Connecting the solar dynamo below the surface with ejection of twisted magnetic fields above the surface

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MPS

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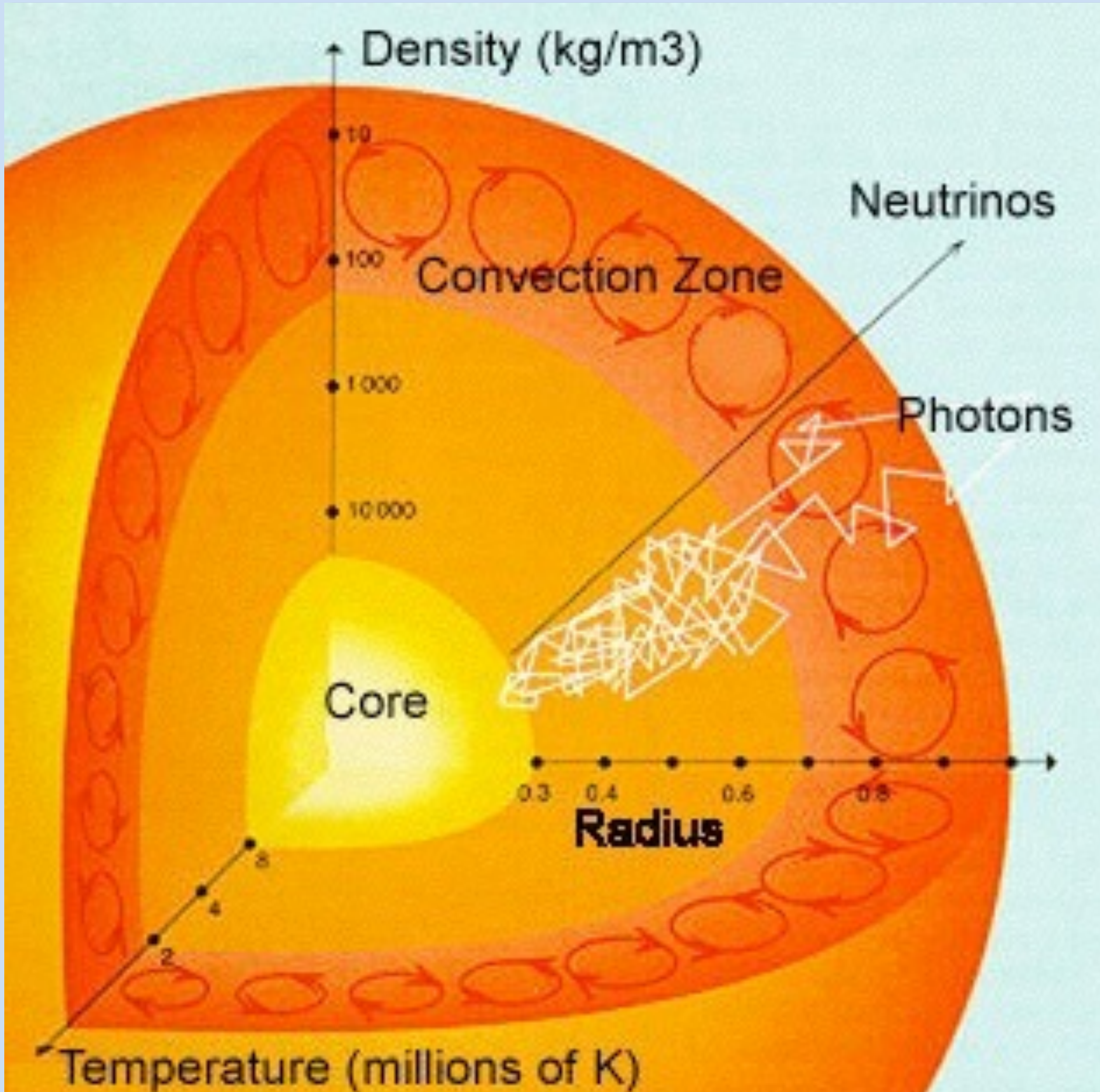
Maarit J. Käpylä, Aalto University

MARIE CURIE ACTIONS

Helicity

The glue to connect them all.

Helicity in the Sun



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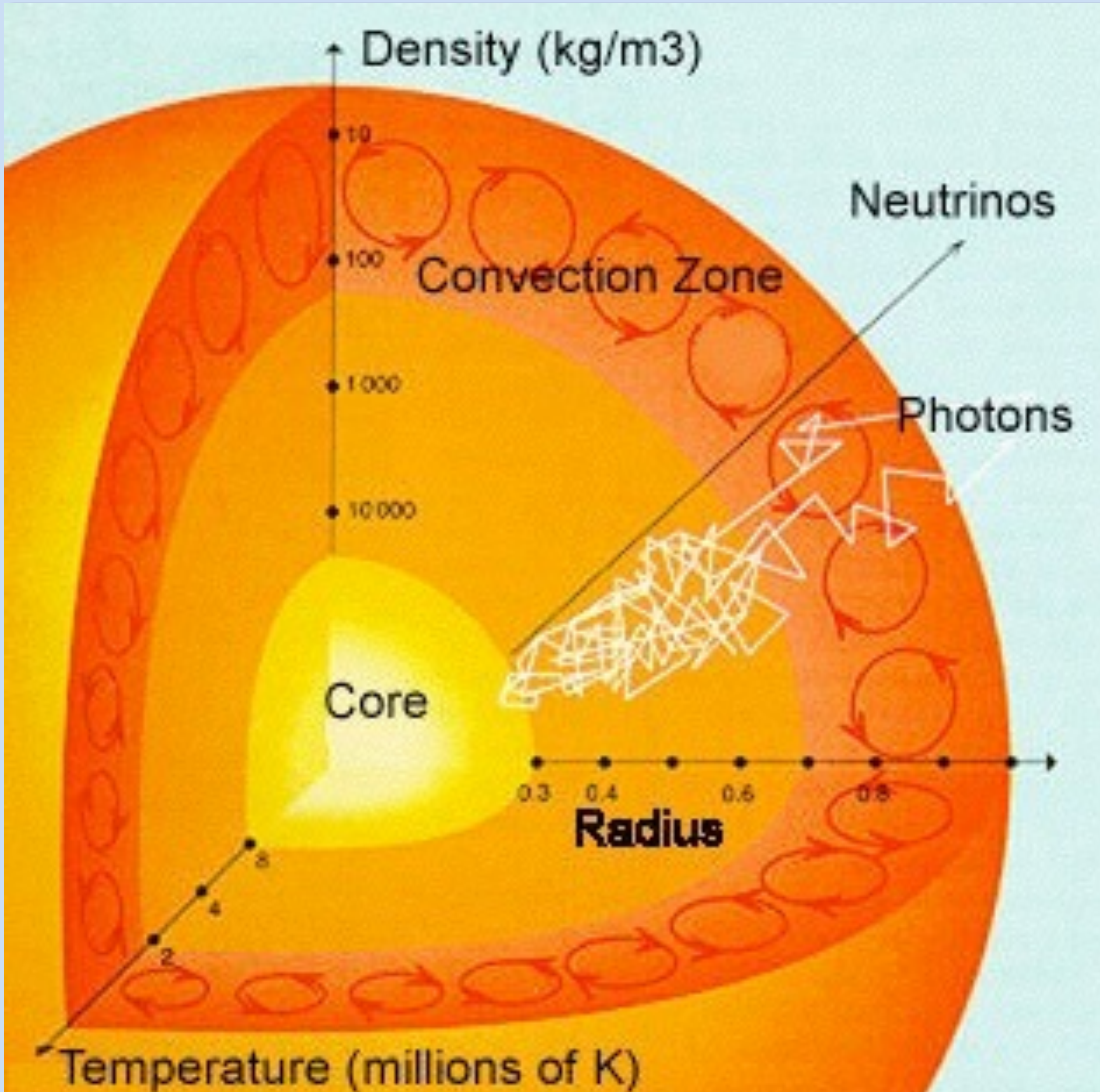
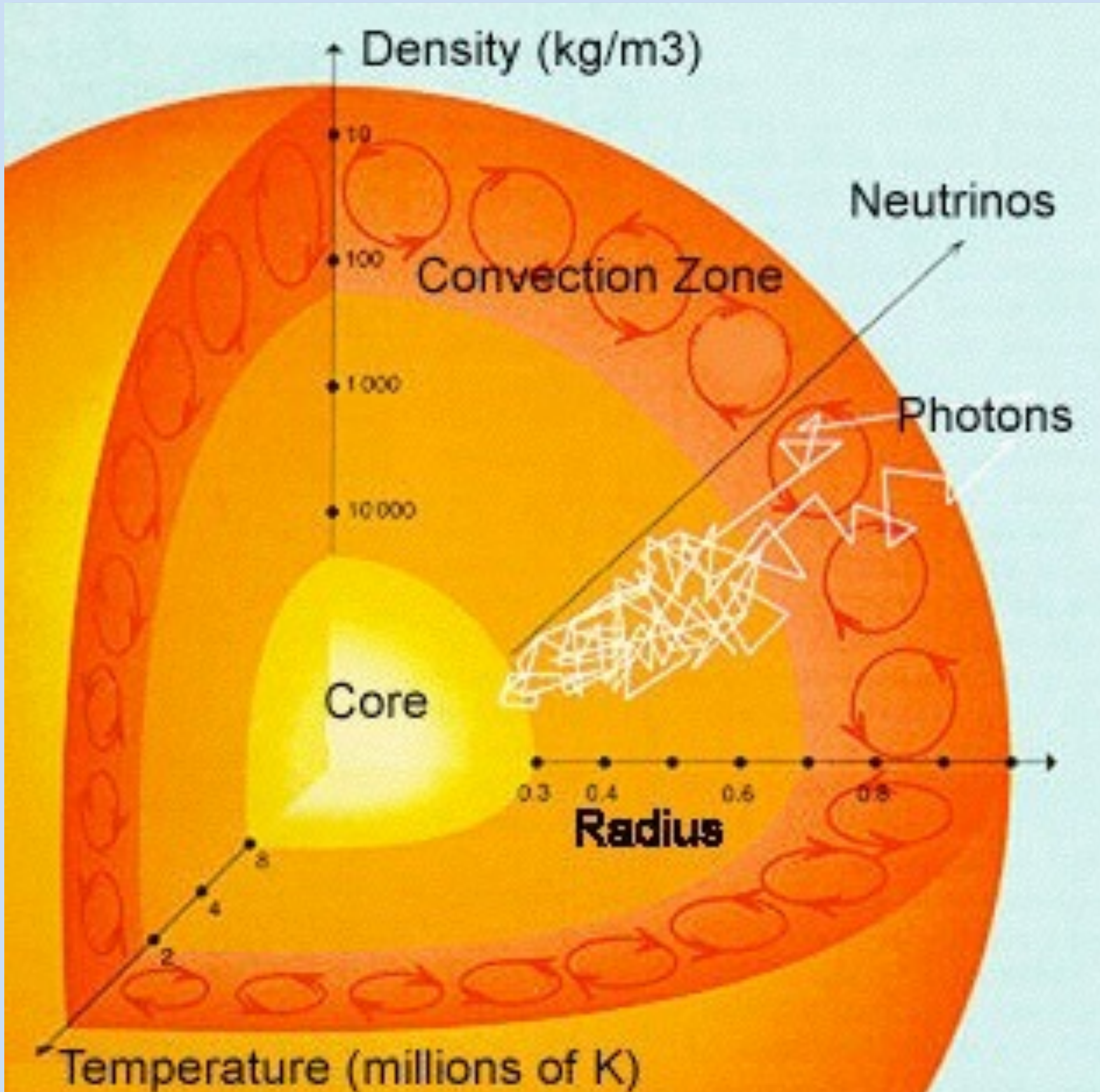


Nonalignment of rotation and gravity

Helicity in the Sun

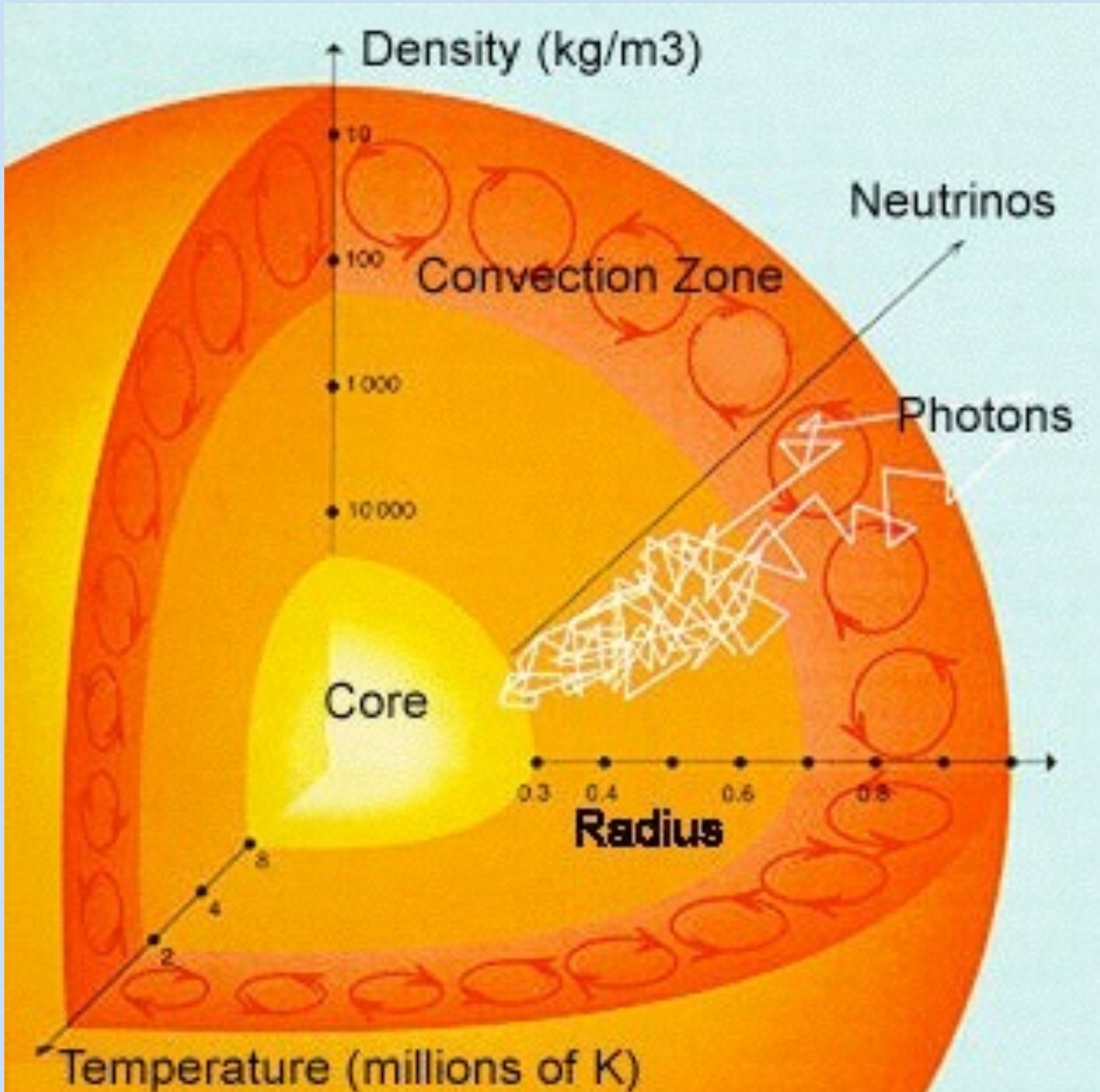


Nonalignment of rotation and gravity

↓

Kinetic helicity

Helicity in the Sun



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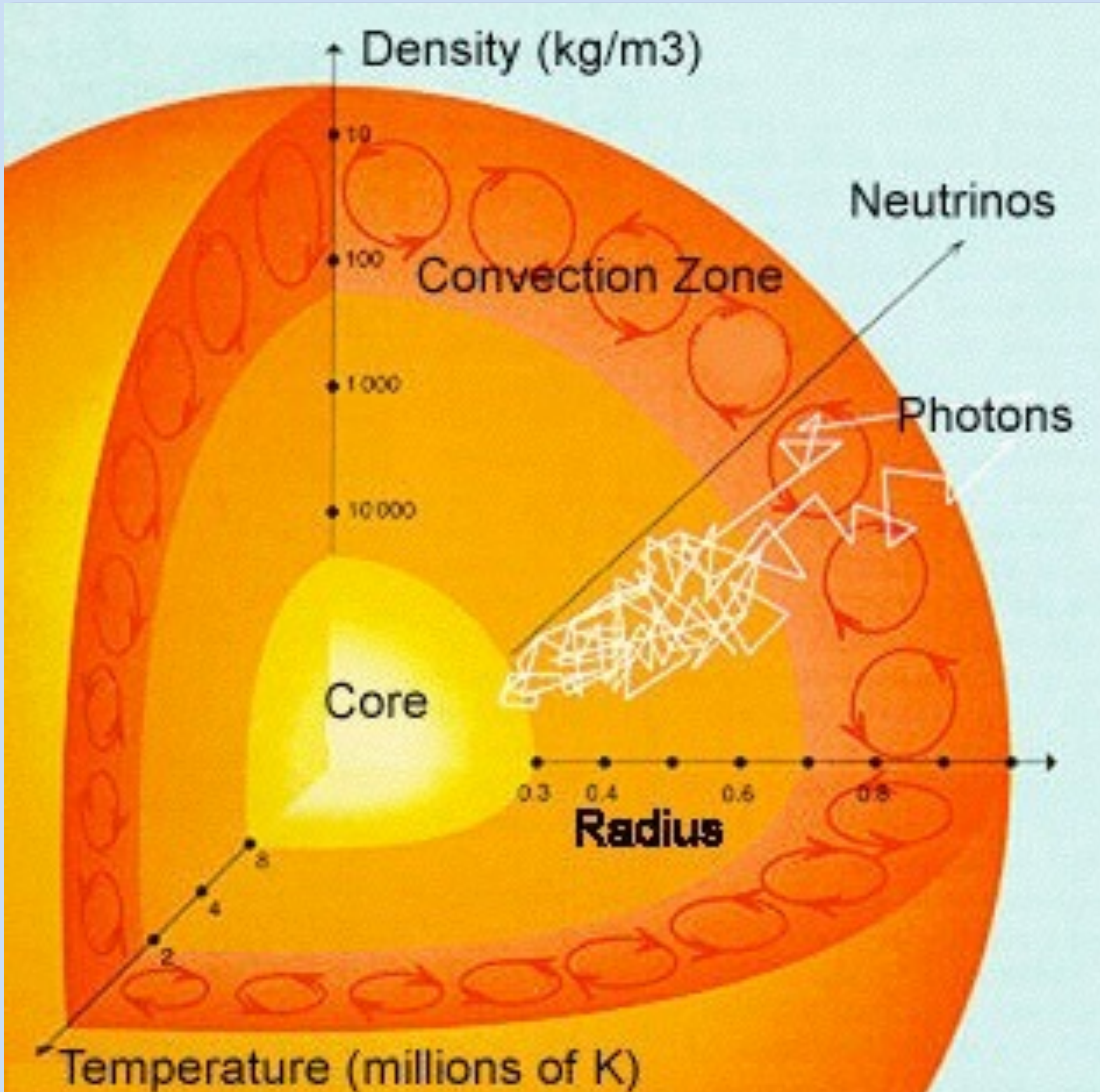
Alpha-effect

Helicity in the Sun



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Magnetic helicity
+ catastr. quenching

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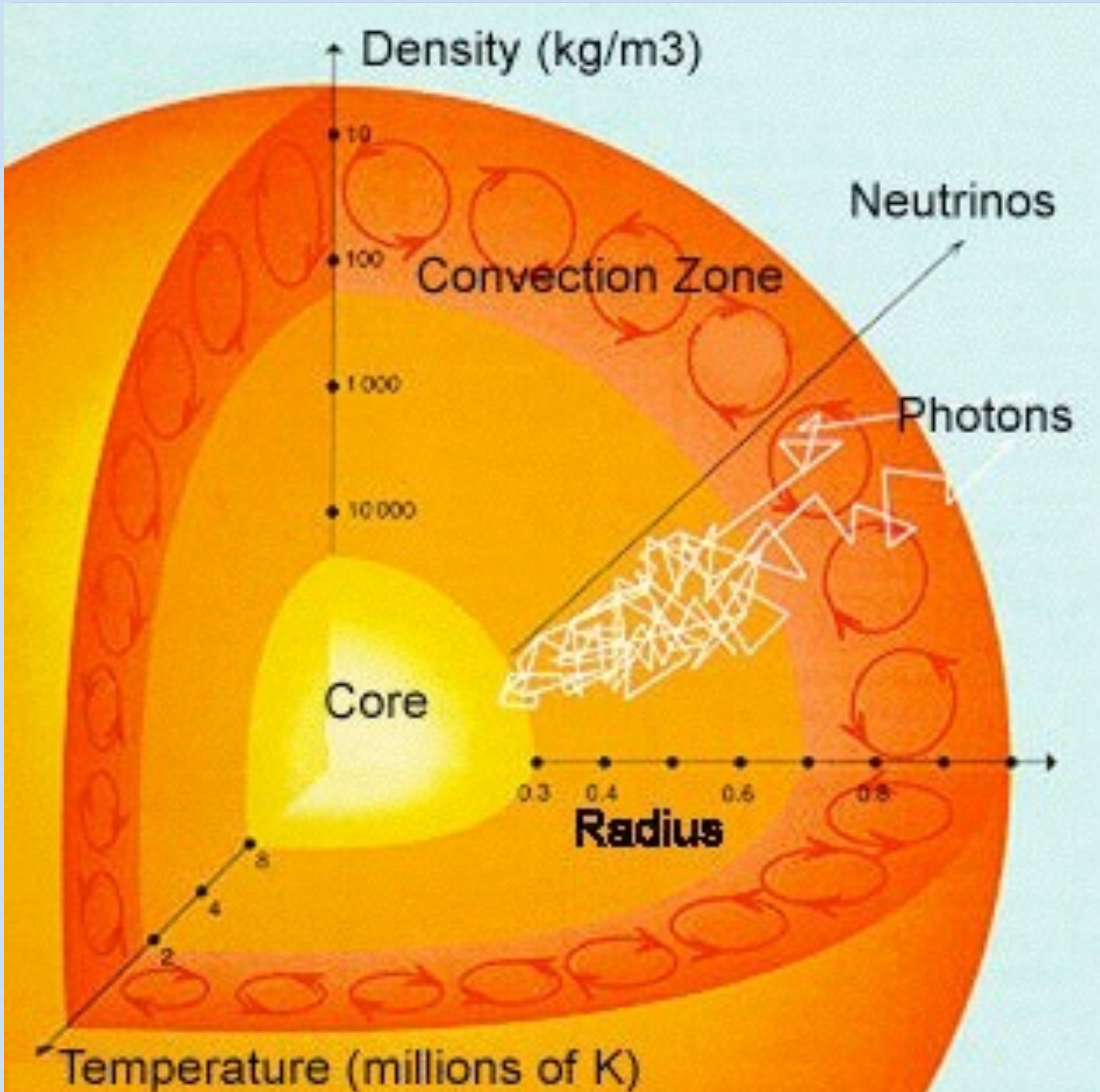

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Alpha-effect

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Magnetic helicity + catastr. quenching

