Extended and variable radio structure of gamma-ray binaries. The case of PSR B1259-63/LS 2883

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Reunión abierta de la RIA: Ciencia y oportunidades tecnológicas en la era SKA
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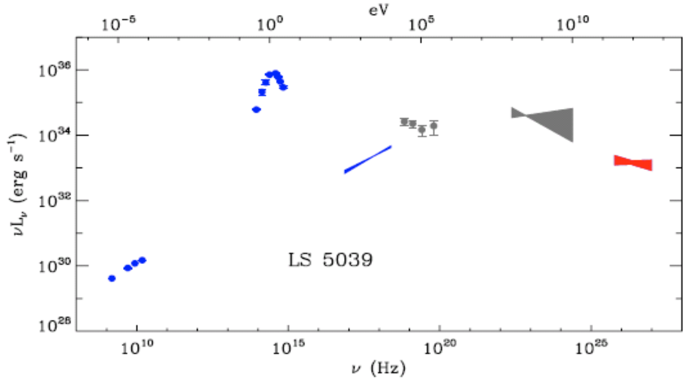
Outline

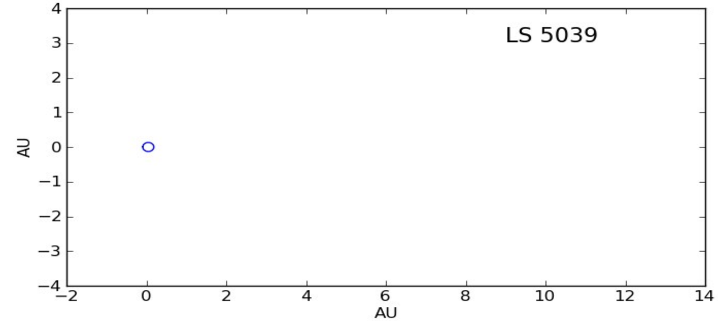
- Gamma-ray binaries
- VLBI observations of PSR B1259-63/LS 2883
- The role of SKA

Gamma-ray Binaries

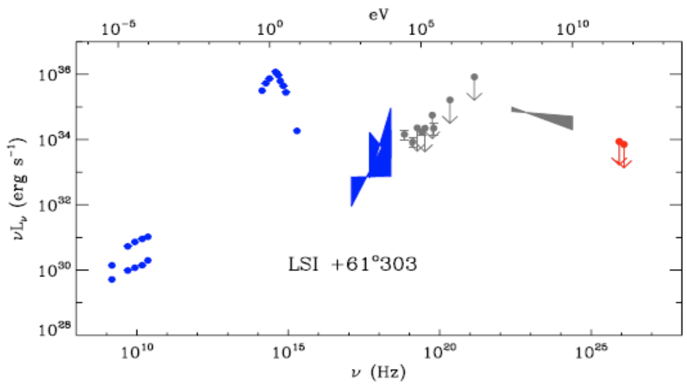
Gamma-ray binaries

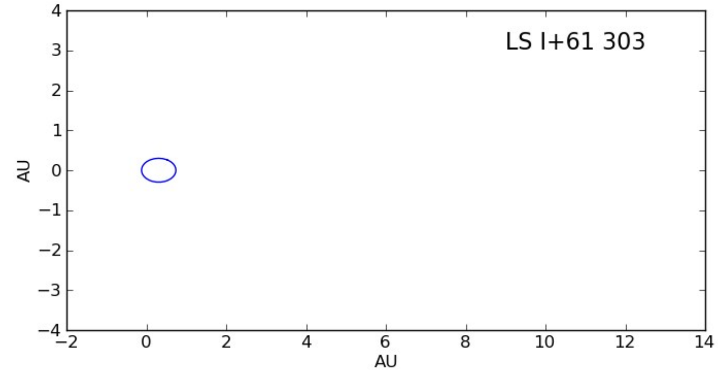
LS 5039
P_{orb} = 3.9 days
O6.5V + ?



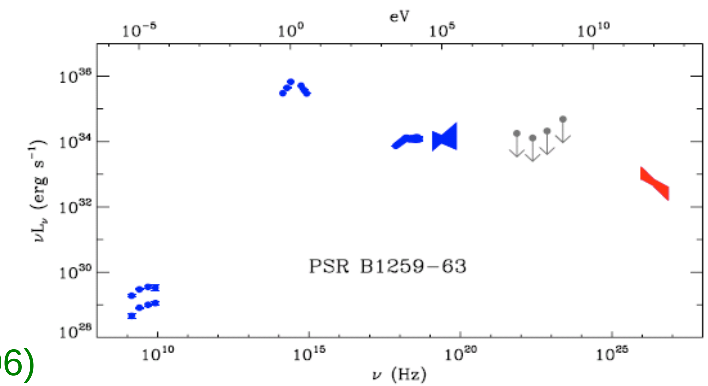


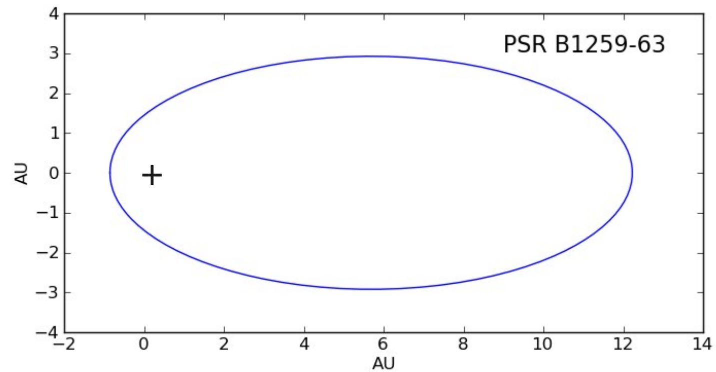
LS I +61 303
P_{orb} = 26.5 days
B0Ve + ?





