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Spectral analysis of the XMM-Newton data of GX 339-4 in the low/hard state of 2013 outburst: Disk truncation radius and other issues

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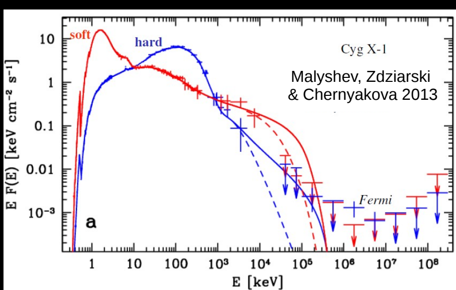
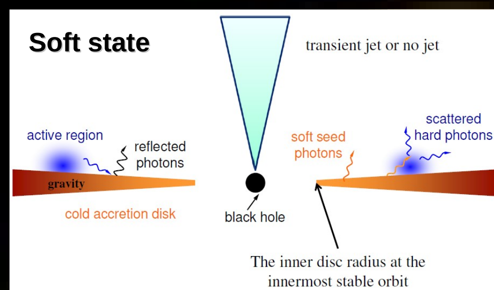
Abstract: We analyze three XMM-Newton observations of the black hole binary source GX 339-4 taken during the decay phase of 2013 outburst when the source was in low/hard state. Our analysis indicates large truncation radius (~10-50 r_g) for the three observations, which is in agreement with that obtained by Plant et al. (2014) for the same observations. We further extend the result in favour of the standard accretion scenario of the low/hard state. We find the reflection fraction to be small, which is consistent with the hot plasma filling the part of the source below the truncation radius. We further test our result against various models e.g., radius-dependent ionization and various ISM abundances. Finally, we try to find conditions of the inclination and the elemental abundance under which our fits are consistent with the mass function results of the source.

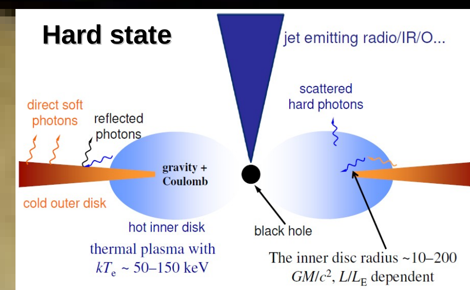
Two primary States of X-ray binaries

The **soft state** is dominated by thermal emission from the accretion disk, extending to the innermost stable orbit (ISCO). Additional high energy tail from Compton upscattering of the blackbody photons by relativistic electrons with a non-thermal distribution, with the spectrum measured up to ~10 MeV.

The **hard state** is dominated by Compton upscattering, reflection off the disk and sub-dominant thermal emission from the disk. Disputed geometry: (i) either the disk is truncated at a radius r_{in} and replaced by a hot inner flow (standard scenario), (ii) or, a disk extending till ISCO with a corona.

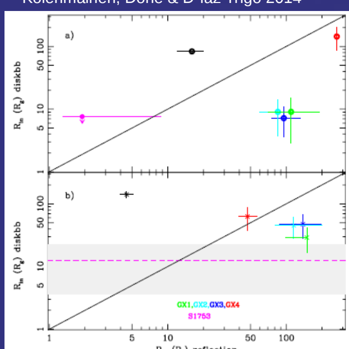






Disputes in inner radius (r_{in})

Kolehmainen, Done & D´ıaz Trigo 2014



The generic model for the hard state is **diskbb+comptonization+reflection.** The r_{in} can be determined in two ways:

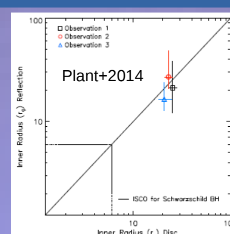
(i) From the normalization of the diskbb function as

$$N \sim (R_{in}/D)^2 \cos(i), \text{ and } r_{in} = c' R_{in}$$

Here, R_{in} is the 'apparent' radius, D is the distance, i is the inclination and c' is the correction factor to calculate the true inner radius.

(ii) By modeling the iron line profile from the reflection component.

The resulting values of r_{in} calculated by these two methods do not agree with each other for GX 339-4 in hard state (see the Figure on the left)



Recent study by Plant+2014 with three data of GX 339-4 taken in *imaging mode* shows a definite match (see Figure above and Table in the right). The only concern is the low inclination angle that would require a large black hole mass

