VLBI morphological variability of LS 5039 and its birth place

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Gamma-ray Binaries

Gamma-ray binaries

A new population of binary systems with emission from radio to TeV:

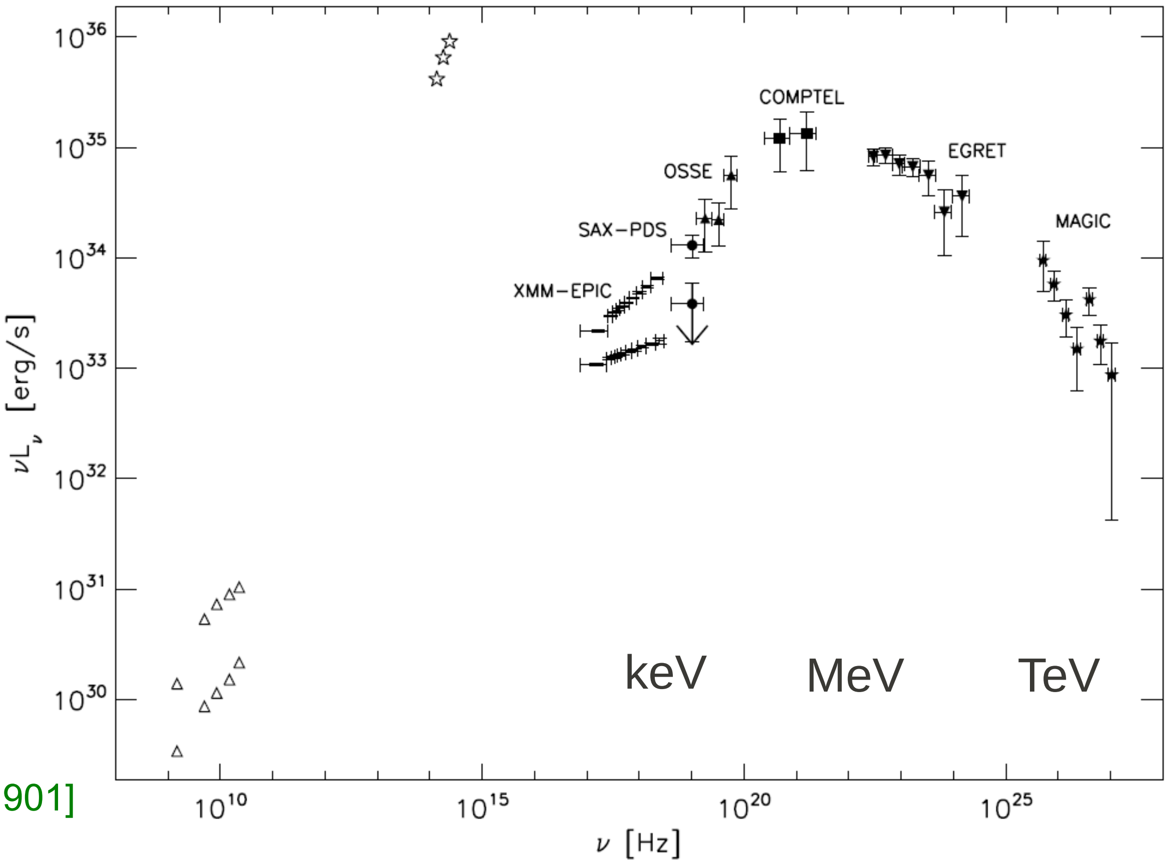
- Massive star (OB) + compact object.
- Highly interacting binary. Close orbits.
- Broadband non-thermal emission.
- Display emission > 10^{11} eV – TeV.
- The energy output is dominated by the emission above the MeV.

- Known systems:

LS 5039
LS I +61 303
PSR B1259-63

HESS J0632+057?

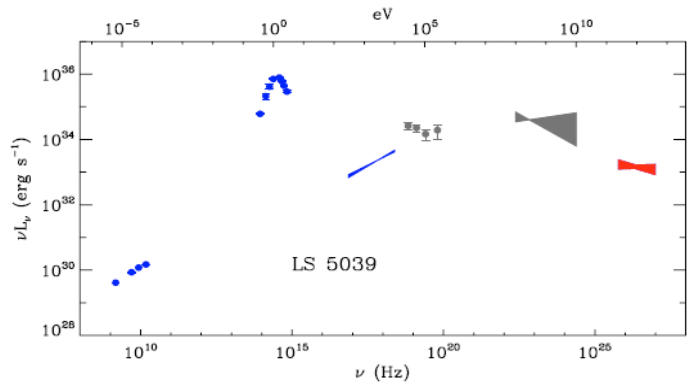
Broadband spectrum of LS I +61 303

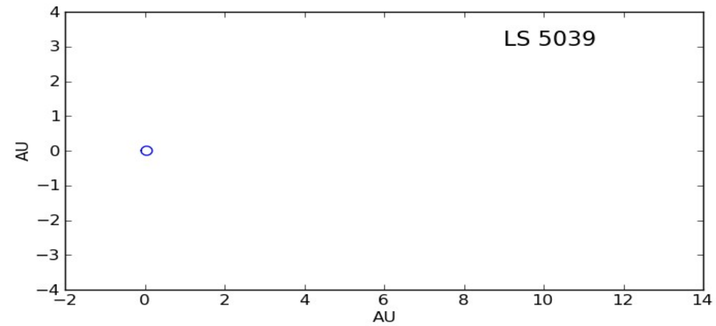


[Sidoli et al. 2006, A&A 459, 901]

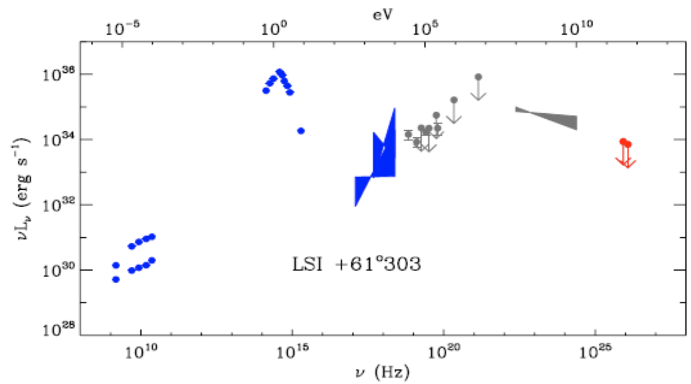
Gamma-ray binaries

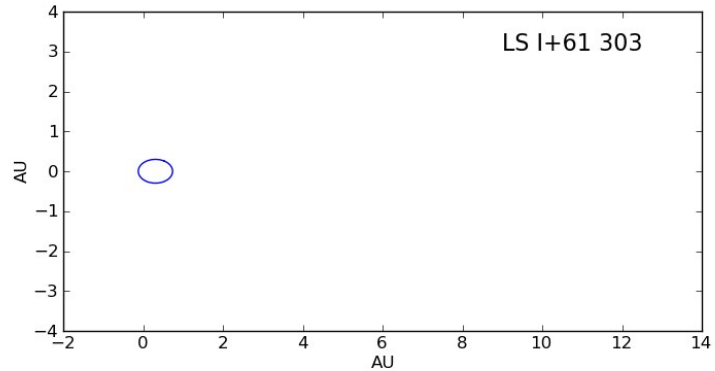
LS 5039
P_{orb} = 3.9 days
O6.5V + ?