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





Dubus (2006)

Gamma-ray binaries

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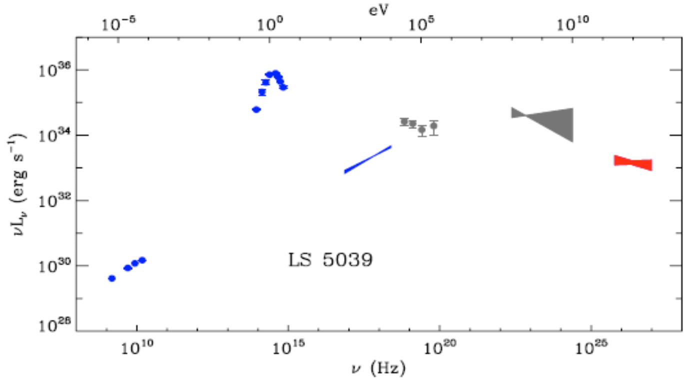

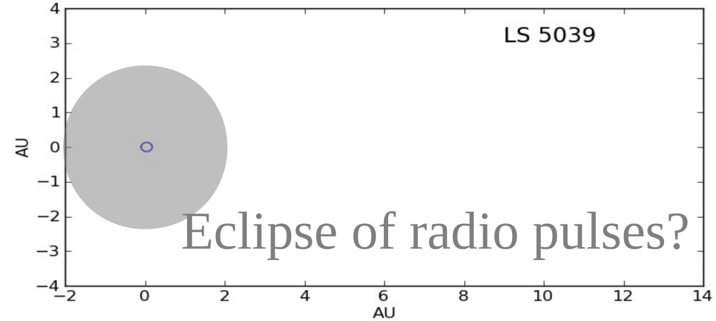

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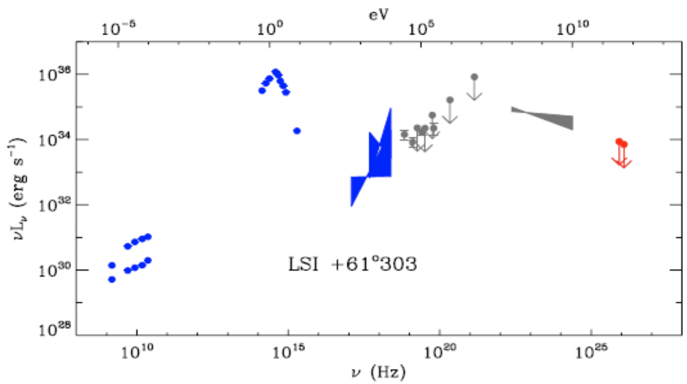

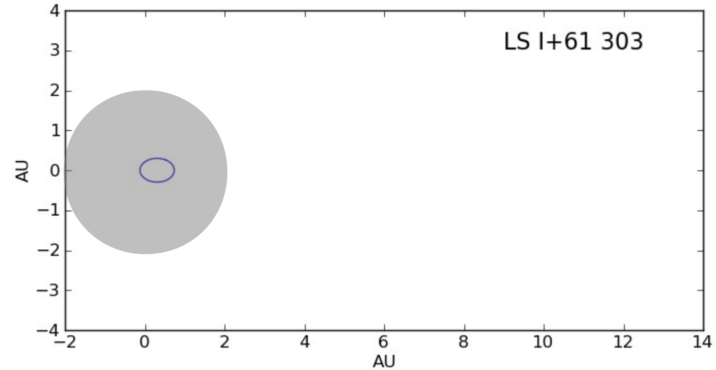

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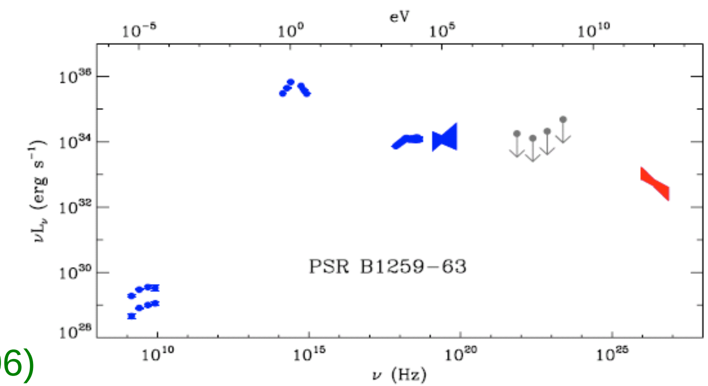
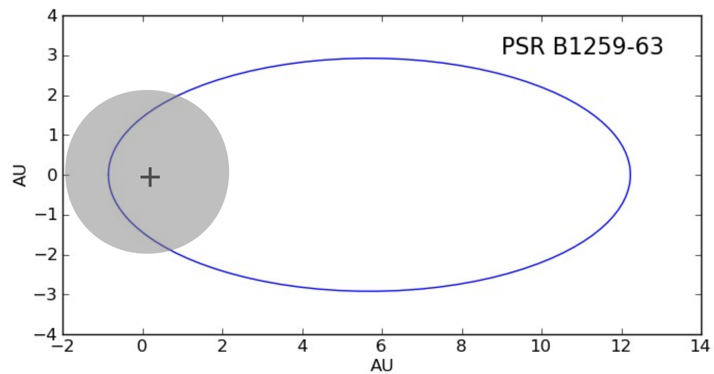
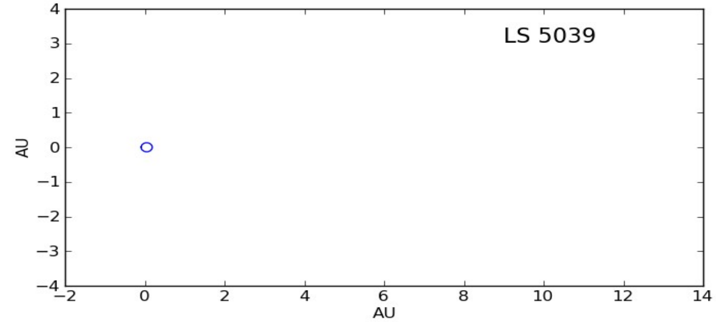


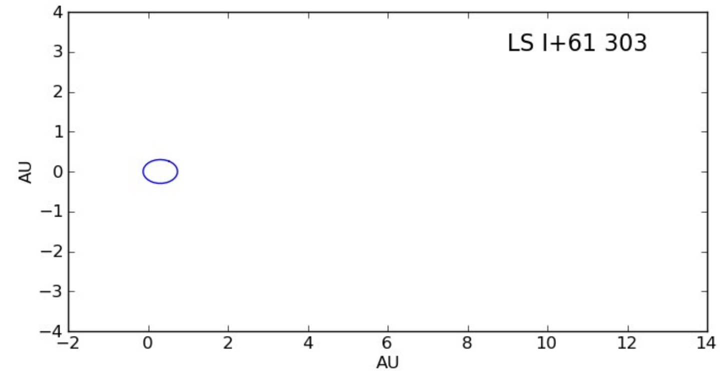


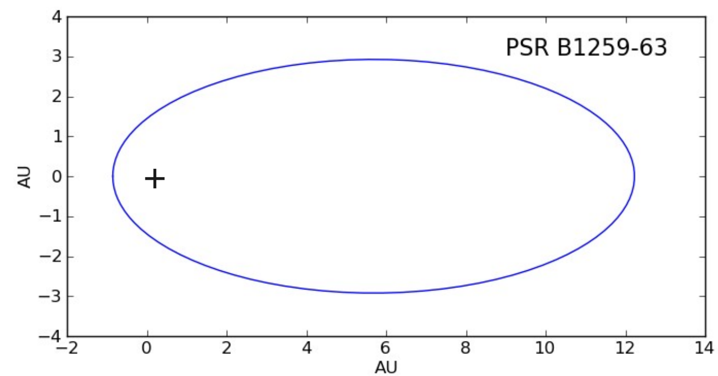
Dubus (2006)

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	✓	?



