UNVEILING THE SUPER-ORBITAL MODULATION OF LS I +61 303 IN X-RAYS

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Outline

Jian Li

- Introduction
- Evidence of super-orbital modulation observed in X-ray
- Summary

1. Introduction of LSI +61 303

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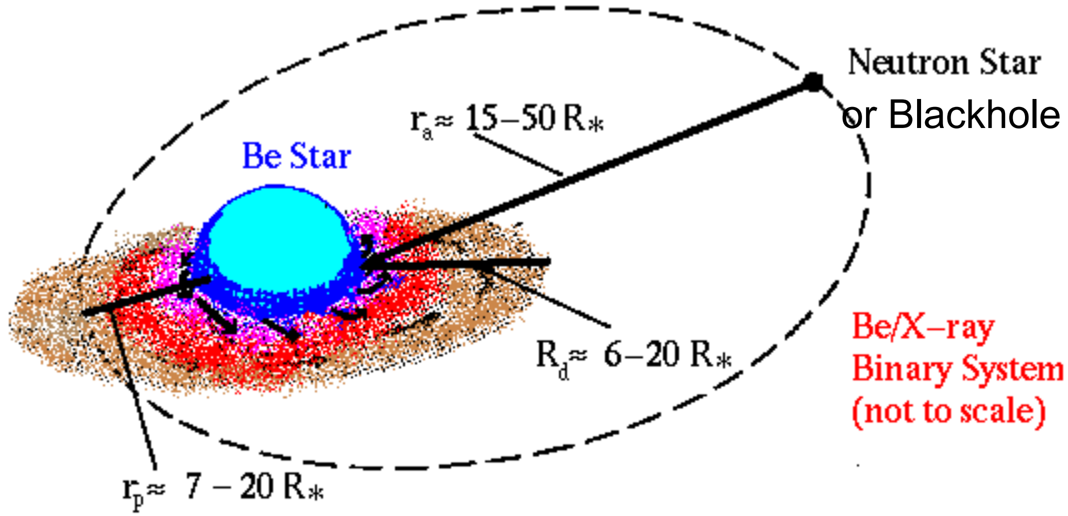

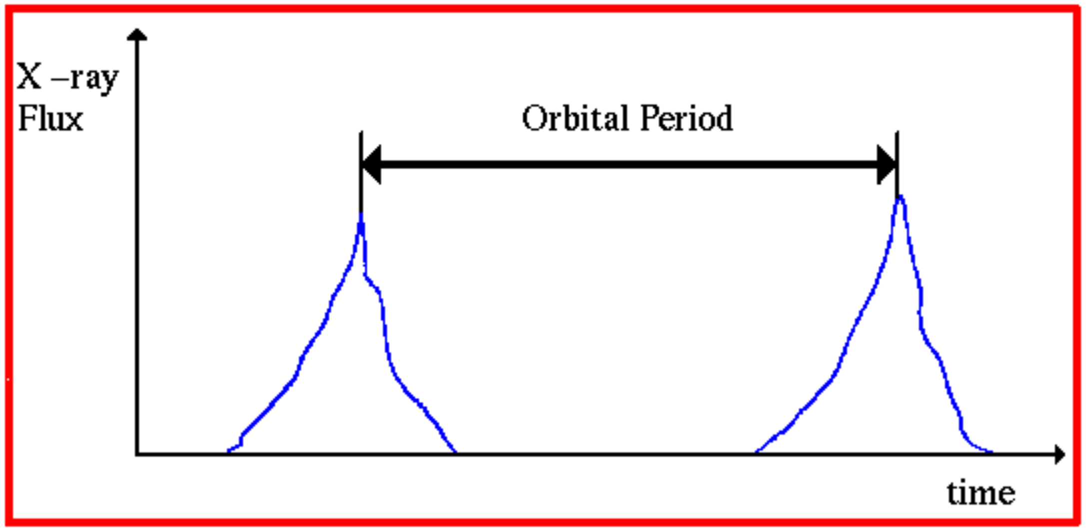

LSI +61 303 is a high mass X-ray binary system located at a distance of 2±1 kpc with an orbit period of 26.496±0.0028 days.

Hosting a B0 Ve main sequence star with a mass of ~12.5±2.5 $M_\odot$ and a radius of ~10 $R_\odot$

A compact object (1-4 $M_\odot$)with unknown nature.

Conventional model for a Be/X-ray binary

The picture is based on a diagram from Snow (1987, in *Physics of Be stars*, Cambridge University Press).

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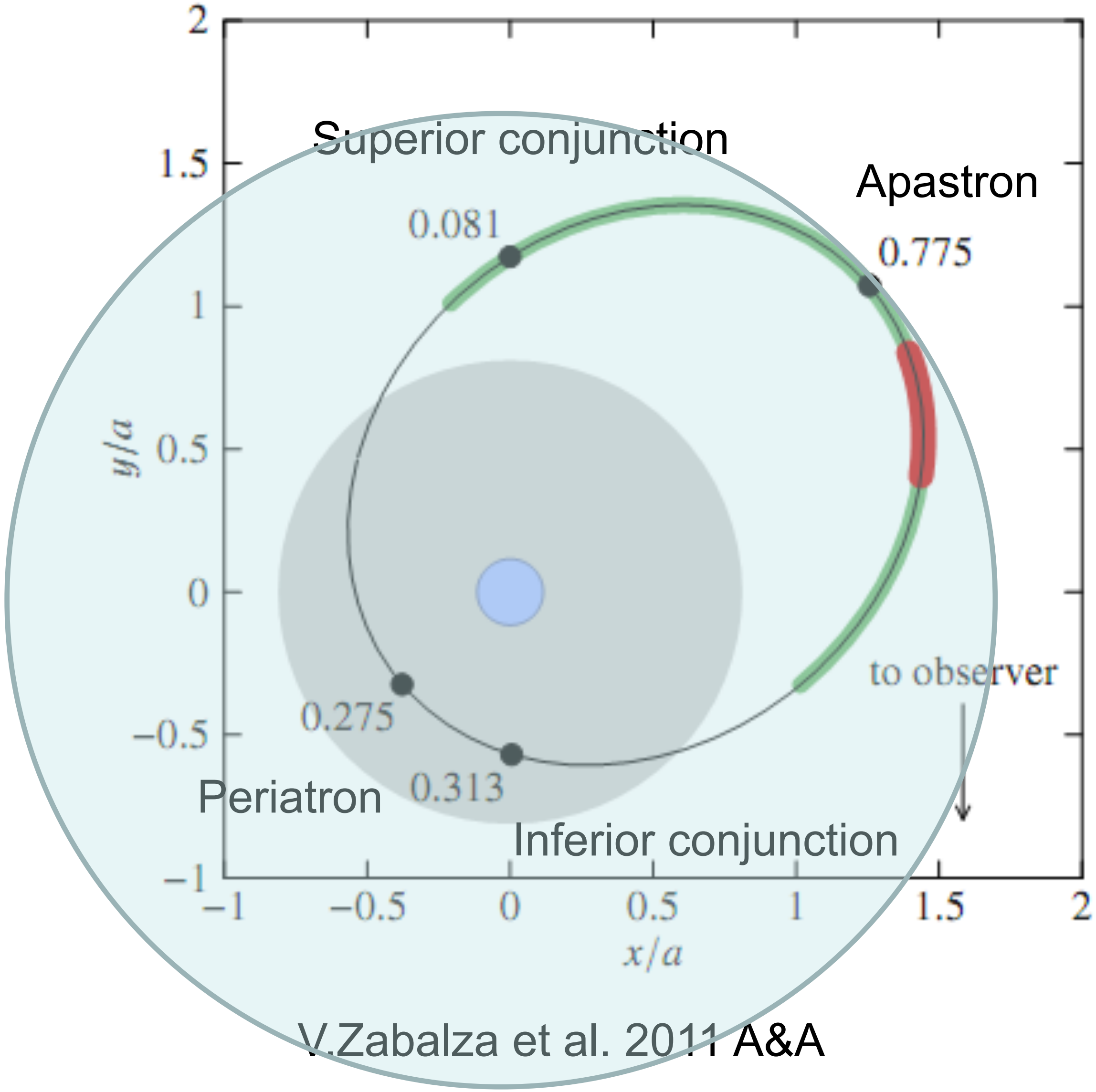

