A new gamma-ray feature in LS I +61°303

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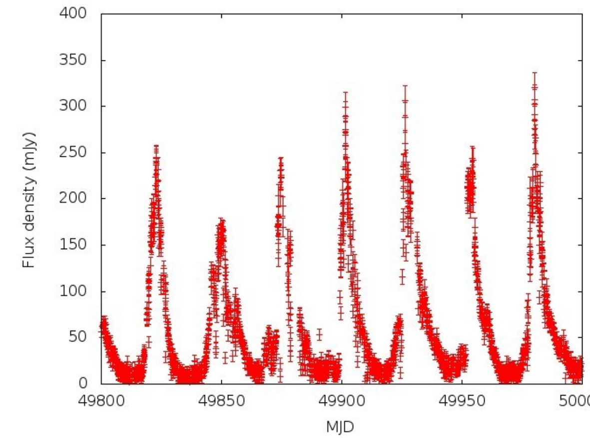
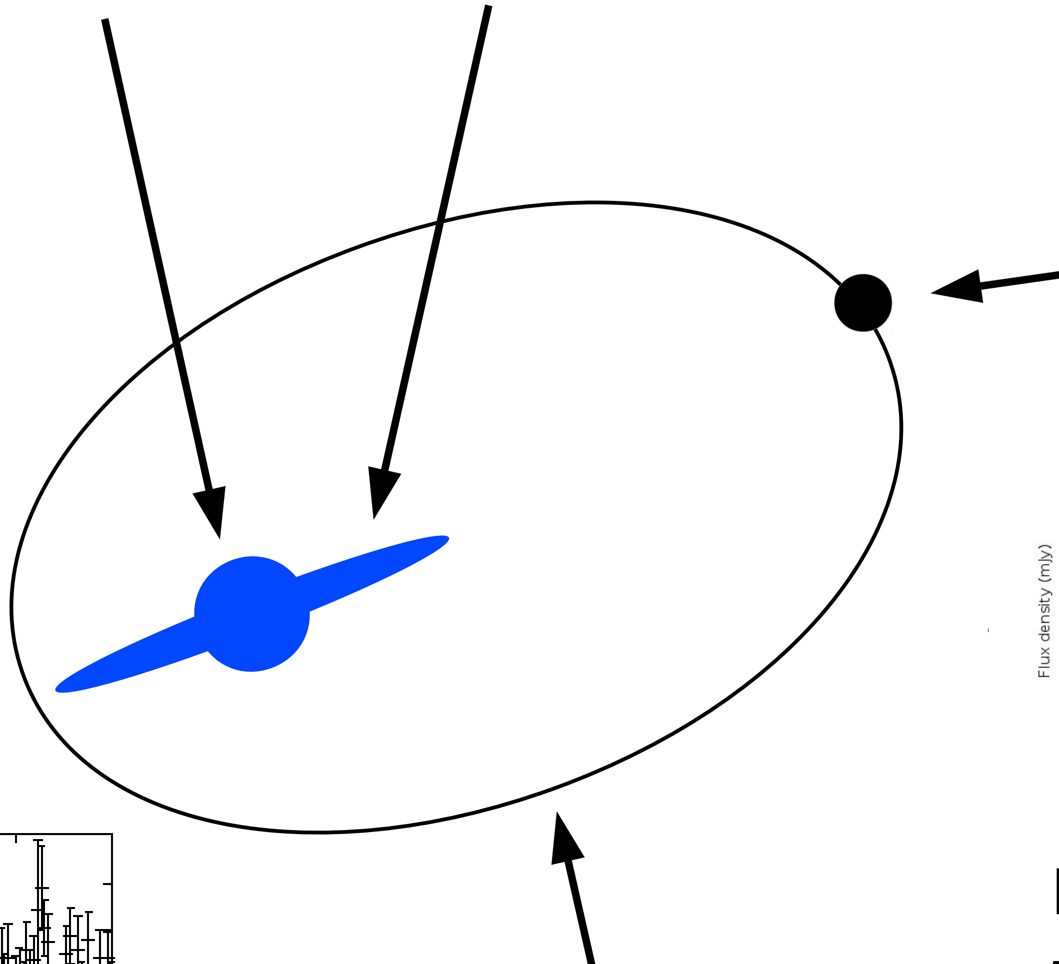
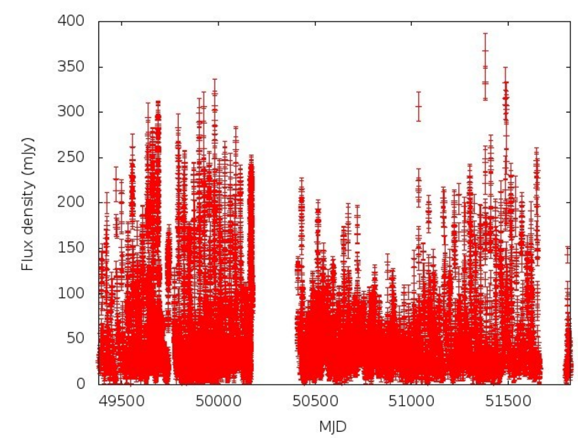
The stellar system LS I +61°303

Orbital periodicity $P_1 = 26.4960 \pm 0.0028\,\mathrm{d}$

(Gregory, 2002)



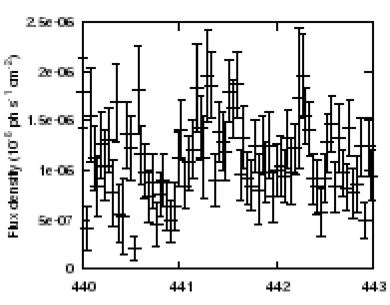




Long-term periodicity

$P_{long} = 1667 \pm 8\,\mathrm{d}$

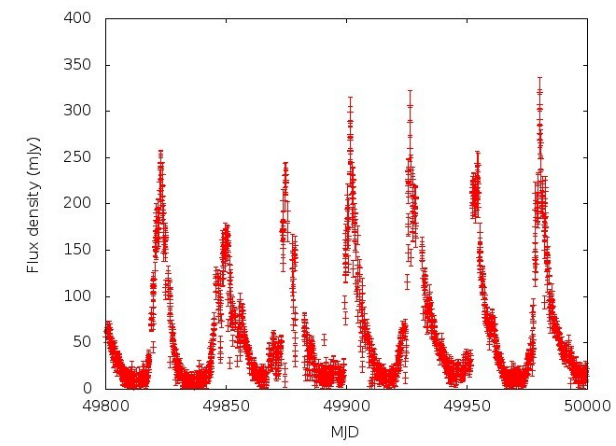
(Gregory, 2002)

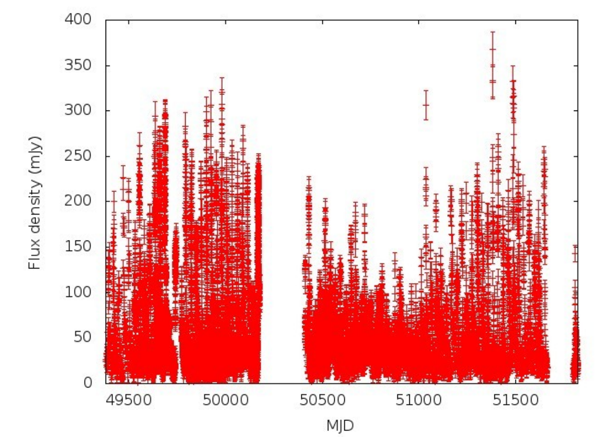


Orbital periodicity $P_1 = 26.4960 \pm 0.0028\,\mathrm{d}$

Long-term periodicity $P_{long} = 1667 \pm 8\,\mathrm{d}$

(Determined from radio data; Gregory, 2002)





GBI 8.3 GHz radio data (Ray *et al.*, 1997)

Orbital phase $\Phi = \frac{t - t_0}{P_1} - \mathrm{int}\left(\frac{t - t_0}{P_1}\right)$

Long-term phase $\Theta = \frac{t - t_0}{P_{long}} - \mathrm{int}\left(\frac{t - t_0}{P_{long}}\right)$

$t_0 = 43366.775\,\mathrm{MJD}$ (First radio detection; Gregory & Taylor, 1978)

Phase of periastron $\Phi_{periastron} = 0.230 - 0.273$

(Casares *et al.*, 2005; Aragona *et al.*, 2009)

