The X-ray Universe 2011

Interacting Binary Systems, (Galactic) Black Holes & Micro-quasars

X-ray Spectral variability in Ultraluminous X-ray Sources

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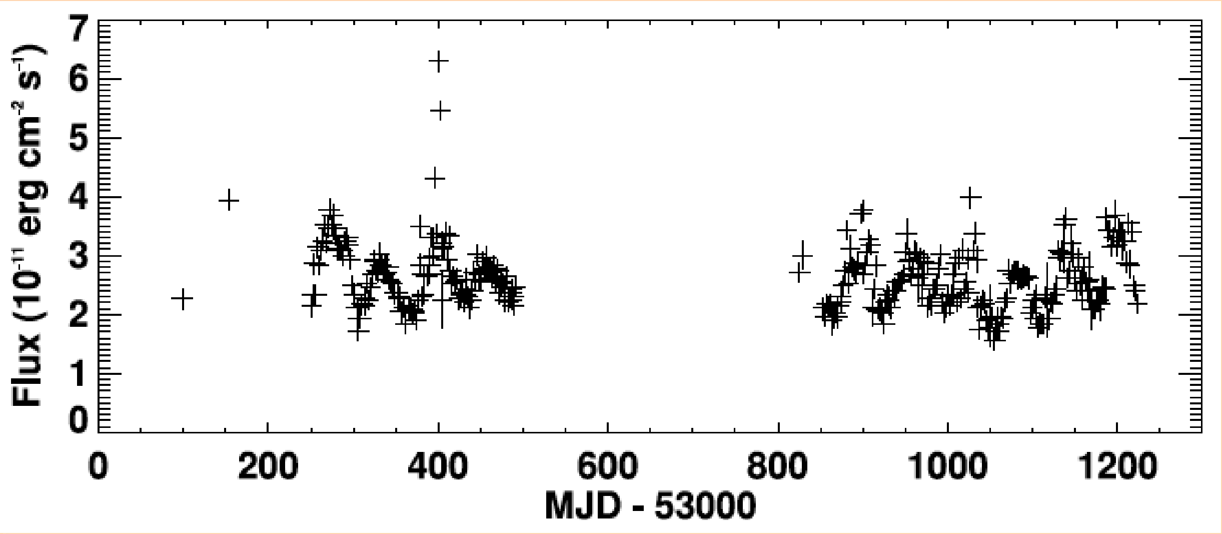
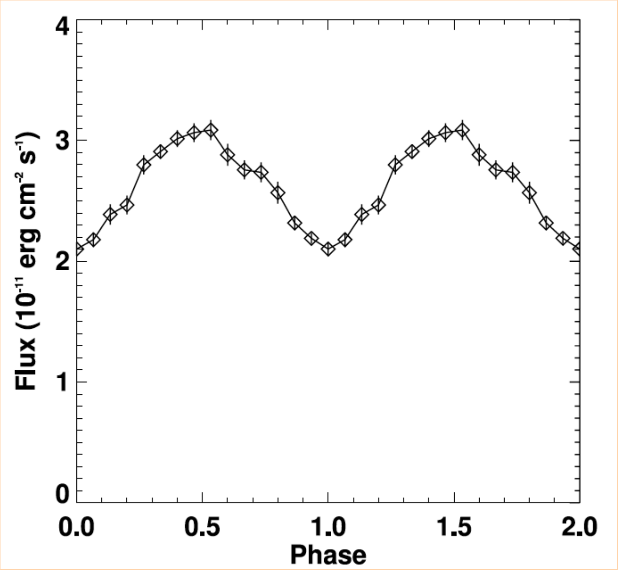
Ultra Luminous X-Ray sources (ULXs)

- Extragalactic, point-like sources;
- Off-nuclear;
- High values of Luminosity ($10^{39} - 10^{41}$ erg s^{-1});
- Luminosities higher than the Eddington luminosity on a 10 $M_{\odot}$ Black Hole (BH);
- Some of them (M82 X-1, NGC 5408 X-1) show regular modulation in the X-ray flux, interpret as orbital period (e.g. Kaaret & Feng 2007, Strohmayer 2009);





SPECTRAL VARIABILITY

Miller et al.(2003) found that the XMM-Newton spectra could be fitted with a soft component (multicolor blackbody disc) and a power-law. Scaling the mass with the normalization of the MCD component, they inferred the existence of an Intermediate Mass Black Hole.

Stobbart et al.(2006) showed the presence of spectral curvature above 2 keV in several sources. They explained it with an optically thick corona coupled to the disc at high accretion rates.

Goncalves & Soria(2006) also questioned the robustness of the cool disc-blackbody spectral component.

In the longest observations some sources appear to show a break in the spectrum at energies above ~ 3-5 KeV.
Gladstone et al.(2009) show that this spectra can be modelled through a cool comptonizing corona atop an accretion disc.

Detailed spectral variability analyses were performed by Feng & Kaaret (2009), Kajava & Poutanen (2009). Vierdayanti et al.(2010), Dewangan et al.(2010) on XMM-Newton, Chandra and Swift data of a number of ULXs.

