Growing Magnetic Fields through Turbulence

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Overview

- Simulations of supersonic magnetised turbulence, representative of turbulence in the ISM
- Outline:
  1) Magnetic fields within star formation
  2) Turbulence in the ISM
  3) Numerical method and new developments
  4) Simulation results

MHD in Star Formation

- Magneto-Rotational Instability in accretion discs
  - Provides angular momentum transport out of the inner disc

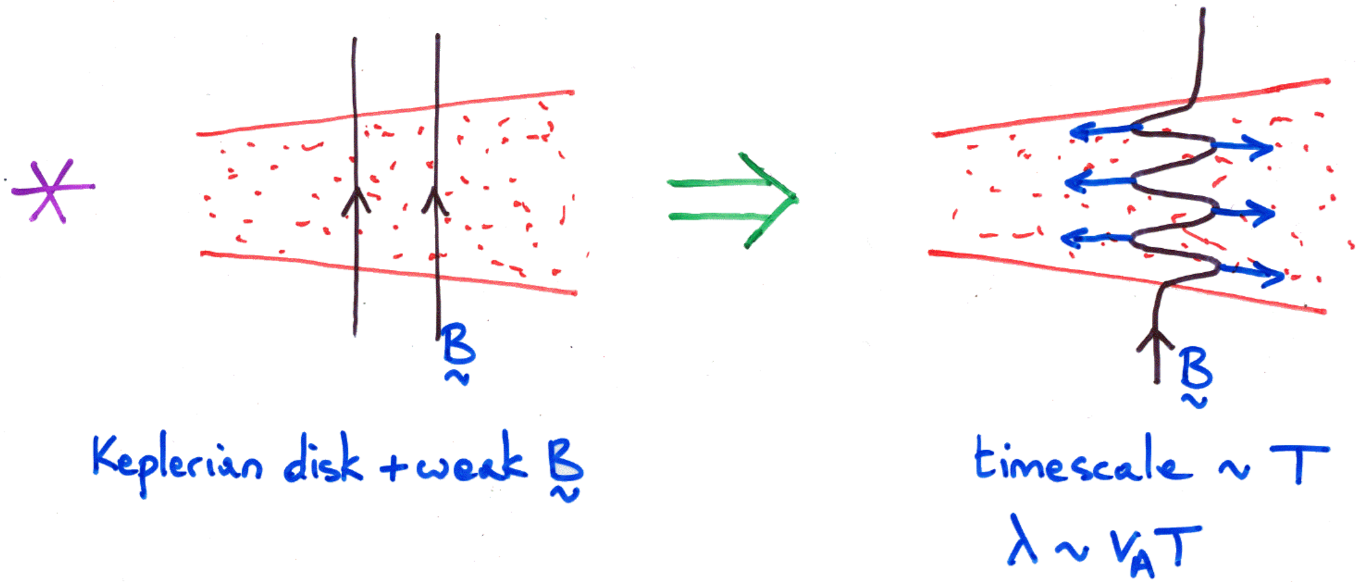
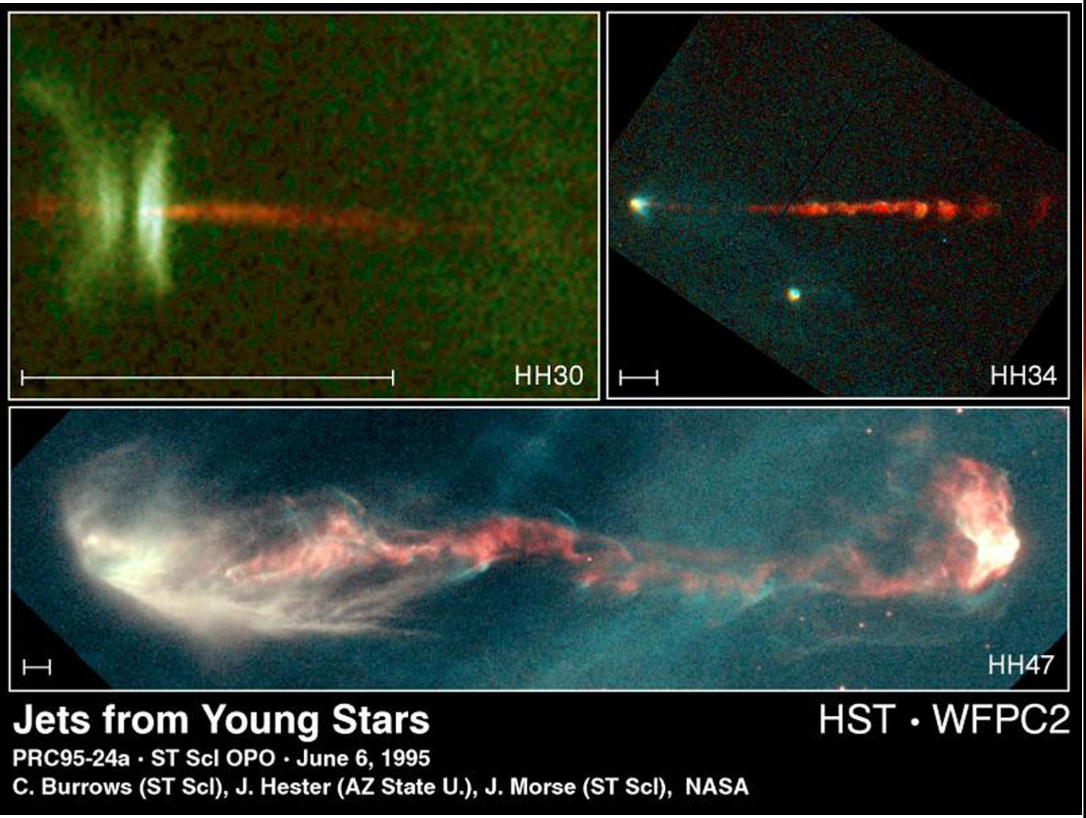
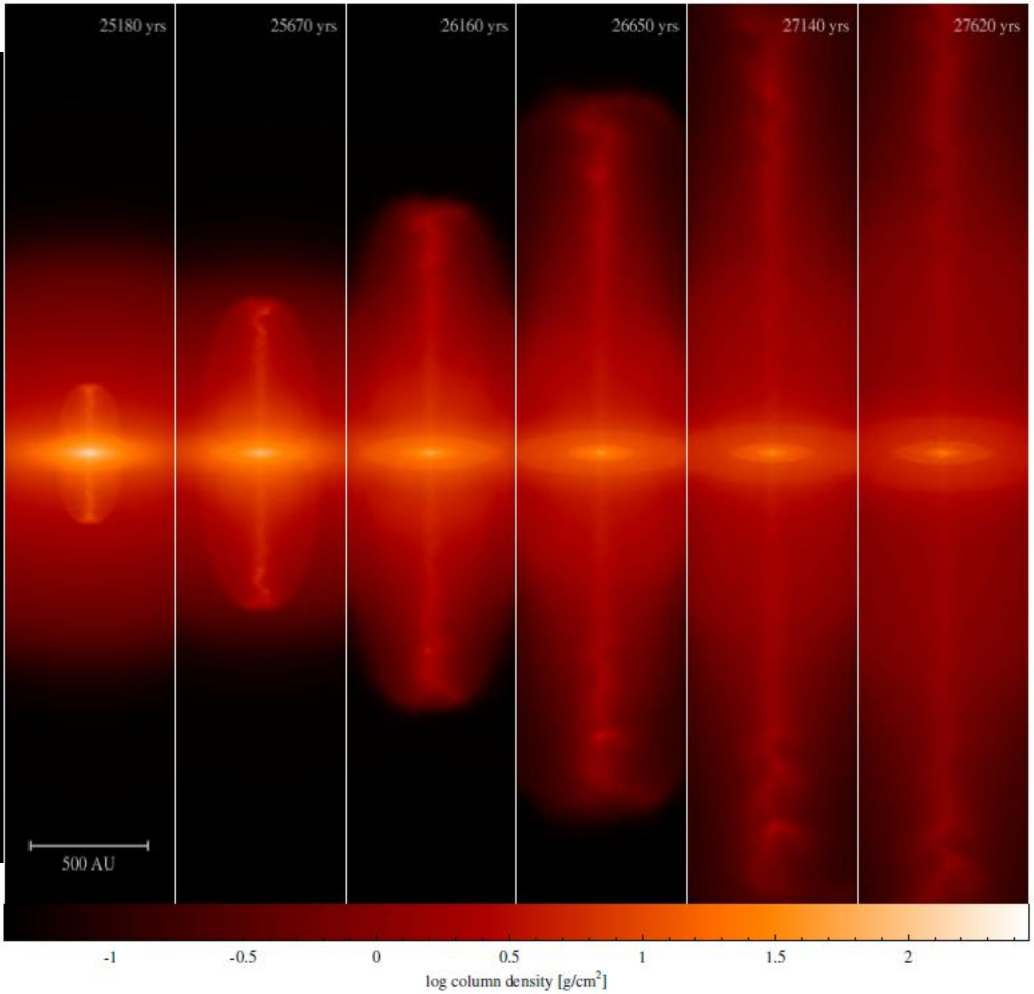


