Minutes-duration optical flares with supernova luminosities

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Outline

- 1.Background introduction
- 2.Properties of observation
- 3.Central engine and radiative process
- 4.Summary

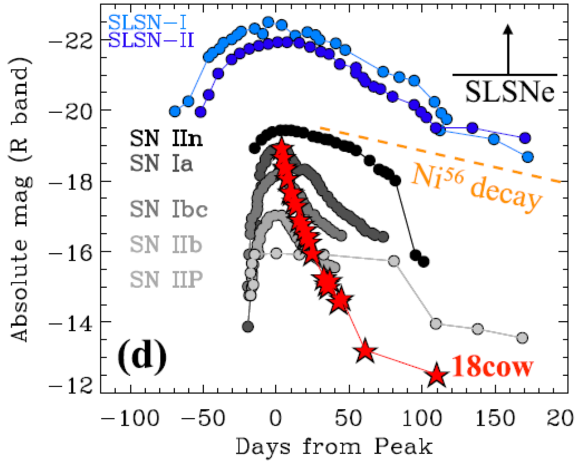
1.1 Fast Blue Optical Transients

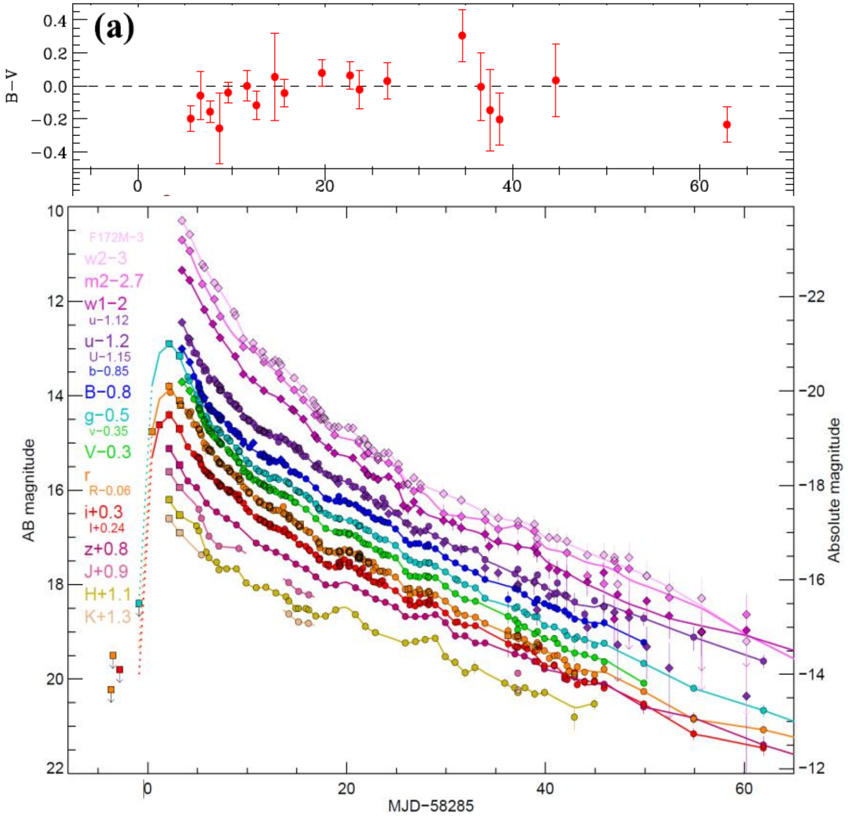
- The brightest Fast Blue Optical Transients (FBOTs) are mysterious extragalactic explosions that represent a new class of astrophysical phenomena.
- Characteristic: an extremely rapid rise to maximum light (typically $<$ 10 days);
  highly optical luminosity ($\geq 10^{43}$ erg/s);
  blue colors;
  decline over several months;
  atypical optical spectra;

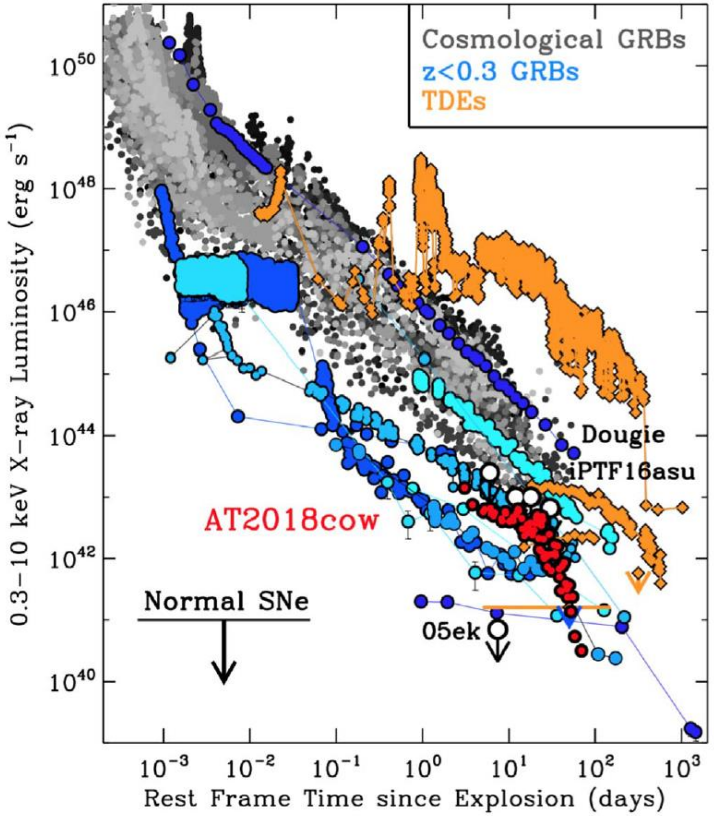
Evolutions are difficult to explain within the context of core-collapse of massive stars which are powered by radioactive decay of Nickel-56 and evolve more slowly.

