New views on the X-ray emission of gamma-ray binaries
With focus on LSI +61 303

Diego F. Torres

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Context and focus

- Observations on LS I 61 303 by Chandra (MNRAS 2010, arXiv 1002.2223)
- Observations on LS I 61 303 by INTEGRAL (MNRAS 2010, arXiv 1006.1427)
- Observations on LS I 61 303 by RXTE/PCA (ApJ Letters 2010, arXiv 1007.2272)
- (ApJ, submitted)

With Chandra (95 ks) we did the deepest search for pulsations and accretion lines in soft X-rays and checked for a previously suggested hint of extended X-ray emission. The observation was at phase 0.94-0.98 (close to the apastron passage) in clocking mode.

With INTEGRAL we searched for long-term hard X-ray emission changes, constructed for the first time a 0.1 phase bin (averaged) lightcurve, and looked for the orbital periodicity. 2.1 Ms analyzed.

With RXTE we have long-term coverage (monitoring observations every other day for more than 3 years, >35 orbits). Allows to study long-term lightcurve (and spectra) variability from an orbit-by-orbit basis up. Allows to search for orbital periodicity(es).

Context and focus

• It seems all of this should have been done by now… but no.

• Soft X-ray pointed observations of LS I +61 303 have in general been too limited to cover full orbits of the system, period of ~26.5 days, or to study long-term evolution of the X-ray orbital profile.

• Observations by XMM-Newton (Neronov & Chernyakova 2006; Chernyakova et al. 2006, Sidoli et al. 2006), Chandra (Paredes et al. 2007), ASCA (Leahy et al. 1997), ROSAT (Goldoni & Mereghetti 1995; Taylor et al. 1996), and Einstein (Bignami et al. 1981) were all too short to cover even a single full orbit.

• Longer term-observations of LS I +61 303 were performed using RXTE-ASM (see Leahy 2001) and Swift-XRT (Esposito et al. 2007) and, at harder X-rays, by INTEGRAL-IBIS/ISGRI (Chernyakova et al. 2006). There was only a ~6 months continuous coverage of LS I 61 303 in 2007 (Smith et al. 2009).

• Essentially: from one to few months of coverage, leading to no orbital periodicity or to only hints of it, somewhat confusing claims of the existing of one or two peaks in the lightcurves, and intra-orbital flux evolution.

• There were no deep Chandra observation in clocking mode; nor continuous coverage with high sensitivity to see inter-orbital lightcurve variability with high confidence, and the hard X-ray observations were short enough to lead basically just a detection.

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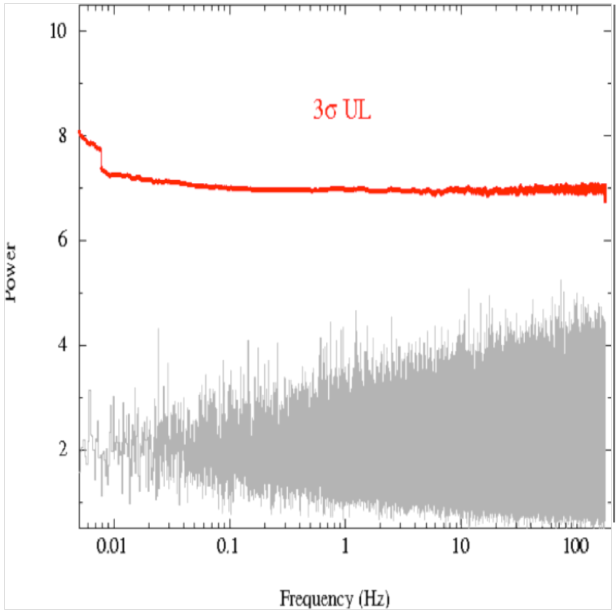
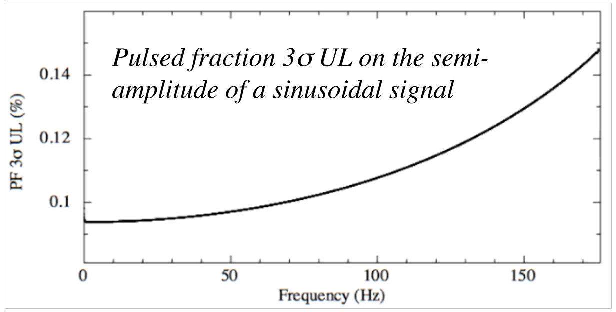
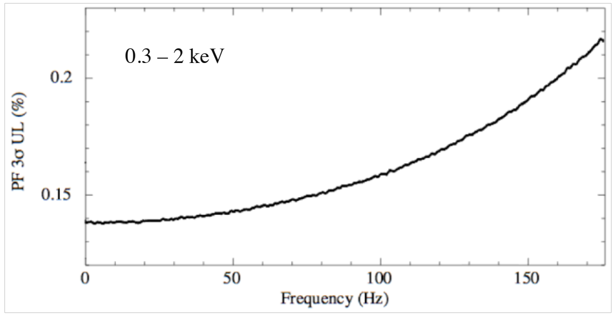
Pulsation X-ray search: the current status

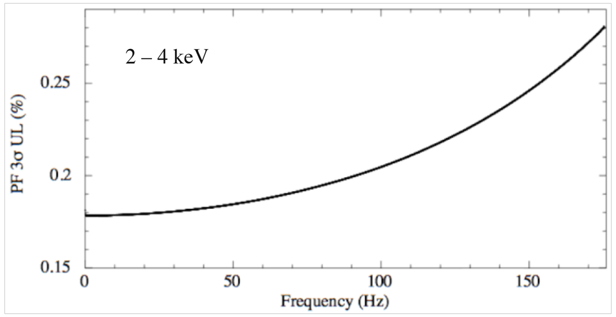
LS I +61 303

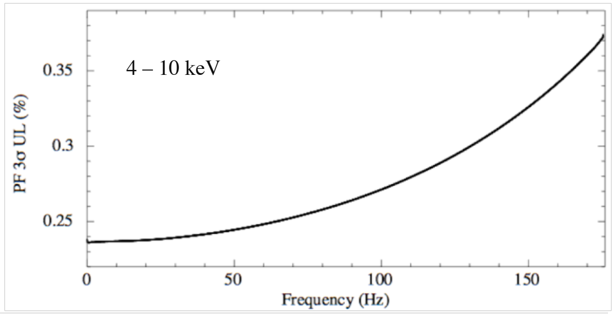
95 ks Chandra observation near apastron











- Search for periods with frequencies 0.005 – 175 Hz (timing resolution of the CC-mode: 0.00285 s)

- Pulse fraction upper limits between 7 – 15 % for the whole energy range (larger in smaller energy bands)

- No significant short bursts in bins of 0.1 s

from Rea, DFT, van der Klis, Jonker, Mendez, Sierpowska-Bartosik, MNRAS 2010

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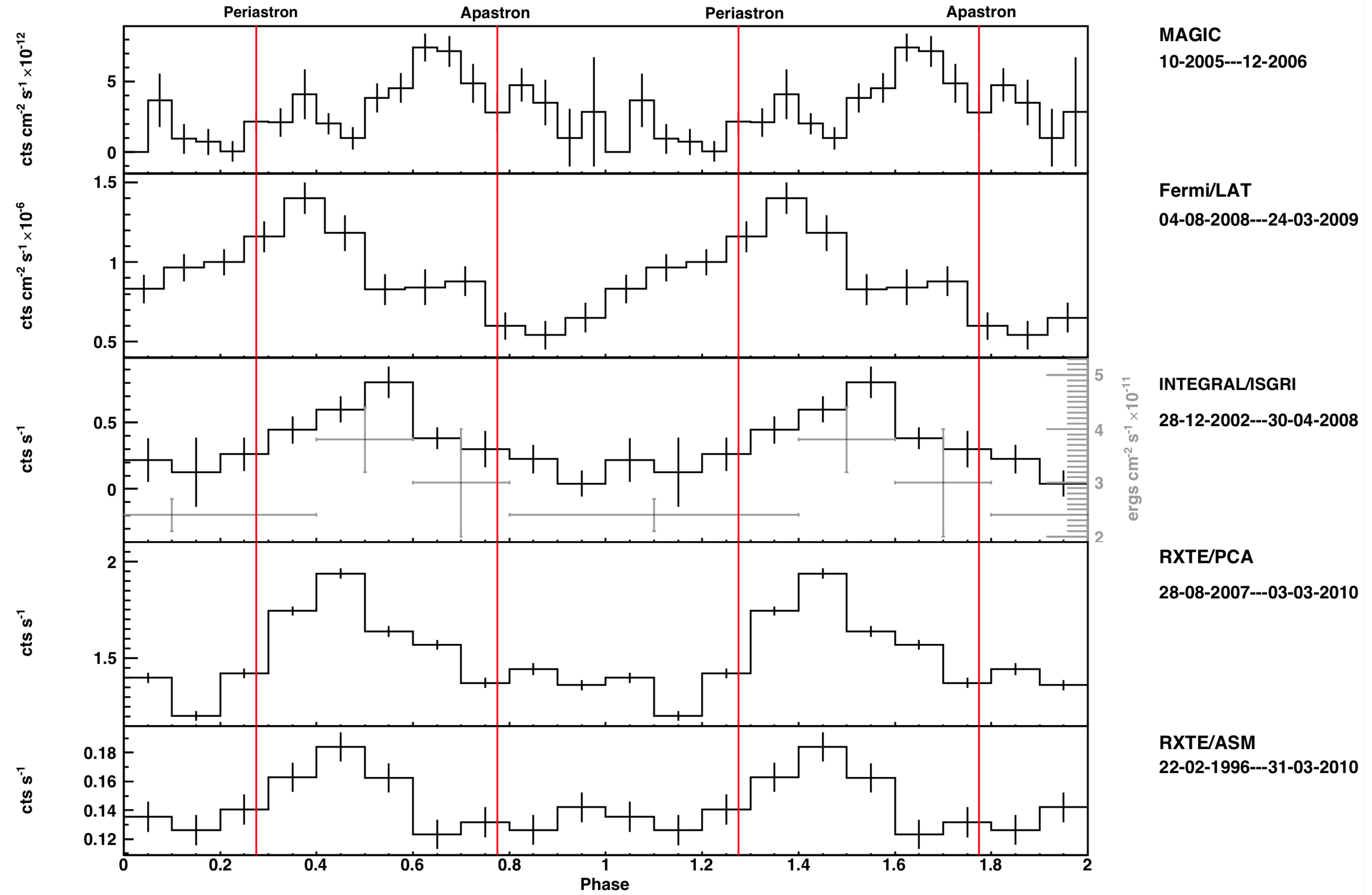
INTEGRAL observations



From Zhang, DFT, et al. MNRAS 2010

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RXTE observations

ApJ Letters, 2010

Variability in the orbital profiles of the X-ray emission of the γ-ray binary LS I +61°303

Diego F. Torres[1,2], Shu Zhang[3], Jian Li[3], Nanda Rea[1], G. Andrea Caliandro[1], Daniela Hadasch[1], Yupeng Chen[3], Jianmin Wang[3,4] & Paul S. Ray[5]

- Rossi X-ray Timing Explorer (RXTE) Proportional Counting Array (PCA) monitoring of LS I +61 303, covering 35 full cycles of its orbital motion (from Sept. 2007 to March 2010). 483 ks of exposure.

- The largest continuous X-ray monitoring dataset analyzed to date for LS I +61 303 (increase earlier coverage by a factor of 6).

- Such an extended analysis allows us to report:
  - a) the discovery of variability in the orbital profiles of the X-ray emission,
  - b) the existence of a few short flares on top of the overall behavior typical of the source, which given the PCA field-of-view, may or may not be associated with LS I +61 303
  - c) the determination of the orbital periodicity using soft X-ray data.

- We analyze the consequences of the variability.

