The Peculiar X-Ray Transient Swift J0840.7-3516: An Unusual Galactic Low-mass X-Ray Binary?

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Swift J0840.7–3516 is an X-ray transient discovered with Swift/BAT in 2020 February. We investigated its X-ray properties using extensive data from Swift, MAXI, NICER, and NuSTAR. The source flux increased for ~10^3 s after the discovery, decayed rapidly over ~5 orders of magnitude in five days, and then remained almost constant over nine months. Large-amplitude short-term variations on timescales of 1–10^4 s were observed throughout the decay. In the initial flux rise, the source showed a hard power-law-shaped spectrum with a photon index of ~1.0 extending up to ~30 keV, above which an exponential cutoff was present. The photon index increased in the following rapid decay and became ~2 at the end of the decay. A spectral absorption feature at 3–4 keV was detected in the decay.

These properties are different from typical X-ray binaries and other variable galactic and extragalactic sources such as cataclysmic binaries, flare stars, active galactic nuclei, and gamma-ray bursts. One possibility of the source nature is a Galactic low-mass X-ray binary with multiple unusual properties. Indeed, optical spectroscopy after the decay (Coti Zelati et al. 2021) suggested that it is an ultra compact X-ray binary.

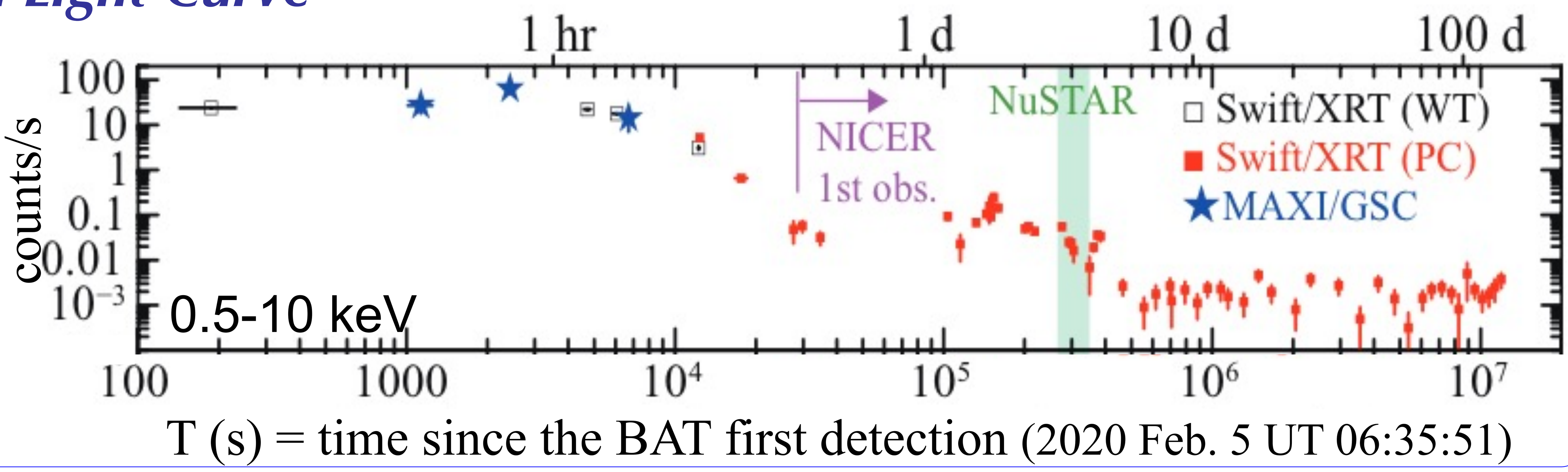
Shidatsu et al. (2021), ApJ, 910, 144

Source Info. & Long-term Light Curve

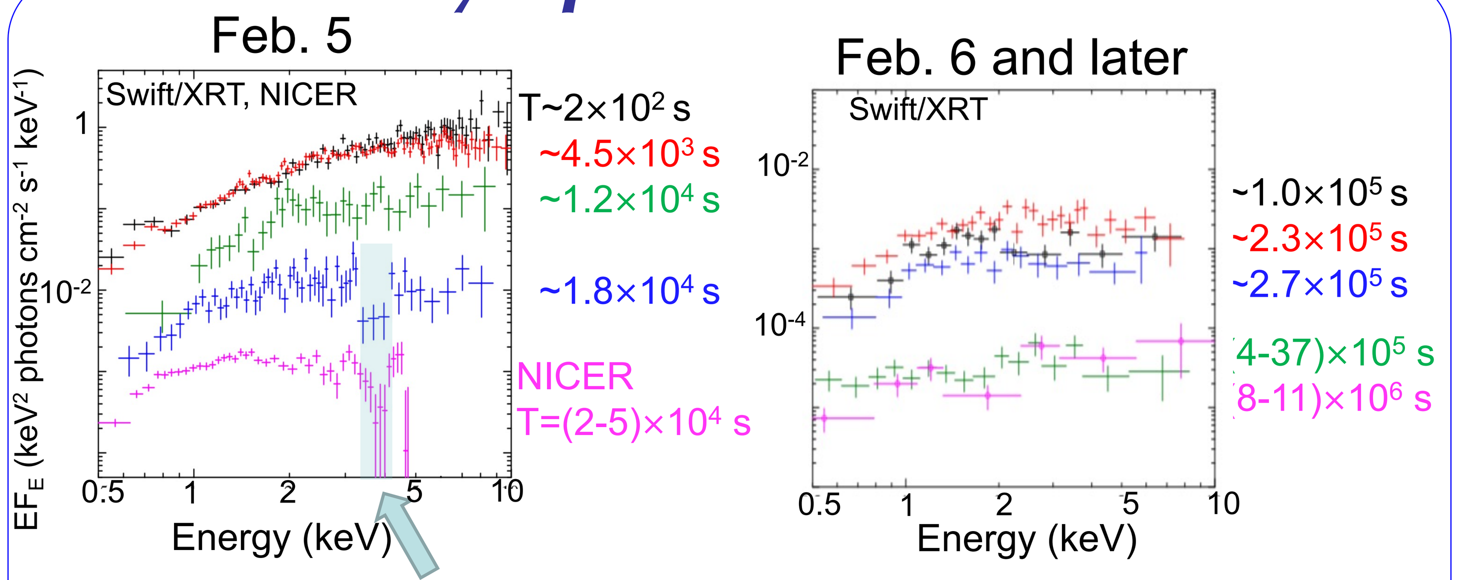
Discovery: 2020 Feb. 5 UT 06:35:51 (T = 0 s) with Swift/BAT (Evans+ 2020, GCN #26982)

Source position:
(RA, Dec)(J2000) = (130.17017, -35.27356)
(l, b) = (256.280814, 4.016782)

