The reflection component in the NS X-ray binaries: analogies and differences with the BH class

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High Energy View of Accreting Objects: AGN and X-ray Binaries
Agios Nikolaos
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Black holes and NS

Common ingredients

- Disk + corona
- At least two different accretion regimes (soft state vs. hard states)
- Disk reflection signatures
- High frequency features
- Both systems useful for probing strong gravity effects

Important differences

- NS have *boundary layer* emission
- Strong gravity in NS yes, but effects limited by the NS surface (don't worry about spins, *no need to use laor*)

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Relativistic lines in NS LMXBs

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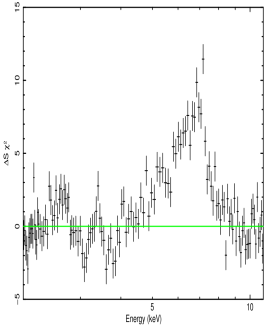
- Atoll: Ser X-1 (Bhattacharyya 2007)
- Atoll: 4U 1636-536 (Pandel 2008)
- Atoll: 4U 1705-44 (Di Salvo 2009; Reis 2009)
- Atoll: 4U 1820-30 (Cackett 2009)
- Zeta: GX 340+0 (D’Aí 2009)
- Zeta: GX 349+2 (Iaria 2009; Cackett 2009)
- Tr. ms: SAX J1808.4-3658 (Papitto 2009; Cackett 2009)



Reference

NS LMXB: SAX J1808.6-3658
Papitto et al., 2009, A&A
XMM data

Relativistic lines in NS LMXBs

How solid are these detections? Arguments for:

- Physically plausible explanation and simple spectral fitting
- Ubiquity: AGN and black-holes and NS accreting binaries
- Goodness of the fit: compare $\Delta\chi^2$ with the Gaussian profile
- Broadband spectral modelling of the reflection component and self-consistency

How solid are these detections? Arguments against:

- A broadening of the Fe Kα lines can be caused by other physical process:
  - Compton broadening in a moderately optically thick flow
  - Compton downscattering in an inflowing/outflowing relativistic wind
  - Blending of many lines
- Reliability of the spectra used for the analysis *(are broad lines artificially produced by pile-up?)*

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Relativistic lines, pile-up and statistics

Pile-up in bright sources

- Relativistic origin of broad lines in XRB mostly relies on comparison between Gaussian (symmetric line profile) and relativistic reflection profiles (`diskline, laor, kyrline, kdline`);
- Line shape constraints are dependent on the spectrum quality (count rate, exposure, S/N ratio), bright objects are expected to be biased..
- ..but bright objects are more easily subject to spectral distortions due to presence of pile-up in CCD cameras;

Pile-up cure

- It is possible to avoid strong pile-up by excising the core of the point spread function
- Excising always causes loss of statistics and degradation of spectral information

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A simple exercise on the influence of pile-up

Simulated theoretical spectra convolved with a pile-up model

- Analysis of the response of in-flight CCD cameras to pile-up (Chandra, XMM-Newton, Suzaku, Swift/XRT)
- Selected faked spectra from bright NS/BH LMXB
- Convolved spectra with the Davis (2005) pile-up model
- Analysis of spectral distortions as a function of pile-up degree

Miller J., D'Aì et al. *ON RELATIVISTIC ACCRETION DISK SPECTROSCOPY IN COMPACT OBJECTS WITH X-RAY CCD CAMERAS*, ApJ in press (Arxiv:1009.4391)

Results from this exercise

Our results suggest that severe photon pile-up acts to falsely narrow emission lines, leading to falsely large disk radii and falsely low spin values. In contrast, our simulations suggest that disk continua affected by severe pile-up are measured to have falsely low flux values, leading to falsely small radii and falsely high spin values. ***The results of these simulations and existing data appear to suggest that relativistic disk spectroscopy is generally robust against pile-up when this effect is modest.***