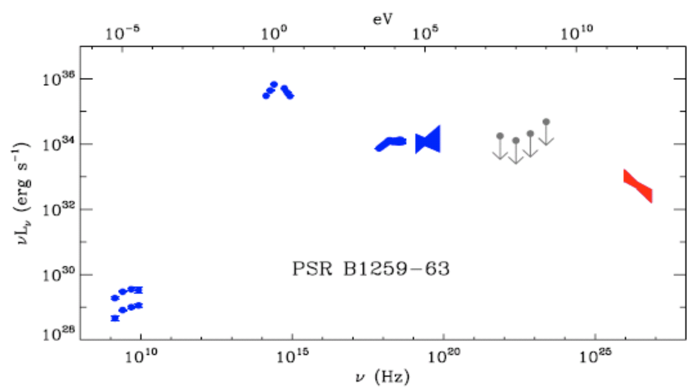


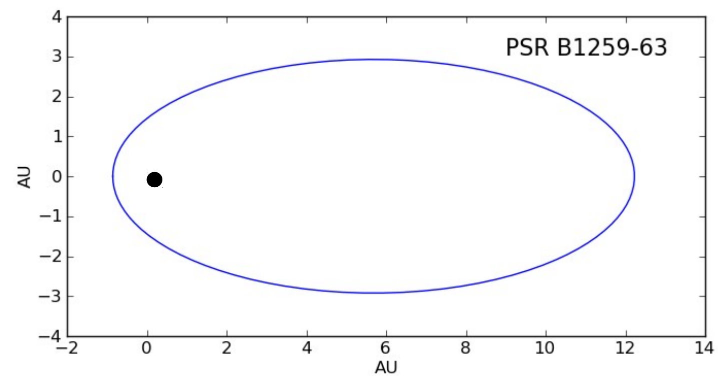
LS I +61 303
P_{orb} = 26.5 days
B0Ve + ?



