A Few *Observational* Issues in the Study of Microquasars

Wei Cui
Department of Physics
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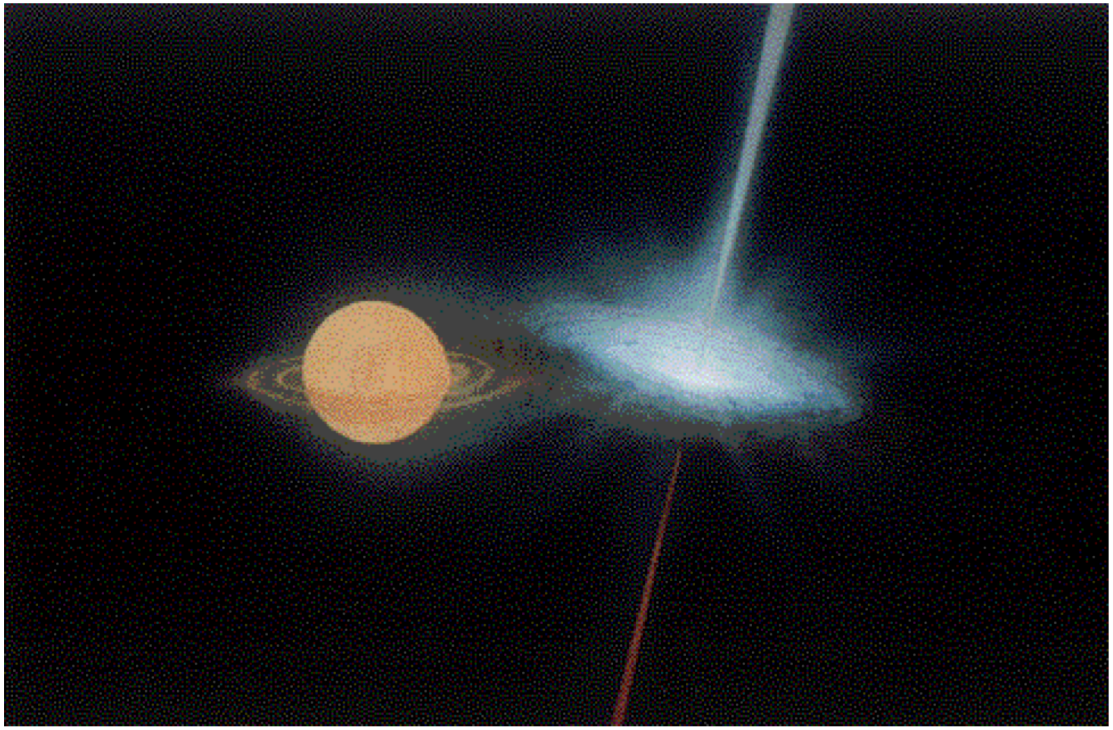
Black Hole Candidates



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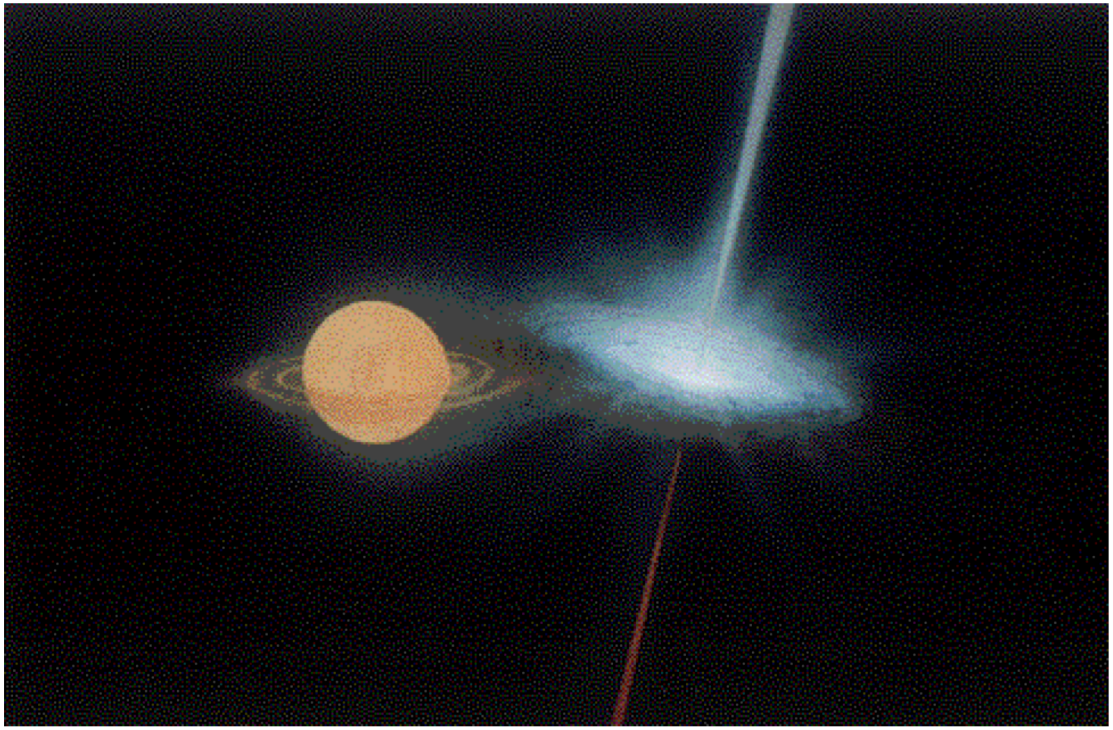

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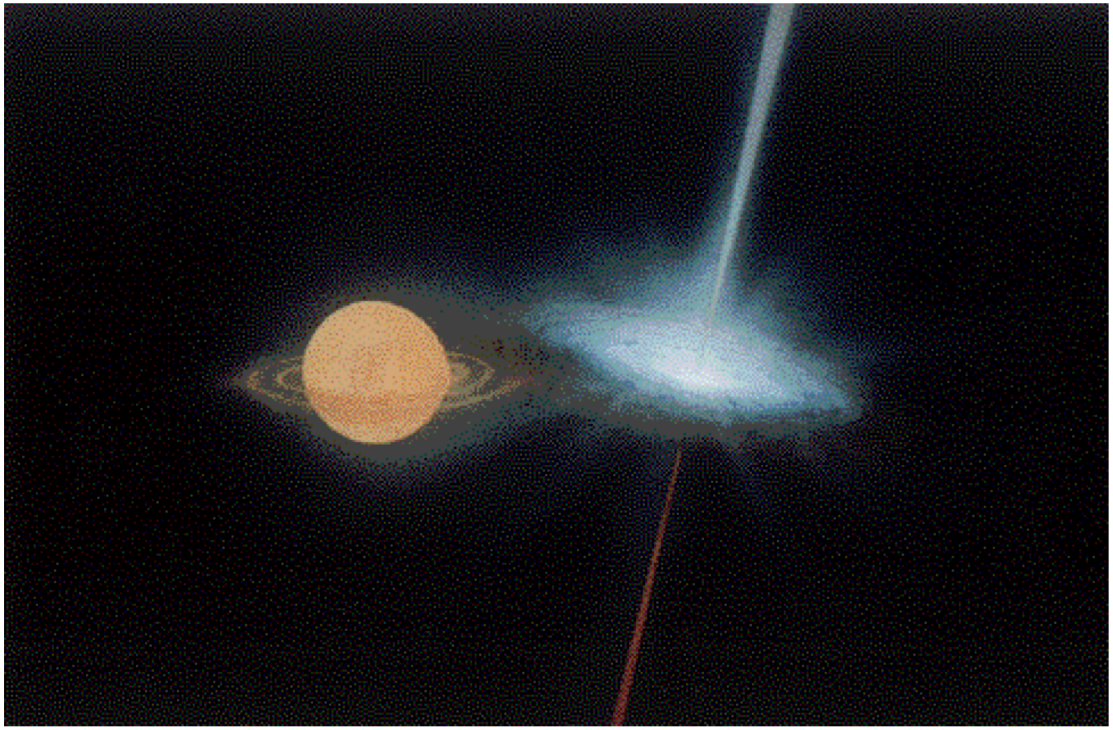

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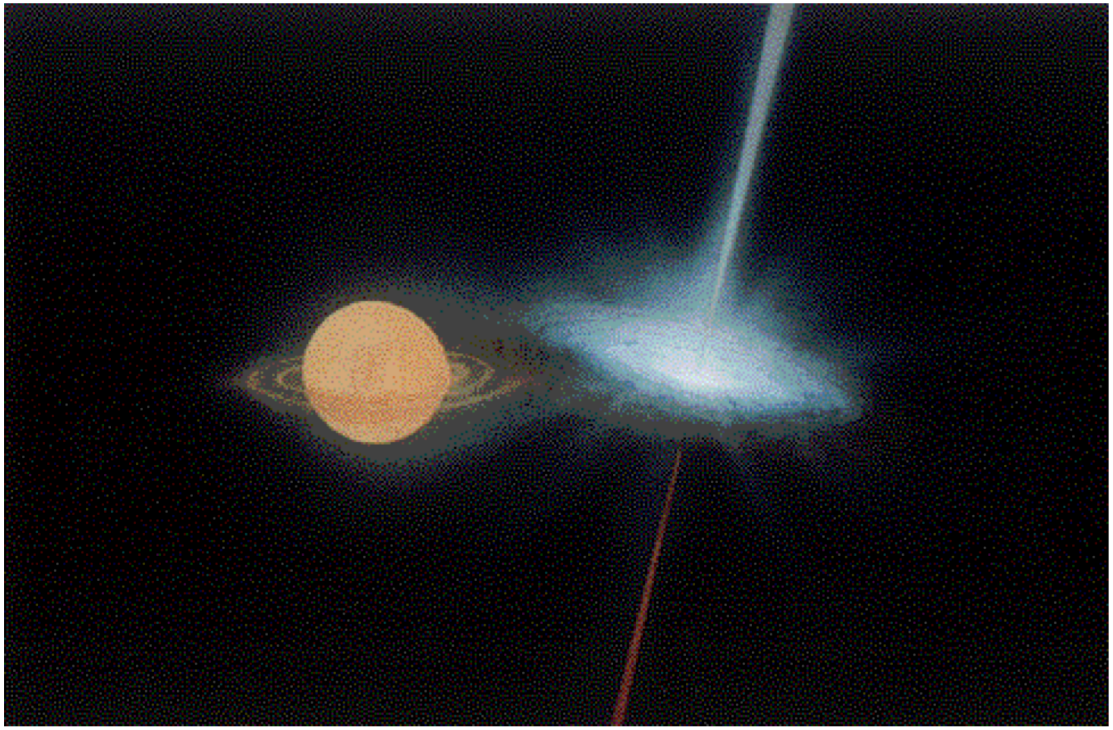

