma_T n_e$ (where ν is frequency) is Lorentz invariant⁶⁶, so we have $\sigma_T = \sigma'_T/\Gamma^2$, where
 758 σ'_T is the cross section in the rest frame of the gas. Ultimately, we find that the photospheric radius
 759 R_{ph} (the radius where $\tau = 1$) is

$$R_{\text{ph}} = \frac{1.1 \times 10^{11} \text{ cm}}{\Gamma^2 \beta^3 \eta}, \quad (10)$$

760 where $\beta = v/c$. Requiring R_{ph} to be smaller than the radius inferred from the light-crossing time,
 761 we find

$$\gamma^4 \beta^3 > 0.06 \eta^{-1}. \quad (11)$$

762 We obtain $\beta \gtrsim 0.4$ for $\eta = 1$ and $\beta \gtrsim 0.6$ for $\eta = 0.1$. So, the outflow must be fast, but need not
 763 be fully relativistic.

764 Given that LFBOTs with light curves similar to that of AT2022tsd are rare, occurring at <
 765 0.1% of the core-collapse supernova rate⁴, and only ~ 10 LFBOTs have been discovered thus far,
 766 it is unlikely that the outflow in AT2022tsd is as tightly collimated as the jets in GRBs (for which
 767 $\sim 1/100$ events are observed on-axis). In the extreme case that all the ZTF LFBOTs produced
 768 similar outflows, and that AT2022tsd was the only member of the class viewed on-axis so far
 769 (although flares cannot be ruled out for all but one of the previously discovered LFBOTs; Methods
 770 section 6), we estimate a beaming fraction of $f_b = 1/6 = 1 - \cos\theta$, and find $\theta \approx 30^\circ$ for the
 771 opening angle of the outflow. This estimate of the opening angle is consistent with the current
 772 (limited) radio limits on off-axis jets in such objects: the radio emission in AT2018cow (by far the
 773 most nearby event, with the most sensitive limits) cannot⁵ rule out an off-axis jet with $\theta = 30^\circ$ and
 774 energy $E_J < 10^{51}$ erg.

775 **8 Analysis of Early Optical LFBOT Emission**

776 The peak-light measurements of AT2022tsd are well described by a blackbody. From the AT2022tsd
 777 ZTF+PS1 *gri* measurements, we infer $T_{\text{eff}} = (3.3 \pm 1.8) \times 10^3$ K and $R_{\text{ph}} = (6.8 \pm 3.0) \times 10^{14}$ cm
 778 or 45 ± 20 AU. These values are very close to those of AT2018cow at peak light. We do not
 779 have similar constraints on the blackbody parameters during the decline, but we note that the
 780 photospheric radius of AT2018cow's optical emission reached 6×10^{13} cm by 60 d^{28,94} and 10^{12} cm

781 by 700 d⁸.

782 The fact that the inferred blackbody radius at peak optical light is much larger than the
783 inferred size of the emitting region during the flares could have several possible explanations. One
784 possibility is that during the first month (when no flares were detected), the blackbody-emitting
785 region expanded enough to become optically thin, finally enabling the smaller flare-emitting region
786 to be observed. Another possibility is geometric: that the component producing the flares is
787 on-axis, while the optically thick blackbody-emitting region is off-axis. Finally, it could be that
788 the flares arise from a jet that took time to burrow through the optically thick material, leaving an
789 open passage through which we are observing.

790 The rapid fade rate of AT2018cow imposed a limit on the nickel mass^{5,28} of $M_{\text{Ni}} < 0.1 M_{\odot}$.
791 The slower fade rate of AT2020mrf implied⁷ a limit of $M_{\text{Ni}} \lesssim 0.26 M_{\odot}$. The light curve of
792 AT2022tsd is not well sampled on the decline, but as shown in Figure 2 is close to being able to
793 accommodate the light curve of SN 1998bw, which had⁸⁹ a nickel mass of 0.3–0.6 M_{\odot} . However,
794 the spectrum at close to $\Delta t = 30$ d showed no supernova features, suggesting that the emission is
795 still dominated by another mechanism.

796 The persistent blue colours of AT2018cow led to the suggestion that the optical light curve
797 could be powered by reprocessing of the central X-ray source⁵, while the light curve of AT2020mrf
798 was found to redden over time⁷. Although the peak colour of AT2022tsd’s light curve is clearly
799 blue, we have limited information on the colour of the underlying light curve during the decline.
800 A NOT observation at $\Delta t = 26$ d shows $g = 21.85 \pm 0.07$ mag, $r = 22.11 \pm 0.09$ mag, and
801 $i = 21.98 \pm 0.10$ mag; however, the observations consisted of only a single exposure in each filter,
802 and the source was known to have started flaring at this time (from the detection of flares with
803 ZTF), so the contribution of variability and flaring to the observed colour is unclear.

804 **9 Analysis of Radio Emission**

805 For previously observed LFBOTs, the radio emission has been modeled using a standard equipartition
806 analysis, commonly used in the supernova literature⁷². This framework assumes that the peak
807 frequency is the synchrotron self-absorption frequency^{5,7,11,53,59,60} and that the underlying electron
808 population has been shock-accelerated into a power-law electron energy distribution. The steep
809 above-peak spectral indices observed in several objects (AT2018cow at early times⁵³, CSS161010¹¹,
810 and AT2020xnd⁶⁰) has also been used to argue that the underlying electron population may instead

811 be a relativistic Maxwellian⁹⁶.

812 In this section, we apply a similar analysis to the radio emission from AT2022tsd. At $\Delta t =$
 813 40 d, the spectral index is $f_\nu \propto \nu^{-0.5 \pm 0.3}$ (Extended Data Figure 3), consistent with expectations
 814 for optically thin emission from a power-law distribution of electrons in the slow-cooling regime.
 815 We assume a constant fraction of energy in electrons and magnetic fields, i.e., $\epsilon_e = \epsilon_B = 1/3$. This
 816 gives a shock radius of⁷²

$$R = (8.8 \times 10^{15} \text{ cm}) \left(\frac{F_p}{\text{Jy}} \right)^{9/19} \left(\frac{D_A}{\text{Mpc}} \right)^{18/19} \left(\frac{\nu_p}{5 \text{ GHz}} \right)^{-1}. \quad (12)$$

817 At $\Delta t = 40$ d, the peak flux density $F_p \gtrsim 0.3$ mJy, and the peak frequency $\nu_p \lesssim 100$ GHz (both
 818 rest frame). The angular diameter distance $D_A = 3 \times 10^{27}$ cm. So, we find a shock radius of
 819 $R \gtrsim 6 \times 10^{15}$ cm and an implied mean shock speed until that time of $v \gtrsim 0.06c$, among the slowest
 820 inferred radio ejecta speeds for LFBOTs, but very similar to AT2020mrf⁷ (Extended Data Figure
 821 3).

822 We can estimate the magnetic field strength of the shock as⁷²

$$B = (0.58 \text{ G}) \left(\frac{F_p}{\text{Jy}} \right)^{-2/19} \left(\frac{D_A}{\text{Mpc}} \right)^{-4/19} \left(\frac{\nu_p}{5 \text{ GHz}} \right). \quad (13)$$

823 We find $B \lesssim 6$ G. Using the energy in magnetic fields U_B , the total shock energy U is⁵³

$$U = \frac{U_B}{\epsilon_B} = (1.9 \times 10^{46} \text{ erg}) \frac{1}{\epsilon_B} \left(\frac{F_p}{\text{Jy}} \right)^{23/19} \left(\frac{D_A}{\text{Mpc}} \right)^{46/19} \left(\frac{\nu_p}{5 \text{ GHz}} \right)^{-1}. \quad (14)$$

824 We find $U \lesssim 3 \times 10^{48}$ erg. Finally, we can estimate the ambient density n_e as⁵³

$$n_e = (20 \text{ cm}^{-3}) \frac{1}{\epsilon_B} \left(\frac{L_p}{10^{26} \text{ erg s}^{-1} \text{ Hz}^{-1}} \right)^{-22/19} \left(\frac{\nu_p}{5 \text{ GHz}} \right)^4 \left(\frac{t_p}{1 \text{ d}} \right)^2. \quad (15)$$

825 Taking $L_p \gtrsim 6 \times 10^{29} \text{ erg s}^{-1} \text{ Hz}^{-1}$, we find $n_e \lesssim 6 \times 10^5 \text{ cm}^{-3}$, close to the value inferred for
 826 AT2018cow at $\Delta t = 22 \text{ d}$ ⁵³. So, although we infer near-relativistic velocities from the optical flares
 827 (Methods section 7), we infer nonrelativistic shock speeds from the radio emission, implying that
 828 the radio emission is not always probing the fastest-moving material in LFBOTs.

829 **10 Host Galaxy of AT2022tsd**

830 We fit the broadband photometry, which we extracted with the software package `LAMBDA`⁹⁷
831 from the Pan-STARRS images¹⁷³, and the absolute-flux-calibrated Keck spectrum from AT2022tsd
832 with the software package `Prospector` version 1.2.1¹⁰¹. This program uses the `Flexible`
833 `Stellar Population Synthesis (FSPS)` code¹⁰² to generate the underlying physical model
834 and `python-fsps`¹⁰⁴ to interface with FSPS in python. The FSPS code also accounts for
835 the contribution from the diffuse gas based on `Cloudy` models¹⁰⁵. We use the dynamic nested
836 sampling package `dynesty`¹⁰³ to sample the posterior probability.

837 We note that the wavelength range of the Keck spectrum was limited to $\lambda_{\text{rest}} = 3525\text{--}6700 \text{ \AA}$.
838 The lower cutoff is set by the lower bound of the stellar library `MILES`¹⁰⁶ used in `Prospector`.
839 The upper cutoff is set by the data quality of the Keck spectrum.

840 We assume a simple galaxy model: a Chabrier initial-mass function (IMF)⁹⁸ and a linearly
841 increasing star-formation history (SFH) at early times followed by an exponential decline at late
842 times (functional form $t \times \exp(-t/\tau)$, where t is the age of the SFH episode and τ is the e -folding
843 timescale). This model is attenuated with the Calzetti⁹⁹ model.

844 Supplementary Information Figure 1 shows the observed photometry (black data points) and
845 spectrum (grey), and the best fit (blue). The shaded region indicates the region of the spectrum used
846 in the `Prospector` fit. We measure a mass of the living stars in the host galaxy of $\log(M/M_{\odot}) =$
847 $9.96_{-0.09}^{+0.06}$ and a star-formation rate of $0.55_{-0.19}^{+1.36} M_{\odot} \text{ yr}^{-1}$.

848 **11 Progenitor of AT2022tsd**

849 The fast timescale of the LFBOT, the luminous and variable X-ray emission, the shallow radio
850 SED peaking in the sub-mm bands, and the characteristics of the optical flares (Methods section 2,
851 Methods section 7) all support the idea that AT2022tsd involves a near-relativistic outflow powered
852 by a compact object for months. In addition, as with previous LFBOTs such as AT2018cow
853 and AT2020xnd, the X-rays cannot arise from an extension of the synchrotron spectrum from
854 the radio-emitting electrons^{5,53,60}: although the spectral index connecting the millimeter to X-ray
855 emission could be consistent with optically thin synchrotron (Supplementary Information Figure 2),
856 the spectral index of the X-ray emission is not consistent. The X-rays could potentially arise
857 from inverse-Compton scattering of the ultraviolet-optical photons off the radio-emitting electrons;

858 however, we do not have sufficient data to measure the temporal decay index of the optical light
859 curve during the same period of time as the X-rays were observed.

860 In this section, we discuss the implications of the above properties for the physical origin
861 of AT2022tsd and other LFBOTs. The location of AT2022tsd at ~ 6 kpc from the centre of a
862 dwarf star-forming galaxy (Figure 1; Methods section 10), and the fast timescale of the LFBOT,
863 strongly disfavour a supermassive black hole as the compact object. So, we consider stellar- and
864 intermediate-mass black hole engines, both of which have been proposed to explain LFBOTs^{5,8,19,28}.

865 The first possibility we consider is that AT2022tsd is powered by a stellar-mass compact
866 object. LFBOTs have been argued to arise from failed supernovae^{5,28} or alternatively by the merger
867 of a compact object with a star¹⁹. In these scenarios, there could be three possible energy sources:
868 magnetospheric activity, rotational spindown (for a neutron star), or accretion (for a black hole).
869 We strongly disfavour a magnetospheric energy origin: the total radiated energy in X-rays alone
870 exceeds 10^{50} erg, while the energy in each flare is $\sim 10^{47}$ erg, and the magnetic energy budget
871 of a magnetar would be challenging: $U_B = (2 \times 10^{49} \text{ erg})(B/10^{16} \text{ G})^2(R/10 \text{ km})^3$. However,
872 both rotation or accretion could be possible, very similar to what was argued to explain the TDE
873 candidate J1644+57 as a massive-star collapse event¹⁰⁷.

874 For a stellar-mass compact object, the luminosity of the X-ray emission and optical flares
875 ($10^{44} \text{ erg s}^{-1}$) is highly super-Eddington: $L = 10^6 L_{\text{Edd}} (M/M_{\odot})$. Such a luminosity is compatible
876 with our inference of a near-relativistic outflow or jet (Methods section 7), which could reduce
877 the intrinsic luminosity by several orders of magnitude. As in J1644+57, the jet would have to
878 be powered for 100 d, which means that for a core collapse followed by black hole accretion
879 scenario^{109–111}, the progenitor would have to be extended (a red supergiant¹⁰⁷). Therefore, the
880 failed explosion of a rapidly rotating red supergiant is one plausible progenitor. The prolonged
881 high accretion rate would also be compatible with the merger and tidal disruption scenario¹⁹.

882 A challenge for the stellar-mass compact object scenario is the minute- to hour-timescale
883 of the flares. By analogy to known flaring systems (Table Supplementary Information Table 1),
884 possible flare mechanisms are shocks^e, magnetic reconnection events, or turbulence in the jet; the
885 flares themselves could also arise from geometry (jet precession, orbital motion in the case of a
886 binary). For most of these physical mechanisms, the flare duration should scale with the black hole

^eIf the emission is shock-powered, the variability timescale means it would have to arise from internal rather than external shocks: external shocks cannot²² produce bursts with $\delta t \ll T$.

887 mass, and the duration should be related to the light-crossing time of the black hole. For example,
888 for Sagittarius A* the time between flares is 10^3 – 10^4 times the light-crossing time t_{cross} , which is
889 $t_{\text{cross}} = 2GM/c^3 = 10$ s for a $10^6 M_{\odot}$ black hole. So, a supermassive black hole can have time
890 intervals as long as a day; scaling this down to 1 – $10^2 M_{\odot}$ would give 1 – 10 s as the time between
891 flares, which is clearly far too short. To explain the long flare durations, the source of the variability
892 would have to be far from the compact object, likely in the outer regions of an accretion disk¹⁹.
893 This could also be a reason to favour an accretion source for the energy, rather than rotation.

894 Another possible explanation for the flare durations is that the central engine is an intermediate-mass
895 black hole (IMBH). An IMBH TDE was found to be consistent with the LFBOT observed in
896 AT2018cow^{28,30}, and an accretion disk around an IMBH was found to be a more natural explanation
897 for the long-lived ultraviolet (UV) emission than a stellar-mass black hole⁸. The variable X-ray
898 light curve decaying as t^{-2} is similar to what has been observed in relativistic SMBH TDEs.
899 However, the IMBH picture for AT2018cow is challenged^{5,19} by the presence of extended dense
900 circumburst matter^{53,67}, and the occurrence of LFBOTs in host-galaxy environments that resemble
901 those of core-collapse supernovae¹¹².

902 Although IMBH TDEs remain a possibility, we consider the simplest explanation for LFBOTs
903 to be massive-star core-collapse events. In this scenario, AT2022tsd involves a near-relativistic
904 outflow powered by accretion onto a stellar-mass compact object, i.e., a very long-duration GRB
905 analog¹⁰⁷, with high angular momentum from the collapse and accretion of an outer envelope in
906 the failed explosion of an extended star^{19,54}, or from the merger and tidal disruption of a star by a
907 stellar-mass black hole¹⁹. The accretion disk gives rise to the significant asphericity observed¹⁰⁸,
908 and the flares arise from a process occurring far from the compact object, such as in the outer edges
909 of the accretion disk, or where the outflow dissipates its kinetic energy into radiation. The lack of
910 detected flares in AT2018cow (Methods section 6) could be due to viewing angle: AT2018cow is
911 thought to have been observed close to the plane of the circumburst “disk,” rather than face-on^{5,8}.
912 A different viewing angle for AT2022tsd could also help to explain the significantly more luminous
913 X-ray emission. If this association is correct, high-cadence follow-up optical observations of future
914 LFBOTs could reveal the beaming angle of their outflows.