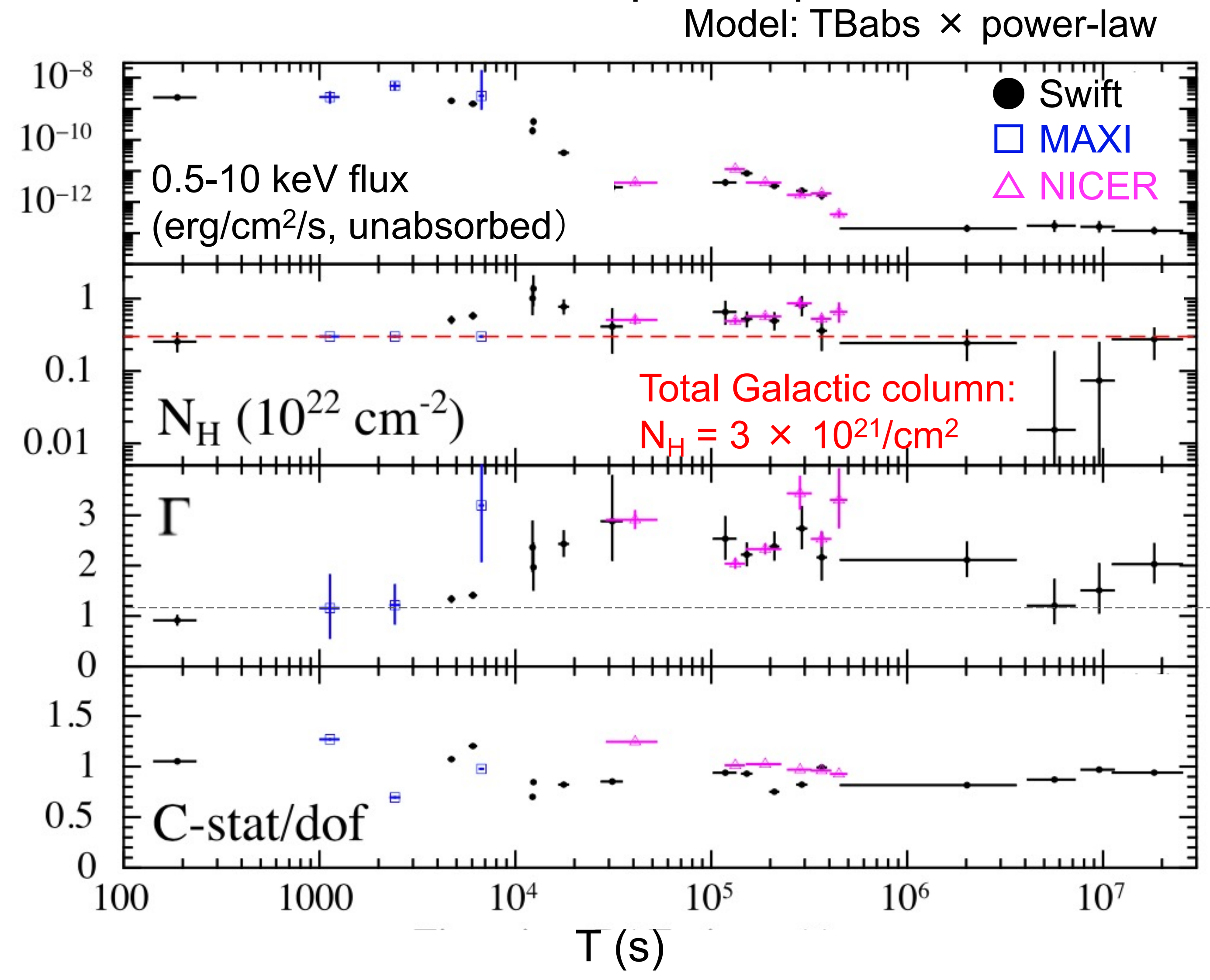
Characteristics of the long-term light curve:
- rapid flux decay after the flux peak (5 orders of magnitude in ~5 days)
- almost constant flux after the rapid decay