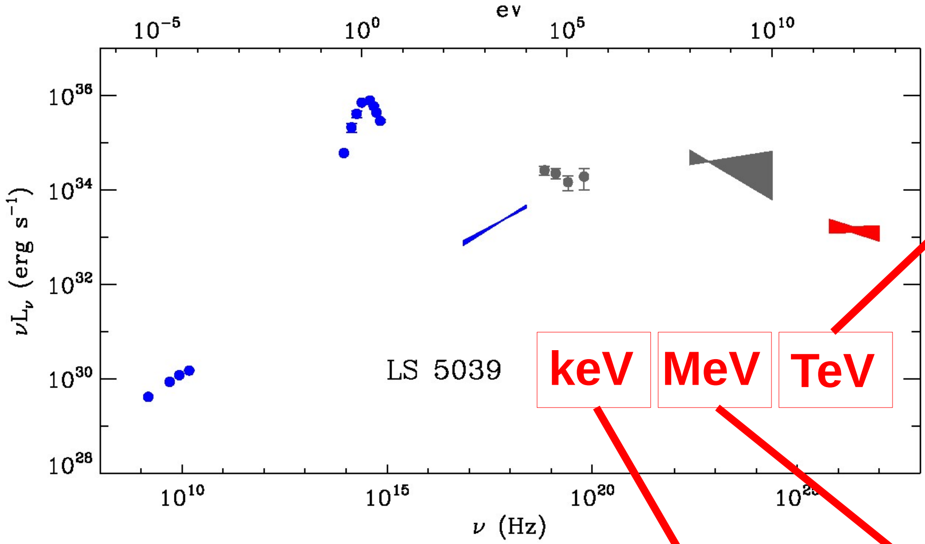


PSR B1259-63
P_{orb} = 3.4 years
O8.5-9Ve + pulsar



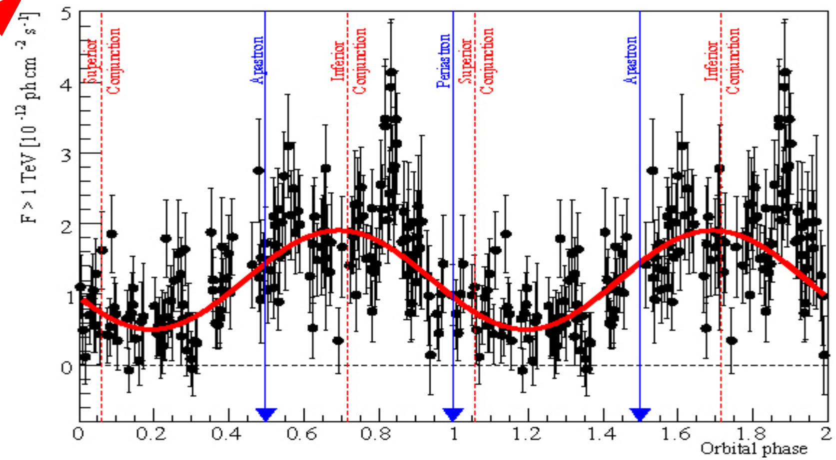


High energy emission from LS 5039

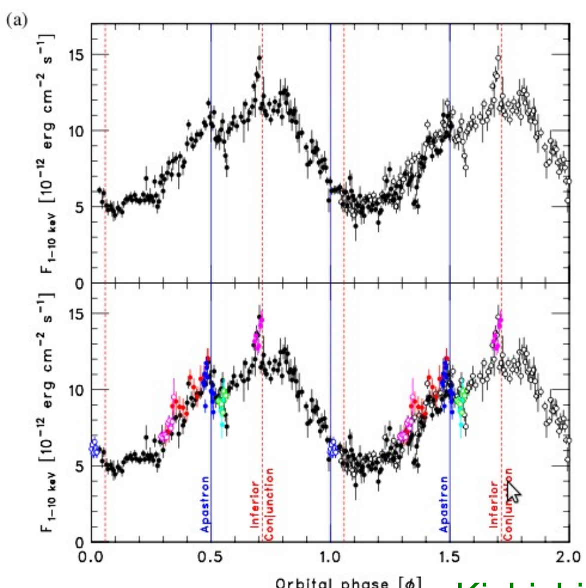


keV MeV TeV

HESS

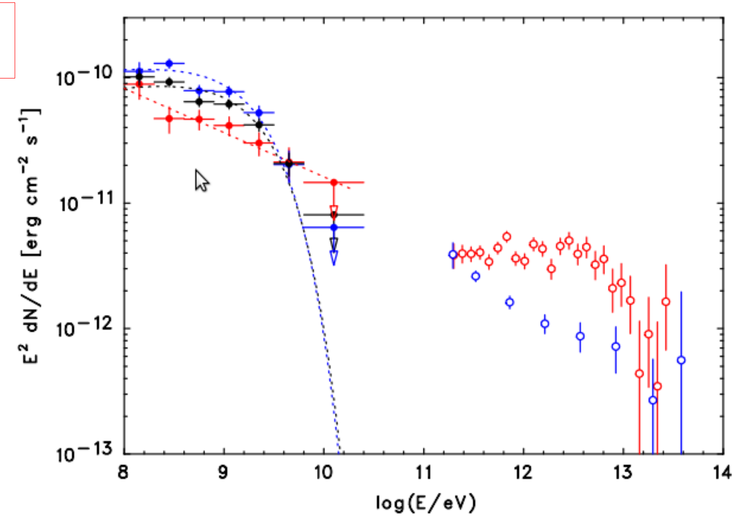


Aharonian et al. 2006, A&A 460, 743



XMM-Newton
ASCA
Chandra
Suzaku

Fermi



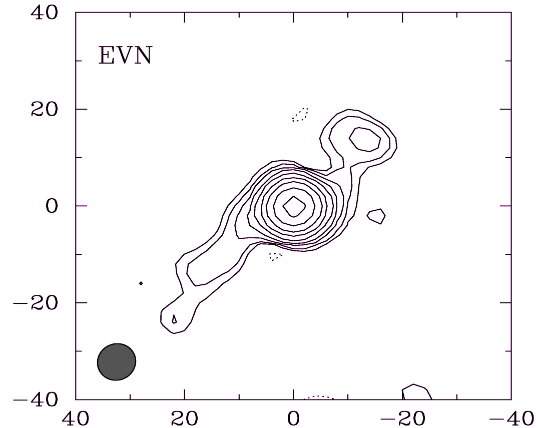
Kishishita et al. 2009, ApJ 697, L1

Abdo et al. 2009, ApJ 706, L56

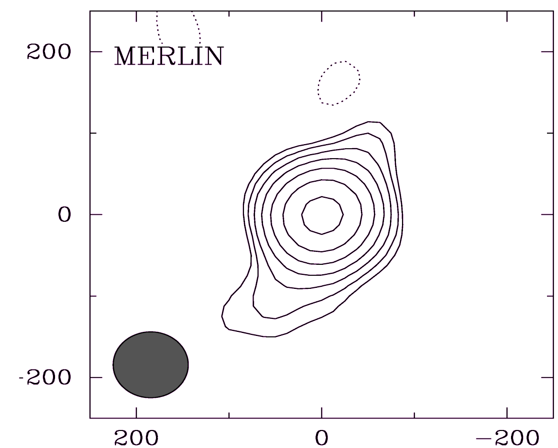
Radio morphology of LS 5039

- At all scales it shows elongated bipolar extended emission with P.A. between 125-150º up to 100 mas (250 AU).
- VLBA images show a changing morphology on the orbital timescales.

EVN (5 GHz)

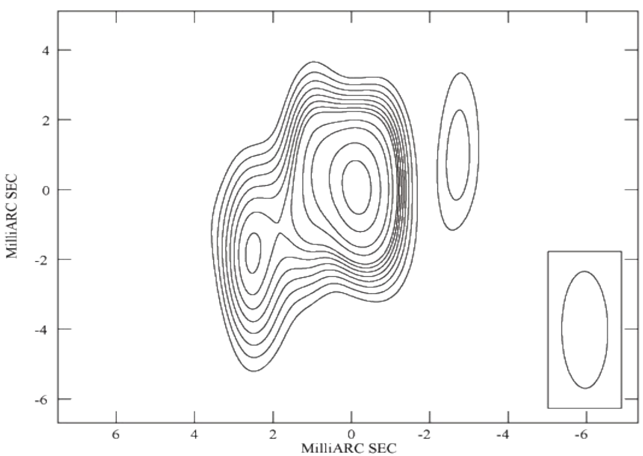


MERLIN (5 GHz)

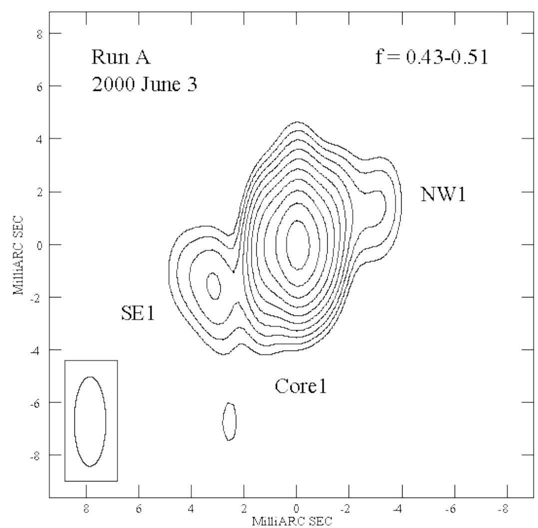


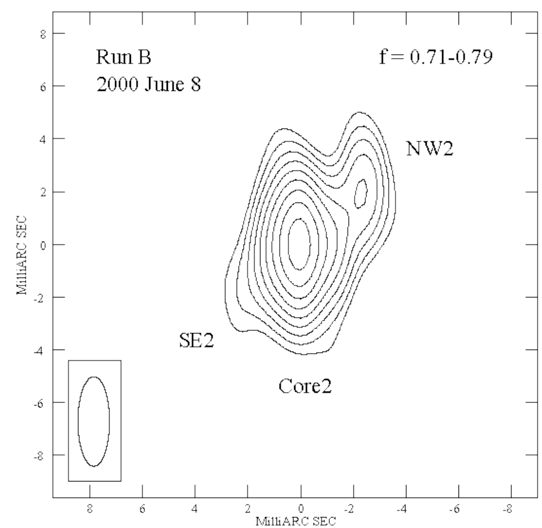
[Paredes et al. 2002, A&A, 393, L99]

VLBA (5 GHz)



[Paredes et al. 2000, Science, 288, 2340]



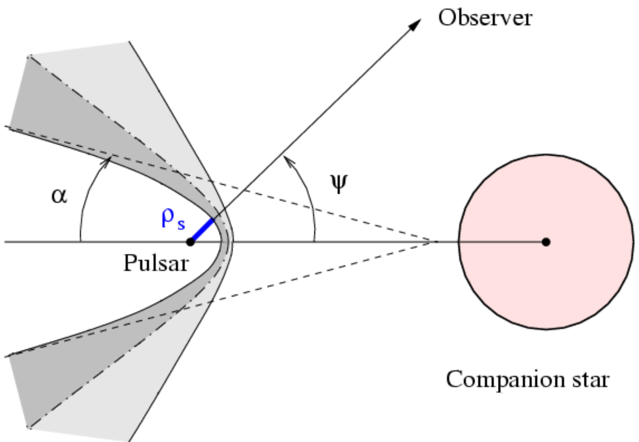


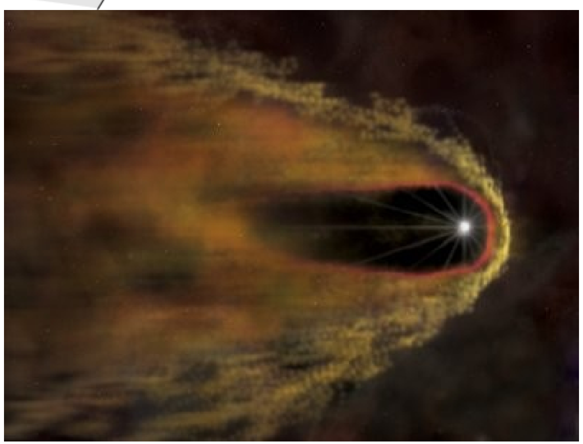
[Ribó et al. 2008, A&A, 481, 17]

