Simultaneous long-term monitoring of LS I +61°303 by OVRO and *Fermi*-LAT

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Condensed summary

Long-term phase-offset between radio and GeV emission from X-ray binary LS I +61°303 explained in a scenario of a precessing jet.

1. Context

Previous long-term monitorings of the γ-ray-loud X-ray binary LS I +61°303 have revealed the presence of two features in the power spectra at periods $P_1 \approx 26.5$ days and $P_2 \approx 26.9$ days. The interference of the two periods results in a long-term modulation of $\sim$ 4.5 years. After nine years of simultaneous monitoring of LS I +61°303 by the Owens Valley Radio Observatory and the *Fermi*-LAT, two cycles of the long-term period are now available.

2. The light curves

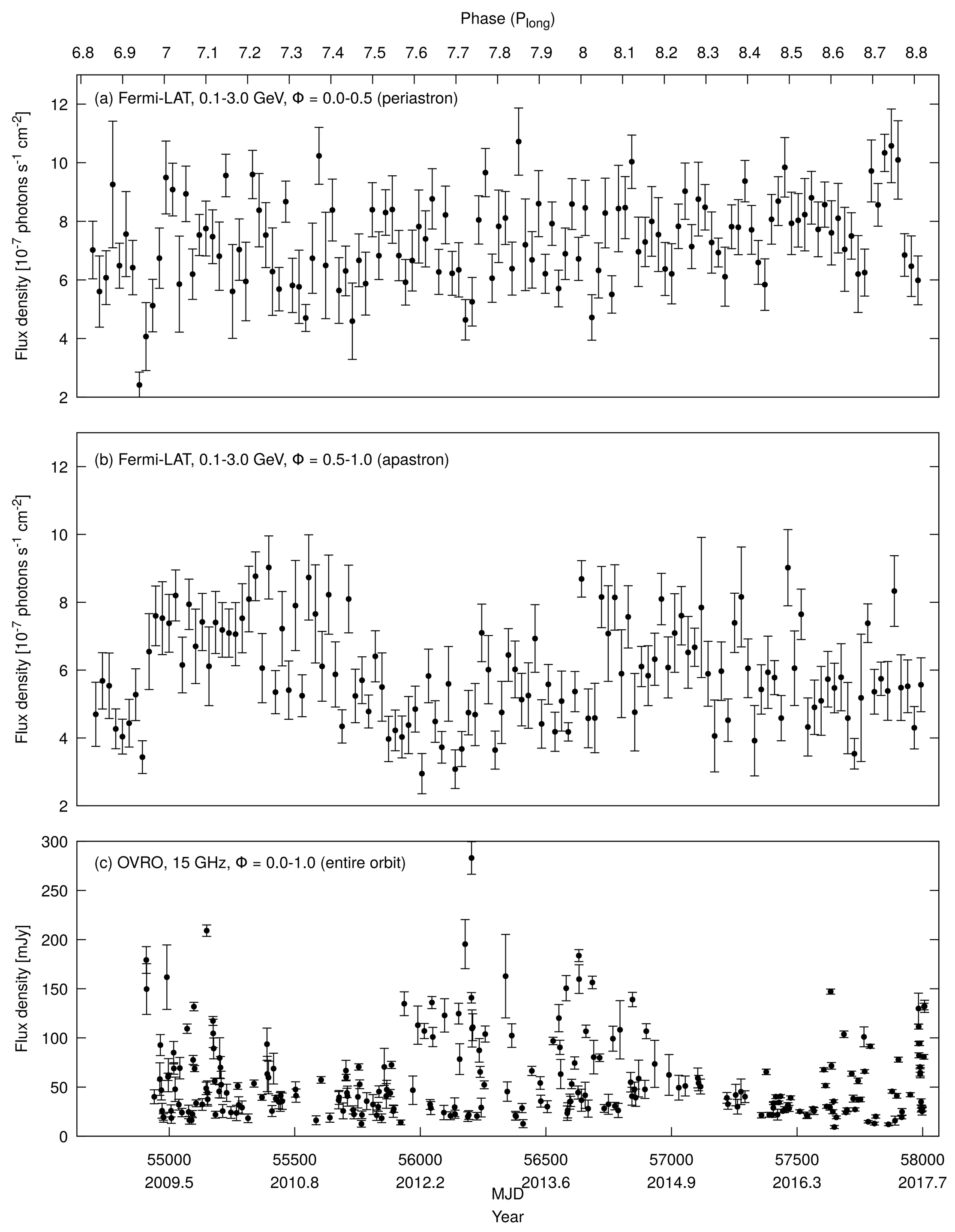

Fig. 1 Gamma-ray and radio light curves of LS I +61°303 resulting from long-term monitoring by *Fermi*-LAT and OVRO, respectively.

5. Beating and phase offset

The sum of two sine functions,