915 **12 Data for Optical Parameter Space of Different Transient Classes**

916 Figure 1 plots AT2022tsd in optical transient parameter space. We include data for core-collapse
917 supernovae (CC SNe^{4,77}), Type Ia SNe⁷⁷, superluminous SNe (SLSNe⁷⁷), luminous fast blue
918 optical transients (LFBOTs^{3,5,7,11,12,28,53,54,56,57,60}), long-duration gamma-ray burst (LGRB) afterglows^{113,145},
919 a blazar flare¹⁴⁶, the kilonova AT2017gfo^{114–117}, the optically discovered relativistic TDE AT2022cmc¹¹⁸,
920 and the first peak in the optical light curves of low-luminosity GRBs^{119–122}. Measurements are as
921 close as possible to the rest-frame g band. Light curves to the upper left of the dashed line² cannot
922 be powered by the decay of radioactive isotopes because the nickel mass M_{Ni} would exceed the
923 ejecta mass M_{ej} . For the LGRB optical flashes, we started with a sample of LGRB afterglows¹¹³
924 and kept light curves that had either a well-resolved peak or observations that started within 100 s
925 of the burst.

926 To measure the duration of the light curve of AT2022tsd, we interpolated the light curve and
927 determined the amount of time the transient spent above half-maximum of peak. We performed
928 a Monte Carlo with 500 samples; the measurement plotted is the mean and the error bar is the
929 standard deviation. The error bar on the peak absolute magnitude is the 1σ confidence interval.

930 **13 Data for Optical, X-ray, and Millimeter Light curves of Different Transient Classes**

931 Figure 2 plots optical, millimeter, and X-ray light curves of different extragalactic transients. In
932 the optical panel, the LFBOT data are of AT2018cow^{5,6,28,53}, AT2020xnd^{54,59,60}, and AT2020mrf⁷.
933 We show the optical light curve of the stripped-envelope supernova SN 1998bw¹¹⁹ (GRB 980425).
934 Light curves of AT2018cow and AT2020xnd have been scaled to the redshift of AT2022tsd; the
935 light curve of AT2020mrf has been shifted to match the peak luminosity of AT2022tsd. The
936 millimeter panel shows relativistic TDEs^{118,123,124}, LGRBs^{125–128}, low-luminosity GRBs (LLGRBs^{129,130}),
937 CC SNe^{131–135}, and LFBOTs^{53,60}. For clarity, points marking AT2022tsd are outlined. The X-ray
938 panel shows TDEs^{24,118}, LFBOTs^{5–7,11,53,59,60}, LGRBs⁷, LLGRBs^{120,136,137,139,158}, and CC SNe¹⁴⁰.
939 For clarity, points marking AT2022tsd and AT2020xnd are outlined.

940 **14 Data for Table of Flaring Sources**

941 Table Supplementary Information Table 1 summarises the properties of high-amplitude ($\gtrsim 10\times$)
942 flares from a variety of source classes, including the peak luminosity L_{flare} , the amplitude (ratio
943 of the flare to the persistent flux; Amp.), and (when applicable) how long the flaring lasts after

944 the main transient event. Classes include ultraluminous X-ray sources (ULXs¹⁵⁰); a mysterious
945 flaring source GRB 070610 thought to be Galactic in origin^{25–27}; neutron star (NS) phenomena
946 such as giant flares (GFs) from soft gamma-ray repeaters (SGRs^{142,143}) and nanoshots from the
947 Crab pulsar¹⁵¹; stellar-mass black hole systems such as X-ray binaries (XRBs¹⁴¹) in the Milky
948 Way and GRBs¹⁴⁵ in distant galaxies; and supermassive black hole systems including TDEs^{23,152},
949 Sagittarius A*¹⁴⁴, M87¹⁵³, blazars¹⁴⁶, and events displaying quasi-periodic eruptions (QPEs¹⁵⁴).

950 **15 Data for Radio Parameter Space Plot**

951 In Extended Data Figure 3, we show a plot that is commonly used to characterise radio transients⁷².
952 We include data for CC SNe (Type II^{155,156} and Type Ib/Ic^{132,134,157–159}), TDEs¹⁶⁰, LLGRBs^{129,139,158,161},
953 LFBOTs^{5,7,11,12,53,60}, and two objects discovered by radio surveys (RT^{162,163}). Lines of constant
954 shock speed ($R/\Delta t$) are shown, as well as lines of constant mass-loss rate \dot{M} (scaled to wind
955 velocity v) in units of $10^{-4} M_{\odot} \text{ yr}^{-1}/1000 \text{ km s}^{-1}$. The lines assume that the radio peak is due to
956 synchrotron self-absorption⁷².

957 **16 Observations and Data Processing**

958 **Palomar 48-inch Samuel Oschin Telescope** AT2022tsd was discovered in data from the Zwicky
959 Transient Facility (ZTF^{164,165}) custom mosaic camera¹⁶⁶, which is mounted on the 48-inch Samuel
960 Oschin Telescope (P48) at Palomar Observatory. Three custom filters are used (g_{ZTF} , r_{ZTF} , and
961 i_{ZTF} ¹⁶⁶), and images reach a typical dark-time limiting magnitude of $r \approx 20.5$ mag. ZTF images
962 are processed and reference-subtracted¹⁶⁷ by the IPAC ZTF pipeline¹⁶⁸. Every 5σ point-source
963 detection is saved as an “alert.” Alerts are distributed in Avro format¹⁶⁹ and to discover AT2022tsd
964 were filtered based on a machine-learning “real-bogus” metric¹⁷⁰, a star-galaxy classifier¹⁷¹, and
965 light-curve properties.

966 Point-spread-function (PSF)-fit forced photometry was performed on archived difference
967 images from the ZTF survey using the ZTF forced-photometry service¹⁶⁸. The J2000 coordinates
968 supplied to the service were RA, Dec = 50.0453078, 8.7488721 (decimal degrees), the coordinates
969 of AT2022tsd in the first ZTF alert. The date range was 17 March 2018 (the default value for the
970 beginning of the ZTF survey) to 30 December 2022. Observations obtained ≥ 15 d prior to the
971 first ZTF alert for AT2022tsd all originated from the same ZTF field (506), CCD ID (03), and CCD
972 quadrant (03).

973 We followed forced-photometry service guidelines^f to further process the data. We verified
974 that the *r*- and *g*-band reference images were constructed using ZTF images from 2018, years
975 prior to the transient. The *i*-band reference image was constructed using ZTF images from as
976 late as 30 September 2022, but since reference images are constructed using outlier-trimmed
977 averaging¹⁶⁸ this is unlikely to affect our results; the only *i*-band detection was a flare seen in
978 a single image. Four of the observations obtained ≥ 15 d prior to the first ZTF alert for AT2022tsd
979 were flagged as being possibly impacted by bad pixels (with the `procstatus==56` warning).
980 Two of the four images were available via IPAC; visual inspection showed that the bad-pixel
981 region was $8''$ from the transient position, sufficiently far away to not impact the photometry,
982 so we kept them in our measurements. The remaining two images were not available, so we
983 removed them to be conservative. To identify images impacted by bad weather conditions, we
984 examined the `zpmaginpsci`, `zpmaginpscirms`, and `scisigpix` metrics. We identified
985 two images with outlier values of `zpmaginpsci < 25.5` and removed them. For each filter, we
986 determined the median flux value of all measurements prior to 10 d before the first ZTF alert of
987 AT2022tsd. We subtracted this median value from the flux measurements before converting them
988 to magnitudes. Finally, we ensured that the PSF-fit reduced χ^2 values had an average value of ~ 1
989 for observations in each filter. A signal-to-noise ratio (S/N) threshold of 3 was used to identify
990 detections. Nondetections are reported as 5σ .

991 **Pan-STARRS** We performed forced photometry on images from the Panoramic Survey Telescope
992 and Rapid Response System (Pan-STARRS1¹⁷²⁻¹⁷⁴). The typical PS1 observing sequence is 4×45 s
993 per night, with the four exposures separated over 1 hr. Filters are *i*, *w*, and *z*¹⁷². We detected two
994 high-significance (6.4σ and 7.9σ) flares (at $\Delta t = 71.1$ d and $\Delta t = 81.1$ d; Figure 2; Extended Data
995 Figure 4). In addition, the high-cadence observations during the transient event show no variability,
996 supporting the idea that there is an underlying “LFBOT” distinct from the optical flares.

997 **ATLAS** We obtained forced photometry at the position of AT2022tsd from the Asteroid Terrestrial-impact
998 Last Alert System (ATLAS¹⁷⁵⁻¹⁷⁷). ATLAS surveys the sky in cyan (*c*) and orange (*o*) filters that
999 are similar to the PS1 *g + r* and *r + i* filters, with a 1 d cadence. In three *o*-band observations, we
1000 have three low-significance (formally $< 3\sigma$) detections at the position of AT2022tsd. Stacking the
1001 observations results in a clear detection, so we consider these reliable flux measurements.

^f<https://irsa.ipac.caltech.edu/data/ZTF/docs/forcedphot.pdf>

1002 **Liverpool Telescope** We obtained g - and r -band images of AT2022tsd using the IO:O camera on
1003 the Liverpool Telescope¹⁷⁸ (LT) on 15 different nights, from 2022 September 23 to 2023 January
1004 23. We performed astrometric alignment on images that had been reduced using the standard LT
1005 pipeline. Image subtraction was conducted using PS1 as a reference and a custom IDL routine
1006 (the PS1 image was convolved to match the PSF of the LT image, then subtracted). Transient
1007 photometry was performed using seeing-matched aperture photometry fixed at the transient location,
1008 and calibrated relative to a set of SDSS secondary standard stars in the field (as measured from the
1009 unsubtracted images). The LT photometry of AT2022tsd is presented in Supplementary Table 1.

1010 **Thai National Telescope** AT2022tsd was observed with ULTRASPEC¹⁷⁹, a high-speed imaging
1011 photometer mounted on the 2.4 m Thai National Telescope. Each frame had a 30 s exposure time,
1012 with 15 msec of dead time between frames. The first epoch was on 2022 December 19, and
1013 consisted of 406 r -band frames, followed by a 2 min break to adjust the position of the lower
1014 telescope dome shutter, and then by another 161 r -band frames. The second epoch was on 2022
1015 December 20, and consisted of 387 g -band frames, a 2 min break, then an additional 91 frames.
1016 Images were taken in 2×2 binning, leading to a slight undersampling of the PSF ($0.9''$ pixels in
1017 $\sim 2''$ seeing). Image subtraction and photometry were performed relative to PS1 using the same
1018 methods and codes as the LT analysis, but with a fixed $2''$ radius aperture.

1019 **Himalayan Chandra Telescope** We observed AT2022tsd with the 2 m Himalayan Chandra Telescope
1020 (HCT) on 2022 December 26 under a Director’s Discretionary Time proposal. We obtained a series
1021 of 5 min exposures in the R band from 13:47 to 20:25, covering almost all of the first *Chandra*
1022 *X-ray Observatory* observing window. Seeing and focus were generally poor and vary greatly over
1023 the course of the observation. A stacked subset of the best-quality images is used as a reference and
1024 all other images are differenced relative to this one by cross-convolution of the respective PSFs.
1025 We did not detect any clear flares, with a limiting magnitude per exposure of $R \gtrsim 22$ mag. It is
1026 possible that there are some weak flares at the detection threshold, but the detections are not robust
1027 owing to the variable PSF size and shape over the course of the observation window.

1028 **GROWTH India Telescope** We observed AT2022tsd on 26 December 2022 using the GROWTH-India
1029 Telescope (GIT¹⁸⁰) located at the Indian Astronomical Observatory (IAO), Hanle-Ladakh, simultaneously
1030 with the Himalayan Chandra Telescope (see previous section). Images were observed in an open
1031 filter configuration with a 300 s exposure time. Images were analysed using a method similar to
1032 the one employed on other facilities. We used a stacked image containing all observations from

1033 the night as the reference image to subtract host-galaxy emission in the region of the transient,
1034 and performed forced aperture photometry using a $2''$ radius aperture. No significant flares were
1035 detected during the observation sequence.

1036 **Magellan-Baade Telescope** Starting at 04:30 on 2022 December 15, we obtained five 3 min
1037 g -band exposures of AT2022tsd using the Inamori-Magellan Areal Camera & Spectrograph (IMACS¹⁸¹)
1038 mounted on the 6.5 m Magellan-Baade telescope at Las Campanas Observatory. This sequence
1039 shows an unambiguous, high-S/N (~ 70) flare detection peaking in the middle of the five-exposure
1040 sequence, and is what led to our initial visual discovery of the short-timescale behaviour of this
1041 event. Image subtraction is performed using a stack of flare-free g -band images from Keck/LRIS
1042 taken in January as a reference, and forced aperture photometry is applied to the difference image.

1043 **Nordic Optical Telescope** Starting at 02:30 on 2022 October 4, we obtained an epoch of $ugri$
1044 observations of AT2022tsd using the Alhambra Faint Object Spectrograph and Camera (ALFOSC)
1045 on the 2.56 m Nordic Optical Telescope (NOT) at the Observatorio del Roque de los Muchachos
1046 on La Palma (Spain). Following the discovery of flaring, we obtained two additional epochs of
1047 observations, the first in g (five 60 s exposures the night of 2022 December 16) and the second in
1048 g and r (5×90 s exposures in each) the night of 2022 December 23. A flare was detected in the
1049 final g -band epoch. Image subtraction in g is performed using a stack of the 2022-12-16 epoch
1050 as a reference; image subtraction in r is performed using a stack of the 2022-12-22 observations.
1051 Individual flare-free exposures from the Keck/LRIS observations are used as references for i and
1052 u . Photometry is performed using a fixed aperture of $1''$ radius. The NOT photometry is presented
1053 in Supplementary Table 1.

1054 **Palomar Hale 200-inch** On 2023 January 27, we observed the position of AT2022tsd for 3 hr
1055 using the Caltech HIgh-speed Multi-color camERA (CHIMERA¹⁸²) on the Palomar 200-inch
1056 Hale telescope. The seeing was $2.5\text{--}3''$. A total of 210 exposures of 50 s each were obtained
1057 simultaneously in the g and r filters. Images were reduced using a custom pipeline modified from
1058 that of ULTRACAM¹⁸³, and image subtraction was performed using PS1 as a reference using
1059 the same techniques as for LT and ULTRASPEC. Photometry was performed using a $2.5''$ -radius
1060 aperture.

1061 **Lulin Observatory** Between 14:38 and 17:27 on 2022 December 26, we obtained 27 g -band
1062 images with the Lulin One-meter Telescope (LOT) and 31 r -band images with the 40 cm Super
1063 Light Telescope (SLT), coordinated with *Chandra X-ray Observatory* observations (Section 16).

1064 Each exposure was 300 s, with varying seeing conditions (with an average of 2.8"). The g images
1065 were subtracted from a PanSTARRS template, with no detection of AT2022tsd in any image.
1066 Combining all 27 g images results in a 3σ limit of $g > 22.0$ mag. To perform image subtraction on
1067 the r -band images, a template image was acquired with the SLT. The 3σ upper limits for individual
1068 frames are provided in Supplementary Table 1.

1069 **European Southern Observatory New Technology Telescope** We observed AT2022tsd on two
1070 nights (2022 December 18, 19) using ULTRACAM¹⁸³. On December 18 we obtained 116 i -band
1071 frames with a 20 s exposure time, totaling 38 min of data; the deadtime between each frame is
1072 24 ms. The seeing was 1–1.5". On December 19 we obtained 556 r -band frames with a 20 s
1073 exposure time, totaling 3 hr 5 min of data. The deadtime between each frame is again ~ 24 ms.
1074 The seeing started out at 1", but worsened to 2.5" toward the end of the run. We subtracted a dark
1075 image and removed remaining bad/hot pixels in the vicinity of the transient by taking the median
1076 value of the eight surrounding pixels. Image subtraction was performed using a consistent method
1077 as for the other observations, using stacks formed from flare-free sections of the data taken the
1078 same night. For the first night, which shows no flaring, we use a stack of the entire night; for the
1079 second night we use a stack of the first 97 images (all acquired prior to the flare). Photometry was
1080 performed using a fixed 1.5"-radius aperture and calibrated to nearby Pan-STARRS standards.