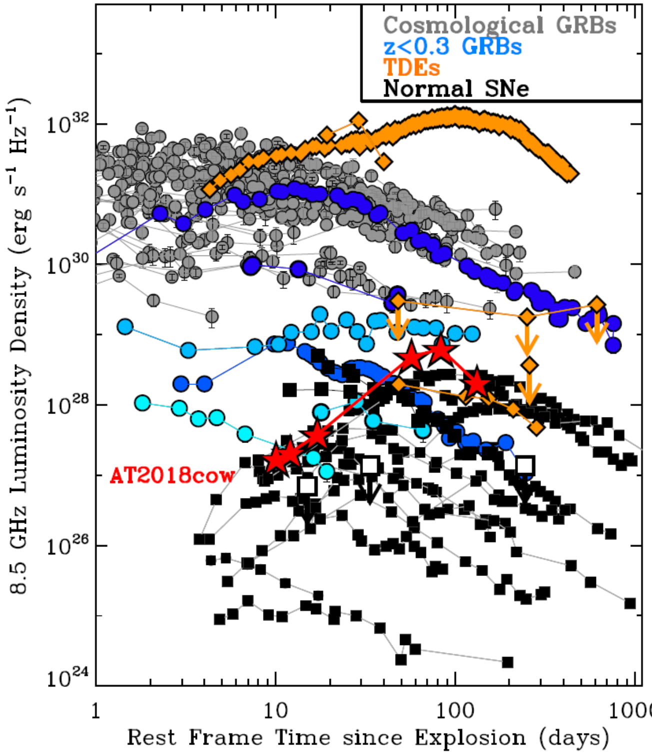
1.2 Most notably AT2018cow

- Rapid rise time : < 3days
- Luminosity = 4×10^{44} erg/s. (brightest so far)
- Its brightness rise of more than 5.7 magnitudes in just 4 days
- The UV/optical/NIR flux rapidly decays.





