Unusual Hard X-ray Flares Caught in NICER Monitoring of the Binary Supermassive Black Hole Candidate AT2019cuk/Tick Tock/SDSS J1430+2303

Scan here for the paper!

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A SMBH Binary Near Coalescence?

Supermassive black hole binaries (SMBHBs) have important implications on our understanding of black hole growth, the black hole—host galaxy connection, and gravitational wave astrophysics, yet there are still many uncertainties on their rates and EM emission properties.

- **AT2019cuk (AKA Tick Tock):** claimed to be an SMBHB that would merge in the next few months, based on decreasing period in ZTF light curve (Jiang+22)
- If true, AT2019cuk could be the ***first*** SMBHB merger caught by EM observations!

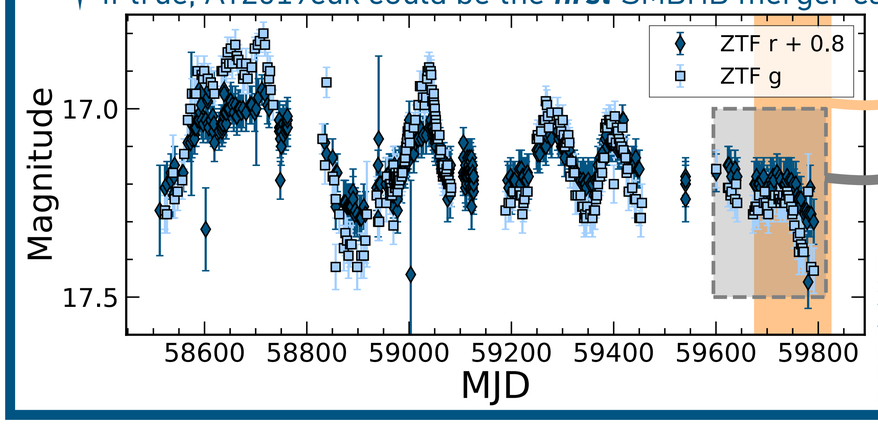


Figure 1: ZTF light curve of AT2019cuk from 2019–2022. The apparent periodic behavior with decreasing period was used to claim that AT2019cuk is a SMBHB. The orange period denotes the expected merger time (Jiang+22), and the grey box shows the time period studied in this work (Jan.–Aug. 2022).

The 2022 Observing Campaign

If AT2019cuk is really a SMBHB, then this would have huge implications for our understanding of EM emission in SMBH mergers.

So, we followed up AT2019cuk with **high-cadence, multi-wavelength monitoring**, including:

- X-ray with NICER and Swift
- UV with Swift
- Optical with ZTF + SomangNet (Small Telescope Network of Korea, see Im+21)

None of these observations showed periodicity on the claimed ~30 days or less... **challenges binary hypothesis**!

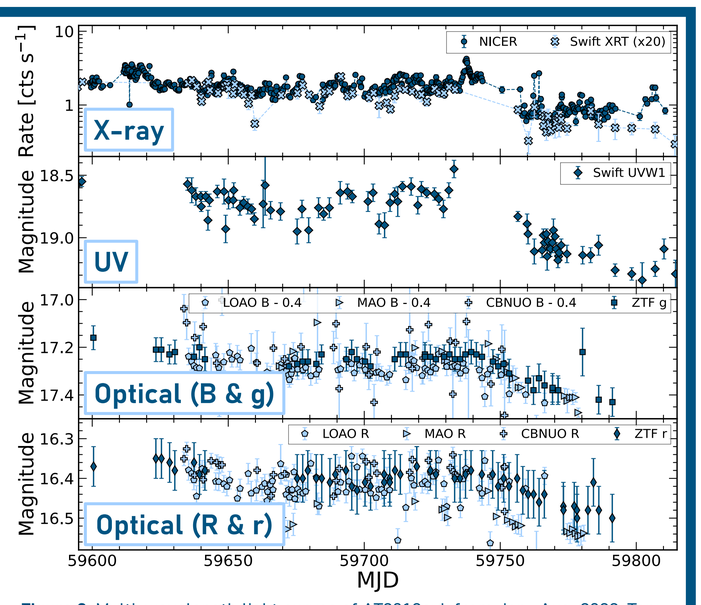
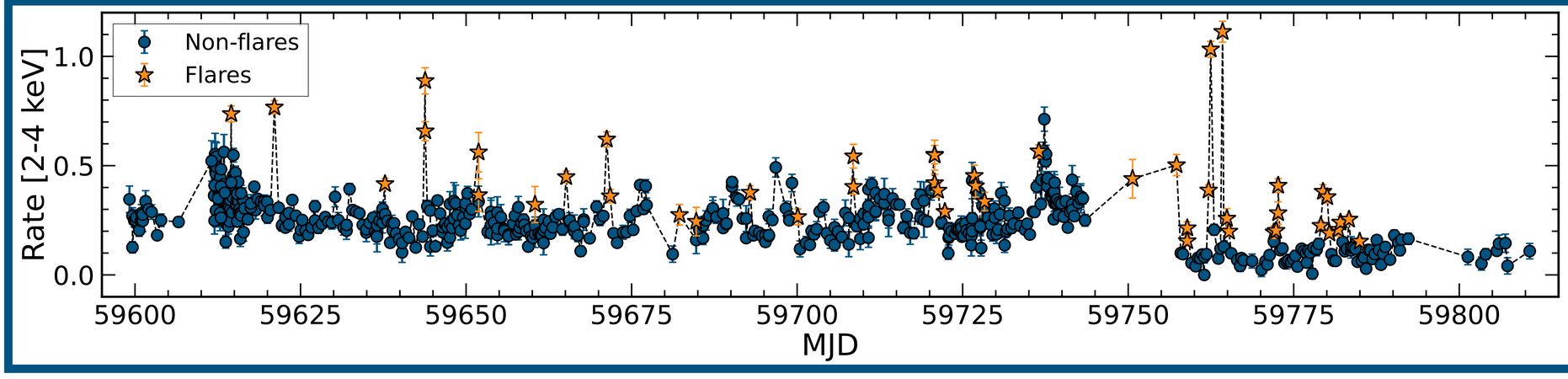


