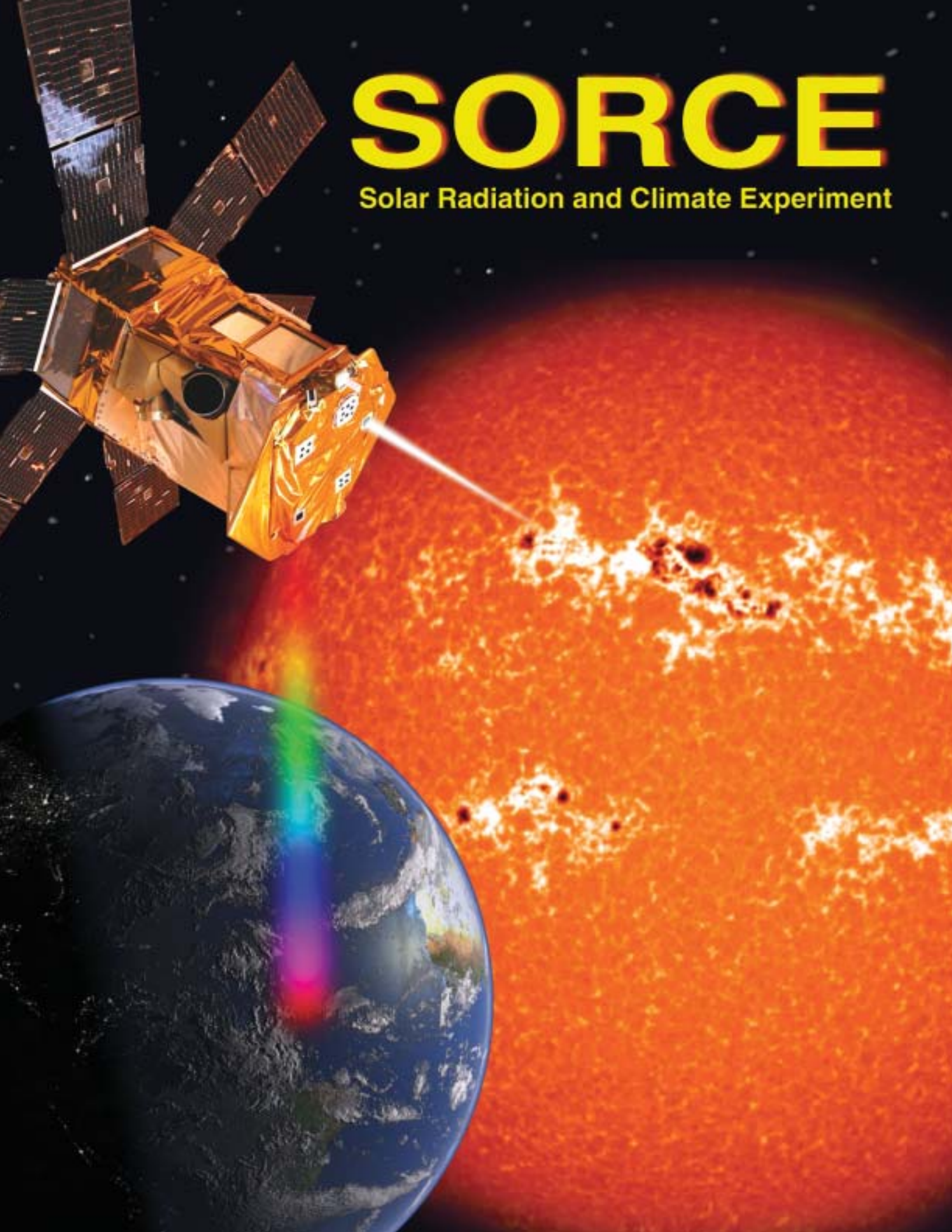


SORCE

Solar Radiation and Climate Experiment



Key Individuals Associated with the SORCE Mission

SORCE Principal Investigator:

Gary Rottman, Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder

SORCE Co-Investigators:

Tom Woods, SORCE Project Scientist, XPS Instrument Scientist, LASP, University of Colorado, Boulder
Jerry Harder, SIM Instrument Scientist, LASP, University of Colorado, Boulder
Greg Kopp, TIM Instrument Scientist, LASP, University of Colorado, Boulder
George Lawrence, Instrument Scientist, LASP, University of Colorado, Boulder
William McClintock, SOLSTICE Instrument Scientist, LASP, University of Colorado, Boulder
Dominique Crommelynck, Royal Meteorological Institute of Belgium, Brussels
Peter Fox, National Center for Atmospheric Research, High Altitude Observatory (HAO), Boulder, Colorado
Claus Fröhlich, World Radiation Center, Davos, Switzerland
Judith Lean, Naval Research Laboratory, Washington, DC
Julius London, Astrophysical, Planetary, and Atmospheric Sciences, University of Colorado, Boulder
Peter Pilewskie, NASA Ames Research Center, Moffett Field, California
Ray Roble, National Center for Atmospheric Research, HAO, Boulder, Colorado
Paul Simon, Institute d'Aeronomie Spatiale, Brussels, Belgium
Oran White, National Center for Atmospheric Research, HAO, Boulder, Colorado

SORCE Program Management:

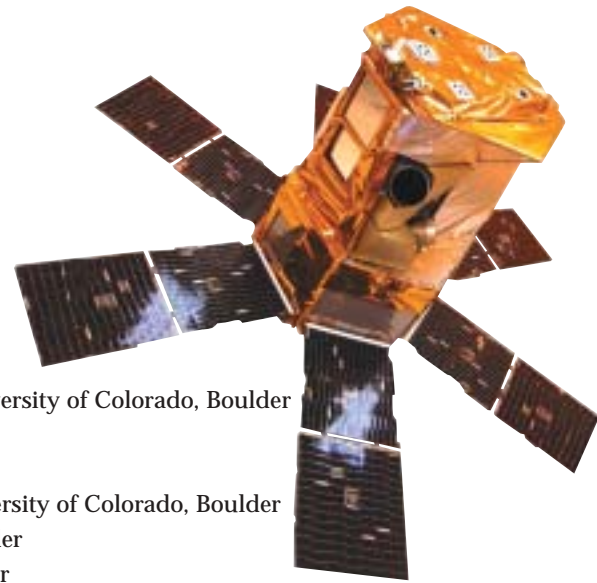
Tom Sparn, SORCE Program Manager, LASP, University of Colorado, Boulder
Mike Anfinson, LASP, University of Colorado, Boulder
Brian Boyle, LASP, University of Colorado, Boulder
Tim Holden, LASP, University of Colorado, Boulder
Rick Kohnert, LASP, University of Colorado, Boulder
Chris Pankratz, LASP, University of Colorado, Boulder
Sean Ryan, LASP, University of Colorado, Boulder

Rob Fulton, Spacecraft Program Manager, Orbital Sciences Corporation, Dulles, Virginia
Philip Burkholder, Orbital Sciences Corporation, Dulles, Virginia
Ed Kozlosky, Orbital Sciences Corporation, Dulles, Virginia
Dave Oberg, Orbital Sciences Corporation, Dulles, Virginia

SORCE NASA Management:

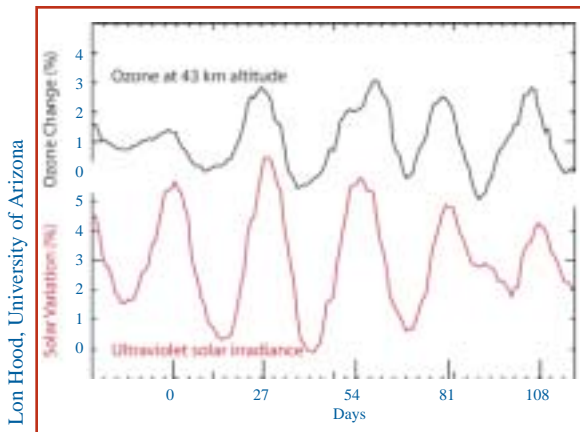
William Ochs, SORCE Project Manager, NASA Goddard Space Flight Center
Robert Cahalan, SORCE Project Scientist, NASA Goddard Space Flight Center
Doug Rabin, SORCE Deputy Project Scientist, NASA Goddard Space Flight Center
Debbie Dodson, Mission Business Manager, NASA Goddard Space Flight Center
Michael King, Earth Observing System Senior Project Scientist, NASA Goddard Space Flight Center
Don Anderson, SORCE Program Manager, NASA Headquarters

The SORCE mission is the result of the dedication and contributions of the entire Operations, Engineering, and Technical staff at LASP, Orbital Sciences Corporation, and NASA.



Understanding the Sun's Influence on the Earth

The Sun is the dominant energy source for the entire Earth system. It warms the Earth, heating the lands and ocean. It maintains our atmosphere, generates clouds, and cycles our planet's water. It drives the winds and the ocean currents. The Sun's energy sustains and nurtures all life including plant, animal, and human.



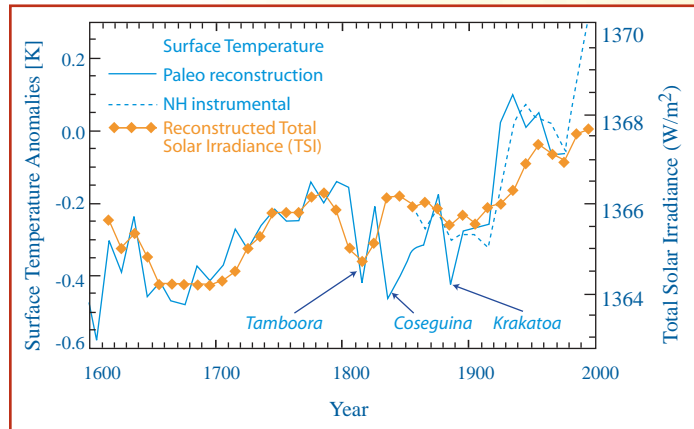
Lon Hood, University of Arizona

When the Sun is active its radiation displays a clear variation related to its 27-day rotation period. Ozone, one of the important greenhouse gases in the stratosphere and Earth's biological shield, responds accordingly.

How Does the Sun Affect Earth's Climate?

Energy balance equations predict that if the Sun varies by a modest amount, say 1%, the global average surface temperature will change by about 0.7° C. Some empirical models estimate that the Sun varied by nearly 0.5% since pre-industrial times. Climate models indicate such a change may account for over 30% of the warming that has occurred since 1850.

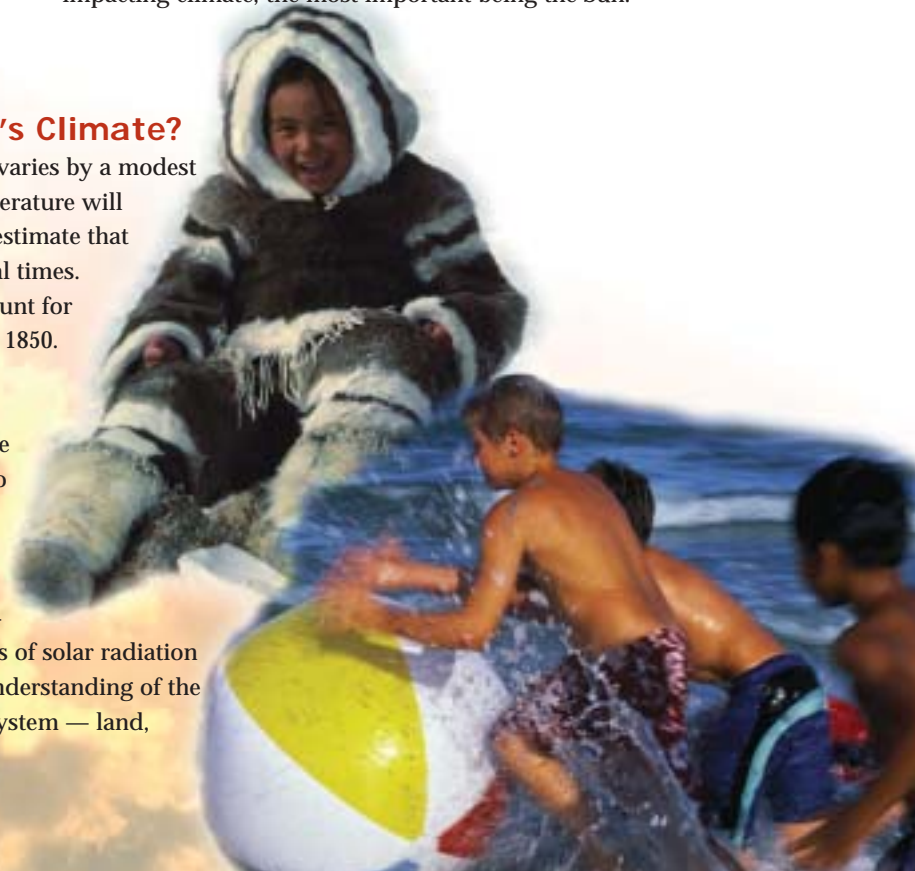
Feedbacks can enhance the Sun's influence. The amount and distribution of important greenhouse gases — H₂O, CO₂, and O₃ — vary in response to radiation changes. Water vapor and ozone are especially sensitive to changes in the Sun's *ultraviolet* radiation, and both observations and models show a close relationship of their concentrations to solar irradiance. Different wavelengths of solar radiation are absorbed at different altitudes. A complete understanding of the solar influence will consider the entire coupled system — land, ocean, and atmosphere.



