Swift-BAT observations of cyclotron lines in HMXB

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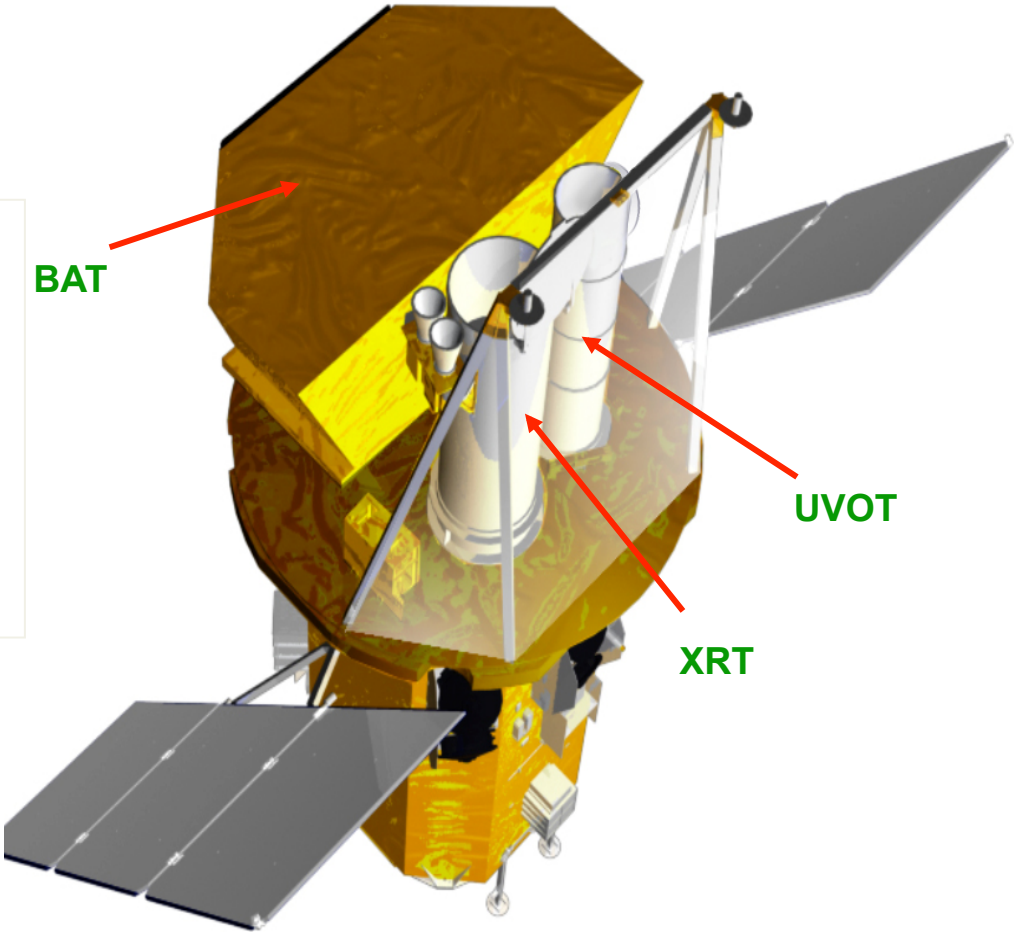
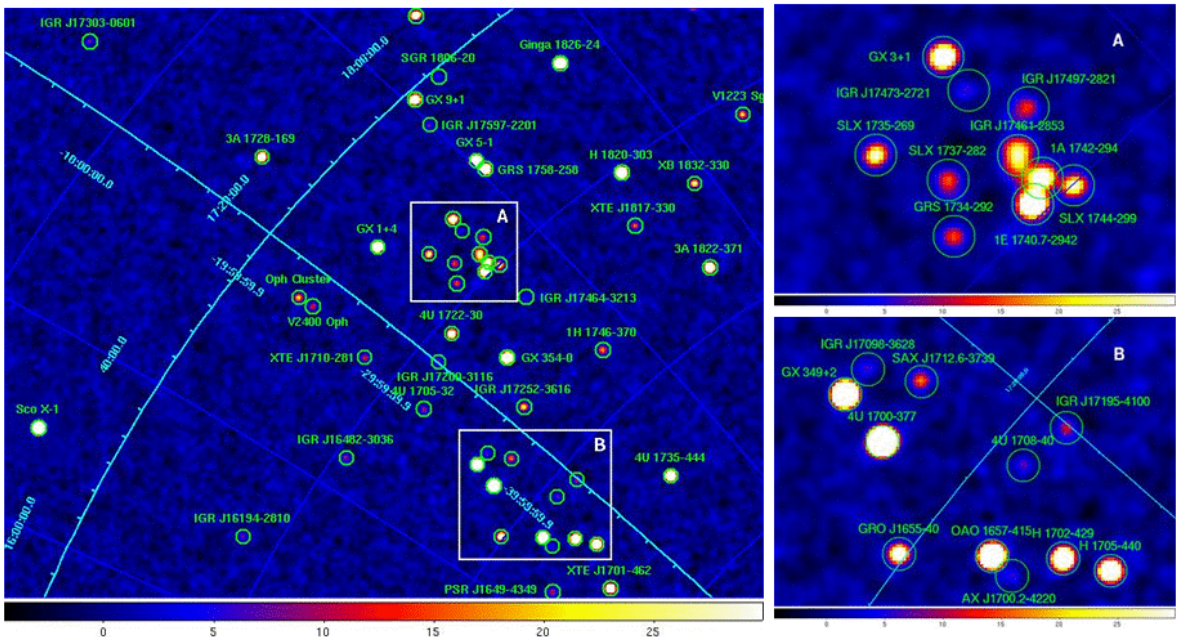
The Swift Observatory

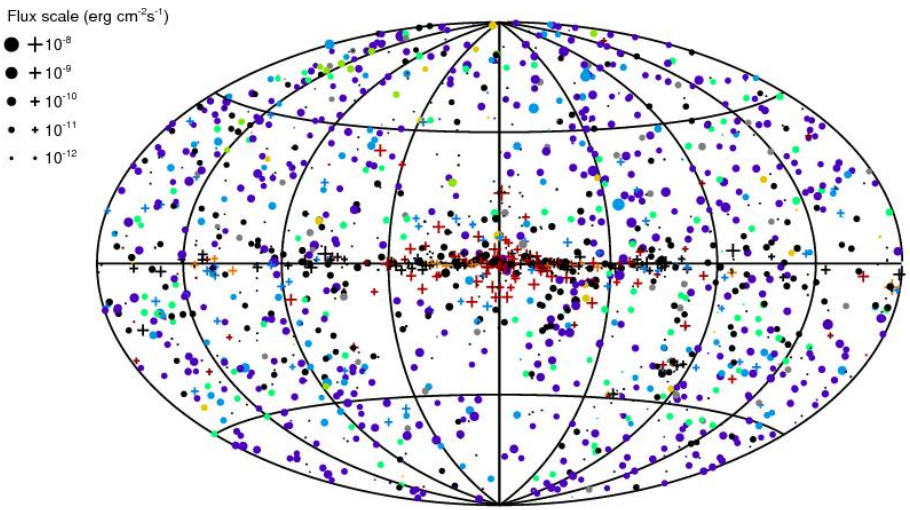
Burst Alert Telescope (BAT)
- coded mask telescope
- 17 arcmin PSF (FWHM)
- 1.4 sr field of view (~20% of the sky)
- 15-150 keV
- 50-100 pointings per day
- 300 s temporal resolution (survey mode)



BAT Palermo Catalogue

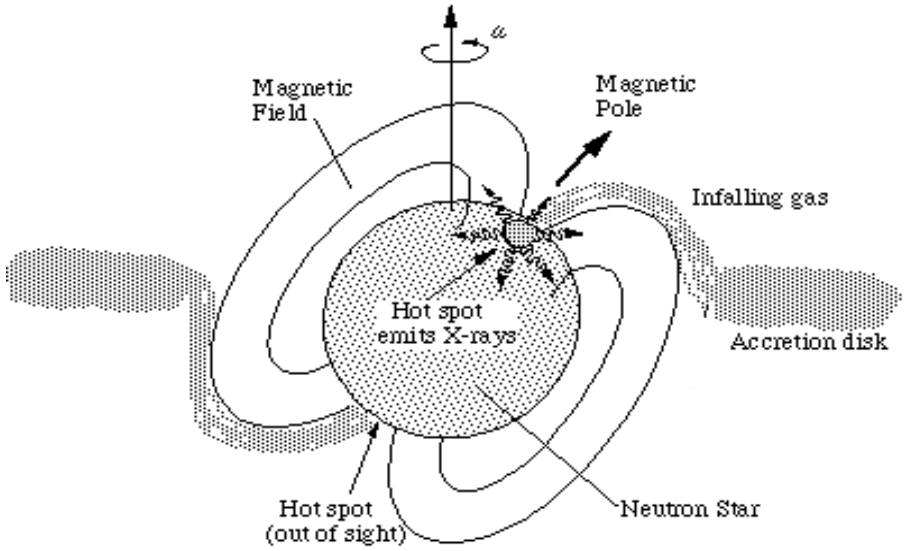
BAT_Imager: software of data reduction and scientific product generation dedicated to coded mask telescope (**Segreto et al. 2010**)