$$\sin\omega_1 t + \sin\omega_2 t = 2\sin\left(\frac{\omega_1+\omega_2}{2}t\right)\cos\left(\frac{\omega_1-\omega_2}{2}t\right),$$

gives a beating with beat frequency $\omega_{\rm beat} = \omega_1 - \omega_2$. A phase-shift δ of the sine wave oscillating at ω_2 results in

$$\begin{aligned} & \sin\omega_1 t + \sin(\omega_2 t + \delta) \\ = \; & 2\sin\left(\frac{\omega_1+\omega_2}{2}t + \frac{\delta}{2}\right)\cos\left(\frac{\omega_1-\omega_2}{2}t - \frac{\delta}{2}\right), \end{aligned}$$

the phase shift δ affecting the lower frequency ω_2 has the effect of phase-shifting the slowly oscillating cosine term by $-\delta/2$, i.e., in the opposite direction. The envelope, however, which has a frequency of $\omega_{\rm beat} = 2\omega_{\rm cos}$ is shifted by $-\delta$, which means it experiences the same phase shift as the sine wave at ν_2 but in the opposite direction.

3. Timing analysis

Lomb-Scargle timing analysis results.

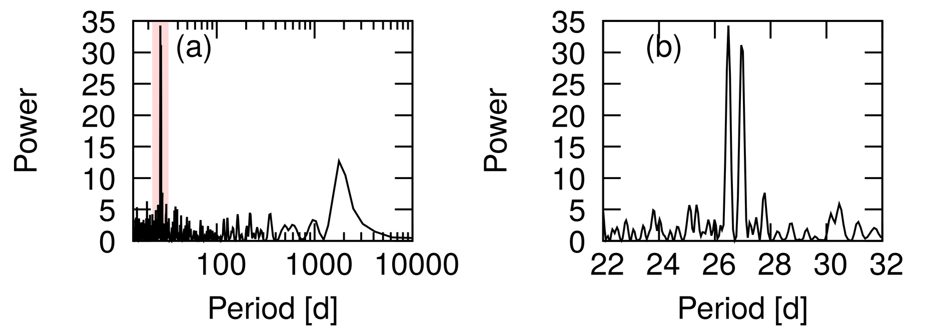

Fig. 2 Radio, periods found:
$P_1 = 26.49 \pm 0.06$ d (orbit),
$P_2 = 26.95 \pm 0.06$ d (precession),
$P_{\rm beat} = 1771 \pm 258$ d (beating).