1081 As part of ePESSTO+ (the Public European Southern Observatory Spectroscopic Survey of
1082 Transient Objects project¹⁸⁴), we observed AT2022tsd on three nights (2022 December 22, 24,
1083 and 30) in the g and r bands using the Faint Object Spectrograph and Camera (v.2; EFOSC2¹⁸⁵)
1084 mounted on the 3.58 m European Southern Observatory (ESO) New Technology Telescope (NTT)
1085 under the observing program 1108.D-0740 (PI C. Inserra). On the first two nights, the observation
1086 sequence was 5×95 s exposures in g followed by 5×95 s exposures in r . A flare is seen at the
1087 beginning of the g -band sequence from the second epoch; otherwise no variability was evident.
1088 On the third night, the sequence was altered such that images were obtained in alternating filters
1089 ($5 \times gr$) and no flare was detected. The data were reduced using the standard pipeline⁸, which is
1090 based on iraf/pyraf. Image subtraction was performed using the last exposure of each sequence as
1091 a reference image; photometry was performed using a 1.0"-radius aperture in all observations.

1092 **Kitt Peak 84-inch Telescope** On 2022 December 20, we observed the position of AT2022tsd
1093 for 2 hr using the Spectral Energy Distribution Machine (SEDM¹⁸⁶) version 2 on the Kitt Peak

⁸<https://github.com/svalenti/pessto>

1094 84-inch (KP84) Telescope. A total of 60 exposures of 120 s each were obtained in the clear filter.
1095 Flat-fielding was performed using a super-sky flat constructed using a median stack of all exposures
1096 taken on the field. Pan-STARRS r -band imaging was used as the reference image, which resulted
1097 in an acceptable removal of the host despite the unfiltered nature of the observations. Photometry
1098 was performed using a fixed $1.5''$ -radius aperture and calibrated to nearby Pan-STARRS standards.
1099 We subtracted a median flux level from all flux values.

1100 **Large Array Survey Telescope** We observed AT2022tsd using eight telescopes in the Large
1101 Array Survey Telescope (LAST^{187,188}). The target was observed on 2023 January 12, 13, and
1102 15, and also on several nights during December 2022. The 2022 observations were taken under
1103 poor conditions and are not reported here. We obtained 20 s exposures in continuous mode (i.e.,
1104 no dead time between images). A total of 10.9 hr of observations in 3 nights were obtained. The
1105 observations were reduced using the LAST pipeline^{187,189,190}), and forced PSF photometry was
1106 conducted on the individual images in the transient position. The source position was fitted but it
1107 was forced to be within 0.5 pixels ($0.62''$) of the initial position. In each image, we also performed
1108 forced photometry on all *Gaia*-DR3¹⁹¹ stars within $500''$ from the transient position. These sources
1109 were used for the photometric calibration.

1110 Since in many cases, we observed the transient location simultaneously with several LAST
1111 telescopes, in Supplementary Table 2 we provide a 2 min binning of the unsubtracted measurements.
1112 We did not detect any flares.

1113 **W. M. Keck Observatory** We obtained five epochs of observations of AT2022tsd using the Low
1114 Resolution Imaging Spectrometer (LRIS¹⁹²) at the W. M. Keck Observatory; it is equipped with
1115 an atmospheric dispersion corrector. The first epoch, obtained as part of a program with PI A. V.
1116 Filippenko, was a 40 min exposure starting at 13:52:48.69 on 2022 September 23. The setup was
1117 a $1''$ slit, blue grism 600/4000, red grating 400/8500, and dichroic 560. Binning was 1×1 in both
1118 the red and blue CCDs, and the position angle of the slit was 30° counterclockwise from north.
1119 The wavelength coverage was 3138–10,259 Å.

1120 The second epoch was a 40 min exposure starting at 14:13:16 on 2022 October 6. The setup
1121 was a $1''$ slit, blue grism 400/3400, red grating 400/8500, and dichroic 560. Binning was 1×2
1122 (spatial, spectral) in the blue CCD and 1×1 in the red, and the position angle of the slit was 61°
1123 counterclockwise from north. The wavelength coverage was 3109–9646 Å. The data were obtained
1124 as part of a ToO program with PI R. Margutti.

1125 We obtained two imaging epochs in the g and I bands (PI M. Kasliwal), each comprising
1126 four exposures totaling 20 min. The first epoch started at 2022 October 19 10:35 and the second
1127 epoch started at 2023 January 17 07:12. Finally, we obtained one imaging epoch in the u and I
1128 bands (PI J. Cooke). The observation comprised five exposures of 5 min each, beginning at 10:36
1129 on 2022 December 29.

1130 All spectra and images were reduced using LPipe¹⁹³. For the last two image sequences (in
1131 December and January), we performed image subtraction using the last image of the sequence as
1132 the reference; for the first (October) imaging sequence we use stacks of the January observations
1133 as a reference. Photometry was performed using a 1.25''-radius aperture. The g and I images are
1134 calibrated relative to PS1. The u -band image was calibrated relative to a LT-IO:O calibration of
1135 the field taken on two photometric nights in January 2023.

1136 The pipeline-reduced LRIS spectra show a slight inconsistency between the wavelength
1137 calibrations in the blue region owing to flexure, which was rectified using an additional 2 Å shift
1138 calculated using the position of a weak 5200 Å night-sky line. Even after this correction, there
1139 remains an offset of 2 Å between host emission-line features in the two Keck spectra, which is
1140 apparent in all the lines. The night-sky-line positions are consistent, however, so this is likely due
1141 to slightly different slit positions and orientations.

1142 **Upgraded Giant Metrewave Radio Telescope** We triggered upgraded Giant Metrewave Radio
1143 Telescope (uGMRT) observations of AT2022tsd during 2023 March 04.51 to 2023 April 02.42 in
1144 frequency bands 1000–1460 MHz (Band 5), 550–750 MHz (Band 4), and 250–500 MHz (Band 3).
1145 The data were recorded in total intensity mode with bandwidths 400 MHz (Band 5) and 200 MHz
1146 (Band 4 and Band 3) split into 2048 channels. The temporal resolution was 10 s. We used 3C147
1147 as the flux density calibrator and J0323+055 as the phase calibrator. The data were analysed¹⁹⁴
1148 using the Astronomical Image Processing Software (AIPS¹⁹⁵) The data were initially flagged and
1149 calibrated using standard tasks in AIPS. The fully calibrated data were imaged using task IMAGR.
1150 A few rounds of phase-only self-calibration were performed to improve the image quality. The
1151 details of the GMRT observations are presented in Supplementary Information Table 5. The quoted
1152 errors include map root-mean-square (RMS) and a 10% calibration error added in quadrature.

1153 **Very Large Array** Seven epochs of Karl G. Jansky Very Large Array (VLA¹⁹⁶) observations
1154 were obtained of AT2022tsd from 2022 October 2 to 2023 April 5 under Program ID 2022B-157
1155 and ToO Program ID 2023A-393. The first epoch was obtained during the D-to-C configuration

1156 change, the next four epochs were obtained in the C configuration, and the final two epochs
1157 were obtained in the B configuration. All observations used 3-bit samplers, full polarization, and
1158 employed 3C147 and J0321+1221 as flux-density and phase calibrators, respectively.

1159 Data were calibrated using the VLA pipeline available in the Common Astronomy Software
1160 Applications (CASA¹⁹⁷). Epoch 2 was hampered by poor phase stability at high frequencies,
1161 affecting the Ka and Q-band observations. Additional flagging was performed manually and the
1162 calibration pipeline was rerun, albeit with continued high RMS noise at these high frequencies.
1163 Prior to imaging each observation, additional radio-frequency interference (RFI) was removed by
1164 flagging amplitudes higher than 3σ . For the Epoch 4 Ku-band observation we flagged additional
1165 spectral windows manually to excise RFI.

1166 For imaging, we adopted Briggs weighting (`robust=0.5`) and `nterms=2`. For some
1167 high-frequency observations we adopted natural weighting because it significantly improved the
1168 S/N of the image. The pixel scale was chosen to oversample the beam size by a factor of ≥ 10 in all
1169 images. In each image, we verified that the source was unresolved using `imfit`. For the Epoch
1170 4 Ku-band observation the source appeared slightly resolved, perhaps due to underlying diffuse
1171 host-galaxy emission, or the fact that the source lies along a sidelobe. In all cases we adopted
1172 the maximum pixel flux as the flux density. To determine the uncertainty in the flux density we
1173 measured the RMS noise in a nearby region of the image unaffected by any sources.

1174 To search for short-timescale variability, we imaged each scan of the 15 GHz observations
1175 individually. We chose 15 GHz because the VLA is more sensitive at this frequency than at higher
1176 frequencies, and because the length of the cycle time is well suited to searching for variability on
1177 the timescale of the observed AT2022tsd flares. Each observation had 6–8 scans, each scan lasted
1178 ~ 7 min, and scans were typically separated by 1 min. The resulting S/N per scan ranged from
1179 $< 3\sigma$ (no detection, most common in Epoch 1 and Epoch 2) to S/N = 8 (in Epochs 5 and 6). We
1180 did not detect any definitive variability. The strongest variations we measured were during Epoch
1181 3 (when the source apparently brightened from $28 \pm 8 \mu\text{Jy}$ to $45 \pm 8 \mu\text{Jy}$, then faded to nondetection
1182 with RMS $8 \mu\text{Jy}$) and Epoch 6 (when the source apparently faded from $70 \pm 9 \mu\text{Jy}$ to $37 \pm 8 \mu\text{Jy}$
1183 across two scans). However, these variations are fairly marginal; in the Epoch 6 observation, the
1184 corresponding flux density of another source in the field was $65 \mu\text{Jy}$ and then $75 \mu\text{Jy}$, suggesting
1185 that the true uncertainty is $\sim 10 \mu\text{Jy}$. In that case, the fading is only $\sim 3\sigma$.

1186 Using the B-configuration Ku-band observation, we obtain the following measurement of the

1187 position of AT2022tsd: standard equinox J2000 right ascension $\alpha = 03^{\text{h}}20^{\text{m}}10^{\text{s}}.873$ and declination
1188 $\delta = +08^{\circ}44'55''.739$ (uncertainty 0.009").

1189 **Submillimeter Array** AT2022tsd was observed with the SMA on 2022 October 4 with 7 antennas
1190 for a total of 5.95 hr on source, under ToO program 2022A-S019. The atmospheric opacity was
1191 poor and variable, changing from 0.28 to 0.18 over the night. Observations were performed using
1192 R×A and R×B receivers both tuned to LO frequencies of 225.55 GHz. All 48 GHz of bandwidth
1193 were used to generate a single continuum channel. Observations of the nearby quasars 0238+166
1194 and 0423-013 were used as the primary phase and amplitude gain calibrators with absolute flux
1195 calibration performed by comparison to Neptune and Uranus while passband calibration was
1196 derived using BL Lac. Calibration was performed using the MIR IDL package for the SMA,
1197 with subsequent analysis performed in MIRIAD. No source was detected. The final image has an
1198 RMS of 0.27 mJy and synthesised beam of $3.9'' \times 3.2''$.

1199 **Atacama Large Millimeter/submillimeter Array** AT2022tsd was observed with ALMA as part
1200 of DD time (Project code 2022.A.00010.T) during Cycle 9 using Bands 6–8. Observations were
1201 performed on 2022 October 19 ($\Delta t \approx 43$ d; Band 7), 2022 October 21 ($\Delta t \approx 45$ d; Band 8), and
1202 2022 October 22 ($\Delta t \approx 46$ d; Band 6) with Δt epochs in the observer frame. The ALMA 12 m
1203 antenna array was in its C-3 configuration, with 43–46 working antennas and baselines in the range
1204 15.1–457.3 m. The on-source integration time was 11 min in Band 6, 50 min in Band 7, and 2.0 hr
1205 in Band 8. Observations used dual-sideband (2SB) receivers with a total bandwidth of 7.5 GHz.
1206 The total bandwidth was divided into four 1.875 GHz basebands centred on 224, 226, 240, and
1207 242 GHz (Band 6); 336.5, 338.5, 348.5, and 350.5 GHz (Band 7); and 398, 400, 410, 412 GHz
1208 (Band 8).

1209 All calibration and imaging was done with CASA. The data were calibrated and imaged
1210 with the standard ALMA pipeline, using J0309+1029 to calibrate the complex gains, and using
1211 J0238+1636 (Bands 6 and 7) or J0423-0120 (Band 8) to calibrate the bandpass response and apply
1212 an absolute flux scale. AT2022tsd is unresolved in the Band 6 and Band 7 data, and partially
1213 resolved in the Band 8 data (i.e., the fitted width is larger than the synthesised beam). The S/N
1214 in the resulting images is 11 in Band 6, 12 in Band 7, and 7 in Band 8. The ALMA results are
1215 summarised in Supplementary Information Table 5.

1216 We searched for variability across each observation. The Band 6 observations started at
1217 04:02 and ended at 04:13 on 2022-10-22, spanning 11 min. We imaged each of the two scans

1218 individually, for a per-scan S/N of 6–9, with no significant difference in the flux density between
1219 scans. The Band 7 observations started at 04:29 and ended at 05:43 on 2022-10-19, spanning 1 hr
1220 14 min. We imaged each of the eight on-target scans individually, for a per-scan S/N of 4–7, and
1221 did not detect any significant changes between scans. The time per scan was 4.5–7 min. Finally, the
1222 Band 8 observations started at 04:55 and ended at 08:10 on 2022-10-21, spanning 3 hr 15 min. We
1223 imaged each of the 19 on-target scans individually, and did not detect emission from AT2022tsd in
1224 any scan.

1225 **Northern Extended Millimeter Array (NOEMA)** We obtained six epochs of observations of
1226 AT2022tsd with NOEMA. Multiband observations were done when the source flux and weather
1227 permitted it, with Band 1 (100 GHz), Band 2 (150 GHz), and Band 3 (230 GHz) under the ToO
1228 program S22BD. A total of 14 observations were obtained, and interferometer array configurations
1229 ranged from compact (D) to more extended (C) and (B). The primary flux calibrators were MWC349
1230 and LKHA101, and the time-dependent phase and amplitude calibrators were the QSOs B0306+101
1231 and B0256+075. The data reduction was done with the CLIC software (GILDAS package¹⁹⁸).
1232 Dual-polarization UV tables were written for each of the receiver sidebands. The resulting calibrated
1233 UV tables were analysed in the MAPPING software (also from the GILDAS package) and point-source
1234 UV plane fits were performed. The NOEMA results are summarised in Supplementary Information
1235 Table 5.

1236 We searched for flux variability over the course of the two highest-S/N observations: the
1237 Band 2 observation during the night of 2022 October 29–30, and the Band 1 observation during the
1238 night of 2022 November 18–19. The UV point position for the combined data was fit separately
1239 for the LSB and the USB, in order to account for minor calibration errors. Then, point-source
1240 fits were performed to each of the five on-target scans. Each scan lasted 22.5 min, and the total
1241 observation window was 2.5 hr. The S/N in each scan ranged from 3–4. No significant variability
1242 was detected.

1243 **Neil Gehrels Swift Observatory** AT2022tsd was observed by the X-ray Telescope (XRT²⁰⁰)
1244 onboard the *Neil Gehrels Swift Observatory* under a series of time-of-opportunity (ToO) requests,
1245 with a total of 14 segments. The first segment began at 09:13 on 2022 October 4 ($\Delta t = 28.2$ d,
1246 observer frame), and the last segment ended at 21:10 on 2022 December 17 ($\Delta t = 102.7$ d,
1247 observer frame). The source was not detected in the last segment, so we did not pursue further
1248 XRT observations. All XRT observations were obtained in the photon-counting mode, and are

1249 summarised in Supplementary Information Table 3. The transient was also observed by the Ultra-Violet/Optical
1250 Telescope (UVOT²⁰¹), but the only emission detected was from the host galaxy.

1251 To measure the count rate from each observation, we used the analysis tools developed by
1252 the *Swift* team^{202,203}. We used iterative centroiding and binned by observation. To convert from
1253 count rate to unabsorbed flux, we fit for an average spectrum using the first five observations.
1254 Using a Galactic neutral hydrogen column density¹⁹⁹ of $n_H = 2.11 \times 10^{21} \text{ cm}^{-2}$, the data were
1255 well described by a power law with photon index $\Gamma = 2.1_{-0.4}^{+0.5}$, giving a 0.3–10 keV count rate to
1256 flux conversion factor of $5.10 \times 10^{-11} \text{ erg cm}^{-2} \text{ ct}^{-1}$. An independent analysis of the *Swift* data⁶⁵
1257 found a consistent value for the photon index of $\Gamma = 2.00_{-0.15}^{+0.17}$.