RXTE observations: all data put together

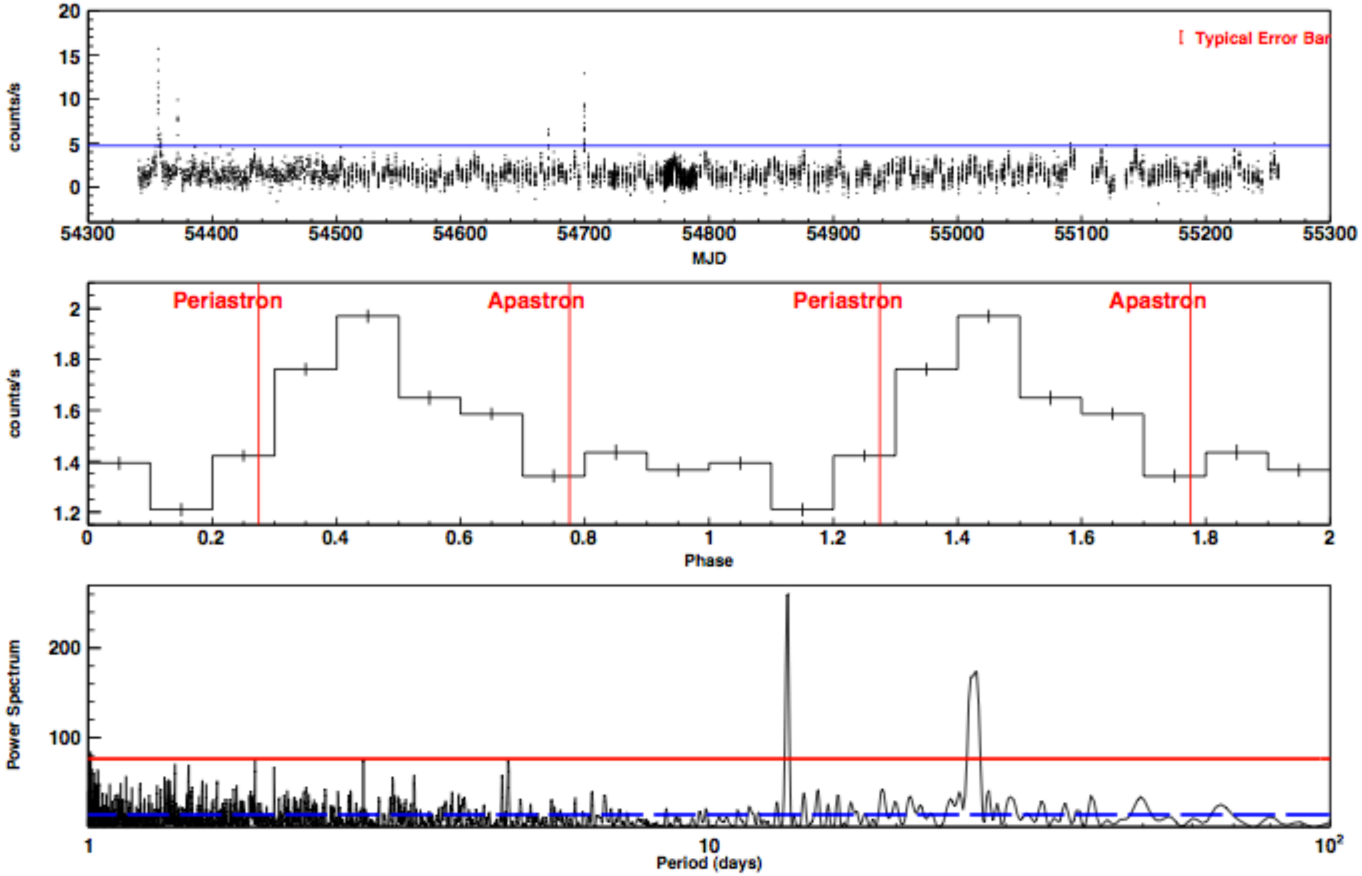
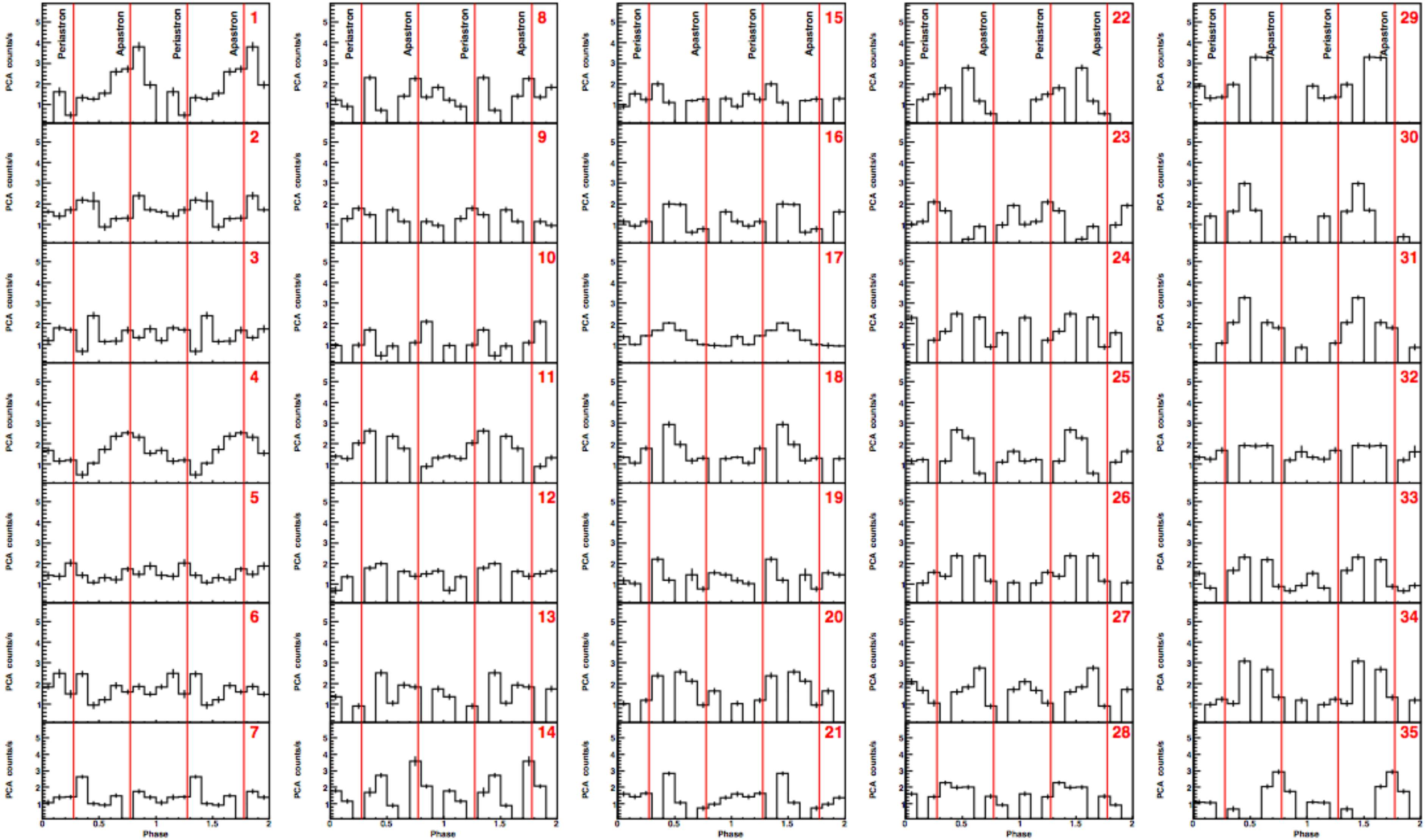


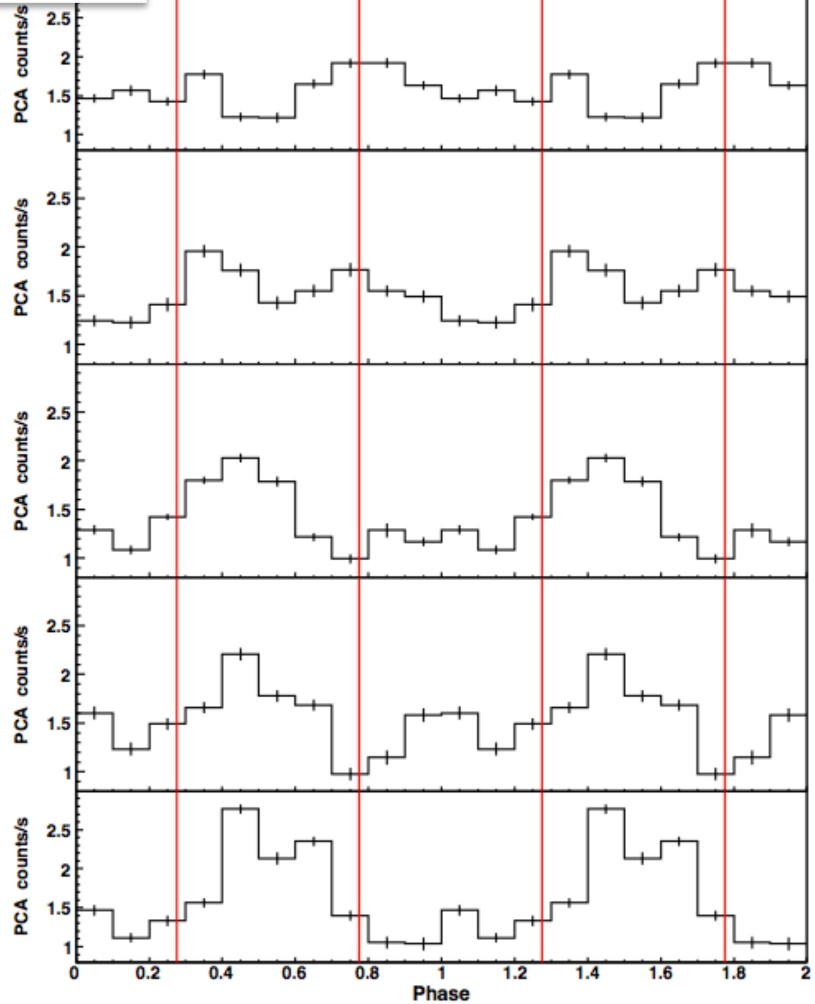
Fig. 1.— Top: Binned 3–30 keV lightcurve, with 64-second resolution, of the RXTE-PCA data of LS I +61° 303 from 2007 September to 2010 March. The horizontal line represents the upper flux cut considered in our analysis. Middle: Folded lightcurve with orbital ephemeris of LS I +61° 303 using the complete RXTE/PCA dataset. Bottom: Power spectrum of the whole RXTE-PCA data. The white noise (dashed line) and the red noise (solid line) at the 99% confidence level are plotted in the power spectrum.

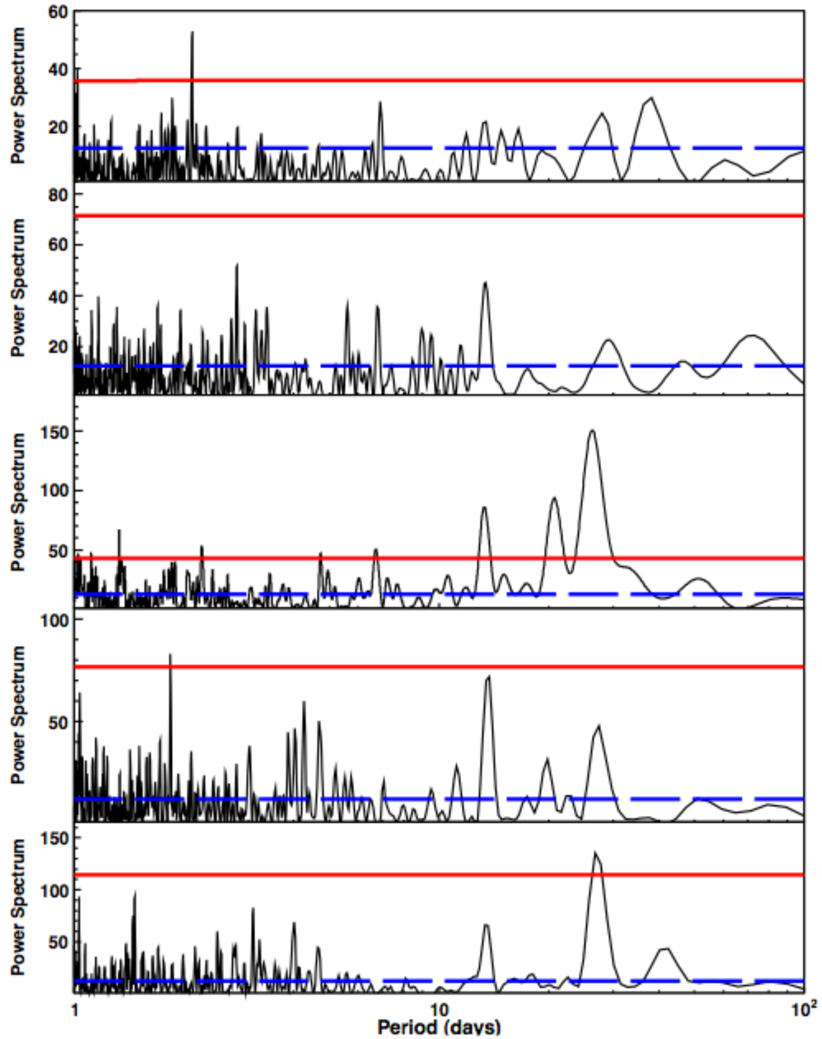
RXTE observations: orbit by orbit folding



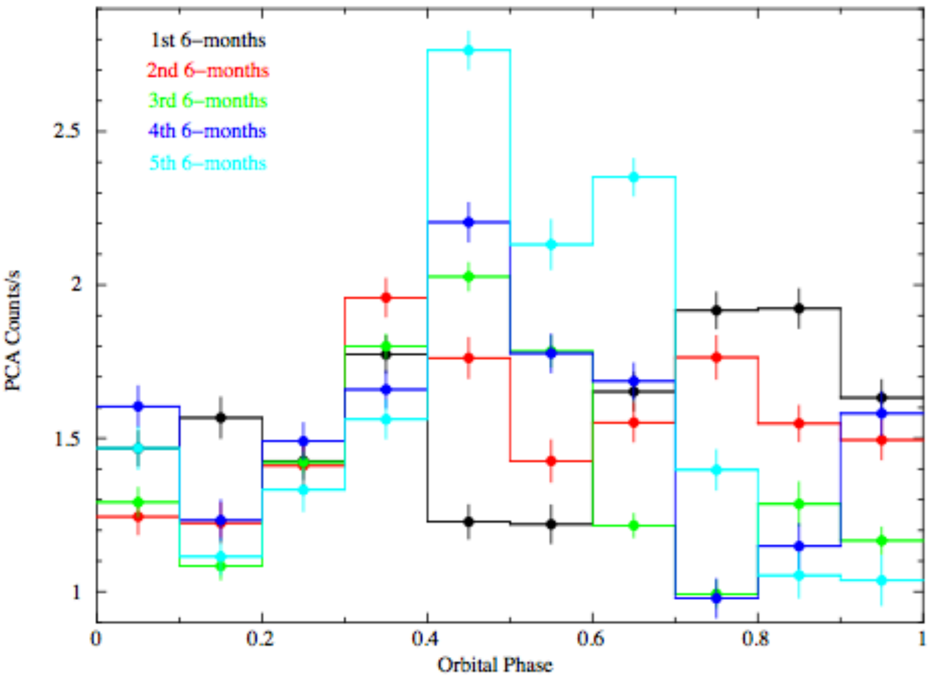
RXTE observations: dividing the sample in 5 6-months sets

