High-resolution spectral analysis of transient pulsars in the SMC

N. La Palombara
(IASF Milano)
L. Sidoli, P. Esposito, S. Mereghetti, F. Pintore, A. Tiengo

IASF

The X-ray Universe 2017

Rome (I)

6-9 June 2017

INAF

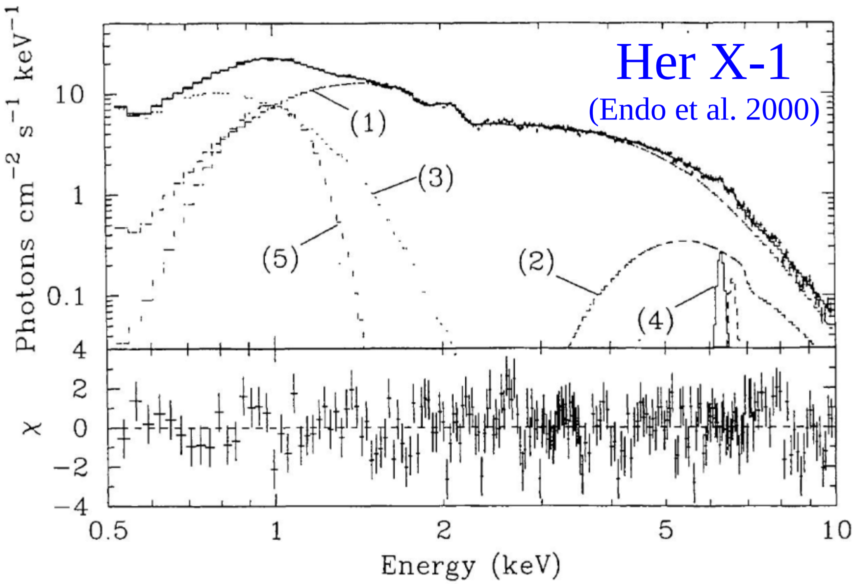
Spectral properties of High Mass X-Ray Binaries

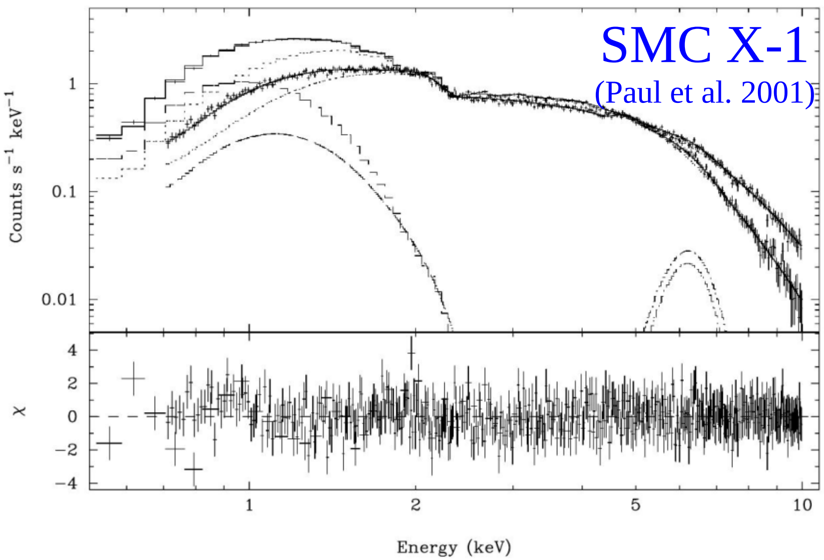
X-ray spectrum between 0.1 and 10 keV:

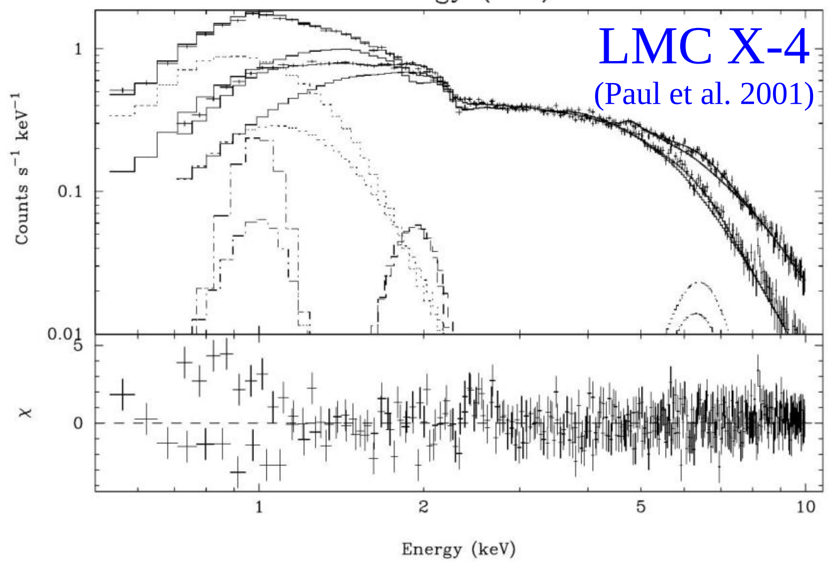
- usually described with a rather flat power law (photon index Γ ~ 1) with an exponential cut-off
- often with Fe Kα emission line

BUT

several XBPs have a marked data excess above the main power–law component

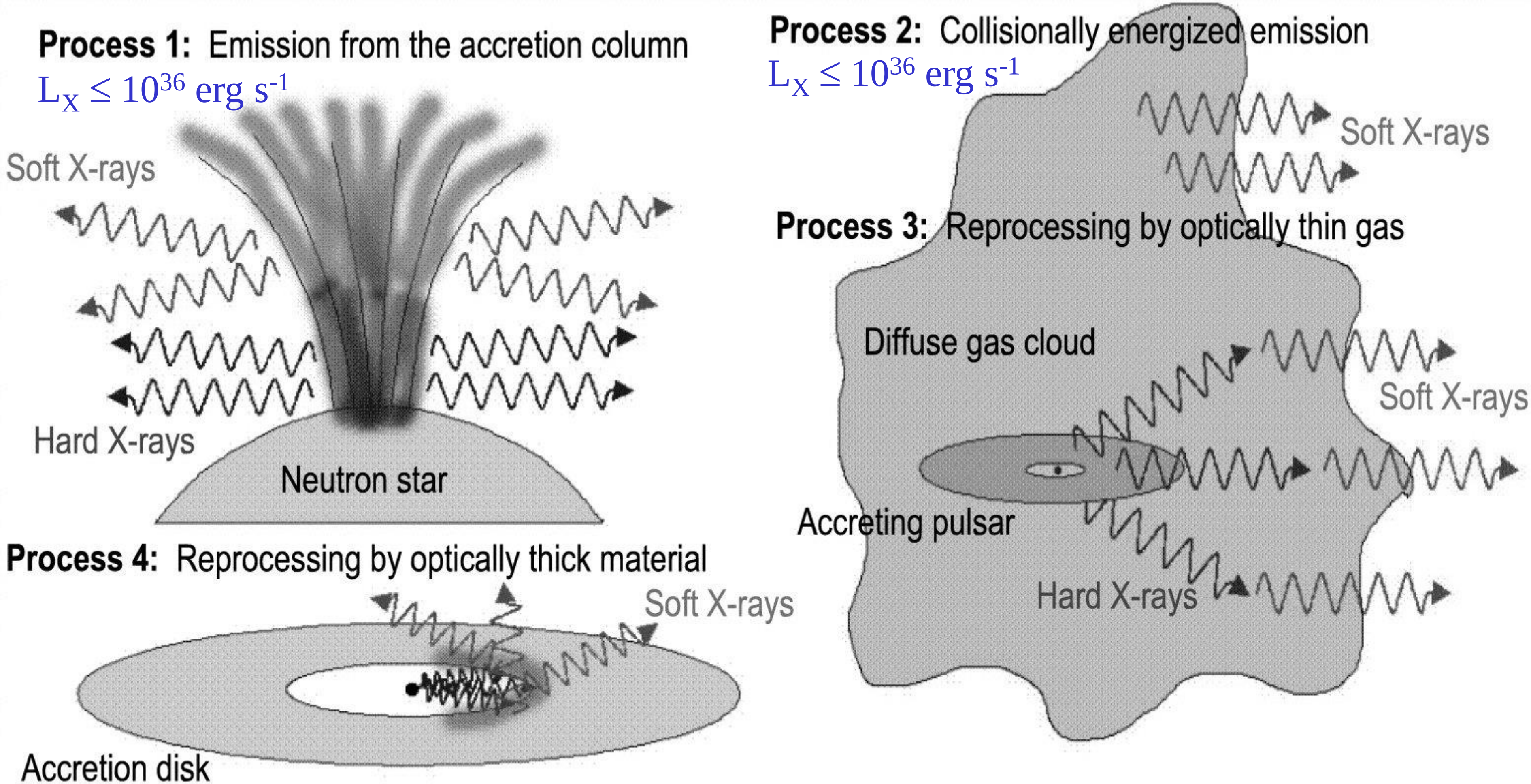






Spectral properties of High Mass X-Ray Binaries

Hickox et al., 2004: the origin of the thermal excess depends on the source luminosity



