BLACK HOLE LOW-MASS X-RAY BINARY: 4U 1755-338

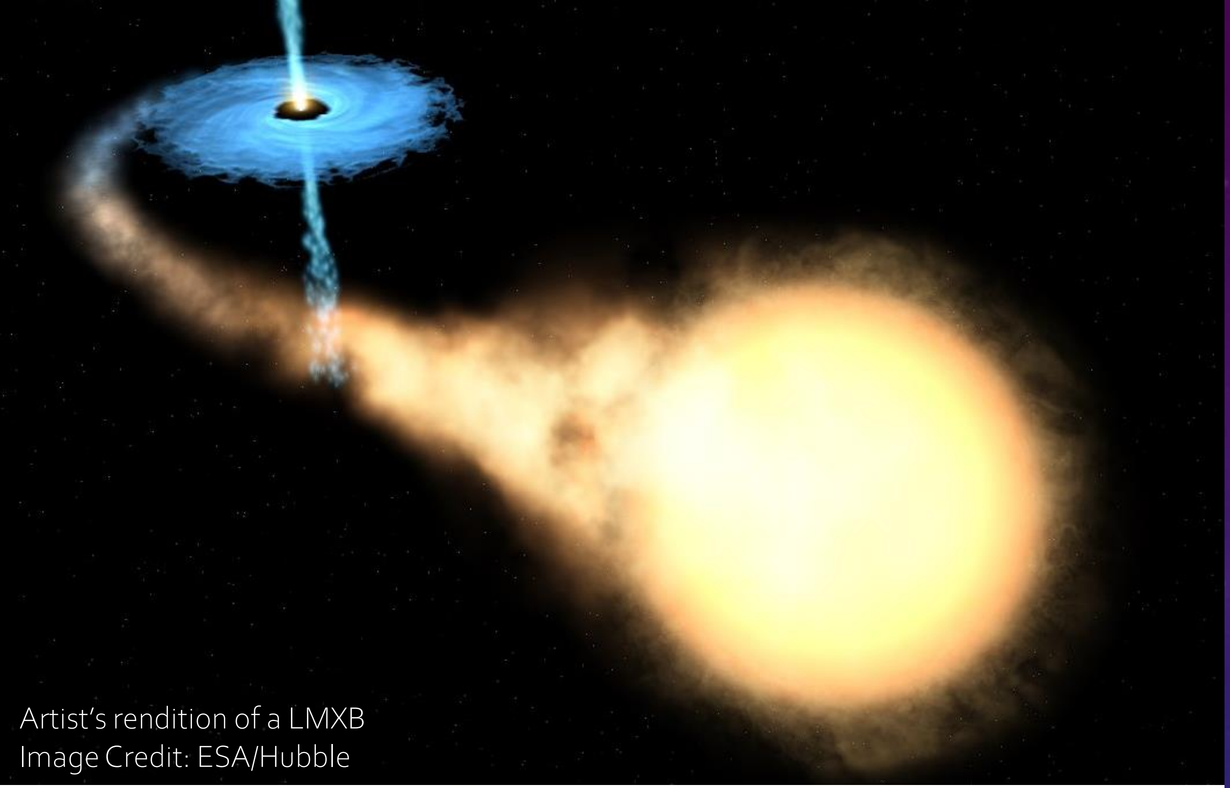
Long-term Monitoring with NICER.

Skye Heiland

OUTLINE

- What is a low-mass X-ray binary (LMXB)?
  - Introduction to 4U 1755-338
  - The observational side of things
- Properties of black hole (BH) LMXBs
  - Spectral states and the hardness-intensity diagram (HID)
  - Quasi-periodic oscillations (QPOs)
  - Time and reverberation lags
- Future planned work
  - Direct mass measurements

WHAT IS A LMXB?


Artist's rendition of a LMXB
Image Credit: ESA/Hubble

- A compact object and a faint star $(\leq 1\ \mathrm{M}_\odot)$ orbiting each other.
  - Companion star (usually) feeds its compact neighbour via Roche-lobe overflow.
  - Creates a hot accretion disk that shines in the X-ray, and a much sparser corona.
  - Distributed towards the center of the galaxy – but can be displaced substantially over time.
- Further classified based on a multitude of factors.
  - Persistent or transient?
  - Nature of the compact object.
  - Faint or very luminous?

