Supernovae

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Plan of talk

- Introduction - Supernovae.
- Progenitor problem.
- Radio emission from Supernovae.
- Modeling and physical parameters.
- Potential of low-frequency observations.
- Summary and Future directions.

Supernovae

- Marks the death of a star.
- Luminosity ~ a billion suns.
- Interesting Astrophysical events

  Chemical evolution

  Cosmological distance indicator

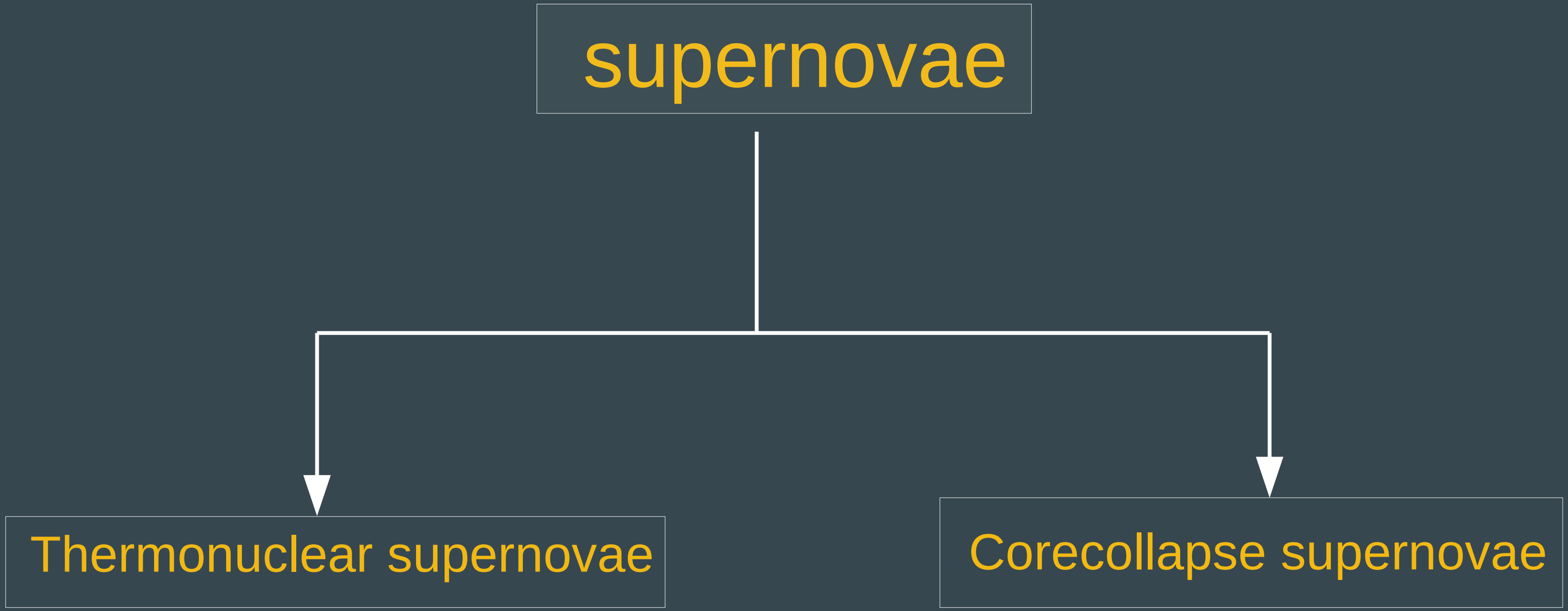
  Particle acceleration

  Shock physics

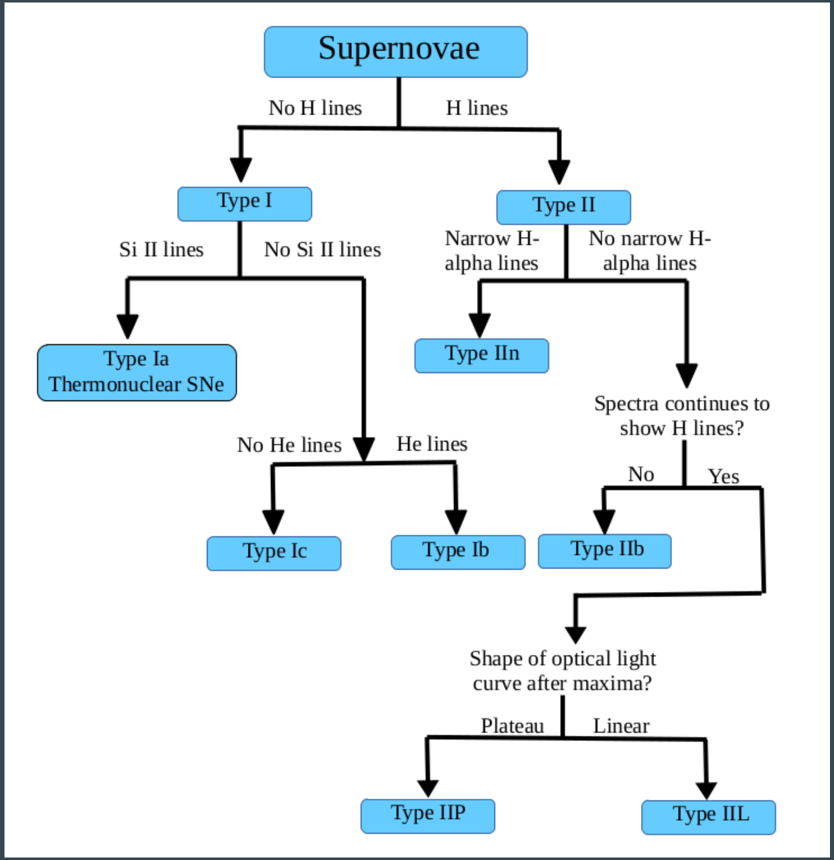
  Star formation

  Galactic evolution

Image credit: “Supernova Explosions” - book by David Branch and J Craing Wheeler


supernovae
Thermonuclear supernovae
Corecollapse supernovae

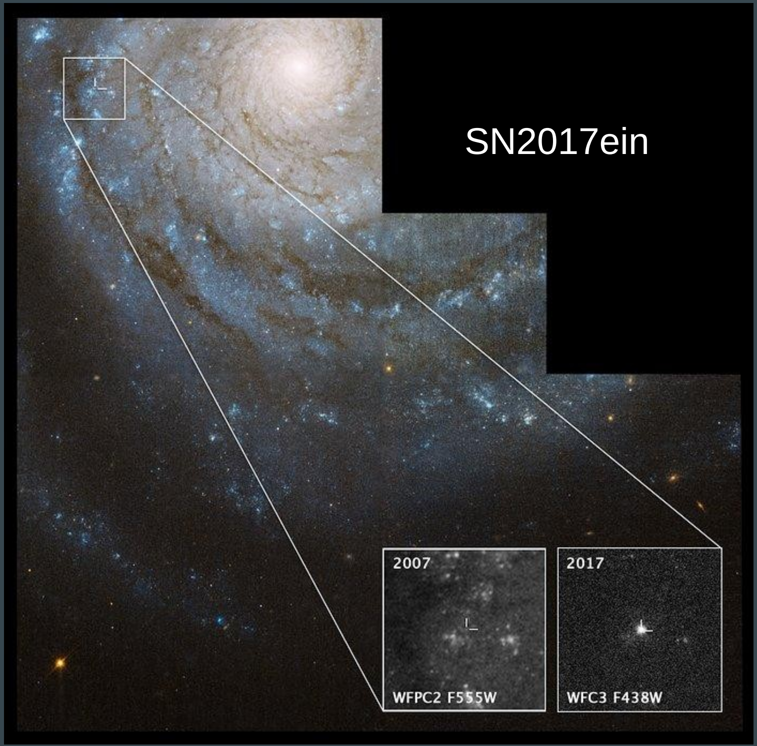
Different types of supernovae



Progenitor problem

- Supernovae exhibit diverse observational signatures.
- What are the progenitors of different types of SNe?
- What are the end stages of massive stars that leads to different types of explosion?

