Discovery of extended and variable radio structure from the gamma-ray binary system PSR B1259-63/LS 2883

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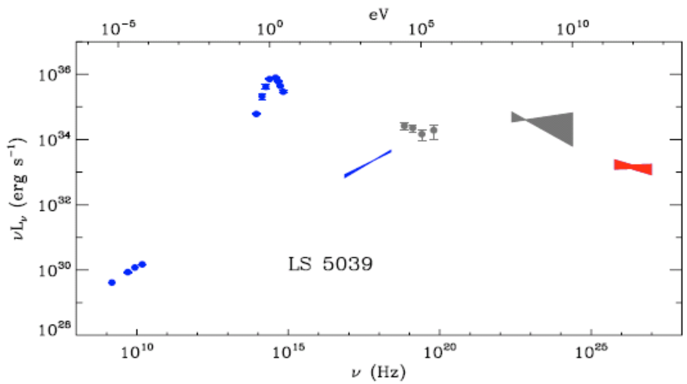
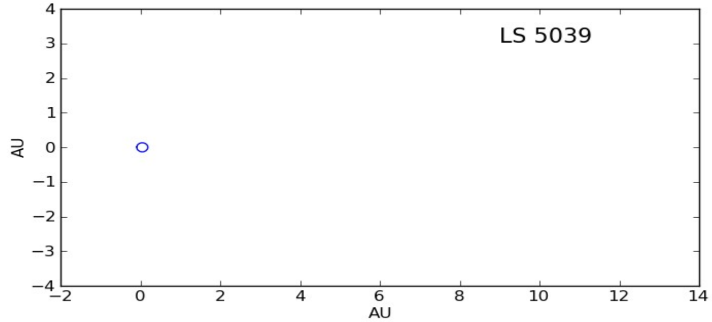
Variable Galactic Gamma-ray Sources
Heidelberg – December 2, 2010

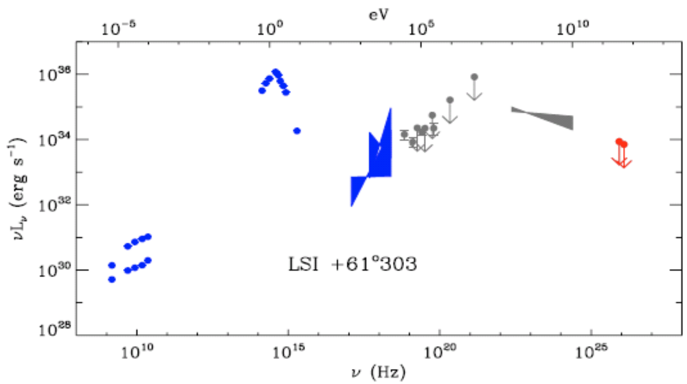
Gamma-ray binaries

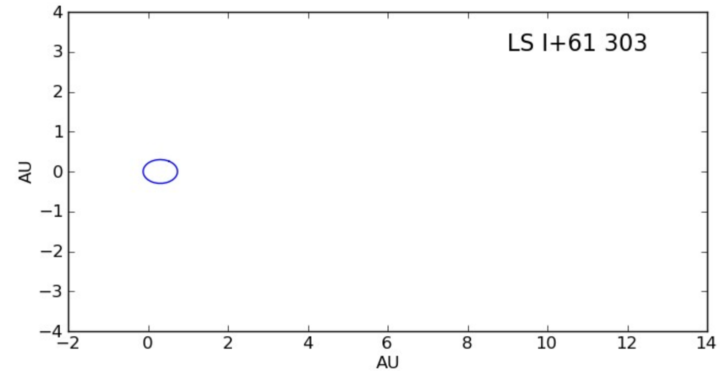
LS 5039
P_{orb} = 3.9 days
O6.5V + ?



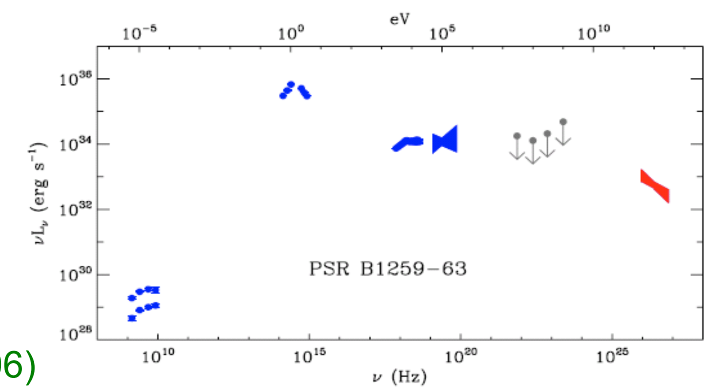


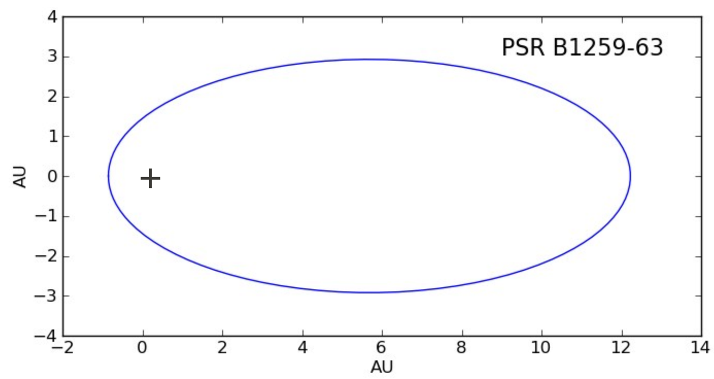
LS I +61 303
P_{orb} = 26.5 days
B0Ve + ?





PSR B1259-63
P_{orb} = 3.4 years
O8.5Ve + pulsar





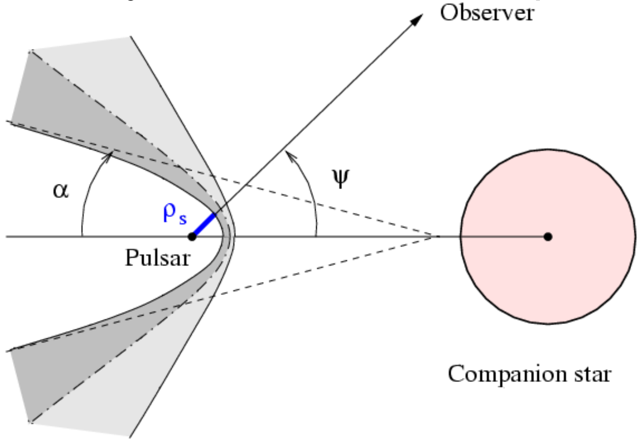
Dubus (2006)

