Air and Space this Week

Item of the Week

SOLAR AND HELIOSPHERIC OBSERVATORY (*SOHO*)

Originally appeared December 9, 2024

KEY WORDS: SOHO Sun Heliosphere L1

Last week (12/2) was the 29th anniversary of the launch of the SOHO *spacecraft, on a joint ESA/NASA mission to explore the Sun, from its inner core to the solar wind. The spacecraft was built by ESA, launched by NASA, and is managed from NASA Goddard Space Flight Center. Its twelve instruments were provided by European and American scientists.* SOHO*'s primary mission was for only two years, but it is* ***still*** *fully operational in a halo orbit centered on the L1 point in Space (on a line between the Sun and Earth where their gravitational pull is equal).* SOHO *is one of the many spacecraft presently studying the Sun, the source of life and most of the energy we use today.*

EARLY SOLAR MISSIONS

A number of satellites have the designation "Explorer," either as their primary name or as a secondary name. Many of them had solar observations as (part of) their mission. For a list of the Explorer Program satellites, see: https://nssdc.gsfc.nasa.gov/multi/explorer.html.

Pioneers 6-9: Launched in the late 1960s, these four (plus *Pioneer 10* which failed to reach orbit) were part of an interplanetary space weather network.

***Helios A* and** *B* were German/NASA satellites for exploring the solar wind, among other things. NSSDCA for *Helios A*: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1974-097A *NSSDCA* for *Helios B*: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1976-003A.

Ulysses was to have been a two-part mission to use a gravitational assist from Jupiter to allow for an orbit that would pass over the poles of the Sun, one spacecraft built by ESA and the other by NASA. The first was launched from STS-41, the 11th flight of the Space Shuttle *Discovery*, on October 10, 2006. NASA cancelled its flight in 1981. The Ulysses mission was covered in a previous Item of the Week; see here.

NSSDCA entry: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1990-090B.

Ramaty High Energy Solar Spectroscopic Imager (***RHESSI***) was a NASA mission designed to study solar flares. It was launched on a Pegasus missile air dropped from an L-1011 aircraft, on February 5, 2002. NSSDCA entry: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2002-004A.

***Geotail*:** Launched July 24, 1992; joint NASA/JAXA mission to study solar wind influence on Earth's magnetosphere; finally failed on 11/28/2022; more info: https://science.nasa.gov/mission/geotail

***Ionospheric Connection Explorer* (*ICON*):** Launched: October 10, 2019; NASA mission to observe the effects of the solar wind on Earth's ionosphere; contact lost on November 25, 2022 (successfully completed 2-year mission objectives). More info: https://science.nasa.gov/mission/icon

SOHO MISSION PLANNING AND OBJECTIVES

Scientific understanding of the Sun and its effects on the Earth are hugely important, as shown by the earlier missions listed above. Satellite and instrument technology was improving quickly, and ESA and NASA teamed up to create the state-of-the-art detectors and supporting satellite components needed to make critical observations.

The three main scientific objectives of the SOHO mission are:

- Investigation of the outer layer of the Sun, which consists of the chromosphere, transition region, and the corona. The instruments CDS, EIT, LASCO, SUMER, SWAN, and UVCS are used for this solar atmosphere remote sensing.
- Making observations of solar wind and associated phenomena in the vicinity of L_1. CELIAS and COSTEP are used for "in situ" solar wind observations, aimed at understanding why the corona is so hot and how the solar wind is accelerated (questions resolved by the later *Parker Solar Probe*).
- Probing the interior structure and dynamics of the Sun. GOLF, MDI, and VIRGO are used for helioseismology.
- BONUS #1: *SOHO* is the main source of near-real-time data for space weather prediction. More than just a heads-up for aurora seekers, such predictions are important for satellite managers and electrical grid engineers on Earth. Corona Mass Ejections can induce damaging levels of electrical current in satellite systems and generate overloads in the grid (for essentially the same reason you don't put a fork in your microwave oven!).
- BONUS #2: *SOHO* data revealed over 5000 new comets to date, mostly small Sun-grazers that did not survive perihelion passage. The population of such objects is a key component in understanding the dynamics and evolution of the Solar System.

