Case Studies

The Evolution of Coronal Loops

Berkeley, CA - October 2002

Contributed by:
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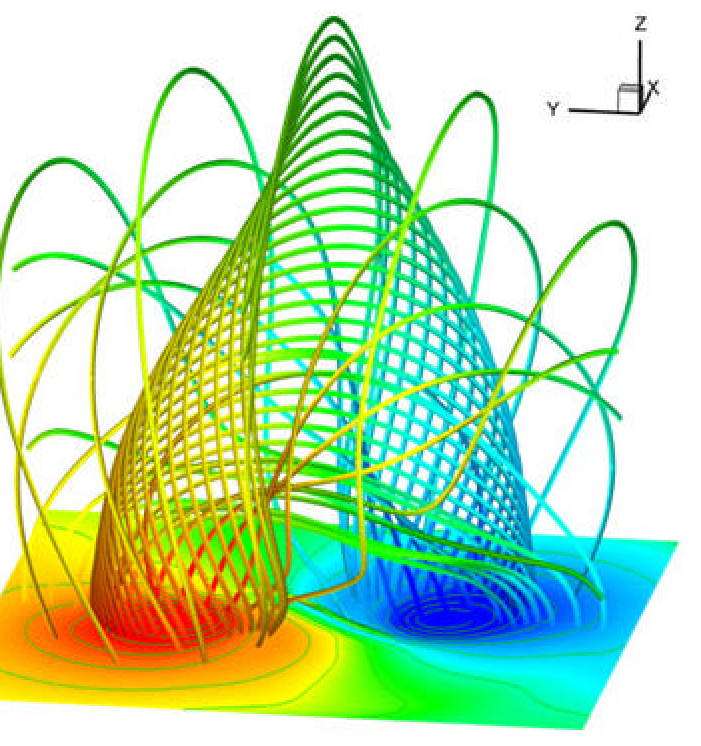

Understanding the dynamics of the solar atmosphere helps explain eruptions called coronal mass ejections (CME). Predicting the cause of these eruptions is an important scientific challenge.

Plasma
Plasma is a distinct state of matter containing electrically charged particles that affect its electrical properties and behavior. In addition to being important in many aspects of our daily lives, plasmas may constitute more than 99 percent of the visible universe. Plasma is often called the fourth state of matter, the other three being solid, liquid and gas.

Solar Atmosphere
Both the Sun's atmosphere and its surface consist of plasma. The density of plasma in the solar atmosphere — called corona — is orders of magnitude less than at the surface — called photosphere. Because of this, the behavior of plasma in these two regions is very different.

At the surface — photosphere — forces associated with plasma's fluid pressure are comparable to the magnetic forces imposed on plasma from the Sun's magnetic field. In contrast, the more rarefied (or less dense) plasma of the corona is primarily controlled by the magnetic field. As a result, coronal plasma tends to align itself along the magnetic field lines. This forms large scale arches and arcades which constrain the plasma like huge magnetic pipes. These massive, super-heated, electrified gas configurations are called coronal loops.

Coronal Loops
The Sun is covered in millions of coronal loops at any given time. The most massive arches are more than 300,000 miles high and would span the Earth 30 times.

The footpoints of coronal loops anchor at the solar surface. Dense fluid motion on the surface slowly moves the footpoints around. This slow motion can hardly be detected over long periods of time. Thus, the corona appears relatively quiet.

The loops can persist in the corona for days, or even weeks, then suddenly erupt over the course of several hours. Huge bubbles of gas threaded with magnetic field lines — called coronal mass ejections (CME) — are released during some of the explosions.

The Sun undergoes an eleven year cycle of activity. As the cycle approaches its maximum, the frequency of CMEs increase from approximately once a week to several each day.

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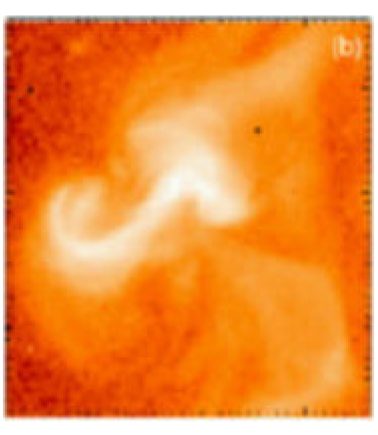

Figure 1: Image of the low-lying sigmoidal lines in the solar atmosphere.

