# Discovery of a narrow, phase-dependent feature in the X-ray spectrum of RX J0720.4-3125*

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NWO

comp star

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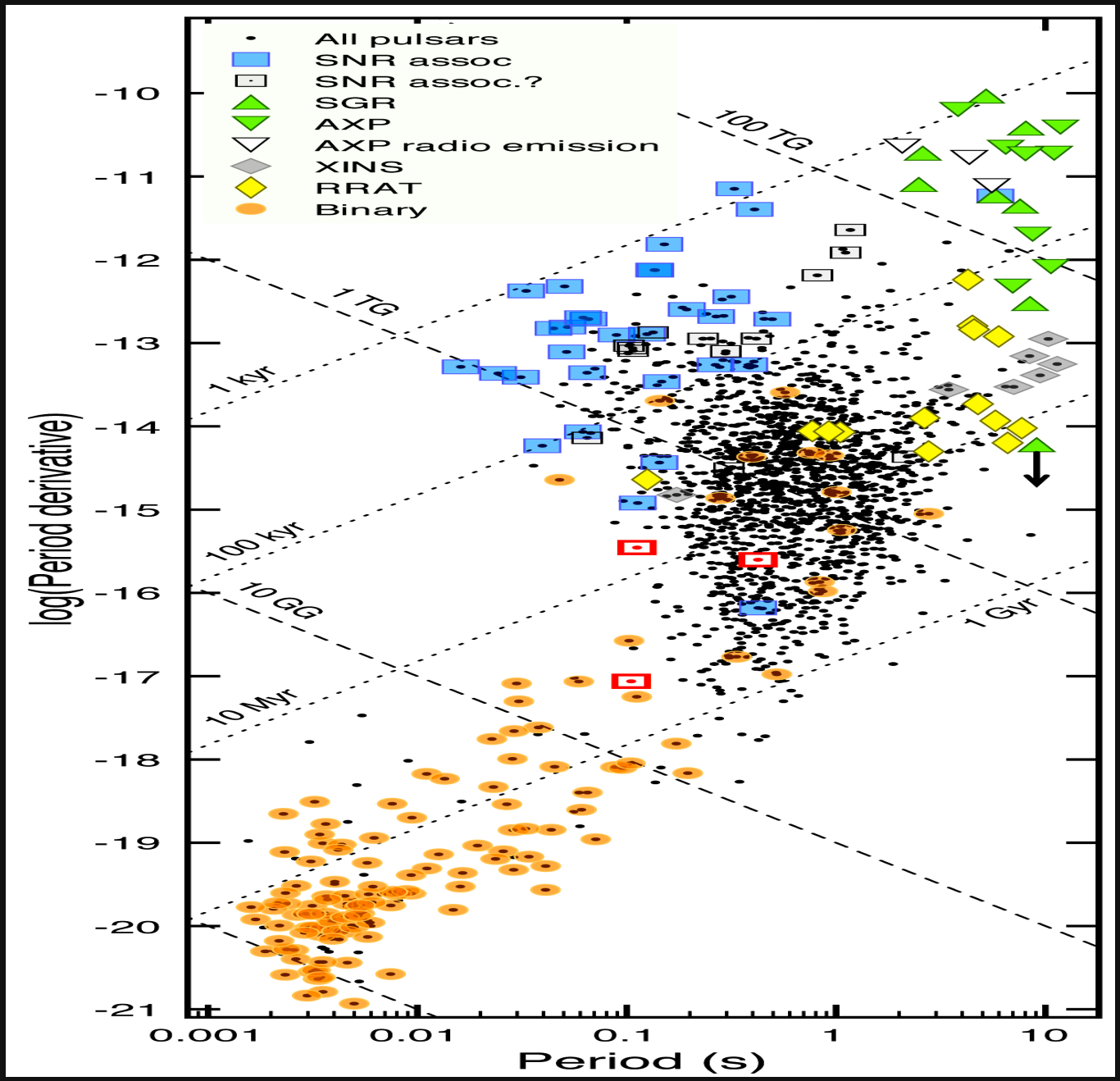



