Chandra-HETGS Observations of LMC X-1

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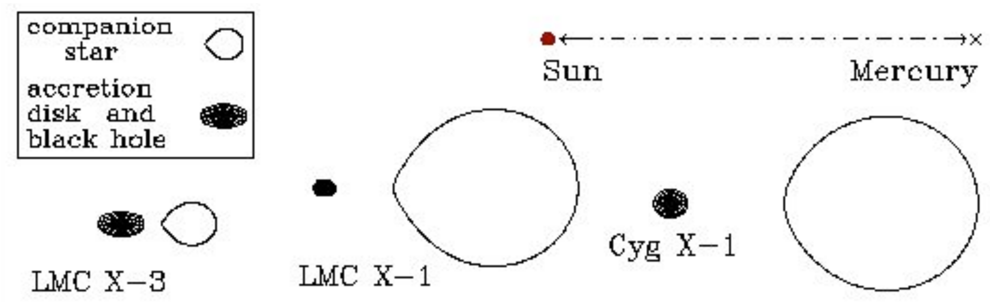
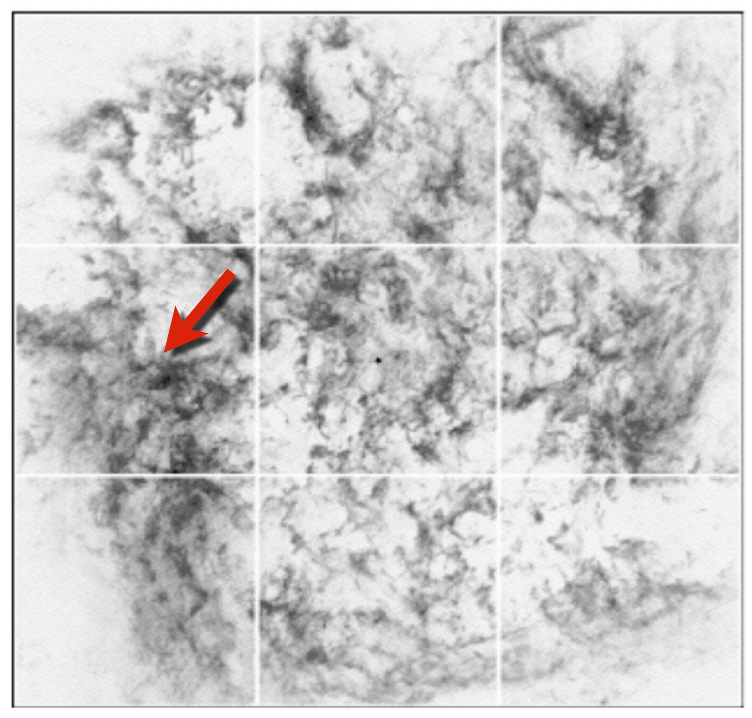
The High Mass X-ray Binary, Black Hole Candidate (BHC) system LMC X-1 is among those that have been claimed to exhibit evidence for near maximal spin. However, compared to other systems, LMC X-1 is rather unusual in that it never shows evidence for reaching a "stable" minimum effective area. Here we show a series of Chandra-High Energy Transmission Gratings observations that cover a number of different orbital phases. We find spectroscopic evidence for emission from the high mass companion's wind. Additionally, we explore whether there is orbital phase-dependent absorption by this wind, as had been previously suggested by us. We then use Comptonization models (eqpair with diskpn seed photon input) to describe the continuum spectrum, and highlight those aspects of the fits that are driving the suggestion for maximal spin.