Orbital periodicity in *Fermi LAT* data

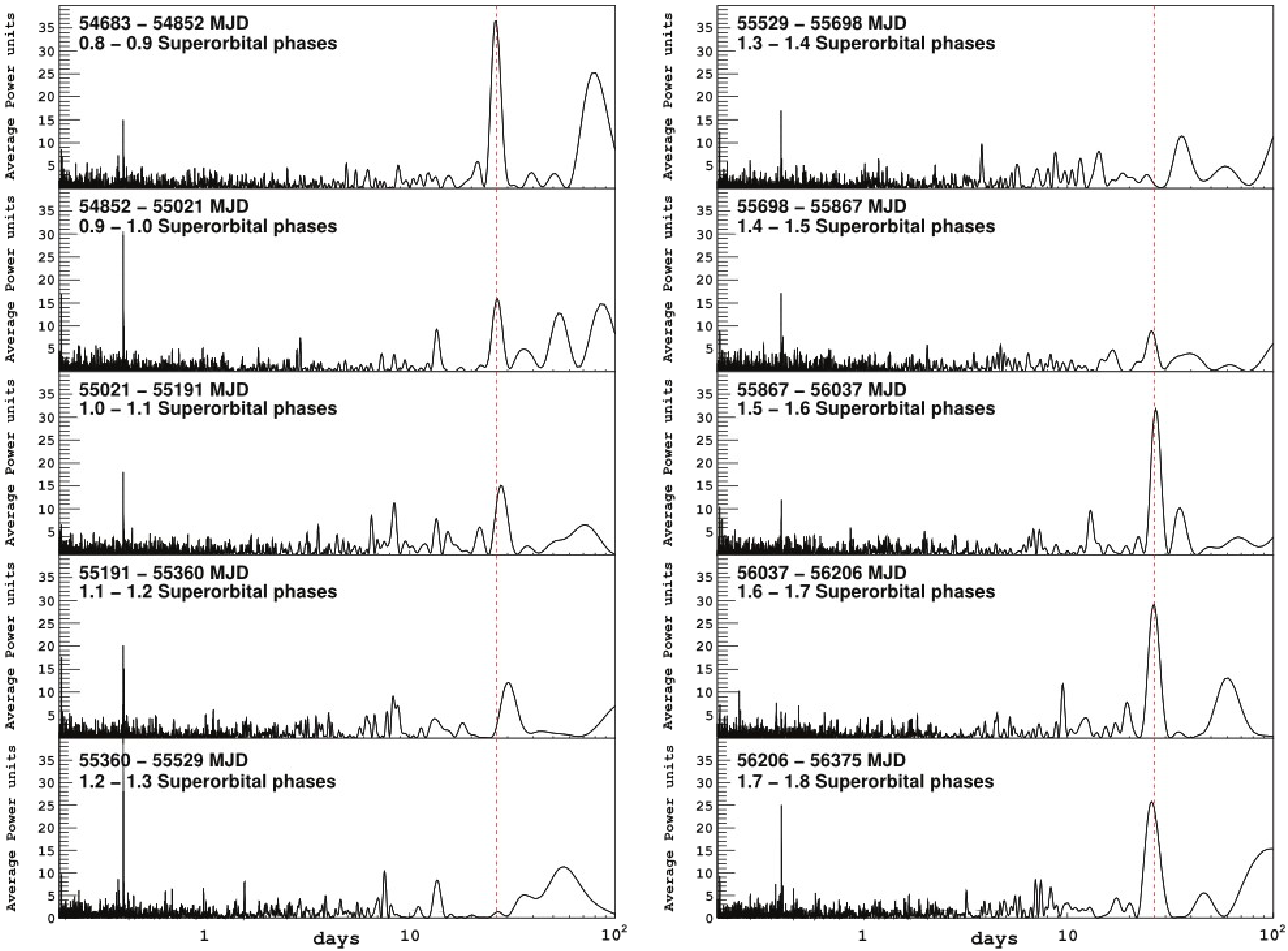


Figure 4 in Ackermann *et al.* (2013)

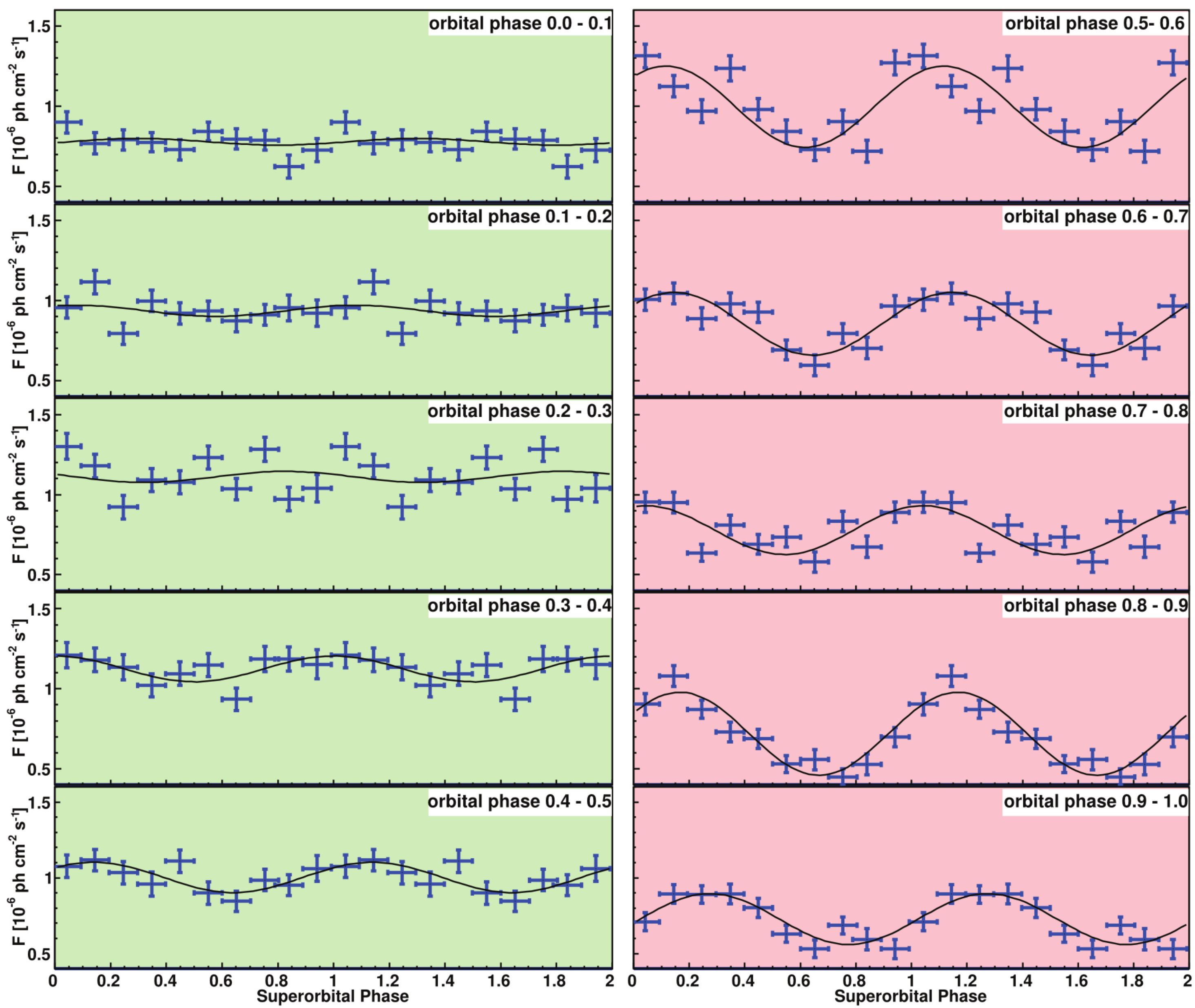
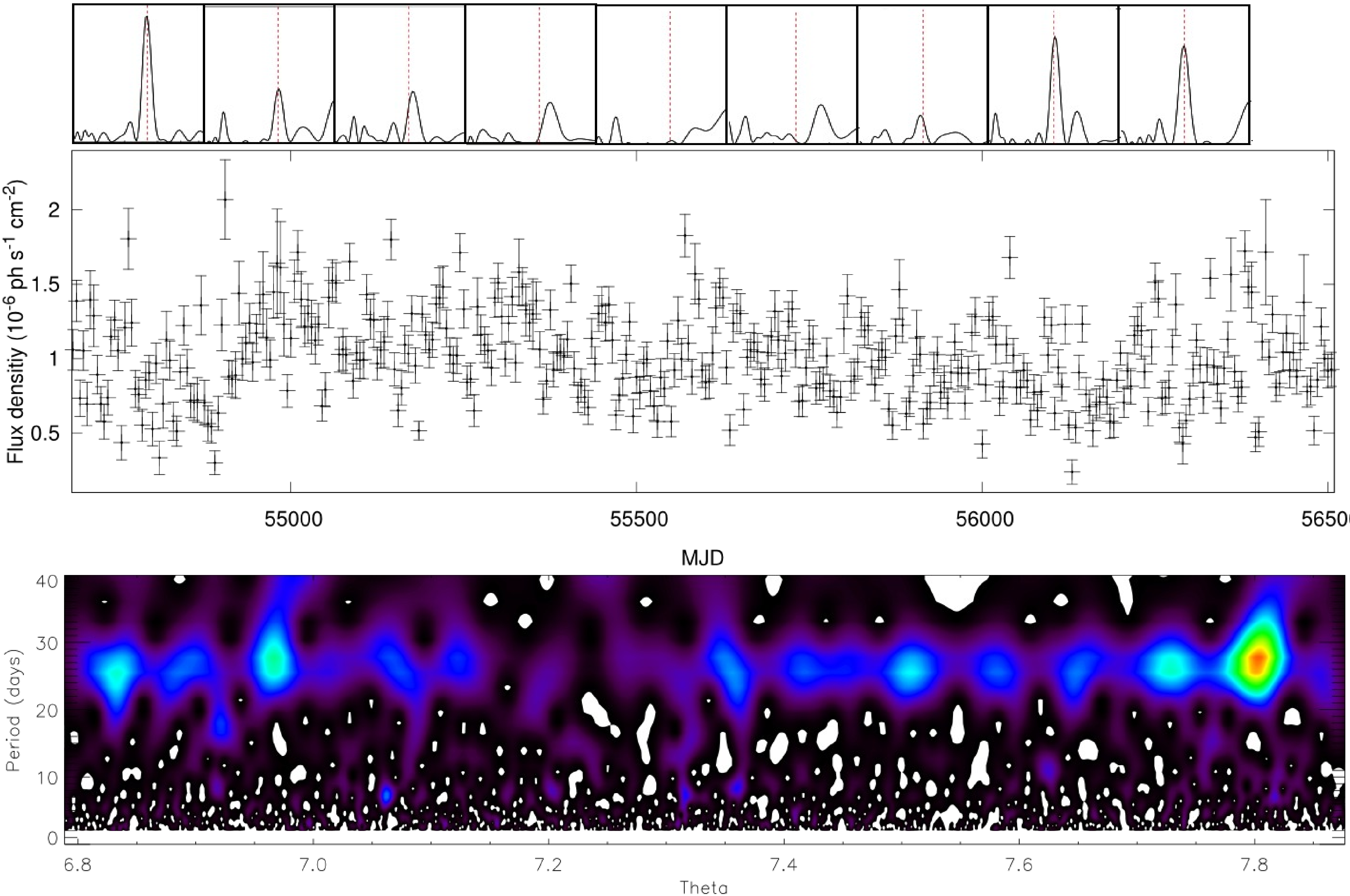


