Revealing inhomogeneities in supernovae shocks and their environments via low frequency radio observations

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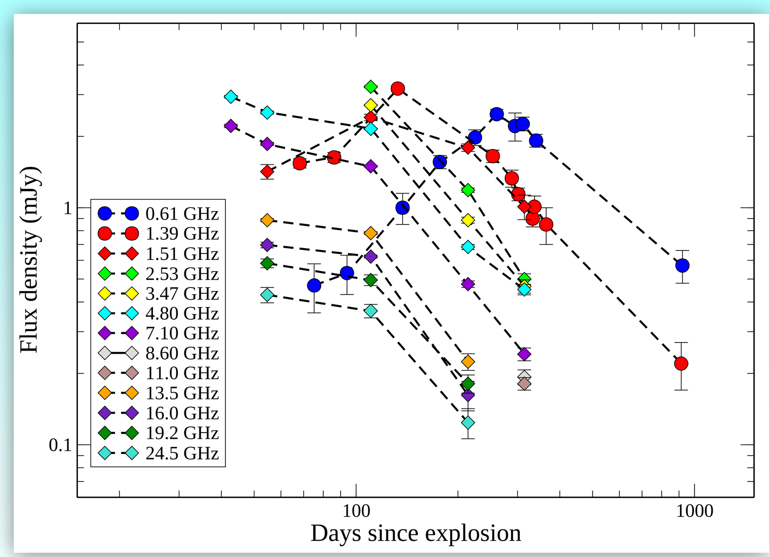
EXTREME PHENOMENA IN THE COSMOS - Of Deaths, Shocks & Aftermaths

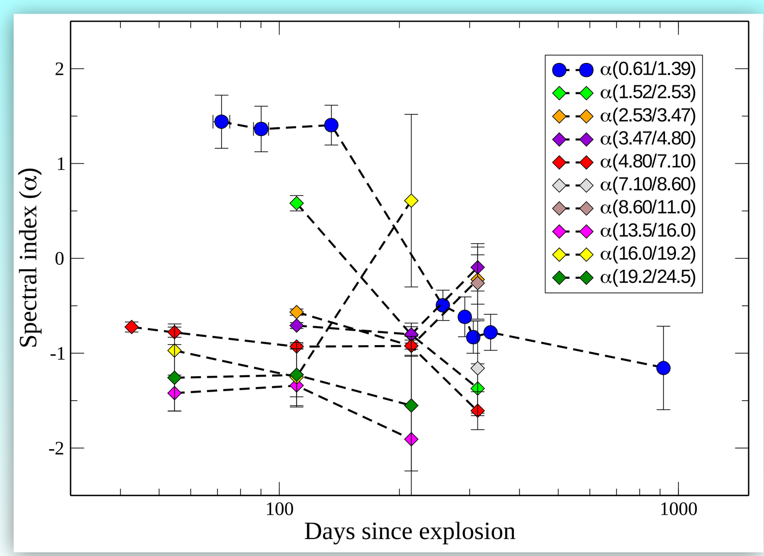
Abstract

Low frequency radio observations are crucial in revealing the inhomogeneities in the radio emitting supernovae shocks, as well as in the medium surrounding them. In this talk, we present radio observations of a stripped-envelope Type Ib supernova Master OT J120451.50+265946.6 (SN J1204) taken with the Giant Metrewave Radio Telescope (GMRT) as well as the Very Large Array (VLA). Our low frequency GMRT data taken when the SN was in the optically thick phase, interpreted along with the VLA data and non-detection in X-ray bands, reveal inhomogeneities in the structure of the radio emitting region. We suggest a model in which the inhomogeneities of the magnetic field distribution give rise to optical depths of different opacities, and superposition of those lead to a flatter spectral index in the optically thick region, seen in SN J1204. Our model predicts that the inhomogeneities should smooth out at late times, which will be tested via ongoing 325 MHz GMRT observations. In addition, our observations also indicate that the shock is crossing through a dense shell starting around 50 days after the explosion, for around a month in duration. This reveals a non-smooth mass-loss history of the progenitor star. I will discuss the implication of our findings and discuss this in context of other radio bright stripped-enveloped SNe.

