

# **Discovery of a Tight Binary Black Hole System Revealed via Quasi-Periodic Outflows**

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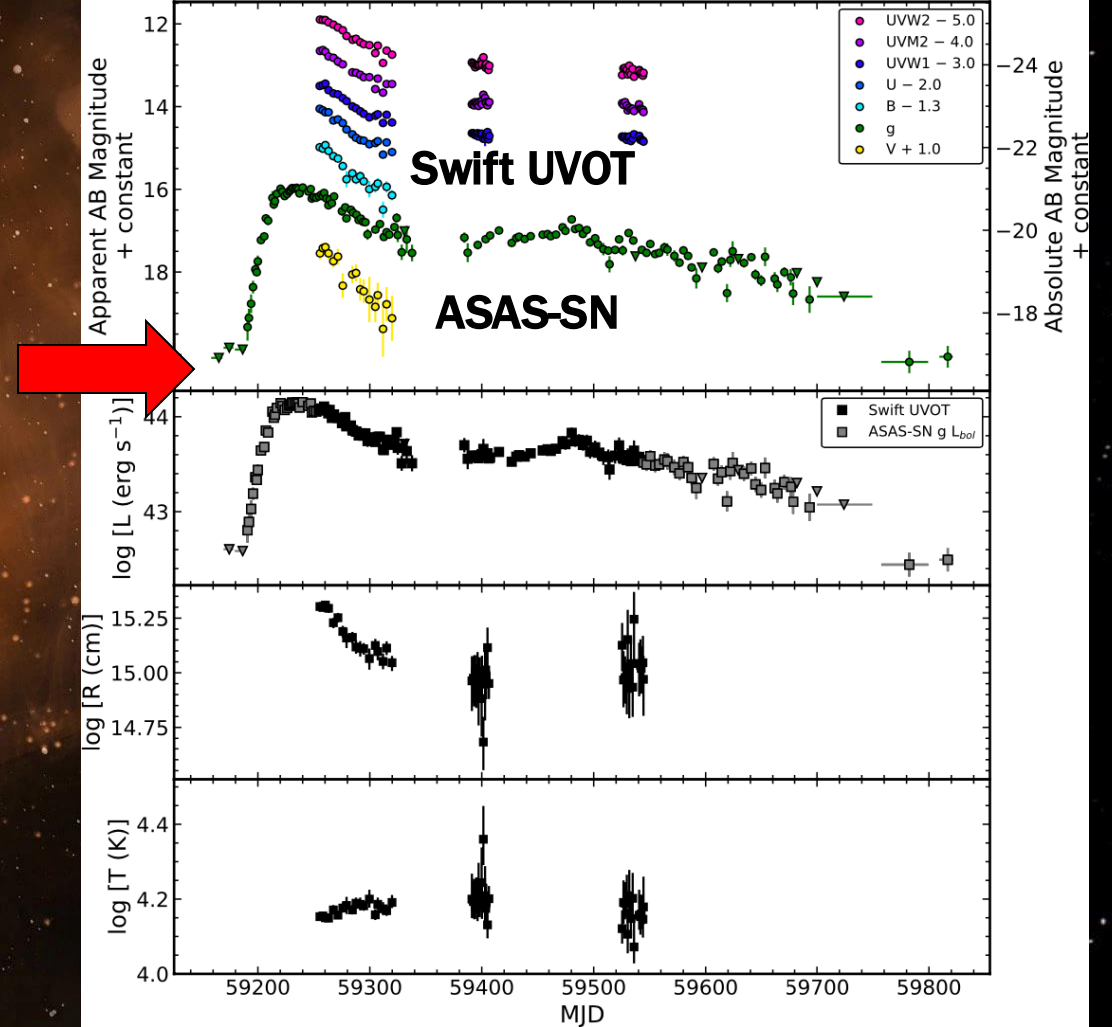
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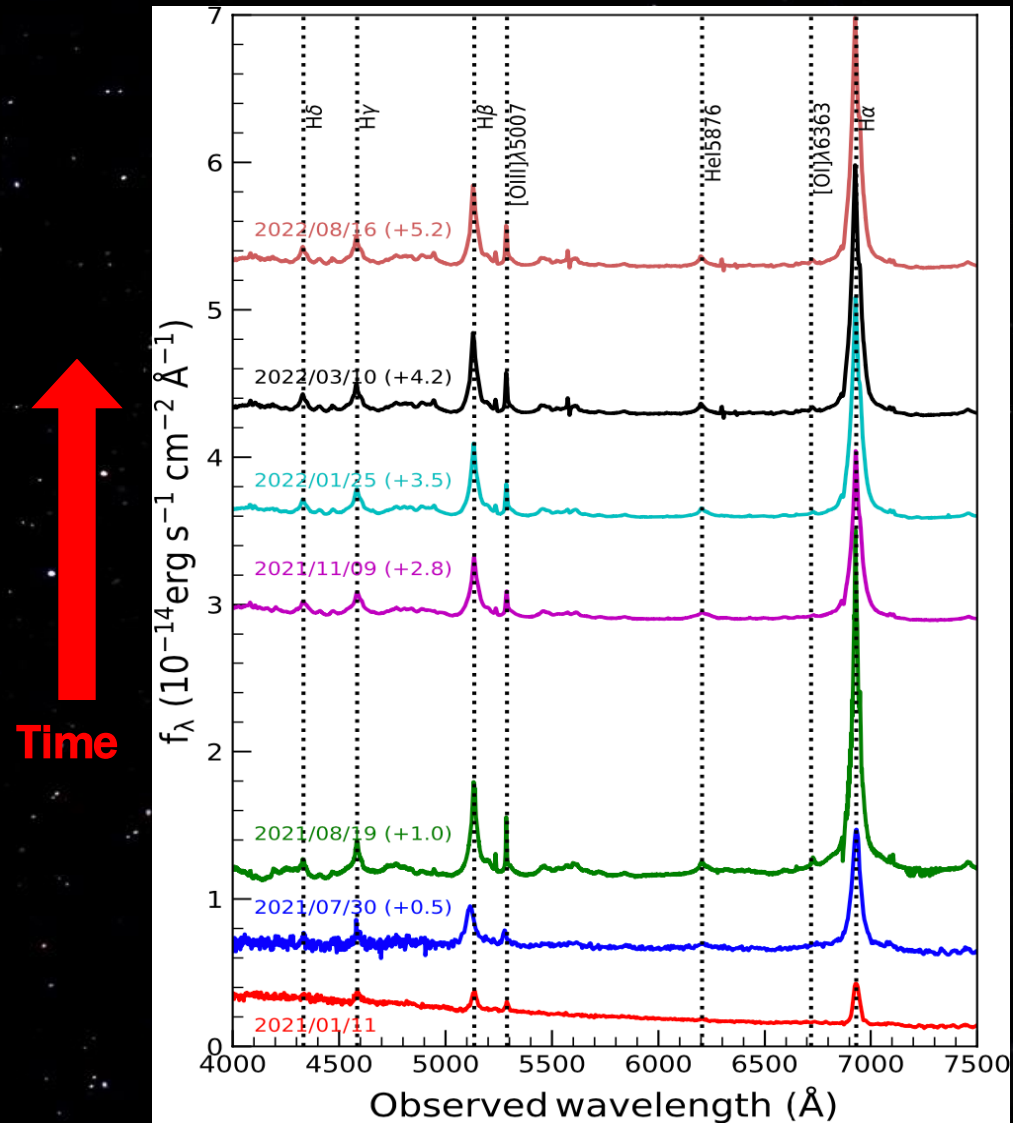
# ASASSN-20qc