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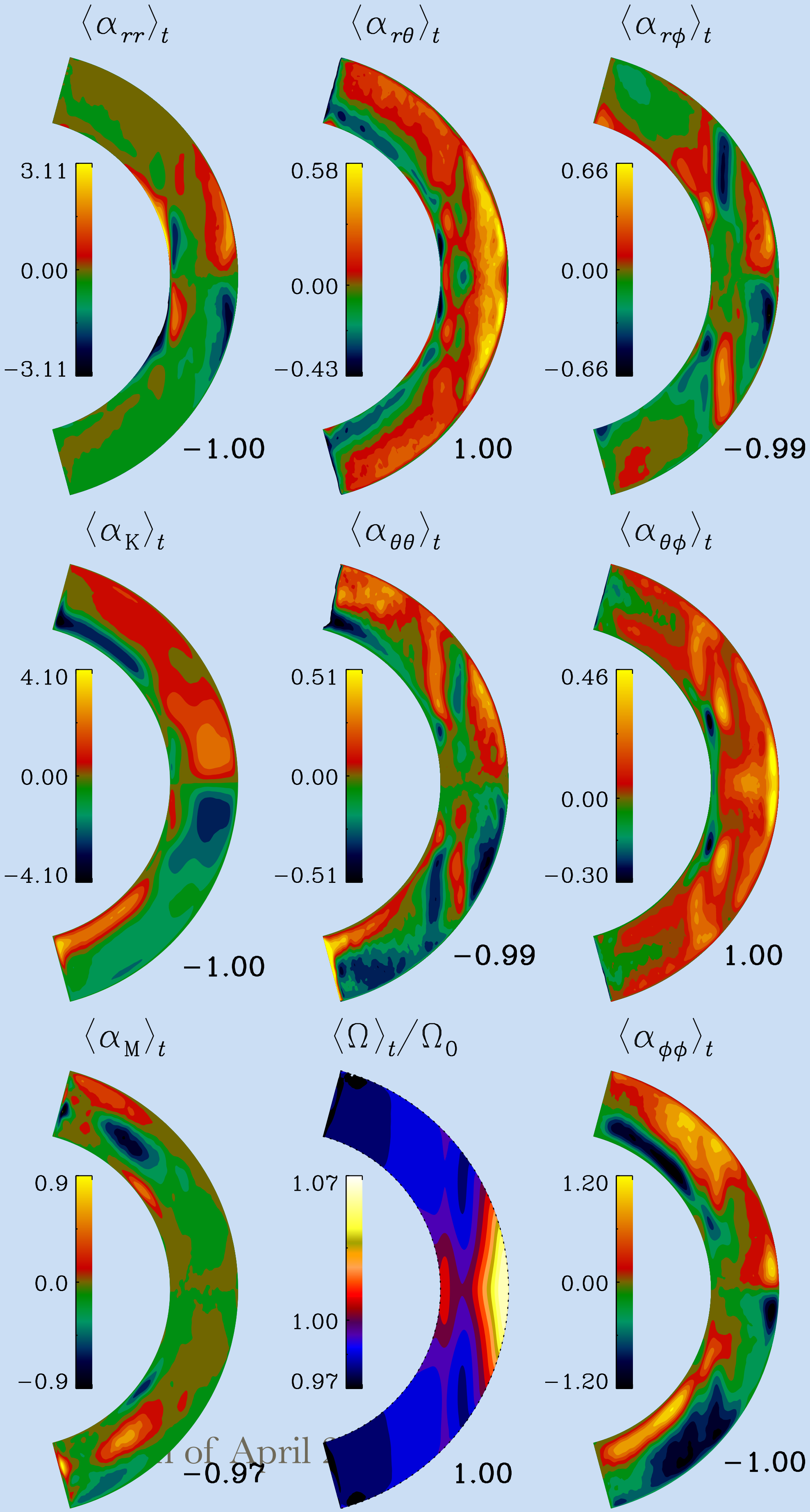
Space weather

Alpha effect



$$\alpha = \frac{\tau_c}{3}\left(-\overline{\boldsymbol{\omega}\cdot\boldsymbol{u}} + \frac{\overline{\boldsymbol{j}\cdot\boldsymbol{b}}}{\overline{\rho}}\right)$$

Alpha effect

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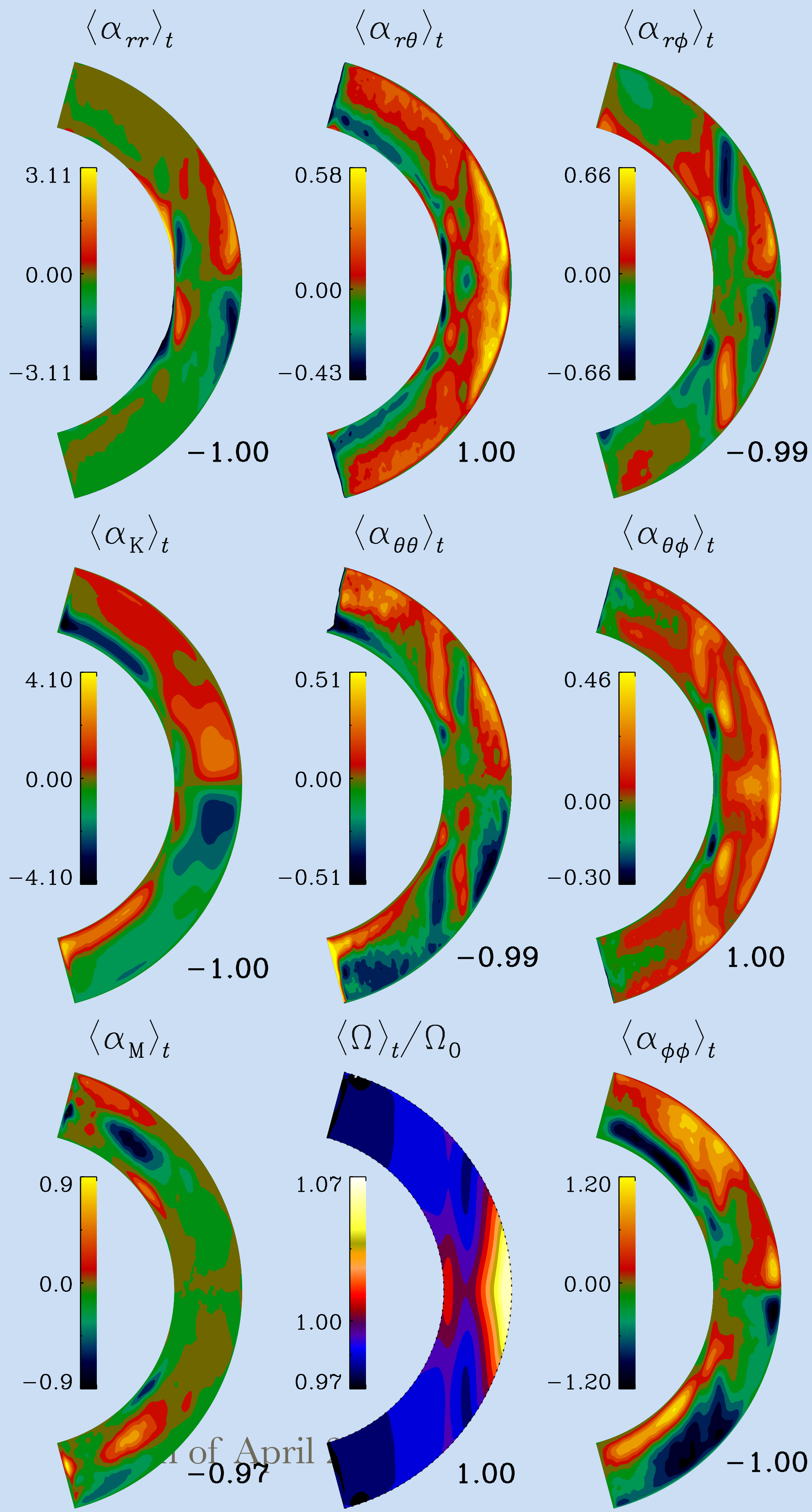
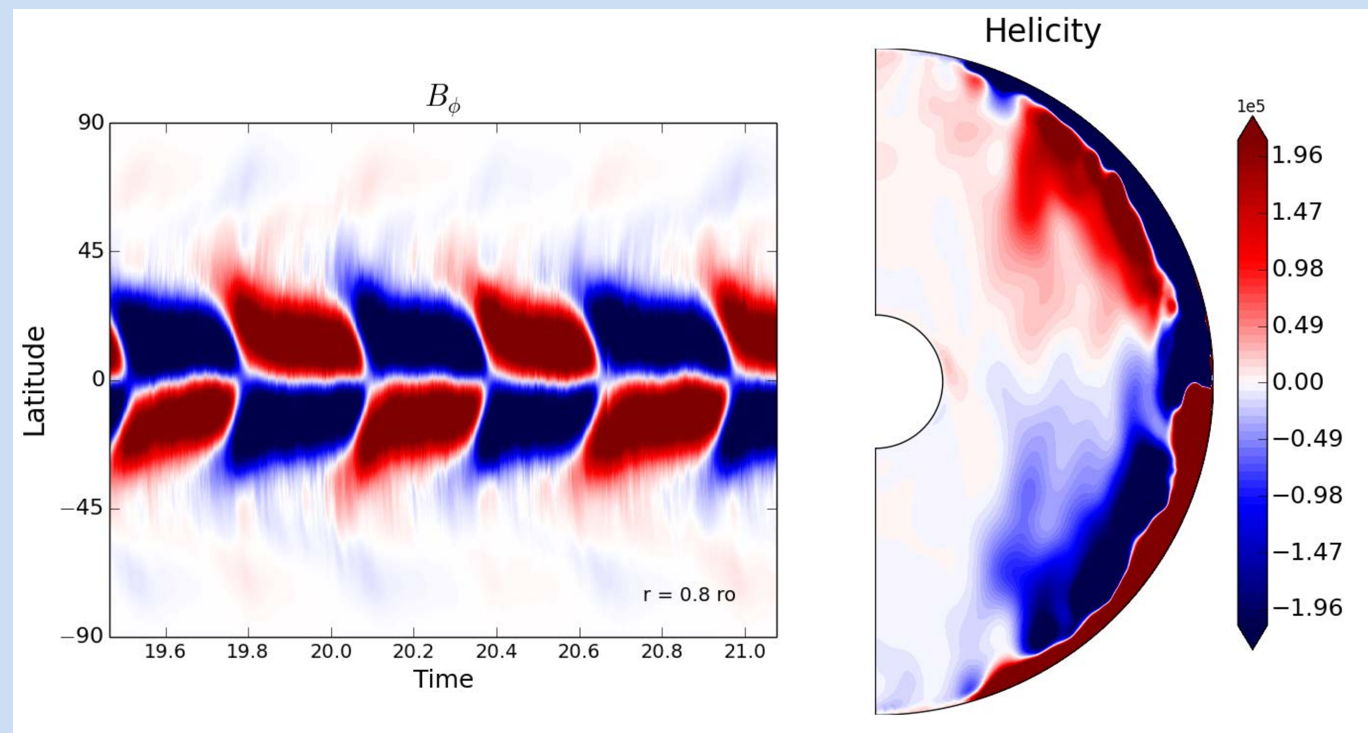
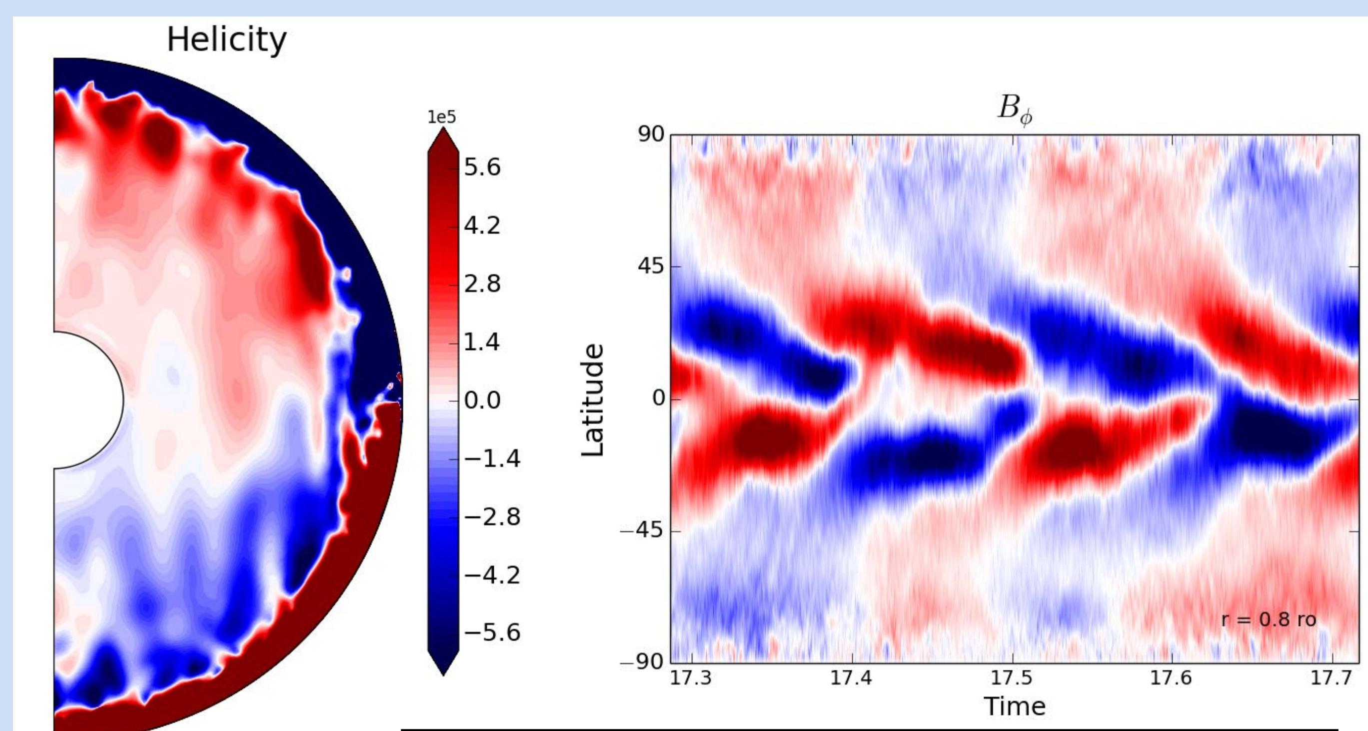
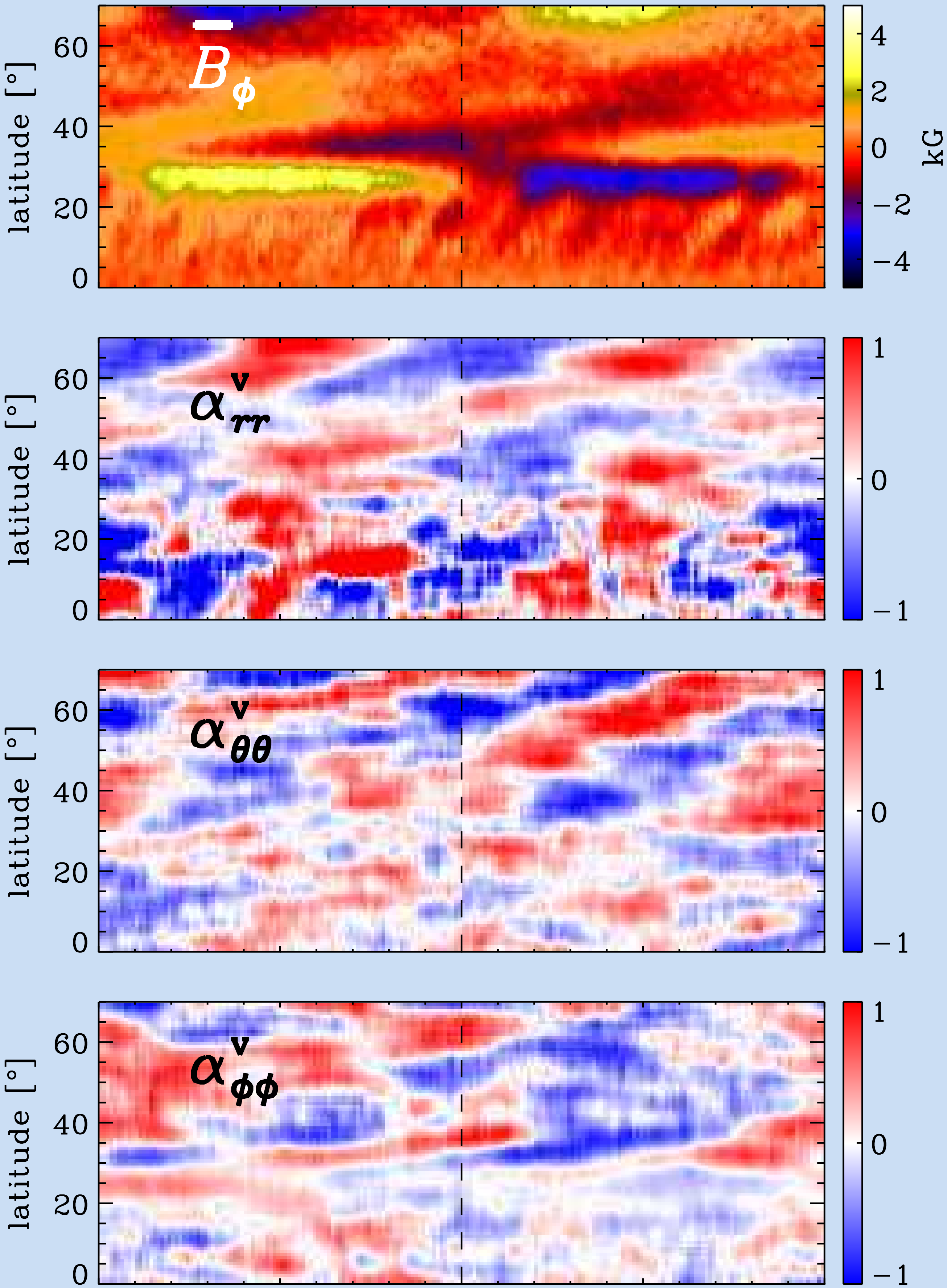


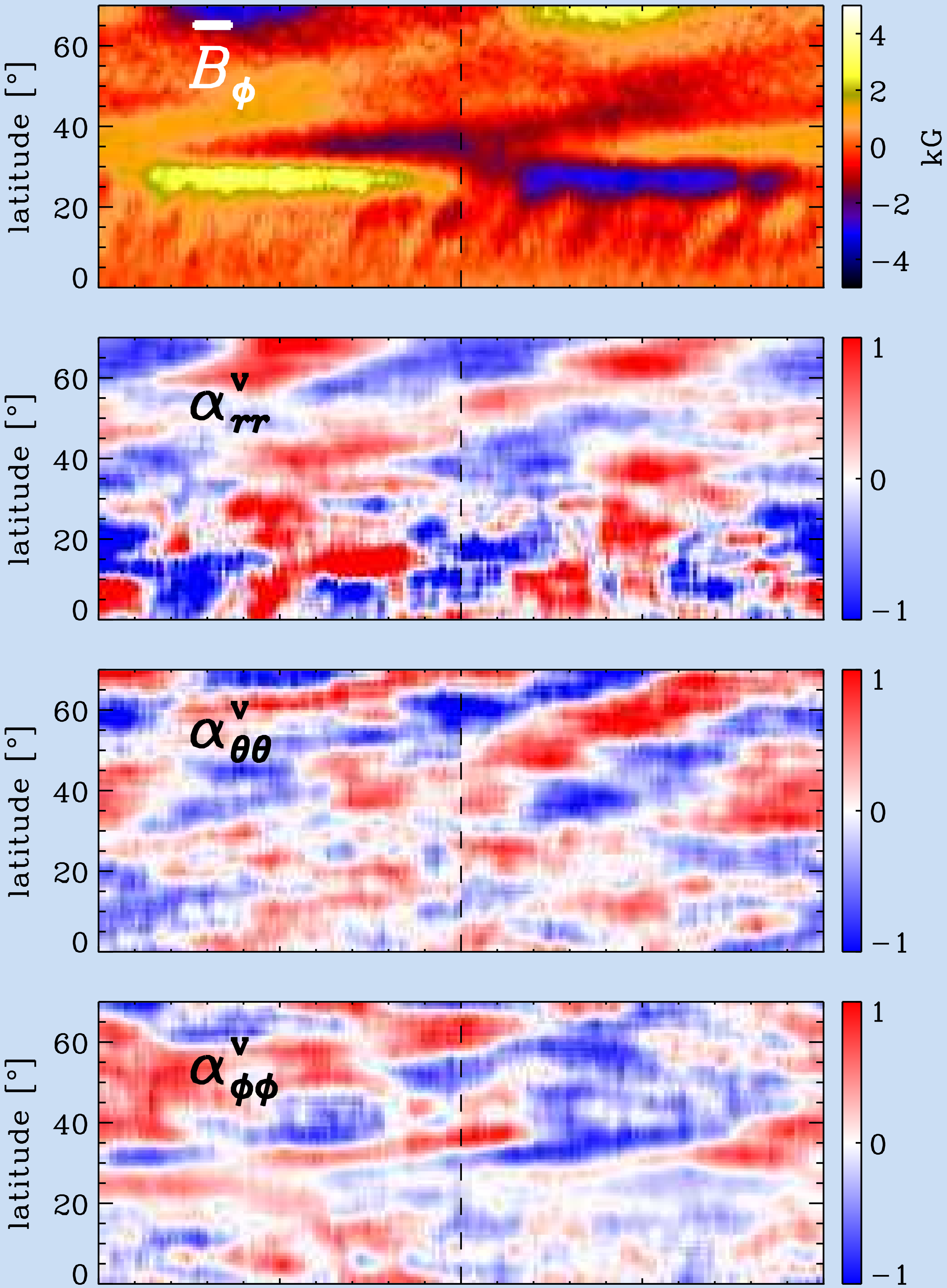




Duarte et al., 2016



$$\alpha = \langle \alpha \rangle_t + \alpha^{\rm v}.$$



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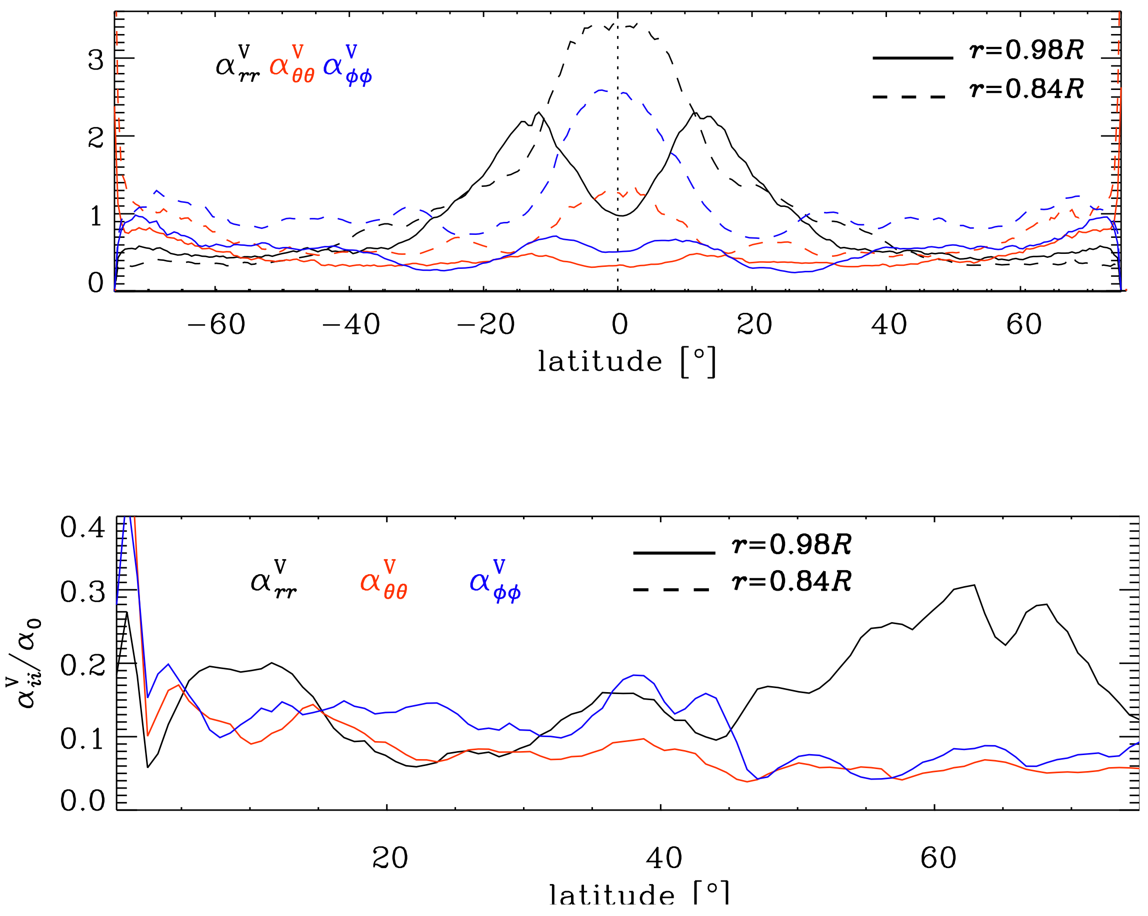
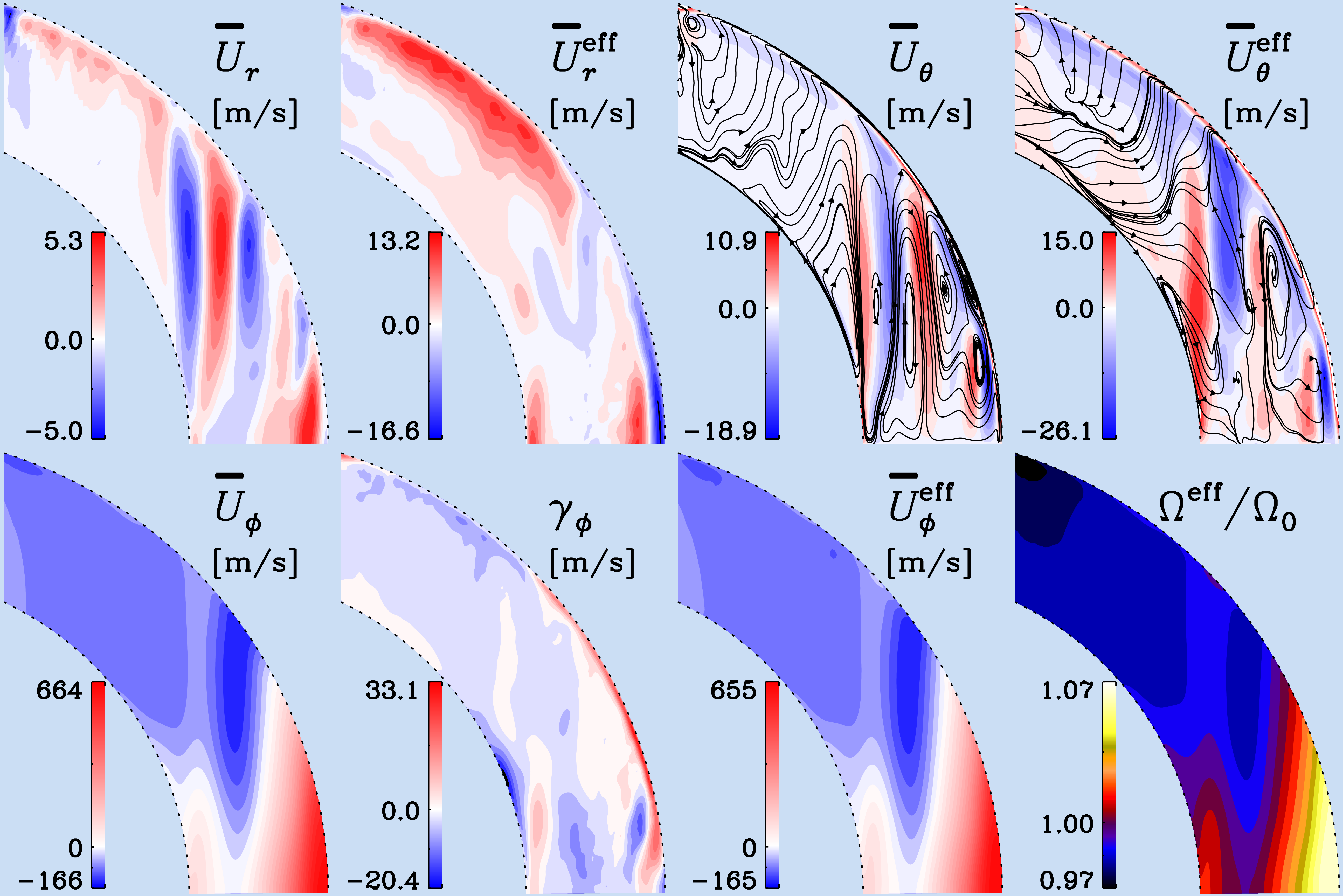
$$\alpha^{\mathrm{v}}_{ii} = \sqrt{\langle \alpha^{\mathrm{v}\,2}_{ii} \rangle_t},$$



