Low Frequency Radio Observations of Gamma-Ray Binaries

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Introduction

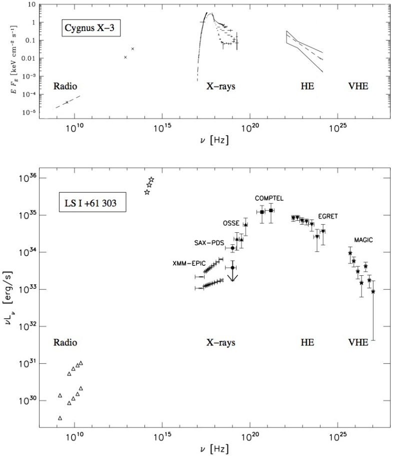
- High-Energy Astrophysics
  - High Energy (HE): 100 MeV – 100 GeV
  - Very High Energy (VHE): $\gtrsim$ 100 GeV
- There are some binary systems detected as high energy and/or very high energy gamma-ray emitters.
- Emission from radio to gamma-rays.
- Formed by
  - A *normal star* (the donor star)
  - A *compact object* (neutron star or black hole)
- Two types of these systems:
  1. X-ray binaries
  2. Gamma-ray binaries

X-ray binaries

Strong luminosity in X-rays:
NT-SED dominated by the X-ray emission.

Gamma-ray binaries

Strong luminosity in gamma-rays:
NT-SED dominated by the gamma-ray emission.



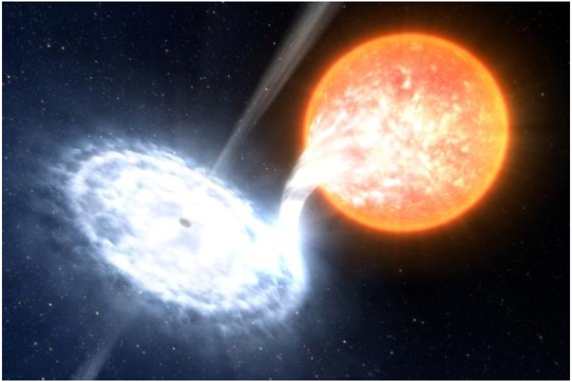
Adapted from Moldón, PhD Thesis, 2012

Note: NT-SED: non-thermal spectral energy distribution

Microquasar scenario

The compact object accretes matter from the star

- X-rays: accretion disk or corona
- HE: jets & compact object vicinity
- Radio: jets



Credit: ESO

Introduction

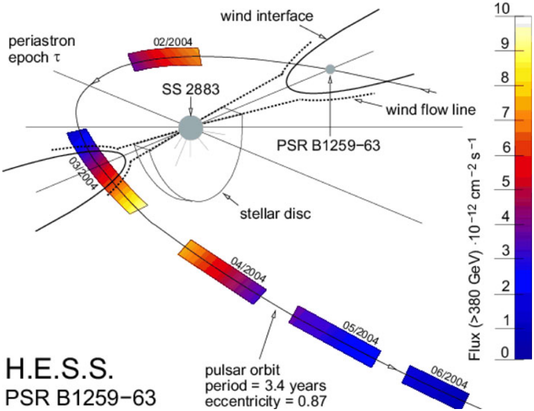
Binary pulsar scenario

(young non-accreting pulsar scenario)

Strong shock between both winds:

- Relativistic pair plasma wind from the pulsar
- Stellar wind from the massive companion star

Originally proposed by Maraschi & Treves (1981)



Aharonian et al. (2005)

Introduction

The radio emission is strongly related with the gamma-ray emission.

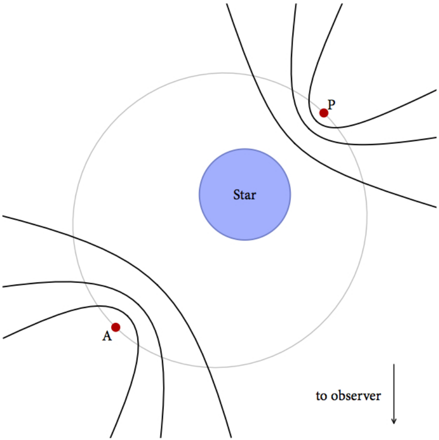
- Three main non-thermal emission processes:
  1. Synchrotron emission ($\ll 1$ GHz)
  2. Inverse Compton
  3. Bremsstrahlung
- Low frequencies:
  - synchrotron emission from the low-energy electrons

$$P(\nu) \propto \nu^{\alpha}$$

  - Emitting region:
    - Far away from the binary system (Durant et al. 2011)
    - arcsec-arcmin scales (Bosh-Ramon & Barkov 2011)
    - no variability (Bosh-Ramon & Barkov 2011)

