3D MHD MODELING OF THE GALAXY.

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Abstract

We show the results of our 3D MHD simulations of the flow of the Galactic ISM into a spiral perturbation in the potential. The gas shoots up before the arm, flows over, and falls behind as it approaches the next arm. This hydraulic jump behavior is a consequence of the extra stiffness that the magnetic field adds to the gas flow. We also show synthetic $l-v$ and $v-b$ diagrams for an imaginary observer inside our modeled galactic disk.

Keywords: ISM: kinematics and dynamics — MHD — galaxies: spiral, structure

1. Introduction

Recent changes in our view of the galactic ISM have forced us to take another look at problems galactic structure that we thought were already solved. One of such problems is the spiral structure of disk galaxies. Early work showed that the gas should present only a small amount of vertical motion triggered by the encounter of the flow with the spiral arms. Today, we know that the non-thermal components of the ISM pressure are likely to dominate over the thermal component, yielding a medium that is less compressible than previous models accounted for. The extra stiffness that these pressures add to the medium forces it to react in a different way, as it was shown in [4]. The gas actually develops a combination of a shock and a hydraulic jump.

In this work, we extended those simulations to three dimensions and included a large fraction of the galactic disk, in order to look for global trends. Also, we looked for the observational signature of the model by generating synthetic observations.

2. The simulations.

We performed three-dimensional MHD simulations using the code ZEUS to model the ISM response to a spiral gravitational perturbation. The gas starts in vertical and radial hydrostatic equilibrium, following the circular orbits defined

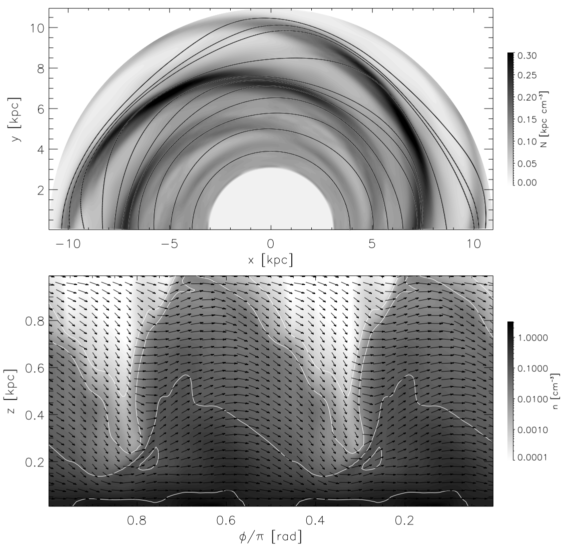

Figure 1. Structure of the four-arm case after 800 Myr. In the upper panel, the grayscale shows the half-disk column density, and the lines show the integrated pattern frame velocity field in the midplane. In the lower panel, the grayscale shows a density cut along a cylindrical surface at $r = 8$ kpc with contours at each decade, down from $n = 1$ cm^{-3}. The arrows show the velocity field component parallel to that surface, in the pattern reference frame. Since ours is a trailing spiral, the gas flows clockwise in the upper panel, and from left to right in the lower one.

by the background gravitational potential,the pressure gradient (thermal plus magnetic), and the magnetic tension. The equation of state for the initialization is isothermal with a temperature $T = 10^4$ K. The calculation is performed in the reference frame of the spiral perturbation, which moves with an angular velocity of 12 km s^{-1} kpc^{-1}. The perturbation locus is a logarithmic spiral.

Figure 1 shows the structures of our four-arm model after 800 Myr. As the gas enters the arm, a combination of a shock and a hydraulic jump is formed. The extra stiffness the magnetic field adds to the ISM makes the gas jump over the obstacle the spiral arm represents. The gas shoots up before the arm, forming an forward leaning shock, and falls back down after the arm, generating a secondary shock. In isothermal cases with no magnetic field [1], there is much less vertical motion, the forward shock is nearly vertical, and there is no secondary shock.

3. Synthetic observations.

In Figure 1 the arms seem to be discontinuous. Each of the sections follows a spiral tighter ($11^{\rm o}$ pitch angle) than the perturbation. This pitch angle has the

