Effects of magnetism on convection

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DYNAMO ACTION IN STRATIFIED CONVECTION WITH OVERSHOOT

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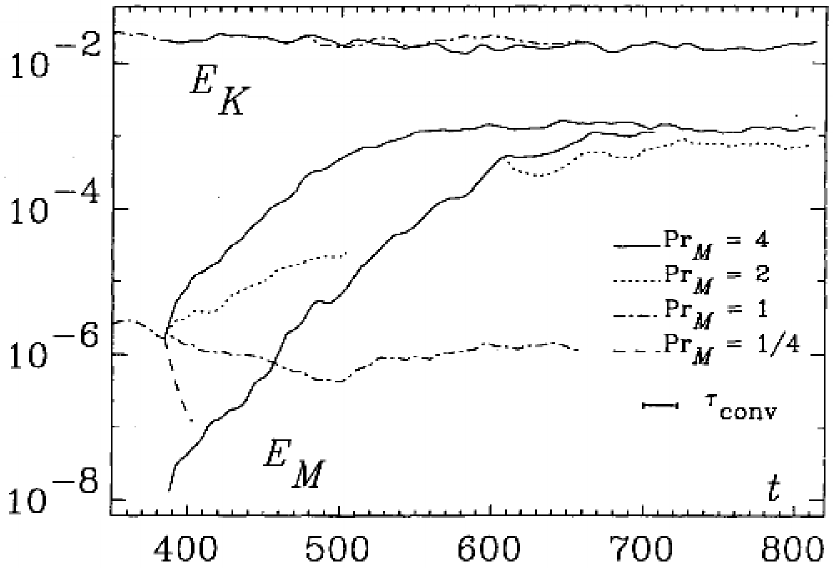
ABSTRACT

We present results from direct simulations of turbulent compressible hydromagnetic convection above a stable overshoot layer. Spontaneous dynamo action occurs followed by saturation, with most of the generated magnetic field appearing as coherent flux tubes in the vicinity of strong downdrafts, where both the generation and destruction of magnetic field is most vigorous. Whether or not this field is amplified depends on the sizes of the magnetic Reynolds and magnetic Prandtl numbers. Joule dissipation is balanced mainly by the work done against the magnetic curvature force. It is this curvature force which is also responsible for the saturation of the dynamo.

Subject headings: convection — MHD — stars: interiors — turbulence



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Numerical evidence for a small-scale dynamo approaching solar magnetic Prandtl numbers

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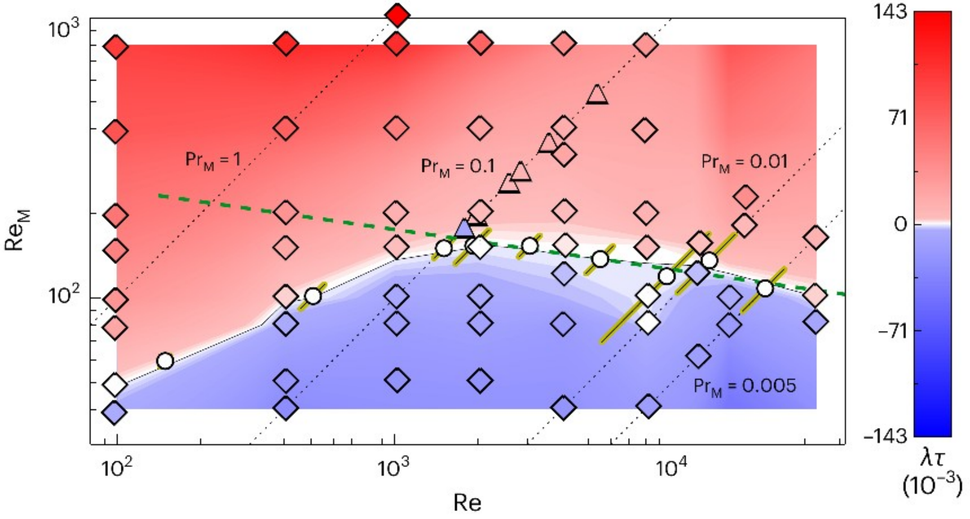
Magnetic fields on small scales are ubiquitous in the Universe. Although they can often be observed in detail, their generation mechanisms are not fully understood. One possibility is the so-called small-scale dynamo (SSD). Prevailing numerical evidence, however, appears to indicate that an SSD is unlikely to exist at very low magnetic Prandtl numbers (Pr_M) such as those that are present in the Sun and other cool stars. Here we have performed high-resolution simulations of isothermal forced turbulence using the lowest Pr_M values achieved so far. Contrary to earlier findings, the SSD not only turns out to be possible for Pr_M down to 0.0031 but also becomes increasingly easier to excite for Pr_M below about 0.05. We relate this behaviour to the known hydrodynamic phenomenon referred to as the bottleneck effect. Extrapolating our results to solar values of Pr_M indicates that an SSD would be possible under such conditions.