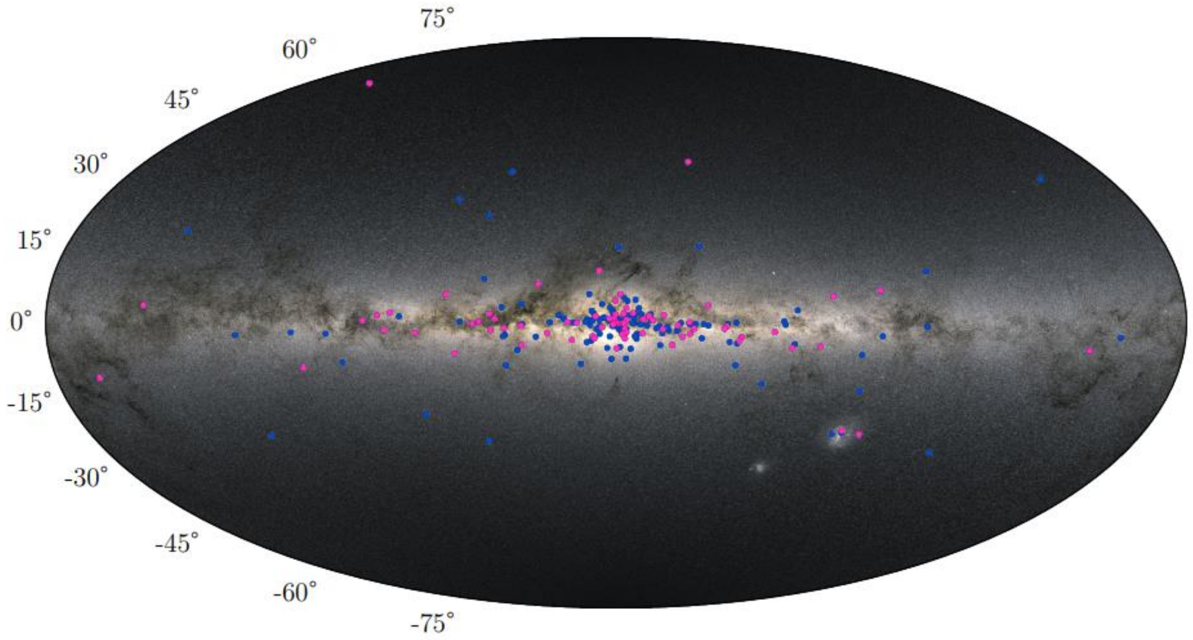
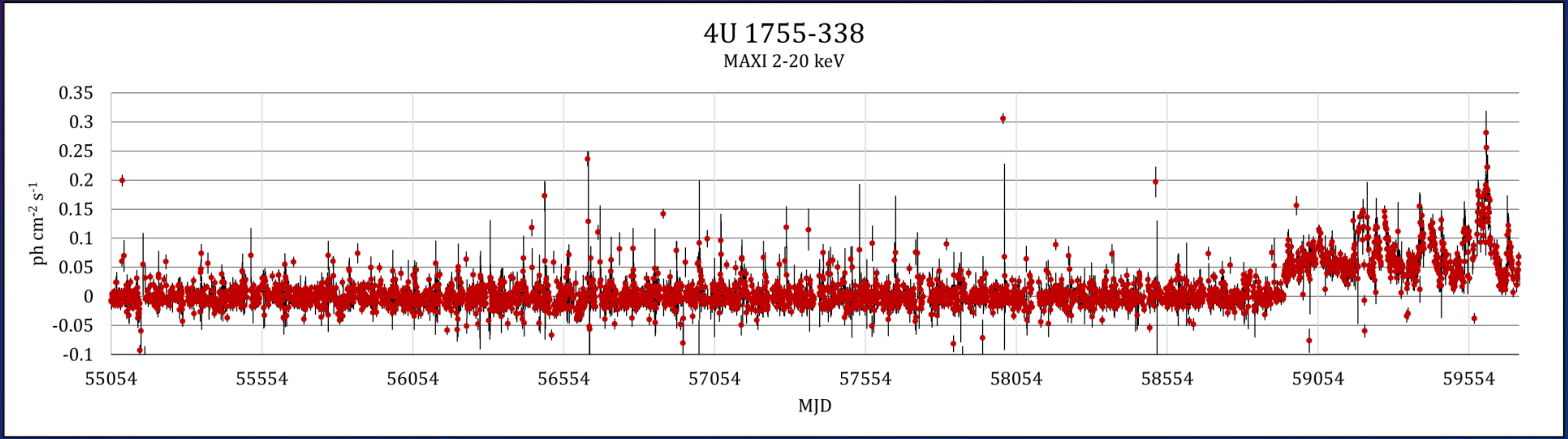


Fig. 9 from Bahramian & Degenaar (2022) showcasing the spatial distribution of LMXBs in our galaxy .

OUR SOURCE: 4U 1755-338

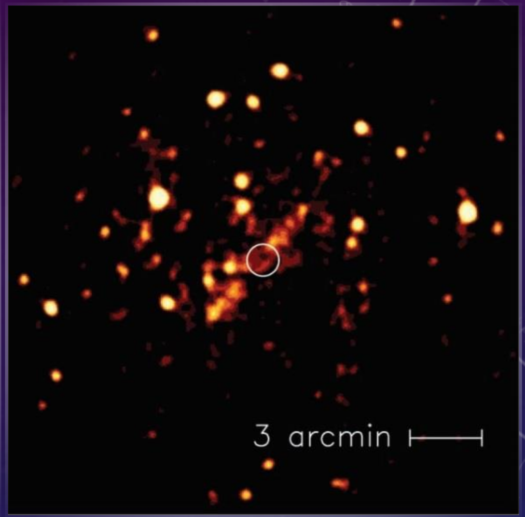
- "Quasi-persistent" BH LMXB.
- Originally discovered in the late 1960s, remained prominent and persistent for ~30 years.
  - "Ultrasoft" x-ray spectrum with a hard x-ray tail, much like other black hole candidates of the time. (White et al. 1984, Pan et al. 1995).
  - Observations by Rossi in 1996 revealed that it had "turned off," flux cut by roughly two orders of magnitude.
  - Remained quiescent until April 2020 when it began outbursting again – remains bright to this day!