(Pasham, Tombesi, Sukova et al. 2024)

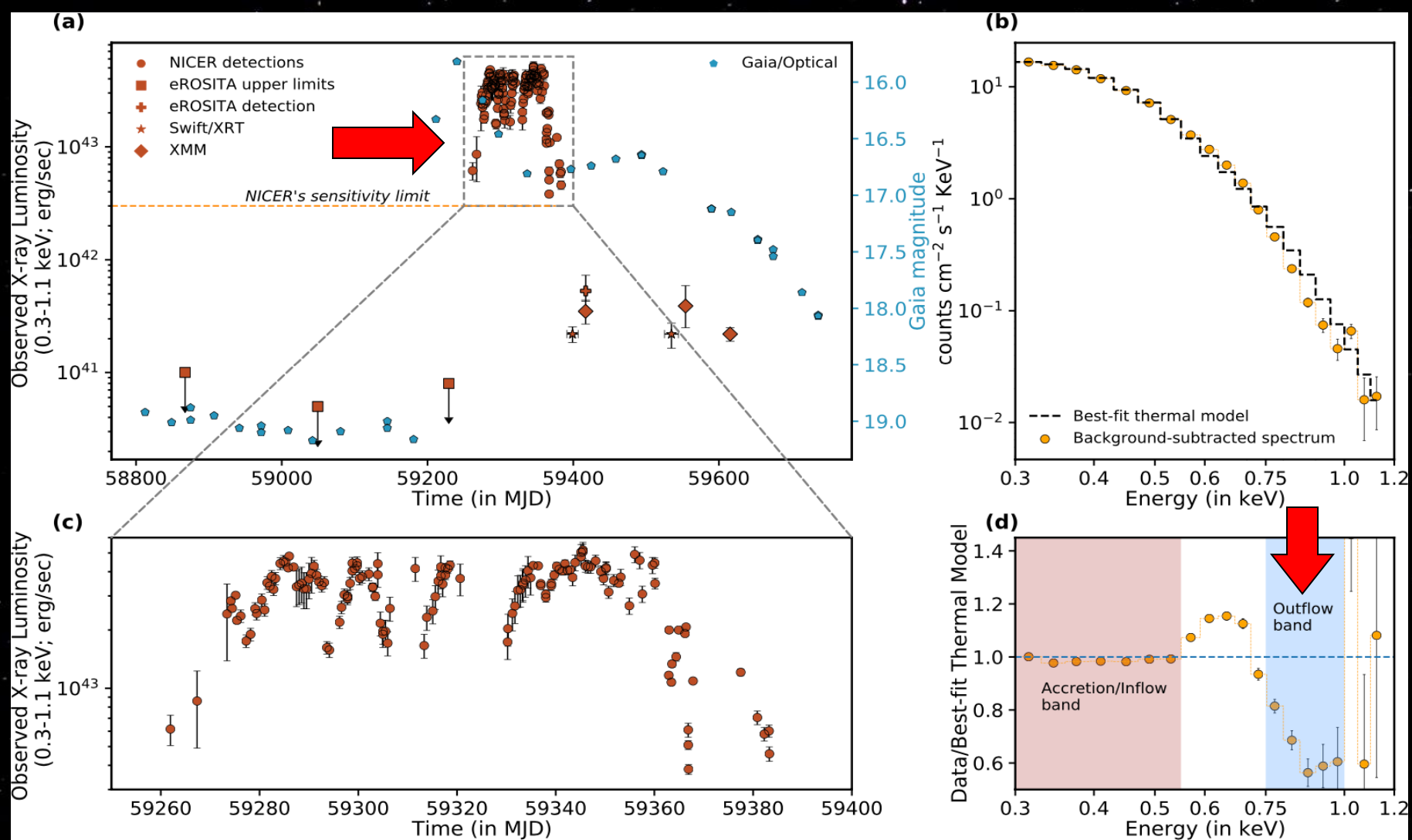


- Astrophysical flare from the nucleus of a galaxy at  $z = 0.056$ .
- Discovered by ASASS-SN in optical on 20 Dec. 2020. Seen also by the Gaia Space Observatory.
- Optical light curve shows smooth rise, peak, and decay on  $\sim 150$  days, broadly consistent with fallback time of debris from a TDE.
- Time evolution of optical/UV bbody temperature and radius during outburst very similar to TDEs.

