Magnetic fields in disk galaxies

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Magnetic fields

- Present-day disk galaxies have equipartition magnetic fields that are dynamically relevant today
- Magnetic fields are crucial for many anisotropic transport processes (CRs, thermal conduction, viscosity, …)

Questions

- What is the origin of the present-day galactic magnetic fields?
- What determines the strength and structure of galactic magnetic fields?
- How do galactic magnetic fields evolve over time?

The Auriga project

The code

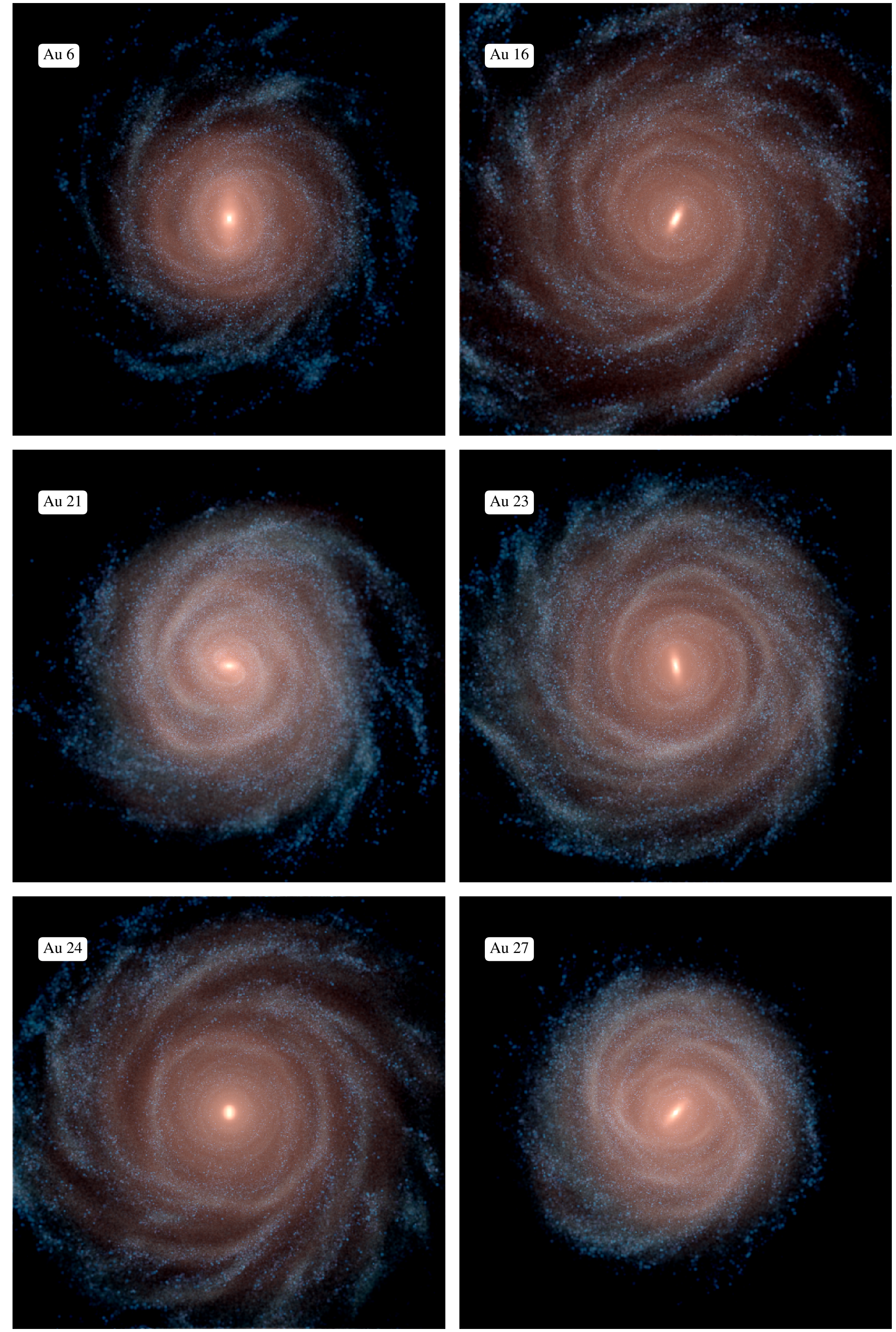
- *AREPO* - moving mesh code (Springel 2010)
- Second order hydro solver (Pakmor+2016)
- **Ideal MHD** (Pakmor+2013)
- Zoom initial conditions

The galaxy formation model

- Primordial and metal line cooling
- Sub-resolution model for star formation (Springel+03)
- Mass and metal return from stars to ISM
- Cold dense gas stabilised by pressurised ISM
- Thermal and kinetic energy from Supernovae modelled by isotropic wind - launched outside of SF region
- Black Hole seeding and accretion model (Springel+05)
- Thermal feedback from AGN in radio and quasar mode
- **Uniform magnetic field of 10^{-10} G seeded at z=128**

Simulation suite (Grand+2016)

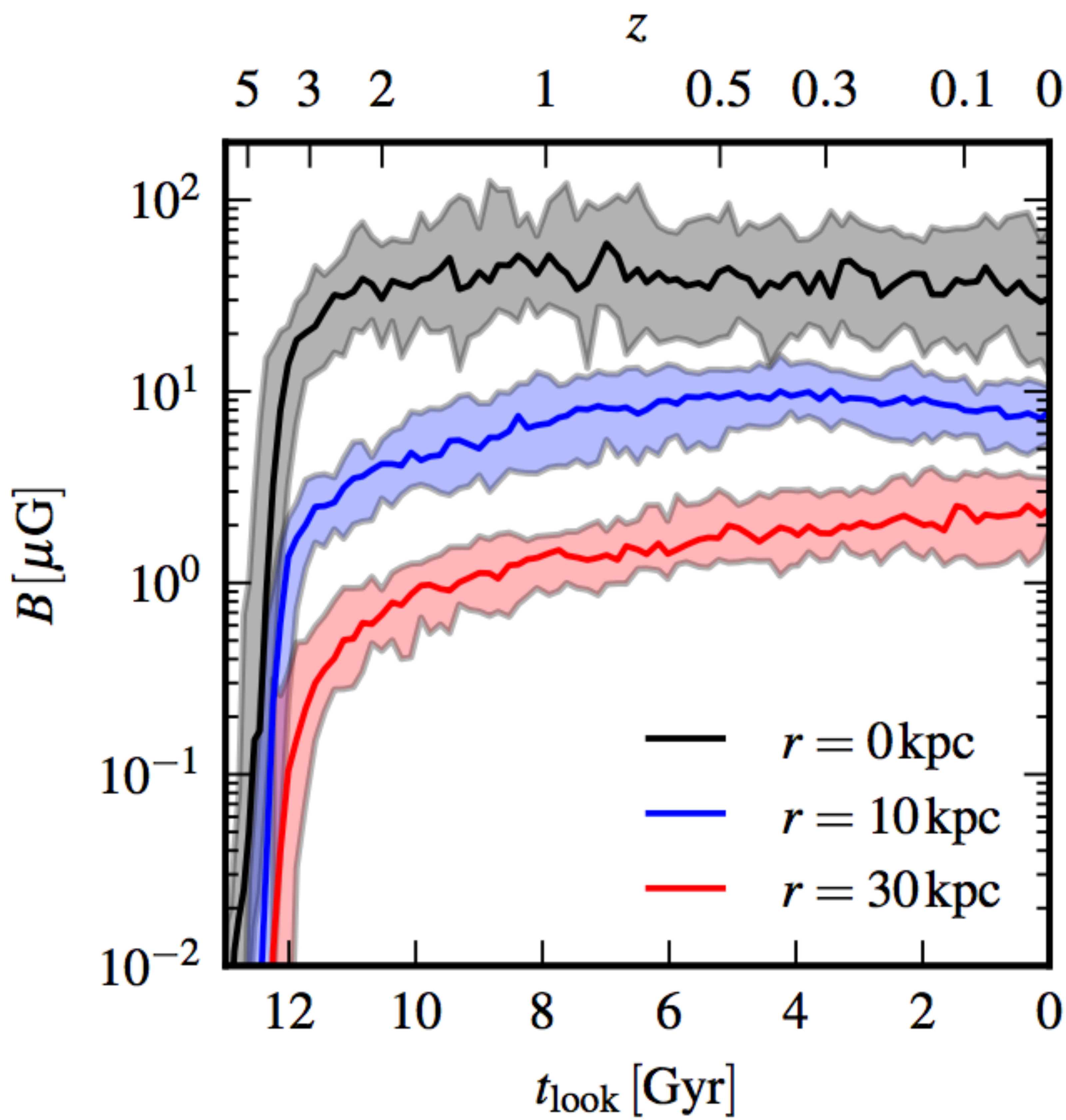
- 30 galaxies @lvl4, baryons 50000 $M_\odot$
  ~5M resolution elements in halo, 2M star particles
- **6 galaxies @lvl3, baryons 6000 $M_\odot$**
  ~50M resolution elements in halo, 15M star particles



