Broadband Spectroscopy of Microquasar Systems

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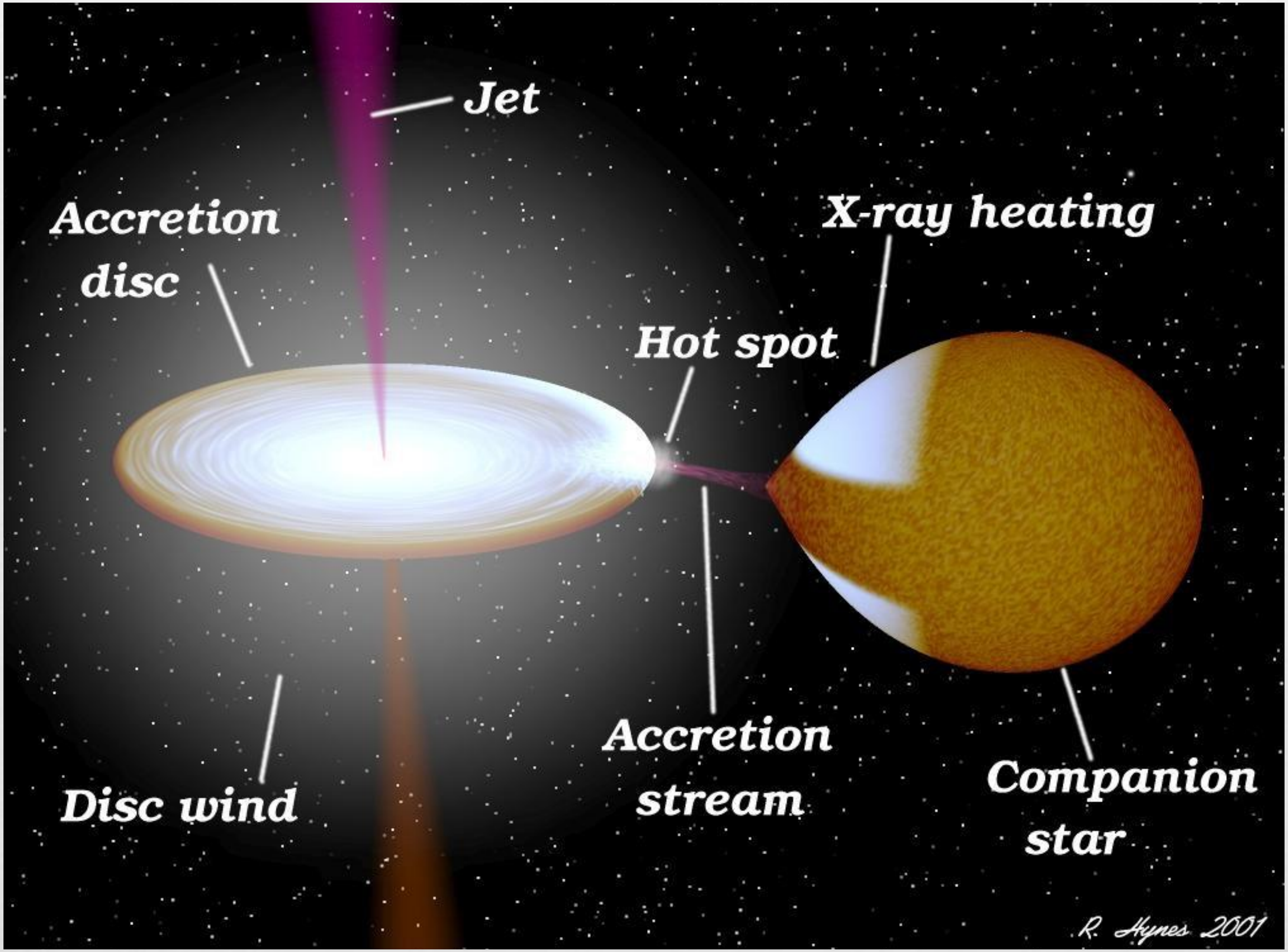
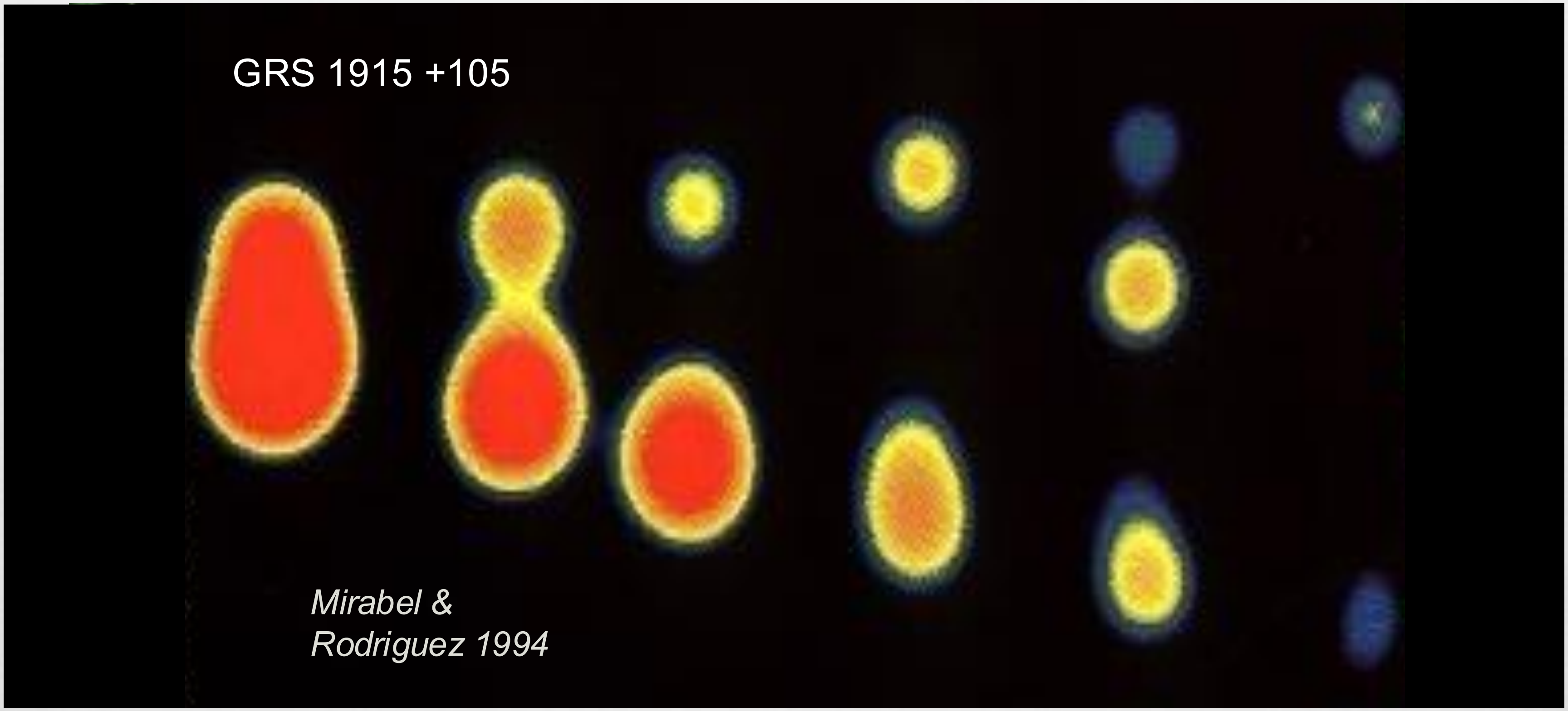
X-Ray Binary Blueprint



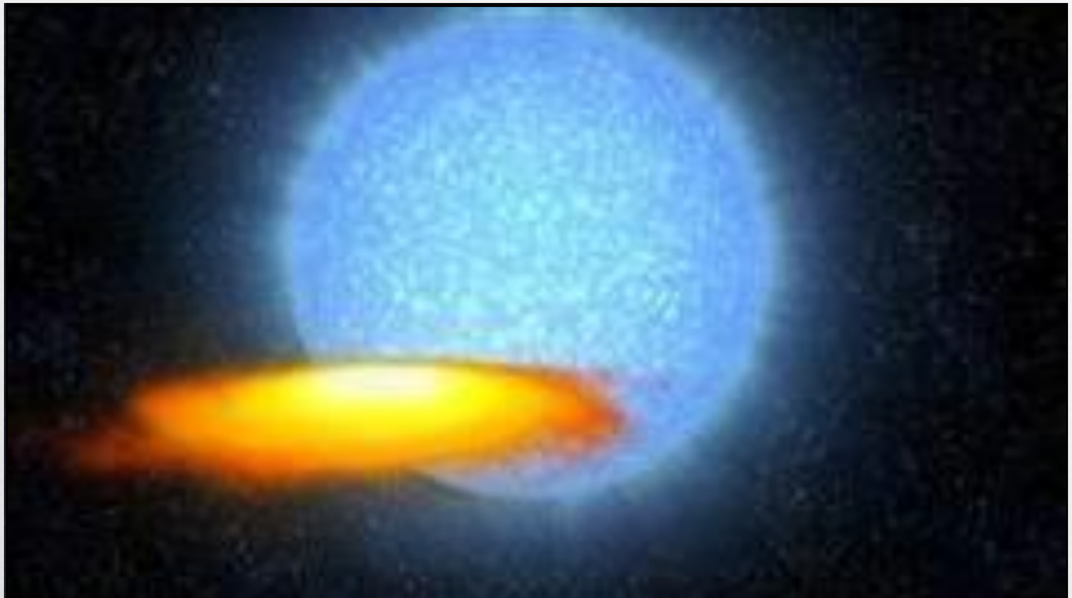
1,000,000 km

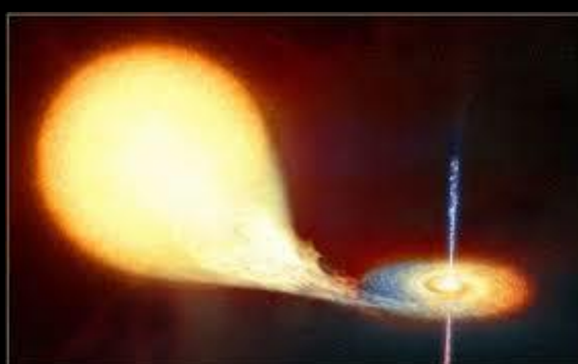
Microquasars



- Coined for (apparent) superluminal jets from X-ray binaries, by analogy with quasars

HMXB and LMXB archetypes





Illustrations by NASA

1) Wind-fed (persistent, HMXB)

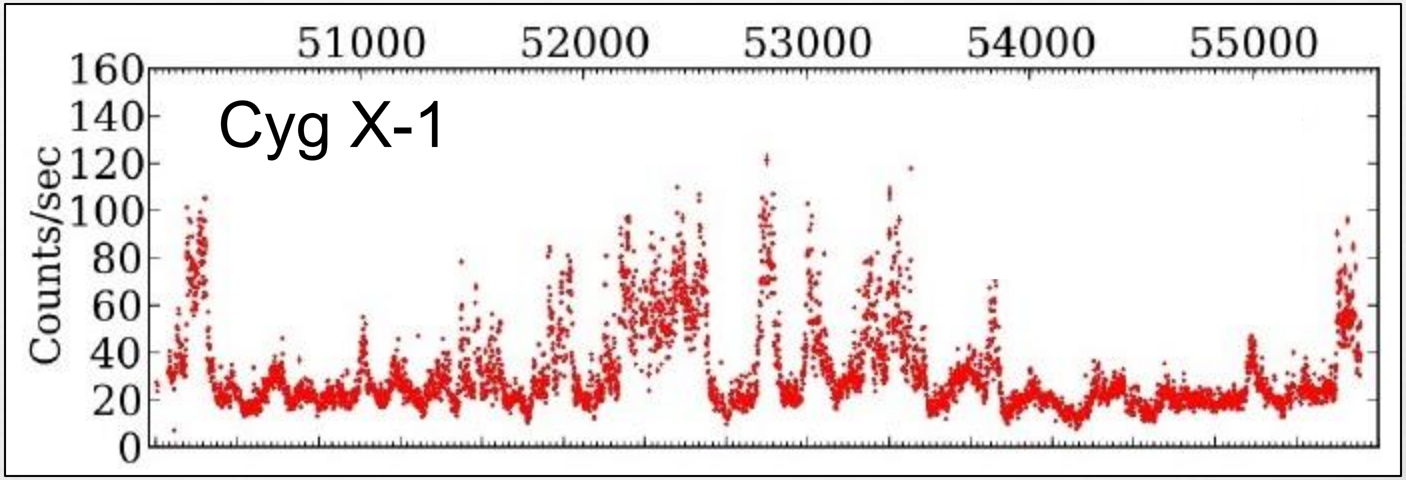
- O-B giants
- $L_{opt}/L_X \sim 10$

2) Roche-lobe overflow (transient, LMXB)

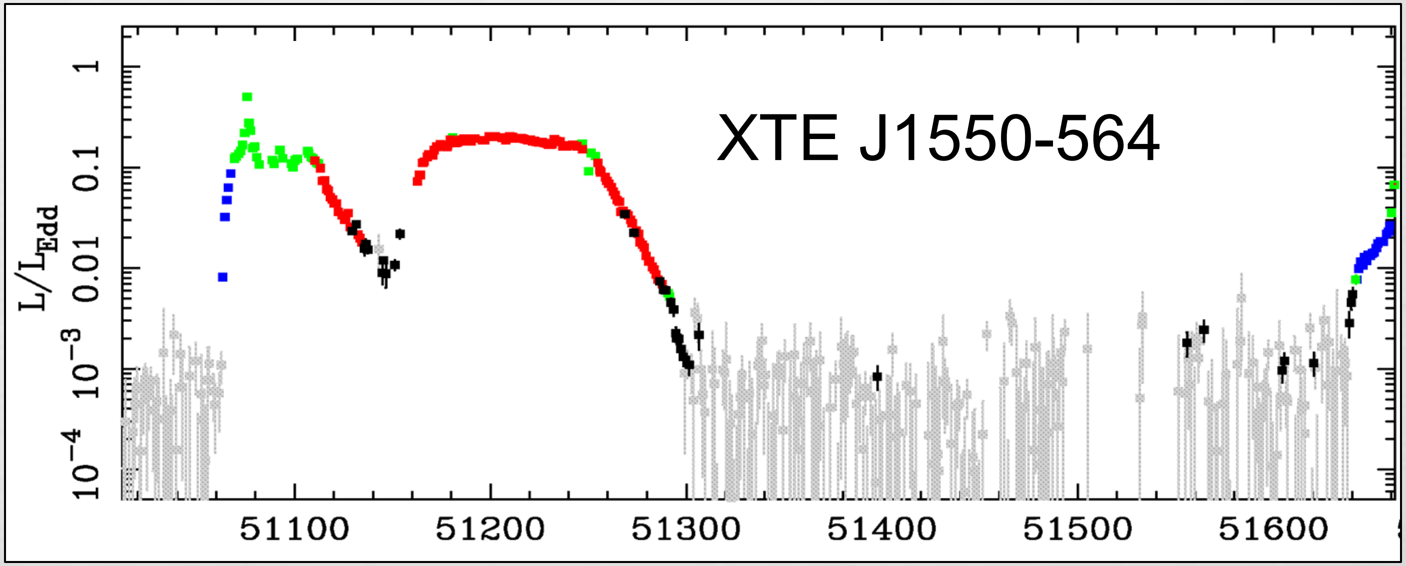
- K-M dwarf
- $L_{opt}/L_X \sim 10^{-2}$

