Characterizing the Black Hole Candidate AT2019wey using *NICER* and Multi-wavelength Observations

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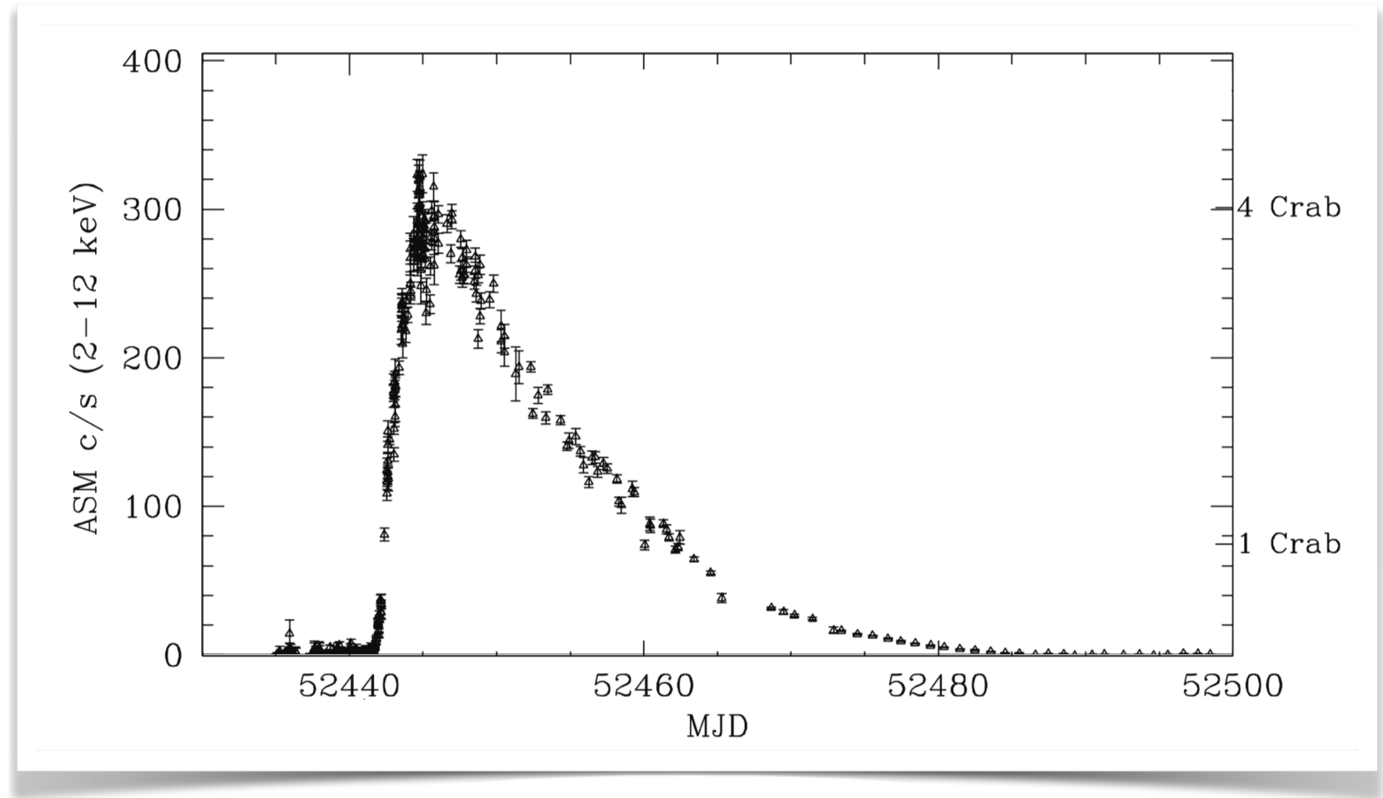
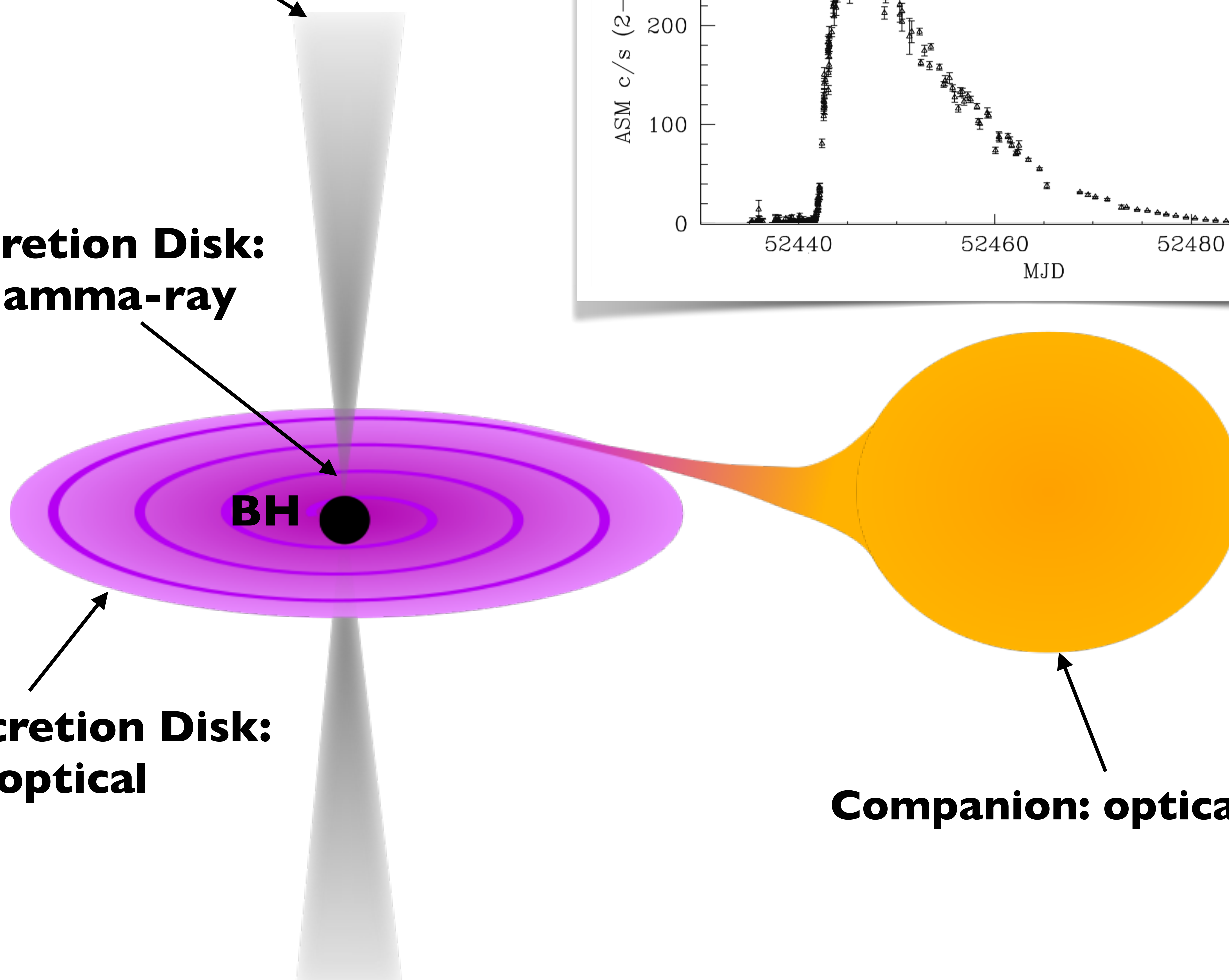
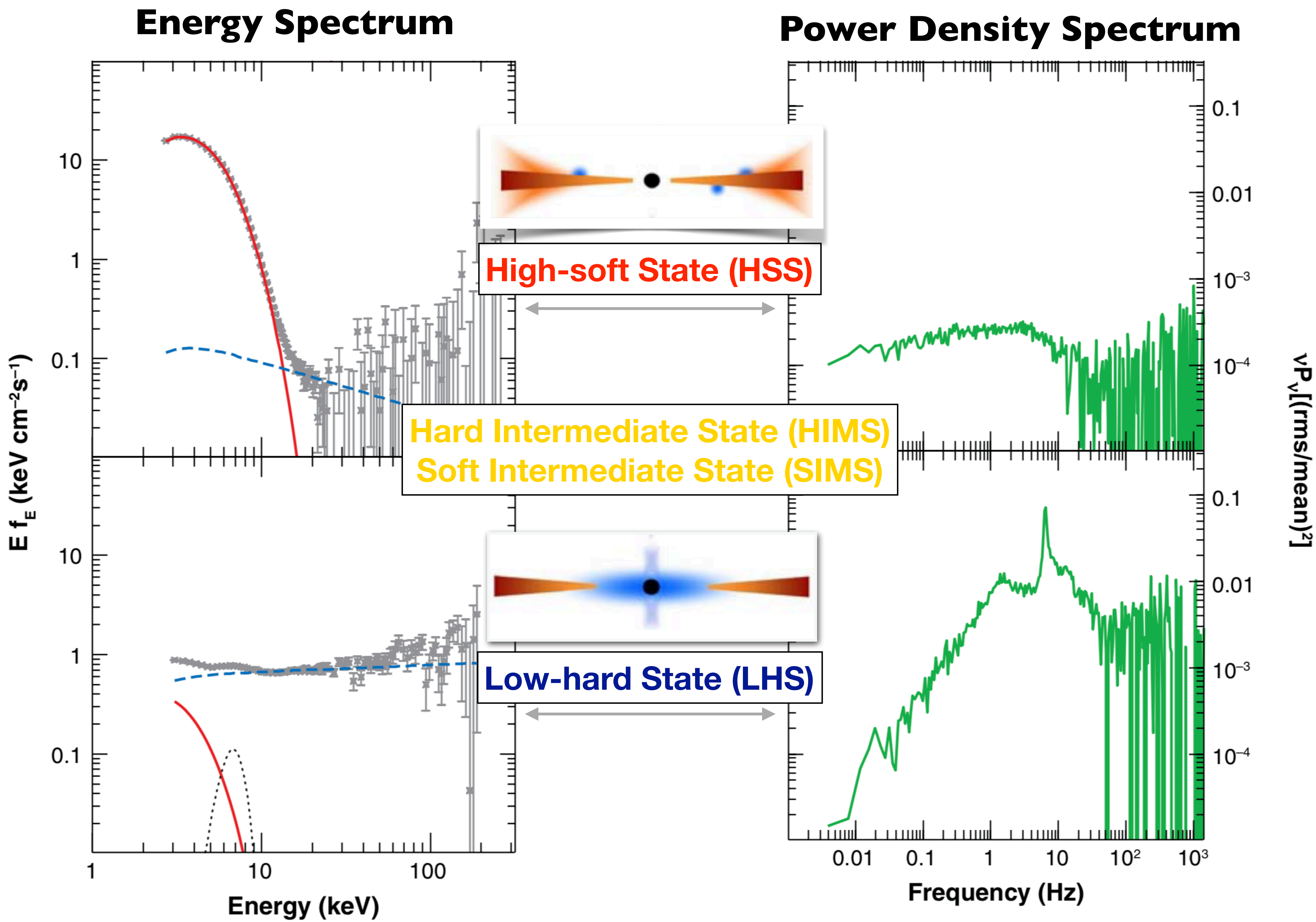
Galactic Low-mass Black Hole Binaries (LMBHBs)