Direct detection efforts

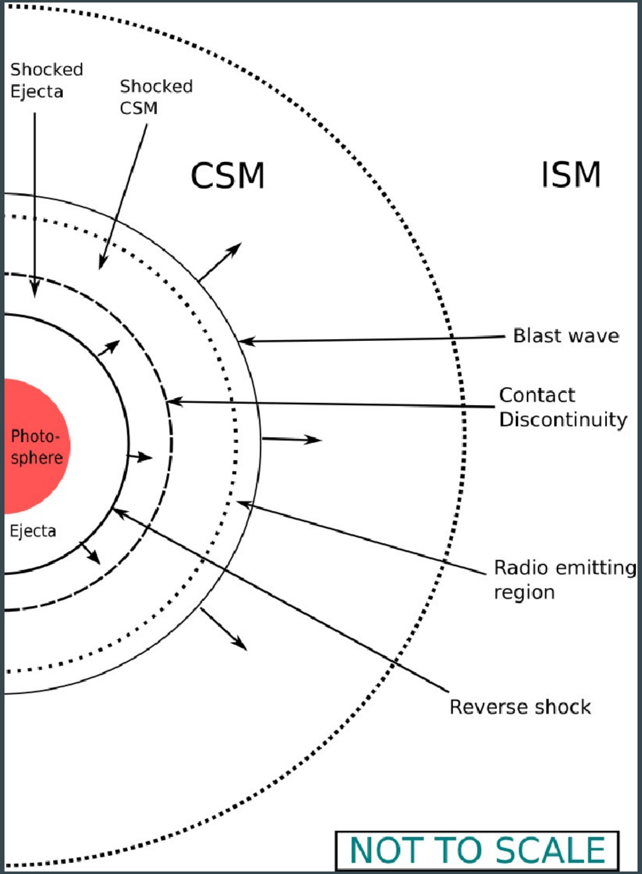


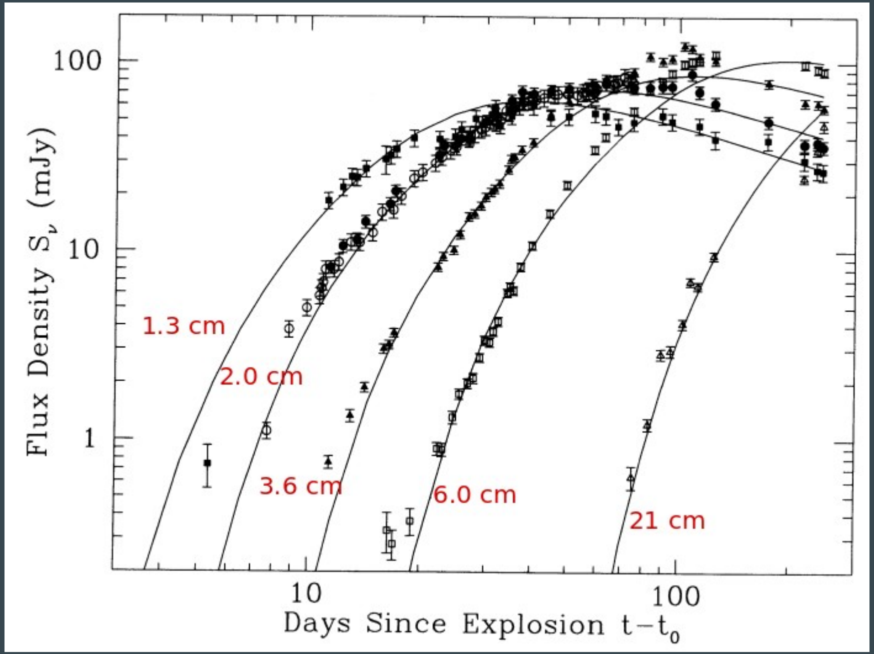
Direct detection of progenitor exists for ~ 30 SNe

(Van Dyk et al. 2017)

Image credit:https://www.spacetelescope.org/images/opo1847b/

Radio emission from supernovae





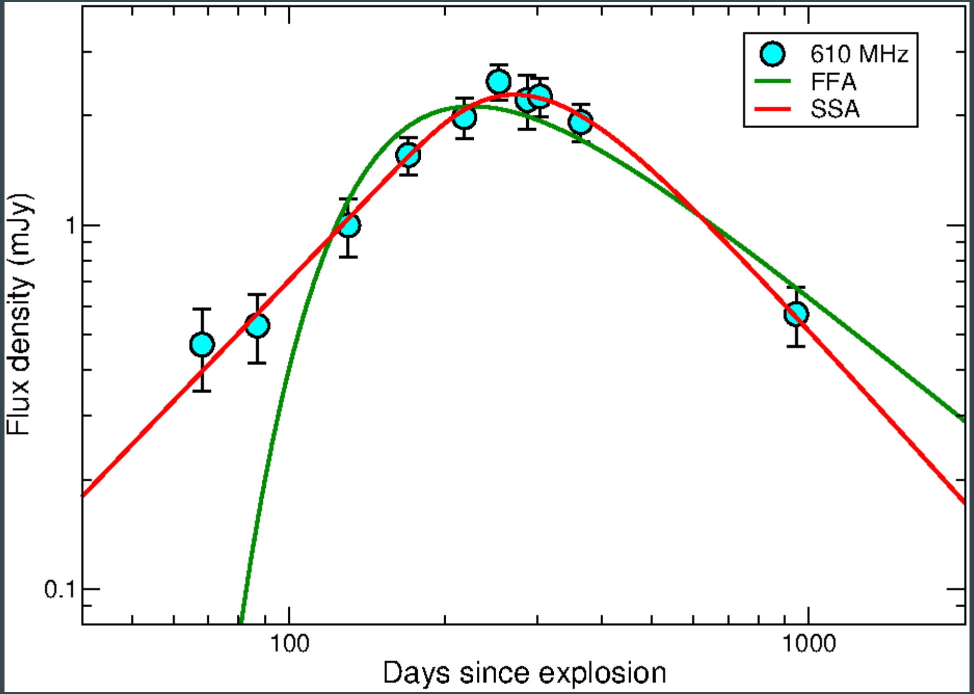
Shock-driven synchrotron emission with associated absorption processes.

(Van Dyk et al. 1994)

Dominant absorption processes

Free-free absorption (FFA) by the ionized medium.

Synchrotron self-absorption (SSA) from the same relativistic electrons.



(Chandra et al. 2019)