Turbulent pumping



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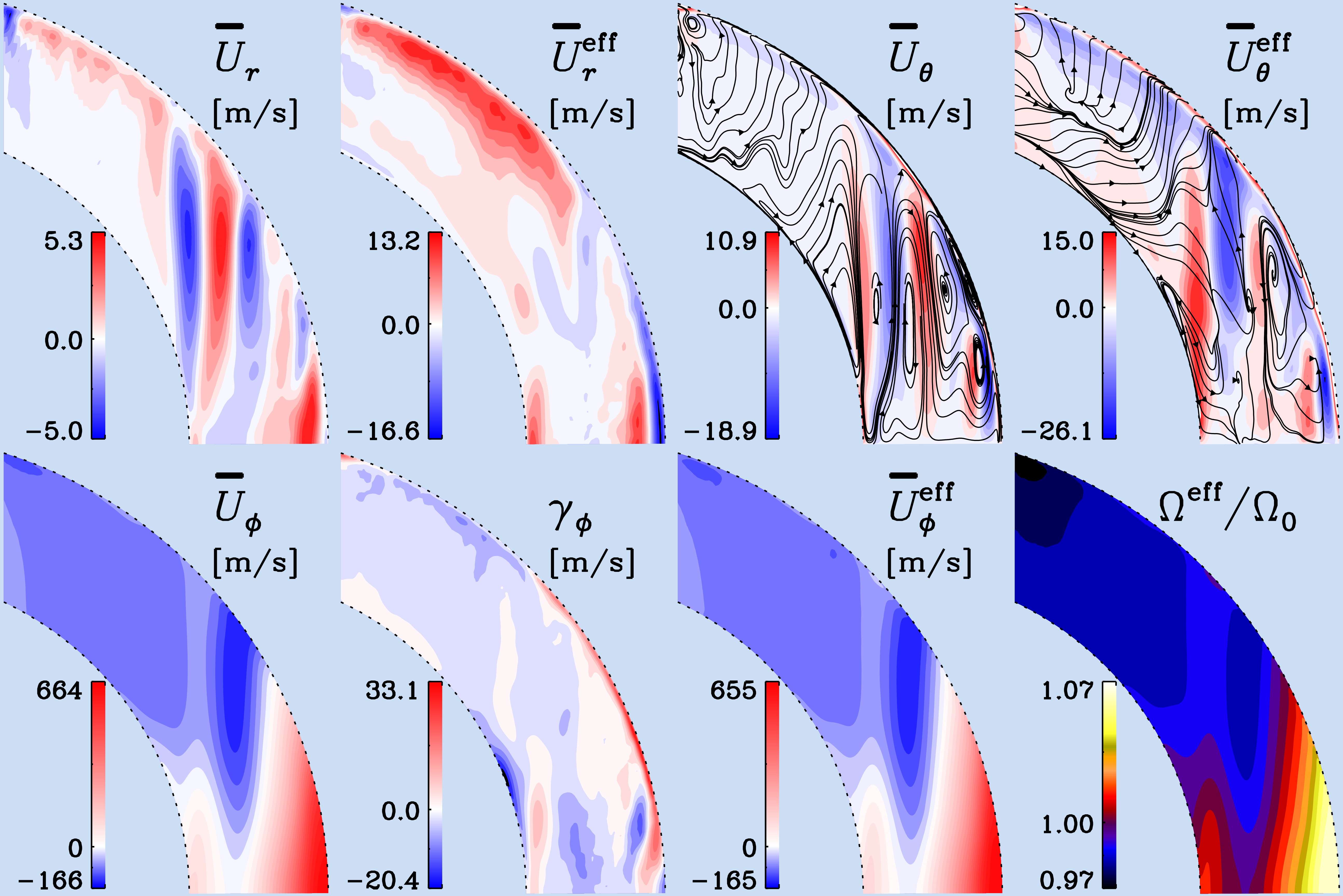

Warnecke et al., 2016

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A realistic boundary condition for the magnetic field is important.

The Two Layer Model

Lower layer:

Convection zone

Dynamo action

→ Generation of magnetic field

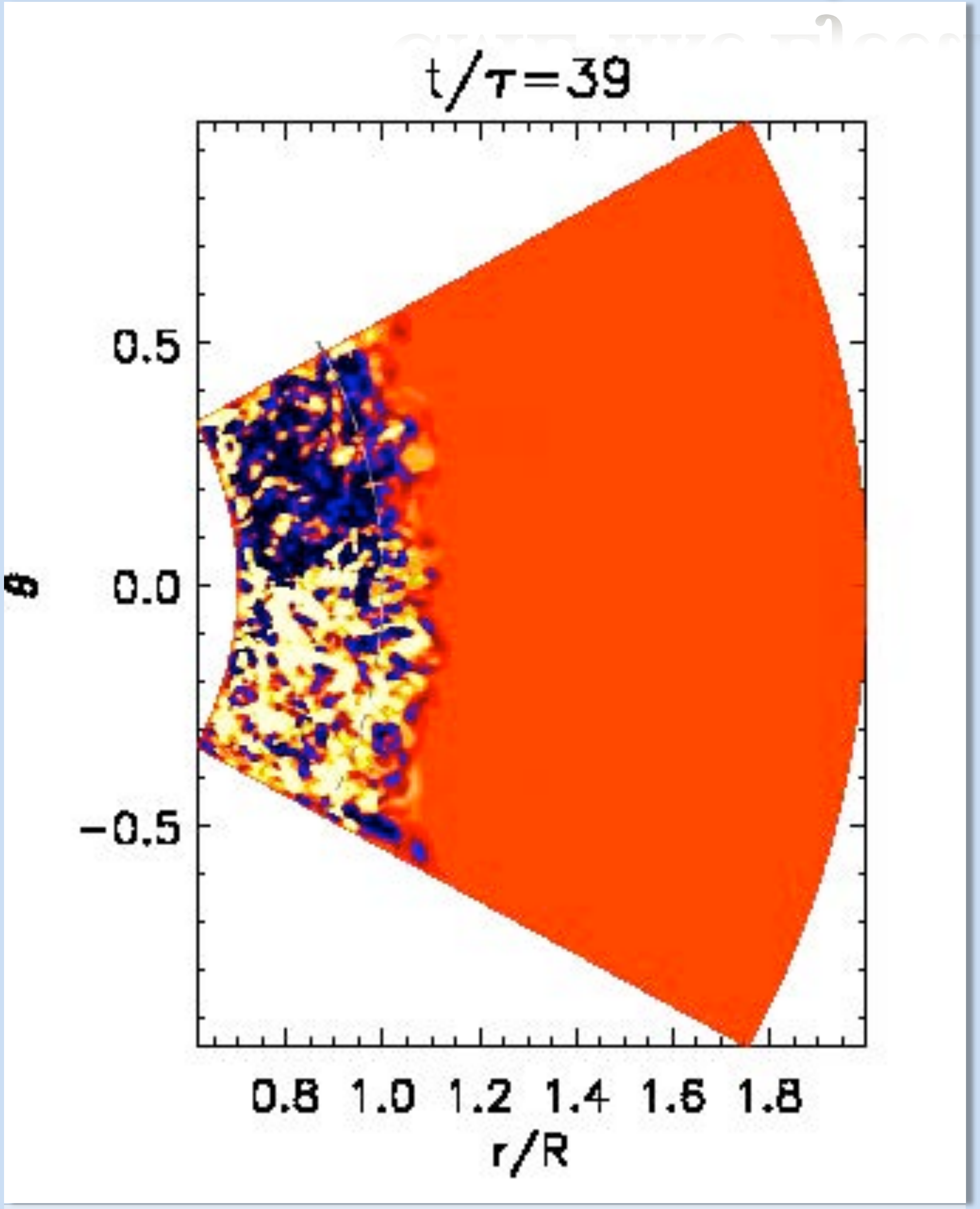
Upper layer:

Simplified coronal model

Magnetic flux emerges from the lower layer and gets ejected.

Both layers are in one simulation.

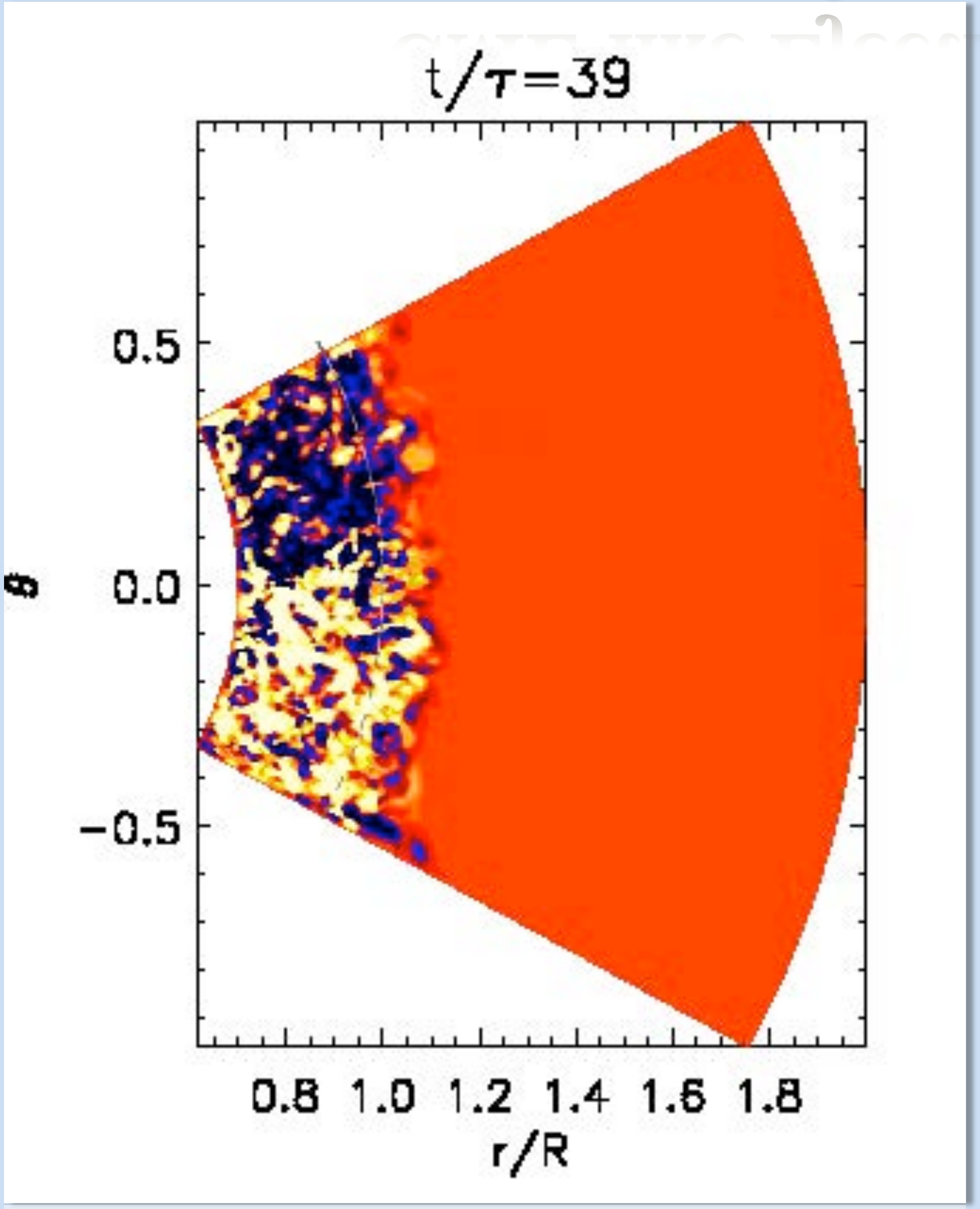
CME-like Ejections



Current helicity density

- proxy for magnetic helicity
- gauge invariant
- represent helical structures
- can be measured on the Sun

CME-like Ejections



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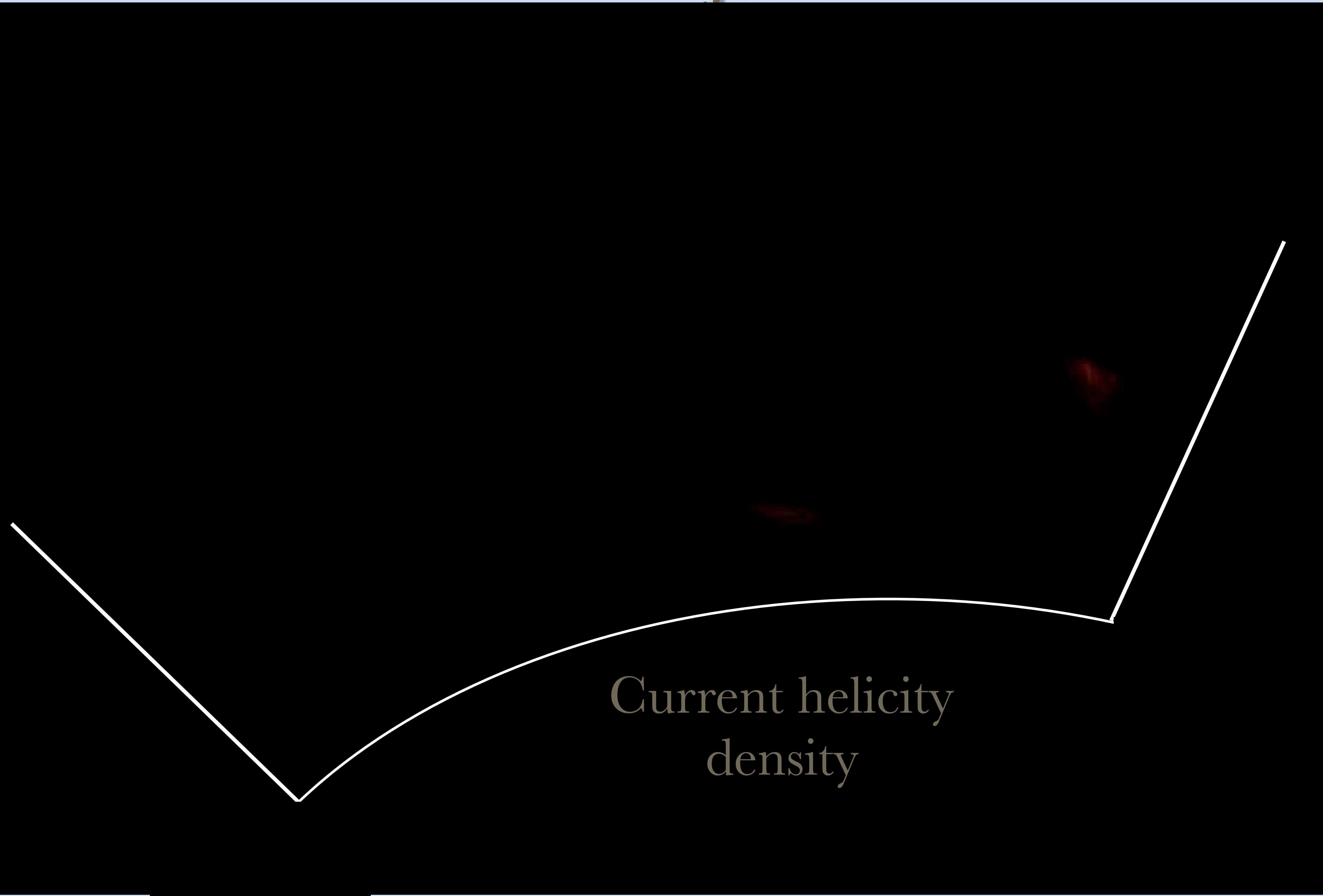

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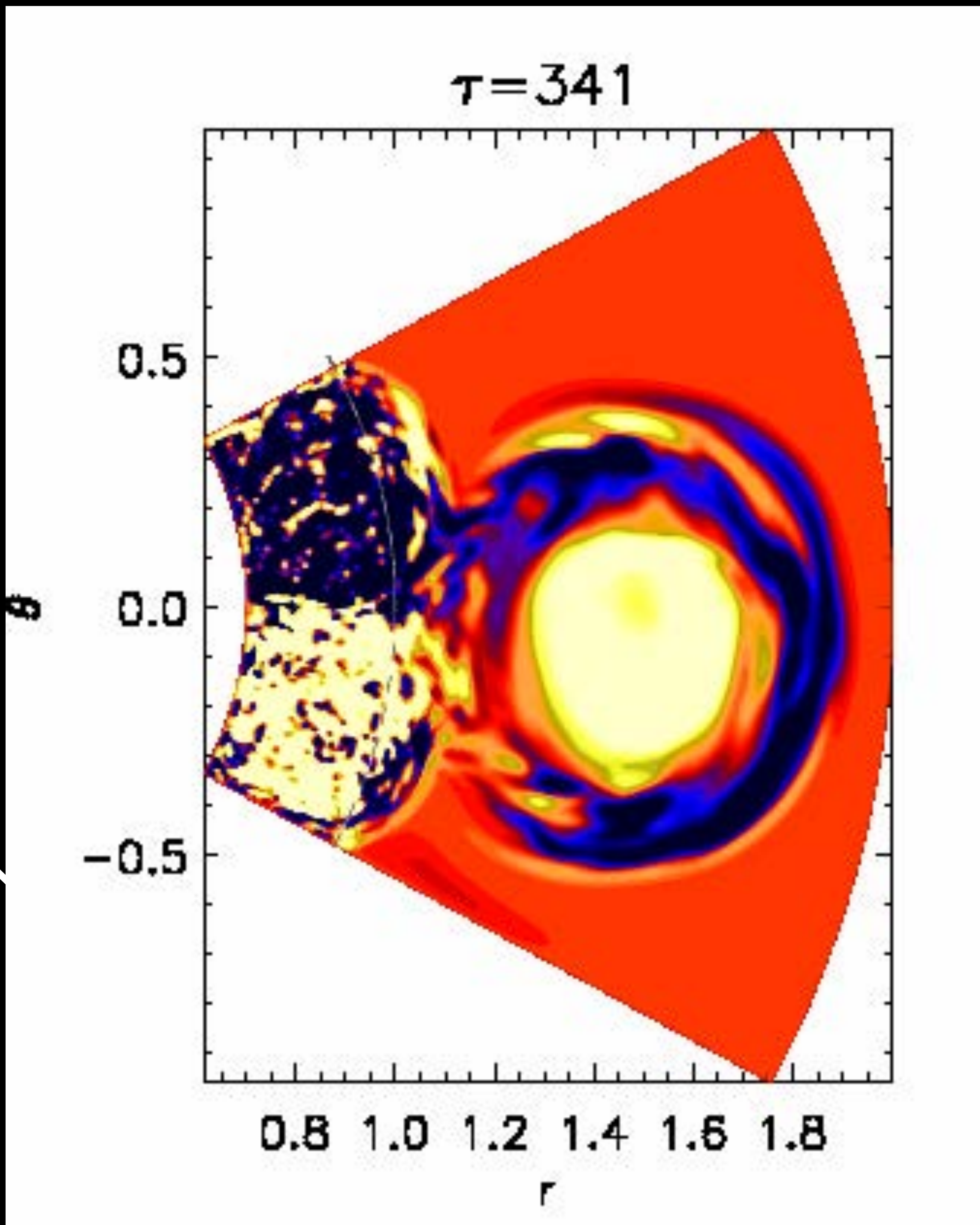

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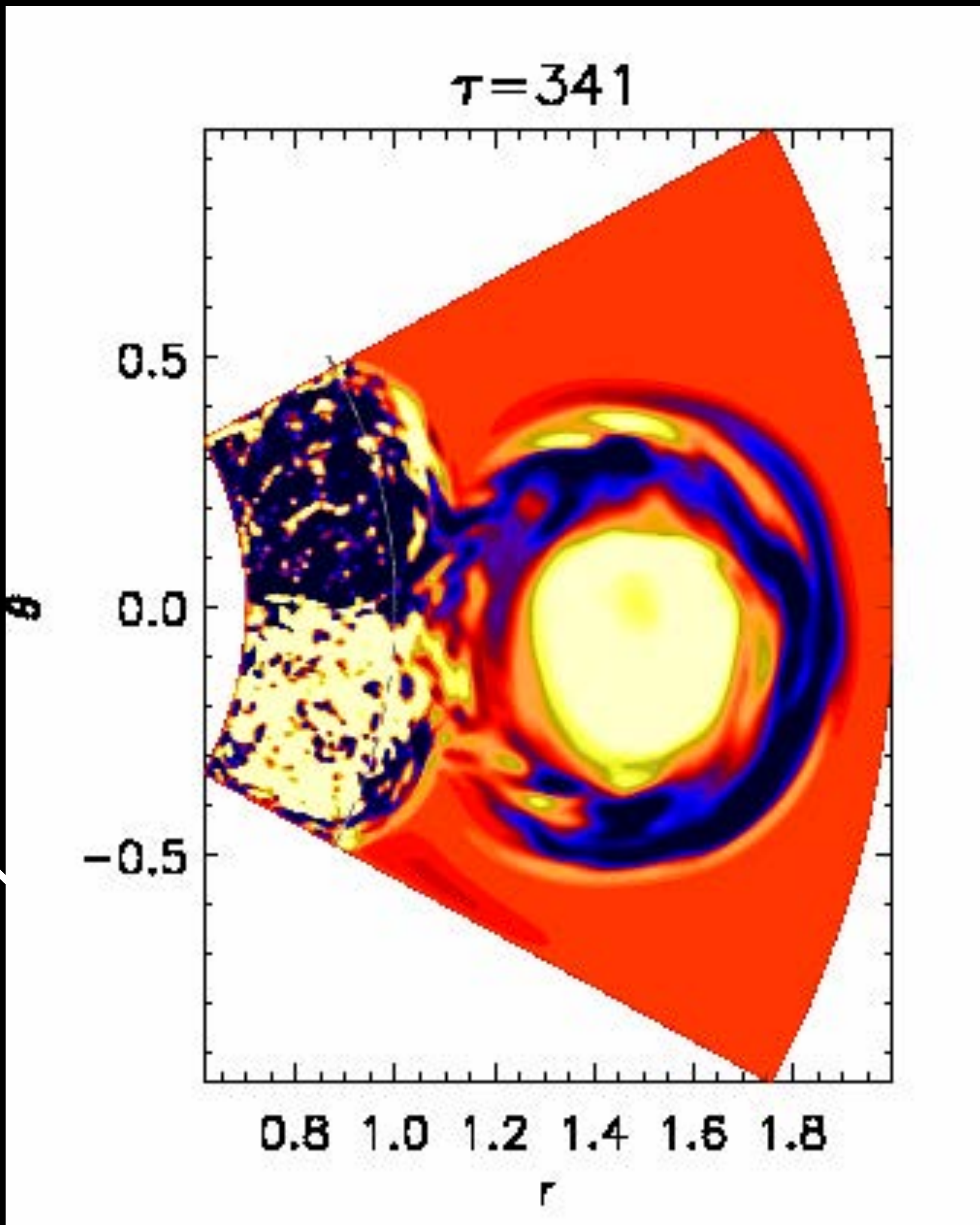