Characteristic X-ray Activity

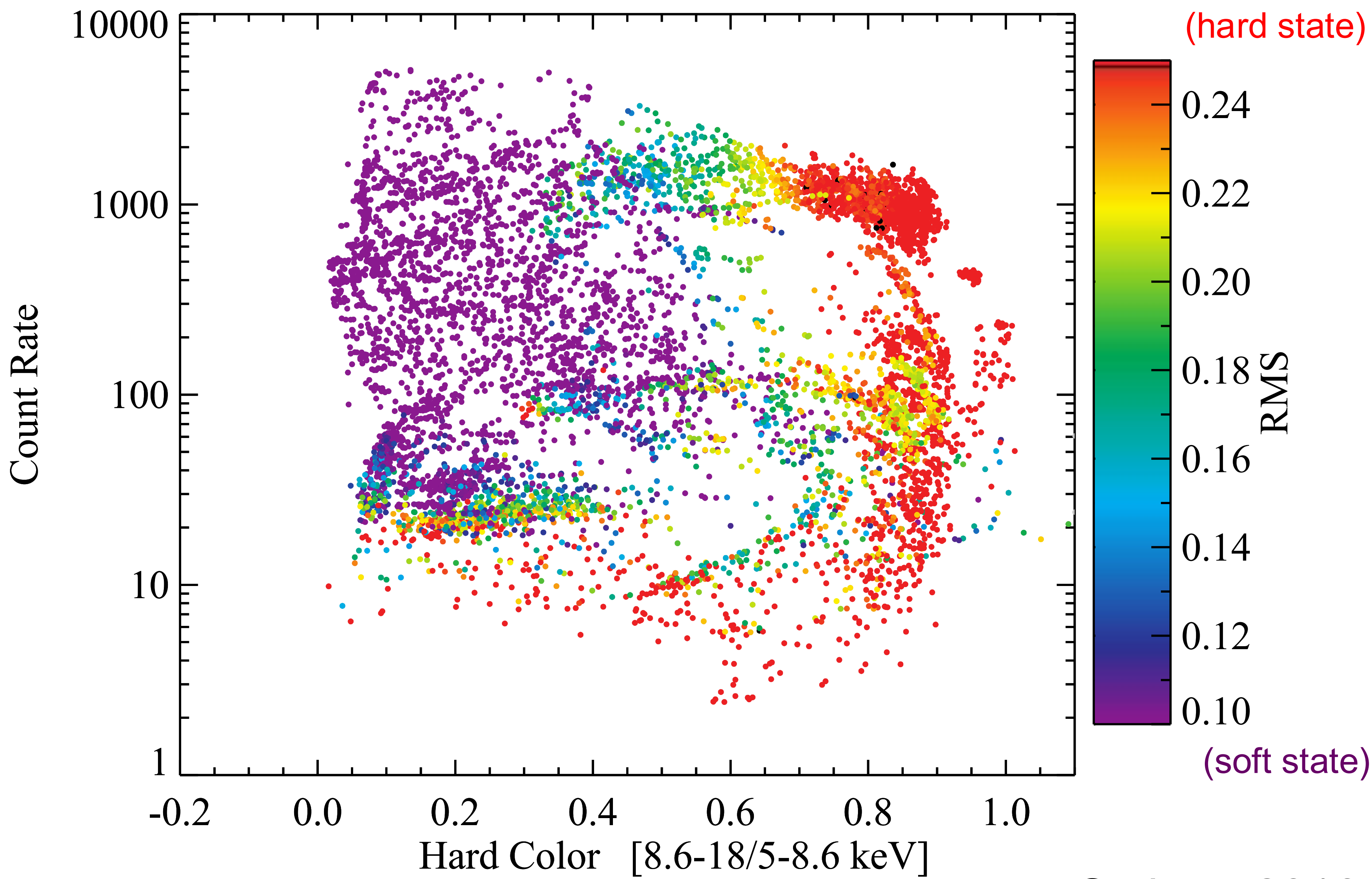
- Persistent



- Transient

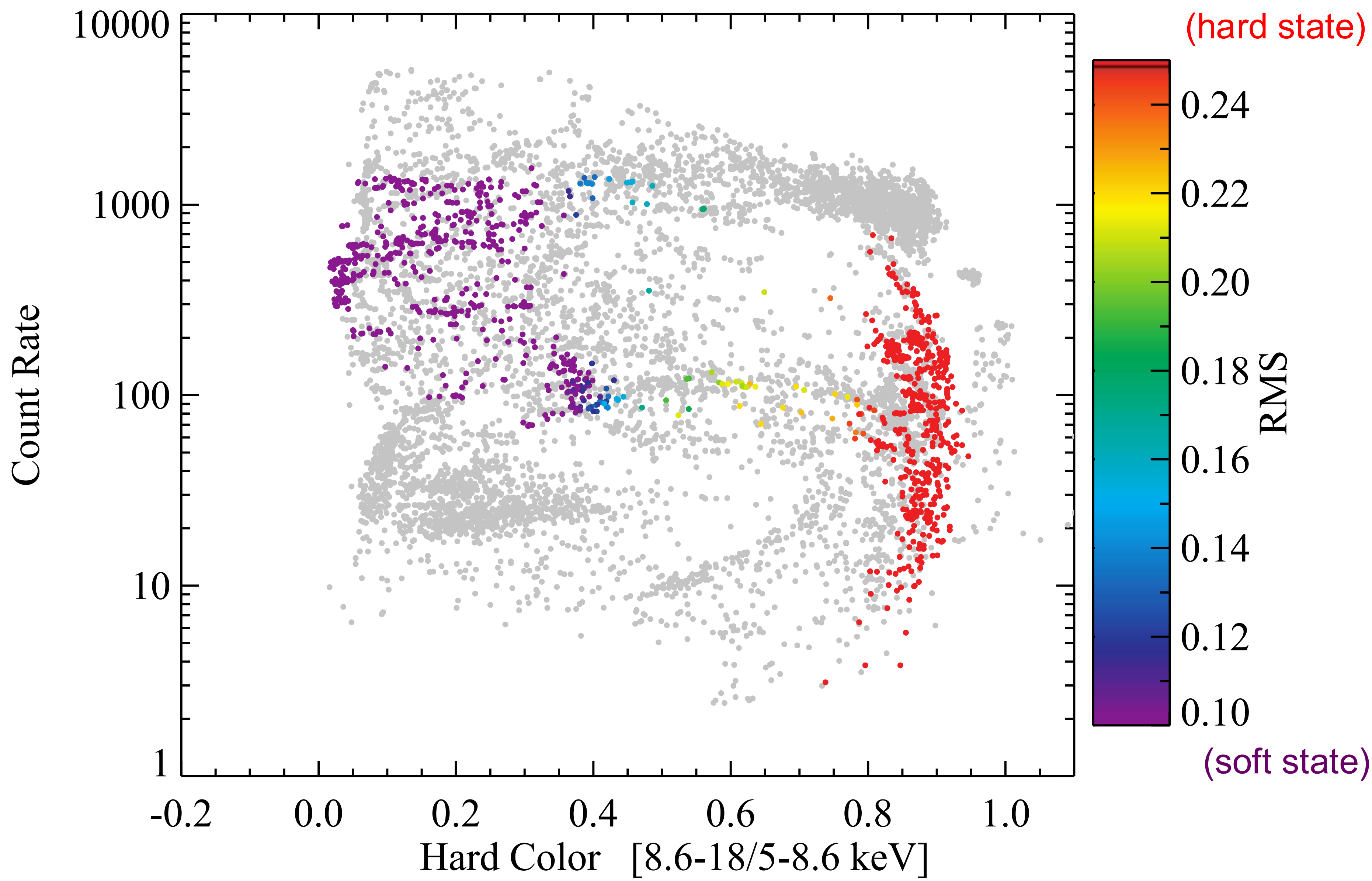


The RXTE View of BHs - HID



Steiner+2016

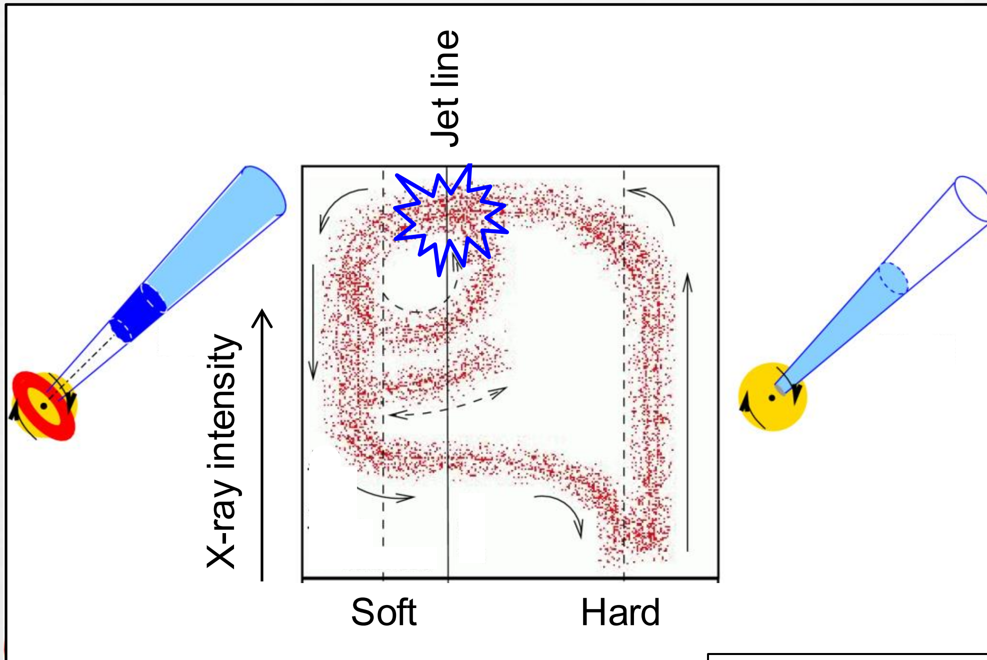
GX 339-4 as template



States, Turtles, and Jets

Type 1

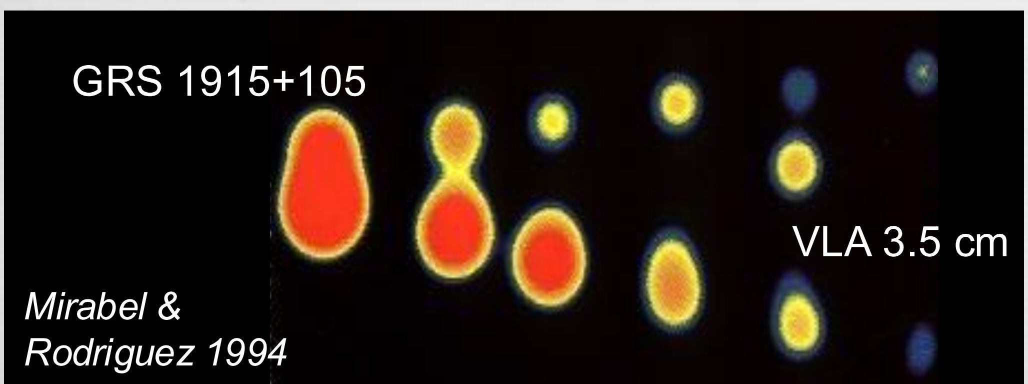
Pc-scale ballistic jets: Seen episodically near X-ray maximum at $L_X \sim L_{Edd}$



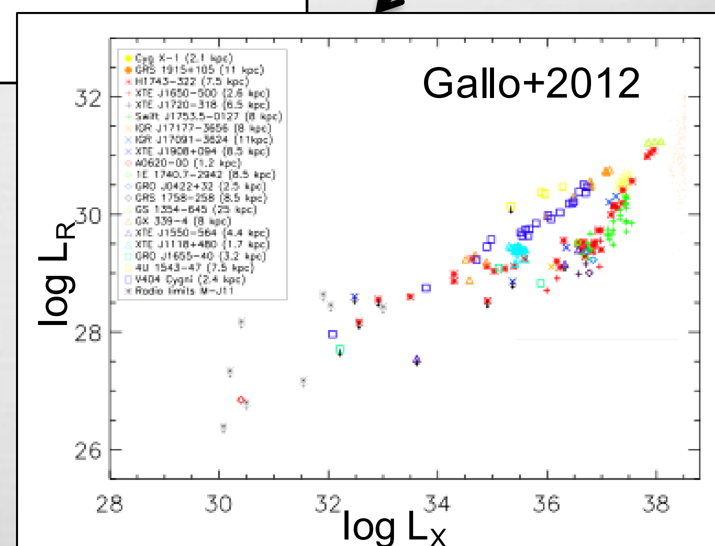
Fender, Belloni & Gallo 2004

Type 2

AU-scale steady jets: Seen continuously in low hard sate at $L_X \sim$ few% L_{Edd}

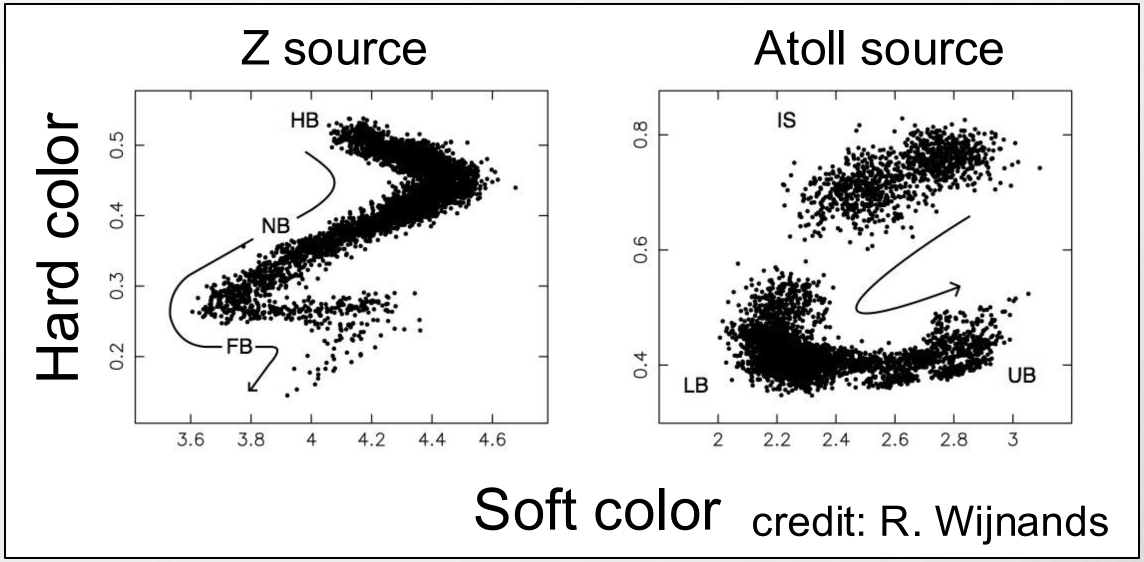


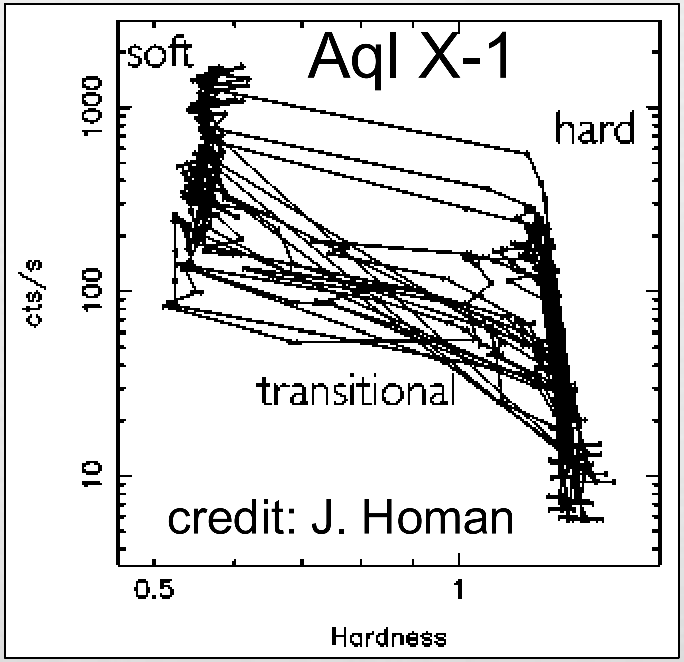
Mirabel & Rodriguez 1994



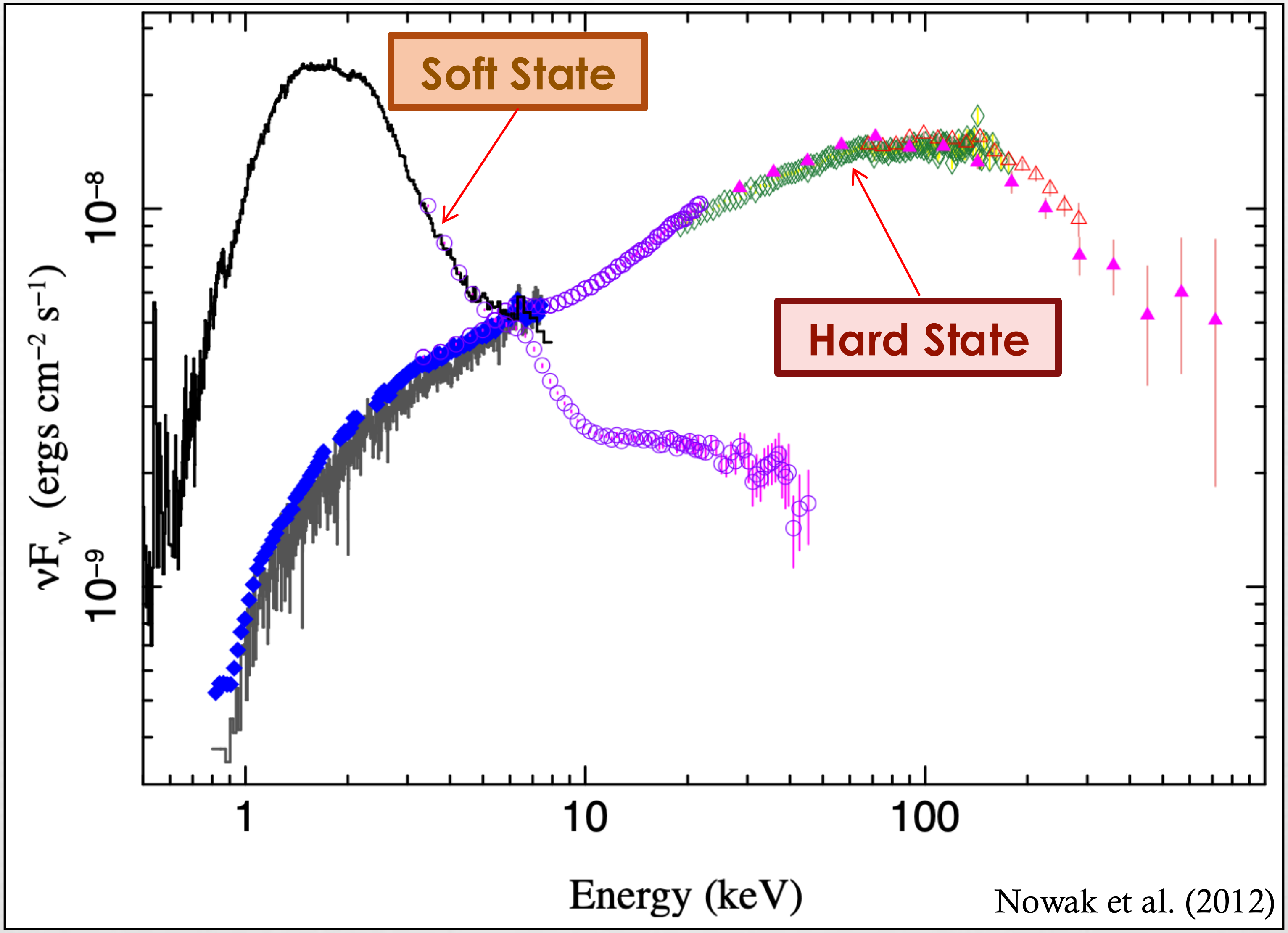
Neutron Star LMXB Systems

- 2 main types
  - Z- vs Atoll
- Distinguished by color-color patterns at short-timescales
- Atoll sources appear very similar to BH soft and hard states:





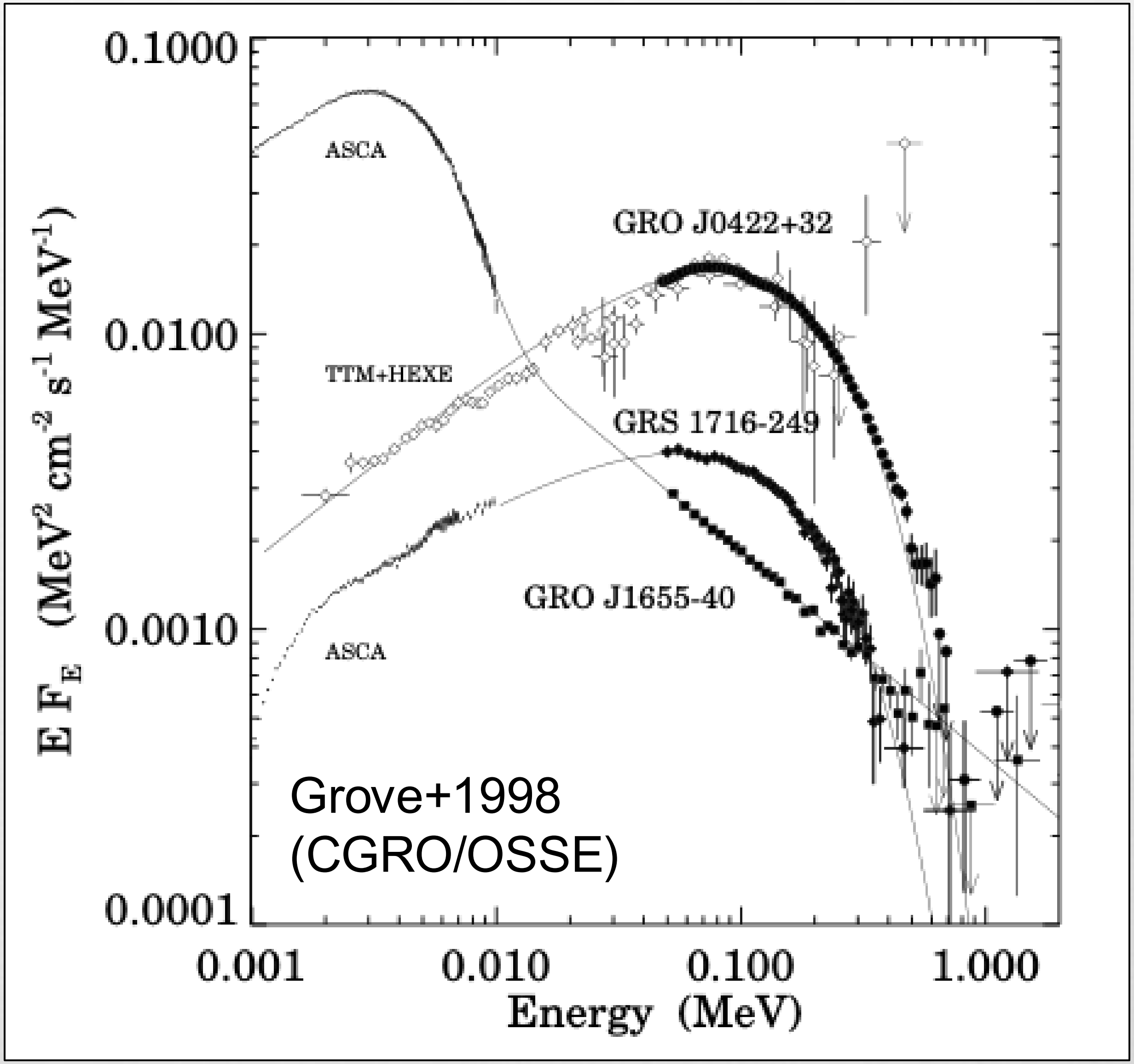
X-ray States of Cygnus X-1

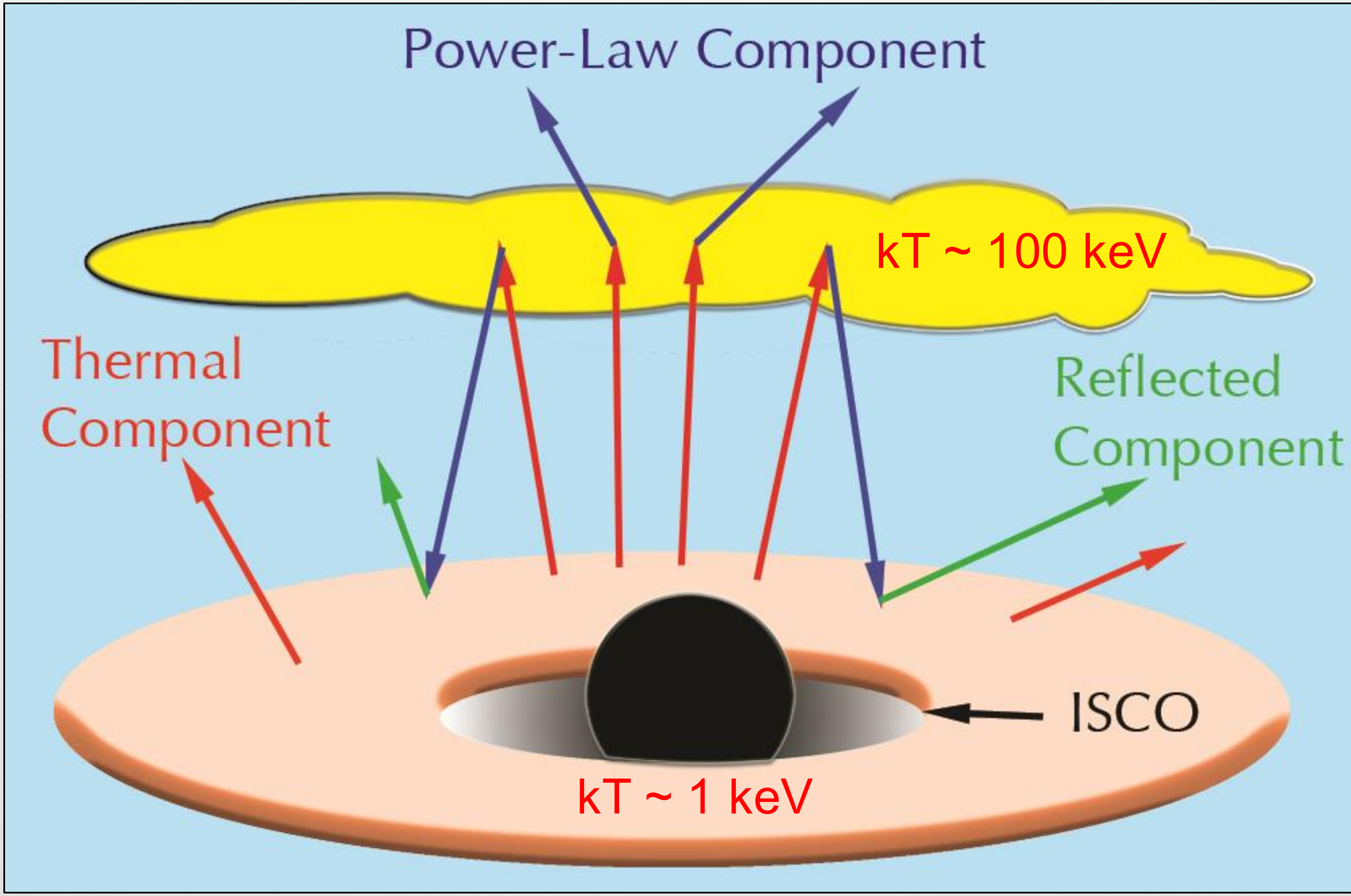


Cyg X-1 was the prototype for BH state dichotomy (Tananbaum+1972)

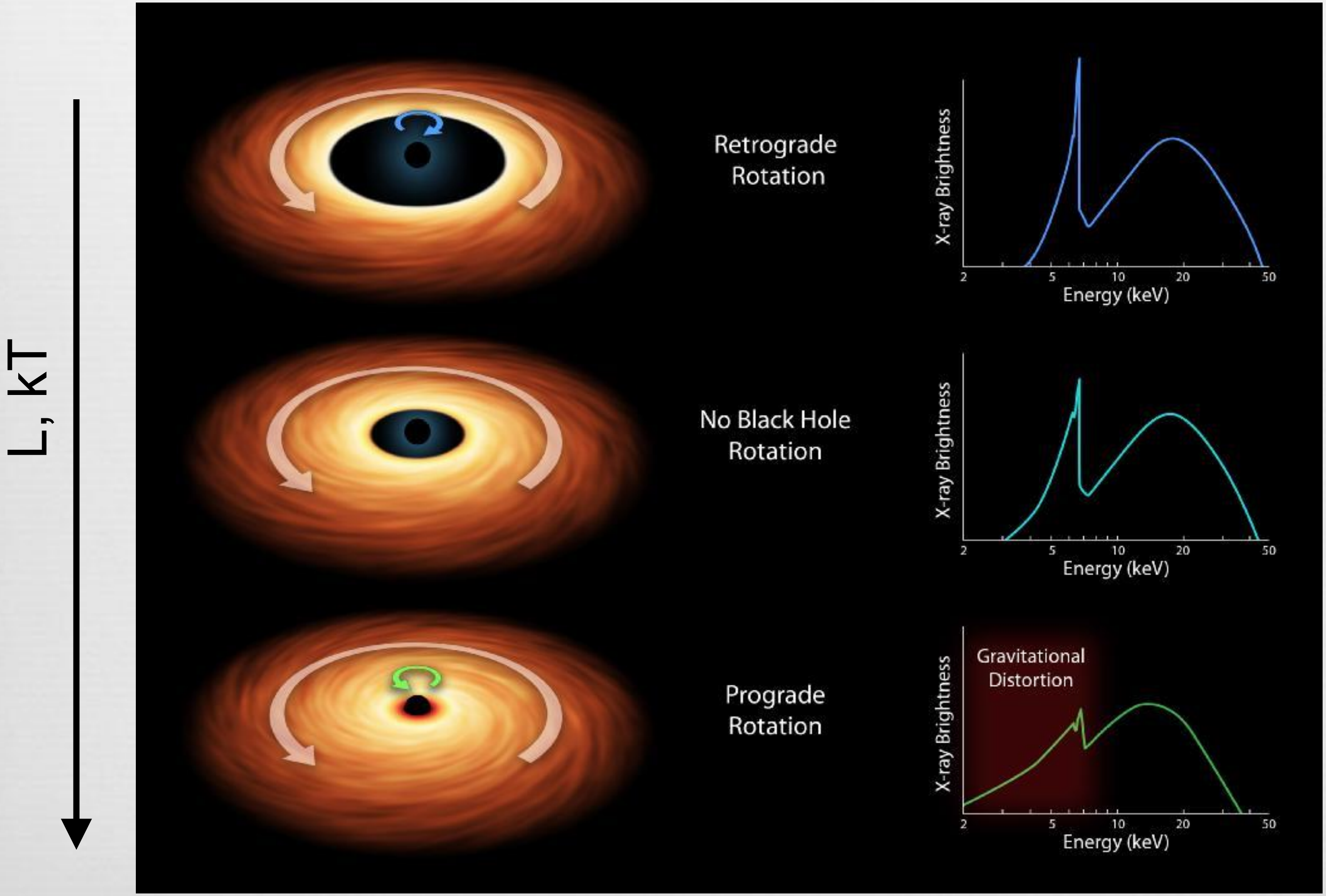
Taking a Harder Look

- Few studies extend out to MeV, but these seem to show:
  - unbroken power-laws in soft states
  - thermal cutoff in hard states

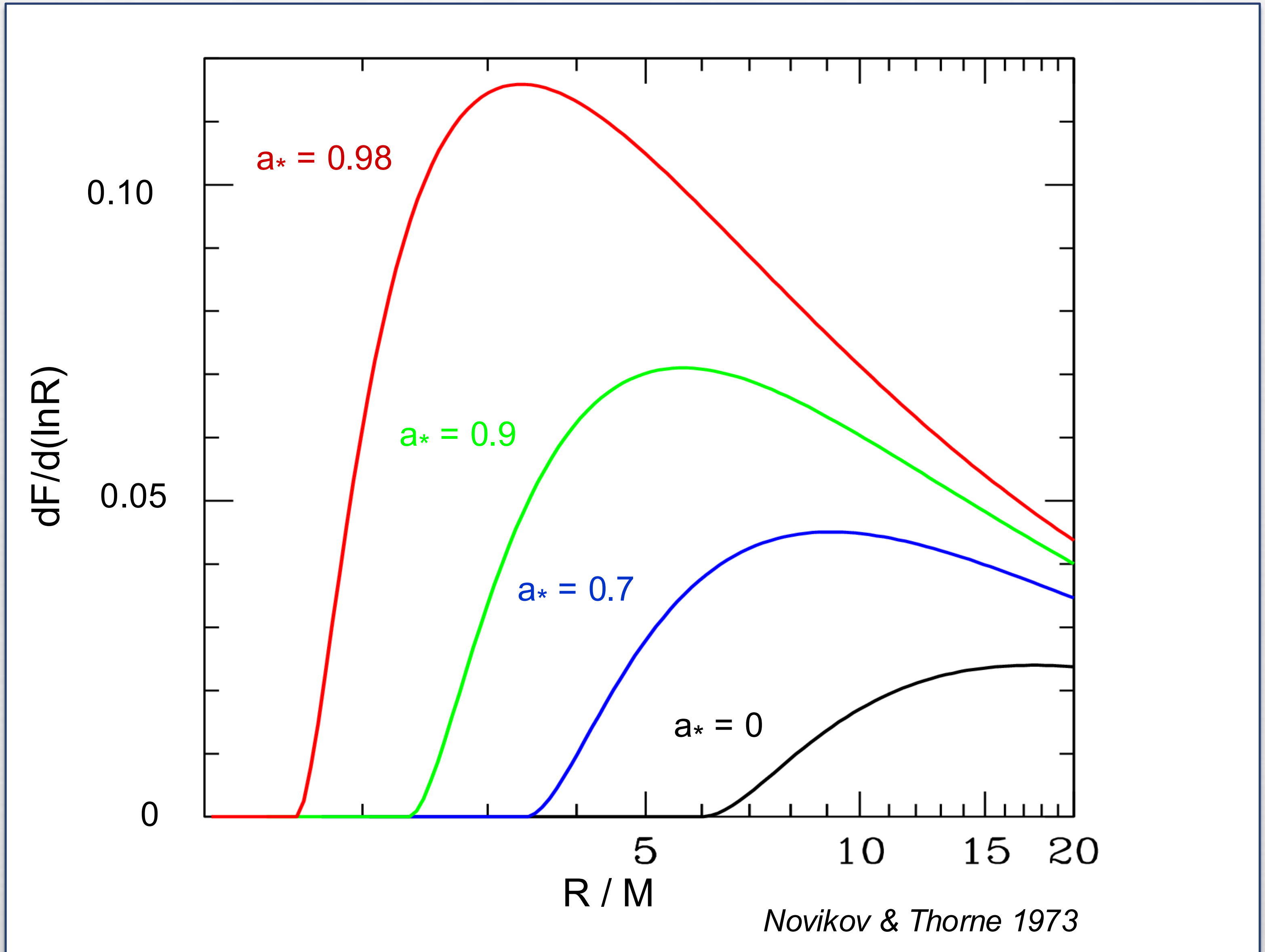



Power-Law Component
kT ~ 100 keV
Thermal
Component
Reflected
Component
ISCO
kT ~ 1 keV

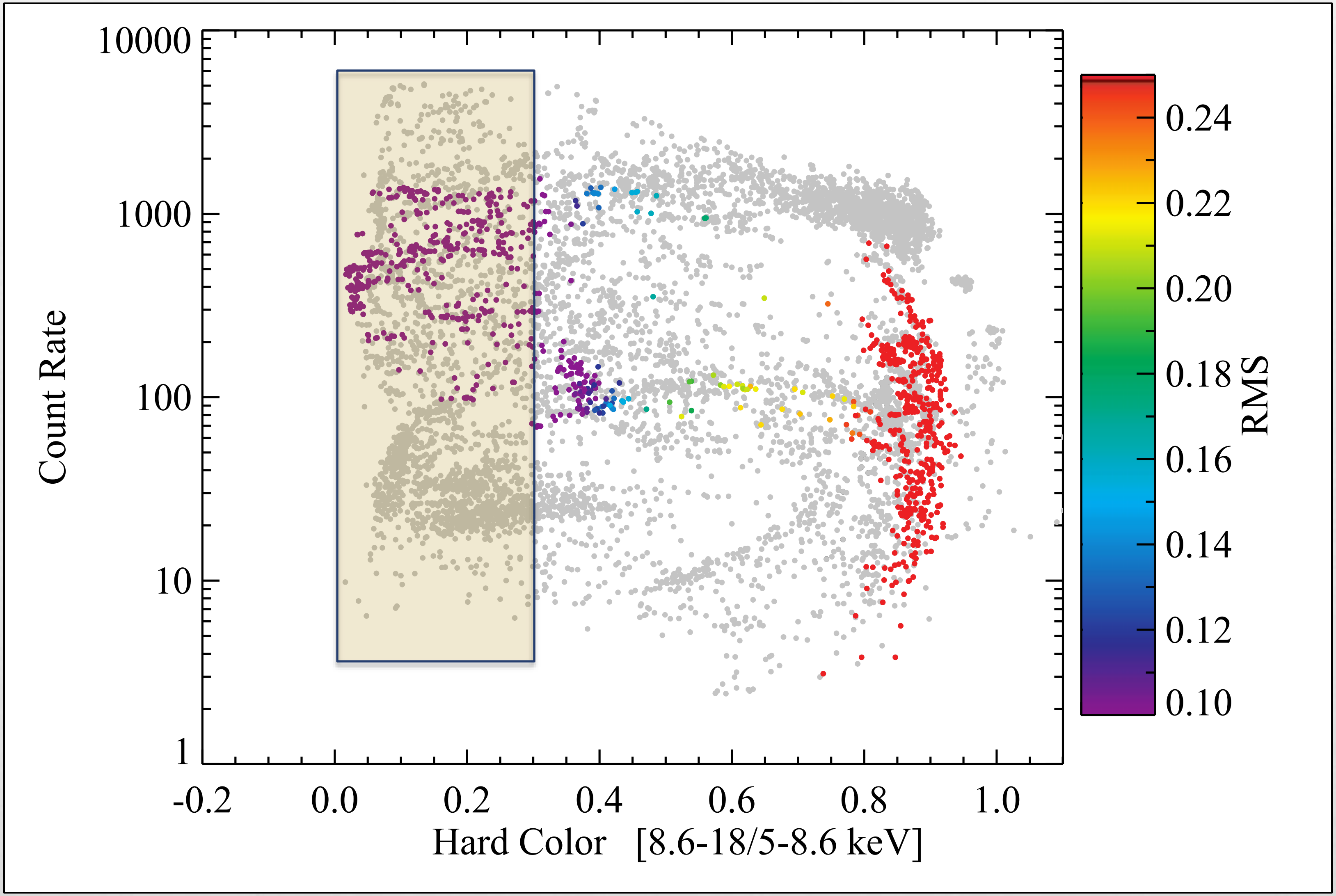
Relativistic Distortion of Emission Features With Spin