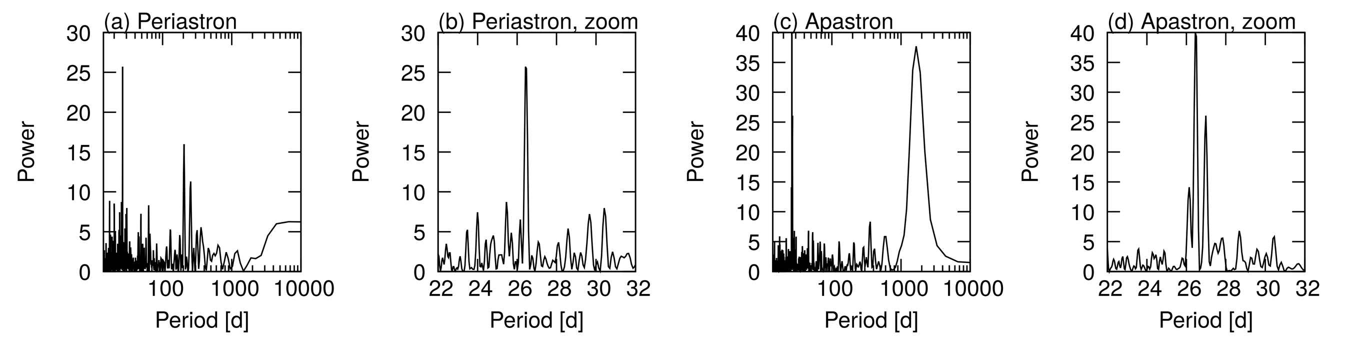

Fig. 3 GeV, periods found:
$P_1 = 26.43 \pm 0.05$ d (periastron, $\Phi = 0.0 - 0.5$),
$P_1 = 26.45 \pm 0.05$ d (apastron, $\Phi = 0.5 - 1.0$),
$P_2 = 26.99 \pm 0.05$ d (precession, only detected apastron),
$P_{\rm beat} = 1659 \pm 211$ d (beating, only detected apastron).

4. Results

Phase offsets $\phi_{0,\rm radio} - \phi_{0,\rm GeV}$ between radio and GeV:

$$\begin{aligned} \Delta\phi_0(P_2) &= 0.20 \pm 0.03, \\ \Delta\phi_0(P_{\rm long}) &= -0.26 \pm 0.03. \end{aligned}$$

Nearly the same but with opposite sign. Mathematical explanation in box "Beating and phase offset", physical explanation in "Jet scenario".

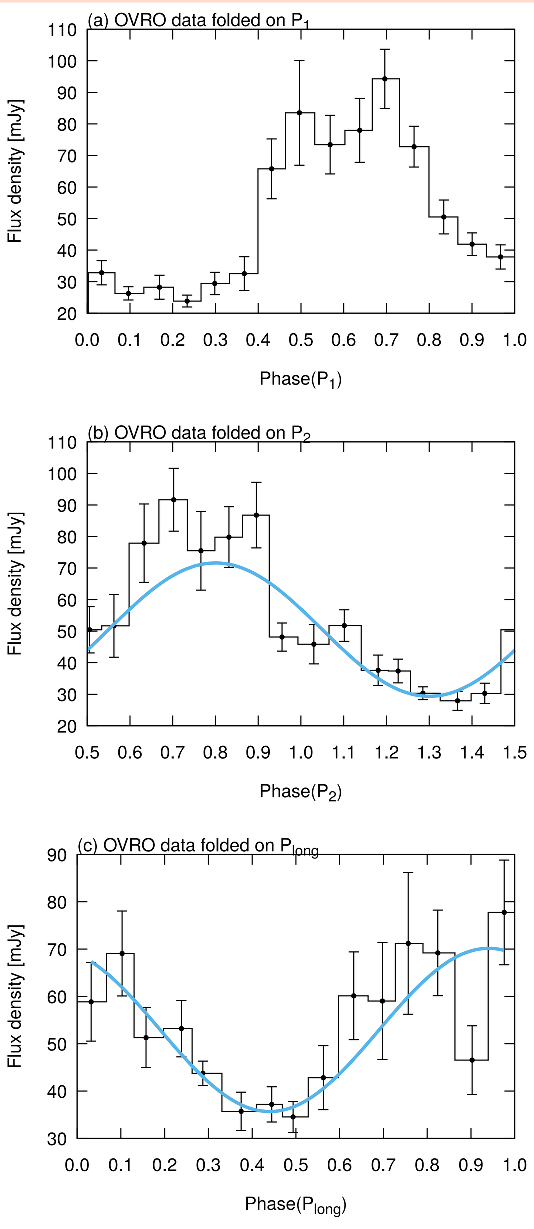

Fig. 4 OVRO radio data folded on the found periodicities.

