Change in the cyclotron line energy of A0535+26 during its August/September 2005 outburst

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Five Years of INTEGRAL - Sardinia
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Outline

1. Introduction and first results
2. Latest results
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A0535+26

Transient Be/X-ray binary

- Type II outbursts (giant), $L_X > 10^{37}\mathrm{ergss}^{-1}$
- Type I (normal), associated with periastron, $L_X \sim 10^{36-37}\mathrm{ergss}^{-1}$
- quiescence states, persistent low luminosity, $L_X \lesssim 10^{36}\mathrm{ergss}^{-1}$

Discovered in 1975 during a giant outburst (Rosenberg et al. 1975)

Neutron star

- $R \sim 10\mathrm{km}$, $M \sim 1.4\mathrm{M}_\odot$
- $P_{spin} \sim 103\mathrm{s}$
- $B \sim 4 \times 10^{12}\mathrm{G}$

HDE 245770 - O9.7, IIIe

- $14\mathrm{M}_\odot$, $14\mathrm{R}_\odot$
- $1.41\mathrm{L}_\odot$
- $T_{eff} = 26000\mathrm{K}$

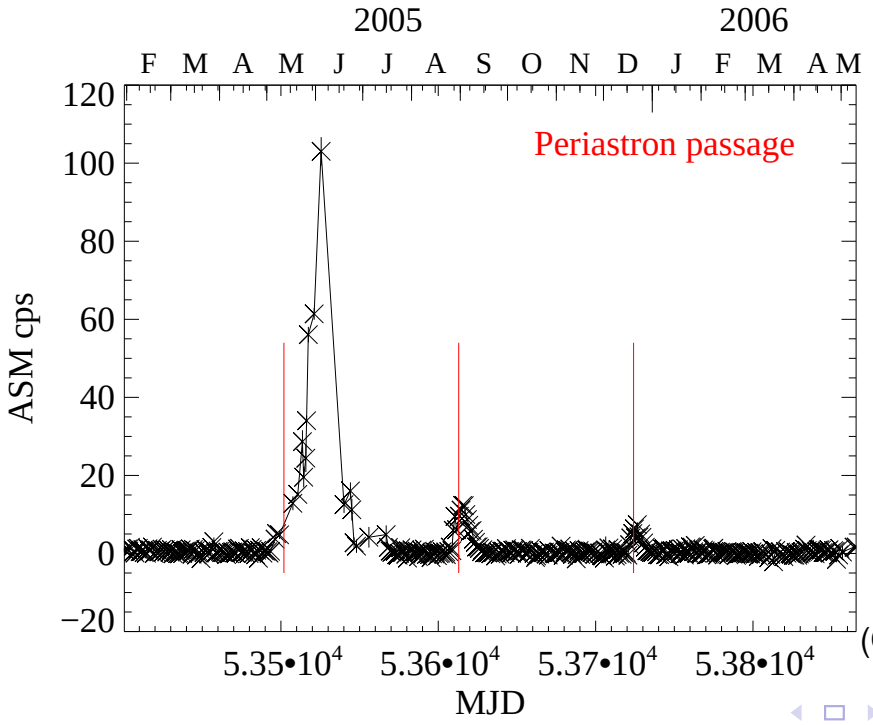
- $P_{orb} = 111\mathrm{days}$, $e = 0.47$
- $d \sim 2\mathrm{kpc}$

Review: Giovannelli & Graziati 1992

Transient Source

From 1994 until 2005 it has been in quiescence.

- May/June 2005: giant outburst, $L_{(15-195\mathrm{keV})} \sim 4.8 \times 10^{37}\mathrm{ergss}^{-1}$ (Tueller et al. 2005)
- Aug/Sept 2005: normal outburst, $L_{(15-195\mathrm{keV})} \sim 0.6 \times 10^{37}\mathrm{ergss}^{-1}$
- December 2005: normal outburst $L_{(15-195\mathrm{keV})} \sim 0.2 \times 10^{37}\mathrm{ergss}^{-1}$



(Caballero et al. 2007)

