Assessing the Effects of Comptonization on Black Hole Spin Estimates for LMC X-1

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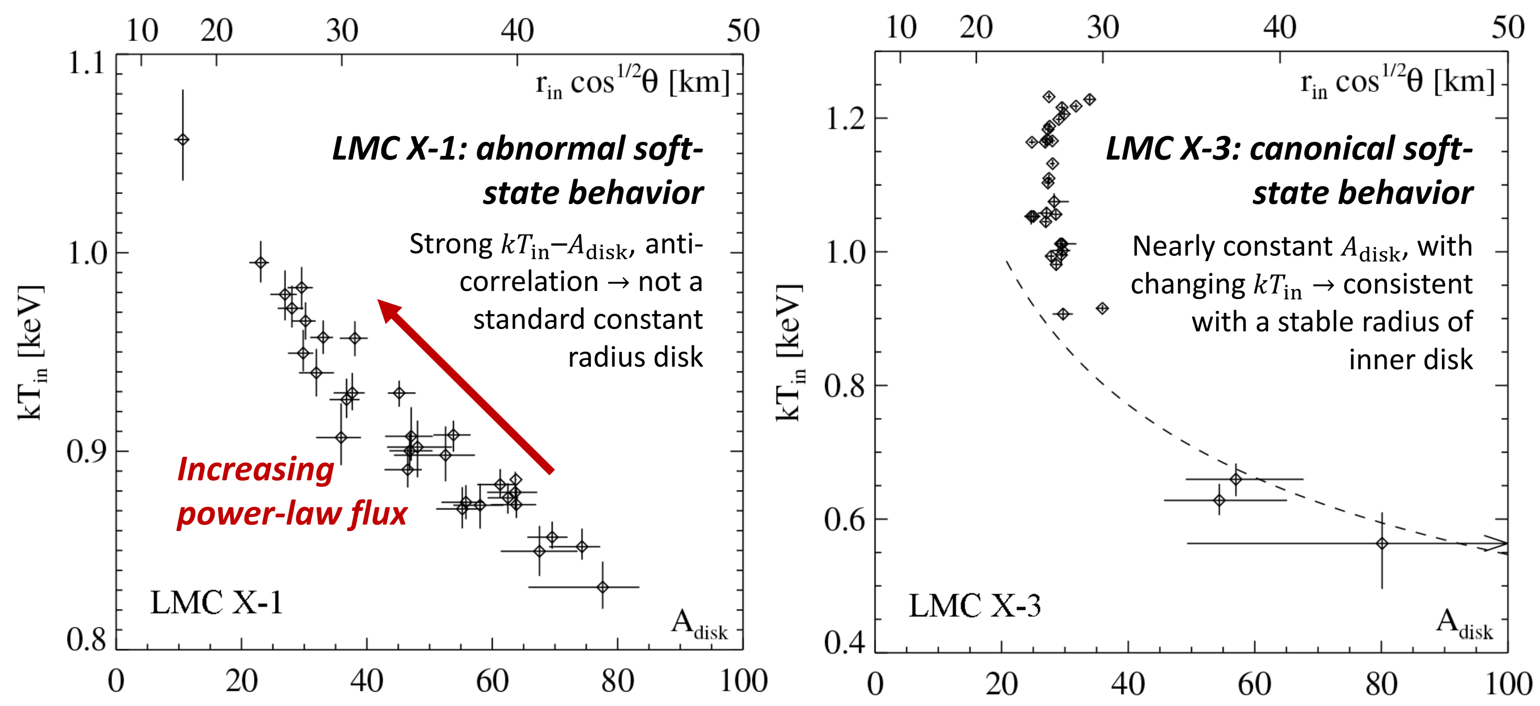
The black hole candidate LMC X-1 is a persistently soft-state high-mass X-ray binary hosting a 10.9⊙ black hole viewed at an inclination of 36.4°. It shows an unusual luminosity–temperature relationship, and its inferred spin depends strongly on assumptions about disk structure and the treatment of the seed-photon spectrum. To investigate the role of Comptonization in shaping its thermal continuum, we analyze 10 Chandra HETG observations using eqpair as our primary spectral model. The model provides good fits to the broadband continuum after accounting for the absorption/emission features, while also reproducing the unusual normalization–temperature trend. This suggests that scattering in a warm, optically thick layer may play an important role in this system. We fit the spectra with a second Compotinization-based model, thcomp × kerrbb, which provides a comparably good spectral fits. Its MCMC analysis reveals a strong anti-correlated degeneracy between the spin and the disk color-correction factor, indicating that the inferred spin is not independently well constrained in most observations. These results suggest that LMC X-1's unusual thermal behavior may be better explained by changes in the disk atmosphere or corona than by large changes in the inner disk radius. As a cross check, we apply eqpair to XMM-Newton observations of LMC X-1, which follow the same unusual normalization–temperature trend seen with Chandra.