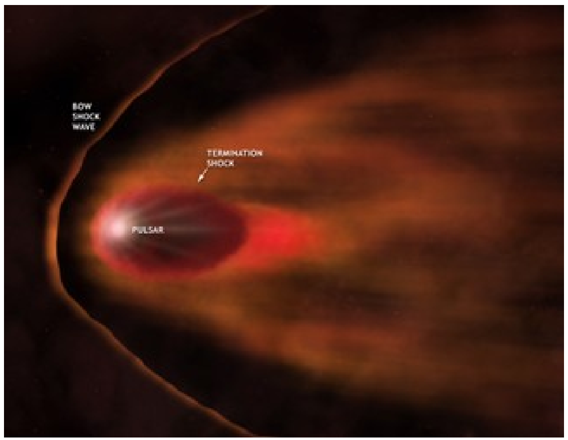


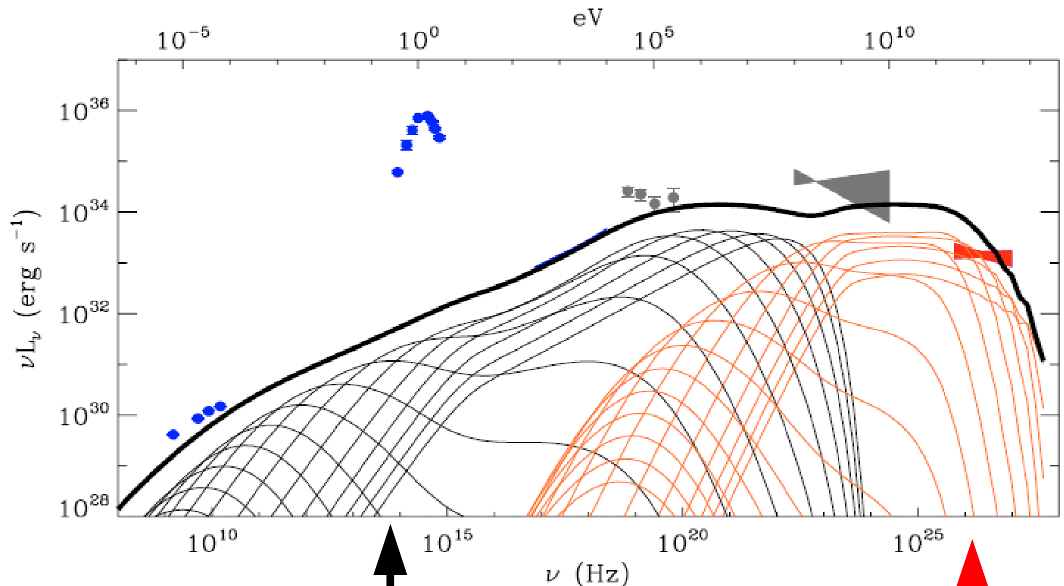


Non-accreting pulsar scenario

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.





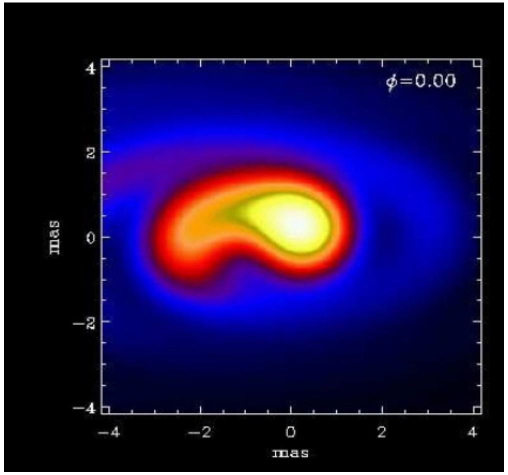
Adiabatically expanding flow produce the synchrotron emission from radio to X-rays

UV photons from the companion star suffer inverse Compton scattering with the UV photons from the companion star

Expected behaviour at mas scales

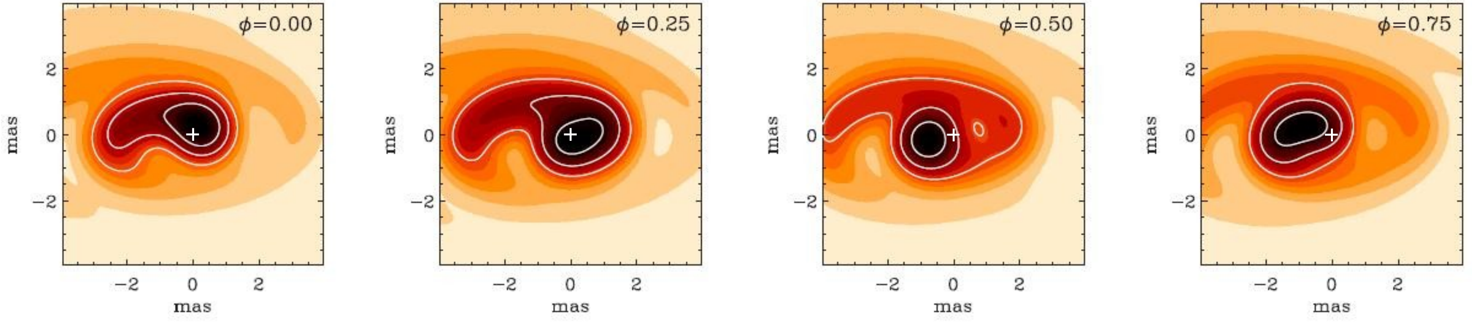
The cometary tail changes its direction continuously.
The peak of the emission follows the path of an elliptic orbit.