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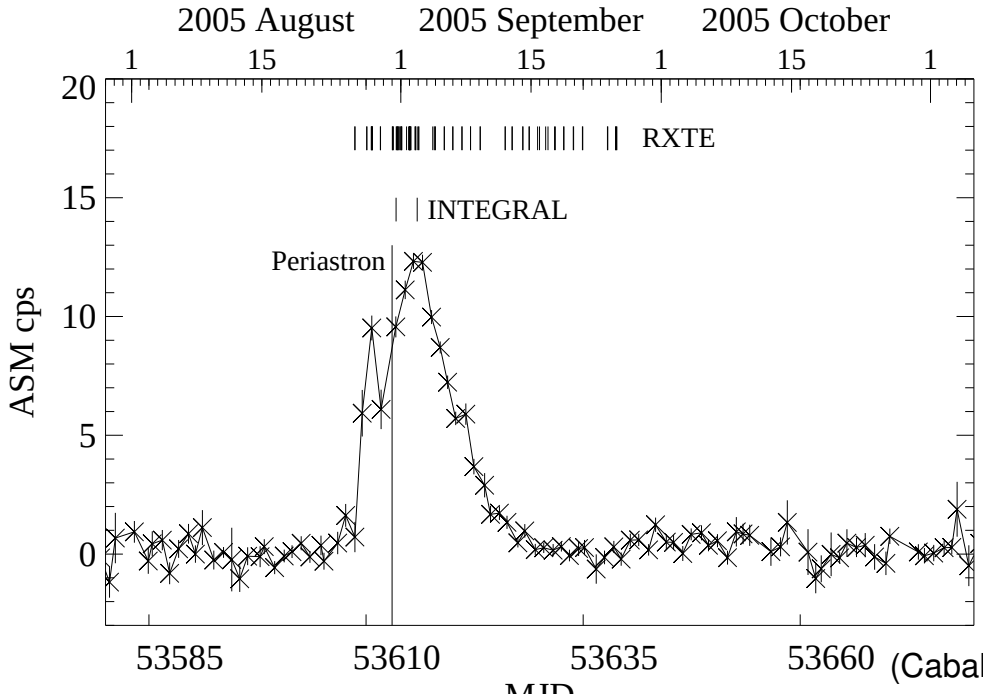
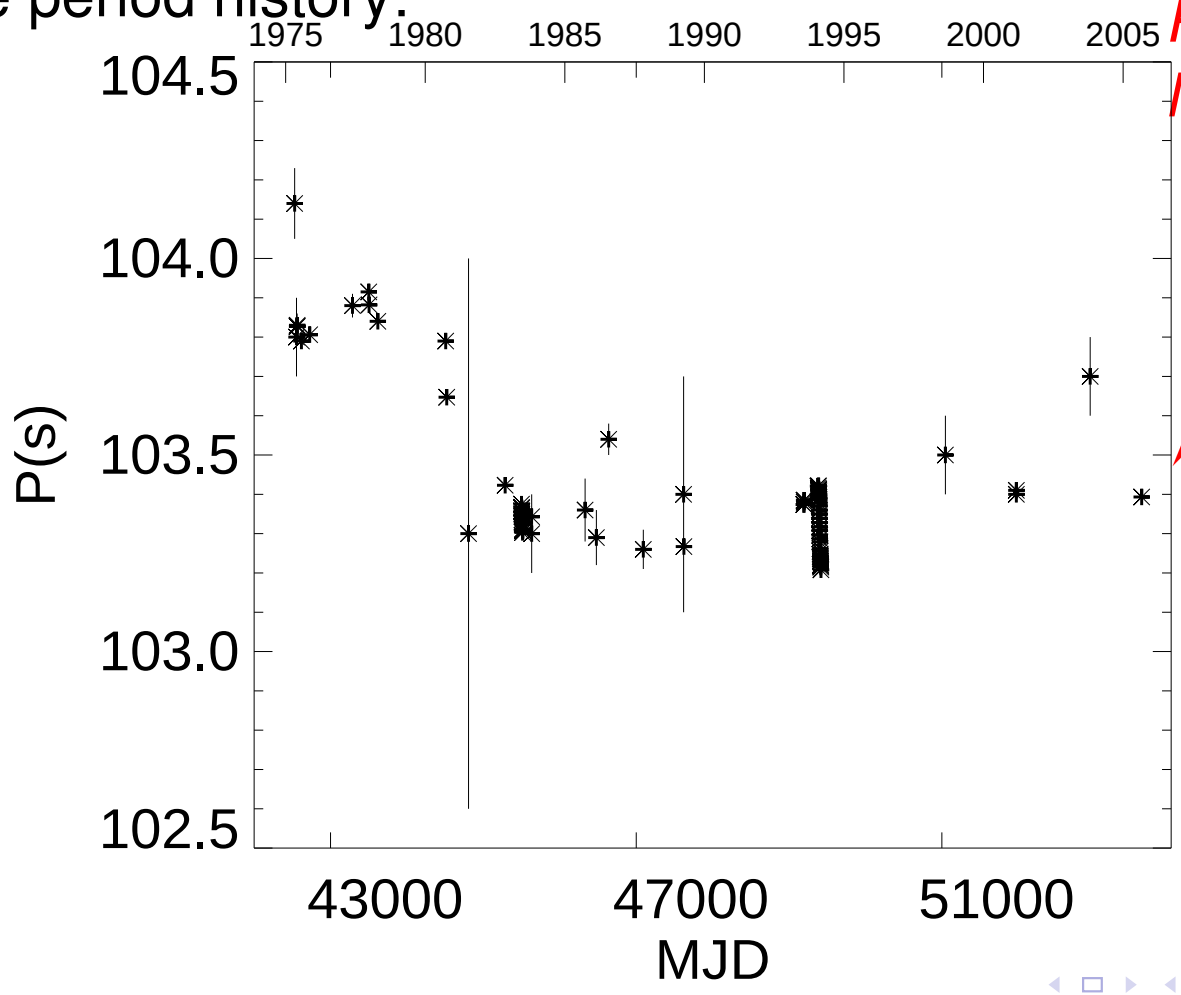


(Caballero et al. 2007)

Timing analysis with INTEGRAL

Pulse period determined with high accuracy using IBIS-ISGRI data.

Pulse period history:



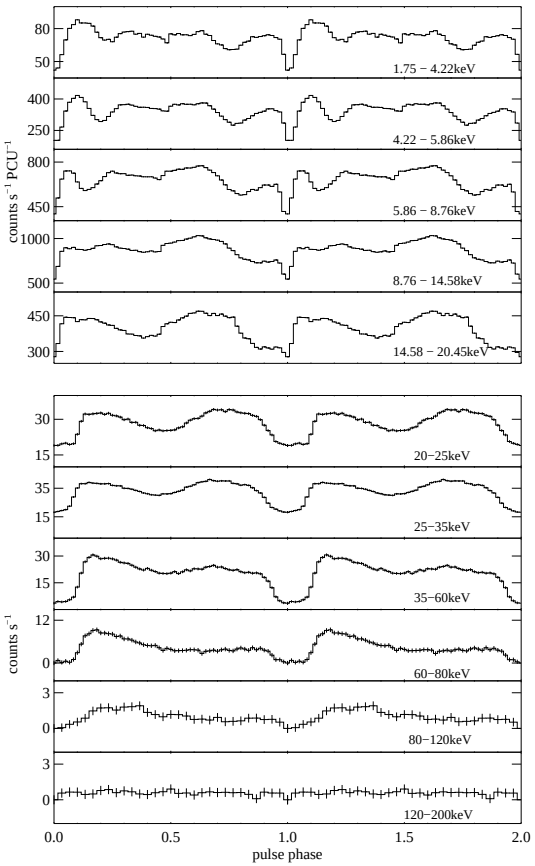
$P = 103.39315(5)$ at $MJD53614.5137$

(Fig. Caballero et al. 2006, updated with value from Hill et al. 2007)

Pulse profiles

Pulse profiles consistent with profiles from past outbursts

Aug/Sep 2005 normal outburst
$L(23-53\mathrm{keV}) \sim 0.23 \times 10^{37}\mathrm{ergs}^{-1}$



