Aspects of X-ray data analysis for accreting compact objects: theory and results

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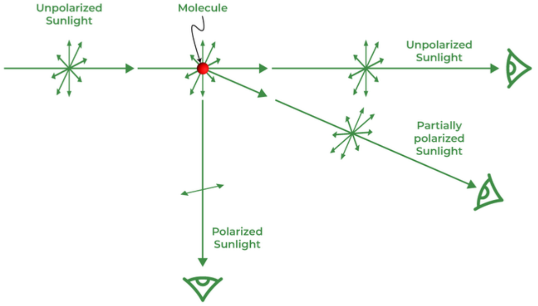
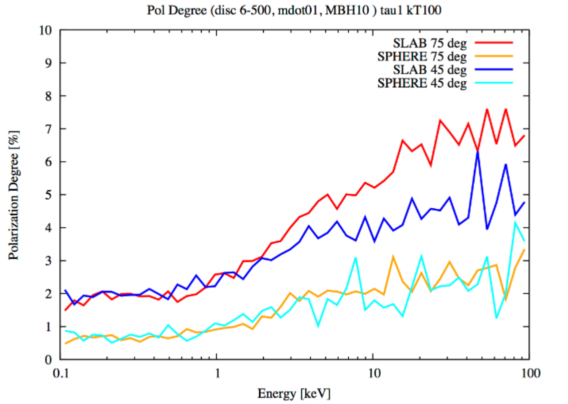
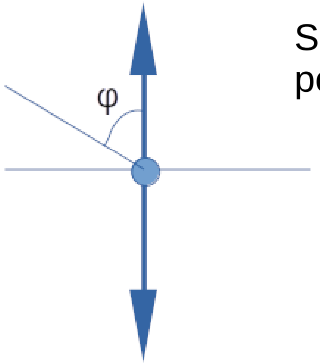
Previous lecture