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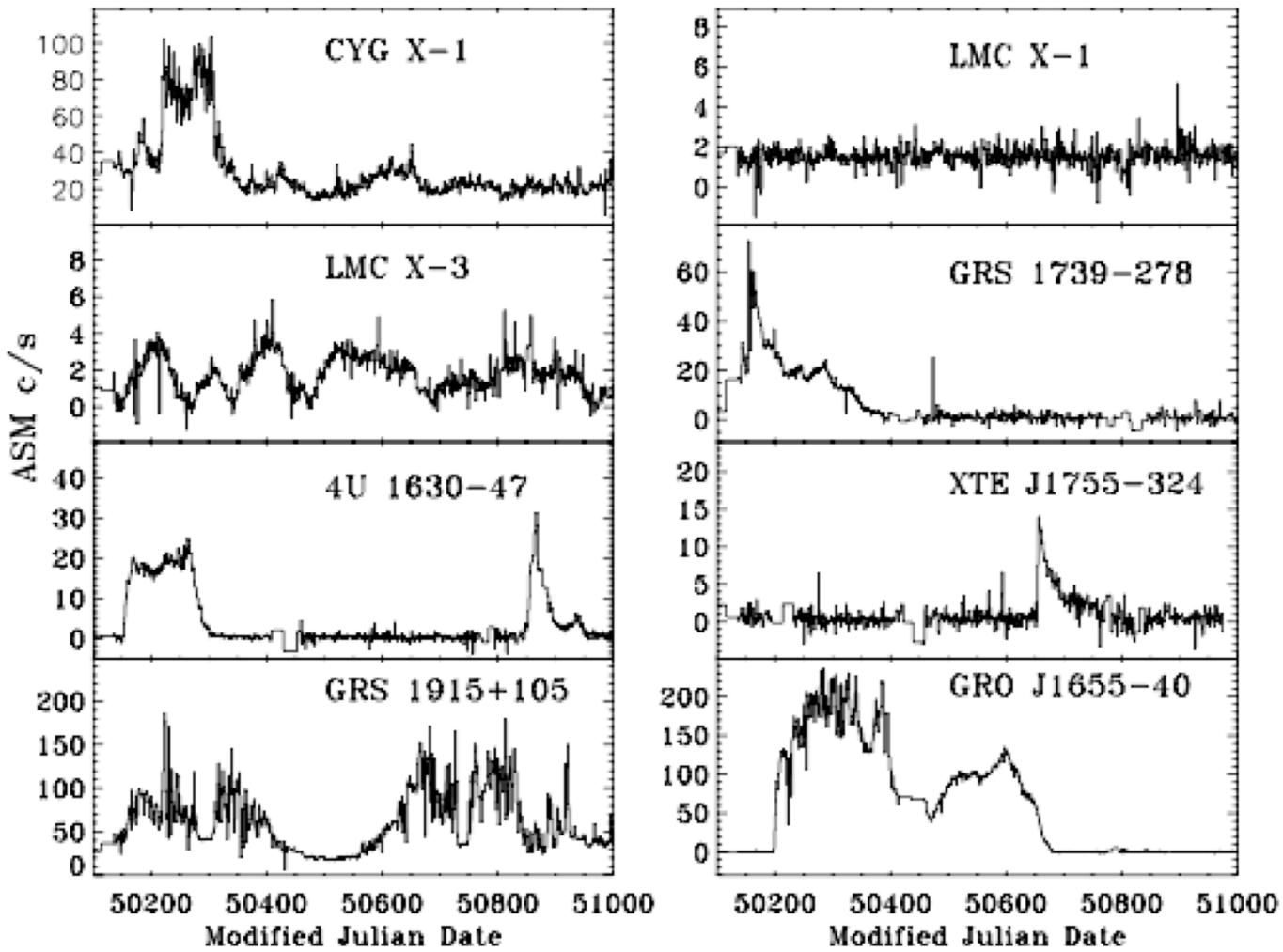
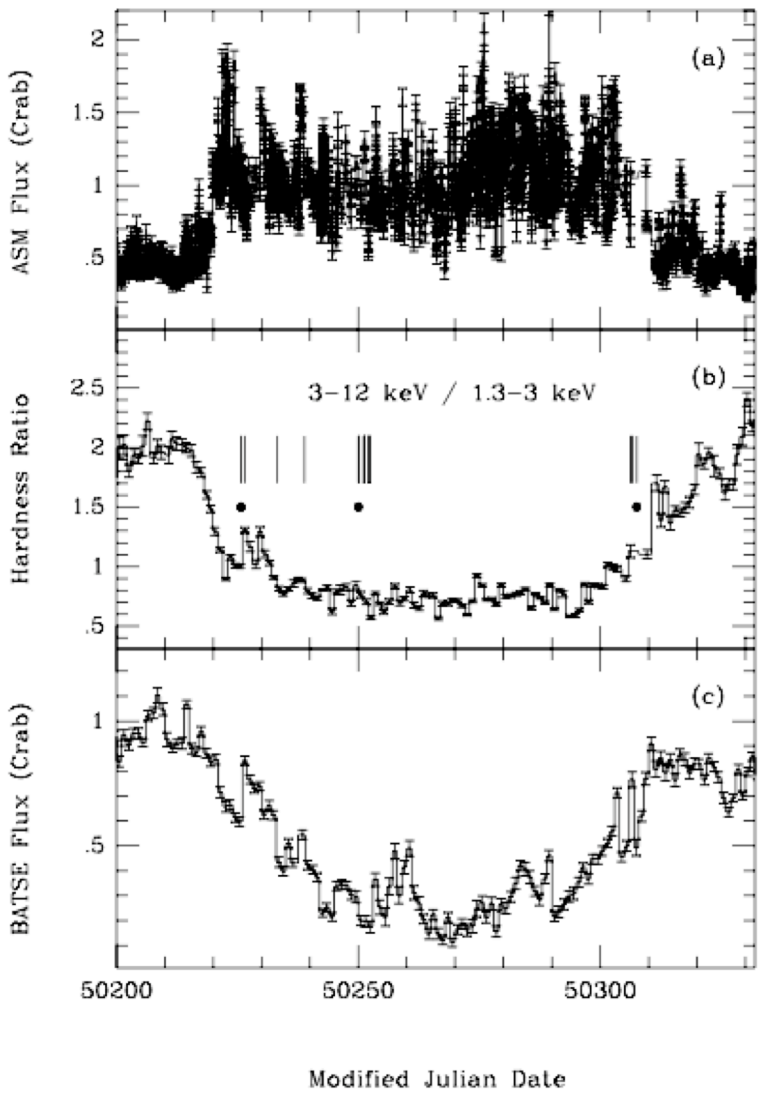
Microquasar = BHC + Jets

Complex Phenomenology



Issue #1: Spectral States



CYGNUS X-1

Low vs High

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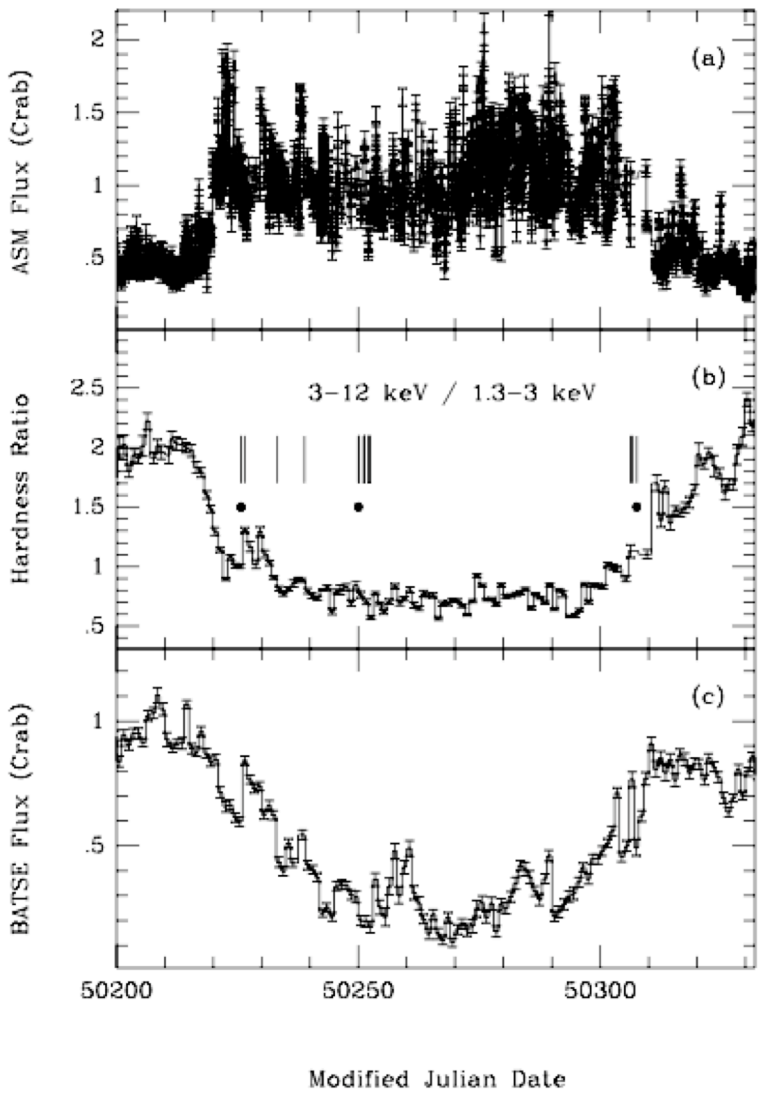

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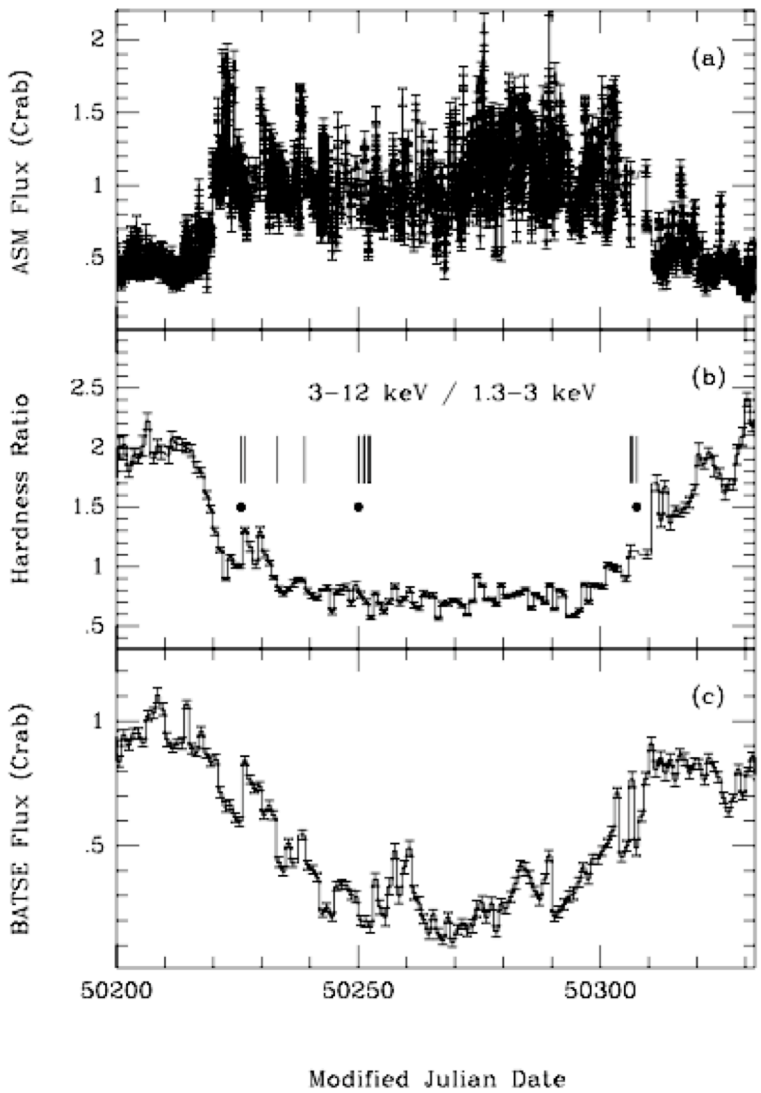

CYGNUS X-1

Low vs High

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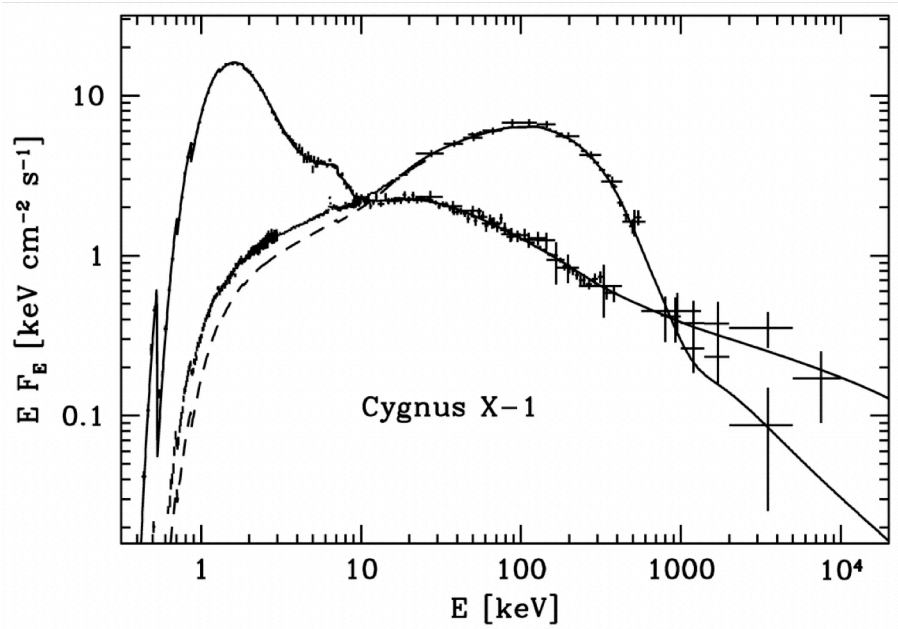
Low/Hard
vs
High/Soft

