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

Universal Correlation between the Ejected Mass and Total Flare Energy for Solar and Stellar Cold Plasma Ejection

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We often find spectral signatures of chromospheric cold plasma ejections accompanied by flares in various spatial scales in the solar and stellar atmospheres. However, no physical quantities such as mass and energy have been estimated for flare energies covering over ten orders of magnitude until now.

This study analyzed the spectra of cold plasma ejections associated with small-scale flares and solar flares (energy 10^{25} -10^{29} erg) by performing Hα imaging spectroscopy with the Solar Dynamics Doppler Imager on the Solar Magnetic Activity Research Telescope (SMART/SDDI) to supply smaller energy samples. We determined the ejected mass by cloud model fitting to the Hα spectrum. We estimated flare energy by differential emission measure analysis using Atmospheric Imaging Assembly onboard Solar Dynamics Observatory (SDO/AIA) for small-scale flares and by estimating the bolometric energy for large-scale flares.

By comparing our analyzed results on the Sun with observations interpreted as stellar filament eruptions, we found a $M \propto E_{tot}^{2/3}$ relationship between the ejection mass M and the total flare energy E_{tot} (Figure 1). In addition, we constructed a theoretical scaling law for ejection mass and the total flare energy. We showed that the scaling law could explain the observations by taking into account the difference in the coronal magnetic field strength (from 5 G to 50 G) (Figure 1). These results suggest that cold plasma ejections with flares taking place on the Sun and stars in a wide range of the energy scale are caused by a common mechanism.

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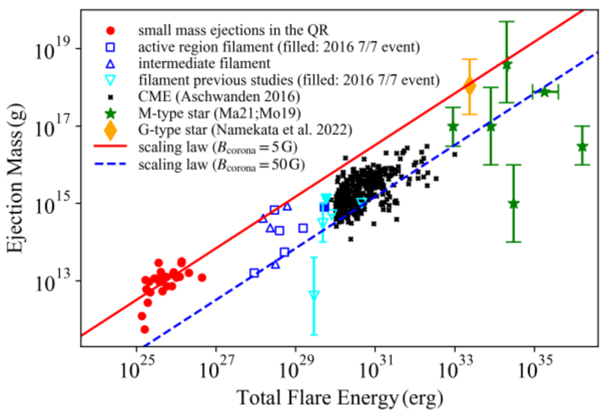

Figure 1.
Relationship between total flare energy and ejected mass for various scale flares. The red circles, blue squares, and blue triangles represent small mass ejections in the quiet region, the active region filament, and the intermediate filament eruptions analyzed in this study, respectively. The light blue triangles represent filament eruptions in previous studies (Jain & Sorathia 1987; Ohyama & Shibata 1999; Christian et al. 2015; Namekata et al. 2022). The filled blue square and light blue triangle represent the same event, the July 7, 2016 filament eruption analyzed in Namekata et al. (2022). The black crosses represent CMEs (Aschwanden 2016). The green stars and orange diamond represent signs of cold plasma ejections with stellar flares on M-type (Moschou et al. 2019; Maehara et al. 2021, shown Mo19 and Ma21 in the figure) and G-type stars (Namekata et al. 2022), respectively. The solid red line and the dashed blue line show the cases of B_{corona} = 5 G and B_{corona} = 50 G in our scaling law, respectively.