PCA 1.75 – 4.22keV

PCA 4.22 – 5.86keV

PCA 5.86 – 8.76keV

PCA 8.76 – 14.58keV

PCA 14.58 – 20.45keV

ISGRI 20 – 25keV

ISGRI 25 – 35keV

ISGRI 35 – 60keV

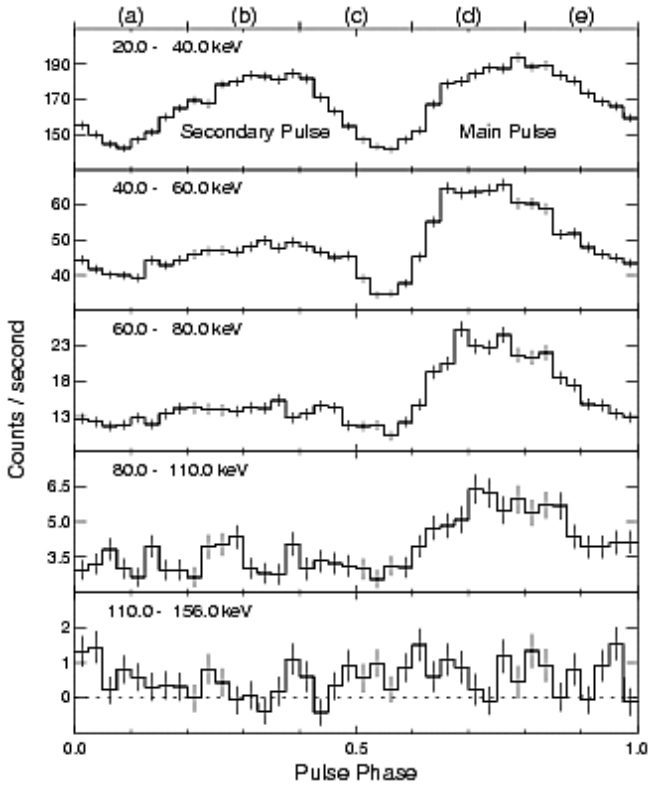
ISGRI 60 – 80keV

ISGRI 80 – 120keV

ISGRI 120 – 200keV

(Caballero et al. 2007)

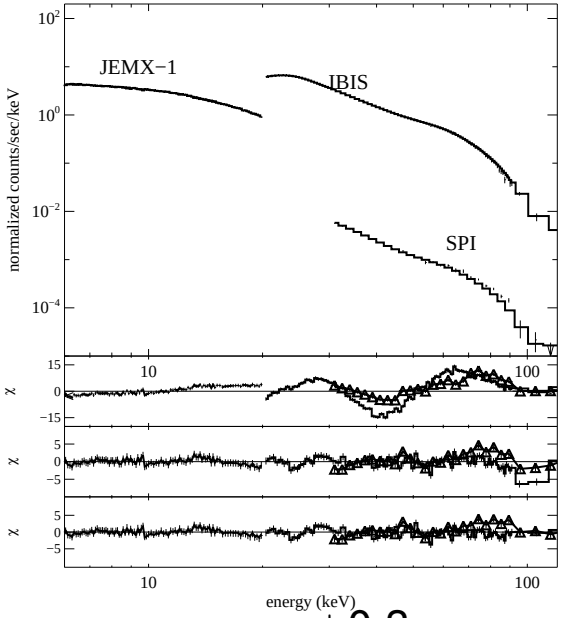
March/April 1989 giant outburst
$L(23-53\mathrm{keV}) \sim 1.26 \times 10^{37}\mathrm{ergs}^{-1}$
TTM/HEXE observations

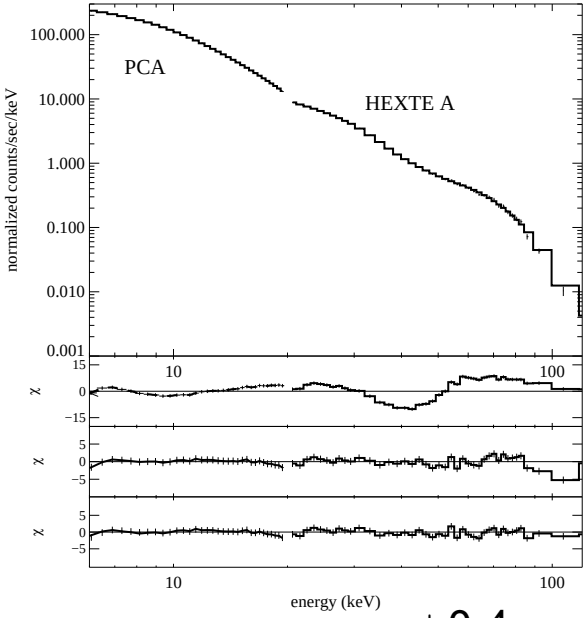


(Kendziorra et al. 1994)

Confirmation of two cyclotron lines at 45keV, 100keV

⋆ March/April 1989 giant outburst TTM/HEXE observations
$E_1 \sim 45\mathrm{keV}$, $E_2 \sim 100\mathrm{keV} \Rightarrow B \sim 4 \times 10^{12}\mathrm{G}$ (Kendziorra et al. 1994)
⋆ February 1994 giant outburst OSSE observations $E_1 \sim 100\mathrm{keV}$
$\Rightarrow B \sim 10^{13}\mathrm{G}$ (Grove et al. 1995)
⋆ August/September 2005 normal outburst:





$$E_{cyc} = 11.6\mathrm{keV} B \times 10^{12}\mathrm{G}$$
$$\Rightarrow B \sim 4 \times 10^{12}\mathrm{G}$$

(Caballero et al. 2007)

$E_1 = 45.9^{+0.3}_{-0.3}$ keV
$E_2 = 102^{+4}_{-3}$ keV

$E_1 = 45.9^{+0.4}_{-0.3}$ keV
$E_2 = 103^{+3}_{-3}$ keV

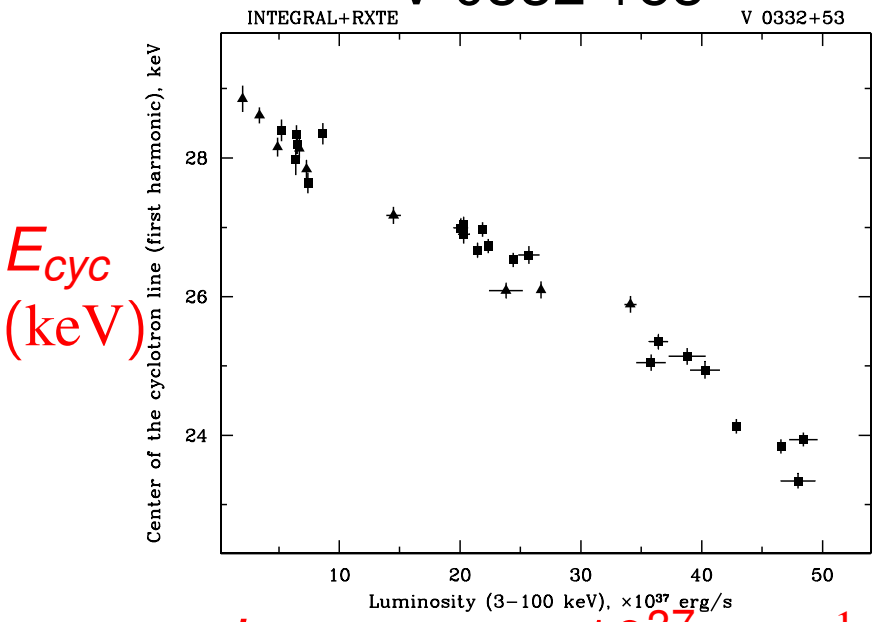
Cyclotron line evolution with luminosity