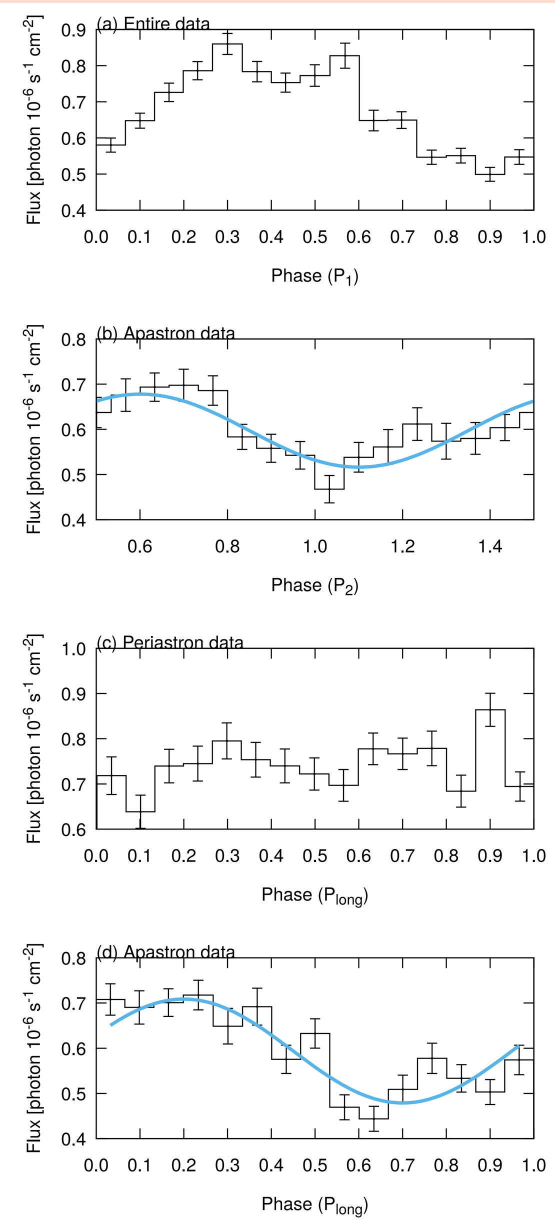

Fig. 5 *Fermi*-LAT GeV data folded on the found periodicities.

	ϕ_0	χ^2
$P_2 = 26.926$ d		
Fermi-LAT	0.35 ± 0.02	1.09
OVRO	0.55 ± 0.02	2.40
$P_{\rm long} = 1659$ d		
Fermi-LAT	0.95 ± 0.02	2.12
OVRO	0.69 ± 0.02	1.17

Table 1 Phase origin ϕ_0 resulting from fitting sine functions of the form $f(\phi) = A\sin(2\pi(\phi - \phi_0)) + B$ to the folded radio and GeV data.