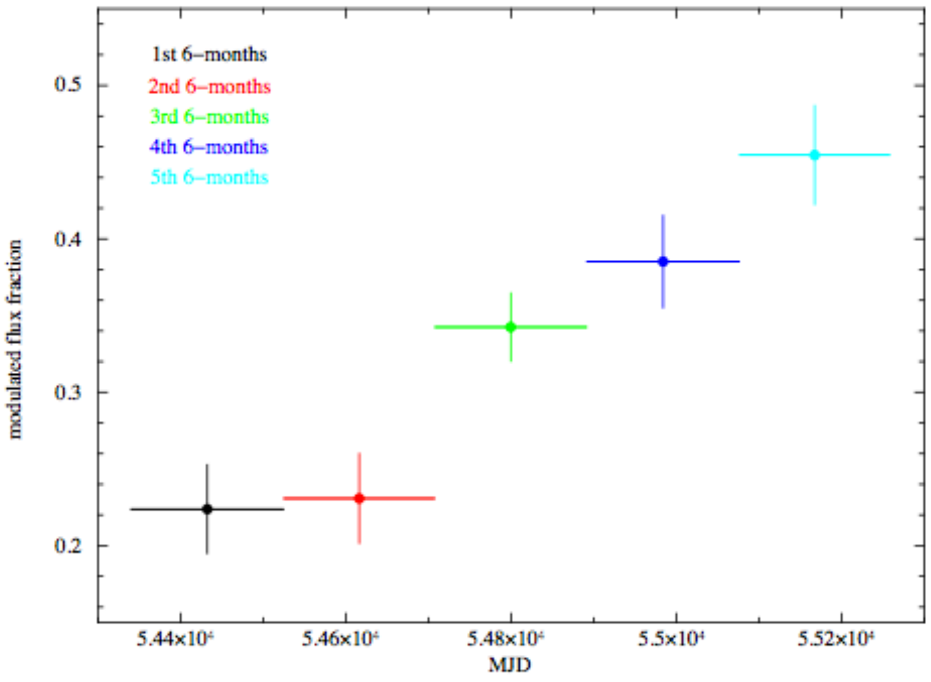
28/8/2007 — 28/2/2008
29/2/2008 — 29/8/2008
30/8/2008 — 01/3/2009
02/3/2009 — 02/9/2009
03/9/2009 — 03/3/2010





RXTE observations: analyzing variability





Note 1) that the lightcurves do not peak in the same place, 2) that the average value does not change 3) that sometimes two peaks *seem* present 4) that at fixed phase, there are significant flux variations (>7σ)

The modulated flux fraction is obtained as (Max−Min)/(Max+Min), where Max and Min are the maximum and minimum counts/s of each for the 6-months orbital profile after the background correction as a function of time (one point for each of the 6 months periods considered).

RXTE observations: analyzing variability

28/8/2007 — 28/2/2008
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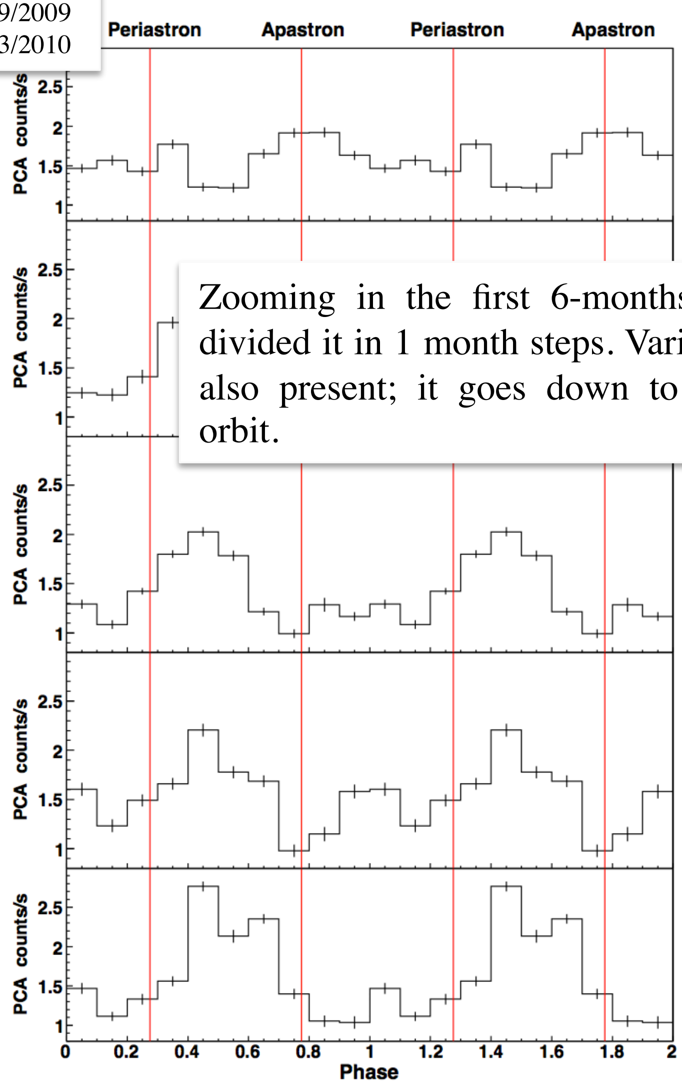
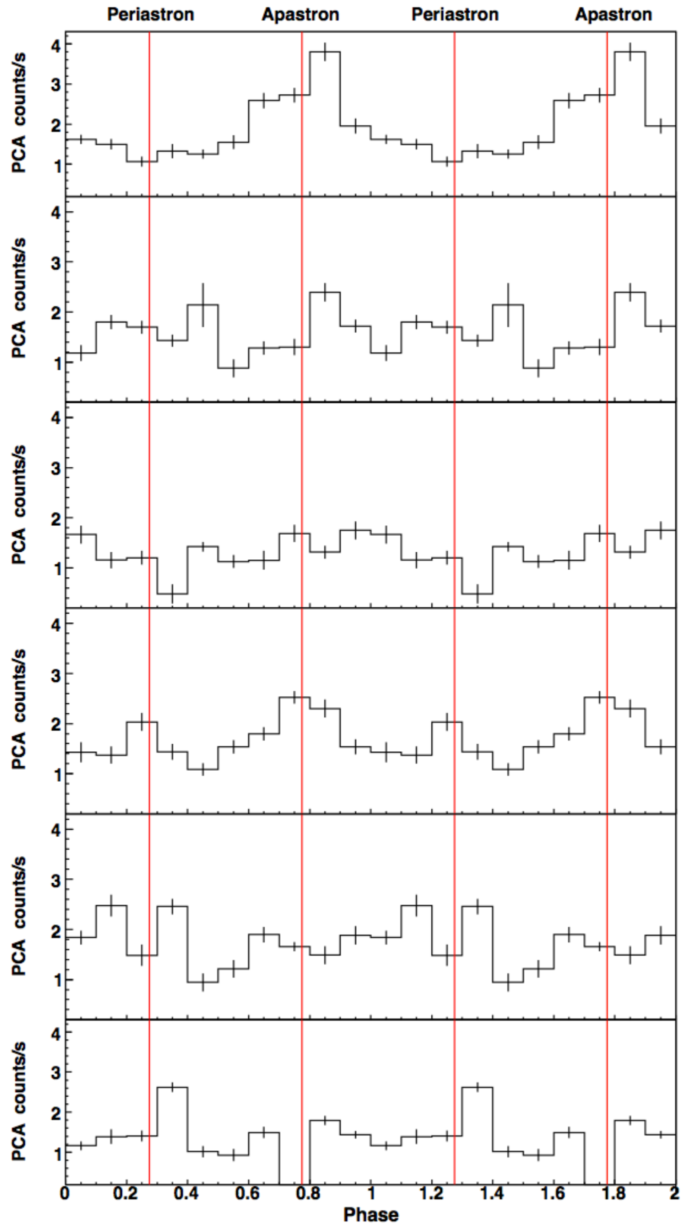
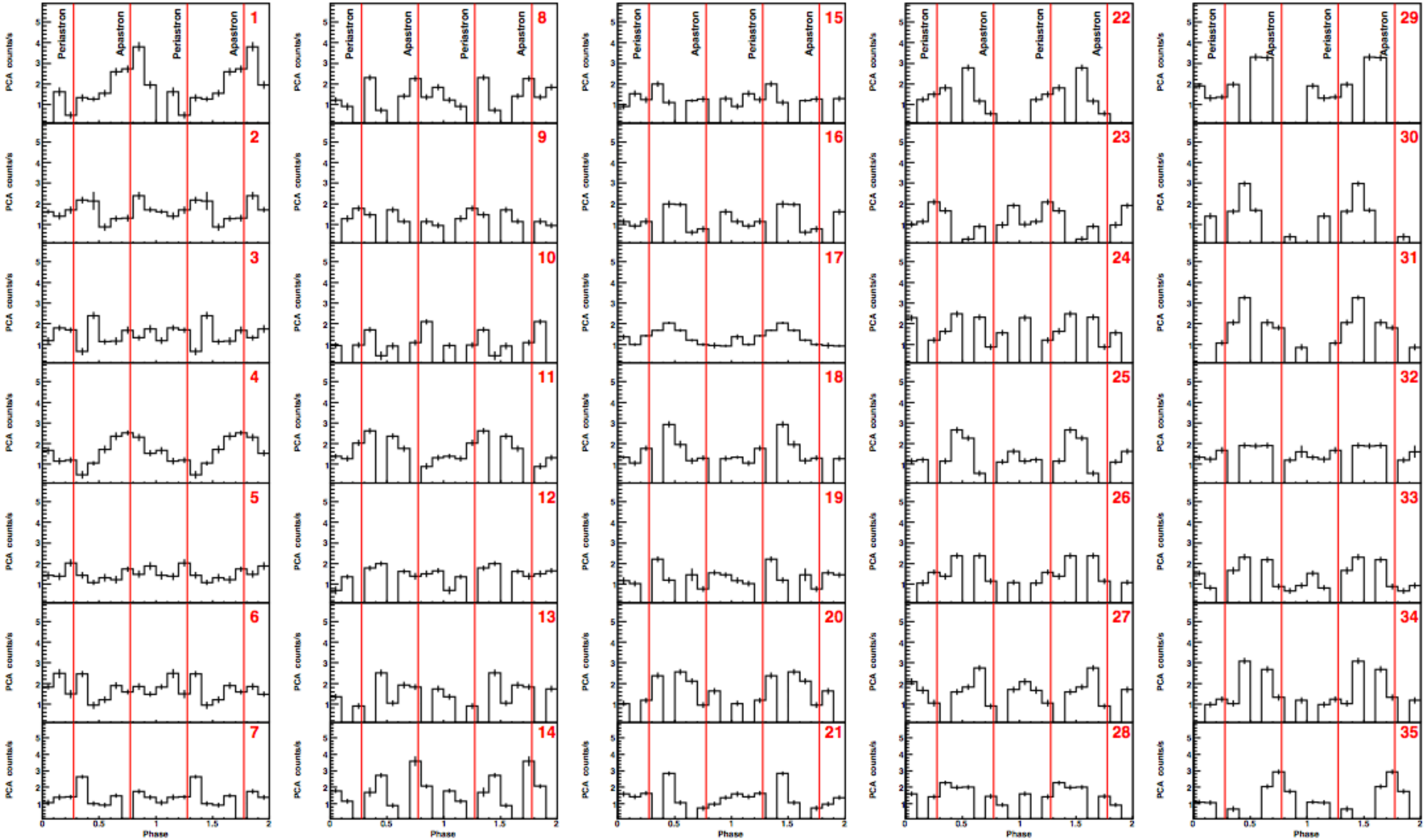


