A European X-ray Astrophysics Mission

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ABSTRACT

An X-ray Spectroscopy, Timing and Variability mission studied by the Eurpoean Space Agency is described. Five instruments (Bragg Spectrometer, Large Area Proportional and Scintillation Counter Detectors, Wide Field X-ray Cameras and a Gamma-Ray Burst Monitor) are discussed and estimates of their performance are given. Their scientific aims are summarised and sample observing programmes are discussed.

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II. THE PAYLOAD, THE SPACECRAFT AND THE MISSION.[1]

A possible payload for the X-80 mission is indicated in table I.

Table I. Scientific Payload for the X-80 Mission

Instrument	Photon Energy Range (keV)	Aims
Large area proportional counter (LAPC) (sensitive area 2500 cm^2)	1.2 - 20	Source variability (< 1 ms to days). Moderate resolution spectroscopy. Monitor for crystal spectrometers
Wide field (WFC) cameras (4 units, FOV ~ 1.4 ster)	2.0 - 20 (imaging) 2.0 - 50 (timing)	Source variability (seconds to years). All sky monitor (days to years). Localisation and study of transients, X-ray and weak gamma-ray bursts
Crystal spectrometer (projected area 6 panels typically 1000 cm^2 each)	4 intervals in the 0.5 - 10 keV energy range (O, Si, S, Fe)	High resolution spectroscopy. Spectral variability. Spectral mapping of extended sources.
Phoswich detector system (sensitive area 650 cm^2)	15 - 200	Source variability and moderate resolution spectroscopy. Cyclotron line spectroscopy.
Gamma-ray burst detector	40 - 130	Localisation of intense gamma-ray bursts and hard X-ray transients

1. Further details may be found in the ESA assessment study document No. SCI(80)5 Paris, June 1980. Science team members were R. Berthelsdorf, A. Brinkman, N. Lund, C. Reppin, R. Rocchia, A. Scheepmaker, H. Schnopper, G. Spada, R. Staubert, M. Turner. ESA staff involved were R. Laine, H. Olthof, B. G. Taylor.

While the payload has the ability to study source variability over a wide energy range by means of the large area proportional counters (LPAC) and the phoswich, it can also monitor instantaneously a field of 1.4 steradian with the aid of the wide field cameras (WFC). The free standing Bragg crystal spectrometers allow high resolution studies of source spectra over selected wavelength ranges. In addition the two broad band systems (LAPC and Phoswich) compliment the Bragg instrument by covering a larger photon energy range, albeit at lower resolution, and by permitting the slope and intensity of the continuous spectrum to be determined.

While missions like the Einstein observatory and the proposed Advanced X-ray Astronomy Facility (AXAF) are general purpose analogues of the Palomar 200" optical telescope, it is clear that the huge cost of such systems means that their number will inevitably be restricted. However some enormously exciting physics can be undertaken by the study of the 300-400 brightest sources with a mission of the kind described here. This possibilitiy has been recognized by several different nations and space agencies. Thus, in a time of fiscal stringency, it would seem appropriate that the possibilities of joint action in this area be examined carefully.

Following the Uhuru, Ariel V and HEAO-1 survey missions and the outstanding results that have been obtained with the Einstein obsrvatory, it has become apparent that observations at X-ray wavelengths are of fundamental importance in astronomy. X-rays are generated in high temperature ($T > 10^6$ K) plasmas or by the interactions of energetic charged particles with magnetic fields or lower energy photons. In order to understand the physics involved, it is necessary to proceed with the detailed study of the brighter X-ray sources. This work should include a complete investigation of source variability over a wide spectral range together with high resolution spectroscopic observations of the high temperature plasmas that give rise to X-ray emission in many galactic and extra-galactic sources. Furthermore, it is the combination of spectroscopic and photometric observations in a single mission that can lead to major advances in our understanding of the physics of these sources. We will return to a discussion of the individual instruments later after a description of the spacecraft and some preliminary ideas on mission operations have been presented.

The principal parameters of the mission are given in table II. The spacecraft is compatible with half of the Ariane launcher capacity. Thus launching costs can be reduced if a suitable partner can be found. At a height of 600 km, the mission lifetime will be at least 3.5 years. The solar array is designed for an "end of life" capability of 385 watts. Since the most demanding angular

Table II Details of the X-80 Mission

ORBIT:	Circular, 600 km, 0° inclination
LAUNCHER:	ESA Ariane
MASS:	Instruments 500 Kg Spacecraft 400 Kg
DIMENSIONS:	Height ~ 3.2 m Diam. ~ 2.3 m max.
ATTITUDE CONTROL:	3 Axis inertia wheel Target acquisition to ± 5' Attitude determination i) Star sensors to ± 0.5' ii) Coarse + fine sun sensors iii) Gyros Orientation - anywhere within ± 30° of plane perpindicular to solar vector.
POWER REQUIREMENT:	~ 200 watts total
DATA SYSTEM:	Mean rate - 44 K bits/s Peak rate - 250 K bits/s Downlink rate - 700 K bits/s Mass memory - 250 M bit Data dump - 1 per orbit at Kourou Ground link - 8 K bits/s to ESOC, Darmstadt

resolution requirement is about 5' as set by the Bragg spectrometer and the WFC, the attitude control and measurement system parameters indicated in the table are more than adequate. Inertia wheel angular momentum is unloaded by a cold Nitrogen gas system. Use of a large bubble memory can allow peak data rates of 250 K bits/s to be sustained from individual instruments for periods of up to 20 minutes.

The proposed 600 km equatorial orbit will provide an environmment of low and stable particle background. The spacecraft will not pass through the radiation belts or the South Atlantic magnetic anomaly. Since the spacecraft is in near-earth orbit, significant regions of the sky are obscured from view at any given time. However the large slew capability will allow the pointing axis to be moved rapidly between sources. Ground stations within 10° of the equator can be used. While both Malindi in Kenya and Kourou in French Guyana are available, the mission has been planned on the basis of 6 minute contacts with Kourou occurring once per orbit.

Although the solar array is a fixed structure, the sun-pointing face can be tilted by up to ± 30° off the sun-line, and still provide adequate power. With a 3-axis stabilised spacecraft, which is free to roll about the solar vector, the narrow field instruments can view anywhere within a band on the sky, which is 60° wide by 360°. The viewing band rotates around the sky with the Earth's motion and the whole celestial sphere is accessible within a six month season. Thus, any source can be observed for up to 2 months at a time, every half year, and observing is then only interrupted for a period in the orbit when the earth obscures the instrument field of view.

The optical axes of the narrow field instruments are perpendicular to the plane containing the WFC and the sun. The optical axes of the cameras are 60 degrees wide. The fields of the 4 cameras are adjacent to one another. The ± 30° solar off-set in the plane of the cameras allows us with the proposed lay-out to view the whole sky except for ± 30° around the sun. This cone can in principle be reduced further, by shifting the cameras nearer to the sun but in view of thermal problems, related to the solar illumination of the mask, the present design is constrained to ± 30°. The full width zero response (FWZR) of the WFC is four times 34 degrees squared i.e. 11% of the celestial sphere. With one attitude change per orbit, 9 orbits are needed to scan the whole sky.

As the satellite is in a low earth orbit, large regions of the celestial sphere are obscured by the earth at any instant. When a narrow field instrument target is occulted by the earth, it would be useful to switch to another one to maximise observation time. However such manoeuvres, typically 1-2 radians, should be accomplished in a few minutes. It should be noted however that the proposed lay-out of four wide field cameras has the advantage that in no situation are all the cameras obscured by the earth.

The organization of the ground operations is illustrated in Figure 1. During spacecraft contacts with Kourou, data from the on-board bubble memory are recorded at the station while commands for spacecraft and instrument reconfiguration and attitude manoeuvring are uplinked. After each pass, data are transmitted to the ESA control centre (ESOC) at Darmstadt by means of a permanent 44 k bit/s link. However this link has yet to be implemented. The present 8 k bit/s link would in fact be entirely adequate. At ESOC, after quick look analysis, data from the individual instruments will be sent to the appropriate institutes by telephone lines.