V.Zabalza et al. 2011 A&A

Orbital geometry (26.5 days period) of LS I +61 303 looking down on the orbital plane

LS I +61 303 is visible in radio, X-ray to very high energy (GeV and TeV)

Single peak orbital light curve both in X-ray and radio. (different from PSR B1259-63)

The X-ray peak is always before radio peak.

1. Introduction of LSI +61 303

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Compare to ~26.5 days orbit period, a super-orbital period is confirmed by Gregory (2002) at 1667±8 days through of more than 20 years radio data on LS I +61 303.

1667 days ~ 63 orbits~ 4.6 years

1. Introduction of LSI +61 303

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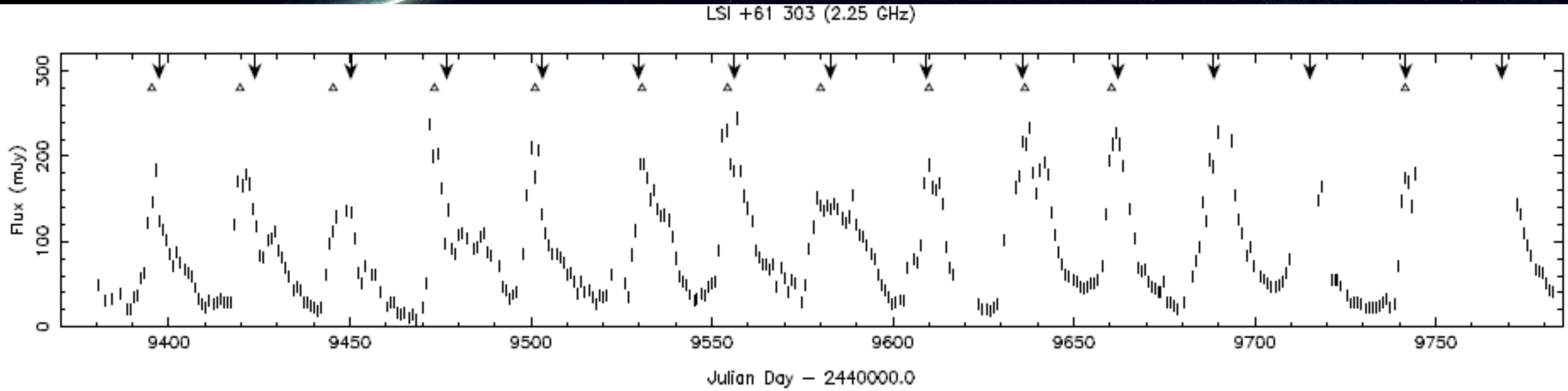
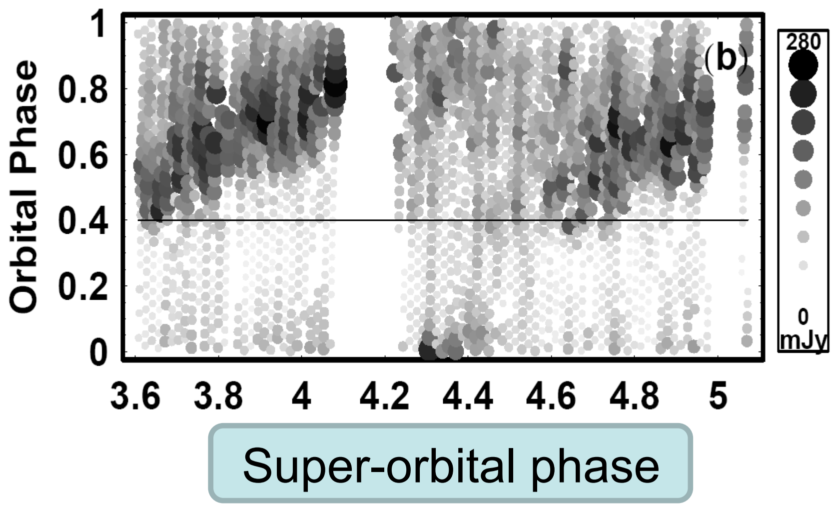
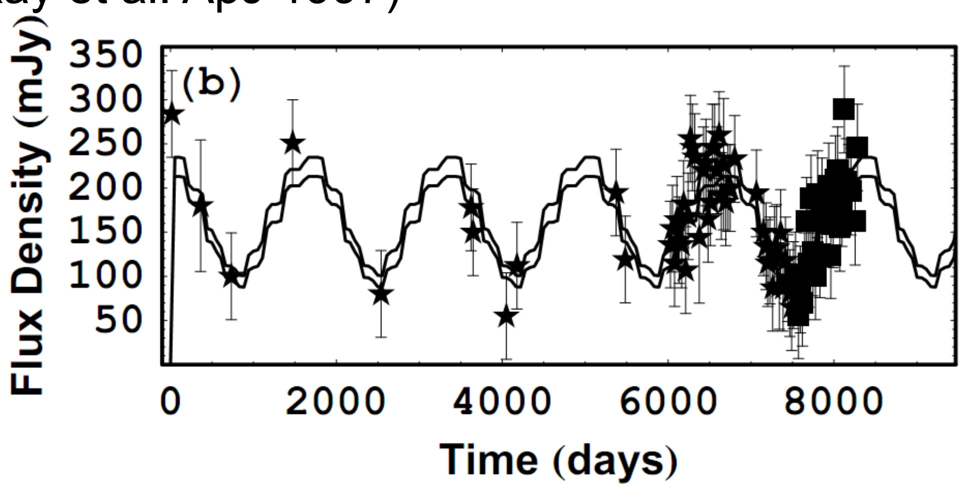


