Chandra-HETGS Observations of LMC X-1

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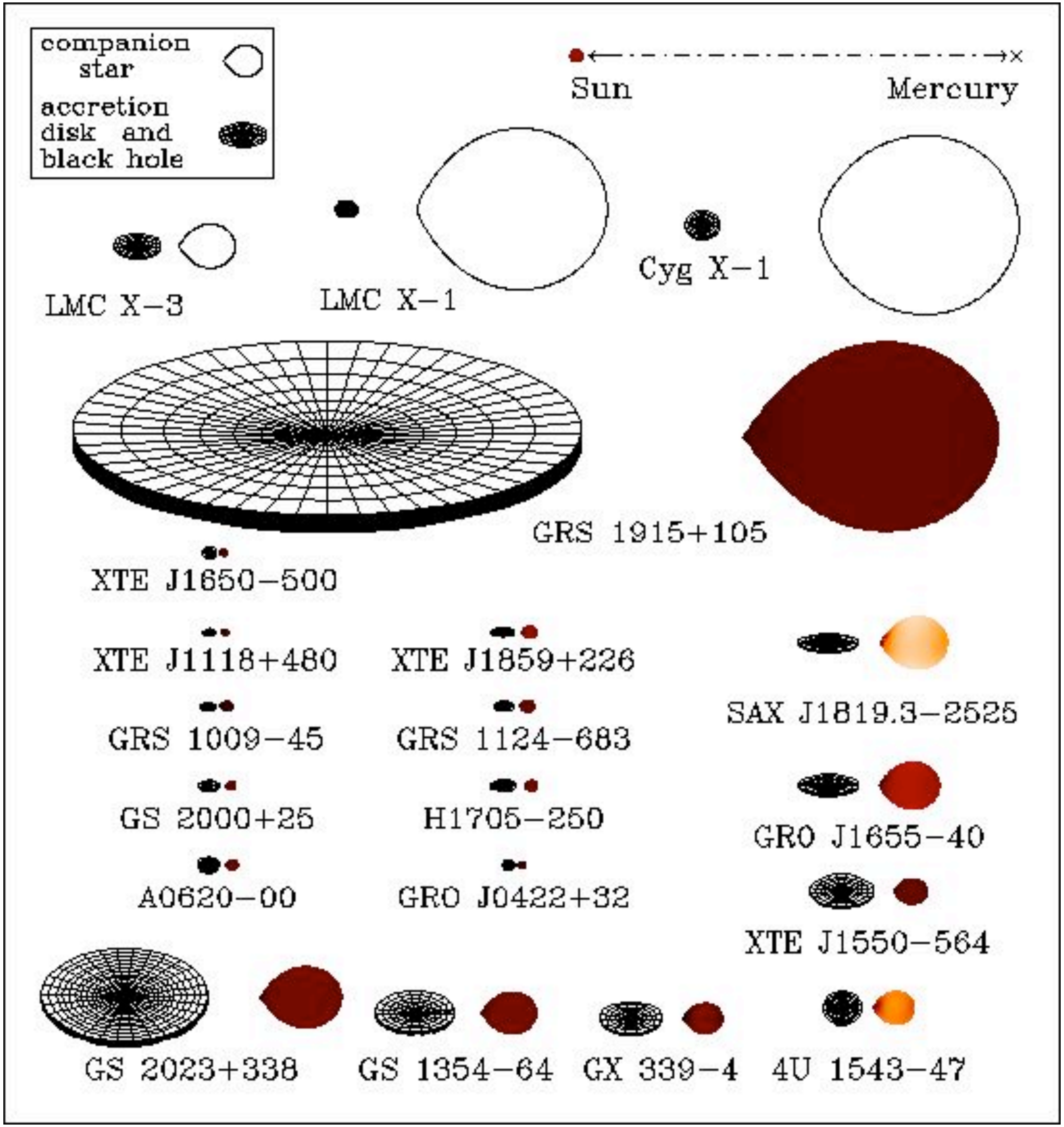
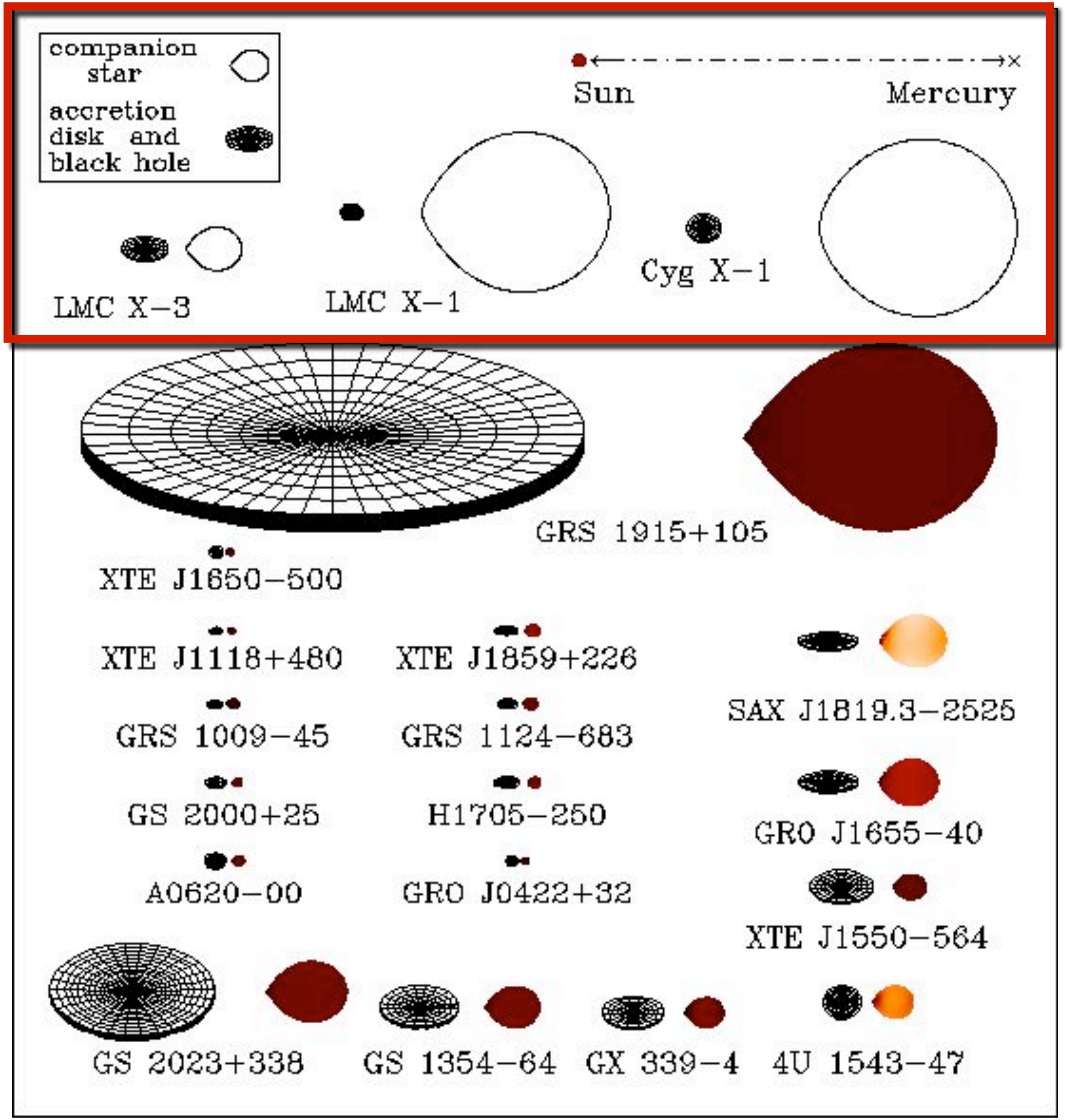
& Jörn Wilms (University of Bamberg)


companion star
accretion disk and black hole
Sun
Mercury
LMC X−3
LMC X−1
Cyg X−1
GRS 1915+105
XTE J1650−500
XTE J1118+480
XTE J1859+226
SAX J1819.3−2525
GRS 1009−45
GRS 1124−683
GS 2000+25
H1705−250
GRO J1655−40
A0620−00
GRO J0422+32
XTE J1550−564
GS 2023+338
GS 1354−64
GX 339−4
4U 1543−47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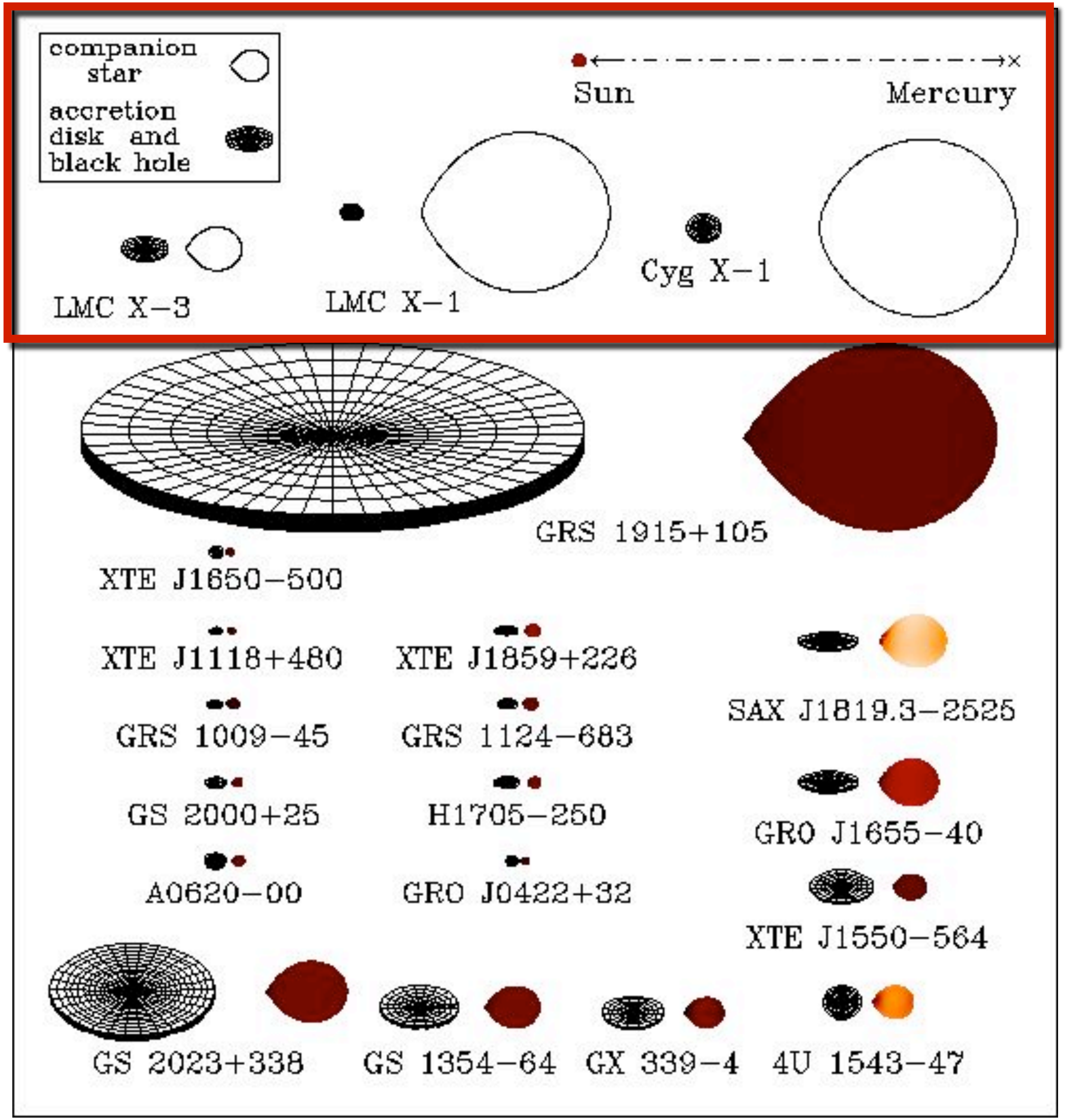
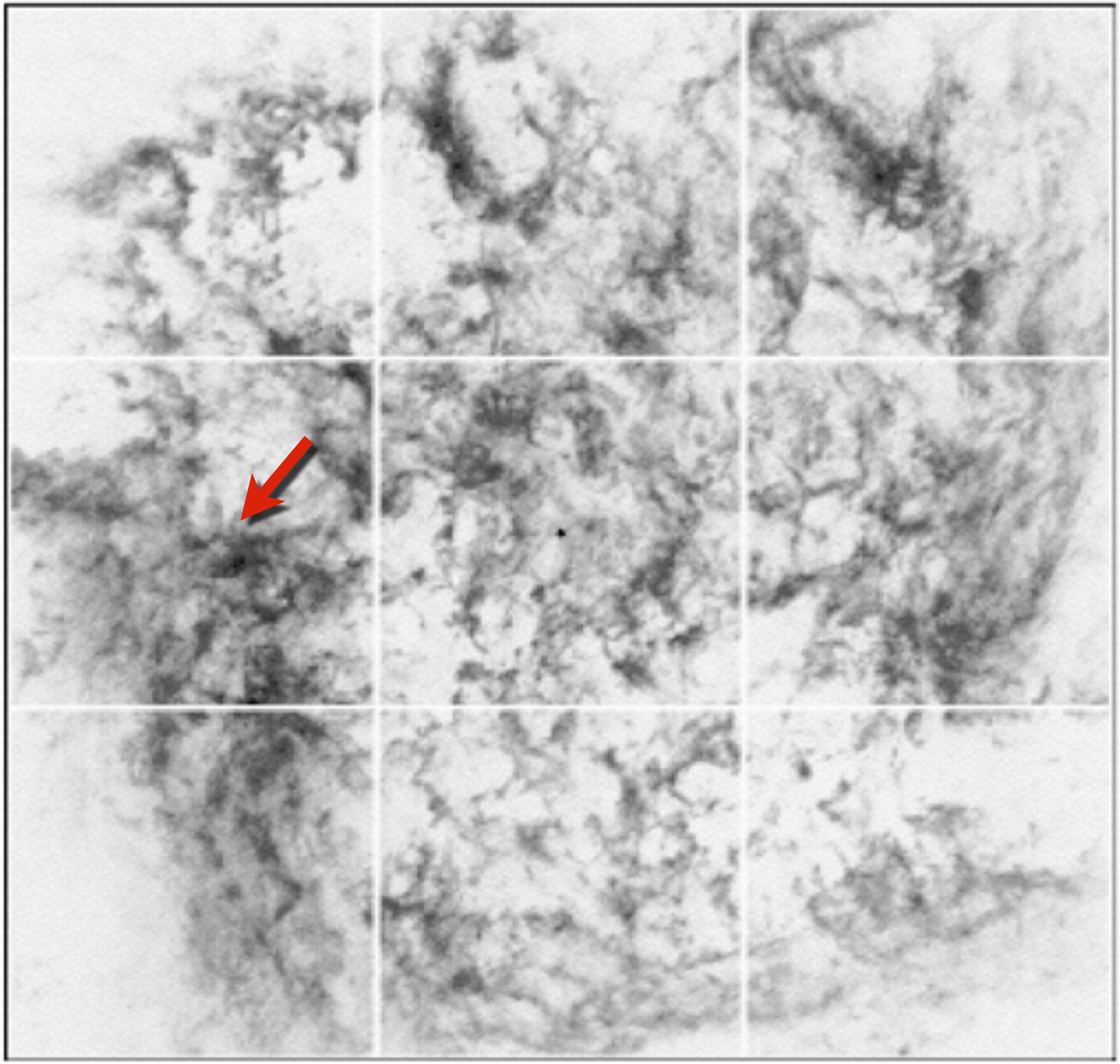
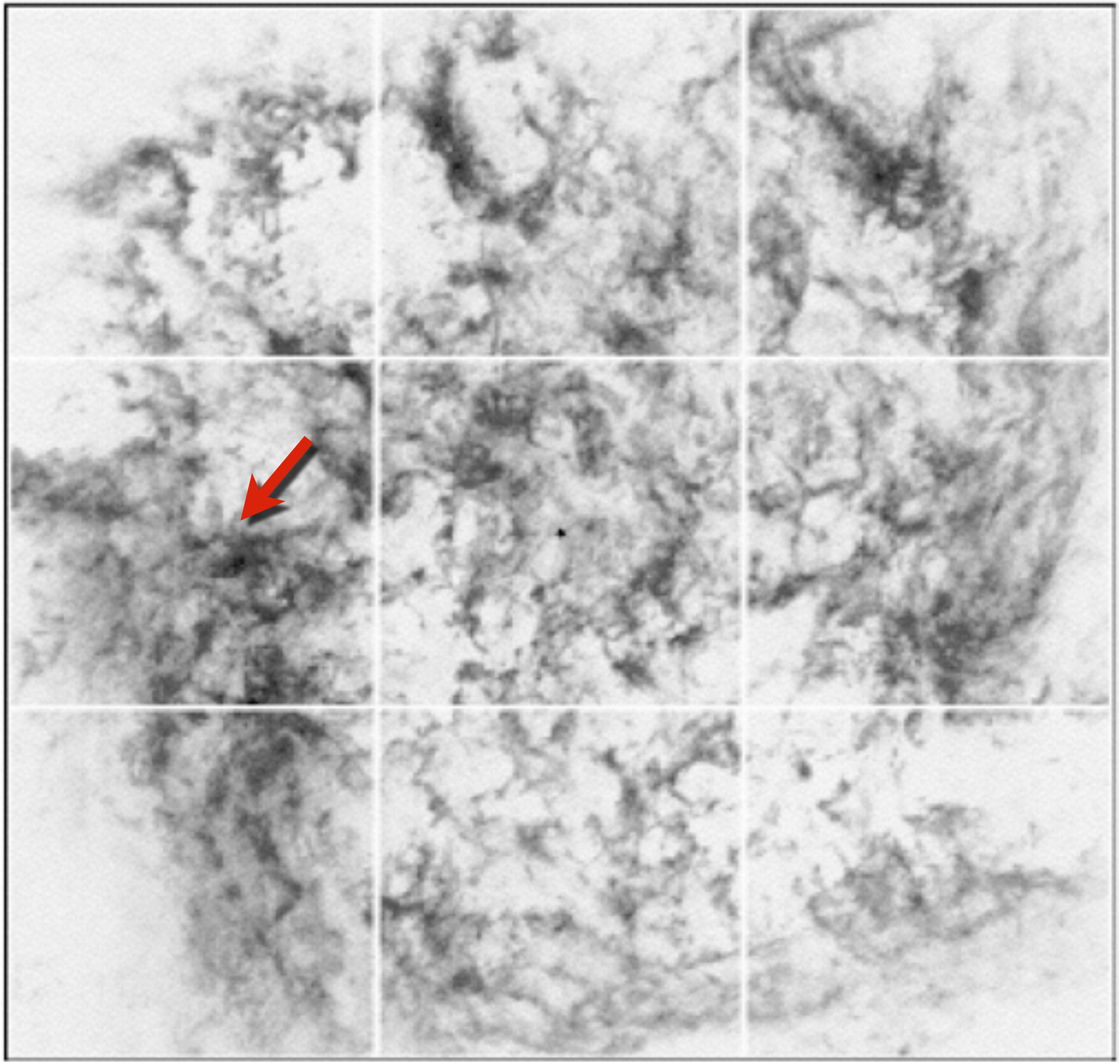