SPECTRAL VARIABILITY

Miller et al (2003) found that the continuum could be fitted with a soft component (multicolor
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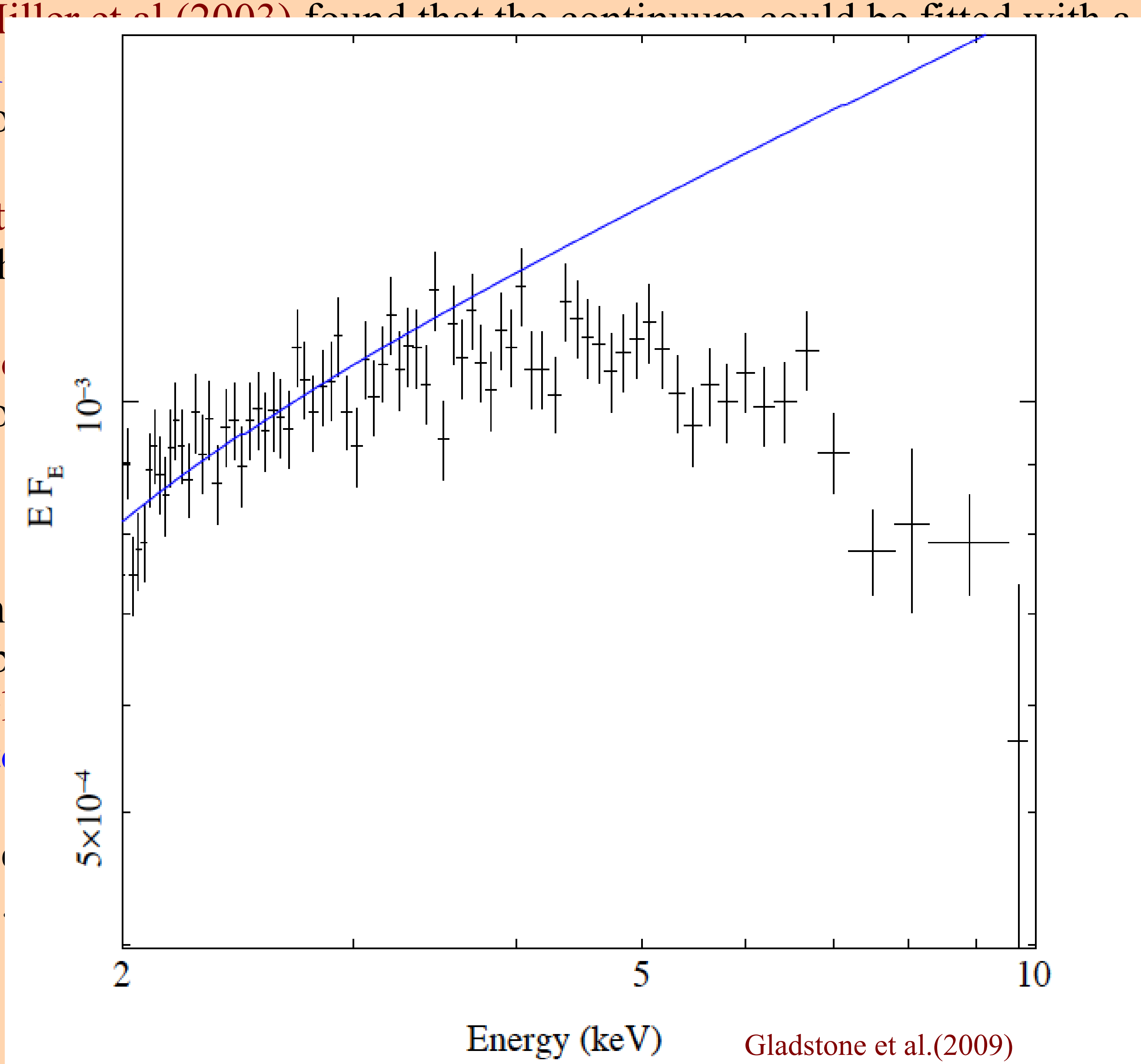
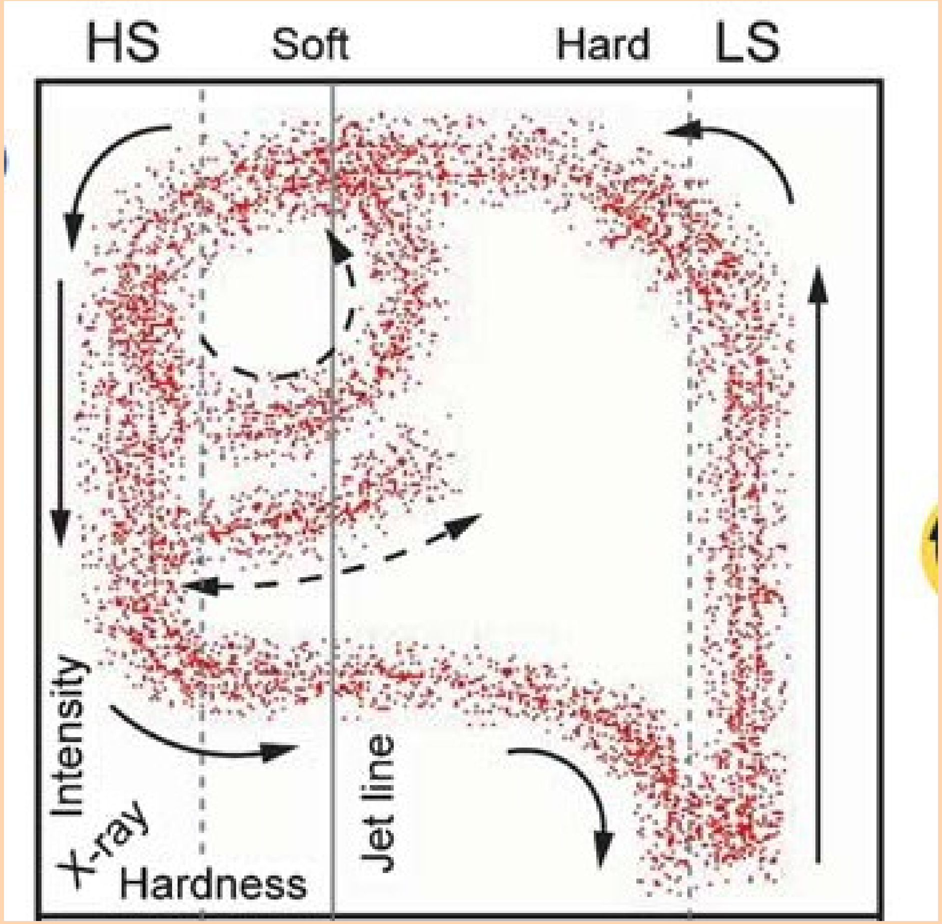


Gladstone et al.(2009)

SPECTRAL VARIABILITY

In order to increase our understanding of ULXs and shed light on the mechanism at the origin of their powerful emission, it is crucial to investigate the evolution of their accretion flow through the variability of their X-ray spectra.



Fender, Belloni & Gallo (2004).

SPECTRAL ANALISYS of NGC 1313 X-1, X-2 and NGC 5204 X-1

We analyzed 13 out of the 17 XMM-Newton observations of NGC 1313 X-1 and X-2, and 6 XMM-Newton observations of NGC 5204 X-1.

We checked the consistency of Comptonization model plus a multicolor blackbody disc (diskbb+comptt in Xspec) on the basis of the variability patterns of its spectral parameters.

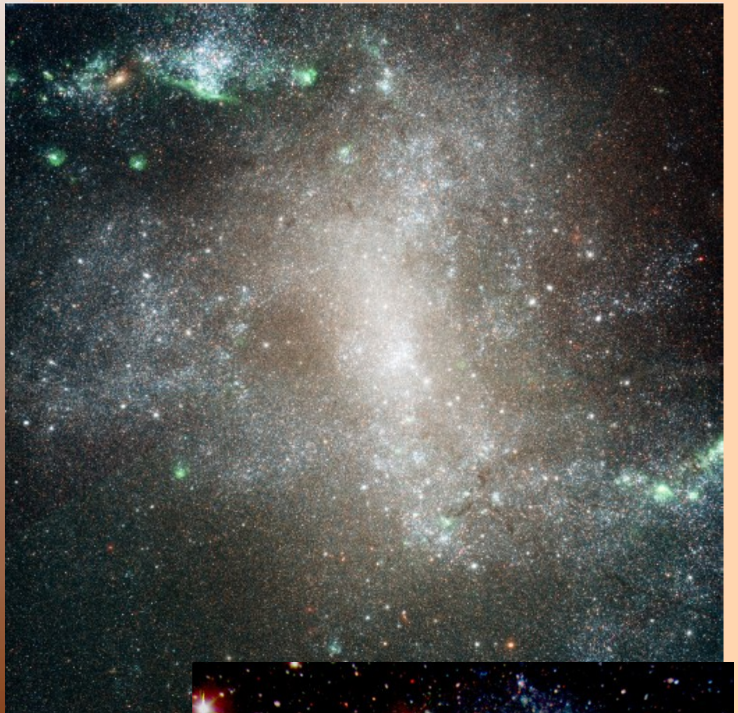
MULTI-COLOR BLACKBODY DISC (Mitsuda et al. 1984)

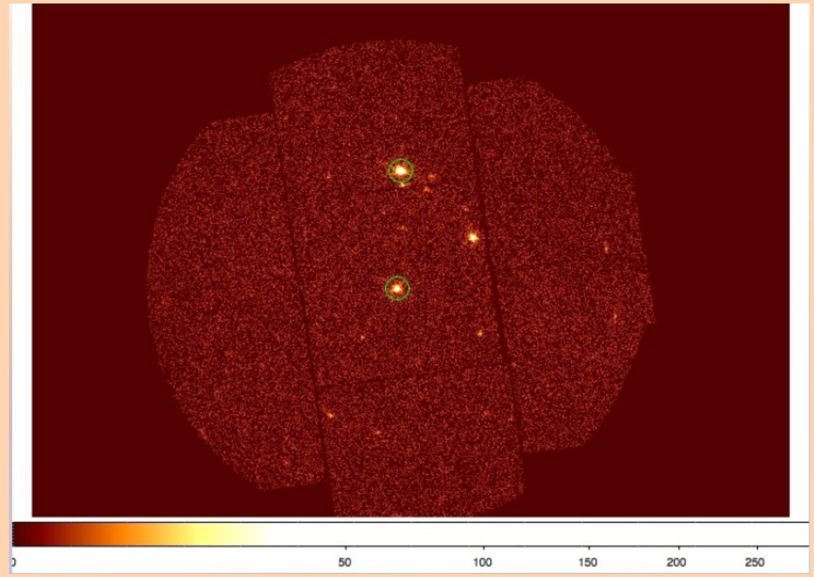
COMPTT (Titarchuck 1994): analytic approximation to non-relativistic thermal comptonization which assumes that the seed photons for comptonization have a Wien spectrum.