Figure 3 in Ackermann *et al.* (2013)

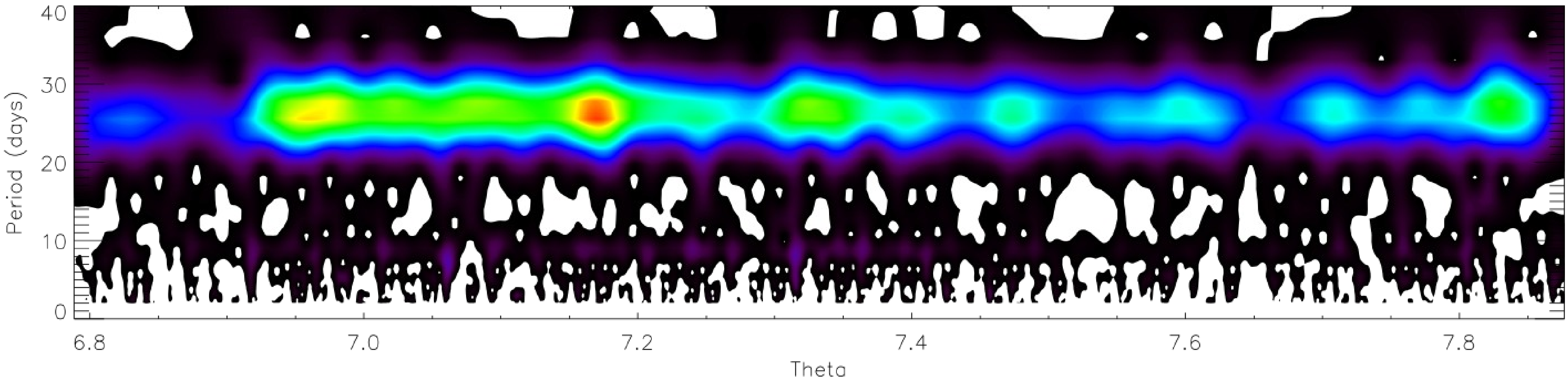
Wavelet analysis of *Fermi* LAT data



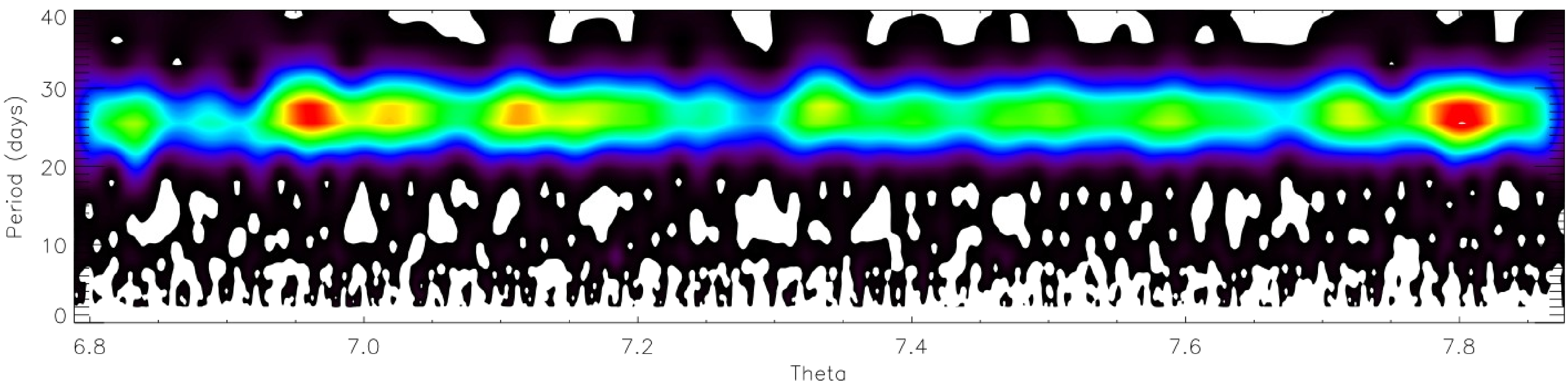
Jaron & Massi (2014, reviewed by A&A)

Wavelet analysis of *Fermi* LAT data

Φ = 0.5-1.0 (apoastron)

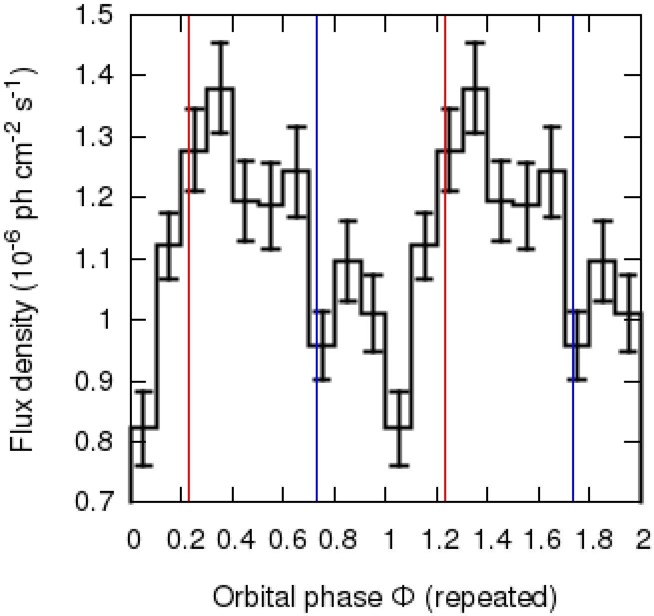


Φ = 0.0-0.5 (periastron)

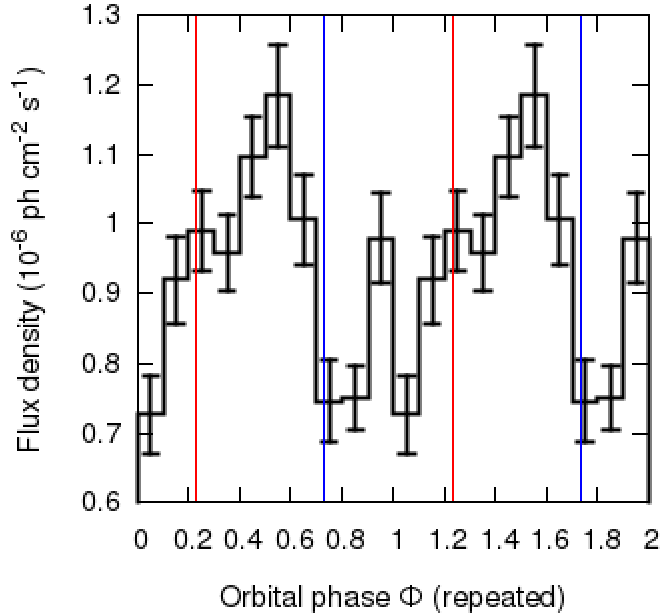


Jaron & Massi (2014, reviewed by A&A)

