The Very Low Frequency Emission of Gamma-Ray Binaries

Benito Marcote

In collaboration with M. Ribó, J. M. Paredes,
C. H. Ishwara-Chandra (GMRT)
J. Swinbank, J. Broderick, S. Markoff, R. Fender, R. Wijers (LOFAR)

Universitat de Barcelona

Institut de Ciències del Cosmos

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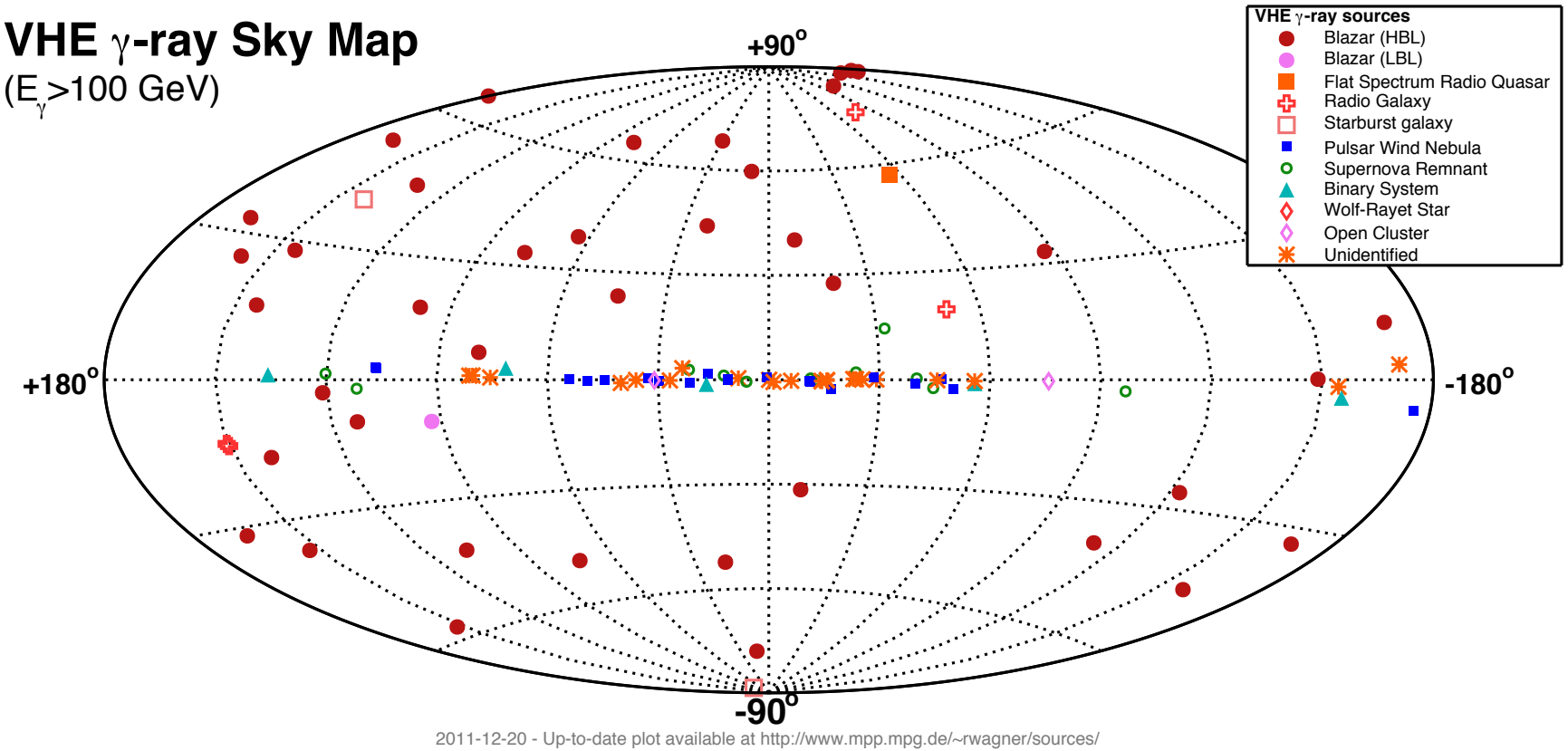
Outline

1. Introduction
2. Goals
3. Results for LS 5039
4. Results for LS I +61 303
5. Conclusions

High energy γ-ray astrophysics

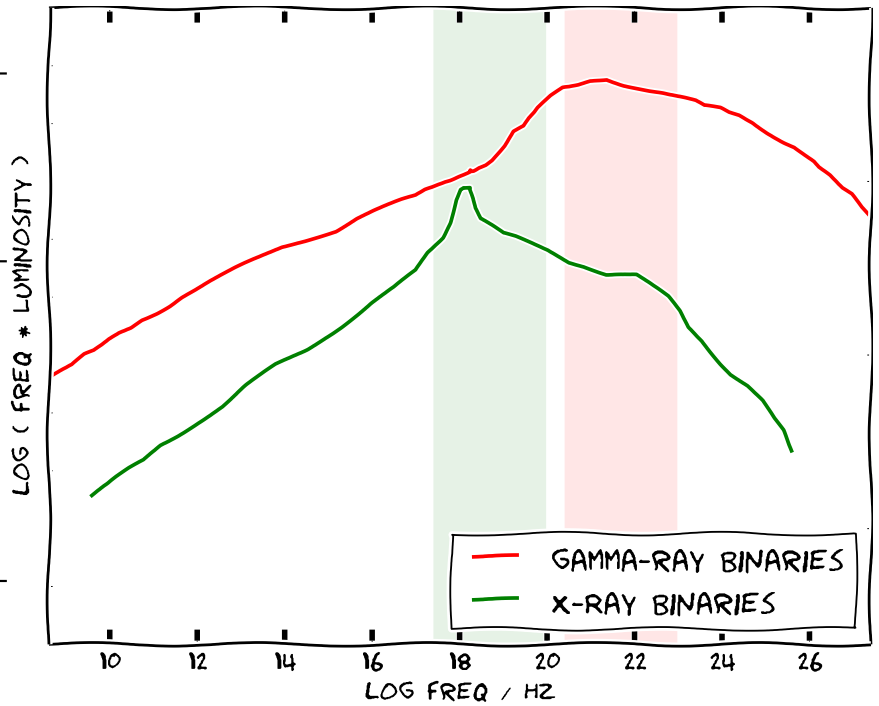


- Very High Energy ($>$ 100 GeV) sky seen by Cherenkov telescopes
- Only a few TeV sources have been associated with binary systems

Gamma-Ray Binaries

Binary systems which host a compact object orbiting a high mass star that have the non-thermal maximum of the Spectral Energy Distribution in γ-rays (Paredes et al. 2013, Dubus 2013)

System	Main star	P/ days
Cygnus X-3	WR	0.2
Cygnus X-1 ??	09.7Ve	5.6
MWC 656 ??	Be	60.4
PSR B1259–63	09.5Ve	1236.7
HESS J0632+057	B0 Vpe	315.0
LS I +61 303	B0 Ve	26.5
1FGL J1018.6–5856	O6V	16.6
LS 5039	06.5V	3.9



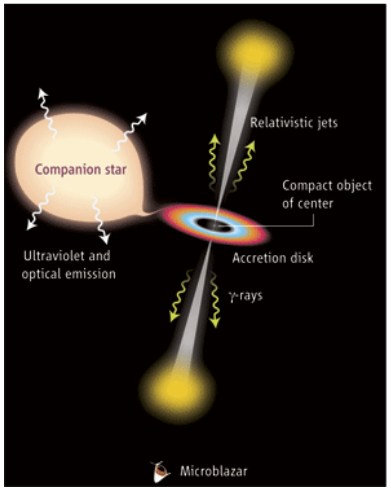
Green: X-ray binaries with gamma-ray emission

