Magnetic Fields in Galaxies

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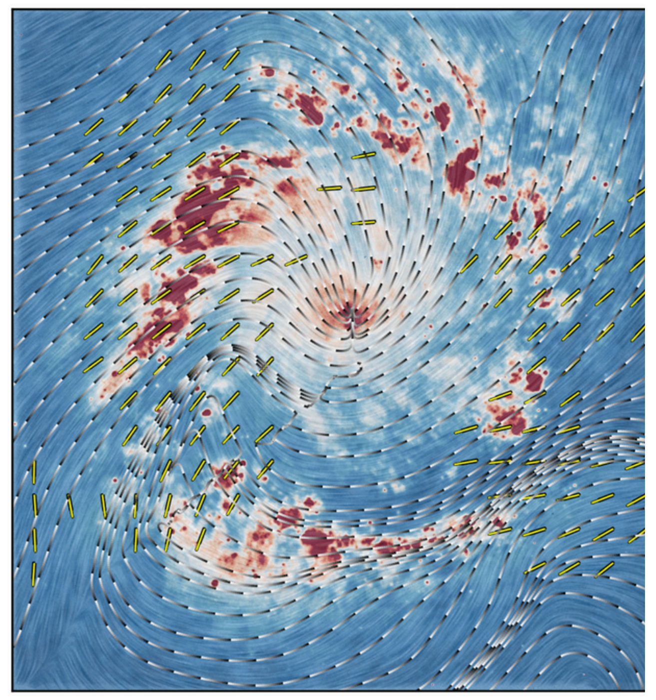
Background

Magnetic fields play an important role in the evolution of galaxies. An initial weak magnetic field seeded by some mechanism, like the Biermann Battery or Weibel instability, is thought to have been amplified by dynamos--the conversion of kinetic energy to magnetic energy [1]. Although present-day magnetic fields can be measured using observational tracers like synchrotron emission, we cannot observe how they evolve.

[2]

Starburst ring of NGC 1097: B-field orientation and direction within



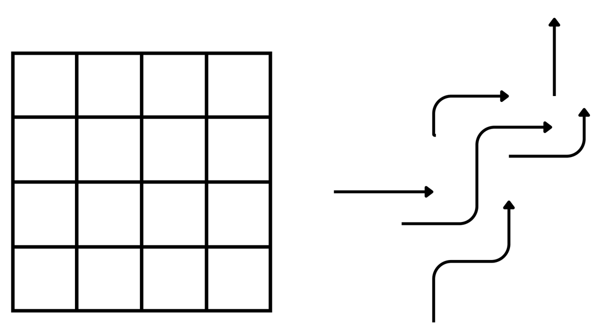
Magnetohydrodynamic (MHD) simulations allow us to make synthetic observations of their evolution by simulating the motion of ionized gas in the presence of magnetic fields.

Objectives:

- Compare simulation results obtained using three MHD codes: **ART**, **RAMSES**, and **AREPO**
- Use packages, like yt, to analyze data from isolated gas disk simulations run using the same initial conditions

Codes Used in this Project

Code	Mesh	Divergence Cleaning Scheme
ART	Cartesian AMR	Dedner [5]
RAMSES	Cartesian AMR	Constrained Transport [6]
AREPO	Voronoi	Powell [7]



