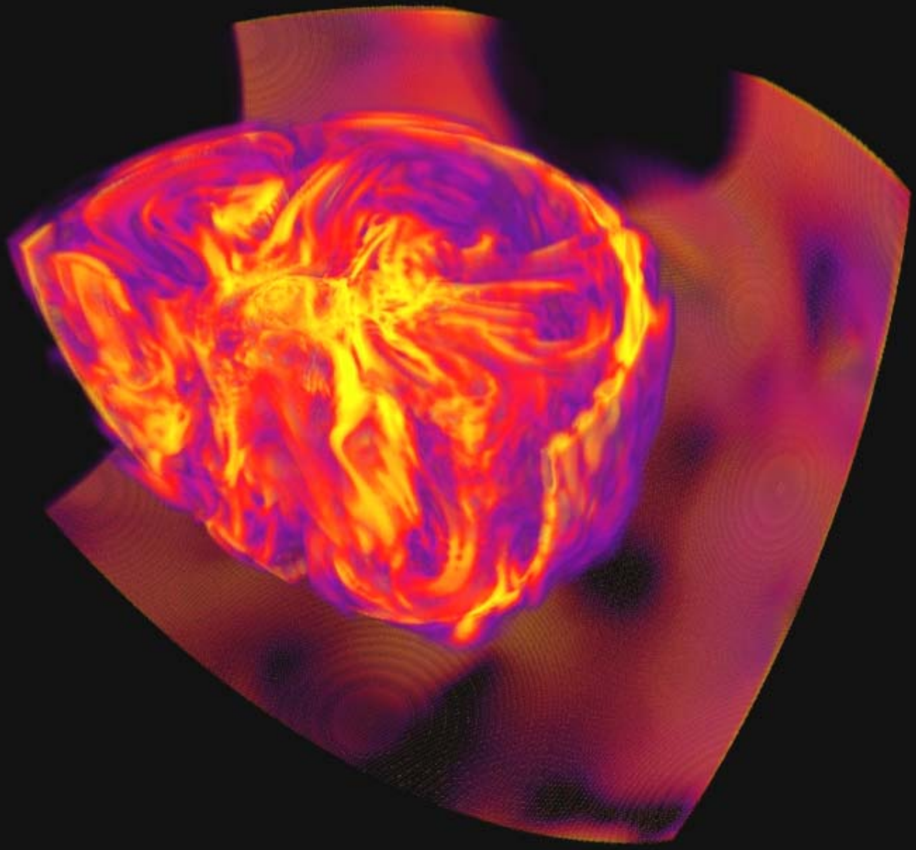
Convective Core Dynamos in Ap Stars



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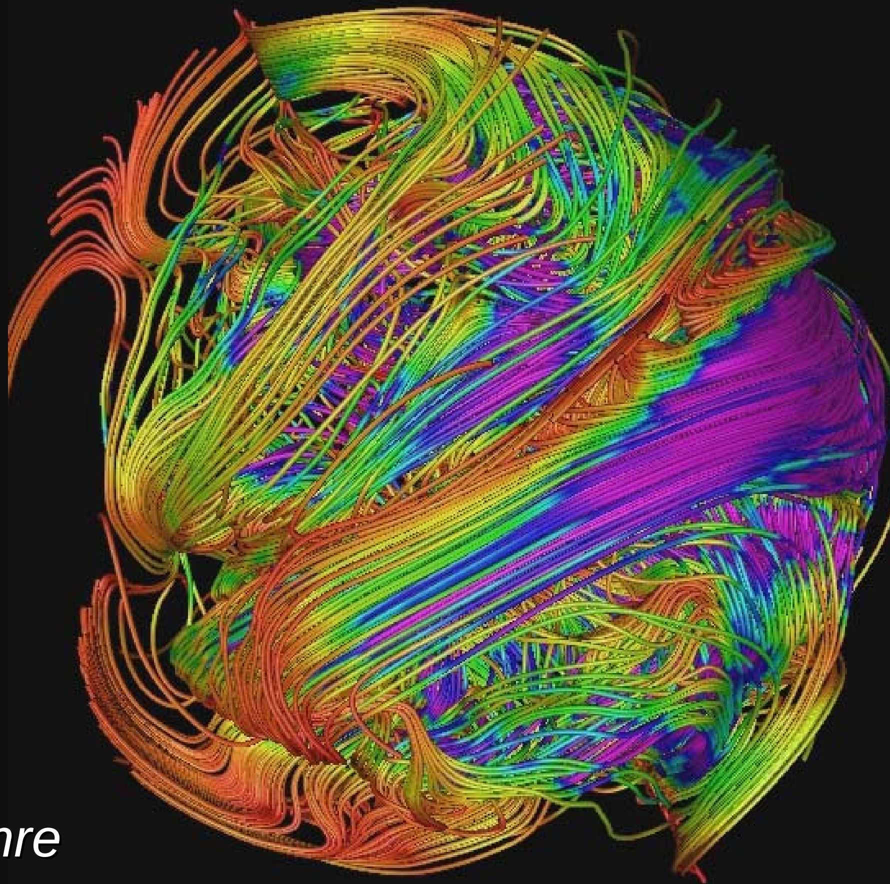
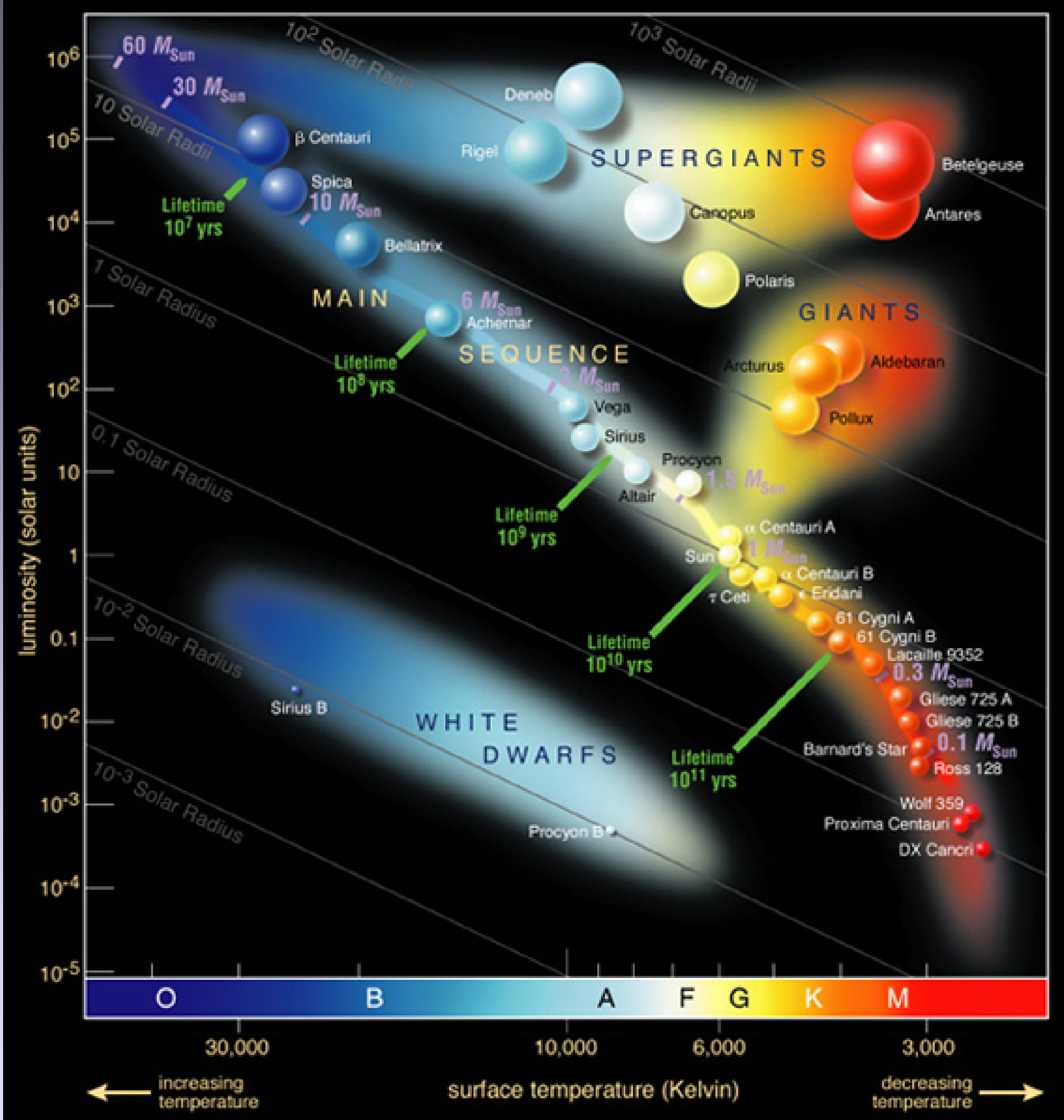