- One of the few persistent BHC
- HMXB: Focused Wind-Fed
- Soft X-ray Dominated State
- Line of Sight will Often Intersect Secondary Wind



Elmegreen, Kim, Staveley-Smith (2001)



- 21 cm Map of LMC
- LMC X-1 Sits Near 30 Doradus Star Forming Region

Elmegreen, Kim, Staveley-Smith (2001)

- Mass: 10.9 +/- 1.6 Solar Masses, Inclination $36.^\circ4$ +/- $1.^\circ9$ (Orosz et al. 2009)

- Distance: 48.1 kpc

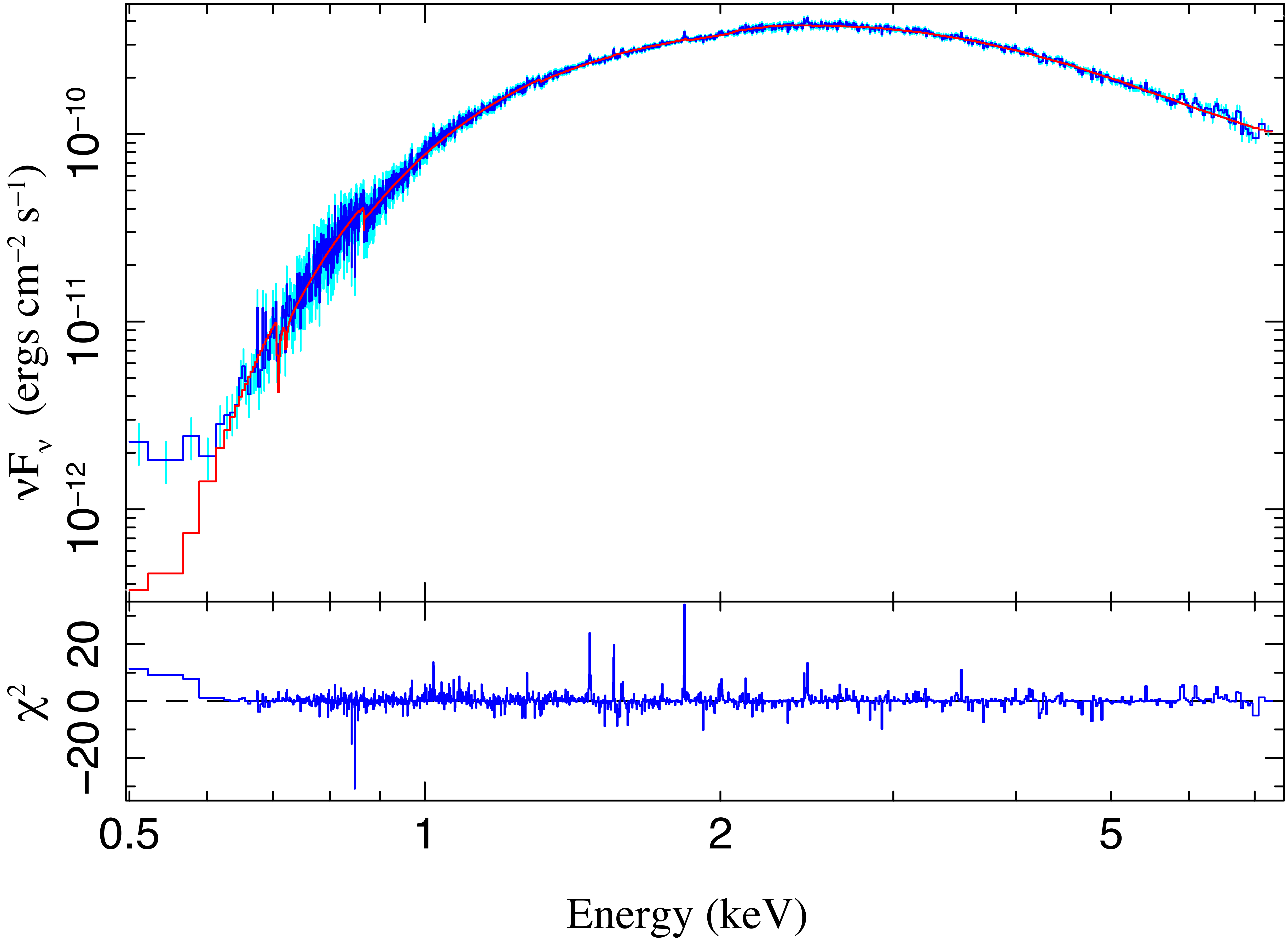
- Absorbed 0.5–8 keV Flux ≈ 10% L_{Edd}

- Orbital Period 3.909 Days, O7/8 Giant Companion

- Sits 0.5° from 30 Doradus Star Forming Region => Larger column than much of the rest of the LMC (e.g., > LMC X-3)

- Performed 10 Chandra-HETGS Observations over ~ 1 month: 150 ksec
- Study Accretion Flow Emission — Primarily the Accretion Disk
- Direct Measure of Absorption Edges
- Spectroscopic Signatures of Secondary
- Study Orbital Variations?

Fit: Absorbed, Comptonized Disks



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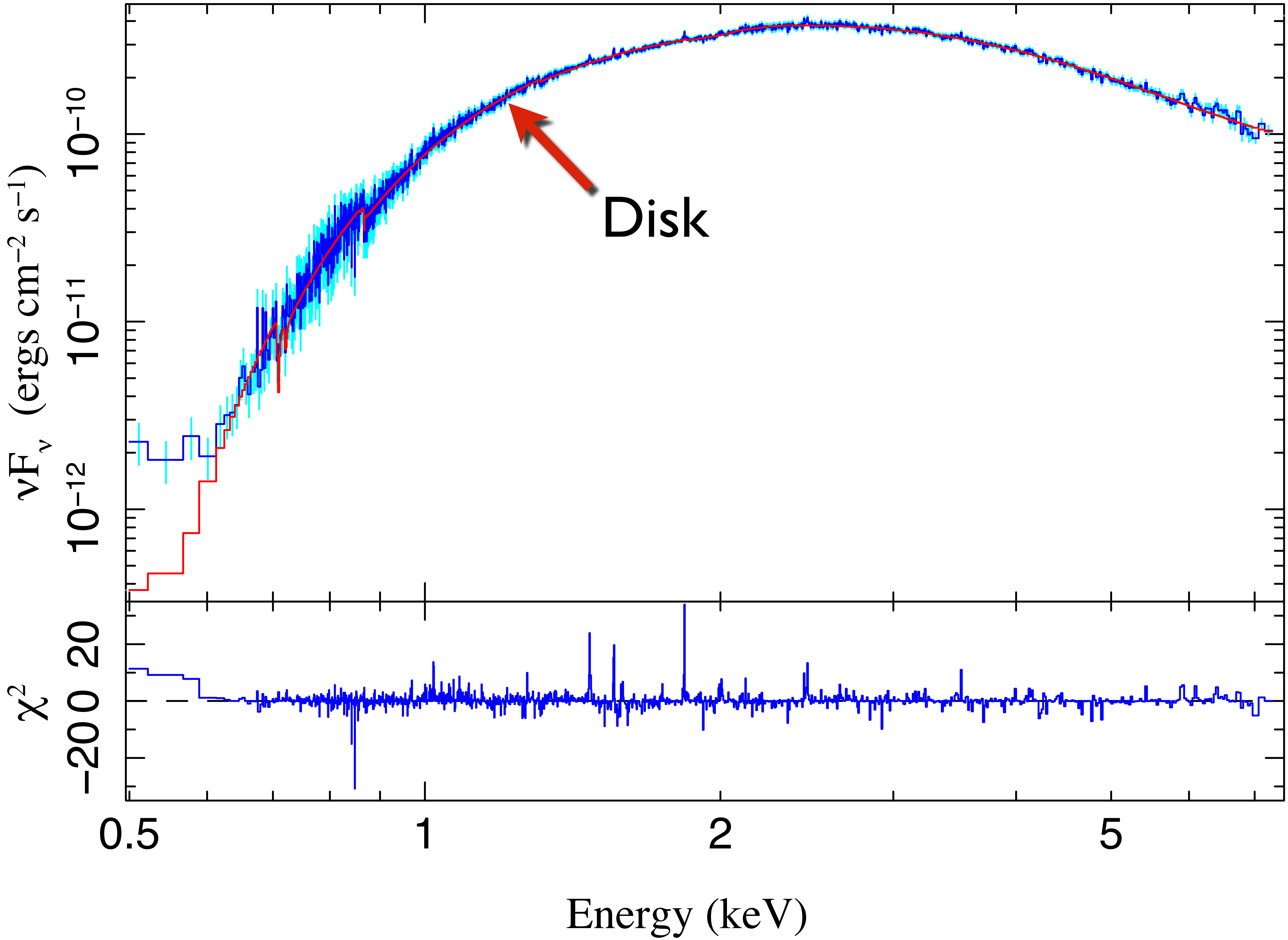

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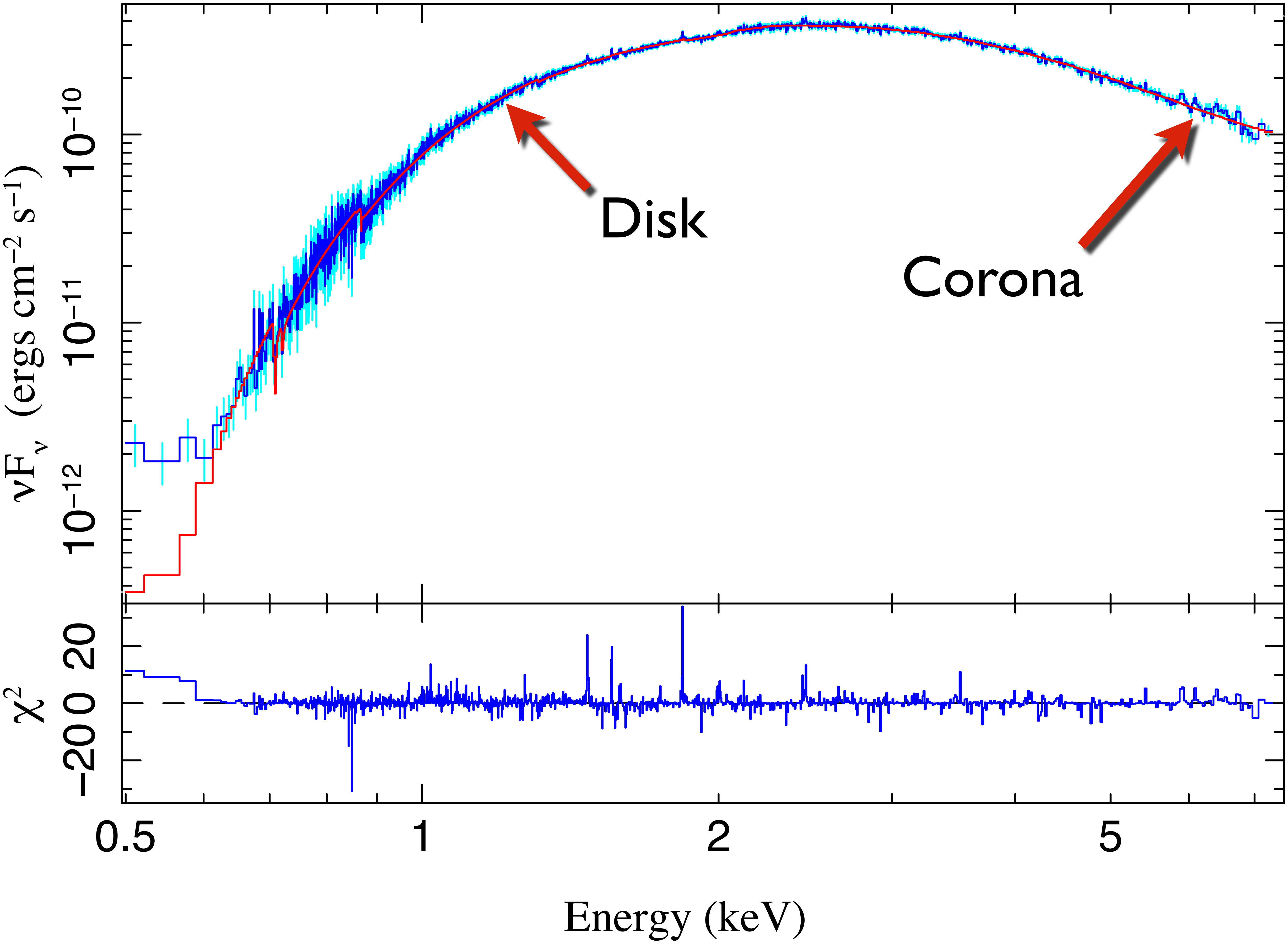

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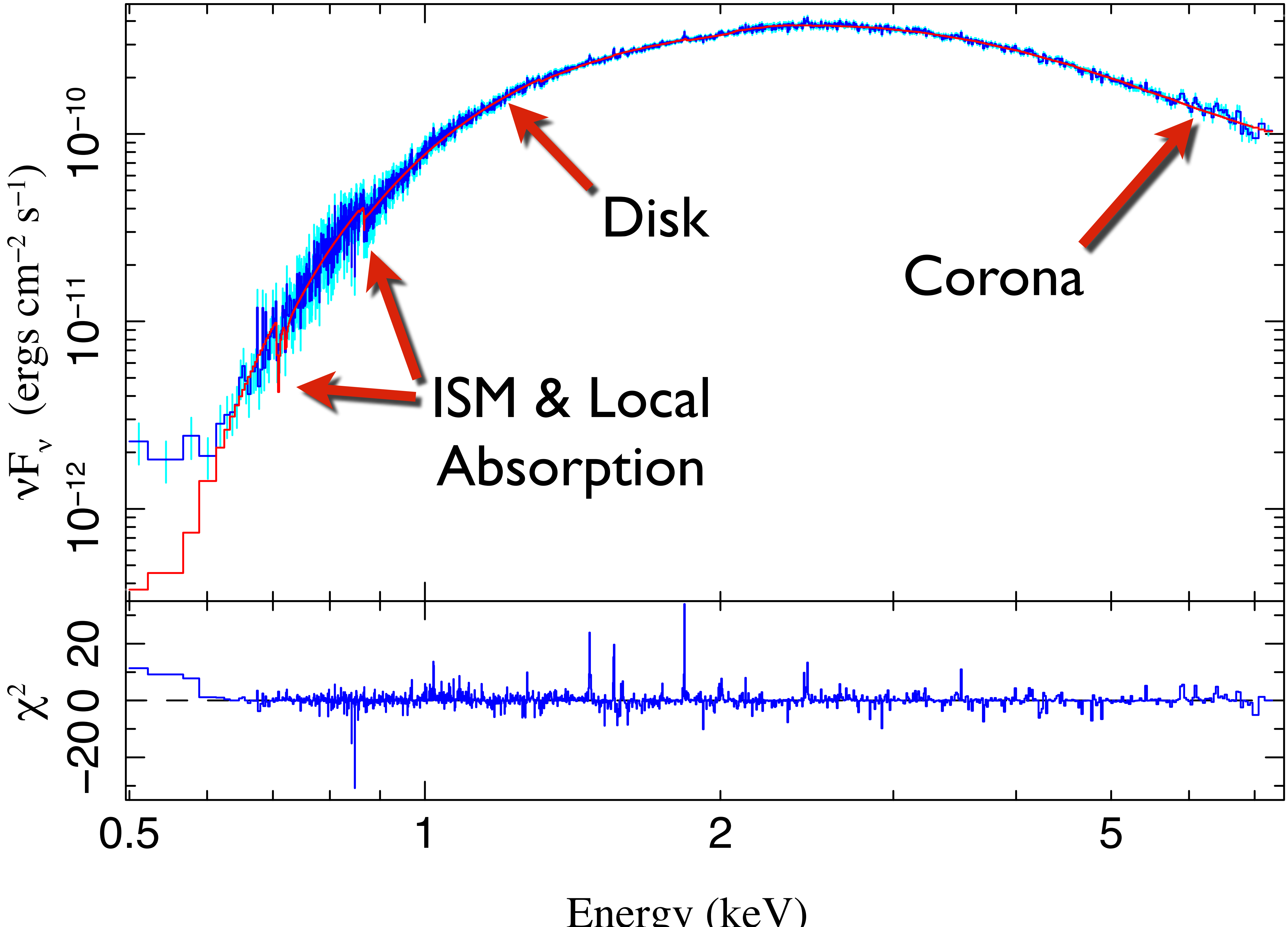

