Non-ideal MHD turbulent decay in molecular clouds

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Why is this interesting?

There are a few reasons ...

- Molecular clouds appear to have longer lifetimes than expected
  - They require some kind of support (turbulence?)
  - How much power/momentum flux is needed to support the clouds?
- Larson's law suggests that turbulence is present
  NB: see Heyer et al (2009)
- Large-scale turbulence in molecular clouds may influence star formation

Why multifluids?

- Molecular clouds are weakly ionised
- Charge-to-mass ratios vary widely
- No *a priori* reason to believe single fluid approach
- Traditionally approximated by ambipolar (low density) or resistive (high density) diffusion
- Wardle (2004) and subsequent papers have suggested that the Hall effect may also be significant

Relevant conditions

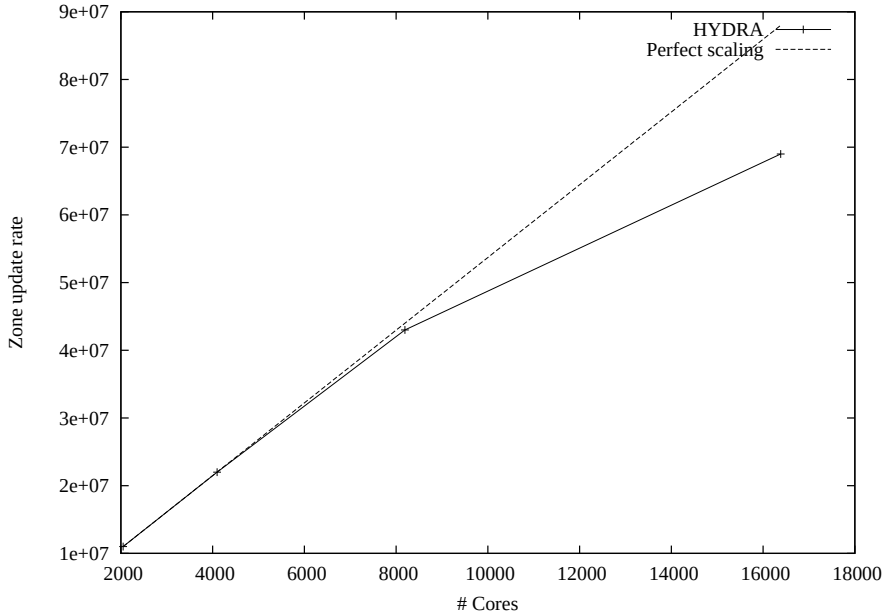
- Molecular cloud turbulence is known to be supersonic
- Reasonable to approximate the system as isothermal
- Scale of the system is large (so periodic boundary conditions are not unreasonable)

Numerical model

We use the scheme of O'Sullivan & Downes (2006, 2007)

- Super-time-stepping for ambipolar diffusion
- Hall Diffusion Scheme for Hall effect
- Assume weak ionisation (e.g. Falle 2003)
- Neutrals advanced using a Godunov-type method
- Method of Dedner used to control $\nabla \cdot \boldsymbol{B}$

