Magnetic cycles and equatorward migration in simulations of turbulent convection

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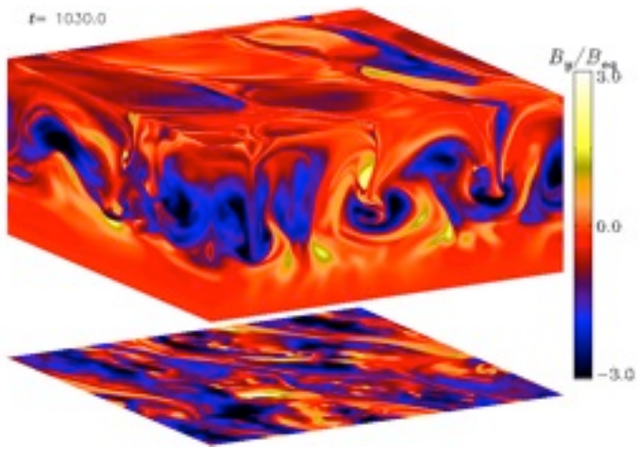
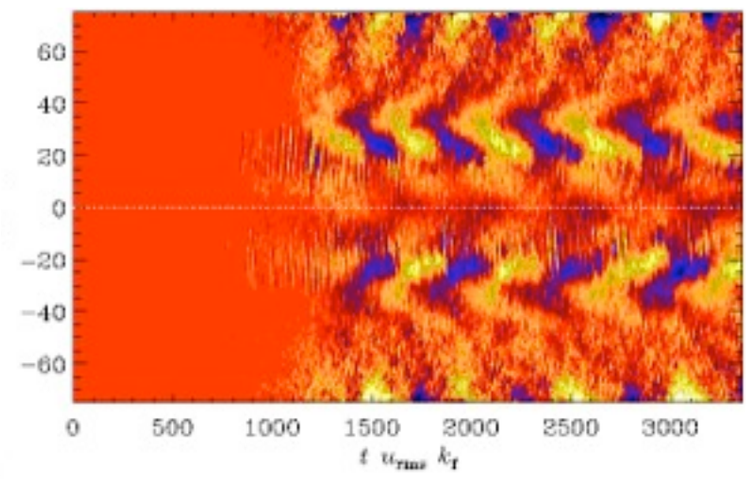
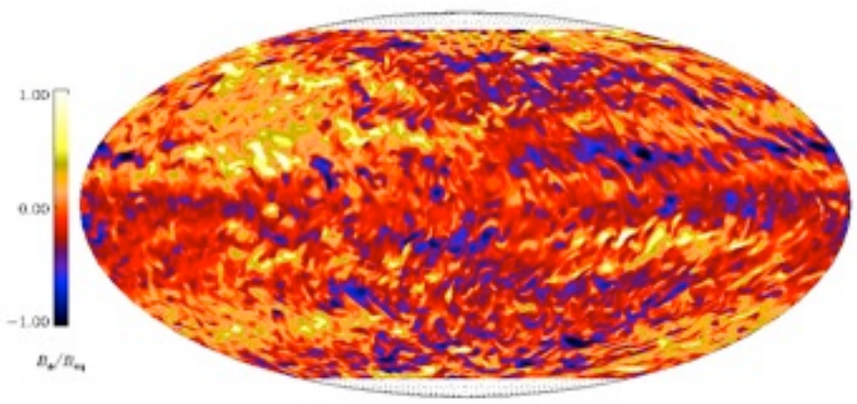
NORDITA



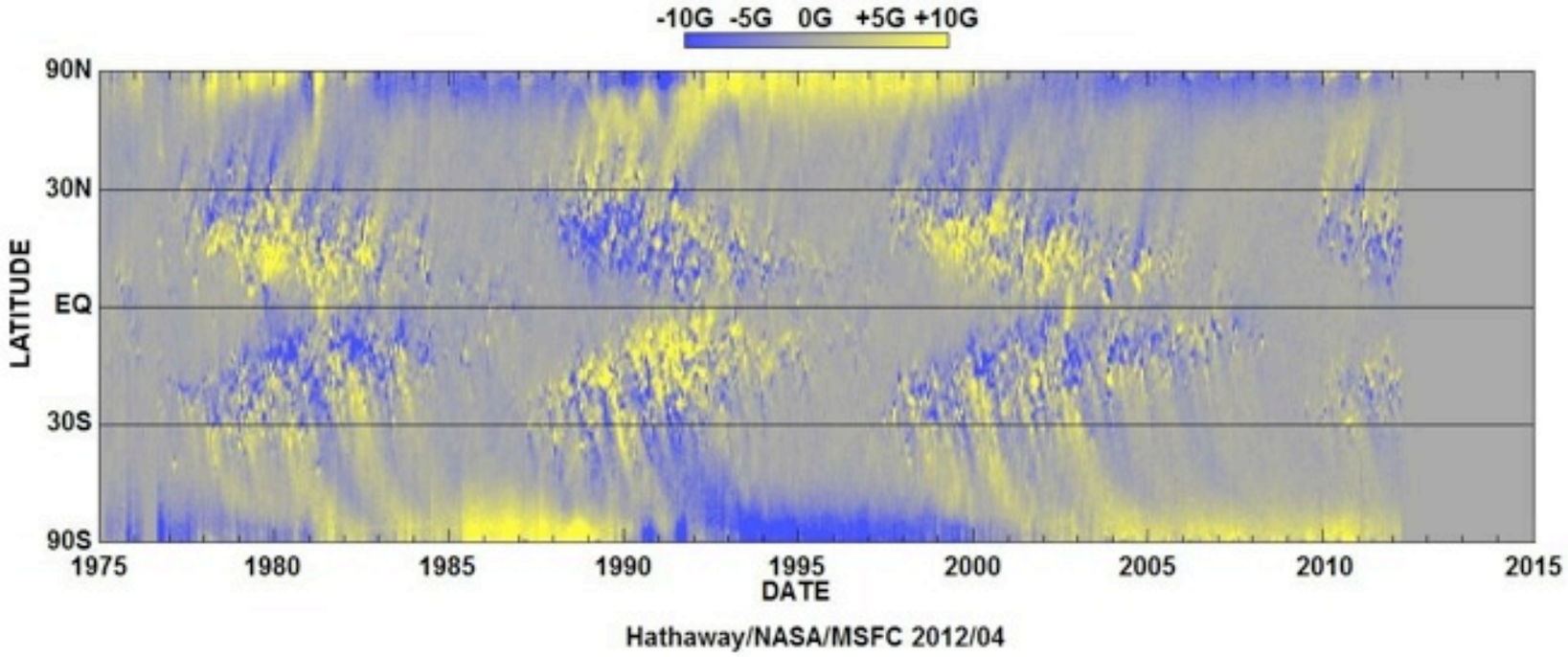




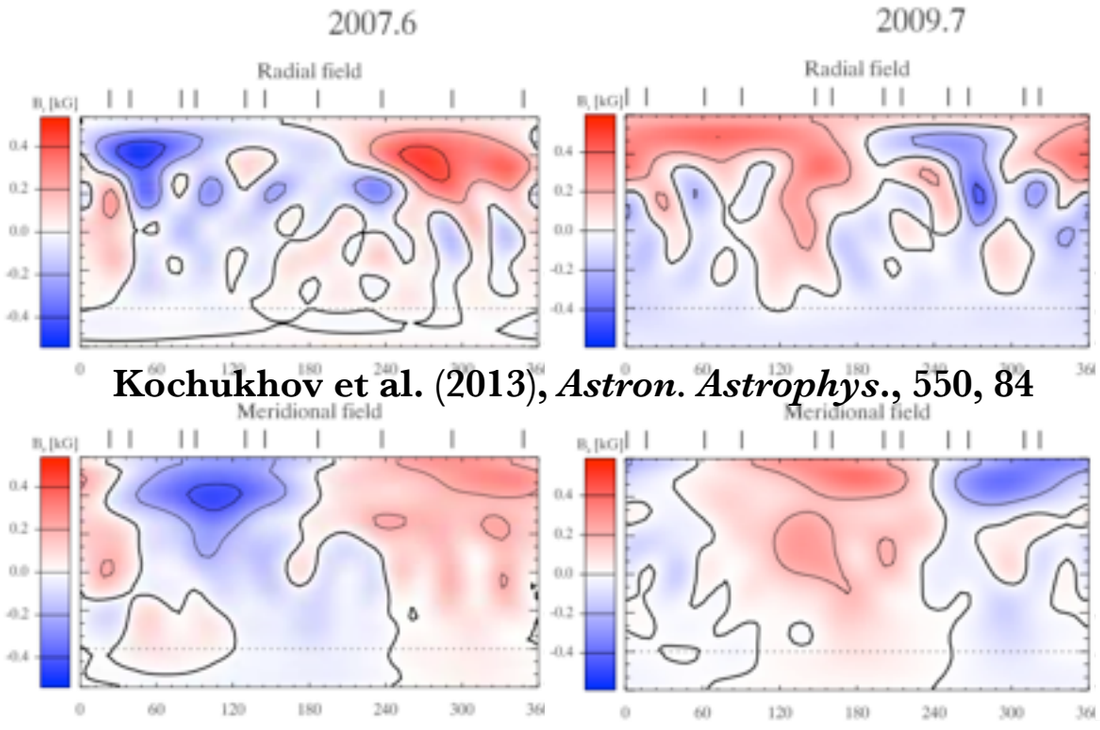
Differential rotation and magnetism across the HR diagram, Stockholm, 11th Apr 2013

Solar cycle

The Sun is the only star that has a cycle *for certain*…

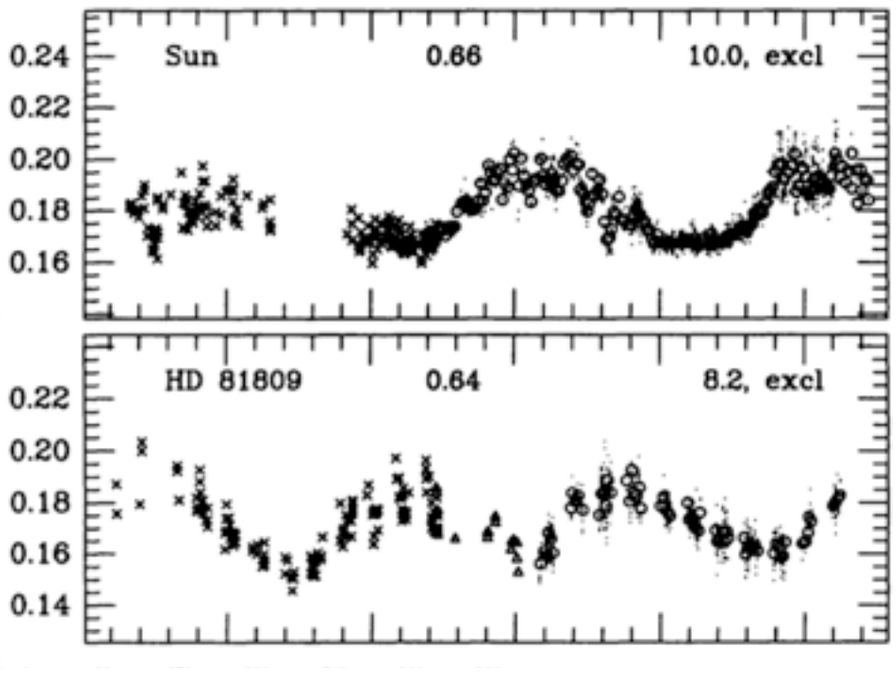


… but there are pretty good indications that other stars also have cycles.