Although several of our observations show acceptable fits using only the comptt component, in some cases adding the diskbb component leads to a significant improvement in the fit. Therefore, in order to perform a comparison within the framework of a unique spectral model, here we assume the diskbb+comptt as reference model.

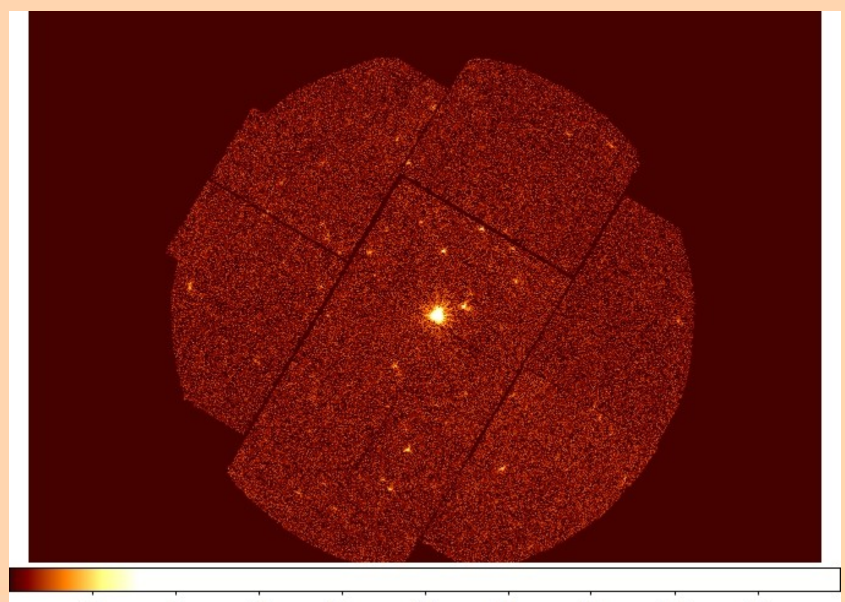
We tied the temperature of the disc (T_{disc}) to that of the seed photons (T_0) for comptonization.

NGC 1313 & NGC 5204



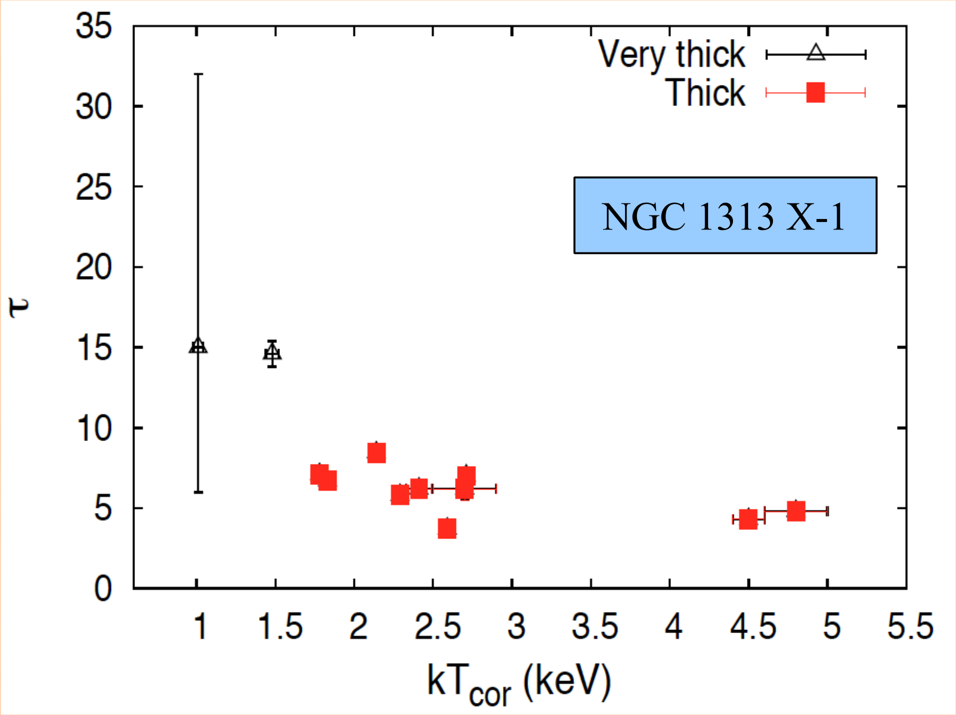


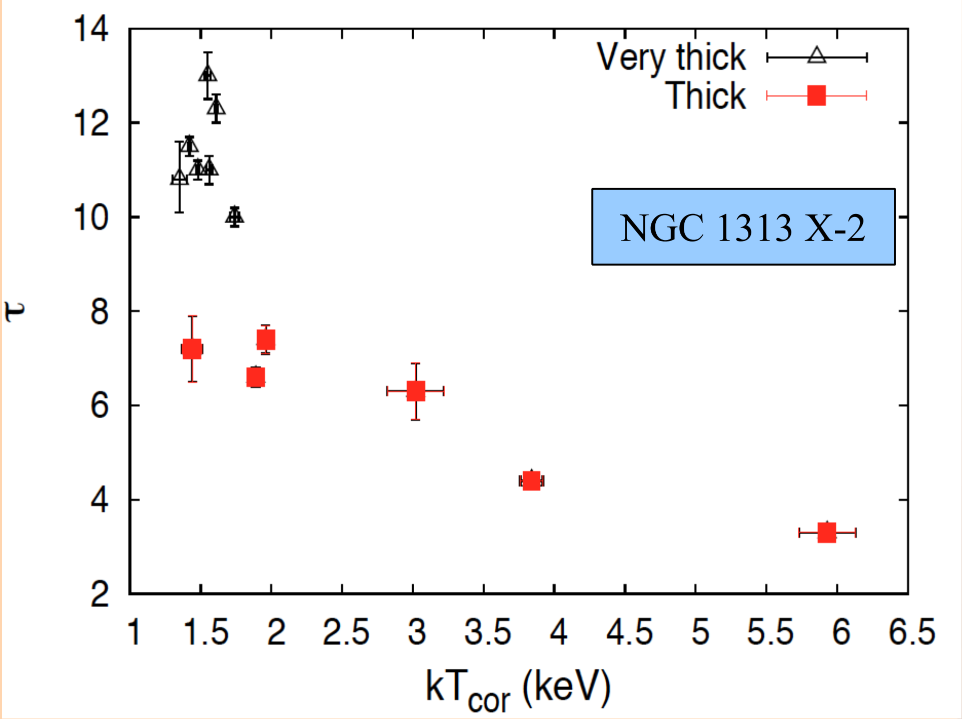
The barred spiral galaxy NGC 1313 hosts three ULXs;



