5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

High resolution simulation of solar convection zone in Fugaku

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1. Introduction

It is widely known for several hundred years that the solar equator is rotating faster than the polar region. Helioseismology has been developed in the last three decades and revealed the detailed rotation profile, called differential rotation [1]. Solar physicists think that the thermal convection in the solar interior transports the angular momentum and constructs the differential rotation. Many numerical studies are conducted to understand the generation mechanism of the differential rotation. While early-day numerical simulations succeeded in obtaining the solar-like differential rotation, i.e., the fast equator [2], recent high-resolution simulations tends to become anti-solar regime, i.e., the fast pole. This differential rotation is obtained because the convection velocity in the solar interior is probably faster than the real solar value. This problem is called the "Convective conundrum," which states the big difference between observations and numerical simulations [3]. Here we use the Japanese flag-ship supercomputer, Fugaku, to attack the problem.

2. Model

We carry out unprecedentedly high-resolution magnetohydrodynamic simulations for the solar convection zone. The whole sphere is covered with the Yin-Yang grid [4]. The radial domain extends from the base of the convection zone ($0.71R_\odot$) to the near-surface ($0.96R_\odot$), where $R_\odot$ is the solar radius. Three cases with different resolutions are prepared that is High: $384 \times 3072 \times 6144$, Middle: $192 \times 1536 \times 3072$, and Low: $96 \times 768 \times 1536$ in the ordinary spherical geometry. We adopt the solar parameters, such as the solar rotation rate and the solar luminosity, to reproduce the solar situation as precisely as possible.

3. Result

Figure 1 shows the obtained differential rotation. In the Low case (panel a), the polar region is rotating faster than the equator, consistent with the previous result but is different from the actual solar rotation. With increasing the resolution (panels b and c), the rotation profile becomes similar to the solar one. In the High case, the turbulent magnetic energy well exceeds the kinetic energy. We find that the magnetic field has a significant role in transporting the angular momentum.

4. Conclusion

For the first time, we reproduce the solar differential rotation with the solar parameters without using any manipulation. The sophisticated treatment of the convection and the magnetic field leads to an unprecedented situation of the solar convection zone.

Reference

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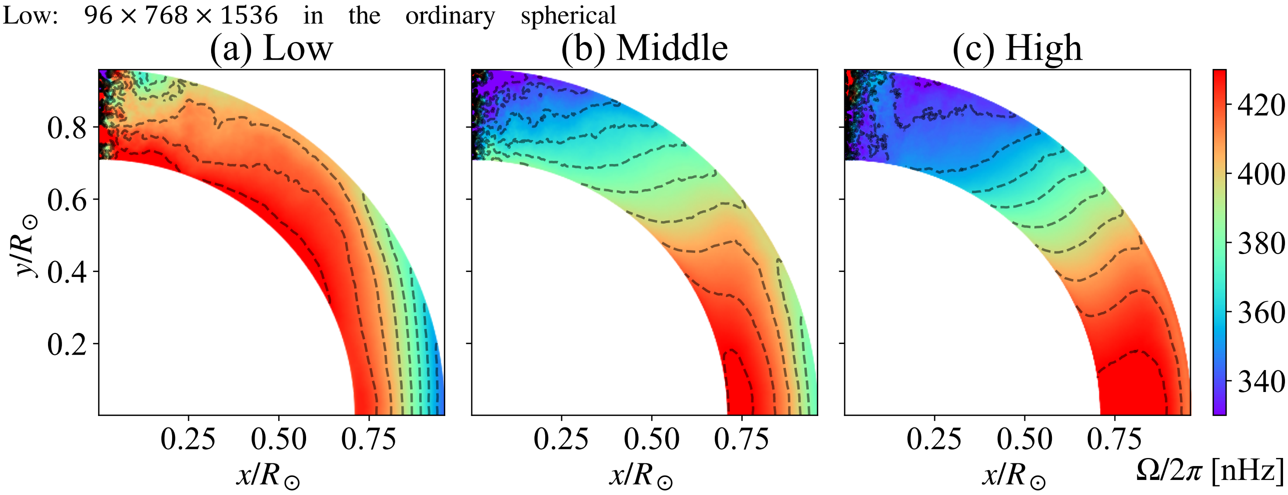

Figure 1 Dependence of the differential rotation on the resolution is shown. Panels a, b and c show the results from Low, Middle, and High cases.