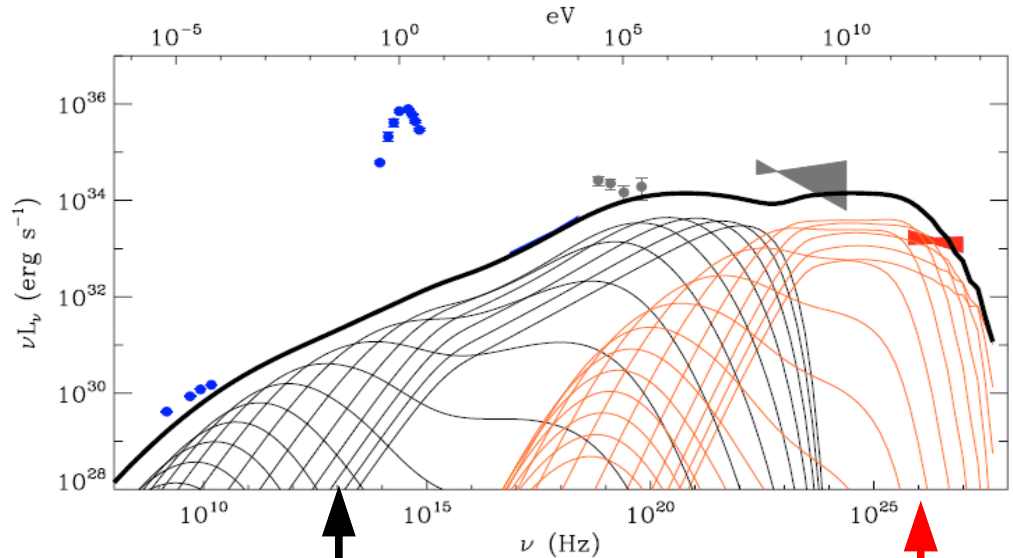
Non-accreting pulsar scenario

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

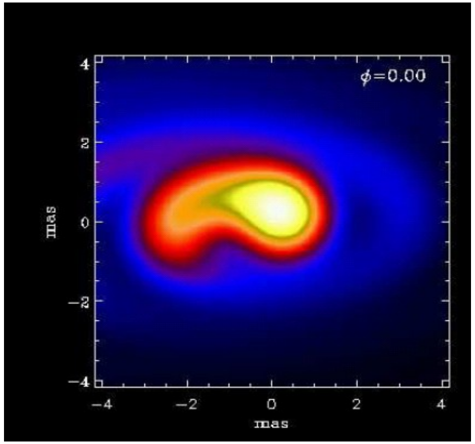
Expected behaviour at mas scales

Particles move downstream away from the pulsar at a speed v (initially ≈c/3). The expected radio morphology is similar to the one produced in isolated pulsars moving through the ISM but, as a consequence of the orbital motion of the binary system, the tail of the flow follows an elliptical path during the orbital cycle.

The cometary tail changes its direction continuously.

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

→ Astrometric and morphological changes expected



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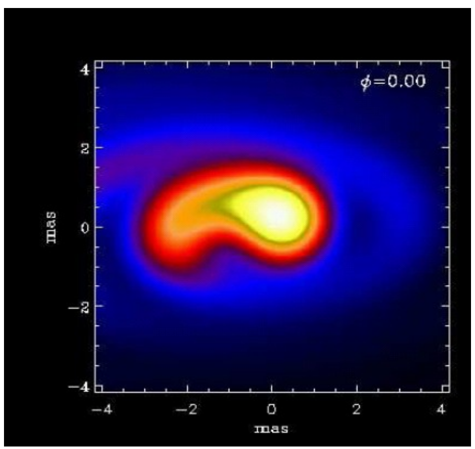
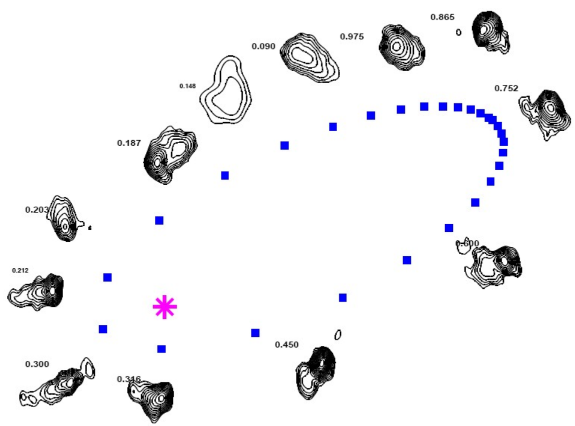
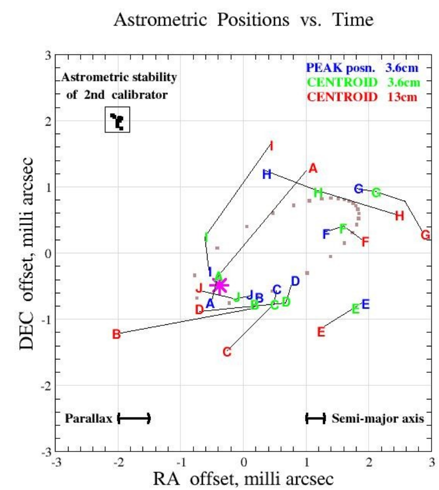
LS I +61 303

