SUPERNOVA REMNANTS

AN ODYSSEY IN SPACE AFTER STELLAR DEATH

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RADIO EVOLUTION OF SUPERNOVA REMNANTS INCLUDING NON-LINEAR PARTICLE ACCELERATION

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Introduction

Supernova remnants (SNRs) are believed to accelerate particles up to high energies $\sim 10^{15}\,\mathrm{eV}$ through the mechanism of diffusive shock acceleration (DSA). Radio, X-ray and gamma-ray emission from cosmic ray (CR) electrons supports this picture. Over 10% of the total SNR energy must go into accelerated particles. Those particles will have a dynamical effect on the shock.

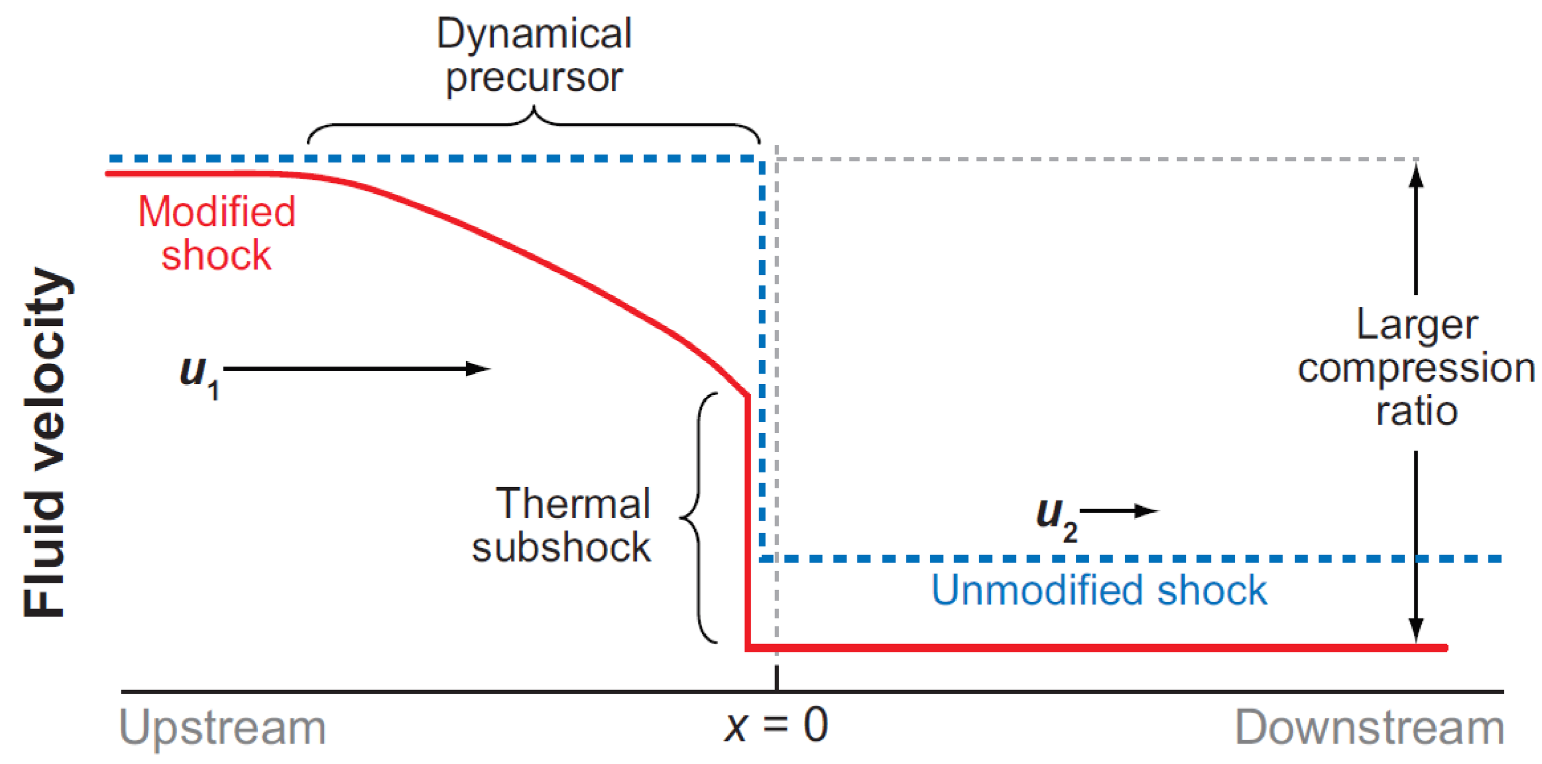
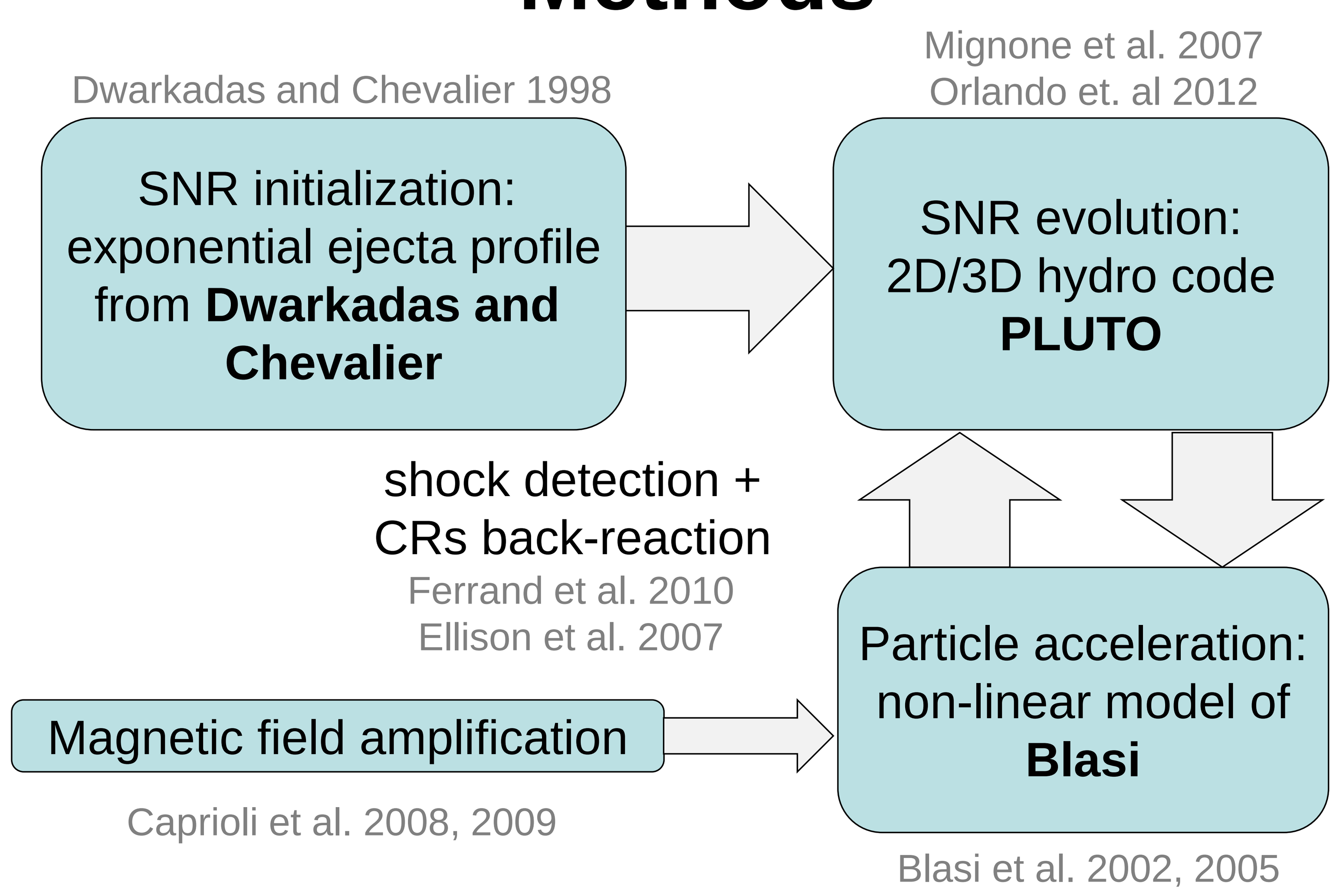