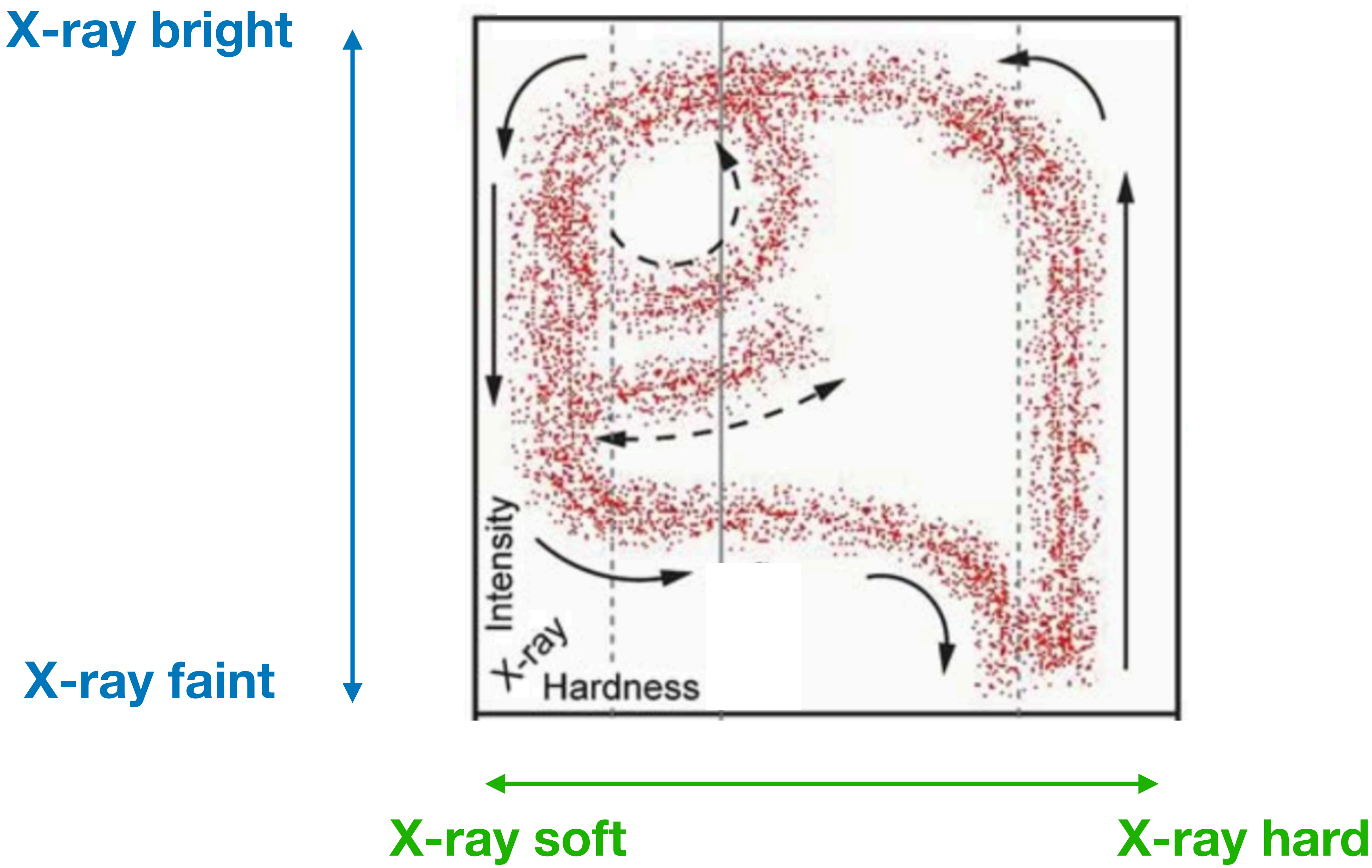
LMXBs: State Transition

Remillard & McClintock+2006



LMXBs: State Transition

Remillard & McClintock+2006

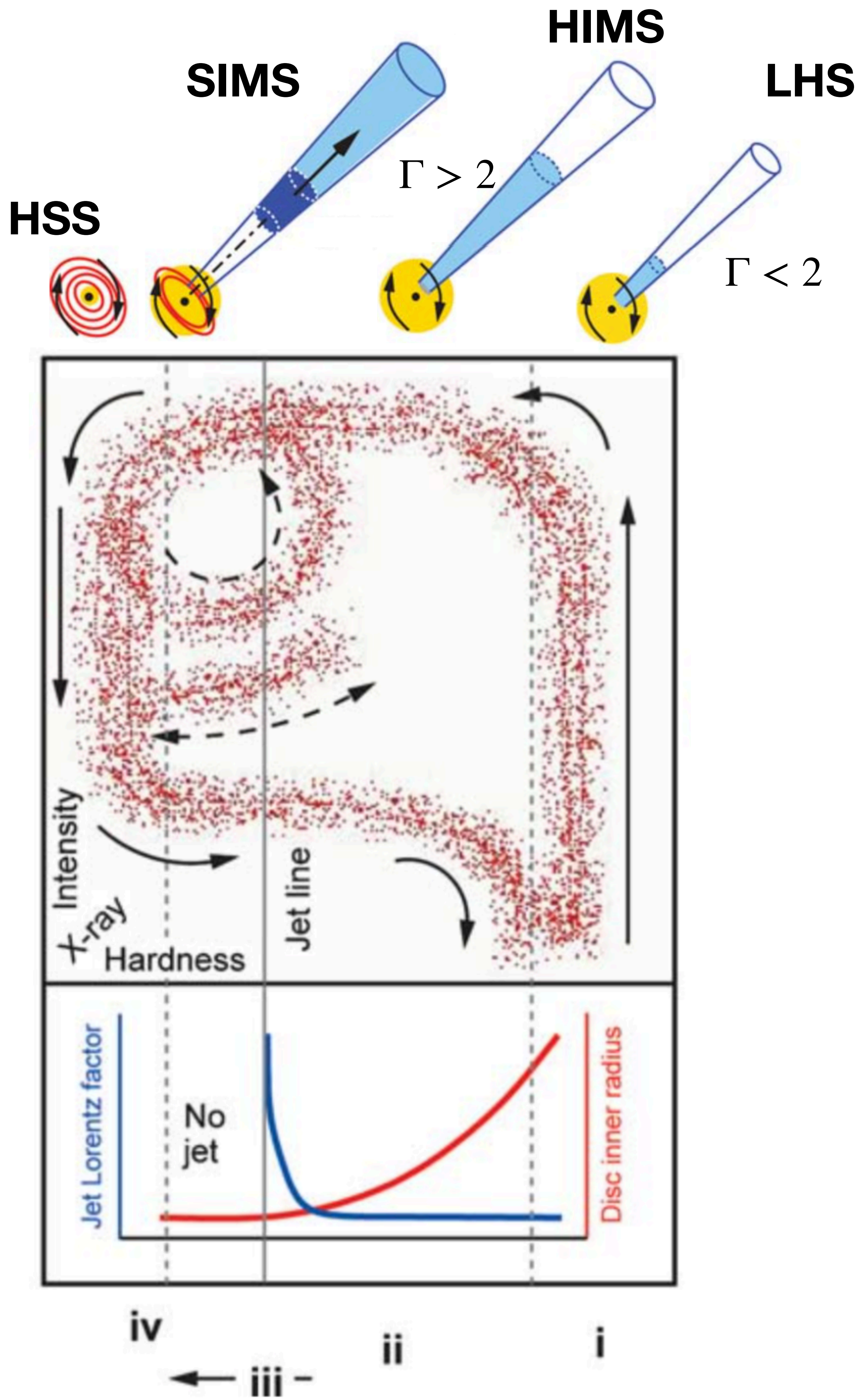


A hysteresis ("q"-shape) loop on the hardness—intensity diagram (HID)

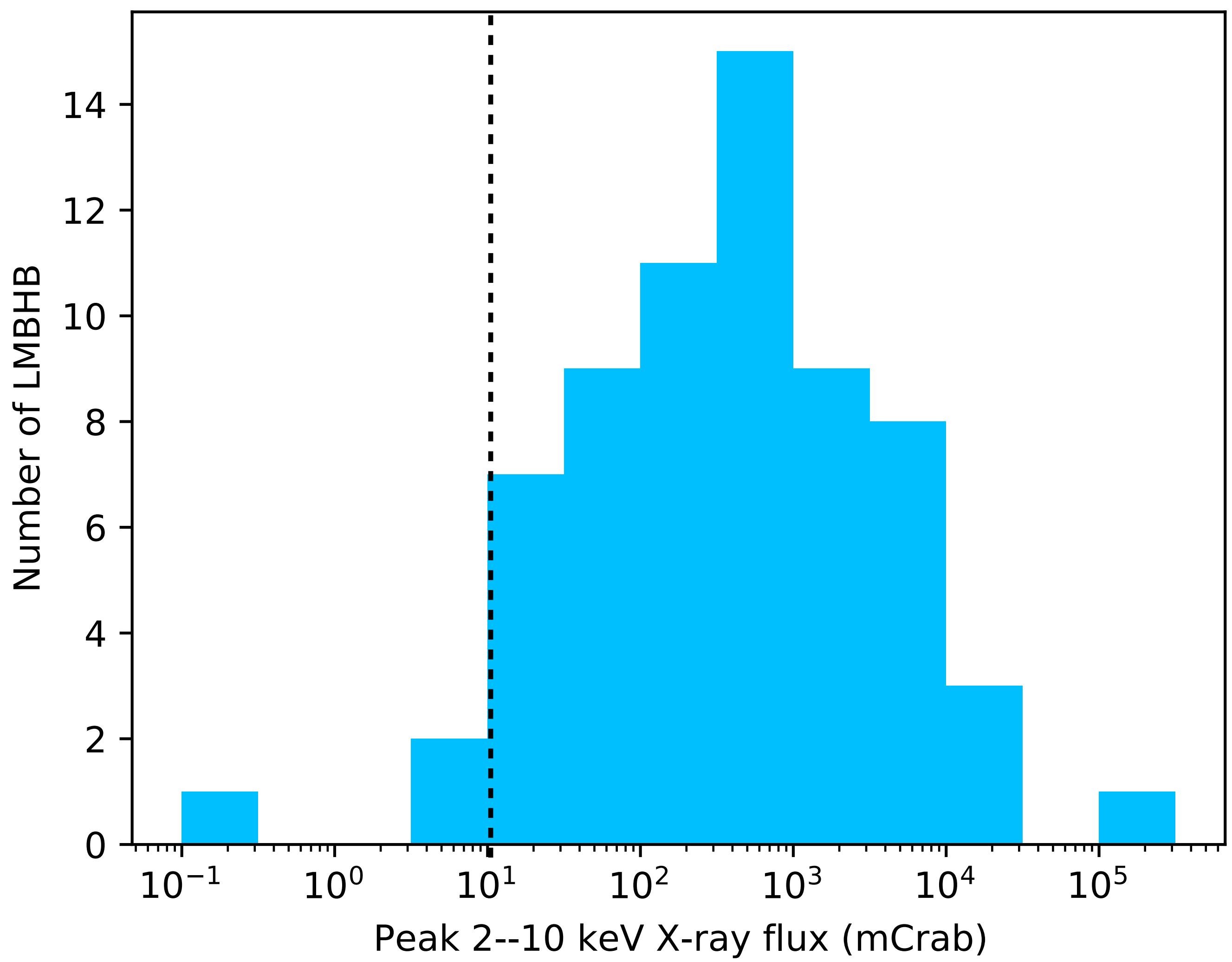
quiescence → LHS → IMS → HSS → IMS → LHS → quiescence

LMXBs:
Disk-Jet Coupling

Fender+2004



LMBHB: the known sample



Corral-Santana+2016

Discovered by X-ray All Sky Monitors (ASMs)

- *Swift*/BAT (15—150 keV), sensitivity **@ ~16mCrab**
- *MAXI* (2—10 keV), sensitivity **@ ~10mCrab**
- Monitoring of the Galactic Center

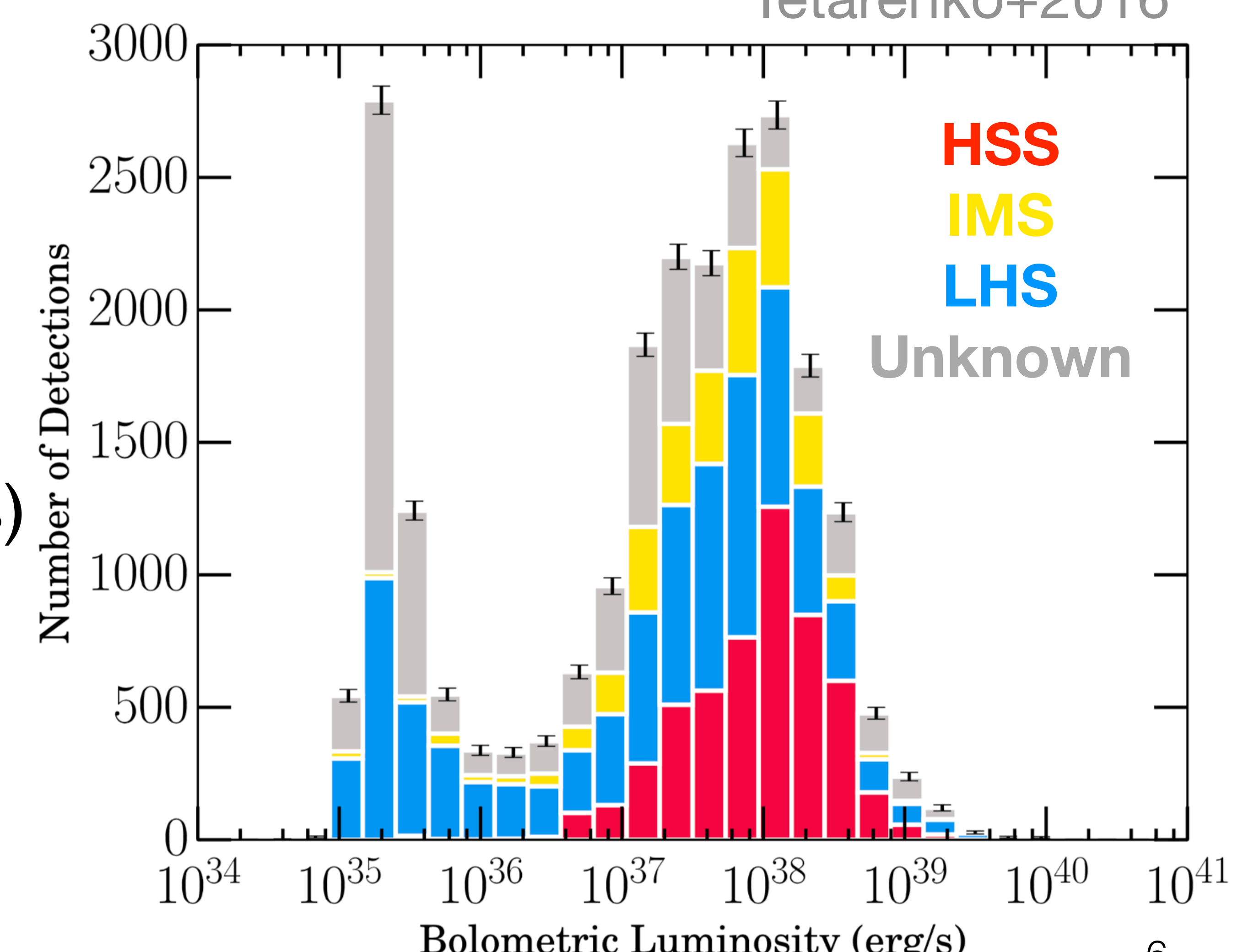
Find sub-luminous LMBHBs

BH luminosity function, demographics

Study **hard-only outbursts**

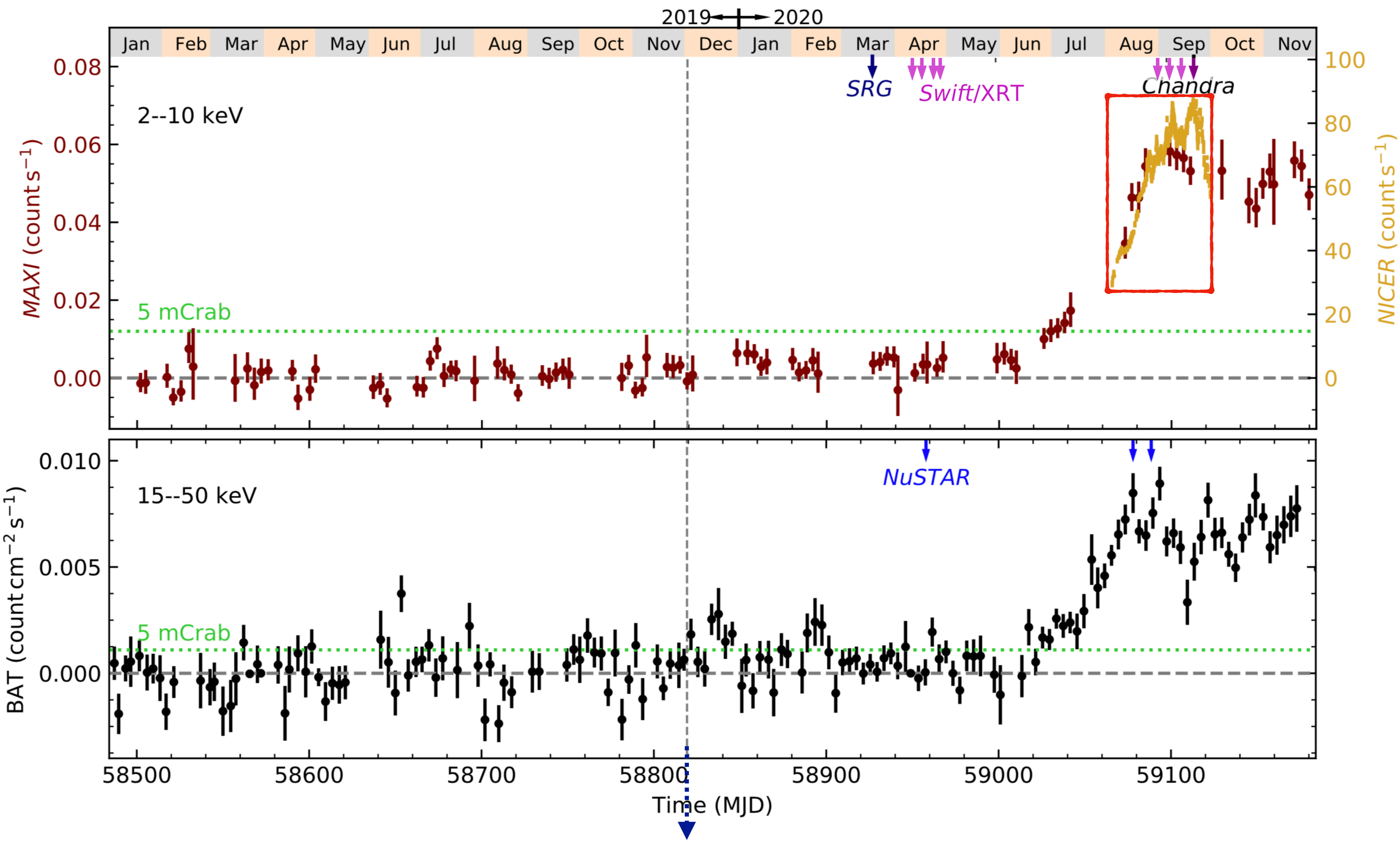
- Lower peak luminosities
- Lower mass accretion rates
- Shorter orbital periods

Tetarenko+2016



AT2019wey

- Discovered by *SRG* in March 2020, ~1 mCrab
- Palomar/Keck spectra show hydrogen lines at z=0