Super-Eddington regime
High accretion rates
Shock formation in accretion column
Height of schock $\propto \dot{m}$

Sub-Eddington regime
Low accretion rates
No shock is formed

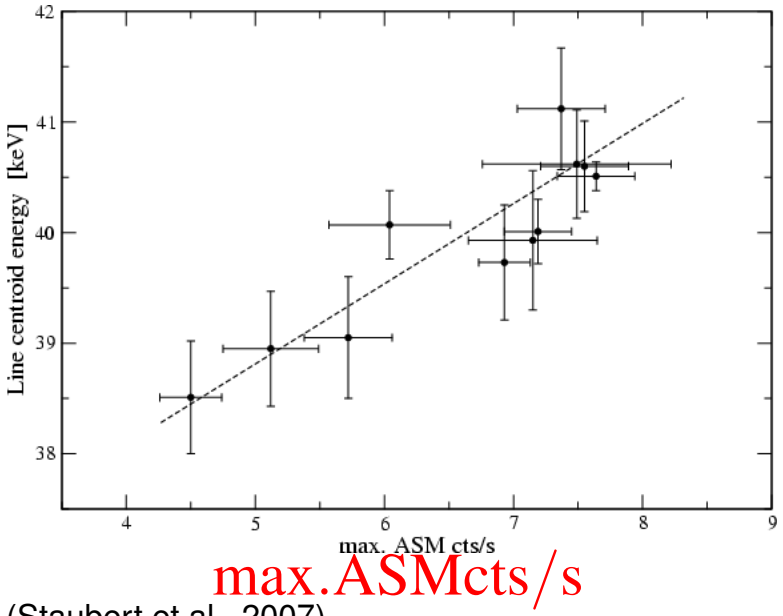
(Basko & Sunyaev 1976)

V 0332 +53



(Tsygankov et al., 2006)

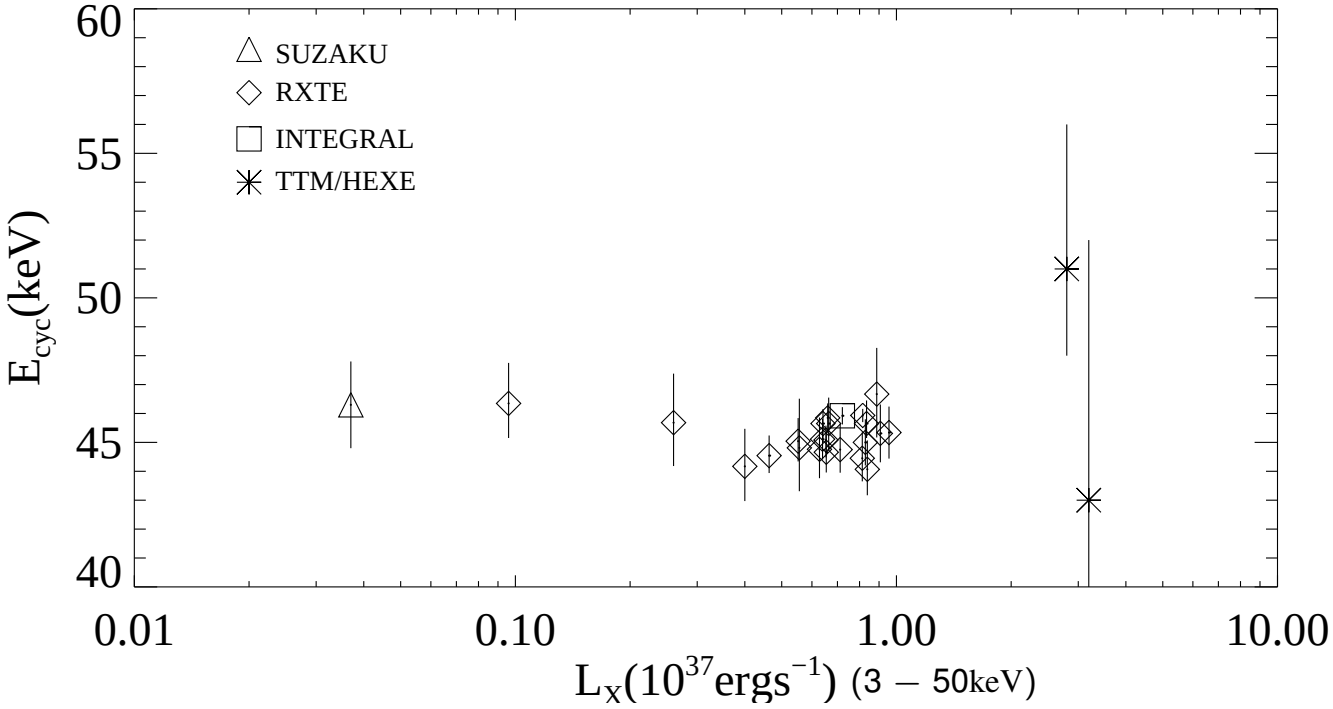
Her X-1



(Staubert et al., 2007)

Cyclotron line evolution with luminosity

The centroid of the cyclotron line is consistent with being constant with the luminosity for A0535+26