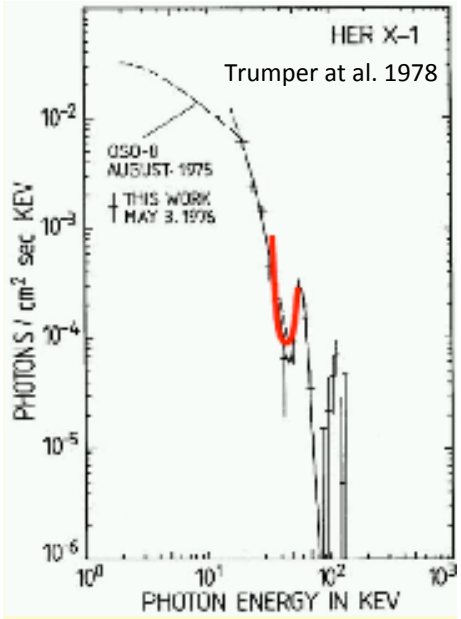




The 100-month BAT catalogue includes more than 1700 sources

Cyclotron lines in accreting neutron stars





- In the presence of a strong magnetic field the accreting material is channeled along the field lines.
- The energy of the plasma electrons traveling along the magnetic field is quantized according to the Landau levels.
- Photons may undergo resonant scattering off these electrons, producing a characteristic absorption feature in the spectrum emitted by the NS.
- The energy of the fundamental line and the spacing between the harmonics are approximately proportional to the strength of the magnetic field in the region where the line forms.

$E_{cyc} = 11.6\ B\ (10^{12}\ G)\ (1+z)^{-1}\ keV$

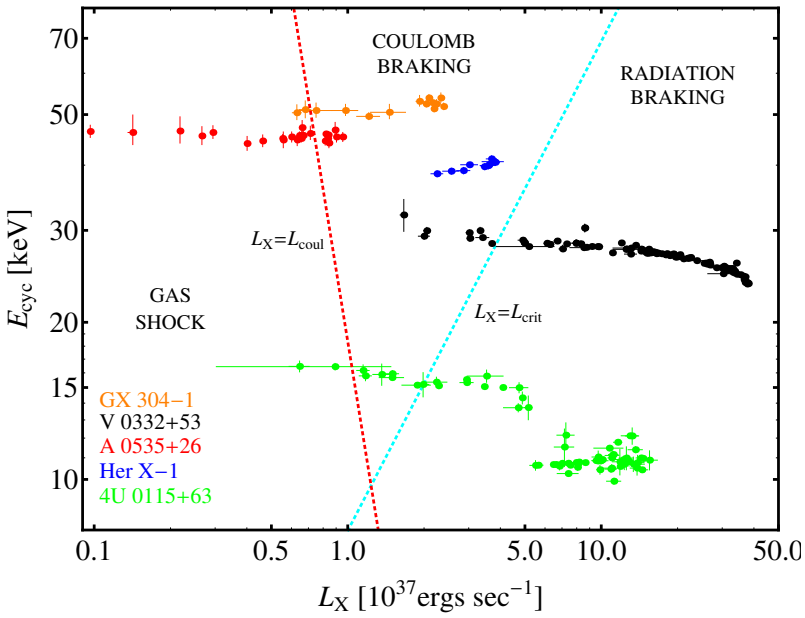
Cyclotron lines in accreting neutron stars

Cyclotron lines observed in ~25 HMXB (Revnivtsev et al. 2015)
B ranges between 0.9 10^{12} G (Swift J1626.6-5156) and 6.7 10^{12} G (GRO J1008-57)

<u>Significant variability of CRFS energy with luminosity</u>

HMXB seems to be divided into two groups (positive correlation and negative correlation)

Becker et al. 2012



Hypothesis: different behaviour could reflect different accretion regime

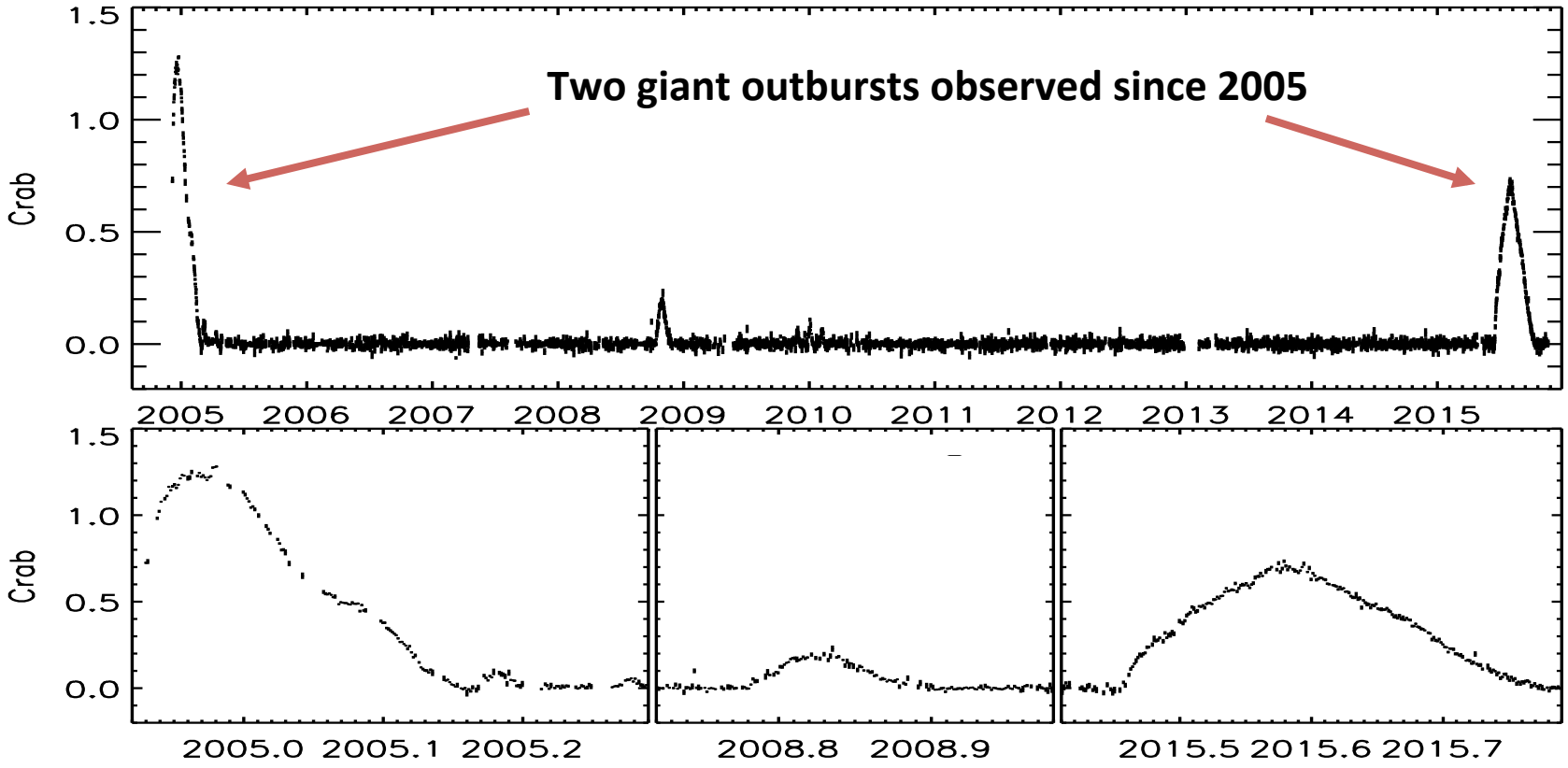
-- deceleration of the plasma to rest dominated by radiation pressure (**negative** correlation)
→ the line forming region moves **upward** with increasing luminosity

-- deceleration dominated by Coulomb interaction (**positive** correlation)
→ the line forming region moves **downward** with increasing luminosity