Judith Lean, Naval Research Laboratory

After accounting for the increase in CO₂ and other greenhouse gases, the Earth's surface temperature corresponds with the increase in solar radiation, except during major volcanic eruptions (arrows).

There are also many indirect effects that are at least as important. Other factors entering the climate puzzle, including greenhouse gases, aerosols, and atmospheric circulation, are driven by solar radiation, and they influence each other by complex feedbacks. To establish the impact humans have on climate, we must have solid knowledge of any natural factors impacting climate, the most important being the Sun.



By How Much Does the Sun's Radiation Vary?



Energy from the Sun makes life on Earth possible. Solar energy also drives the Earth's climate, and slight variations in solar radiance could offset (or increase) global warming. (Photograph courtesy of Philip Greenspun.)

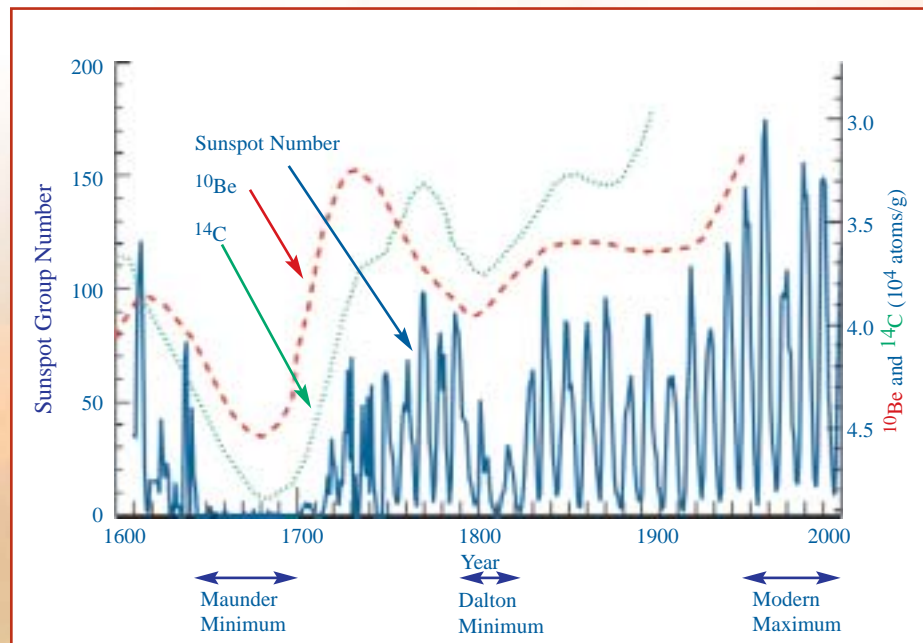
The 23.5° angle between Earth's spin axis and its orbit about the Sun gives rise to the seasonal cycle, causing the length of the day and the sunlight angle to vary during the year. As a result, summer is much warmer than winter, and polar regions are dramatically colder than the tropics. Also, Earth's orbit about the Sun is an ellipse, not a circle, with the Earth slightly closer to the Sun in early January than it is in July. This results in about 7% more sunlight reaching the Earth in January than in July. Both of these seasonal effects, the tilt of the Earth's axis and the orbital distance to the Sun, are stable and very predictable, and the resulting annual cycle in sunlight remains essentially the same year after year during recent centuries, though the Earth's orbit and the Sun's brightness (TSI) have both evolved over much longer time scales.

A more important and difficult question is whether the Sun's radiation itself varies — are there intrinsic changes in the total energy output of the Sun — the so-called “total solar irradiance” (TSI)? Following the development of the telescope in about 1609, Galileo Galilei, Thomas Harriot, and others independently studied small blemishes or "spots" on the surface of the Sun. Since that time observers have compiled meticulous records of the number and character of these *sunspots*. Sunspots visible from the Earth change from day-to-day, and in 1843 S. Heinrich Schwabe recognized a distinctive 11-year sunspot cycle. In the 17th century astronomers observed almost no sunspots for a period of almost 50 years. During this period, referred to as the *Maunder Minimum*, winters in Europe were much longer and colder than today. Since then, the trend suggests a gradual increase in solar output.

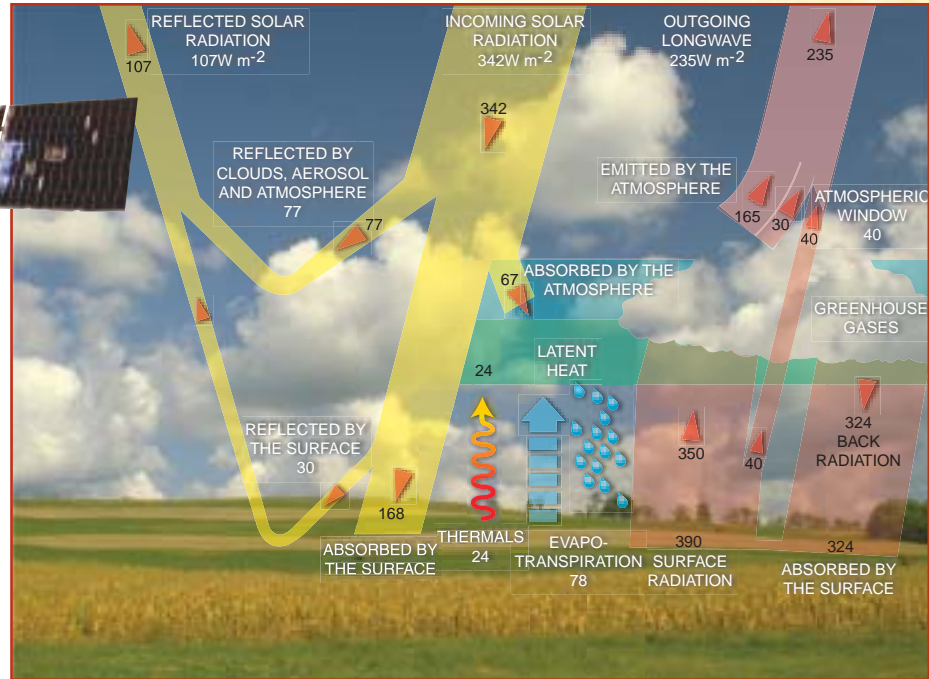
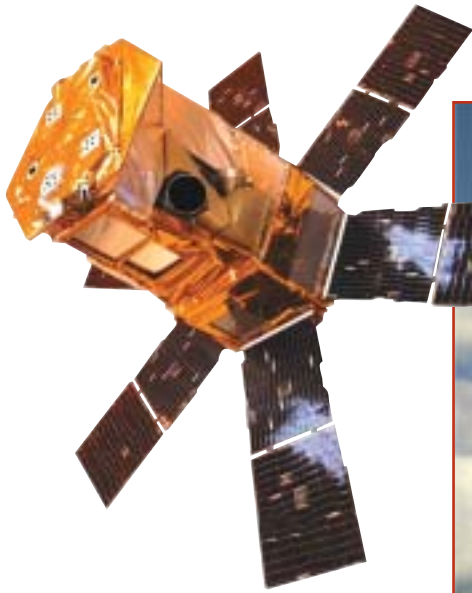


Galileo Galilei (1564 - 1642).

The record of sunspots begins with Galileo's observations in 1610 and extends to the present. The 11-year solar cycle was recognized by S.H. Schwabe in 1843. The amplitude of the cycle changes dramatically and even disappears for many years.



Judith Lean, Naval Research Laboratory (derived from work by J. Beer, D. Hoyt, and M. Stuiver)

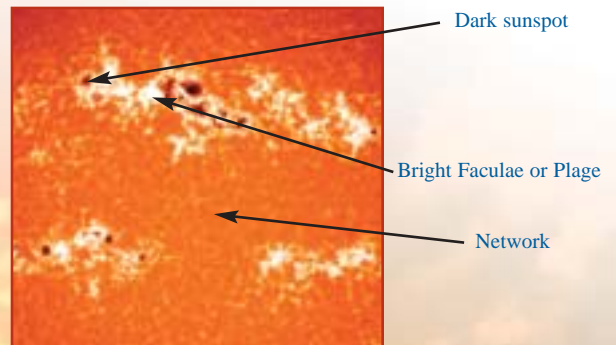
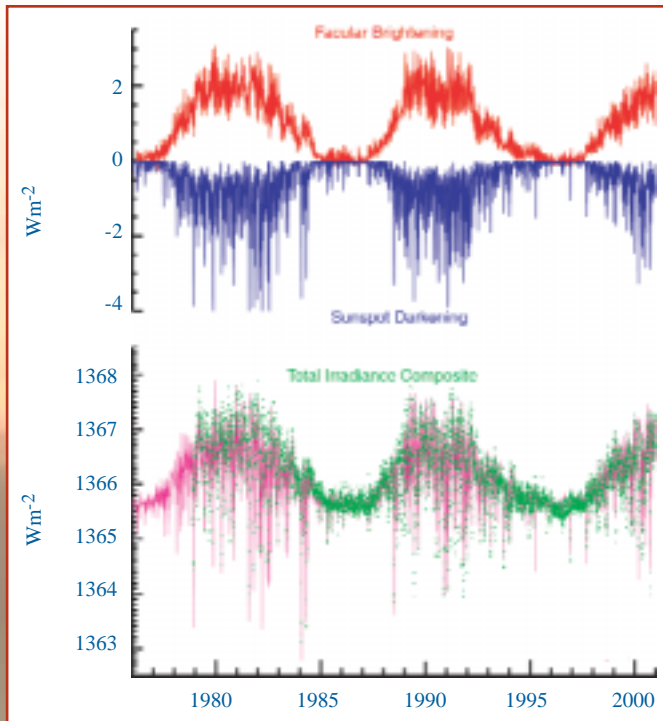


Jeff Kiehl and Kevin Trenberth, National Center for Atmospheric Research

This radiation balance picture shows how incoming solar energy is distributed among parts of the Earth's atmosphere and surface.

Understanding Solar Irradiance

One often confusing fact is that the Sun is brighter during times when it displays more dark sunspots! The total radiation from the Sun can be approximated by a background or “quiet sun” value, diminished by dark sunspots and augmented by bright *faculae* and bright network. When averaged over the Sun's surface, the subtle *facular brightening* during the Sun's 11-year activity cycle dominates over the more obvious sunspot darkening. Empirical models of the TSI based on these three indices - sunspot darkening, and facular and network brightening - compare favorably with the actual TSI observations. Such empirical models provide one approach for validating irradiance time series from data sets of different observations, and moreover these models provide a technique to estimate solar irradiance over previous time periods when only the sunspots, not the faculae, were observed.



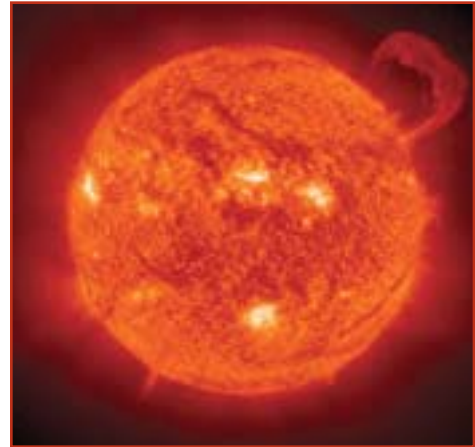
Observations of TSI are approximated quite well by a constant value of solar radiation minus the darkening of sunspots and augmented by the amount of bright faculae and network. Though sunspots darken the sun, faculae more than compensate in their brightness, so that on average the Sun is brighter in years having more sunspots.

SORCE Will Monitor Solar Irradiance Daily

“One activity ranks above all others for determining solar influences on global change: Monitor the total and spectral solar irradiance from an uninterrupted series of spacecraft radiometers employing in-flight sensitivity tracking.”
— 1994 NRC Report

History of Solar Irradiance Observations

Only a portion of the Sun’s radiation penetrates the Earth’s atmosphere to its surface, and at some wavelengths the radiation is absorbed entirely. It is therefore not possible to use ground-based observations of the Sun to estimate the top-of-the-atmosphere radiation. Although there was an ambitious ground observing program during most of the 20th century, it provided only ambiguous estimates of irradiance, and little or no information on whether the Sun varied.

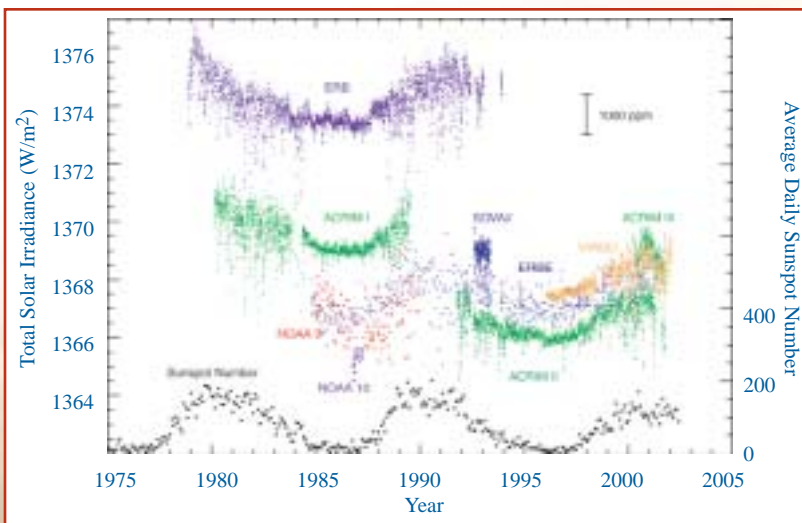


The evolution of active regions on the Sun is the primary cause for solar variability. The active regions change over all time scales - seconds to centuries.

