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Is the X-ray pulsar 1A0535+262 a sub-critical system?

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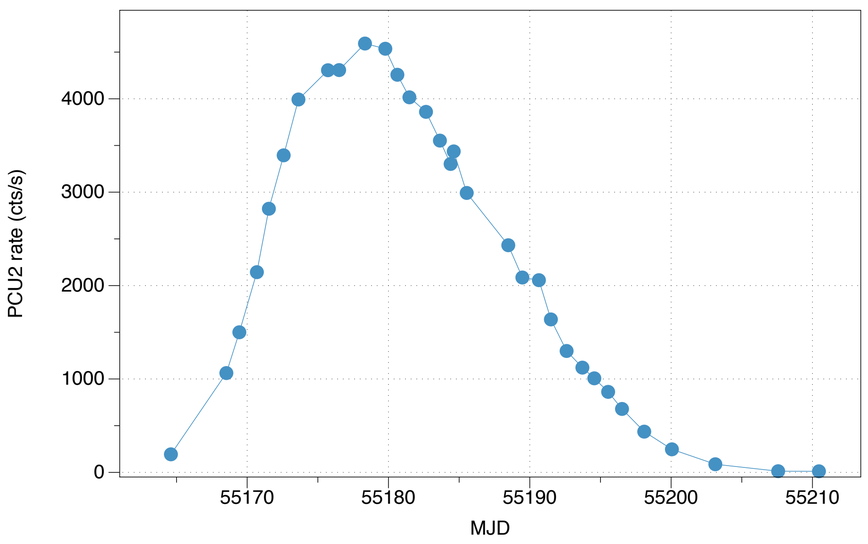


X-ray light curve during the 2009 giant outburst, as obtained from PCA count-rate

ABSTRACT:

We report RXTE and Swift/BAT spectral analysis of the Be/X-ray pulsar 1A 0535+262 during the 2009 giant outburst. Previous works have shown that there is no universal trend between the cyclotron resonant scattering feature (CRSF) and flux. Some sources show a positive correlation, other ones a negative correlation. Recently, some attempts have been done to phenomenologically explain this bimodal behavior in terms of two different regimes of accretion, the sub-critical one and the super-critical one, depending on a specific luminosity limit, which is different for different sources, and is proportional to the magnetic field of the neutron star (Becker et al. 2012). Our results from Swift/BAT data show hints for a long-term correlated behavior of the CRSF energy with X-ray luminosity, consistently with previous analysis on the short-term scale.
This would locate the system in the sub-critical regime.
Nevertheless, our RXTE/PCA data, which apparently show the same correlation, are affected by an overestimation of the background due to the very high count rate. Trying to eliminate this effects results in a shift of the line energy which weakens the correlation with luminosity.
The work is still in progress, but suggests that 1A 0535+262 fits in the proposed framework, being a sub-critical system. Its strong magnetic field prevents the source from reaching the correspondingly high critical luminosity, although in the bright outburst analyzed here, the peak luminosity gets close and possibly exceeds the critical value.

INTRODUCTION:

Be/X-ray binaries (Be/XRBs) constitute a sub-class of high-mass X-ray binaries (HMXBs) in which the companion is a Be star, i.e. a non-supergiant fast rotating OB-star that during its life has shown at some point spectral lines in emission.

They are also characterized by infrared excess. Both phenomena are thought to arise from a common cause, namely the presence of an extended circumstellar envelope around the stellar equator, made up by ionized gas that is expelled from the star in a way that is not yet completely understood.

Be/XRBs are characterized by high variability on a wide range of both time scales (from seconds to years) and wavelength, although the fastest variability is observed in the X-ray band.

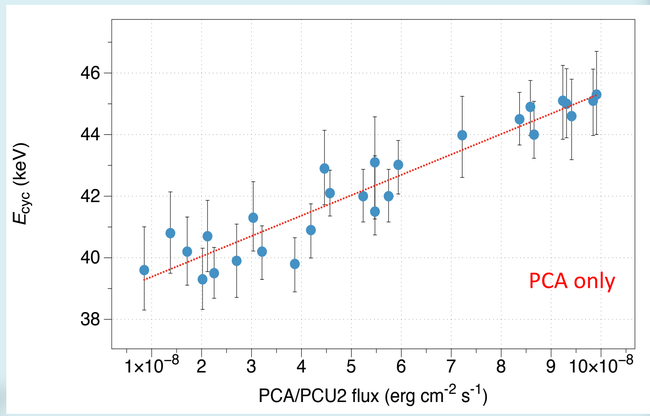
The Be/X-ray binary 1A 0535+26 was discovered during a giant outburst with *Ariel V*. At a distance of ~2 kpc, it consists of the B0IIIe optical companion and a pulsating neutron star, in an eccentric orbit. The system has been observed at different luminosity states associated with the activity of the Be star: quiescence, with X-ray luminosities L_X $<10^{36}$ erg s^{-1}, normal outbursts, with luminosities L_X ~$10^{36–37}$ erg s^{-1} and giant outbursts, that can reach luminosities $L_X > 10^{37}$ erg s^{-1} (see, e.g., Finger, Wilson & Harmon 1996).

The X-ray spectrum of 1A 0535+26 is characterized by a CRSF, located at ~46 keV, and a first harmonic at ~100 keV.
No significant correlation between the cyclotron line energy and the X-ray luminosity has been observed up to now on a long-term basis (see, e.g, Caballero et al., 2011).