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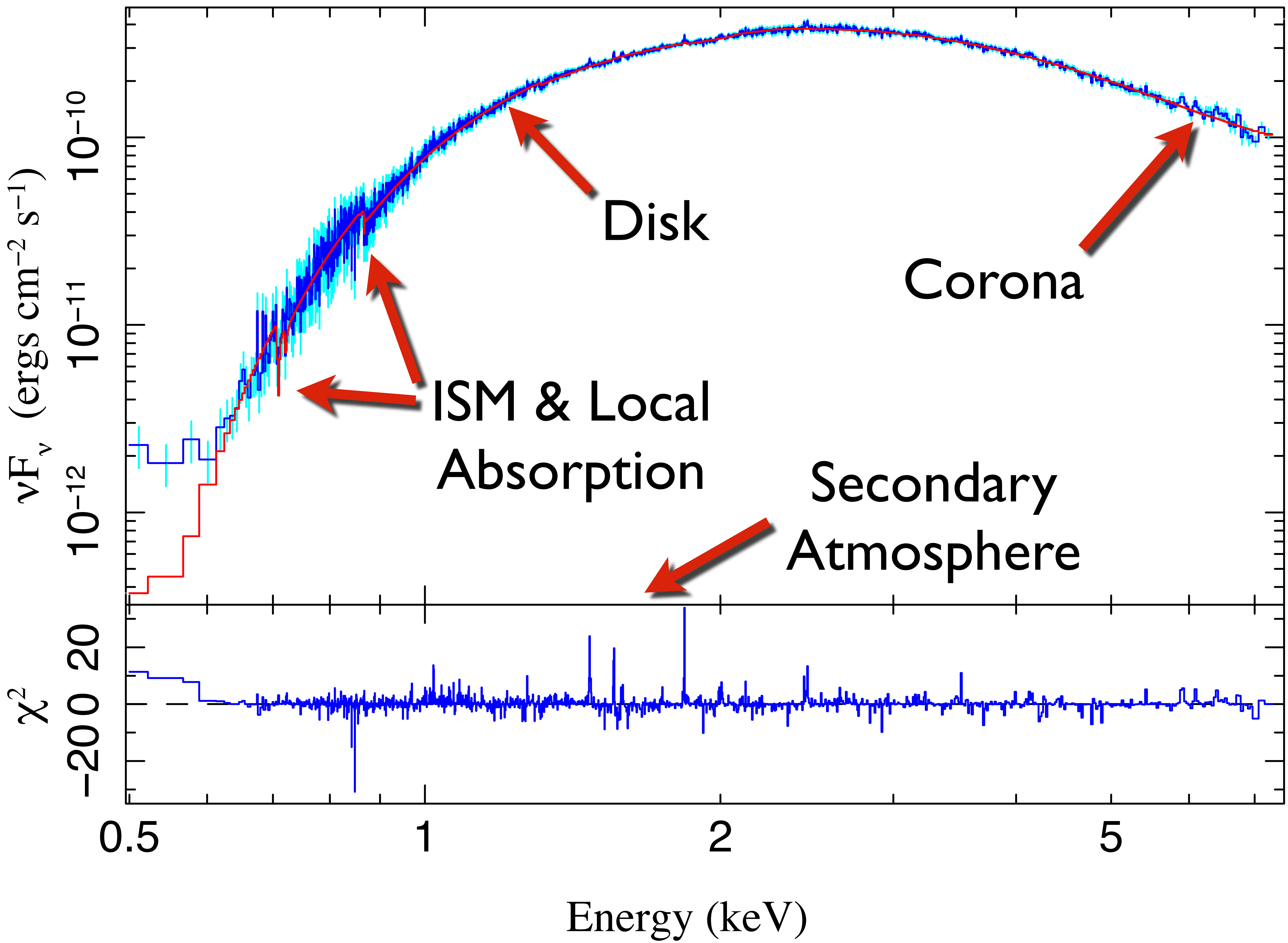

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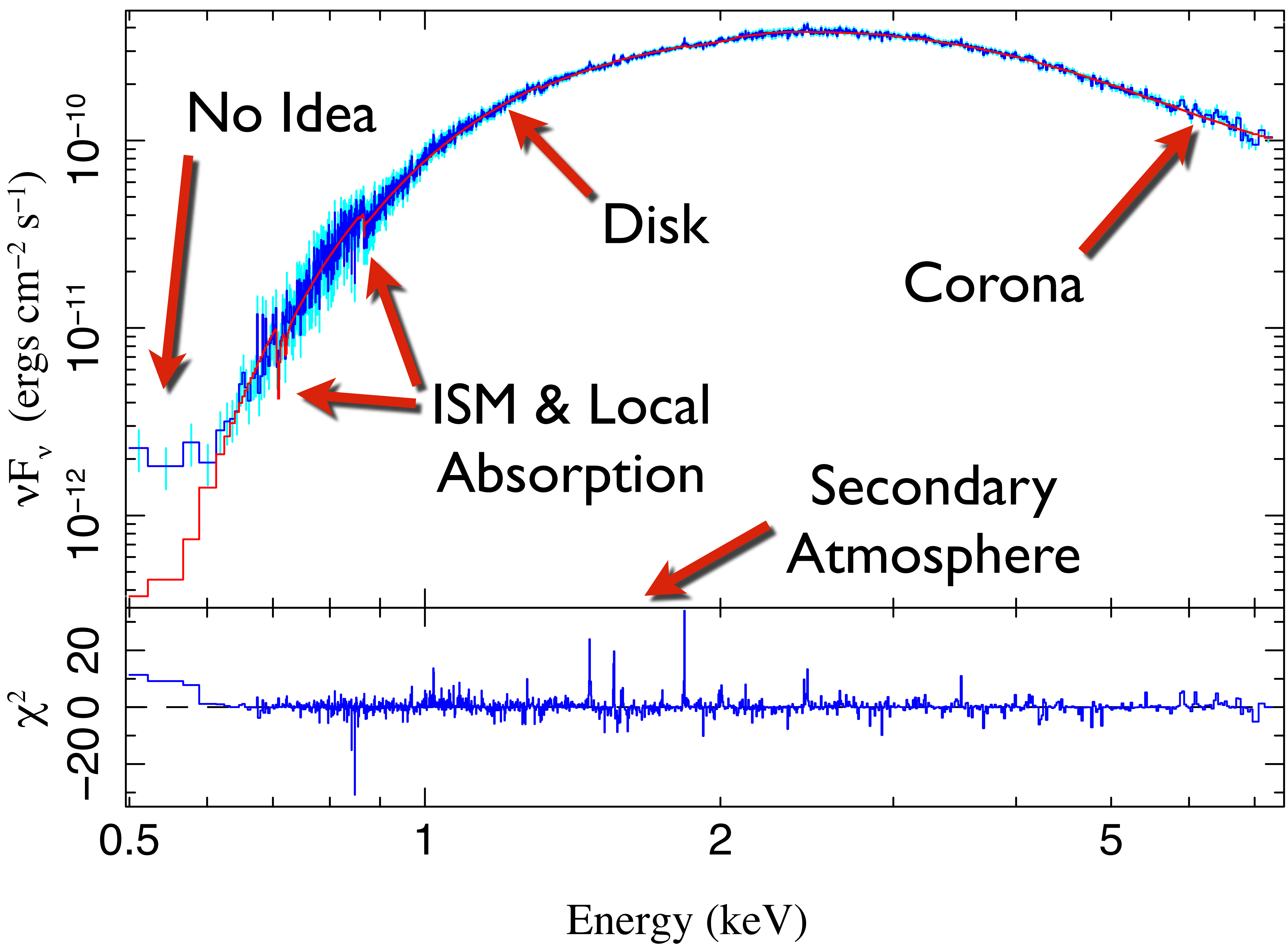
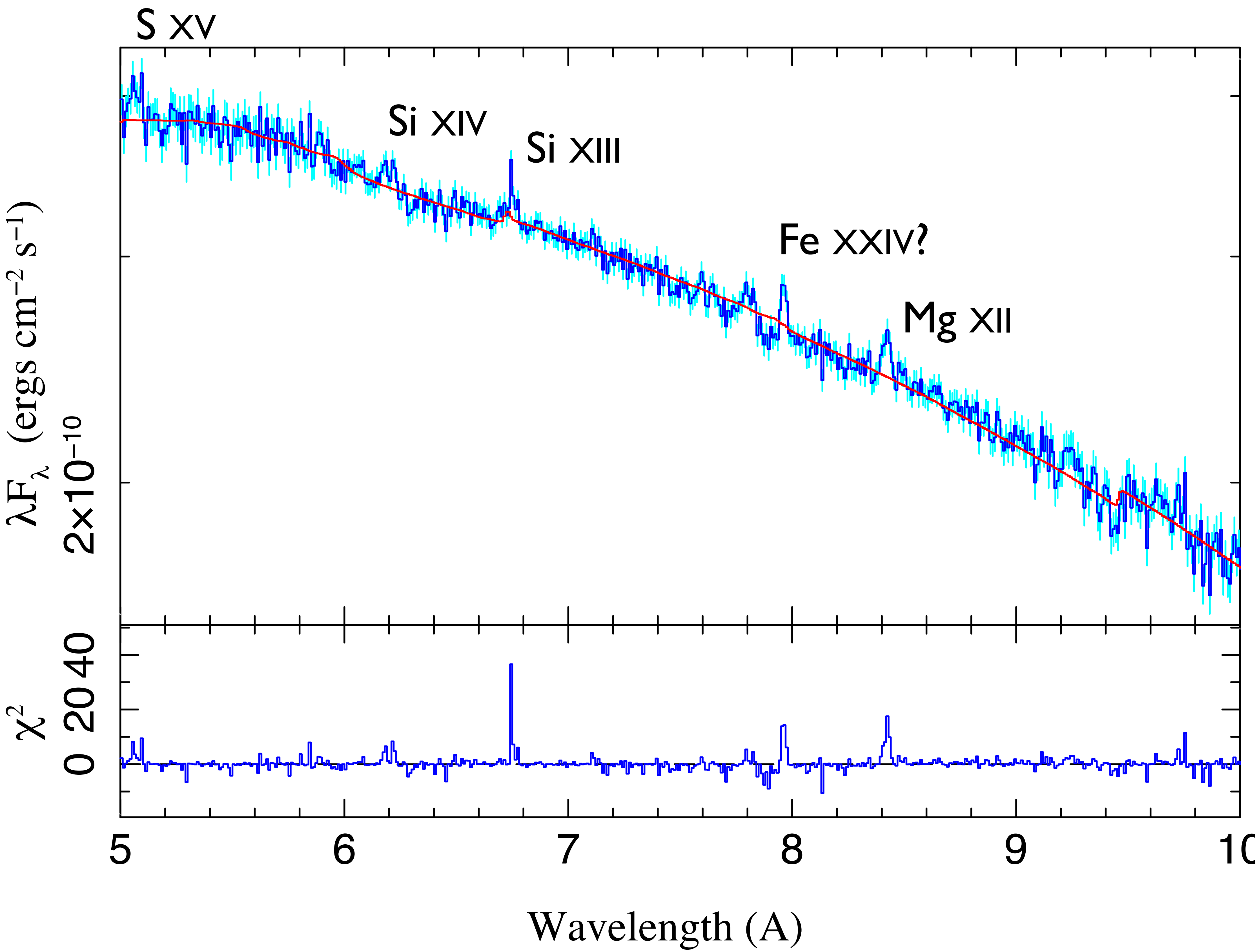
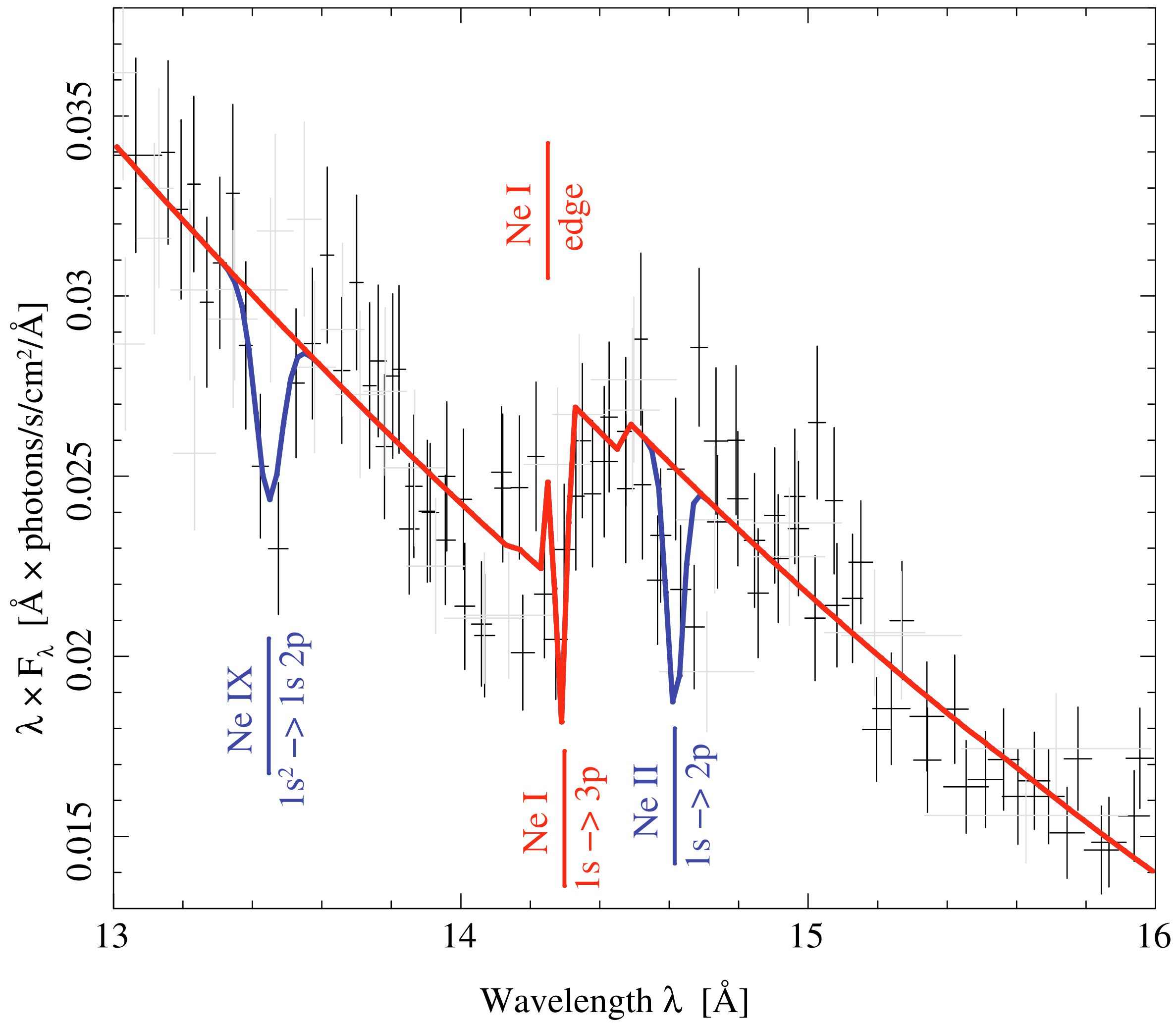


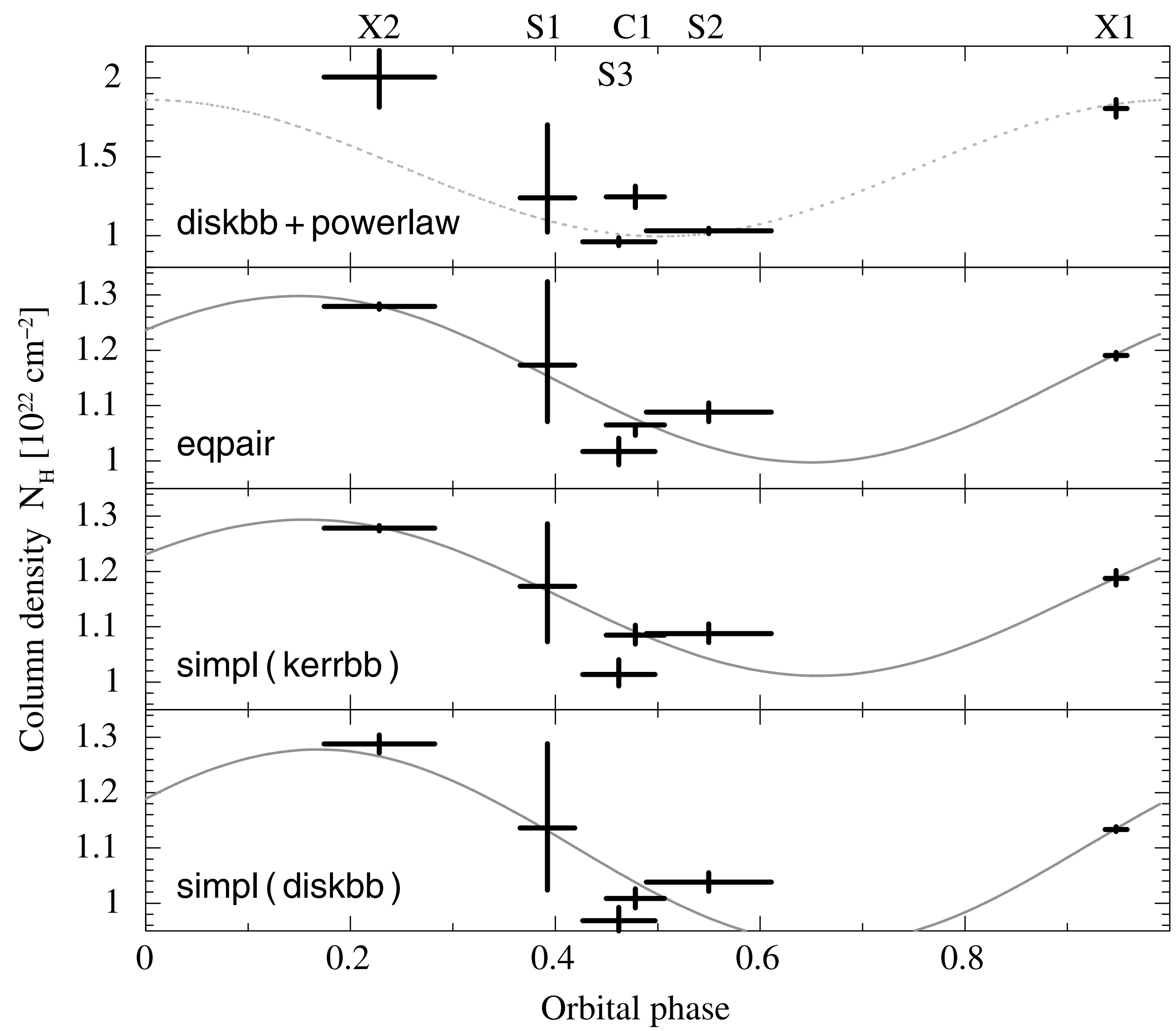
Emission from Secondary



- Velocities are Inconclusive: ≤ 500 km s^{-1}
- Widths: ≈ 500 km s^{-1}
- No Evidence for Orbital Phase-Dependence
- This is in contrast to Cyg X-1
  - Hard State: Orbital Phase-Dependence
  - Soft State: No Lines (Totally Ionized Wind)
  - See Poster # 18 by Ivica Miškovičová