Flux history of LSI +61 303 at 2.25 GHz (Ray et al. ApJ 1997)



Intensity plots of the daily averaged flux densities



The peak flux density light curve vs. time in JD (Gregory 2002)

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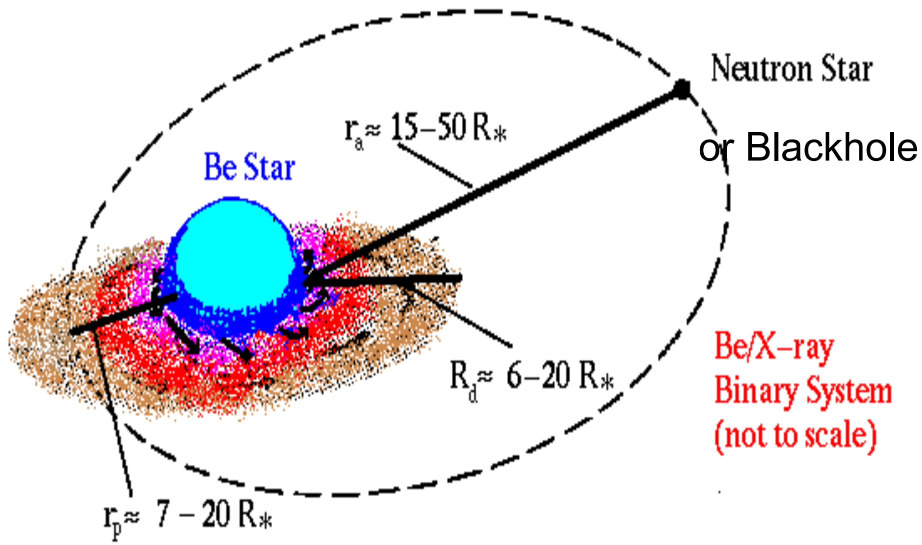
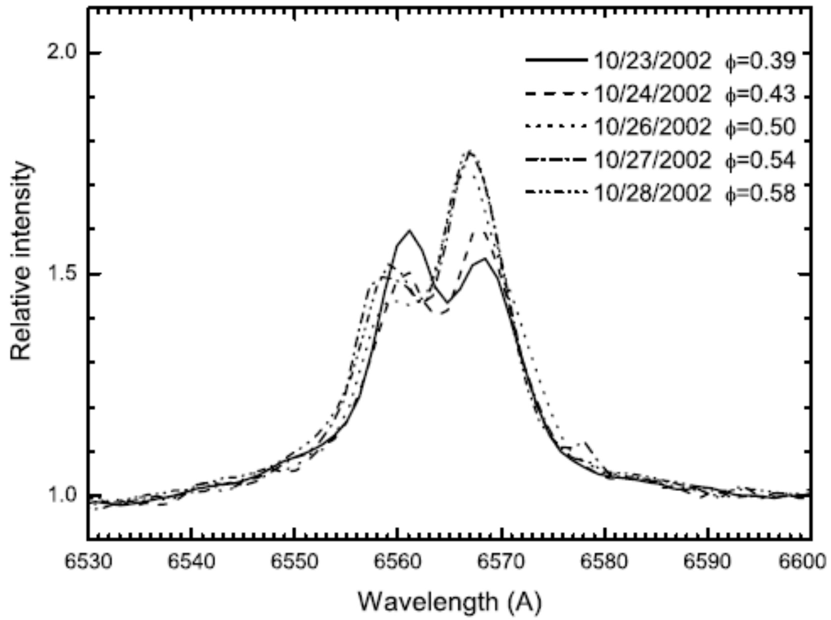
Super-orbital modulation is also seen in Hα emission line parameters (Zamanove et al. 1999; Zamanove et al. 2000). Hα emission comes mainly from the Be star disk (Hunushik, Kozok & Kaizer 1988) and its equivalent width is well known to stand for the size of the disk.

Based on the same period of super-orbital modulation in Hα, The 1667 days super-orbit modulation are likely due to quasi-cyclic variation in the circumstellar disk properties.

(Paredes, 1987; Gregory et al 1989).





Hα emission line of LSI + 61 303
(Liu & yan, 2005 New Astronomy)

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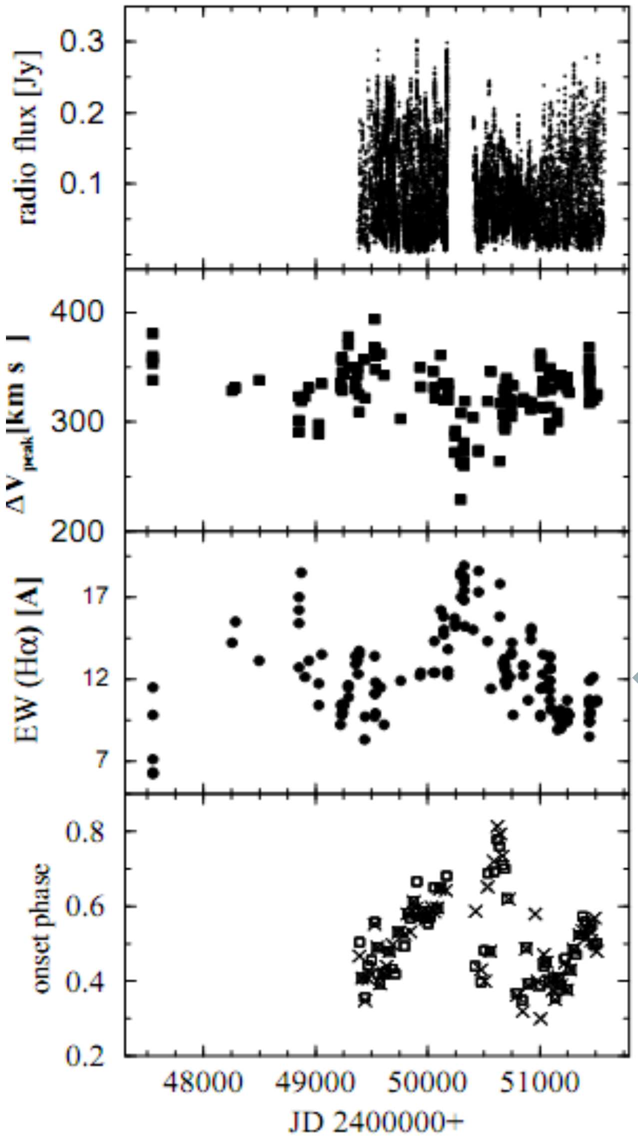