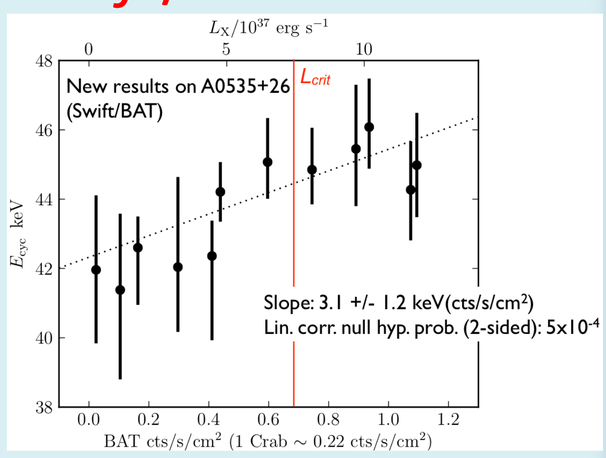
RXTE

RXTE followed the source during the full outburst, lasting one month and a half. Unfortunately, at the outburst peak HEXTE stopped rocking, resulting in unreliable background data after that event.

We performed spectral analysis with PCA data only in the 3-60 keV energy range. We fitted the spectra continuum with a phenomenological model consisting of a photo-absorbed power law with exponential cutoff multiplied by a Lorentzian absorption profile to account for the CRSF. Our results show a supposed positive correlation of the line energy with luminosity.

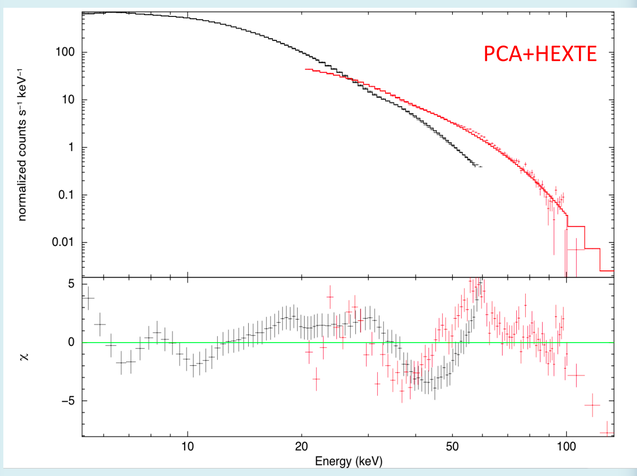


Swift/BAT



Spectral analysis of Swift/BAT data give first hints for a positive correlation of the line energy with luminosity in a long-term study.

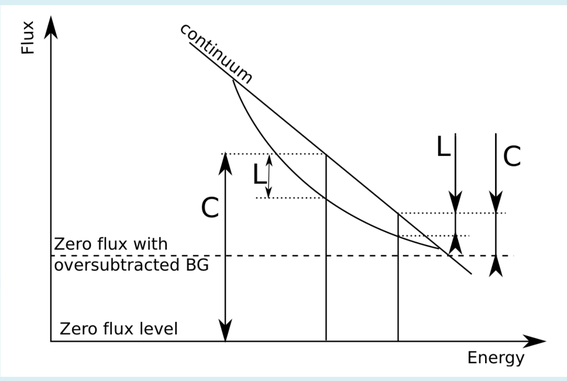
We then explored HEXTE data during the rise of the outburst, finding **no agreement with PCA**: the two instruments detect the line at different values.



PCA background overestimation

It is known that in the case of a very bright source, the PCA background model is overestimated. In the spectral analysis, this effect can be eliminated by modifying (reducing) the normalization of the background spectrum using the `recorn` model of XSPEC. We found that not taking the above effect into account leads to **a systematic shift of the best-fit centroid of a multiplicative absorption line** (e.g. XSPEC `gabs`, `cyclabs` models) to higher energies. Indeed, in case of an inclined continuum with the photon flux decreasing with energy, the best-fit centroid of a multiplicative absorption line is located at the energy where the ratio L/C reaches its maximum.

Over-subtraction of the background effectively reduces the absolute value of the continuum flux C at a given energy. As can be seen in the figure on the right, the energy at which L/C-ratio reaches its maximum shifts to higher energies.
We note that an additive line with a negative normalization (XSPEC `gaussian`) is not subject to this effect because the centroid energy in this case correspond just to the energy of a maximal absolute L-value. This effect was tested both with real and simulated spectra of A0535+26.



This work is in progress and especially the effect on the line energy to flux correlation is still being analyzed.

Conclusions…

Our preliminary Swift/BAT and RXTE spectral analysis of the 2009 outburst from 1A 0535+262 gives hints for a correlated behavior of the CRSF energy with luminosity on a long-term scale. This would agree with results from pulse-amplitude-resolved spectroscopy (Klochkov et al., 2011), where a correlation was indeed shown. A hint of a positive correlation was also observed during the flaring phase preceding the 2005 outburst (Caballero et al. 2008). A subcritical state in A0535+026 would agree with the display of just one branch (the horizontal branch) in the HID during the 2009 outburst (Reig & Nespoli 2013).
The RXTE/PCA background overestimation affects the position of the line, resulting in a line shift which varies with flux. Further analysis is still needed to fully disentangle the CRSF behavior from instrumental effects.