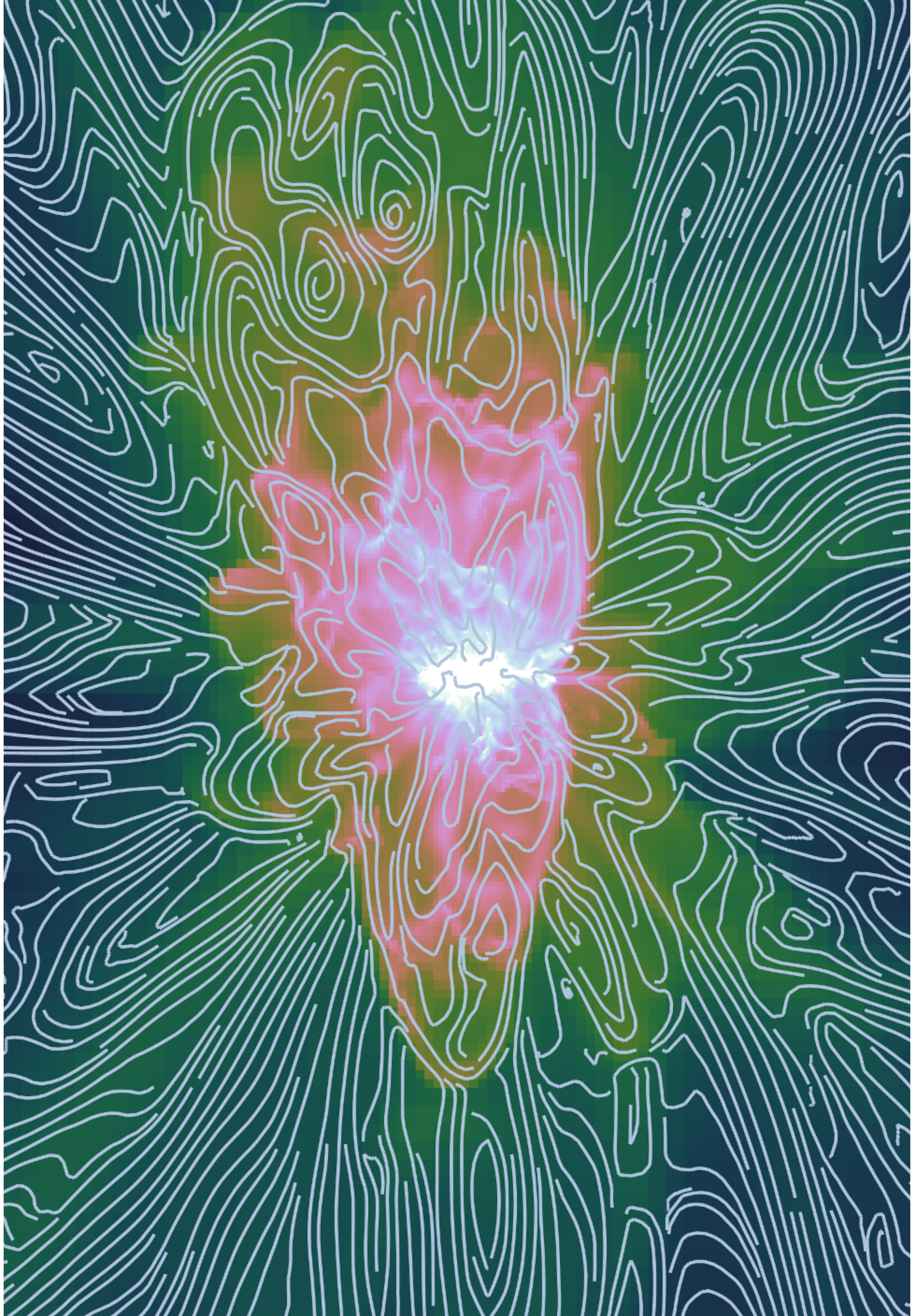

MHD turbulence and a small-scale dynamo in dwarf galaxy simulations

Paris, 6th October 2016

Universität Zürich[UZH]

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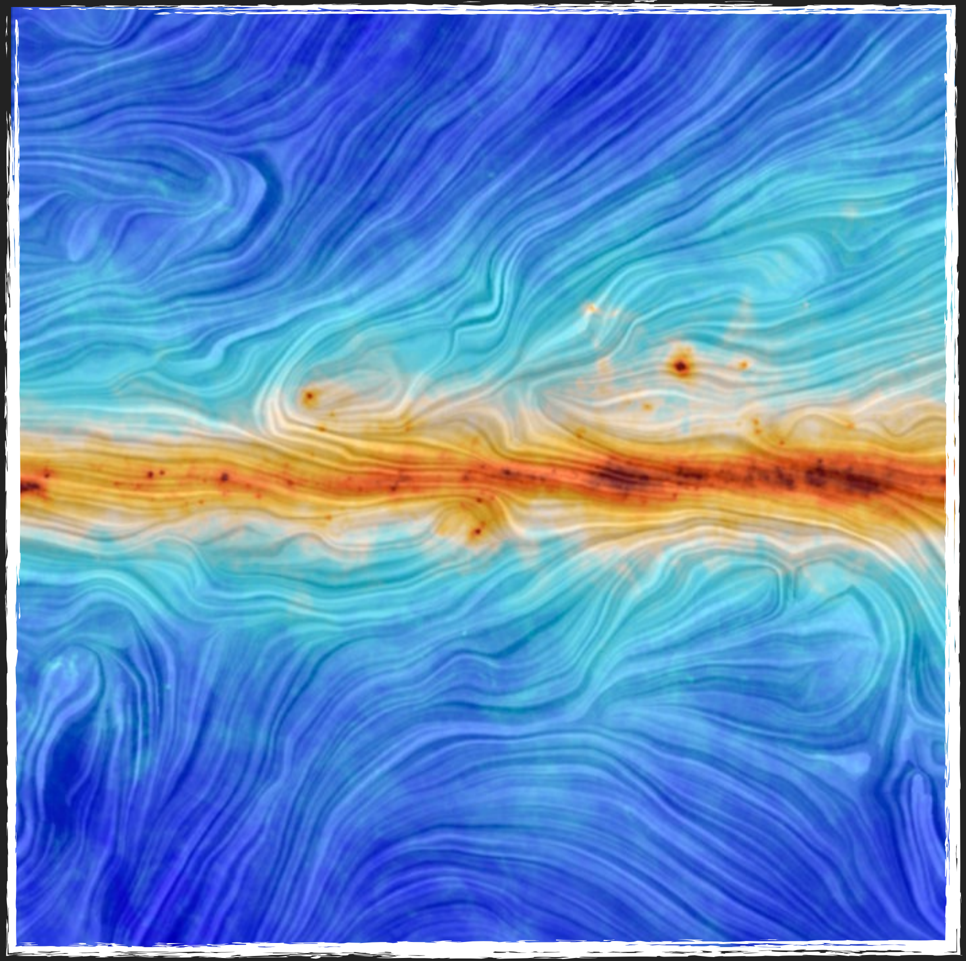
MAGNETIC FIELDS IN GALAXIES

