Radio observations of gamma-ray binaries

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ASTROFLASH

PANTERA Stars

Variable Galactic Gamma-Ray Sources VI — 14 April 2023 (Innsbruck)

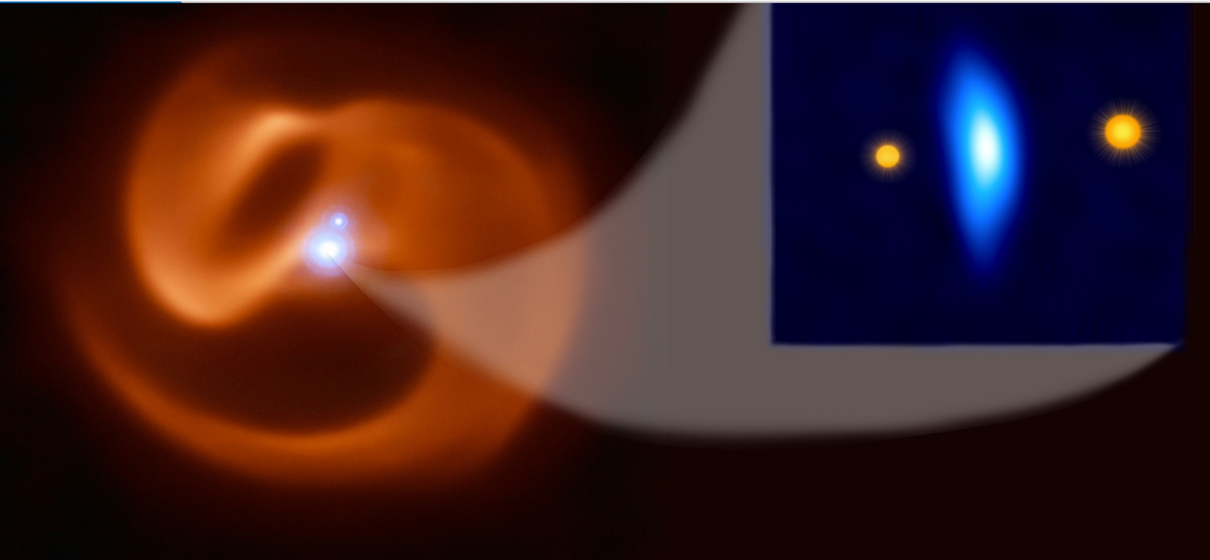
This is not a talk with results...

just on-going or planned analyses

...but a Roadmap

for the coming 1–2 years at radio frequencies

Colliding Wind Binaries



HD 93129A (Benaglia, Marcote et al. 2015), Apep (Marcote et al. 2021), ...

RS Oph outburst in 2021

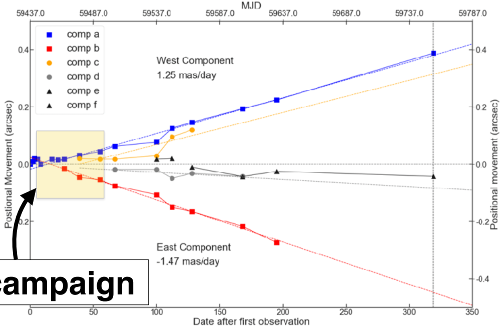
Radio campaign (EVN + eMerlin) from 14 to 320 days after the outburst.

Early results in (Munari, Giroletti, Marcote et al. 2022).

Expansion velocity of $\sim 4\,070$ (East) and $3\,470\ \mathrm{km\ s^{-1}}$ (West)

