Impact of Supernovae on Molecular Cloud Evolution

Dynamics and Structure

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Introduction

We perform numerical simulations of colliding streams of the WNM, including magnetic fields and self–gravity, to analyse the formation and evolution of molecular clouds subject to supernova feedback from massive stars.

Simulation Setup

The equations of MHD together with selfgravity and heating and cooling are evolved in time using the FLASH code [Fryxell et al., 2000]. We use a constant heating rate Γ and the cooling function Λ according to [Koyama and Inutsuka, 2000] and [Vázquez-Semadeni et al., 2007]. The table below lists the initial conditions.

Parameter	Value	Parameter	Value
Flow Mach number $\mathcal{M}_f$	2.0	Alfvén velocity v_a [km/s]	5.8
Turbulent Mach number $\mathcal{M}_s$	0.5	Alfvénic Mach number $\mathcal{M}_a$	1.96
Temperature [K]	5000	Plasma Beta $\beta = P_{th}/P_B$	1.93
Number density n $\left[cm^{-3}\right]$	1.0	Flow Length [pc]	112
Isothermal sound speed c_s [km/s]	5.7	Flow Radius [pc]	64
Adiabatic sound speed c_γ [km/s]	7.4	Flow Mass [$\mathrm{M}_\odot$]	$9 \cdot 10^4$
Magnetic field $\lvert\underline{B}\rvert \propto \underline{e}_x$ [μG]	3.0	Mass–to–Flux μ/μ_{crit}	0.96

The Supernova Subgrid Model

The supernova feedback is included into the model by means of a Sedov blast wave solution. We define a volume of radius $R = 1\,pc$ centered on the sink particle. Within this volume each grid cell is assigned a certain radial velocity $\underline{v}_c$. This velocity depends on the kinetic energy input. Additionally we inject thermal energy, which then gives the total amount of injected energy of $E_{sn} = 10^{51}\,erg$ with 65 % thermal and 35 % kinetic energy according to the Sedov solution. The cell velocity is

$$\underline{v}_c = U_{sh}\frac{r}{R}$$

where U_{sh} is the shock velocity, depending on the kinetic energy input.

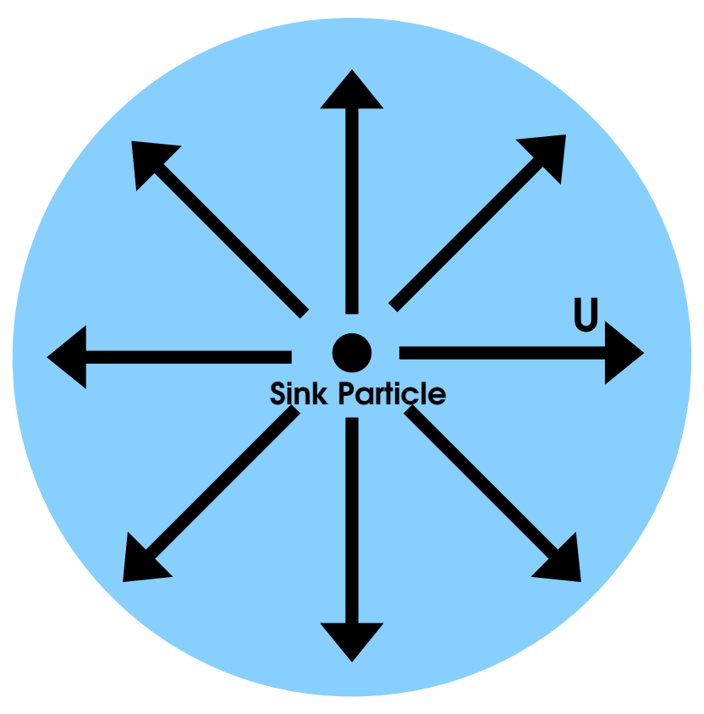


Figure 1: *Schematic of the energy injection.*

We normalise to the ratio of the observed supernova rate [Tammann et al., 1994] and the Galactic star formation rate [Mac Low and Klessen, 2004], thus achieving $\nu_{sn} = \frac{1}{44\,M_\odot}$. In addition we still impose a lifetime of the sink particle to account for the high accretion rates due to the lack of other feedback mechanisms.