X-ray SED

McConnell et al. 1998



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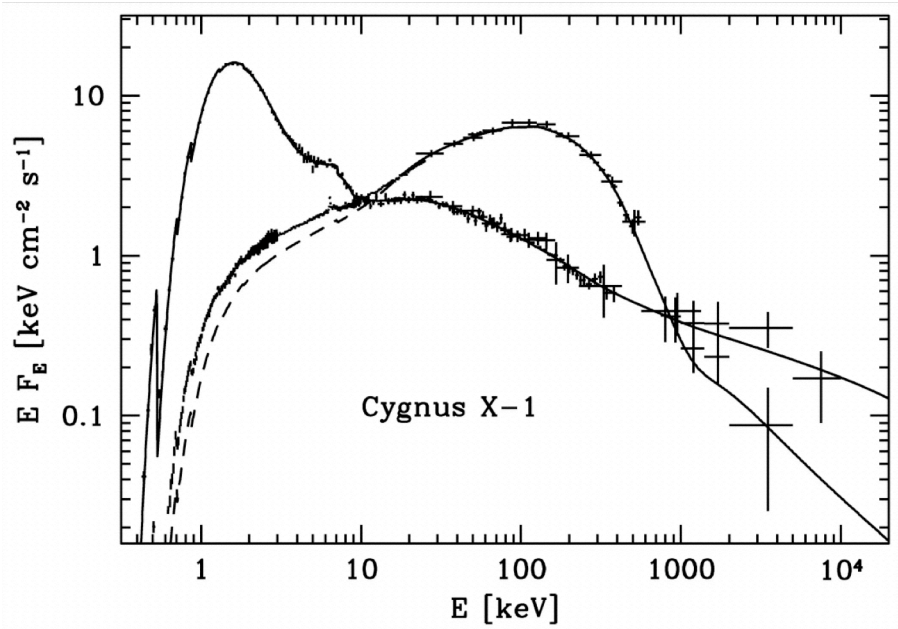
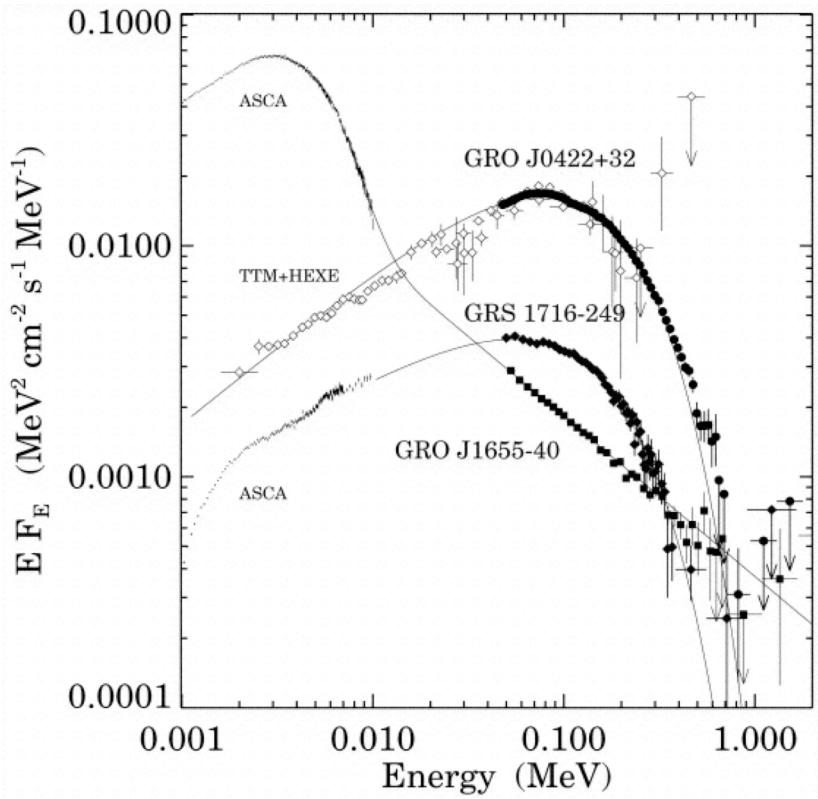
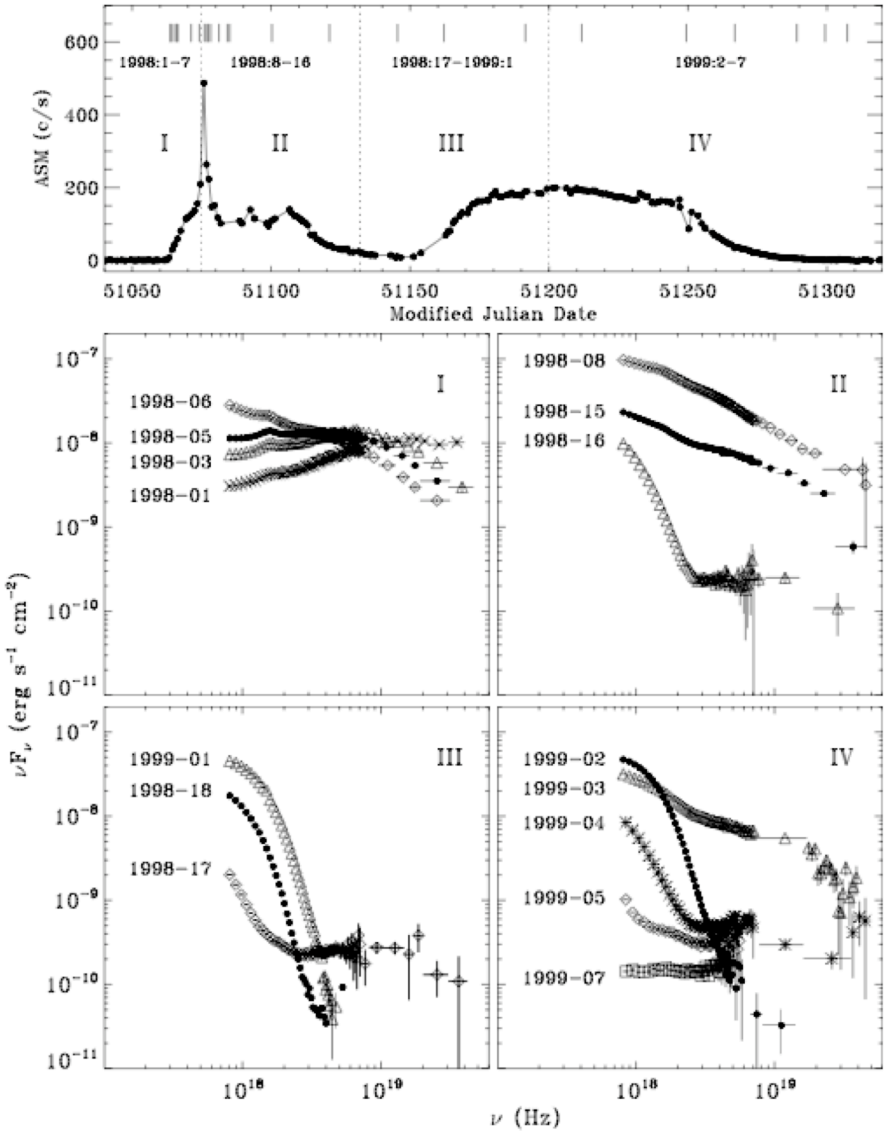


Grove et al. 1998



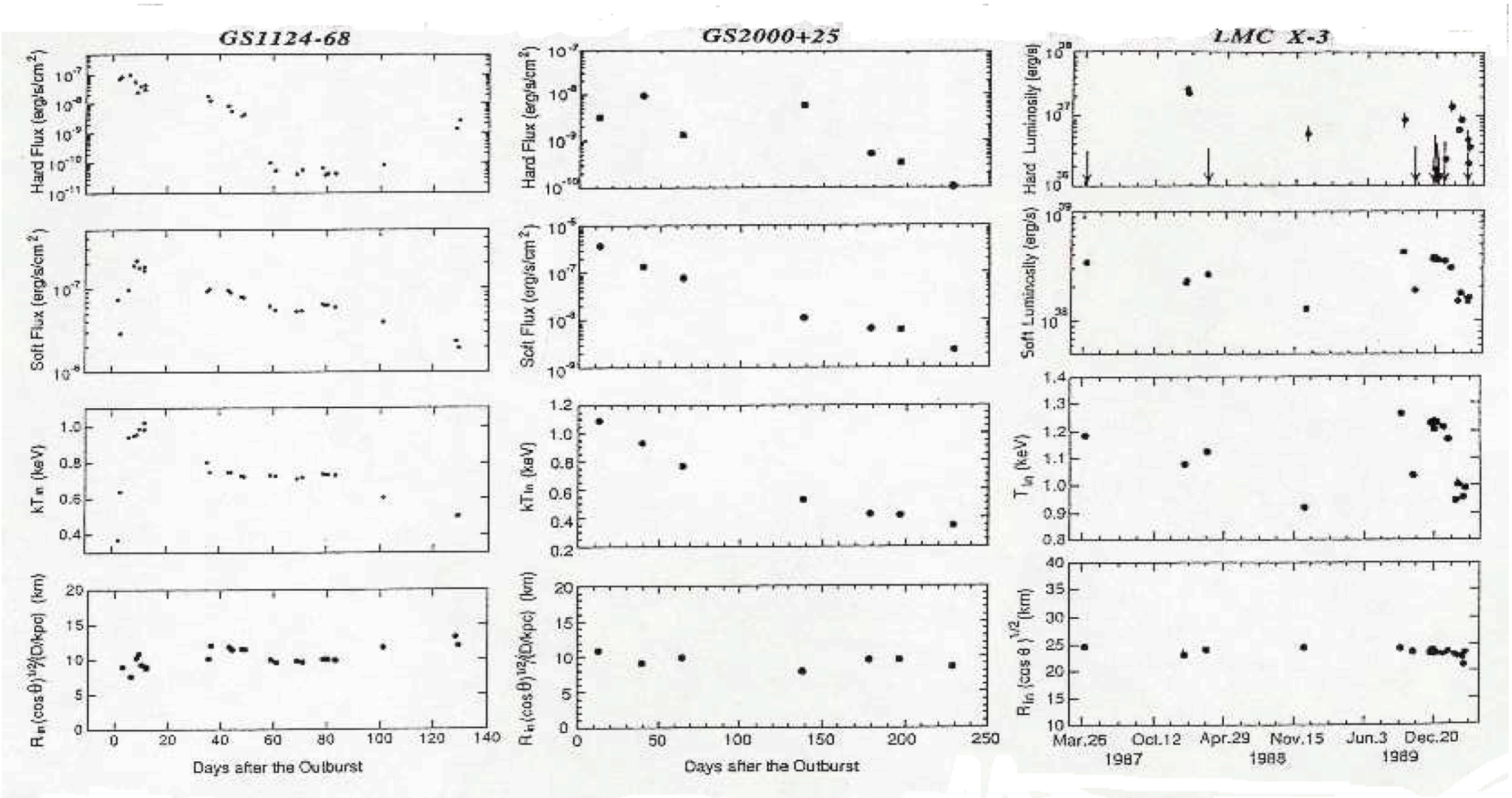
Evolution of SED



XTE J1550-564

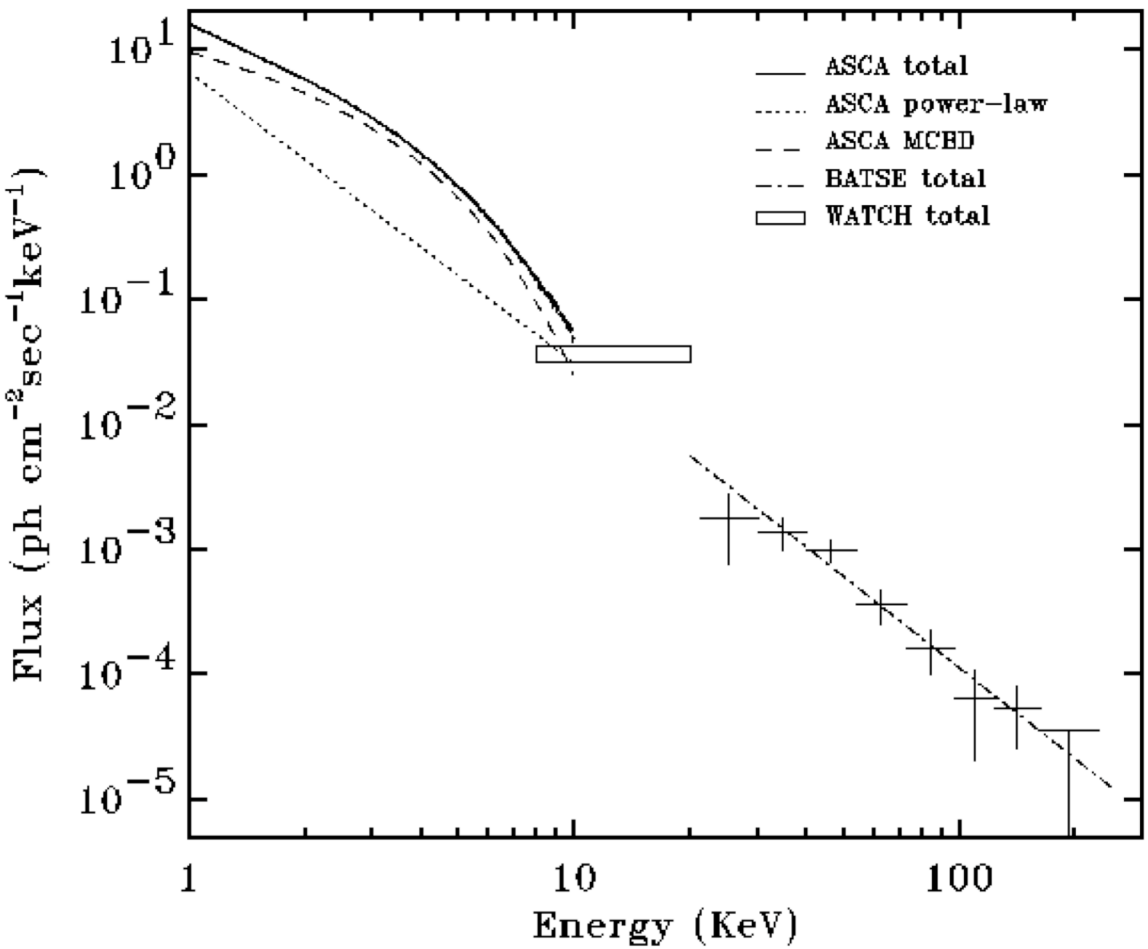
Xue, Wu, & Cui 2006

Issue #2: Recovering Disk Emission



Tanaka & Lewin 1995

GRO J1655-40: Spinning Black Hole?