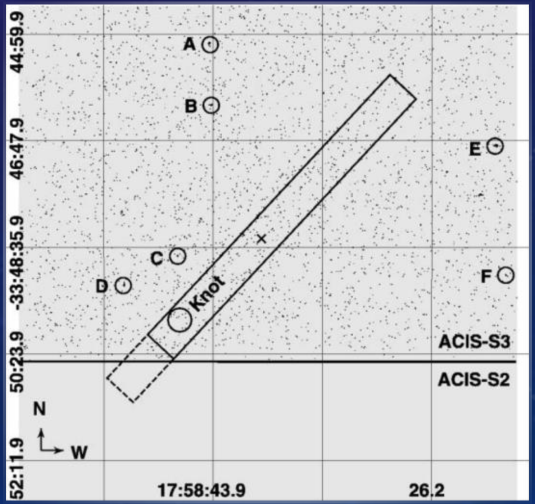
2-20 keV MAXI light curve from August, 2009 to present.

OUR SOURCE (CONT'D)

- Observations by XMM-Newton during quiescence (Angelini & White, 2003)
  - Long "fossil" jet-like features, later confirmed to be diffuse by Chandra; most likely synchrotron emission (Park et al. 2005).
  - Further evidence of this being a galactic BH.
- The big question: What caused such an extended quiescent period?
  - A little hard to answer, so let's break this down into smaller questions.
  - First, how are we observing our source?

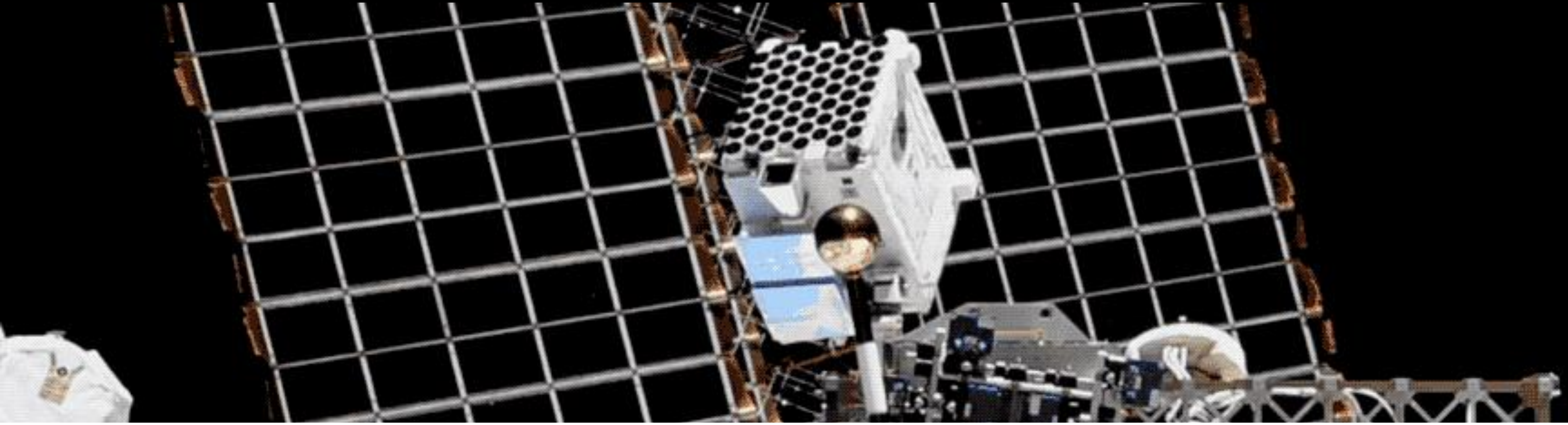


XMM-Newton Image presented by Angelini & White (2003). 4U 1755-338 is marked by the white circle.



Chandra image presented by Park et al. (2005) of the same subject. The rectangular region outlines the jets of the above image.

OBSERVING WITH NICER



NICER aboard the ISS
Image Credit: NASA

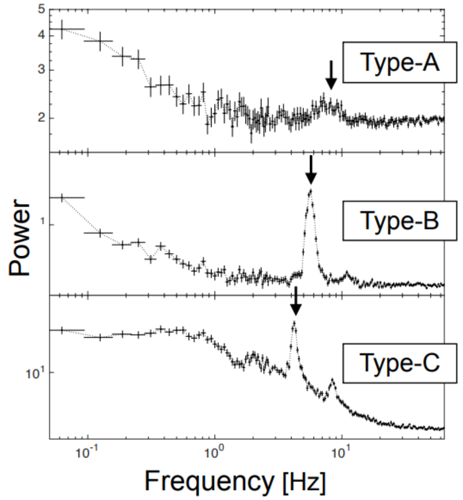
- **N**eutron Star **I**nterior and **C**omposition **E**xplorer – it almost makes sense.
- An array of 56 X-ray detectors and focal plane modules (FPMs) launched in 2017 – 50 in practice.
    - Each captures photons and records their energy, as well as time of arrival to within $300\ \mathrm{ns}$ of UTC.
    - Bandpass of $0.2 - 12.0\ \mathrm{keV}$ with an effective area of $\sim 1900\ \mathrm{cm}^2$ at $1.5\ \mathrm{keV}$.
    - Allows for very high count rates with negligible deadtime effects.
- Has been observing our source for approx. 2 years, with 92 observations to search through.

SOME PROPERTIES OF BH LMXBs

and some of our results.