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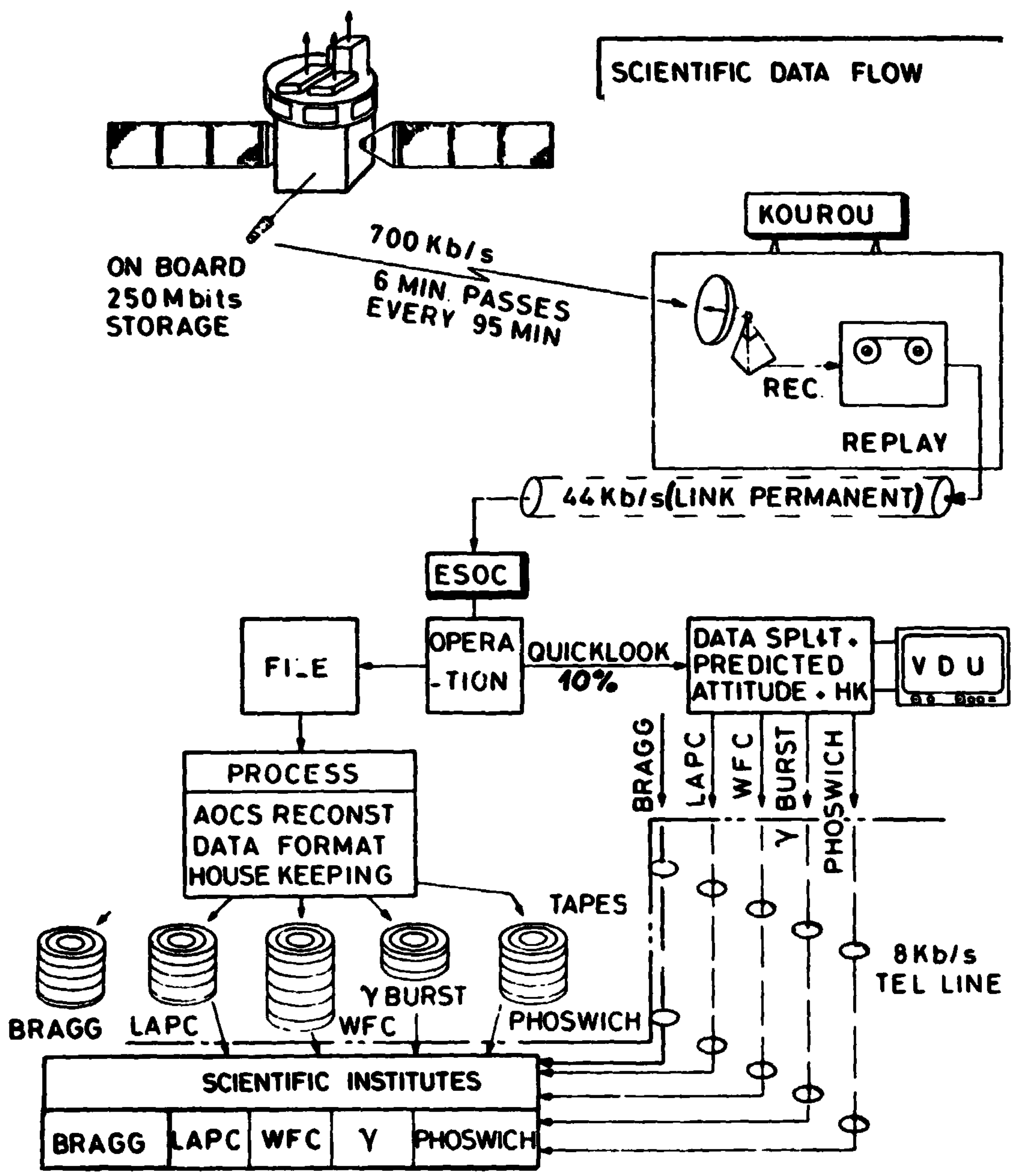

Figure 1.

Data flow on the ground after its reception from the Space-craft.

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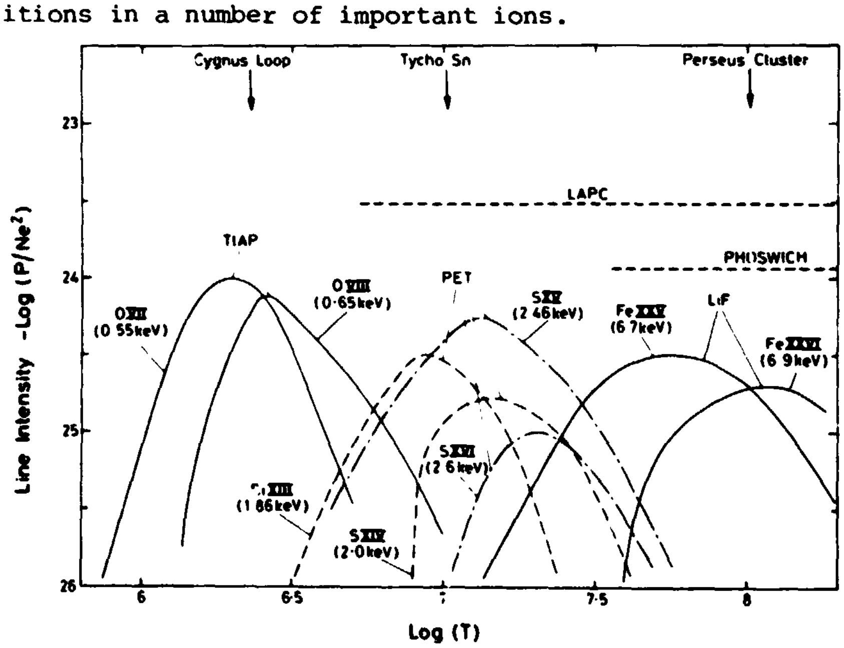
III. THE BRAGG SPECTROMETERS

High resolution spectroscopy permits us to study the physics of energetic coronal and photoionised plasmas which are known to be present in many sources both inside and outside the galaxy. Measurements of emission line intensities in these plasmas will allow estimates of gas temperature density and ionisation state, element abundance and gas velocity to be made for a variety of objects. The detection of absorption features can provide similar information in cases where intense compact X-ray sources are imbedded in extended gas clouds.

The proposed instrument includes four separate crystal spectrometers sensitive in the energy range 0.5 to 10.0 keV to spectral features arising from cosmically abundant elements that are ionised in 10^6 K to 10^8 K plasmas. The range of temperatures covered by the spectrometers is shown in Figure 2. The role of the broad band detectors is also indicated. It is clear that these detectors complement the spectrometer by their sensitivity to high temperature plasma over a wide range of temperatures.

Figure 2.
Line intensity plotted against electron temperature for the strong transitions in a number of important ions.



The crystal panels are spherically curved and focus onto two dimensional position sensitive detectors. Curvature in the plane of dispersion establishes a wavelength scale on one dimension of the detector. Curvature in the other plane permits the mapping of extended sources and minimises the detector active volume for each wavelength resolution element. Focussing spectrometers have been discussed by Dasgupta (1961) in the neutron diffraction context and by Schnopper (1966). A detailed description of the conical focussing geometry was presented by Woodgate (1973). The advent of position sensitive detectors allowed the development of parallel entry systems (Rapley et al., 1977) which eliminate the need for scanning in wavelength. This provides for much more reliable data analysis and interpretation, particularly for rapidly varying sources.