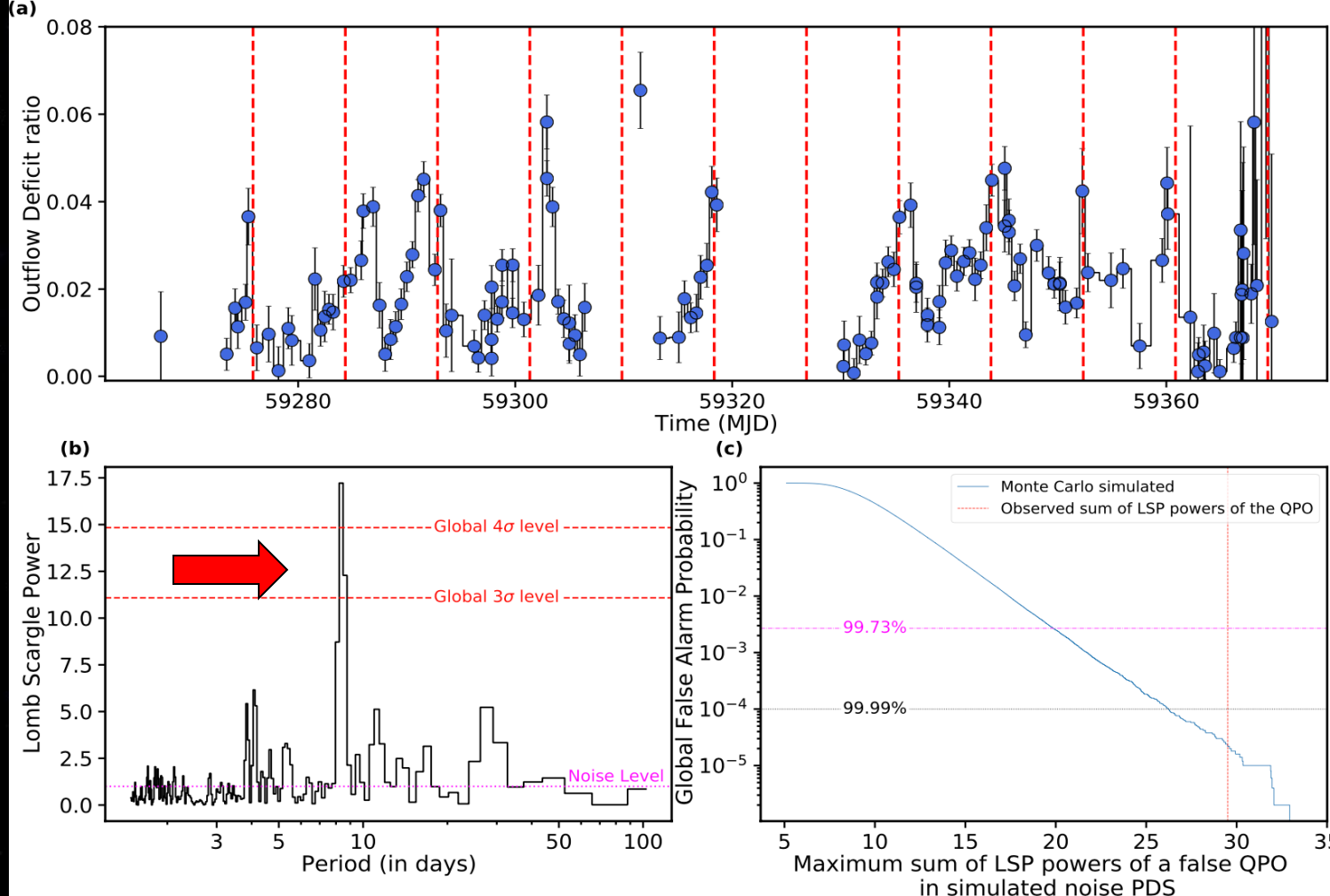
# A Dormant SMBH Waking Up



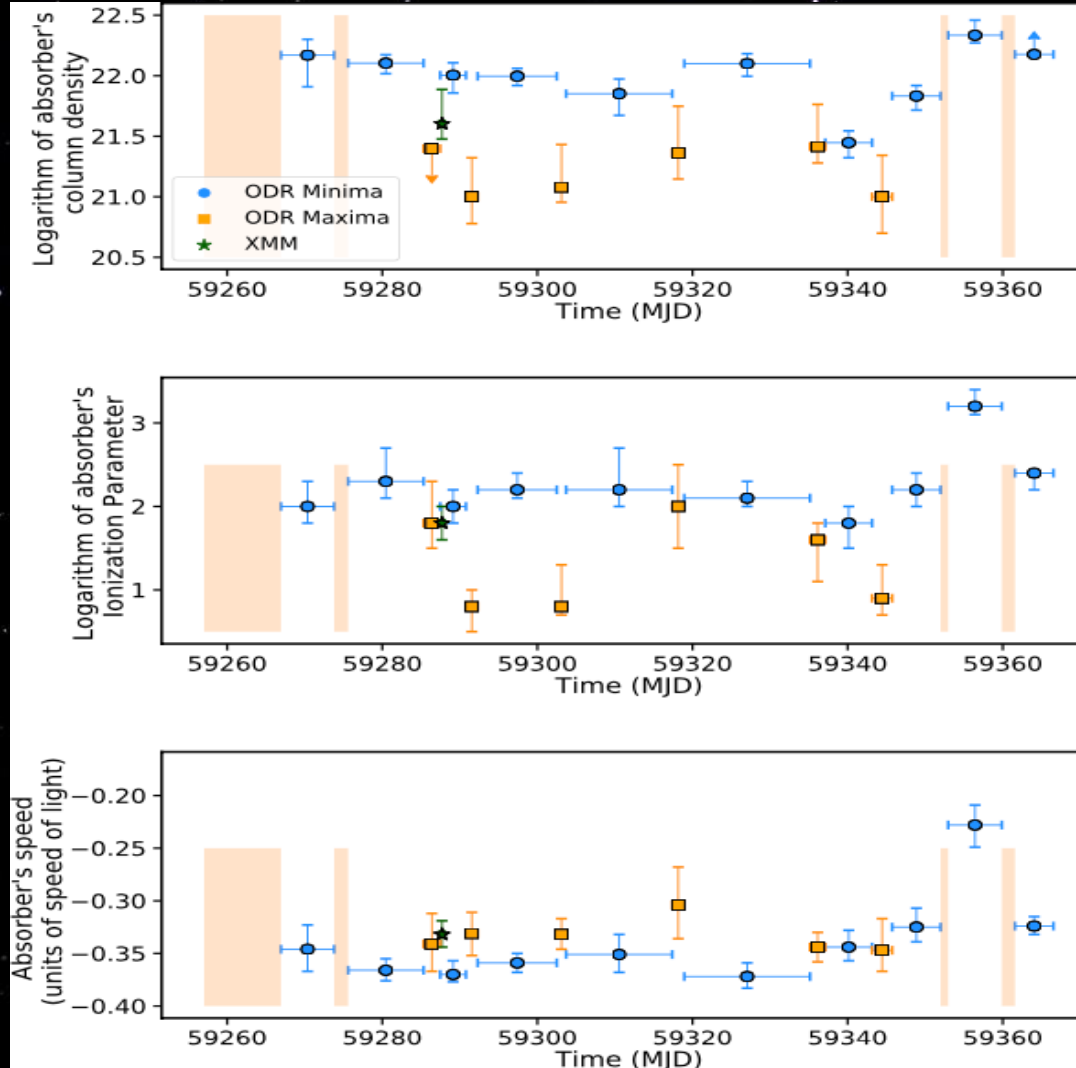
- Follow-up optical spectra show broad H and O emission lines (BLR) increasing in intensity.
- SMBH mass estimated to be  $\log (M/M_{\odot}) \simeq 7.5$ .