- Optical first detection by the ATLAS sky survey in Dec 2019

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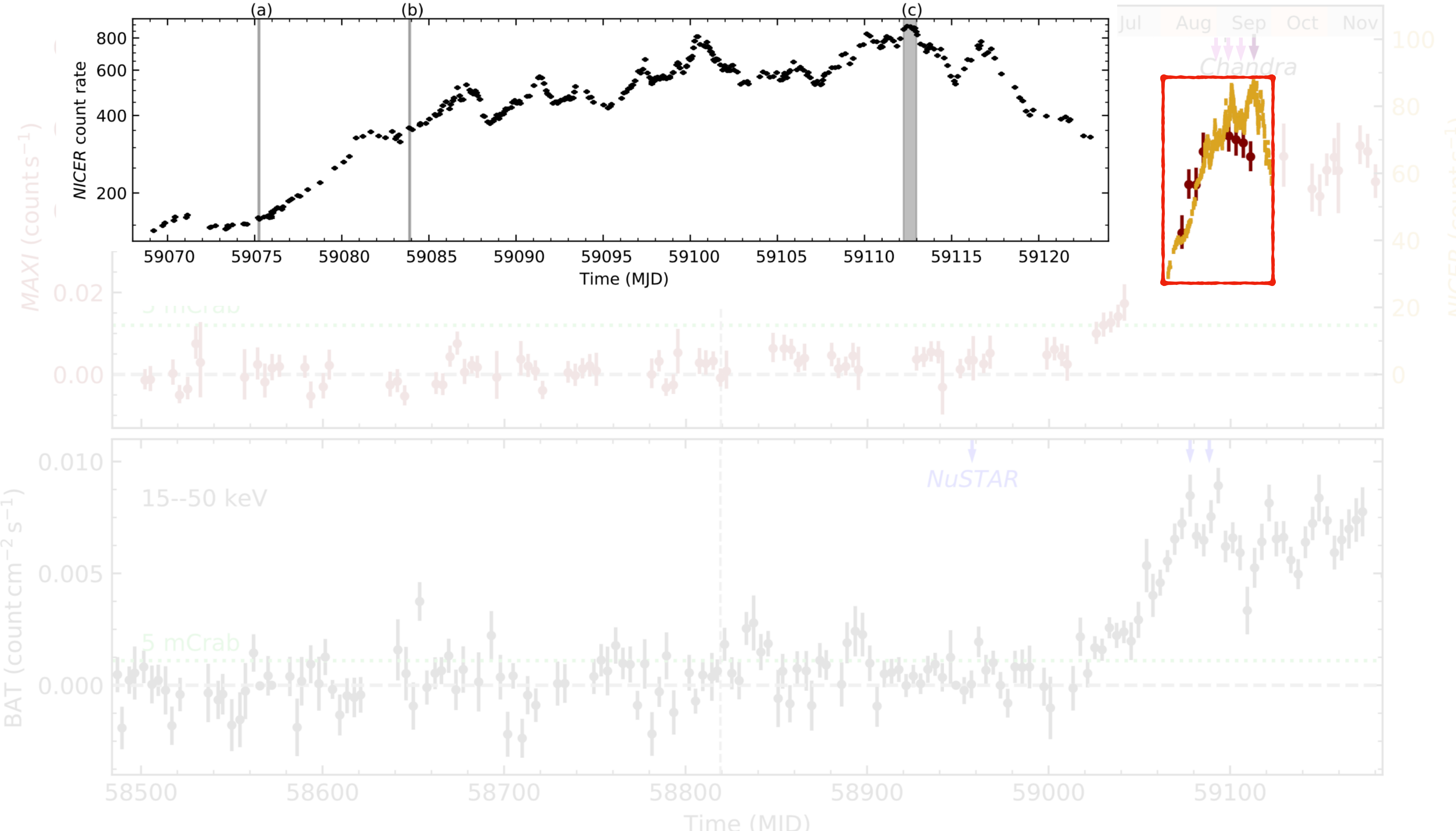
NICER X-ray Light Curve



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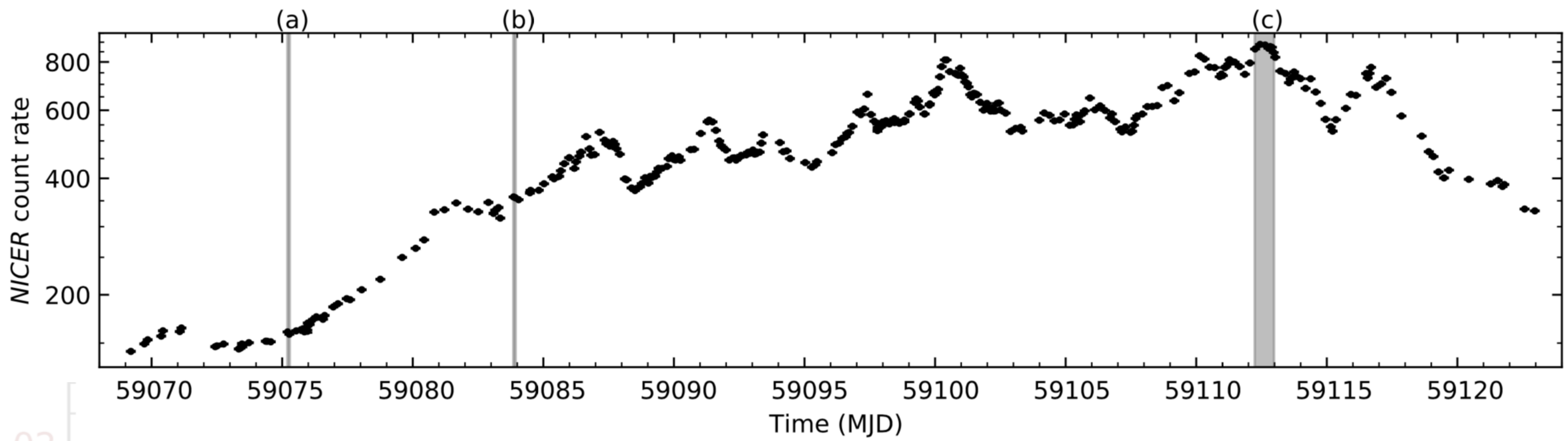
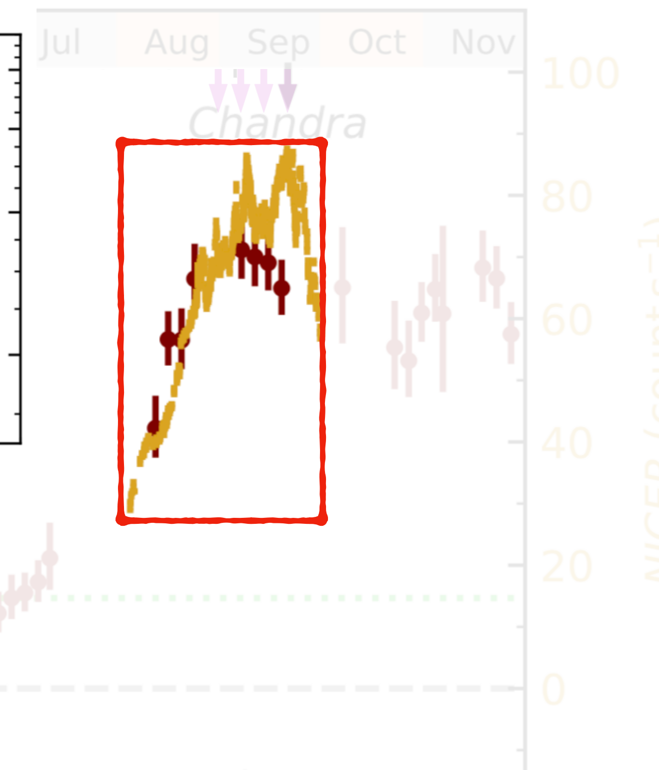
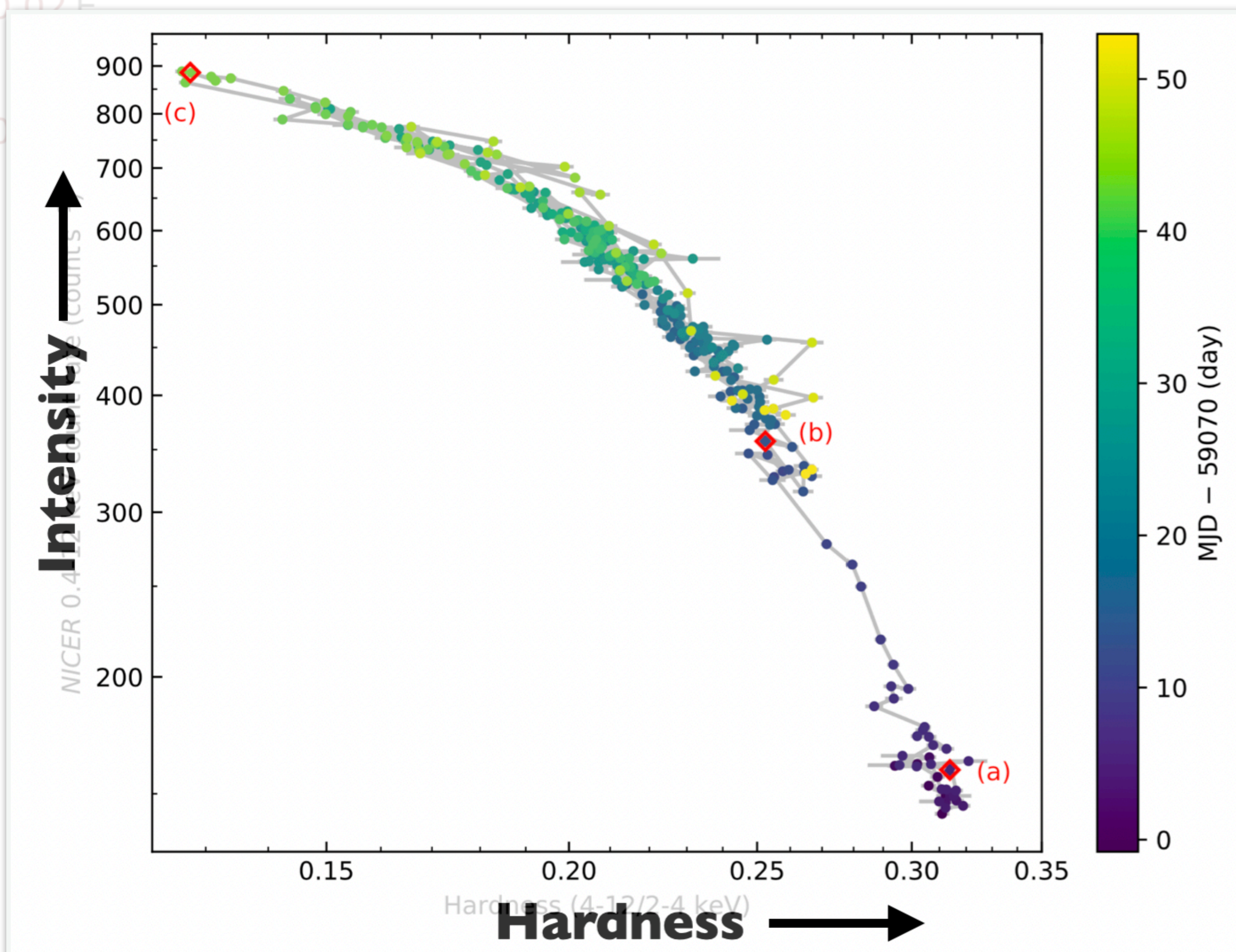
NICER X-ray Spectral Evolution







On the HID, AT2019wey did not follow the "q-shape" track

Smilar to MAXI J1836-194 (Lucchini+2021), perhaps common in hard-only outbursts

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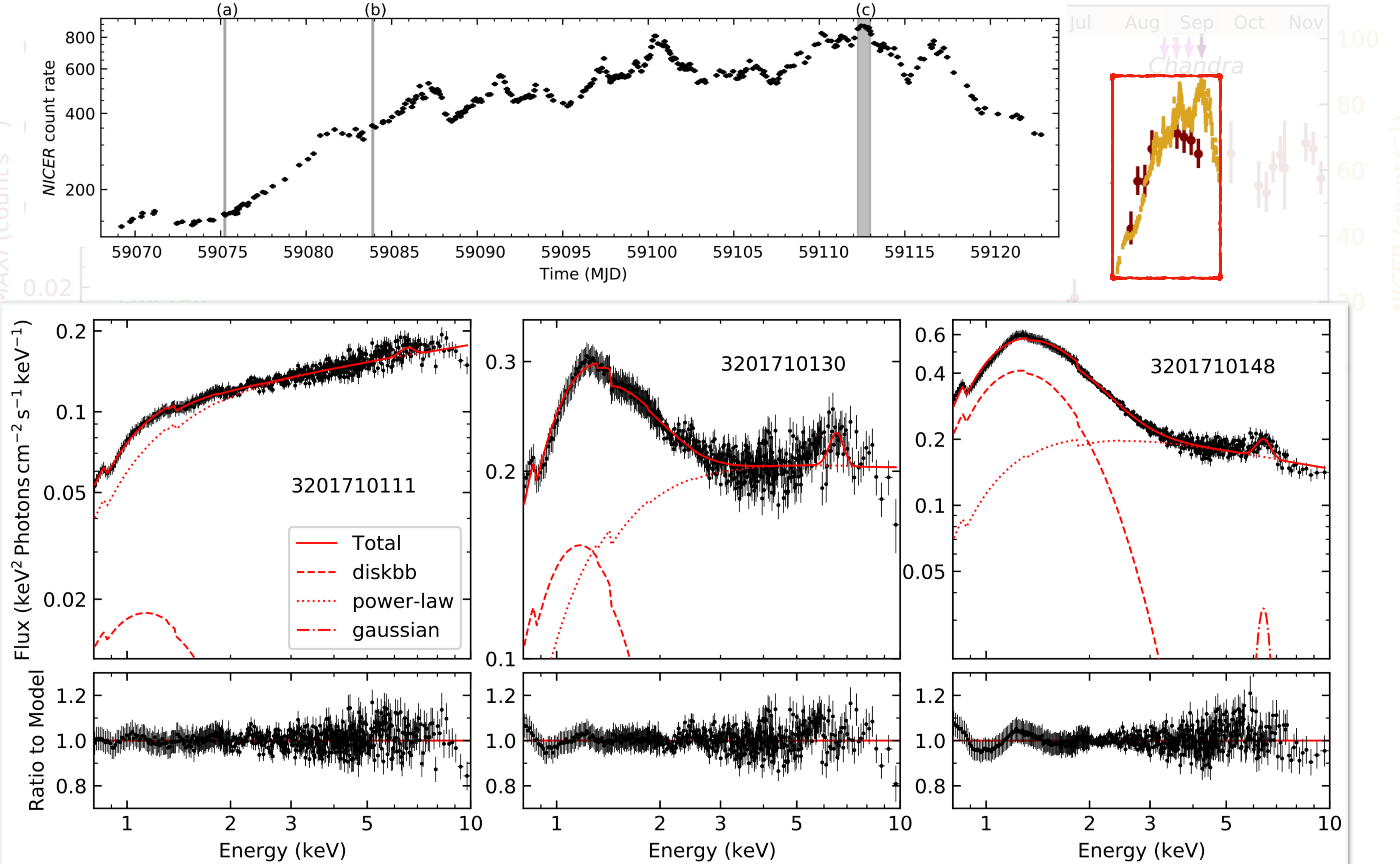
NICER X-ray Spectral Evolution