$$B_{pole} \approx 6.4 \times 10^{19} \sqrt{P\dot{P}G}$$

$$\tau_c = \frac{P}{2\dot{P}}$$


$d \lesssim 500$ pc

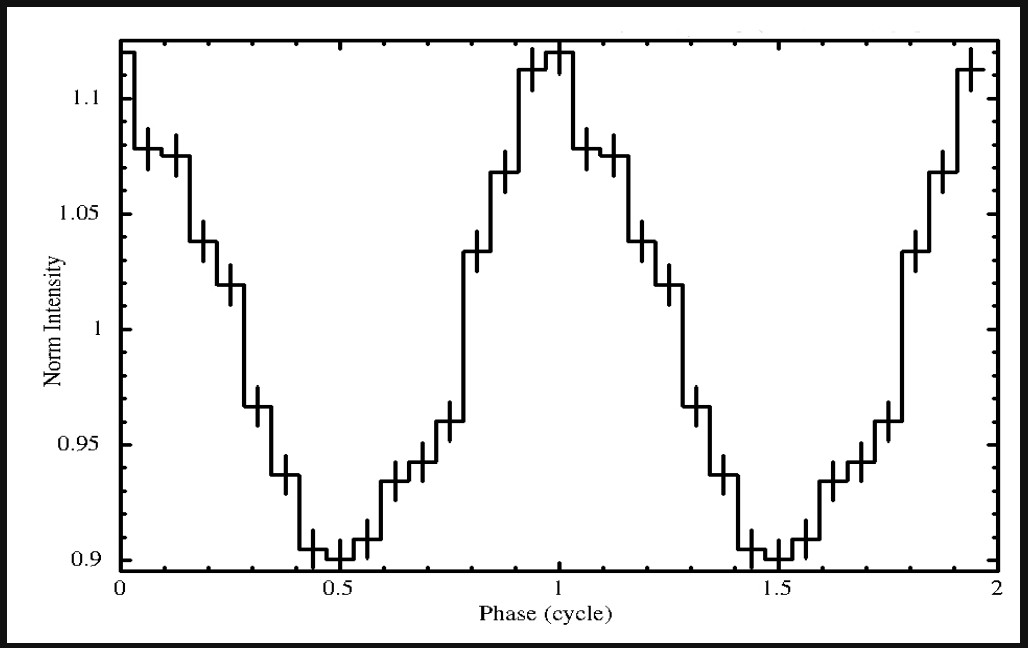
$P \backsim 3 - 11$ s

$B_{dip} \approx 10^{13}$ G

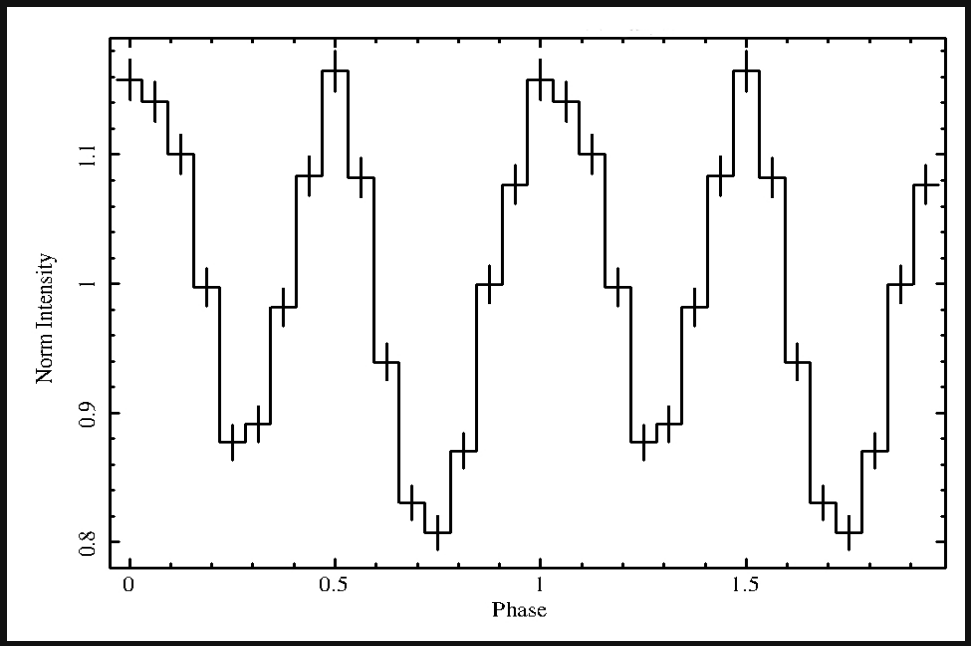
$\tau_c \approx 10^6$ yr

$L_x \approx 10^{30\text{-}33}$ erg $s^{-1}$

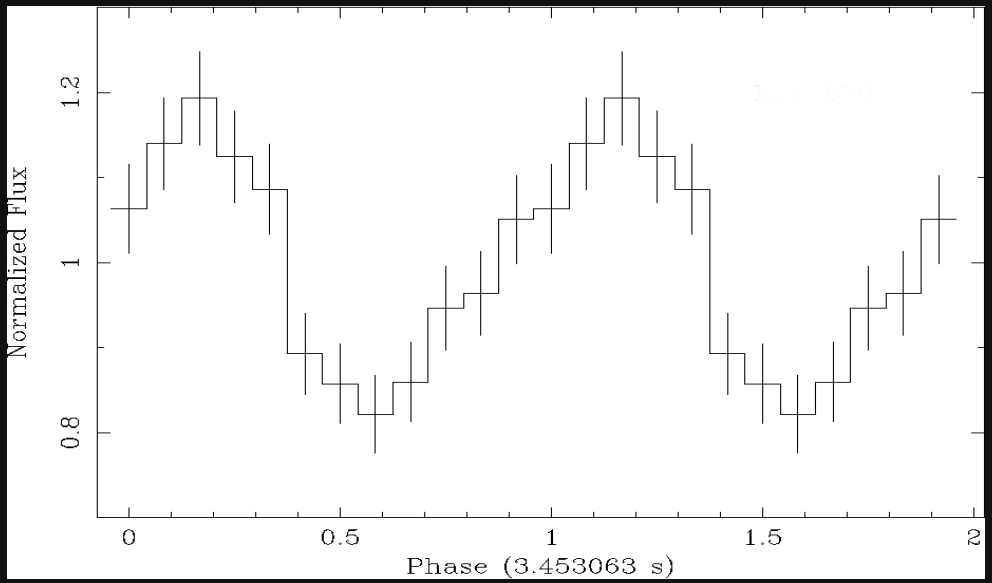
RX J0720.4-3125

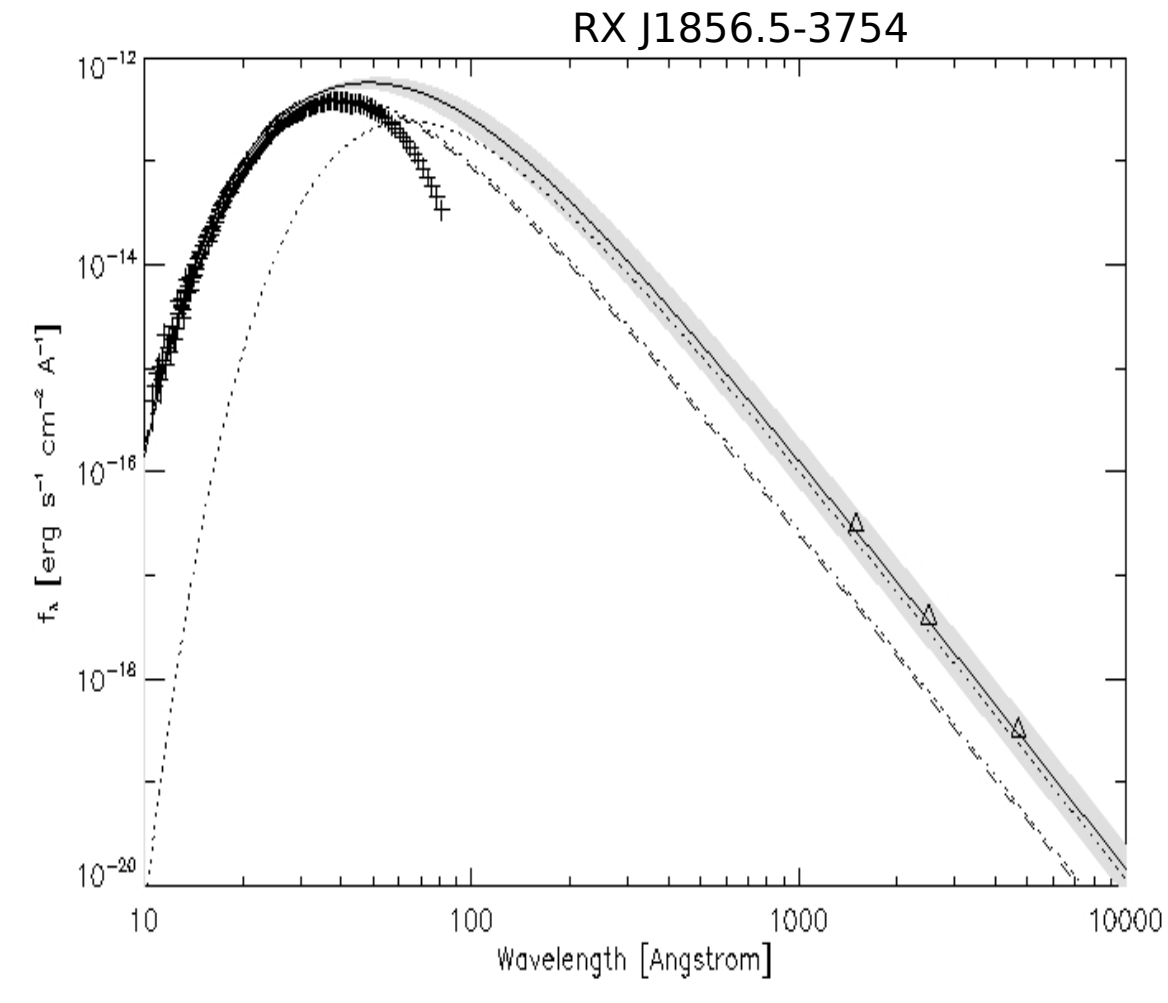



RX J1308.6+2127




RX J0420.0-5022






Sartori et al. 2012

X-ray spectra

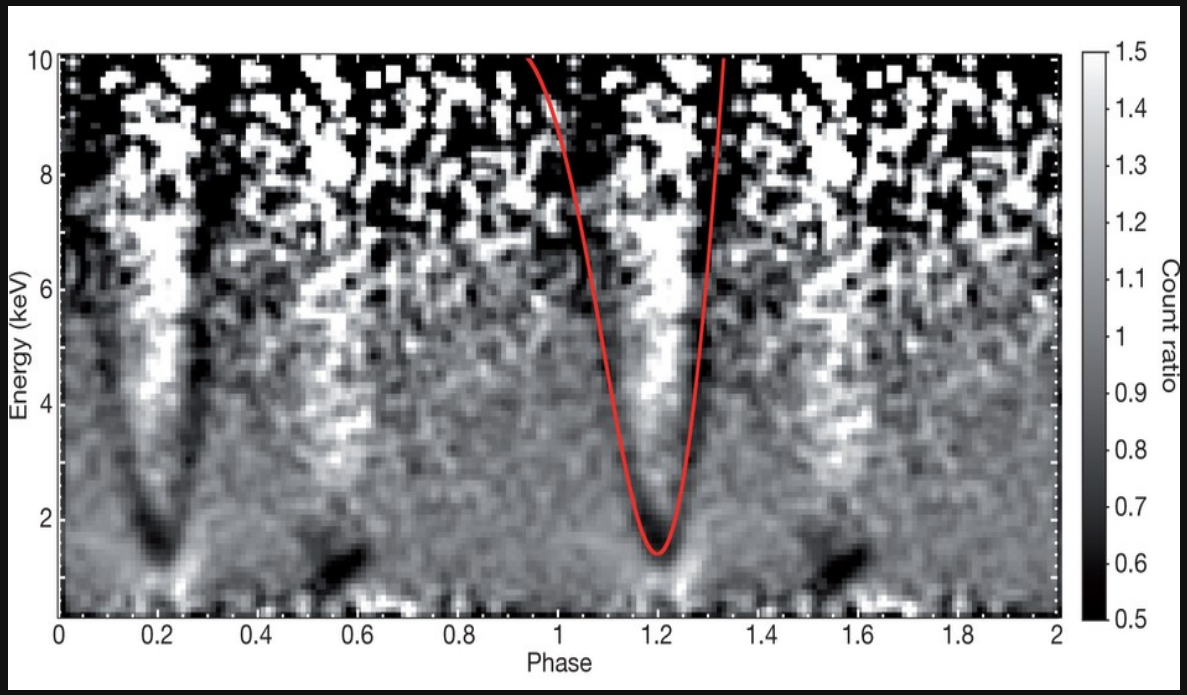
$kT_{BB} \approx$ 50-100 eV
broad feature $E_{line} \approx$0.2-0.8 keV

Origin: 1. proton cyclotron resonances
2. atomic transitions
3. inhomogeneous surface temperature distribution