Dhawan et al. 2006, mqw.conf

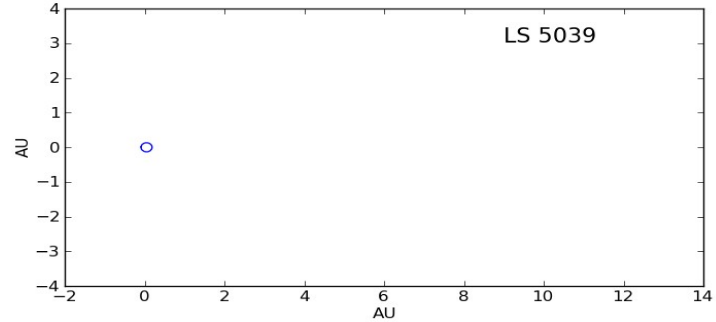


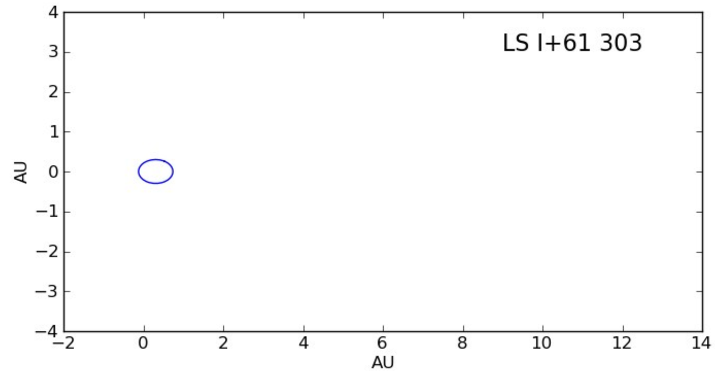


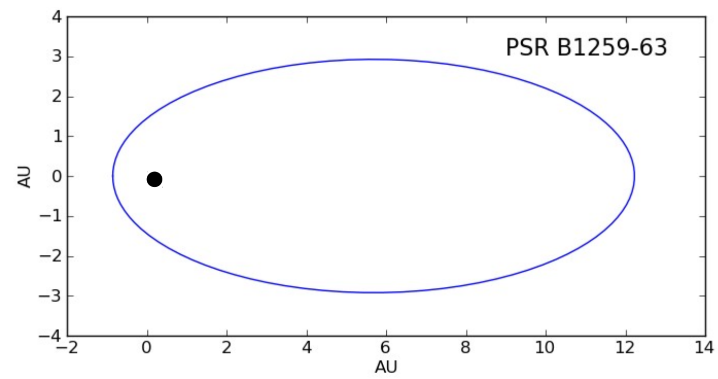


Gamma-ray binaries

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

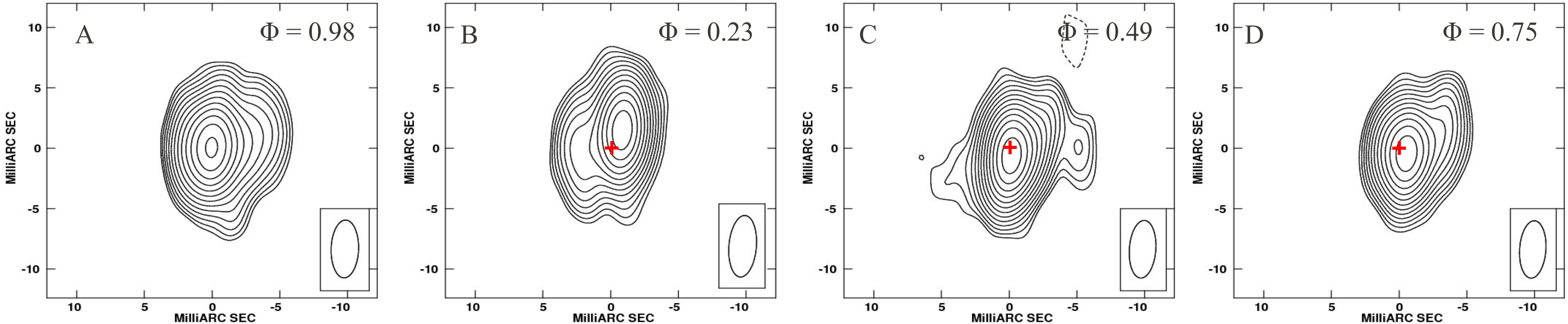


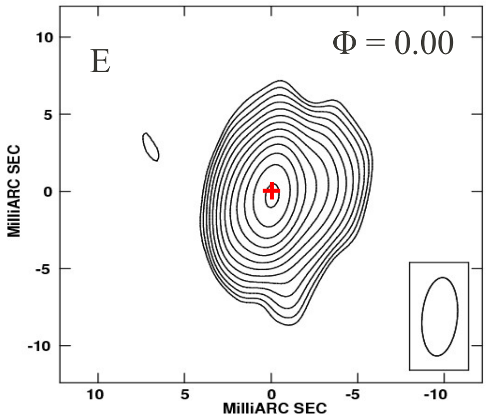




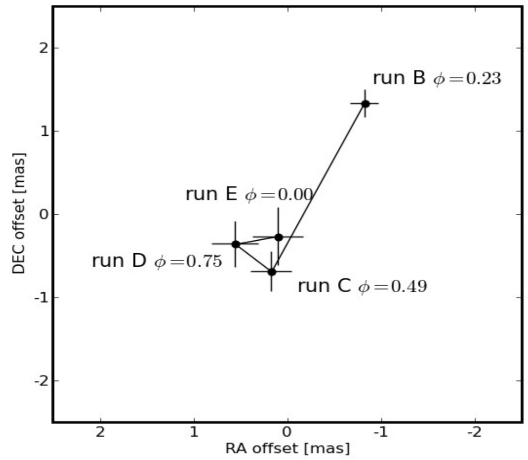
LS 5039

Astrometrical/morphological changes





[Moldón et al., in preparation]