The design of spherically curved spectrometers is discussed by Griffiths elsewhere in these proceedings. We will therefore simply list, in table III the parameters of the system chosen for the X-80 mission. The wavelength

Table III Spectrometer Parameters

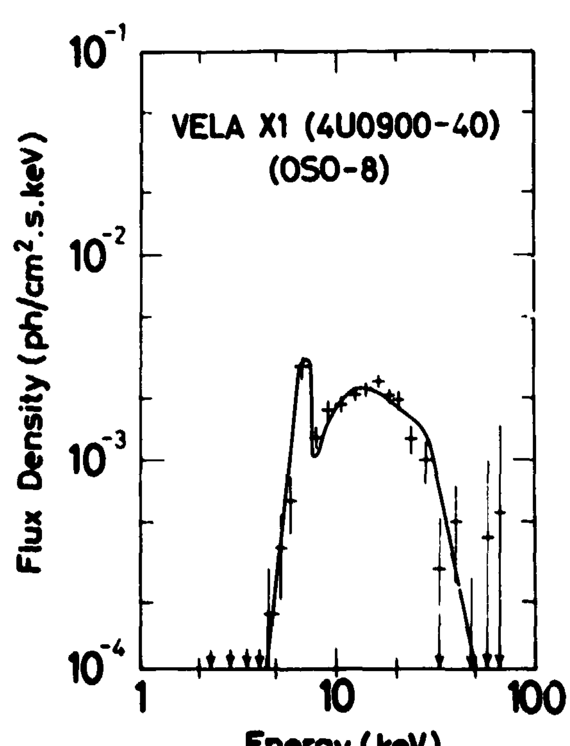
Line System	Crystal	2d (Å)	Wavelength Range	Resolution	Projected Area
Iron	LiF (220)	2.85	1.7-2.0 Å	2.3 mÅ	1440 cm^2
Sulphur	PET 1	8.73	4.8-5.5 Å	4.0 mÅ	930 cm^2
Silicon	PET 2	8.73	6.1-6.8 Å	6.1 mÅ	695 cm^2
Oxygen	TlAP	25.76	18.-22. Å	92 mÅ	1470 cm^2

resolution is set by crystal properties on the assumption that a spatial resolution of better than 1 mm can be achieved in the detectors. A number of important transitions are listed in table IV. A spectrometer of this kind can be

Table IV Important Transitions

Crystal	Transitions and Wavelengths			
	1s^2-1s2p^{1}P	1s^2-1s2p^{3}P	1s^2-1s2s^{3}S	1s-2p^{2}P
LiF	Fe XXV (1.852Å)	Fe XXV (1.857Å)	Fe XXV (1.867Å)	Fe XXVI (1.790Å)
PET 1	S XV (5.039Å)	S XV (5.067Å)	S XV (5.099Å)	S XVI (4.729Å)
PET 2	Si XIII (6.650Å)	Si XIII (6.690Å)	Si XIII (6.737Å)	Si XIV (6.182Å)
TIAP	O VII (21.602Å)	O VII (21.804Å)	O VII (22.100 Å)	O VIII (18.969Å)

Figure 3.
An Fe absorption edge in the spectrum of 4U 0900-40. Data from the GSFC OSO-8 spectrometer (Becker et al., 1978).



used for a large number of astrophysically important observations. Figure 3 shows a spectrum of the source 4U 0900-40 (Vela XI) obtained with the OSO-8 proportional counter spectrometer (Becker et al., 1978). A deep iron absorption edge is apparent. However the proportional counter ($\frac{E}{\Delta E}$ < 10) can not establish the energy of the feature with sufficient precision to allow the Fe ionisation stage to be deduced. Alternatively photoionisation interactions by X-rays from the compact source with the surrounding gas may give rise to a range of ionisation stages the dynamic behaviour of which could supply important clues to the geometry and distribution of the accreting gas. It is clear also that precise determination of fluorescent emission line wavelengths can provide information of similar value though in this case, broadening due to Compton scattering or mass motions could render the observation more difficult for the crystal spectrometers to undertake.

A similarly exciting possibility may exist for the study of the gas distributed around the nuclei of Seyferts and other active galaxies. Evidence for the presence of variable iron emission features in the spectra of two active galaxies (Hayes et al., 1980, Hall et al, 1981) has been obtained with proportional counter detectors. Models for the production of this emission involve fluorescence emission from the gas in the broad line region (Hayes et al.) or recombination radiation from a hypothetical shell of fully ionised gas that exists very close to the nucleus (Fabian and Ross, 1981). In the former case, an increase in the luminosity of the nucleus (Lx) leads to an increase of the fluorescent line intensity. For the latter model, a reduction in Lx is required to permit the iron nuclei to recombine with electrons. In either case identification of the appropriate model and understanding the interaction of the active nucleus with its surroundings requires that individual lines be resolved and the wavelengths identified.

The role of X-ray emission line observations in the spectra of extended cluster sources is too well known to require much discussion here. However there is a tendancy to dismiss observations of the intra-cluster medium because difficulties with understanding the evolution of the clusters and their media render the use of these objects for cosmological testing much less simple than was once supposed. While this is undoubtedly true, it merely emphasises the tendancy of all cosmological testing techiques to become more complicated as they become better understood. Meanwhile a wealth of information on the formation and evolution of clusters and galaxies would be available from the study of density and temperature variations in intra-cluster media if the X-ray observations of adequate wavelength resolution and sensitivity could be carried out.

Finally it is obvious that the X-ray line emission from supernova remnants can provide a wealth of diagnostic information on the temperature, density, ionisation state and element abundances of the hot plasma. In particular there has been much discussion of the latter two points. Given the presently available low resolution Fe emission data from proportional counters, it is not possible to establish unambiguously the relative intensities Fe XXV and Fe XXVI features which, together with temperature information, would allow departures from ionisation balance to be recognised. Work at longer wavelengths with the Einstein FPCS clearly indicates the possibilities (Winkler et al., 1981) but emphasises the need for good wavelength resolution.

The potential of the spectrometers can be judged from the data presented in Figures 4a and b where minimum detectable line fluxes (at 5 σ) are plotted against continuum flux with observation time as a parameter. In Figure 4a, cluster sources are treated as both compact (i.e. 5' by 5') and extended targets. The broad line case for Cas A assumes expansion at the current shock velocity.

The sensitivities of all four systems are more than sufficient to achieve the aims outlined in previous paragraphs. In particular the Oxygen line spectrometer (Figure 4b) is 100 times more sensitive than the Einstein FPCS.

The scientific role of the Bragg Spectrometers may be summarised in the following manner.

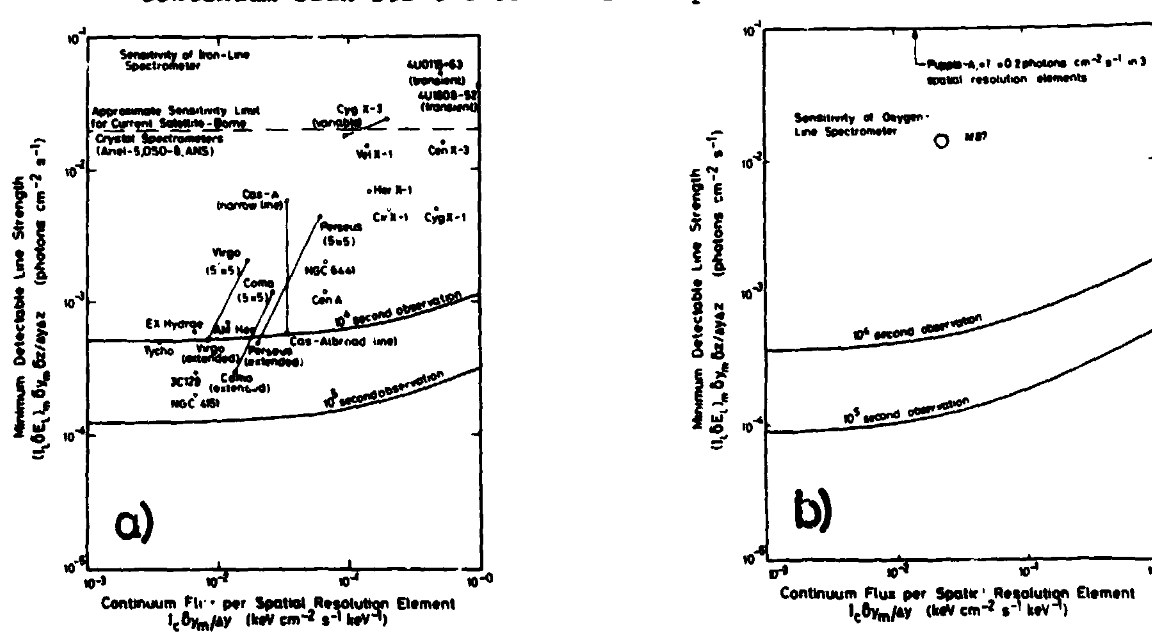
Study: High temperature (10^6 - 10^8K) and photo-ionised plasmas in emission and absorption (estimate temperature, density, ionisation state, abundance, gas velocities, redshifts).

