Ten years of SOHO

SOHO is one of the most successful space missions in history and has provided scientists and the public with a wealth of spectacular images and scientific data. It has revolutionized our understanding of the Sun, solar eruptions and of space weather effects.

Since its launch on 2 December 1995, SOHO has revolutionized our understanding of the Sun. SOHO has provided the first images of structures and flows below the Sun's surface and of activity on the far side of the Sun. It has discovered sunquakes, mapped the evolution of large-scale flow patterns below the surface, and eliminated uncertainties in the internal structure of the Sun as a possible explanation for the "neutrino problem".

SOHO has revealed the Sun's extremely dynamic atmosphere, provided evidence for upward transfer of magnetic energy from the surface to the outer solar atmosphere, the corona, through a "magnetic carpet", and identified the source regions of the fast solar wind. Furthermore, it has revolutionized our understanding of solar-terrestrial relations and dramatically boosted our space weather forecasting capabilities by providing a continuous stream of images covering the dynamic atmosphere, extended corona, and activity on the far side of the Sun.

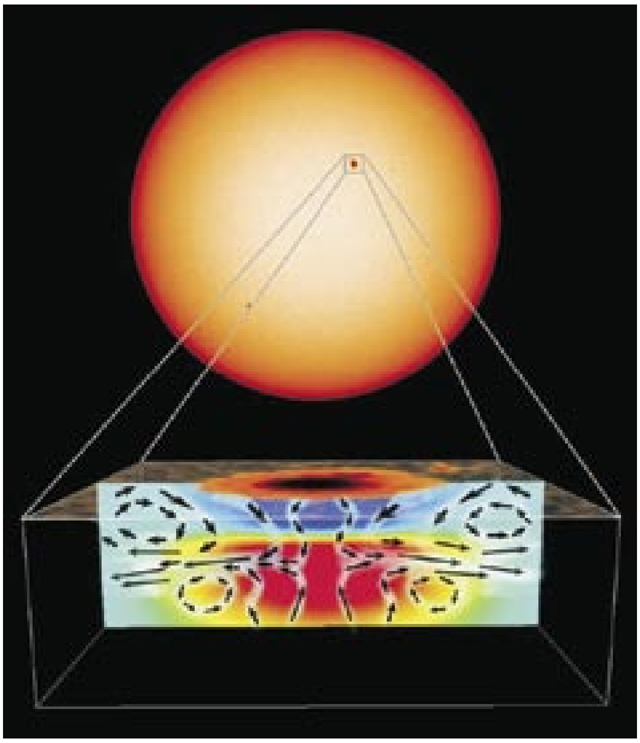


Figure 1: Using advanced analysis techniques, SOHO's MDI instrument can reveal the temperature and flow structure beneath sunspots.

Author: Pål Brekke
Norwegian Space Center
Pål Brekke received a Dr. Scient degree in 1993 from the Institute of Theoretical Astrophysics, University of Oslo with focus on the ultraviolet (UV) emissions from the Sun. He was part of the Norwegian SOHO team until 1999 when he joined ESA as the Deputy Project Scientist for SOHO at NASA Goddard Space Flight Center. Since 2004 is has worked as a Senior Advisor at the Norwegian Space Centre in Oslo.
He received a Fulbright Fellowship in 1994, ESA´s´Eceptional Achievement Award in 2002, Laurels for Team Achievements from the International Academy of Astronautics in 2003.

Making the Sun transparent

Just as seismology reveals the Earth's interior by studying earthquake waves, solar physicists probe the interior of the Sun using a technique called helioseismology. The oscillations detectable at the visible surface are due to sound waves reverberating through the Sun's inner layers. New methods called "local area helioseismology" allowed the construction of the first true 3-D images and flow maps of the interior of a star, and even first images of the far side of our Sun. Applying the novel acoustic tomography method to MDI data, scientists could for the first time study the structure of sunspots below the Sun's surface. They were thus able to answer two long-standing puzzles about these blemishes on the Sun that have been a source of wonder to mankind ever since they were described (and drawn in painstaking detail) by Galileo Galilei: How deep do the spots extend below the surface, and how can sunspots last for several weeks without flying apart? The MDI team found the answers. They discovered strong, converging downflows, which stabilize the structure of the sunspots, and they found that sunspots are relatively shallow (Fig. 1).