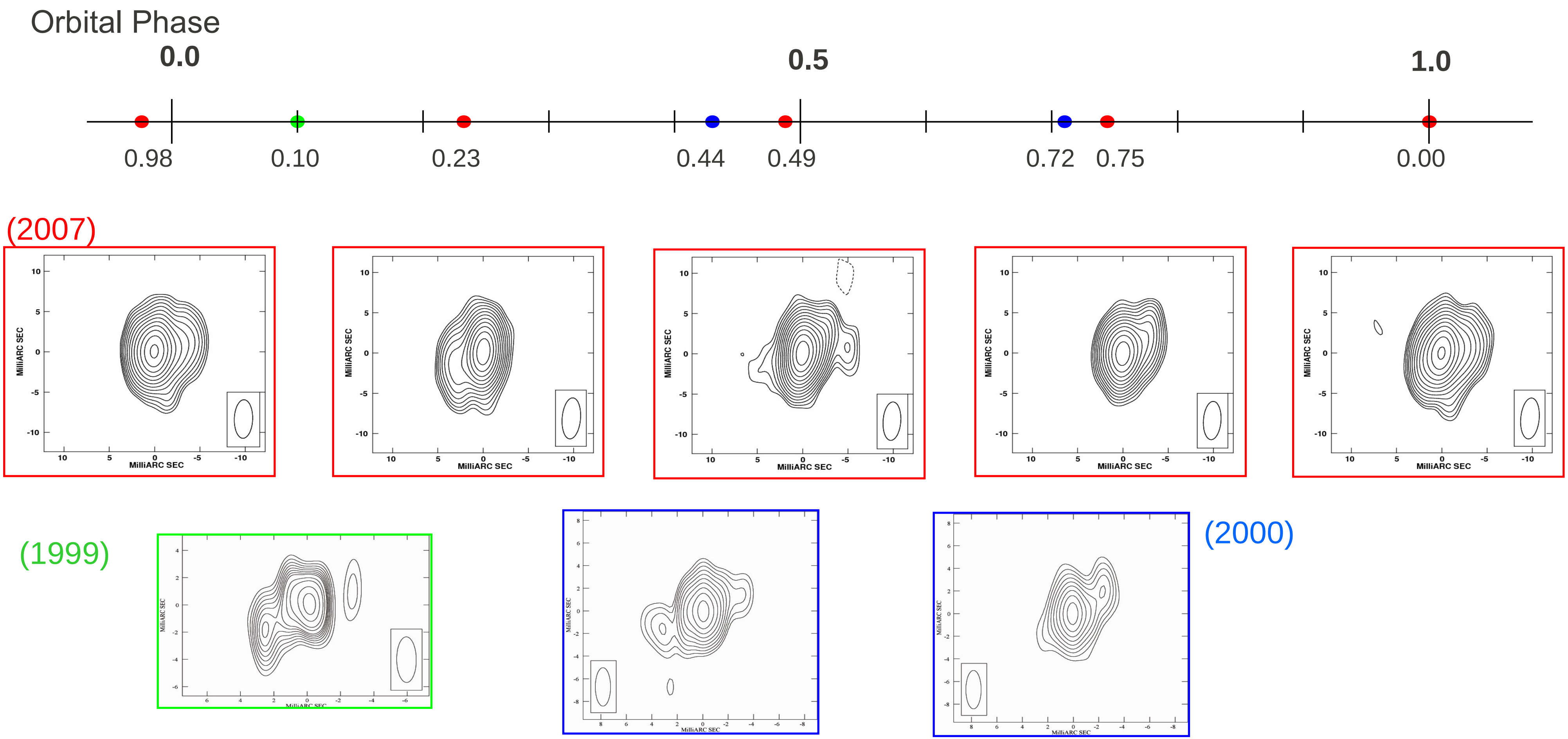


$\Delta = 2.3 \pm 0.3$ mas (7.9σ)

After periastron, the peak of the emission moves towards North-East a few mas. Our accuracy is not enough to trace the peak displacement along the orbit.

New observations at higher frequencies required!

Orbital morphological variability



- Images at the same phase have similar morphology.
- Images between adjacent runs show a hybrid morphology of the two runs.

Orbital Morphological Variability

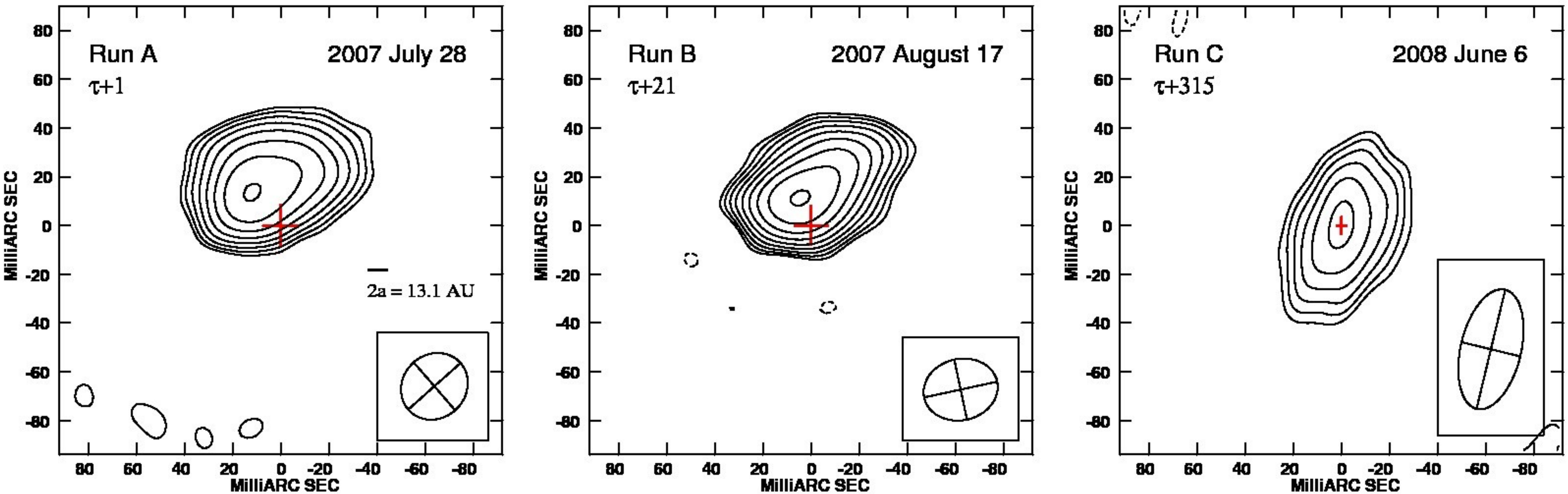
Link with PSR B1259-63/LS 2883

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

PSR B1259-63

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

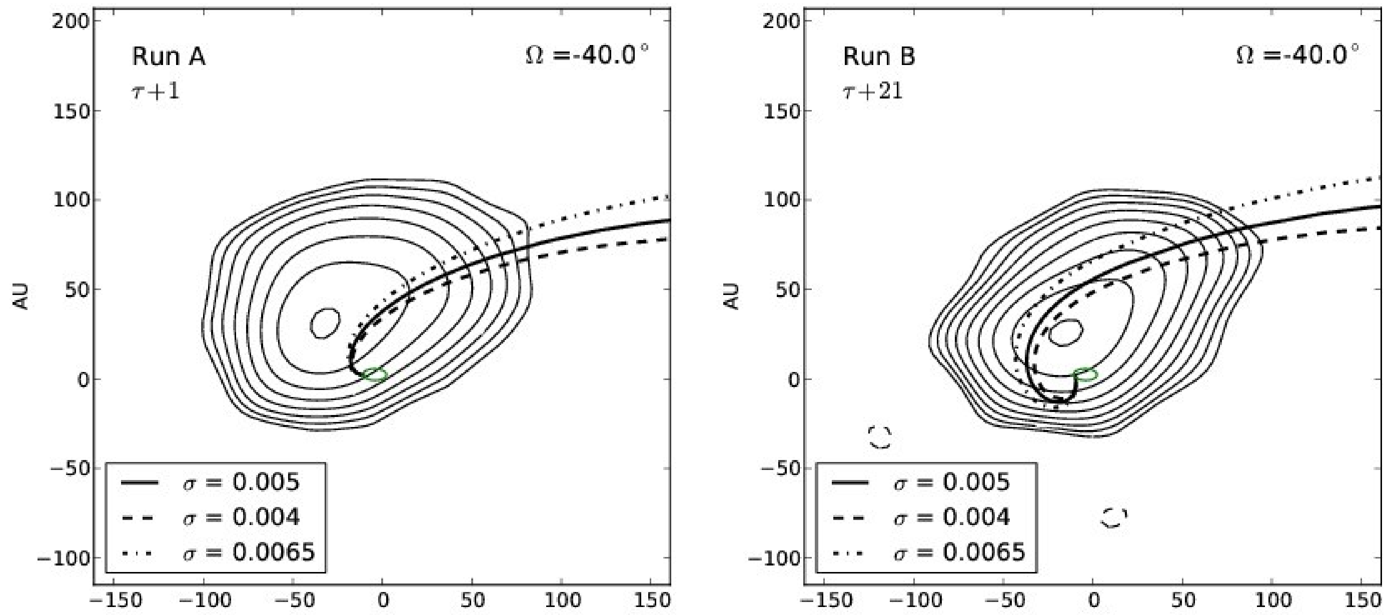
[Moldón, Johnston, Ribó, Paredes & Deller, in preparation]



- 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 20 and 50 AU from the binary system and with a total extension of 60 mas (140 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.