Red: known gamma-ray binaries

Gamma-Ray Binaries

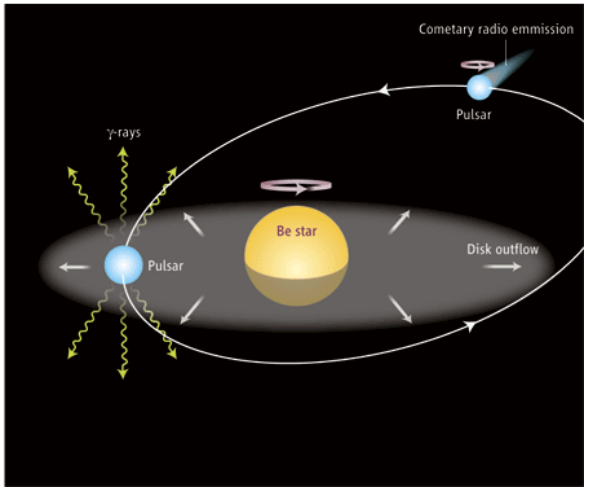
Different scenarios are required to describe the two kind of sources

Microquasar



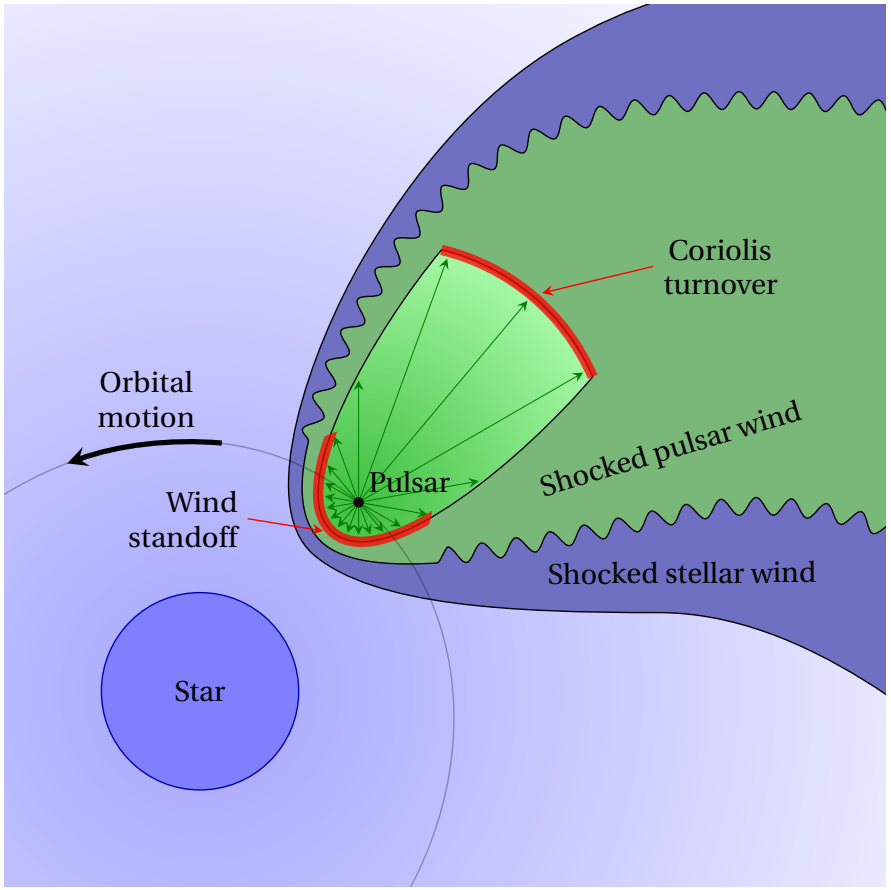
Cygnus X-1
Cygnus X-3

Non-accreting pulsar wind



Mirabel (2006)

PSR B1259–63

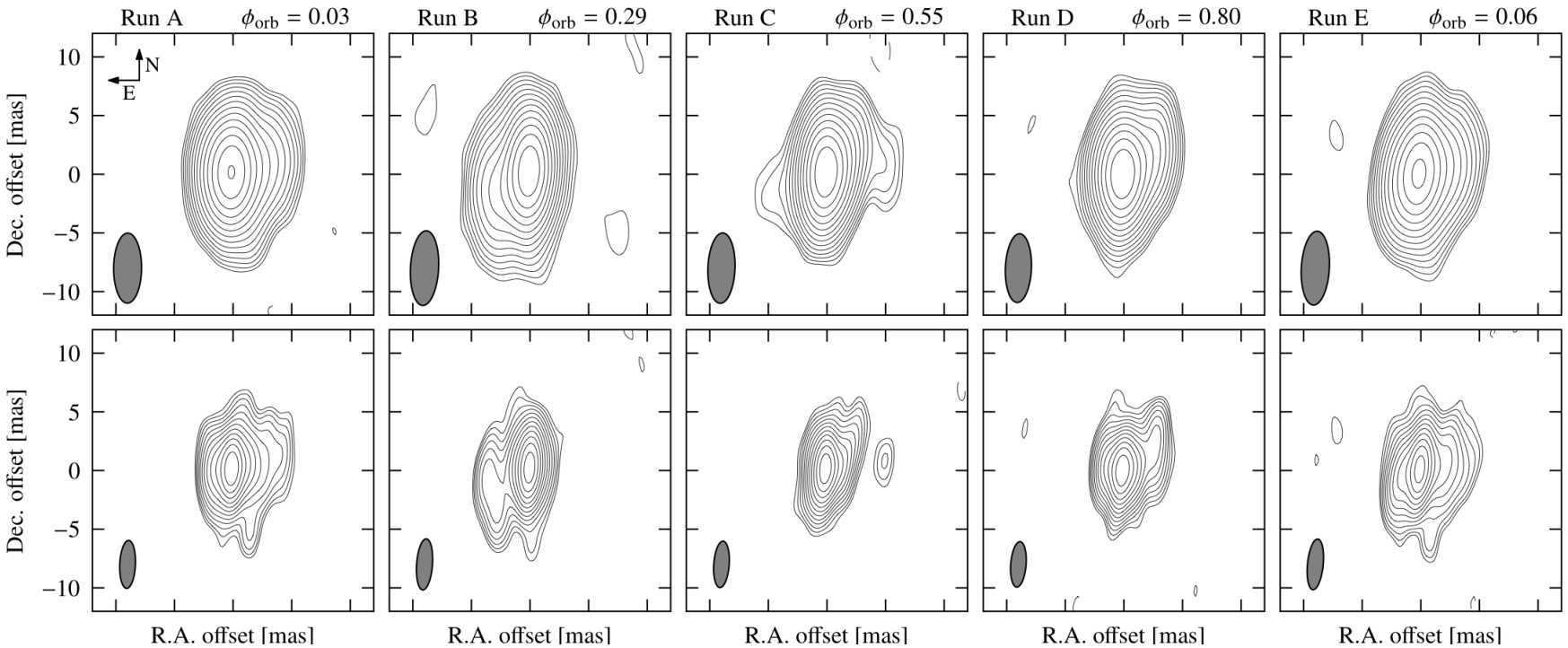


Model for LS 5039 from Zabalza et al. (2012)

Radio observations

For the explored gamma-ray binaries we observe:

- No pulses observed except for PSR B1259–63 Cañellas et al. (2012)
- Radio structures at mas scales show periodic orbital morphological variability Moldón (2012)



Moldón et al. (2012)

Goals

At $\nu \ll 1$ GHz all these sources have been poorly explored.

We expect...