Zhang et al. 1996

Important Technical Issues:

Zhang, Cui, & Chen 1997

- "Color correction" $$T_{col} = f_{col} T_p$$
- "Torque-free" inner boundary condition $$r_p = r_{in} / \eta$$
- Gravitational and Doppler shifts $$T_{col} = f_{gr} f_{col} T_p$$
- Gravitational lensing $$F_{obs} = g F_i$$

$$r_{in} = \eta(a_*) D \left[\frac{F_{obs}}{2\sigma g(\theta, a_*)} \right]^{1/2} \left[\frac{f_{col} f_{gr}(\theta, a_*)}{T_{col}} \right]^2$$

Lessons Learned: A Retrospective View

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- Empirical modeling is not physical.
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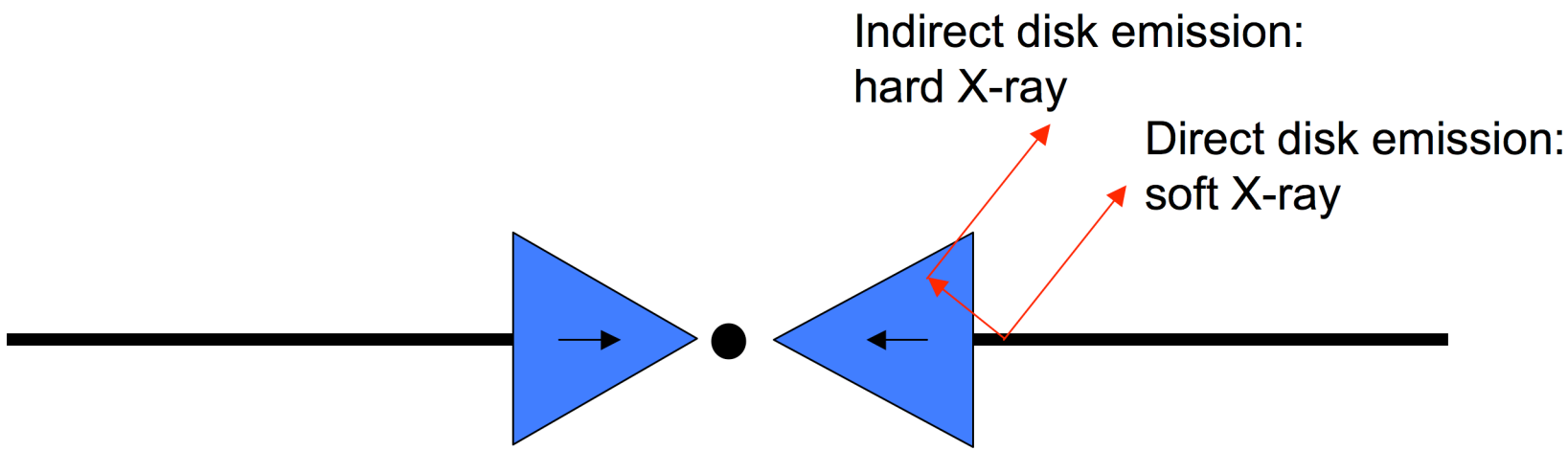
- Coupling between the disk and the Comptonizing "corona" must be taken into account.
  - Model dependent: seed photons, emission geometry

Emission Geometry and Coupling



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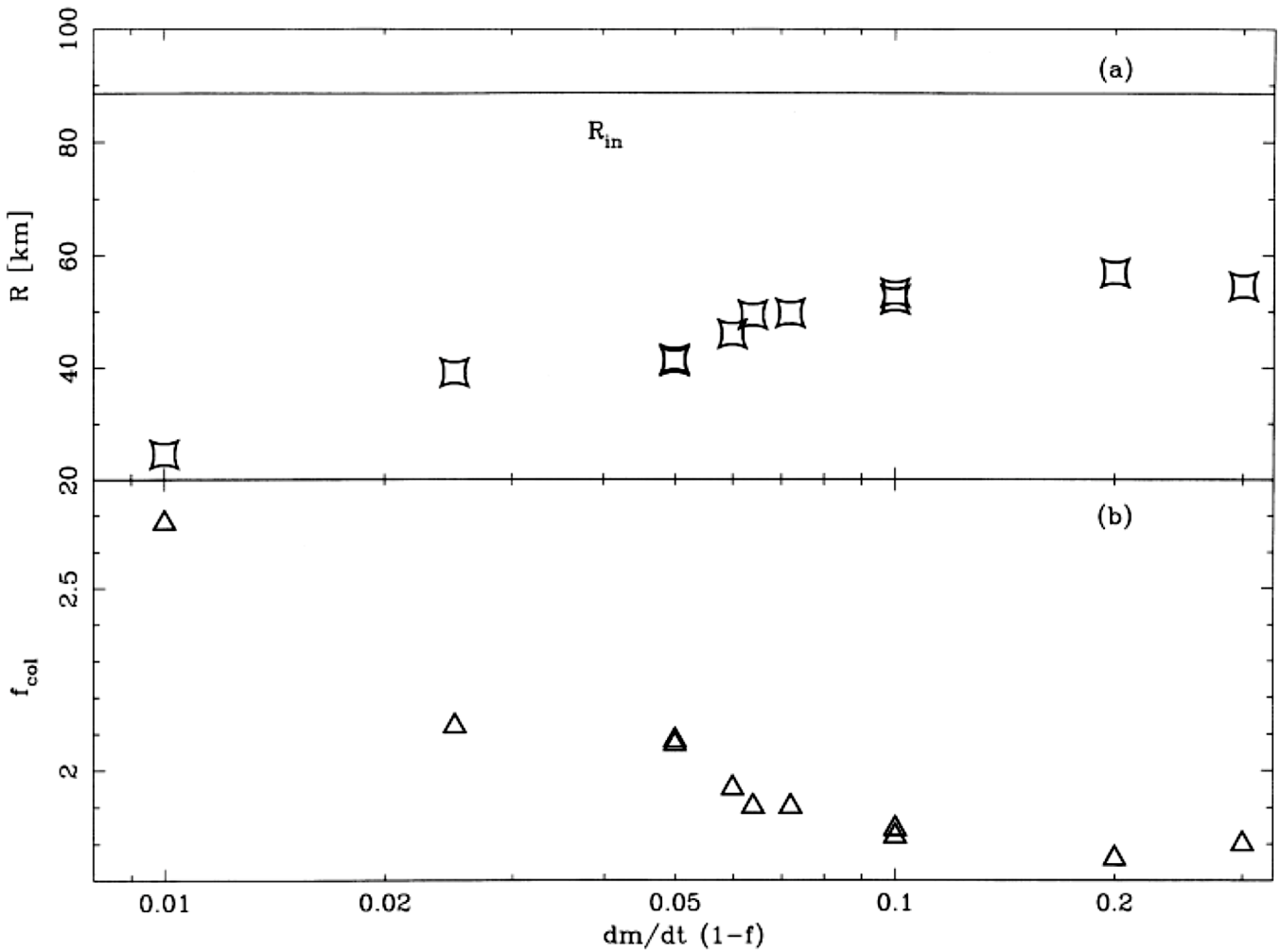
- Empirical modeling might not be physical.
  - E.g., the power-law approximation of a Comptonized Spectrum
- Coupling between the disk and the Comptonizing "corona" must be taken into account.
  - Model dependent: seed photons, emission geometry

- Full GR treatment is needed to minimize theoretical uncertainties.
- Correct treatment of electron scattering may be very important.
  - Evidence for variable color correction

The need to *measure* color correction



Merloni et al. 2000

Determining Color Correction

- Model the soft component with the multicolor disc model, which gives T_{col}
- Repeat it with a Comptonization model, which gives T_{eff} and T_e (and τ_d).
- Perform consistency check: $T_{col} \sim T_e$ for $\tau_d >> 1$.
- Compute the spectral hardening factor

$$f_{col} = T_{col} / T_{eff}$$

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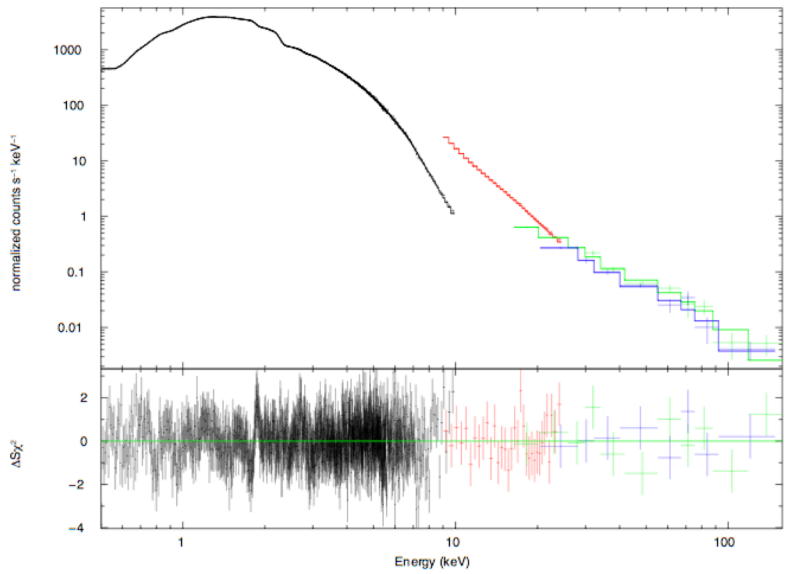
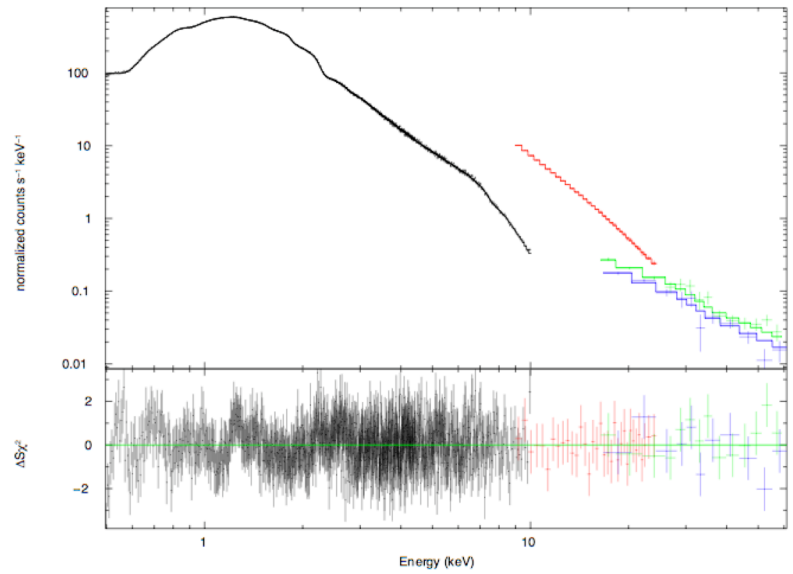
Follow-ups:

Cui et al. 2002, Zhang, X.L. 2005 (thesis), Pszota & Cui 2007

XMM-Newton Spectra of GX 339-4





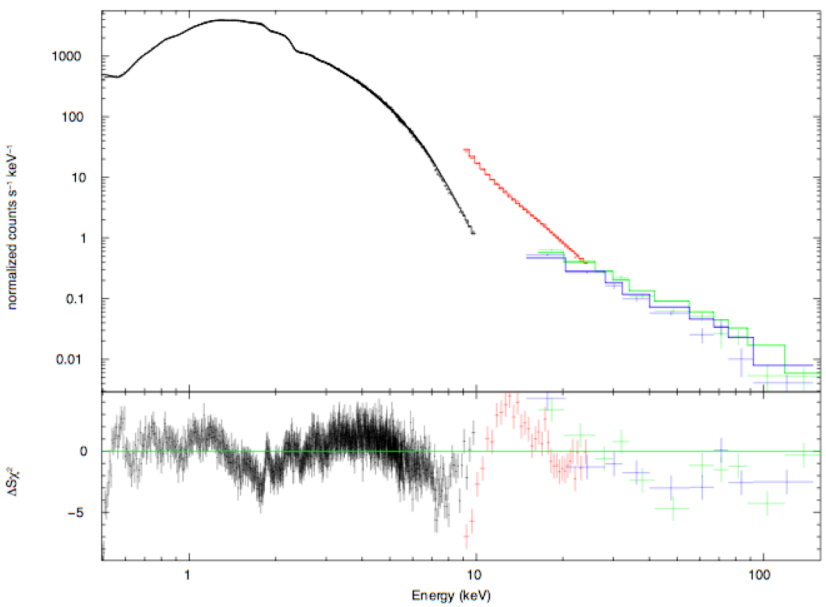
$$f_{col} = 1.48^{+0.09}_{-0.08}$$

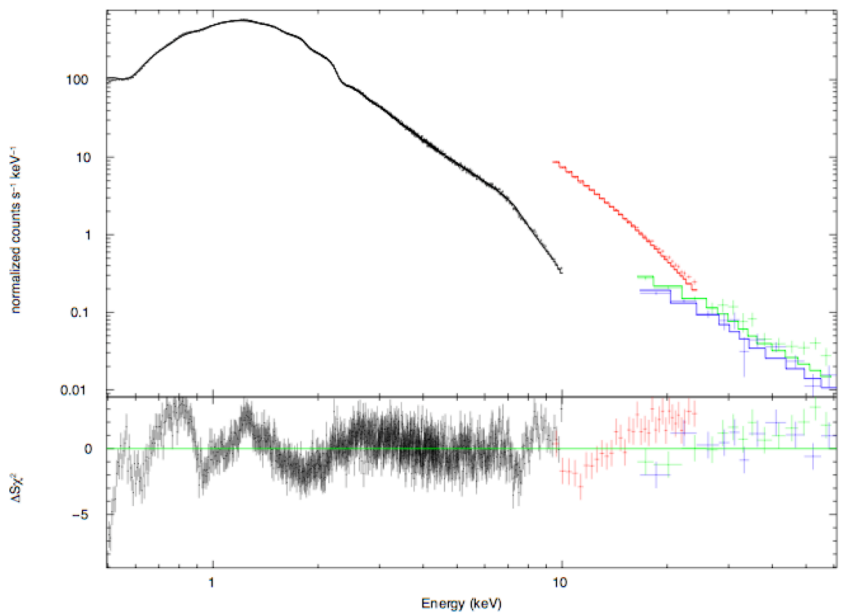
$$f_{col} = 1.35 \pm 0.01$$

Pszota & Cui 2007

Modeling with Relativistic Model #1

kerrbb: the color correction accounted for with a free parameter

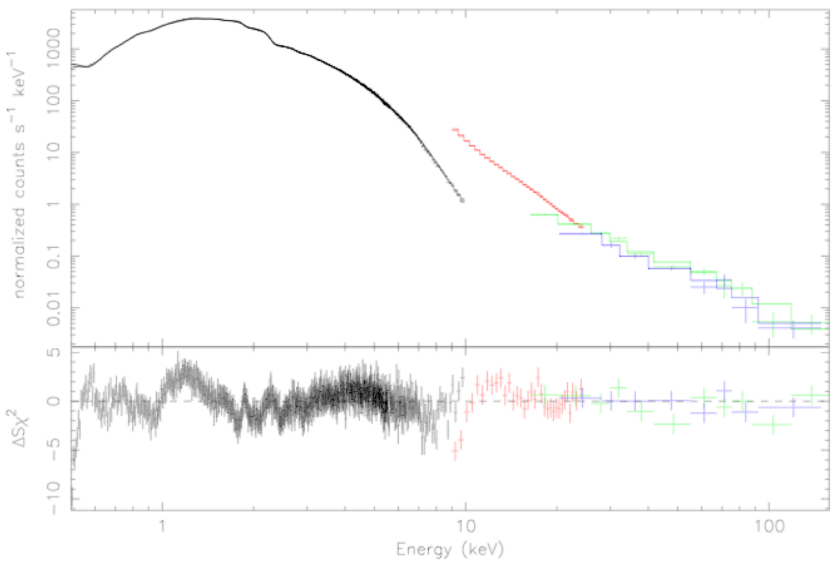


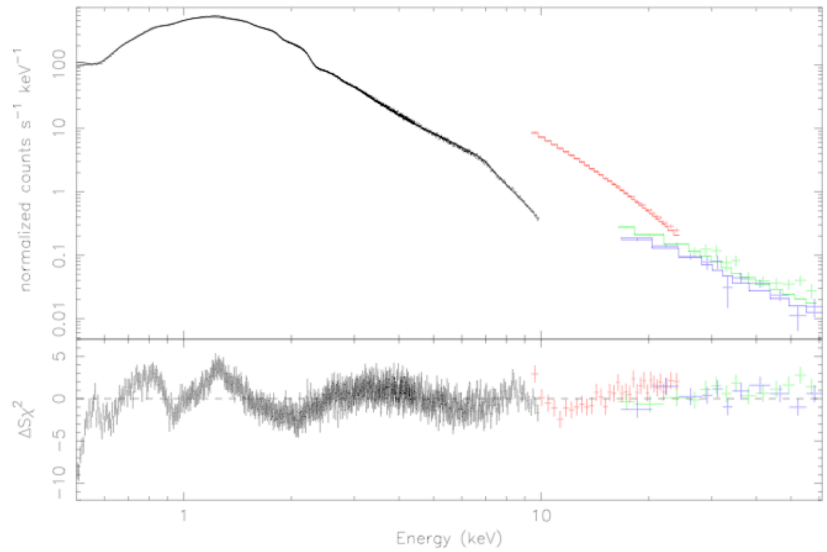


Pszota & Cui 2007

Modeling with Relativistic Model #2

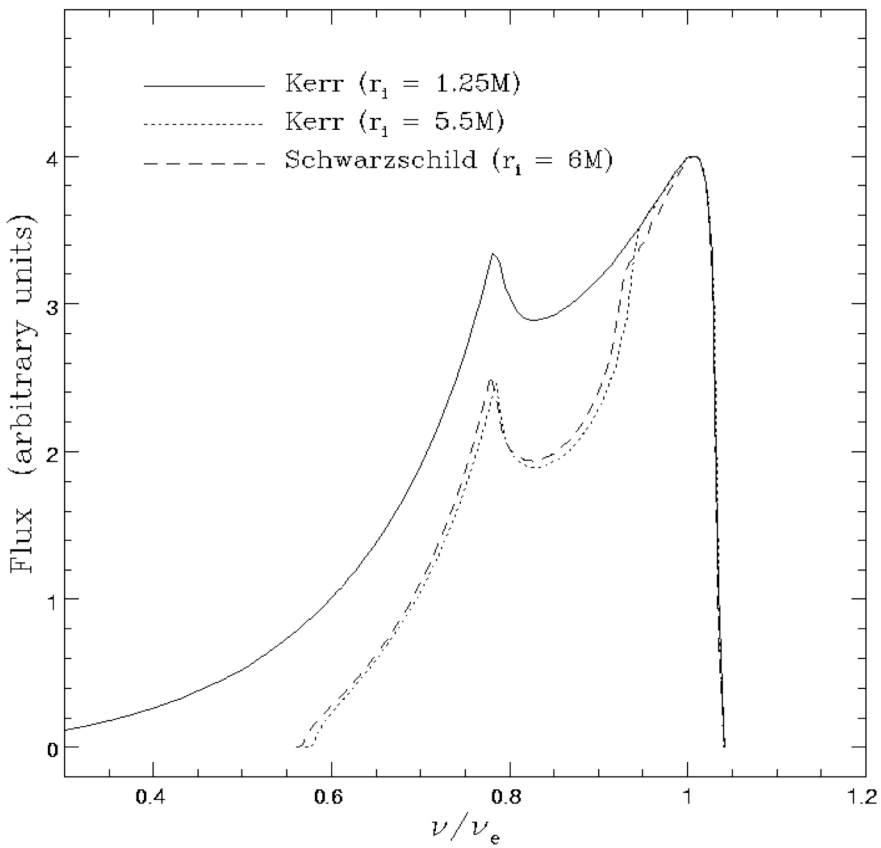
bhspec: the color correction accounted for with full radiative transfer calculation through the disk



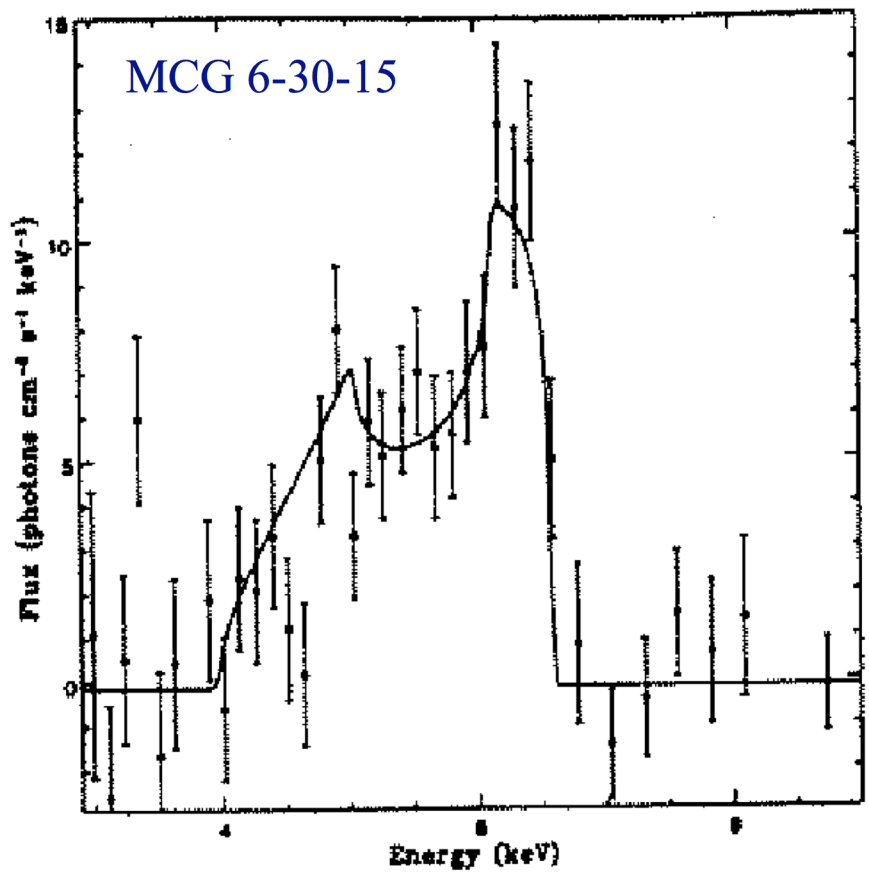


Pszota & Cui 2007

Issue #3: Relativistic Fe Line

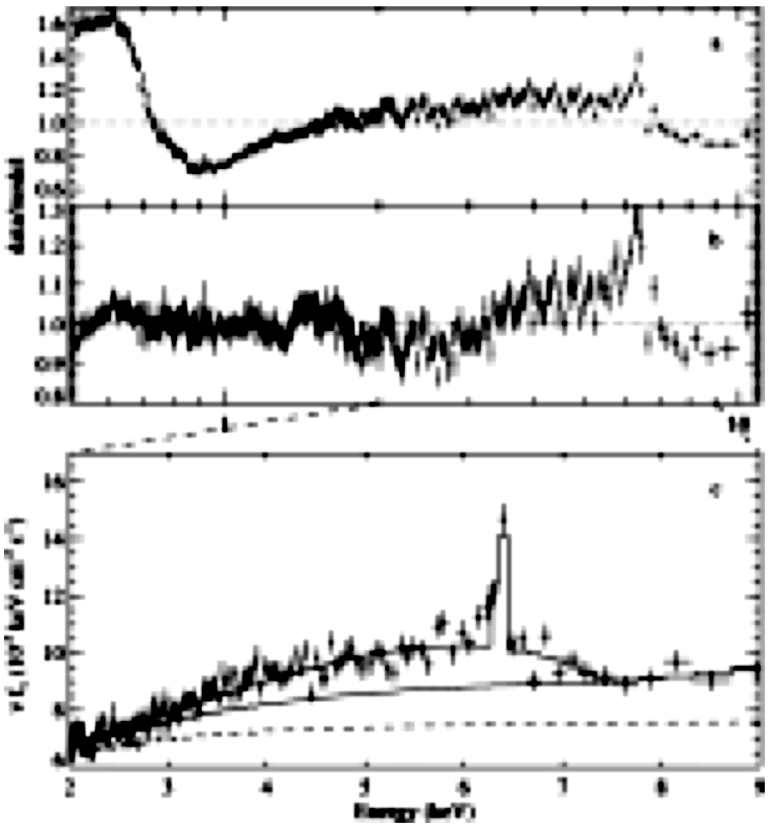


Bromley, Chen, & Miller 1997



Tanaka et al. 1995

Subtlety



Wilms et al. 2001

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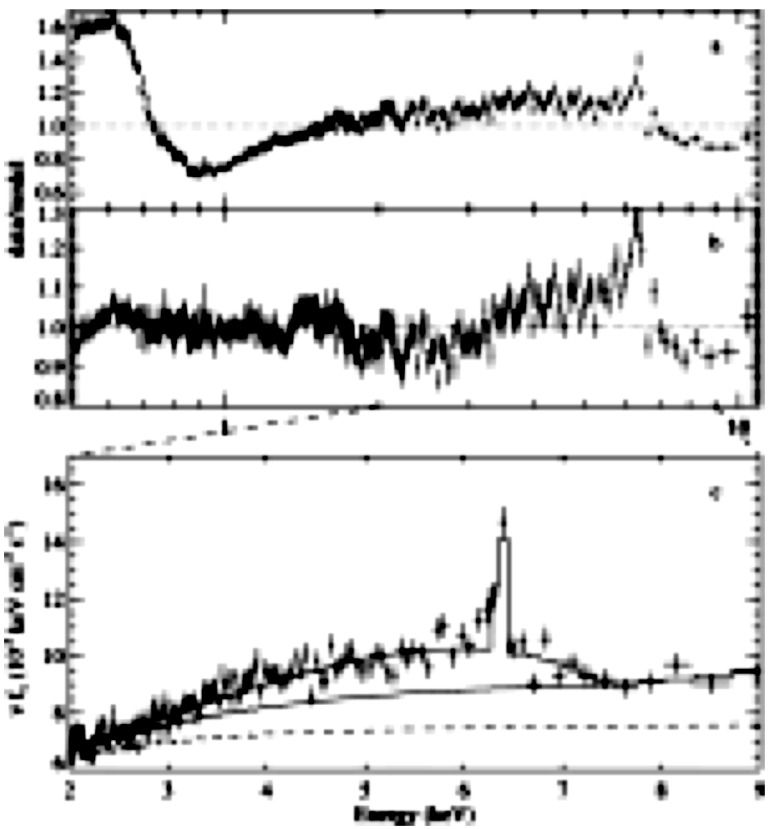

