# XMM-Newton observations of the two Anomalous X-ray pulsars 1RXS J170849.0-400910 and 1E1048.1-5937

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Neutron Stars at the Crossroads of Fundamental Physics,
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Together with:

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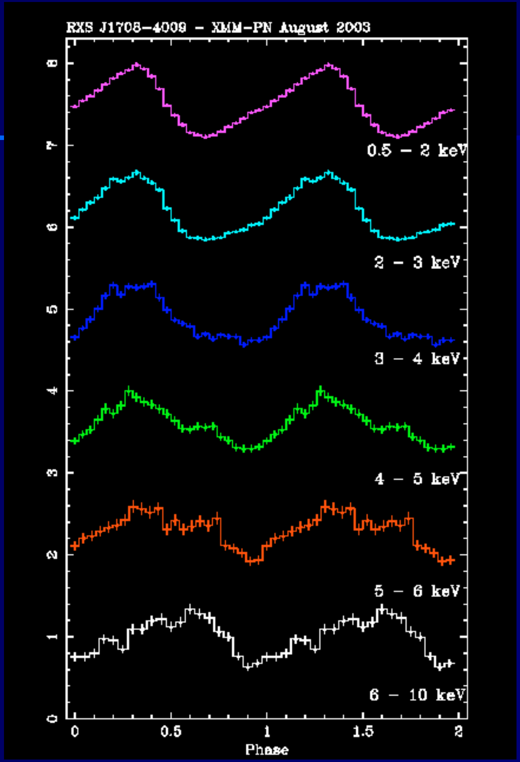
M. Mendez, R. Turolla, T. Oosterbroek, F. Haberl

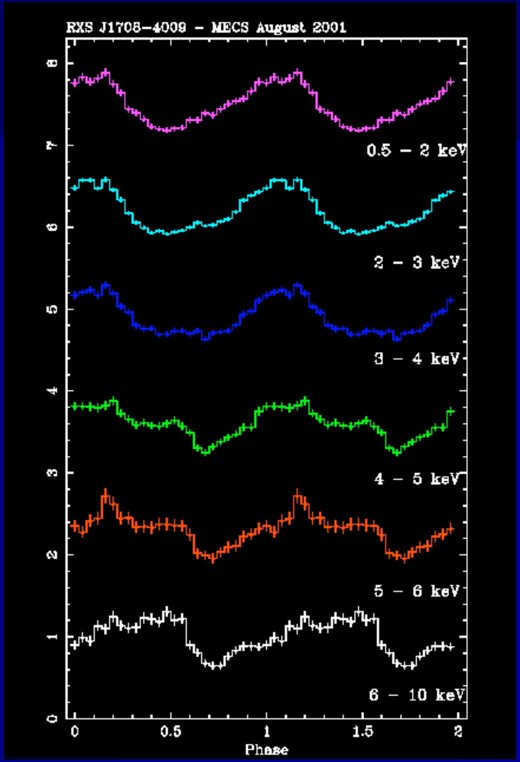
# Post glitch variability of 1RXS J1708

## Rea et al, 2005, MNRAS, 361, 710

- first observed with Rosat (1996) and Asca (1997)
- Early data: fairly stable rotator (Israel et al 1999)
- Two glitches in the last 4 yrs, with different recoveries (Kaspi et al 2000/2003, Dall'Osso et al 2003)
- PPS of two Sax obs: 1) large spectral variability with spin phase 2) strong energy dependence of pulse shape (Israel et al, 2001; Rea et al 2003)
- Absorption line at ~8keV reported at 4 $\sigma$ in the phase resolved spectrum taken during the longest Sax observation (taken in 2001 when the source was not totally recovered from the second glitch. Rea et al. 2003)
- Then observed with Chandra (unpublished) and for the first time with XMM (50 ks, 28-29 Aug 2003. Rea et al. 2005)

# Post glitch folded light curve





Sax
(source not totally recovered from the glitch)
30% PF in 0.1-2 keV
17% PF in 6-10 keV

