Galaxy Simulations with Magnetic Field

A. Konstantinou[1,2], E. Ntormousi[2,3], K. Tassis[1,2], A. Pallottini[3], D. Decataldo[3,4], A. Ferrara[3]

[1] Department of Physics, University of Crete, Voutes, 70013 Heraklion, Greece
[2] Institute of Astrophysics, Foundation for Research and Technology-Hellas, Voutes, 70013 Heraklion, Greece
[3] Scuola Normale Superiore, Piazza dei Cavalieri, 7 56126 Pisa, Italy
[4] Institute of Theoretical Physics, University of Oslo, Sem Sælands vei 13 Svein Rosselands hus, 0371 Oslo

Introduction

Magnetic fields play a crucial role in galaxy evolution because they can influence all the essential processes taking place in it, including star formation, the expansion of feedback regions, and the propagation of cosmic rays. Since the galaxy evolution studies cannot be complete without the inclusion of magnetization, our goal is to explore its role in a wide variety of galaxies with different masses, metallicities and star formation efficiencies in order to identify the secular processes responsible for driving a galactic dynamo.

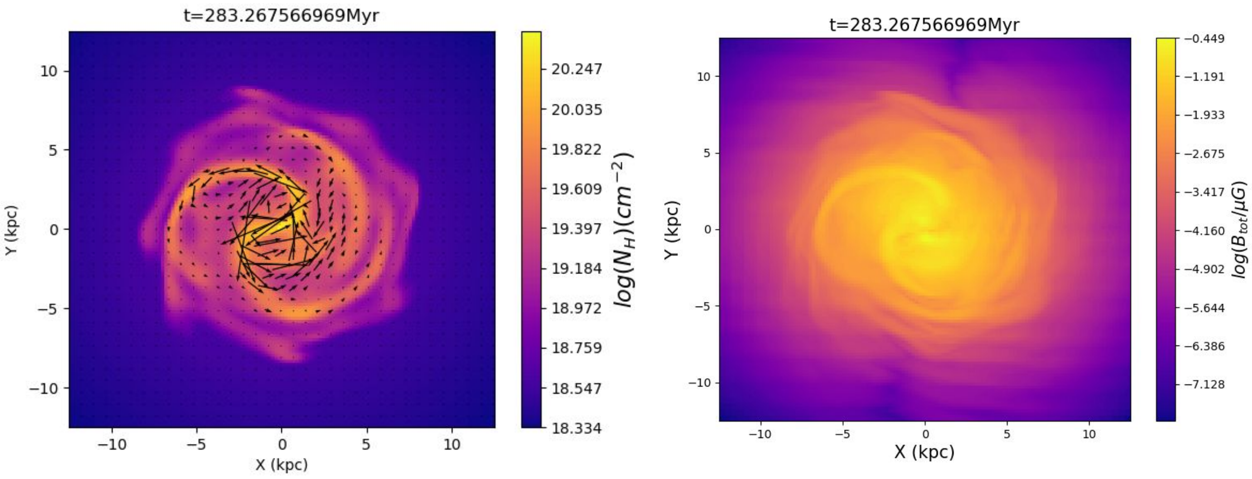

Figure 1: Face on maps of a spiral galaxy simulation with RAMSES at t≈283 Myr (z=0) with a toroidal magnetic field. We show the column density of the gas with the magnetic field lines (left) and the total magnetic field (right).

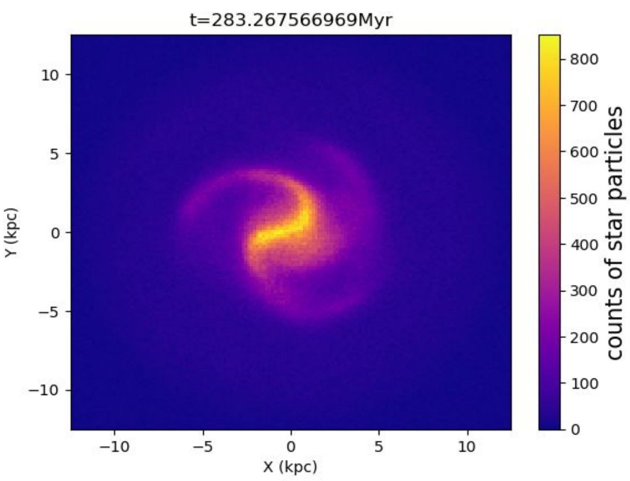

Figure 2: The same galaxy snapshot as in Fig.1, showing the distribution of star particles.