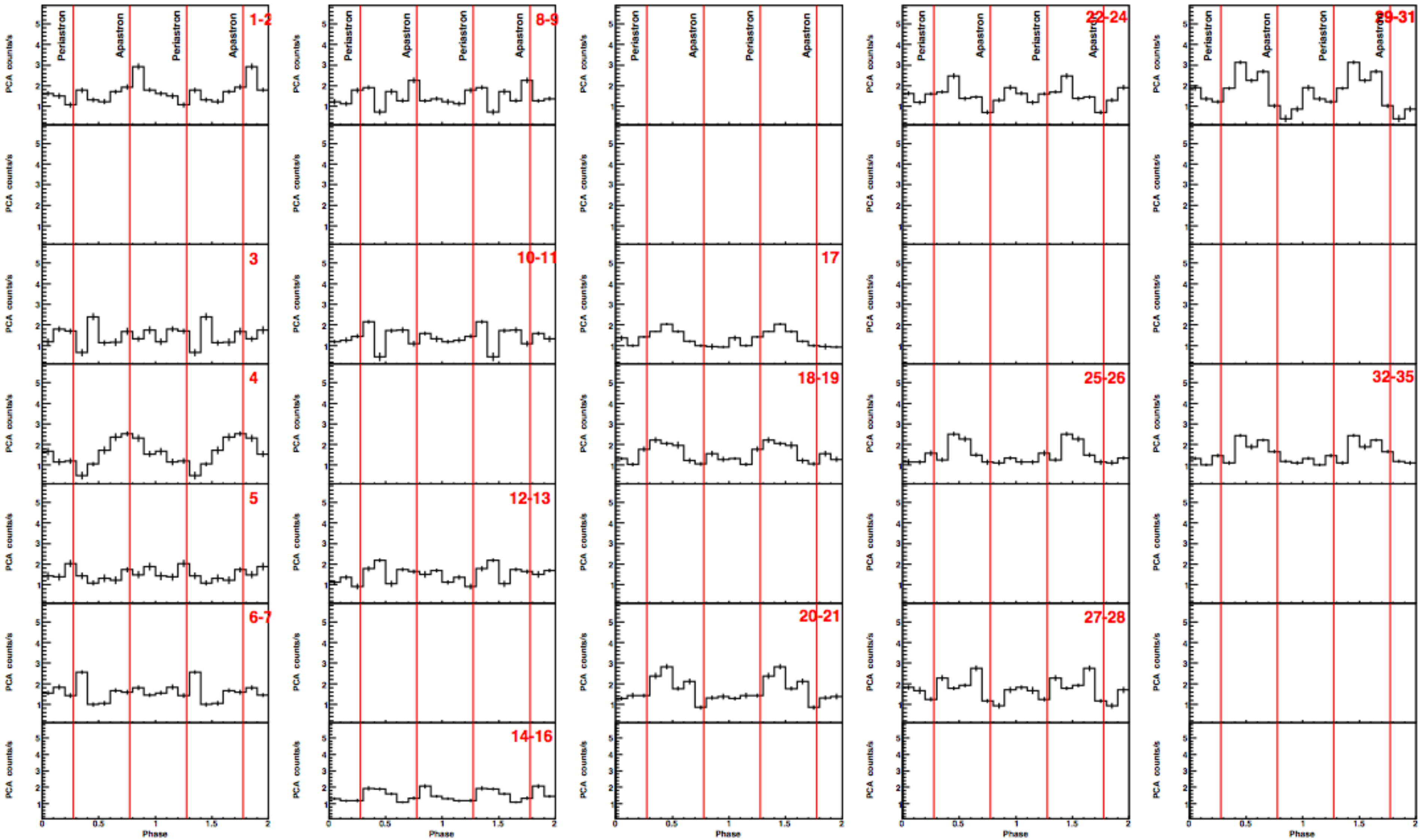
Zooming in the first 6-months period: divided it in 1 month steps. Variability is also present; it goes down to orbit to orbit.



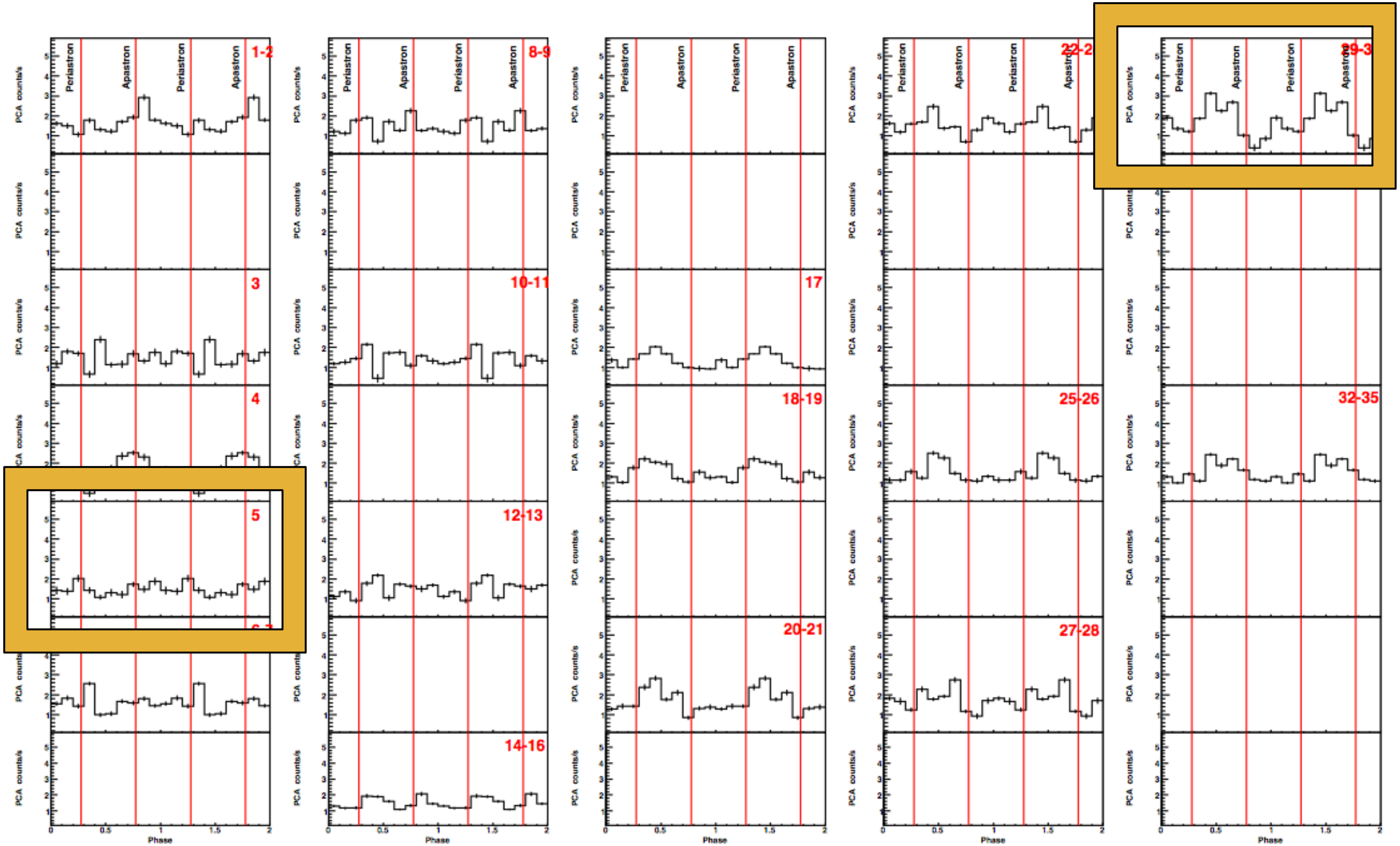
RXTE observations: orbit by orbit folding / note the phase gaps



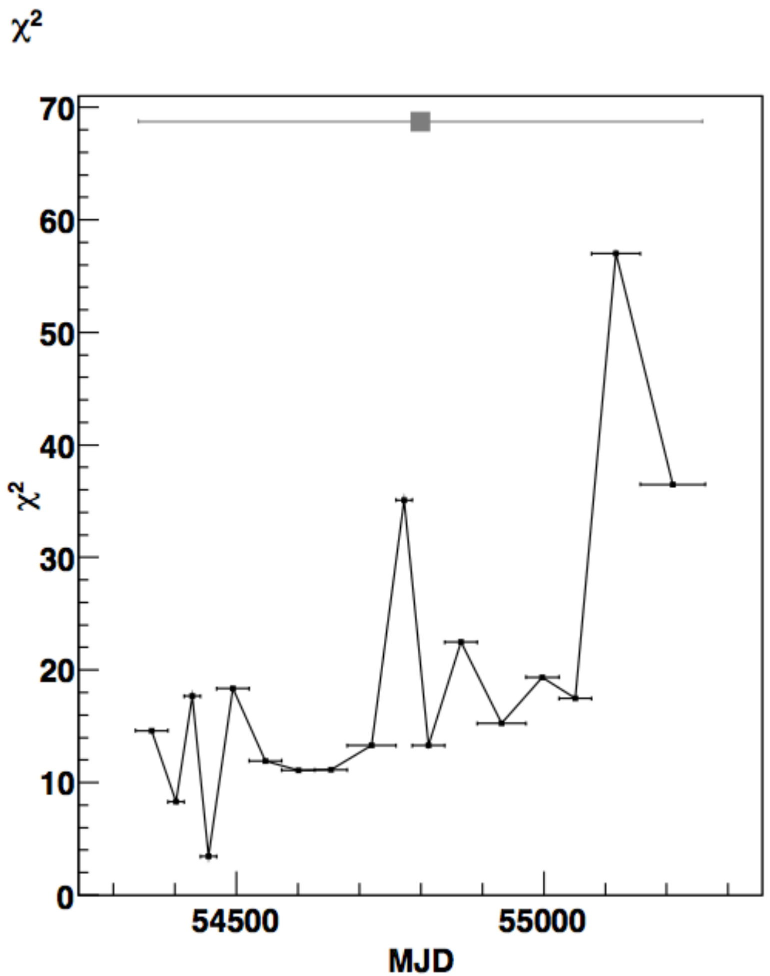
RXTE observations: grouping orbits, when does the peak happens?

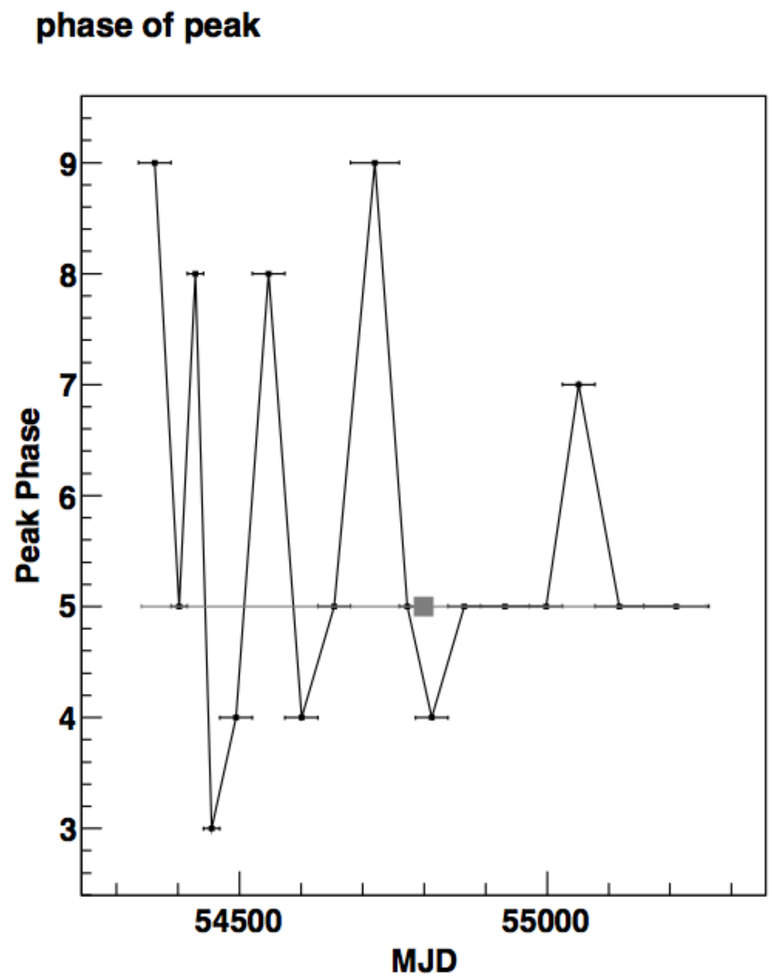


RXTE observations: grouping orbits, very different profiles



RXTE observations: when does the peak happens?

