The properties of the soft excess in the transient X-ray binary pulsars of the Small Magellanic Cloud

N. La Palombara[1], Lara Sidoli[1], Paolo Esposito[2], Fabio Pintore[1], Andrea Tiengo[2], Sandro Mereghetti[1]

(1 - INAF / IASF Milano, 2 - IUSS Pavia)

Spectral properties of High Mass X-Ray Binaries

X–ray spectrum between 0.1 and 10 keV:

- usually described by a rather flat power law (photon index $\Gamma \sim 1$) with an exponential cut-off
- often with Fe Kα emission lines

BUT

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

Only in a few cases this low–energy component shows pulsations

⇓

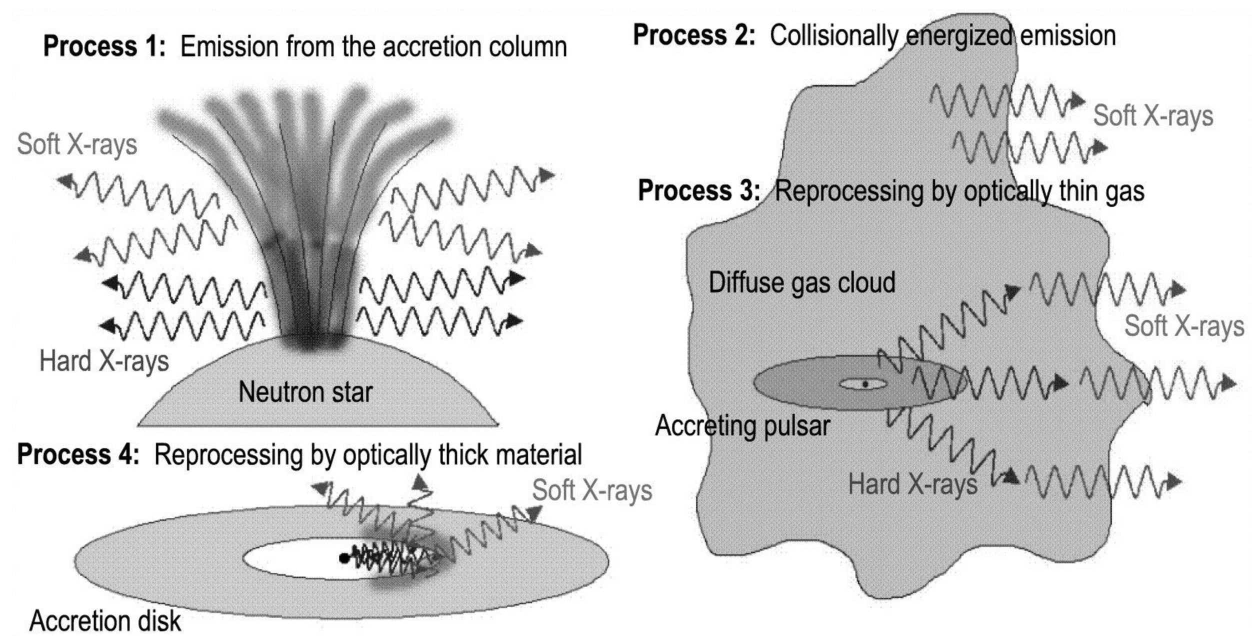
the debate about its origin remains open

Study of the soft part of the spectrum in Galactic sources affected by the interstellar absorption present in the Galactic plane

⇓

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

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



Transient BeXRBs in the SMC

Ideal sources 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 started in 2011