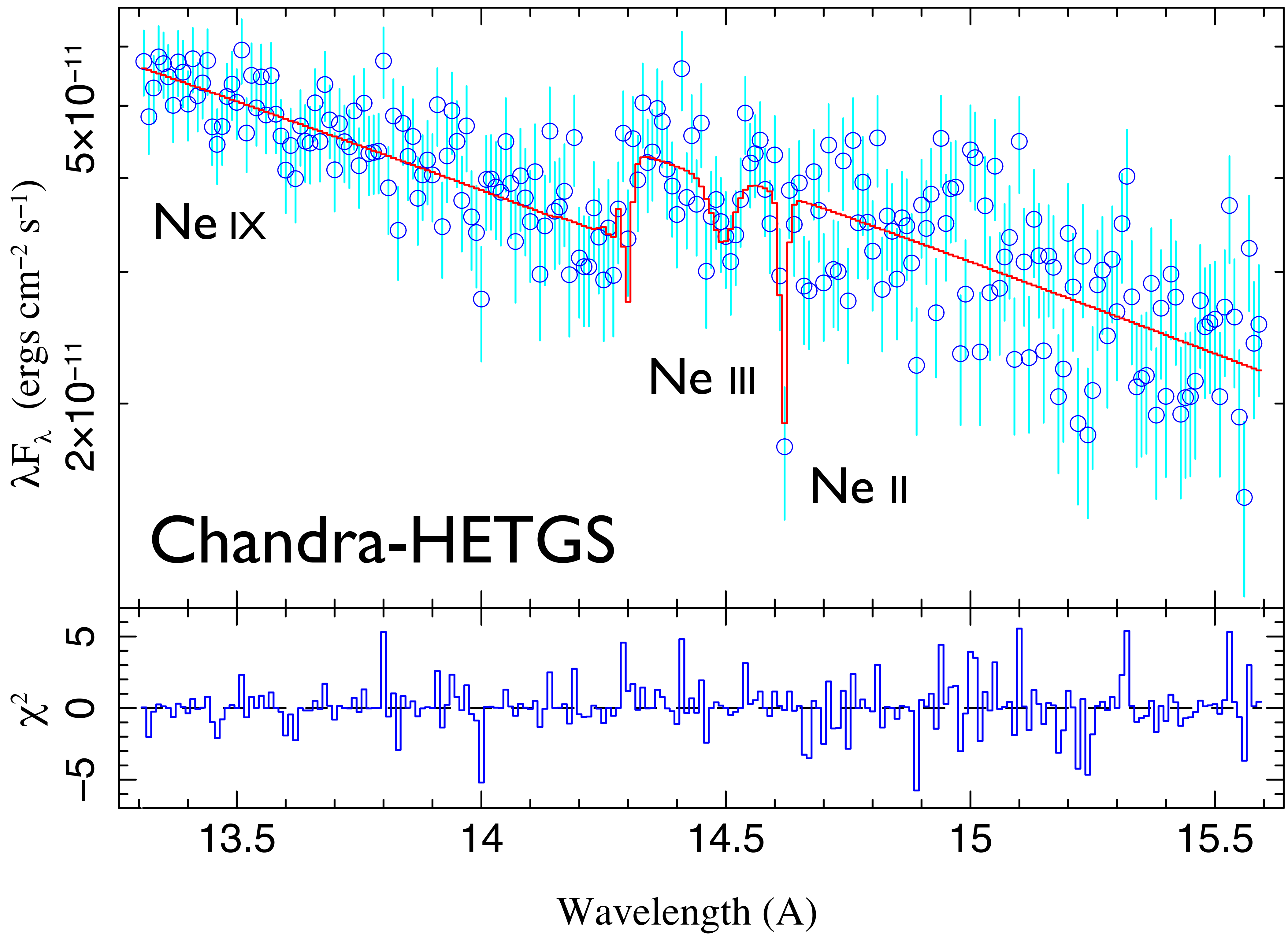
Absorption Edge Structure



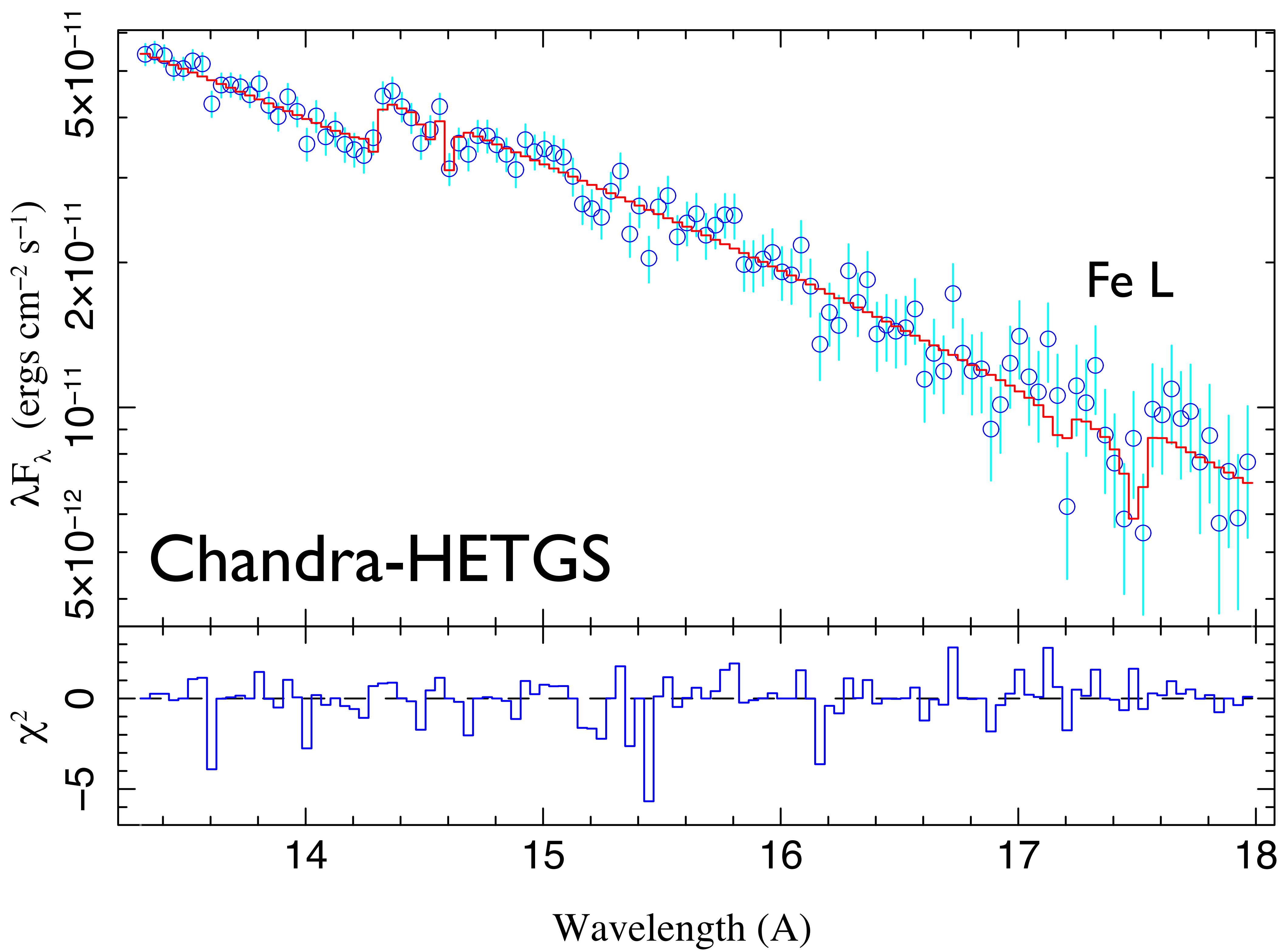


Hanke et al. (2009) - RGS, Epic, Swift, Chandra

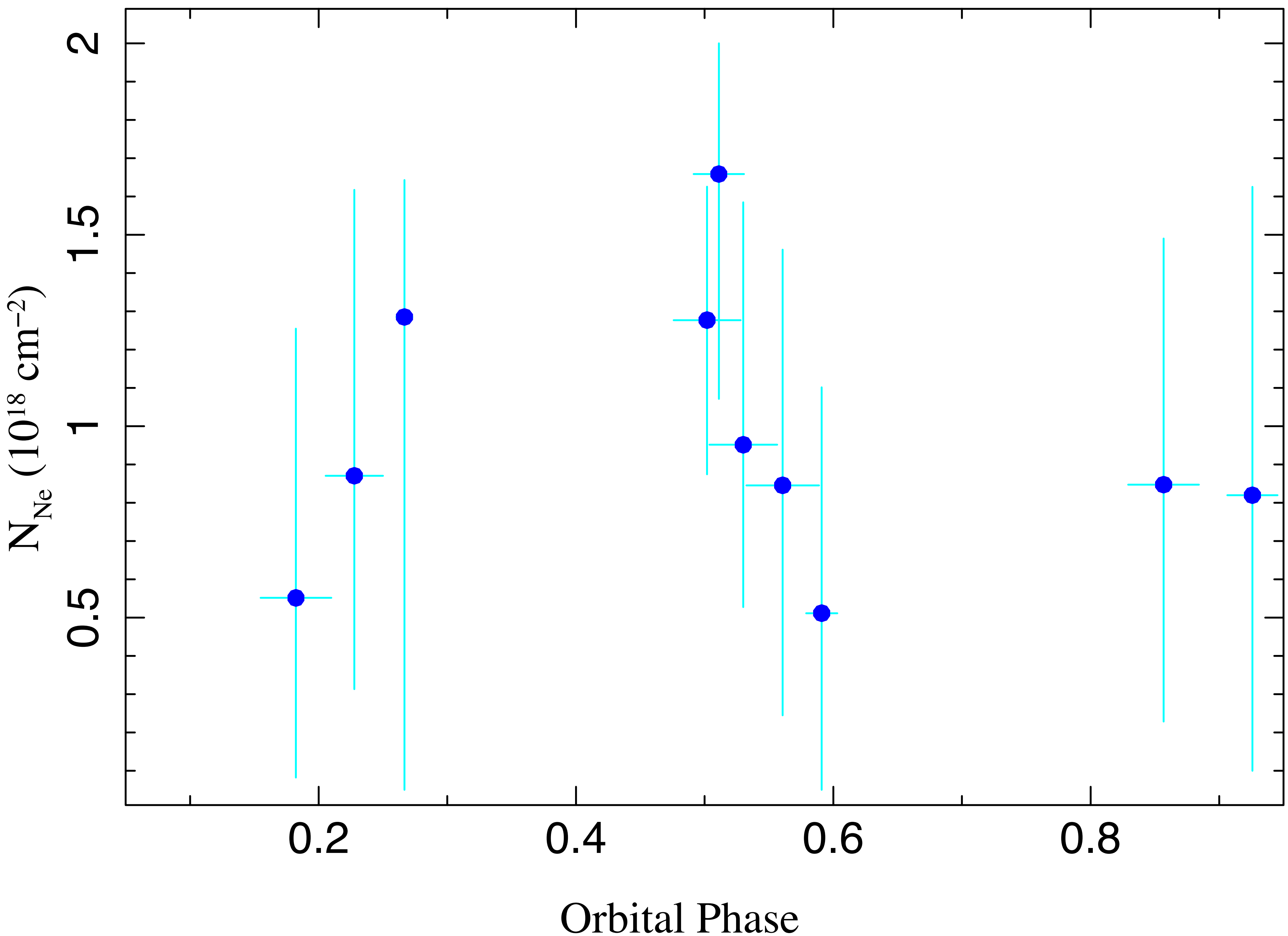
Absorption Edge Structure



Absorption Edge Structure



Absorption vs. Orbital Phase



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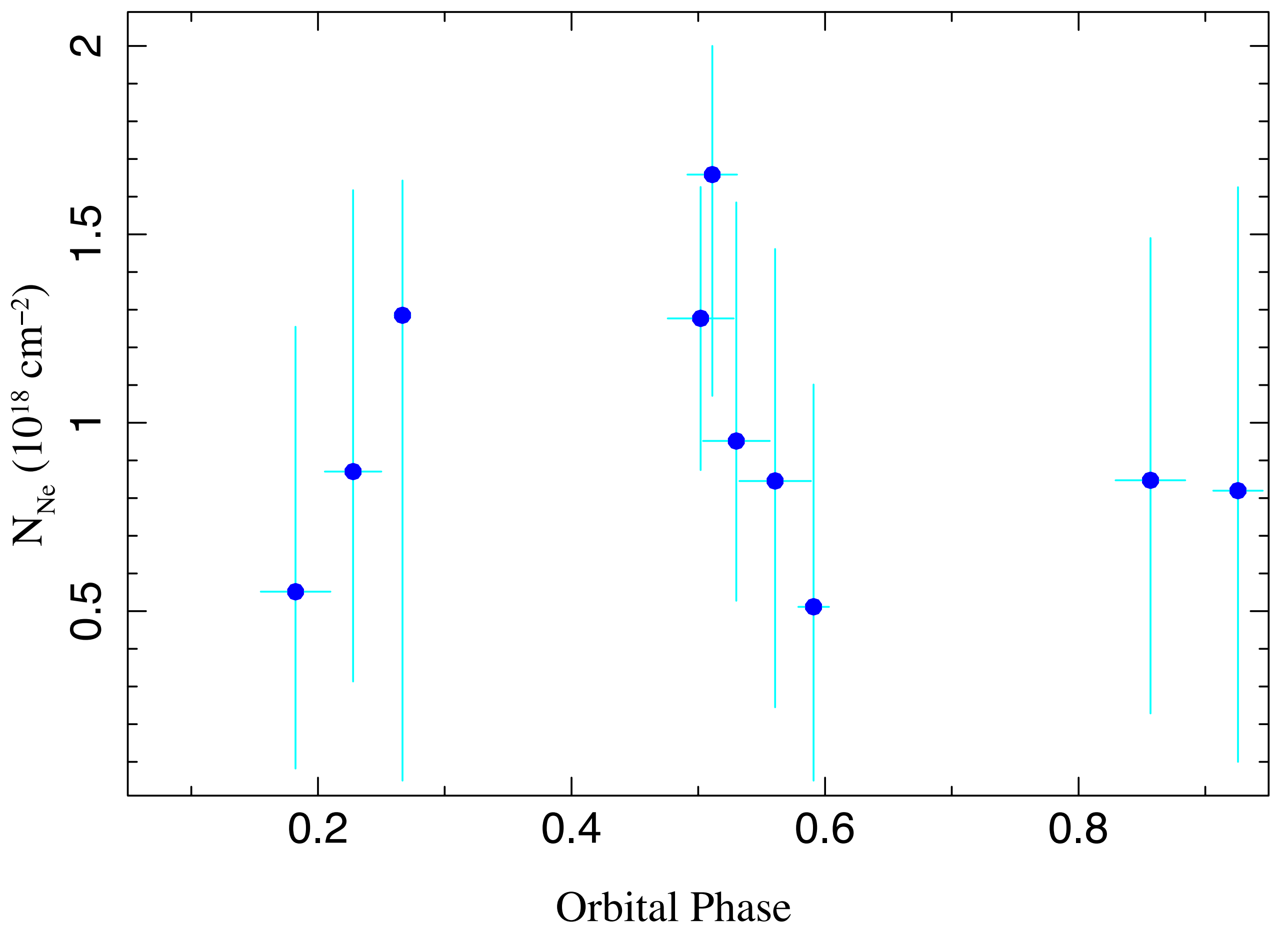
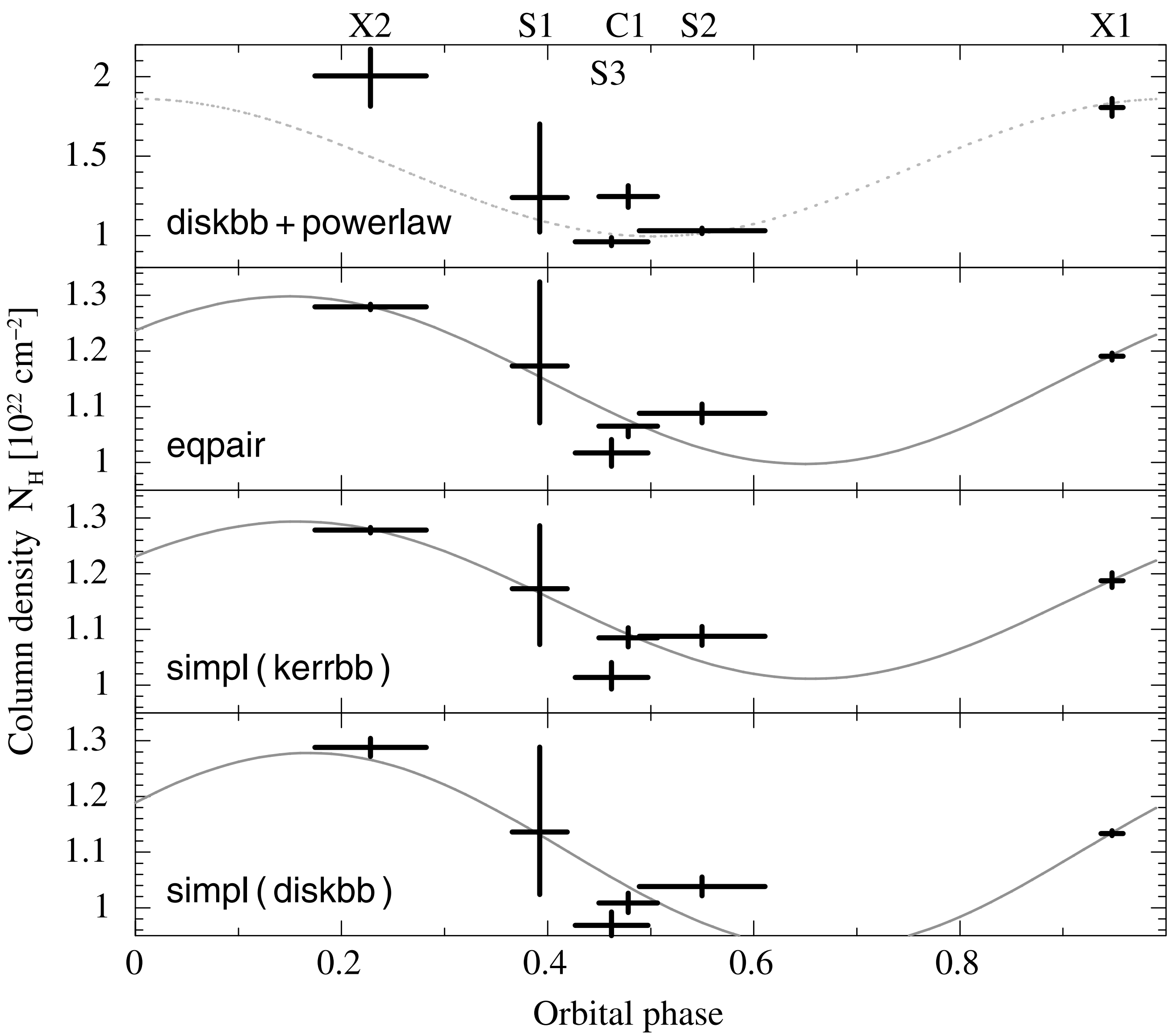
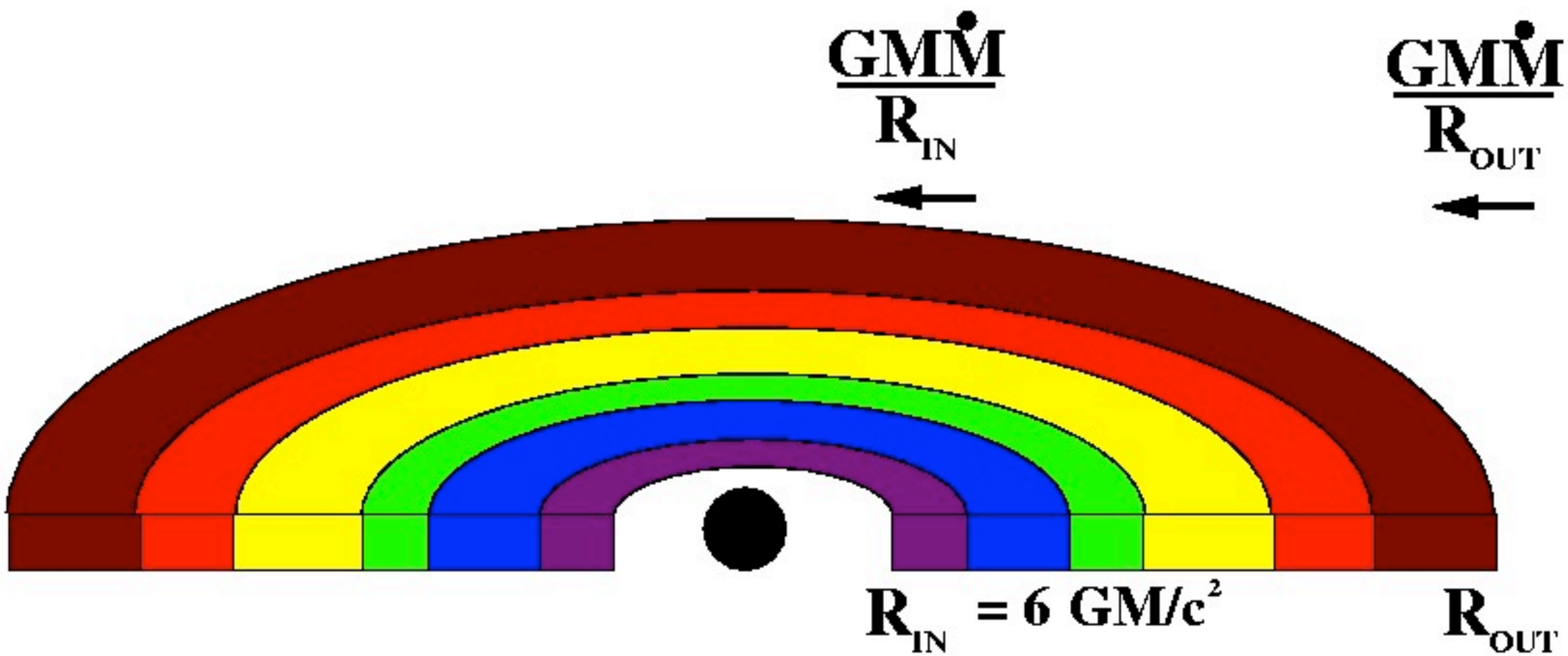