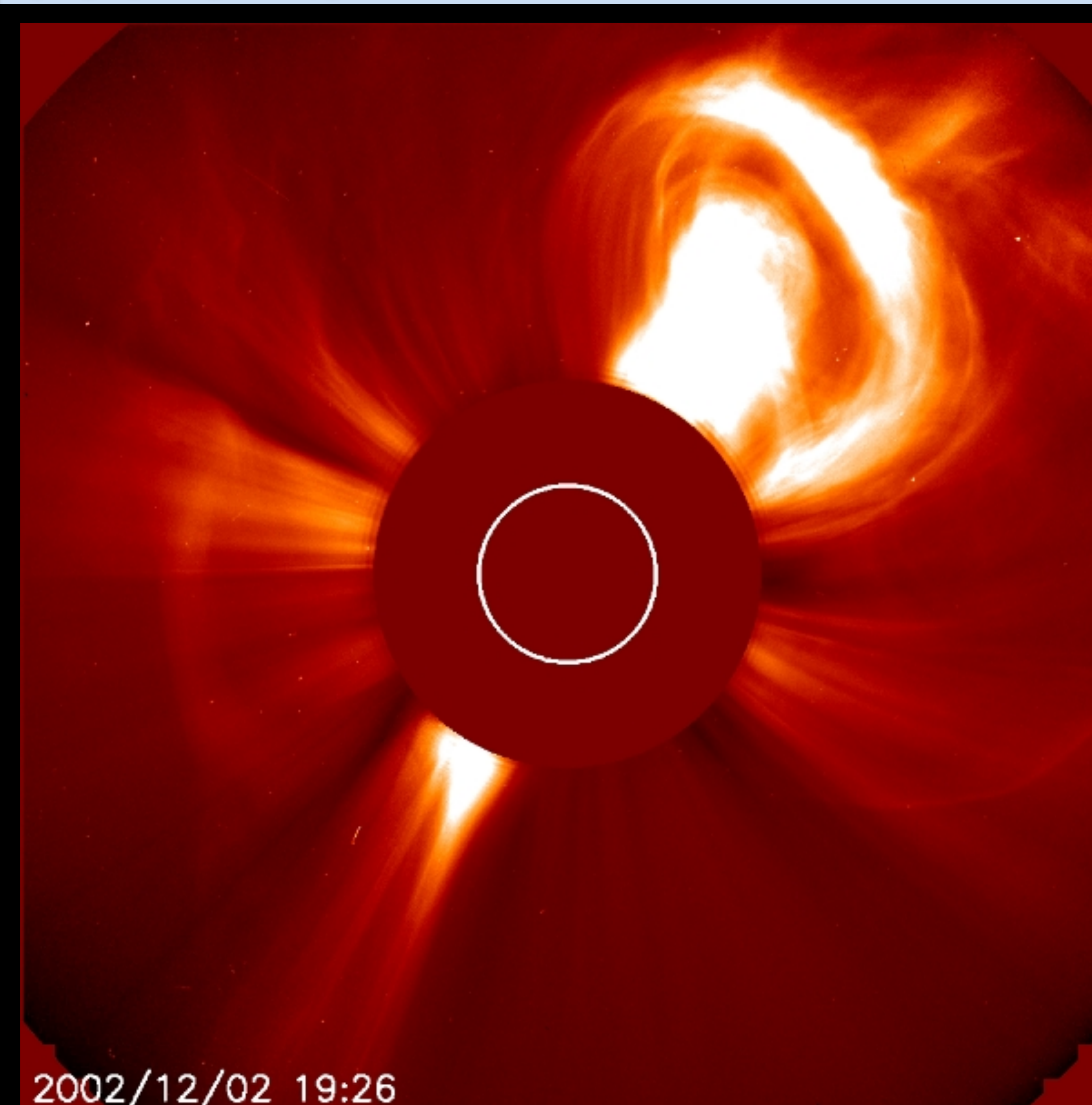

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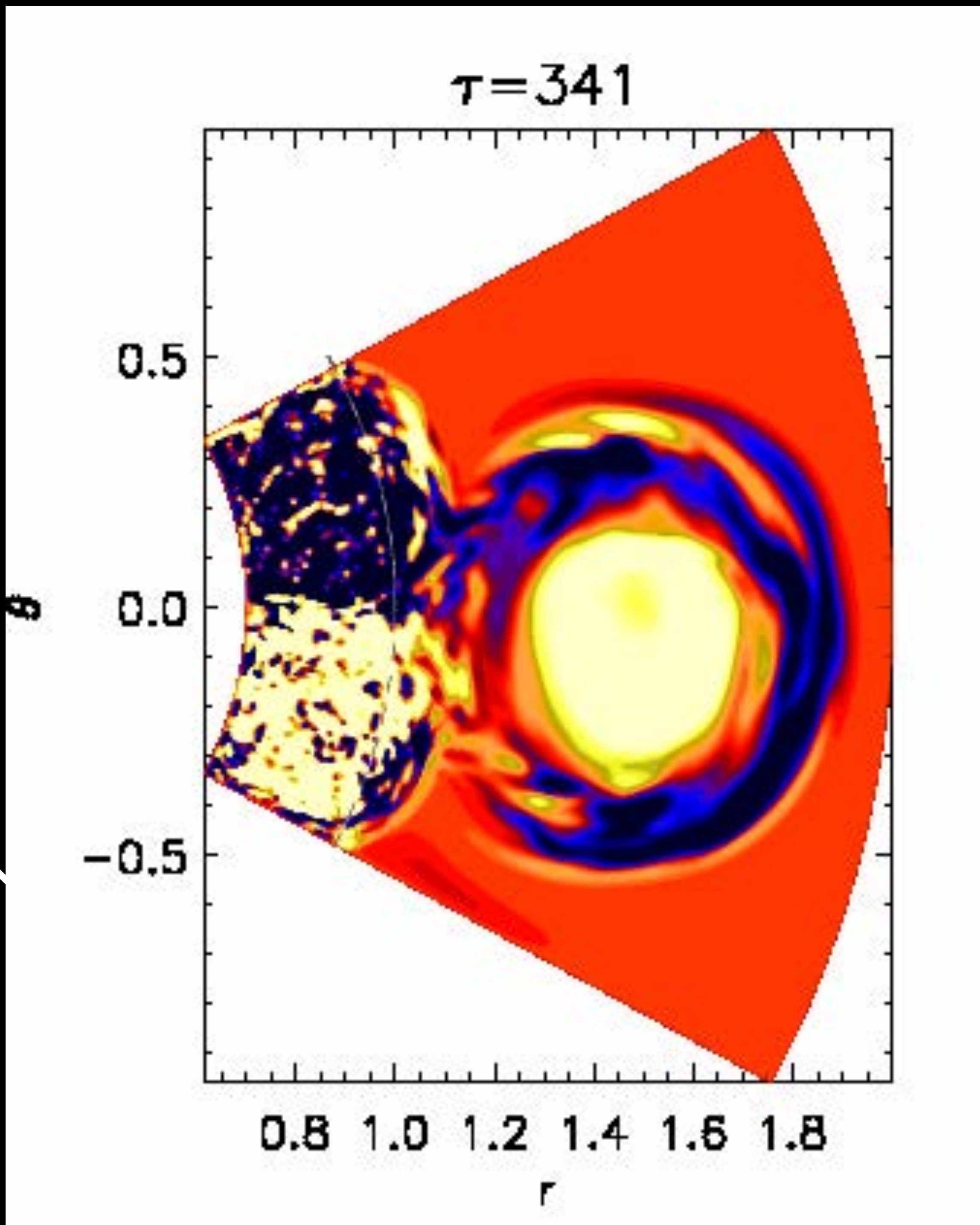

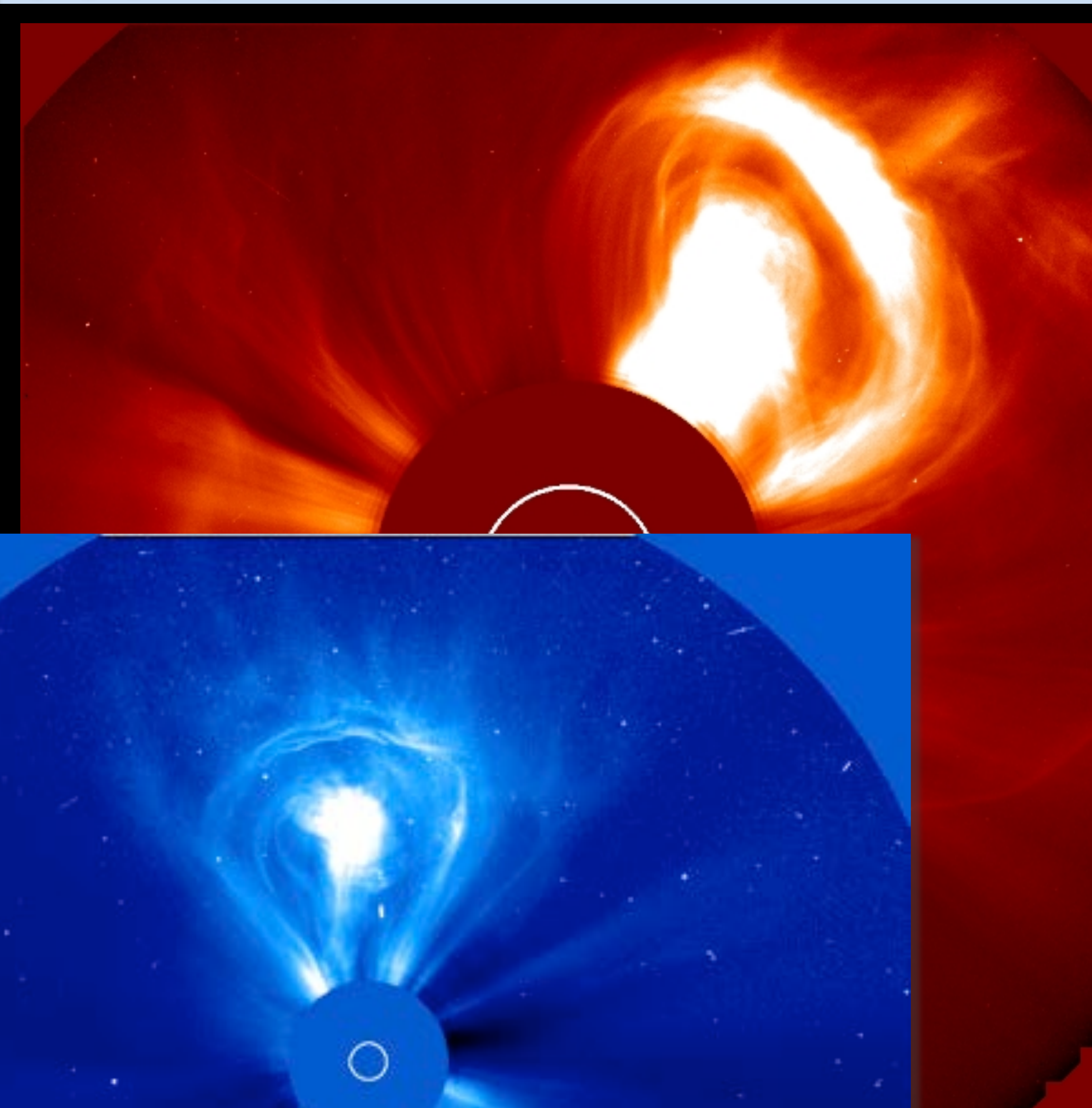

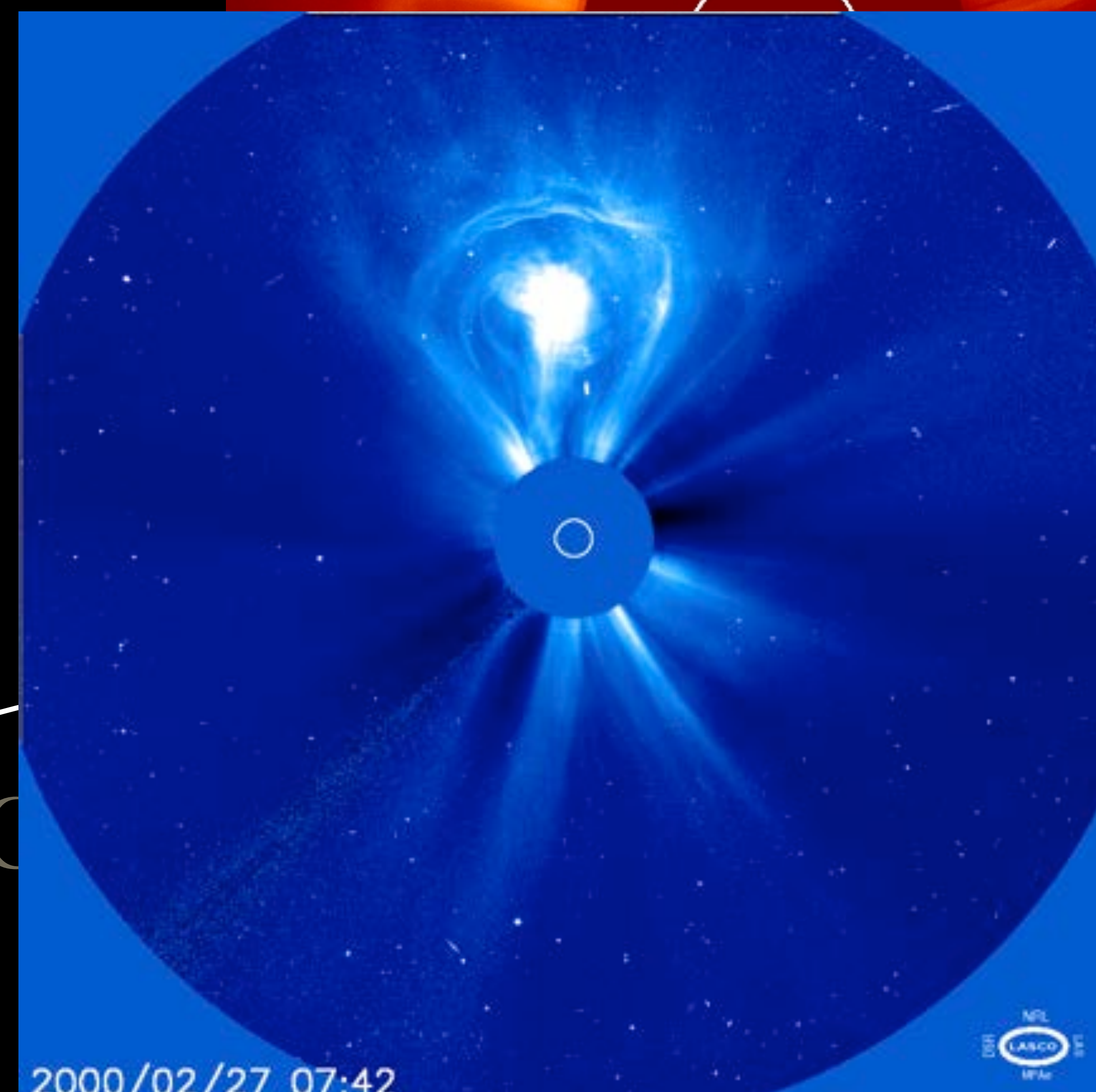

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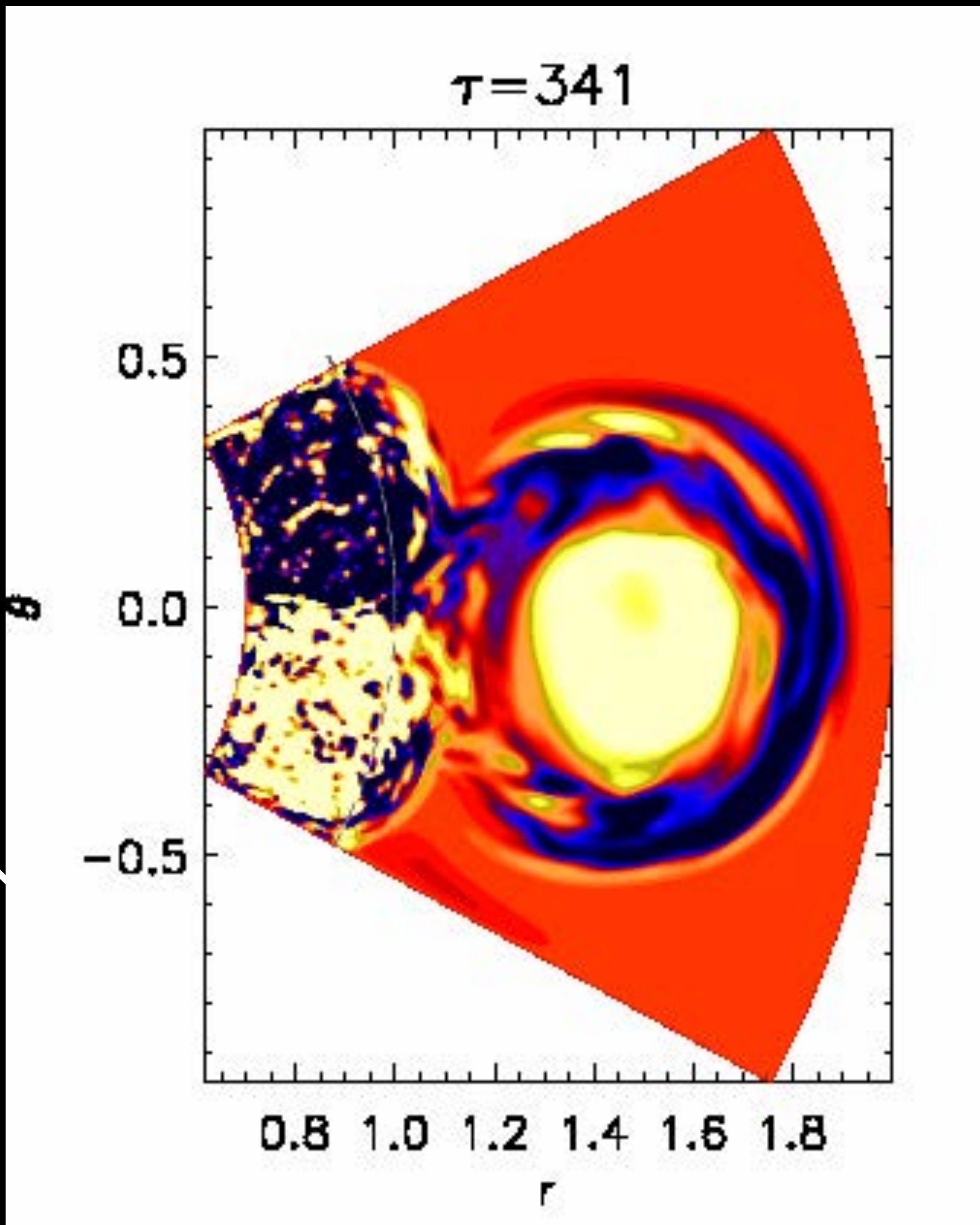

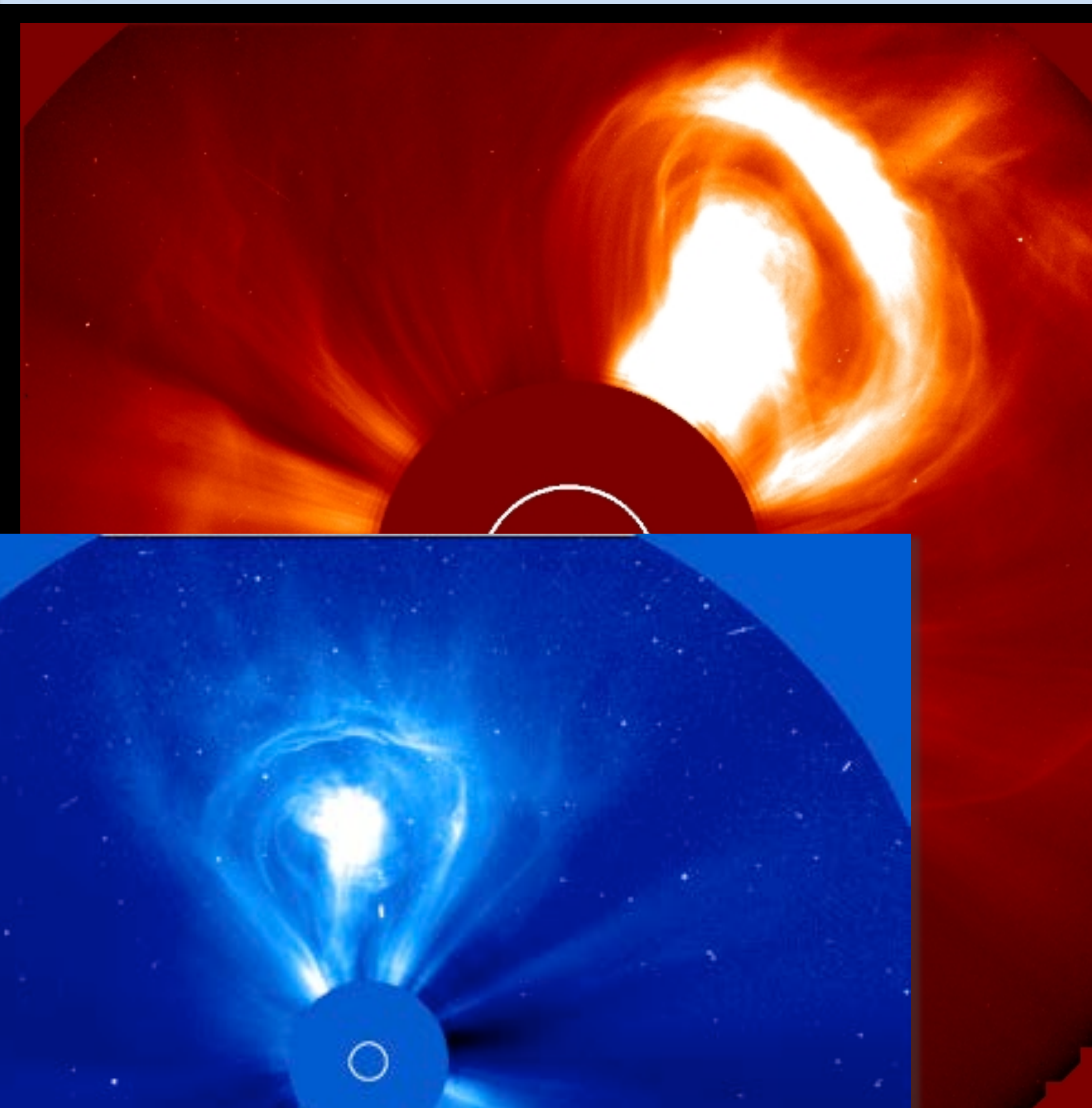

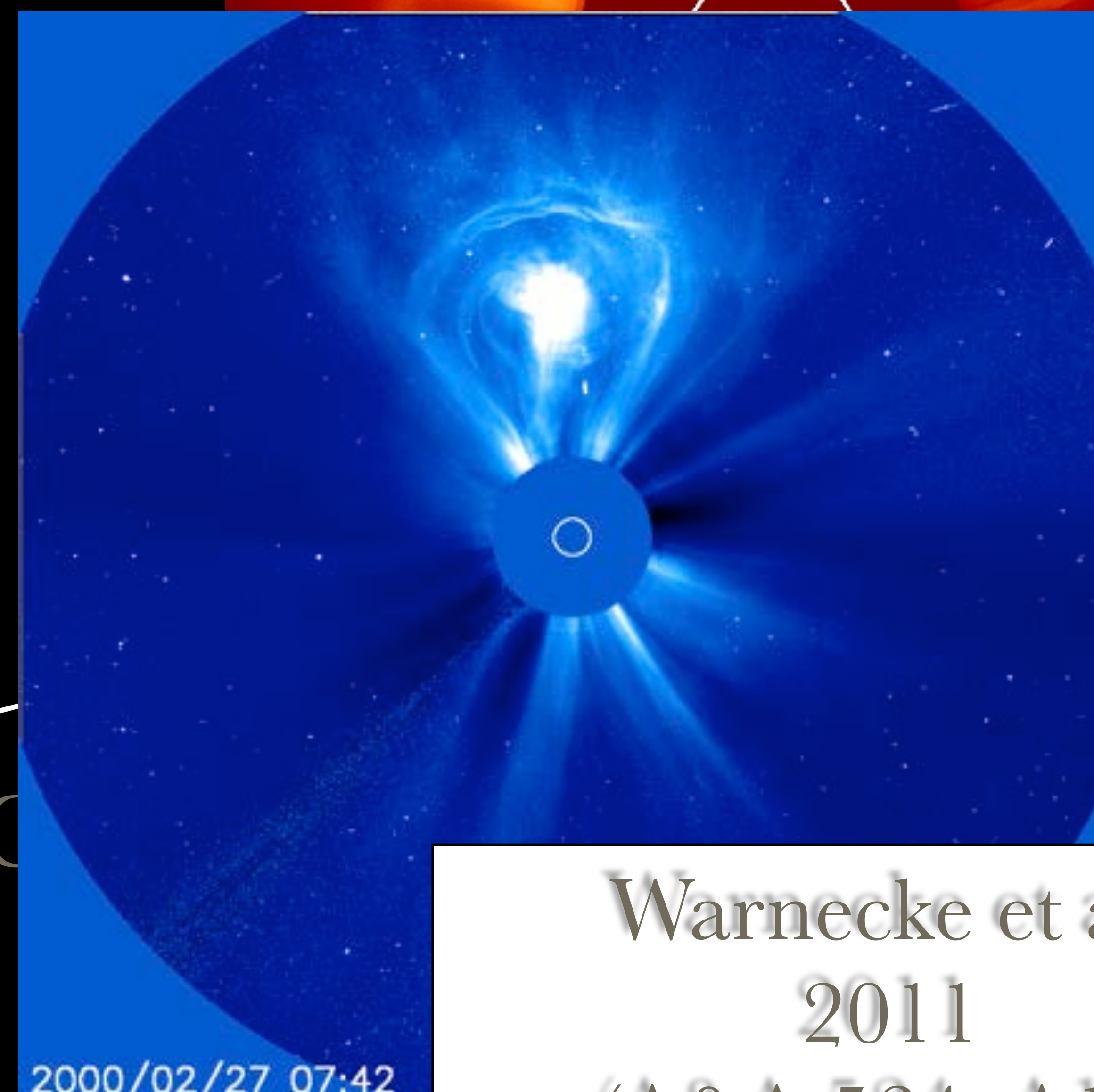

Warnecke et al. 2011 (A&A 534, A11)