Supernova Master OT J120451.50+265946.6 (SN J1204)

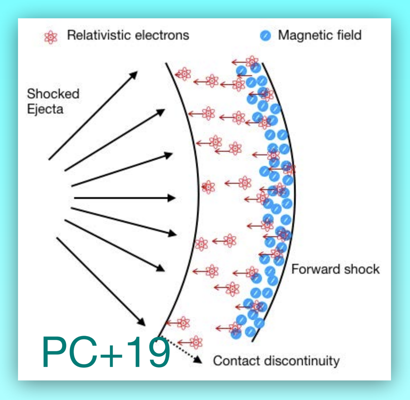
- Type Ib supernova/ GMRT and VLA observations covering epochs 40-1200 days, 0.33 GHz - 25 GHz frequency bands.
- Several X-ray observations with the *Swift-XRT* and one observation with *ChandraXO*, no detection (PC+2019).

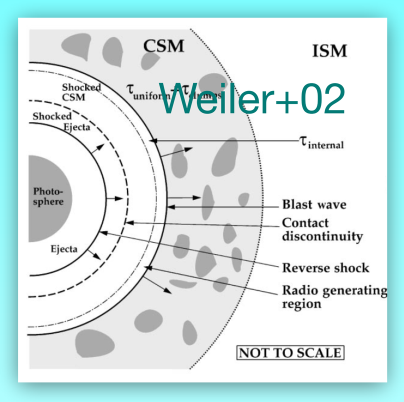


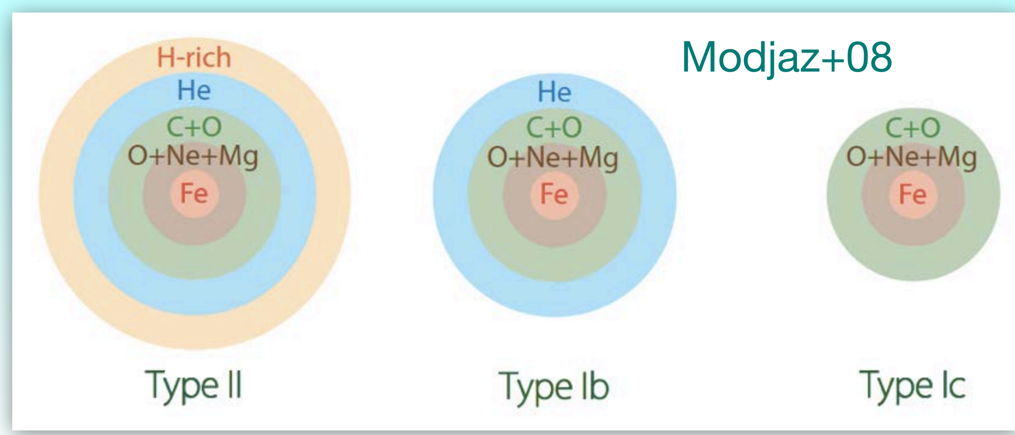


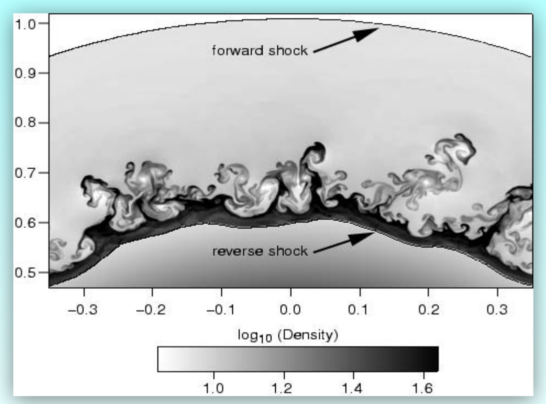
Realistic models of radio emission in Supernovae

- Inhomogeneous mass-loss rate
- Non-smooth wind structure
- Instability in the magnetic field amplification zone
- Inhomogeneous forward sock







