FORMATION OF SMALL-SCALE STRUCTURES IN THE INTERSTELLAR MEDIUM

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ABSTRACT. We consider formation of small scale structures in the process of interstellar cloud destruction by shock waves. We calculate statistical properties of HI column densities, optical depth and brightness temperature in 21 cm line. We discuss possible relation of the small-scale structures found in numerical models to the so called "low-N(HI)" clouds observed recently in the interstellar medium.

Key words: interstellar medium, neutral hydrogen, shock waves.

1. Introduction

Physical properties of the neutral atomic gas are of great importance for the star formation and overall dynamics of the interstellar medium (ISM). The sizes of structures in the neutral component of the ISM vary from several AU (tiny scale atomic structures) to several parsecs (standard HI clouds) (Kulkarni & Heiles 1987, Dickey & Lockman 1990, Heiles & Troland 2003, 2005). Recently a possibly new population of HI clouds has been discovered (Braun & Kanekar 2005, Stanimirović & Heiles 2005). Such structures have HI column densities among the lowest ever detected for cold neutral medium, $\sim 10^{18}$ cm^{-2}; these structures are called "low-N(HI)" clouds (Stanimirović et al 2007).

Formation of "low-N(HI)" clouds can be associated with various dynamical processes taking place in the interstellar medium. For instance, Hennebelle & Audit (2007) have described turbulent atomic gas formed by colliding flows, which reproduce observational features of turbulent HI flows resonably well. Such dynamical processes as destruction of interstellar HI clouds by shock waves, stellar wind, or cloud collisions seem to produce similar structures. During the interaction of shock wave with a cloud its external layers become turbulent due to Kelvin-Helmholtz instability, form vortices and filaments which finally leave the cloud (Klein et al 1994, Vietri et al 1997);such filaments can appear as isolated HI structures. Their size depends on the size of a detroyed cloud and in general varies in a wide range.

Here we consider a possibility of formation of small scale HI structures in the process of interstellar cloud destruction by shock waves.

2. Model

In our model a spherical homogeneous cloud of the density $n = 1$ cm^{-3} and the radius $a = 2$ pc is immersed under pressure equilibrium into a homogeneous intercloud medium with the temperature $T = 10^4$ K and the density $n = 0.1$ cm^{-3}. At initial time, $t = 0$, a planar shock wave (assumingly from a distant supernova) encounters the cloud with the Mach number $\mathcal{M} = 10$. The computational zone of size 60×10 pc is a cylinder with 1200 grids in z-direction, and 200 radial grid points. Numerical simulations were performed with using ZEUS-2D code (Stone & Norman 1992). Energy losses include the cooling by collisional exitation of atomic hydrogen, CII and OI fine-structure transitions (Hollenbach & McKee 1989).

To compare our simulations with observational features of interstellar structures we calculate synthetic spectrum and optical depth of the 21 cm line. We find the spin temperature for each elememt of neutral gas ($T \le 10^4$ K). We consider only collisional excitation of the 21cm line by HI atoms and electrons (Field 1958). Collisional de-excitation rates by hydrogen atoms and electrons are taken from Kuhlen et al (2005) and Liszt (2001). We take the electron fraction in

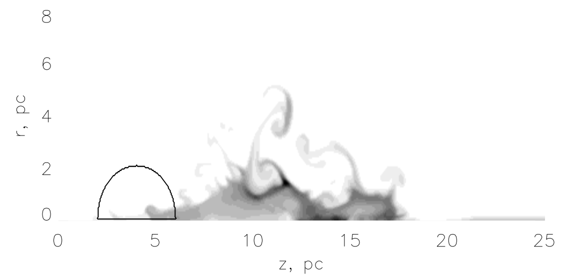

Figure 1: Density disribution in the computational domain for time 8×10^{13} s.