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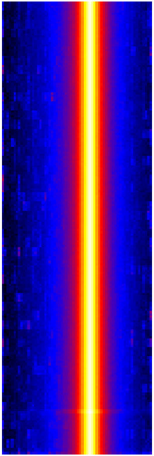
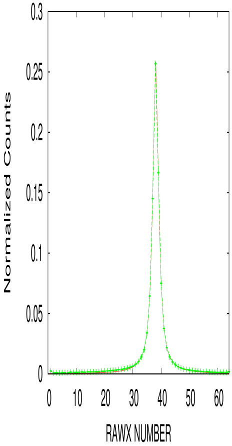
On the influence of pile-up: REAL DATA

Extraction of spectra from different anulii around the PSF

- Real data from a XMM-Newton observation of 4U 1705-44 in the soft state
- EPIC/PN in timing mode (no image but very fast read-out time)
- Average count rate whole CCD $\sim$ 750 cts/s
- Point spread function cover the whole exposed CCD.



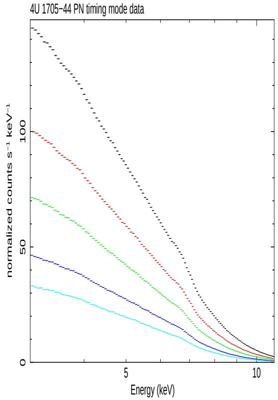


On the influence of pile-up: REAL DATA

DATA: XMM-Newton observation 4U1705-44 in the soft state

Loss of counts due to excising the PSF

Numb. excised rows	Perc. counts	count rate
0 (RAWX0)	95%	709
1 (RAWX1)	66%	498
2 (RAWX2)	47%	355
3 (RAWX3)	31%	230
4 (RAWX4)	22%	166
5 (RAWX5)	10%	77



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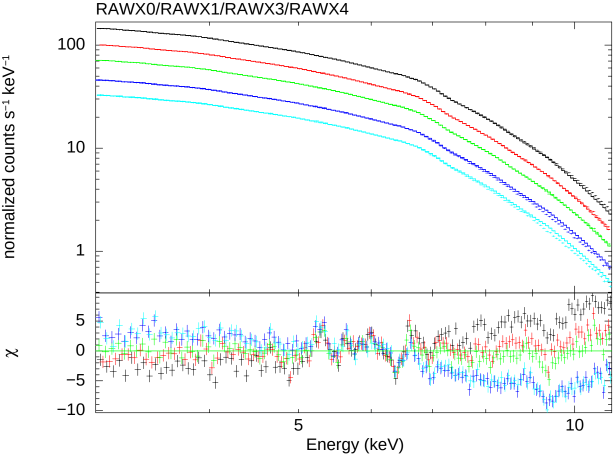

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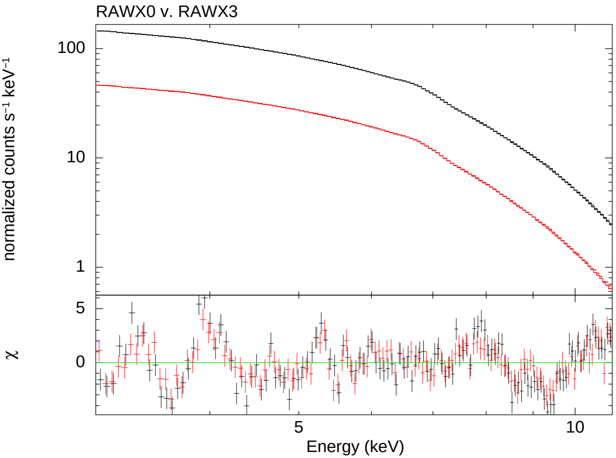

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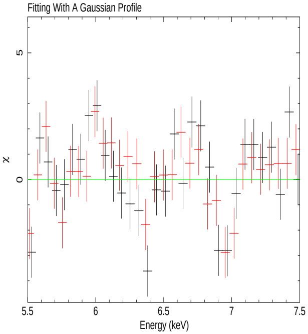
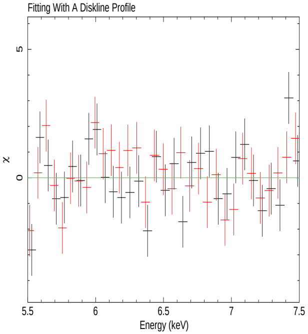