Observations of solar irradiance from space began in the 1960s and reached some level of maturity and reliability in the late 1970s, providing the first view of the full solar spectrum. The more energetic ultraviolet part of the spectrum was a discovery that provided new insight into the complexities of solar physics and improved our understanding of the temperature and structure of the Earth’s upper atmosphere. By the mid-1970s observations were indicating that the ultraviolet varied by large amounts - perhaps factors of 2 near 120 nm and factors approaching an order of magnitude for much of the extreme ultraviolet (EUV) at wavelengths below 30 nm.

Today’s Record of Total Solar Irradiance

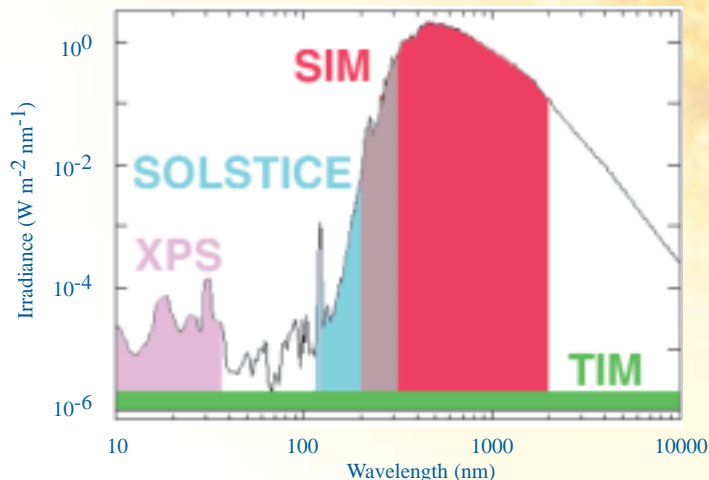
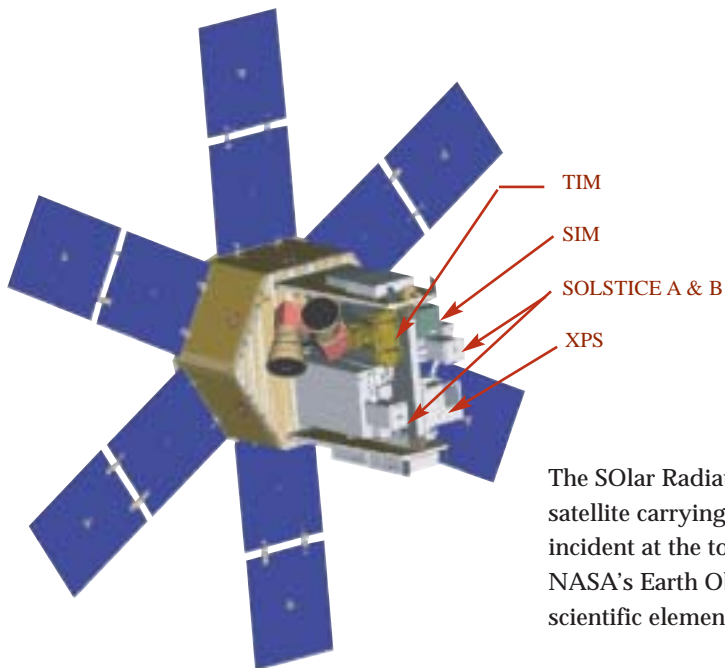
Total Solar Irradiance monitoring using *electrical substitution radiometers* (ESRs) from the vantage point of space began with the launch of the Nimbus 7 satellite in November 1978. This was soon followed by an Active Cavity Radiometer Irradiance Monitor (ACRIM) instrument on the Solar Maximum Mission and by the Earth Radiation Budget Experiment (ERBE). More recently, second and third ACRIM instruments have been launched, in addition to



Record of TSI observations since 1978 from 9 independent instruments. The instruments agree in the amount of variation during each solar cycle, but the averages over each solar cycle disagree because of different calibration scales of the instruments. Disagreements are getting smaller as calibration methods improve.

the launch of two instruments on the NASA/ESA Solar and Heliospheric Observatory (SOHO). The various data sets are offset, but they are in basic agreement and show conclusively that variations of TSI track the passage of sunspots across the solar disk with an amplitude of about 0.2%, and that long-term *solar cycle* variations are on the order of 0.1%. The offset between the early observations are on the order of $\pm 0.3\%$, which is attributed to uncertainties in instrument calibrations. The agreement between more recent observations has improved to about $\pm 0.05\%$. The SORCE will continue these important TSI observations, and will further improve their accuracy to the order of $\pm 0.01\%$.

The SORCE Mission



Schematic of the solar spectrum and a reference used to identify the role of each of the SORCE instruments. SOLSTICE and SIM overlap from 200 nm to 320 nm.

The Solar Radiation and Climate Experiment (SORCE) is a small free-flying satellite carrying four scientific instruments to measure the solar radiation incident at the top-of-the-Earth's atmosphere. This mission is one element of NASA's Earth Observing System (EOS), which is the major observational and scientific element of the U.S. Global Change Research Program.

How Do the SORCE Instruments Measure Solar Radiation?

Scientists and engineers at the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP) designed, built, calibrated, and tested four science instruments for flight on-board SORCE. These are the Total Irradiance Monitor (TIM), the Spectral Irradiance Monitor (SIM), two Solar Stellar Irradiance Comparison Experiments (SOLSTICE), and the XUV Photometer System (XPS). The TIM continues the record of total solar irradiance (TSI), but incorporates modern, state-of-the-art technologies of the electrical substitution radiometer (ESR), while at the same time taking full advantage of the best heritage of previous radiometers. The SIM provides the first continuous measurement of spectral irradiance from 200 to 2000 nm with a newly developed prism spectrometer, also including a newly designed miniaturized ESR. There are two identical SOLSTICE instruments that measure solar ultraviolet irradiance from 115 to 320 nm. These have the unique capability of directly comparing the Sun to a number of bright blue stars, which are used as long-term calibration standards. The XPS instrument measures broadband spectral irradiance from 1 to 34 nm, and is designed similarly to the XPS on the TIMED (Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics) satellite launched in 2001.

SORCE will operate on orbit for a period of five years, with a design goal of six years. The spacecraft carrying and accommodating the instruments was developed by Orbital Sciences Corporation in Dulles, Virginia. This spacecraft is three-axis stabilized with a control system to point the instruments at the Sun and at the calibration stars. The launch is scheduled to occur in December 2002 from the Kennedy Space Flight Center in Cape Canaveral, Florida aboard a *Pegasus XL* launch vehicle. Once in orbit, LASP will operate SORCE from its Mission Operations Center in Boulder, Colorado for the mission duration. LASP is responsible for the acquisition, management, processing, and distribution of the science data.

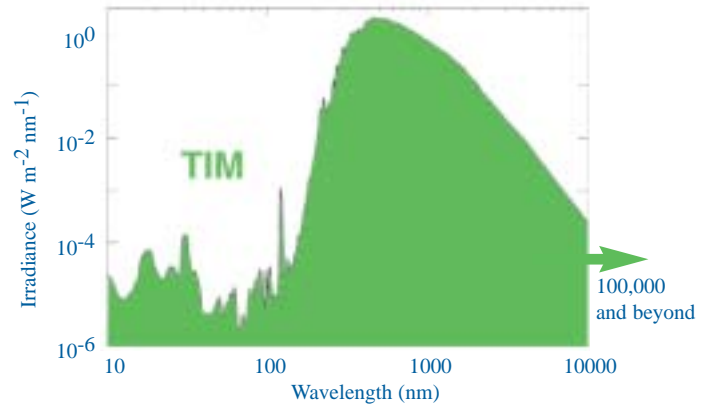


The SORCE spacecraft with the Solar Arrays deployed at Orbital Sciences Corporation, during Integration and Test (I&T).

Total Irradiance Monitor (TIM)



TIM is a radiometer that measures TSI with 0.01% absolute accuracy.



Objective

The TIM will provide a measurement of total solar irradiance (TSI) with an *absolute accuracy* of 0.01% and a relative stability of 0.001% per year. Imperative for climate modeling, this instrument will report the total radiative input at the top of the Earth's atmosphere four times each day.

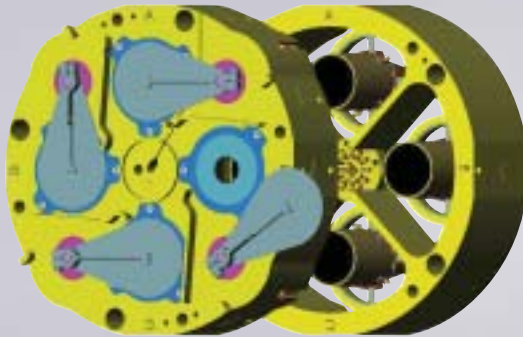
Measurement Concept

This new instrument uses the best heritage of previous radiometers, but is enhanced with modern, state-of-the-art technologies including phase-sensitive detection, metallic absorptive materials, and digital electronics. Any one of four electrical substitution radiometers (ESRs) can measure the incident solar power. A precision aperture defines the area through which sunlight is collected, and the ratio of sunlight power to area gives the solar irradiance (Watts per square meter – W/m^2). The TIM achieves extremely low noise using phase sensitive detection at the shutter frequency. This detection method reduces sensitivity to noise, thermal drifts, and thermal emission from the instrument itself, improving the signal/noise ratio compared to traditional time domain analysis. Using this technique, the TIM has demonstrated noise levels less than 0.0002%.

What is an Electrical Substitution Radiometer, or ESR?

The TIM measurement of solar radiation is a thermal measurement and the radiation sensor is a gold-coated silver cone. Each of the four identical cones has a precision temperature sensor and heater wire on the outside. The cones are used in pairs – one cone is active and the other is the reference. When a shutter in front of the active cone opens, solar radiation passes through a precision aperture and is absorbed by the active cone's black interior. Sophisticated electronics sense a temperature rise and quickly reduce electrical power to the active cone in order to maintain thermal balance to the reference, which remains shuttered. The amount of electrical power removed from the active cone is "equivalent" to the power of the incident solar radiation.



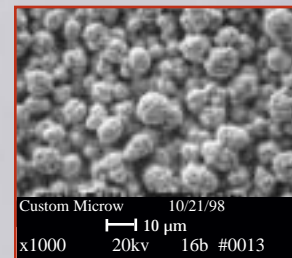


Irradiance: The TIM Measures Power Over a Known Area

Sunlight entering any one of the four ESRs is modulated by a shutter (the rightmost one is shown in its open position). A precision aperture behind each shutter accurately determines the area over which sunlight is collected. This radiant power is then measured by a black absorptive ESR. The ratio of power to area gives the total solar irradiance.

How Do the TIM ESRs Work?

The TIM is an ambient temperature solar radiometer using four absorptive ESRs. Each ESR has an independent shutter and a NIST-calibrated *precision* aperture. Each sensor is an electrodeposited silver cone with an interior coating of *nickel phosphorus* (NiP), a metallic black absorbing layer stable under exposure to solar ultraviolet light. Several temperature sensors in the TIM allow corrections for thermal changes. The thermal background from the instrument itself is established from measurements of dark space during the night portion of each orbit.



NiP is the robust, metallic absorptive layer inside the ESRs.

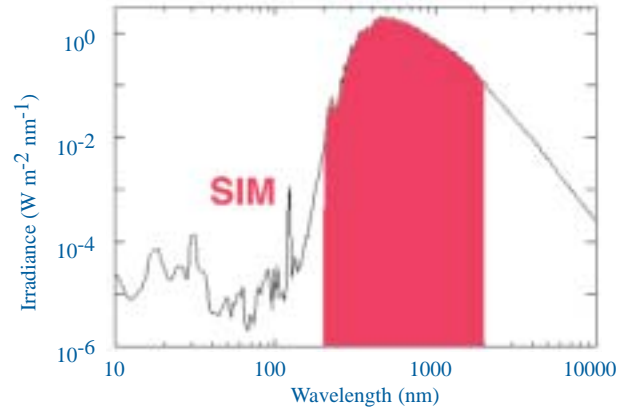
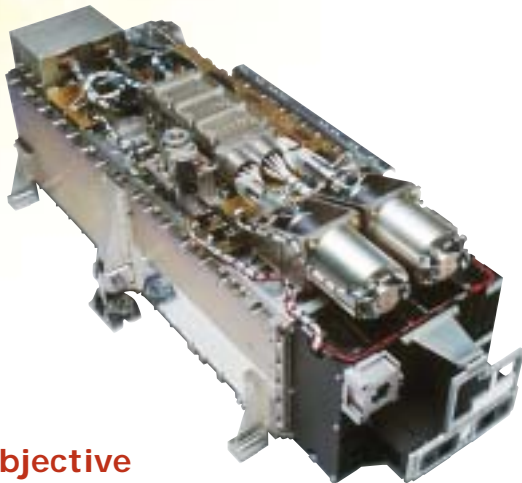
Four ESRs provide redundancy and calibration comparisons. To monitor the stability of the ESR absorptance, the TIM will use the four ESRs to characterize instrument degradation with varying duty cycles. Comparisons between nearly simultaneous measurements of the TSI from the different ESRs indicate absorptance changes attributable to solar exposure.