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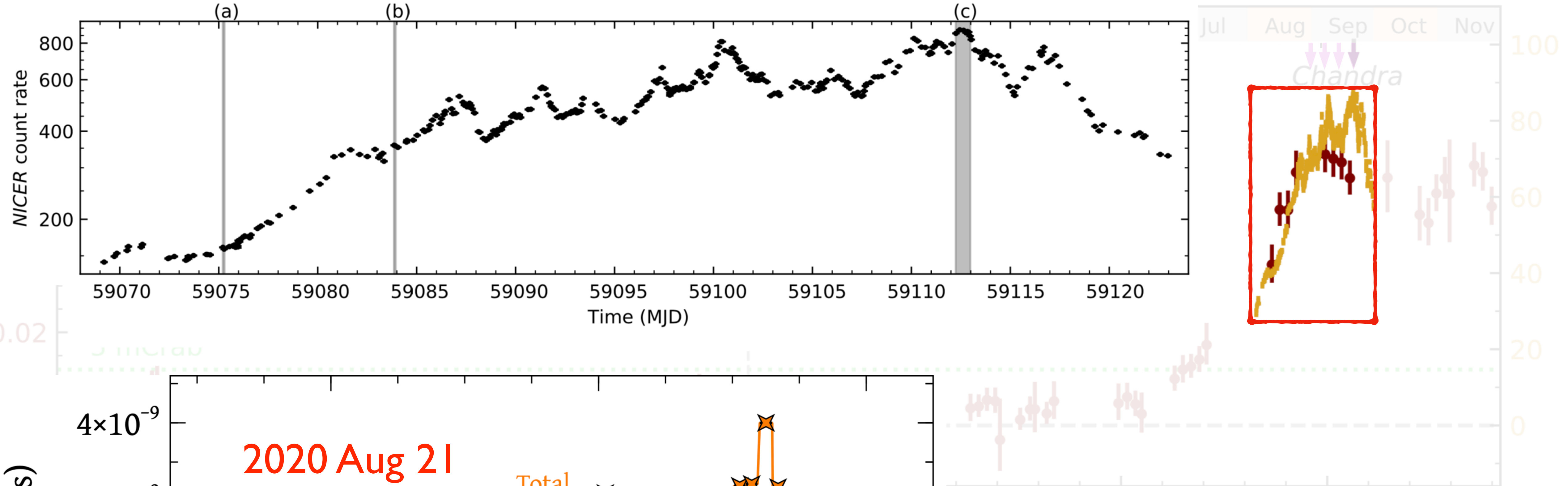

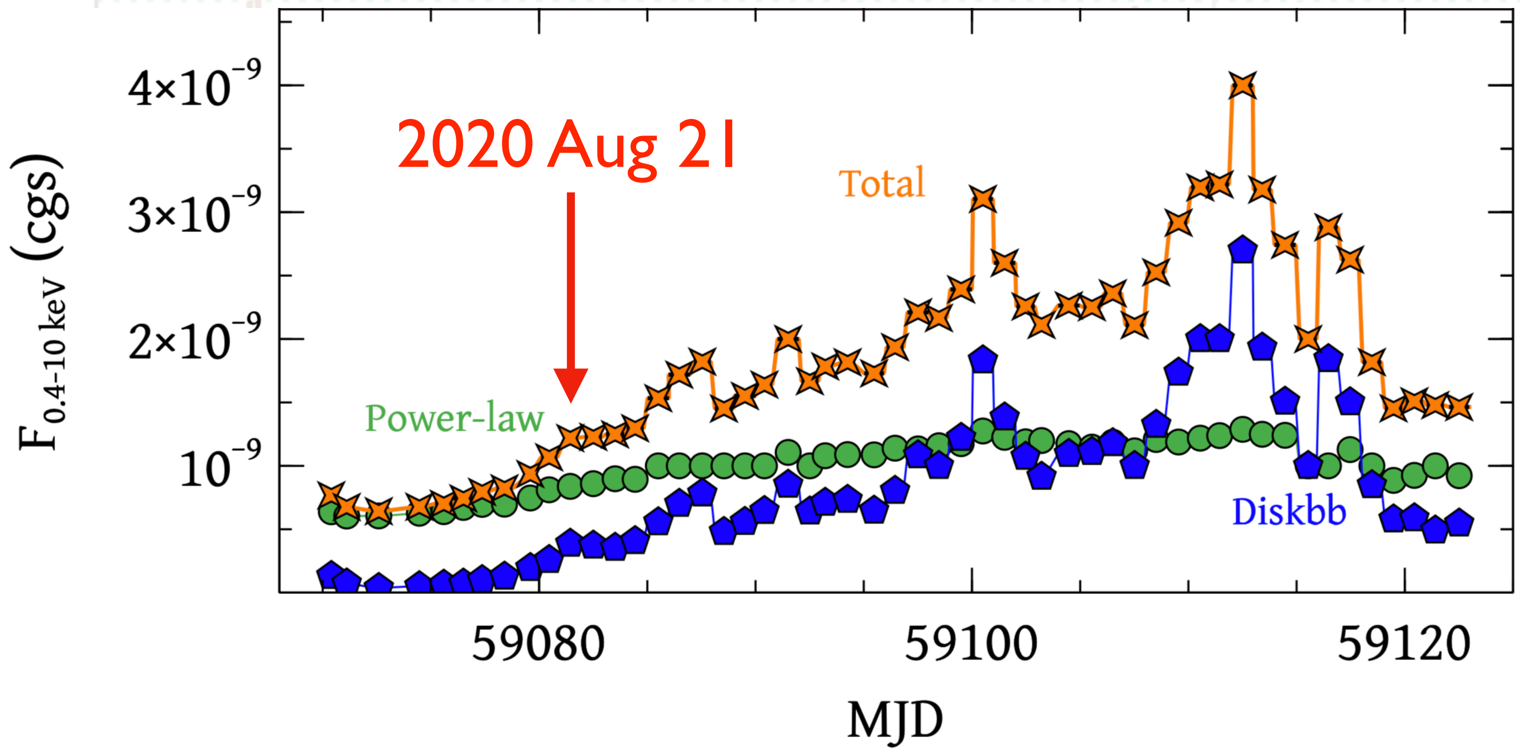

The brightening was due to the appearance of a thermal component;
But the power-law component was always a significant contribution

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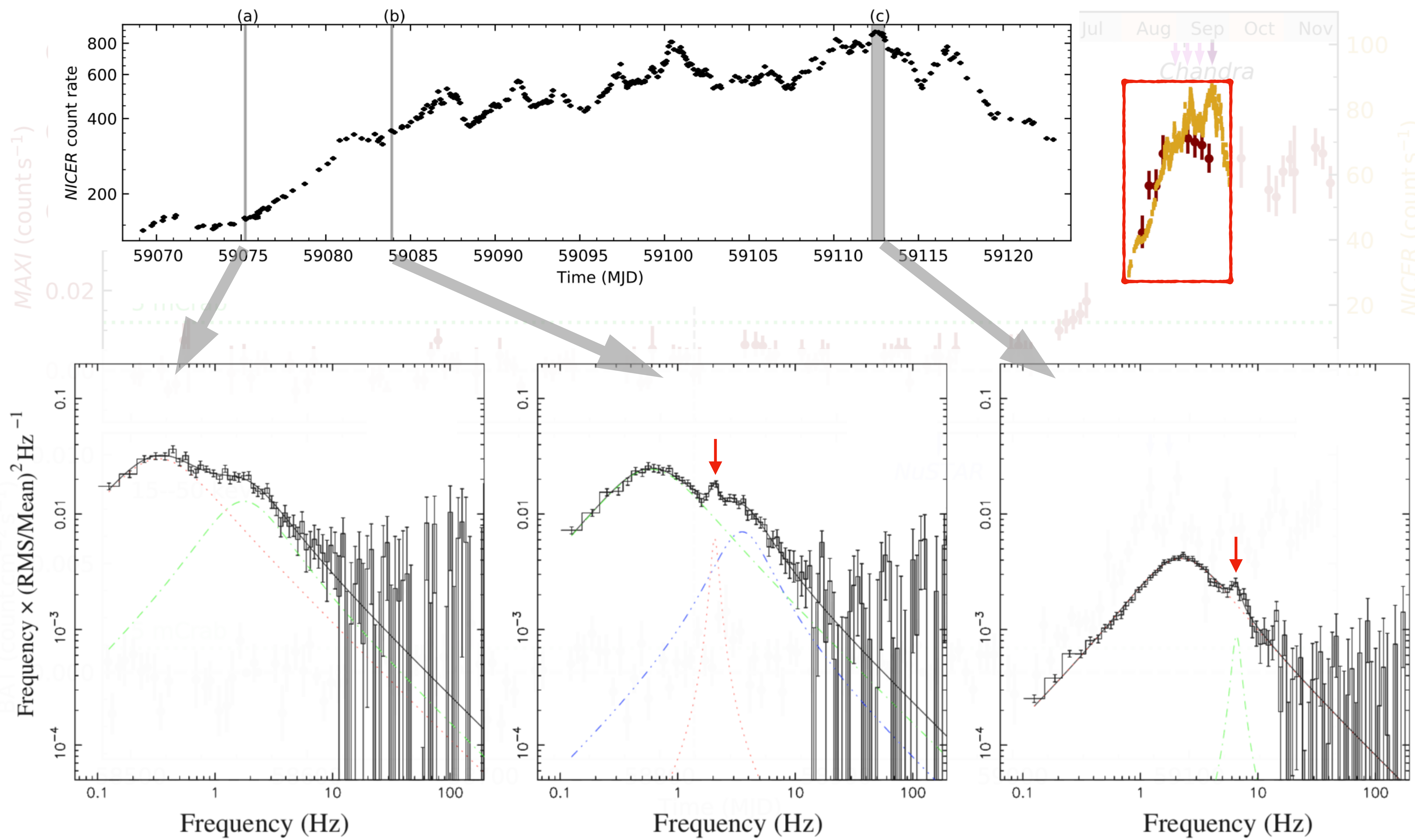
NICER X-ray Timing Evolution



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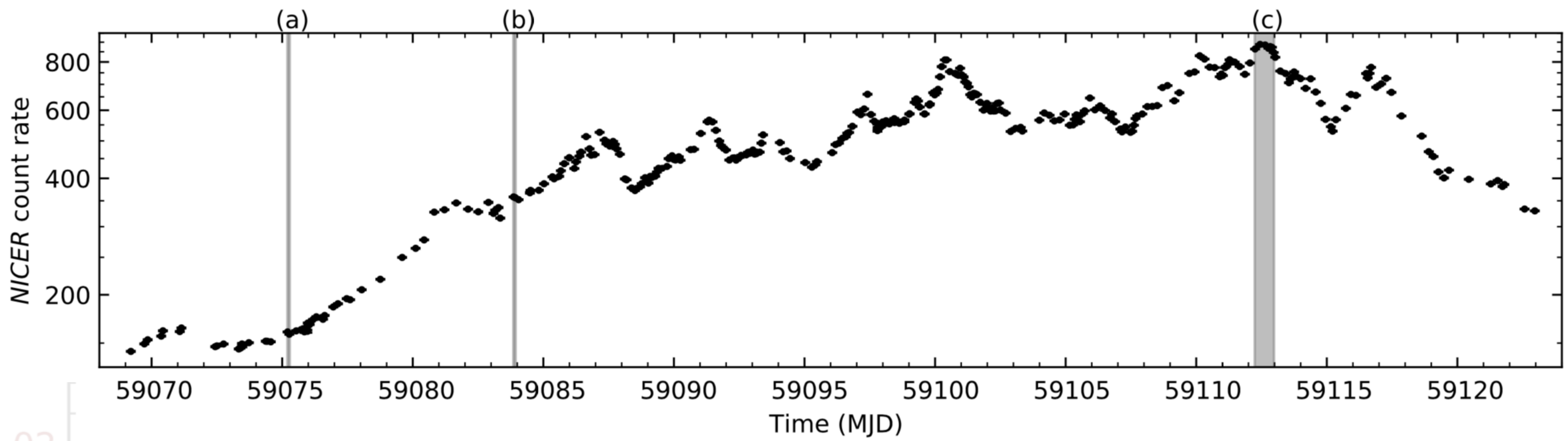
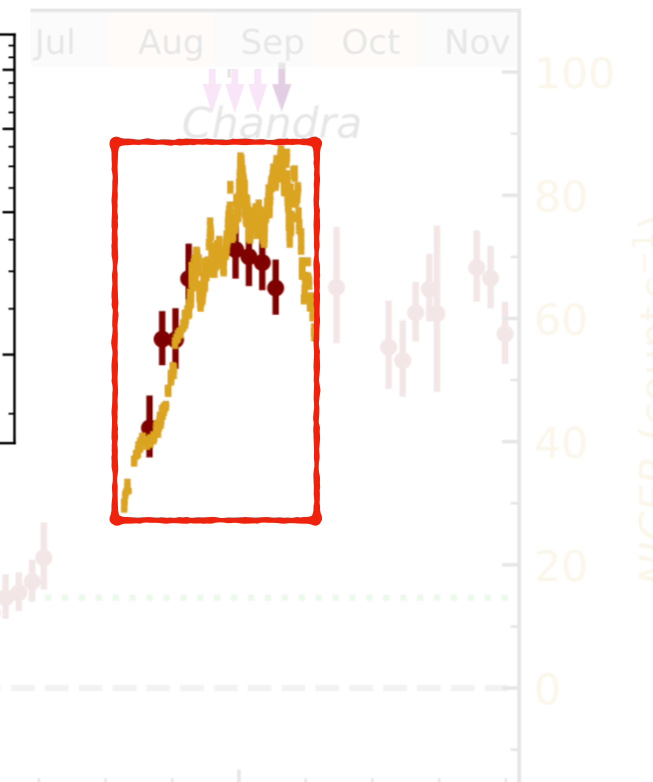
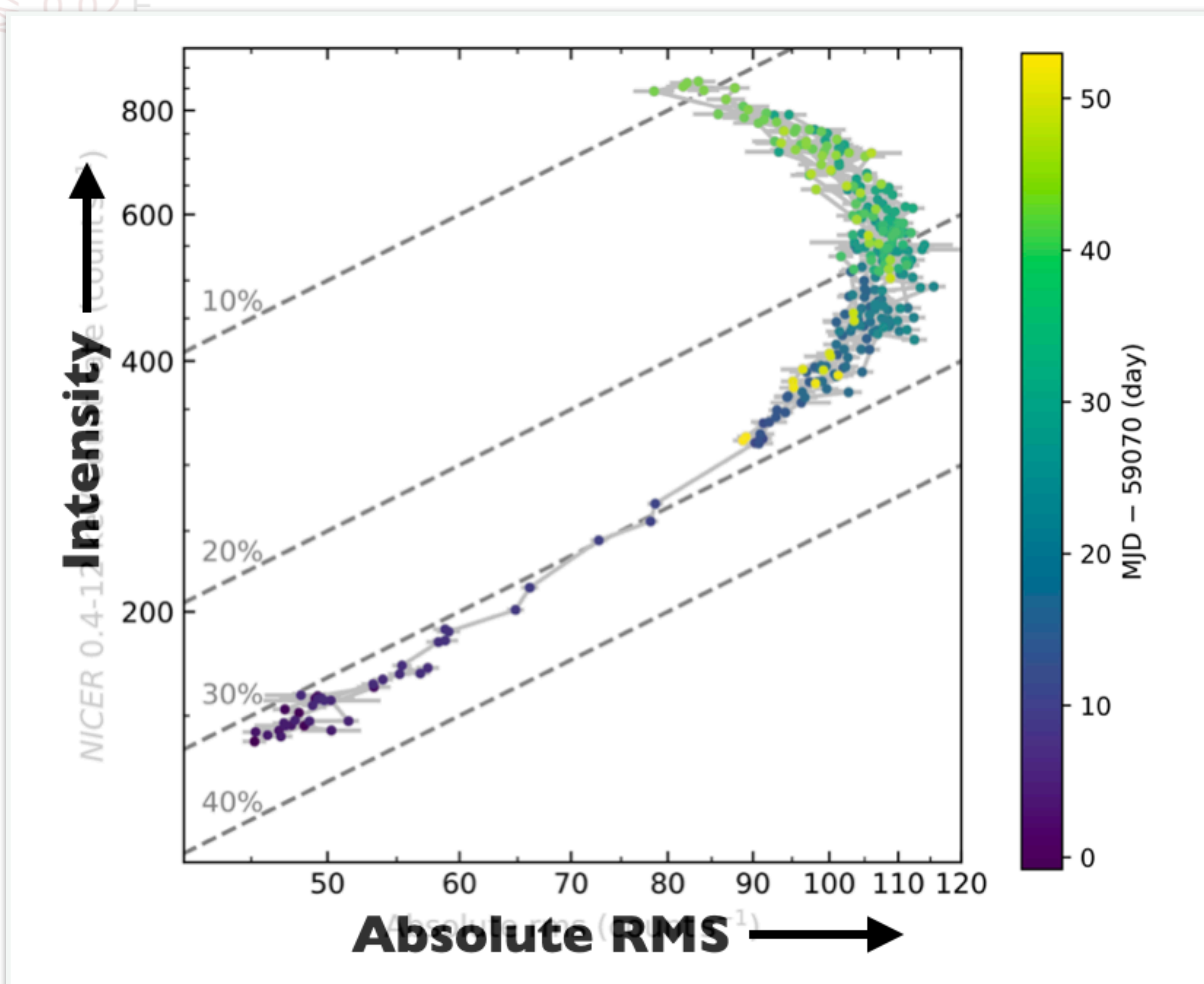






