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

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

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We present a new possible dynamo mechanism for generating the magnetic fields of the giant planets. The mechanism relies on the presence of barotropically unstable differential rotation. We assume that zonal jet currents within the outer molecular hydrogen layer exert a drag at the top of the deep electrically conducting region. Because of the planet's rapid rotation, this boundary forcing drives nearly geostrophic axisymmetric motions in the conducting region.

For a given forcing, measured by the critical Rossby number Ro_c, a shear instability of the zonal flow develops in the form of a global Rossby mode. The wavenumber of the mode depends on the width of the zonal jets. For $Ro \geq Ro_c$, we obtain self-sustained magnetic fields at magnetic Reynolds numbers greater than 10^3. The propagation of the Rossby wave and its non-axisymmetric structure are both crucial for dynamo action. The amplitude of self-sustained axisymmetric poloidal magnetic field plausibly depends on the wavenumber of the shear instability, and hence on the width of the zonal jets.

For narrow jets, the poloidal magnetic field is dominated by an axial dipole whereas in the case of wide jets, the axisymmetric poloidal field is weak. Hence, this new dynamo mechanism explains the differences between the magnetic fields of Saturn and Jupiter on one hand and Uranus and Neptune on the other hand by the observed features of their atmosphere.