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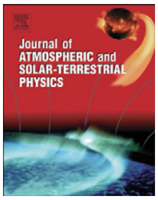

Prominence 3D reconstruction in the STEREO era: A review

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ABSTRACT

Since the launch of the STEREO mission (October 2006) the determination of the real prominence shapes and trajectories during eruptions in three dimensions (3D) became easily viable, thanks to the stereoscopic observations, available for the first time, acquired by the twin STEREO spacecraft. These data give us now a unique capability to identify twisted or ribbon-like structures, helical or planar motions, and to investigate the existence of a real critical height for prominence eruptions without projection effects. All these parameters are of fundamental importance for understanding the physical phenomena triggering the eruption and affecting their early evolution. Many different techniques have been developed and employed after the beginning of the “STEREO era”, but important information on the 3D structure of prominences was also derived before STEREO. Hence, the present paper is aimed at reviewing different reconstruction techniques developed both before and after the availability of stereoscopic observations and discusses the advancement made so far on these issues thanks to the pre- and post-STEREO data.

1. Introduction: study of solar prominences

Solar prominences (called filaments, when observed on-disk—Fig. 1) are cool and dense structures, with plasma electron temperatures around $5\times10^3-1.5\times10^5$ K and electron densities of $1.3\times10^9-3\times10^{11}\,\mathrm{cm}^{-3}$ (Patsourakos and Vial, 2002). The filament plasma is denser and cooler than the surrounding coronal plasmas which are invisible in images in relatively cool lines such as Hα and He II λ304; filaments are usually observed as dark structures against the chromosphere because they scatter light from the chromosphere and photosphere. They are also observable against the solar background in the extreme ultraviolet (EUV) lines if the background is sufficiently bright that they scatter light at these wavelengths also. However, during episodes called “activations”, filament threads or whole sections of filaments are occasionally seen in emission in various EUV lines as well as in Hα, indicating the occurrence of plasma heating (Labrosse et al., 2010; Mackay et al., 2010). Prominences are believed to be kept in equilibrium by the surrounding magnetic field, and many different models have been proposed so far to understand the prominence formation, mass supply, stability and to explain their instabilities leading to prominence eruptions and coronal mass ejections (CMEs). Nevertheless, the final solutions to these problems have not been found so far (see Patsourakos and Vial, 2002 for a comprehensive review on the prominence science from SOHO data, Labrosse et al., 2010 and Mackay et al., 2010 for two more recent reviews on quiescent prominences). In particular, because of close association with the occurrence of flares and CMEs, understanding the processes involved in filament eruptions continues to be an active area of research (see, e.g. Tonooka et al., 2000; Schmieder et al., 2004; Sterling et al., 2007). Recent solar missions such as STEREO, but also HINODE and SDO, improved our capabilities to perform multi-spacecraft studies of prominence eruptions (see, e.g. Bemporad et al., 2009; Landi et al., 2010).

It is well known that erupting filaments generally exhibit helical structures (e.g. Athay et al., 1983; Rust and Kumar, 1984) and the handedness and full 3D velocity vector of many untwisting CME helixes have been derived from spectroscopic observations acquired by the SOHO *UV Coronagraph Spectrometer* (UVCS; see review by Kohl et al., 2006 and references therein). For this reason a very important quantity often used to characterize the degree of instability of filaments is the magnetic helicity H (Berger and Field, 1984), defined as $H=\int_V \mathbf{B}\cdot\mathbf{A}\,dV$, where V is the volume where H is measured, $\mathbf{B}$ is the magnetic field and $\mathbf{A}=\nabla\times\mathbf{B}$ is the vector potential. The magnetic helicity mainly quantifies how much a set of magnetic flux tubes are sheared and/or wound around each other and can be written as the sum of “twist” and “writhe”: the twist measures how much the field lines wind about the magnetic axis of the rope, whereas the writhe quantifies the helical deformation of the axis itself (see Fig. 2, left panels). It has been shown that an important condition for the formation and maintenance of a filament is a “handedness” property known as chirality, which requires the filaments to be either of two types: dextral or sinistral (see review by Martin, 1998 and references therein). The chirality χ of a filament is defined by the sense of rotation (twist) of the magnetic field in reversing from upward pointing on the positive

