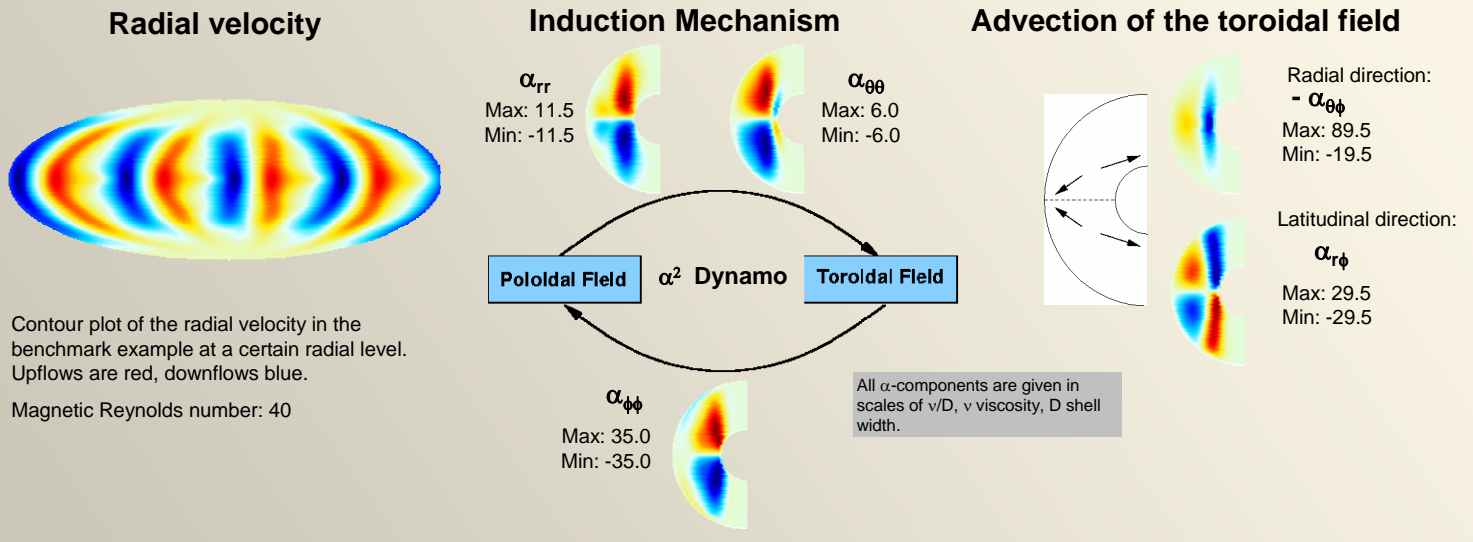# Mean-field view on geodynamo models

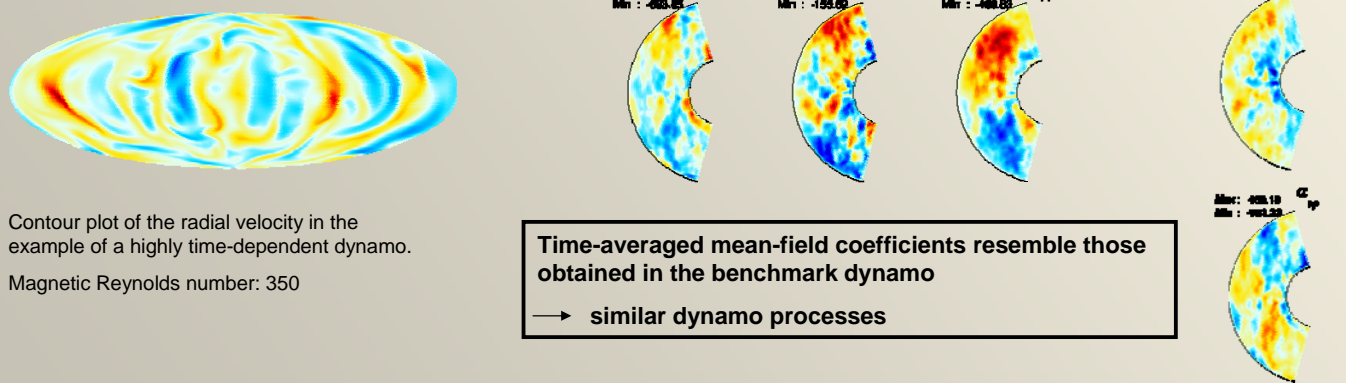## M. Schrinner, Max-Planck-Institut für Sonnensystemforschung

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Mean-field theory provides a useful description of magnetohydrodynamic processes leading to large-scale magnetic fields in various cosmic objects. In mean-field theory, the coefficients occurring in the expansion of the mean electromotive force in terms of the mean magnetic field and its derivatives are used to analyse and to simulate dynamo action. In this study, we consider dynamo processes in a rotating spherical shell similar to the Earth's outer core; mean-fields are defined by azimuthal averaging. We have developed techniques for determining mean-field coefficients and have applied them to a three-dimensional simulation of rotating magnetoconvection and a quasi-stationary dynamo (the benchmark example). In both examples, the tensorial mean-field coefficients are highly anisotropic and demonstrate the existence of an α^2–mechanism along with a strong γ–effect operating outside the inner core tangent cylinder. We also considered a highly time dependent dynamo. The resulting time-averaged mean-field coefficients resemble those obtained in the magnetoconvection and benchmark dynamo examples indicating similar dynamo processes. With the aim of comparing mean-field simulations with related direct numerical simulations (DNS), a two-dimensional mean-field model has been constructed. The match between direct numerical and mean-field simulations is best if at least 17 mean-field coefficients are kept. In the magnetoconvection example, the azimuthally averaged field is in good agreement with the result given by the mean-field model. However, the match is not satisfactory in the benchmark example. There, the traditional representation of the mean electromotive force including no higher than first-order derivatives is not justified. The lack of a clear scale separation renders the traditional mean-field approach inappropriate in this example.

Strongly columnar convection

Radial velocity

Contour plot of the radial velocity in the benchmark example at a certain radial level. Upflows are red, downflows blue.

Magnetic Reynolds number: 40

Induction Mechanism

α_{rr}
Max: 11.5
Min: -11.5

$\alpha_{\theta\theta}$
Max: 6.0
Min: -6.0

Poloidal Field — α^2 Dynamo — Toroidal Field

$\alpha_{\phi\phi}$
Max: 35.0
Min: -35.0

All α-components are given in scales of ν/D, ν viscosity, D shell width.

Advection of the toroidal field

Radial direction:
$-\alpha_{\theta\phi}$
Max: 89.5
Min: -19.5

Latitudinal direction:
$\alpha_{r\phi}$
Max: 29.5
Min: -29.5

Fully developed convection

Contour plot of the radial velocity in the example of a highly time-dependent dynamo.

Magnetic Reynolds number: 350

α_{rr}
$\alpha_{\theta\theta}$
$\alpha_{\phi\phi}$
$-\alpha_{\theta\phi}$
$\alpha_{r\phi}$

Time-averaged mean-field coefficients resemble those obtained in the benchmark dynamo

→ **similar dynamo processes**

Comparison between direct numerical simulations and mean-field models

B_r B_θ B_ϕ

DNS

Mean-Field

Magnetoconvection

Good agreement between direct numerical simulations and mean-field calculations if at least 17 mean-field coefficients are kept.

Benchmark dynamo

No satisfactory agreement, mean-field model slightly subcritical, lack of a clear scale separation

B_r B_θ B_ϕ

DNS

Mean-Field