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Numerical Modeling of Solar and Stellar Dynamos
- Current Status and Future Perspectives -

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An ultimate goal of the solar and stellar interior physics is to reproduce starspots self-consistently from magnetic fluxes generated and sustained by some sort of dynamo process in the stellar interior under the framework of the magnetohydrodynamics (MHD). We now approach the mystery of the stellar magnetism through the numerical modeling and simulation of MHD convections.

A substantial progress has been made in the past decade. Several numerical studies have succeeded to demonstrate that large-scale magnetic field with qusi-periodic polarity reversals are spontaneously organized in spherical-shell MHD convections (e.g, Ghizaru et al. 2010; Kapyla et al. 2012; Masada et al. 2013; Augustson et al. 2015; Yadav et al. 2015; Hotta et al. 2016).

Despite some differences in the setup and method, there is a common outcome of convective dynamo simulation in these studies: diffuse, non-concentrated, magnetic flux extending over the convection zone and/or the tachocline instead of the "confined magnetic flux bundle" which is expected in and is the core of the standard solar/stellar dynamo scenario (see, e.g., Charbonneau 2010).

Although the magnetic flux emergence-like events from dynamo-generated distributed magnetic fluxes have been observed in some numerical models (e.g., Nelson et al. 2013; Fan & Fang 2014), still no one knows whether they are occurring in the actual Sun and stars, i.e., the formation mehanism of the starspots at the surface is still a matter of considerable debate. There is still a large gap between the numerical models of the convective dynamo in the interior and the observable starspots emergence process at the stellar surface. Bridging the gap between them should be the next milestone challenge for the solar and stellar interior physics.

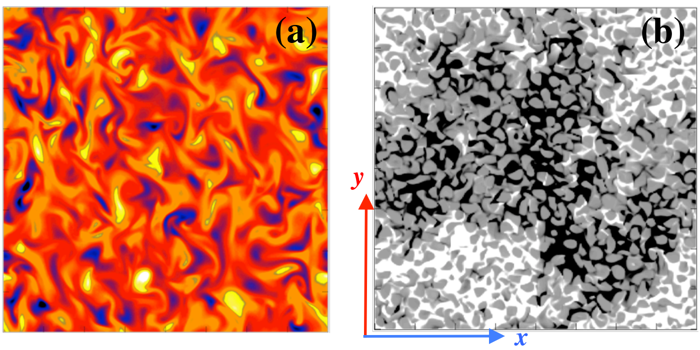

Fig 2. Surface magnetic structures of the (a) weakly-stratified (MS14) and (b) strongly-stratified (MS16) convective dynamo models. The vertical component (z-direction) of the magnetic field is visualized in both panels.

In the talk, I review the current status of the numerical modeling of solar and stellar dynamos with focusing on the features of the convective dynamo processs realized in recent simulation studies. Then, I report our first step for bridging the gap between the dynamo in the interior and the starspots formation at the stellar surface, i.e., our first successful simulation of the spontaneous formation of surface magnetic structures from large-scale dynamo in strongly-stratified convection (Masada & Sano 2016). A possible physical mechanism of the surface magnetic structure formation is also discussed in relation to the strength of the rotation and density stratification.

References:

1. Ghizaru et al. 2010, ApJ, 715, L133
2. Kapyla et al. 2012, ApJ, 755, L22
3. Masada et al. 2013, ApJ, 778, 11
4. Augustson et al. 2015, ApJ, 809, 149
5. Yadav et al. 2015, A&A, 573, A68
6. Hotta et al. 2016, Science, 351, 6280
7. Charbonneau 2010, LRSP, 7, 3
8. Nelson et al. 2013, ApJ, 762, 73
9. Fan & Fang 2014, ApJ, 789, 35
10. Masada & Sano 2014, ApJL, 794, L6 (MS14)
11. Masada & Sano 2016, ApJL, 822, L22 (MS16)

Fig 1. Granular convection seen in a strongly-stratified stellar atmosphere model (MS16)