Process 1: $L_X \leq 10^{36}$ erg s^{-1}

Process 2: $L_X \leq 10^{36}$ erg s^{-1}

Process 4: $L_X \geq 10^{38}$ erg s^{-1}

Process 3: $L_X \leq 10^{36}$ erg s^{-1}

Spectral properties of High Mass X-Ray Binaries

$L_X \geq 10^{38}$ erg s^{-1}:	reprocessing of hard X-rays by the optically thick accretion material	SMC X-1, LMC X-4, Cen X-3, RX J0059.2-7138, XTE J0111.2-7317
$L_X \leq 10^{36}$ erg s^{-1}:	emission by photoionized or collisionally heated gas	Vela X-1, AX J0103-722, RX J0101.3-7211
	or	
	thermal emission from the accretion column	4U 1626-67, X Per
$L_X \sim 10^{37}$ erg s^{-1}:	either or both the above processes are possible	Her X-1, A0538-66, EXO 053109-6609.2

Spectral properties of High Mass X-Ray Binaries

Hickox et al., 2004:

'a soft spectral component is a very common, if not ubiquitous,

feature intrinsic to accreting X-ray pulsars'

BUT

the debate about its origin remains open

Study of Galactic sources affected by the interstellar absorption in the Galactic plane

⇓

only in few cases it is possible to detect and investigate the soft excess

Transient BeXRBs in the SMC

Ideal site to investigate the *soft* spectral component in the HMXRBs:

- Several (> 100) sources
- $L_X \sim 10^{38}$ erg s^{-1} in outburst
- $N_H < 10^{21}$ cm^{-2}

} High count statistics at low energies

- Small uncertainties on the source distances ⇒ reliable estimate of L_X

Program of ToO observations with *XMM-Newton*

⇓

4 sources observed in *outburst*:

- RX J0059.2-7138 (March 2014) ⇒ Sidoli et al. 2015, MNRAS 449, 3710
- SMC X-2 (October 2015) ⇒ La Palombara et al. 2016, MNRAS 458, L74
- IGR J01572-7259 (May 2016) ⇒ La Palombara et al., in preparation
- SXP 59 (April 2017)

RX J0059.2-7138

1993:

- discovered with ROSAT, with $L_X \sim 3 \times 10^{38}$ erg s^{-1} (Hughes 1994)
- pulse period of 2.76 s (pulsed fraction *PF* ~ 37 %) measured with ASCA (Kohno,Yokogawa & Koyama 2000)
- observation of a spectral soft component (Kohno,Yokogawa & Koyama 2000)

December 2013: first observation

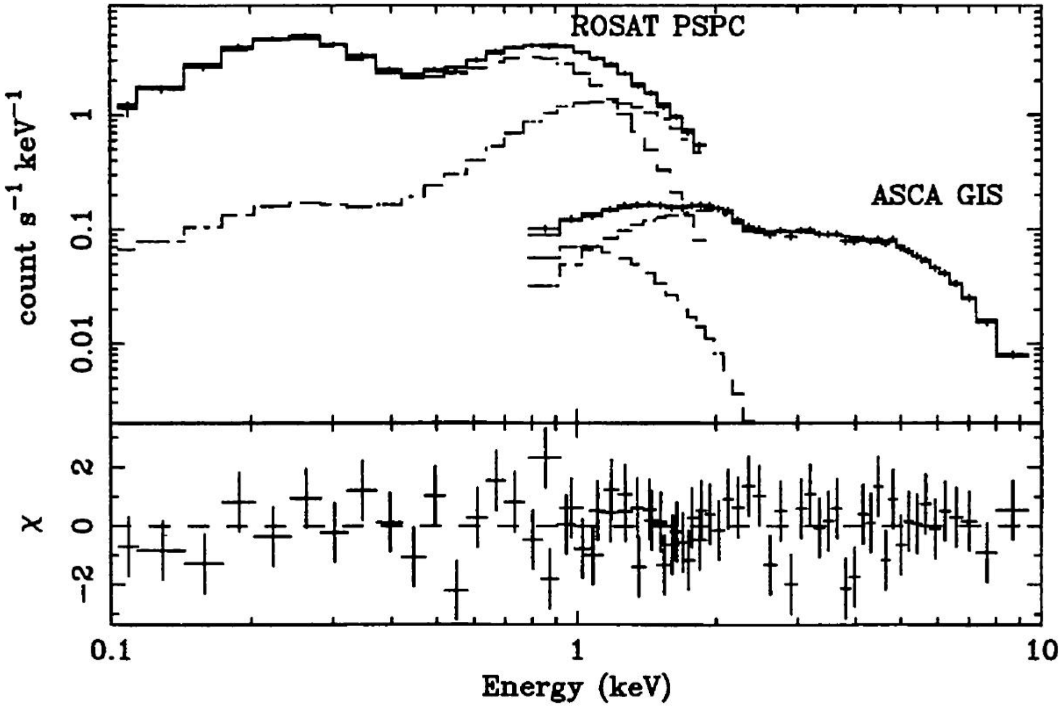
of an *outburst* since 1993,

with $L_X \sim 7 \times 10^{37}$ erg s^{-1}

(ATel 5756, Krimm et al. 2014)

⇓

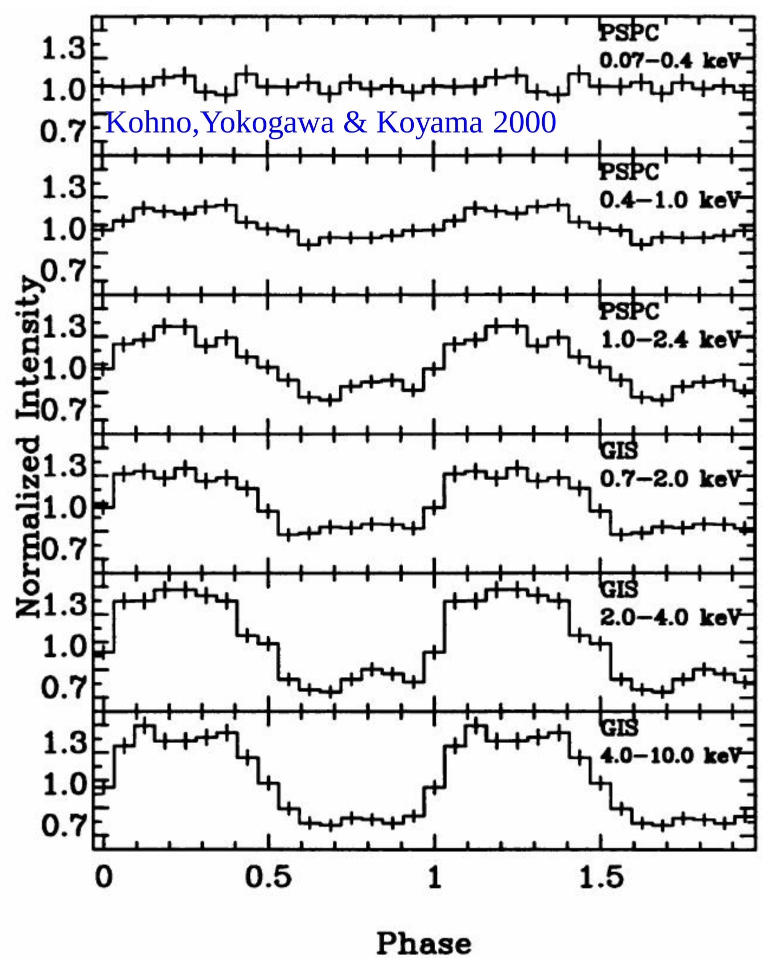
XMM-Newton observation (20 ks)

