Winds of Change:
The Physics of Accretion, Ejection, and X-ray Variability in GRS 1915+105

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Einstein Fellow, Boston University

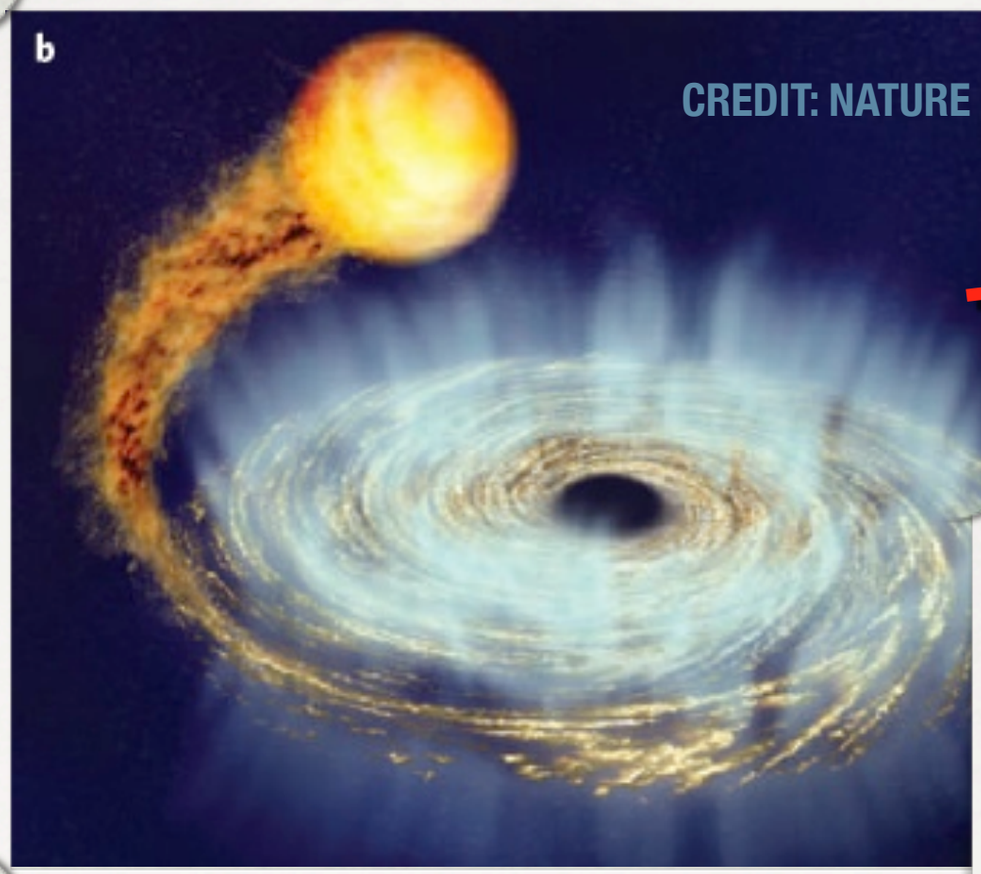
Winds of Change: The Physics of Accretion, Ejection, and X-ray Variability in GRS 1915+105

Julia Lee, Ron Remillard

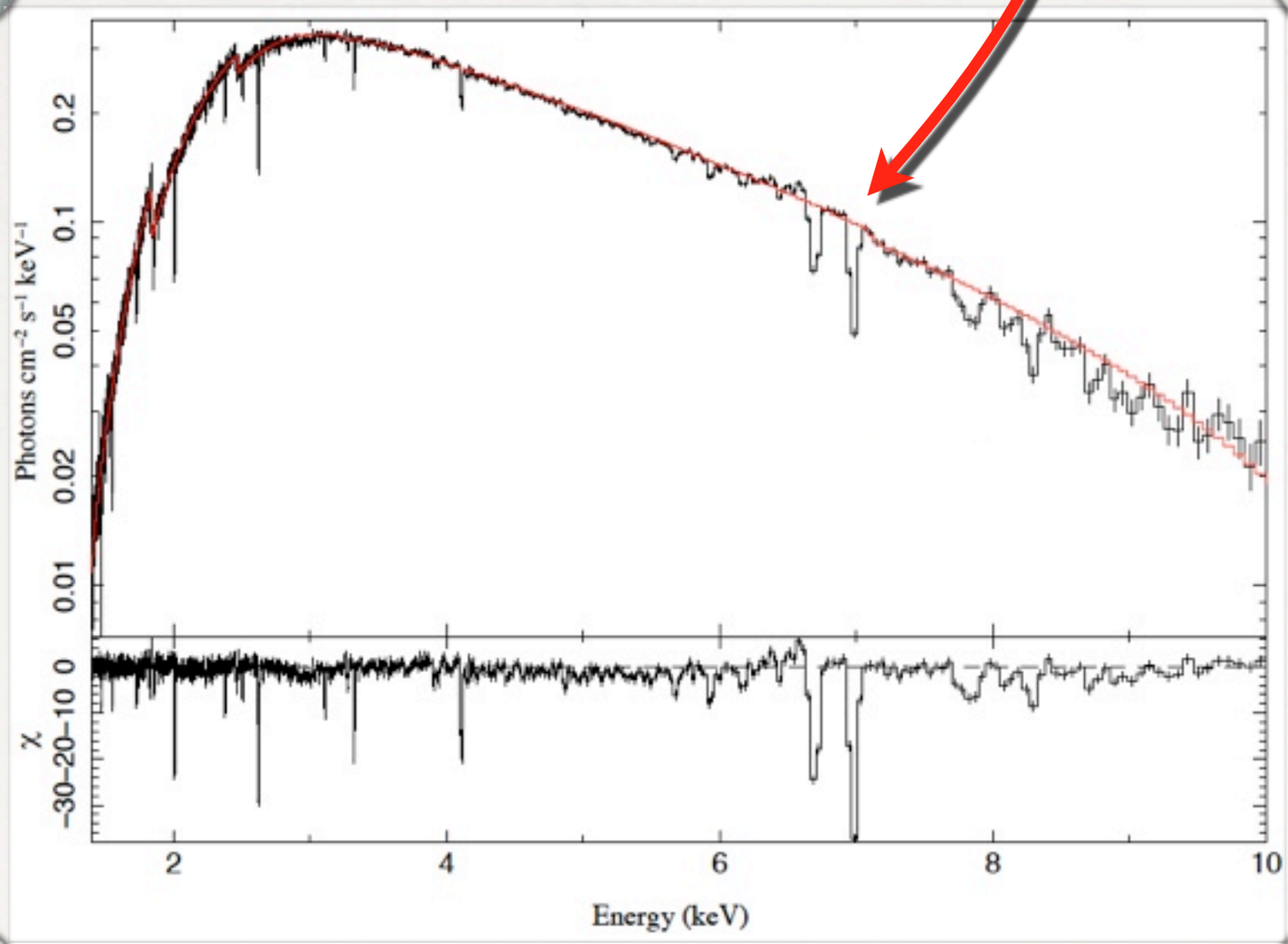
Outline

- (Brief) introduction to GRS 1915+105
- Connection between black hole and its environment, winds
- High-resolution X-ray spectral variability on long and short time scales

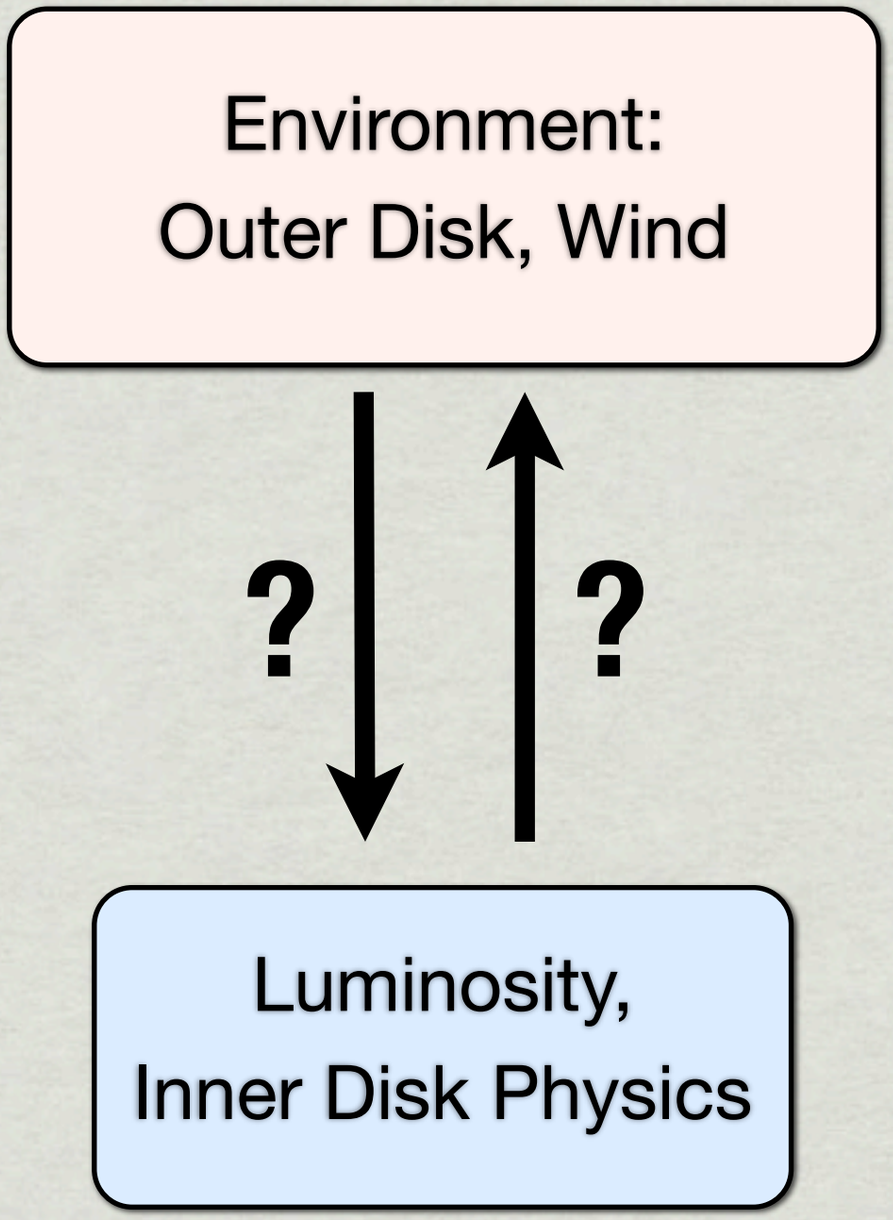
Ionized Winds



- Associated with accretion disk (Lee et al. 2002; Miller et al. 2006, 2008)
- Typically launched ***and*** ionized by intense radiation fields
- Visible in high-resolution X-ray spectra from *Chandra*

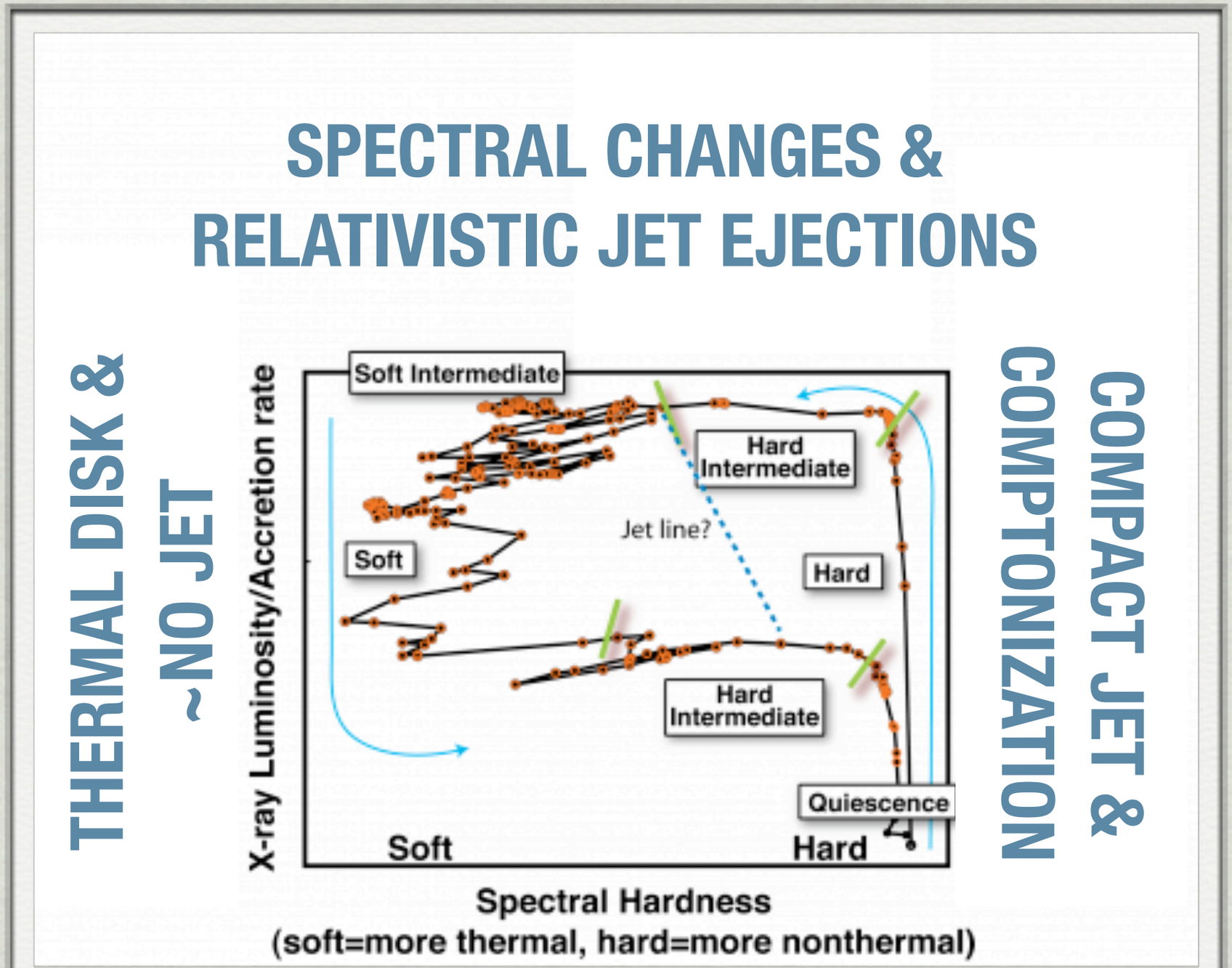


Accretion and Ejection



The Disk-Jet Connection

FENDER ET AL 2005
BELLONI ET AL 2010,
CORBEL ET AL 2011
S. MARKOFF



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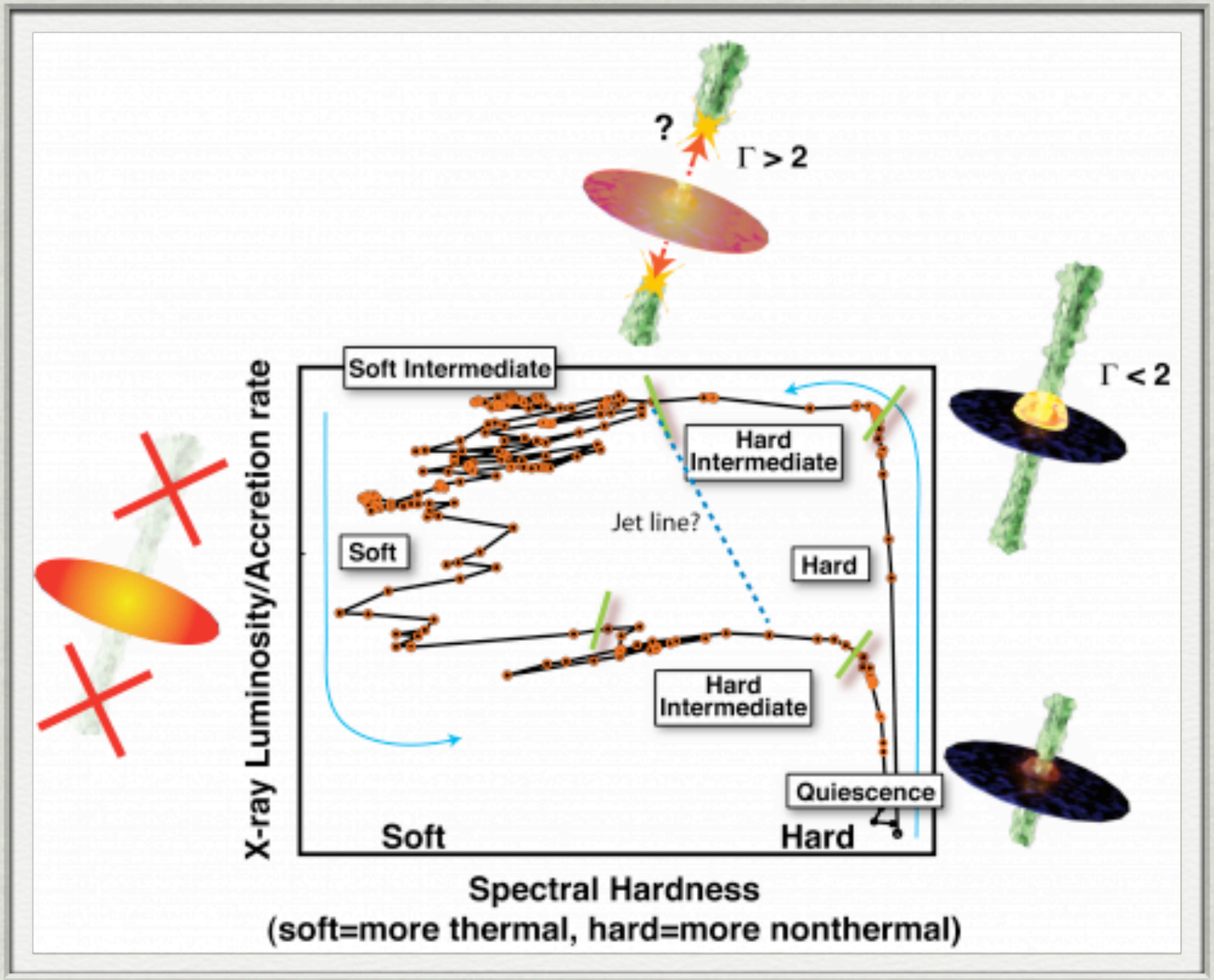
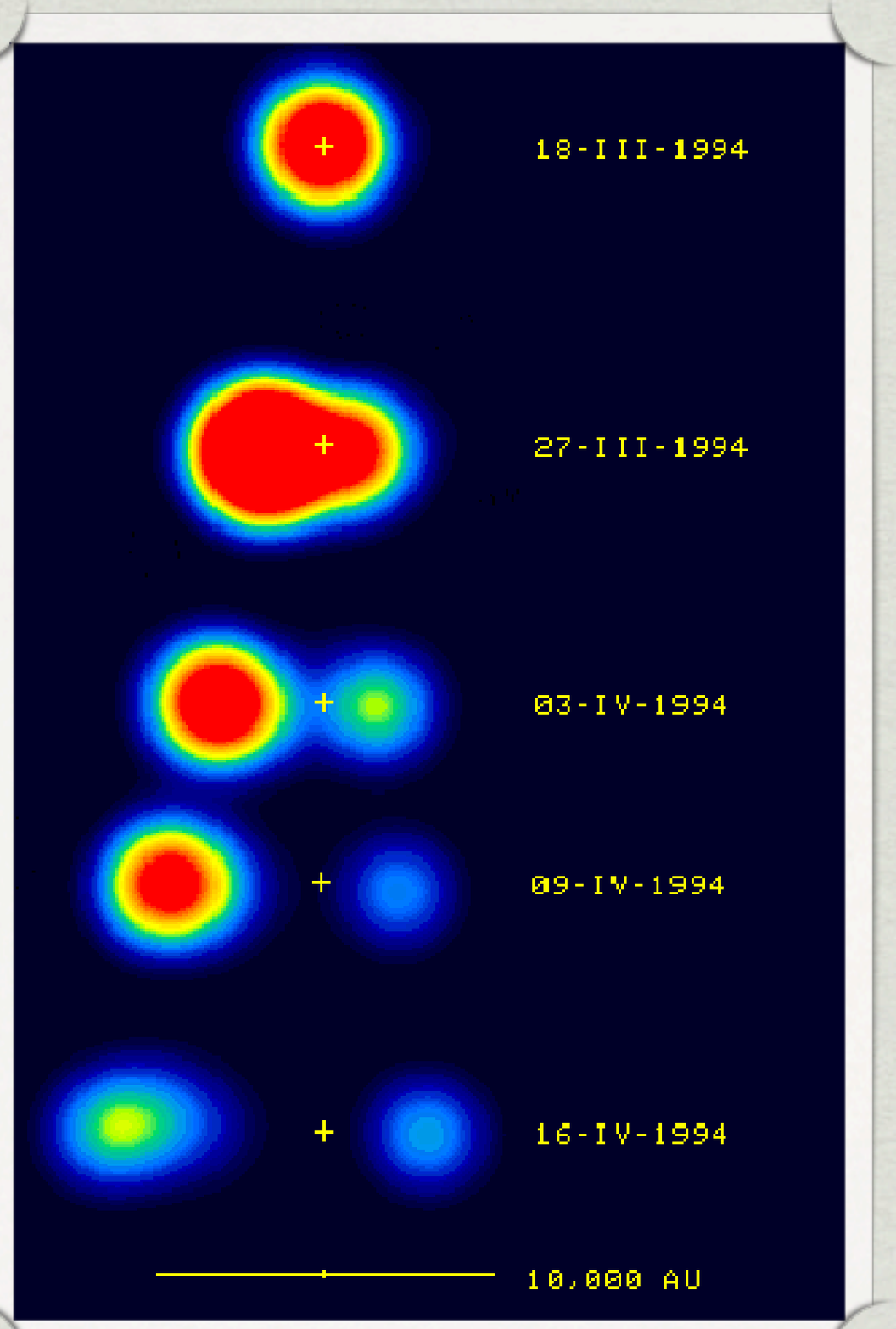
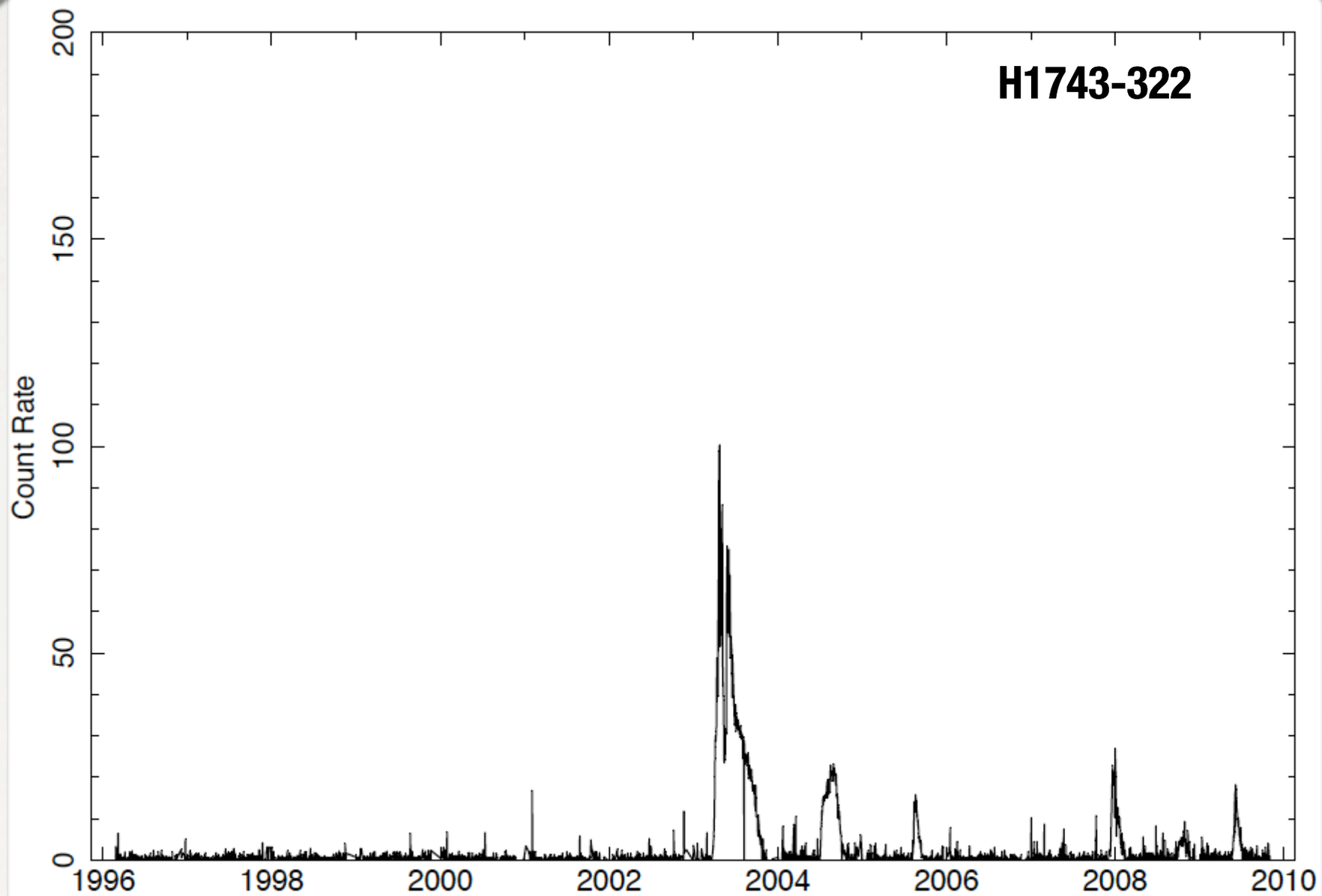


GRS 1915+105

- 10.1±0.6 $M_\odot$ black hole, 33.85±0.16 d orbit, K/M giant secondary (Steeghs et al. 2013)
- First known Galactic source of superluminal jets (Mirabel & Rodriguez 1994)
- Extreme X-ray variability (e.g. Belloni et al. 2000)
- In outburst for ≳18 years!