Collaborators:

Matt Browning, Sacha Brun & Juri Toomre

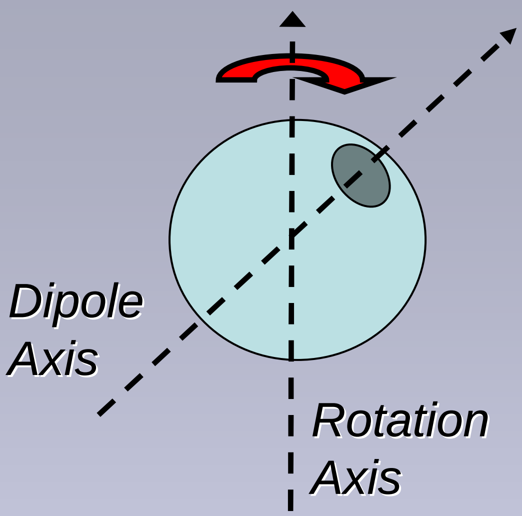
A-Type Stars



Bennet, et al. 2003

Peculiar A-Type (Ap) Stars

- *Abnormally strong abundances of Si and various rare earth metals (Hg, etc.)*



- *Magnetic: typical field strengths of a few hundred Gauss.*

- *Field strengths and line widths vary periodically: Oblique Rotator Model*

- *Rotation periods from days to decades (magnetic braking?)*

Source of Magnetic Field?

- *Core-dynamo? (but diffusion time through radiative zone very long)*

- *Primordial magnetic field?*

Approach

- *MHD equations solved in <u>spherical geometry</u> using the Anelastic Spherical Harmonic (ASH) code*
- *Model inner 30% of 2 solar mass A-type star (convective core + some of radiative envelope)*
- *Stratification and luminosity from 1-D stellar model (2x density contrast across core)*