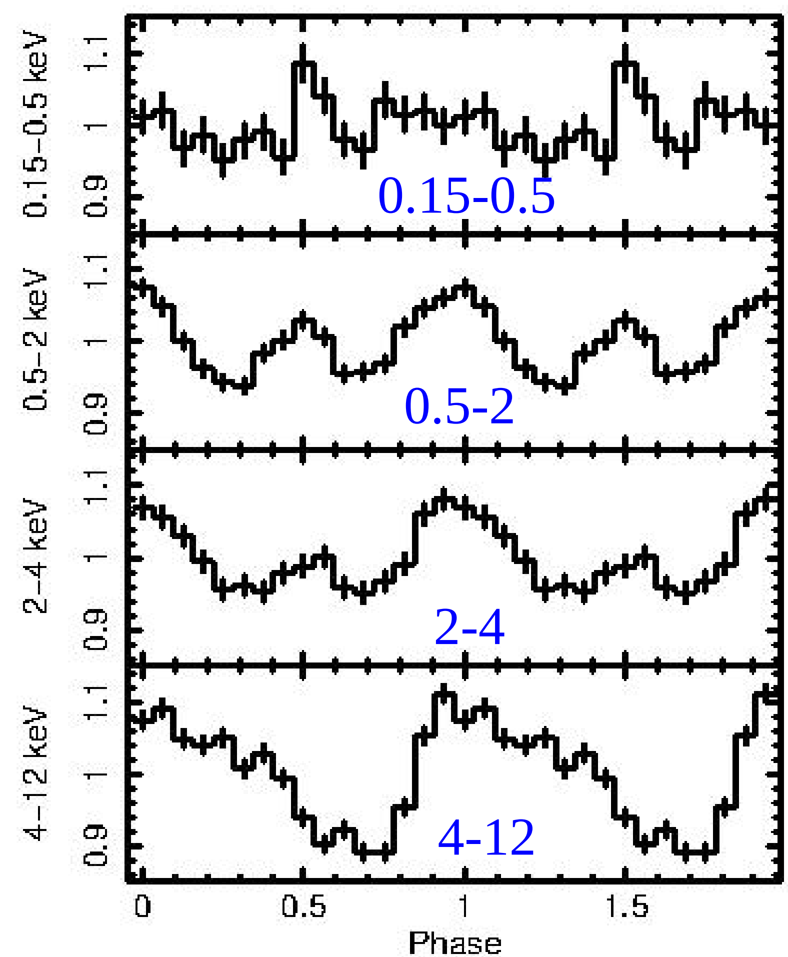


XMM-Newton observation of RX J0059.2-7138: timing analysis

2013: $L_X \sim 7 \times 10^{37}$ erg s^{-1}, detection of pulsed emission also at E < 0.5 keV, *PF* ~ 9 %

ASCA + ROSAT



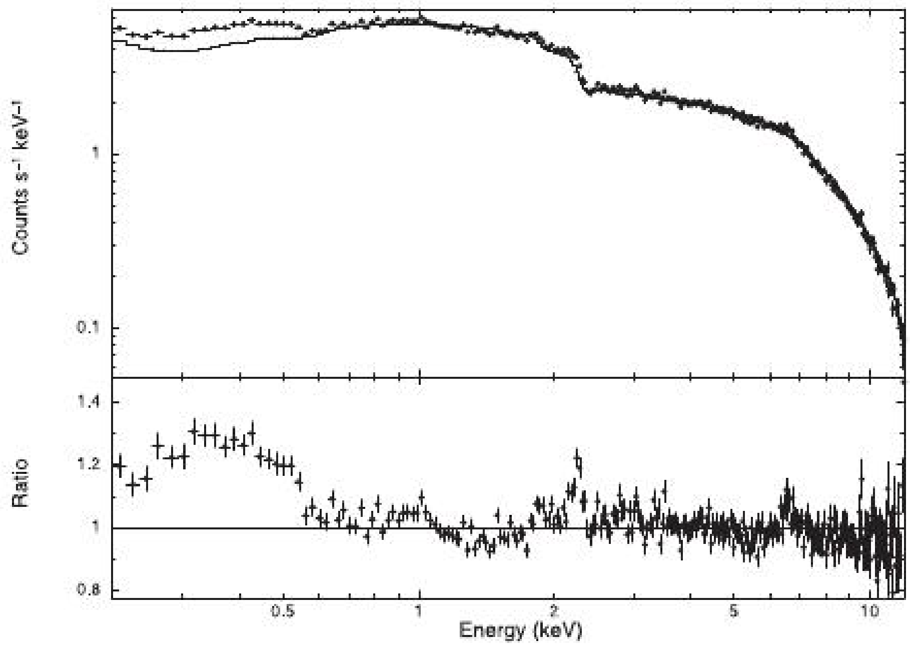


XMM

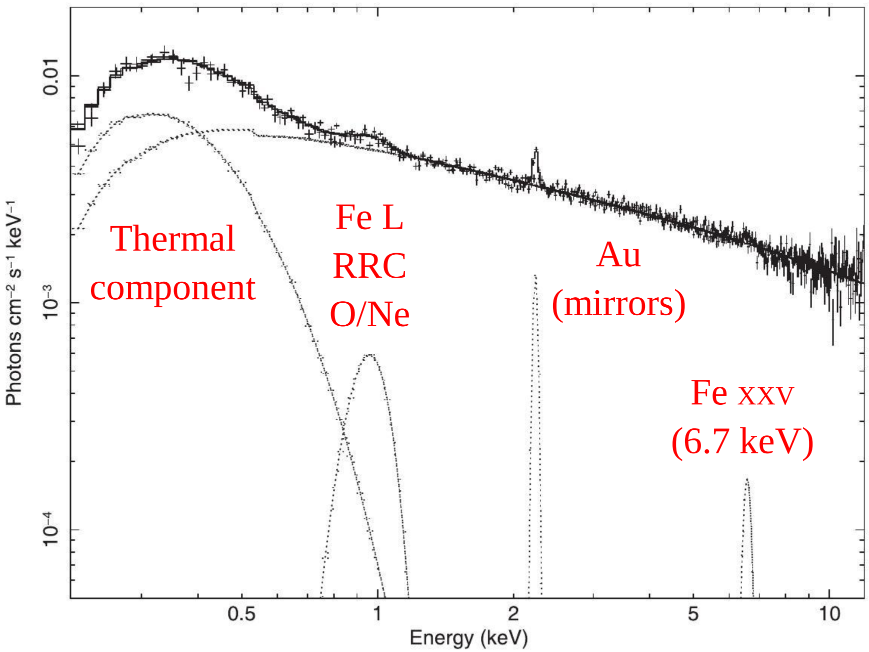
XMM-Newton observation of RX J0059.2-7138: *EPIC* spectrum

EPIC spectrum:

- Significant SE which dominates the PL emission at E < 0.5 keV
- L_{SE} ~ 1.5 % of L_{TOT} (~ 44 % in 1993)
- SE fit with either a BB (kT_{BB} = 93 eV, R_{BB} ~ 350 km) or a thermal plasma model (MEKAL: kT_{ME} = 210 eV, R_{ME} > 6×10^5 km, A < 0.007)



