Unveiling the Super-orbital Modulation of LS I +61 303 in X-rays

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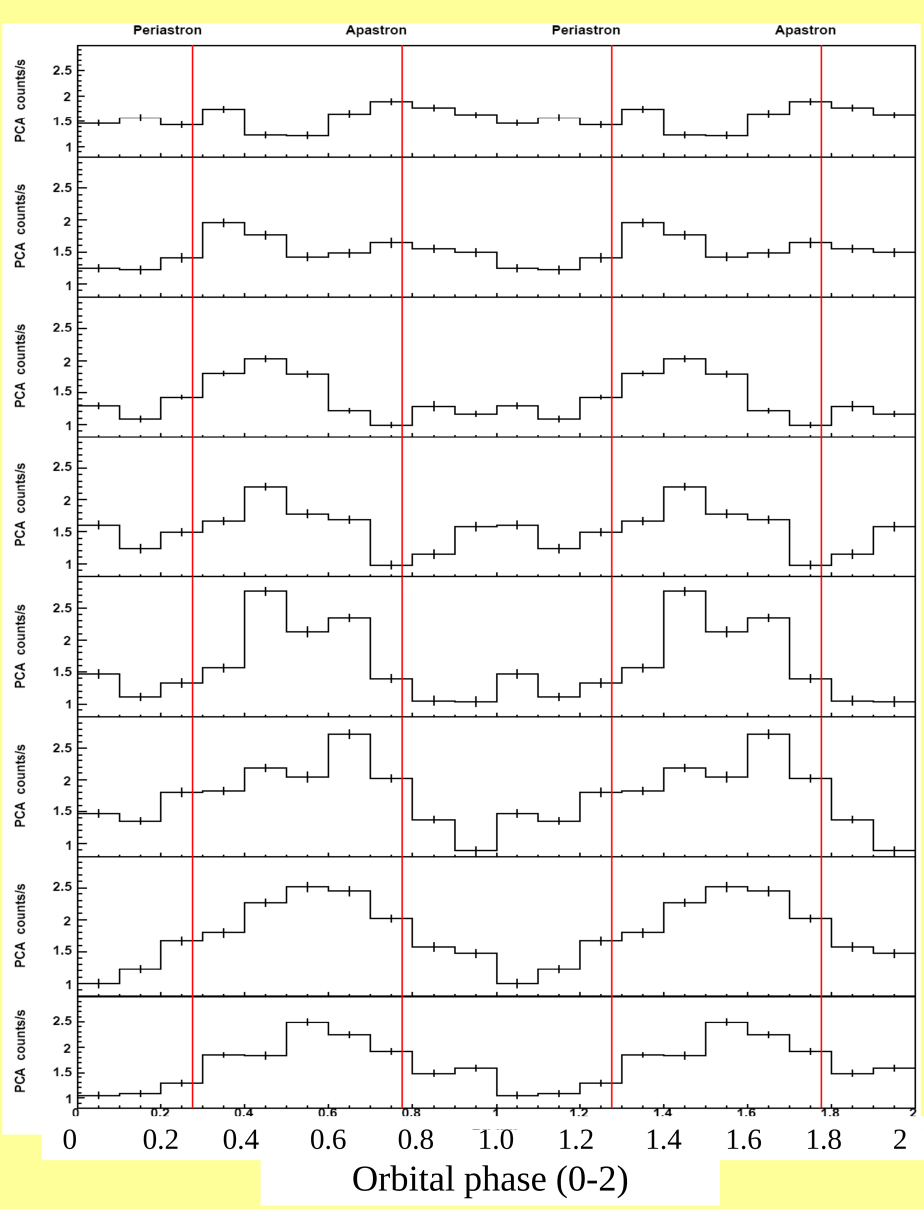
Abstract

LS I +61 303 is a Be X-ray binary with 26.5 days orbit period. It is one of the few X-ray binaries emitting high energy gamma-rays but its nature is still under debate, with rotationally powered pulsar-composed systems and microquasar being discussed. However, it enters a low TeV state in recent years for an unknown reason. From the longest monitoring of LS I +61 303 by RXTE we found evidence for the 1667 days super-orbital modulation in X-ray, which is probably related to the recent low state of TeV emission. The super-orbital modulation has already been detected at non-contemporaneous radio and optical measurements. We have found in phase super-orbital variability between optical frequencies and X-rays. However, the super-orbital variability at X-rays is lagged from radio frequency for 281.8+/- 44.6 days. We propose that the system's compact object is a high magnetic field, slow period pulsar.

