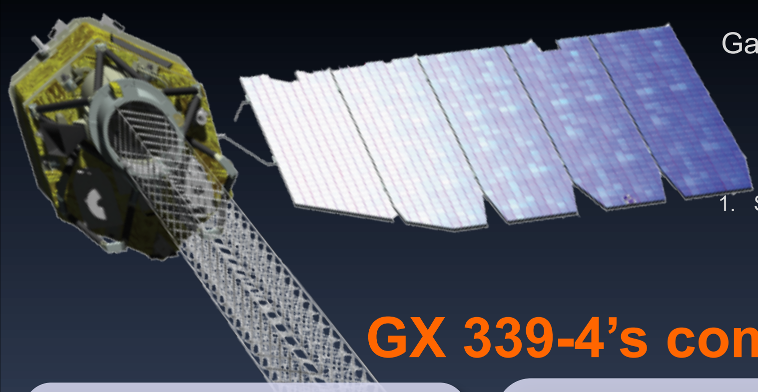
Nuclear Spectroscopic Telescope Array



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GX 339-4's complex accretion geometry

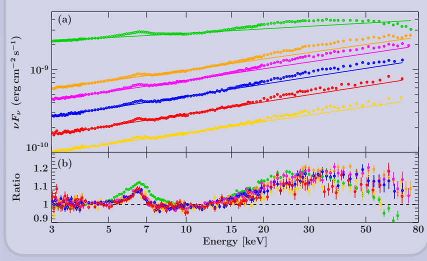
The inner accretion disk radius in the hard state

Black hole binaries typically undergo strong spectral changes during an outburst. During the brightest stages, they are found in the so-called "soft state", in which a thermal spectrum dominates the X-ray flux.

At the beginning and end of an outburst, however, they are found in the "hard state" in which the spectrum is dominated by a power-law continuum from the corona with a superimposed reflection spectrum.

The reflection spectrum is produced by reprocessing of the coronal continuum in the accretion disk, resulting in a prominent fluorescence iron Kα line at 6.4 keV and a Compton hump between 10-20 keV.

The plot below shows typical hard state spectra from the 2013 outburst and from the 2015 outburst in green. The data were modeled with a power-law only to highlight the reflection features.

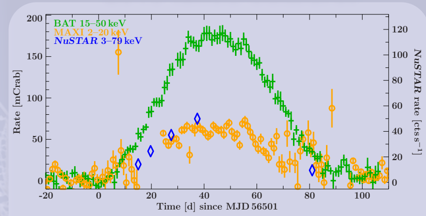


It has been postulated that in the hard state the **inner accretion disk should be truncated** outside the innermost stable circular orbit (ISCO) at several 100 r_g and replaced by an advection dominated accretion flow (ADAF, Esin et al. 1997).

The truncation radius can be inferred observationally from the influence of relativistic effects from the strong gravity of the black hole on the reflection spectrum. To measure these subtle changes, high sensitivity and spectral resolution over a broad band are necessary, to disentangle the underlying continuum from the reflection spectrum. The *Nuclear Spectroscopic Telescope Array* (*NuSTAR*, Harrison et al. 2013), being the first focusing hard X-ray telescope, is ideally suited for this study.

Scan this code for a link to our paper accepted in ApJ describing the 2013 results in detail: **arXiv:1506.01381**

2013 failed outburst



From August to October 2013 we followed an outburst with 5 *NuSTAR* and *Swift*/XRT observations. The outburst never left the low-hard state (a so-called "failed outburst"). The figure above shows the *Swift*/BAT and MAXI light curves as well as the *NuSTAR* observations.

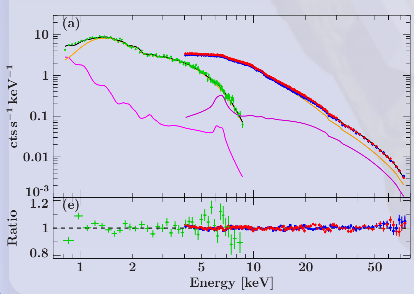
We find that the spectrum **cannot be described by a standard reflection spectrum** within sensible physical parameters. Instead we need to invoke a **more complex geometry**. The best model uses a power-law with a significantly harder ($\Delta\Gamma\approx0.3$) photon-index as input to the reflector compared to the observed primary power-law with $\Gamma\approx1.5$.

This result is independent of the reflection model used (reflionx, Ross & Fabian 2005 or xillver, Garcia et al. 2010) and assumptions about the accretion disk emissivity.

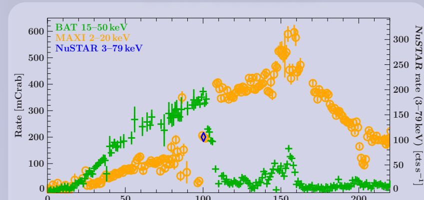
While this model does not allow us to constrain the spin independently (we assume a=0.98, Milller et al. 2008), we find a **marginal truncation of the inner accretion disk** and measure the inclination to be between 40-60 degrees.

The model is further improved by adding a **narrow, neutral Fe Kα line** on top of the reflection spectrum, which will be discussed in detail in Tomsick et al. (2015, in prep.) using simultaneous *Suzaku* data.

The plot below shows the XRT and *NuSTAR* spectrum of observation 4 as an example. The reflection component is shown in magenta.



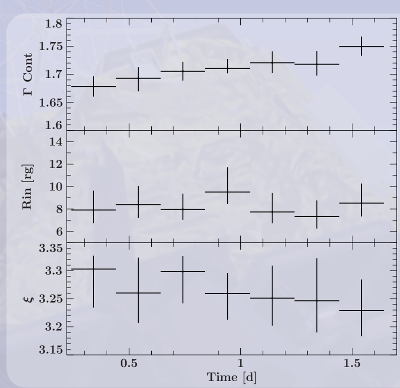
2015 outburst



GX 339-4 showed renewed activity at the end of 2014 and *NuSTAR* observed the outburst on January 13, 2015. As shown in the figure above the observation caught the end of the hard state before the source switched quickly to the soft state.

The *NuSTAR* spectrum is clearly softer than in the 2013 observations, with a photon-index around $\Gamma\approx1.8$. Again the best-fit model requires a **harder photon-index for the reflector** ($\Gamma\approx1.4$). We significantly detect a **weak thermal contribution from the disk**, and describe it using the kerrbb model. GX 339-4 was continuously softening over the observation, which prompted us to split the data into 7 bins (about 8 ks exposure each).

The plot below shows the spectral evolution as function of time. The inner radius of the accretion disk and the ionization are constant within the uncertainties, while the **photon index is softening significantly**. We find indications for a marginally truncated accretion disk, but that result is strongly dependent on the assumed geometry and emissivity index.



Esin, A. A., McClintock, J. E., & Narayan, R., 1997, ApJ, 489, 865
García, J., & Kallman, T. R., 2010, ApJ, 718, 695
Harrison, F. A., et al., 2013, ApJ, 770, 103
Miller, J. M., et al., 2008, ApJ, 679, L113
Ross, R. R., & Fabian, A. C., 2005, MNRAS, 358, 211

NuSTAR

www.nustar.caltech.edu

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