→ Astrometric and morphological changes expected



VLBI observations provide images at AU scales at ~2.5 kpc:

$$1-100\,mas \;\rightarrow\; 2.5-250\,AU$$



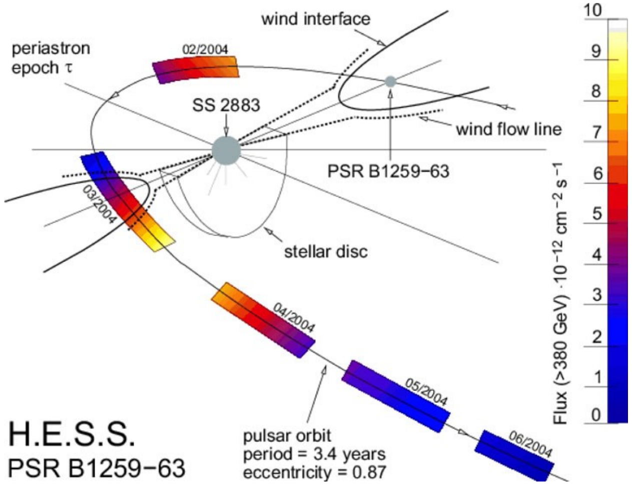
Dubus (2006)

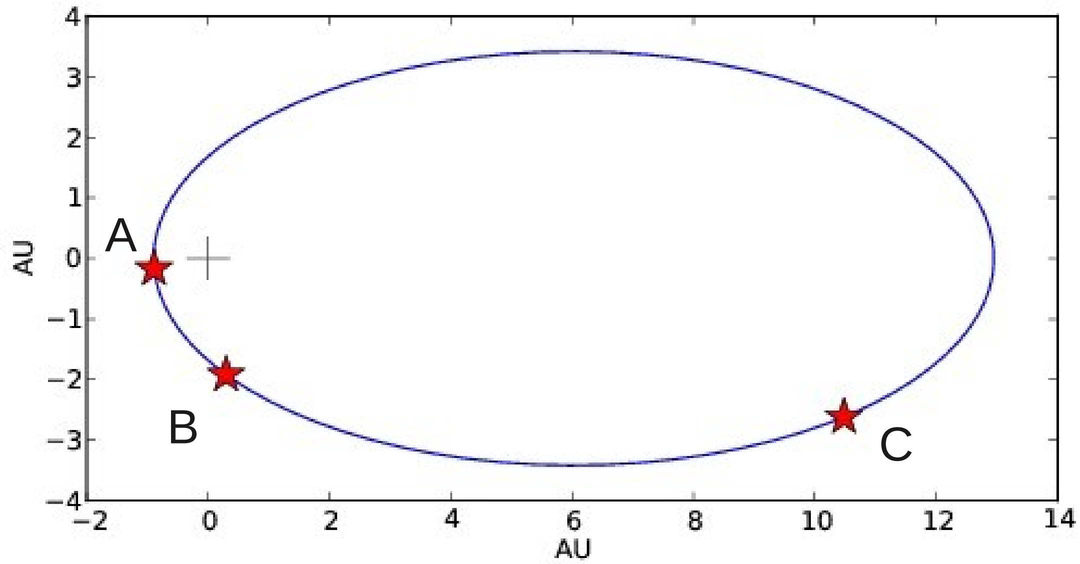
VLBI observations of PSR B1259-63/LS 2883

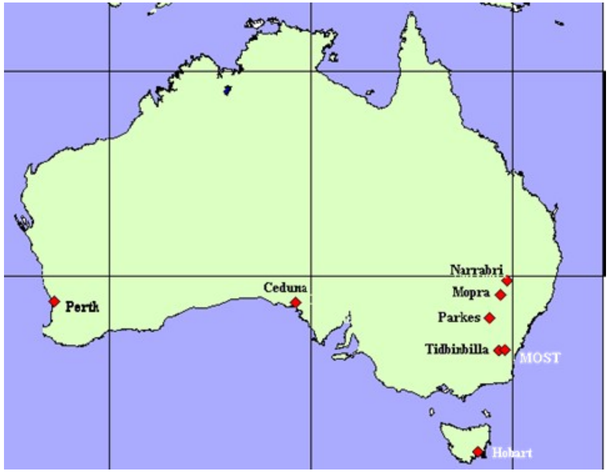
(The only gamma-ray binary with a confirmed pulsar)

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).





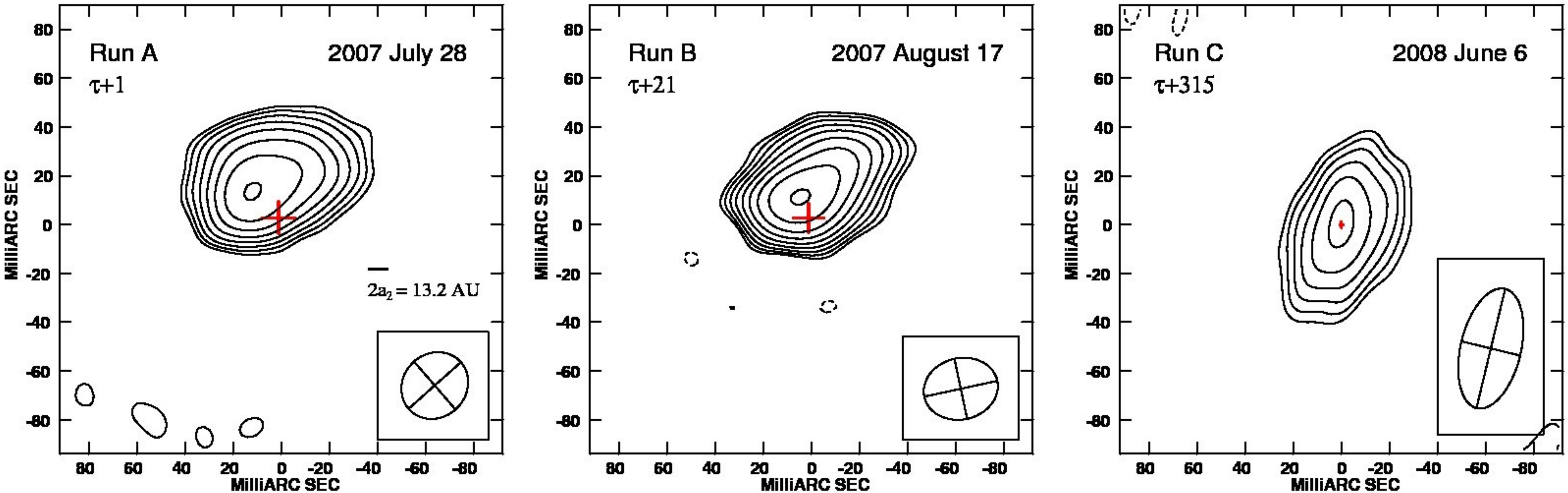


Run	MJD	Epoch	Orbital phase
A	54309.25	T+1	0.0010
B	54329.18	T+21	0.0170
C	54623.48	T+315	0.2551

