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SN 2007gr: a Normal Type Ic Supernova with a Mildly Relativistic Radio Jet?

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A nearby type Ic supernova, SN 2007gr was observed with the EVN in two epochs 60 days apart (second observation also included the Green Bank Telescope). In both cases one of the EVN stations was the Westerbork Synthesis Radio Telescope (WSRT), which recorded the observational data not only in the VLBI mode, but also in its normal interferometric mode. Thus it provided an important reference observation. In the first epoch the fluxes measured by the VLBI network and the WSRT alone match well. However in the second epoch the peak brightness observed in the VLBI experiment is much lower than the total flux recorded by the WSRT. There could be multiple reasons for this discrepancy: a resolution effect, coherence losses in VLBI, or extended emission contaminating the WSRT measurement. With new WSRT observations we costrain the level of background emission and find that there is still a difference between the corrected total flux density and the VLBI peak brightness. If one assumes that this is dominated by resolution, this would correspond to an average apparent expansion speed of $\sim 0.4c$.

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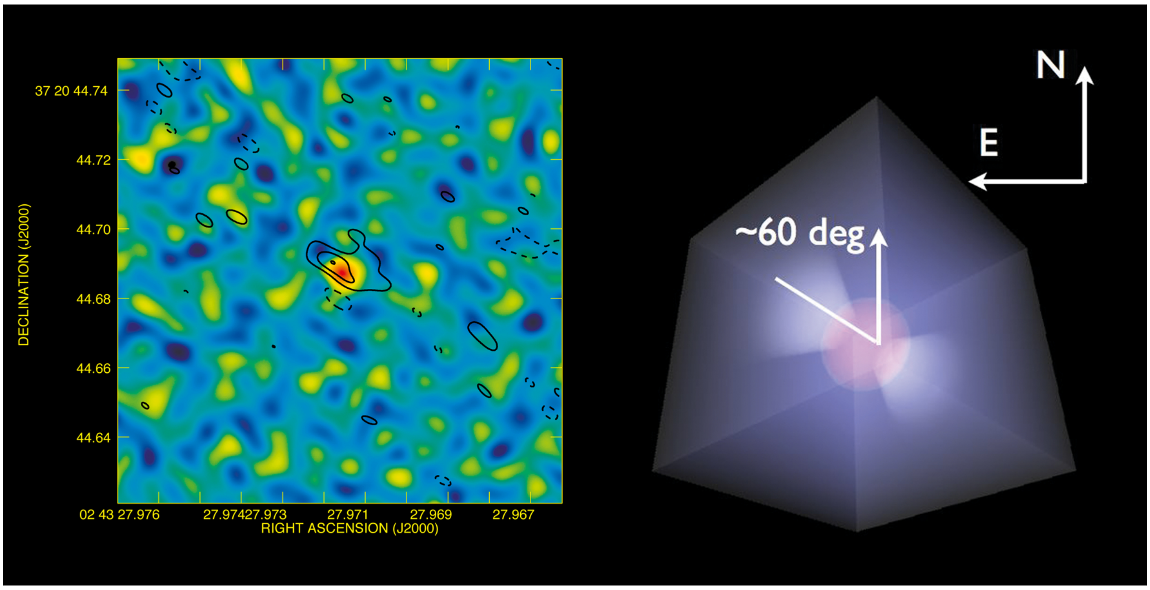

Figure 1: Left: **EVN and EVN+GBT observations of SN 2007gr.** The colors, ranging from −150 to 441 μJy/beam, show the map of SN 2007gr observed on 6-7 September 2007 at 5 GHz with the "e-EVN". The off-source noise in the map is 75 μJy/beam, and the peak is 422 μJy/beam (5.6σ). The black contours show the naturally weighted and tapered EVN+GBT image of SN 2007gr on 5-6 November 2007. At this epoch the off-source noise is 13 μJy/beam, and the peak is 60 μJy/beam (4.7σ). Right: **Geometry of the SN explosion** from 3D radiative transfer simulations.

