THE SAX MISSION FOR X-RAY ASTRONOMY

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Abstract. The satellite for X-ray astronomy SAX, to be launched at the end of 1993, is devoted to systematic, integrated and comprehensive, studies of galactic and extra-galactic sources in the energy band 0.1–200 keV, and is under joint development by the Italian Space Agency (ASI) and the Netherlands Agency for Aerospace programs (NIVR), with the participation of SRU/SRON and SSD/ESTEC. The basic scientific objectives can be summarized as follows:

- Broad band spectroscopy ($E/\Delta E=12$) from 0.1–10 keV with imaging resolution of 1 arcmin.
- Continuum and line spectroscopy ($E/\Delta E=5$–20) in the energy range 3–200 keV.
- Variability studies of bright source energy spectra on timescales from milliseconds to days and months.
- Systematic long term variability studies over the entire sky down to a source intensity of 1 mCrab.

The payload consists of four concentrator/spectrometers (3 units 1–10 keV, 1 unit 0.1–10 keV, for a total effective area of 200 cm^2 at 7 keV), a high pressure gas scintillation counter (3–120 keV, effective area of 300 cm^2 at 6 keV), a phoswich scintillation counter (15–200 keV, effective area of 600 cm^2 at 60 keV) which are all coaligned, and is completed by two wide field cameras (2–30 keV, 20 deg $\times$ 20 deg FWHM, and effective area of 250 cm^2, pointing orthogonally with respect to the other instruments.

The three axis stabilised satellite will be placed into a circular orbit at 600 km with inclinatiobn of two degrees by an Atlas G-Centaur. The minimum mission lifetime will be two years but extendable upto four years.

1. The Sax Mission Overview

SAX, 'Satellite for Astronomy in X-rays', is a major joint program of the Italian Space Agency (ASI) and the Netherlands Agency for Space Programs (NIVR). SAX finished its Phase B activities in 1988 and entered its Phase C/D (a continuous phase) in April 1989. The satellite will be launched at the end of 1993. The chief characteristics of the mission, spacecraft, and payload instruments, are given in Table 1. In the past two decades a succession of X-ray astronomy satellites, from Uhuru to the Einstein Observatory, EXOSAT and Ginga, have led to the discovery of more than 1000 individual X-ray sources and after the completion of the first all-sky survey by an imaging X-ray telescope on board Rosat, this number can be expected to increase by nearly an order of magnitude. The results so far have

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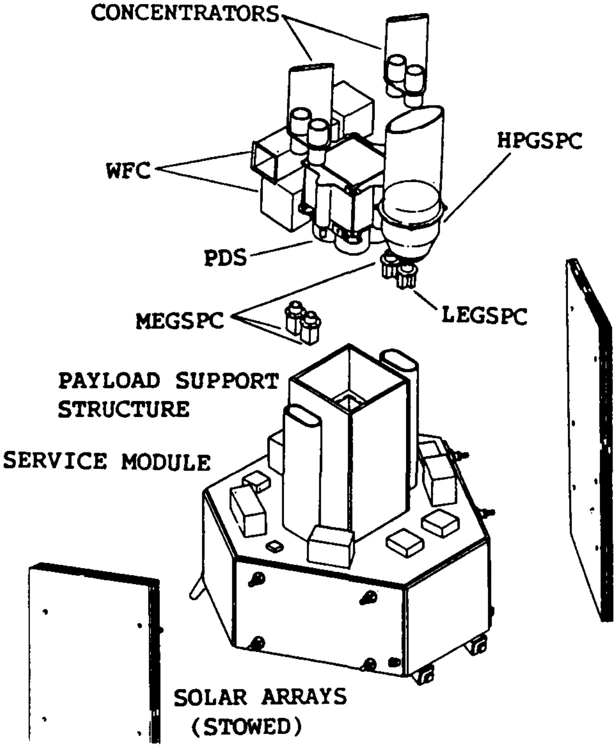

Fig. 1. SAX spacecraft and payload.

demonstrated the importance of extending X-ray observations with simultaneous spectroscopic, spectral and time variability studies over a broadened energy range, and thus the scientific objectives of SAX and the choice of its payload instruments have been made to carry out systematic and comprehensive observations in the 0.1-200 keV energy range with special emphasis on spectral and timing measurements.