PSR B1259-63

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.

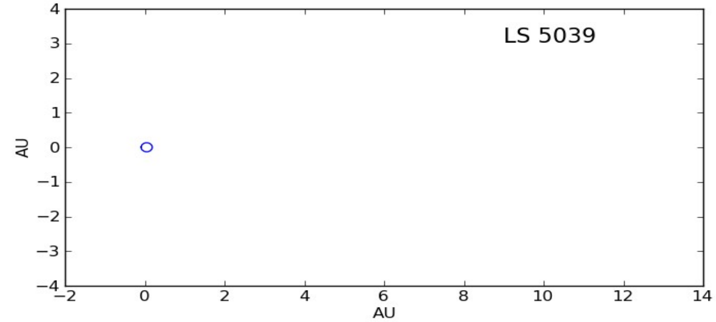


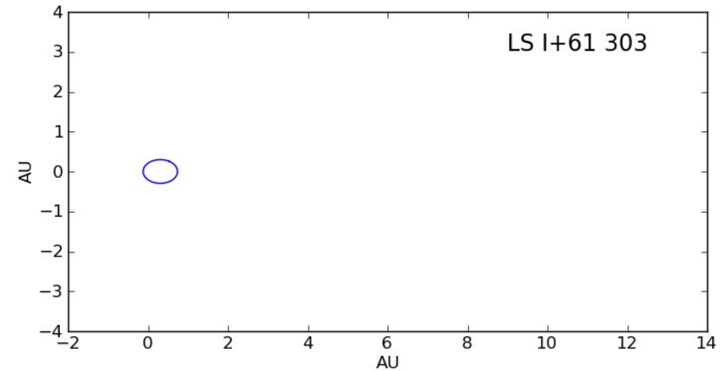
[Moldón, Johnston, Ribó, Paredes & Deller, in preparation]

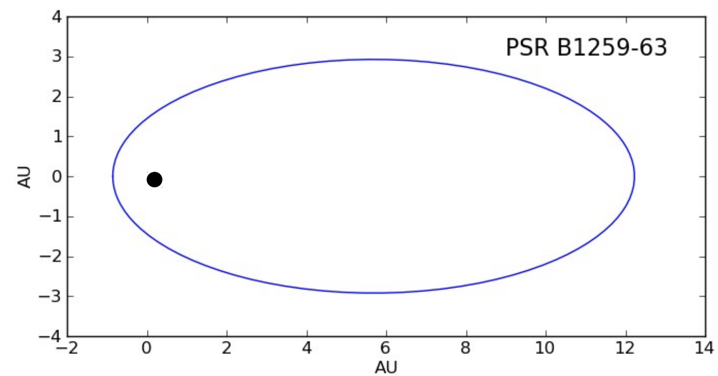
The detected morphology can be accounted for if:
Ω ~ −40º
σ ~ 0.005

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	✓	✓ orbital variability







Summary

1. The radio morphology at mas scales of LS 5039 shows changes in 24 h. There is orbital morphological variability. The peak of the emission suffers a 1-2 mas displacement after periastron.

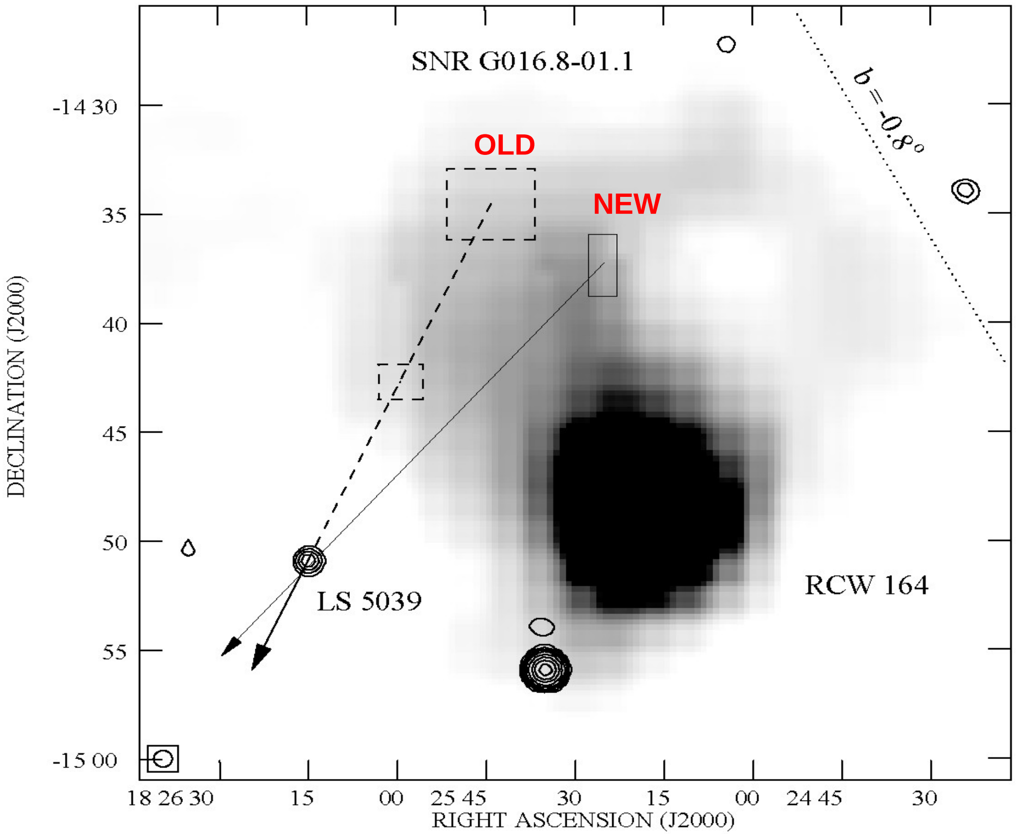
2. New VLBI observations are required at higher frequencies to trace the core motion along the orbit.

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

Birth Place of LS 5039

The origin of LS 5039

Ribó et al. (2002) computed the trajectory of LS 5039 for the last 10^5 yr using astrometry from 1998 to 2002. Their result marginally suggests an association with SNR G016.8-01.1



[adapted from Ribó et al. 2002, A&A, 384, 954]

Including new positions from 2003 to 2007, the association seems more robust. The past trajectory of LS 5039 is compatible with the center of SNR G016.8-01.1.

$$\mu_\alpha \cos\delta = 7.3 \pm 0.3 \text{ mas yr}^{-1}$$
$$\mu_\delta = -8.2 \pm 0.9 \text{ mas yr}^{-1}$$