V0332+53

P_{spin} = 4.4 s
P_{orb} = 34 d
L_x = Transient 10^{38} erg s^{-1}

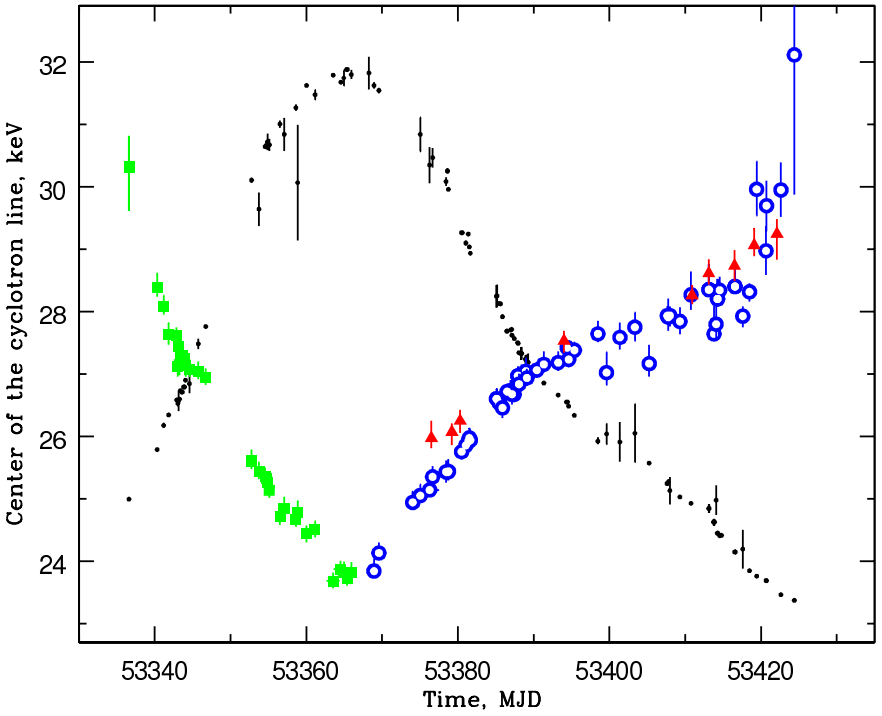
BAT light curve

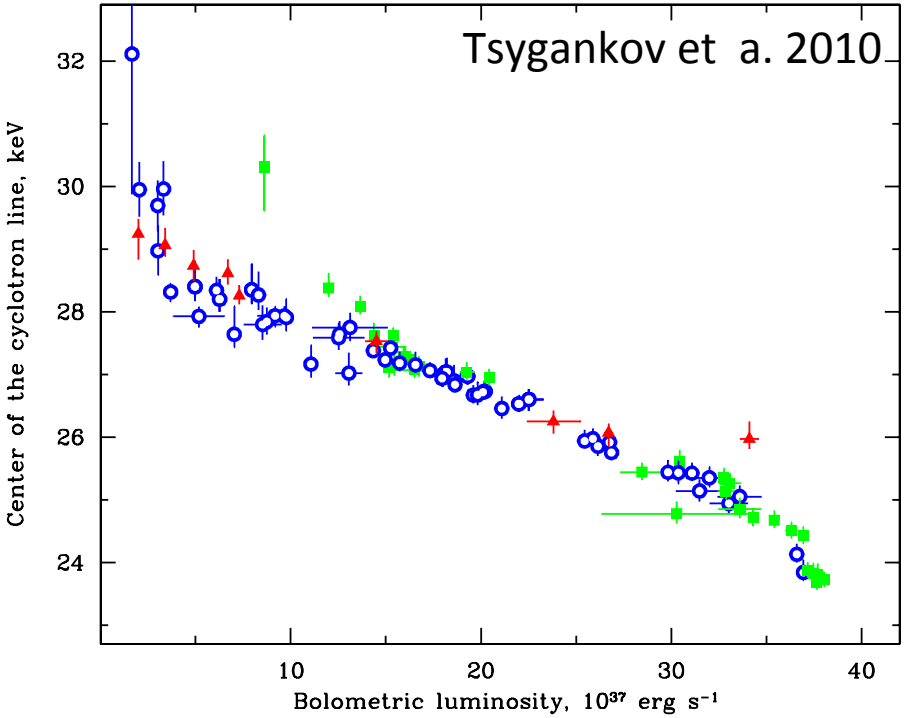


V0332+53

The 2005 outburst

Negative correlation E_{cycl} [keV]≃−0.143(±0.002) L_{37}+29.56(±0.03) (Tsygankov et al. 2010)





RXTE (green and blue) and INTEGRAL (red) results show that the linear trends E_{cyc} vs L_x in the rising and in the fading part of the 2005 outburst are consistent.

V0332+53

The 2015 outburst

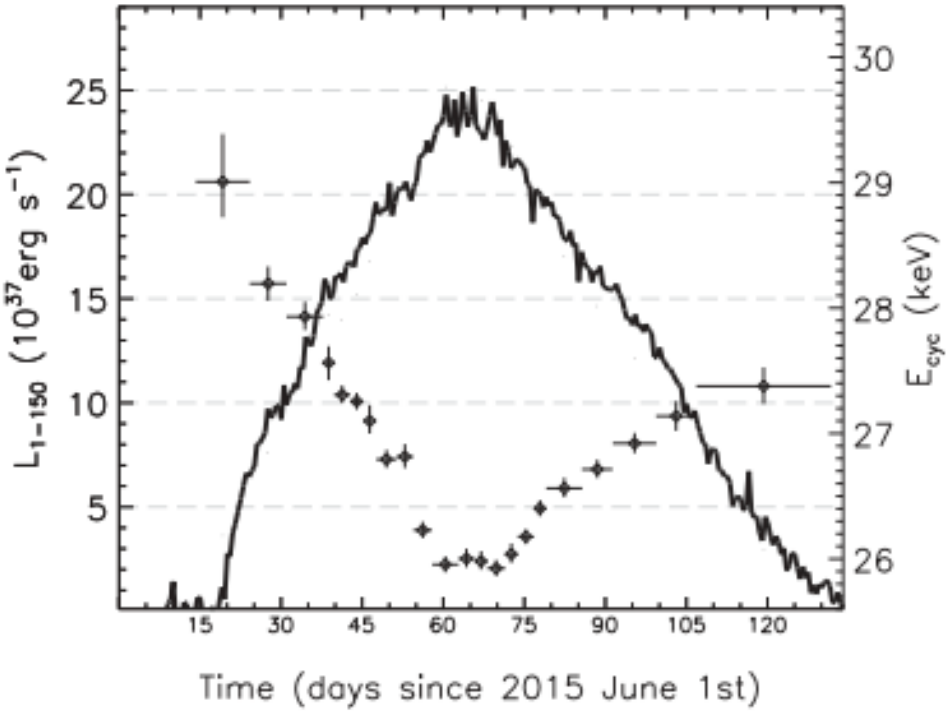
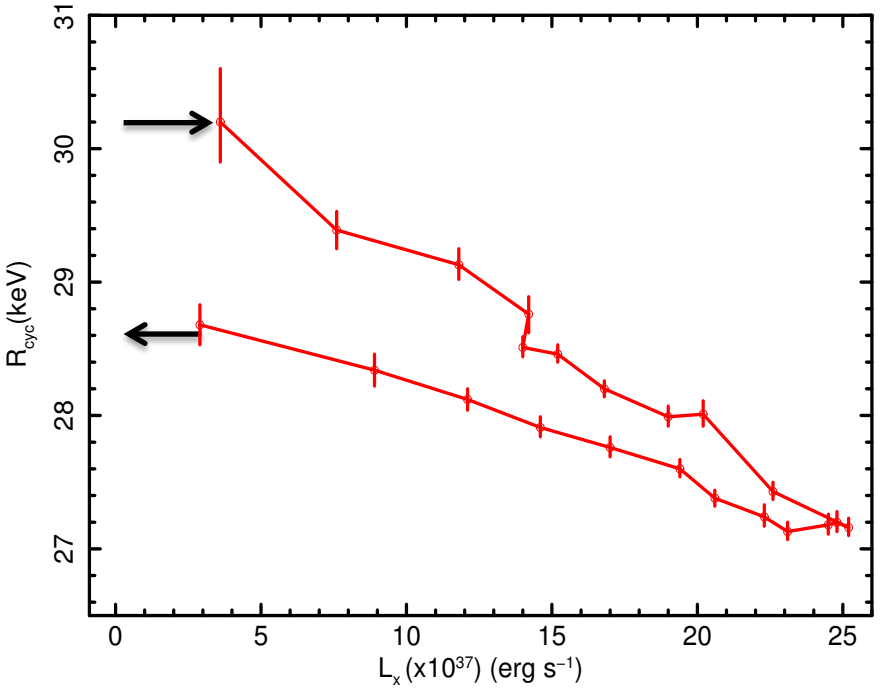


Figure 1. Temporal evolution of the X-ray luminosity (left axis, solid line) and of the energy of the CRSF fundamental line (right axis, diamond points)