Figure 2: Multi-wavelength light curves of AT2019cuk from Jan.–Aug. 2022. Top: X-ray light curve from NICER and Swift XRT. Second panel: UV light curve from Swift UVOT. Bottom two panels: Optical light curves from ZTF and SomangNet. No periodic behavior is seen in any wavelength.

Hard X-ray Flares in High-Cadence NICER Monitoring of AT2019cuk



X-ray monitoring with NICER revealed these **peculiar hard X-ray flares** that have never been seen before in an AGN. The flares have the following properties:

- Last for ~ a day
- Recurrence times range from 1-15 days with no apparent periodicity
- Hard X-ray spectra ($\Gamma \lesssim 1.4$)

Figure 3: Hard X-ray light curve from NICER (2–4 keV band, from Jan.–Aug. 2022). Flaring data points are identified with a hardness ratio cut and shown as orange stars, whereas non-flaring data points are shown in blue circles. Flares are repetitive, aperiodic, and last for ~a day.

Spectral Evolution of the Flares

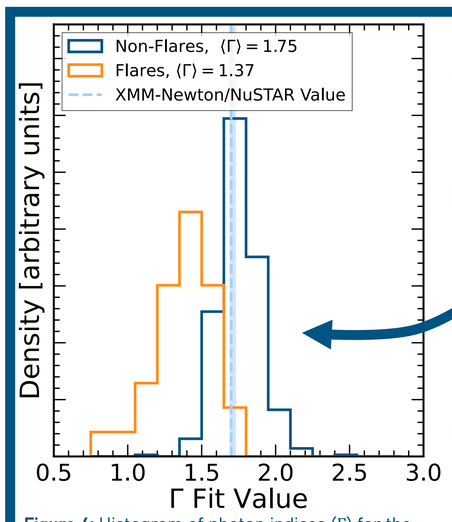


Figure 4: Histogram of photon indices (Γ) for the NICER data, using a partial covering ionized absorber and power law model. The flares (in orange) are significantly harder than non-flares (in dark blue). The non-flares agree with the XMM-Newton/NuSTAR value (light blue dashed line).

Flares have harder X-ray spectra than non-flares and **reach extremely low photon indices** for AGN

NICER HID shows **extreme spectral evolution of flares**, whereas non-flares follow standard AGN behavior

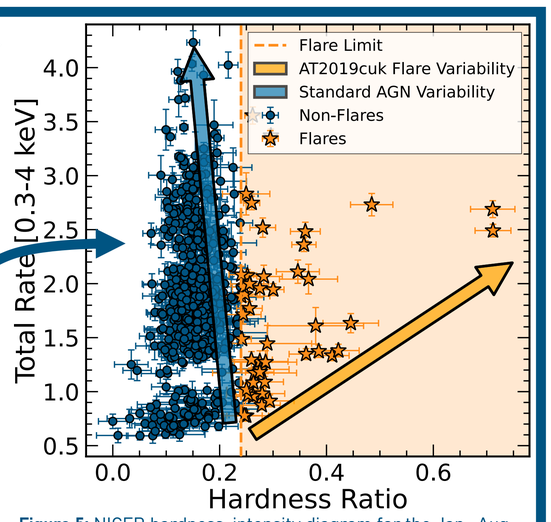


Figure 5: NICER hardness-intensity diagram for the Jan.–Aug. 2022 observing period. The hardness ratio is defined as the 2–4 keV count rate divided by the 0.3–2 keV count rate. The vertical orange dashed line denotes the hardness ratio used to define a flare. Flares show unusual harder-when-brighter behavior, whereas non-flares follow standard AGN variability.

