# The role of helicity in dynamos driven by rapidly rotating convection

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### Summary

Recent work has shown how large-scale vortices may form in rapidly rotating (and hence helical), plane layer convection. Here we consider the nature of the dynamo that may result from such vortices, and explain how this new dynamo mechanism fits in with classical mean-field dynamos and small-scale (fast) dynamos that have previously been found in this convective system.

## 1 Helicity and large-scale magnetic field generation

Understanding the generation of large-scale magnetic fields remains one of the most important problems in astrophysical fluid dynamics. Mean field electrodynamics (see, for example, [1, 2]) is a beautiful theory that describes the evolution of large-scale (mean) magnetic fields in terms of transport tensors, the most important being the so-called $\alpha$ tensor, whose properties depend on the statistics of the small-scale turbulence. The most striking result of mean field dynamo theory is that mean field generation can occur through the $\alpha$-effect only if the flow lacks reflexional symmetry. The simplest measure of lack of reflexional symmetry is the flow helicity; helical flows therefore underpin all large-scale dynamos. However, the picture is not entirely straightforward. Whereas non-zero helicity is a necessary condition for large-scale field generation (at least through an $\alpha$-effect), helical flows of themselves are not guaranteed to act as large-scale dynamos. The situation at high magnetic Reynolds number $Rm$, the case of astrophysical relevance, is particularly complicated.

Here I shall consider the particular example of dynamos driven by rotating, plane layer convection — possibly the simplest non-trivial dynamo configuration — in order to illustrate the various types of dynamo that can occur in flows with helicity.

## 2 Plane layer rotating convection

Dynamos driven by rotating, plane layer Boussinesq convection were first considered in the pioneering studies of [3, 4], and have subsequently received considerable attention through both analytical and numerical investigations.

Close to the onset of convection, the local value of $Rm$, based on the narrow convective cell size, is small. The fluctuating and mean magnetic fields are then simply related (so-called 'first order smoothing') and mean field theory can be readily applied; furthermore, there is a direct link between the helicity of the flow and the mean magnetic field generated. For more vigorous, although still strongly helical, convection, two other factors come into play. One is that the mean e.m.f. may be much smaller than local values of the e.m.f. [5]; this may be thought of as a lack of correlation between cyclonic eddies in Parker's classical picture. The other is that small-scale dynamo action may become dominant [6], thereby swamping any mean field mechanism.

Recent work has revealed that rotating convection may support yet another type of dynamo mechanism. Computational studies [7, 8] have shown that large-scale vortices (LSVs) may form as the result of a mean-field *hydrodynamic* instability (see figure 1). Here we look at the nature of the dynamo action that can result from these LSVs, showing how the magnetic field may be either large-scale (i.e. on the scale of the LSVs) or small-scale (on the scale of the convective eddies), depending on the magnetic Prandtl number [9]. Thus there are three very different types

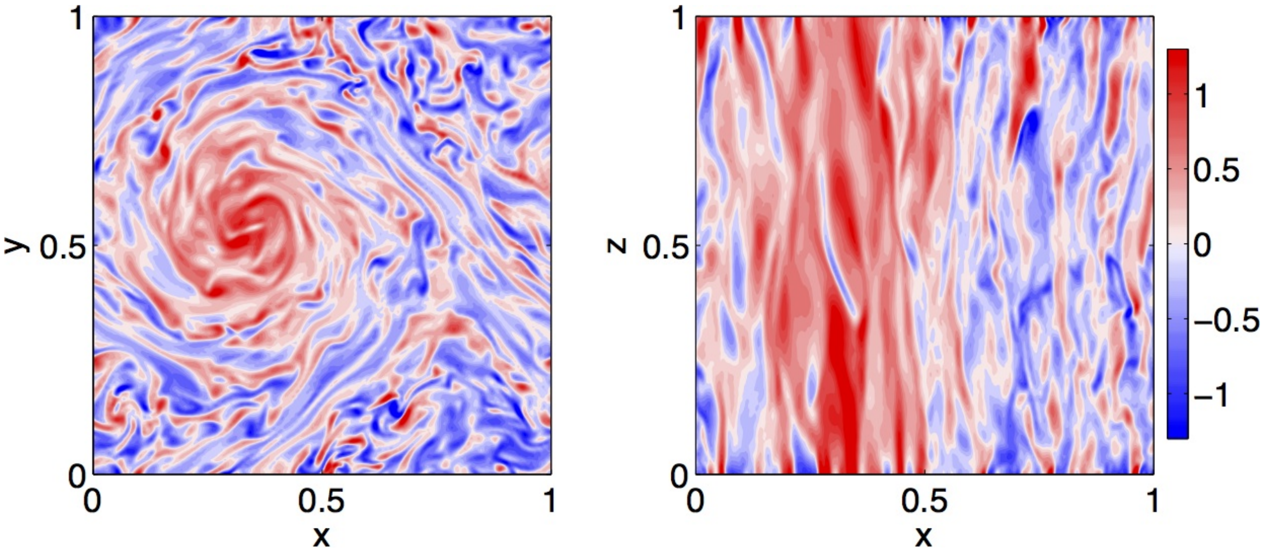

Fig. 1: Top and side views of the vertical vorticity: Ekman number $= 5 \times 10^{-6}$, Rayleigh number $= 8 \times 10^{8}$, Prandtl number = 1.

of dynamo mechanism possible in this system. We shall discuss where these lie in the parameter space defined by the Rayleigh number, the Ekman number and the magnetic Prandtl number, and where each of these might be of significance in planetary and stellar dynamos.

## References

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