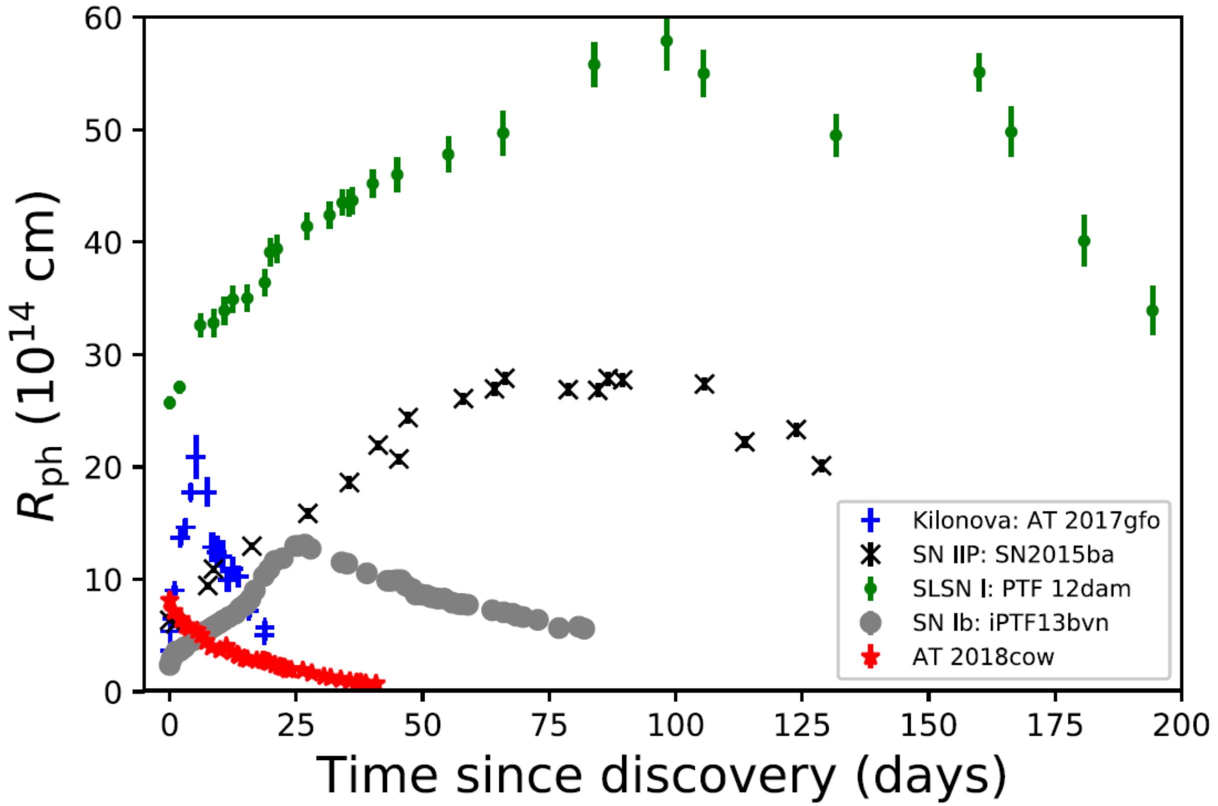




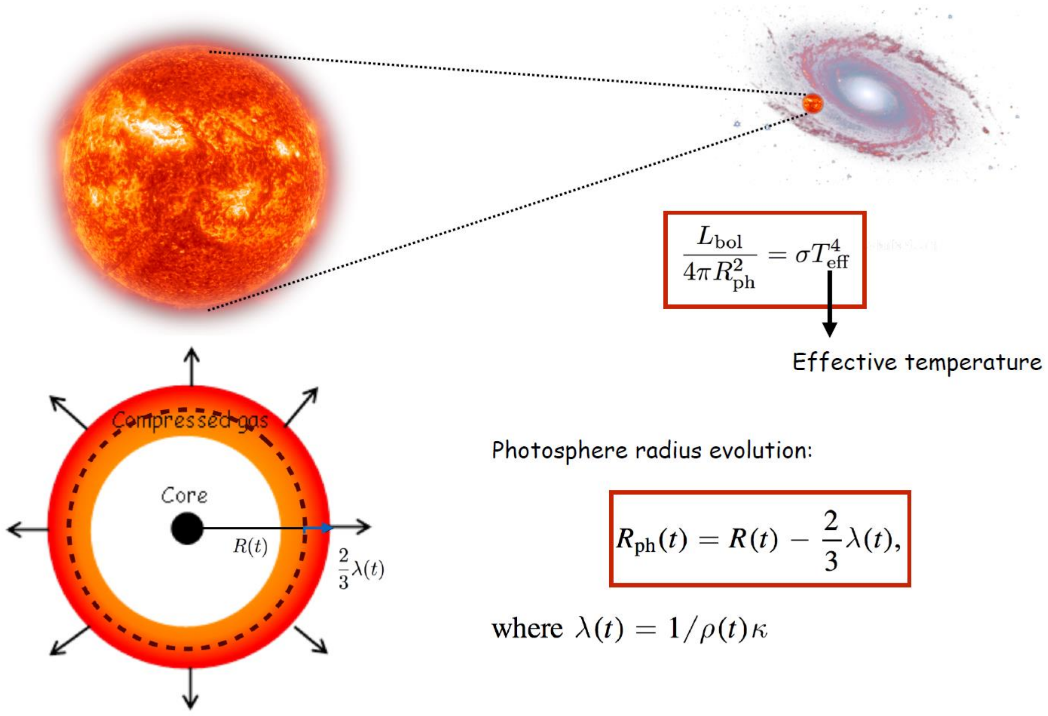
1.3 Photospheres radius evolution

- The widths of the R_{ph} peaks depend on the physical parameters of the explosions (e.g., Mej, E_K, and κ), but the general evolution behavior is similar.

- This behavior means that it is essentially impossible for AT 2018cow to be a supernova.



Photospheres from different sources

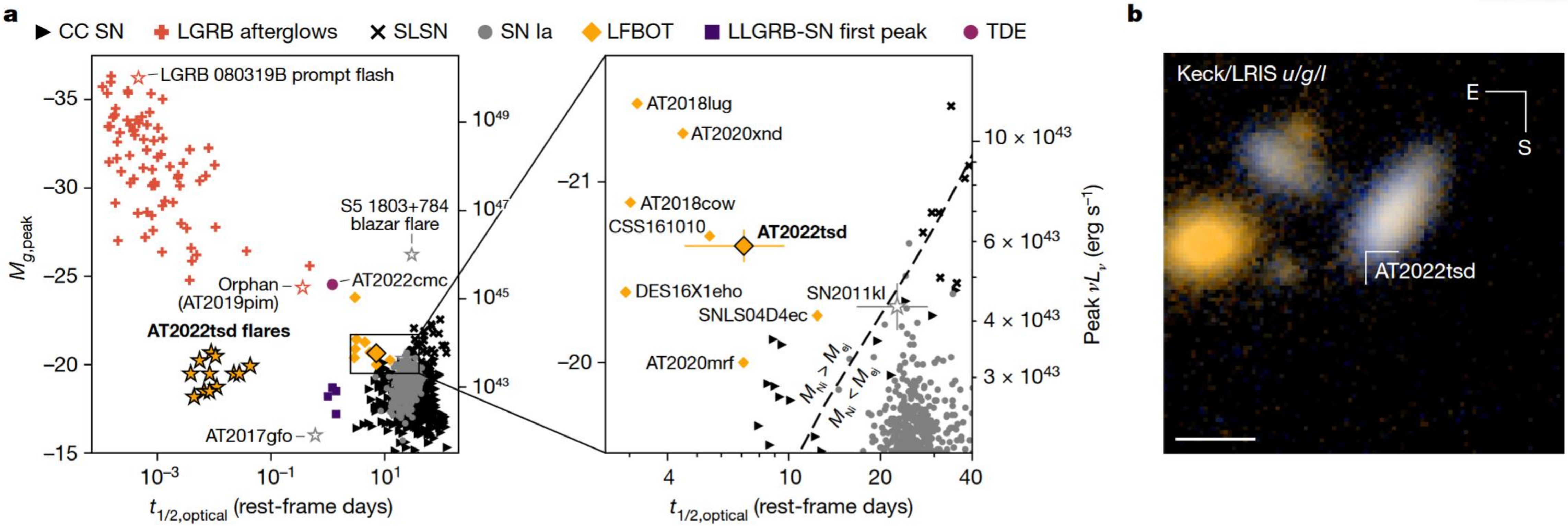


1.4 Prompt γ-ray, high-energy Cosmic-Ray and Neutrino ?

- No evidence for a burst of γ-rays associated with AT 2018cow down to the IPN threshold.
- The predicted high-energy neutrino fluence from AT2018cow is below the sensitivity of the IceCube Observatory, and estimates of the cosmically integrated neutrino flux from FBOTs are consistent with the extreme-high-energy upper limits posed by IceCube.
- High-energy γ rays exceeding GeV energies are obscured for the first months to years by thermal photons in the magnetar nebula, but are potentially observable at later times.

