Supernovae driven Turbulence in the interstellar medium

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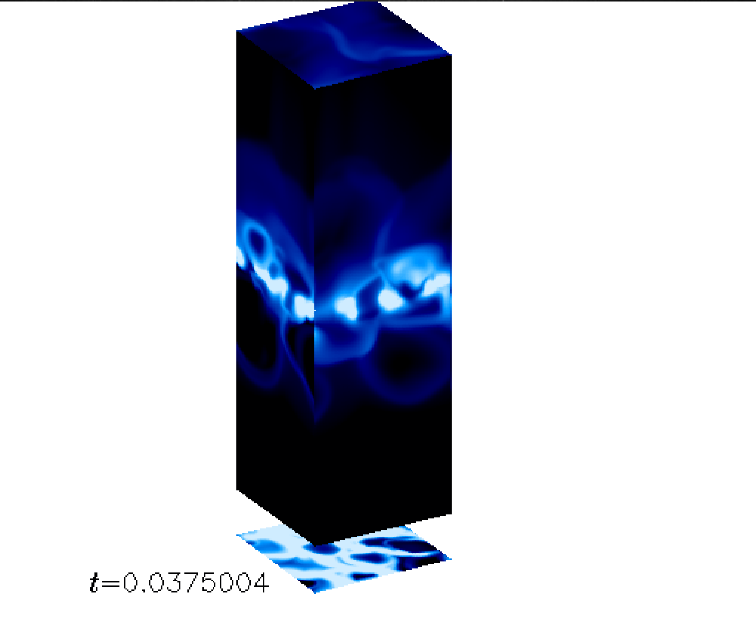
48 million years: supernova explosions without magnetism



Description of the model

- shearing box periodic radial and azimuthal (x,y)
- gravity profile (Ferrière 2001)

$$g_z = \frac{g_\alpha \ z}{\sqrt{z^2 + 200\mathrm{pc}^2}} + \frac{g_\beta \ z}{1\mathrm{kpc}^2}$$

- isothermal hydrostatic equilibrium

$$\rho(z) = \rho_0 exp\left(\frac{0.4g_\alpha - 2g_\alpha\sqrt{z^2+0.2^2} - g_\beta \ z^2}{2\tau_0}\right)$$

$$p(z) \propto \rho(z), \ T(0) = 8000\mathrm{K}$$

- radiative cooling, uv heating, regular magnetic field

Supernovae modelling

- Heating rate: 10^{51} ergs, $10M_{\odot}$ 4 times per Myrs per kpc^2
- Pseudo random distribution uniform in the plane, gaussian in height about the midplane
- verify Sedov-Taylor and snowplough growth in monotomoic uniform interstellar medium

$$R = \left(\frac{25}{3\pi}\right)^{\frac{1}{5}} \left(\frac{E}{\rho_0}\right)^{\frac{1}{5}} t^{\frac{2}{5}} \qquad \text{(Dyson \& Williams 1997)}$$

$$R = R_0 \left(1 + 4\frac{\dot{R}_0}{R_0}(t - t_0)\right)^{\frac{1}{4}} \qquad \text{(snowplough phase)}$$

The transition velocity $\dot{R}_0$ can be calculated from (Woltjer 1972)

$$\dot{R}_0 \propto \rho_0^{2/17} E^{1/17}$$

Thermal with or without initial kinetic energy

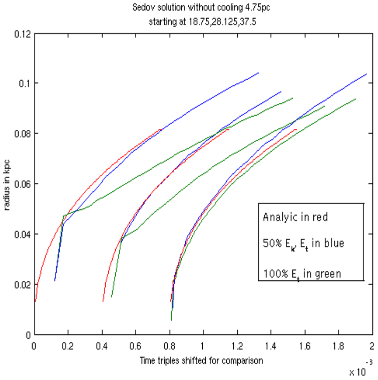


Figure: Comparing growth rates with and without kinetic energy injection into concentric spheres to analytic Sedov model

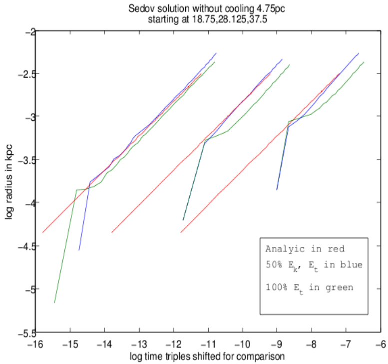


Figure: Comparing log growth rates with and without kinetic energy injection into concentric spheres to analytic Sedov model