(See Orosz et al. 2009)

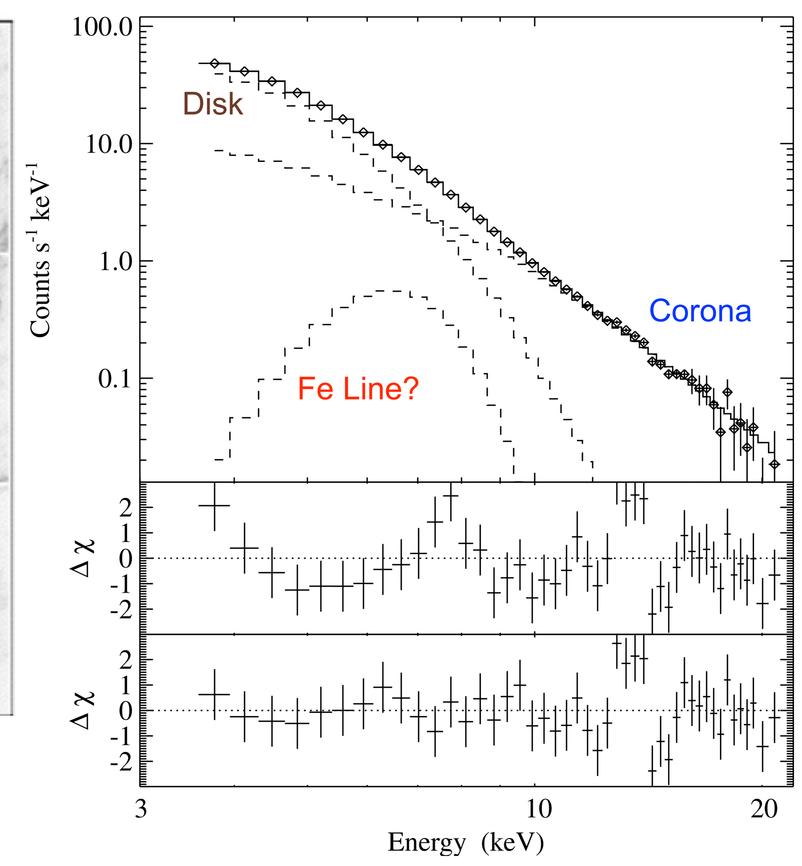
- One of the few persistent Galactic Black Hole Candidates
- Mass: 10.9 ±1.6 M$_\odot$, Inclination 36.4° ±1.9°, Distance 48.1 kpc
- Orbital Period 3.909 Days, O7/8 Giant Companion
- Sits 0.5° from 30 Doradus Star Formation Region, hence a larger column than much of the LMC (e.g., LMC X-3).
- Absorbed 0.5–8 keV Flux ≈ 10% L_{Edd}
- Claimed rapidly spinning black hole (Gou et al. 2009, Steiner et al. 2012)

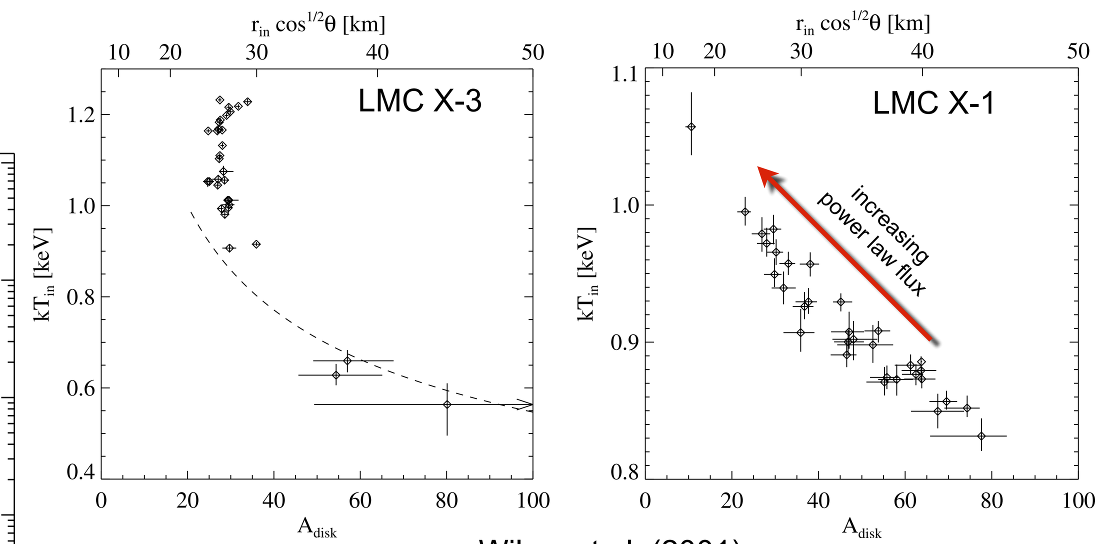
30 Doradus Star Formation Region
(21 cm Map of LMC)