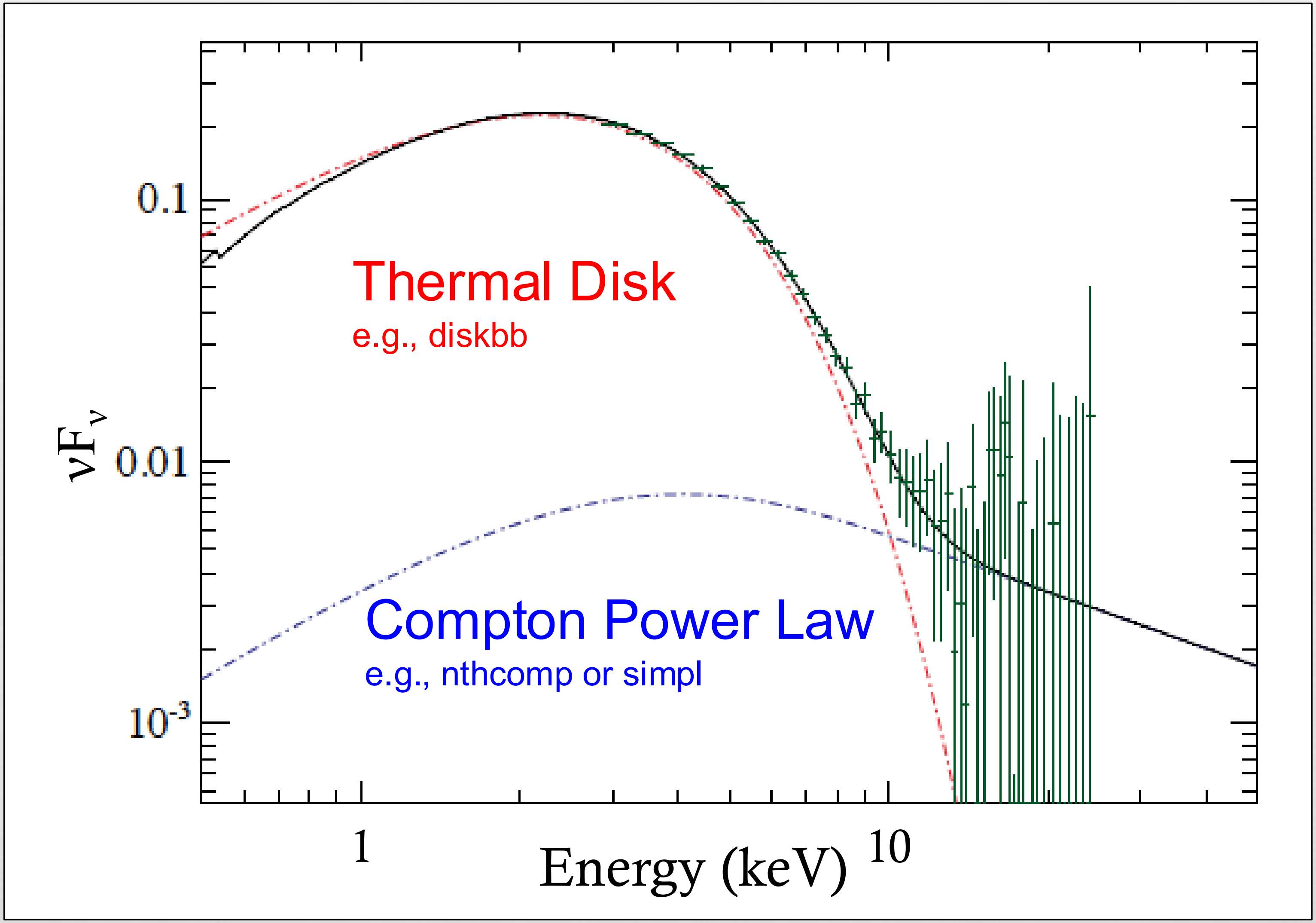
Thermal-Disk Emission



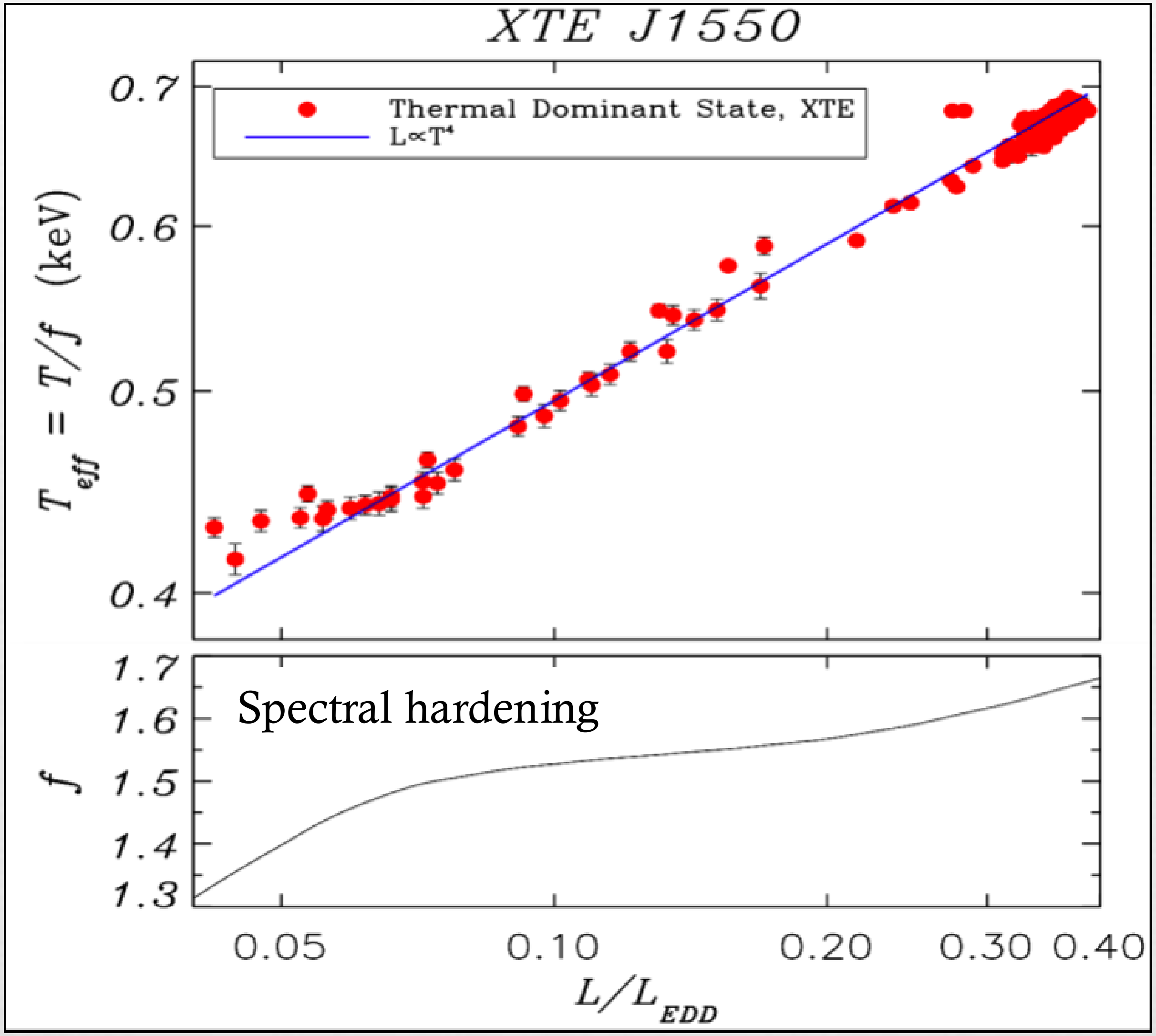
Soft State:
Thermal Disk Dominated



A typical soft-state spectrum



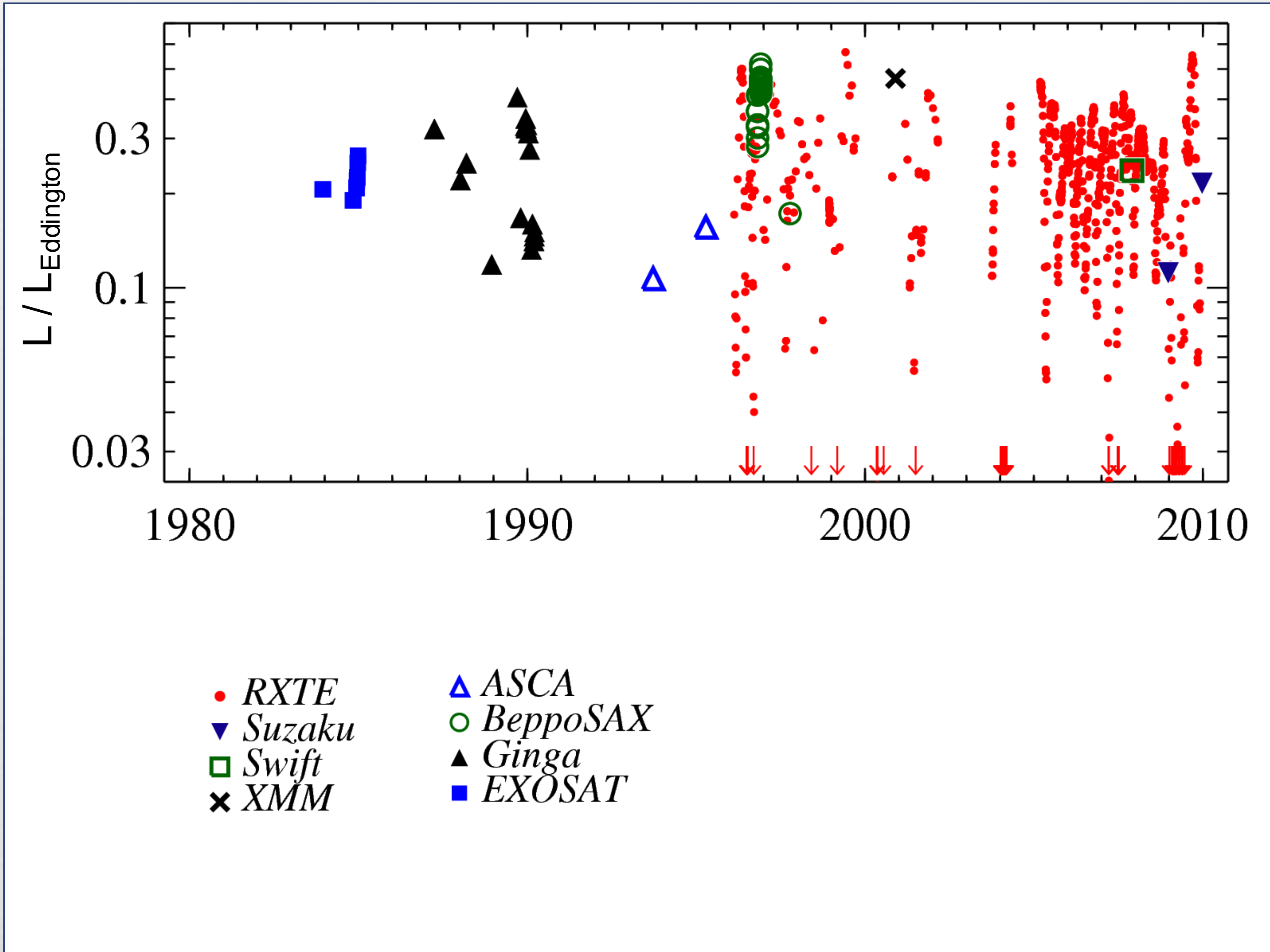
L~T^4 in soft states



e.g., Tanaka & Lewin 1995

LMC X-3: 1983-2009

Steiner et al. 2010



LMC X-3: 1983-2009

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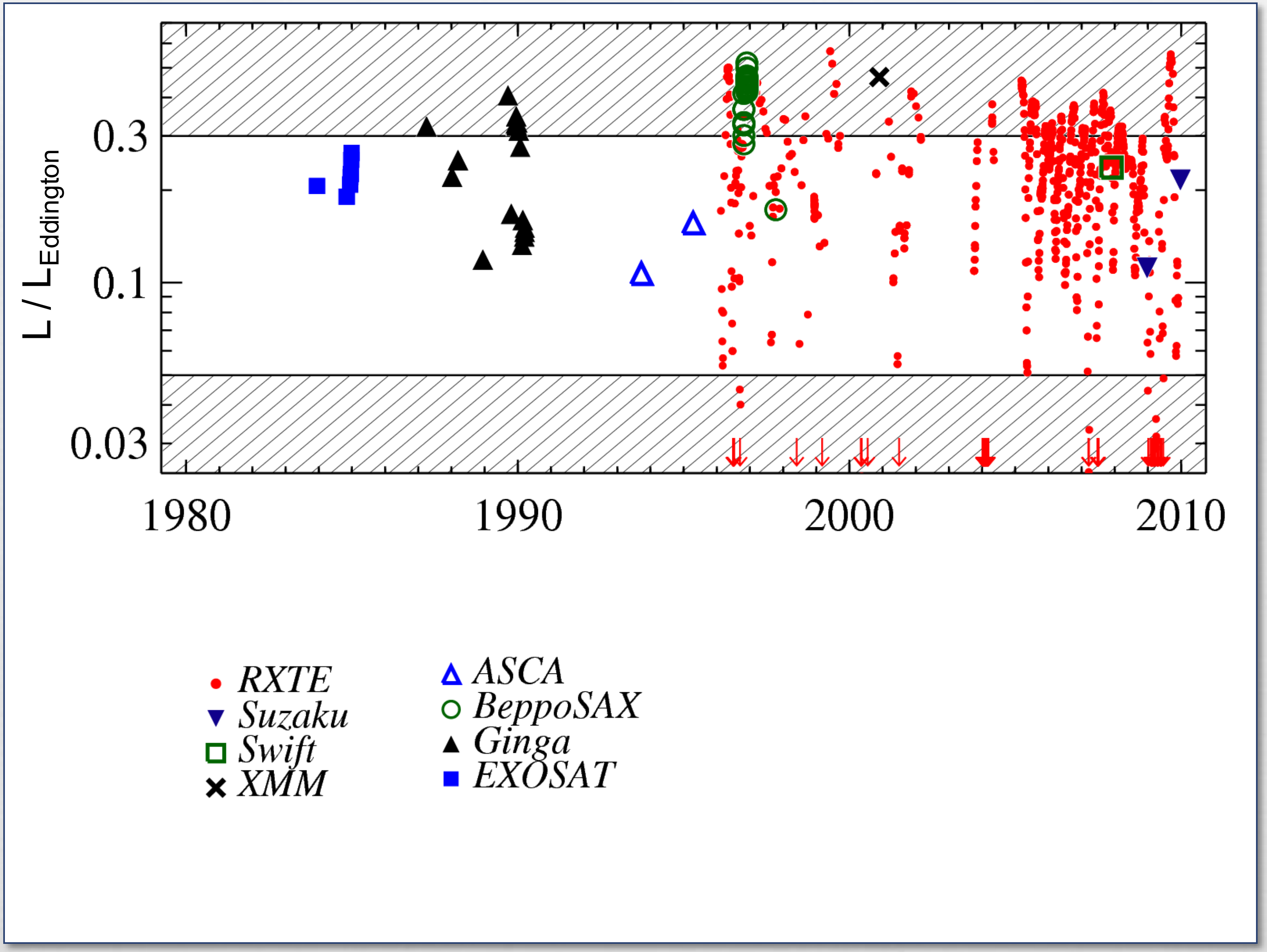

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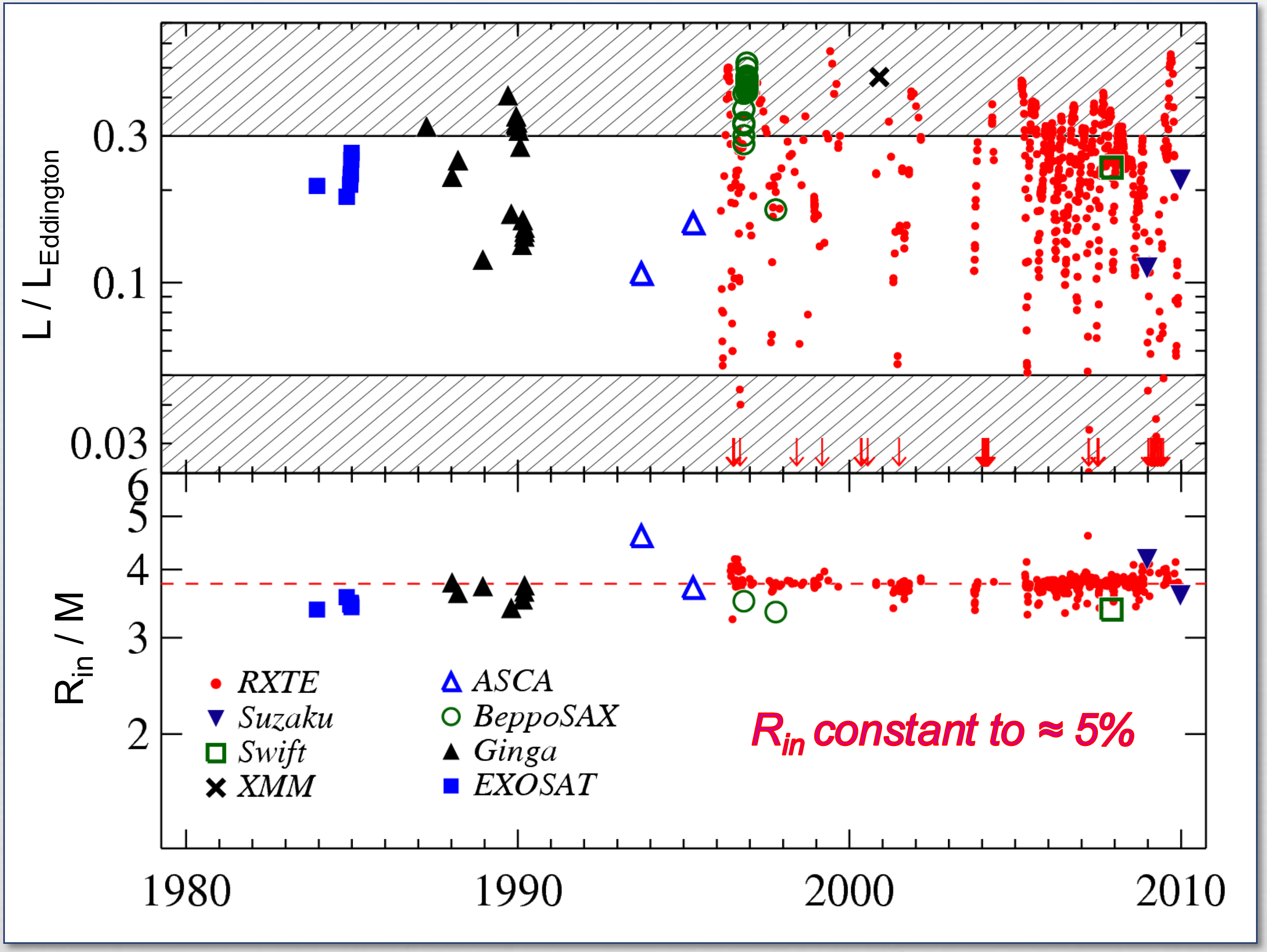
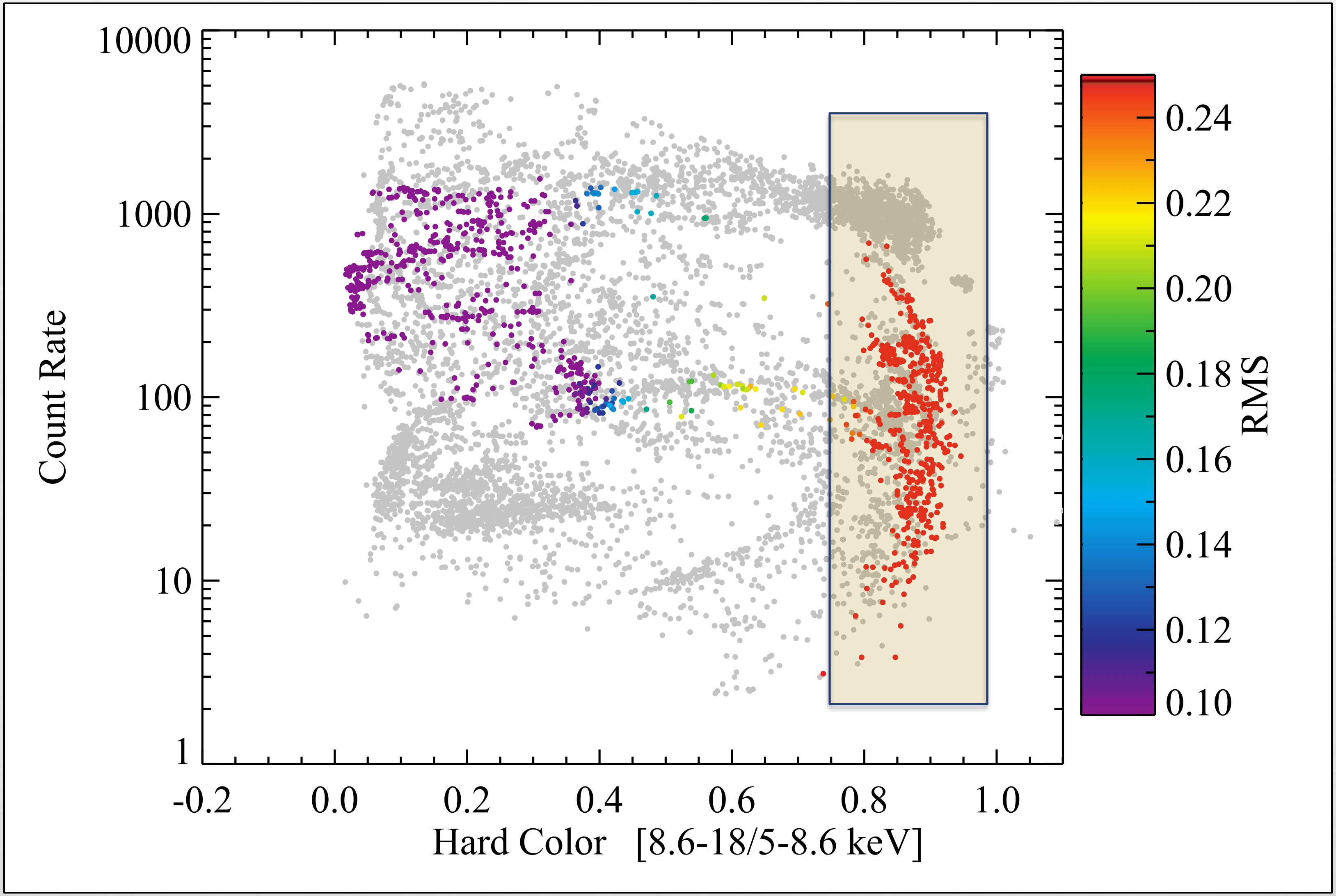
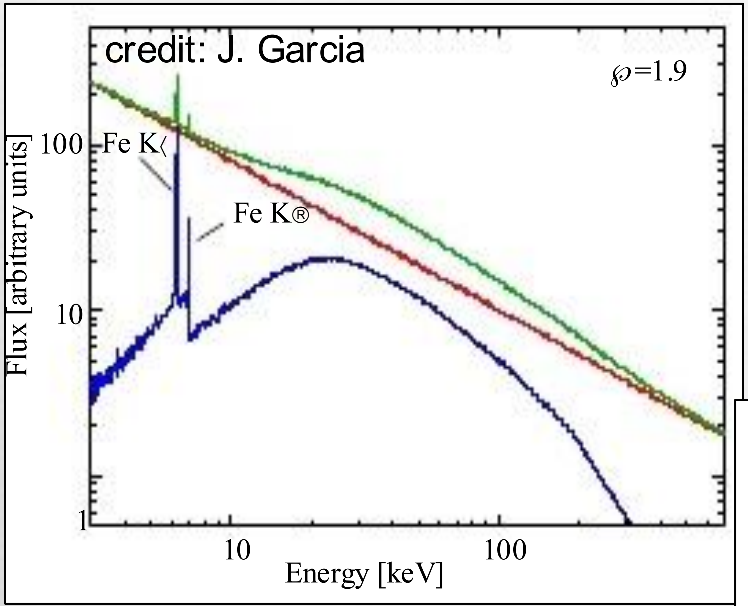