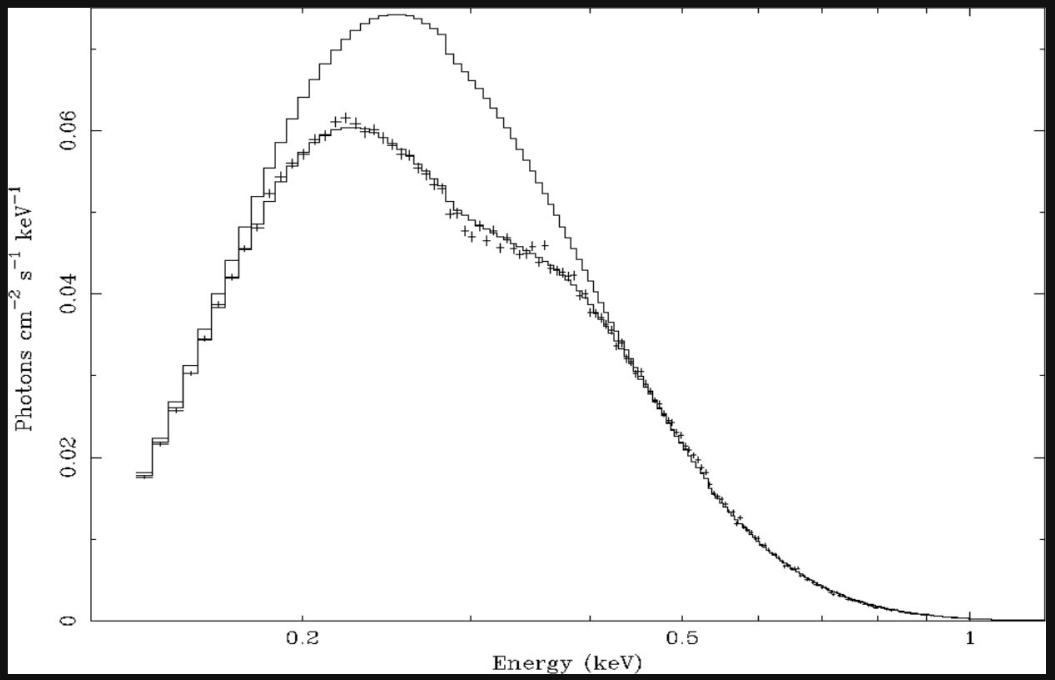
1. CCO 1E 1207.4-5209: $E_{line} \backsim 0.7$ , 1.4 keV
2. PSR J1740+1000: $E_{line} \backsim 0.6$ keV
3. RRAT PSR J1819-1458: $E_{line} \backsim 1.1$ keV
4. Magnetars:

   1RXS J170849-400910 ($E_{line} \backsim 8$ keV) and SGR 1806-20 ($E_{line} \backsim 5$ keV)

