Global Mean Field Dynamo simulations with SPMHD

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Mean Field Theory.....

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{V} \times \vec{B} - \eta \nabla \times \vec{B})$$

$$\vec{B} = \langle \vec{B} \rangle + \vec{b} \qquad \vec{V} = \langle \vec{V} \rangle + \vec{v}$$

Statistical Properties

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{V} \times \vec{B} - \eta \nabla \times \vec{B} + \vec{\xi})$$

$$\vec{\xi} = \alpha \vec{B} + \gamma \times \vec{B} - \beta \nabla \times \vec{B} - \delta \times \nabla \times \vec{B} + \ldots$$

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{V} \times \vec{B} + \alpha \vec{B} - \beta \nabla \times \vec{B})$$

Nice model and workhorse for theoreticians

Theory

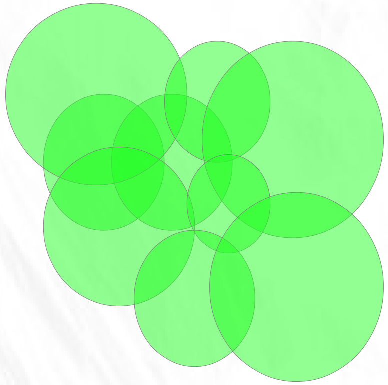
Non Linear Approach

(from B,V get alpha,beta, etc)

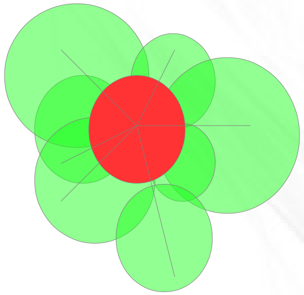
Kinematic approach

(from alpha, beta, etc get B,V)

SPMHD



- Lagrangian Scheme
- The mass is discretized, not volume
- Huge dynamical range
- We use a compact Kernel to “smooth” the properties and build derivatives



NOT “Vanilla” SPMHD

- DivB cleaning (Stasyszyn et al. 2012)
- Non-ideal MHD (Bonafede et al. 2011)
- Advanced viscosity formulation (C&D 2012)

Non-Ideal SPMHD

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\alpha \vec{B} - \beta \nabla \times \vec{B})$$

- Numerical Options:

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\alpha \vec{B} - \beta \nabla \times \vec{B})$$

Or?

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\alpha \vec{B}) - \nabla \beta \times \nabla \times \vec{B} + \beta \nabla^2 \vec{B}$$

Or?

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\alpha \vec{B}) - \nabla \times (\beta \times \nabla \times \vec{B})$$

Therefore we have plenty of possible implementations, with their respective performance and different accuracies

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Or?

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\alpha \vec{B}) - \nabla \times (\beta \times \nabla \times \vec{B})$$

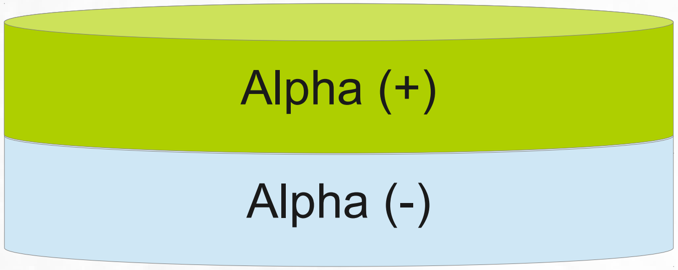
+ rearrangement of SPH kernel derivatives

Therefore we have plenty of possible implementations, with their respective performance and different accuracies