Magnetic field amplification

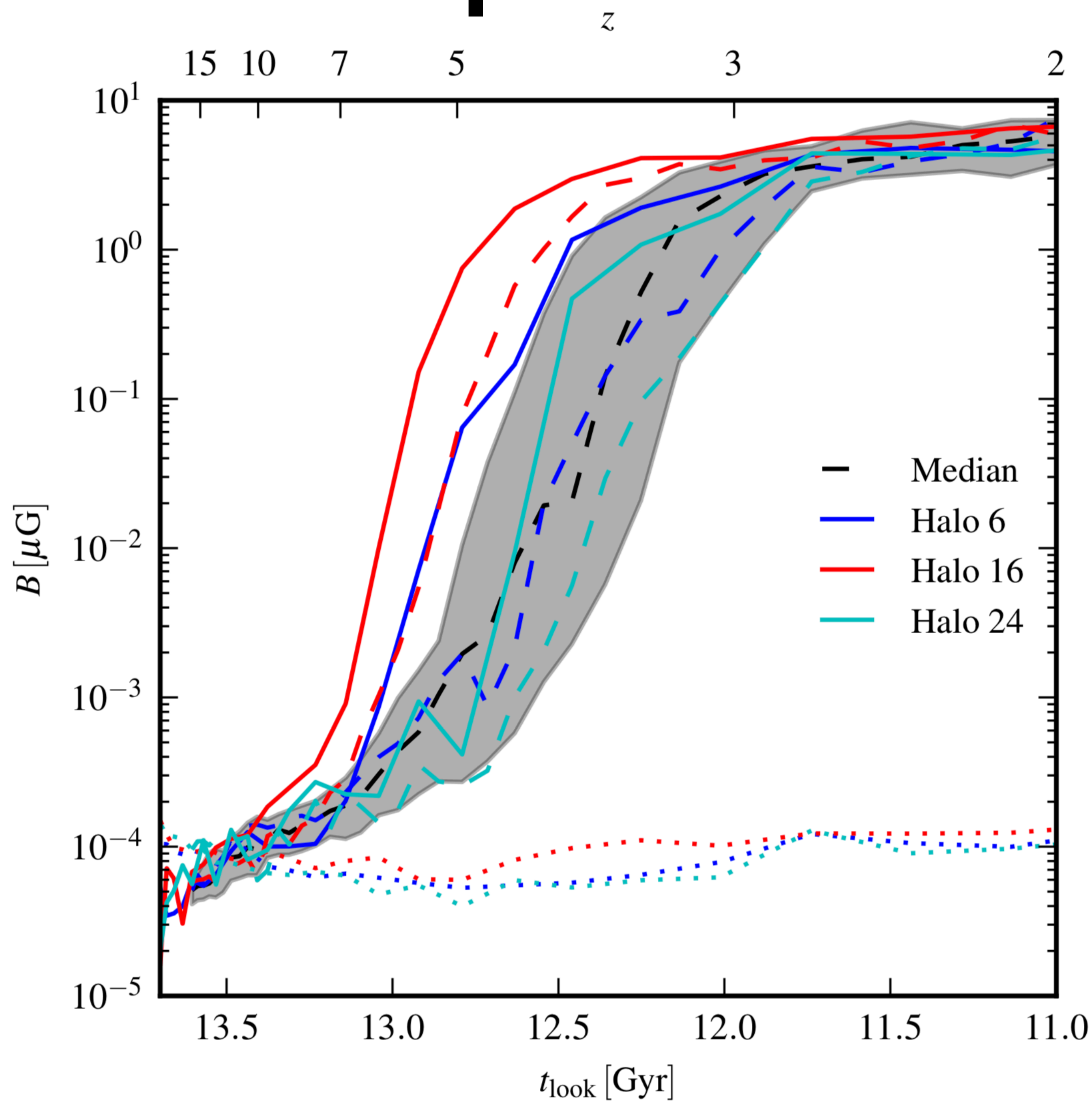
Amplification in two phases:

- Exponential amplification in early phase z < 3
- Linear amplification in later phase 2 < z < 0
- No linear amplification in the center of the disk

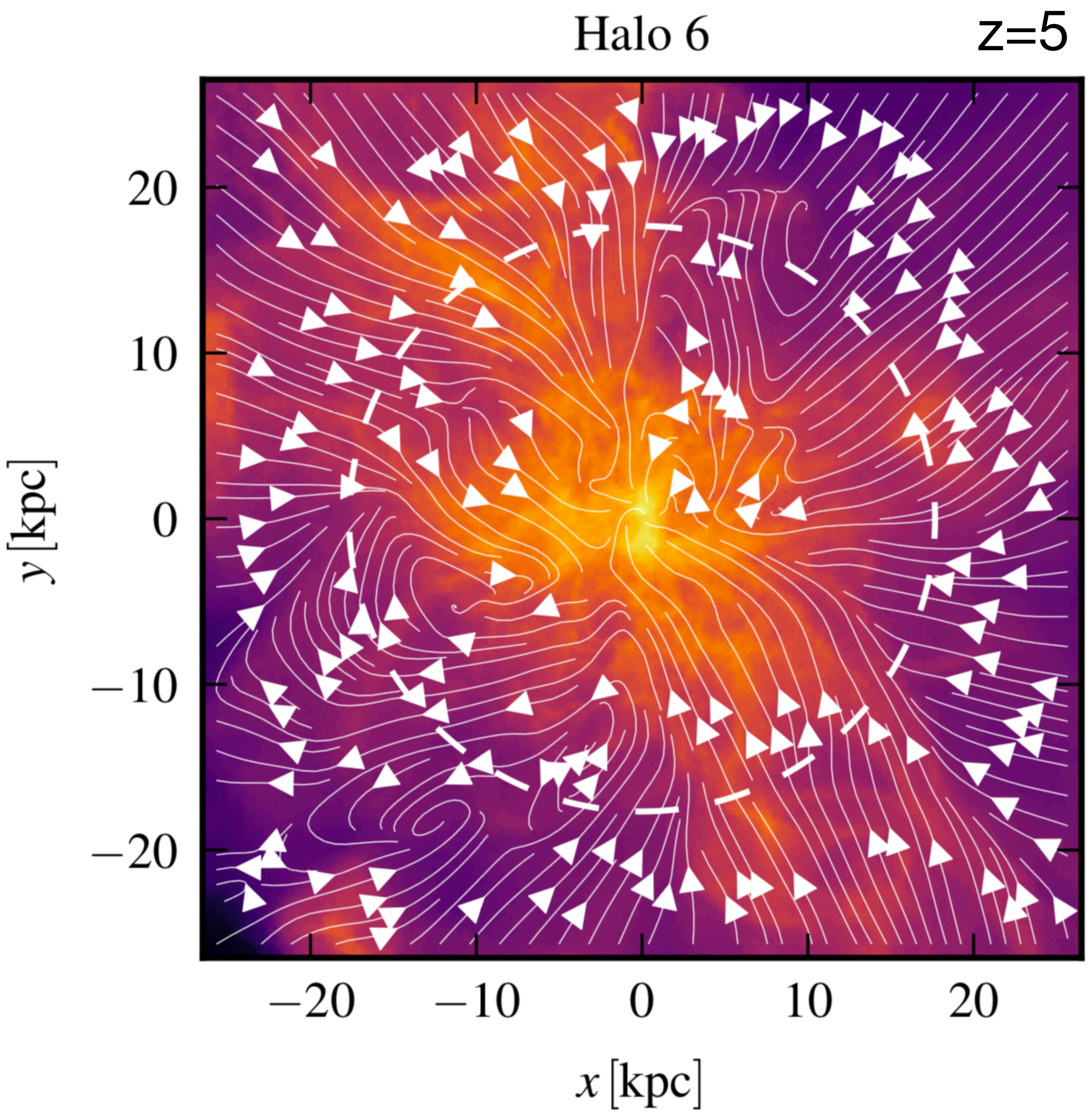


Magnetic field amplification

- Amplification far beyond adiabatic contraction
- Exponential amplification starts around z~7
- Saturation reached around z=3-2
- Faster amplification at higher resolution