The Gamma-Ray Binary LS 5039

- Binary system with a O6.5 star ($m = 11.3$)
  $\alpha = 18^{\mathrm{h}}\ 26^{\mathrm{m}}\ 15.0593^{\mathrm{s}}$
  $\delta = -14^{\circ}\ 50'\ 54.301''$
- Optically stable
- No pulsations in radio or X-rays
- HE emitter (Paredes et al. 2000)
- VHE emitter (Aharonian et al. 2005)
- Orbital variability in X-rays (Bosh-Ramon et al 2005)
- Orbital variability at TeV energies (Aharonian et al. 2006)



Zabalza, PhD Thesis (2011)

The Gamma-Ray Binary LS 5039

Radio emission

At $\sim$GHz frequencies:

- Non-thermal, persistent and variable emission
- No strong radio outbursts or periodic variability
- 1.5 – 15 GHz (Martí et al. 1998)

$$S_\nu[\mathrm{mJy}] = (52 \pm 1)\ \nu[\mathrm{GHz}]^{-0.46\pm0.01}$$

  Emission persistent with a variability $\lesssim 30\%$.

- VLBA: asymmetrical bipolar extended emission (Paredes et al. 2000)
  Periodic morphological variability at mas scales (Moldón et al. 2012b)
- Low frequencies (235 and 610 MHz):
  Godambe et al. (2008): inverted spectrum (positive spectral index)
  Pandey et al. (2007): no cut-off at these frequencies
  Large variability ($\sim 80\%$) at 235 MHz?

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The Gamma-Ray Binary LS 5039

Objectives

1. Characterize the behaviour of LS 5039 at low and very low frequencies
2. Detection of the large scale structure expected by the theoretical models (Durant et al. 2011)
3. Clarify if LS 5039 shows large variability at low frequencies.

* To do that, we have analyzed archival data but also we have conducted new observations

Radio Observatories

The Very Large Array (VLA)

13^{th} Synthesis Imaging Workshop. NRAO, Socorro. May-June, 2012

The Low Frequency Array (LOFAR)

2-month stay in Amsterdam. January-March, 2012

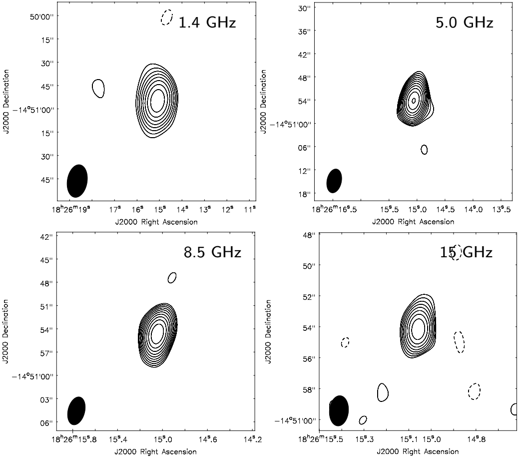
The Giant Metrewave Radio Telescope (GMRT)

3-week stay in Pune (India) to reduce GMRT data. August, 2012

Observations and Results

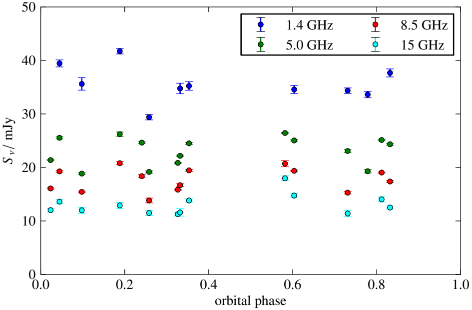
16 observations
From September 23, 2002 to October 21, 2002
Project code: AP444
Time-on-source: from 20 to 60 min.
At 1.4, 5.0, 8.5 and 15 GHz.
BC or C VLA configuration.