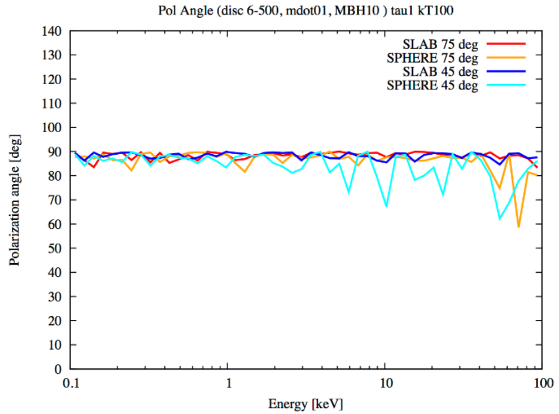


Polarization as a result of scattering



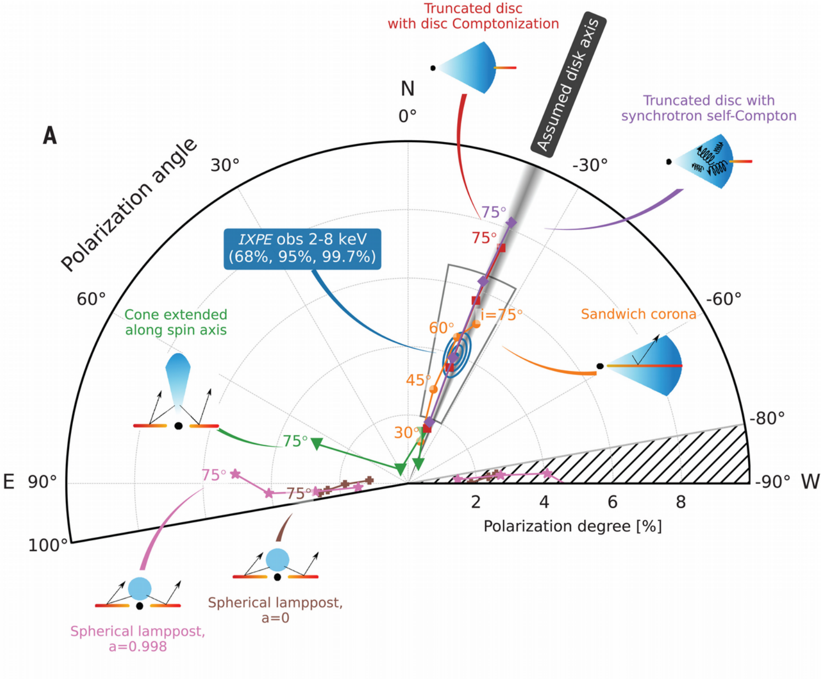


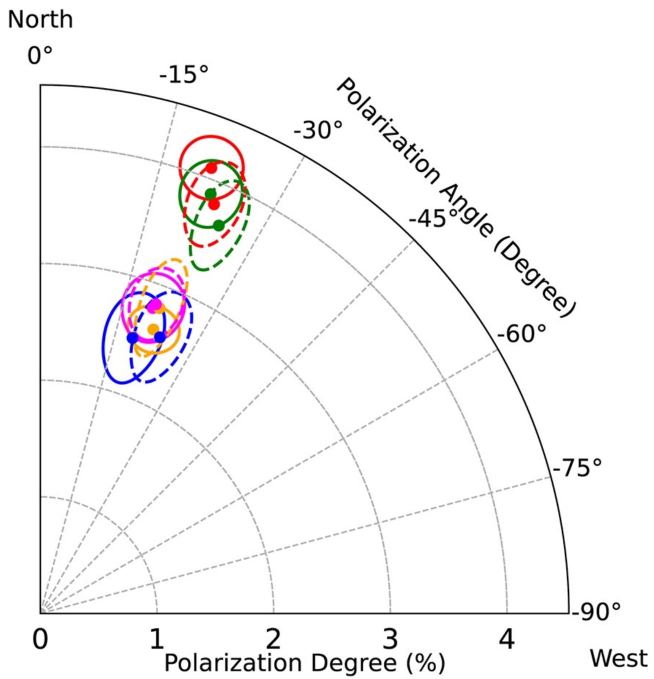
Scattering of a polarized light



Tamborra et al., 2018, A&A, 619, A105

Previous lecture





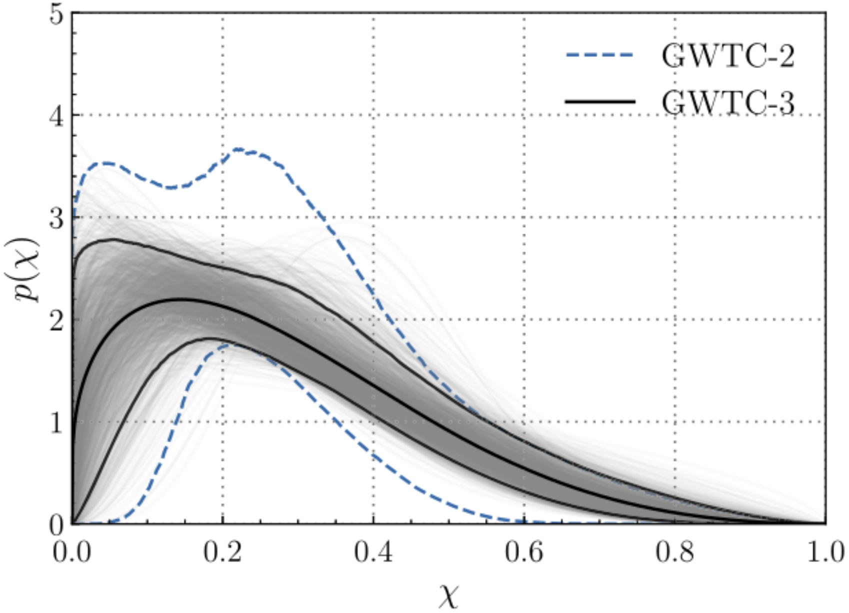
The observed trends are incompatible with models

Krawczynski et al., 2022, Science, 378, 650

Jana & Chang, 2023, MNRAS, 527, 10837

Spins of black hole X-ray binaries

Distribution of spin values of merging black hole systems, from gravitational wave observations – preference for small values of spin



Abbot et al. (LVK collaboration), Phys Rev X, 13, 011048

Determination of the spin of black holes in XRB and GW sources

Spectrum of the thermal emission from an accretion disk depends on the spin of the black hole, a, because both the temperature and the normalization of this component depend on the extent of the disk towards the black hole (ISCO radius depends on a)

This method was used to determine a in a number of sources, mostly high mass XRB. Results were generally that the **spin is high**, close to the limiting value of a=0.998

On the other hand high mass XRB are progenitors of the systems where the merger of black holes produces bursts of gravitational waves, observed by Earth observatories, like Ligo-Virgo-Kagra. Spins of the merging black holes are determined from the GW profiles, they are generally small (previous slide).