Fig. 1. $H\alpha$ and radio observations over the period 1989 - 2000. The regular Hα observations cover more than 2500 days. From top to bottom are plotted the radio flux density at 2.25 GHz, the $\Delta V_{\rm peak}$ of Hα, the EW(Hα), and the onset phase of the outburst relatively to the orbital (P_1) period. In the bottom panel, the squares refer to 2.25 GHz and (×) - to 8.3 GHz. The traces of the ∼4 yr modulation are visible in all panels.

R. Zamanov A&A 2000

Super orbital variability of Ha equivalent width

1. Introduction of LSI +61 303

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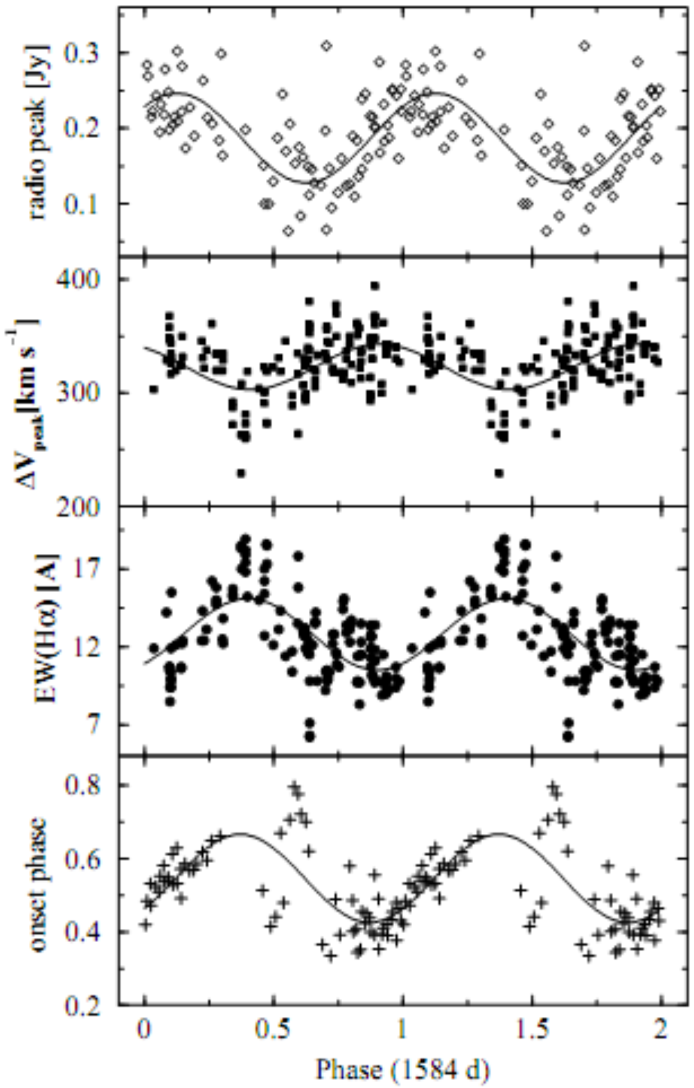

Fig. 2. The radio and Hα parameters folded on P_2=1584 day period with phase zero at JD2443366.775. The upper panel represents the radio outburst peak flux. The Hα panels are the same as in Fig. 1. The bottom panel represents the averaged values of the onset phase from 2.25 GHz and 8.3 GHz.

Super orbital variability of Ha equivalent width (folded)

R. Zamanov A&A 2000

1. Introduction of LSI +61 303

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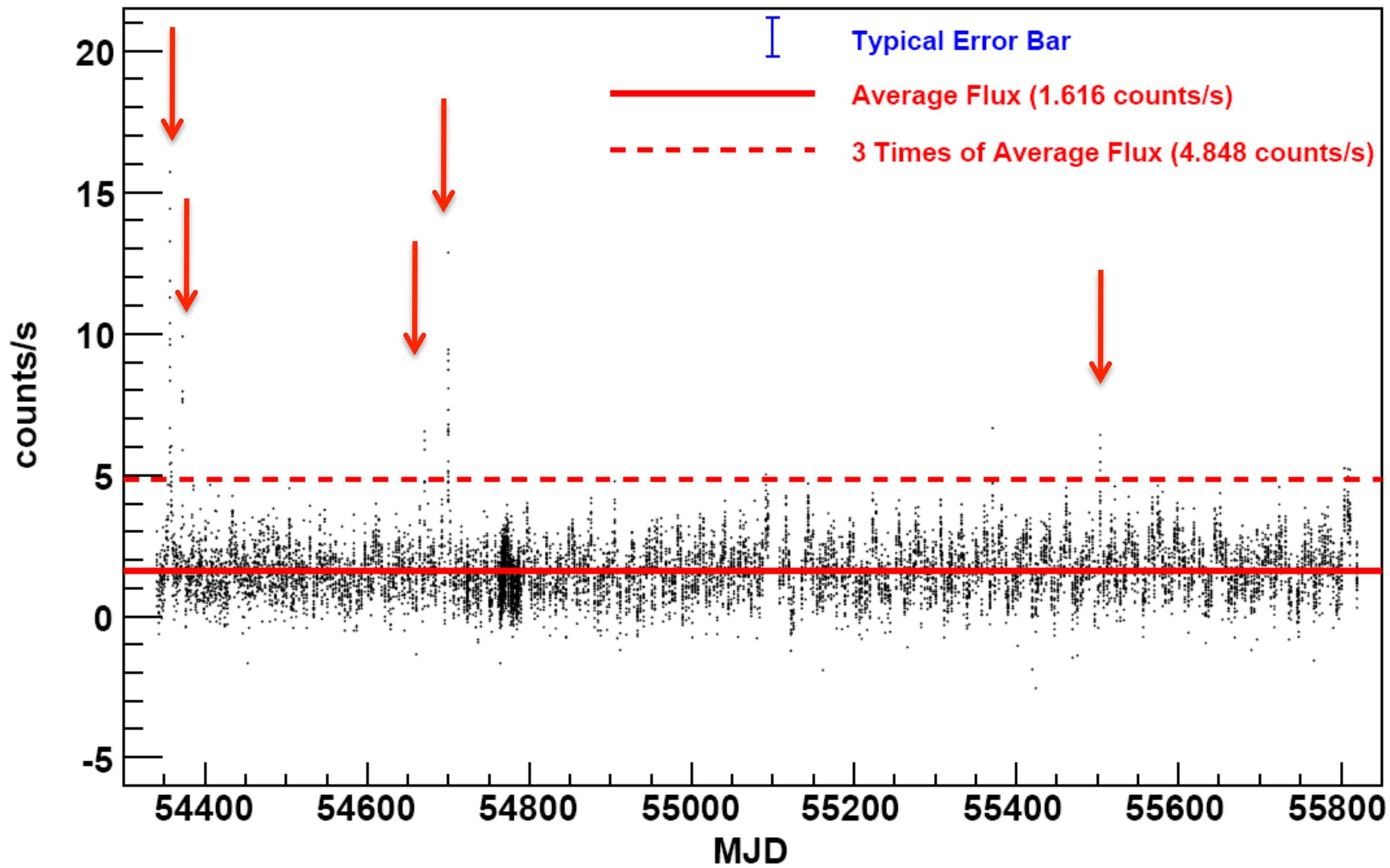
- Super-orbital modulation in radio and Hα promotes us to find similar modulation evidence in X-ray and link it to the mass loss rate of the Be star.