ESA/Planck: dust emission/polarisation



Origin and evolution of cosmic magnetic fields still poorly understood

- **Milky Way field strength ~ several 10 μG (Beck 2015)**
- **Comparable results also at high redshift (Bernet et. al. 2008)**
- **Weak magnetic fields of ~10^{-20} G can be created by Biermann battery (Biermann 1950) in shocks or ionization fronts (Gnedin et. al. 2000)**
- **Can also have primordial origin < 10^{-9} G comoving (Planck 2015)**
- **Dynamo amplification (conversion of kinetic energy into magnetic energy) believed to act on weaker magnetic fields, but which dynamo? How?**

NUMERICS

$$\partial_t \rho + \nabla \cdot (\rho \boldsymbol{u}) = 0 \quad (1)$$

$$\partial_t (\rho \boldsymbol{u}) + \nabla \cdot (\rho \boldsymbol{u}\boldsymbol{u}^{\mathrm{T}} - \boldsymbol{B}\boldsymbol{B}^{\mathrm{T}} + P_{\mathrm{tot}}) = 0 + \nu\, \Delta(\rho u) \quad (2)$$

$$\partial_t E + \nabla \cdot [(E + P_{\mathrm{tot}})\boldsymbol{u} - (\boldsymbol{u} \cdot \boldsymbol{B})\boldsymbol{B}] = 0 \quad (3)$$

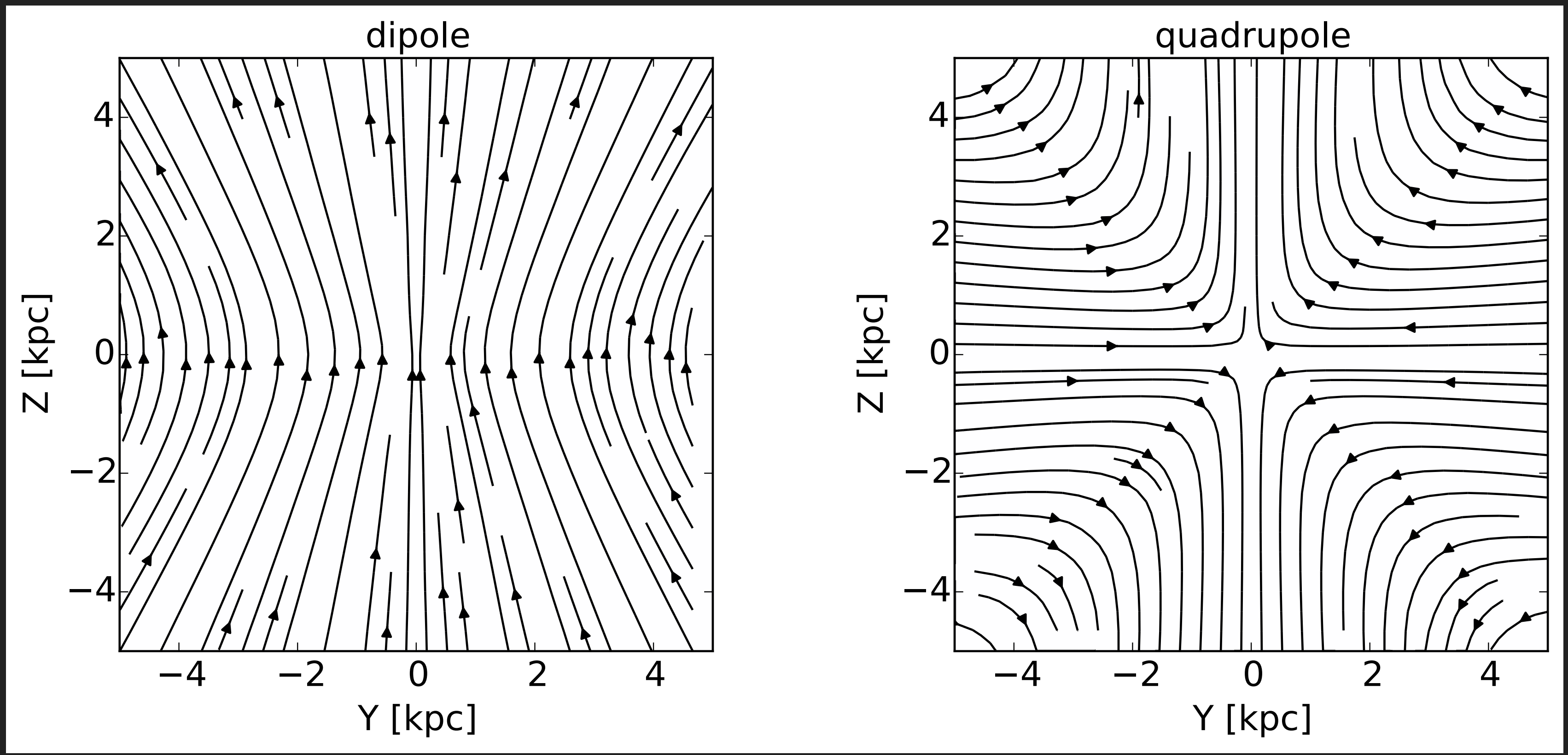
$$\partial_t \boldsymbol{B} - \nabla \times (\boldsymbol{u} \times \boldsymbol{B}) = 0, + \eta\, \Delta B \quad (4)$$