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 et al. 2011]



- 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.

$$M_1 = 31\,M_o$$
$$M_2 = 1.4\,M_o$$
$$P_{orb} = 1236.7243\,d$$
$$d = 2.3\,kpc$$

$$v_{wind,\infty} = 1350\,km\,s^{-1}$$
$$\dot{E}_{sp} = 1\times10^{36}\,erg\,s^{-1}$$
$$\dot{M} = 0.6\times10^{-7}\,M_o\,yr^{-1}$$

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

$$i = 22.2^o$$
$$e = 0.8699$$
$$\omega_p = 318.6659^o$$

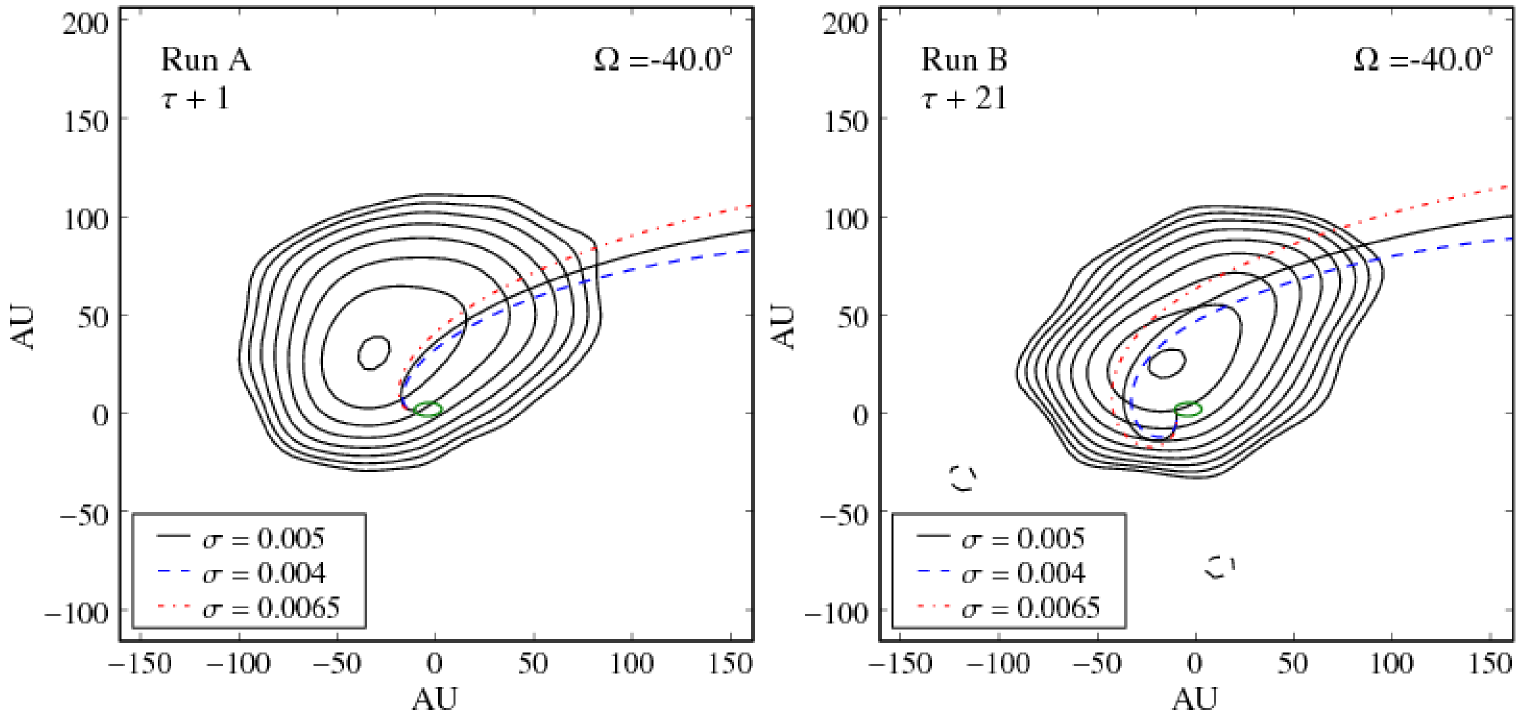
Only two free parameters:

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

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

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.