QUASI-PERIODIC OSCILLATIONS

- One of the most commonly referenced phenomena regarding XRBs.
- As their name would suggest, oscillations that have a *variable* period, often accompanied by harmonics.
  - Show up as broad peaks in the *power spectrum* (DFT) of a light curve.
  - Come in several types, A, B, or C; classified based on frequency range, amplitude, quality factor, and harmonics.
  - Physical origin is still up for debate!



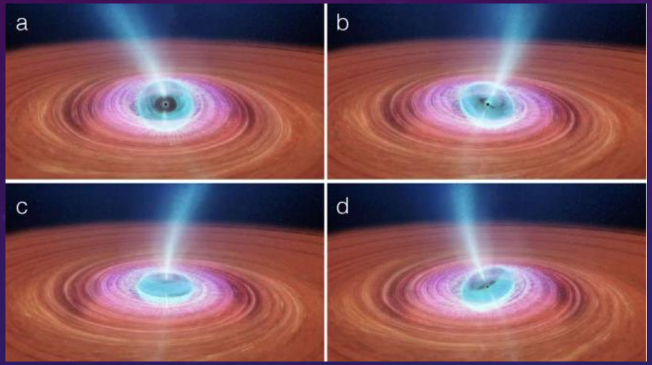
	A	B	C
ν	~6 Hz	~6 Hz	0.1-30 Hz
Q	1-3	$\gtrsim 6 (\gtrsim 2)$	$\gtrsim 6 (\gtrsim 2)$
rms	$\sim 1 - 5\%$	$\sim 1 - 10\%$	$\sim 1 - 25\%$
noise	weak red	weak red	strong flat-top

Fig. and table from Motta et al. (2011 and 2015) characterizing different types of LF QPOs.

ORIGIN OF QPOs

Two big models!
(For type C QPOs)

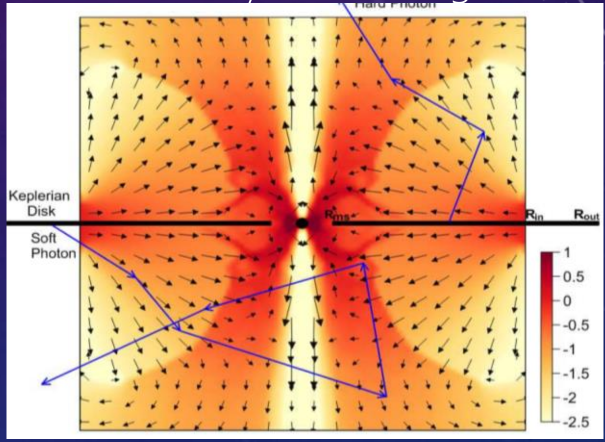
Lense-Thirring Precession



Ingram & Motta (2020)

- Relativistic frame-dragging effect.
- Assumes that the accretion disk is misaligned to the BH spin axis, causing matter to precess with frequency
$$\nu_{LT}(r) \propto r^{-3}$$
- Causes rapid change in inclination angle towards the observer – frequency evolves as truncation radius changes.

Oscillatory Shock Regions



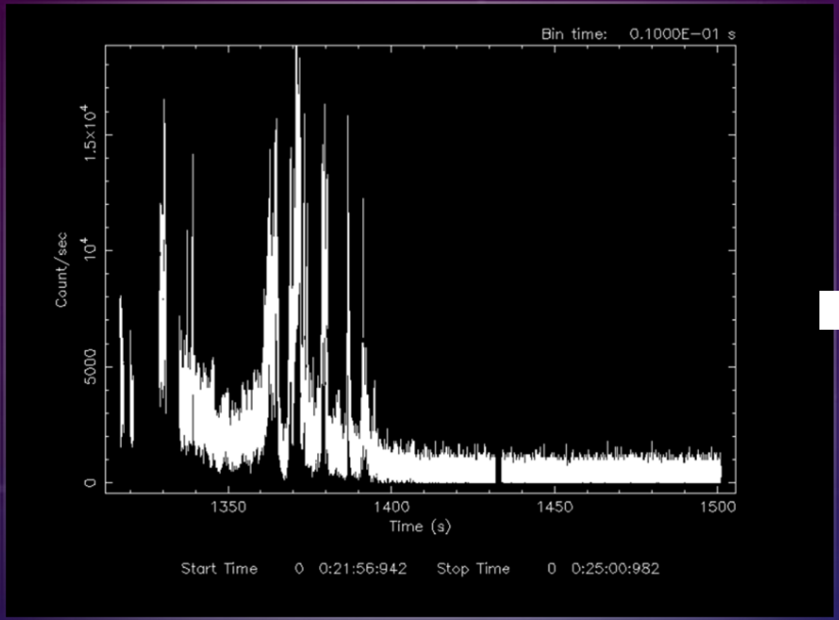
Garain et al. (2013)

- Result of infalling matter forming a shock region.
- Assumes a TCAF model: an Keplerian accretion disc sandwiched by a sub-Keplerian corona w/ different accretion rates.
- Causes a shock and sharp change in density between the pre- and post-shock disc that oscillated around some mean radius r_{shock}.