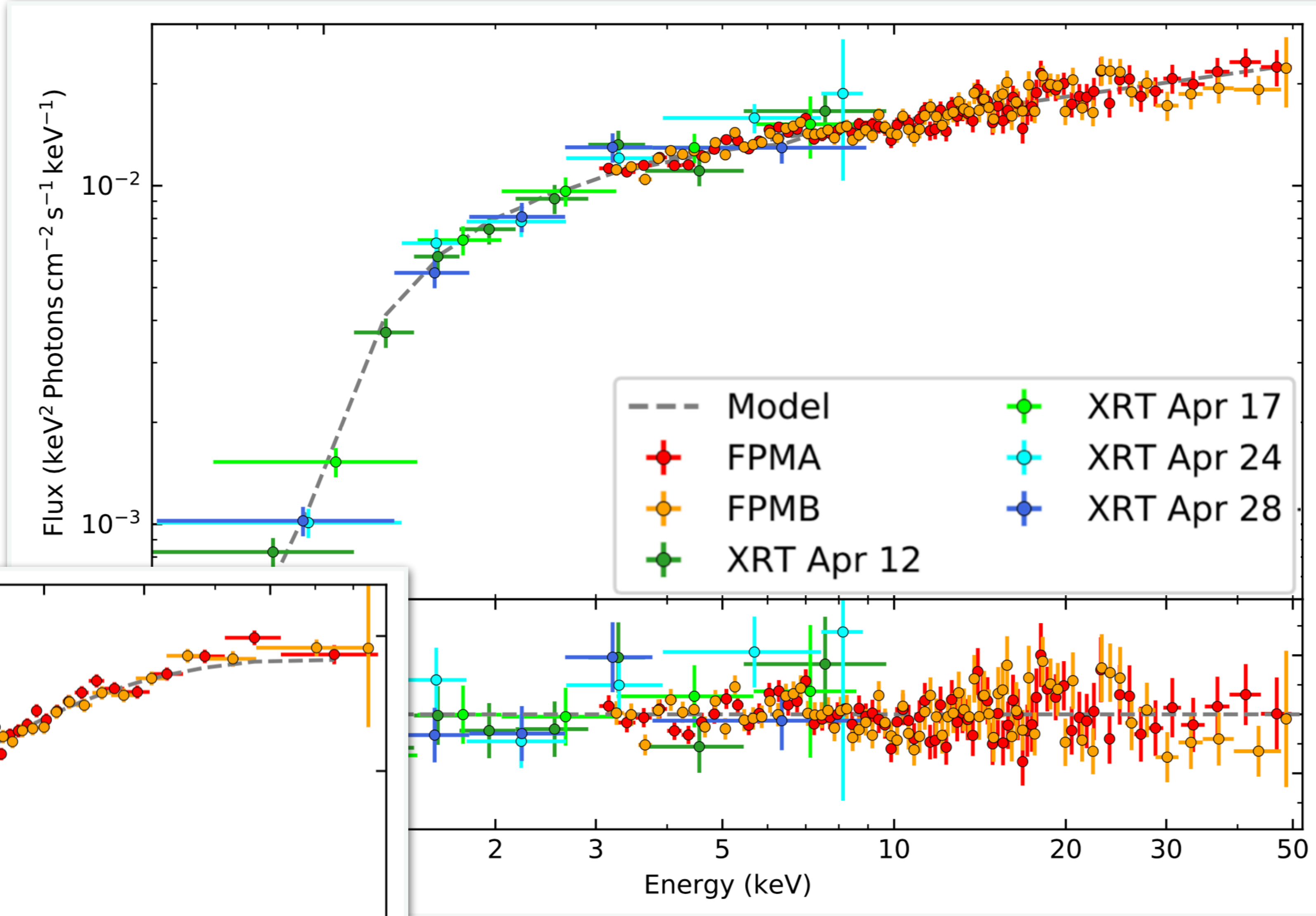
On the absolute rms-intensity diagram (RID), AT2019wey follows the hard-line (HL): fractional rms ~ 30%; and left the HL around

