Luminosity-related spectral changes in accreting pulsars: indication of two accretion regimes

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Abstract

The high-quality data taken with RXTE, INTEGRAL, and Suzaku on a number of bright transient and persistent X-ray pulsars allowed a detailed study of their spectral properties as a function of luminosity, i.e. of the mass accretion rate. Our recent analysis of the the luminosity-related spectral changes observed in several accreting pulsars on the time scale of single X-ray pulsations (i.e. a few seconds) combined with the long-term spectral variations reported previously allowed us to distinguish between two different types of spectral behavior of the sources. We interpret these two types as a manifestation of two distinct accretion regimes. We argue that the regime realized in a particular pulsar depends on the average mass accretion rate and the neutron star parameters. The eRosita observations will allow one to study the luminosity-dependent spectral changes and, therefore, possible diversity of accretion regimes on the basis of a larger sample of pulsars.

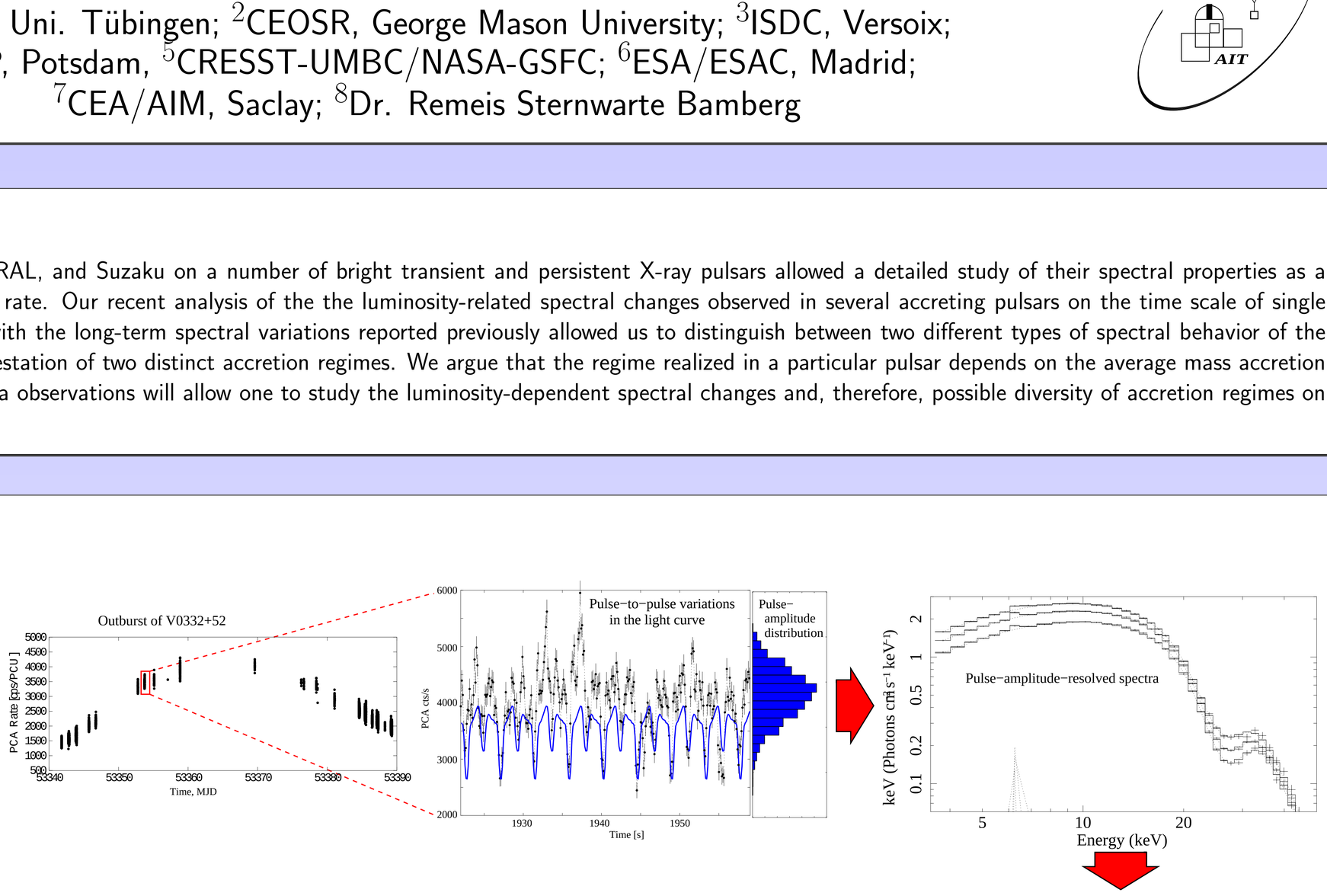
Pulse-to-pulse spectroscopy

We explored the variability of individual X-ray pulses *(pulse-to-pulse variability)*. For our study, we used the archival data taken with RXTE and INTEGRAL on **V 0332+53, 4U 0115+63, A 0535+26**, and **Her X-1**, which are all well established cyclotron line sources, i.e. their spectra contain *Cyclotron Resonant Scattering Features (CRSFs)* whose energy is proportional to the B-field strength.