Elmegreen, Kim, Staveley-Smith (2001)

RXTE Observations (Nowak et al. 2001)

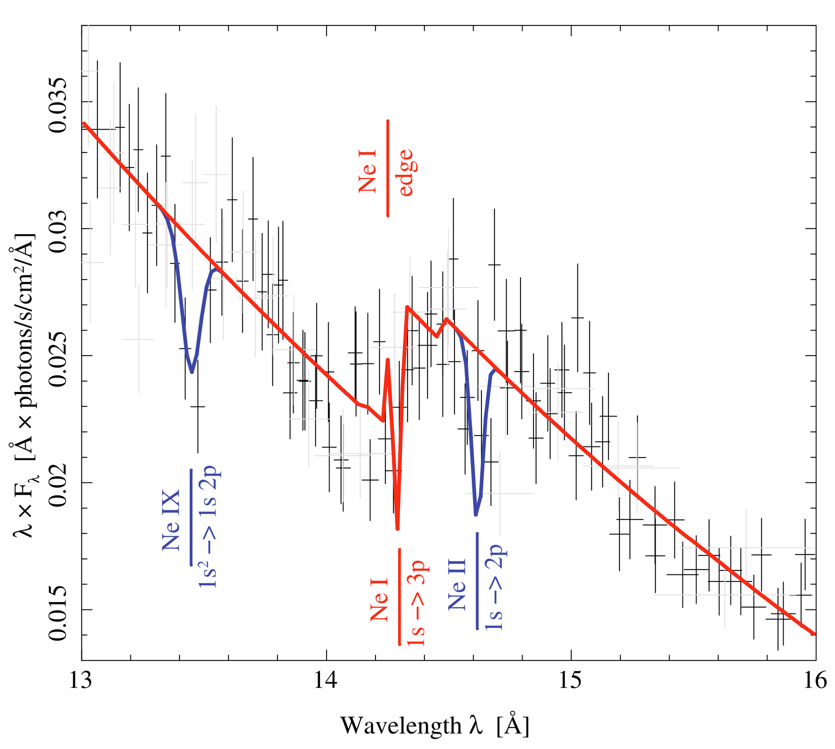


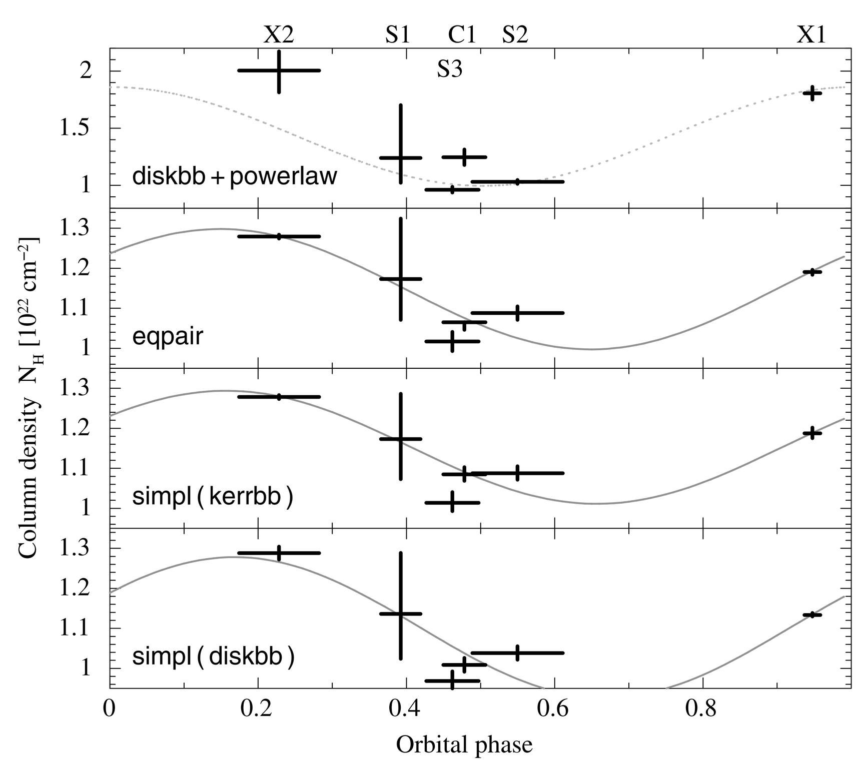


Wilms et al. (2001)

- Soft Spectra of both LMC X-1 and LMC X-3 well-described by absorbed diskbb spectrum plus power law (& maybe broad Fe line)
- LMC X-3 shows classic behavior of constant disk radius, varying disk temperature, for softest spectra.