$$\nabla \cdot \boldsymbol{B} = 0. \quad (5)$$

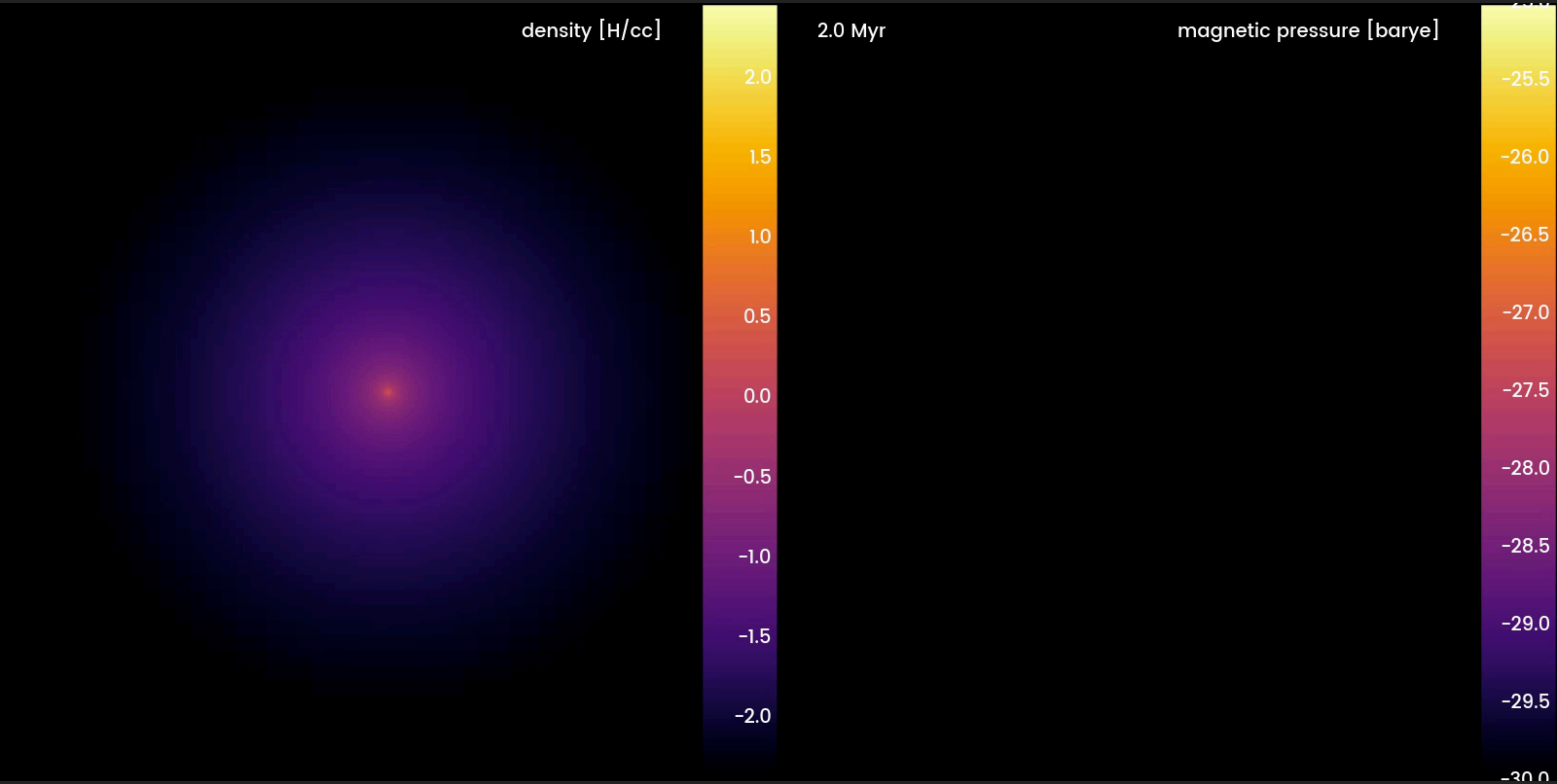
- **RAMSES-MHD: Ideal MHD equations with HLLD solver**
- **Viscosity ν and and diffusion η are governed by numerical scheme, i.e. depend on resolution, but are of similar strength**
  $P_M = \nu / \eta \sim 1$
- **Additionally subgrid physics: star formation, supernova feedback (delayed cooling) on the ISM**

ISOLATED COOLING HALO

- 10^{10} solar mass halo with cooling gas
  (set-up first used in Teyssier et al. 2013)
- Various initial magnetic field topologies
  toroidal, dipole and quadrupole shape, following gas density $B \sim \rho^{2/3}$ or constant (high Alfven speeds ⚡)
- Feedback will destroy initial topology because field lines follow gas motion



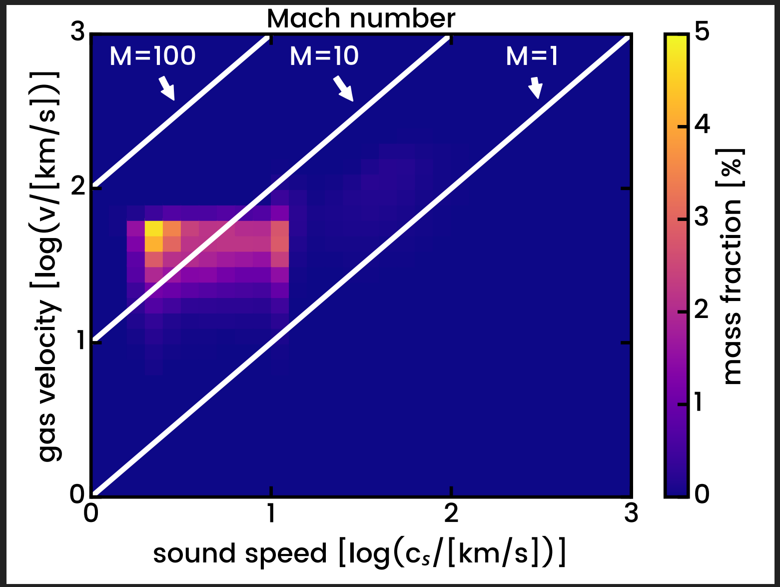
THERE WE GO!