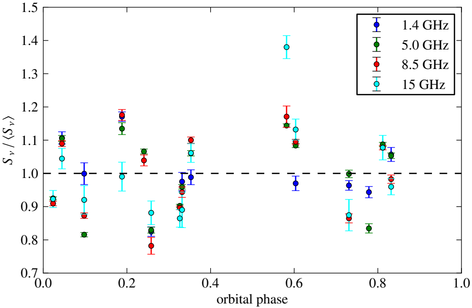
Point-like source



Observations and Results

VLA Monitoring





Observations and Results

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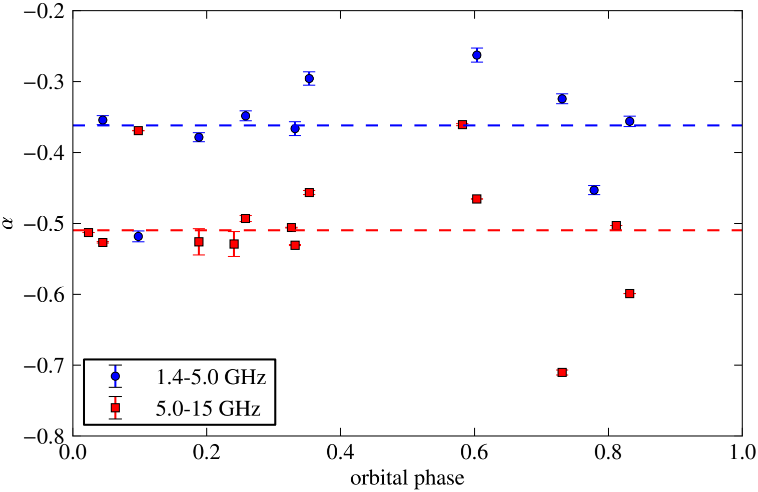


Observations and Results

Two archival Low Frequency VLA observations

December 16 and 18, 2006

Time on Source : 80 and 60 min.

$\phi_{\rm pp} \sim 0.5$ and 0.0

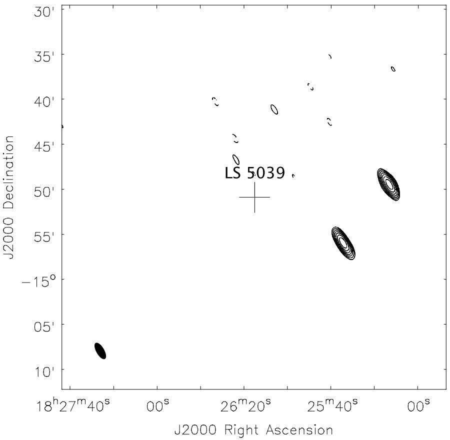
$\nu = 330$ MHz

Primary beam $\sim$ 2.5 degrees

Synth. beam: 1.99×0.82 arcsec.

rms $\approx$ 40 mJy

3-σ Upper-limit $= 120$ mJy beam^{-1}



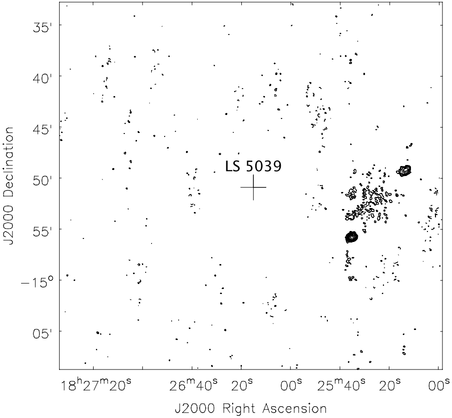
Observations and Results

LOFAR Observation

One deep LOFAR observation
(*commissioning observation*)
October 1, 2011
Time on Source : 6-hour
$\phi_{\rm pp} \sim 0.7$
$\nu = 110\text{–}160$ MHz
23 core + 9 remote stations used

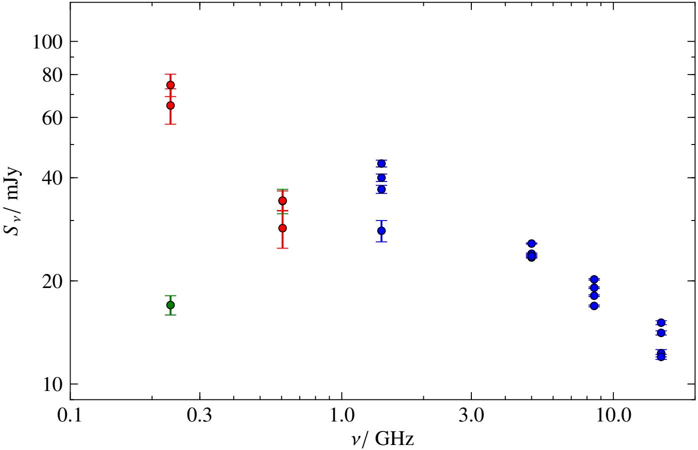
Primary beam $\sim$ 5 degrees
Synth. beam: 15.4 $\times$ 10.8 arcsec.