A Few Specifics

Re ~ 175

Rm ~ 900

Pr = 0.25

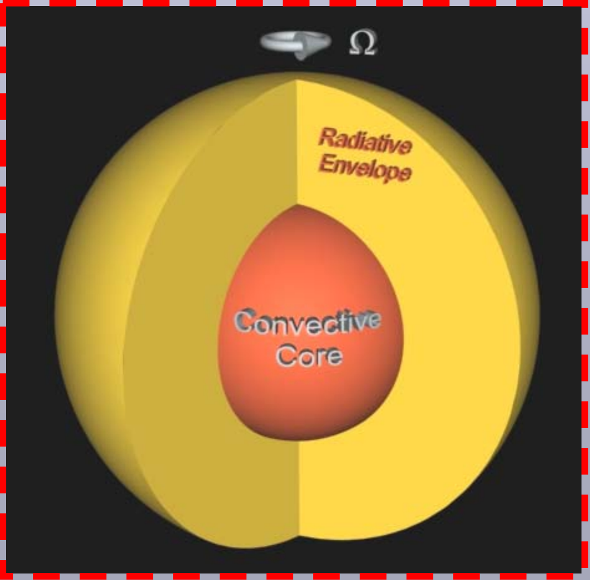
Pm = 5

N_r = 82

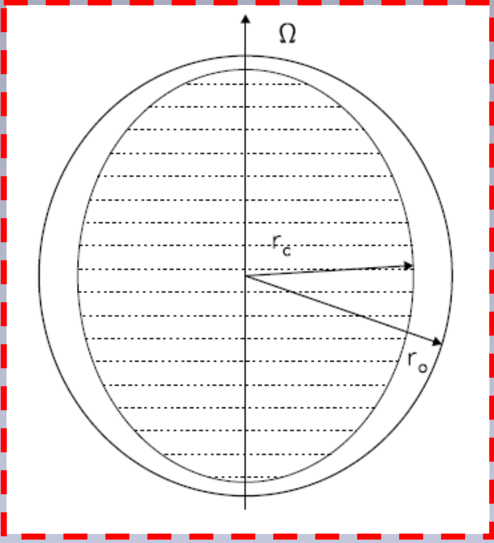
L_{max} = 170

PC / Constant Flux Boundaries

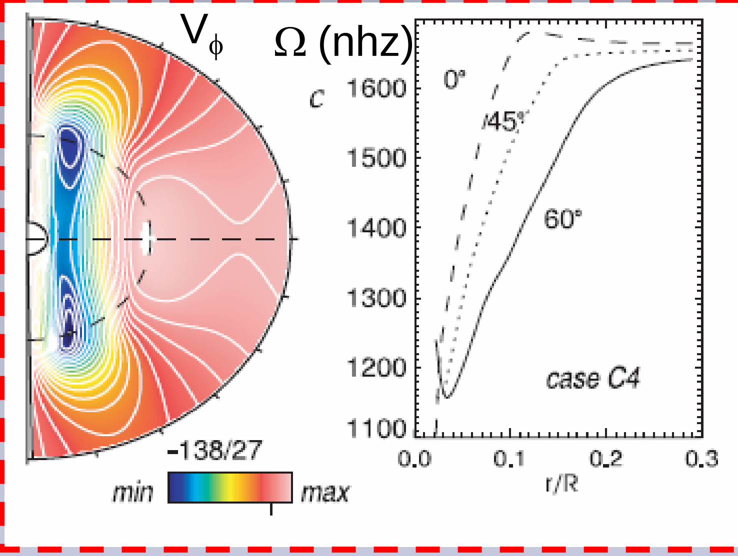
Energy Generation ~T^8



Convection and Dynamo Action in A-stars

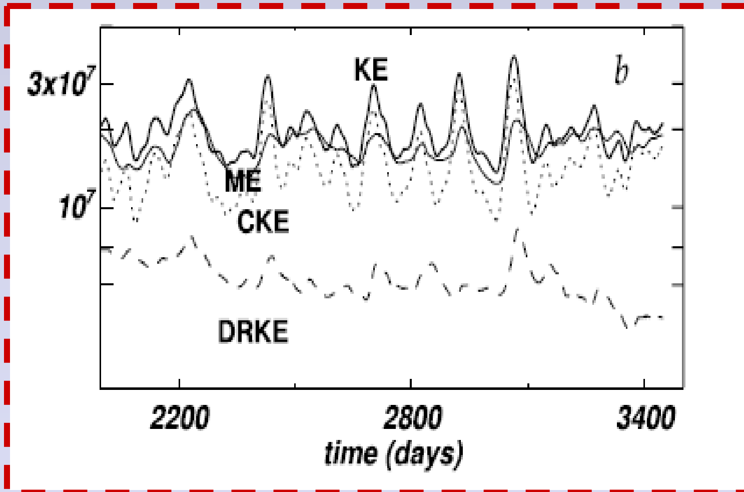


- Prolate Core
- Differentially Rotating



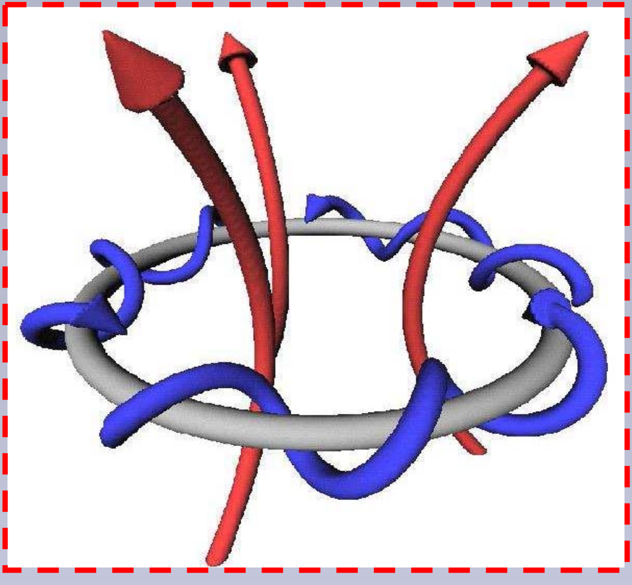
Browning, Brun, & Toomre 2004

- Strong dynamo action (~ 70kG fluctuating fields within core)
- Magnetic fields in rough equipartition with convection
- Diminished differential rotation



Brun, Browning & Toomre 2005

Primordial Magnetic Fields



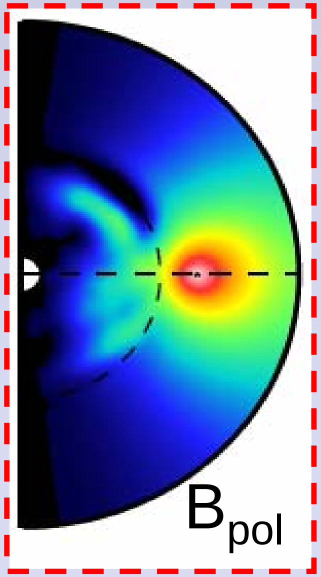
Braithwaite & Spruit 2005

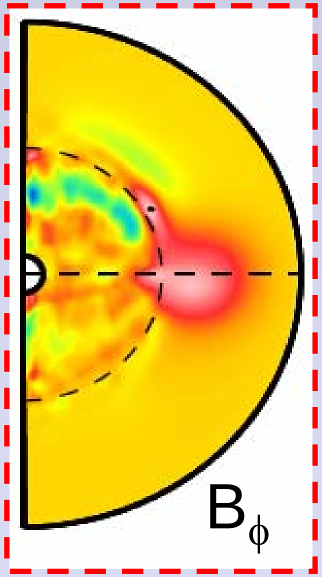
Braithwaite & Nordlund 2006

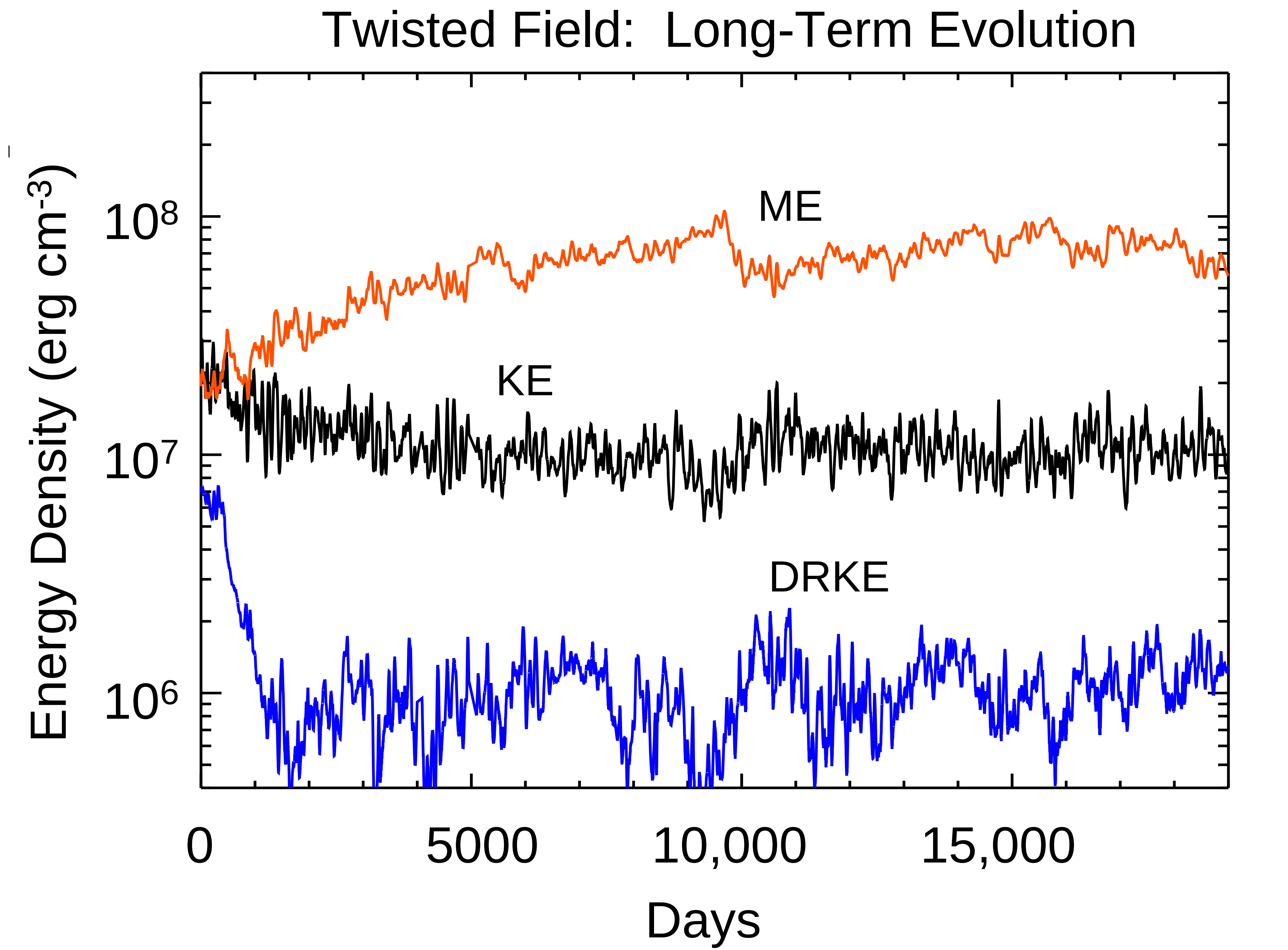
- Need toroidal and poloidal components for stabilty
- Simulations suggest twisted torus
- How might such a field interact with the core dynamo?