What Is Inside the TIM?

- Sunlight enters through vacuum doors that open on orbit and maintain cleanliness during ground tests and instrument integration.
- Entering sunlight is modulated by a shutter, one for each of the four ESRs.
- Precision *apertures* determine the area through which sunlight is collected.
- Four internal baffle sections reduce off-axis light.
- The selected active ESR measures incident sunlight power, while an adjacent reference ESR behind a closed shutter compensates instrument thermal drifts and noise.



Spectral Irradiance Monitor (SIM)



SIM measures spectral solar irradiance from 200 to 2000 nm.

Objective

This newly developed spectrometer will provide *spectral solar irradiance* measurements in the near-ultraviolet, *visible* and near *infrared* four times per day. The wavelength coverage — from 200 to 2000 nm — overlaps the observations of SOLSTICE. Solar variability models, with the additional constraint of TSI observations, predict very small fractional changes — only 0.1 to 0.01% — in the visible/near infrared spectrum. Understanding the wavelength-dependent solar variability is of primary importance for determining long-term climate change processes.

Historical Background

Prior to SORCE, the time history of spectral irradiance variability in the visible part of the spectrum is not nearly as complete, or as reliable, as the total solar irradiance and the solar ultraviolet radiation records. SIM will make the first continuous record of the top-of-the-atmosphere spectral solar irradiance in the visible/near infrared region.

Measurement Concept

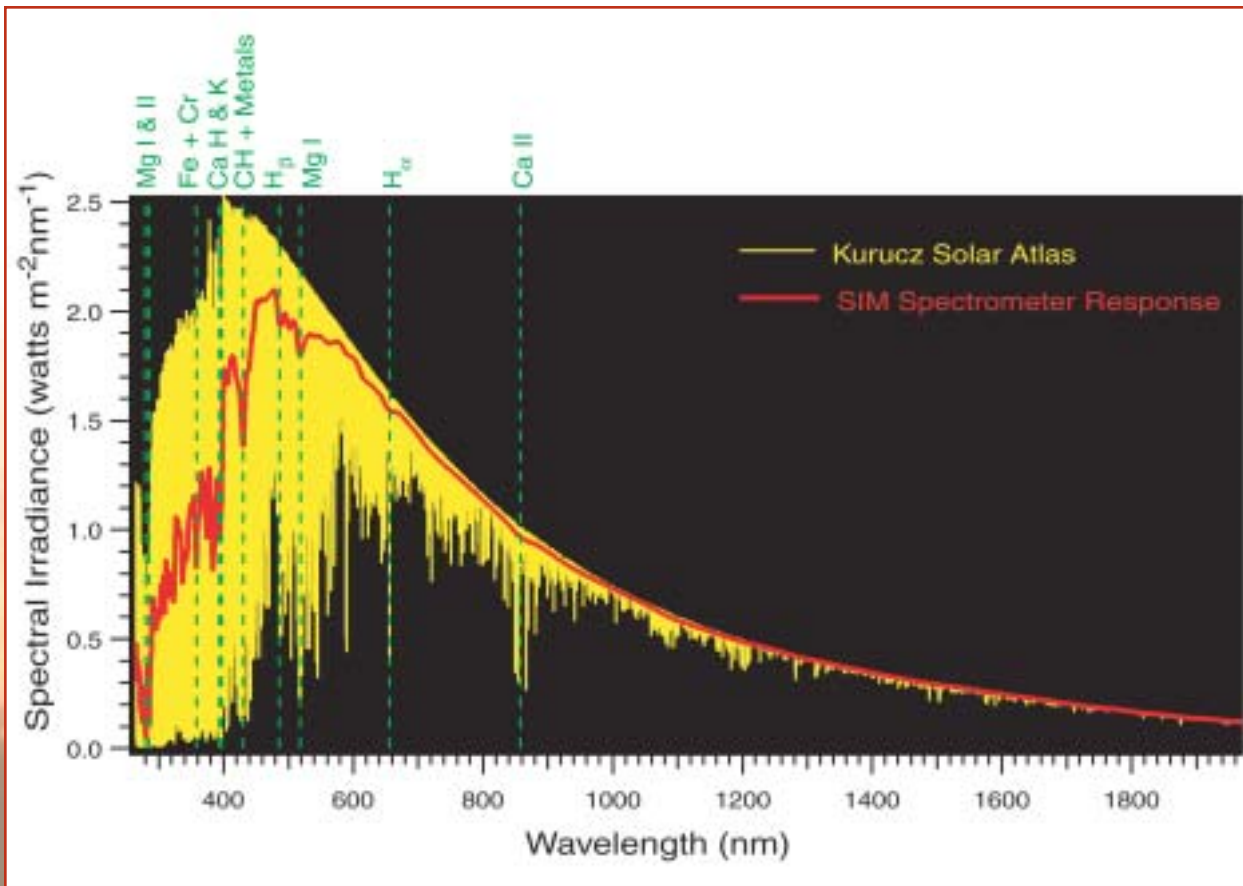
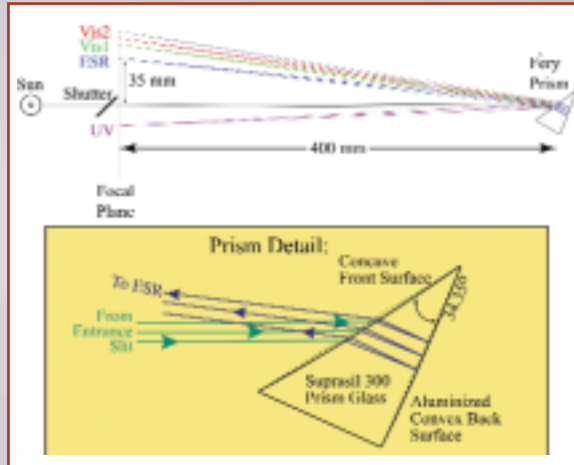
SIM is a prism spectrometer and uses a single optical element — a prism — to both disperse and focus solar radiation. This is a slight modification of an optical design first proposed by Charles Fery in 1910. The single optical element minimizes the SIM susceptibility to deterioration of sensitivity on orbit. In the focal plane of the spectrometer there are five exit slits, four with photodiodes and the fifth with a miniaturized version of an electrical substitution radiometer (ESR) to serve as an absolute detector. In fact, SIM includes two completely independent and identical (mirror-image) spectrometers in a single housing. The two instruments provide both redundancy and self-calibration capability to track changes in prism transmission.

How Does the SIM ESR Work?

The SIM ESR operates on the same principle as the TIM sensors, but with some modification. The light signals at the focal point of the spectrometer are some 1000 times smaller than the full TSI of TIM. Therefore in place of the silver cones used for TIM, miniature synthetic diamond strips are used. Like the TIM sensors, these diamond sensors are also blackened with nickel phosphorous (NiP) to become highly absorbing, and also have thermistors and replacement heaters to provide their thermal control. The two identical sensors, one detecting sunlight from the spectrometer, while the reference does not, are balanced.

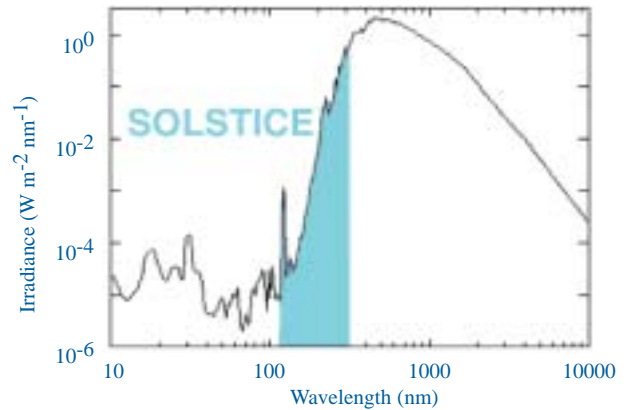
How does the SIM Prism Spectrometer Work?

The *Fery prism* has a concave front surface and a convex aluminized back surface. The prism is made of a special quartz (*Suprasil 300*) that is expected to remain very stable in the harsh environment of space. The prism is on a precisely controlled rotation table, and turning the prism disperses different color (wavelength) to each detector. The prism can slowly scan the entire solar spectrum, or it can be positioned to dwell at a single wavelength. The wavelength of the radiation that falls at each detector is accurately determined from the prism's *index of refraction* and angle of rotation. The spectrometer's resolution is a function of wavelength and varies from 0.5 nm in the ultraviolet to about 33 nm in the near infrared.



SIM covers 200 - 2000 nm with sufficient resolution to resolve the more prominent features in the solar spectrum.

Solar Stellar Irradiance Comparison Experiment (SOLSTICE)



Two identical and fully redundant SOLSTICE instruments measure ultraviolet (115 to 320 nm) solar and stellar radiation.

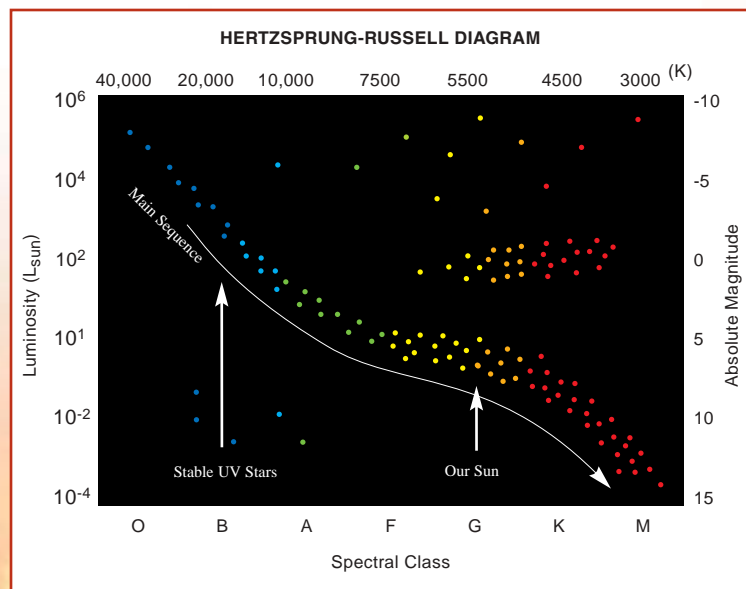
Objective

Previous solar measurements show that far ultraviolet irradiance varies by as much as 10% during the Sun's 27-day rotation, while the bright 121.6 nm *hydrogen Lyman- α* emission may vary by as much as a factor of two during an 11-year solar cycle, dramatically affecting the energy input into the Earth's atmosphere. SOLSTICE measures the spectral solar irradiance in the far (115 to 190 nm) and mid ultraviolet (190 to 320 nm) with a spectral resolution of 0.1 nm. The instrument is designed to provide an absolute accuracy of better than 5%.

SOLSTICE also measures the irradiances from a group of 18 bright B and A *spectral type* blue stars for calibration purposes. This is possible because the intrinsic variability of these stars is insignificant.

Historical Background

The first SOLSTICE instrument, also built by LASP, was launched aboard the Upper Atmosphere Research Satellite (UARS) in 1991. The SORCE instrument observes the Sun and bright, blue, early-type stars using the very same optics and detectors. The stellar targets establish long-term to the instrument sensitivity. UARS SOLSTICE has unequivocally demonstrated the validity of the solar-stellar comparison technique. Observing the exact same set of stars, the SORCE SOLSTICE will make measurements with improved accuracy and stability.



M. Haynes, Cornell University

Astronomers use the *Hertzsprung-Russell diagram* to classify stars by temperature and brightness (luminosity). Bright blue stars on the Main Sequence in the upper left corner have very stable ultraviolet irradiances. Cool, fainter stars like our Sun are relatively stable in visible light, but may be highly variable in the ultraviolet.

Measurement Concept

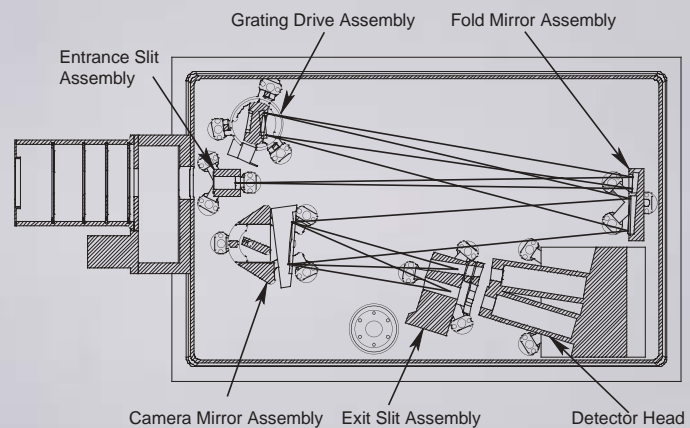
The in-flight calibration technique establishes the instrument response as a function of time throughout the SORCE mission, providing solar data that are fully corrected for instrumental effects to an accuracy of better than 1%. Moreover, the SOLSTICE technique provides a method of directly comparing solar irradiance measurements made during the SORCE mission with previous and subsequent observations. Future generations of observers will be able to repeat this experiment and directly compare their ultraviolet solar-stellar irradiance ratios, thereby establishing solar variability over arbitrarily long time periods.