Hard State:

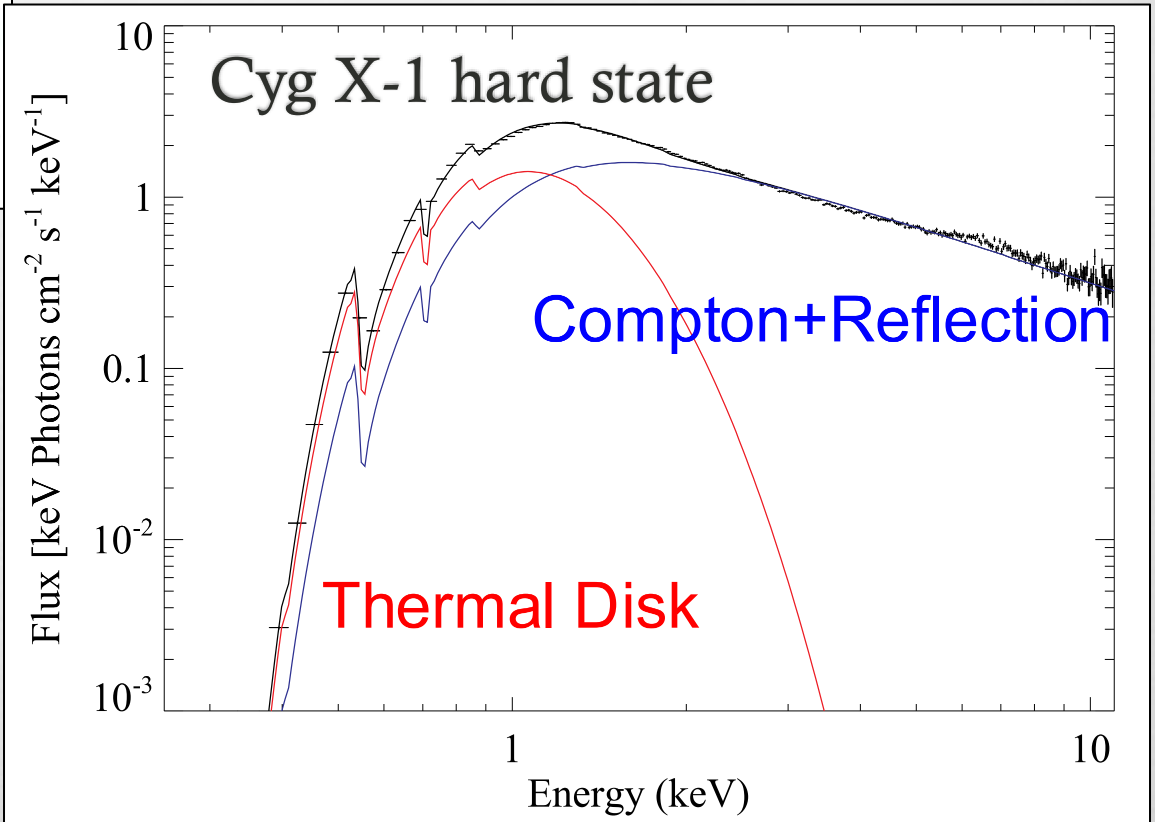
Compton and Reflection Dominated



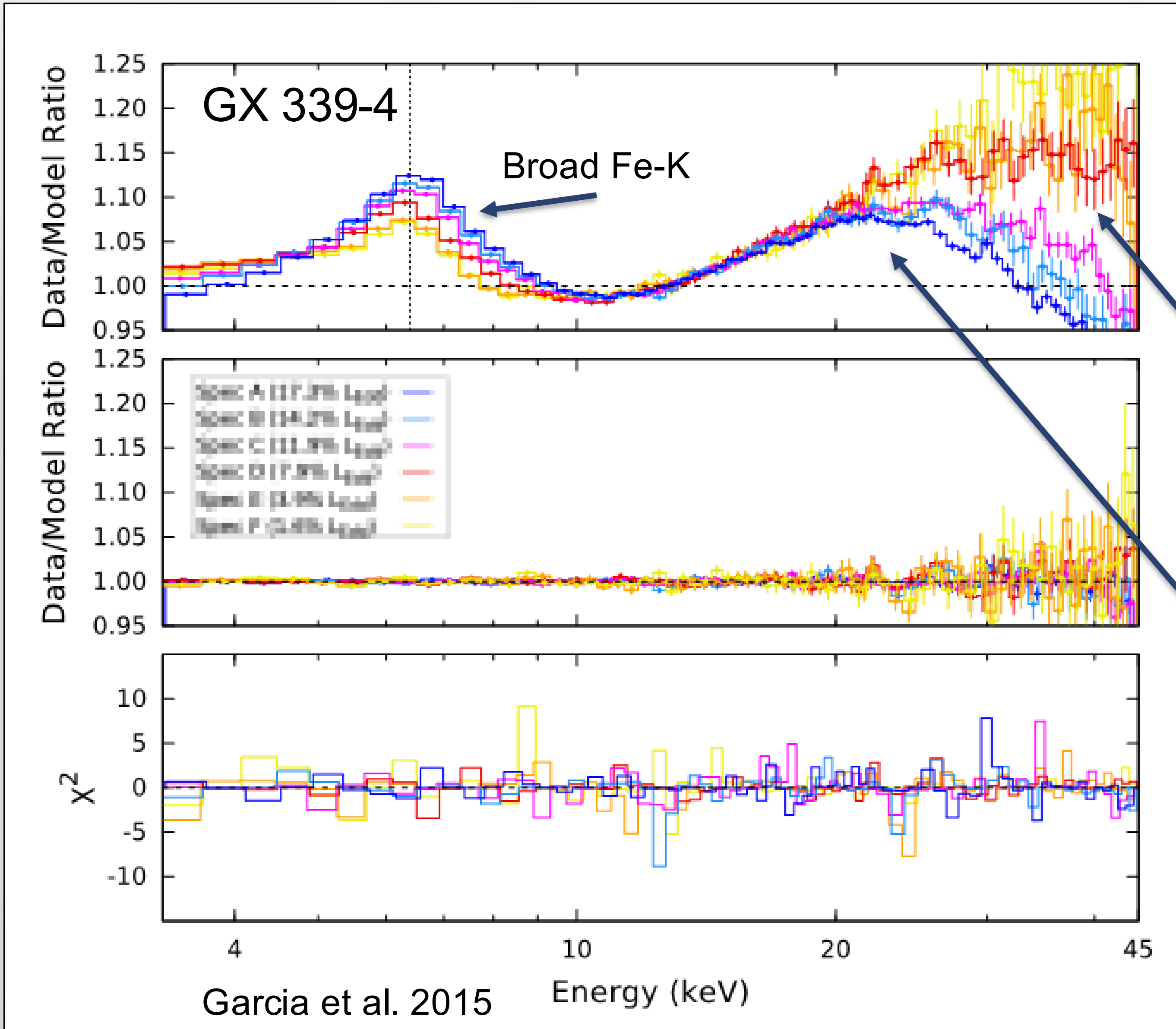
Hard State Spectra



- Dominated by (Compton) power-law and reflection components.



Hard State Residuals Show Reflection

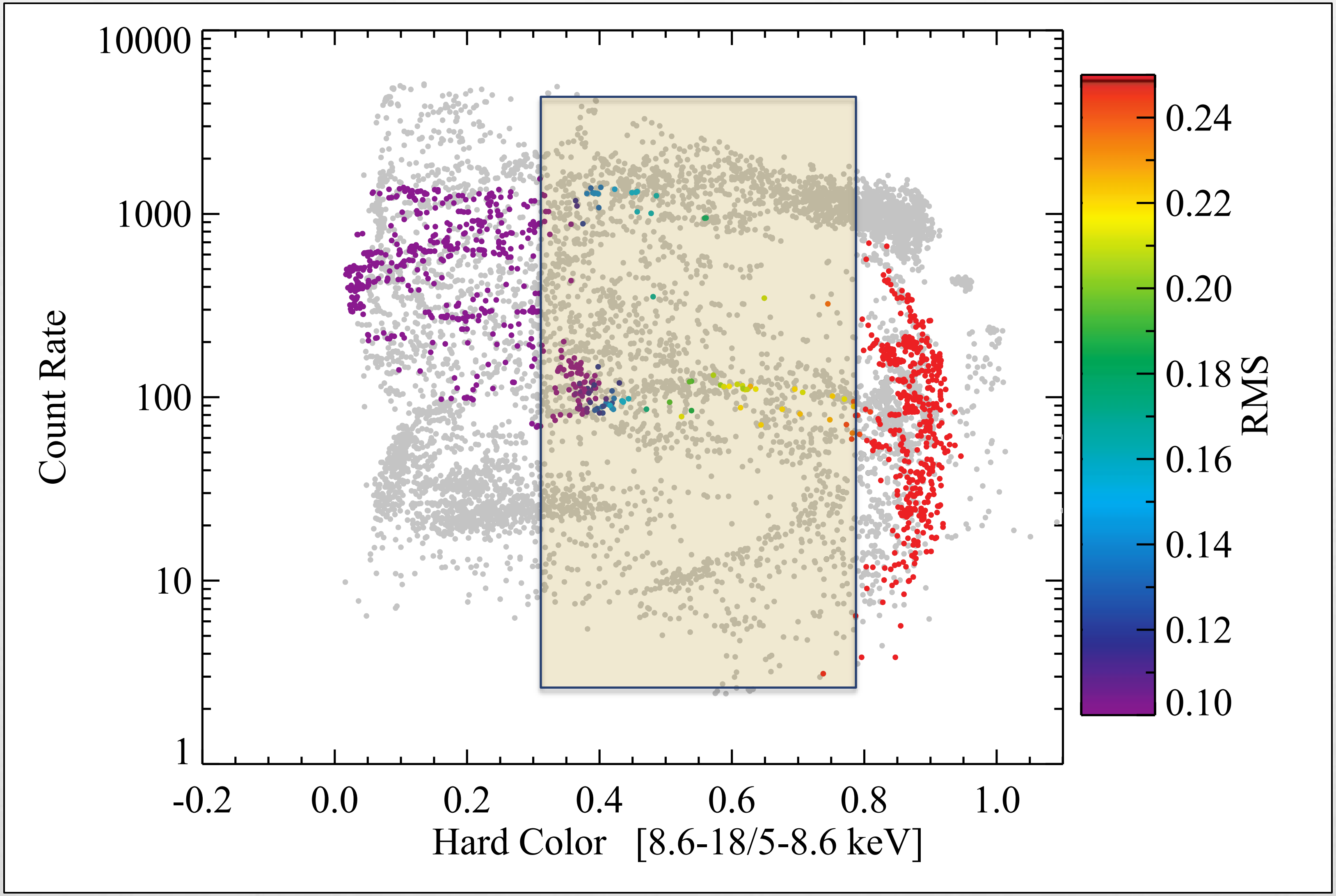


This high-energy cutoff energy follows coronal electron temperatures (Sasha's talk ahead). This shows that the coronal electrons cool as the source brightens.

Compton hump

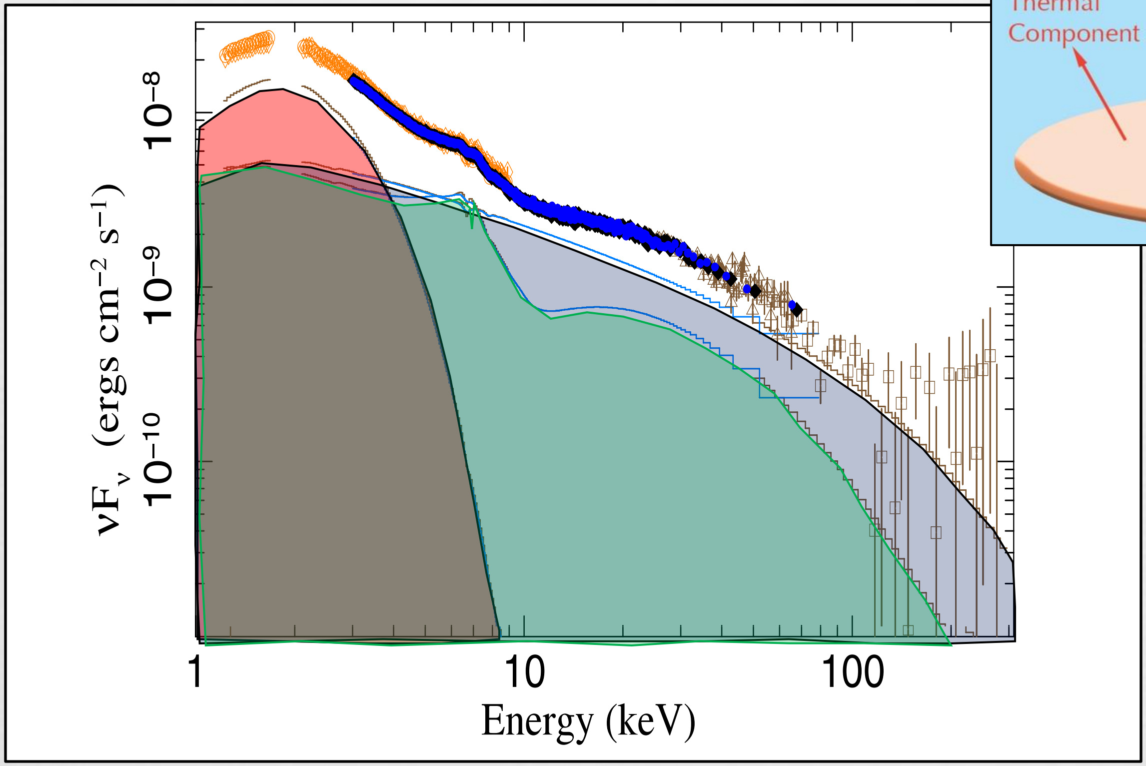
Intermediate States:

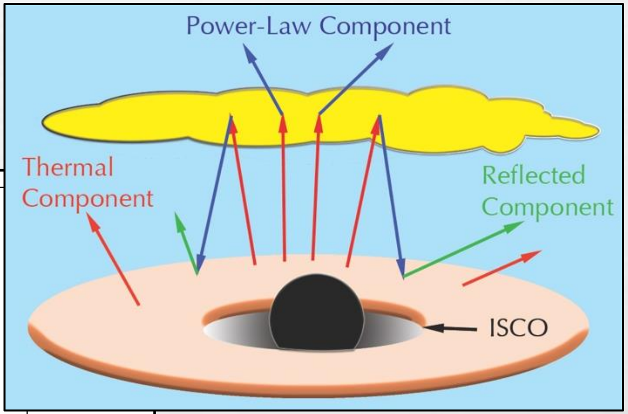
Messy!



