Constraining magnetic field amplification in SN shocks using radio observations of SNe 2011fe and 2014J

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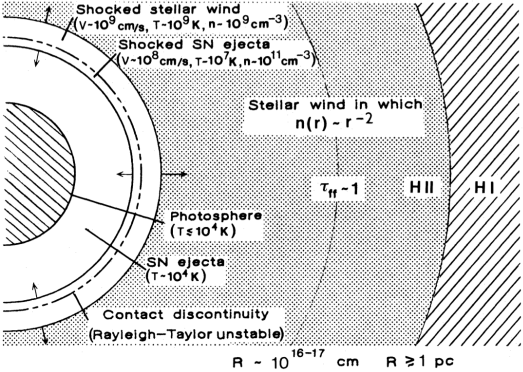
SN 2011fe and SN 2014J

- Very nearby : SN 2011fe (M101, 6.4 Mpc), SN 2014J (M82, 3.4 Mpc)
- SN 2011fe and SN 2014J $->$ Type Ia.
- Explosion of single WD (SD) or merger of two WDs (DD).
- SD $->$ enriched CSM, $\rho_w \propto r^{-2}$ (Ingeneral)
- DD $->$ low density surrounding, $\rho_w \propto$ const

SN CSM Interaction

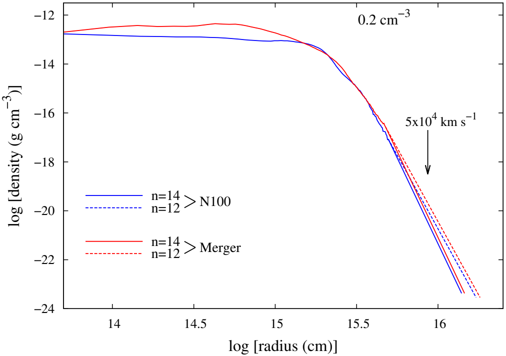
Lundqvist & Fransson 1988



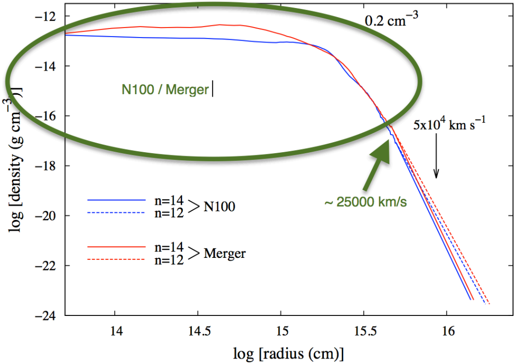
- Synchrotron radiation from shock fronts.

Ejecta profile

SNe 2011fe & 2014J $->$ Normal Type Ia (Röpke et al. 2012, Churazov et al. 2014)

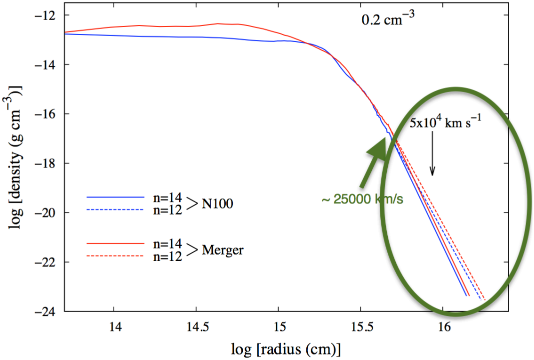


Ejecta profile



N100/Merger Model : Seitenzahl et al. 2013 / Pakmor et al. 2012

Ejecta profile



$\longrightarrow \rho_{o,ej} \propto r^{-n}$; $12 < n < 14$

Radio emission

- Energy distribution of electrons : $dN/dE = N_0 E^{-p}$
- From SSA radio luminosity in optically thin regime [EK et al. 2017 (under review)]:

$$L_{\nu,\mathrm{thin}} \propto \left(\frac{n-3}{n}\right)^{3.86} T_{\mathrm{bright}}\ \epsilon_{\mathrm{rel}}^{1.71}\ \epsilon_{\mathrm{B}}^{1.07}\ \nu^{-1}\,(n_{\mathrm{ISM}})^{\frac{1.93n-8.43}{n}}\ t^{\frac{(2.86n-25.3)}{n}}$$

$$\epsilon_{\mathrm{e}} = u_e/u_{th}$$

$$\epsilon_{\mathrm{B}} = u_B/u_{th}$$

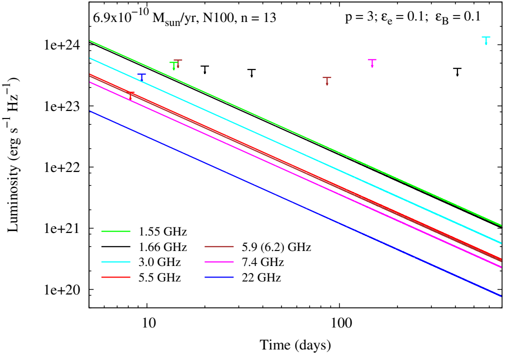
Usually assumed equipartition of energy, i.e $\epsilon_{\mathrm{e}} = \epsilon_{\mathrm{B}}$