Kochukhov et al. (2013), *Astron. Astrophys.*, 550, 84

Baliunas et al. (1995), *Astrophys. J.*, 438, 269



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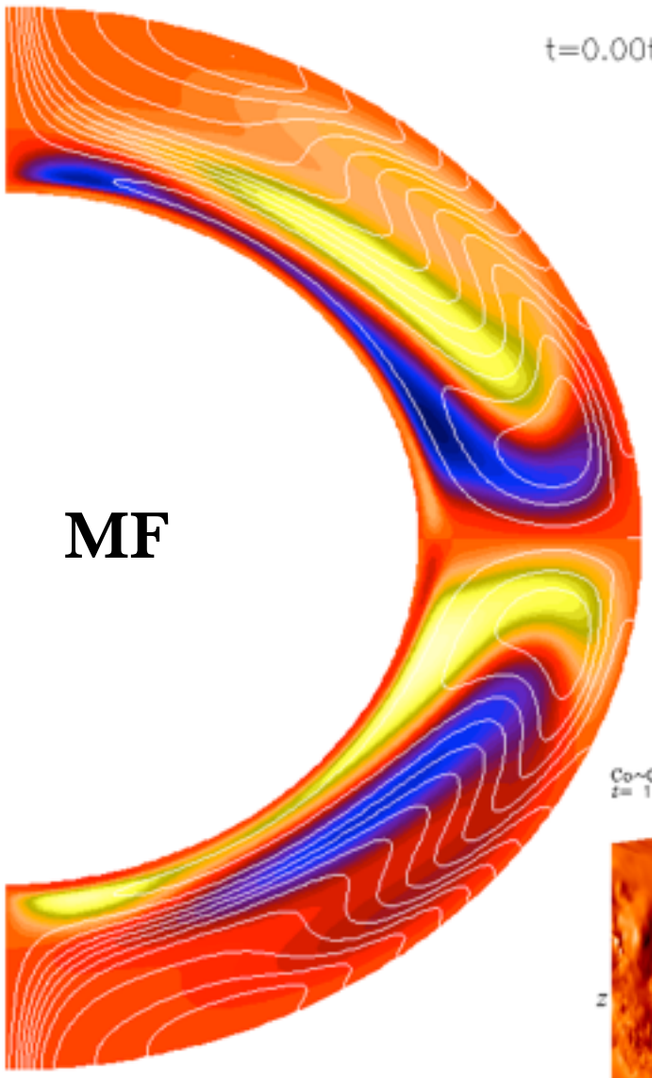
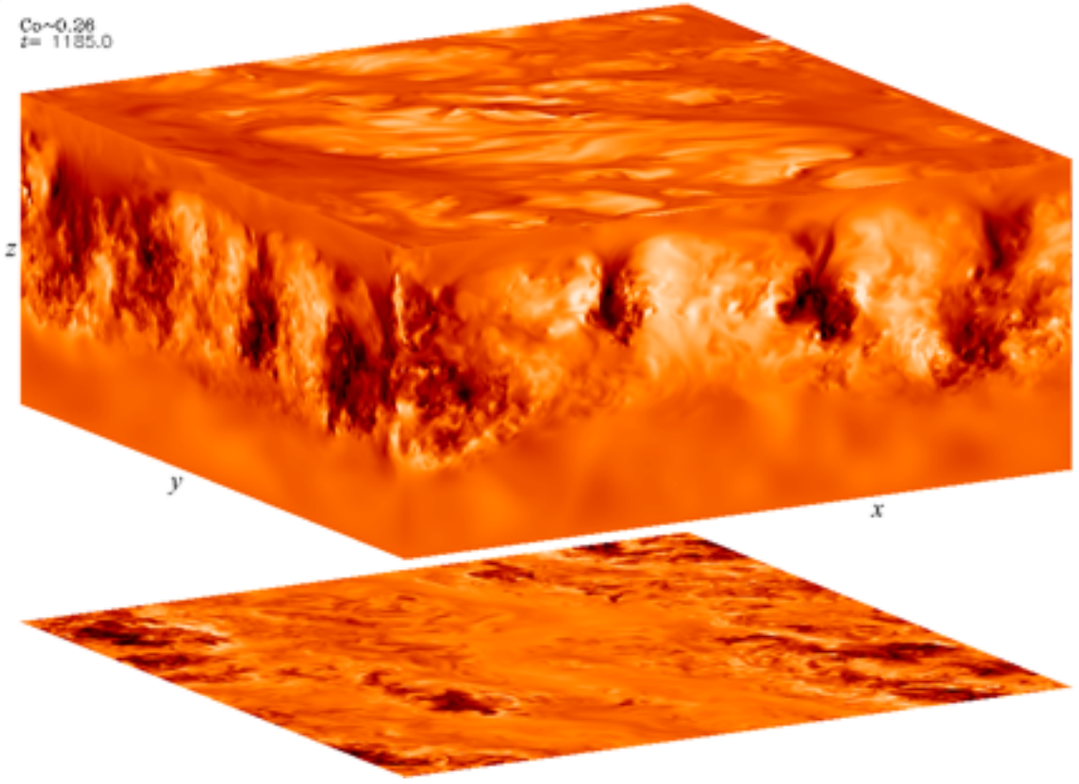
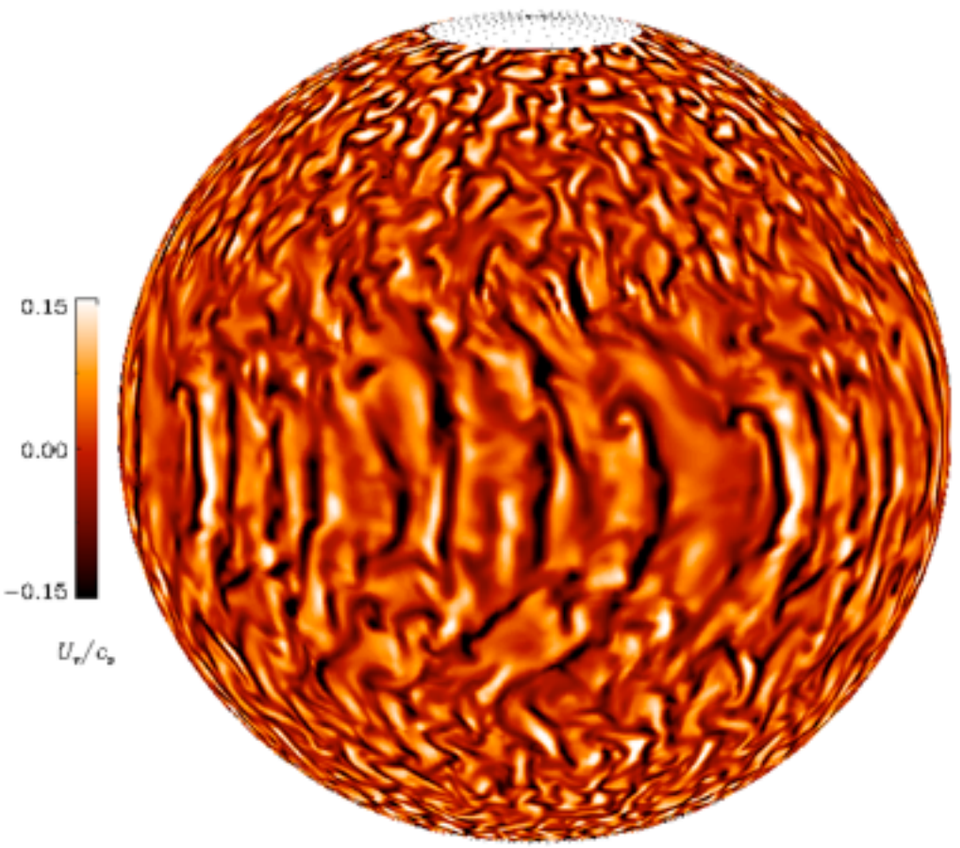
Typical numerical models

MF

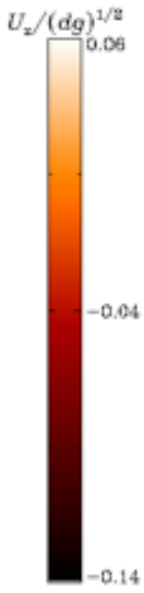


Local DNS





(Semi-)global DNS



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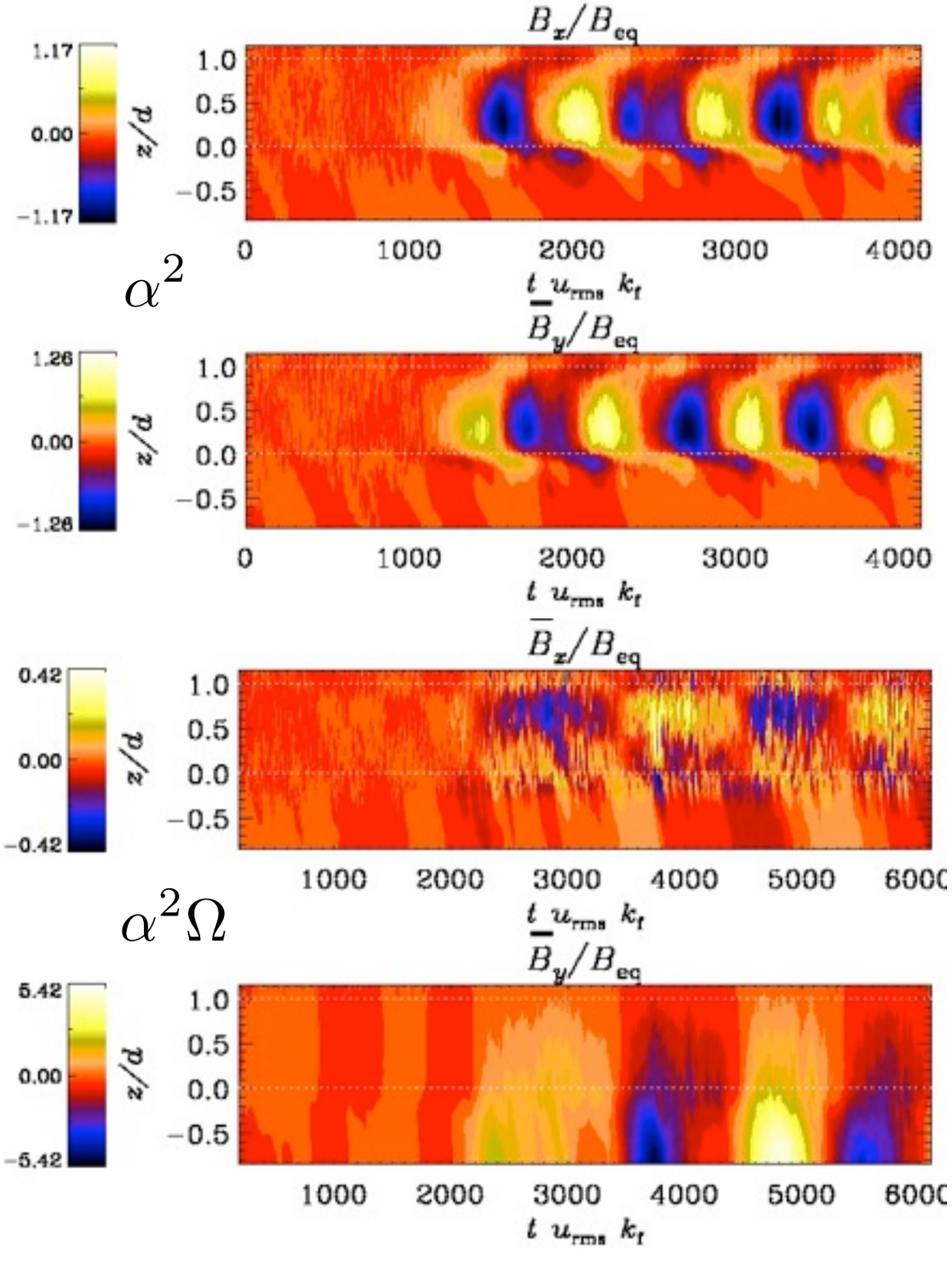
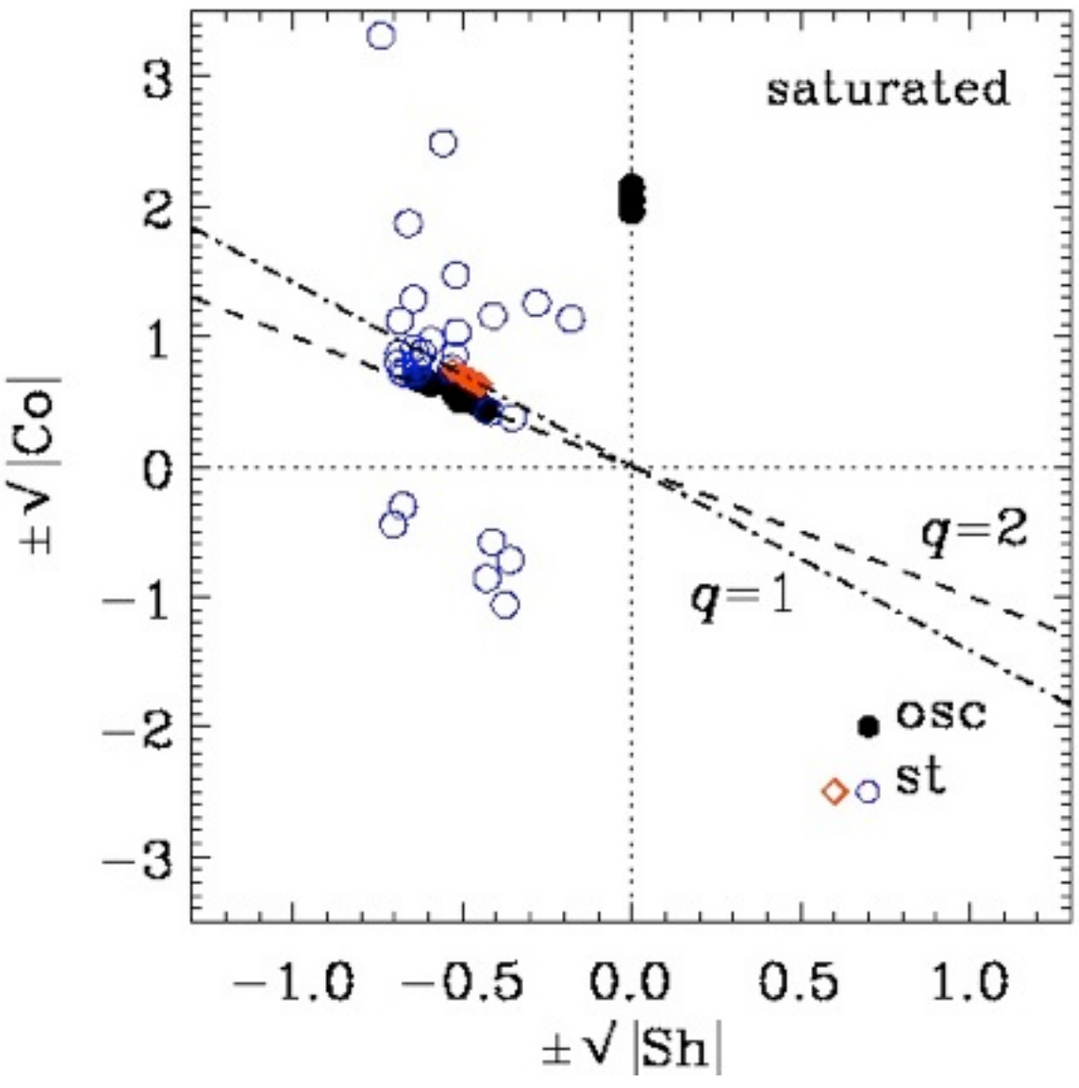
Dynamo cycles from local simulations

Oscillatory solutions are obtained in a limited parameter range.



