Role of the Effective Prandtl Number on the Solar Convective Amplitude and Stratification, and Angular Momentum Transport

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Abstract

We have investigated a possible physical process to alleviate the huge discrepancy of the large-scale solar convective velocity between numerical simulations and local helioseismic observations (convective conundrum). It was shown for the first time that, if the solar convection is essentially magnetized and operates in an effectively high Prandtl number regime, the low wavenumber convective power can be efficiently suppressed owing to the enhanced subadiabatic layer in the deep convection zone. On the other hand, it was also found that the high-Prandtl number convection tends to transport the angular momentum radially inward, leading to a differential rotation inconsistent with observations. This study strongly suggests that the problems of convective heat transport and the angular momentum transport consists two sides of the same coin and must be solved integratedly.

Reasons for using of JSS2

Large-scale convection simulations covering several tens of deep density scale heights were required to investigate the behavior of the low wavenumber convective power.

Achievements of the Year

To begin, we have developed a new numerical simulation code from scratch to solve the fully-compressible thermal convection in a three-dimensional cartesian box.

After the validity of the numerical code was verified, several sets of large-scale convection simulations were conducted using JAXA/JSS2 (Figure.1, Movie. 1).

It is shown that, in an effectively high-Prandtl number regime, the thermal convection is dominated by strong downflow plumes that can transport heat in a highly non-local manner.　As a result, a subadiabatic (convectively-stable) layer formed near the base owing to the continuous deposition of low entropy meterials is enhanced and extended vertically upward.

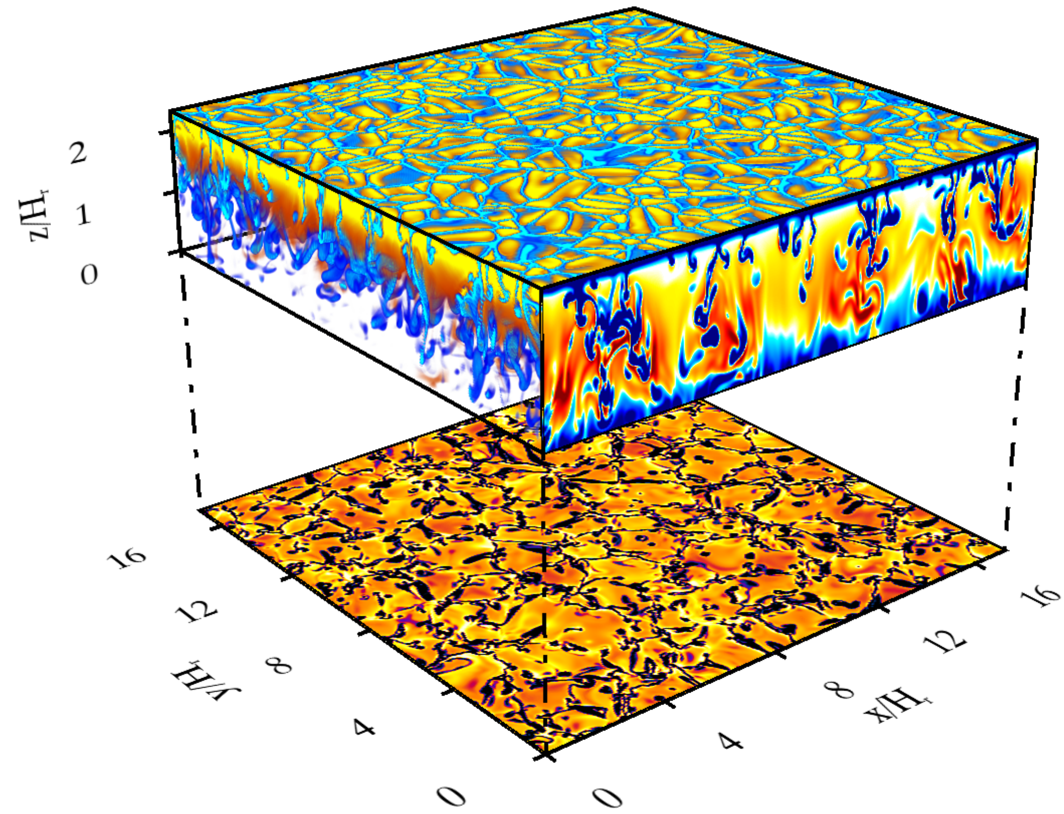

Fig.1 Entropy structure of the high-Prandtl number thermal convection. The subsurface horizontal cut is shown at the bottom layer.