Comparison with Sedov and Snowplough solutions

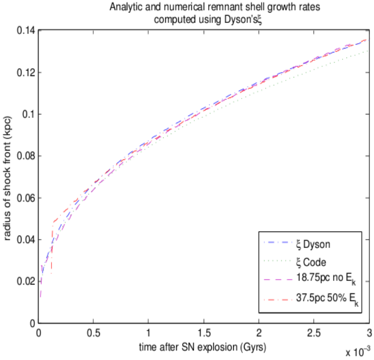


Figure: Comparing adiabatic simulations with analytic results for different ξ

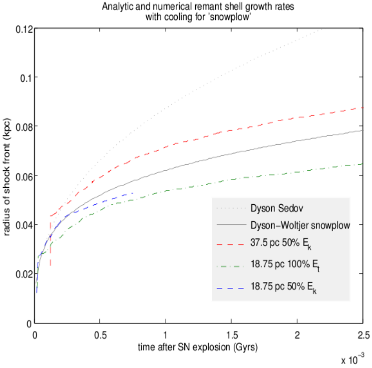


Figure: Comparing simulations with cooling to analytic snowplough model

Instabilities: kinetic energy injection - reverse shock

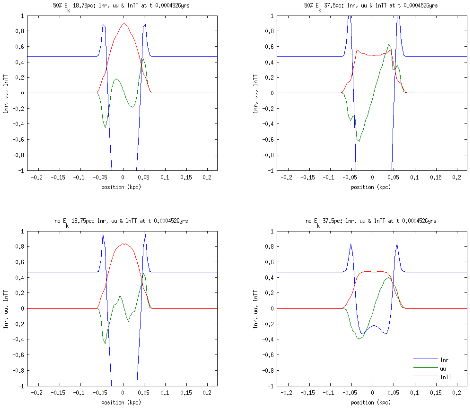


Figure: Line profiles through the remnant origin (density, shock velocity and temperature): adiabatic Sedov simulations initiated with/without kinetic energy in remnants of 18.75/37.5 parsecs

Instabilities: cooling function - snowplough phase

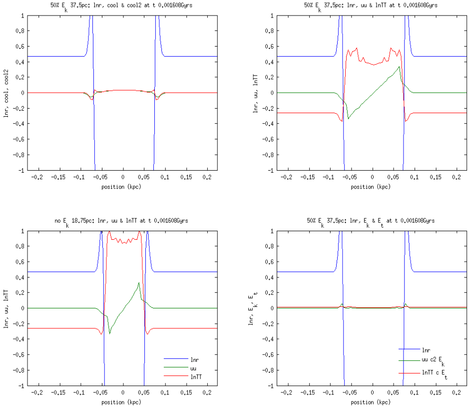


Figure: Line profiles (cooling function, velocity and temperature, thermal and kinetic energy): snowplough simulations initiated with kinetic energy in remnants of 37.5 parsecs

Thermal instabilities: unresolved cooling and heating

cooling rate $\Lambda(T)$	(cgs)	temp range	code value	T
0		$T < 100K$	0	
2.238×10^{-32}	T^2	$T < 2000K$	252.41	$(100K)$
1.0012×10^{-30}	$T^{1.5}$	$T < 8000K$	101000.9	$(2000K)$
4.624×10^{-36}	$T^{2.867}$	$T < 10^5K$	808064.2	$(8000K)$
1.780×10^{-18}	$T^{-0.65}$	$T < 10^6K$ **	1.129×10^9 0.253×10^9	(10^5K) (10^6K)
3.2217×10^{-27}	$T^{0.5}$	$T < 10^9K$	3.634×10^6	(10^6K)

- ** in original transition at $4 \times 10^7 K$ continuous (Rosen et al. 1993)
- Updated to continuous profile (Sánchez-Salcedo et al. 2002) by (Brandenburg et al. 2006)
- uv-heating constant smoothly vanishes above 8000K(Wolfire et al. 2003)

Magnetic fields

$$\frac{\partial \mathbf{A}}{\partial t} = \cdots - \eta\mu_0 \mathbf{j}, \quad \frac{\partial \mathbf{u}}{\partial t} = \cdots + \frac{\mathbf{j}\times\mathbf{B}}{\rho}, \quad \rho T\left(\frac{\partial s}{\partial t}\right) = \cdots + \rho^2\Lambda(T) + \eta\mu_0\mathbf{j}^2 + \cdots$$

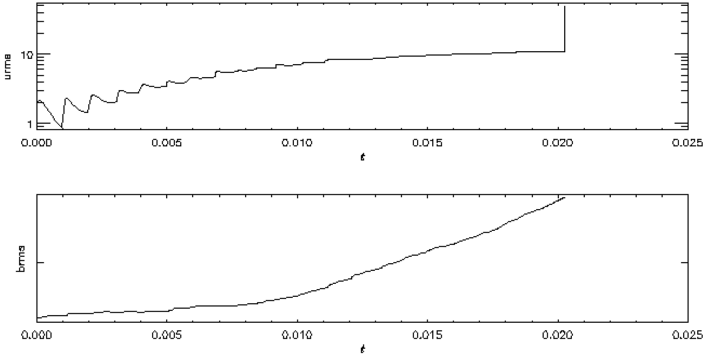


Figure: Increasing magnetic flux in diffuse medium generates exponential velocity due to Ohmic heating and Lorentz force