Observations used in this work:

Source	Instrument	mid MJD	Exp. (ks)
V0332+53	RXTE	53354 (Outb. 2004)	23.7
4U0115+63	RXTE	51249 (Outb. 1999)	32.8
A0535+26	RXTE	53615 (Outb. 2005)	30.8
	INTEGRAL	53615 (Outb. 2005)	104.7
Her X-1	RXTE	52600 (Main-On)	98.7

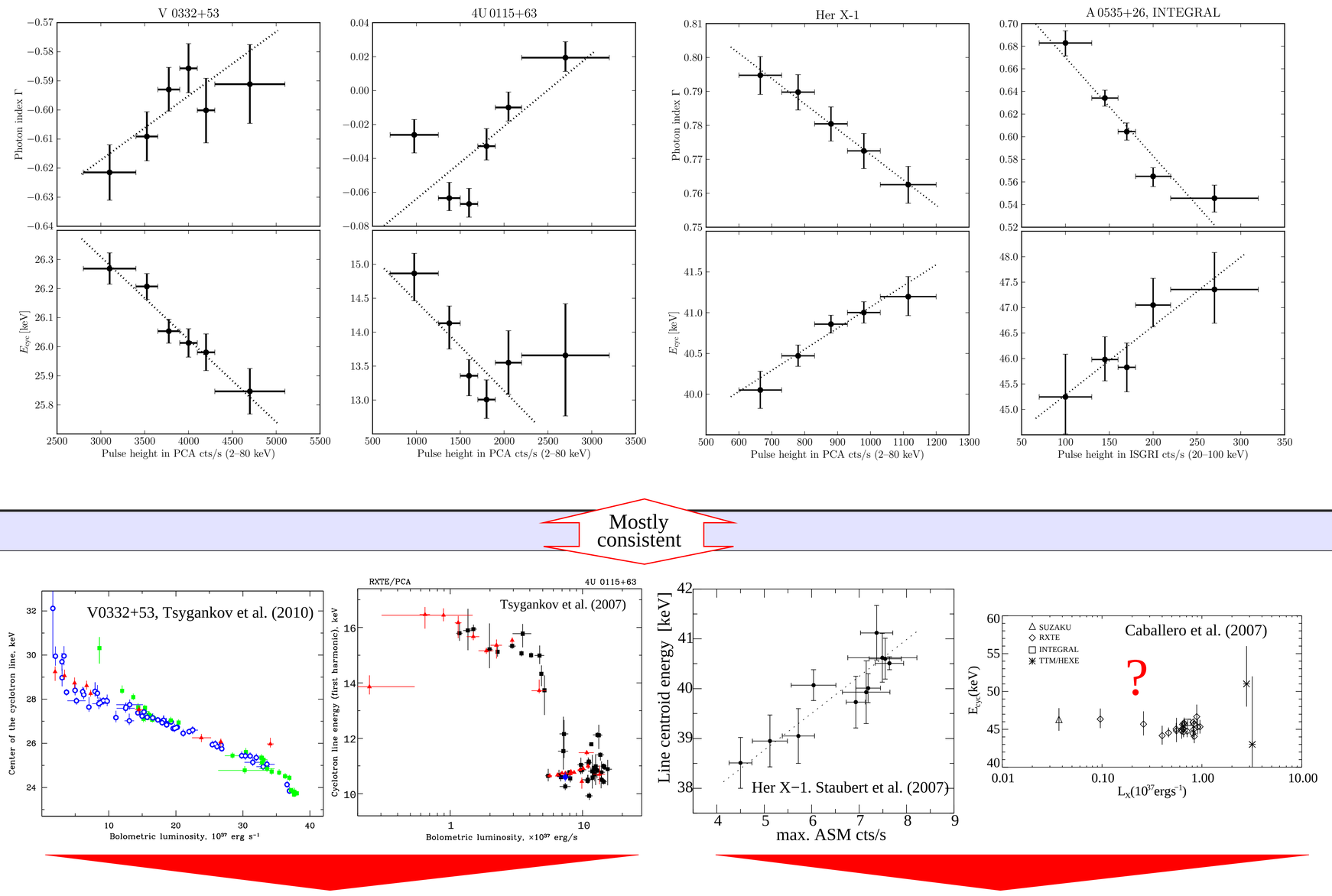
For each pulsar we extracted a high-resolution light curve where single pulses are clearly distinguishable (see the figures on the right). For each pulse we calculated its mean count rate, which we call the *amplitude* of the pulse. The blue histogram shows the distribution of the pulse amplitudes. Then, we grouped together pulses of similar amplitude which allowed us to explore the **variation of the X-ray spectrum as a function of pulse amplitude.**
The pulsars' spectra were modeled using a "standard" power-law/cutoff model. The powerlaw was characterized with the photon index Γ: $I(E) \propto E^{-\Gamma}$. The cyclotron absorption features were modeled with Gaussian absorption lines. The variation of the cyclotron line centroid energy $E_{\rm cyc}$ as a function of pulse amplitude is shown in the two bottom raws of graphs.
One can clearly distinguish between two types of variations: left two columns vs. right two columns (see also the section below).



