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Report

Space Telescopes: an International Perspective*

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Abstract: The purpose of this paper is to review current and planned Space Astronomy missions from an international perspective, with principal attention to the programs of the USA, Europe, Japan and the USSR. The review focusses on extra-solar astrophysics, and the capabilities and broad research objectives of numerous individual spacecraft are described. These collectively span more than seventeen decades in wavelength and thus provide an essential complement to ground-based astronomy. Many of the missions offer significant opportunities for Australian participation via three complementary routes. First through Guest Investigator programs analogous to that offered for the *Hubble Space Telescope (HST)*. Second, through the proposed establishment of an Australian Space Astronomy Data Centre to gain access to archival data from HST and other missions (the creation of such an archival facility in Canada is highlighted as a pertinent example). Third, via the contribution of instrumentation or ground support services. This latter category includes the *Radioastron* VLBI mission for which an agreement with the USSR has already been signed. In addition, an unprecedented opportunity has arisen for Australia to provide a ground station for the *Infrared Space Observatory (ISO)*, due to be launched by ESA in 1993. In return for providing this service, the Australian astronomical community would receive a guaranteed share of the ISO observing time during the two year mission. Finally, Australian astronomers have been invited to contribute an advanced All-sky X-ray Monitor for the Soviet *Spectrum-X-Gamma* mission in 1993. This opportunity, and also the Radioastron initiative, have arisen under the USSR-Australia Space Research Agreement signed in December 1987.

1. INTRODUCTION

Space Astronomy has matured to the point where pioneering all-sky surveys have been conducted in most of the spectral regions inaccessible from the ground. Accordingly, the broad thrust of international space programs is to provide Observatory-Class telescopes which are capable of undertaking exceedingly sensitive studies of individual objects in a manner analogous to ground-based facilities. The various missions planned for the next decade collectively cover an extraordinarily wide spectral regime ranging from low frequency radio wavelengths (~ 100 cm; ~ 300 MHz) to extremely energetic gamma-rays ($\sim 10^{-15}$cm; ~ 30 GeV).

Space-borne measurements offer great advantages even for wavelengths that can be observed from the ground. These include diffraction-limited imaging free of atmospheric distortion, highly eccentric orbits that allow very long exposures without Earth blockage, dramatically reduced sky backgrounds at infrared wavelengths, and extremely long baselines for radio interferometry. At the latter wavelengths, space VLBI offers an angular resolution that approaches the scale of accretion disks surrounding massive black holes in distant quasars, while at the opposite wavelength extreme, gamma-ray telescopes provide the only access to some of the highest energy phenomena occurring in the Universe. Space Astronomy is thus assuming a rapidly increasing role in contemporary astrophysics, and one which will see orbital facilities dominating ground-based research in the coming decades. It is therefore imperative that Australian astronomers participate to the fullest possible extent, especially by taking advantage of cost-effective opportunities that arise.

With the latter impetus in mind, the aim of this paper is to draw together and to summarize the numerous current and future space astronomy missions through to the end of the century. A partial survey of this type has also been undertaken by Kriss (1987) in the context of multi-wavelength astrophysics. In the present review, only *approved* missions intended for astrophysics beyond the Solar System are examined. The capabilities and astrophysical objectives of the various missions are outlined, and opportunities for Guest Investigator and other forms of participation by Australian astronomers are highlighted. Special attention is given to the Infrared Space Observatory for which a ground-tracking role is being vigorously pursued through the Australian Space Office. The need for a regional data analysis facility to support HST archival research is also emphasized, and as a pertinent example, the establishment of such a national centre in Canada is highlighted. Last, the USSR-Australia Space Research Agreement offers an outstanding opportunity to fly a collaborative all-sky X-ray monitor on the Soviet Spectrum-X-Gamma mission in ~ 1993.

The review below is organized into two main sections, corresponding to current and future space astronomy missions.

2. CURRENT ASTRONOMICAL MISSIONS

Few space astronomy missions are currently in progress, due in large part to the Challenger catastrophe in January 1986 which has delayed several spacecraft, including the Hubble Space Telescope. This has proved to be a particularly unfortunate situation in view of the historic eruption of Supernova SN 1987A in the Large Magellanic Cloud on February 23, 1987. Nevertheless, four spacecraft are presently conducting highly successful astrophysical research programs which include observations of SN 1987A.

2.1 International Ultraviolet Explorer

The International Ultraviolet Explorer (IUE) is a remarkably long-lived mission launched by NASA, ESA and the British SERC in January 1978. Despite diminishing solar power output and the loss of four of the six gyros, observing efficiency has

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not been significantly impaired and operations are expected to continue well into the next decade, even if a further gyro fails. Observing time on IUE remains heavily over-subscribed, and the Observatory has the distinction of having the highest citation rate of *any* astronomical facility.