Why LMC X-1 is unusual

- Standard continuum-fitting assumption: stable inner disk radius
- LMC X-1: persistently soft, but variable disk atmosphere or Comptonizing layer alters disk temperature ($kT_{\rm in}$), apparent area ($A_{\rm disk}$), and inferred spin (a^*)

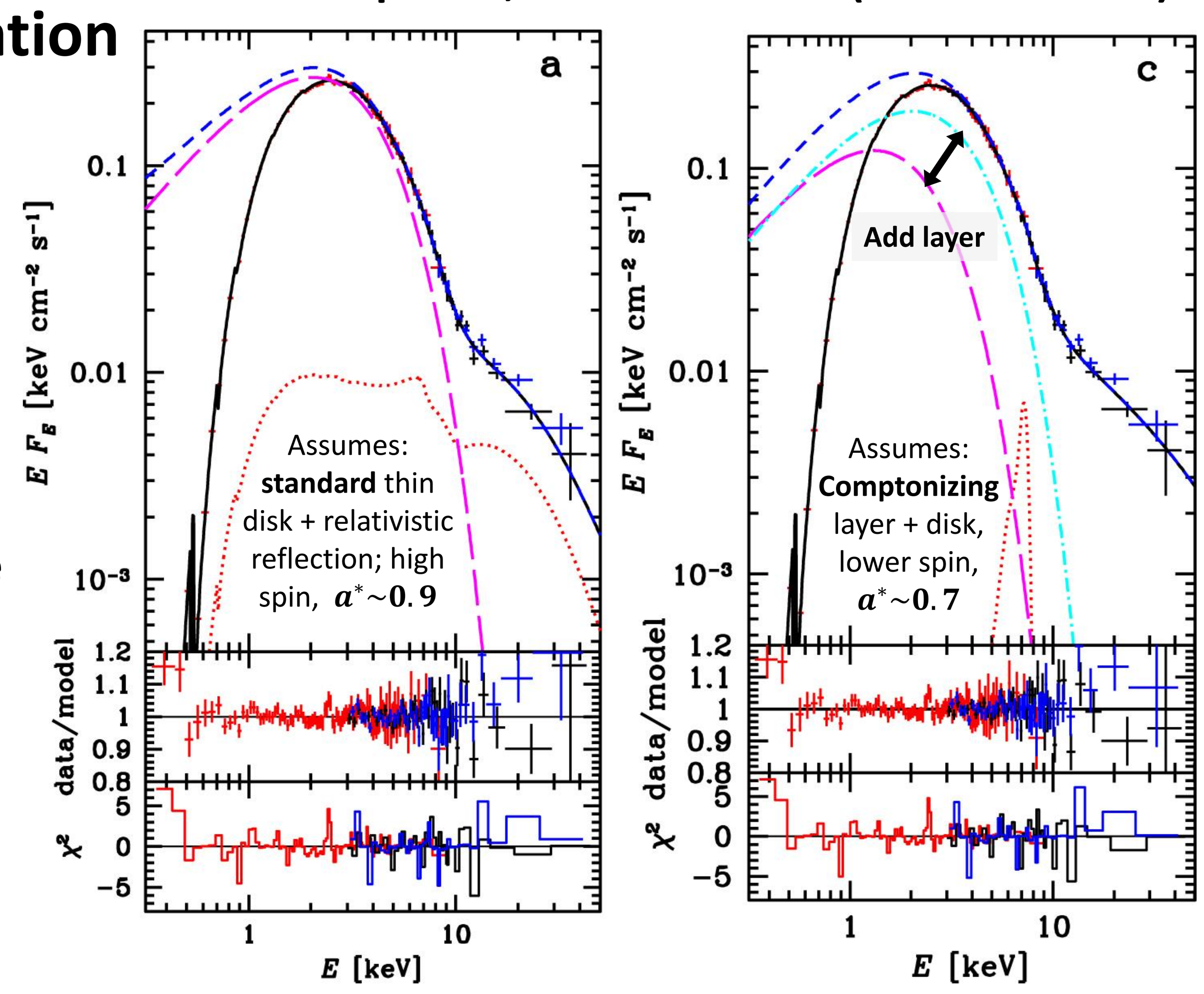
Disk-temperature vs. normalization, RXTE (Wilms et al.)



