Space Weather Scientists Use 3D Simulation to Predict Potentially Dangerous Solar Eruptions

Manifested as brilliant observational forms such as flares, filament eruptions and coronal mass ejections (CMEs), solar eruptions, as major drivers of space weather, have a dark side. From time to time, billions of tonnes of ionized gas or plasma are expulsed from the solar atmosphere at millions of kilometers an hour, which could destroy satellites and disrupt power grid and mobile phone networks on Earth.

Due to such possibly devastating consequences on Earth, space scientists have been striving to unravel the mystery of solar eruptions. Recently, they took an important step forward towards a better understanding of CMEs and a possible answer to the crucial question of how solar eruptions are triggered on the Sun.

Researchers from the National Space Science Center (NSSC) in Beijing and the University of Alabama in Huntsville (UAH) successfully performed a data-driven magnetohydrodynamic (MHD) simulation of a realistic CME initiation process that had happened about two years before.

While it is a common belief among space physicists that solar eruptions are caused by disruptions of the magnetic field in the Sun's corona, the physical mechanism of CME initiation remains largely unknown because the coronal magnetic field is difficult to measure. Although

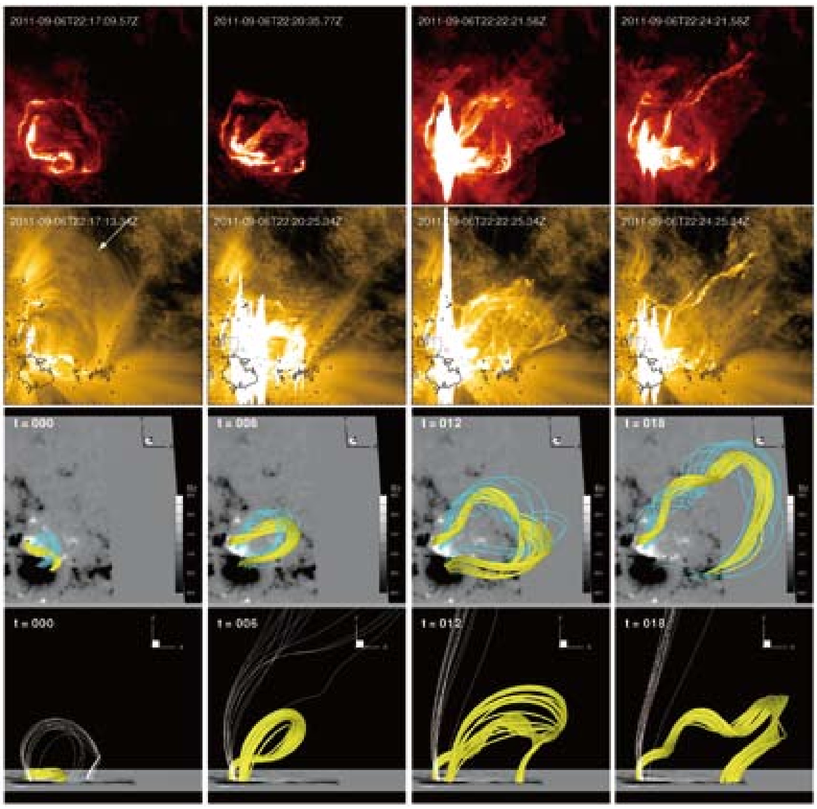

Figure 1. Observations (the top two rows) and MHD simulation (the bottom two rows) of the sigmoid eruption in AR 11283 on 2011 September 6. The SDO/AIA observations are shown in 304 and 171 channels, respectively, and the contours overlying the images are the line-of-sight photospheric magnetic field with ±500 Gauss. Viewing angle in the third row is aligned with the observations, while the fourth row is side view from the south. Two sets of the core field lines (cyan and yellow) are shown, and the yellow lines correspond to the sigmoid. Another set of lines that initially touch the null point are traced from the negative polarity to show their reconnection and opening. The gray image at the bottom represents the photospheric field. (Adopted from *ApJL*, 2013, 771, L30)

researchers from all over the world have performed various numerical simulations of the initiation process of CMEs, the problem stays because those simulations are mostly conducted with idealized magnetic field models, which are unable to recover the complex configurations of the realistic coronal field and thus cannot simulate real solar eruptions.