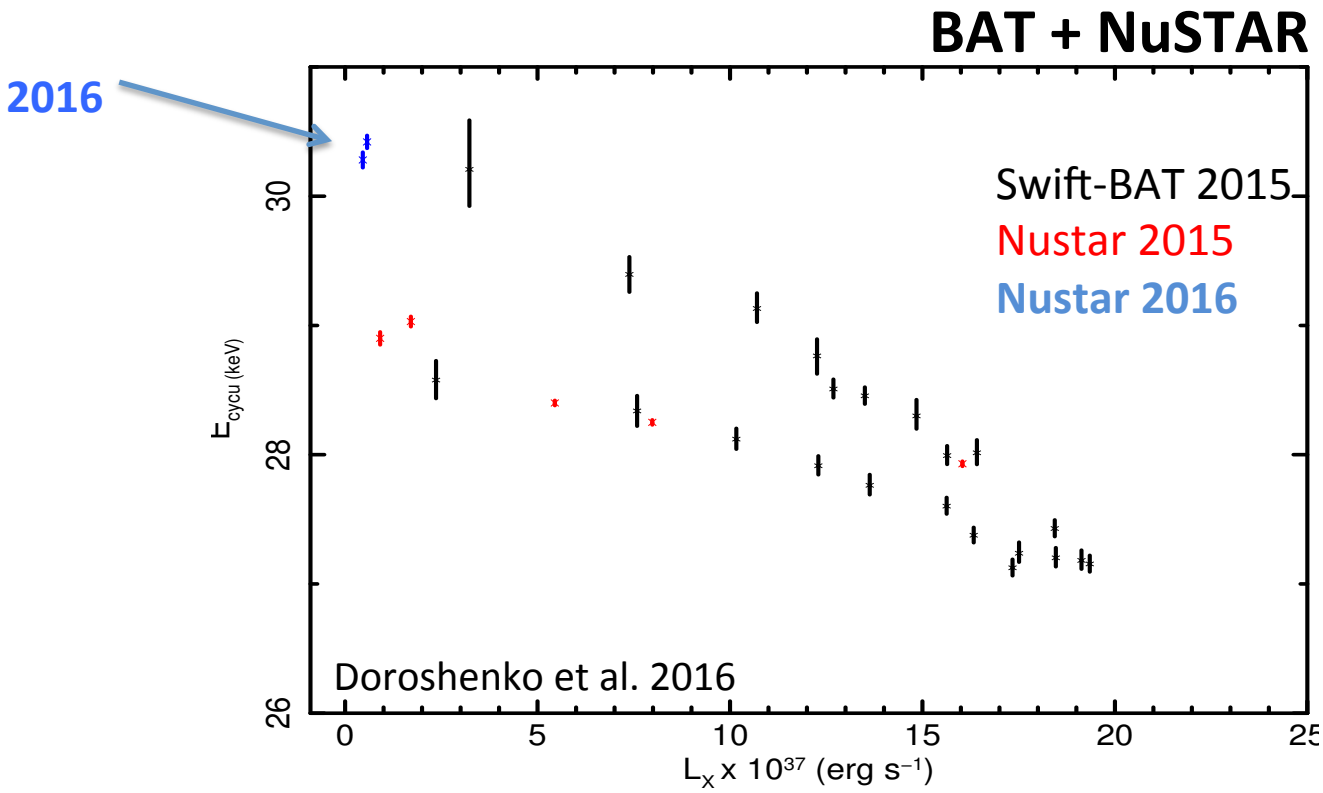
Cusumano et al. 2016



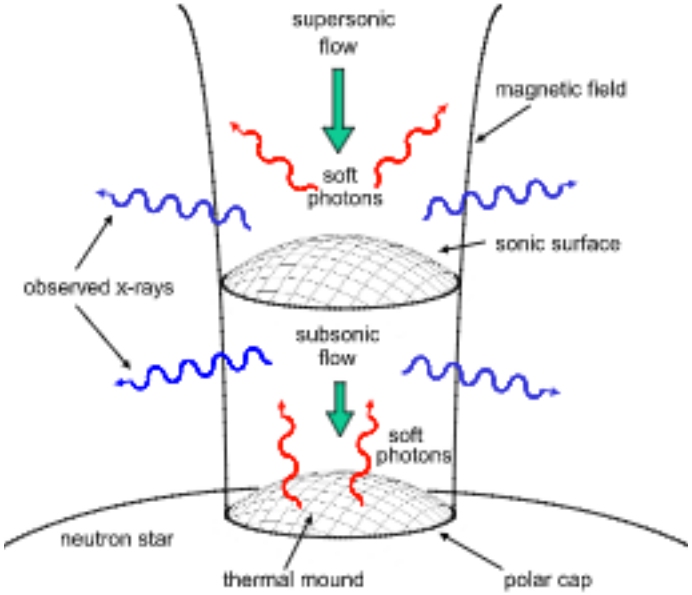
The energy of the cyclotron line does not follow the same path: lower values in the declining phase with respect to the rising phase. At the end of the outburst we have a drop in the energy of the line of 1.5 keV or a "drop" of ~1.7 × 10^{11} G of the observed B field.

V0332+53

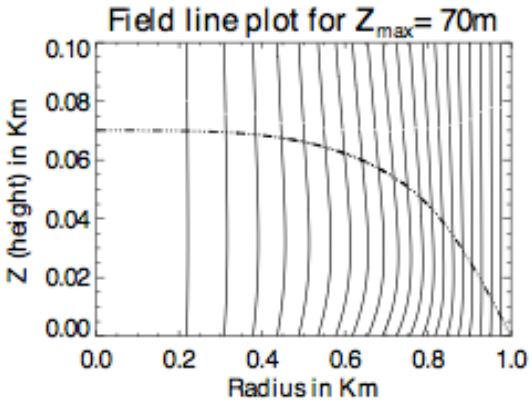
The 2015 outburst and beyond

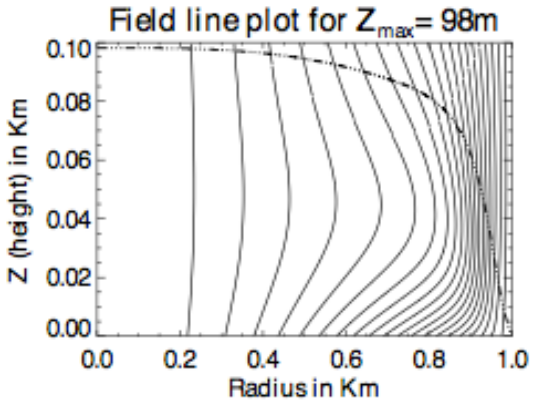


5 NuSTAR pointed observations (red points) have confirmed the Ecyc behaviour during the 2015 outburst. Two new observations in 2016 , during periastron passage of V0332+53, have shown that the Ecyc has recovered its pre-outburst position in the spectrum.



Becker & Wolf 2007

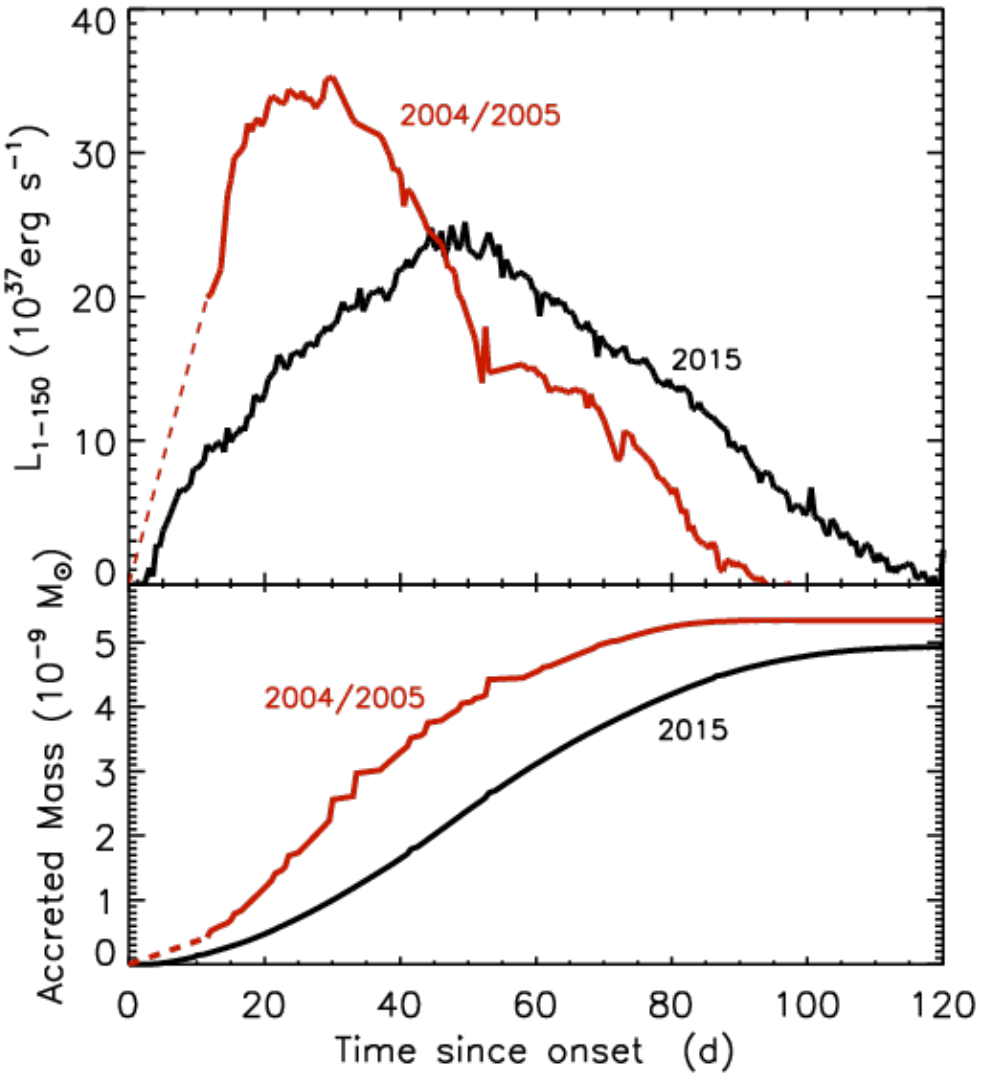




Bhattacharya & Mukherjee 2011

Accreting matter may accumulate onto the polar cap forming a magnetically confined mound, where the gas pressure balances the magnetic stresses. This would produce a **distortion** of the field lines (Brown & Bildstein 1998, …., Bhattacharya & Mukherjee 2011, …….) dependent on the height of the mound and a decrease of the field component along the accretion column.

