MHD simulations of ram pressure stripping of a disk galaxy

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Abstract

The removal of the ISM of disk galaxies through ram pressure stripping (RPS) has been extensively studied in numerous simulations (Vollmer et al. 2001, Roediger & Brüggen 2008, Tonnesen & Bryan 2009, 2010). These models show that this process has a significant impact on galaxy evolution (the truncation of the ISM will lead to a decrease in the star formation and the galaxy will become redder). Nevertheless, the role of the magnetic fields (MF) on the dynamics of the gas in this process has been hardly studied, although the influence of the magnetic fields on the large scale structure is well established. This motivated us to perform a 3D simulation of a disk galaxy with an isothermal, non-self gravitating and magnetized gaseous disk in hydrostatic equilibrium with the galaxy potential. The galaxy experiences the RPS under the wind-tunnel approximation in order to understand the effects of magnetic fields in ram pressure stripping.

Model

We performed a 3D MHD simulation using the AMR code RAMSES (Teyssier 2002) in a 120 kpc box. The gas is assumed isothermal with $T = 10^4$K and non-self gravitating and is set up in rotational equilibrium with a potential similar to the Allen & Santillan (1991) (modified to emulate an M33-like galaxy), the centrifugal force, the thermal and magnetic pressure gradients and the magnetic tension. To obtain the gas distribution in the disk, we define the density profile in the midplane ($z = 0$) and then we assume hydrostatic equilibrium to solve the density distribution at any z (Gómez & Cox 2002). The magnetic field is azimuthal and its magnitude depends on the gas density. For comparison, we ran a hydro (HD) simulation ($B = 0$) with the same set up for the ICM and the gas disk.

References

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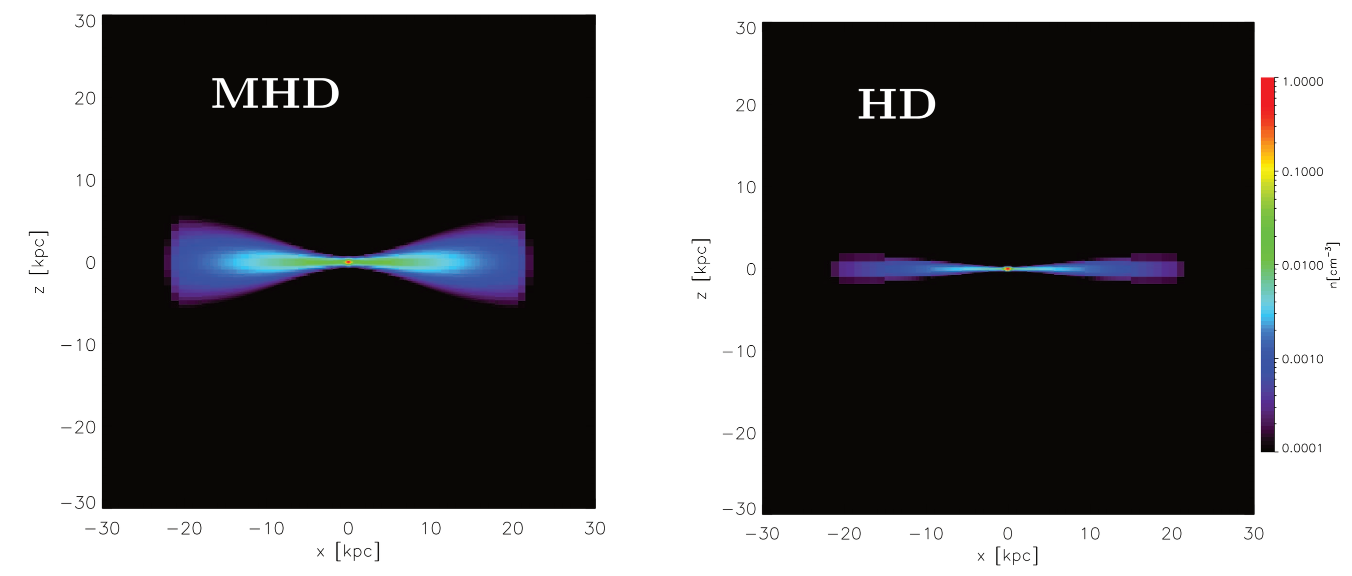
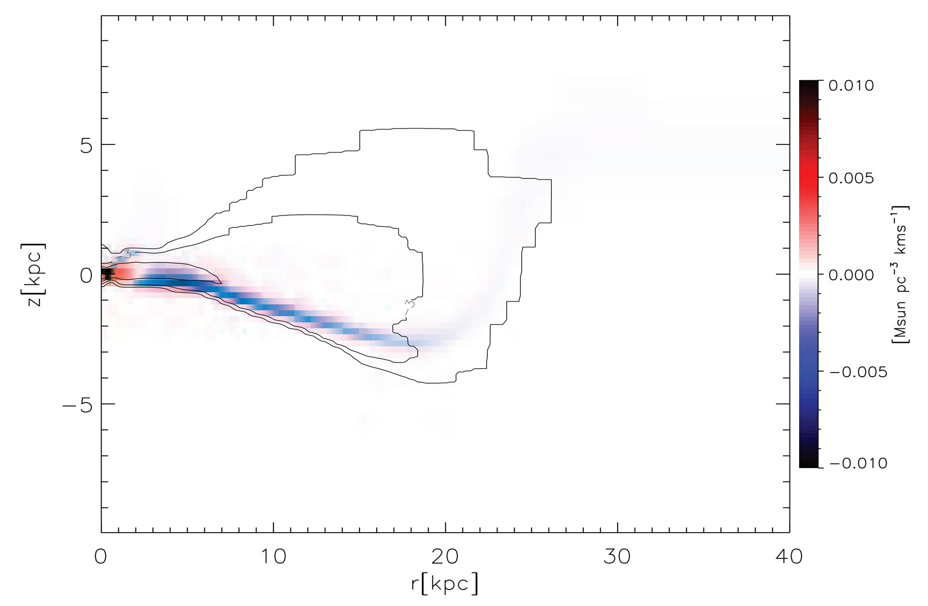
Initial condition