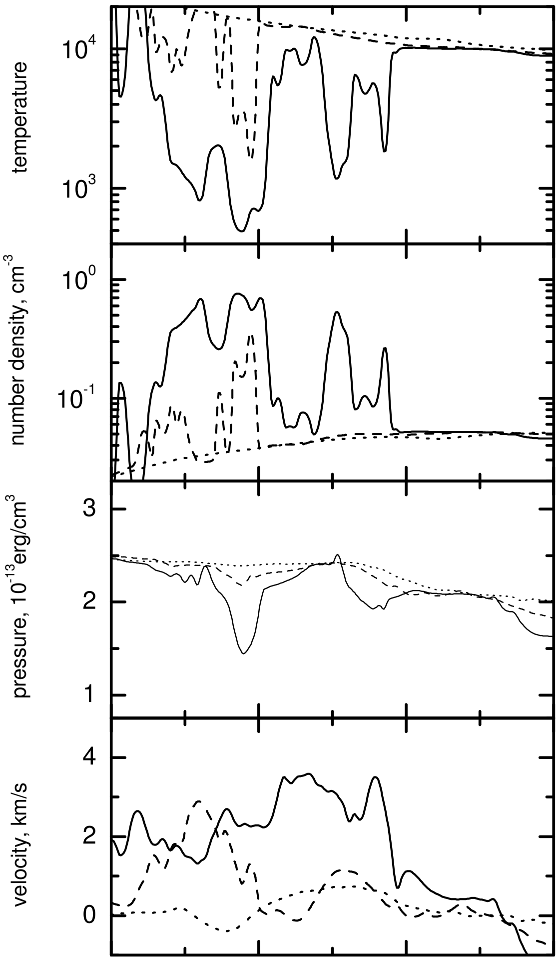

Figure 2: Temperature, density, pressure and velocity distributions for time 8×10^{13} between 5 and 20 pc along lines of sight at the distance from the axis of symmetry 1, 3 and 5 pc are depicted by solid, dashed and dotted lines, correspondingly.

neutral gas 10^{-3}, however, the influence of electrons on the brightness temperature is negligible. The velocity resolution of the spectra calculated here is 1 km s^{-1}. To calculate the total spin temperature along line of sight we find average harmonic value for each velocity interval (e.g. Kaplan, Pikel'ner 1963).

3. Results

Figure 1 presents the distribution of density at $t = 8 \times 10^{13}$ after the shock wave encounters the cloud. The cloud is destroyed onto many filaments stretched along the axis of symmetry. In most dense filaments n reaches ~ 1 cm^{-3}.

Figure 2 shows the disributions of temperature, density, pressure and velocity along three lines of sight (LOS) at distance 1, 3 and 5 pc from the axis of symmetry. The first LOS is rather close to the symmerty axis and crosses many filaments including cold and dense clumps. One can find a region with minimum temperature $\sim$ 500 K and density ~ 1 cm^{-3}. The pressure in the region is quite low, so that this clump will be further contracted in the direction of the line of sight. The more distant LOS passes through the postshocked medium with a small fraction or even without material from cloud, therefore we can distinguish features of the disrupted cloud from the postshock gas.

Figures 3 and 4 depict the 21 cm syntethic spectra and optical depth for the three lines of sight. For time $t = 8 \times 10^{13}$ s the brightness temperature and optical depth have clear maximum only for the first LOS. Indeed, this line crosses a group of clumps seen around $z = 10$ pc in Fig. 2. The velocity of the group is close to 3 km s^{-1}. Although the group reveals a complexity of the structure, the spectral features are relatively smooth. The largest parameters of spectral lines are: the brightness temperature is about 9 K, the extinction is ~ 0.006, the width of the line is ~ 5 km s^{-1}. These numbers are very similar to typical numbers for the so called "low-N(HI)" clouds (Braun & Kanekar 2005, Stanimirović & Heiles 2005). At later time $t = 1.2 \times 10^{14}$ s the brightness temperature and the extinction value decrease about half, while the line becomes wider, ~ 10 km s^{-1}. For the other two LOS the line is sufficiently broad without obvious spectral features. These LOS represent the postshock gas with a limited number of filaments.

We calculate column densities along one hundred lines of sight parallel to the axis of symmetry, with the velocity resolution 1 km s^{-1}. Figure 5 presents the simulated distributions for N(HI) along the whole set of lines of sight in all velocity intervals. The sample of the LOS is sufficiently complete in the sense that this distribution is stable against variations of the number of LOS. For $t = 8 \times 10^{13}$ s the number of spectral features decreases with column density sharply, so that