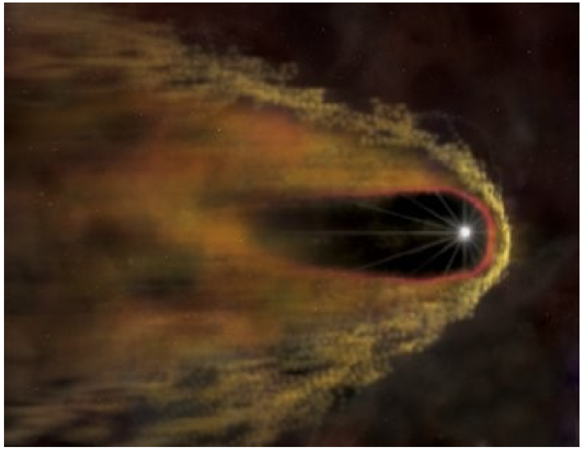
Gamma-ray binaries at AU scales

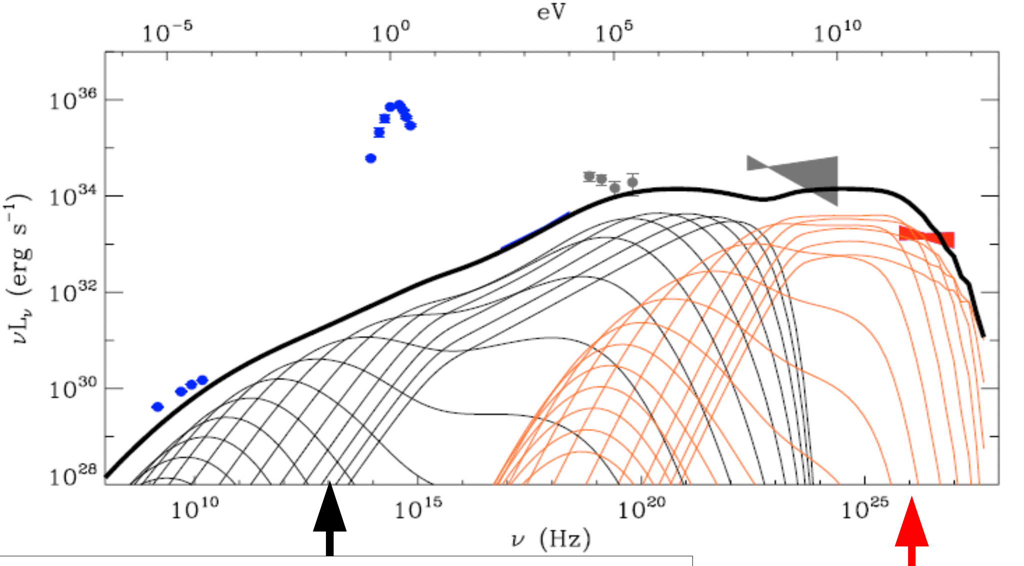
Radio emission in a binary pulsar

An intense shock between the relativistic wind of a non-accreting pulsar and the stellar wind is produced. Particle acceleration at the termination shock leads to synchrotron and inverse Compton emission.

The shocked material is contained by the stellar wind behind the pulsar, producing nebula extending away from the stellar companion.







Adiabatically expanding flow produce the synchrotron emission from radio to X-rays

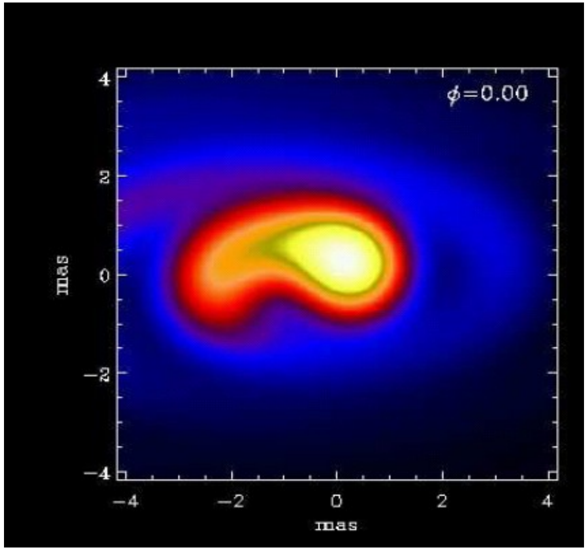
UV photons from the companion star suffer inverse Compton scattering with the relativistic electrons from the pulsar wind

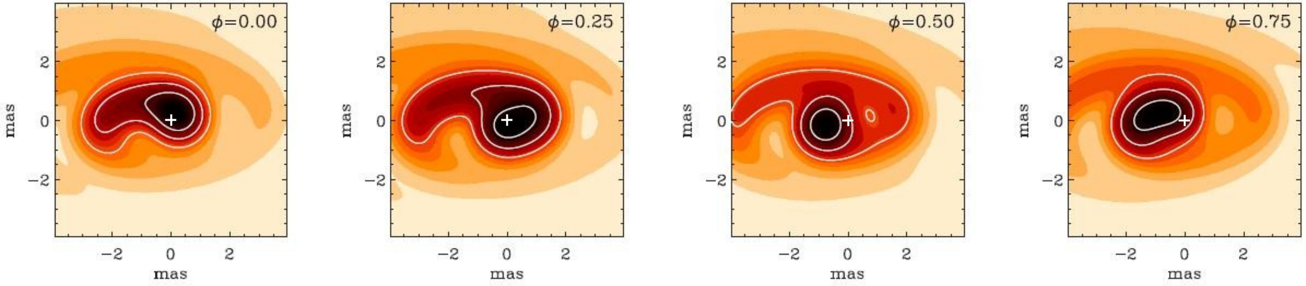
Expected behaviour at mas scales

The cometary tail changes its direction continuously.

The peak of the emission follows the path of an elliptic orbit.

→ Astrometric and morphological changes expected



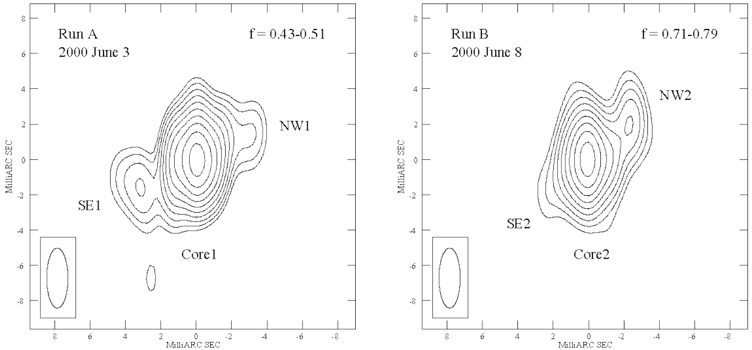


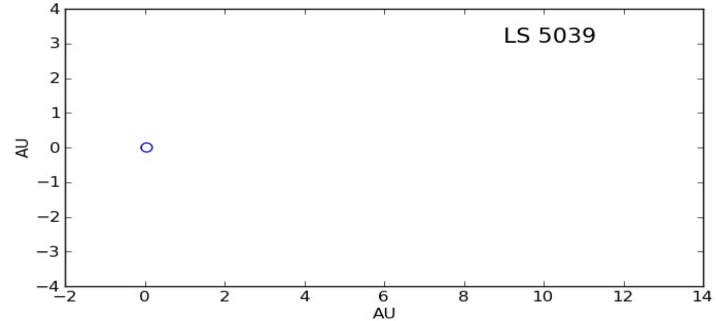
Dubus (2006)

VLBI observations provide images at AU scales at ~2.5 kpc: $1-100\,mas \rightarrow 2.5-250\,AU$

Gamma-ray binaries morphology

LS 5039
P_{orb} = 3.9 days
O6.5V + ?





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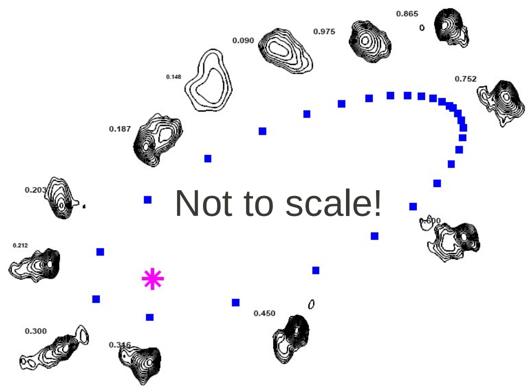
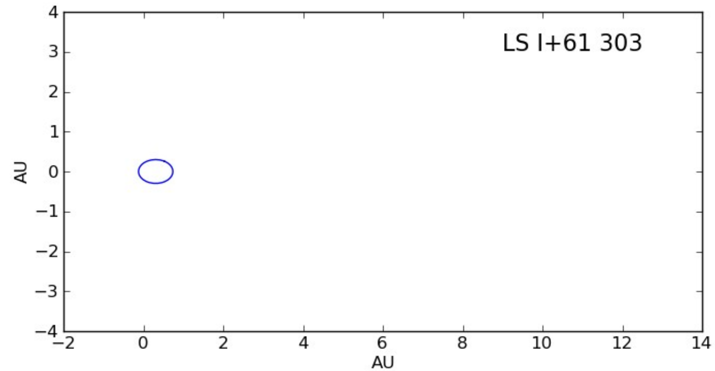
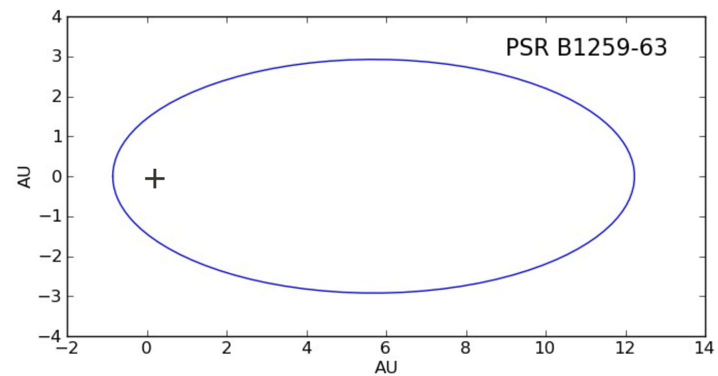