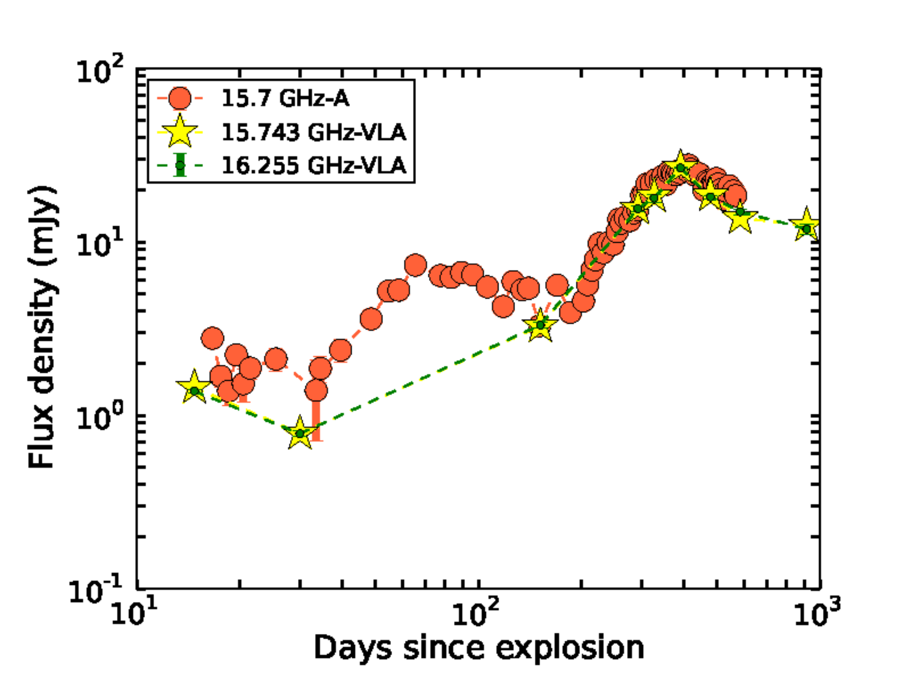
Physical parameters of the system

Pre-explosion mass-loss rate of progenitor system

Density structure of the CSM

$$\tau_{\mathrm{ffa}} = \int_{R_s}^{\infty} \kappa_{\mathrm{ffa}} n_e n_i dr$$

$$n_e = \frac{\dot{M}}{4\pi r^2 w \mu_e m_H}$$



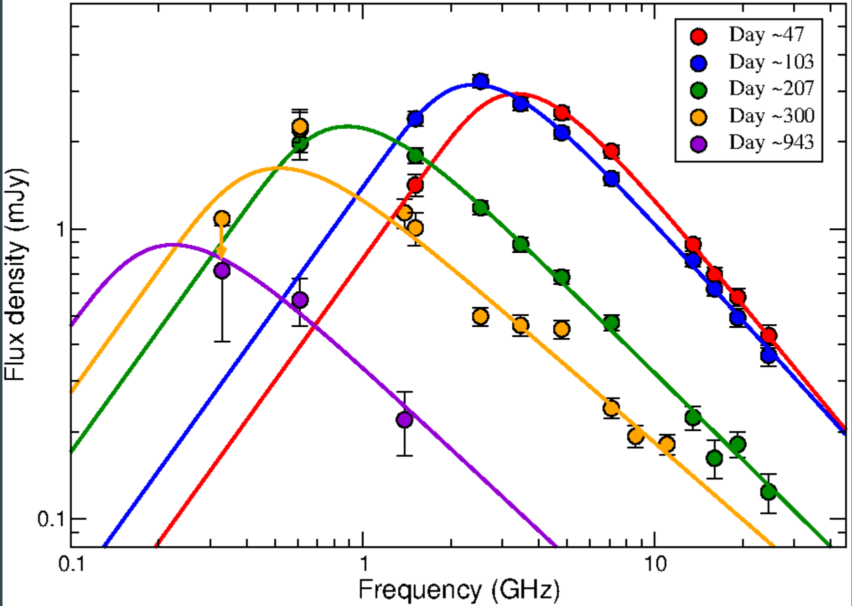
(Anderson et al. 2017)

Physical parameters of the system

Shock radius, velocity and magnetic fields

$$S_\nu \propto \frac{\pi R^2}{D^2} B^{-1/2} \nu^{5/2}$$

$$S_\nu \propto \frac{4\pi f R^3}{3D^2} N_0 B^{(p+1)/2} \nu^{-(p-1)/2}$$



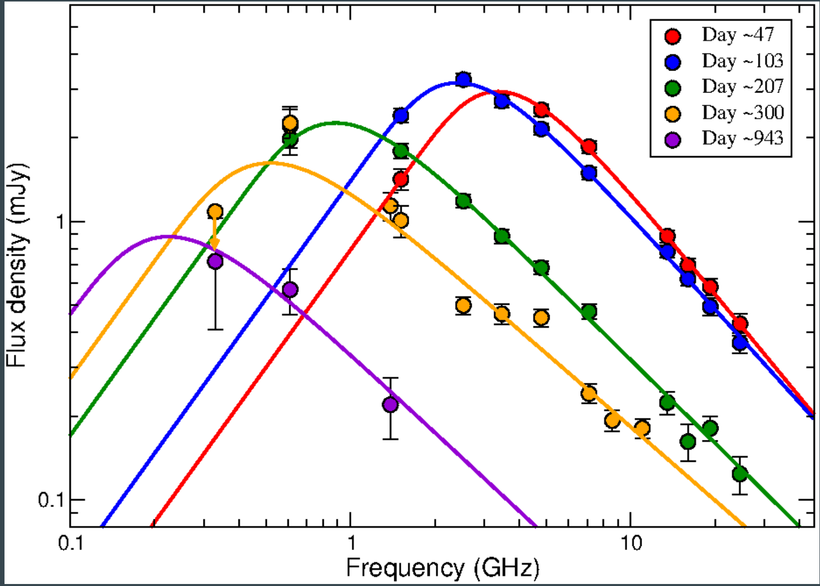
(Chandra et al. 2019)

Physical parameters of the system

Shock radius, velocity and magnetic fields

$$R_p = 8.8 \times 10^{15} f_{eB}^{-1/19} \left(\frac{f}{0.5}\right)^{-1/19} \left(\frac{S_p}{\mathrm{Jy}}\right)^{9/19} \left(\frac{D}{\mathrm{Mpc}}\right)^{18/19} \times \left(\frac{\nu_p}{5\,\mathrm{GHz}}\right)^{-1} \mathrm{cm}$$

$$B_p = 0.58 f_{eB}^{-4/19} \left(\frac{f}{0.5}\right)^{-4/19} \left(\frac{S_p}{\mathrm{Jy}}\right)^{-2/19} \left(\frac{D}{\mathrm{Mpc}}\right)^{-4/19} \times \left(\frac{\nu_p}{5\,\mathrm{GHz}}\right) \mathrm{G.}$$