- LMC X-1 is *completely different*. Disk temperature and radius vary together, while power law flux *increases* with disk temperature.
- Formally, expect $r_{in}\cos^{1/2}\theta \approx 90$ km for LMC X-1 parameters and a *Schwarzschild* black hole (modulo color-correction factors)

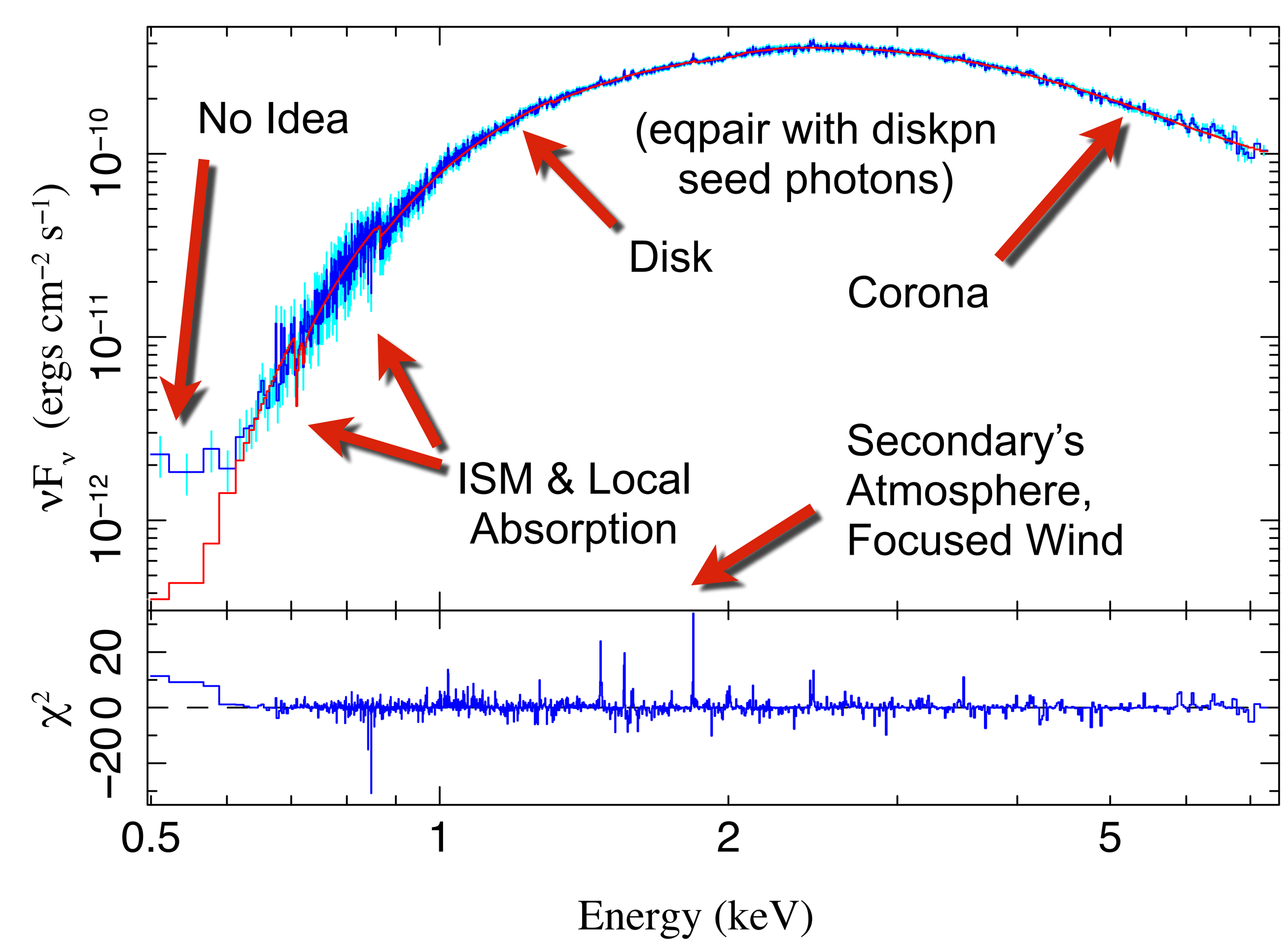
Prior Chandra, XMM, & Swift Observations
(Hanke et al. 2010)

