EPSC Abstracts
Vol. 13, EPSC-DPS2019-1898-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Dynamo Action of Jupiter's Zonal Winds

Johannes Wicht (1), Thomas Gastine (2), Lucia D. V. Duarte (3) and Wieland Dietrich (1)
(1) Max Planck Institute for Solar System Research, Germany (wicht@mps.mpg.de), (2) IPGP, France, (3) College of Engineering, Mathematics and Physical Sciences, University of Exeter, UK

Abstract

Gravity data from NASA's Juno mission finally constrain the depth of Jupiter's fierce zonal winds, indicating that they must slow down considerably at a depth of about $0.96\,r_J$, where r_J is the mean radius at the one bar level. Juno's magnetometer reveals the planet's internal magnetic field with unprecedented details. We combine the new zonal flow and magnetic field models with an updated electrical conductivity profile to assess the zonal wind induced dynamo action, concentrating on the region down to about $0.96\,r_J$ where the dynamo dynamics is dominated by Ohmic diffusion (Rm<1). Since the Dynamo action remains quasi-stationary it can reasonably be estimated. We predict that the locally induced radial field reaches rms values of about 10^{-6} T in this region and may just be detectable by the Juno mission. Very localized dynamo action and a distinct pattern that reflects the zonal wind system increases the chance to disentangle it from the background field. New estimate of the zonal flow related Ohmic heating show that they never exceed new revised predictions for the total dissipative heating in Jupiter and therefore cannot be used to constrain the depth on the zonal winds.

1. Introduction

Juno gravity measurements indicate that the speed of the equatorially antisymmetric zonal flow contributions must be significantly reduced at a depth of about 3000 km below the one bar level, which corresponds to a radius if $0.96\,r_J$ [4] and [5]. This conclusion likely extends to the equatorially symmetric wind contributions, which obey the same physical processes.

A lower depth of about $0.96\,r_J$ was already suggested previously [6] since the zonal-wind induced Ohmic heating would otherwise exceed the total heat emitted from Jupiter's interior. More recently, mean field dynamo models predict that the radial component of the related Locally Induced Field (LIF) may reach 1 % of the background field and could thus be detectable by the Juno magnetometer [1].

We readdress the question of zonal wind related dynamo action based on a new electrical conductivity profile [3], the new magnetic field model JRM09 [2], and two zonal Juno-based flow models [4, 5]. A third option of a geostrophic flow is also explored.

2. Method

We restrict our analysis to the region where the magnetic Reynolds number based on the magnetic diffusivity scale height remain smaller than one. For the flow models and electical conductivity models explores here, this roughly correspond to the region above $0.965\,r_J$. Dynamo simulation [7] confirm that the dynamo action in the region remains quasi-stationary and the the current density $\mathbf{j}$ obeys the simplified Ohm's law

$$\mathbf{j} = \sigma\left(\mathbf{U}\times\tilde{\mathbf{B}}\right) \tag{1}$$

where σ is the electrical conductivity, $\mathbf{U}$ the zonal flow and $\tilde{\mathbf{B}}$ the background field, which can be deduced from downward continuing the JRM09 model under the potential field assumption.

The locally induced field can then reasonably be estimated by uncurling $\mathbf{j} = 1/\mu\nabla\times\mathbf{B}$, assuming that the gradients imposed by the electrical conductivity profile dominate derivatives.

A reassessment of the energy budget shows that the total Ohmic heating should be balanced by the convective power input. The power input can be estimated to 1.2×10^{18} W, which is 3.6 times larger than the heat flux out of the planet. Zonal flow related Ohmic heating can simply be estimated based on the electrical current estimates.

3. Results

The maximum dynamo action is always reached at the bottom of our considered layer, i. .e. at r_1 where the magnetic Reynolds number reaches one. Radius

r_1 lies somewhere between $0.96\,r_J$ and $0.97\,r_J$, depending on flow and conductivity model. The locally induced field (LIF) is rather small scale and reaches rms amplitudes which are three orders of magnitude smaller than the background (or surface) field.