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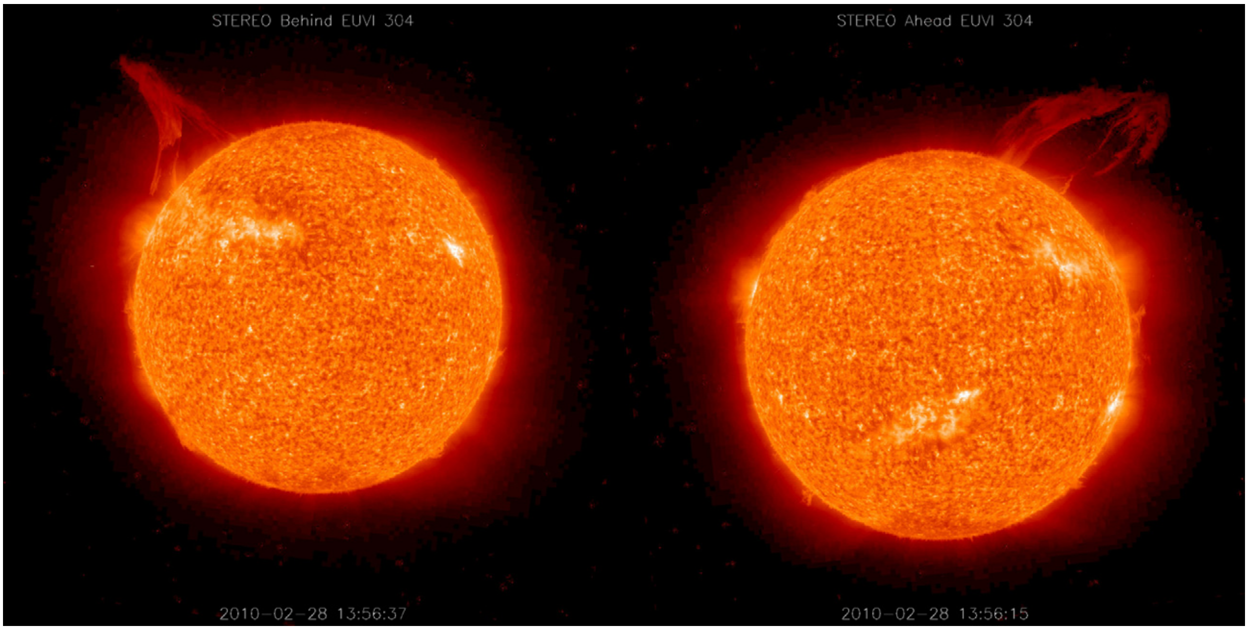

Fig. 1. A huge prominence eruption recently observed by the twin EUVI telescopes onboard STEREO-B (left) and STEREO-A (right) spacecraft. These observations have been acquired with the He II 304 Å filter (corresponding to a plasma temperature around $\sim 8 \times 10^4$ K) on February 28, 2010, when the angle between the STEREO spacecraft was 137.0°).

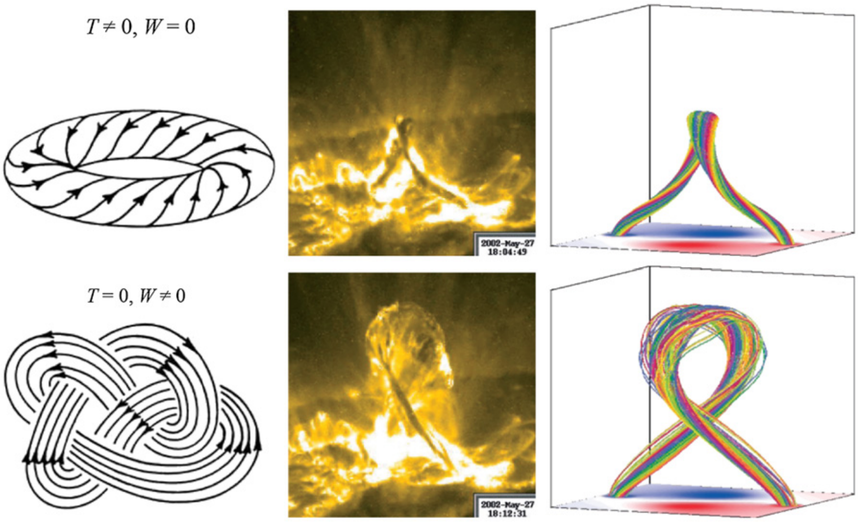

Fig. 2. Left panels: cartoon showing an example of possible magnetic field configurations, where the contribution to the total helicity is separately due only to the twist T (top) or to the writhe W (bottom) of field lines (adapted from Ricca, 1994). Middle and right panels: the confined filament eruption on 2002 May 27 observed by TRACE, and magnetic field lines of the kink-unstable flux rope in the simulation by Török and Kliem (2005); the flux rope axis at the state shown in the bottom frame of the simulation has a writhe of $W = 0.67$.

side of the polarity reversal boundary to downward pointing on the negative side (see, e.g. Martin, 2003); H is a quantitative, mathematical measure of χ.

Helicity H is believed to play a very important role not only in the filament formation, but also in the filament destabilization. For instance, evidence of the existence of a previously unrecognized form of dynamic chirality (handedness) called the “roll effect” has been found in erupting prominences (Martin, 2003). Also, the so-called “helical kink” instability of a magnetic flux rope (see Fig. 2, middle and right panels) is expected to occur when the twist exceeds a critical value (Hood and Priest, 1981). In a high magnetic Reynold number plasma (i.e. in ideal MHD) H is a conserved quantity (even taking into account the effects of magnetic reconnection; Berger and Field, 1984) and the erupting filaments, different from stable filaments, exhibit large scale twist or writhe, clearly appearing as helical-like patterns and rotations during their eruptions. Hence, it is generally believed that prominence eruptions and resulting CMEs are the most efficient way the Sun has to globally “carry out” the excess of helicity built in its interiors by the solar dynamo. The observed rotation of the erupting filament is generally interpreted as a conversion of twist into writhe in a kink-unstable magnetic flux rope (see, e.g. Zhou et al., 2006). Moreover, the conservation of the helicity between filament and the interplanetary *counterpart* of CMEs (ICMEs) is used to associate filament eruptions and magnetic clouds: statistically, the direction of the axial field and helicity of ICMEs (also related to their geoeffectiveness) are consistent with those of the erupted filaments (e.g. Yurchyshyn et al., 2001, 2005).