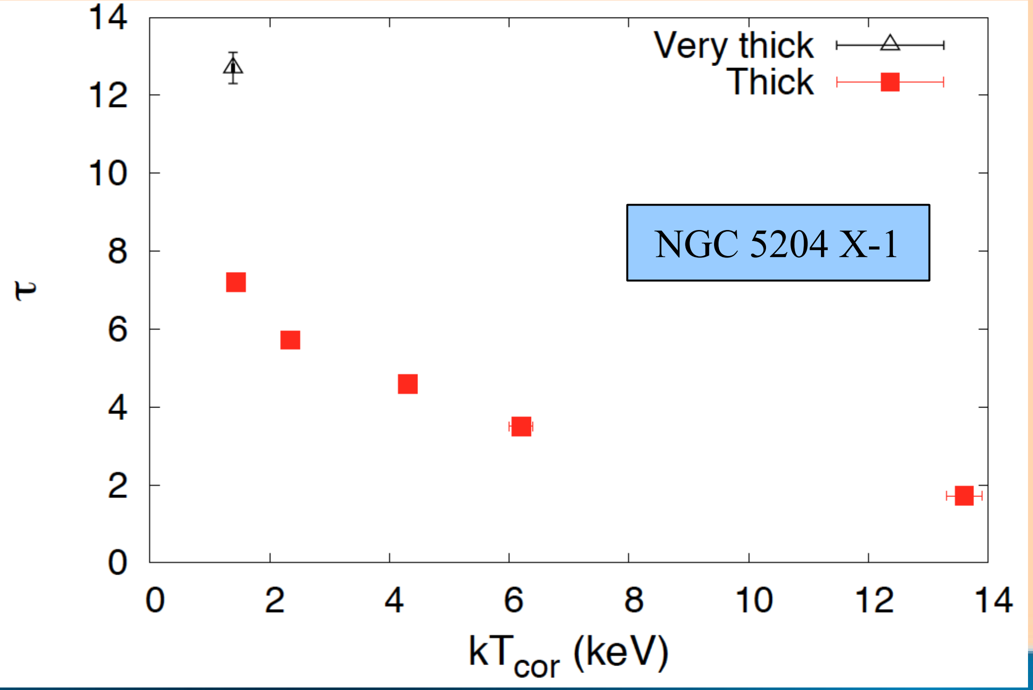
NGC 5204 is an irregular galaxy with 1 ULX;

Two "spectral states" (1)