SOHO INSTRUMENTATION

SOHO's 12 instruments are mounted on its Payload Module. Each can be aimed separately and can be used in combination with one another. Here they are, listed alphabetically:

Coronal Diagnostic Spectrometer (CDS): Measures density, temperature, and movement in the solar corona; see: https://solar.bnsc.rl.ac.uk

Charge Element and Isotope Analysis System (CELIAS): Determine composition and abundance of ions in the solar wind, and provide a 30-minute notice of fluctuations in the solar wind; see: https://sci.esa.int/web/soho/-/30956-heliosphere

Comprehensive SupraThermal and Energetic Particle Analyzer (COSTEP): Measures energetic particles emitted by the Sun; see: https://www.ieap.uni-kiel.de/et/ag-heber/costep/index.php

Extreme Ultraviolet Imaging Telescope (EIT): Observe the solar corona in the far ultraviolet part of the spectrum, produced by ionized iron and ionized helium, revealing details of the corona's structure; see: https://en.wikipedia.org/wiki/Extreme_ultraviolet_Imaging_Telescope

Energetic and Relativistic Nuclei and Electron Experiment (ERNE): Paired with COSTEP, ERNE detects and measures energy eruptions from the Sun that accelerate gas atoms to extremely high energy; see: https://srl.utu.fi/projects/erne.

Global Oscillation at Low Frequencies (GOLF): The Sun undergoes resonating acoustic oscillations whose frequency can provide clues as to the nature of the solar interior; see: https://web.archive.org/web/20000209174909/http://golfwww.medoc-ias.u-psud.fr/instru.html.

Large Angle and Spectrometric Coronagraph (LASCO): LASCO uses three coronagraphs to look at the solar corona. Its electronics are paired with those for EIT. For more information, see: https://lasco-www.nrl.navy.mil/index.php?p=content/about_lasco.

Michelson Doppler Imager (MDI) was designed to measure movement and magnetic fields in the solar photosphere; see: http://soi.stanford.edu/science/obs_prog.html. Its use was suspended in 2011 because a better instrument was available on the *Solar Dynamics Observer*.

Solar Ultraviolet Measurement of Emitted Radiation (SUMER): Measured the flow of plasma, temperatures, and density in the solar corona; see: https://web.archive.org/web/20060615104607/http://www.mps.mpg.de/en/projekte/soho/sumer

Solar Wind Anisotropies (SWAN): Looks away from the Sun to detect hydrogen atoms in the interplanetary medium that came in from interstellar space being impacted by the solar wind. For more on SWAN, see: https://sci.esa.int/web/soho/-/30956-heliosphere.

UltraViolet Coronograph Spectrometer (UVCS) measured temperature and density in the solar corona; see: https://lweb.cfa.harvard.edu/uvcs.

Variability of Solar Irradiance and Gravity Oscillations (VIRGO) measures oscillations of the solar "surface" and the total solar energy output to gain insights into the solar interior, complementing the mission of the GOLF instrument. For more info, see: https://www.ias.u-psud.fr/virgo/virgomain.html.

SOHO PROBLEMS AND SOLUTIONS

Problem 1

A cat may have nine lives, but *SOHO* has had but three (so far). The spacecraft lost its lock on the Sun on June 24, 1998, during a series of gyroscope calibrations and related maneuvers and entered its Emergency Sun Reacquisition control mode. The SOHO team went to work to recover the spacecraft, but it entered the ESR mode again the next day twice. All contact was lost very soon thereafter. The spacecraft was spinning and losing power, because its solar panels were no longer aimed at the Sun. ESA immediately sent a team to the U.S. to help. The joint efforts paid off on July 23, when radar from Arecibo and Goldstone located the spacecraft and was able to determine its attitude. It was travelling sideways, and rotating slowly. On August 3, a carrier wave signal was detected, indicating that the spacecraft was still alive. Additional work led to downlinking of telemetry on August 8, and engineers began planning for *SOHO*'s recovery. It would take time to thaw out frozen thrusters and re-orient the spacecraft correctly. Full operation came slowly, and was completed on October 21, 1998.

The spacecraft was dependent on three gyroscopes to orient itself properly, and after full operation was restored, only one was operational. It failed on December 21, making *SOHO* totally reliant on its thrusters, consuming their fuel at a ruinous rate. If no solution was found, the second life of *SOHO* would be rather short.

ESA engineers were up to the task! They figured out a new gyro-less operational mode requiring minimal thruster use, and successfully implemented it on February 1, 1999. Their fix allowed SOHO's third life to continue to the present day, and beyond. But not without another problem cropping up.