More impressing is probably SOHOs ability to make holographic reconstruction of active regiona on the far side of the Sun. Advance warning of magnetic storms brewing on the far side that could rotate with the Sun and threaten Earth is therefore of vital importance for space weather forecasting.

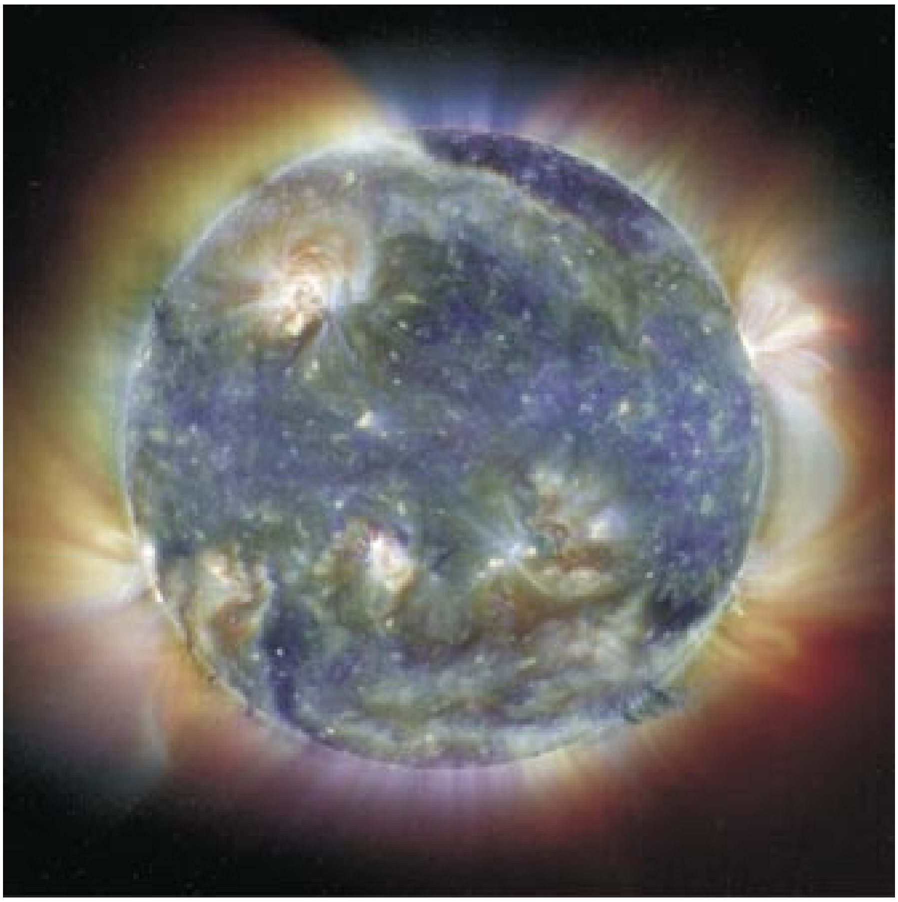


Figure 2: Composite image of the solar corona with three wavelengths (171 Å as blue, 195 Å as yellow and 284 Å as red) combined to show solar features unique to each wavelength. The 171 Å filter shows Fe IX/X emission at about 1 million degrees, the 195 Å filter shows Fe XII at about 1.5 million degrees, and the 284 Å filter shows Fe XIV at about 2.5 million degrees.

The Sun's Dynamic Corona

The outer atmosphere of the Sun, the so-called corona, has a typical temperature of about 1 million degrees and emits light mainly in the ultraviolet (UV) part of the spectrum. It is this radiation from the Sun's hot corona that controls the composition and dynamics of Earth's upper atmosphere. Water vapour and ozone are especially sensitive to changes in the Sun's UV radiation. Fortunately, Earth's atmosphere protects us from this harmful radiation. On the other hand, this also means that we cannot observe the Sun in these wavelengths from Earth. In order to understand the Sun's EUV output and variations thereof, we have to leave Earth's atmosphere behind and observe the Sun from space.

