CD-I12 AAPPS-DPP2018

2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Rotating MHD waves and their implications for planetary dynamos

Kumiko Hori[1,2], Robert J. Teed[3], Chris A. Jones[2]

[1] Graduate School of System Informatics, Kobe University, [2] Department of Applied Mathematics, University of Leeds, [3] School of Mathematics and Statistics, University of Glasgow

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

The magnetohydrodynamics of rotating fluids--referred to as rotating MHD--describes situations where rotation occurs together with a magnetic field. Its relevance is found in geophysics and astrophysics including Earth's liquid iron core and Jupiter's metallic hydrogen region, in which the dynamo action is believed to operate. In the magnetostrophic dynamos, in which the Coriolis, pressure, and Lorentz forces dominate the force balance, unique wave motions can occur in both axisymmetric and non-axisymmetric modes. Identifying those wave motion could allow us to get insights about the planetary dynamos that are seated in the deep interiors. To explore the relevance of waves and the dynamics, we use direct numerical simulations of MHD dynamos driven by convection in rapidly rotating spherical shells.

Axisymmetric, torsional Alfven waves are a special class of the MHD waves, as confined to cylindrical surfaces about the rotational axis [1]. The excitation of the 4-6 year fluctuations in Earth's core and its link to the length-of-day variations have been shown [2]. The state-of-the-art geodynamo simulations with the incompressible, Boussinesq approximation being assumed [3] have supported the wave excitement and illustrated their propagation outwards, initiated at the bottom of the fluid core and damped at the top boundary to the rocky mantle. The speed can be a proxy for the strength of the radial magnetic field.

Magnetic Rossby waves are non-axisymmetric and typically travel in azimuth along the internal toroidal field. 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 [4]. The long-hypothesized wave motion was recently exemplified in geodynamo models [5,6] to reveal its propagation, riding on background zonal flows, and steepened waveforms, arising from nonlinear Lorentz terms. The detection however necessitates an update of historical geomagnetic data sets and/or its inverted core flow models. This will be the key to infer the hidden, toroidal field and to constrain the dynamo mechanism.

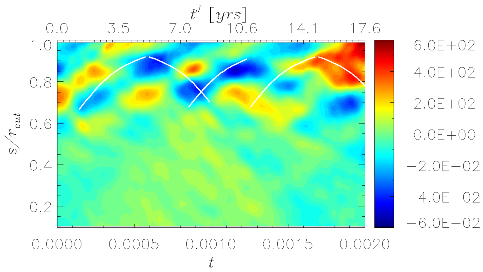

Figure 1 Time radius section of axially- and azimuthally-mean zonal velocity <uφ'>. In Jovian model E of [7]. White curves indicate phase paths of torsional Alfven waves: a dashed line does a transition to the molecular region, ~ 0.85 of Jupiter radius RJ.

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; compressibility of the fluid will bring some modifications. The ongoing Juno measurements have been defining the spatial and temporal structure of the intrinsic, magnetic field.

Adopting Jovian dynamo models [7] coupling with the overlying molecular hydrogen region partly, we find Jovian torsional waves to be reflected at the metallic transition and to be standing, rather than travelling (figure 1). Those wave properties may highlight the top of the metallic region, which has been poorly constrained. The zonal oscillations on timescales of ten years, at shortest, yield potential changes of the planet's length-of-day of amplitude no greater than tens milliseconds. Also, the deep-origin disturbances can trigger consequent variations of surface zonal wind at the molecular envelope. Nonaxisymmetric motion predominantly comprises of fast magnetic Rossby waves (figure 2) that travel eastwardly with speeds slightly faster than the nonmagnetic mode, with respect to the mean zonal flows. The correction terms, though they arise at the following order, could be used to evaluate the density variation and/or the magnetic field within the dynamo region.

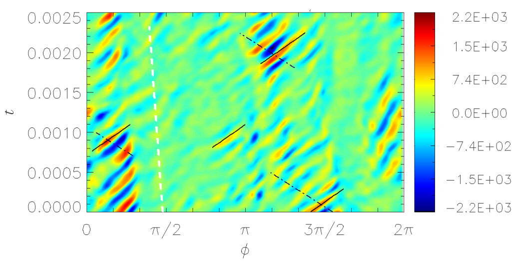

Figure 2 Azimuth time section of axially-mean radial velocity <us'> at radius ~ 0.48 RJ. In model A of [7]. White dashed, black solid, and black dotted lines represent paths of zonal flow advection, phase paths of compressibility-induced Rossby wave plus advection, and ray paths of the wave and advection, respectively.

References

[1] Braginsky 1970, Geomagn. Aeron. 10, 1-8
[2] Gillet et al. 2010, Nature 465, 74-77
[3] Teed et al. 2015, Earth Planet. Sci. Lett. 419, 22-31
[4] Hide 1966, Philos. Trans. R. Soc. London Ser. A 259, 615-647
[5] Hori et al. 2015, Geophys. Res. Lett. 42, 6622-6629
[6] Hori et al. 2018, Phys. Earth Planet. Int. 276, 68-85
[7] Jones 2014, Icarus 241, 148-159