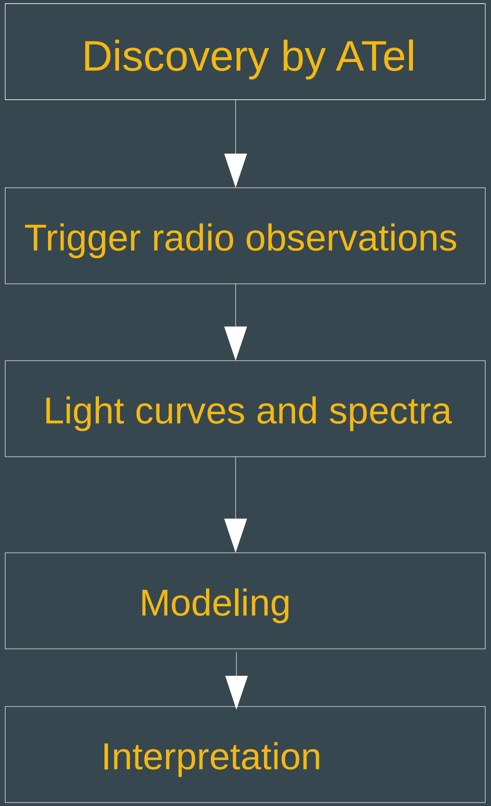
(Chevalier 1998, Chandra et al. 2019)

Radio observations of SNe are interesting

- Give important information about the progenitor system.
- Clues about the density structure of the CSM.
- Estimates of shock radius, velocity, and magnetic field.
- Mass-loss rate of the progenitor system.

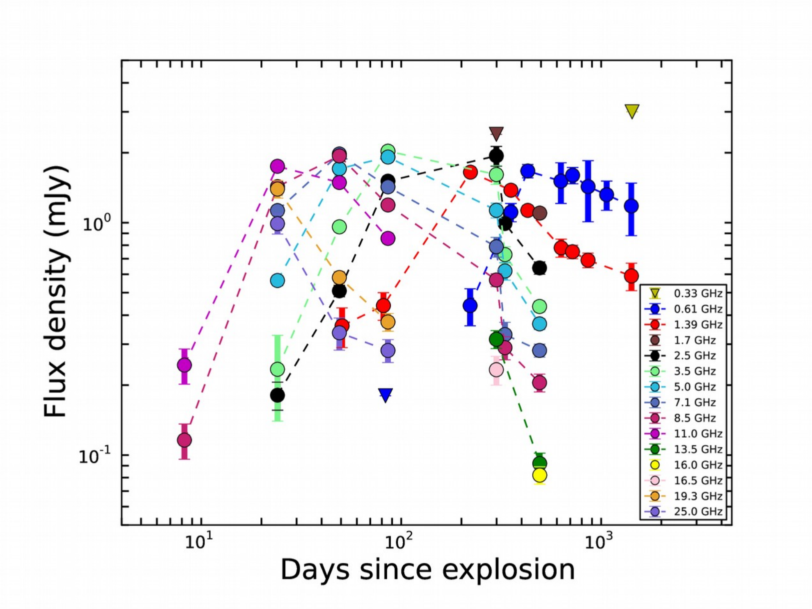
Through the evolution of a supernova in radio bands - role of uGMRT

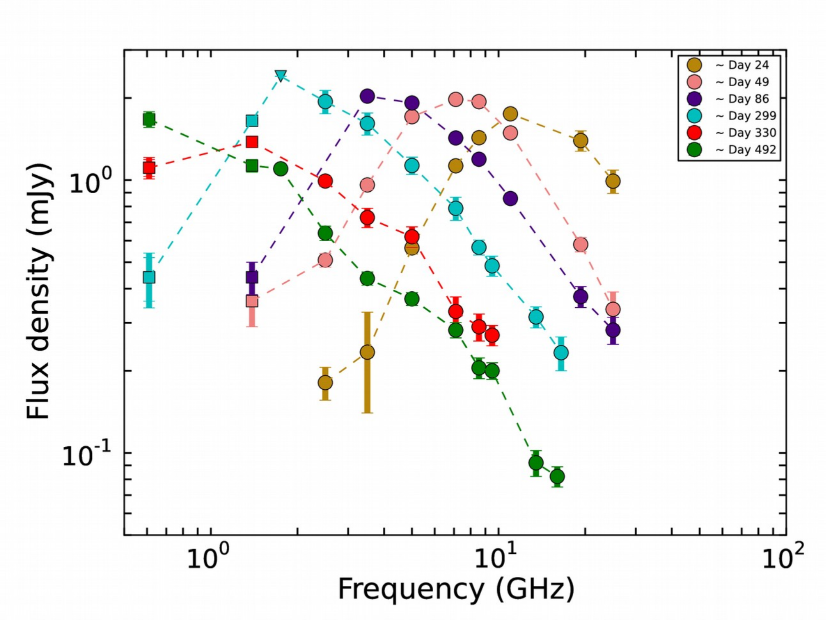
SN2016gkg – monitoring for ~ 1000 days



- SN2016gkg – type IIb supernova.
- Exploded on 2016 Sep 16.
- Galaxy NGC 613 at 26 Mpc.
- Progenitor identified from archival HST image.