- Absorption mechanisms arising from the spectrum (Bosch-Ramon 2009)
- A large extended structure, "*nebula*" at arcsec-arcmin scales (Bosch-Ramon et al. 2011)
- A more steady emission along the time (Durant et al. 2011)

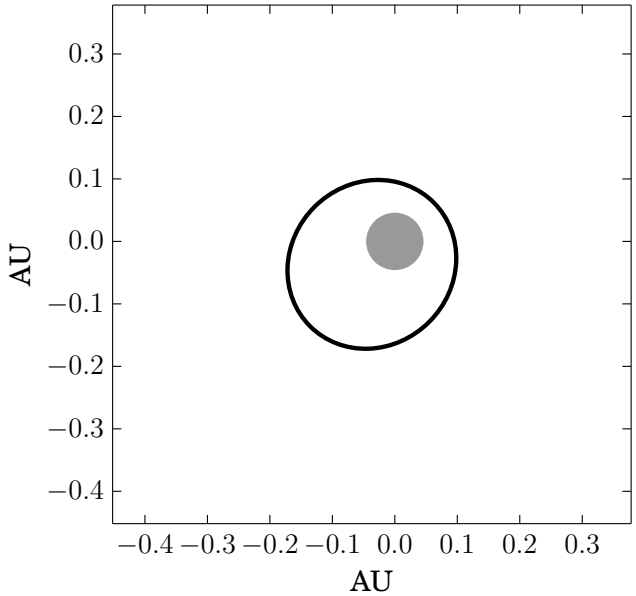
Goals of this work

- Determine the low-frequency spectrum of two gamma-ray binaries
- Search for variability
- Search for absorption mechanisms
- Infer the geometry of the system and emission models
- Detect for first time the predicted extended emission

Explored gamma-ray binaries

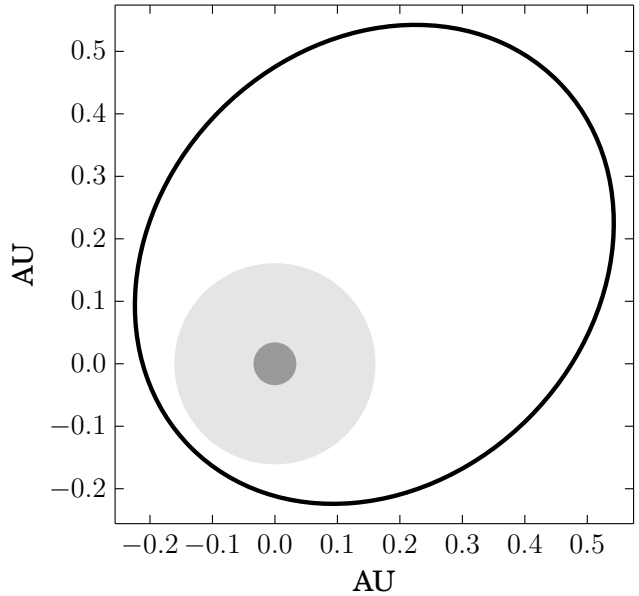
LS 5039

O6.5 V star (23 ± 3 $M_\odot$)
$P \approx 3.9$ d
$d = 2.5 \pm 0.5$ kpc
$e = 0.35 \pm 0.04$
Gamma-rays: periodic outburst
Radio: not periodic, small variability
Casares et al. (2005)



LS I +61 303

B0 Ve star (12.5 ± 2.5 $M_\odot$)
$P \approx 26.5$ d
$d = 1.9 \pm 0.1$ kpc
$e = 0.54 \pm 0.01$
Gamma-rays: periodic outburst
Radio: double outburst
Aragona et al. (2009)



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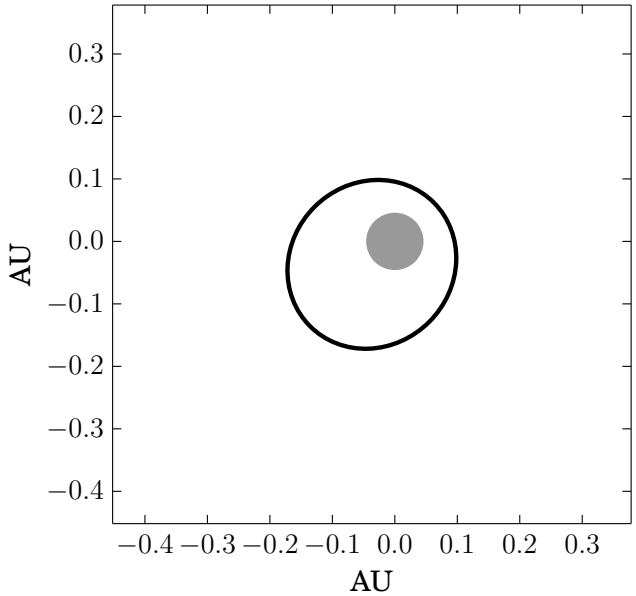

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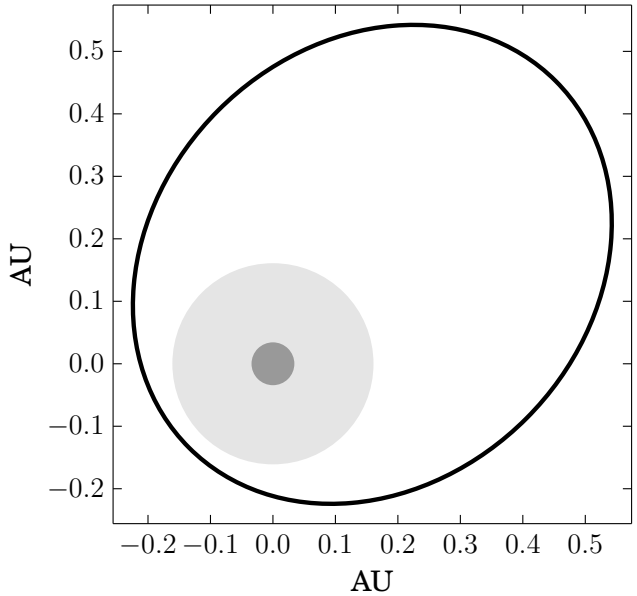


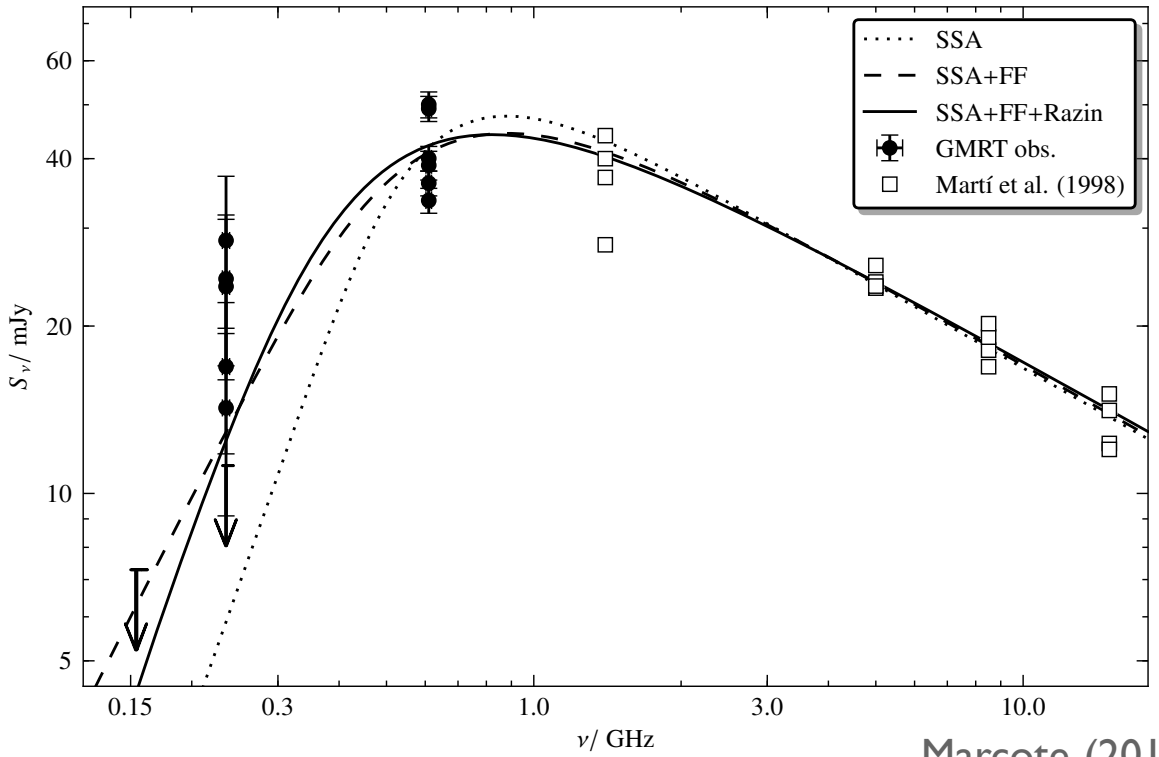
LS 5039 Archival GMRT & published VLA data