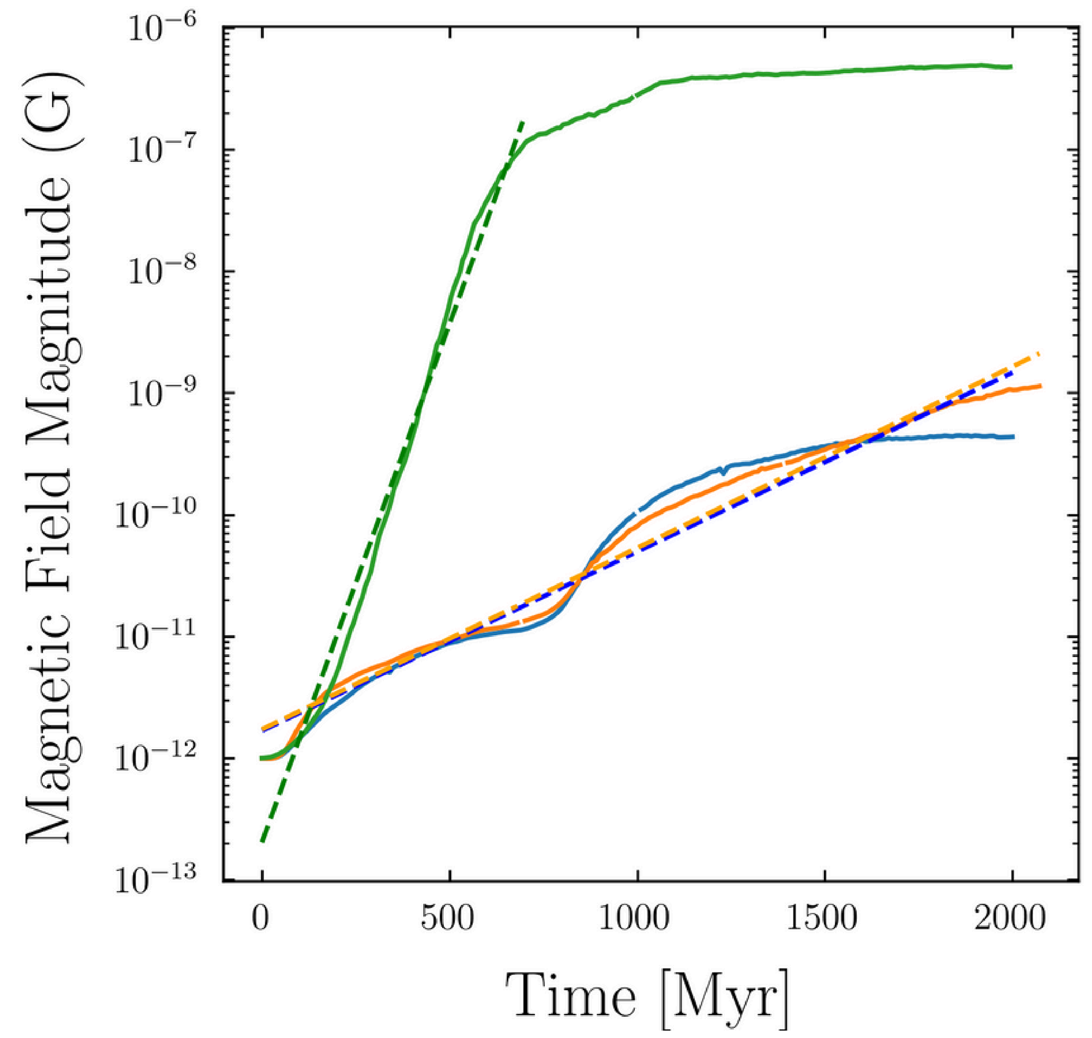
[3][4]

