

The Sun's X-ray Emission During the Recent Solar Minimum

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The Sun recently underwent a period of a remarkable lack of major activity such as large flares and sunspots, without equal since the advent of the space age a half century ago. A widely used measure of solar activity is the amount of solar soft X-ray emission, but until recently this has been below the threshold of the X-ray-monitoring Geostationary Operational Environmental Satellites (GOES). There is thus an urgent need for more sensitive instrumentation to record solar X-ray emission in this range.

Anticipating this need, a highly sensitive spectrophotometer called Solar Photometer in X-rays (SphinX) was included in the solar telescope/spectrometer TESIS instrument package on the third spacecraft in Russia's Complex Orbital Observations Near-Earth of Activity of the Sun (CORONAS-PHOTON) program, launched 30 January 2009 into a near-polar orbit. SphinX measures X-rays in a band similar to the GOES longer-wavelength channel.

Over the most inactive times of recent months, SphinX has measured the X-ray level to be about 20 times less than the GOES lower threshold. From the spectral capability of SphinX, it is possible to determine the temperature of the X-ray emission, and with imaging data it is possible to deduce the physical characteristics of the Sun's corona at this unusual time and compare the Sun's present X-ray luminosity with that of nearby stars.

Monitoring X-ray Activity

The orbit of CORONAS-PHOTON allows it to view the Sun for 60 or more minutes of its 96-minute orbital period. The SphinX instrument, calibrated using the Berlin Electron Storage Ring Company for Synchrotron Radiation (BESSY) synchrotron and a long-pipe facility at Palermo, Italy [Sylwester *et al.*, 2008], consists of three diode detectors placed behind three different sized apertures (D1, D2, and D3, with areas of 21.50, 0.495, and 0.0101 square millimeters, respectively) sensitive to X-rays with energy between 1 and 15 kiloelectron volts (0.8–10 angstroms). The detectors are silicon wafers with beryllium windows, which results in an energy resolution significantly better than many previous spacecraft spectrometers. The TESIS package [Kuzin *et al.*, 2009] also includes two full-Sun extreme-ultraviolet telescopes sensitive to the ranges 130–136, 171, and 290–320 angstroms with spatial resolution of 1.7 arc seconds.

Figure 1 shows the X-ray flux curve from SphinX detector D2 from 20 February 2009 (the date the instrument was turned on) to 10 October 2009. Data have been smoothed, and gaps in the plot are due to spacecraft

nighttime periods, passages through the auroral radiation belts, etc. As seen from the data, X-ray activity remained low until late April, with only a few flares above the GOES threshold. From April to July, the light curve showed some upward excursions, associated with the passages of active regions with sunspots, but activity then decreased.

The radiation seen in February, March, and August 2009 was low, hovering at around 10 counts per second, equivalent to 5×10^{-10} watts per square meter. By contrast, radiation in July was between 200 and 700 counts per second. Over the entire period, there are small, short-term variations of a few percent as well as some 600 recognizable increases identifiable with tiny flares, only 80 of which are above the GOES threshold.

Despite these tiny flares, the X-ray levels registered on SphinX were much lower in general than any seen in the previous four solar cycles, when reliable spacecraft measurements began about 50 years ago.

A Window to the Sun

The spectroscopic capability of SphinX yields information on the physical characteristics of the X-ray emission. At times of low activity, emissions can

typically be measured only in the 1.2- to 2.4-kiloelectron-volt spectral range. By comparing the observed emissions with those calculated from the CHIANTI code [Dere *et al.*, 1997], an atomic physics code used extensively by solar astronomers, it was possible to derive the temperature, electron density, and volume of the solar corona that gives rise to the X-ray emissions. A 441-second period on 21 February was chosen for analysis when the X-ray level was extremely low (4.7×10^{-10} watts per square meter; for comparison, during much of the previous solar minimum the X-ray level was at least 2 orders of magnitude greater). During this time, the SphinX spectrum gave total emission counts of 20,000. A comparison with CHIANTI spectra gave the temperature of the corona at this time as 1.8×10^6 kelvins and the "emission measure" (equal to volume times density squared) as 4×10^{53} particles per cubic meter.