SOHO's Extreme ultraviolet Imaging Telescope (EIT) has provided us with stunning images of the Sun's corona, showing delicate coronal loops, bright flares, and intriguing coronal holes (Fig. 2). EIT and the UV spectrometers SUMER and CDS have demonstrated that the outer solar atmosphere is extremely dynamic and time variable in nature and that plasma flows play an extremely important role.

SOHO, the Space Weather Watchdog

While the Sun's total radiative output is reassuringly constant, it is at the same time a dynamic and violent star. Besides emitting a continuous stream of plasma in the solar wind, the Sun periodically releases huge amounts of matter in what are called coronal mass ejections (CMEs; Fig. 3). CMEs are the most powerful eruptions in the solar system, with billions of tons of electrified gas being propelled from the Sun's atmosphere into space at millions of kilometers per hour. These immense clouds of material, when directed towards Earth, can cause large magnetic storms in the magnetosphere and the upper atmosphere. Researchers believe that CMEs are launched when solar magnetic fields become strained and suddenly 'snap' into a new configuration, like a rubber band that has been twisted to the breaking point.

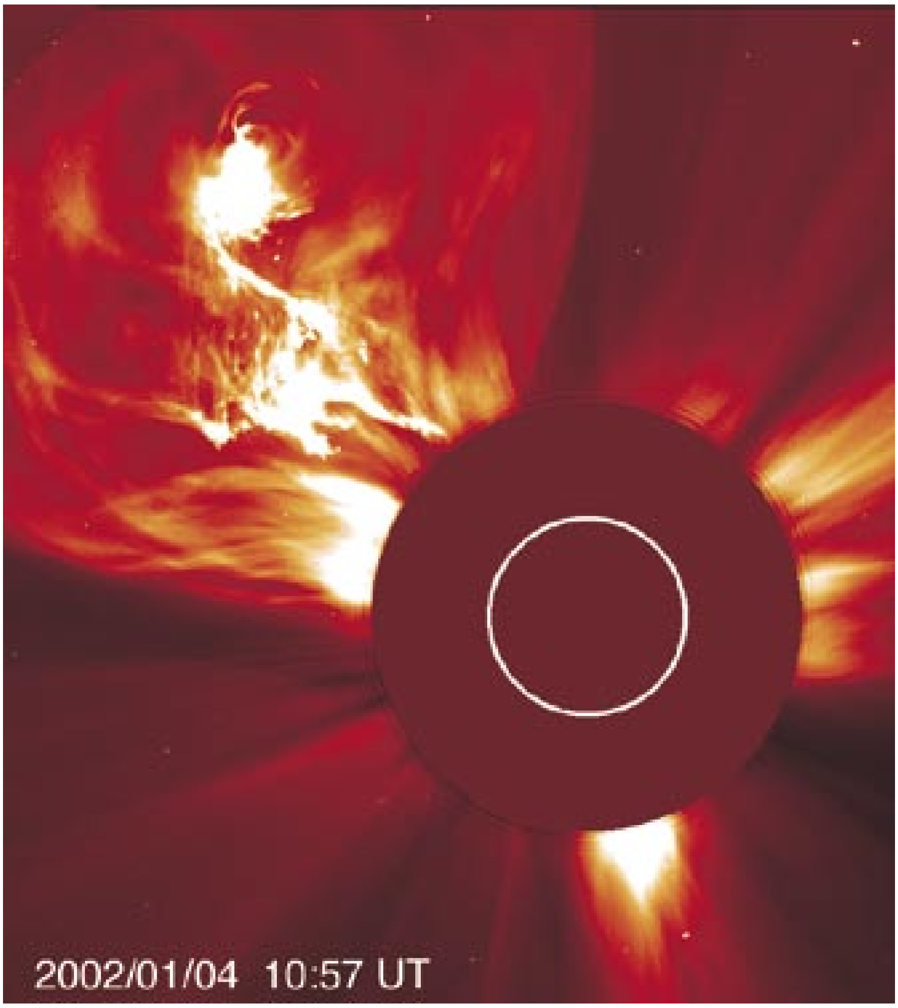


Figure 3: This fiery coronal mass ejection shows stunning details in the ejected material. This image was taken by SOHO's LASCO coronograph. The direct sunlight is blocked by an occulter (red disk), revealing the surrounding faint corona. The white circle represents the approximate size of the Sun.