$$\nabla \cdot \mathbf{B} = 0$$

Eulerian vs. Lagrangian approaches to discretization

Results

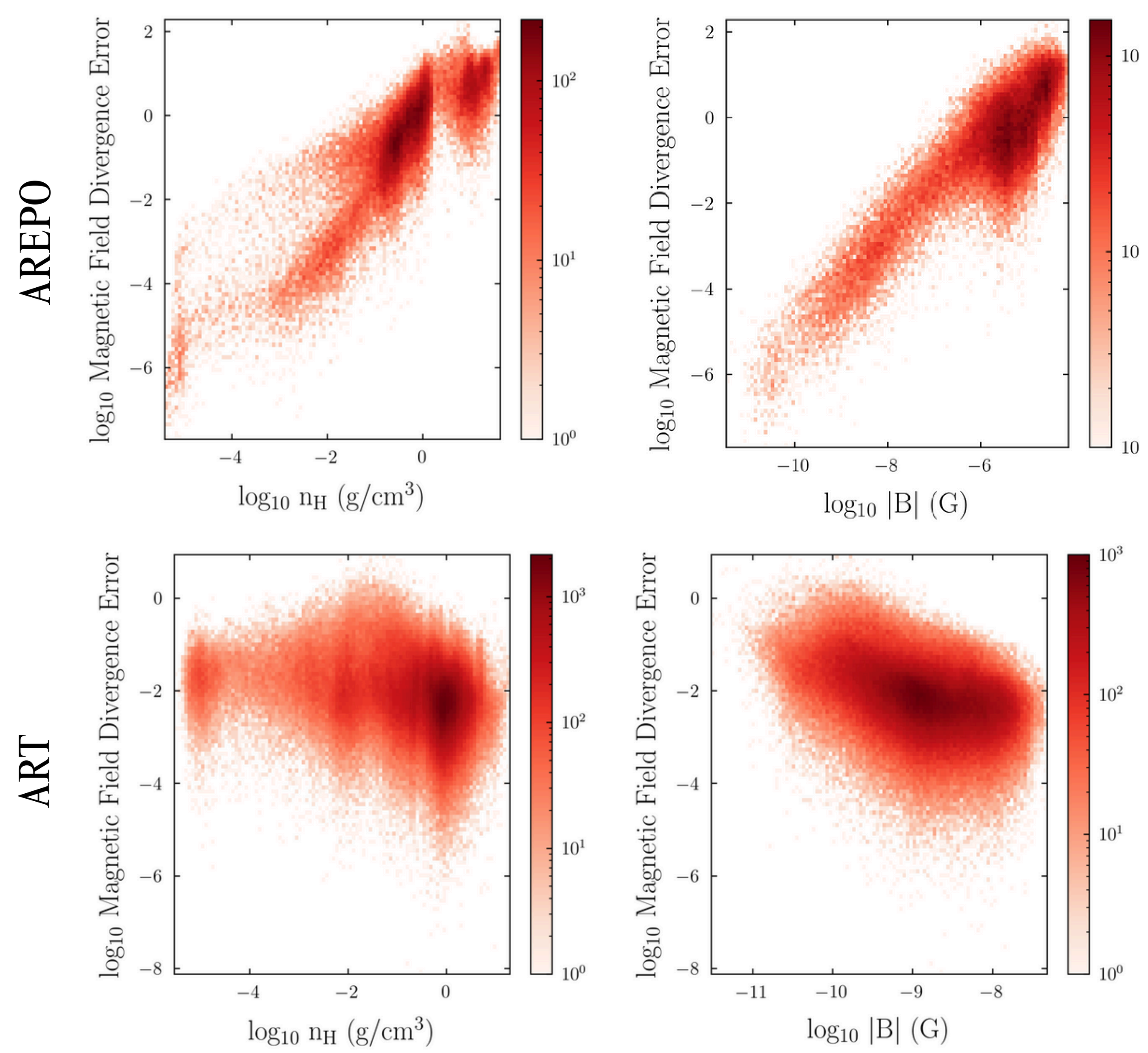
Average Magnetic Field Strength



We observed a difference in the saturation level of the average magnetic field strengths. The field strength saturates at a level three orders of magnitude greater in AREPO than in ART and RAMSES.

The average magnetic field strength we measure within 30 kpc from the galactic center in our AREPO simulation grows six times faster than in ART or RAMSES.