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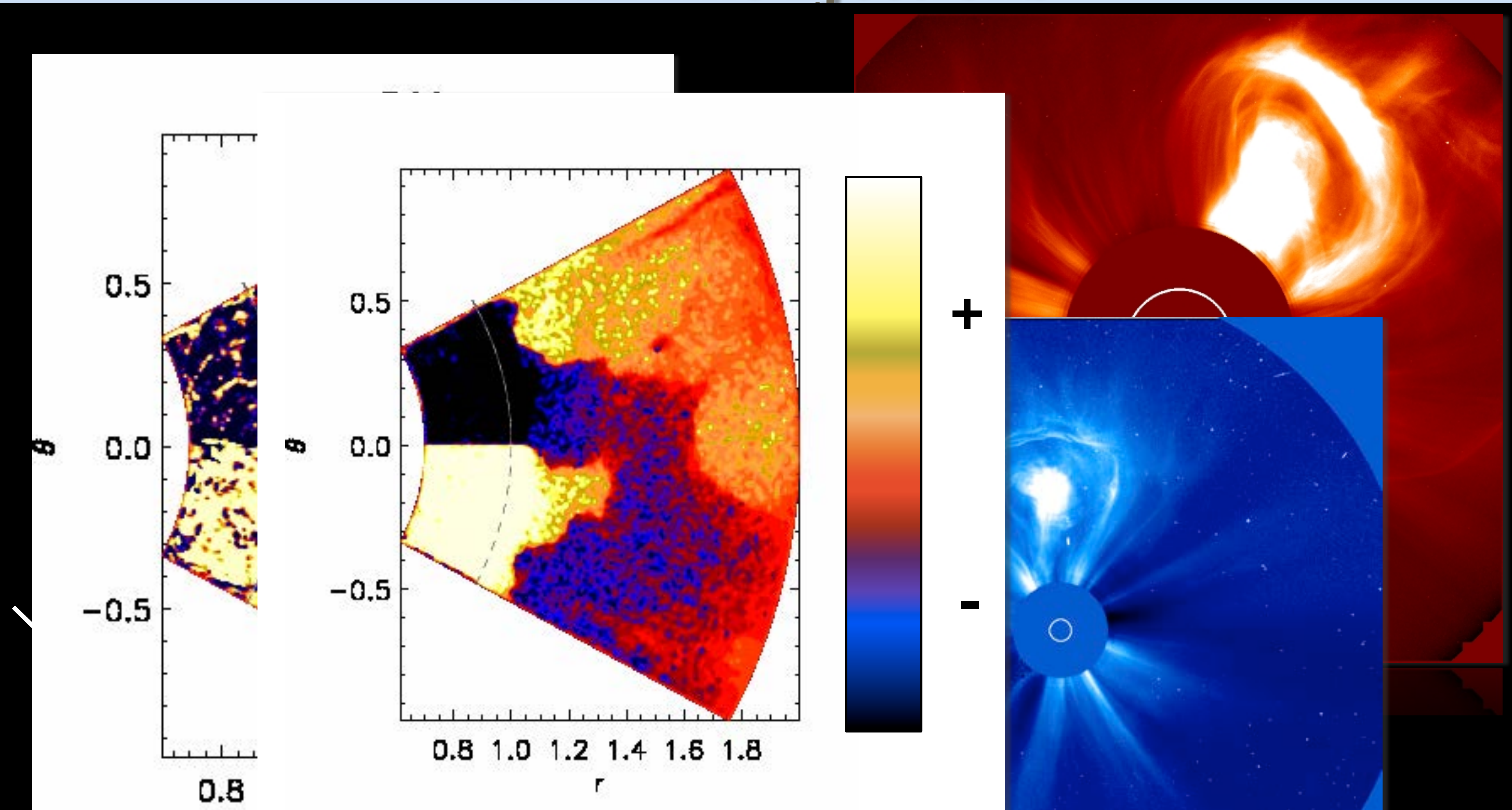

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Ejections in Cartesian forced turbulence

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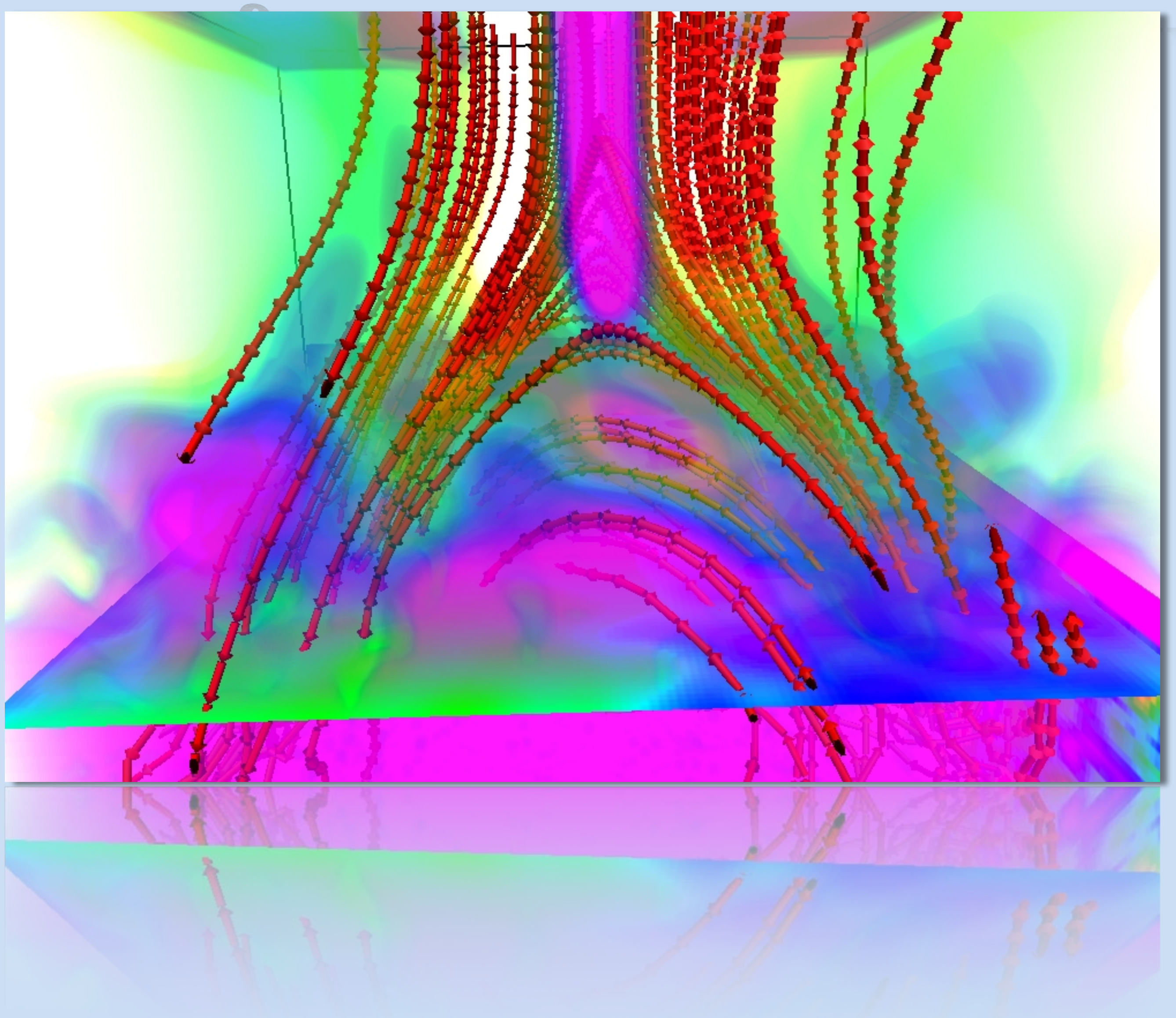

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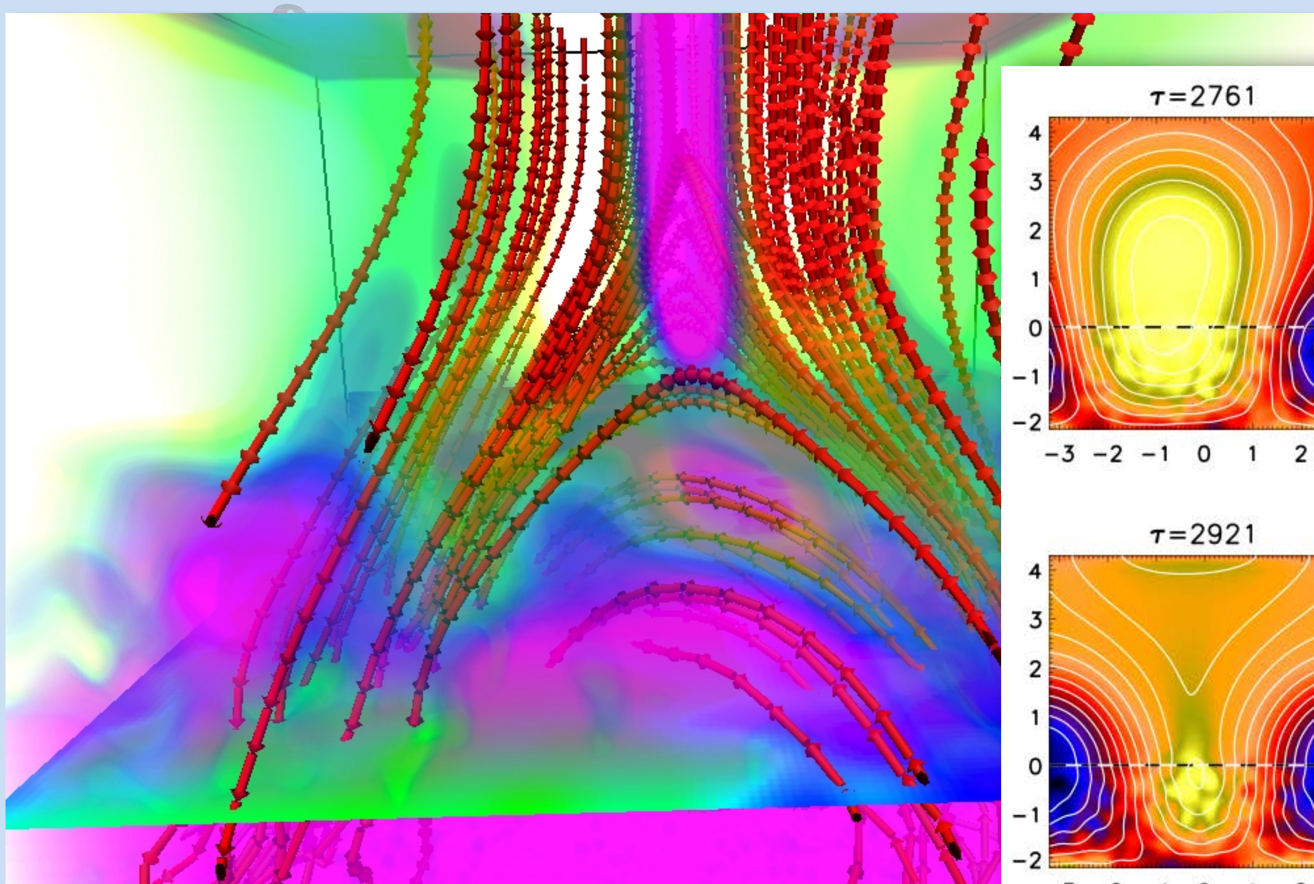
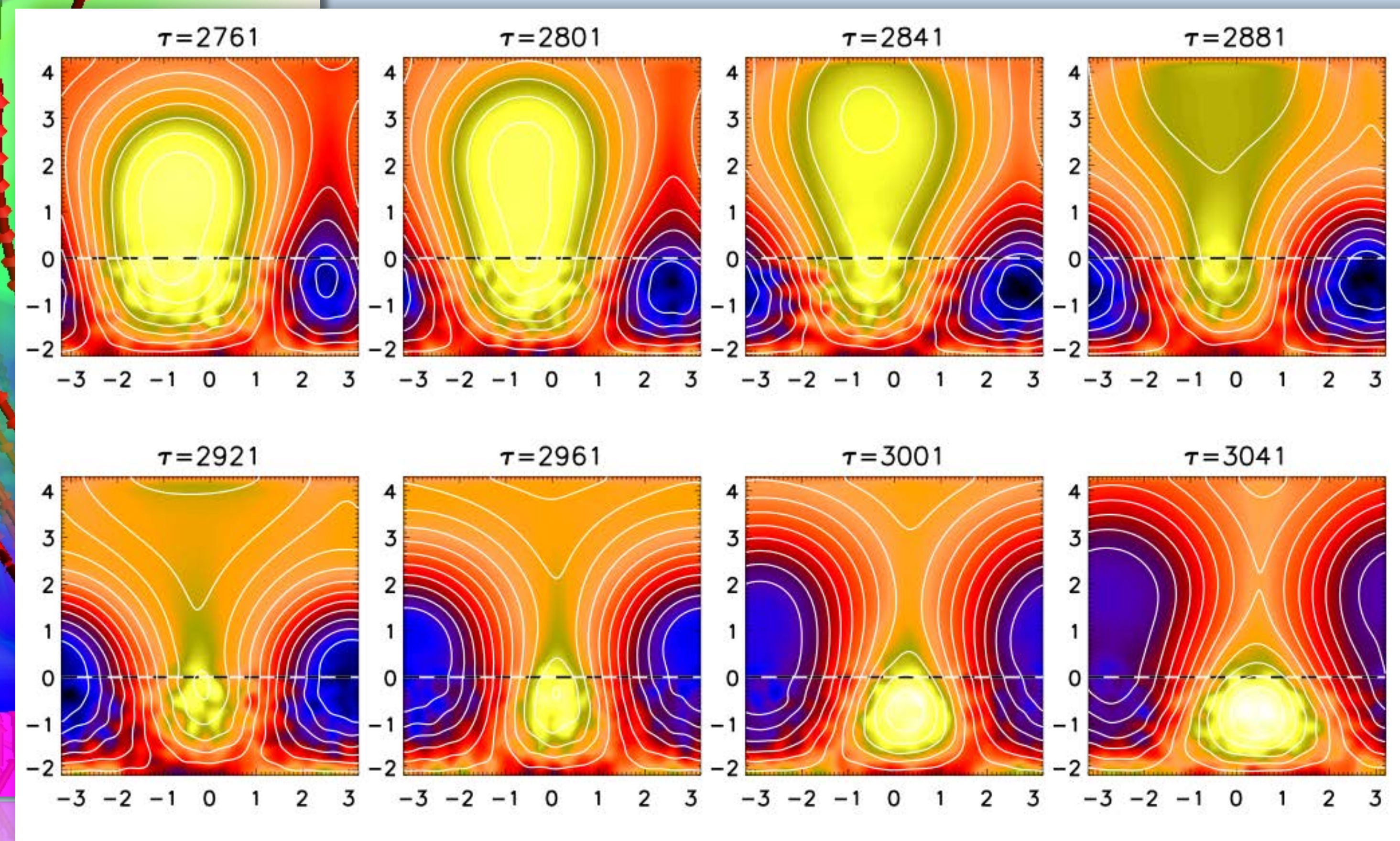
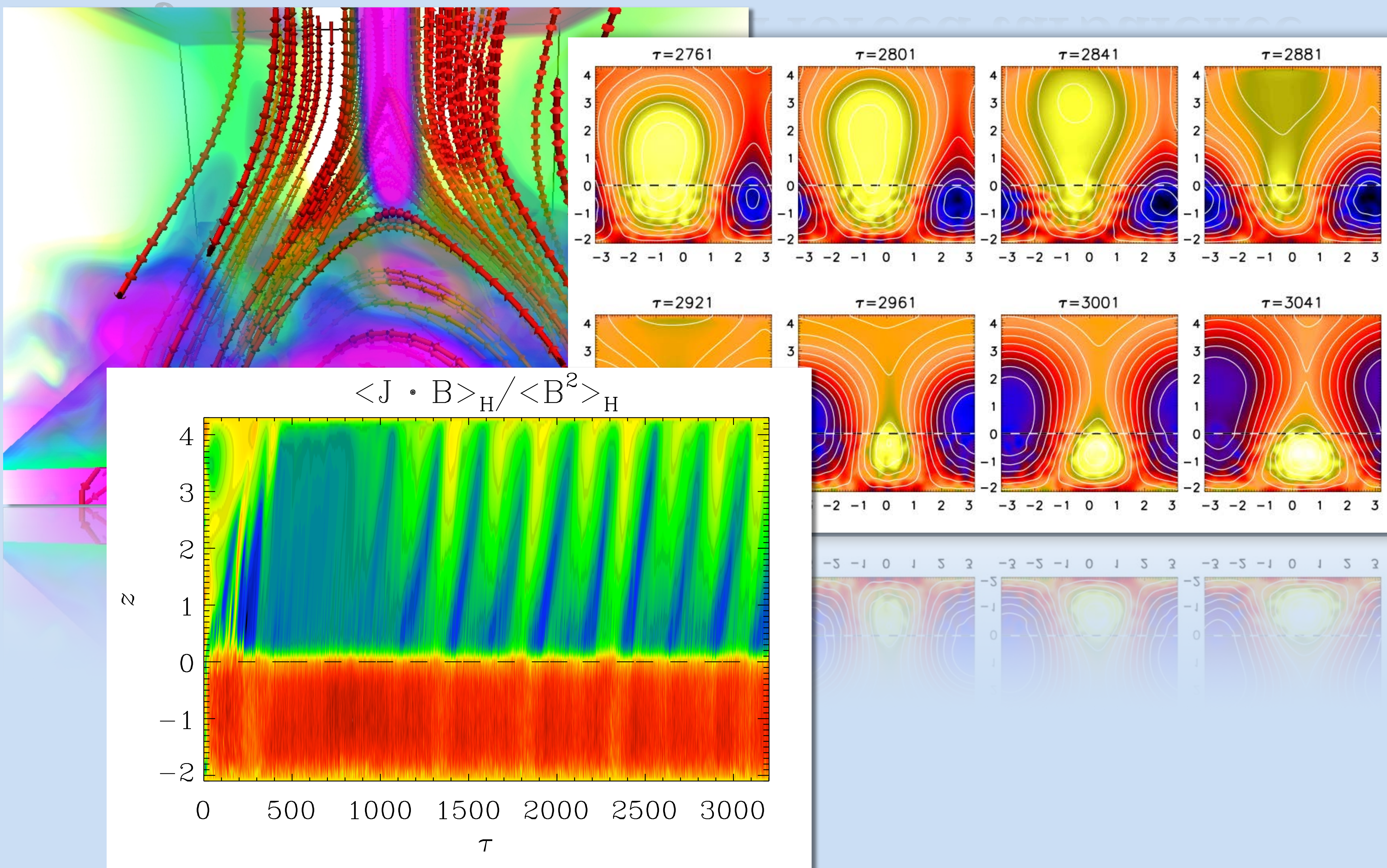