Deduce: Intra-cluster gas origin, gas motion around active neculei, binary system gas dynamics, ISM density and composition, SN element production, stellar corona and active star gas dynamics, extra galactic distances.

Observe: QSO's and other active galaxies, Clusters of galaxies, X-ray binaries, Supernova remnants, Active stars and stellar coronae, X-ray bursters and transients

Figure 4.

Minimum detectable line strength plotted against continuum flux for two of the four spectrometers



a) Iron line instrument.

b) Oxygen line instrument

IV. THE WIDE FIELD CAMERAS (WFC)

The Wide Field Camera is a Dicke or transform camera (Dicke, 1968) comprising a mask with a random array of holes located above a position sensitive detector. X-ray sources will cast shadows of the mask onto the detector. Correlation or deconvolution analysis is used to reconstruct an image of the sky field. An ideal mask pattern will have a flat spatial frequency response out to the frequency represented by the 'unit' hole in the mask. Deconvolution of the image will then reconstruct the sky brightness distribution. The Wide Field Camera is therefore able to provide high sensitivity over a wide field of view due to the large 'open' area of the mask, combined with good angular resolution.

Four cameras are arranged so as to allow maximum sky access. Rotation of the spacecraft around the Sun axis, combined with the $\pm 30^{\circ}$ allowable off-set, makes nearly the whole sky available to the WFC array at any one time, except for a cone of 30° radius around the Sun. The field of view of the WFC system is 1.4 ster. The characteristics of the camera are given in Table V. The mask is 60 cm x 60 cm and contains a pattern of 0.5 mm square holes based on a Pseudo-Random-Noise sequence, repeated once in each dimension. It is mounted a distance of 48.6 cm from the position sensitive detector which has a FWHM position resolution of 0.5 mm in both dimensions over an active area 30 cm x 30 cm. For a perfect position sensitive detector the angular resolution would be set by the mask hole size and the detector-mask separation, yielding an angular resolution of 3.4 arc minutes. In the present case the resolution of mask and detector are equal giving an optimised angular resolution of $\sim$ 5 arc minutes.

The resolution degrades slightly off axis due mainly to the deeper penetration of energetic photons. Due to the predominance of low energy photons in the spectra of most sources the effect is slightly (resolution - 5 arc minutes).

The above configuration, with a repeated mask pattern and a collimator gives in principle perfect coding of the image, even for sources at the edge of

Table V. Characteristics of Wide Field Cameras

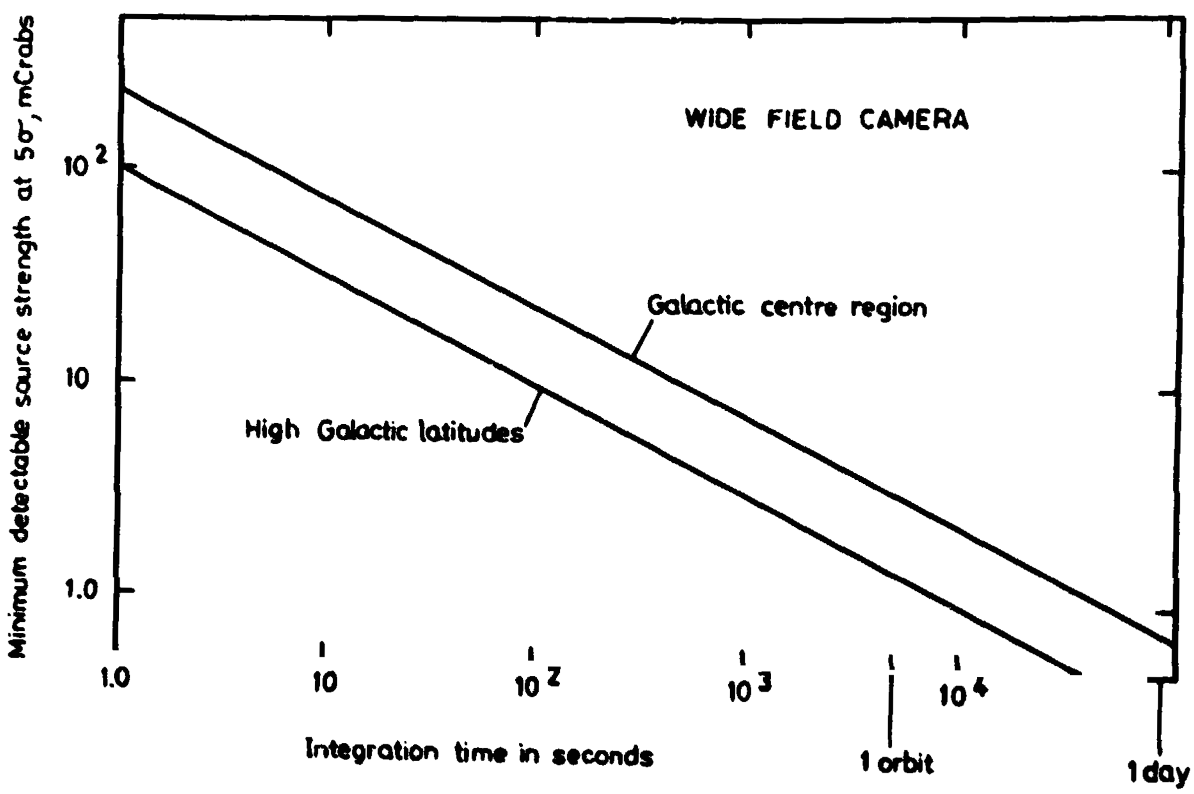
Configuration	4 wide field cameras
Field of view	34° x 34° FWZR per camera
Solid angle	0.35 ster per camera
Angular resolution	5 arc min
Error box area	1(arc min)^2 limited by camera internal alignment
Energy range: imaging	2.0 - 10 keV full field 2.0 - 20 keV centre of field
timing	2.0 - 50 keV
Energy resolution	20% at 6 keV
Sensitive area	320 cm^2 per camera (mask transmission, 50%)
Background (diffuse)	150 cts/sec per camera
Mask area	60 cm x 60 cm
Detector area	30 cm x 30 cm
Gas filling	Xe/CH_4 at 2 atm.
Window material	125 micron beryllium
Camera alignment	60° ± 1° between cameras
Total mass	126 kg

the field of view (Proctor, 1978). The mask can be constructed by etching the pattern into a stainless steel foil, or by electro-deposition of nickel. The position sensitive detector measures 40 cm x 40 cm 7.5 cm and is sealed with a 125 micron Be window. The Xe/CH_4 filling gas limits penetration of high energy photons. The detection efficiency exceeds 10% over the range 2 to 50 keV and spectra can be obtained throughout. Positioning is limited to the ranges 2 to 10 keV due to photon penetration problems at the edge of the field of view; in the center of these fields of view however a position resolution of a few arc minutes can be achived over the energy range 2 to 20 keV.

The sensitivity of instruments of this type has been discussed by many authors (Dicke 1968, Palmieri 1974, Gunson 1976). It depends on area, background and observing time. Because of the large field of view the background is dominated by the diffuse X-ray emission at high galactic latitude and by the contribution of strong sources in the galactic plane. The charged particle component can be reduced to an insignificant level. The minimum detectable source strength at a 5 sigma confidence level is shown in Figure 5 as a function of the observation time for a high galactic latitude and the galactic center region. The instruments ability to observe intensity changes in the source is shown in Figure 6a.