The payload complement includes a medium energy (1-10 keV) concentrator/spectrometer, MECS, consisting of three units, a low energy (0.15–10 keV) concentrator/spectrometer, LECS, a high pressure gas scintillation proportional counter (3–120 keV), HPGSPC, and a phoswich detector system (15–200 keV), PDS, all of which have narrow fields of view and point in the same direction. Two wide field cameras (2–30 keV), WFC, which point in diametrically opposed directions perpendicular to the narrow field instruments complete the payload. The spacecraft and payload are shown in Fig. 1.

SAX will be launched by an Atlas G-Centaur directly into a 600 km orbit at 2 degrees inclination. The payload will thus nearly avoid the South Atlantic Anomaly, and take full advantage of the screening effect of the Earth's magnetic field in reducing the cosmic ray induced background (proton fluxes typically a factor of 20 lower than in the Exosat orbit above the radiation belts), while undergoing the minimum

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TABLE I
The Main Characteristics of the SAX Mission,Spacecraft and Payload Instruments

Orbit	
Type	Circular at 2 deg inclination to the equator
Height	600 km (BOL)/450 km (EOL)
Lifetime	2 years extendable to 4 years
Period	97 min (Sun eclipse 37 min)
Ground contact	11 min per orbit
Launch Date/Vehicle	End of 1993/Atlas G-Centaur
Spacecraft	
Total Mass/Power	1200 kg / 800W (Sunlight), 790W (Eclipse)
Payload Mass/Power	385 Kg/290 W
Pointing	
Observation time	Typically 10^4 to 10^5 sec
Abs. pointing error	3 arcmin (Three axis stabilised)
Abs. pointing stability	1 arcmin
Pointing Reconstruction	1 arcmin
Telemetry	
Mass Memory Capacity	450 Mbits
Average effective rate	70 Kbps
Maximum effective rate	100 Kbps
Dump rate to ground	1 Mbps

Payload Instruments

	Aperture FWHM	Ang. Res.	Total Eff. Area	Energy Res. FWHM
Concentrator/Spectrometer	30′	1′ 200 cm^2 7 KeV	8% 6 KeV	
(3 units, 1–10 KeV, MECS)			56 cm^2 0.2 KeV	28% 0.27 KeV
(1 unit, 0.1–10 KeV, LECS)				
High Pressure Gas Scint.	60′	–	280 cm^2 60 KeV	3% 60 KeV
Proportional Counter			300 cm^2 6 KeV	10% 6 KeV
(3–120 KeV, HPGSPC)				
Phoswich Detector System	87′	–	140 cm^2 200 KeV	17% 60 KeV
(15–200 KeV, PDS)			680 cm^2 20 KeV	
Wide Field Cameras	$20° \times 20°$	5′	250 cm^2 (/unit through mask)	20% 6 KeV

Sensitivity	Photons/cm^2 s KeV at 5 sigma in 10^4 s	Emission lines at 5 sigma Pht/cm^2 s in 10^4 s
Conc/spectr (4 units)	4.4×10^{-6} (1–10 KeV)	1.5×10^{-5} at 6.7 KeV
HPGSPC	3×10^{-5} (10–30 KeV)	1×10^{-3} at 51 KeV
	2×10^{-5} (35–120 KeV)	
PDS	1.2×10^{-5} (15–30 KeV)	2×10^{-4} at 51 KeV
	5.3×10^{-6} (30–80 KeV)	
	3.8×10^{-6} (80–200 KeV)	
WFC/unit	3 mCrab (2–30 KeV)	
PDS (Gamma-bursts)	10^{-6} erg/cm^2 s (100–600 KeV)	