How does Comptonization affect spin estimates?

- **Yes** — Adding a Comptonizing layer can lower the inferred a^* (Zdziarski et al.)
- **Can spin still be measured?** — Test whether LMC X-1 gives a consistent, lower a^* when the disk atmosphere is modeled

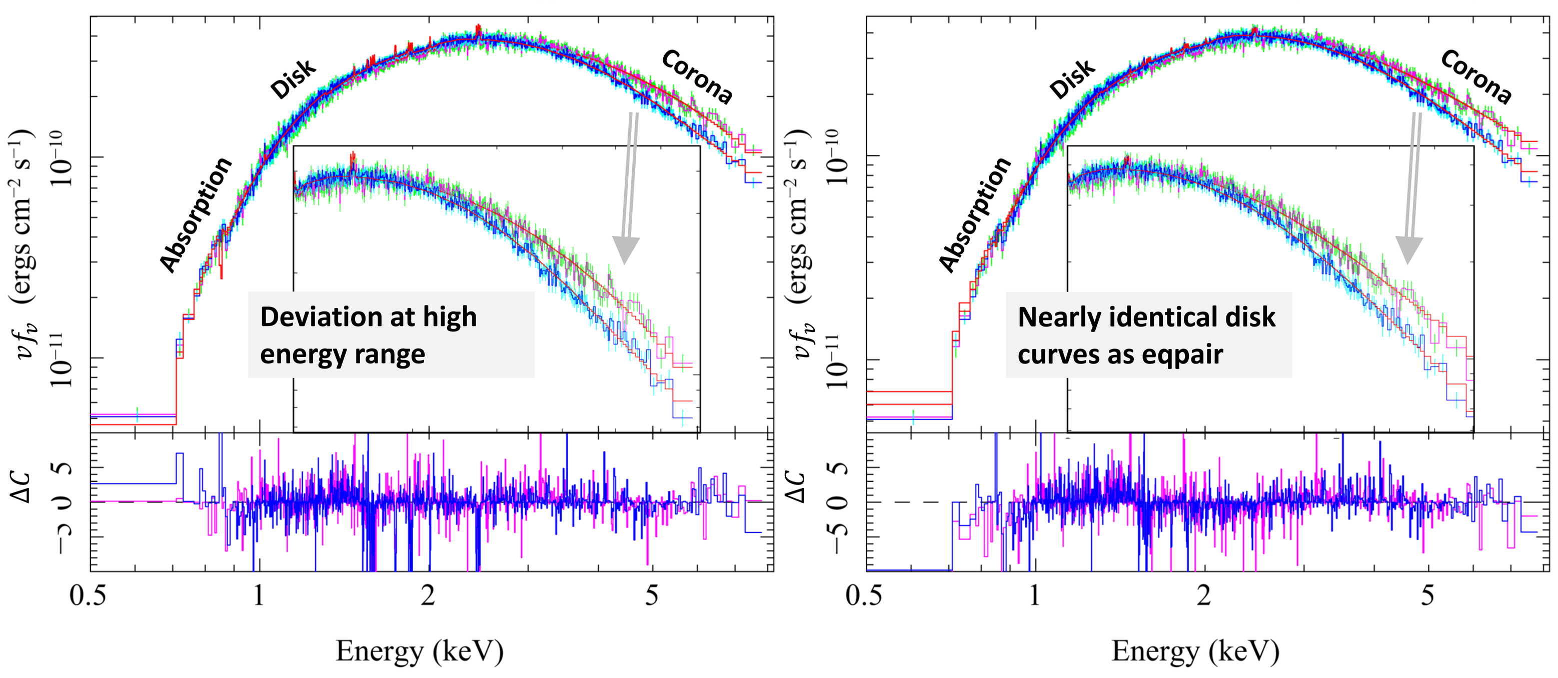
LMC X-1 Spectra, NICER+NuSTAR (Zdziarski et al.)