V0332+53

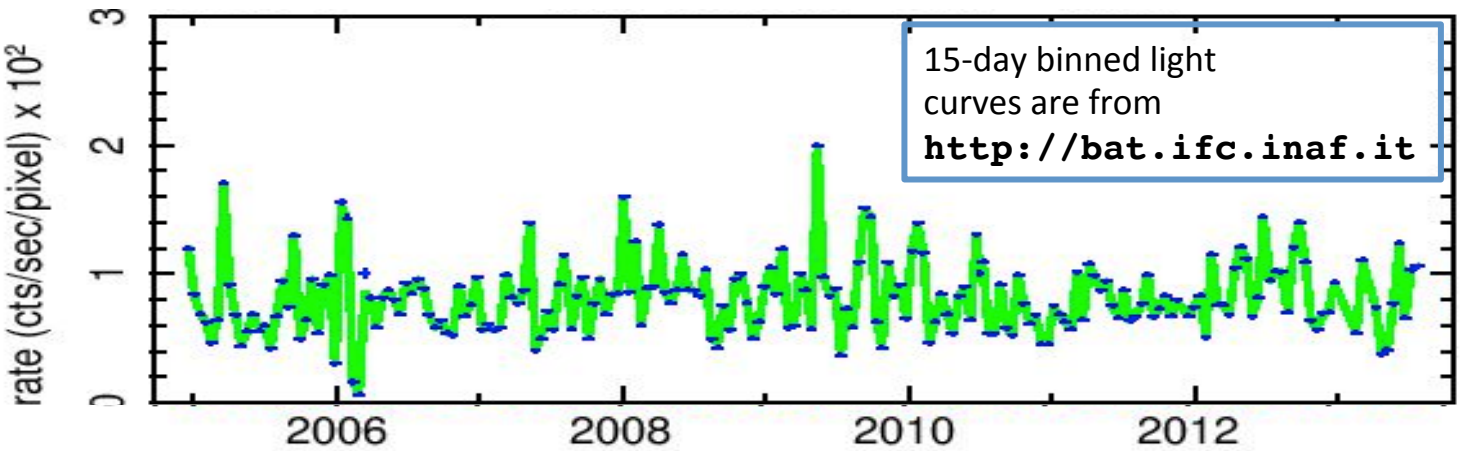


Higher peak luminosities, the magnetic polar cap is larger and the field at its border is weaker, preventing the gas confinement.

OR

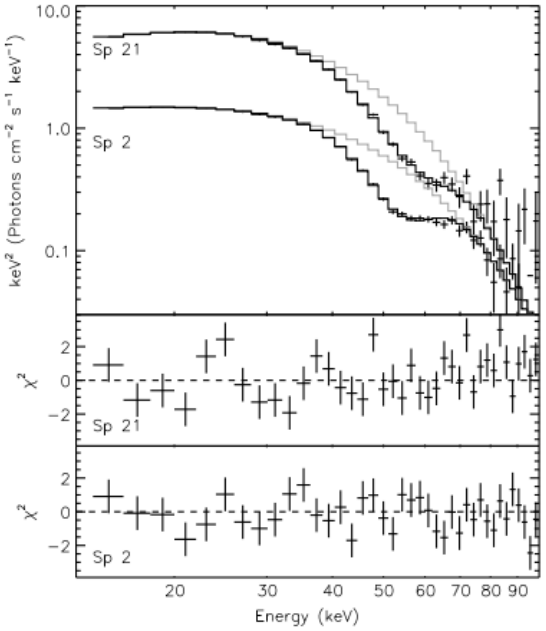
The mound may have formed at an early stage of the outburst, reaching in a short time the maximum size for a stable structure. After that, an equilibrium was reached where the plasma settling on the mound was balanced by the matter leaking out from the mound.

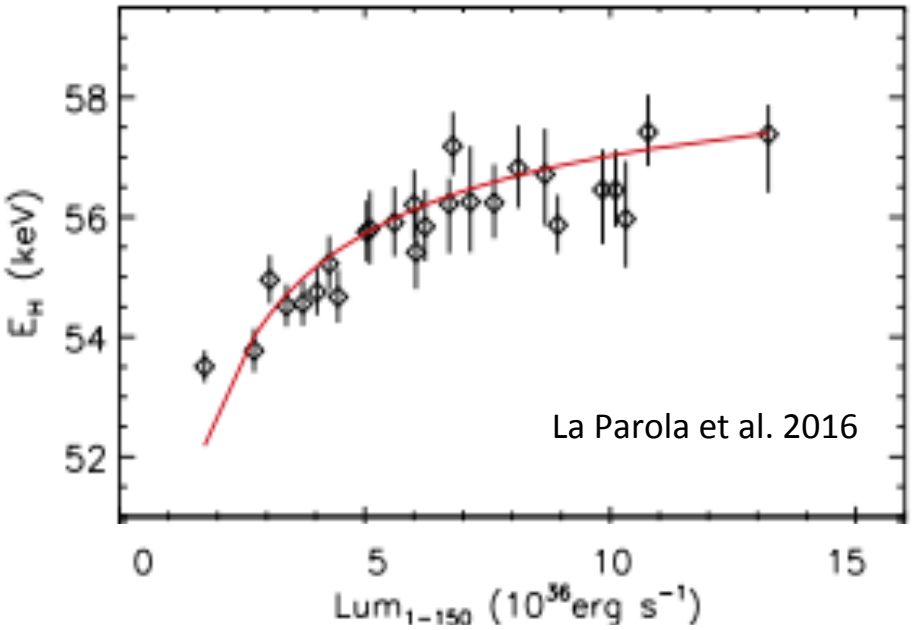
Vela X-1



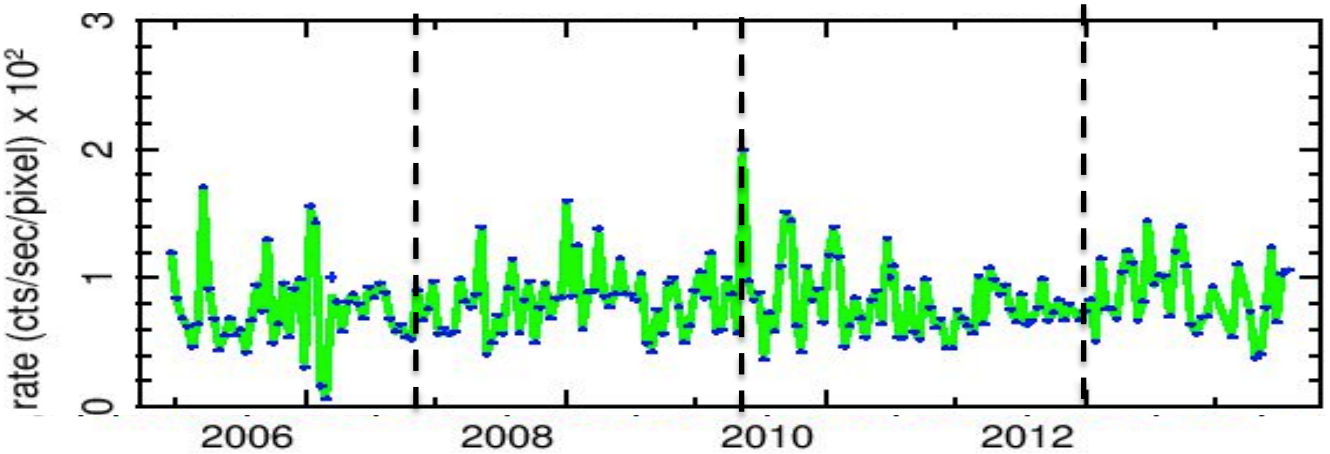
P_{spin} = 283 s
P_{orb} = 8.9 d
L_x = 5 10^{36} erg s^{-1}