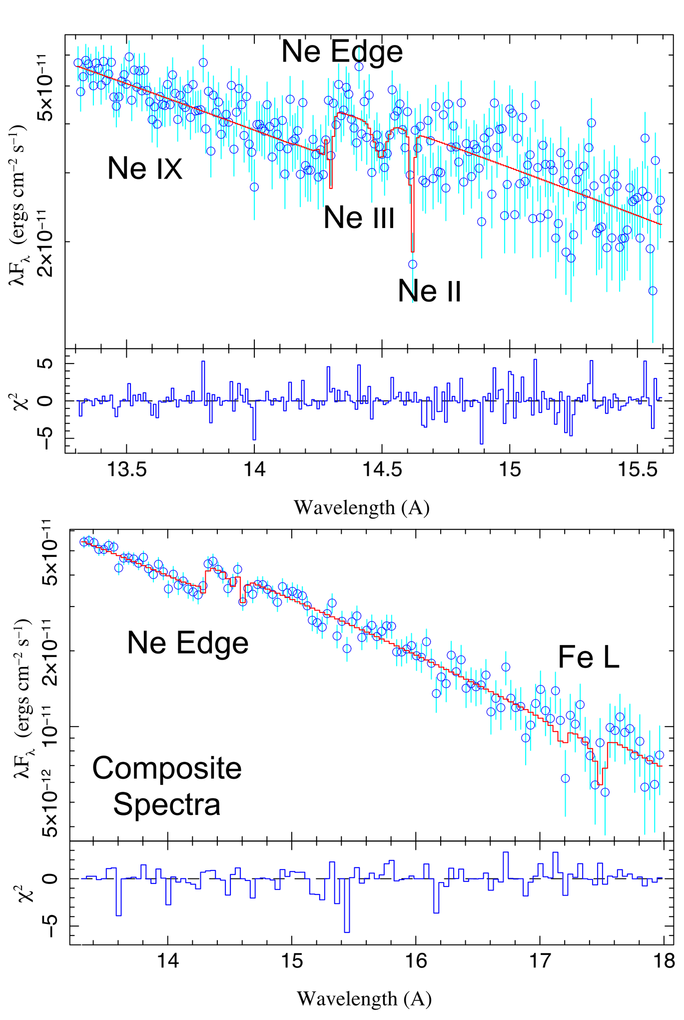


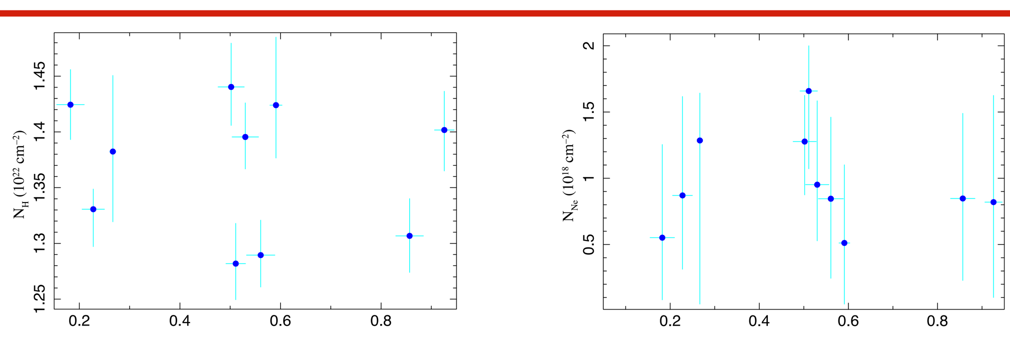


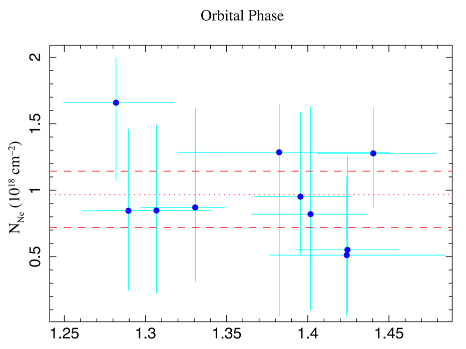
- Hanke et al. (2010) described absorption with abundances suitable for LMC (i.e., lower than solar)
- Hypothesized that absorption is orbital phase-dependent, suggesting origin primarily local to the binary system

Composite Chandra Observation (10 Pointings over 1 Month, 150 ksec) Fit: Absorbed, Comptonized Disks