Caballero et al. 2007

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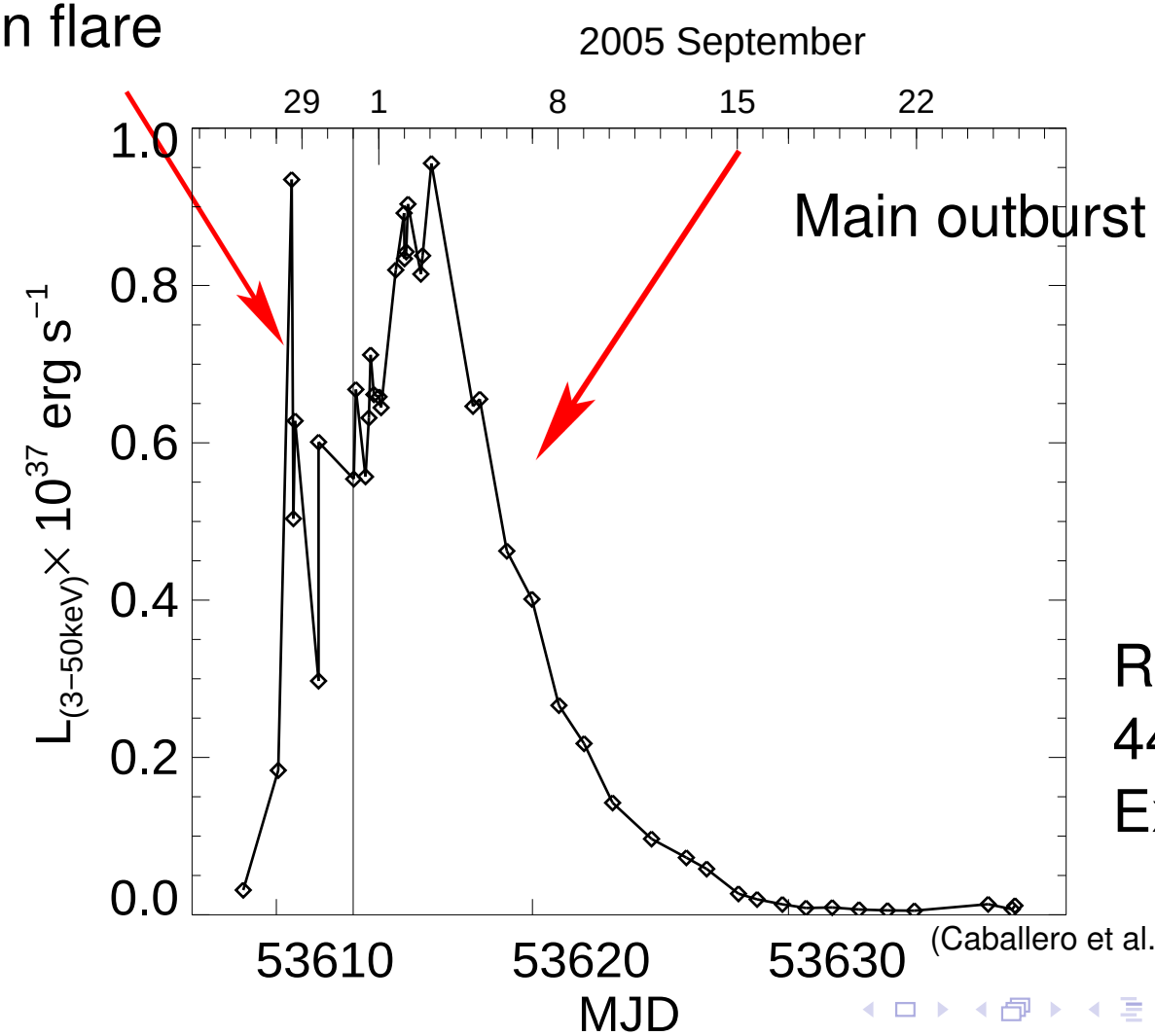
Evolution of timing and spectral parameters during the outburst - RXTE

Pre-periastron flare

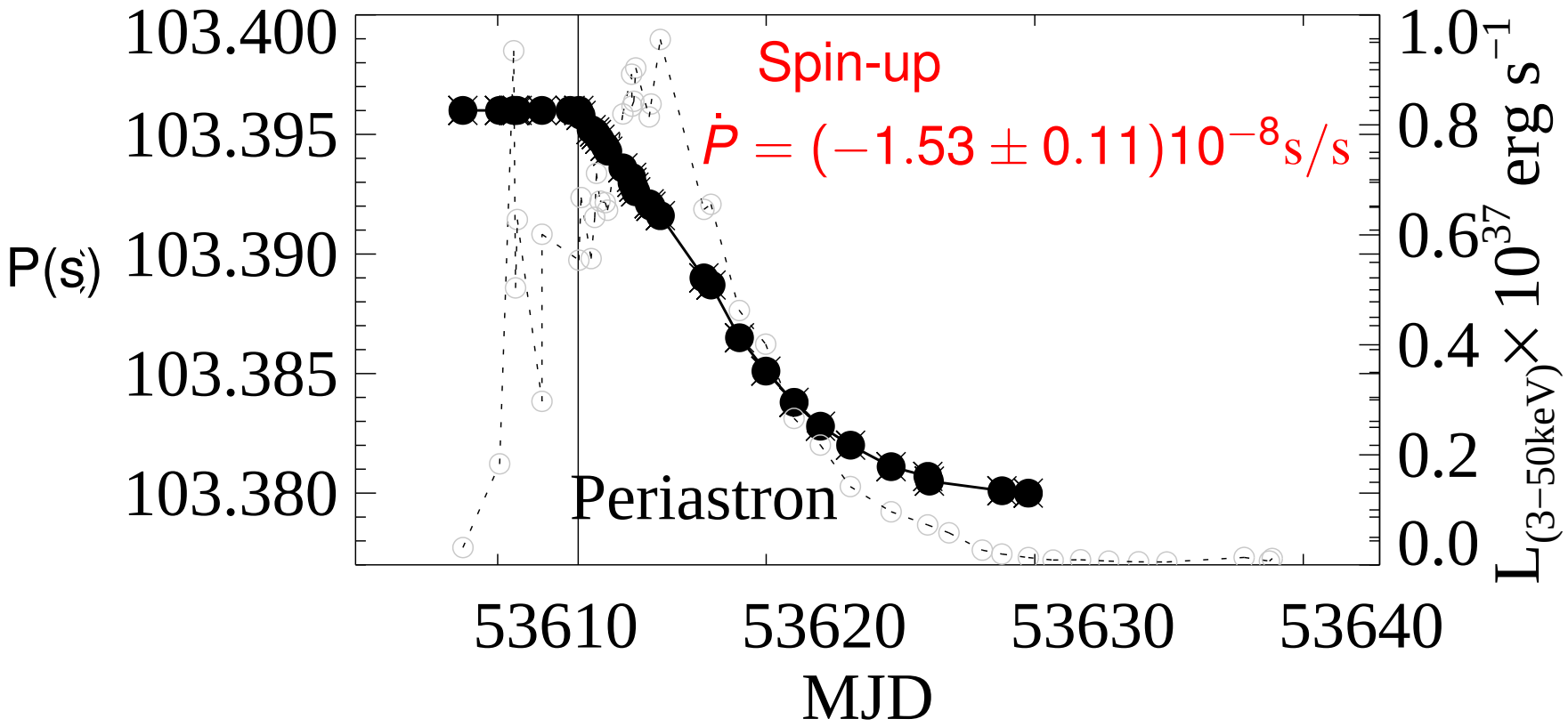


RXTE
44 pointed obs.
Exp. 198.4ks

(Caballero et al. 2007, to be submitted)