Long-Term X-ray Variability



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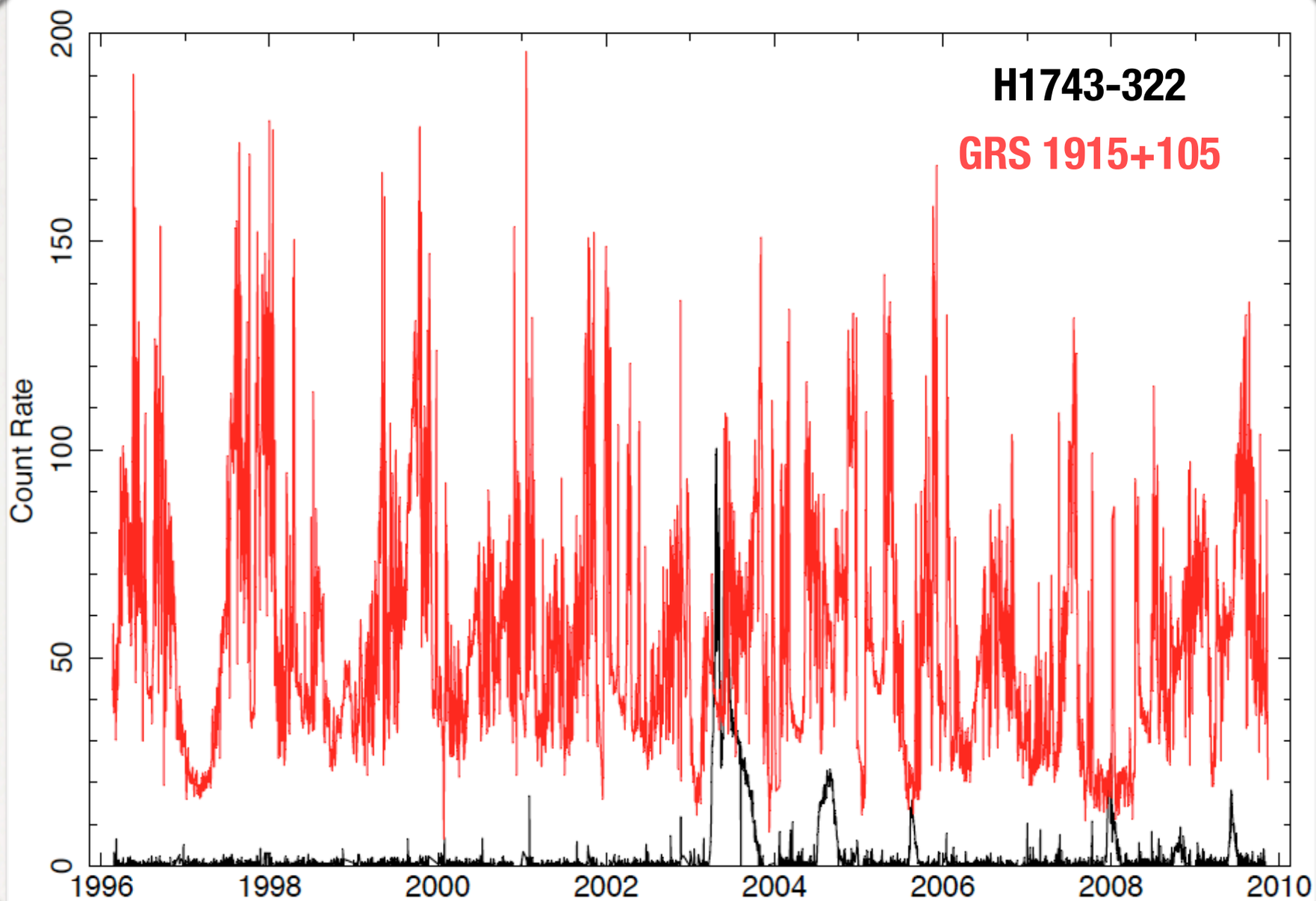
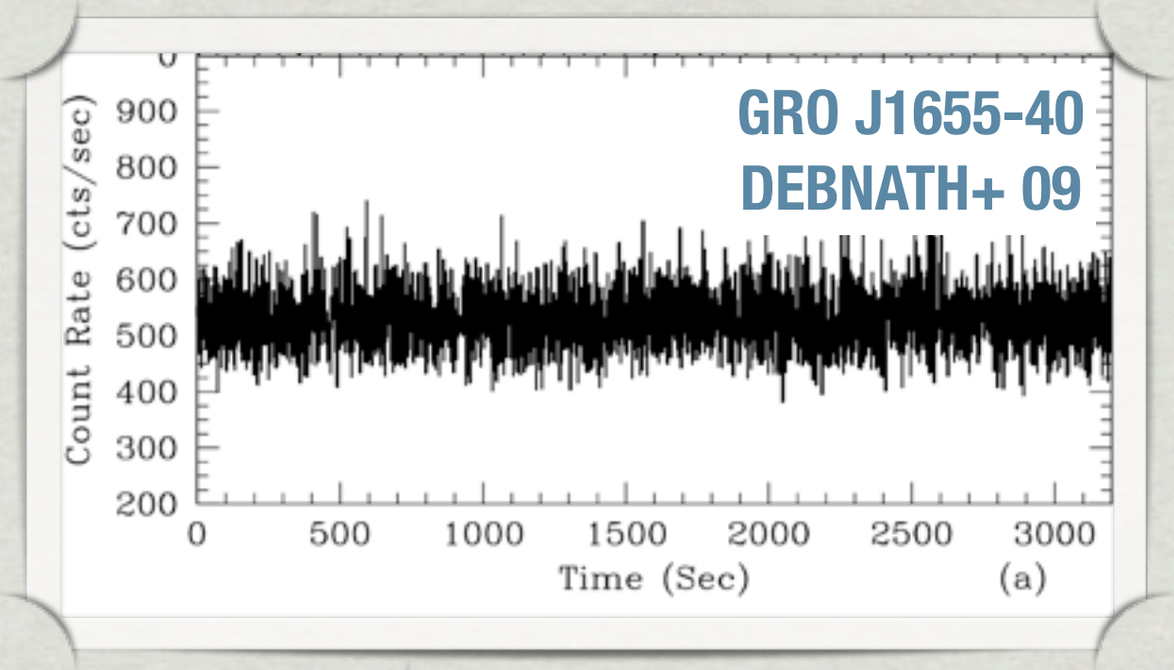
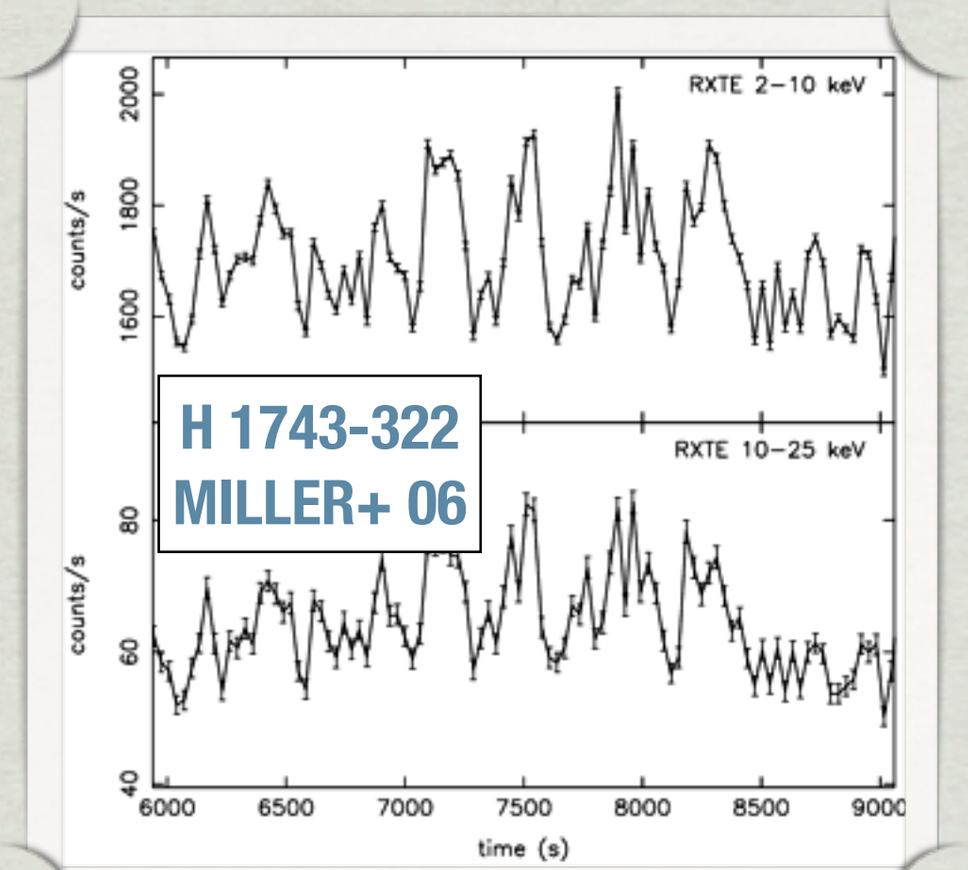
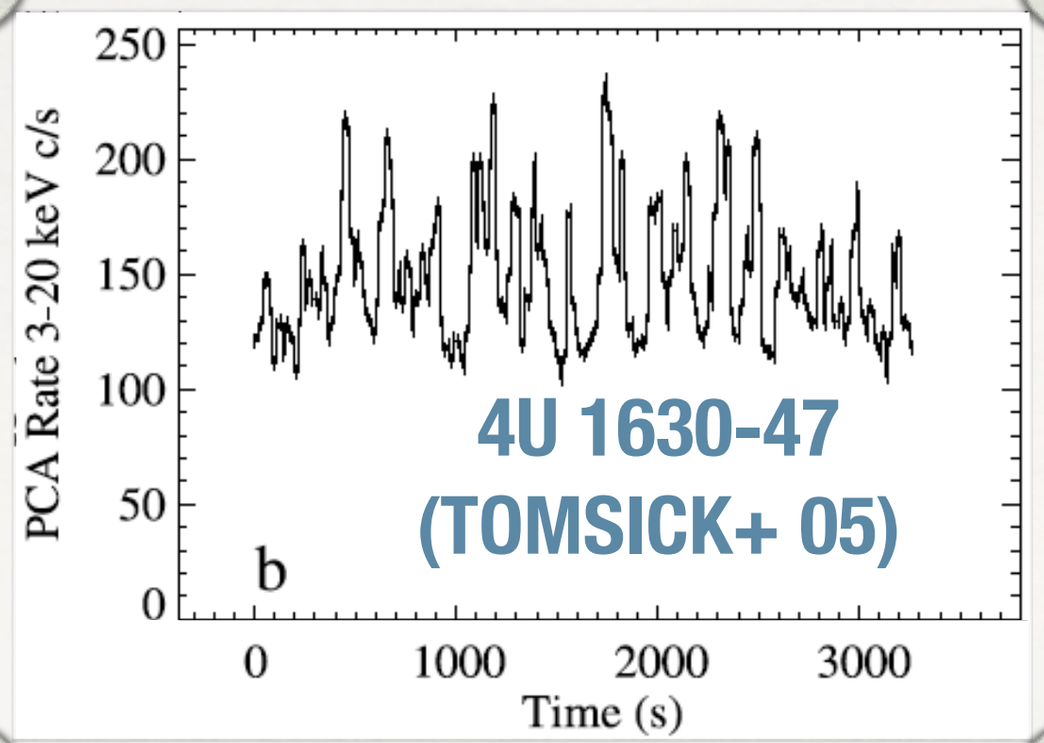


Fast X-ray Variability







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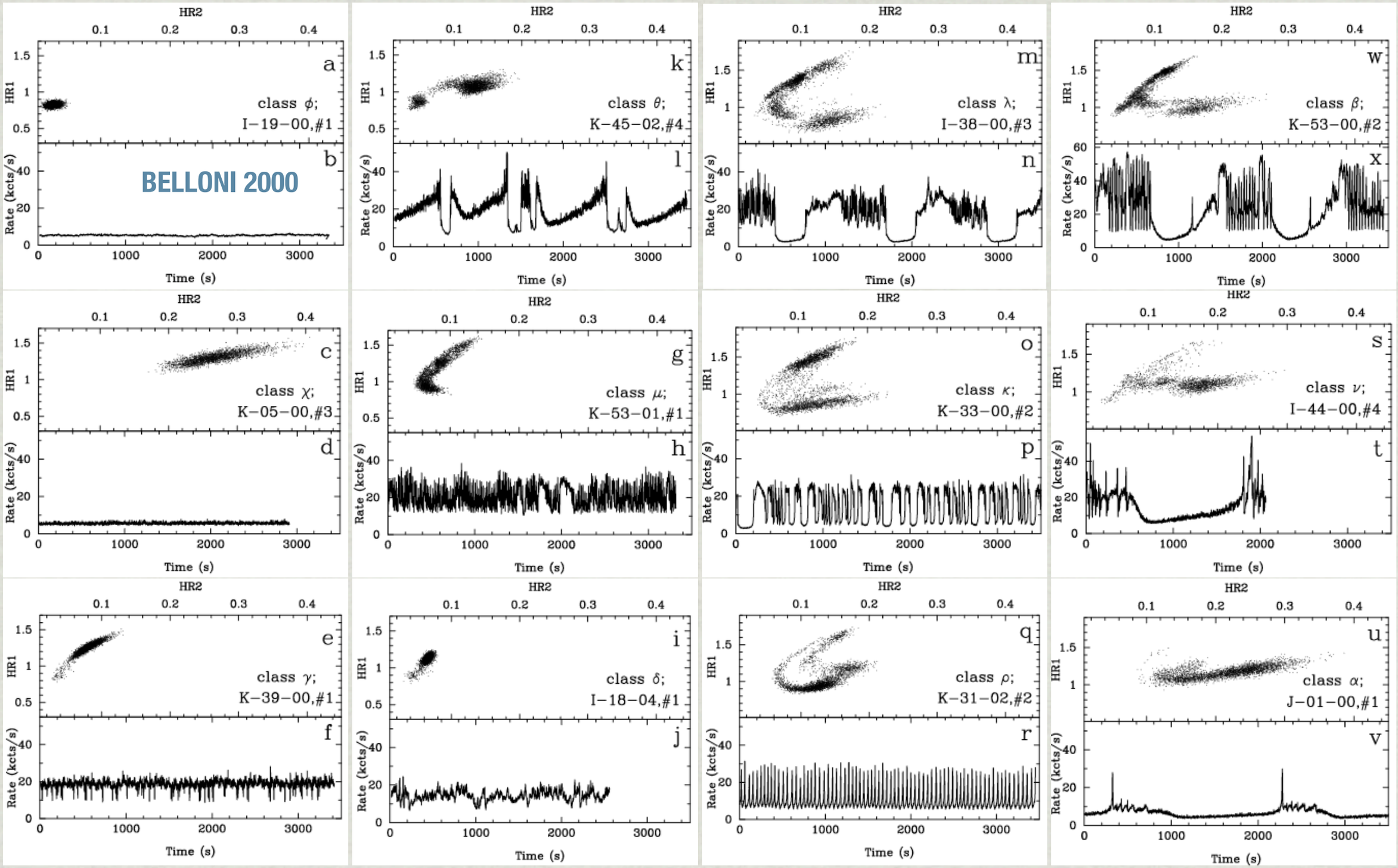

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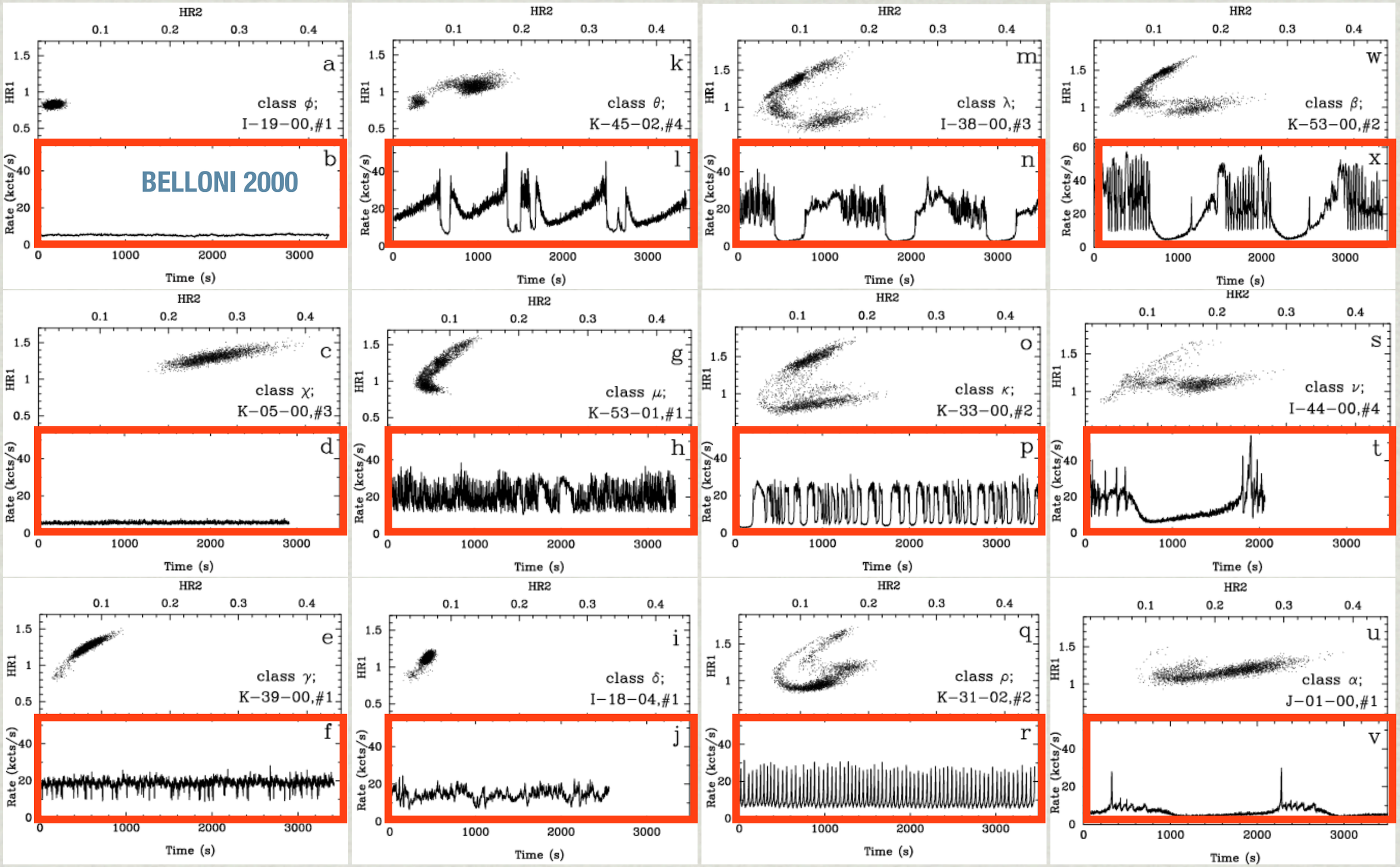

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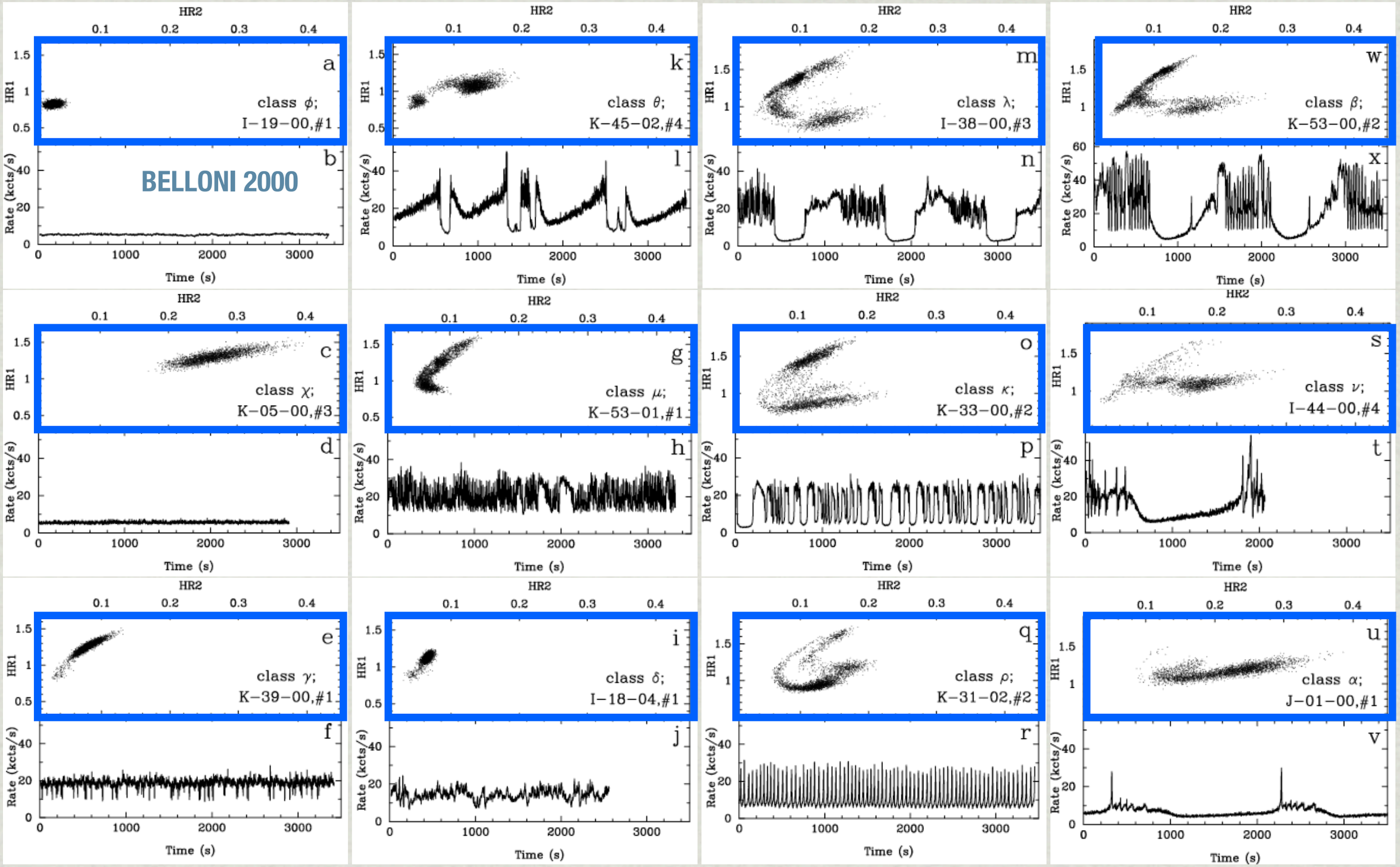

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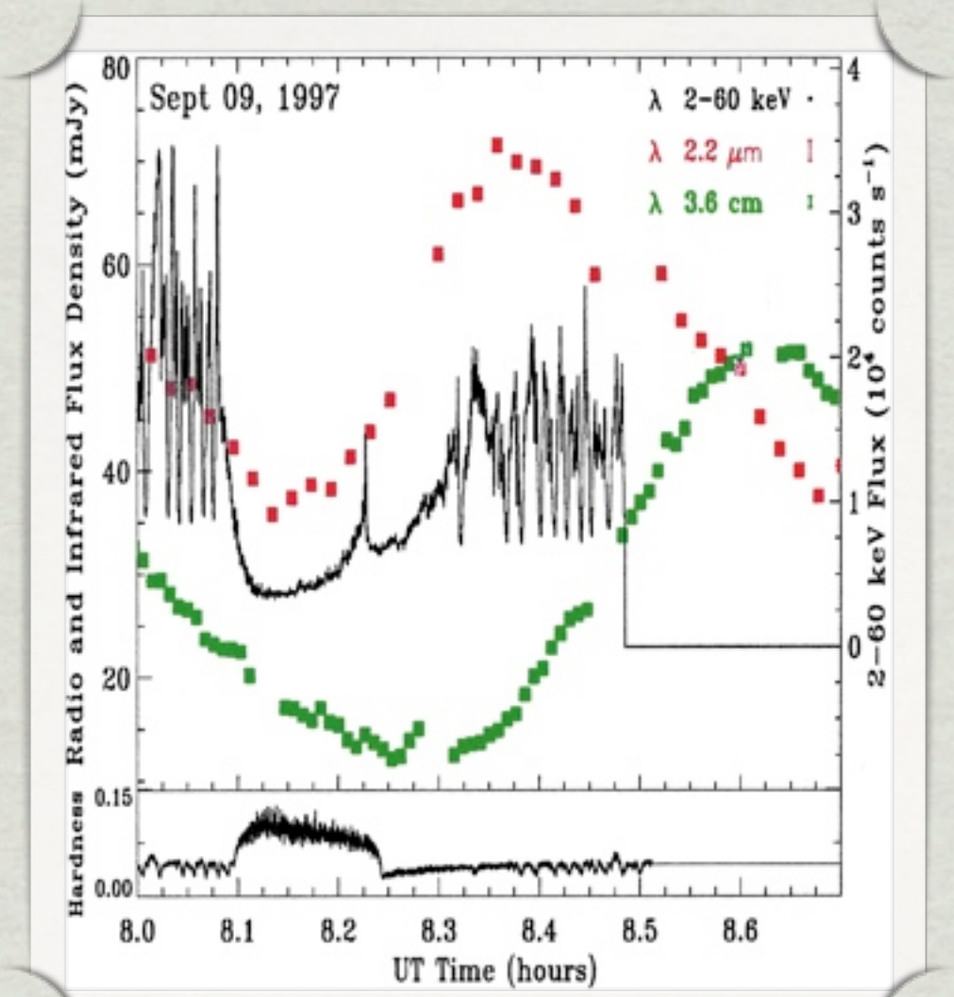

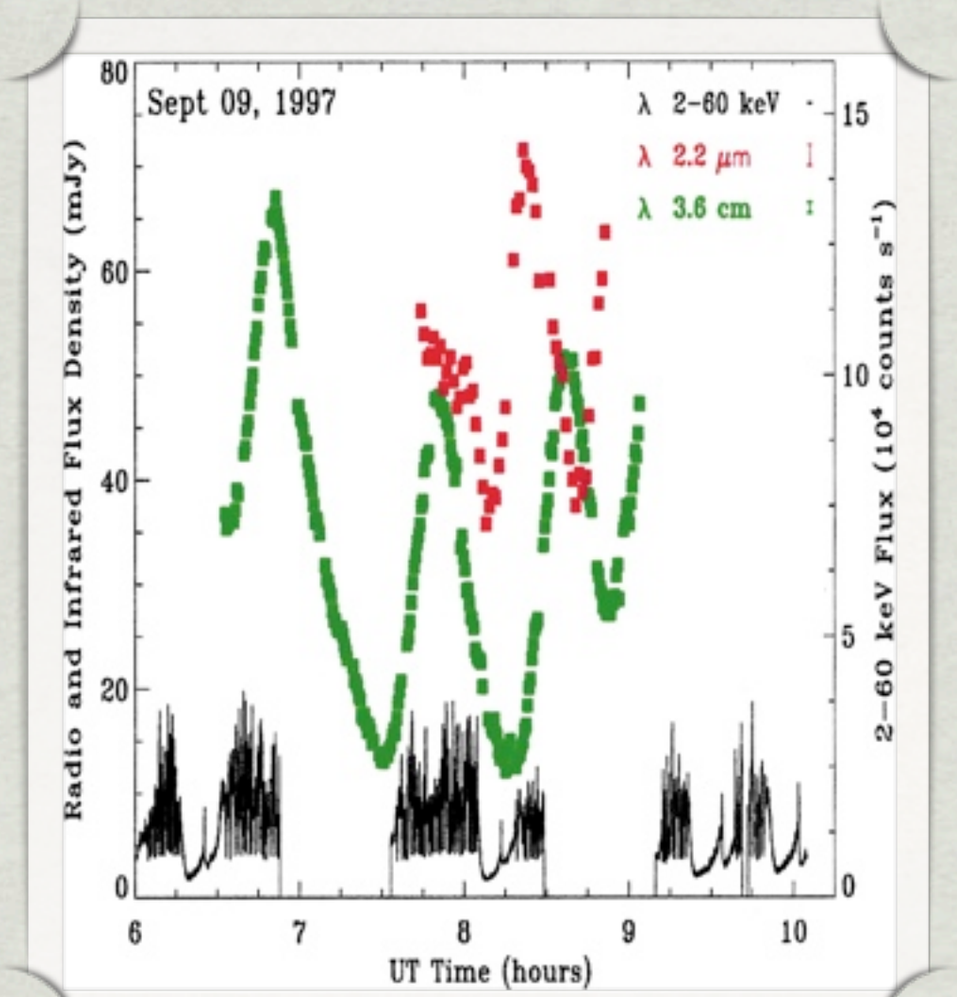

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- Variability classes are “limit cycles” of accretion and ejection

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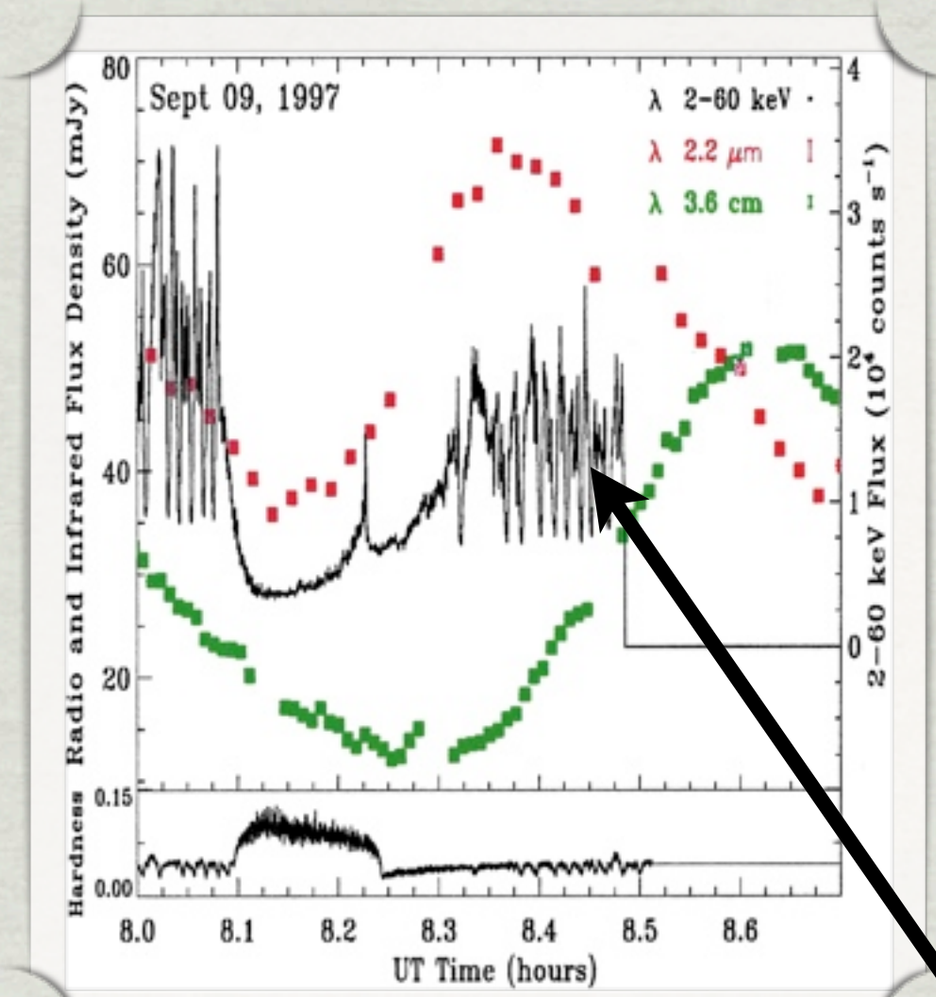