Methods

We run magnetohydrodynamic (MHD) simulations of galaxies and Giant Molecular Clouds (GMCs) using the RAMSES Adaptive Mesh Refinement (AMR) code (Teyssier, 2002; Fromang, Hennebelle and Teyssier, 2006). All the relevant physics for galaxy evolution is included: dark matter and stars, represented by collisionless particles, and a multi-phase gaseous disk, treated as a magnetized fluid. We use a custom version of the RAMSES code that follows the chemistry of H_2 formation and dissociation through the KROME package (Grassi et al. 2014). We create the initial conditions of the spiral galaxies using the DICE code (Perret 2014).

Initial Conditions

- Virial mass: 10^{10} $M_\odot$
- Redshift (z): 0
- Dark Matter Halo: 97.5%
- Stellar Disk: 1.425%
- Gaseous Disk: 0.075%
- Gaseous Halo: 1%

Effects of sub-grid star formation and feedback modelling

One of our first findings is that the sub-grid models for star formation and supernova feedback currently implemented in RAMSES are not ideal for studying the evolution of the magnetic field. Specifically, we discovered a numerical artifact of the particle-based star formation algorithm on the magnetic field evolution.

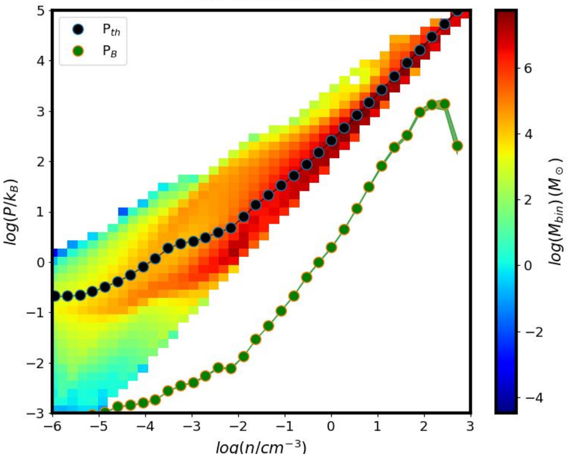

Figure 3: Gas-phase diagram of a galaxy simulation with RAMSES in the form of 2D mass-weighted histograms in the log pressure-log density space. The black dots indicate the mean thermal pressure, and the green dots the magnetic pressure per density bin.

Galaxy models with star formation turned on, present a sudden drop in the magnetic pressure in the high-density gas by at least two orders of magnitude compared to the same regimes in simulations without star formation (Figure 3).

We investigated the origin of this artifact by studying the effect of a single stellar particle forming at the center of a control numerical volume. Figure 4 shows the results of this experiment: there is a clear change in magnetic pressure at the particle creation site as we increase the mass of the star.

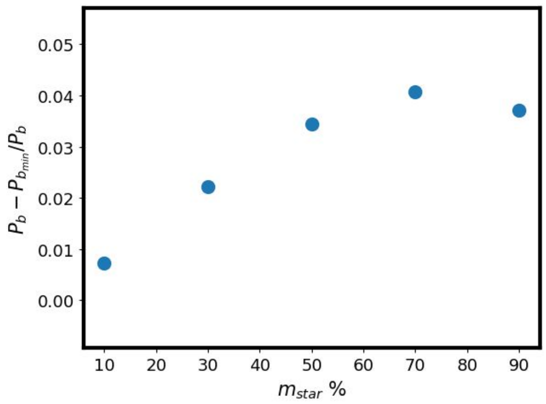

Figure 4: Decrease of the magnetic pressure as a function of the percentage of stellar mass in the cell.

Future plans

- Investigation of the effects of SN delay and early feedback on the magnetic field evolution in the GMC.
- Simulations of three galaxies using KROME with and without feedback and different SN delays.
- Study of the magnetic field evolution in galaxy mergers.