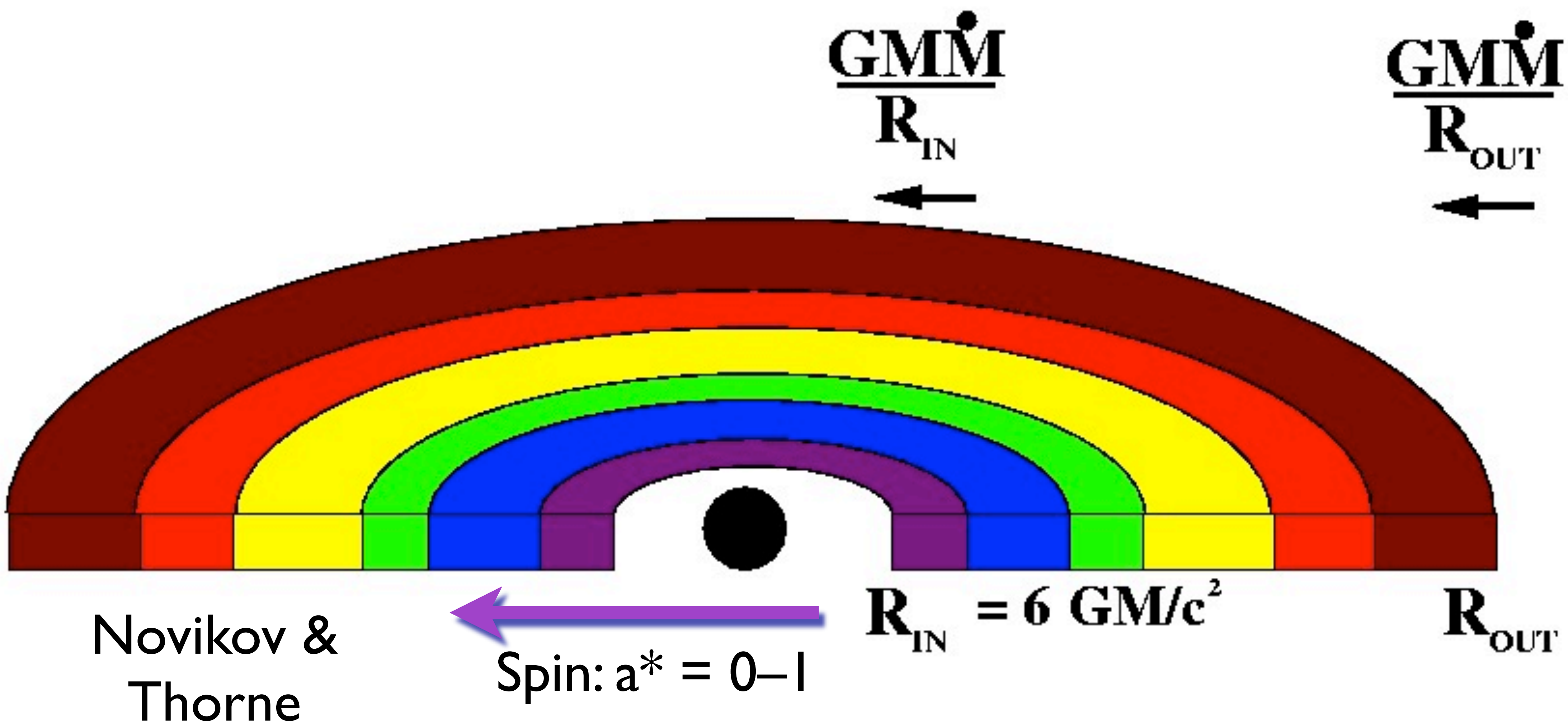


Shakura-Sunyaev Disk



$$F = \frac{3\dot{M}}{8\pi}\Omega^2\left[1 - \beta\left(\frac{R_i}{R}\right)^{1/2}\right]$$

Shakura-Sunyaev Disk



$$F = \frac{3\dot{M}}{8\pi}\Omega^2 \left[1 - \beta\left(\frac{R_i}{R}\right)^{1/2}\right]$$

An Aside on Thermodynamic Efficiency of Radiative Processes

- Blackbody radiation is the "most thermodynamically efficient"

$$\boxed{N_{BB} \propto T_{BB}^3 \ , \ y \equiv \frac{4kT_c}{m_e c^2} \ \max(\tau_{es}, \tau_{es}^2)}$$

- For the same average photon energy, and same total luminosity, non-thermal requires *greater area*

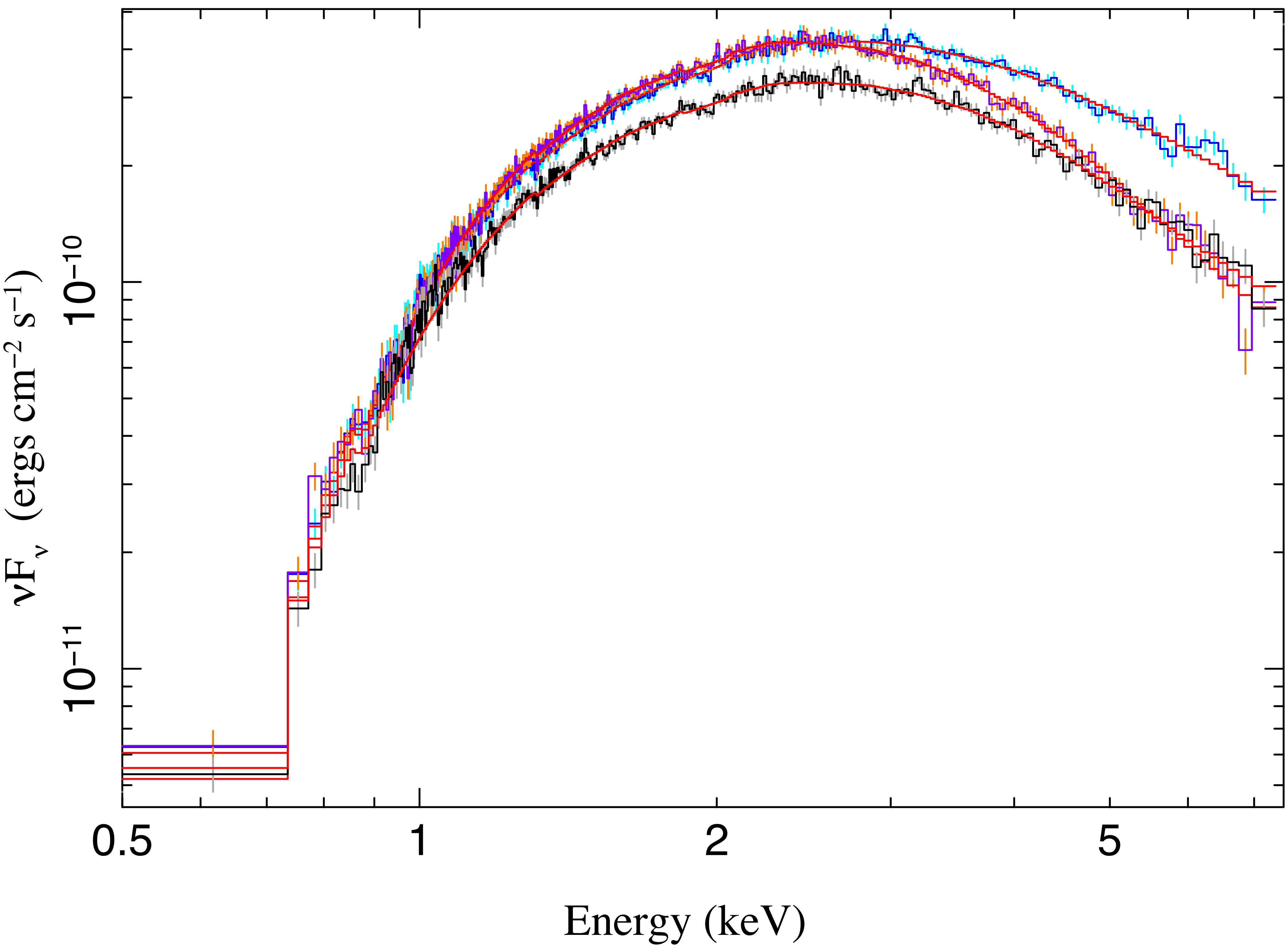
An Aside on Thermodynamic Efficiency of Radiative Processes

- Also true for atmospheric electron scattering: "Modified Blackbody"

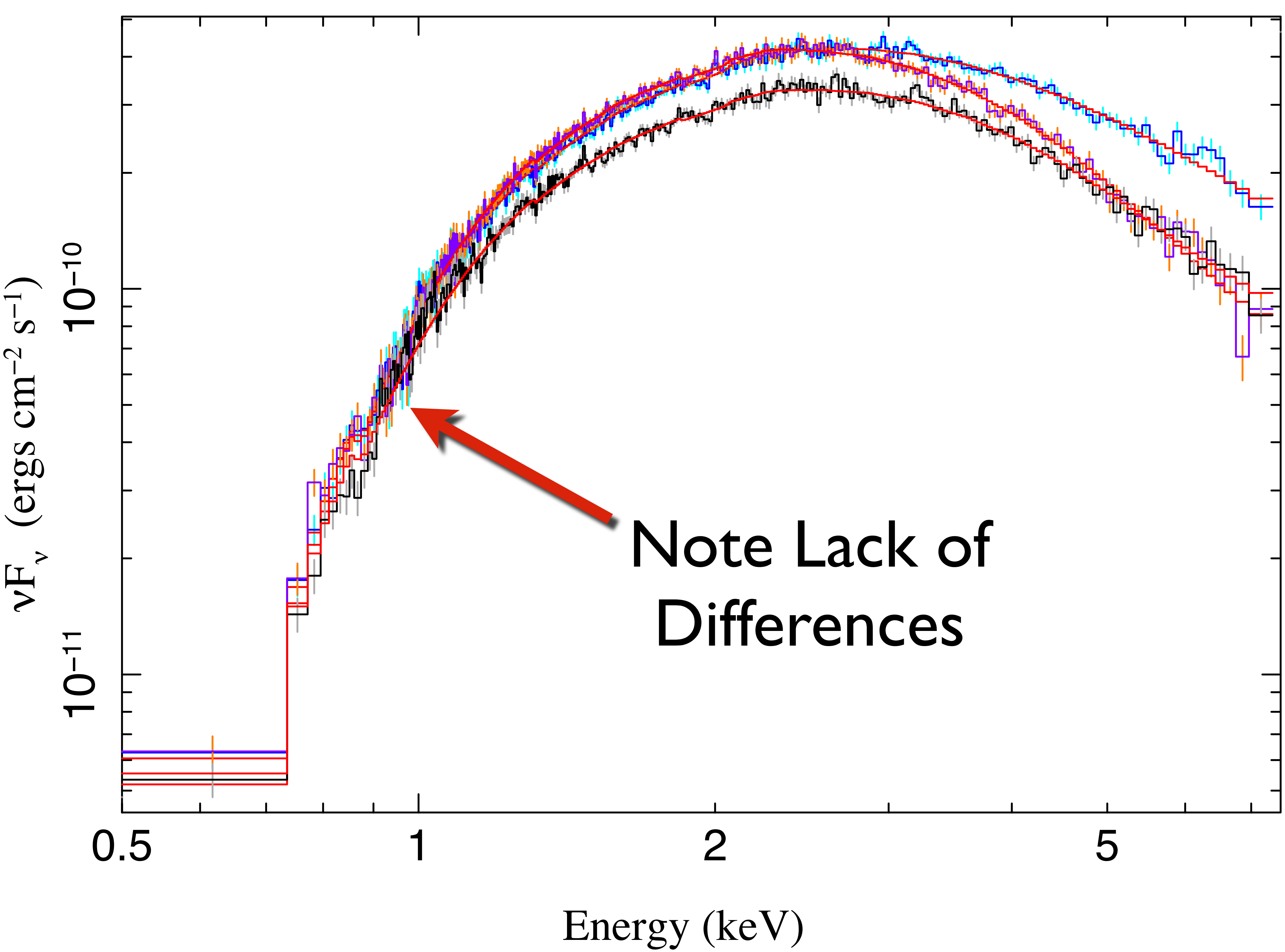
$$\boxed{F \sim \sigma T^4 \left(\frac{\kappa_R}{\kappa_{es}}\right)^{1/2} \quad , \quad \kappa_R \ll \kappa_{es}}$$

- "Color Correction": $T_C = f_C T_{Eff}$, $f_C > 1$, Area scales as f_C^4
- Essentially any "correction" means the area is bigger than required for just blackbody