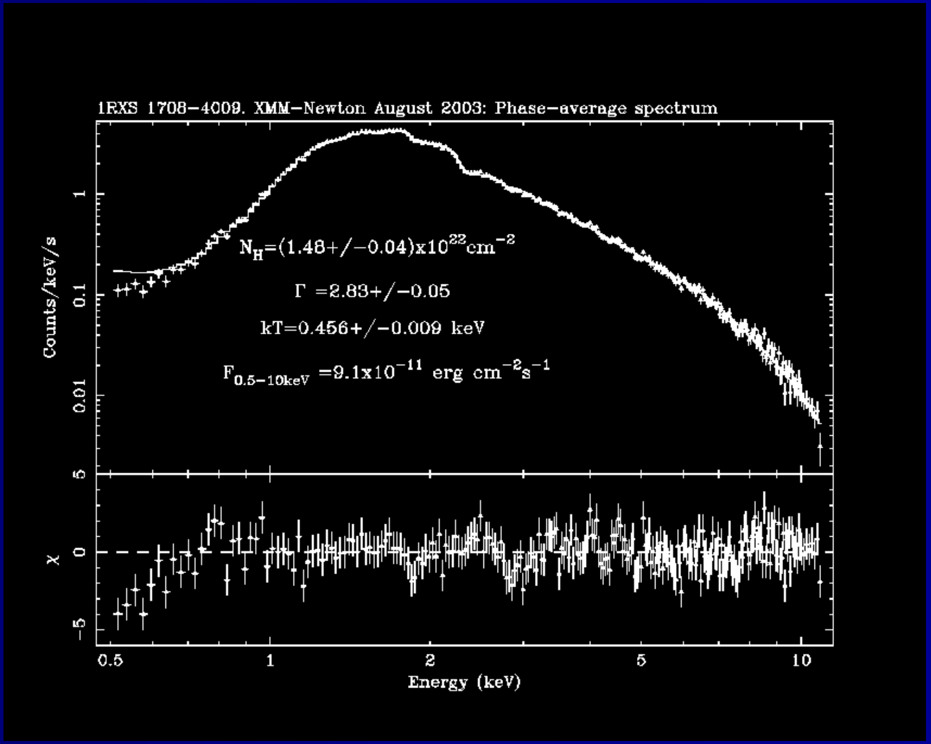
XMM
(Post glitch)
39% PF in 0.5-2 keV
29% PF in 6-10 keV

(consistent with those pre-glitches)

# Phase-averaged XMM PN spectrum

All parameters but $\Gamma$ consistent with the last Sax measurements (source not totally recovered from the glitch)

Post glitch: a clear softening in the spectrum correlated with a decrease of flux of a factor ~2.