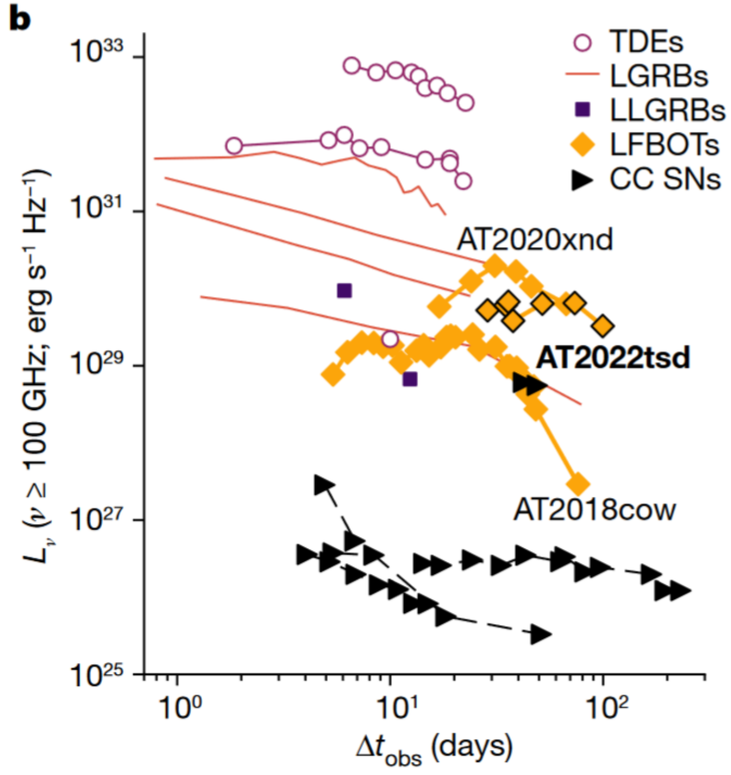
2.1 Discovery of AT2022tsd

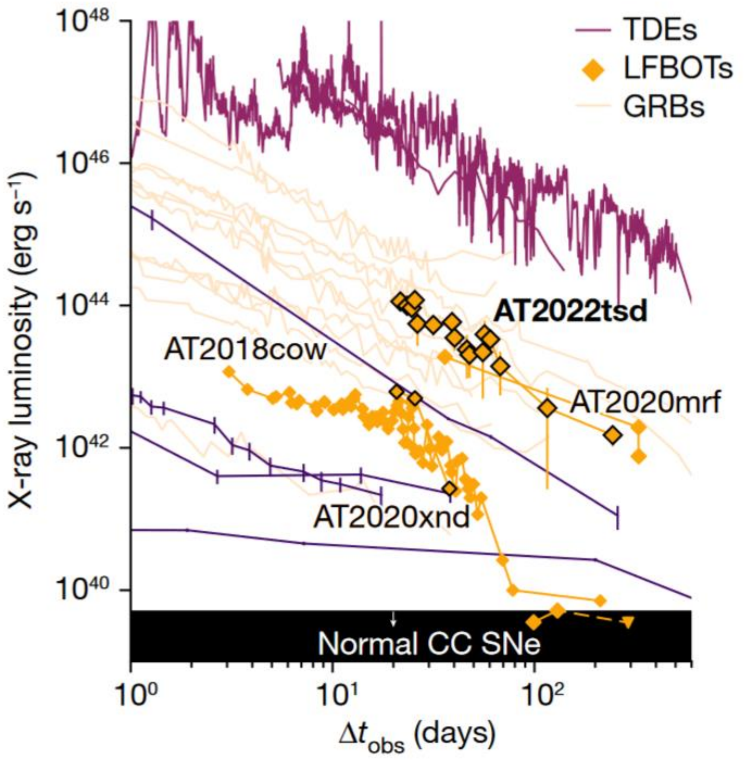
- Time : 2022-09-07
- Redshift of host galaxy : 0.2564 ± 0.0003
- magnitude : $m_r = 20.36 \pm 0.23$ mag
- The light-curve evolution was faster than that of typical supernovae