white:
field lines of $\langle B_{yz}\rangle_x$

color coded:
$\langle B_x\rangle_x$

Ejections in Cartesian forced turbulence



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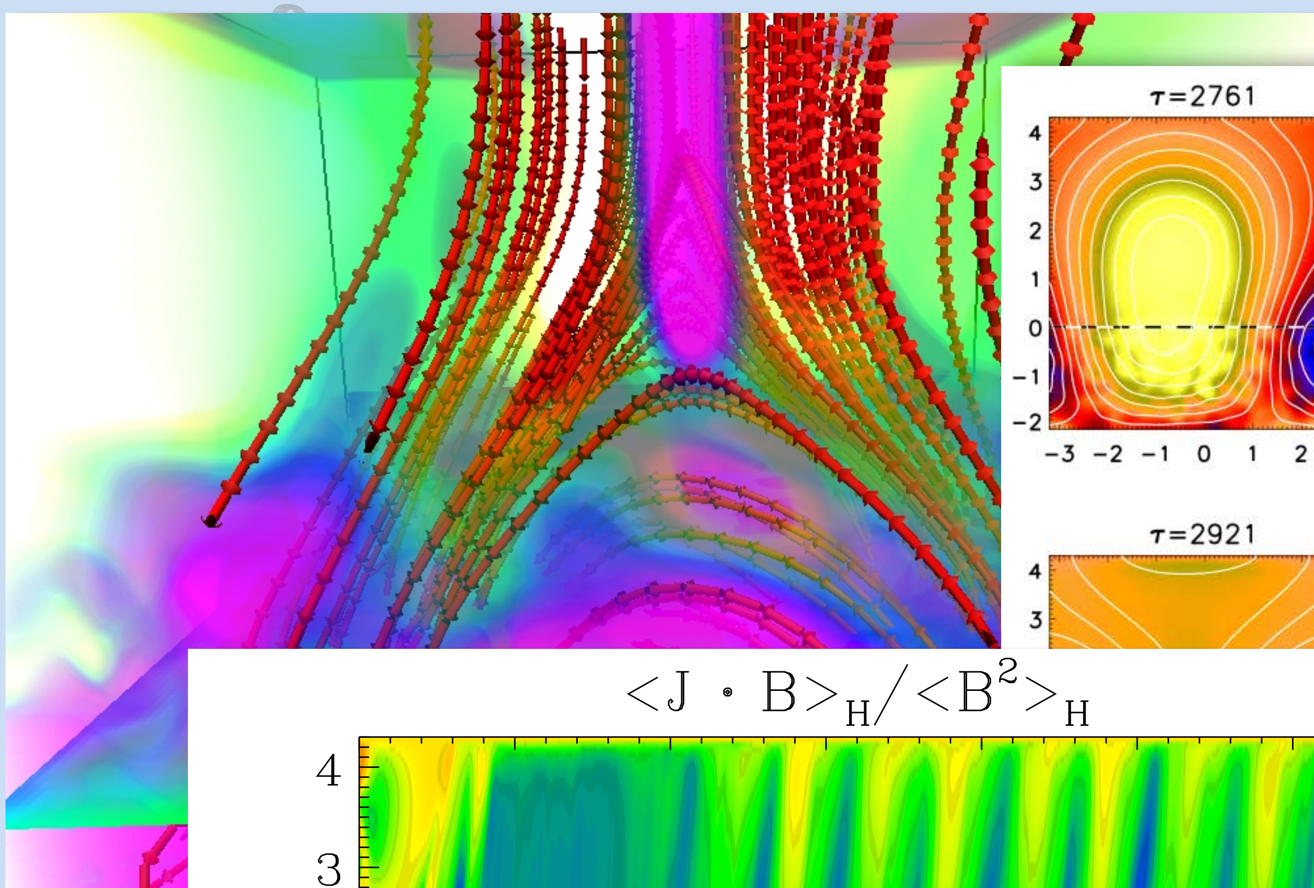
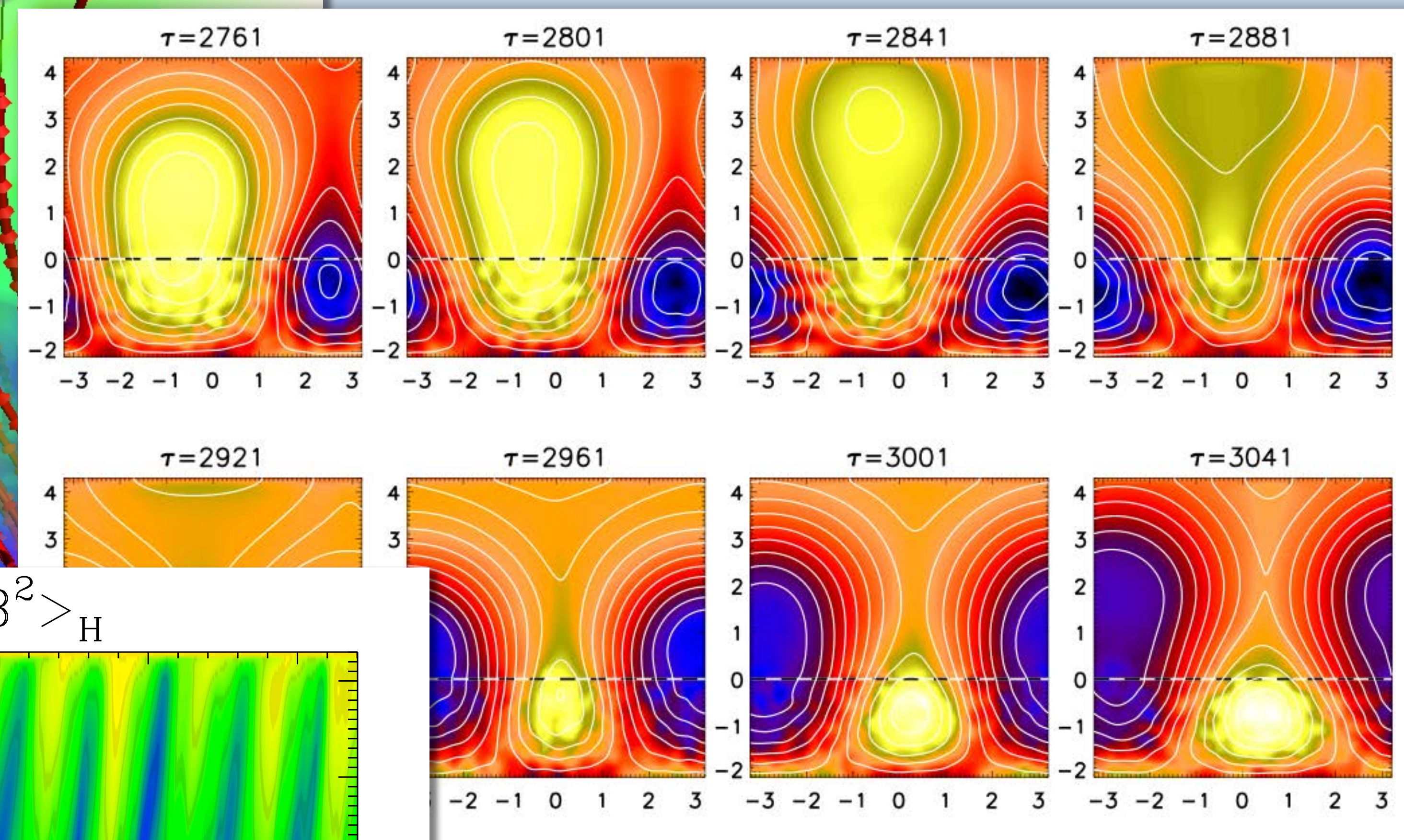
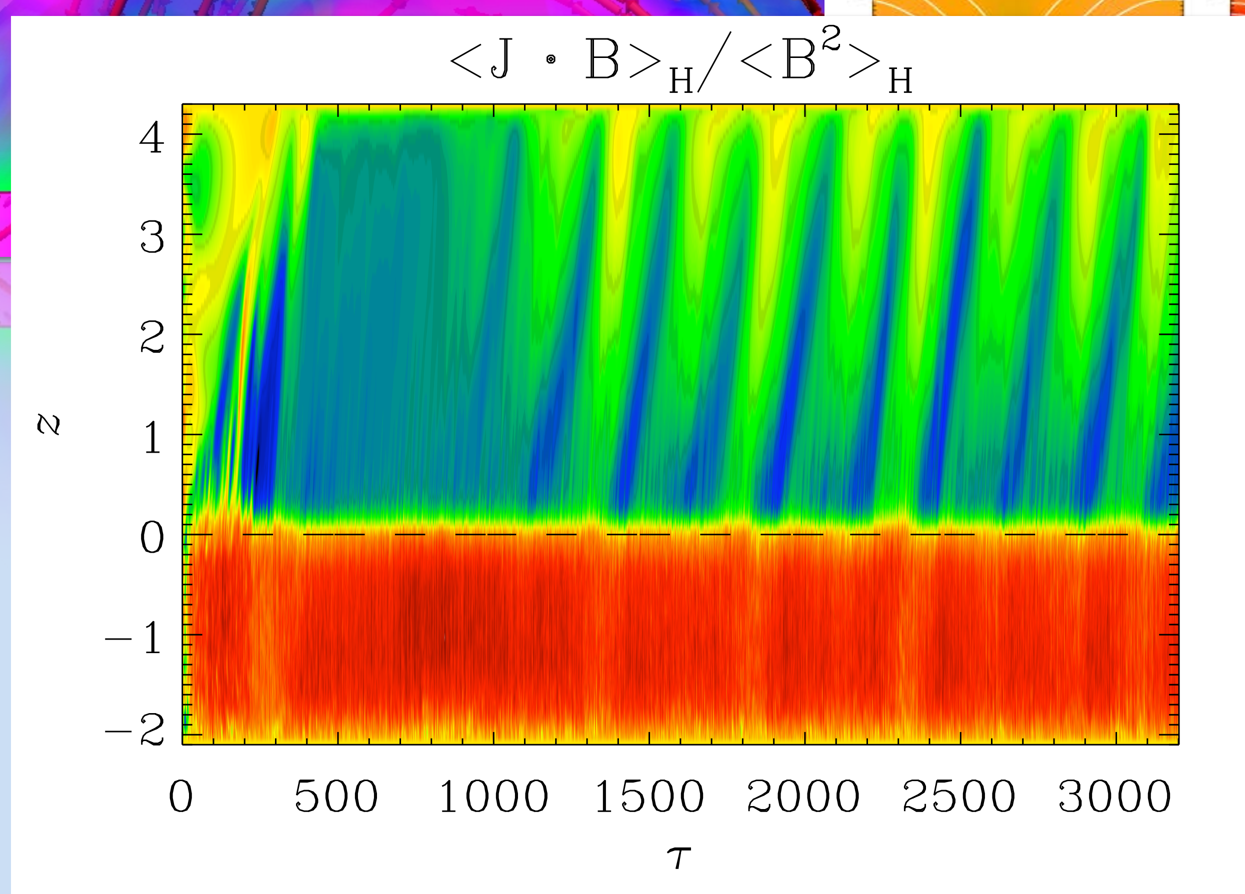
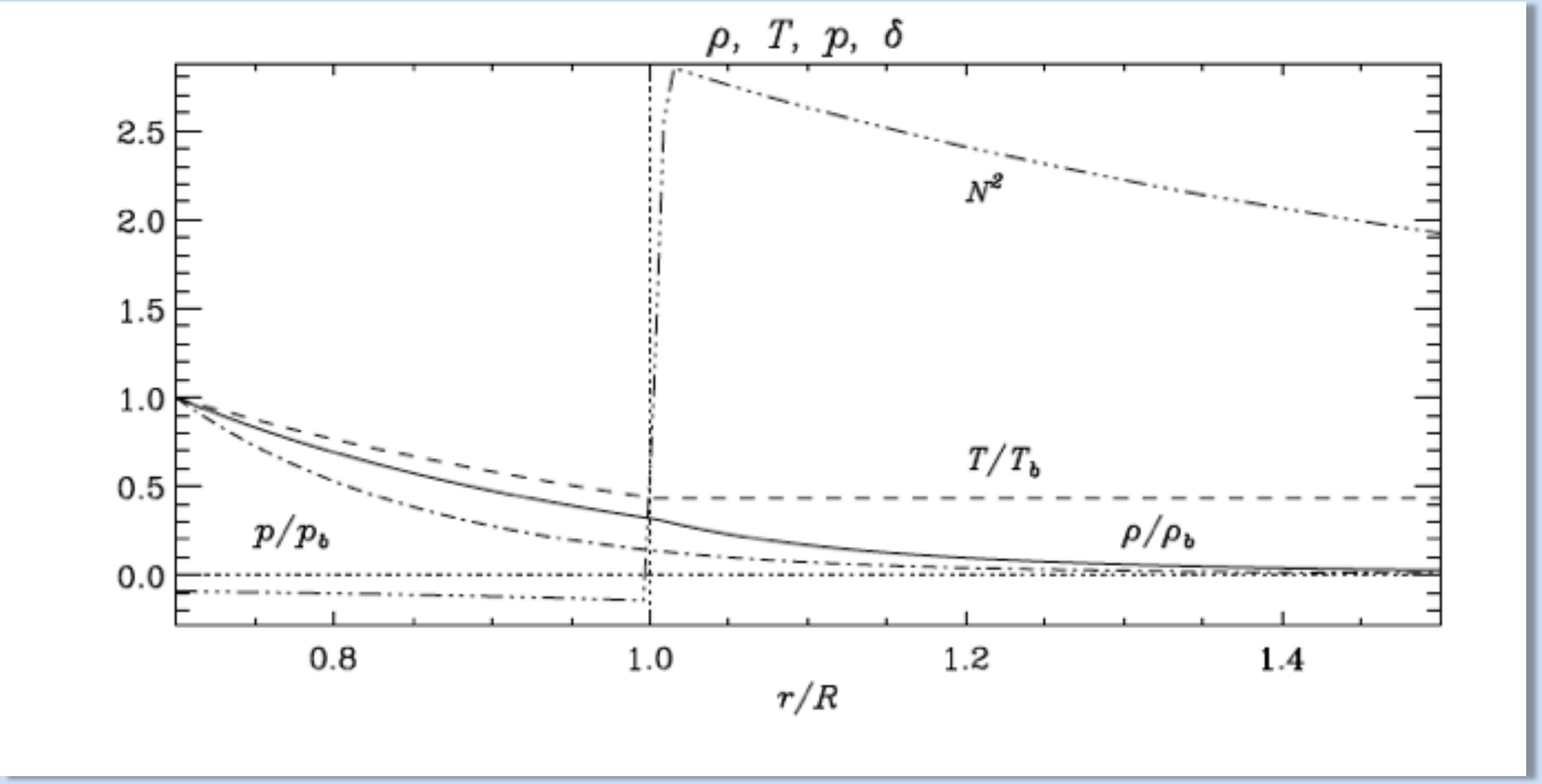




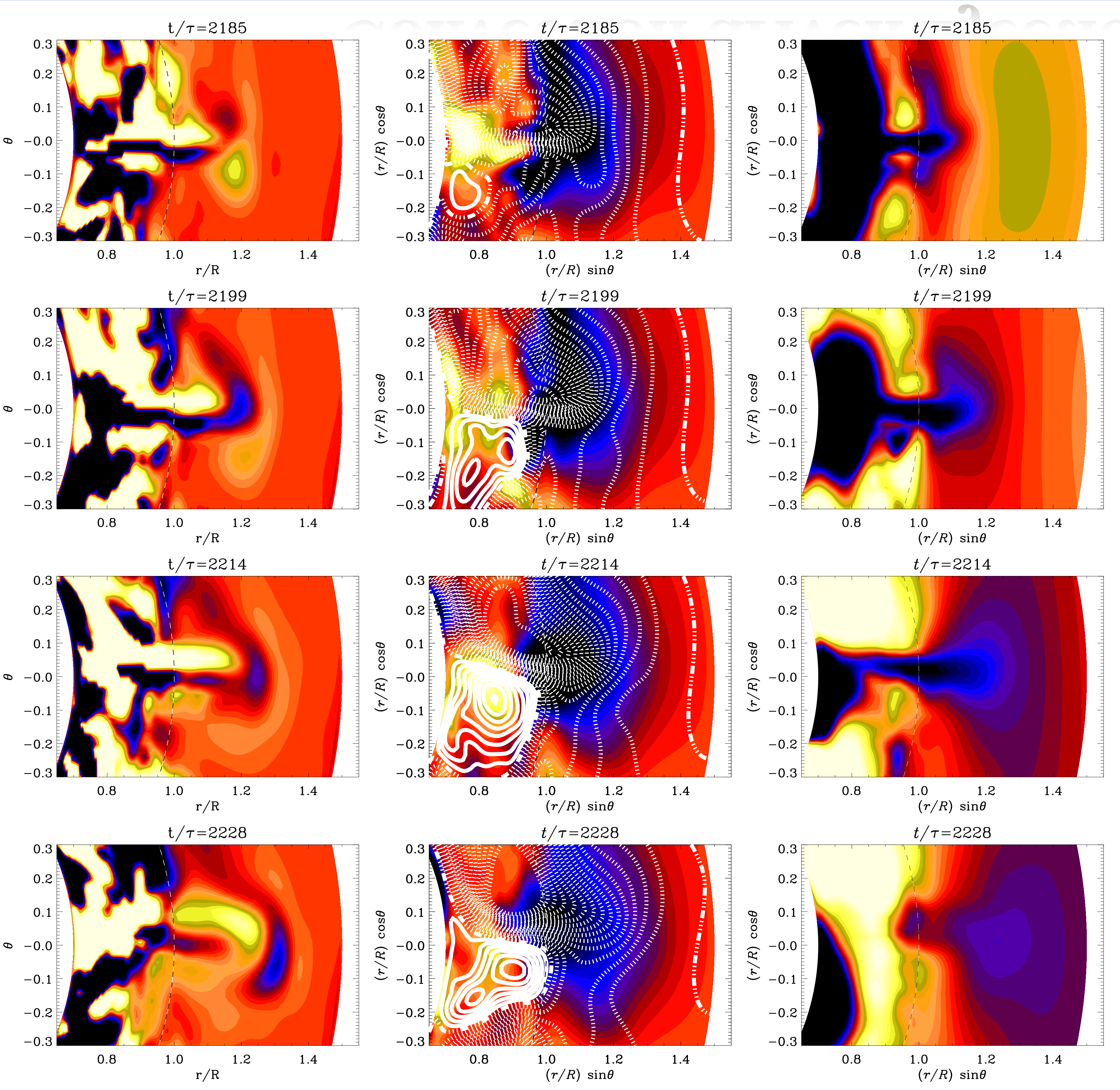


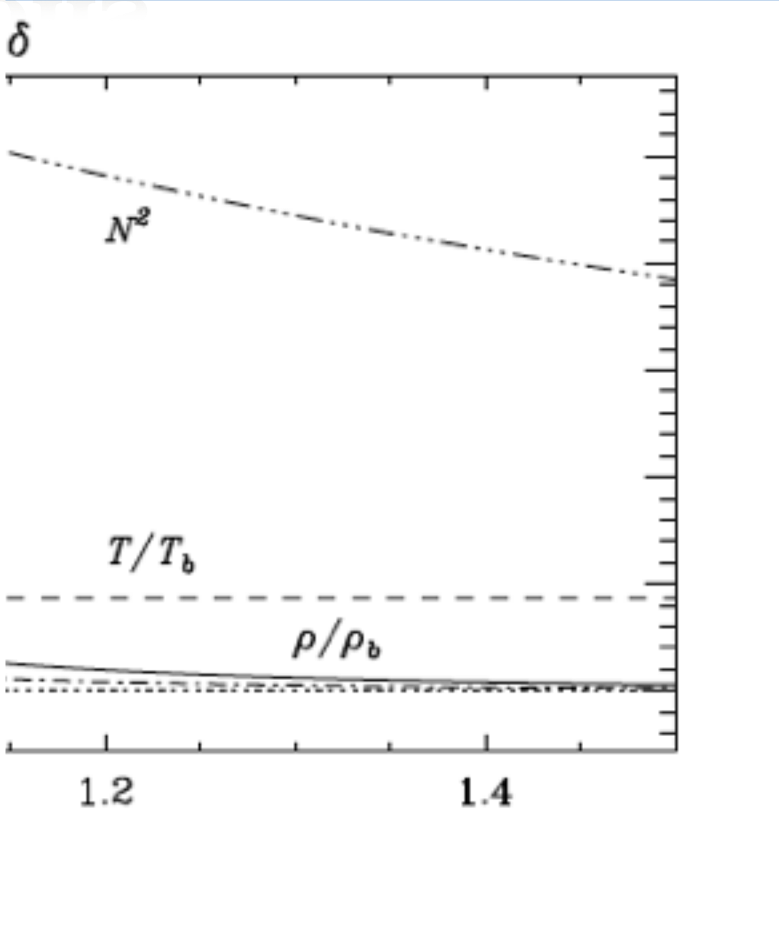
Warnecke
& Brandenburg 2010
(A&A 523, A19)



Self-consistent convection with a coronal layer

Convection driven Ejections





Warnecke et al. 2012 (Sol. Ph. 280, 299)

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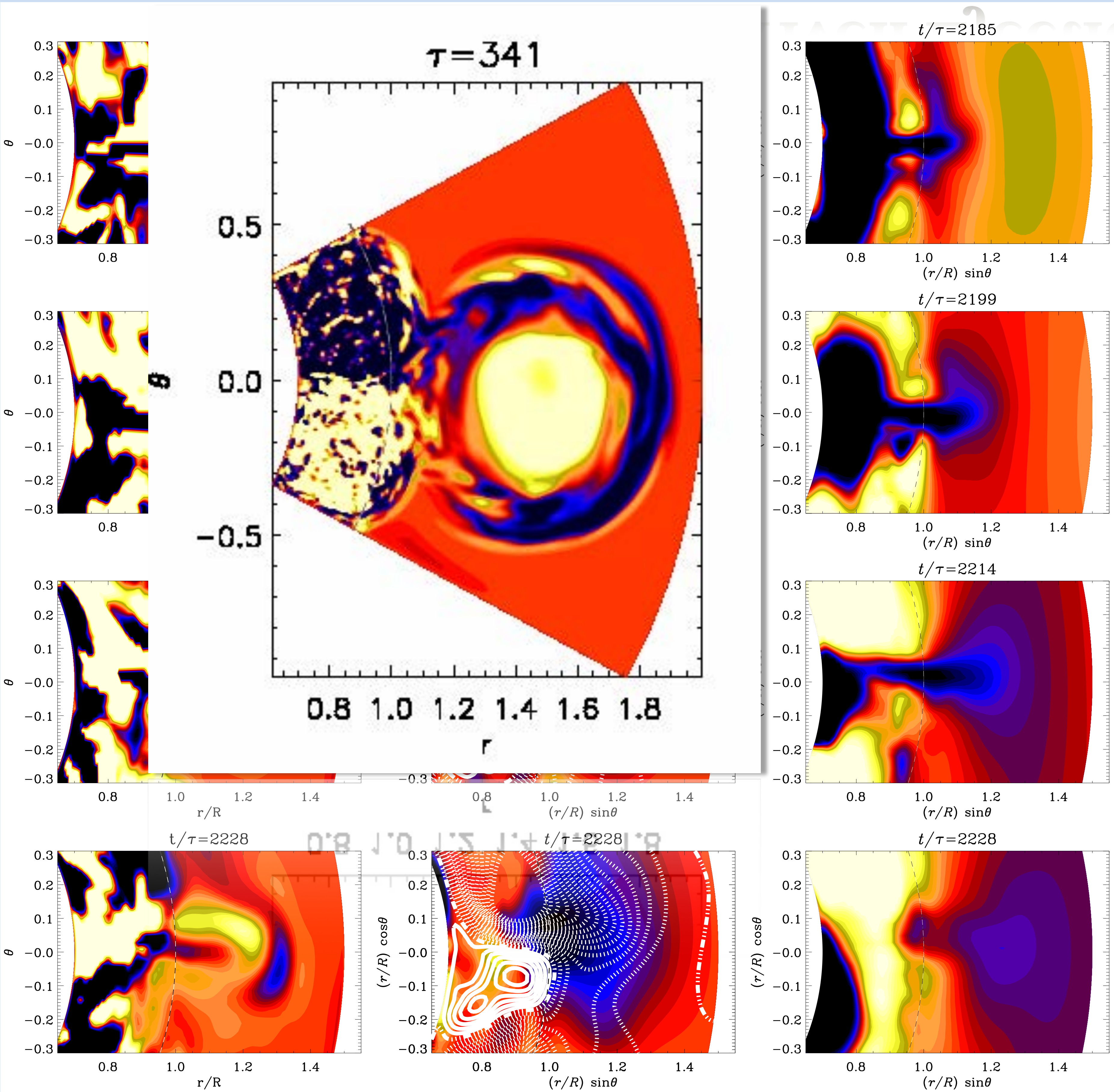