The IUE instrumentation (Boggess *et al.* 1978) comprises a 45 cm f/15 Cassegrain telescope and two échelle spectorgrpahs: Short Wavelength (1150-2100 Å) and Long Wavelength (1825-3300 Å). Both spectrographs have low dispersion (6 Å) and high disperson ($R \sim 10^4$) modes, and use two-dimensional vidicon cameras for read-out of the échelle format. Entrance apertures can be selected between a 3 arcsec circle or a 10 × 20 arcsec ellipse. The IUE instrumentation also incorporates a Fine Error Sensor (FES) which is not only used for acquisition and tracking of stars brighter than $V = 15.5$, but can also provide photometric data in V magnitudes for objects with $V \leq 13.5$. A blind offset capability is available for targets that are not visible to the FES.

The IUE spacecraft pioneered the application of a high altitude orbit for astronomy. It is in a 24 hour geosynchronous orbit, and is controlled on a shared basis from ground stations at Villafranca, Spain and the NASA Goddard Space Flight Center. Observations are conducted in real-time from these centres, and also from a regional facility at the University of Colorado. Requests for IUE observing time are solicited by the three participating agencies on a six monthly basis. An extensive data archive comprising >50,000 high and low dispersion spectra has been assembled during the long lifetime of the mission. This archive is a unique resource for astrophysical research and is now becoming available in very accessible optical disk format.

The application of IUE ranges from objects in the Solar System to Active Galactic Nuclei (for a review of IUE scientific achievements, see the Proceedings of IUE Symposia). One of the most important contributions of IUE has been the far-ultraviolet monitoring of the outburst and evolution of SN 1987A. These observations confirmed the occurrence of an 'ultraviolet flash' predicted by supernova theory, and revealed the enormous expansion velocities in the early phases ($\sim$40,000 km s^{-1}).

2.2 Ginga

Ginga is the third in the ASTRO series of X-ray astronomy satellites launched by the Institute of Space and Astronautical Science in Japan, following the successful Hakucho and Tenma missions. It was launched with exquisite timing on February 5, 1987, only 18 days before the explosion of SN 1987A. The spacecraft is in a low Earth orbit and carries three separate instruments provided in collaboration with British and US groups (Makino 1987):

- The primary instrument is a coaligned array of eight Large Area proportional Counters (LAC) sensitive between 1.5-30 keV. The effective area is 4000 cm^2, and the collimated array has a combined field of view of 1.1° × 2.0° FWHM.
- An All-Sky Monitor (1.5-30 keV) which has a sensitivity of $\sim 40 \mu$Jy in a 20 minute daily scan of the sky accomplished by rotating the spacecraft through 360°. It has a 1° × 45° field of view and can locate transient X-ray sources to <0.5° (Tsunemi *et al.* 1988).
- A Gamma-ray Burst Detector (1.5-480 keV) based on proportional and scintillation counters and having a time resolution of 31.25 ms.

The early results and the astrophysical potential of Ginga have been reviewed by Tanaka (1987a) and Koyama (1988). The very large effective area of the LAC extends the capabilities of other X-ray missions in two important areas: the measurement of energy spectra over 2-30 keV for much fainter sources, and the study of fast time variability in bright sources with a far higher statistical precision than previously achieved. Exceedingly high quality X-ray spectra have been measured for faint supernova remnants, cataclysmic variable, Wolf-Rayet stars, RS CVn stars, and somewhat surprisingly, very hard and variable X-ray emission has been detected in galactic molecular clouds. Such high temperature emission ($T \sim 10^8$K) is thought to arise from near the surface of pre-main-sequence stars imbedded in the clouds (Takano *et al.* 1988). Ginga has also obtained unsurpassed spectra for various extra-galactic targets comprising normal galaxies, clusters of galaxies, and active galactic nuclei. The latter group includes the first broadband measurements of a statistically useful sample of quasars, of great importance for determining the origin of the cosmic X-ray background. A notable result from the Ginga All-Sky Monitor was the detection in April 1987 of a bright X-ray nova, ASM 2000+25 (Makino *et al.* 1988).

Ginga has played a critical role in monitoring SN 1987A since the optical outburst (Dotani *et al.* 1987, Tanaka 1987b). The onset of hard X-ray emission (>5 keV) was detected in July 1987, several months before theoretical predictions. Despite the difficulty of disentangling the emission from other X-ray sources in the LMC, an X-ray spectrum has been measured and the evolution of the X-ray flux continues to be followed. In January 1988, a flare-like soft X-ray event lasting several days was recorded and is thought to have been the result of shock heating of a dense circumstellar cloudlet. Ginga is also monitoring SN 1987A for the emergence of an X-ray pulsar; these measurements will increase in sensitivity as the supernova becomes optically thin at the higher X-ray energies (Mitsuda *et al.* 1988).