SGR 0418+5729: $E_{line} \gtrsim 2$ keV




A Tiengo *et al. Nature* 500, 2013




Haberl et al. 2004

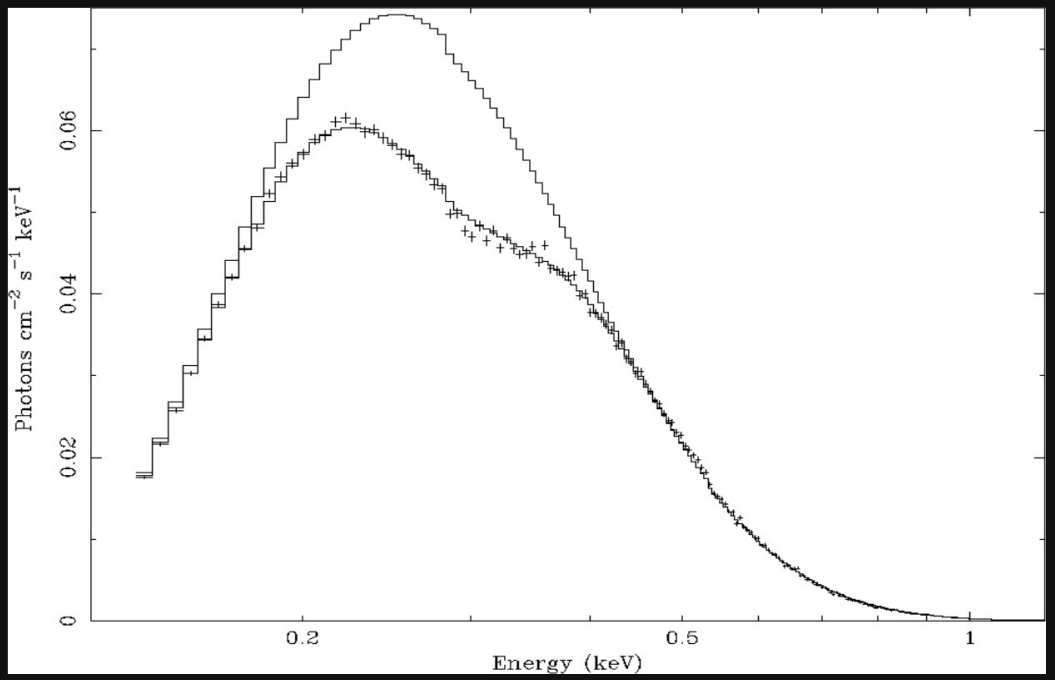
P = 8.39 s

Phase averaged spectrum shows a broad feature

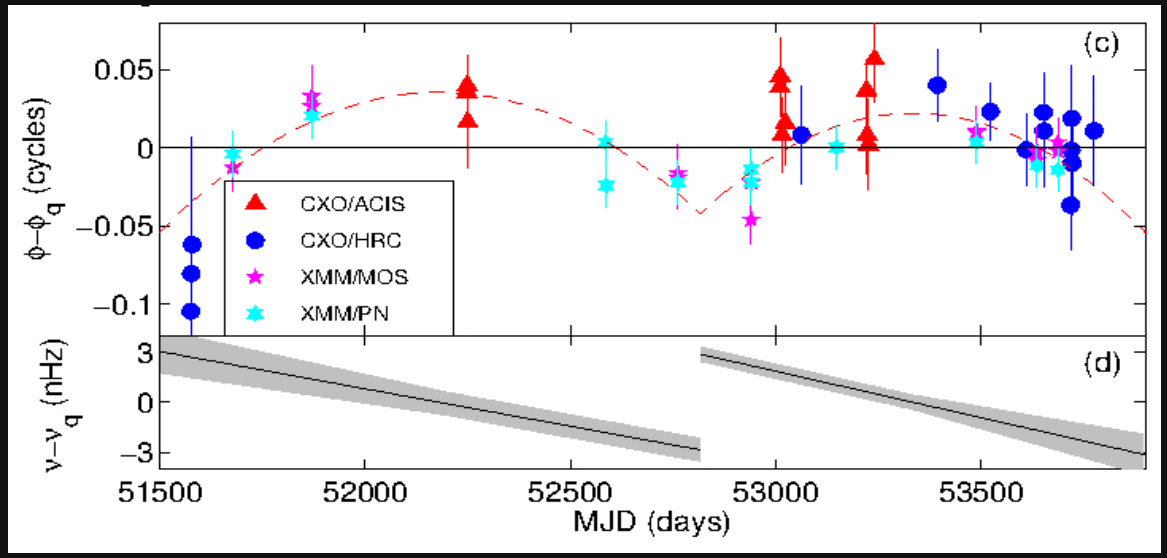
$E_{line}$ ~ 270 eV

σ ~ 70 eV

$kT_{BB}$ ~ 85 eV




Haberl et al. 2004




Van Kerkwijk et al. 2007

P = 8.39 s

Phase averaged spectrum shows a broad feature

$E_{line}$ ~ 270 eV

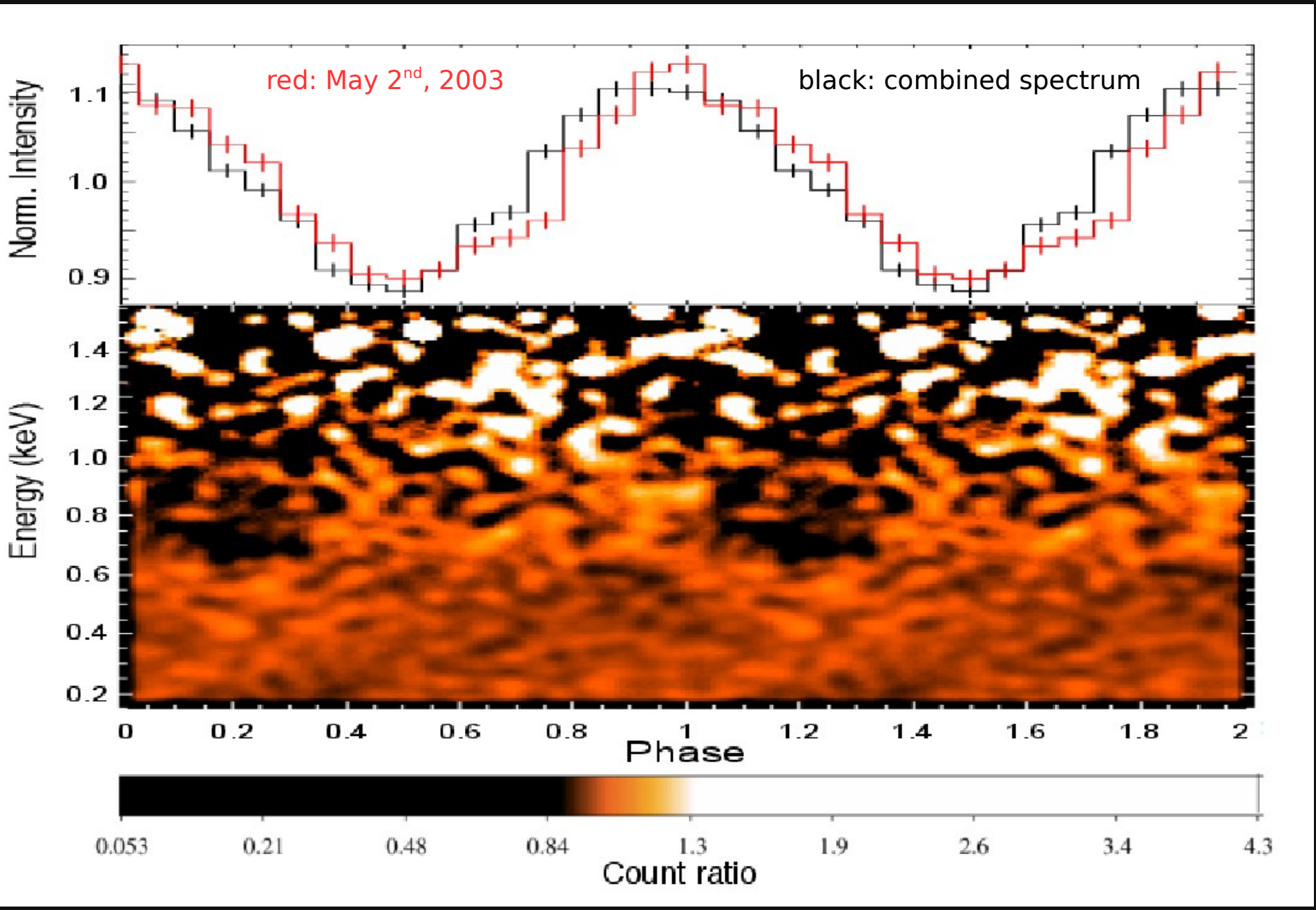
σ ~ 70 eV

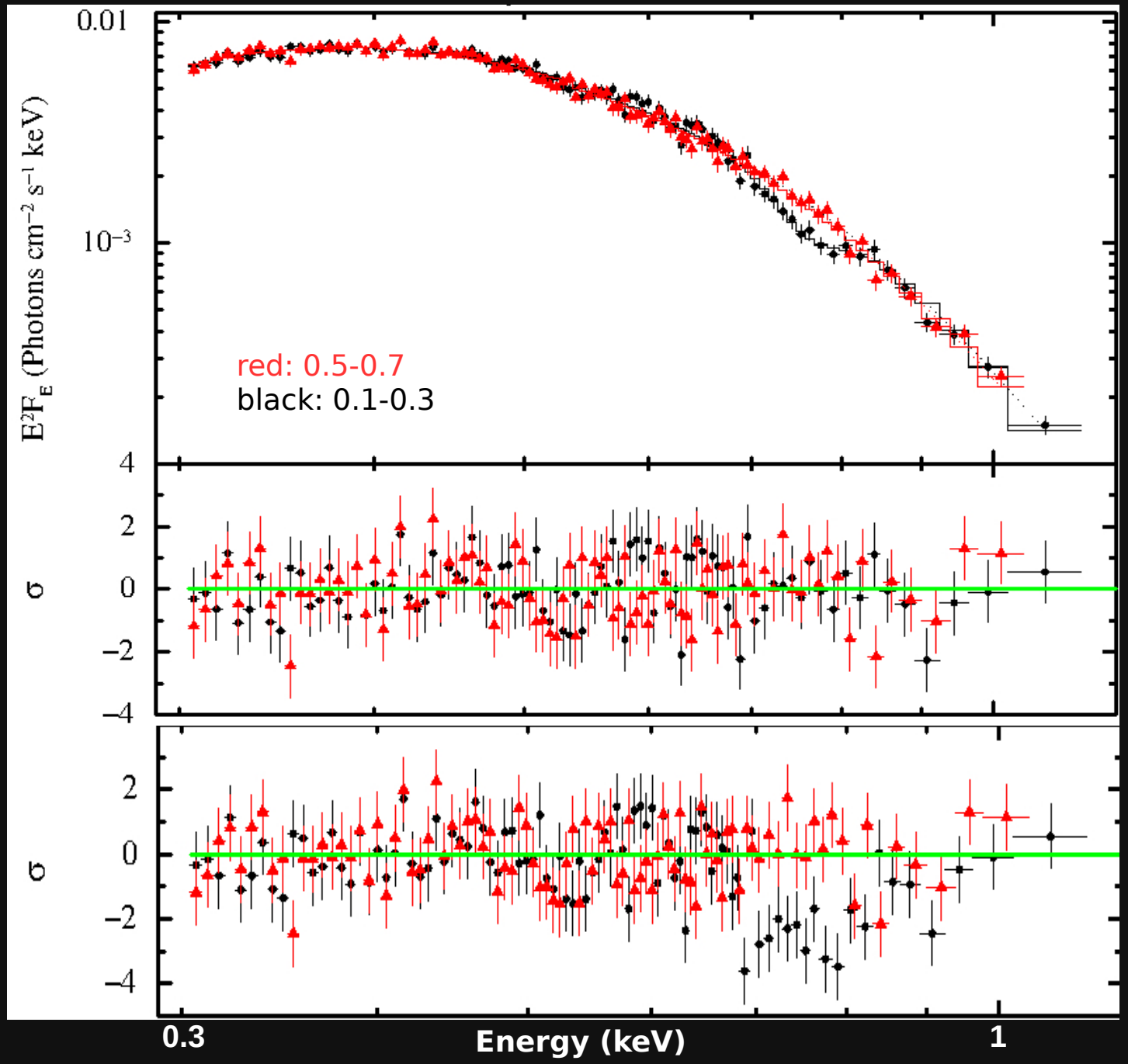
$kT_{BB}$ ~ 85 eV

Long-term variations in timing and spectral parameters

↓

Timing anomalies glitch


red: May 2nd, 2003
black: combined spectrum
Nom. Intensity
1.1
1.0
0.9
Energy (keV)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Phase
0.053
0.21
0.48
0.84
1.3
1.9
2.6
3.4
4.3
Count ratio




