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Inhomogeneities in the radio emitting shock in supernova MASTER OT J120451.50+265946.6

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Abstract

Radio observations of a stripped-envelope Type Ib supernova Master OT J120451.50+265946.6 (SN J1204) with the Giant Metrewave Radio Telescope (GMRT) as well as the Very Large Array (VLA) reveal inhomogeneities in the structure of the radio emitting region. We suggest that the inhomogeneities of the magnetic field distribution in the shock give rise to optical depths of different opacities, and superposition of these optical depths lead to a flatter spectral index in the optically thick region, as seen in SN J1204. We predict that the inhomogeneities should smooth out at late times. We also find that the shock is passing through radio emitting shell at early epochs.

1 Introduction

The progenitor systems of supernovae (SNe) are poorly constrained from direct detection efforts from pre-explosion images (Smartt, 2009). However, independent constraints on the properties of SNe progenitors can be obtained by studying the interaction of SNe ejecta with their circumstellar medium (CSM), formed due to mass lost from the progenitor systems during their evolutionary phases. Radio emission, emitted via the synchrotron mechanism, is one of the best signatures to study the interaction and probes the properties of the CSM (Chevalier, 1982).

Supernova Master OT J120451.50+265946.6 (hereafter SN J1204) was discovered on 2014 October 28.87 (UT) by Gress et al. (2014) with an optical magnitude $m_v = 13.9$ in a galaxy NGC 4080 at a distance $d \sim 15$ Mpc. SN J1204 was classified as a type Ib SN (Srivastav et al., 2014). Here we present the results of an extensive radio follow up of SN J1204 with the GMRT, combined with the publicly available data with the VLA.

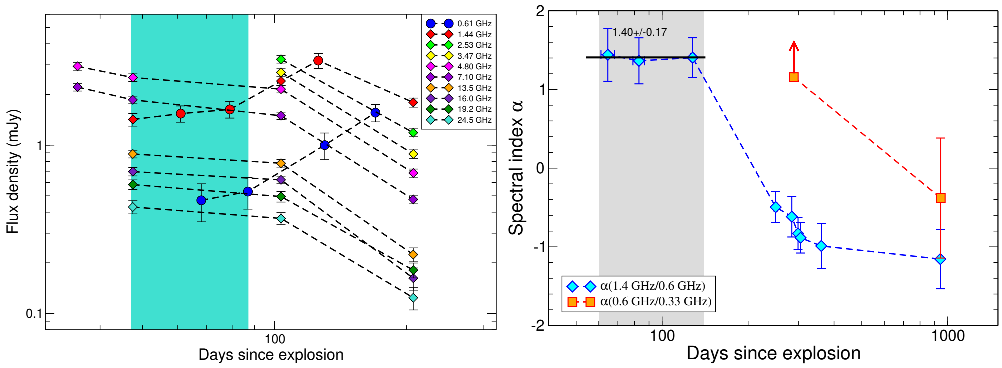

Figure 1: Light curves of SN J1204 at GMRT and VLA frequencies (left panel). All GMRT data points are represented using circle symbols and all VLA data points are represented using diamond symbols. In the right panel, we plot the spectral index evolution between 1390 and 610 MHz (blue diamonds) and between 610 and 325 MHz bands (orange squares).

2 Observations and results

The GMRT observations cover a period for about 3 years in the frequency bands of 1390, 610 and 325 MHz. We also use publicly available archival VLA data for SN J1204 at five epochs from 2014 October 31 to 2015 July 31 spanning a frequency range of 1–24 GHz. In Fig. 1, we plot all the radio data from 0.33 GHz to 24.5 GHz frequency bands covering the epochs $\sim$35 days till $\sim$1158 days. The data are optically thin at frequencies higher than 2.53 GHz onwards,. We also investigate spectral indices in the optically thick phase, which are mainly at the GMRT frequencies. We notice that during the first three epochs, the spectral indices are $\alpha(1390/610) \sim 1.4$, much flatter than the spectral index 2.5 expected in the SSA model or steeper value in the FFA model (Fig. 1).

Neither the free-free absorption (FFA) nor the synchrotron self-absorption (SSA) models provide a good fit to the radio data of SN J 1204. The low frequency light curves show flattening at the early epochs in the optically thick phase. Björnsson (2013) and Björnsson & Keshavarzi (2017) have explained the flatter optically thick evolution of the radio spectra in terms of inhomogeneities in the radio emitting region caused by the variations in the distribution of magnetic fields and relativistic electrons. We developed an analytical inhomogeneous model based on their work and find that the radio data are best represented by an inhomogeneous model (Fig. 2) and (Chandra et al., 2019)).

The radio data indicate presence of a dense circumstellar shell at early epochs, suggesting peculiar mass-loss event a few decades before the explosion (Chandra et al., 2019).

3 Conclusions

Radio observations of SN J1204 up to around 1200 days reveal inhomogeneities in the radio emitting region, which is responsible for the flattening of the optically thick spectral index to

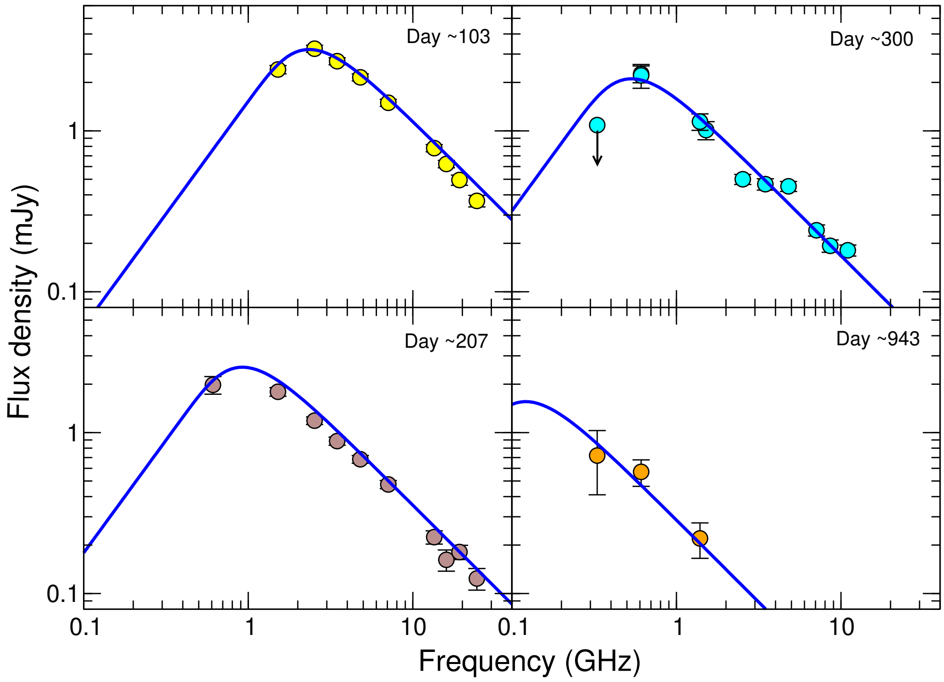

Figure 2: The best fit inhomogeneous SSA model is able to reproduce the data well.

~ 1.4. We propose that the inhomogeneities will smoothen out with time. The earlier radio data also suggest a peculiar mass-loss event a few decades before explosion.

Acknowledgments

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