NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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STEREO - Solar TErrestrial RElations Observatory

The Solar TErrestrial RElations Observatory (STEREO) mission is the third in a coordinated sequence of science missions within the Solar Terrestrial Probes (STP) program. The principal objective of STEREO is to understand the origin and consequences of coronal mass ejections (CMEs), the most energetic solar eruptions. CMEs are responsible for the largest solar energetic particle events, are the primary cause of major geomagnetic storms, and may play an important role in the solar sunspot cycle via the removal of magnetic flux generated by the solar dynamo.

CORONAL MASS EJECTIONS

One of the most important scientific advances of the space age was the discovery of CMEs — powerful eruptions in which as much as ten billion tons of the Sun's atmosphere can be blown into interplanetary space. Traveling outward from the Sun at speeds up to 2000 kilometers per second, CMEs can create major disturbances in the interplanetary medium and, when they encounter the Earth, trigger severe magnetic storms. CME-driven shocks are also thought to play a significant role in the acceleration of solar energetic particles, which can damage spacecraft and harm astronauts. But, while CMEs are seen routinely with existing instruments, those directed toward Earth are the least likely to be detected.

Despite the importance of CMEs, their origin and evolution are still not well understood, and we have no clear idea of their structure nor extent in interplanetary space presenting a challenge for fundamental science. What forces initiate and drive CMEs? What is the role of magnetic reconnection? What is the origin of the associated waves, shocks, and particle radiation? These fundamental questions cannot be addressed conclusively with the single-vantage-point observations currently available. In order to understand and forecast CMEs, we need three-dimensional (3D) images of them and measurements of the ambient solar corona and heliosphere. We must be able to follow CME-generated disturbances from the Sun to the orbit of Earth. We need to know the state of the ambient solar wind in front of these disturbances and need accurate measurements of the pre-CME corona and of CME timing, size, geometry, mass, speed, and direction as well as know the strength and polarity of the associated magnetic fields. Astrophysical analogues of mass ejections, which may operate in accretion disks and active galactic nuclei, will be better understood when we understand CMEs.

THE EXPLORATION INITIATIVE AND SPACE WEATHER

As humans have moved into space, major advances have been made in global communications, navigation, weather prediction, and other areas relying on satellite technology. However, the dynamic Sun can affect satellite tracking, reliability, the safety of humans in space, as well as communications and navigation equipment.

STEREO will greatly accelerate the development of reliable space weather forecast techniques. Measurements from STEREO will provide early warnings of solar eruptions, which are important for forecasting radiation at the space station, as well as having implications for communications and weather satellites and many other areas of human activity.

STEREO is also an early prototype of a warning system for the protection of astronauts throughout the solar system. As we reach out to the Moon and Mars, an increased human presence in space will require knowledge of the changing space environment to safeguard our astronauts and spacecraft.

STEREO SCIENCE

STEREO Science Objectives:

- Understand the causes and mechanisms of coronal mass ejection (CME) initiation.
- Characterize the propagation of CMEs through the heliosphere.
- Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium.
- Improve the determination of the structure of the ambient solar wind.

Two space based observatories, one drifting ahead of Earth and one behind, will accomplish the measurement goals. Simultaneous image pairs will be obtained by STEREO at gradually increasing angular separations in the course of the mission, and substantial new physical insight will be gained simply from visual examination of the stereo images. In addition, a wide range of image analysis and reconstruction techniques, such as automatic feature tracking and magnetic field constrained reconstruction, can also be applied. Stereoscopic observations with Extreme Ultraviolet (EUV) telescopes will resolve many disputes, including questions of magnetic reconnection and loop–loop interactions.

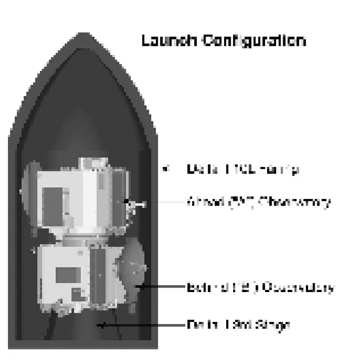
In situ measurements will provide accurate information about the state of the ambient solar wind and energetic particle populations ahead of CMEs while also determining the plasma, magnetic field, and energetic particle characteristics of the interplanetary disturbances as they pass. These measurements will enable definitive tests of CME and interplanetary shock models.