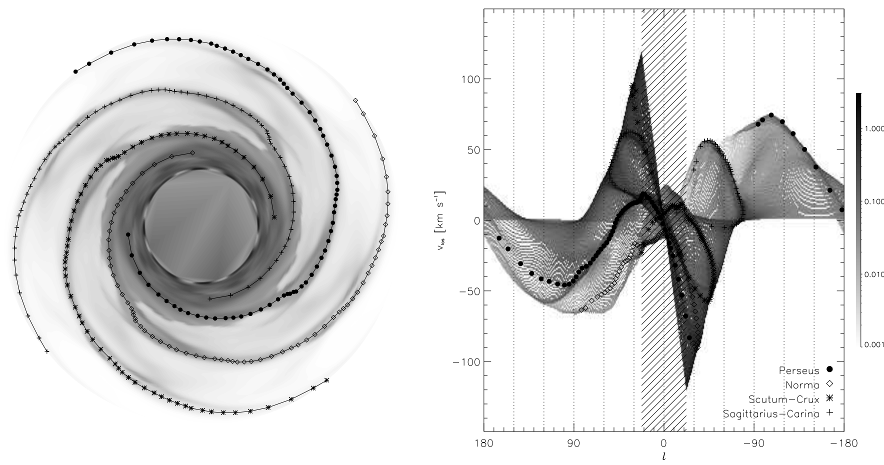

Figure 2. $Left$: Loci of the spiral arms traced by fitting a sinusoidal function to the vertical column density, for each radius. The grayscale is the midplane density of the model. $Right$: $l - v$ diagram for $b = 0^{\rm o}$, with the spiral arms from the left panel traced on it. The shaded region marks the "hole" in our simulation grid. Many features of the observed $l - v$ diagrams are reproduced: the asymmetry in the inner rotation curve, the non-zero mean velocity in the $l = 180^{\rm o}$ direction, and the high column density ridges, usually associated to spiral arms. Notice that not all the ridges correspond to arms, and not all the arms trace back to ridges.

advantage that the resulting arms are a good approximation to the Milky Way's spiral arms as traced in [5].

The right panel of Figure 2 shows a longitude-velocity diagram, as seen by an observer situated 8 kpc from the galactic center. When we can trace the gaseous spiral arms into the simulated $l - v$ diagram, we notice that most of the ridges correspond to spiral arms, although the relation is not one-to-one. For example, around $l = 120^{\rm o}$, at the Perseus arm, the line of sight goes through a large velocity gradient, which spreads the arm in velocity space.

Figure 3 shows the $v - b$ diagram for the $l = 75^{\rm o}$ direction. Such line-of-sight crosses the Perseus arm at a projected velocity $v \sim -30$ km s^{-1} and the Norma arm at $v \sim -60$ km s^{-1}. This diagram shows structures consisting on a relatively narrow, horizontal column with large vertical wings on the left edge of the column. When the vertically thin interarm gas encounters the spiral arm, it decelerates rapidly. That velocity gradient spreads the gas structure along the horizontal axis of the $v - b$ diagram, creating the horizontal column structure in the midplane. Moving farther away from the observer, we have the vertically swelled structure of the arm itself, which appears in Figure 3 as the high latitude wings. Between $b \sim 5^{\rm o}$ and $7^{\rm o}$, the gas is speeding up above the arm increasing its line-of-sight velocity, causing the wings to slightly bend

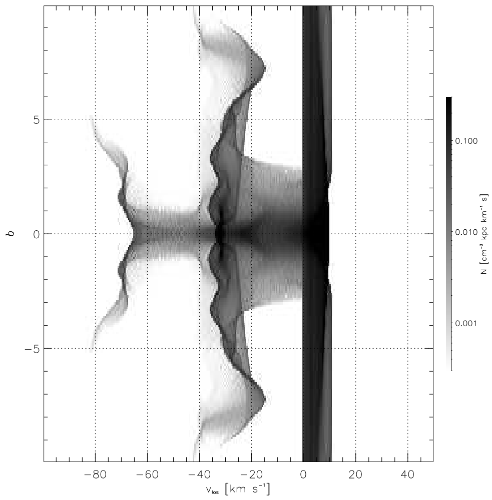

Figure 3. $v - b$ diagram along $l = 75^{\mathrm{o}}$. The horizontal column-and-wings shapes are consequences of the three dimensional structure of the spiral arms, as discussed in the text.

back over the column. This column-and-wings structure appears to be present in the Leiden/Dwingeloo HI survey.

Further discussion of this model and its observational consequences can be found in [2] and [3].

References

[1] Gómez, G. C. and Cox, D. P. 2002, ApJ, 580, 235

[2] Gómez, G. C. and Cox, D. P. 2003, ApJ, *submitted*

[3] Gómez, G. C. and Cox, D. P. 2003, ApJ, *submitted*

[4] Martos, M. A. and Cox, D. P. 1998, ApJ, 509, 703

[5] Taylor, J. H. and Cordes, J. M. 1993, ApJ, 411, 674

4. Discussion

Bania: Can your model launch clouds to velocities $\sim$ 50 km s^{-1} beyond $v_{terminal}$, i.e., make clouds like the ones Lockman is now seeing with the GBT?

Gómez: These models have not generated such large velocities, so far. Also, we do not have enough resolution to say anything about clouds like those.

Mac Low: The 50 km s^{-1} clouds of Lockman are probably due to the SN-driven Galactic fountain acting *on top of* the dynamics shown in this talk.