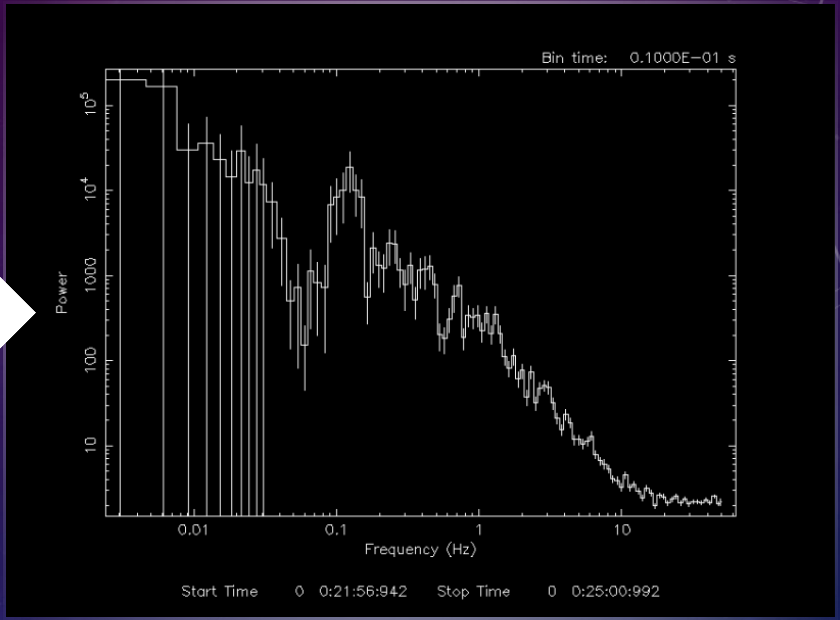
OUR QPOs

Obs ID: 5201080108
April 2022

0.3 – 10.0 keV light curve

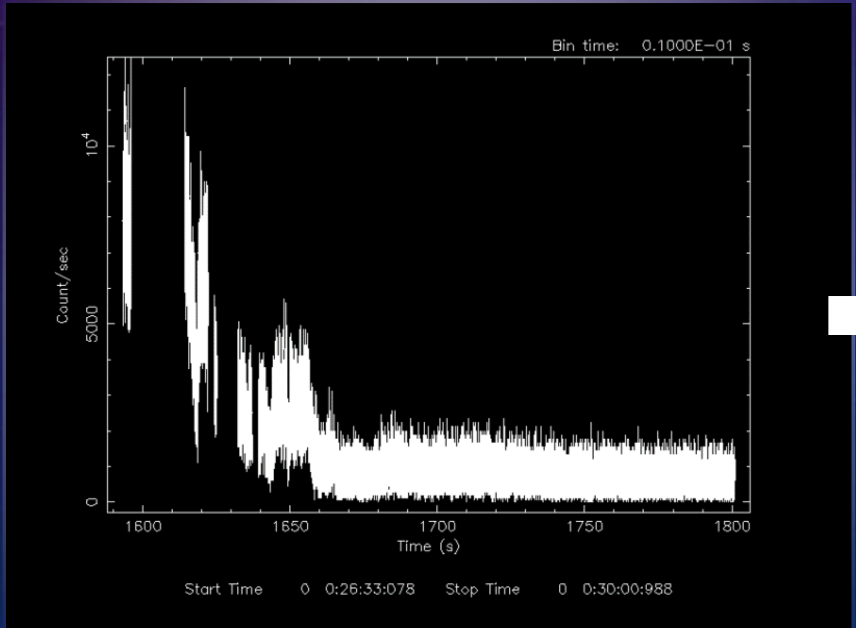


DFT

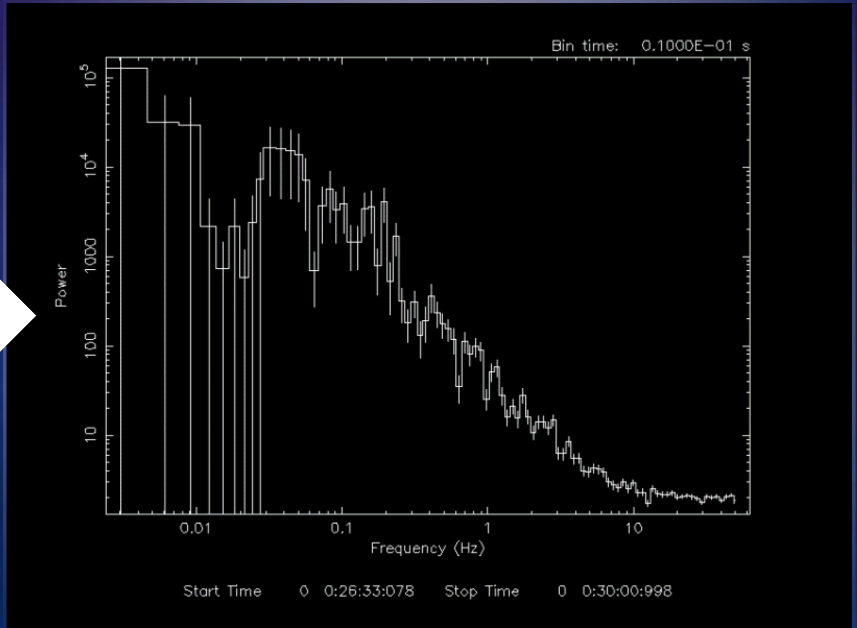


Obs ID: 4201080116
June 2021

0.3 – 10.0 keV light curve



DFT



TIME LAGS

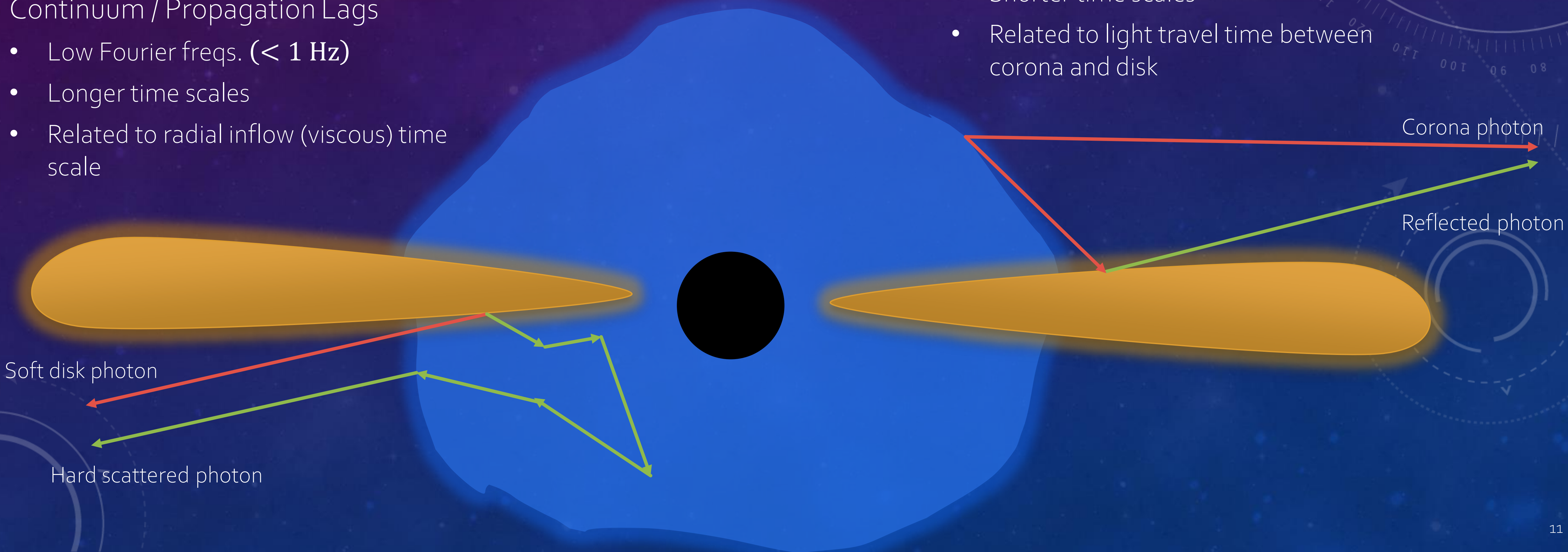