$N_H = 1.9 \times 10^{20}$ $cm^{-2}$

$KT_{BB} = 83.0+/-0.1$ eV

$E_{line} = 745\ ^{+17}_{-27}$ eV

$\sigma_{line} = 42\ ^{+51}_{-33}$ eV

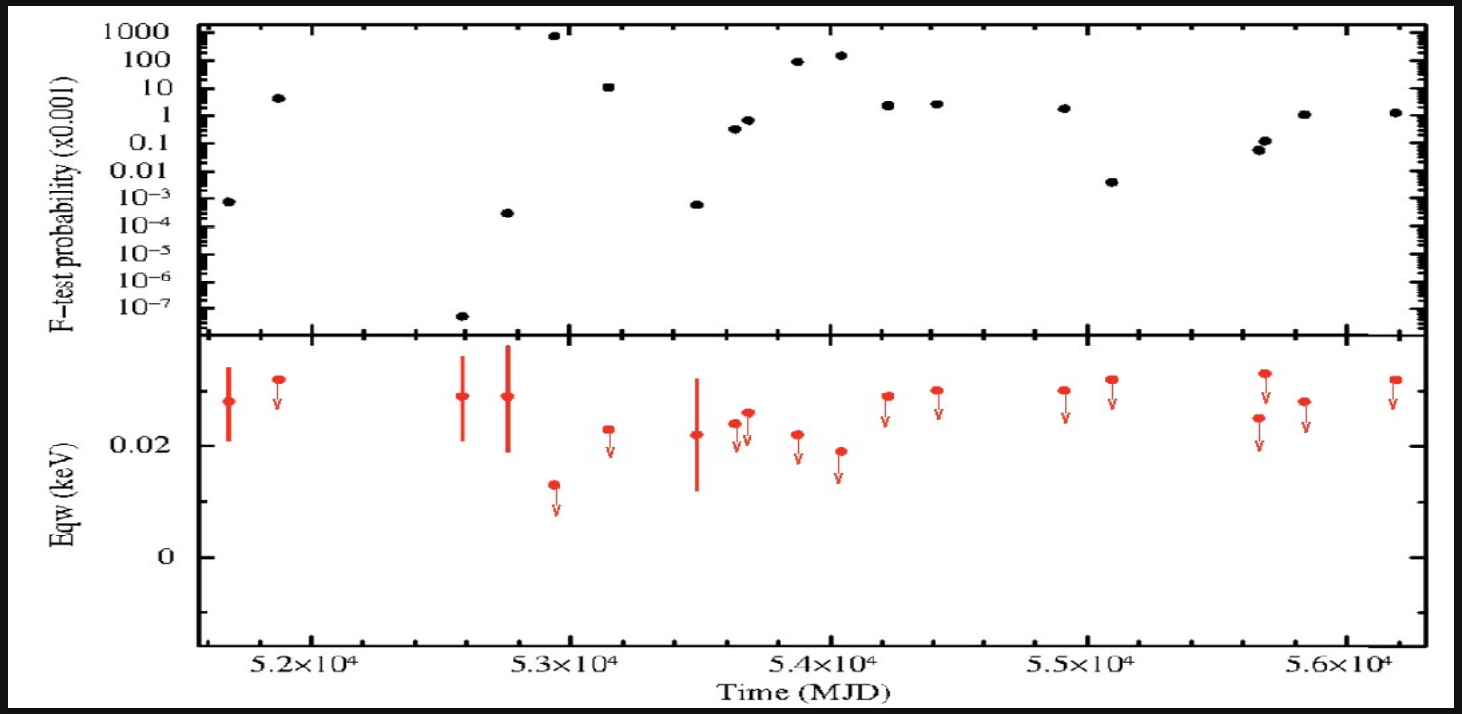
$Eqw = 28\ ^{+9}_{-11}$ eV

$\chi_\upsilon^2 = 0.88$ for 89 dof

Significance ~ 5σ

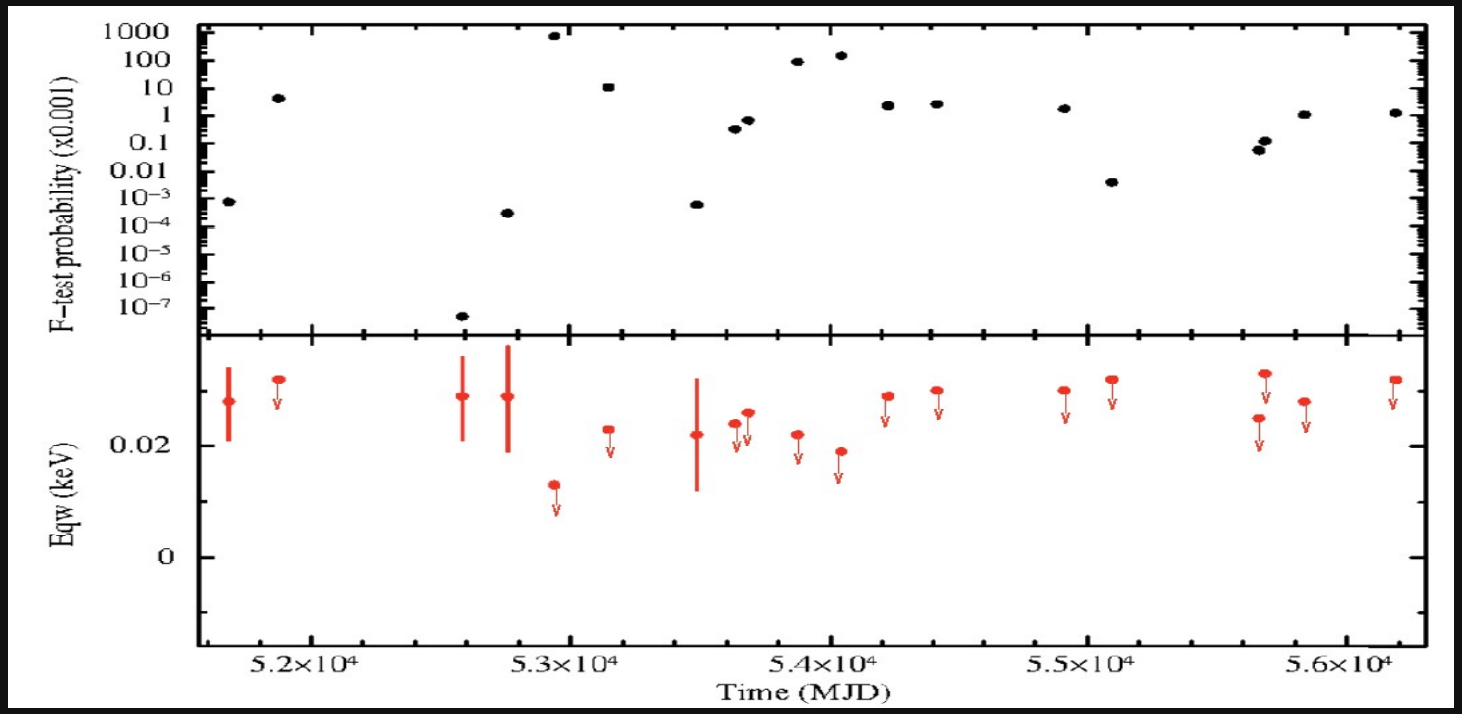

time
time
49ks
25ks
28ks
30ks
72ks
Glitch Time: 52866+/-73 days (June 3rd – Oct 27th)
18ks
35ks
43ks
44ks
38ks
19ks
20ks
20ks
23ks
20ks
17ks
20ks
27ks
25ks
25ks
Energy (eV)

# SEARCHING FOR THE PHASE-DEPENDENT FEATURE IN ALL *XMM-Newton* OBS

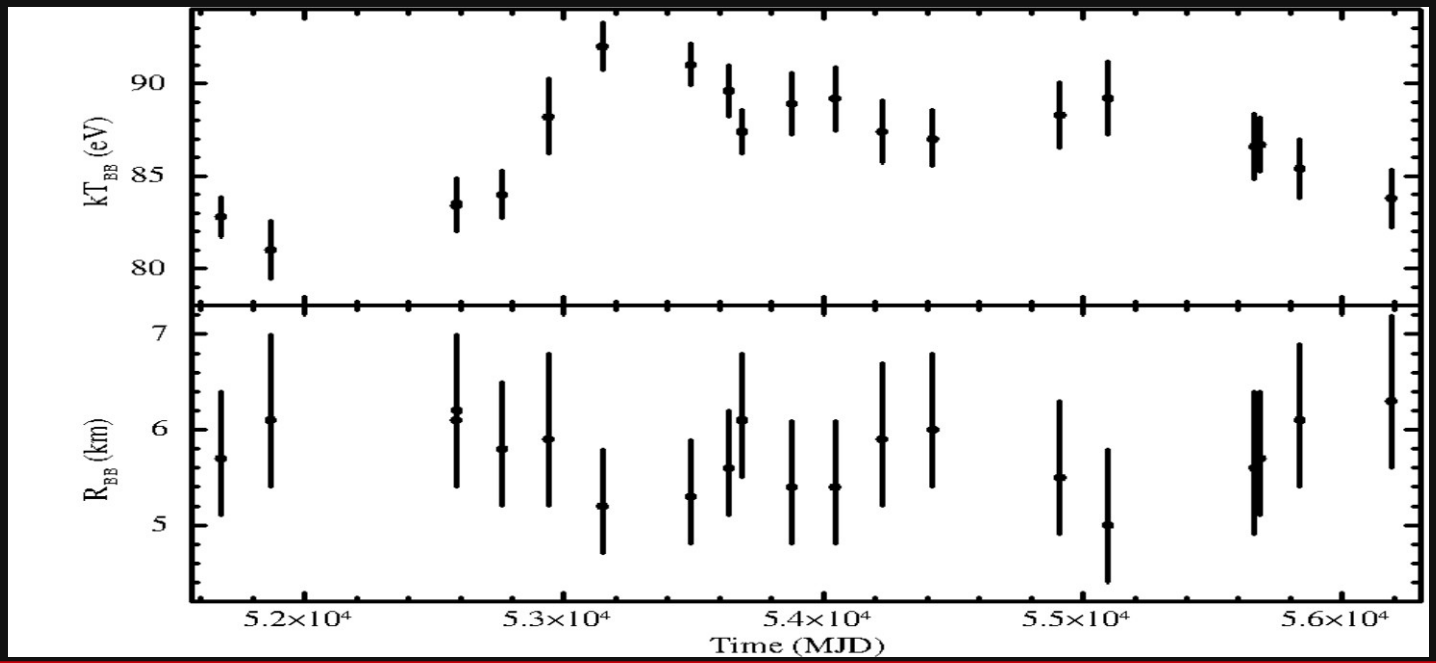



F-test probability and Eqw as a function of time for the phase-resolved spectra in the 0.1-0.3 phase range