La Parola et al. 2016





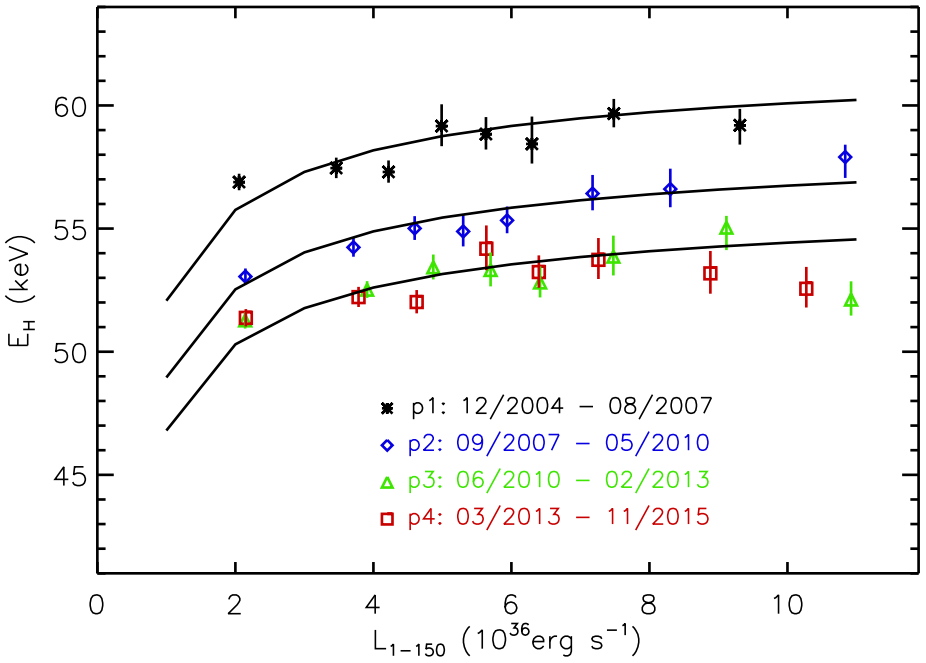
Vela X-1



La Parola et al. 2016

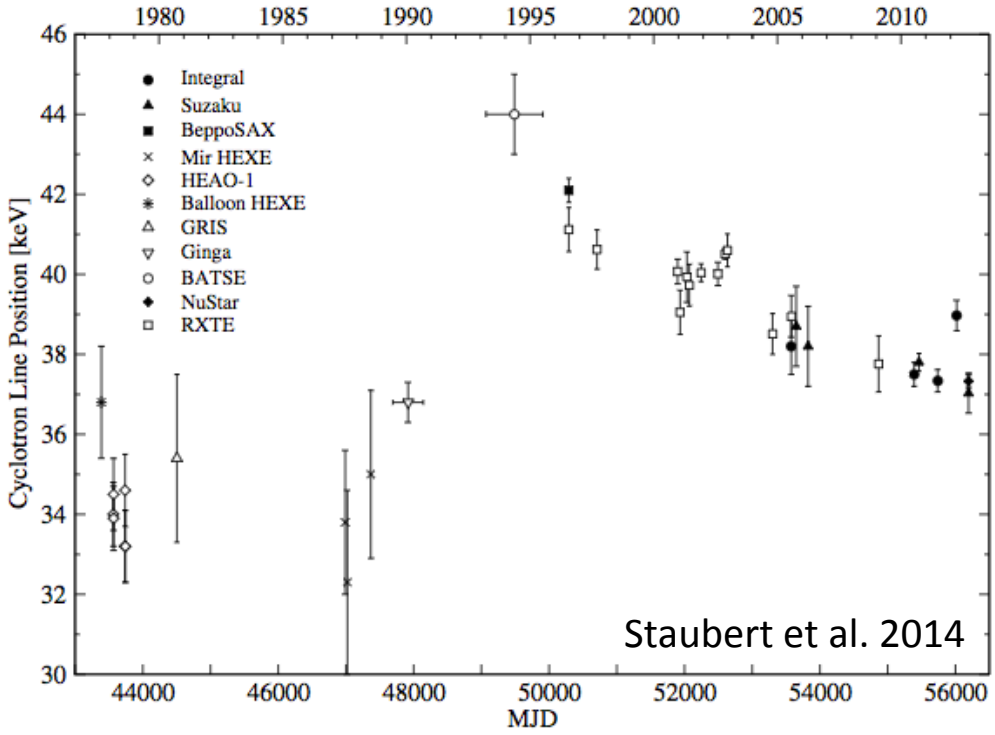
Long term variation in the CRSF of Vela X-1

The CRSF second harmonic energy decreases by ~0.36 keV/year between the first and the third time interval, corresponding to an apparent decay of the magnetic field of ~3×10^{10} G/year.



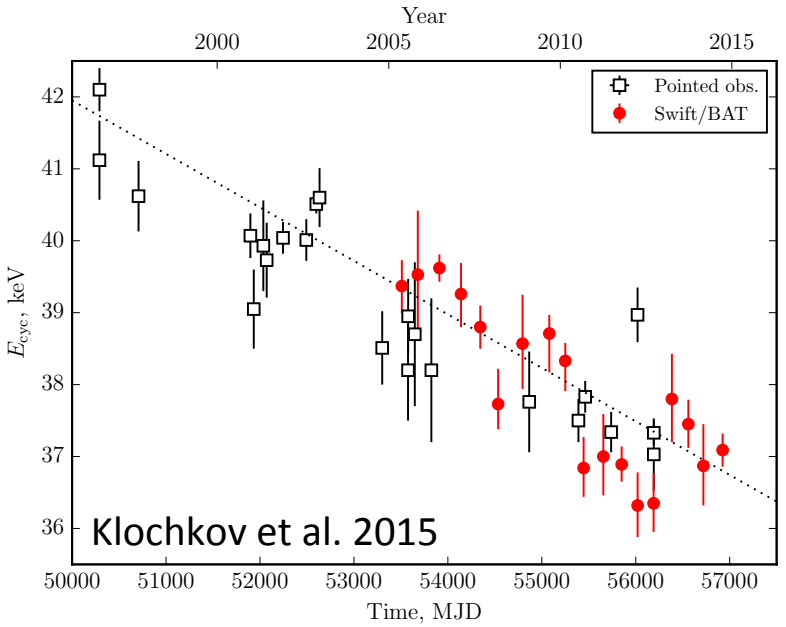
Her X-1

A long term variation of the cyclotron energy



After a strong upward jump in the early 1990s, the cyclotron line energy has gradually decreased by ~4.5 keV along the 19 years from 1996 to 2015. This trend was unveiled by using the results from many different telescopes.

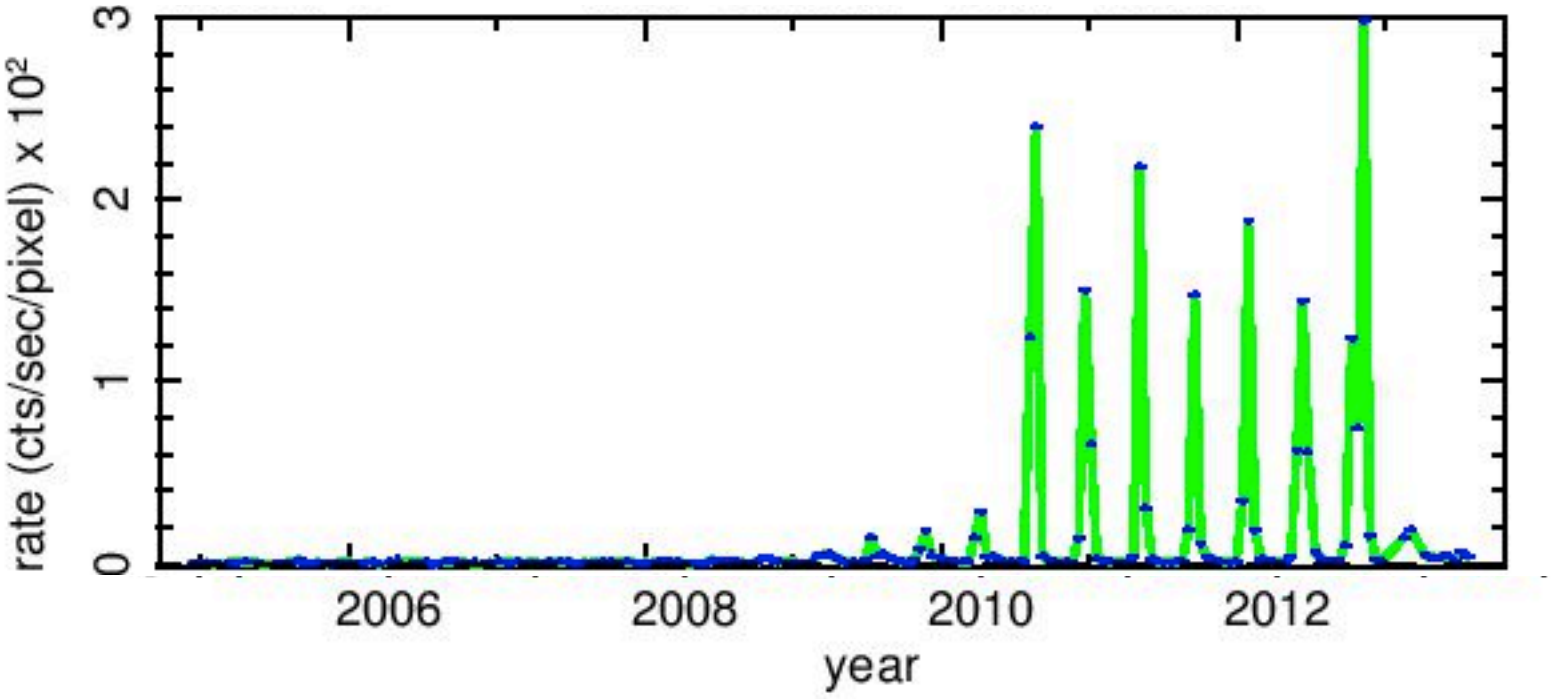
The analysis of the archival Swift/BAT observations from 2005 to 2014 confirms this trend .