- Information also contained in the phase difference between light curves in different energy bands!
  - Two distinct types of lags:

Reverberation Lags

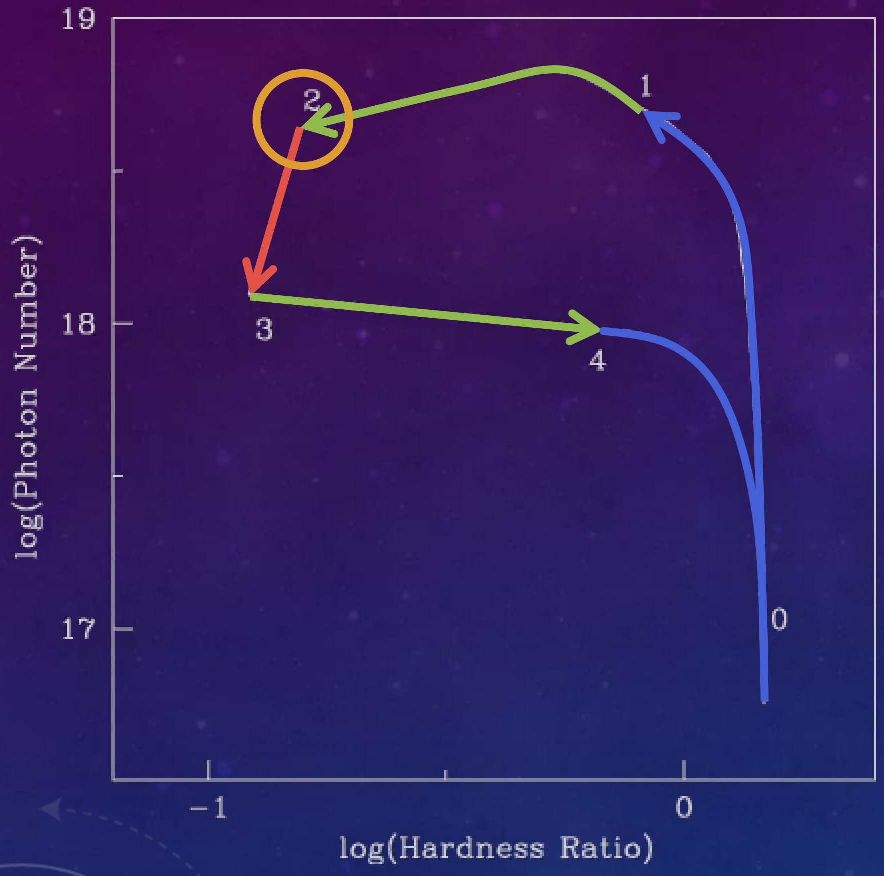
- High Fourier freqs. $(> 1\ \mathrm{Hz})$
- Shorter time scales
- Related to light travel time between corona and disk