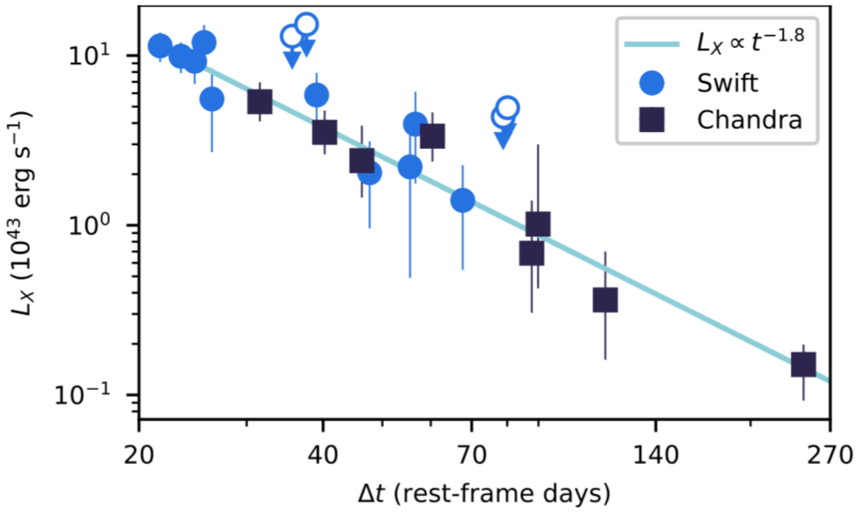


2.2 Radio and X-ray emission

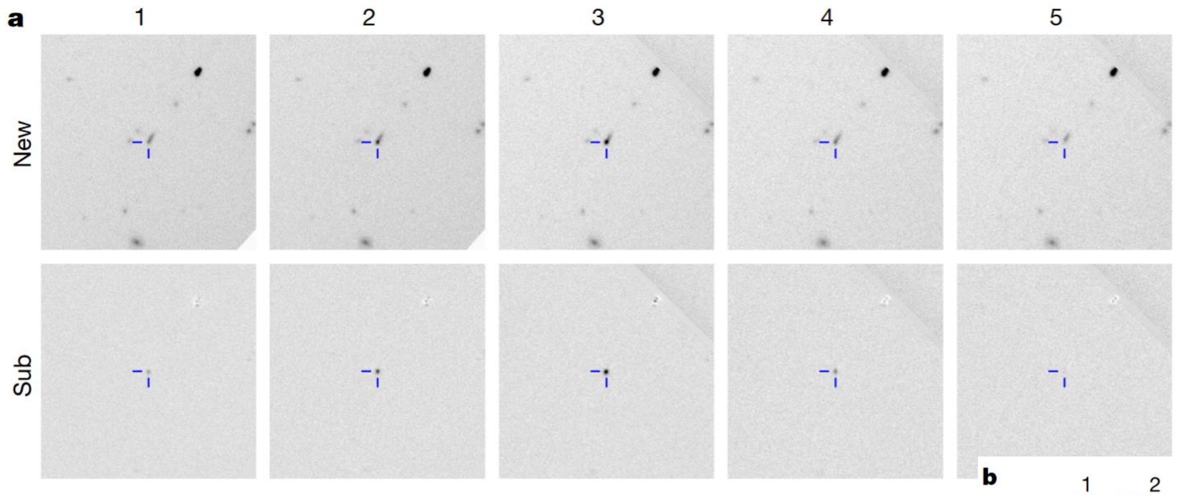
- Luminous radio emission that peaked at hundreds of GHz for more than a month.
- Luminous X-ray emission and steadily fading over nearly 300 days.
- The multiwavelength properties of AT2022tsd are most similar to those of AT2018cow-like transients (luminous fast blue optical transients or 'LFBOTs'), suggesting a common origin.