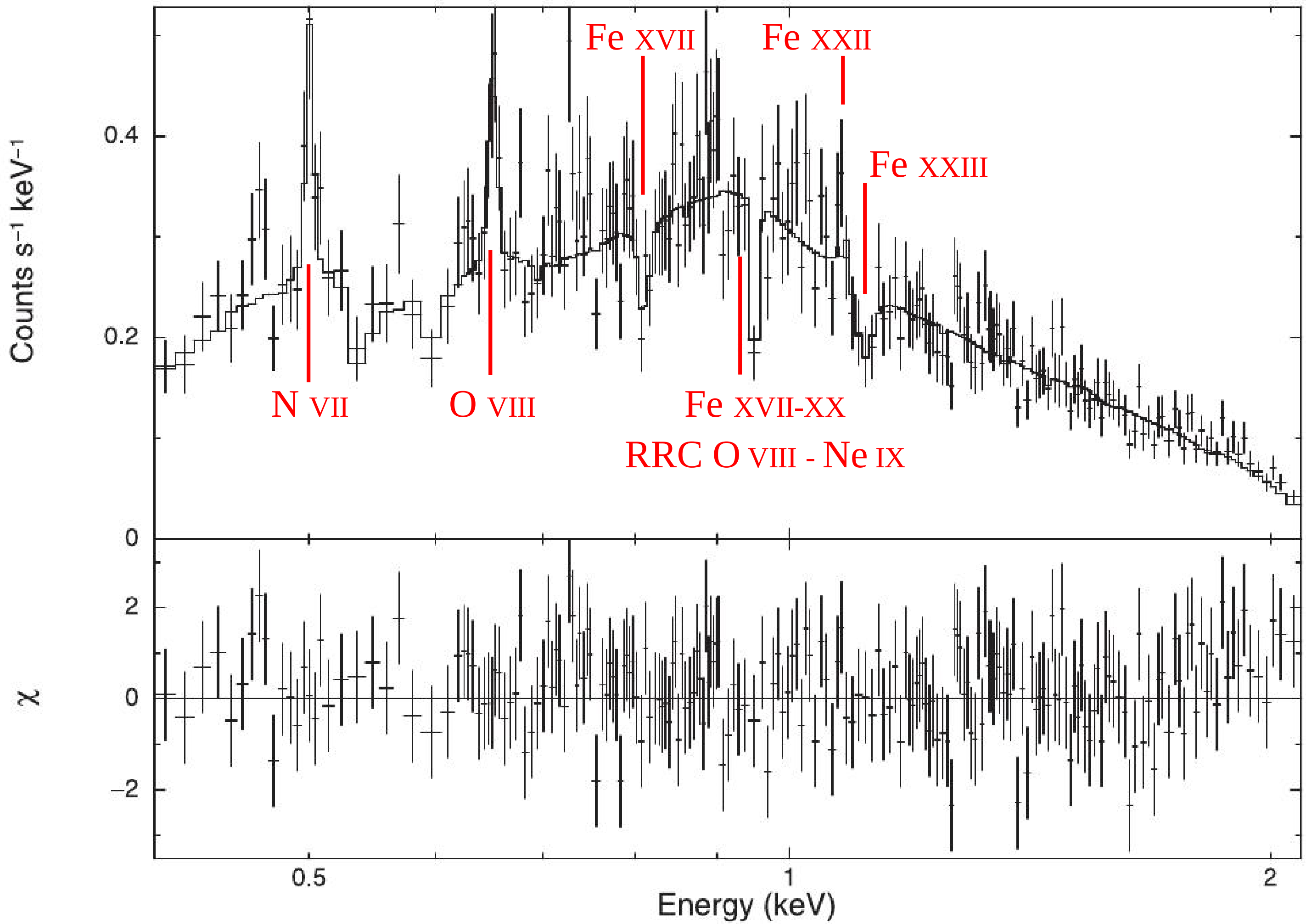
EPIC PN spectrum, PL model



EPIC best-fit model

XMM-Newton observation of RX J0059.2-7138: *RGS* spectrum

first detection of several absorption and emission lines due to N, O, Ne, and Fe



large residuals if continuum is described with a PL+MEKAL model

SMC X-2

1977: discovered with SAS3 (L_X = 8.4x10^{37} erg s^{-1}; Li, Jernigan & Clark 1977; Clark et al. 1978)

2000: second *outburst* observed with RXTE (L_X ~ 3x10^{37} erg s^{-1})

⇒ P_{spin} = 2.37 s (Corbet et al. 2001)

2011:

- OGLE: periodic variability of the optical counterpart (P = 18.62 ± 0.02 d, Schurch et al. 2011)
- RXTE: periodic modulation of the pulse period (P = 18.38 ± 0.02 d, Townsend et al. 2011)

September 2015: first observation of an outburst since 2000 (ATel 8088, Negoro et al. 2015; ATel 8091, Kennea et al. 2015), with L_X ~ 10^{38} erg s^{-1} (~ $L_{X,\,1977}$)

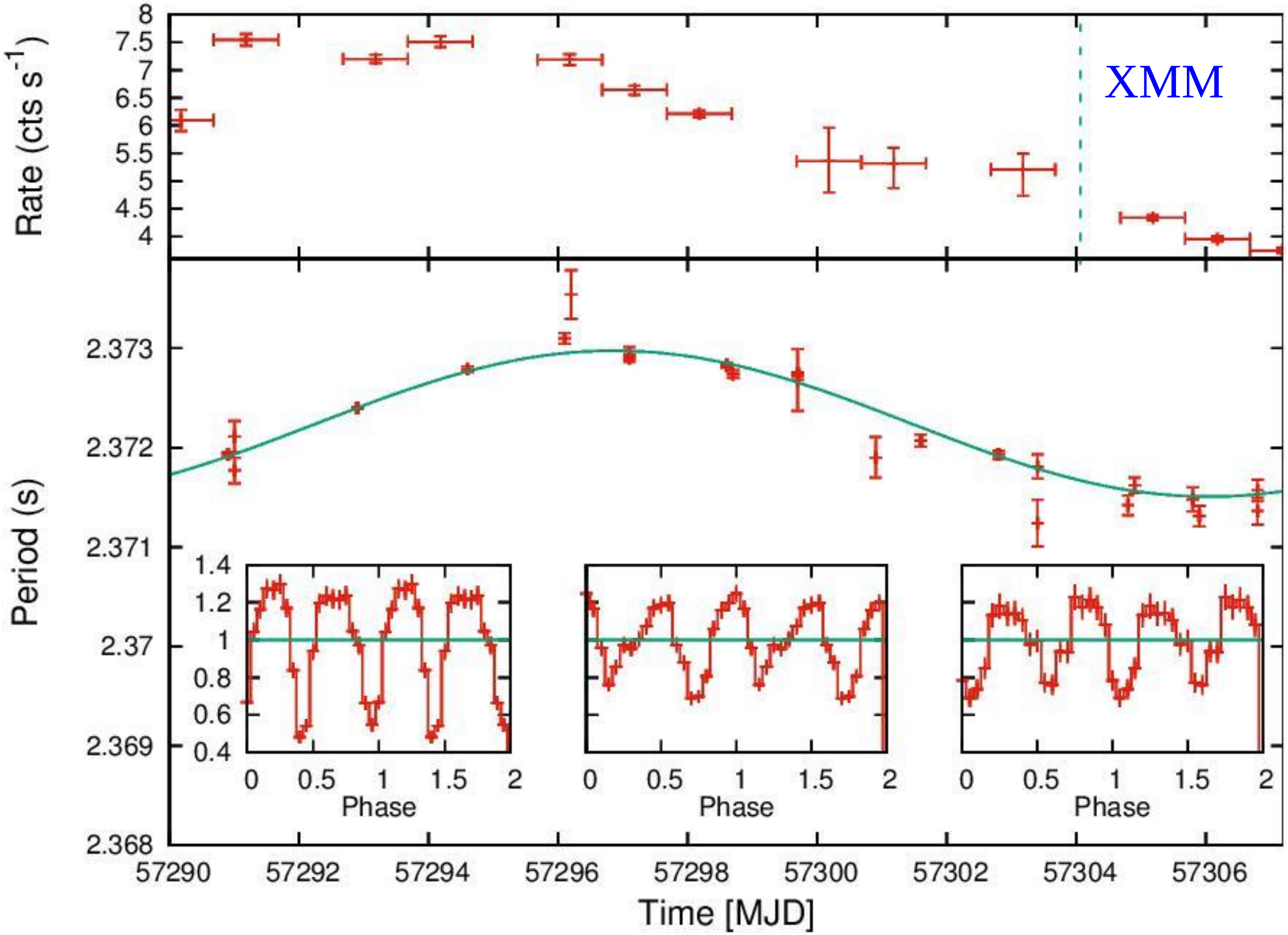
Swift observations of SMC X-2: timing analysis