Fig 1. Schematic shock profile. Dotted blue line, unmodified shock; solid red line, shock modified by accelerated particles (Reynolds 2008)

Methods



The equation that describes the diffusive transport of particles in one dimension (Blasi et al. 2005):

$$\frac{\partial}{\partial x}\left[D\frac{\partial}{\partial x}f(x,p)\right]-u\frac{\partial f(x,p)}{\partial x}+\frac{1}{3}\frac{du}{dx}p\frac{\partial f(x,p)}{\partial p}+Q(x,p)=0$$

where D is diffusion coefficient, $f(x,p)$ is distribution function, u is the fluid velocity.

The expected synchrotron SNR luminosity is given by the expression (Berezhko & Volk 2004):

$$L_\nu \cong 3.0\times\ 10^{-21}\ V_{\mathrm{ef}}\ B_\perp \int_{p_{\min}}^{p_{\max}} p^2 f_{\mathrm{e}}(p) F\left(\frac{\nu}{\nu_{\mathrm{c}}}\right) dp$$

in $\mathrm{erg/(s\,Hz)}$, where V_{ef} represents effective emitting volume depending on volume filling factor and current shock radius, $B_\perp$ is the magnetic field component perpendicular to the line of sight, $f_{\mathrm{e}}(p)$ is electron distribution function, $p_{\min}$ and $p_{\max}$ are minimum and maximum electron momentum, ν_{c} is electron critical frequency and $F(x)$ represents synchrotron function. We only consider the emission from the shell and don't account for spatial dependence of electron distribution function.

Results

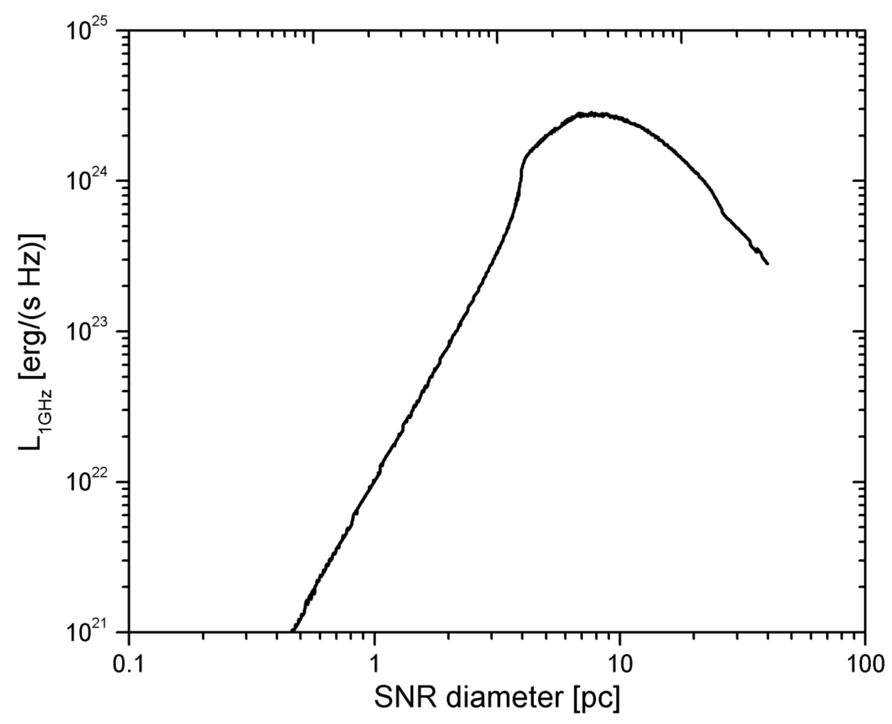


Fig 2. The integrated SNR radio luminosity at $\nu = 1\,\mathrm{GHz}$ as a function of SNR diameter in the case of SNR with explosion energy $E_{\mathrm{sn}} = 10^{51}\mathrm{erg}$, ISM density of $0.1\,cm^{-3}$, for about 15000 yr of evolution and injection momentum $p_{\mathrm{inj}} = 3.6\,p_{\mathrm{th}}$