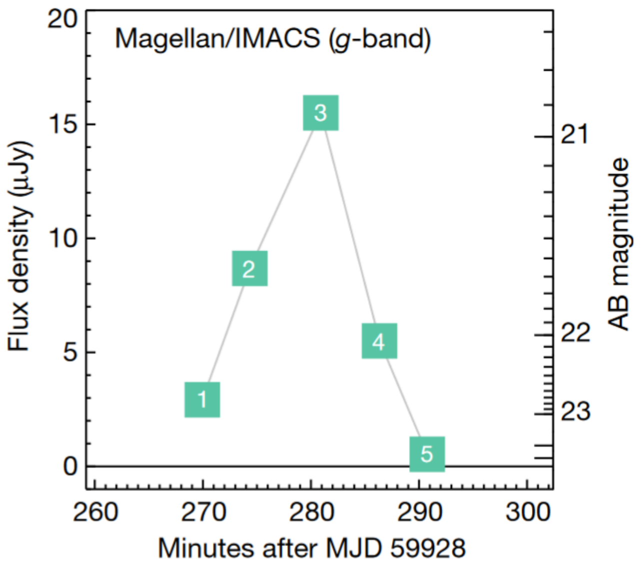


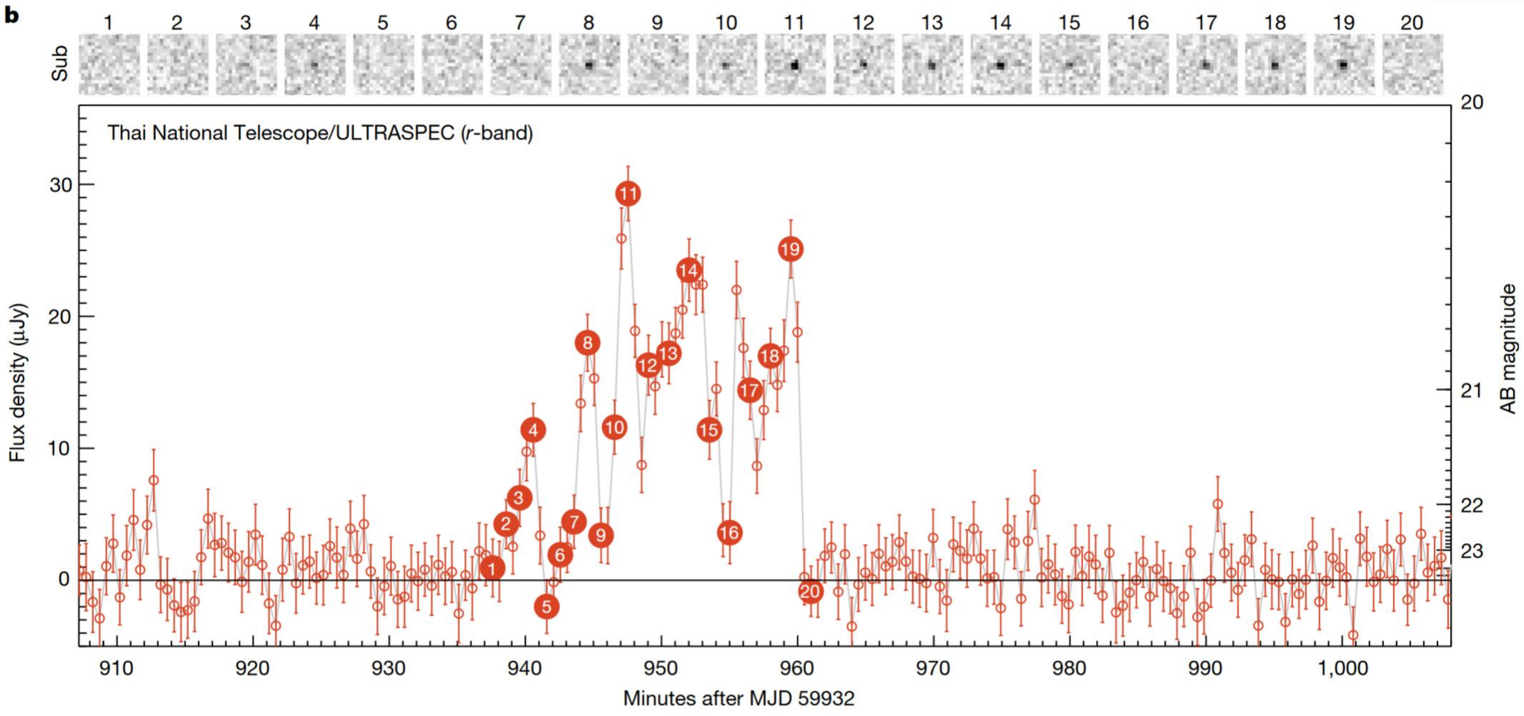


2.3 Minutes-duration optical flares



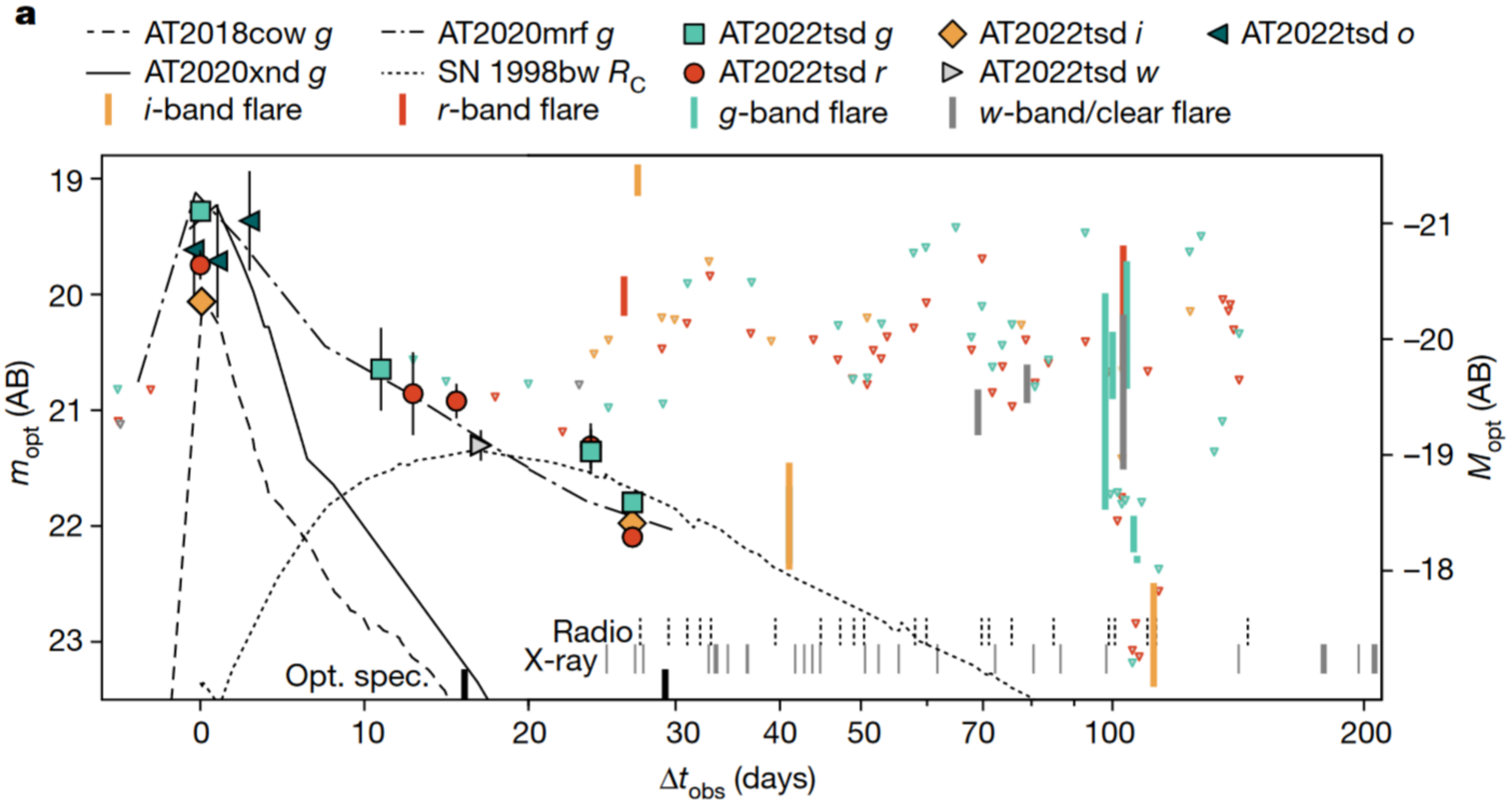
- Time : 100 days after the initial transient discovery.
- Luminosity : νLν ≈ 10^{44} erg s^{-1}.
- Flux variations exceed an order of magnitude on timescales shorter than 20 s .
- Complex temporal profiles that vary between flares.

