Supernova Environmental Impacts
Proceedings IAU Symposium No. 296, 2013
A. Ray & R. A. McCray, eds.

doi:10.1017/S174392131300999X

Radio studies of relativistic SN 2009bb

Alak Ray[1], Naveen Yadav[1], Sayan Chakraborti[2], Alicia Soderberg[2] and Poonam Chandra[3]

[1]Tata Institute of Fundamental Research, Mumbai 400005, India
email: akr@tifr.res.in, nyadav@tifr.res.in

[2]Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA

[3]National Centre for Radio Astrophysics, TIFR, Pune 411007, India

Abstract. A local sub-population of type Ib/c supernovae (stripped envelope SNe) with mildly relativistic outflows have been detected as sub-energetic Gamma Ray Bursts (GRBs) or X-ray Flashes (XRFs) and as radio afterglows without detected GRB counterpart. SN 2009bb belongs to the last class of objects. The long term radio observations with (J)VLA and GMRT of this SN map the dynamics of the relativistic ejecta characteristic of Central Engines associated with GRBs. We present here GMRT observations of this SN from October 2009 onwards.

Keywords. shock waves, supernovae, radio continuum: general, circumstellar matter

Relativistic bulk motion of matter is implied (Piran 1999, Piran 2004) in long duration gamma ray bursts (GRBs) that are linked to core-collapse explosion of a stripped envelope massive star (Paczynski 1986, Woosley 1993). In the collapsar model (MacFadyen & Woosley 1999), matter flows towards a newly formed black hole or rapidly spinning, highly magnetized neutron star, constituting the central engine from which powerful jets are launched along the spin axis which plow through the collapsing star eventually attaining relativistic speeds and producing the GRB. The association of energetic core collapse SN 1998bw with the underluminous low redshift ($z = 0.0085$) GRB 980425, as well as spectroscopic identification of SN features well after the GRB event, established the SN-GRB connection (Hjorth & Bloom 2012 and references therein). These SNe belong to a rare subclass of type Ibc SNe called the broad-line Ic's. The central engine driven objects have been discovered mainly through their concomitant gamma-ray emission, but the discovery of luminous radio emission from the type Ibc SN 2009bb that was undetected in gamma-rays despite extensive search led to the measurement of a substantial relativistic outflow that must be powered by the central engine (Soderberg *et al.* 2010). The outflow speed was measured by combining observations of SN 2009bb from the VLA and the GMRT at multiple epochs. These are well fitted by Synchrotron Self Absorption (SSA) models which can lead to radiosphere locations interpreted from a combination of spectral peak frequencies and fluxes.

We report GMRT observations of SN 2009bb from October 2009. The GMRT and earlier VLA data are plotted in Fig 1.

The radius evolution with time measured from the SSA spectrum showed the SN had mildly relativistic ejecta (Soderberg *et al.* 2010, Chakraborti & Ray 2011). The magnetic field amplified by the shock and how it evolves with time and the role of such central engine driven explosions as accelerators of Ultra High Energy Cosmic Ray accelerators are described in Chakraborti *et al.* 2011.

Table 1. GMRT observations of SN 2009bb

Observation Dates	Days after explosion	Frequency (MHz)	Flux density (mJy)
22Oct−01Nov 2009	218−223	325	12.0±0.26
		610	6.3±0.70
		1280	4.4±0.30
09Feb−18Feb 2010	328−337	325	7.2±0.29
		610	3.6±0.05
		1280	1.2±0.07
17Apr−25Apr 2010	395−403	325	7.4±0.34
		610	3.6±0.09
		1280	1.9±0.05
26Dec−31Dec 2010	648−653	325	6.1±0.12
		610	1.9±0.05
		1280	0.9±0.05
26Apr−05May 2011	769−778	325	4.6±0.19
		610	1.4±0.08
		1280	0.7±0.05
04Jan−13Jan 2012	1022−1031	325	5.9±0.18
		610	1.4±0.06
		1280	0.7±0.03
17Jul−20Jul 2012	1217−1220	325	4.4±0.15
		610	2.0±0.04

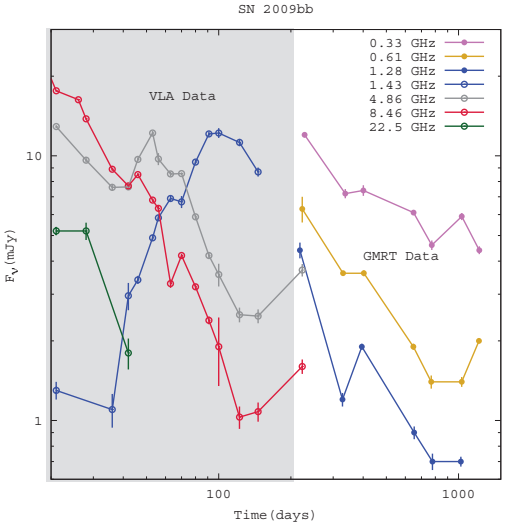

Figure 1. Radio light curves of SN 2009bb at indicated frequencies

References

Chakraborti, S. & Ray, A. 2011, *ApJ*, 729, 57
Chakraborti, S., Ray, A., Soderberg, A. M., & Loeb, A. 2011, *Nature Communications*, 2, 175
Hjorth, J. & Bloom, J. S. 2012, *in "Gamma-Ray Bursts", Cambridge Astrophysics Series 51, eds. C. Kouveliotou, et al., Cambridge University Press (Cambridge)*, p. 169
MacFadyen, A. I. & Woosley, S. E. 1999, *Ap J*, 424, 262
Paczynski, B. 1986, *Ap J*, 308, L43
Piran, T. 1999, *Phys. Reports*, 314, 575
Piran, T. 2004, *Rev. Mod. Phys*, 76, 1143
Soderberg, A. M., Chakraborti, S., *et al.* 2010, *Nature*, 463, 513
Woosley, S. E. 1993, *ApJ*, 405, 273

https://doi.org/10.1017/S174392131300999X Published online by Cambridge University Press