As a matter of force –
Systematic biases in idealized turbulence simulations

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SnowCluster 2018
Snowbird, Utah, Mar 18, 2018
Motivation

- Large dynamical range in clusters
- Captured only to a certain degree in simulations → idealized subvolumes
- Example: Turbulence in a box
- Assumption: Realization of driving does not matter
  → unfortunately not quite true

[Image credit top: Walker+ MNRAS 2017]
Driven turbulence in a box

- Isothermal, isotropic, homogeneous MHD turbulence
- Subsonic $M_s \approx 0.5$ and super-Alfvénic
- Analyzed stationary regime (50 snapshots over 2.5 turnover times $T$)

- Solenoidal driving with varying
  - Autocorrelation time: $\delta$ in time $\leftrightarrow$ finite corr. time
  - Normalization: Constant energy injection rate $\dot{E} \leftrightarrow$ constant RMS acceleration $\langle a \rangle$
Kinetic energy spectra

- Shorter autocorrelation time $T_{\text{corr}}$
  $\rightarrow$ more power in compressive modes

- Dynamically relevant (different slope in total energy) for $F_\delta^E$
  $\Rightarrow$ Don’t end up with/on the wrong slope
Energy input and alignment

- Energy input: $\dot{E} = \rho u \cdot a$

- To reach same $M_s$: shorter autocorrelation time $T_{corr}$ requires more power in the acceleration field

- (Limited) dynamic alignment with increasing $T_{corr}$

$\Rightarrow$ more efficient energy input
Faraday rotation measures are exact only if $\rho$ and $B$ are uncorrelated [Beck+ 2003 A&A]

Competing effects

- Negative correlation from total pressure equil.
  \[ \rho_{\text{tot}} = \rho_{\text{th}} + \rho_{\text{mag}} \approx \text{const.} \]
  [see also Yoon+ 2016 ApJ]
- Positive correlation from frozen in flux compression
Density distributions

- $\delta$ in time simulation: broad and symmetric
- Finite corr. forcing: peaked and skewed

$\Rightarrow$ Direct result of compressive modes
Results

Magnetic field measurements


- $\delta$ in time forcing: peaked and centered (on true $B$ value)
- Finite corr. forcing: broad and offset (from true $B$ value)

$(\text{Natural})$ underestimation of magnetic field strength
Forcing parameters directly influence physics on all scales

- Shorter forcing autocorrelation times require
  - more power in the acceleration field that seeds
  - more power in compressive modes, which modify
  - \((\rho - B)\) correlations and distributions

\(\delta\) in time forcing is unrealistic and numerically not resolved

\(\Rightarrow\) Results from simulations using \(\delta\) in time forcing should be interpreted with care