At $\sim$GHz frequencies, LS 5039 exhibits (Martí et al. 1998):

- Synchrotron emission (power-law with $\alpha = -0.46 \pm 0.01$)
- Emission persistent with a variability $\lesssim 30\%$

At 235/610 MHz: Pandey et al. (2007), Godambe et al. (2008)

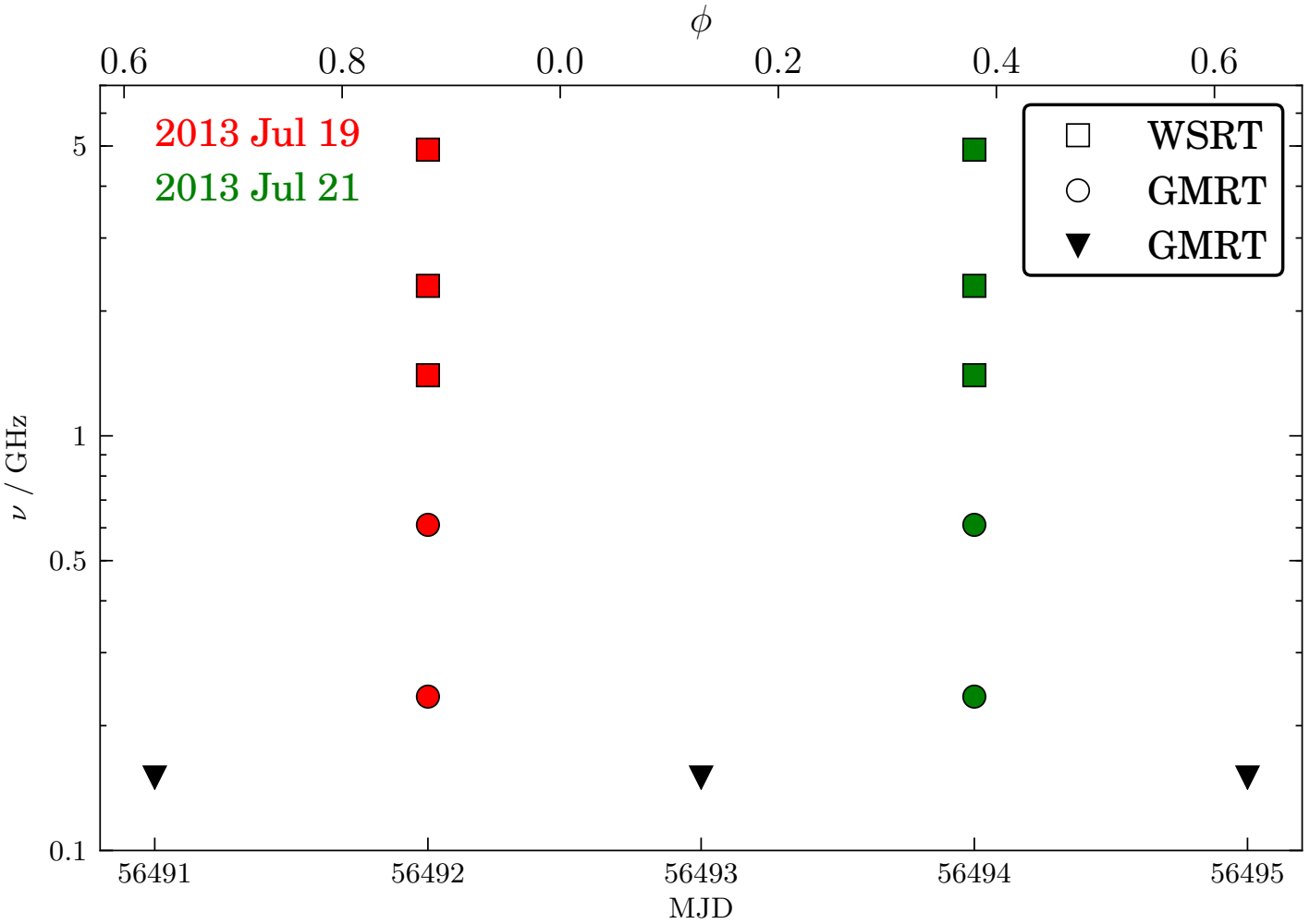
Analyzing not published archival GMRT observations:



Marcote (2012) Master Thesis

LS 5039 New GMRT & WSRT observations

We conducted simultaneous observations with GMRT and WSRT from 2013 July 18 to 22: 150, 235/610 MHz, 1.4, 2.3, 5.0 GHz:



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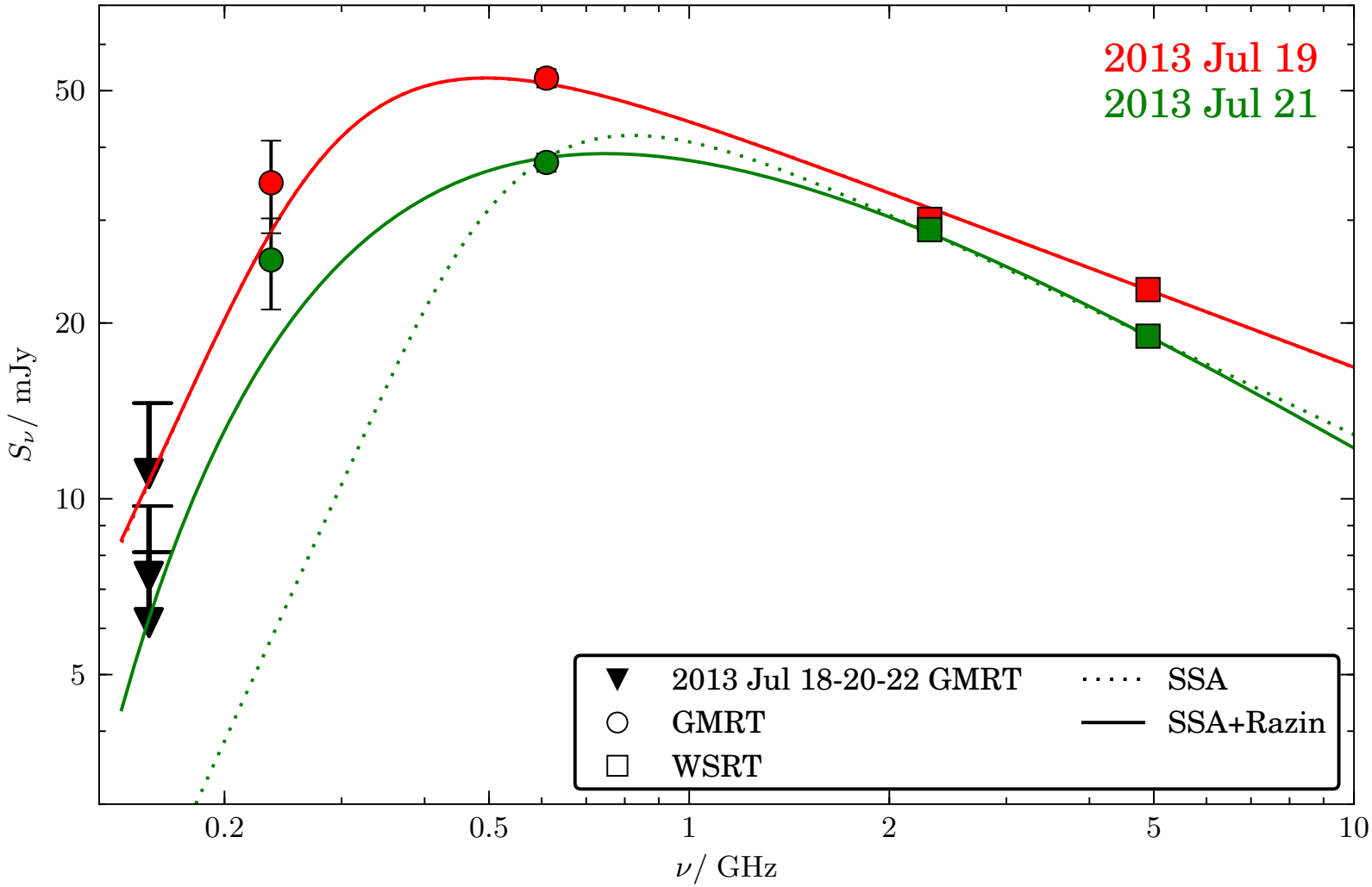