1.Evidence of super-orbital modulation in X-rays

Folded 3−30 keV RXTE/PCA orbital light curves (orbital phase 0-2) of eight separate six-month periods



28/08/2007 - 28/02/2008

29/02/2008 - 29/08/2008

30/08/2008 - 01/03/2009

02/03/2009 - 02/09/2009

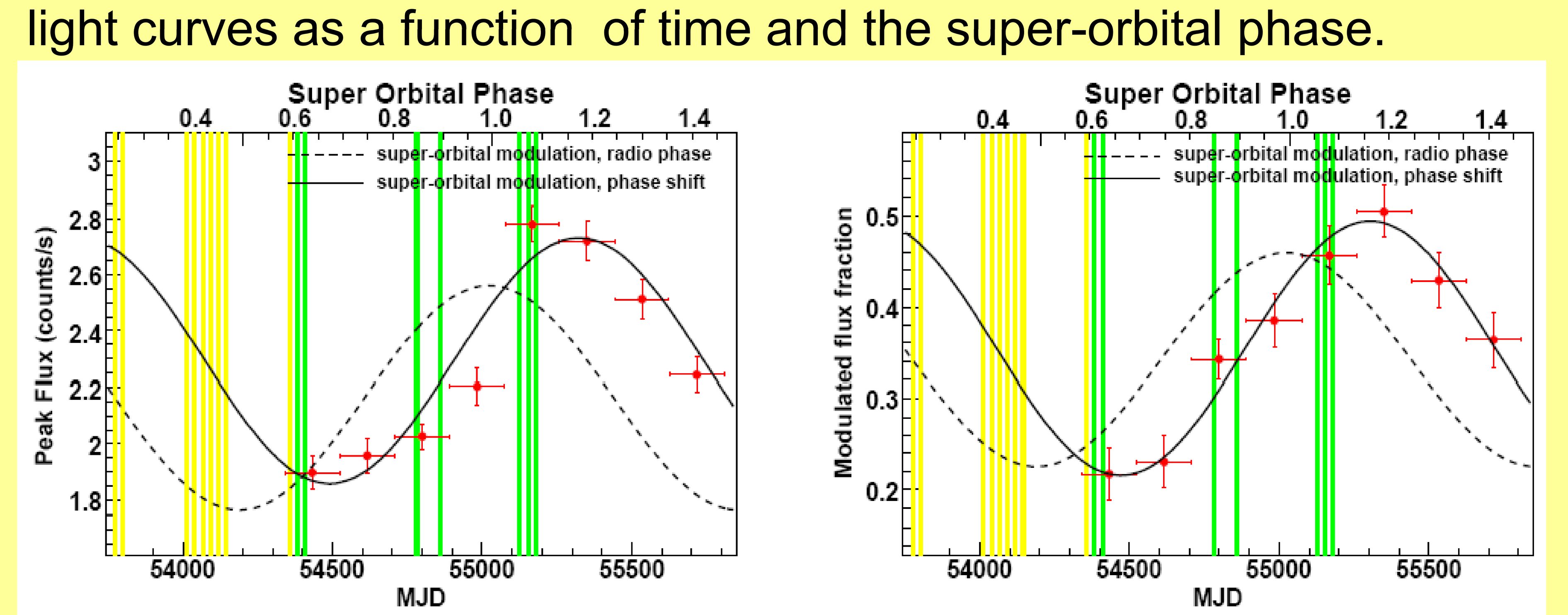
03/09/2009 - 03/03/2010

04/03/2010 - 04/09/2010

04/09/2010 - 04/03/2011

05/03/2011 - 15/09/2011

Peak flux (left) and modulation fraction (right) for each six-month orbital light curves as a function of time and the super-orbital phase.