The LIF has a specific pattern that reflects the correlation of background field and the zonal zonal wind system. Figure (1) compares Jupiter field model JRM09 with the locally induced field. The LIF is particularly strong where the strong zonal winds around the equator meet the 'big blue spot' in the field model JRM09.

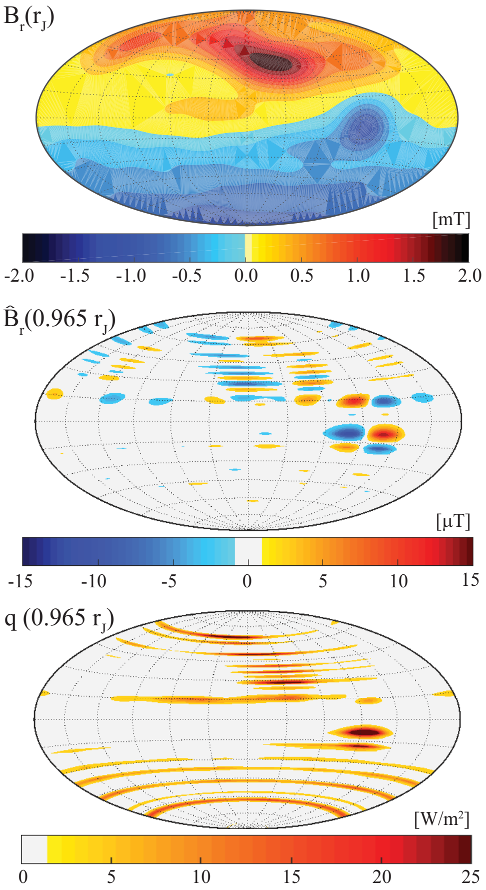

Figure 1: Panel a) Radial field in the Jupiter field model JRM09 [2]. Panel b) Estimated locally induced radial field for a given zonal flow model [5]. Panel c) Heat flux due to zonal flow induced Ohmic heating.

The total Ohmic heating never exceeds the estimate upper bound of 1.2×10^{18} W in the layer above r_1 considered here, even for our geostrophic flow model. The heat production can thus not serve as an additional constraint for the depth of the zonal winds. However, the Ohmic heating shows strong lateral variation illustrated in panel c) of figure (1). These may lead to local variations in temperature or dynamics that could be detectable by a spacecraft.

4. Summary and Conclusions

Zonal flow and magnetic field models constrained by Juno mission data were used to estimate the dynamo action of the zonal winds down to about $0.96\,r_J$, their anticipated depth. We predict a locally induced radial magnetic field which is about three orders of magnitude smaller than the background field. Though being rather weak, the specific small scale pattern, which reflects zonal winds and the background field, may help in its detection by a spacecraft. Similar conclusions hold for the Ohmic heating pattern. However, the total Ohmic heating never exceeds the newly estimated upper bound and cannot serve as an additional constraint for the depth of the zonal winds.

Acknowledgements

This work has been supported by the DFG special priority programs 'PlanetMag' (1448) and 'Diversity of Exoplanets' (SPP 1992).

References

[1] Cao, H. & Stevenson, D. J., J. Geophys. Res., Vol. 122, pp. 686-700, 2017

[2] Connerney, J. E. P., Kotsiaros, S., Oliversen, R. J., et al., Geophys. Res. Lett., Vol. 45, pp. 2590-2596, 2018

[3] French, M., Becker, A., Lorenzen, W., et al., Astrophys. J. Supp., Vol. 202, eid 5, 2012

[4] Kaspi, Y., Galanti, E., Hubbard, W. B., et al., Nature, 555, pp. 223-226, 2018

[5] Kong, D., Zhang, K., Schubert, G., & Anderson, J. D., Proc. Nat. Ac. Sci., Vol. 115, pp. 8499-8504, 2018

[6] Liu, J., Goldreich, P. M., & Stevenson, D. J., Icarus, Vol. 196, pp. 653-664, 2008

[7] Wicht, J., Gastine, T. and Duarte, L. D. V., J. Geophys. Res: Planets, doi: 10.1029/2018JE005759, 2019