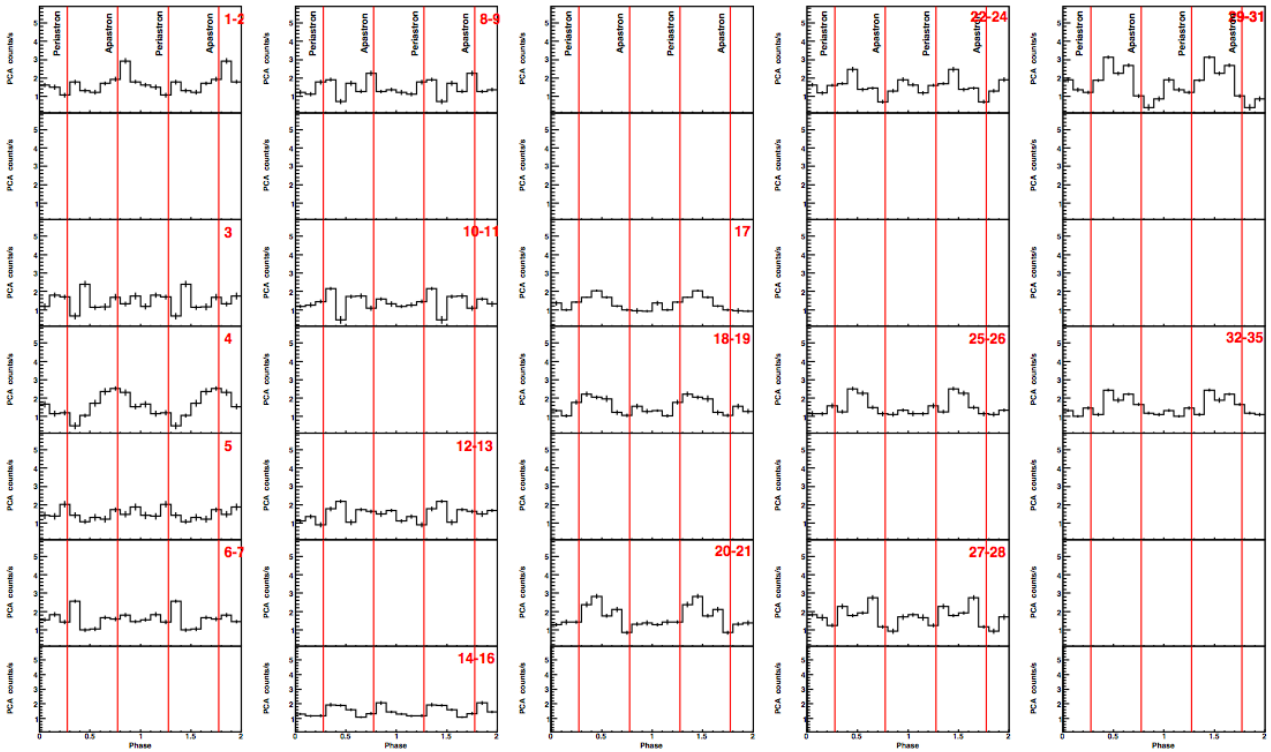


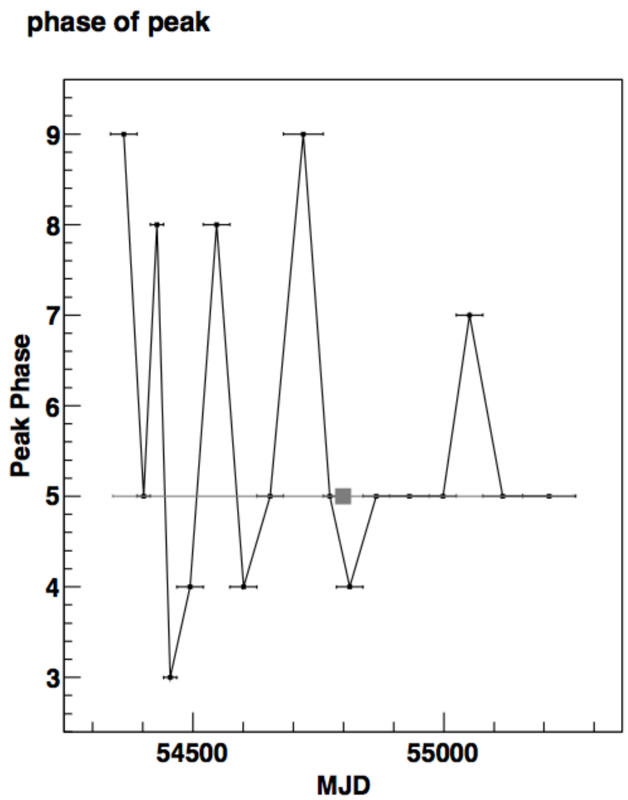


The left panel shows how far from a horizontal constant line the folded lightcuve is (how variable the flux from LS I 61 303 is at each timescale).

The right panel shows where (in which of the 0.1-phase bins) the peak of the X-ray emission is found. In both panels the grey point represents the average value along the whole observation.

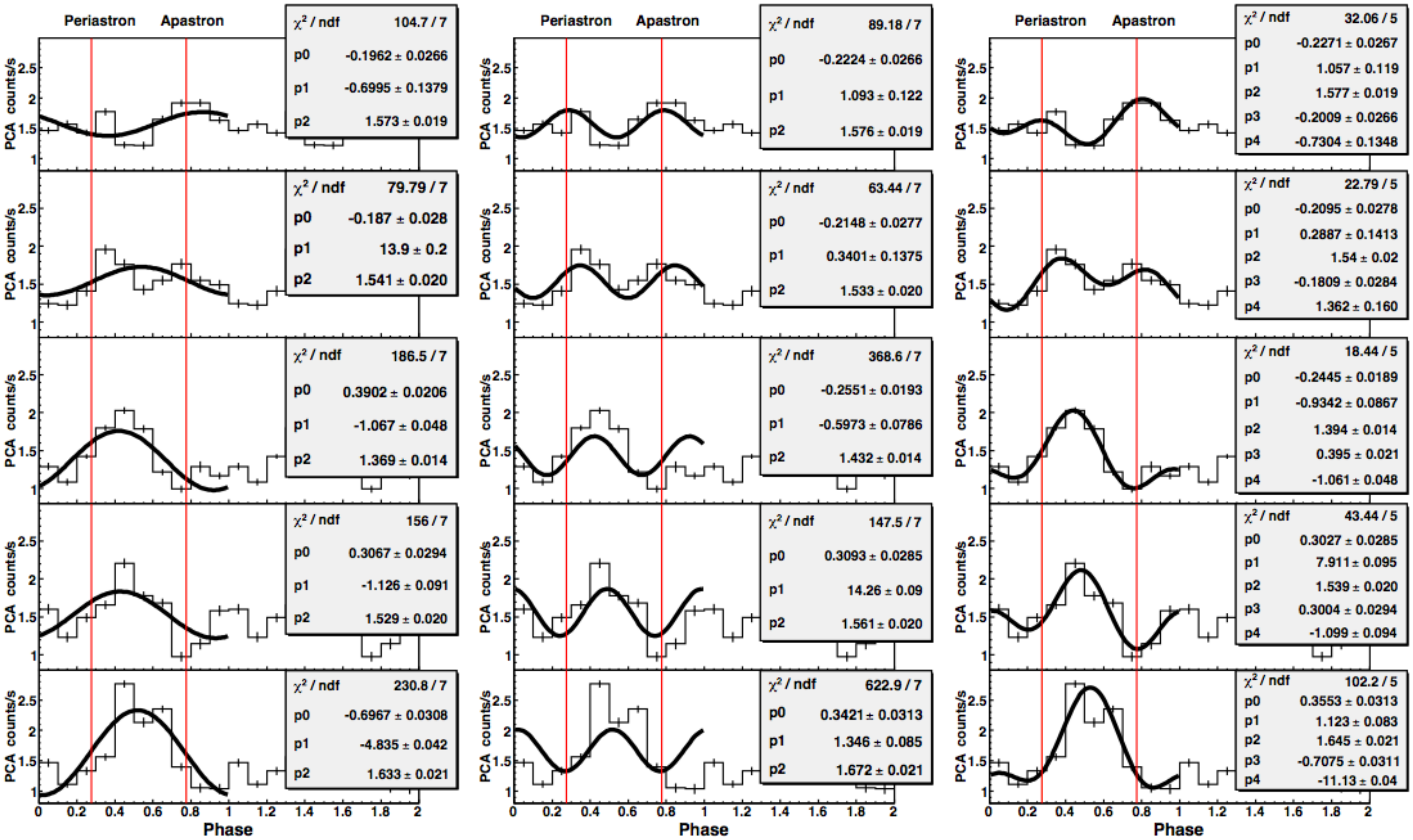
RXTE observations: when does the peak happens?



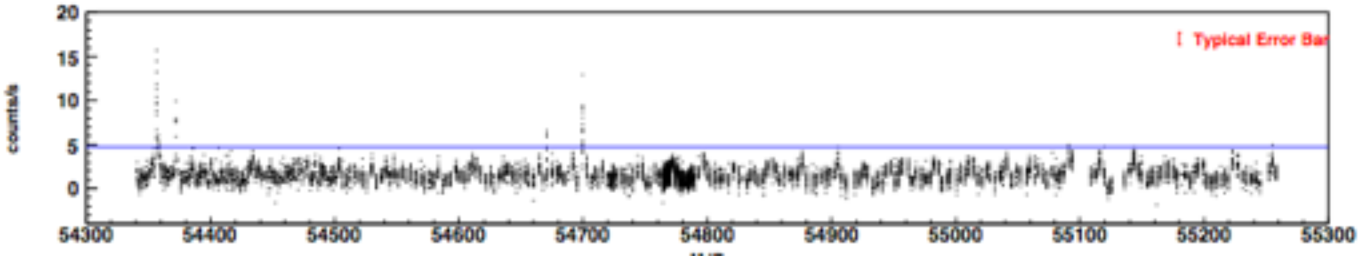


Each point in the right panel is obtained from each of the folded (grouped) lightcurves on the left.

One or two peaks? Not really.



Where are the flares?



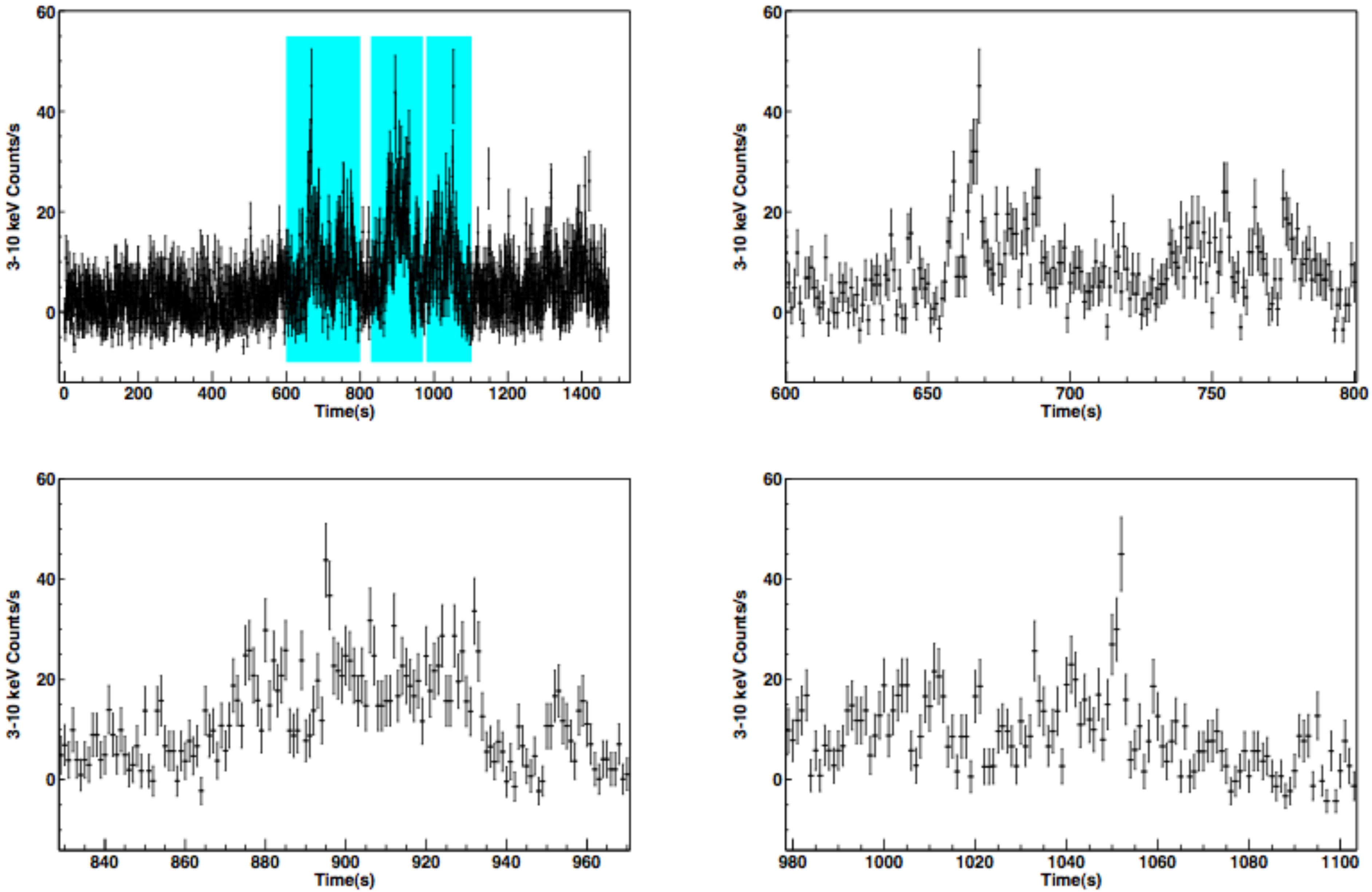
There are a total of five flares found on top of the typical behavior of LS I +61 303.

4 out of the five flares are grouped in the 0.6–0.9 orbital phase bin of LS I +61 303.

If the flares do not correlate with the orbital phase, the possibility of the resulting configuration is 2.8×10^{-3}.

This may be indicative of an association, but certainly not a compelling proof.

Flare inner structure and QPOs in the flares?