Radio observations and modeling





Radio flux density **F(freq, time)**

(Nayana et al. 2022)

Modeling radio light curves and spectra

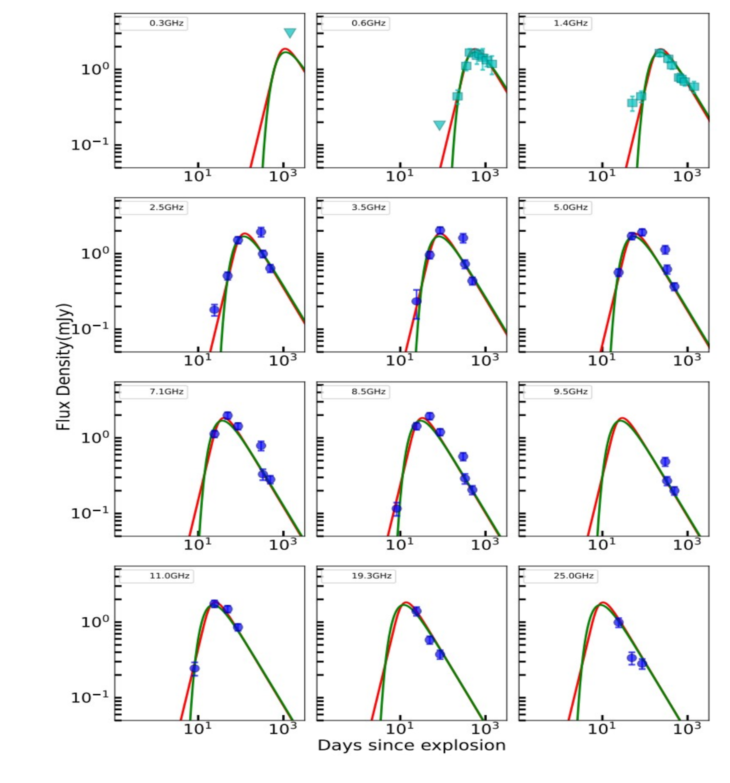
$$S(\mathrm{mJy}) = K_1 \left(\frac{\nu}{5\ \mathrm{GHz}}\right)^{\alpha} \left(\frac{t - t_0}{1\ \mathrm{day}}\right)^{\beta} e^{-\tau_{\mathrm{external}}} \left(\frac{1 - e^{-\tau_{\mathrm{CSM_{clumps}}}}}{\tau_{\mathrm{CSM_{clumps}}}}\right) \left(\frac{1 - e^{-\tau_{\mathrm{internal}}}}{\tau_{\mathrm{internal}}}\right)$$

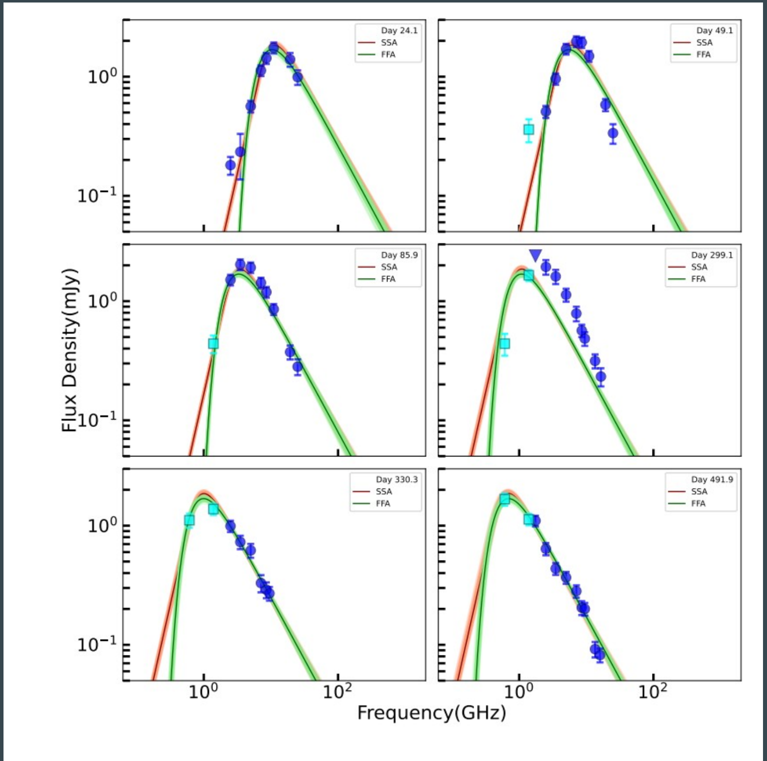
FFA

SSA

(Weiler 2022)