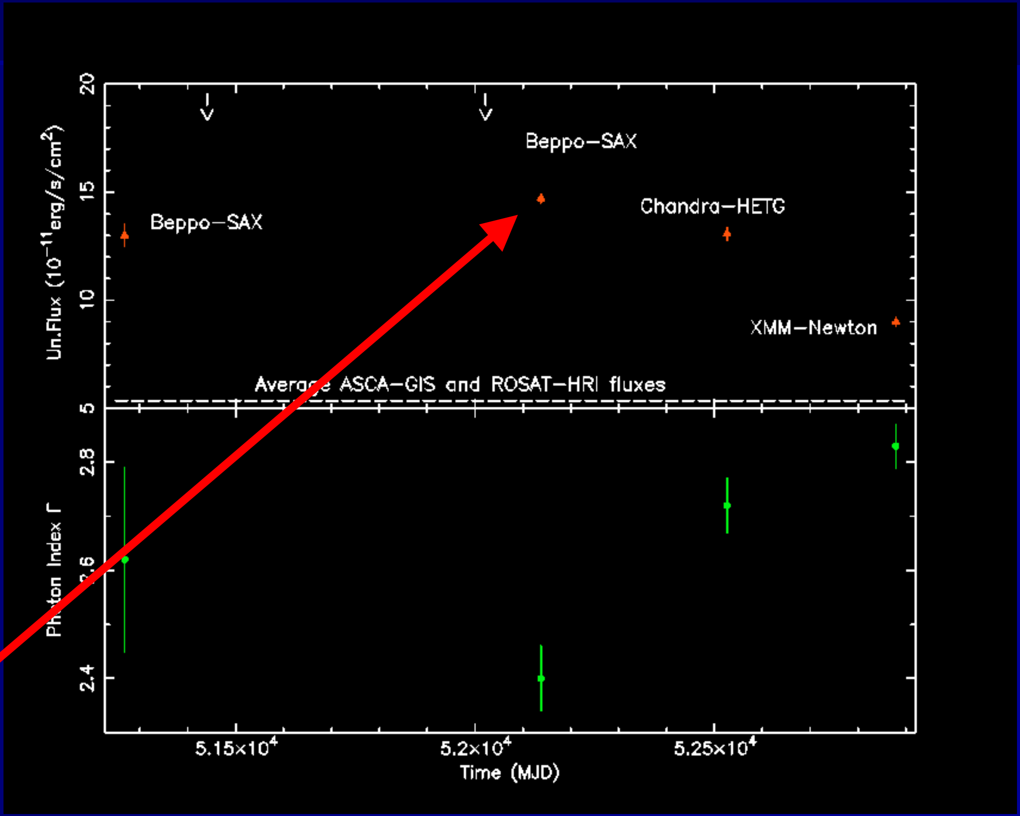


# Long term evolution of the source flux and spectral hardening

Obs spanning 5 years

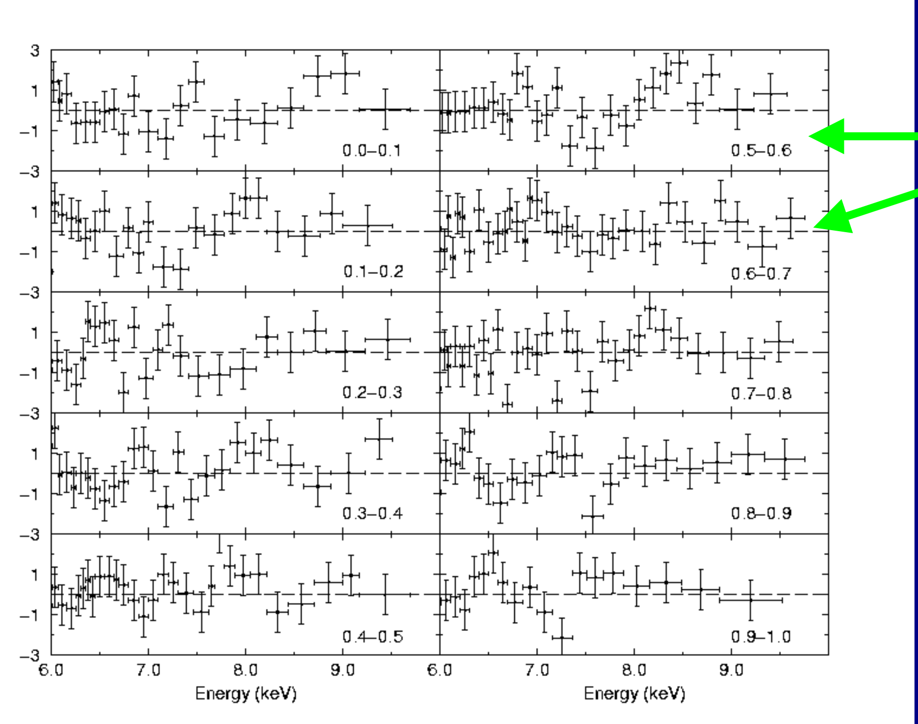
Γ-L correlation

The spectrum became harder as the flux rose in correspondence of the two glitches and then softened as the luminosity dropped, following the glitch recovery



Absorption line at ~8keV reported at 4 σ in the phase resolved SAX spectrum taken when the source was not totally recovered from the second glitch.
POSSIBLY Cyclotron feature. (Rea et al. 2003)

# Post glitch: no evidence for absorption features in XMM data



Residuals of the spectral fit at different phase intervals (Epic-PN)

Phase intervals with line detection in SAX data (Rea et al. 2003)

Spectral fit at this phases adding a cyclabs model.

$E_{line}$ =8.1keV
width = 0.2 keV
Step in depth

- 95% upper limit in depth: 0.15
- SAX line depth: 0.8 at 90% CL

Hints for other lines: around ~7keV in a few phase intervals, but in all cases CL < $2\sigma$