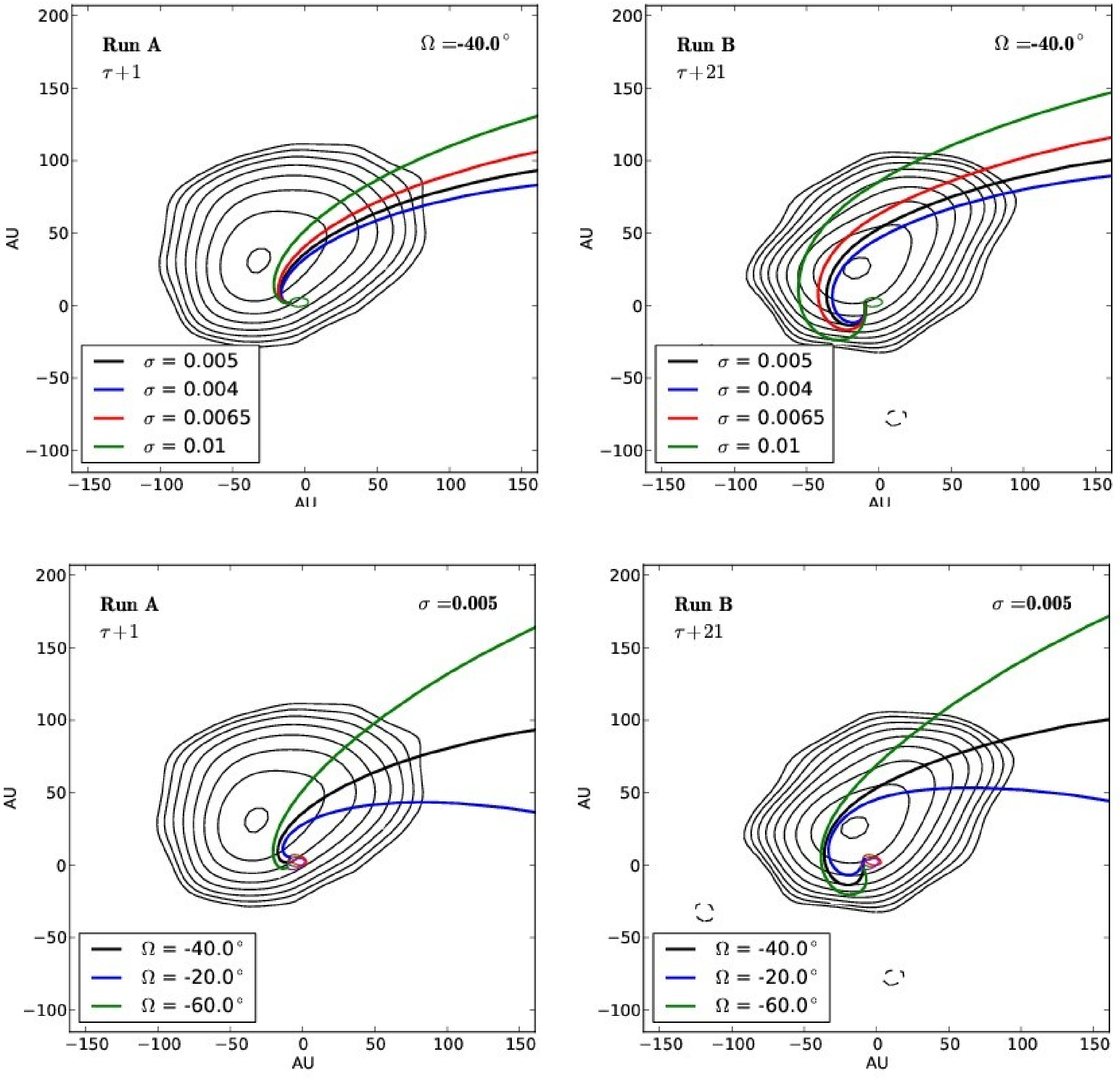


[Moldón et al. 2011]

The detected morphology can be accounted for if:

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

Kinematical interpretation (3)



Gamma-ray binaries

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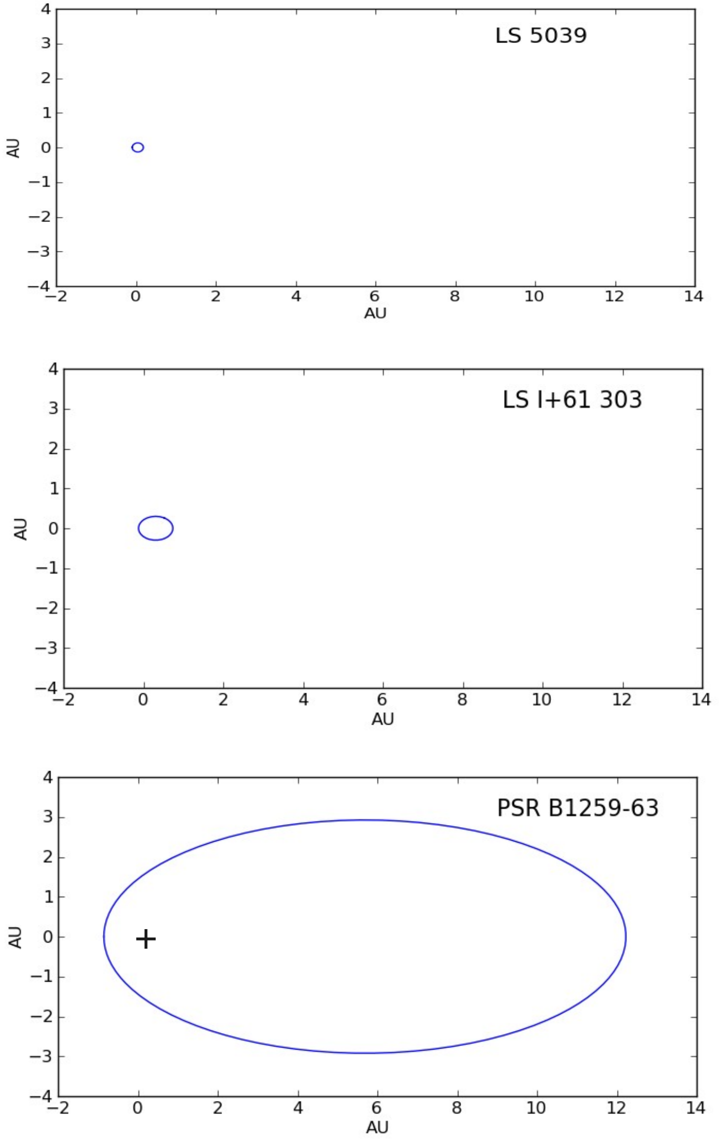
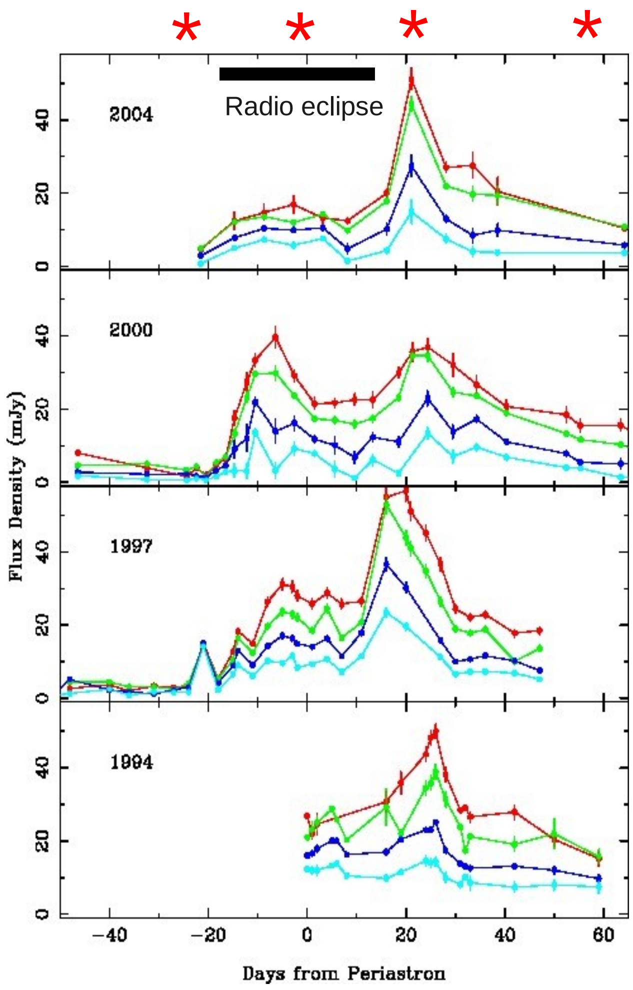
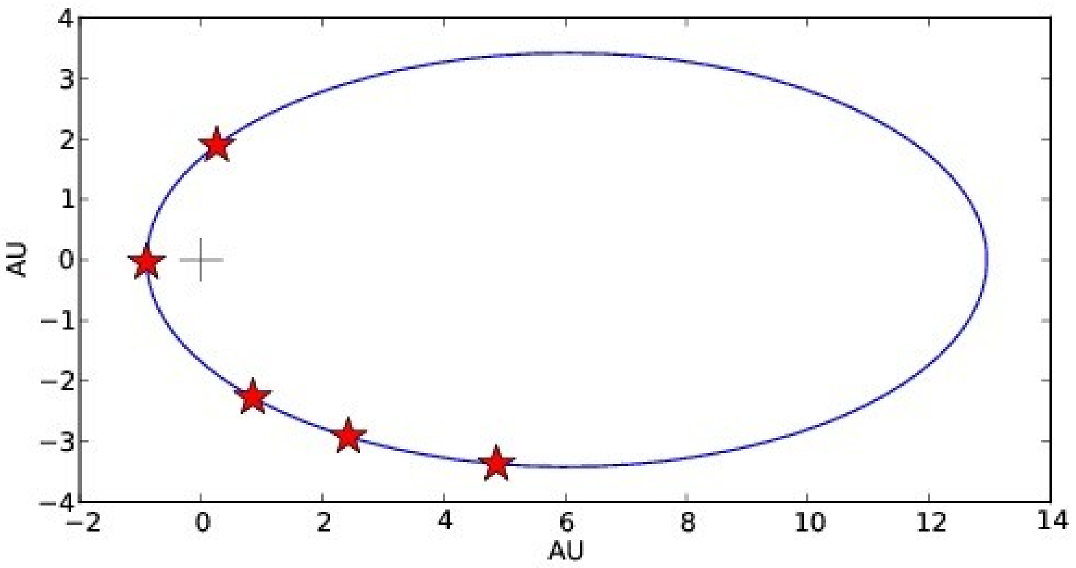
PSR B1259-63 P_{orb} = 3.4 years	✓	✓ orbital variability