# SEARCHING FOR THE PHASE-DEPENDENT FEATURE IN ALL *XMM-Newton* OBS

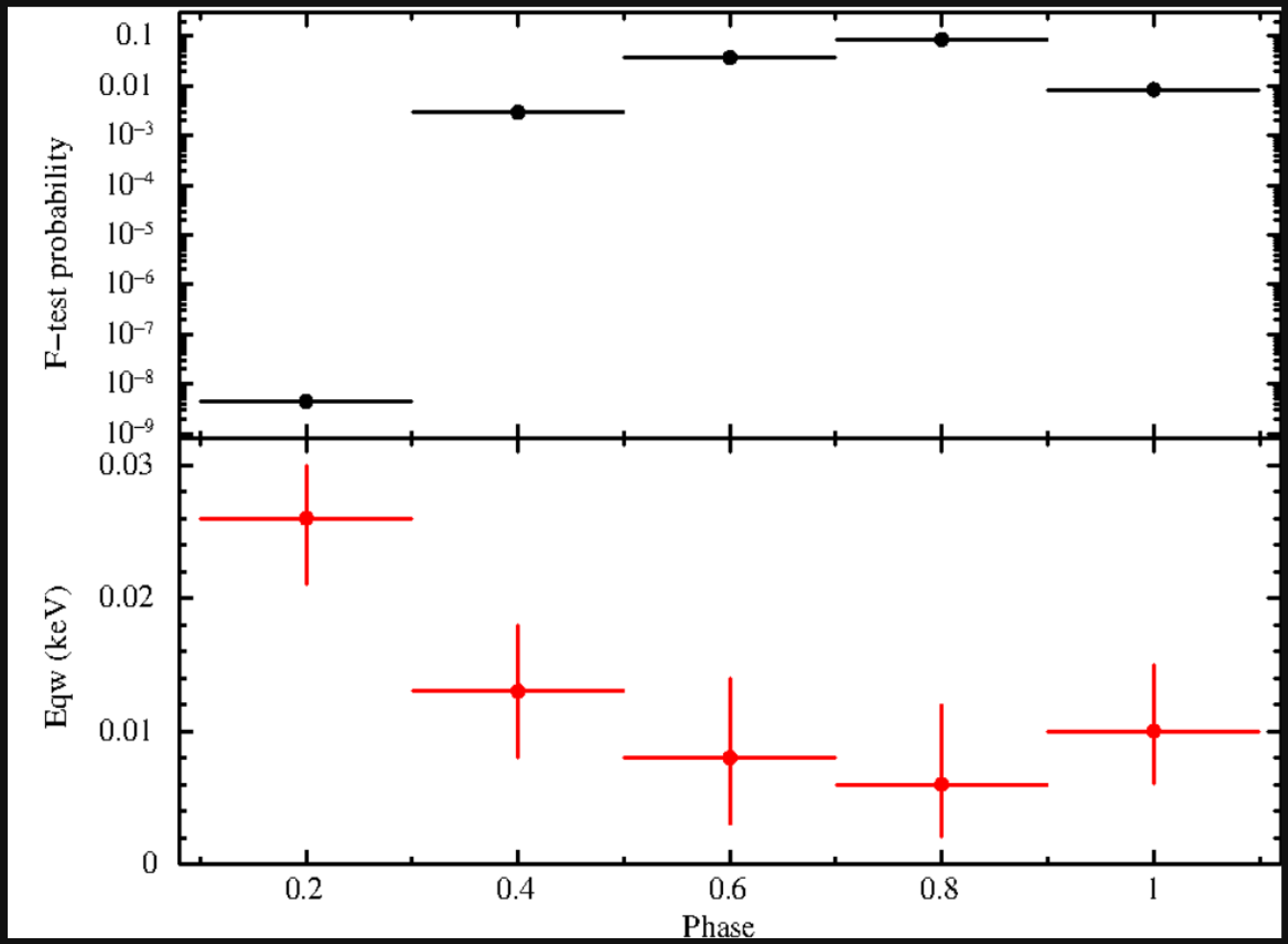



F-test probability and Eqw as a function of time for the phase-resolved spectra in the 0.1-0.3 phase range




Temporal evolution of BB parameters for all the phase-averaged spectra

# SEARCHING FOR THE PHASE-DEPENDENT FEATURE IN ALL *XMM-Newton* OBS




Combined spectrum

$E_{line} = 787_{-14}^{+15}$ eV

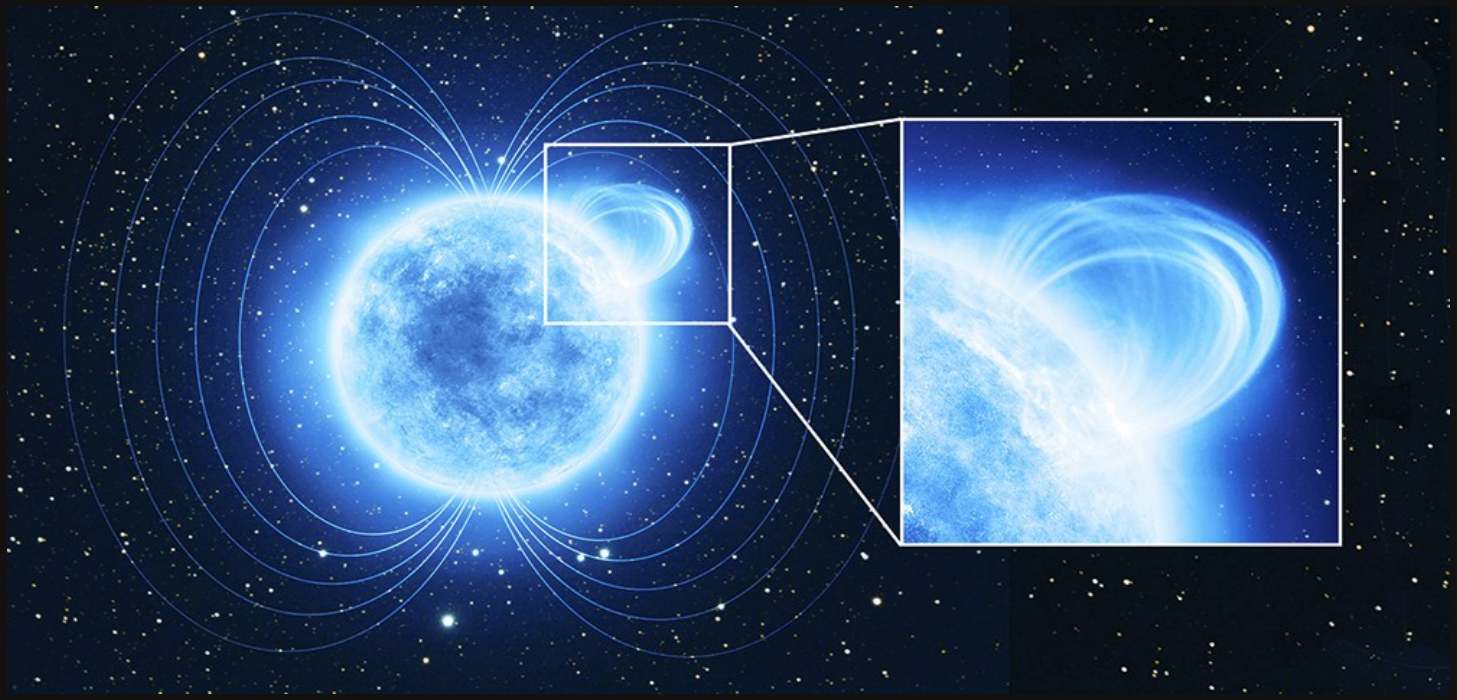
$Eqw = 26_{-5}^{+4}$ eV

Significance ~ 6σ

1. Discovery of a phase-dependent absorption feature, constant over ~ 12 yr

2. Possible origin: proton cyclotron resonant scattering in a magnetic loop

$$E_{line} = \frac{q B_{loop} \hbar}{m} \frac{1}{1+z} \longrightarrow B_{loop} \approx 1.8 \times 10^{14}\ \mathrm{G}$$



$B_{dip,eq} \approx 2.5 \times 10^{13}\ \mathrm{G}$

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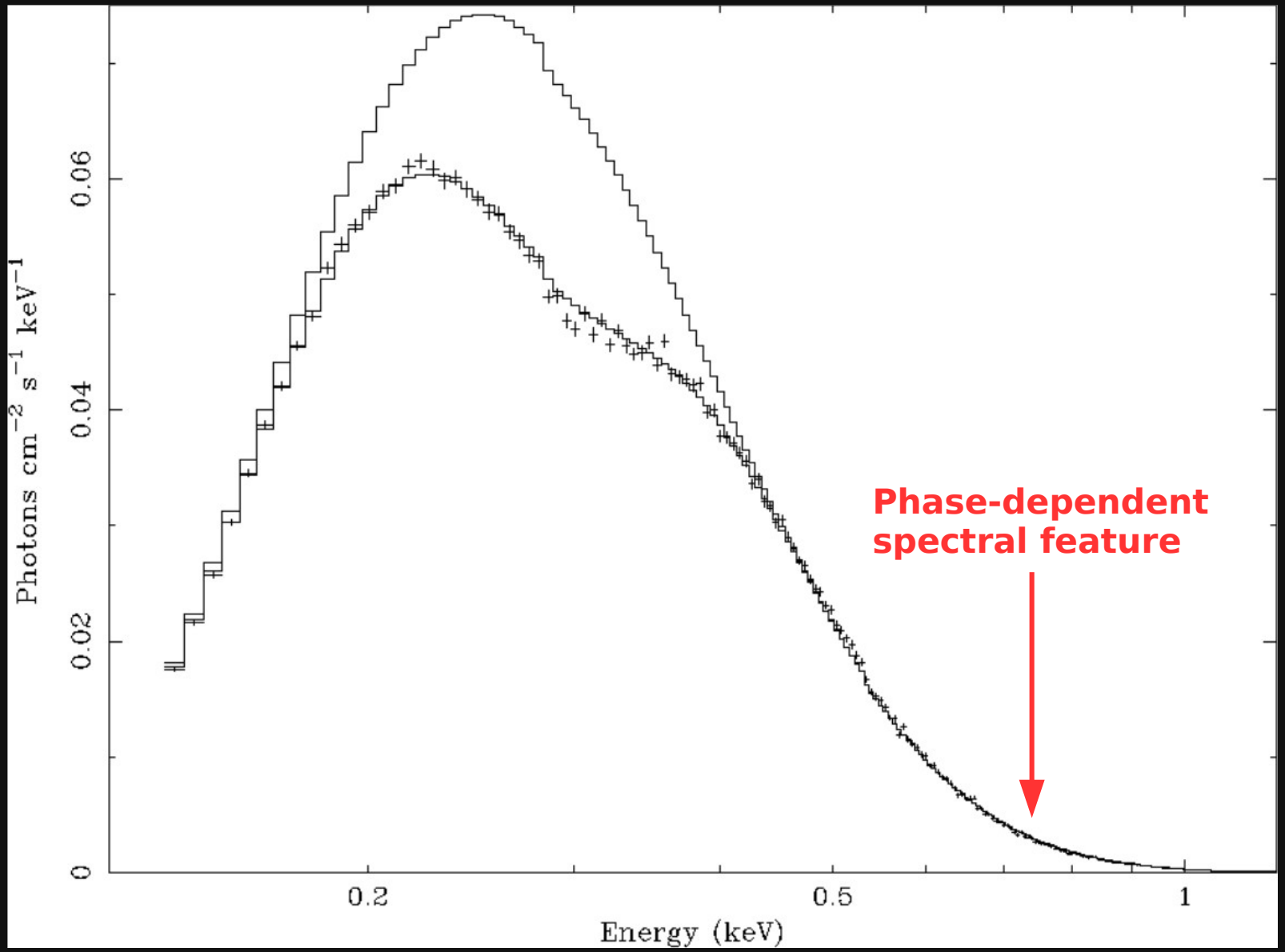