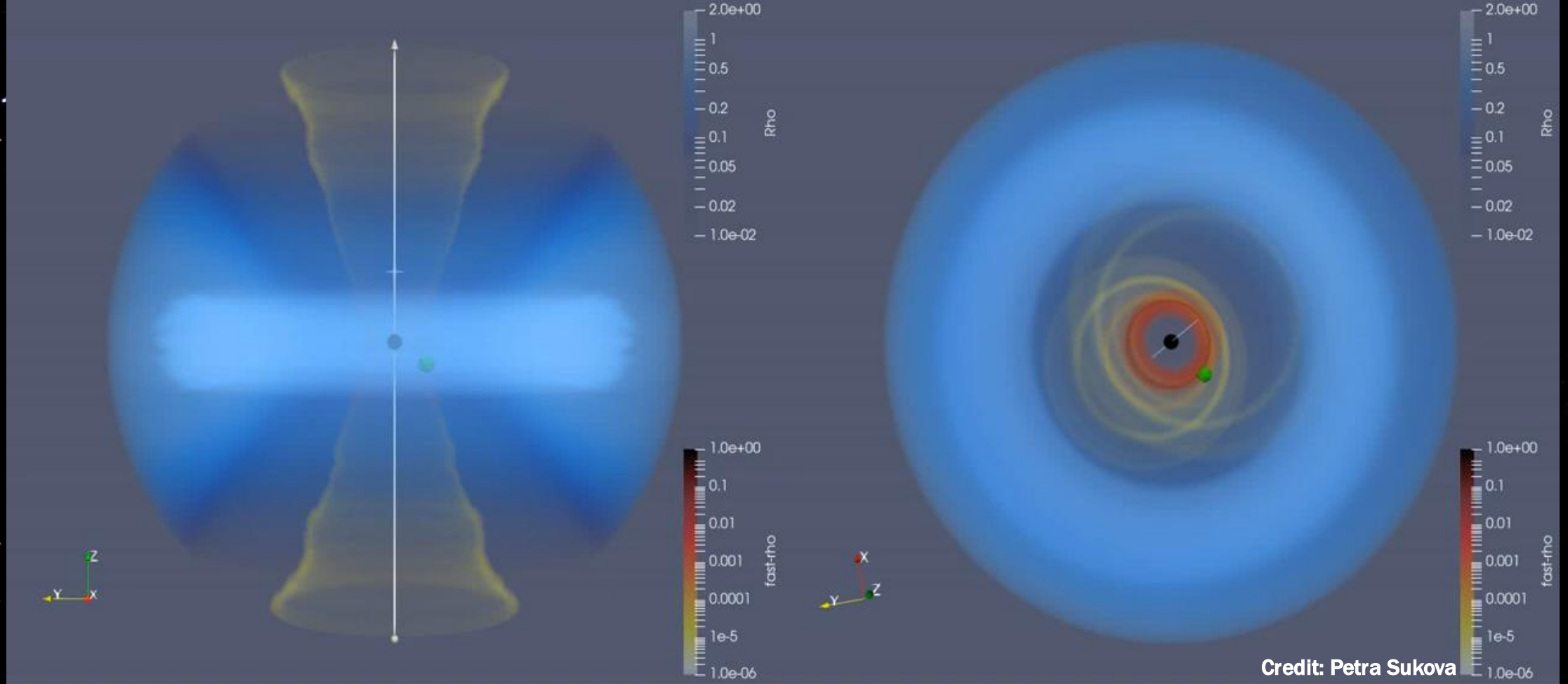
- About two months after optical discovery, Swift detected X-rays and NICER started a high-cadence (one - two per day) monitoring program.
- Time delay between X-ray - optical outbursts and thermal soft X-ray spectrum similar to TDEs.
- NICER and XMM-Newton spectra (0.3-1.1 keV) show black body with broad absorption trough.