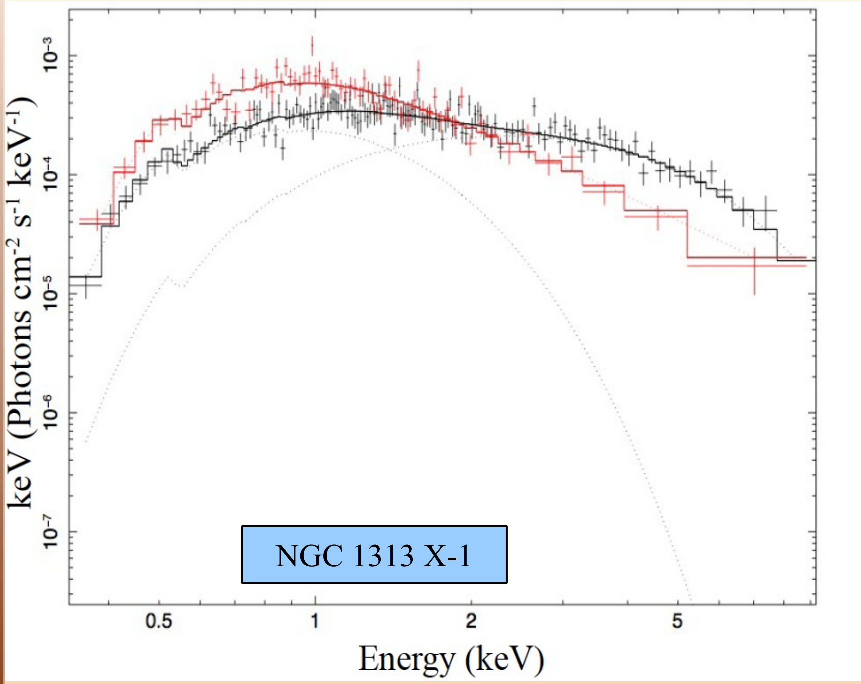


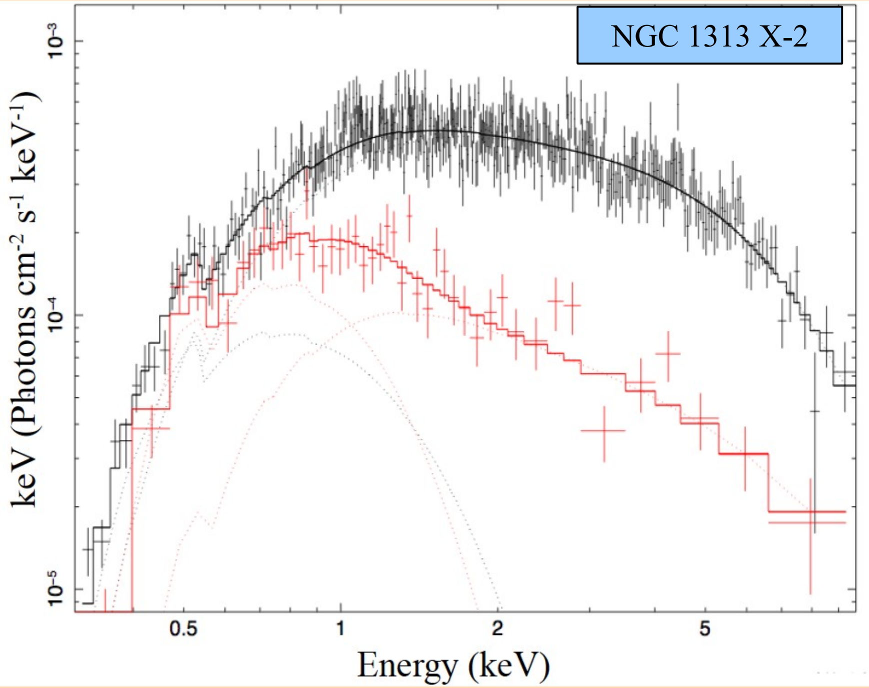


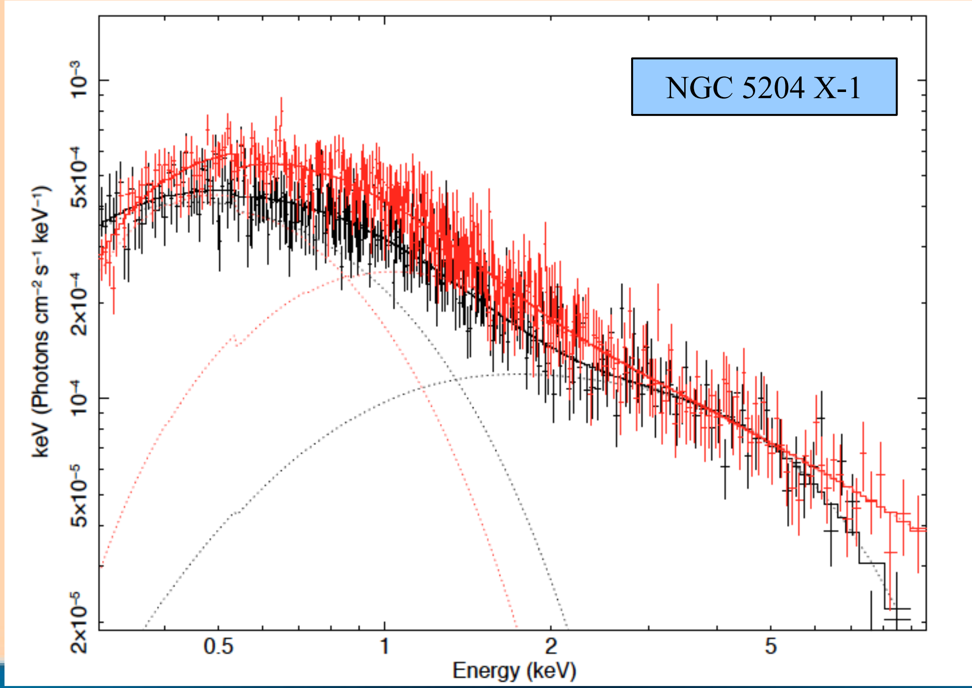
The spectra populate two distinct regions characterized by very large optical depths ($\tau > 10$) and low temperatures ($kT_{cor} \sim 1.5$ keV), on one side, and smaller optical depths ($\tau < 8$) and a range of temperatures ($kT_{cor} \sim 1.5$-6 keV), on the other side (Pintore & Zampieri 2010, 2011).



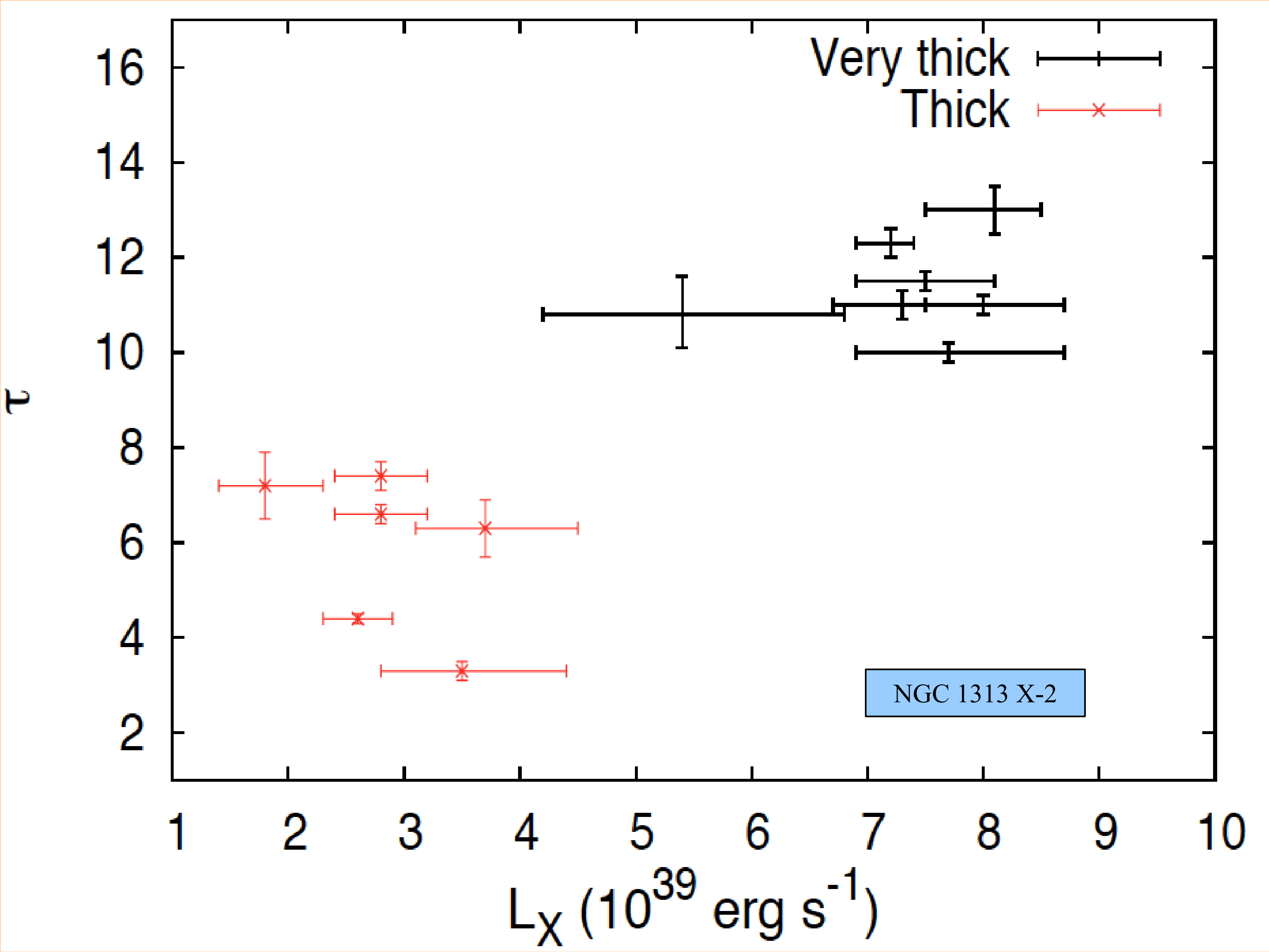
Two "spectral states"(2)