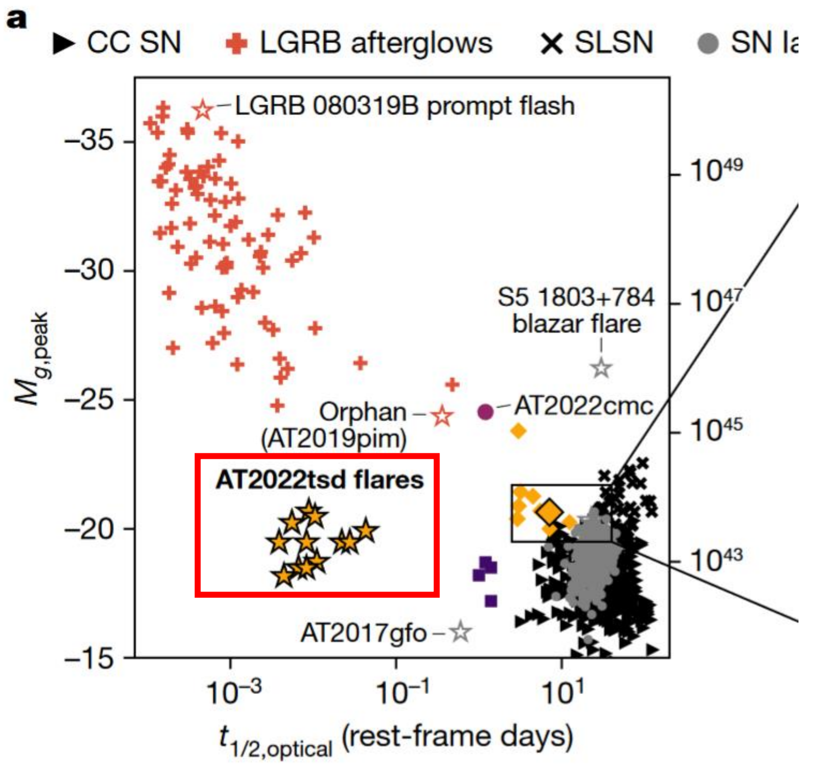




2.3 Minutes-duration optical flares

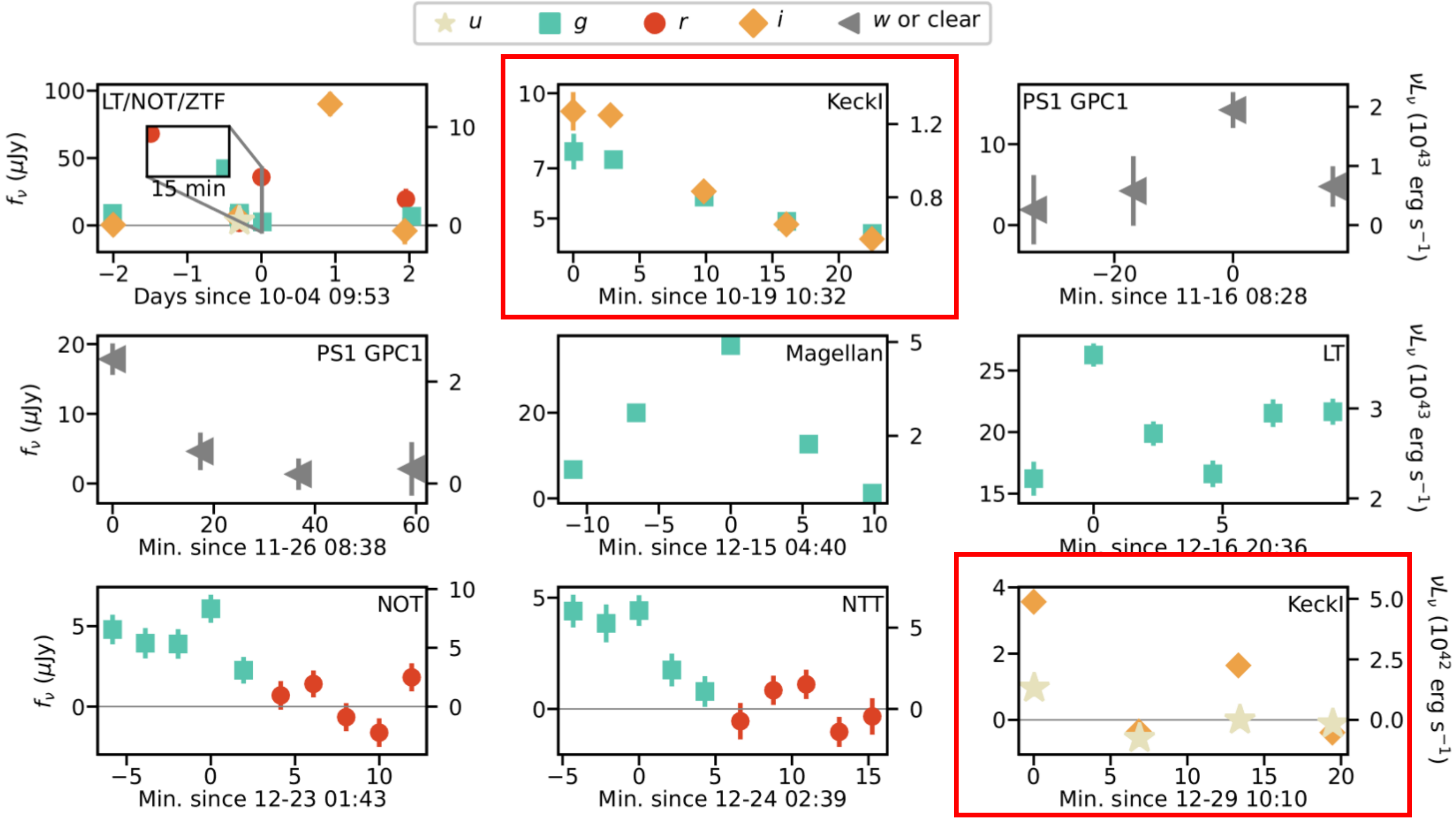
- The flares are as bright as AT2022tsd.
- No flares were detected on Radio and X-ray bands.
- The flares occur over a period of months.