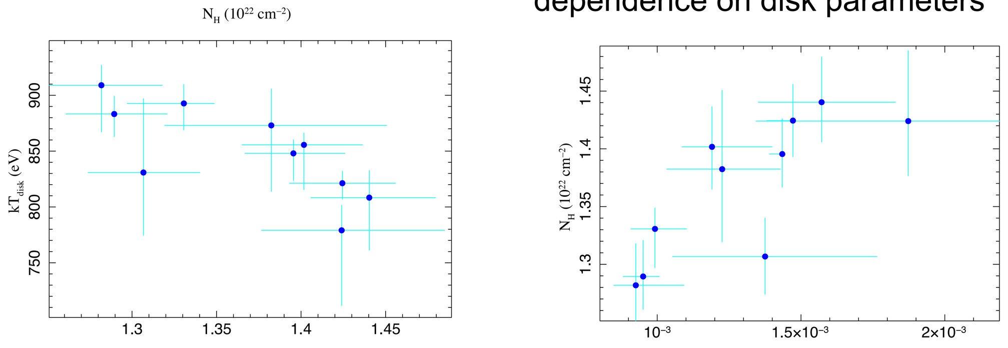


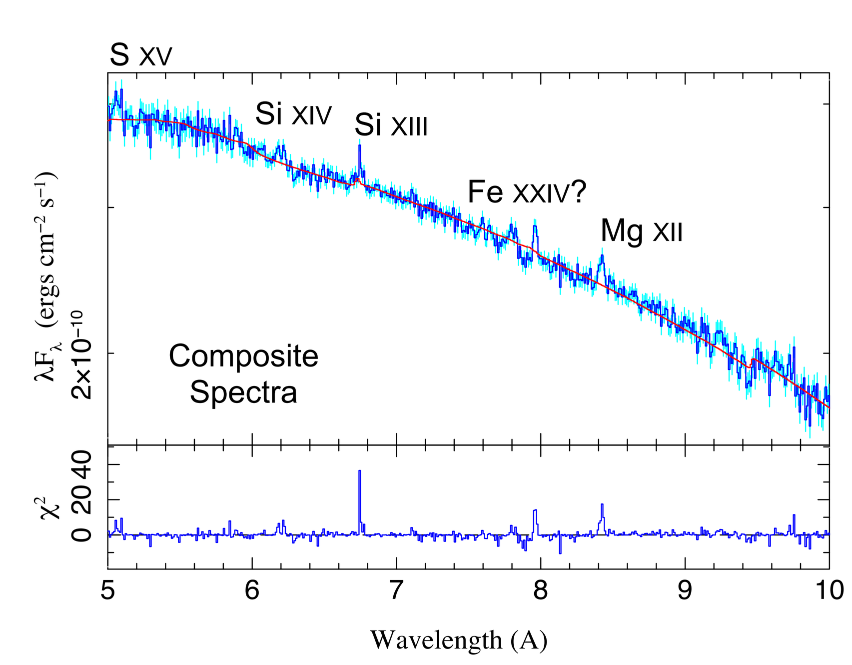






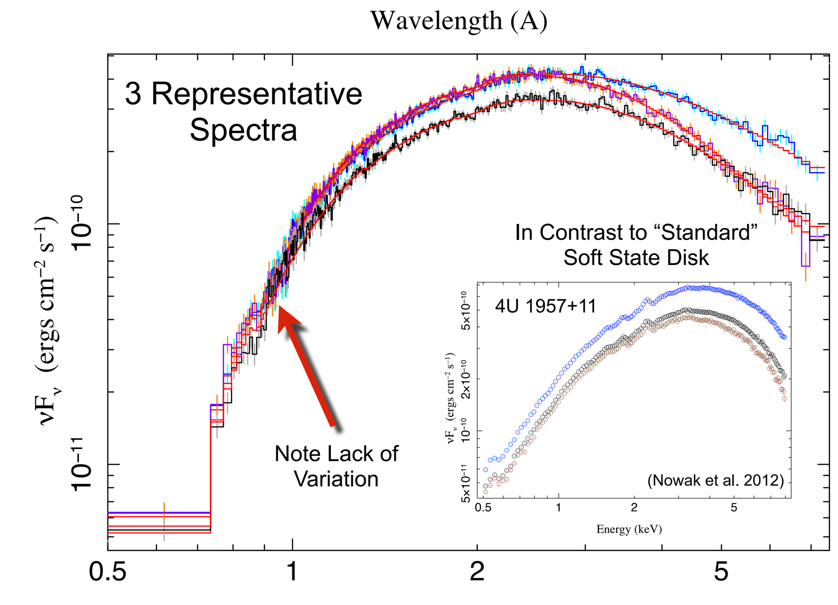
- Neutral column varies by ±10%, but no obvious dependence on orbital phase
- Neon edge not correlated with either orbital phase or neutral column
- Individual neon edge measurements are consistent with composite spectra
- Neutral column has systematic dependence on disk parameters