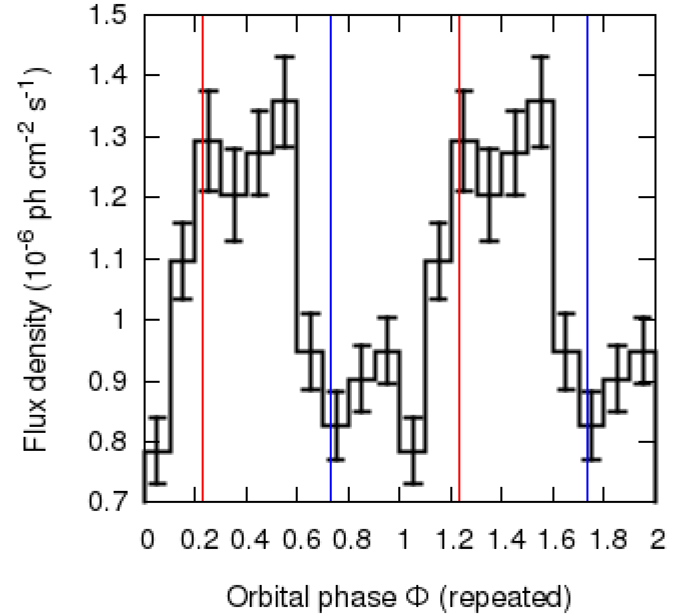
Results Folded *Fermi* LAT gamma-ray light curves



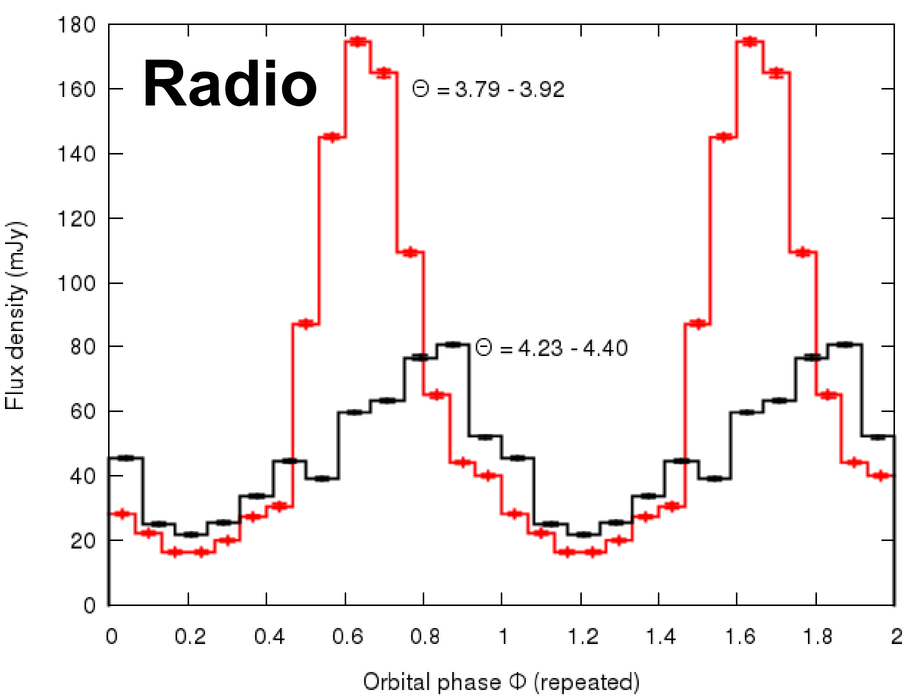
$\Theta = 7.12 - 7.22$

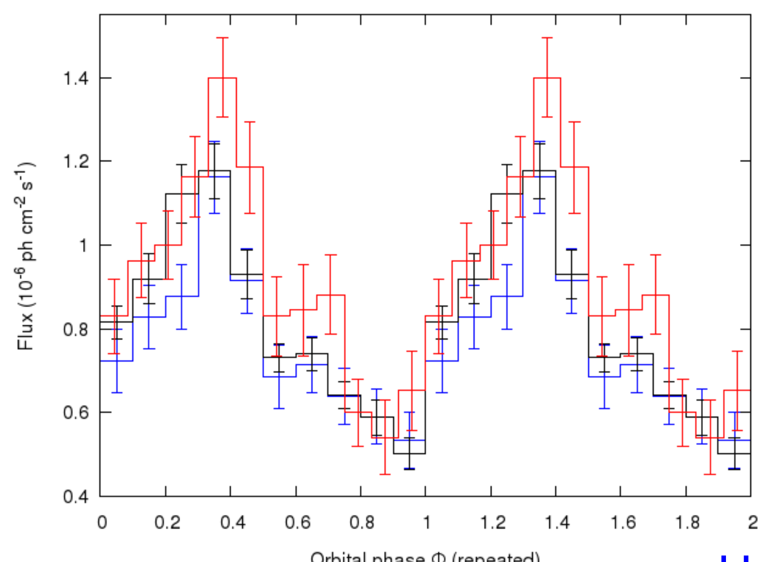


$\Theta = 7.22 - 7.32$



$\Theta = 7.32 - 7.42$





Folded light curves for Θ = 6.79 - 6.92.

Abdo *et al.* (2009)

Hadasch *et al.* (2012)

Jaron & Massi (2014, reviewed by A&A)

Conclusion

In the interval $\Theta \approx 7.2$, where timing analysis fails in finding a periodicity in GeV gamma-ray emission, there occur on the contrary two periodical signals, one in the orbital phase interval $\Phi = 0.0 - 0.5$ (periastron), and the other in the interval $\Phi = 0.5 - 1.0$ (apoastron).

Our conclusion is that it is the presence of this second periodicity that disturbs the timing analysis. Indeed, two peaks along the orbit are evident when data at $\Theta = 7.12 - 7.42$ are folded with the orbital phase.

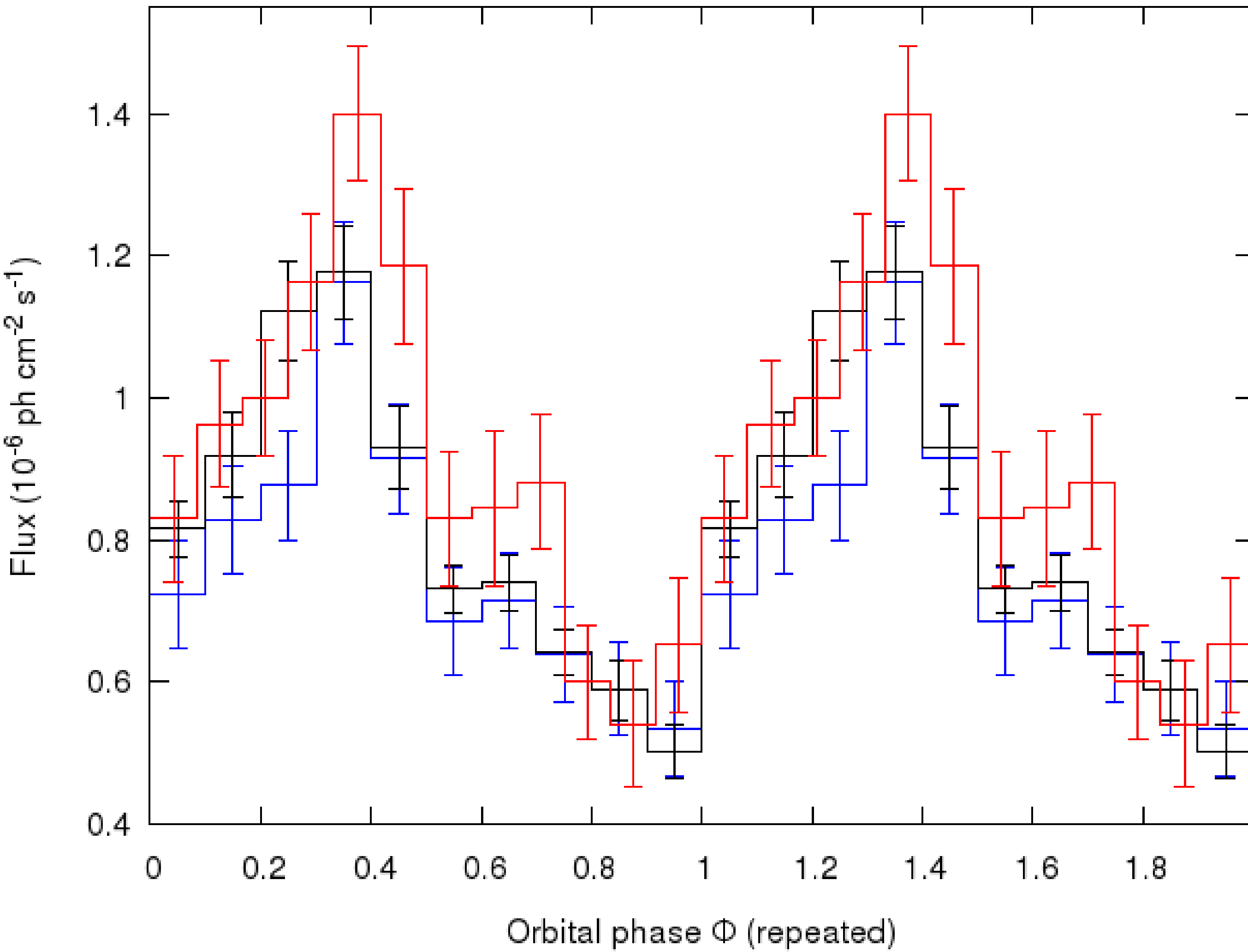
Thank you!