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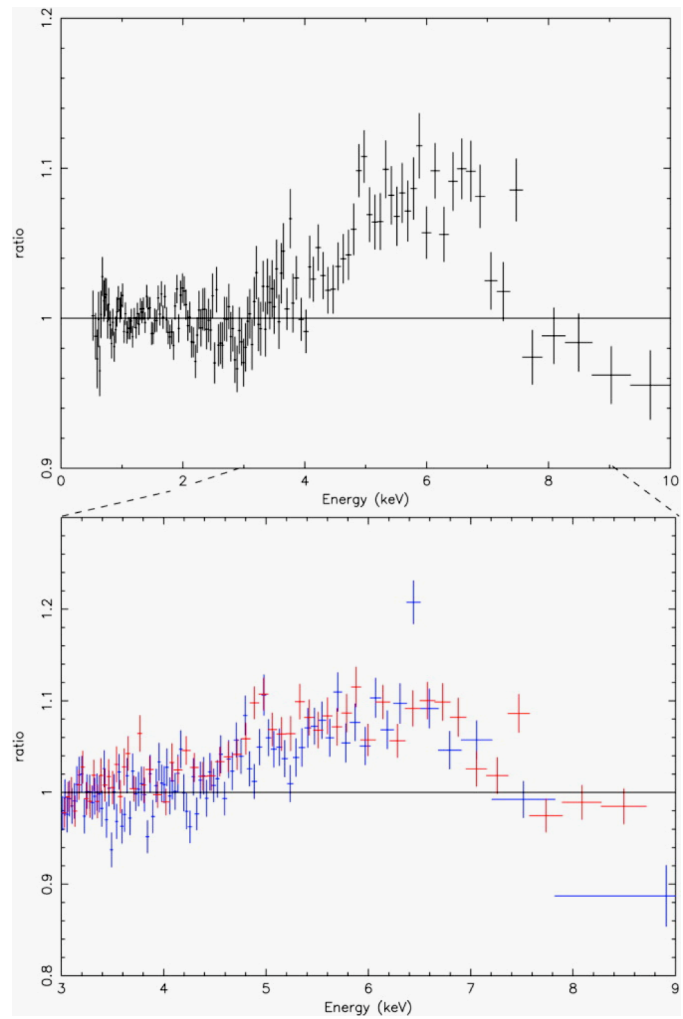
XTE J1650-500



Miller et al. 2002

Uncertainties

- Sensitive to continuum modeling
- Variability of the line profile
- Theoretical uncertainties
  - Emissivity profile, outer boundary condition
- Observational uncertainties
  - Inclination angle

Issue #4: QPOs

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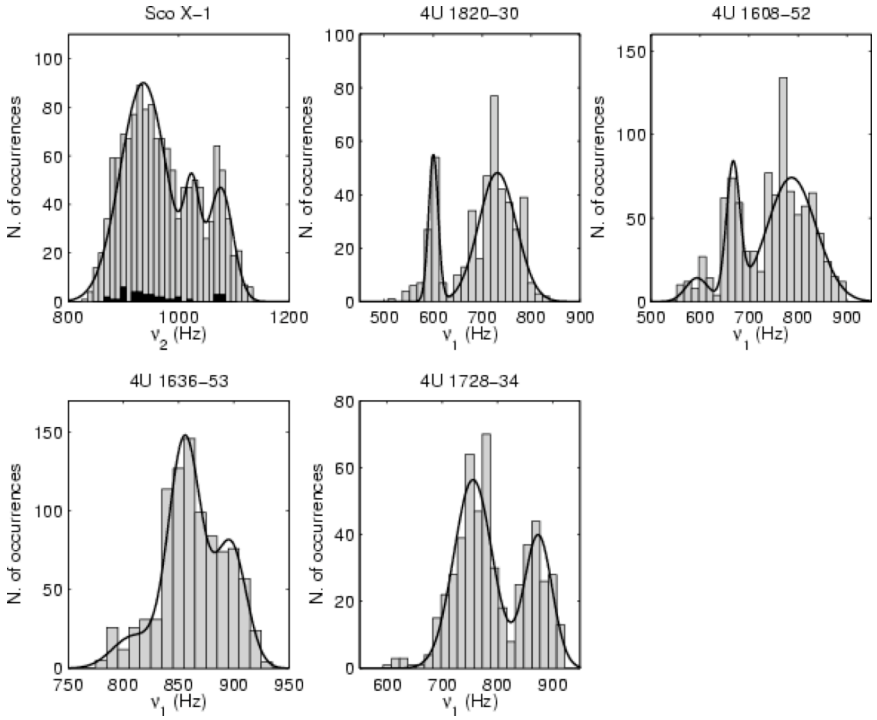

Belloni et al. 2005

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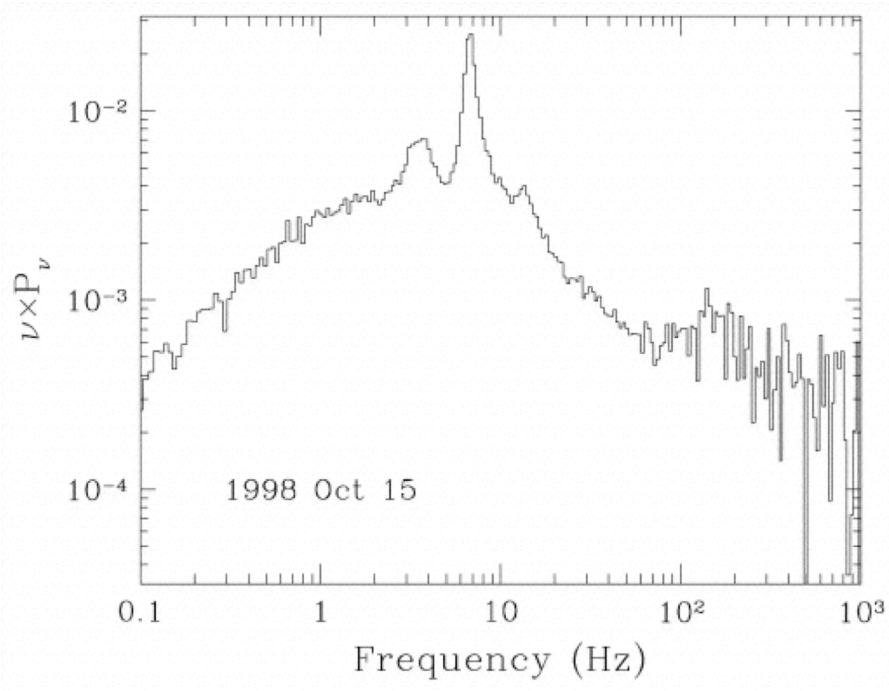
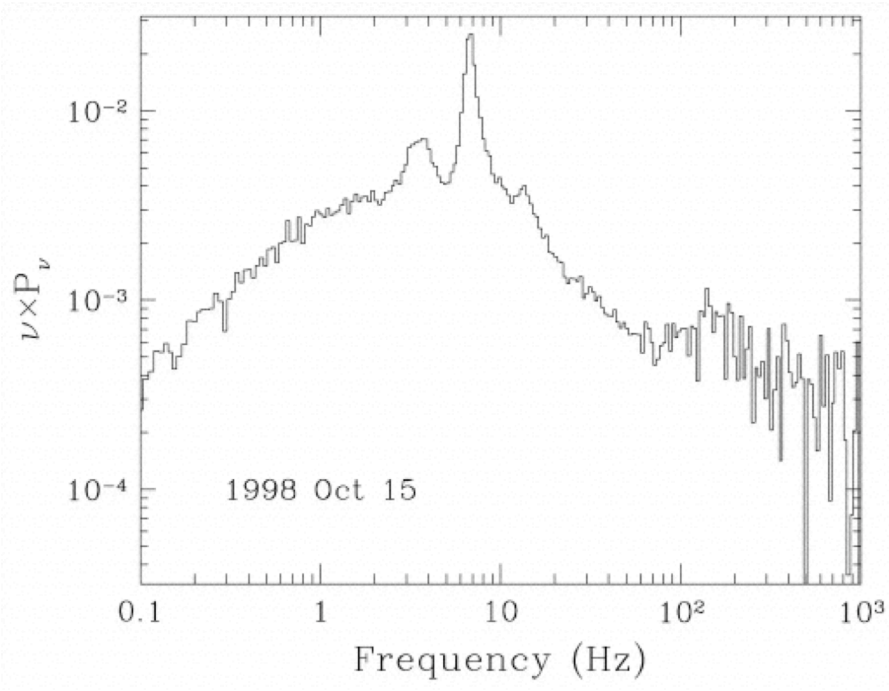


Remillard et al. 2002

Issue #4: QPOs

Do you see QPOs at 92, 143, 184, 276 Hz?



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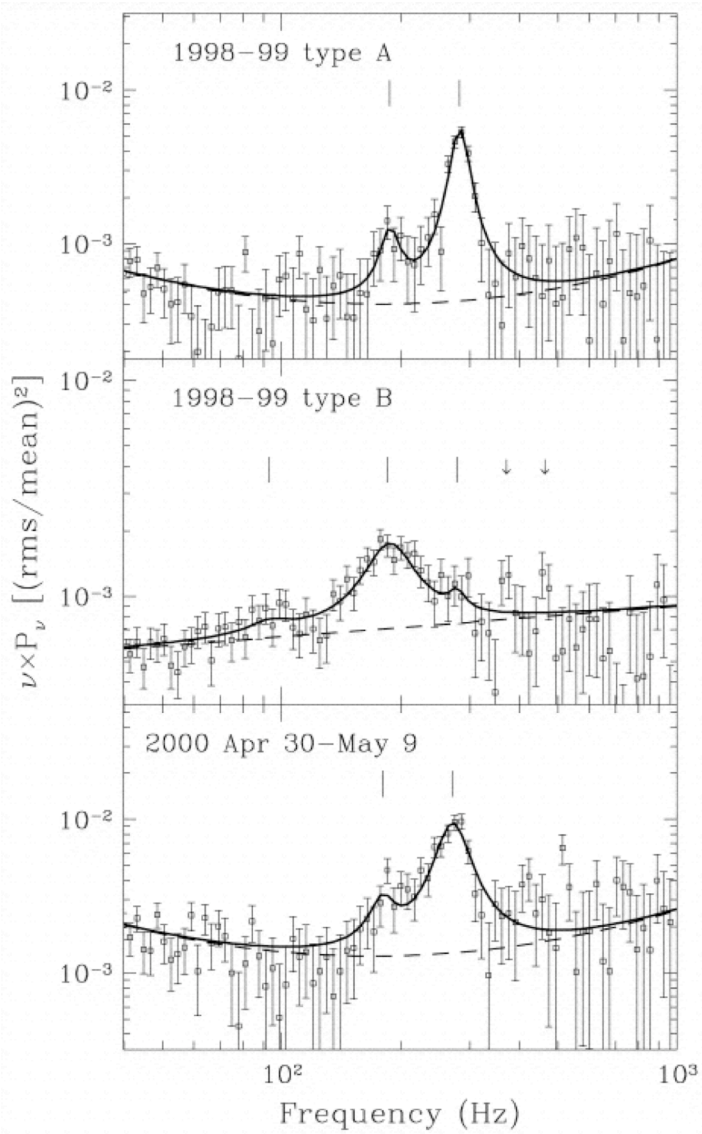