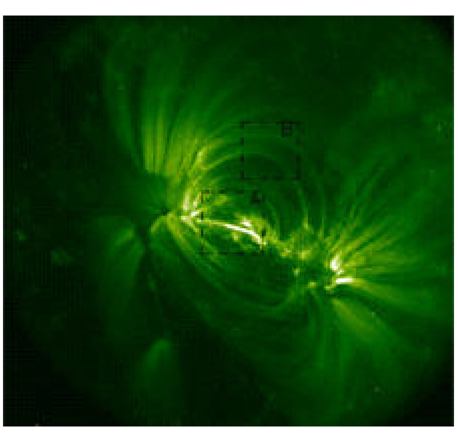

Figure 2: Image captured using a sun-observing satellite called TRACE (Transition Region and Coronal Explorer). This image reveals thread-like loop structures.

Coronal Mass Ejections
Massive CME (also called Space Storms) sends billions of tons of plasma into space. Magnetic flux and ejected mass cause major disturbances in the interplanetary medium. Earth-directed CMEs send huge bursts of charged particles that disrupt radio communications, cause surges in power grids and damage satellites.

The exact causes and mechanism of CME are not well understood and debated in the scientific community. Since some of the explosions are directed towards our planet and carry massive amounts of magnetized plasma, understanding these events and developing predictive capabilities is a very important scientific challenge. While the importance of the predictive capabilities for solar eruptive activity is clear, much remains to be understood about coronal plasma dynamics.

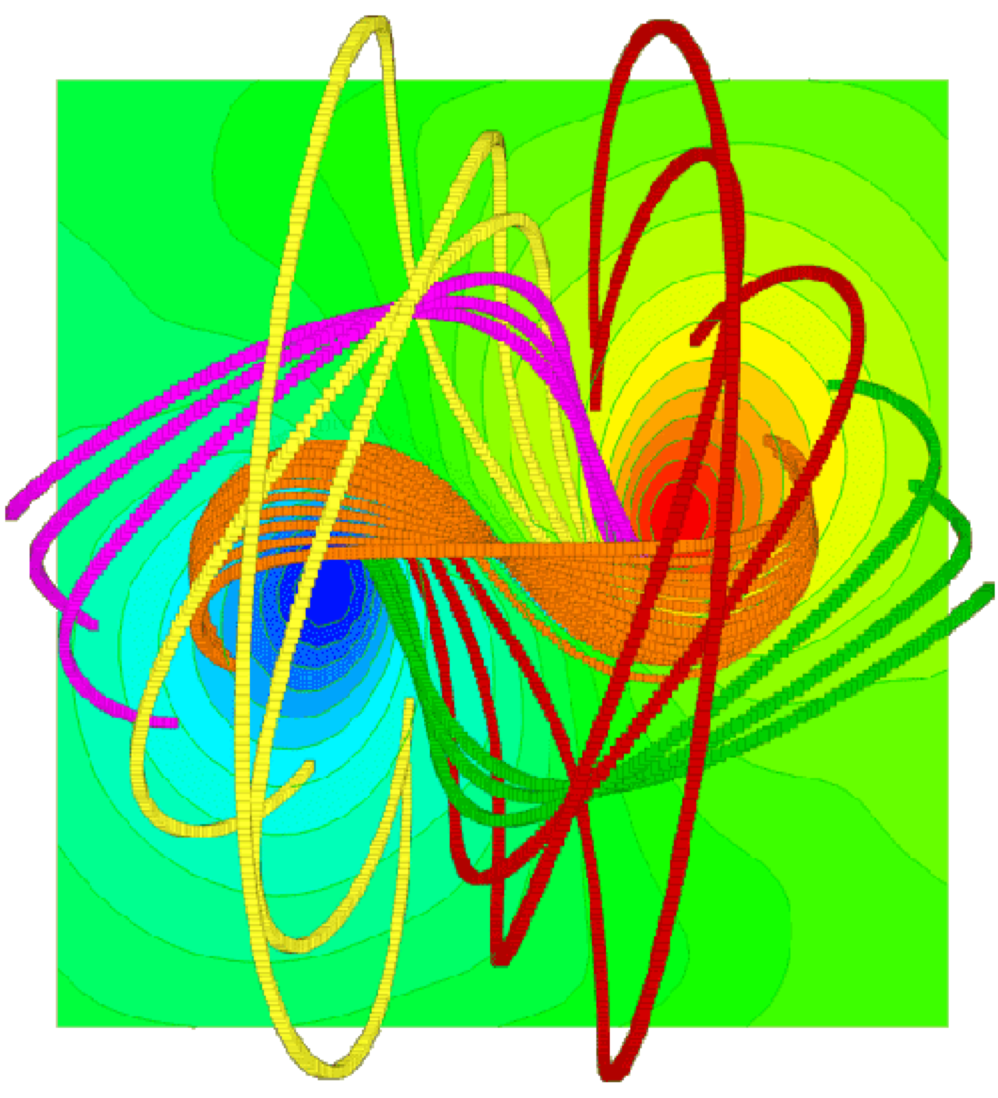

Figure 3: Top view of the twisting magnetic fields lines formed by the rotational motion at the photosphere. You can see the low-lying sigmoidal lines (orange) that look similar to figure 1.