There is thus a discrepancy between the values of spin determined by the two methods.

A way to address this problem is to re-analyse the accretion disk emission, including distortions caused by e.g. warm coronae. Results, presented in the following pages, indicate that these models describe the data as well as the original models of the disk emission, but the inferred values of spin are small, compatible with those inferred from GW sources.

Disk emission in X-ray binaries – Cyg X-1

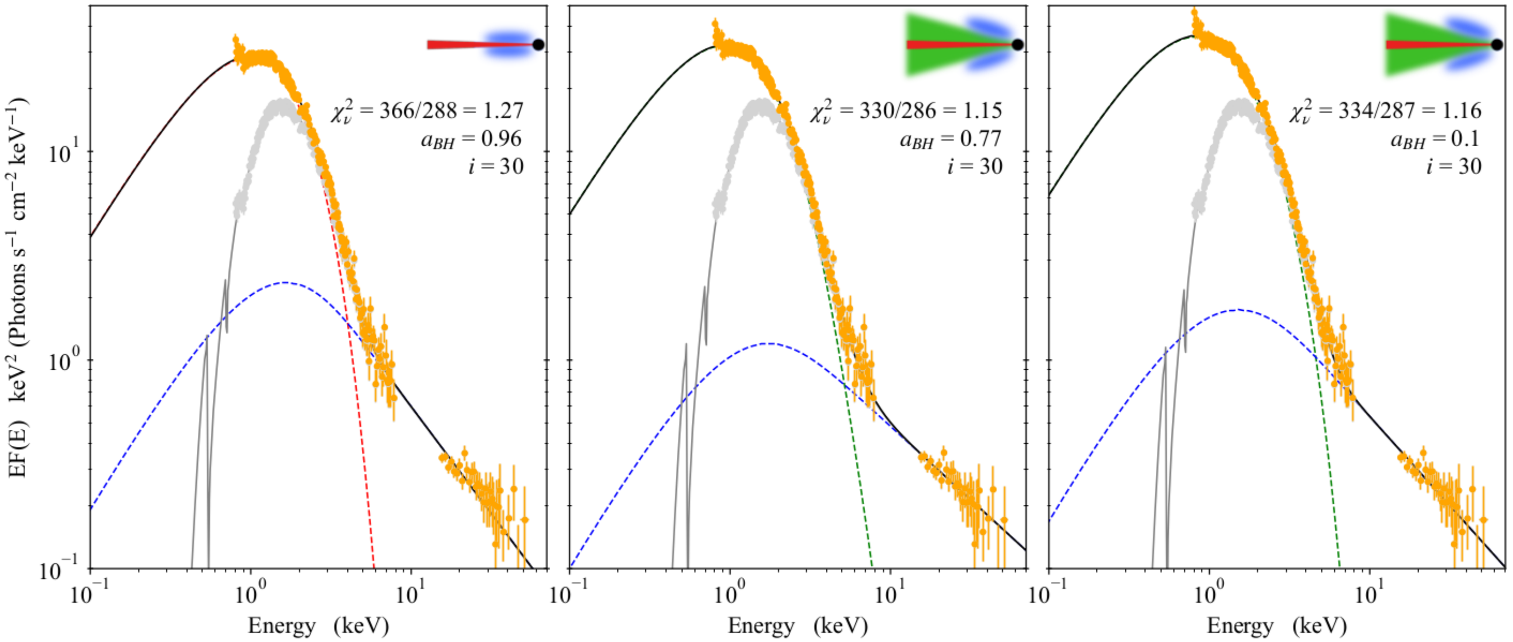


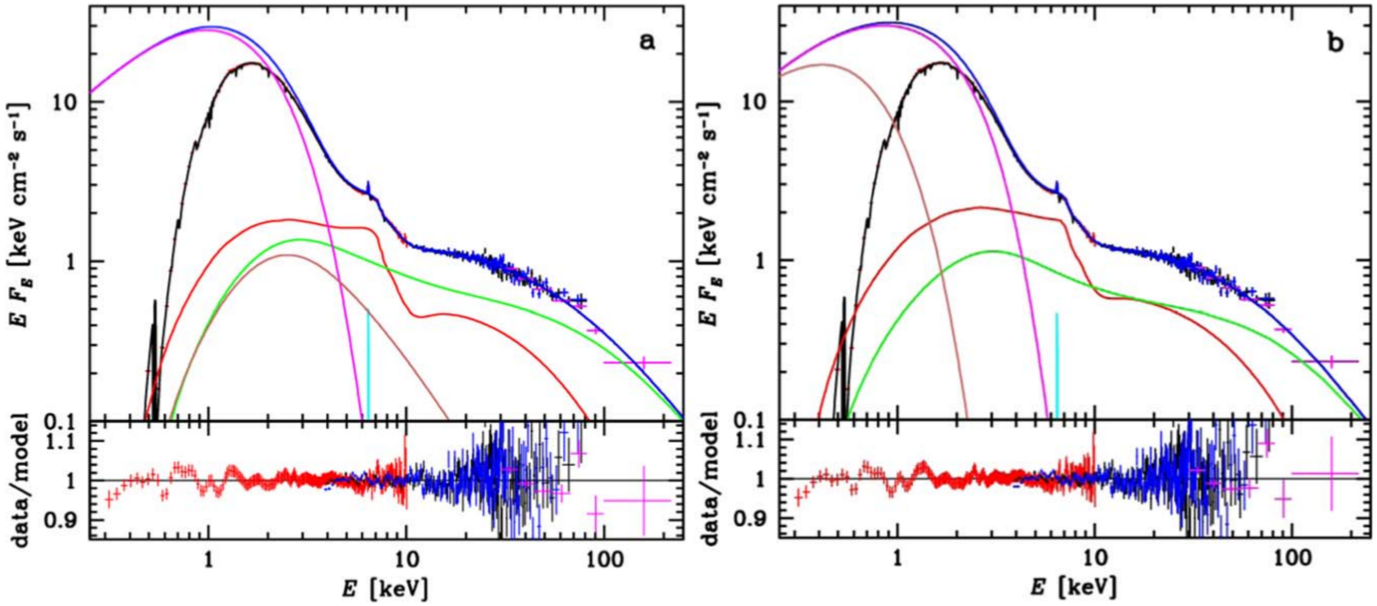
FIG. 2.— Cyg X-1 spectra for for: *Left*: A standard accretion disk (red), modeled with KERRBB, and a hot Comptonizing plasma (blue) giving the high energy emission - as sketched in the top right corner; model **(a)**. *Middle*: A standard accretion disk entirely covered by a warm Comptonizing plasma (green), and then an inner hot Comptonizing plasma (blue); model **(b)**. *Right*: Same as middle, but with the spin fixed at $a_{\rm BH} = 0.1$. Note that the low BH spin is fully consistent with the X-ray spectral data.

Belczynski et al., 2023, A&A, 690, A21

Disk emission in X-ray binaries – Cyg X-1

THE ASTROPHYSICAL JOURNAL LETTERS, 967:L9 (12pp), 2024 May 20 Zdziarski et al.

$$a = 0.87^{+0.04}_{-0.03}$$



$$a = 0^{+0.07}$$

Figure 6. The NICER (red), NuSTAR (black and blue), and INTEGRAL (magenta) unfolded spectra (top panel) and data-to-model ratios (bottom panel) for (a) Model 1 and (b) Model 4. The spectra are normalized to NuSTAR A. The total model spectrum and the unabsorbed one are shown by the solid black and blue curves, respectively. The unabsorbed disk, scattered, reflected, and narrow Fe Kα components are shown by the magenta, green, red, and cyan curves, respectively. In panel (a) the brown curve shows the disk spectrum scattered by the thermal electron component of the hybrid distribution, and in panel (b) it shows the underlying disk spectrum before going through the Comptonization top layer.