The LASCO team has compiled an extensive catalog which summarizes the properties (mass, speed, acceleration, angular width and position, etc.) of the more than 10,000 CMEs observed since launch. This catalog has been used in numerous studies, including investigations about solar cycle variations of CMEs. The rate of CMEs increases by more than an order of magnitude from 0.5 CMEs per day during solar minimum to over 6 CMEs per day during solar maximum.

Solar Storms end Effects on Earth

Apart from causing beautiful aurorae borealis, the disturbances associated with CMEs can damage satellites, disturb telecommunication devices, pose a radiation hazard to orbiting astronauts, lead to corrosion in oil pipe lines and cause current surges in power lines. As our society becomes increasingly dependent on space-based technologies, our vulnerability to "space weather" becomes more obvious, and the need to understand it and mitigate its effects becomes more urgent. In recent years, forecasting the conditions in the near-earth environment and the "geo-effectiveness" of CMEs and solar flares has become one of the key research areas in solar and solar-terrestrial physics, and SOHO is playing a pioneering and leading role in this new discipline.

Over two weeks in October/November 2003, the Sun featured three unusually large sunspot groups which gave rise to 11 X-class flares (including the strongest ever recorded), numerous CMEs and two significant proton storms (Fig. 4). Satellites, power grids, radio communication and navigation systems were significantly affected. The events, among the best-observed ever, will be the subject of analysis for years to come. The events caused unprecedented attention from the media and the public. Images from SOHO appeared in nearly every major news outlet. Furthermore, the great public interest wiped out all existing SOHO web traffic records, with the SOHO web server serving over 31 million page requests and 4.3 Terabyte of data in just one month.

SOHO, the Comet Finder

SOHO is providing new measurements not only about the Sun. As of February 2006, the LASCO instrument has detected over 1100 comets, most of them so-called sun-grazers. These comets pass by very close to the Sun and acquire a prominent tail as the Sun heats their icy cores. Nearly half of all comets for which orbital elements have been determined (since 1761) were discovered by SOHO, over two thirds of those by amateurs accessing LASCO data via the Web. This is a field where amateurs can actively contribute to scientific research, and each day, numerous people from all over the world download the near real-time data to search for new comets.

As the brightest, most spectacular comet ever observed by SOHO, Comet NEAT (C/2002 V1) provided some enticing data for further study, thanks to a grazing encounter with a coronal mass ejection (Fig. 5). The LASCO C3 observations during 16-20 February 2003 suggest an interaction between the comet's ion tail and other magnetic fields in the outer corona at the time of the oblique impact with the CME. This is the first time such an interaction has been imaged. It is also the closest to the Sun that a comet has been directly observed.