Figure 5.

Wide Field Camera Sensitivity plotted against integration time



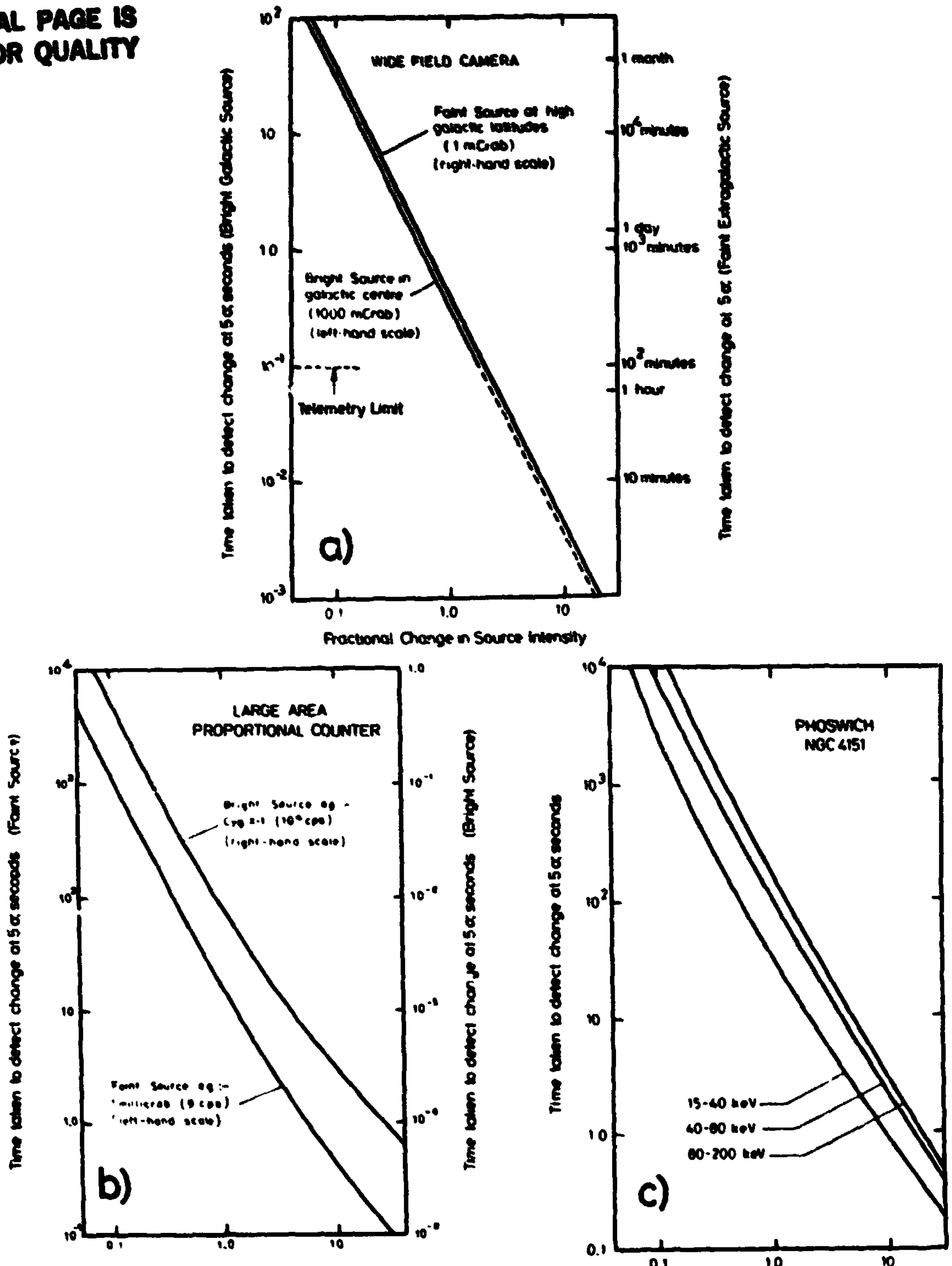


Figure 6.
Time taken to detect a specific fractional change in source intensity a) Wide Field Camera, b) Large area proportional counter and c) Phoswich.

However the performance of the instrument is best illustrated by simulation. Deconvolved images of the galactic centre region and a reigon of high galactic latitude (Coma) are shown in Figure 7.

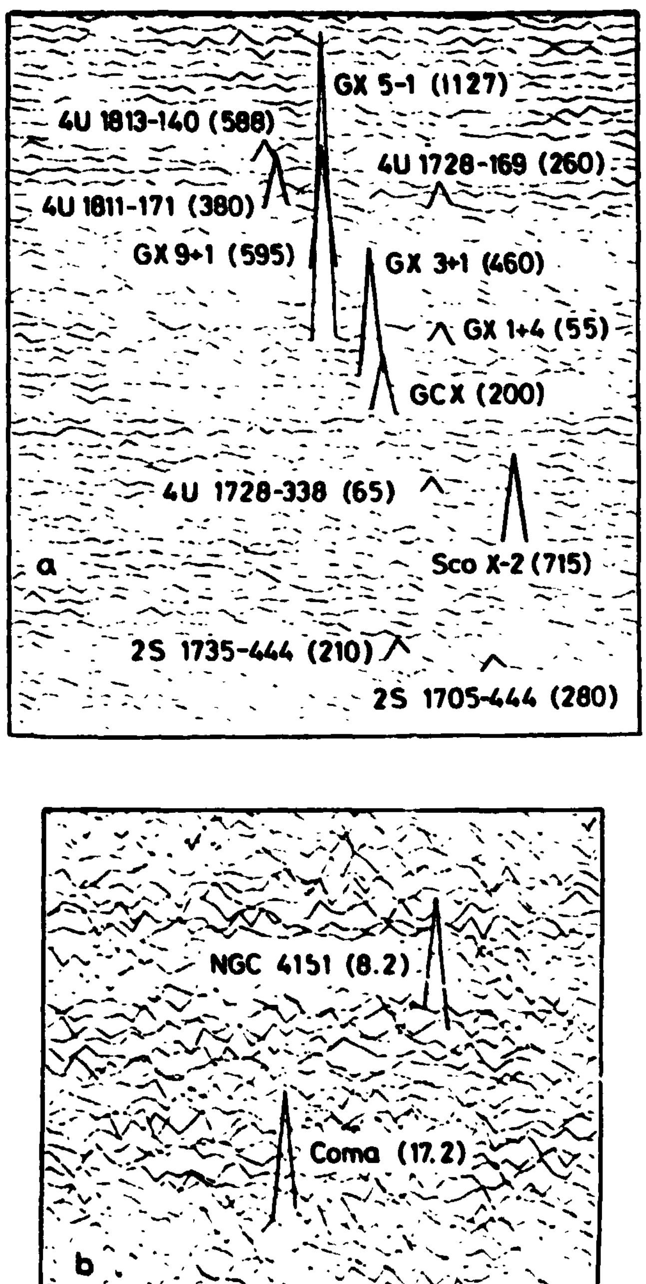


Figure 7.
Simulated performance of the WFC(for a) a 100s observation of the galactic centre region and b) 5000s observation of the Coma region. Source intensities (MiliCrab) are shown in brackets.

Since the scientific role of a wide field camera system is rather easy to understand we will simply sumarise the appropriate scientific aims.

Study: Galactic and extragalactic X-ray variability, long term behaviour of X-ray binaries, X-ray transient and burst activity.

Deduce: Properties of active galactic nuclei (size, energy release), X-ray masses, neutron star, white dwarf, or black hole presence, accretion disk properties, transient and burst source mechanisms.

Observe: QSO's and other active galaxies, X-ray binaries, X-ray transients, X-ray bursters, Galactic bulge sources, Active stars.