Warnecke et al. (2023), *Nature Astron.*, **7**, 662

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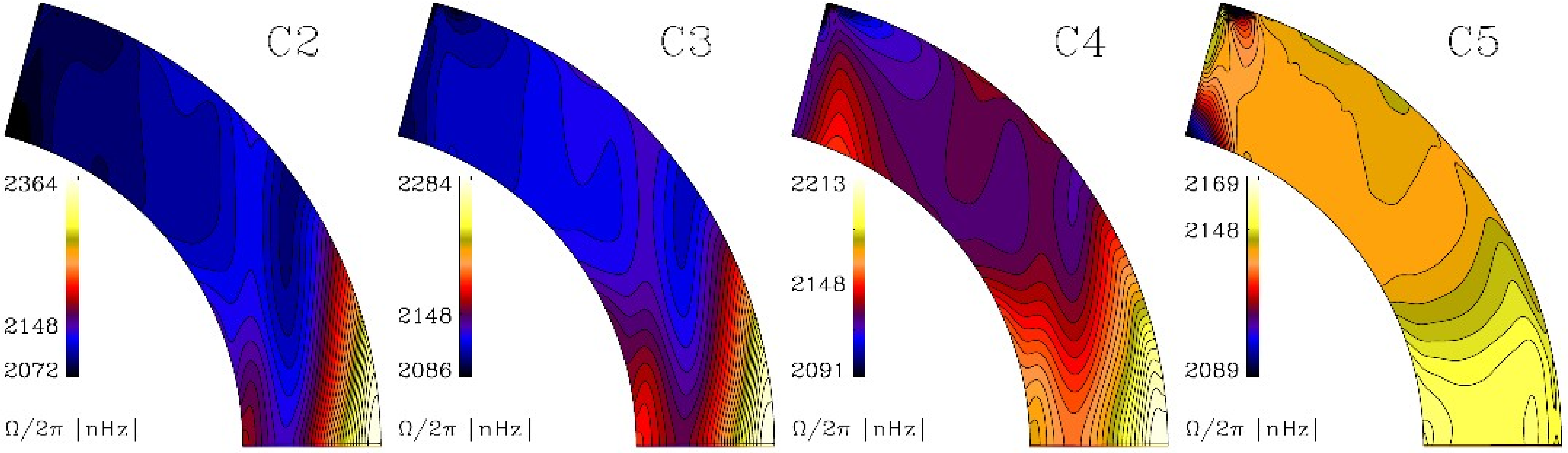

$\mathrm{Re_M} = 14$ $\mathrm{Re_M} = 29$ $\mathrm{Re_M} = 44$ $\mathrm{Re_M} = 146$

$$\mathrm{Re_M} = \frac{u_{\mathrm{rms}}}{\eta k_1}, \; k_1 = \frac{2\pi}{\Delta r}.$$