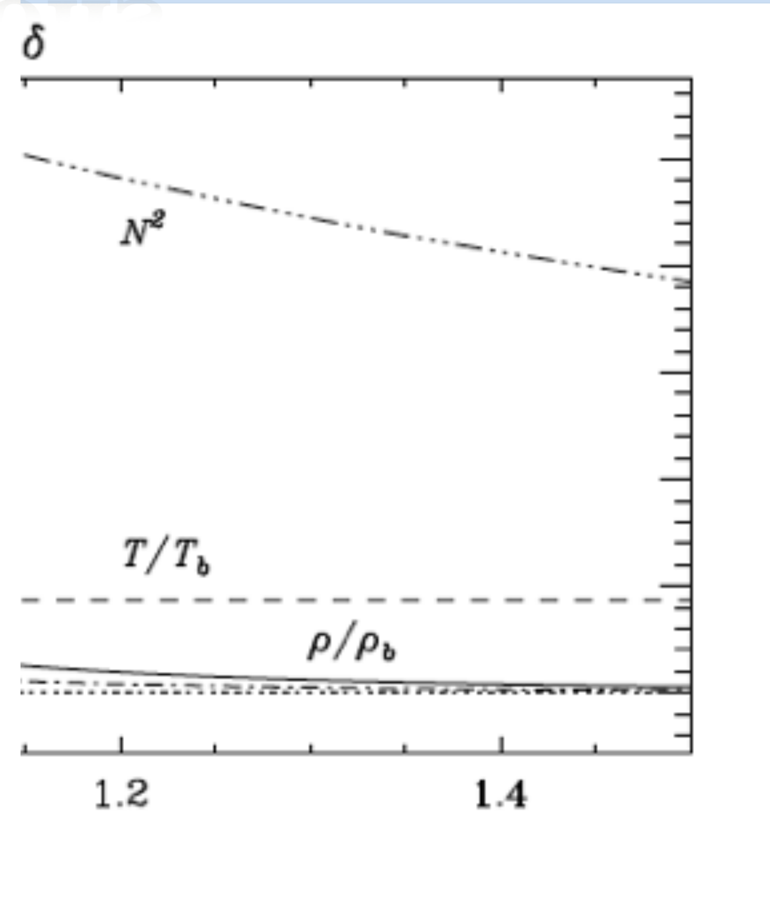

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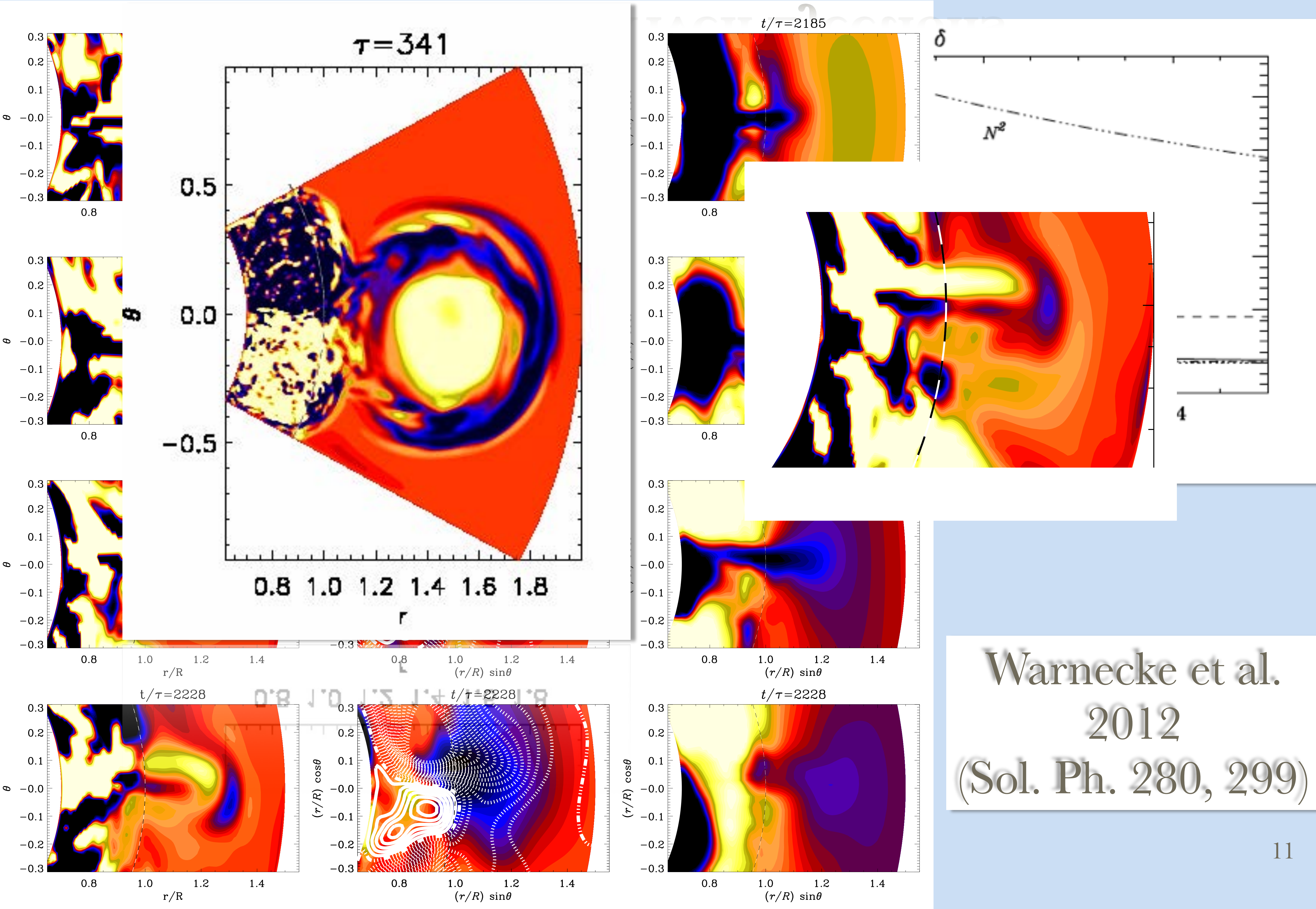

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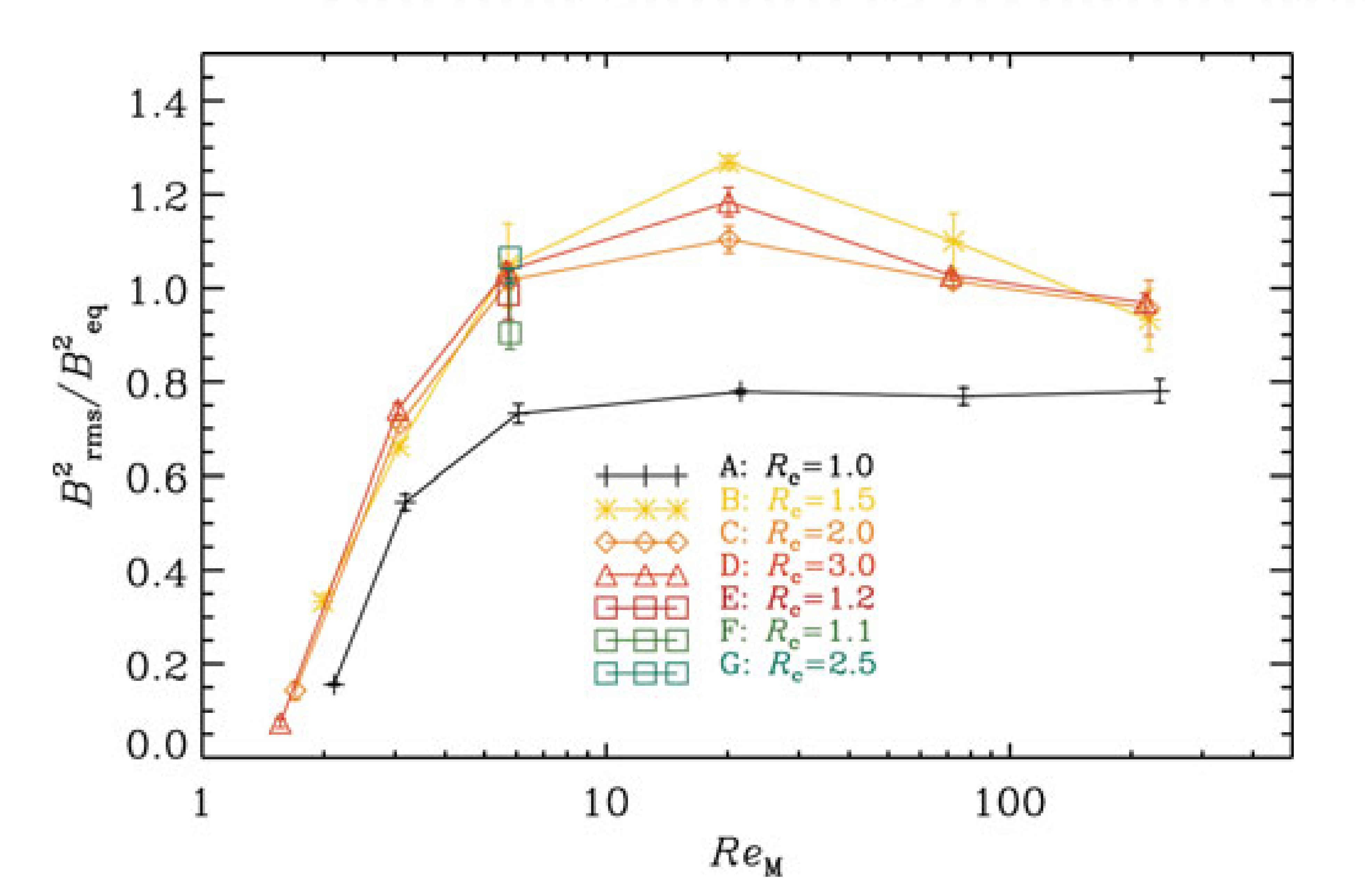
Corona supports dynamo action



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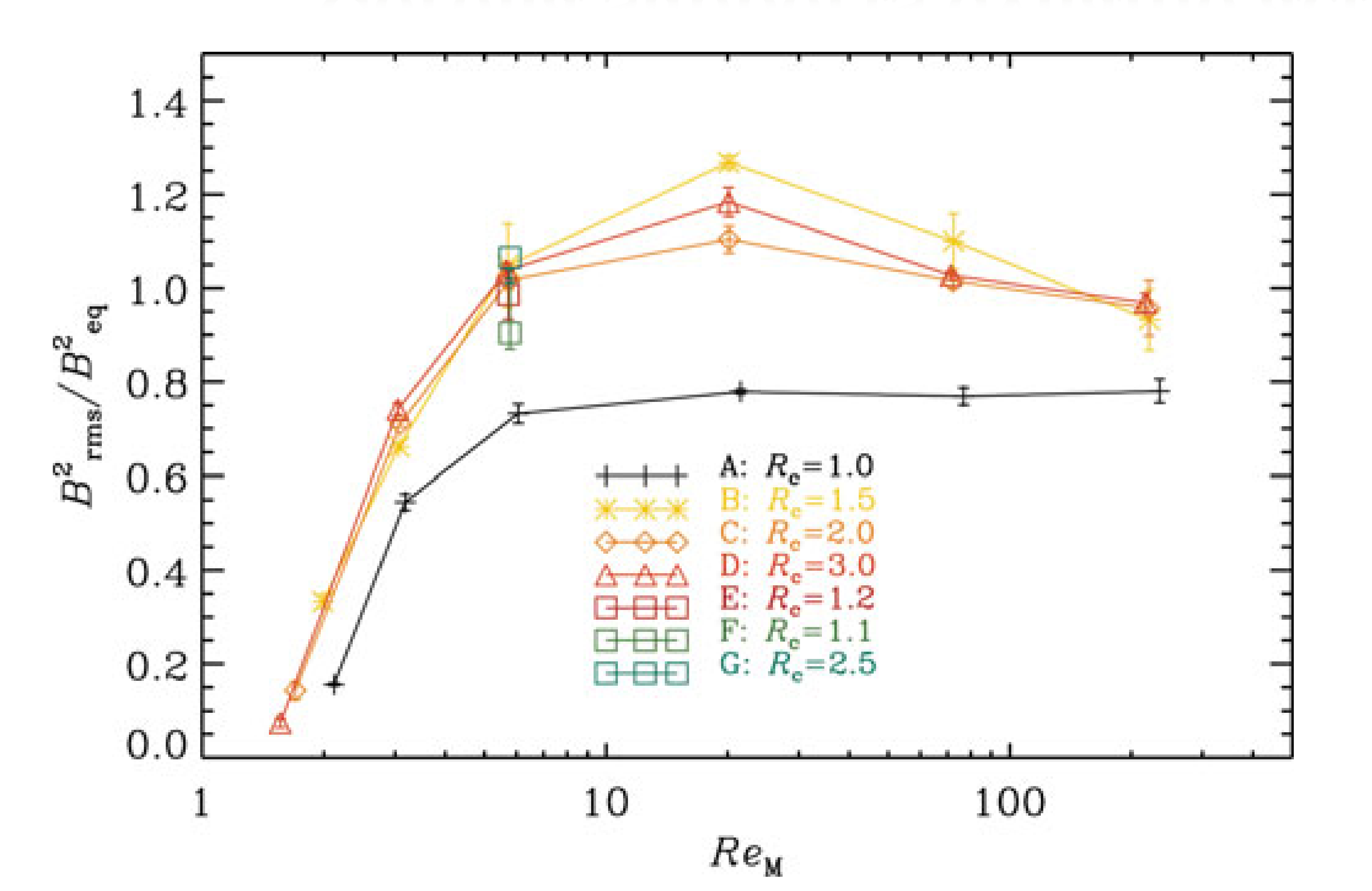


Warnecke et al., 2014
IAU proceeding

Coronal model driven by emerging flux simulation

flux-emergence simulation

from / similar to Cheung et al (2010) ApJ 720, 233

– flux rope rises from bottom and breaks through surface

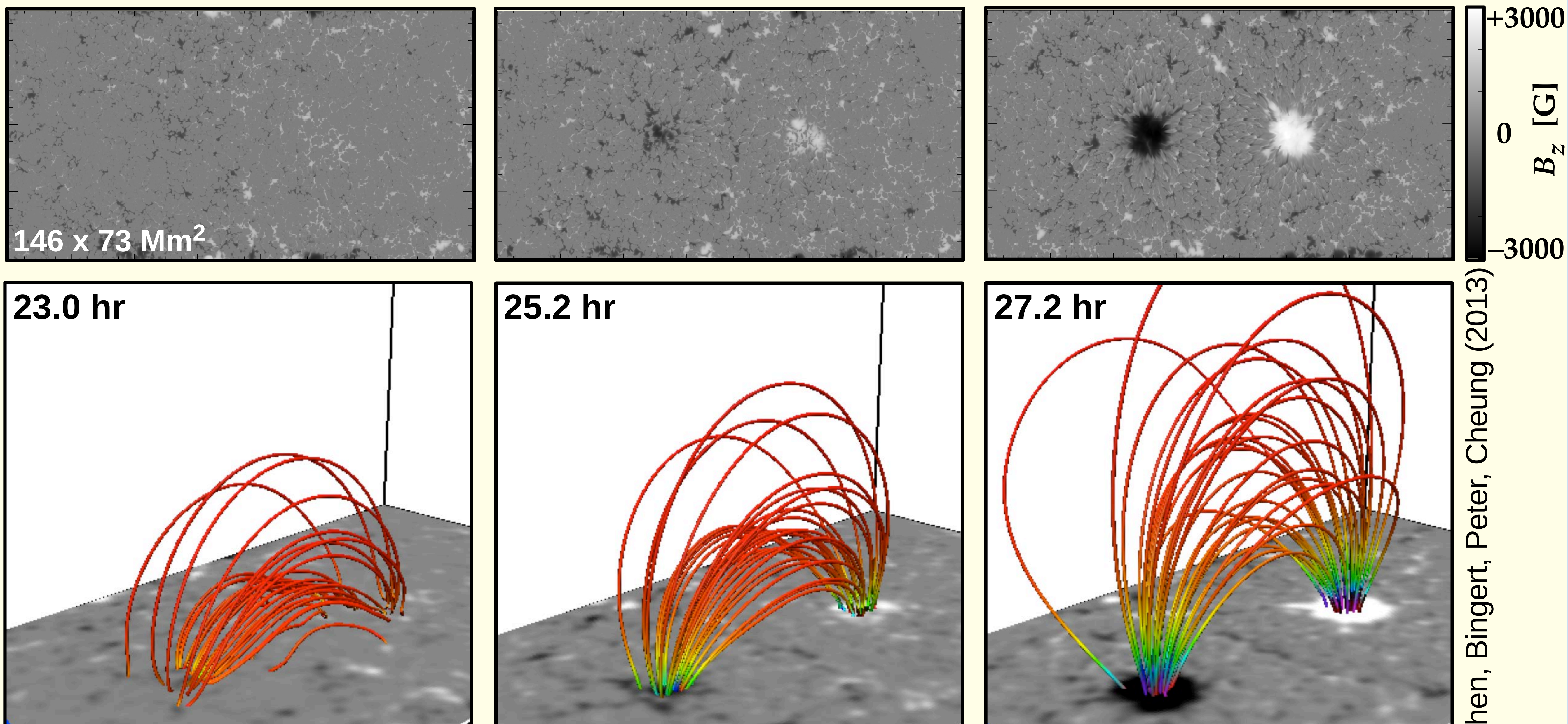
→ pair of sunspots

coronal simulation

– use photospheric layer (T, ρ, v, B) as time-dependent lower boundary

→ magnetic field expands

→ coronal loops form

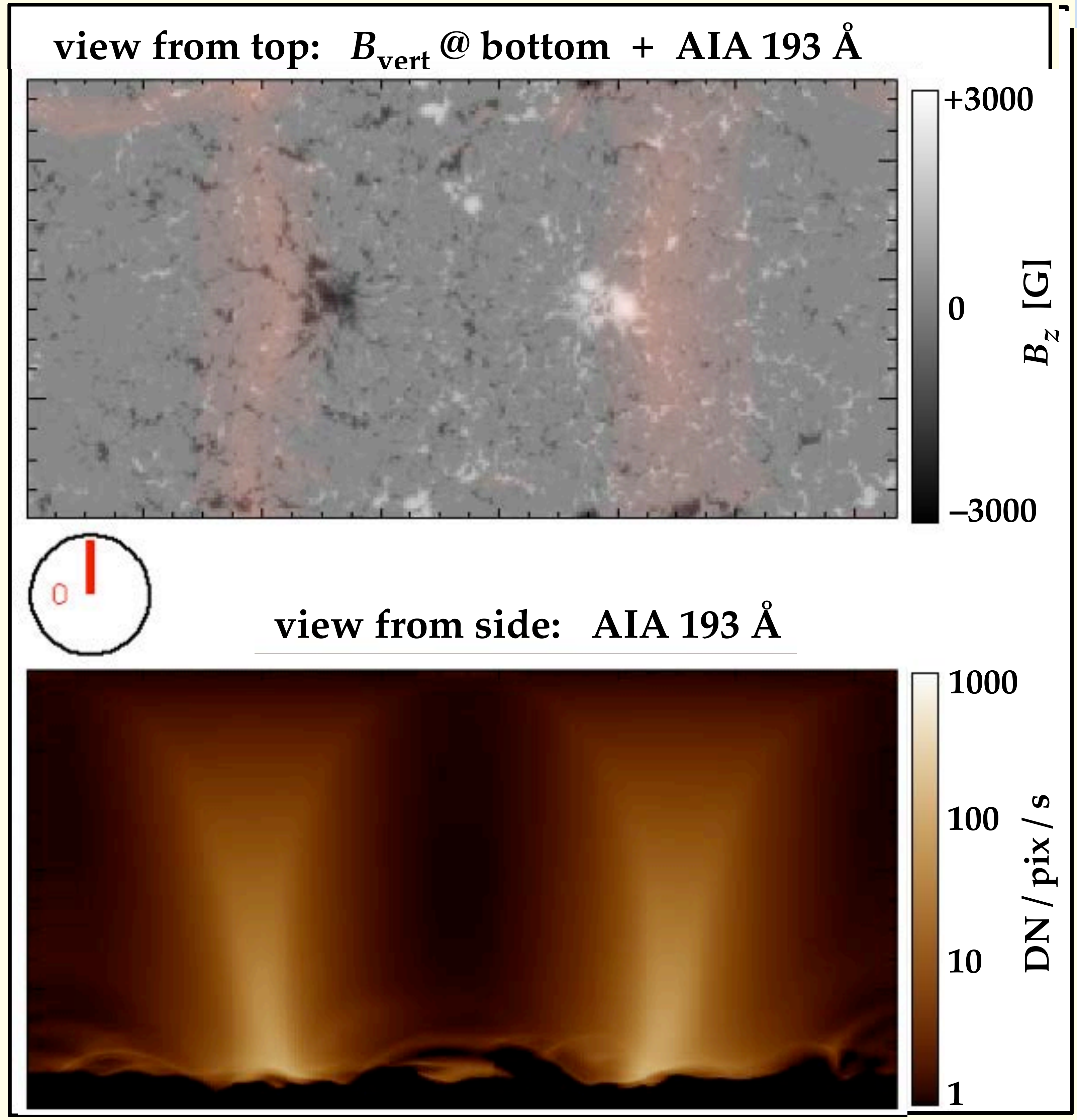


Coronal model driven by emerging flux simulation

- loops form at different places at different times

- loop footpoints are in sunspot periphery (penumbra)

synthesized coronal emission (1.5 10^6 K)



34 min
out of 10 hrs

Chen, Bingert, Peter, Cheung (2013

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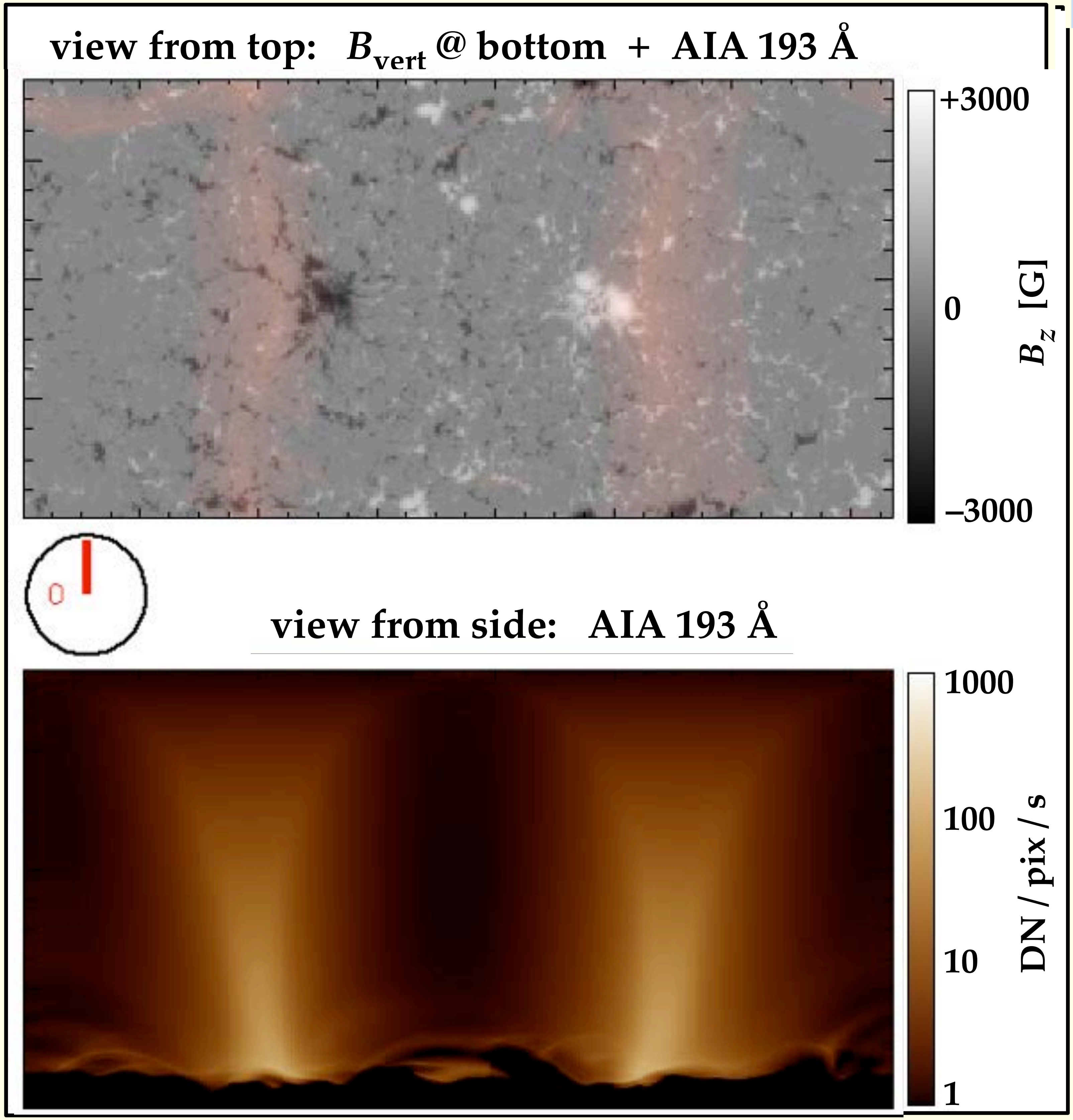