Parameter	Observation 1	Observation 2	Observation 3
N_H (10^{22} cm^{-2})	$0.76^{+0.01}_{-0.02}$	0.74±0.01	$0.74^{+0.03}_{-0.02}$
A_O	$1.52^{+0.03}_{-0.06}$	$1.50^{+0.05}_{-0.04}$	$1.55^{+0.04}_{-0.02}$
T_{in} (keV)	0.16±0.01	0.16±0.01	0.17±0.01
N_{DBB} (10^5)	$1.34^{+0.28}_{-0.18}$	$1.09^{+0.21}_{-0.19}$	$0.89^{+0.43}_{-0.20}$
$r_{in\,(DBB)}$ (r_g)	25^{+3}_{-2}	29±3	26^{+3}_{-6}
Γ	1.62±0.02	1.65±0.01	$1.59^{+0.02}_{-0.03}$
N_{Comp}	0.092±0.01	0.14±0.01	0.08±0.01
$r_{in\,(Fe)}$ (r_g)	21^{+17}_{-9}	27^{+6}_{-6}	16^{+7}_{-4}
$i(°)$		30^{+5}_{-4}	
$\log\xi$ (erg cm s^{-1})	3.17±0.06	$3.03^{+0.05}_{-0.03}$	$3.17^{+0.06}_{-0.05}$
N_{Fe} (10^{-6})	0.34±0.03	$0.26^{+0.03}_{-0.04}$	$0.32^{+0.03}_{-0.02}$
χ^2/ν		5322/5219	

Simultaneous fitting with modification of diskbb model

We first fit the spectra simultaneously using the model given by Plant+14. We reduce the XMM data with an oversampling factor of 3, which was not done by Plant+14. We find similar result (see lower left Table). The reflection fractions are low. We also check the results by replacing the **relxill** by **relxill_ion** model. This allows a radial variation of the ionization parameter. We found negligible improvement, and the parameters remain similar.

Finally, we modify the diskbb function so that the r_{in} and i are now treated as input parameters. These are then linked with those of the reflection component. The normalization can be modified as

$$N = \left[\frac{2.1817.f_v^2}{c'^2.D_{10}^2}\right]\frac{\cos(i)}{\sin^6(i)} r_{in}^2$$

Here, f_v is mass function =5.8 ± 0.5 $M_\odot$ (Hynes+2003). We study for different correction, fixing all other parameters

Parameter	Obs 1	Obs 2	Obs 3
N_H		0.68 ± 0.02	
A_O		1.37 ± 0.05	
T_{in} (keV)	0.16 ± 0.006	0.16 ± 0.01	0.17 ± 0.005
N_{DBB} (10^5)	$0.58^{+0.18}_{-0.14}$	$0.76^{+0.26}_{-0.19}$	$0.47^{+0.14}_{-0.11}$
r_{in} (r_g)	16.5	18.9	14.8
Γ	1.58 ± 0.03	1.63 ± 0.02	1.56 ± 0.03
$N_{nthcomp}$	0.094 ± 0.025	0.15 ± 0.01	0.088 ± 0.023
$i(°)$		$27.4^{+4.0}_{-5.3}$	
$r_{in(Fe)}$ (r_g)	$21.7^{+52.3}_{-11.7}$	$19.1^{+15.6}_{-11.0}$	$20.6^{+23.2}_{-7.6}$
$\log\xi$ (erg cm s^{-1})	$3.45^{+0.16}_{-0.11}$	$3.11^{+0.13}_{-0.12}$	$3.44^{+0.12}_{-0.10}$
A_{Fe}		$3.67^{+2.38}_{-1.09}$	
refl_frac	$0.59^{+*}_{-0.32}$	$0.25^{+0.09}_{-0.08}$	$0.59^{+*}_{-0.24}$
χ^2/ν		421.7/457	

Parameter	Obs 1	Obs 2	Obs 3
N_H		$0.69^{+0.02}_{-0.03}$	
A_O		1.36 ± 0.05	
T_{in} (keV)	0.16 ± 0.005	0.15 ± 0.006	0.17 ± 0.005
Γ	1.59 ± 0.04	1.64 ± 0.01	1.58 ± 0.03
$N_{nthcomp}$	0.10 ± 0.02	0.16 ± 0.01	0.10 ± 0.02
$i(°)$		$30.84^{+2.54}_{-1.78}$	
r_{in} (r_g)	$13.63^{+4.18}_{-2.65}$	$16.11^{+4.94}_{-3.16}$	$12.45^{+3.69}_{-2.34}$
$\log\xi$ (erg cm s^{-1})	$3.42^{+0.14}_{-0.09}$	$3.07^{+0.08}_{-0.06}$	$3.36^{+0.09}_{-0.13}$
A_{Fe}		$4.05^{+6.12}_{-1.18}$	
refl_frac	$0.52^{+0.48}_{-0.27}$	$0.23^{+0.09}_{-0.10}$	$0.43^{+0.33}_{-0.28}$
χ^2/ν		426.5/460	

Future: use the method for all observations

As the inclination is still low, the result is still a matter of concern.

We are now extending our study to incorporate all the observations of GX 339-4 in low/hard state taken by XMM-Newton. We shall study various cases e.g., (i) fitting for different correction factor, (ii) fit using the mass function as variable and hence compare its value, (iii) the axis of the inner disk can be different from that of the binary orbit. Hence, we shall also try this case.

The following figure shows the unfolded *EF(E)* spectrum with the residual taken from our preliminary study. This will be updated.