Mayya Tokman
Mayya Tokman, Ph.D. is a visiting Assistant Professor of Mathematics at the University of California, Berkeley. She models the dynamics of coronal loops and their evolution using three-dimensional magneto-hydrodynamic numerical simulations. In particular, she studies the response of coronal loops to the slow rotational motion of their footpoints anchored in a denser plasma at the surface of the Sun.

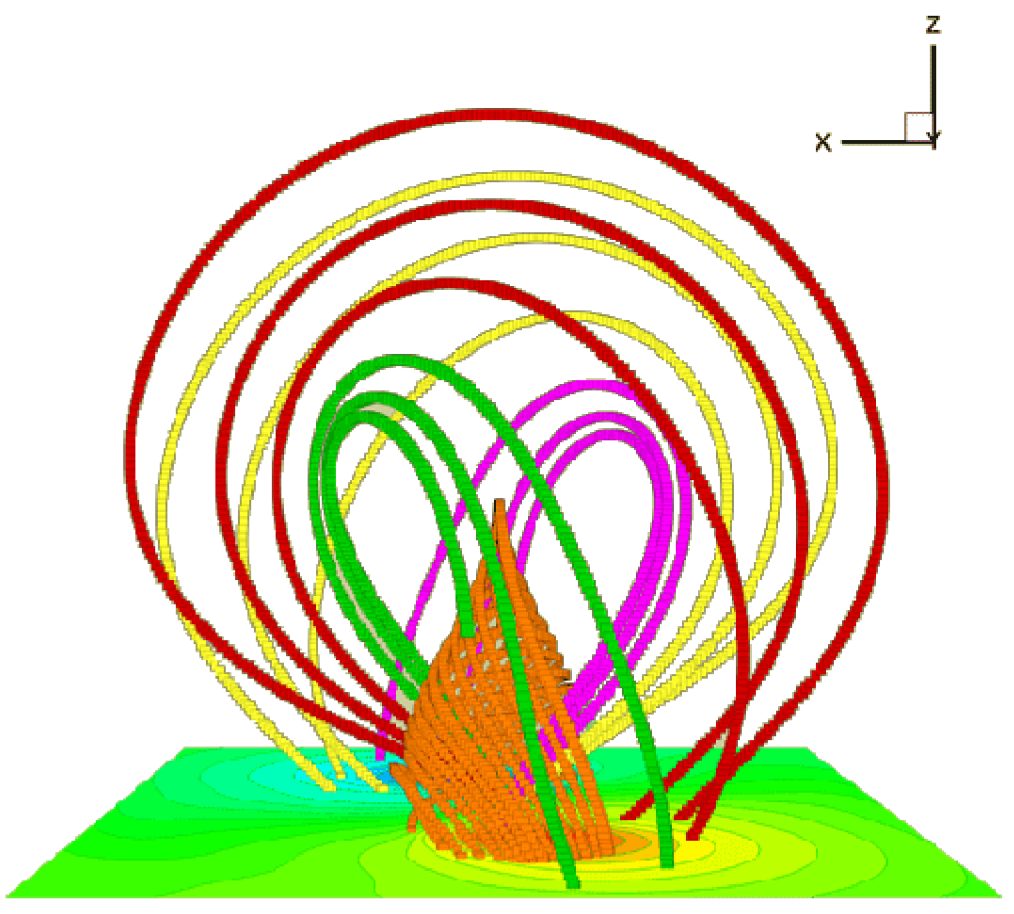

Figure 4: Side view of twisting magnetic fields lines formed by the rotational motion at the photosphere. The formation of geometrically different regions as a result of such dynamics are visible. You can see the low-lying sigmoidal lines (orange) and the overlaying arcades (yellow and red). The green, purple, red and yellow streamlines are magnetic field lines anchored to the solar surface (bottom contour plot).

The results of her research shows formation of sigmoids (orange lines in figures 3 and 4) and overlying arcades (yellow and red lines in figures 3 and 4) which closely resemble those seen in observations (figures 1,2, 5 and 6). Her simulation results indicate that these structures form as a result of the slow rotation of the coronal loop footpoints. Further enhancements to the model will help understand the physics and evolution of coronal loops in more detail.

Figure 5: This TRACE image is one of the sharpest pictures ever taken of magnetic arches.

Figure 6: Image of a coronal mass ejection (CME). You can see the similarity between Figure 4 and 6.

Credits

- **Figure 1:** Sigmoid Image. Sterling, et al. 2000.
- **Figure 2:** Image of coronal mass ejection (CME) observed by the Solar Maximum Mission. Image enhanced and reprinted from Illing & Hundhausen, 1983.
- **Figure 5 and 6:** Images provided by the TRACE solar observatories project.