Dr. JIANG Chaowei and Prof. FENG Xueshang from the State Key Laboratory of Space Weather under NSSC and their UAH colleagues developed a novel way to simulate realistic eruptions by combining a field extrapolation method and a time-dependent numerical MHD model, which has successfully reproduced a major CME eruption of AR 11283 on September 6, 2011 (Figure 1).

Using a nonlinear force-free field extrapolation code, CESE-MHD-NLFFF, they reconstructed the 3D coronal magnetic field immediately prior to its eruption (Figure 2). Study of this pre-eruption field revealed an interesting S-shaped magnetic flux rope, called Sigmoid, which was observed as a high-temperature, S-shaped coronal loop by the *Atmospheric Imaging Assembly* (AIA) on board the *Solar Dynamic Observatory* (SDO). By topology analysis, they also showed that the overlying field of the Sigmoid contains a magnetic null point, at which the coronal field strength is zero and magnetic reconnection is prone to occur. Furthermore SDO/AIA observed a quasi-circular chromospheric flare ribbon, which is a result of the null point reconnection, appearing just prior to the eruption.

These evidences suggest that the eruption was triggered by magnetic reconnection at the null, which reduced the overlying field that stabilized the sigmoidal flux rope, and resulted in a loss-of-equilibrium of the system. The pre-eruption field was then input as initial condition into the MHD model, which reproduced the entire eruption process. The resemblance between the MHD simulation and SDO/AIA observations is remarkable.

Their research was published in a recent issue of the *Astrophysical Journal Letters* (*ApJL*). "Such a fully integrated work is a major technical achievement in solar physics," one of the *ApJL* reviewers noted.

"The success of this simulation has inspired us to study further into the numerical modeling of eruption events in a quantitative way, and to help solve the long-standing puzzle of how solar eruptions are triggered and driven, for the eventual purpose of forecasting them," said Dr. JIANG, lead author of the article from NSSC in Beijing.

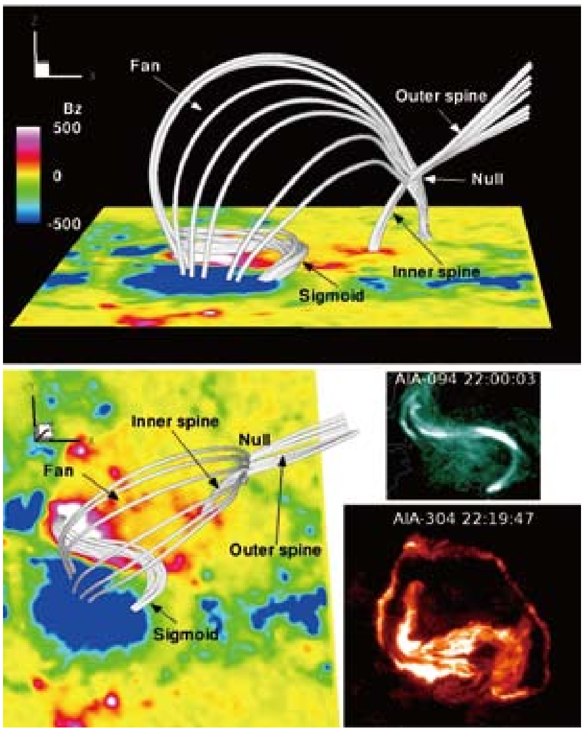

Figure 2. Topology of the coronal magnetic field prior to the eruption. The white thick lines represent the magnetic field lines and the colored map represents the observed photospheric field. The top panel is a side view and the bottom is the SDO view. Compared on the bottom right are the sigmoid observed in SDO/AIA-94 channel and the circular flare ribbon observed in AIA-304. The sigmoid field consists of the low-lying S-shaped lines, which closely resemble the observation in AIA-94. Field lines closely touching the null outline the spine-fan topology of the null, at which the field lines form an X-point configuration. The null point locates about 18 arcsec (13 Mm) above the photosphere and about 50 arcsec away from the sigmoid in the same direction of the eruption. (Adopted from *ApJL*, 2013, 771, L30)

Prof. FENG Xueshang (right) and Dr. JIANG Chaowei.