- Synchrotron Self-Absorption can only explain the spectrum of Jul 19
- Free-Free Absorption does not change appreciably the spectra
- Razin effect seems to be needed for the spectrum of Jul 21

LS 5039 New GMRT & WSRT observations

From the previous spectra we infer:

2013 Jul 19: SSA

- $B \sim 0.2$ G
- $R \sim 9 \cdot 10^{13}$ cm

2013 Jul 21: SSA+Razin

- $B \sim 5 \cdot 10^{-4}$ G
- $R \sim 1 \cdot 10^{14}$ cm

Bosch-Ramon (2009) predictions:

$$B \sim 10^{-4}\text{–}0.6 \text{ G}, \quad R \sim 10^{14}\text{–}10^{17} \text{ cm}$$

Razin effect

- The emission from relativistic charges surrounded by a cool, collisionless plasma is exponentially suppressed at low frequencies.
- Widely reported in Colliding Wind Binaries, but not in microquasars

Explored gamma-ray binaries

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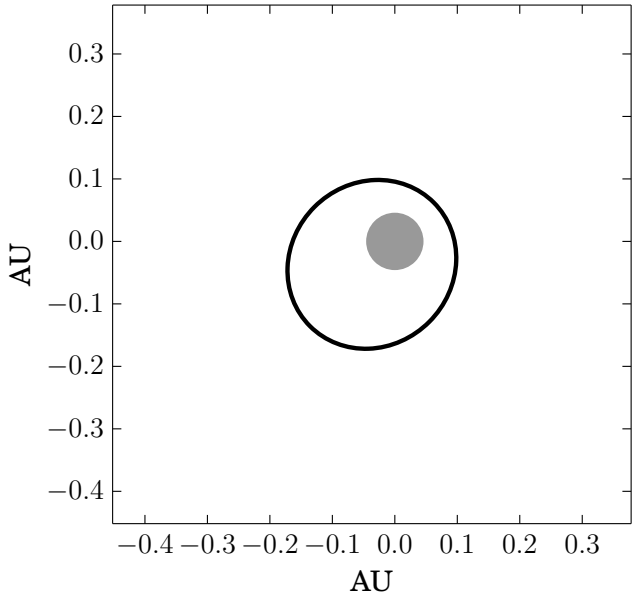

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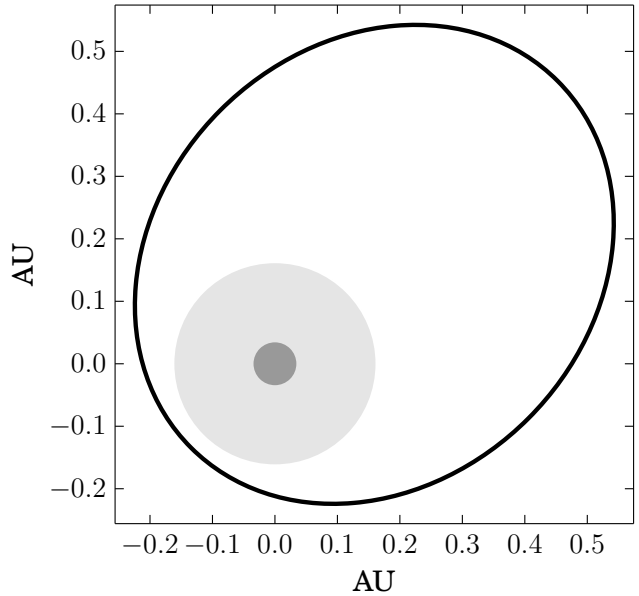
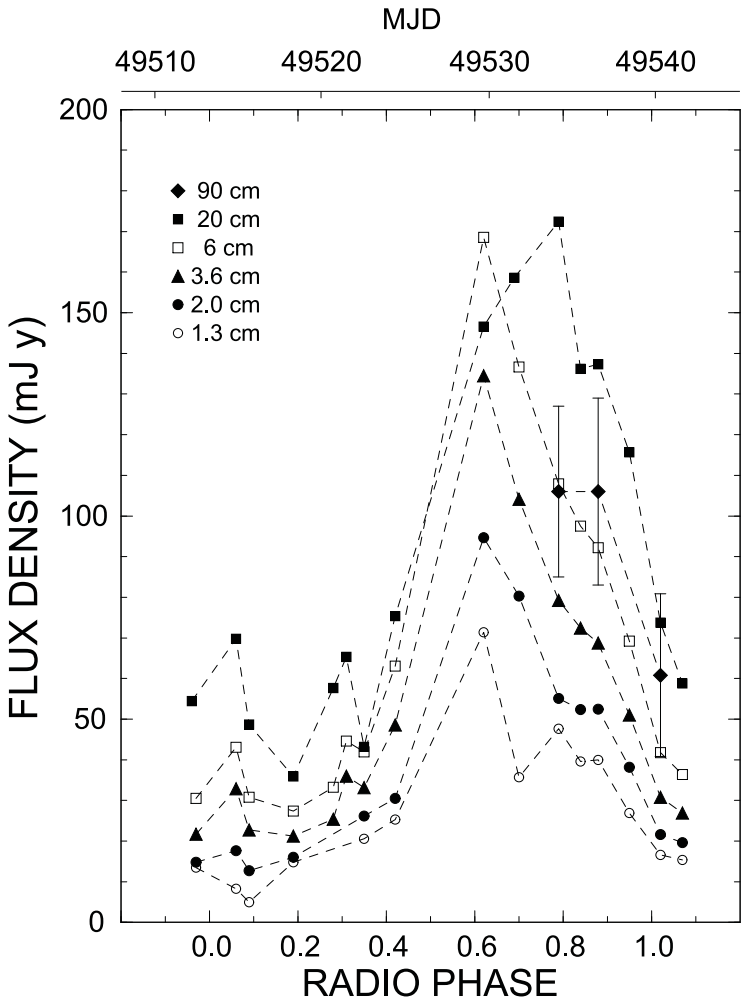
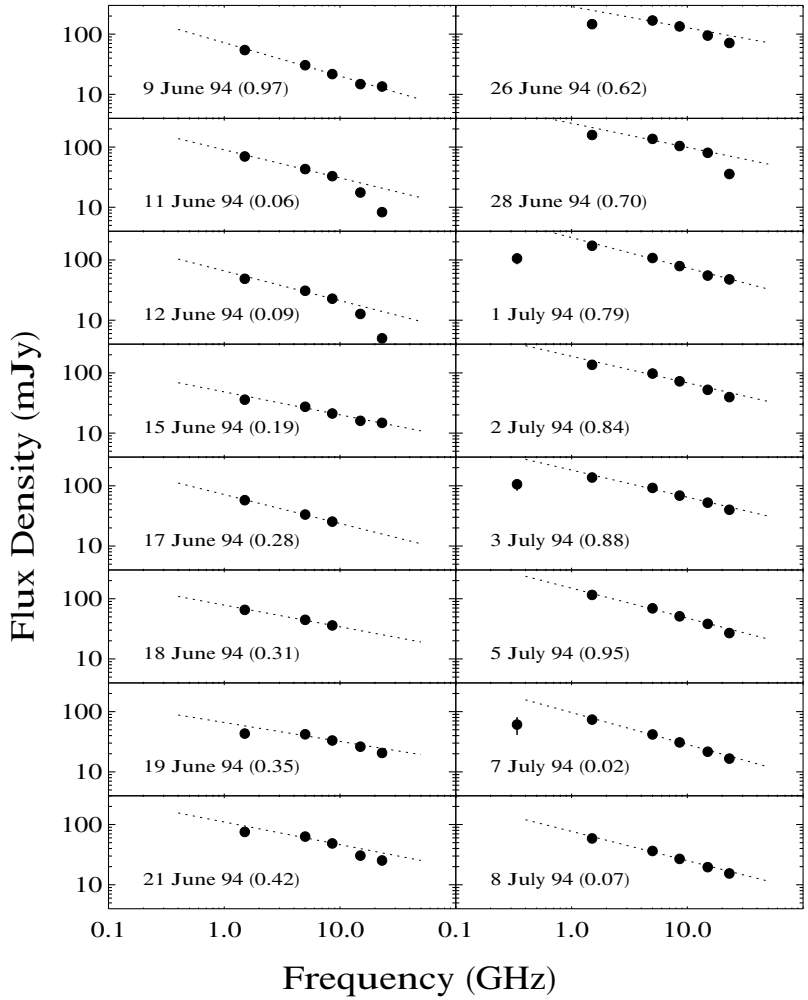