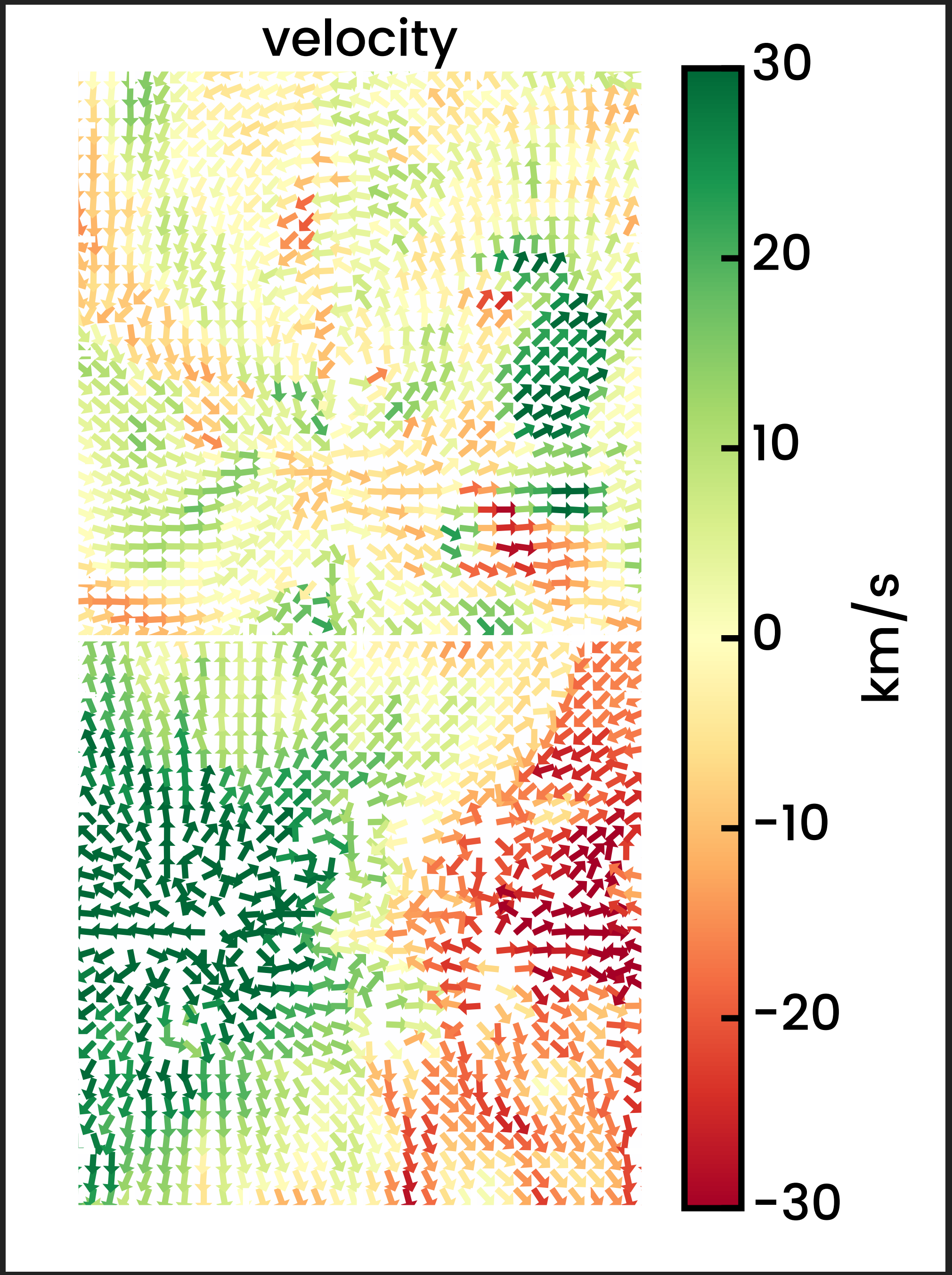

density [H/cc]
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
2.0 Myr
magnetic pressure [barye]
-25.5
-26.0
-26.5
-27.0
-27.5
-28.0
-28.5
-29.0
-29.5

TURBULENT DISK

- As gas cools down, it quickly falls onto disk
- Stars are born and die
- Feedback breaks loose
- Disk becomes puffed up, strong winds develop
- Galactic fountain spawns a giant washing machine

