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 covers larger angular scales than it has been reported up to now. Here we present preliminary results of the first deep radio observations of the gamma-ray binary LS I +61 303 with LOFAR, which is sensitive to extended structures on arcsecond to arcminute scales.

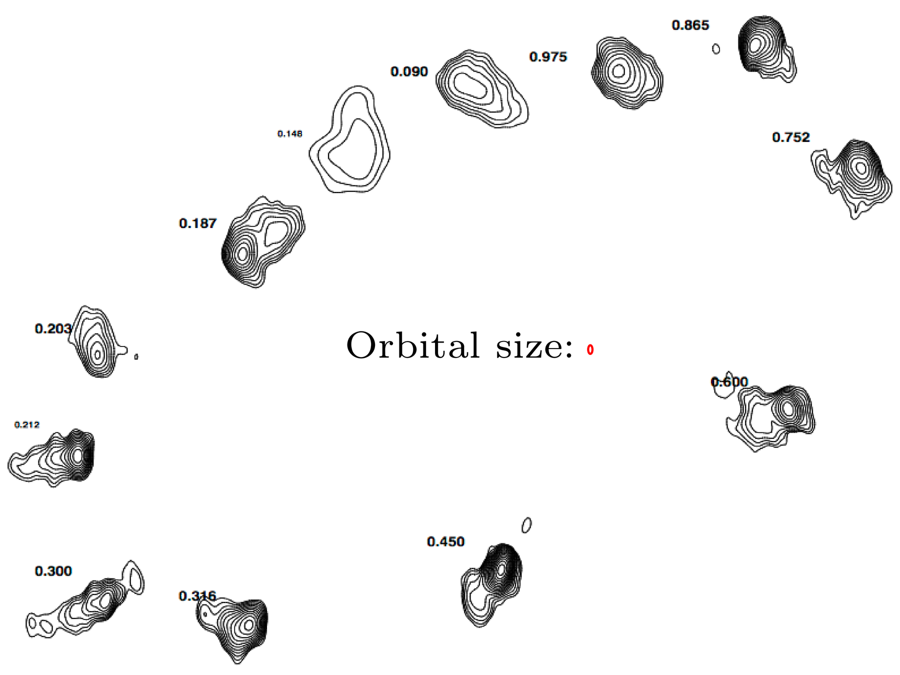
Introduction to Gamma-Ray Binaries

Gamma-ray binaries are binary systems consisting of a compact object and a young massive star which have a non-thermal spectral energy distribution (SED) dominated by MeV-GeV photons (see Paredes 2011 and Dubus 2006). This emission is displayed across all the electromagnetic spectrum, from radio to HE (100 MeV – 100 GeV) and/or VHE ($\gtrsim$ 100 GeV) gamma-rays. Up to now, only a few Galactic gamma-ray binary systems are known, and the physical properties of these powerful accelerators are still under discussion.

At radio wavelengths, we observe the synchrotron emission by the outflows. Extended structure is resolved by VLBI (see poster of J. Moldón). For the low-energy electrons, Durant et al. (2011) noted that they should remain unaffected on any plausible dynamical timescale. Therefore, at very low frequencies we would expect to see synchrotron radio emission on much larger angular scales than it has been reported up to now, without variability along the orbit (see Bosch-Ramon & Barkov 2011). This emission has remained unobserved due to the very poor resolution of the previous radio observatories at these very low-frequencies.

LS I +61 303

LS I +61 303 is a Gamma-Ray Binary discovered as a γ-ray emitter 30 years ago with periodic radio outbursts coincident with its orbital period of $P = 26.5$ days (Taylor & Gregory, 1982). However, the origin of its 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 the VLBA observations shown below.



LS I +61 303 at 3.6 cm by Dhawan et al. (2006).

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LOFAR

The LOw Frequency ARray (LOFAR) is a digital radio interferometer with stations in The Netherlands, France, Germany, Sweden and the United Kingdom which will observe continuously a large fraction of the northern hemisphere (see Heald et al. 2011 for a recent update). LOFAR detects photons in the frequency range 30–240 MHz, 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 Key Science Projects of LOFAR are:

- Epoch of reionisation.
- Deep Extragalactic Surveys.
- Transient Sources and Pulsars.
- Ultra High Energy Cosmic Rays.
- Solar Science and Space Weather.
- Cosmic Magnetism.

The LOFAR radio telescope consists of many low-cost antennas, distributed in 24 core, 18 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 range 120–240 MHz. LOFAR started preliminary observations in 2008, and detailed commissioning observations in 2011. In the final configuration, the resolution and sensitivity of LOFAR will reach 0.65 arcsec and 10 mJy beam^{-1} at 60 MHz or 0.2 arcsec and 0.3 mJy beam^{-1} at 240 MHz per hour of observation.