Mostly consistent

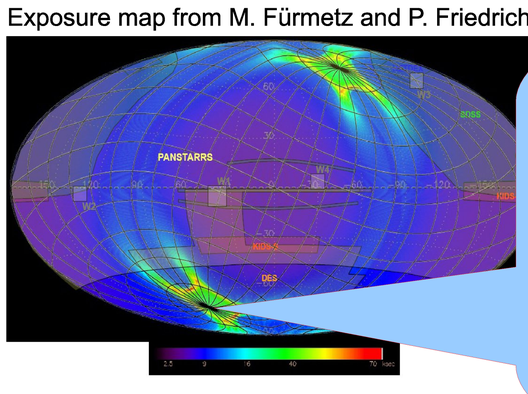
Long-term luminosity-related spectral changes

In the four sources the variation of the CRSF energy $E_{\rm cyc}$ with luminosity was measured on the long time scale (e.g. during the outbursts) and reported in the literature (see figures on the right).
Apart from A 0535+26 (no correlation is seen) $E_{\rm cyc}$–Flux correlations are consistent with our pulse-to-pulse results (the section above and Klochkov et al. A&A, 2011).
The two groups of pulsars most probably correspond to two distinct accretion regimes that are at work in different sources depending on whether their luminosity is above or below some critical value L_C (Becker et al., in prep.).



Prospects for eROSITA

Exposure map from M. Fürmetz and P. Friedrich, 2010



From Liu+ catalog (trunc.)

Name	Type
LMC X-4	HMXB, pulsar
J0529.8-6556	HMXB, Pulsar, Transient
CAL E	HMXB, Pulsar, Transient
053109-6609.2	HMXB, Pulsar, Transient
J0544.1-7199	HMXB, Transient, Pulsar
J0544-665	HMXB
J0538-66	HMXB, Pulsar, Transient
J0535.0-67.00	HMXB, Transient
0535-668	HMXB, Pulsar, Transient
J0544.1-710	HMXB, Pulsar, Transient

The emerging diversity of the accretion regimes is of key importance for understanding of the physics and configuration of the accretion flow close to the neutron star surface. Our study of the luminosity–spectrum dependencies was performed on a very limited sample of X-ray pulsars and needs to be checked with other sources. The monitoring capability of eRosita will allow us to extend part of our analysis (not related to CRSF which is unreachable for eRosita) to a larger sample by **measuring the slope of the X-ray continuum below ∼2-10 keV at different luminosity states of transient sources**.

For bright X-ray pulsars, high timing resolution of the eRosita detectors will even allow us to perform pulse-amplitude-resolved spectroscopy (as described above) and, therefore, to explore the luminosity-dependence of the spectral continuum on the observations where flux level of the source did not change.
The Liu+ 2006 catalog of XRBs contains 28 transient accreting pulsars which might be included in the sample using eRosita data. Additional observations are expected to be performed during the follow-up phase.