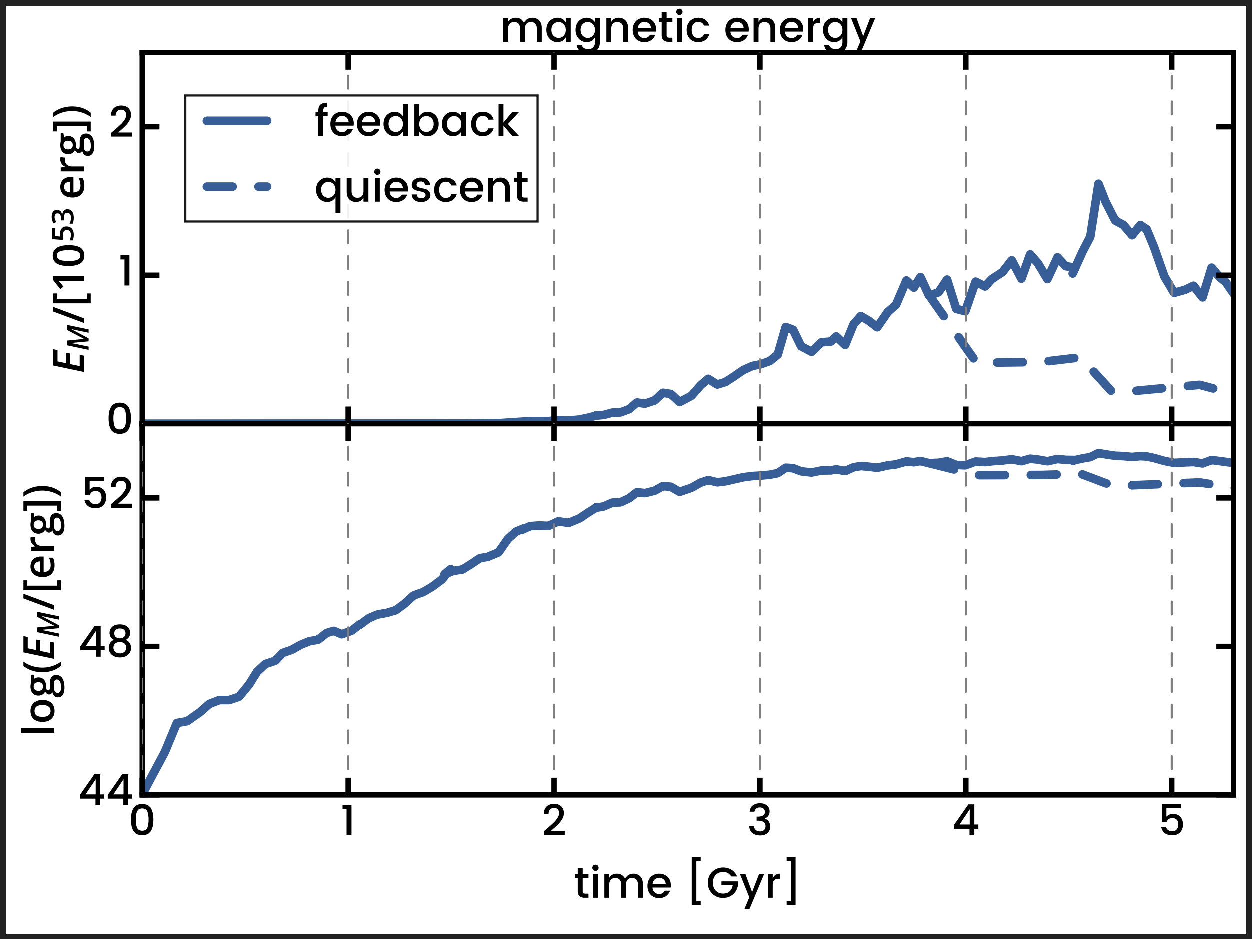
➜ Supersonic turbulence (M~10)