2.3 Minutes-duration optical flares

- Two different Keck/LRIS observations revealed red flare colours.
- u – I = 1.41 ± 0.31 mag or $\beta = -1.6 \pm 0.1$, in which $f_\nu \propto \nu^\beta$



3. Central engine and radiative process

- 1.Minute-timescale optical flares at supernova-like luminosities,
- 2.With order-of-magnitude amplitude variations,
- 3.Persisting for 100 days.

There is no precedent in the literature

- 1.Previously observed flaring behaviour was orders of magnitude less luminous,
- 2.Persisting for only a few minutes,
- 3.Much longer durations or much higher photon energies.

The fact that these optical flares were observed in the aftermath of an extragalactic transient is even more unusual.

3. Central engine and radiative process

1.The timescales,

2.The enormous energetics,

3.The high brightness temperature ,

4. The requirement of optically thin emission for the flares .

- Which strongly imply that the flare-emitting outflow has at least near-relativistic ($v/c \gtrsim 0.6$) velocities.

However, there is no direct evidence for ultrarelativistic speeds, including a lack of associated detected prompt high-energy emission, a lack of detected variability at radio wavelengths and the subrelativistic speeds inferred from a basic equipartition analysis of the radio data.

Table 1 | Summary of basic constraints from different emission components

Component	Property	Constraint
Prompt optical	Photospheric radius	$(6.8\pm3.0)\times10^{14}$ cm
	Effective temperature	$(3.3\pm1.8)\times10^{3}$ K
Optical flares	Radiated energy	10^{46}–10^{47} erg
	Radius (light-crossing time)	$<(9\times10^{11}\,\mathrm{cm})\Gamma^{2}$
	Brightness temperature	$>(2\times10^{10}\,\mathrm{K})\Gamma^{-4}$
	Equipartition magnetic field strength	$(10^{4}\,\mathrm{G})\Gamma^{-12/7}$
	Equipartition energy	$(10^{43}\,\mathrm{G})\Gamma^{18/7}$
	Velocity	$\gtrsim0.6c$
Radio	Shock radius (equipartition)	$\gtrsim6\times10^{15}$ cm
	Shock speed (average)	$\gtrsim0.06c$
	Magnetic field strength	$\lesssim6$ G
	Shock energy	$\lesssim3\times10^{48}$ erg
	Ambient density	$\lesssim6\times10^{5}\,\mathrm{cm}^{-3}$
X-rays	Radiated energy	$>10^{50}$ erg
Host galaxy	Stellar mass	$\log(M/M_{\odot})=9.96^{+0.06}_{-0.09}$
	Star-formation rate	$0.55^{+1.36}_{-0.19}\,M_{\odot}\,\mathrm{year}^{-1}$

3. Central engine and radiative process

- The conclusion is that the flares in AT2022tsd arose from a near-relativistic outflow that was powered by a compact object over a period of 100 days.

- The possible power sources for the outflow are:
  - 1. the rotational spindown of a newborn neutron star.
  - 2.accretion onto a stellar-mass or intermediate-mass compact object.
    - the compact object could be a newly formed stellar-mass black hole or, a neutron star, stellar-mass black hole or intermediate-mass black hole if the process was tidal disruption followed by the formation of an accretion disk.

3. Central engine and radiative process

- Several models have been proposed to explain LFBOTs and this paper consider three most likely in light of the newly discovered flares:
  1.the collapse of a supergiant star,
  2.the merger and tidal disruption of a Wolf–Rayet star by a compact object,
  3.the tidal disruption of a white dwarf by an intermediate-mass black hole.

- Accretion processes and jets from systems involving black holes could produce fast and luminous flares, and explaining AT2022tsd as an analogue of observed flares from supermassive black hole tidal disruption events (TDEs) and blazars might be most natural for an intermediate-mass black hole owing to the flare duration and time between flares.
- If AT2022tsd arose from a stellar-mass black hole, the accretion rate would be highly super-Eddington .Such a rate could be compatible with a merger and tidal disruption scenario.
- The high accretion rate could arise from the collapse of a supergiant star and subsequent formation of an accretion disk; the identification of these systems is a long-standing goal for understanding the conditions that determine whether a star will explode.

4.Summary

- 1. FBOTs are mysterious extragalactic explosions and we still don't know the origin.
- 2.AT2022tsd is a newly discovered FBOT with multiwavelength emissions.
- 3. Minutes-duration optical flares was found after 100 days since discovery of AT2022tsd.
- 4.Luminous flares might arise from a compact object.
- 5. Three most likely model :the collapse of a supergiant star, the merger and tidal disruption of a Wolf–Rayet star by a compact object and the tidal disruption of a white dwarf by an intermediate-mass black hole.

Thanks