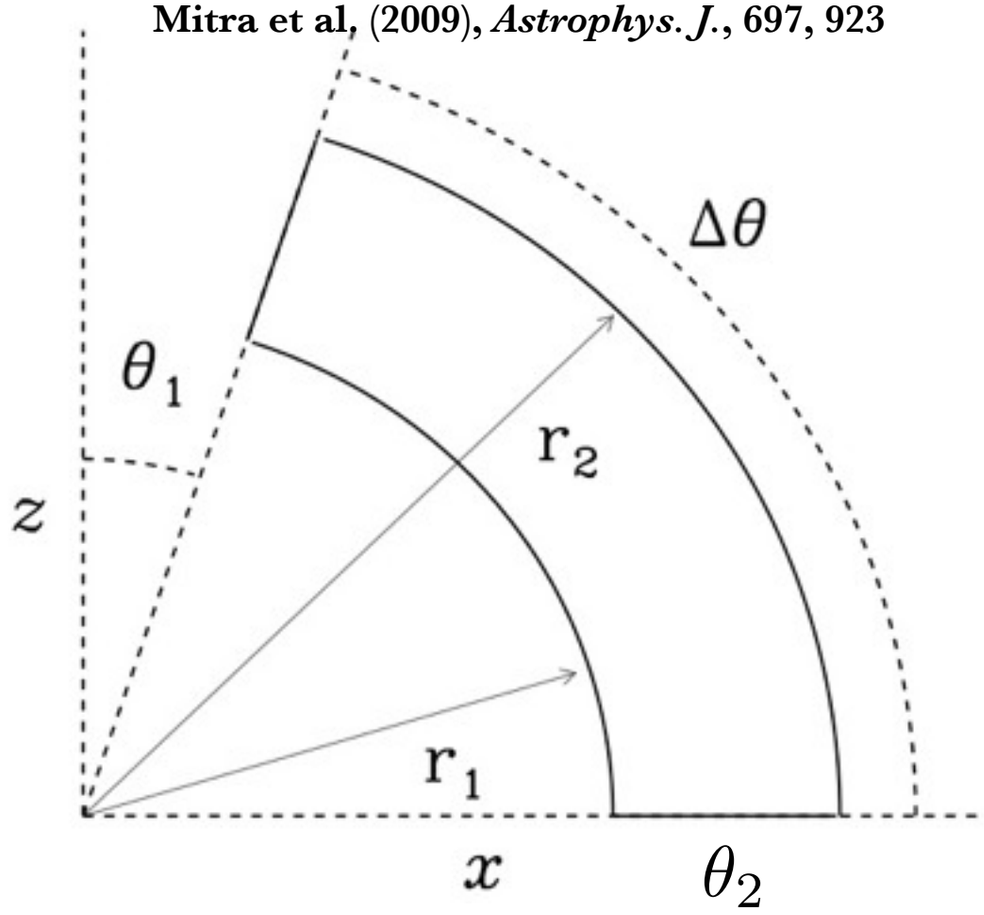
$$\mathrm{Co} = \frac{2\Omega}{u_{\rm rms} k_{\rm f}} \qquad \mathrm{Sh} = \frac{S}{u_{\rm rms} k_{\rm f}}$$

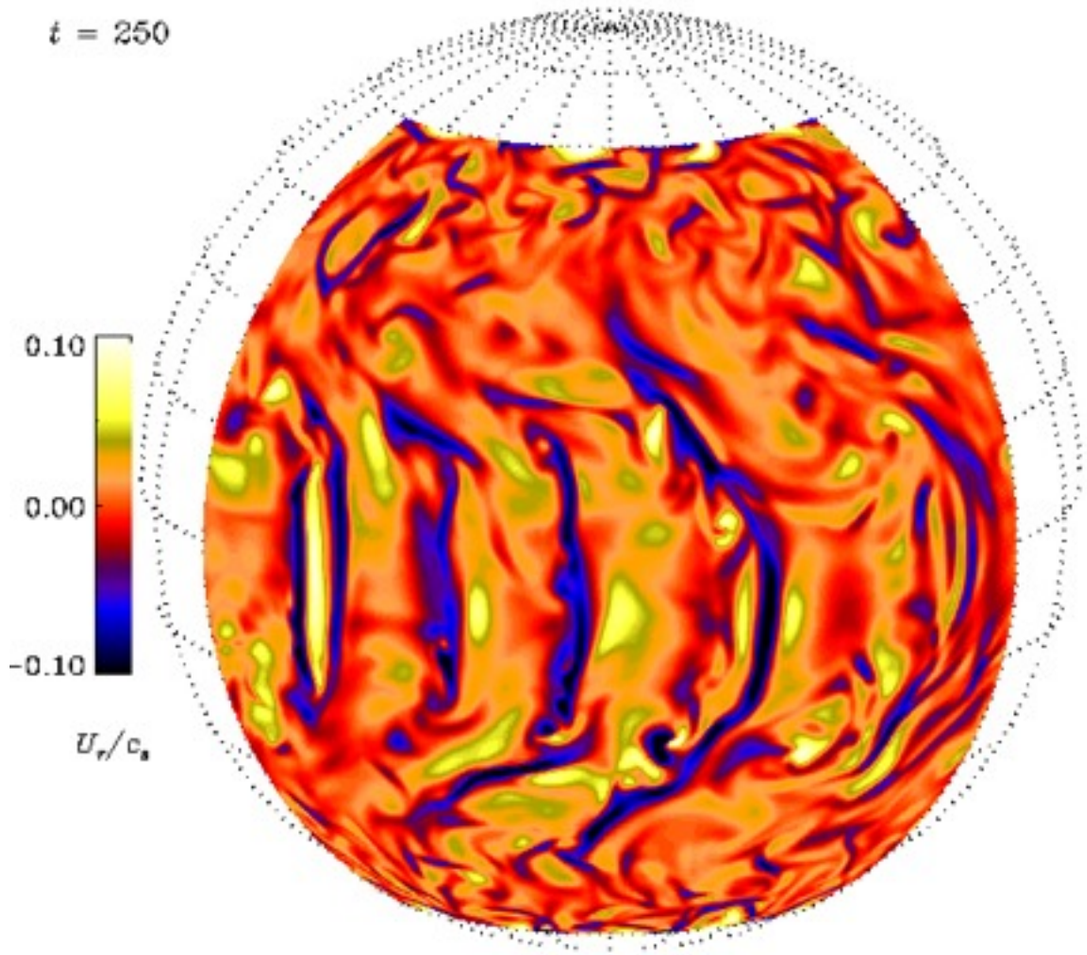


Käpylä et al. (2013), *GAFD*, 107, 244

Wedge geometry

Mitra et al, (2009), *Astrophys. J.*, 697, 923





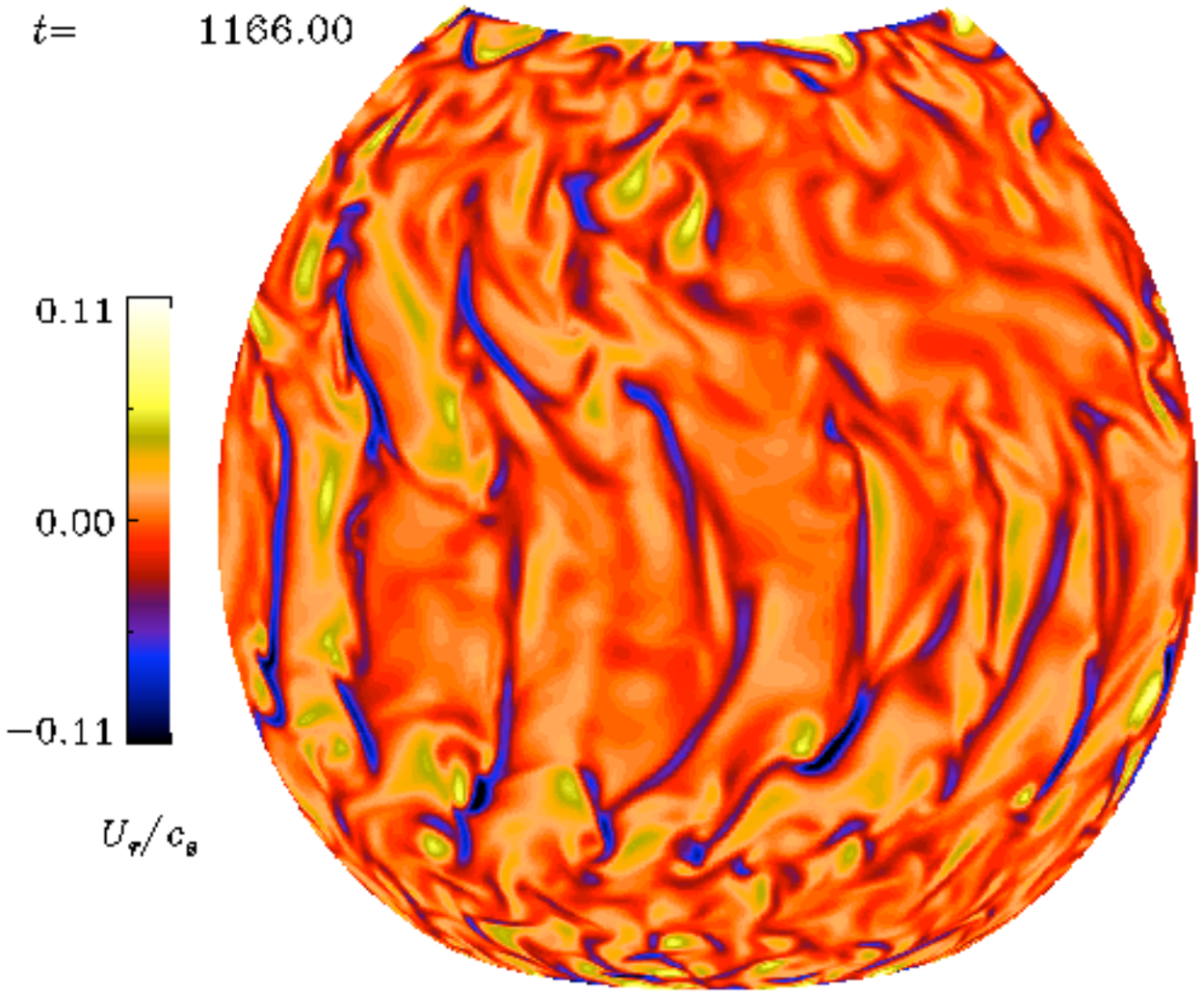
Käpylä et al. (2010b), *Astron. Nachr.*, 331, 73

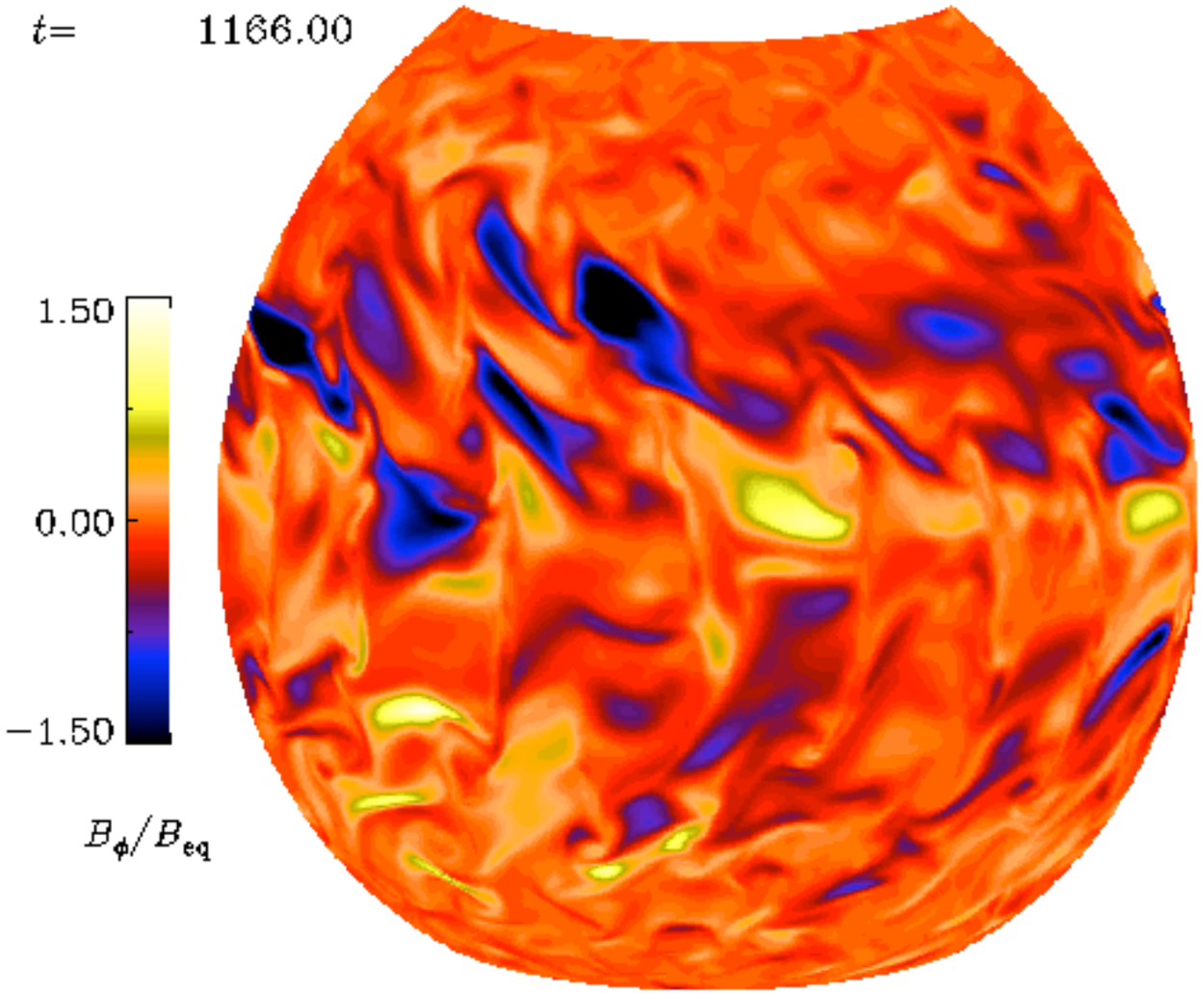
$0.7R < r < R$ $\quad \theta_1 < \theta < \theta_2$ $\quad 0 < \phi < \Delta\phi$ $\quad k_{\mathrm{f}} = 2\pi/\Delta R$

We model a spherical sector (`wedge') where only parts of the latitudinal and longitudinal extents are taken into account.