Disk emission in X-ray binaries – LMC X-1

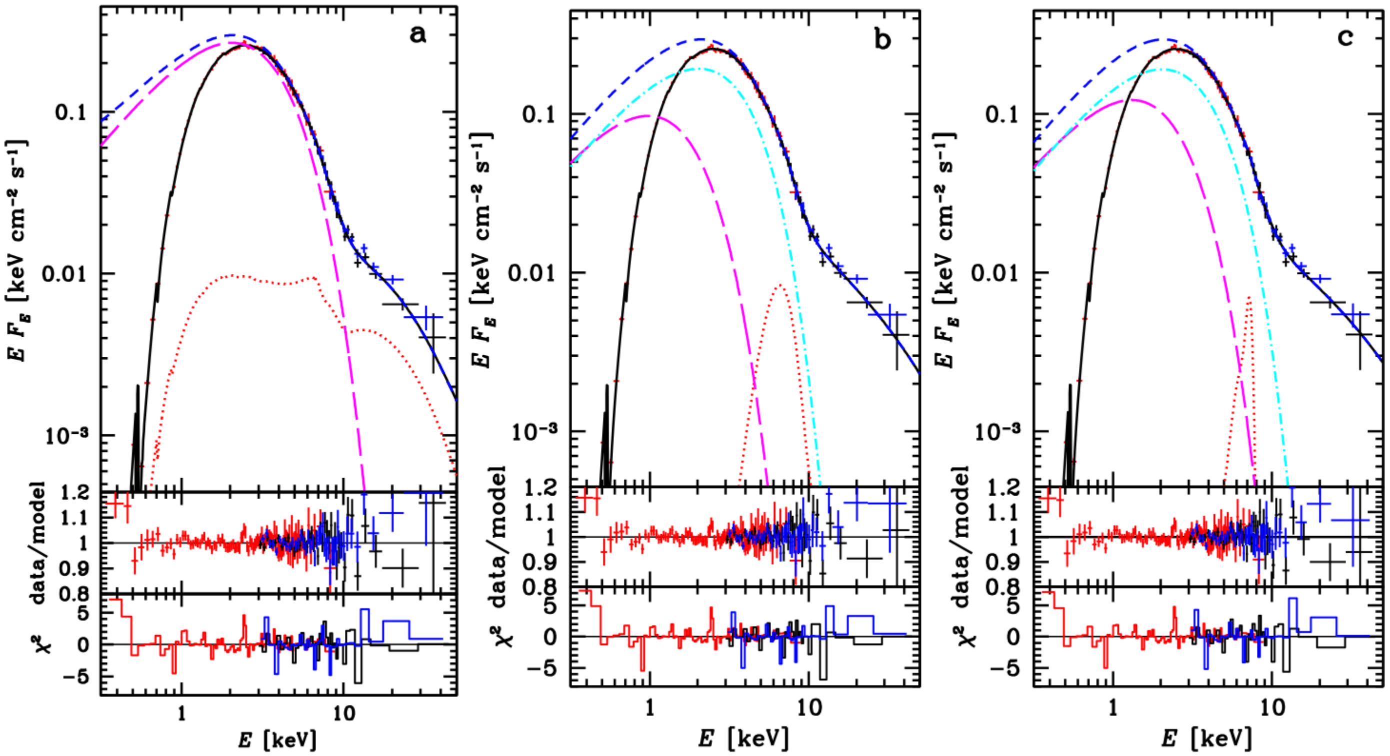


Figure 3. The NICER (red) and NuSTAR (black and blue) unfolded spectra, data-to-model ratios, and χ^2 contributions for (a) model 2, $a_* = 0.94$; (b) model 4, $a_* = 0.40$; and(c) model 5, $a_* = 0.72$. The spectra are normalized to NuSTAR A. The total model spectra are shown by black solid lines, the reflection components are plotted by red dotted curves, and the unabsorbed models are shown by the blue short-dashed curves. The magenta long-dashed curves show the disk components before Comptonization, and the cyan dotted–dashed curves in (b) and (c) show the disk component after Comptonization in the disk skin.