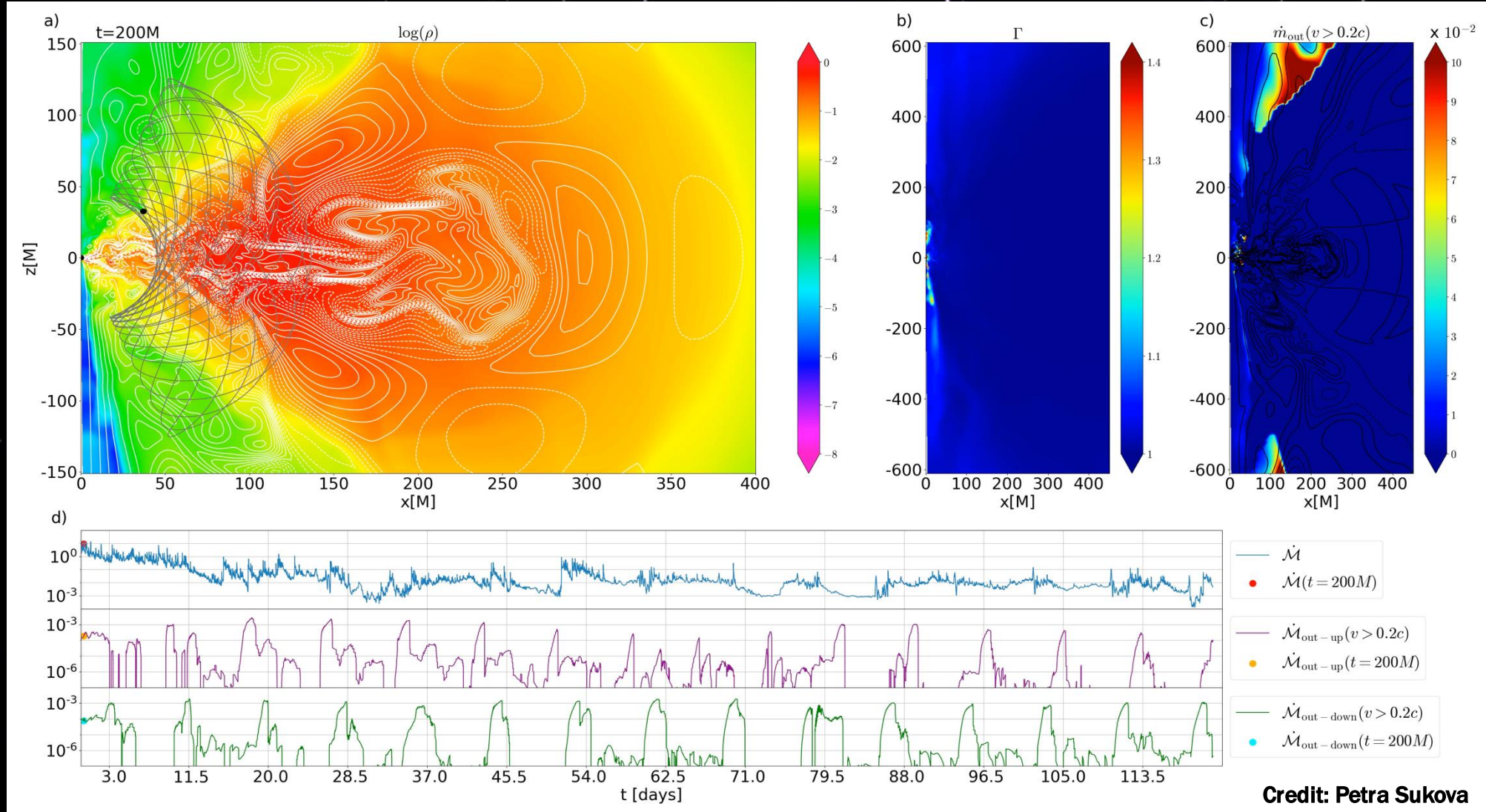
- Time-resolved NICER spectroscopy show variable X-ray absorption.
- Absorption and emission traced by outflow deficit ratio (ODR): counts 0.7-1 keV/0.3-0.5 keV.
- The ODR shows repeating variations with a  $\sim 8.3$ -day quasi-periodicity!!
- Lomb-Scargle periodogram of ODR curve shows peak at  $8.3 \pm 0.3$  days. Confidence level  $>4.2\sigma$  from extensive Monte Carlo simulations.



- Time-resolved NICER X-ray spectra from maxima and minima in the ODR curve.
- Modeling indicates O VIII blue-shifted at  $\sim 30\%$  speed of light: Ultra-Fast Outflow (UFO).
- UFO with  $v \sim 0.3c$  has column density  $10\times$  higher during ODR minima ( $10^{22}$  vs  $10^{21}$   $\text{cm}^{-2}$ ).
- New phenomenon of Quasi-Periodic Outflows (QPOuts)!



- **Several theoretical models considered:** precessing inner disk, clumpy or slow outflow, X-ray reflection, disk instabilities, quasi-periodic eruptions, and repeating partial TDE.
- **All disfavored, except:** close binary system with perturber on inclined orbit with SMBH. **Outflows triggered when secondary crosses primary inner accretion flow.**
- **GRMHD simulations show persistent magnetized outflow from inner disk, mass-loaded periodically when the secondary crosses the primary disk.**



- Extensive GRMHD simulations show QPOuts due to orbiting intermediate-mass black hole (IMBH) with  $M=10^2\text{-}10^4 M_{\odot}$  at  $\sim 100 r_g$  (less than a milli-parsec!) from primary SMBH.
- Electro-magnetic “precursor” of Extreme and Intermediate Mass Ratio Inspirals (E/IMRIs)
- GW emission from ASASSN-20qc weak now, but tighter systems potentially detectable with LISA!