Soft X-ray Spectral Evolution

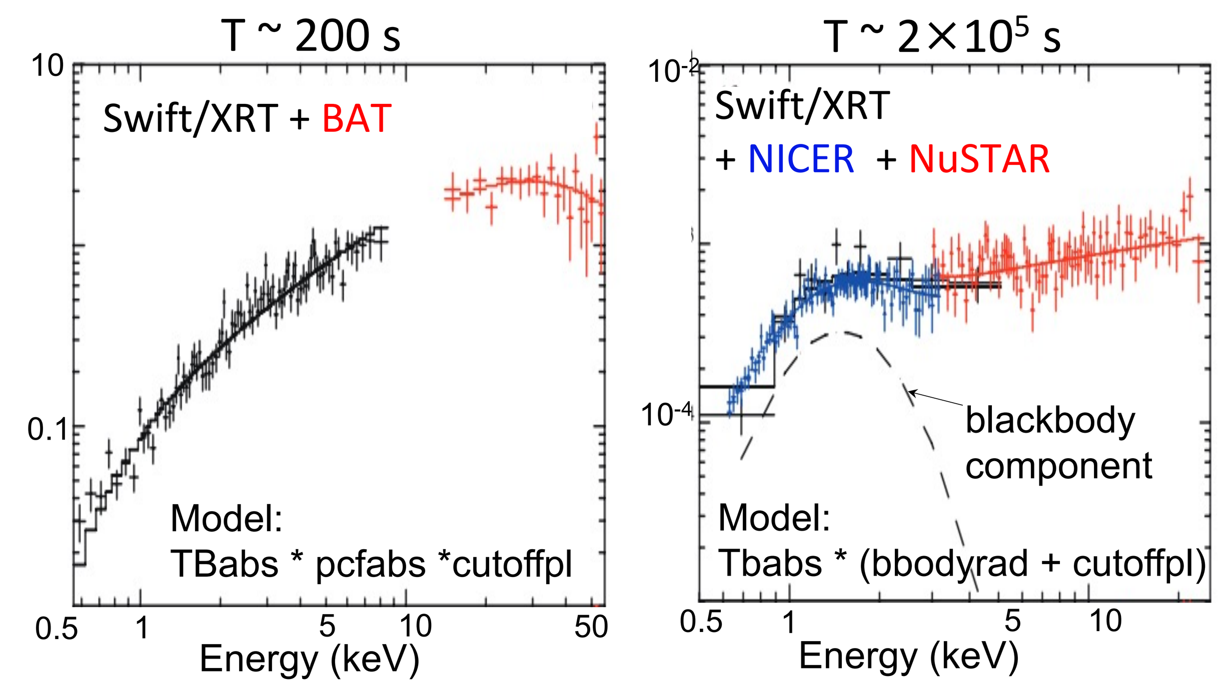


Time evolution of spectral parameters
Model: TBabs × power-law



- The soft X-ray spectrum can be characterized by an absorbed power-law model.
- At the initial phase, the source showed the hardest spectrum with a photon index of ~1, which gradually increased with decreasing flux and finally reached Γ ~ 2 after the decay. The absorption column density was comparable to the total Galactic column, although some variations were present.
- A possible absorption feature at ~3.4 keV was detected with Swift and NICER between T~2 × 10^4 and 5 × 10^4 s, when the light curve exhibited a plateau following the first steep decay. It is unclear what is the origin of the absorption. If it is the neutral Fe K edge, the redshift is estimated to be z = 1.1.

Wide-band X-ray Spectra



Best-fit parameters (T ~ 200 s)
N_H^{TB} <1.8 × 10^{21} /cm^2
Γ = $1.2^{+0.3}_{-0.1}$
E_{cut} = 36^{+30}_{-9} keV
N_H^{pcf} = $1.7^{+1.3}_{-0.5}$ × 10^{22} /cm^2
Cf^{*1} = $0.7^{+0.04}_{-0.15}$
X^2/dof = 96/97

Best-fit parameters (T ~ 2×10⁵ s)
N_H^{TB} = (2.1 ± 0.5) × 10^{21} /cm^2
Γ = $1.7^{+0.1}_{-0.2}$
E_{cut} > 49 keV
T_{bb} = 0.33 ± 0.05 keV
R_{bb} = $2.0^{+0.8}_{-0.5}$ (8 kpc/D) km
X^2/dof = 150/170

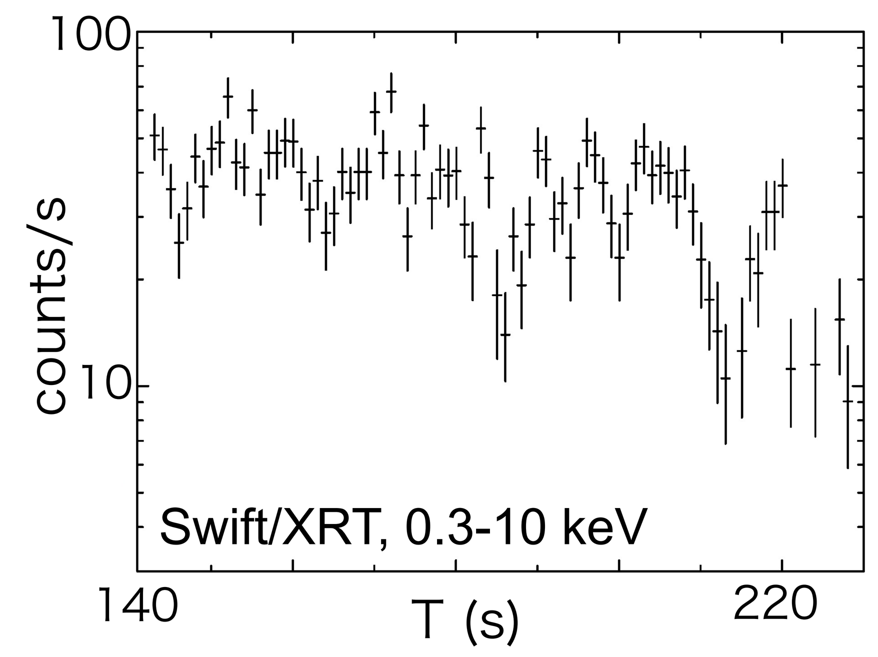
*1 Covering fraction of the partial absorber
*2 When replacing the blackbody to disk blackbody model, we obtain a very small inner disk radius (Rin = $1.4^{+0.7}_{-0.4}$(8 kpc/D)(cos i/cos 60deg)$^{-1/2}$ km).