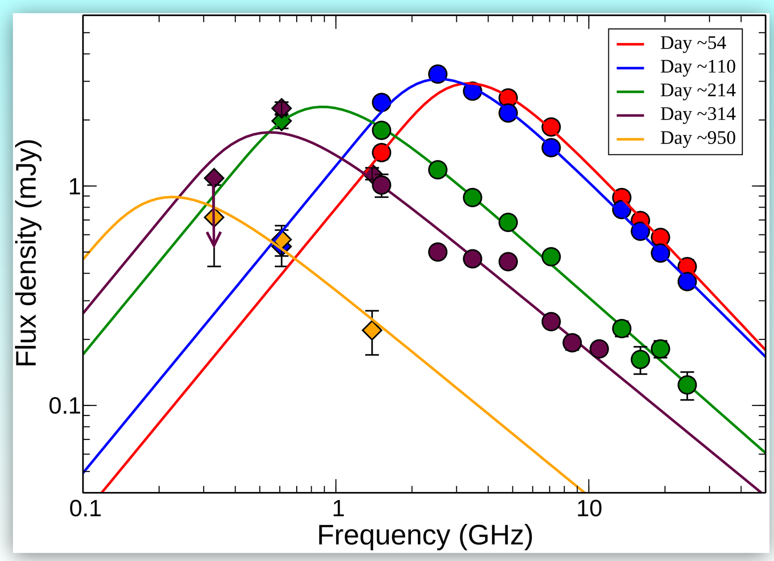


Chevalier, Blondin 1995

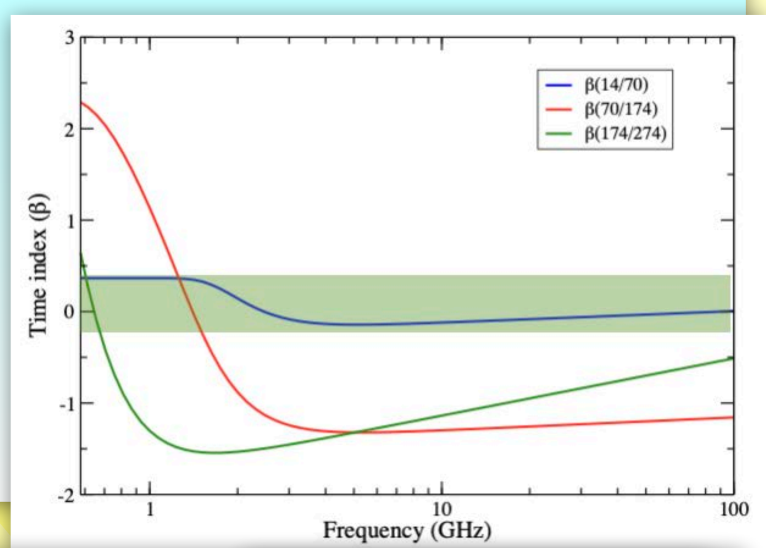
Shock crossing the Shell in SN J1204

- No significant evolution between 47 and 103 days.
- Time evolution nearly stalled.
- Possible if shock is passing through a dense shell.
- We estimate shock crossing shell *47< t < 87.*

