Numerical Simulations of Solar Magnetism : Organization of Large-scale Magnetic Structure in Turbulent Stratified Convection

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It is well-known that Sunspots are the surface manifestations of an underlying large-scale magnetic field within the Sun. However, since it is not yet possible to carry out numerical simulation in parameter regimes that accurately reproduce the solar interior, the question of the origin of sunspots remains unresolved. An ultimate goal of the solar interior physics is to reproduce them self-consistently from magnetic fluxes generated and maintained by some sort of dynamo process in the solar interior under the framework of the magnetohydrodynamics.

A substantial progress has been made in the past decade. Several numerical studies have succeeded to demonstrate that large-scale magnetic field with quasi-periodic polarity reversals are spontaneously organized in spherical-shell MHD convections (e.g, Ghizaru et al. 2010; Kapyla et al. 2012; Hotta et al. 2016). Despite some differences in the setup and method, there is a common outcome of these convective dynamo simulations: diffuse, non-concentrated, magnetic flux extending over the convection zone instead of the "confined magnetic flux bundle" which is expected in the standard solar dynamo scenario.

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, i.e., the formation mechanism of the sunspots 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 sunspot emergence process at the surface.

In this talk, I first review the current status of the numerical modeling of solar dynamos with focusing on the features of the convective dynamo process realized in recent simulation studies. Then, I will report our study for bridging the gap between the dynamo in the interior and the sunspot formation at the solar surface, i.e., our first successful simulation of the spontaneous formation of surface magnetic structures from large-scale dynamo in a strongly-stratified convection (Masada & Sano 2016, see also Masada & Sano 2014a,b). A possible mechanism of the surface magnetic structure formation is also discussed in relation to the strength of the rotation and density stratification.