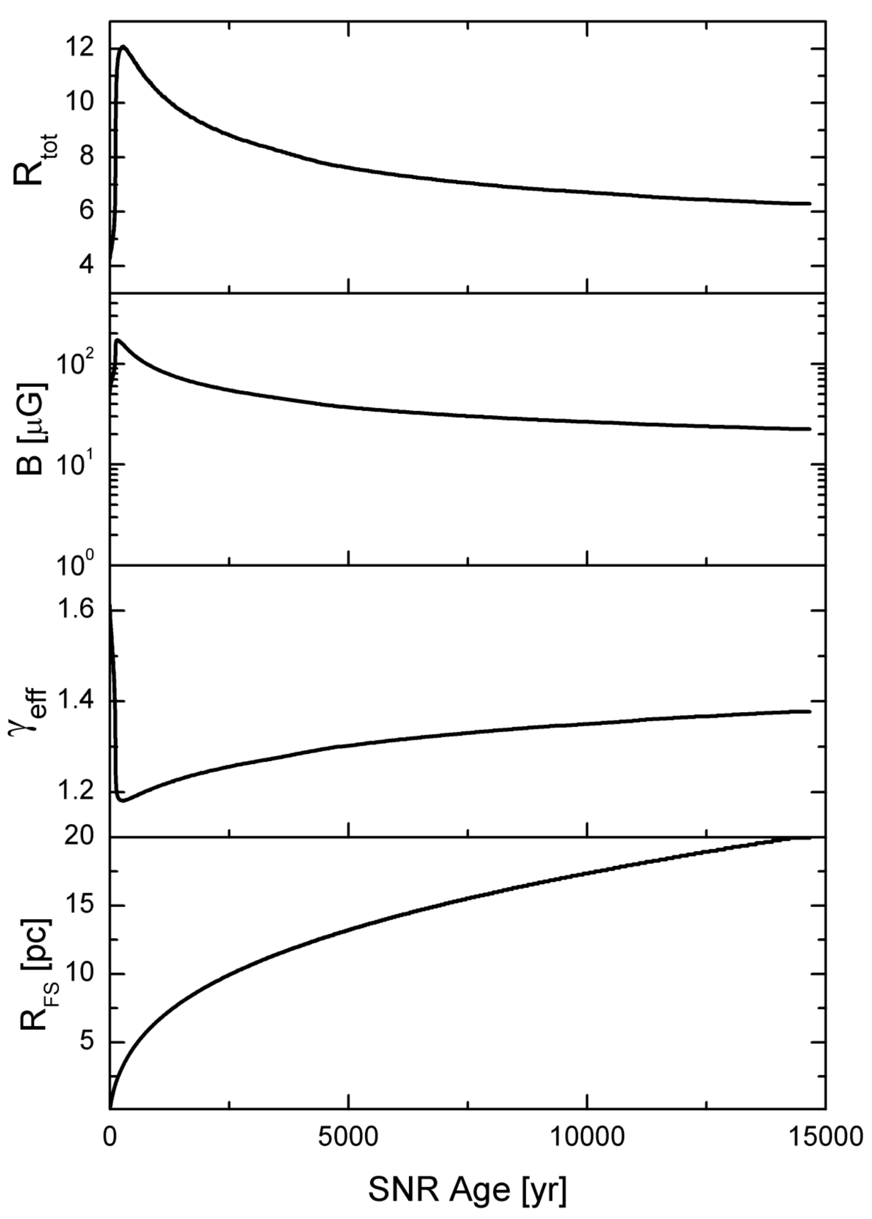


Fig 3. Evolution of SNR parameters: R_{tot} represents total shock compression, B is amplified magnetic field, effective adiabatic index γ_{eff} and forward shock radius R_{FS}. Parameters from Fig. 2.