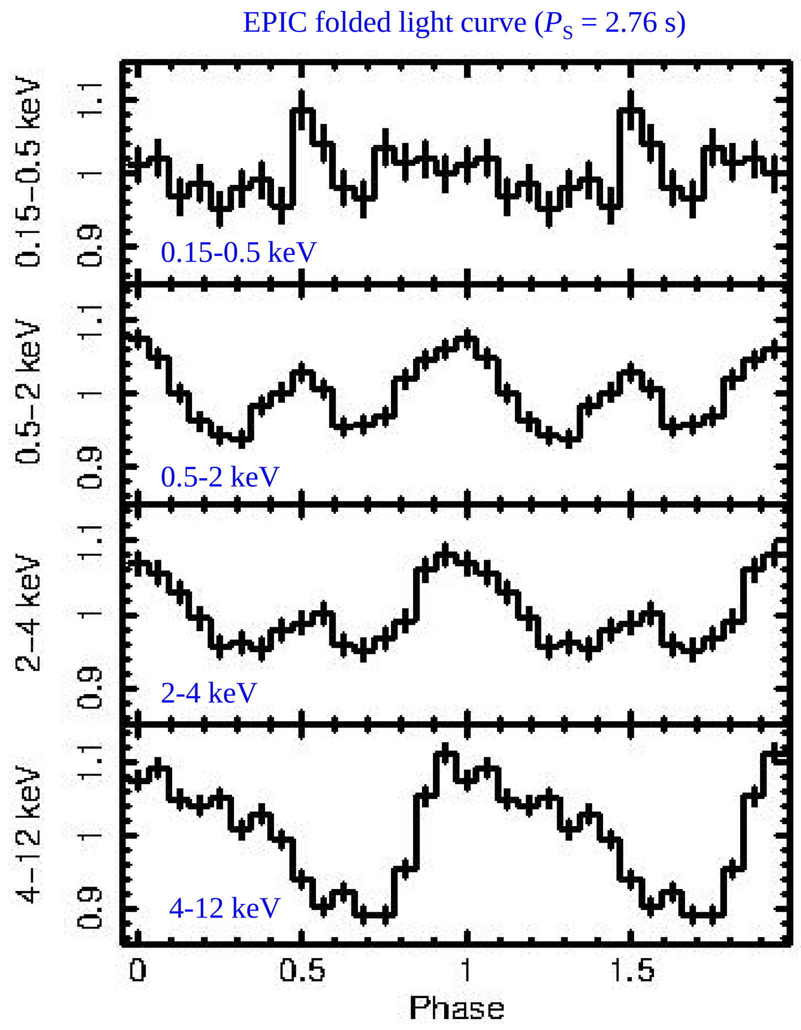
⇓

4 sources observed in *outburst*:

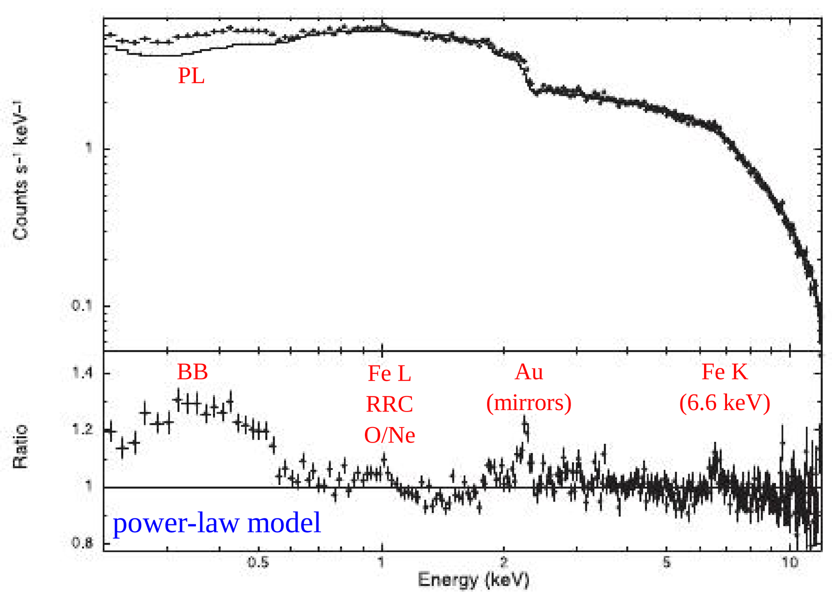
- RX J0059.2–7138: March 2014 (Sidoli et al. 2015, MNRAS 449)
- SMC X-2: October 2015 (La Palombara et al. 2016, MNRAS 458)
- IGR J01572-7259: May 2016 (La Palombara et al. 2018, MNRAS 475)
- SXP 59.0: April 2017 (La Palombara et al. 2018, A&A 619)