Present observations

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





Run	MJD	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

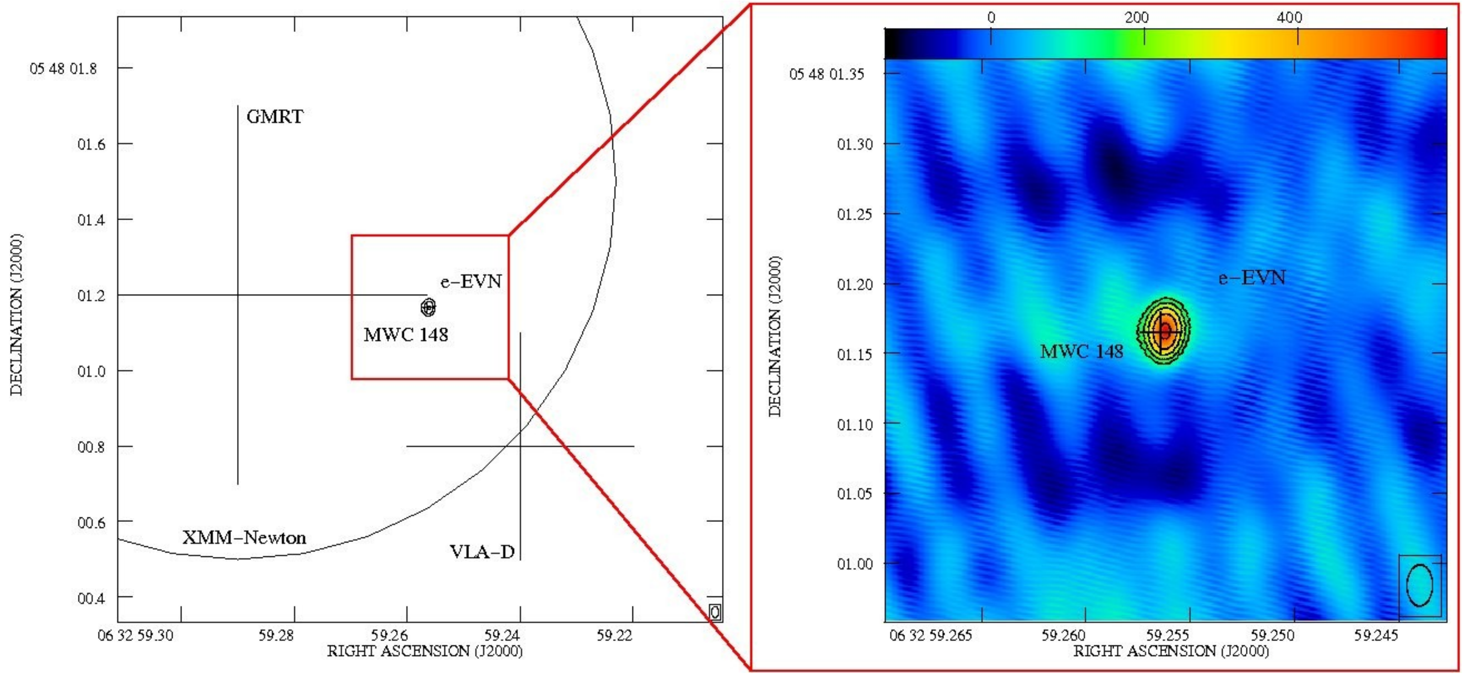
The role of SKA

The role of SKA: sensitivity

The already known gamma-ray binaries (LS 5039, LS I 61 303, PSR B1259-63) have a flux density between 20-80 mJy at ~ GHz. A new population of gamma-ray binaries is appearing, with flux densities one order of magnitude fainter.

HESS J0632+057
P = 320 ± 5 days
0.9 mJy at 1.6 GHz
0.2 mJy at 5 GHz
e-EVN observations

[Moldón et al., 2011, ATel #3180]



1FGL J1018.6-5856
P = 16.58 ± 0.04 days.
2-5 mJy at 5.5 GHz
distance = 6-12 kpc

[Corbet et al., 2011, ATel #3221]

New full EVN observations on HESS J0632+057 show a 150 µJy extended source, and a peak displacement of ~ 15 mas in 30 days.

[Moldón et al., in preparation]

The role of SKA: resolution

Now we are exploring the extended emission at scales ~10 times bigger than the binary orbit. VLB-resolution is necessary, specially for small orbits (LS 5039, peak displacements ~ 0.1-1 mas) or distant objects (1FGL J1018.6-5856, extended emission 1-2 mas?).