V. THE LARGE AREA PROPORTIONAL COUNTER (LAPC)

The instrument that covers the energy range 1.2 to 20 keV is a large area array (0.25 m^2) of sealed proportional counters. The energy resolution of proportional counters is moderate (19% at 6 keV) compared with other medium energy detectors (gas scintillator 10% at 6 keV, solid state detectors 3% at 6 keV) however, they have a lower ultimate background noise, can be produced with thin windows, are simpler and cheaper to build, and have by far the lowest mass per unit sensitive area. In addition their energy resolution has been demonstrated to be adequate for broad band spectroscopy.

The characteristics of the LAPC are given in Table VI. The modules are mounted, via two pivots and a tilt mechanism, to the spacecraft. This enables a ± 2° offset from the source for background determination. The detectors have a gas depth of 4 cm. The 37 micron beryllium window is supported against the internal pressure of 2 atmospheres by a collimator formed from Hexcell material giving a circular field of view of 45' diameter (FWHM). The gas used will be mainly Argon for efficient background rejection but will contain sufficient Xenon to give 10% efficiency out to 20 keV. Two anode layers will be used, these will incorporate guard wires, end guard cathodes (Bailey 1978) and when used in anticoincidence will give 5 sided protection to the upper layer for low background observations. In addition risetime discrimination will be employed for efficient background rejection. For bright sources the layers will operate in series to give a wider energy range.

Table IV. Characteristics of the Large Area Proportional Counter Array

Configuration	3 modules, 2 made up of 2 detectors and 1 made up of 4 detectors
Sensitive area	0.25 m^2
Field of view	45' x 45' FWHM
Energy range	1.2 - 20 keV at > 10% efficiency
Rate from Cyg X-1	~ 10^4 counts per second
Background	< 10 counts per second
Detector dimensions	40 cm x 20 cm x 35 cm
Window	37 micron beryllium
Gas filling	Argon/Xenon/quench at 2 atm.
Total mass	79 kg

The counter bodies will be of stainless steel and sufficient mass and volume has been allowed to permit inexpensive construction methods for detectors and collimators. This is particularly important with an instrument of this size.

Preamplifiers will be mounted on the back of each detector, together with high voltage generators. The pulses from each anode layer will be digitised with a 128 channel ADC and associated with a counter identification code, and time bits sufficient to time the photon arrival to ± 8 microseconds. Depending on the total count rate, selections from this information will be presented to the spacecraft data handling system for storage and subsequent transmission.

To accomodate the occasional very high data rate (~ 250 kbps) experienced during observations of the brightest sources, the experiment will contain a high capacity buffer memory. This will feed the data, collected over short periods to the spacecraft data handling system at a compatible rate. For most observations the data rates will vary between 1 and 20 kbps.

The time resolution and sensitivity of the LAPC are shown in Figure 6b and 8 respectively.

VI. THE PHOSWICH DETECTOR SYSTEM

For the energy range 15 - 200 keV, an inorganic scintillation detector system is employed. The total sensitive area (~ 0.8 x geometric area due to collimator efficiency) will be 560 cm^2. Two different 'sandwiched' scintillation crystals, called a Phoswich, provide 2π protection against background events in a relatively low cost per unit area detector. X-ray induced scintillations in the 'front' crystal (NaI (Tl)) are distinguished from background induced scintillaitons in the 'rear' crystal (CsI (Na)) by means of the different fluorescent decay times of the two scintillators. A CsI (Na) scintillator shield surrounds the Phoswich and collimator so as to increase discrimination against charged particles and gamma rays. The bottom part of the detector is covered by a passive graded shield (Pb-Sn-Cu) to reduce the background counting rate in the CsI (Na) element of the Phoswich.

A Phoswich in combination with an inexpensive plastic scintillator shield gave background rates of a few x 10^{-4} counts $cm^{-2}sec^{-1}keV^{-1}$ (independent of detector area) in balloon flights (Scheepmaker 1976, Kendziorra 1977). The

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high energy experiment on the HEAO-a satellite (A-4) consisting of Phoswich detectors with an active CsI shield gave similar background rates (Primini 1979). The background rate in the proposed instrument will be lower than the A-4 experiment due to the equatorial orbit. Table VII gives the main characteristics of the instrument and Figures 6c and 9 show the time resolution and sensitivity, respectively.

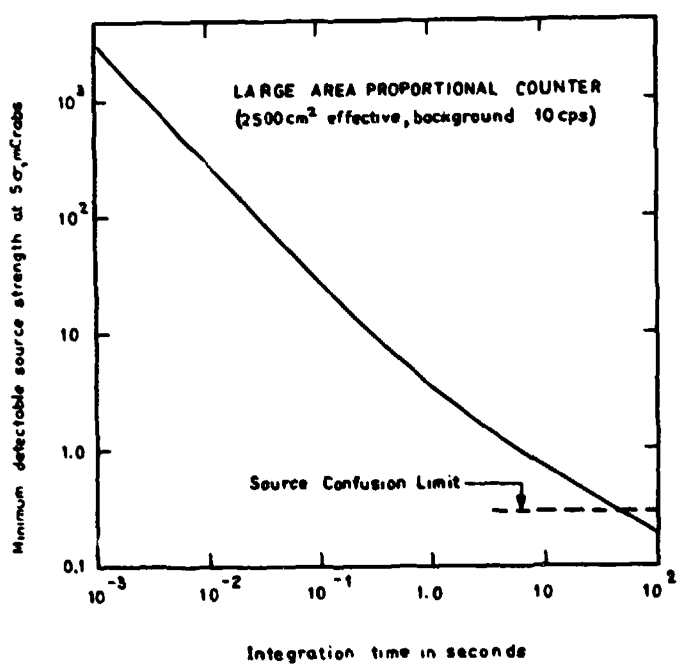

Figure 8.

LAPC sensitivity plotted against observing time.

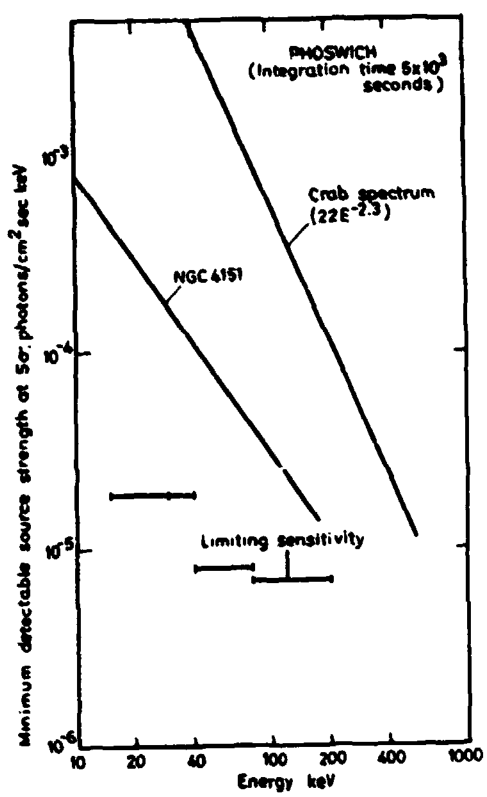

Figure 9.

PHOSWICH sensitivity plotted against observing time.

Table VII. Characteristics of Phoswich Detector System

Configuration	One unit comprising 4 Phoswich detectors
Field of view	1.9° x 1.9° FWHM
Energy range	15 - 200 keV
Energy resolution	30% at 20 keV, 19% at 50 keV, 12% at 200 keV
Geometric area	800 cm^2
Envelope	100 cm x 65 cm x 65 cm
Total mass	125 kg
Background	15-30 keV 3.1 x 10^{-4}cts/cm^2 sec keV 30-40 keV 2.3 x 10^{-4}cts/cm^2 sec keV 40-80 keV 1.7 x 10^{-4}cts/cm^2 sec keV 80-200 keV 1.1 x 10^{-4}cts/cm^2 sec keV

Each Phoswich detector consists of a 14 cm x 14 cm x 0.3 cm thick NaI (Tl) crystal, viewed by a 5 inch photomulitiplier through a CsI (Na) crystal 5 cm thick. The Phoswich is hermetically sealed in an enclosure, with a 1 mm Be X-ray entrance window and a quartz exit window. Four of these detectors, each with a geometric crystal area of ~ 200 cm^2 will make up the instrument.