Data analysis

- Fermi Science Tools v9r27p1
- Script like_lc.pl by R. Corbet
- Data from MJD 54683 to 56509 (08/05/2008 - 08/05/2013)
- Only event class photons were used
- Photons with zenith angle > 105° were excluded
- Spatial model for Galactic diffuse emission (gal_2yearp7v6_v0.fits)
- Instrument response function P7V6
- Model files generated from the 2FGL catalog (Nolan et al., 2012)
- All sources within 15° of LS I +61°303 were included in the model
- Time bin sizes of 1 and 5 days
- Energy range 100 MeV to 300 GeV

Jaron & Massi (2014, submitted to A&A)

Comparison with previous results



Folded light curves for Θ = 6.79 - 6.92.

Abdo *et al.* (2009)

Hadasch *et al.* (2012)

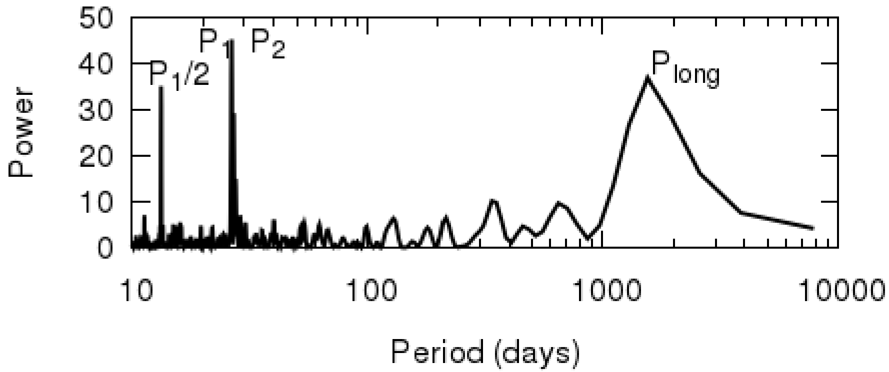
Jaron & Massi (2014, submitted to A&A)

Lomb-Scargle timing analysis

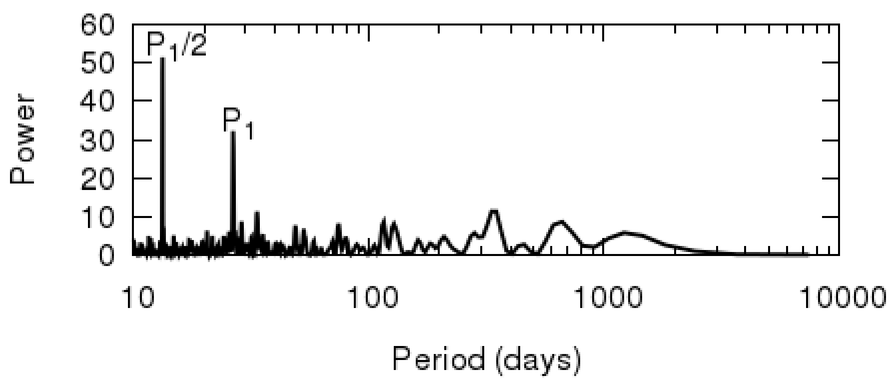
Gamma

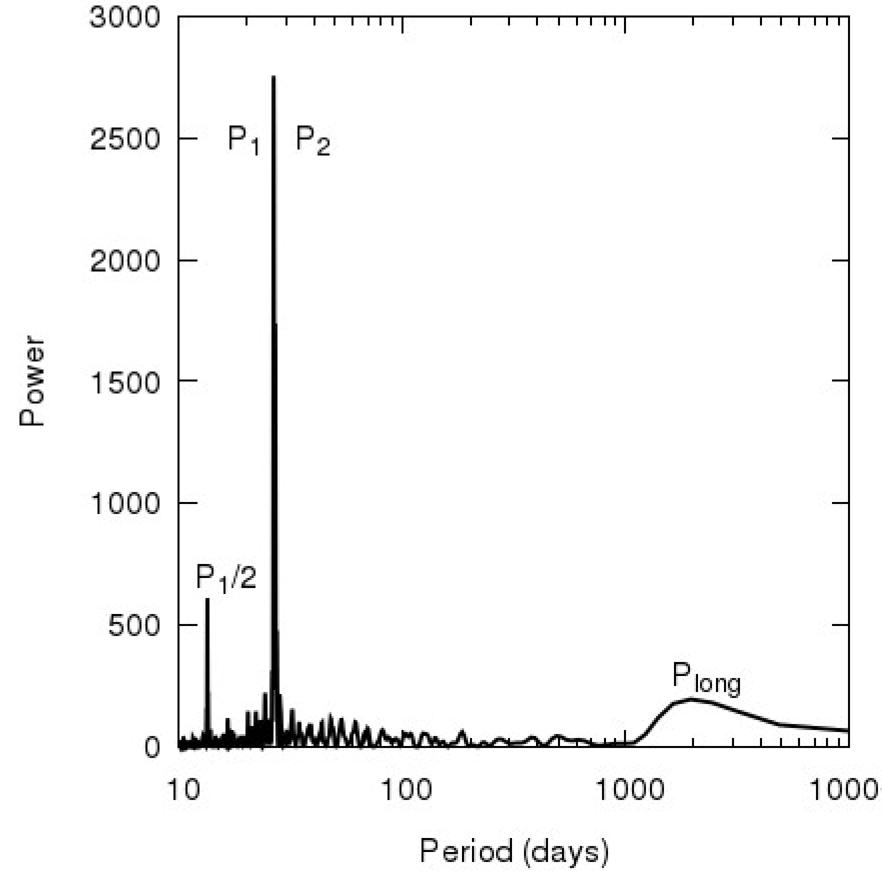
Radio 8.3 GHz

$\Phi = 0.5 - 1.0$ (apoastron)



$\Phi = 0.0 - 0.5$ (periastron)

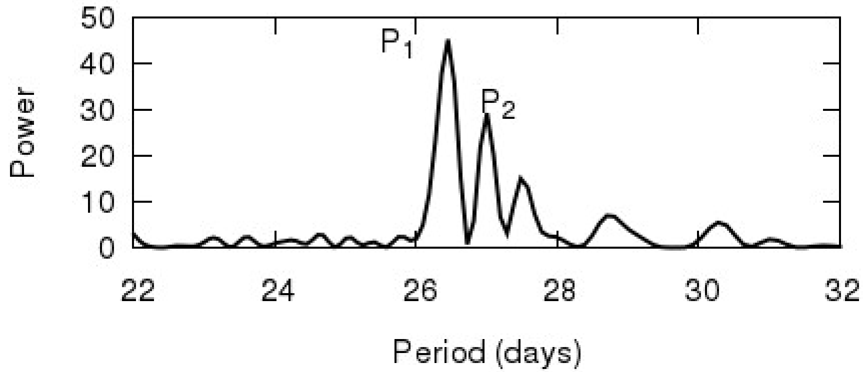




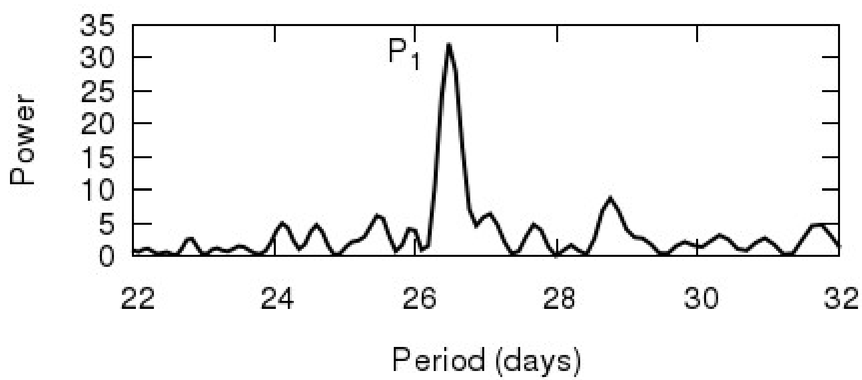
Jaron & Massi (2014, submitted to A&A)