Haberl et al. 2004

- Work in progress

Same spectral analysis on all the M7

New candidate feature in RX J1308.6+2127

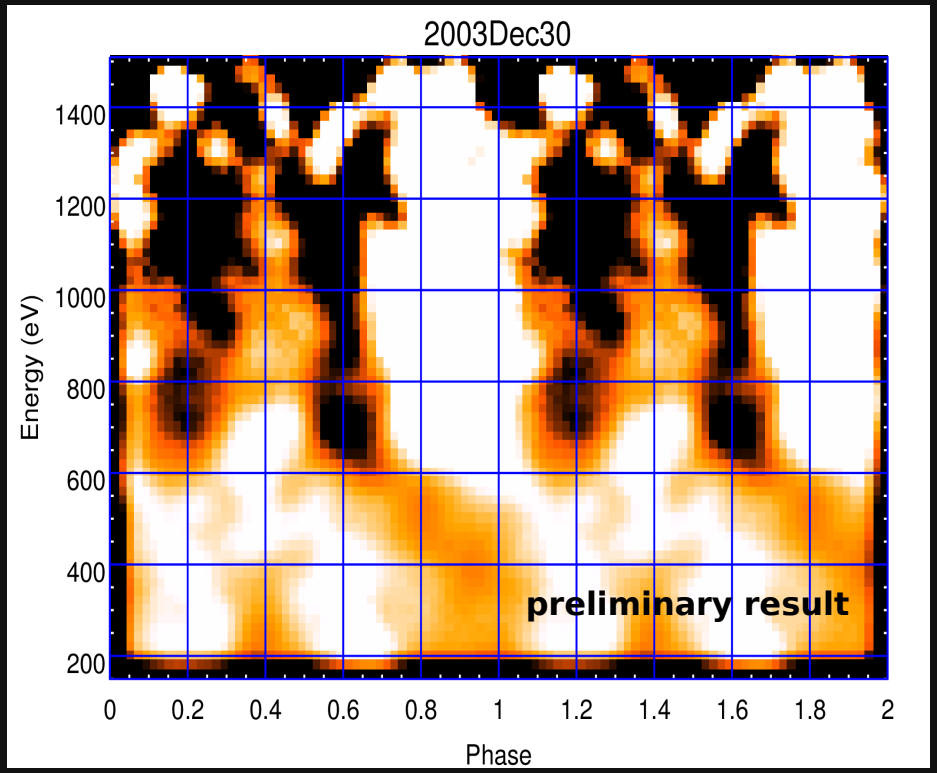


TABLE 1
SUMMARY OF THE *XMM-Newton*/EPIC-PN OBSERVATIONS OF RX J0720.4−3125[a]

| Obs. ID | Obs. Date YYYY-MM-DD | Read-out mode / filter | Live time (ks) | Source net count rate (counts $s^{-1}$) | Pile-up fraction ratios $r$=0"–30" |
|---|---|---|---|---|---|
| 0124100101 | 2000 May 13 | FF / thin | 42.8 | 6.46(1) | 0.963(3) |
| 0132520301 | 2000 Nov 21 | FF / medium | 22.7 | 5.60(2) | 0.964(4) |
| 0156960201 | 2002 Nov 06 | FF / thin | 25.6 | 6.60(2) | 0.969(3) |
| 0156960401 | 2002 Nov 08 | FF / thin | 27.1 | 6.54(2) | 0.966(3) |
| 0158360201 | 2003 May 02 | SW / thick | 51.0 | 3.480(8) | 1.011(3) |
| 0161960201 | 2003 Oct 27 | SW / thin | 12.6 | 7.52(2) | 1.013(5) |
| 0164560501 | 2004 May 22 | FF / thin | 32.0 | 6.96(1) | 0.971(3) |
| 0300520201 | 2005 Apr 28 | FF / thin | 38.1 | 6.86(1) | 0.968(3) |
| 0300520301 | 2005 Sep 22 | FF / thin | 39.1 | 6.93(1) | 0.969(3) |
| 0311590101 | 2005 Nov 12 | FF / thin | 33.5 | 6.75(1) | 0.970(3) |
| 0400140301 | 2006 May 22 | FF / thin | 17.6 | 6.83(2) | 0.970(4) |
| 0400140401 | 2006 Nov 05 | FF / thin | 17.6 | 6.90(2) | 0.966(4) |
| 0502710201 | 2007 May 05 | FF / thin | 17.4 | 6.80(2) | 0.968(4) |
| 0502710301 | 2007 Nov 17 | FF / thin | 20.1 | 7.71(2) | 0.971(4) |
| 0554510101 | 2009 Mar 21 | FF / thin | 16.7 | 6.84(2) | 0.967(4) |
| 0601170301 | 2009 Sep 22 | FF / thin | 15.0 | 6.77(2) | 0.968(4) |
| 0650920101 | 2011 Apr 11 | FF / thin | 17.6 | 6.61(2) | 0.973(4) |
| 0670700201 | 2011 May 02 | FF / thin | 23.6 | 6.73(2) | 0.965(3) |
| 0670700301 | 2011 Oct 01 | FF / thin | 22.2 | 6.60(2) | 0.972(3) |
| 0690070201 | 2012 Sep 18 | FF / thin | 22.3 | 6.60(2) | 0.970(3) |

[a] FF: full-frame (time resolution of 73 ms); SW: small window (time resolution of 6 ms). Live time refers to the duration of the observations after filtering for background flares (see text). Count rates refer to the spectra extracted within a circular region with PATTERN = 0. Errors on the count rates are quoted at the $1\sigma$ confidence level. Pile-up fraction ratios were calculated for single events alone and in the 0.1–1.2 keV energy range using the `SAS epatplot` tool.

TABLE 2
PULSE PHASE SPECTROSCOPY FOR MAY, 2ND 2003 OBSERVATION.