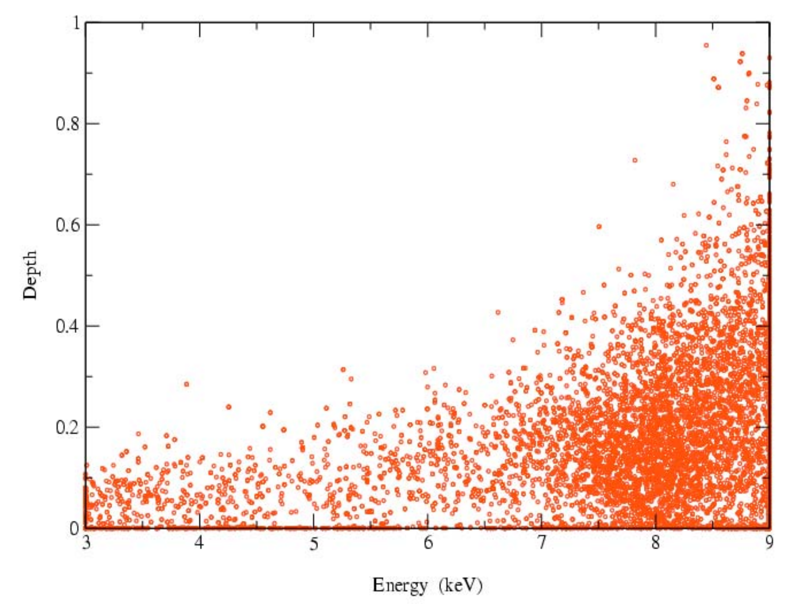
# Re-analysis of Sax detection

1) Line significance not affected by background subtraction or extraction region

2) F-test CL 4$\sigma$

3) Monte Carlo simulation of 10000 spectra

Continuum model and same number of photons as in Sax spectrum.



32 spectra with depth >0.8 in 10000
Prob line being a fluctuation <0.32 %
Detection Rea confirmed at 99.68 CL.

# Onset of a twist in the magnetosphere?

- Glitching activity
- Observed $\Gamma$-L correlation
- Possibly, transient appearance of a cyclotron line

Thompson, Lyutikov and Kulkarni (2002):

Magnetars (AXPs and SGRs) differ from radiopulsars since their internal magnetic field is twisted up to 10 times the external dipole.

At intervals, it can twist up the external field ⇒ stresses build up in the NS crust, crustal fractures, glitches.

# A twisted magnetosphere?

- A key feature of twisted MSs is that they support current flows.
- The presence of charged particles (e- and ions) produces both a large resonant scattering depth and an extra heating of the star surface (by returning currents).
- e- distribution spatially extended + $\omega_{res} = \omega_{res}$ (B)
  ⇒ repeated scatterings could lead to the formation of a high energy tail (instead of a narrow line)
- Both scattering depth and released luminosity increase with the twist angle
  ⇒ since spectral hardness increases with depth this implies a positive $\Gamma$-L correlation (as observed) !

See also talks by N. Rea and R. Turolla on Friday

# A twisted magnetosphere?

- Transient appearence of a cyclotron line during the epoch in which the twist was substantial

- Magnetospheric charges also provide a substantial depth to the resonant proton scattering

- If the X-ray luminosity at the resonant frequency is large enough to exceed the luminosity produced by the returning currents $L^{rc}_{x}$, ⇒ ions are effectively confined in a thin layer close to the surface ⇒ appearance of a line instead of tail!

- Two conditions for (transient) line formation:
  - Large Twist angle
  - $L(\omega_i) > L^{rc}_{x}$

TLK02: Cyl. Simmetry, self-similar, whole star surface: $L^{rc}_{x} \sim 10^{35}$ erg/s

# Long term spectral variations in 1E1048
## Tiengo et al, 2005, A&A, 437, 997

- 1E1048 is key for understanding the connection between AXPs and SGRs

- First AXP for which X-ray bursts have been discovered

- One of those with hardest spectrum and most variable period evolution (both typical of SGRs)

- Flux variations reported in the past with different satellites (Oosterbroek et al, 98)

- recently more firmly established by two XMM and two Chandra observations (Mereghetti e al, 2004) and by the RXTE monitoring programme (Gavriil & Kaspi, 2004)

3 XMM observations spanning more than 3 years: systematic study of long terms changes based on a homogeneous dataset

| Observation | Date | Duration |
|---|---|---|
| A | 2000 Dec 28 | 8 ks |
| B | 2003 June 16 | 50 ks |
| C | 2004 July 08 | 30 ks |

