STEREO—The Solar Terrestrial Relations Observatory: Guest Editors' Introduction

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The Solar TErrestrial REIations Observatory (STEREO) project at APL is unique among the Space Department's current set of NASA missions. Although APL's Dr. David Rust chaired the Science Definition Team (SDT) that defined the mission,[1] APL's role during implementation and operations has primarily been engineering. This role stands in contrast to our other NASA missions, where APL provides both science and engineering. Appropriately, this issue of the Johns Hopkins APL Technical Digest *focuses on the engineering solutions provided by APL for the STEREO mission. As a whole, these solutions were essential to enabling the required scientific observations as well as to keeping the mission within its prescribed cost and schedule constraints.*

Although APL continues to focus on the engineering and operations of the two Solar TErrestrial RElations Observatory (STEREO) spacecraft, our efforts would be meaningless without the strong scientific backbone being provided by institutions from around the world. In his article elsewhere in this issue, Michael Kaiser, the STEREO Project Scientist from Goddard Space Flight Center (GSFC), provides the scientific context for the mission. The engineering articles, which make up the remainder of the volume, for the most part, stand on their own. As such, the intent of this editorial is to provide historical perspective, an update on STEREO's scientific discoveries, and a reflective look at how this mission has affected both APL and GSFC—We believe for the better.

Like most NASA science missions, the STEREO mission was conceptualized well before its implementation. The first appearance of a multi-spacecraft mission was in 1991 NASA planning documents. In June 1992, at the 23rd meeting of the Solar Physics Division of the American Astronomical Society, two mission concepts were presented that were eventually combined into the STEREO mission.[2] After further discussion and mission proposals, NASA convened a Science Definition Team (SDT). The output of the SDT formed the basis of the STEREO mission we have today. The STEREO project at APL started in 1999; the two spacecraft (Ahead and Behind) were launched on 26 October 2006 at 0052 UTC. After spending two to three months in Earth orbit, the two spacecraft reached their heliocentric vantage points in January 2007. Each spacecraft drifts symmetrically ahead and behind the Earth and, as of mid-2009, are each approximately 47° from the Earth–Sun line, with sufficient resources to provide decades of solar observations (Fig. 1). STEREO completed its primary mission in January 2009 and now is in its first extended mission.

For those familiar with the 11-year solar cycle, STEREO's launch in 2006 seems odd because the 2-year primary mission coincided with the solar cycle minimum, when solar activity is at its lowest. It also has turned out that this solar minimum, between cycles 23 and 24, has been unusually long and quiet compared to the two previous cycles for which we have substantial solar and interplanetary observations (Fig. 2). Although the occurrence of coronal mass ejections (CMEs) is highest during solar maximum, there is sufficient solar activity during solar minimum for STEREO to meet its science objectives, mainly:

1. Understand the causes and mechanisms of CME initiation.
2. Characterize the propagation of CMEs through the heliosphere.
3. Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium.
4. Improve the determination of the structure of the ambient solar wind.

While it would seem that an active Sun is a necessity to meet these objectives, a quiet Sun with the