The observatories will:

- Image the solar atmosphere and heliosphere from two perspectives simultaneously
- Track disturbances in 3D from their onset at the Sun to beyond Earth's orbit
- Measure energetic particles generated by the CME disturbances
- Sample fields and particles in the disturbances as they pass near Earth's Orbit

The STEREO scientific program does not depend on the phase of the solar cycle because CMEs and the other phenomena to be studied are common to all phases of the cycle.

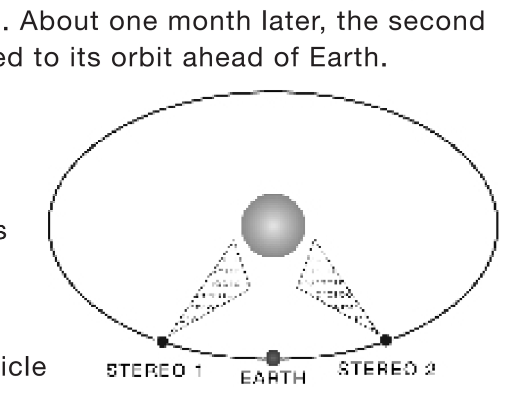
LAUNCH and ORBIT



The STEREO observatories will launch together on a Boeing Delta-II 7925-10L Expendable Launch Vehicle (ELV) from the Cape Canaveral Air Force Station (CCAFS) near the Kennedy Space Center (KSC) in Florida. The twin STEREO observatories are housed within the launch vehicle's third stage, stacked one on top of the other.

STEREO will use a series of lunar swing-bys to escape Earth's orbit and place the twin observatories into their respective orbits. Although lunar gravity has previously been used to manipulate the orbit of a single spacecraft, the STEREO mission is the first ever to use lunar swing-bys for more than one spacecraft. For the first 3 months after launch, the observatories will fly in an orbit from a point close to Earth to one that extends just beyond the Moon's orbit. The orbits of the two observatories will be synchronized to encounter the Moon about two months after launch. At that point, one observatory will use the Moon's gravity to redirect it to an orbit lagging behind Earth. About one month later, the second observatory will encounter the Moon a second time and be redirected to its orbit ahead of Earth.

The "Ahead" spacecraft will orbit around the Sun in approximately 344 days while the "Behind" spacecraft will orbit around the Sun in approximately 389 days. The satellites move away from the Earth at about 22.5 degrees per year and thus from each other at 45 degrees per year.



KSC will be responsible for launching the observatories, performing range and flight safety operations as well as maintaining launch vehicle tracking and control during ascent and spacecraft separation.

OPERATIONS CENTERS

NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD manages the STEREO mission. Project Scientist: Mr. Michael Kaiser, Project Manager: Nicholas Chrissotimos.

GSFC provides science instrument management, systems engineering, mission assurance and reliability, science and data analysis, data archiving, and coordination of Education and Public Outreach (EPO) efforts.

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) in Laurel, MD. is responsible for the design, construction, integration, testing, and mission operations of the observatories, as well as the ground system. Project Manager: Mr. Edward Reynolds

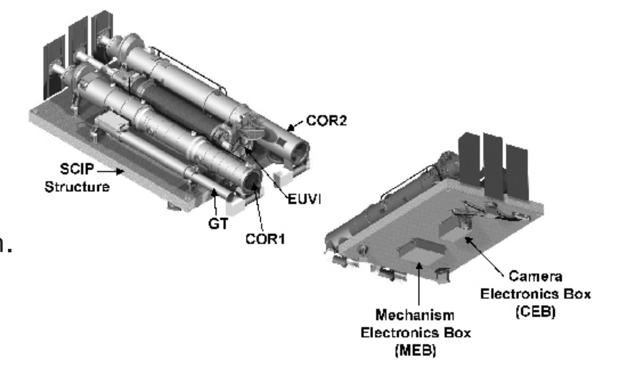
The Mission Operations Center (MOC) will be located at JHU/APL. The STEREO Science Center (SSC) will be located at NASA's GSFC.

