5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Magnetic Rossby waves and torsional Alfvén waves in planetary dynamos

Kumiko Hori[1]

[1] Graduate School of System Informatics, Kobe University, Japan.

e-mail (speaker): khori (at) people.kobe-u.ac.jp

Magnetohydrodynamic waves excited in deep interiors of rapidly rotating planets can produce variations in the planetary magnetic fields and some linked properties. In strong-field dynamos, in which the inertial and viscous forces are small compared to the magnetostrophic forces, namely Coriolis, pressure, Lorentz, and buoyancy forces, unique wave motions can occur in both axisymmetric and nonaxisymmetric modes.

Axisymmetric, torsional Alfvén waves are a special class of the MHD waves, as confined to cylindrical surfaces about the rotation axis [1]. The excitation of the 4-6 year fluctuations in Earth's fluid core, in which the geodynamo operates, and its link to the length-of-day variations have been shown [2]. The propagation speed can be a proxy for the strength of the poloidal magnetic field within the geodynamo.

Magnetic Rossby waves are non-axisymmetric and typically travel in azimuth along the internal toroidal field. Exploring this wave class will hence be the key to infer the hidden, toroidal field and to constrain the dynamo mechanism. The presence of magnetic field splits the fundamental rotating wave into fast and slow modes: the slow one was proposed to account for the geomagnetic westward drift of a few hundreds of years [3]. We exemplified the long-hypothesised wave motion in DNS of geodynamo models to reveal its propagation, riding on background zonal flows, and steepened waveforms [4,5]. Meanwhile we asymptotically analysed the weakly-nonlinear, long wave in quasi-geostrophic (QG) MHD models and showed the slow Rossby waves may behave like solitons, whose evolution should be governed by the Korteweg-de Vries equation [6,7]. The solitary wave solution (figure 1 left) may be of particular geophysical interest. An isolated, anticyclonic gyre was found to persist, at least, for a hundred years in Earth's core [8] (figure 1 right).

Exploration is extending to other planets, such as Jupiter. The gas giant's strong magnetic field and rapid rotation may reasonably host rotating MHD waves excited in the metallic region, in which Jovian dynamo is believed to operate. Adopting Jovian dynamo models coupling with the overlying molecular hydrogen region partly, we found the torsional Alfvén waves would reasonably be excited [9]. The deep-origin disturbances could trigger consequent variations of zonal flow and temperature at the molecular envelope. Now records of infrared observations covered more than three Jovian years to characterise the variability in the cloud deck [10]. Together with a modern data-driven technique, dynamic mode decomposition [e.g. 11,12], we are identifying the wave signals on timescales of several years [13] (figure 2). This may provide a novel window to the internal dynamics and dynamo.

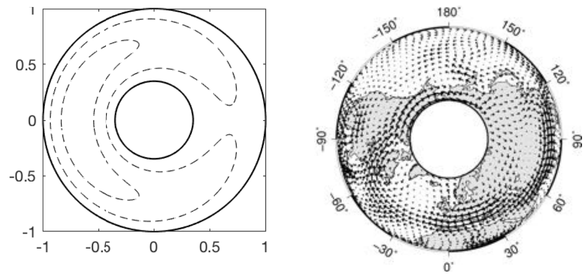

Figure 1. (Left) Streamlines of the 1-soliton solution of our QG-MHD spherical model [7]. (Right) The gyre revealed by core flow models inverted from the geomagnetic secular variation [8].

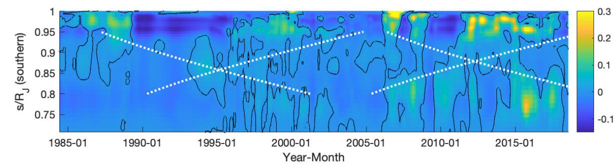

Figure 2. Anomaly of Jupiter's 5μm brightness [after 10]. White dotted curves indicate potential phase paths of torsional Alfvén waves [13].

References

[1] S.I. Braginsky, Geomagn. Aeron. **10**, 1-8 (1970).

[2] N. Gillet, D. Jault, E. Canet, and A. Fournier, Nature **465**, 74-77 (2010).

[3] R. Hide, Phil. Trans. R. Soc. Lond. A **259**, 615-647 (1966).

[4] K. Hori, C.A. Jones, and R.J. Teed, Geophys. Res. Lett. **42**, 6622-6629 (2015).

[5] K. Hori, R.J. Teed, and C.A. Jones, Phys. Earth Planet. Int. **276**, 68-85 (2018).

[6] K. Hori, Proc. Japan Soc. Fluid Mech. Annual Meeting 2019, 174 (2019).

[7] K. Hori, S.M. Tobias, and C.A. Jones, J. Fluid Mech. **904**, R3(1-14) (2020).

[8] M.A. Pais, D. Jault, Geophys. J. Int. **173**, 421-443 (2008).

[9] K. Hori, R.J. Teed, and C.A. Jones, Earth Planet. Sci. Lett. **519**, 50-60 (2019).

[10] A. Antuñano, L.N. Fletcher, *et al.*, Astron, J. **158**, 130(28pp) (2019).

[11] P.J. Schmid, J. Fluid Mech. **656**, 5-28 (2010).

[12] K. Hori, S.M. Tobias, and R.J. Teed, Proc. Japan Soc. Fluid Mech. Annual Meeting 2020, 104 (2020). (Also in arXiv:2009.13095 [physics.flu-dyn].)

[13] K. Hori, C.A. Jones, S.M. Tobias *et al.*, in prep.