Fitting With A Gaussian Profile


Fitting With A Diskline Profile

On the influence of pile-up: REAL DATA

Comparing spectral parameters

	RAWX0 *modest pile-up*	RAWX3 *negligible pile up*	Error (σ)
wabs	2.23	2.53	2.2
bbody kT	0.530	0.513	2.1
bbody N ($\times$ 10^{-2})	3.58	3.92	1.5
flux BB ($\times$ 10^{-9})	3.0	3.3	3
kT_o	1.23	1.26	2.0
kT_e	5.33	4.35	10.0
τ	6	6	
comptt N	0.22	0.27	10.0
flux comptt ($\times$ 10^{-9})	7.1	6.5	6
Fe line EW (eV)	56	59	< 1

Arguments against the reflection scenario

Other physical mechanisms that can produce broad iron lines

- Blending of lines at different ionization states.
  Chandra high-resolution data do not support this argument.
- Thermal Compton broadening.
  It requires a fine tuning of electronic temperature and optical depth across a variety of sources and accretion regimes.It's a symmetric profile.
- Bulk motion Comptonization / downscattering inside a converging (or outflowind) relativistic wind.
  It predicts a different line shape, with no blue wings, contrary to what observed.

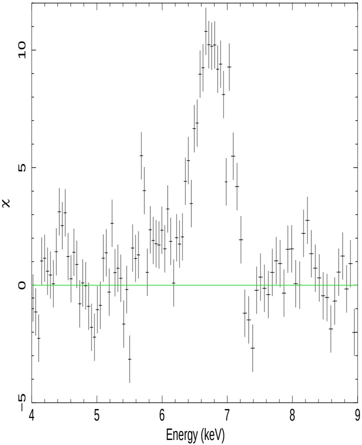
The case GX 340+0

Diskline parameters

Line energy at 6.69 ± 0.02 keV
Inclination 34.6 ± 1.3
Emissivity index 2.50 ± 0.10
Inner disk radius 13 ± 3 R_g
Outer radius > 3000 R_g

Reference

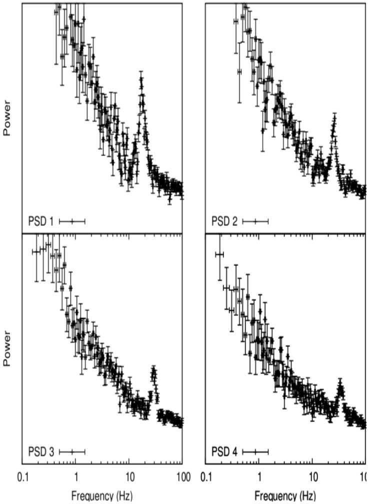
D'Aí A. et al., 2009, ApJL
arXiv:0906.3716



GX 340+0: linking the fast temporal variability

The HBO QPO

- During the observation, the HBO QPO moved, in correlation with the count rate, from 17 Hz to 40 Hz
- The kHz QPO upper peak is correlated to the HBO frequency → 500 to 750 Hz (see Jonker et al. 2000)
- The tracking is consistent with a inner disk movement (9.8-12.1 R_g), but uncertainties in the inner radius measurements large.



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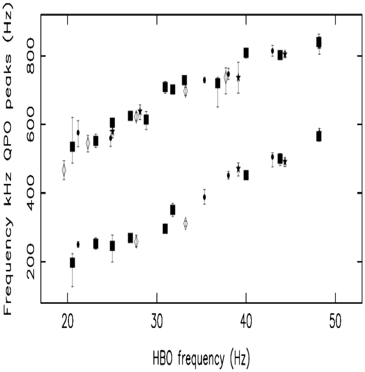

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HBO (Hz)	kHzQPO (Hz)	R_{in} km	R_{in} km
17.7 ± 0.2	496	26.6	32^{+40}_{-16}
25.7 ± 0.2	605	23.5	26^{+10}_{-14}
29.4 ± 0.2	654	22.3	28^{4}_{-8}
34.6 ± 0.4	725	20.8	26^{+12}_{-14}
38 ± 2	770	20.0	14^{+36}_{-2}

Need for a self-consistent reflection model

Why a reflection model?

