The SphinX Spectrometer for solar soft X-rays

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Solar **Ph**otometer **in X**-rays (SphinX) was an instrument designed to observe the Sun in the energy range 1.2 - 15.0 keV. SphinX was incorporated within the Russian TESIS X and EUV telescope complex aboard the *CORONAS-Photon* satellite which was launched on January 30, 2009 at 13:30 UT from the Plesetsk Cosmodrome in northern Russia. Since February 2009, SphinX was measuring solar X-ray radiation nearly continuously till the end of the mission in early December 2009. The principle of SphinX operation is explained. Information on SphinX data archive and the calibration is presented together with general recommendations for the data use.

1 Introduction

SphinX was a fast and sensitive spectrophotometer for observations of solar soft X-ray radiation in the energy range 1.2-15.0 keV with an energy resolution of 0.4 keV and a time resolution down to fraction of a second. SphinX initiated the measurements on February 20, 2009 about three weeks after the satellite launch. Since that time the instrument observed the Sun nearly continuously and collected measurements with a telemetry rate up to 150 MB/day till the end of active satellite operation i.e. 29 November, 2009.

For measurements of solar X-ray flux SphinX used four pure, 500 μm thick, silicon crystals placed inside XR-100CR detectors. The detectors were manufactured by US Amptek company. Each detector had 12.5 μm thick beryllium entrance window. Three of the detectors (called D1, D2 and D3) formed the main SphinX measurement block and were exposed directly to solar X-rays. The detector D1 operated with its nominal effective area (19.63 mm^2). Over the detectors D2 and D3 there were apertures placed in order to limit their sensitivity. The detector D1 with the highest effective area was designed to measure low intensity solar photon fluxes. Pileup and saturation in detector D1 would take place even for moderate solar flux. The aperture of the second detector D2 (0.495 mm^2) was chosen so that it gave good signal/noise ratio (S/N) measurements during moderate solar fluxes for which pileup in D1 could become a problem. The third detector D3 with the smallest aperture (0.01008 mm^2) could measure substantial signal for strong solar flux when pileup in detector D2 would appear (detector D1 would be completely saturated at such high flux values). The aperture of D3 detector was so small that it would not saturate even for the strongest solar flares. Thus, using this three detector block, it was possible to observe solar fluxes from the very small X-ray activity level to the strongest ever observed flares. The fourth detector D4 was in a special SphinX fluorescence measurement channel which was designed to measure X-ray fluorescence emission excited by solar radiation in narrow selected energy bands.

SphinX observed the Sun in the deepest in almost a century solar activity minimum. Thus much of the instrument broad measurement capabilities were unexploited. Due to low solar flux during the mission, detectors D3 and D4 measured the noise only. Detector D2 provided some useful signal but its measurements were always accompanied with simultaneous measurements from D1 detector with much better signal to noise ratio. Thus for flux and spectral variability analysis it is sufficient to use D1 measurements only.

The operation of SphinX consisted of two phases. In the first short lasting phase SphinX team was changing the instrument operation modes and on-board software in order to fix the optimum instrument operation conditions and data collection strategy. This optimum strategy was activated on April 6, 2009 and from that time the second phase of the mission lasted with no further instrument settings.

More information on SphinX, its data reduction and dissemination can be found in [1] and [2].

2 SphinX data

During its operation SphinX measured in the event counting mode and spectral mode.

In the event counting mode every single output pulse from the detector electronic system was processed. Output pulse was produced by electronics when an X-ray photon hit the detector crystal. The pulse amplitude was proportional to the photon energy. When pulse event was detected its amplitude was attributed to corresponding energy channel by the PHA electronics and the time of arrival was recorded. Next the event time and energy were stored by the SphinX onboard computer into telemetry memory frames each of eight kB in size. A single frame could store information for several thousands of events.

From the analysis of SphinX calibration data it was found that the optimum number of energy channels for flight SphinX operations is 256. In this way the energy bin width was few times smaller than FWHM. Thus all SphinX multichannel analyzers had 256 energy bins covering the useful energy range 1.2 - 15.0 keV. (Nominal energy range is 0 - 15 keV but due to amplifier detection threshold and filter transmissions useful range extends from 1.2 keV onwards.) Individual event arrival times were determined with the 1 μs accuracy.

In the spectral mode, the events, detected in a given detector electronics system, were collected in a selected number of energy bins and stored as histograms in the telemetry frame together with the exposure times. Only 256-channel and ancillary, 4-band spectra (so called basic mode observations) were recorded during the mission.

The most versatile SphinX observing mode is the event counting mode. Indeed all the other observation modes, including the basic mode, can be reconstructed from the event data. The spectral mode was however useful for a fast onboard computer processing which was intended to serve the instrument quickly and autonomously in selected pre-programmed ways depending on the results of online analysis of the flux rates determined based on the basic mode records.

The eight kB memory frames containing SphinX events and spectra were packed by the onboard computer and send to telemetry with the cadence of usually one second. Sometimes the cadence was set to five or eight seconds in order to save on global telemetry quota. Together with SphinX events and spectra, an additional information on start/end times for each frame and housekeeping data were also send to telemetry. The data received from telemetry at the ground station were sent via internet to Solar Physics Division of Space Research Centre Polish Academy of Sciences (SRC-PAS) for further processing. These data were decompressed and separated into binary files containing typically several thousands of telemetry frames and covering a couple of hours of the observing time.