Individual spectra at various epochs

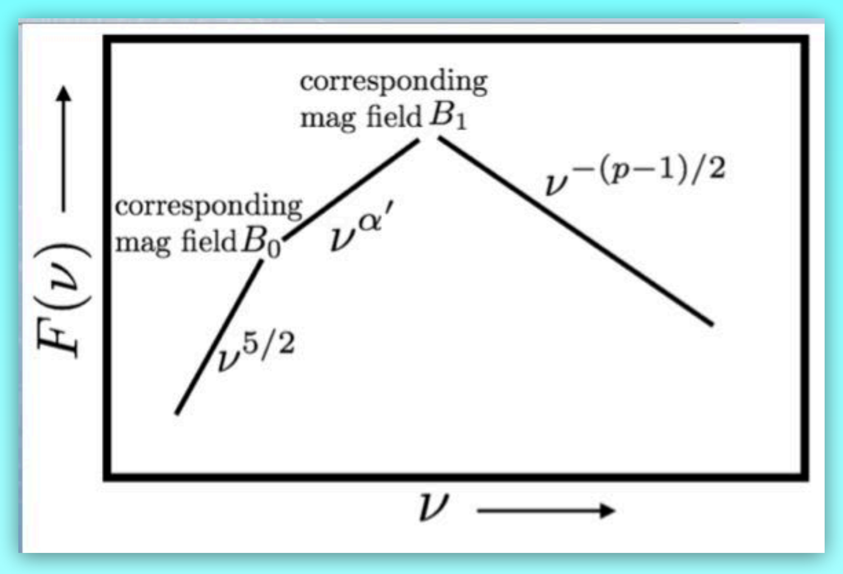


Temporal evolution between epochs



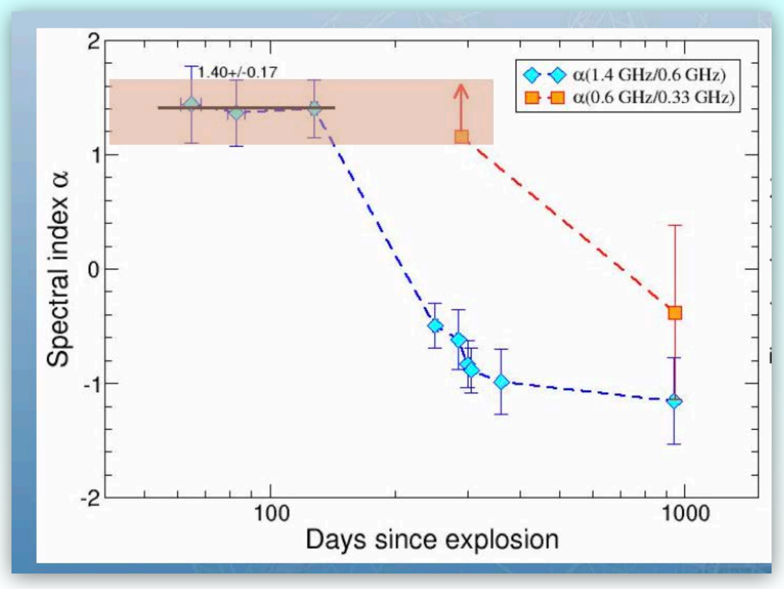
Inhomogeneities in the radio emission in SN J1204.

- Flatter spectral indices (α=1.4 ; α_{SSA}=2.5; α_{FFA}-> exponential)
- Inferred particle energy index p=1.35 (very hard; typical p=2.2-3.0)
- Inferred radio of emitting regions much smaller than

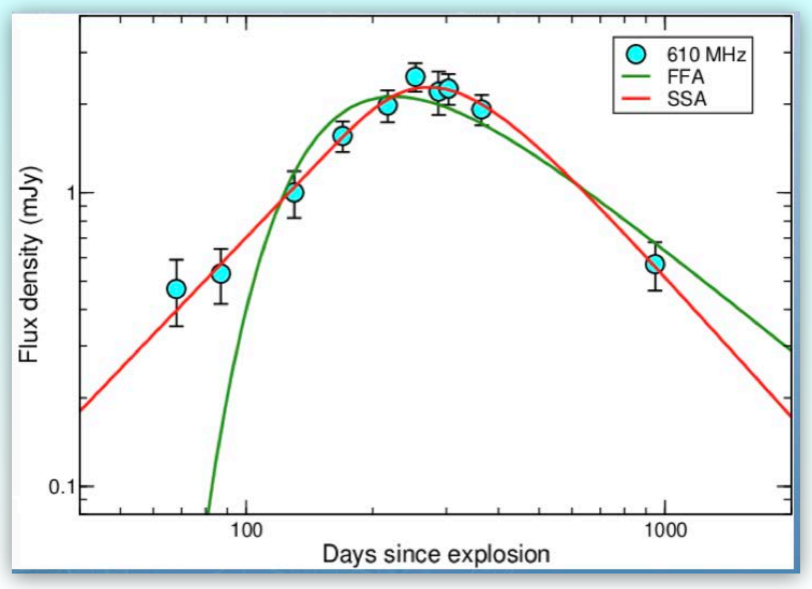


$$F(\nu) \propto \begin{cases} \nu^{\frac{5}{2}}, & \nu < \nu_{\rm abs}(B_0) \\ \nu^{\alpha'} \text{ where } \alpha' = \frac{3p+7+5\delta'-a(p+4)}{p+2(1+\delta')}, & \nu_{\rm abs}(B_0) < \nu < \nu_{\rm abs}(B_1) \\ \nu^{\frac{-(p-1)}{2}}, & \nu > \nu_{\rm abs}(B_1)\,, \end{cases}$$

