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The Fourier Imaging X-Ray Spectrometer (FIXS)

for the

Argentinian, Scout-launched

Satelite de Aplicaciones Cientificas - 1 (SAC - 1)

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ABSTRACT

The Fourier Imaging X-Ray Spectrometer (FIXS) is one of four instruments on SAC-1, the Argentinian satellite being proposed for launch by NASA on a Scout rocket in 1992/3. FIXS is designed to provide solar flare images at X-ray energies between 5 and 35 keV. Observations will be made on arcsecond size scales and subsecond time scales of the processes that modify the electron spectrum and the thermal distribution in flaring magnetic structures.

FIXS will be capable of imaging X-ray sources that are as large as 3 arcminutes in extent with a resolution as small as 2 - 3 arcseconds. It will have a sensitivity two orders of magnitude greater than that of the Hard X-ray Imaging Spectrometer (HXIS) on SMM. These advanced capabilities are made possible on such a small spin-stabilized spacecraft by using a Fourier-transform imaging technique. Six rotating modulation collimators (RMCs), each with its own xenon proportional counter, are used to measure over 150 spatial Fourier components of the X-ray image. The amplitudes and phases of the Fourier components are determined in real time on board the spacecraft so that ~1000 images per flare can be telemetered. Reconstructed X-ray images can be obtained during a flare in up to 15 energy channels every 2 s; for larger flares, less complete images will be produced on subsecond time scales. This technique of measuring the spatial Fourier components of a source and reconstructing the X-ray image on the ground is mathematically analogous to the imaging technique used in multi-baseline radio interferometry.

The Fourier Imaging X-Ray Spectrometer - FIXS

The FIXS instrument, consisting of six modulation collimators mounted on a rotating spacecraft, is designed to provide images of solar flares at X-ray energies between 5 keV and 35 keV. In this energy range, FIXS will have significantly improved sensitivity, angular resolution, and time resolution compared to any other X-ray imager previously flown or planned for the next solar maximum. The primary objective is to investigate the processes of particle acceleration and plasma heating in solar flares. In particular, FIXS will address the following scientific questions:

- What are the sites of particle acceleration and interactions and how do they evolve spatially and spectrally during flares?
- What role in the overall flare process do energetic electrons play, particularly those with energies below ~50 keV, where the bulk of the total energy in electrons must reside?
- What are the sites of plasma heating and how does the thermal energy propagate during flares?
- What is the relationship between the thermal flare plasma and the energetic particles and what role does the "superhot" plasma ($T_e > 3 \times 10^7$ K) play?

To achieve these objectives, FIXS will be capable of imaging X-ray sources that are as large as 3 arcminutes in extent with a resolution as small as 2 - 3 arcseconds. It will have a sensitivity two orders of magnitude greater than that of the Hard X-ray Imaging Spectrometer (HXIS) on SMM and will obtain complete images in up to 15 energy channels every 2 s, with less complete images on subsecond time scales for larger flares. Relative motion of sources from one image to the next will be detectable at the 1 arcsecond level or better. The high sensitivity and fine angular resolution will allow studies to be made on the arcsecond size scales and subsecond time scales which are characteristic of the flaring magnetic structures and of the processes that modify the electron spectrum and the thermal distribution. The high sensitivity and full Sun coverage will allow the spatial study of many flares during the lifetime of SAC-1, thus providing a large sample of flares for statistical analysis.

One aspect of the scientific potential of FIXS can be demonstrated by comparing its capabilities with the expected source dimensions and time scales in two competing solar flare models. For the thick-target model, FIXS can be expected to detect substantial changes in the X-ray spectrum around 20 keV on size scales of 2 - 3 arcseconds. This is because a 20 keV electron loses 5 keV in a column density of 1.8 x 10^{19} cm^{-2}, which, for a typical density of 10^{11} cm^{-3}, corresponds to a distance of 1.8 x 10^{8} cm or 2.4 arcseconds. The time scale of ~20 ms is probably beyond the capability of FIXS to resolve. For the thermal model, the high-temperature source expands into the coronal plasma at the ion sound speed of ~10^{8} cm s^{-1} or 1 arcsecond per second. Thus, FIXS should be able to clearly detect the temperature difference across the thermal conduction fronts and trace their movement along the magnetic loop down to the footpoints. The vastly different signatures of the X-ray images in the FIXS data and their evolution during the impulsive phase should allow a clear separation to be made between the two models.