Modeling the Interaction

- Add poloidal + toroidal field to previous dynamo simulation of Brun et al. (2005)
- 10% Magnetic energy increase
- Also examine higher order multipoles

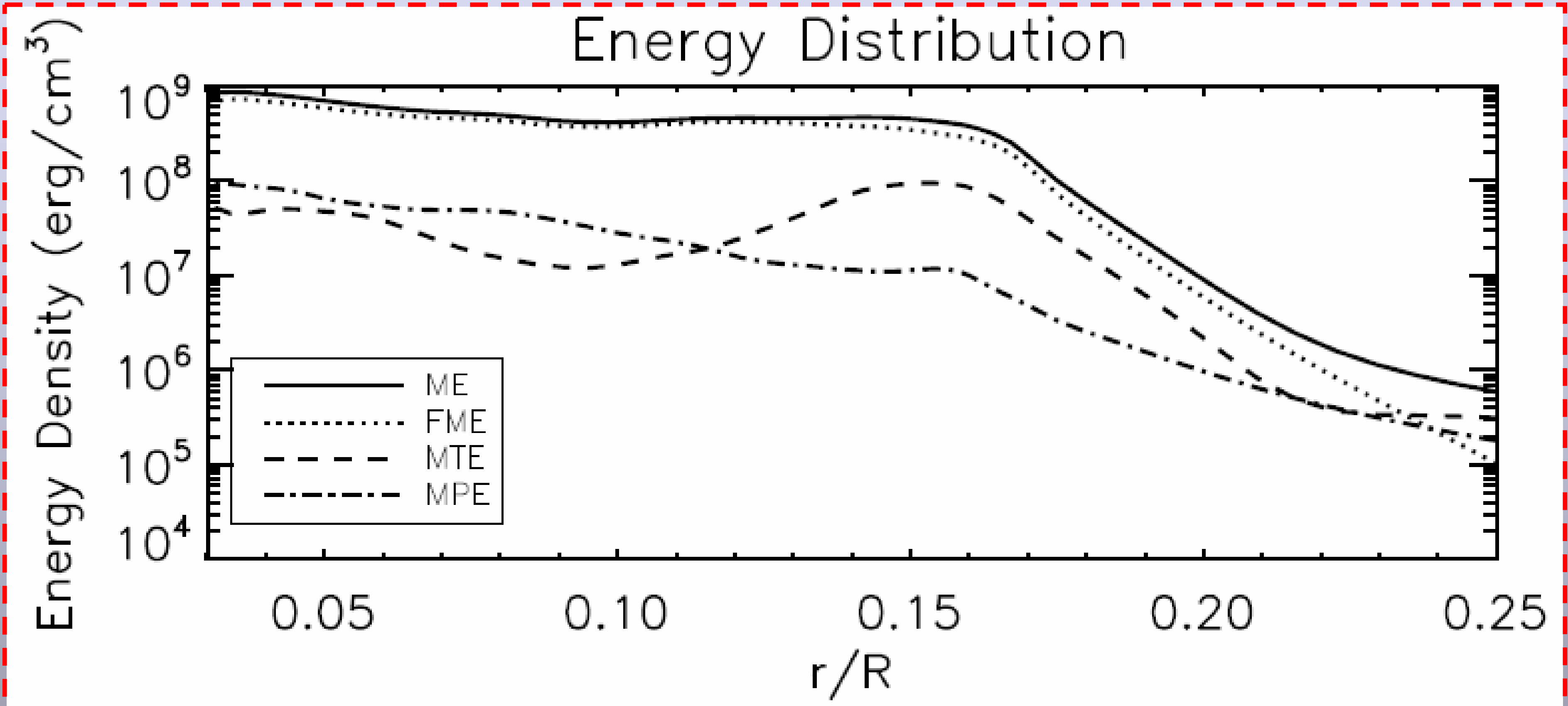






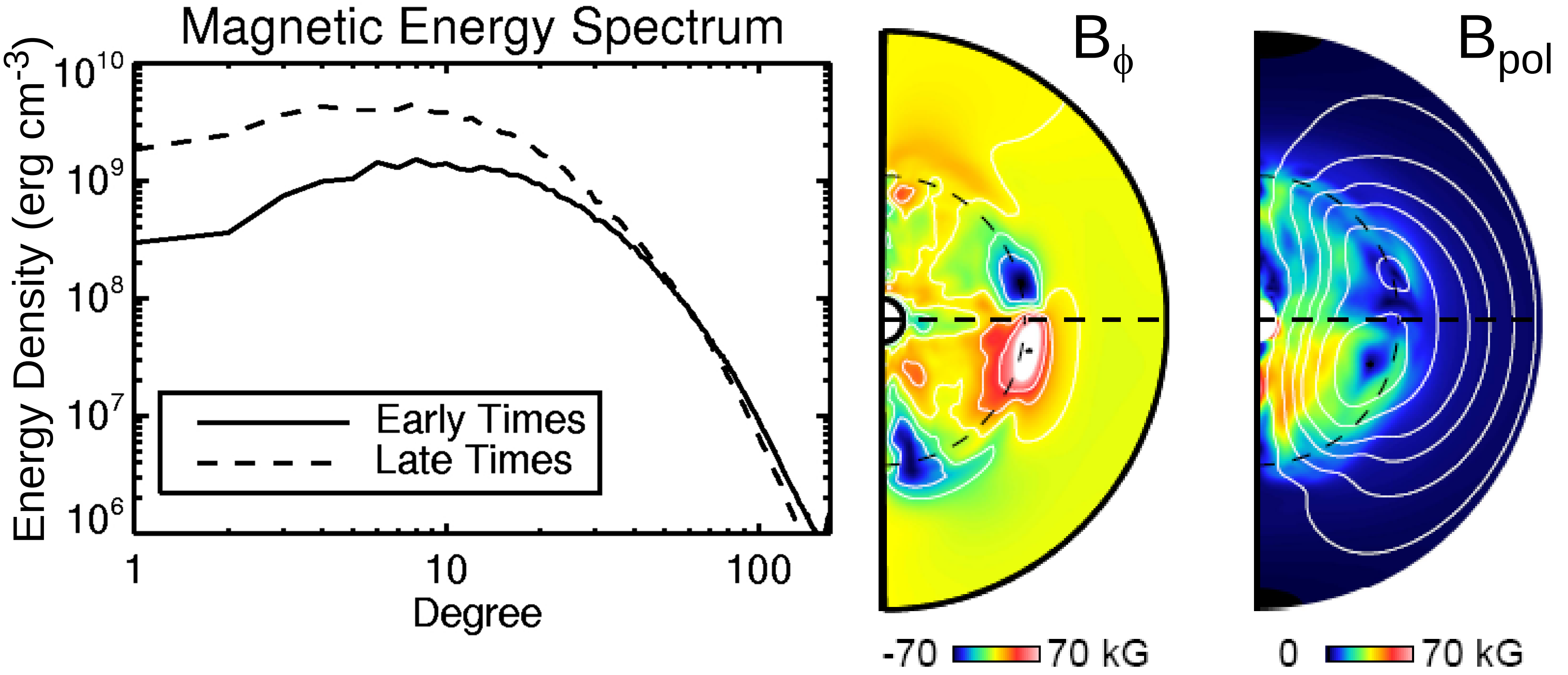
Twisted Field: Long-Term Evolution
Energy Density (erg cm-3)
10^8
10^7
10^6
ME
KE
DRKE
0
5000
10,000
15,000
Days