Image courtesy of Mark Wardle

MHD in Star Formation

- Jets and Outflows from protostars

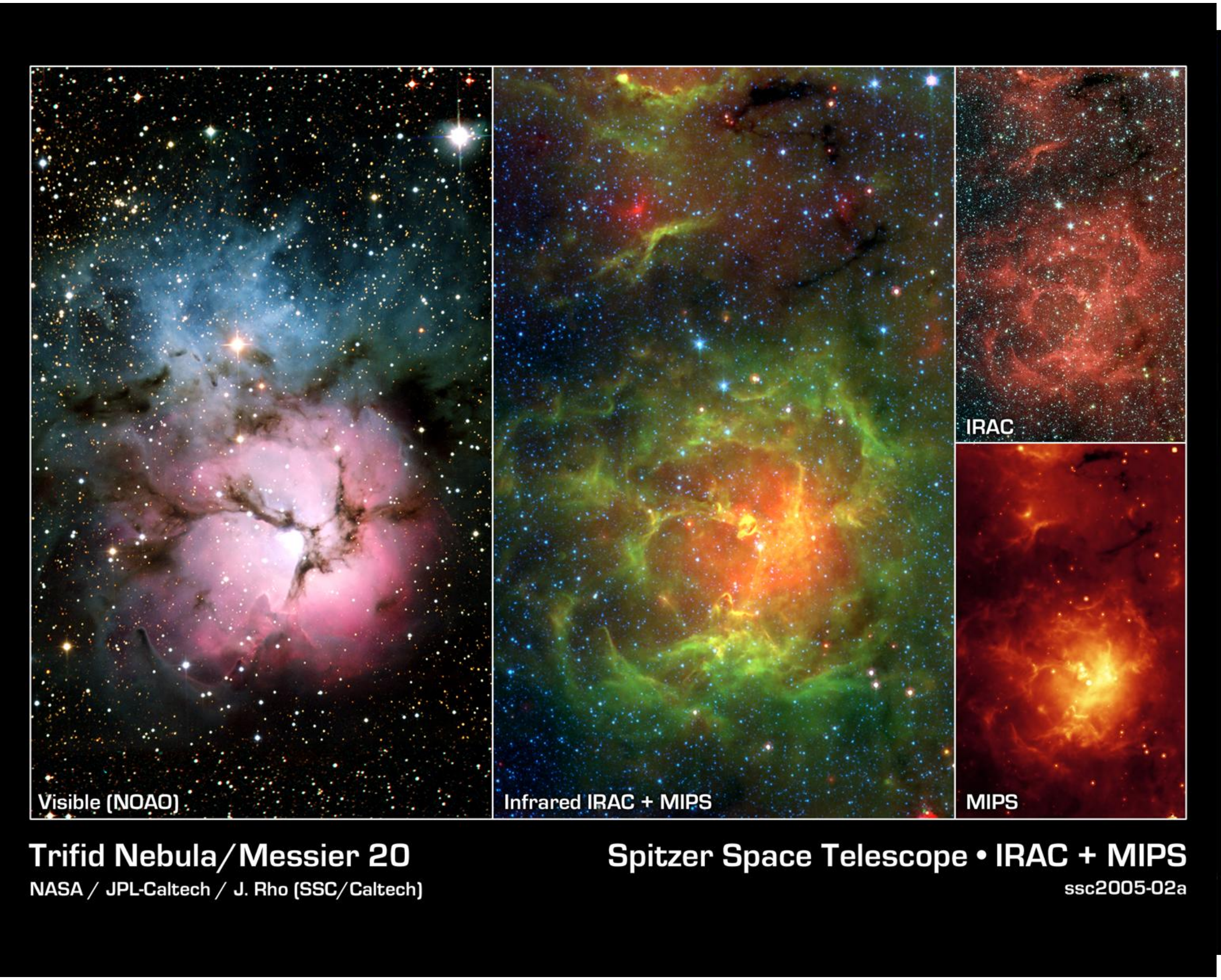


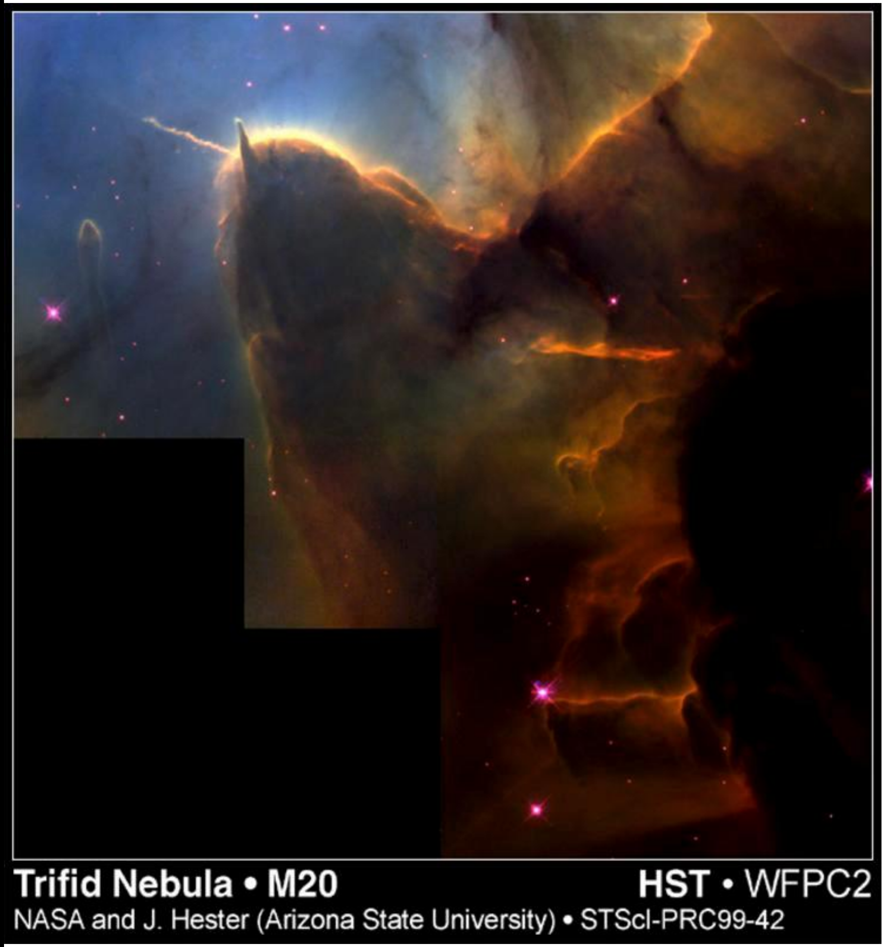


Price, Tricco, Bate (2012)

MHD in Star Formation

- Magnetised turbulence in the Interstellar Medium

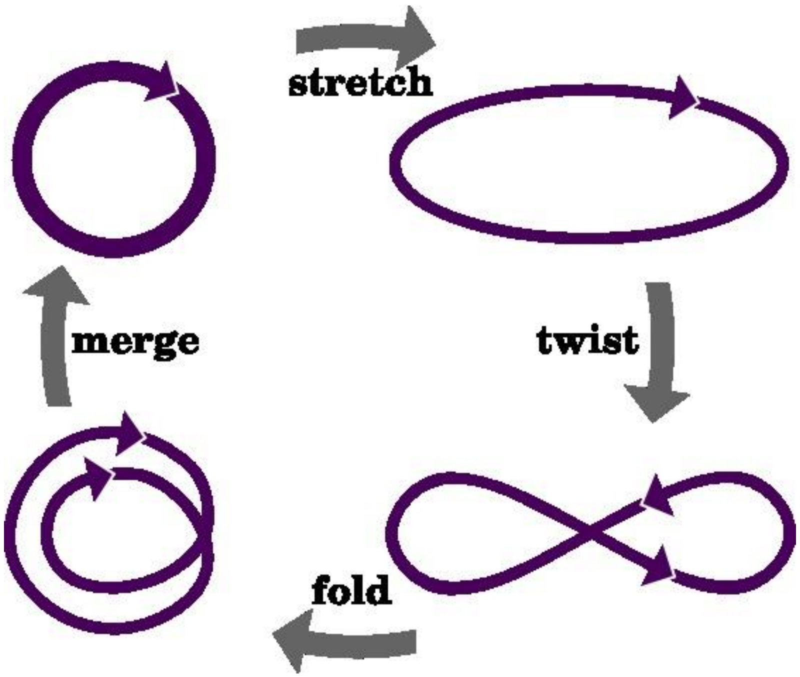




Turbulence in the ISM

- Pure hydro context:
  - Primary role in star formation rate, and efficiency of gas conversion to stars
  - Supersonic turbulence, causes dense filaments within which star formation occurs
- MHD:
  - Small scale dynamo exponentially amplifies magnetic field