RX J0059.2-7138

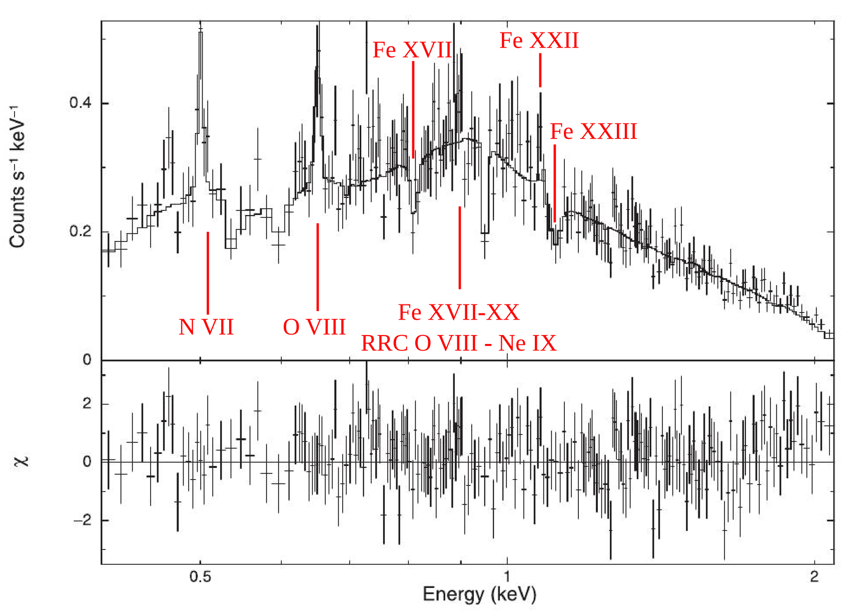
EPIC folded light curve (P_S = 2.76 s)