Normal field condition for *B* at the outer radial boundary and perfect conductor at all other boundaries. Impenetrable stress-free boundaries on all boundaries.

Dynamo cycles from simulations I

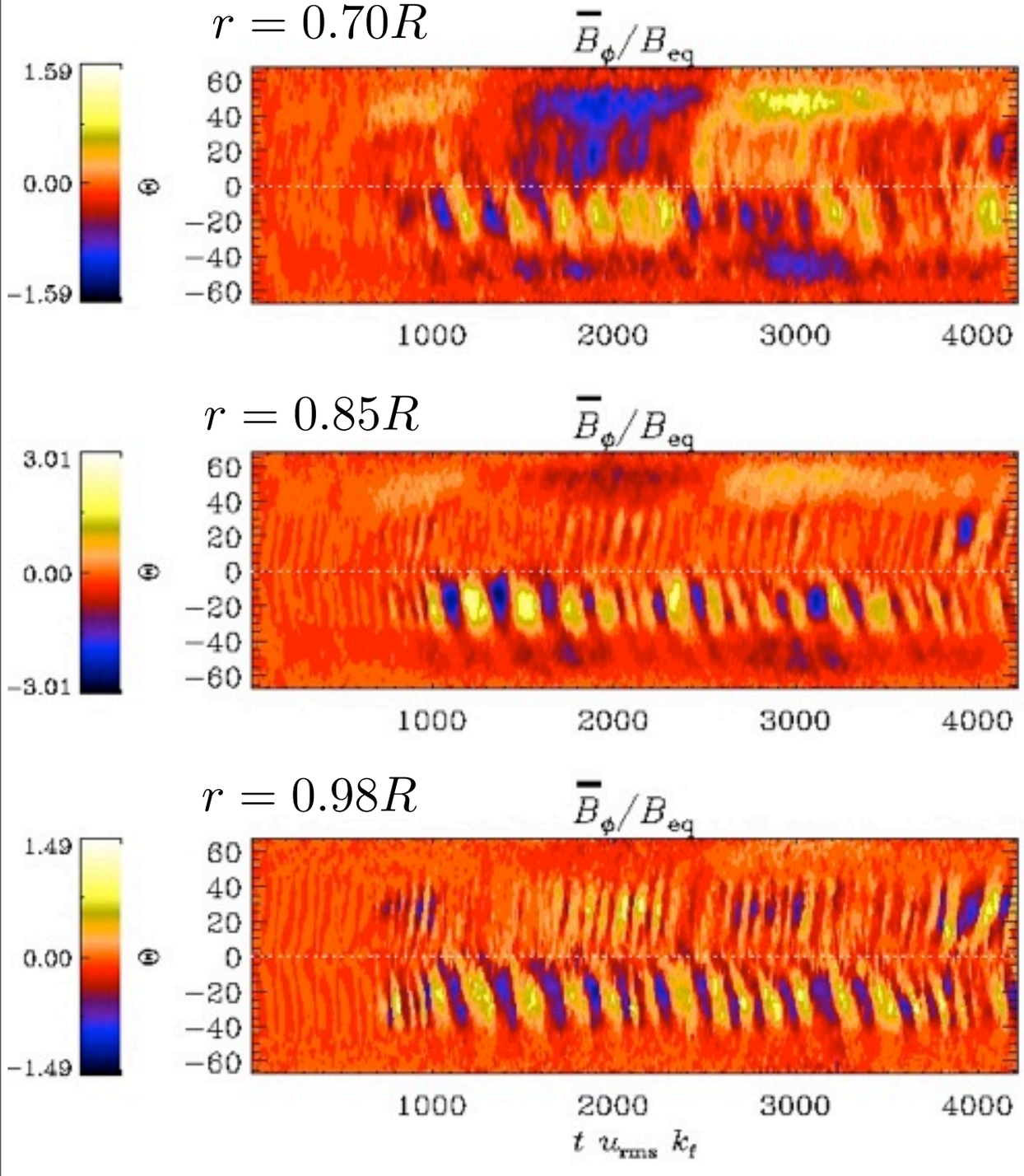




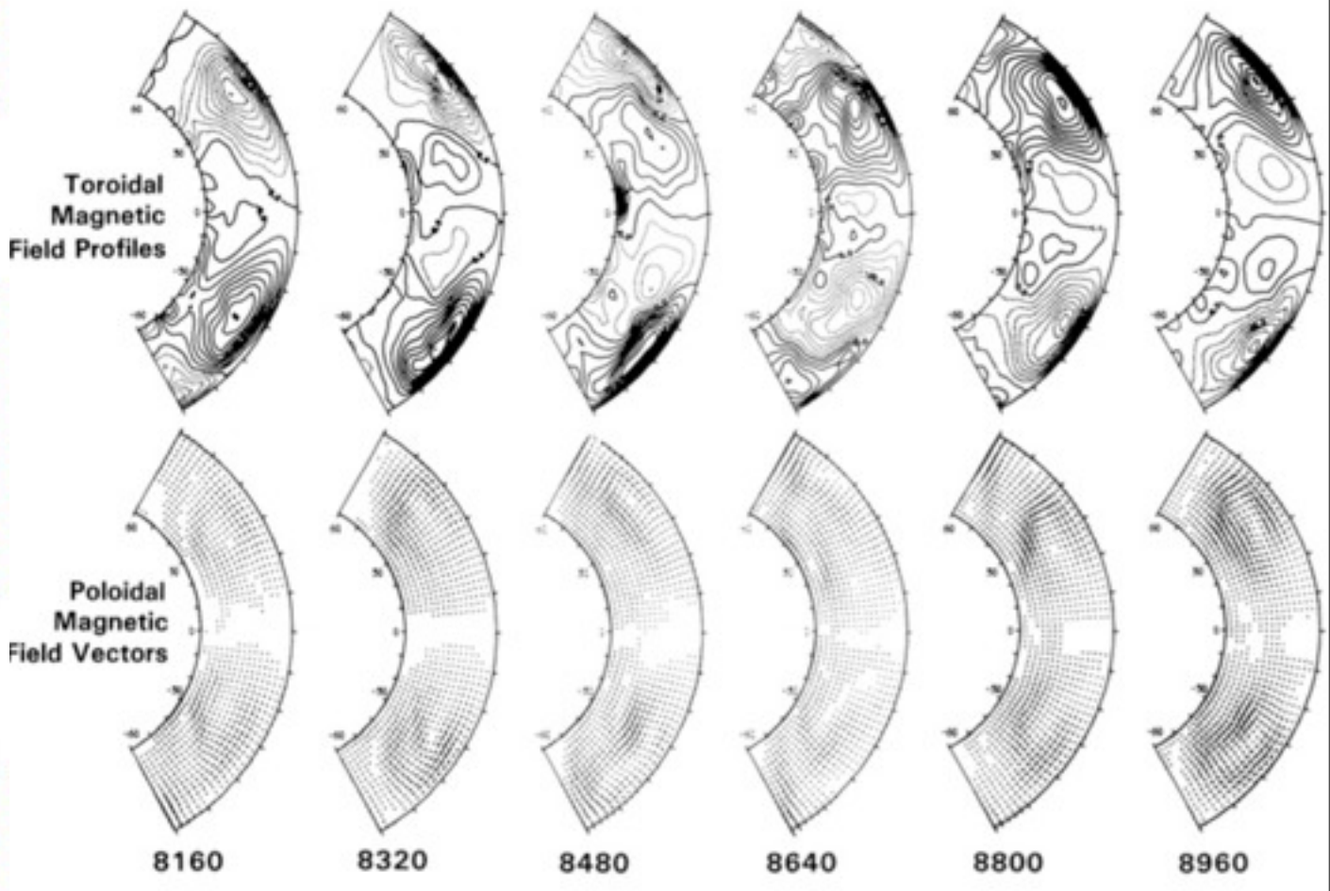
Käpylä et al. (2010), *Astron. Nachr.*, 331, 73

Dynamo wave propagating towards the poles instead of the equator.

Dynamo cycles from simulations II



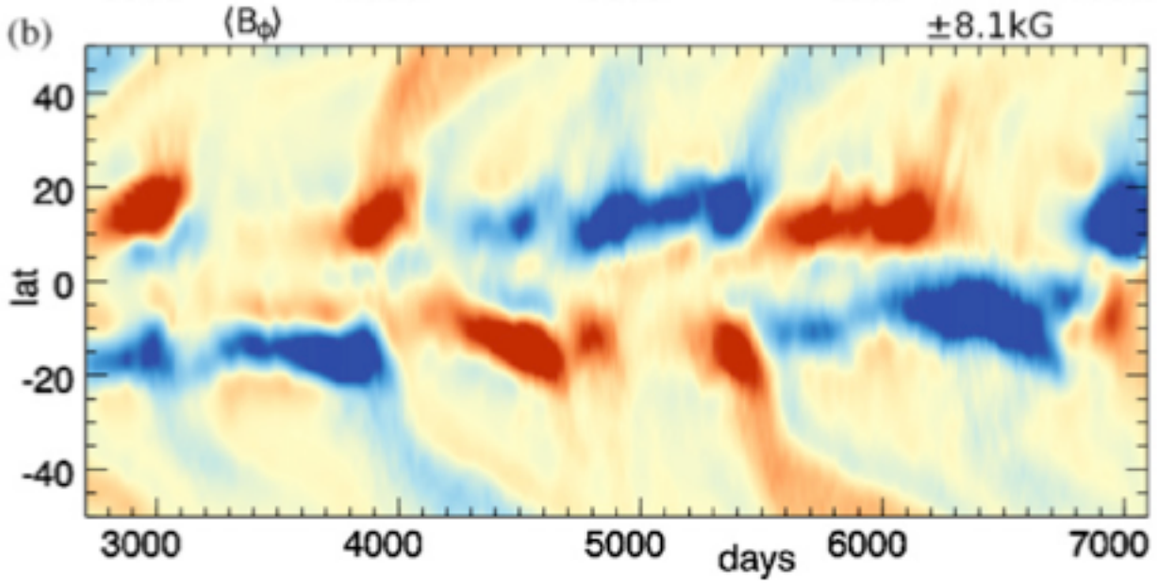
Käpylä et al. (2010), *Astron. Nachr.*, 331, 73



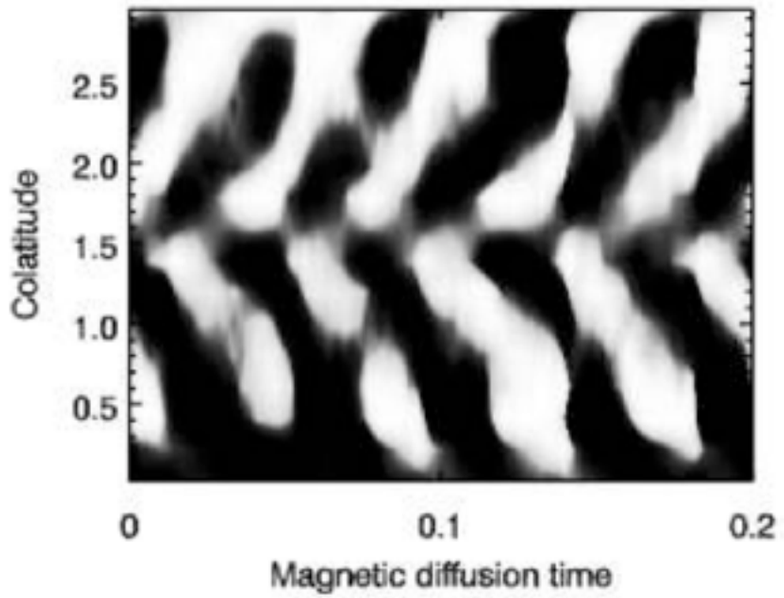
Gilman (1983), *Astrophys. J. Suppl.*, 53, 243