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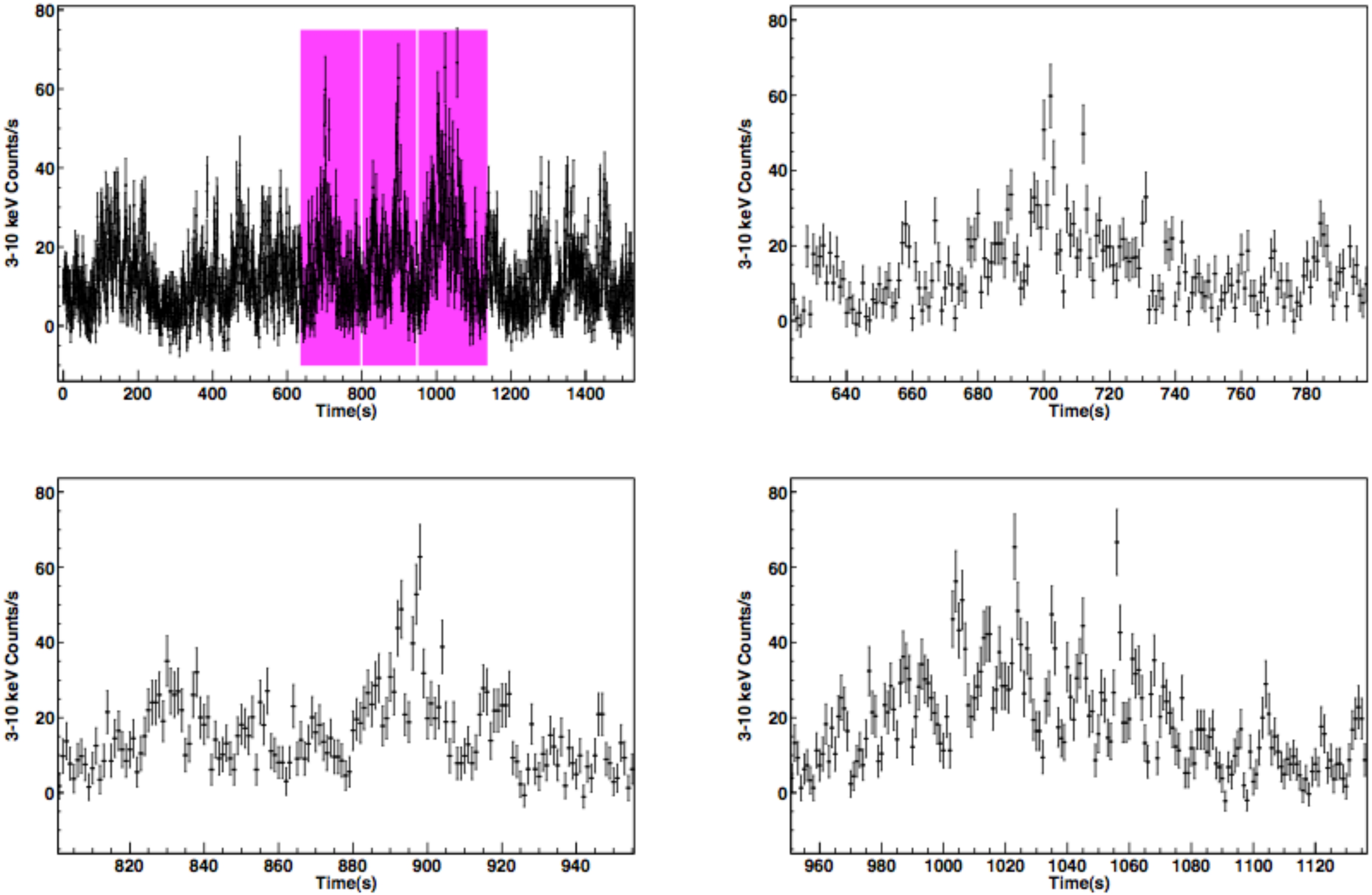
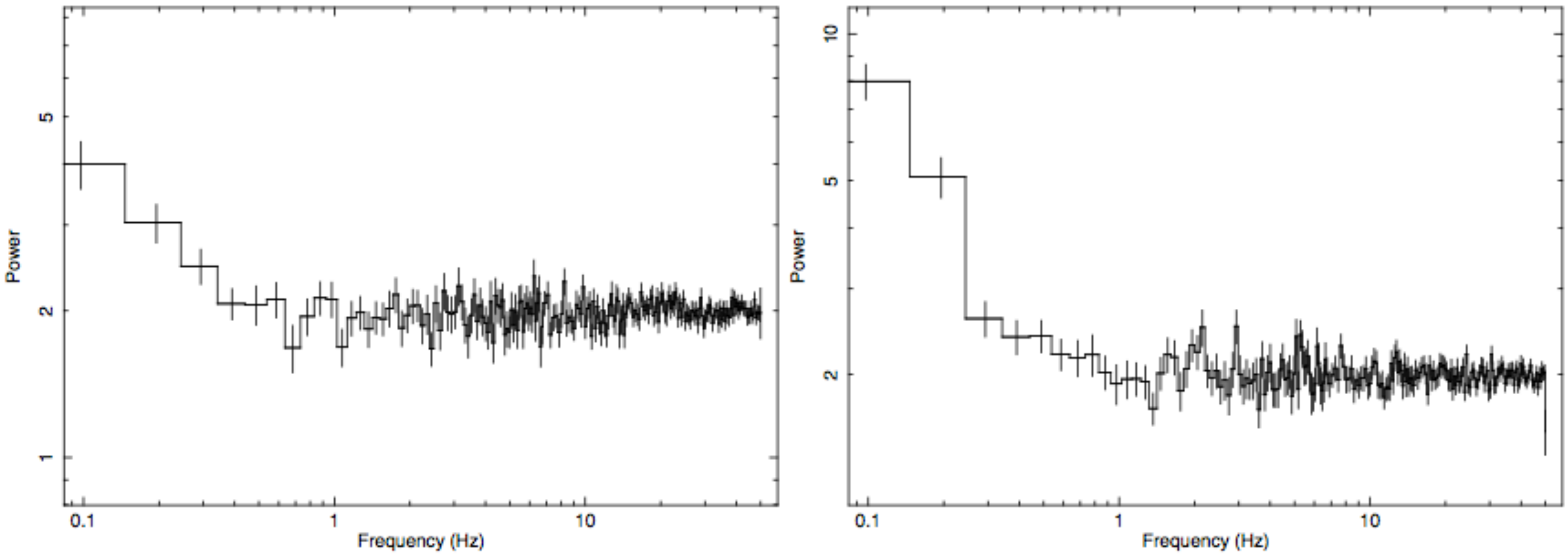


Flare inner structure and QPOs in the flares?



Timing analysis (the flares 4th and 5th are shown) does not show any structure in the power spectrum. A QPO-like structure in the power spectrum of the 5th flare is not significant; despite already being quoted in the literature as if.

RXTE observations: some conclusions

• The X-ray emission from LS I +61 303 presents a periodical behavior (visible only for long integration times) whose shape evolution in time is not maintained at any of the scales explored.

• The X-ray emission may be orbitally modulated due to the interaction of a stellar wind flow with a pulsar wind or a jet, but that the details of such variability may strongly depend on the intrinsic behavior of the Be stellar wind present in the system

- **The study of short-term, simultaneous multifrequency observations produce local-in-time information useful for determining the process or the primaries leading to the radiation emitted, but not to establish a steady overall behavior.**

- **The fact that the X-ray and the TeV emission from LS I +61 303 are correlated in a single short observation cannot be used to claim that the position in phase of the maxima in the lightcurves are maintained on timescales longer than the simultaneous observations themselves.**

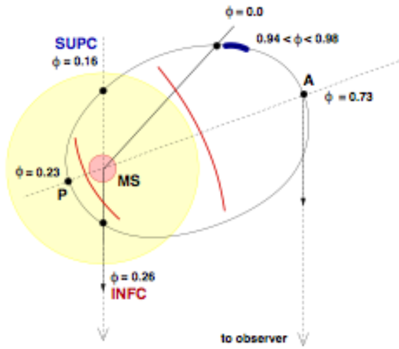
- **In fact, given the variable nature of the X-ray emission a correlation found in a short observation might not be sufficient proof that this correlation maintains in time.**

- **If indeed TeV and X-ray emission are always correlated, the TeV maximum should also vary. In addition, the relative strengths of the emission in these bands can be affected by the level of absorption at which the maximal photon production happens in a different manner from orbit to orbit.**

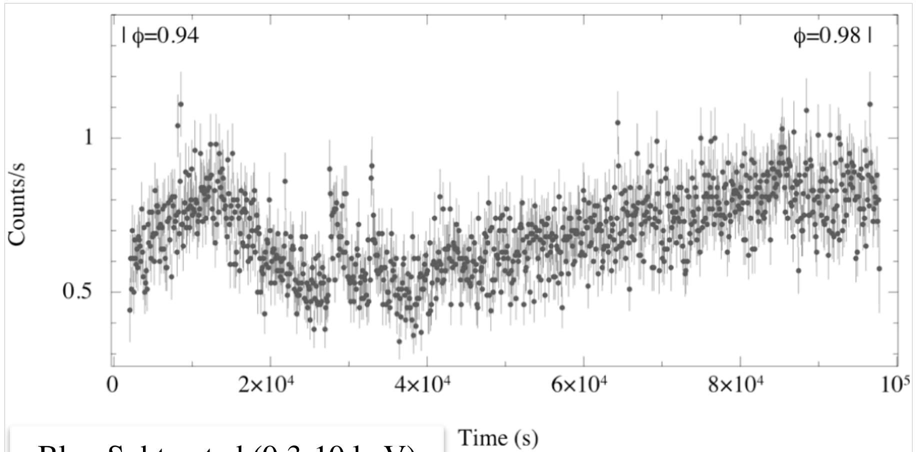
X-ray variability in gamma-ray binaries

LS I +61 303

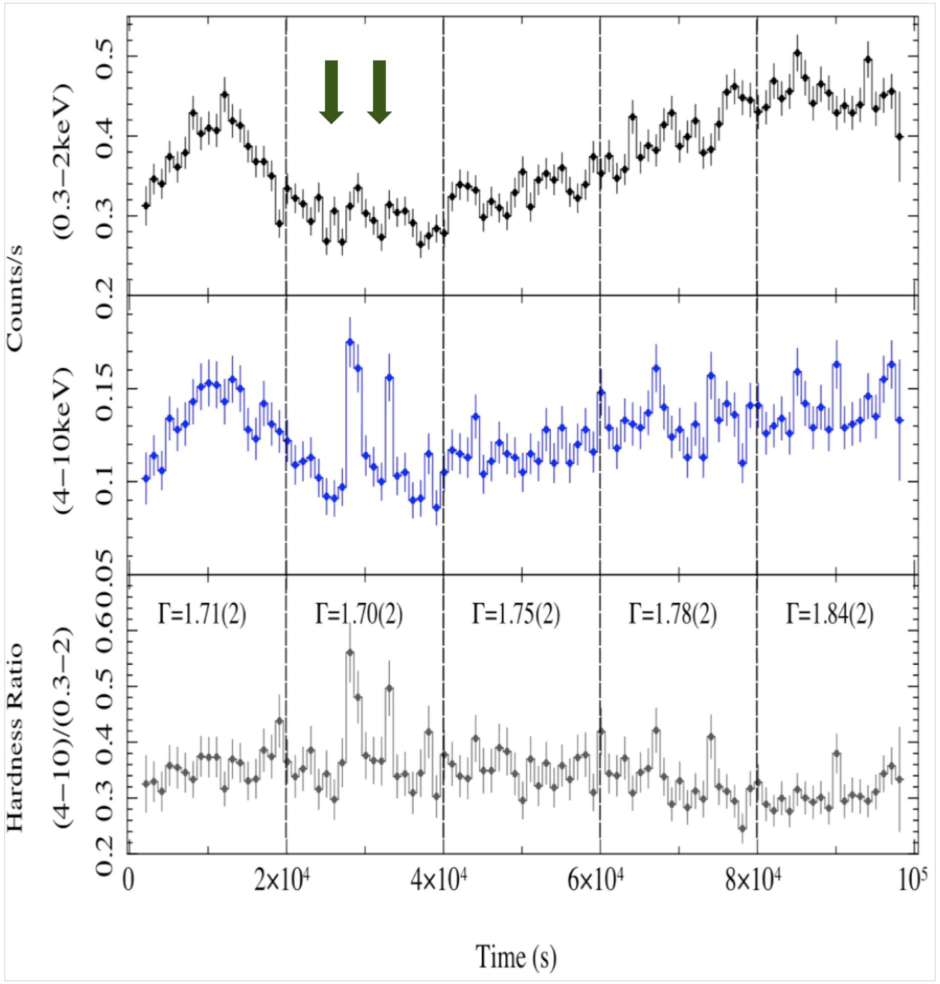
95 ks Chandra observation near apastron



1ks binning lightcurves in five time intervals



Bkg. Subtracted (0.3-10 keV) lightcurve binned at 100s

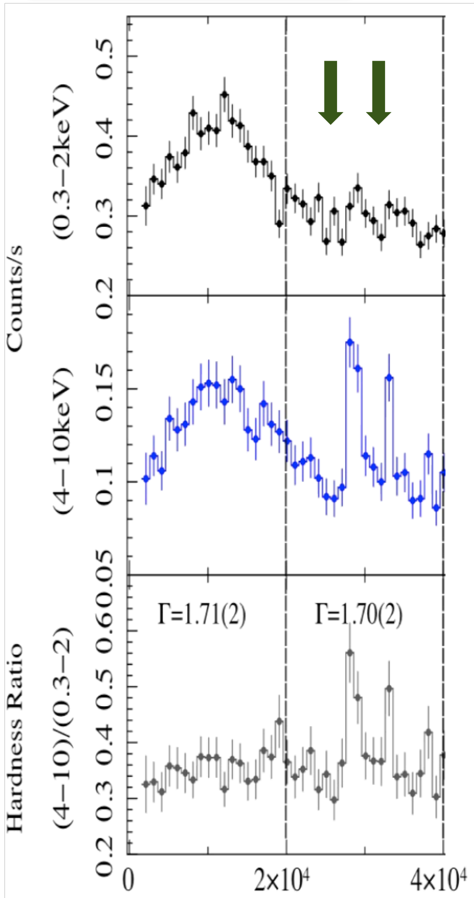


- On top of a slow variability of a factor of ~ 2, there were 2 flares lasting ~3 and 1.5 ks
- Not unseen in this source: Sidoli et al. 2006; Paredes et al. 2007; Esposito et al. 2007; Smith et al. 2009 have found some similar flares

From Rea, DFT, van der Klis, Jonker, Mendez, Sierpowska-Bartosik, MNRAS 2010

Do we understand these flares in pulsar models?