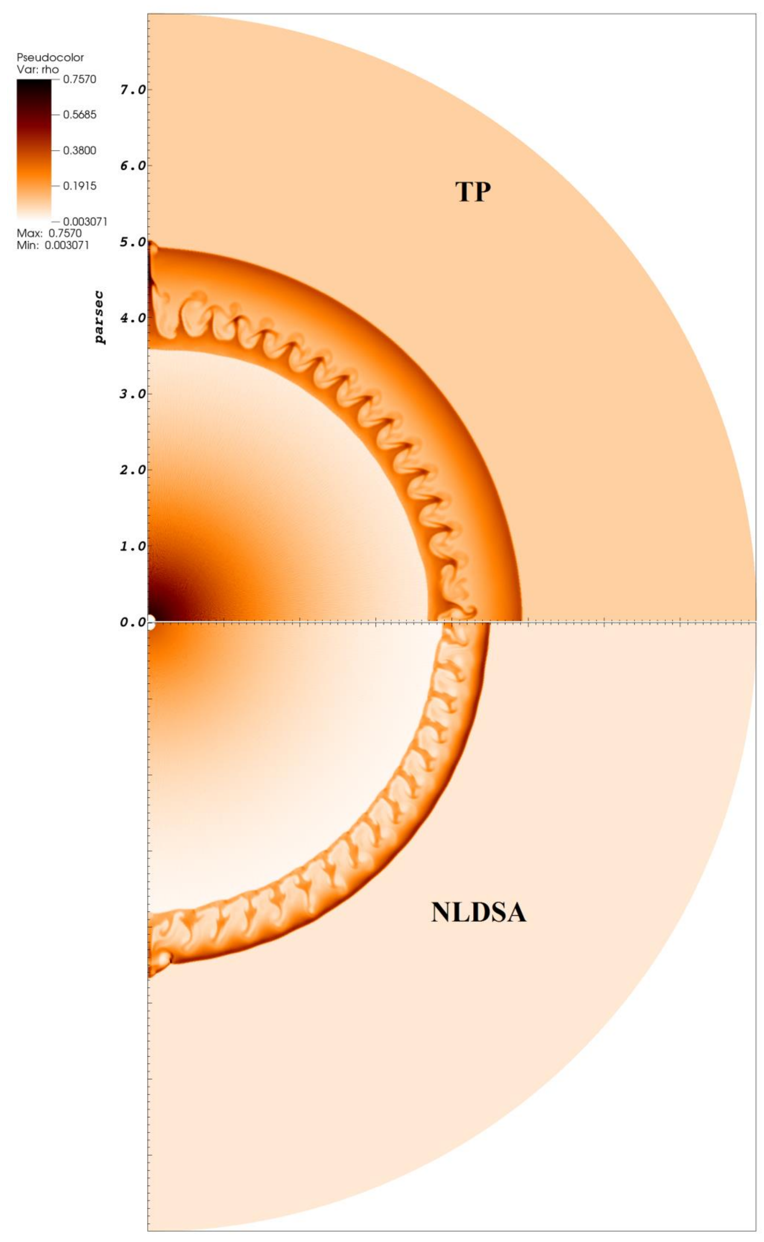


Fig 4. Maps of density. Snapshot at time 500 years from 2D test particle (TP) and non-linear hydrodynamic simulation (NLDSA).

Conclusions

We are able, for the first time, to simulate the radio evolution of SNRs undergoing efficient DSA without limiting assumptions on its spatial structure or temporal evolution. Due to the growing number of accelerated CRs, the expected SNR luminosity increases during the free expansion phase, reaches a peak value at the beginning of the Sedov phase and then decreases.

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