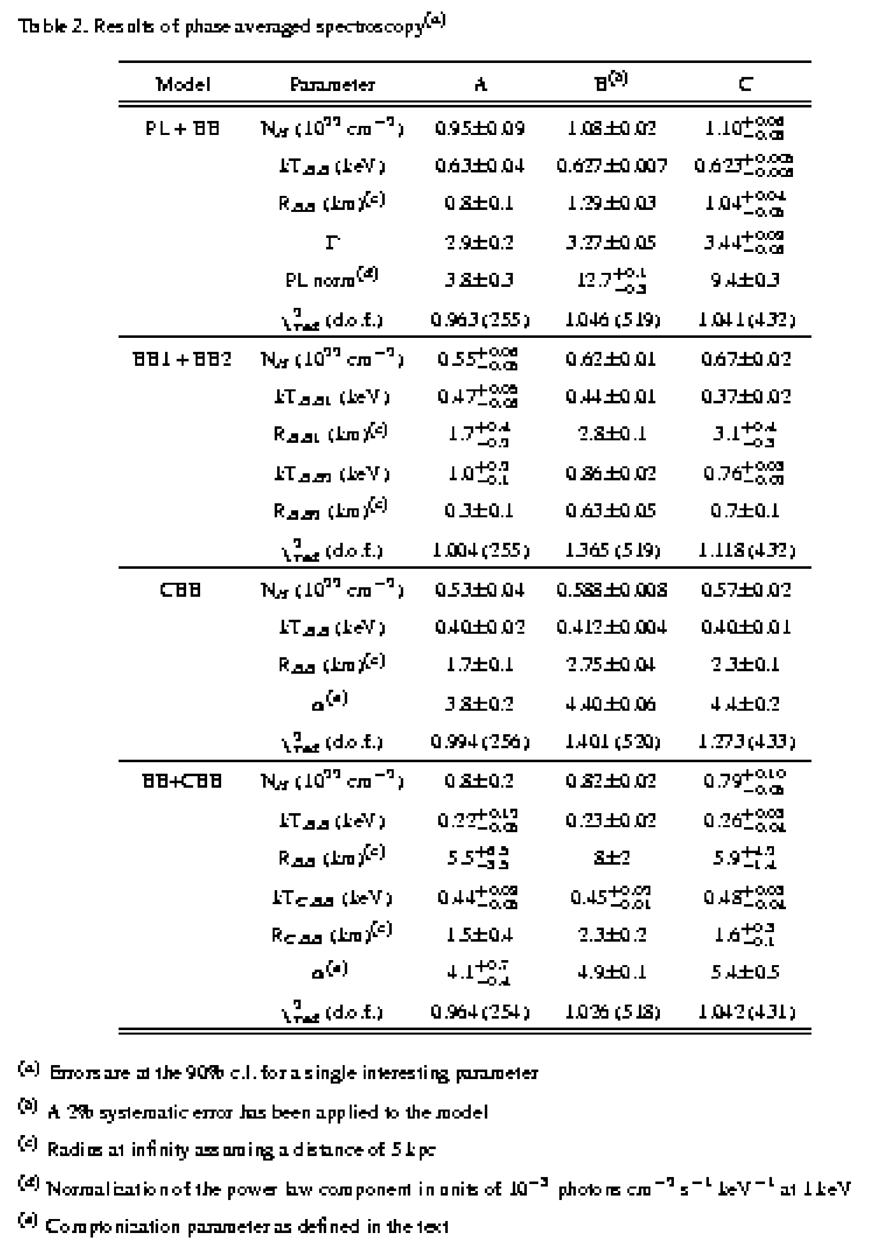


Table 2. Results of phase averaged spectroscopy[a]

