First LOFAR Observations of Gamma-Ray Binaries

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Abstract

Gamma-ray binaries display High Energy (100 MeV–100 GeV) and/or Very High Energy ($\gtrsim$ 100 GeV) gamma-ray emission and non-thermal radio emission which can be resolved with long-baseline radio interferometers, revealing the presence of outflows. It is expected that at very low frequencies the synchrotron radio emission might be absorbed by different mechanisms like synchrotron self-absorption, free-free absorption and the Razin effect. Here we present preliminary results of the first deep radio observations of the gamma-ray binaries LS I +61 303 and LS 5039 with LOFAR, which is sensitive to frequencies $\sim$ 150 MHz. None of the sources is detected with 3-σ upper-limits of 150 mJy and 20 mJy, respectively.

Gamma-Ray Binaries

Gamma-ray binaries are binary star systems with the non-thermal Spectral Energy Distribution maximum located in the gamma-ray domain. The known systems up to now are composed by a compact object (either a black hole or a neutron star) and a young massive star. Only a few gamma-ray binaries have been discovered: LS 5039, LS I +61 303, PSR B1259–63, HESS J0632+057 and 1FGL J1018.6–5856. The physical properties of these powerful accelerators are still under discussion (Paredes 2011).

The radio spectrum is produced by the synchrotron emission from accelerated particles in the outflows, which have been imaged at mas scales at ~GHz frequencies (Moldón et al. 2012). Although a microquasar scenario with a jet powered by accretion was initially proposed (Paredes et al. 2006), the most recent observations favor a young non-accreting pulsar scenario where the electrons are accelerated by the shock between the relativistic wind of a pulsar and the wind of the stellar companion (Dubus 2006, Bosch-Ramon et al. 2012). Synchrotron self-absorption, free-free absorption, and maybe the Razin effect are expected to be present below 1 GHz for these systems.

LOFAR

The Low Frequency Array (LOFAR) is a digital radio interferometer with stations in The Netherlands, France, Germany, Sweden and the United Kingdom (see Heald et al. 2011 for a review). LOFAR detects photons in the 30–240 MHz frequency range, which has never been explored by any large-scale interferometer before. Operating in this new frequency window LOFAR promises to revolutionize wide ranging areas of astrophysics.

The LOFAR radio telescope consists of many low-cost antennas, distributed in 24 core, 9 remote and 8 international stations, with baselines from 100 m to 1.500 km. There are two types of antennas: Low Band Antennas (LBA) observing at 30–80 MHz and the High Band Antennas (HBA), in the 120–240 MHz range. LOFAR started the Cycle 0 in the fall of 2012. The resolution and sensitivity of LOFAR, considering the full array, reach 0.65 arcsec and 3 mJy beam^{-1} at 60 MHz or 0.2 arcsec and 0.2 mJy beam^{-1} at 240 MHz per hour of observation.

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LS I +61 303

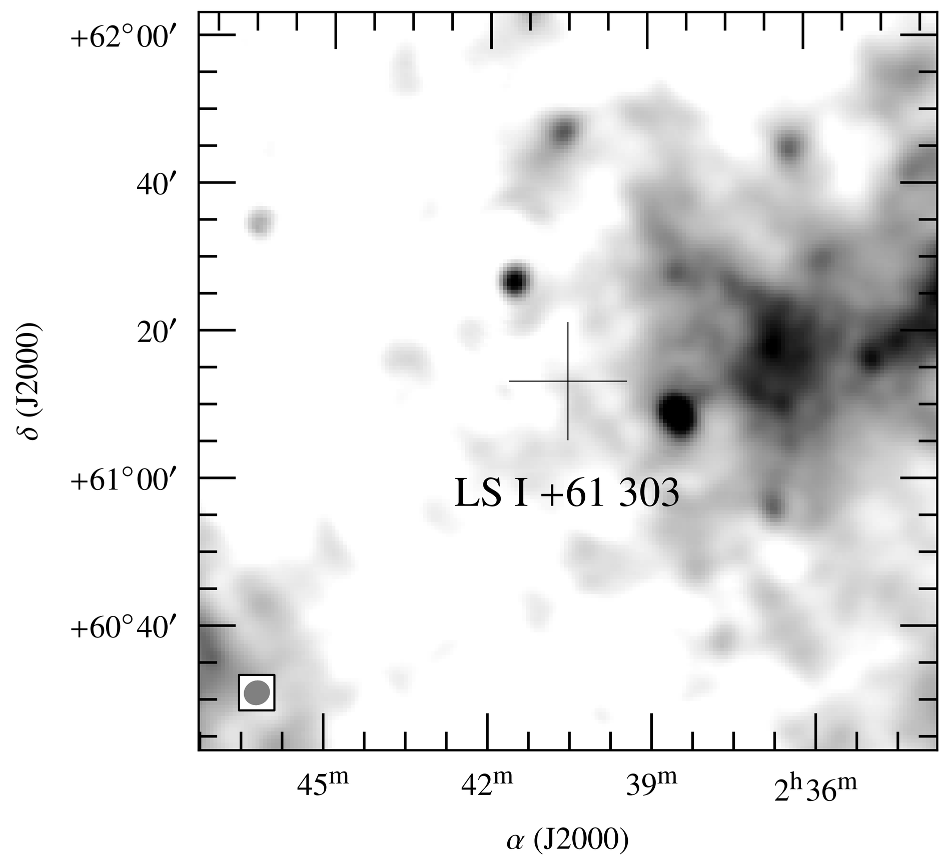
LS I +61 303 is a Gamma-Ray Binary with a young Be star and a compact object orbiting it every 26.5 days (Taylor & Gregory 1982). Its radio emission shows periodic radio outbursts with a period in average coincident with its orbital period. However, the origin of this radio emission is still unclear, and it could be due to a jet or to an outflow produced after the shock between the winds of the putative pulsar and the star. This last scenario has been proposed to explain VLBA monitoring observations (Dhawan et al. 2006).