1258 **Chandra X-ray Observatory** AT2022tsd was observed by the *Chandra X-ray Observatory* under
1259 two programs (Proposal 24500280, PI D. Matthews; DDT Proposal 23508884, PI A. Ho) for
1260 a total of eight epochs. The first epoch began on 2022 October 16 and the most recent epoch
1261 began on 2023 July 16. Exposure times ranged from 12 ks to 40 ks. After the detection of
1262 the Magellan/IMACS flare, we were granted 40 ks of *Chandra* observations under Director’s
1263 Discretionary Time, divided into two windows (2022 December 26 and 29), to search for simultaneous
1264 X-ray and optical flares. We conducted simultaneous ground-based optical observations with the
1265 Himalayan Chandra Telescope, the Lulin Observatory, and Keck/LRIS (Methods section 16). A
1266 single optical flare was detected with Keck/LRIS on 29 December (Extended Data Figure 4), but
1267 no X-ray flare counterpart was detected.

1268 We reduced each epoch using the Chandra Interactive Analysis of Observations (CIAO²⁰⁴)
1269 software package (v4.15). Counts were extracted from AT2022tsd using a circle with radius
1270 $2''$, and background counts were measured in source-free regions near AT2022tsd. We used
1271 `specextract` to bin the spectrum (with 5 counts per bin for all epochs). The routine `sherpa`
1272 was used to fit the spectrum in the range 0.5–6 keV, with the background subtracted, using a
1273 model with photoelectric absorption and a single-component power law (`xsphabs.abs1 ×`
1274 `powlaw1d.p1`). We set the Galactic hydrogen density to be the same as for the *Swift* observations.
1275 In all epochs, the data were well described by a power law (reduced $\chi^2 = 0.2$ –1.2). In the
1276 highest-S/N observation, we found $\Gamma = 1.98 \pm 0.23$; all other epochs had a best-fit Γ consistent
1277 with this value. An independent analysis of the *Chandra* data⁶⁵ found a consistent value for the
1278 photon index of $\Gamma = 1.89_{-0.08}^{+0.09}$. After obtaining the best-fit model of the spectrum, we used
1279 `sample_flux` to measure the 0.5–6 keV flux of the source. The best-fit flux measurements are

1280 listed in Table Supplementary Information Table 4. To convert to the *Swift* 0.3–10 keV range
1281 (Extended Data Figure 2) we multiplied the 0.5–6 keV values by a factor of 1.77.

1282 For the final epoch of observations, we binned three observations that were obtained on
1283 three different days, close together in time (2023 June 11–16), after confirming by analysing each
1284 observation individually that there was no strong variability between epochs. To bin, we used
1285 `merge_obs` to create a merged file, and used `srcflux` to compute the count rate. There were
1286 insufficient counts to perform a spectral fit, so we adopted the same spectral index as for the other
1287 epochs ($\Gamma = 2$).

1288 For each sufficiently bright observation, we used `dmextract` and 500 s bins to construct a
1289 light curve of AT2022tsd. We also extracted the light curve of the background region. The light
1290 curves of AT2022tsd and the background are shown in Extended Data Figure 2, with 1σ error bars.

1291 **References**

- 1293 45. GROWTH India Telescope. <https://sites.google.com/view/growthindia/>.
- 1292
1294 46. Beck, R., et al. PS1-STRM: neural network source classification and photometric redshift
1295 catalogue for PS1 3π DR1. *Mon. Not. R. Astron. Soc.*, **500**, 1633 (2021).
- 1296 47. Oke, J. B., & Gunn, J. E. Secondary standard stars for absolute spectrophotometry. *Astrophys.*
1297 *J.*, **266**, 713 (1983).
- 1298 48. Finkbeiner, D. P., Davis, M., & Schlegel, D. J. Extrapolation of Galactic Dust Emission at 100
1299 Microns to Cosmic Microwave Background Radiation Frequencies Using FIRAS. *Astrophys.*
1300 *J.*, **524**, 867 (1999).
- 1301 49. Schlegel, D. J., Finkbeiner, D. P., & Davis, M. Maps of Dust Infrared Emission for Use
1302 in Estimation of Reddening and Cosmic Microwave Background Radiation Foregrounds.
1303 *Astrophys. J.*, **500**, 525 (1998).
- 1304 50. Schlafly, E. F., & Finkbeiner, D. P. Measuring Reddening with Sloan Digital Sky Survey Stellar
1305 Spectra and Recalibrating SFD. *Astrophys. J.*, **737**, 103 (2011).

- 1306 51. van der Walt, S. J, Crellin-Quick, A., & Bloom, J. S. SkyPortal: An Astronomical Data
1307 Platform. *The Journal of Open Source Software*, **4(37)**, 1247 (2019).
- 1308 52. Coughlin, M. W., et al. A data science platform to enable time-domain astronomy. *arXiv*
1309 *e-prints*, arXiv:2305.00108 (2023).
- 1310 53. Ho, A. Y. Q., et al. AT2018cow: A Luminous Millimeter Transient. *Astrophys. J.*, **871**, 73
1311 (2019).
- 1312 54. Perley, D. A., et al. Real-time discovery of AT2020xnd: a fast, luminous ultraviolet transient
1313 with minimal radioactive ejecta. *Mon. Not. R. Astron. Soc.*, **508**, 5138 (2021).
- 1314 55. Jiang, J.-. an ., et al. MUSSES2020J: The Earliest Discovery of a Fast Blue Ultraluminous
1315 Transient at Redshift 1.063. *Astrophys. J. Lett.*, **933**, L36 (2022).
- 1316 56. Pursiainen, M., et al. Rapidly evolving transients in the Dark Energy Survey. *Mon. Not. R.*
1317 *Astron. Soc.*, **481**, 894 (2018).
- 1318 57. Arcavi, I., et al. Rapidly Rising Transients in the Supernova—Superluminous Supernova Gap.
1319 *Astrophys. J.*, **819**, 35 (2016).
- 1320 58. Gal-Yam, A. Observational and Physical Classification of Supernovae. In Alsabti, A. W. &
1321 Murdin, P. (eds.) *Handbook of Supernovae*, 195 (2017).
- 1322 59. Bright, J. S., et al. Radio and X-Ray Observations of the Luminous Fast Blue Optical Transient
1323 AT 2020xnd. *Astrophys. J.*, **926**, 112 (2022).
- 1324 60. Ho, A. Y. Q., et al. Luminous Millimeter, Radio, and X-Ray Emission from ZTF 20acigm1
1325 (AT 2020xnd). *Astrophys. J.*, **932**, 116 (2022).
- 1326 61. Phinney, E. S. Manifestations of a Massive Black Hole in the Galactic Center. *The Center of*
1327 *the Galaxy*, **136**, 543 (1989).
- 1328 62. Levan, A. J., et al. An Extremely Luminous Panchromatic Outburst from the Nucleus of a
1329 Distant Galaxy. *Science*, **333**, 199 (2011).
- 1330 63. Burrows, D. N., et al. Relativistic jet activity from the tidal disruption of a star by a massive
1331 black hole. *Nature*, **476**, 421 (2011).

- 1332 64. Cenko, S. B., et al. Swift J2058.4+0516: Discovery of a Possible Second Relativistic Tidal
1333 Disruption Flare?. *Astrophys. J.*, **753**, 77 (2012).
- 1334 65. Matthews, D., et al. Unprecedented X-Ray Emission from the Fast Blue Optical Transient
1335 AT2022tsd. *Research Notes of the American Astronomical Society*, **7**, 126 (2023).
- 1336 66. Rybicki, G. B., & Lightman, A. P. Radiative Processes in Astrophysics. *Radiative Processes*
1337 *in Astrophysics*, **400** (1986).
- 1338 67. Nayana, A. J., & Chandra, P. uGMRT Observations of a Fast and Blue Optical Transient—AT
1339 2018cow. *Astrophys. J. Lett.*, **912**, L9 (2021).
- 1340 68. Fender, R. P., et al. Spectral evidence for a powerful compact jet from XTE J1118+480. *Mon.*
1341 *Not. R. Astron. Soc.*, **322**, L23 (2001).
- 1342 69. Tetarenko, A. J., et al. Measuring fundamental jet properties with multiwavelength fast timing
1343 of the black hole X-ray binary MAXI J1820+070. *Mon. Not. R. Astron. Soc.*, **504**, 3862 (2021).
- 1344 70. Fender, R. P., et al. Comprehensive coverage of particle acceleration and kinetic feedback from
1345 the stellar mass black hole V404 Cygni. *Mon. Not. R. Astron. Soc.*, **518**, 1243 (2023).
- 1346 71. Falcke, H., et al. The Simultaneous Spectrum of Sagittarius A* from 20 Centimeters to 1
1347 Millimeter and the Nature of the Millimeter Excess. *Astrophys. J.*, **499**, 731 (1998).
- 1348 72. Chevalier, R. A. Synchrotron Self-Absorption in Radio Supernovae. *Astrophys. J.*, **499**, 810
1349 (1998).
- 1350 73. Blandford, R. D., & Königl, A. Relativistic jets as compact radio sources. *Astrophys. J.*, **232**,
1351 34 (1979).
- 1352 74. Fulton, M., et al. Pan-STARRS observations of AT2022tsd. *Transient Name Server AstroNote*,
1353 **206**, 1 (2022).
- 1354 75. Chomiuk, L., Metzger, B. D., & Shen, K. J. New Insights into Classical Novae. *Annual Review*
1355 *of Astronomy and Astrophysics*, **59**, 391 (2021).
- 1356 76. Fremling, C., et al. The Zwicky Transient Facility Bright Transient Survey. I. Spectroscopic
1357 Classification and the Redshift Completeness of Local Galaxy Catalogs. *Astrophys. J.*, **895**, 32
1358 (2020).

- 1359 77. Perley, D. A., et al. The Zwicky Transient Facility Bright Transient Survey. II. A Public
1360 Statistical Sample for Exploring Supernova Demographics. *Astrophys. J.*, **904**, 35 (2020).
- 1361 78. Szkody, P., et al. Cataclysmic Variables in the Second Year of the Zwicky Transient Facility.
1362 “*Astron. J.*”, **162**, 94 (2021).
- 1363 79. Polzin, A., et al. The Luminosity Phase Space of Galactic and Extragalactic X-ray Transients
1364 Out to Intermediate Redshifts. *arXiv e-prints*, arXiv:2211.01232 (2022).
- 1365 80. Coppejans, D. L., & Knigge, C. The case for jets in cataclysmic variables. *New Astron.*
1366 *Reviews*, **89**, 101540 (2020).
- 1367 81. Morales-Rueda, L., & Marsh, T. R. Spectral atlas of dwarf novae in outburst. *Mon. Not. R.*
1368 *Astron. Soc.*, **332**, 814 (2002).
- 1369 82. Han, Z., et al. Spectroscopic properties of the dwarf nova-type cataclysmic variables observed
1370 by LAMOST. *PASJ*, **72**, 76 (2020).
- 1371 83. Fertig, D., Mukai, K., Nelson, T., & Cannizzo, J. K. The Fall and the Rise of X-Rays from
1372 Dwarf Novae in Outburst: RXTE Observations of VW Hydri and WW Ceti. *Pub. Ast. Soc.*
1373 *Pac.*, **123**, 1054 (2011).
- 1374 84. Bruch, A. A comparative study of the strength of flickering in cataclysmic variables. *Mon.*
1375 *Not. R. Astron. Soc.*, **503**, 953 (2021).
- 1376 85. Ilbert, O., et al. Photometric Redshifts and Stellar Mass Assembly in the 2-deg² COSMOS
1377 Field. *Panoramic Views of Galaxy Formation and Evolution*, **399**, 169 (2008).
- 1378 86. Lomb, N. R. Least-Squares Frequency Analysis of Unequally Spaced Data. *Astrophys. and*
1379 *Space Sc.*, **39**, 447 (1976).
- 1380 87. Scargle, J. D. Studies in astronomical time series analysis. II. Statistical aspects of spectral
1381 analysis of unevenly spaced data.. *Astrophys. J.*, **263**, 835 (1982).
- 1382 88. Tsvetkova, A., et al. The Konus-Wind Catalog of Gamma-Ray Bursts with Known Redshifts.
1383 II. Waiting-Mode Bursts Simultaneously Detected by Swift/BAT. *Astrophys. J.*, **908**, 83
1384 (2021).

- 1385 89. Cano, Z., Wang, S.-Q., Dai, Z.-G., & Wu, X.-F. The Observer's Guide to the Gamma-Ray
1386 Burst Supernova Connection. *Advances in Astronomy*, **2017**, 8929054 (2017).
- 1387 90. Ho, A. Y. Q., et al. Gemini, Swift, and VLA Observations of AT2022abfc, a Radio-loud Fast
1388 Optical Transient Coincident with a $z=0.212$ Galaxy. *Transient Name Server AstroNote*, **275**,
1389 1 (2022).
- 1390 91. Readhead, A. C. S. Equipartition Brightness Temperature and the Inverse Compton
1391 Catastrophe. *Astrophys. J.*, **426**, 51 (1994).
- 1392 92. Longair, M. S. High Energy Astrophysics. *High Energy Astrophysics*, (2011).
- 1393 93. Moffet, A. T. Strong Nonthermal Radio Emission from Galaxies. *Galaxies and the Universe*,
1394 **211** (1975).
- 1395 94. Chen, Y., et al. Late-Time HST Observations of AT 2018cow I: Further Constraints on the
1396 Fading Prompt Emission and Thermal Properties 50-60 Days Post-Explosion. *arXiv e-prints*,
1397 arXiv:2303.03500 (2023).
- 1398 95. Gottlieb, O., Tchekhovskoy, A., & Margutti, R. Shocked jets in CCSNe can power the zoo of
1399 fast blue optical transients. *Mon. Not. R. Astron. Soc.*, **513**, 3810 (2022).
- 1400 96. Margalit, B., & Quataert, E. Thermal Electrons in Mildly Relativistic Synchrotron Blast
1401 Waves. *Astrophys. J. Lett.*, **923**, L14 (2021).
- 1402 97. Wright, A. H., et al. Galaxy And Mass Assembly: accurate panchromatic photometry from
1403 optical priors using LAMBDA. *Mon. Not. R. Astron. Soc.*, **460**, 765 (2016).
- 1404 98. Chabrier, G. Galactic Stellar and Substellar Initial Mass Function. *Pub. Ast. Soc. Pac.*, **115**,
1405 763 (2003).
- 1406 99. Calzetti, D., et al. The Dust Content and Opacity of Actively Star-forming Galaxies. *Astrophys.*
1407 *J.*, **533**, 682 (2000).
- 1408 100. Schulze, S., et al. The Palomar Transient Factory Core-collapse Supernova Host-galaxy
1409 Sample. I. Host-galaxy Distribution Functions and Environment Dependence of Core-collapse
1410 Supernovae. *Astrophys. J. Supp.*, **255**, 29 (2021).