GX 304-1

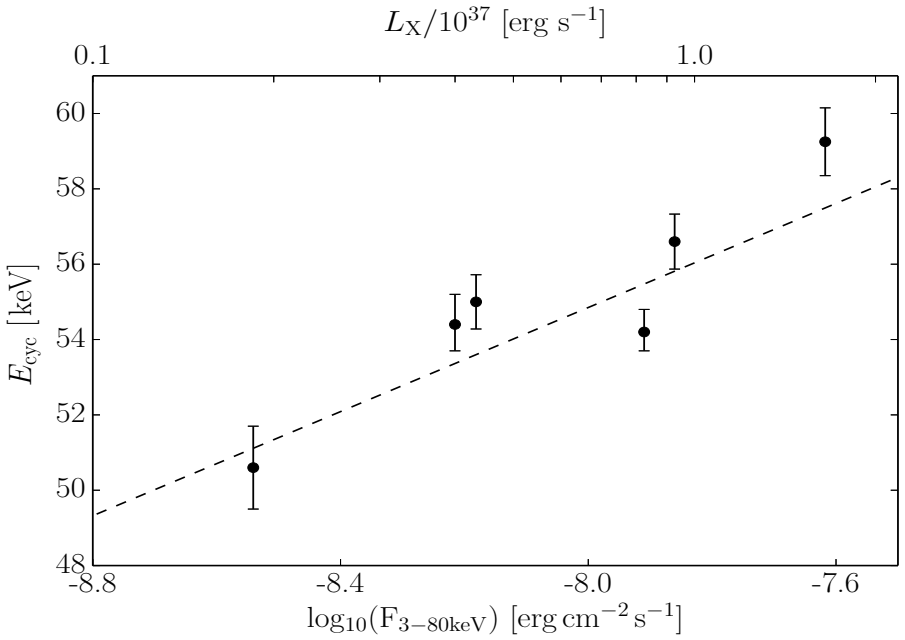
P_{spin} = 272 s
P_{orb} = 132.5 d
Ecyc ~52 keV

In a quiescent state since 1980, the source resumed its outburst activity after 2008



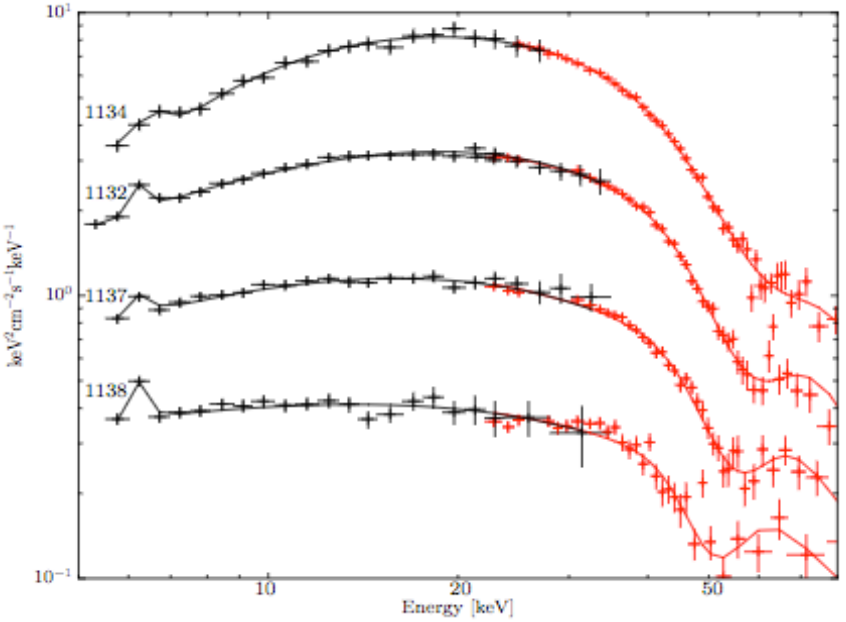
GX 304-1

INTEGRAL results on the January 2012 outburst (Malacaria et al 2015)



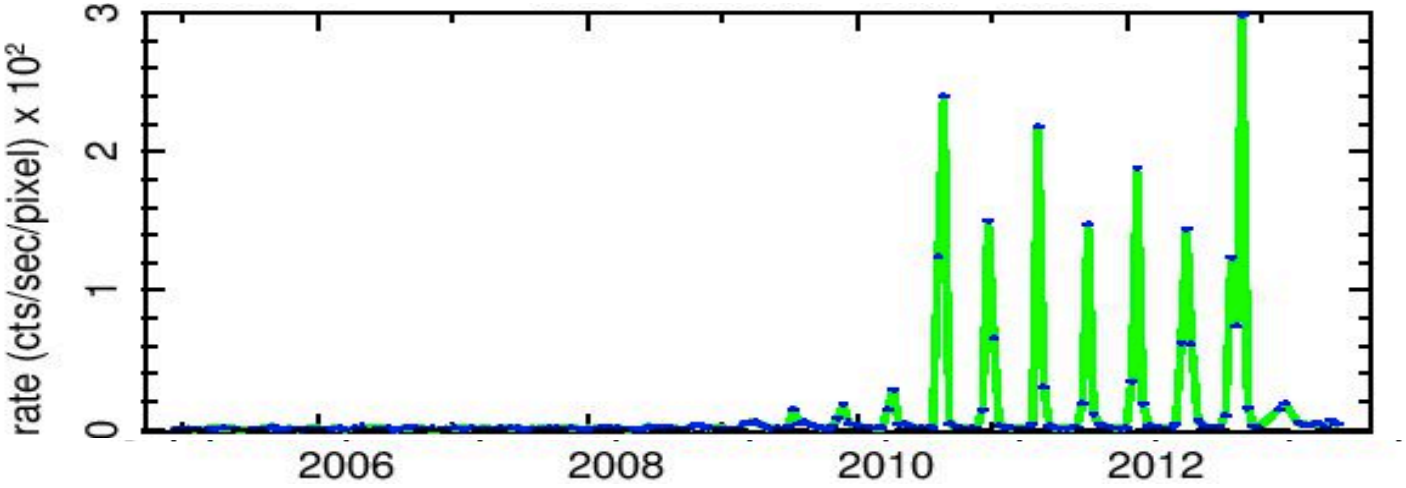
Cyclotron line centroid energy as a function of the logarithm of flux in the 3-80 keV range.

The slope of the correlation is 6.51 keV/$\log_{10}$

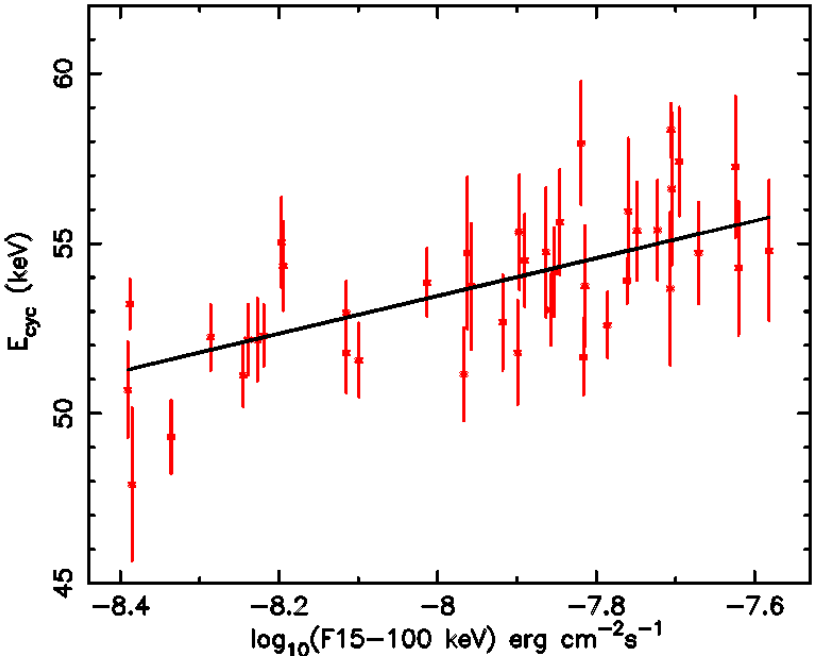


Phase averaged spectra of four INTEGRAL observation. JEM-X1 (black) and ISGRI (red)

