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Solar Magnetism: Exploration with Local Convective Dynamo Modeling
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A grand challenge in astrophysics is the origin of self-organizing properties of the magnetic field in highly turbulent flows. The solar magnetism is the front line in this area. The solar magnetic field shows a remarkable spatiotemporal coherence though it is generated by turbulent convective dynamo operating within its interior. Our understanding on the solar magnetism has been accelerated over the past decade in response to broadening, deepening and refining of numerical dynamo modelings. However, it is still unclear what dynamo mode is excited in the solar interior and how it regulates magnetic cycle with equatorward sunspot migration and periodicity of 22 years. To gain a deeper understanding of the solar dynamo mechanism, we are currently working on the convective dynamo simulation in a local stratified system.

Here we report a successful direct numerical simulation (DNS) of oscillatory large-scale dynamo spontaneously excited in a rotating stratified convection. The figure shown below is the simulation result; the time-radius diagram of the mean horizontal magnetic fields. Our simulation model consists of three layers like as the solar interior: bottom and top stably stratified layers and mid-convection zone (the area between white-dashed lines). It is found that the large-scale magnetic field is organized in the bulk of the convection zone and shows a well-regulated oscillatory behavior. The mean-field component is the strongest at around the mid-convection zone and propagates from there to top and base of the convection zone. The polarity is then gradually reversed over the period of about 200 convective turn-over time. It is noteworthy that there is a phase difference of about $\pi/2$ between B_x and B_y . The simulated spatiotemporal evolution of the large-scale magnetic field is quite reminiscent of the solar butterfly diagram although there is a difference in the propagation direction between the simulated field and the sunspot field.

To explore the underlying dynamo mechanism, we construct a mean-field electrodynamics model with dynamo coefficients directly computed from the DNS. The nonlinear back-reaction of the mean-field on the dynamo coefficients (both α- and η-quenching) is self-consistently taken into account. We demonstrate that the simulated large-scale dynamo is quantitatively reproduced by our DNS-driven mean-field dynamo model, and is interpreted as a manifestation of oscillatory α^2-dynamo mode. We will describe the basic physics which characterizes the cycle period and amplitude of the large-scale magnetic field sustained by the α^2-dynamo, and then discuss its playing role in the solar magnetism. This is the first to quantitatively demonstrate the presence of the oscillatory α^2-dynamo mode as a natural outcome of the rotating stratified convection, and raises an unignorable question about the conventional solar dynamo model relying strongly on the profiles of the mean flows, such as the differential rotation and meridional circulation.

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