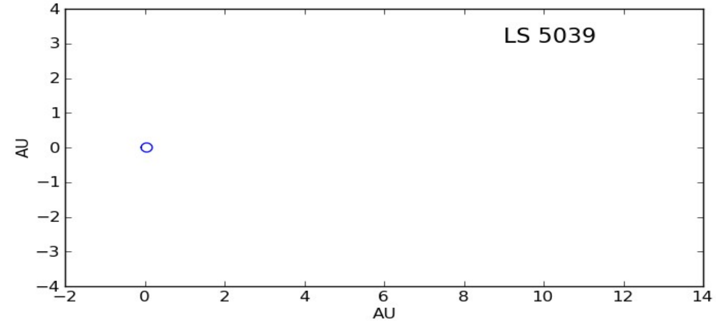
PSR B1259-63
P_{orb} = 3.4 years
O8.5-9Ve + pulsar

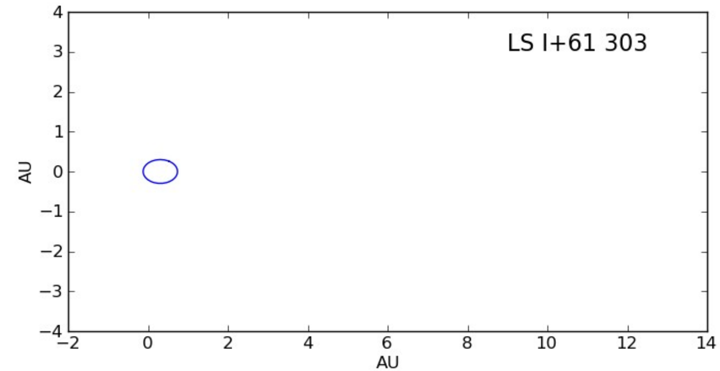
?

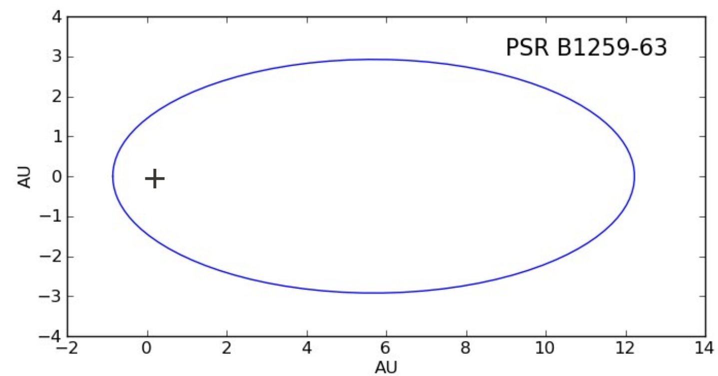


Gamma-ray binaries

	Pulsar	VLBI
LS 5039 P_{orb} = 3.9 days	?	✓ periodic orbital variability
LS I +61 303 P_{orb} = 26.5 days	?	✓ periodic orbital variability
PSR B1259-63 P_{orb} = 3.4 years	✓	?





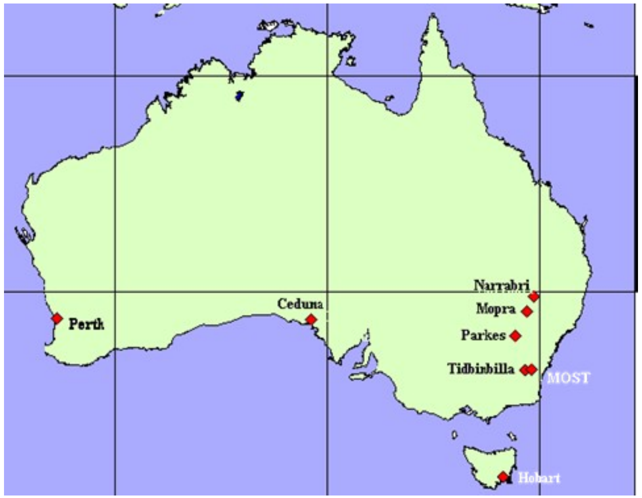


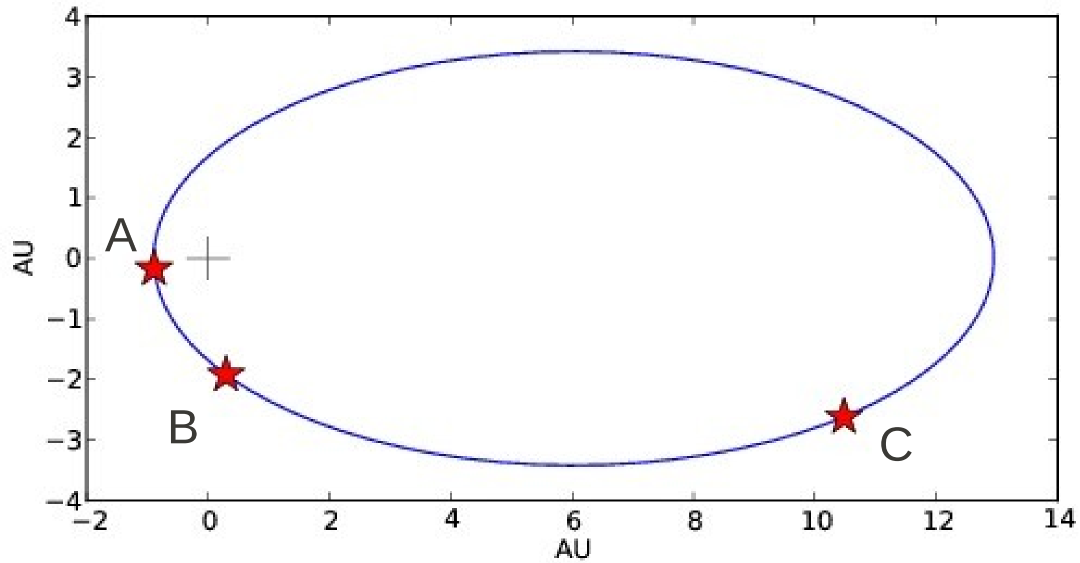
VLBI observations of PSR B1259-63/LS 2883

(The only gamma-ray binary with a confirmed pulsar)

PSR B1259-63 (2007 periastron passage)

We observed PSR B1259−63 with Long Baseline Array (LBA) observations conducted during the 2007 periastron passage at three different orbital phases (T+1, T+21 and T+315). We used 5 antennas of the array. Observations at 2.3 GHz (13 cm).