Magnetic Energy Distribution



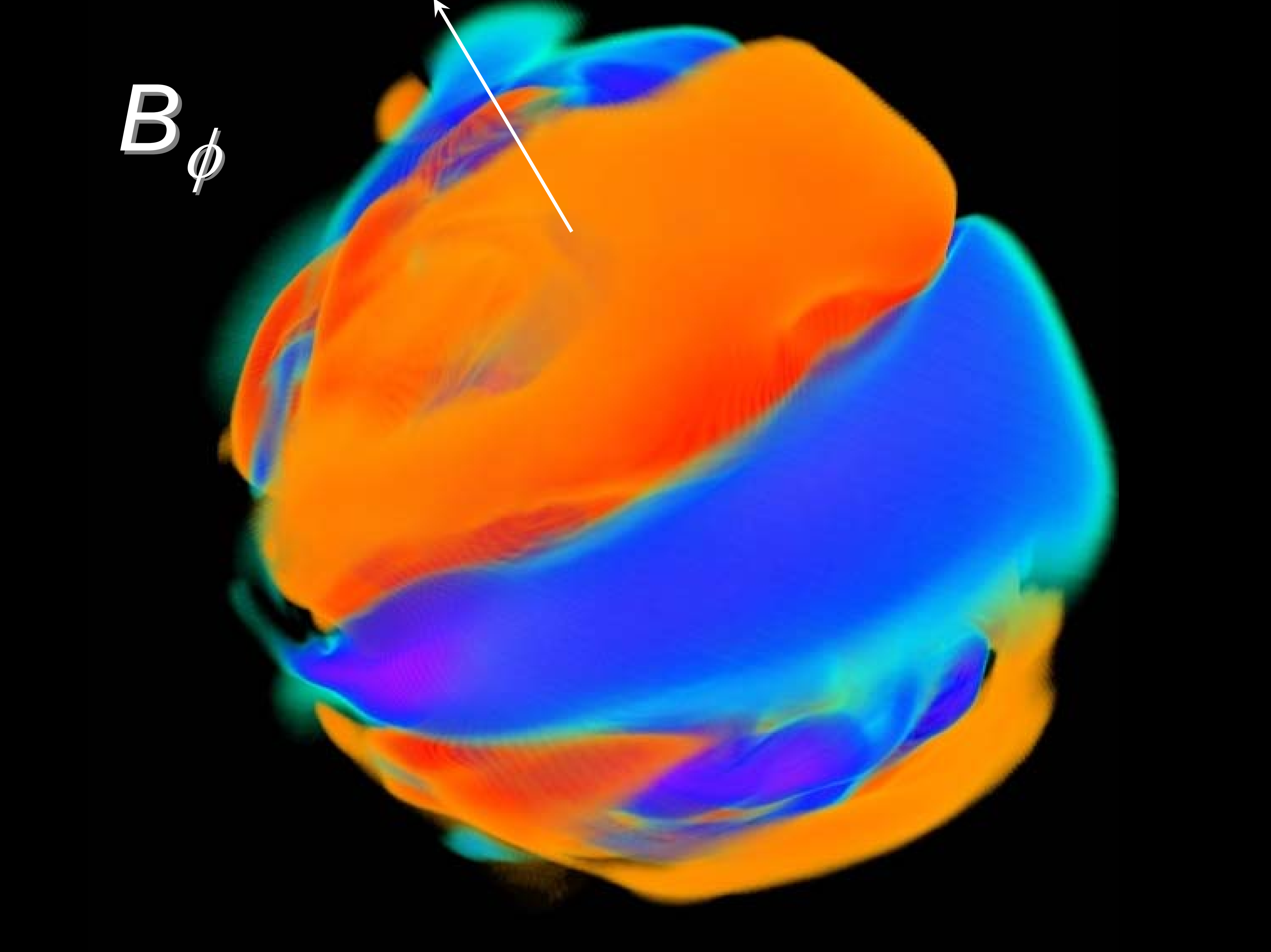
- *Most ME from nonaxisymmetric fields*
- *Strong axisymmetric fields near edge of convective core*