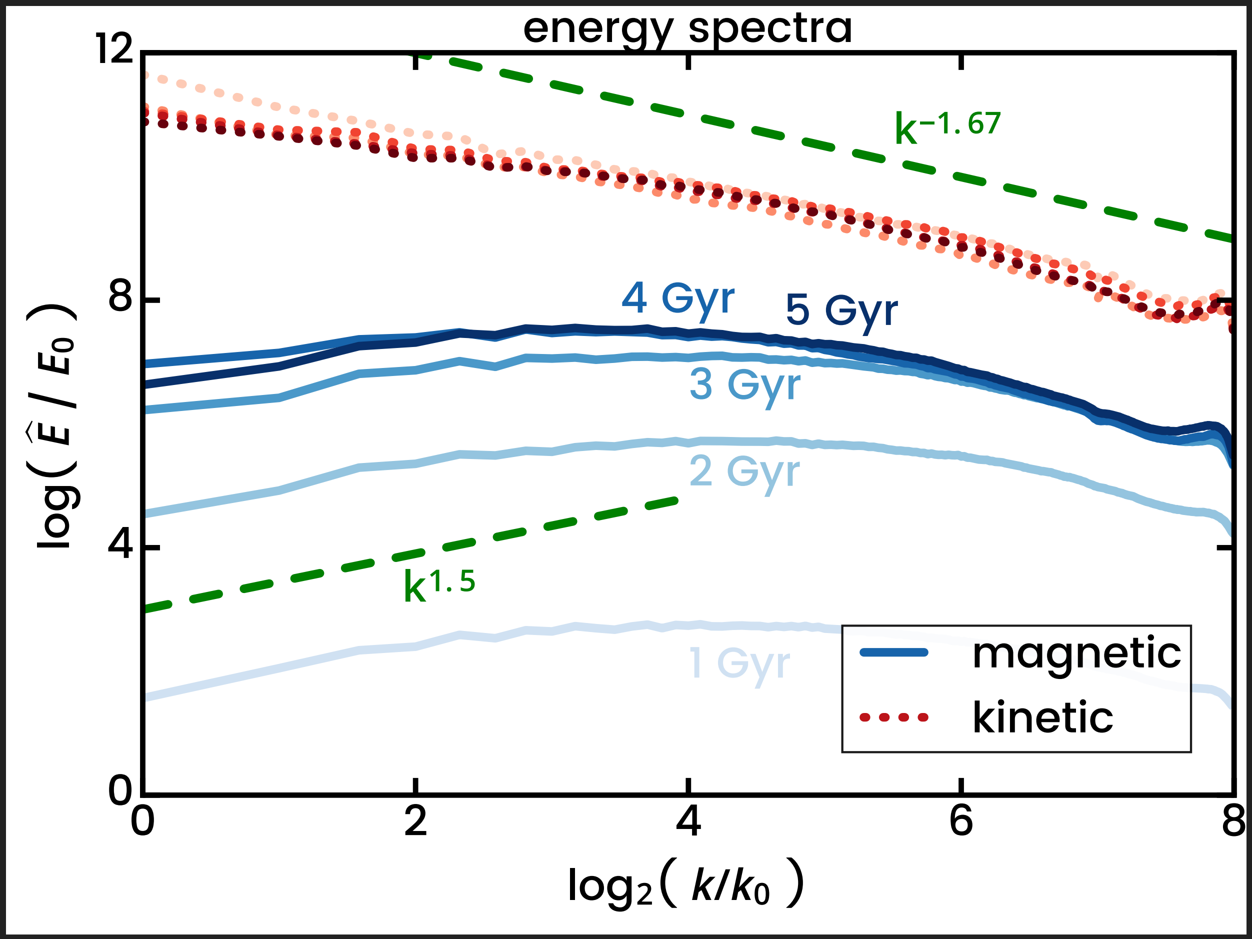




SMALL-SCALE DYNAMO

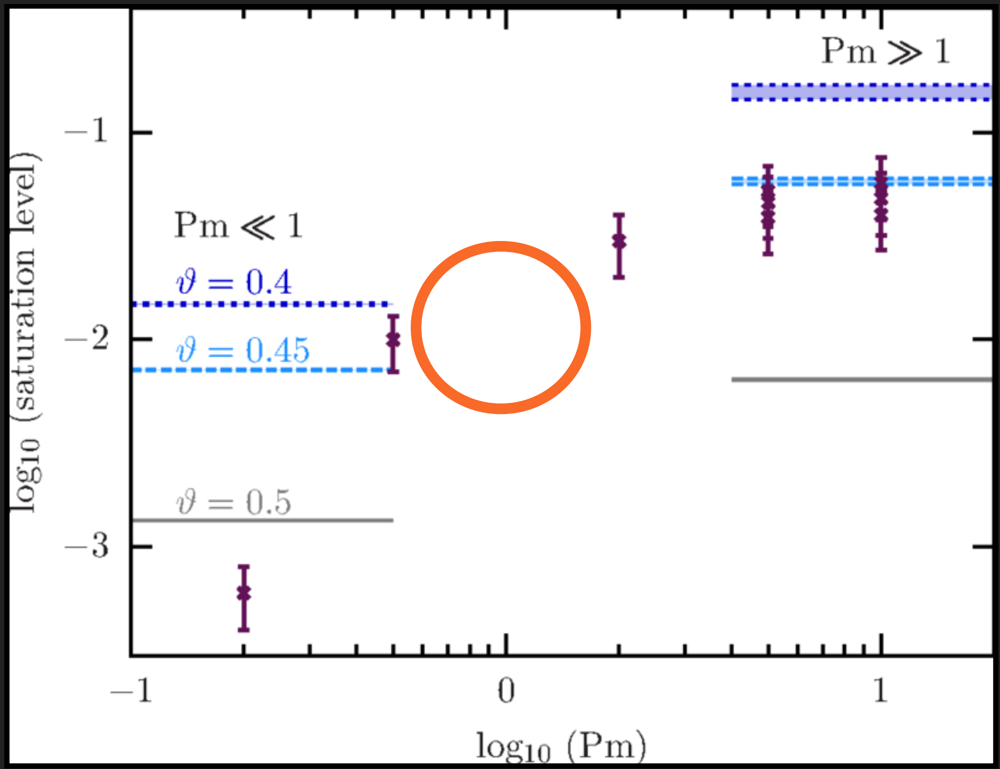
- Magnetic energy grows on all scales, first exponentialy, then linearly, then stops
- Kinetic energy spectrum develops Kolmogorov slope $E_{kin} \sim k^{-5/3}$
  Magnetic energy bottlenecked $k^{3/2}$ -slope as predicted by Kazantsev theory