LS I +61 303



- Variability not observed in isolated pulsars

- In an accretion scenario, flares like these can be explained by variability in the accretion rate

- In the rotational-powered pulsar scenario, as the interaction between the pulsar wind and clumps in the Be wind.

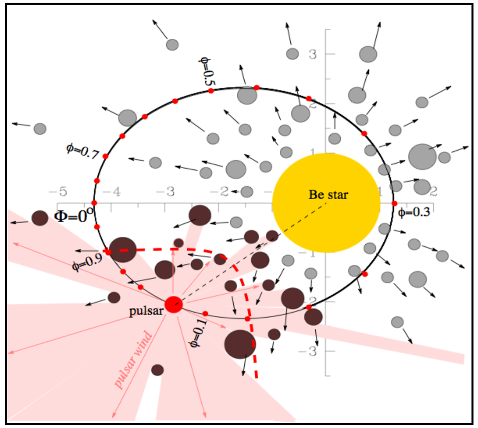
$$R_w \sim v\Delta t \sim 10^{11}\left(\frac{v}{10^7\ \mathrm{cm/s}}\right)\left(\frac{\Delta t}{10\ \mathrm{ks}}\right)\ \mathrm{cm}$$

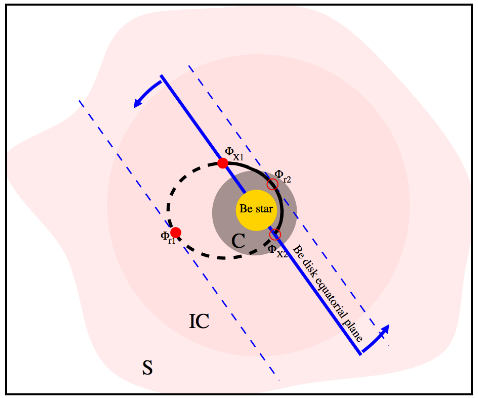
$$t_{esc} \sim D/v_{wind} \sim 100\left(\frac{10^{12}\ \mathrm{cm}}{D}\right)\left(\frac{10^7\ \mathrm{cm/s}}{v_{wind}}\right)\ \mathrm{ks}$$

$$t_{diff} \simeq 3\times10^6\left(\frac{R_w}{10^{11}\ \mathrm{cm}}\right)^2\left(\frac{B}{1\ \mathrm{G}}\right)\left(\frac{10\ \mathrm{MeV}}{E}\right)\ \mathrm{s}$$

$$t_{synch} \simeq 3\times10^5\left(\frac{1\ \mathrm{G}}{B}\right)^2\left(\frac{10\ \mathrm{MeV}}{E}\right)\ \mathrm{s},$$

$$t_{IC} \simeq 10^4\left(\frac{L_*}{10^{38}\ \mathrm{erg/s}}\right)\left(\frac{D}{10^{12}\ \mathrm{cm}}\right)^2\left(\frac{10\ \mathrm{MeV}}{E}\right)\ \mathrm{s}$$

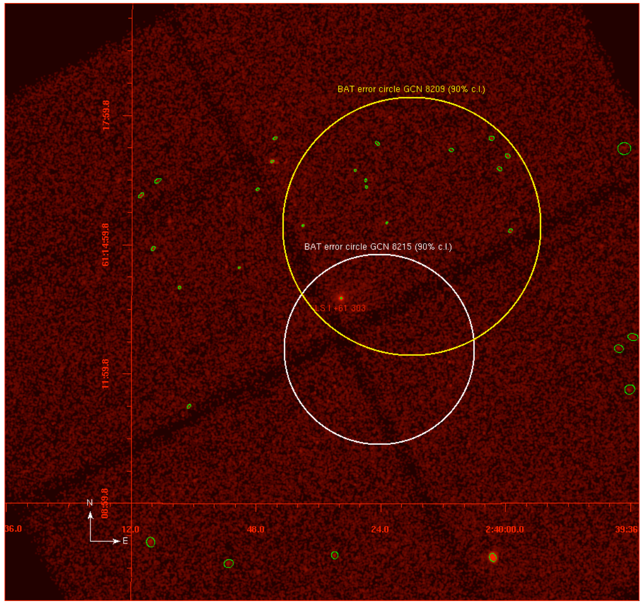


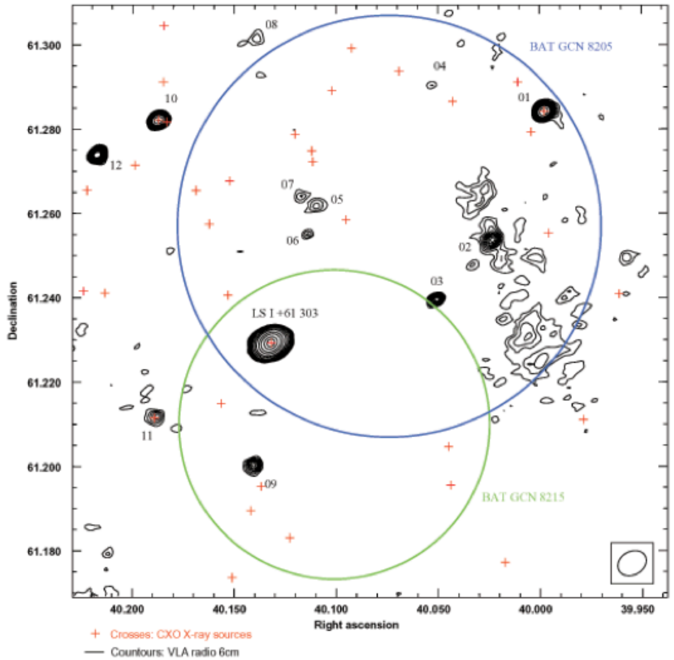


If the typical density of a clump in the wind is n ~ 10^{10} cm^{-3} and its size is R ~ 10^{11} cm, then δNH ~ n R ~ 10^{21}cm^{-2} . The strong dependence between NH, Γ and the power-law normalization, intrinsinc to the power-law modeling, might hide this variability in an increase of the hardness of the emission

Neronov & Chernyakova. et al. 2007

Shorter timescales variability resembling a magnetar?





• On 2008 September 10th, Swift-BAT triggered on a short SGR-like burst from the direction of LS I +61 303.
• The other telescope onboard, Swift-XRT did not detect the burst because started observing 921s after the BAT trigger.
• The burst location, lightcurve, duration, fluence, and spectra were fully consistent with a SGR/AXP

• Archival analysis of Chandra ACIS-I observation showed many faint sources in the field of view, some with VLA detections (16 compact radio sources within a 10 arcmin field of view with a peak flux density above four times the rms noise).

•Magnetars are not associated with compact radio sources.
•Thus, any X-ray source without a radio counterpart within the field of view could be the origin of the burst.

GCN 8209, 8211, 8215; ATELs 1715,1731, 1740

Accretion signatures in gamma-ray binaries?

•The presence of spectral lines is highly dependent on the continuum spectrum and on the orbital phase of the system.

• The best data available for these kind of studies come e.g., from the XMM-Newton satellite (large collecting area, spectral resolution, grating spectrometer).

•However, at a given orbital phase, only very short observations have been taken (aiming at monitoring the continuum spectral variability over the orbit).

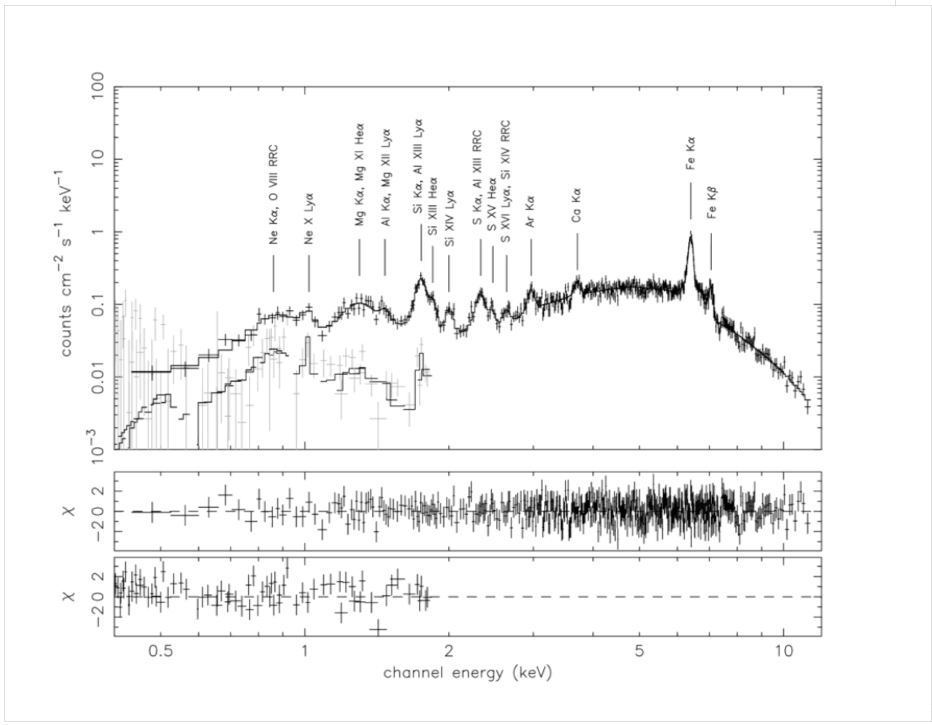
- •In the past XMM-Newton spectra of, e.g, LS 5039, an EW ~ 60 eV is the current 1σ limit on the presence of Fe Kα (and only in a small part of the orbit). In the available Suzaku observations, the limit on the detection of lines is 40 eV (see Takahashi et al. 2009).

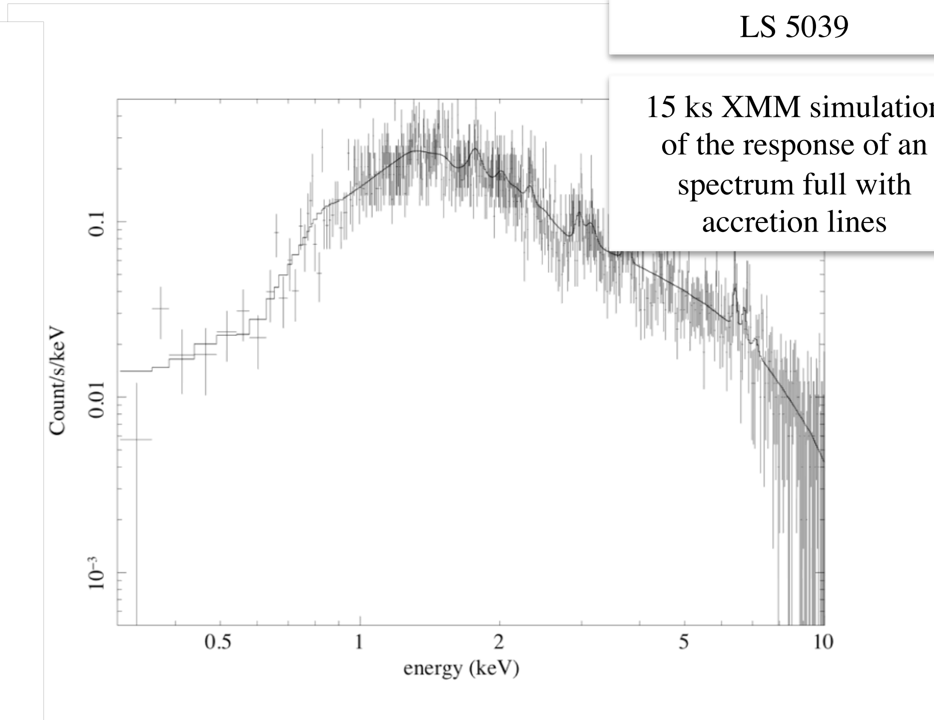
•With the current short pointings (at a given orbital phase) there are not enough counts to use the high-resolution spectral capabilities.