Density maps of the gas disk for the initial condition at $y = 0$ for the MHD (left) and HD (rigth) models. The MHD disk is thicker in the outskirts than in the center of the galaxy, showing a "bow tie" shape due to the presence of the MF, whilst the HD disk is thinner and has a nearly constant height. The ICM has $n = 10^{-5}\,\mathrm{cm}^{-3}$ and its velocity grows linearly in time, from $300\,\mathrm{km\ s}^{-1}$ at $t = 0$ to $1000\,\mathrm{km\ s}^{-1}$ in 700 Myr.

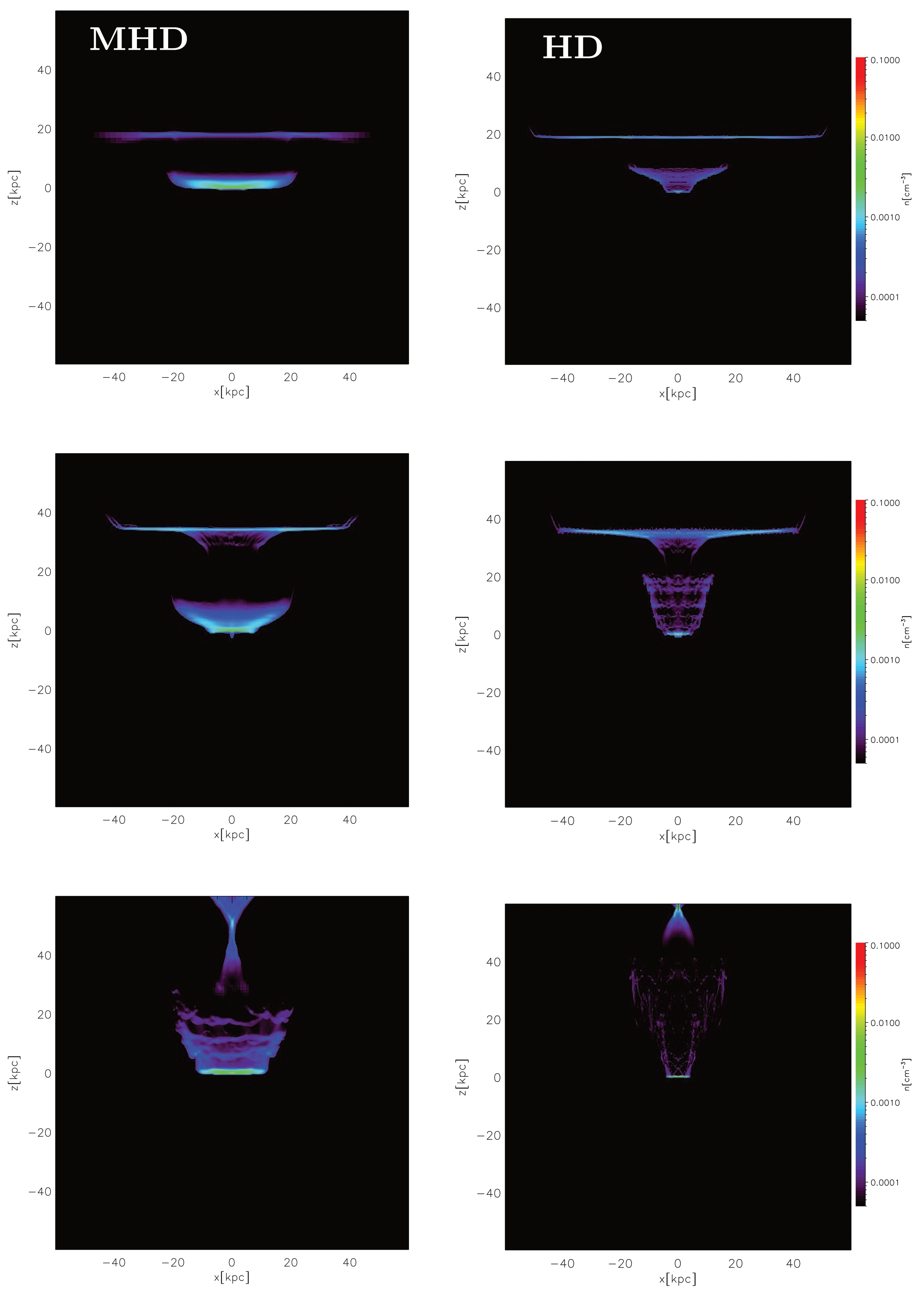


Oblique shocks

Since the MHD disk is flared due to the MF, oblique shocks are produced at the face of the ICM-ISM interaction. The shocks generate an inflow of gas towards the galactic center. Nevertheless, this phenomenon is present in earlier times of evolution and stops when the wind sweeps the gas disk. The figure shows the flux calculated at 100 Myr, with blue representing gas moving to the galactic center and red is gas moving away, with the gas density overlaid black in contours.



Evolution



The figures show the proyected gas density at $t = 190$ Myr (top), $t = 310$ Myr (middle), $t = 500$ Myr (bottom) for the MHD (left) and HD (right) runs. At $t = 90$ Myr, for the MHD run most of the gas in $z < 0$ was swept by the wind which starts to erode the disk at large radii. The HD model shows a bit denser gas tail at