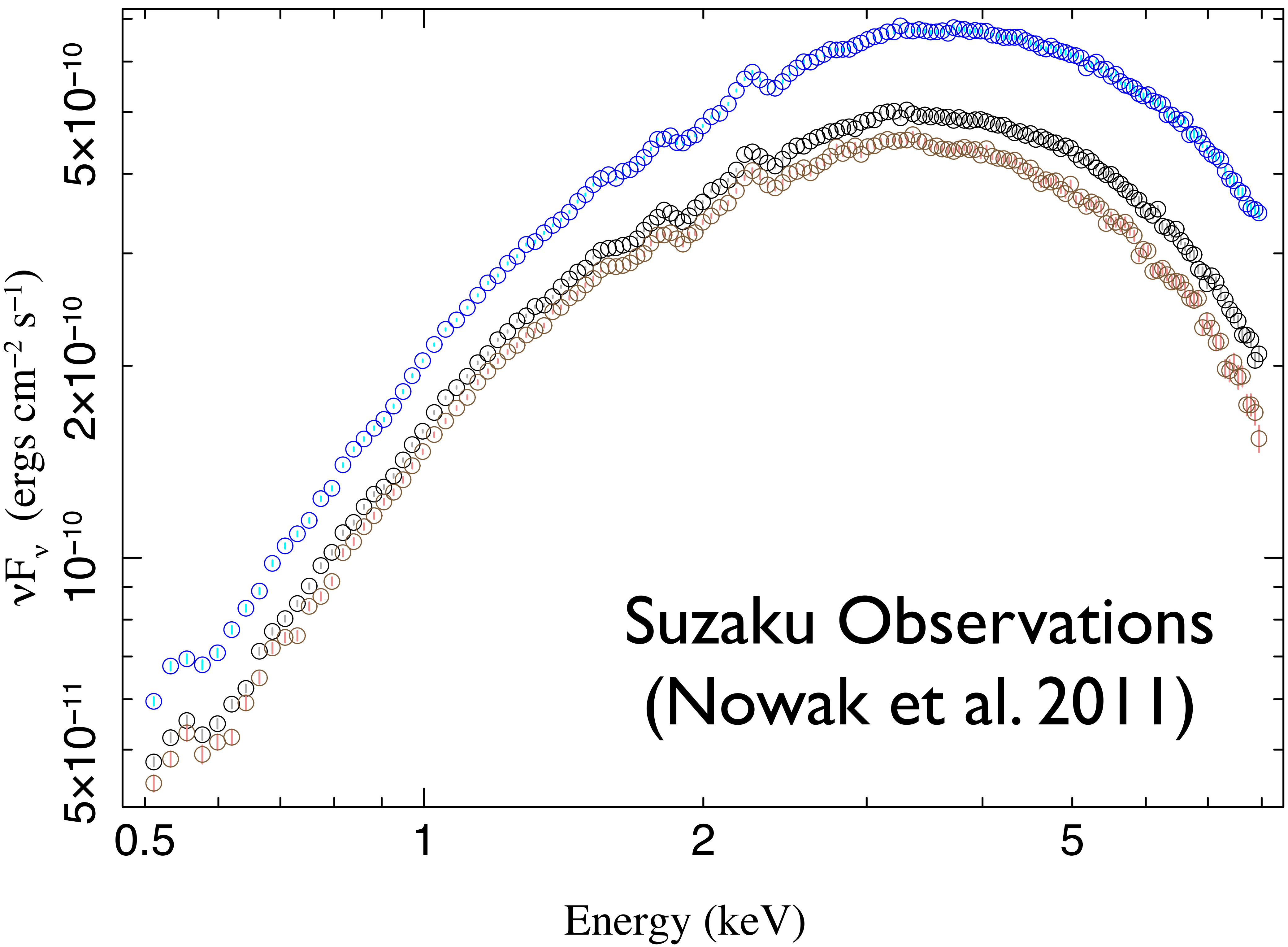
LMC X-1 HETGS Spectra



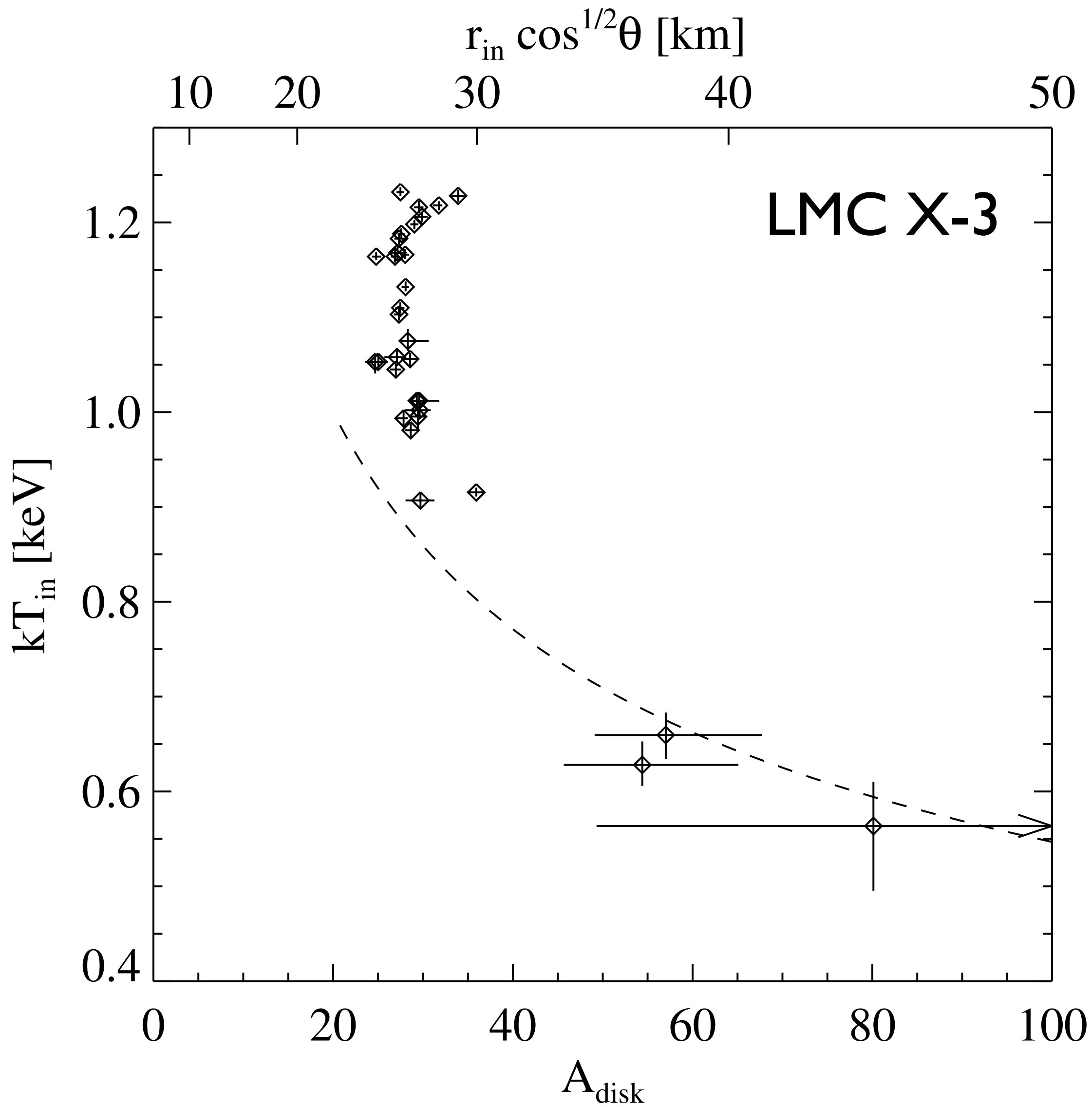
LMC X-1 HETGS Spectra

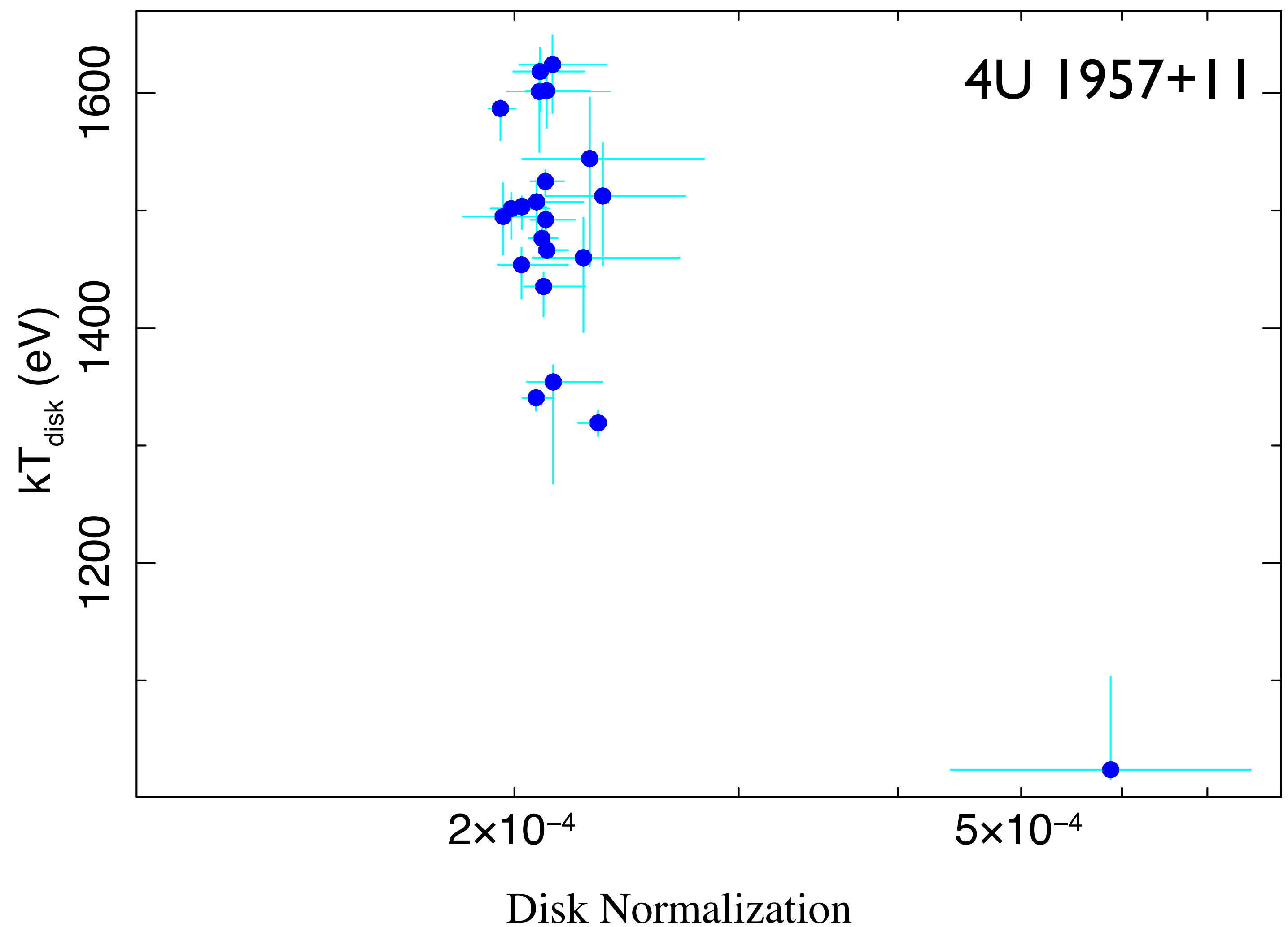


Contrast to 4U 1957+11



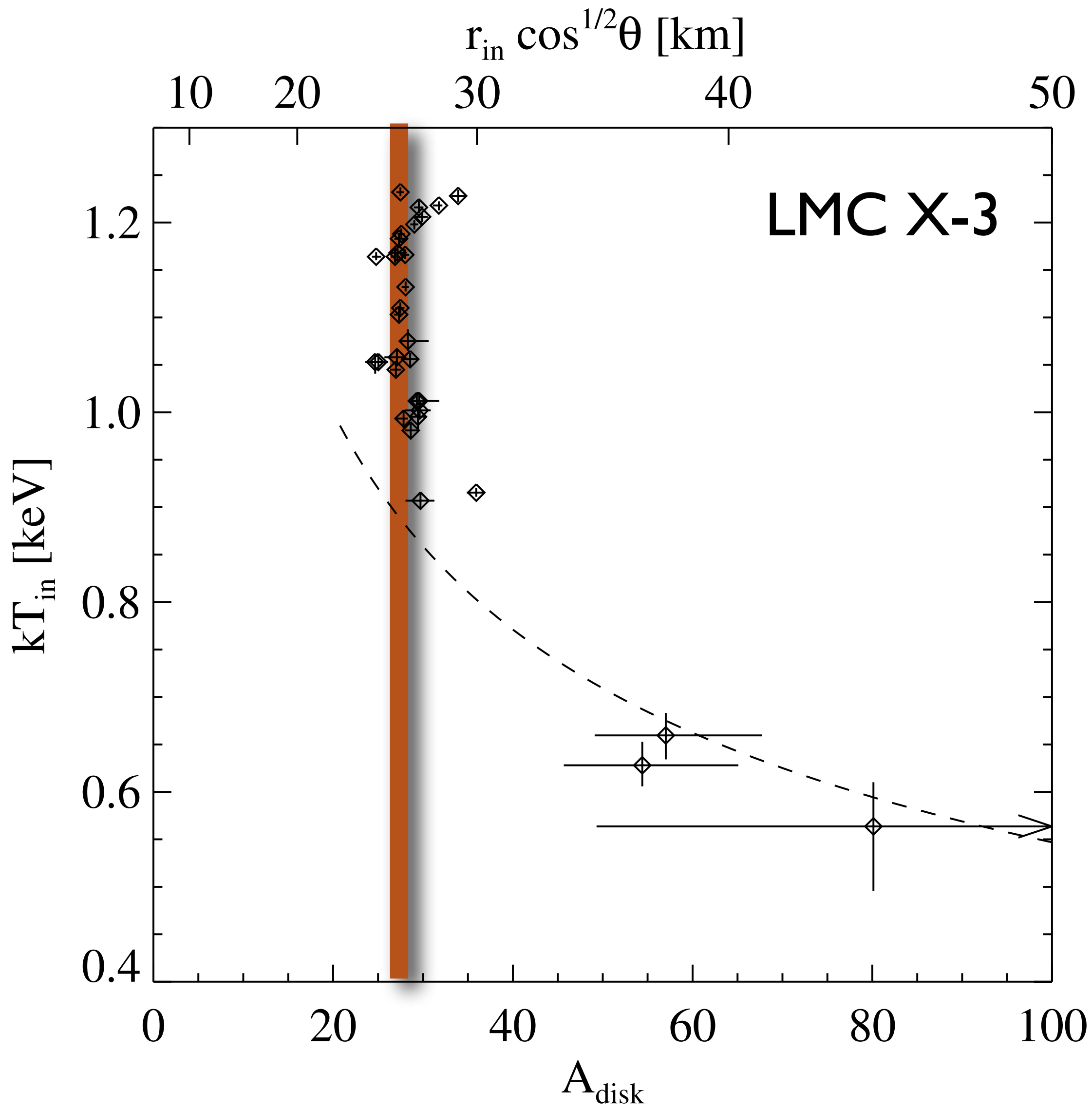
Soft State = Constant Radius

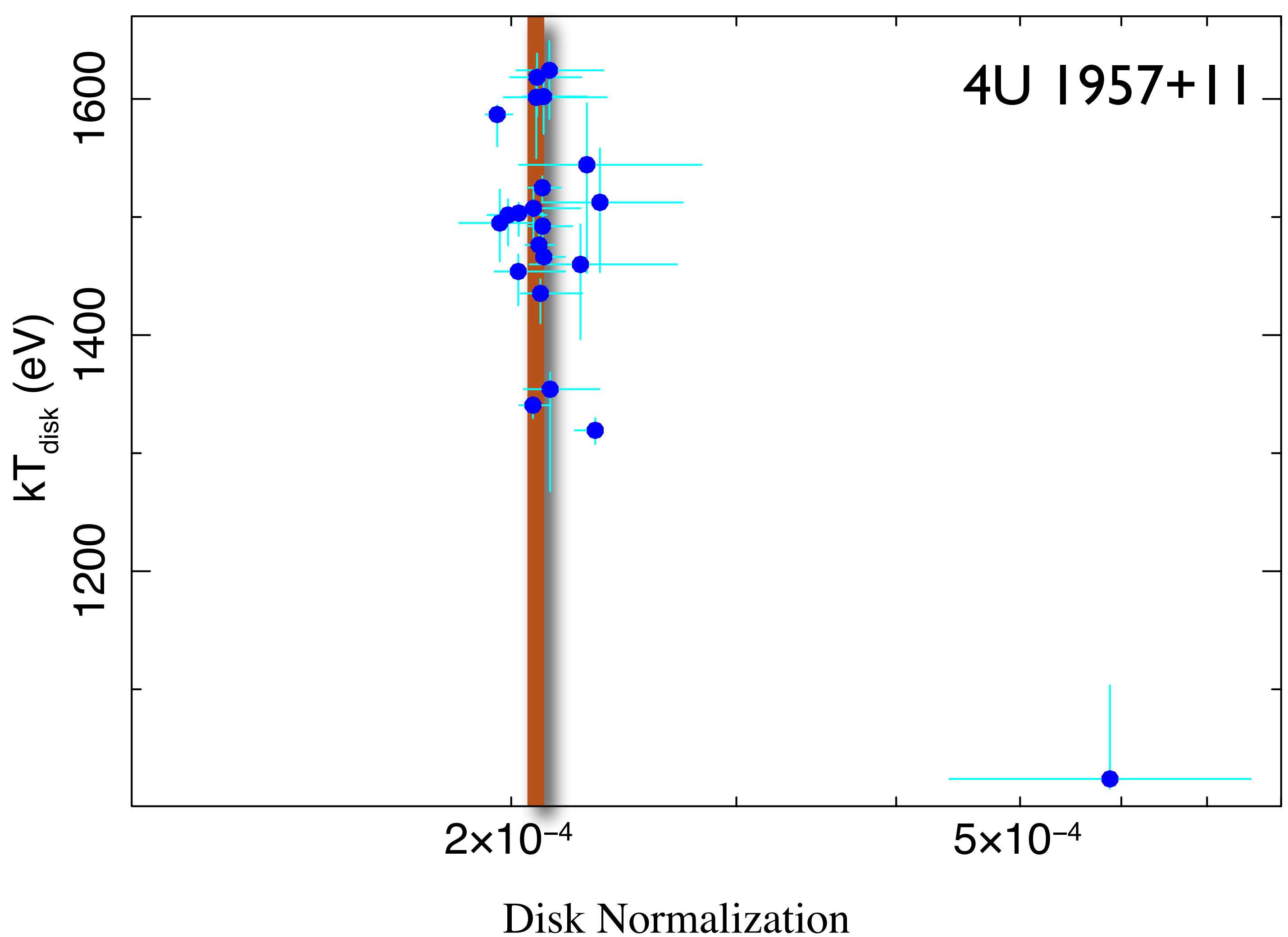




RXTE Observations (Wilms et al. 2001, Nowak et al. 2008)