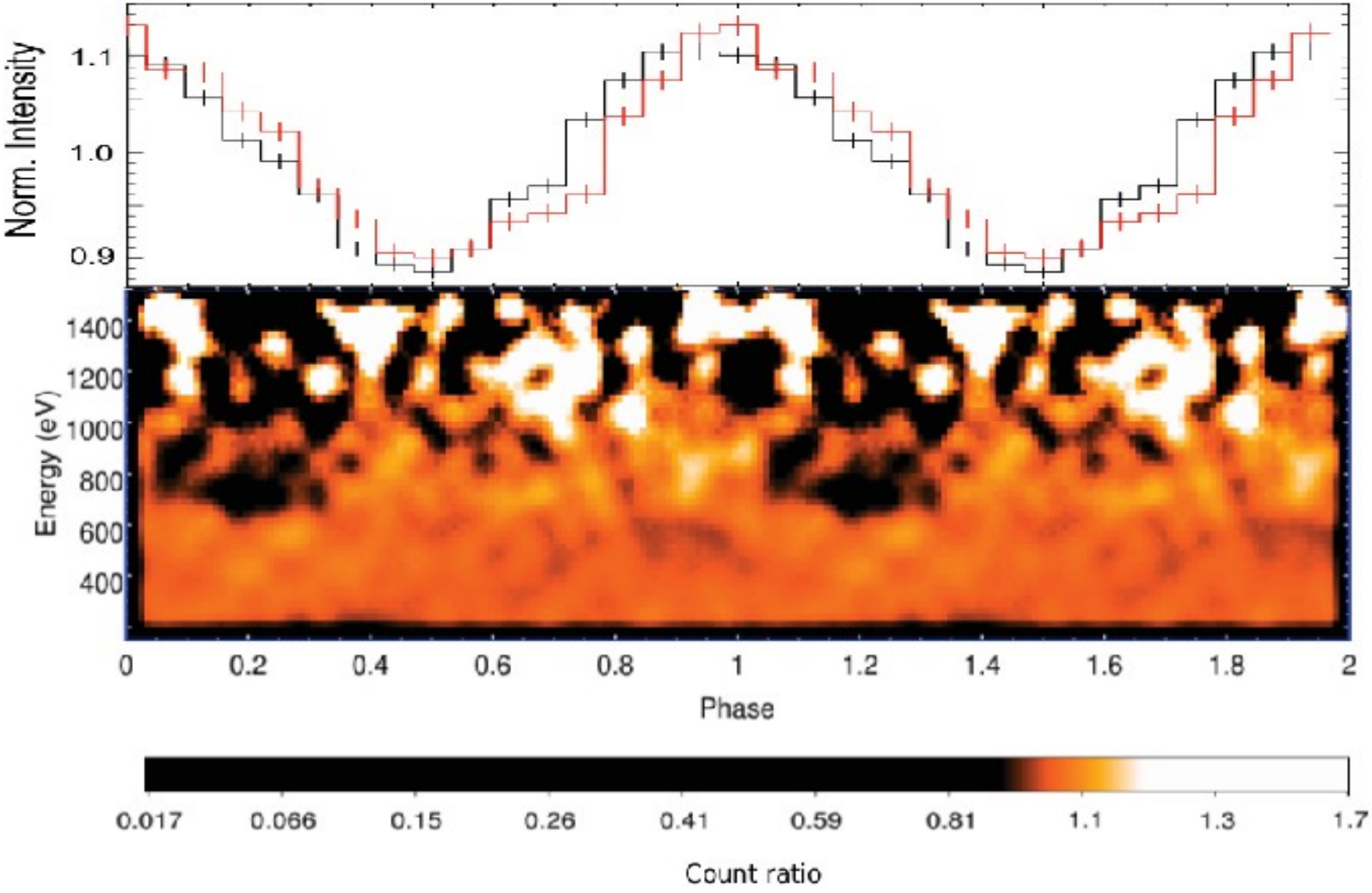
| Parameter[a] | 0.1–0.3 | 0.3–0.5 | 0.5–0.7 | 0.7–0.9 | 0.9–1.1 |
|---|---|---|---|---|---|
| | | | BB | | |
| $kT_{BB}$ (eV) | 81.1(6) | 81.9(6) | 82.2(6) | 82.6(6) | 82.5(9) |
| $R_{BB}$ (km) | $6.4^{+0.6}_{-0.5}$ | $6.0^{+0.6}_{-0.5}$ | $6.1^{+0.6}_{-0.5}$ | $6.4^{+0.6}_{-0.5}$ | $6.4^{+0.7}_{-0.6}$ |
| Flux[b] | 1.16(2) | $1.09^{+0.01}_{-0.02}$ | 1.14(2) | 1.26(2) | 1.26(2) |
| Unabs. Flux[b] | 2.20 | 2.04 | 2.13 | 2.34 | 2.34 |
| NHP | $7.2\times10^{-2}$ | $5.9\times10^{-1}$ | $6.9\times10^{-1}$ | $4.2\times10^{-2}$ | $2.7\times10^{-1}$ |
| $\chi^2_\nu$ | 1.22 | 0.96 | 0.92 | 1.26 | 1.09 |
| dof | 92 | 90 | 92 | 97 | 75 |
| | | | BB+GAUSS | | |
| $kT_{BB}$ (eV) | $83.0^{+1.5}_{-0.9}$ | 82.4(9) | $82.2^{+0.7}_{-0.6}$ | 82.7(8) | $82.4^{+1.0}_{-0.9}$ |
| $R_{BB}$ (km) | 6.0(6) | $6.0^{+0.6}_{-0.5}$ | $6.1^{+0.6}_{-0.5}$ | $6.3^{+0.6}_{-0.5}$ | 6.4(6) |
| $E_{line}$[c] (eV) | $745^{+17}_{-27}$ | 745 | 745 | 745 | 745 |
| $w_{line}$[c](eV) | $41.7^{+51.3}_{-33.8}$ | 41.7 | 41.7 | 41.7 | 41.7 |
| \|Norm\| | $9.2^{+3.5}_{-9.2}\times10^{-5}$ | $\leq2.7\times10^{-5}$ | $\leq1.7\times10^{-5}$ | $\leq2.9\times10^{-5}$ | $\leq2.4\times10^{-5}$ |
| Eq. Width (eV) | $28^{+9}_{-11}$ | $6^{+9}_{-5}$ | $\leq8$ | $\leq11$ | $\leq13$ |
| F-test[b] ($10^{-3}$) | $3.5\times10^{-7}$ | 232 | 1000 | 750 | >1000 |
| NHP | $7.9\times10^{-1}$ | $6.0\times10^{-1}$ | $6.6\times10^{-1}$ | $3.6\times10^{-2}$ | $2.5\times10^{-1}$ |
| $\chi^2_\nu$ | 0.88 | 0.95 | 0.93 | 1.27 | 1.11 |
| dof | 89 | 89 | 91 | 96 | 74 |

[a] $N_H$ was frozen at the value obtained for the phase averaged spectra: $N_H = 1.9\times10^{20}\mathrm{cm}^{-2}$.

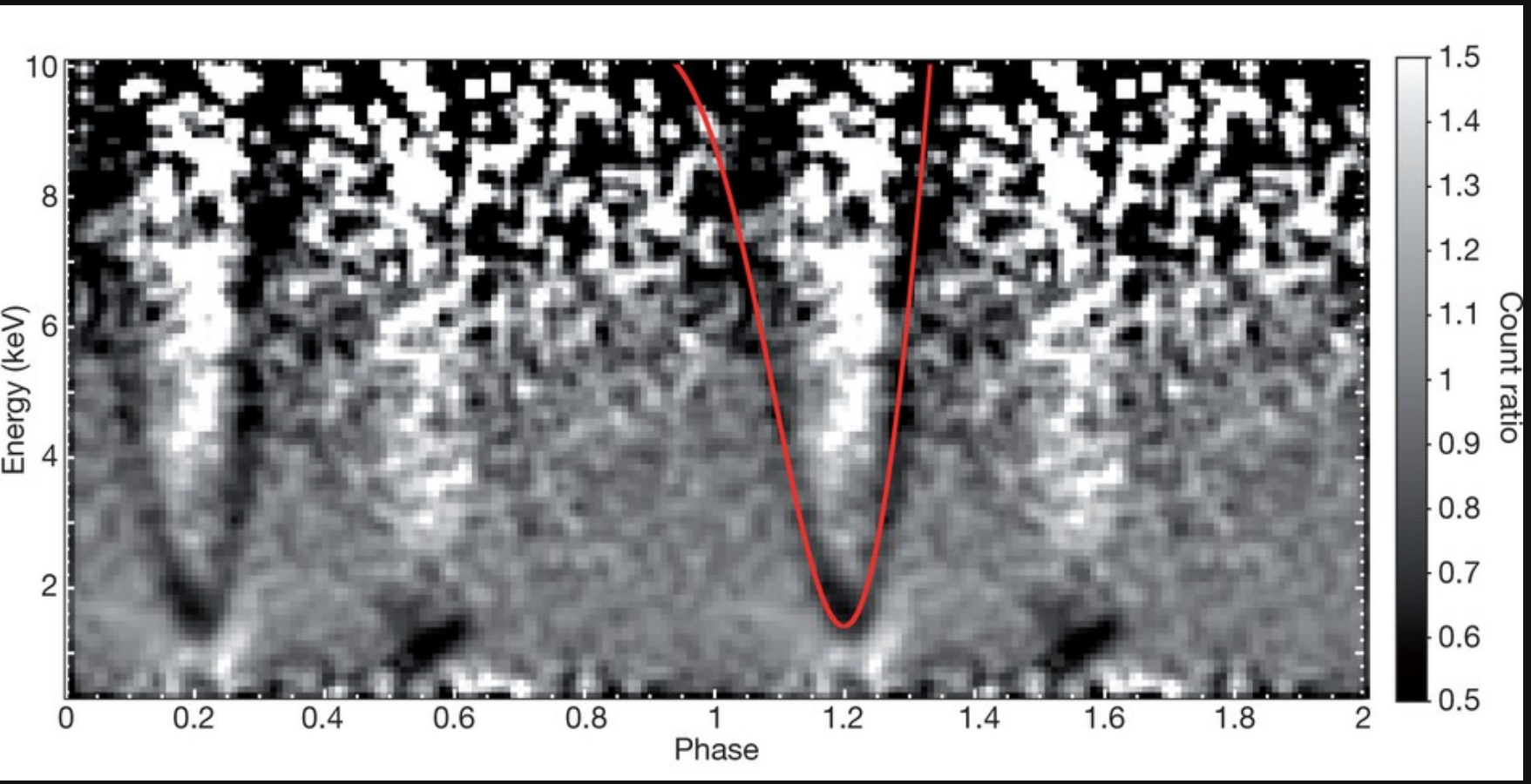
[b] Fluxes are calculated in the 0.1–2 keV energy range, and in units of ($10^{-11}$ $\mathrm{ergs}^{-1}\mathrm{cm}^{-2}$)

[c] Line energy and width were frozen at the value obtained for the phase interval 0.1 – 0.3: $E_{line}$ = 745 eV and $\sigma$ = 42 eV.

# NORMALIZED ENERGY VS PHASE IMAGE



# LOW-FIELD MAGNETAR SGR 0418+5729




A Tiengo *et al. Nature* **500**, 2013

$B_{dip} = 6 \times 10^{12}$ G

Absorption feature at a phase-dependent energy : $E_{line} \gtrsim 2$ keV

Proton cyclotron scattering ---> $B > 2 \times 10^{14}$ G