| Model | Parameter | A | B[b] | C |
|---|---|---|---|---|
| PL + BB | $N_H$ ($10^{22}$ cm$^{-2}$) | 0.95±0.09 | 1.08±0.02 | $1.10^{+0.04}_{-0.03}$ |
| | $kT_{BB}$ (keV) | 0.63±0.04 | 0.627±0.007 | $0.623^{+0.008}_{-0.008}$ |
| | $R_{BB}$ (km)[c] | 0.8±0.1 | 1.29±0.03 | $1.04^{+0.04}_{-0.05}$ |
| | $\Gamma$ | 2.9±0.2 | 3.27±0.05 | $3.44^{+0.03}_{-0.03}$ |
| | PL norm[d] | 3.8±0.3 | $12.7^{+0.1}_{-0.3}$ | 9.4±0.3 |
| | $\chi^2_{red}$ (d.o.f.) | 0.963 (255) | 1.046 (519) | 1.041 (432) |
| BB1 + BB2 | $N_H$ ($10^{22}$ cm$^{-2}$) | $0.55^{+0.06}_{-0.05}$ | 0.62±0.01 | 0.67±0.02 |
| | $kT_{BB1}$ (keV) | $0.47^{+0.05}_{-0.05}$ | 0.44±0.01 | 0.37±0.02 |
| | $R_{BB1}$ (km)[c] | $1.7^{+0.4}_{-0.3}$ | 2.8±0.1 | $3.1^{+0.4}_{-0.3}$ |
| | $kT_{BB2}$ (keV) | $1.0^{+0.2}_{-0.1}$ | 0.86±0.02 | $0.76^{+0.03}_{-0.03}$ |
| | $R_{BB2}$ (km)[c] | 0.3±0.1 | 0.63±0.05 | 0.7±0.1 |
| | $\chi^2_{red}$ (d.o.f.) | 1.004 (255) | 1.365 (519) | 1.118 (432) |
| CBB | $N_H$ ($10^{22}$ cm$^{-2}$) | 0.53±0.04 | 0.588±0.008 | 0.57±0.02 |
| | $kT_{BB}$ (keV) | 0.40±0.02 | 0.412±0.004 | 0.40±0.01 |
| | $R_{BB}$ (km)[c] | 1.7±0.1 | 2.75±0.04 | 2.3±0.1 |
| | $\alpha$[e] | 3.8±0.2 | 4.40±0.06 | 4.4±0.2 |
| | $\chi^2_{red}$ (d.o.f.) | 0.994 (256) | 1.401 (520) | 1.273 (433) |
| BB+CBB | $N_H$ ($10^{22}$ cm$^{-2}$) | 0.8±0.2 | 0.82±0.02 | $0.79^{+0.10}_{-0.05}$ |
| | $kT_{BB}$ (keV) | $0.22^{+0.12}_{-0.05}$ | 0.23±0.02 | $0.26^{+0.03}_{-0.04}$ |
| | $R_{BB}$ (km)[c] | $5.5^{+8.5}_{-3.5}$ | 8±2 | $5.9^{+4.2}_{-1.4}$ |
| | $kT_{CBB}$ (keV) | $0.44^{+0.09}_{-0.05}$ | $0.45^{+0.07}_{-0.01}$ | $0.48^{+0.03}_{-0.04}$ |
| | $R_{CBB}$ (km)[c] | 1.5±0.4 | 2.3±0.2 | $1.6^{+0.3}_{-0.1}$ |
| | $\alpha$[e] | $4.1^{+0.7}_{-0.4}$ | 4.9±0.1 | 5.4±0.5 |
| | $\chi^2_{red}$ (d.o.f.) | 0.964 (254) | 1.036 (518) | 1.042 (431) |

[a] Errors are at the 90% c.l. for a single interesting parameter

[b] A 2% systematic error has been applied to the model

[c] Radius at infinity assuming a distance of 5 kpc

[d] Normalization of the power law component in units of $10^{-3}$ photons cm$^{-2}$ s$^{-1}$ keV$^{-1}$ at 1 keV

[e] Comptonization parameter as defined in the text

The "canonical" AXPs model works for all spectra

Two BBs ok for A, but rejected by higher quality spectra

A simple Comptonization model (CBB) to physically link PL and BB

# CBB: A Simple Comptonization model

- soft thermal photons (star surface?) upscattered by relativistic e$^-$ (e$^\pm$) with small opt. depth $\tau$ and mean Lorentz factor $<\gamma>$

$$I_e(E) \propto I_i(E')(E/E')^{1-\alpha}$$
$$\alpha = 1 - \ln \tau_{es}^{B} / \ln A$$
$$A \sim 4 < \gamma^2 > / 3$$