Instrument Characteristics

The FIXS design is based on a Fourier-transform imaging technique. Six rotating modulation collimators (RMCs), one of which is shown in Figure 1, are used to allow up to 144 spatial Fourier components of the X-ray image to be measured during each half rotation of the spacecraft, i. e., every ~2 s. The amplitudes and phases of these Fourier components are determined on board the spacecraft in real time so that the information that must be telemetered is reduced to a minimum within the constraints of the available bit rate. The X-ray images are reconstructed on the ground from these Fourier components with the same mathematical techniques used at the VLA and other multi-baseline radio interferometers.

A schematic diagram of a single modulation collimator is shown in Figure 1. The two tungsten grids are separated by 40 cm with identical slit widths and slit spacings. The two grid planes are parallel to each other and the slits are also all parallel and uniformly spaced. The normal to the grid planes, i. e., the axis of the collimator, is parallel to the spacecraft spin axis. The slit widths range from 16 microns for sources with angular sizes as small as 2 - 3 arcseconds to 350 microns for sources that are as large as 3 arcminutes. A xenon proportional counter placed below the bottom grid detects the temporally modulated X-ray signal and provides spectral information with 2 - 3 keV (FWHM) energy resolution between 5 keV and 35 keV. The thickness of xenon at two atmospheres is 5 cm, thus giving ~30% absorption at 30 keV. A graduated aluminum absorber above the counter prevents saturation from the intense flux of soft X-rays during a large flare while transmitting most of the higher energy photons. The sensitive area of the proportional counter and the area of the bottom grid are both circles with a diameter of 6 cm while the top grid has a diameter of 10 cm. In this way the full 6-cm diameter area is always covered by the top grid even when the spin axis of the spacecraft is 3° from the direction to the Sun, the maximum offset angle to be allowed by the spacecraft aspect control system.