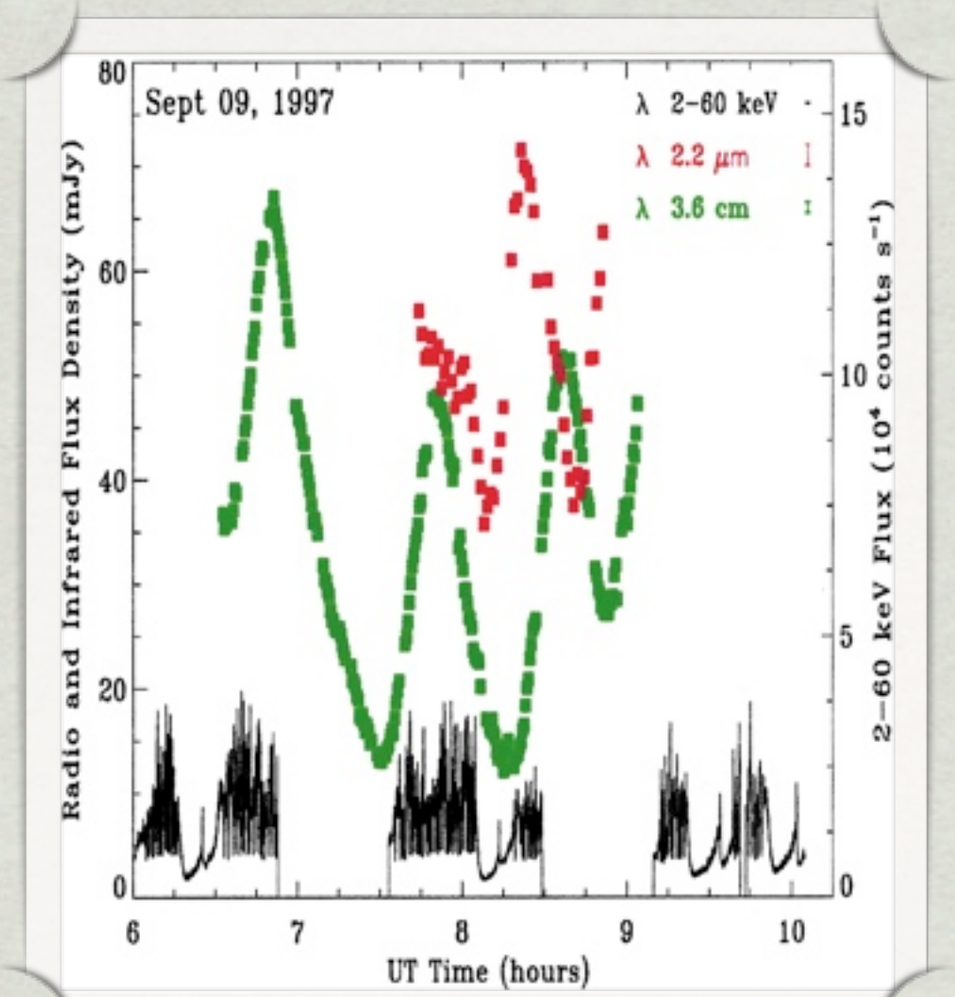

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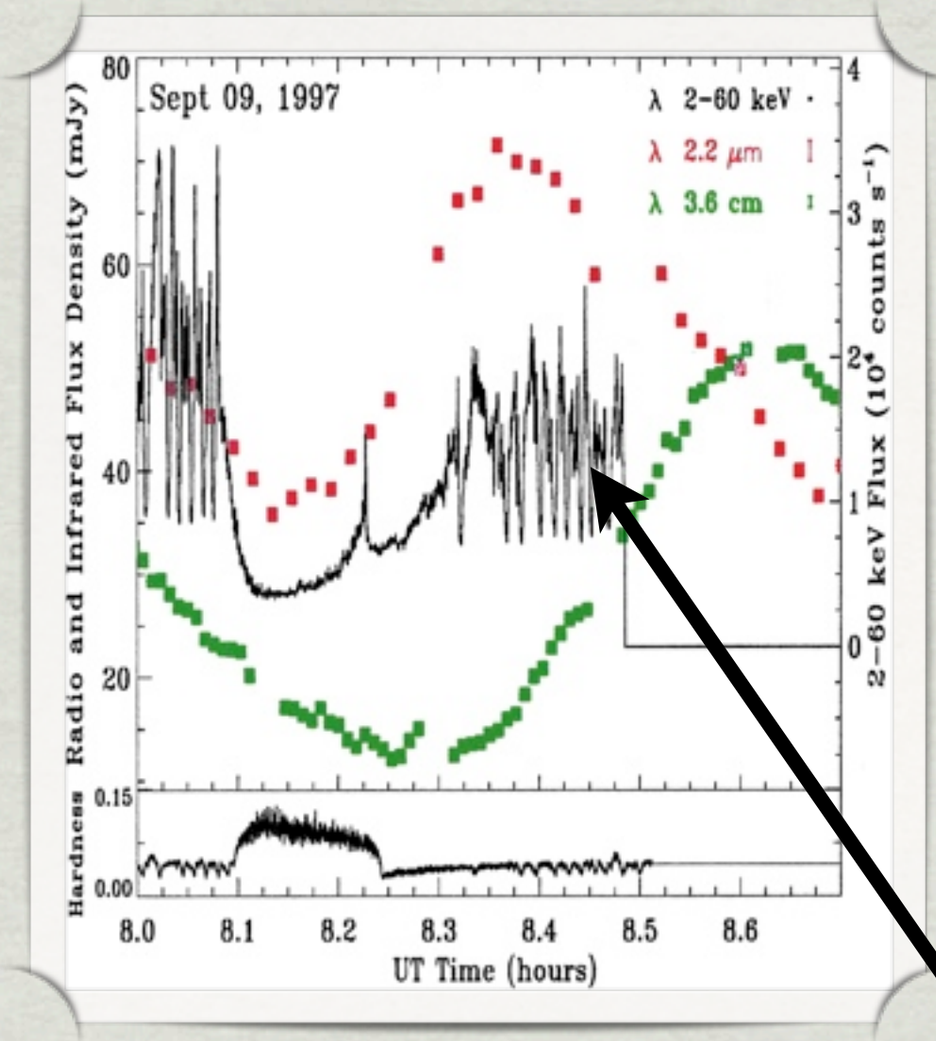

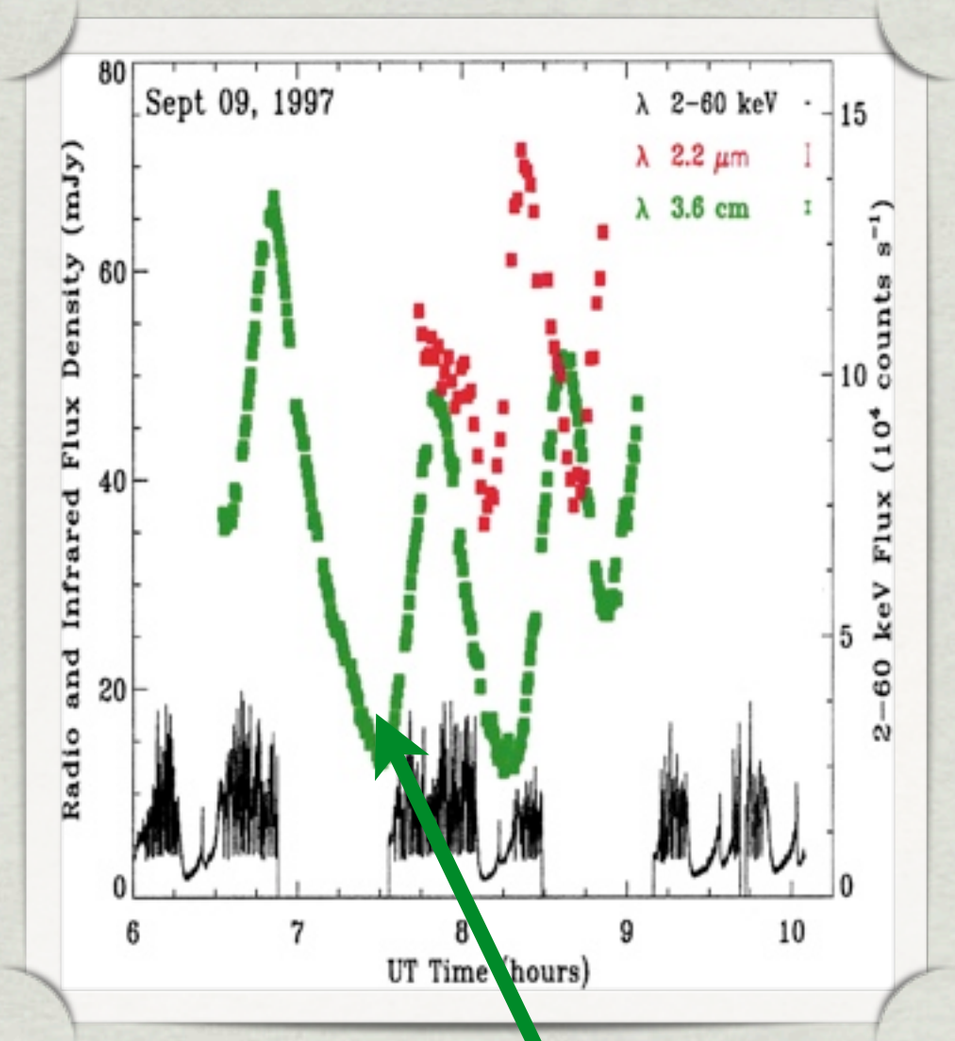

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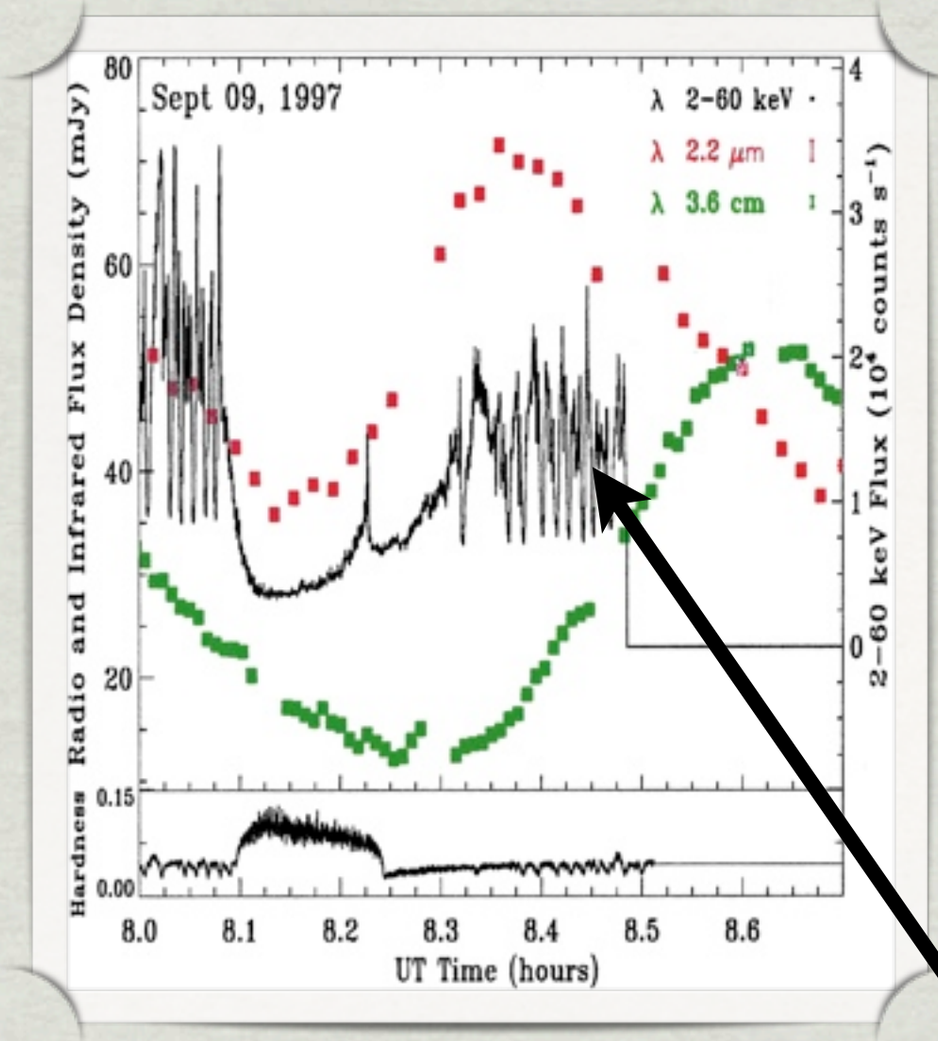

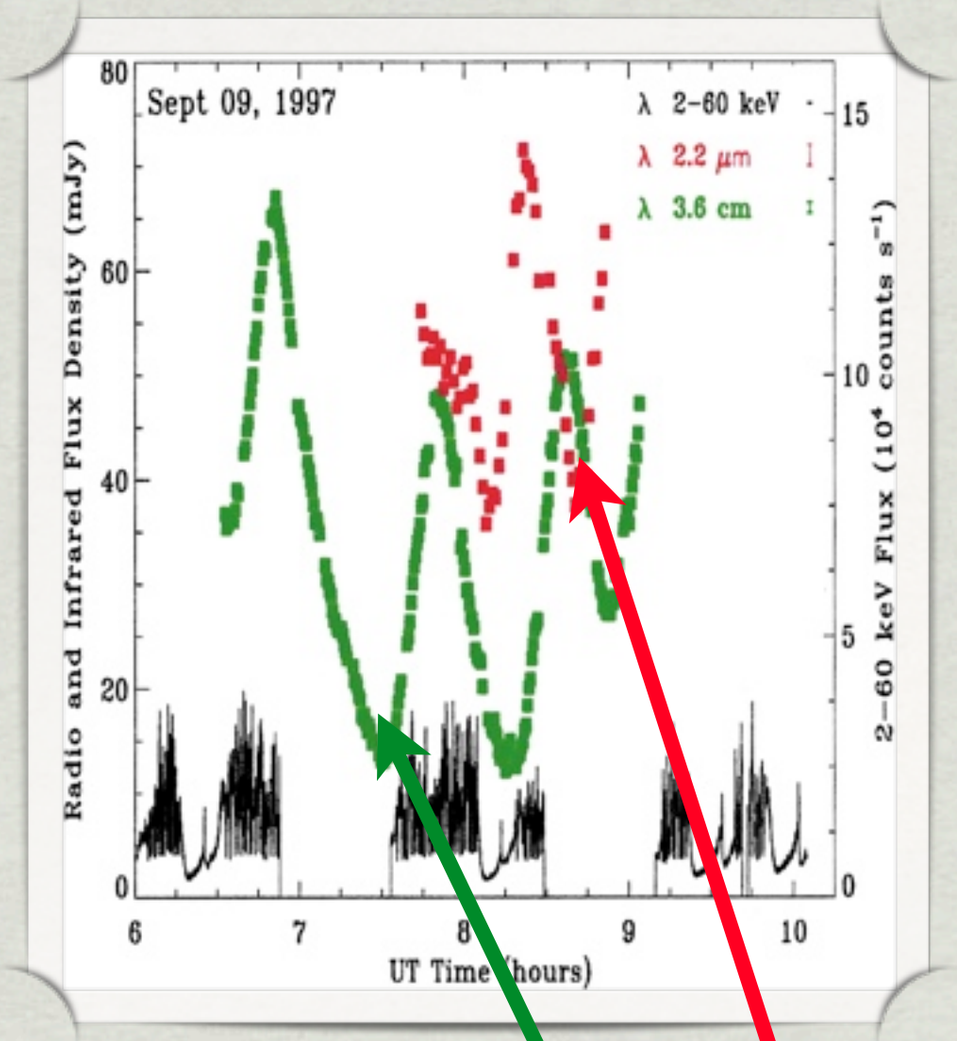

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Physics of Variability?

- GRS 1915+105 exhibits extreme variability on many timescales: seconds to decades!
- Strong *spectral* variability: rapidly-changing accretion processes, jet ejections
- Great for studying the connections we're looking for!

Thesis Goal:

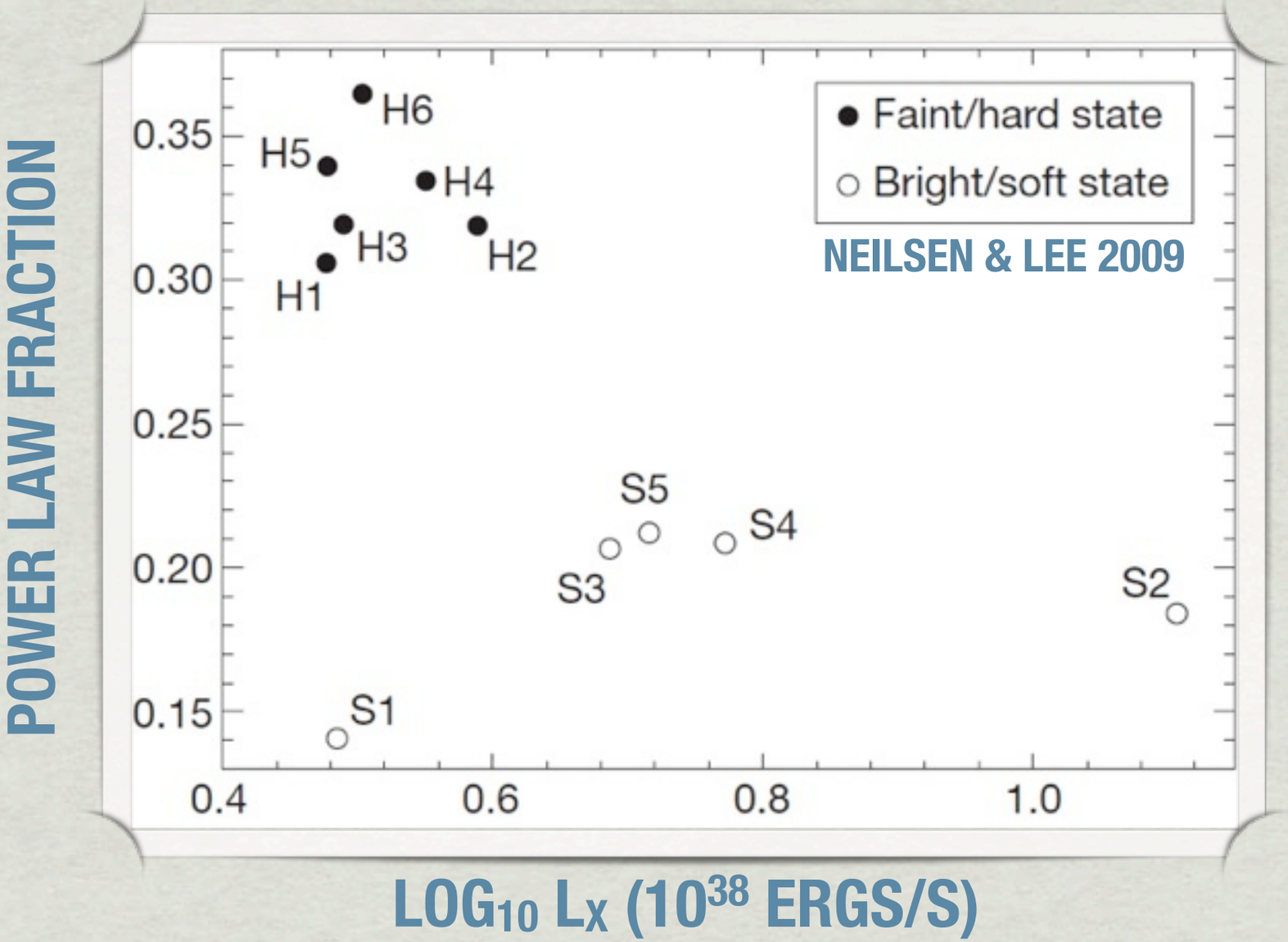
- Use high-resolution X-ray spectra to understand the accretion processes driving this behavior.
- How are the inflow, outflows, and radiation field coupled?

A Global View

- Track outflows with 11 archival Chandra HETGS observations over a ~10 year interval (Neilsen & Lee 2009, *Nature*)

- Track radiation processes with simultaneous RXTE observations. Measure *power law fraction* to quantify thermal/nonthermal emission

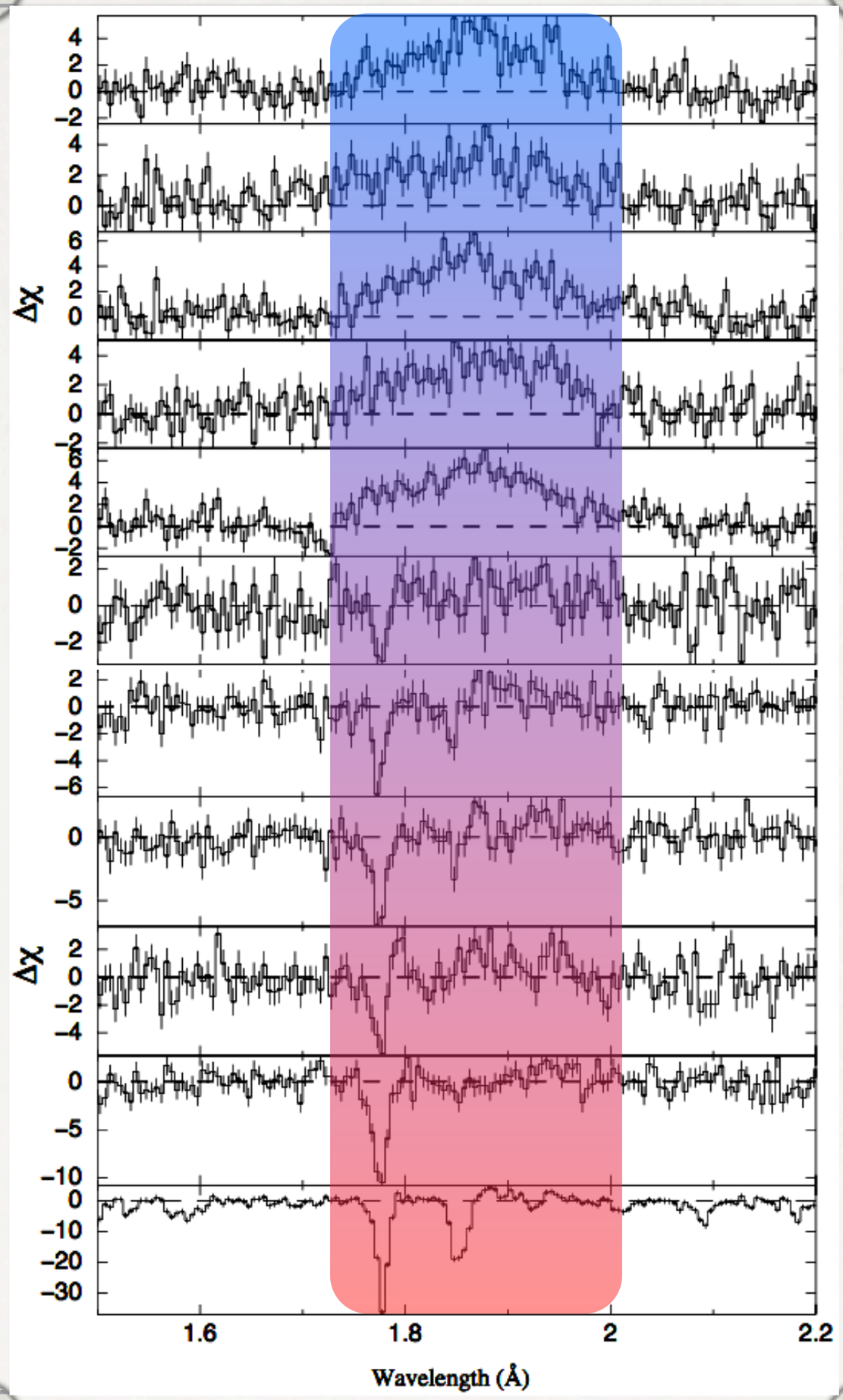
11 Observations



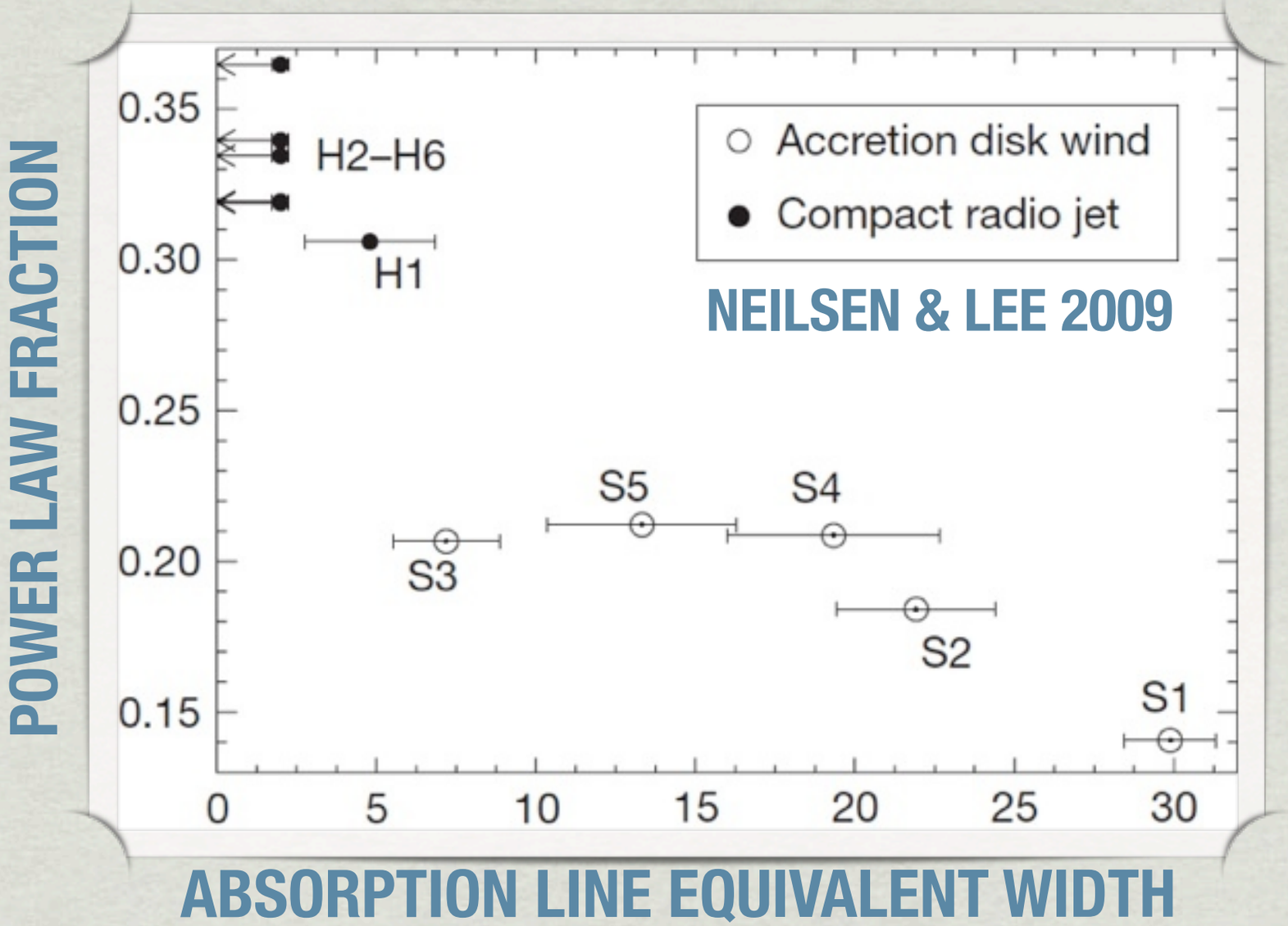
- Power law fraction vs X-ray luminosity
- Interestingly, spectral lines vary with power law fraction

Spectral Lines and Hard Flux

- Iron line spectra on right
- Sometimes broad emission lines, narrow absorption lines (Neilsen & Lee 2009)
- As power law fraction decreases (downwards), emission gradually changes to absorption!
- ***Interpretation***:
- Iron Emission line: accretion disk illuminated by base of the radio jet
- Iron Absorption lines: Fe XXVI, hot (10^6 K) accretion disk wind (1000 km/s blueshift)
- Connection between radiation, outflows



