# Delayed and Fast-rising Radio Flares from an Optical and X-Ray-Detected Tidal Disruption Event in the Center of a Dwarf Galaxy

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## Introduction

When a star passes too close to a supermassive black hole (SMBH), it can be squeezed and torn apart once the tidal force of the SMBH exceeds the star's self-gravity. Such tidal disruption events (TDEs) can generate luminous flares typically peaking in X-rays and ultraviolet.

With the development of optical surveys, dozens of TDEs have been discovered so far. Some optically selected TDEs show delayed X-ray and radio emission, and there are several scenarios to explain this phenomenon. Such as the delayed onset of accretion (Piran et al. 2015), an ionization breakout of X-ray radiation from the obscuration by optically thick ouflow (Metzger & Stone 2016) ...

Discriminating between these scenarios will help to determine dependence of jet production on the accretion rate.

AT 2018cqh is a candidate TDE in a dwarf galaxy discovered by SRG/eROSITA (Bykov et al. 2024). Its X-ray is delayed by ~ 590 days compared to the optical flare. Here we report the detection of delayed and rapidly rising radio emission from AT 2018cqh.

## Observations and Results

### Optical:

1. It is a 0.06 $M_{sun}$ star disrupted by 2.5 $\times 10^6$ $M_{sun}$ BH.
2. Host is Seyfert II galaxy.
3. The monochromatic luminosity at the ZTF r band is ~ $10^{43}$ erg $s^{-1}$.

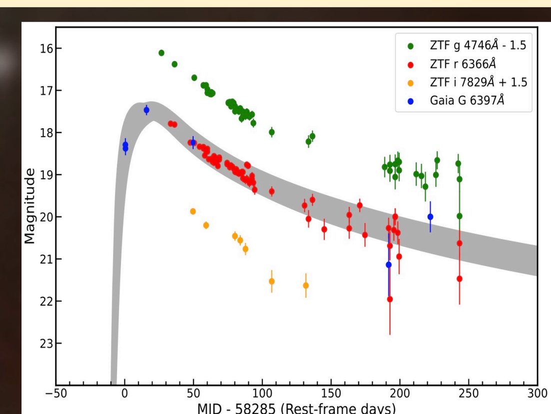

*Figure 1. Optical light curves of AT 2018cqh observed with ZTF and Gaia. The best model derived by fitting ZTF r-band and Gaia G-band light curves using MOSFIT code are shown in gray curves.*

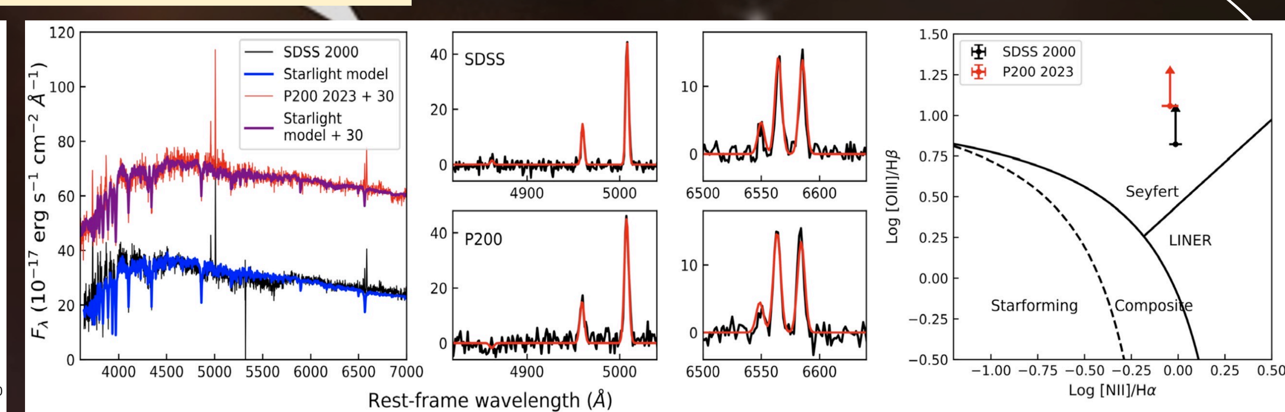

*Figure 2. Left panel: P200/DBSP spectrum of AT 2018cqh, as compared with the archival SDSS spectrum. Middle panel: a zoomed-in view of emission-line profile fitting for the Hβ, [O III], and Hα + [N II] doublet lines. Right panel: The optical classification of AT 2018cqh.*

### X-ray and Radio lightcurve:

1. The X-ray brightening was delayed around 590 days after the optical discovery.
2. The temporal evolution of the radio emission has three phases: an initial steep rise of at least 175 days, a flattening lasting about 544 days, and a phase with another steep rise. This suggests a peculiar flux evolution with a changing steep power law ($F_\nu \propto t^\alpha$) from index $\alpha > 6.6$, $\alpha > 0.9$ to $\alpha > 29.0$. This has never been seen in TDEs before.