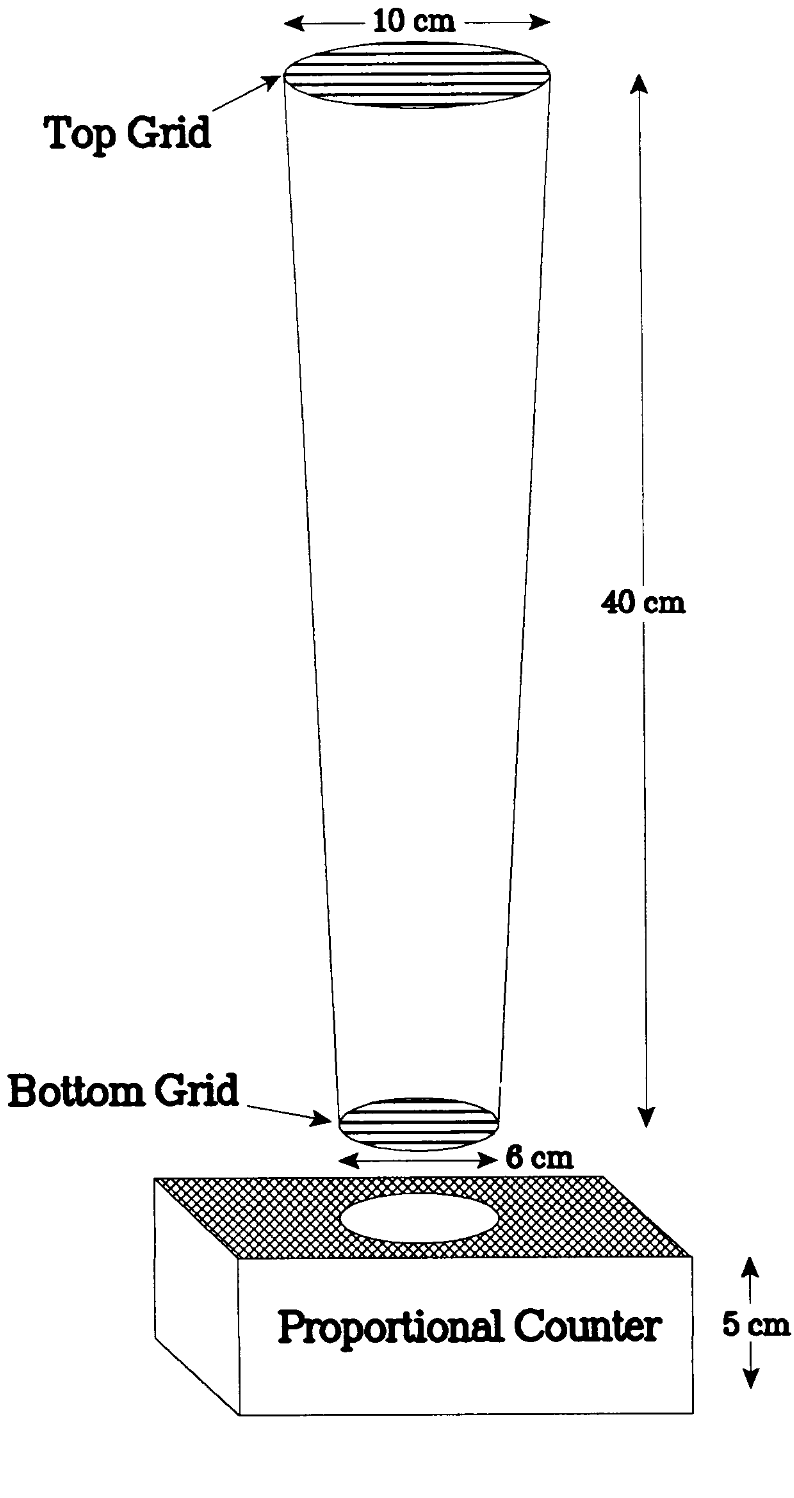

Figure 1. Schematic diagram of one of the six modulation collimator/detector units that make up the FIXS instrument.

The Aspect System

The aspect of the collimators is determined at all times from a solar limb detector that uses a lens mounted on the top grid with a slit and photocell mounted on the bottom grid. This aspect system is shown schematically in Figure 2. The solar image formed by the lens is projected onto the bottom grid plane. As the spacecraft rotates with the spin axis offset from the solar direction by 1 - 3°, the solar image passes over the slit to provide a modulated signal from the photocell. The times of passage of the slit across the solar limbs are marked by rapid increases or decreases in the signal and these times provide a strobe for data collection and also allow the angular distance from the spin axis to sun-center to be determined. Smaller modulations in the photocell output as the slit crosses the solar disc will result from the presence of sunspots. The exact times of these dips will be used on the ground to determine the azimuthal location of the spin axis around the solar direction and hence will allow the flare locations to be determined unambiguously.

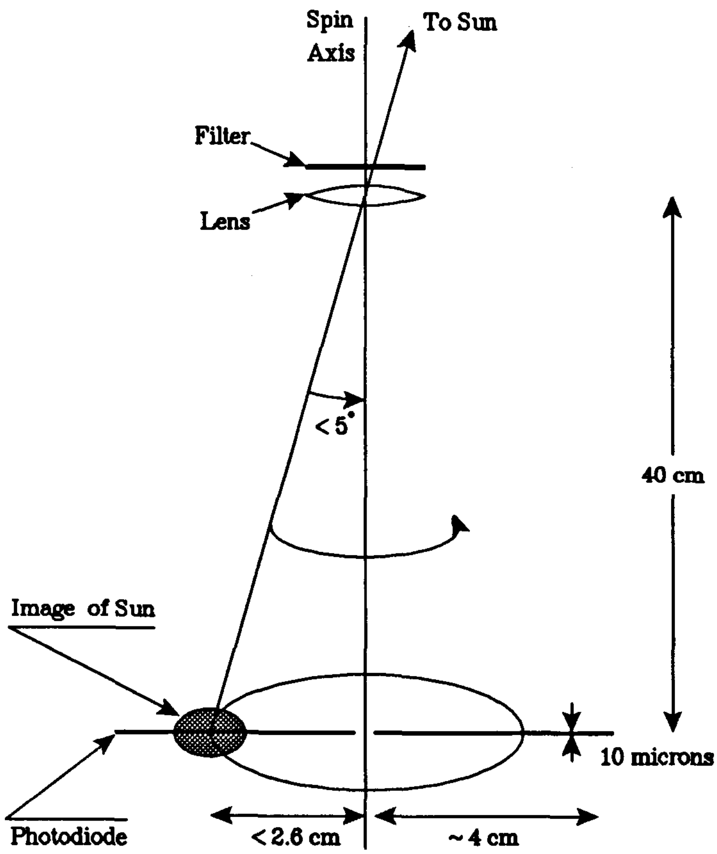

Figure 2. The proposed FIXS aspect system.