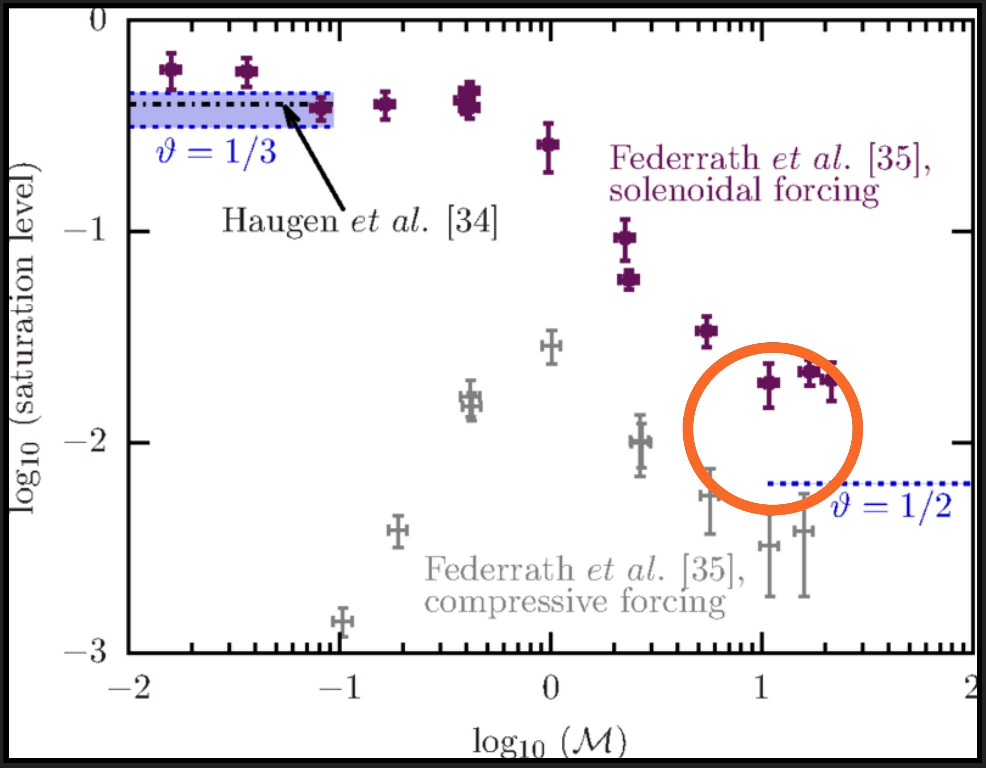


SATURATION

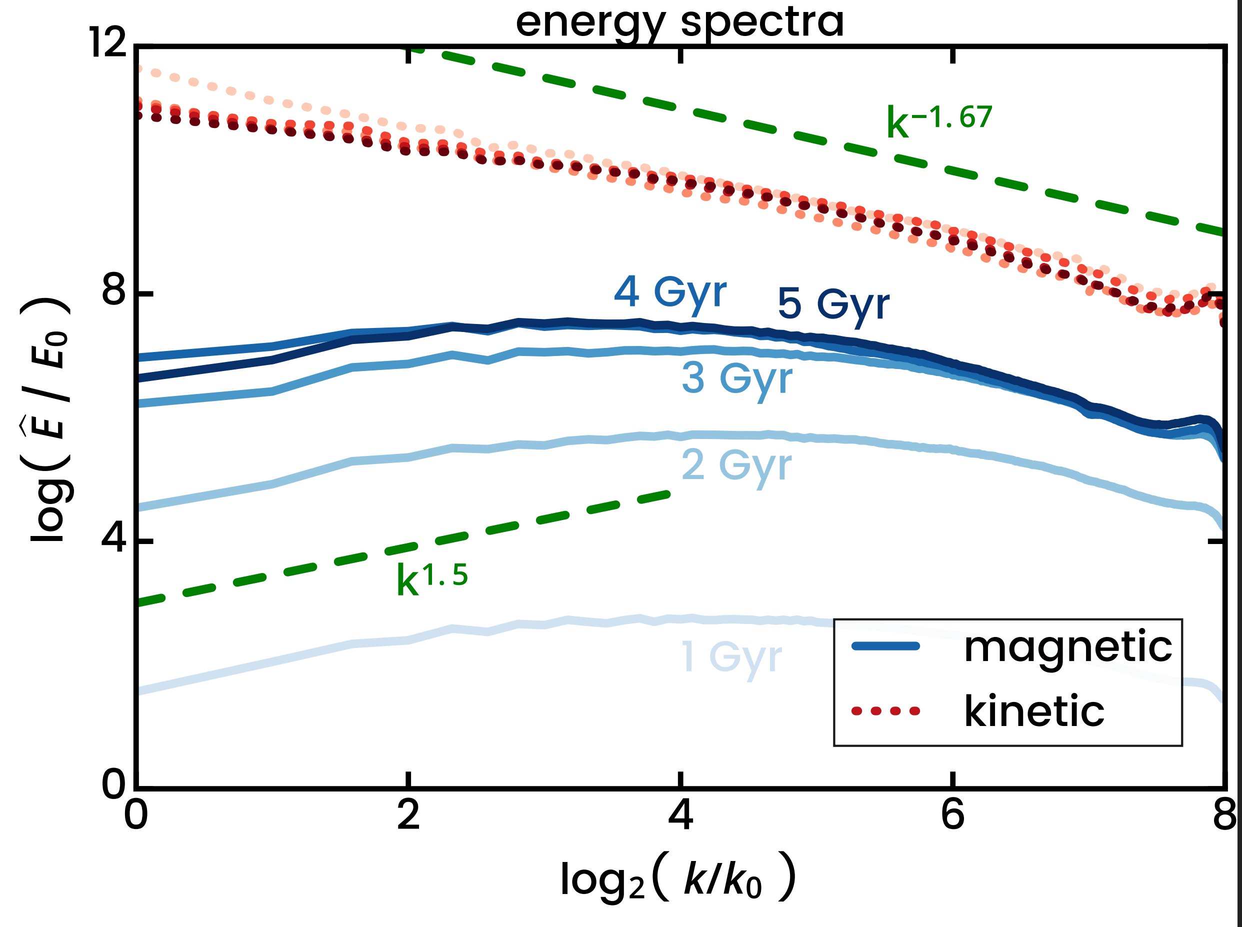
- Saturation is at ~ 1% of equipartition energy
- This result is in very good agreement with other simulations and theory that small-scale dynamo saturation occurs *below* equipartition