Gamma

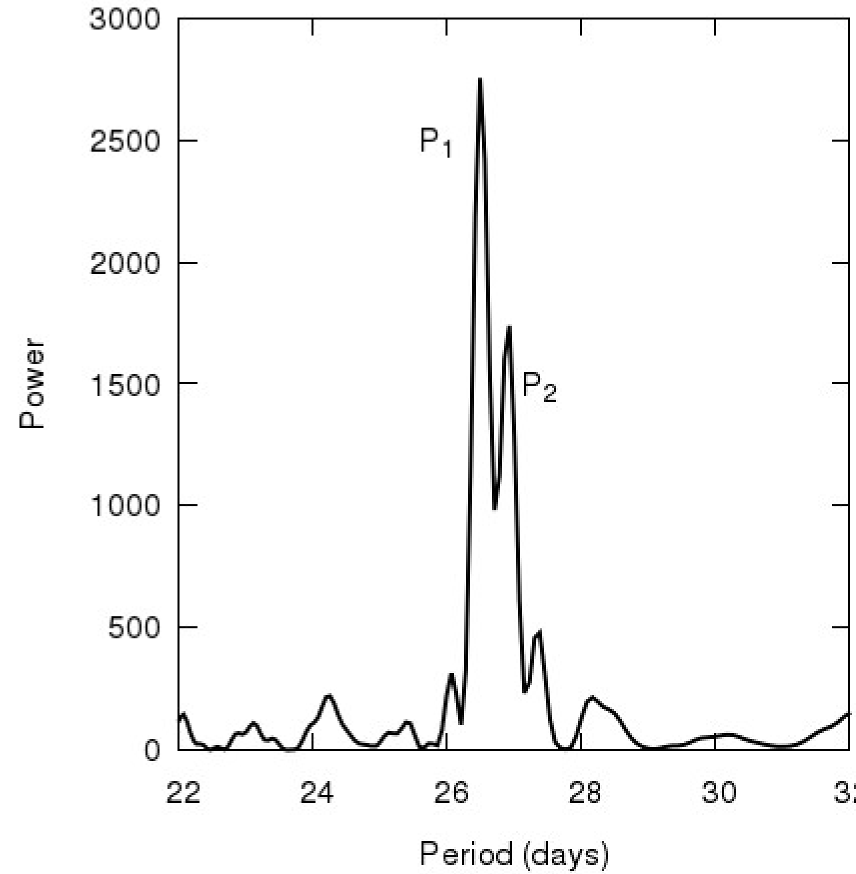
$\Phi = 0.5 - 1.0$ (apoastron)



$\Phi = 0.0 - 0.5$ (periastron)

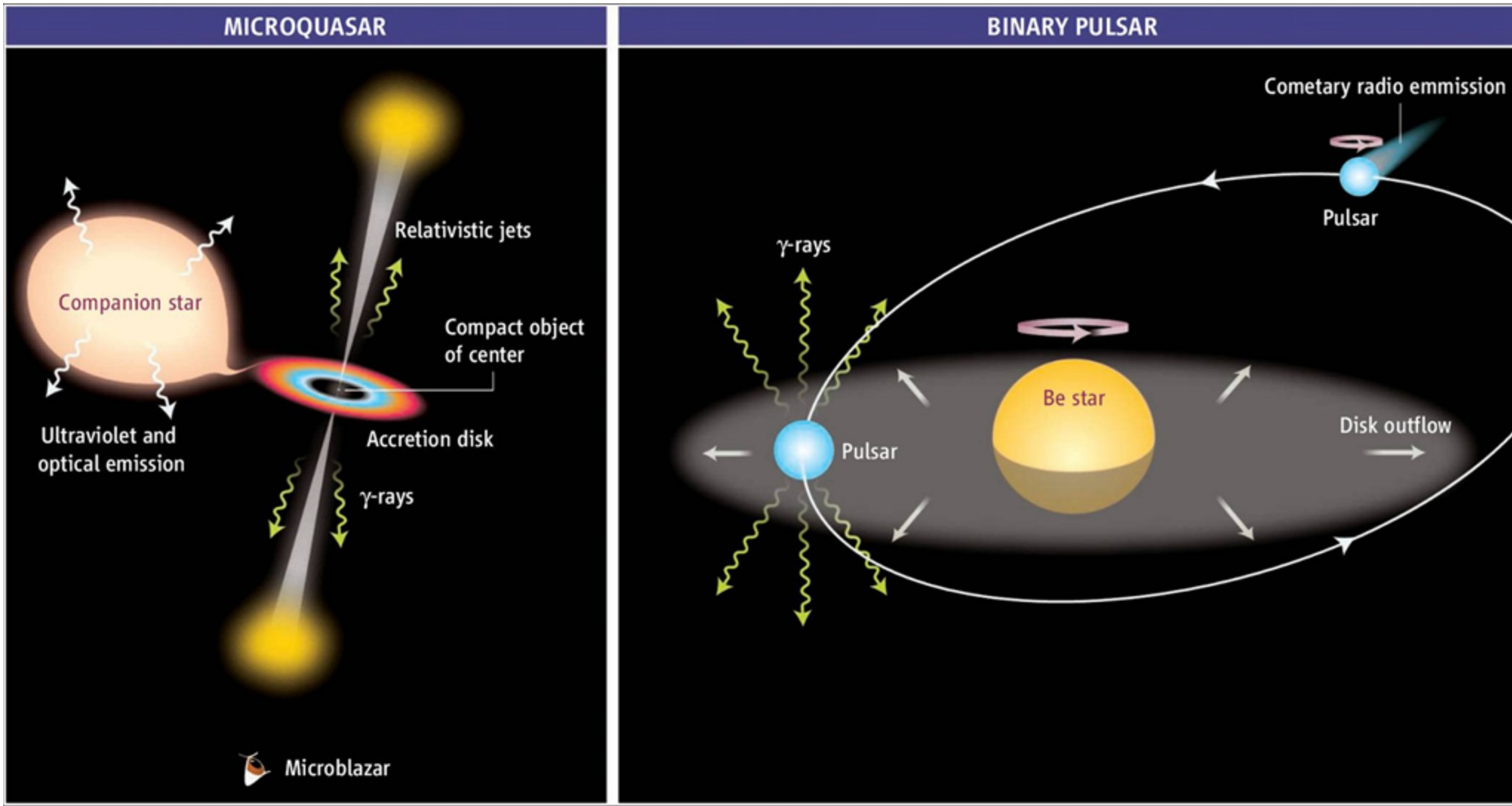


Radio 8.3 GHz



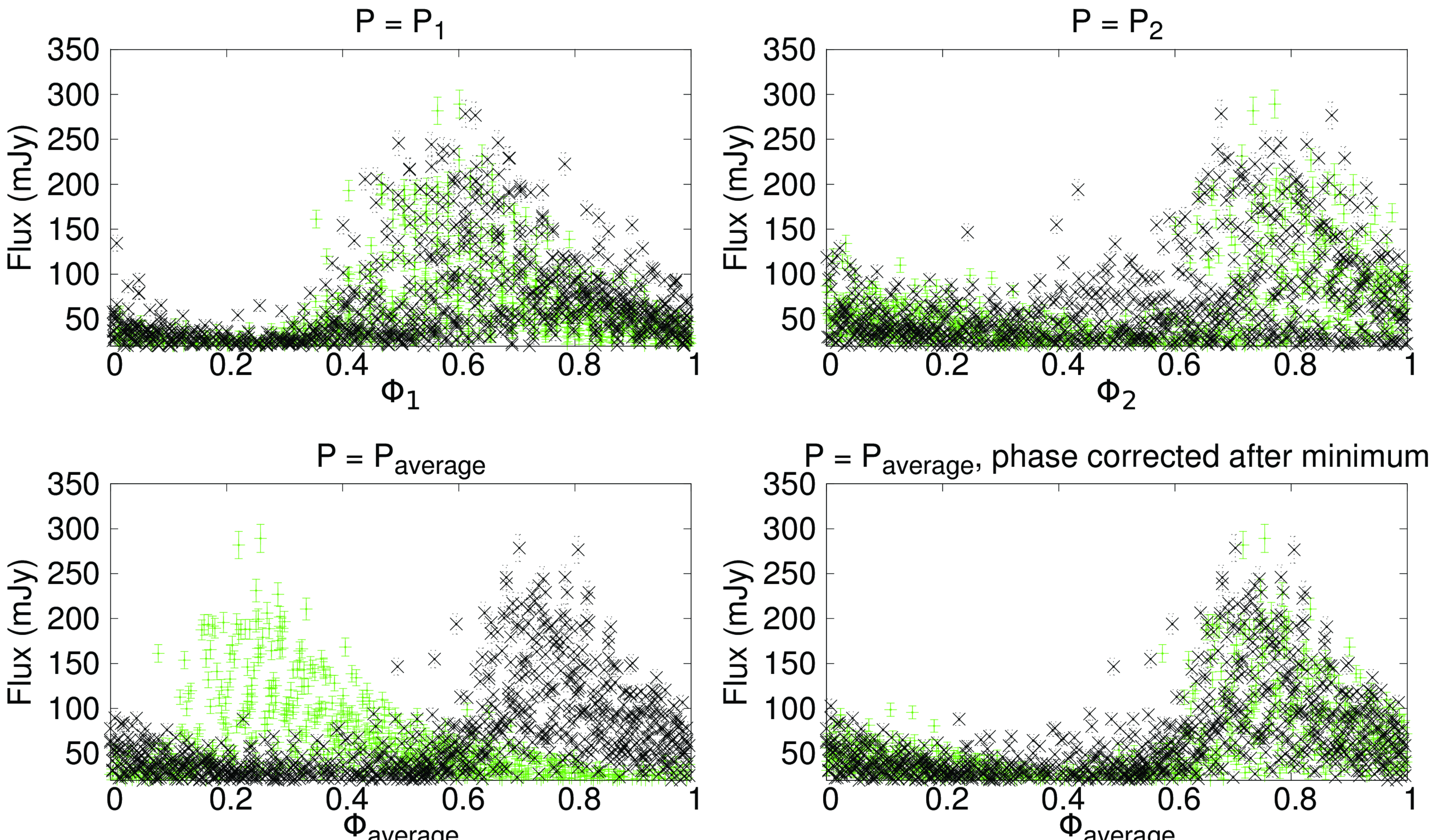
Jaron & Massi (2014, submitted to A&A)