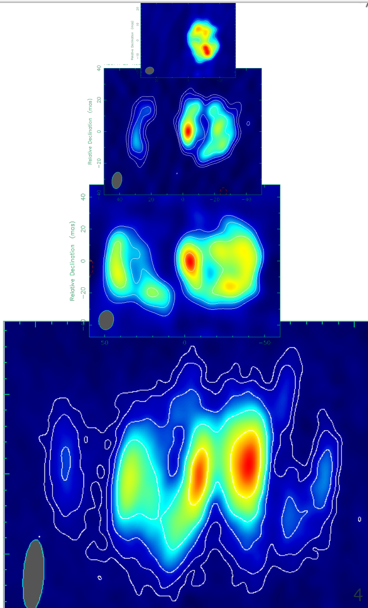
PRELIMINARY

courtesy of
T. O'Brien,
D. Williams



EVN campaign

17

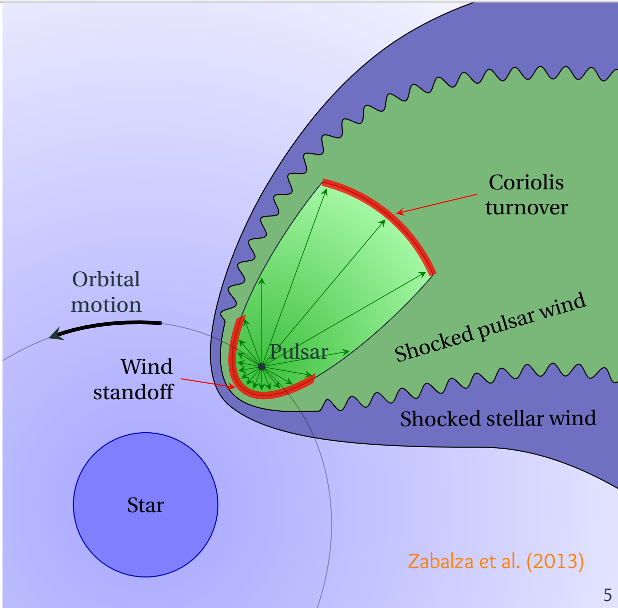


Gamma-ray binaries (γBs)

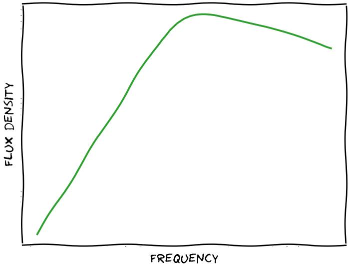
Only nine systems discovered to date:

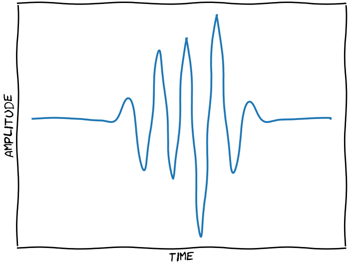
System	Main star	P_{orb} / days
LS 5039*	O6.5 V	3.9
LMC P3	O5 III	10.3
4FGL J1405.1−6119	O6.5 III	13.7
1FGL J1018.6−5856	O6 V	16.6
LS I +61 303	B0 Ve	26.5
HESS J1832−093	B8-1.5V	86.3
HESS J0632+057	B0 Vpe	317.3
PSR B1259−63	O9.5 Ve	1 236.7
PSR 2032+4127	B0 Ve	18 000

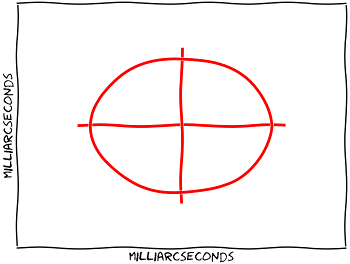
In orange the γBs with a confirmed pulsar or neutron star.



Zabalza et al. (2013)