EPIC pn spectrum



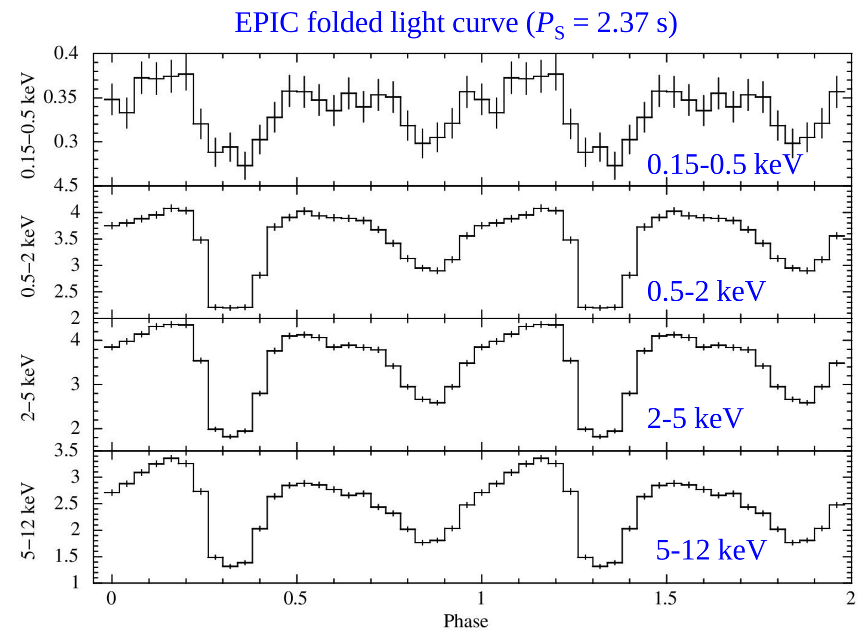
RGS spectrum



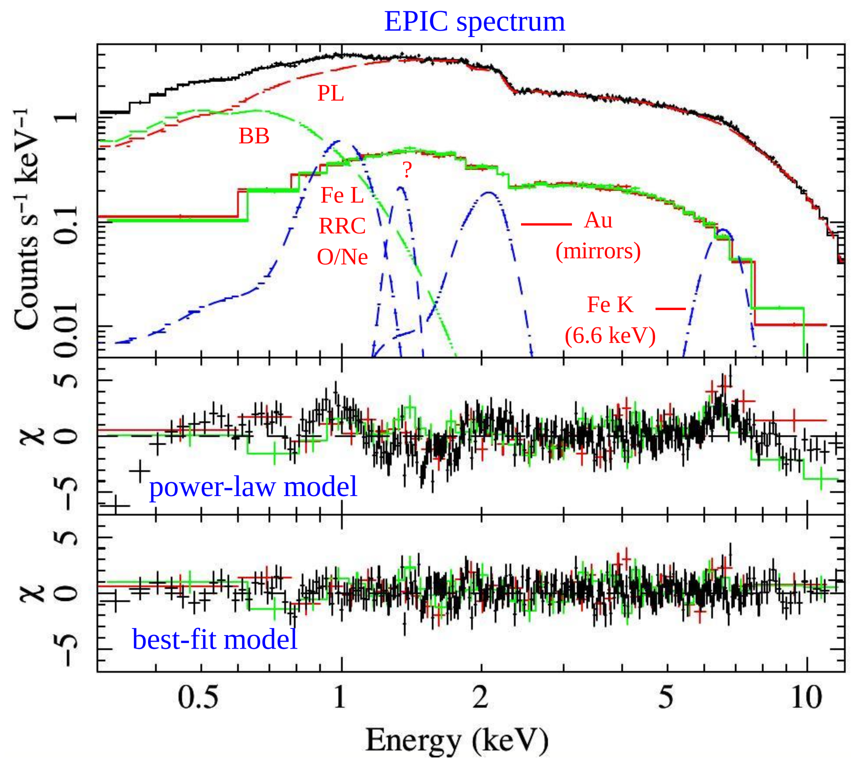
large residuals in the RGS spectrum if continuum is described with a PL+MEKAL model

SMC X-2

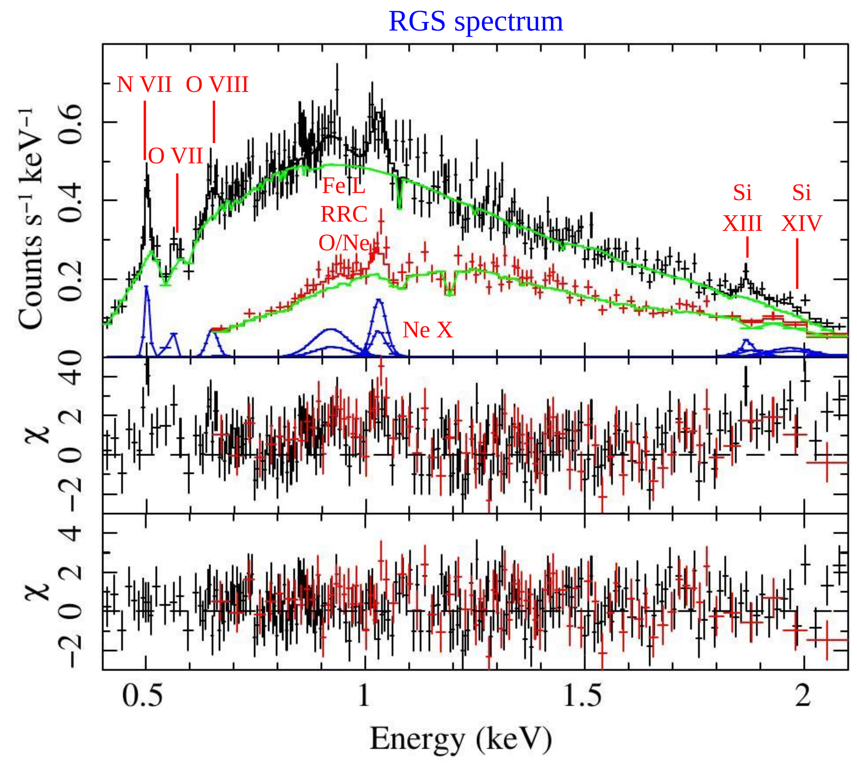
EPIC folded light curve (P_S = 2.37 s)