Scaling



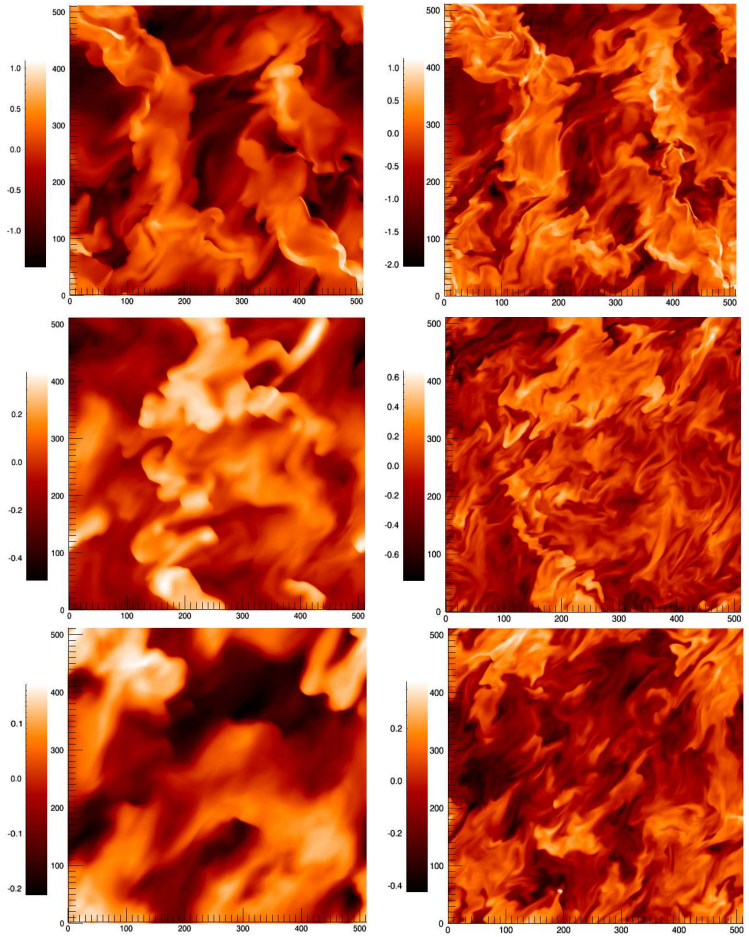
Hard scaling on BG/P system in IBM Watson Research Lab (512^3)

Initial Conditions

Chosen to maximise any possible influence of the Hall effect.

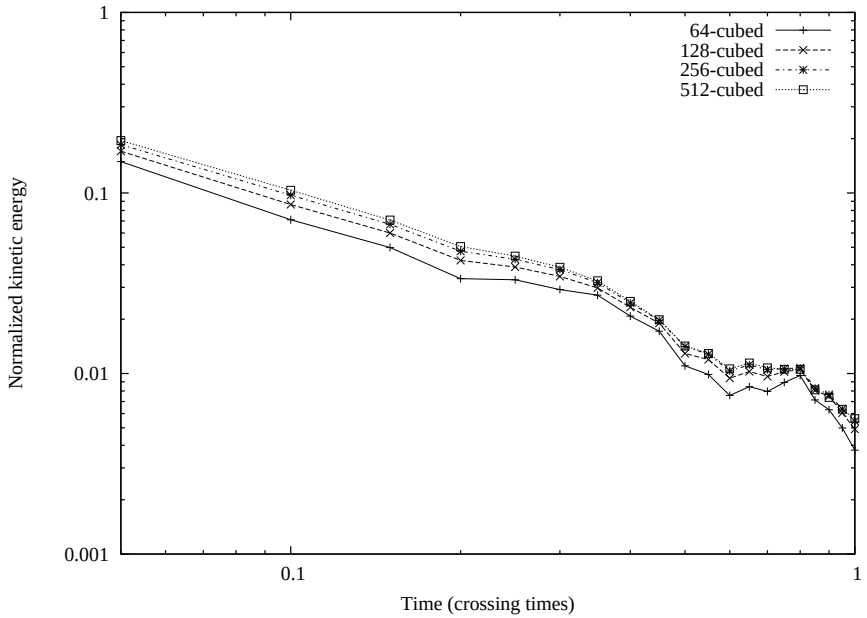
- $L_{\mathrm{box}} = 0.2\,\mathrm{pc}$ (periodic boundary conditions)
- $c_s = 0.55\,\mathrm{km\,s^{-1}}$(crossing time is about 1.8 Myr)
- $\mathbf{B} = \frac{1}{\sqrt{3}}(1,1,1)^{\mathrm{T}}\,\mathrm{mG}$
- $n = 10^6\,\mathrm{cm}^{-3}$
- Each component of $\mathbf{v}$ is initialised as a sum of 16 wave-vectors with random amplitudes and phases (no driving, solenoidal, rms Mach number of 5)
- For a first step, fix our resistivities in time and space