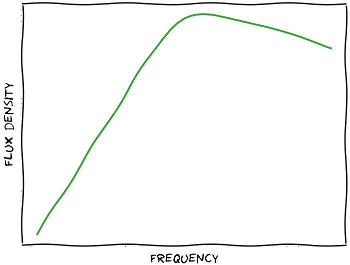




low
radio frequencies

very high
time resolution

very high
angular resolution



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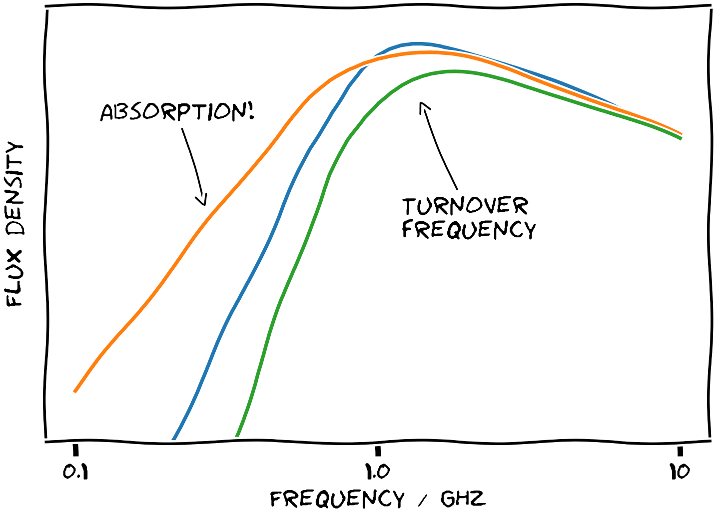
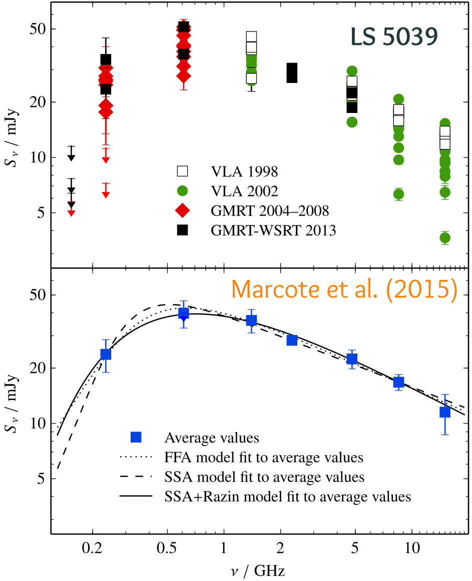
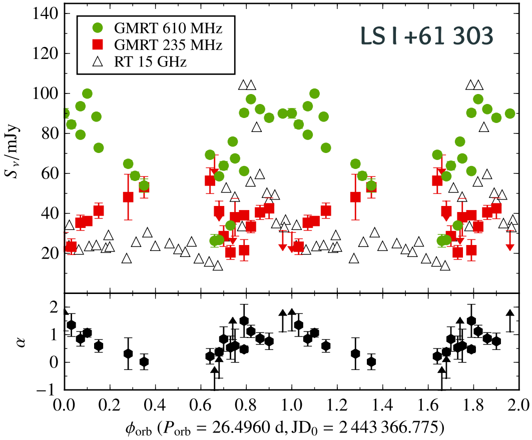
Low radio-frequency emission of gamma-ray binaries



Synchrotron self-absorption (SSA)   Free-free absorption (FFA)   SSA + Razin effect

Low-frequency radio emission of LS 5039 and LS I +61 303





Marcote et al. (2016)

Low-frequency radio emission of LS I +61 303

Wind velocity of $1\,500 \pm 500$ km s^{-1}

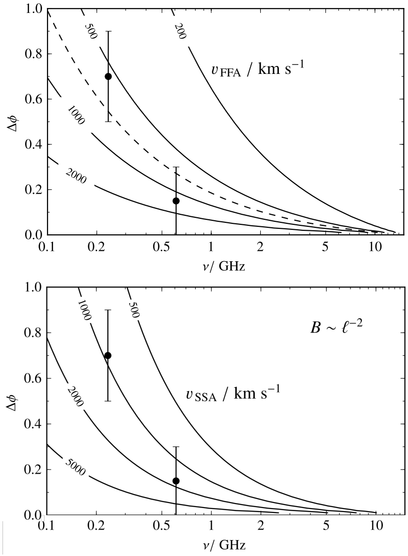
Absorption processes?