$\epsilon_{\mathrm{ion}} \sim 0.1 - 0.15$ (Caprioli & Spitkovsky 2014, ApJ, 783, 91)

We asuume $\epsilon_{\mathrm{e}} = 0.1$

Light curves (SN 2014J)

$$\rho_w \propto r^{-2},\ v_w = 100\,\mathrm{km\ s^{-1}}$$



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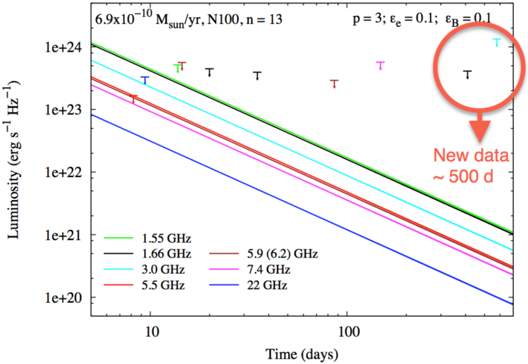
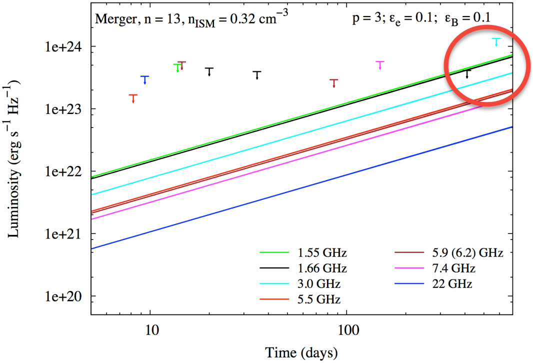
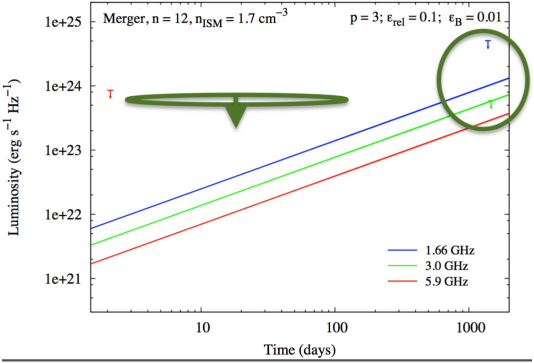


EK et al. 2017 (under review)

$\rho_w \propto$ const



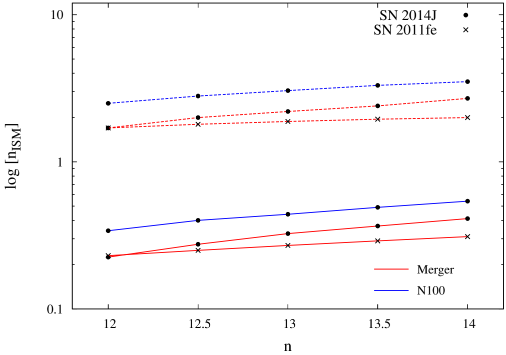
SN 2011fe



⟶ Post 4 yrs

Upper limit on $n_{\rm ISM}$

EK et al. 2017 (under review)

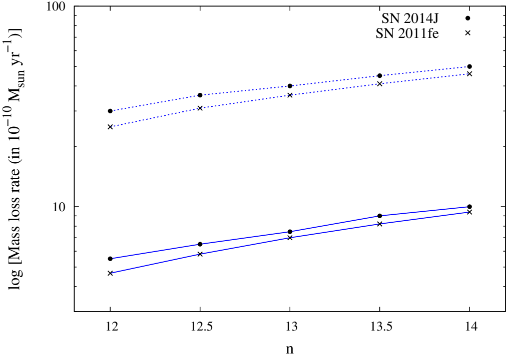


$\longrightarrow \epsilon_{\rm B}$ =0.01, $n_{\rm ISM} <\sim 2\ cm^{-3}$

$\longrightarrow \epsilon_{\rm B}$ =0.1, $n_{\rm ISM} <\sim 0.\ 4\ cm^{-3}$

EK et al. 2017 (under review)