Pulse period evolution

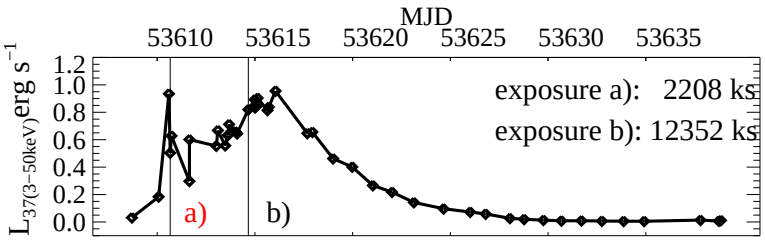
Constant period during the flare $P = 103.3960(5)\mathrm{ms}$



(Caballero et al. 2007, to be submitted)

Pulse profiles evolution

Strong variation of energy dependent pulse profiles



a) FLARE b) NEAR MAXIMUM

PCA $1.75 - 2.98$keV

PCA $2.98 - 4.63$keV

PCA $4.63 - 6.28$keV

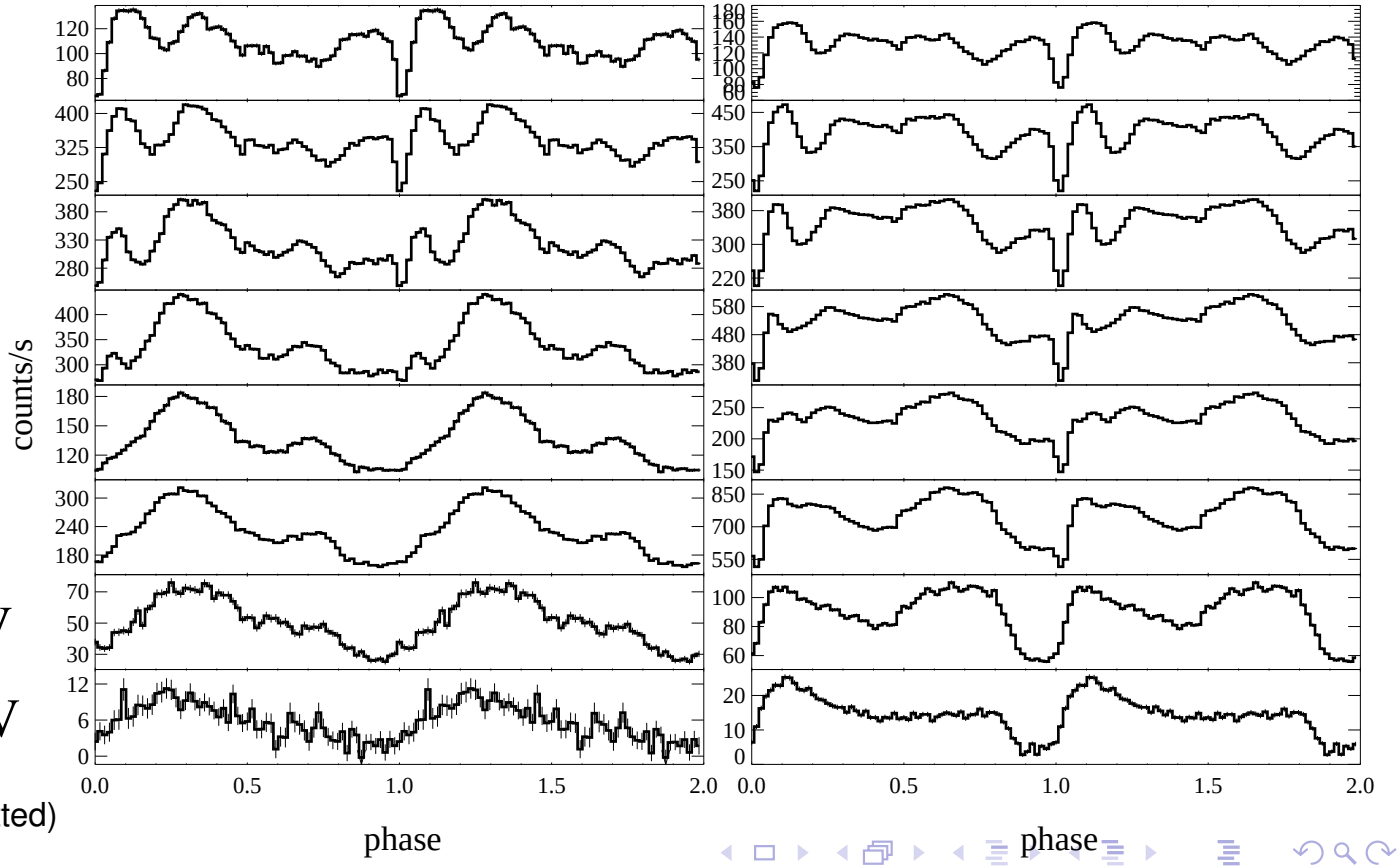
PCA $6.28 - 8.76$keV

PCA $8.76 - 10.42$keV

PCA $10.42 - 20.45$keV

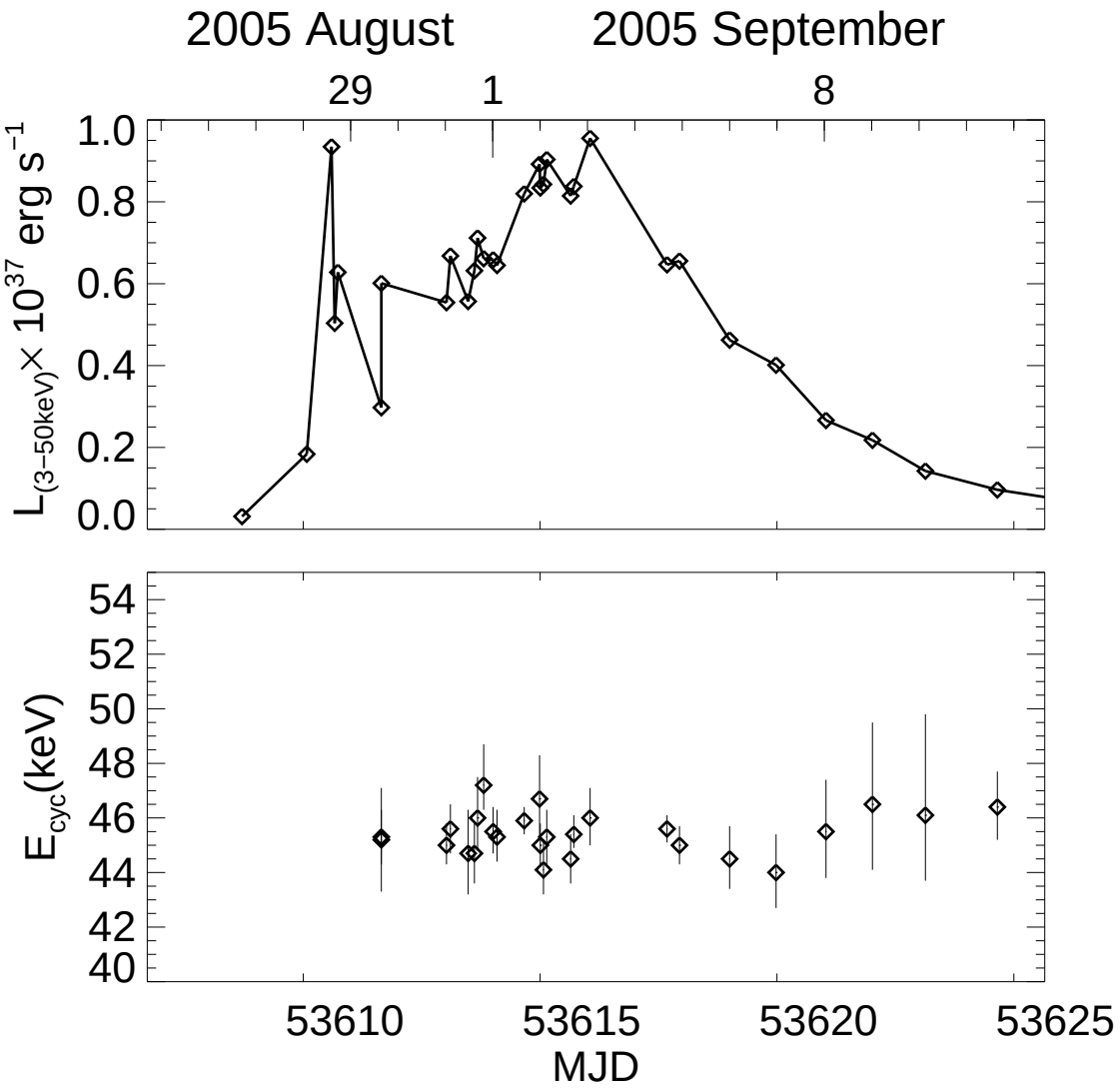