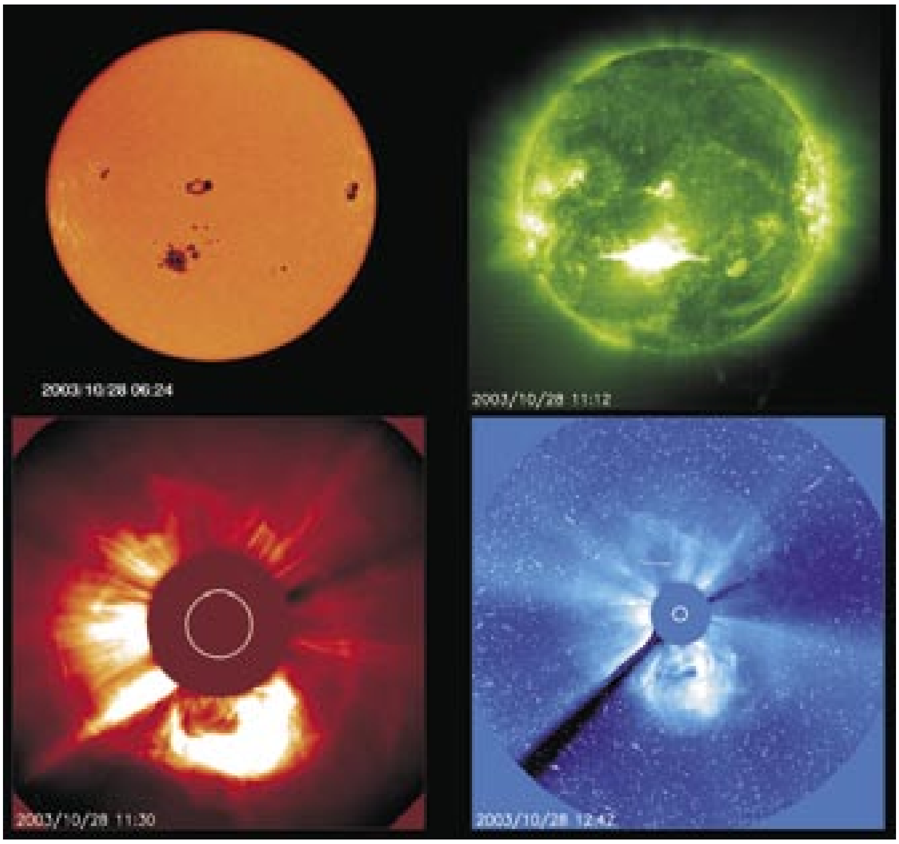


Figure 4: Active Region 10486 unleashed a spectacular show on 28 October 2003: An X 17.2 flare, a fast-moving coronal mass ejection and a strong solar energetic particle event. From top left: Giant sunspot groups seen by MDI in white light. Flare as seen by EIT in 195 Å emission. The fast-moving CME in the LASCO C2 coronagraph, then in the LASCO C3 coronagraph with the particle shower becoming visible as "snow" in the image. The fast-moving cloud impacted Earth's magnetosphere a mere 19 hours later, almost a record speed.