Energy decay



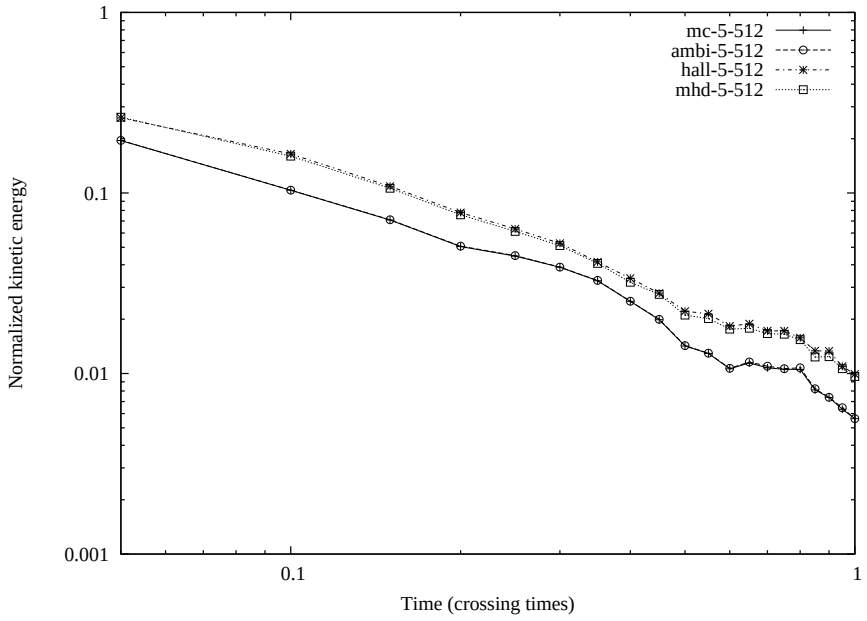
Snapshots of slices of the flow at different times

Energy decay



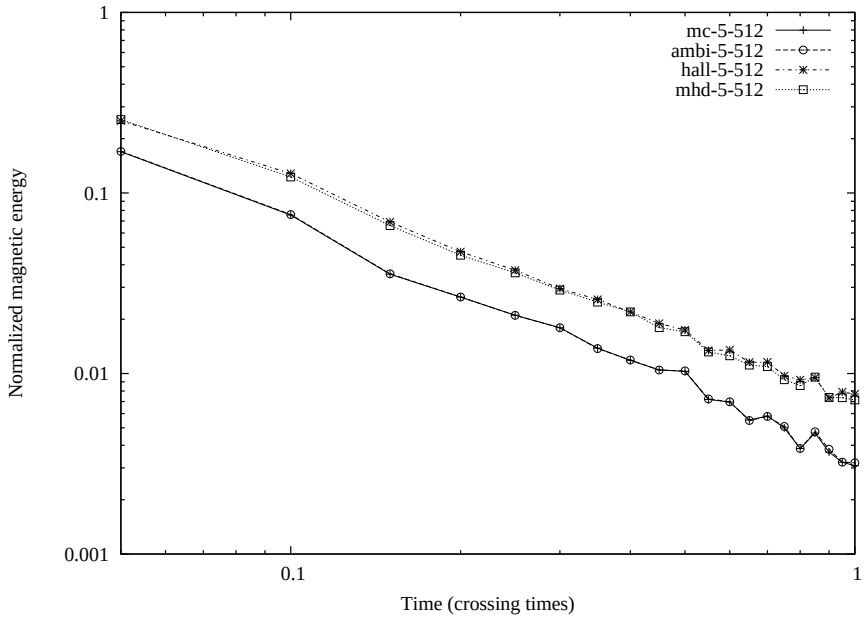
Kinetic energy decay for differing resolutions