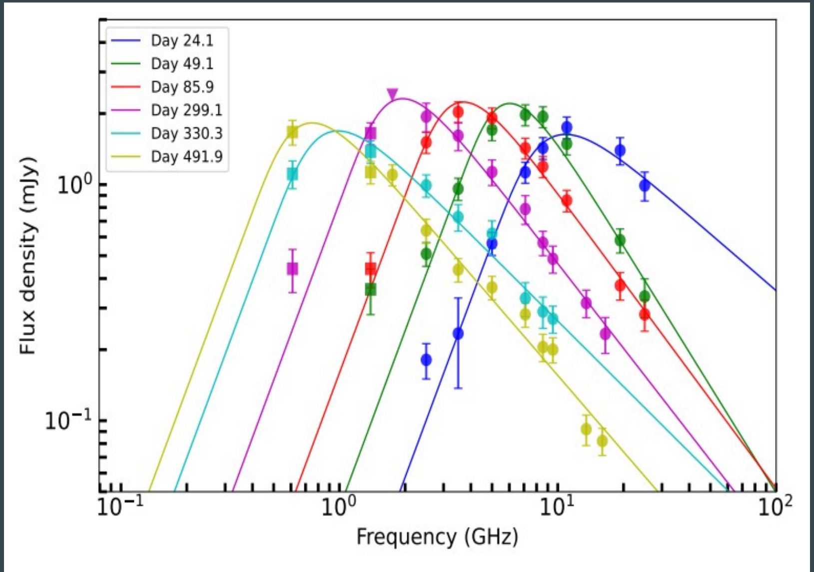
Modeling radio light curves and spectra

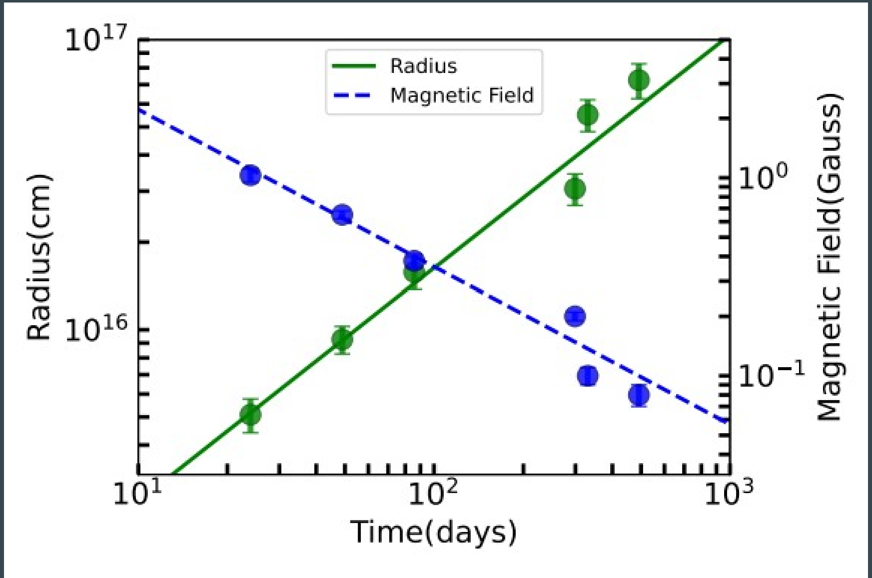




Reduced chi_square = 3.2 (SSA) 4.4 (FFA)