rms $\approx$ 11 mJy
3-σ Upper-limit = 33 mJy beam^{-1}



Observations and Results

Variability of LS 5039



- Martí et al. (1998)
- Godambe et al. (2008)
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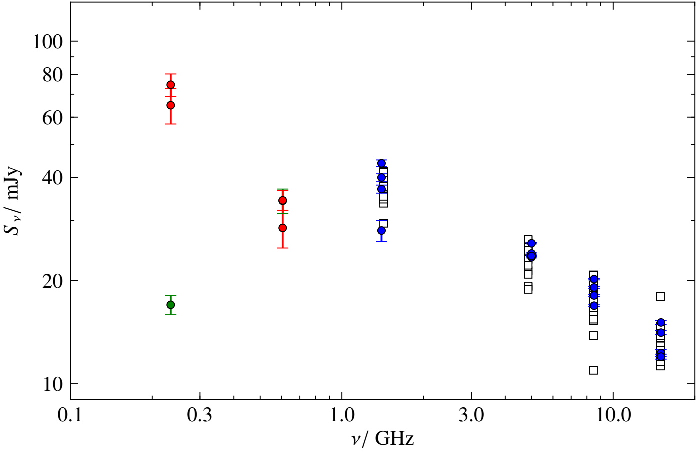

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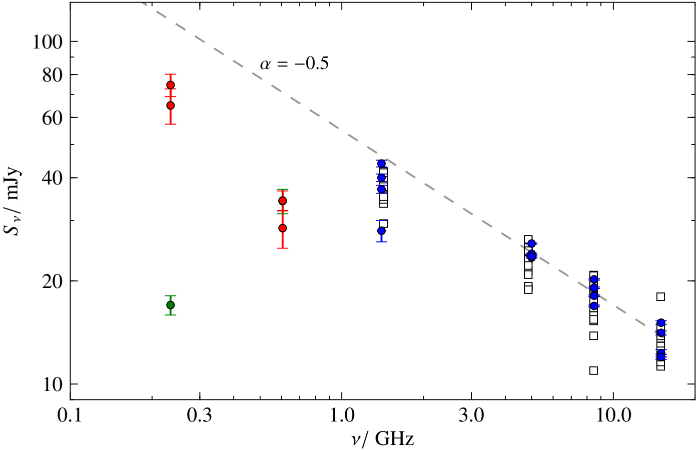

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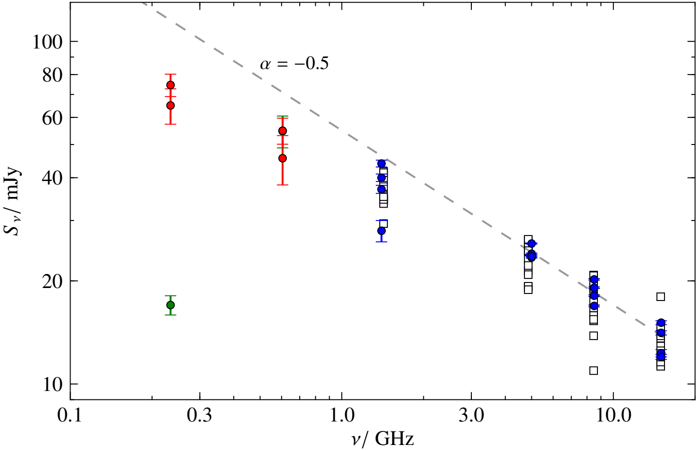

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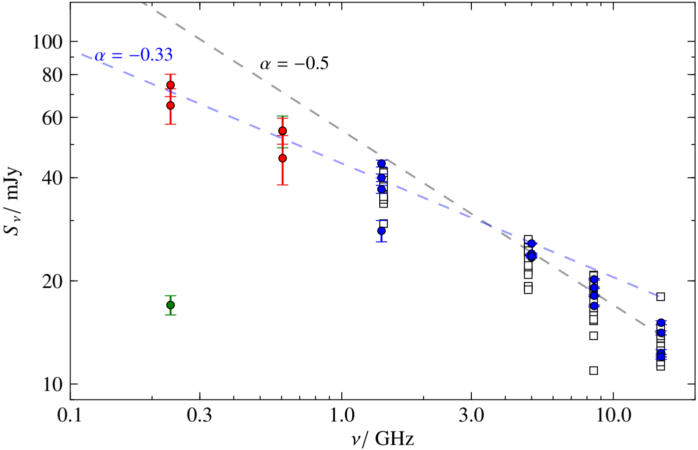