Acknowledgements

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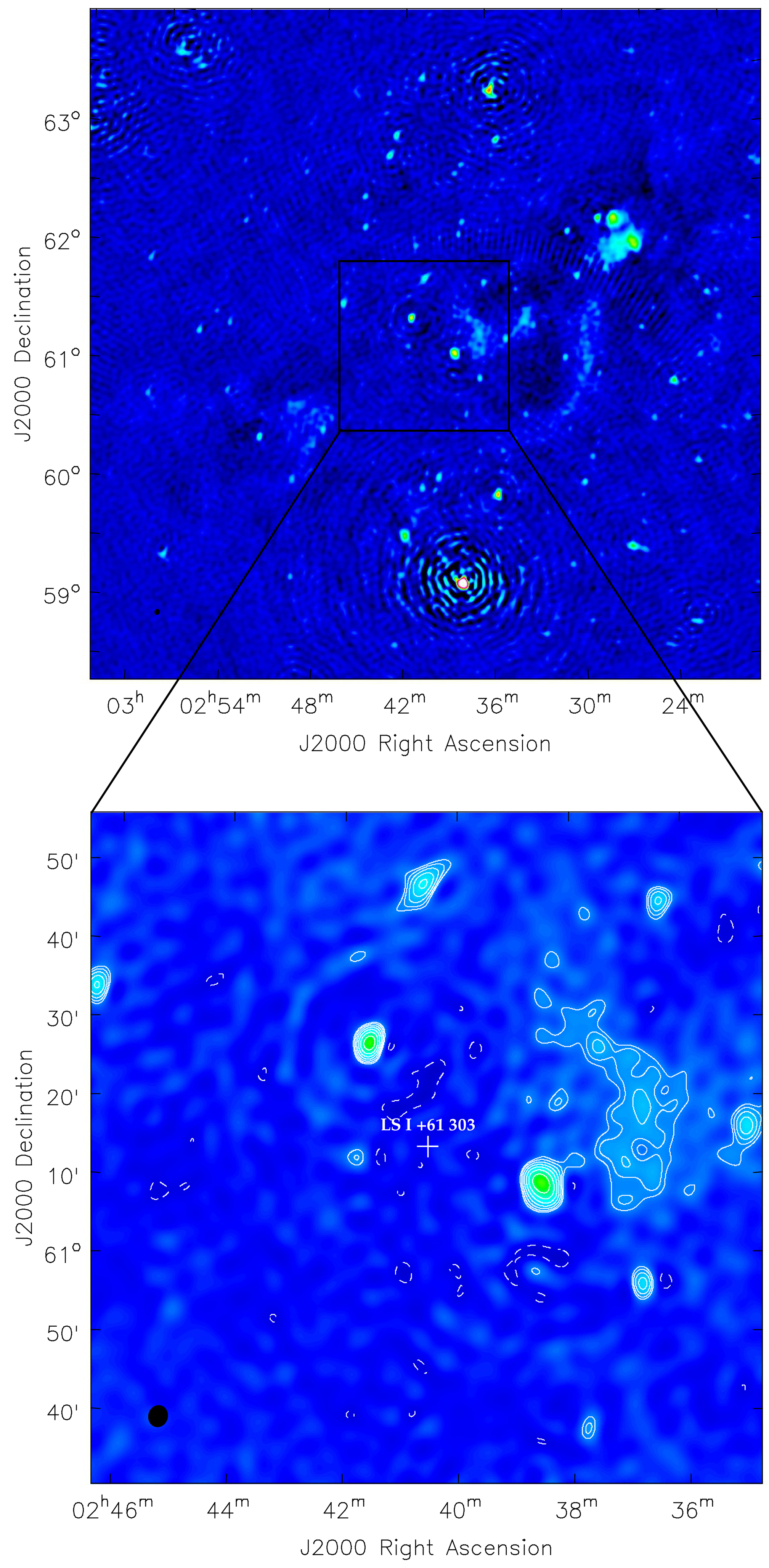
Observations and Results

We present the first LOFAR observation of LS I +61 303 made on September 30, 2011 for a 6 hour round with the HBA at 120–180 MHz and 244 subbands. For this observation 23 core stations + 9 remote stations were used. The data was analysed with the LOFAR Standard Imaging Pipeline and CASA software (NRAO). Here we show the results for the integration of 40 subbands (120–130 MHz), removing *uv*-distances shorter than 100λ. The primary beam is $\sim$ 6 degrees.



At this stage we obtain a non-detection of LS I +61 303 with a *rms* $\approx$ 60 mJy beam^{-1} and a resolution of $\approx$ 2.5 arcmin. The contours start at 3σ *rms* level. Extrapolating the results of Strickman et al. (1994), we expect a flux of $\approx$ 44 mJy at 125 MHz for LS I +61 303. This is lower than the *rms* of our preliminary image. However, in the final image we expect to have a *rms* of $\sim$ 10 mJy beam^{-1}, so LS I +61 303 should be detectable above 3σ confidence level.

Although a better performance is required to detect this kind of sources, LOFAR will experience significant improvements during this and the following years, with the addition of international stations. At the end of the commisioning stage, LOFAR will have a much better sensitivity and the best angular resolution for low-frequency observations. This will allow us to determine if an extended emission from gamma-ray binaries is plausible, and if the variability along the orbit (as in LS I +61 303) seen at higher frequencies is still present or not.