Energy decay



Kinetic energy decay for different physics

B evolution



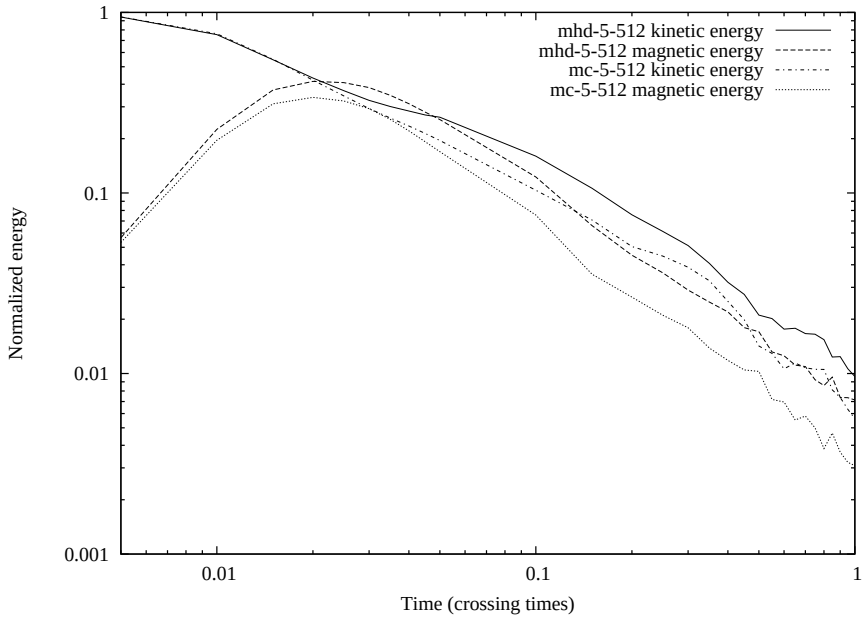
Magnetic energy decay for the different simulations

Energy decay rates

Simulation	β_{K}	β_{B}	β_{Tot}
mc-5-512	1.40	1.37	1.39
ambi-5-512	1.40	1.35	1.38
hall-5-512	1.25	1.18	1.22
mhd-5-512	1.26	1.19	1.23

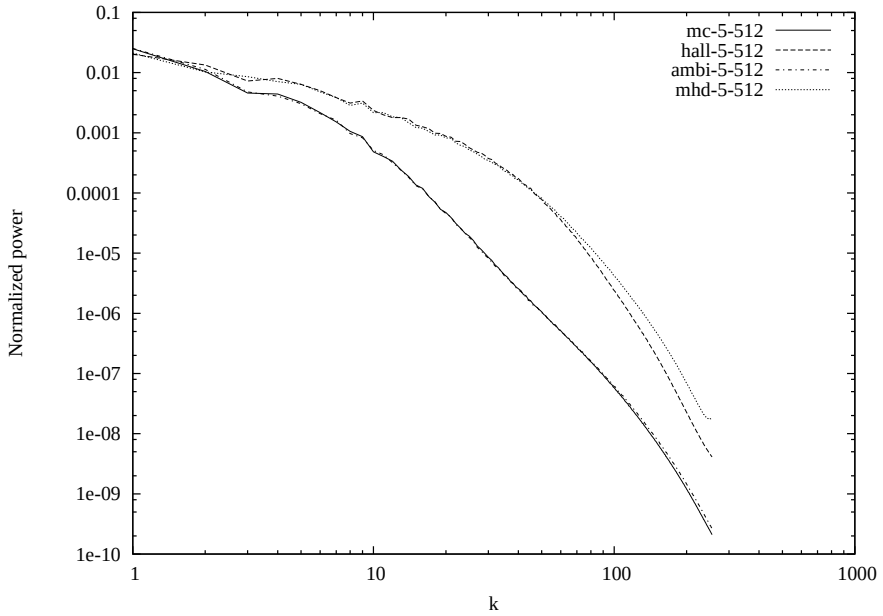
Exponents of energy decay fitted over interval $[0.2t_{\mathrm{c}}, t_{\mathrm{c}}]$.

