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Three-dimensional simulation of the fast solar wind driven by compressional MHD turbulence

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Large-amplitude fluctuations with a broadband energy spectrum extending from MHD to electron scales are observed to exist in the solar wind[1]. In the near-Sun solar wind, turbulence is believed to heat and accelerate the plasma. Understanding the nature and evolution of (MHD) turbulence is thus crucial to clarify how the solar wind is formed. Most of the previous models ignore the compressional mode but focus on Alfvén waves in discussing solar wind turbulence. However, the solar wind acceleration region is found to exhibit large density fluctuation[2,3] that appear to promote the evolution of turbulence[4], and therefore, one needs to take into account the plasma compressibility.

Motivated by the fact plasma compressibility possibly plays a crucial role, we, for the first time, performed a 3D compressible MHD simulation of the solar wind. The solar wind acceleration by turbulence and its feedback to turbulence is solved simultaneously with an observationally constrained boundary condition.

Figure 1 shows snapshots of the simulation in the meridional (vertical) plane. The maximum temperature exceeds one million Kelvin and the termination speed is beyond 600 km s^{-1}, reproducing the properties of fast solar wind. The structures of upward and downward Alfvén waves indicate the imbalanced nature of the turbulence: minor (downward) wave possesses more chaotic structure than major (upward) wave. Such a structure difference is predicted by a model of imbalanced (cross helical) MHD turbulence[5].

The origin and role of density fluctuation are seen in Figure 2. Panel (b) shows the spatial correlation between the amplitude of density fluctuation and the growth rate of Alfvén-wave instability (PDI) that generates density fluctuation. Panel (c) shows that density fluctuation enhances the wave reflection rate by a factor of 10. From these two results, we conclude that Alfvén waves are reflected by PDI. Since the reflection of Alfvén waves drives AWT, our model can be called PDI-driven AWT model.

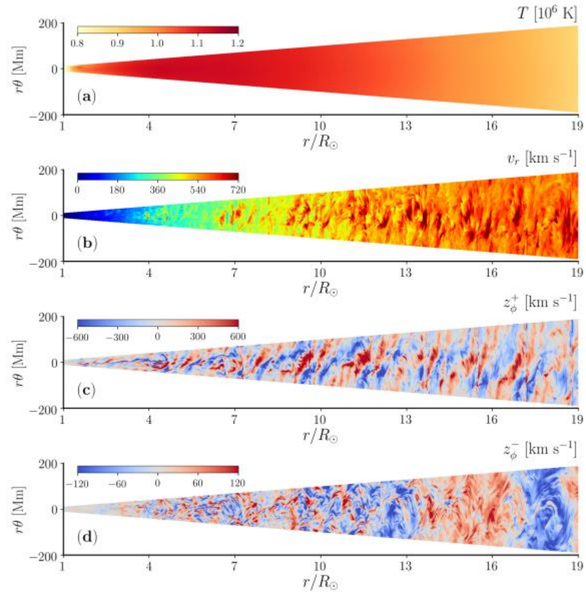

Figure 1: snapshots of the simulation result in a meridional plane. Each panel from top to bottom corresponds to plasma temperature, solar wind velocity, amplitude of upward Alfvén wave, amplitude of downward Alfvén wave, respectively.

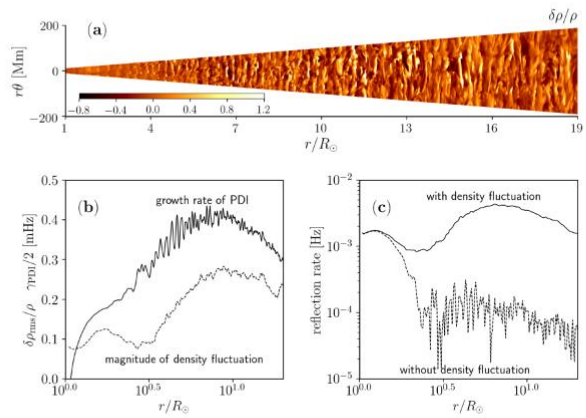

Figure 2 (a): a snapshot of the density fluctuation in a meridional plane. (b): radial profile of the density fluctuation and growth rate of PDI. (c): Alfvén-wave reflection rates with and without density fluctuation versus radial distance.

References

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