LS I +61 303 Published data

Contrary to LS 5039, this system shows a large variability in radio

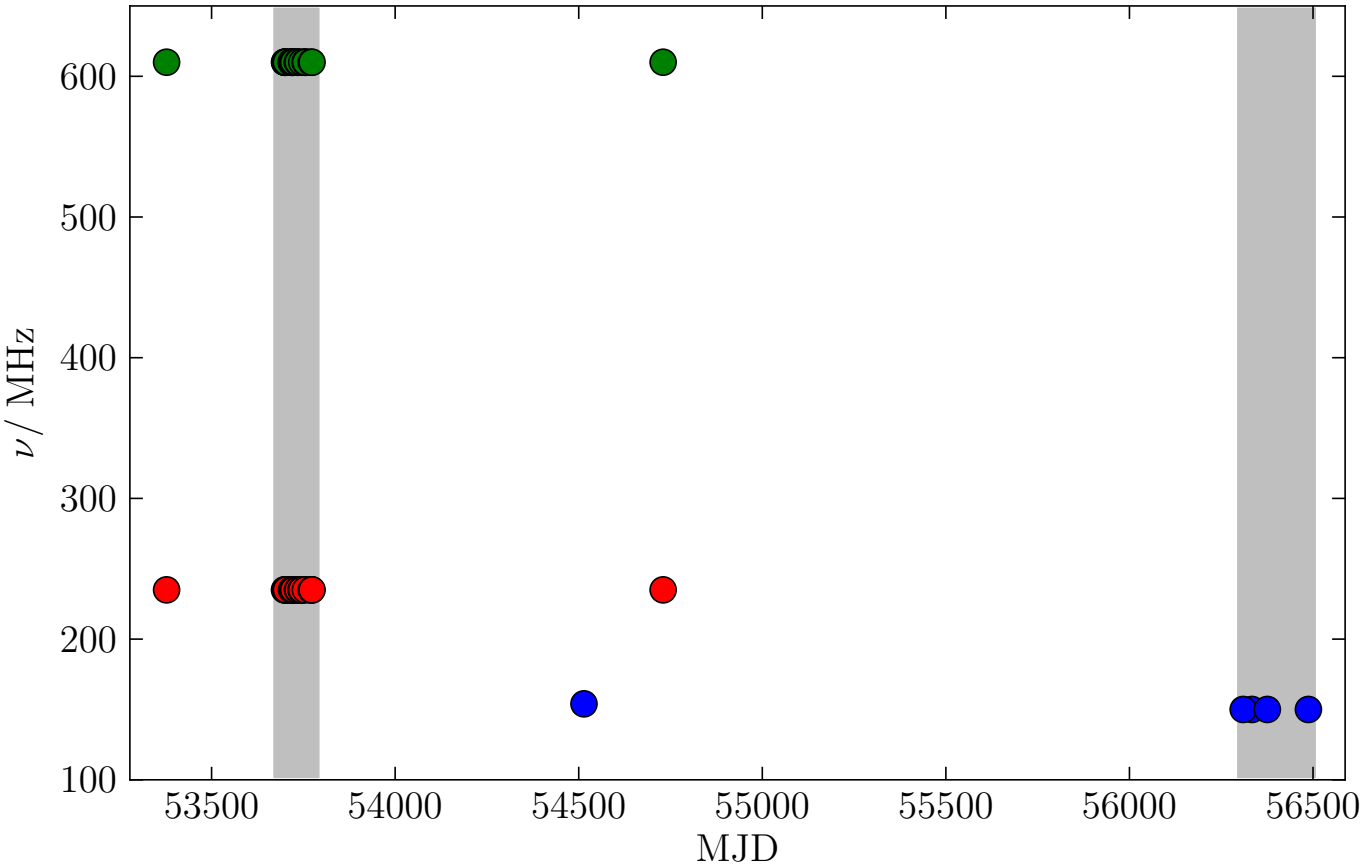




Strickman et al. (1998)

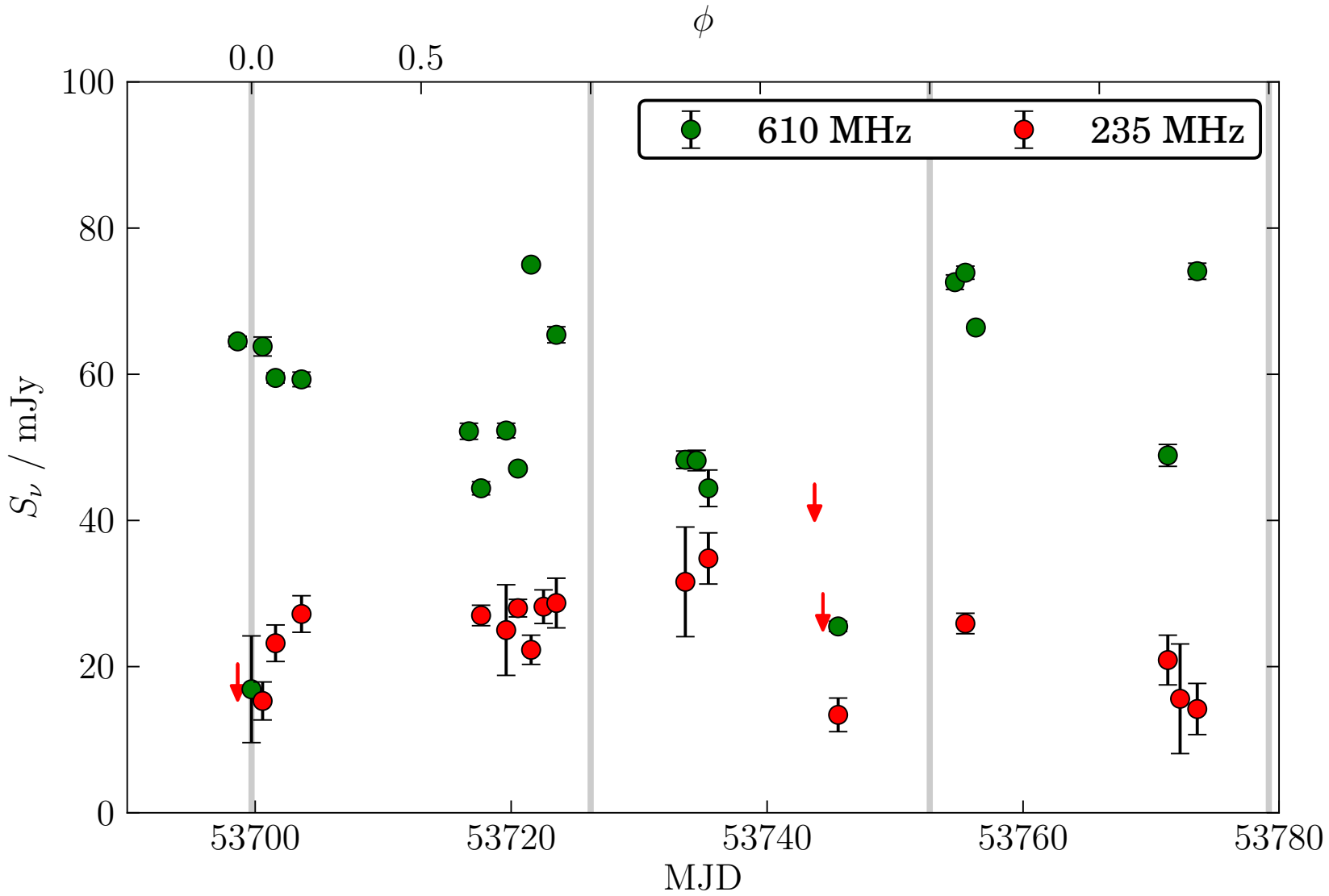
LS I +61 303 Archival GMRT & new LOFAR data