Participation in the Ginga X-ray program is possible in collaboration with astronomers at the individual Japanese institutions (Tanaka 1987a). Collaborative observations of X-ray binaries have been undertaken using the 2.3 m telescope at Siding Spring Observatory, although truly simultaneous measurements are only possible in the hours just after sunset or before sunrise due to the ~90° sun-angle constraint of Ginga. The lifetime of Ginga will most probably be limited by the onboard batteries, but there is hope that continuity will be maintained until the launch of the next Japanese X-ray satellite, ASTRO-D, in February 1993.

2.3 Kvant/MIR Astrophysics Module

The High Energy Astrophysics program of the USSR is growing at a very rapid pace and has a substantial international content. The most ambitious instrumentation flown thus far is the Roentgen X-ray package contained in the Kvant (Quantum) module which was docked with the MIR Space Station in April 1987 (see Beatty 1987 for details of the physical assembly). Four separate X-ray/γ-ray instruments span an energy range of 2-1300 keV:

- HEXE, a High Energy X-ray Experiment utilizing a Phoswich scintillator detector sensitive to hard X-rays between 15-250 keV and having a geometric area of 1000 cm^2. A rocking collimator permits accurate background determination (Reppin *et al.* 1983).
- PULSAR X-1, a phoswich detector having a geometric area of 800 cm^2 and an energy range of 20-1300 keV. A related experiment, PULSAR X-1V, is used for gamma-ray burst studies over 2π steradians.

- SIRENE-2, a Gas Scintillation Proportional Counter with an effective area of ~300 cm^2, an energy range of 2-80 keV, and an energy resolution of <10% FWHM at 6 keV (Smith 1983).
- TTM, which is a coded-mask camera with a wide field of view (8° × 8° FWHM) and a position resolution of ~2 arcmin between 2-30 keV (Brinkman *et al.* 1983).

All four X-ray/γ-ray instruments in the Roentgen package are coaligned, and pointing is accomplished by appropriate manoeuvering of MIR, with stabilization of the entire spacecraft complex being provided by gyroscopic flywheels in the Kvant module. Because of the spacecraft pointing constraint, together with the multi-purpose nature of MIR and the high orbital inclination (and background), the duty cycle for astronomical observations is relatively low. Nonetheless, the Roentgen package provides a unique hard X-ray capability, and particularly valuable high energy observations are being undertaken of SN 1987A (Sunyaev *et al.* 1987) to complement the lower energy observations from Ginga. As reported by Sunyaev *et al.* (1988), broad-band X-ray spectroscopy has also been undertaken of ASM2000+25, the bright X-ray nova discovered by Ginga.

In addition to the Roentgen X-ray package, the Kvant module contains the Glazar far ultraviolet telescope provided by Switzerland and the USSR (Baitty 1987). The 40 cm telescope has an independent pointing system capable of 2 arcsecond accuracy, and is equipped with an image intensifier optimized for ~1640Å. Images over a ~1.3° field are recorded on film, and an 8 minute exposure reaches ~17th magnitude. Glazar is being used to undertake surveys of Markarian galaxies, stellar associations, as well as observations of SN 1987A. There are plans to install a second Glazar telescope on one of the free docking ports of MIR in order to significantly extend the far ultraviolet survey capability.

2.4 Astron

The Soviet ASTRON mission was launched in March 1983 and carries a far ultraviolet telescope as the primary instrument, together with a pair of coaligned X-ray spectrometers mounted on either side. The spacecraft is in a 4 day high altitude orbit measuring 200,000 × 2000 km.

The ultraviolet telescope was built in collaboration with France and is described by Boyarchuk *et al.* (1984). It consists of an 80 cm diameter primary mirror and an articulating 26 cm diameter secondary mirror which provide a ~30 arcmin field. Both mirrors are aluminized and over-coated with magnesium fluoride to maintain UV reflectivity. A Rowland spectrograph in the focal plane records spectra in four wavelength intervals using scanning photo-multipliers. The first three intervals correspond to first order, and the bandpasses and resolutions are as follows: (1100-1600Å; $\Delta\lambda = 14$Å), (1524-2600Å; $\Delta\lambda = 0.4$Å or 28Å), and (2414-3500Å; $\Delta\lambda = 28$Å). The fourth channel, corresponding to zero order between 1700-6000Å, is used to verify stable tracking of star images on the spectrograph aperture. Three entrance apertures are provided, and measure 1, 12 and 75 arcsecs in diameter. Precise tracking (~0.3 arcsec) of objects is accomplished using sensors in the focal plane that send fine adjustment signals to the secondary mirror. Offset tracking to a precision of ~2 arcsec is also possible for faint targets using a bright guide star ($V < 8.5$). Targets as faint as 15^m have been observed in the latter mode.