Astrometric projects:

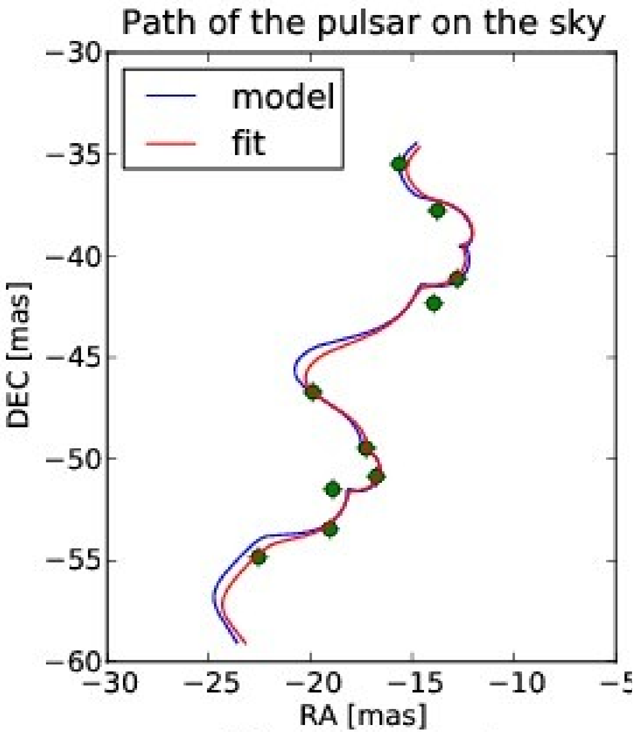
- Proper motion of the binary system.
- Measure the path on the sky of a pulsar in a binary system.

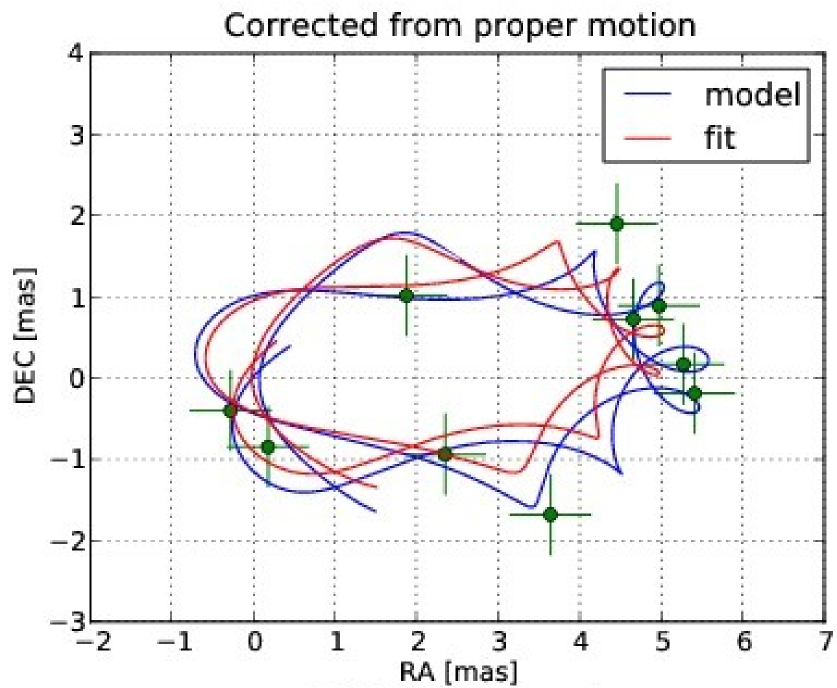
Model:

· Pulsar orbit
· Proper motion
· Earth motion

Parameters:

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

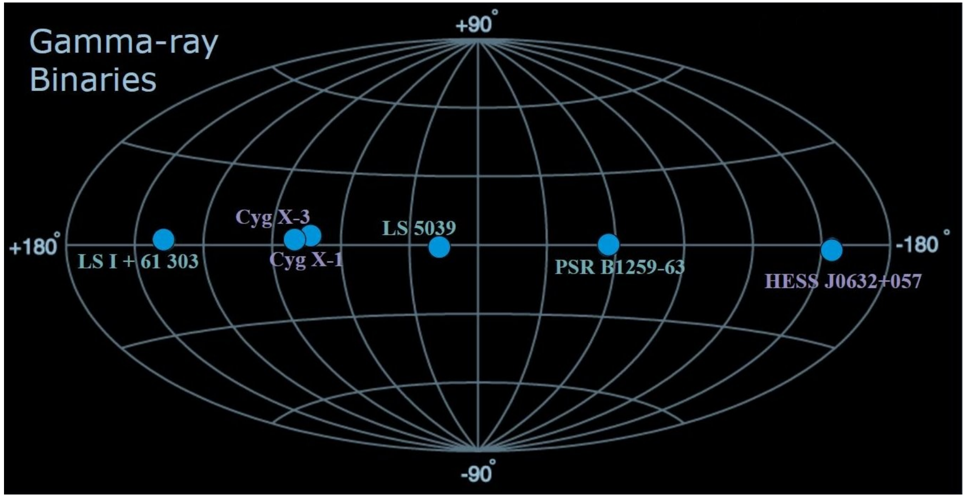




The role of SKA: location

Gamma-ray binaries are galactic sources that contain a high-mass stellar companion. They are found in the galactic plane.

SKA will significantly improve the observations in the Southern hemisphere.



Joined observations:

Complementary to other VLBI arrays, joined observations possible. Example:

e-VLBI observations between Europe, East Asia, and Australia, 12500 km baselines [Giroletti et al., 2011]

Main current VLBI arrays:

	sensitivity	uv-coverage	availability	hemisphere
VLBA	good (upgrade)	good	continuous observing	north
EVN	best	best	sessions + monthly e-EVN	north
LBA	Normal	scarce	sessions (+additionals)	south

Conclusions

1. Gamma-ray binaries display extended and variable synchrotron radio emission and peak displacement. Best frequencies: 1-10 GHz.

2. We are interested in exploring the ranges of 1 μJy–1 mJy and 0.1–100 mas.

3. Regular but transient sources. Should be studied in time scales of 1–100 days.

4. A new population of faint binaries is being discovered, and a sensitivity improvement will be required in a few years.

5. SKA will provide μJy sensitivity and long baselines (3000 km).

6. Joined observations with external antennas is required. (3000-12000 km baselines). Regular and special sessions required.

7. Subarray capability and continuous observing would allow monitoring of transient sources (some binaries have a small duty cycle).