Cyg X-1

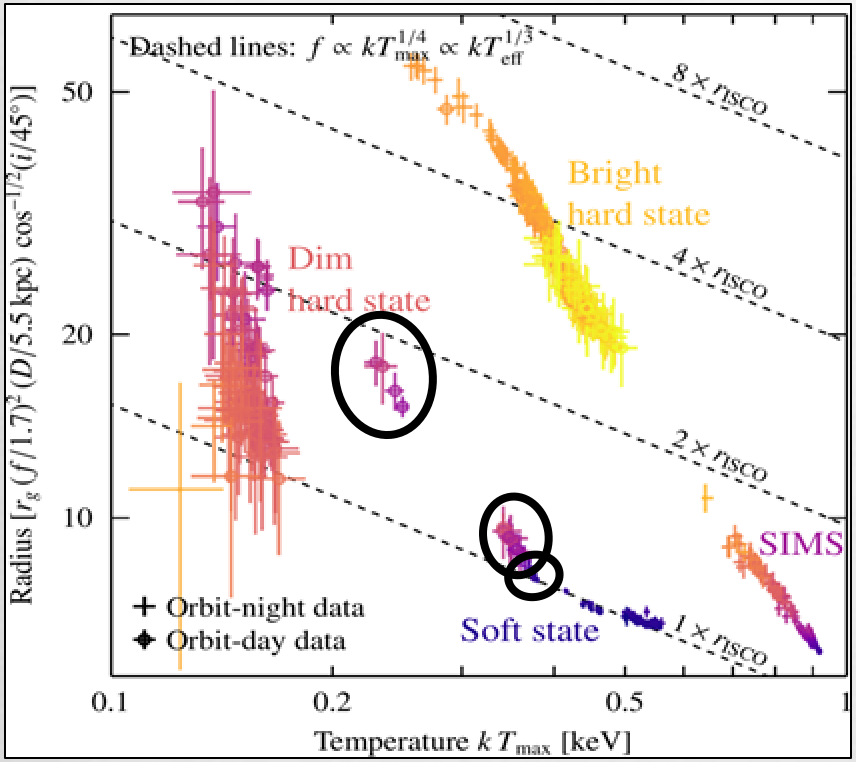
soft-intermediate state

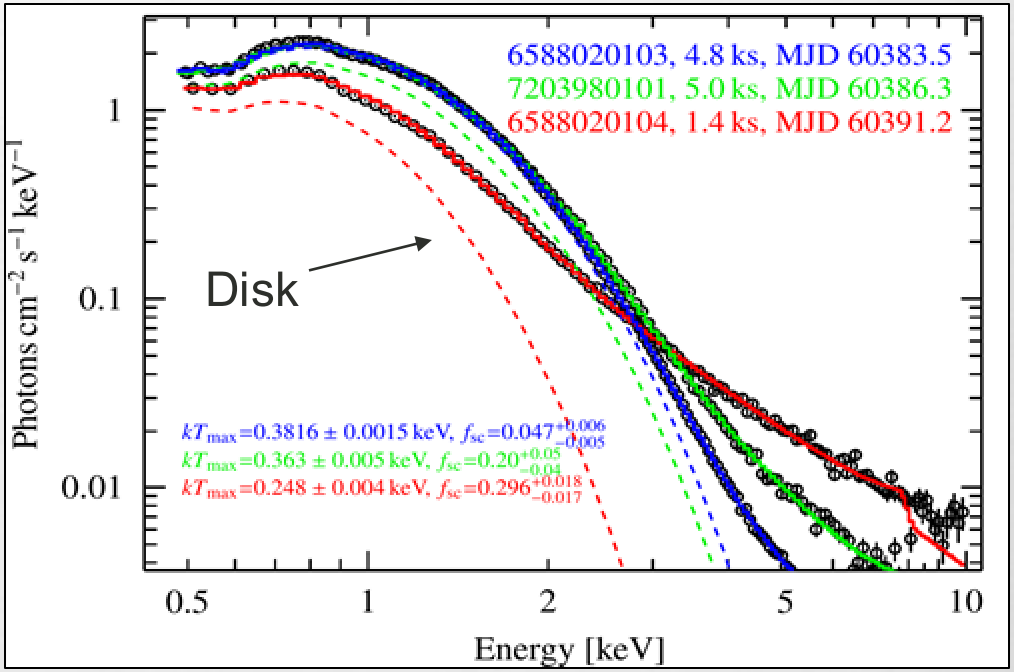




Tomsick+2014

Continuum Thermal-Fitting Models can Explore Question of Disk Truncation Onset



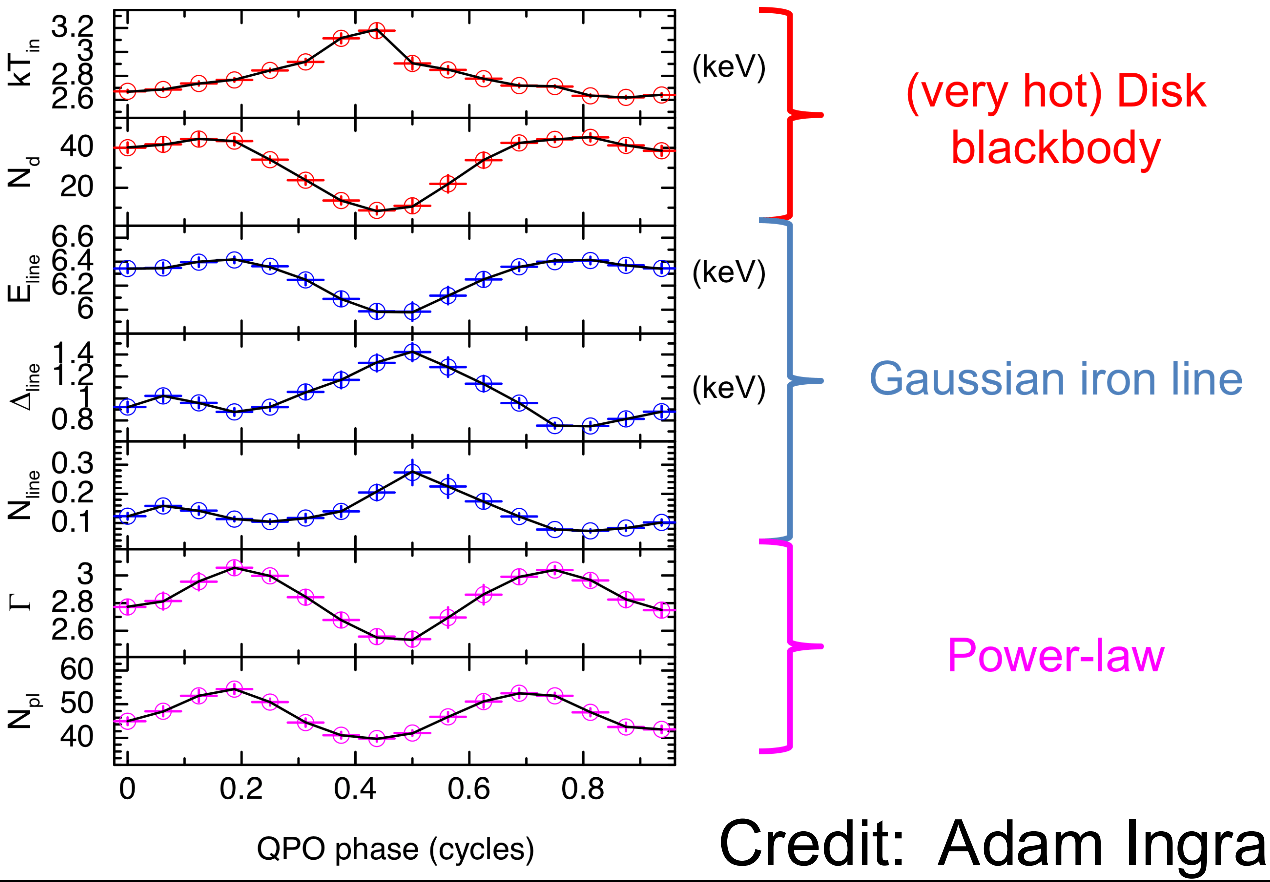


(More at Ole's talk this afternoon)

Application:

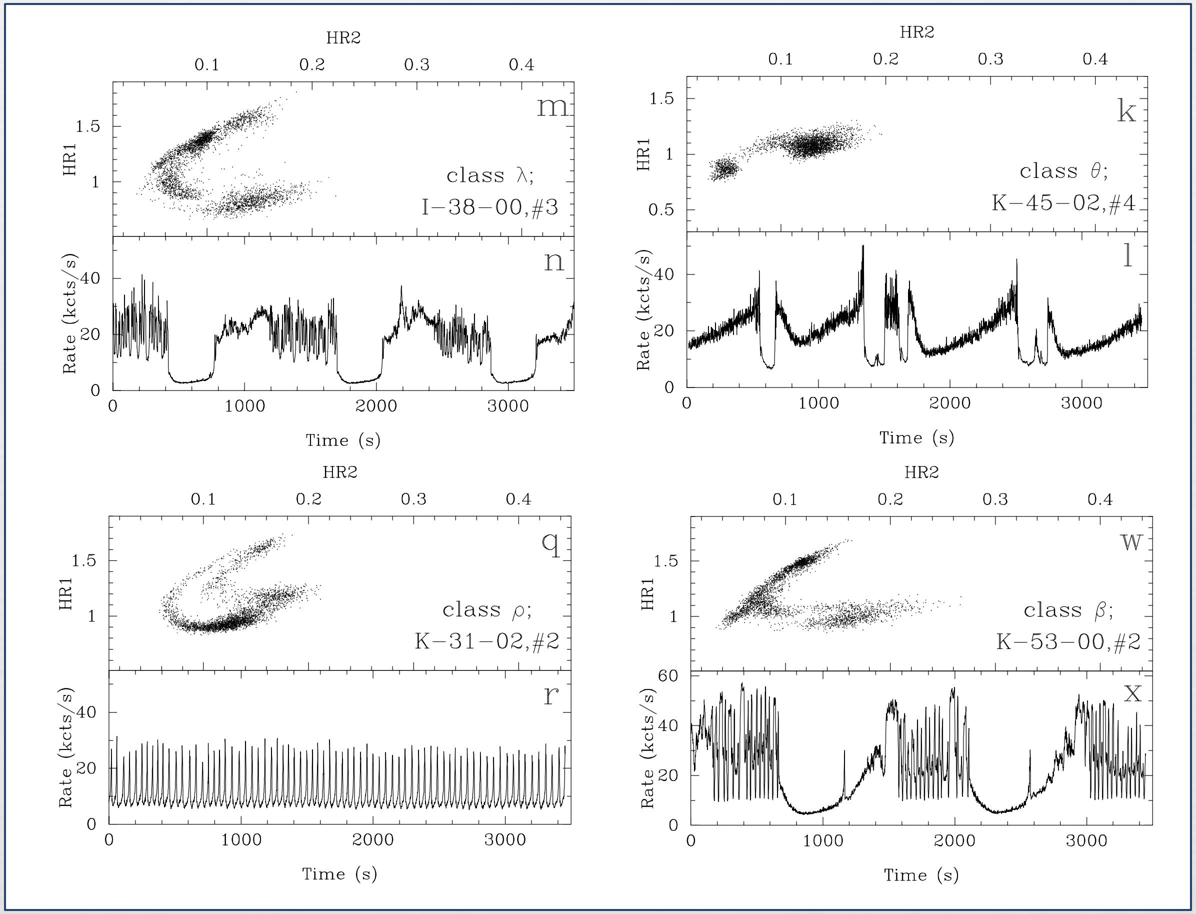
“Fast” Continuum Spectroscopy

Phased Spectral Fitting Over MAXI J1535's QPO



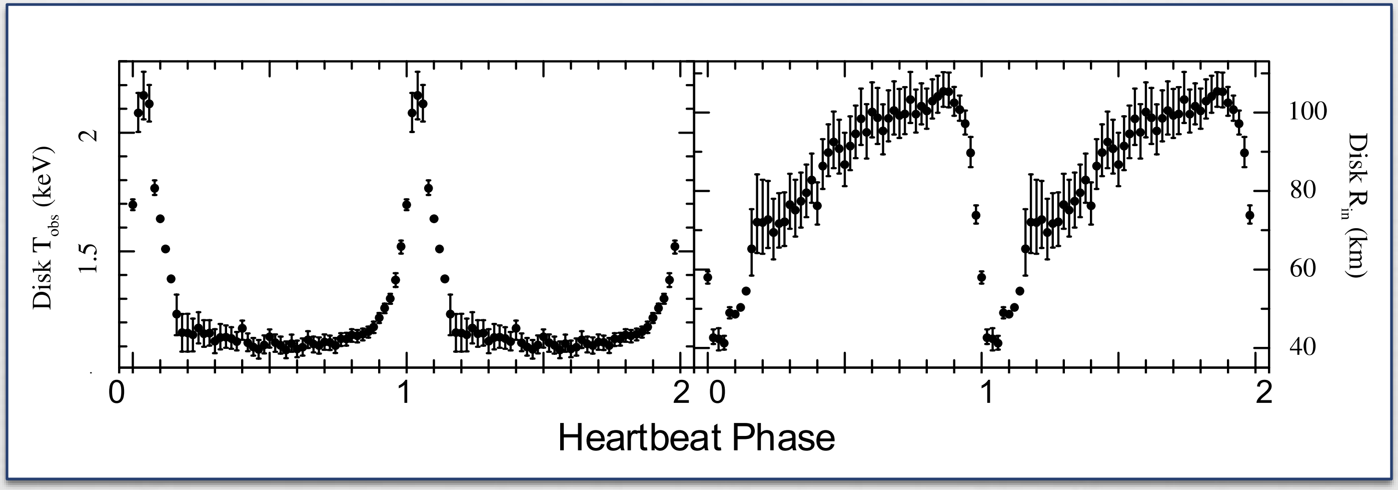
Credit: Adam Ingram

GRS 1915+105's exotic modes



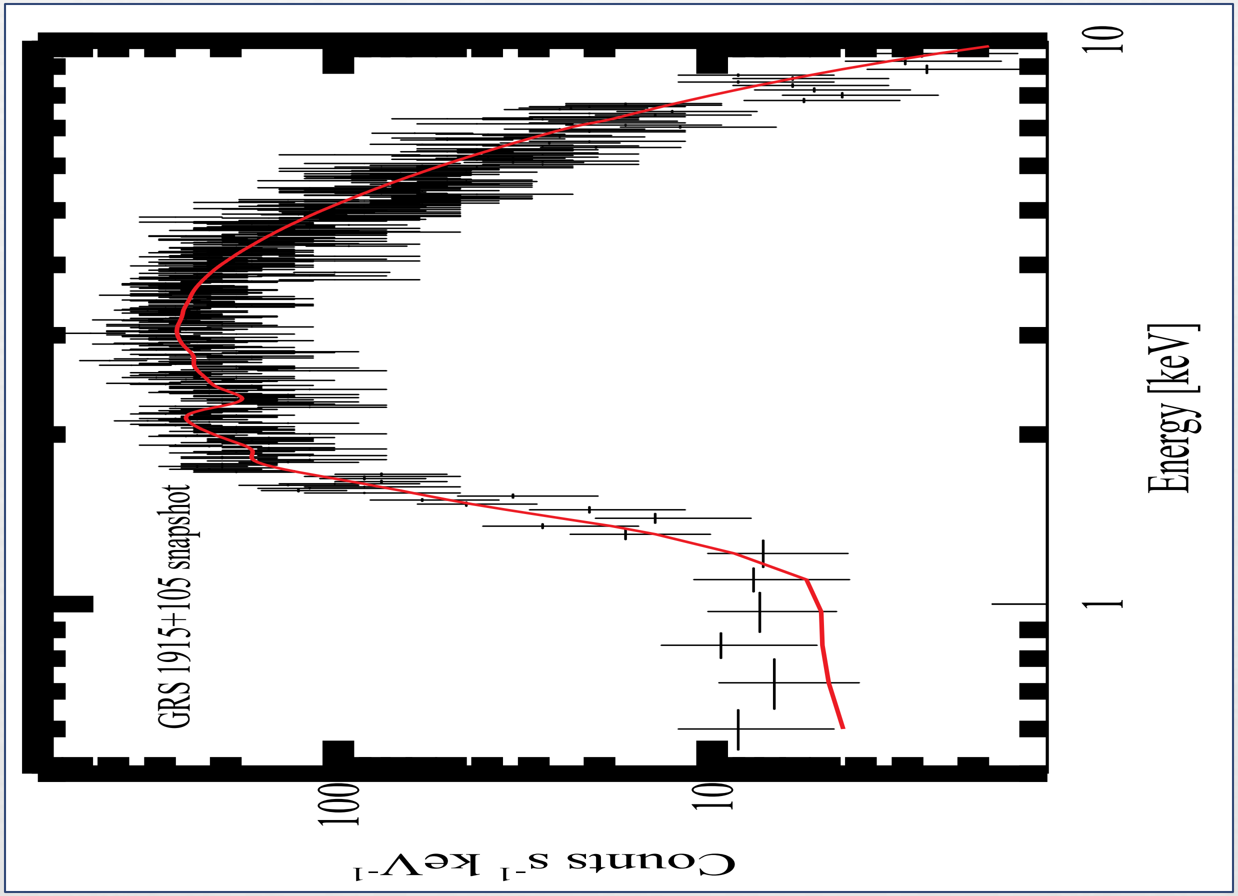
Belloni+2000

GRS 1915+105's "Heartbeat"