- The high quality of the XMM-Newton spectra allow broad-band (0.5-12 keV) self-consistent reflection models to be tested
- This allows to better constrain:
  1. the ionization structure of the disk reflecting skin
  2. the spectral shape of the ionizing incident flux
  3. to weight the chemical abundance of iron/other metal
  4. to self-consistenly evaluate the total energetic contribution in extrapolated bands

The **refbb** component

- Table model of reflection from an optically thick slab of costant density
- Model developed from the **reflion** code (Ross & Fabian, 1993; Ballantyne et al. 2004 on 4U 1820-30)
- *Incident radiation a **black-body** spectrum*
- Lines and edges from Fe, O, Si, Mg, N and C and variable Fe/other metals ratio

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The soft state of 4U 1705-44

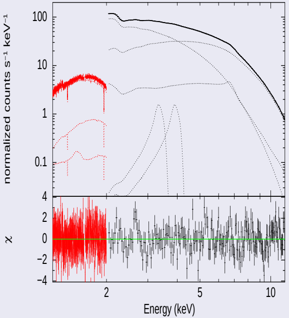
1705 - Spectral parameters

- Disk temp. 1.15 $\pm$ 0.03 keV
- BB temp. 1.91 $\pm$ 0.01 keV
- log ξ 2.36 $\pm$ 0.07
- Luminosity $\sim 1 \times 10^{38}$ erg s^{-1}
- Fractional BB flux 60%
- Fractional diskbb flux 30%
- Fractional refbb flux 10%

How reflection reprocesses the incident radiation

0.1-1.0 keV	1-10 keV	10-100 keV
63 %	32 %	5 %

1705 - refbb model



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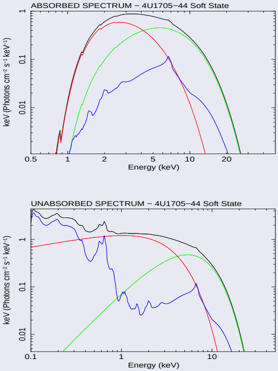

Self-consistent constraints in the soft state: a truncated disk at 2 R$_{NS}$

Thermal disk emission

$$N_{DBB} = \left(\frac{R_{in}}{D_{10kpc}}\right)^2 \times cos\theta \tag{1}$$

$$R_{in} \rightarrow 11.2 \pm 0.5\ km \tag{2}$$

Inner radius under-estimated by a factor of ∼ 2 (Merloni et al. 2000)
Corrected estimate is ∼ 11 R$_g$ ∼ 2 R$_{NS}$.

Reflection signatures

	Diskline	Refbb
R$_{in}$ (R$_g$)	14 ± 2	< 13
Incl.	39 ± 1	35 ± 2
Betor	2.3 ± 0.1	2.3 ± 0.1

Ratio of continuum emission components

$$\frac{L_{BL}}{L_{disk}} \sim 2 \tag{3}$$

with $\nu_{spin} \sim 300$ Hz
R$_{in}$ ∼ R$_{BL-out}$ 1.8–2.1 R$_{NS}$
from Popham & Sunyaev, 2001

Conclusions

Talk Highlights

- Reflection features are potentially a key tool to investigate the pit of NS and BHs.
- It is possible to cope with moderatly pile-up affected spectra to achieve meaningful data interpretation
- Good fitting is not *the ultimate answer*. This paradigma still deserves supporting corroborance.
- Temporal analysis must cope with spectral analysis.
- Reflection in soft states of NS may be due to reflection of the boundary layer emission that has a thermal shape (no Compton bump).