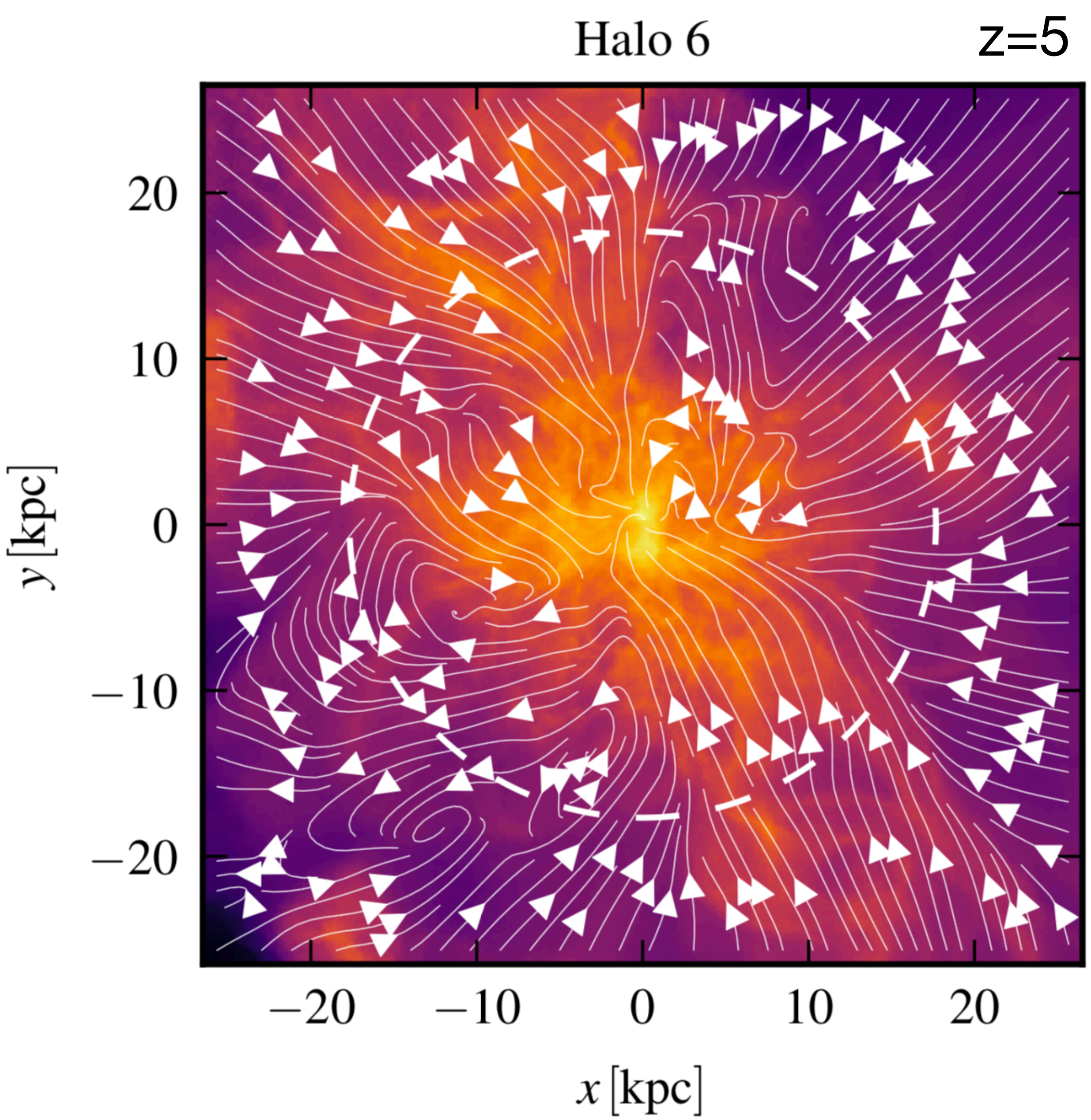


Turbulent dynamo

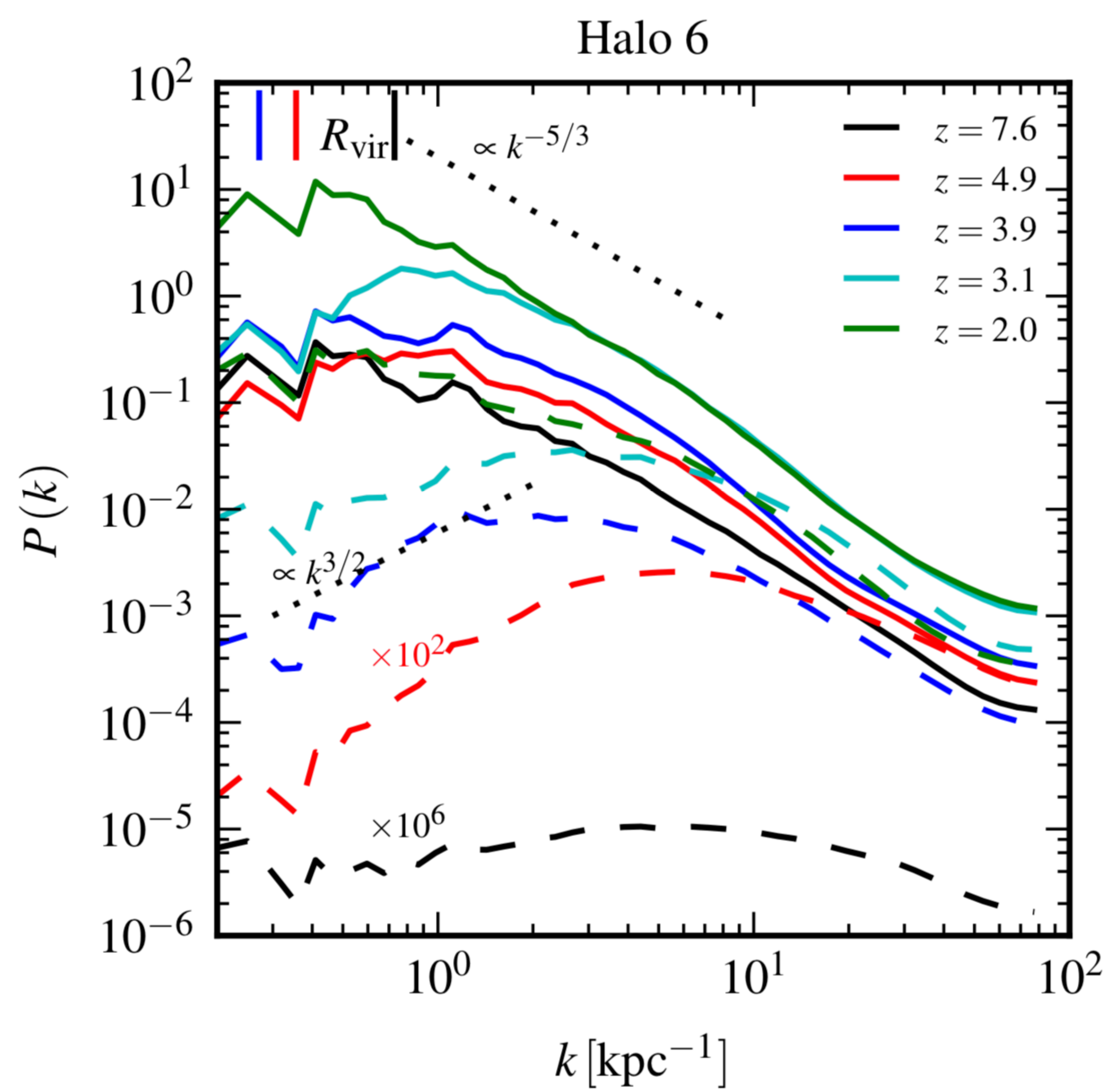


Column density overlaid with velocity field

Turbulent dynamo



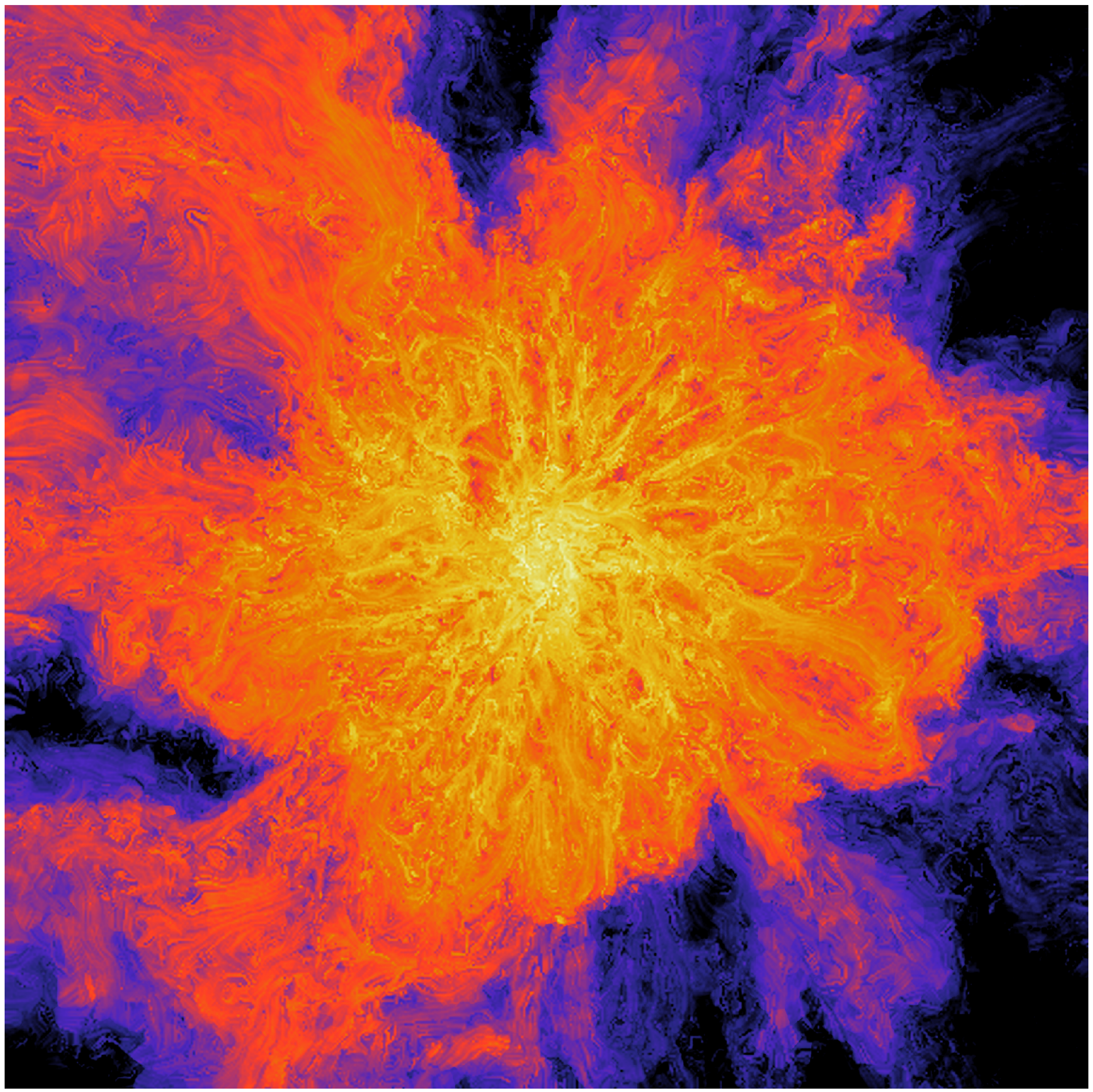
Column density overlaid with velocity field