The two models



Mirabel (2006)

GBI 8.3 GHz data



Massi & Jaron (2013, A&A)

- Old method: Assume orbital period P_1 as periodicity of the radio outburst $\Rightarrow$ timing delays with sawtooth trend (Gregory, 2002).
- Periodicity of the observed radio outburst: $P_{\text{average}} = 26.70 \pm 0.05\,\text{d}$.
- Phase jump of 0.5 during every minimum of the long-term modulation.
- Easy formula for the prediction of the observed radio outburst:

$$\Phi_{\text{outburst}} = \begin{cases} 0.2 & \text{for } K \text{ odd,} \\ 0.7 & \text{for } K \text{ even,} \end{cases}$$

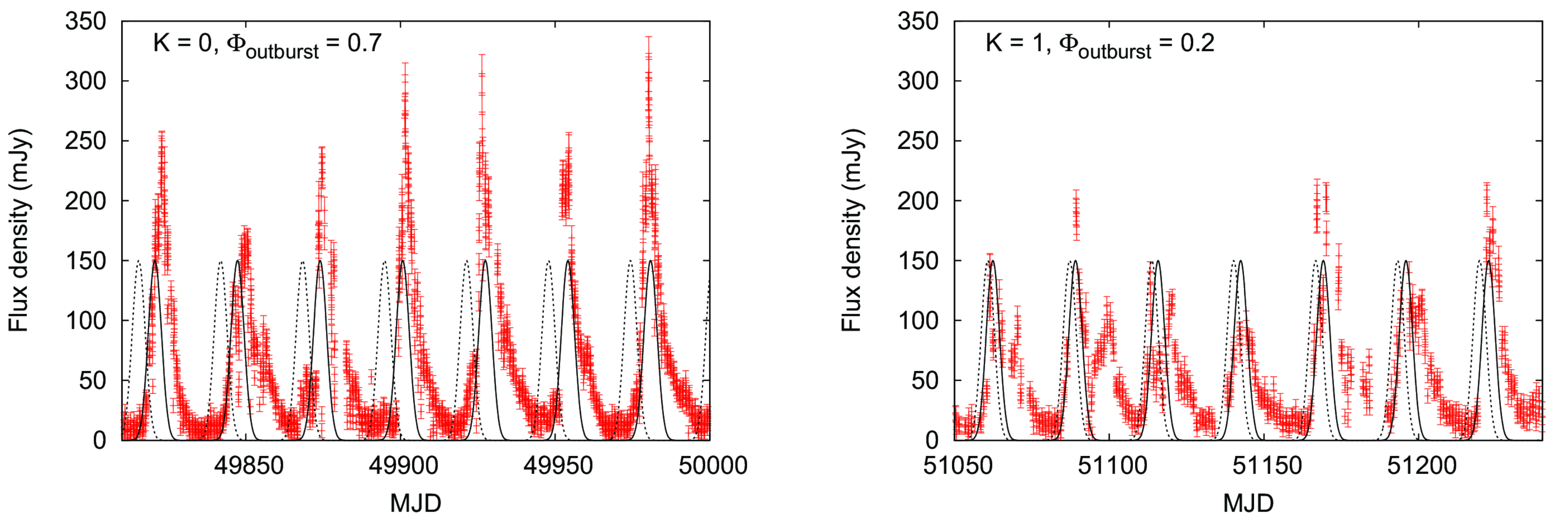
  with

$$K = \text{int}\left(\frac{t - 49174\,\text{MJD}}{P_{\text{long}}}\right).$$

- By minimizing the variance of timing delays we determined $P_{\text{average}} = 26.704 \pm 0.004\,\text{d}$ (Jaron & Massi, 2013).

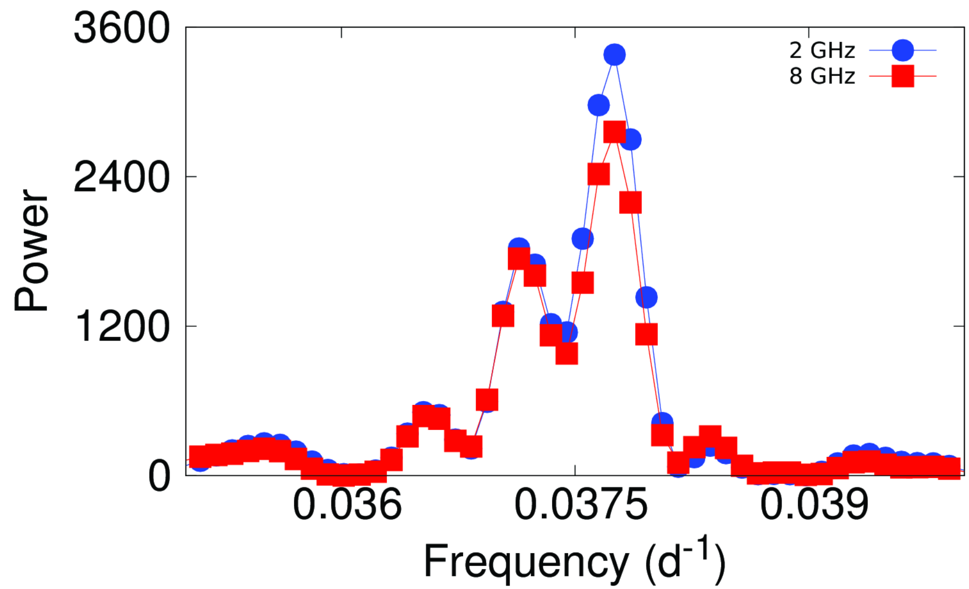
Illustration of the prediction

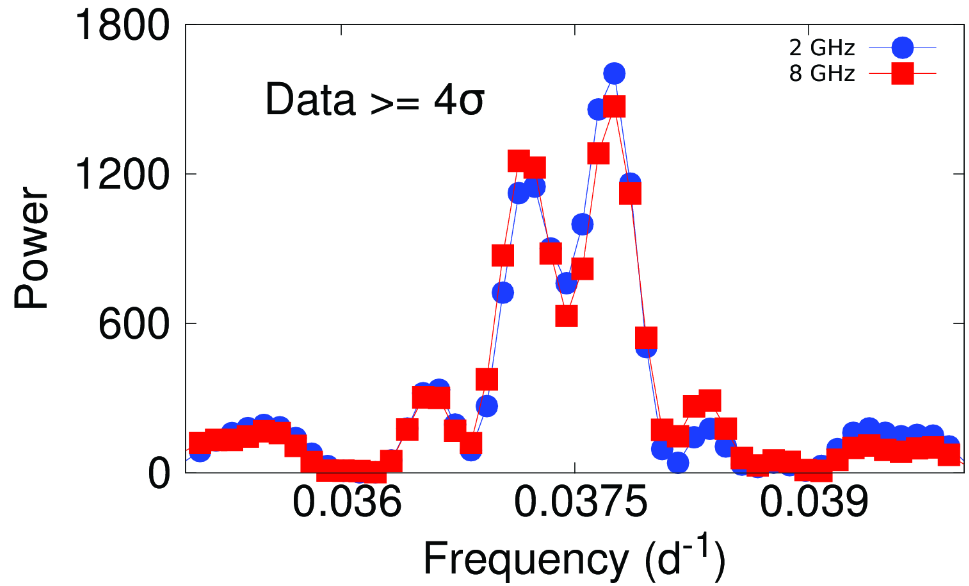
$$f(t) = A\left[\frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{P}(t - t_0) - 2\pi\Phi_{\mathrm{outburst}}\right)\right]^n$$



Solid line: our prediction, dotted line: old method.