The most comprehensive monitoring campaign at soft X-rays done so far was with PCA on RXTE, providing a continuous monitoring since 2007-08-28 till the end of 2011
(more than 4 years).

2. Evidence of super-orbital modulation in X-ray

Jian Li



- RXTE/PCA light curve of LSI + 61 303 in 3-30 keV, 64s time bin. (2007-08-28---2011-09-15)
- Red line stand for the average flux while dotted line stand for 3 times of average flux, which is the criteria by which we cut the data

J. Li et al, 2012

2. Evidence of super-orbital modulation in X-ray

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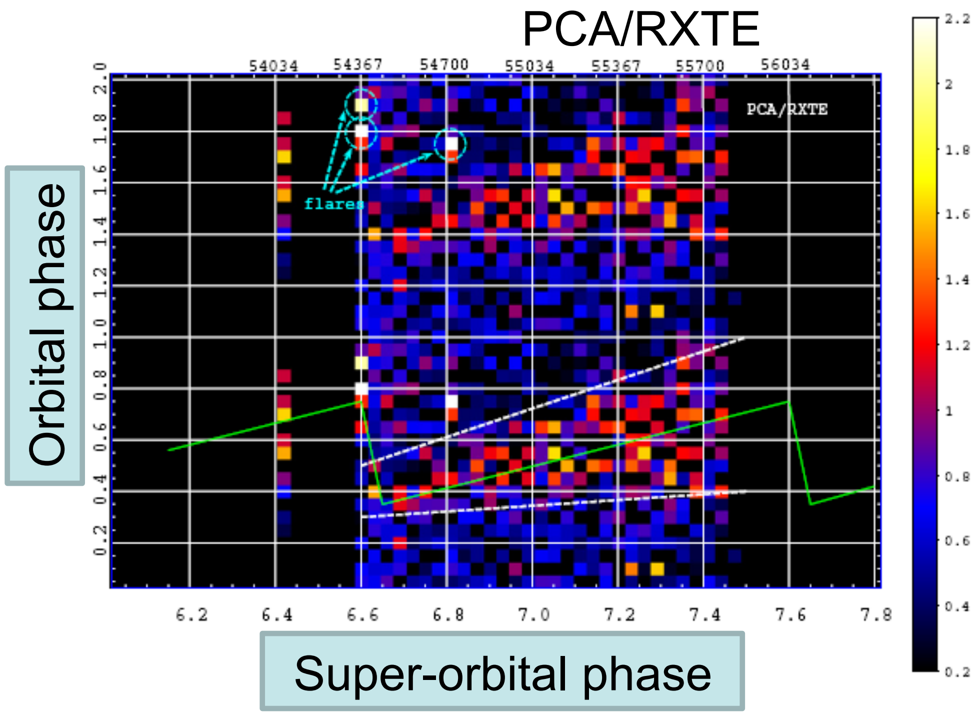

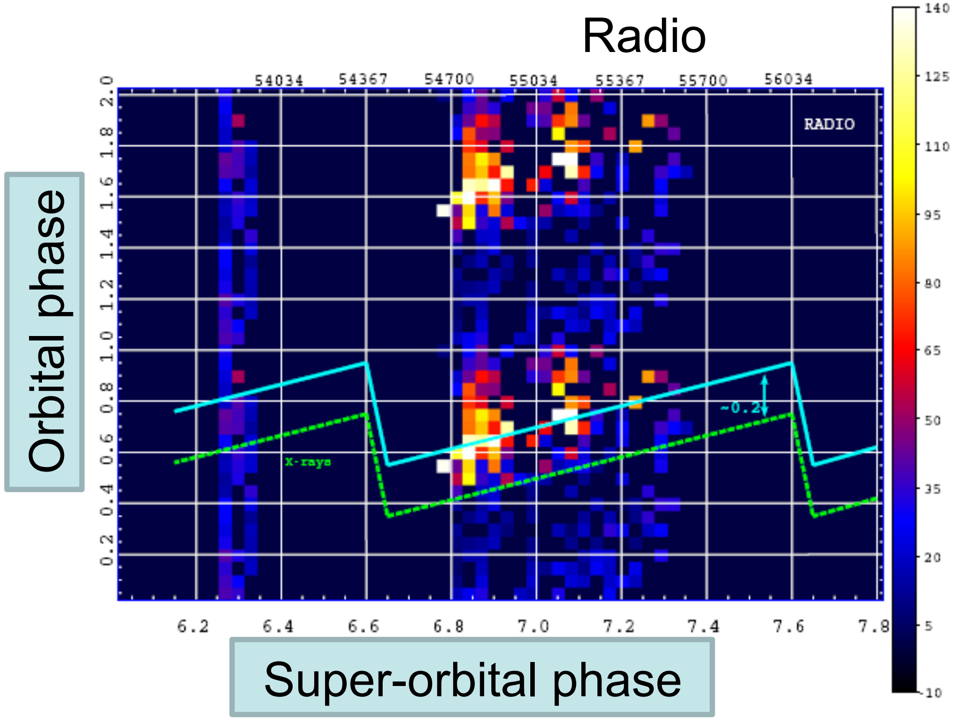

RXTE observations give an evidence for a peak phase drift in X-rays as well. Simultaneous observations with Ryle and AMI telescopes (15.4 GHz) shows that phase of the X-ray activity period always precedes the phase of the radio outburst by 0.2 orbita phase (5.3 days).