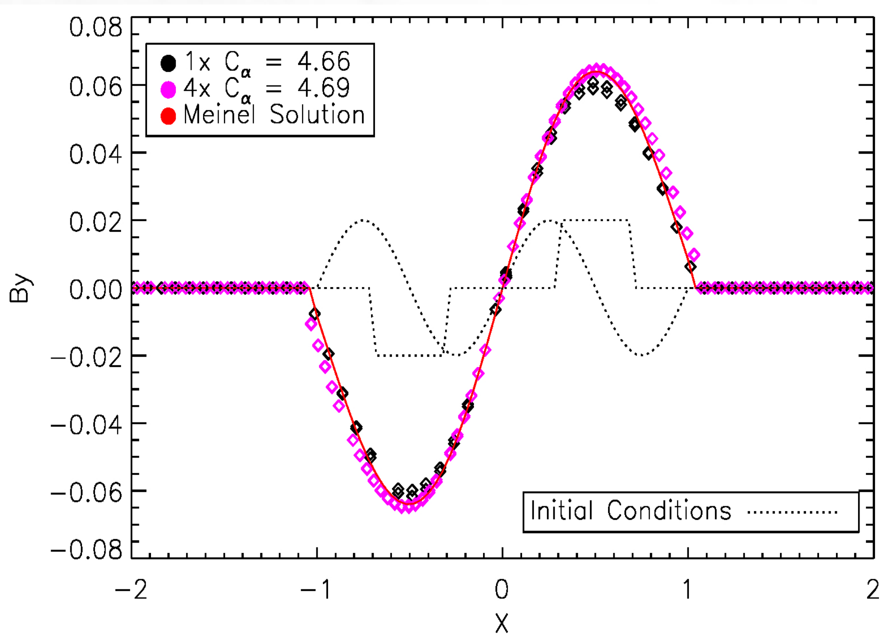
SPMHD - Tests

- Meinel (1990)
  - α^2

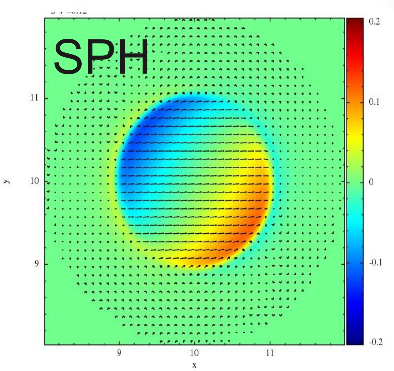
$$\alpha_{crit} = \left(\frac{\pi}{H} + \frac{x_1^1}{R_0} \right)^{1/2}$$