74 observations with *Swift*/XRT in *Windowed Timing* mode

⇓

P_{spin} modulations due to

P_{orb} = 18.38±0.96 d



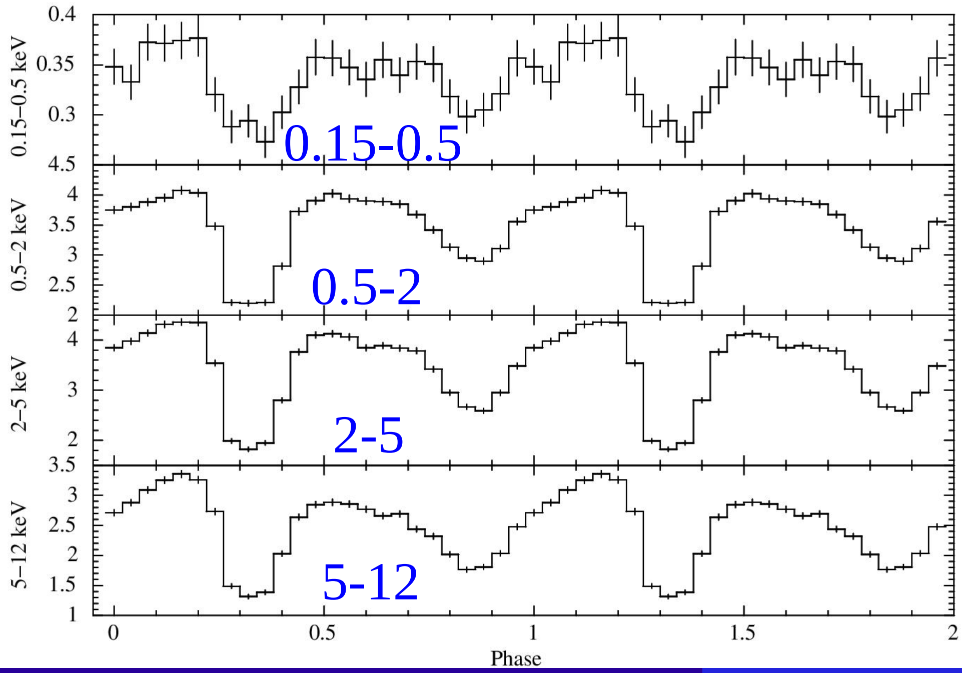
XMM-Newton observations of SMC X-2: timing analysis

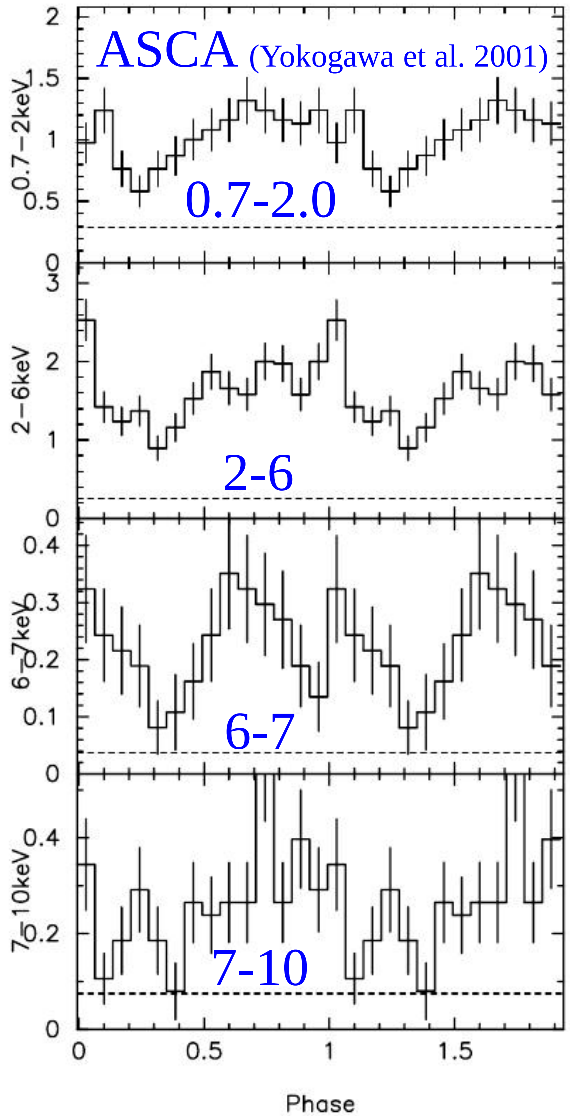
XMM-Newton observation (30 ks):

- First detection of pulsed emission also at E < 0.5 keV
- Double-peaked pulse profile also at E < 0.5 keV

  at variance with what observed with ASCA
- Pulsed fraction = 30-40 % (as in 2000)