INSTRUMENT PACKAGES

The STEREO observatories carry a complement of four scientific investigations (two instruments and two instrument suites, with a total of 13 instruments per observatory) as follows:

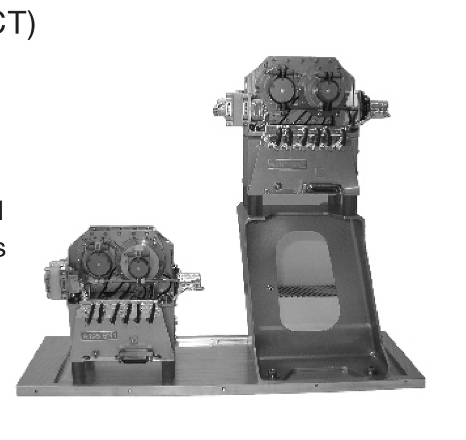
Sun-Earth Connection Coronal and Heliospheric Investigation (SECCHI)
http://stereo.nrl.navy.mil/

- Consists of 4 instruments: an Extreme Ultraviolet Imager, two White-Light Coronagraphs and a Heliospheric Imager
- This suite of remote sensing instruments is designed to study the three-dimensional evolution of CMEs from birth at the Sun's surface through the corona and interplanetary medium to their eventual impact at Earth.
- PI institution: Naval Research Laboratory, Washington DC
- Principal Investigator: Dr. Russell Howard, Project Manager: Ms. Becky Baugh



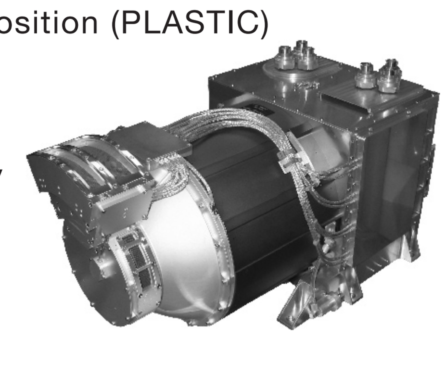
In situ Measurements of PArticles and CME Transients (IMPACT)
http://sprg.ssl.berkeley.edu/impact/

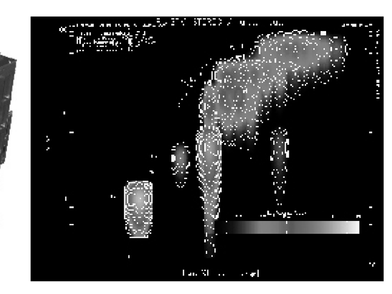
- Consists of seven instruments: three are located on a 6-meter deployable boom, four are located on the main body of the spacecraft
- IMPACT will measure the interplanetary magnetic field, thermal and suprathermal solar wind electrons, and energetic electrons and ions.
- PI institution: University of California – Berkeley Space Sciences Laboratory
- Principal Investigator: Dr. Janet Luhmann, Project Manager: Mr. David Curtis



PLAsma and SupraThermal Ion Composition (PLASTIC)
http://stereo.sr.unh.edu/

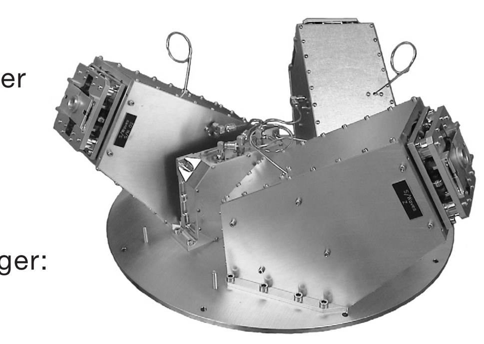
- The PLASTIC experiment supplies key diagnostic measurements of the mass and charge state composition of heavy ions and characterizes CMEs and ambient solar wind plasma.
- PI institution: the University of New Hampshire
- Principal Investigator: Dr. Antoinette Galvin, Project Manager: Mr. Steven Turco