6. Jet scenario

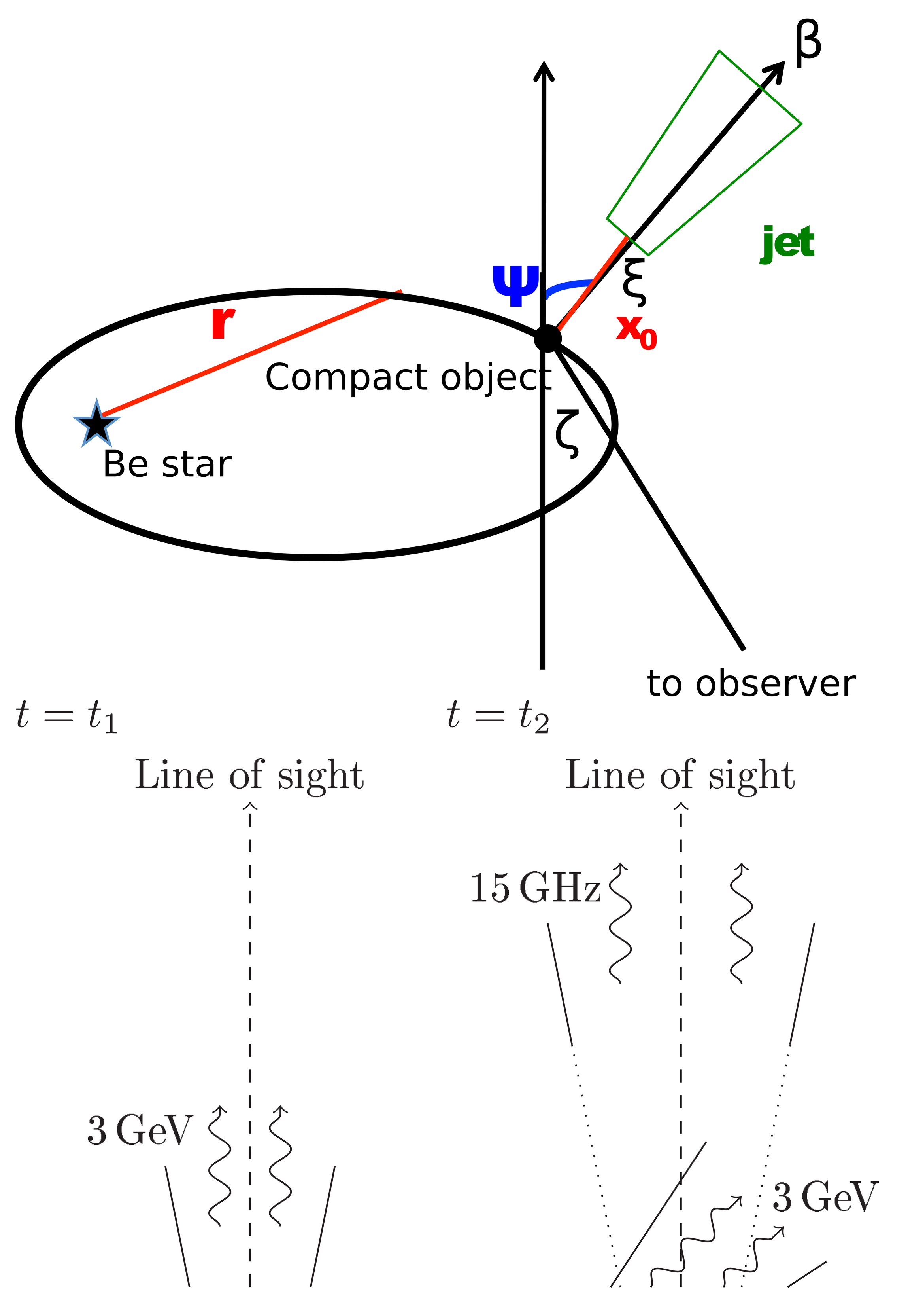

Fig. 6 Sketch of a scenario in which the GeV emission is produced upstream (i.e., earlier in time) in the jet as compared to the 15 GHz radio emission. Left: At time t_1 the GeV emission is emitted into the direction of the line of sight. Right: At time t_2 this population of electrons has cooled to and emits at radio at 15 GHz. The new population of electrons, now emitting at GeV energies, are ejected into a different direction because of jet precession. The difference between t_1 and t_2 translates to a difference in phase when folding the radio and the GeV data on the precession period.

Acknowledgements

This work has made use of public *Fermi* data obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA Goddard Space Flight Center. The OVRO 40 m Telescope Monitoring Program is supported by NASA under awards NNX08AW31G, NNX11A043G, NNX14AQ89G, and by the NSF under awards AST-0808050, AST-1109911.

Reference

Jaron, F., Massi, M., Kiehlmann, S., & Hovatta, T., 2018, MNRAS, 478, 440, doi:10.1093/mnras/sty1037