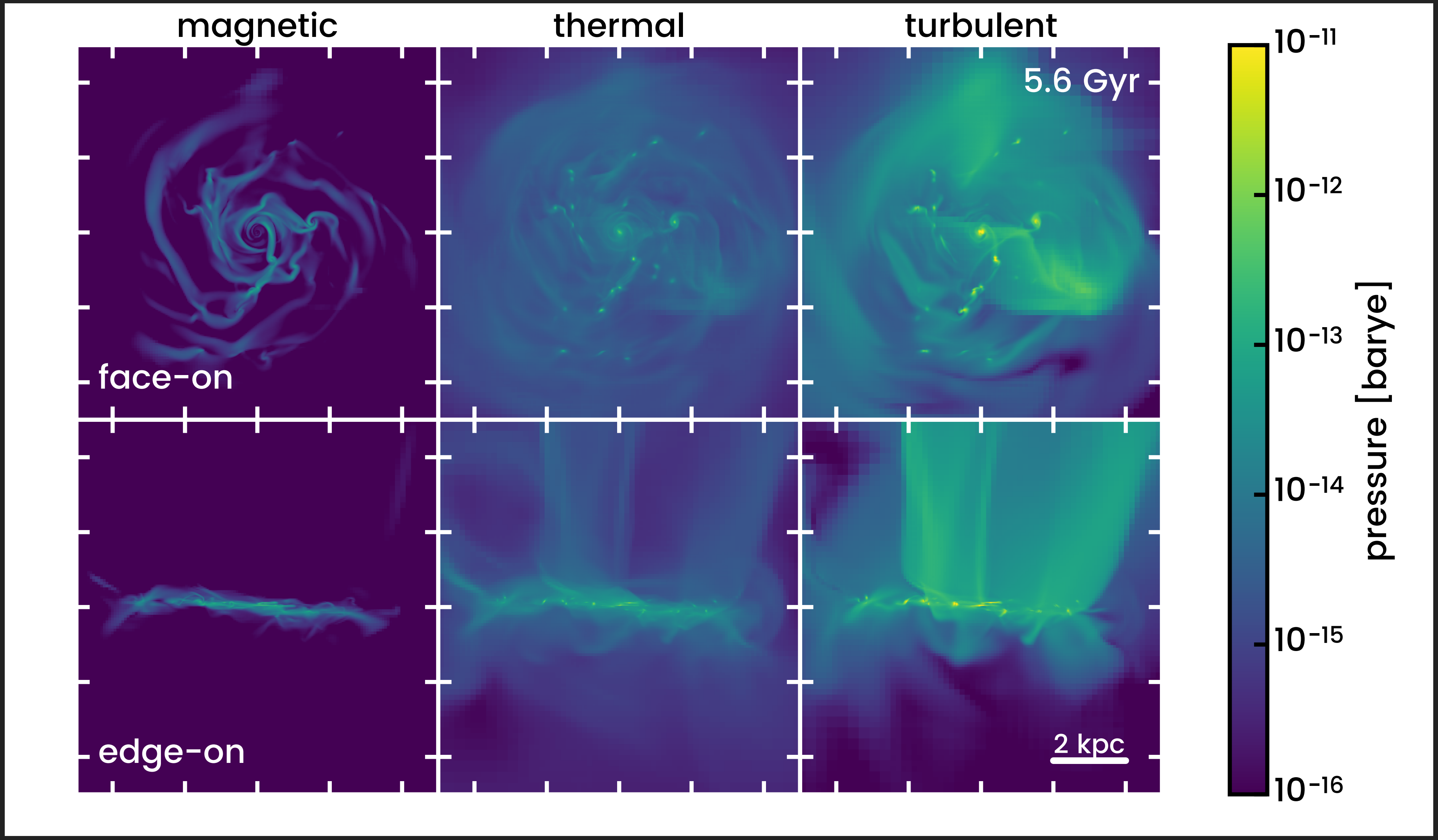
Schober et al., 2015



Schober et al., 2015

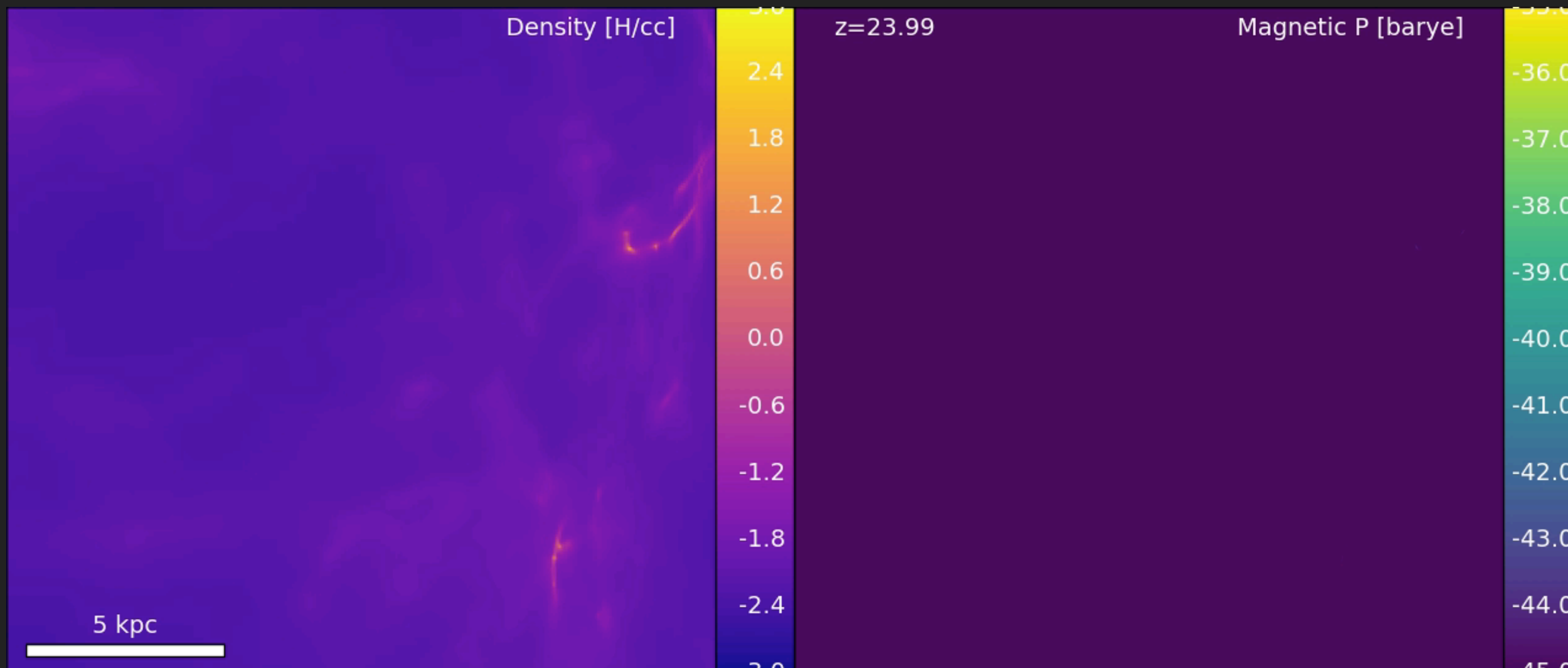


QUIESCENCE



- **When the disk becomes more quiescent, it cools down and falls back onto a thin disk**
- **Magnetic field locally in equipartition at μG-strength in dense arms**

IN A NUTSHELL



- **Weak seed fields from early Universe become amplified by small-scale dynamo, saturation possibly already at high redshift**
- **Possibly followed by different era with less feedback, large-scale dynamo, mergers, etc.**

  ➜ Rieder, Teyssier, 2016 MNRAS 457, pp 1722
  ➜ Rieder, Teyssier, 2016 (?) in prep.

ONE MORE THING…

- **Common cluster queuing systems terminate jobs after a time limit, e.g. 24h, so all progress since last output gets lost**
- **UNIX signal 10 will trigger RAMSES to output current snapshot immediately**

  ```
  scancel --signal=10 <jobid>
  ```
- **SLURM can be instructed to send signal at certain time before job termination, e.g.**

  ```
  #SBATCH --signal=10@300
  ```

  for 5 minute output.