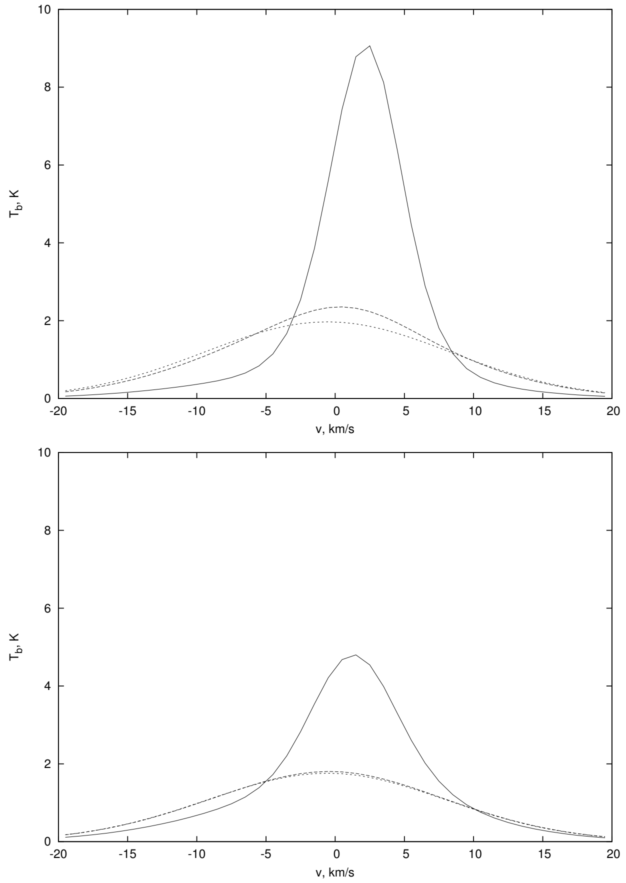

Figure 3: Brightness temperature along lines of sight at the distance from the axis of symmetry 1, 3 and 5 pc is depicted by solid, dashed and dotted lines, correspondingly. Upper panel is for $t = 8 \times 10^{13}$ s , lower – for $t = 1.2 \times 10^{14}$ s .

the most probable column density is $\sim 10^{18}$ cm^{-2}. At later time one can observe two well pronounced peaks in the N(HI) distribution; the average column density remains still close to the value at earlier times. This value almost coincides with the typical column density for “low-N(HI)” clouds Stanimirović & Heiles 2005. It is worth noting that the average column density weakly grows in time, however the increase over several cloud disruption times is rather small.

4. Conclusion

In this contribution we considered the physical and statistical properties of filaments formed during destruction of an interstellar homogenious cloud by a shock wave. We found that:

- small scale structures form during disruption of interstellar clouds by shock waves;

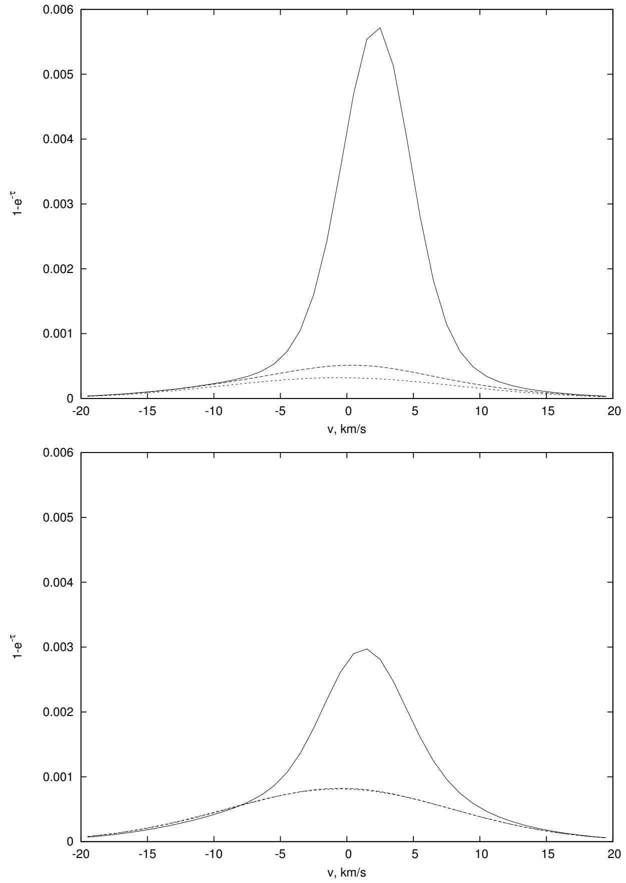

Figure 4: Optical depth along the same lines as in Figure 3.