The data in binary files were successively reduced to level-0 format. In the level-0 format SphinX event counting and spectral mode observations are stored as arrays using Interactive Data Language (IDL) native file format.

Analysis and interpretation of level-0 data is possible but necessitates a full knowledge of all instrumental effects which are embedded in the data.

In 2010, the SphinX data from the second phase of the mission were reduced to level-1 format. Reduction of data from the first mission phase is more difficult due to many changes of the instrument software and settings in that time and therefore cannot be performed automatically. However level-1 data for the first mission phase can be obtained from SRC-PAS on request.

3 SphinX data format, access and calibration Information

SphinX team recommends level-1 data for the external users. Level-1 data are of scientific grade and can be used without further knowledge of the instrument related issues.

On-line access to SphinX level-1 data is possible via internet catalogue available on dedicated SphinX server at the site $http://156.17.94.1/sphinx\_l1\_catalogue/SphinX\_cat\_main.html$

This catalogue comes with legend and description of the content. From level-1 catalogue it is also possible to download SphinX calibration FITS file and useful IDL software developed at SRC-PAS for data processing.

SphinX level-1 data are stored as event lists in Flexible Image Transport System (FITS) files. Well documented and standardized Office of Guest Investigator Programs (OGIP) FITS format was used for preparation of SphinX level-1 FITS files. A description of the OGIP FITS format also can be found on the level-1 catalogue website.

In the level-1 FITS files all kinds of SphinX events are stored. A special flag is associated with each particular event with description of its origin. These flags can be used to select events according to user specific needs. For instance, one can use flag to filter out events caused by X-ray photons. These can be used next for construction of the higher level data products (lightcurves or spectra) and together with the calibration information used for scientific analysis of the observations.

Data from X-ray tests of SphinX performed in Palermo at the XACT facility (2007) and at Bessy II synchrotron in Berlin (2008) were finally processed in 2010 in order to prepare all necessary calibration information for the SphinX data reduction and analysis. The calibration information is stored in a single OGIP FITS file - SphinX response FITS file. This FITS is named $SPHINX\_RSP\_256\_nom\_D1.fts$ and contains detector response matrix (DRM) and tables for conversion of SphinX channels to energy. SphinX response FITS file also can be downloaded from the instrument level-1 catalogue page.

4 Application of SphinX data

SphinX had no spatial resolution over the solar disk and therefore observed the Sun as a star. Thus the data analysis focuses mainly on properties of spectra and lightcurves costructed from detector events. The data were collected during the deepest ever solar minimum observed in X-rays. There were no other instruments observing at that time with so high energy and temporal resolution as SphinX had and sensitivity covering similar energy range. Thus SphinX measurements give a unique reference point - the measurements of the lowest level of solar activity in X-rays. Hence SphinX data allow for analysis of previously unknown quiet Sun X-ray flux, observations of soft X-ray emission associated with emerging active regions, investigations of small flare energetics and studies of the statistical properties of coronal activity. An example of the SphinX spectrum for a very low solar activity level mesured By SphinX in the time interval 2009-09-11 10:35:00 - 2009-09-12 23:20:00 is shown in Figure 1.

An interesting feature of SphinX spectra obtained during very low activity times is that they cannot be fully explained using isothermal model only. There is an excess of the spectral signal over the isothermal best fit to data as is seen in Figure 1. The data and fit begin to diverge there at 2.5 keV. For the quiet Sun conditions the discrepancy of data and the isothermal fit is small because the signal has low statistical significance between 3 keV and 4 keV where it deeps into the level of orbital background arising from energetic particles. The contribution of the particle background is still under investigation. Longer integration time intervals for spectra accumulation are necessary in order to determine the properties of SphinX emission and background seen above 3keV.

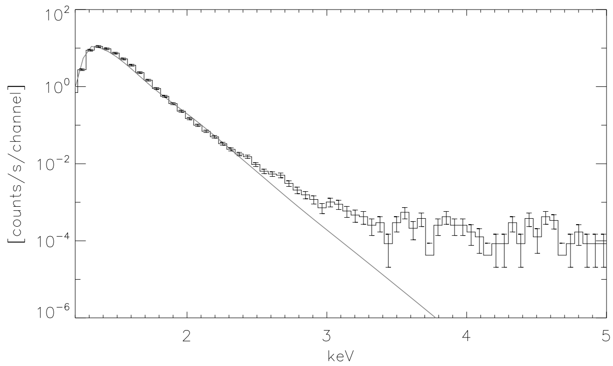

Figure 1: The SphinX solar X-ray spectrum measured for a very low activity period. The best isothermal model fit folded with DRM is shown in dashed line

The excess of spectral signal over the isothermal fit becomes much more pronounced for increased levels of solar activity. Explanation to the SphinX spectral shape in general necessitates more temperature components in the fit model. One possible additional contribution to be taken into account is the spectrum due to envisaged axion interaction with magnetic field. This contribution would be particularly important for higher solar activity intervals.

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