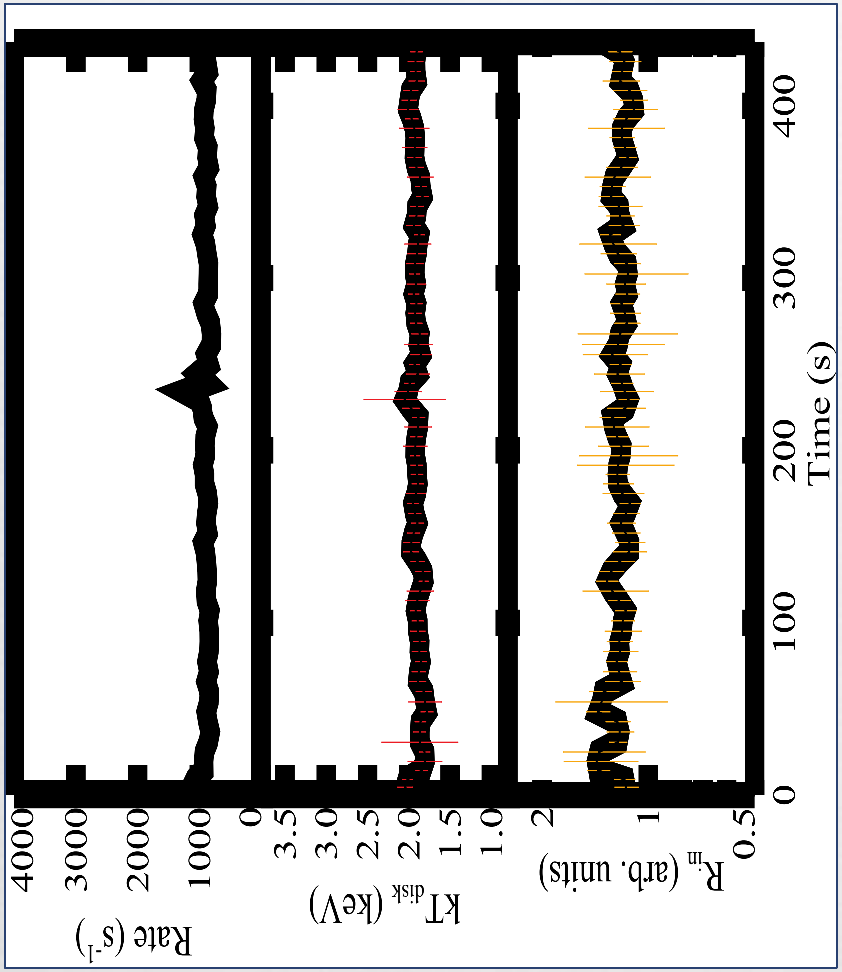


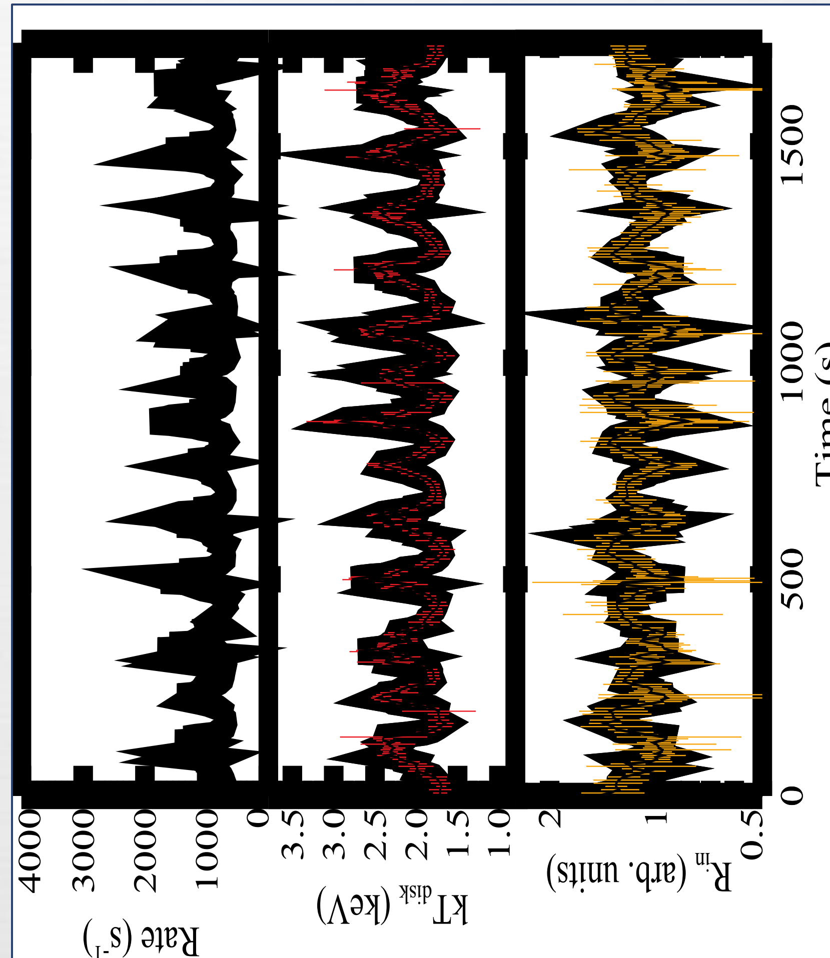
From 14 ks phased RXTE PCA data; Neilsen+2011

A 3-s "heartbeat" spectrum with NICER



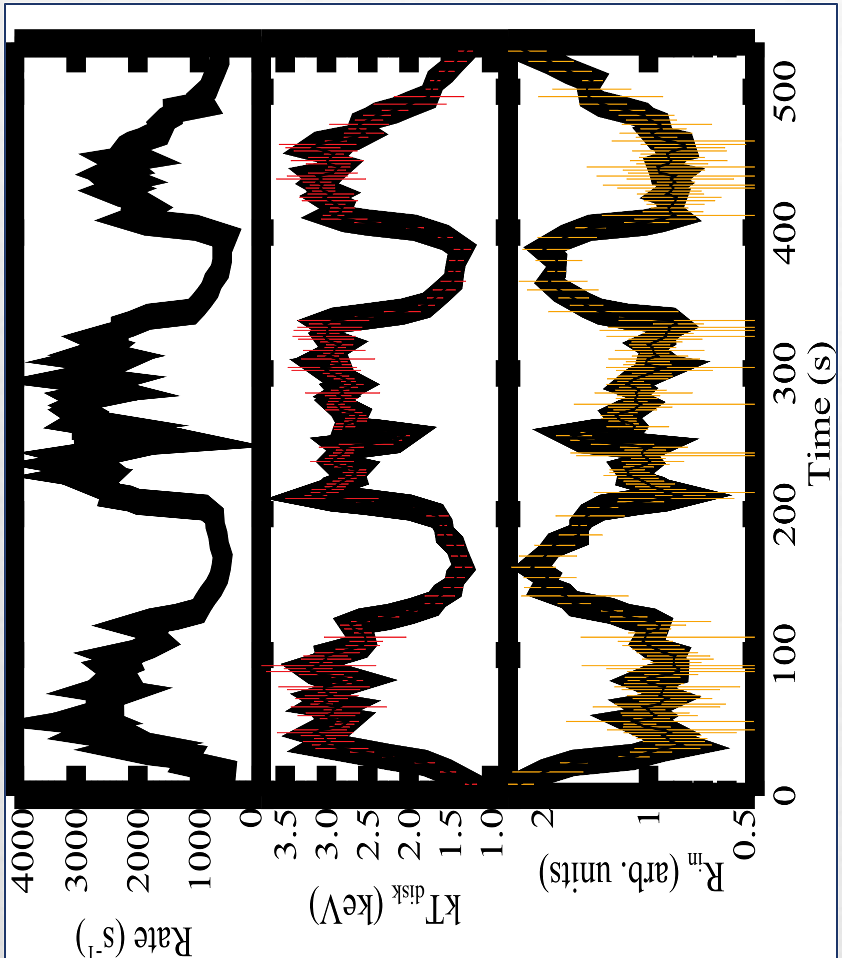
GRS1915 steady and “heartbeat” modes

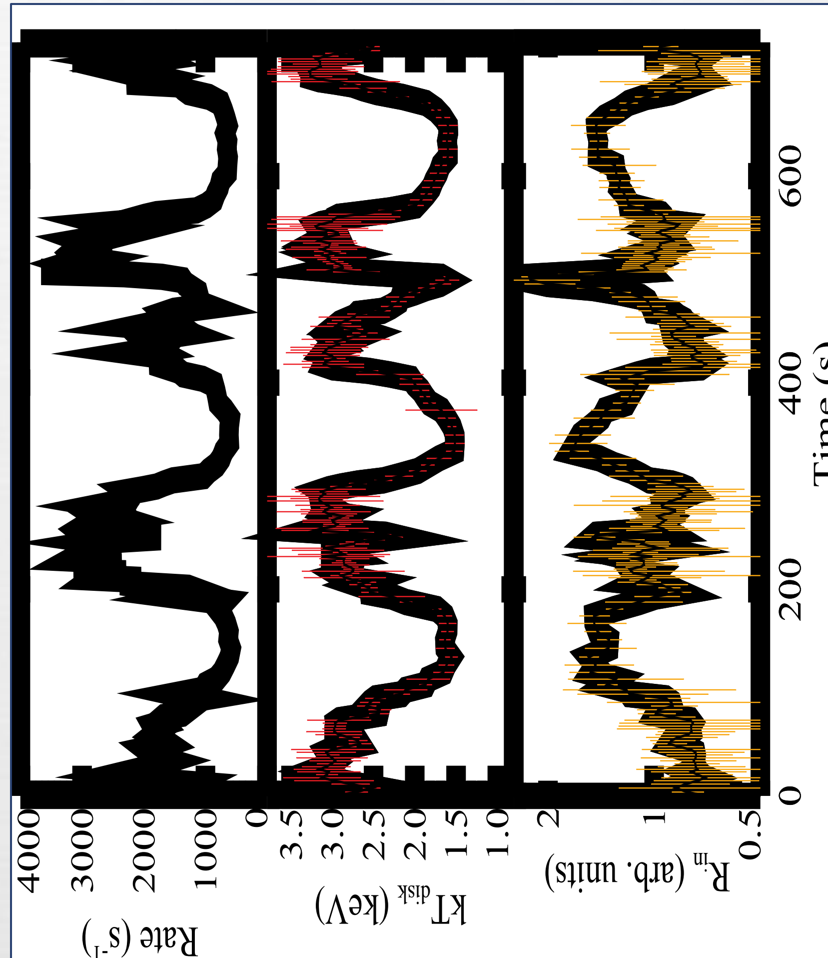




fit with a Comptonized disk model:
*tbabs * (simpl x ezdiskbb)*

Ample signal allows fitting aperiodic modes too

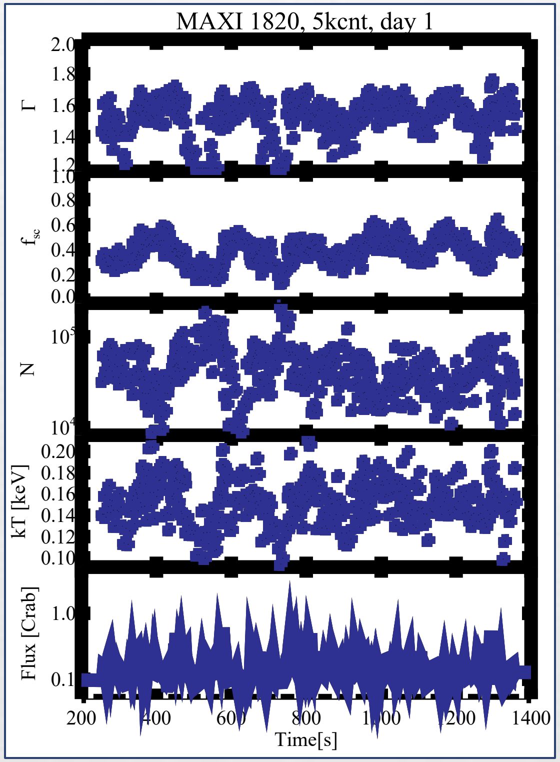


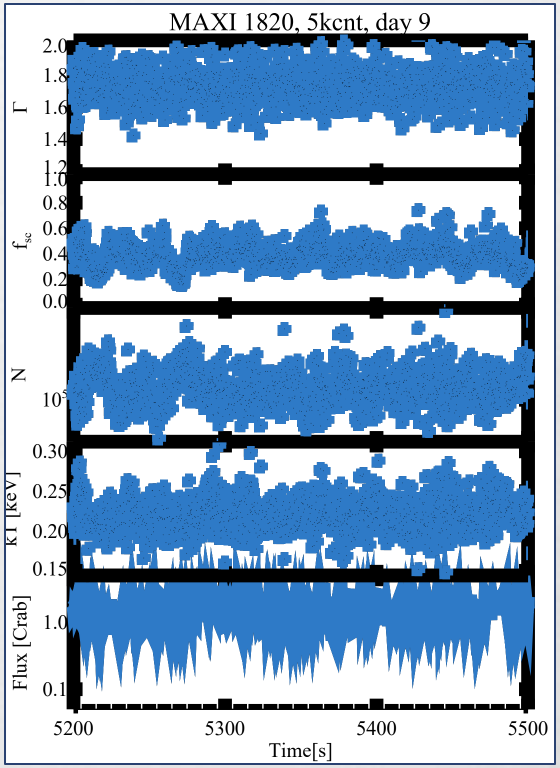


Continuum Fits of MAXI J1820+070

(Overly) simplistic model adopted
- thermal vs nonthermal only
- assumes Comptonization

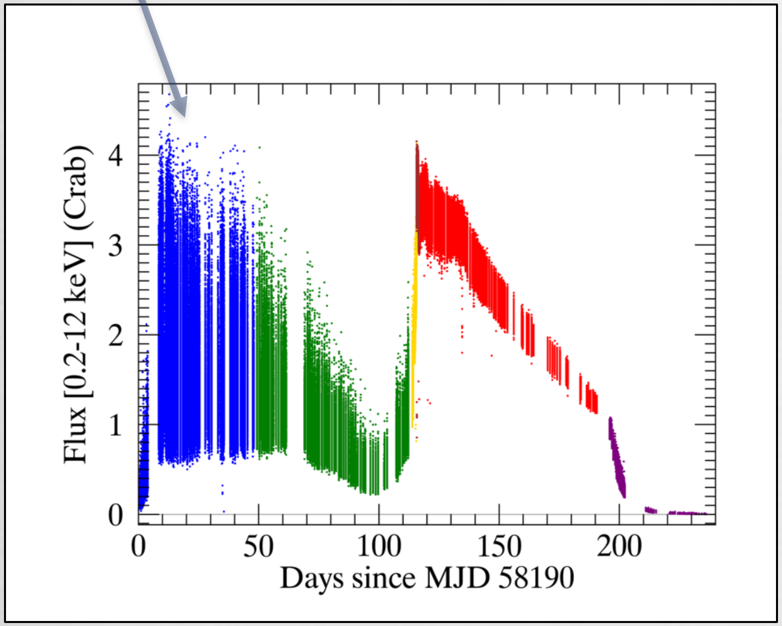
*tbabs * (simpl x ezdiskbb)*

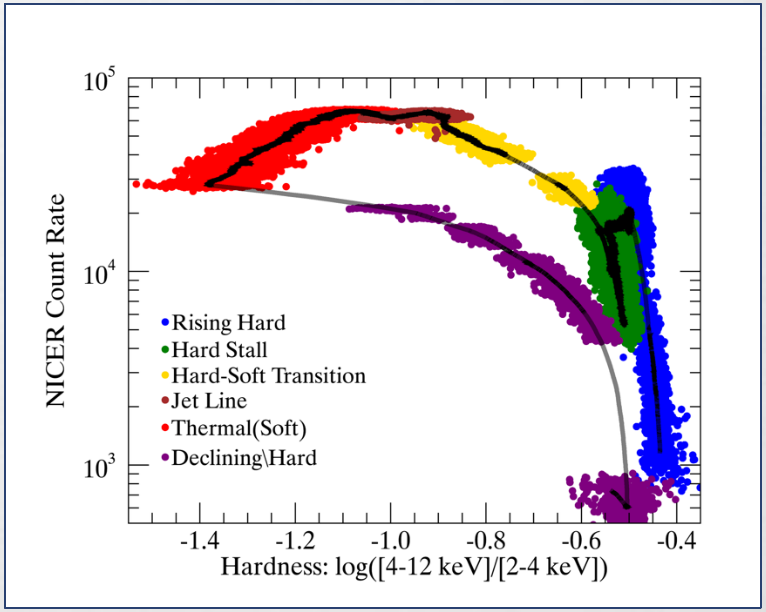




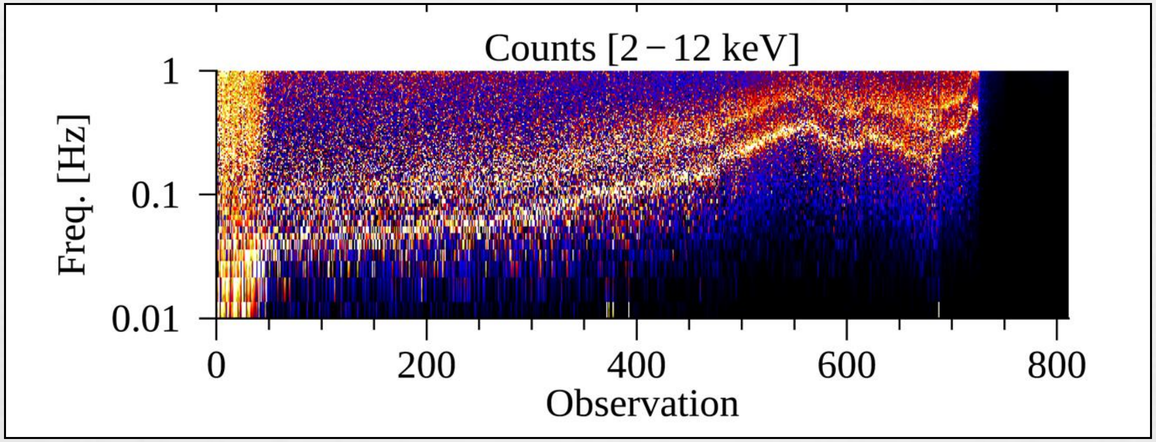
MAXI J1820+070 in 2 million 5kcnt segments

Time as short
as ~0.2s (< 1s inner-disk viscous timescale)!



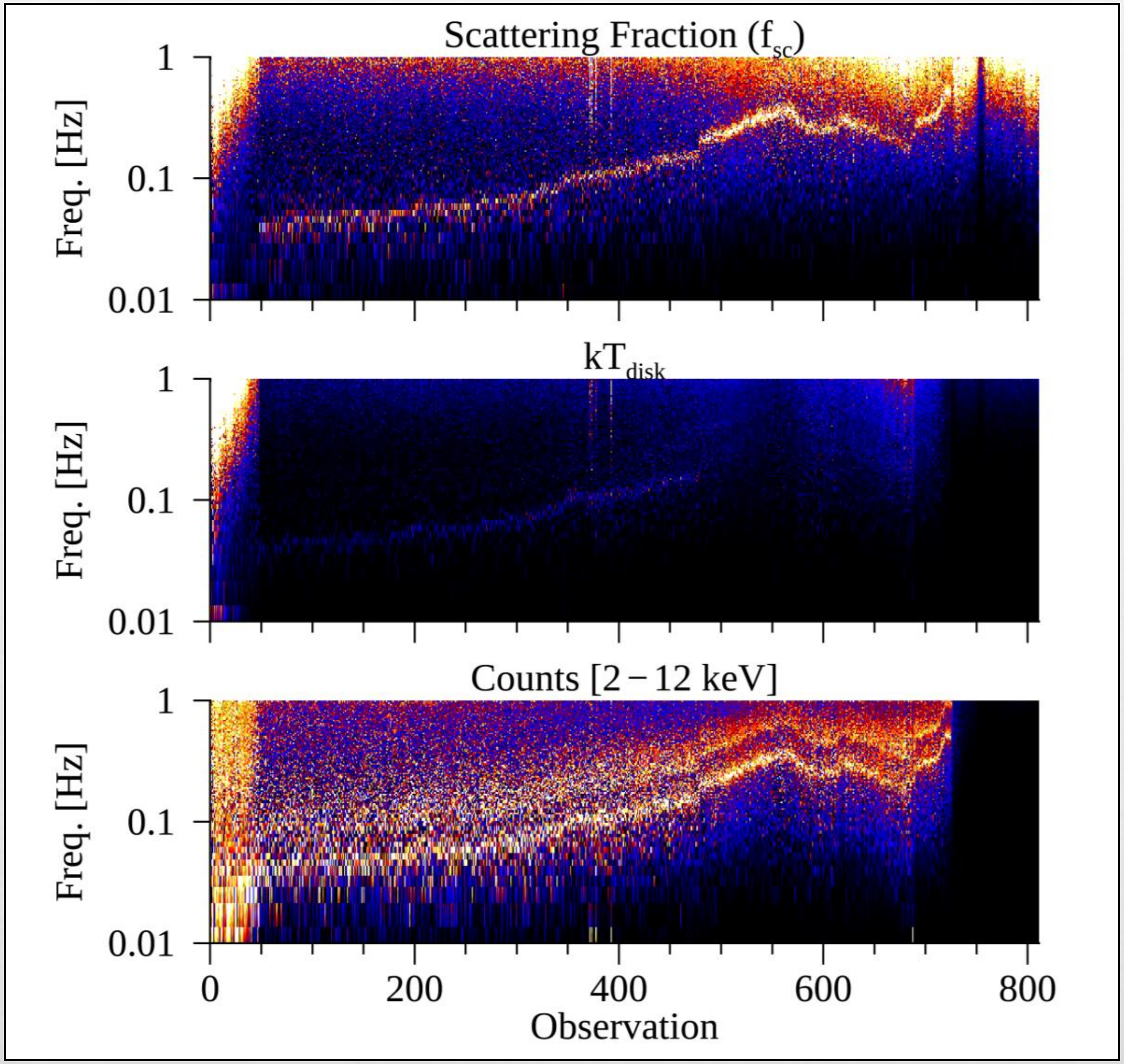


Timing Properties of Fast-Fitted Spectra show QPO's origin



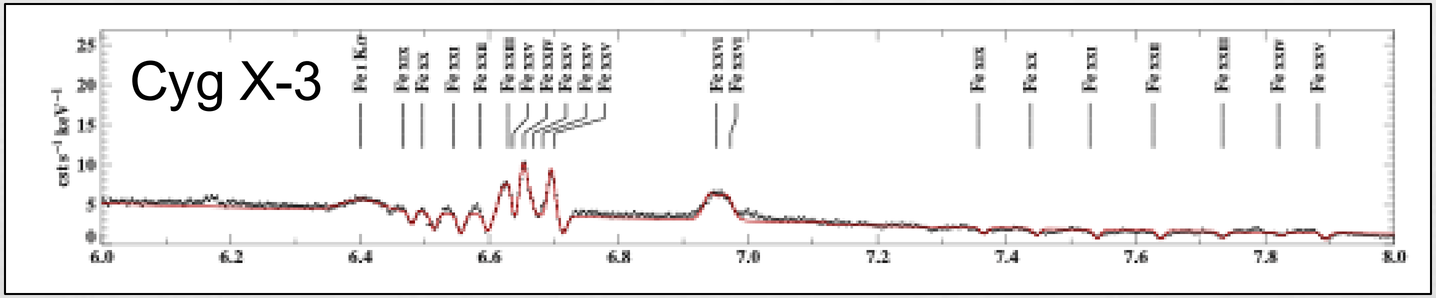
Poshak & Phil's talks tomorrow will discuss QPOs / timing