Small Scale Dynamo

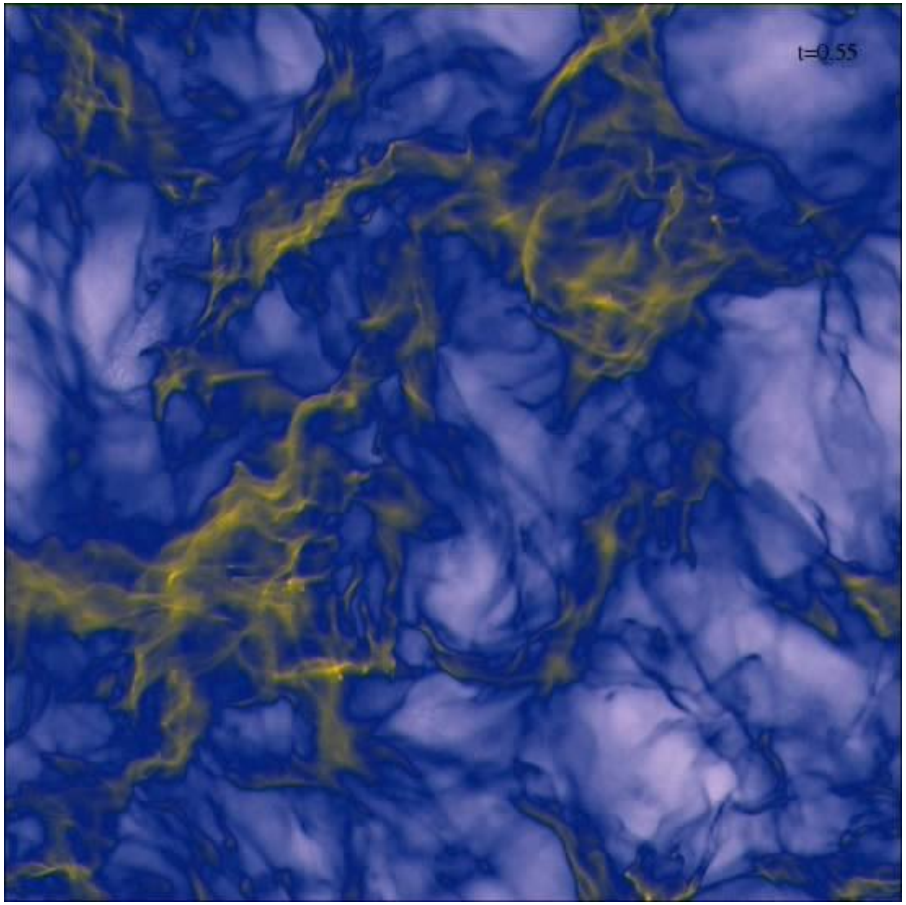


- Stretch-Twist-Fold mechanism amplifies magnetic field on small scales
- Growth rate determined by Reynolds and Prandtl numbers

$$\mathrm{Pm} = \frac{\mathrm{Re}}{\mathrm{Rm}}$$

Turbulence Simulations

- Simulation details:
  - Mach 10 turbulence
  - Isothermal equation of state
  - Periodic boundary conditions
  - Solenoidal stochastic forcing
  - Initially weak magnetic field (E_{mag} 10^{10} weaker than E_{kin})
- Results compared against grid based Flash code
- Extends the pure hydro comparison of Price, Federrath (2010)



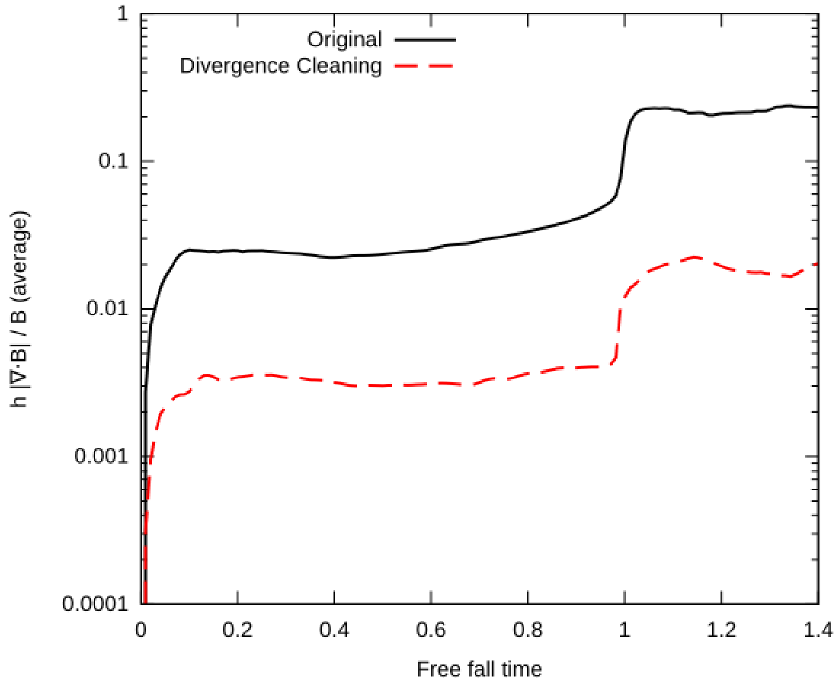
Numerical Method: SPH

- Discretise fluid into set of particles which simulate fluid motion
- Well suited for star formation:
  - Couples well with N-body methods
  - Strong conservation properties, very stable
  - Inherently adaptive, resolution traces mass
- Most difficult numerical aspect of MHD:

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

Constrained Divergence Cleaning

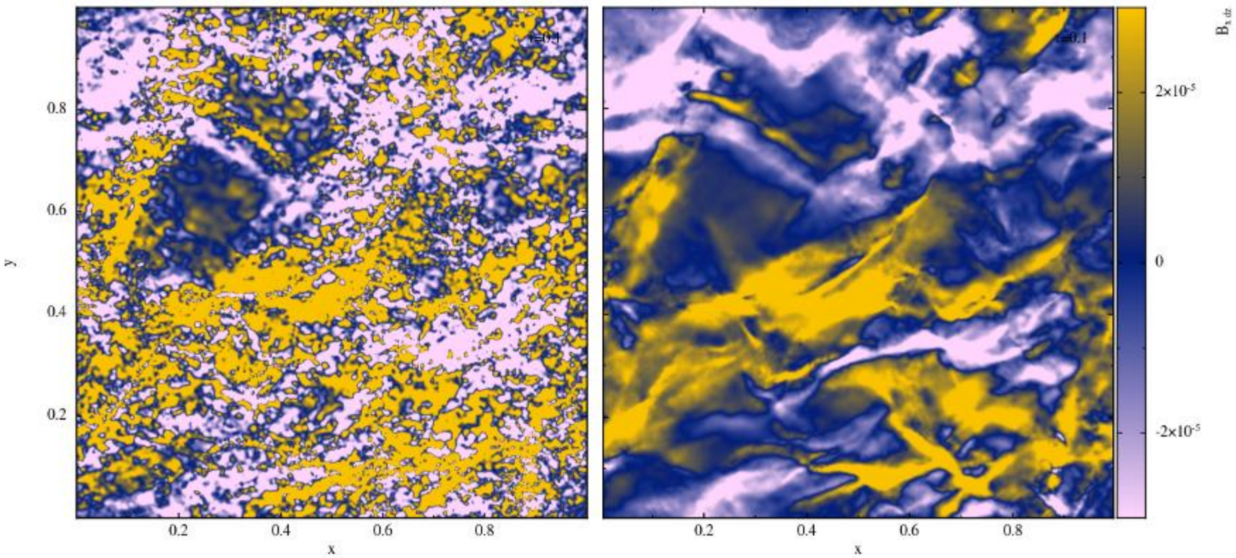
- Hamiltonian formulation of hyperbolic divergence cleaning
  - Ensures energy conservation, guaranteed to always decrease divergence of the field
  - Retains conservation and stability properties of SPH
  - Accounts for Lagrangian motion of particles
  - Approximately 10x decrease in divergence error



Tricco, Price (2012)

