Solar Flares with Circular Ribbons

Jeongwoo Lee[1,2]

[1] Institute of Space Sciences, Shandong University, [2] Physics Department, New Jersey Institute of Technology

e-mail (speaker): leej@njit.edu

Solar flares are among the most energetic events in the solar system, and understanding how the sun can release so rapidly vast amounts of magnetic energy remains as a great challenge in astrophysics and plasma physics. Flare observations have typically targeted at the optical brightenings at the footpoints of the field lines reconnecting in the corona as readily accessible from the ground-based observations before coronal images from space-borne observations are available. This phenomenon called *flare ribbons* has served as the main source of information on the physics of magnetic energy release as their dynamics and dimension carry information on the physical quantities in the reconnecting current sheet in the corona.

Solar flares can be categorized into two types according to the flare ribbon topology. A typical type is two-ribbon flares in which two parallel linear ribbons appear in both side of magnetic polarization inversion line (PIL), and separate away from each other during the flares. This phenomenon is now understood in terms of magnetic reconnection in either 1D X-point or 2D current sheet (CS), which moves away from the sun [1]. The other type is circular-ribbon flares (CRFs), which occur in a special magnetic configuration with a central parasitic magnetic field encompassed by the opposite magnetic polarity fields. Such a magnetic configuration implies a dome-shaped magnetic fan surface with spine fields in and out of the dome, thus capable of truly 3D magnetic reconnection at a magnetic null point (NP). Figure 1 shows an example of CRF in which a circular ribbon, fan, and spine fields are visible in UV images, and NP is inferred from the magnetogram of Solar Dynamics Observatory (SDO) [2]. Studies of CRFs therefore prompt a paradigm shift from 2D CS to 3D NP reconnection.

Earlier studies of CRFs, drew our attention to how magnetic reconnection occurs in a single NP topology [3]. A number of numerical simulations have been performed to test whether CS develop at NP or along the fan via shearing or rotational perturbations. Magnetic reconnection in the CS may then occur by either small-scale local instabilities (e.g., tearing mode instability) or a large-scale instability (e.g., kink-like instability). Observations further reveal that CRFs have various properties far more complicated than can be explicable by the single NP reconnection theory. For instance, ribbons do not instantaneously brighten up everywhere but sequentially along themselves. Spines and related ribbons appear in a finite volume, and circular ribbons can also expand with time. To understand these behaviors, it appears that we may need to incorporate previous ideas developed for two-ribbon flares into CRFs. It is also found that some CRFs occur in the presence of a filament under its fan surface, which erupts through the overlying fan. Such observations imply the breakout type reconnection, a major candidate mechanism for solar eruption [4].

Studies of CRF are now regarded as one of the most novel and interesting areas of solar physics research. This talk will start with basic theoretical ingredients of CRFs and review recent progresses achieved for trigger mechanisms and eruptions during CRFs. Future challenges in both observational studies and theoretical modeling of CRF phenomena will also be discussed.

References

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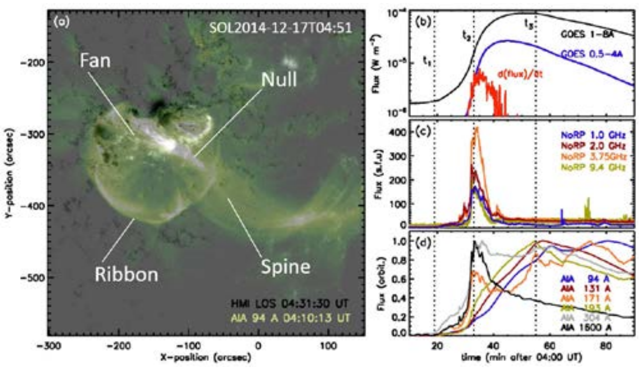

Figure 1. An example of CRF (SOL2014-12-17T04:51). Left panel: a magnetogram (BW) overlaid with EUV 94 Å intensity (green) from SDO. Right panels: GOES soft X-ray lightcurves, Nobeyama Radiopolarimeer (NoRP) microwave flux, and normalized (E)UV fluxes.