Glatzmaier (1985), *Astrophys. J.*, 291, 300

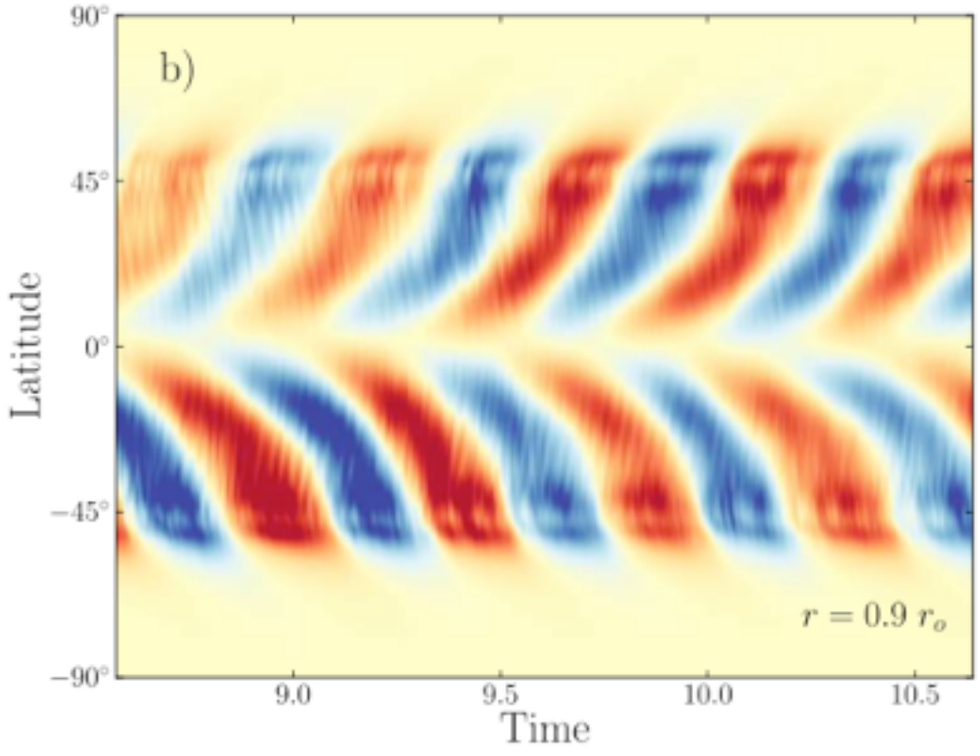
Dynamo cycles from simulations III



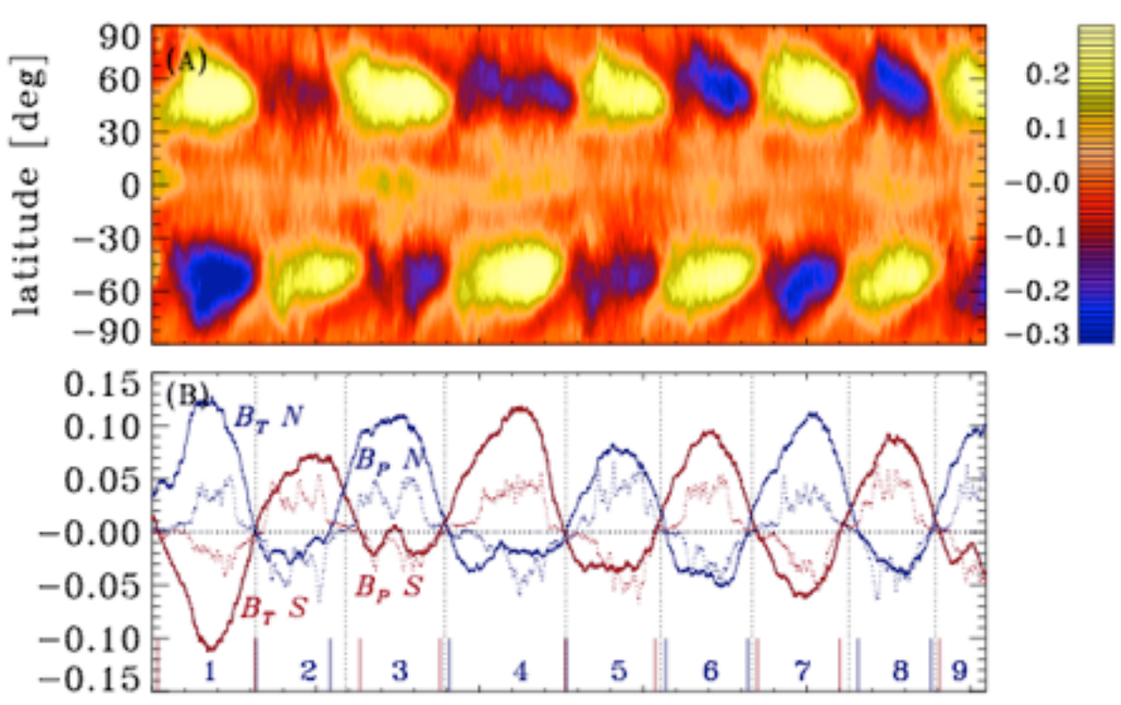
Brown et al. (2011), *Astrophys. J.*, 731, 69



Schrinner et al. (2012), *Astrophys. J.*, 752, 121



Gastine et al. (2012), *Astron. Astrophys*, 546, 19



Ghizaru et al. (2010), *Astrophys. J. Lett*, 715, 133

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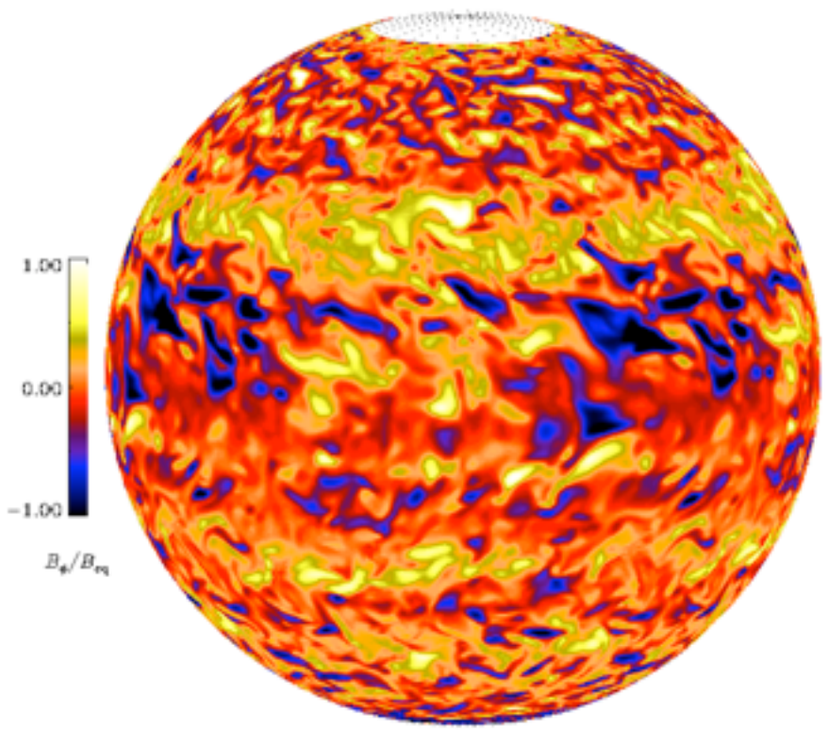
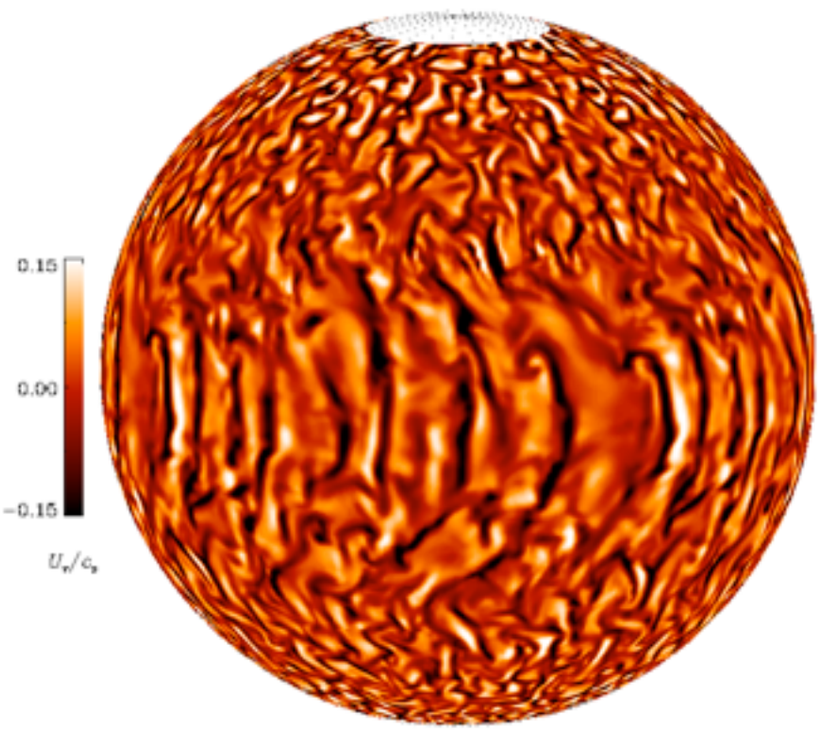
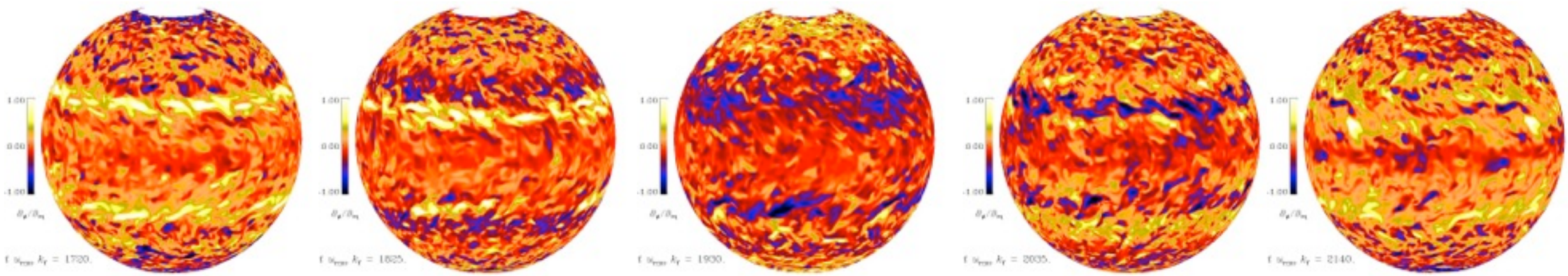
Dynamo cycles from simulations IV

Gradual improvements to the model: increased density stratification, more efficient convection, black-body boundary condition for the entropy.





B_ϕ $\Delta t/\tau = 105$ U_r



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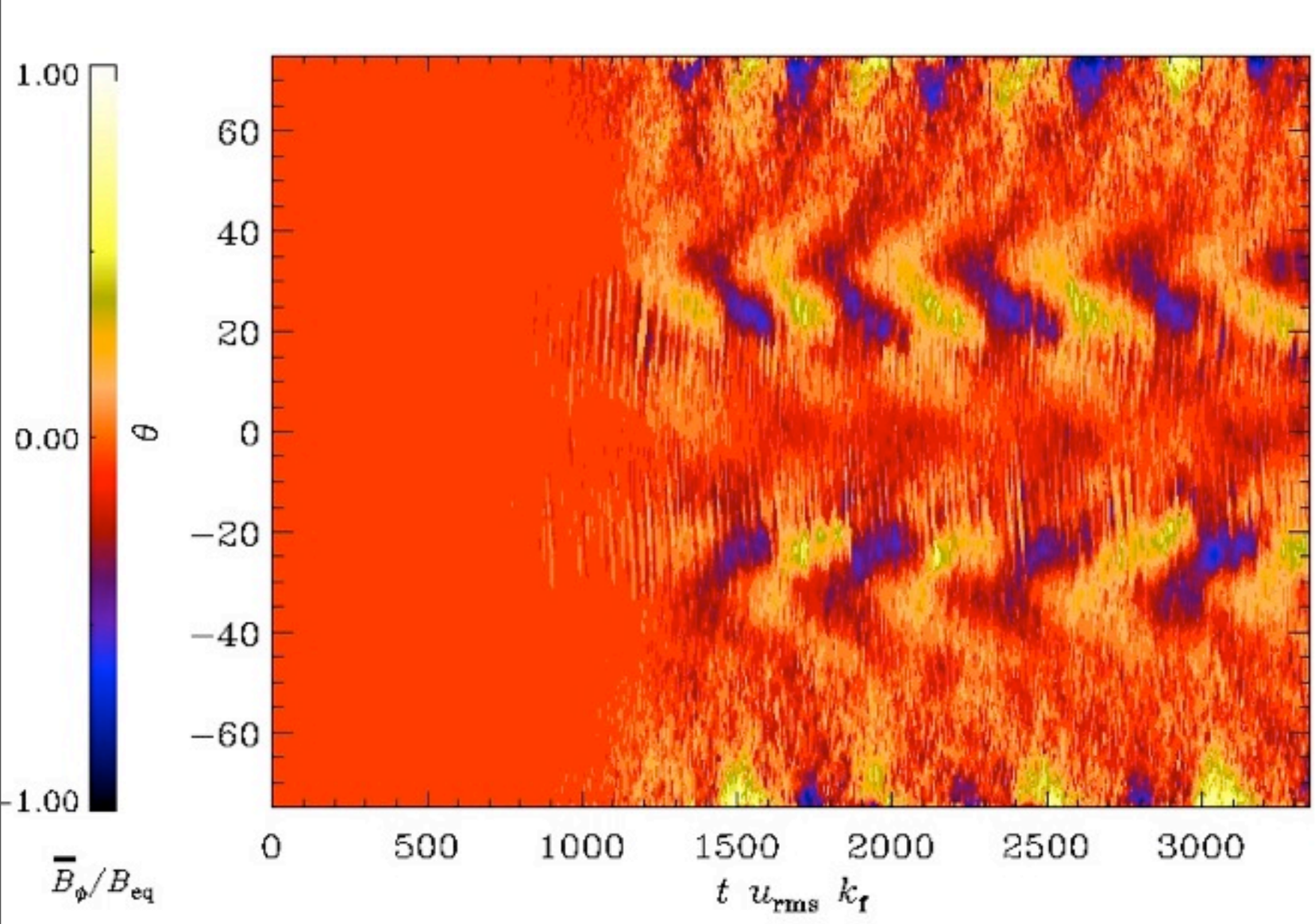
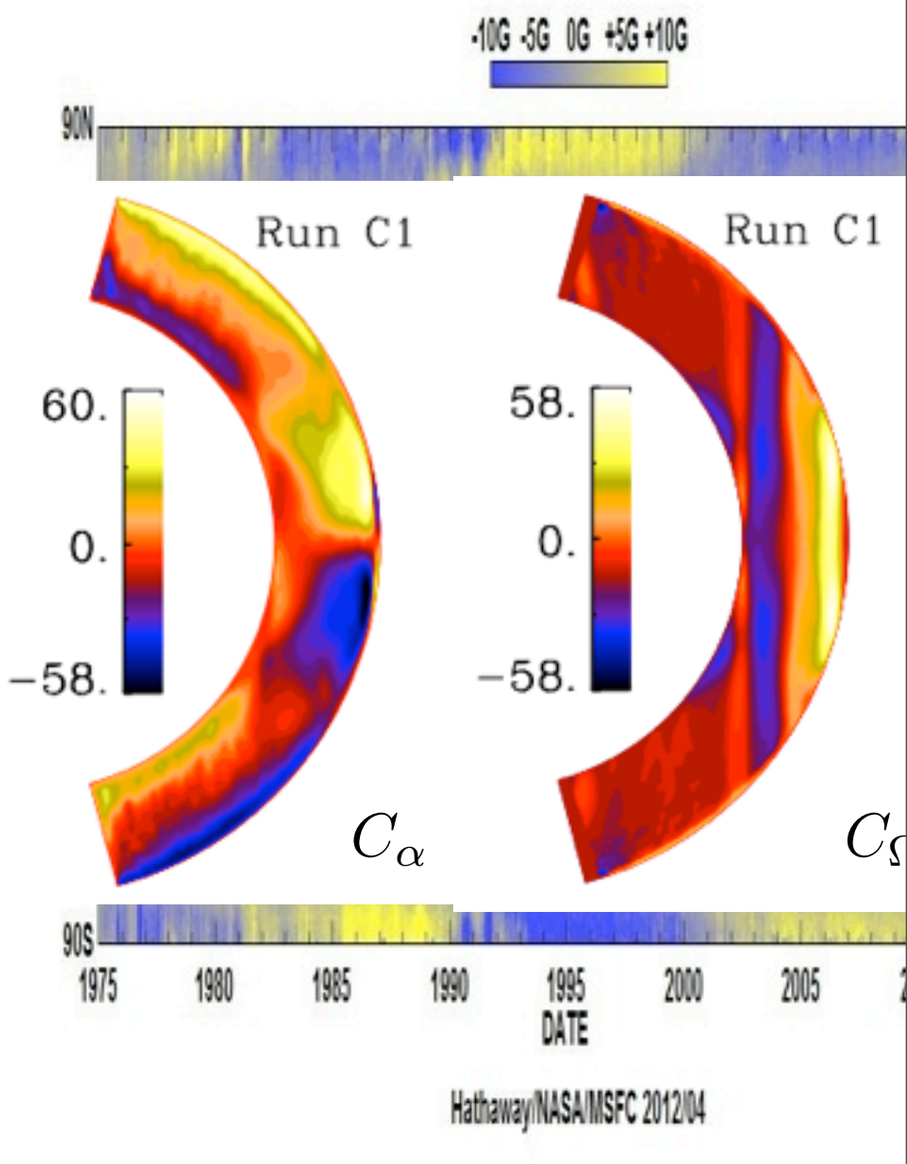
Dynamo cycles from simulations V