Chandra spectra: Consistent Comptonized-disk fits

- **Data/Modeling**: 10 Chandra HETG spectra fitted jointly with tbvarabs × eqpair and tbvarabs × thcomp(kerrbb)
- Why both?
  - ***a. eqpair***: physical Comptonization model with a thermal disk+corona; tracks coronal changes and the variable high-energy tail. No direct spin yielded.
  - ***b. thcomp(kerrbb)***: relativistic thin-disk(kerrbb) + Comptonizing layer(thcomp); yields spin (a^*) and color-correction factor (f_c). Extra uncertainty
- **Absorption: *tbvarabs***: LMC-abundance absorption, interstellar + local column.

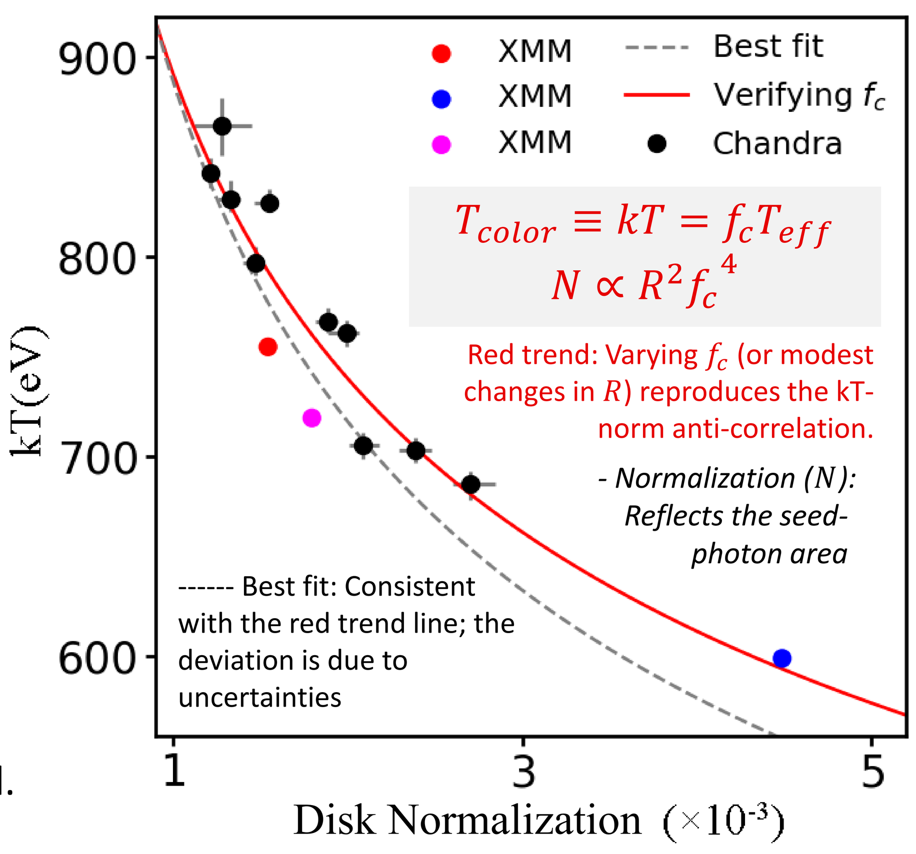
Tbvarabs x eqpair | **Tbvarabs x thcomp(kerrbb)**