Problem 2

The Y-axis stepper motor on *SOHO*'s high-gain antenna malfunctioned in 2003, causing data periodic data blackouts. However, ESA and NASA engineers found a solution. They would use SOHO's low-gain antenna during the blackout periods, in combination with an on-board data recorder and the use of the biggest antennae in the Deep Space Network, resulting in only minor reduced data flow during the times when the high-gain antenna could not be used.

What a great example of engineering teamwork!

RESULTS

Bottom Line Up Front: *SOHO* was so successful that its mission has been extended many times, the first being in 1997, and it is still in operation today. It met all of its pre-mission science objectives almost completely, and provided additional information on Solar System dynamics. The one thing that *SOHO* did not fully complete, the understanding of the corona's high heat and the acceleration of solar wind particles to very high speed, was advanced significantly, informing the design of the *Parker Solar Probe* and its instruments, which have succeeded in providing the necessary data and observations.

By any rational analysis, the SOHO mission was, and still is, a resounding success!

ONGOING AND SUBSEQUENT SOLAR MISSIONS

WIND

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1994-071A

Launched: November 1, 1994; reached L1 in 2004 (delay due to *SOHO* and *ACE* at L1)

Primary mission: Study solar wind radio waves and plasma in the Earth's magnetosphere

Status: Operational

More info: https://wind.nasa.gov

***Advanced Composition Explorer* (*ACE*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1997-045A

Launched: August 25, 1997, now in a halo orbit at L1

Primary mission: Analyze solar wind ions and galactic cosmic ray nuclei

Status: Operational (The Solar Energetic Particle Ionic Charge Analyzer failed in 2005)

More info: https://science.nasa.gov/mission/ace

***Thermosphere Ionosphere Mesosphere Energetics and Dynamics* (*TIMED*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2001-055B

Launched: December 7, 2001, now in Earth orbit

Primary mission: Study influence of Sun (and humans) on T, I, and M parts of our atmosphere

Status: Operational

More info: http://www.timed.jhuapl.edu/WWW/index.php

***Solar Terrestrial Relations Observatory A* & *B* (*STEREO*)**

NSSDCA: *STEREO A*: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2006-047A

STEREO B: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2006-047B

Launched: October 26, 2006

Primary mission: The two spacecraft were launched together, but were put into different heliocentric orbits, one closer to the Sun (leading) and one further away (trailing). On 2/6/2011, the two were 180° apart, allowing simultaneous observation of the entire Sun.

Status: *STEREO A* is still operational; *STEREO B*'s mission ended on October 17, 2018

More info: https://science.nasa.gov/mission/stereo

***Interstellar Boundary Explorer* (*IBEX*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2008-051A

Launched: October 19, 2008, now in a three-lobed orbit inside the orbit of the Moon

Primary mission: Map the "boundary" of the Heliosphere by collecting particles from there.

Status: Operational

More Info: http://ibex.swri.edu/mission/index.shtml

***Solar Dynamics Observatory* (*SDO*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2010-005A

Launched: February 11, 2010

Primary mission: Monitor Sun's interior, atmosphere, magnetic field, and energy output

Status: Operational, but the building housing the mission data center recently flooded, making data temporarily unavailable; see: https://blogs.nasa.gov/sunspot/2024/12/03/data-from-2-nasa-solar-missions-temporarily-unavailable

More info: https://sdo.gsfc.nasa.gov

***Interface Region Imaging Spectrograph* (*IRIS*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2013-033A

Launch: June 27, 2013

Primary mission: Observe chromosphere to determine flow of energy and plasma to corona

Status: Operational, but present data access prevented by flooding (see SDO above)

More info: https://iris.gsfc.nasa.gov

***Deep Space Climate Observatory* (*DSCOVR*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2015-007A

Launched: February 11, 2015, now in a halo orbit at L1

Primary mission: Conduct real-time observations of solar wind for geomagnetic storm warnings

Status: Operational

More info: https://science.nasa.gov/mission/dscovr

***Magnetospheric Multiscale* (*MMS*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2015-011A
https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2015-011B

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2015-011C

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2015-011D

Launched: Fleet of four satellites on March 15, 2015, all now in Earth orbit

Primary mission: Investigate how Sun and Earth magnetic fields interact

Status: Operational

More info: https://lasp.colorado.edu/mms/sdc/public

***Global-scale Observations of the Limb and Disk* (*GOLD*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2018-012B

Launched: January 25, 2018, now in Earth orbit

Primary mission: Measure density and temperature in Earth's thermosphere and ionosphere