EPIC spectrum



RGS spectrum



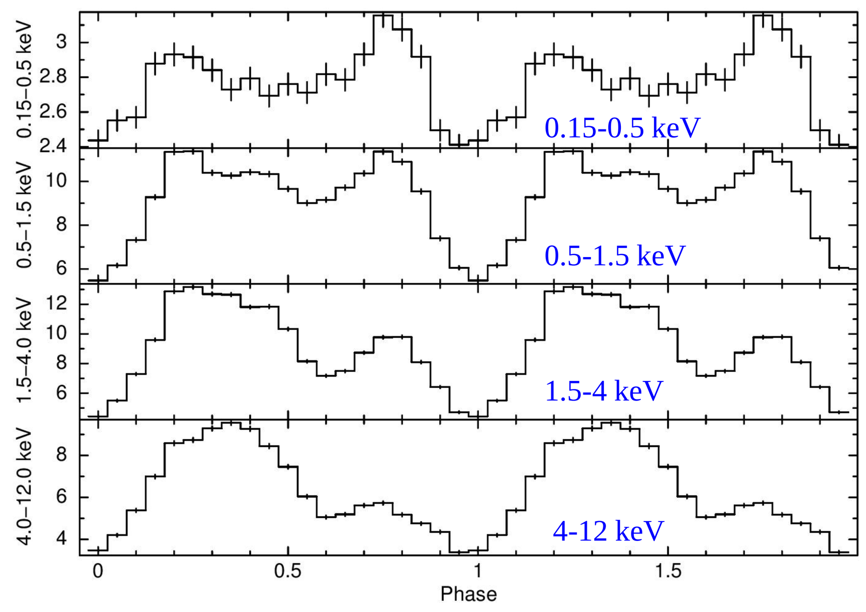
- large residuals in the RGS spectrum if continuum is described with a PL+APEC model
- predominance of the forbidden line O VII (f) in the He-like O VII triplet

⇓

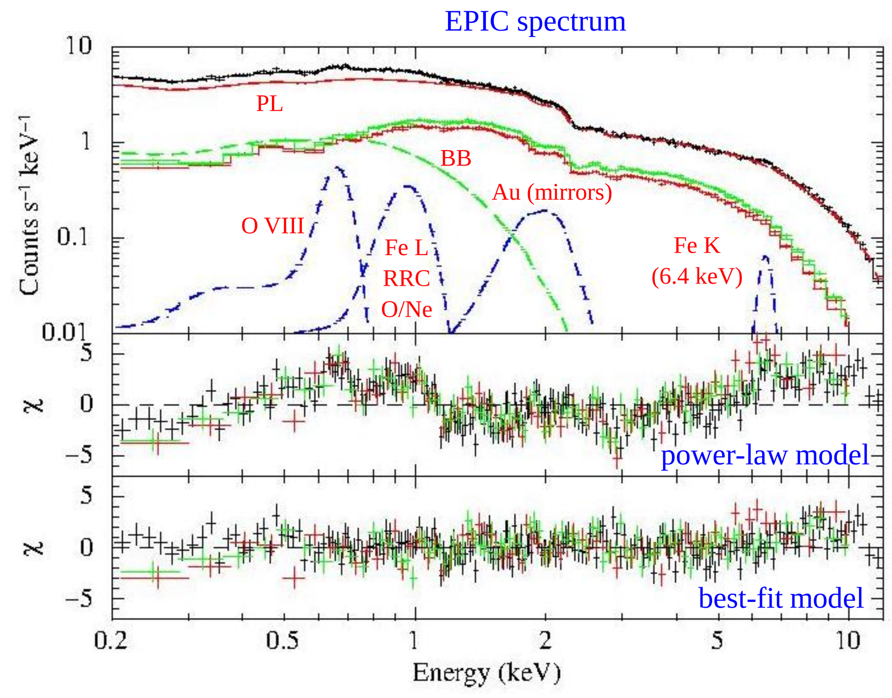
emission from photoionized plasma in regions above the disc