Solar-like propagation of activity belts for the first time...



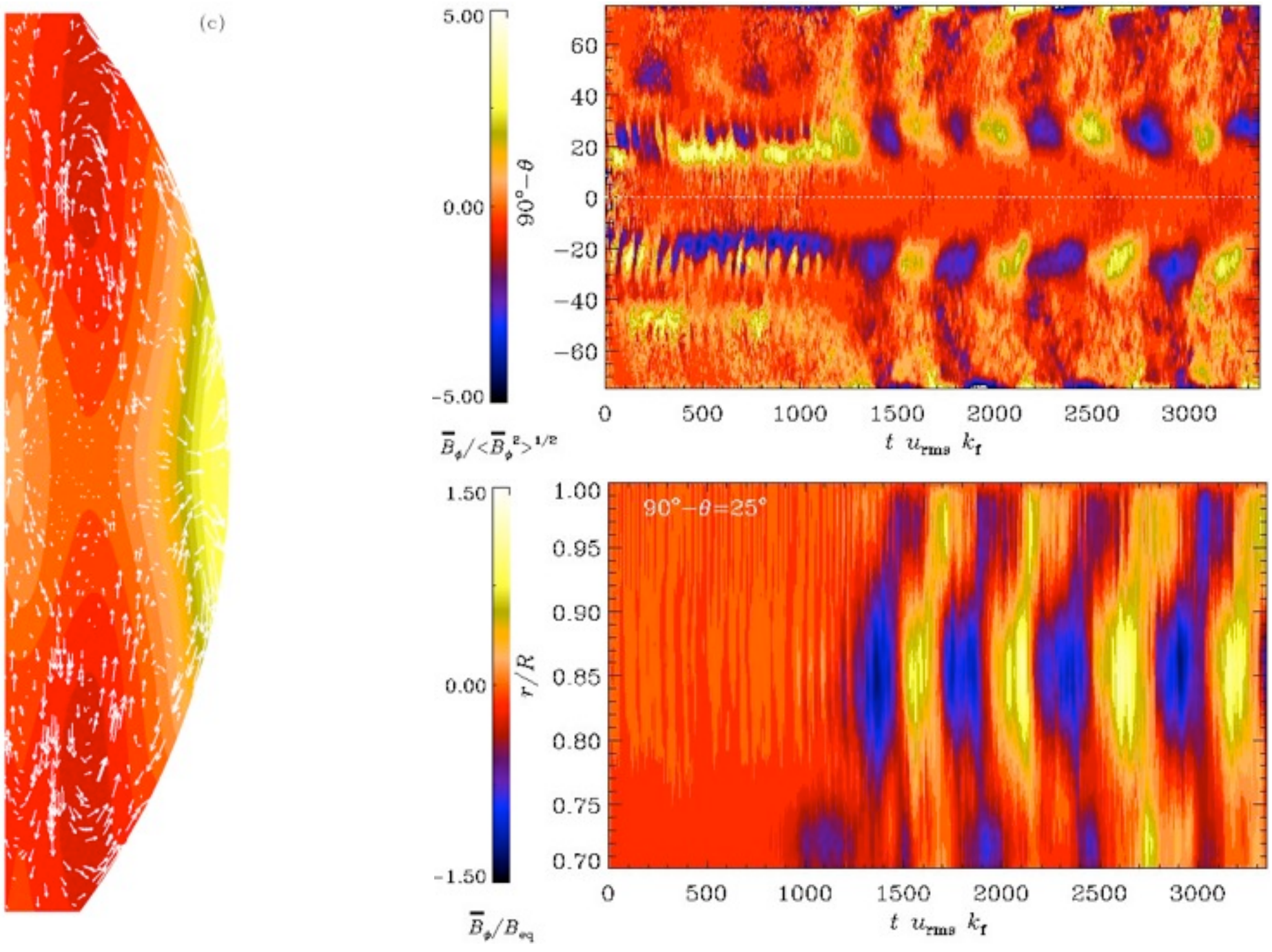


Käpylä et al. (2012), *Astrophys. J. Lett.*, 755, 22

... but why??? Test-field method to the rescue.

Dynamo cycles from simulations VI

Multi-cell circulation, cycles appear in the nonlinear regime, magnetic fields appear to be generated in the whole convection zone.



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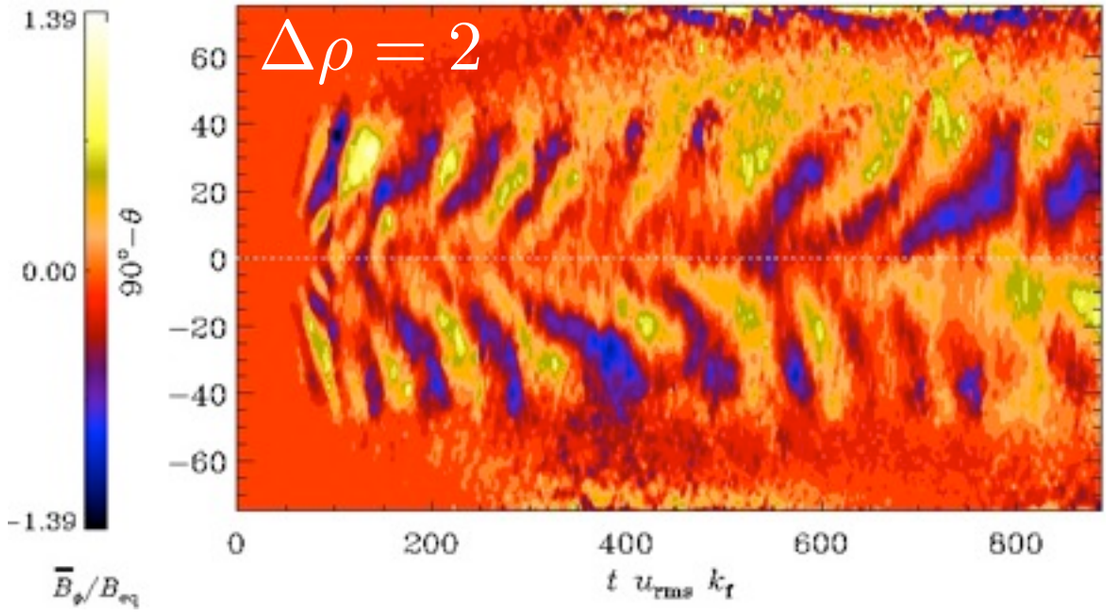
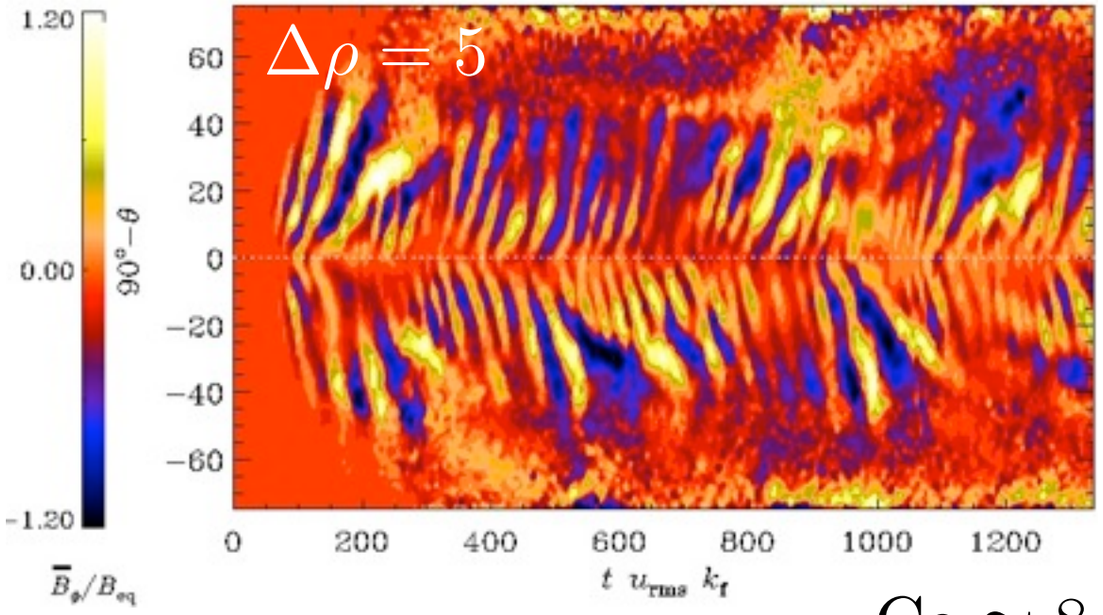
Dynamo cycles from simulations VII

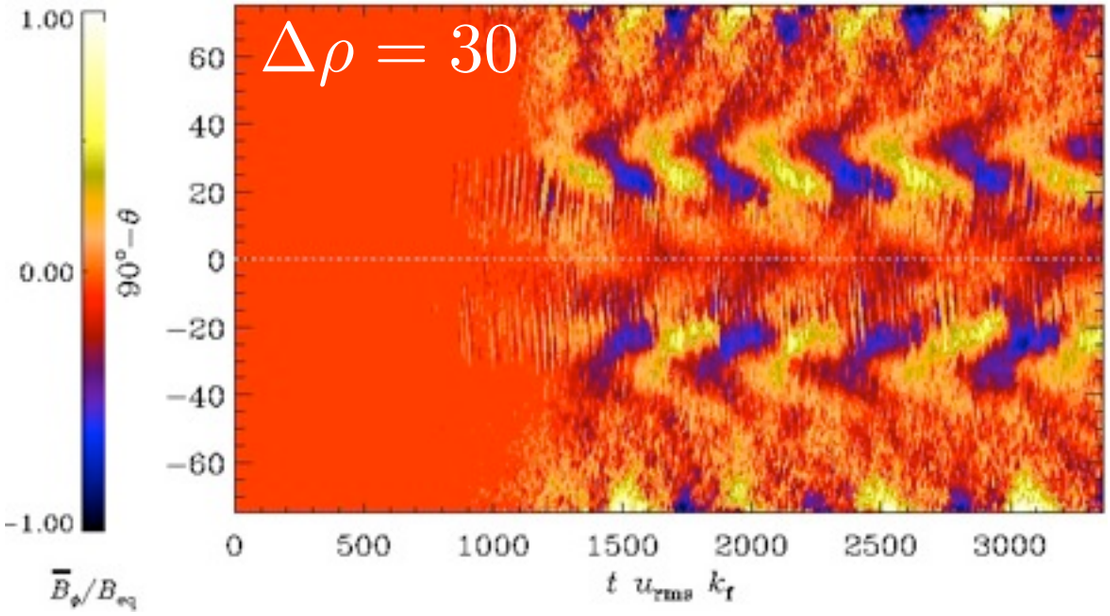
Dependence on density stratification?