On-Board Data Analysis

The on-board determination of the amplitude and phase of the spatial Fourier components from the temporally modulated X-ray signals from the six RMCs is designed to minimize the number of bits to be telemetered. Basically the method involves the use of three microprocessors, one to analyze data from the aspect system and to determine the coarse flare location, one to bin the data for the 144 Fourier components, and one to handle commands and data transmission. Once a flare has begun, its coarse location is determined by comparing the modulated signal from the coarsest RMC with the time profiles expected for sources at different radial distances from the spin axis. These time profiles for half a rotation are stored in the memory of the microprocessor for every arcminute in radial distance from 1° to 5°. By finding the profile that best fits the observed modulation, the flare radial distance from the spin axis and its azimuthal location can be determined and passed on to the second microprocessor.

Once the coarse flare location has been determined, the period of the modulation is known for each 15° of rotation since these are also stored in memory for all radial distances and azimuths. The second microprocessor bins the X-ray data from each RMC and for each energy channel or group of channels modulo these periods for the corresponding rotation angles. The resulting 4-bin distributions contain the information on the amplitudes and phases of all the Fourier components plus the unmodulated background counting rates, and these are stored for later telemetry. In this way, the number of bits that must be telemetered is reduced to a minimum without sacrificing the quality of the images, the time resolution, or the energy resolution of the instrument. Data for over 500 images can be transmitted within the constraints of telemetering 2 Mbits of data every 12 hours imposed by the spacecraft and the single Argentinian ground station. These images can be selected as desired to give high time resolution during the impulsive phase, for example, high energy resolution at less frequent intervals, or poorer time resolution over a longer total time interval for more gradually varying flares. One constraint is that data for images obtained on successive rotations cannot be easily summed together on the spacecraft prior to transmission because of the precession of the spin axis.

Satelite de Aplicaciones Cientificas - 1 (SAC - 1)

Fundamental Parameters

Spacecraft	
Mass:	161 kg
Scientific payload:	30 kg
Orbit:	Polar, dawn-dusk, sun-synchronous
Type:	Spin-stabilized
Spin axis:	1 - 3 degrees from direction to Sun
Spin rate:	15 rpm
Origin:	Argentina
FIXS Instrument	
Mass:	14 kg
Power:	11 watts
Telemetry:	2 Mbits per dump, one dump per 12 hours
Maximum length:	50 cm