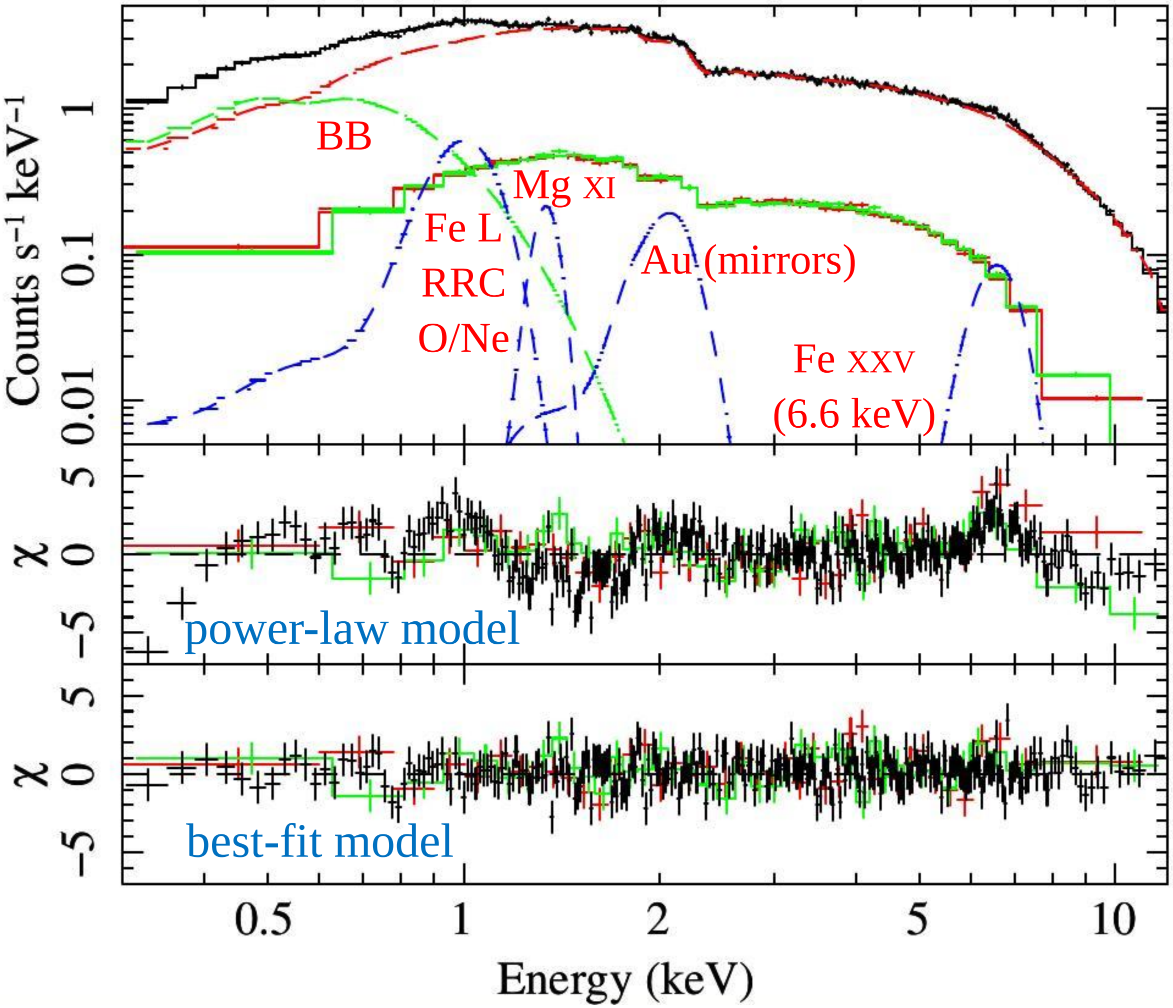
XMM





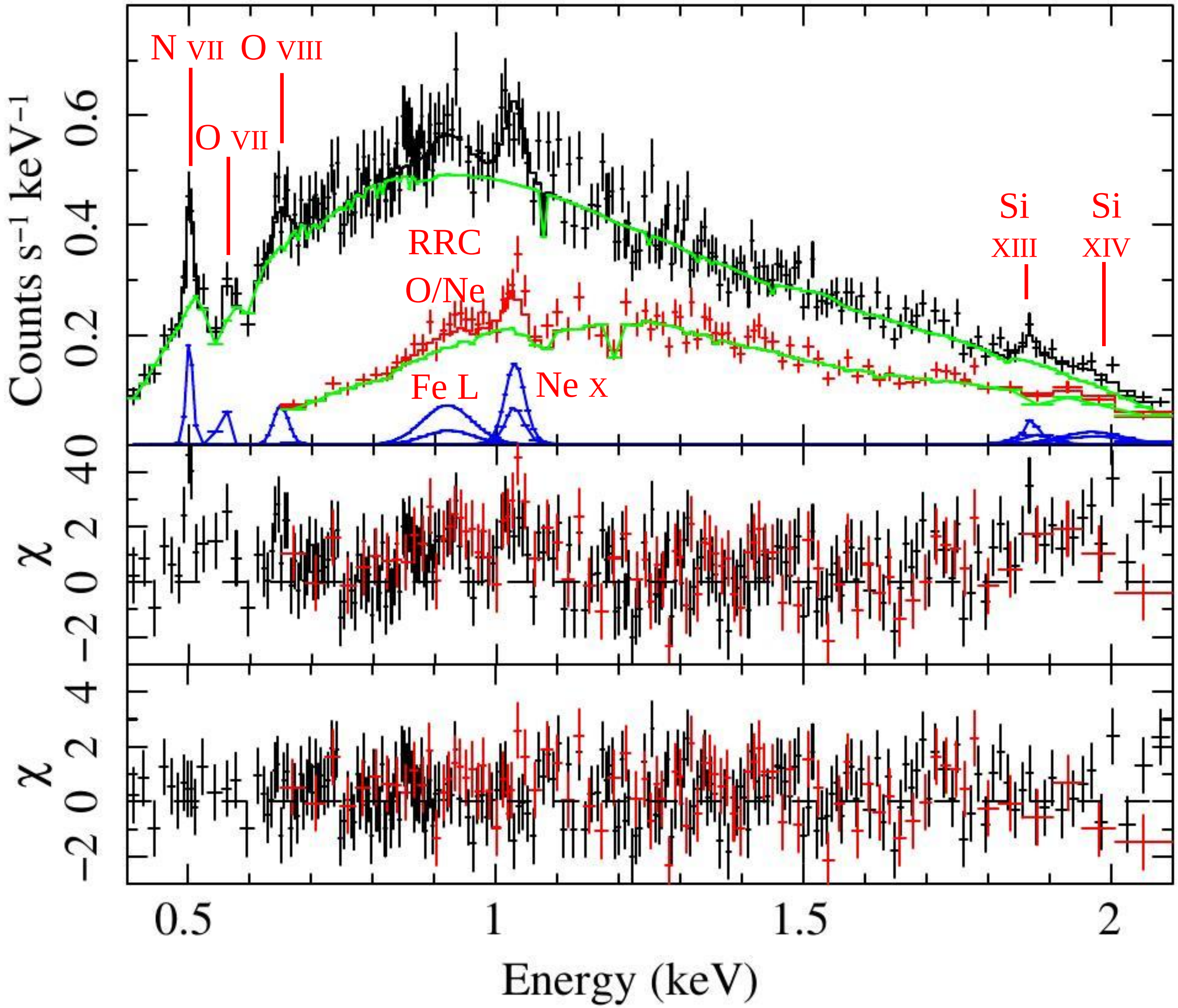
XMM-Newton observations of SMC X-2: *EPIC* spectrum

- First observation of the SE (2-6 % of the total flux) which dominates at E < 0.5 keV
- SE fit with either a BB (kT_{BB} ~ 130 eV, R_{BB} ~ 320 km) or with emission from collisionally ionized gas (APEC, kT_{APEC} ~ 1.2 keV)
- First detection of Fe emission line



XMM-Newton observations of SMC X-2: *RGS* spectrum

first detection of several emission lines due to N, O, Ne, Si, and Fe



large residuals in the RGS spectrum if continuum is described with a PL+APEC model

Common properties of RX J0059.2-7138 and SMC X-2

- Characteristics SE: BB model ⇒ kT_{BB} ~ 0.1 keV, R_{BB} ~ 300 km, L_{BB}/L_{PL} = 2-3 %
- Emission lines due to N, O, Ne, Si, and Fe, from matter with very different ionization levels ⇒ not compatible with a single-temperature plasma
- Large residuals in the RGS spectrum if continuum is described with a PL+MEKAL/APEC model
- SMC X-2: predominance of the forbidden line O VII (f) in the He-like O VII triplet
- High luminosity: $L_X \sim 10^{38}$ erg s^{-1}
- $R_{repr} \sim 10^8$ cm ~ R_m
- $L_X \sim 10^{38}$ erg s^{-1} ⇒ *PF* ~ 30-40 % (RX J0059 in 1993 and SMC X-2 in 2015)

⇓

- soft excess: reprocessing of the primary emission by the <u>optically thick</u> inner edge of the accretion disc
- narrow lines: emission from <u>optically thin</u> photoionized circumsource matter

IGR J01572-7259

2008:

- discovered with INTEGRAL in the Magellanic Bridge (Coe et al. 2008)
- follow-up observations performed with *Swift* and *RXTE* (McBride et al. 2010)

$\Rightarrow P_{spin} = 11.578$ s, hard spectrum ($\Gamma = 0.4$), $L_X = 6.5 \times 10^{35}$ erg s^{-1}

2013:

- *Swift*/BAT: periodic modulation in the light curve (P = 35.6 ± 0.5 d, Segreto et al. 2013)
- OGLE: periodic variability of the optical counterpart (P = 35.1 ± 0.1 d, Schmidtke et al. 2013)

$\Rightarrow$ orbital period

April 2016: detection of an outburst with Swift/BAT (ATel 9021, Krimm et al. 2016), with $L_X = 4.1 \times 10^{37}$ erg s^{-1}

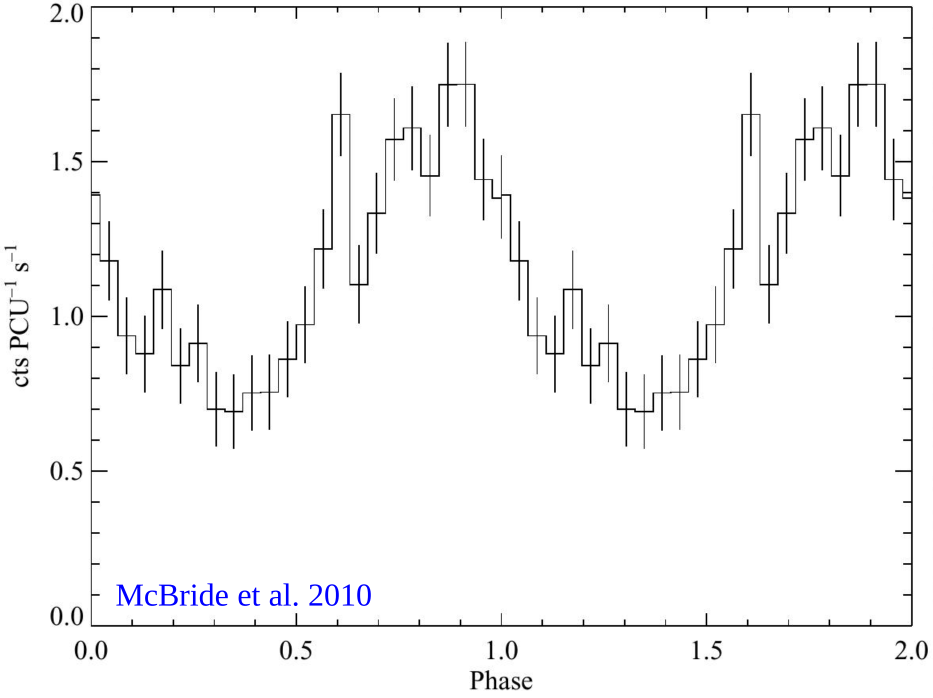
$\Downarrow$

Trigger of a ToO observation with *XMM-Newton* (28 ks)

