6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Inertial range of magnetorotational turbulence: reduced magnetohydrodynamics and ultra-high resolution simulations

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Turbulence driven by magnetorotational instability (MRI) has long been believed to play a central role in angular momentum transport and plasma heating in astrophysical accretion flows [1,2]. Despite the prodigious amounts of theoretical and numerical studies, there are many open questions in magnetorotational turbulence. For example, what is the scaling of the turbulent spectra? What is the partition of turbulent energy between magnetohydrodynamic (MHD) modes?

In this study, we aim to address these problems using two approaches, reduced MHD and ultra-high resolution simulations of full MHD. For the former, we simplify the MHD equations by assuming the presence of a mean magnetic field in the near-azimuthal direction [3]. Doing so enables us to access the inertial range of MRI turbulence at a relatively cheap numerical cost. Solving the reduced MHD, we show that (1) both magnetic and kinetic energy spectra converge to $k^{-3/2}$ (k is the wavenumber) and (2) slow-mode-like fluctuations dominate the Alfvénic fluctuations by a factor of two.

As for the second approach, i.e, ultra-high resolution simulations, we use a pseudospectral code CALLIOPE [4] to solve incompressible MHD in local shearing coordinates. We simulate the MRI turbulence with unprecedented high resolution at Fugaku, the Japanese flagship supercomputer. Previously, it has been known that the magnetic spectrum is much steeper than $k^{-5/3}$, while the kinetic spectrum is close to $k^{-3/2}$. Our ultra-high resolution simulation shows a break in the magnetic spectrum beyond which the spectrum is almost $k^{-3/2}$. Therefore, both the magnetic and the kinetic spectra are $k^{-3/2}$, indicating that the inertial range is reached. Furthermore, we decomposed the magnetic field and the flow field to Alfvénic and pseudo-Alfvénic (high beta limit of slow modes) fluctuations. The decomposed spectra resemble the spectra obtained by the reduced MHD simulations (indeed, the pseudo-Alfvénic fluctuations are twice as large as the Alfvénic fluctuations). These results support the validity of reduced MHD approximations with near-azimuthal mean fields.

References
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