- the 21 cm line profiles of small scale structures are close to the observed in the ISM at the lower end of column densities;

- the simulated column densities at intermediate times (a few dynamical times) are very close to the observed HI column densities in low-N(HI) clouds.

We can assume thus that the formation of small scale structures is a common feature of dynamical processes in the interstellar medium, and recently observed low-N(HI) clouds may be attributed to interstellar cloud destruction by shock waves from SNe.

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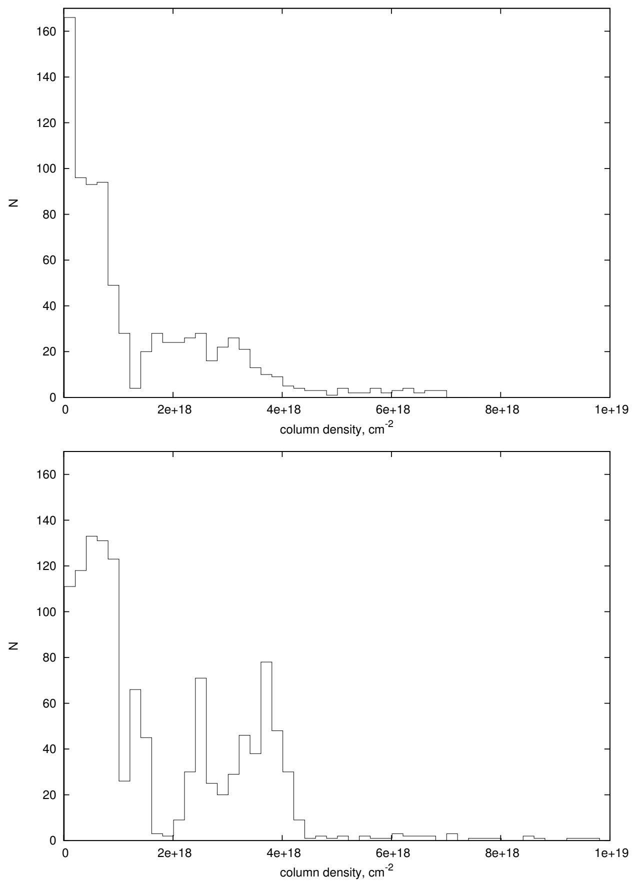

Figure 5: The distribution N(HI) for all line of sight for $t = 8 \times 10^{13}$ (upper) and $t = 1.2 \times 10^{14}$ (lower).

References

Braun R. & Kanekar N.: 2005, *Astron. Astrophys.,* **436L**, 53.

Dickey H. and Lockman F.: 1990, *Ann. Rev. Astron. Astrophys.,* **28**, 215.

Field G.B.: 1958, *Proc. IRE,* **46**, 240.

Heiles C., Troland T.: 2003, *Astrophys. J.,* **586**, 1067.

Heiles C., Troland T.: 2005, *Astrophys. J.,* **624**, 773.

Hennebelle P., Audit E.: 2007, *Astron. Astrophys.,* **465**, 431.

Hennebelle P., Audit E., Miville-Deschenes M.-A.: 2007, *Astron. Astrophys.,* **465**, 445.

Hollenbach D., McKee C. F.: 1989, *Astrophys. J.,* **342**, 306.

Kaplan S. A., Pikel'ner S. B.: 1963, *Mezhzvezdnaya sreda*, Moscow, *in Russian.*

Klein R.I., McKee C.F., Colella P.: 1994, *Astrophys. J.,* **420**, 213.

Kuhlen M., Madau P., Montgomeri R.: 2006, *Astrophys. J.,* **637L**, 1.

Kulkarni S. R., Heiles C.: 1987, *Interstellar processes*, /ed. Hollenbach D., Thronson H.

Liszt H.: 2001, *Astron. Astrophys.,* **371**, 698.

Stanimirovic S., Heiles C.: 2005, *Astrophys. J.,* **631**, 371.

Stanimirovic S., Heiles C., Kanekar N.: 2007, *ASP Conf. Ser.,* **365**, 22.

Stone J.M., Norman M.L.: 1992, *Astrophys. J.,* **390**, L17.

Vietri M., Ferrara A., Miniati F.: 1997, *Astrophys. J.,* **483**, 262.