- 1411 101. Johnson, B. D., Leja, J., Conroy, C., & Speagle, J. S. Stellar Population Inference with
1412 Prospector. *Astrophys. J. Supp.*, **254**, 22 (2021).
- 1413 102. Conroy, C., Gunn, J. E., & White, M. The Propagation of Uncertainties in Stellar Population
1414 Synthesis Modeling. I. The Relevance of Uncertain Aspects of Stellar Evolution and the Initial
1415 Mass Function to the Derived Physical Properties of Galaxies. *Astrophys. J.*, **699**, 486 (2009).
- 1416 103. Speagle, J. S. DYNESTY: a dynamic nested sampling package for estimating Bayesian
1417 posteriors and evidences. *Mon. Not. R. Astron. Soc.*, **493**, 3132 (2020).
- 1418 104. Foreman-Mackey, D., Hogg, D. W., & Morton, T. D. Exoplanet Population Inference and the
1419 Abundance of Earth Analogs from Noisy, Incomplete Catalogs. *Astrophys. J.*, **795**, 64 (2014).
- 1420 105. Byler, N., Dalcanton, J. J., Conroy, C., & Johnson, B. D. Nebular Continuum and Line
1421 Emission in Stellar Population Synthesis Models. *Astrophys. J.*, **840**, 44 (2017).
- 1422 106. Sánchez-Blázquez, P., et al. Medium-resolution Isaac Newton Telescope library of empirical
1423 spectra. *Mon. Not. R. Astron. Soc.*, **371**, 703 (2006).
- 1424 107. Quataert, E., & Kasen, D. Swift 1644+57: the longest gamma-ray burst?. *Mon. Not. R.*
1425 *Astron. Soc.*, **419**, L1 (2012).
- 1426 108. Maund, J. R., et al. A flash of polarized optical light points to an aspherical 'cow'. *Mon. Not.*
1427 *R. Astron. Soc.*, (2023).
- 1428 109. Woosley, S. E. Gamma-Ray Bursts from Stellar Mass Accretion Disks around Black Holes.
1429 *Astrophys. J.*, **405**, 273 (1993).
- 1430 110. Kashiyama, K., & Quataert, E. Fast luminous blue transients from newborn black holes. *Mon.*
1431 *Not. R. Astron. Soc.*, **451**, 2656 (2015).
- 1432 111. Woosley, S. E., & Heger, A. Long Gamma-Ray Transients from Collapsars. *Astrophys. J.*,
1433 **752**, 32 (2012).
- 1434 112. Lyman, J. D., et al. Studying the environment of AT 2018cow with MUSE. *Mon. Not. R.*
1435 *Astron. Soc.*, **495**, 992 (2020).
- 1436 113. Kann, D. A., et al. The Afterglows of Swift-era Gamma-ray Bursts. I. Comparing pre-Swift
1437 and Swift-era Long/Soft (Type II) GRB Optical Afterglows. *Astrophys. J.*, **720**, 1513 (2010).

- 1438 114. Cowperthwaite, P. S. *et al.* The Electromagnetic Counterpart of the Binary Neutron
1439 Star Merger LIGO/Virgo GW170817. II. UV, Optical, and Near-infrared Light Curves and
1440 Comparison to Kilonova Models. *Astrophys. J. Lett.* **848**, L17 (2017).
- 1441 115. Kasliwal, M. M. *et al.* Illuminating gravitational waves: A concordant picture of photons
1442 from a neutron star merger. *Science* **358**, 1559–1565 (2017).
- 1443 116. Drout, M. R. *et al.* Light curves of the neutron star merger GW170817/SSS17a: Implications
1444 for r-process nucleosynthesis. *Science* **358**, 1570–1574 (2017).
- 1445 117. Villar, V. A., Berger, E., Metzger, B. D. & Guillochon, J. Theoretical Models of Optical
1446 Transients. I. A Broad Exploration of the Duration-Luminosity Phase Space. *Astrophys. J.*
1447 **849**, 70 (2017).
- 1448 118. Andreoni, I., et al. A very luminous jet from the disruption of a star by a massive black hole.
1449 *Nature*, **612**, 430 (2022).
- 1450 119. Galama, T. J., et al. An unusual supernova in the error box of the γ -ray burst of 25 April
1451 1998. *Nature*, **395**, 670 (1998).
- 1452 120. Campana, S., et al. The association of GRB 060218 with a supernova and the evolution of
1453 the shock wave. *Nature*, **442**, 1008 (2006).
- 1454 121. D’Elia, V., et al. GRB 171205A/SN 2017iuk: A local low-luminosity gamma-ray burst.
1455 *Astron. Astrophys.*, **619**, A66 (2018).
- 1456 122. Ho, A. Y. Q., et al. SN 2020bvc: A Broad-line Type Ic Supernova with a Double-peaked
1457 Optical Light Curve and a Luminous X-Ray and Radio Counterpart. *Astrophys. J.*, **902**, 86
1458 (2020).
- 1459 123. Zauderer, B. A., et al. Birth of a relativistic outflow in the unusual γ -ray transient Swift
1460 J164449.3+573451. *Nature*, **476**, 425 (2011).
- 1461 124. Yuan, Q., Wang, Q. D., Lei, W.-H., Gao, H., & Zhang, B. Catching jetted tidal disruption
1462 events early in millimetre. *Mon. Not. R. Astron. Soc.*, **461**, 3375 (2016).
- 1463 125. Sheth, K., et al. Millimeter Observations of GRB 030329: Continued Evidence for a
1464 Two-Component Jet. *Astrophys. J. Lett.*, **595**, L33 (2003).

- 1465 126. Perley, D. A., et al. The Afterglow of GRB 130427A from 1 to 10^{16} GHz. *Astrophys. J.*, **781**,
1466 37 (2014).
- 1467 127. Laskar, T., et al. First ALMA Light Curve Constrains Refreshed Reverse Shocks and Jet
1468 Magnetization in GRB 161219B. *Astrophys. J.*, **862**, 94 (2018).
- 1469 128. Laskar, T., et al. A Reverse Shock in GRB 181201A. *Astrophys. J.*, **884**, 121 (2019).
- 1470 129. Kulkarni, S. R., et al. Radio emission from the unusual supernova 1998bw and its association
1471 with the γ -ray burst of 25 April 1998. *Nature*, **395**, 663 (1998).
- 1472 130. Perley, D. A., Schulze, S., & de Ugarte Postigo, A. GRB 171205A: ALMA observations.
1473 *GRB Coordinates Network*, **22252**, 1 (2017).
- 1474 131. Weiler, K. W., et al. Long-Term Radio Monitoring of SN 1993J. *Astrophys. J.*, **671**, 1959
1475 (2007).
- 1476 132. Soderberg, A. M., et al. A relativistic type Ibc supernova without a detected γ -ray burst.
1477 *Nature*, **463**, 513 (2010).
- 1478 133. Horesh, A., et al. An early and comprehensive millimetre and centimetre wave and X-ray
1479 study of SN 2011dh: a non-equipartition blast wave expanding into a massive stellar wind.
1480 *Mon. Not. R. Astron. Soc.*, **436**, 1258 (2013).
- 1481 134. Corsi, A., et al. A Multi-wavelength Investigation of the Radio-loud Supernova PTF11qej
1482 and its Circumstellar Environment. *Astrophys. J.*, **782**, 42 (2014).
- 1483 135. Maeda, K., et al. The Final Months of Massive Star Evolution from the Circumstellar
1484 Environment around SN Ic 2020oi. *Astrophys. J.*, **918**, 34 (2021).
- 1485 136. Kouveliotou, C., et al. Chandra Observations of the X-Ray Environs of SN 1998bw/GRB
1486 980425. *Astrophys. J.*, **608**, 872 (2004).
- 1487 137. Tiengo, A., Mereghetti, S., Ghisellini, G., Tavecchio, F., & Ghirlanda, G. Late evolution of
1488 the X-ray afterglow of GRB 030329. *Astron. Astrophys.*, **423**, 861 (2004).
- 1489 138. Soderberg, A. M., et al. Relativistic ejecta from X-ray flash XRF 060218 and the rate of
1490 cosmic explosions. *Nature*, **442**, 1014 (2006).

- 1491 139. Margutti, R., et al. The Signature of the Central Engine in the Weakest Relativistic
1492 Explosions: GRB 100316D. *Astrophys. J.*, **778**, 18 (2013).
- 1493 140. Dwarkadas, V. V., & Gruszko, J. What are published X-ray light curves telling us about young
1494 supernova expansion?. *Mon. Not. R. Astron. Soc.*, **419**, 1515 (2012).
- 1495 141. Fender, R. P., Pooley, G. G., Brocksopp, C., & Newell, S. J. Rapid infrared flares in GRS
1496 1915+105: evidence for infrared synchrotron emission. *Mon. Not. R. Astron. Soc.*, **290**, L65
1497 (1997).
- 1498 142. Svinkin, D., et al. A bright γ -ray flare interpreted as a giant magnetar flare in NGC 253.
1499 *Nature*, **589**, 211 (2021).
- 1500 143. Frederiks, D., et al. Giant flare in SGR 1806-20 and its Compton reflection from the Moon.
1501 *Astron. Lett.*, **33**, 1 (2007).
- 1502 144. Marrone, D. P., et al. An X-Ray, Infrared, and Submillimeter Flare of Sagittarius A*.
1503 *Astrophys. J.*, **682**, 373 (2008).
- 1504 145. Racusin, J. L., et al. Broadband observations of the naked-eye γ -ray burst GRB080319B.
1505 *Nature*, **455**, 183 (2008).
- 1506 146. Nesci, R., et al. Multiwavelength flare observations of the blazar S5 1803+784. *Mon. Not. R.*
1507 *Astron. Soc.*, **502**, 6177 (2021).
- 1508 147. Fender, R., & Belloni, T. GRS 1915+105 and the Disc-Jet Coupling in Accreting Black Hole
1509 Systems. *Annual Review of Astronomy and Astrophysics*, **42**, 317 (2004).
- 1510 148. Yuan, F., & Narayan, R. Hot Accretion Flows Around Black Holes. *Annual Review of*
1511 *Astronomy and Astrophysics*, **52**, 529 (2014).
- 1512 149. Raiteri, C. M., et al. Blazar spectral variability as explained by a twisted inhomogeneous jet.
1513 *Nature*, **552**, 374 (2017).
- 1514 150. Mucciarelli, P., Zampieri, L., Treves, A., Turolla, R., & Falomo, R. X-Ray and Optical
1515 Variability of the Ultraluminous X-Ray Source NGC 1313 X-2. *Astrophys. J.*, **658**, 999 (2007).
- 1516 151. Hankins, T. H., Kern, J. S., Weatherall, J. C., & Eilek, J. A. Nanosecond radio bursts from
1517 strong plasma turbulence in the Crab pulsar. *Nature*, **422**, 141 (2003).

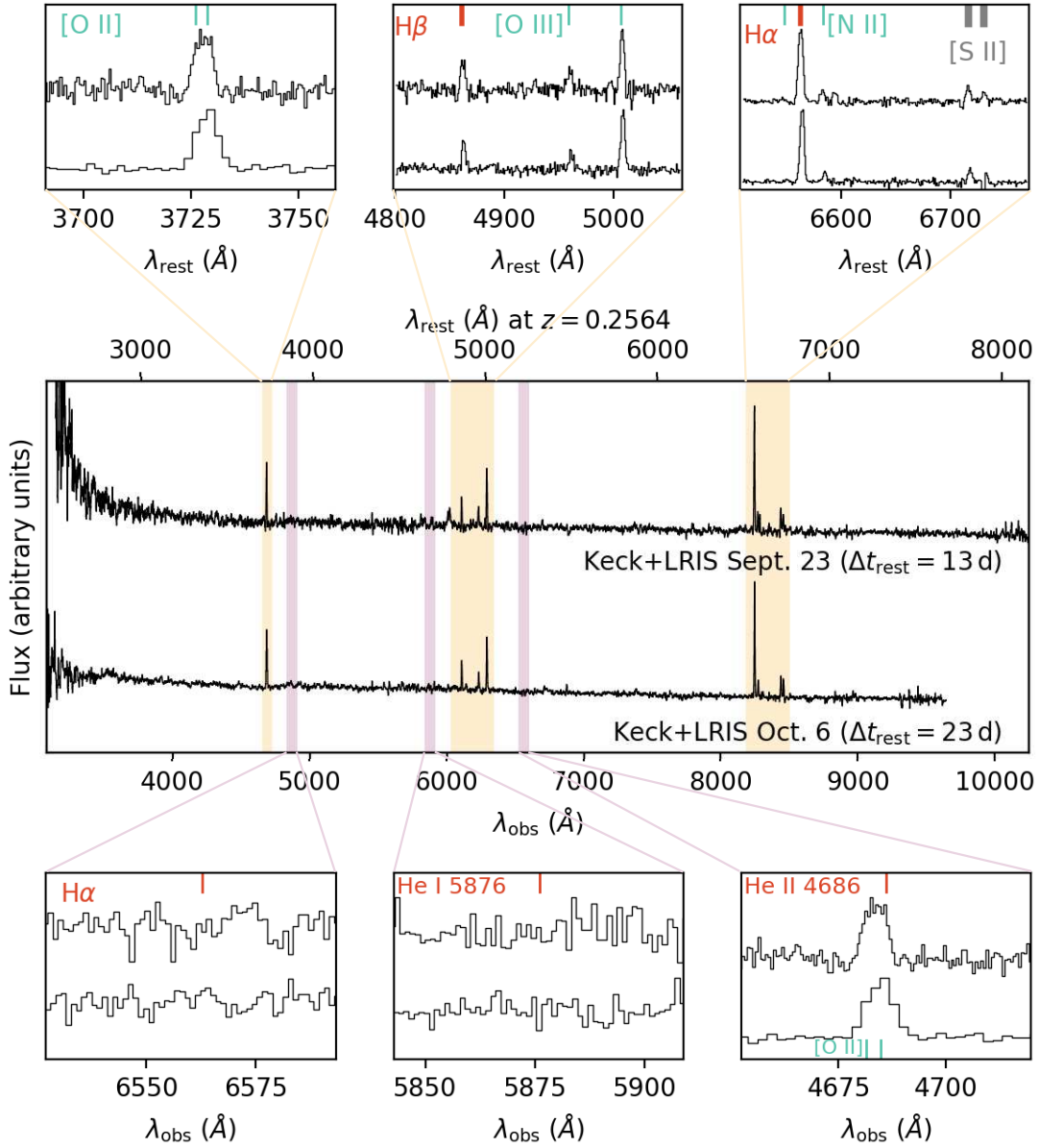
- 1518 152. Payne, A. V., et al. Chandra, HST/STIS, NICER, Swift, and TESS Detail the Flare Evolution
1519 of the Repeating Nuclear Transient ASASSN-14ko. *arXiv e-prints*, arXiv:2206.11278 (2022).
- 1520 153. Abramowski, A., et al. The 2010 Very High Energy γ -Ray Flare and 10 Years of
1521 Multi-wavelength Observations of M 87. *Astrophys. J.*, **746**, 151 (2012).
- 1522 154. Miniutti, G., et al. Repeating tidal disruptions in GSN 069: Long-term evolution and
1523 constraints on quasi-periodic eruptions' models. *Astron. Astrophys.*, **670**, A93 (2023).
- 1524 155. Weiler, K. W., Sramek, R. A., Panagia, N., van der Hulst, J. M., & Salvati, M. Radio
1525 Supernovae. *Astrophys. J.*, **301**, 790 (1986).
- 1526 156. van Dyk, S. D., Weiler, K. W., Sramek, R. A., & Panagia, N. SN 1988Z: The Most Distant
1527 Radio Supernova. *Astrophys. J. Lett.*, **419**, L69 (1993).
- 1528 157. Soderberg, A. M., et al. The Radio and X-Ray-Luminous Type Ibc Supernova 2003L.
1529 *Astrophys. J.*, **621**, 908 (2005).
- 1530 158. Soderberg, A. M., Chevalier, R. A., Kulkarni, S. R., & Frail, D. A. The Radio and X-Ray
1531 Luminous SN 2003bg and the Circumstellar Density Variations around Radio Supernovae.
1532 *Astrophys. J.*, **651**, 1005 (2006).
- 1533 159. Salas, P., Bauer, F. E., Stockdale, C., & Prieto, J. L. SN 2007bg: the complex circumstellar
1534 medium around one of the most radio-luminous broad-lined Type Ic supernovae. *Mon. Not. R.*
1535 *Astron. Soc.*, **428**, 1207 (2013).
- 1536 160. Alexander, K. D., Berger, E., Guillochon, J., Zauderer, B. A., & Williams, P. K. G. Discovery
1537 of an Outflow from Radio Observations of the Tidal Disruption Event ASASSN-14li.
1538 *Astrophys. J. Lett.*, **819**, L25 (2016).
- 1539 161. Laskar, T., Coppejans, D. L., Margutti, R., & Alexander, K. D. GRB 171205A: VLA
1540 detection.. *GRB Coordinates Network*, **22216**, 1 (2017).
- 1541 162. Dong, D. Z., et al. A transient radio source consistent with a merger-triggered core collapse
1542 supernova. *Science*, **373**, 1125 (2021).
- 1543 163. Mooley, K. P., et al. Late-time Evolution and Modeling of the Off-axis Gamma-Ray Burst
1544 Candidate FIRST J141918.9+394036. *Astrophys. J.*, **924**, 16 (2022).