change in magnetic cut-off. This choice of orbit is particularly important in order to minimise the background and systematic effects caused by spallation and changes in incident charged particle fluxes around the orbit to achieve the necessary sensitivity of the PDS for weak source observations, estimated at 1% of the background in this orbit, essential if the broad band sensitivity of SAX is to be ensured. SAX has an official design lifetime of two years but is expected to remain in operation for up to four years. The satellite will achieve one arcminute pointing stability continuously for a typical maximum single observation time of 10^5 seconds, with a postfacto pointing reconstruction accuracy of 1 arcmin. The chief attitude constraint derives from the need to retain the normal to the solar arrays within 30 degrees of the Sun (occasional excursions to 45 degrees will be made for WFC) to ensure proper battery maintenance and allow observation to be continued throughout the Sun eclipse periods whith all the instruments. Thus while the whole sky will be available during one year, during a single orbit, and subject to eclipse by the Earth (which has a diameter of about 130 degrees at 600 km) the narrow field instruments will have a band in the sky 60 degrees wide available for observations which includes about 50% of the sky, and the WFC a slightly larger band commensurate with their field of view. In the mission plan the narrow field instruments will normally have the first choice of observation direction while the WFC will observe the regions of the sky available to them. Periodically the WFC will be given priority to perform long term studies of centain sky regions e.g. the galactic centre and along the galactic plane. During each orbit upto 450 Mbits of information will be stored on board and relayed to the ground during station passage. The average data rate available to the instruments will be approximately 70 kbits, but peak rates of upto 100 kbps will be catered for. The ground station for telecommand uplink and telemetry retrieval will be situated near the Equator (at the San Marco Base, Malindi, Kenya), while the Operations Control Centre connected by a communications relay satellite link will be in Italy. The SAX mission development is supported by a consortium of Institutes in Italy together with Institutes in The Netherlands and the Space Science Department of the ESA. A collaboration with the Max Planck Institute for Extraterrestrial Physics also exists for X-ray mirror testing and the calibration of the concentrator mirrors. The composition of the consortium is as follows:

– Istituto per le Tecnologie e lo Studio delle Radiazioni Extraterrestri, ITESRE / CNR, Bologna

– Istituto di Astrofisica Spaziale, IAS/CNR, Frascati

– Istituto di Fisica Cosmica e Tecnologie Relative, IFCTR/CNR and Unit GIFCO, Milano

– Istituto di Fisica Cosmica d Applicazioni dell'Informatica, IFCAI/CNR and Unit GIFCO, Palermo

– Istituto dell'Osservatorio Astronomico, Universit di Roma *La Sapienza*

– Space Research Utrecht, SRON, The Netherlands

– Space Science Department, SSD, of ESA, Noordwijk, The Netherlands

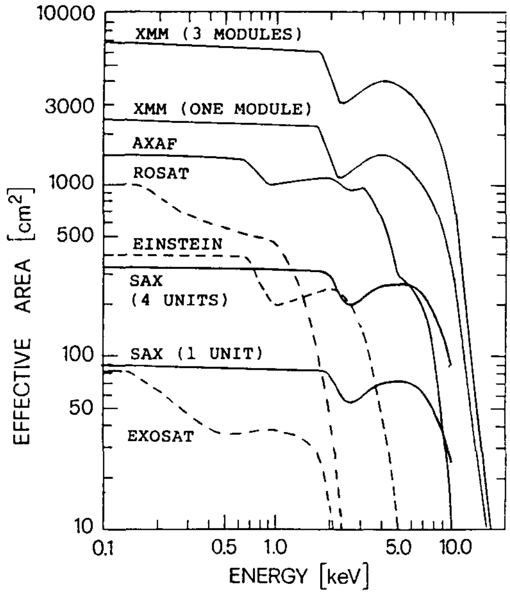

Fig. 2. Effective area of several X-Ray satellites.

2. Brief Description of the SAX Payload Instruments

The main characteristists of the SAX payload instruments, described also by Spada (1983) and Perola (1990), are given in Table I.

2.1. The Concentrator/Spectrometer

The instrumentation consists of four separate concentrator mirror assemblies each with a focal length of 185 cm and a position sensitive, Xenon filled, gas scintillation proportional counter (GSPC) in the focal plane. The mirror assemblies, for which the prototype development and testing has been performed by IFCTR and IFCAI, are composed of 30 nested gold coated, confocal, double cone approximations to a Woltjer 1 paraboloid/hyperboloid configuration with a focal length of 185 cm. They will be produced by electroforming nickel (0.2–0.4 mm) onto the gold coated surface of super polished mandrils. X-ray tests on the mirrors have shown that the design goal of less than 10 angstroms of surface roughness has been reached, and that an angular resolution of slightly less than one arc minute HPR will be achieved, Citterio et al (1988, 1990). The concentrators are designed to maximize their effective area around 7 keV for iron line studies as shown in Fig. 2. The sum of the effective areas of the 4 units compared with AXAF is particularly notable in this respect.