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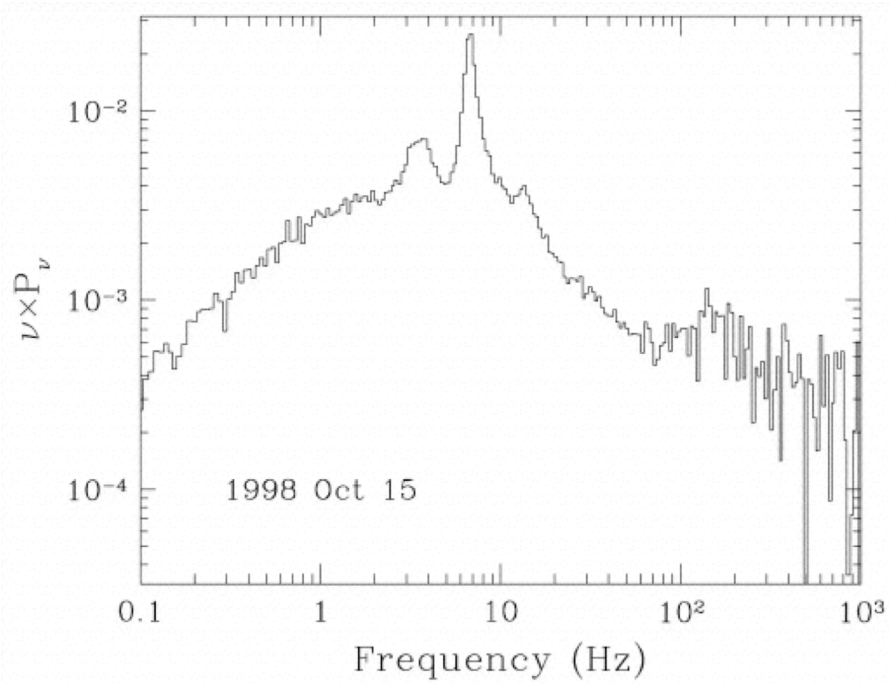
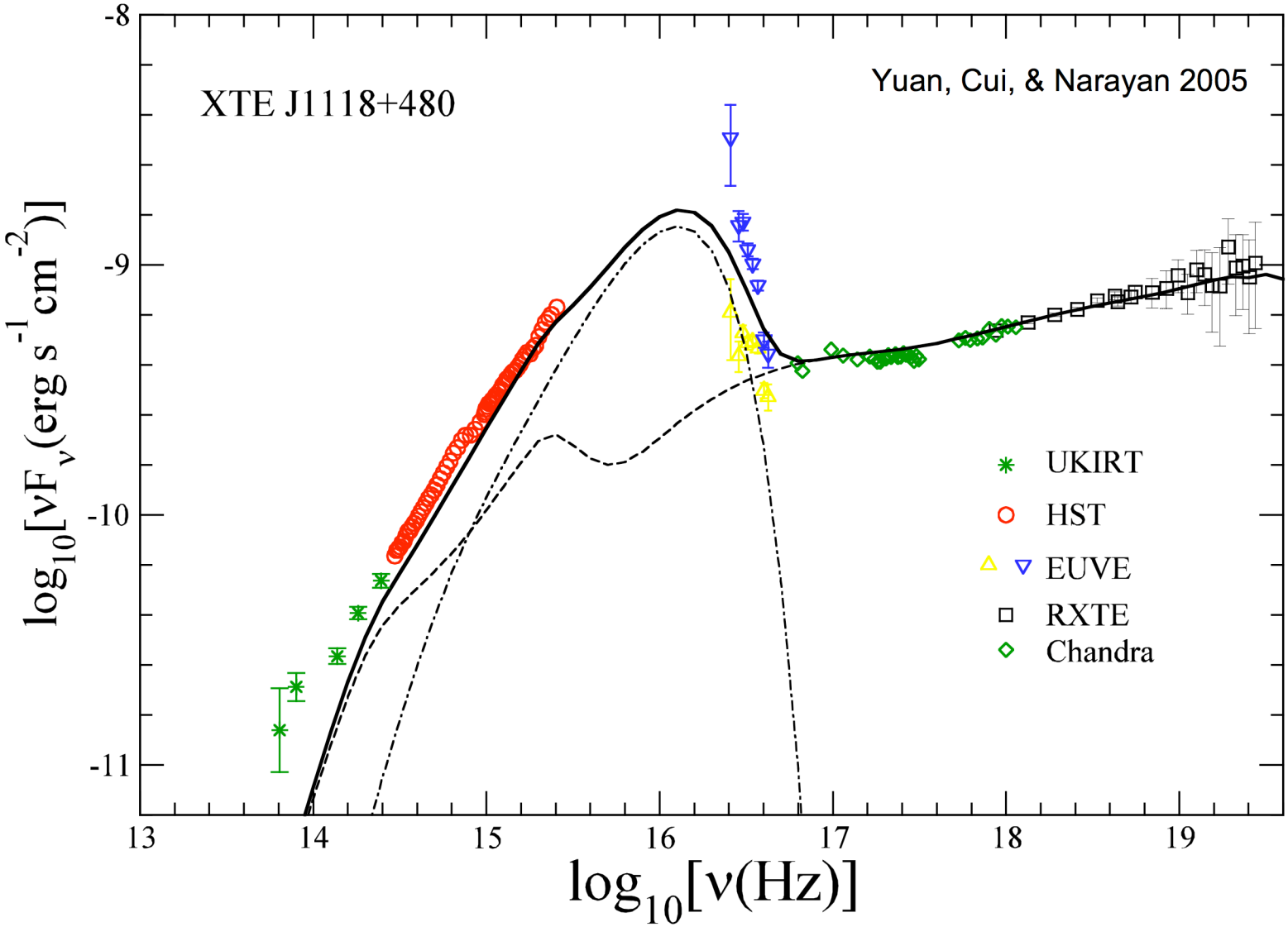
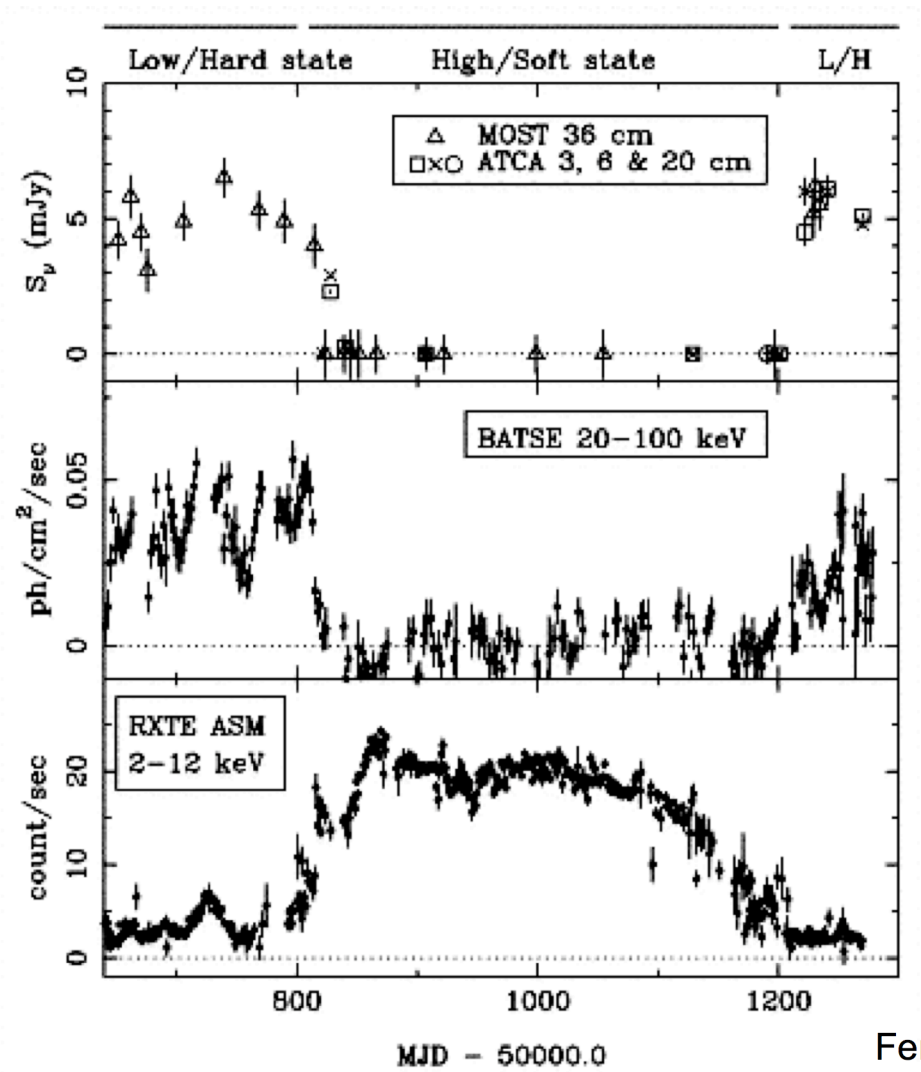