- Free-free absorption:
  $\upsilon_{\rm FFA} = 700 \pm 200$ km s^{-1}

- Synchrotron self-absorption:
  $\upsilon_{\rm SSA} = 1\,000 \pm 140$ km s^{-1}

Emitting region $2.4^{+1.7}_{-1.1}$ AU
(LS I +61 303's semimajor axis is ~ 0.4 AU)

Marcote et al. (2016)



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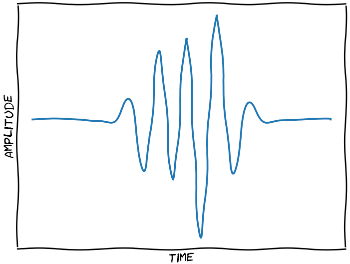
radio frequencies



very high
time resolution

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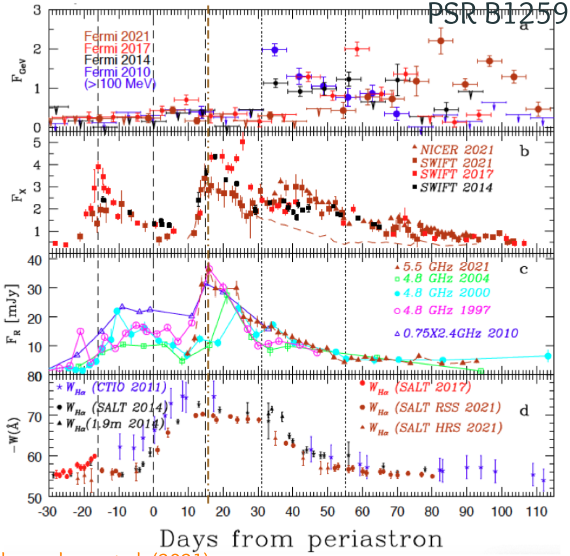
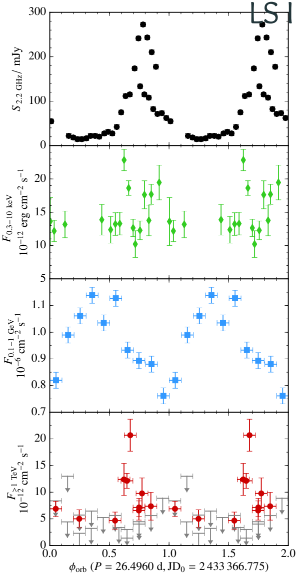
Intra-hour variability and flaring activity

PSR B1259−63

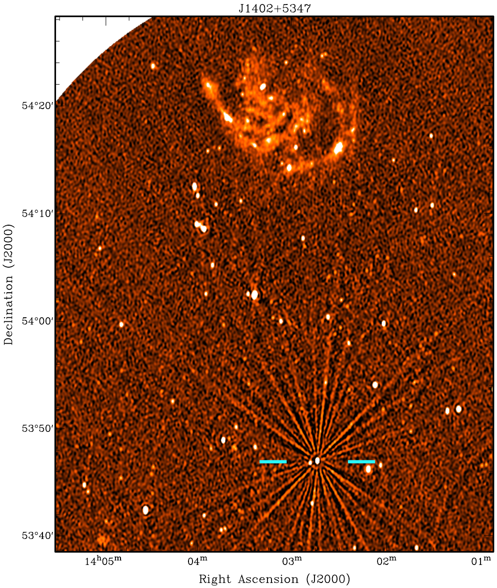


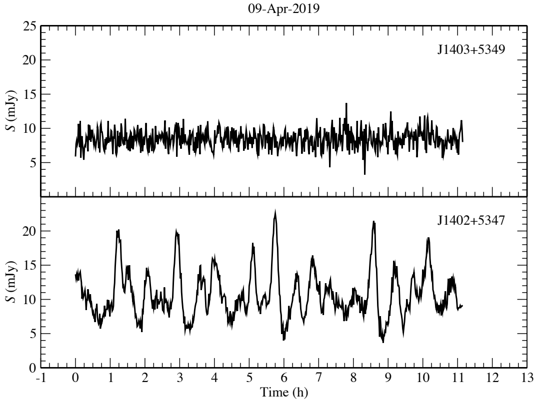
Chernyakova et al. (2021)