Results

Cloud Morphology

The cloud, being formed by the colliding streams, is primarily dominated by dense clumps and filaments that undergo local gravitational collapse [Banerjee et al., 2009]. The already formed sink particles are located along the filamentary network within the cloud complex. The thickness of the cloud is dominated by the initial compressions of the WNM flows and is thus roughly 10 pc. After the SN have gone off, the cloud complex is destroyed and the dense gas is dispersed and redistributed over the entire surrounding ISM.

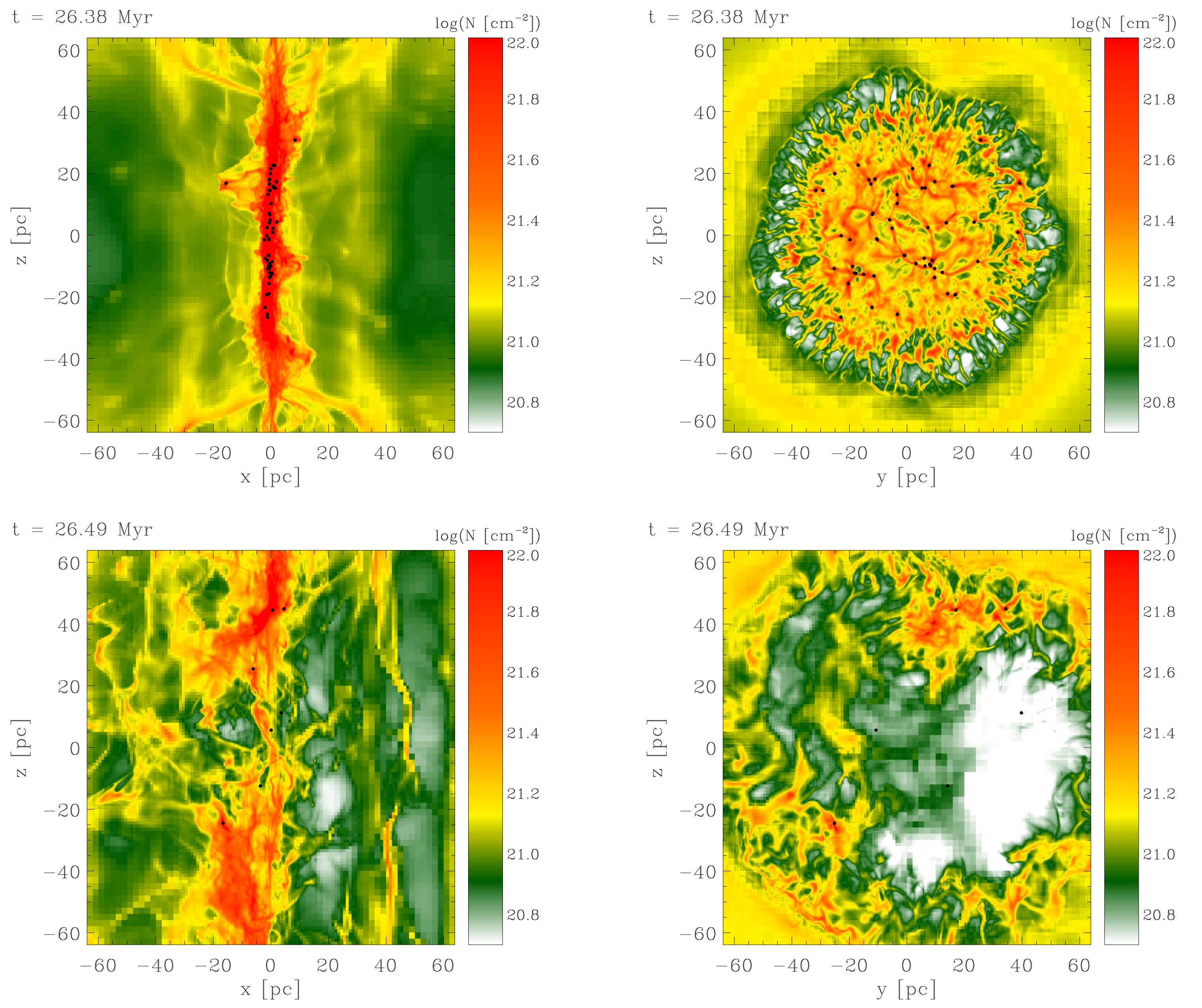


Figure 2: Column Density maps perpendicular (right) and parallel (left) to the flows for the case of $\mathcal{M}_s = 0.5$. **Top:** Without feedback. **Bottom:** With feedback.

