論文の内容の要旨
論文題目 Thermal Convection, Magnetic Field, and Differential Rotation in Solar-type Stars (太陽型星における熱対流、磁場、そして差動回転)
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Turbulent thermal convection fills the solar convection zone. Understanding thermal convection is crucial for the transport of energy and angular momentum, and the generation and the transport of magnetic field. The central interest in this thesis is the interaction of small- and large-scale convection in the solar and stellar convection zone. To this end, we develop a significantly efficient numerical code that is able to cover broad temporal and spatial scales. We adopt the reduced speed of sound technique (RSST). The RSST is simple to implement and requires only local communication in parallel computations. In addition, this method allows performing simulations without neglecting important physical processes including the solar near surface and achieves small-scale convection in the global domain.

Using the numerical code, we perform non-rotating high-resolution calculations of solar global convection, which resolve convective scales of less than 10 Mm. The main conclusions of this study are the following. 1. The small-scale downflows generated in the near surface layer penetrate down to deeper layers and excite small-scale turbulence in the region of $> 0.9R_{\odot}$, where $R_{\odot}$ is the solar radius. 2. In the deeper convection zone ($< 0.9R_{\odot}$), the convection is not affected by the location of the upper boundary. 3. Using an LES (Large Eddy Simulation) approach we achieved small-scale dynamo action and maintained a field of $0.15 - 0.25B_{\mathrm{eq}}$ throughout the convection zone, where B_{eq} is the equipartition magnetic field to the kinetic energy. 4. The overall dynamo efficiency significantly varies in the convection zone as a consequence of the downward directed Poynting flux and the depth vari-

ation in the intrinsic convective scales. For a fixed numerical resolution the dynamo relevant scales are better resolved in the deeper convection zone and are therefore less affected by numerical diffusivity, i.e. the effective Reynolds numbers are larger.

Then, we carry out high-resolution calculation of thermal convection in the spherical shell with rotation to reproduce the near surface shear layer (NSSL). It is thought that the NSSL is maintained by thermal convection for small spatial scales and short time scales, which causes a weak rotational influence. The calculation with the RSST succeeds in including such a small scale as well as large-scale convection and the NSSL is reproduced especially at high latitude. The maintenance mechanisms are the following. The Reynolds stress under the weak influence of the rotation transports the angular momentum radially inward. Regarding the dynamical balance on the meridional plane, in the high latitude positive correlation $\langle v_r' v_\theta' \rangle$ is generated by the poleward meridional flow whose amplitude increases with the radius in the NSSL and negative correlation $\langle v_r' v_\theta' \rangle$ is generated by the Coriolis force in the deep convection zone. The force caused by the Reynolds stress compensates the Coriolis force in the NSSL.