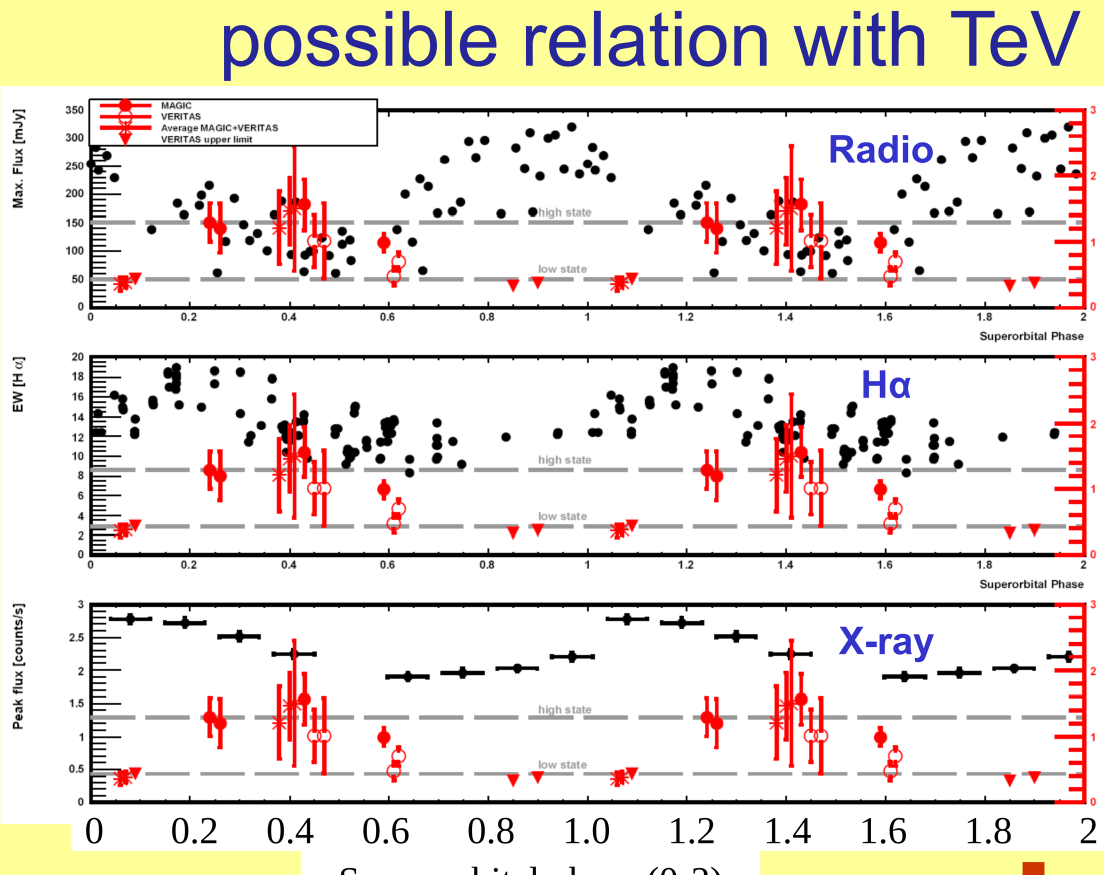


The dotted line shows the sinusoidal fitting with a period and phase fixed at parameters from super-orbital modulation in radio, which is unacceptable. The solid curve stands for sinusoidal fitting obtained by fixing the period at the 1667 days value, but letting the phase vary. This lead to acceptable fit and a phase shift of 281.8 ± 44.6 days. 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 emissions are in low state while boxes in yellow are TeV emissions in high state.