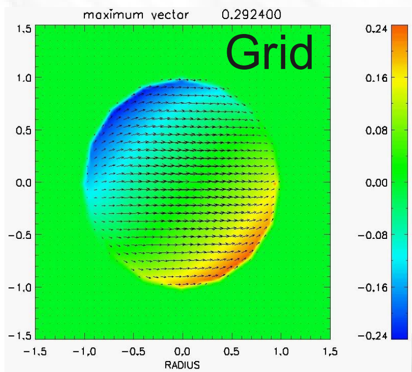


Alpha Quenching $$\alpha = \frac{\alpha_0}{B/B_{eq} + 1}$$



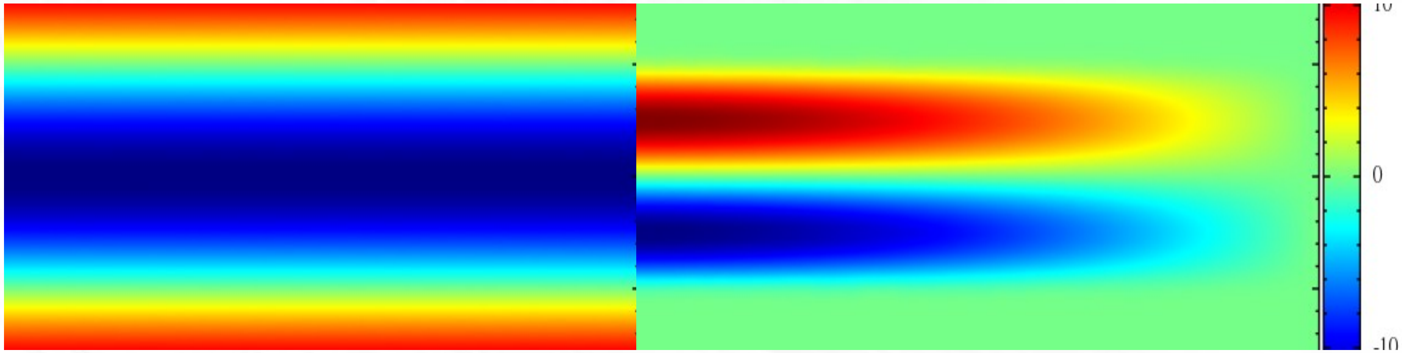
  - Anisotropic



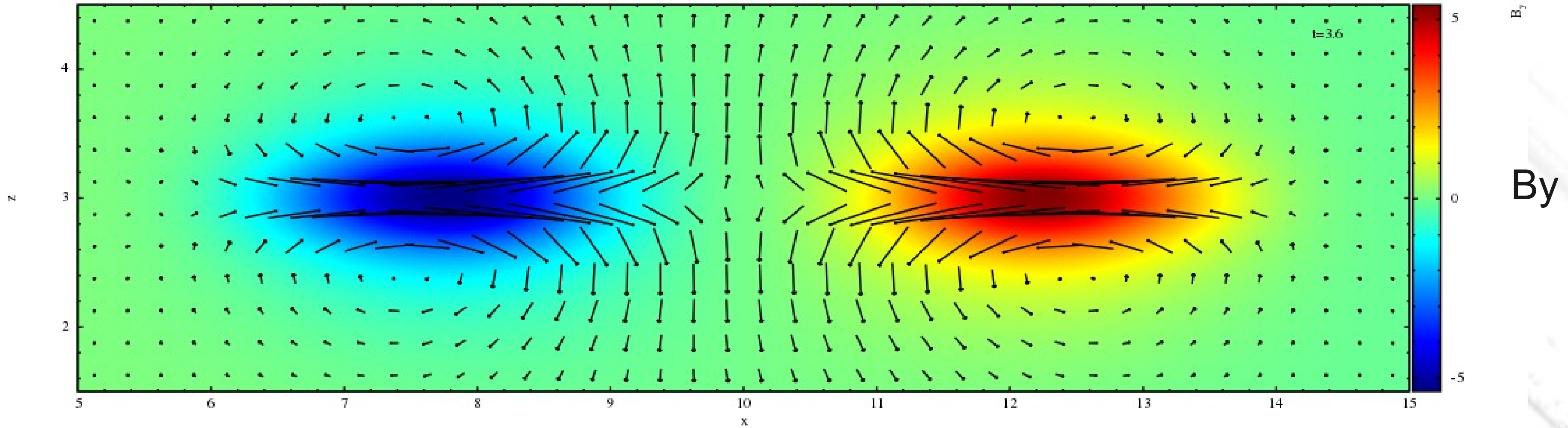


SPMHD - Tests

- α-Ω
  - Rotation: Brandt's law
  - Disk Geometry with several boundary conditions



Magnetic field solution:



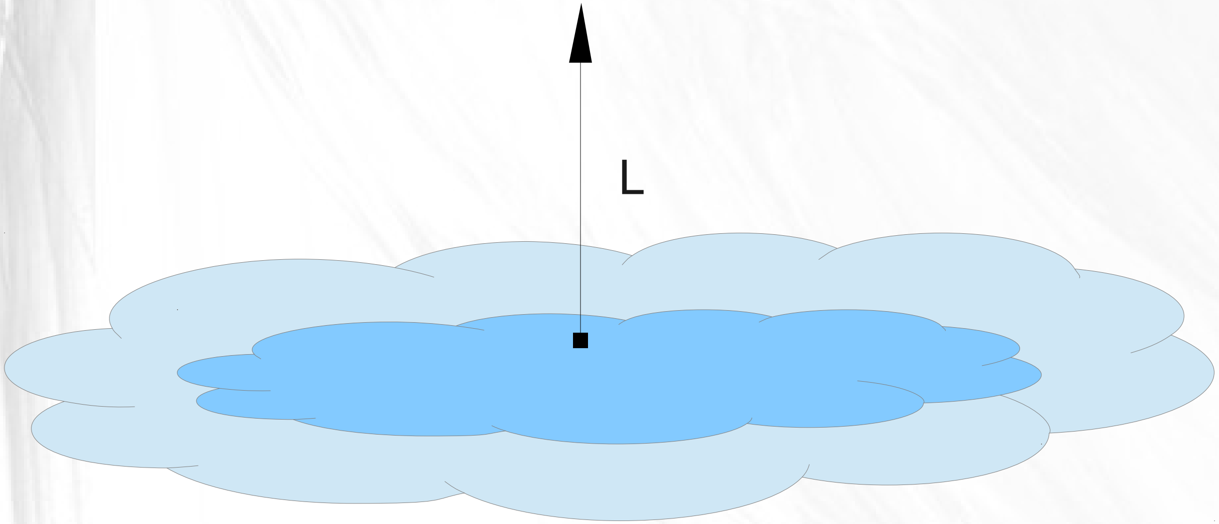
SPMHD - Tests

	Critical C_α			Symmetry	Period
	Analytic	SPH	Grid		
Isotropic α	4.95	4.69	4.92	S0	–
Anisotropic α	–	5.60	6.20	A1	1.8 Gy
$\alpha - \Omega$	–	0.40	0.52	S0	–

- Status
  - α and β terms implemented
  - α^2-dynamo tested (iso/anisotropic case)
  - α-ω dynamo tested
    - CωCα = constant, when changing ω (50-200)
  - Resolution convergence