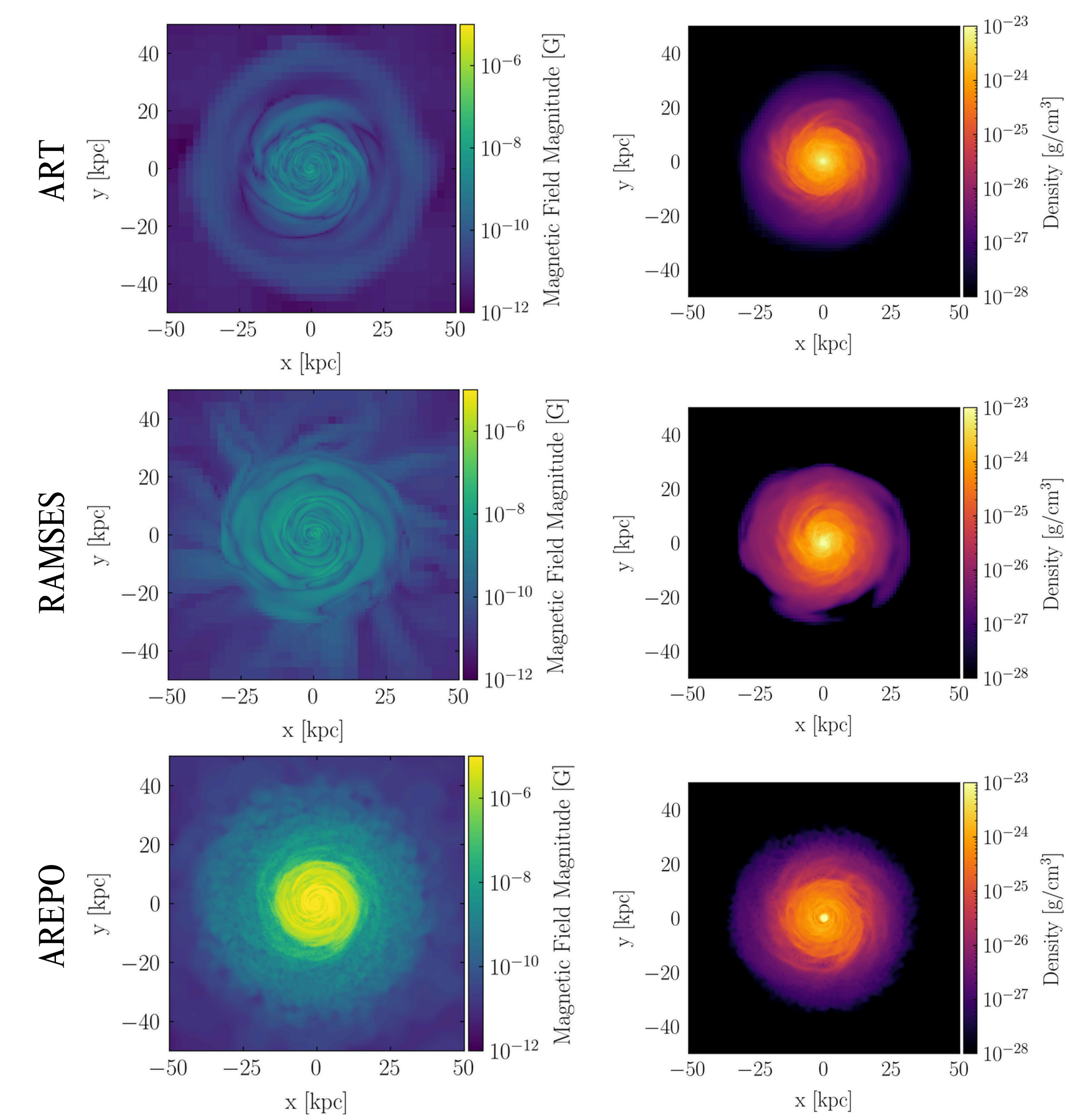
Dimensionless divergence error



A positive correlation exists between the divergence error and the magnetic field magnitude and gas density for AREPO.

For ART, there is a slightly negative correlation between the divergence errors and density and magnetic field.

Slice Plots at 2 Gyr (x 10^9 year)



Summary

- The magnetic field strength measured in the simulation run using quasi-Lagrangian/moving mesh code AREPO amplifies at a faster rate and saturates at a higher level compared to Eulerian codes ART and RAMSES
- Future studies could stellar feedback or compare with another Lagrangian code (SWIFT)

References

1. Bradenburg and Ntormousi (Annu. Rev. Astron. Astrophys 2023)
2. Lopez-Rodriguez et al. (The Astrophysical Journal 2021b)
3. Teyssier (Astronomy and Astrophysics 2002)
4. Springel (Monthly Notices of the Royal Astronomical Society 2010)
5. Dedner et al (Journal of Computational Physics 2001)
6. Evans and Hawley (Astrophysical Journal 1988)
7. Powell et al (Journal of Computational Physics 1999)