Soft State = Constant Radius





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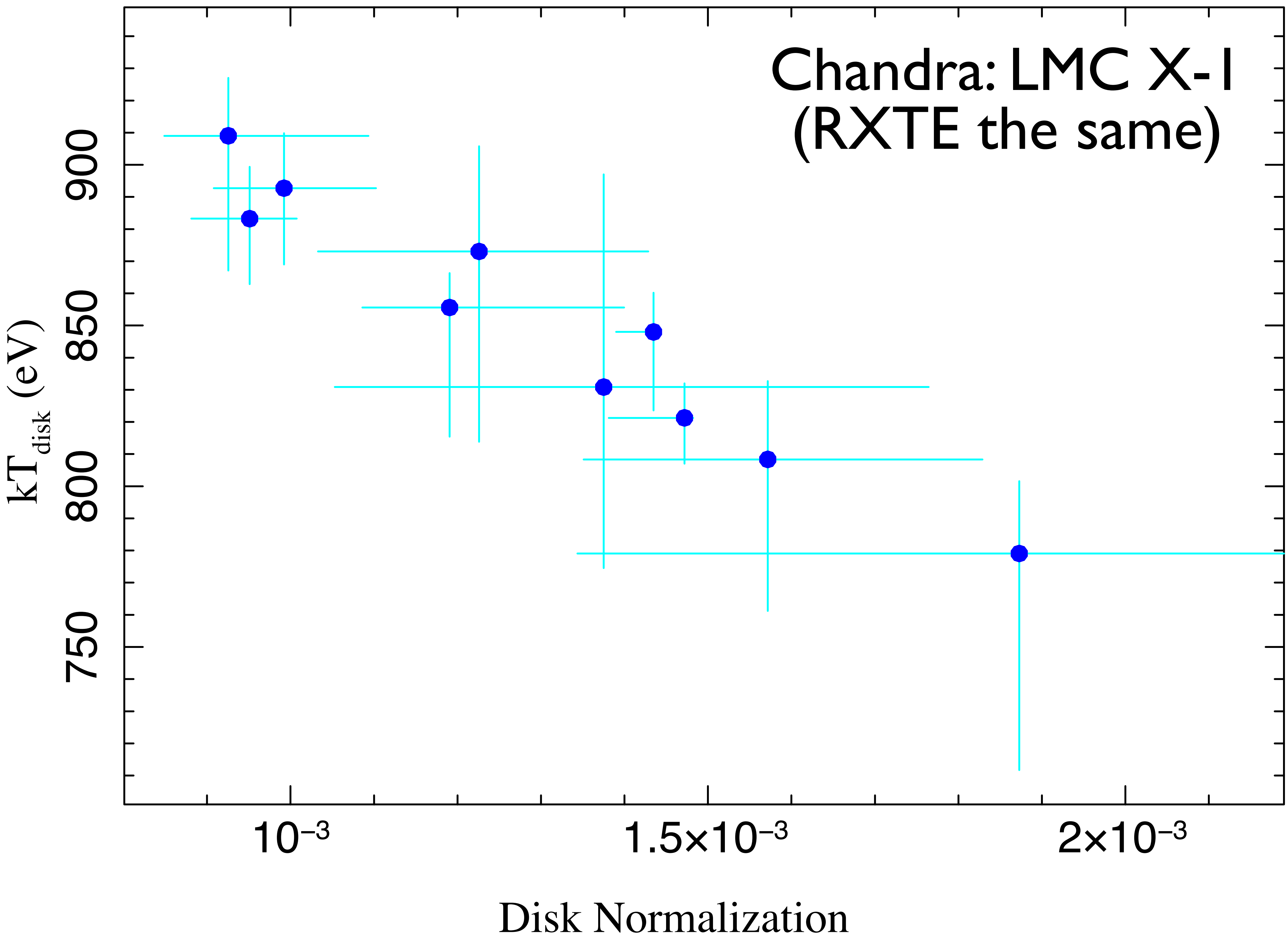
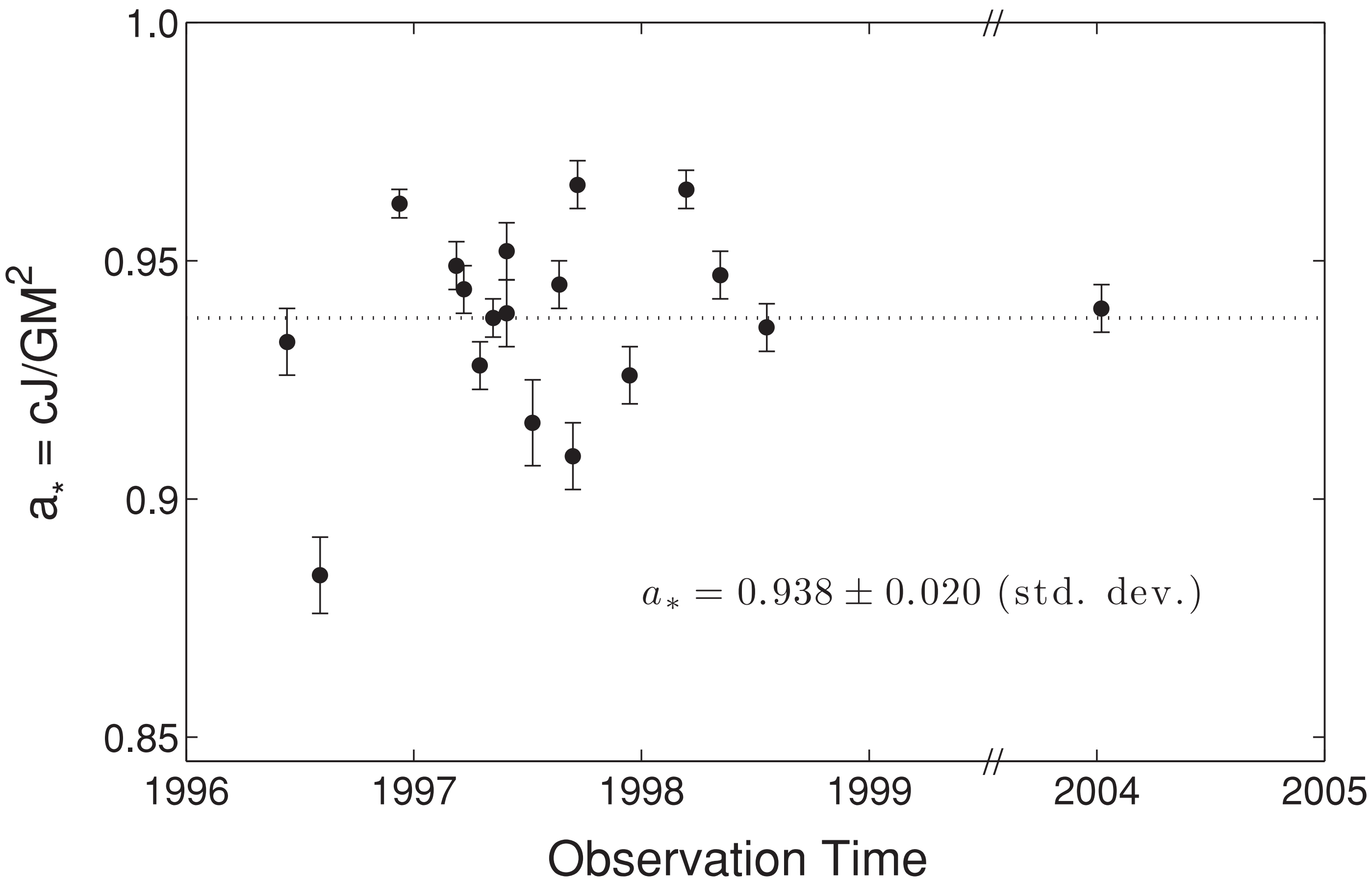
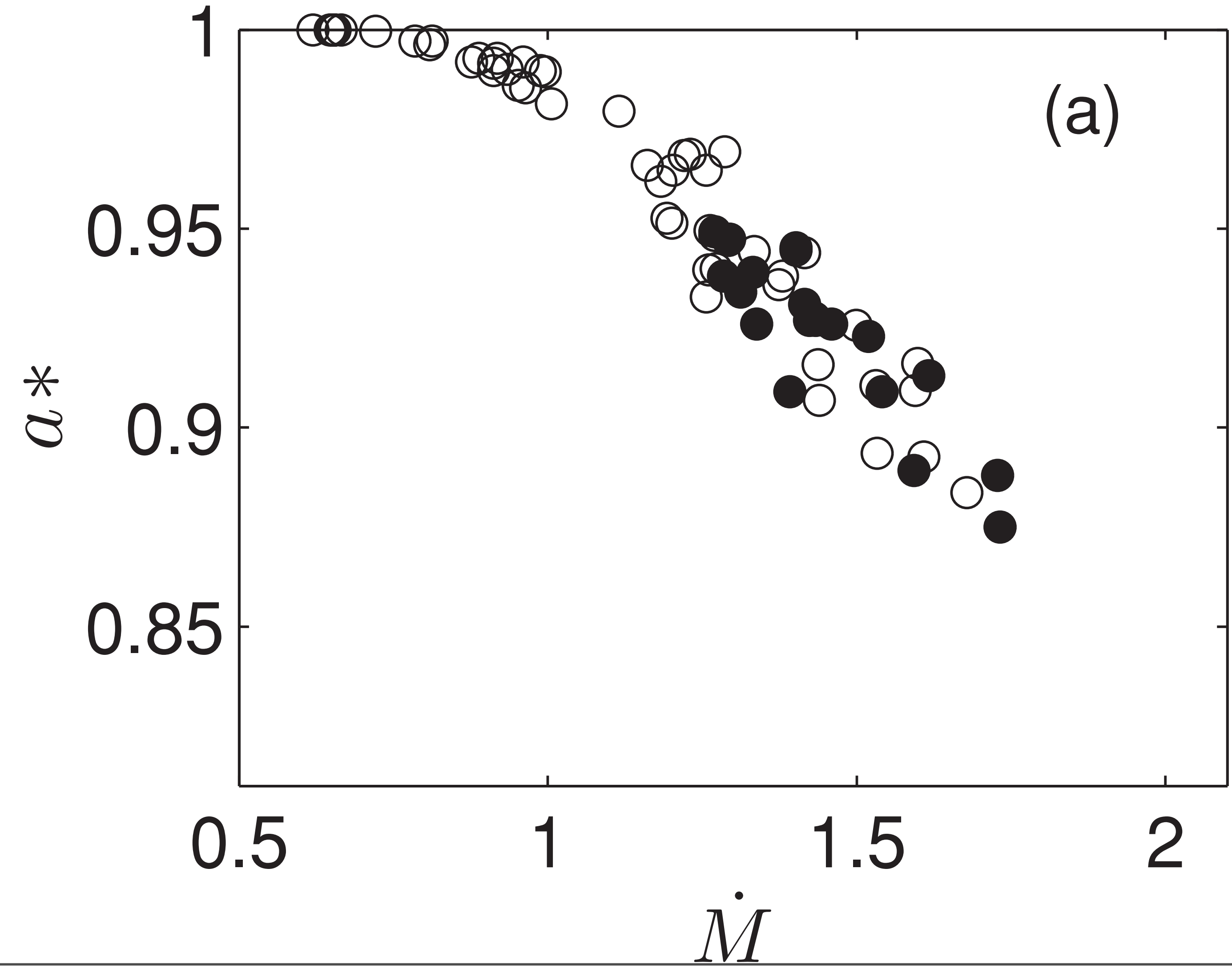


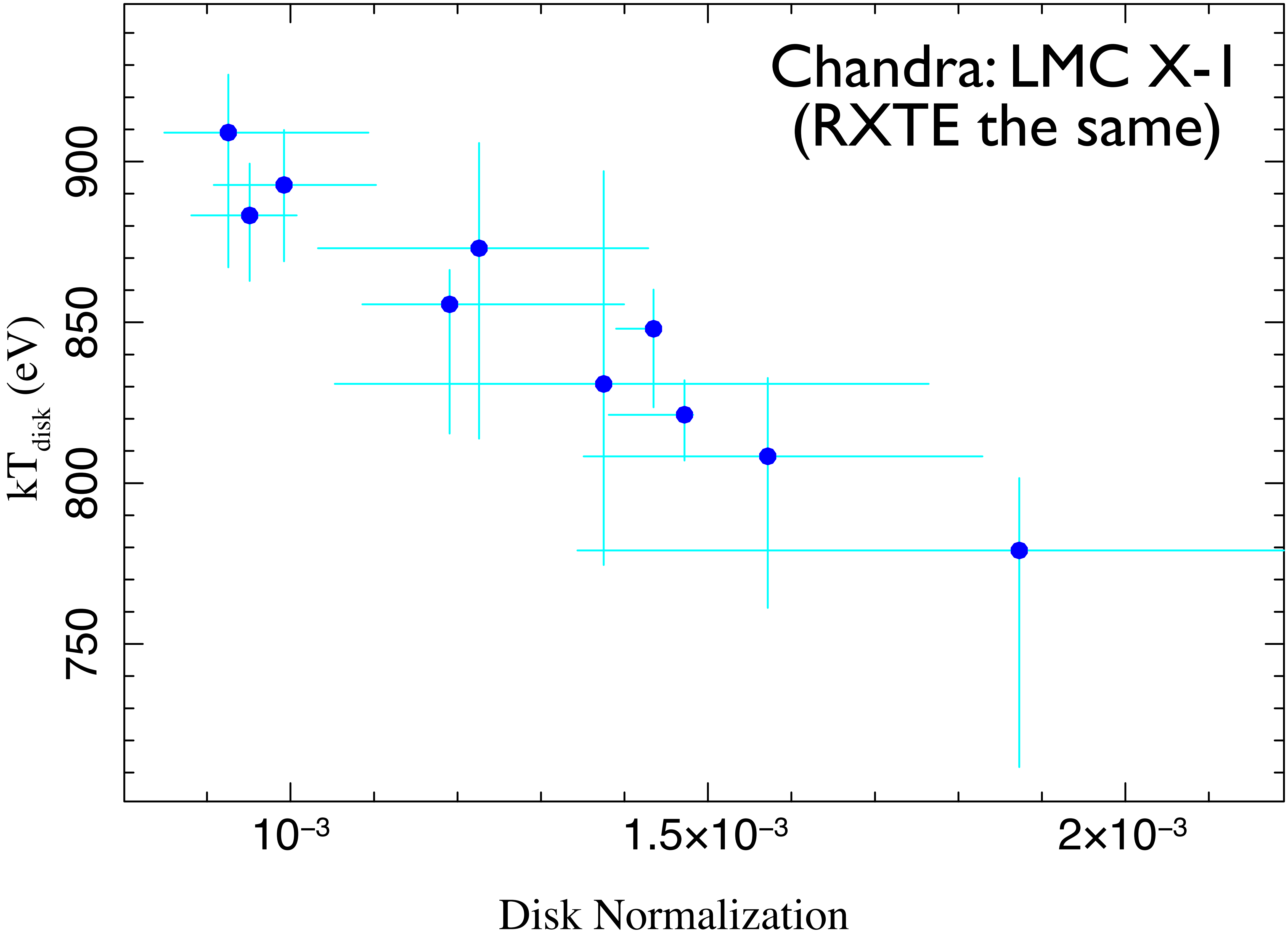
(Wilms et al. 2001, MNRAS, 320; Nowak et al. in prep)





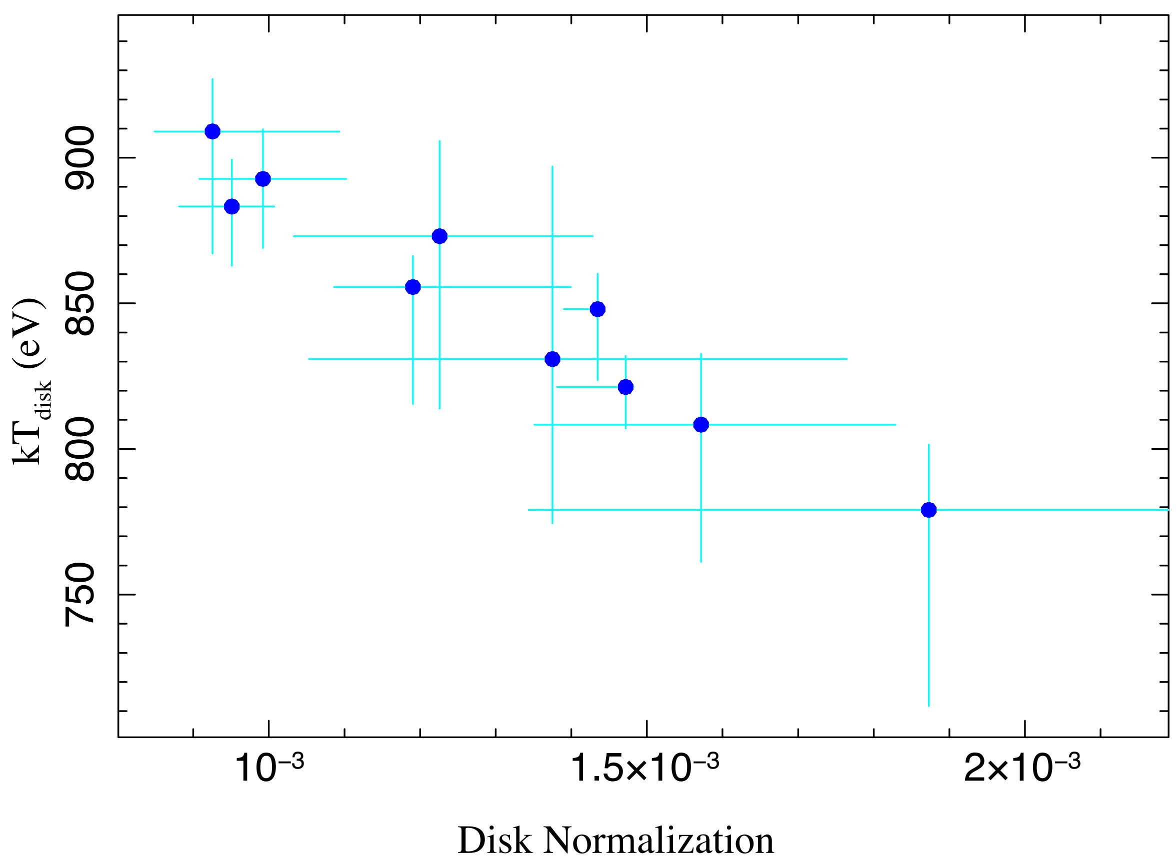
Gou et al. (2009) - Spin fits really are a comment on emitting area – for a given fitted temperature, small emitting area