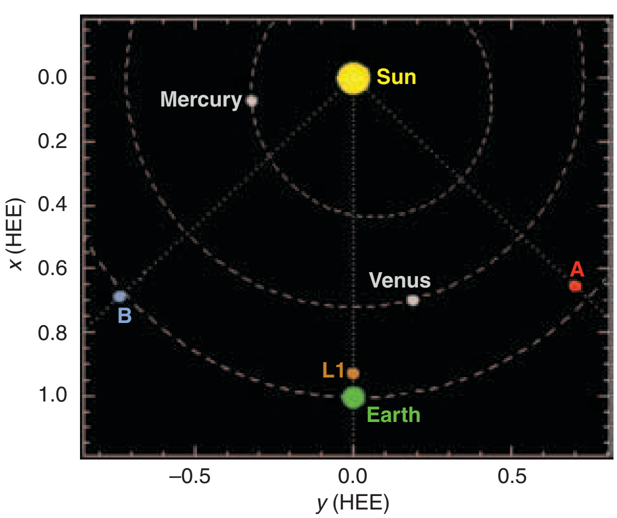


Figure 1. Positions of STEREO A and B on 20 Apr 2009, 20:00 UT.[3] This image plots the current positions of the STEREO Ahead (red) and Behind (blue) spacecraft relative to the Sun (yellow) and Earth (green). The dotted lines show the angular displacement from the Sun. The first Lagrange Point (L1), which ACE and SOHO are orbiting, also is shown. Units are in astronomical units (AU). The location of the Lagrange Point is not to scale.

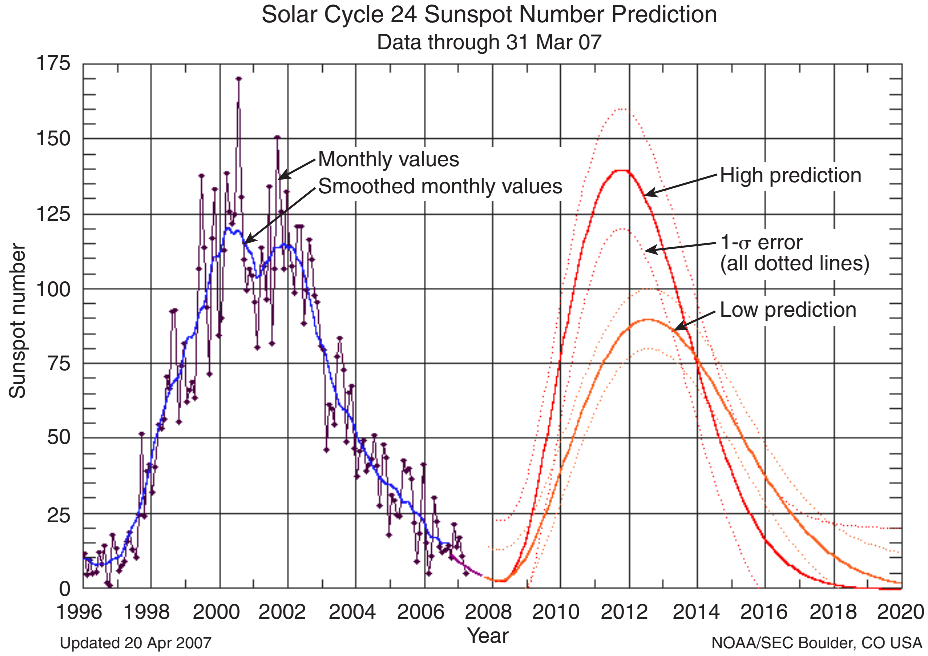
occasional CME provides the scientific community with event independence and a relatively "simple background" environment to observe the onset, eruption, and transport of CMEs through the inner solar system. During solar maximum, the Sun can be a hodge-podge of active regions, which makes isolation of a particular CME source difficult. Furthermore, the participation of the rest of the Sun in CME generation is difficult to distinguish when the Sun is active. The independent, traceable events that occur during solar minimum provide those working on theory-based numerical simulations of these events ideal case studies on which to base and validate their models.

Based on the observations made by both STEREO spacecraft, scientists for the first time have developed an understanding of the size, shape, and structure of CMEs. Knowledge of their three-dimensional structure has allowed scientists to better define the physics underlying CMEs (Fig. 3). Using these models and observations from each STEREO spacecraft, the STEREO science team was able to reconstruct Earth-bound CMEs and predict the observations by the Solar and Heliospheric Observatory (SOHO) spacecraft located near the first Lagrange Point, 1.5 million km away from the Earth along the Earth–Sun line.