IGR J01572-7259

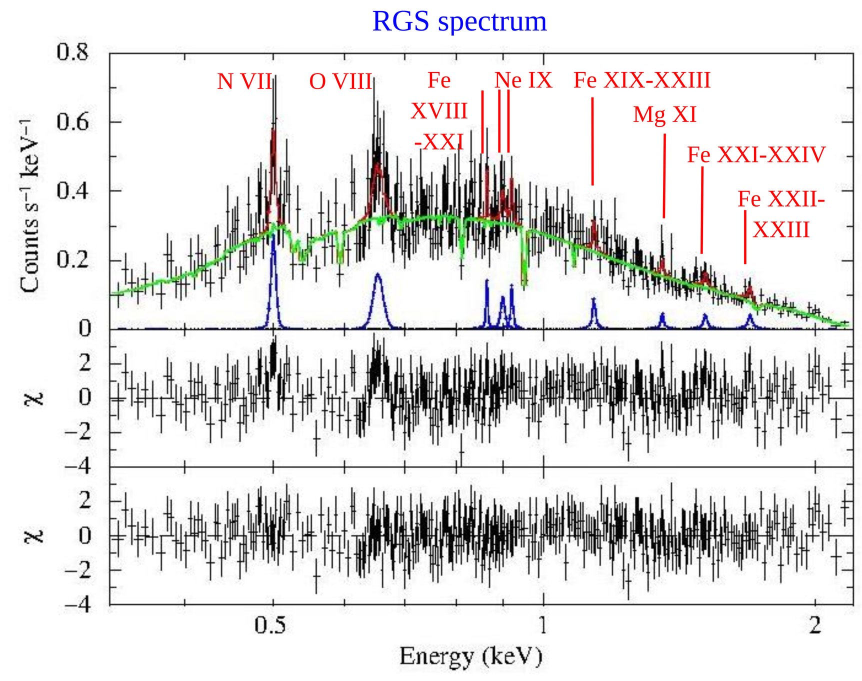
EPIC folded light curve (P_S = 11.58 s)



EPIC spectrum



RGS spectrum



APEC model for SE: R > 10^{11} cm ⇒ inconsistent with SE variability

Phase-resolved spectroscopy:

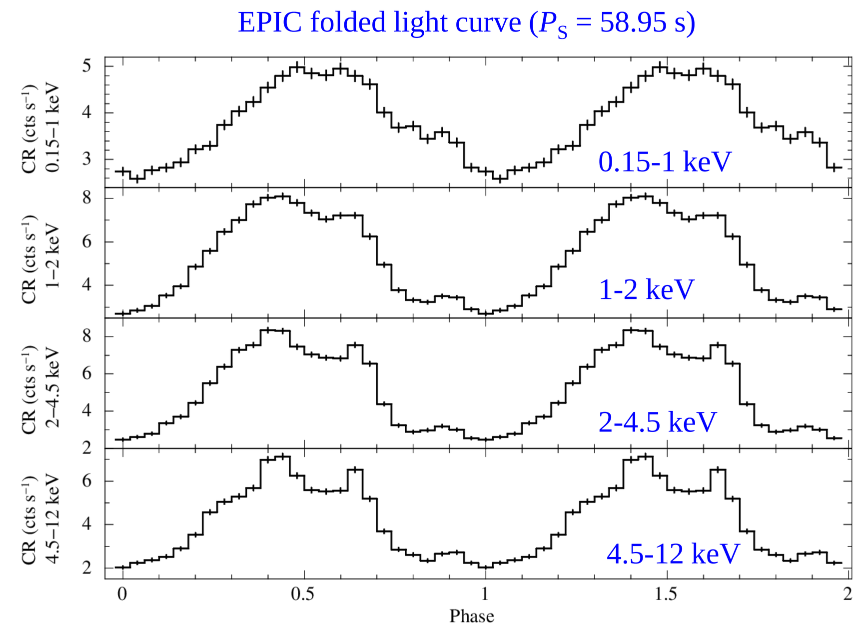
- No evidence of the BB component in the first peak of the folded LC
- Peak of the BB flux coincident with the second (low-energy) peak
- BB variability: smooth pulse shape; shift of $\Delta\Phi \sim 0.5$ from the first (high-energy) peak; small width ($\Delta\Phi \sim 0.3$)