RXTE Data



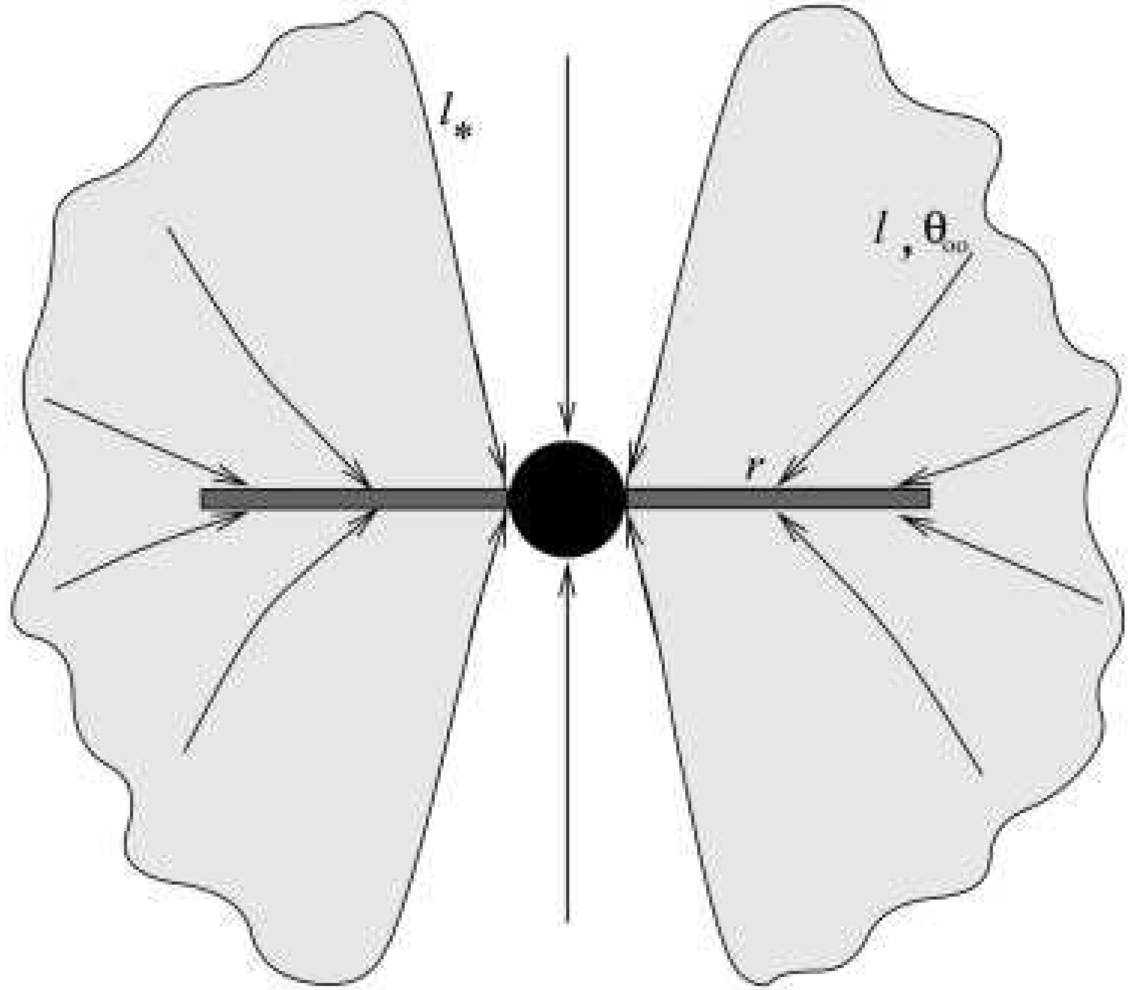
(Wilms et al. 2001, MNRAS, 320; Nowak et al. in prep)

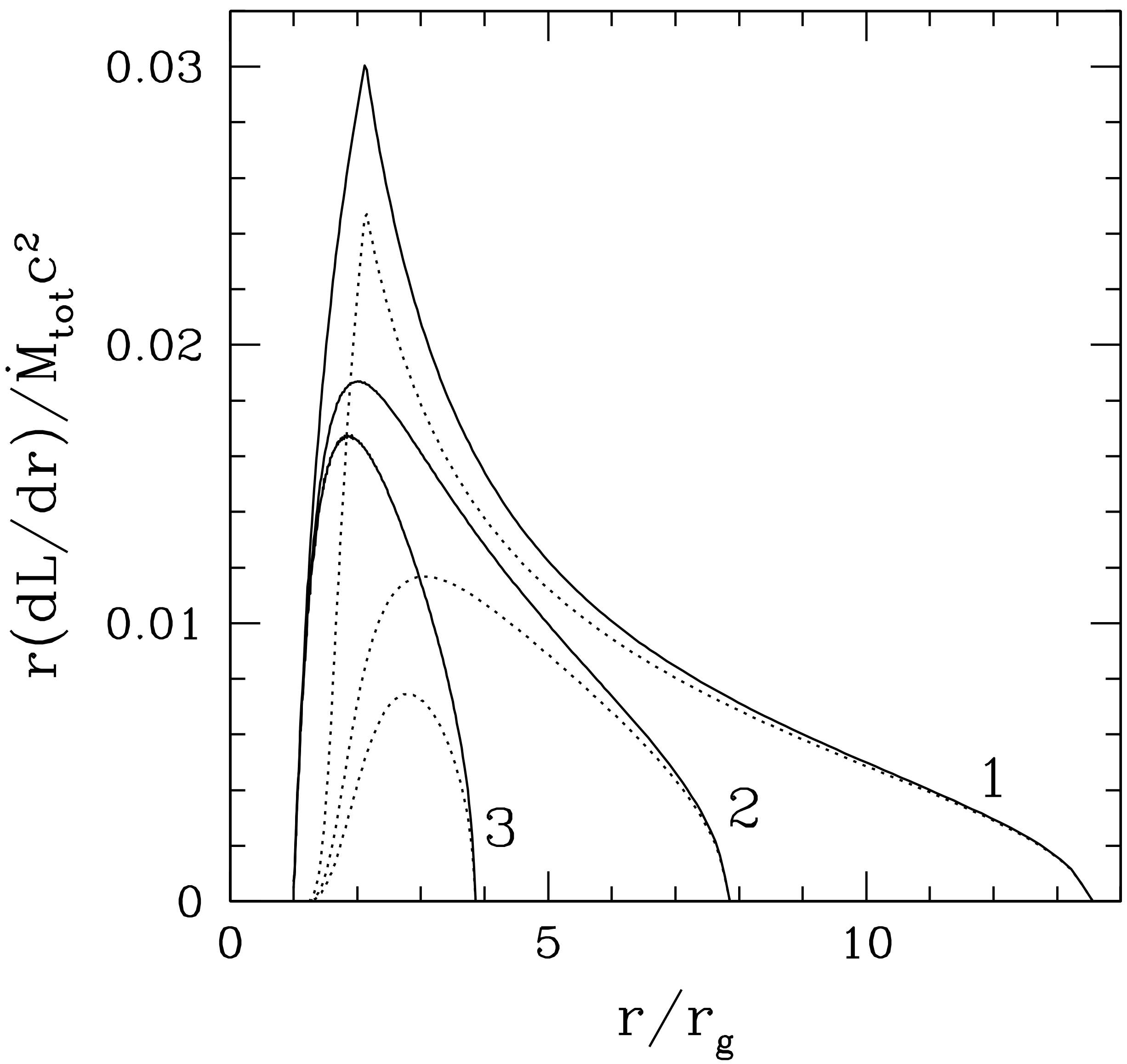
Chandra: LMC X-1
(RXTE the same)



(Wilms et al. 2001, MNRAS, 320; Nowak et al. in prep)

Is This Because it's Wind-Fed?



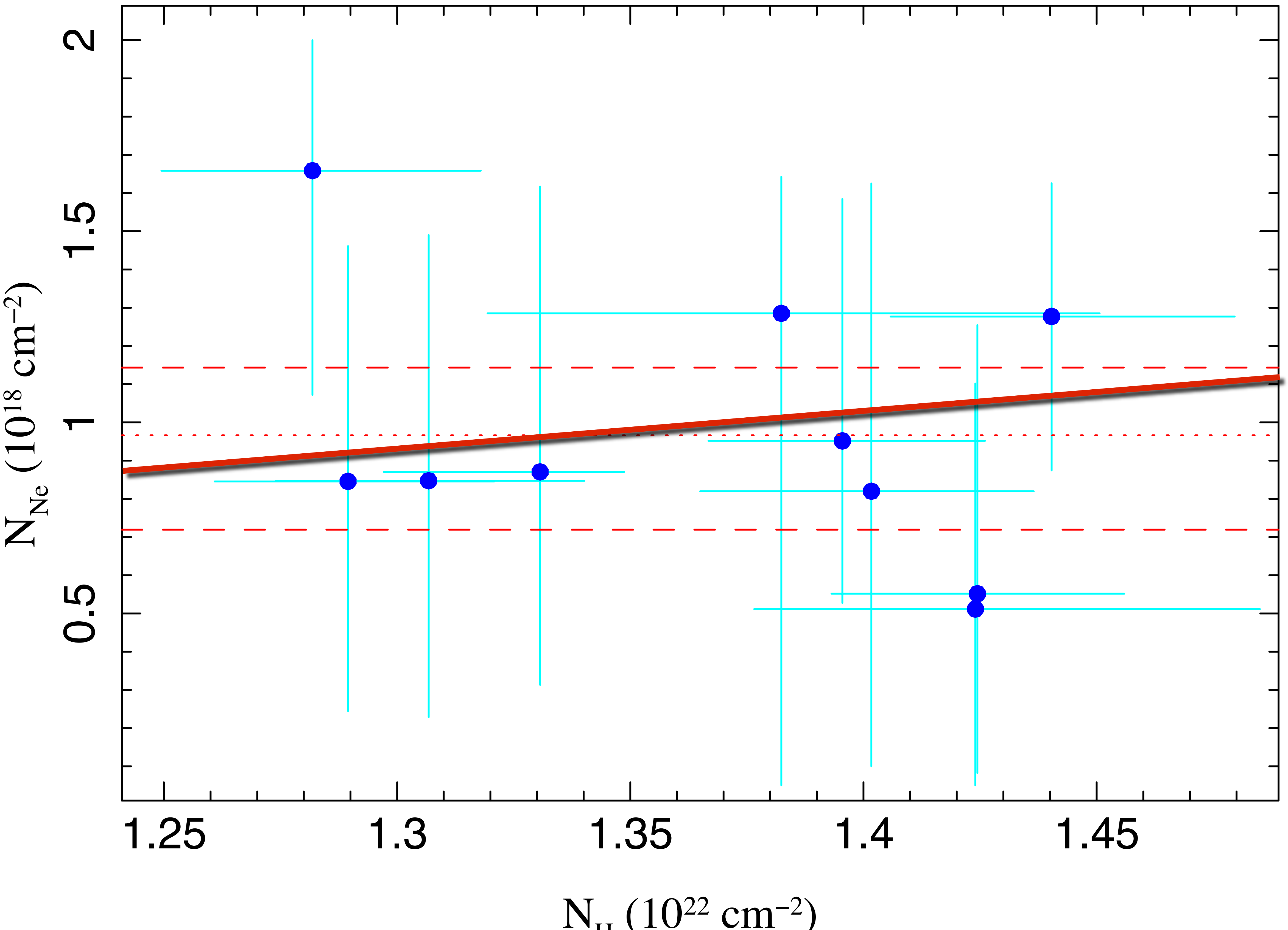


Beloborodov & Illiaronov (2001)

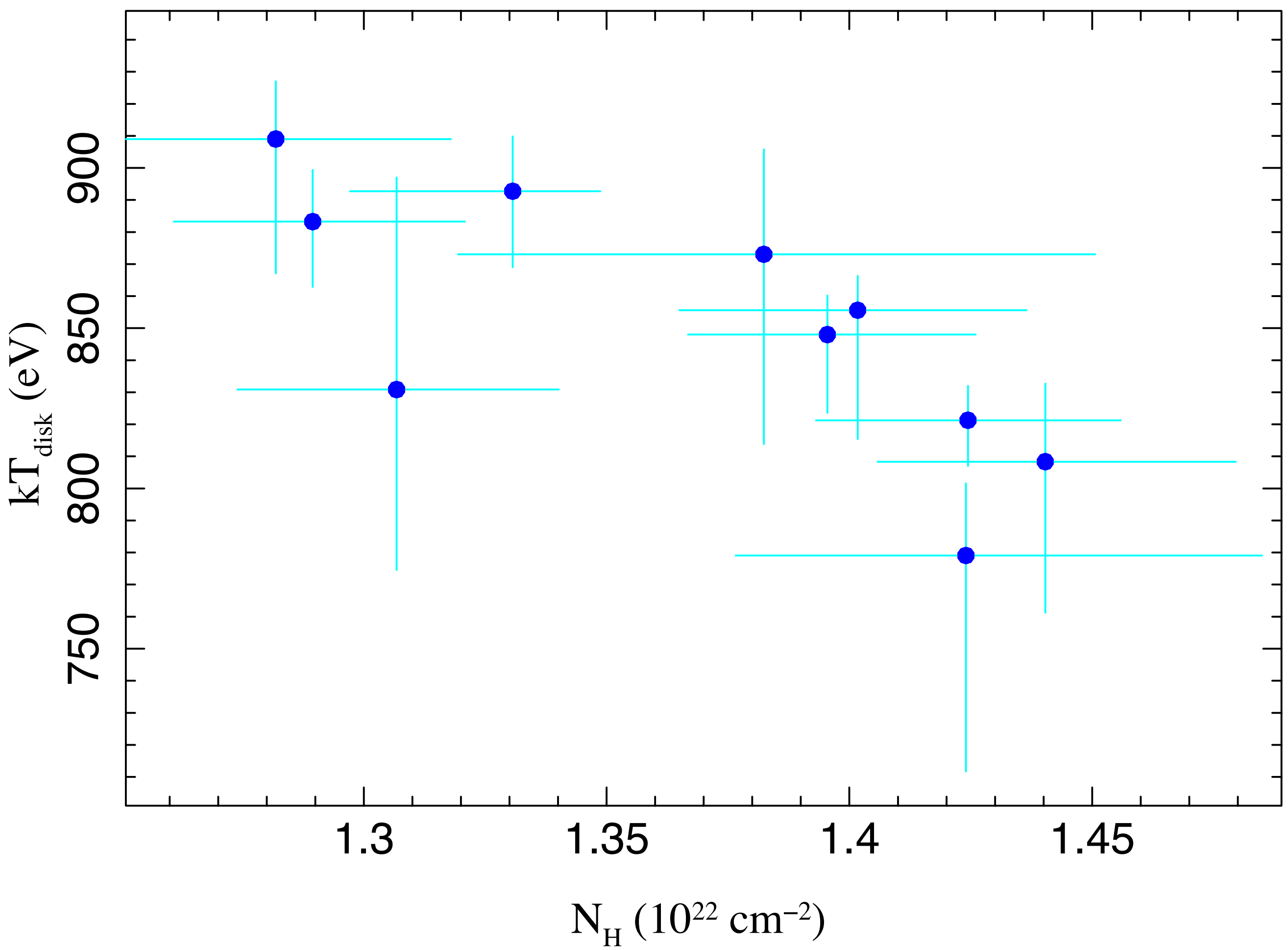
Summary

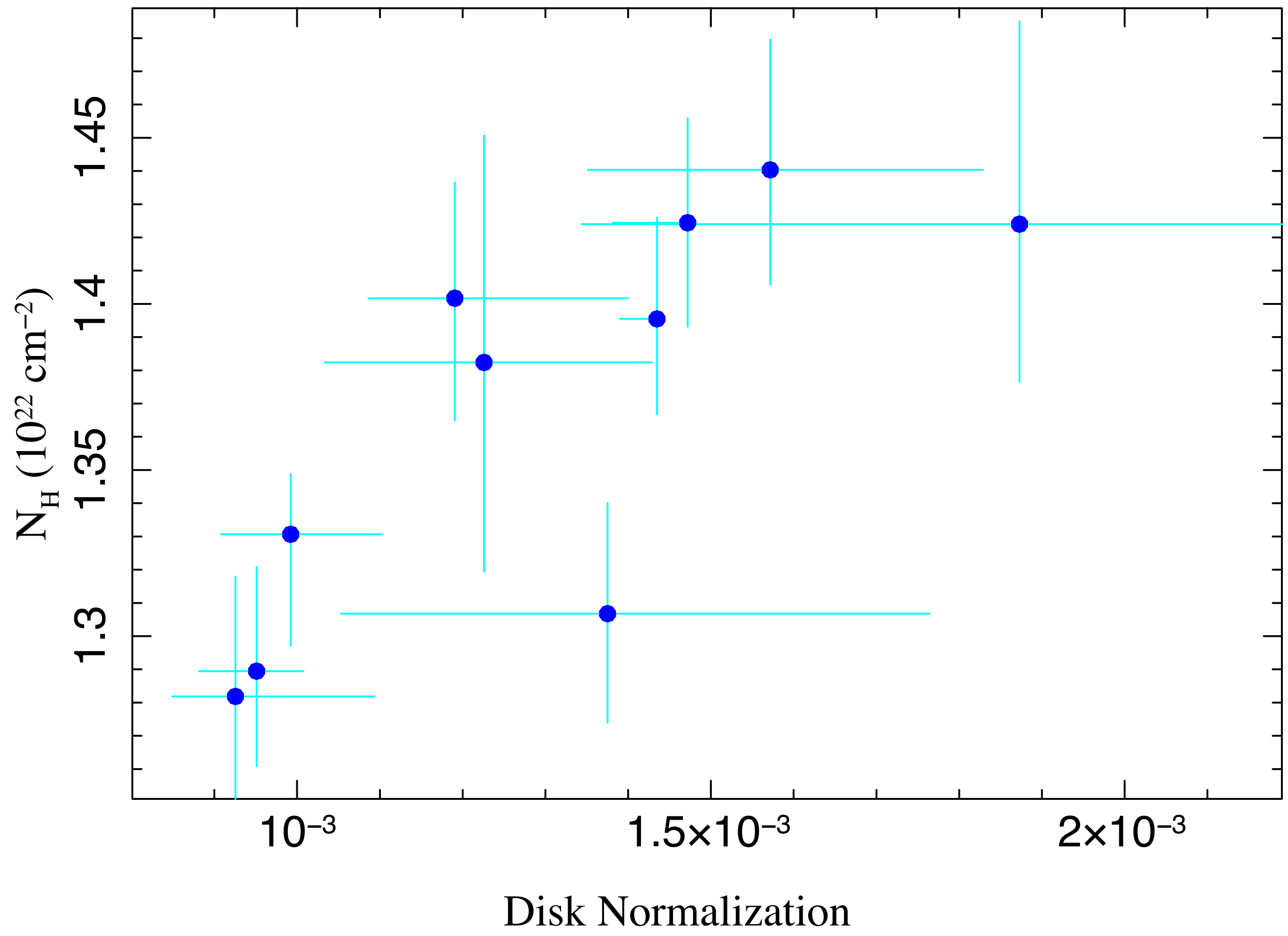
- See Emission Lines at All Orbital Phases, Despite High, Soft Flux => Strong Wind
- See Absorption Stronger than ISM, with Large Variability => Strong Wind
- "Disk" Has a Small, and Highly Variable, Emitting Area => Strong Wind?

— Extra Slides —


2
1.5
1
0.5
N_{Ne} (10^{18} cm^{-2})
1.25
1.3
1.35
1.4
1.45
N_H (10^{22} cm^{-2})

Disk-Absorption Correlations





Disk-Corona Correlations