LS I +61 303



Intra-hour variability on radio sources

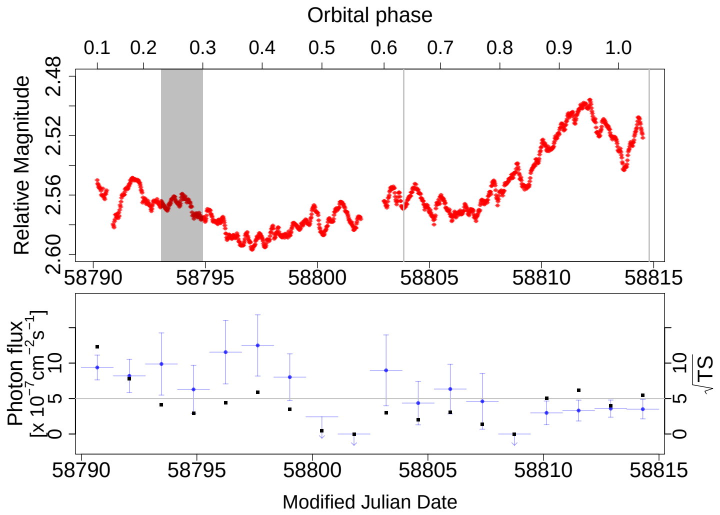




Oosterloo et al. (2020)

⟶ *Note that this is not a gamma-ray binary!*

LS I +61 303 on intra-hour scales

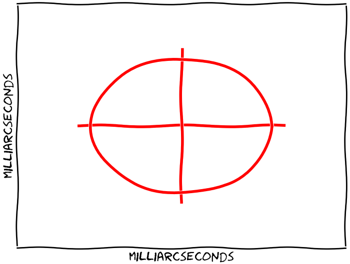


Optical light-curve from TESS, with shock-powered flares? (Mestre et al. 2022)

Fast Radio Bursts

Extremely bright ($\sim 10^{40}$ erg s^{-1}) millisecond-duration bursts (magnetars-related?)

Lyutikov et al. (2020), Barkov & Popov (2022)



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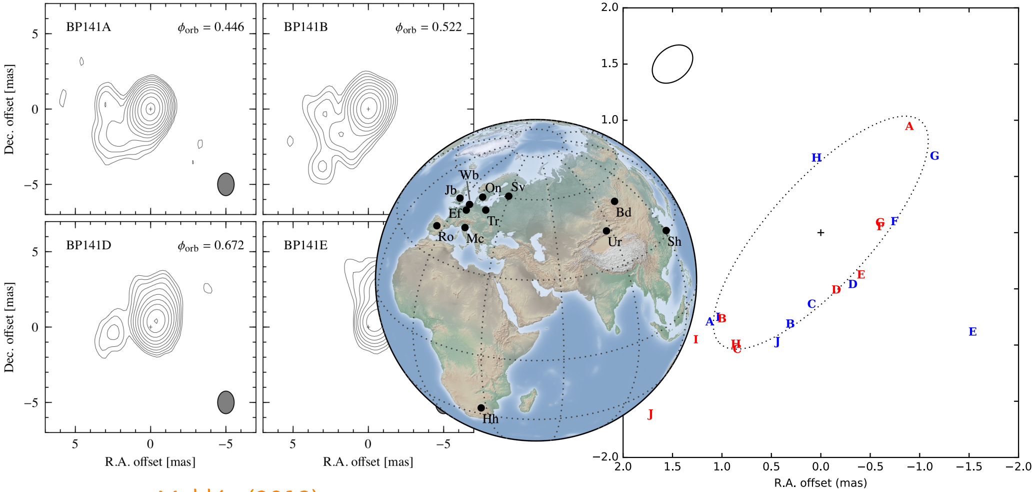
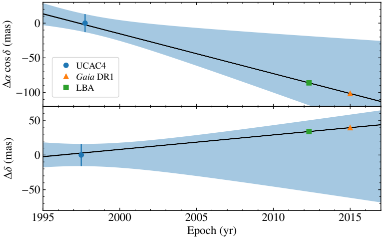
LS I +61 303 on milliarcsecond (AU) scales