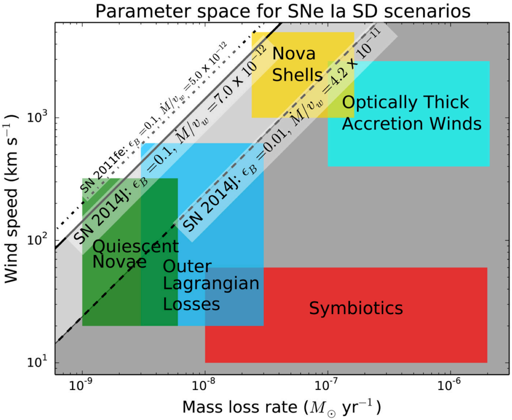
$v_w = 100\,\text{km s}^{-1}$



$\longrightarrow \epsilon_B = 0.01$,
$\dot{M} <\sim 4 \times 10^{-9}\,M_\odot\,yr^{-1}$

$\longrightarrow \epsilon_B = 0.1$, $\dot{M} < 10^{-9}\,M_\odot\,yr^{-1}$

Pérez-Torres et al. 2014



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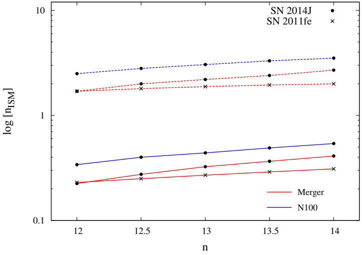
DD Channel

DD scenario

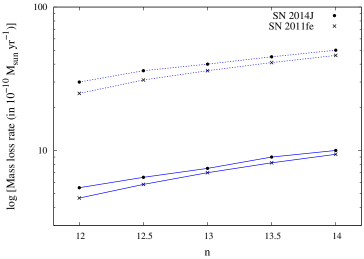
- From H I column density (Chomiuk et al. 2012, Ritchey et al. 2015) particle density around both SNe 2011fe and 2014J can be expected $\sim 1\ \mathrm{cm}^{-3}$.
- $n_{\rm ISM} \sim 1\ \mathrm{cm}^{-3}$ achievable when $\epsilon_{\rm B}$ =0.01.



SD scenario

MS/He Companion

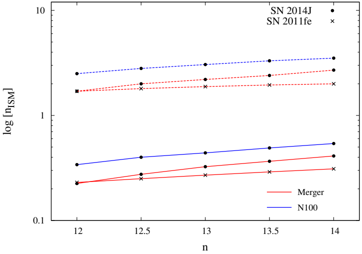
- For $\epsilon_{\rm B}$ =0.1
  $\dot{M} < 10^{-9}(v_w/100~{\rm km~s^{-1}})^{-1}\,{\rm M_\odot~yr^{-1}}$.
- This requires acceretion efficiency of WD $>$ 99%.
- Accretion efficiency less restricted for $\epsilon_{\rm B}$ =0.01



SD channel

Spin up/down model

- ISM like environment expected around progenitor system. (Justham 2011)
- We examine with N100 model.
- N100 predict $n_{\rm ISM} <\sim 2\ cm^{-3}$ for $\epsilon_{\rm B}$ =0.01.



SD channel

SD Channels: Recurrent Nova

- Tenuous medium around SN.
- Not possible to predict radio luminosity from our model.
- No H,metal, Na ID line in nebular spectra : Not very likely progenitor system for SNe 2011fe and 2014J (Lundqvist et al. 2015).

ϵ_e and ϵ_B from Core collapse

- Radio + Xray modeling of SN 2002ap $- > \epsilon_e/\epsilon_B \sim 1$.
  (Björnsson & Fransson 2004)

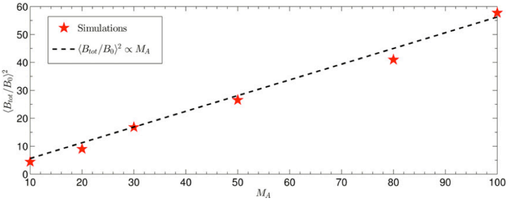
- SN 1993J $- > \epsilon_e/\epsilon_B \sim 3 \times 10^{-2}$.
  (Fransson & Björnsson 1998)

- SN 2011dh $- > \epsilon_e/\epsilon_B \sim 30$.
  (Soderberg et al. 2012)

- SN 2013df $- > \epsilon_e/\epsilon_B \sim 200$.
  (Kamble et al. 2016)

Connclusions

Caprioli & Spitkovsky 2014, ApJ, 794, 46



- $u_B \propto M_A$ for $M_A \sim 100$
- $u_e \propto M_A^2$. For shocks with $M_A \sim 100$ $\frac{u_e}{u_B} \approx M_A$.
- The above relation may true for SN shocks with $M_A \sim$ few $\times$ 1000.
- No radio emission detected from any Type Ia : $\epsilon_{\rm B}$ could be < 0.1 in SN shocks.