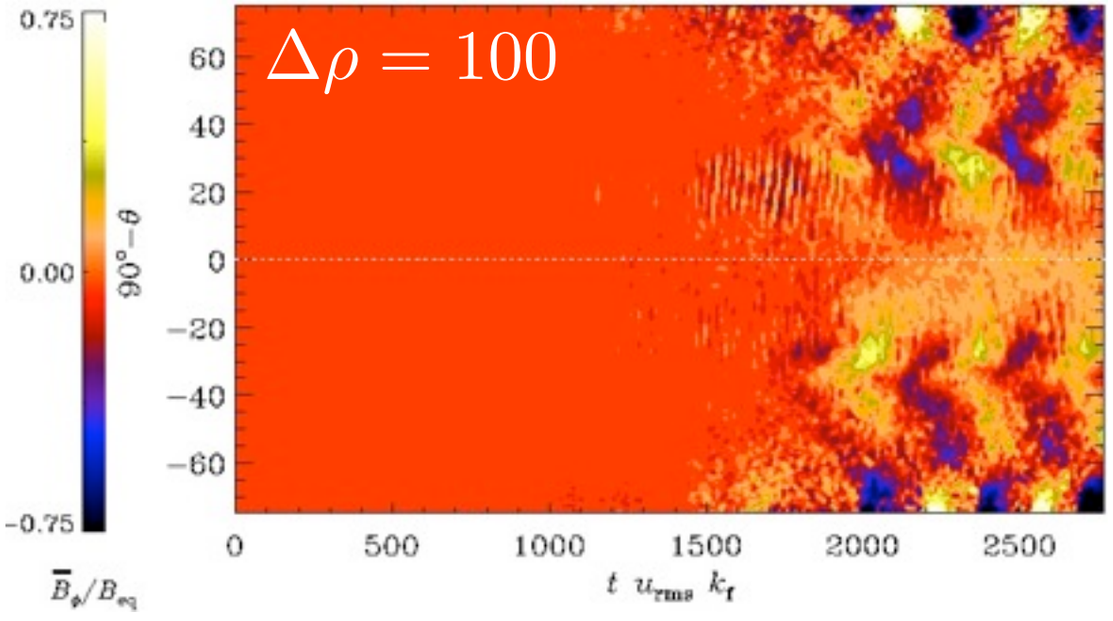
Co ≈ 14





Co ≈ 8

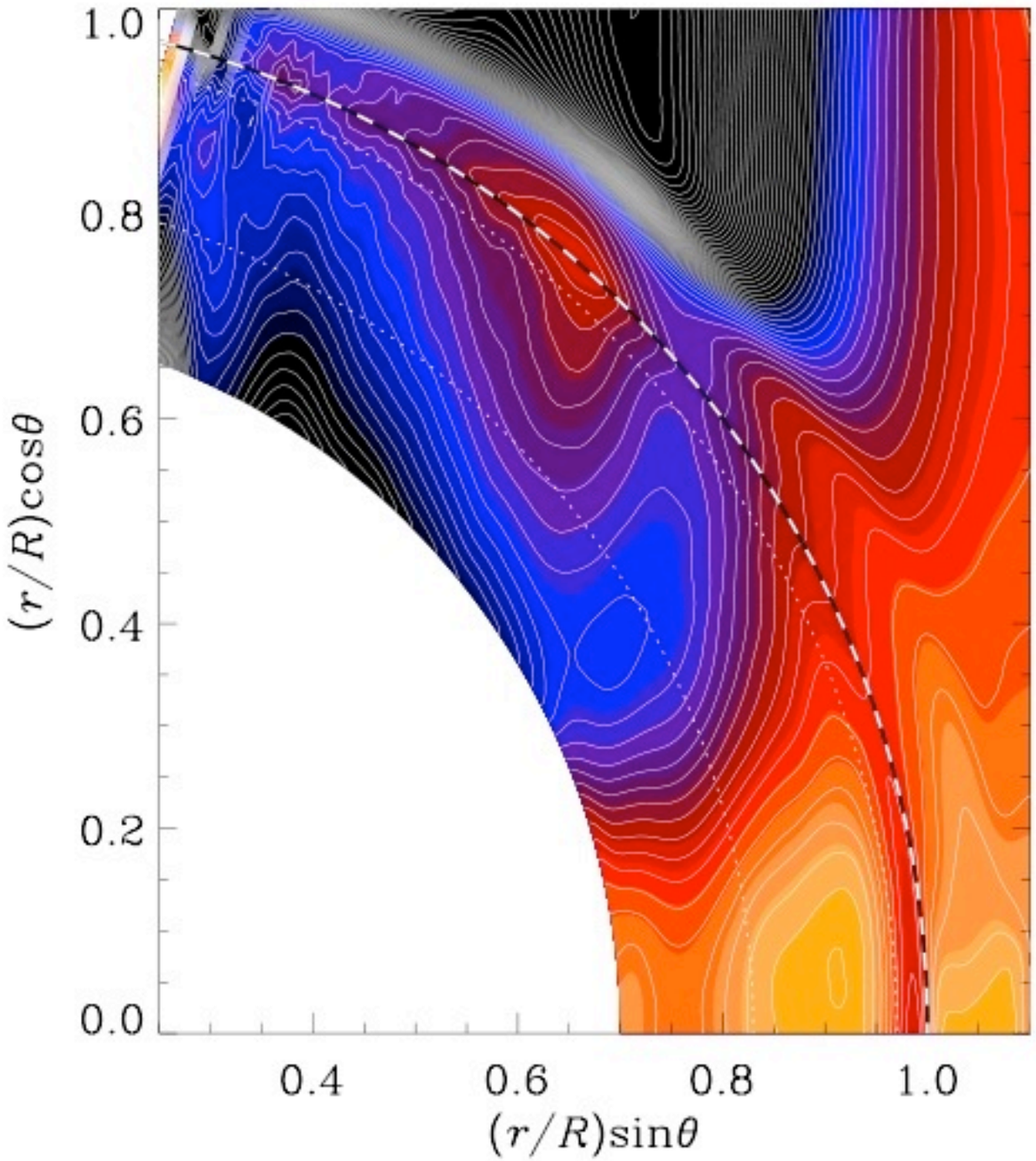


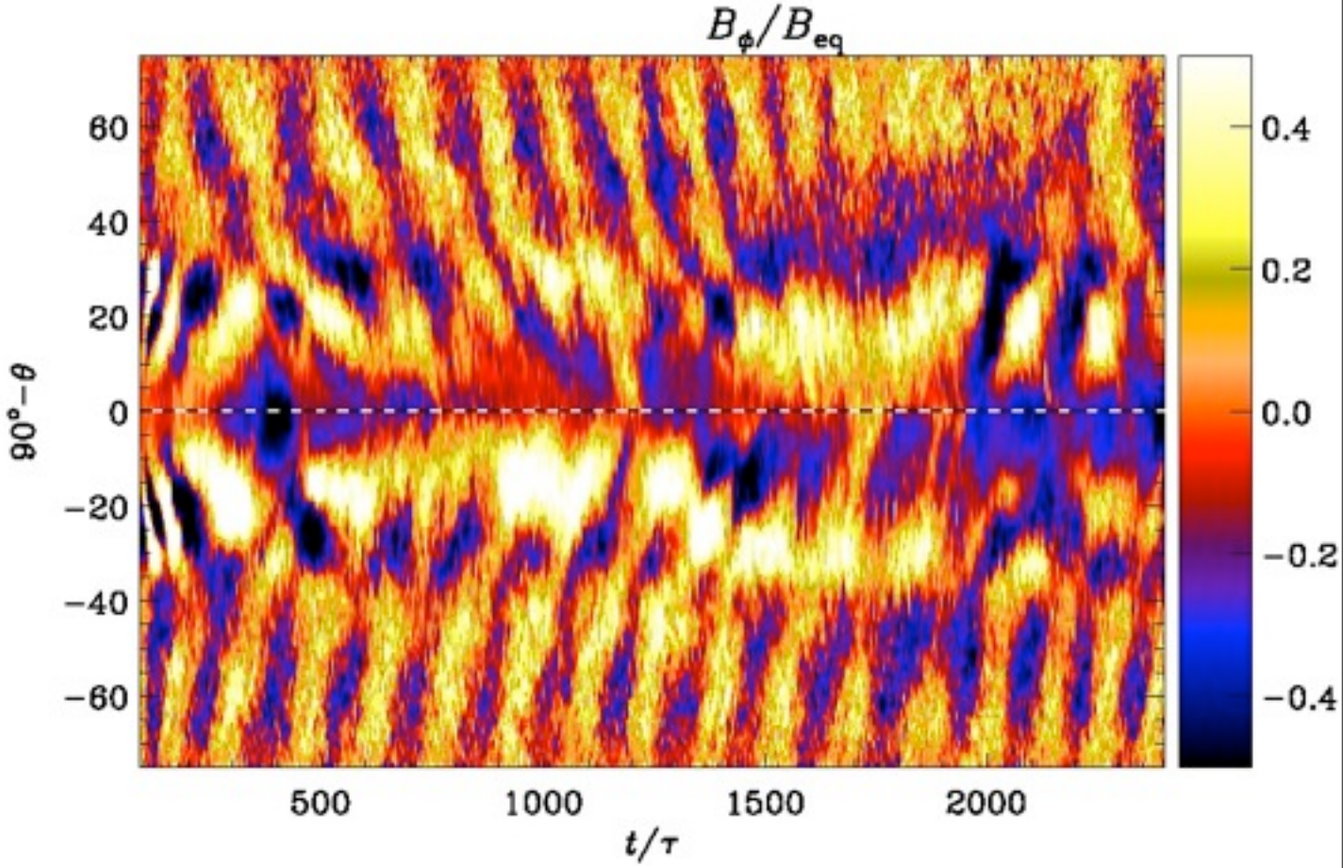


Käpylä et al. (2013), *Astrophys. J.* (submitted), arXiv:1301.2595

Runs with a simplified corona

Spoke-like rotation profile and equatorward migration.





Warnecke et al. (2013), *Astrophys. J.* (submitted), arXiv:1301.2248

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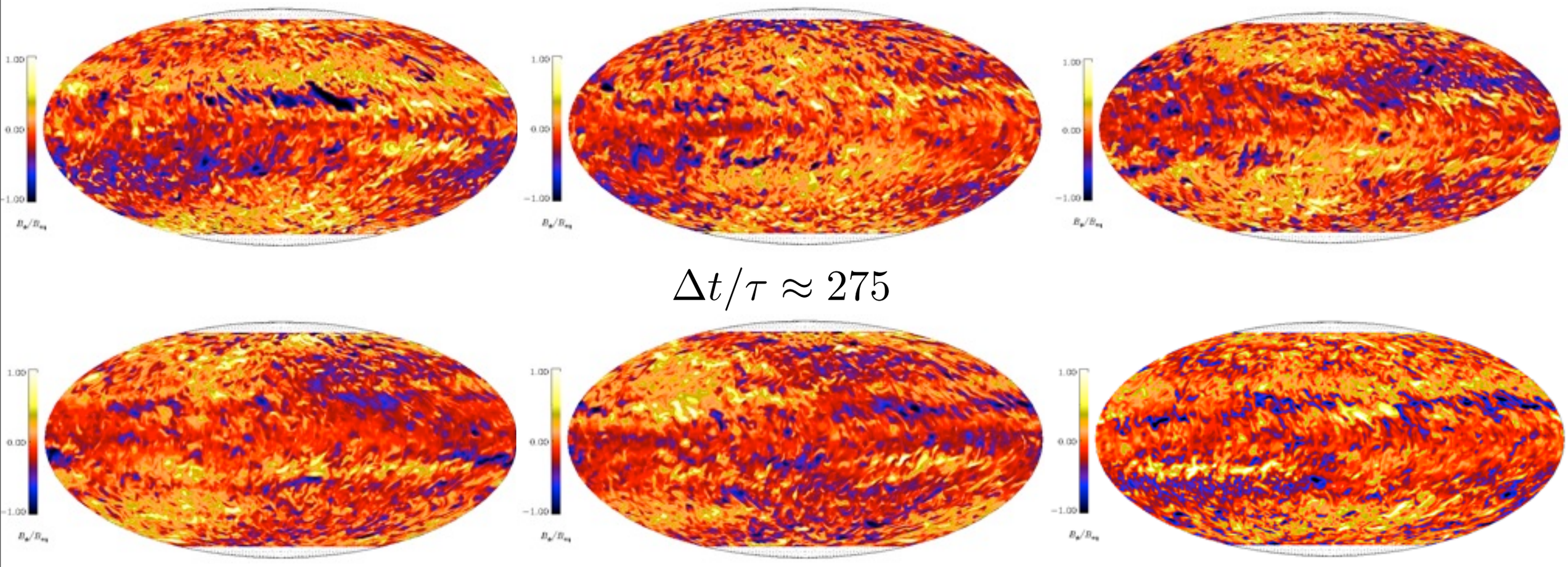
Non-axisymmetric magnetic fields

Mean-field theory predicts that non-axisymmetric fields should appear when rotation is rapid enough (e.g. Krause & Rädler (1980); Moss & Brandenburg (1995), GAFD, 80,229).



Käpylä et al. (2013), *Astrophys. J.* (submitted), arXiv:1301.2595

[Elizabeth's talk tomorrow!]

