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

Numerical Study on Excitation of Turbulence and Oscillation in Above-the-loop-top Region of a Solar Flare

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Solar flares are multi-wavelength brightening phenomena caused by magnetic reconnection, and are the largest magnetic energy release process in the solar system. Solar flares form "flare loops" that shine in soft X-rays, and at the top end of the loops is a region called the "above-the-loop-top (ALT)", which is sometimes detected in hard X-ray. As the reconnection jets dissipate most of their kinetic energy in the ALT region, this place is particularly important for energy conversion in solar flares. The origin of nonthermal electrons could be related to the process in the ALT regions, since radio and hard X-ray observations indicate either acceleration or trapping of nonthermal electrons there [1].

Despite the importance of the ALT regions, it is observationally difficult to identify the locations and to investigate the local processes because of their weak emission and small size. Theoretical studies are therefore required. Using two-dimensional magnetohydrodynamic (2D MHD) simulations, Takasao & Shibata 2016 [2] found that the ALT region is forced to oscillate by the reconnection jet. Reeves et al. 2020 [3] detected the local oscillation at the flare loop top with spectroscopic imaging observations, which indicates that the ALT oscillation indeed occurs in the real flare and that the oscillation signal can be used to probe the location.

Although the 2D models provide the general picture of the ALT regions, 3D modeling is required for better comparison with observations. The theoretical study [2] suggests that the oscillation period depends on the local plasma parameter and the ALT region size, but it may also depend on the structure in the third dimension. In addition, observations suggest turbulence around the ALT regions [4], which emphasize the importance of 3D modeling.

We have performed high-spatial resolution 3D MHD simulations of a solar flare to investigate the ALT dynamics in 3D. We utilize the public MHD code Athena++ [5]. Figure 1 (a-1) to (a-4) displays the evolution of the ALT region. The development of turbulent flows is prominent. We found that the instability rapidly grows around the top of the ALT region with a bad curvature and produces turbulence (see the panel (b) of Figure 1). Previous studies focus on the instability at the bottom of the ALT region [6], but we found that the instability developing around the top grows more rapidly, possibly because of its small curvature radius. In addition, the ALT oscillation is found to occur even in the presence of turbulence, which implies the robustness of the mechanism. We will discuss the possible impacts on the electron trapping in ALT region on the basis of our simulations.

References

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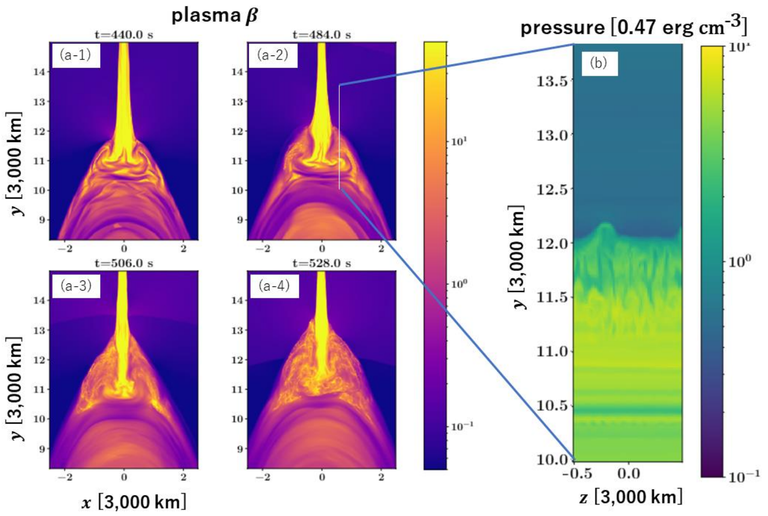

Figure 1. Panel (a-1) - (a-4) show the development of turbulence on ALT region. The color shows plasma beta. Panel (b) show the pressure on the z-y slice cut with the white line in panel (a-2).