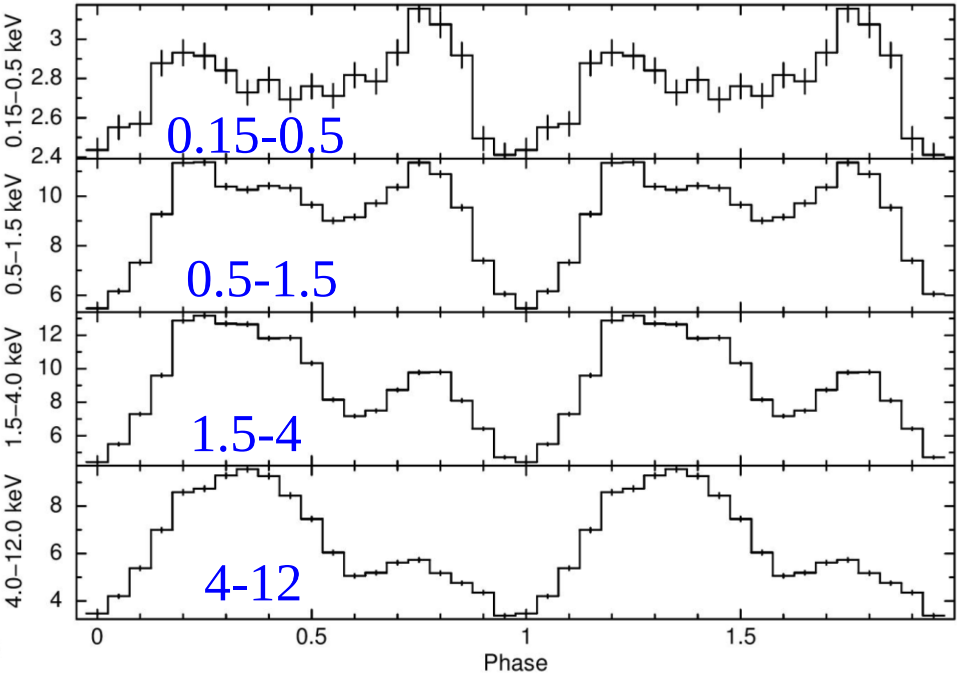
XMM-Newton observation of IGR J01572-7259: timing analysis

- First detection of pulsed emission also at low energies
- Significant energy dependence of the pulse profile
- Pulsed fraction increasing with E (~ 15 % @ E < 0.5 keV, ~ 45 % @ E > 1.5 keV)