GX 304-1

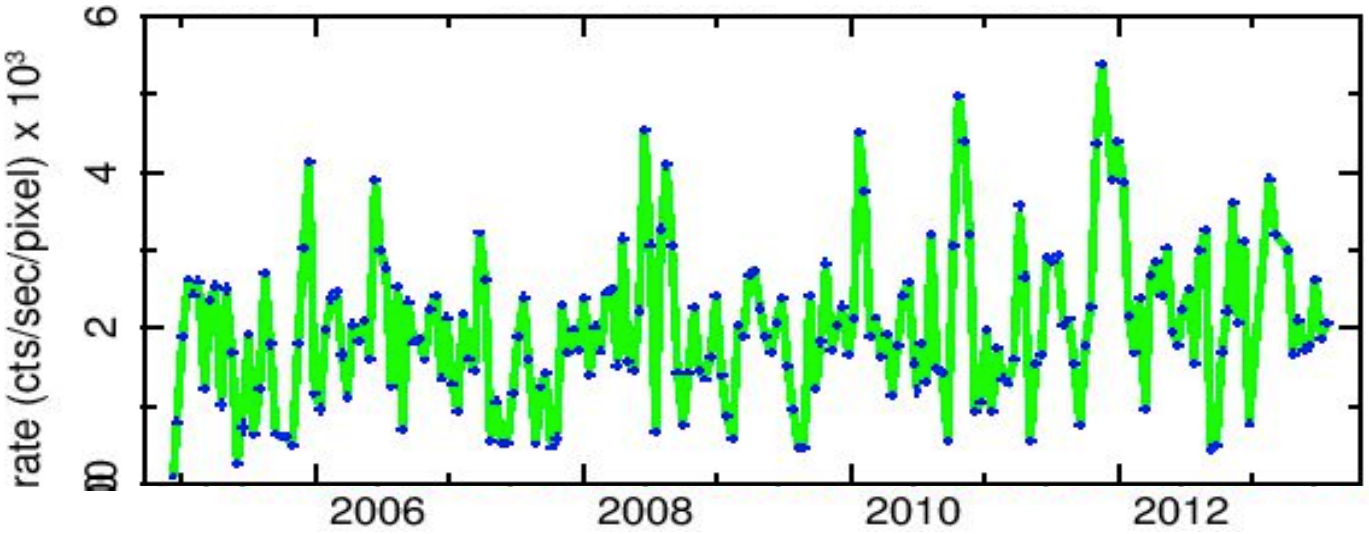


The analysis of the BAT spectra collected during the major outbursts observed between 2010 and 2013 confirm the positive correlation

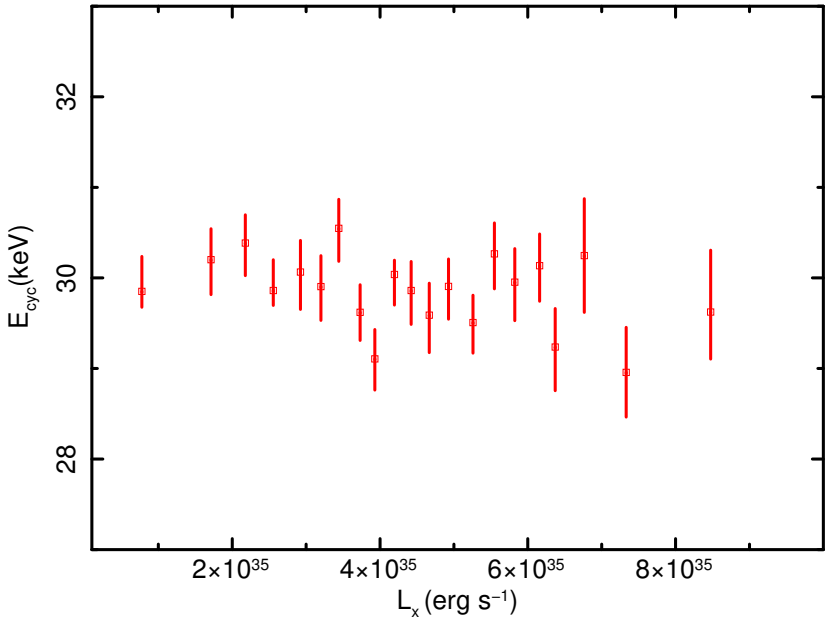


PRELIMINARY

Cen X-3

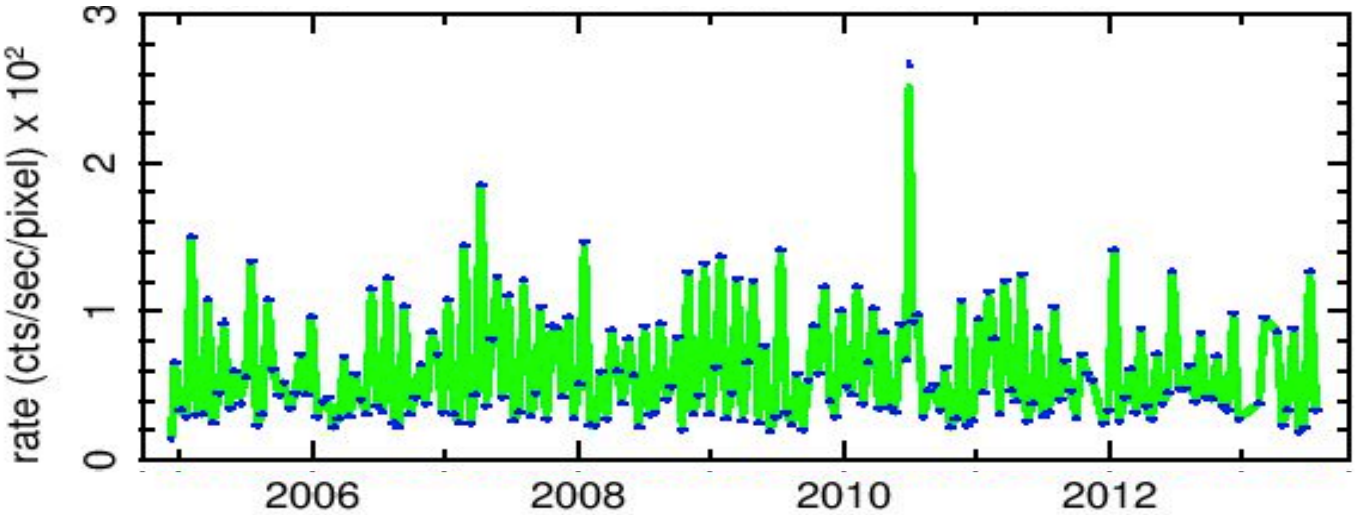


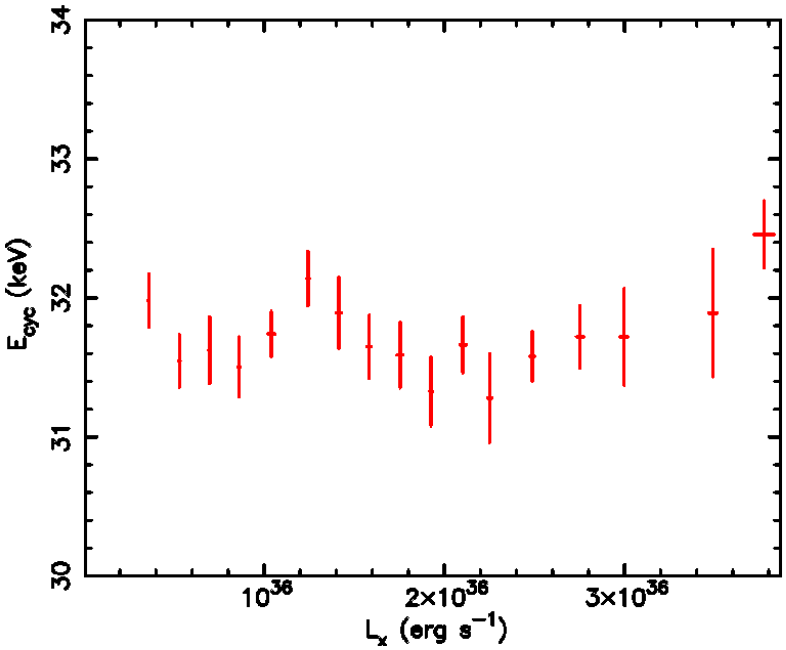
The BAT observations of Cen X-3 do not reveal any clear evidence of correlation between E_{cyc} and L_x



PRELIMINARY

GX 301-2





The BAT observations of GX 301-2 do not reveal any clear evidence of correlation between E_{cyc} and L_x

PRELIMINARY

Conclusion

The BAT survey data can be exploited for detailed study of cyclotron line features in several accreting neutron star.

BAT unveils a very diversified picture of the cyclotron line behaviour in accreting NS

- a bi-modal correlation of the line energy with the luminosity is observed in several sources
- some sources show a long term drift of the cyclotron line energy
- Other sources do not show any significant correlation of the line energy with time or luminosity

NEW RESULTS

V 0332+53 → a drop in the cyclotron line energy between the beginning and the end of the 2015 outburst, followed by a recovery in the following months: the first observation of an hysteretic behaviour

Vela X-1 → a long time evolution of the cyclotron line energy