- 1545 164. Graham, M. J., et al. The Zwicky Transient Facility: Science Objectives. *Pub. Ast. Soc. Pac.*,
1546 **131**, 078001 (2019).
- 1547 165. Bellm, E. C., et al. The Zwicky Transient Facility: System Overview, Performance, and First
1548 Results. *Pub. Ast. Soc. Pac.*, **131**, 018002 (2019).
- 1549 166. Dekany, R., et al. The Zwicky Transient Facility: Observing System. *Pub. Ast. Soc. Pac.*,
1550 **132**, 038001 (2020).
- 1551 167. Zackay, B., Ofek, E. O., & Gal-Yam, A. Proper Image Subtraction—Optimal Transient
1552 Detection, Photometry, and Hypothesis Testing. *Astrophys. J.*, **830**, 27 (2016).
- 1553 168. Masci, F. J., et al. The Zwicky Transient Facility: Data Processing, Products, and Archive.
1554 *Pub. Ast. Soc. Pac.*, **131**, 018003 (2019).
- 1555 169. Patterson, M. T., et al. The Zwicky Transient Facility Alert Distribution System. *Pub. Ast.*
1556 *Soc. Pac.*, **131**, 018001 (2019).
- 1557 170. Duev, D. A., et al. Real-bogus classification for the Zwicky Transient Facility using deep
1558 learning. *Mon. Not. R. Astron. Soc.*, **489**, 3582 (2019).
- 1559 171. Tachibana, Y., & Miller, A. A. A Morphological Classification Model to Identify Unresolved
1560 PanSTARRS1 Sources: Application in the ZTF Real-time Pipeline. *Pub. Ast. Soc. Pac.*, **130**,
1561 128001 (2018).
- 1562 172. Tonry, J. L., et al. The Pan-STARRS1 Photometric System. *Astrophys. J.*, **750**, 99 (2012).
- 1563 173. Chambers, K. C., et al. The Pan-STARRS1 Surveys. *arXiv e-prints*, arXiv:1612.05560
1564 (2016).
- 1565 174. Flewelling, H. A., et al. The Pan-STARRS1 Database and Data Products. *Astrophys. J. Supp.*,
1566 **251**, 7 (2020).
- 1567 175. Tonry, J. L., et al. ATLAS: A High-cadence All-sky Survey System. *Pub. Ast. Soc. Pac.*, **130**,
1568 064505 (2018).
- 1569 176. Smith, K. W., et al. Design and Operation of the ATLAS Transient Science Server. *Pub. Ast.*
1570 *Soc. Pac.*, **132**, 085002 (2020).

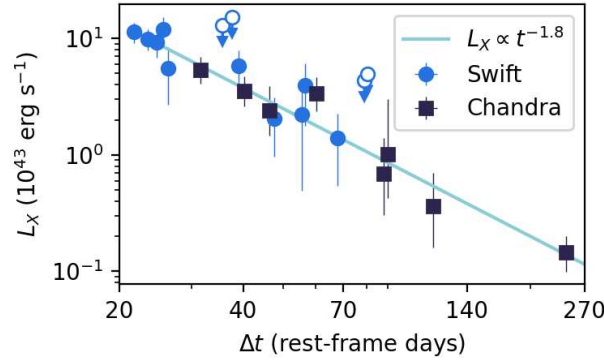
- 1571 177. Shingles, L., et al. Release of the ATLAS Forced Photometry server for public use. *Transient*
1572 *Name Server AstroNote*, **7**, 1 (2021).
- 1573 178. Steele, I. A., et al. The Liverpool Telescope: performance and first results. *Proc. SPIE*, **5489**,
1574 679 (2004).
- 1575 179. Dhillon, V. S., et al. ULTRASPEC: a high-speed imaging photometer on the 2.4-m Thai
1576 National Telescope. *Mon. Not. R. Astron. Soc.*, **444**, 4009 (2014).
- 1577 180. Kumar, H., et al. India’s First Robotic Eye for Time-domain Astrophysics: The
1578 GROWTH-India Telescope. “*Astron. J.*”, **164**, 90 (2022).
- 1579 181. Dressler, A., et al. IMACS: The Inamori-Magellan Areal Camera and Spectrograph on
1580 Magellan-Baade. *Pub. Ast. Soc. Pac.*, **123**, 288 (2011).
- 1581 182. Harding, L. K., et al. CHIMERA: a wide-field, multi-colour, high-speed photometer at the
1582 prime focus of the Hale telescope. *Mon. Not. R. Astron. Soc.*, **457**, 3036 (2016).
- 1583 183. Dhillon, V. S., et al. ULTRACAM: an ultrafast, triple-beam CCD camera for high-speed
1584 astrophysics. *Mon. Not. R. Astron. Soc.*, **378**, 825 (2007).
- 1585 184. Smartt, S. J., et al. PESSTO: survey description and products from the first data release by the
1586 Public ESO Spectroscopic Survey of Transient Objects. *Astron. Astrophys.*, **579**, A40 (2015).
- 1587 185. Buzzoni, B., et al. The ESO Faint Object Spectrograph and Camera / EFOSC. *The Messenger*,
1588 **38**, 9 (1984).
- 1589 186. Blagorodnova, N., et al. The SED Machine: A Robotic Spectrograph for Fast Transient
1590 Classification. *Pub. Ast. Soc. Pac.*, **130**, 035003 (2018).
- 1591 187. Ofek, E. O., et al. The Large Array Survey Telescope – System Overview and Performances.
1592 *arXiv e-prints*, arXiv:2304.04796 (2023).
- 1593 188. Ben-Ami, S., et al. The Large Array Survey Telescope – Science Goals. *arXiv e-prints*,
1594 arXiv:2304.02719 (2023).
- 1595 189. Ofek, E. O. MAAT: MATLAB Astronomy and Astrophysics Toolbox. *Astrophysics Source*
1596 *Code Library*, ascl:1407.005 (2014).

- 1597 190. Ofek, E. O. A Code for Robust Astrometric Solution of Astronomical Images. *Pub. Ast. Soc.*
1598 *Pac.*, **131**, 054504 (2019).
- 1599 191. Gaia Collaboration, et al. Gaia Early Data Release 3. Summary of the contents and survey
1600 properties. *Astron. Astrophys.*, **649**, A1 (2021).
- 1601 192. Oke, J. B., et al. The Keck Low-Resolution Imaging Spectrometer. *Pub. Ast. Soc. Pac.*, **107**,
1602 375 (1995).
- 1603 193. Perley, D. A. Fully Automated Reduction of Longslit Spectroscopy with the Low Resolution
1604 Imaging Spectrometer at the Keck Observatory. *Pub. Ast. Soc. Pac.*, **131**, 084503 (2019).
- 1605 194. Nayana, A. J., et al. 325 and 610 MHz radio counterparts of SNR G353.6-0.7 also known as
1606 HESS J1731-347. *Mon. Not. R. Astron. Soc.*, **467**, 155 (2017).
- 1607 195. Greisen, E. W. AIPS, the VLA, and the VLBA. *Information Handling in Astronomy -*
1608 *Historical Vistas*, **285**, 109 (2003).
- 1609 196. Perley, R. A., Chandler, C. J., Butler, B. J., & Wrobel, J. M. The Expanded Very Large Array:
1610 A New Telescope for New Science. *Astrophys. J. Lett.*, **739**, L1 (2011).
- 1611 197. McMullin, J. P., Waters, B., Schiebel, D., Young, W., & Golap, K. CASA Architecture and
1612 Applications. *Astronomical Data Analysis Software and Systems XVI*, **376**, 127 (2007).
- 1613 198. Gildas Team GILDAS: Grenoble Image and Line Data Analysis Software. *Astrophysics*
1614 *Source Code Library*, ascl:1305.010 (2013).
- 1615 199. Willingale, R., Starling, R. L. C., Beardmore, A. P., Tanvir, N. R., & O'Brien, P. T. Calibration
1616 of X-ray absorption in our Galaxy. *Mon. Not. R. Astron. Soc.*, **431**, 394 (2013).
- 1617 200. Burrows, D. N., et al. The Swift X-Ray Telescope. *Space Science Reviews*, **120**, 165 (2005).
- 1618 201. Roming, P. W. A., et al. The Swift Ultra-Violet/Optical Telescope. *Space Science Reviews*,
1619 **120**, 95 (2005).
- 1620 202. Evans, P. A., et al. An online repository of Swift/XRT light curves of γ -ray bursts. *Astron.*
1621 *Astrophys.*, **469**, 379 (2007).
- 1622 203. Evans, P. A., et al. Methods and results of an automatic analysis of a complete sample of
1623 Swift-XRT observations of GRBs. *Mon. Not. R. Astron. Soc.*, **397**, 1177 (2009).

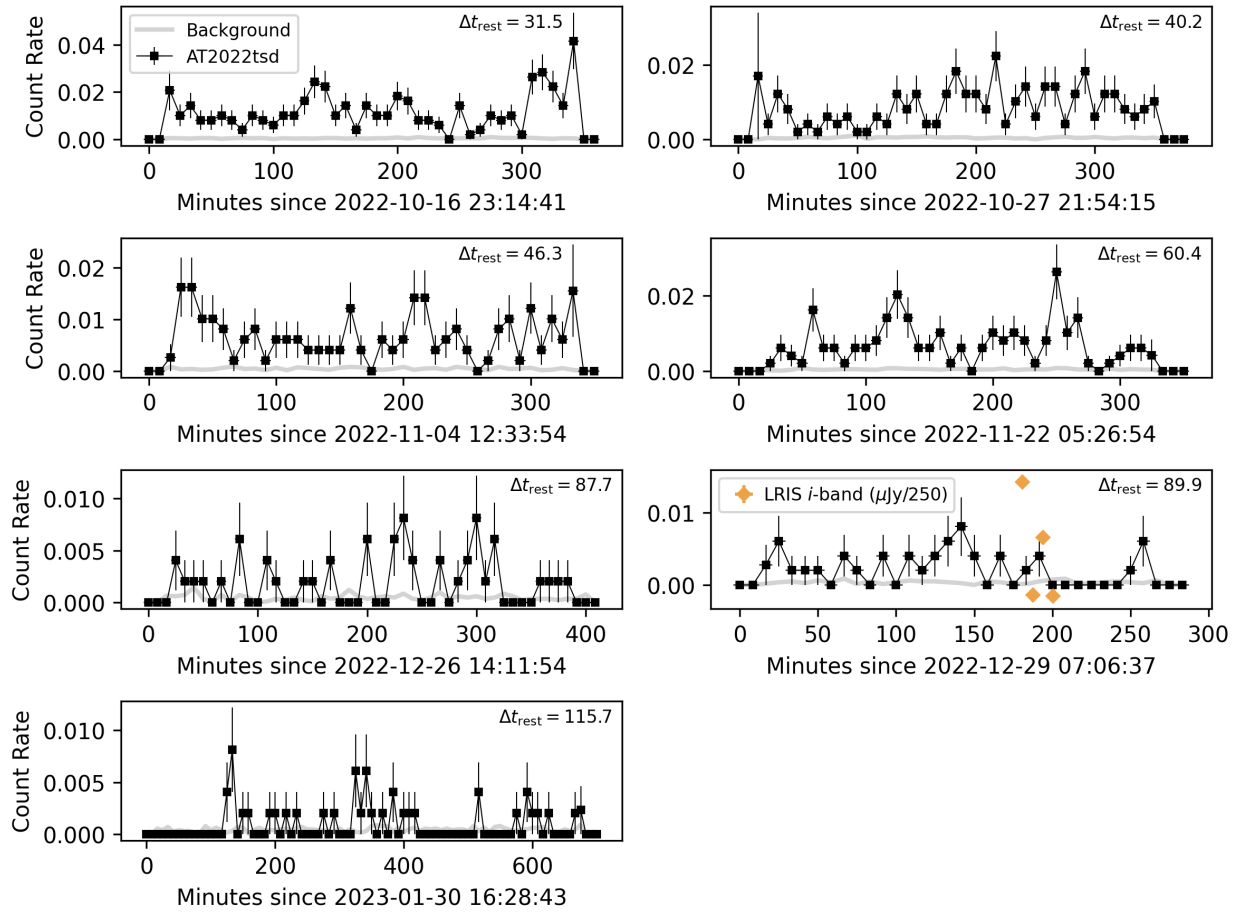
- 1624 204. Fruscione, A., et al. CIAO: Chandra's data analysis system. *Proc. SPIE*, **6270**, 62701V
1625 (2006).
- 1626 205. Taggart, K., & Perley, D. A. Core-collapse, superluminous, and gamma-ray burst supernova
1627 host galaxy populations at low redshift: the importance of dwarf and starbursting galaxies.
1628 *Mon. Not. R. Astron. Soc.*, **503**, 3931 (2021).



Extended Data Figure 1: Optical spectra of AT2022tsd obtained with Keck/LRIS, binned using 3\AA bins. Regions with identified narrow host-galaxy emission lines, used to measure the best-fit redshift of $z = 0.2564 \pm 0.0003$, are marked. Regions used to search for $z = 0$ emission lines, as would be expected from a foreground Galactic transient, are also marked.

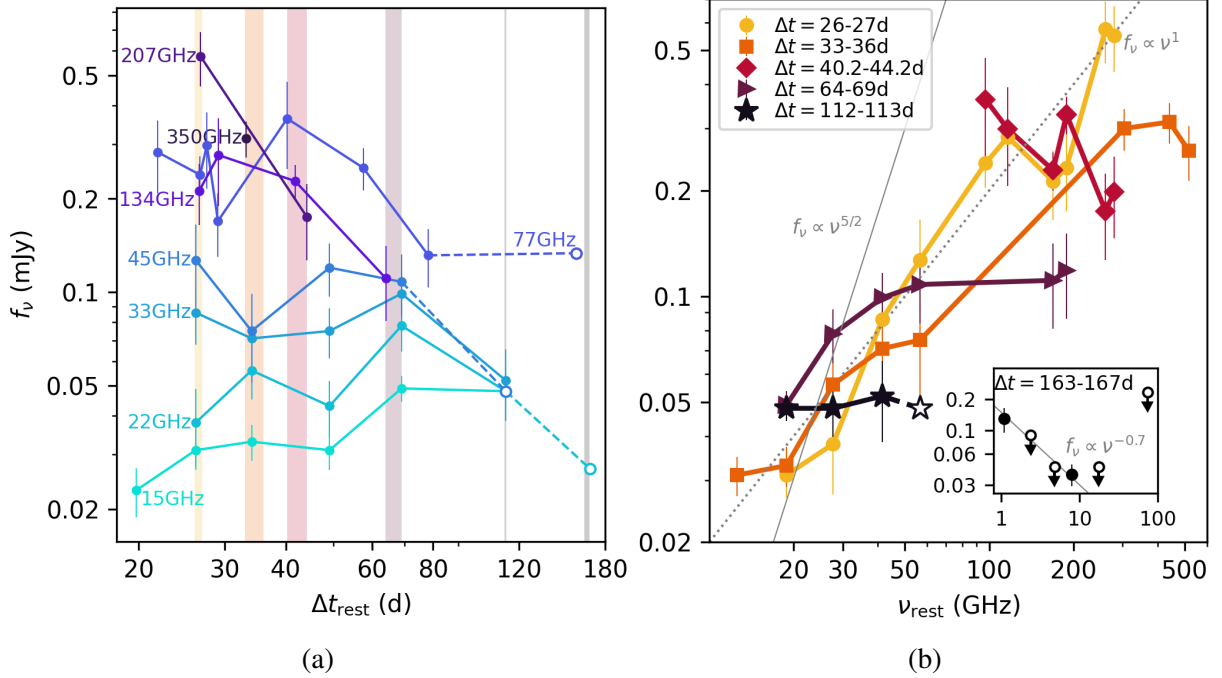


(a) X-ray (0.3–10 keV) light curve.

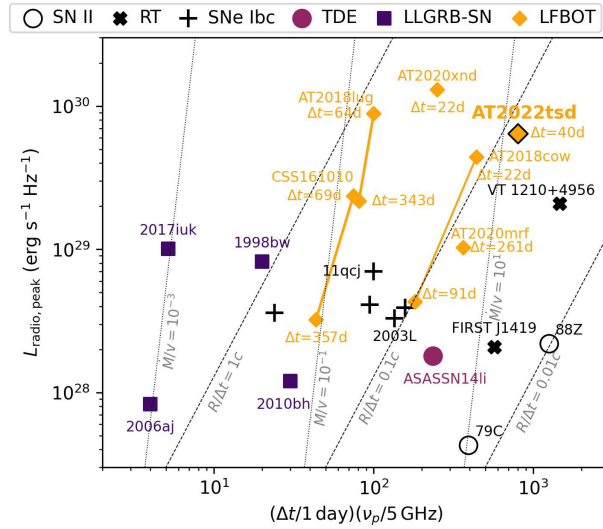


(b) Individual epochs of *Chandra* observations resolved in time.