Magnetic and kinetic power spectra

Magnetic field structure

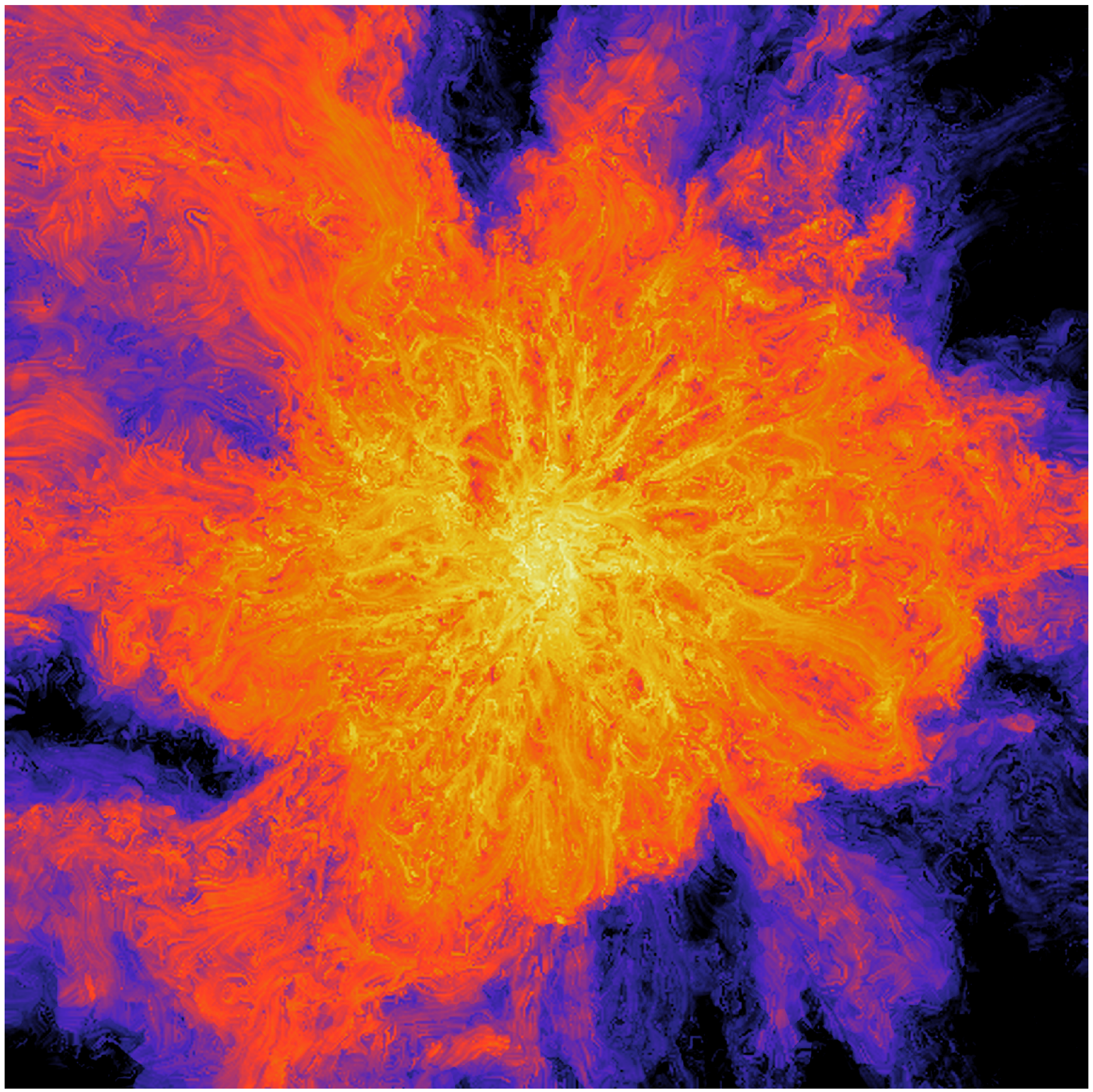
z=2



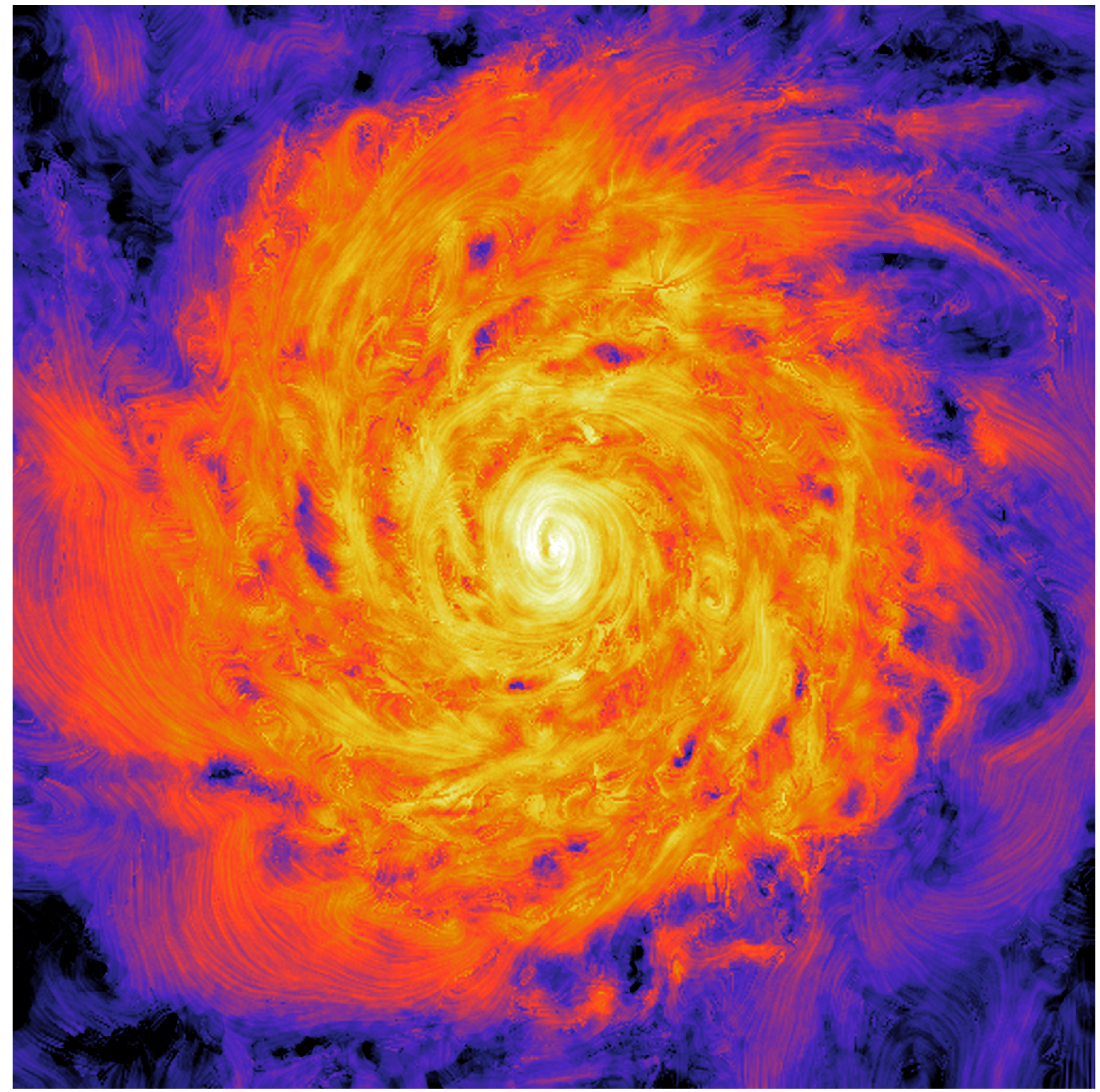
Halo 6

Magnetic field structure

z=2



z=0



Halo 6

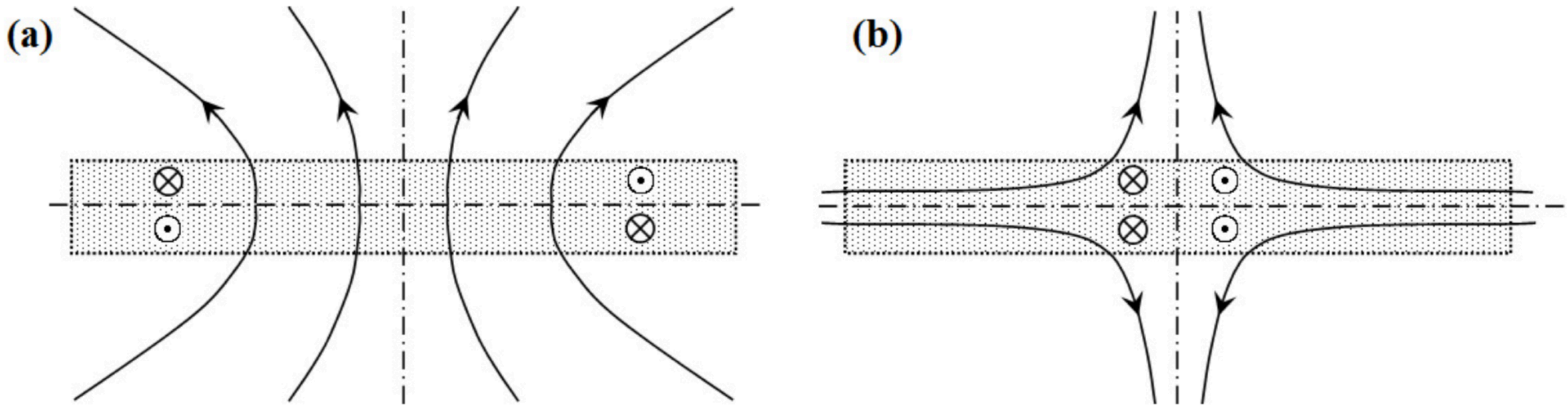
Galactic dynamo?

$$B_r(-z) = -B_r(z), \quad B_\phi(-z) = -B_\phi(z)$$