K. et al. (2017), *Astron. Astrophys.*, **599**, 4

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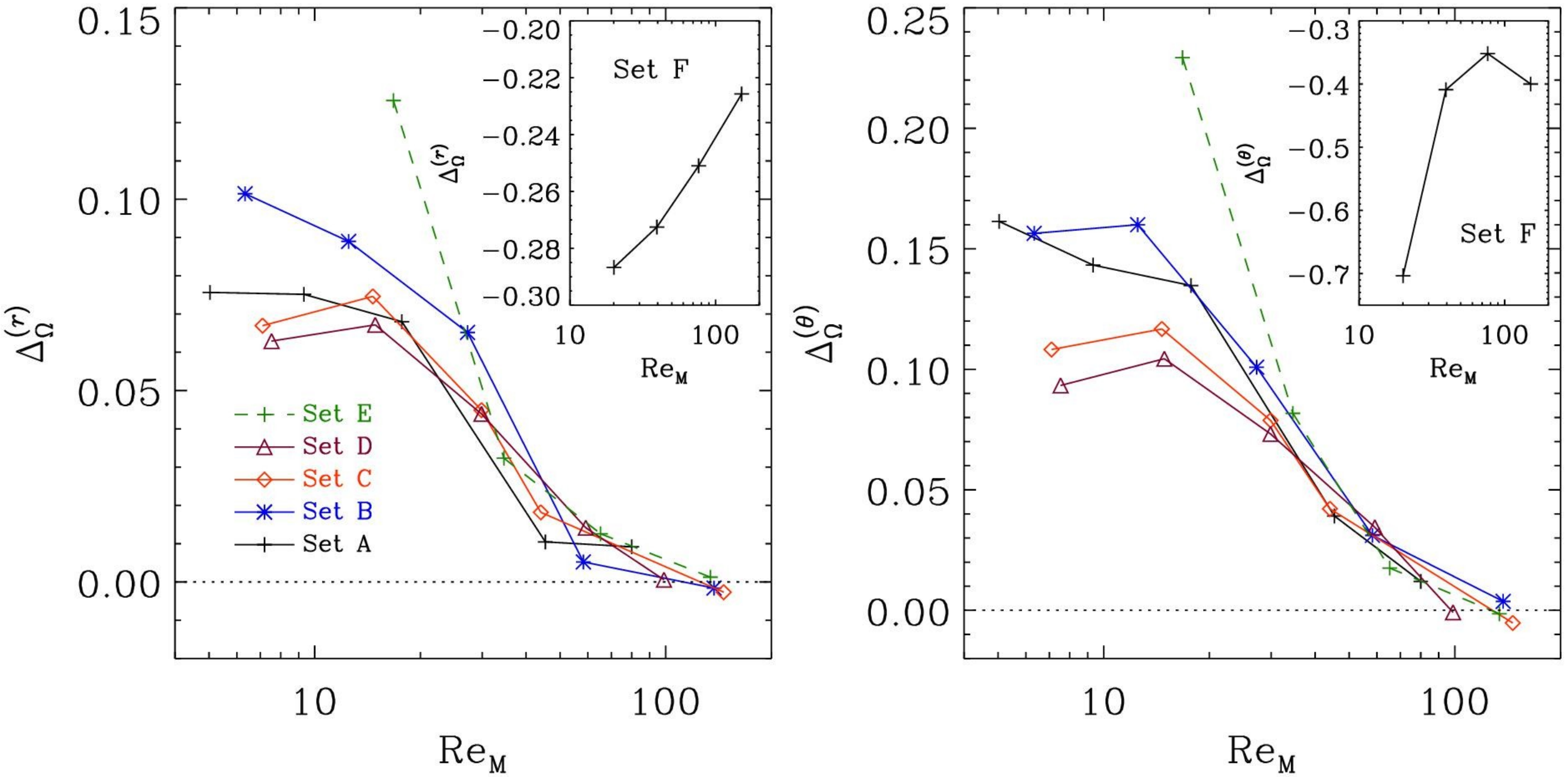

$$\Delta_\Omega^{(r)} = \frac{\Omega_{eq} - \Omega_{bot}}{\Omega_{eq}}, \quad \Delta_\Omega^{(\theta)} = \frac{\Omega_{eq} - \Omega_{pole}}{\Omega_{eq}}$$

K. et al. (2017), *Astron. Astrophys.*, **599**, 4

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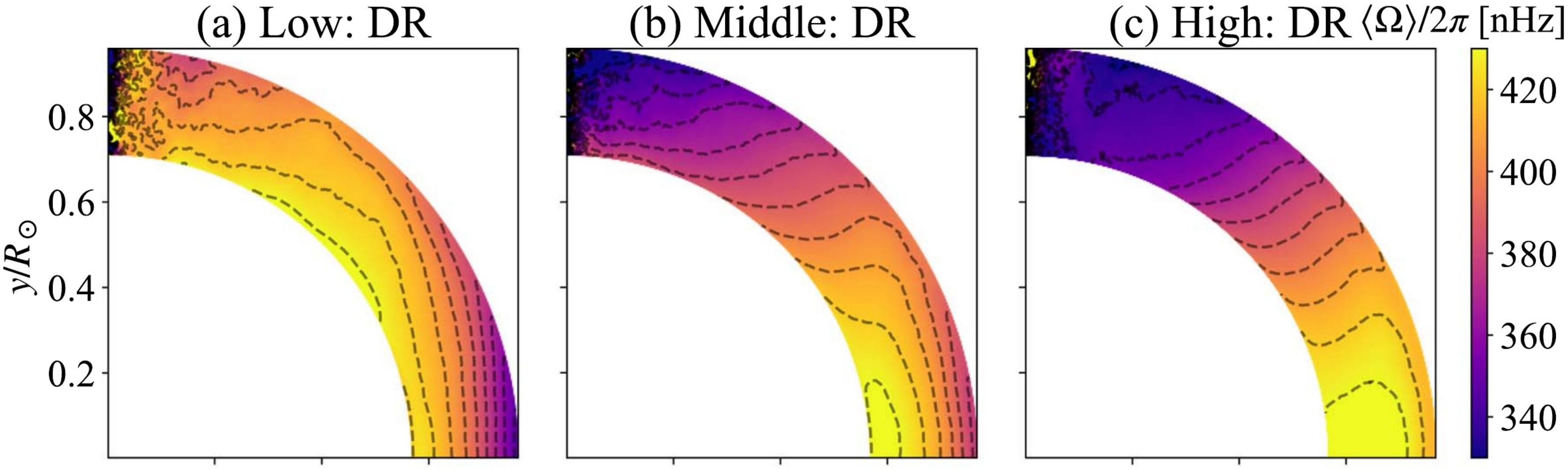

iLES simulations with solar rotation and luminosity (= $\mathrm{Co}_{\mathrm{F}}^{\odot}$).