Jaron & Massi (2013, A&A)





- Two periodicities:

$$P_1 = 26.49 \pm 0.07\,\mathrm{d}$$
$$P_2 = 26.92 \pm 0.07\,\mathrm{d}$$

- High signal to noise ratio,
  $\Rightarrow$ Peaks gain different power.
- Could be the reason why P_2 has not been found in the past.

Massi & Jaron (2013, A&A)

- Periodic changes in the density of the equatorial disk of the Be star.
- Common phenomenon in Be stars, but then periodic changes in the V/R ratio of Hα line are observed.

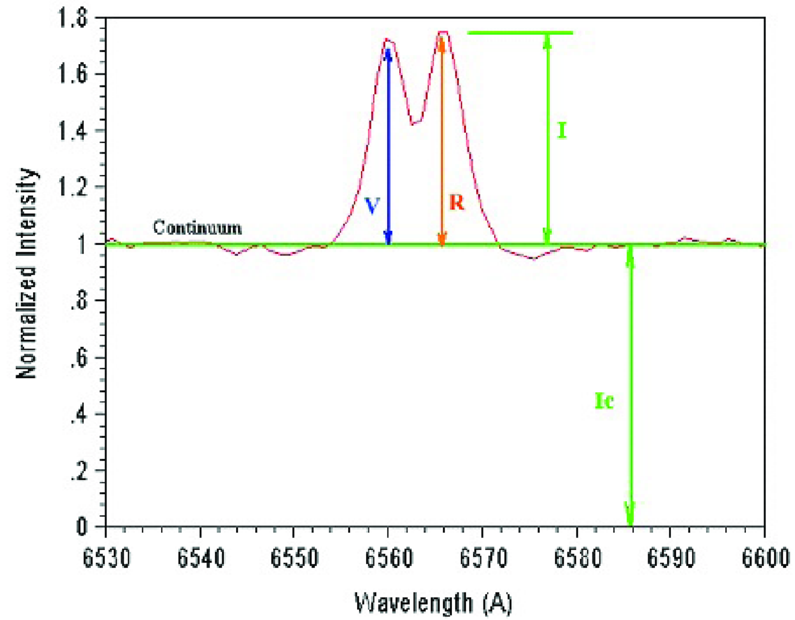
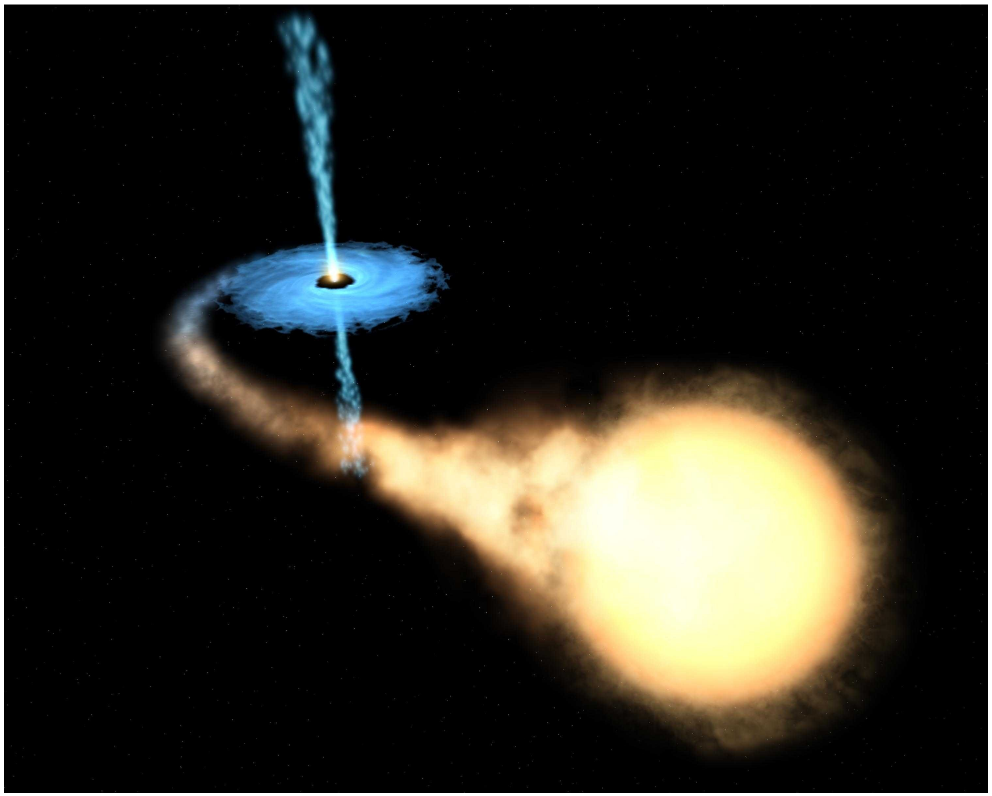


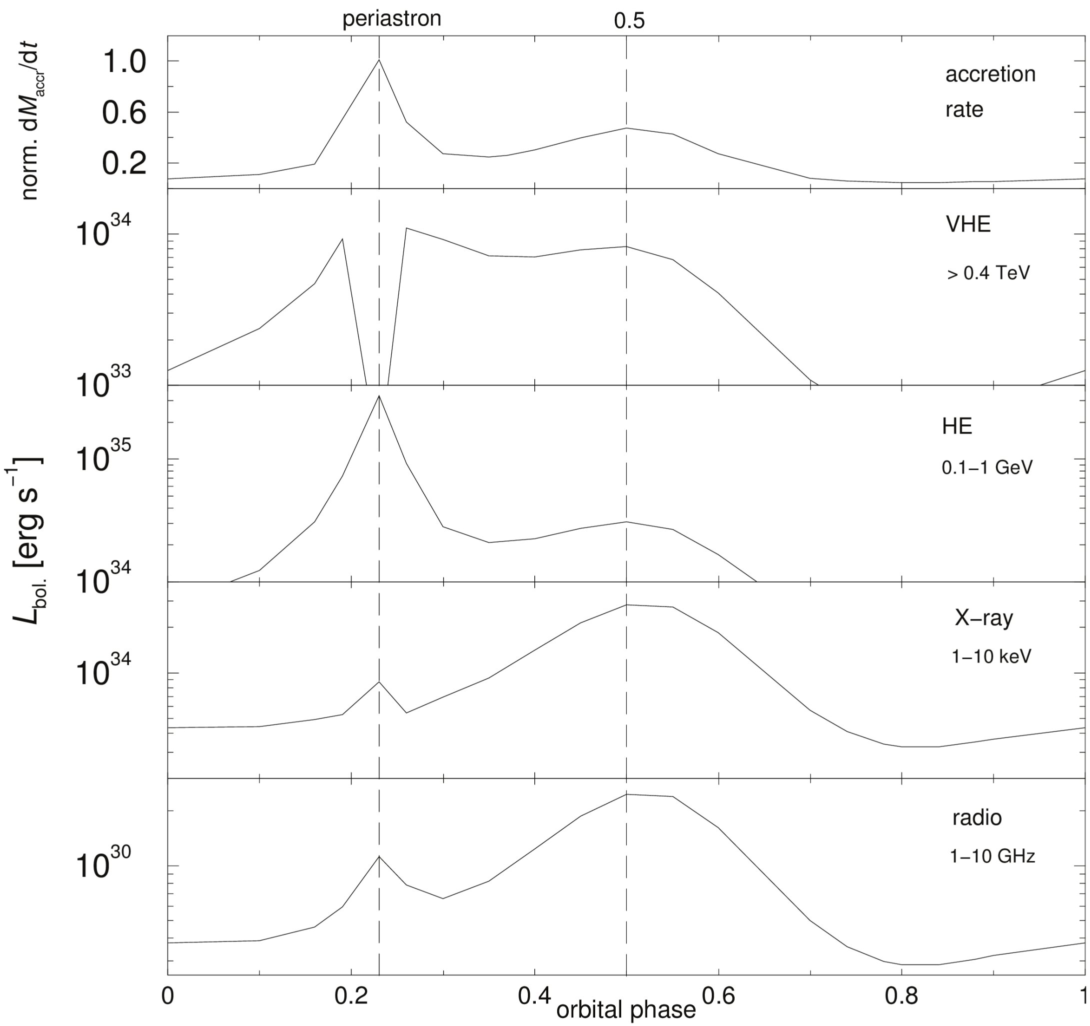
Figure: http://www.astrosurf.com/buil/us/spe2/hresol7.htm

- Long-term periodicity P_{long} not found in the V/R ratio of the Hα line of LS I +61°303 (Zamanov et al., 1999)

Two peak accretion model



http://hubblesite.org/newscenter/archive/releases/2002/30/image/a/



Bosch-Ramon *et al.* (2006)

Both the long-term periodicity and the orbital shift of the radio outburst can be explained by variable Doppler boosting (Massi & Jaron, 2013) as shown in Massi and Torricelli (2014).