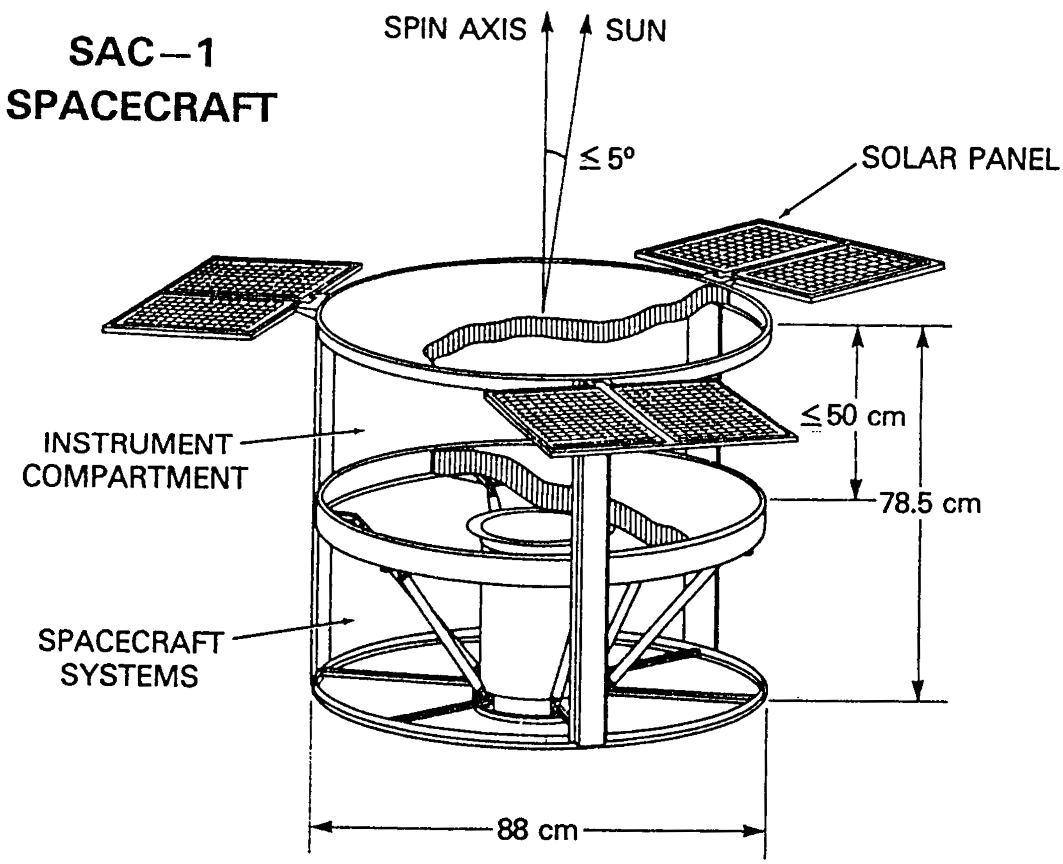

Figure 3. Schematic diagram of the proposed SAC-1 spacecraft

Fourier Imaging X-Ray Spectrometer
FIXS

Basic parameters and capabilities.

Design:	Multiple rotating modulation collimators.
Number of subcollimators:	6 tungsten grids, 50 microns thick
Slit widths:	16, 27, 46, 87, 175, 350 microns
Distance between grids:	40 cm
Rotation rate:	15 rpm
Energy range:	5 - 35 keV
Energy resolution:	1 - 2 keV
Number of channels:	15
Efficiency:	10^{-6} at 5 keV, 0.0015 at 6.5 keV, 0.16 at 10 keV, 0.66 at 20 keV, 0.4 at 30 keV
Angular resolution:	3 arcseconds for strongest flares
Field of view:	Whole Sun
Source sizes imaged:	up to 3 arcminutes
Time resolution:	2 s for complete two-dimensional image from ~300 Fourier components, 0.1 s for one-dimensional image from 6 to 8 Fourier components
Effective area:	40 cm^2
Maximum number of images per flare:	>1000

Fourier Imaging X-Ray Spectrometer
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Collimator Specifications

Collimator type:	Parallel-slit bigrid subcollimators
Number of subcollimators:	6
Top grid diameter:	10 cm
Bottom grid diameter:	6 cm
Separation:	40 cm
Angular resolutions:	8, 14, 24, 45, 90, 180 arcsecond (first harmonic) 2.7, 4.7 and 8 arcsec (third harmonic)
Slit widths:	16, 27, 46.5, 87, 175, 350 microns
Material:	Tungsten
Thickness:	50 microns
Sensitive area:	7 cm^2 per subcollimator

Detector Specifications

Type	Xenon proportional counters
Number:	6
Dimensions:	12 cm long, 6.3 cm diameter
Weight:	~0.5 kg
Window:	Beryllium 10 mil (0.025 cm) thick
Window area:	Circular with a diameter of 6 cm
Absorber:	Aluminum, 0.025 cm thick
Fill gas:	97% xenon, 3% CO_2, at two atmospheres
Voltage:	<3000 volts
Power:	30 - 40 mW
Energy Range:	5 - 35 keV
Resolution:	1 - 2 keV
Lifetime:	$>10^{12}$ total counts
Channels:	15
Manufacturer:	Reuter Stokes or LND or PGT/Outukumpu(Finland)

Comparison with Previous Instruments

HXIS on SMM

Energy range:	3.5 - 30 keV, 6 channels
Angular resolution: (FWHM)	8 arcseconds (fine field of view) 32 arcseconds (coarse field of view)
Field of view:	2.7 arcminutes (fine), 6.4 arcminutes (coarse)
Time resolution:	1.5 s nominal, >10 s actual
Effective area per pixel:	0.077 cm^2

SXT on Hinotori

Energy range:	5 - 40 keV or 17 - 40 keV, 1 channel
Angular resolution:	~10 arcseconds
Field of view:	Full Sun
Time resolution:	~6 s (1/4 of spin period)
Total sensitive area:	~10 cm^2
Effective area:	~1 cm^2

Comparison with Future Instruments

Hard X-Ray Telescope on Solar-A

Energy range:	15 - 100 keV, 4 channels
Angular resolution:	~5 arcseconds
Field of view:	Full Sun
Time resolution:	0.5 s
Total sensitive area:	1.5 cm^2 (average) x 64 elements
Effective area:	

GRID on a balloon

Energy range:	20 keV - 1 MeV
Angular resolution:	1.7 arcsecond
Field of view:	Full Sun
Time resolution:	0.1 - 2 s
Total sensitive area:	~600 cm^2
Effective area:	~150 cm^2

Soft X-Ray Telescope on Solar-A

Energy range:	<4 keV
Angular resolution	3 arcseconds
Field of view:	selectable
Time resolution:	n/a
Effective area:	4 cm^2