Run	Epoch	Epoch	Orbital phase
A	54309.25	T+1	0.0010
B	54329.18	T+21	0.0170
C	54623.48	T+315	0.2551

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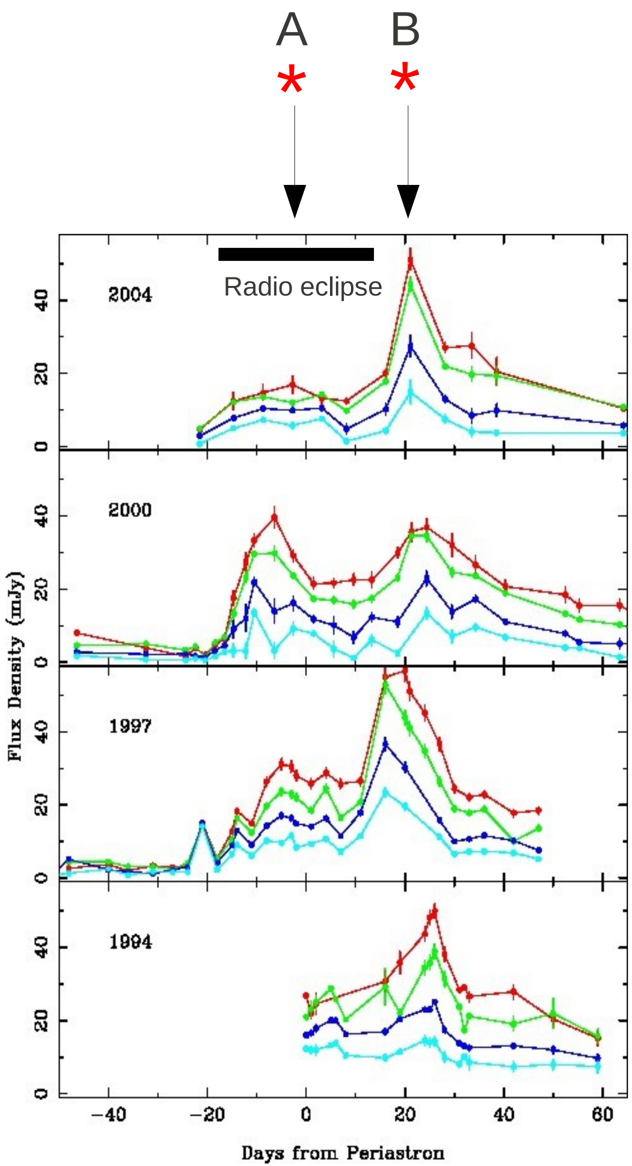

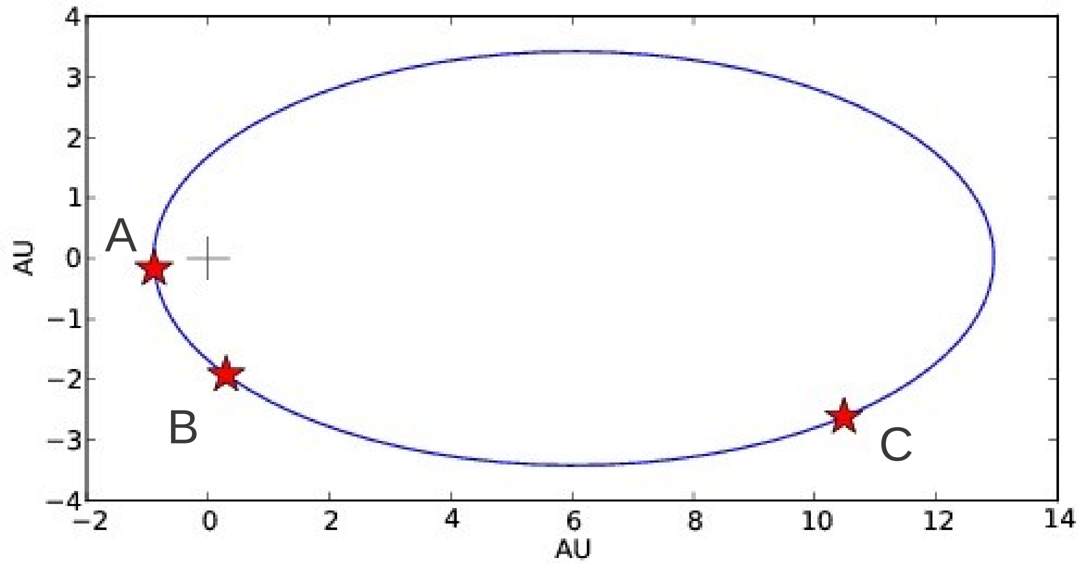

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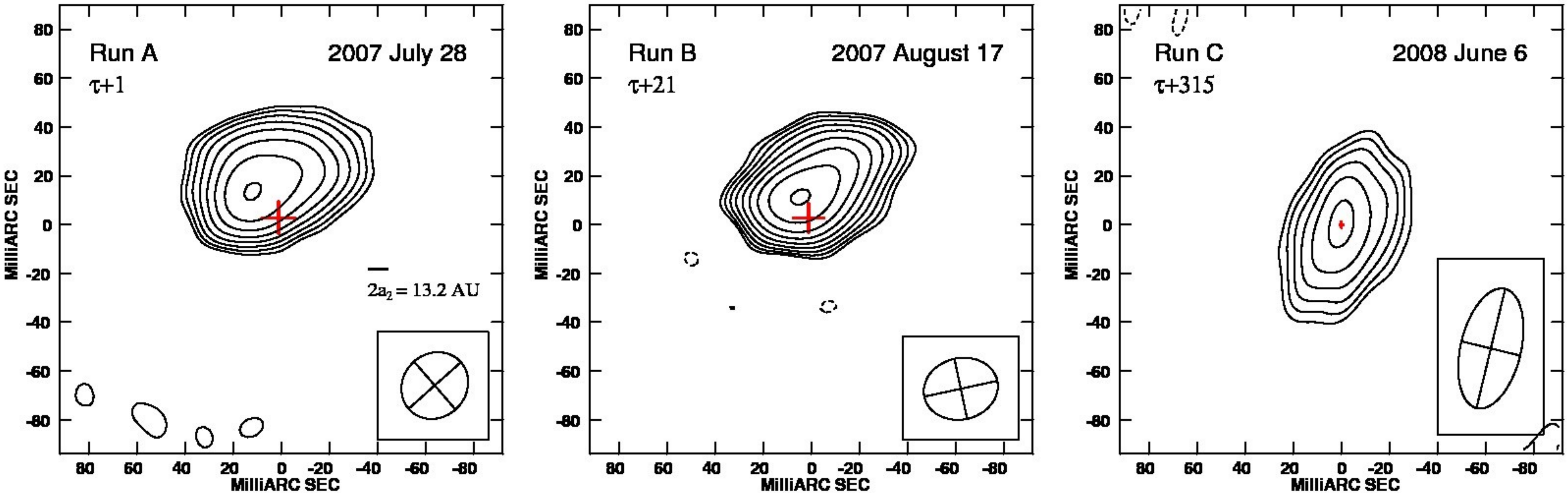
VLBI observations of PSR B1259-63 (2007)

We have just found extended emission from PSR B1259−63 with Long Baseline Array (LBA) observations conducted during the 2007 periastron passage.

[Moldón, Johnston, Ribó, Paredes & Deller, submitted to ApJL]



- We confirm that non-accreting pulsars orbiting massive stars can produce variable extended radio emission at AU scales.
- The peak of the radio nebula is detected at distances between 10 and 50 AU from the binary system and with a total extension of 50 mas (120 AU).
- The discovery of such a structure in PSR B1259−63 reinforces the link with the other known gamma-ray binaries, LS 5039 and LS I +61 303, for which the detection of pulsations is challenging.

Kinematical interpretation (1)

Given the limitations of our data (only two images, and with limited astrometry), we have used a simple kinematical model, economical in free parameters, to check if it can trace the extended structures detected far from the binary system.