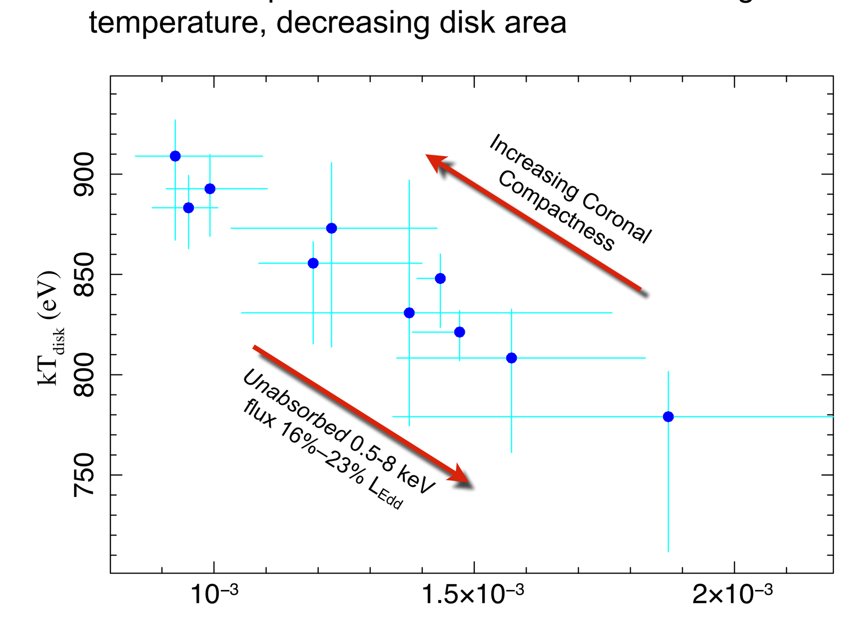


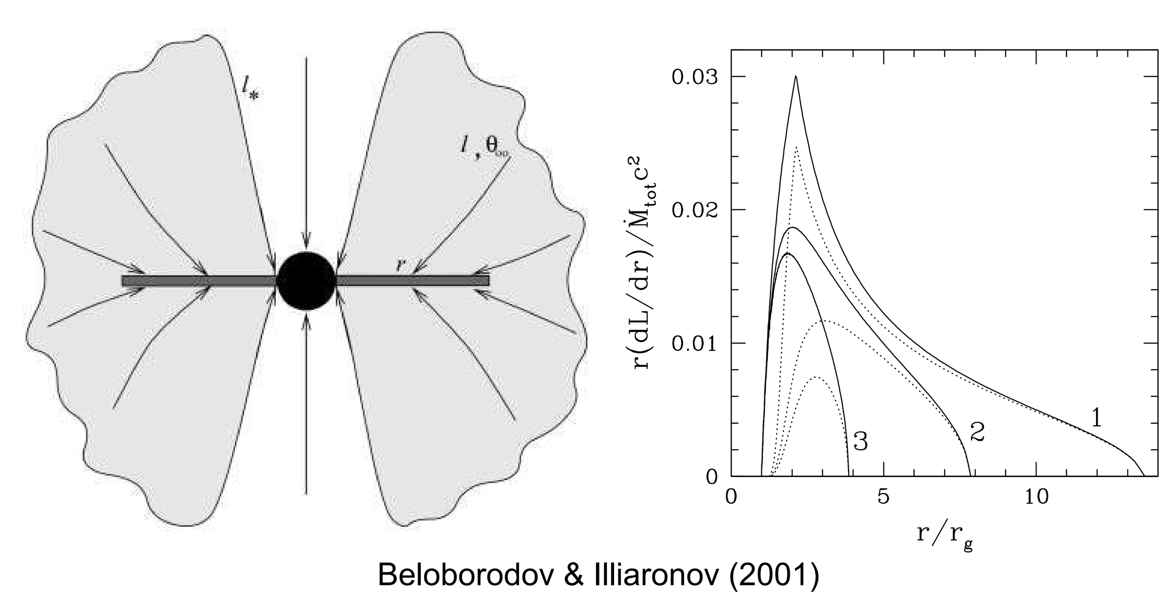


- Line widths are ≈ 500 km s^{-1}
- Line positions are at rest to within ≤ 500 km s^{-1}
- No evidence of orbital phase dependence
- This is in contrast to Cyg X-1: hard state shows phase-dependent lines, soft state no lines (completely ionized)

- Chandra-HETG shows same disk temperature/radius correlations as RXTE. *Not* the "usual" soft state behavior
- Spectra relatively constant 0.5–1 keV, variable 1–8 keV
- No constant inner disk radius, but … value always ≪ Schwarzschild for any "reasonable" color-correction
- Coronal compactness increases with increasing disk temperature, decreasing disk area







Beloborodov & Illiaronov (2001)

- Does LMC X-1 even have a "standard" accretion disk?
- For example, for quasi-spherical inflow (i.e., a wind-fed system), an inner disk-like structure has been hypothesized to form (Beloborodov & Illiaronov 2001)
- Emission profile is disk-like, *with small emitting area*, and depends upon wind specific angular momentum
- Are spin measurements accurate in the case of LMC X-1?

Summary

- LMC X-1 exhibits emission lines at all orbital phases, despite the strong, soft X-ray flux.
- The fitted absorption is higher than expected from the ISM alone, and shows variability (albeit possibly systematic).
- The "disk" does not show the "usual" correlations between temperature and normalization, and never appears to settle into a constant radius state.
- The "disk" has a very small, highly variable area and an anti-correlated, high temperature.
- Are all these properties a consequence of the wind-fed nature of the LMC X-1 system?
- Given this question, has the spin been accurately measured? Or do we first need to understand the correlated variations among absorption, disk temperature and area, and coronal parameters?

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