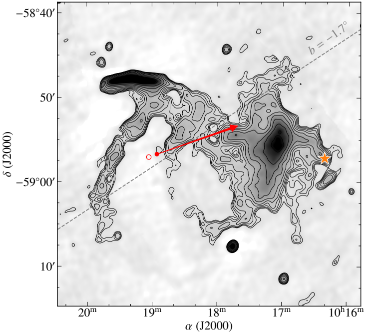


Moldón (2012)

Wu et al. (2018)

1FGL J1018.6−5856 on milliarcsecond (AU) scales

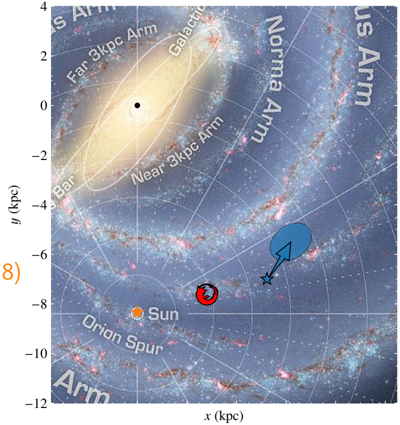


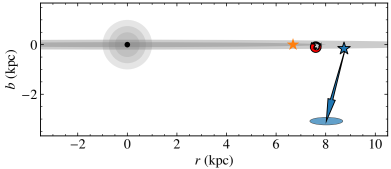


Marcote et al. (2018)

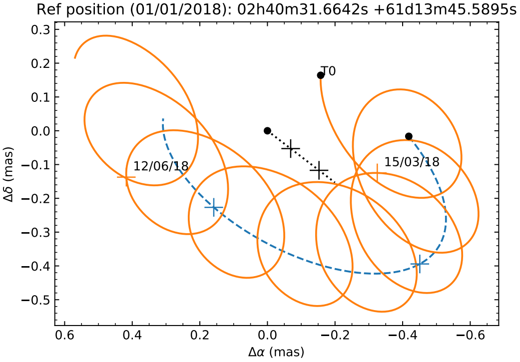
...but see *Gaia*/DR3

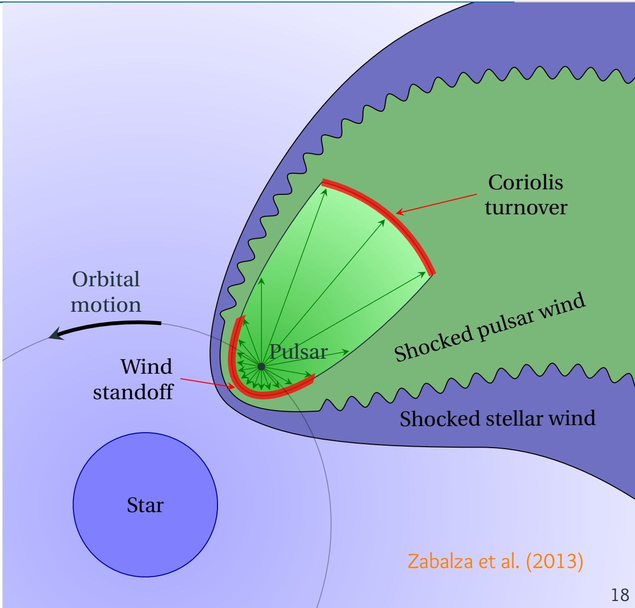
Fortin et al. (2022)





