EPSC Abstracts
Vol. 6, EPSC-DPS2011-236, 2011
EPSC-DPS Joint Meeting 2011

Polar spots in rapidly rotating stars: stellar wind and evolution of exoplanets

T.V. Zaqarashvili (1,5), R. Oliver (2), J.L. Ballester (2), M. Carbonell (3), M.L. Khodachenko (1), H. Lammer (1), M. Leitzinger (4) and P. Odert (4)

(1) Space Research Institute, Graz, Austria (2) Departament de Física, Universitat de les Illes Balears, Palma de Mallorca, Spain, (3) Departament de Matemàtiques i Informàtica, Universitat de les Illes Balears, Palma de Mallorca, Spain, (4) Karl-Franzens Universität Graz, Graz, Austria, (5) Abastumani Astrophysical Observatory, Ilia state University, Georgia

Abstract

We aim to study large-scale shallow water waves in the tachoclines of rapidly rotating stars and their connection to the periodicity and the formation of starspots at high latitudes. Shallow water magnetohydrodynamic equations are used to study the dynamics of large-scale waves at the rapidly rotating stellar tachoclines in the presence of toroidal magnetic field. We found that low frequency magnetic Rossby waves tend to locate at poles, but high frequency magnetic Poincaré waves are concentrated near the equator in rapidly rotating stars. Unstable magnetic Rossby waves may lead to the local enhancement of magnetic flux at high latitudes of tachoclines in rapidly rotating stars. The enhanced magnetic flux may rise upwards due to the magnetic buoyancy in the form of tubes and appear as starspots at polar regions. Magnetic Rossby waves may also cause observed short term periodicity in the stellar magnetic activity. These results have important implications for the evolution of the stellar wind and exoplanets in young Sun-like stars.

1. Introduction

Rotation and convection lead to stellar dynamo activity, which results in the strong concentration of magnetic fields in the surface. These magnetic features are called *starspots* and they represent the sunspot analog on other stars. It is generally accepted that starspots appear at all latitudes in rapidly rotating stars: at polar regions [1] and at the equators [2]. Observation of starspots at all latitudes complicates the explanation of their appearance. Magnetic tubes may tend to the polar regions due to the Coriolis force acting during the rising across the convection zone [3]. On the other hand, the transport of photospheric magnetic flux towards the polar regions by meridional advection may also lead to the appearance of all-latitude spots [4].

2. Results

Here we study the linear dynamics of shallow water waves in rapidly rotating stellar tachoclines with toroidal magnetic field. We derive analytical dispersion relations and find the dependence of the wave frequencies on various parameters, which are expressed by angular velocity, reduced gravity and magnetic field strength. Then we plot the latitudinal structure of the first few harmonics. We find that high frequency magnetic Poincaré waves are located mainly at low latitudes, but low frequency magnetic Rossby waves are located near the poles in rapid rotators. The latitudinal differential rotation and toroidal magnetic field may lead to the instability of magnetic Rossby waves, which may enhance the magnetic flux at polar regions. Then the enhanced magnetic flux may rise upwards due to the magnetic buoyancy and appear as polar spots.

3. Polar spots, young stellar winds and impact on early planetary environments

With enhanced high-energy emissions and frequent flares young stars are also expected to have more powerful stellar winds [5]. Polar starspots may completely change the structure of stellar winds in the rapidly rotating, young solar analogs. It is known that the dense slow solar wind is initiated above active regions with closed magnetic field lines at low latitudes, while the fast solar wind originates mostly at high-latitude coronal holes with opened field lines. The polar appearance of starspots may force the slow stellar wind to flow from the polar regions i.e. almost parallel to the rotation axis. Then this may change the current views about the magnetic braking of stellar rotation in the young age of their evolution.

Stellar magnetic activity has tremendous influence on the planetary evolution. Coronal mass ejections in young, more active stars may lead to the erosion of atmospheres in exoplanets [6]. On the other hand, the polar spots in young stars could change the structure of coronal magnetic fields as well as the formation of prominences, which are the actual cause of CMEs. The polar location of prominences may trigger polar CMEs, which propagate significantly out off the ecliptic plane. Then the propagation of shocks and magnetic ropes/clouds out off the ecliptic plane may completely change the current picture of stellar-planetary interaction.

The magnetic Rossby waves (Rossby waves in magnetised fluids) may cause the observed intermediate periodicity in the stellar activity similar to the solar case [7].

4. Summary and Conclusions

Large-scale magnetic Rossby waves may play significant role in the dynamics of rapidly rotating stars. Here we study the shallow water MHD waves in the tachoclines of rapid rotators. We consider a rotating spherical coordinate system and a toroidal magnetic field in the tachocline. We derived the dispersion relations for high (magnetic Poincaré waves) and low (magnetic Rossby waves) frequency spectrum separately in the approximation of rapid rotation. We found that magnetic Rossby waves tend to locate mainly at the polar regions, while magnetic Poincaré waves are located at low latitudes. Magnetic Rossby waves may lead to the enhancement of magnetic flux at the polar regions and trigger its eruption towards the surface in the form of magnetic flux tubes. Then the magnetic tubes may form starspots at the polar region. Magnetic Rossby waves may cause the observed intermediate period oscillations in the magnetic activity of rapidly rotating stars, such as young solar proxies. The polar location of prominences during the fast rotating period of the young star may trigger polar CMEs, which propagate significantly out off the ecliptic plane and completely change the current picture of the solar/stellar plasma interaction with young planetary environments.

Acknowledgements

The work was supported by the Austrian Fonds zur Förderung der wissenschaftlichen Forschung (projects P21197-N16 and P22950-N16). T.V.Z. acknowledges financial support from the Georgian National Science Foundation (under grant GNSF/ST09/4-310). R.O., M.C. and J.L.B. acknowledge financial support from grant AYA2006-07637 and Feder funds.

References

[1] Strassmeier, K.G., Astrophys. J., 348, 682, 1990.

[2] Donati, J.F., Collier Cameron, A., Hussain, G.A.J. & Semel, M., Monthly Not. Roy. Astron. Soc., 302, 437, 1999

[3] Schüssler, M. and Solanki, S.A., Astron. Astrophys., 264, 13, 1992

[4] Schrijver, K.J. & Title, A.M., Astrophys. J., 551, 1099, 2001

[5] Wood, B.E., Müller, H.-R., Zank, G. P., Linsky, J. L., Astrophys. J., 574, 412, 2002

[6] Khodachenko, M.L. et al., Coronal Mass Ejection (CME) Activity of Low Mass M Stars as An Important Factor for The Habitability of Terrestrial Exoplanets. I. CME Impact on Expected Magnetospheres of Earth-Like Exoplanets in Close-In Habitable Zones, Astrobiology, 7, 167-184, 2007.

[7] Zaqarashvili, T.V., Carbonell, M., Oliver, R., and Ballester, J.L., Magnetic Rossby waves in the solar tachocline and Rieger-type periodicities, ApJ, 709, 749-758, 2010.