- *Blue+cyan: Combined 6 observations, with hot/thin coronae ($\tau_p < 1$)*
- *Magenta+green: Combined 4 observations, with cool/thick coronae ($\tau_p > 1$)*

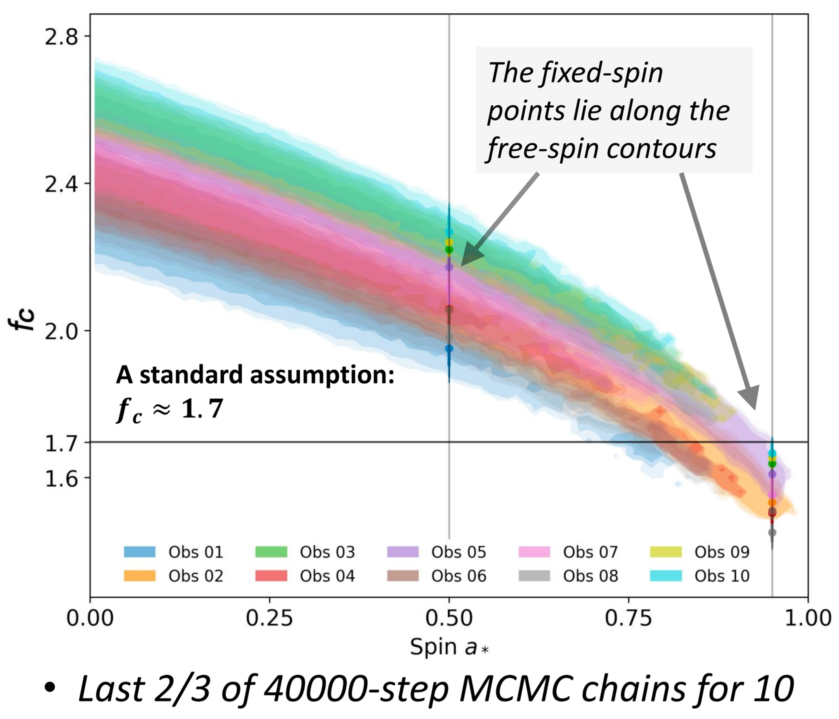
LMC X-1: Abnormal disk kT-normalization relation (Chandra + XMM)

- **Trend**: Unlike in canonical soft states, N rises as kT falls
- **Interpretation**: May result from changes in f_c or modest variation in the inner disk radius (R). Varying f_c can reproduce the anti-correlation.
- **Spin implication**: Seed-photon treatment and scattering geometry affect f_c, T, and inferred a^*
- **XMM-Newton:** Fitted with the same model, tbvarabs × eqpair; all observations follow the trend.



MCMC constraints on spin and color correction

- **Model:** tbvarabs × thcomp(kerrbb)
- **Free-spin contours:** The shaded regions show the posterior contours in $a^* - f_c$ plane when a^* is free.
- **Fixed-spin comparison:** The colored points with error bars at $a^* = 0.5$ and 0.95 show the corresponding f_c constraints from runs with spin fixed.
- **Degeneracy:** All observations follow a consistent anti-correlation between a^* and f, with higher a^* to a lower f_c. The data therefore constrain a combination of a^* and f_c, rather than spin independently.



- *Last 2/3 of 40000-step MCMC chains for 10 Chandra HETG observations*

Summary

- LMC X-1 is persistently soft, but its disk does not show a constant-radius behavior.
- Comptonization can modify the seed disk spectrum, varying f_c, kT, normalization and inferred spin (a^*)
- eqpair: reproduces the abnormal kT-normalization anti-correlation, tracks changes in the Comptonizing corona.
- thcomp(kerrbb): Consistent with Comptonized-disk fit. MCMC reveals an $a^* - f_c$ degeneracy. (Most observations allow a broad spin range, while Obs 10 shows a more compact posterior with a weaker anti-correlation.)
- XMM-Newton observations provide a cross-instrument and cross-epoch check; all three observations follow the kT-normalization anti-correlation.
- The results favor a variable disk atmosphere / corona rather than large intrinsic changes in disk radius.
- Upcoming: XRISM + NuSTAR observations of LMC X-1

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