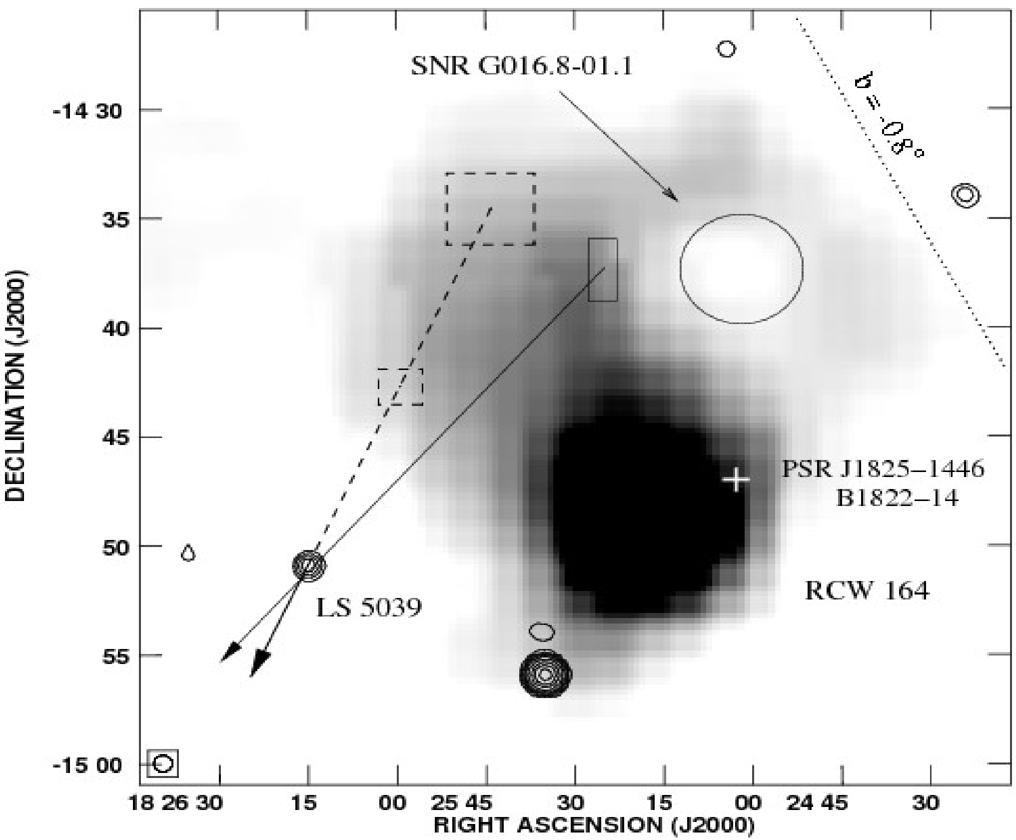
PRELIMINARY

We searched for other possible compact objects that could be born in this SNR.

The origin of PSR J1825-1446

PSR J1825−1446 is the closest compact object to the SNR. Screening of the ATNF Pulsar Catalogue do not show any other probable candidate.

[ATNF Pulsar Catalogue, Manchester et al. 2005, AJ, 129, 1993]



[adapted from Ribó et al. 2002, A&A, 384, 954]

$P = 0.279$ s $\dot{E} = 4.1 \cdot 10^{34}$ erg·s^{-1}

$\tau_c = 1.95 \cdot 10^5$ yr DM = 357 cm^{-1} pc

Dist = 5.45 kpc

We started a VLBA project one year ago to measure the proper motion of PSR J1825−1446. Correlation using pulsar gating.

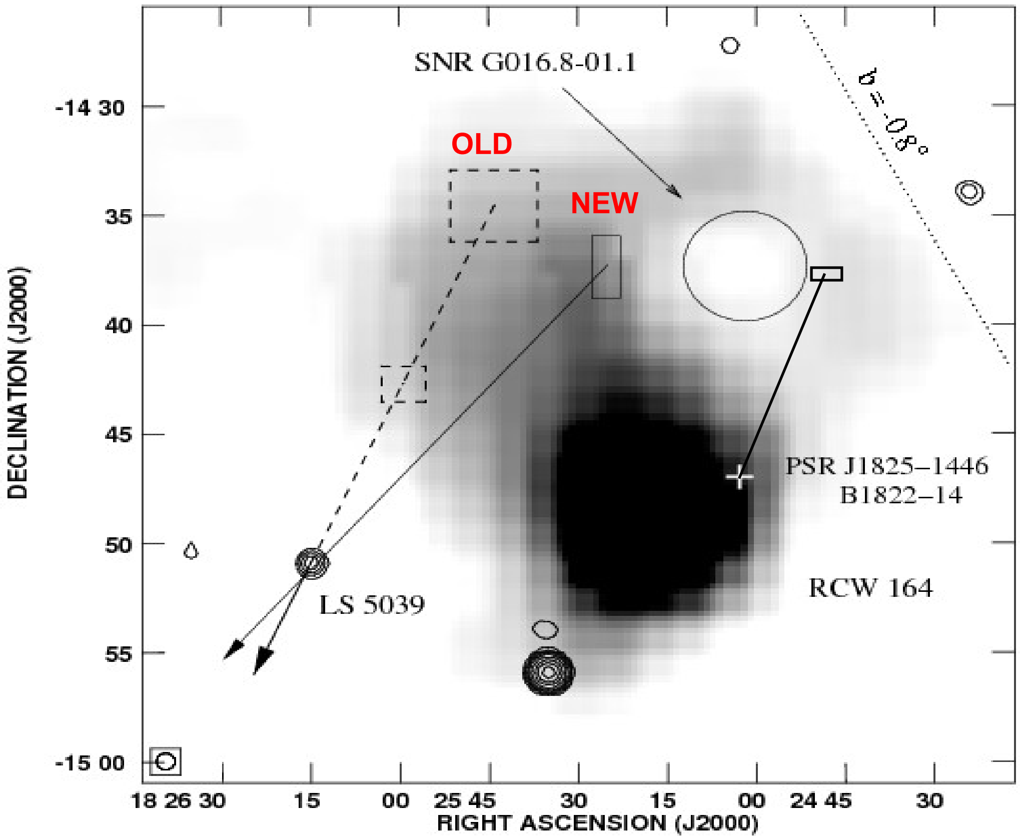
$$\mu_\alpha \cos\delta = 10.7 \pm 1.6 \text{ mas yr}^{-1}$$
$$\mu_\delta = -28.2 \pm 0.3 \text{ mas yr}^{-1}$$

The projected 2D velocity at 5.5 kpc is:

$$v_{2D} = 781 \pm 17 \text{ km} \cdot \text{s}^{-1}$$

PSR J1825−1446 is a high speed pulsar.

Who is coming from the SNR?



PRELIMINARY

Updated proper motion of LS 5039 suggests an origin in SNR G016.8–0.1. about 10^5 yr ago. However, PSR J1825–1446 appears to come from the same SNR about 10^4 yr ago, although the characteristic age is one order of magnitude bigger. (Moldón et al., in preparation)

Summary

1. The radio morphology at mas scales of LS 5039 shows changes in 24 h. There is orbital morphological variability. The peak of the emission suffers a 1-2 mas displacement after periastron.

2. New VLBI observations are required at higher frequencies to trace the core motion along the orbit.

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. LS 5039 appears to come from SNR G016.8-01.1. If this is the case, the compact object in LS 5039 would be ~ 10^5 years old.

5. PSR J1825-1446 *also* appears to come from SNR G016.8–01.1. If this is the case, the characteristic age would be one order of magnitude overestimated.