M. Chernyakova et al, 2012

2. Evidence of super-orbital modulation in X-ray

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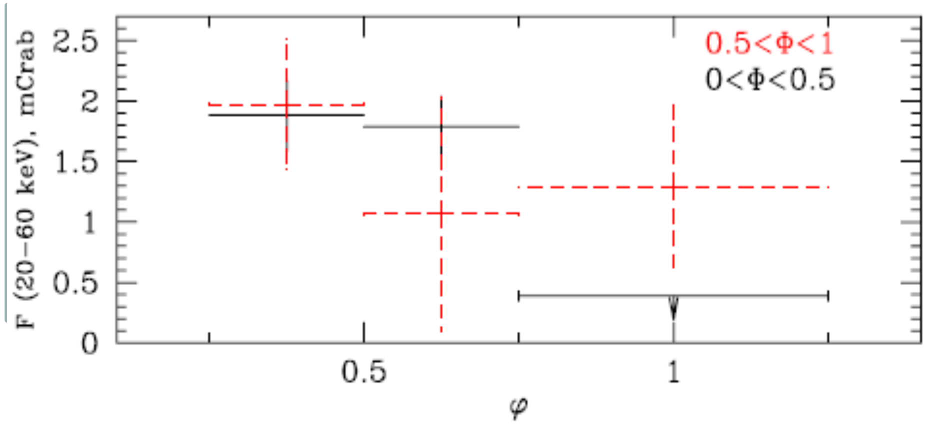
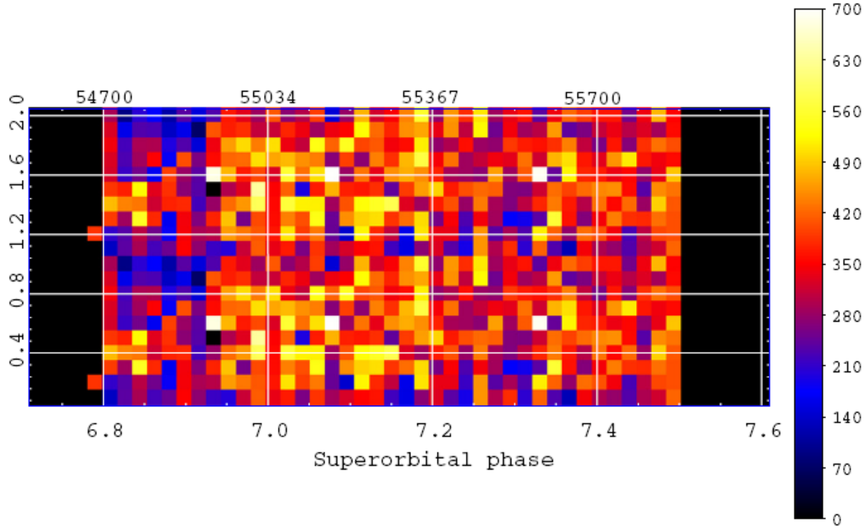
INTEGRAL/ISGRI

Fermi/

M. Chernyakova et al, 2012





Orbital phase

Super-orbital phase

The maximum flux at 20 - 60 keV happens during the orbital phase 0.25< φ <0.5 in the super-orbital cycle phase 0.5< Φ <1. The maximum shifts toward 0.25 < φ < 0.75 in the super-orbital phase 0 < Φ < 0.5.

Super-orbital modulation in the GeV band is puzzling. Orbital modulation was clearly observed at the beginning at the super-orbital phase 6.8 < Φ < 6..9. However afterwards a clear orbital modulation pattern disappeared.

2. Evidence of super-orbital modulation in X-ray

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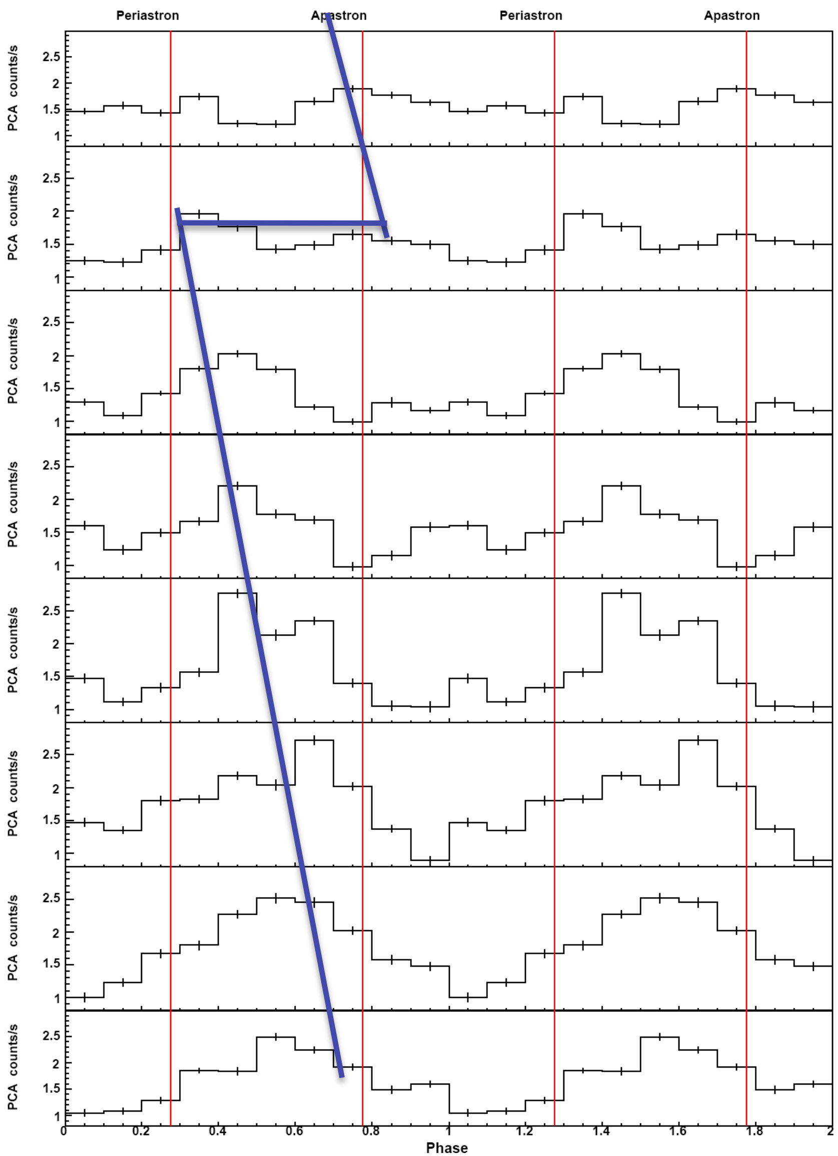