Although the public at large may more easily relate to visual imagery, some of the most exciting discoveries are coming out of the *in situ* instrumentation on board each spacecraft. STEREO *in situ* measurements are being used by the National Oceanographic and Atmospheric Administration (NOAA) to anticipate space weather events and warn Earth 1 to 2 weeks in advance. Previously, only several hours of warning were provided by the Advanced Composition Explorer (ACE), also located near the first Lagrange Point. An increase in charged-particle activity affects human space flight, Earth-orbiting spacecraft, and even power grids. The STEREO Behind spacecraft has been particularly useful for measuring the solar wind conditions that the Earth will experience days to weeks later as the Sun rotates the prevailing structure our way.

Taking advantage of the deep solar minimum, scientists who focus on *in situ* measurements have been using magnetometer data from the STEREO spacecraft to infer what happened during low solar-activity periods before the Space Age. The STEREO magnetometers are observing some of the most frequent episodes of low magnetic fields and solar wind densities on record. With ACE as a third observation point upstream of the Earth, researchers are attempting to understand the conditions surrounding the low fields and sparse solar wind and their connection to Earth.

As this editorial comes to a close, it is important to acknowledge the human element behind any project. The science and engineering that goes into a project the size of STEREO is substantial. This project would not be



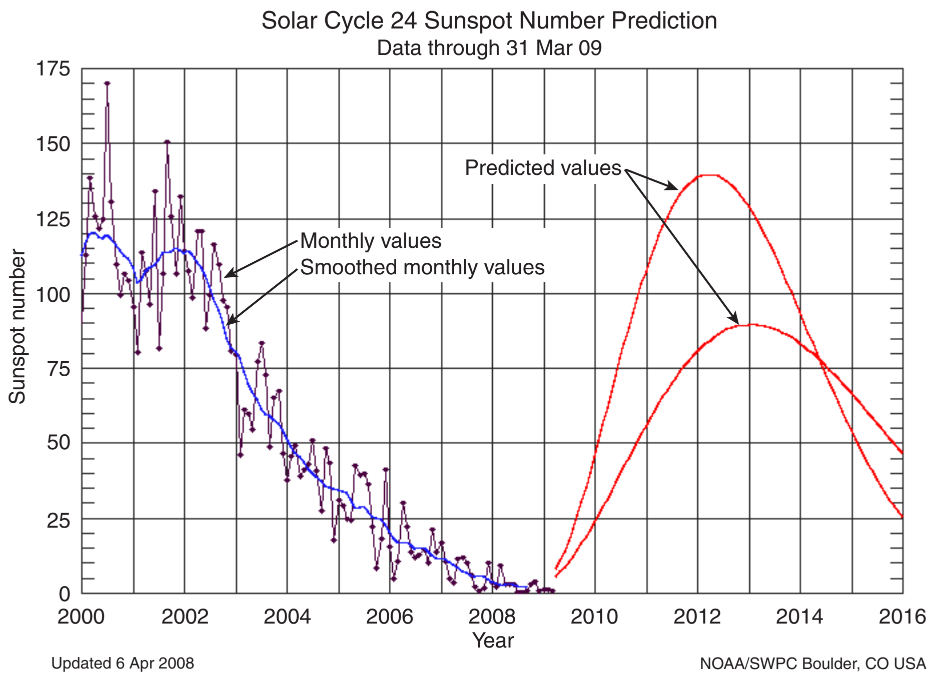


Figure 2. Sunspot numbers during solar cycle 23 and predictions for solar cycle 24. The upper graph shows predictions made in March 2007,[4] and the lower one shows predictions made in March 2009.[5] Note the long tail in the 2009 actual data. In 2007, cycle 24 was predicted to be well underway during the first quarter of 2009.

possible without the combined output of hundreds of scientists and engineers from around the world. Even something as short as this editorial has input from teams at APL, GSFC, University of California at Berkeley, and the University of New Hampshire. The STEREO mission did not have a short development schedule. Its development and current operations now span a full decade. The fact that so many participants view the STEREO project with fondness and in a positive light after working on it for a substantial portion of their career is a testimony to the men and women serving as engineers, scientists, technicians, managers, and support staff.