dipolar, odd

$$B_r(-z) = B_r(z), \quad B_\phi(-z) = B_\phi(z)$$

quadrupolar, even

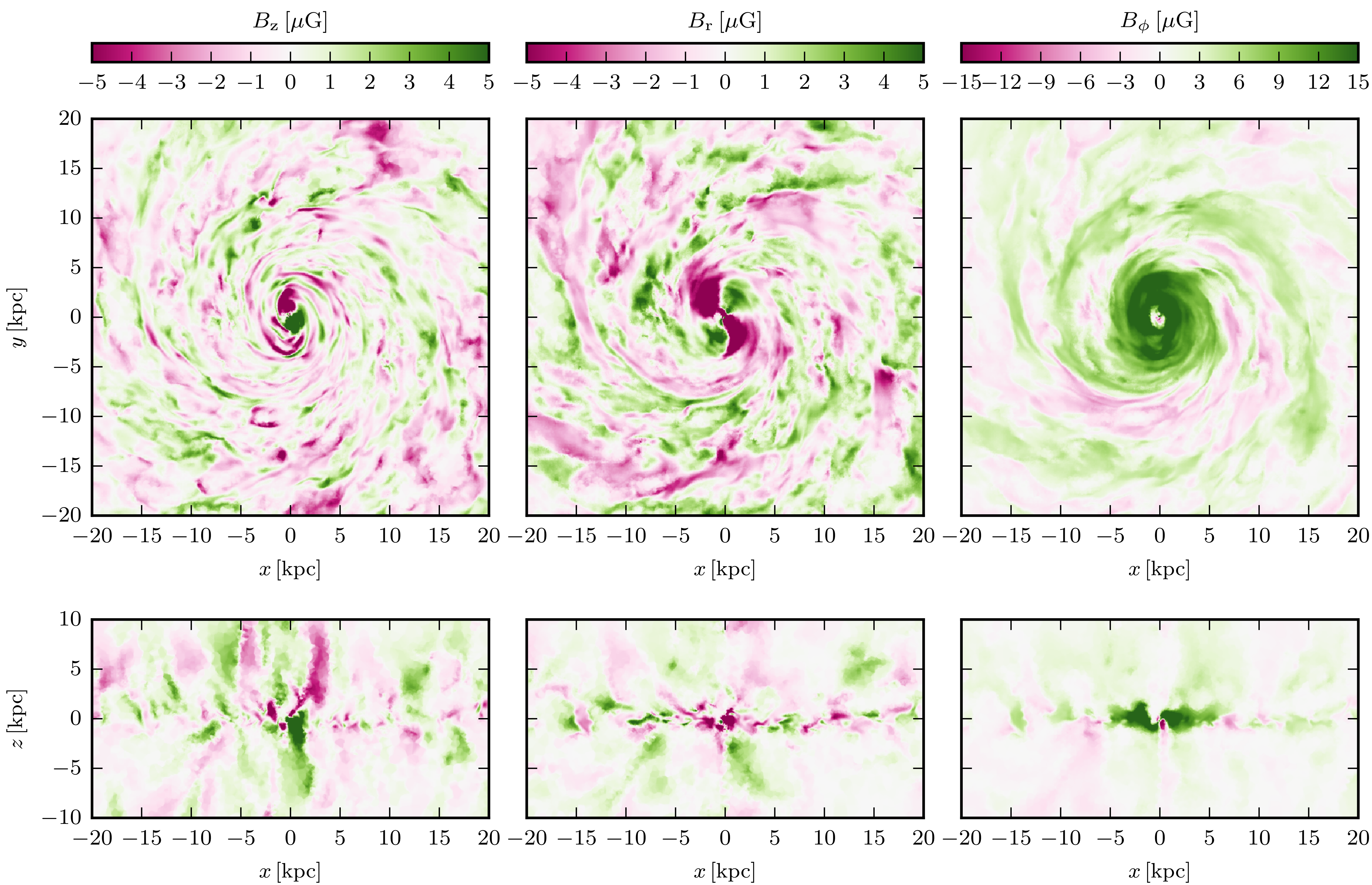


$B_r = B_\phi = \frac{\partial B_z}{\partial z} = 0,$ at $z = 0$

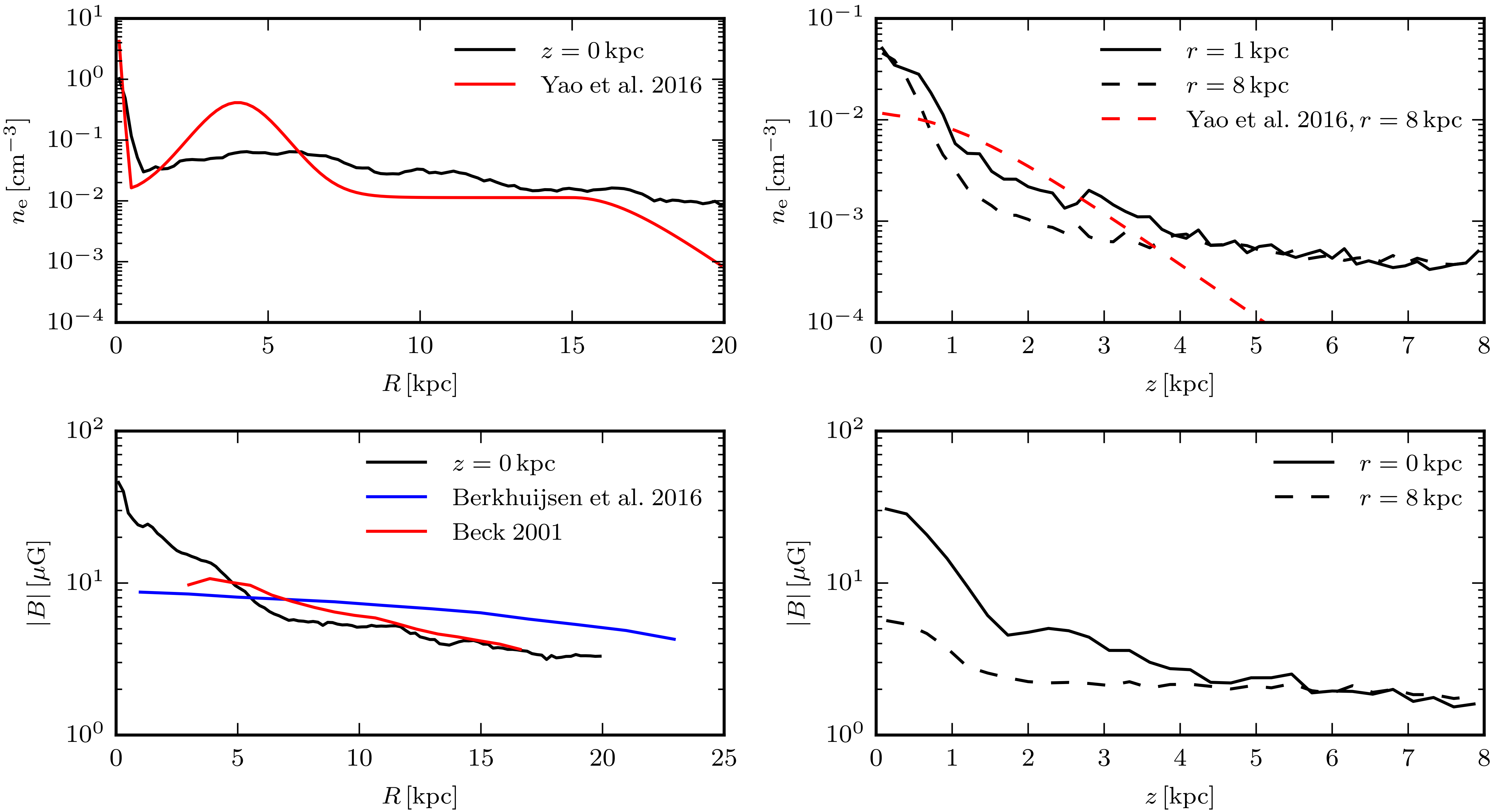
$\frac{\partial B_r}{\partial z} = \frac{\partial B_\phi}{\partial z} = B_z = 0,$ at $z = 0$