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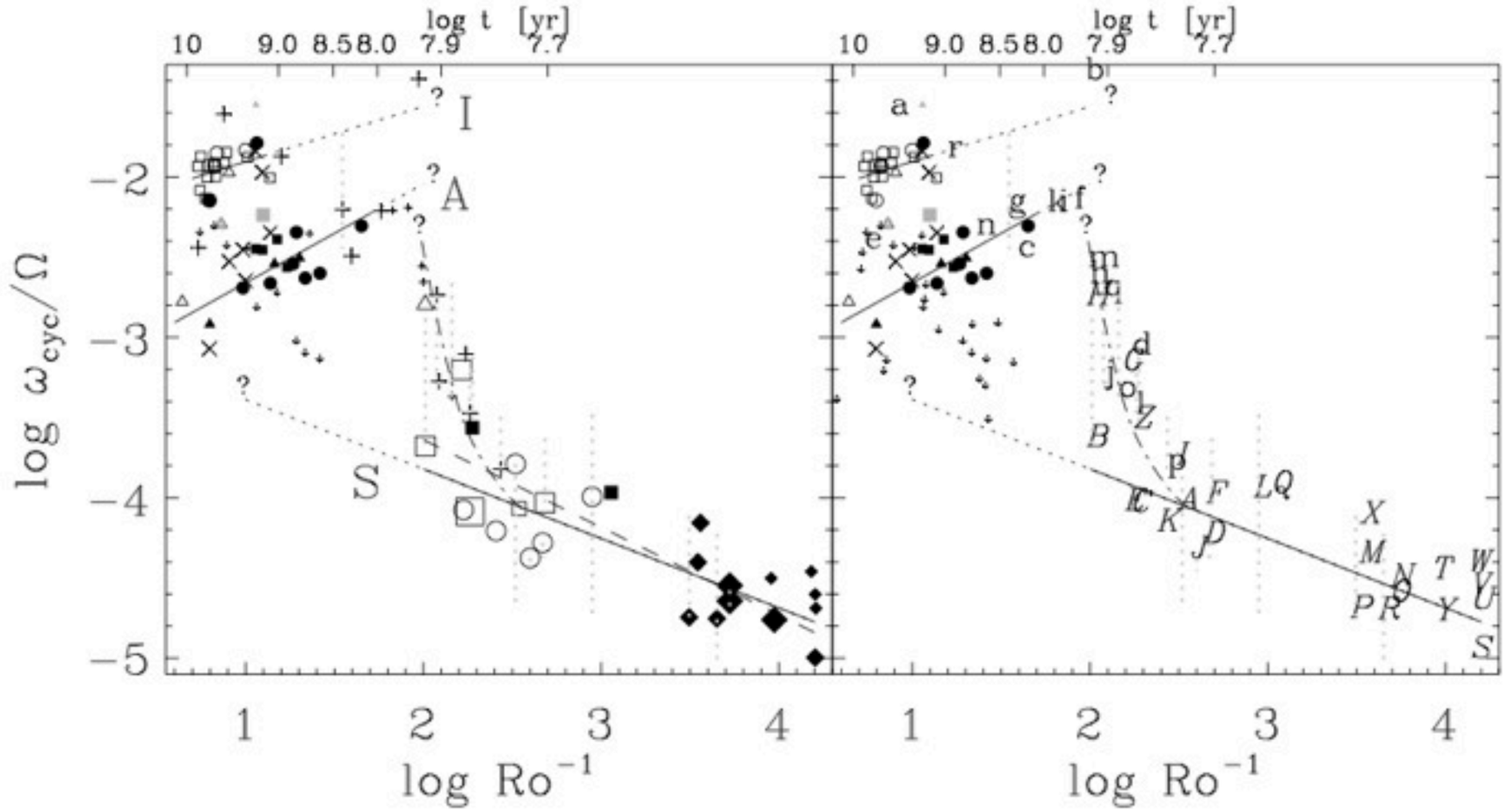
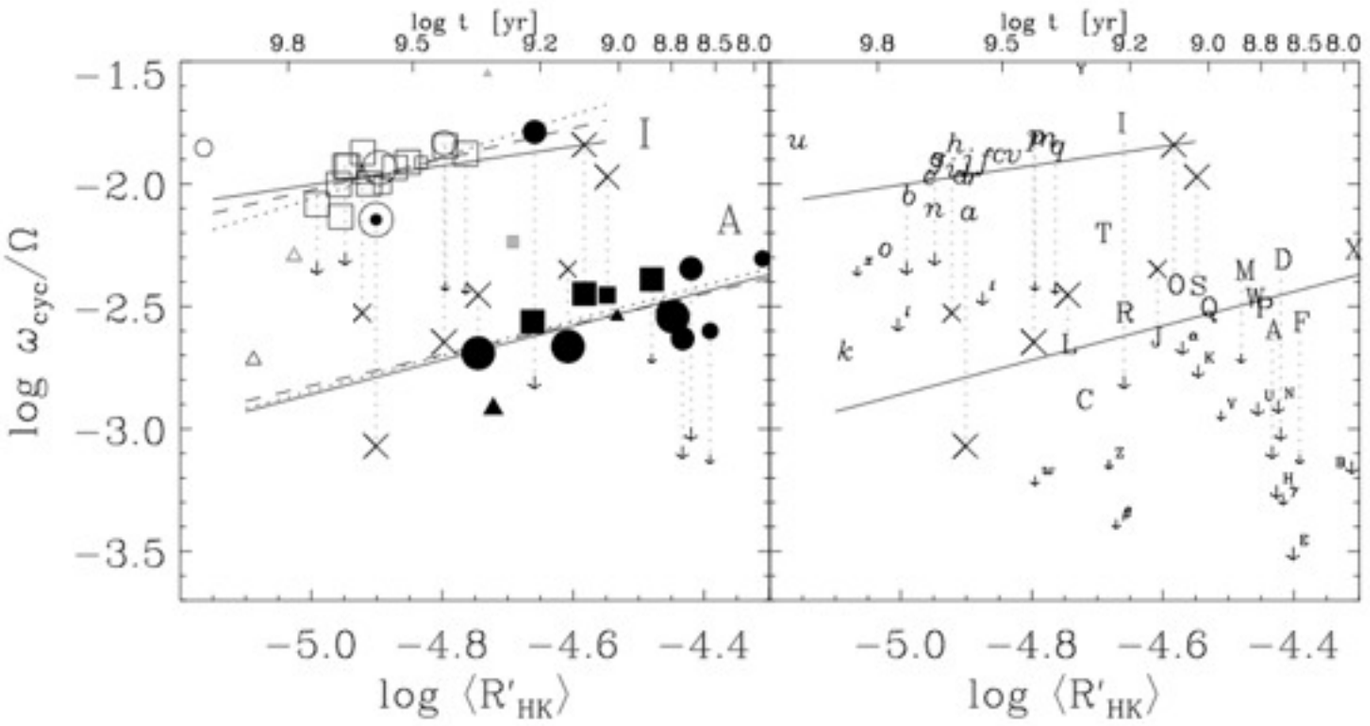
Stellar cycles from observations



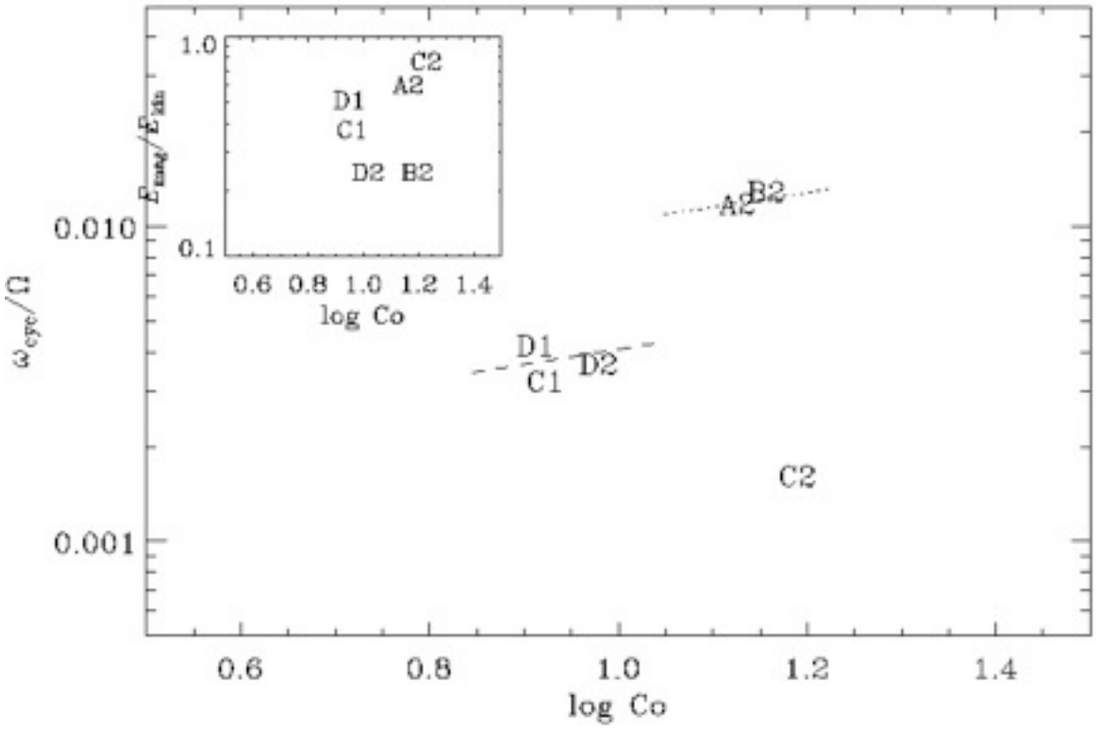
Saar & Brandenburg (1999), *Astrophys. J.*, 524, 295

- **Classification of dynamos based on the ratio of cycle to rotation frequency.**

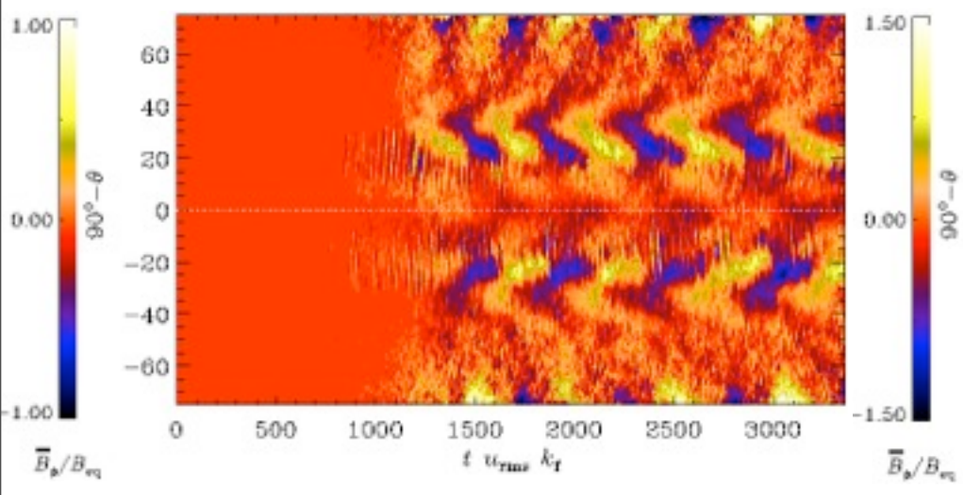
Classification of dynamo simulations?

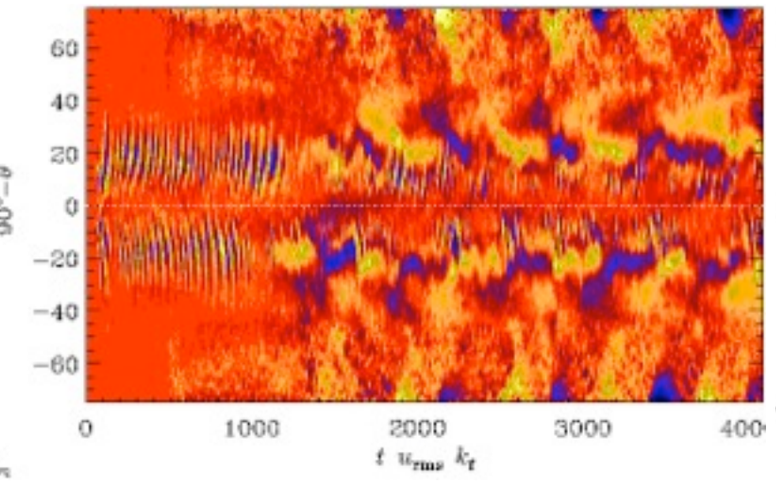


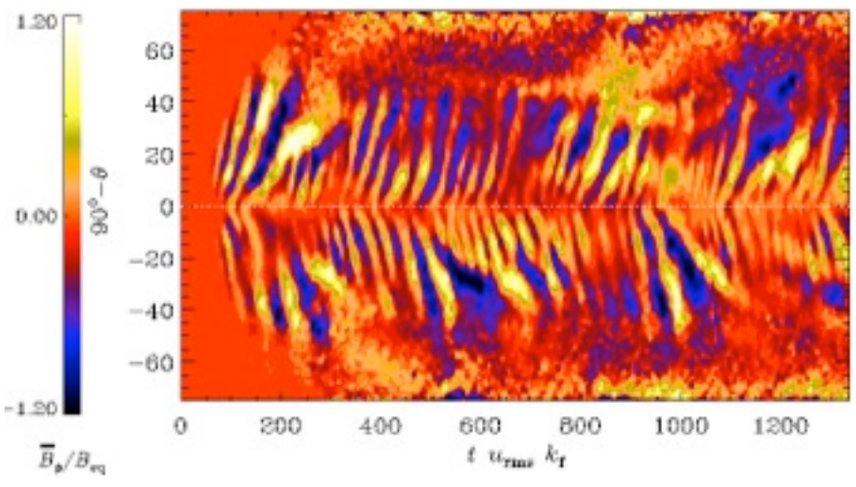
Saar & Brandenburg (1999), *Astrophys. J.*, 524, 295



Käpylä et al. (2013), *Astrophys. J.* (submitted), arXiv:1301.2595







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Conclusions

- **Local simulations produce cyclic solutions in a limited parameter regime.**

- **Dynamo simulations in global geometry are beginning to reproduce many features of the Sun and more rapidly rotating stars, i.e. equatorward migration and non-axisymmetric large-scale fields.**

- **Time to start classifying dynamo models vs. observational results.**

Email your talks!

pkapyla@gmail.com

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