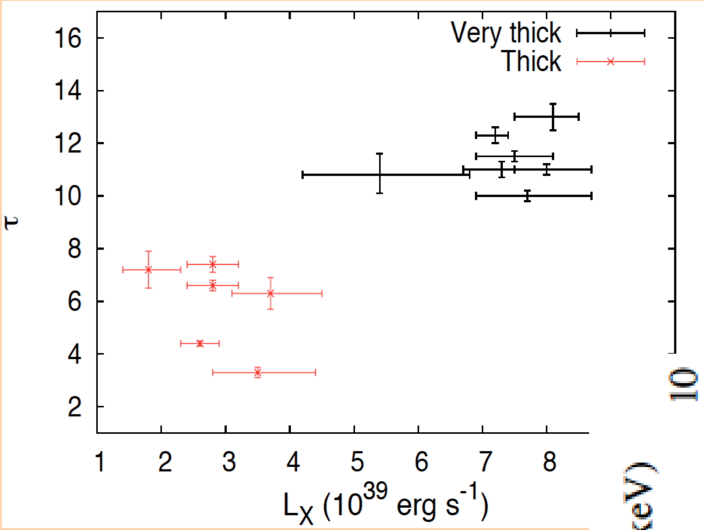
Optical depth vs Total luminosity

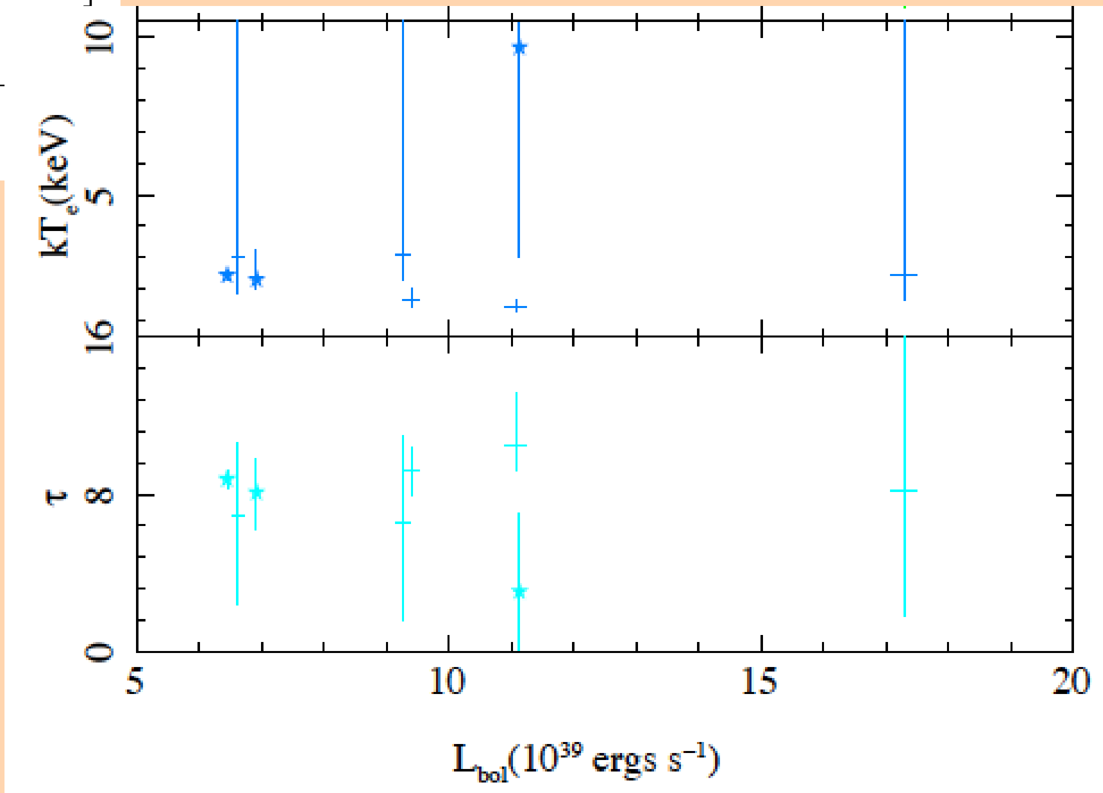


Optical depth versus unabsorbed total luminosity (in the 0.3-10 keV range) for X-2;

The two states appear to correlate with total luminosity, the very-thick corona state being more luminous; in agreement with the results obtained for Ho IX X-1 by Vierdayanti et al.(2010) .

Optical depth vs Total luminosity





Optical depth versus unabsorbed total luminosity (in the 0.3-10 keV range)

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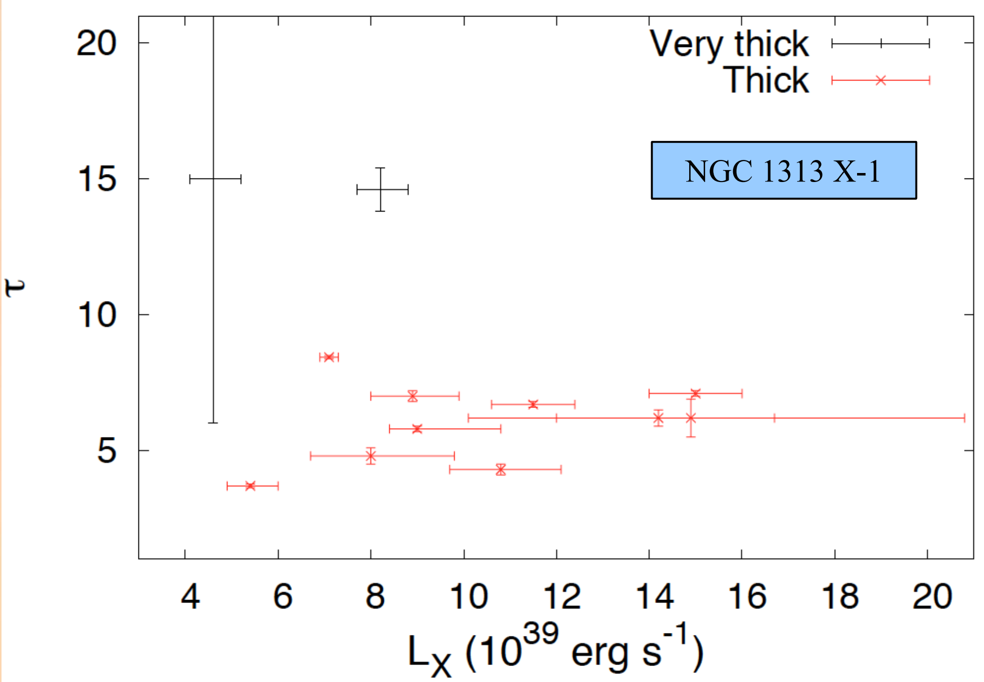
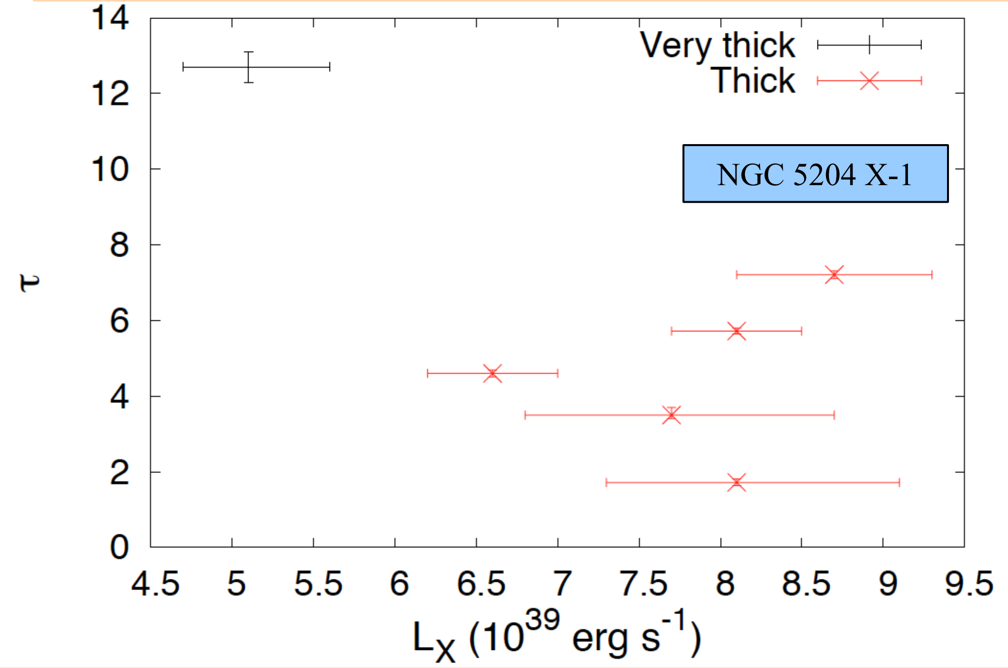
Optical depth vs Total luminosity