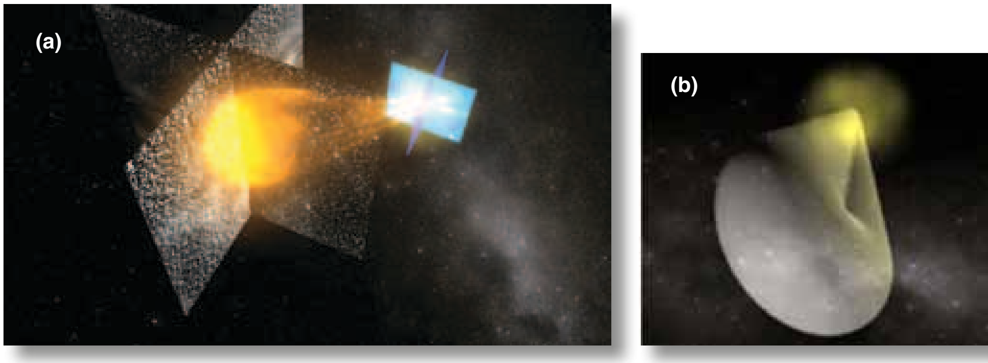


Figure 3. (a) In the composite, each plane contains an image from one of the STEREO imagers: the images in the foreground are from the heliospheric imagers, and those in the background are from the coronagraphs. The images going into the page are take from STEREO A, and the images going right to left are from STEREO B. (b) The observations in (a) have resulted in the mathematical representation shown in this 3D CME model.[6]

During the last years of development and during current operations, teams were/are "badge-less" within practical constraints. We believe that this collaborative environment has had effects beyond STEREO, resulting in a stronger relationship between GSFC and APL. Systems like STEREO are extraordinarily complex, and if we want to continue to build objects of equal or greater complexity, acknowledging the human element in their creation is critical. STEREO's legacy is not just the scientific knowledge that it adds to our collective understanding, but it is also the personal way that it touches those who participated and treated the endeavor as if it were "not just a job."

REFERENCES

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[4]NOAA Space Weather Prediction Center, *Solar Cycle 24 Prediction*, http://www.swpc.noaa.gov/SolarCycle/SC24/index.html (accessed 20 Apr 2009).

[5]NOAA Space Weather Prediction Center, *Solar Cycle Progression*, http://www.swpc.noaa.gov/SolarCycle/index.html (accessed 20 Apr 2009).

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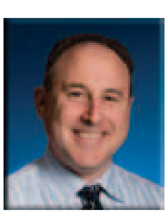
Andrew S. Driesman is a member of the Principal Professional Staff in APL's Space Department. He has an extensive background in the systems engineering, integration, and architecting of complex spacecraft for both scientific and military use. Mr. Driesman provided technical leadership for the development of the nearly identical STEREO spacecraft, from conceptual design through a successful launch and 2+ years of on-orbit operations. His work also has included board-level analog designs for Space Shuttle payloads, board- and subsystem-level design for balloon and sounding rocket payloads, and systems-level design for missile payloads and satellites. Mr. Driesman also has provided systems engineering support for the Discoverer II Synthetic Aperture Radar Constellation, Hypervelocity Light Gas Gun, and launch-point detection payload conceptual design studies for the Defense Advanced Research Projects Agency and APL. In addition to his current STEREO responsibilities, Mr. Driesman currently is the Group Supervisor for the Space Systems Applications Group. **Ronald A. Denissen** is a member of the Principal Professional Staff in APL's Space Department. He holds a B.S.E.E. from Old Dominion University and a M.S.E.E. from The Johns Hopkins University. He currently is assigned as the Project Manager of the STEREO mission. Mr. Denissen has held numerous engineering and management positions in his 25+ years at APL. He is a member of the Institute of Electrical and Electronic Engineers and the American Institute of Aeronautics and Astronautics. For further information on the work reported here, contact Andy Driesman. His e-mail address is andrew.driesman@jhuapl.edu.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