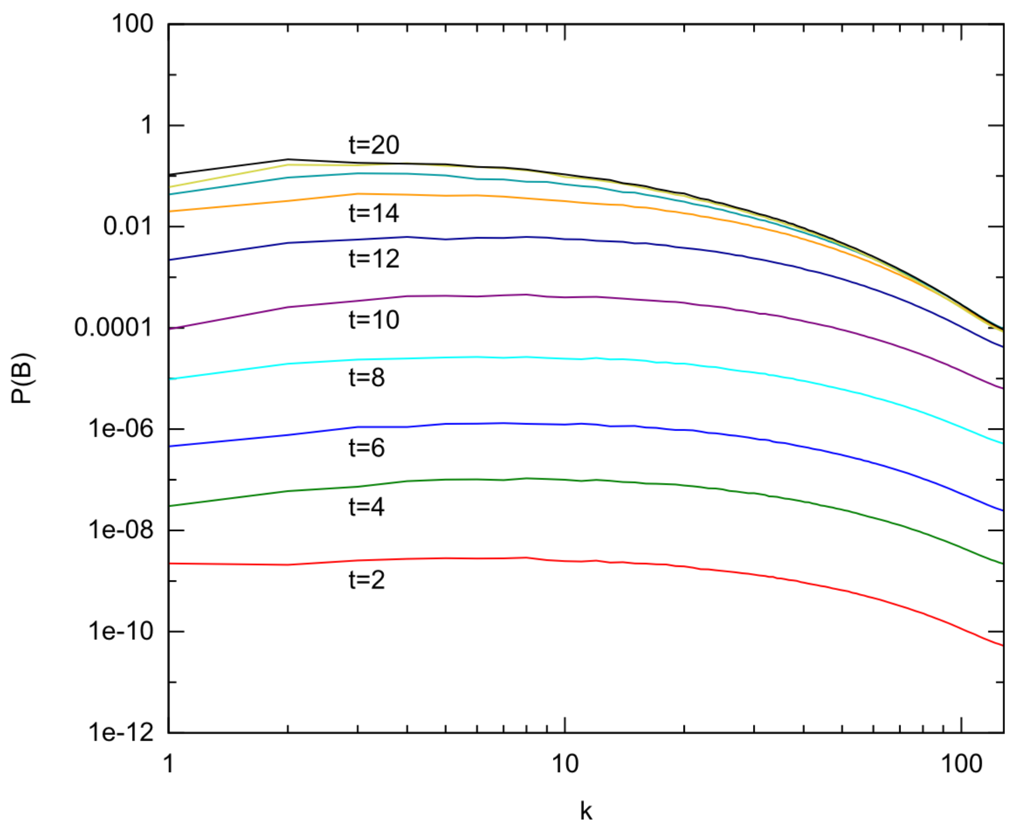
Shock Capturing

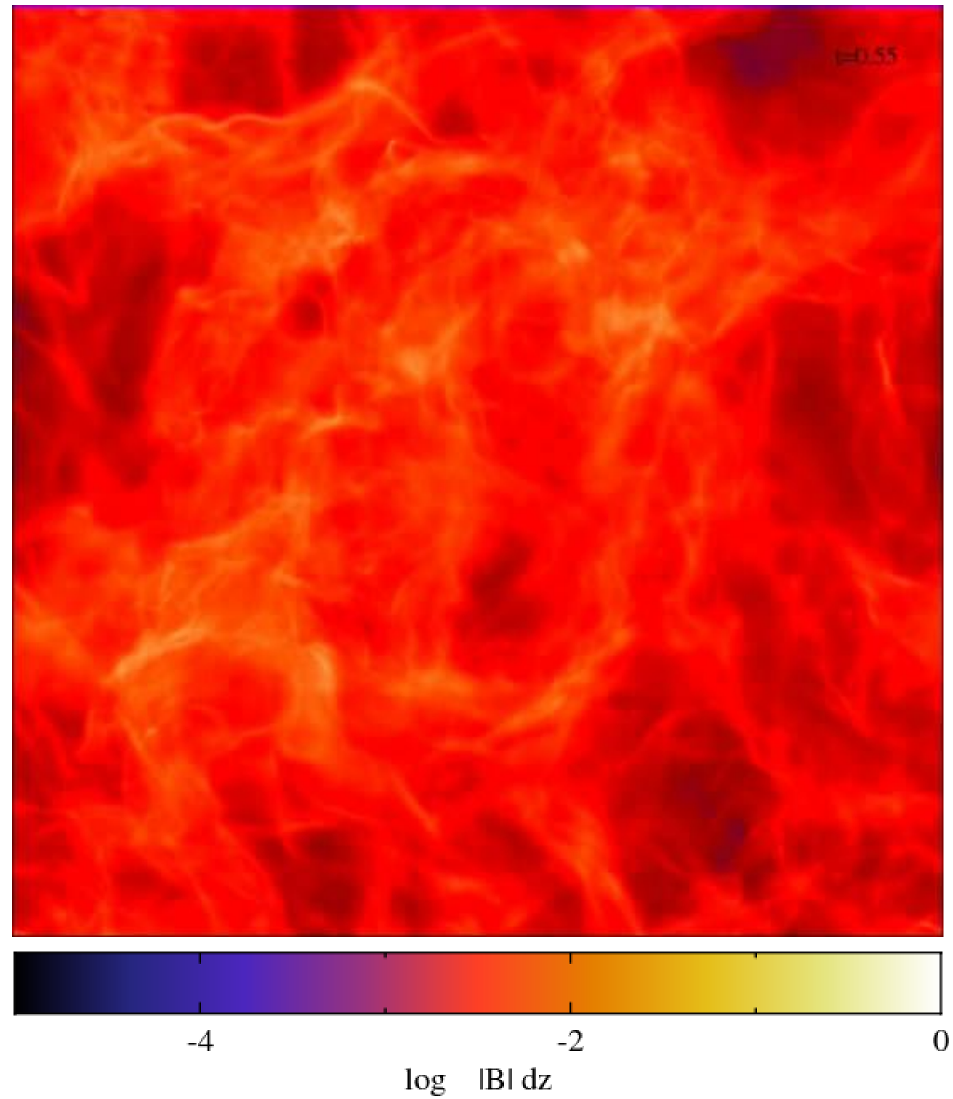
- Magnetic shocks captured by using Artificial Resistivity
- Resistivity switch activates resistivity only near shocks
- New switch: sets AR $\propto |\nabla \mathbf{B}| / |\mathbf{B}|$
  - ie, relative degree of discontinuity in the magnetic field
  - Invariant to field strength, captures shocks as field is amplified