Following Kennel & Coronitti (1984) we trace the past trajectory of particles accelerated at the standoff distance. We use the approximation of a non-turbulent adiabatically expanding flow, also described in Dubus (2006). The flow speed depends only on the magnetization parameter σ when σ << 1. We only consider intertaction with an isotropic polar wind.

$$\sigma = \frac{B_1^2}{4\pi n_1 u_1 \gamma_1 m c^2}$$

$$M_1 = 23.6\, M_0$$
$$M_2 = 1.4\, M_0$$
$$P_{orb} = 1236.7243\, d$$
$$d = 2.3\, kpc$$

$$v_{wind,\infty} = 1350\, km\, s^{-1}$$
$$\dot{E}_{sp} = 1 \times 10^{36}\, erg\, s^{-1}$$
$$\dot{M} = 0.6 \times 10^{-7}\, M_0\, yr^{-1}$$

$$i = 24.7^o$$
$$e = 0.8699$$
$$\omega_p = 318.6659^o$$

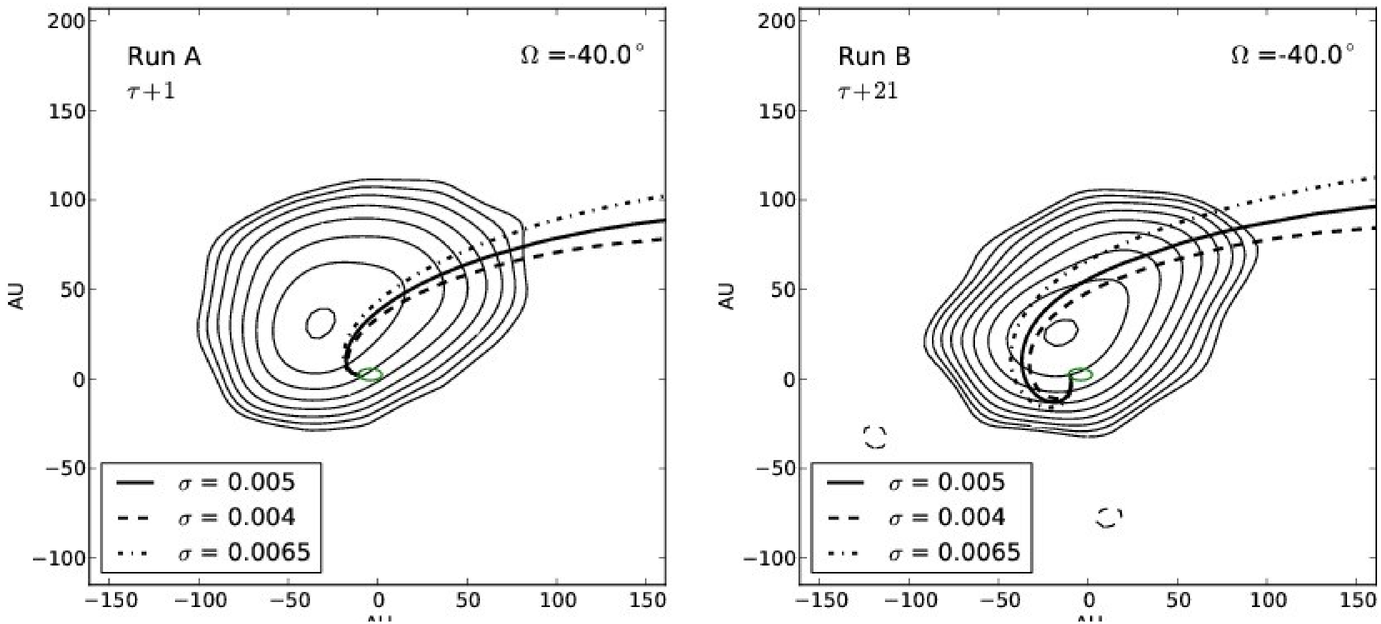
[Negueruela et al. (2010), Wang et al. (2004), McCollum et al. (1993), Vink et al. (2000)]

Only two free parameters:

$$\Omega$$
$$\sigma$$

Kinematical interpretation (2)

A simple kinematic model of the outflow allow us to constraint the orientation of the orbit, given by the longitude of the ascending node, Ω, and the magnetization of the pulsar, σ.

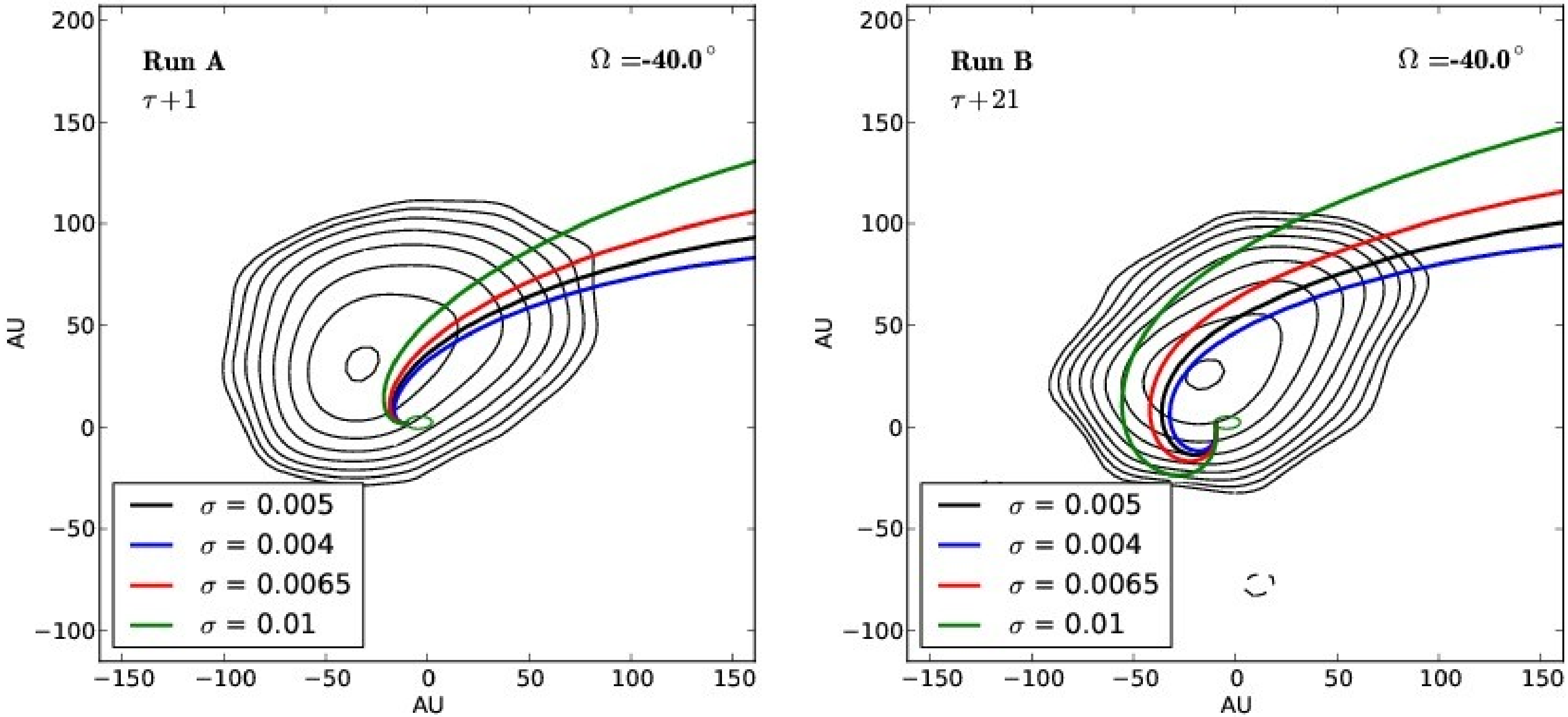


[Moldón, Johnston, Ribó, Paredes & Deller, submitted to ApJL]