To distinguish X-ray events in the NaI (Tl) crystal (~ 25 μs decay time), information from both a pulse shape discriminator (PSD) and a pulse height analyser (PHA) is used. To ensure that the distinction between NsI (Tl) and CsI (Na) events is maintained, the temperatures of the Phoswiches have to be maintained at 20 ± 10°C. This precaution is important in view of the strong temperature dependence of the fluorescent decay time of NaI (Tl).

To detect a weak X-ray source and determine its spectrum it is necessary to observe the source and background for equal periods of time. This is achieved by rocking the collimator some degrees from the centre position every few minutes.

The roles of the two broad band detectors may be sumarised as follows.

Study: Continuous plasma and non-thermal spectra, hard X-ray spectra, galactic and extragalactic source variability (millisec to years), source periods, cyclotron features.

Deduce: Properties of active nuclei (size, energetics), non-thermal cluster properties, nature of X-ray binaries (Black holes, neutron stars, white dwarfs), accretion disc properties, transient and burst mechanisms, neutron star magnetic fields, supernova and ISM properties, nature of X-ray background.

Observe: QSO's and other active galaxies, Clusters of galaxies, X-ray binaries, Supernova remnants, X-ray bursters and transients, Galactic bulge sources, Active stars and stellar coronae.

VII. THE GAMMA BURST MONITOR

The detector is based on a modification of the rotation modulation collimator (RMC) principle. The X-ray photons are detected in a scintillator mosaic consisting of alternating strips of CsI (Na) and NaI (Tl). The strips are 5 mm wide and 2mm thick. The mosaic is 80 mm in diameter and is viewed by a single 75 mm phototube. A large circular shadow mask consising of 5 mm wide tungsten strips 0.5 mm thick separated by 5 mm gaps is placed above the scintillator mosaic.

By means of a small motor the scintillator mosaic and the shadow mask are kept revolving around the symmetry axis at a spin rate of 60 revolutions per minute. During the spin, the tungsten strips will alternatively obscure the NaI - and the CsI - strips as seen from a source position in the sky. The obscuration (modulation) sequence is characteristic for each possible source position within the 120° field of view.

The important difference between the present design with the scintillator mosaic, and the conventional RMC design employing a single scintillator and two parallel shadow grids is that time fluctuations in the source flux, which is a well established characteristic of the gamma-burst sources, are not confused with the instrument modulation of the flux.

The signals from the two kinds of scintillator crystals can be separated at the output of the photomultiplier tube due to the different decay time characteristics of the light emission of the crystals.

Computer simulations of the detector performance have indicated that the burst sources can be located to better than 20 arc minutes for bursts with ~ 500 detected photons in the 30-130 keV interval (see Figure 10). This assumes that the burst duration is not much less than half the spin period.

The number of Vela-type bursts of this magnitude is roughly 25 per year within the field of view of the detector. The characteristics of the Gamma Burst Monitor are given in Table VIII.

Transient X-ray sources with hard spectra can also be positioned with this instrument. The expected background counting rate in the equatorial orbit is rougly 5 cps. A source of the same strength as the Crab can be localised within one orbit of observation.

The instrument will include a microprocessor with memory in which data can be stored at high rates during a burst. The microprocessor will also perform a deconvolution of the RMC patterns and determine source positions on line. Any decision to reorient the satellite for the purpose of studying a transient source with the narrow field instrument is thus facilitated and such a decision could be taken as early as the next ground station pass.

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Table VIII. Characteristics of the Gamma Burst Monitor

Field of view	120° (FWHP) 132° (FWZR)
Solid angle	3.1 sterad
Angular resolution	.20 arc minutes
Energy range	30 - 130 keV
Geometric area	50 cm^2
Detector size	25 cm x 25 cm x 25 cm
Total mass	6 kg

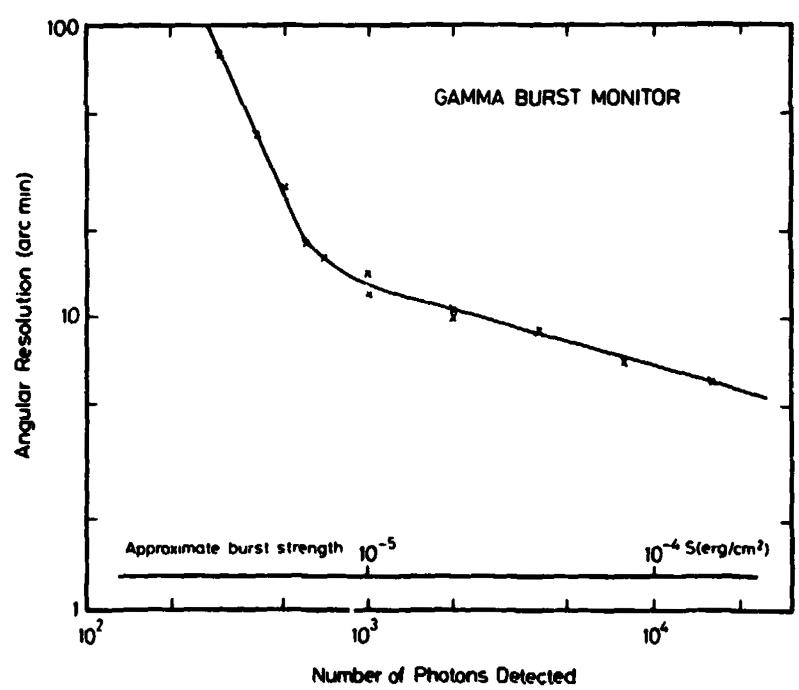

Figure 10.

Angular resolution of the Gamma Burst Monitor as a function of burst strength.

The role of the gamma burst monitor may be outlined in the following way.

Study: Hard X-ray transients and gamma ray bursts.

Deduce: Sky distribution of gamma ray burst sources.

Positions of X-ray transients allowing in-depth studies by the narrow field instruments.

Observe: All sky monitoring. As the purpose of the gamma burst monitor is to detect new, unknown sources over a very wide field of view, it does not constrain the pointing strategy of the spacecraft.

VIII INSTRUMENT DATA HANDLING

In a mission such as X80 where the need to acquire data at high rates and with good timing is dictated by the scientific requirements, it is necessary to permit some flexibility in assigning telemetry to the various instruments.

Bit allocations and the expected counting rates from the five instruments are given in Table IX. Time resolution to 0.1 seconds is available from spacecraft timing and telemetry synchronisation. Higher time resolution is derived from within the instrument.

The total mean bit rate available is 44 kbits/second with peak rates up to ~ 220 kbits/second. The LAPC and WFC can individually exceed this mean rate, for example when the LAPC observes Cyg X-1, or the WFC monitors the galactic centre. However these observations will occur infrequently and never simultaneously. For such an observation one instrument will have exclusive use of the data handling system and will fill the bubble memory in less than one orbit, the observation then being halted till data are telemetered to ground. Since the longest observation allowed by earth occultation will rarely exceed 60 minutes the available data capacity will in general be sufficient. For a few very bright sources, the LAPC will only observe for about 20 minutes, which is adequate to realise the scientific objectives. In all other cases the instruments will operate together and the total data capacity will not be exceeded.

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Table. IX Instrument Data Rates

	Source	Counting Rate (c/s)	Data Rate (kb/s)
Bragg Spectrometer			
Detector ID 2 bits X-Y position 18 bits Detector energy 6 bits Rise time 6 bits TOTAL 32 bits/event	Maximum envisaged flux on all spectrometers	80	2.5
LAPC			
Energy 7 bits	Cyg X-1	10^4	240
Detector ID 4 bits	NGC 4151	200	4.8
Timing 12 bits	Background	10	0.3
Spare 1 bit Total 24 bits/event			
Phoswich			
Energy 7 bits	Crab	290	7
Detector ID 2 bits	NGC 4154	8	0.2
Pulse shape 7 bits	Background[x]	30	0.7
Time 7 bits Veto 1 bit TOTAL 24 bits/event			
WFC			
Position 20 bits	Crab (1 camera)	590	16.5
Energy 4 bits Camera Ident. 2 bits	Galactic centre (1 camera)	1750	49
Spare 2 bits	Diffuse back-ground (4 cameras)	600	16.8
TOTAL 28 bits/event	Particle background (4 cameras)	60	1.7
Gamma Burst Mon.			0.1

[x]based on a wide pulse shape window; further optimisation of signal to noise ratio can be done on the ground.