SPMHD – Proof of Concept

Galaxy Model



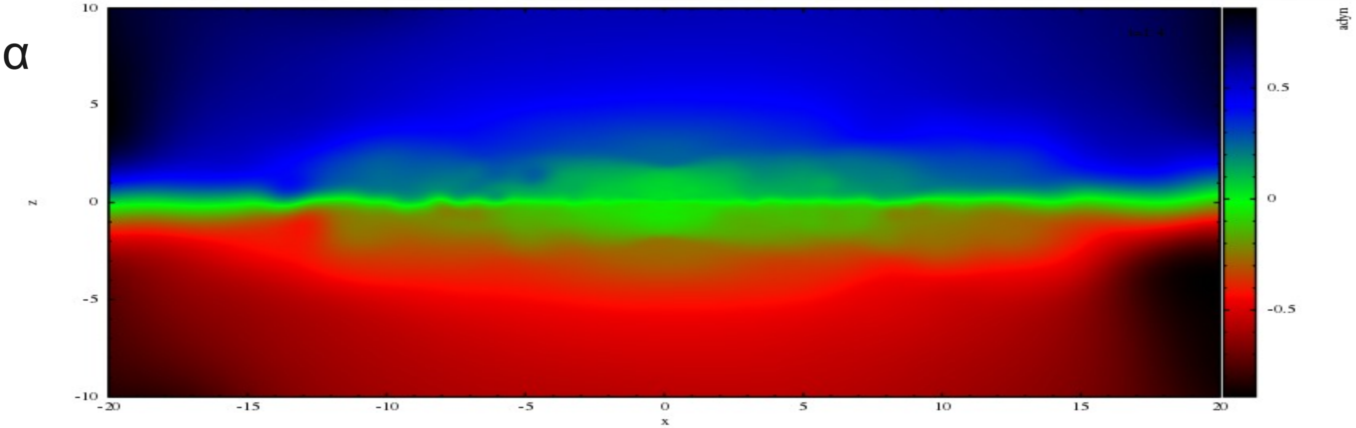
$$\beta \approx \frac{1}{\rho}$$

$$\alpha \approx \pm\rho$$ Sign given by angular momentum

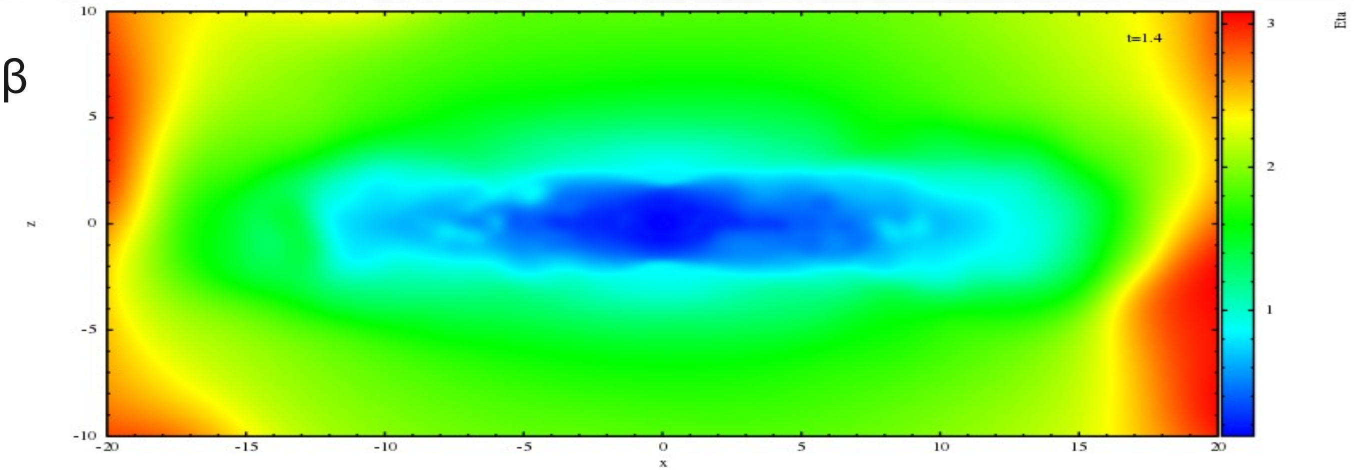
Ω ~ 150 Km/s

SPMHD – Proof of concept

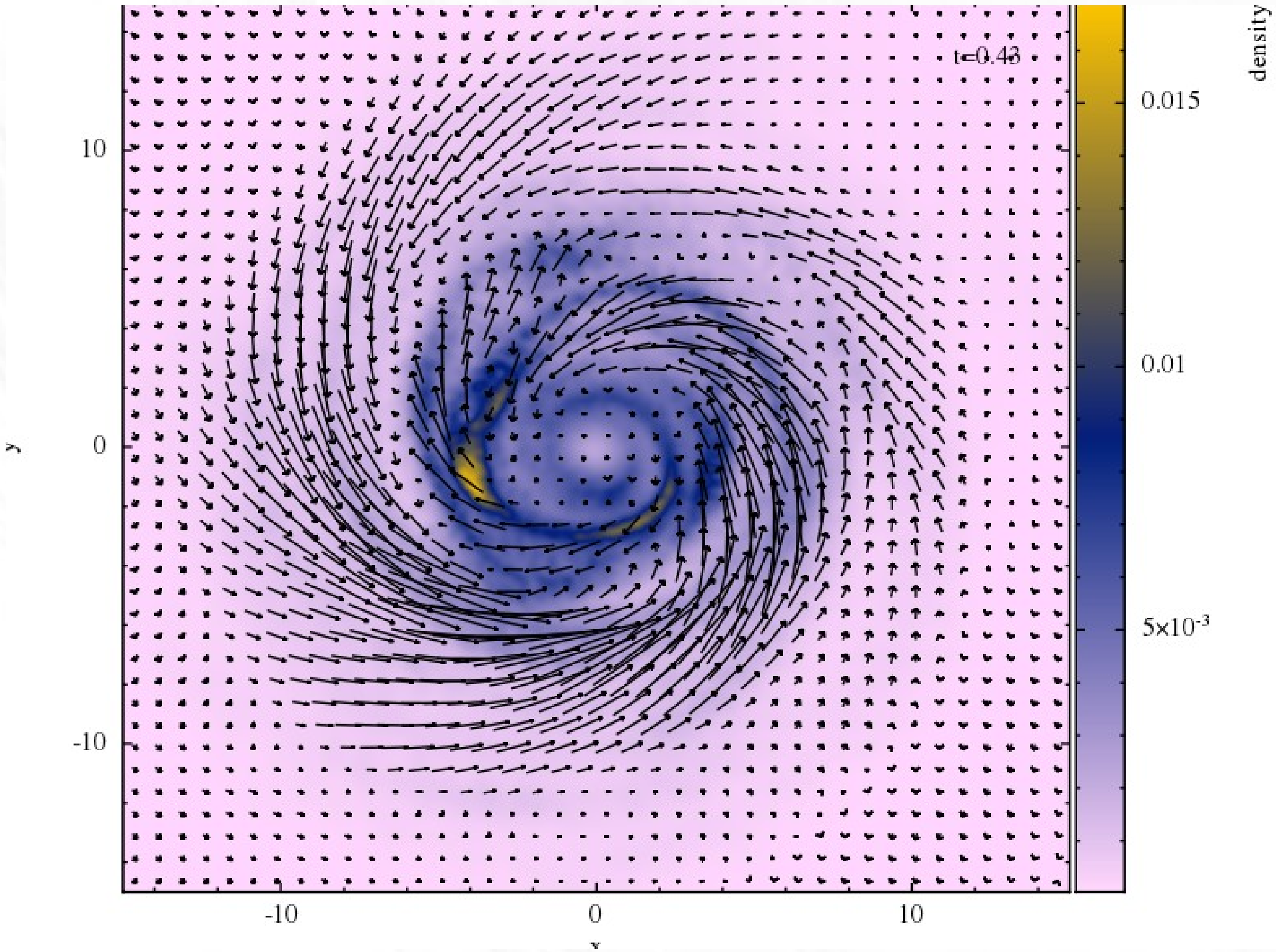
α



β

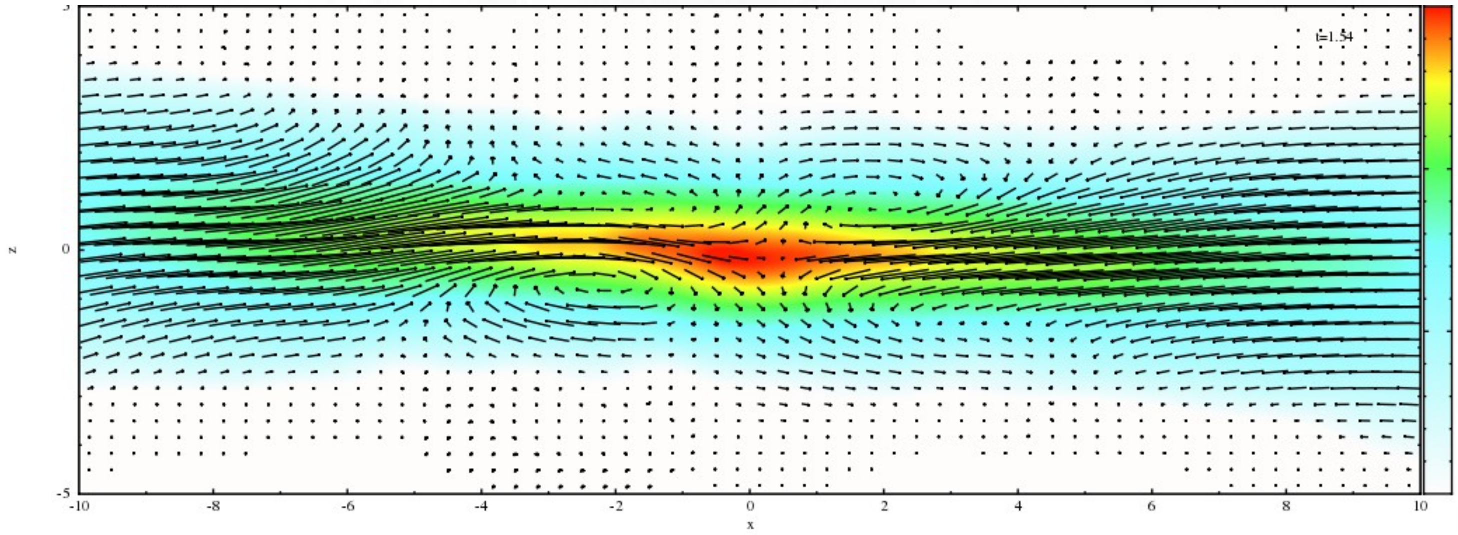


SPMHD – Proof of concept



Slice trough the center of the galaxy, showing reversal features

SPMHD – Proof of concept



Edge on cut of the Galaxy

- Status
  - We test the sub-grid model with simple mean field coefficient recipients in Galaxy simulations
  - We are able to find some (transient) characteristic features found in galaxies.

- Status and Prospects
  - We implemented the mean field equations in SPMHD
  - Consist checks with solutions (analytically or/and numerically)
  - Concept proof of Disk Galaxy initial conditions
  - New estimator for Turbulent component

- Next Steps
  - Build estimators for local quantities.
  - Use Mean field coefficients derived from local high resolution simulations in global simulations (AIP).
  - Generate mock observations to compare with real galaxies.

Thank you!