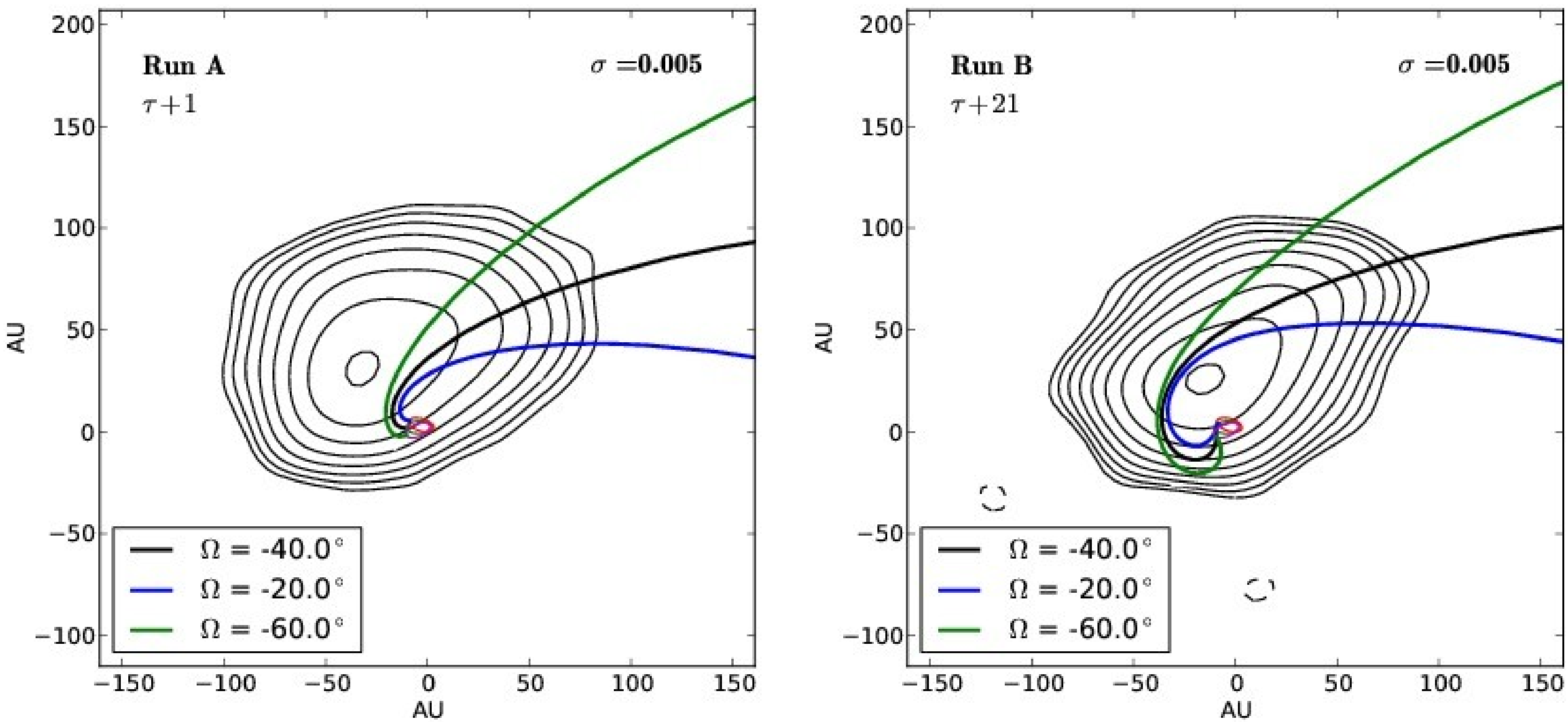
The detected morphology can be accounted for if:

$$\Omega \simeq -40^{\circ}$$
$$\sigma \simeq 0.005$$

Kinematical interpretation (3)



Kinematical interpretation (4)



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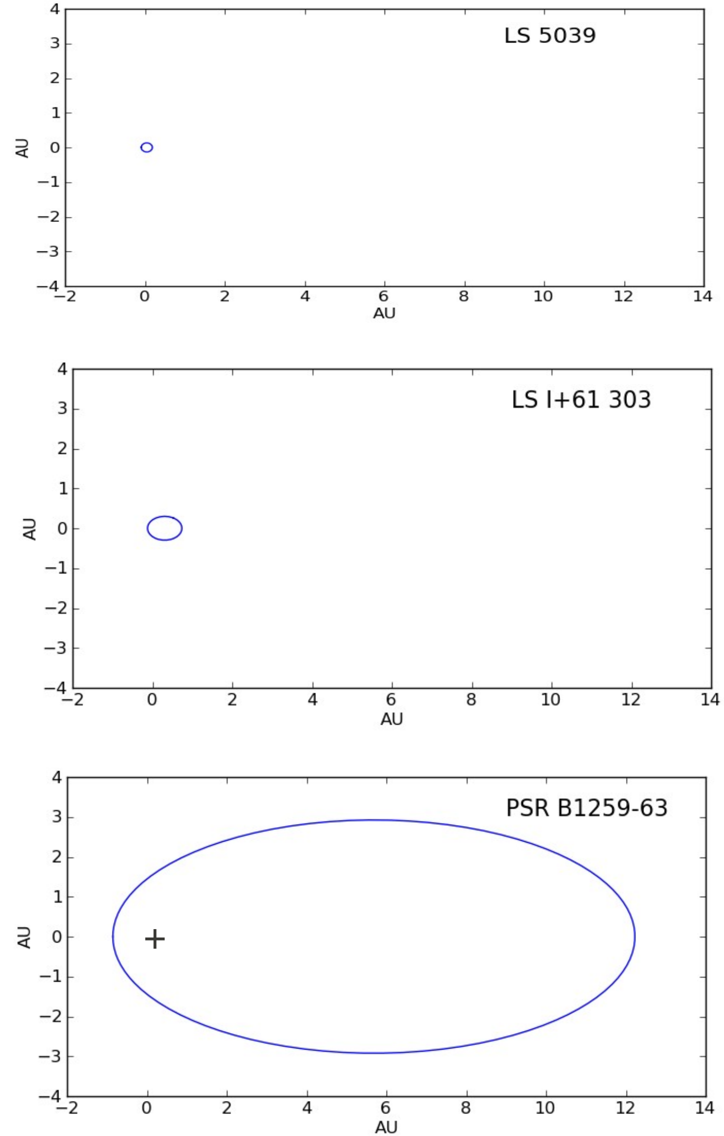
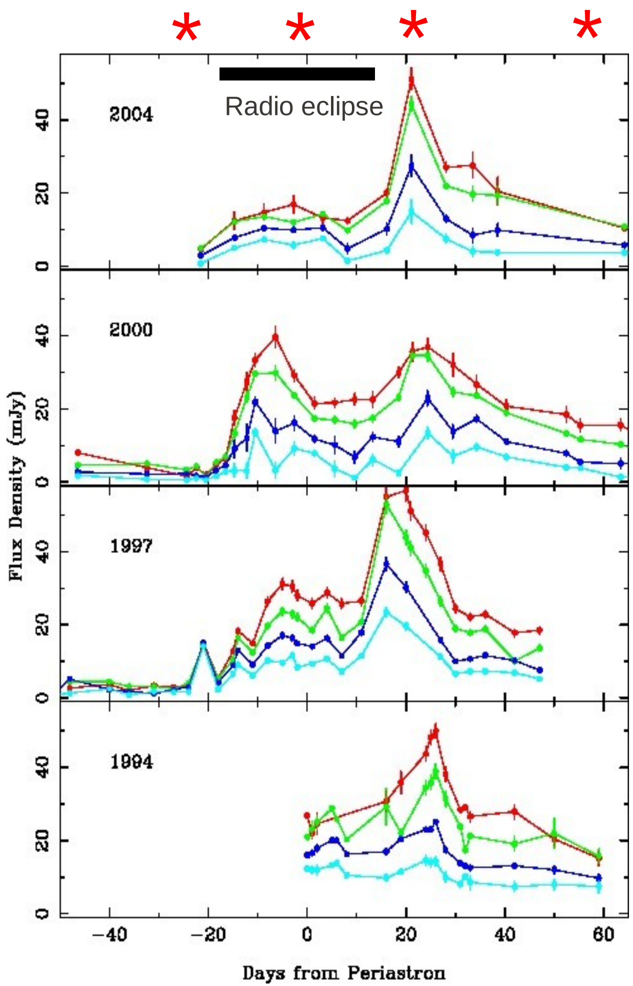
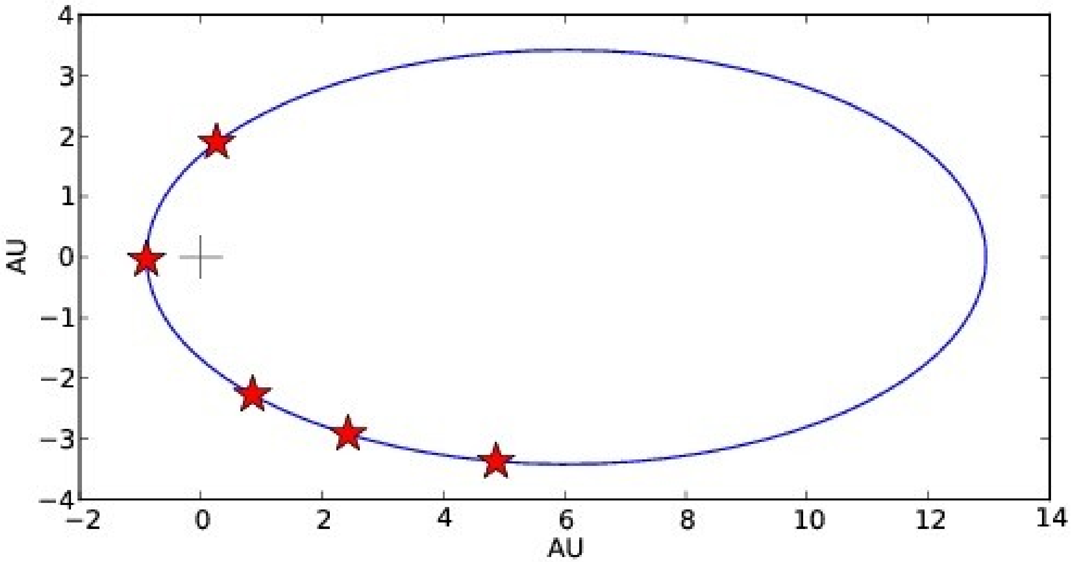