Accretion signatures: a word of caution

- Consider the binary 4U 1700-37,
    - A very similar HMXB to LS 5039 (i.e., similar companion star and 4-days orbital period, but no TeV emission, and clearly accreting) located at ~ 1.5 kpc

- Left: XMM-Newton spectrum of 4U 1700-37 (first published by van der Meer et al. 2005).
- Right: how would these accretion lines look, assuming all are present, in the available data for LS 5039





LS 5039

15 ks XMM simulation of the response of an spectrum full with accretion lines

Pulsation search

• Deep searches for pulsations have been performed in the radio band at several frequencies. However, no radio pulsations have been detected so far from candidates.

- • At PSR B1259–63's periastron there is no radio pulsation. Its periastron (given the large orbit, 3.4 year period) is approximately the same size than the major axis of the orbit of LS I +61 303 (26 days period) and it is way larger than LS 5039's obit (4 days period).

• The strong massive companion winds might have prevented radio pulsations to be detected because of the strong free-free absorption all over the orbits.

• PSR B1259-63 does not show X-ray pulsation either in the periastron (~15% pulsed fraction).

- • X-ray emission not-magnetospheric dominated?
- • beam not well-pointed?

• A clearly difficult game, hopefully to be aided by GeV observations.

Pulsation X-ray search: the current status (II)

LS 5039

~100 ks Chandra

But given the size of the orbit of LS 5039 as compared with LS I +61 303, we do not expect much difference in the results.

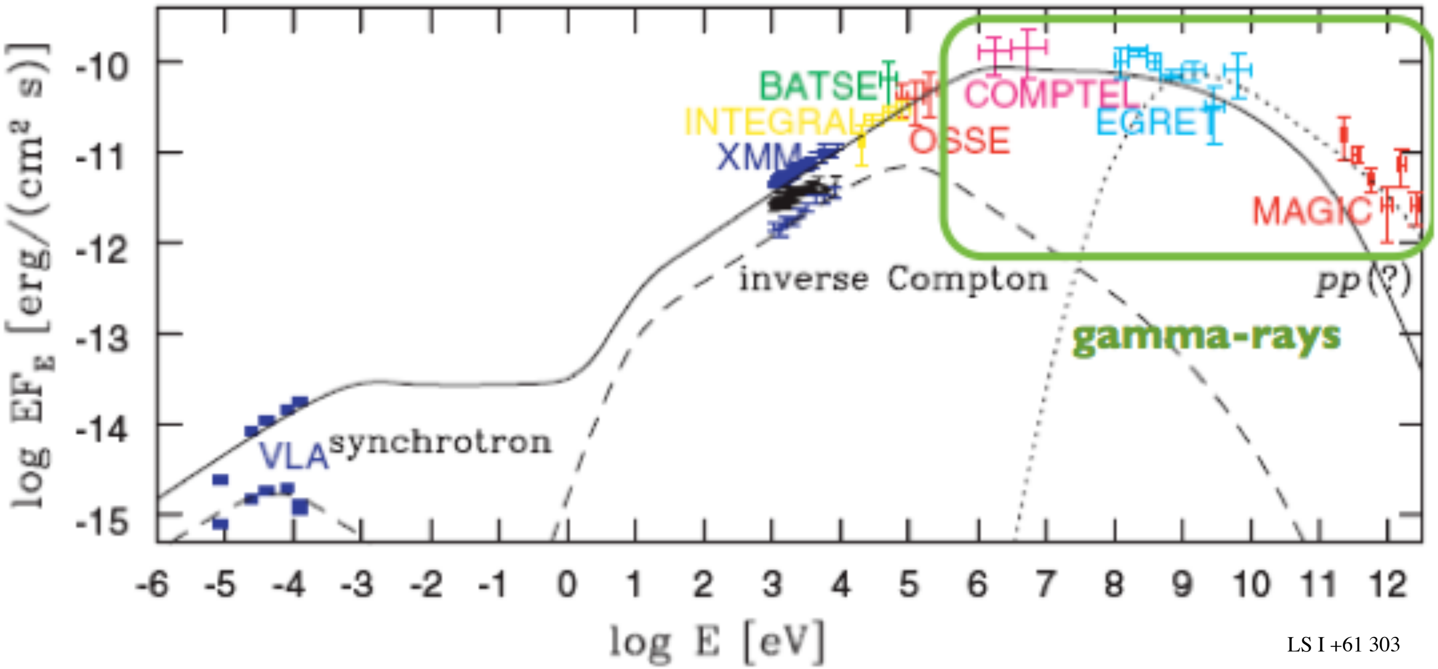
?

from Rea, DFT, van der Klis, Jonker, Mendez, Sierpowska-Bartosik 2010b; in preparation

Gamma-rays from binaries and gamma-ray binaries

•gamma-ray binaries:
 when gamma-ray emission above 10 MeV dominates the SED output (apart the star)

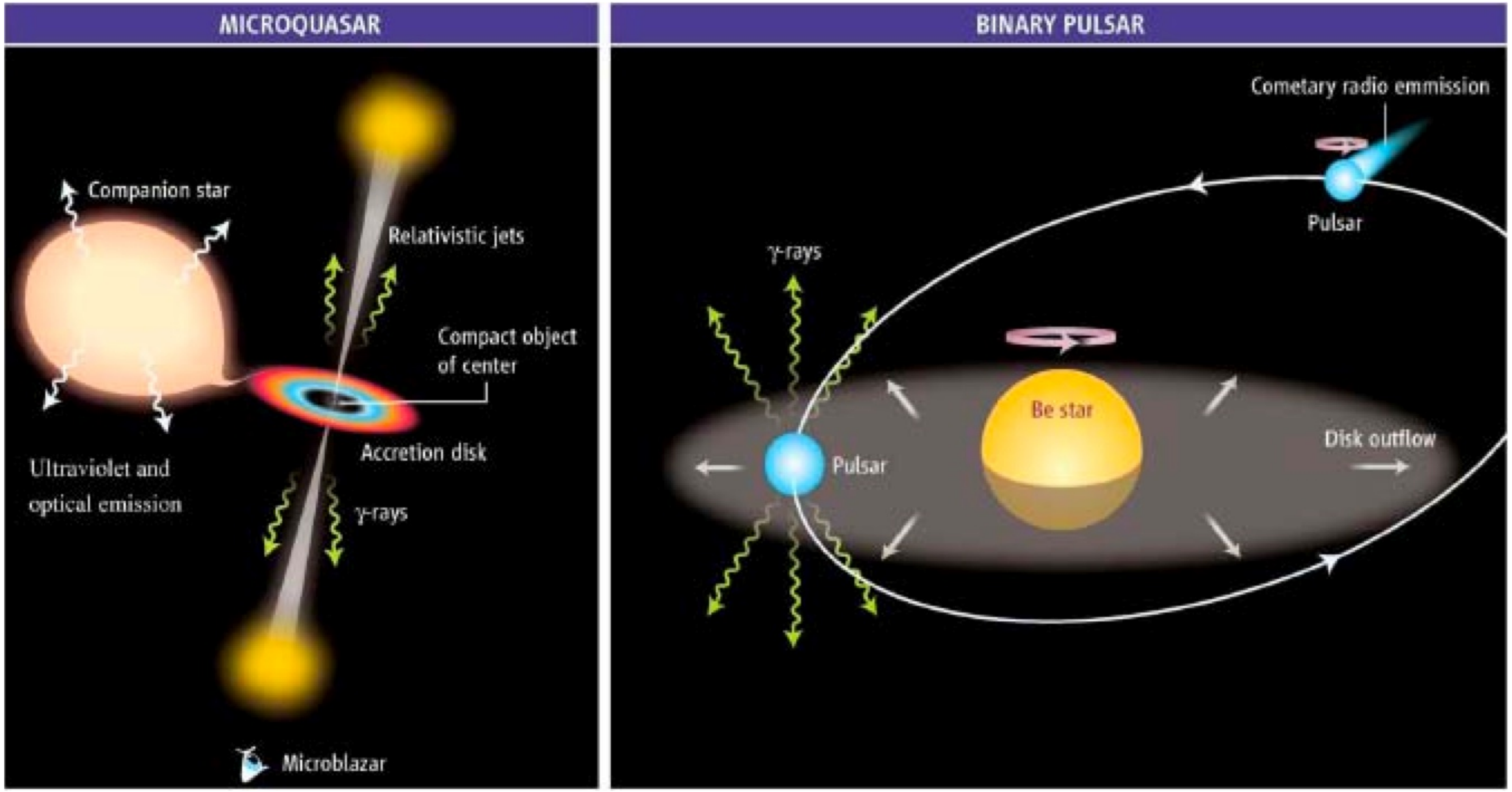
•This is the case for LS 5039, PSR B1259-63, LSI+61 303
•This is not the case for Cyg X-1 (for which $L_{vhe} \sim 10^{-4} L_x$)
•Other clear distinctive phenomenology: orbital variability vs. flares



LS I +61 303

Plot from Chernyakova et al. 2006

Dichotomy in composition



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Long-term monitoring of LS I +61°303 with INTEGRAL

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- We investigated the hard X-ray spectral and timing properties of this source using the IBIS/ISGRI instrument on-board the INTEGRAL satellite.

- We carry out a systematic analysis based on all available INTEGRAL data since December 28, 2002 up to April 30, 2009.

- The total exposure time analyzed amounts to 2.1 Ms

- The source is best detected in the 18-60 keV band, with a significance level of 12.0σ. The hard X-ray data are best fit with a simple power law with a photon index of ~ 1.7±0.2. We detect a periodical signal at 27 ± 4 days, matching the orbital period of 26.496 days previously reported at other wavelengths.

- The hard X-rays orbital lightcurve is obtained and compared with those derived at other frequencies.

INTEGRAL observations

Table 1. The flux and significance of LS I +61°303 obtained from the mosaic images of the combined ISGRI/IBIS observations.

Energy (keV)	flux ct/s	flux mCrab	sig. σ
20-40	0.21±0.02	1.60±0.16	10.0
40-100	0.16±0.02	2.10±0.28	7.6
100-300	0.07±0.02	5.00±1.25	4.0
18-60	0.32±0.03	1.60±0.13	12.0

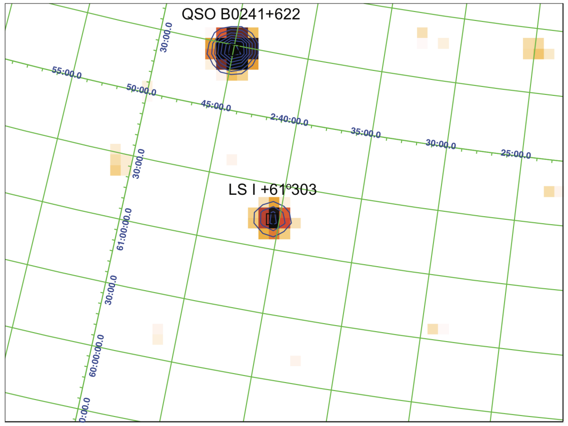

Figure 1. The mosaic image of the LS I +61°303 sky region derived by combining all ISGRI data at the 18 – 60 keV band. The strongest source is QSO 0241+622 (at the upper part of the image) and the relatively faint one is LS I +61°303. The significance level is given in the color scale. The contours start at a detection significance level of 5 σ, with a step of 3 σ.

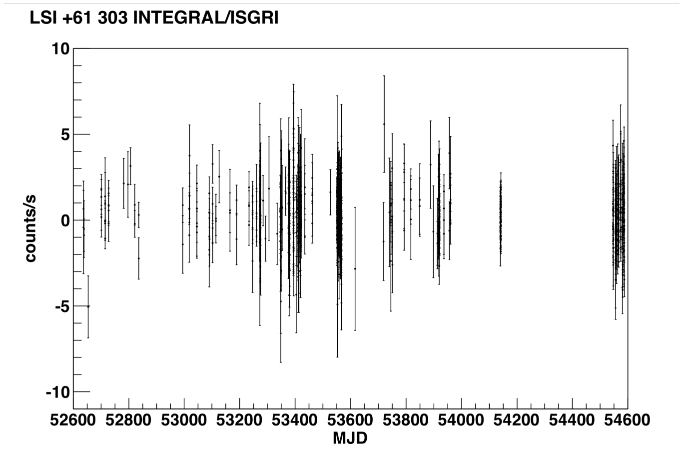

Figure 2. The ISGRI lightcurve at 18-60 keV. The bin size is one scw and the error bar is 1σ.

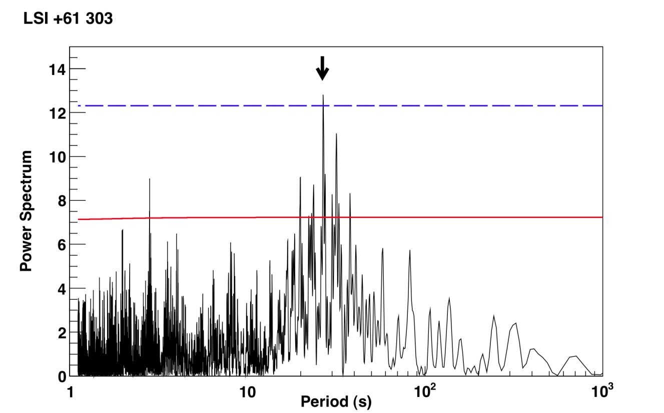

Figure 3. The Lomb-Scargle power spectrum based on the ISGRI lightcurve (18 – 60 keV). The white noise (dashed line) and the red noise (solid line) at the 99% confidence level are plotted. The LS I +61°303 orbital period of 26.496 days is indicated with an arrow.

The Fermi context