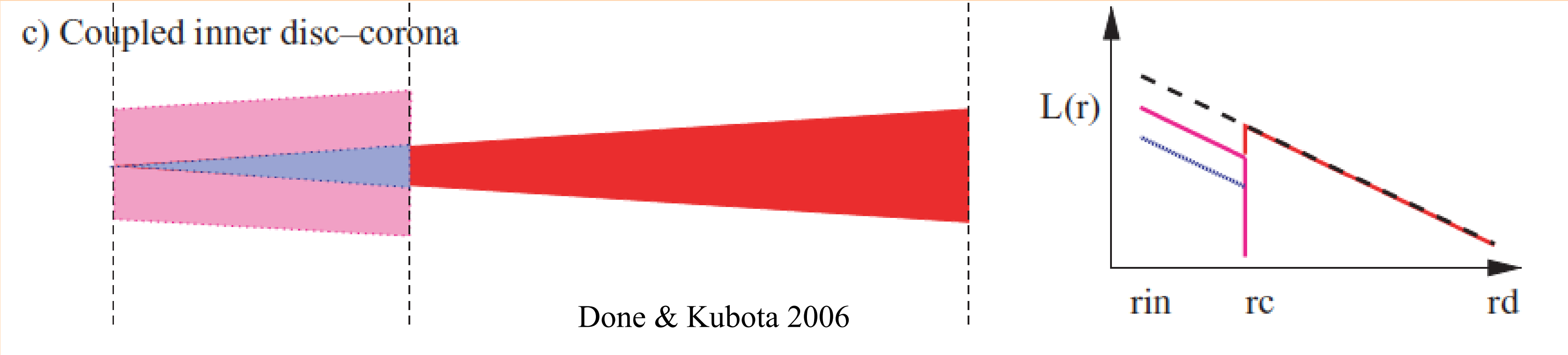


For NGC 5204 X-1 and NGC 1313 X-1, the two states do not appear to correlate with total luminosity;

A more physical approach: Ratio of seed photons temperature to the disc temperature

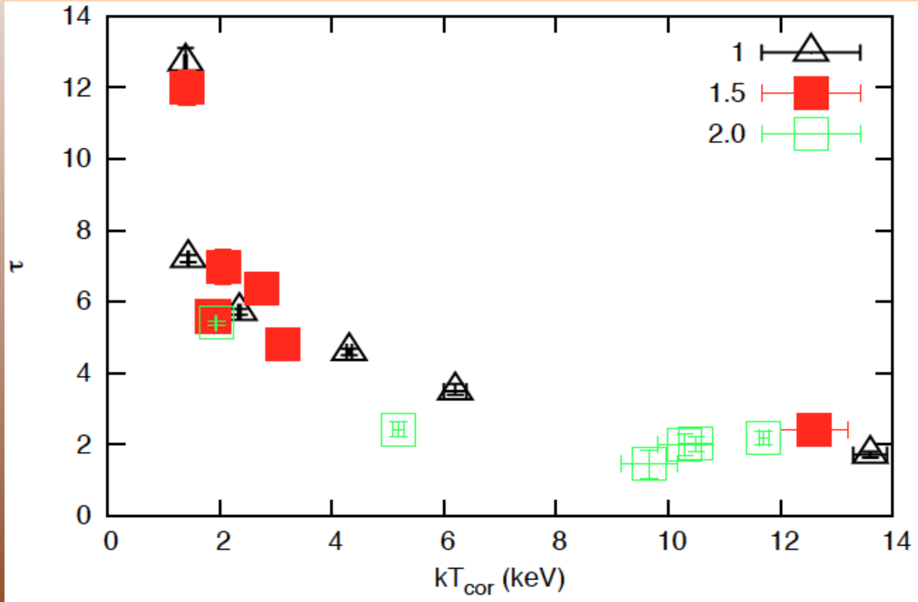
The comptonizing coronae of the comptt model turn out to be optically thick. This poses a problem, as in these physical conditions the disc underneath the corona is masked by it.

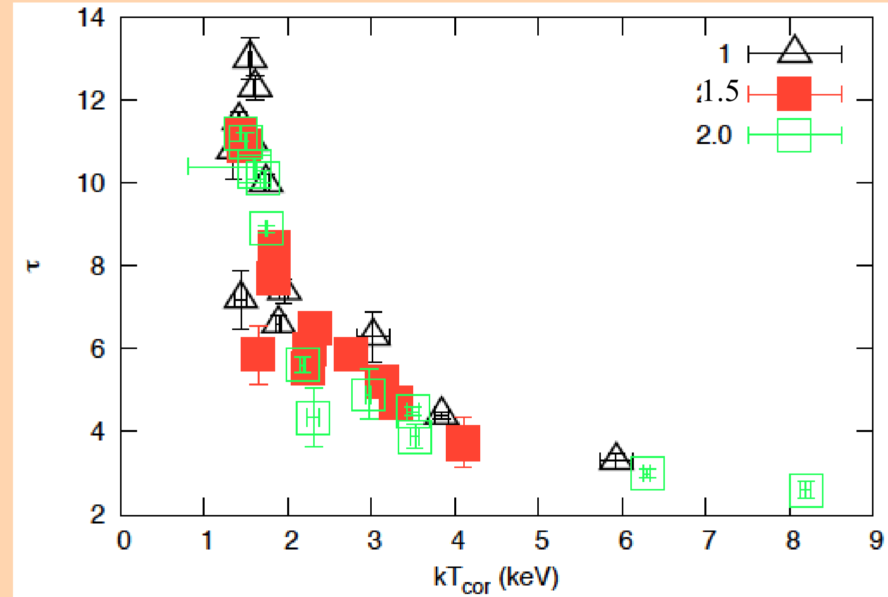
If the corona is optically thick and is absorbing a constant fraction "*f*" of the accretion power, the actual inner disc temperature T_0, is lower than the inner temperature of the disc in absence of the corona T_1, as $T'_1 = T_1(1-f)^{1/4}$ (e.g. Gladstone et al.2009).



Thus, we have $T'_1 \approx T_T\,(R_T / R_1)^{3/4}(1-f)^{1/4}$. Assuming that $f \leq 90\%$ and that the corona is compact ($R_T \leq 4R_1$), the inner disc temperature T'_1, which is also the seed photons temperature, is larger than the temperature of the outer visible disc T_T , and $1 \leq T'_1/T_T = T_0/T_{disc} \leq 2.5$.

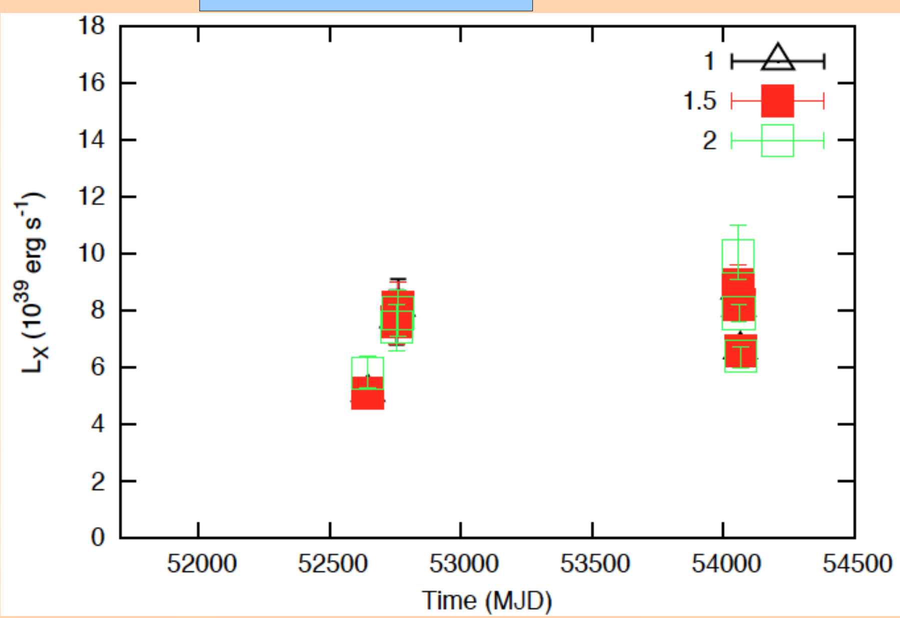
Results (Ts=1.5-2.0*Td)