2010 periastron passage of PSR B1259-63/LS 2883

Present observations

We will monitor the orbital variability of the nebula with the LBA during the 2010 periastron passage (Dec 15, 2010). We have 5 observations planed covering a wide range of true anomalies.





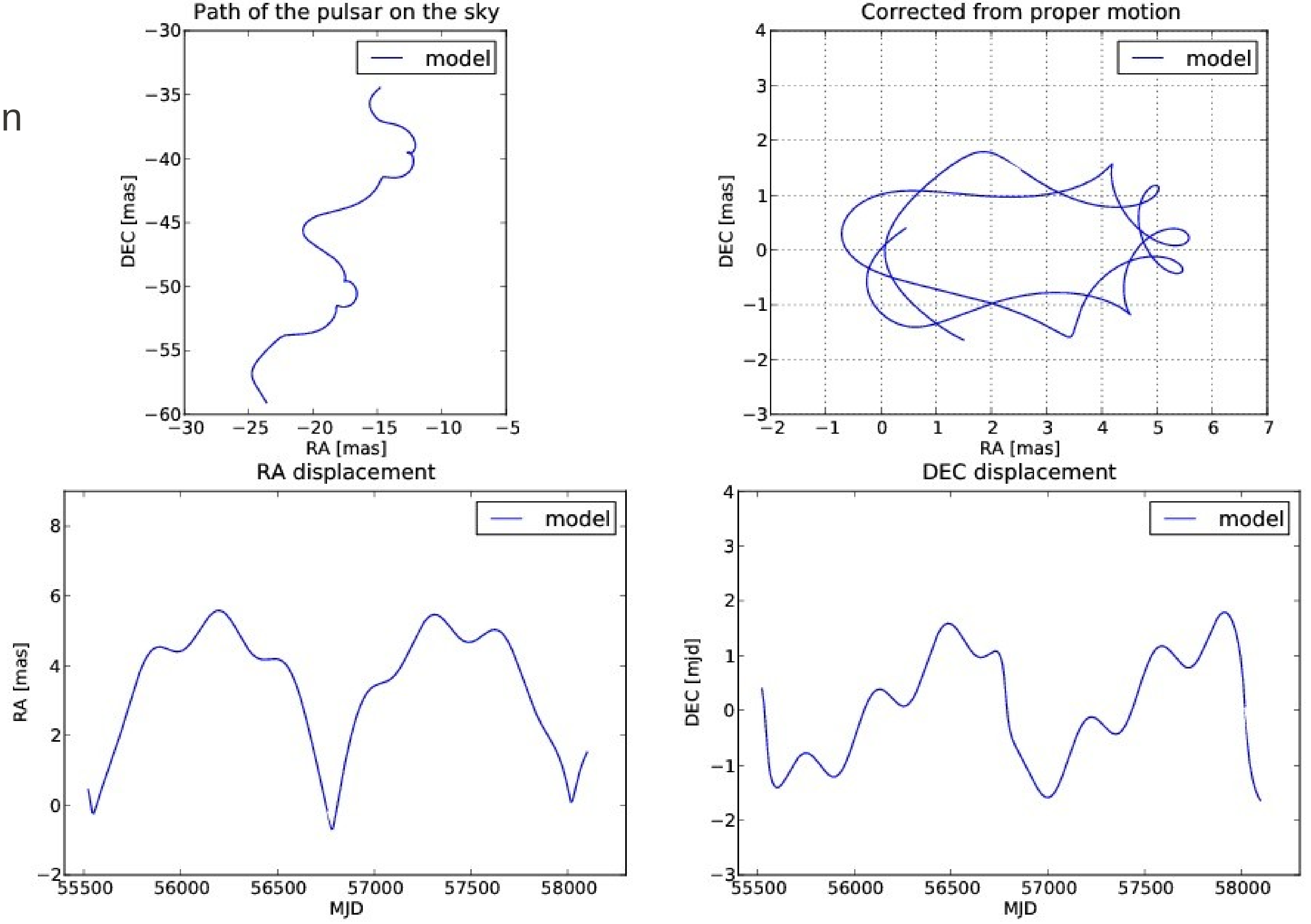
Run	Epoch	Epoch	Orbital phase
✓ A	55524	T-21	0.9833
B	55545	T+0	0.0003
C	55574	T+29	0.0237
D	55600	T+55	0.0447
E	55652	T+107	0.0868

Future projects

Model:
- Pulsar orbit
- Proper motion
- Earth motion

Parameters:

$$\alpha_{0,} \delta_0$$
$$\mu_\alpha \cos\delta , \mu_\delta$$
$$\pi , d$$
$$inc , M_{1,} a_2$$
$$\Omega$$



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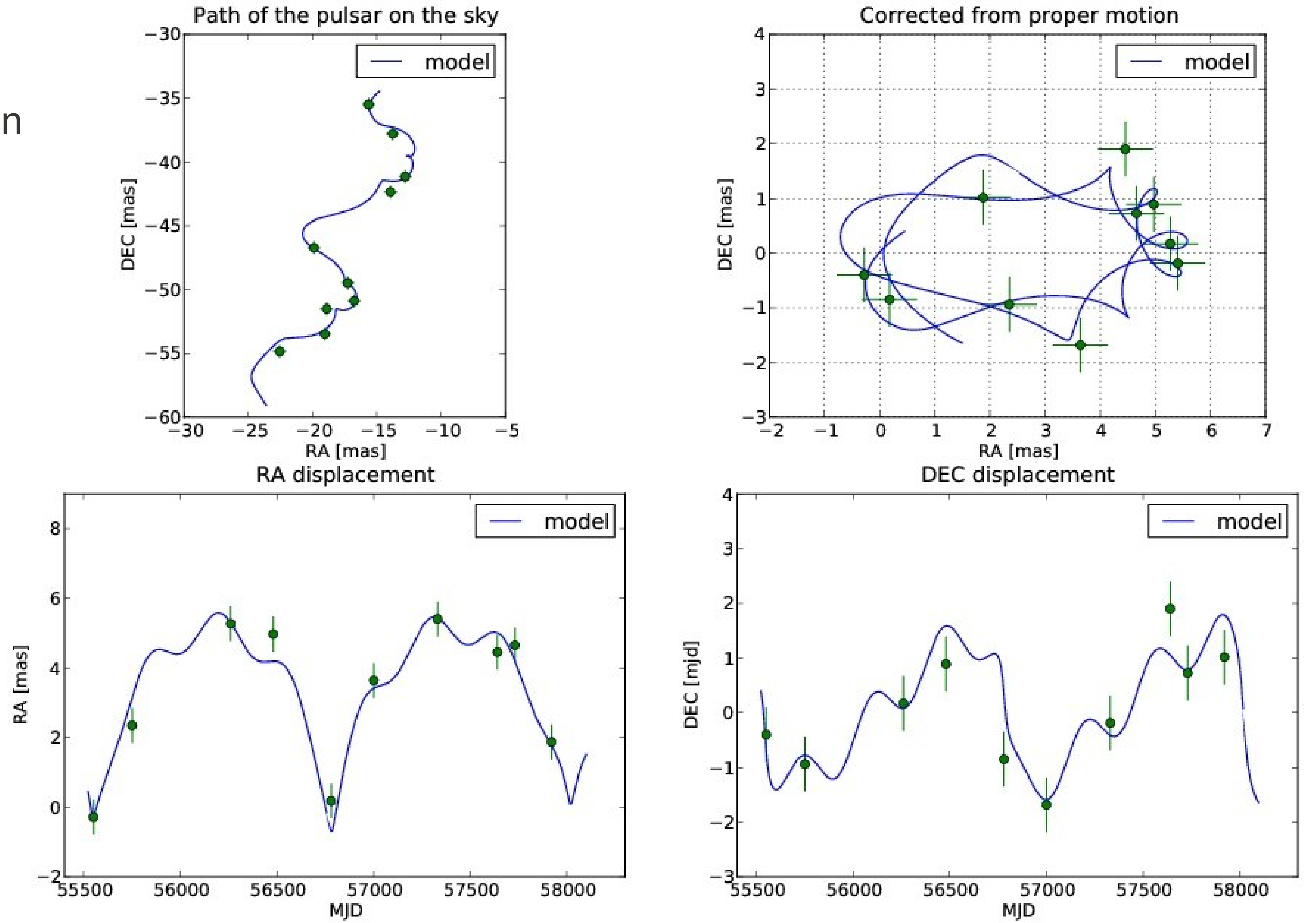