Shukurov 2004

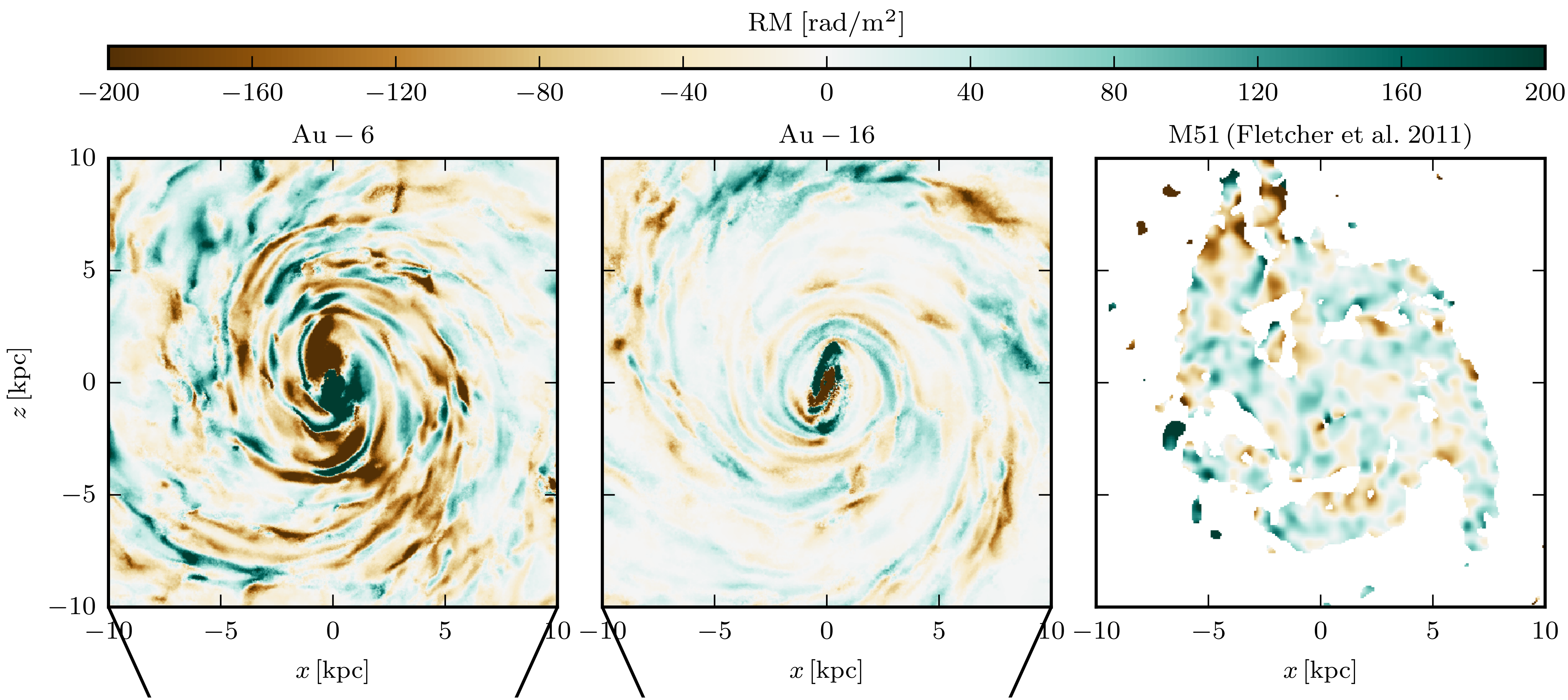
The magnetic field of Au-6 at z=0



The magnetic field of Au-6 at z=0

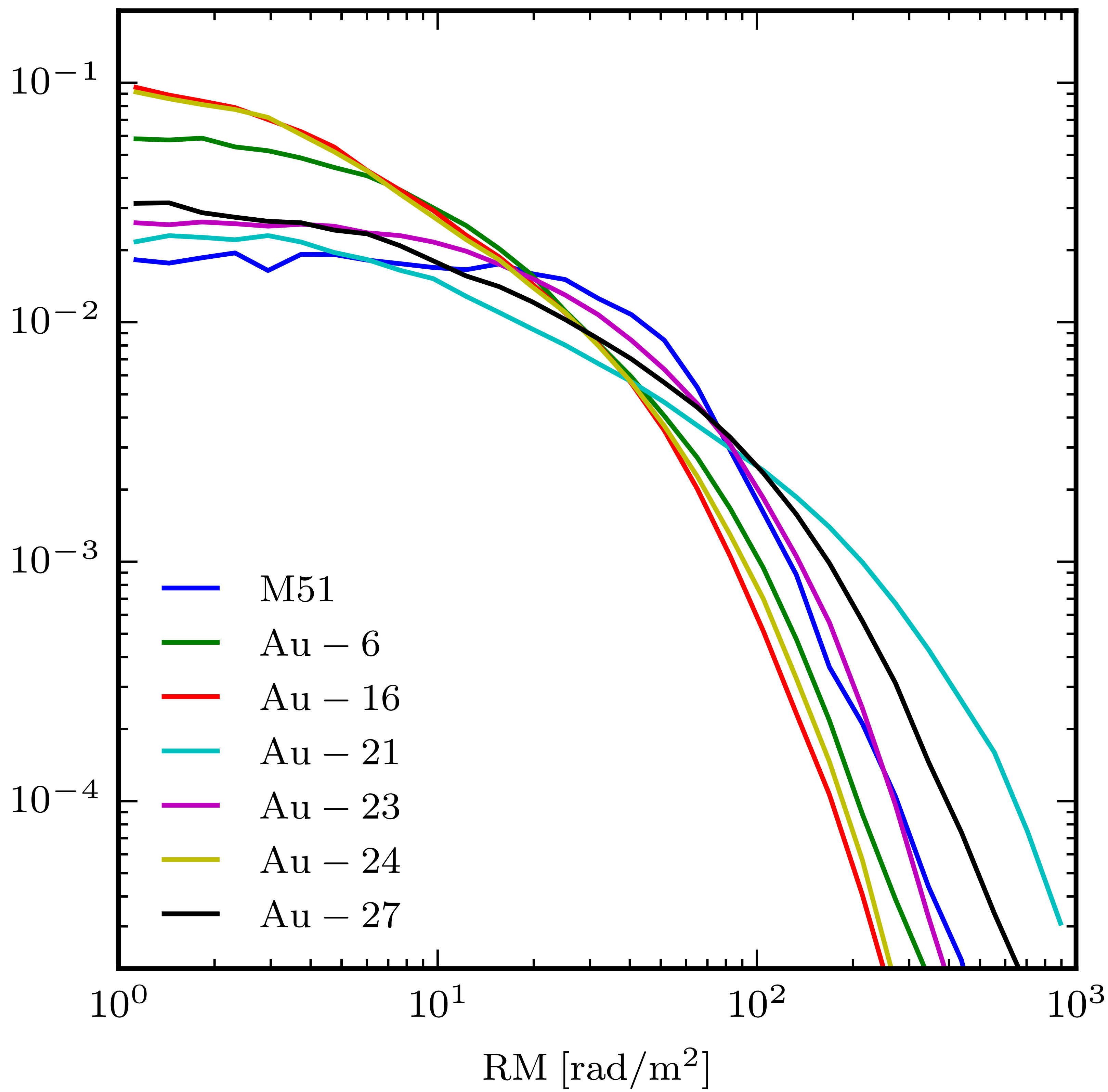


Faraday rotation maps for an external observer

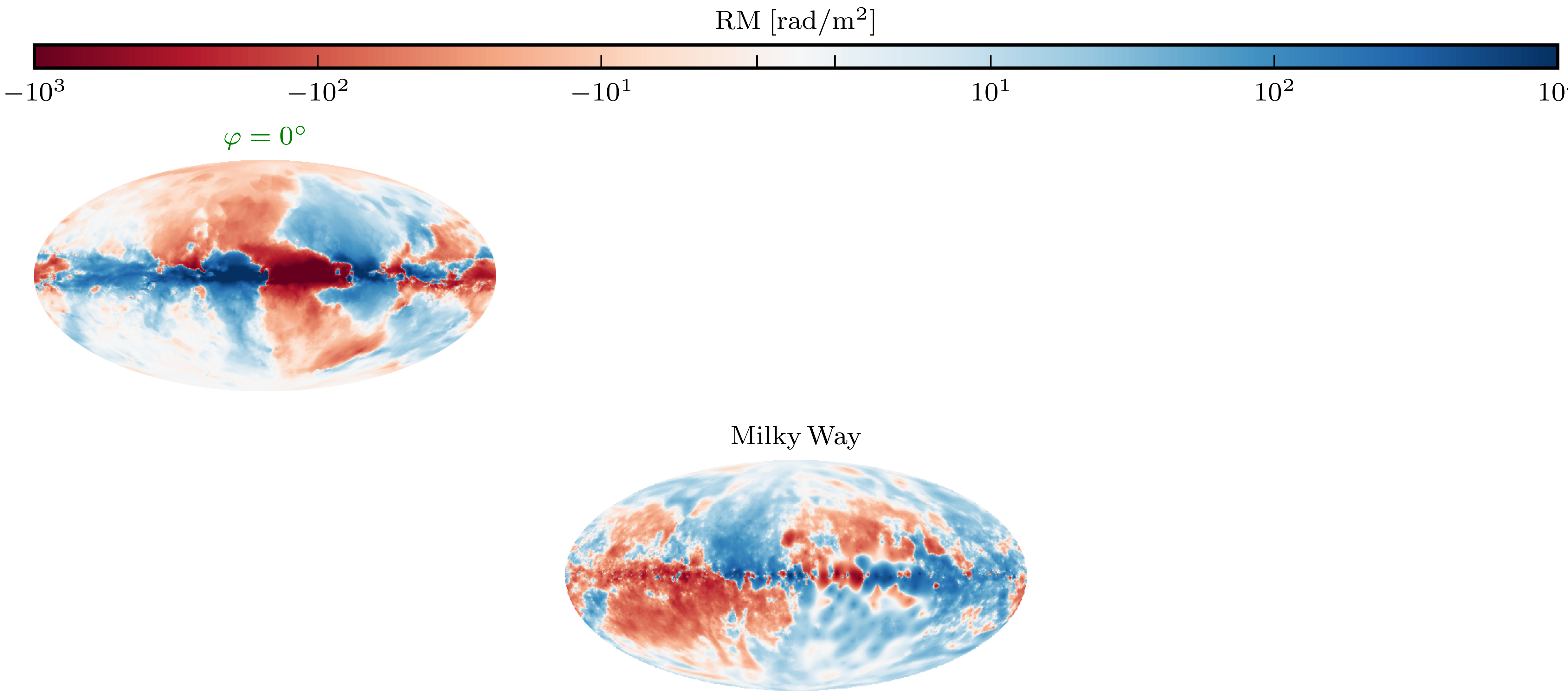


$$RM \propto \int n_e B_r dr$$

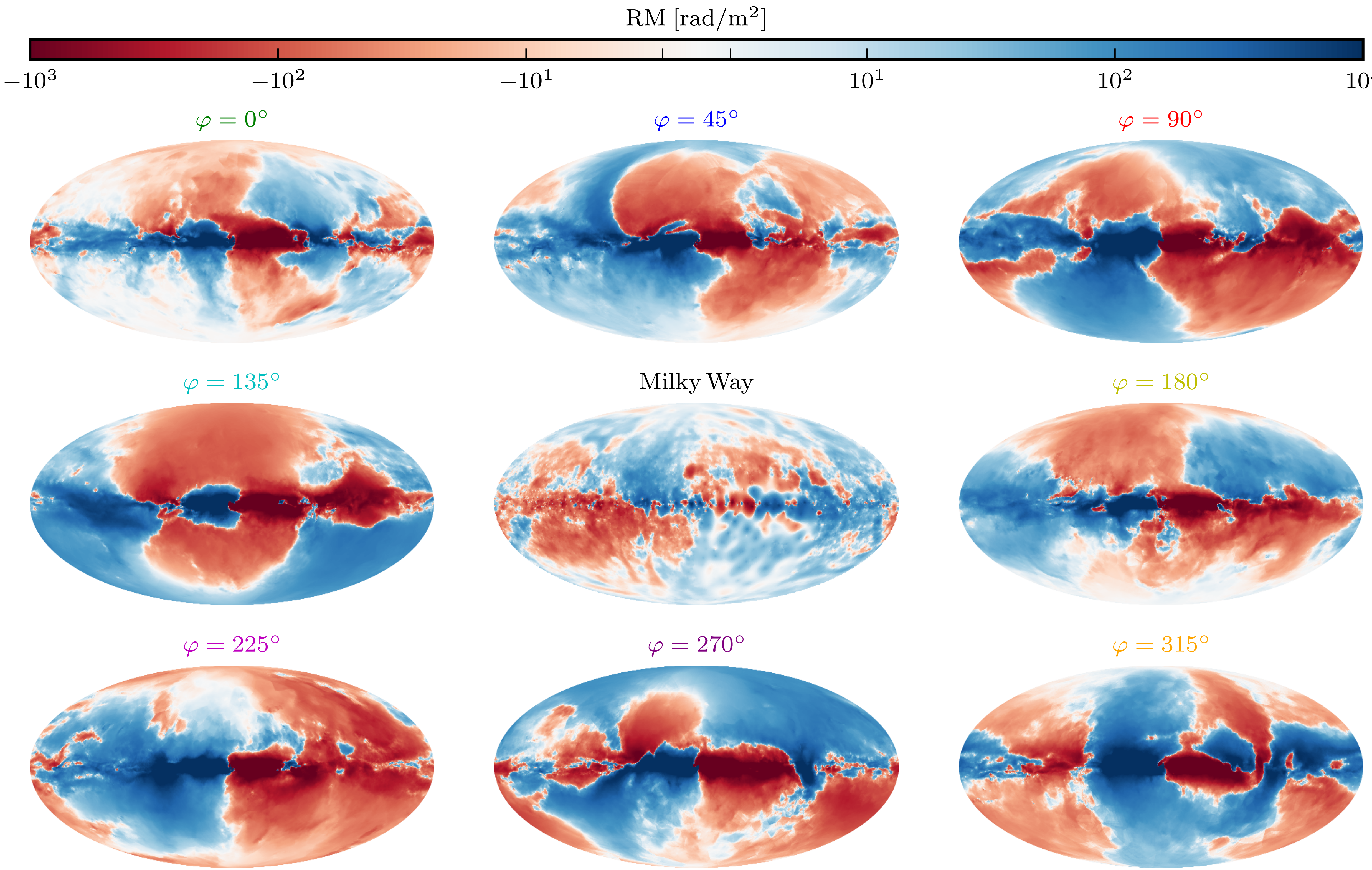
Histogram of faraday rotation maps



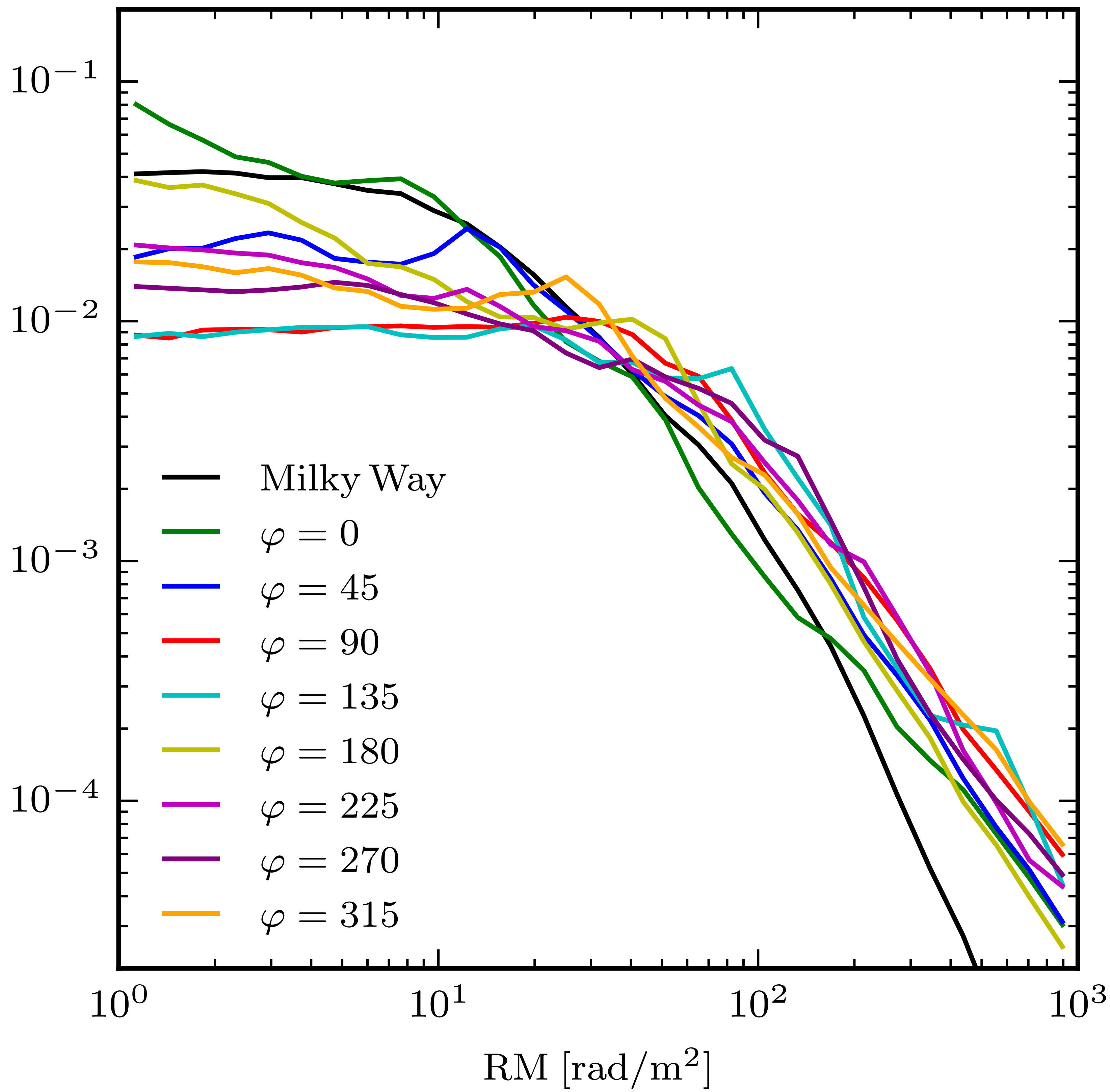
Faraday rotation maps of Au-6