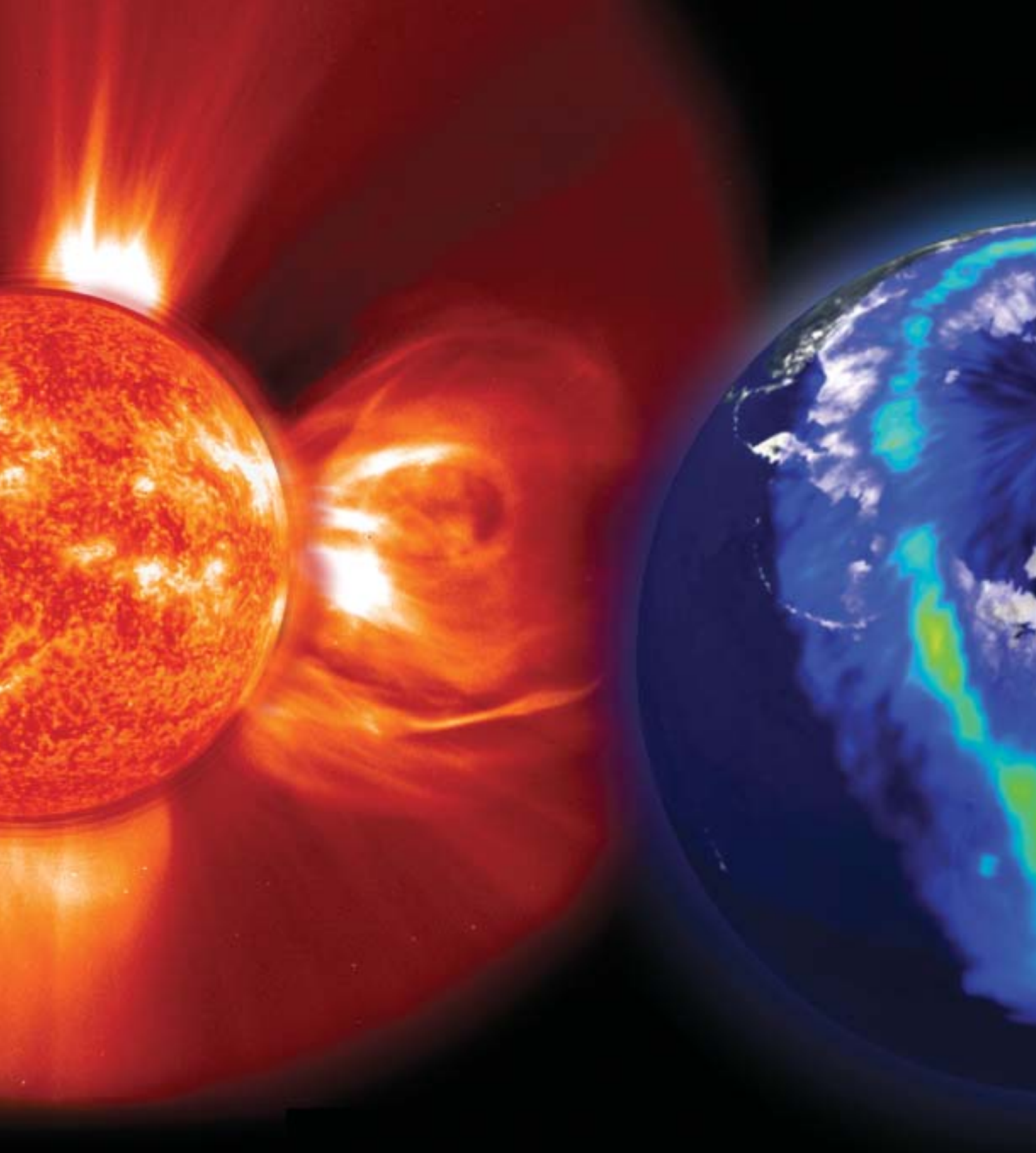
One of the largest young fields of stars inside our Milky Way galaxy. The false colors correspond to the temperatures of the stars. Blue stars are monitored by SOLSTICE to determine the changing transmission of the SOLSTICE spectrometer to ultraviolet radiation.

How Does the SOLSTICE Spectrometer Work?

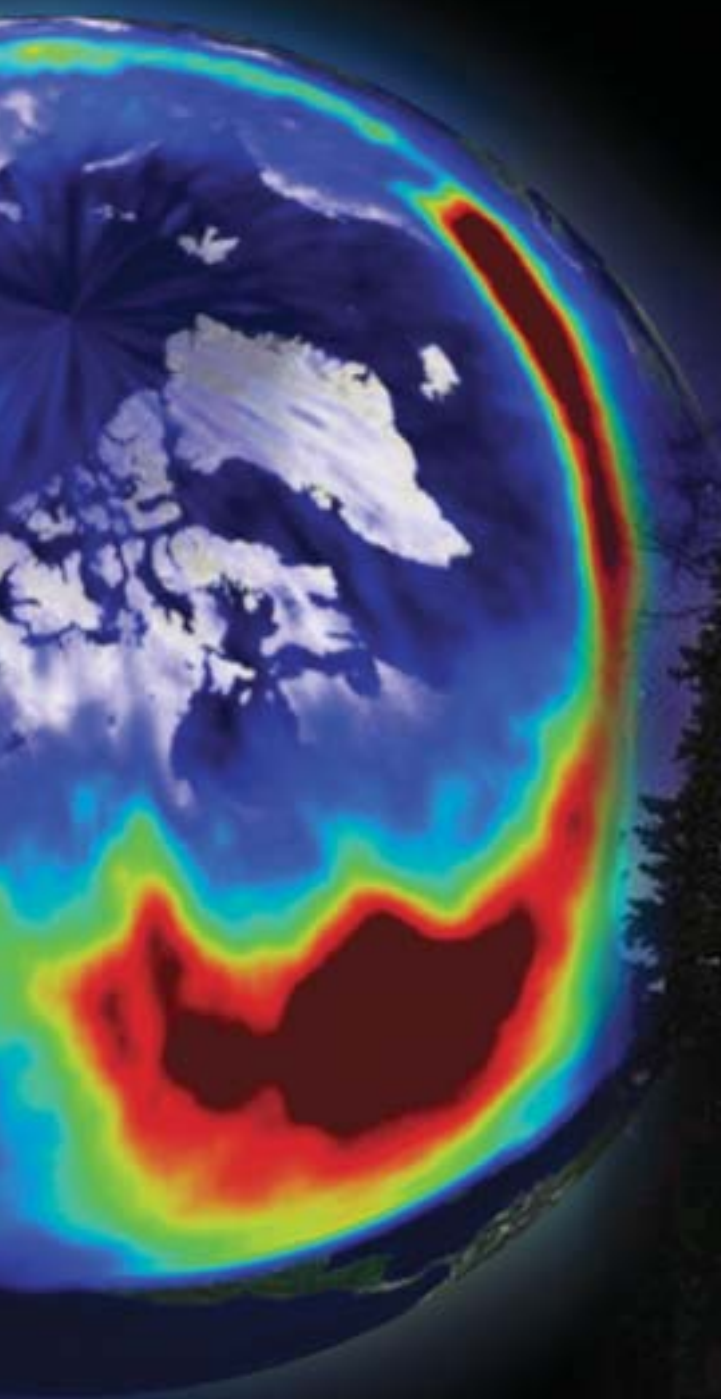
SORCE has two identical SOLSTICE instruments on-board – for redundancy and for cross calibration. Solar or stellar light passes through the instrument entrance aperture and is directed to a plane diffraction grating by a plane fold mirror. The grating diffracts a narrow wavelength band of the original beam to a second plane fold mirror, and then to the camera or focusing mirror. The camera mirror images that narrow wavelength band through an exit slit and onto one of two detectors. A mechanism adjusts the camera mirror to select either the outboard (far ultraviolet) or inboard (near ultraviolet) exit slit-detector pair. The large aperture increases the instrument sensitivity by 20,000 enabling SOLSTICE to measure the stars with the same optical-detector system that observes the Sun.



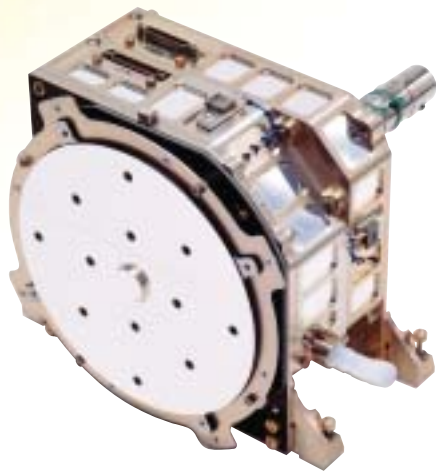
A cross sectional view of the SOLSTICE instrument showing the optical path. Each channel is equipped with a pair of detectors for redundancy over the 5-year SORCE mission life. The camera mirror is mounted on a mechanism that selects either the far or mid ultraviolet detector by ground command.



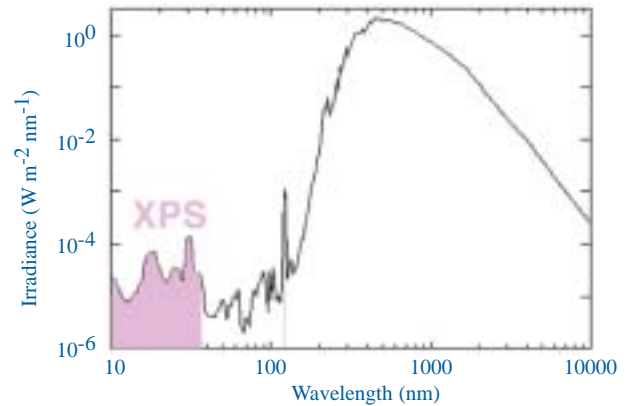
Left: Sun image from EIT (Extreme ultraviolet Imaging Telescope, 30.4 nm) superimposed on a LASCO (Large Angle Coronagraph) image of the corona. Center: strong geomagnetic storm from space in UV from NASA's Polar mission superimposed on a static image of Earth, with red indicating greatest UV intensity. Right: aurora image courtesy of Jan Curtis. The solar wind that produces Earth aurora consists of charged particles which each carry high energy but these are so few that their *total* energy is much smaller than the energy of the electromagnetic radiation measured by SORCE. (Composite by Steele Hill, NASA Goddard Space Flight Center)



XUV Photometer System (XPS)



XPS measures spectral solar irradiance from 1 to 34 nm.



Objective

The XPS measures the solar *soft X-ray* (XUV) irradiance from 1 to 34 nm and the bright hydrogen emission at 121.6 nm (H Lyman- α). The solar XUV radiation is emitted from the hot, highly-variable *corona* on the Sun, and these high-energy photons are a primary energy source for heating and ionizing Earth's upper atmosphere. The XPS is most sensitive to solar flare events when the solar XUV radiation can change by a factor of 2 to 10.

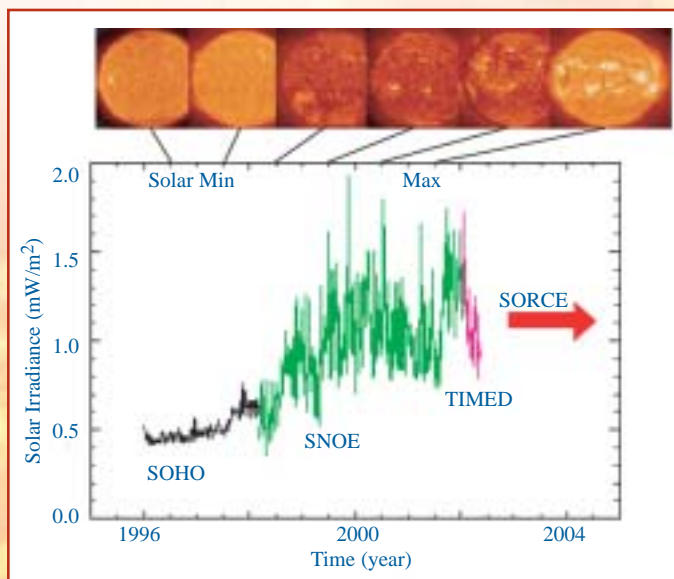
Historical Background

Studies of the solar XUV radiation began in the 1950s with space-based rocket experiments, but knowledge of the solar XUV irradiance — both its absolute magnitude and its variability — has been questionable due to the very limited number of observations. With the launch of the Solar & Heliospheric Observatory (SOHO) in 1995, the Student Nitric Oxide Explorer (SNOE) in 1998, and the Thermosphere-Ionosphere-Mesosphere-Energetics-Dynamics (TIMED) spacecraft in 2001, there is now a continuous data set of the solar XUV irradiance. The SORCE XPS, which evolved from earlier versions flown on SNOE and TIMED, will extend these solar XUV irradiance measurements with improvements in accuracy, spectral range, and temporal coverage.

How Does the XPS Work?

XPS contains twelve photometers consisting of silicon photodiodes with thin-film filters, each having a spectral bandpass of about 7 nm. These filtered Si photodiodes are very stable over long time periods and with extended solar exposure. They have been adopted by the National Institute of Standards and Technology (NIST) as secondary radiometric detector standards.

Time series of XUV radiation through the onset of solar cycle 23. Images at the top are obtained in bright helium emission at 30.4 nm by the SOHO EIT. These images indicate how different the Sun looks and behaves in the XUV compared to the visible. Sunspots, which are dark in the visible, are associated with strong magnetic fields that appear bright in the corona. Data shown here are from different wavelength bands, but scaled to SNOE 2-7 nm data.