Early-time evolution



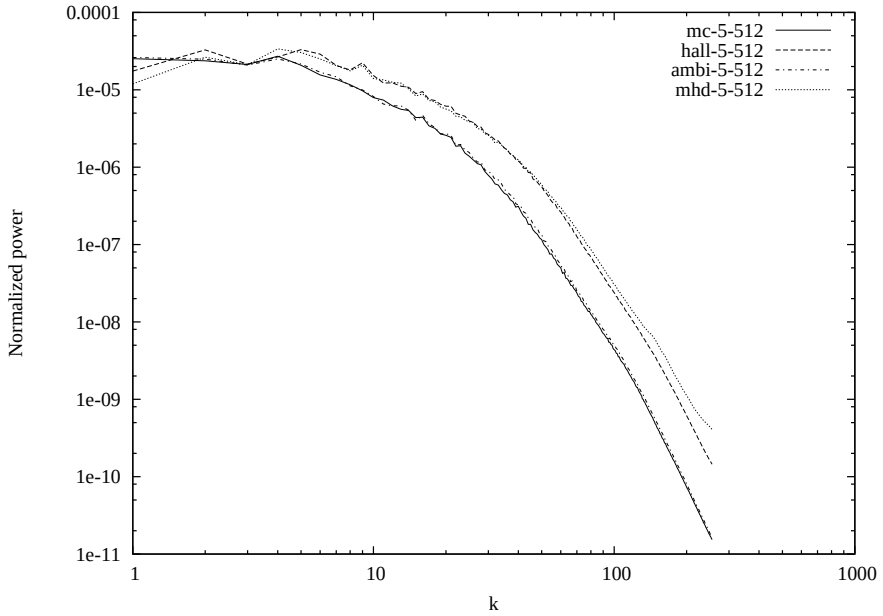
Time evolution of kinetic and magnetic energy

Power spectra



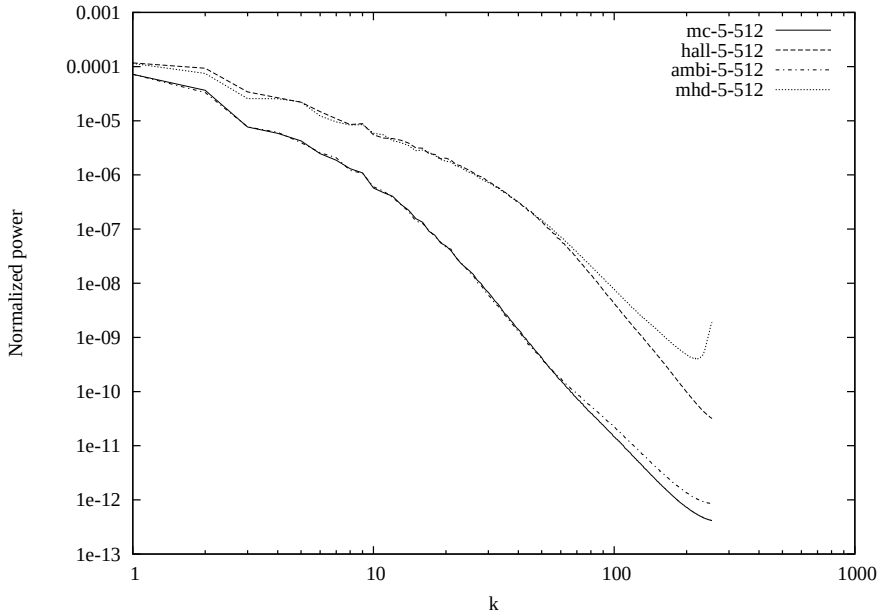
Density power spectrum at $t = t_c$

Power spectra



Velocity power spectrum at $t = t_c$

Power spectra



Magnetic power spectrum at $t = t_c$

Power spectra

Simulation	Density	Velocity	Magnetic field
mc-5-512	2.09[a], 4.06[b]	1.47	2.17[a], 4.96[b]
ambi-5-512	2.04[a], 4.03[b]	1.49	2.21[a], 4.75[b]
hall-5-512	1.41	1.20	1.65
mhd-5-512	1.45	1.17	1.59

[a]: Fitted over $4 \leq k \leq 10$
[b]: Fitted over $10 \leq k \leq 100$

Conclusions

- Ambipolar diffusion enhances turbulent decay
- Hall effect appears to have little impact
- Power spectra strongly influenced by ambipolar diffusion
- Hall effect important at high k (effects more notable in B-field)