Winds vs Jets



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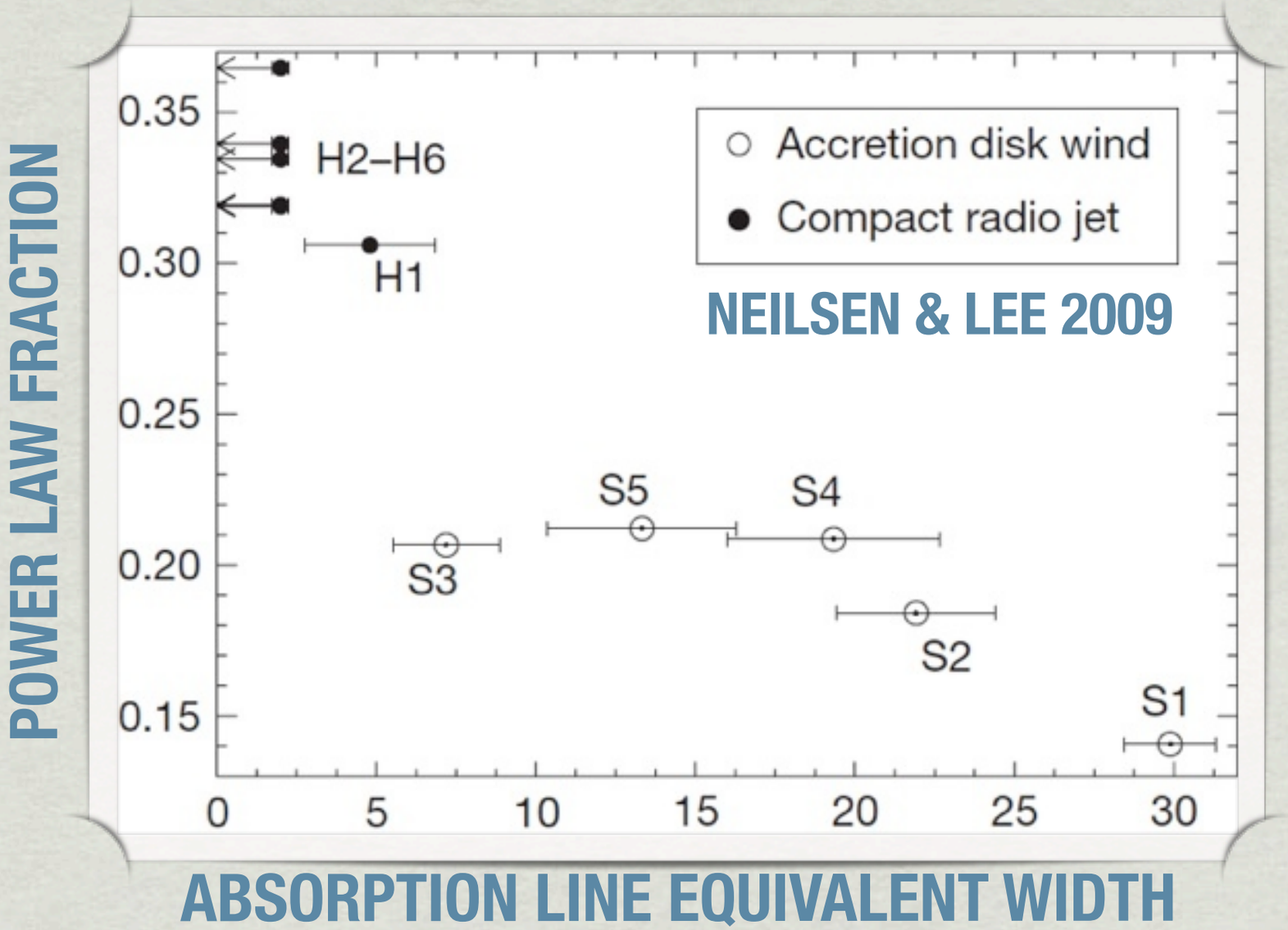

- Jets linked to hard flux
- Disk wind measured in absorption

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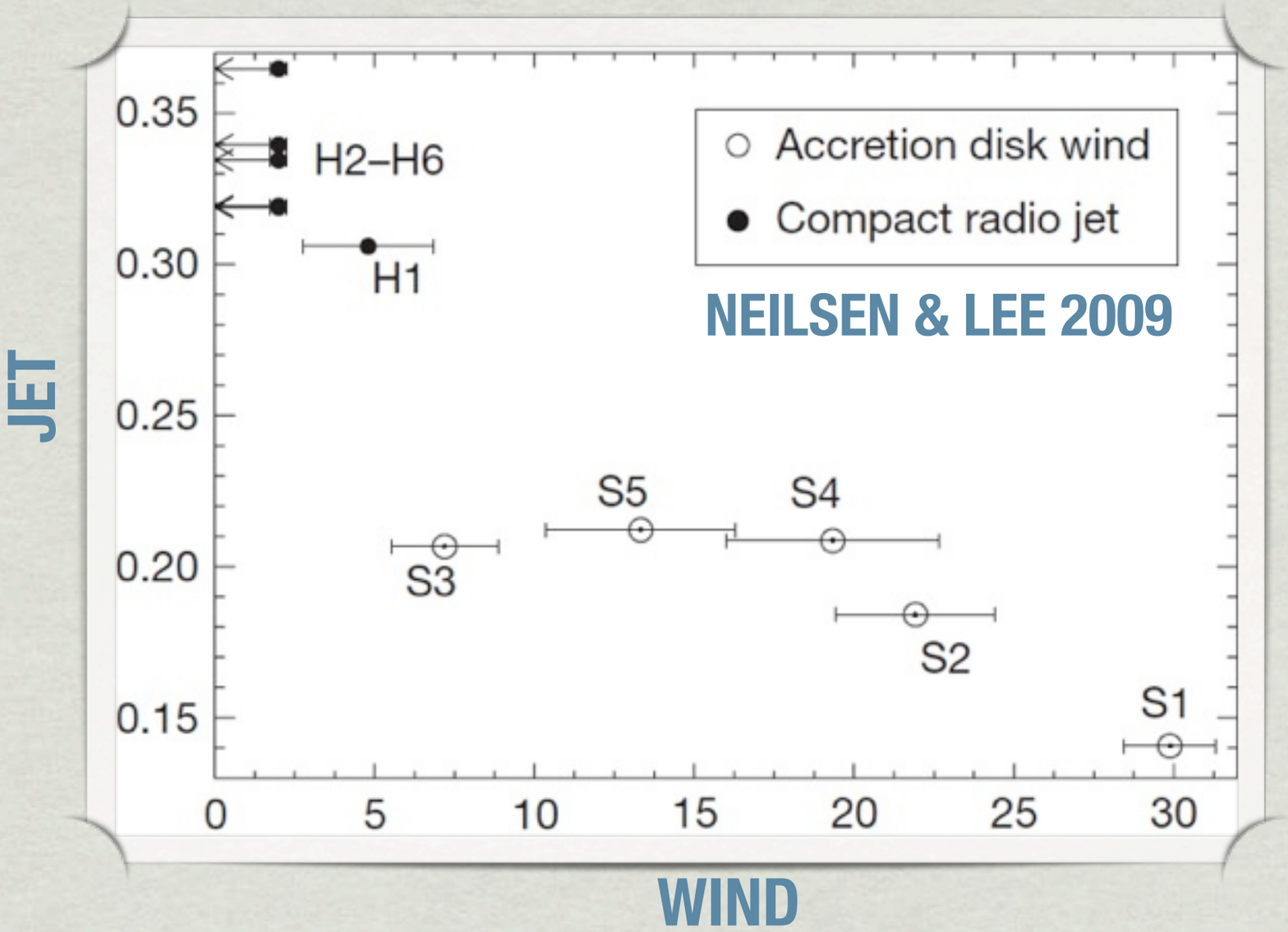

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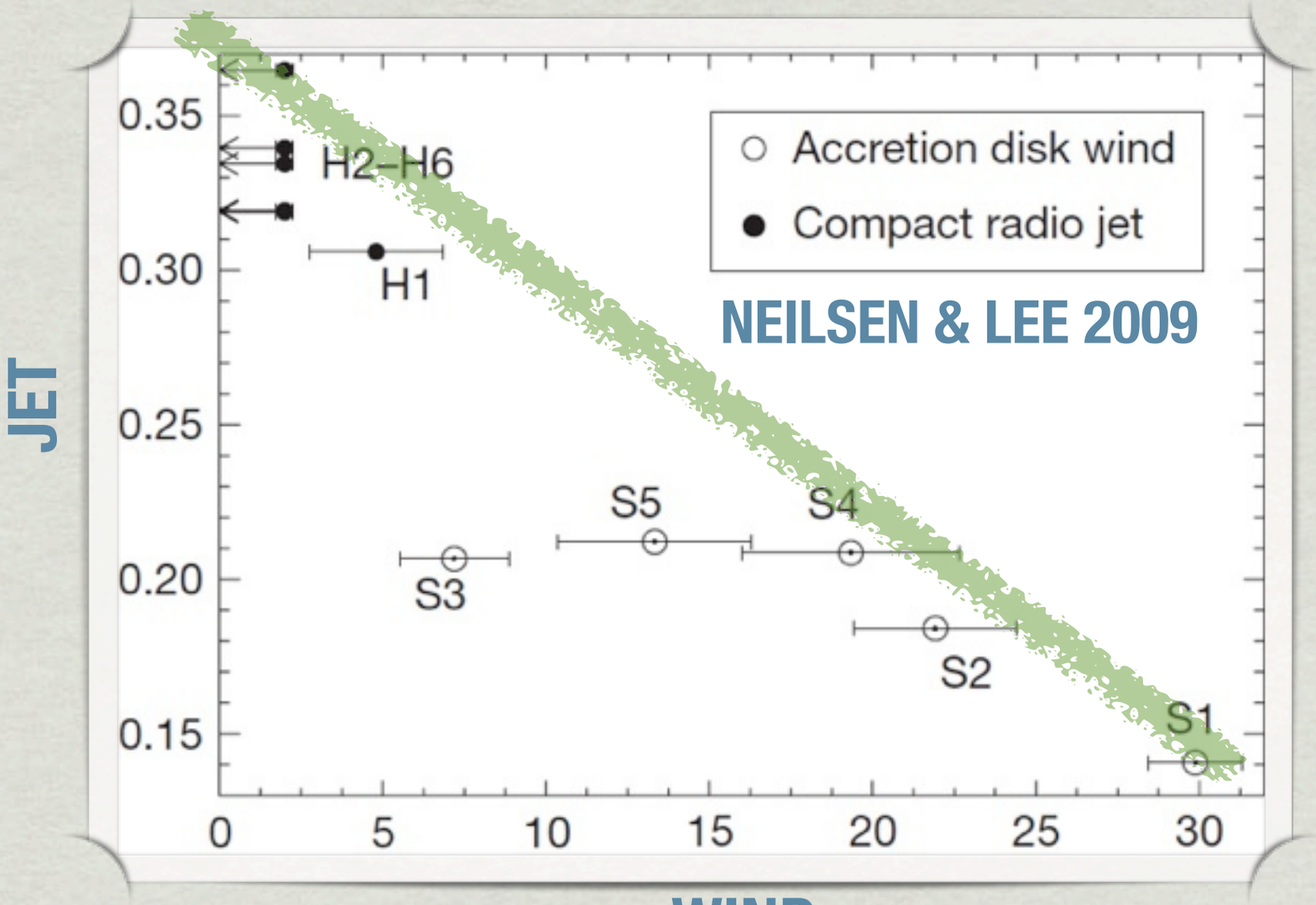

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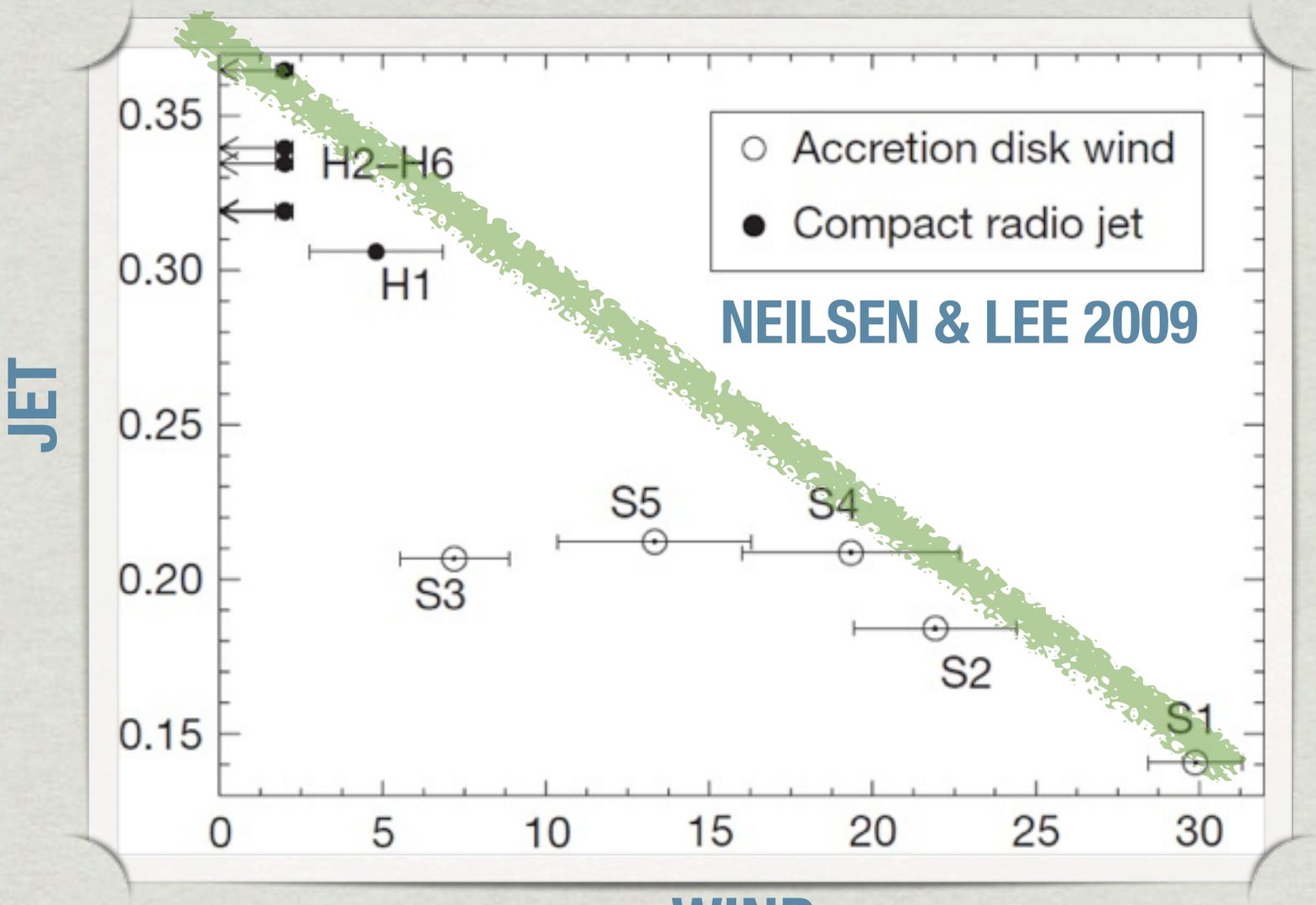

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- Key Points:
- On avg, the wind and the jet carry the same mass away from the black hole
- Pivot point: both wind and jet are present, but weak

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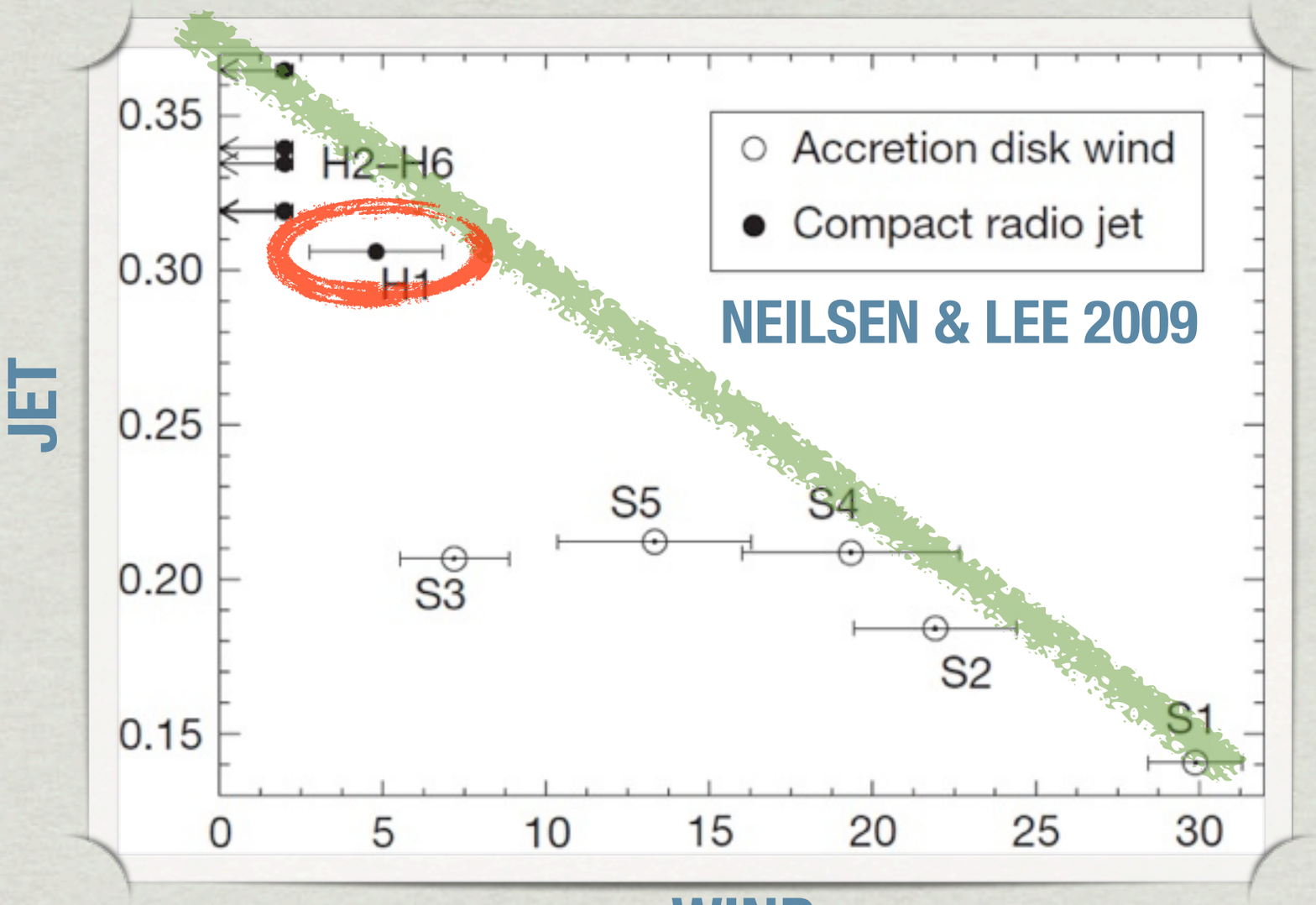

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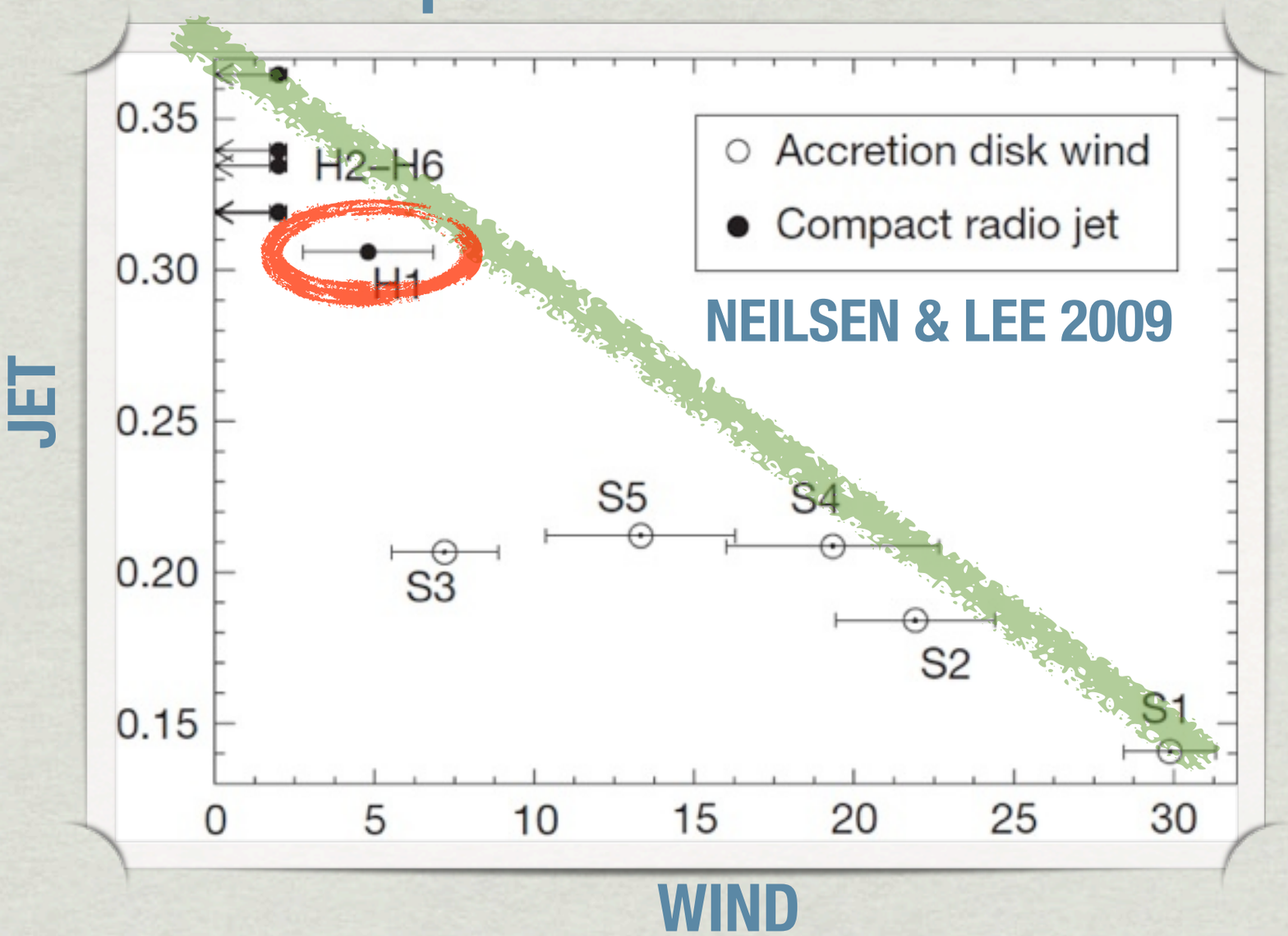
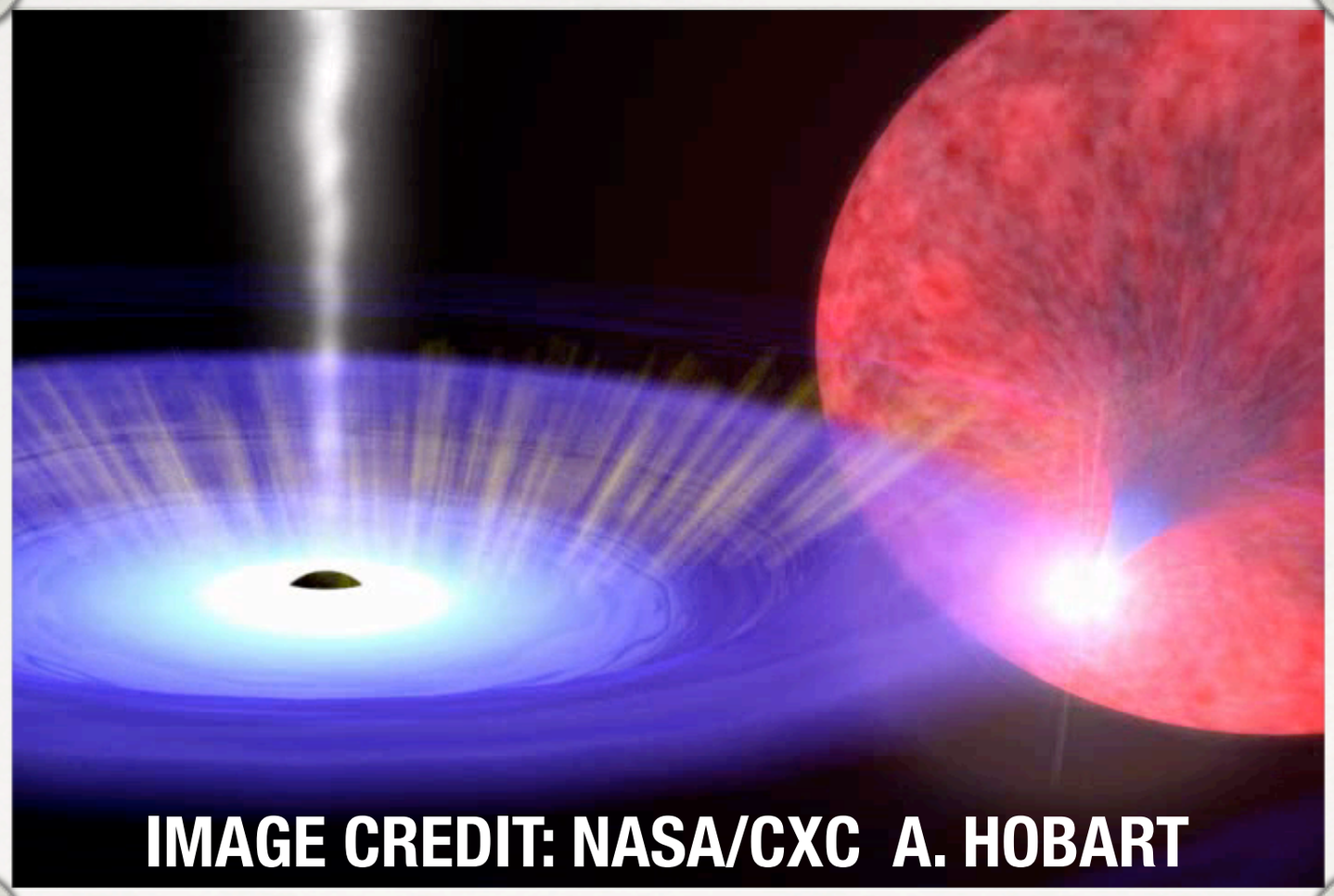
Implications



- Wind and jet directly competing for their matter supply—wind gets stronger at the expense of the jet
- Gradual interaction between wind and jet mediated by hard X-rays, radiation processes (Lee et al. 2002; Miller et al. 2006, 2008).

Wind-Jet Interaction

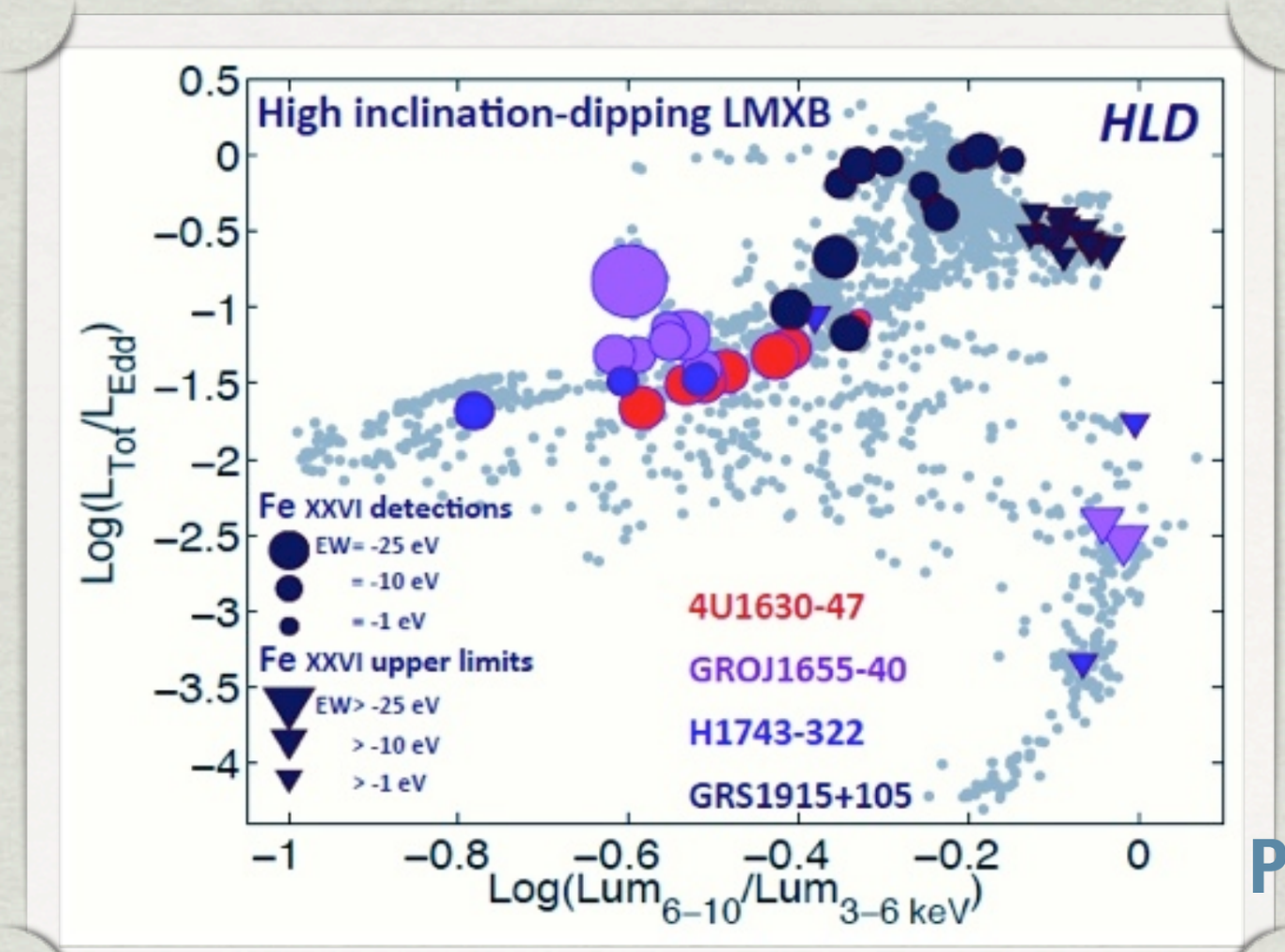


- Winds may **quench jets** by altering flow of gas onto BH (Neilsen & Lee 2009)
- GRS 1915+105 can self-regulate, just like supermassive systems!