Three of the GSPC's will have 50 micron beryllium windows which are essentially opaque below about 1.2 keV, and be read out by crossed wire anode Hamamatsu photomultipliers. Laboratory tests on the prototype by IFCAI have demonstrated an energy resolution of 8% FWHM at 6 keV and a position resolution of 0.75 mm FWHM at the same energy, equivalent to 0.76 arcminute HPR. Their energy resolution will be comparable with that of the solid state spectrometer of the Einstein Observatory and better by a factor of more than two than that of previously flown proportional counters at the iron K-line at approximately 7 keV. The fourth GSPC developed by SSD/ESTEC will have a 1.5 micron thick polypropylene window to extend its energy range down to 0.1 keV, and be viewed by a nine anode readout Hamamatsu photomultiplier. Laboratory tests on the prototype have produced an energy resolution of 28% FWHM at 0.27 keV and a performance at higher energies equal to that of the other GSPC's. This detector is described in detail by Favata and Smith (1989). The source confusion limit of the Concentrator/Spectrometers reached in 4×10^4 s will be approximately three times below the lower limit Rosat all-sky survey,, and thus they will be fully capable of exploiting the survey in the selection of representative samples of faint objects for detailed studies upto 10 keV.

The High Pressure Gas Scintillation Proportional Counter The xenon filled gas cell of the HPGSPC, is viewed by an Anger camera arrangement of seven photomultiplier tubes, and surrounded at the sides and from below by a graded lead/tin shield. The X-ray event arrival position is used to correct the event energy with an overall improvement of about a factor of two in energy resolution when compared with proportional counters. Special care has been taken in the structural design of the beryllium entrance window (1300 microns) to reduce its thickness to a minimum for the low energy response while allowing the gas cell to be filled to 5 atmospheres to increase the sensitivity at higher X-ray energies. The escape gate technique is used above the xenon K-edge at 34.5 keV to further enhance the instrument's energy resolution and background rejection. A rocking collimator is used for alternatively sampling the flux in the source direction and the background. The prototype instrument is under development at IFCAI and described in detail by Giarrusso et al (1989). The very good energy resolution (about 5 times better than that of the PDS) will be particularly important in the detailed study of narrow cyclotron lines, both in emission and absorption, as illustrated by the simulation of the Her X-1 cyclotron line in absorption in Fig. 3. It will also complement the iron line studies of the concentrator/spectrometers and the source continuum observations of these and the PDS.

2.2. The Phoswich Detector System

The instrument is based on a central group of four phoswich units (3 mm of NaI(Tl) above 50 mm of CsI(Na), surrounded at the sides by an anticoincidence shield of CsI(Na) and with a plastic scintillator particle shield over the aperture. The source direction is viewed trough two collimators that can be offset to sample the background. The instrument, developed by ITESRE and IAS using the Lapex balloon borne telescope as test bed is described in Frontera et al (1990). Extrapolating the background from the Lapex results to the SAX orbit has confirmed the sensitivity of the PDS. The energy resolution, demonstrated on the prototype to be better than 17% FWHM at 60 keV, combined with its high source flux sensitivity over a

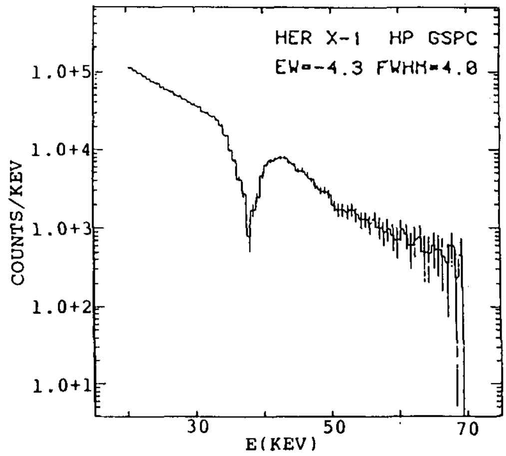

Fig. 3. Simulated spectrum of Her X-1].