Continuum / Propagation Lags

- Low Fourier freqs. $(< 1\ \mathrm{Hz})$
- Longer time scales
- Related to radial inflow (viscous) time scale



SPECTRAL STATES AND THE HID



- When BH LMXBs flare up, they typically follow a specific track on a hardness-intensity diagram (left)
  - Sometimes called the BHB "Hysteresis Loop" or the "q"

Hard State:
- Hardest corona, weak disk
- Compact radio jet
- Prominent Fe-K line
- Highest RMS; Type-C QPOs and reverb. lags

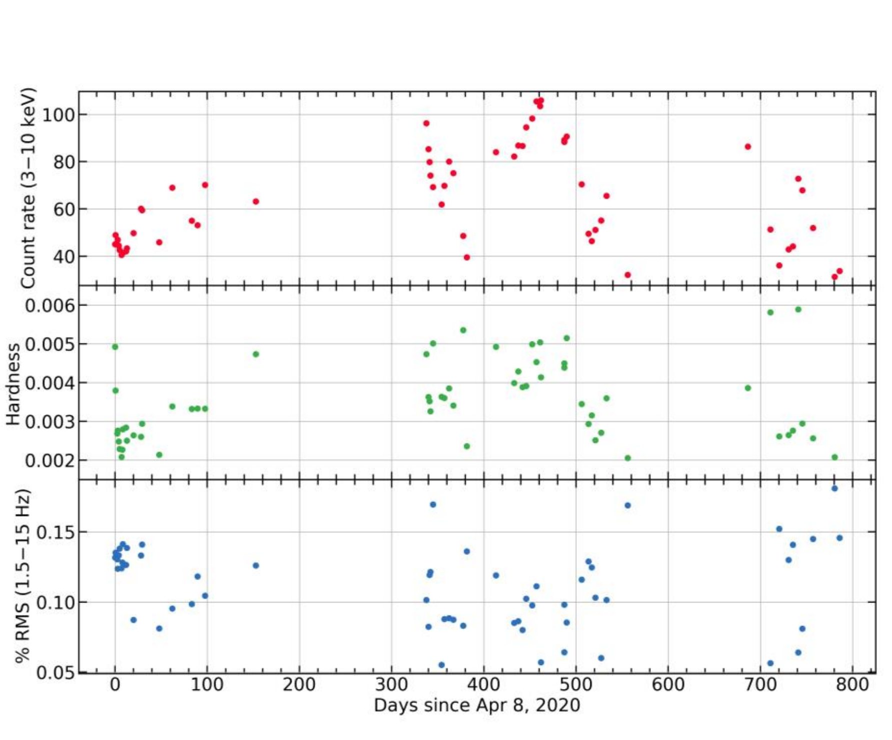
Hard-Intermediate State:
- Softening corona, stronger disk
- Compact radio jet disappears
- Prominent Fe-K line
- High RMS; Type-C QPOs and reverb. lags

Soft-Intermediate State:
- Still softer corona, stronger disk
- Ballistic radio jet
- Prominent Fe-K line
- Low RMS; Type-B QPOs

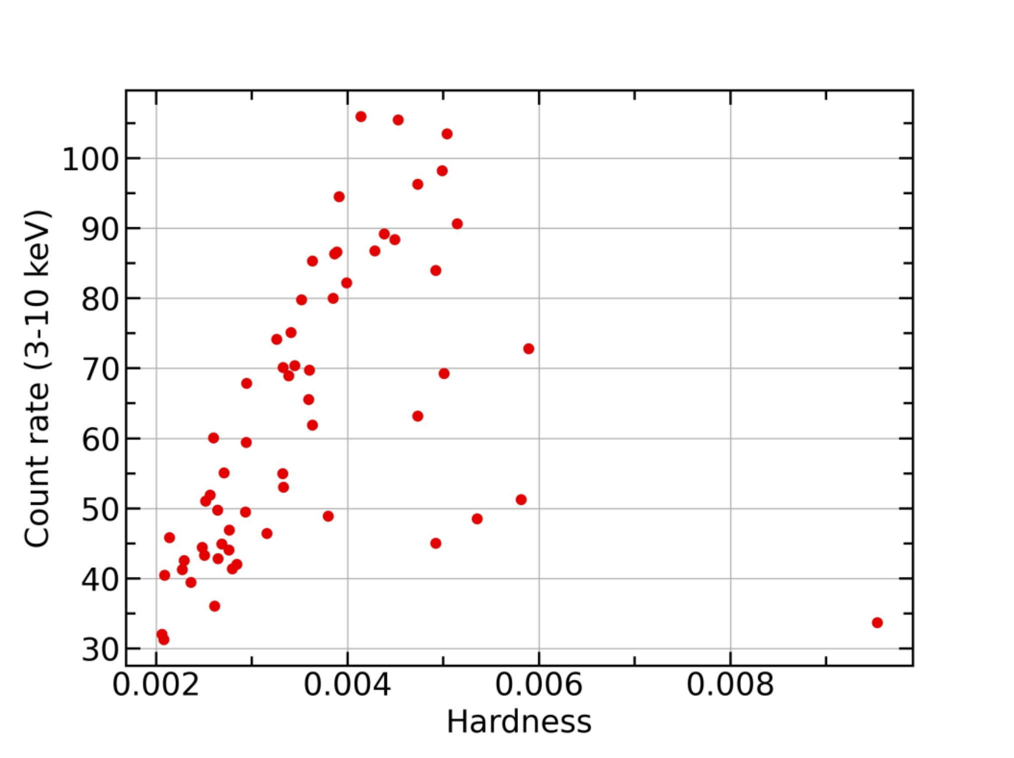
Soft State:
- Weak corona, strongest disk
- No radio jet, equatorial winds
- Less prominent Fe-K line
- Lowest RMS; rare Type-A QPOs