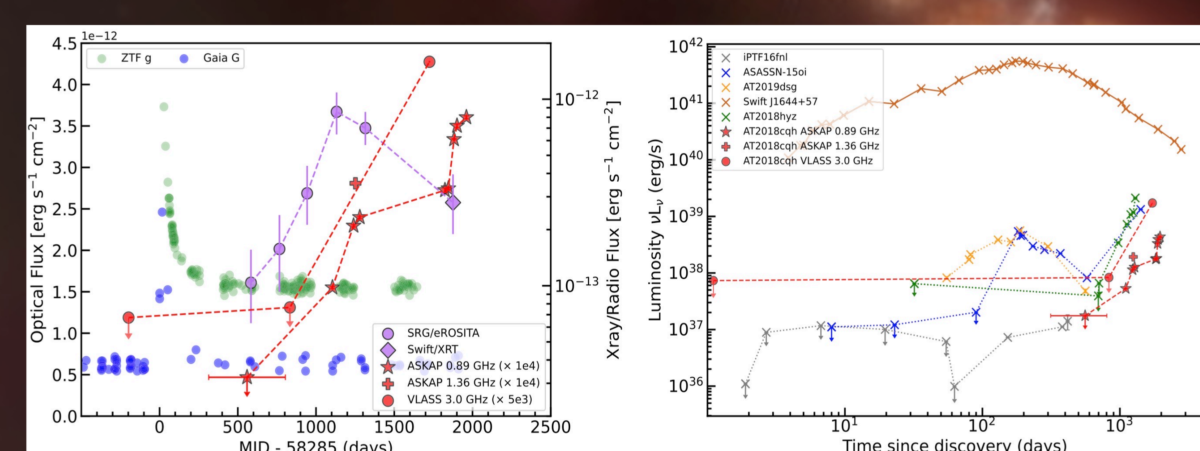

*Figure 3. Left panel: light curves of AT 2018cqh in the optical (ZTF r band and Gaia G band), and radio (0.89, 1.36, and 3 GHz). Right panel: the luminosity evolution of AT 2018cqh, including the upper limits. Also shown for comparison with other TDEs.*

### Radio SED fitting:

1. Peak flux and peak frequency of SED increase steadily with time.
2. Ambient density of CNM increases with Req, may suggest that the outflow enters a high-density CNM structure.

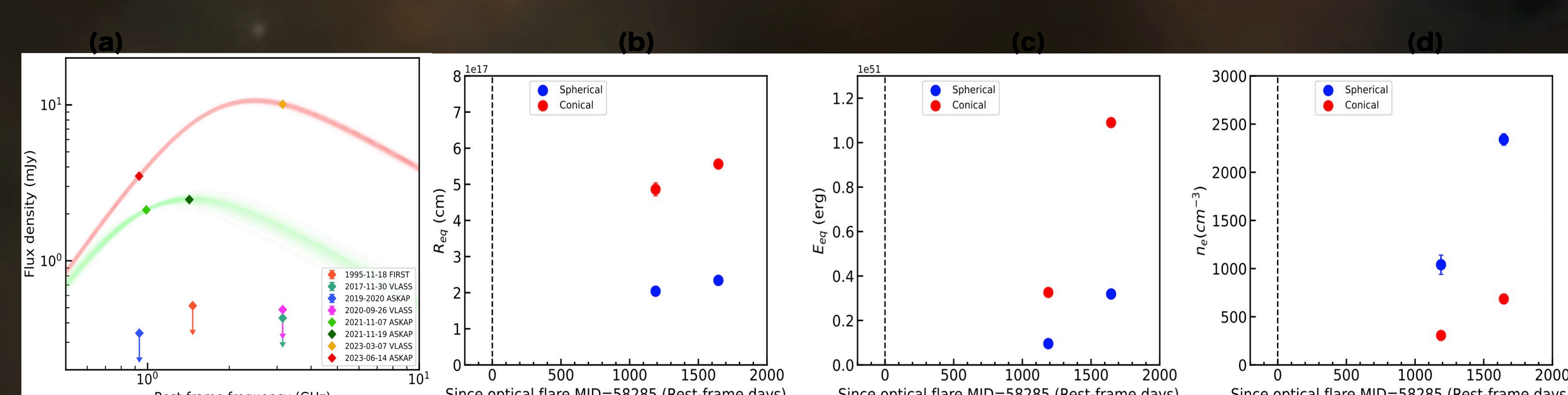

*Figure 4. (a): The radio SEDs for two epochs that have quasi-simultaneous observations at different frequencies. The red and green lines represent the best fit to each SED from our MCMC modeling. (b)(c)(d): The evolution of radius (b), kinetic energy (c), and ambient density (d) as a function of time.*