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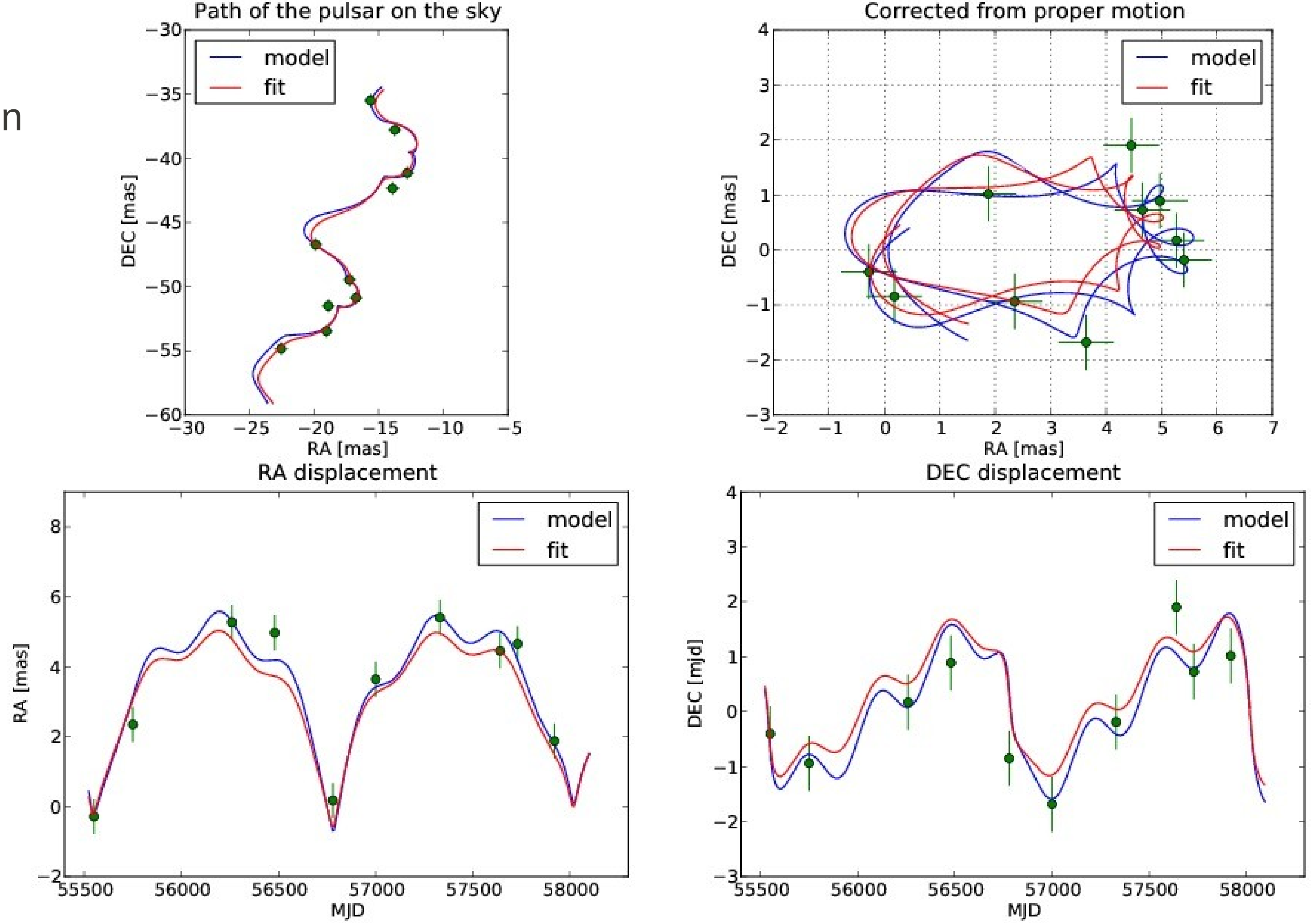

Summary

1. We confirm that non-accreting pulsars orbiting massive stars can produce variable extended radio emission at AU scales.

2. The peak of the radio nebula is detected at distances between 20 and 50 AU from the binary system and with a total extension of 50 mas (120 AU).

3. The discovery of such a structure in PSR B1259–63 reinforces the link with the other known gamma-ray binaries, LS 5039 and LS I +61 303, for which the detection of pulsations is challenging.

4. VLBI radio observations can put constrains on physical parameters of the system.

5. We will have new VLBI observations covering the 2010 periastron passage.

PSR B1259-63

Parameter	Symbol	Value	Reference
Pulsar period	P	47.762506780(2) ms	1
Period derivative	$\dot{P}$	$2.276554(2) \times 10^{-15}$	1
Characteristic age	τ_c	3.3×10^5 yr	2
Surface magnetic field	B	3.3×10^{11} G	2
Spindown luminosity	$\dot{E}_{\rm sp}$	8×10^{35} erg s^{-1}	3
Spectral type	–	O8.5 Ve	4
Effective temperature	$T_{\rm eff}$	$33\,000^{+2\,000}_{-1\,000}$ K	4
Surface gravity	$\log\ g$	$3.8^{+0.3}_{-0.2}$	4
Radius	R_1	$8.9^{+1.8}_{-1.5}\ R_\odot$	4
Optical luminosity	$L_{\rm opt}$	$3.2^{+1.7}_{-1.0} \times 10^{38}$ erg s^{-1}	4
Mass	M_1	$23.6^{+21.9}_{-9.5}\ M_\odot$	4
Distance	d	2.3 ± 0.4 kpc	4
Mass function	$f(M_2)$	$1.53\ M_\odot$	5
Terminal wind velocity	v_∞	1350 ± 200 km s^{-1}	6
Orbital period	$P_{\rm orb}$	1236.72432(2) days	1
Reference epoch	T_0	MJD 48124.34911(9)	1
Semimajor axis	a_2	$6.6^{+1.9}_{-0.8}$ AU	4
Inclination	i	$24\overset{\circ}{.}7^{+5.9}_{-5.4}$	4
Eccentricity	e	0.8698872(9)	1
Argument of periastron	ω_2	$138.6659(1)^\circ$	1
Longitude of ascending node	Ω	-40°	See text
Proper motion (rigth ascension)	$\mu_\alpha \cos\delta$	-1.4 ± 2.7 mas yr^{-1}	7
Proper motion (declination)	μ_δ	-3.2 ± 1.9 mas yr^{-1}	7

[Moldón, Johnston, Ribó, Paredes & Deller, submitted to ApJL]