LS I +61 303 on milliarcsecond (AU) scales

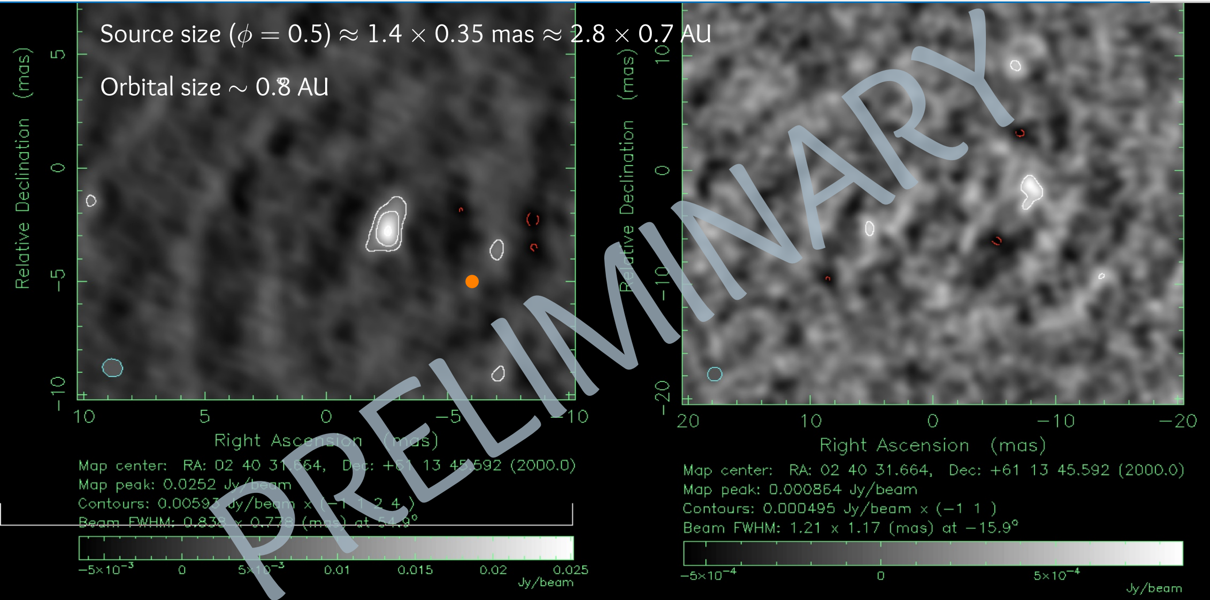




LS I +61 303 on milliarcsecond (AU) scales

Source size ($\phi = 0.5$) $\approx 1.4 \times 0.35$ mas $\approx 2.8 \times 0.7$ AU

Orbital size ~ 0.8 AU



Take home messages

- All gamma-ray binaries are strong non-thermal radio emitters
- Expanding the observing strategies can reveal the full radio-emitting structure
- Further steps forward via very-high-time or very-high-angular resolution radio observations
- Potential connection between (young magnetar) gamma-ray binaries and Fast Radio Bursts?
- *Plus several results coming on colliding wind binaries, novae,...*

Comments are welcome!

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Modeling the LS 5039 spectrum

The three spectra show a similar shape but with subtle differences:

- Avg. spectrum: SSA+Razin
- July 19 spectrum: SSA
- July 21 spectrum: SSA+Razin

Fit	p	$\Omega B^{-1/2}$ $\left[10^{-16}\ \mathrm{G}^{-1/2}\right]$	$K\ell B^{(p+2)/2}$ $\left[10^{3}\ \mathrm{cm\ G}^{(p+2)/2}\right]$	ν_R $\left[10^{8}\ \mathrm{Hz}\right]$
Avg. spectrum	2.16 ± 0.04	500 ± 800	3 ± 5	4.1 ± 0.2
July 19	1.867 ± 0.014	3.9 ± 0.3	$(2.1 \pm 0.9) \times 10^6$	–
July 21	2.24 ± 0.08	200 ± 600	0.4 ± 1.7	4.1 ± 0.7

- Estimating the free-free opacity from the stellar wind:

$$\tau_\nu^{\mathrm{FF}} \propto \dot{M}\, \nu^{-2} \ell^{-3} v_\mathrm{w}^{-2} T_\mathrm{w}^{-3/2}$$

Modeling the LS 5039 spectrum

Coherent picture from fits and τ_ν^{FF}

- Avg. spectrum: SSA+Razin
- July 19 spectrum: SSA
- July 21 spectrum: SSA+Razin

- Coherent picture with:

$$\begin{aligned} \ell &\sim 0.85 \text{ mas } (\sim 2.5 \text{ AU}) \\ B &\sim 20 \text{ mG} \\ n_e &\sim 4 \times 10^5 \text{ cm}^{-3} \\ \dot{M} &\sim 5 \times 10^{-8} \, M_\odot \text{ yr}^{-1} \end{aligned}$$