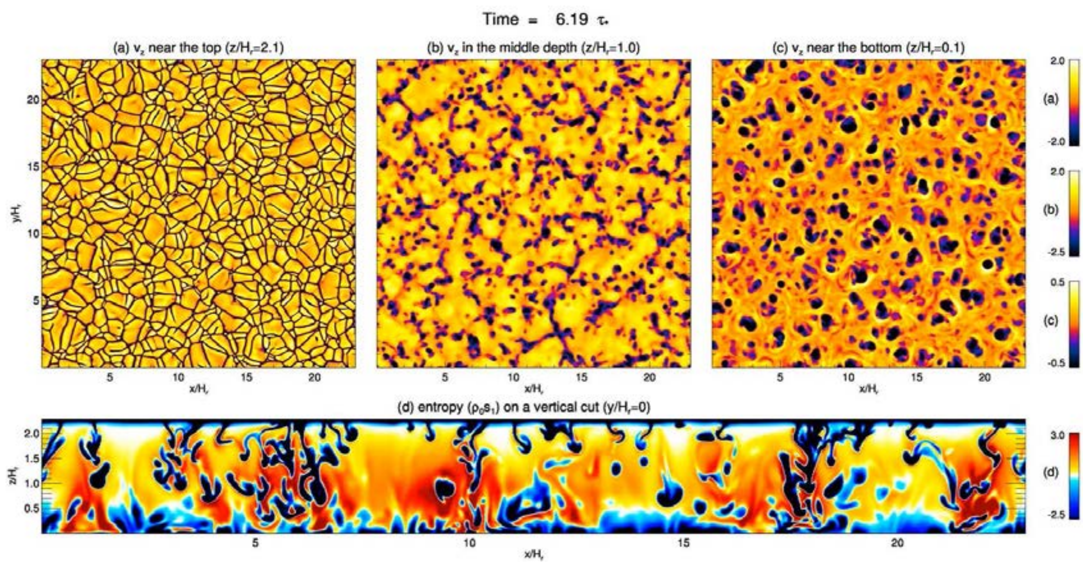

Fig.2 Upper panels: vertical velocity at (a) the surface, (b) middle convection zone, and (c) base. Lower panel: vertical cut of the entropy.

Publications

- Peer-reviewed papers

1) Y. Bekki, H. Hotta, and T. Yokoyama., "Convective velocity suppression via the enhancement of the subadiabatic layer: Role of the effective Prandtl number", The Astrophysical Journal, 851;74 (2017)

- Oral Presentations

1) Y. Bekki, H. Hotta, and T. Yokoyama., "Effects of the enhanced subadiabatic layer in effectively high-Prandtl number thermal convection", AAS 48th SPD Meeting, Portland, OR, USA. (2017. 8. 25).
2) Y. Bekki, H. Hotta, and T. Yokoyama., "Effects of Prandtl number on stratified thermal convection with and without rotation", Helicity Thinkshop 3, Tokyo, Japan. (2017. 11. 21).

- Poster Presentation

1) Y. Bekki, H. Hotta, and T. Yokoyama., "Deep convective amplitude and stratification in an effectively high-Prandtl number thermal convection", IAU Symposium 340, Jaipur, India. (2018. 2. 19-24).

Usage of JSS2

- **Computational Information**

Parallelization Methods	MPI
Thread Parallelization Methods	N/A
Number of Processes	256 - 1024
Elapsed Time per Case	120.00 hours

- **Resources Used**

Fraction of Usage in Total Resources*1 (%): 0.05

Details

Computing Resources		
System Name	Amount of Core Time (core x hours)	Fraction of Usage*2 (%)
SORA-MA	335,961.12	0.04
SORA-PP	0.00	0.00
SORA-LM	0.00	0.00
SORA-TPP	0.00	0.00

File System Resources		
File System Name	Storage assigned(GiB)	Fraction of Usage*2 (%)
/home	100.14	0.07
/data	5,769.73	0.11
/ltmp	2,929.69	0.22

Archiver Resources		
Archiver System Name	Storage used(TiB)	Fraction of Usage*2 (%)
J-SPACE	0.00	0.00

*1 Fraction of Usage in Total Resources: Weighted average of three resource types (computing, file system, and archiver)

*2 Fraction of Usage: Percentage of usage relative to each resource used in one year