2013 Update

- GRS 1915+105 is an exceptional system...
- Is there any evidence that winds may play a role in jet suppression around *other* black holes?
- We know where jets are launched in outburst... what about winds?
- Ponti et al. (2012): Archival study of observations sensitive to disk winds

Winds Follow Jets in Outburst!



PONTI ET AL. 2012

- Historically, winds appear in the top branch of the outburst "q," where the accretion flow changes and steady jets disappear
- Consistent with the suppression of jets by winds

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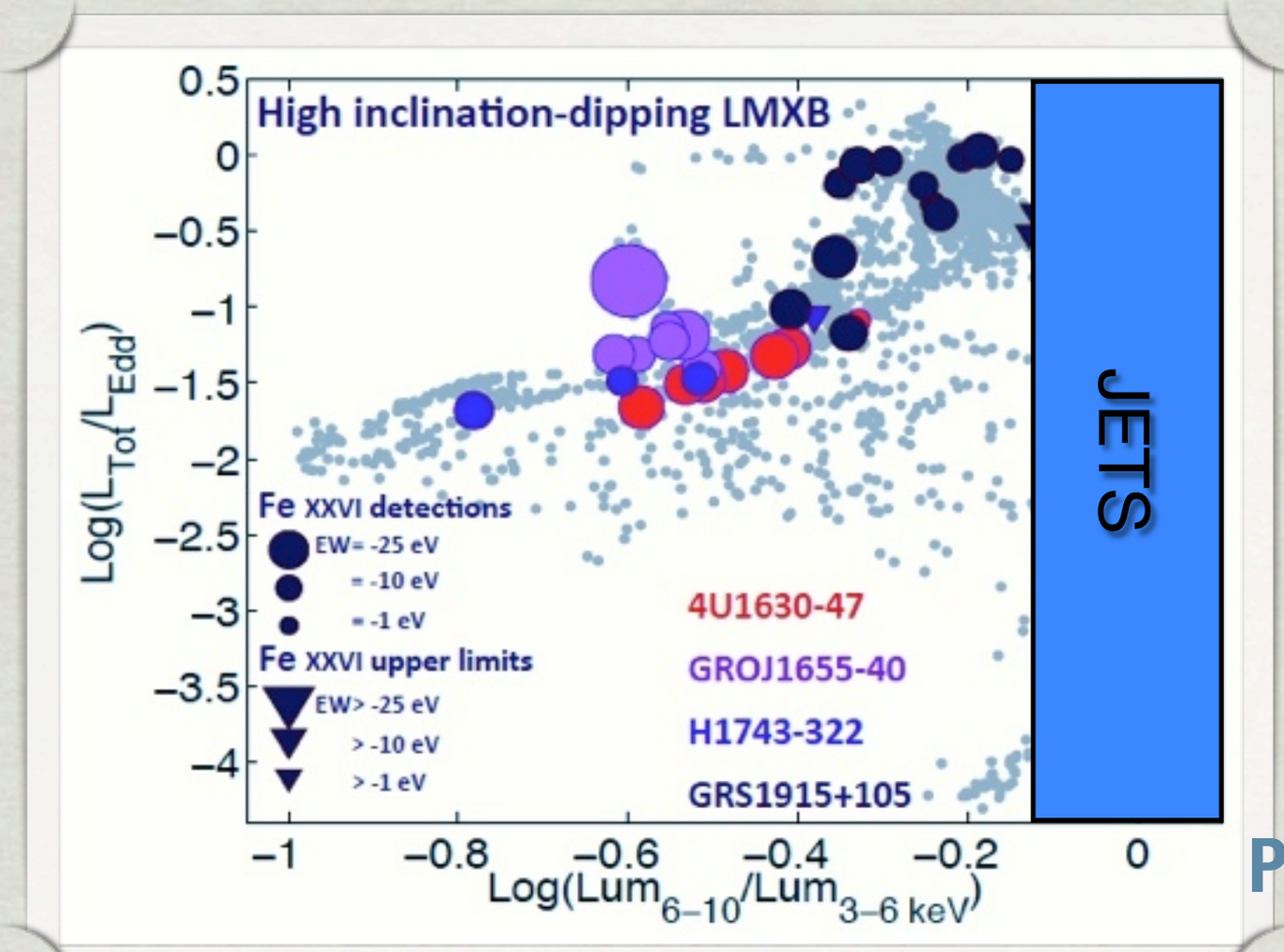

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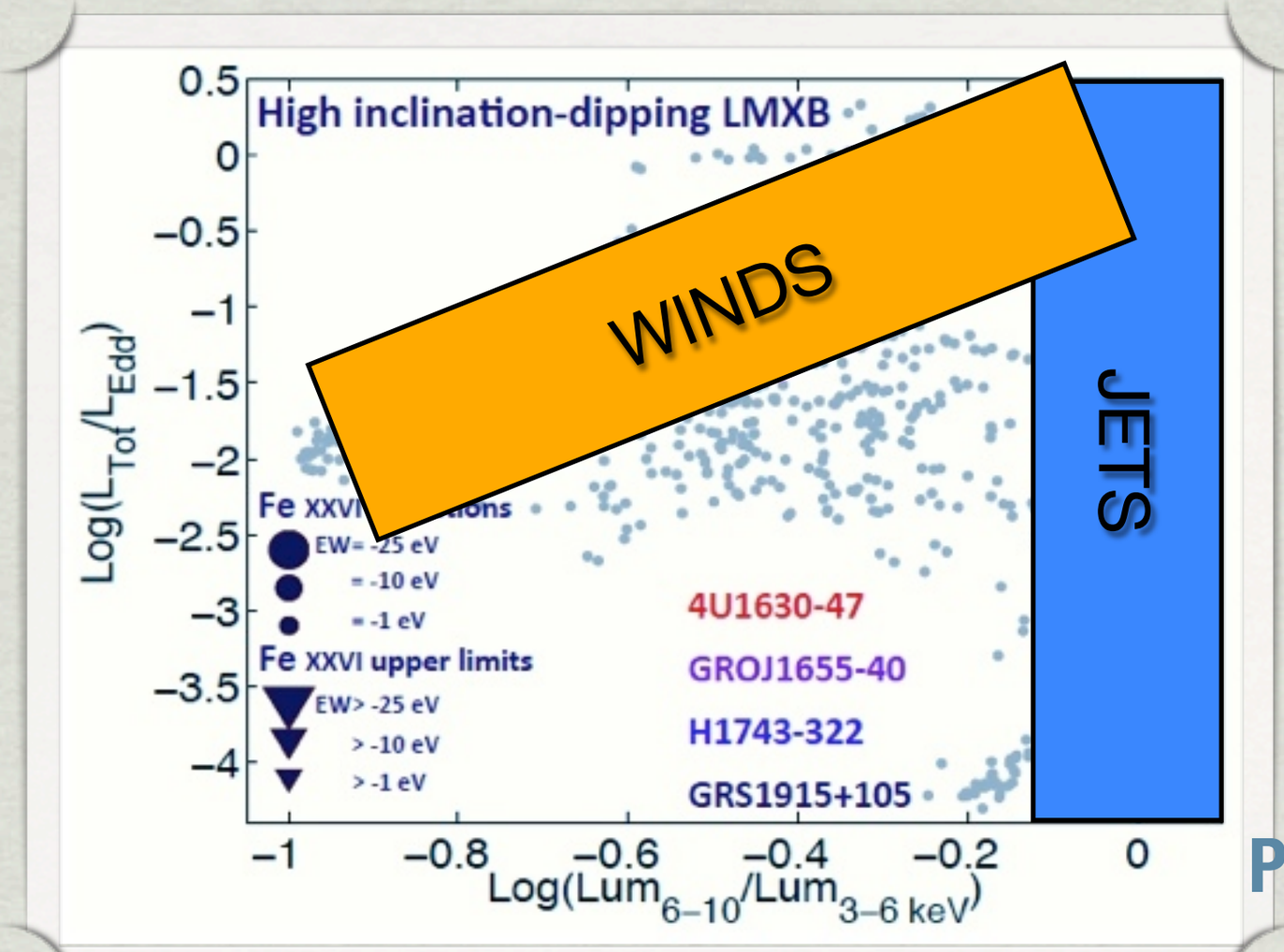

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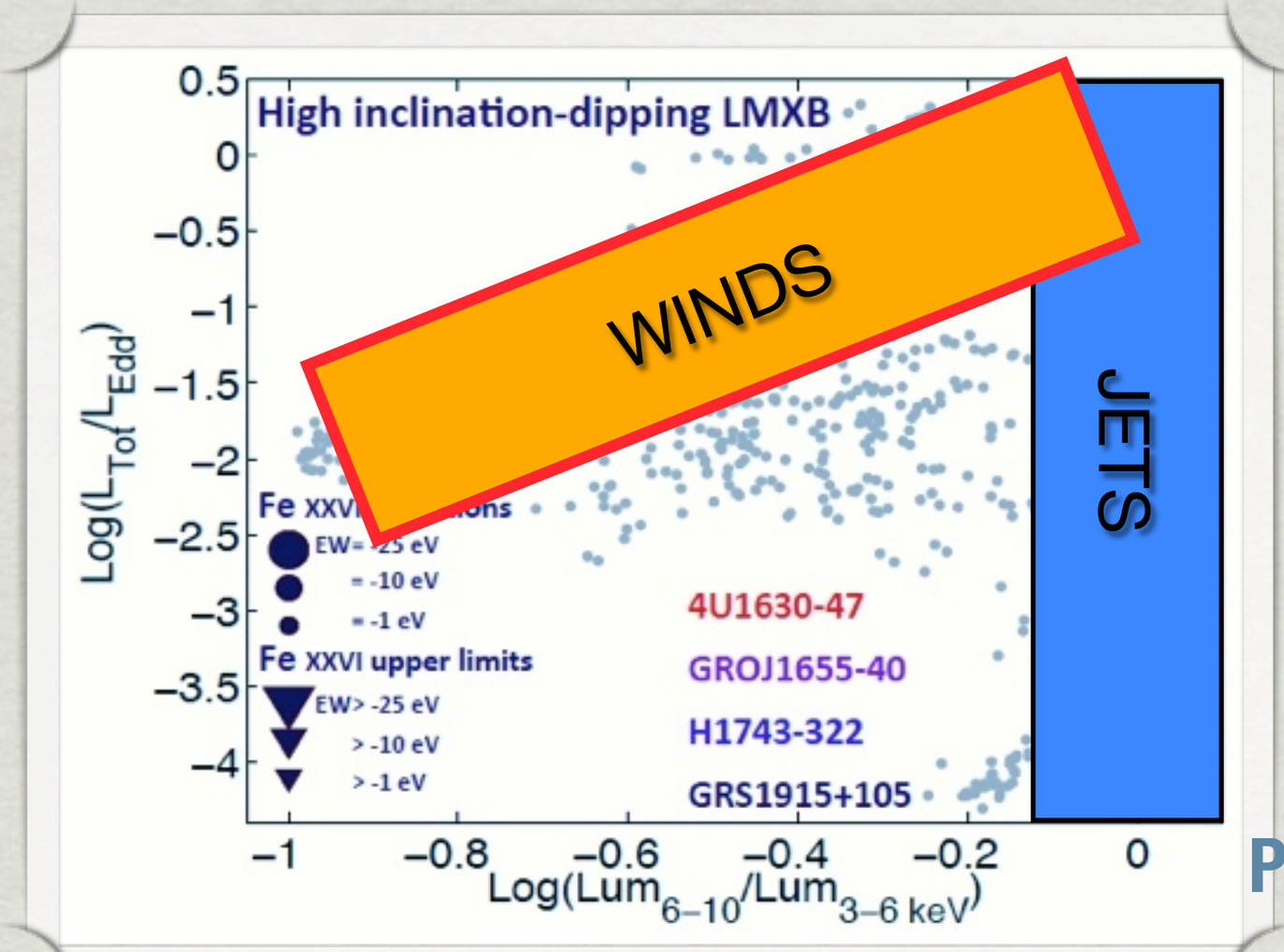

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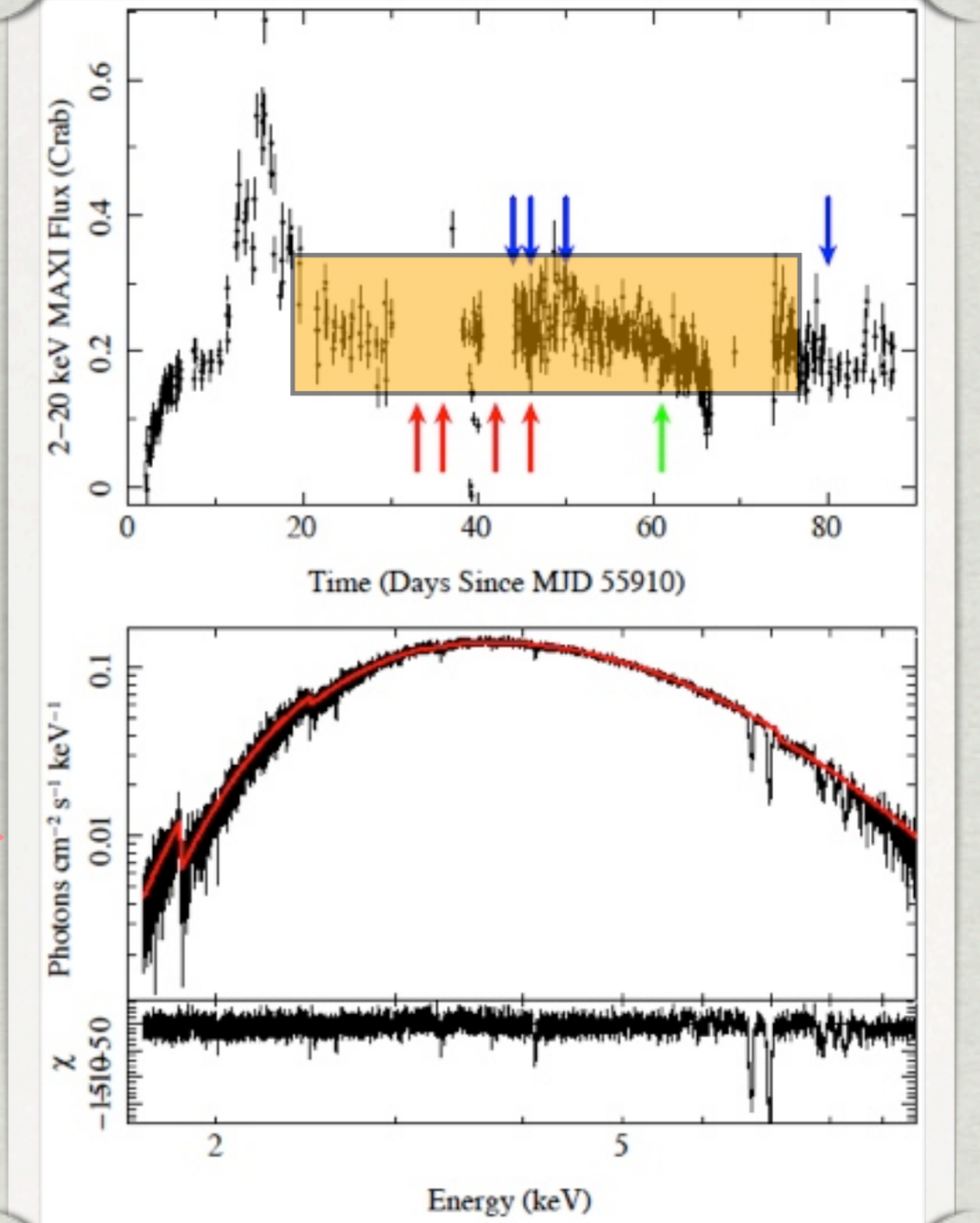
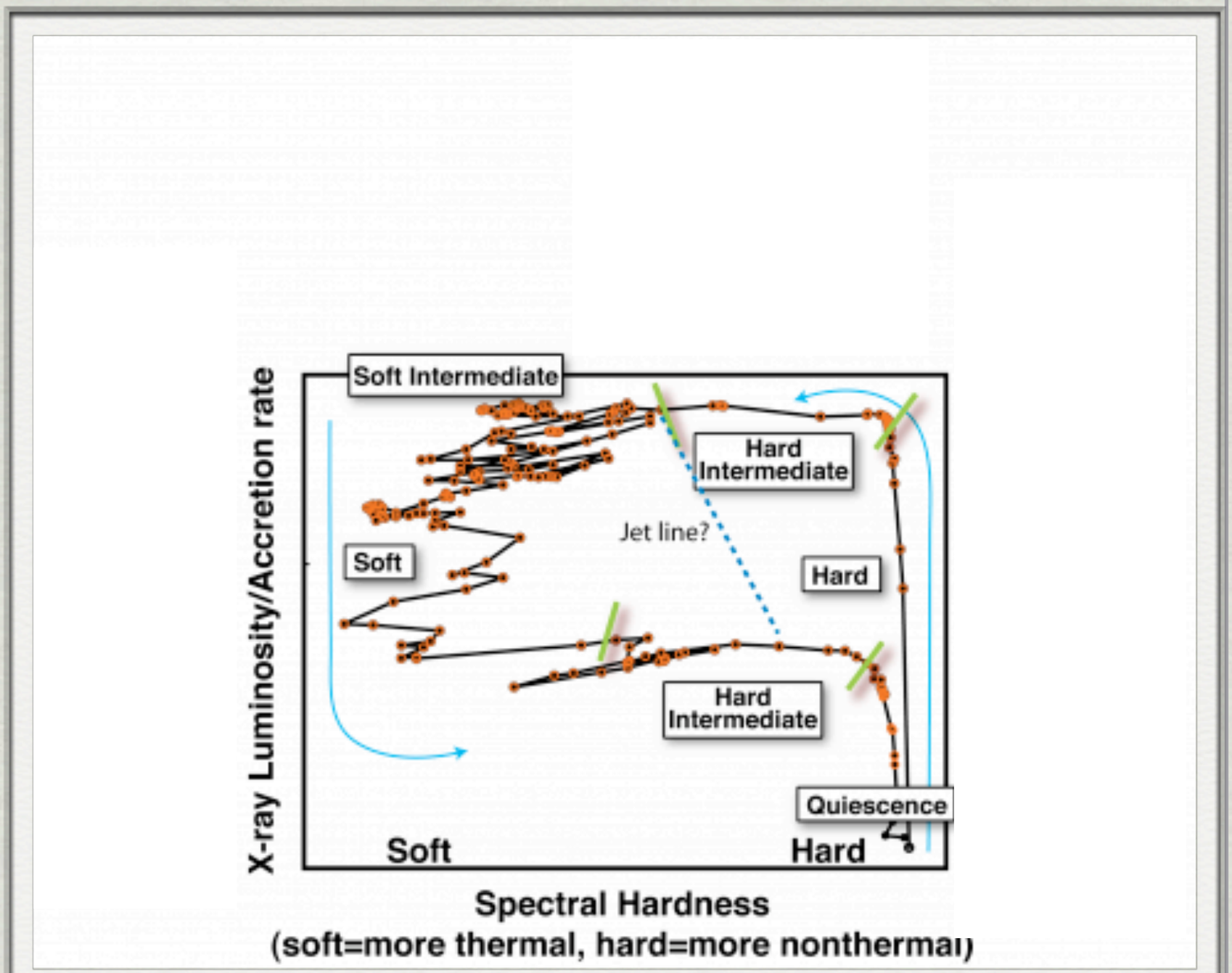
Tested With New Observations

- Target of Opportunity observations of 4U 1630-47 (PI: Neilsen)
- Based on Ponti et al. 2012, designed to catch a disk wind
- Very successful!!!
- Winds reliably appear during this outburst phase (Neilsen et al. 2013, in prep)



Lingering Questions of Causality

- Do winds start to appear before jets or after jets?
- Chandra Cycle 15 proposal (PIs Neilsen, Motta, Ponti et al.)
- Combine timing/ spectral information to track winds as they arise



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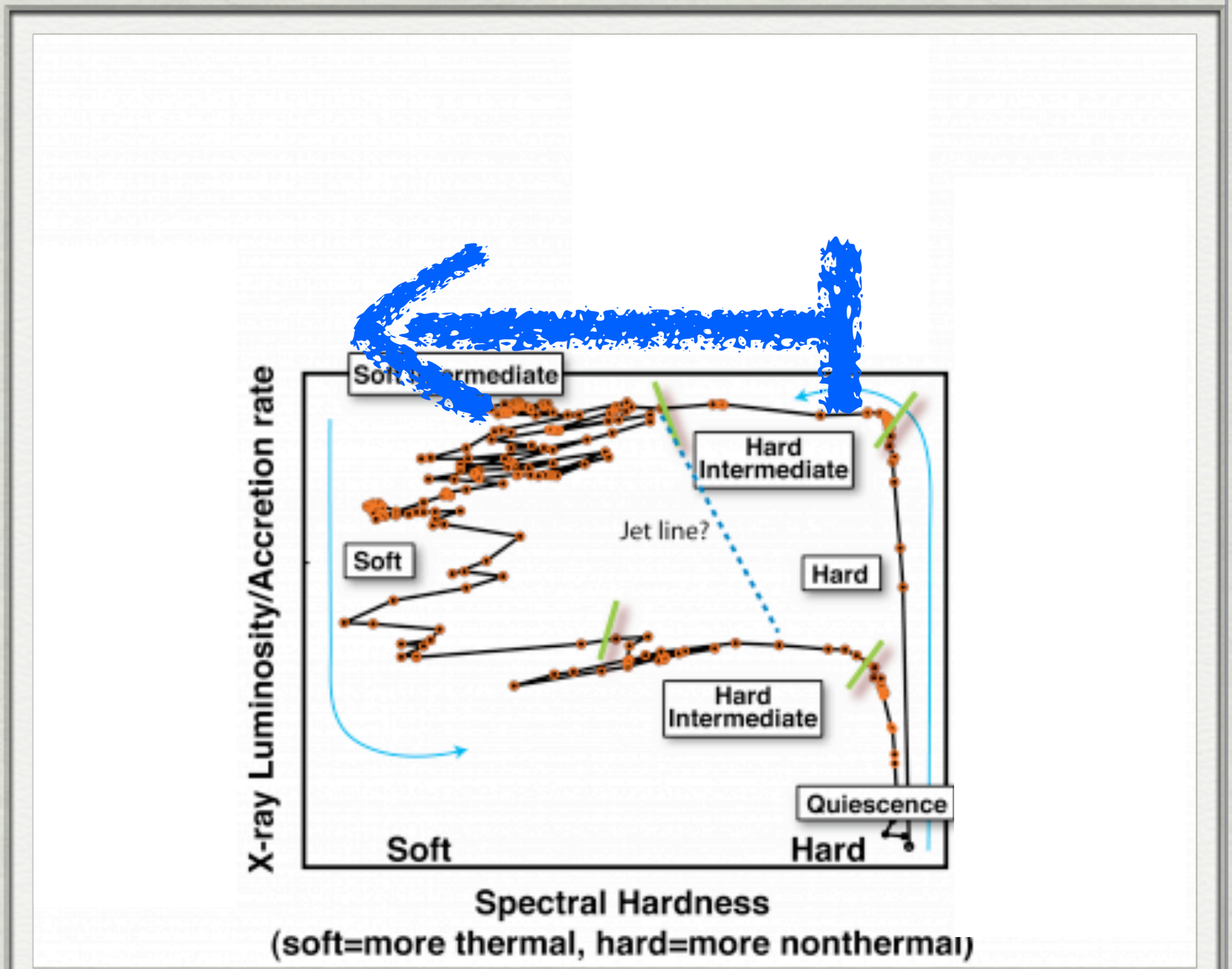

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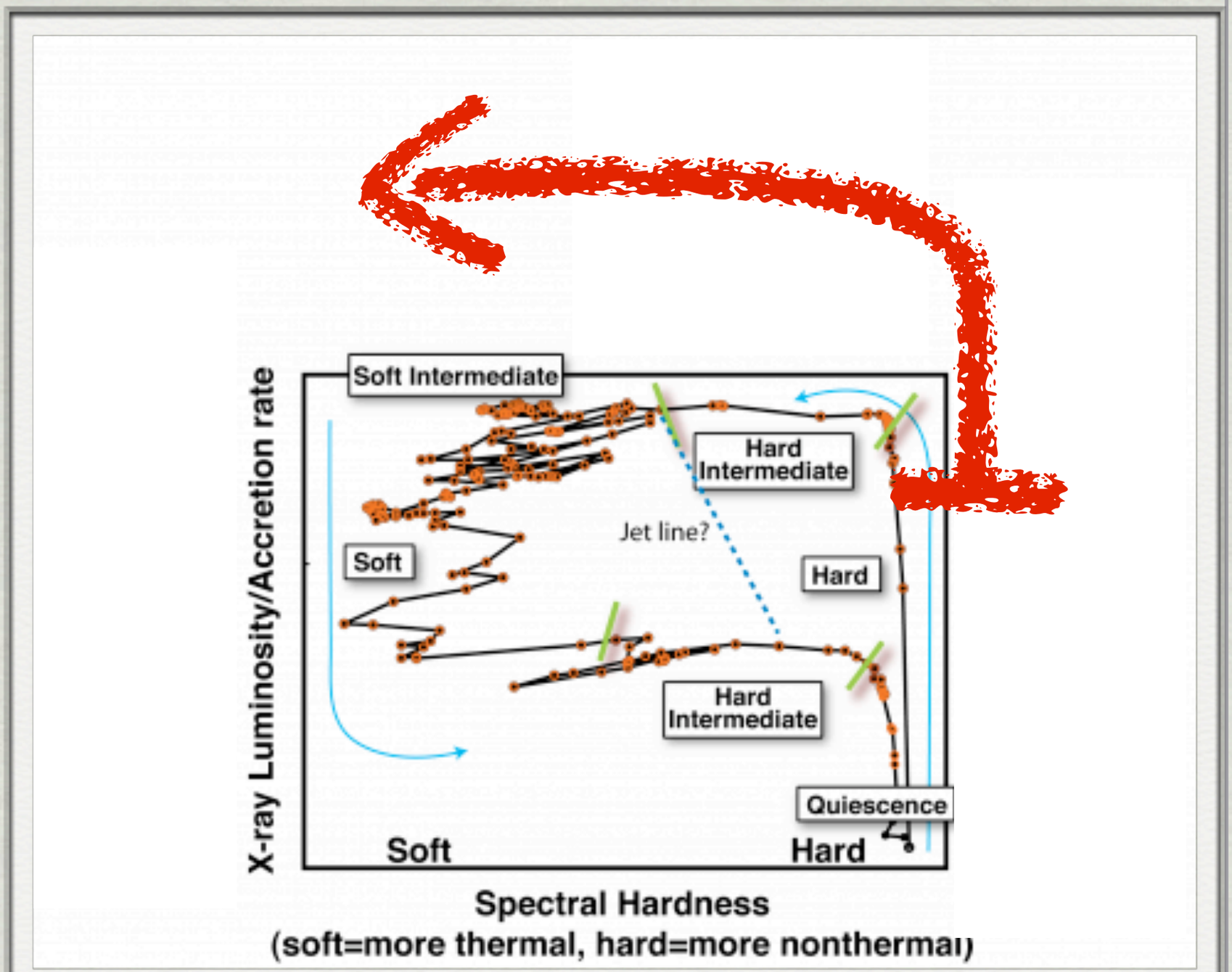
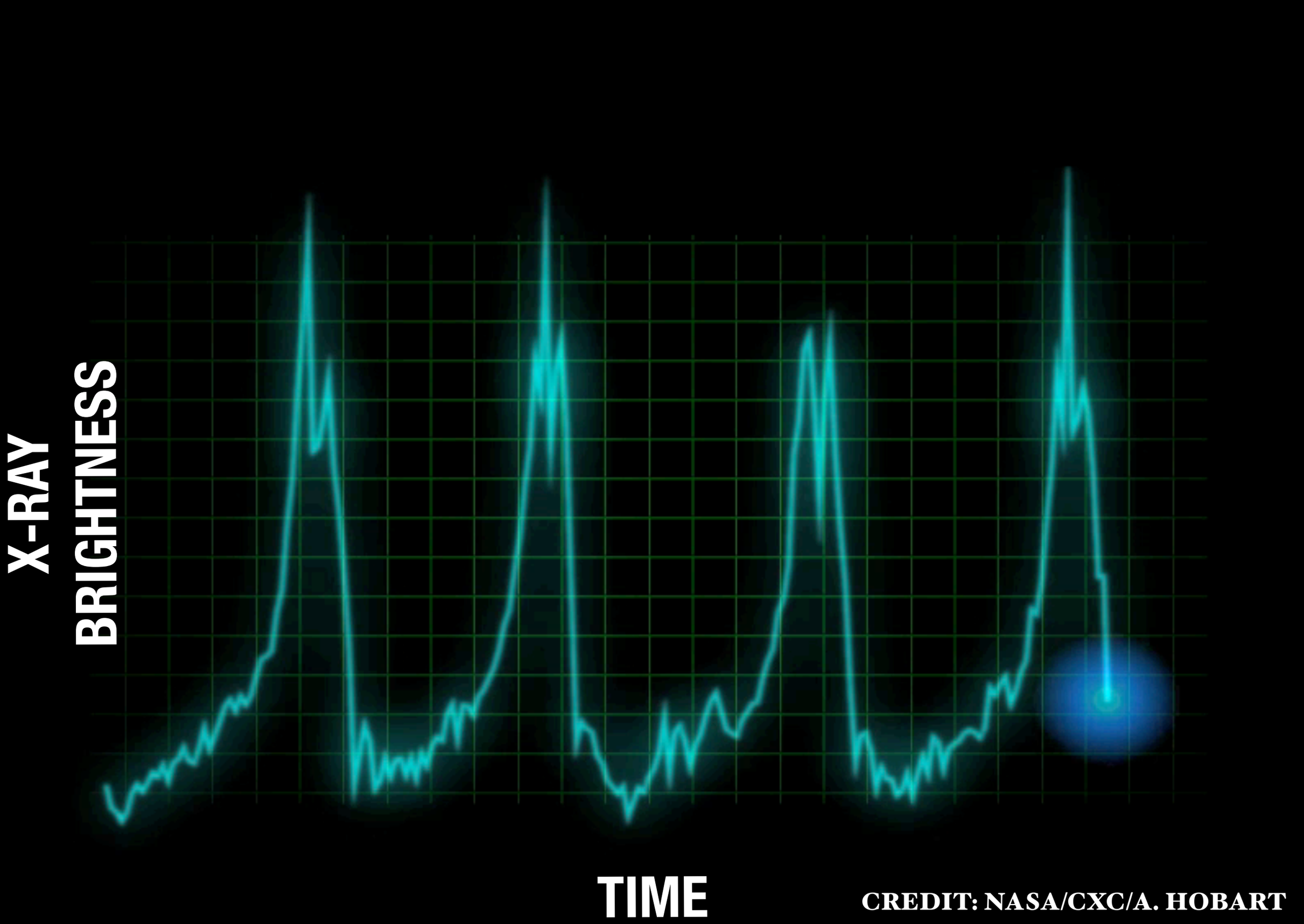