These values can be combined with the volume of the corona estimated from the imaging TESIS instrument. A TESIS image also taken on 21 February 2009 with the 171-angstrom pass-band reveals the corona at this time to have a volume of 3×10^{25} cubic meters, in agreement with the X-ray corona seen by the Hinode spacecraft's X-ray telescope at this time. By combining emission measure and volume, an average density of the corona— 10^{14} particles per cubic meter—was derived. This is much less than coronal densities during previous solar minima, which have been typically of the order of 10^{15} particles per cubic meter or more.

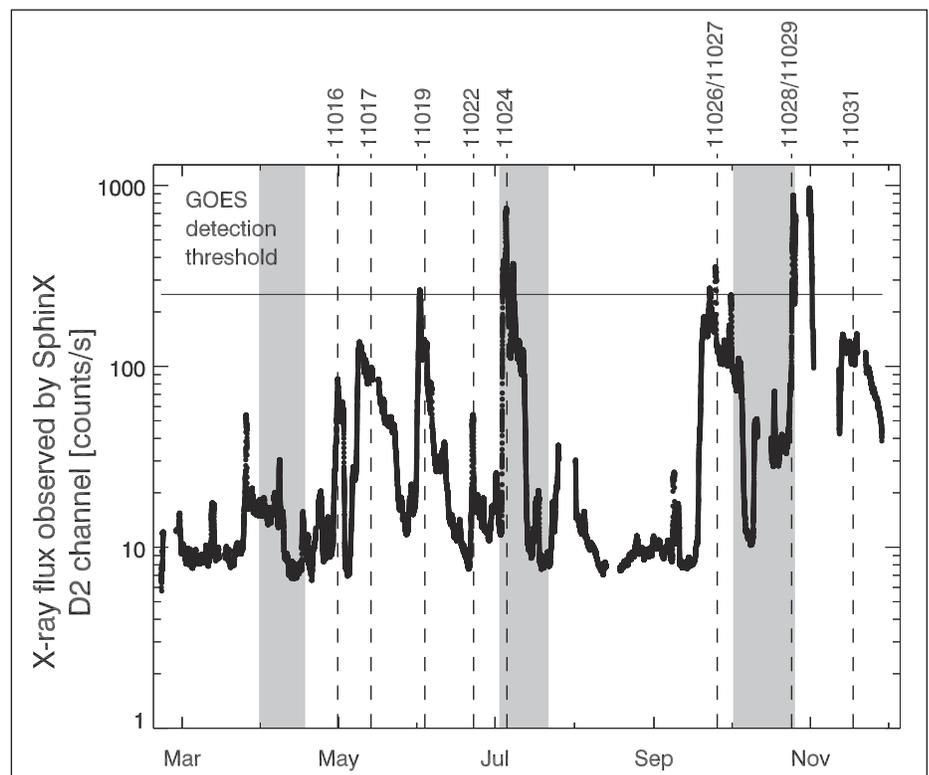


Fig. 1. Total solar 0.8- to 10-angstrom X-ray flux from 20 February 2009 to 10 October 2009 as measured by the Solar Photometer in X-rays (SphinX) D2 detector. The third Complex Orbital Observations Near-Earth of Activity of the Sun (CORONAS-PHOTON) satellite was in uninterrupted sunlight during the gray areas indicated. Active regions associated with X-ray flux increases are shown (e.g., sunspot regions 11016 and 11017) as identified by the U.S. National Oceanic and Atmospheric Administration.

The corona's total thermal energy, estimated to be 2×10^{23} joules, is also much less than typical for solar minima.

The Sun and Nearby Stars

SphinX measurements of the Sun's recent X-ray output are showing it to be the dimmest X-ray star in its immediate stellar neighborhood. SphinX X-ray spectra can be extrapolated to the spectral range of the X-ray instrument on Germany's Röntgensatellit (ROSAT) that observed nearby stars, many of which have coronae just like the Sun's. Using stellar luminosities from the ROSAT All-Sky Survey (RASS) [Schmitt *et al.*, 1995], it was found that the Sun's X-ray luminosity, averaging 1.3×10^{18} watts between February and October 2009, was less than the X-ray luminosity of all stars within 23 light years of the Sun, and was 100 times less than that of Alpha Centauri A, widely considered to be the Sun's "twin star" from the point of view of its optical output.

SphinX estimates of the Sun's X-ray luminosity in the ROSAT X-ray energy range are in fact some 50 times less than those during the previous solar minimum, when the Sun would have been considered quite normal in its X-ray output compared with nearby stars.