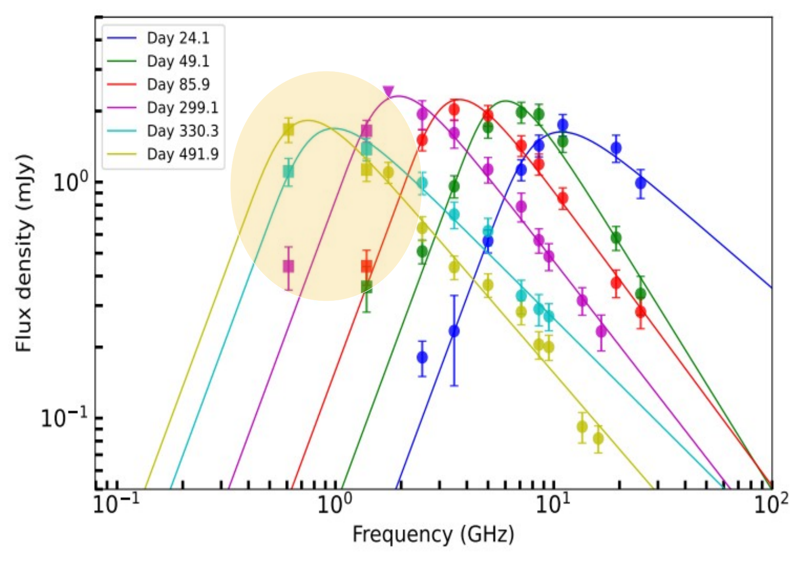
Shock parameters and their evolution

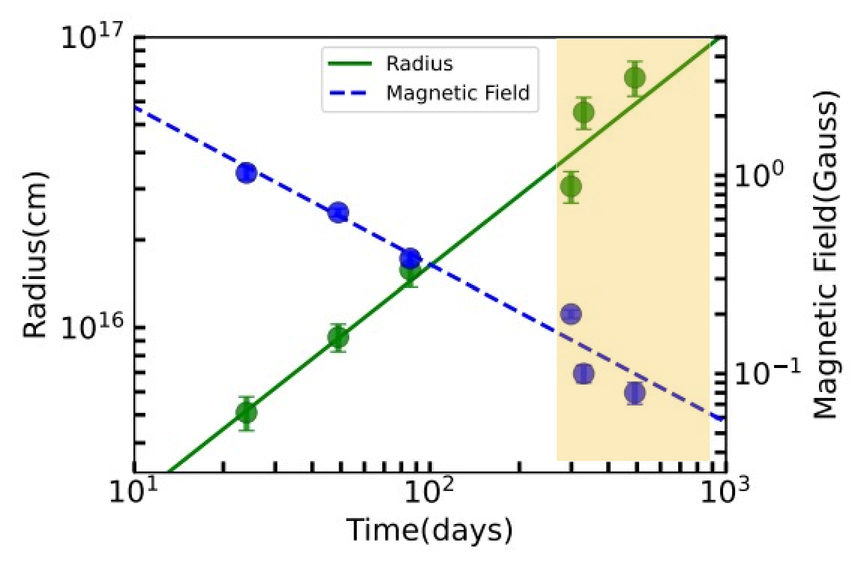




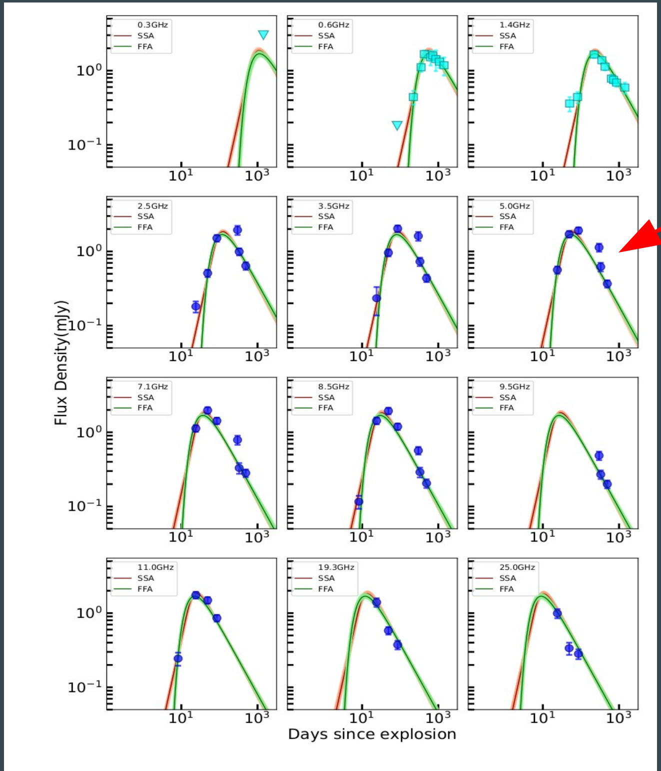
- R_{shock} ~ (5-72) X 10^{15} cm at t ~ 24 to 492 days.
- B ~ (1 – 0.08) Gauss.
- Mass-loss rate ~ (2 – 5) X 10^{-6} M_{sun}/year.

Unique role of uGMRT observations

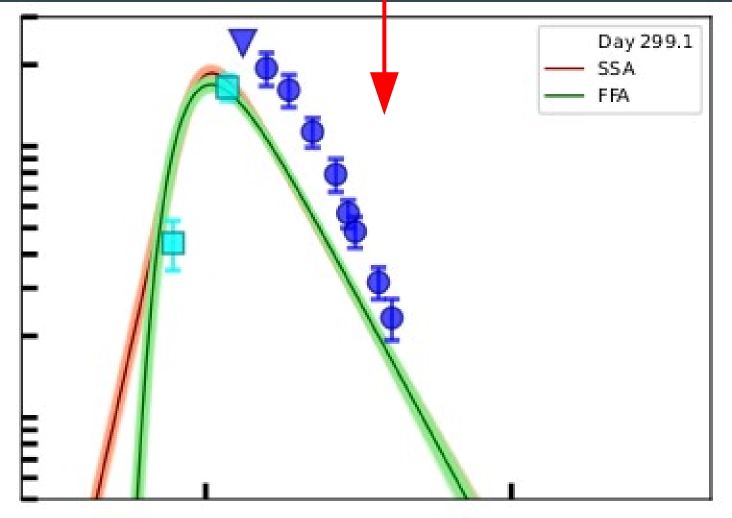




Signatures of non-uniform CSM



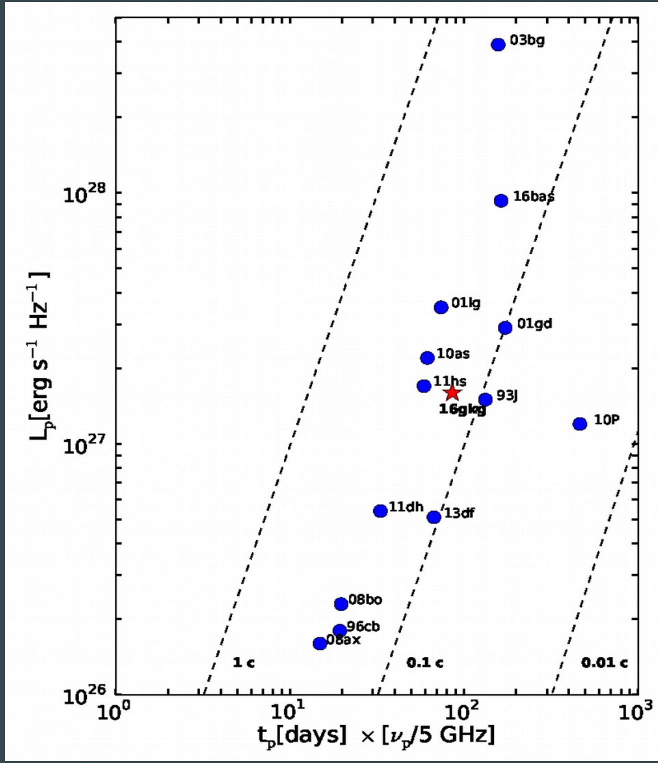
Moderate flux density enhancements indicating non-uniform CSM density



Clues on progenitor system

- Compact and extended progenitors of SNIIb.
- R(93J) ~ 600 R_{sun} R(08ax) ~ (30-50) R_{sun}
- SSA model fits the data better.
- Mdot ~ 10^{-6} M_{sun}/yr → typical of WR stars.
- V_{shock} ~ 0.1 c.
- Position in L_p-t_p diagram.

Progenitor of SN2016gkg is relatively compact → in line with the results from HST archival image analysis R ~ 70 R_{sun}.



(Aldering 1994, Folatelli 2015, Kilpatrick 2021)

Summary

- Radio observations of supernovae is a powerful tool to understand the progenitor scenario, energetics, and environments.
- Various physical parameters – mass-loss rate, shock radius, velocity, shock deceleration parameter, and magnetic fields.
- Low-frequency (sub-GHz) observations are particularly interesting to probe the extended environment of these events and to disentangle the dominant absorption processes.