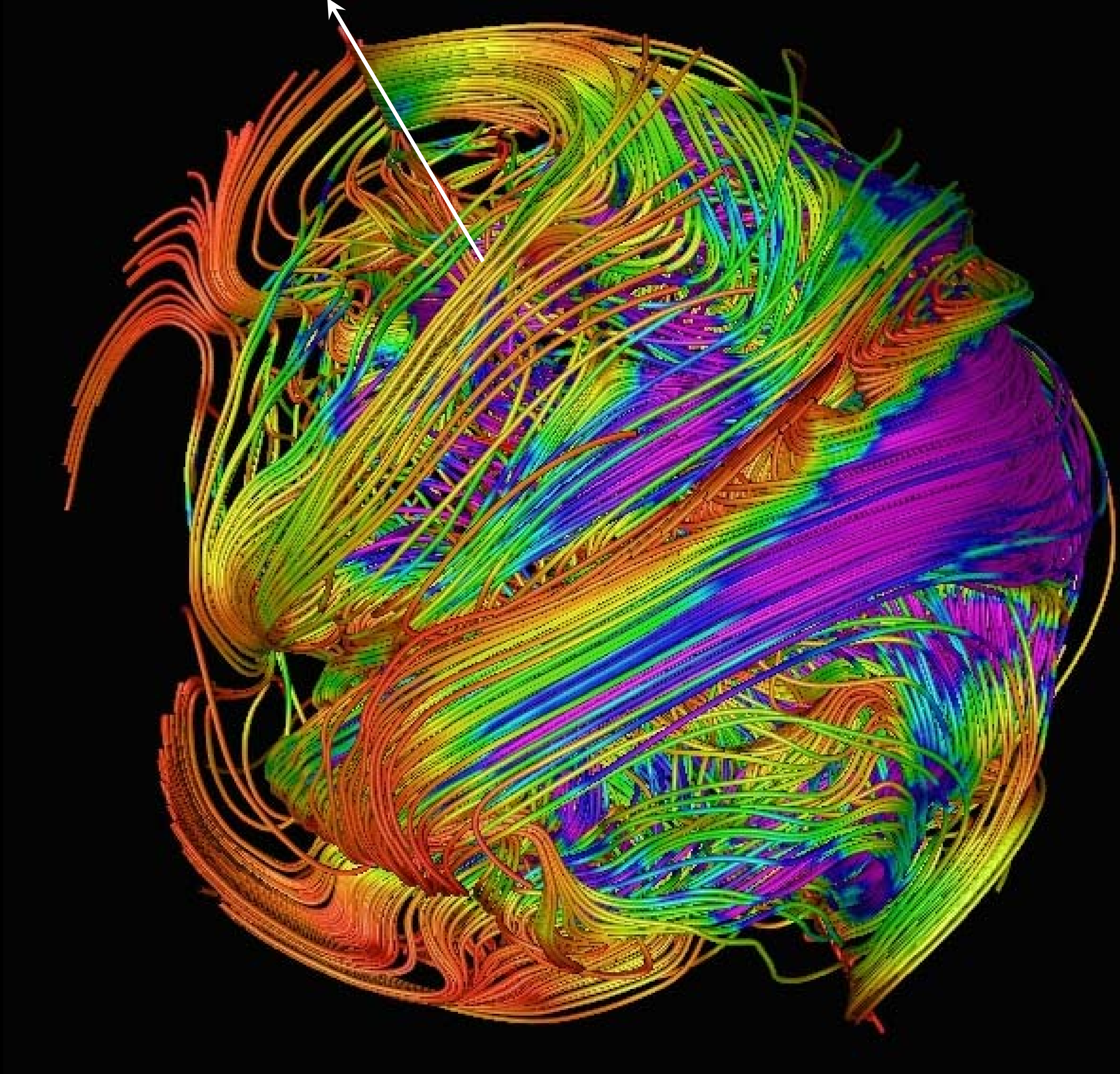
Growth of Large-Scale Structure

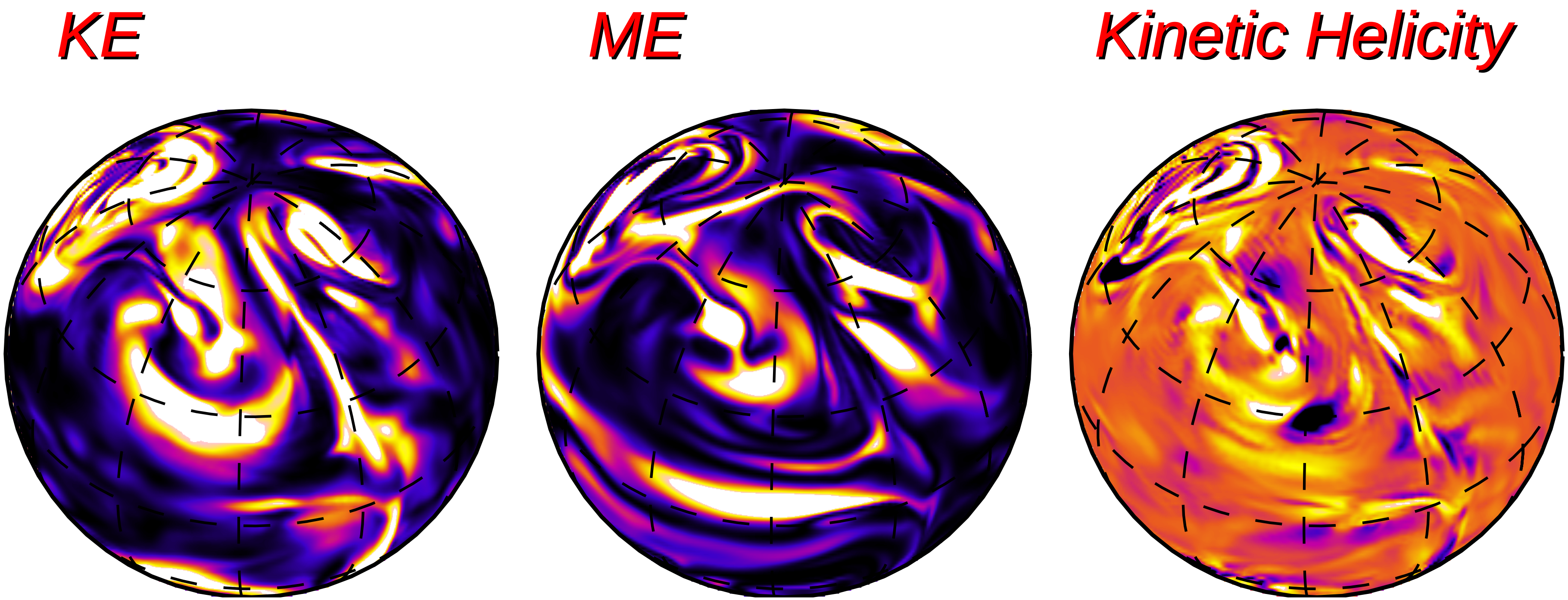


Featherstone, Browning, Brun, & Toomre 2007

- *Growth of large-scale magnetic fields at late times*
- *Large helical structures emerge near equator in averages*
- *Rough antisymmetry about equator*