Back to GRS 1915+105

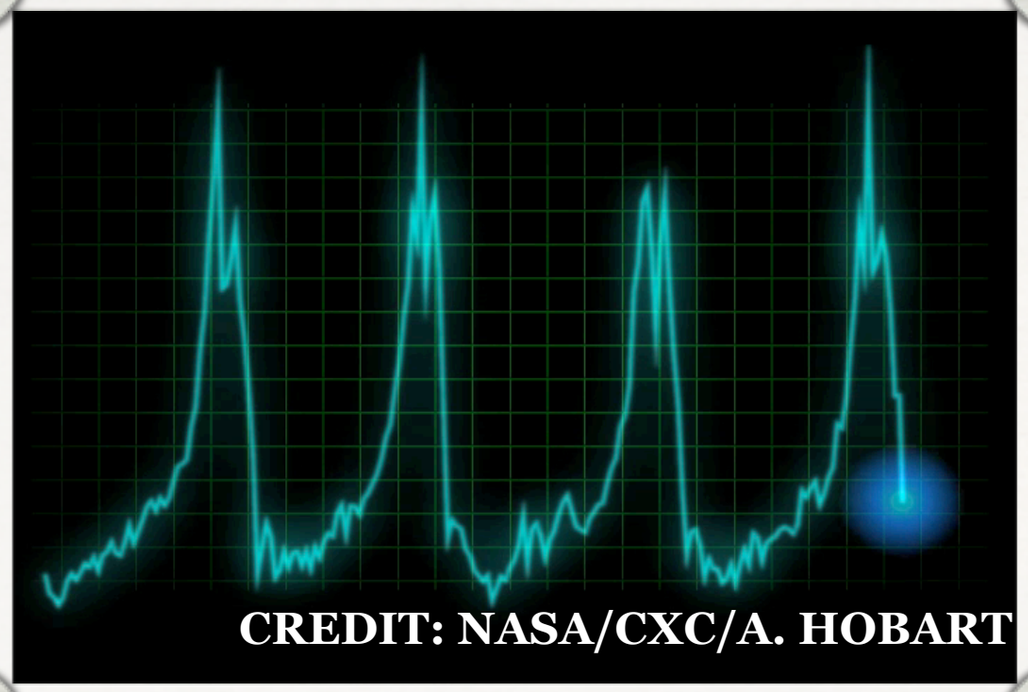
- Winds appear to suppress jets on long time scales in GRS 1915+105.

- How does the wind-jet connection work? What is the significance of the extreme X-ray variability?



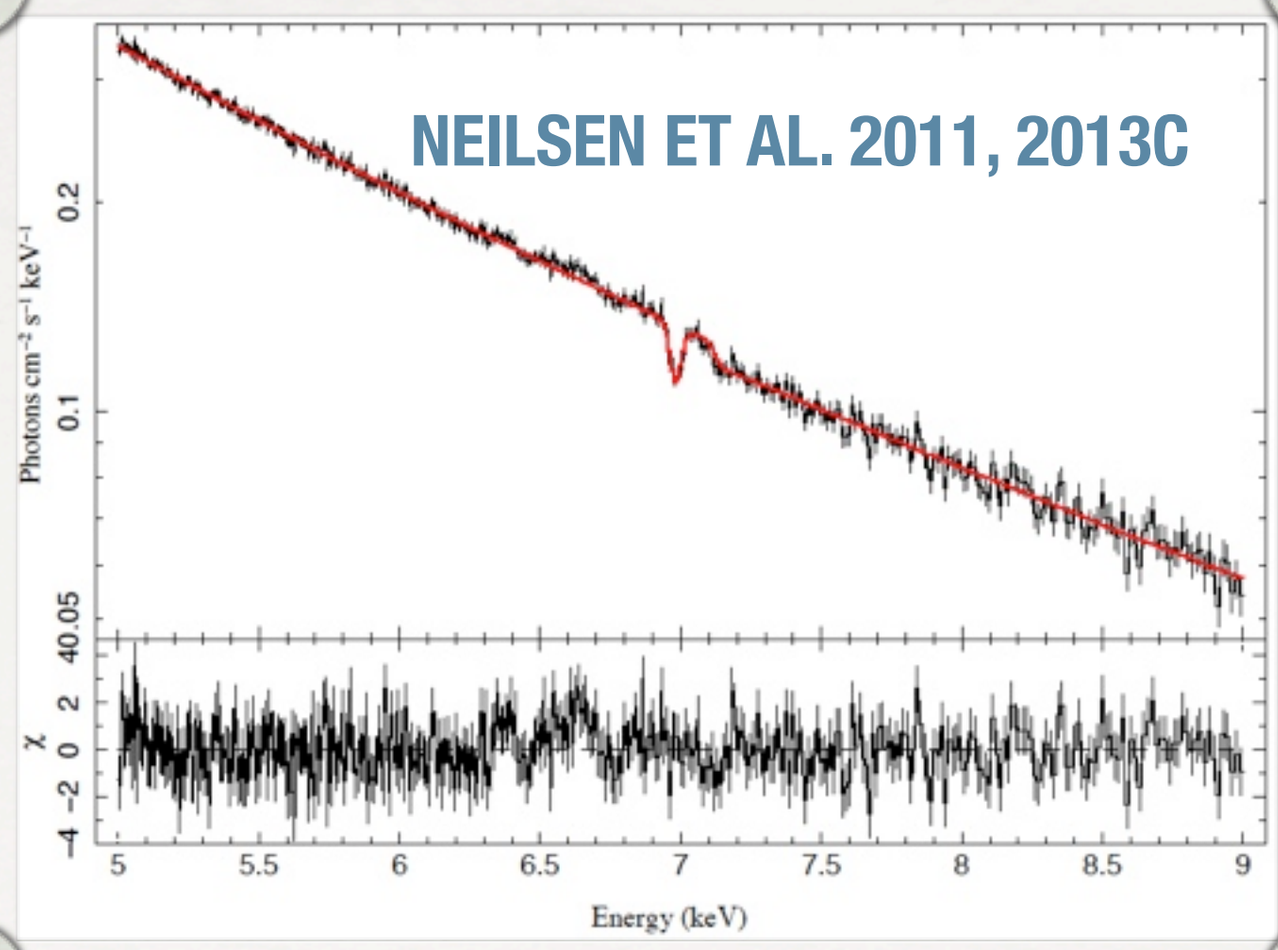
CREDIT: NASA/CXC/A. HOBART

The ‘Heartbeat’ State of GRS 1915+105



- Strong, strange 50-second pulse observed by RXTE
- Disk instability driven by radiation pressure

- Chandra observations of this ‘heartbeat’ reveal a disk wind!



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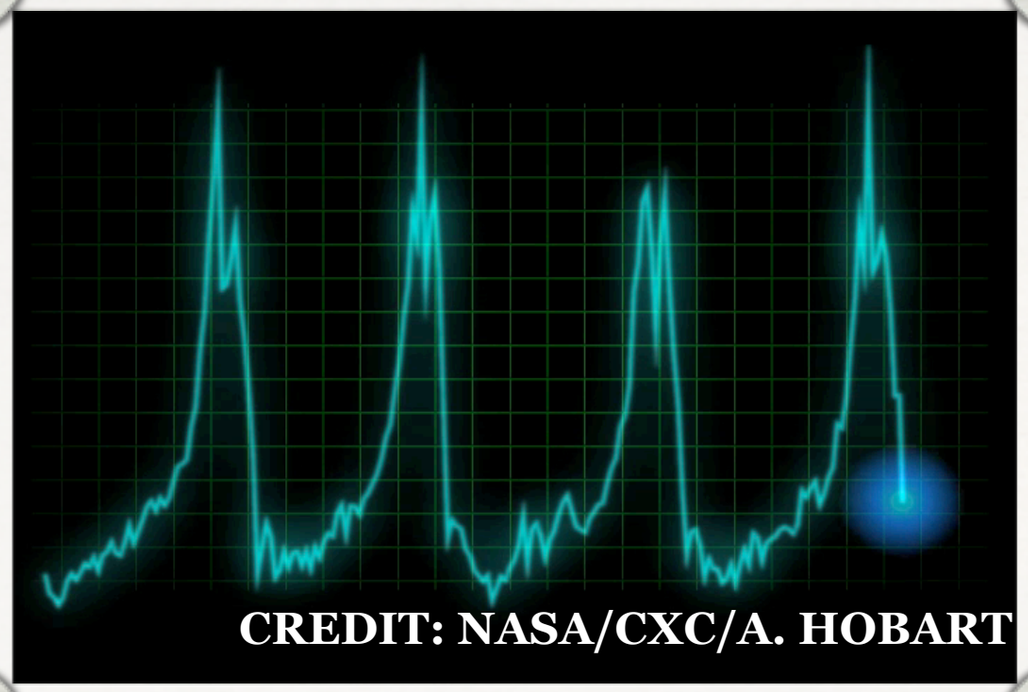

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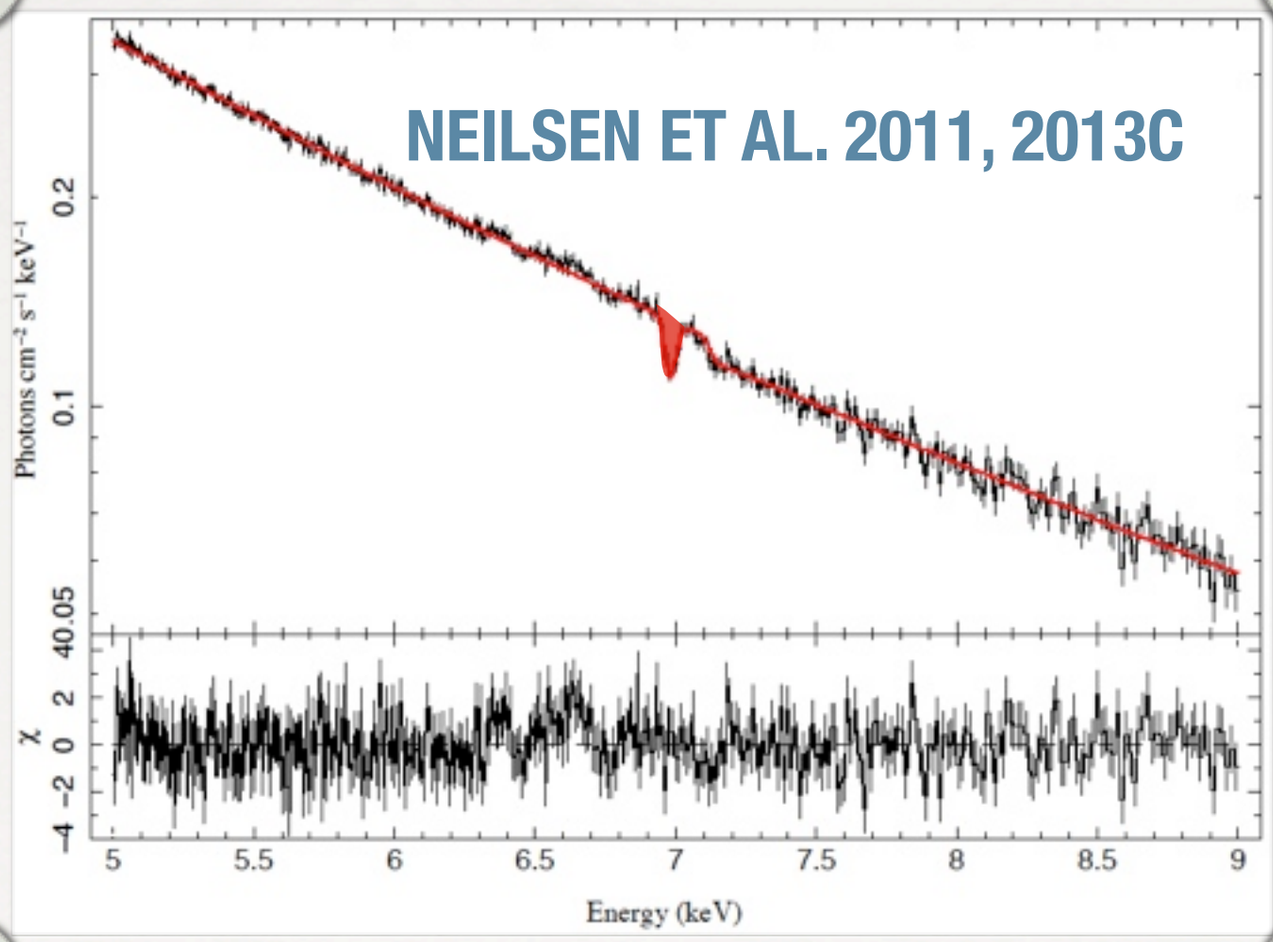

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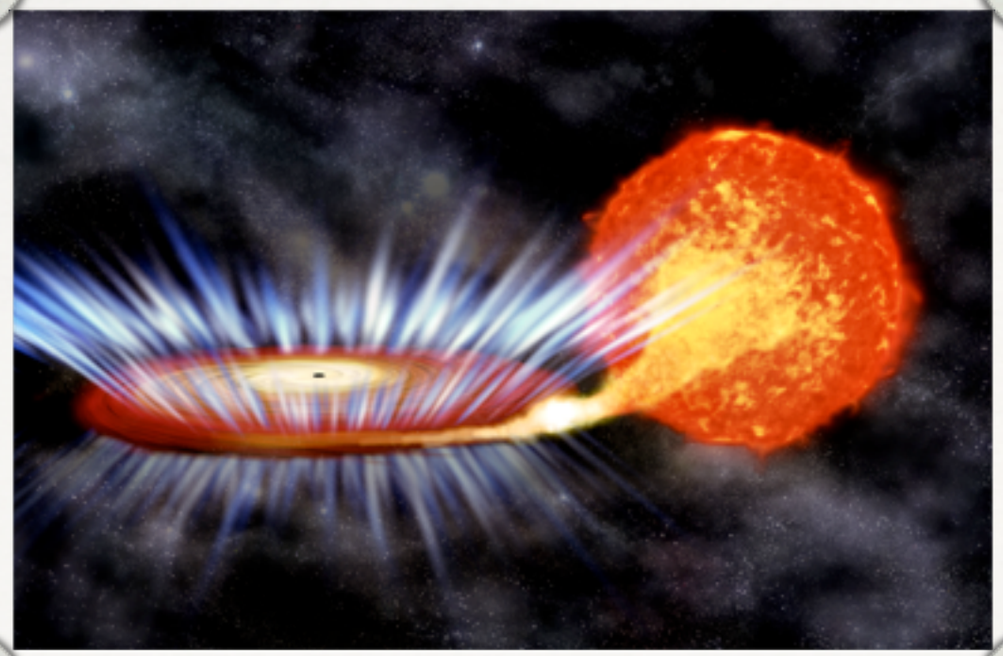

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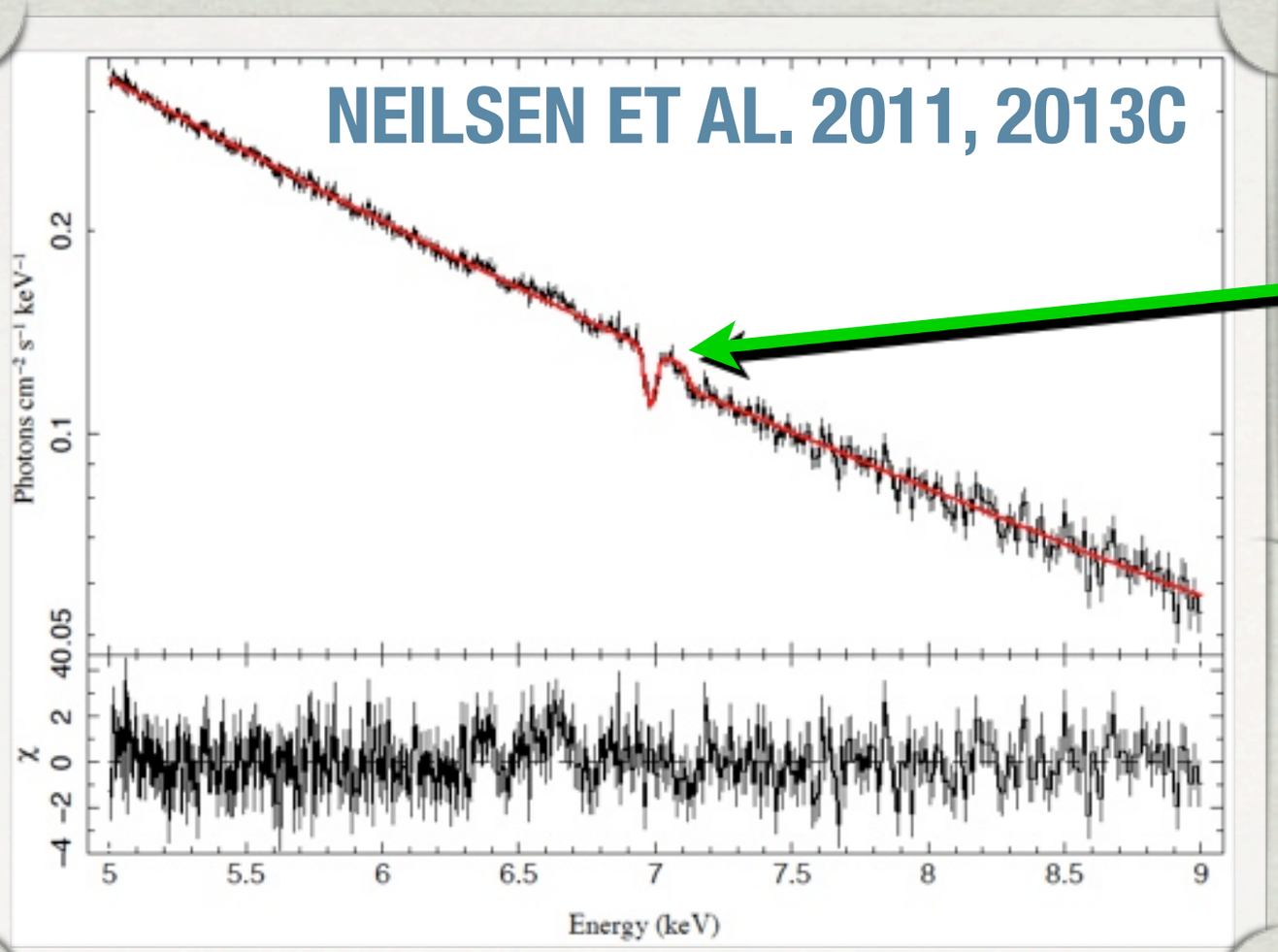
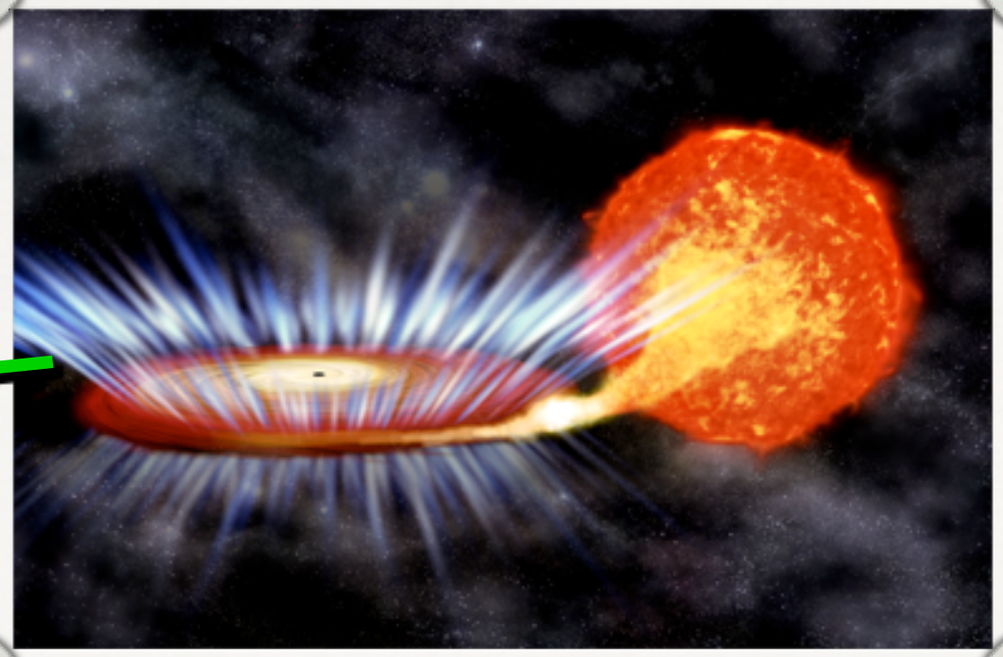
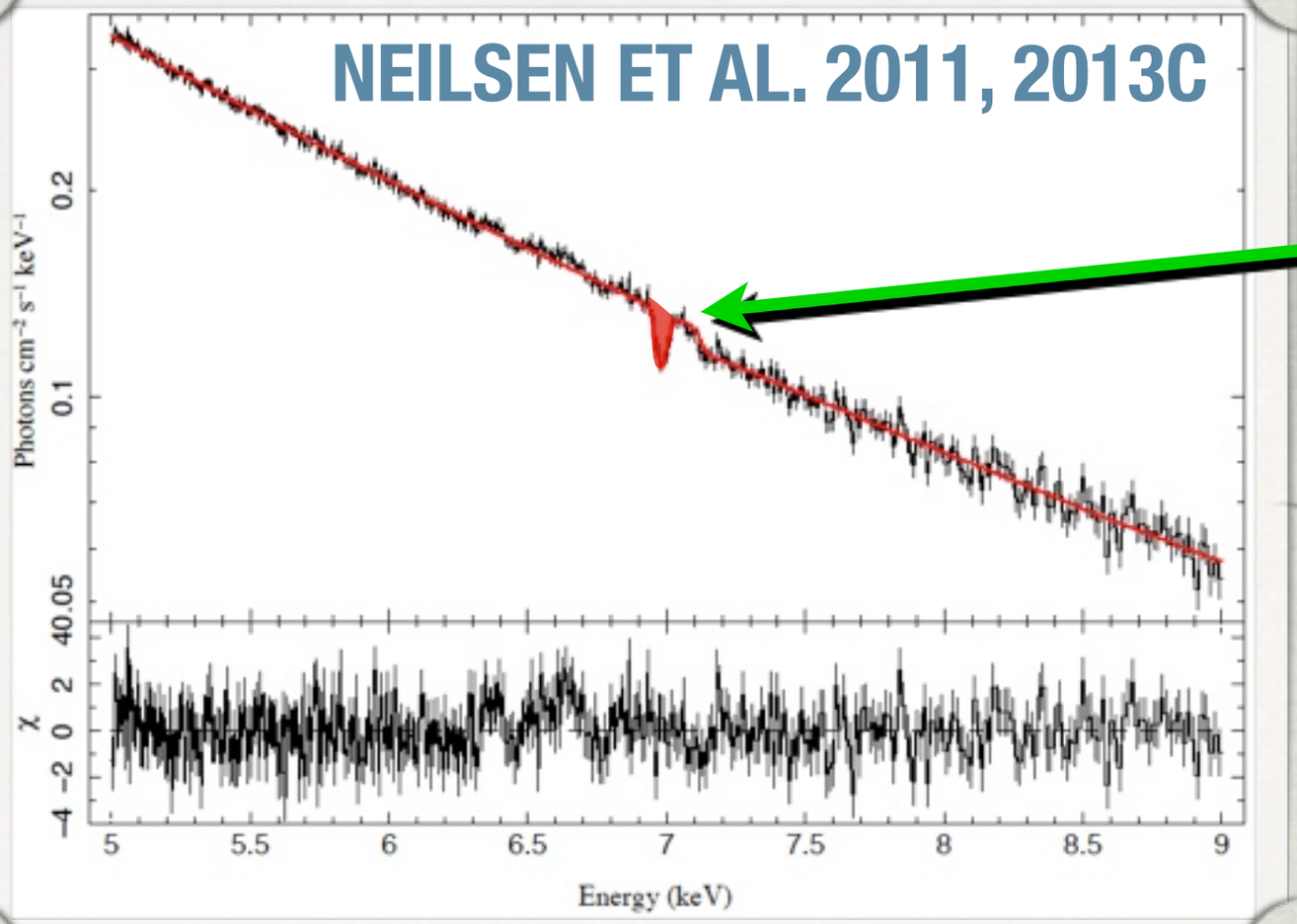
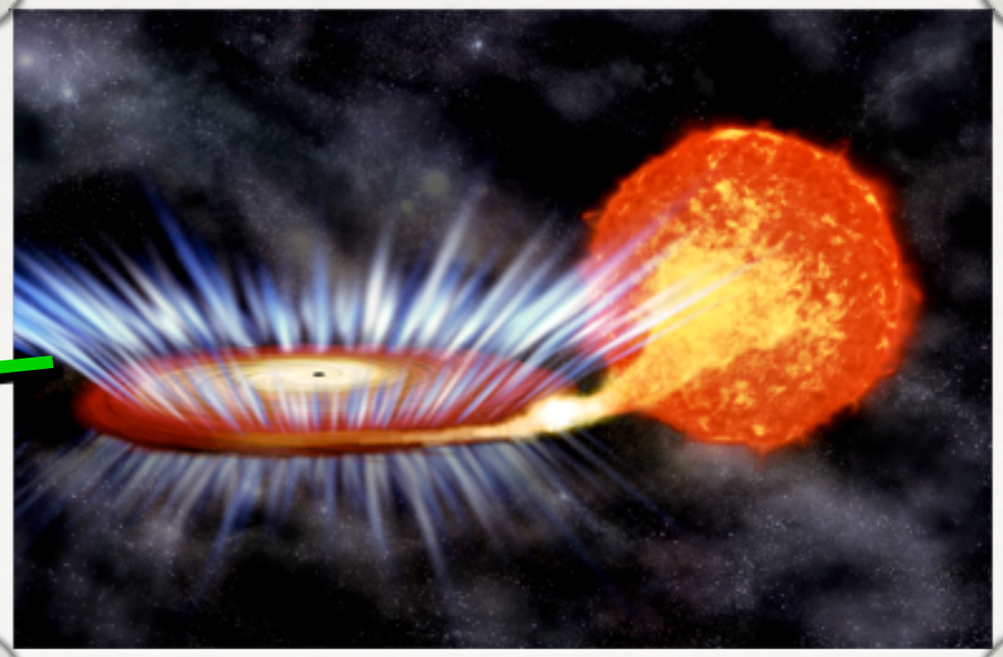