- We analyzed $\sim$ 30 unpublished archival GMRT observations at 235/610 MHz in 2005–2006 and one observation at 150 MHz in 2008
- We performed with the TKP 6 LOFAR observations in Cycle 0 at $\sim$150 MHz



LS I +61 303 Archival GMRT & new LOFAR data

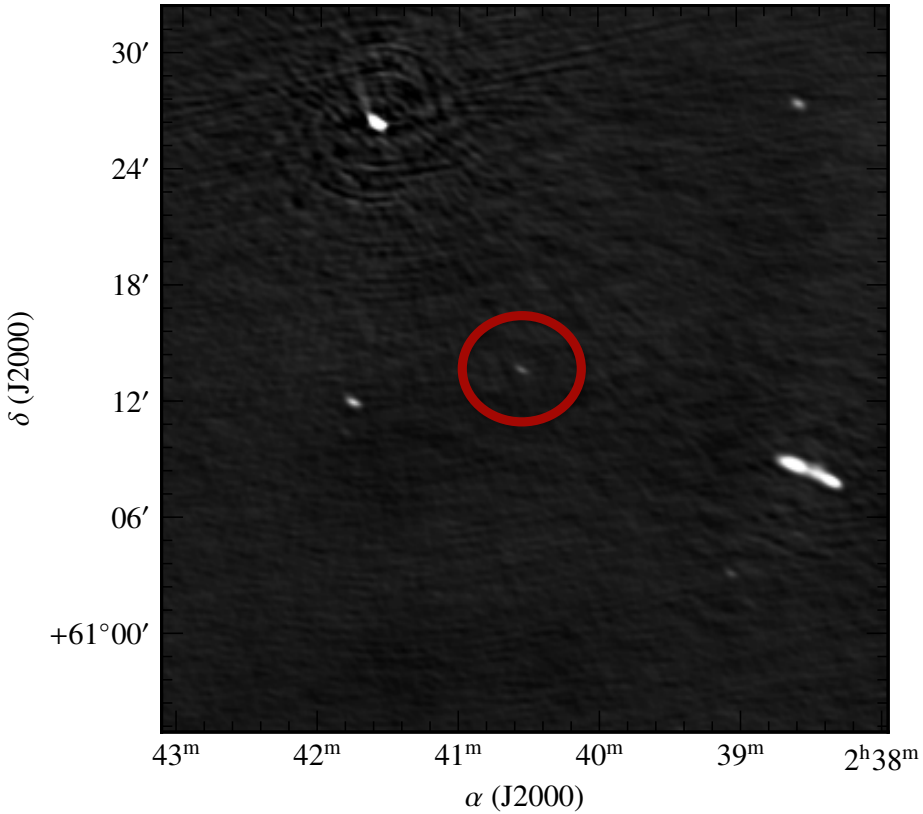
GMRT data from Nov 2005 to Feb 2006.



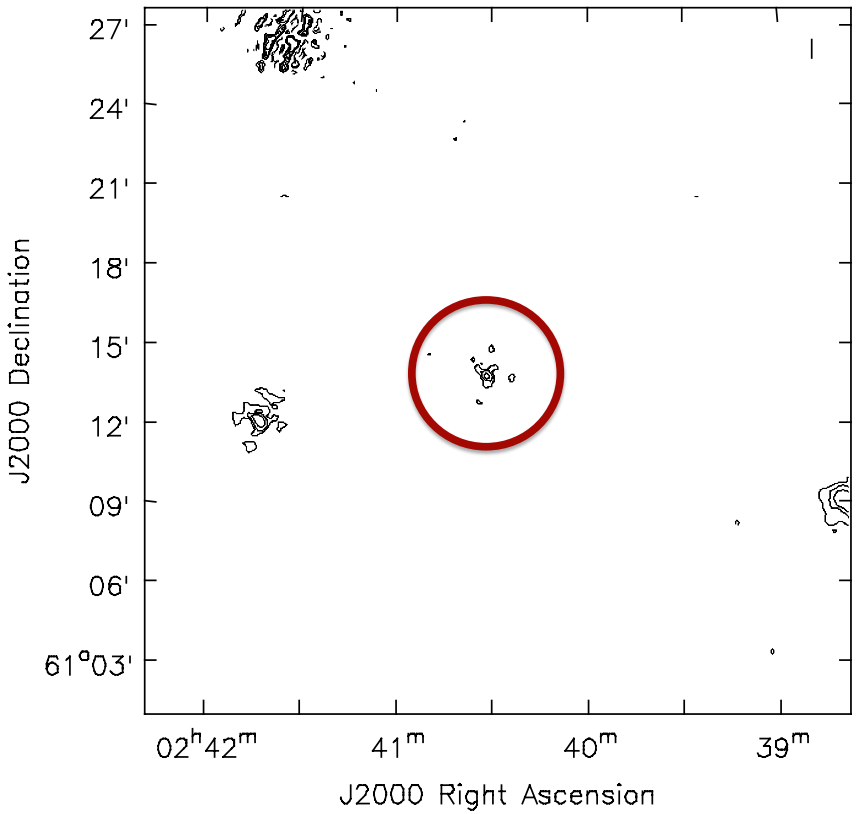
LS I +61 303 Archival GMRT & new LOFAR data