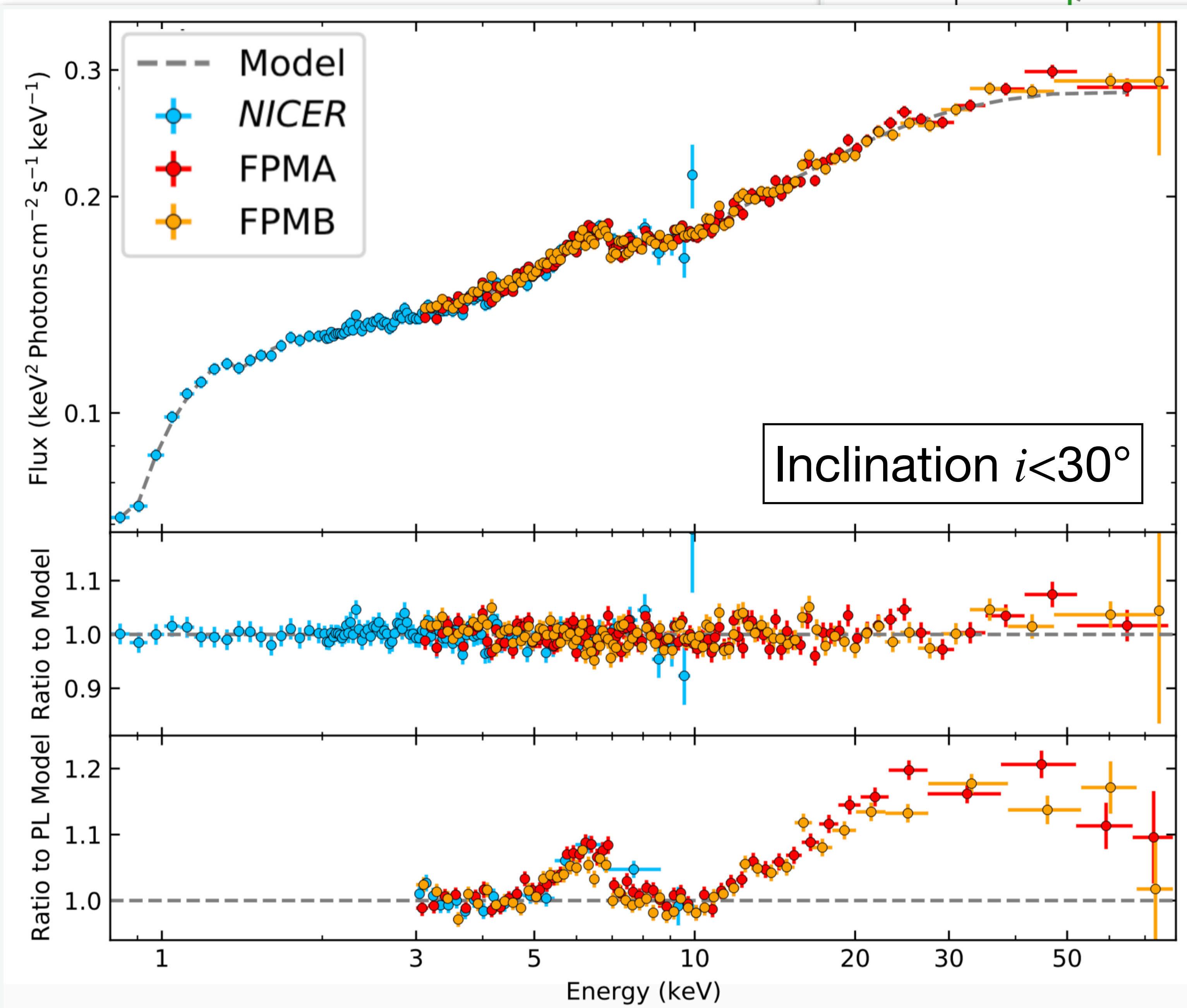
2020 Aug 21

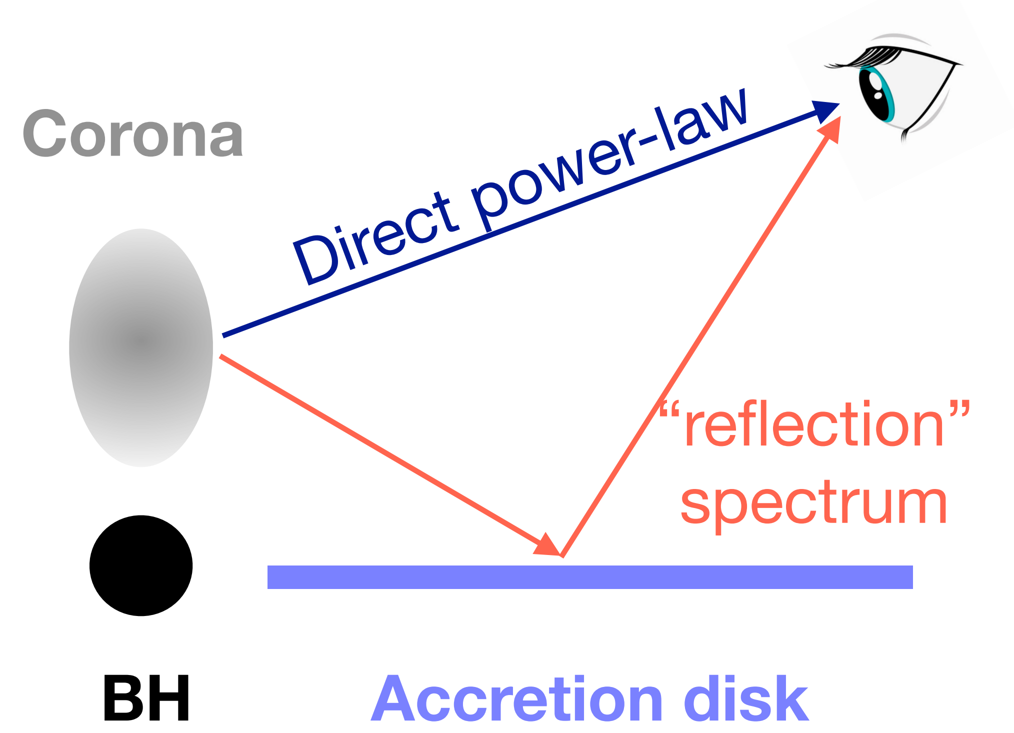
Yao+2021a

Broad-band X-ray Spectra

- LHS: power-law Γ = 1.7
- Rising LHS: relativistic reflection



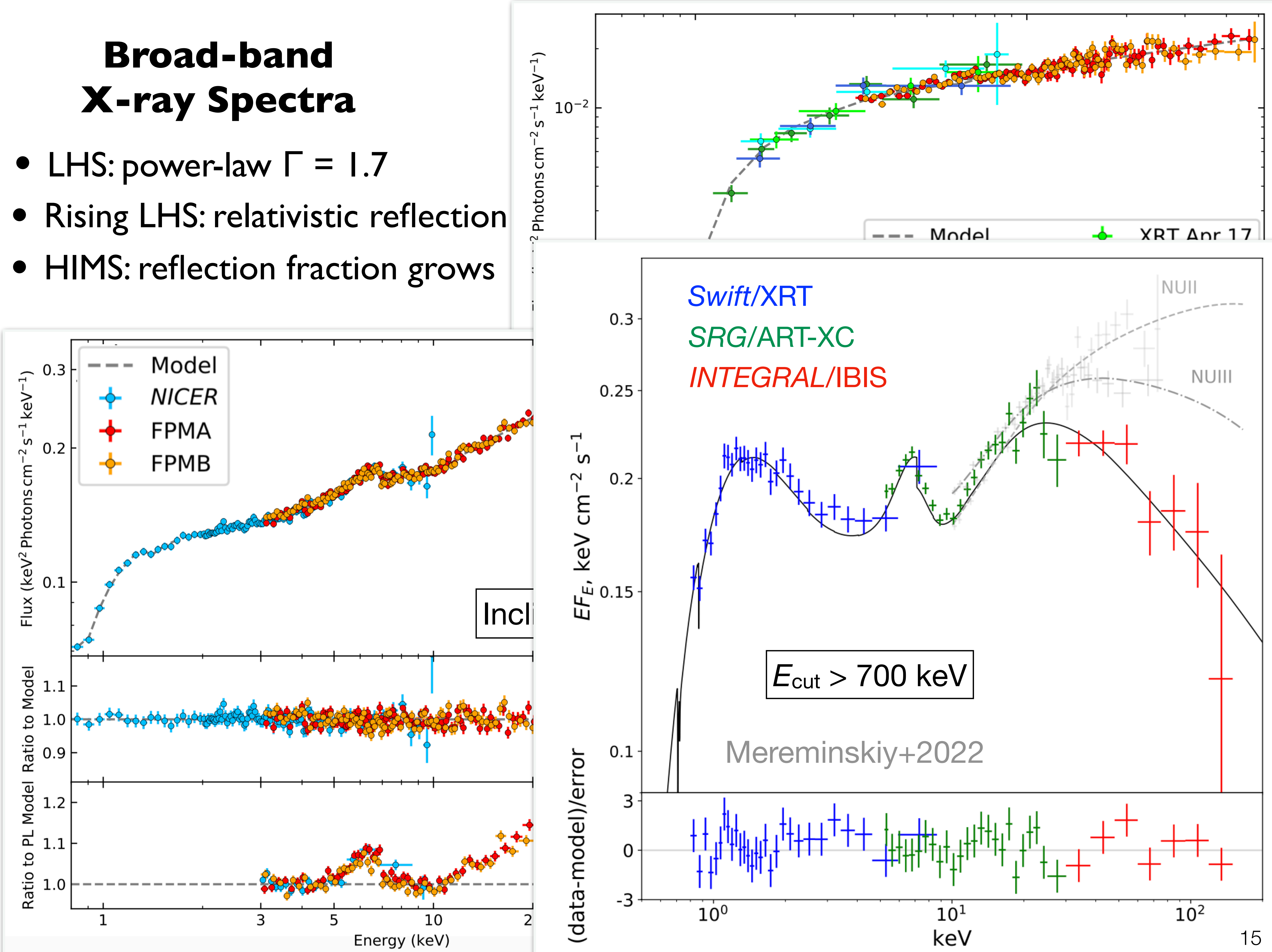




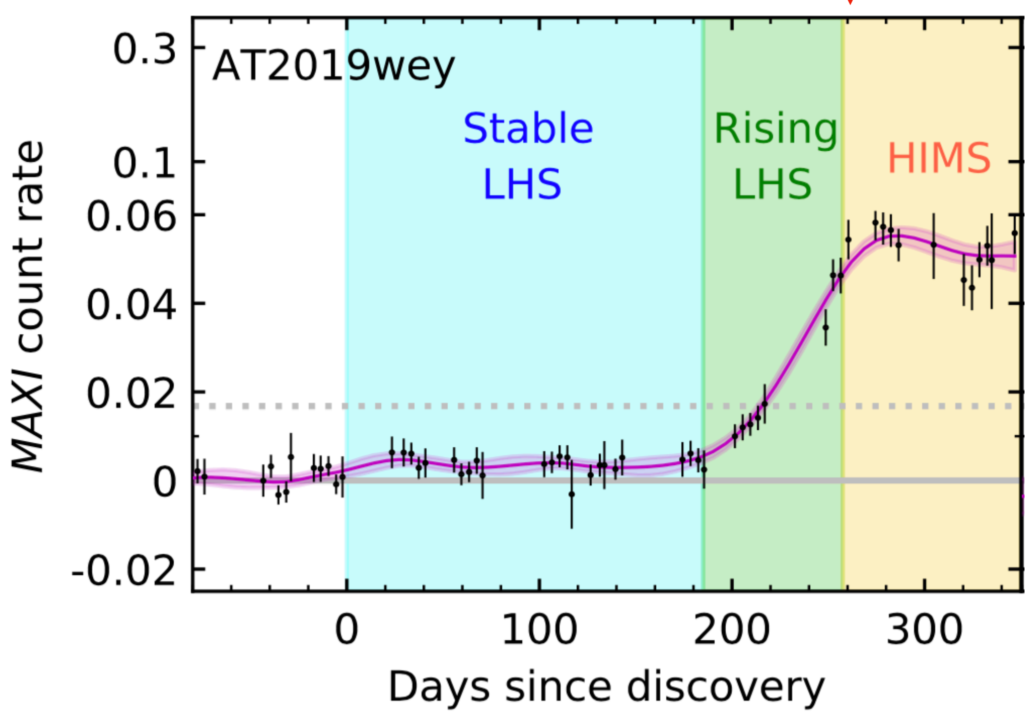
Yao+2021a

Broad-band X-ray Spectra

- LHS: power-law Γ = 1.7
- Rising LHS: relativistic reflection
- HIMS: reflection fraction grows



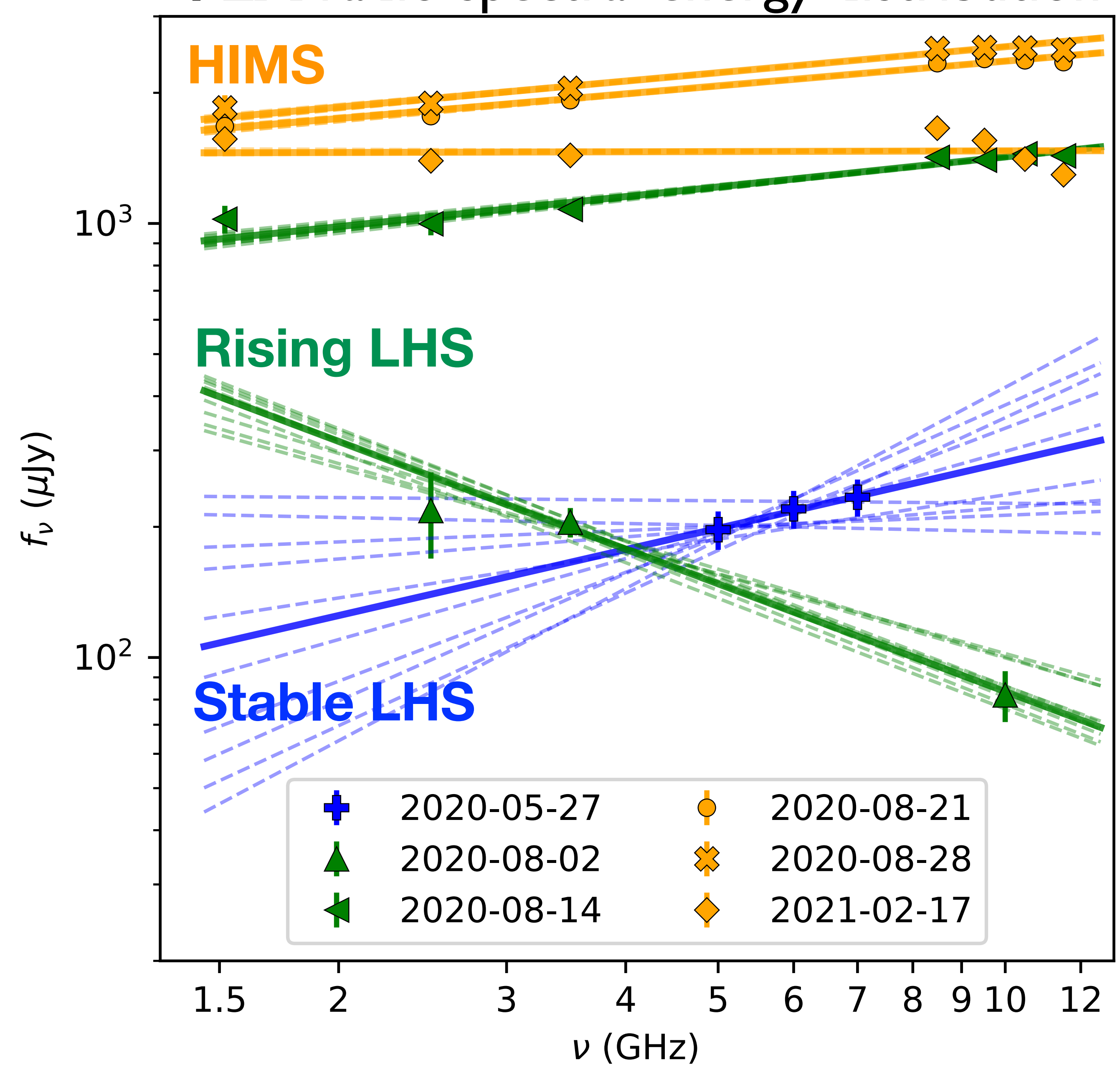
Aug 21, 2020



NICER's great spectral-timing power shows that AT2019wey's X-ray State Transition Follows **Low-hard state → hard-intermediate state**