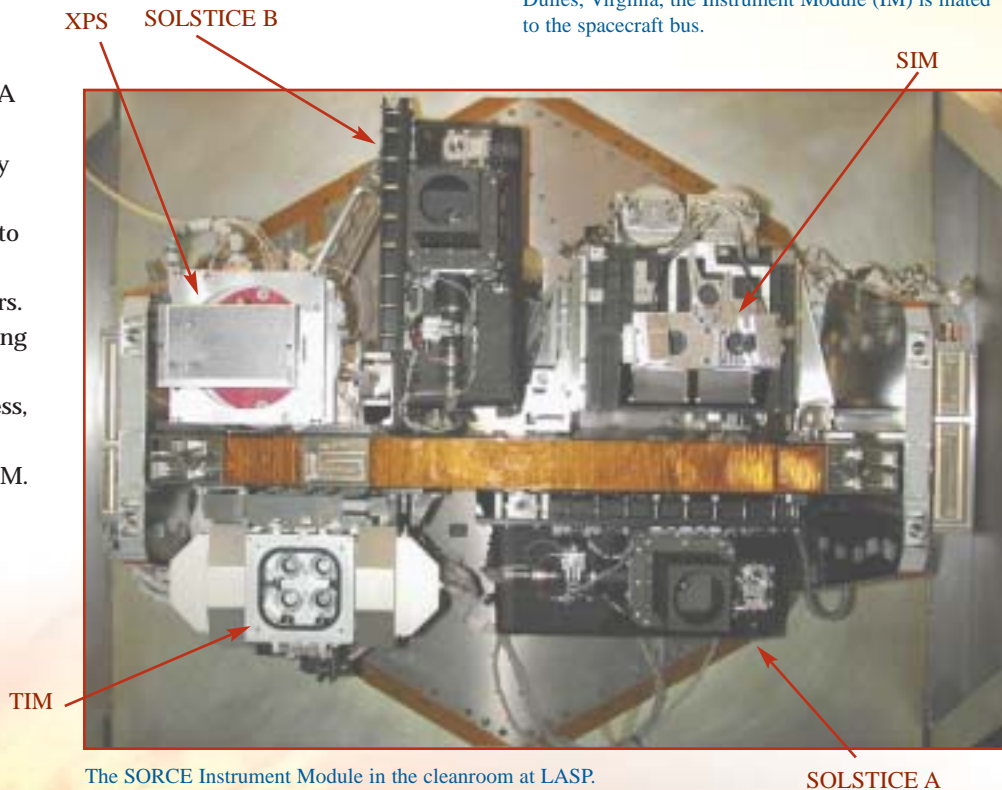


SORCE Instruments Summary



After delivery to the Orbital Space Systems Group in Dulles, Virginia, the Instrument Module (IM) is mated to the spacecraft bus.

The four instruments, TIM, SIM, SOLSTICE A and B, and XPS, are mounted and precisely aligned on an optical bench. Also mounted to the bench are the sun sensor and star trackers. This assembly, including electronic boxes and associated cable harness, is referred to as the *Instrument Module* or IM.

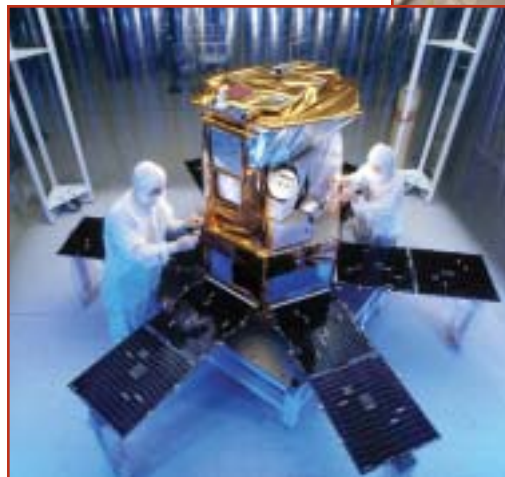
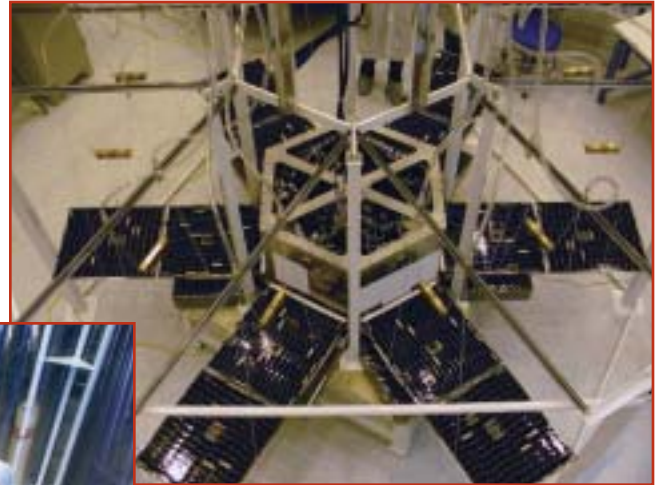


The SORCE Instrument Module in the cleanroom at LASP.

Summary of SORCE Instrument Capabilities

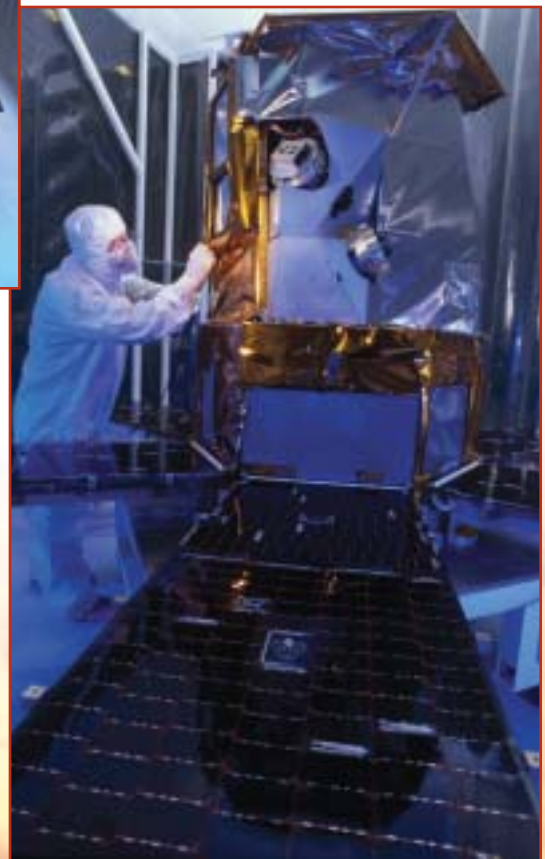
	TIM	SIM	SOLSTICE	XPS
Spectral Range	TSI	200 - 2000 nm	115 - 320 nm	1 - 34 nm, Lyman- α
Spectral Resolution	N/A	0.2 to 33 nm	0.1 nm	5 to 10 nm
Absolute Accuracy (1σ)	100 ppm	300 ppm	3 - 5%	12 - 20%
(Requirement)	150 ppm	1500 ppm	0.5 - 10%	30%
Precision (1σ)	< 1 ppm	< 150 ppm	< 0.5%	< 2%
Relative Accuracy (1σ)	10 ppm/yr	100 ppm/yr	< 0.5%	< 3%/yr
(Requirement)	10 ppm/yr	100 ppm/yr	0.5%	10%/yr

SORCE Spacecraft



The *bus module* of the spacecraft provides all of the on-orbit support required for the instrument suite to obtain the mission science data and transmit them to the ground for processing and distribution. The bus and the instrument module (IM) were developed and integrated separately at the Orbital Sciences Corporation and LASP facilities prior to their system level integration and environmental testing at Orbital.

The SORCE satellite bus is based on Orbital's LEOStar-2™ satellite platform and was customized to meet SORCE mission specific requirements. Engineers and scientists from LASP, Orbital, and NASA worked together throughout the design phase to optimize the hardware components and to maximize performance and reliability.



SORCE Technical Overview

The SORCE satellite uses a 3-axis inertially stabilized, zero momentum design that is capable of precision pointing and attitude knowledge during science observations. The satellite bus includes:

- *S-Band* communications, compatible with NASA's ground network.
- Science data storage with capacity for more than 24 hours of spacecraft data.
- Six *solar array* wings for power generation.
- *Reaction wheels, star trackers, sun sensors, magnetometers* and *torque rods* for *attitude control*.

SORCE General Capabilities

Satellite Mass:	284 kg
Power:	348 watts
Communications:	Redundant S-Band Transceivers
Inertial Pointing:	Slew Rate >1°/sec; Knowledge <60 arcsec
Solar Arrays:	Fixed GaAs
Redundancy:	Nearly Complete
Orbit:	645 km, 40° inclination
Mission Life:	5-year, 6-year goal

The SORCE power system generates, stores, and distributes electrical power to the spacecraft bus and the science instruments. The spacecraft generates its own electrical power through strings of high efficiency solar cells that convert sunlight into electrical power. In sunlight, the solar array delivers sufficient power to recharge the battery in preparation for the next eclipse period. Attitude control is accomplished by a combination of reaction wheels, two star trackers, a fine sun sensor, a control processor, and torque rods and magnetometers.

The spacecraft provides radio communications for space-to-ground and space-to-space interfaces. The subsystem uses *dual transceivers* and a pair of omnidirectional antennas and is completely *redundant*.



A SORCE engineer is checking the bolts connecting the IM platform to the spacecraft bus.

The SORCE Command and Data Handling (C&DH) subsystem controls all aspects of the bus operations. Commands from the ground are received within the C&DH system by way of the radio frequency (RF) subsystem, and acted upon by the spacecraft computer, or passed directly to the IM microprocessor for instrument operations. Data collected during the spacecraft operations are stored and processed through the RF subsystem back to the ground two times each day.

The SORCE satellite bus uses both off-the-shelf components manufactured world-wide, as well as customized components developed in Orbital's manufacturing facility. The spacecraft is integrated and tested for the rigors of space flight in Orbital's cleanroom and environmental test facility in Dulles, Virginia. SORCE takes advantage of Orbital's proven experience in the design, manufacture, and launch of highly reliable quality satellites.

Instrument Module →

Bus Module →



LASP, NASA, and Orbital scientists discuss the SORCE integration progress.

The SORCE Launch

Pegasus Air Launch System

The SORCE satellite will be boosted into orbit by a Pegasus® XL space launch vehicle in a mission originating from the Kennedy Space Center, Cape Canaveral, Florida. Pegasus is a winged, three stage solid rocket booster capable of launching up to 1,000 pounds into *Low Earth Orbit* (LEO).

Pegasus is mated to a specially modified L-1011 carrier aircraft and dropped at approximately 39,000 feet. As a result of this patented air-launch system, Pegasus can be launched from virtually anywhere around the globe. To date Pegasus has conducted 31 missions, launching more than 70 satellites from six different sites worldwide.

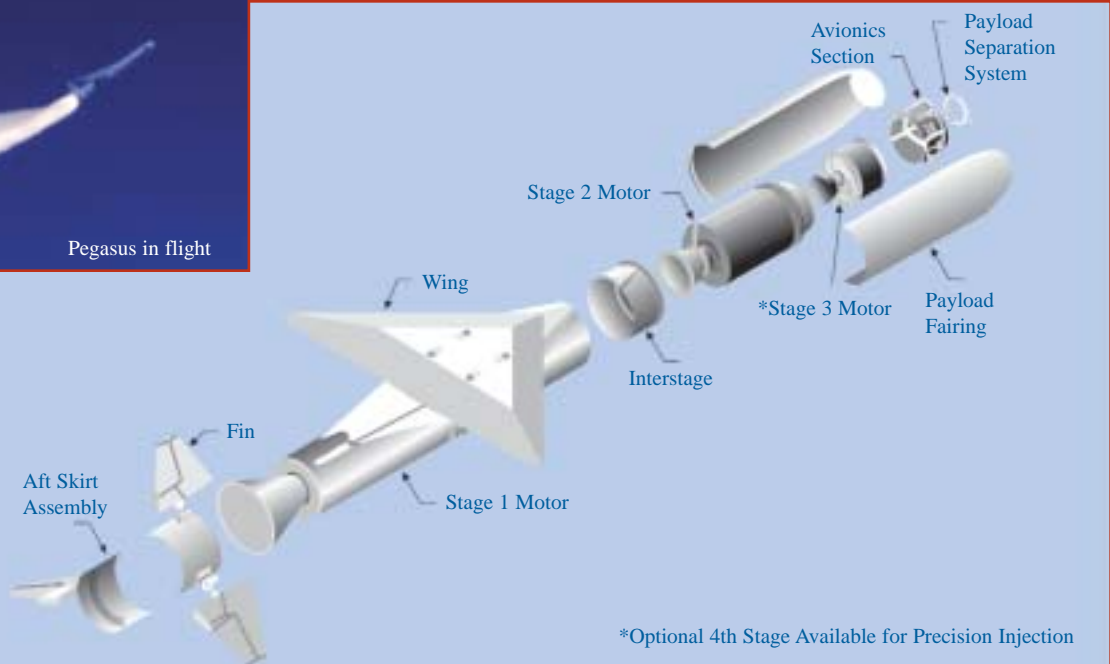


Takeoff of the Pegasus XL space launch vehicle and its L-1011 carrier aircraft.