Extended Data Figure 2: X-ray (0.3–10 keV) light curve of AT2022tsd. (a) Full light curve with best-fit power law of $\alpha = -1.81 \pm 0.13$, where $f_\nu \propto t^\alpha$. Upper limits (3σ) are shown with open circles. (b) Individual *Chandra* observations binned in time with 500 s bins. Diamonds show an optical (*i*-band) flare detected with LRIS during one of the *Chandra* observations. Error bars are 1σ confidence intervals.

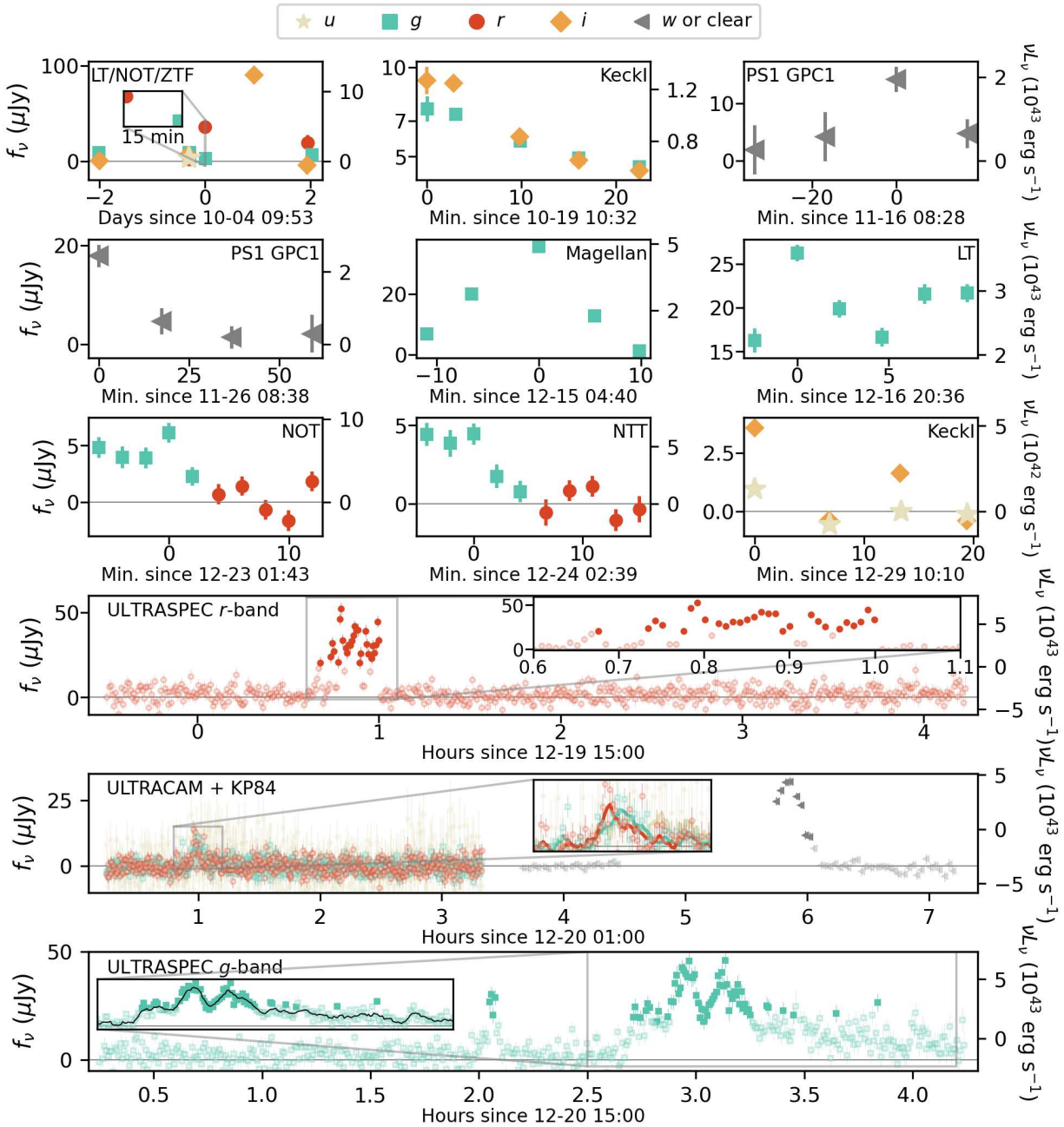


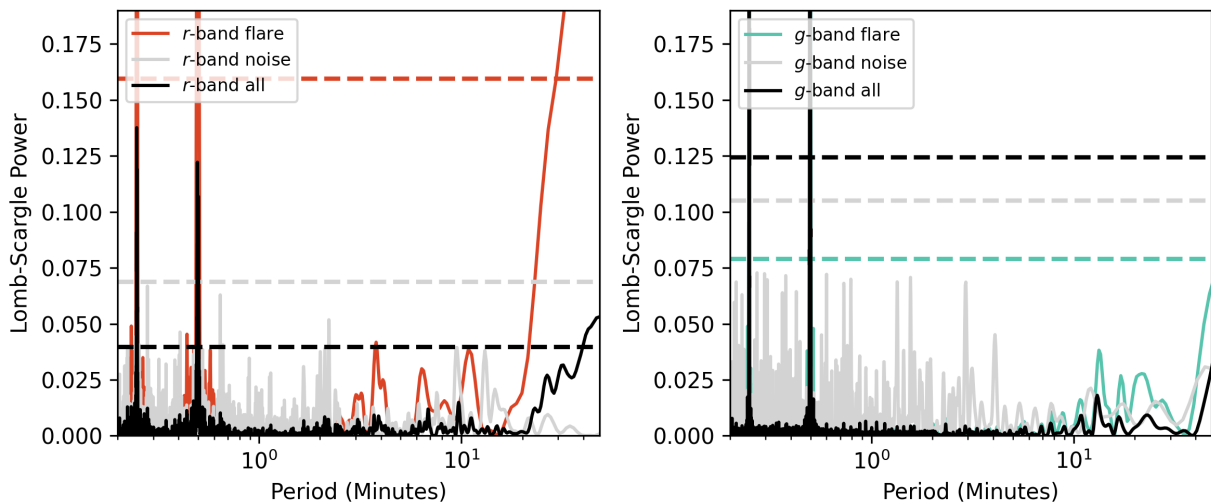
(a) (b)



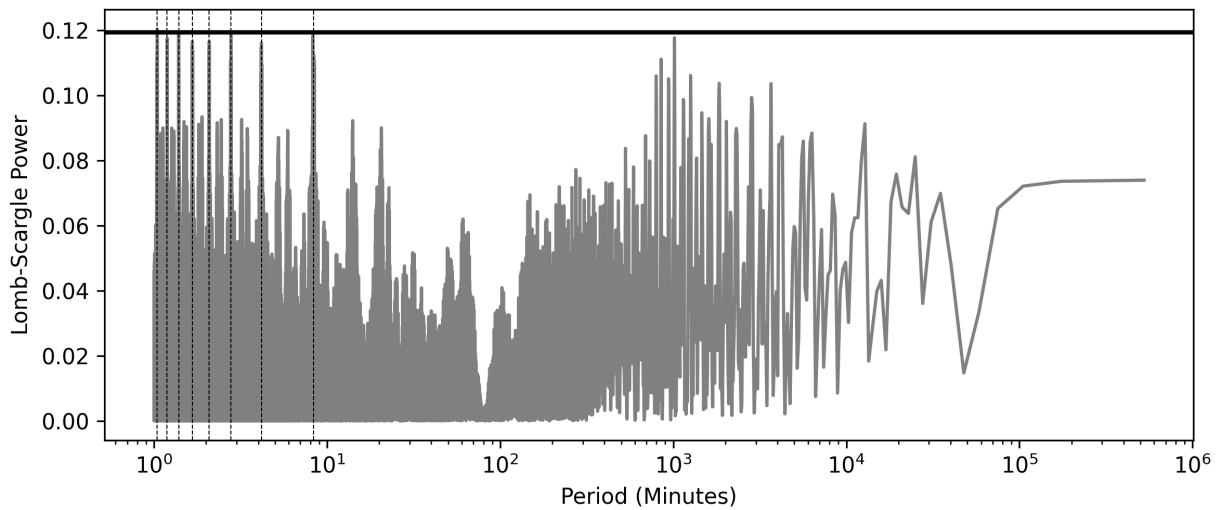
(c)

Extended Data Figure 3: (a) Selected single-band radio light curves of AT2022tsd from the VLA (15–45 GHz), NOEMA (77–207 GHz), and ALMA (350 GHz). Open circles mark 5σ upper limits, and dashed lines connect upper limits to detections. (b) Rest-frame radio SEDs from the six time ranges marked with vertical shaded regions in the left panel. Inset shows SED from late-time observations with the GMRT and VLA. Solid line marks the $f_\nu \propto \nu^{5/2}$ power law expected from synchrotron self-absorption, and dotted line marks the shallower $f_\nu \propto \nu^1$. (c) Peak frequency (ν_p) at a fixed time post-explosion (Δt) vs. peak luminosity of extragalactic radio transients. Error bars are 1σ confidence intervals. See Methods section 12 for additional details and data sources.

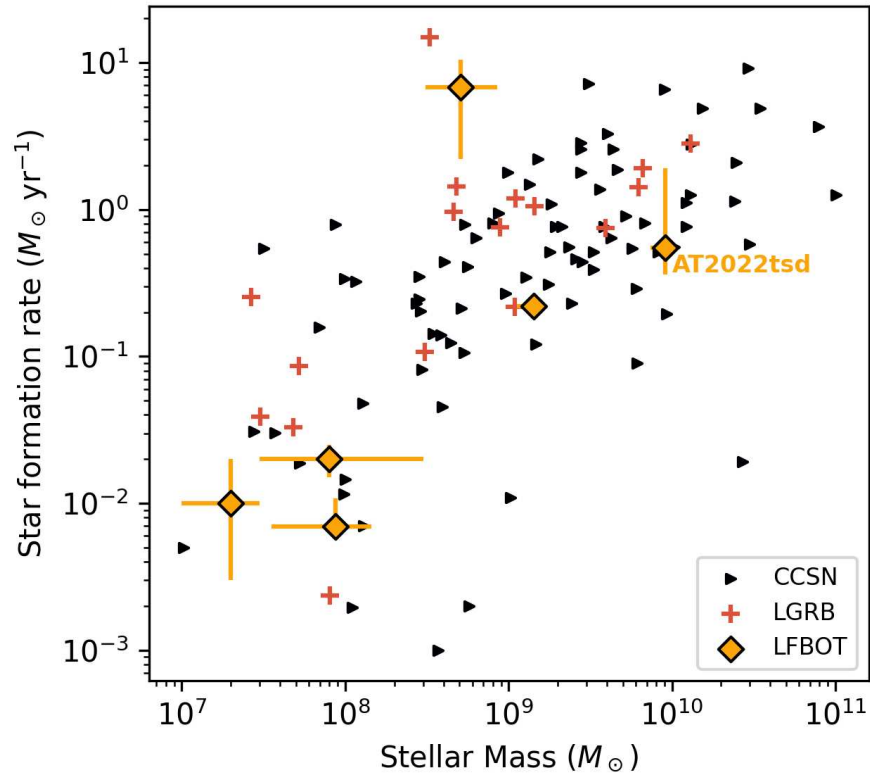




Extended Data Figure 5: Lomb-Scargle periodogram of the ULTRASPEC flares. Each panel shows the periodogram for the flare itself, for a region of the light curve with no significant detections (“noise”), and for the full light curve (“all”). Horizontal dashed lines mark the power expected for a false-alarm peak (with false-alarm probability 2.5%) under the assumption that there is no periodicity present in the data, using a bootstrap simulation. The only peaks higher than this threshold are from the cadence of the observation (30 s, and an alias at half that value), from the overall flare width, and from the duration of the observation.



Extended Data Figure 6: Lomb-Scargle periodogram of the first four epochs of *Chandra* X-ray observations. The horizontal line shows the power expected for a false-alarm peak (with false-alarm probability 2.5%) under the assumption that there is no periodicity present in the data, using a bootstrap simulation. The observed peaks arise from the 500 s sampling and aliases (marked with vertical dotted lines).



Extended Data Figure 7: The stellar mass and star-formation rate (SFR) of AT2022tsd’s host galaxy in the mass-SFR diagram for transient host galaxies²⁰⁵, including core-collapse supernovae²⁰⁵, long-duration γ -ray bursts²⁰⁵, and luminous fast blue optical transients^{7,11,12,28,54}. Error bars are 1σ confidence intervals.

Table Extended Data Table 1: Summary of targeted flare searches, including the number of exposures N_{exp} , the total observing time T_{exp} , the typical depth per exposure, and the number of flares detected. For reference, we include the Magellan/IMACS observation in which flaring was first noticed.

Telescope	Filters	N_{exp}	T_{exp} (min)	Depth (AB mag)	# Flares
Magellan/IMACS	<i>g</i>	4	12	24.2	1
LT/IO:O	<i>gr</i>	134	265	22.6	1
NOT/ALFOSC	<i>gr</i>	15	20	23.5	1
NTT/ULTRACAM	<i>giru</i>	1981	660	22.3	1
TNT/ULTRASPEC	<i>gr</i>	1045	519	22.0	3
KP84/SEDM2	clear	60	120	22.7	1
NTT/EFOSC	<i>gr</i>	30	47	23.7	1
GIT	clear	59	295	21.1	0
HCT	<i>R</i>	55	275	22.4	0
SLT	<i>r</i>	28	140	99.0	0
LOT	<i>g</i>	27	135	99.0	0
KeckI/LRIS	<i>giu</i>	16	71	24.8	2
P200/CHIMERA	<i>gr</i>	420	350	21.3	0
LAST	G_p	646	9312	20.0	0

Table Extended Data Table 2: AT2022tsd flare properties, including time of brightest detection ($t_{\text{peak,obs}}$), time interval in which 90% of the flux was measured (T_{90}), peak luminosity (νL_ν in the specified band), and total energy radiated E_{rad} . Flares are defined as $\geq 5\sigma$ detections, verified visually, with an MJD after 59856.4 ($\Delta t_{\text{obs}} = 27$ d). In cases with flares observed in multiple filters, quantities are calculated using the first filter listed. Note that, with the exception of the ULTRASPEC and ULTRACAM sequences, observations did not capture the start and end of the flare.