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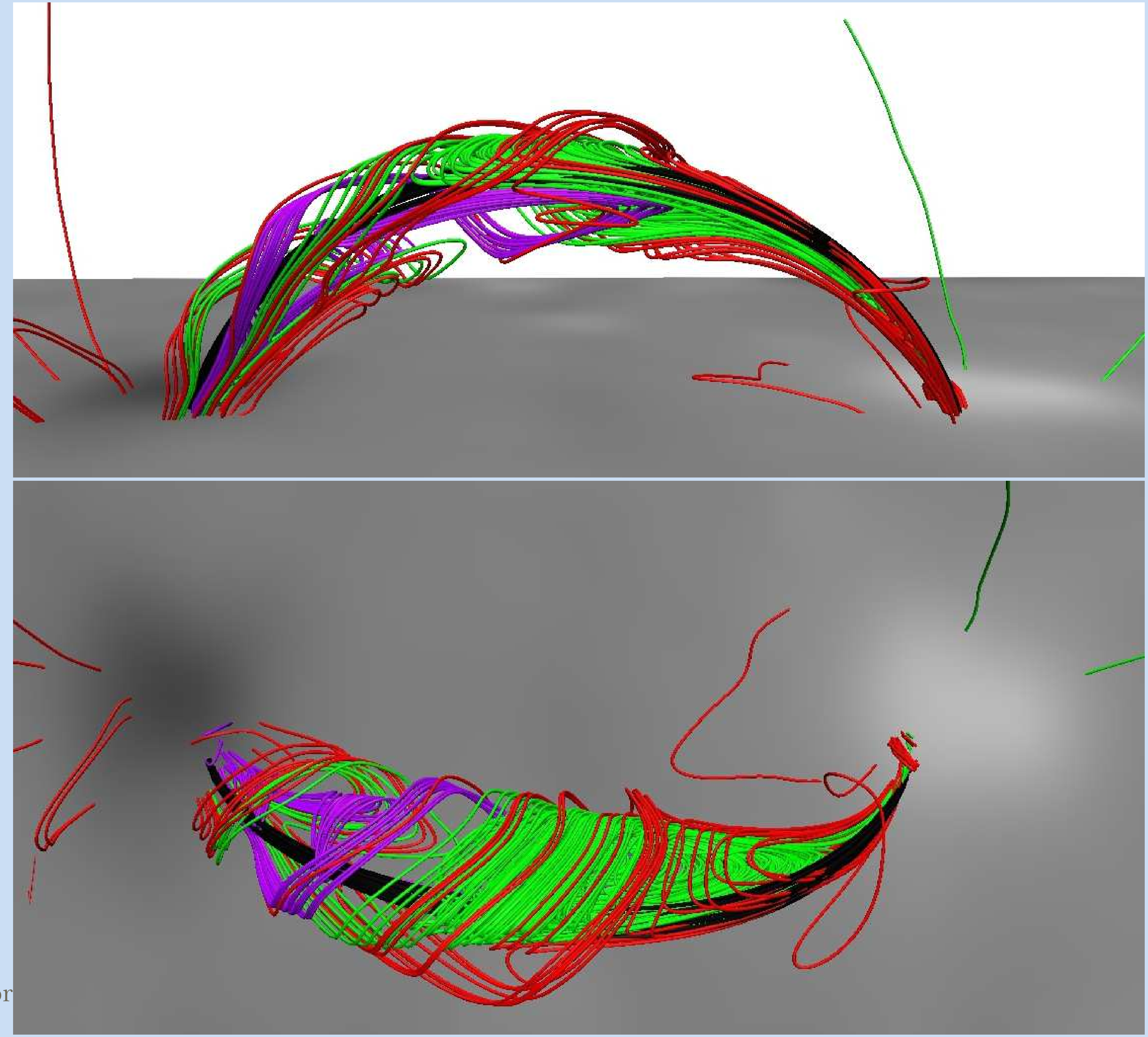
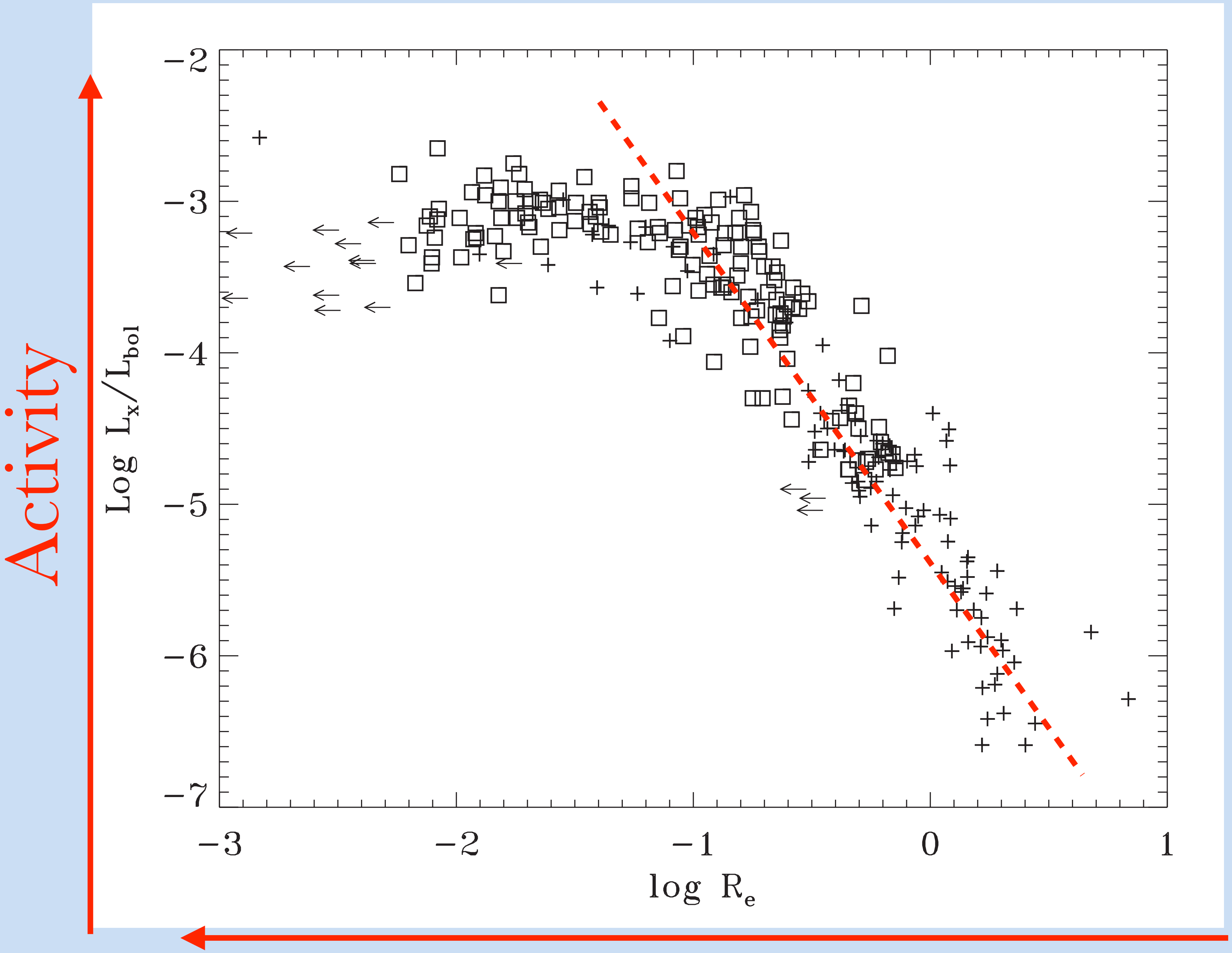
Helical currents in coronal loops



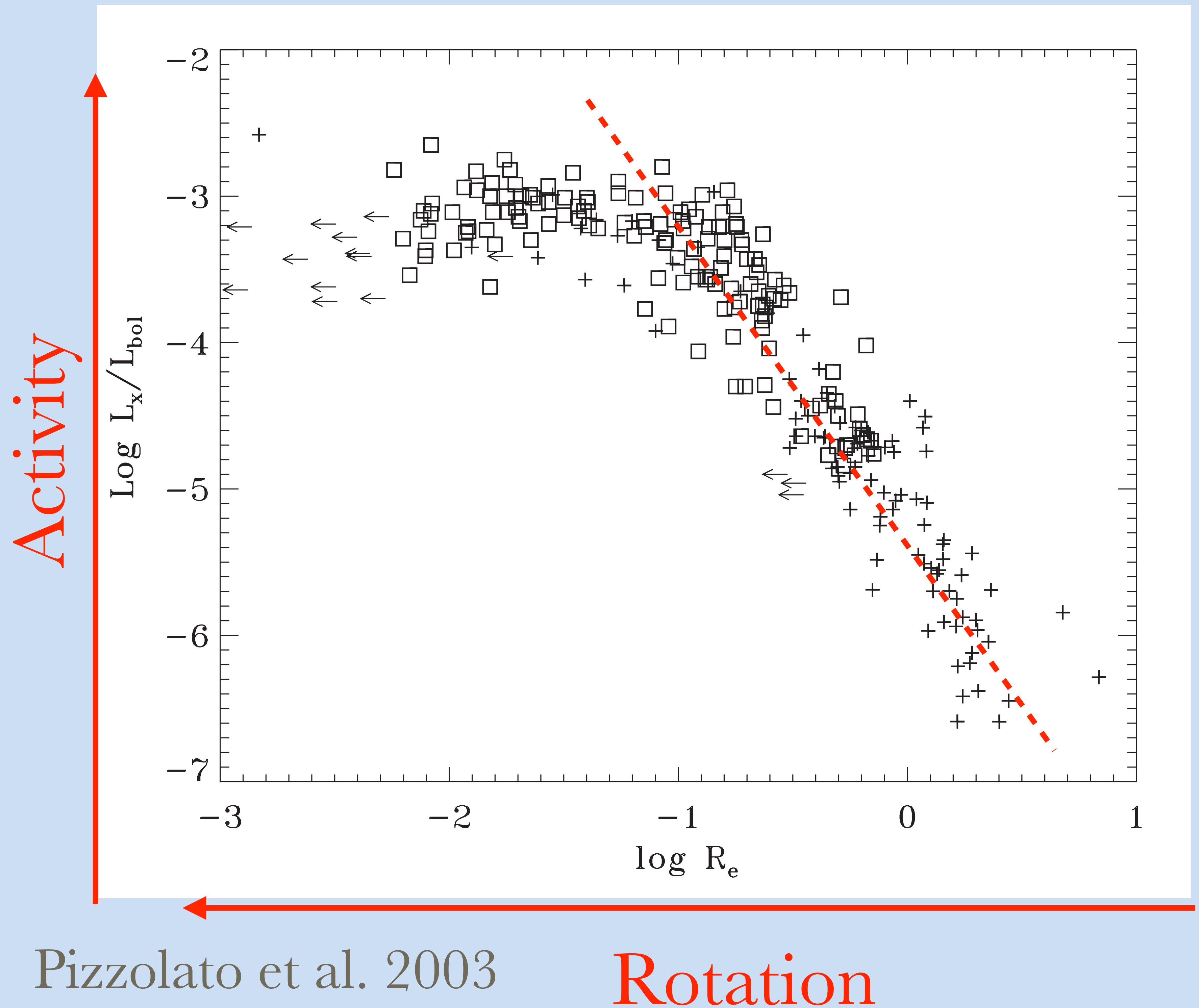
Rotation Activity Relation



Pizzolato et al. 2003

Rotation Activity Relation

$$\nabla\Omega = \text{const}$$



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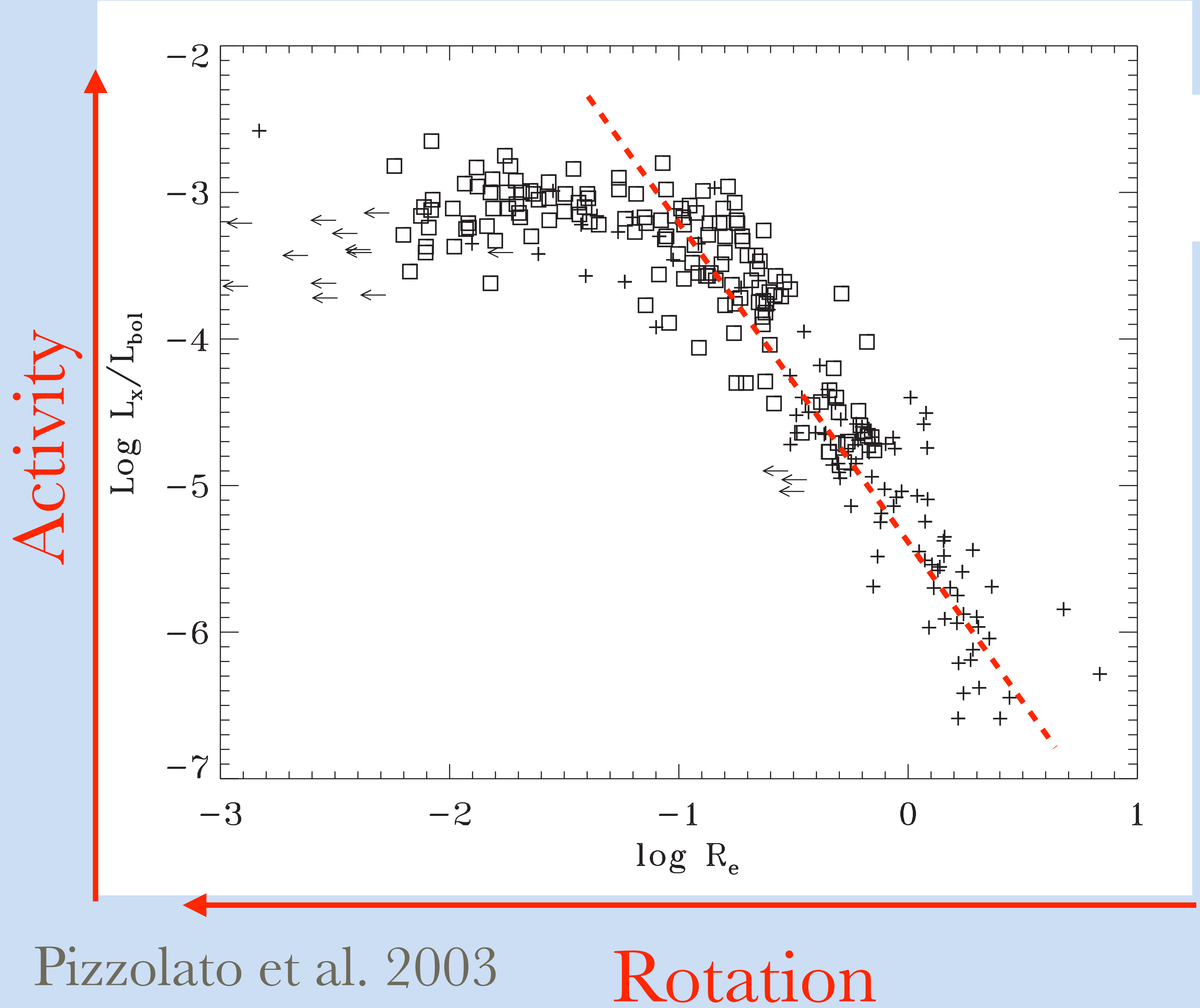

Pizzolato et al. 2003

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Pouquet et al. 1976

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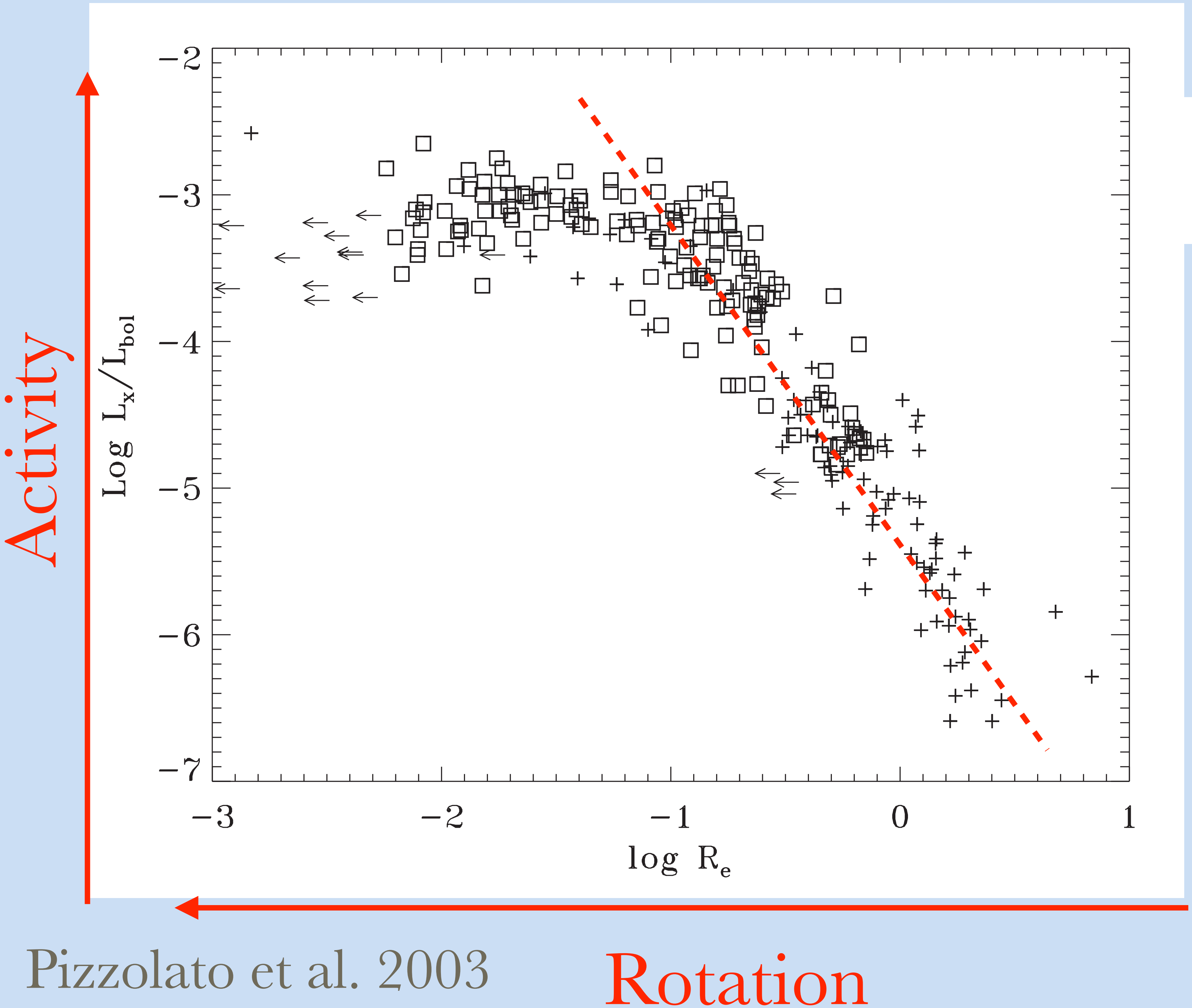

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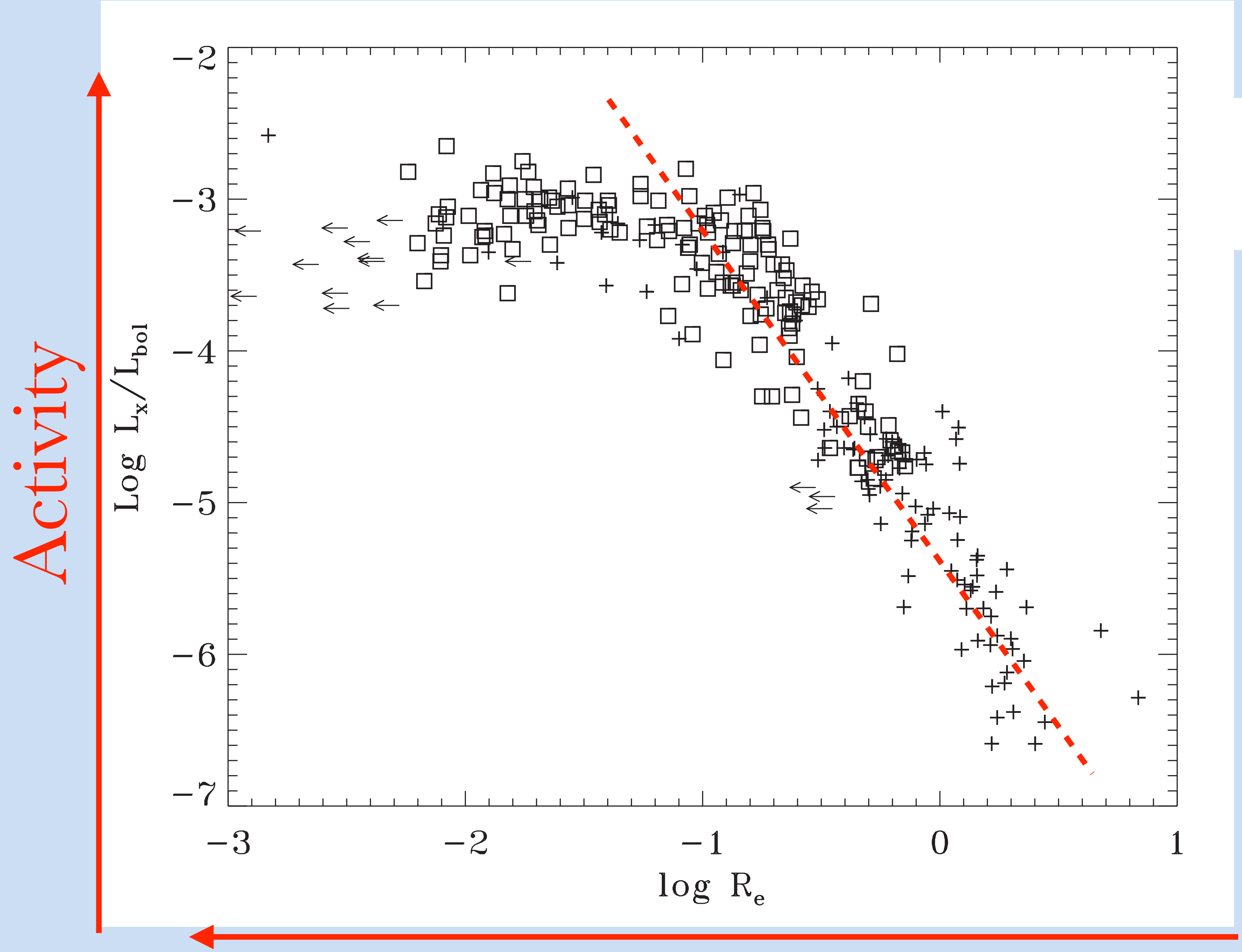

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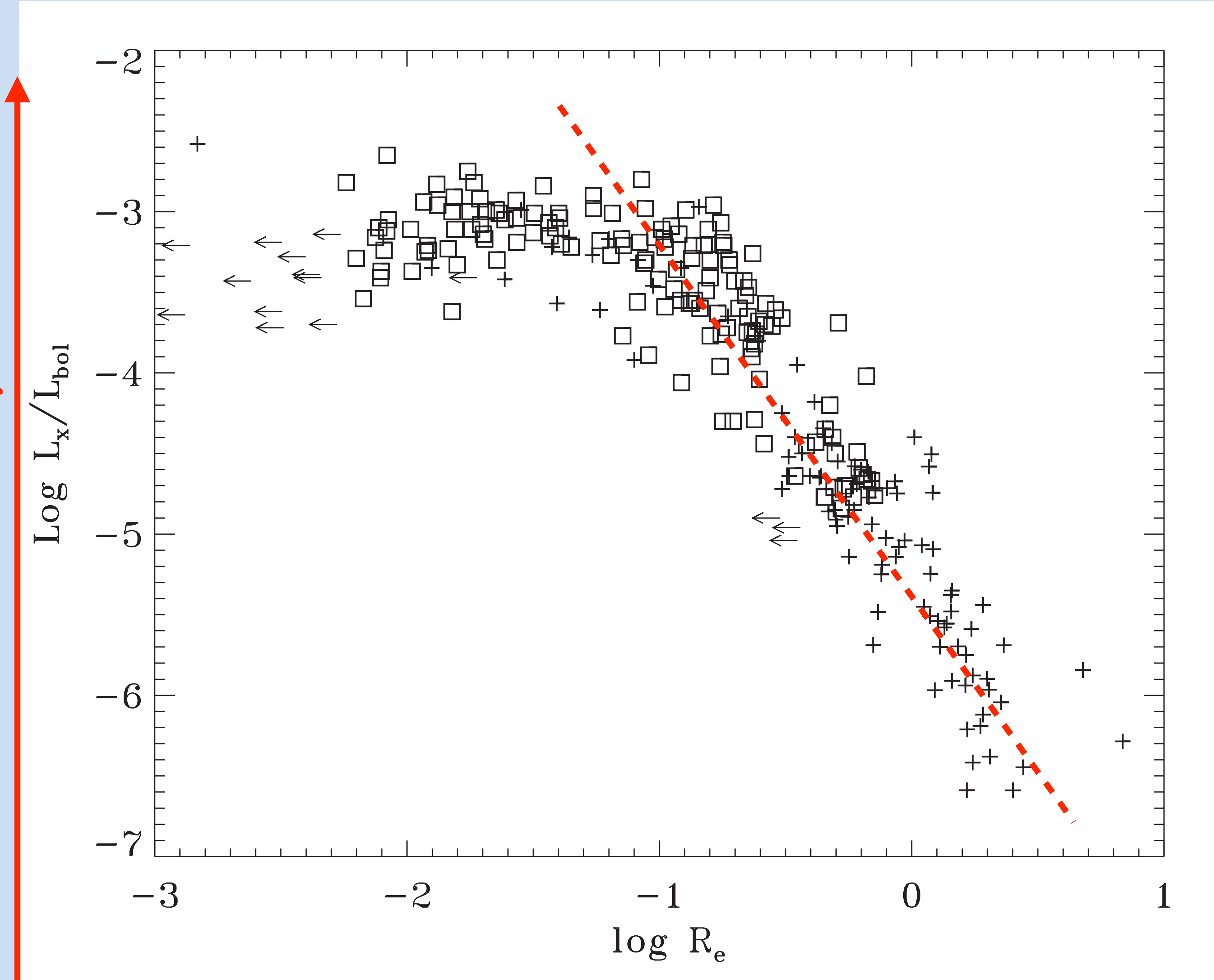
Rotation Activity Relation

Activity



Pizzolato et al. 2003

Rotation

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Pouquet et al. 1976

helicity is a pseudo scalar:

$$\alpha \sim \Omega$$

$$\text{Act.} \approx j \cdot b \approx \omega \cdot u$$

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- Rotation might lead to enhanced activity due to helicity.