Timing Properties of Fast-Fitted Spectra show QPO's origin



X-ray Continuum Spectroscopy Prospects

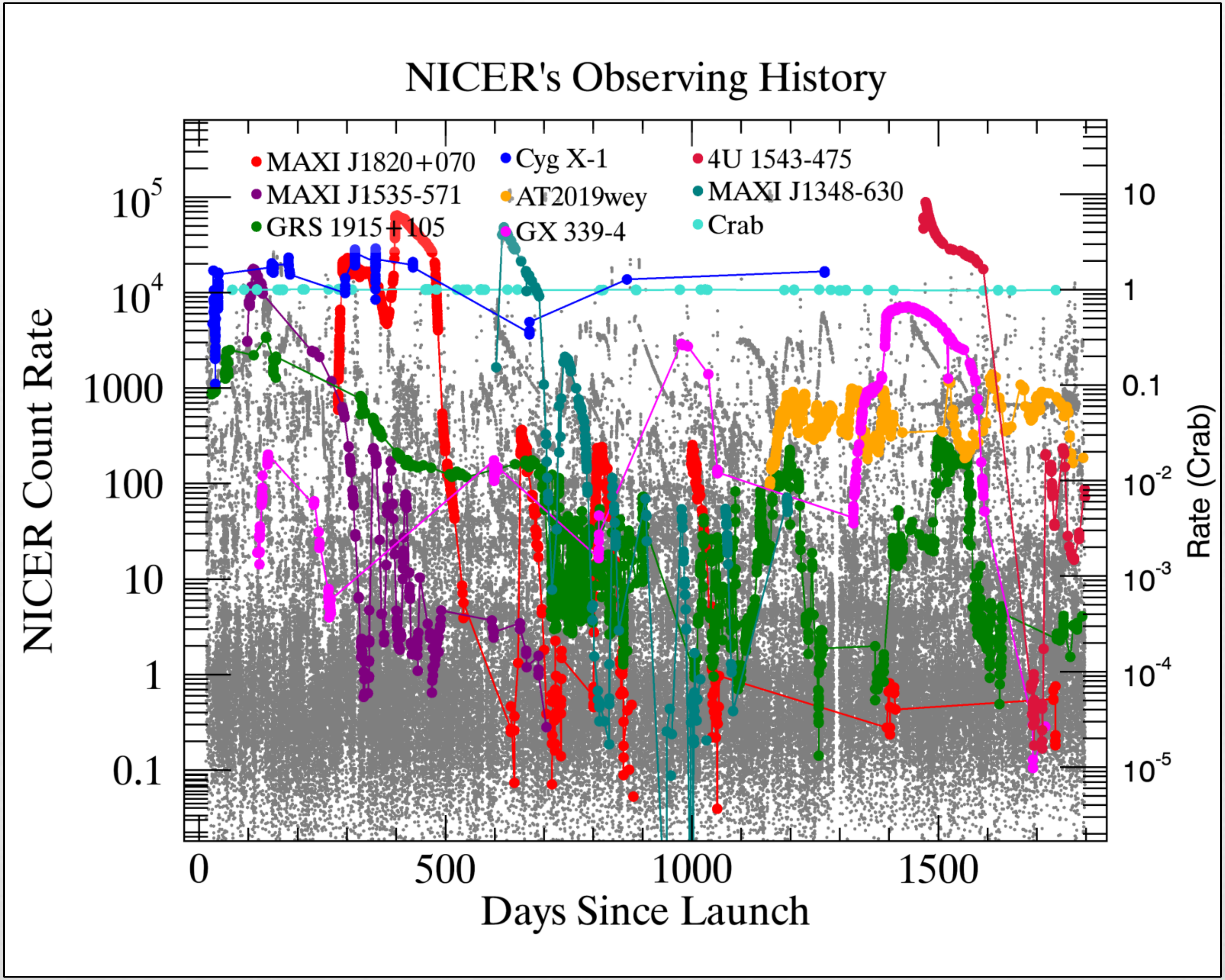
- Large area missions with high-throughput can continue making large strides
  - Can reach new critical timescales with sufficient signal ($\sim 10^4$ counts continuum; $\sim 10^6$ counts reflection)
- Big glass on the ground can enable an expansion from Galactic view to Local Group
- MeV "gap" to be filled with COSI.
- High resolution spectra enable better continuum precision



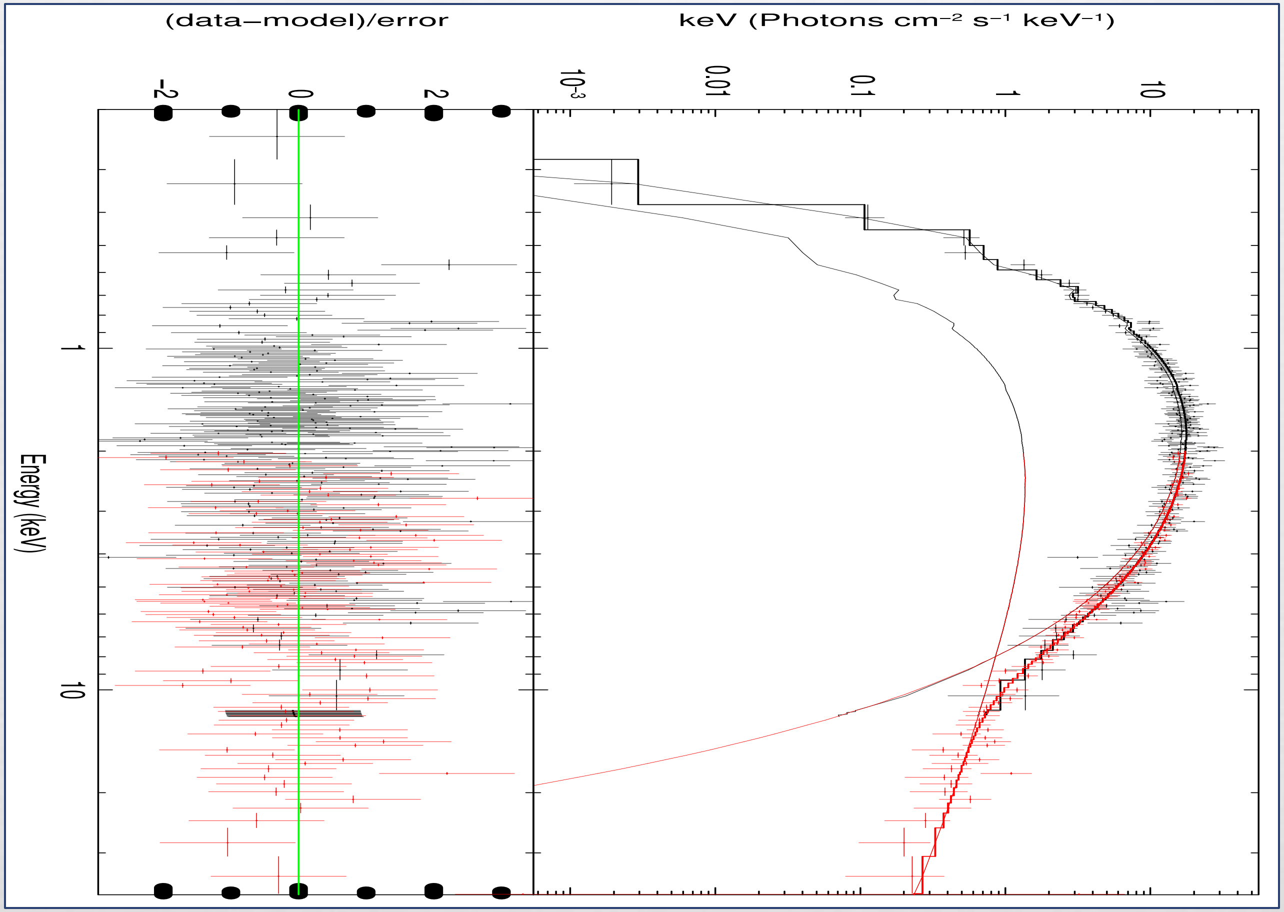
(More in Mike's talk tomorrow)

XRISM+24

The XRB Sky with NICER

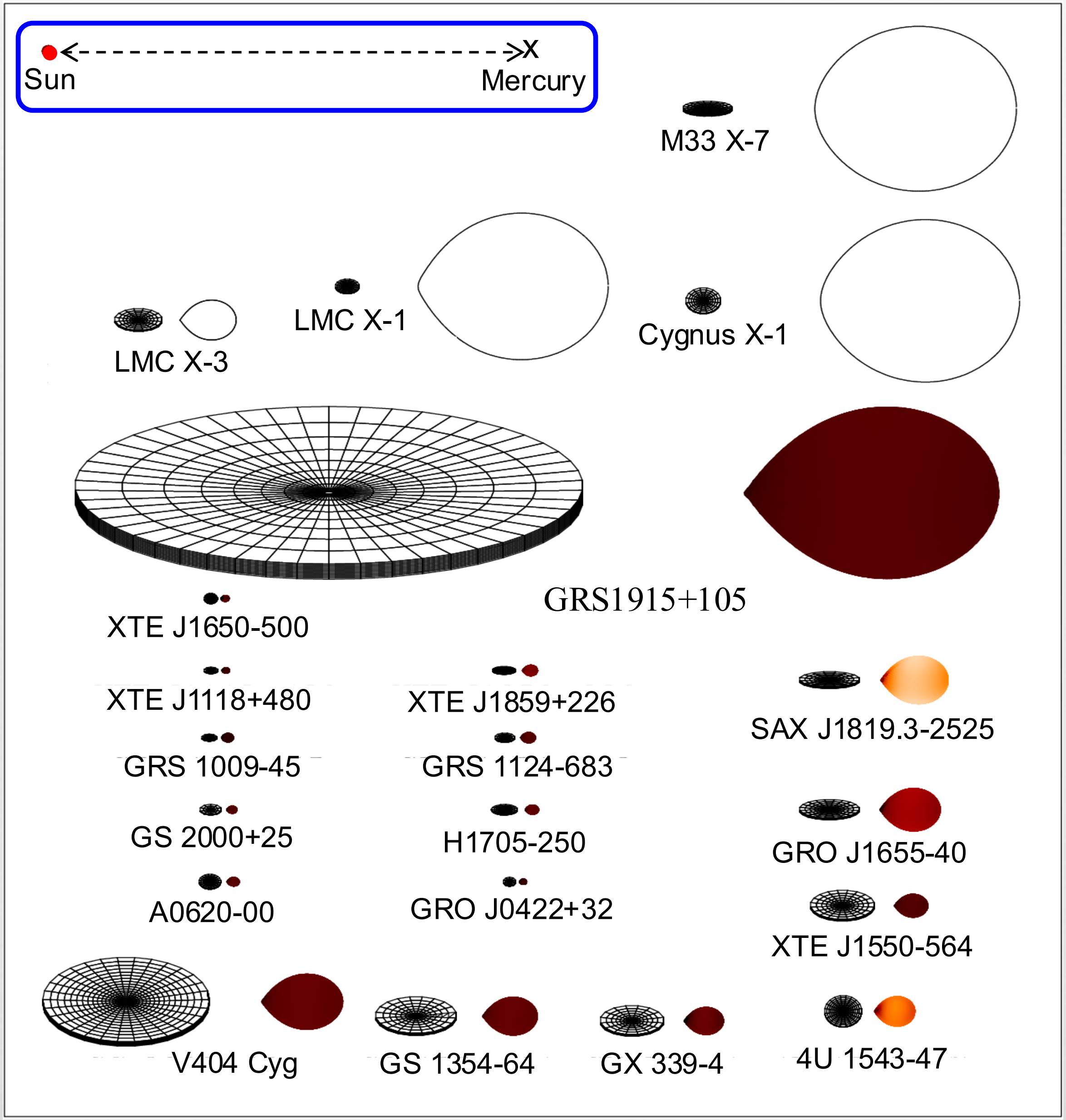


STROBE-X / LOFT / eXTP Design: *Dynamical* timescale continuum spectroscopy



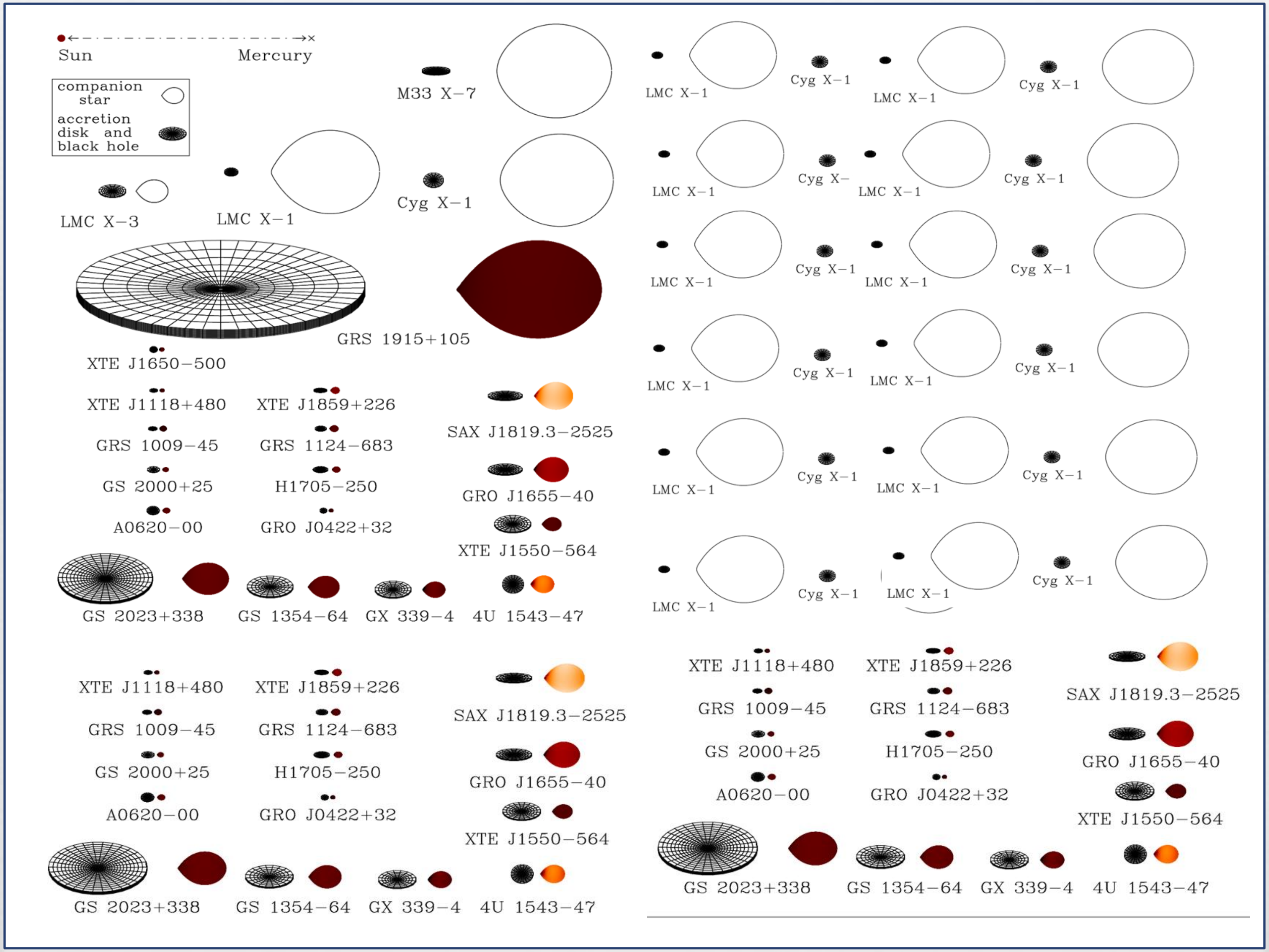
3 Crab
15kCnt
10ms

The Black Hole Binary Zoo



Courtesy: J. Orosz

A Local Group Menagerie with Athena/AXIS?



Closing Thoughts

- Low energy key to thermal disk (0.5-10 keV); high energy key for corona: thermal break and reflection hump (~20-100 keV)
- We've been in a golden age for XRB continuum spectroscopy with the potent combination of NICER+NuSTAR
  - Unmatched sensitivity from 0.3-80 keV on bright XRBs
- In 2 years, COSI ahead will give us an unmatched view of their MeV properties which may help improve our understanding of nonthermal components in the X-ray bands.
- A budding era of X-ray polarimetry is signal-starved whereas continuum spectrosopic data is signal oversaturated (systematics, not statistics limited).
  - Polarimetric inference is intertwined with spectroscopic modeling and I'm optimistic that these will mutually advance (see Sasha's talk)