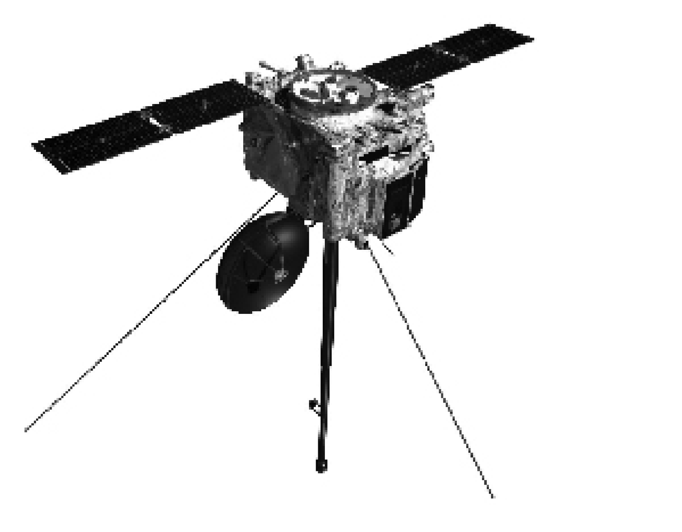


STEREO/WAVES (S/WAVES)
http://www-lep.gsfc.nasa.gov/swaves/swaves.html

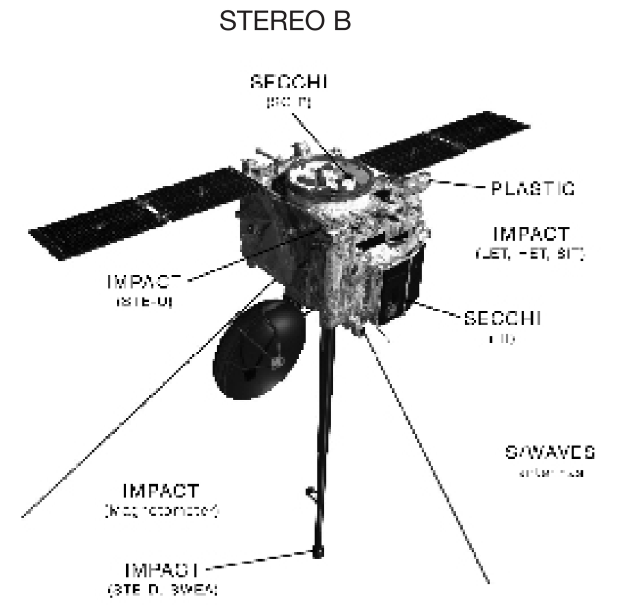
- The S/WAVES instrument is an interplanetary radio burst tracker that tracks the generation and evolution of traveling radio disturbances from the Sun to the orbit of Earth.
- PI institution: Centre National de la Recherche Scientifique Observatory of Paris, France
- Principal Investigator: Dr. Jean-Louis Bougeret, Project Manager: Mr. Keith Goetz



STEREO A

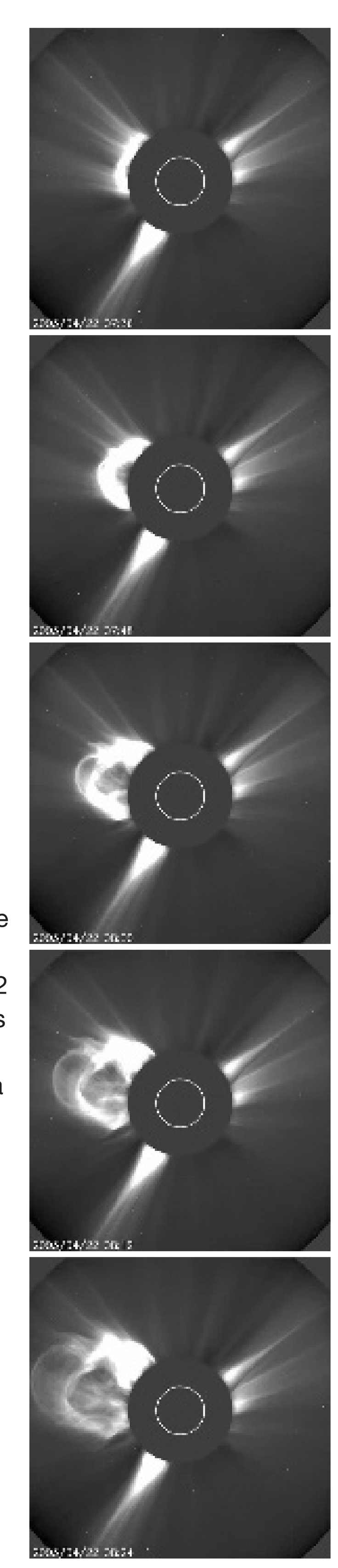


STEREO B



MEASURE THE MOTION OF A CORONAL MASS EJECTION

Grades 6 - 8: Prepared by the SOHO E/PO team (sohowww.nascom.nasa.gov)



An important part of space weather research is to measure the velocity of CMEs and their acceleration as they leave the Sun. This is done by tracking features in the CME and measuring their positions at different times. In the sequence of images shown on the right, you can see a CME erupting from the Sun on the right side of the coronagraph disk (left side of image). The white circle shows the size and location of the Sun. The black disk is the occulting disk that blocks the surface of the Sun and the inner corona. The lines along the bottom of the image mark off units of the Sun's diameter. In this activity, you will learn to calculate the velocity and acceleration of a coronal mass ejection (CME) based on its position in a series of images from the Large-Angle Spectrometric Coronagraph (LASCO) instrument on SOHO.