B_ϕ

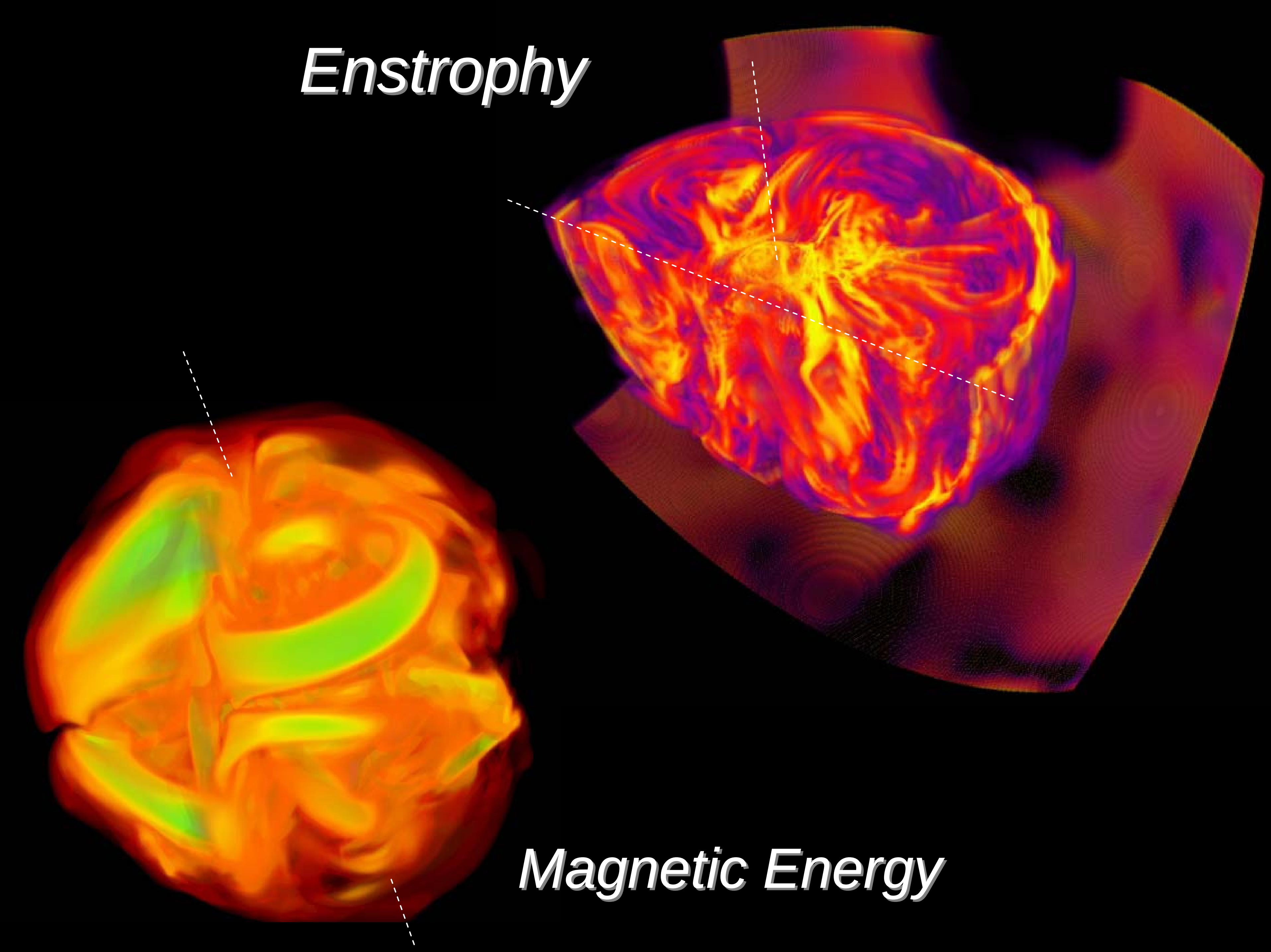




Outer Core ($r = 0.15R_{star}$)

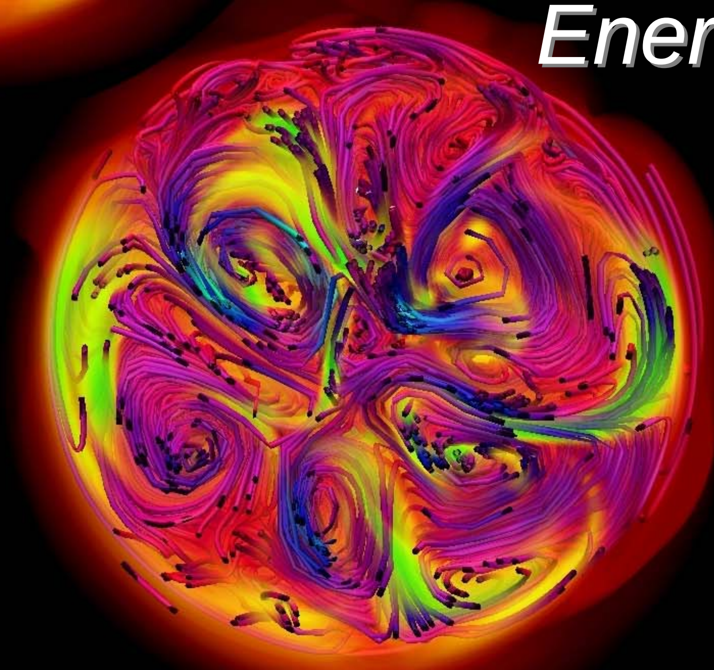
Flows and Fields

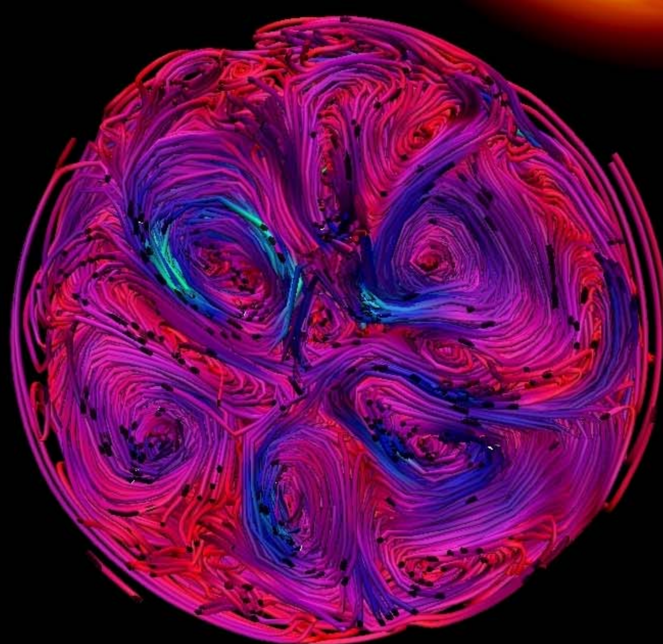
- Regions of strong ME correspond to regions of low KE
- Intermittent regions of weak convection over large portions of the domain
- ME strongest in regions of high kinetic helicity