Status: Operational

More info: https://gold.cs.ucf.edu

***Parker Solar Probe* (*PSP*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2018-065A

Launched: August 12, 2018

Primary mission: Explore solar corona from close range

Status: Operational (primary mission in progress)

More info: https://parkersolarprobe.jhuapl.edu

***Solar Orbiter* (*SolO*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2020-010A

Launched: February 9, 2020; ESA/NASA partnership

Primary mission: Imaging Sun, especially polar regions, and observe solar wind

Status: Operational

More info: https://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter

***Advanced Space-based Solar Observatory* (*ASO-S*)**

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2022-129A

Launched: October 8, 2022

Primary mission: Study solar magnetic field, CMEs, and solar flares

Status: Operational

More information: https://iopscience.iop.org/article/10.1088/1674-4527/19/11/156

Upcoming Mission: **ESA's *Proba-3***: https://earthsky.org/space/proba-3-a-sun-observing-telescope-made-from-2-satellites. Two satellites will be involved, flying in close formation, a mere 150 meters apart. One's shadow will fall on the other, allowing faint objects near the Sun to be seen – a coronagraph much larger than usual! For more on the mission's objectives, see: https://phys.org/news/2024-12-space-mysteries-proba.html

CODA

Of course, study of the Sun began long before spaceflight was possible. Many ground-based telescopes and other equipment have been used to study it. From Galileo's diagrams of sunspots to Horrock's first seeing a Venus transit, to the discovery of helium, to the Big Bear Solar Observatory high in the San Gabes, to the McMath-Pierce Solar Telescope at Kitt Peak, and many, many more, telescopic observations of the Sun have produced important results many times over.

And that trend continues.

The National Solar Observatory is a research center based in Boulder, Colorado. It operates an observatory on New Mexico's Sacramento Peak, and six other sites around the world that comprise the Global Oscillations Network Group. In addition to managing solar facilities, NSO develops advanced instrumentation, supports research, and carries out educational and public outreach. The newest entry in the NSO family is the **Daniel K. Inouye Solar Telescope**, located at the Haleakala Observatory site on Maui is the most powerful ground-based solar telescope, equipped with adaptive optics. It became operational a few years ago; see here.

A European consortium is building a 4-meter class solar telescope facility in Spain's Canary Islands. The design reviews for the telescope and its initial instruments have been completed; if all goes well, the facility will begin operations in 2028. For more on European Solar Telescope, see: https://www.est-east.eu.

ADDITIONAL REFERENCES

SOHO website: https://soho.nascom.nasa.gov/about/about.html

SOHO Latest Images: https://soho.nascom.nasa.gov/data/realtime-images.html

ESA's *SOHO* eoPortal: https://directory.eoportal.org/satellite-missions/soho#SOHO.html.4

SOHO Fact Sheet: https://soho.nascom.nasa.gov/about/docs/SOHO_Fact_Sheet.pdf

SOHO's Recovery: https://www.esa.int/esapub/bulletin/bullet97/vandenbu.pdf

SOHO NASA page: https://soho.nascom.nasa.gov

ESA *SOHO* page:
https://www.esa.int/Science_Exploration/Space_Science/SOHO/SOHO_overview

SOHO Instrument Roster: https://soho.nascom.nasa.gov/about/instruments.html

SOHO Newsroom: https://soho.nascom.nasa.gov/newsroom/newsroom.html

NASA Science page: https://science.nasa.gov/mission/soho

Data from *SOHO*: https://soho.nascom.nasa.gov/data/realtime-images.html

Saving SOHO: https://soho.nascom.nasa.gov/operations/Recovery/aerospace.pdf

SOHO Mission Interruption Report:
https://umbra.nascom.nasa.gov/soho/SOHO_final_report.html

25-Year Celebration page: https://www.nasa.gov/missions/soho/esa-nasas-sun-observing-soho-mission-celebrates-a-quarter-century-in-space

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https://www.esa.int/ESA_Multimedia/Images/2024/03/SOHO_reaches_5000_comets

Wikipedia: https://en.wikipedia.org/wiki/Solar_and_Heliospheric_Observatory

Last Edited on 7 December 2024