broad energy range make the instrument particularly useful in the detailed studies of the continuum in galactic and extragalactic sources and their time variability. It is also well suited to the study of cyclotron line features in know sources and the search for these features in other binary where it will extend the possible measurements of the HPGSPC particularly for broad line features. Additionally, the active shielding around its sides will be used for all-sky monitoring of gamma-ray bursts with a limiting sensitivity of 10^{-6} erg/cm^2 sec and a timing capability of 0.5 to 10 ms.

2.3. The Wide Field Cameras

Each WFC contains a position sensitive proportional counter filled with two atmospheres of xenon, which views the sky through a random mask aperture. These instruments, described by Jager et al (1989), are under construction by SRU/SRON and are a development from their COMIS experiment actually in operation on the Russian MIR space station. The energy range of the WFC's will complement those of the narrow field instruments, while their observation program will include the long term monitoring of both galactic and extragalactic variable sources and the detection/localisation of transients on timescales from 2 ms upwards. Their typical source detection sensitivity is illustrated as a function of time in Fig. 4.

The overall broad band sensitivity of the narrow field instruments can best be illustrated by the simulated results of on a typical AGN in Fig. 5. using all of the narrowfield instruments, from which it is possible to determine the spectral index with an uncertainty approximately one order of magnitude smaller than in previous experiments (Exosat, HEAO-1). Deviations from ther power law (soft excesses or breaks at high energies), if present, shoud be clearly visible.

The narrow field instruments will also be used for time variability studies on time scales from milliseconds to days and months. Their ability is demonstrated in Fig. 6.

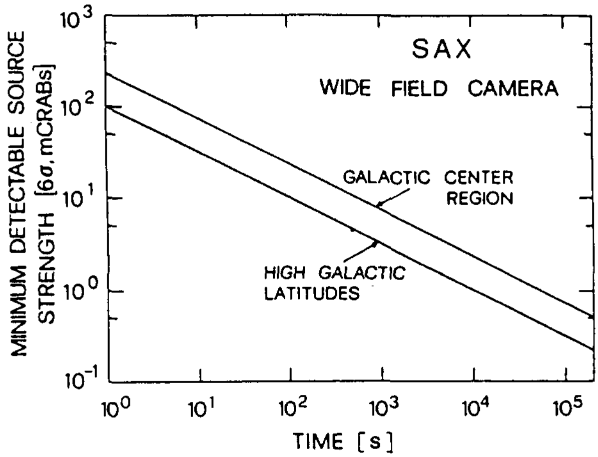

Fig. 4. Simulated spectrum of an AGN.

where the sensitivity of the concentrators/spectrometers is compared with that of the PDS for variability studies on NGC4151 and Cyg X-1. The figure illustrates the balance which has been achieved over such a wide X-ray energy range.

3. SAX Scientific Objectives

The scientific objectives of SAX have been described in detail by Perola (1983, 1990). In the mission life of a least two years SAX will perform between 2000 and 3000 separate observations. These will be based on a core program chiefly devoted to systematic studies of various classes of objects, and a guest observer program allocated about 20% of the time. A selection of the areas in which SAX is expected to make its most significant contribution is given below:

Compact galactic sources: the shape and variability of their continuum and temporal studies of features such as iron fluorescence lines, cyclotron lines and absorption effects as a function of orbital phase and rotation, transient detection and light curve studies.

Supernova remnants: spatially resolved spectra of extended ($\ll$ 1 arcmin) galactic SNRs, and the spectra of the Magellanic Clouds remnants

Stars: coronal emission spectra with a sensitivity comparable to that of the Einstein Observatory upto 10 keV

Active galactic nuclei: spectral and temporal variability studies of their continuum upto 200 keV, the spectra upto 10 keV of very distant sources ($z = 3.2$ for sources equivalent to 3C273) and soft X-ray excess, photoelectric absorption and iron fluorescence line studies.