1. Observations and Results

SN 2007gr was discovered on 15 August 2007 in the bright spiral galaxy NGC 1058 at a distance of 10.6 Mpc. It was one of the closest type Ic supernova detected in the radio band. We carried out electronic VLBI observations with the European VLBI Network (EVN) on 6-7 September 2007 at 5 GHz. The participating telescopes were Darnhall (from MERLIN, UK), Jodrell Bank (MkII, UK), Medicina (Italy), Onsala (Sweden), Torun (Poland) and the phased-array Westerbork Synthesis Radio Telescope (WSRT, Netherlands). The data were streamed real-time to the EVN Data Processor at JIVE at 256 Mbps data rate. We detected an unresolved source with a peak brightness of 422 μJy/beam at 5.6 times the off-source noise level of 75 μJy/beam, fully consistent with the simultaneous WSRT total flux density measurements. The upper limit of 7 milliarcseconds (mas) for its angular diameter size corresponds to a linear size of $\lesssim 1.1 \times 10^{18}$ cm at 10.6 Mpc about 25 days after the explosion, which sets an upper limit of $\lesssim 8.6c$ to the average isotropic apparent expansion speed of the ejecta [1].

To further investigate the evolution of the ejecta on mas scales, we observed again on 5-6 November 2007 (age of about 85 days) with the EVN (including the same stations plus Effelsberg (Germany), Hartebeesthoek (South Africa) and Noto (Italy)) and the Green Bank Telescope (US). We followed exactly the same observing strategy as before, but the data in this case were recorded on disc at a data rate of 1024 Mbps (512 Mbps at the GBT) – these were not only the highest resolution but also the most sensitive radio observations of the source. The measured peak brightness of 60 ± 13 μJy/beam this time was significantly below the total flux density of 260 μJy measured by the WSRT alone [1].

The secondary calibrators and simulations convinced us that this difference was not due to major calibration errors or "decorrelation" in the VLBI data. However, the WSRT measurements might have been contaminated by diffuse emission from the host galaxy. To properly remove the background emission, we performed new WSRT observations of NGC 1058 on 10 June 2010. After subtracting the resulting map from the second epoch SRT image we obtained 150 ± 50 μJy, in agreement with two independent VLA measurements within two weeks of the VLBI observations (see also [2]). This sets an average constraint of 140 ± 18 μJy to the total flux density.

2. Discussion

A point source model fitted to the VLBI *uv*-data is inconsistent with the measured total flux density. Note also that at a distance of 10.6 Mpc the source is in fact expected to be partially resolved at an age of 85 days on mas scales. A ~ 150 μJy Gaussian (or other type of extended model) with size of 1.0 mas gives a reasonable fit to the data. This would correspond to an average expansion speed of $\sim 0.4c$, somewhat lower than derived from the beamsize as lower limit in [1]. We note that a ~ 100 μJy source would be marginally consistent with the measured total flux density, therefore our derived average expansion velocity value should be treated with caution.

The possibility that SN 2007gr expanded spherically at mildly relativistic velocities is intriguing because it would require a severe departure from equipartition (relativistic electrons and/or magnetic fields carrying very small fractions of the internal energy). This may be resolved if the mildly relativistic ejecta were collimated into a narrow bipolar jet [1]. There was also a hint of non-spherical explosion from optical spectropolarimetry data [3]. Polarization of $\sim 3\%$ was detected at the absorption feature of the Ca II triplet, which can be understood in the context of a model in which bipolar explosion with an oblate photosphere is being viewed from a slightly off-axis direction (although spherical photosphere and clumpy Ca II distribution may be an alternative explanation). In the former case, 3D radiative transfer simulations show that the major axis of the SN photosphere had a projected position angle on the sky of about 60 degrees.

To constrain the speed of the ejecta better in type Ic SNe and detect more sources, we require orders of magnitude better signal-to-noise ratios. A large-configuration phase-II SKA with baselines up to about 3000 km will be suitable for this goal at frequencies between 5-10 GHz, although the resolution will be still too small in most of the cases to investigate the geometry of these supernovae. The quality of calibration will be much improved by simultaneous observations of nearby mJy-level sources, strong enough to serve as calibrators for the SKA. Additionally, the SKA with its wide field of view capability may potentially detect (and even discover, independently of optical observations) a large number of SNe and as a real-time and high resolution instrument will be an excellent instrument to monitor these sources, along with other types of extragalactic transients.

References

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