Jets at all Scales
Proceedings IAU Symposium No. 275, 2011
G. E. Romero, R. A. Sunyaev & T. Belloni, eds.

doi:10.1017/S1743921310016297

Is there a mildly relativistic jet in SN2007gr?

Z. Paragi[1], A. J. van der Horst[2], M. Tanaka[3], G. B. Taylor[4], C. Kouveliotou[5], J. Granot[6], E. Ramirez-Ruiz[7], Y. Pidopryhora[1], S. Bourke[1], R. M. Campbell[1], M. A. Garrett[8] and H. J. van Langevelde[1]

[1]Joint Institute for VLBI in Europe (JIVE), Dwingeloo, the Netherlands
[2] NASA Postdoctoral Program Fellow, NASA/MSFC/ORAU, Huntsville, AL, USA
[3] Institute for the Physics and Mathemathics of the Universe, Univ. Tokyo, Kashiwa, Japan
[4] University of New Mexico, Albuquerque, USA
[5] NASA/MSFC, Huntsville, AL, USA
[6] University of Hertfordshire, UK
[7] University of California, Santa Cruz, USA
[8] Netherlands Institute for Radio Astronomy (Astron), Dwingeloo, the Netherlands

Abstract. SN2007gr was an ordinary type Ic supernova, with a hint of asymmetric explosion seen in the optical polarization spectrum. This type of SNe is occasionally associated with long duration gamma-ray bursts which generate ultra-relativistic jets; no relativistic outflows have yet been found by direct imaging in SNe Ib/c explosions. High resolution very long baseline interferometry (VLBI) data and simultaneous total radio flux density measurements indicated that SN2007gr has expanded mildly relativistically. We performed late time Westerbork Synthesis Radio Telescope (WSRT) observations to measure the level of the underlying extended emission. Comparison of the VLBI and the background-subtracted WSRT and independent VLA data indicate an at least partially resolved source with an average expansion velocity of $\geqslant$0.4c, although the VLBI data could be consistent with a fainter source with an expansion velocity of $\sim$0.2c as well.

Keywords. supernovae: general, supernovae: individual (SN 2007gr), ISM: jets and outflows, radio continuum: general, techniques: interferometric

---

SN 2007gr was discovered on 15 August 2007 in the bright spiral galaxy NGC 1058 at a distance of 10.6 ± 1.3 Mpc. It was one of the closest type Ic supernova detected in the radio band. We carried out real-time e-VLBI observations with the European VLBI Network (EVN) on 6-7 September 2007 at 5 GHz, and found 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 $<1.1\times10^{18}$ cm at 10.6 Mpc about 25 days after the explosion, which sets an upper limit of $<$8.6c to the average isotropic apparent expansion speed of the ejecta (Paragi *et al.* 2010).

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 and the Green Bank Telescope (GBT). 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

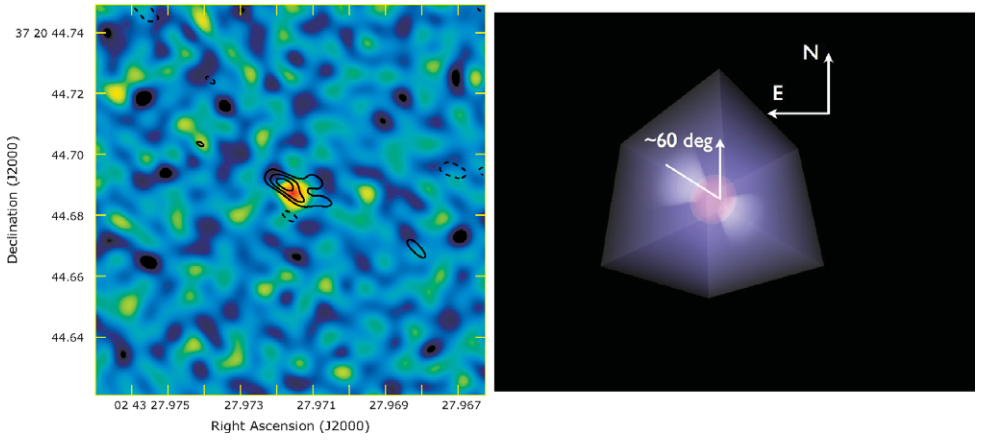

Figure 1. Left: VLBI images of SN 2007gr on 6 September (colours) and 5 November 2007 (contours). Right: Geometry of the SN explosion from 3D radiative transfer simulations. See the text for more details.

below the total flux density of 260 μJy measured by the WSRT (Paragi *et al.* 2010). To properly remove the background emission from the galaxy, we performed new WSRT observations of NGC 1058 on 10 June 2010. After subtracting the resulting map from the second epoch WSRT image we obtained 150±50 μJy, in agreement with two independent VLA measurements within two weeks of the VLBI observations (see also Soderberg *et al.* 2010). This sets an average constraint of 140±18 μJy to the total flux density.

A point source model fitted to the VLBI *uv*-data is inconsistent with the measured total flux density, and also note 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 $\geqslant$ 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 Paragi *et al.* 2010. 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 (Paragi *et al.* 2010). There was also a hint of non-spherical explosion from optical spectropolarimetry data (Tanaka *et al.* 2008). Polarization of ∼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.

References

Paragi, Z., Taylor, G. B., Kouveliotou, C. *et al.* 2010, *Nature*, 463, 516
Soderberg, A. M., Brunthaler, A., Nakar, E. *et al.* 2010, *arXiv*, 1005.1932
Tanaka, M., Kawabata, K. S., Maeda, K., Hattori, T., Nomoto, K. 2008, *ApJ*, 689, 1191

https://doi.org/10.1017/S1743921310016297 Published online by Cambridge University Press