X-ray and Radio Brightened Together
Disk-Jet Coupling

VLA radio spectral energy distribution

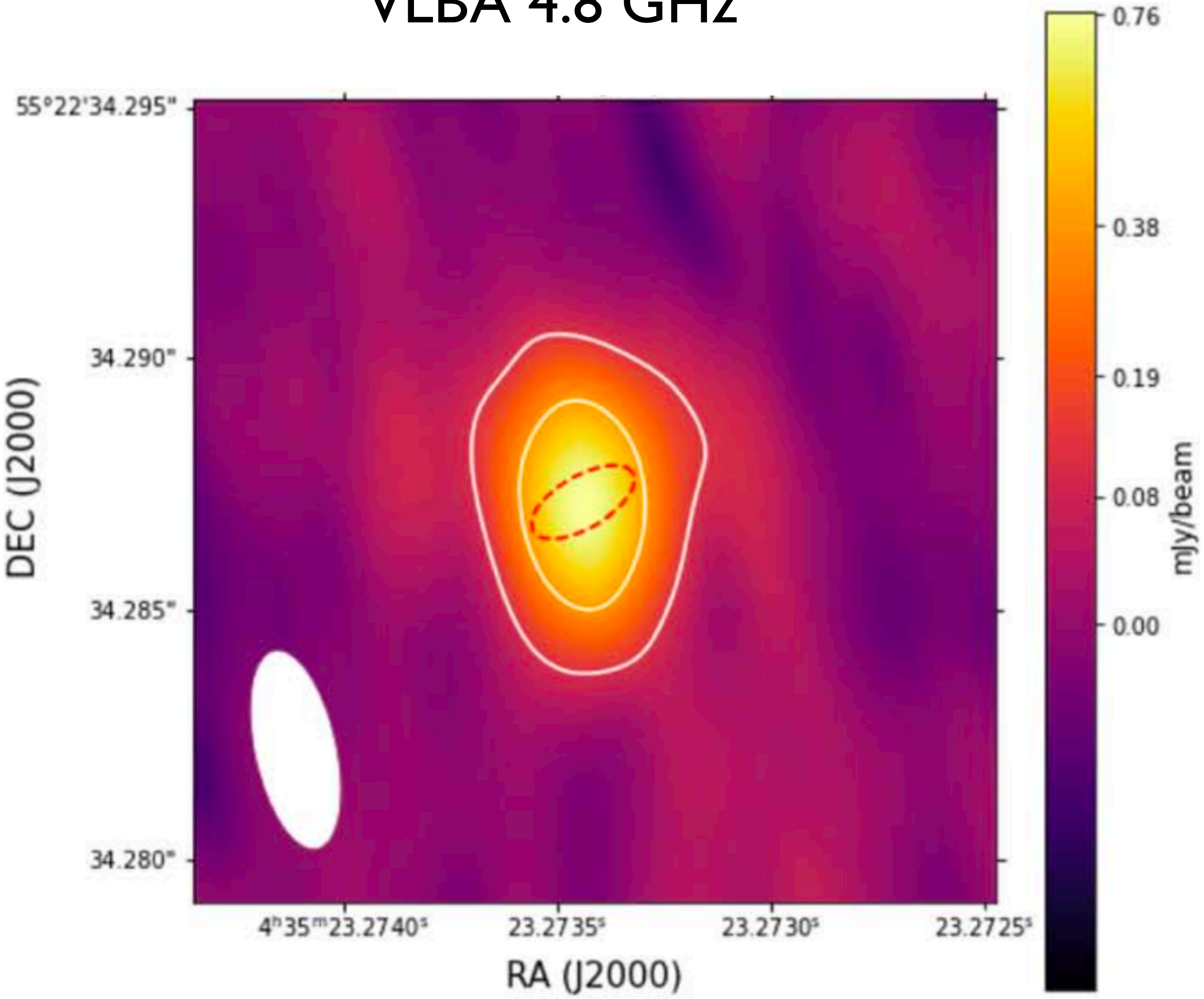


Yao+2021a, b

VLBI Observations: Detection of a Resolved Jet

The 5th XRB with resolved jet detected

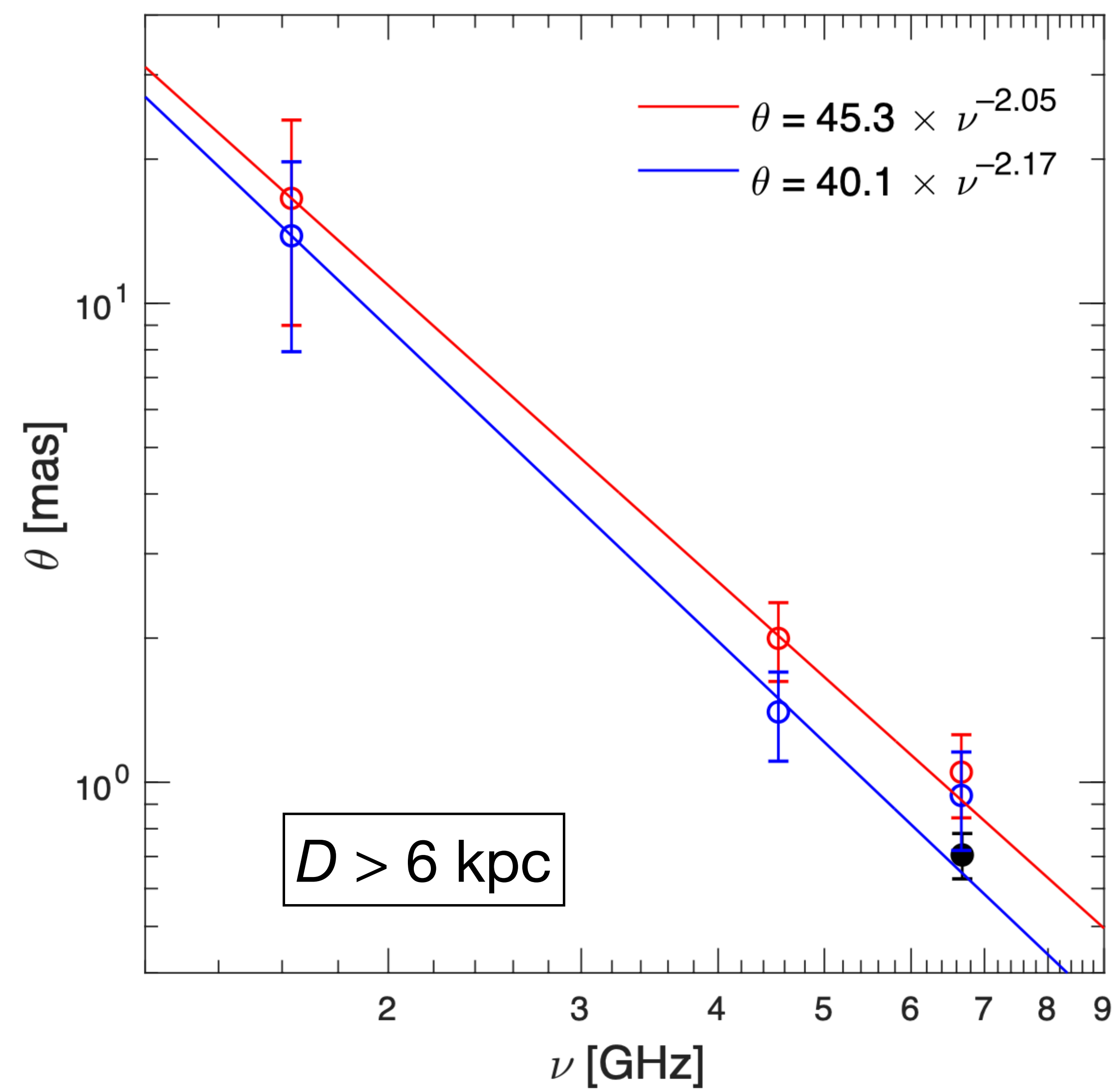
Sep 2020
VLBA 4.8 GHz



Yadlapalli, Ravi, Yao +2021

Scatter broadening from Galactic ISM

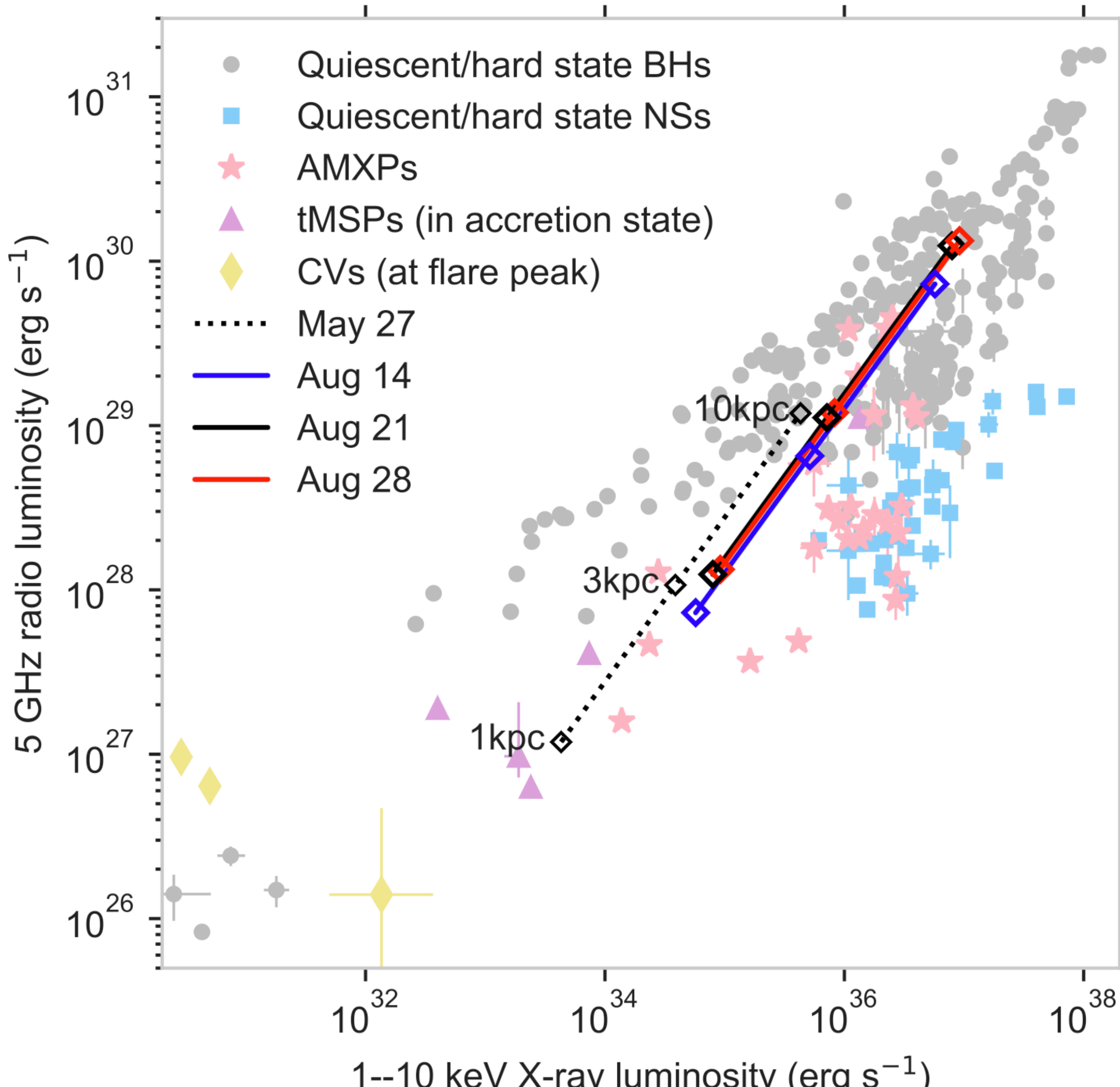
Oct—Dec 2020
EVN, VLBA multi-frequency



Cao+2022

Why is AT2019wey a Black Hole Candidate?

1. Position on the L_R–L_X diagram: closer to BHs (radio luminosity is high)
2. Position on the Γ–L_X -diagram: closer to BHs (power-law index is hard)
3. Position on the L_{opt}–L_X diagram: closer to BHs (optical luminosity is high)
4. Relatively high power-law cutoff energy (E_{cut}>700 keV)



* No pulsation detected in the first 400ks of NICER observations (by Mason Ng).

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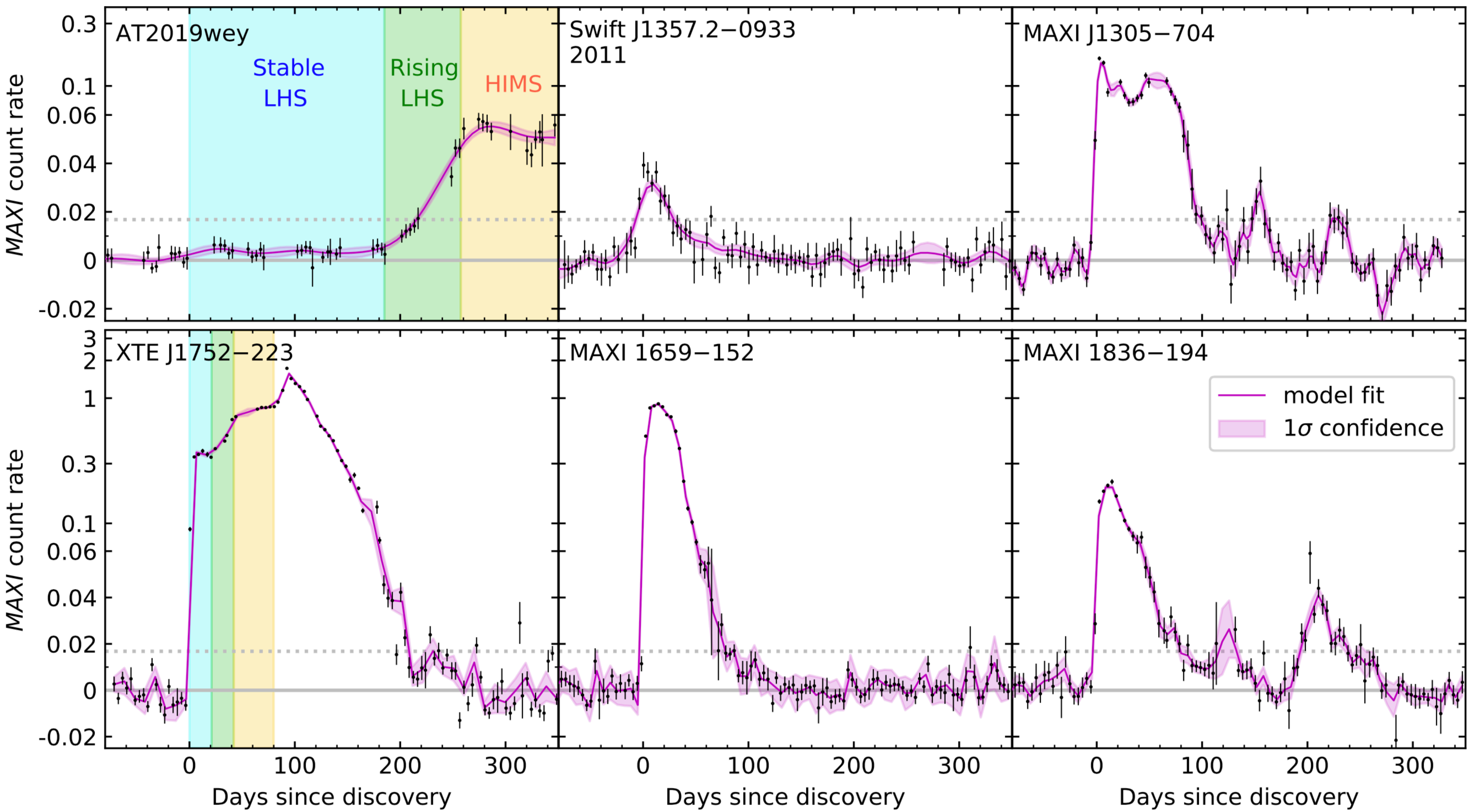
Comparison with other BH outbursts

- Long duration of the initial LHS; Two plateau phases



Yao+2021a

Comparison with other BH outbursts

- Long duration of the initial LHS; Two plateau phases
- Analogous to the "Z Cam" type of dwarf novae

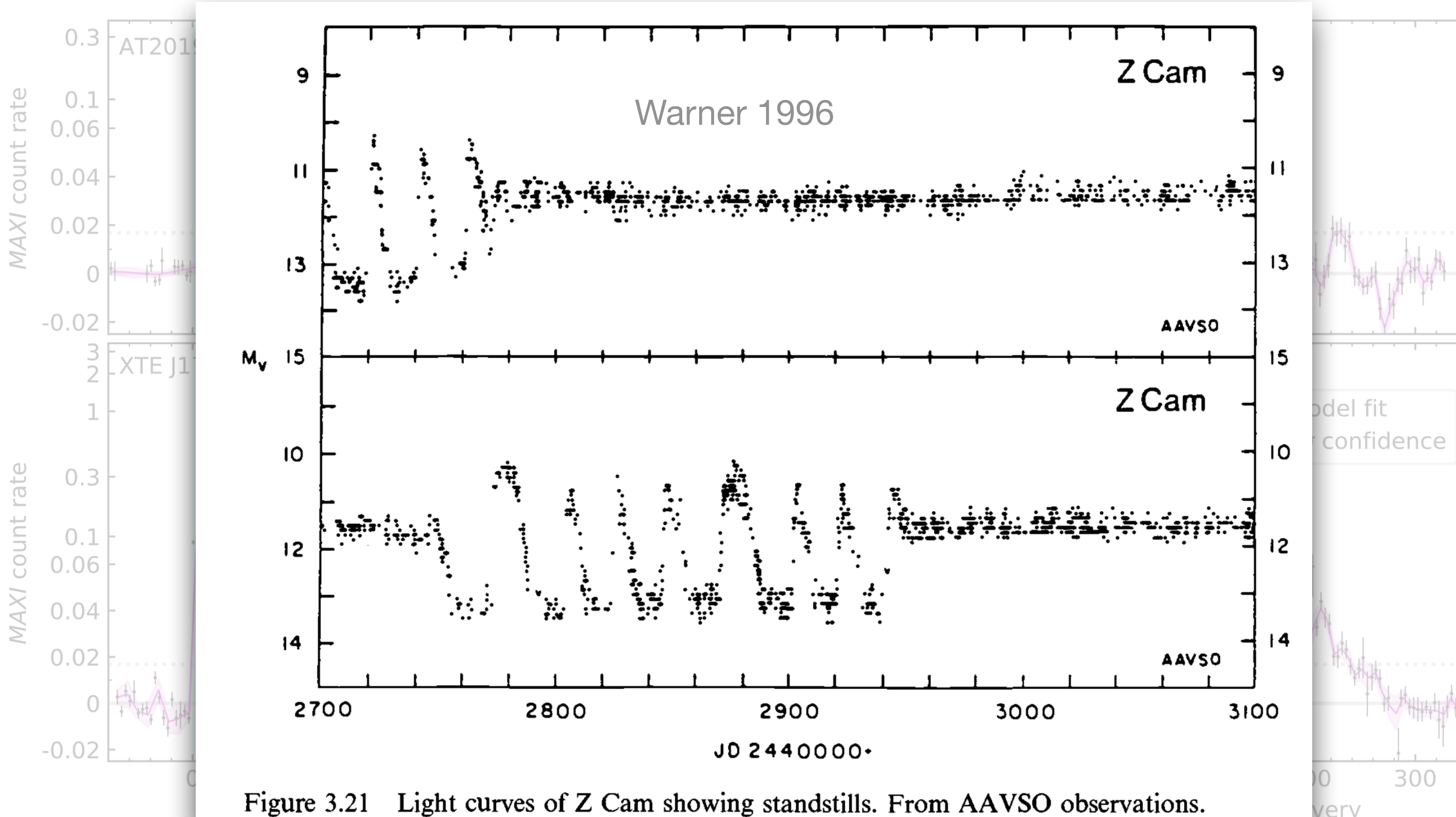
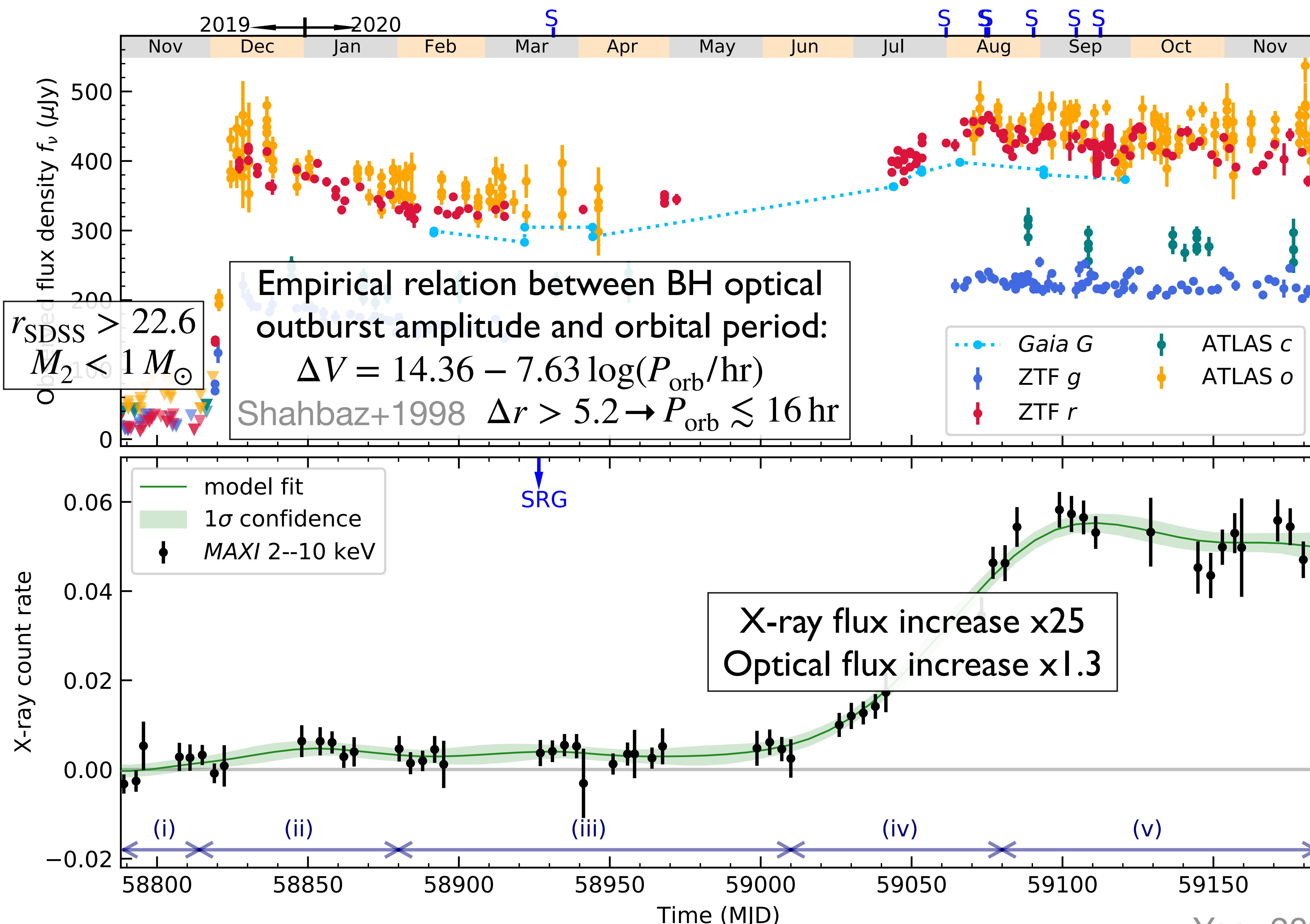


Figure 3.21 Light curves of Z Cam showing standstills. From AAVSO observations.