HEXTE A $20.15 - 45.47$keV

HEXTE A $45.47 - 91.19$keV



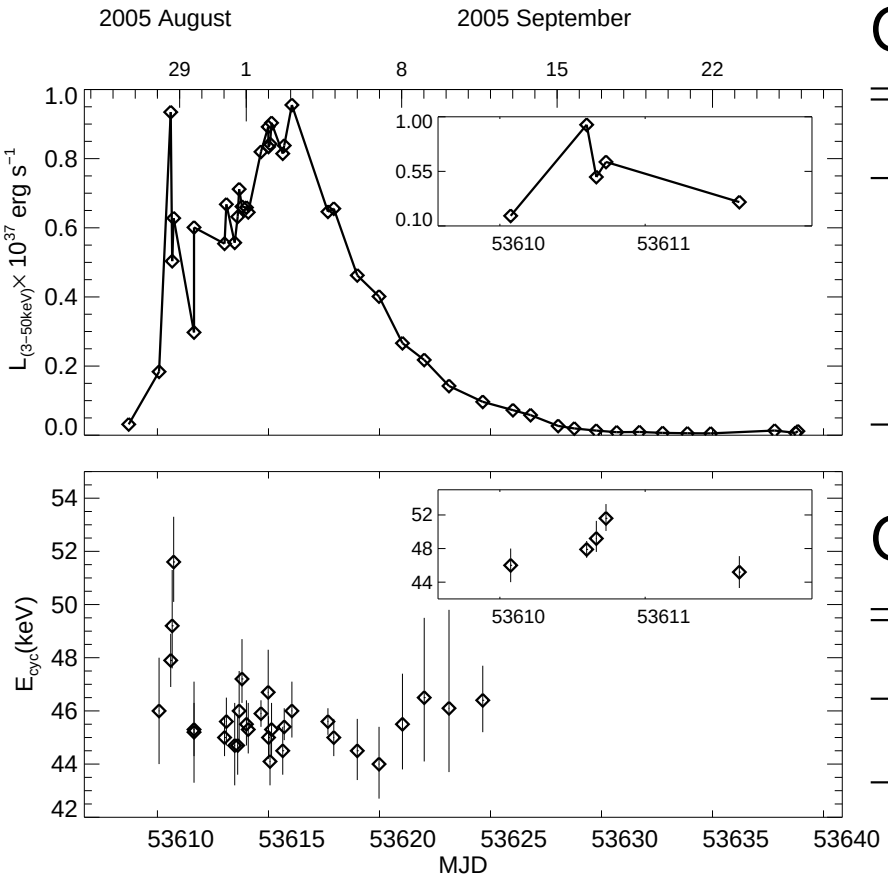
(Caballero et al. 2007, to be submitted)

Spectral evolution - cyclotron energy



Cyclotron line energy

During the pre-periastron flare the energy of the centroid of the cyclotron line is measured at a higher position



Observations flare

E_{fund}(keV)	$L_{(3-50\mathrm{keV})} \times 10^{37}\mathrm{ergs}^{-1}$
$47.9^{+1.0}_{-1.0}$	0.94
$49.2^{+2.1}_{-1.6}$	0.50
$51.6^{+1.7}_{-1.5}$	0.63