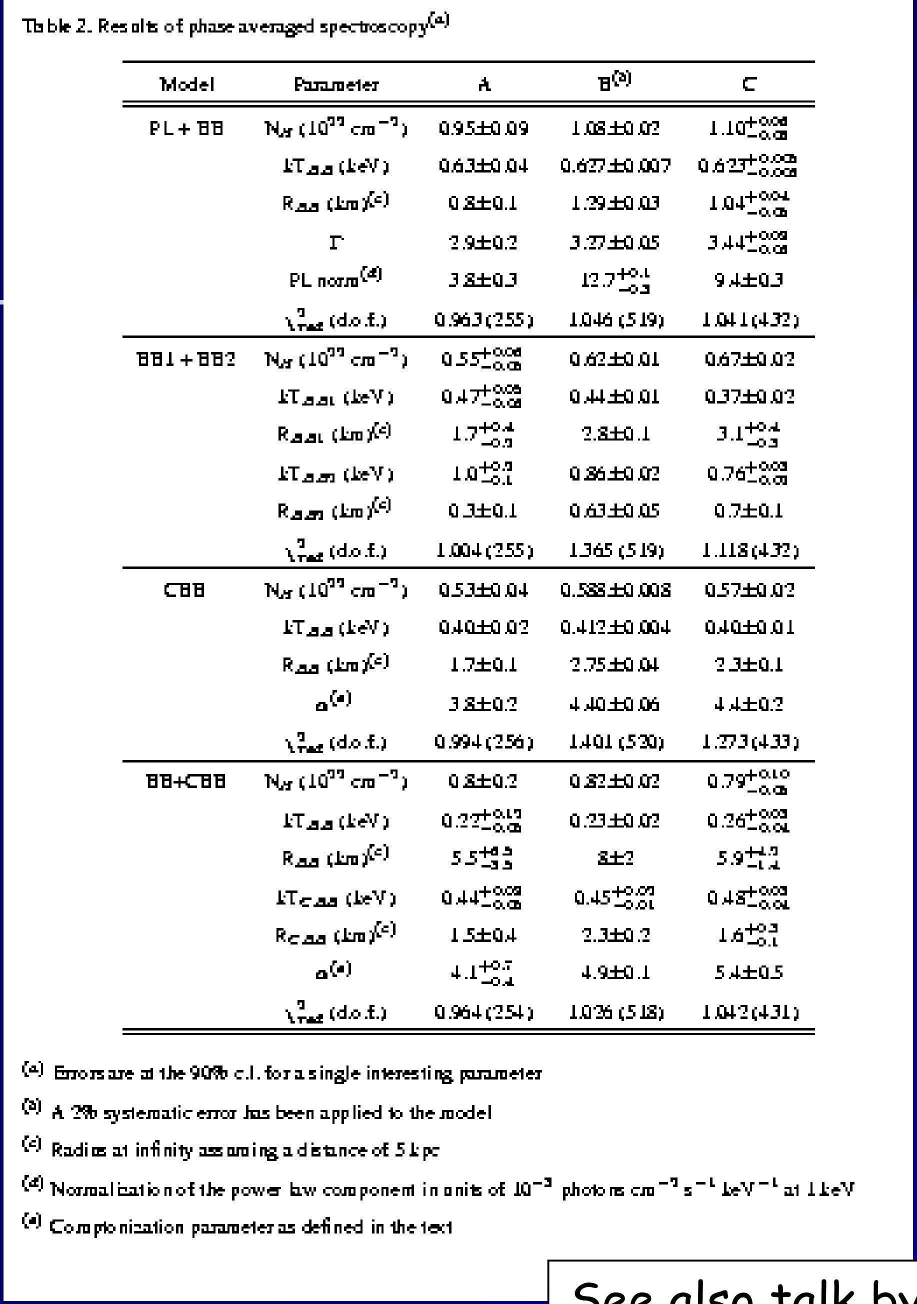
A= mean energy amplification factor per scattering

- Photon spectrum for a BB input:
- Model parameters: C, $T_{BB}$, $\alpha$

$$CE^{-\alpha}\int_0^E dE'E'^{1+\alpha} / [\exp(E'/kT_{BB})-1]$$

$$E << E_B \qquad \sigma_0 \approx \sigma_T \sin^2\vartheta \approx \sigma_T/(4\gamma^2)$$
$$\sigma_X \approx \sigma_T (E/E_B)$$

← $\sigma_X$ dominates for large $\gamma$



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CBB alone does not work, BUT a two component model with CBB and a colder BB does.

The radius of the colder BB is consistent with the star radius.

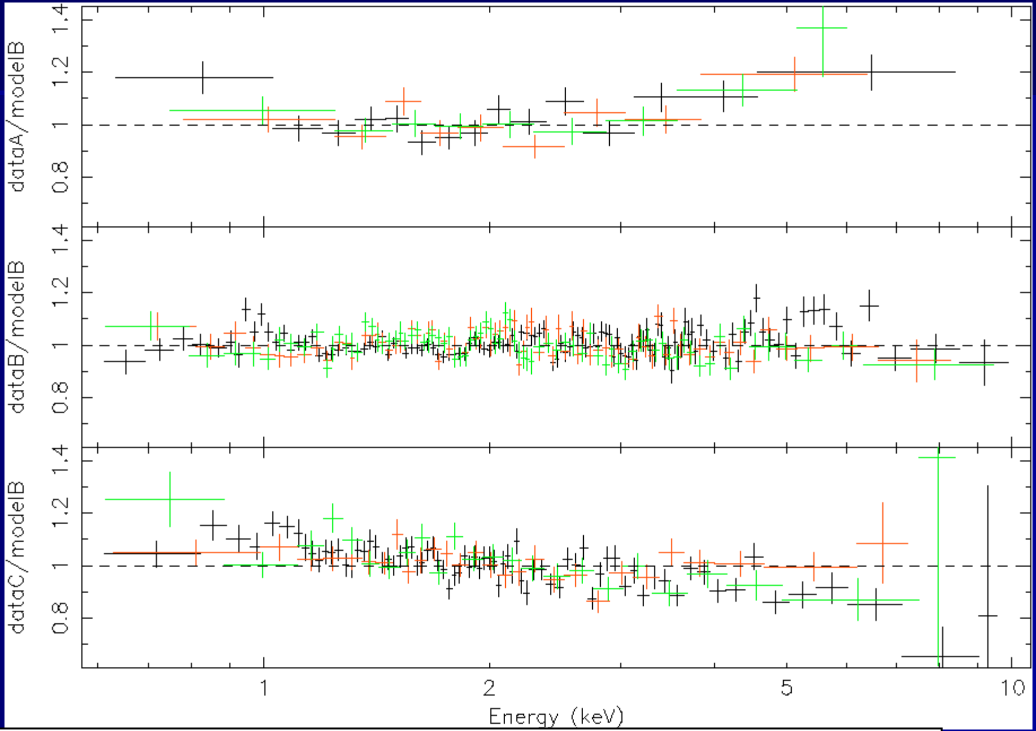
Smaller area associated with the hotter BB.