higher z, and the erosion is stronger in r than in the MHD. In the MHD run at $t = 310$ Myr the gas at $r > 10$ kpc is ripped off of the galaxy and there is a more prominent gas tail, with longitude ~ 20 kpc. The HD run at this time has a slightly longer tail, with longitude > 20 kpc, and narrower than the MHD and the gas disk has a radius of $r \sim 5$ kpc. At $t = 500$ Myr, for the MHD run, between $0 < z < 20$ kpc, the gas tail is narrower with a height of ~ 20 kpc above the midplane, and a smooth appearence. Also the disk has been truncated to $r \sim 10$ kpc. The HD model has tail with a height of ~ 40 kpc, and a more filamentary structure than the MHD one and the HD disk is truncated to a smaller radius ($r \sim 4$ kpc): ram pressure stripping is more efficient in a non-magnetized disk.

Disk truncation

The column density perpendicular to galactic disk is shown at different times for the MHD (left) and HD model (right). The MHD disk remains unperturbed at $t \sim 200$ Myr, then at $t \sim 300$ Myr the wind removes the gas and truncates the disk to $r \sim 10$ kpc having this configuration at $t = 500$ Myr. The HD disk is thinner, hence is perturbed earlier: $r \sim 6$ kpc in 200 Myr. For $t = 500$ Myr, the HD disk is eroded more efficiently than the MHD one, showing a truncated disk with $r \sim 4$ kpc, even for later times.