PERSISTENT SOFT STATE

- Hardness: $7 - 10\ \mathrm{keV}$ vs. $1 - 2\ \mathrm{keV}$
  - Source is very soft, and staying that way.
  - Low RMS, also consistent with soft state.



Code repurposed from Stevens et al. (2018)



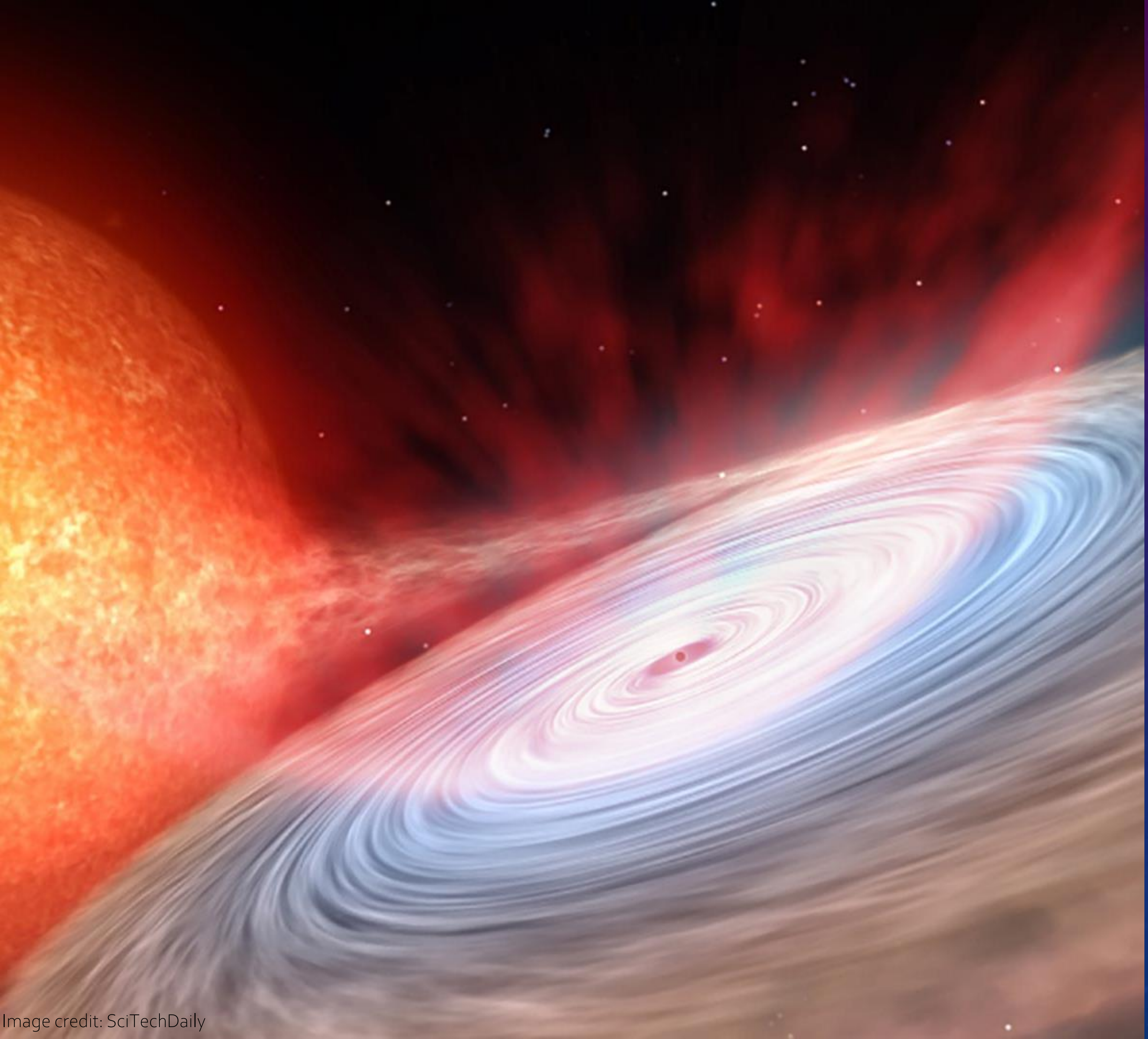


Image credit: SciTechDaily

WHAT'S NEXT?

- Our investigation is far from over
  - Working to automate our search for time lags and QPOs in code.
  - BH mass still unknown, would be very useful to know.
  - Numerical simulations to reproduce spectral data during flaring events will tell us about accretion geometry.

THANK YOU FOR YOUR ATTENTION!

Questions?