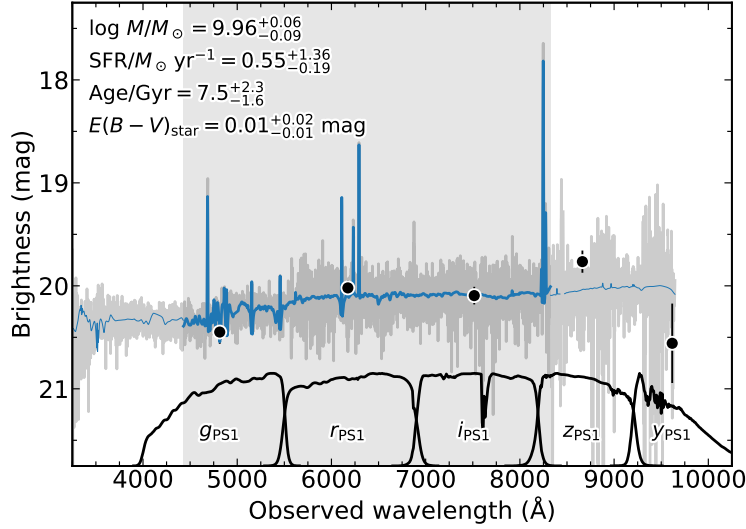
$t_{\text{peak,obs}}$ (MJD)	Telescope	Band	$T_{90,\text{obs}}$ (min)	$L_{\text{peak,obs}}$ (erg s^{-1})	E_{rad} (erg)
59856.4122	P48/ZTF	<i>r</i>	–	$> 4 \times 10^{43}$	–
59857.3403	P48/ZTF	<i>i</i>	–	$> 8 \times 10^{43}$	–
59871.4392	Keck1/LRIS	<i>gi</i>	> 20	$> 1 \times 10^{43}$	$> 2 \times 10^{46}$
59899.3533	PS1/GPC1	<i>w</i>	40	2×10^{43}	4×10^{46}
59909.3598	PS1/GPC1	<i>w</i>	> 50	$> 2 \times 10^{43}$	$> 6 \times 10^{46}$
59928.1951	Magellan/IMACS	<i>g</i>	16	6×10^{43}	6×10^{46}
59929.8585	LT/IO:O	<i>g</i>	10	4×10^{43}	2×10^{46}
59932.6580	TNT/ULTRASPEC	<i>r</i>	19	5×10^{43}	6×10^{46}
59933.0822	NTT/ULTRACAM	<i>rgu</i>	12	8×10^{42}	3×10^{45}
59933.2858	KP84/SEDM2	clear	> 15	2×10^{43}	$> 2 \times 10^{46}$
59933.7107	TNT/ULTRASPEC	<i>g</i>	7	2×10^{43}	8×10^{45}
59933.7556	TNT/ULTRASPEC	<i>g</i>	78	3×10^{43}	1×10^{47}
59936.0720	NOT/ALFOSC	<i>g</i>	> 15	$> 8 \times 10^{42}$	3×10^{45}
59937.1105	NTT/EFOSC	<i>g</i>	> 8	$> 6 \times 10^{42}$	2×10^{45}
59942.4238	Keck1/LRIS	<i>iu</i>	–	$> 3 \times 10^{42}$	–

Table Extended Data Table 3: AT2022tsd flare duty cycle for different apparent-magnitude thresholds, over the date range MJD 59856.41–59942.43 (from the first flare detection to the last flare detection). N_{exp} is the number of exposures brighter than the given magnitude threshold, T_{exp} is the total exposure time, T_{on} is the total time with a flare detected, and the bounds are 97.5% confidence intervals (see Methods section 4) on the duty cycle $T_{\text{on}}/T_{\text{exp}}$.

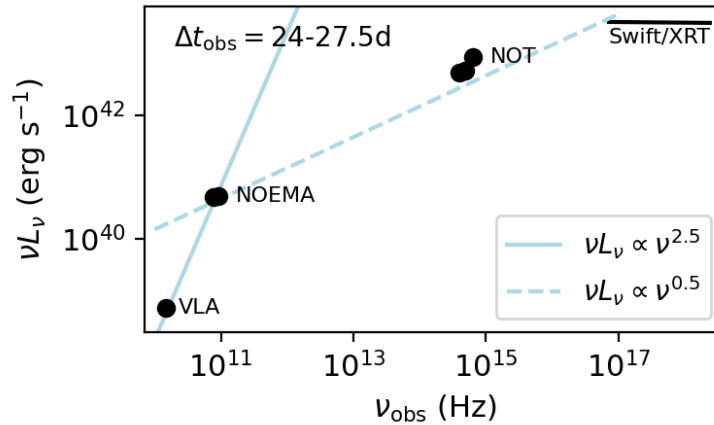
Threshold (AB Mag)	N_{exp}	T_{exp} (Minutes)	$T_{\text{on}}/T_{\text{exp}}$	Bounds
21.0	1271	1142	0.02	[0.001, 0.1]
22.5	68	155	0.1	[0.01, 0.6]
24.0	13	65	0.5	[0.03, 1]

Object	Band	L_{flare} (erg s $^{-1}$)	Amp.	Duration	Persistence
<i>Unknown</i>					
AT2022tsd (this paper)	500 nm	10^{43} – 10^{44}	$\gtrsim 100\times$	10–80 min	$\gtrsim 100$ d
GRB 070610 (BH? NS?)	800 nm	$10^{35}?$	$\gtrsim 100\times$	10 s–mins	5 d
NGC 1313 X-2 (ULX)	0.3–10 keV	10^{40}	$\sim 10\times$	10 min	–
<i>Neutron Stars</i>					
SGR in M81/M82 (GF Spike)	20 keV–10 MeV	1.8×10^{47}	$\sim 10^{11}\times$	0.5 s	–
SGR 1806-20 (GF Tail)	20 keV–10 MeV	1.3×10^{42}	$\sim 10^7\times$	8 min	–
Crab (nanoshot)	8 GHz	10^{34}	$> 1000\times$	2 ns	–
<i>Stellar-mass black holes</i>					
GRS 1915+105 (XRB)	$2.2 \mu\text{m}$	$\gtrsim 10^{36}$	$\lesssim 10\times$	10 min	–
GRB 080319B (GRB)	500 nm	10^{50}	$> 10\times$	40 s	60 s
<i>Supermassive black holes</i>					
AT2019ehz (TDE)	0.3–10 keV	10^{44}	$> 10\times$	10 d	70 d
Sagittarius A*	$2.1 \mu\text{m}$	10^{34}	$\lesssim 10\times$	30 min	–
M87	350 GeV	10^{42}	$\gtrsim 10\times$	Few days	–
S5 1803+784 (blazar)	600 nm	10^{46}	$10\times$	$\gtrsim 1$ month	–
GSN 069 (QPE)	0.4–1 keV	10^{43}	$\gtrsim 10\times$	1 hr	–
ASASSN-14ko (TDE?)	200–500 nm	10^{43} – 10^{44}	$> 10\times$	10 d	–

Table Supplementary Information Table 1: **AT2022tsd exhibited rapid and luminous optical flares over a period of 100 days, which has no precedent in the literature.** Summary of large-amplitude ($\gtrsim 10\times$) flares from representative literature objects. See Methods section 14 for additional details and data sources.



Supplementary Information Figure 1: Observed host-galaxy photometry (black data points) and spectrum (grey) of AT2022tsd with the best fit to host-galaxy properties (blue). The shaded region indicates the region of the spectrum used in the `prospector` fit.



Supplementary Information Figure 2: SED of AT2022tsd at $\Delta t_{\text{obs}} \approx 25$ d post-discovery. X-ray data are shown with a photon index of $\Gamma = 2.01$ across the *Swift*/XRT 0.3–10 keV bandpass. Lines mark power laws connecting the radio to submillimeter data (solid), and the millimeter to X-ray data (dashed).

Table Supplementary Information Table 2: Host-galaxy photometry for AT2022tsd, not corrected for Milky Way extinction. Error bars are 1σ confidence intervals.

Survey	Filter	Brightness (AB mag)
PanSTARRS	<i>g</i>	21.32 ± 0.10
PanSTARRS	<i>r</i>	20.59 ± 0.07
PanSTARRS	<i>i</i>	20.67 ± 0.05
PanSTARRS	<i>z</i>	20.87 ± 0.36
PanSTARRS	<i>y</i>	20.14 ± 0.10

<i>t</i> (UT)	Δt (days)	t_{exp} (ks)	Count Rate (10^{-3} s^{-1})	F_X ($10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2}$)	L_X ($10^{43} \text{ erg s}^{-1}$)
2022-10-04 09:17	22.65 ± 0.24	3.64	10.43 ± 2.06	53.17 ± 10.50	11.43 ± 2.26
2022-10-06 14:55	24.41 ± 0.22	3.78	9.06 ± 1.85	46.19 ± 9.44	9.93 ± 2.03
2022-10-08 02:17	25.65 ± 0.29	2.47	8.46 ± 2.24	43.14 ± 11.43	9.28 ± 2.46
2022-10-09 05:06	26.54 ± 0.29	2.29	10.92 ± 2.91	55.67 ± 14.84	11.97 ± 3.19
2022-10-10 09:47	27.31 ± 0.11	2.37	5.07 ± 2.60	25.85 ± 13.26	5.56 ± 2.85
2022-10-21 16:35	36.60 ± 0.42	1.44	< 11.89	< 60.63	< 13.04
2022-10-24 09:25	38.57 ± 0.24	1.04	< 13.97	< 71.27	< 15.32
2022-10-26 01:27	40.03 ± 0.37	2.77	5.35 ± 1.88	27.30 ± 9.56	5.87 ± 2.06
2022-11-06 01:21	48.65 ± 0.24	4.39	1.86 ± 0.99	9.50 ± 5.04	2.04 ± 1.08
2022-11-16 01:40	56.48 ± 0.11	1.87	2.02 ± 1.57	10.29 ± 8.01	2.21 ± 1.72
2022-11-17 07:44	57.61 ± 0.24	1.96	3.60 ± 1.99	18.38 ± 10.16	3.95 ± 2.18
2022-12-01 02:23	68.65 ± 0.32	5.75	1.28 ± 0.78	6.54 ± 3.99	1.41 ± 0.86
2022-12-15 00:09	79.78 ± 0.38	2.97	< 3.99	< 20.33	< 4.37
2022-12-16 09:52	81.10 ± 0.58	2.67	< 4.50	< 22.97	< 4.94

Table Supplementary Information Table 3: *Swift* XRT (0.3–10 keV) observations of AT2022tsd with epochs Δt since discovery in the rest frame, exposure time t_{exp} , flux F_X , and luminosity L_X . Error bars are 1σ and upper limits are given as 3σ .

t_{start} (UT)	Δt (days)	t_{exp} (ks)	F_X (10^{-14} erg s $^{-1}$ cm $^{-2}$)	L_X (10^{43} erg s $^{-1}$)
2022-10-16 23:14	32.42	20	$14.60^{+3.33}_{-3.22}$	$3.14^{+0.72}_{-0.69}$
2022-10-27 21:54	41.13	20	$10.46^{+2.78}_{-2.22}$	$2.25^{+0.60}_{-0.48}$
2022-11-04 12:33	47.19	20	$7.59^{+2.64}_{-2.40}$	$1.63^{+0.57}_{-0.52}$
2022-11-22 05:26	61.27	20	$9.17^{+3.14}_{-2.53}$	$1.97^{+0.68}_{-0.54}$
2022-12-26 14:11	88.62	24	$1.68^{+2.03}_{-0.92}$	$0.36^{+0.44}_{-0.20}$
2022-12-29 07:06	90.77	16	$2.48^{+4.98}_{-1.57}$	$0.53^{+1.07}_{-0.34}$
2023-01-30 16:28	116.55	40	$0.96^{+1.04}_{-0.51}$	$0.21^{+0.22}_{-0.11}$
2023-07-11 03:37	244.09	16	$0.66^{+0.54}_{-0.43}$	$0.14^{+0.12}_{-0.09}$
2023-07-11 to 2023-07-16	244–248	40	$0.38^{+0.15}_{-0.12}$	$0.08^{+0.03}_{-0.03}$

Table Supplementary Information Table 4: *Chandra X-ray Observatory* 0.5–6 keV observations of AT2022tsd, with epochs Δt since discovery in the rest frame, exposure time t_{exp} , flux F_X , and luminosity L_X . Error bars are 1σ confidence intervals. The final row shows the stacked measurement from three observations conducted on three different days.

Table Supplementary Information Table 5: Radio observations of AT2022tsd with epochs since discovery Δt in the rest frame, observed frequency ν_{obs} , flux density f_ν of the source (if detected), and root-mean-square (RMS) of a region close to the source in the image.

Start Date (UT)	Δt (days)	ν_{obs} (GHz)	f_ν (mJy)	RMS (mJy)	Telescope
2022-10-02 06:50:00	19.75	15.00	0.023	0.004	VLA
2022-10-04 07:20:00	21.36	230.00	–	0.270	SMA
2022-10-04 22:07:00	21.85	77.26	0.283	0.075	NOEMA
2022-10-04 22:07:00	21.85	92.74	0.245	0.065	NOEMA
2022-10-10 08:02:00	26.16	45.00	0.127	0.033	VLA
2022-10-10 08:02:00	26.16	22.00	0.038	0.009	VLA
2022-10-10 08:02:00	26.16	15.00	0.031	0.004	VLA
2022-10-10 08:02:00	26.16	33.00	0.086	0.013	VLA
2022-10-10 21:16:00	26.59	134.76	0.212	0.047	NOEMA
2022-10-10 21:16:00	26.59	150.24	0.232	0.057	NOEMA
2022-10-11 00:45:00	26.71	77.26	0.239	0.035	NOEMA
2022-10-11 00:45:00	26.71	92.74	0.284	0.032	NOEMA
2022-10-11 02:53:00	26.78	207.26	0.574	0.114	NOEMA
2022-10-11 02:53:00	26.78	222.74	0.551	0.117	NOEMA
2022-10-12 02:50:00	27.57	77.26	0.298	0.082	NOEMA
2022-10-12 02:50:00	27.57	92.74	0.316	0.078	NOEMA
2022-10-13 23:24:00	29.05	77.26	0.170	0.039	NOEMA
2022-10-13 23:24:00	29.05	92.74	0.179	0.037	NOEMA
2022-10-14 02:04:00	29.14	134.76	0.277	0.087	NOEMA
2022-10-14 02:04:00	29.14	150.24	0.411	0.117	NOEMA
2022-10-19 04:29:00	33.20	350.50	0.313	0.027	ALMA
2022-10-20 05:44:00	34.04	15.00	0.033	0.004	VLA
2022-10-20 05:44:00	34.04	33.00	0.071	0.010	VLA
2022-10-20 05:44:00	34.04	22.00	0.056	0.007	VLA
2022-10-20 05:44:00	34.04	10.00	0.031	0.004	VLA
2022-10-20 05:44:00	34.04	45.00	0.075	0.021	VLA
2022-10-21 04:54:40	34.81	412.00	0.259	0.038	ALMA

2022-10-22 03:52:39	35.57	242.00	0.300	0.028	ALMA
2022-10-28 00:54:00	40.25	77.26	0.363	0.113	NOEMA
2022-10-28 00:54:00	40.25	92.74	0.299	0.093	NOEMA
2022-10-28 00:54:00	40.25	150.24	0.328	0.037	NOEMA
2022-10-29 23:00:00	41.77	150.24	0.330	0.040	NOEMA
2022-10-29 23:00:00	41.77	134.76	0.228	0.028	NOEMA
2022-11-01 23:03:00	44.16	222.74	0.198	0.052	NOEMA
2022-11-01 23:03:00	44.16	207.26	0.175	0.048	NOEMA
2022-11-08 04:52:00	49.13	15.00	0.031	0.004	VLA
2022-11-08 04:52:00	49.13	22.00	0.043	0.006	VLA
2022-11-08 04:52:00	49.13	33.00	0.075	0.008	VLA
2022-11-08 04:52:00	49.13	45.00	0.120	0.015	VLA
2022-11-18 20:08:00	57.60	77.26	0.252	0.039	NOEMA
2022-11-18 20:08:00	57.60	92.74	0.304	0.030	NOEMA
2022-11-26 22:16:00	64.04	134.76	0.111	0.030	NOEMA
2022-11-26 22:16:00	64.04	150.24	0.119	0.032	NOEMA
2022-12-03 03:26:00	68.98	22.00	0.078	0.007	VLA
2022-12-03 03:26:00	68.98	33.00	0.099	0.009	VLA
2022-12-03 03:26:00	68.98	45.00	0.108	0.018	VLA
2022-12-03 03:26:00	68.98	15.00	0.049	0.004	VLA
2022-12-14 18:56:00	78.25	77.25	0.131	0.028	NOEMA
2022-12-14 18:56:00	78.25	92.74	0.153	0.024	NOEMA
2023-01-27 01:26:00	112.69	45.00	–	0.016	VLA
2023-01-27 01:26:00	112.69	33.00	0.052	0.011	VLA
2023-01-27 01:26:00	112.69	15.00	0.048	0.003	VLA
2023-01-27 01:26:00	112.69	22.00	0.048	0.006	VLA
2023-03-04 12:14	141.70	1.27	0.140	0.033	uGMRT
2023-03-05 12:14	142.50	0.65	–	0.195	uGMRT
2023-03-06 10:19	143.23	0.44	–	0.810	uGMRT
2023-03-23 13:19:00	156.86	77.25	–	0.045	NOEMA
2023-03-23 13:19:00	156.86	92.74	–	0.047	NOEMA
2023-03-31 08:10	163.06	1.37	0.131	0.035	uGMRT
2023-04-01 10:05	163.92	0.65	–	0.165	uGMRT

2023-04-02 10:05	164.71	0.43	–	0.465	uGMRT
2023-04-05 23:00:00	167.53	6.00	–	0.009	VLA
2023-04-05 23:00:00	167.53	10.00	0.038	0.009	VLA
2023-04-05 23:00:00	167.53	22.00	–	0.009	VLA
2023-04-05 23:00:00	167.53	3.00	–	0.018	VLA