See discussion of BH binary "standstill" outbursts in **Esin+2000**, **Shaw+2019**

Optical/X-ray Co-Evolution

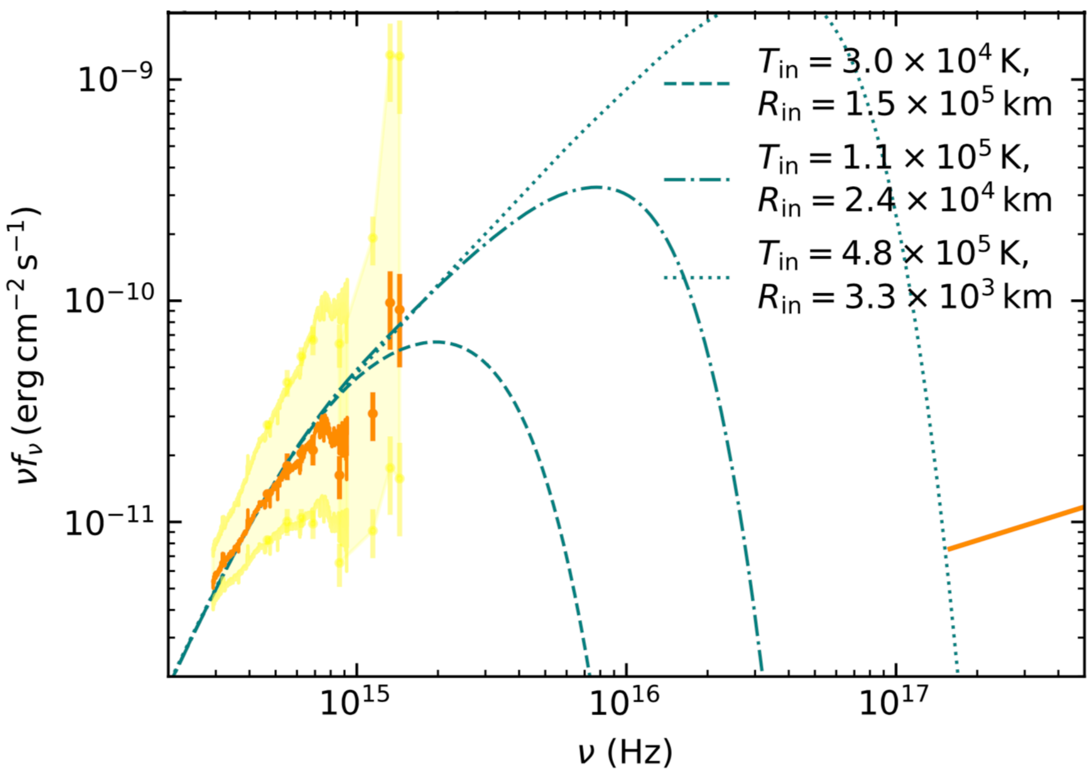


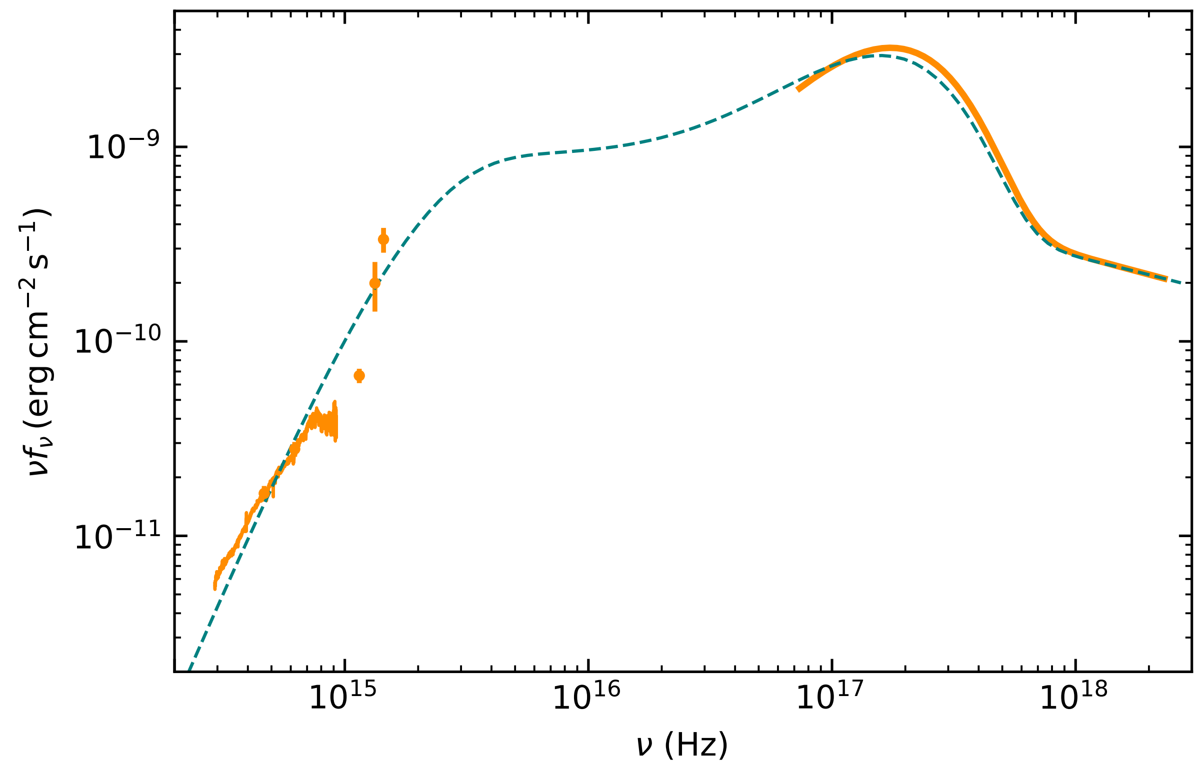
Yao+2021b

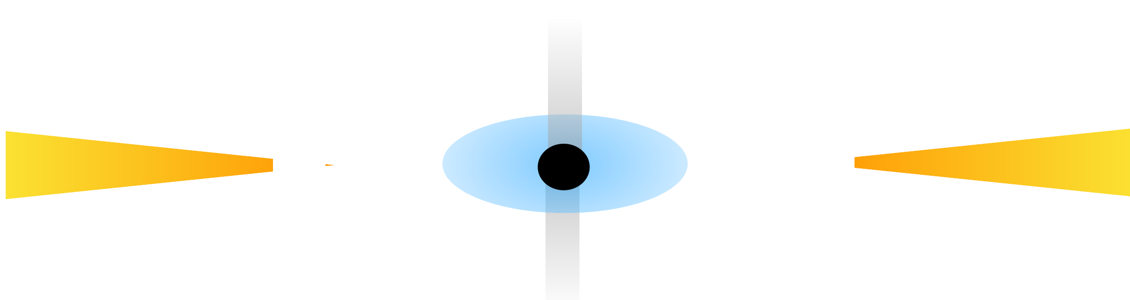
Origin of UV/Optical Emission in LHS & HIMS

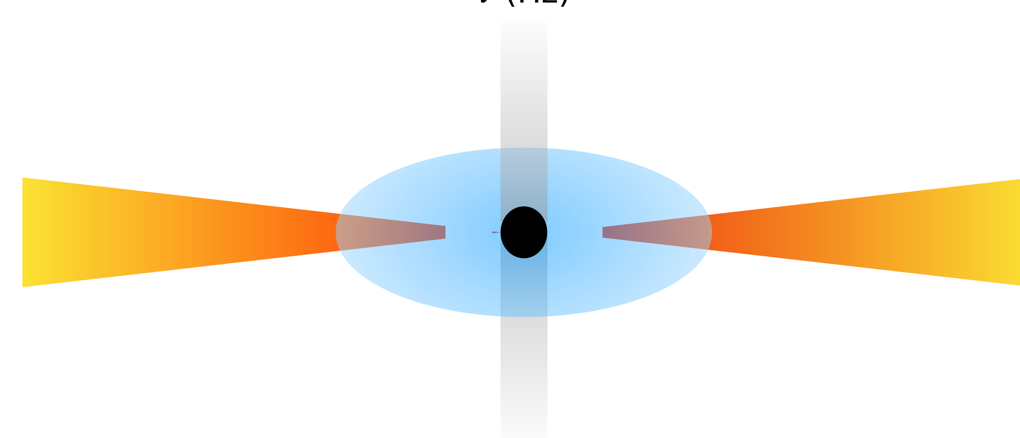
$$L_{\rm opt} = A\, L_{\rm X}^{\beta}$$

- AT2019wey: β ~ 0.1
- Most other LMBHBs: β ~ 0.6 (irradiation/jet) Russell+2006









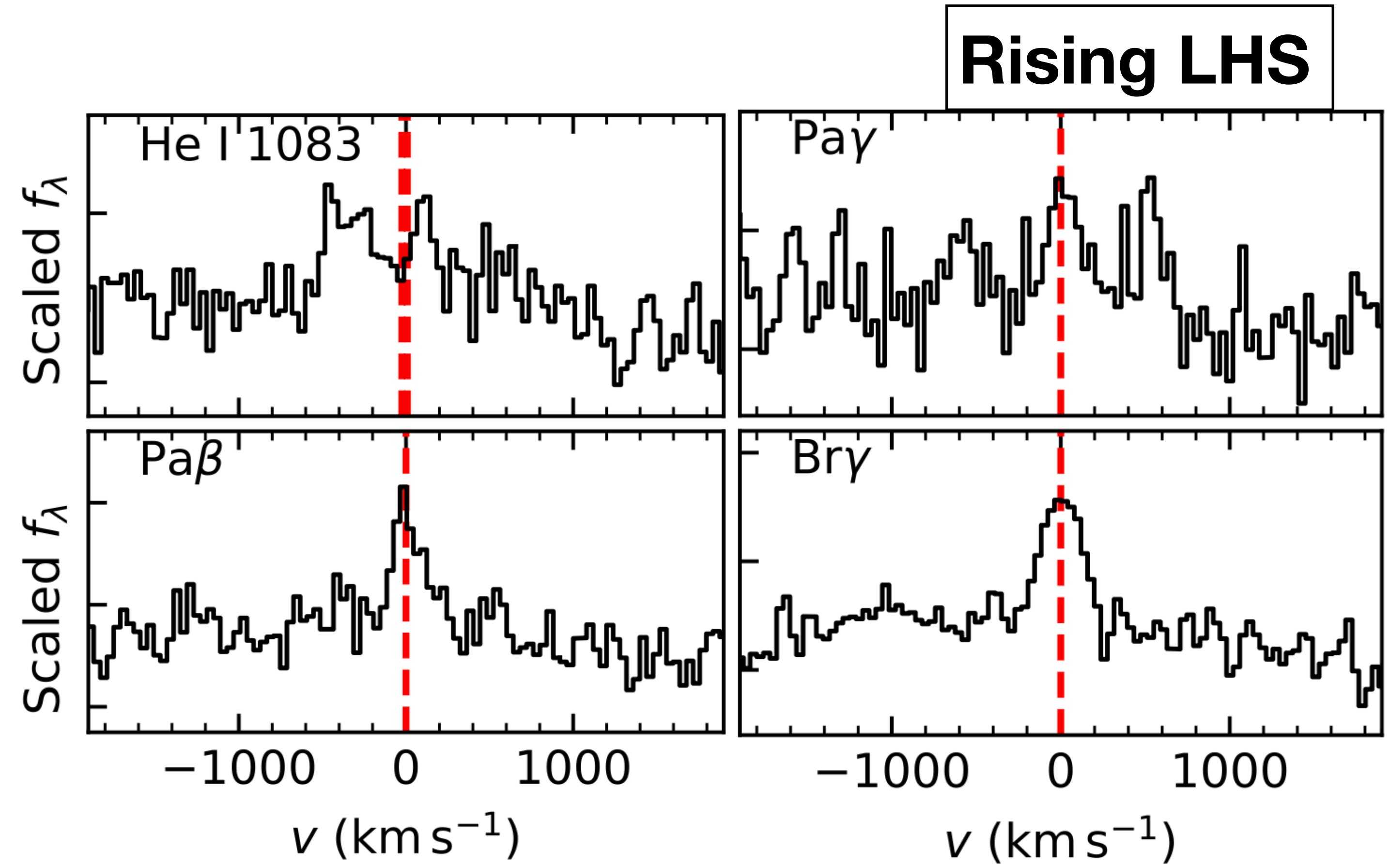
Intrinsic thermal emission from accretion disk with $R_{\rm in}$ > 100 $R_{\rm s}$

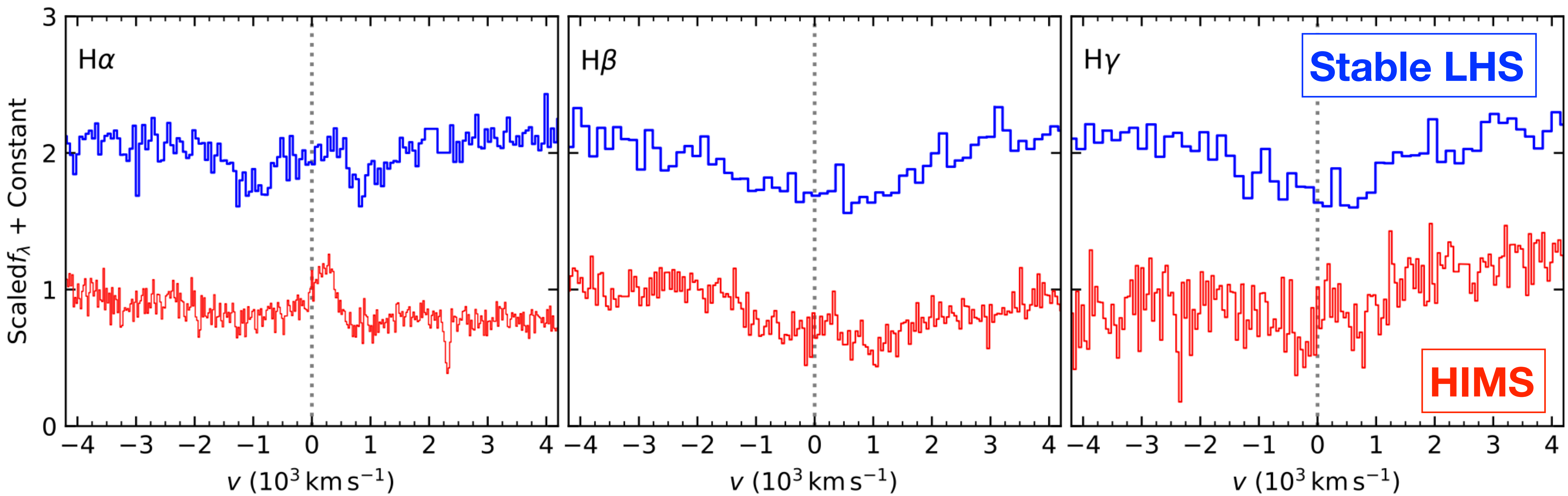
X-ray reprocessing at the outer accretion disk

Yao+2021b

Optical/IR Spectra

- Only H I and He I; No obvious He II in emission
- Hα: single-peaked emission core
- The emission core is stronger during HIMS





Yao+2021b

Summary

- AT2019wey is a new X-ray transient discovered by ***SRG*** in March 2020
- ***NICER*** **spectral-timing analysis** suggests that the X-ray outburst transitioned from the canonical LMXB LHS to the HIMS
- $M_2 < 1\, M_\odot$, $P_{\rm obb} \lesssim 16\,{\rm hr}$; inclination *I*<30° (from ***NICER***+*NuSTAR*)
- Good black hole candidate: high radio/optical luminosity; hard Γ in LHS; hard X-ray power-law cutoff not observed
- Very long durations (months—years) in both the LHS and the HIMS → analogous to "Z Cam" dwarf novae, **stable mass transfer**
- Origin of UV/optical emission: intrinsic disk emission during LHS; irradiation at outer disk during HIMS

References:
- X-ray report: **Yao et al. 2021a, ApJ, 920, 121**
- Radio resolved jet. VLBA: Yadlapalli et al. 2021, ApJL, 909, L27
  EVN: Cao et al. 2022, A&A, 657, 104
- Multi-wavelength inference: **Yao et al. 2021b, ApJ, 920, 120**
  Mereminskiy et al. 2022, A&A, 661, 32