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Supernova-Regulated Interstellar Medium: Simulations of Disk Galaxies

We investigate the hydrodynamic properties of the interstellar medium (ISM), heated and stirred by supernovae (SNe) explosions. The ISM has a strongly multiphase structure; hot ($T \simeq 10^6$ K), warm ($T \simeq 10^4$ K) and cold ($T \simeq 10^2$ K). Its interaction with magnetic fields and cosmic rays and star formation are integral to galaxy composition.

Three critical challenges to designing the numerical model include:

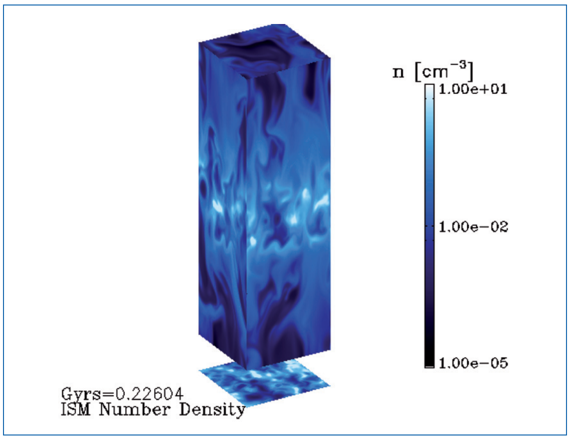

Fig. 1. – Snapshot of the gas density showing the chaotic stratified structure of the ISM. Most of the mass is located near the central plane of the galactic disk, with density falling off exponentially above and below the disk. SN remnants are identified by the dark patches, where most of the gas has been forced out by the explosions.

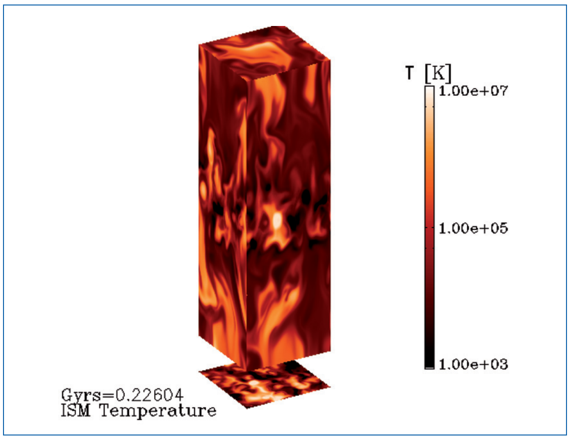

Fig. 2. – Snapshot of the gas temperature, showing the turbulent structure of the ISM. SN remnants are identified by the light (hot) patches. In this turbulent state they lose their spherical shape and can be seen merging and interacting with the powerful shocks from nearby remnants.

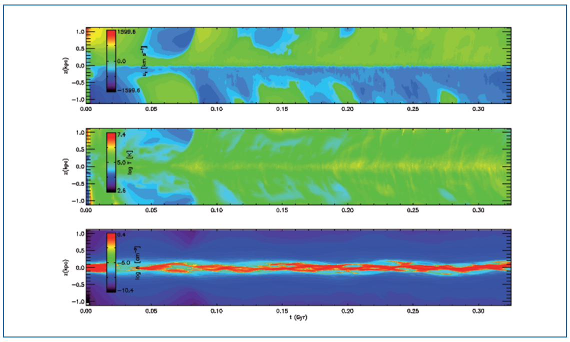

Fig. 3. – Horizontal (*xy*-) averages at each *z* displaying vertical (*z*-) velocity, log temperature and log density evolving in time. As the turbulent pressure from SN activity increases the system stabilizes and large scale inflows abate (top panel), the width of the disk expands (lower panel) and hot gas from the SN explosions heats up the surrounding ISM (middle panel).

(1) SNe explosions generate powerful supersonic shocks exceeding 1000 km s^{-1}. We apply shock capturing viscosity to impose finite gradients at shocks to resolve them numerically.

(2) The scales of temperature and density vary more than six orders of magnitude locally. The length scales of the SNe turbulence are much smaller than the large scale galactic flows of interest. We require high resolution over large domains, demanding calculation of vast data arrays at each step.

(3) The time scale to resolve SNe is about 100 yr, while galactic turnover times are more 100 to 1000 Myrs, so simulations need to be integrated over hundreds of thousand time steps.

We model a region within the galactic disc using a 3D Cartesian mesh of area 1 kpc^2 and extending ± 1 kpc from the galactic plane. This is resolved to approximately (4 pc)^3 with parameters typical of the solar neighbourhood. We apply an external gravity field as derived by (1).

We solve a system of non-ideal MHD equations using the PENCIL CODE[1].

In Figs. 1 and 2 we show snapshots of density and temperature from a typical run at a saturated state of turbulence. The flow field is governed by expanding and interacting bubbles driven by SNe, filled with million+ Kelvin gas of very low densities, and surrounded by a denser, cooler shells swept up by the explosion.

Despite the locally turbulent flow it is evident from Fig. 3, the disk has a well-defined vertical structure. We show the horizontally averaged vertical velocity, log temperature and log density evolving over time. By about 150 Myrs there is no trace of the initial conditions, large scale fluctuations dissipate and a quasi-steady turbulent state then persists indefinitely.

The density shows roughly exponential stratification with vertical gravity balancing thermal and turbulent pressure. Although the temperature is locally chaotic, as viewed in Figure 2, the horizontal averages remain reasonably steady over time.

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References

(1) K. Kuijken and G. Gilmore, *The Mass Distribution in the Galactic Disc - II - Determination of the Surface Mass Density of the Galactic Disc Near the Sun*, MNRAS, **239**, 605-649 (1989).

[1] http://www.nordita.org/software/pencil-code/

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