⇓

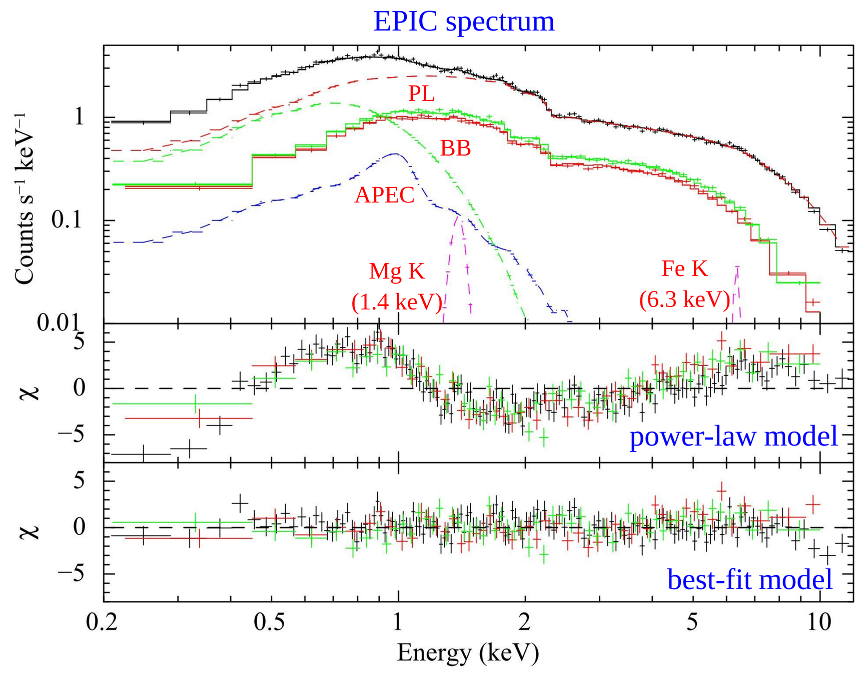
BB related to the PL component but due to different process

SXP 59.0

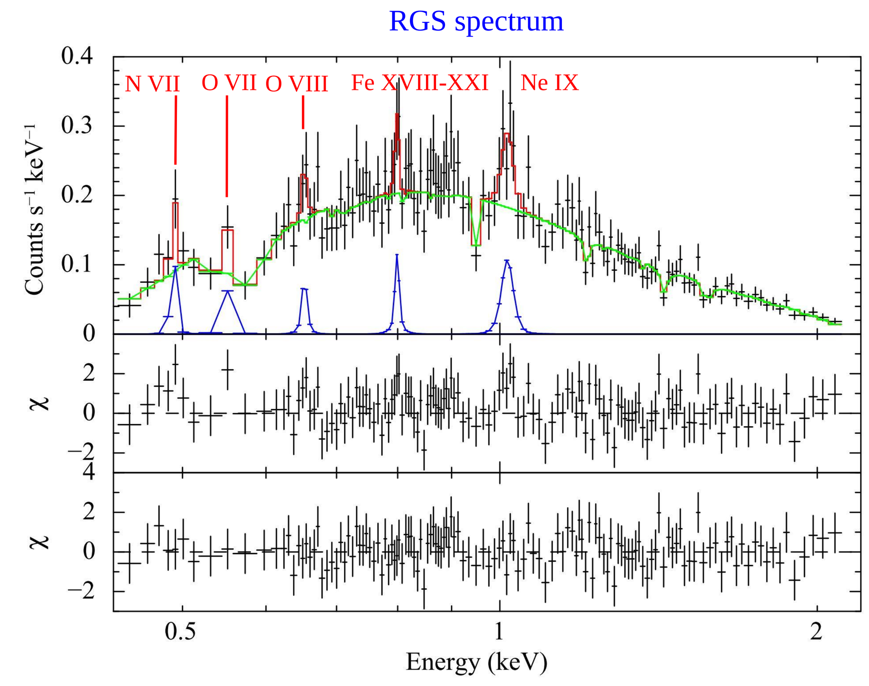
EPIC folded light curve (P_S = 58.95 s)



EPIC spectrum



RGS spectrum



Phase-resolved spectroscopy:

- at the minimum of the folded LC the BB flux is a factor ~2 higher than at the maximum, while the APEC flux is almost constant
- BB temperature almost constant ⇒ flux increase due to size increase
- Simultaneous fit of phase-resolved spectra ⇒ constant BB rejected by the data, constant APEC consistent with data
- Non-pulsating APEC component with R > 10^{11} cm ⇒ consistent with shock region due to wind accretion

Properties of the transient BeXRBs in outburst

- High luminosity: $L_X = 10^{37\text{-}38}$ erg s^{-1}
- BB component with $kT_{BB} \sim 0.1$-0.2 keV, $R_{BB} \sim 100$ km, L_{BB}/L_{PL} = 2-3 %
- d_{BB} (BB distance from central NS) ~ R_m (magnetospheric radius)
- Emission lines due to N, O, Ne, Mg, Si, and Fe
- RGS spectrum described with a PL+MEKAL/APEC model ⇒ large residuals
- Thermal plasma model for SE with R > 10^{11} cm ⇒ inconsistent with SE variability

For SMC X-2:

- Predominance of the forbidden line O VII (f) in the He-like O VII triplet

For IGR J01572-7259:

- Pulse profile strongly energy dependent: secondary peak only at low energies
- Evidence of SE only in the second pulse peak
- BB component: smooth pulse shape; shift of $\Delta\Phi \sim 0.5$ from the first (hard) peak; small width ($\Delta\Phi \sim 0.3$) ⇒ related to the hard component but due to different process

For SXP 59.0:

- SE due to BB+APEC at all pulse phases
- Evidence of pulsating BB component with constant temperature
- No evidence of variable APEC component
- APEC component consistent with shock region around the NS due to wind accretion

Parameter	RX J0059.2-7138[a]		SMC X-2[a]		IGR J01572-7259[a]		SXP59.0
L_X (0.2–12 keV, $\times 10^{37}$ erg s^{-1})	7		14		3.6		3.5
P_{orbit} (days)	82		18.4		35.6		122.1
P_{spin} (s)	2.76		2.37		11.58		58.95
PF (%)	8.9		35		43		53
N_H (10^{20} cm^{-2})	$2.3^{+0.6}_{-0.5}$		18 ± 3		$1.0^{+0.1}_{-0.2}$		12 ± 1
kT_{BB} (eV)	93 ± 5	–	135^{+14}_{-11}	–	218^{+13}_{-14}	–	171^{+11}_{-14}
R_{BB} (km)	350^{+80}_{-50}	–	320^{+125}_{-95}	–	50^{+6}_{-5}	–	110^{+25}_{-15}
f_{BB}/f_{PL} (%)	1.7	–	3.1	–	1.6	–	3.5
kT_{APEC} (keV)	–	0.21 ± 0.03	–	$1.22^{+0.07}_{-0.10}$	–	$1.13^{+0.10}_{-0.08}$	$1.09^{+0.16}_{-0.09}$
N_{APEC} ($\times 10^{-3}$ cm^{-5})	–	25^{+8}_{-6}	–	5 ± 1	–	4 ± 1	$1.0^{+0.6}_{-0.4}$
f_{APEC}/f_{PL} (%)	–	7	–	1.8	–	4.5	1.4
N VII	Yes		Yes		Yes		Yes
O VII	No		Yes		No		Yes
O VIII	Yes		Yes		Yes		Yes
Ne IX	Yes		Yes		Yes		No
Ne X	No		Yes		no		Yes
Mg XI	No		No		Yes		Yes
Si XIII	No		Yes		No		No
Si XIV	No		Yes		No		No
$E_{FeK\alpha}$ (keV)	6.6		6.6		6.4		6.3
d_{BB} (km)	3000		1800		400		570
R_m (km)	900		740		1100		1100

[a] For this source the APEC component is considered an alternative to the BB component.

Conclusions

For the four observed BeXRBs:

- SE: BB + narrow lines (+APEC for SXP 59.0)
- BB component due to reprocessing of the primary emission by the optically thick material at the inner edge of the accretion disc
- narrow lines due to emission from photoionized plasma in regions above the disc
- APEC component due to collisionally heated thermal plasma, probably related to the shocked wind accreted from the companion Be star

X-ray Astronomy 2019

Bologna (I), 9-13 september 2019