50 million year simulation with magnetic fields

Figure: Simulation with 0.5μG field $\propto \rho$ at the midplane

Solutions

- scale height of SN restricted
- seed field reduced to 0.5μG
- seed field $\propto \rho(z)$
- cooling function continuous everywhere
- shock viscosity max for Alfven sound speed
- viscosity$\nu = 0.03, \eta = 0.008, \chi = 0.02$

Results - Is this a Dynamo?

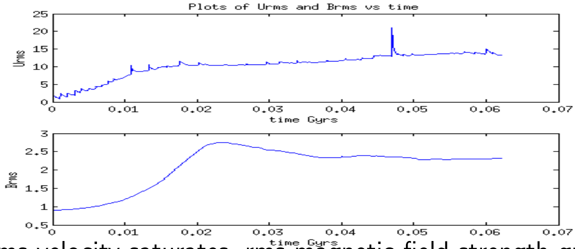


Figure: Rms velocity saturates, rms magnetic field strength grows between 10 and 20 Myrs then stable

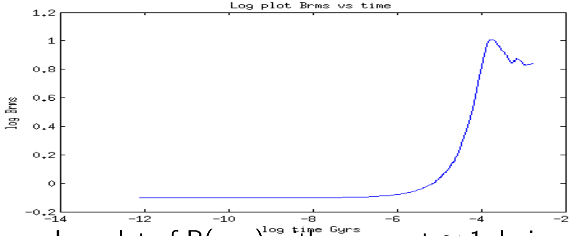


Figure: Log plot of B(rms) with exponent ≈ 1 during growth

Mach speeds

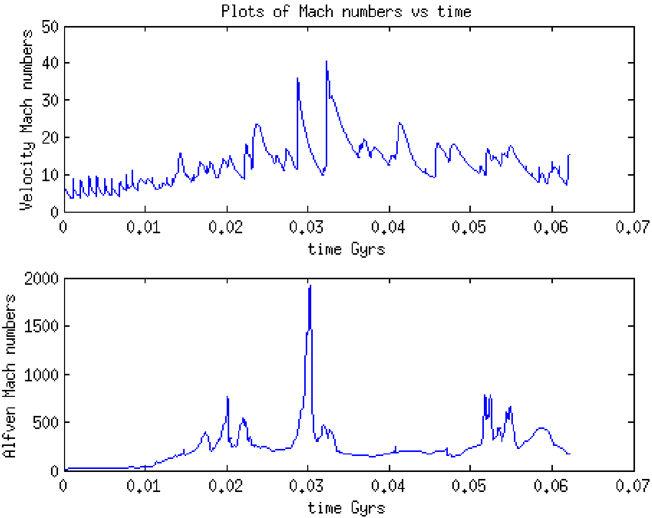


Figure: Maximum mach numbers for velocity and Alfven Mach numbers over time

60 million years: supernova evolved B_x magnetic field

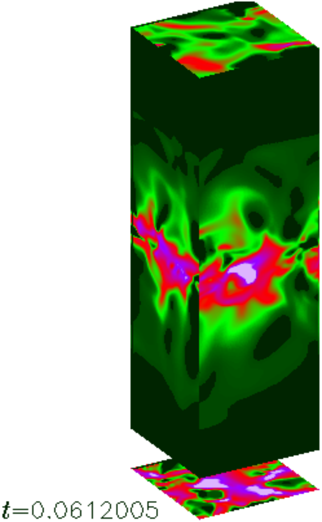


Figure: Growth of the seed magnetic field B_x under supernova driven turbulence. The magnitude increases from 0.5 μG

60 million years: supernova induced B_z magnetic field

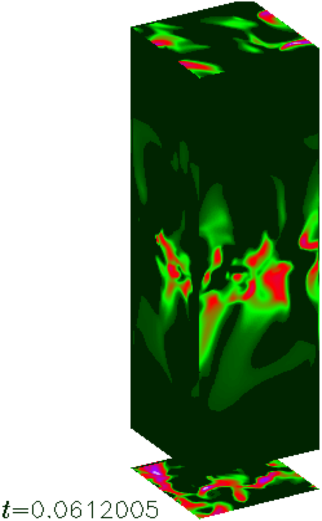


Figure: The vertical magnetic field grows from zero

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