Obs. close to maximum main outburst

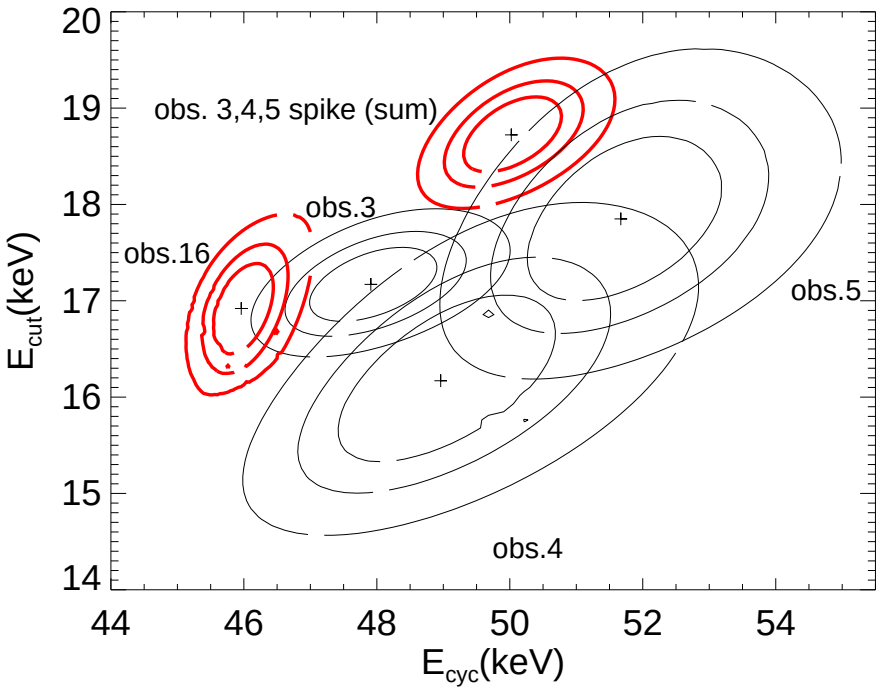
E_{fund}(keV)	$L_{(3-50\mathrm{keV})} \times 10^{37}\mathrm{ergs}^{-1}$
$45.9^{+0.4}_{-0.3}$	0.82

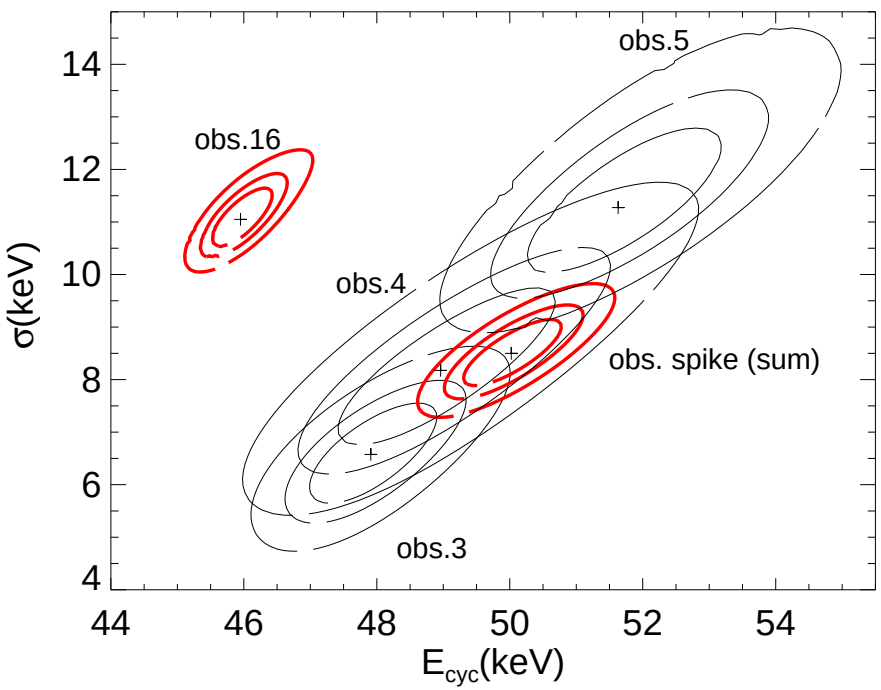
(errors 90% confidence)

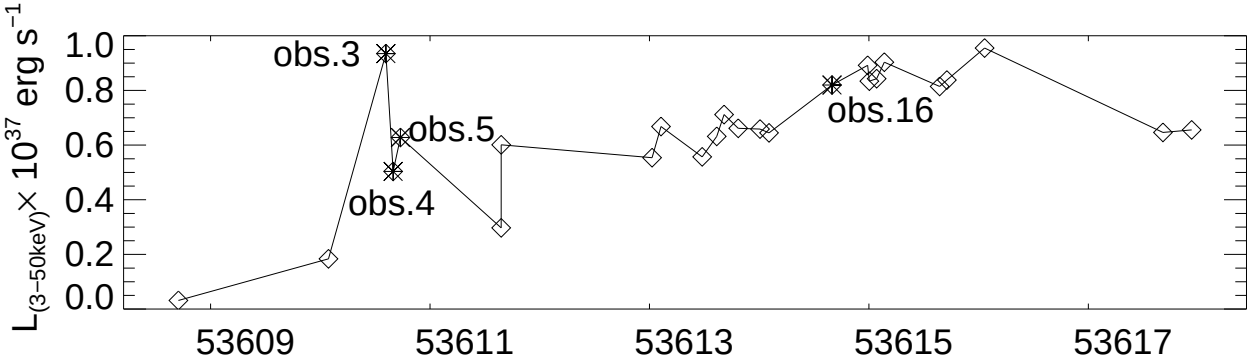
(Caballero et al. 2007, to be submitted)

Change in the cyclotron line energy

$\Delta\chi^2_{critical} = 2.30, 4.61, 9.21$







(Caballero et al. 2007, to be submitted)

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Summary

- **Constant period during pre-periastron flare**
  Spin-up starts at periastron
- **Strong pulse profile variation during the pre-periastron flare and the main outburst**
- **Centroid of cyclotron line higher during the pre-periastron flare, constant during the main outburst**

2S 1845-024 , EXO 2030+375 also show a similar flare before the main outburst (Finger et al. 1999, Camero et al. 2005).

Work and discussion are ongoing

Thanks for your attention!