A dynamo driven by zonal jets at the upper surface in the giant planets
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Abstract

A dynamo mechanism explains the dipolar magnetic field of Jupiter and the multipolar magnetic field of Neptune in terms of the width of the zonal jet streams observed at their surfaces.

The idea
- Surface zonal winds may extend over the whole molecular hydrogen layer [1]
- They can drive motion by viscous or electromagnetic coupling inside the electrically conducting core.
- These shearing motions are unstable and produce a drifting Rossby wave.
- The combination of shear (z-effect) and Rossby wave (r-effect) can produce a self-induced magnetic field.

We find that the width of the jets controls the topology of the resulting magnetic field, in good agreement with Jupiter and Neptune.

Does this also work with variable conductivity in the upper layer?

Due to the rapid increase of electric conductivity with depth in the outer region [2], angular momentum may be transported along the magnetic field lines leading to a so-called Ferraro state [3].

We performed some axisymmetric simulations with variable conductivity to show how the picture is modified. In the case below, the zonal velocity strength is divided by 15, and the velocity profiles go from a Ferraro state (iso-rotation lines aligned with magnetic field lines) to a Proudman-Taylor state (iso-rotation lines aligned with global rotation axis).

Shear instability and Rossby waves

For strong surface forcings, shear instabilities arise (Kelvin-Helmoltz type) in the strongest shear bands. They take form of Rossby waves, azimuthal necklaces of cyclonic and anticyclonic vortices elongated along the axis of rotation, that propagate eastward due to the spherical geometry. The wavenumber is determined by the width of the unstable zonal jet.

Discussion

Our results suggest that the differences in the magnetic fields and the surface zonal winds of the Giant and Ice Giant planets are related through a dynamo mechanism arising from the transport of angular momentum between the surface and the deep conducting region. In the presence of convection, and even for a convectively-driven dynamo, the mechanism described here may still impose a similar relationship between the magnetic field morphology and the zonal wind profile. The following predictions of our model can be tested against the magnetic measurements of the forthcoming Juno mission: (i) the presence of a peak at small azimuthal scale in the magnetic field spectrum that is correlated with the width of the hydrodynamically unstable zonal jets; and (ii) a correlation between the secular variations of zonal jets and the external magnetic field.

References