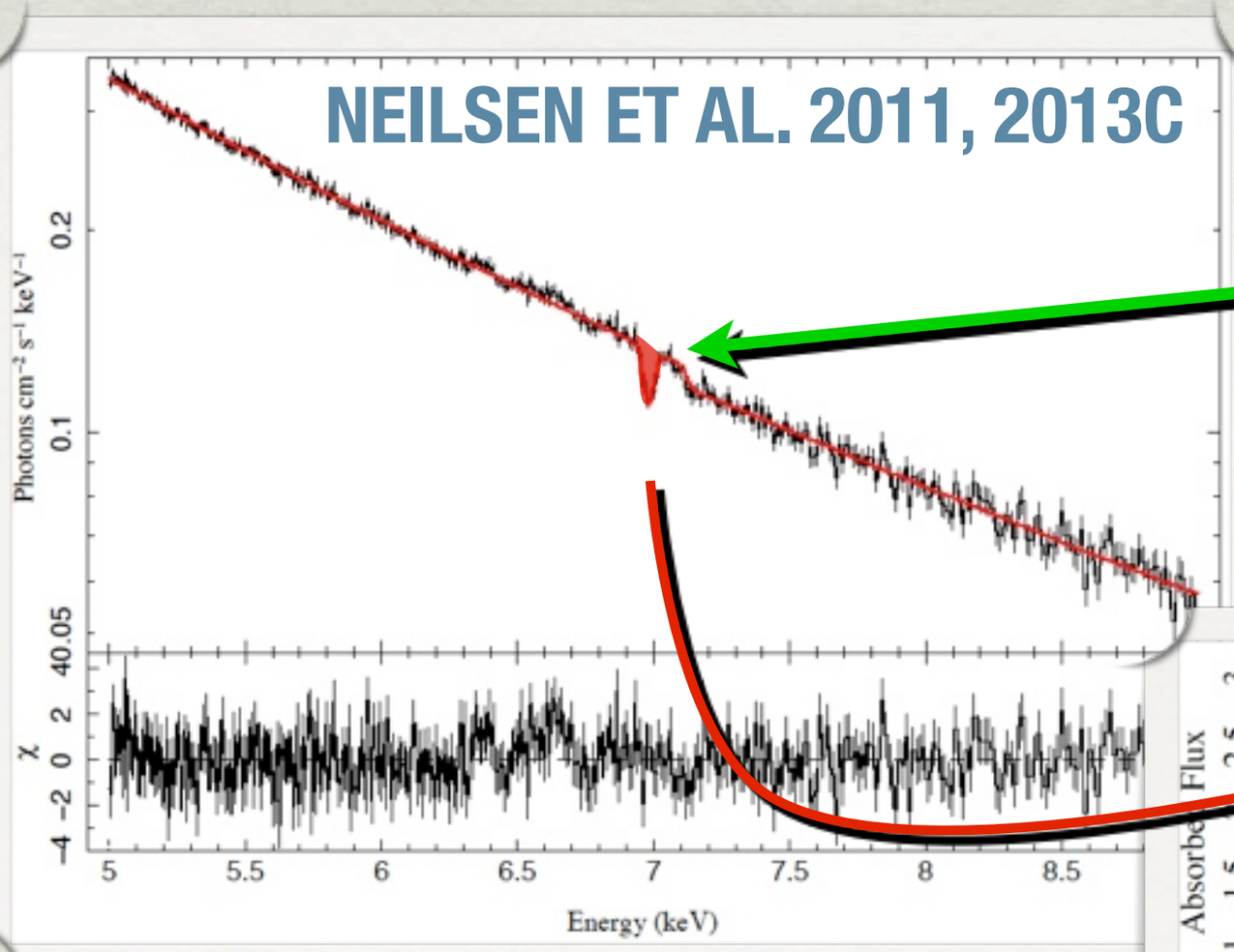
Accretion Disk Wind

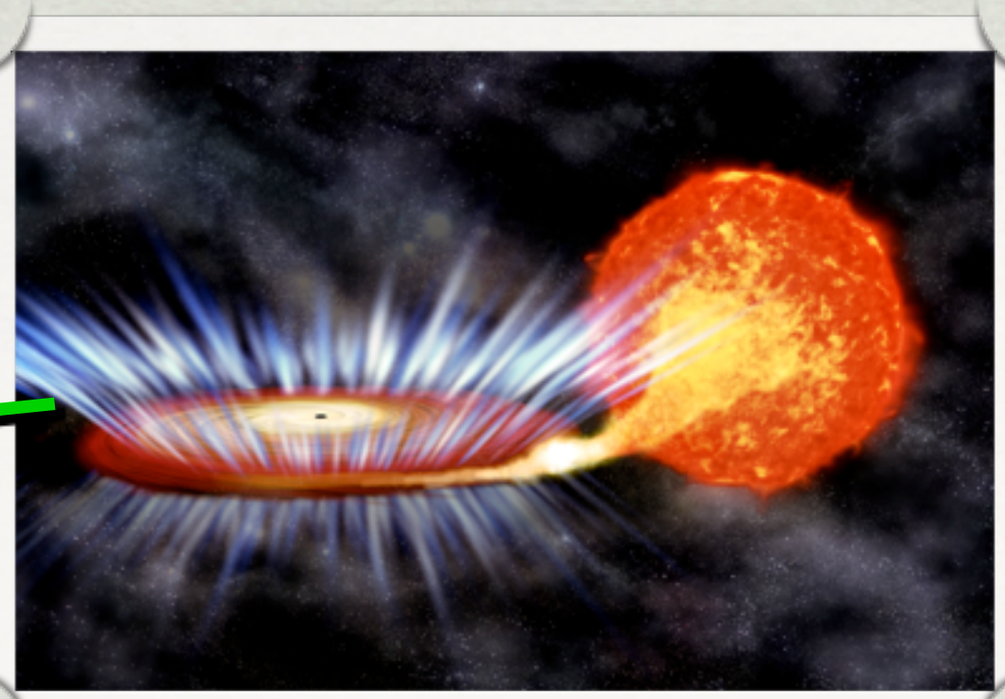


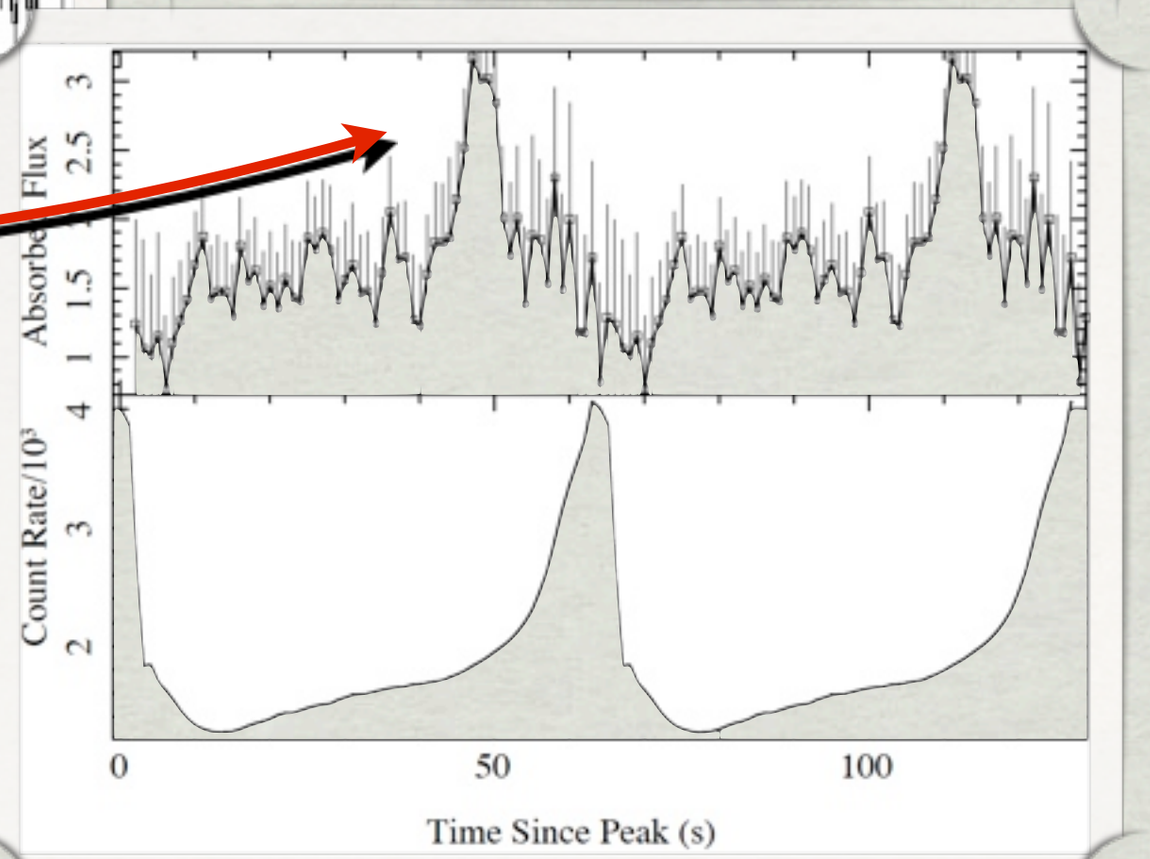


- Phase fold, measure wind at each part of the ‘heartbeat’

Accretion Disk Wind







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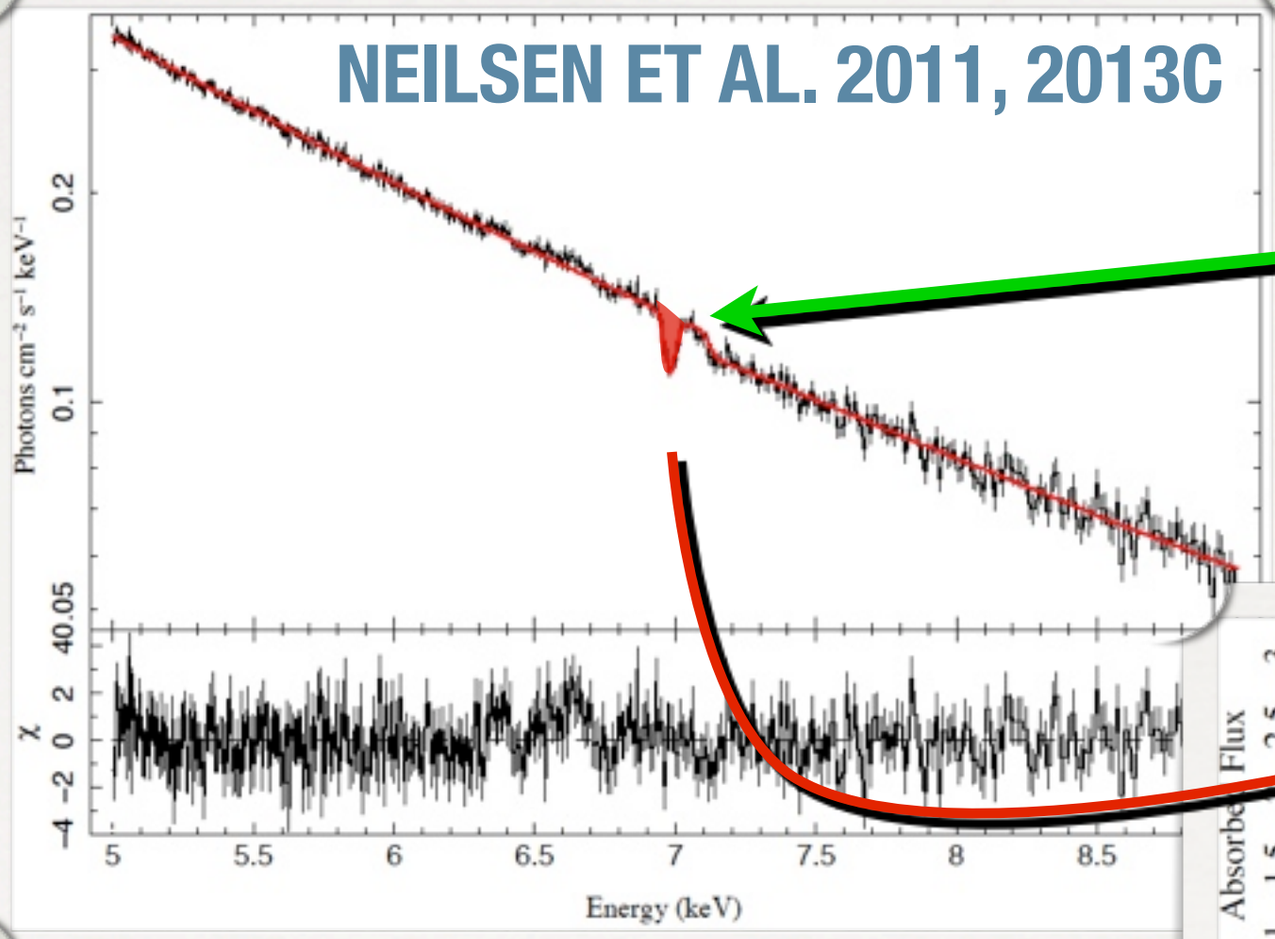
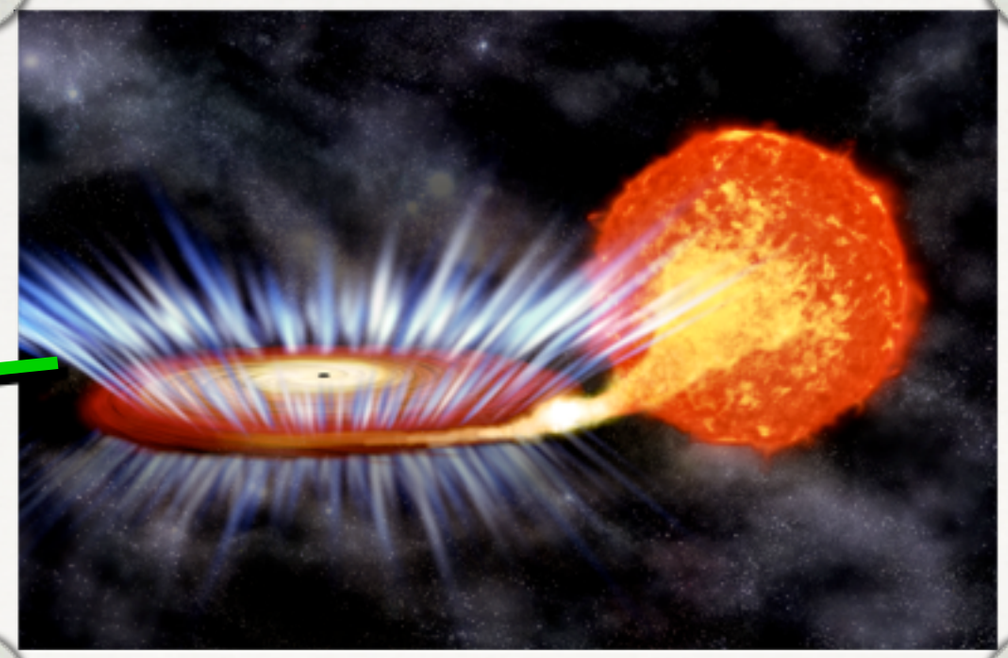
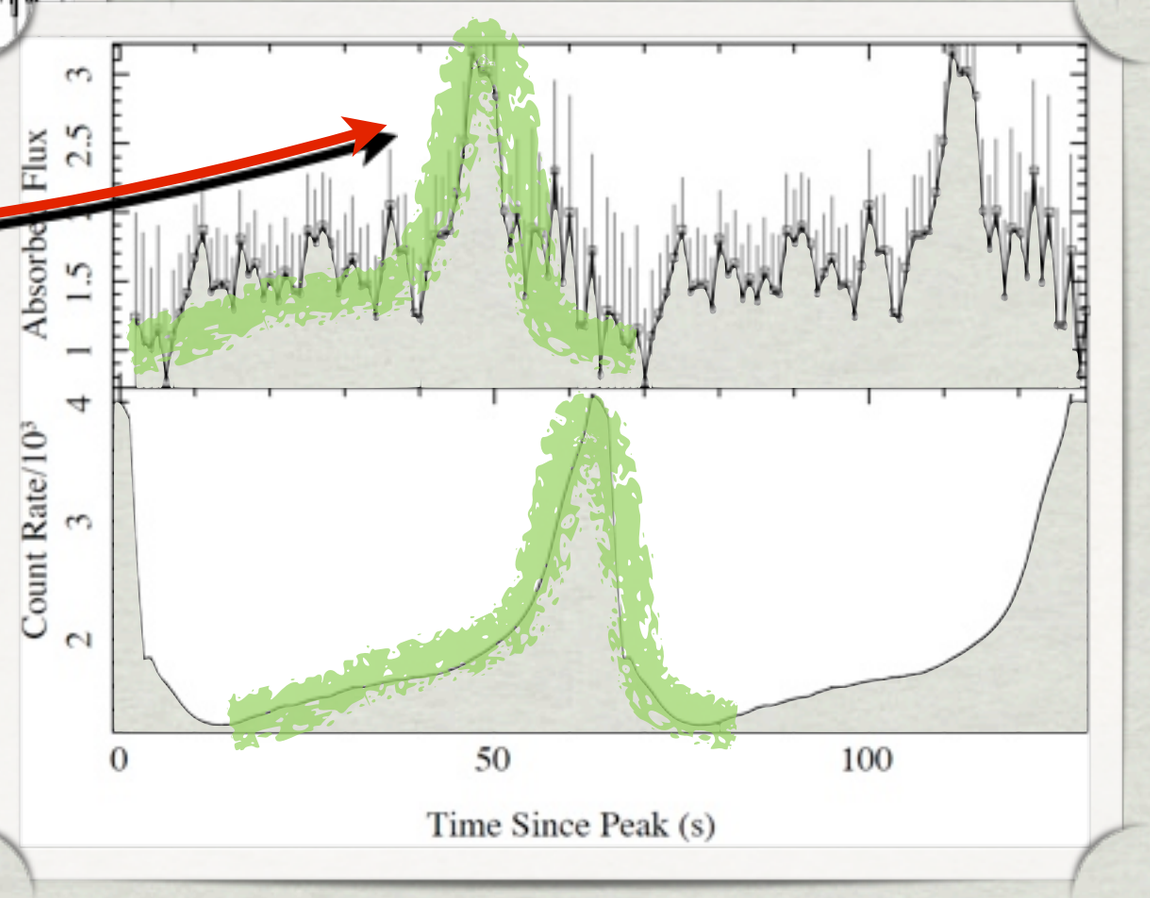
Accretion Disk Wind





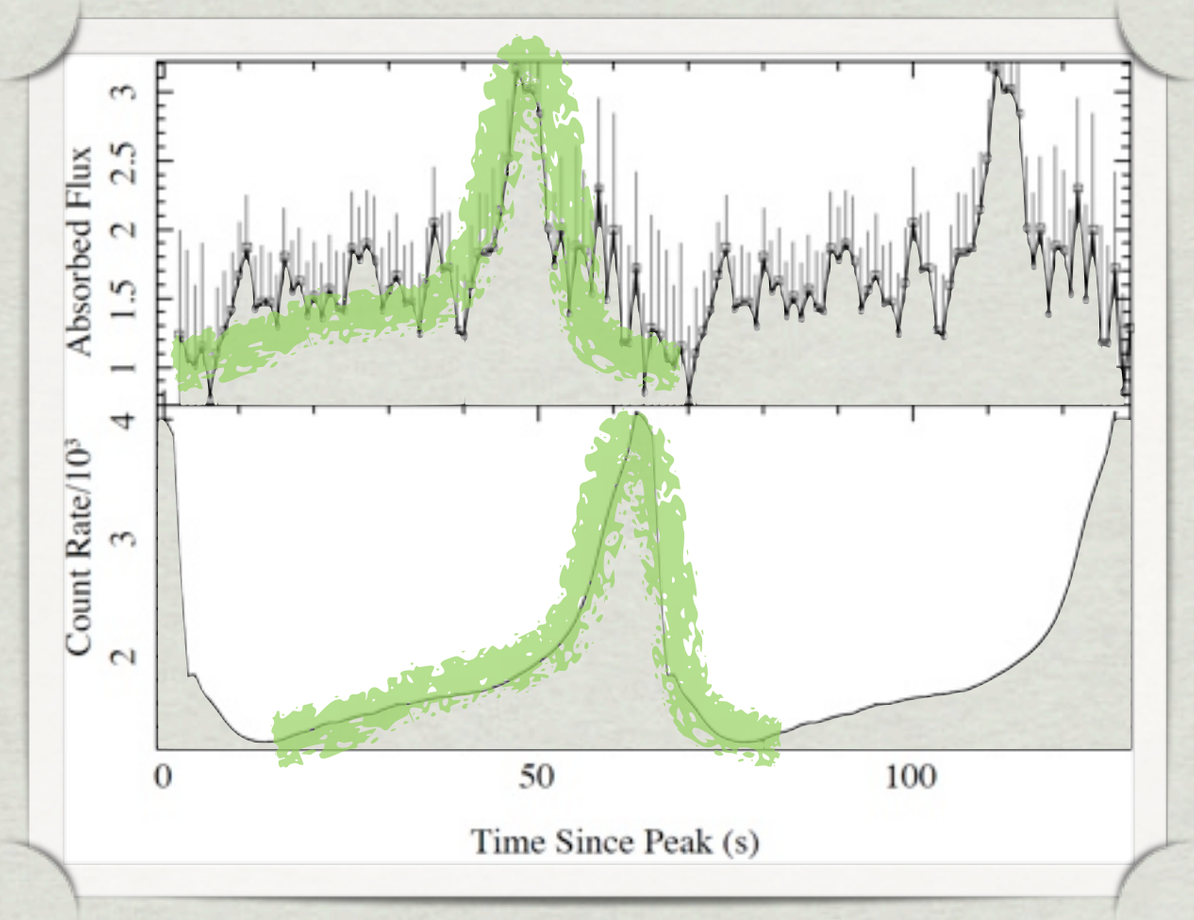


- Phase fold, measure wind at each part of the ‘heartbeat’

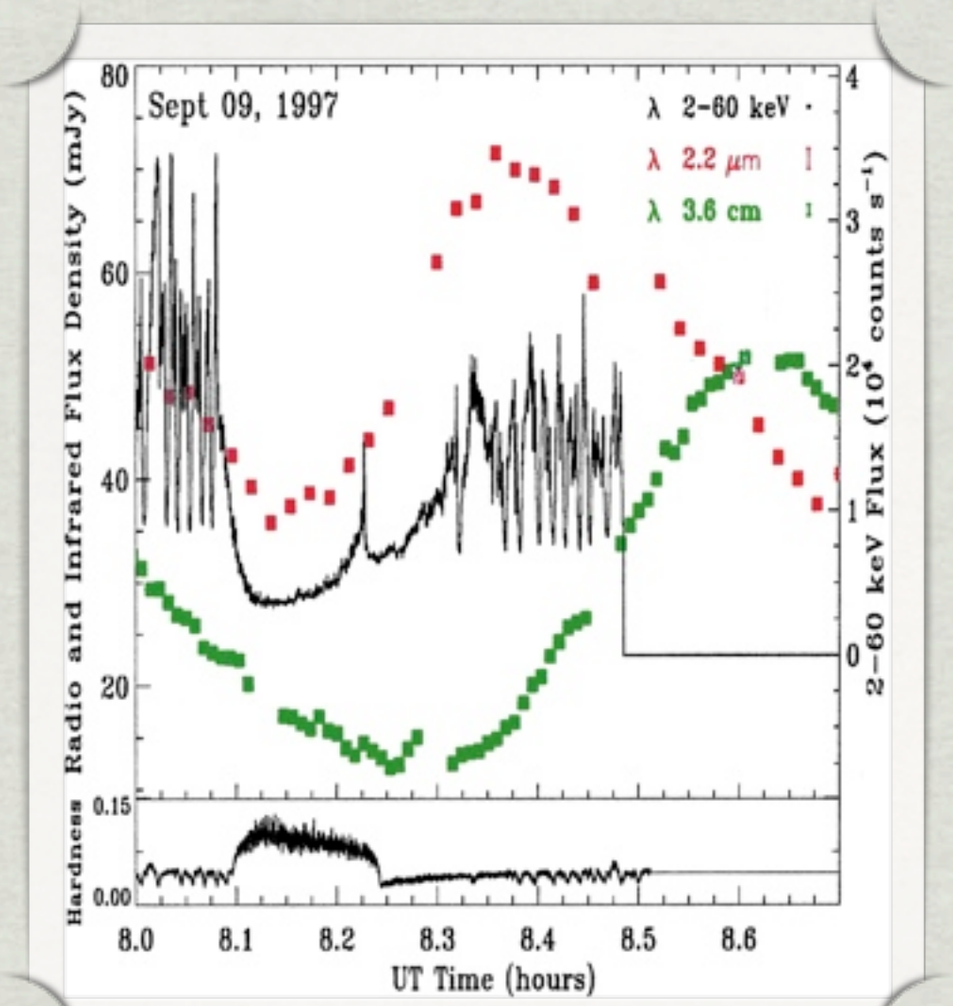
The Heartbeat's Massive Wind

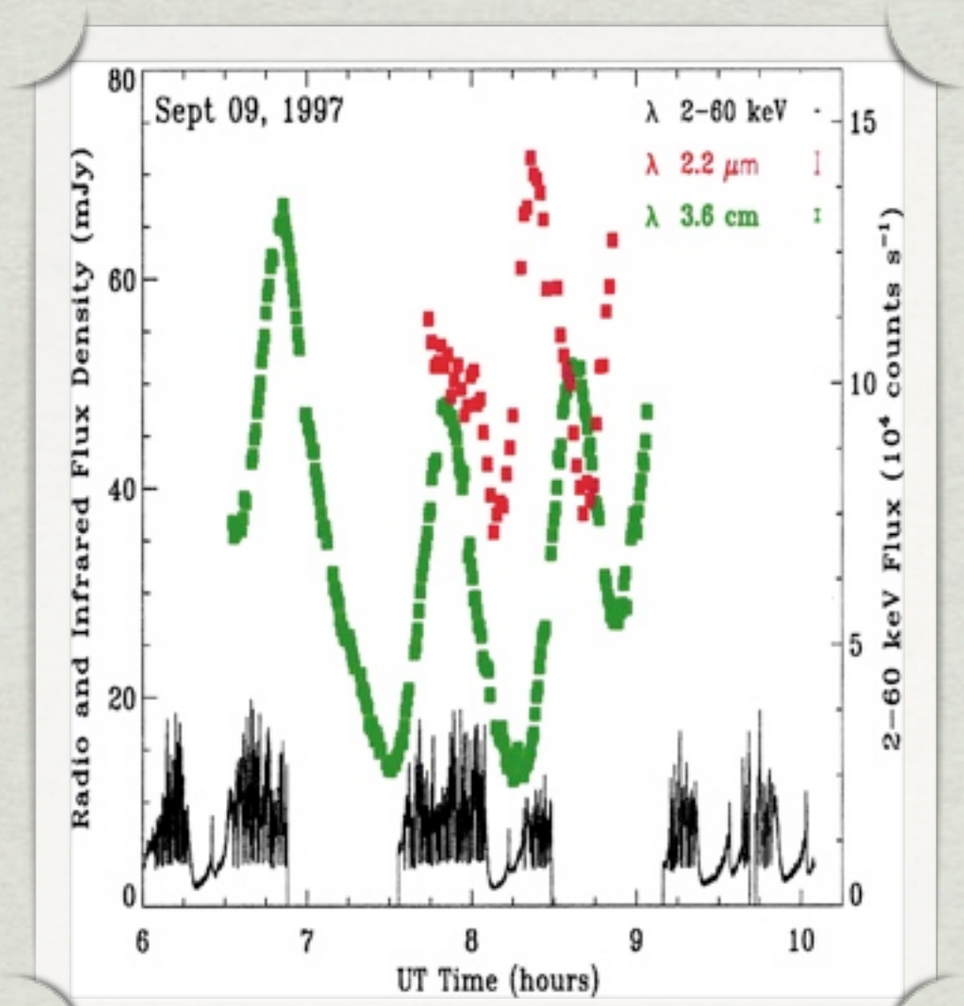
- Each heartbeat reaches the Eddington limit!
- Radiation reaches the outer disk in seconds: drives wind ~instantly
- Arguments from geometry, variability, line properties imply $\dot{M}_{out} \approx 25 \dot{M}_{BH}$ (Neilsen, Remillard, & Lee 2011)
- Has a **huge effect on the disk on time scales of weeks** (Shields et al. 1986; Neilsen, Remillard & Lee 2011)
- Possible jet quenching mechanism?