Folded 3−30 keV light curves of eight separate six-month periods

28/08/2007 - 28/02/2008, MJD 54340 – 54524

29/02/2008 - 29/08/2008, MJD 54525 - 54707

30/08/2008 - 01/03/2009, MJD 54708 - 54891

02/03/2009 - 02/09/2009, MJD 54892 - 55076

03/09/2009 - 03/03/2010, MJD 55077 - 55258

04/03/2010 - 04/09/2010, MJD 55259 - 55443

04/09/2010 - 04/03/2011, MJD 55444 - 55624

05/03/2011 - 15/09/2011, MJD 55625 - 55819

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2. Evidence of super-orbital modulation in X-ray

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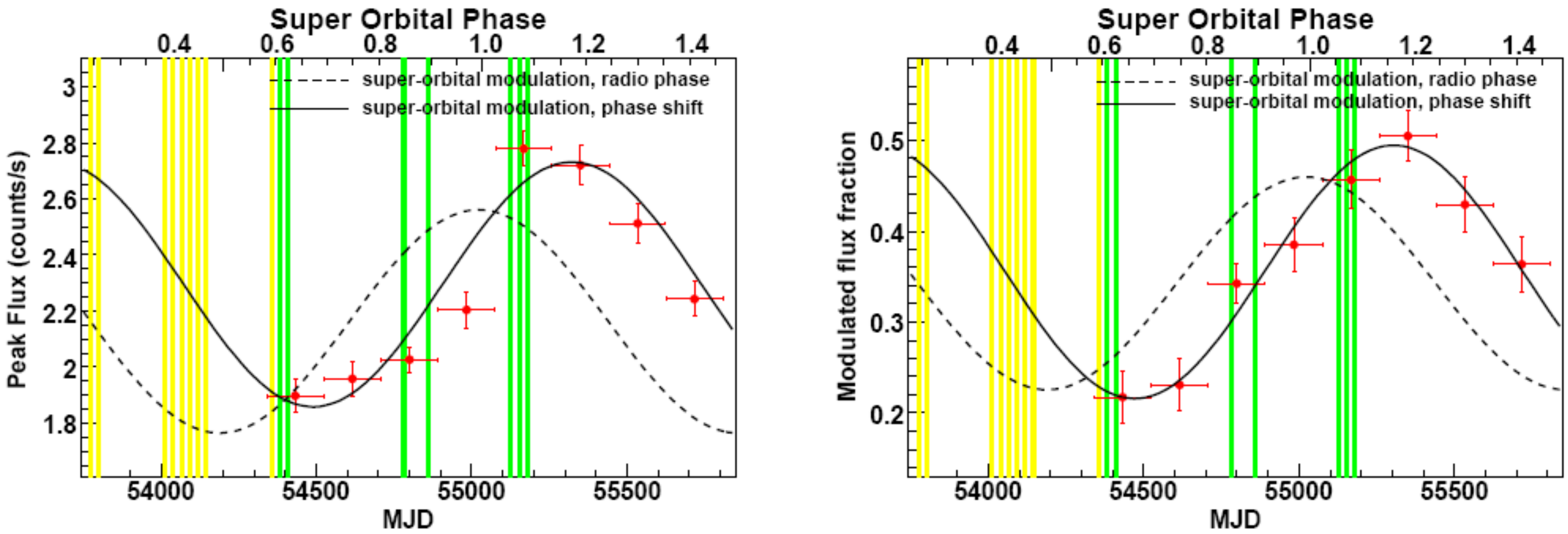

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Left: Peak count rate of the X-ray emission from LS I +61 303 as a function of time and the super-orbital phase.
Right: modulated fraction (defined as (Max-Min) / (Max+Min), Max and Min are from 3-30 keV orbital lightcurve)

The dotted line shows the sine fitting to the modulated flux fraction and peak flux with a period and phase fixed at the radio parameters. The solid curve stands for sinusoidal fit obtained by fixing the period at the 1667 days value, but letting the phase vary.

The colored boxes represent the times of the TeV observations that covered the broadly-defined apastron region. The boxes in green denote the times when TeV observations are in low state while boxes in yellow are TeV observations in high state.

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2. Evidence of super-orbital modulation in X-ray

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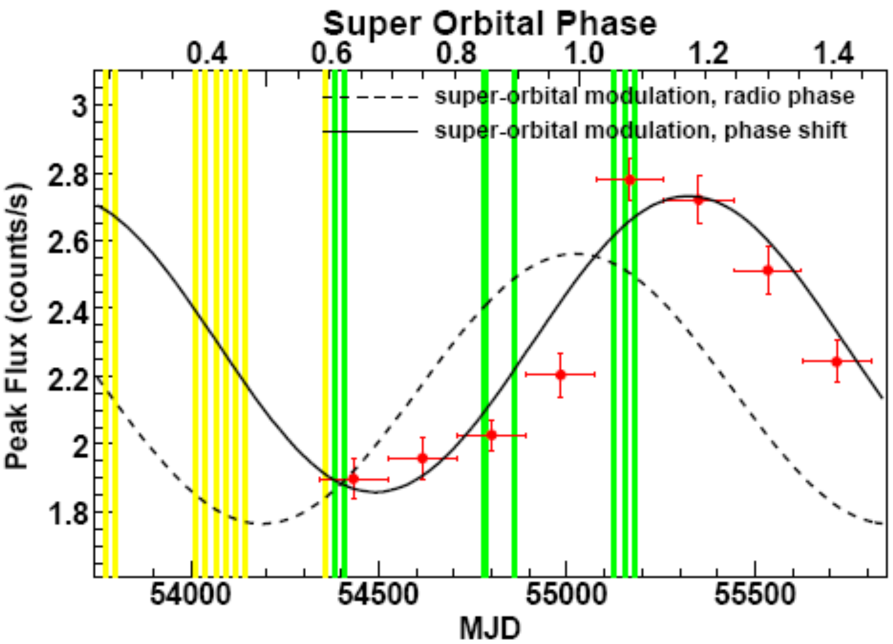