Faraday rotation maps of Au-6

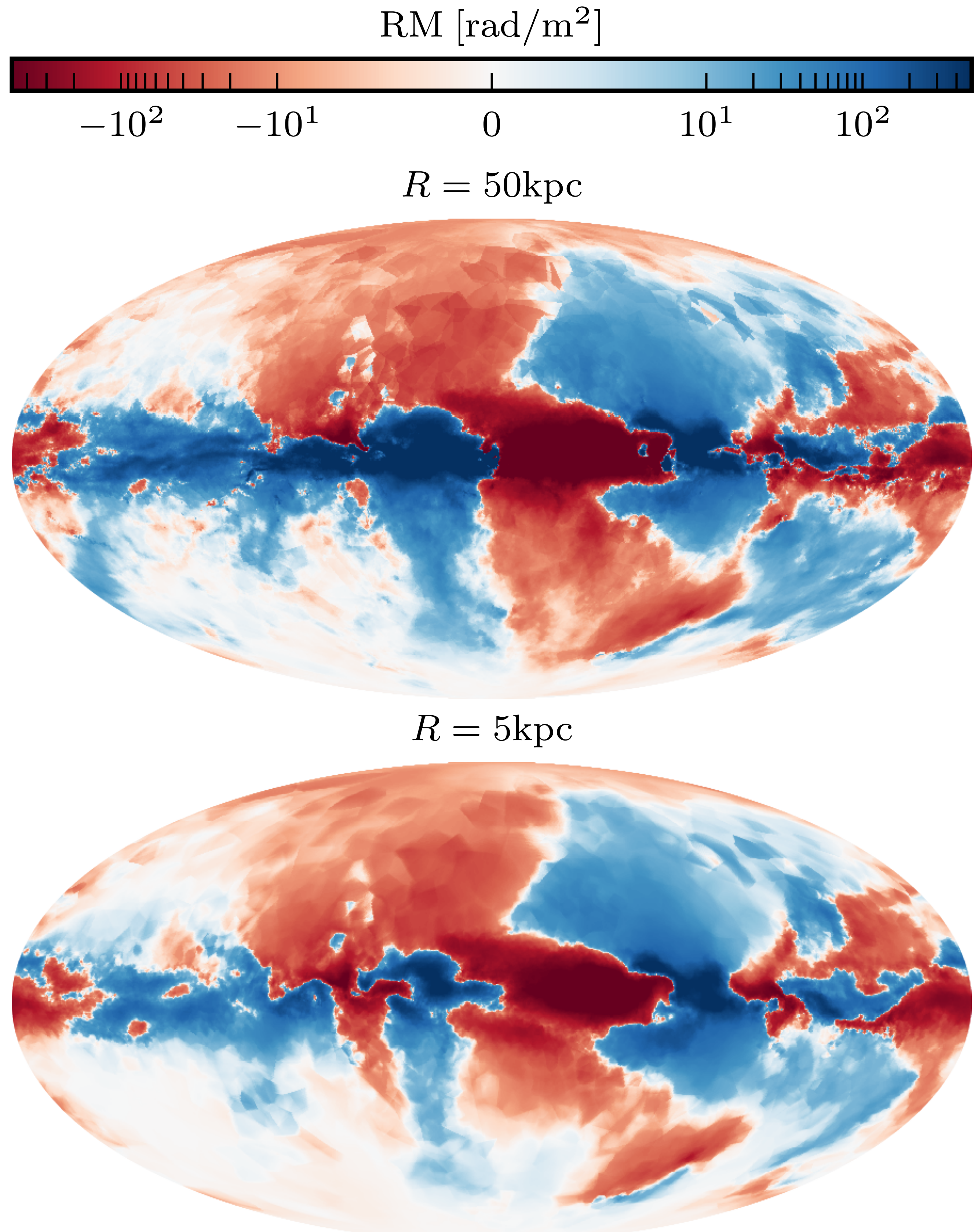


Histogram of faraday rotation maps



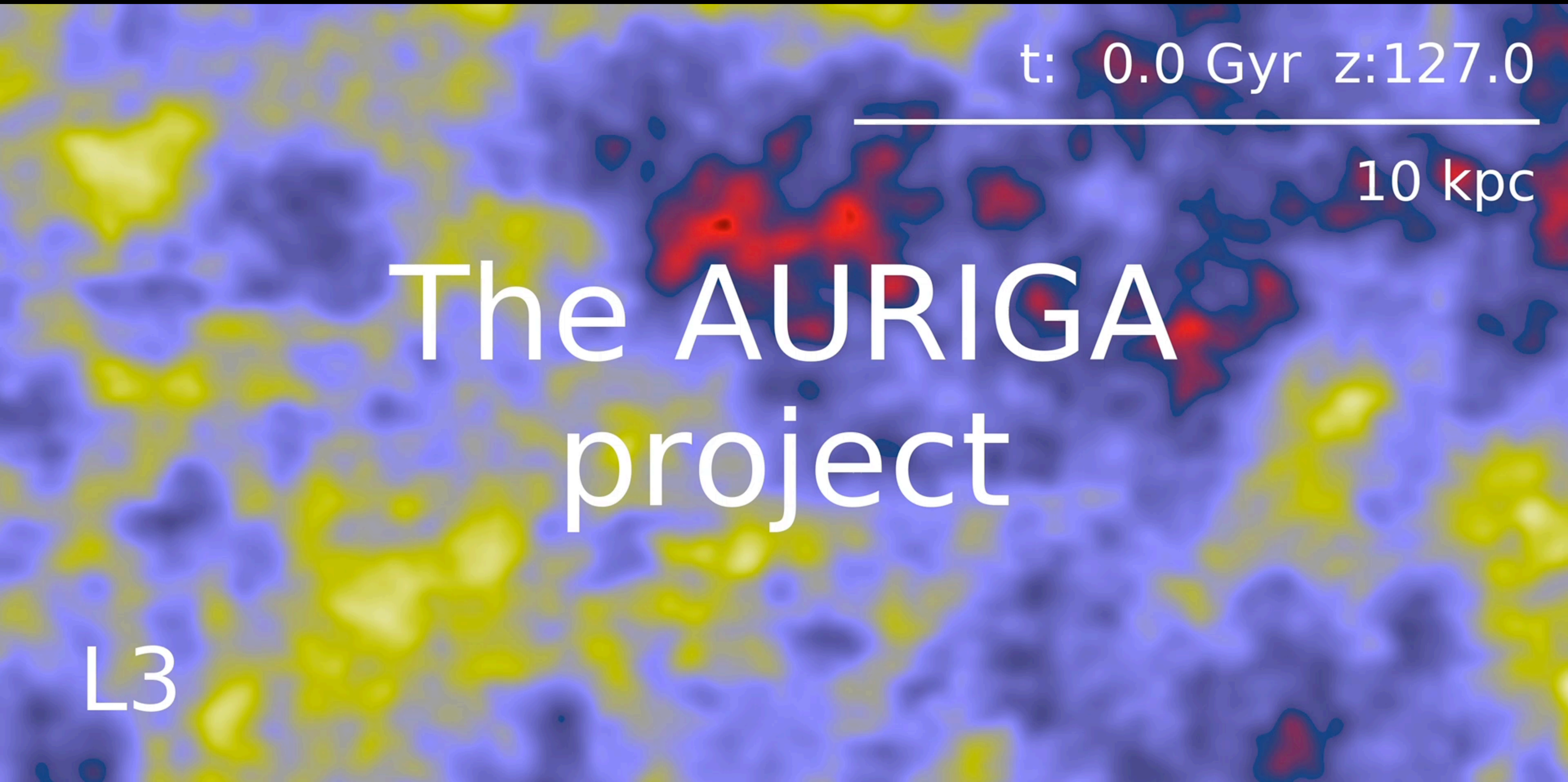
Faraday rotation maps with cutoffs

- All-sky Faraday rotation maps are dominated by the local signal
- Caveat: Approximations for ISM model and galactic wind model!



Conclusions

- We can understand the origin of Galactic magnetic field from cosmological simulations
- Turbulent dynamo saturates before z=2, amplifies magnetic field to 10% of equipartition
- Differential rotation in the disk further amplifies to equipartition, orders magnetic field
- At z=0, the B-field is dominated by the azimuthal field, but without a dominating large-scale dipole or quadrupole
- All-sky Faraday maps of our simulated galaxies vary significantly for different observer positions and are dominated by the local signal!


t: 0.0 Gyr z:127.0
10 kpc
The AURIGA
project
L3