Magnetic cycles and equatorward migration in simulations of turbulent convection

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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


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

Local DNS

(Semi-)global DNS

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Dynamo cycles from local simulations

Oscillatory solutions are obtained in a limited parameter range.

\[ Co = \frac{2\Omega}{u_{\text{rms}} k_f} \quad \text{Sh} = \frac{S}{u_{\text{rms}} k_f} \]

Käpylä et al. (2013), GAFD, 107, 244

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

Dynamo wave propagating towards the poles instead of the equator.

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

Differential rotation and magnetism across the HR diagram, Stockholm, 11th Apr 2013
Dynamo cycles from simulations II

\[ r = 0.70R \]
\[ B_\varphi / B_{eq} \]

\[ r = 0.85R \]
\[ B_\varphi / B_{eq} \]

\[ r = 0.98R \]
\[ B_\varphi / B_{eq} \]

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


Differential rotation and magnetism across the HR diagram, Stockholm, 11th Apr 2013
Dynamo cycles from simulations III


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

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


Differential rotation and magnetism across the HR diagram, Stockholm, 11th Apr 2013
Dynamo cycles from simulations IV

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

Differential rotation and magnetism across the HR diagram, Stockholm, 11th Apr 2013
Dynamo cycles from simulations V

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

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

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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?

\[ \Delta \rho = 2 \quad \text{Co} \approx 14 \]

\[ \Delta \rho = 5 \quad \text{Co} \approx 8 \]

\[ \Delta \rho = 30 \]

\[ \Delta \rho = 100 \]


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Runs with a simplified corona

Spoke-like rotation profile and equatorward migration.


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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).

\[ \Delta t/\tau \approx 275 \]


[Elizabeth’s talk tomorrow!]

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Stellar cycles from observations

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


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Classification of dynamo simulations?


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

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