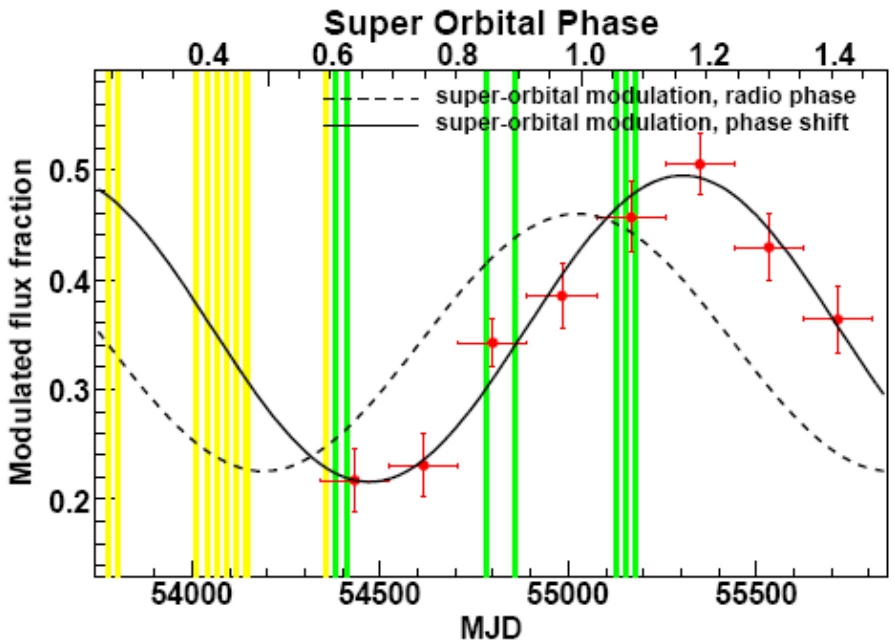

Table 1: Reduced χ^2 for fitting different models to the modulation fraction and the peak flux in X-rays.

	Constant	Linear	Radio	Shifted
Modulation Fraction	88.2 / 7	38.0 / 6	42.1 / 6	1.1 / 5
Peak Flux	212.8 / 7	114.8 / 6	91.8 / 6	4.9 / 5

The phase shift derived by fitting between radio and X-ray is 300.1 ± 39.1 days for maximum flux and 281.8 ± 44.6 days for modulation fraction, which corresponding in phase to ~ 0.2 of the 1667±8 days super-orbital period.

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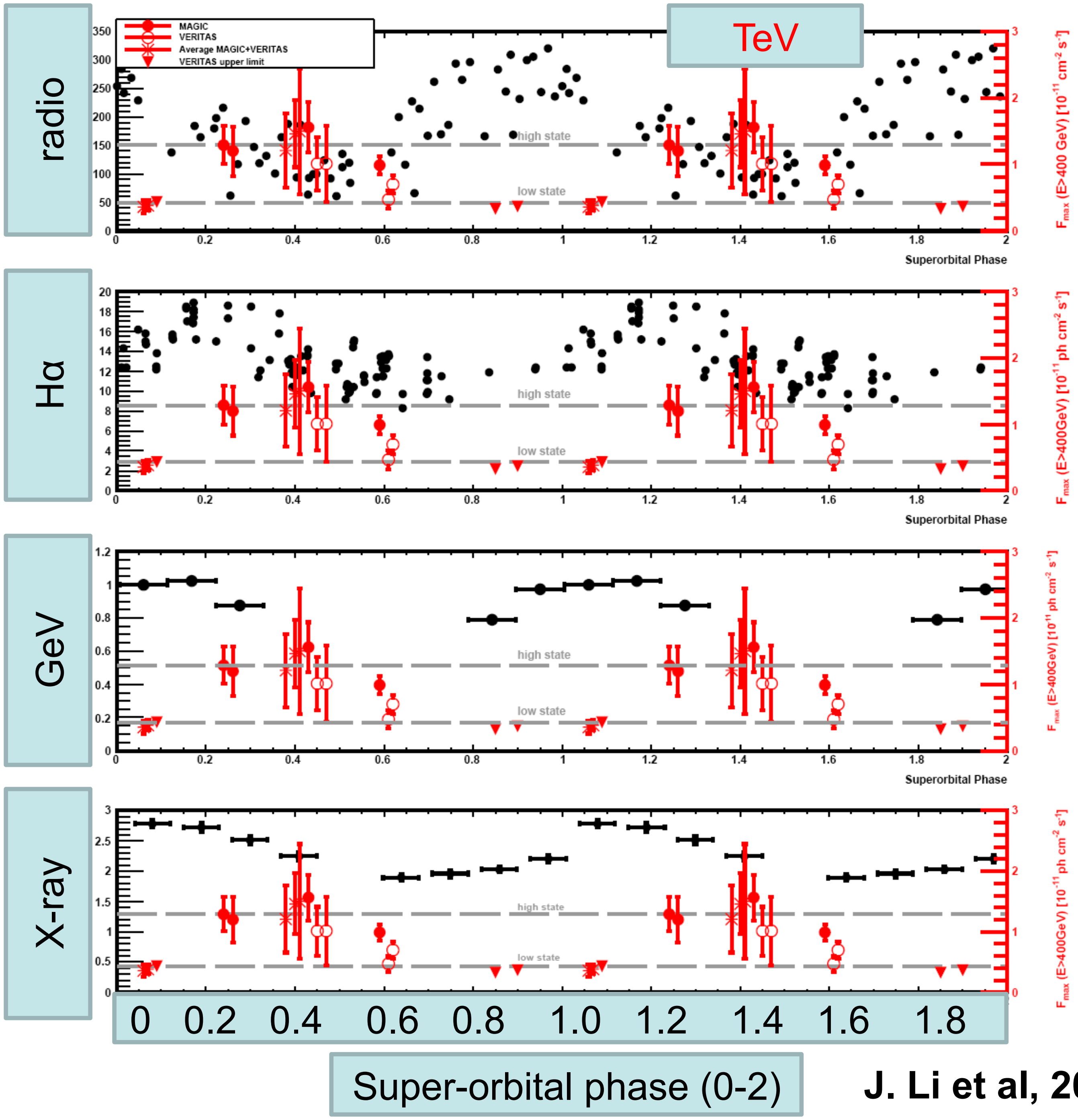

Peak flux per orbit in TeV shown in red (all of them happening in the 0.6–1.0 orbital phase range) as a function of super-orbital phase, together with radio, Ha (black, Zamanov et al.2000). GeV and X-ray data

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3. Summary

Jian Li

Summary:

1. We found evidence for super-orbital modulation in X-rays
   (drift of orbit lightcurve peaks;
   modulation in maximum flux & modulation fraction)

2. Super-orbital modulation in the GeV band is puzzling.

3. There is a phase shift about 290 days in super-orbital modulation between radio and X-ray.

4. The equivalent width of the Hα emission line is in phase with X-ray variation

5. TeV emissions seems to be correlated with super-orbital modulation, but because of limited data, it is still unconfirmed.

Thank you!

- Special acknowledgment to my colleagues :

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