Pegasus XL L-1011



Pegasus in flight

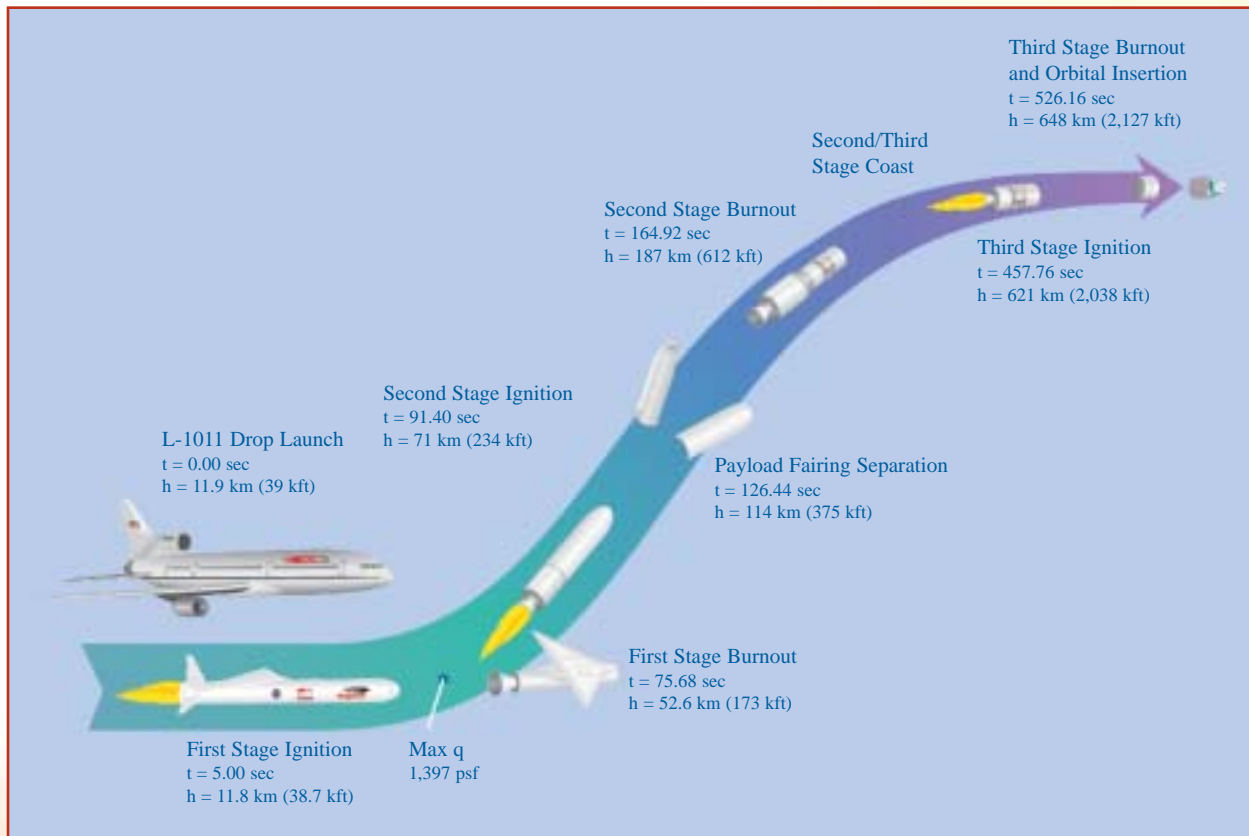


Expanded view of the Pegasus XL vehicle.

*Optional 4th Stage Available for Precision Injection

SORCE Launch Campaign

For the SORCE mission the L-1011 carrier aircraft will drop Pegasus at a pre-designated launch area over the Atlantic Ocean. The vehicle will free-fall for approximately five seconds, with its delta wing providing lift, before firing its first stage rocket motor. From drop to insertion into orbit, the SORCE launch mission will take a little less than 11 minutes.



SORCE launch timeline.



Originating from Kennedy Space Center (KSC), the Pegasus flight path for the SORCE mission. The drop launch will occur approximately 100 miles off the Florida coast. The first communication with the satellite will be at the ground station in Hartebeesthoek, South Africa, approximately 30 minutes after launch.

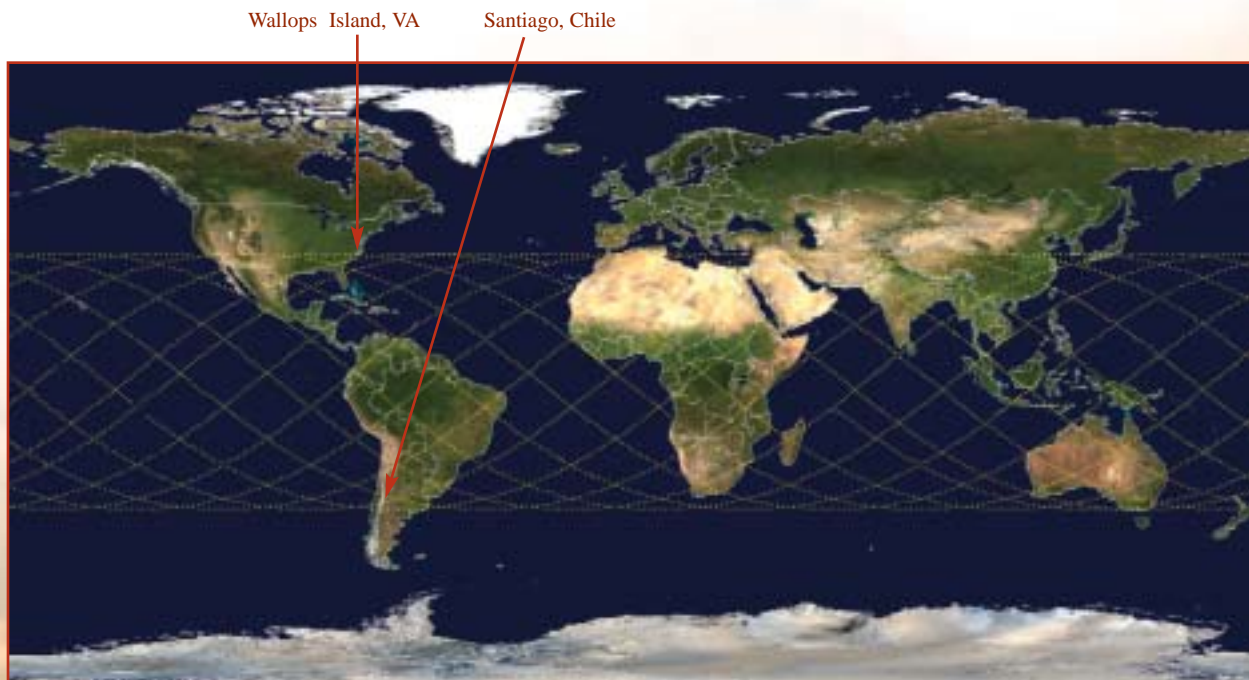
Mission Operations



Operations personnel working in the LASP Mission Operations Center.

The SORCE spacecraft and instruments will operate from the Mission Operations Center (MOC) and Science Operations Center (SOC), located at LASP in Boulder, Colorado. The MOC contains all hardware and software necessary to conduct real-time spacecraft operational activities, including command and control of the satellite, mission planning, and assessment and maintenance of spacecraft and instrument health. The NASA Space/Ground Network provides the communication link to the satellite through primary ground antenna sites (*ground stations*) at Wallops Island, Virginia, USA and Santiago, Chile.

Following commissioning activities during the first 30 days of the mission, normal operations will consist of two contacts per day between the SORCE spacecraft and LASP. During real-time spacecraft contacts, LASP maintains direct communication with the spacecraft via a ground station, receiving and checking real-time telemetry data. Data that have been recorded on the spacecraft are retrieved during these contacts and relayed directly to LASP following each contact. The raw (Level 0) spacecraft telemetry data are immediately ingested into the SORCE project database at LASP, after which data processing and analysis commences. The nominal data volume received from the SORCE spacecraft is approximately 120 megabytes (1 billion bits) per day.



SORCE will orbit the Earth every 90 minutes or 15 times daily. Ground stations at Wallops Island, Virginia and Santiago, Chile provide the communication links to the satellite two times each day.

Science Operations



LASP scientist Jerry Harder reviews the SIM data coming from SORCE.

LASP also operates the Science Operations Center (SOC) for experiment planning, science data processing, and distribution of the finished data product. Within 48 hours of data capture, the SOC will process all science data with the associated instrument and spacecraft engineering data to derive Level 3 science data products in standard geophysical units (W/m^2 or $W/m^2/nm$). The Level 3 data consist of daily and 6-hour average solar irradiances, with higher time resolution data available to meet secondary science objectives, such as studying the passage of faculae and sunspots across the visible surface of the Sun.

SORCE will produce two principal scientific data products: Total Solar Irradiance (TSI) data and spectral solar irradiance (SSI) data. The TSI data products provide a measure of the absolute intensity of solar radiation, integrated over the entire solar irradiance spectrum. To construct this product, measurements from the TIM instrument are combined to produce representative daily and 6-hour values of the Total Solar Irradiance. The SOLSTICE, SIM, and XPS measurements will be separately combined into merged daily and 6-hour average solar irradiance spectra, each containing representative irradiances reported from approximately 1 to 2000 nm.

Science data processing will commence automatically within 24 hours of data reception from the spacecraft. Preview (unfinished) versions of the SORCE data products will be available to the public within approximately 48 hours, with finished research-grade data products being produced approximately 3 months later, after sufficient in-flight calibration data have been collected. Data products will be delivered to the Goddard Distributed Active Archive Center (DAAC) located at the NASA Goddard Space Flight Center in Greenbelt, Maryland for subsequent distribution to the public.



The Mission Operations Center is located at the Laboratory for Atmospheric and Space Physics (LASP) on the University of Colorado, Boulder Campus.

Education and Outreach



The ultimate goal of SORCE and of NASA's Earth Observing System (EOS) Program is to increase scientific understanding of our planet. According to the Earth Science Strategic Plan, one of the four goals of EOS is to "foster the development of an informed and environmentally aware public." Contributions to the advancement of public knowledge about the Earth are key to the program's success.

SORCE has formal educational initiatives designed for kindergarten through graduate levels that include programs to enhance teacher knowledge and research skills; provide support in the form of instructional curriculum, provide earth science research experiences for students; and promote educational activities involving collaborative efforts with partners in the public and private sectors.

The SORCE informal education efforts are directed toward the scientific community and the general public. Mission literature addresses the basic science questions that SORCE will address and specifically what SORCE will accomplish concerning the Sun's influence on climate. This literature includes brochures, NASA Fact Sheets, fact books, handbooks, newsletters, and worldwide websites – all comprising a wealth of information and images, using interactivity and data visualization techniques to encourage an interesting hands-on approach.

The University of Colorado's Science Discovery Program in collaboration with SORCE researchers has developed an elementary school outreach program. This portable, hands-on teaching module has been presented in local schools and is part of the Science Discovery curriculum. The classroom demonstration shows Sun variability and the need for spacecraft measurements of the Sun. A globe in a clear case represent the Earth and its atmosphere, while a variable light is the Sun. Students measure the solar irradiance from a small model of the SORCE spacecraft positioned above the "atmosphere" and from several positions of latitude on the Earth. They note the changes in the measurements as the light source varies and as the case fills with diffusing vapor, which represents our changing atmosphere.

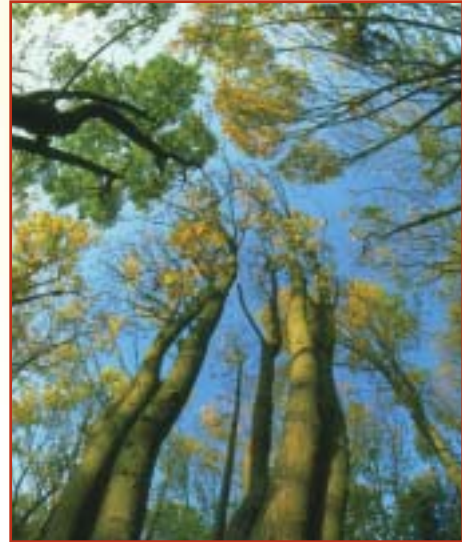
To obtain educational information and materials, visit:
EOS Project Science Office website at
eospsso.gsfc.nasa.gov/eos_homepage/education;

NASA's Earth Science Education website at
www.earth.nasa.gov/education/index.html;

SORCE website at
lasp.colorado.edu/sorce

Sun Facts:

Radius	695,510 km (109 Earth radii)
Mass	1.989×10^{30} kg (332,946 Earth masses)
Volume	1.412×10^{27} m ³ (1.3 million Earths)
Density	151,300 kg/m ³ (center) 1,409 kg/m ³ (mean)
Temperature	15,557,000 K (center) 5,780 K (photosphere) 1,000,000 K and hotter (corona)
Total Solar Irradiance (TSI)	1,366 W/m ² (formerly “solar constant”)
Composition	92.1% hydrogen 7.8% helium 0.1% other



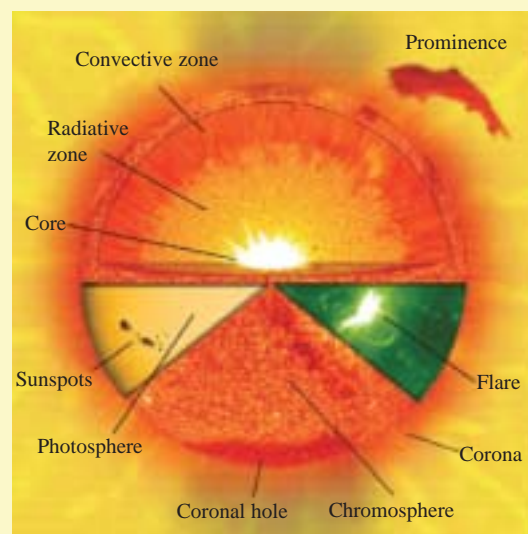
Understanding the Sun:

The immense Sun is very hot and dense in its center and innumerable collisions fragment the abundant hydrogen into its constituent parts - electrons and protons. The protons are squeezed into a small volume due to the pressure of the material above, becoming hotter and more densely concentrated. Nuclear fusion then occurs as the fastest-moving protons collide and fuse to form deuterium. Subsequent reactions merge two deuterium nuclei to form a helium nucleus - with the resulting mass of the helium nucleus slightly less than the mass of the original four protons. The mass difference has been converted into energy according to Einstein's famous equation — $E = mc^2$. Every second the Sun's central nuclear furnace transforms about 700 million tons of hydrogen into helium “ash,” and five million tons of matter disappear as pure energy. Nevertheless, this loss of material is insignificant. In its 4.5 billion-year life the Sun has consumed only a few hundredths of one percent of its original mass.