Cartoon: a magnetically active hot region. Accelerated high energies particle heat the region (producing L) and upscatter soft photons, producing the comptonized spectrum.

See also talk by Maxim Lyutikov on Friday

# Long term variations 2000-2004
# a) Spectral changes

- Spectrum of C significantly softer than B;
- Spectrum of A slightly harder than B



Ratios between spectra taken at the three epochs and the (renormalized) best fit model of obs. B.
Red: MOS1, green: MOS2, black: PN.

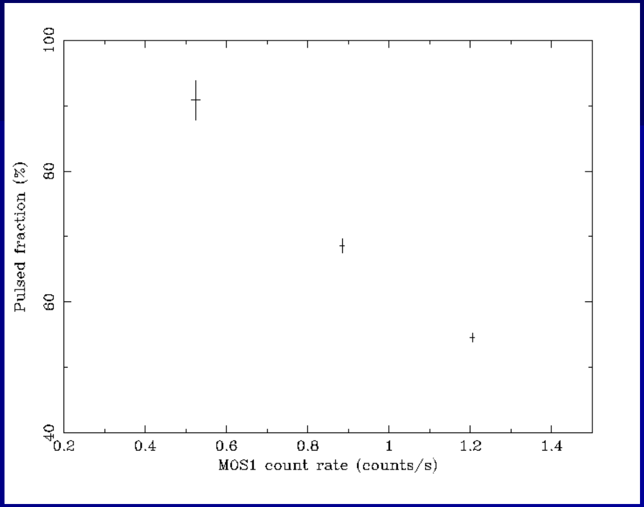
Spectral differences are not related in a monotonic way with L: when the flux is at the highest level (obs B) the spectral hardness is intermediate.

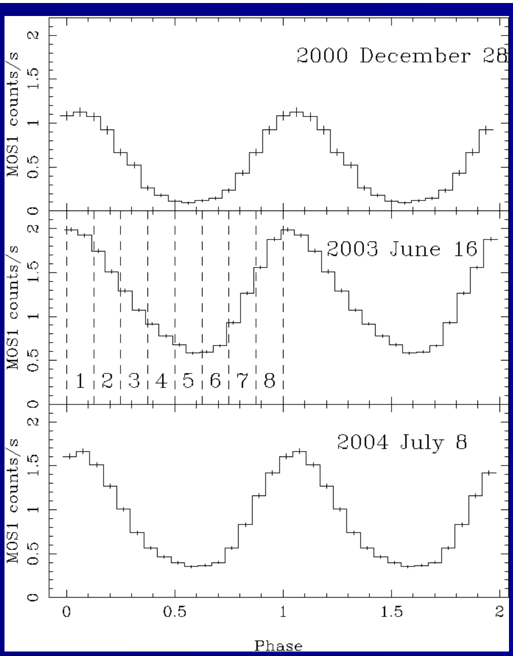
# Long term variations 2000-2004
# b) Pulsed fraction changes

BUT: a coherent pattern is present between pulsed fraction and flux.

PF decreases when the source brightens

Comparison between PF and flux measured with the same detector operating in the same mode in the 3 observations (0.6-10 keV, MOS1)





# Pulsed fraction changes: consequence

Existence of an empirical anti-correlation between flux and PF ⇒ crucial when source energetic is inferred by measurements of the pulsed flux

Ex: RXTE

The total energy release of flares peaking in Nov. 2000 and June 2001 is at least the double (2 and $20 \times 10^{40}$ erg) of the value derived assuming PF = constant = 0.94
(Gavriil and Kaspi 2004)