Flatter α

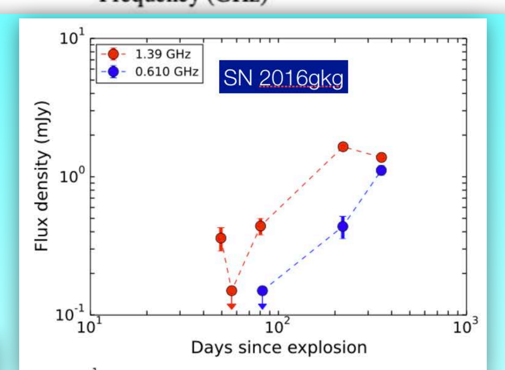


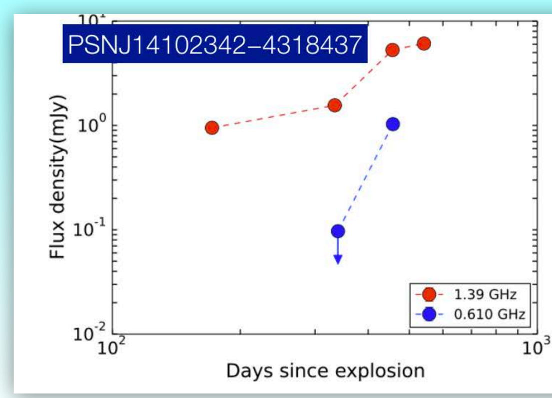
Optically thick light curve at band 4 (550-800

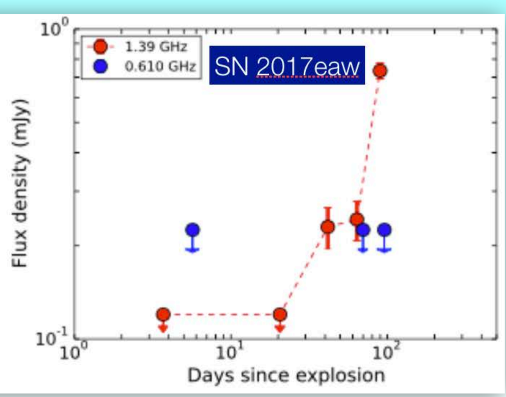


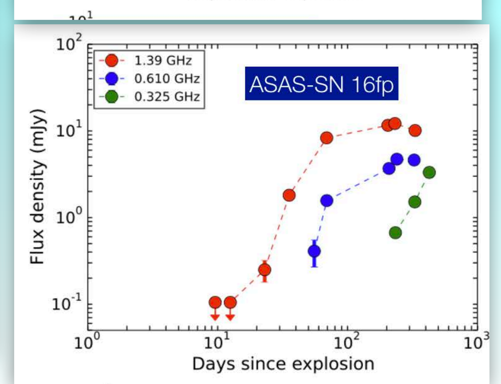
Inhomogeneties at low frequencies

- Upgraded GMRT - many more supernovae with inhomogeneous





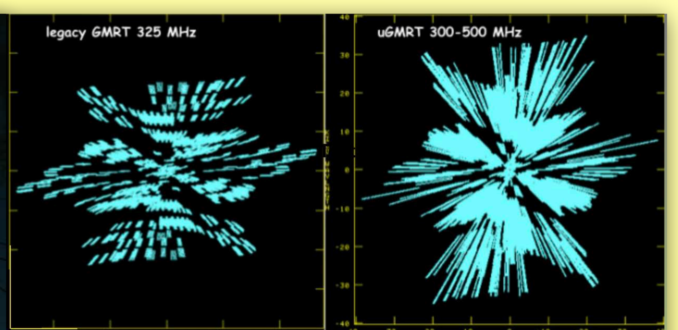


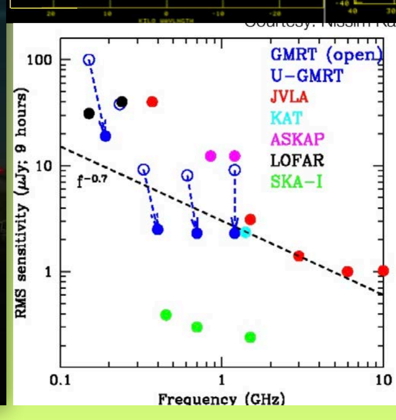


Optically thick LCs of supernovae

Conclusions and future directions

- Upgraded GMRT has continuous coverage and three times higher sensitivity.
- Traces the supernovae in optically thick phase and unravels density evolution.
- Many more Supernovae are expected to be revealed at low frequencies.
- Reference: Chandra, Nayana, Bjornsson et al. 2019, accepted for publication in ApJ (arXiv: 1904.06392)





Better UV coverage, continuous band, 3X higher resolution.