First detections at 150 MHz with GMRT and LOFAR

Point-like source with $S_\nu \sim 30$–80 mJy



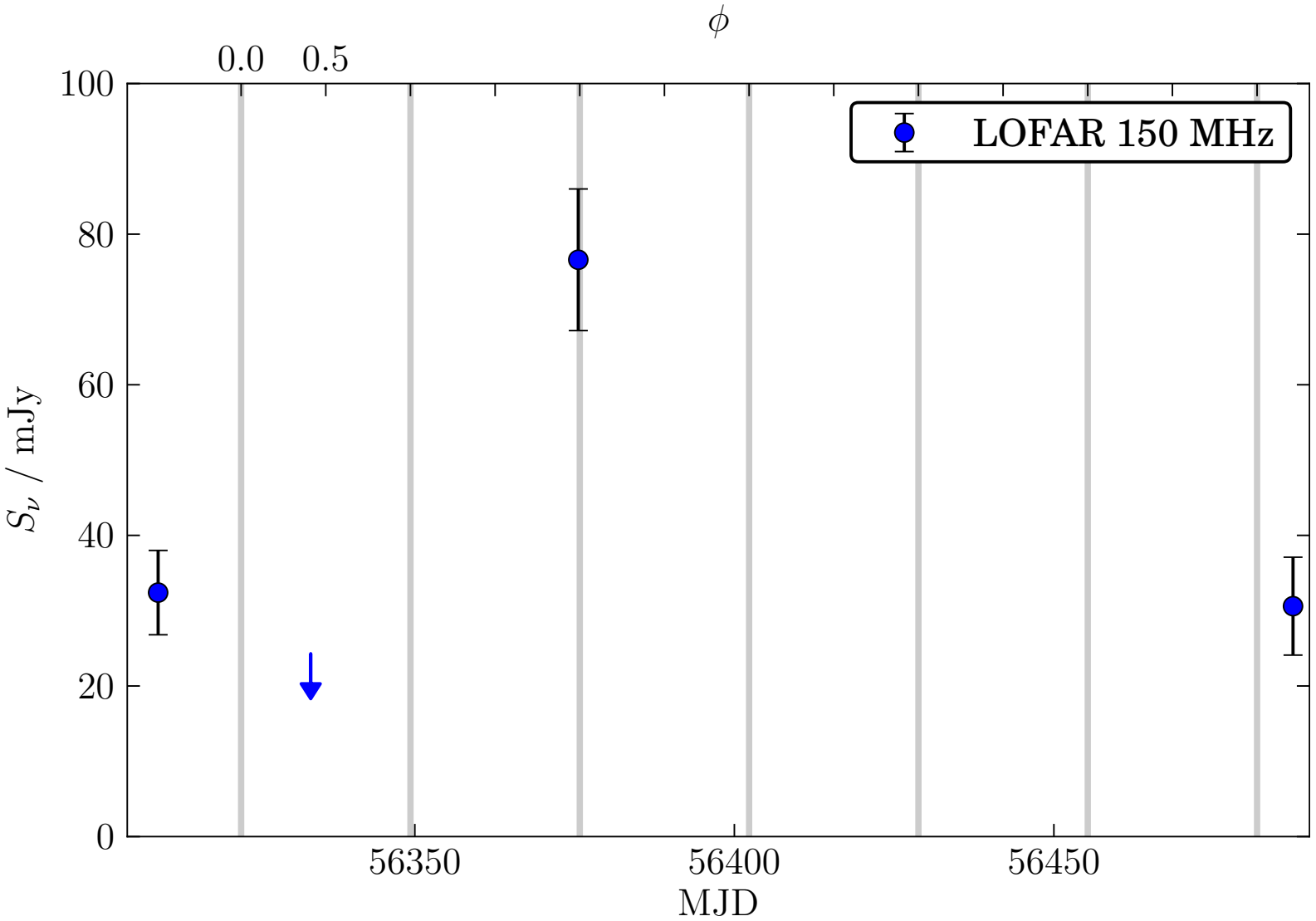
GMRT detection of LS I +61 303 at 150 MHz



LOFAR detection of LS I +61 303 at 150 MHz

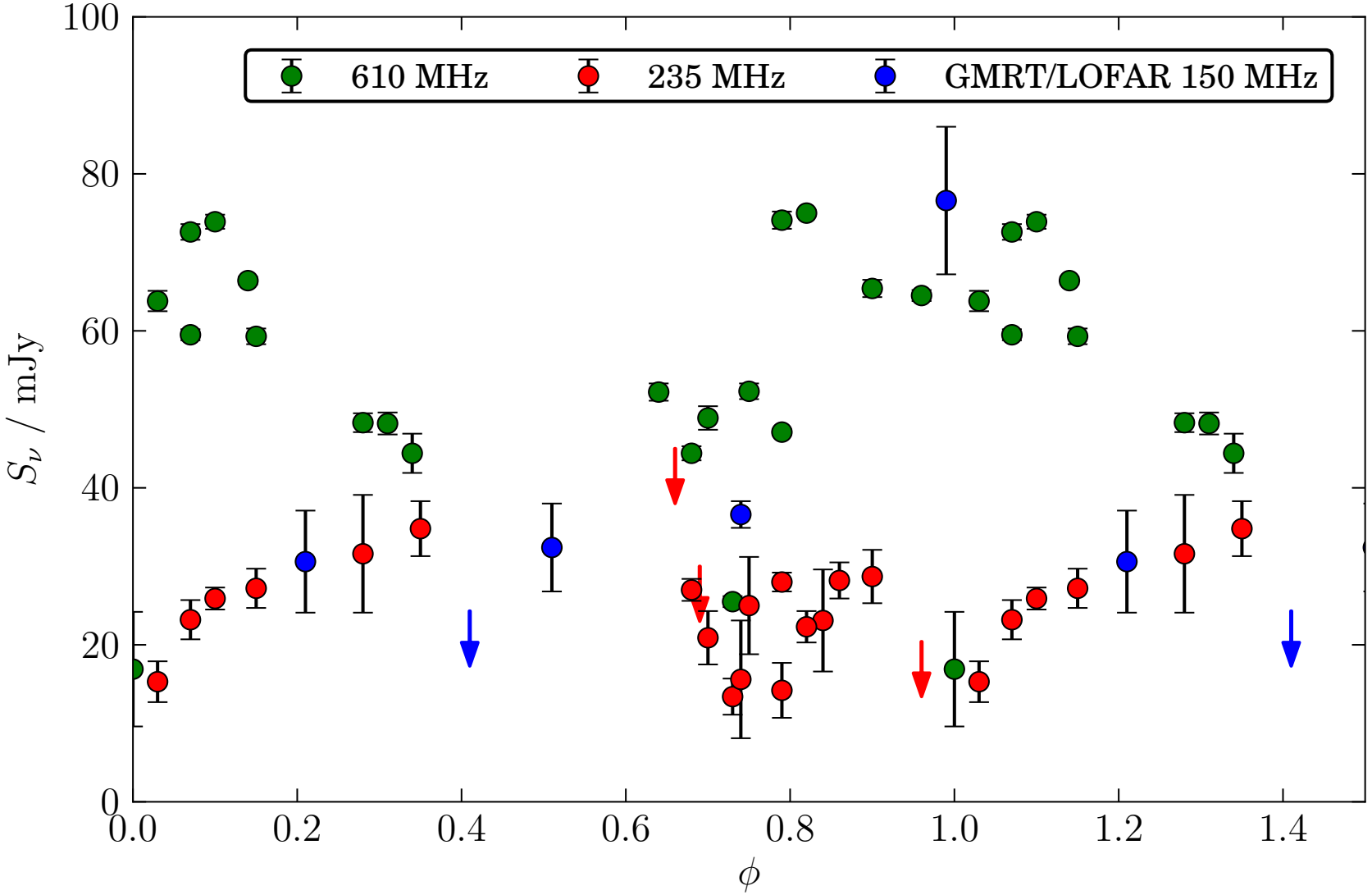
LS I +61 303 Archival GMRT & new LOFAR data

Preliminary LOFAR results:



LS I +61 303 Archival GMRT & new LOFAR data

GMRT & LOFAR data



Conclusions

For LS 5039...

- We have reported a turnover in the spectrum at frequencies below 1 GHz
- The shape of the spectrum changes with the time
- Absorption mechanisms appear at very low frequencies
- No detections at 150 MHz up to now
- Razin effect could imply similarities with CWBs?

For LS I +61 303...

- The first detections at 150 MHz of a gamma-ray binary
- At 610 MHz the light curve still presents maxima and minima
- At 235 MHz the outbursts are not observed
- Variability at 150 MHz could be reported by LOFAR
- Extended emission could remain during the weak point-like emission