MATERIALS: Ruler, calculator, and a set of CME images from the LASCO instrument on SOHO. You can use the ones here or grab some from the web (sohowww.nascom.nasa.gov/gallery/LASCO/las001.gif).

ACTIVITY PROCEEDURES

Step 1: Select a feature of the CME that you can see in all five images—for instance, the outermost extent of the cloud, or the inner edge.

Step 2: Measure its position in each image. Your measurements can be converted to kilometers using a simple ratio:

$$\frac{\text{actual distance of feature from Sun}}{\text{Sun's diameter (1.4 million km)}} = \frac{\text{position of feature as measured on image}}{\text{diameter of Sun as measured on image}}$$

Step 3: Using the distance from the Sun and the time (listed on each image), you can calculate the average velocity. Velocity is defined as the rate of change of position. Using the changes in position and time, the velocity for the period can be calculated using the following equation: v = (s2 - s1) / (t2 - t1), where s2 is the position at time, t2; s1 is the position at time, t1. The acceleration equals the change in velocity over time; that is, a = (v2 - v1) / (t2 - t1), where v2 is the velocity at time t2; v1 is the velocity at time t1. You can record your results in a table.

UNIVERSAL TIME	TIME INTERVAL	POSITION	AVG. VELOCITY	AVG. ACCELARATION

FURTHER QUESTIONS AND ACTIVITIES

Select another feature, trace it, and calculate the velocity and acceleration. Is it different from the velocity and acceleration of the other feature you measured? Scientists often look at a number of points in the CME to get an overall idea of what is happening.

How does the size of the CME change with time? What kind of forces might be acting on the CME? How would these account for your data?

If the CME continues with the same speed as it travels through interplanetary space, how long before it reaches the orbit of the Earth (distance from Sun to Earth is 150 million km)?

VITAL STATISTICS

LAUNCH:

Target Date:	2006
Launch Vehicle:	Delta-II 7925-10L
Launch Site:	Cape Canaveral Air Force Station, FL

MISSION LIFETIME: 2 years (minimum), 5 Year Goal

OBSERVATORY CONFIGURATION:
Two functionally identical spacecraft

Dimensions:	1.1 h x 2.0 d x 1.2 w meters (launch configuration)
	1.1 h x 2.0 d x 6.5 w meters (solar arrays deployed)
Mass:	547 kg (dry mass)
	610 kg (with propellant)
Average Power:	596 watts (EOL)
Data Rate:	427 kbps (X-Band, CCSDS compliant)

PROCESSOR:

Memory:	7.5 Gb (solid state recorder)
Processor:	3 mongoose V processors

CONTRIBUTING INSTITUTIONS

SECCHI
- NASA Goddard Space Flight Center, USA
- Lockheed Martin Solar and Astrophysics Laboratory, USA
- Jet Propulsion Laboratory, USA
- Boston College, USA
- Stanford University, USA
- Southwest Research Corporation, USA
- Max Planck Institute for Solar System Studies, GERMANY
- University of Kiel, GERMANY
- University of Birmingham, UK
- Rutherford Appleton Labs, UK
- Mullard Space Science Lab, UK
- Institut d'Optique Theoretique et Appliquee, FRANCE
- Institut d'Astrophysique Spatiale, FRANCE
- Institute d'Astronomie Spatiale, FRANCE
- Universite d'Orleans, FRANCE
- Centre Spatial de Liege, BELGIUM
- Royal Observatory of BELGIUM

IMPACT
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- University of Maryland, USA
- University of Kiel, GERMANY
- Centre d'Etude Spatiale des Rayonnements, FRANCE
- Los Alamos National Laboratory, USA
- Max Planck Institute for Solar System Studies, GERMANY
- NASA Jet Propulsion Laboratory, USA
- ESTEC-European Space Agency, HOLLAND
- LESIA Observatoire de Paris-Meudon, FRANCE
- University of California, Los Angeles, USA
- Science Applications International Corporation, USA
- NOAA Space Environment Center, USA
- University of Colorado, USA
- University of Michigan, USA
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PLASTIC
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- University of Kiel, GERMANY
- NASA Goddard Space Flight Center, USA

S/WAVES
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- NASA Goddard Space Flight Center, USA
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- Catholic University of America, USA
- University of Athens, Greece
- University of Sidney , Australia
- University of Colorado. USA
- Naval Research Laboratory, USA

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