Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Study of starspots in fully convective stars using three dimensional MHD simulations

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Abstract. Concentrated magnetic structures such as sunspots and starspots play a fundamental role in driving solar and stellar activity. However, as opposed to the sun, observations as well as numerical simulations have shown that stellar spots are usually formed as high-latitude patches extended over wide areas. Using a fully spectral magnetohydrodynamic (MHD) code, we simulate polar starspots produced by self-consistent dynamo action in rapidly rotating convective shells. We carry out high resolution simulations and investigate various properties related to stellar dynamics which lead to starspot formation.

Keywords. magnetic fields, MHD, stars: spots, stellar dynamics

1. Introduction

Spots on solar-stellar surfaces are formed when the magnetic field produced by self-consistent dynamo action is strong enough to be subjected to the buoyancy instability in a particular region. It is also important to note that spots can be cohesively maintained if the magnetic field within them is strong enough to quench the convective flows in the localized region where they form. We carry out three dimensional full MHD simulations in rapidly rotating convective shells using a fully spectral code to investigate starspot dynamics. Specifically in this work, we explore the importance of density stratification in the sustenance of dynamo action and polar spot formation.

2. Simulations & Results

We consider anelastic approximation where the reference state corresponds to an adiabatic ideal gas. The density ρ and temperature T are related as $\rho = T^m$ where m is the polytropic index. For linearly varying gravity, temperature is given by $T = 1 - \frac{Di}{2(1-\eta)}\left(\frac{r^2}{r_o^2} - 1\right)$, where $Di = 2\frac{e^{N_\rho/m}-1}{1+\eta}$ is the dissipation number, $N_\rho = \log\frac{\rho(r_i)}{\rho(r_o)}$ is the density stratification and $\eta = r_i/r_o$ is the aspect ratio. The governing MHD equations used are as given in Yadav *et al.* (2015). The dimensionless control parameters are Ekman number (E), thermal Prandtl number (Pr), magnetic Prandtl number (Pm) and Rayleigh number (Ra) respectively. The three dimensional full MHD simulations are carried out using a fully spectral code MagIC [Wicht (2002)] in a spherical shell of aspect ratio $\eta = 0.35$ with a grid resolution of $512 \times 256 \times 97$ ($N_\phi \times N_\theta \times N_r$) and parameter values $E = 10^{-4}$, $Pr = 10$, $Pm = 10$, $Ra = 10^8$, and $m = 2$ for three different values of density stratification ($N_\rho = 3$, 5 and 7).

The density stratification is a prerequisite for the formation of spots as it generates differential rotation. Self-consistent dynamo action is observed for $N_\rho = 3$ and 5. $N_\rho = 7$

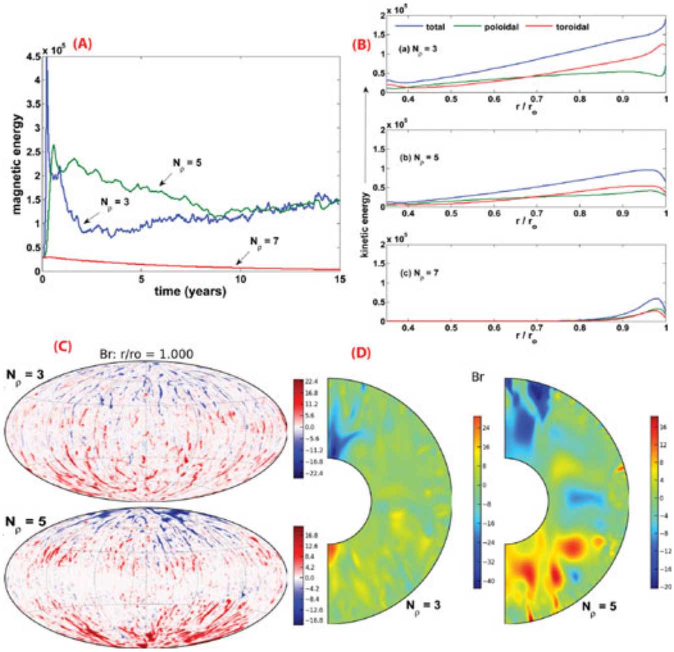

Figure 1. (A) Temporal evolution of outer core magnetic energy for three different density stratifications (N_ρ). (B) Radial variation of kinetic energy averaged over θ, ϕ and time for $N_\rho = 3$, 5 and 7. Plots of the radial component of the magnetic field B_r plotted (C) on the stellar surface and (D) in a meridional slice, for $N_\rho = 3$ and 5. $N_\rho = 5$ shows prominent spots.

does not produce sustained dynamo action [Fig. 1 (A)]. For $N_\rho = 3$, the flow is too strong to be quenched [Fig. 1 (B)] and hence, the generated magnetic field is unable to produce prominent spots on the stellar surface. For $N_\rho = 5$, large patches are observed at high latitudes [Yadav *et al.* (2015)], which are formed by accumulation of smaller structures [Fig. 1 (C) and (D)]. The spots diffuse out and re-accumulate. For $N_\rho = 7$, the high density contrast does not allow flows strong enough to maintain dynamo action.

3. Conclusions

We conclude that the mechanism of starspot formation and their maintenance is dictated by the density stratification in stellar convection zones. The right density stratification generates optimum plasma flow conditions which are suitable for dynamo action as well as sustenance of stellar spots. We also find that the maintenance of coherent stellar spots is subject to dynamic phenomena involving changes in the structures of these polar spots [Rempel & Cheung (2014)].

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References

Brun, A. S., García, R. A., Houdek, G., Nandy, D., & Pinsonneault, M. 2015, *Space Sci. Rev.*, 196, 303

Rempel, M. & Cheung, M. C. M. 2014, *ApJ*, 785, 90

Wicht, J. 2002, *Phys. Earth Planet. Interiors*, 132, 281

Yadav, R. K., Gastine, T., Christensen, U. R., & Reiners, A. 2015, *A&A*, 573, A68

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