Assessing the Validity of the Flares

Could the flares be the result of:

Poor counting statistics?
- No! A simulated NICER data set with the same properties shows no hard flares

NICER instrumental issues?
- No! There is no difference between flares and non-flares in NICER instrumental factors

Nearby AGN in NICER field of view?
- No! Swift sees similar hard X-ray flares, with localization

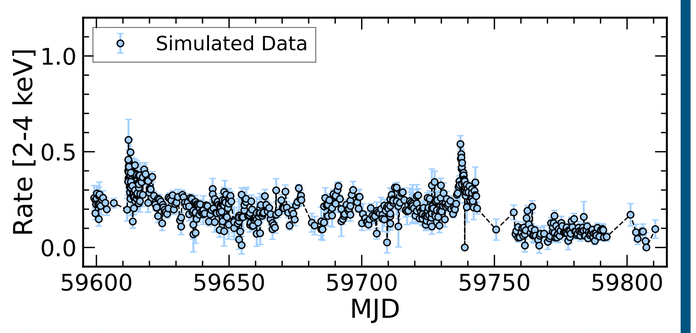


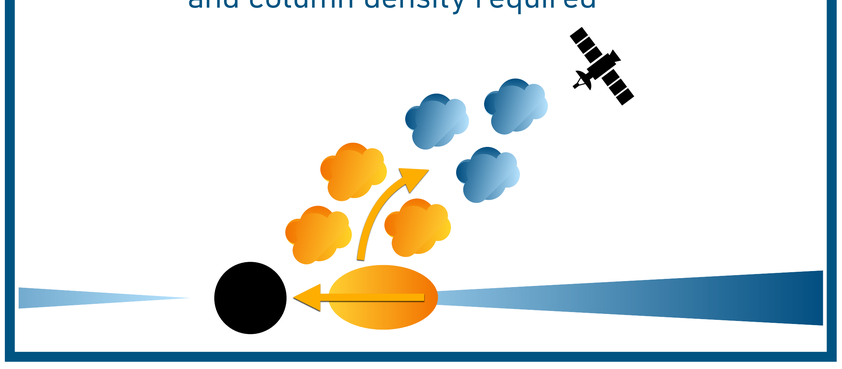
Figure 6: Simulated NICER hard X-ray light curve in the 2–4 keV band. The data is simulated assuming the best fitting XMM-Newton/NuSTAR spectrum with the observed NICER flux and exposure times. No hard X-ray flares are detected, indicating that the flares are not due to poor counting statistics.

⇒ the flares are astrophysical!

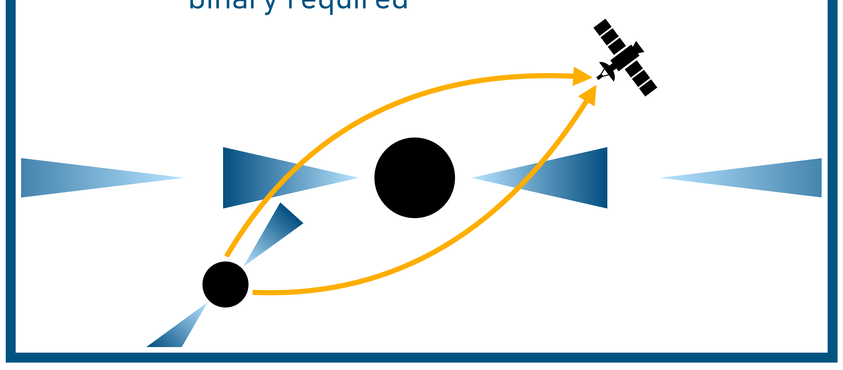
Potential Flare Models – Variable Corona, Variable Obscuration, and Binary Self-Lensing

Variable Corona: flares driven by increased magnetic activity in the corona (e.g. reconnection events)
- **Pros:** timescales, spectral changes, no binary required
- **Cons:** unlike standard corona behavior

Variable Obscuration: flares driven by variation in the properties of the obscuring material
- **Pros:** spectral changes, no binary required
- **Cons:** timescales, simultaneous increase in flux and column density required



Binary Self-Lensing: flares driven by gravitational lensing of mini disks around SMBHBs (e.g. D'Orazio+18)
- **Pros:** timescales, magnification factor
- **Cons:** aperiodic behavior, spectral changes, binary required



Take-Aways

- AT2019cuk/Tick Tock shows **no apparent periodicity** on ~ 30 day timescales or less (as predicted by the SMBHB hypothesis)
- NICER caught these **new, peculiar hard X-ray flares in AT2019cuk** on ~ day timescales, with no apparent periodic behavior
- Nuclear transients, like AT2019cuk, hold **key insights into the nature of the X-ray corona** and NICER is critical in unlocking this behavior.

References

Jiang, N., Yang, H., Wang, T., et al. 2022, arXiv:2201.11633. – Im, M., Kim, Y., Lee, C. U., et al. 2021, Journal of Korean Astronomical Society, 54, 89. – D'Orazio, D. J. & Di Stefano, R. 2018, MNRAS, 474, 2975