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# High Resolution Simulations of Solar Convection Zone and Dynamo

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The solar convection zone is filled with the turbulent thermal convection in a highly stratified plasma. This turbulent motion of the plasma is responsible for the generation of the magnetic field, which causes the sunspots, i.e., the strong magnetic region at the solar surface. The 11-year solar cycle is also maintained.

Due to the unavailability of the detailed observation of the solar interior, numerical calculation is a powerful tool to understand the turbulence and the magnetic field. We adopt a method called the Reduced Speed of Sound Technique (RSST) in which the effective speed of sound is reduced and we can relax the CFL condition for the time step. The massive supercomputers are efficiently used with using the RSST.

We carry out high resolution calculations of the convection zone for the generation of the magnetic field (Figure 1). It is known that the large-scale magnetic field is generated in combination of the differential rotation and the anisotropic turbulence in the low resolution. When the resolution is increased, i.e., the kinetic viscosity and the magnetic diffusivity are decreased, the small-scale chaotic turbulence is generated and the large-scale magnetic field is destructed. In the real solar convection zone, the magnetic diffusivity is much smaller than those achieved in the numerical calculations. while large-scale magnetic field is indicated. Generation mechanism(s) for such magnetic field in high resolution situation must be understood. In a higher resolution calculation with the RSST, we find that the large-scale magnetic field is again recovered. When the resolution is high enough, small-scale magnetic field is amplified efficiently and the magnetic energy exceeds the kinetic energy in the small-scale. Thus, the Lorentz force suppresses the small-scale motion which destroys the large-scale magnetic field [1].

Although the construction mechanism of the large-scale magnetic field begins to be understood as explained above, these are not connected to the generation of the sunspot at the surface, since the surface region is not included in all the calculations due to numerical difficulties caused from the strong stratification. With developing the method and a new numerical code, we, for the first time, include the photosphere in the deep convection zone (Figure 2). The details of the calculation are shown in the talk.

References
1. H. Hotta, M. Rempel, T. Yokoyama, *Science* **351**, 1427 (2016).

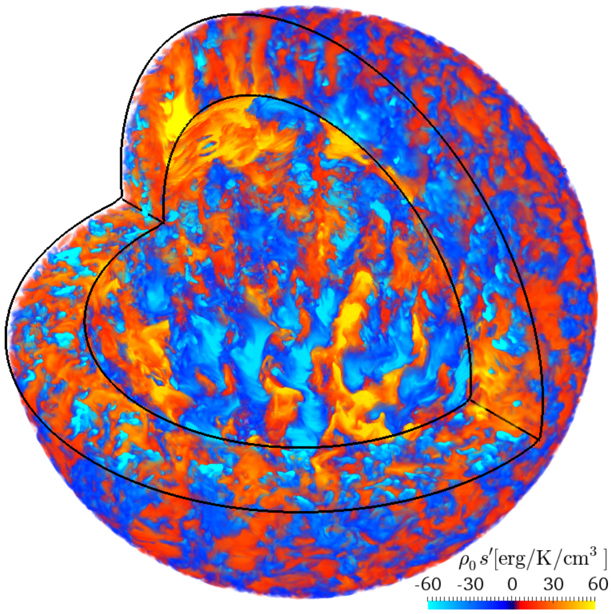


Figure 1: Visualization of full spherical calculation of the solar convection zone. Perturbation of the entropy is shown.

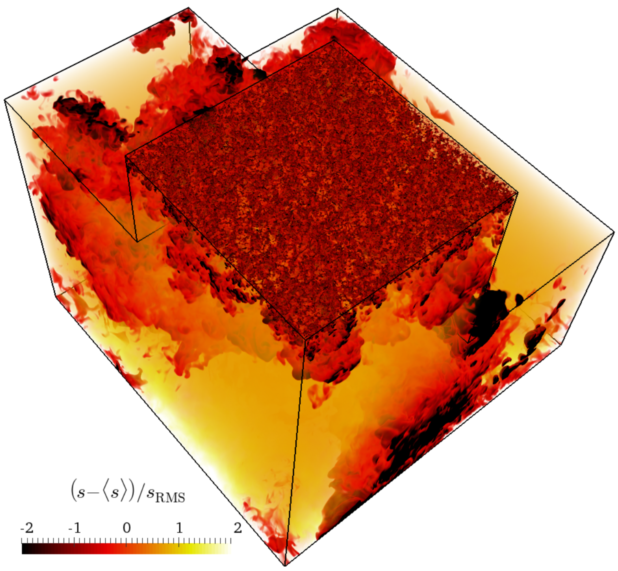


Figure 2: Visualization of a calculation including the solar surface. Perturbation of the entropy is shown.