The two broad-band spectra have more complex structures than the simple absorbed power-law (PL) model.
We tested 4 models below:

(1) absorbed cutoff PL (TBabs*cutoffpl)
(2) (1) w/ partial absorption (TBabs*pcfabs*cutoffpl)
(3) absorbed cutoff PL + blackbody (TBabs*cutoffpl+bbodyrad)
(4) absorbed cutoff PL + diskbb (TBabs*cutoffpl+bbodyrad)

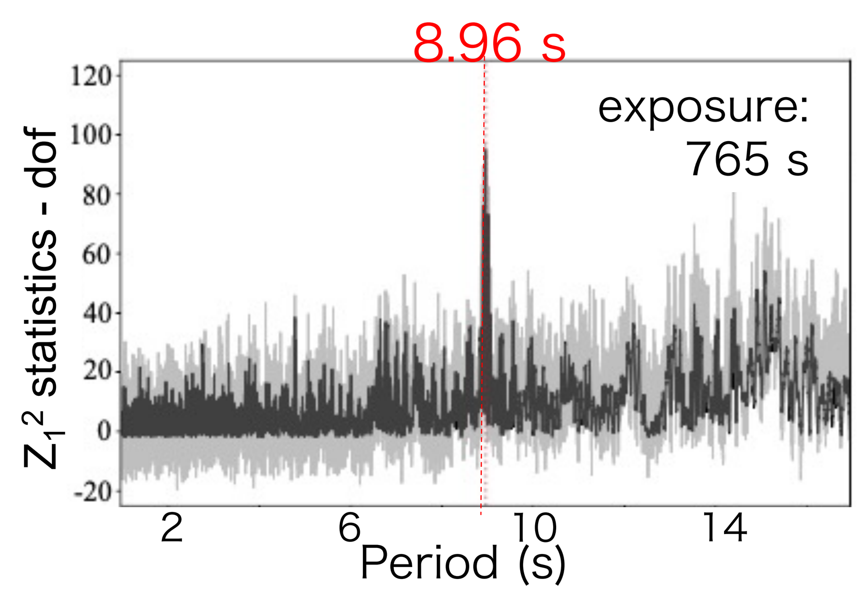
The spectrum at the brightest phase (T~200 s) was best reproduced by (2), while that at the late part of the decay (T~2 × 10^5 s) was by (3) or (4).

Short-term Variability



Significant variations on timescales of 1-10^3 s was seen until the end of the rapid decay.

Periodogram of the first 3 Swift/XRT WT-mode data



8.96 s (quasi-)periodicity was detected in the first 3 Swift observations (T<10^4 s), but not in the other observations.

What is the Nature of the Source?

- Rapid flux decay in ~5 days by ~5 orders or magnitude followed by a long constant-flux period
  → An active galactic nucleus, a gamma-ray burst, and a magnetar are unlikely.
  → The decay time is shorter than typical low-mass X-ray binaries (LMXBs), but there are some sources that show a similar rapid decay (e.g., MAXI J1957+032; Beri et al. 2019, MNRAS, 486, 1620).
- Hard, non-thermal spectra without any significant emission lines
  → A cataclysmic variable and a flare star are unlikely.
  →The photon index around the flux peak (Γ ~ 1) is smaller than that of typical LMXBs (Γ=1.5-1.9), but some shows such very hard spectra.
- Strong short-term variability throughout the decay → consistent with LMXBs

⇒ An LMXB with multiple unusual properties?
Indeed, Coti Zerati et al. (2021, A&A, 650, 69) have recently reported the optical spectrum after the decay is consistent with a Galactic ultra-compact X-ray binary with a hydrogen-deficient companion.