

Scientists Unlock the Secrets of Exploding Plasma Clouds on the Sun

Twisted “ropes” of magnetic field lines erupt from the Sun and tangle with the Earth’s magnetic field.

CHICAGO—The Sun sporadically expels trillions of tons of million-degree hydrogen gas in explosions called coronal mass ejections (CMEs). Such clouds—an example is shown in Figure 1—are enormous in size (millions of miles) and are made up of magnetized plasma gases, so hot that hydrogen atoms are ionized. CMEs are rapidly accelerated by magnetic forces to speeds of hundreds of kilometers per second to upwards of 2000 kilometers per second in several tens of minutes. CMEs are closely related to solar flares and, when they impinge on the Earth, can trigger spectacular auroral displays. They also induce strong electric currents in the Earth’s plasma atmosphere (i.e., the magnetosphere and ionosphere), leading to outages in telecommunications and GPS systems and collapse of electric power grids if the disturbances are very severe.

Since the first observation of a solar flare in 1859, solar eruptions (“explosions”) have attracted much attention of scientists around the world and have been studied with a succession of increasingly sophisticated international satellite missions in the past three decades. A major challenge has been that enormous and complicated plasma structures accelerating away from the Sun can only be observed remotely. As a result, it has been difficult to test theoretical models and establish the correct understanding of the mechanisms that cause such eruptions. Recently, a new international twin-satellite mission called STEREO that can continuously observe the erupting plasma structures from the Sun to the Earth was launched in 2006.

Now, new research by scientists at the Naval Research Laboratory (NRL) in Washington, DC, using the data from STEREO demonstrates for the first time that the observed motion of erupting plasma clouds driven by magnetic forces can be correctly explained by a theoretical model. The work will be presented at the 52nd Annual Meeting of the APS Plasma Physics Division.

The theory, controversial when it was first proposed in 1989 by Dr. James Chen of NRL, is based on the concept that an erupting plasma cloud is a giant “magnetic flux rope,” a rope of “twisted” magnetic field lines shaped like a partial donut (Figure 1). Chen and Valbona Kunkel, a doctoral student at George Mason University, have applied this model to the new STEREO data of CMEs and shown that the theoretical solutions agree with the measured trajectories of the ejected clouds within the entire field of view from the Sun to the Earth. They have also shown that the theoretically predicted magnetic field and plasma properties are in excellent agreement with the satellite data measured near the Earth. This is the first model that can replicate directly observable quantities near the Sun and the Earth as well as the actual trajectories of CMEs.

Interestingly, the basic forces acting on solar flux ropes are the same ones as those in laboratory plasma structures such as tokamaks developed to produce controlled fusion energy. The mechanism described by the theory is also potentially applicable to eruptions on other stars.

Work supported by the Office of Naval Research.

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Abstract: JT3.00001

“Physics of Solar Coronal Mass Ejections (CMEs): Theory and Observation” (Invited Tutorial)

Speaker: J. Chen (NRL)

2:00–3:00 PM, Tuesday, November 9, 2010

References:

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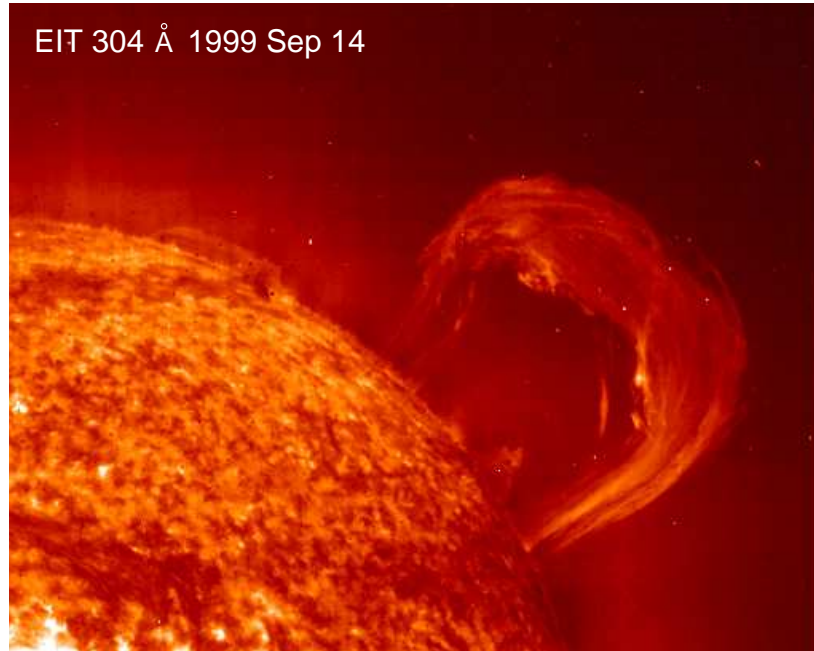


Figure 1: An erupting “prominence” observed using photons at wavelength 304 Å. A prominence is often part of a larger CME plasma structure (not visible in this part of the spectrum). The striated plasma filaments are organized by magnetic fields into strands of a “rope.” In this snapshot, the apex is at about 300,000 km above the solar surface, a distance equal to about 24 Earths placed side by side. Obtained at 07:19 UT, 1999 September 14, by the EIT instrument on the SOHO spacecraft (launched in 1995). Both SOHO and STEREO are international cooperations between the European Space Agency (ESA) and NASA.