RXTE PCA

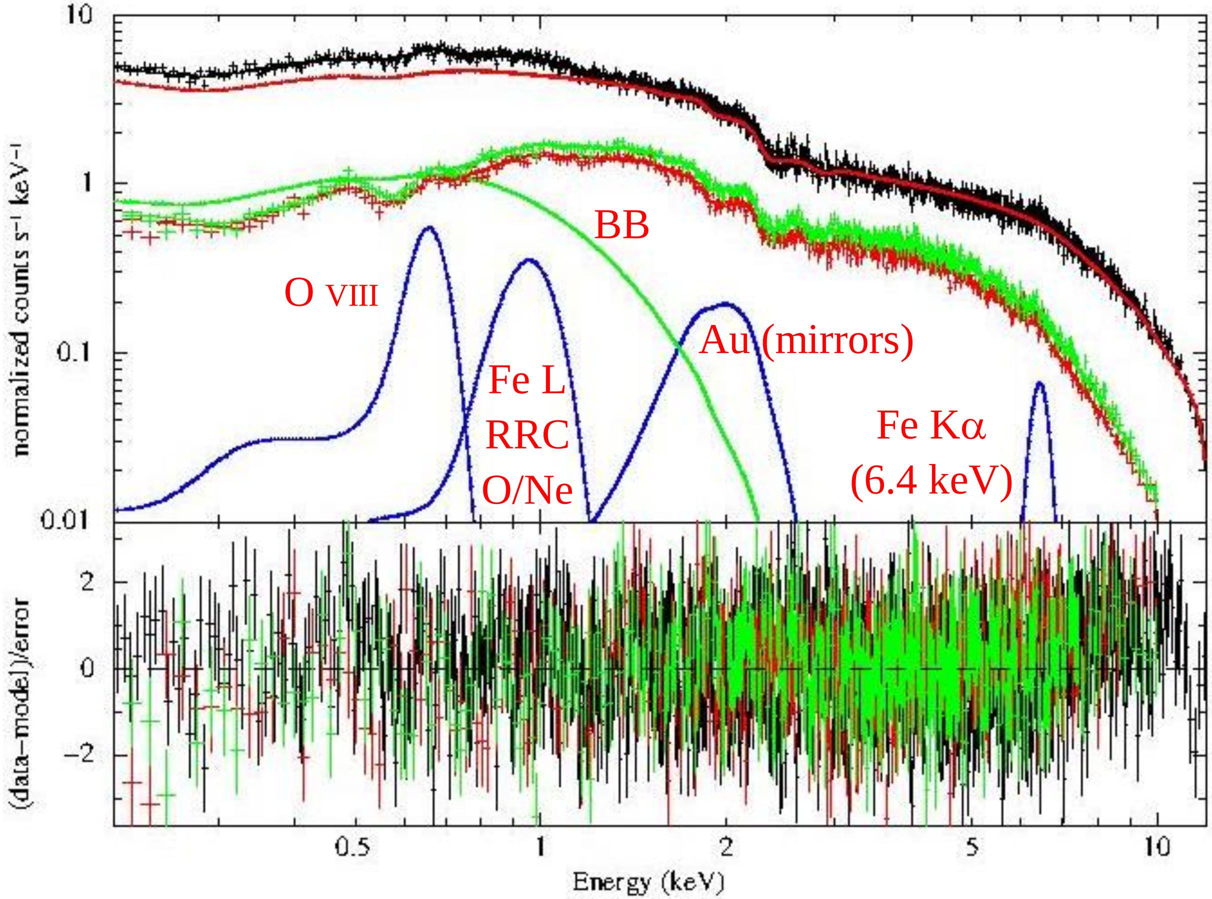


XMM EPIC



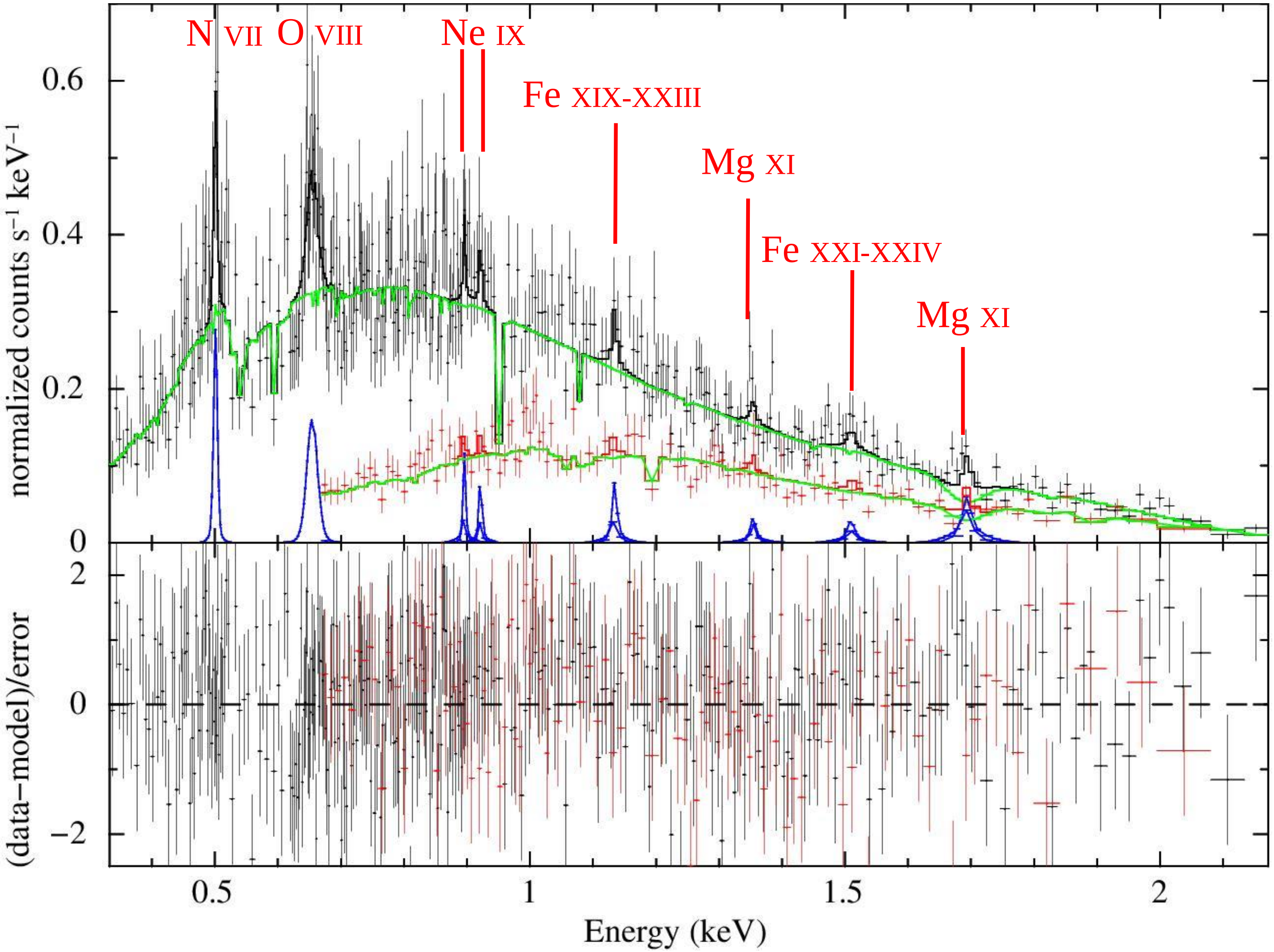
XMM-Newton observation of IGR J01572-7259: *EPIC* spectrum

- First detection of a faint SE (2-5 % of the total flux)
- SE fit with either a BB (kT_{BB} ~ 220 eV, R_{BB} ~ 50 km) or with emission from collisionally ionized gas (APEC, kT_{APEC} ~ 1.1 keV)
- First detection of O and Fe emission lines



XMM-Newton observation of IGR J01572-7259: *RGS* spectrum

first detection of several emission lines due to N, O, Ne, Mg, and Fe



large residuals in the RGS spectrum if continuum is described with a PL+APEC model

Origin of the *soft excess* in IGR J01572-7259?

As in the case of RX J0059.2-7138 and SMC X-2:

- SE: BB model ⇒ L_{BB}/L_{PL} = 2-3 %
- several narrow lines ⇒ large residuals in the RGS spectrum if continuum is described with a PL+APEC model

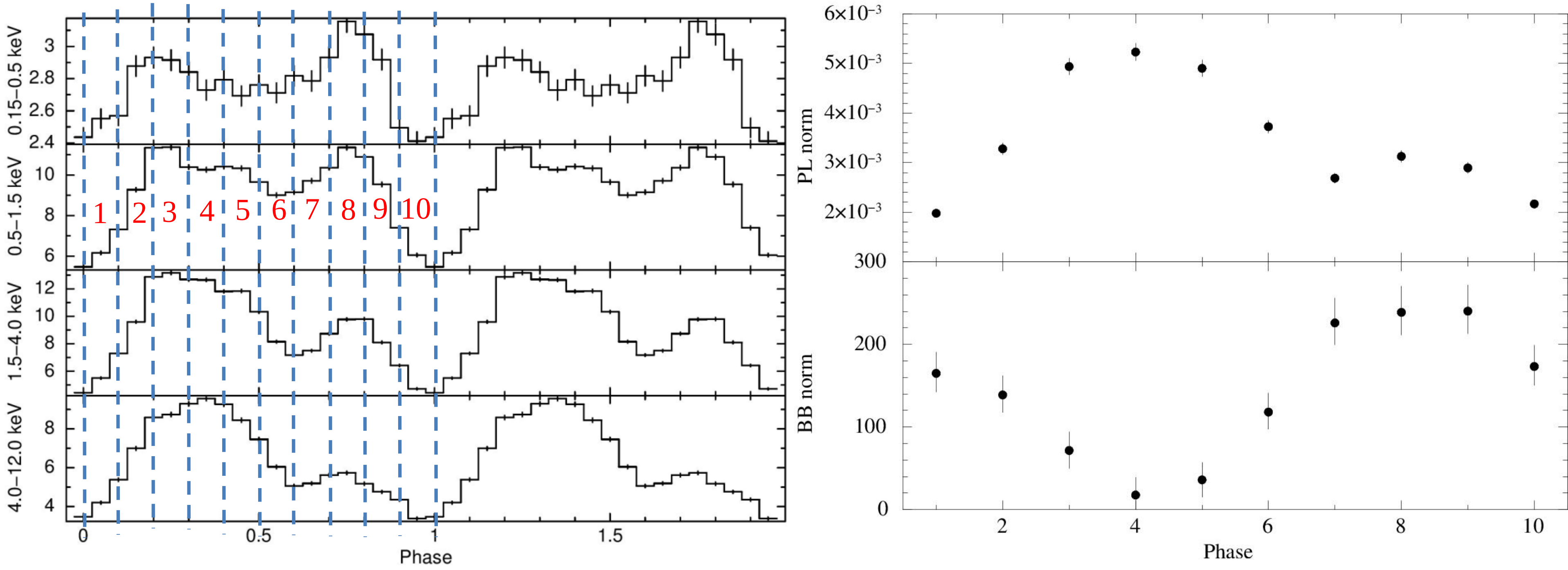
BUT

- no strong evidence for very different ionization levels

  ⇒ emission from a single-temperature plasma?
- intermediate luminosity ($L_X \sim 3\times10^{37}$ erg s^{-1})
- $R_{repr} \sim 3\times10^7$ cm $< R_m \sim 10^8$ cm $< R_{cor} \sim 8.6\times10^8$ cm

Origin of the *soft excess* in IGR J01572-7259?

Evidence of a pulsating BB component:



⇓

BB due to reprocessing of the primary emission by the inner edge of the accretion disc

Conclusions

For the three observed sources:

- SE + narrow lines
- SE: BB with kT_{BB} = 0.1-0.2 keV, $R_{BB} \sim$ 100 km >> R_{NS}, L_{BB}/L_{PL} = 2-3 %

⇓

reprocessing of the primary emission by <u>optically thick</u> material in the inner region of the accretion disc

- narrow lines due to N, O, Ne, Mg, Si, and Fe: large residuals in the RGS spectrum if continuum is described with a PL+MEKAL/APEC model

⇓

emission from <u>optically thin</u> photoionized circumsource matter

Conclusions

For the three observed sources:

- SE + narrow lines
- SE: BB with kT_{BB} = 0.1-0.2 keV, R_{BB} ~ 100 km >> R_{NS}, L_{BB}/L_{PL} = 2-3 %

⇓

reprocessing of the primary emission by optically thick material in the inner region of the accretion disc

- narrow lines due to N, O, Ne, Mg, Si, and Fe: large residuals in the RGS spectrum if continuum is described with a PL+MEKAL/APEC model

⇓

emission from optically thin photoionized circumsource matter

Thanks!