Remillard et al. 2002

Beyond X-rays



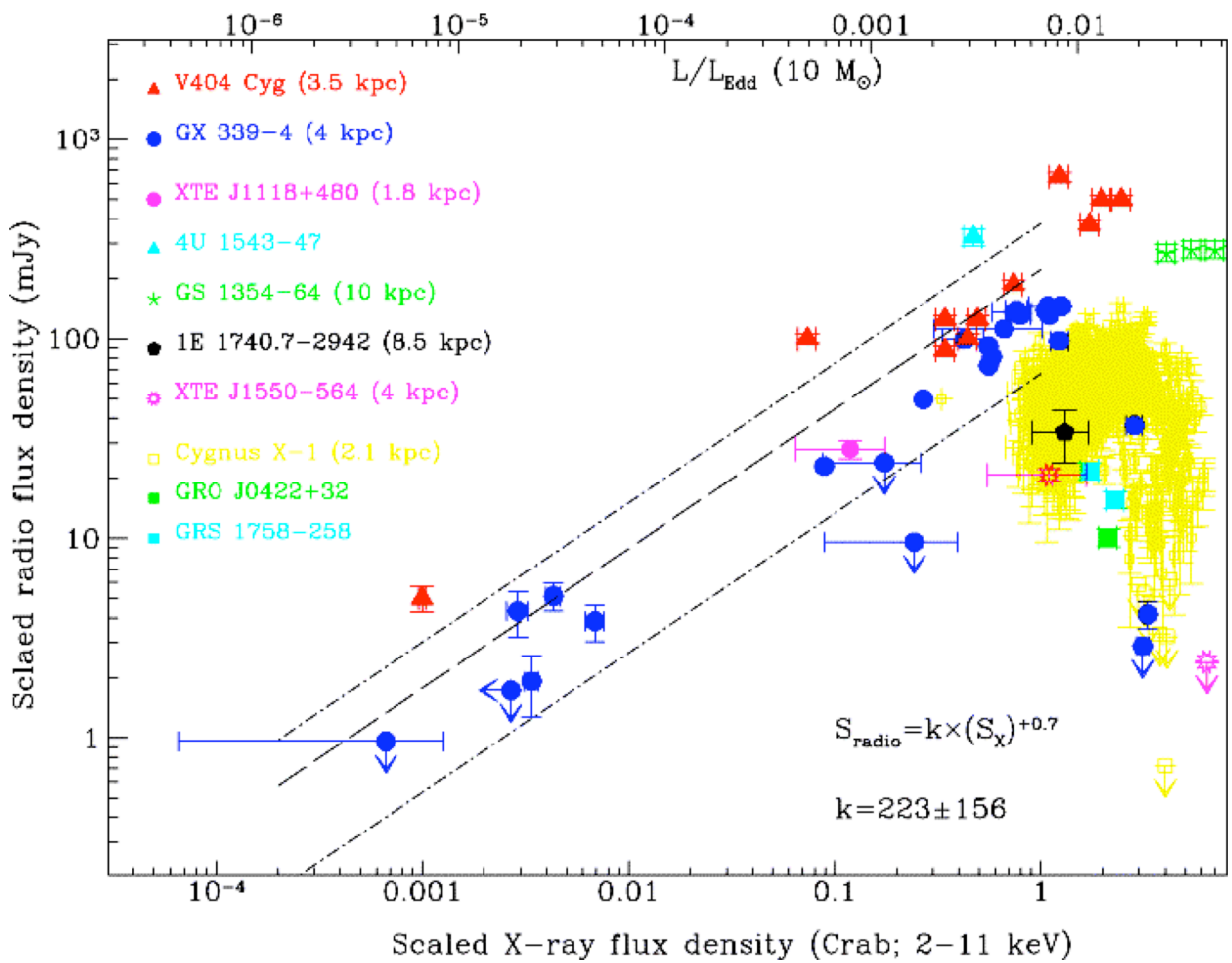
Radio Emission



GX 339-4

Fender et al. 1999

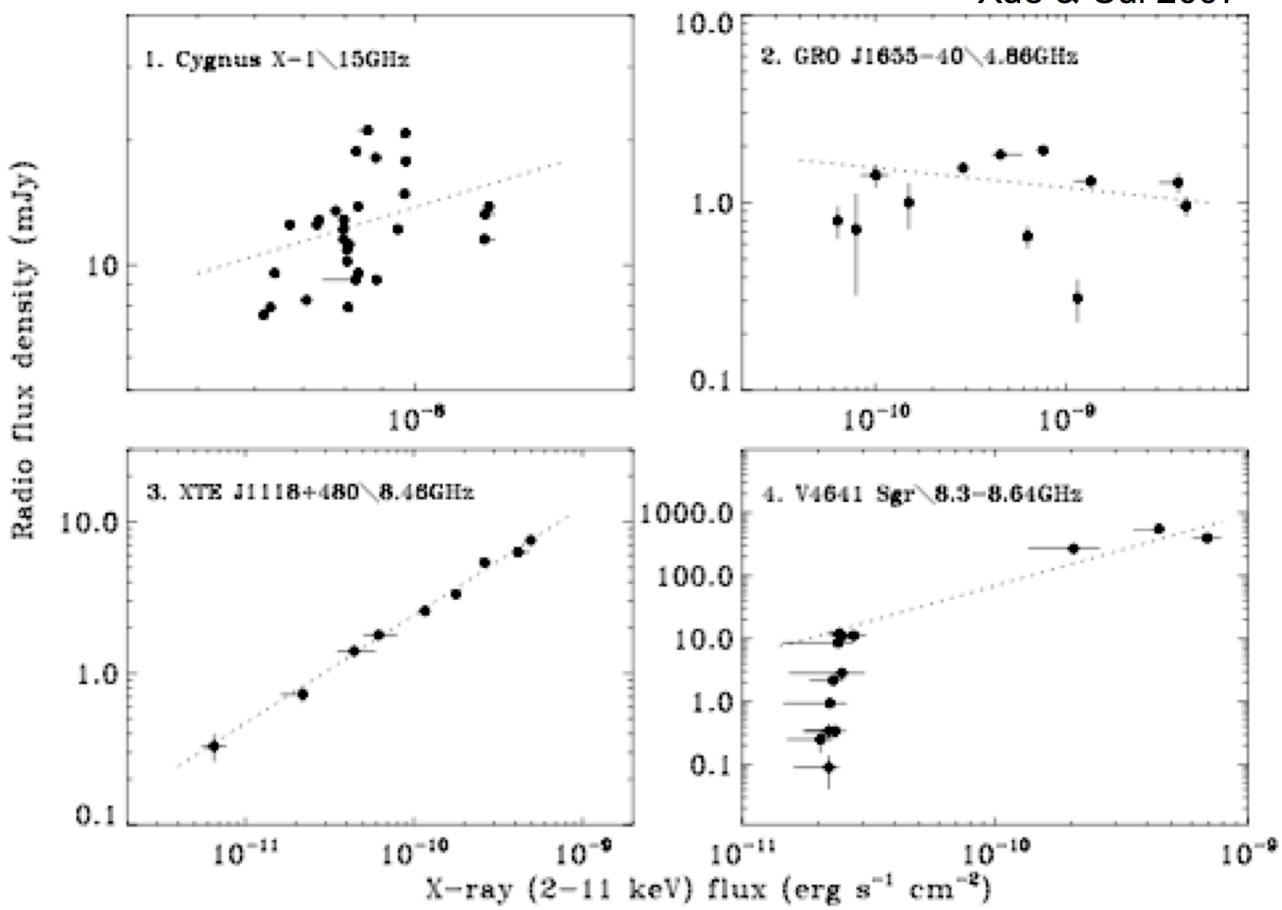
Issue #5: X-ray/Radio Correlation



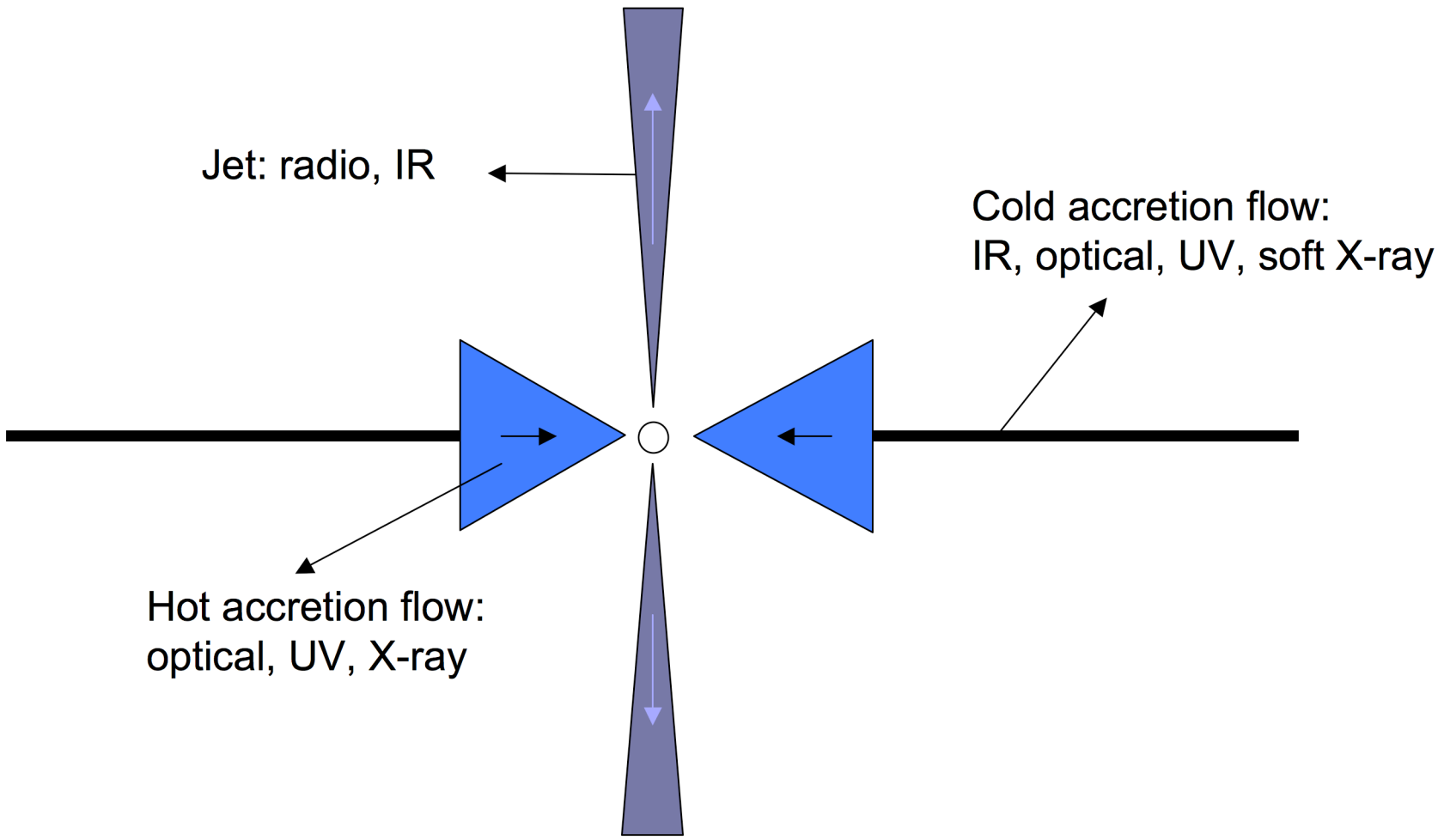
Gallo et al. 2003

No *Universal* Radio/X-ray Correlation

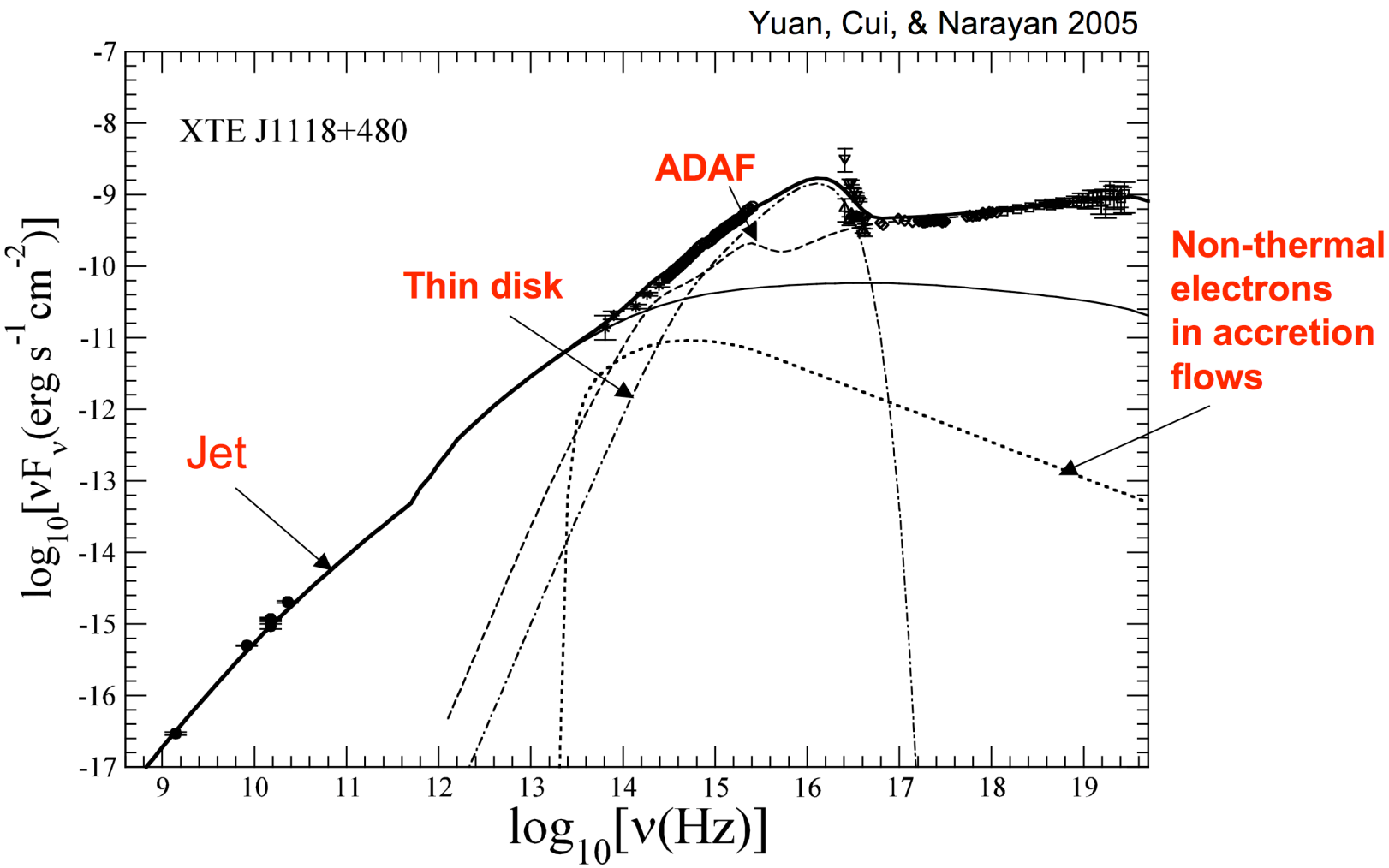
Xue & Cui 2007



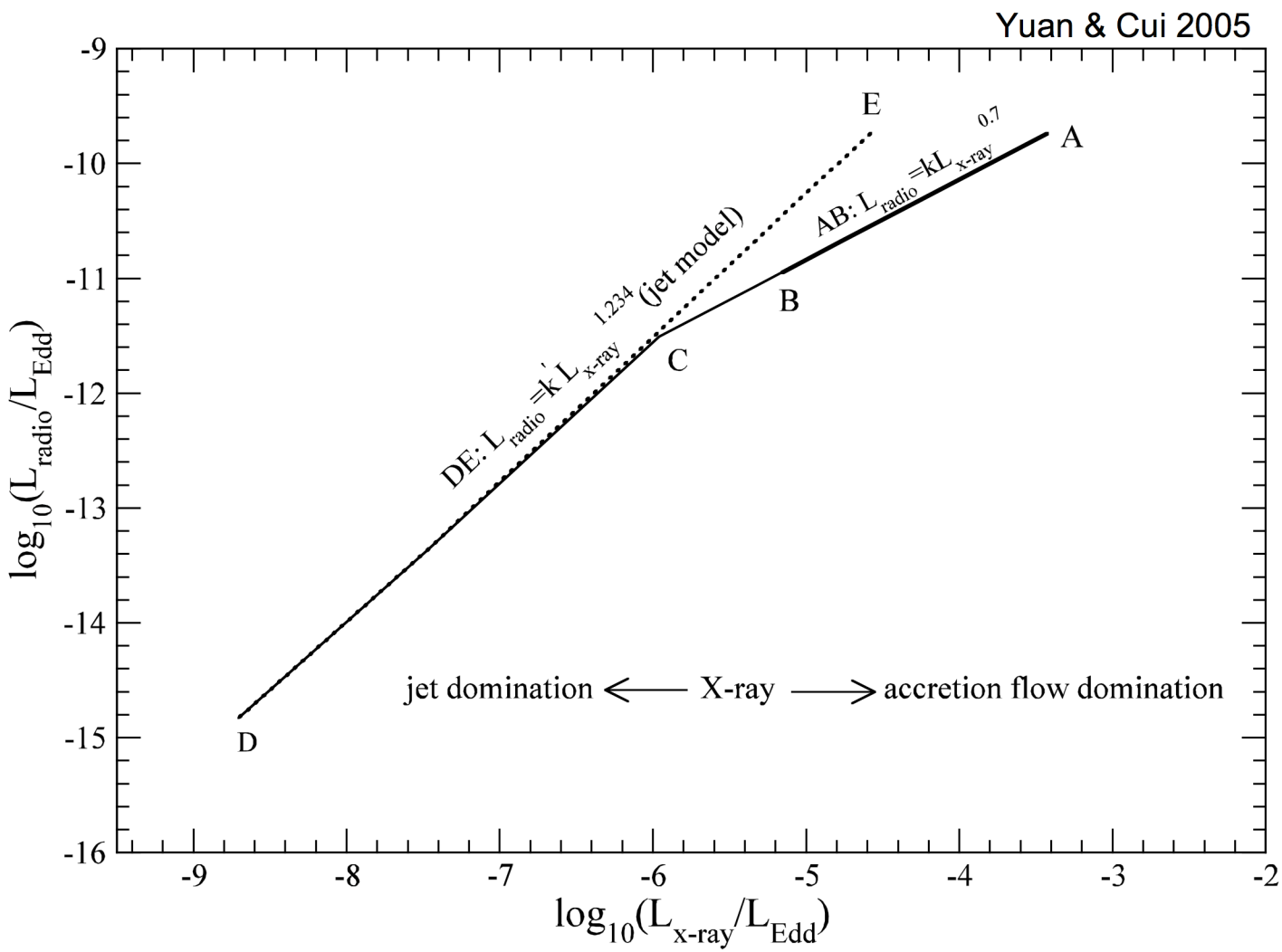
Theoretical Scenarios



A Coupled Jet-Accretion Model



Radio/X-ray Correlation in Quiescence



Conclusions

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  - Low-hard state: dominating hard X-ray emission, peaking at around 100 keV
  - High-soft state: dominating soft X-ray emission, peaking at around 1 keV
- X-ray continuum modeling is a promising technique for probing strong gravity near a stellar-mass black hole but be critical of the conclusions based on low-hard state observations.
  - Weak disk component
  - Coupling between the disk and “corona” emission

Conclusions - Cont’d

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All roads lead to Rome … hopefully

Acknowledgment

Collaborators:

Wan Chen, Ramesh Narayan, Xue-Bing Wu, Feng Yuan, Shuang-Nan Zhang