NEILSEN ET AL. 2011, 2013C



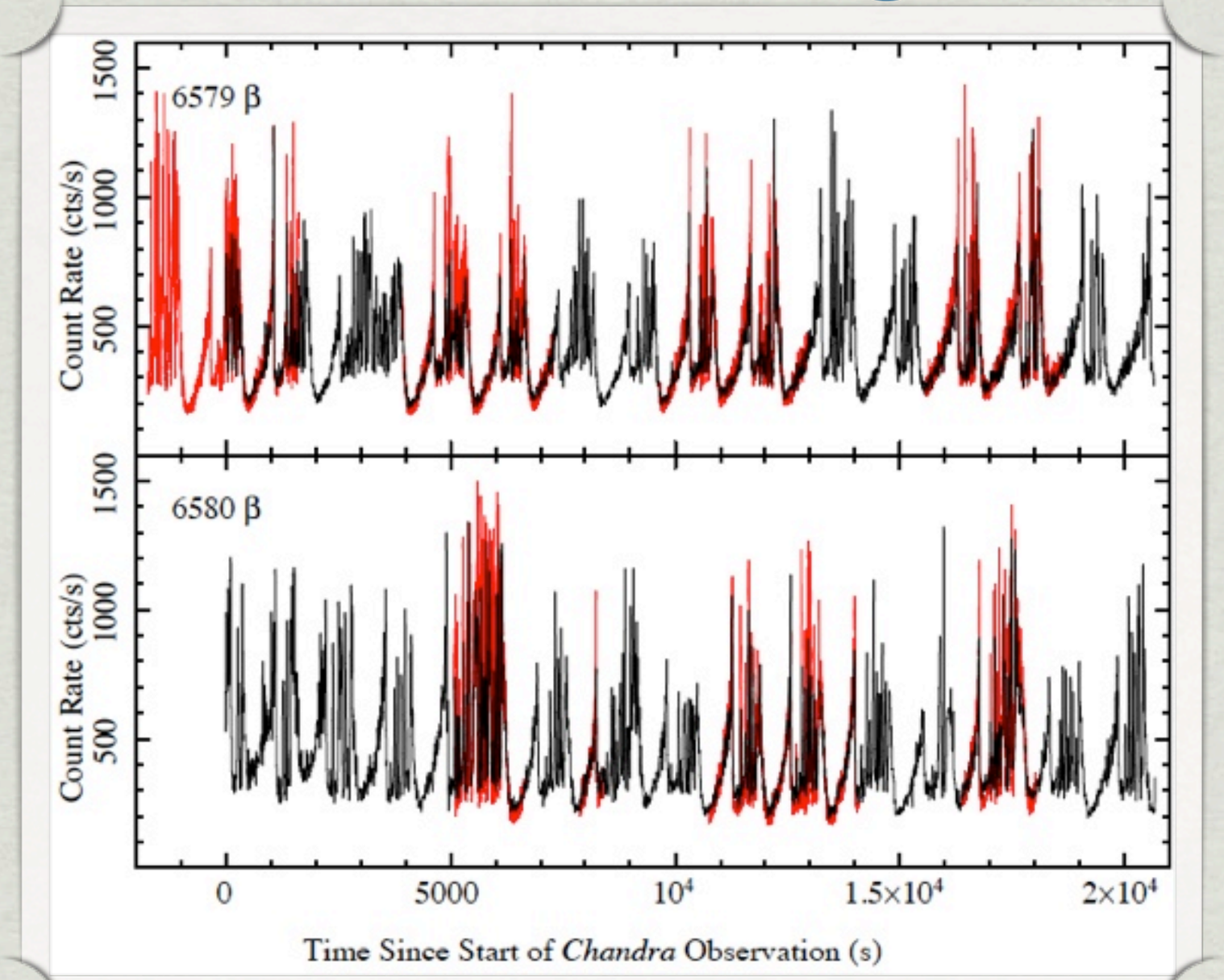
The β State





- Bizarre 30-minute radio/IR/X-ray oscillation
- How does this instability affect the wind?

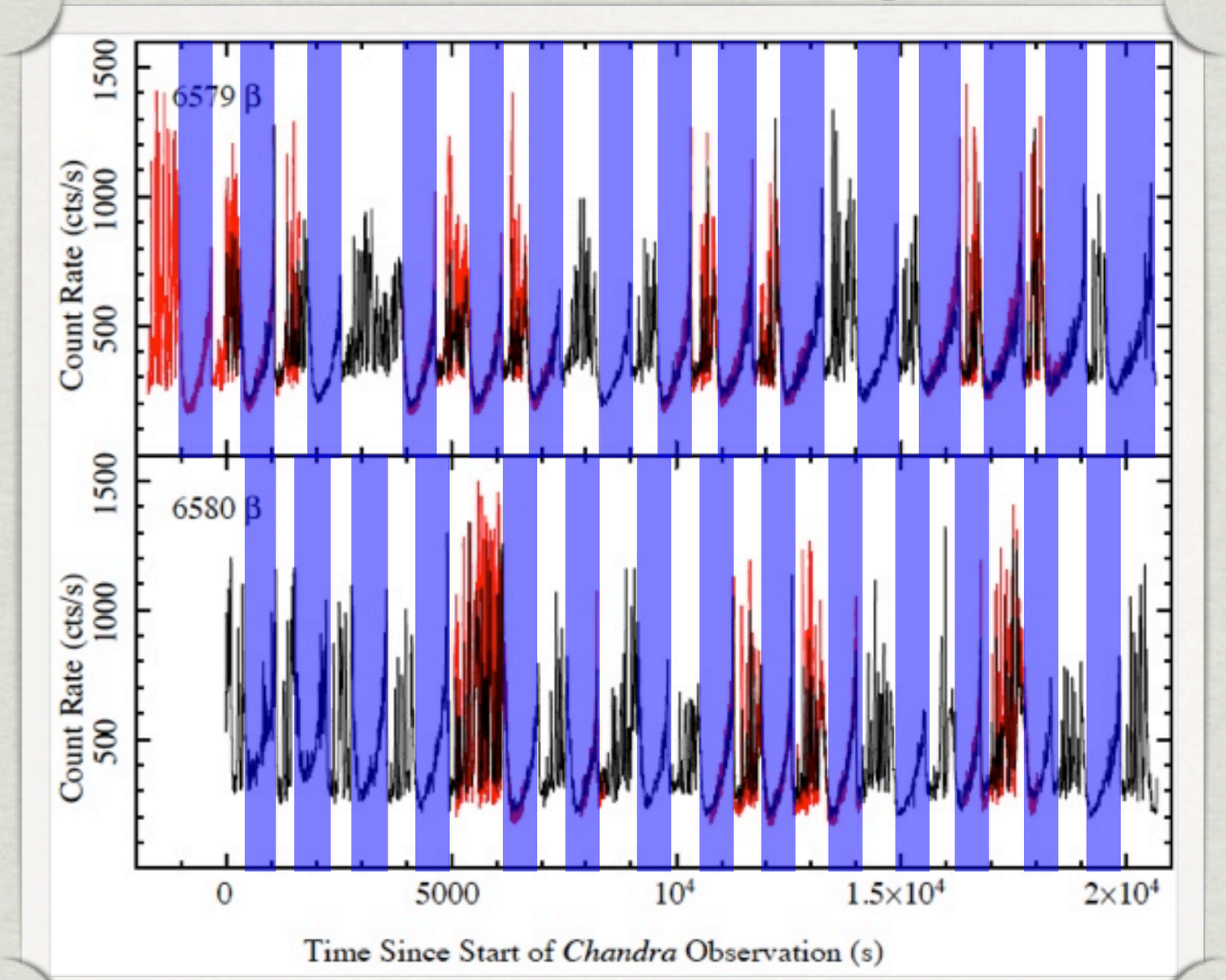
The β State: Lightcurve



NEILSEN, PETSCHEK & LEE 2012

- 2 Chandra HETGS observations with strong winds!
- Divide into intervals of dips and flares

The β State: Lightcurve



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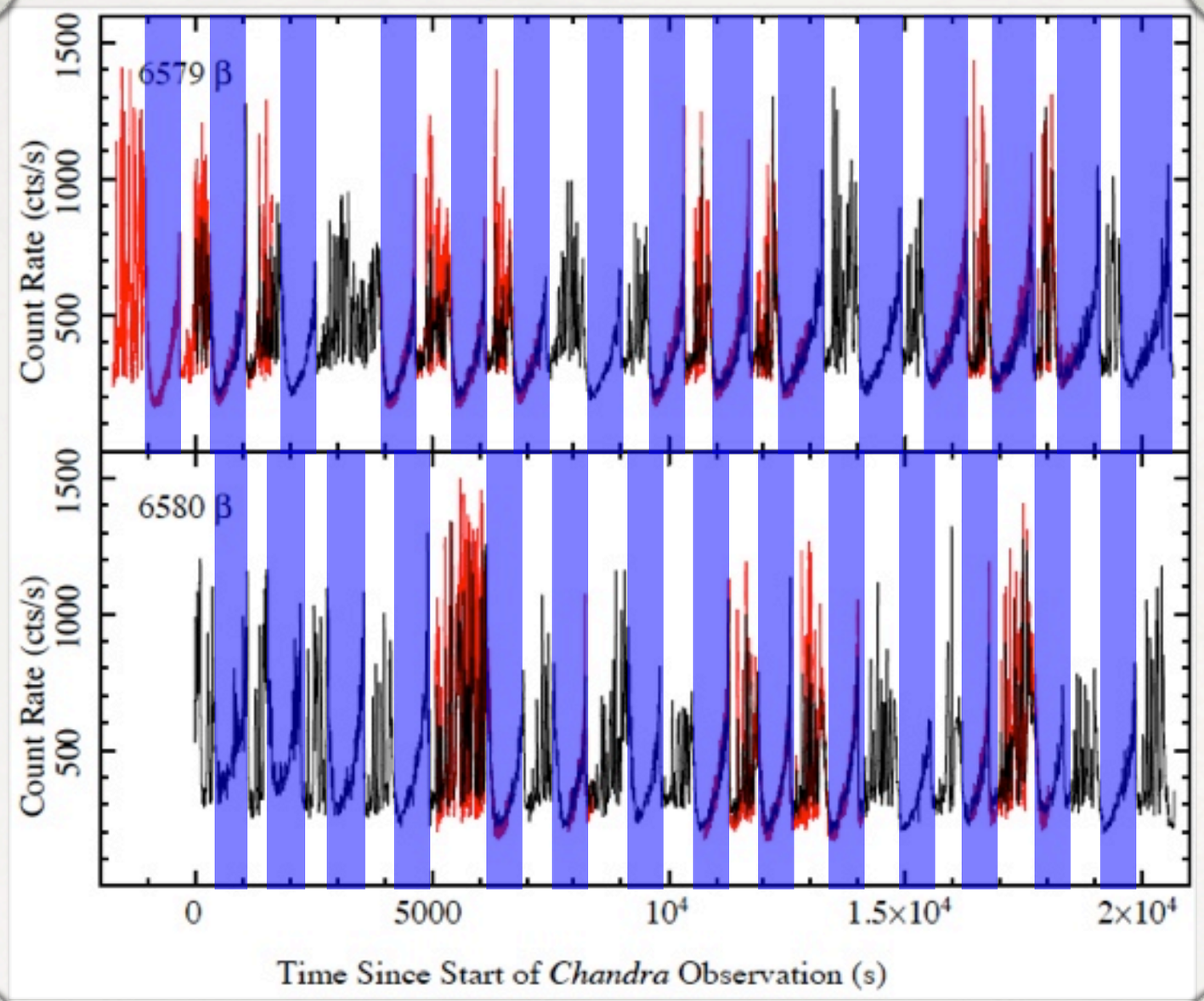
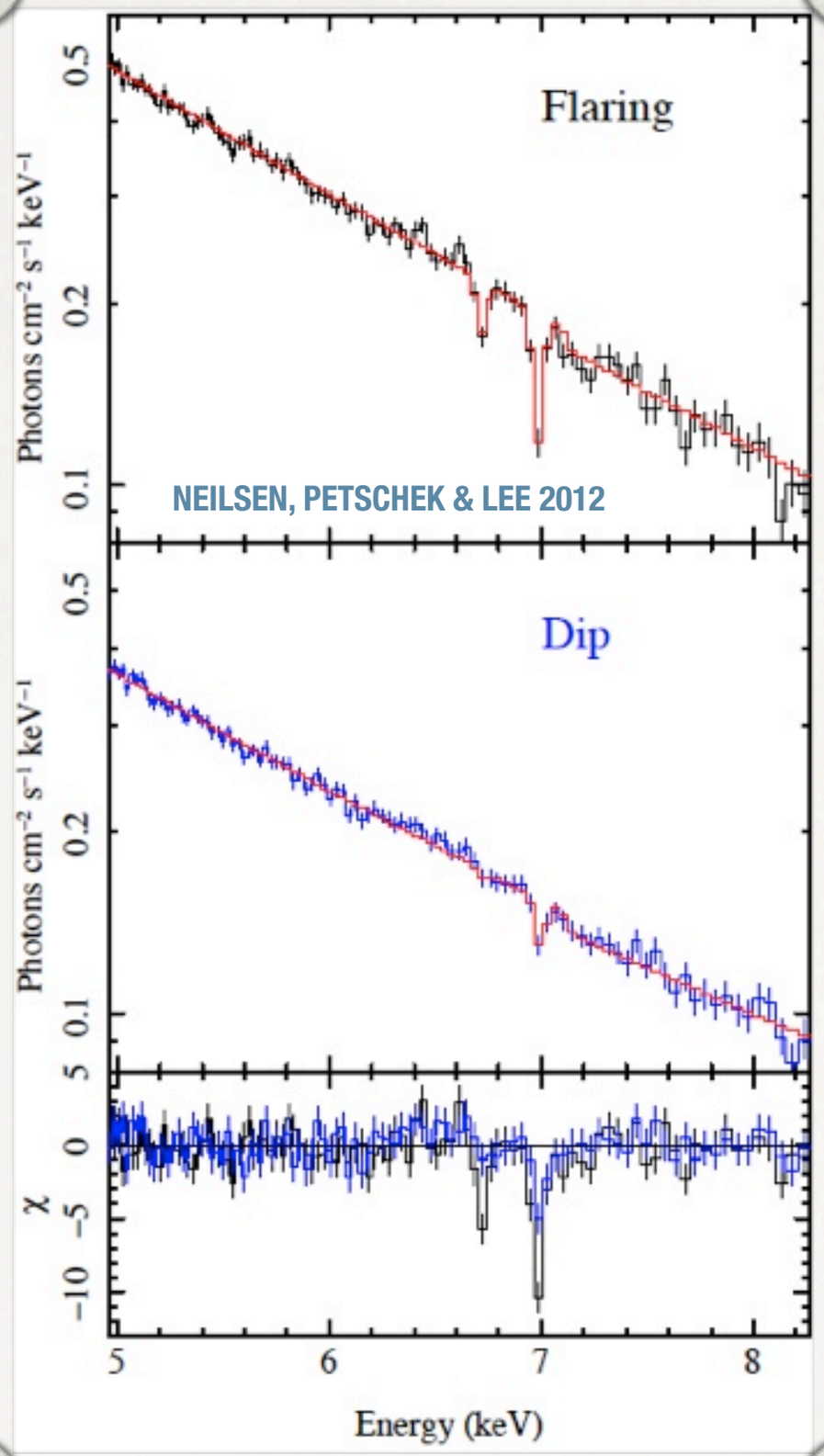
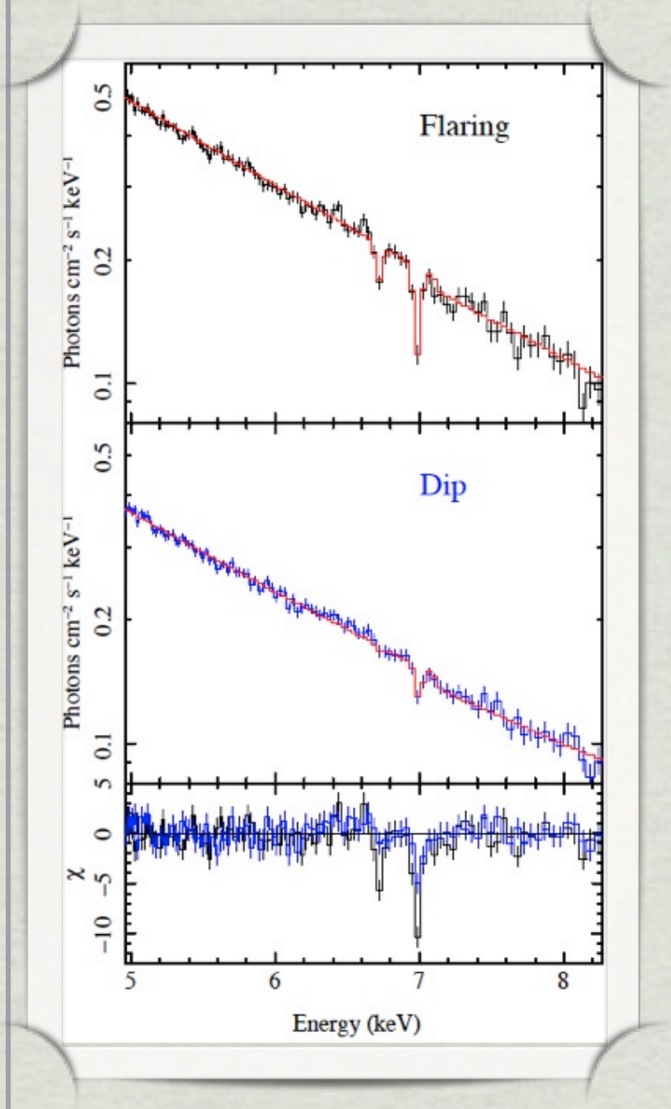
The β State: Spectra

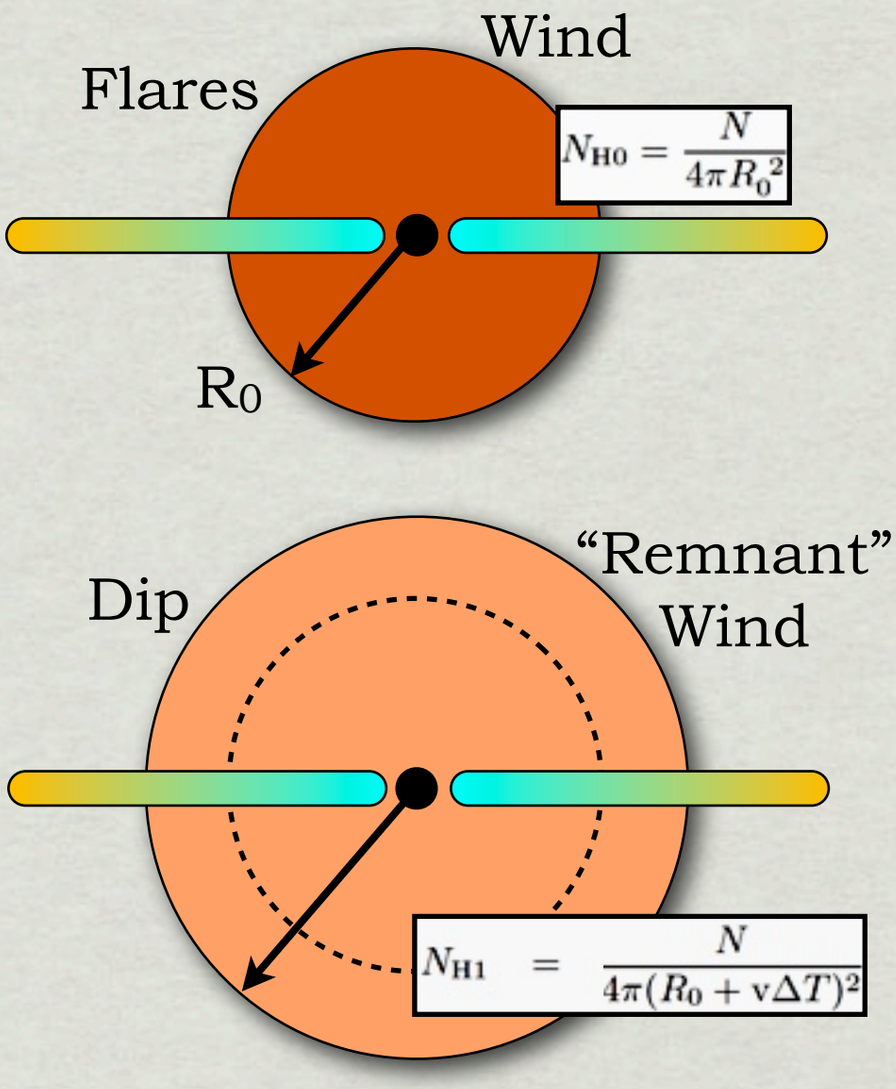


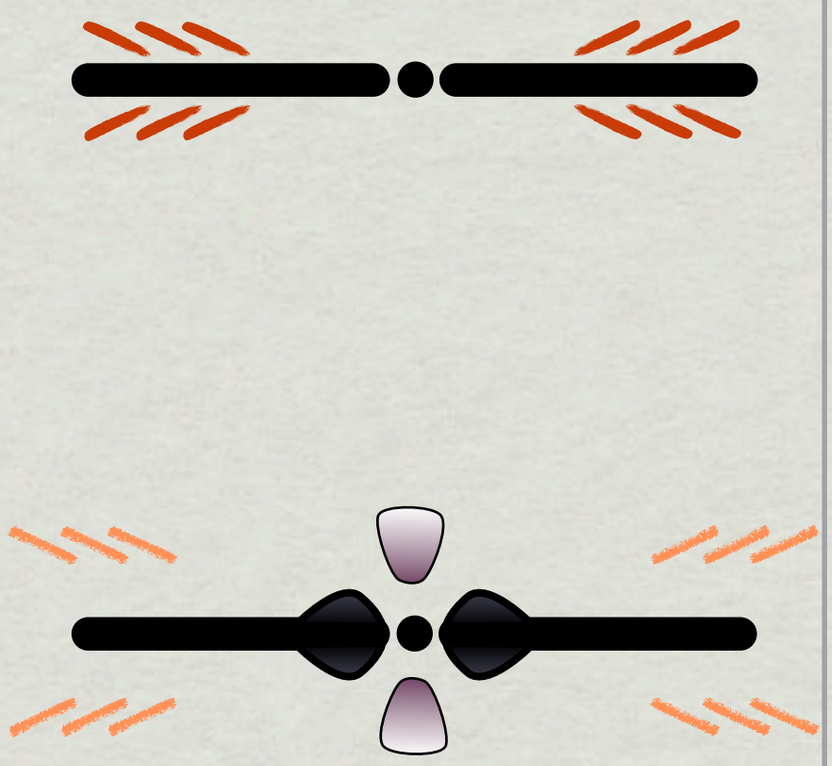


- Significant decrease (2×) in wind column density!

The β State: Physics







SPECTRA **WIND GEOMETRY** **INTERPRETATION**

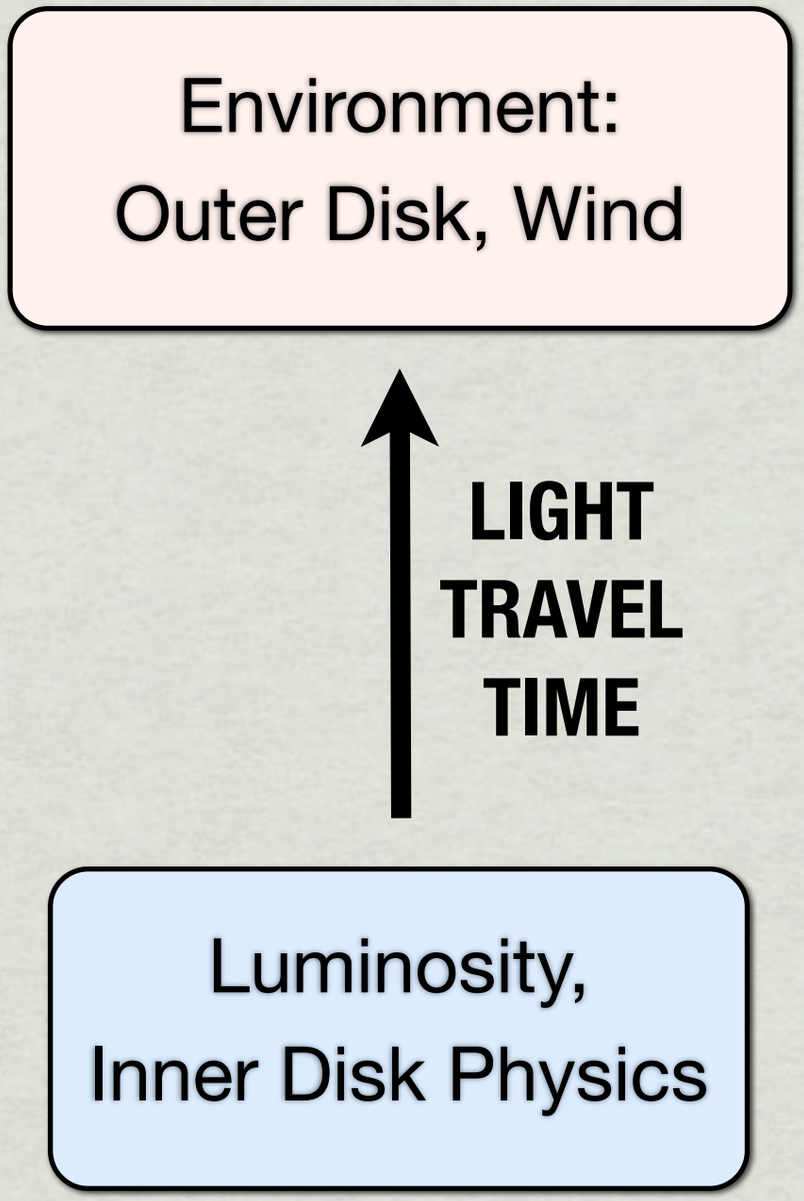
- Changes in the inner disk turn the wind on and off on time scales of ≲minutes!! (Neilsen, Petschek, & Lee 2012)

Summary

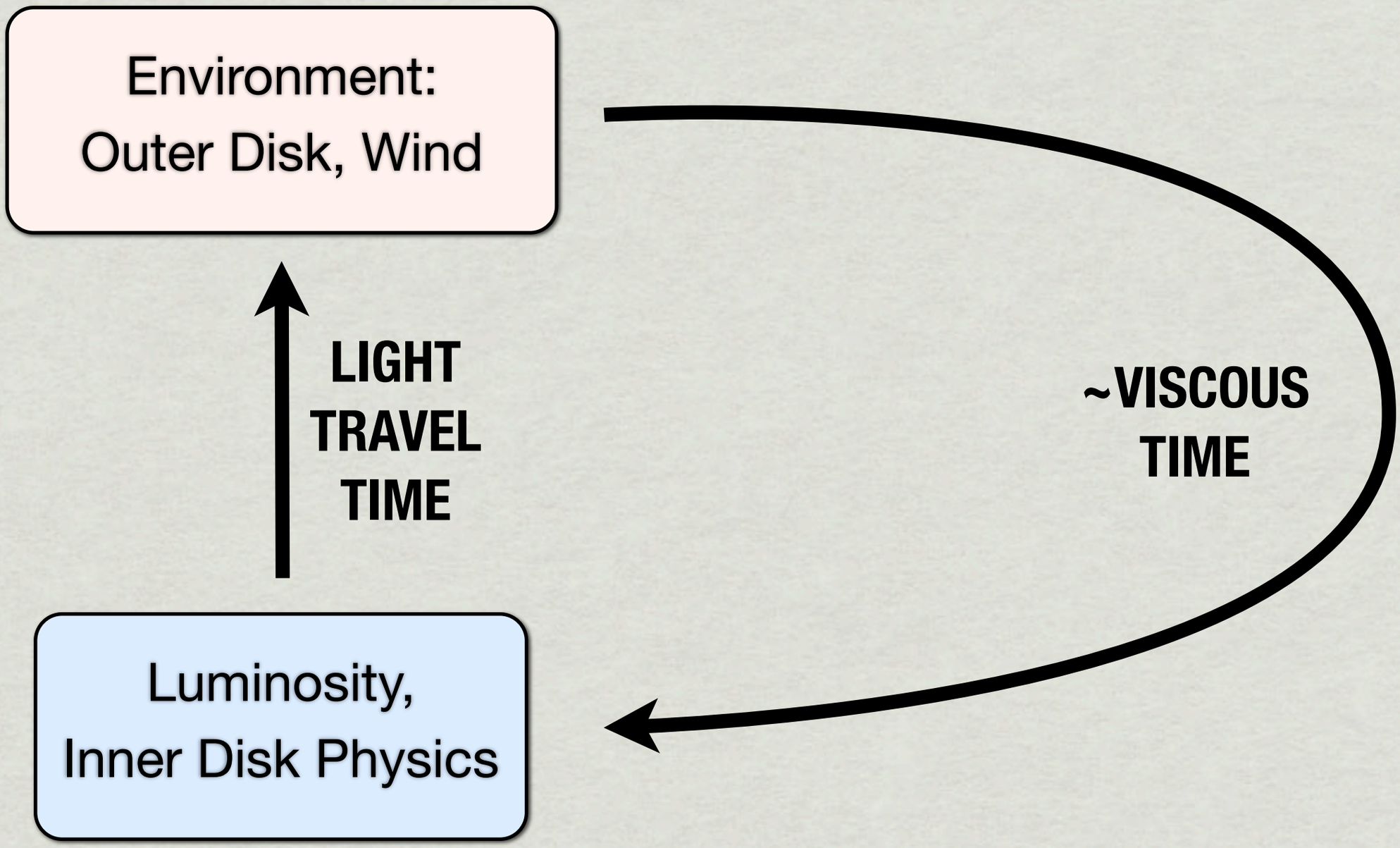
Environment:
Outer Disk, Wind

Luminosity,
Inner Disk Physics

Summary


Environment:
Outer Disk, Wind
LIGHT
TRAVEL
TIME
Luminosity,
Inner Disk Physics

Summary


Environment:
Outer Disk, Wind
LIGHT
TRAVEL
TIME
~VISCOUS
TIME
Luminosity,
Inner Disk Physics

Summary

- Accretion processes richly interconnected
  - Photoionization, Comptonization, irradiation
- Accretion disk winds exert a significant influence on the accretion flow in GRS 1915+105
  - *Control* $\dot{M}$ on long time scales
  - Suppress jets
  - Cause state transitions?