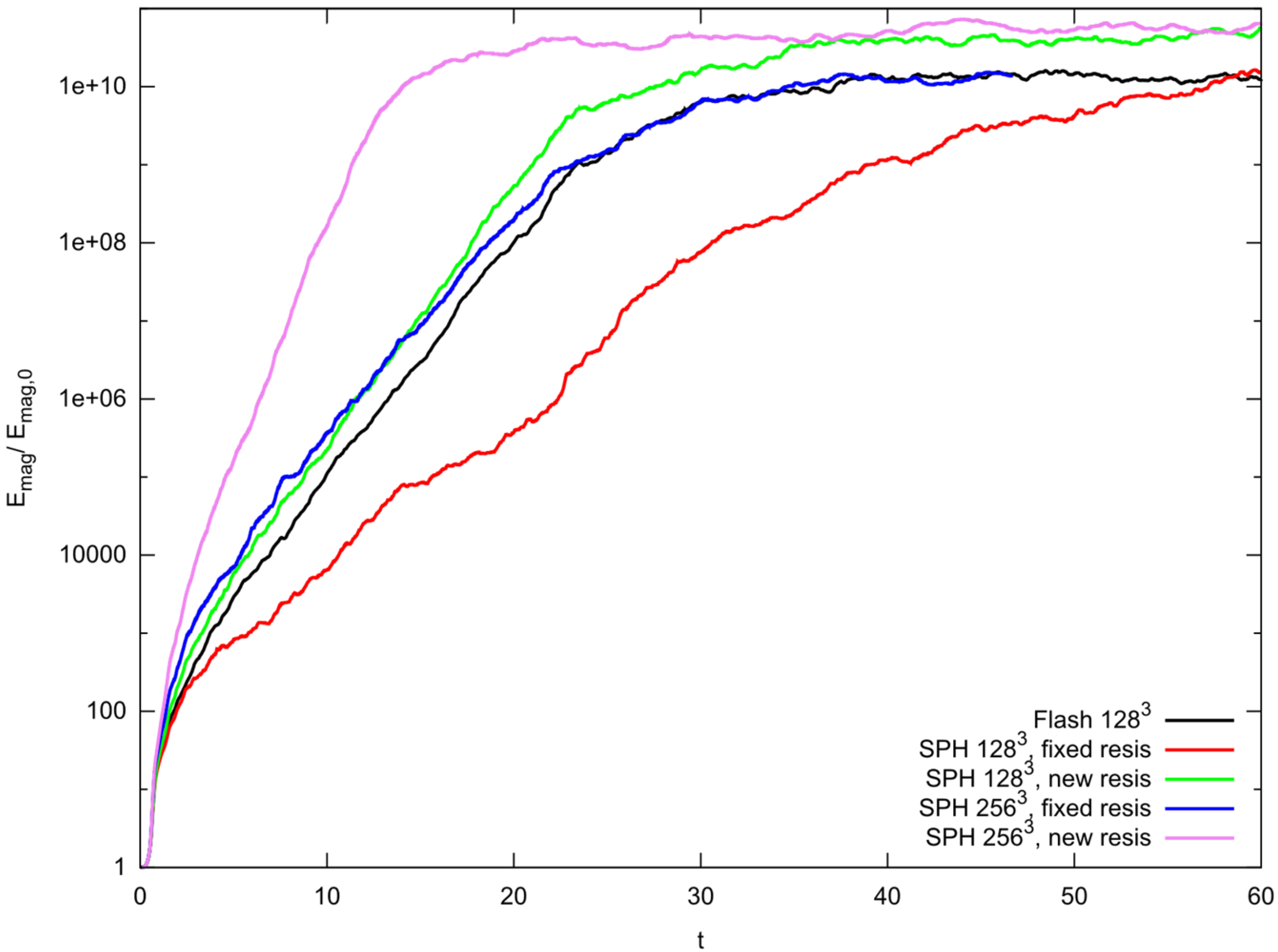
Previous switch　　　　　　New switch

Dynamo Amplification





Energy Growth



Conclusions

- SPH can successfully model dynamo amplification from supersonic turbulence
- New artificial resistivity switch for magnetic shock capturing
- Future Goals:
  - Simulate MRI with SPH
  - Combine MRI + Jets + turbulence in large cluster simulations