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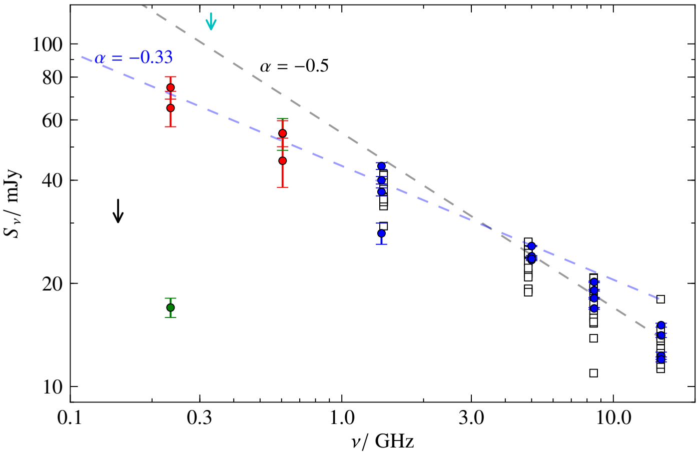

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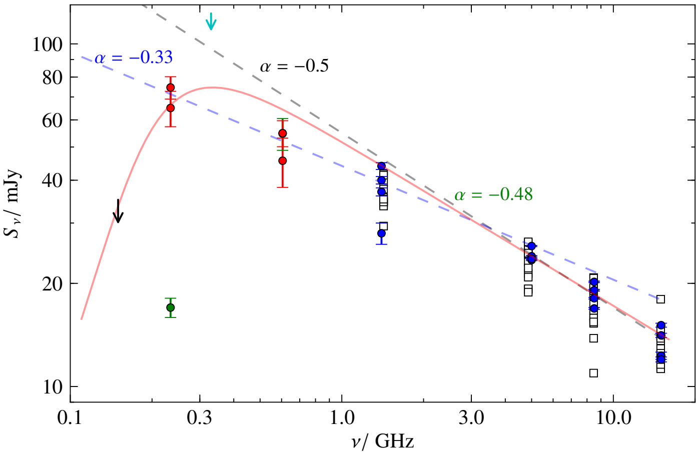
- Pandey et al. (2007) □ VLA monitoring ↓ LOFAR

Observations and Results

Variability of LS 5039



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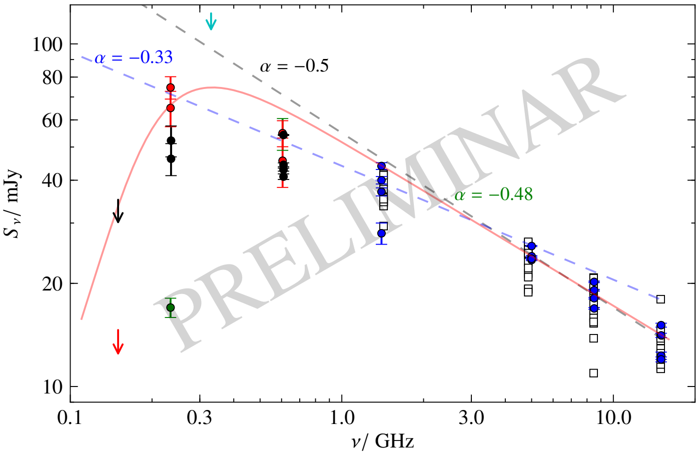

- ● Martí et al. (1998) ● Godambe et al. (2008) ↓ VLA 330 MHz ↓ GMRT
- ● Pandey et al. (2007) □ VLA monitoring ↓ LOFAR ● GMRT

Conclusions

- We have improved the spectra of LS 5039 at low frequencies
- At ~GHz frequencies there is no variability larger than $\sim 30\%$ at different epochs
- Corrected 610 MHz observations fit properly with the rest of the data
- Variability at ~ 230 MHz possibly smaller than previously reported
- Absorption with strong slope: possibly no synchrotron self-absorption

In the future...

- More archival GMRT observations are being analyzed at 235 and 610 MHz.
- We will perform a GMRT monitoring along the LS 5039 orbit at 150 and 235 MHz next year.
- Future LOFAR observations will provide us a better resolution and sensitivity.