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

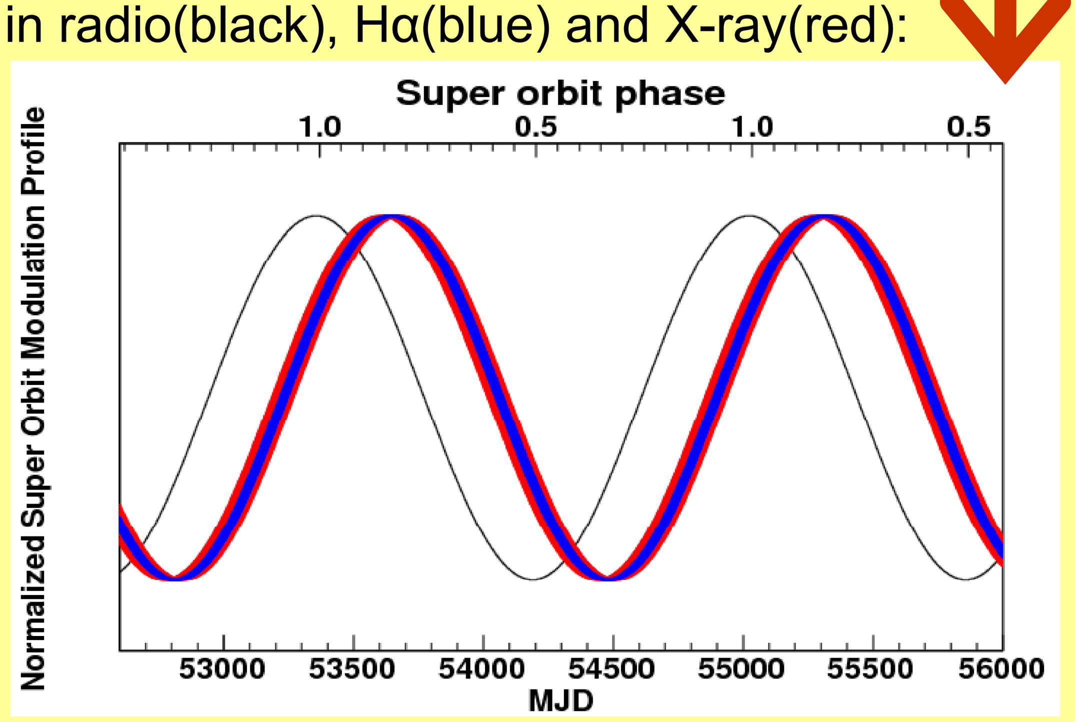
	Constant	Linear	Radio	Shifted
Modulation Fraction	88.2 / 7	38.0 / 6	42.1 / 6	1.1 / 5
Peak Flux	212.8 / 7	114.8 / 6	91.8 / 6	4.9 / 5

2. Super-orbital modulation in radio, optical & X-ray and possible relation with TeV emissions



Peak flux per orbit in TeV (red) together with super-orbital modulation in non-simultaneous radio (top), Hα equivalent widths (middle) and X-ray (bottom) data. TeV emissions seem to be roughly anti-correlated with super-orbital modulation in radio

The profiles of super-orbital modulation in radio(black), Hα(blue) and X-ray(red):



super-orbital modulation profile of X-ray is in phase with Hα but lagged from radio data.

3. Model implications

We propose LS I +61 303's compact object is a high magnetic field, slow period pulsar. It would most likely be subject to a flip-flop behavior, from an ejector in apastron to a propeller in periastron along each 26.5 days eccentric orbits. In ejector state electrons will be accelerated by the shock between pulsar wind and stellar wind, producing TeV emissions through IC scattering with photons from Be star. However, the shock will not form in propeller state, leading to the fact that TeV emissions are only observable in ejector state around apastron.

In a 1667 days super-orbital period, when the mass-loss rate is low (low state of Hα), the pulsar will be ejector around apastron and producing TeV emission there. When at the maximum of the mass-loss rate (high state of Hα), the whole orbit may be in propeller state and there may not be ejector state even at apastron. Then no TeV emissions would be produced.

A TeV and Hα anti-correlation is expected but the scarcity of the TeV data coverage precludes reaching a definite conclusion.

For further details and all references, please refer to our full paper: Jian Li, Diego F. Torres, Shu Zhang et al. 2012, ApJ Letters, 744, 13