Hotta et al. (2022), *Astrophys. J.*, **933**, 199

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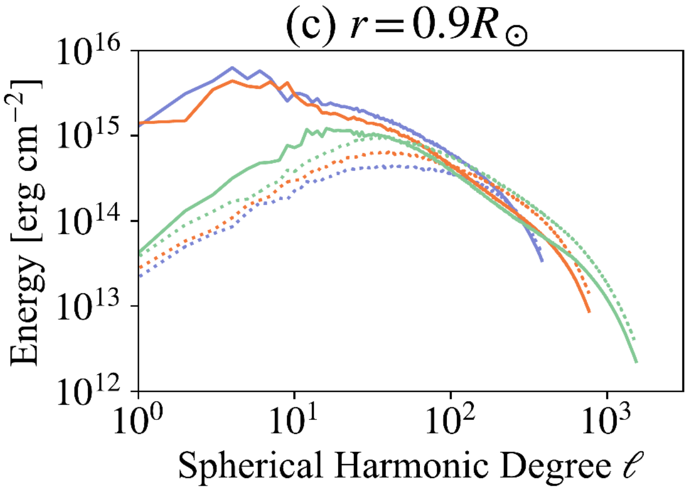
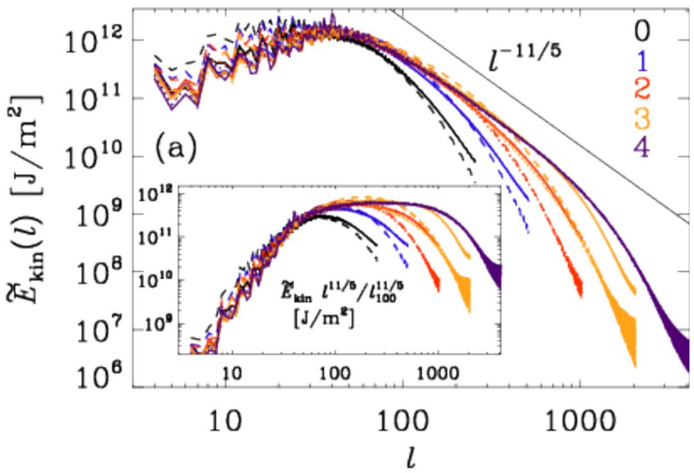
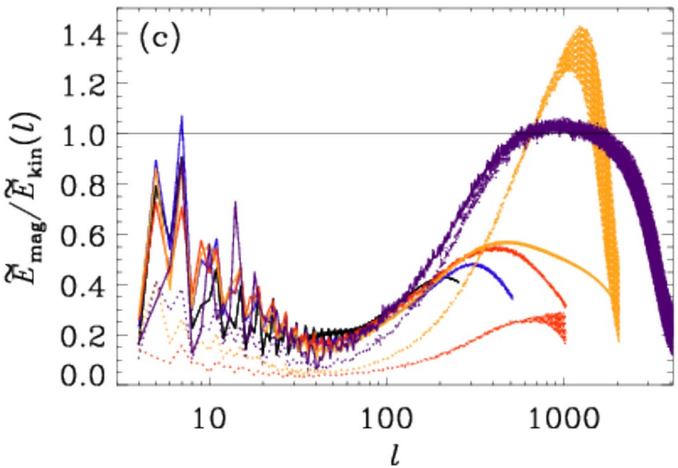


Hotta et al. (2022), *Astrophys. J.*, **933**, 199





Warnecke et al. (2024), *arXiv:2406.08967*

$$\mathrm{Co_F} = \frac{2\Omega H}{u_\star} = 2\Omega H \left(\frac{\rho}{F_{\rm tot}}\right)^{1/3}, \quad \mathrm{Co_F} = (\mathrm{Ra_F^\star})^{-1/3}, \qquad \mathrm{Ra_F^\star} = \frac{\mathrm{Ra_F}}{\mathrm{Pr}^2\,\mathrm{Ta}^{3/2}}.$$

$$\mathrm{Co}_\ell^B \sim \frac{|\boldsymbol{J}\times\boldsymbol{B}|}{|\rho\boldsymbol{u}\cdot\boldsymbol{\nabla}\boldsymbol{u}|} \sim \frac{B^2/(\mu_0\ell_B)}{\rho u^2/\ell_u} = \left(\frac{E_{\rm mag}}{E_{\rm kin}}\right)\left(\frac{\ell_u}{\ell_B}\right) = \frac{2\Omega\ell_u}{u}\frac{B^2}{2\rho\Omega u\mu_0\ell_B} = \mathrm{Co}_\ell\Lambda_\ell.$$