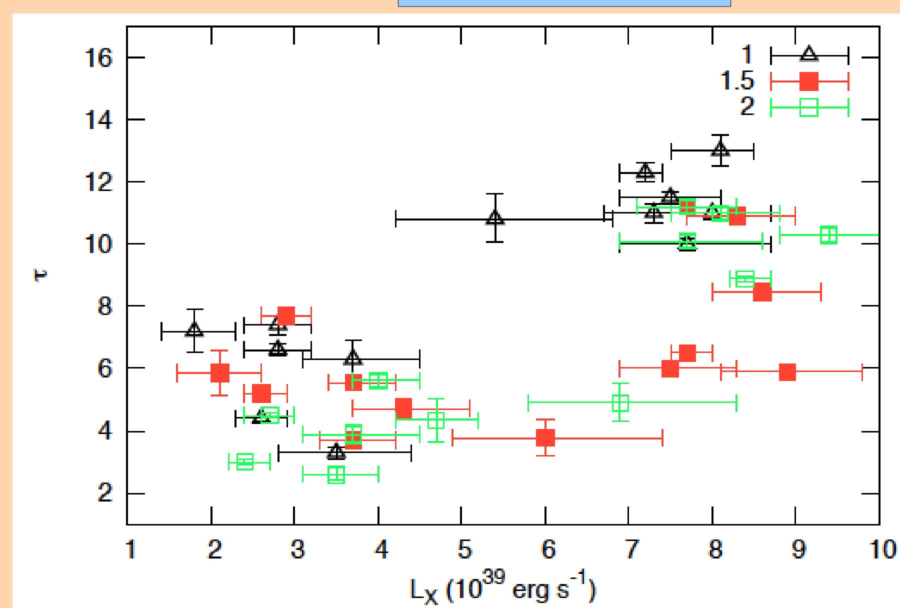




NGC 5204 X-1

NGC 1313 X-2





Chemical abundances

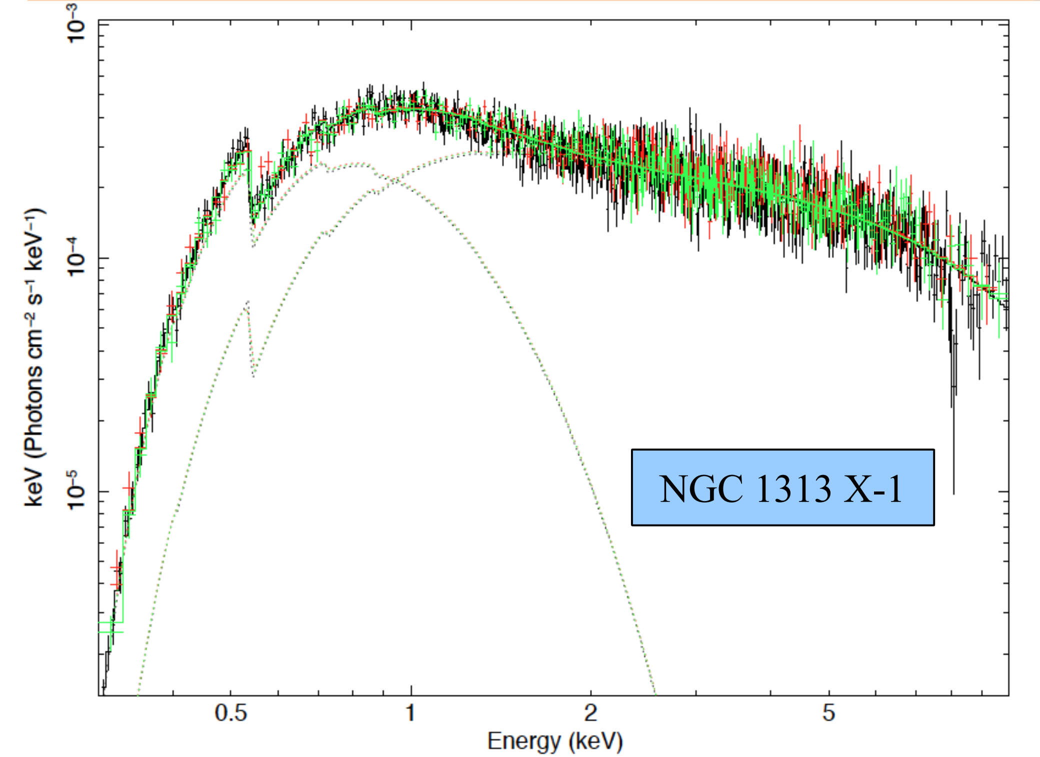
NGC 1313 X-1		
	τ^a	$12 + \log(O/H)^b$
RGS (observation 13)	$0.75^{+0.29}_{-0.25}$	$8.7^{+0.1}_{-0.2}$
EPIC (observation 13)	$0.75^{0.03}_{-0.03}$	$8.72^{+0.02}_{-0.02}$
RGS (stacked)	$0.53^{+0.26}_{-0.23}$	$8.7^{+0.3}_{-0.2}$
NGC 1313 X-2		
	τ^a	$12 + \log(O/H)$
EPIC (observation 13)	$0.46^{+0.05}_{-0.04}$	$8.64^{+0.06}_{-0.05}$

[a] Absorption depth at the threshold energy.
[b] For the solar abundance we assume $12 + \log(O/H) = 8.92$ ($Z_\odot$ = 0.02).

From the Oxygen edge (0.538 keV), as in Winter et al.(2007);

Sub-solar abundances for NGC 1313 X-1 & X-2! Also for NGC 5204 X-1 we found sub-solar abundance (12+log(O/H)=8.61).

Winter et al.(2007) found solar abundances; however they used different spectral models and also a spectrum with lower counting statistics than us for NGC 5204 X-1 and the not well calibrated October 2000 observations for NGC 1313 X-1 and X-2;



Conclusions

• The analysis of all the XMM-Newton observations shows that the spectra of NGC 1313 X-1/X-2 and NGC 5204 X-1 can be well reproduced by a Comptonization model plus a soft disc component in which the coronae are always optically thick;

• The sources appear to show a well defined behaviour in the optical depth versus corona temperature plane;

• Our findings are consistent with the picture described by Gladstone et al.(2009). The three sources are probably accreting at Eddington or super-Eddington regime.

• The correlation of the optical depth to the corona with luminosity that we found for X-2 (assuming $T_0 = T_{disc}$) is in agreement with the results obtained for Ho IX X-1 by Vierdayanti et al.(2010) . Also IC 342 X-1 shows some hint of an increase in the coronal depth as the X-ray luminosity increases (Feng & Kaaret 2009);

• A spectral analysis based on the assumption that the seed photon temperature is equal to the disc temperature has some inconsistencies. Therefore, we adopted a more physical approach in which $1< T_0/T_{disc} <2.5$.

• Using an approach similar to that of Winter et al. 2007, we determined the Oxygen abundance in the EPIC and stacked RGS spectra of NGC 1313 X-1/X-2 and NGC 5204 X-1, and found that it is below solar. Our estimates from the Oxygen K-shell edge are in agreement with the abundance measurements from HII regions in NGC 1313 that give values that are all subsolar (Pilyugin 2001; Hadfield et al. 2007; Ripamonti et al. 2010);

THANKS FOR YOUR ATTENTION!!!