The energy produced by the nuclear reactions in the core proceeds outward in the form of radiation. Although light moves extremely rapidly (about 300,000 kilometers per second), the radiation is absorbed, re-emitted, and scattered so many times that it takes on average 170,000 years to reach the Sun's surface or *photosphere*.

Surrounding the photosphere is an atmosphere of rarefied gases, so thin that it is transparent to the photospheric radiation. Moving outward the layers of the solar atmosphere are referred to as the *chromosphere*, transition region, and corona. These layers outside of the Sun's photosphere are visible to us only when a total solar eclipse hides the much brighter photosphere.

Intense magnetic fields are generated in the interior of the Sun. The influence of these fields is best seen in the photosphere, especially in sunspots and bright active regions, called faculae or *plage*. The internal energy generated by the Sun is exceptionally stable and varies only over extremely long time scales. In comparison, the generation of magnetic disturbance on the Sun is much more variable, and cycles with a period of about 11 years. This cycle is erratic in amplitude, and perhaps even comes and goes every few hundred years.



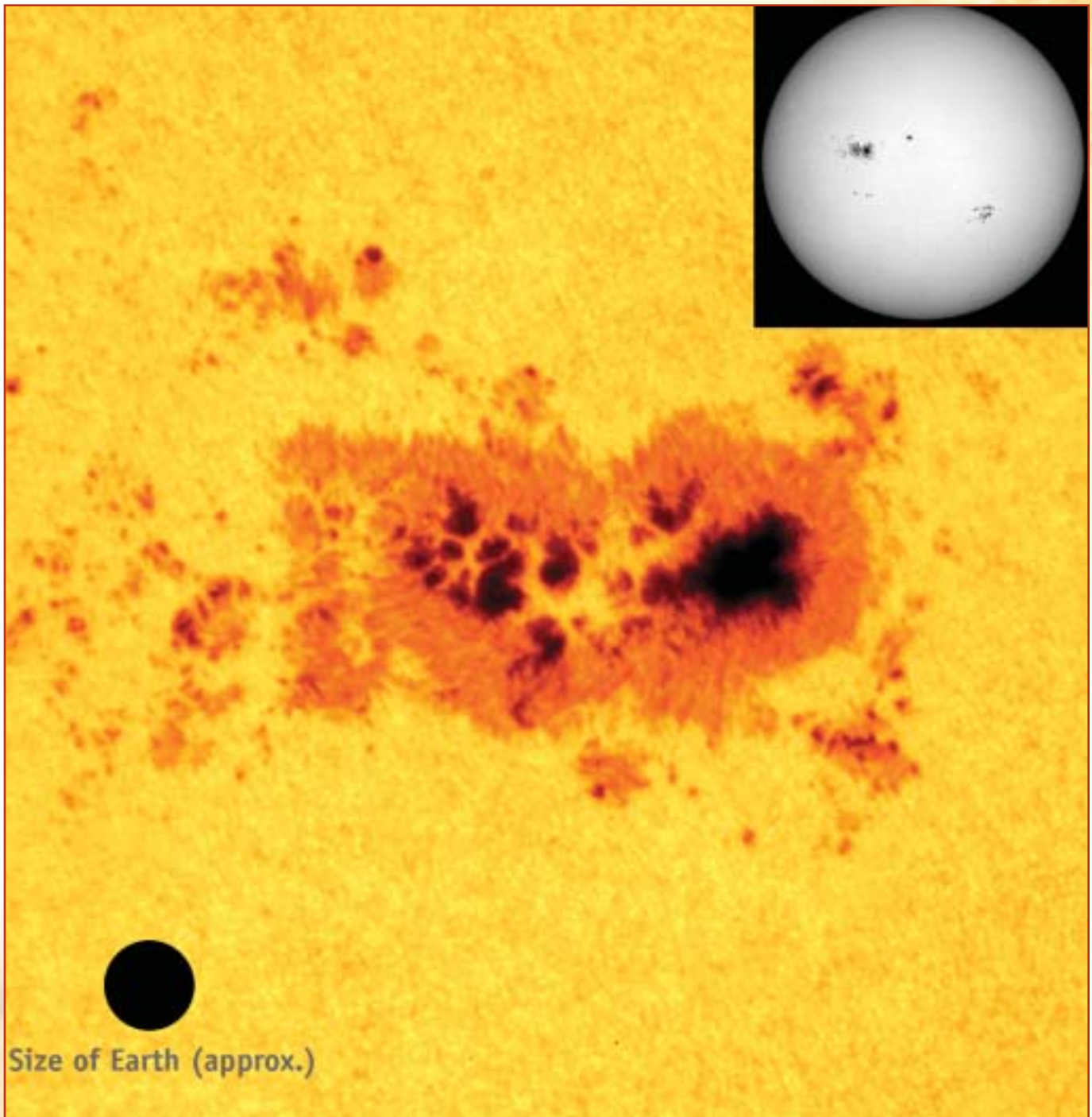
Cutaway version of the Sun showing the interior and several different appearances of the surface—each representing a different wavelength of emission.

Adapted writing from The New Solar System, courtesy of Kenneth R. Lang, Tufts University.

SORCE Glossary *

Absolute accuracy	The extent to which a value or measurement approaches the true value or measurement.
Aperture	The portion of the plane surface perpendicular to the direction of radiation and through which the radiation passes.
Attitude control	Spacecraft subsystem capable of pointing the spacecraft toward a selected target.
Bus module	That portion of the spacecraft not including the science instruments but supporting their operation. The bus module includes the power system, radio system, computer and data handling, and attitude control system.
Chromosphere	Hot layer of solar atmosphere immediately above the photosphere.
Corona	Outermost and hottest layer of the Sun's atmosphere.
Dual transceivers	Redundant radio system capable of receiving commands and sending data.
Electrical Substitution Radiometer (ESR)	Radiation sensor that maintains a constant temperature by supplying additional electrical heater power if light is removed from the sensor, and conversely removes such power when more light is added to the sensor.
Faculae	Irregular bright patches in the solar photosphere, usually accompanying sunspots.
Facular brightening	Brighter faculae seen against the quiet Sun — especially obvious when faculae are near the limb (edge) of the Sun.
Fery prism	A wedge of glass that disperses light into its component colors, but with the additional feature that one face is slightly concave and the other convex so that it focuses the light as well.
Ground station	A radio receiving and transmitting station capable of communicating with a satellite as it passes overhead.
Hertzsprung-Russell diagram	Plot of stars' absolute magnitude plotted against their surface temperature or color, used to study stellar evolution.
Hydrogen Lyman-α emission	Spectral line with energy corresponding to the transition of the hydrogen atom from its ground energy state to its lowest excited state.
Index of refraction	Ratio of the speed of light in a vacuum to the speed of light in another medium — an indication of how much a ray of light is bent as it passes from one medium into vacuum.
Infrared	The portion of the electromagnetic spectrum (light) between visible light and microwaves, invisible to the human eye.
Instrument module (IM)	Portion of the SORCE spacecraft that includes the four scientific instruments and their support electronics and thermal control systems. The IM serves as an optical bench aligning all instruments to a common axis.
Low Earth Orbit (LEO)	An orbital altitude typically around 350 - 1400 km above the Earth's surface.
Magnetometer	A device for measuring the magnitude and direction of the Earth's magnetic field.
Maunder minimum	Historical period roughly from 1645 to 1715 A.D. when sunspots were exceedingly rare.
Nickel Phosphorous (NiP)	Metallic black absorbing layer, stable under ultraviolet exposure.
Pegasus	Orbital Sciences Corporation rocket vehicle that is carried aloft by an airplane (L-1011) and is then released. After a short fall the motor ignites and propels the payload to orbit.
Photosphere	The layer of solar atmosphere that radiates directly to space. In visible light this is the visible "surface" of the Sun.
Plage	Irregular areas of intense brightness seen in the Sun's chromosphere — these regions generally correspond to the faculae and sunspots that lie directly below in the photosphere.
Precision	The quality of being exactly defined. Indicated by the minimum number of significant digits required for an adequate representation of a measurement.
Reaction wheel	A massive wheel on a motor shaft that can be spun one direction or the other to impart angular momentum to the spacecraft, turning the spacecraft about the wheel's axis of rotation.
Redundant	A second (or third) system that can substitute for the primary system if the primary fails.
Relative accuracy	An estimate of how well two measurements compare to each other. Systematic errors in the two measurements will cancel, and the relative accuracy will therefore be better than the absolute accuracy.
S-band	Range of radio frequencies from 1.55 GHz to 3.9 GHz.
Soft X-ray (XUV)	Photon radiation with wavelength of 1 to 200 nm.
Solar array	Area covered by photovoltaic cells that collects solar energy and converts it to spacecraft electrical power.
Solar cycle	The magnetic field strength apparent at the Sun's surface and in its atmosphere rises and falls with an approximate 11-year cycle. Most solar phenomena adhere to this 11-year solar cycle and vary accordingly.
Spectral Solar Irradiance (SSI)	Solar energy per unit time over a unit area perpendicular to the Sun's rays at the top of Earth's atmosphere at a particular wavelength.
Spectral type (OBAFGKM)	Star classification according to its surface temperature (color). The Sun is spectral type G.
Star tracker	An optical device that when pointed to a star or arbitrary star field determines the direction of its line-of-sight.
Sun sensor	An optical device that when pointed at the Sun determines the direction of its line-of-sight toward the Sun's center.
Sunspots	Dark areas on the Sun's photosphere, cooler than their surroundings, associated with intense magnetic fields, and varying in number with a period of approximately 11 years.
Suprasil 300	Synthetic quartz glass free from bubbles and inclusions, characterized by a very high optical transmission in the UV and the visible spectral ranges. Suprasil 300 has the widest transmission range of all known grades of quartz.
Torque rod	Magnetic rod fixed to the spacecraft that when turned on couples to the Earth's magnetic field and imparts a torque to turn the spacecraft. These can be used to control the attitude of a spacecraft.
Total Solar Irradiance (TSI)	Solar energy per unit time over a unit area perpendicular to the Sun's rays at the top of Earth's atmosphere.
Ultraviolet	Radiation of wavelength shorter than visible, down to about 0.1 nanometers. This radiation is invisible to the human eye and is generally harmful to biological systems.
Visible	Radiation detectable by the human eye, from 400 to 700 nanometers.

* First usage of these terms in the text is italicized.



Two views of the Sun from SOHO's MDI (Michelson Doppler Imager) that show the Sun's full disk (black and white) and a close-up in colorized visible light of a large sunspot group on Sept. 23, 2000.

Acknowledgements:

This brochure was prepared under the direction of Gary Rottman, Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, and Robert Cahalan, NASA Goddard Space Flight Center. Reviewers included Michael King, EOS Senior Project Scientist, NASA Goddard Space Flight Center; Don Anderson, SORCE Program Manager, NASA Headquarters; William Ochs, SORCE Project Manager, NASA Goddard Space Flight Center. The brochure was designed by Winnie Humberson, Science Systems and Applications, Inc., and edited by Vanessa George, LASP, University of Colorado, Boulder.

For further information on the SORCE mission, instruments, and data products, visit the SORCE website at: lasp.colorado.edu/sorce or earthobservatory.nasa.gov/Library/SORCE

As there is only one object in the sky on whom we utterly depend, there can be no astronomical question of more practical significance to mankind than that of the Sun's variability. To determine whether the solar constant is varying . . . requires long-term monitoring of both the bulk solar radiation and its terrestrially important spectral components. This assignment is not an easy one, for it demands a capability of sensing changes of no more than 0.1% in a decade, carried out over many decades. In the real world of science the greater challenge may be that of insuring the continuance of such a program.

*— John A. Eddy, "Climate and the Changing Sun,"
in Climate Change 1, 1977, D. Reidel Publishing Company,
Dordrecht-Holland, pp.173-190.*



Goddard Space Flight Center
Greenbelt, Maryland 20771

NP-2002-9-482-GSFC