Enstrophy
Magnetic Energy

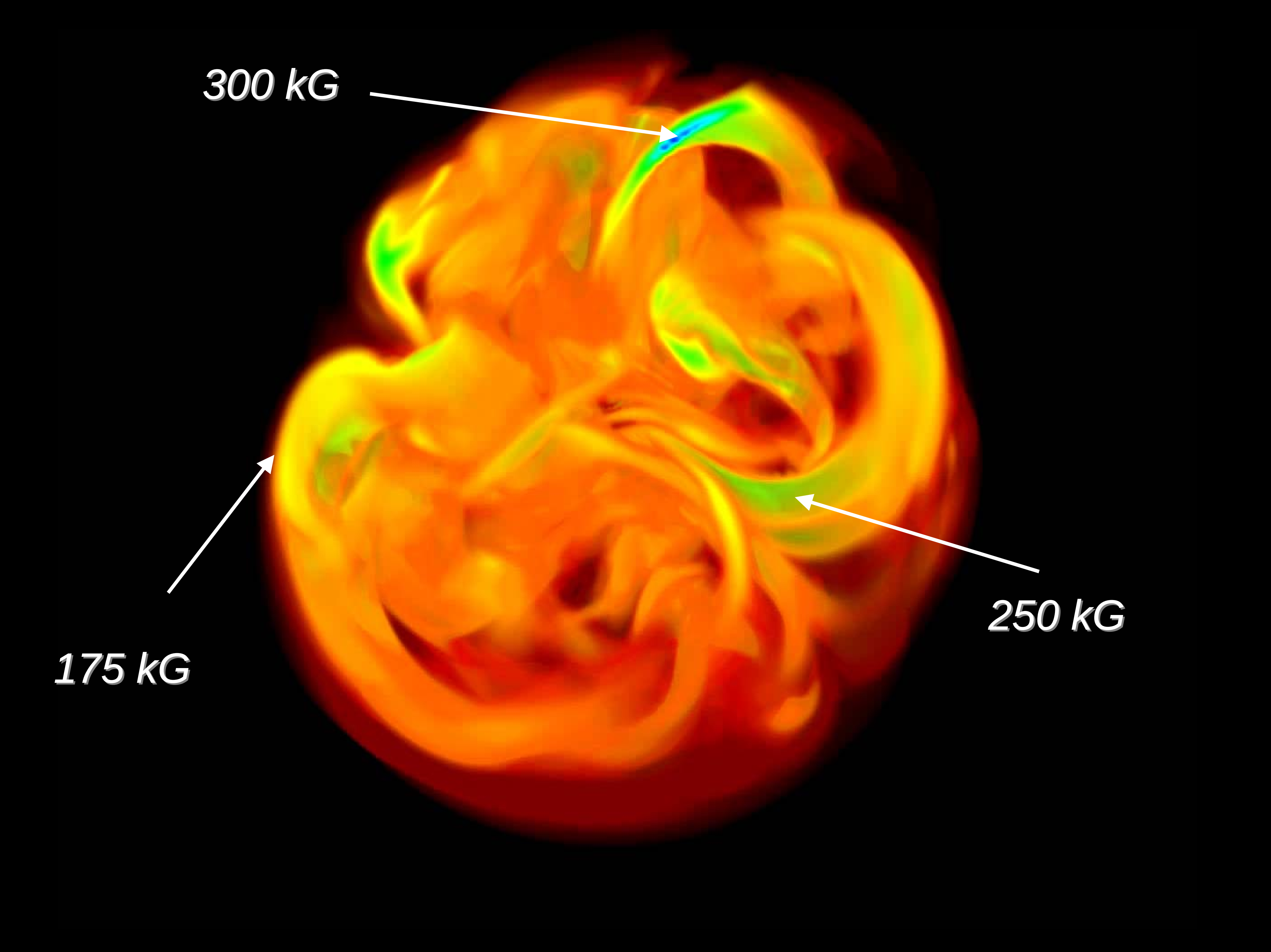
Magnetic Energy

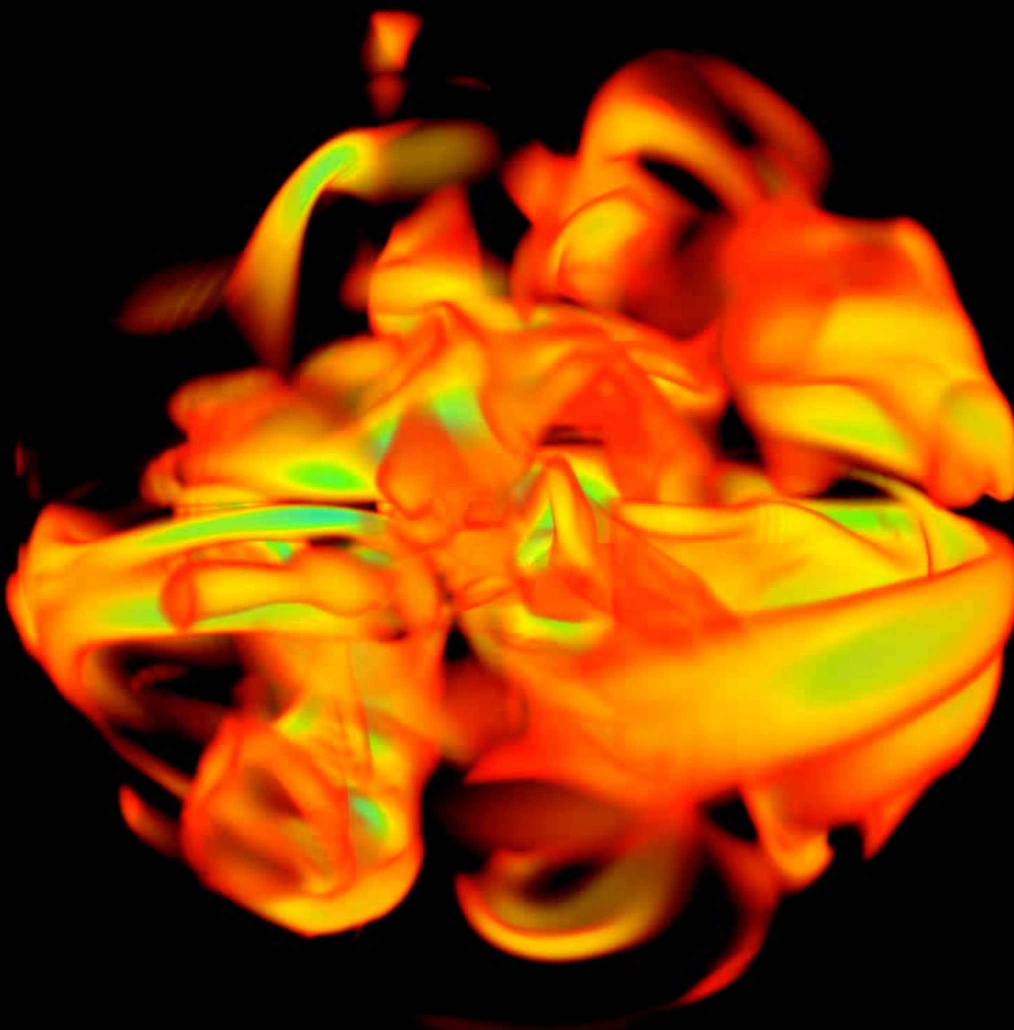
Flow Lines + Magnetic Energy





Flow Lines


300 kG
250 kG
175 kG



Conclusions /Remarks

- *This state seems to depend on imposing a poloidal magnetic field – toroidal field has little effect.*
- *Similar behavior obtained for dipolar, quadrupolar, and octapolar external fields.*
- *l = 8 shows no growth (scale effect?)*
- *Super-equipartion behavior at Pm =1*

Conclusions /Remarks

- *Primordial fields will likely affect the behavior of dynamos within the cores of Ap stars*
- *Imposing poloidal fields may lead to:*
  - *Super-equipartition dynamo action*
  - *Large-scale magnetic structures*
  - *Weakened differential rotation of the core and radiative zone*
- *Such super-equipartition states exhibit alignment of flows and magnetic fields on large (but not small) scales. Coriolis and Lorentz forces dominate.*