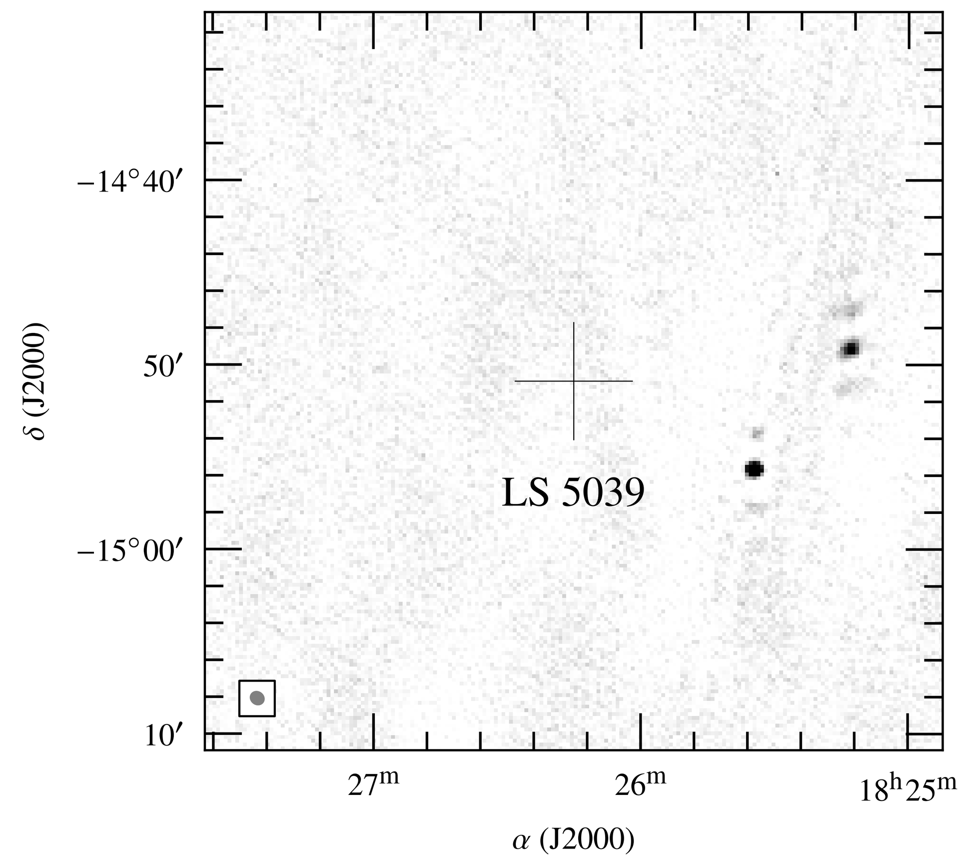
LS 5039

LS 5039 is a Gamma-Ray Binary with a young O6.5 star and a compact object orbiting it every 3.9 days (Casares et al. 2005). Its radio emission is non-thermal, persistent, and variable (Ribó 2002, Martí et al. 1998). No outbursts or periodic variability have been detected. The amplitude of the variability at GHz frequencies is below 25% respect to the mean flux value. The binary pulsar scenario is clearly supported by the periodic morphological variability observed at mas scales by Moldón et al. (2012).

Observations and Results

In this poster we present the first commissioning LOFAR observations of LS I +61 303 and LS 5039 made on September 30 and October 1, 2011 (post-periastron phases of 0.36 and 0.7), respectively, for a 6 hour round with the HBA at 120–180 MHz and 244 subbands (SBs). For these observations 23 core stations + 9 remote stations were used. The data were analysed with the LOFAR Standard Imaging Pipeline and CASA software (NRAO). Here we show an update of the results for the integration of 100 SBs (120–130 MHz) for LS I +61 303 published in Marcote et al. (2012) and the combination of all SBs for LS 5039. Find below the obtained images for LS I +61 303 and LS 5039, respectively. The primary beam is $\sim$ 6 degrees and the synthesized beam is shown in each image in the bottom left corner.





For **LS I +61 303** we obtain a non-detection with a 3-σ upper-limit of $\approx$ 150 mJy and a resolution of $\approx$ 2.5 arcmin (the remote stations were removed). Newer LOFAR observations drop this upper limit to $\sim$ 30 mJy beam^{-1} (Broderick et al. 2013). Extrapolating the results of Strickman et al. (1994) at the same orbital phase, we would expect a flux density in the range $\approx 40-70$ mJy at 125 MHz.

For **LS 5039** we obtain a non-detection with a 3-σ upper-limit of $\approx$ 20 mJy and a resolution of $\approx$ 30 arcsec (the remote stations were kept). Extrapolating the results of Martí et al. (1998) in the range 1.4–15 GHz we would expect a flux density of $\sim$ 100 mJy if no absorption is present at lower frequencies. This result shows that absorption mechanisms below 1 GHz are required.

In both cases an absorption mechanism appears to be required in order to explain the non-detections. Using LOFAR observations, together with GMRT observations, we are determining the spectrum of both sources at low frequencies (100 MHz–1 GHz) in order to unveil these absorption mechanisms and the physical properties of the systems.

Another question that LOFAR might answer for gamma-ray binaries is if extended emission, expected at these low frequencies, is detected (Bosch-Ramon & Barkov 2011).

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