## Discussions

### The nature of delayed X-ray emission:

- The delay of the onset of disk formation due to star debris self-crossing. (Figure 5) 😋
  - *For $M_{BH}$ ~ $10^6$ $M_{sun}$ in AT 2018cqh, the time of circularization ~ 200 - 400 days.*
  - *$R_{bb}$ ~ $2\times10^{11}$ cm ⟶ The soft X-ray emission originates from a compact accretion disk.*
- The X-ray radiation from the inner accretion disk initially be blocked by dense outflow and may escape at later time. (Figure 6) 😕

  *The time scale for the ionization break out of X-ray radiation for $M_{BH}$ ~ $10^6$ $M_{sun}$ is ~ 100 days.*

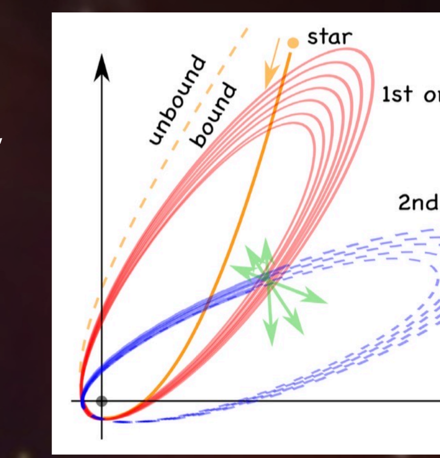

*Figure 5. Self-intersection of the fallback stream in TDEs. (Lu et al. 2020)*

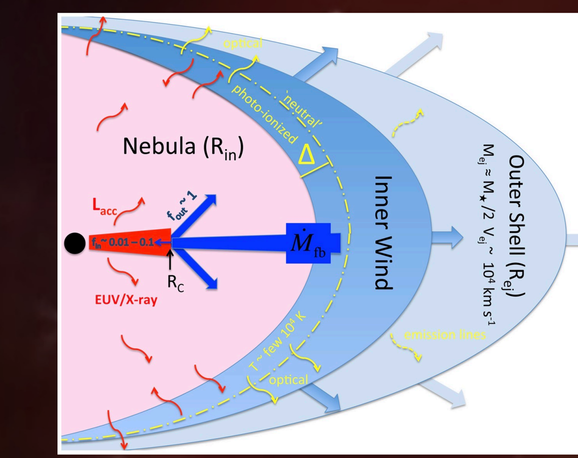

*Figure 6. Schematic illustration of X-ray reprocessing in TDEs (Metzger & Stone 2016)*

### The nature of delayed radio emission:

- Transition in the accretion state of the black hole similar with XRBs. 😋

  *$L_{bol}/L_{EDD}$ ~ 0.1-0.5, and the non-thermal emission likely from the low-luminosity AGN in the quiescent state (Figure 7), therefore AT 2018cqh possible undergo a low-hard to high-soft phase transition, resulting in the delayed launch of an outflow that led to rapidly rising radio emission at the late-time.*

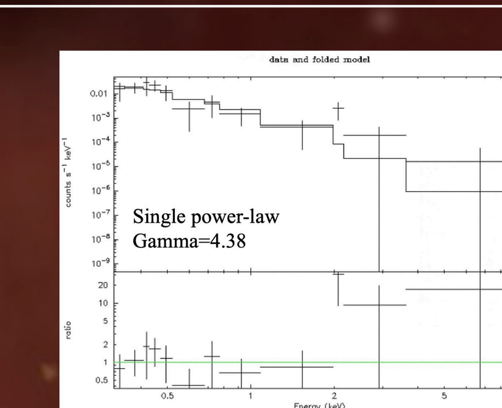

*Figure 7. The Swift/XRT spectrum and the spectral fitting result using a single powerlaw.*

- Off-axis relativistic jet. 😕

  *In the case of AT 2018cqh, the peak flux densities and frequencies are increasing over time, will make the transition to the Newtonian branch never happen.*
- Break out of jet emission that was initially chocked by the disk-wind ejecta. 😕

  *The radio SED evolution of breakout jet expands into the CNM should similar to ASASSN-14li (Alexander et al. 2016), which is inconsistent with what is observed in AT 2018cqh.*
- Outflow from TDE interacts with dense clouds in an inhomogeneous CNM. 😕

  *In this scenario, the peak flux of radio SED should be almost constant (Bu et al. 2023), which is also inconsistent with what is observed in AT 2018cqh.*

## Conclusion

We present the discovery of a delayed radio flare in an optical and X-ray-detected TDE occurring in a dwarf galaxy which central BH mass in the range of 5.9 < log $M_{BH}/M_{sun}$ < 6.4. The temporal evolution of the radio emission have three phases, and the radio SED is found to evolve toward higher peak flux and frequencies. The rapid rise in flux density coupled with the slow decay in the X-ray emission points to a delayed launching of outflow, perhaps due to a transition in the accretion state of the BH.

## Article information

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