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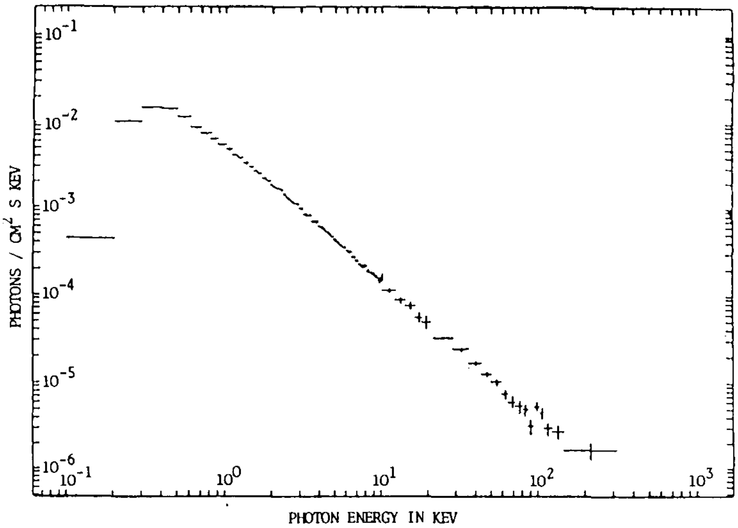

Fig. 5. Variability studies on a large range of timescales.

Clusters of galaxies: spatially resolved spectra upto 10 keV of the nearby clusters with iron fluorescence line and temperature gradient studies and high energy spectra for $z < 0.1$ and temperature measurements out to $z = 1$

Normal galaxies: spectral studies of their extended emission. The SAX payload has been chosen to cover the energy range 0.1–200 keV with a series of instruments in a coordinated fashion to notably extend the spectroscopic and time variability studies performed to date. Its launch date at the end of 1993 will give SAX a first opportunity to take advantage in a systematic way of the many new results that will become available from the all-sky imaging survey of ROSAT, and it will precede the large observatory type missions due for the second half of the 1990's which will concentrate on X-ray astronomy upto 10 keV only.

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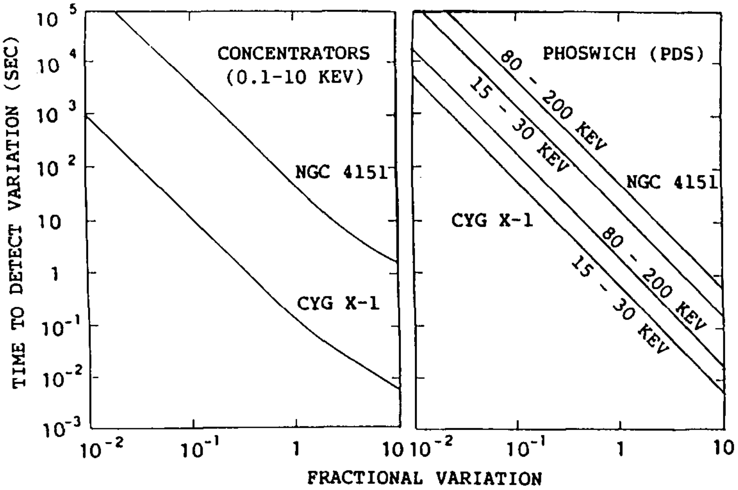

Fig. 6.

References

Citterio, O, et al. : 1988, *Applied Optics* **27**, 1470

Citterio, O, et al.: 1990, *Il Nuovo Cimento* **13C N.2**, 375

Favata, F., and Smith, A.: 1989, *SPIE* **1159**, 488

Frontera, F., et al., 1990, Cospar XXVII, The Hague, in preparation.

Giarrusso, S, et al. : 1989, *SPIE* **1159**, 514

Jager, R., et al. : 1989, *SPIE* **1159**, 2

Perola, G.C.: 1990, *Adv. Space Res.* **10N.2**, 287

Perola G.C.: 1983, in Perola G.C. and Salvati, M., ed(s)., *Proc. of Workshop on Non-thermal and Very High Temperature Phenomena in X-Ray Astronomy*, Rome, 10-20 December 1983, 175

Spada, G., 1983, ibid.

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