The Sun has experienced a truly unusual episode in humanity's observational history. Its X-ray output over the previous minimum was remarkably low, lower than at any time in the past 50 years, since the space age began. Activity is at last picking up in this new year—as a result, the deepest minimum in recent times may be over. Nonetheless, SphinX measurements of the X-ray emission are unique in that they recorded the unprecedentedly low levels of X-ray activity, helping scientists to better understand extremes in the natural variability of the Sun.

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NEWS

U.S. Geological Survey Would Fare Well in Proposed Federal Budget

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The U.S. Geological Survey (USGS) is among the U.S. federal science agencies that would see significant funding increases if Congress approves the Obama administration's proposed budget for fiscal year (FY) 2011. The FY 2011 budget request would provide USGS with \$1.13 billion, an increase of \$21.6 million, or 1.9%, above the FY 2010 enacted level.

"In a time of budget austerity, to have the budget for a science agency like the USGS actually be at a level above 2010—and 2010 was a pretty good budget year for the USGS—is indeed a very good sign," USGS director Marcia McNutt said at a 1 February budget briefing. "What we are seeing in the USGS budget is the reflection from both the president and the secretary [of the Department of the Interior, of which USGS is part] of their commitment that the problems that the nation is facing right now are problems to which science can help us find an answer," she said.

McNutt indicated the proposed budget would provide particularly strong support for USGS science programs—energy, climate, water, and hazards—that are aligned with the agency's science strategy. "It shows how coming up with a strong science plan, a strong science strategy, and sticking to it, did us well," she said.

Within the proposed budget, the Geographic Research, Investigations, and

Remote Sensing account would increase to \$153.4 million, up 5.4% from \$145.6 million. The Land Remote Sensing proposed budget of \$75.9 million would allow the agency to continue operations and maintenance for Landsat 5 and 7. In addition, a program increase of \$13.4 million would fund ground system requirements for the Landsat Data Continuity Mission. Landsat 8 is scheduled to launch in 2012.

Funding for the National Geospatial Program would drop to \$65.9 million from \$70.7 million. Most of that cut would come from a \$3.5 million decrease in funding for the National Map partnerships, which would receive \$10.4 million compared with \$13.9 million in FY 2010. McNutt said the agency looks forward to rebuilding the program again in the future.

The Geologic Hazards, Resources, and Processes account would receive an overall slight increase to \$253.8 million from \$249.1 million. The budget for geologic hazard assessments would bump up modestly to \$92.9 million from \$92.8 million, with funding for volcano hazards assessments targeted to rise a bit to \$25.2 million, up from \$24.4 million. Funding would dip for earthquake and landslide hazards assessments, the Global Seismographic Network, and geomagnetism research.

Geologic Landscape and Coastal Assessments funding would increase to \$77.6 million from \$74.4 million. Included is \$4 million for coastal and marine spatial planning

to increase the availability of geospatial data, among other goals. The budget for mineral resources assessments would dip slightly to \$52.5 million from \$53.8 million, while funding for energy resources assessments would increase moderately to \$30.8 million from \$28.2 million.

The Water Resources Investigations account would decrease to \$228.8 million from \$232.3 million. Funding for hydrologic networks and analysis would increase, with decreases for other line items, including the Groundwater Resources Program, the National Water-Quality Assessment Program, and the Toxic Substances Hydrology Program.

Funding for biological research would dip from \$204.9 million to \$201.3 million. The budget for the agency's Enterprise Information account, which includes support for computers and information systems, would drop to \$41.5 million from \$46 million. Funding for USGS science support would increase 11.8% to \$77.4 million from \$69.2 million.

The proposed USGS budget also requests funding for some initiatives from the secretary of the interior, including \$11 million in additional funding for climate change adaptation, primarily to expand the Department of the Interior's climate science centers. Funding for the agency's Global Change account overall would jump a whopping 23.9% to \$72.1 million, up from \$58.2 million. The New Energy Frontier initiative would receive \$3 million in new funding to study the impact of wind energy options on ecosystems and wildlife populations. The budget also would include funding for the agency to begin an assessment of the availability and use of water resources in the United States through the WaterSMART (Sustain and Manage America's Resources for Tomorrow) program. In addition, \$3.6 million would be slated for the Treasured Landscapes initiative to implement the