Clump Statistics

Clumps are defined as regions with $n > 500\,cm^{-3}$. We show below the mean magnetic field of the clumps (upper left), the number of jeans masses (upper right), the velocity dispersion (lower left) and a calculated clump mass function (CMF) for $t \approx 13\,Myr$ after the first sink particles formed. The characteristic attributes of the dense regions reside a similar behaviour. In case with feedback the less massive clumps are completely destroyed by the ablation processes, which are primarily instabilities and hydrodynamic escape.

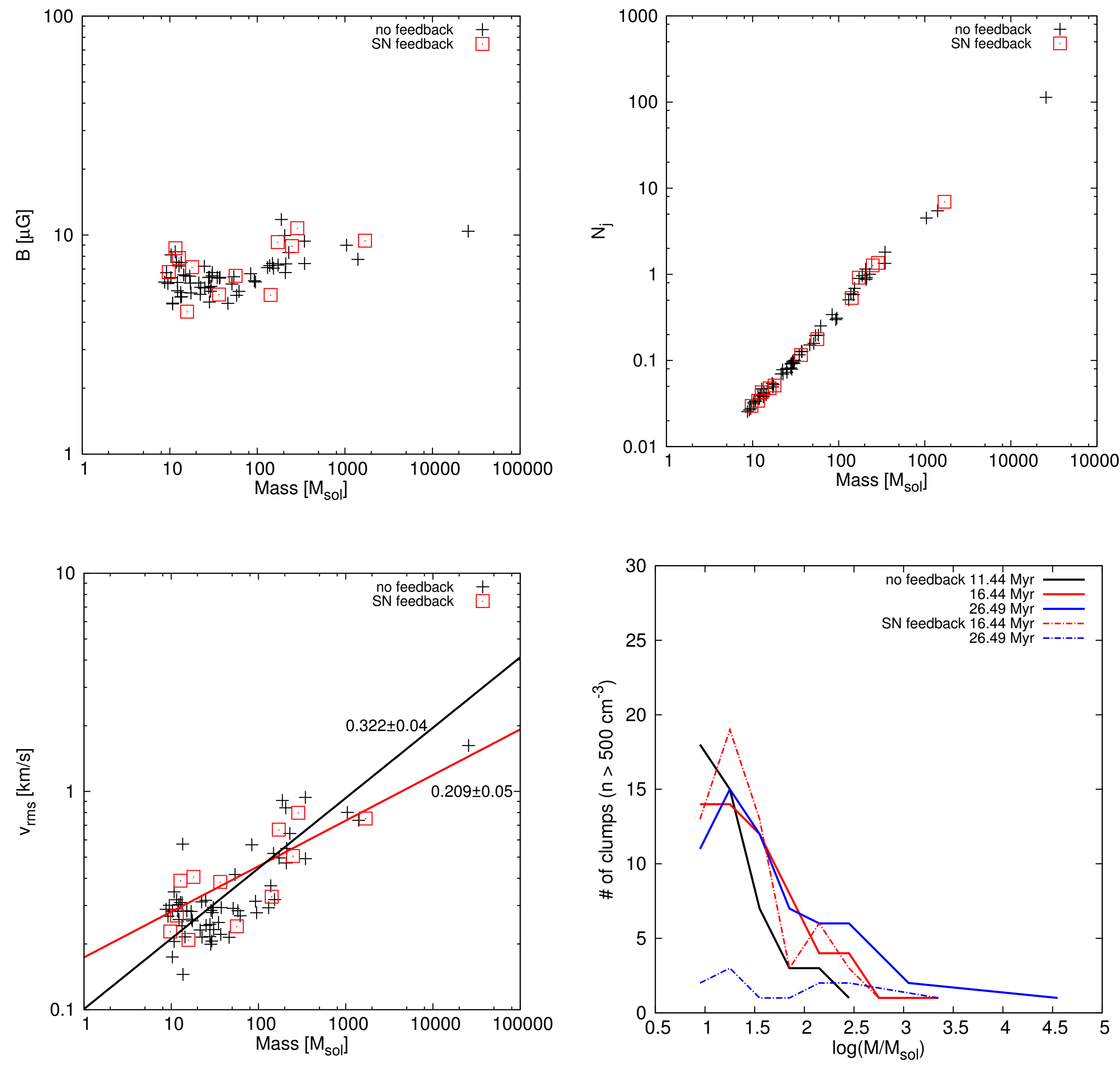
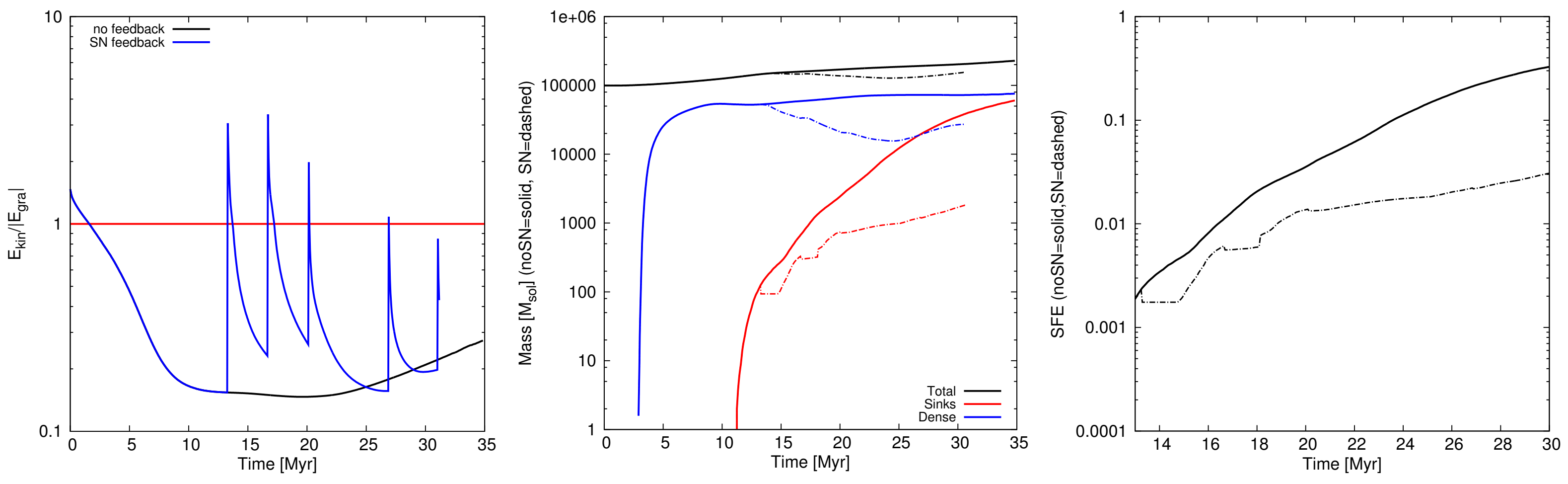


Figure 3: Clump statistics and clump mass function. Since the density of the clumps (not shown) is roughly constant, a Larson type relation for the velocity dispersion can be fitted to the data.

Temporal Evolution



The temporal evolution of the ratio of kinetic to gravitational energy, the evolution of the masses and the resulting star formation efficiency is shown. The supernovae inject thermal as well as kinetic energy into the ambient medium and thus drive shock waves which then interact with the molecular gas. The energy injection results in global unbound states of the gas. The mass of the dense gas is reduced due to the SN feedback and added to the mass of the overall gas reservoir. The sink particle (i.e. stellar) masses reach a state of near saturation since accretion of gas is delayed. The star formation efficiency (SFE), defined as $SFE(t) = \frac{M_*(t)}{M_*(t)+M_{max}(<t)}$ saturates around $\approx 3-4\,\%$.

Conclusions

SNe are **able to disperse** molecular clouds depending on the initial inflow speed and turbulent velocity fluctuations.
Star formation is delayed due to disruption of dense regions.
Clumps and filaments are subject to ablation due to the passage of the SN shock waves.
Reduced accretion rates due to decrease in gas content.
Reduction of SFE by about a factor ten.

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