# Many Open Questions ...

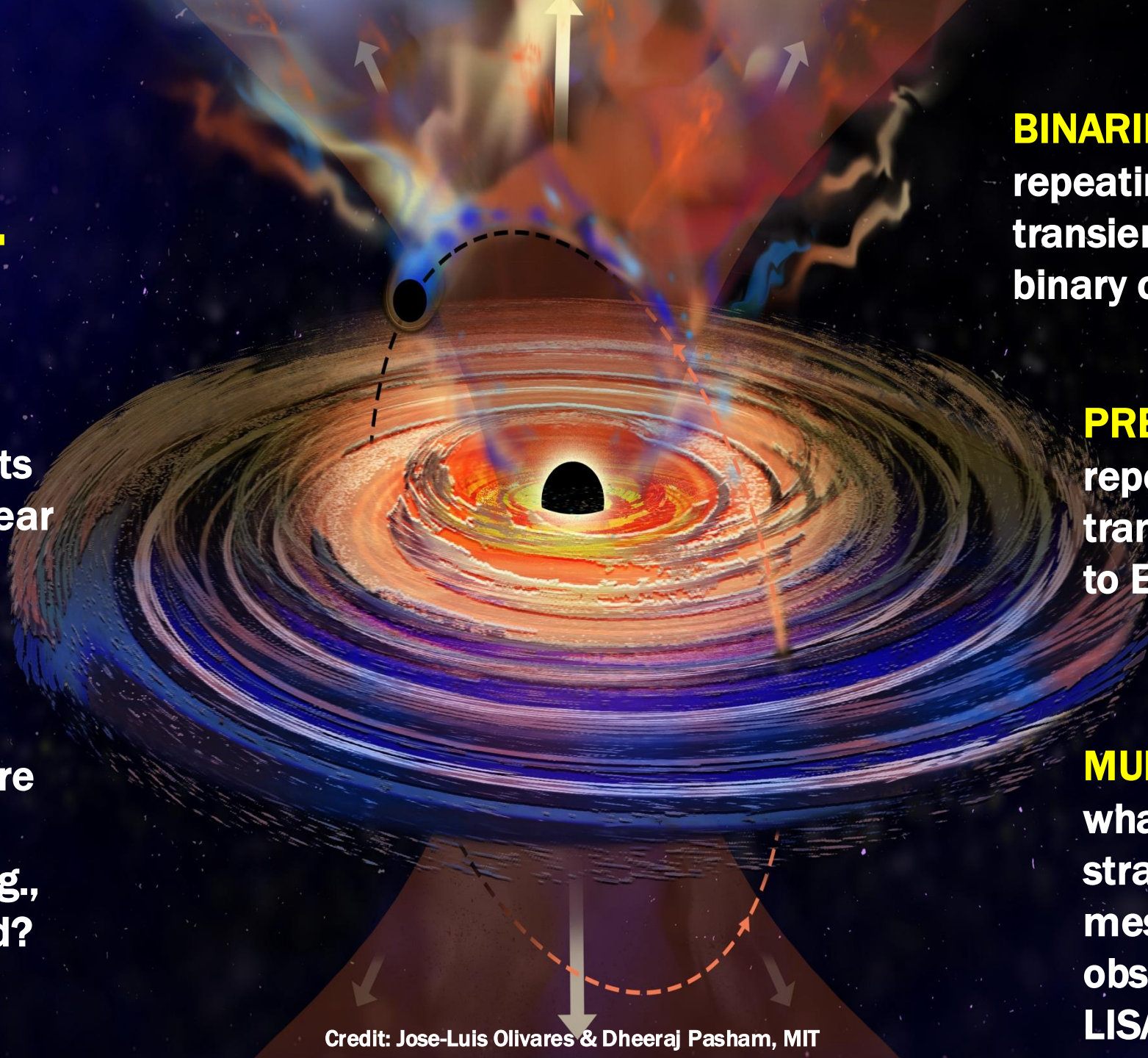
**FREQUENCY:** How common are QPOs and repeating nuclear X-ray transients?

**EM TRANSIENTS:** are X-ray QPOs and other transients (e.g., QPEs, TDEs) related?

**BINARIES:** Are all of repeating nuclear transients related to binary compact objects?

**PRECURSORS:** are repeating nuclear transients precursors to EMRI/IMRI?

**MULTI-MESSENGER:** what are the best strategies for multi-messenger observations with LISA?



A black hole is depicted in the center, surrounded by a glowing, multi-colored accretion disk. The disk transitions from blue and purple on the left to yellow and orange on the right. A bright jet of light is shown emanating from the top of the black hole. The background is a dark space filled with stars and a nebula.

Thank you for your attention!