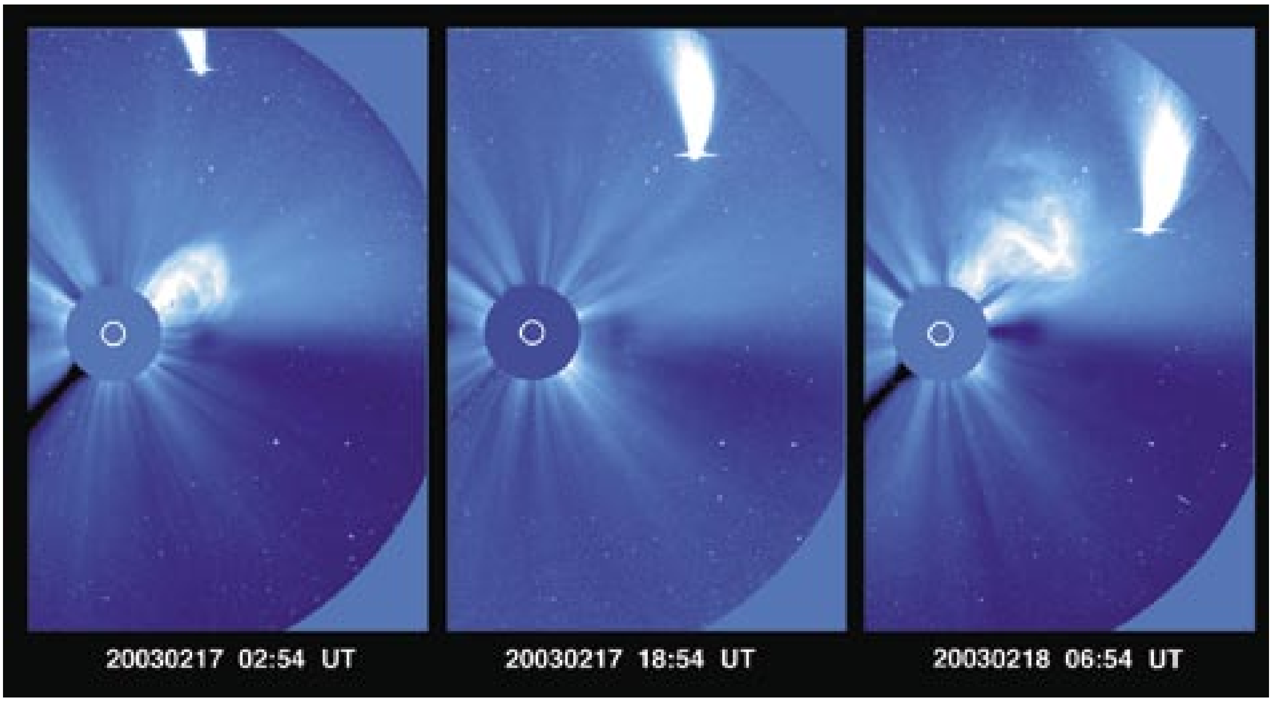


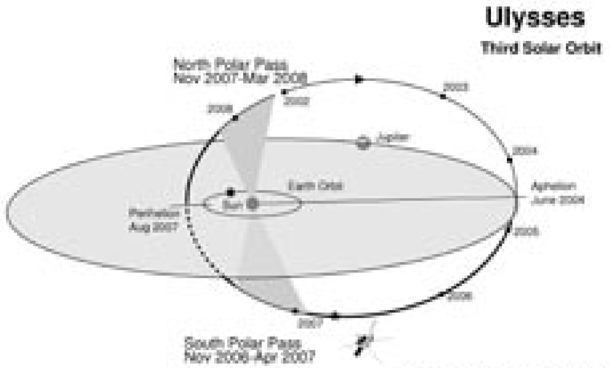
Figure 5: Perihelion passage of comet NEAT (C/2002 V1) in February 2003, as imaged by the LASCO C3 coronagraph.

Conclusions and SOHO's Future

The going has not always been easy. An unexpected loss of contact occurred on 25 June 1998. Fortunately, the mission was completely recovered in one of the most dramatic rescue efforts in space, and normal operations could be resumed in mid-November 1998 after the successful recommissioning of the spacecraft and all twelve instruments. Despite subsequent failures of all three gyroscopes (the last in December 1998), new gyroless control software installed by February 1999 allowed the spacecraft to return to normal scientific operations, providing an even greater margin of safety for the spacecraft. This made SOHO the first three-axis-stabilized spacecraft to be operated without a gyroscope. A third crisis occurred in June 2003, when SOHO's main antenna became stuck. Using the secondary antenna and software for intermittent recording, however, even this problem could be overcome and the observations continue.

In the 10 years since launch, *SOHO* has provided an unparalleled breadth and depth of information about the Sun, from its interior, through the hot and dynamic atmosphere, to the solar wind and its interaction with the interstellar medium. Research using *SOHO* observations has revolutionized our understanding of the Sun and space weather research. The coming years promise to be similarly exciting and rewarding, when SOHO observations will be complemented and enhanced by those from NASA's STEREO and JAXA's Solar-B missions, affording new opportunities for improved understanding of the Sun-heliosphere system. After the launch of NASA's Solar Dynamics Observatory, SOHO's lineal descendant, the capabilities of some SOHO instruments will be eclipsed, but not all. In particular the LASCO coronagraph observations and VIRGO total solar irradiance measurements will continue to be critical and unique contributions to the International Living With a Star (ILWS) program.

Ulysses embarks on third set of polar passes



On 17 November, the joint ESA-NASA Ulysses mission reached an another important milestone on its epic out-of-ecliptic journey: the start of the third passage over the Sun's south pole.

Launched in 1990, the European-built spacecraft is engaged in the exploration of the heliosphere, the bubble in space blown out by the solar wind. Given the capricious nature of the Sun, this third visit will undoubtedly reveal new and unexpected features of our star's environment.

The first polar passes in 1994 (south) and 1995 (north) took place near solar minimum, whereas the second set occurred at the height of solar activity in 2000 and 2001. "During the first polar passes, Ulysses found a well-ordered heliosphere, with clear differences between the solar wind at the poles and equator", says Richard Marsden, ESA's Ulysses Project Scientist and Mission Manager. "At solar maximum things were more complex, making it hard to distinguish any particular region from another."