IX. SAMPLE OBSERVATIONS AND A POSSIBLE MISSION PLAN

In order to demonstrate the capabilities of the various instruments, it is instructive to list the observing times required to achieve a number of aims in the study of three sources. The first of these is NGC 4151, a Seyfert galaxy of typical intensity 3 Uhuru flux units (UFU). The instrument capabilities are listed for an overall observing time of 5 days.

A. LAPC

(i)	Detect NGC 4151	~ 10s
(ii)	Register 10% flux change	~ 300s
(iii)	Detect Fe feature	~ 3000s

B. Phoswich

(i)	Detect NGC 4151	~ 3000s
(ii)	Register 10% flux change	~ 10^4s

C. Bragg Spectrometer

(i)	Detect Fe lines	~ 3.10^4s
(ii)	Measure λ's to ~ 3mÅ	~ 3.10^4s
(iii)	Search for Fe edge	~ 3.10^5s

D. WFC

(i)	Detect NGC 4151	~ 3000s
(ii)	Register 100% flux change	~ 6000s

In the case of the Perseus Cluster which is an extended source of intensity 18 UFU, a one day observation would permit the following to be achieved.

A. Bragg Spectrometer

(i)	Detect Fe lines from the Persus Cluster	~ 1000s
(ii)	Map (5' x 5') in lines	~ 3.10^4s
(iii)	Detect S, Si, O lines (NGC 1275)	~ 1000s

B. Phoswich

(i)	Detect the Perseus Cluster	~ 4000s
(ii)	Establish hard spectrum	~ 9×10^4s

C. LPAC

(i)	Detect the Perseus Cluster	~ 1s
(ii)	Establish medium spectrum	~ 30s
(iii)	Detect Fe line	~ 10s

D. WFC

(i)	Monitor NGC1275 for variability, 100% change	~ 6000s
(ii)	Monitor other cluster galaxies (IC310, NGC1265)	~ 9×10^4s

Finally for the X-ray binary 4U 0900 - 40 (Vela XI), a source of typical intensity 250 UFU, the following observations are possible in a 10 day observing period.

A. LAPC

(i)	Detect 10% flux change in 4U 0900-40	~ 1000s
(ii)	Register Fe emission/absorption features	~ 100/1000s

B. Phoswich

(i)	Detect 100% flux change in 4U 0900-40	~ 1000s
(ii)	Search for cyclotron features	~ 3×10^5s

C. Bragg Spectrometer

(i)	Detect Fe Lines/edges	~ $10^3/10^5$s
(ii)	Measure λ's to 3mÅ	~ $10^3/10^5$s

Pointed instruments monitor for binary phase, related events and for pulse phase features.

D. WFC

(i)	Detect 4U 0900-40	~ 1s
(ii)	Register 100% flux change	~ 3s

It is also instructive to outline an observing programme for a three year mission in order to demonstrate how the instruments can work together. Table X shows such a programme.

Table X. Three Year Mission Observing Programme

1.	50 QSO's and active galaxies	400 days
2.	50 clusters of galaxies	200 days
3.	50 X-ray binaries	200 days
4.	50 active stars and coronae	100 days
5.	20 supernova reemnants	50 days
6.	Sky-survey with WFC (3 days every 10 days)	300 days
7.	Galactic centre region with WFC	50 days

It should be noted that many wide field camera aims can be satisfied by rotating ± 30° around the pointing direction determined by the narrow field instruments. Furthermore, it will be possible to conduct short observations of some sources with narrow field instruments during the wide field camera all sky surveys. The WFC and the Gamma Burst Monitor will continuously monitor a large fraction of the sky for the occurrence of bursts and transients.

X. CONCLUSIONS

The X-ray sky survey missions undertaken by spacecraft such as Uhuru, Ariel V and HEAO-1 and the high resolution observations carried out with the Einstein Observatory (HEAO-2) at longer wavelengths have established X-ray astronomy as one of the most exciting and productive branches of astrophysics. The European mission, EXOSAT, to be undertaken in 1981 through 1983 is expected to make an extensive contribution in enlarging the scope of the subject.

Appropriately instrumented follow-on missions must now be prepared for detailed studies of energy spectra and time variability, to develop our understanding of the sources which include such diverse and physically interesting objects as clusters of galaxies, quasars, neutron stars and black holes. Although other missions (e.g. ASTRO-C, XTE) have been studied, the mission proposed here is unique in combining spectroscopic, timing and variability observations. It is designed to perform an integrated, systematic and comprehensive study of X-ray sources from a single free-flying satellite with the goal of obtaining:

- a determination of mass, dimensions, magnetic fields, and other basic information on matter under extreme conditions as found, for example, in neutron stars and degenerate white dwarfs.
- characteristic signatures of black holes and confirmation of their existence.
- an understanding of accretion processes on compact objects.
- detailed information on the conditions prevailing in high temperature plasmas, e.g. in stellar coronae, supernova remnants, galactic nuclei and clusters of galaxies, thereby gaining insight on evolutionary processes.
- a description of the photoionised gas that exists in binary systems and in the broad line regions around active galactic nuclei.
- an understanding of the innermost regions of active galaxies.

Five instruments, consistent with these goals are described, namely Bragg Crystal Spectrometers, Large Area Proportional Counters, Crystal Scintillators (Phoswich), Wide Field Cameras and a Gamma Burst Monitor.

The case for high resolution observations with crystal spectrometers is now overwhelming in view of the strong iron emission and absorption features detected by the proportional counters on Ariel V, OSO-8 and HEAO-1 and of oxygen, iron silicon and sulphur emission by the SSS and FPCS instruments on the Einstein Observatory. The Bragg Spectrometer has sufficient sensitivity to study the detailed structure of these features for a large number of X-ray sources with observation times of typically 10^4 seconds. The Large Area Proportional Counter will have sufficient sensitivity to perform sub-millisecond timing on bright sources and to study time and spectral variability in faint sources. It also has the broad spectral range to provide a monitor function for the crystal spectrometers. The Phoswich detector will extend the spectral and variability measurements from a few keV to some 200 keV and will permit the detailed study of the recently discovered cyclotron features. The Wide Field Cameras will image the sky to detect, locate and meausre X-ray transient events, as well as X- and gamma-ray bursts. Furthermore it provides an efficient means of monitoring all X-ray sources on timesclaes of days to years A gamma ray burst monitor is included to provide wide field observations at higher energies.

The mission can be readily undertaken on a free-flying satellite with modest performance requirements on attitude control ($\sim \pm 5$ arc min), and measurement (0.5') power ($\sim$ 350 watts) and mass ($\sim$ 900 kg). A low altitude (600 km) circular orbit at low inclination (approx. 0 deg.) is optimum and can easily be achieved with the Ariane vehicle launched from Kourou.

The Spectroscopy, Timing and Variability mission must be seen as a logical follow-on in X-ray astronomy for the mid-1980's, to capitalise on the non inconsiderable financial and manpower resources already invested and to consolidate the expertise and experience which have been firmly established in Europe. However in times of financial stringency on both sides of the Atlantic, the possibilities for collaboration should be examined carefully by both ESA and NASA.

ACKNOWLEDGEMENTS

I am grateful for the considerable effort put into the mission phase A study by the members of the X-80 study team. I have used their report extensively in preparing this presentation. The efforts of R. A. Laine (ESTEC, Future Projects Office), H. Olthof (ESA HQ, AWG Secretary), A. Peacock and B.G. Taylor (ESTEC, SSD) in bringing the study to a successful conclusion are also acknowledged with gratitude.

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