The X-ray experiment on ASTRON is described by Golinskaya *et al.* (1984). It consists of two identical units, each comprising an array of proportional counters sensitive between 2-25 keV. The total effective area is ~1780 cm^2 and the field of view is 3° FWHM. Observations are conducted in pointed and scanning modes when the cosmic ray background is sufficiently low (>75,000 km).

ASTRON continues to function well in orbit, having exceeded its design lifetime of 1.5 years (Massevitch 1988, private communication). As described by Boyarchuk *et al.* (1984), the spacecraft has been used in a wide range of far ultraviolet spectroscopic observations that cover stellar mass loss, a search for heavy elements in Ap stars, the properties of hot binary components, and the UV emission of galaxies. Although few results have been reported in the literature, ASTRON was used in March 1987 to obtain valuable early epoch spectra of SN 1987A (Boyarchuk *et al.* 1987). A second ASTRON mission, also carrying UV and X-ray instruments, is planned for ≥1995.

3. FUTURE ASTRONOMICAL MISSIONS

Table 1 presents a summary of the approved space astronomy missions of the United States, Europe, Japan and the Soviet Union, together with nominal launch dates to the Year 2000. The four current missions described above are also included, as well as a glossary of spacecraft acronyms used throughout this paper. The programs of the United States (ie NASA) fall mainly into two classes corresponding to the 'Great Observatories' series (HST, GRO, AXAF and SIRTF), and the lower cost Explorer class. Similarly, the missions of the European Space Agency (ESA) are divided into two categories based on the far-sighted Horizon 2000 Space Science Plan formulated in 1984 (Bonnet 1989); these correspond to 'Cornerstone' missions such as XMM and FIRST, and 'Blue Box' missions which are analogous to the US Explorer category. The greatest emphasis of the space astronomy programs of Japan and the U.S.S.R. is in the area of High Energy Astrophysics. These latter programs are proving vital in bridging the long gaps between US and European X-ray missions.

In the sections below, the various forthcoming missions are reviewed in *approximate order of energy*, beginning with the radio domain.

3.1 Radioastron

The Soviet Radioastron mission is expected to be the first orbiting Very Long Baseline Interferometry (VLBI) facility, and is presently scheduled for launch in 1992. The VLBI technique of aperture synthesis has been used with great success in a terrestrial mode for over a decade, and has recently been proven in a space-borne mode using the 4.9 metre communications antennae of the NASA Tracking and Data Relay Satellite, combined with radio telescopes at Tidbinbilla and in Japan to provide a baseline of 2.2 Earth diameters (Levy *et al.* 1986). Radioastron will be launched into a highly elliptical orbit having dimensions of ~26,000 km by ~85,000 km, thereby providing a baseline which is almost an order of magnitude longer than the maximum achievable on Earth. The apogee of the orbit will be directed towards the north ecliptic pole so that the entire sky will be accessible during the course of one year.

Radioastron will carry a folded 10 metre diameter telescope with four circularly polarized feeds operating at 0.327, 1.67, 4.83 and 22.2 GHz. At the highest frequency, the interferometer beamwidth will be 30 micro-arcseconds, and the RMS sensitivity for a 24 hour observation will be 10^{-29} W m^{-2} Hz^{-1}.

There will be substantial Australian participation in the Radioastron mission under the USSR-Australia Space Research Agreement signed in December 1987. Australia, through the CSIRO, will provide the 1.67 GHz receiver for the spacecraft,

TABLE 1
Current and Planned Space Astronomy Missions

Launch	USA	Europe	Japan	USSR
1978	←—— IUE ——→			
1983				ASTRON
1987			GINGA	KVANT [a]
1988				GAMMA-1
1989	COBE	HIPPARCOS		GRANAT
1990	←—— HST ——→			
	ASTRO-1 [b]	ROSAT		
	GRO			
1991	EUVE			
1992 [c]	ASTRO-2 [b]	SAX		RADIOASTRON-cm
	SHEAL-2 [b]			RELIKT-2
1993		ISO	ASTRO-D	SPECTRUM-X
			IRTS	
1994	XTE			AELITA
1995				SPECTRUM-γ
1996	AXAF			
1997				
1998		XMM		RADIOASTRON-mm
??	SIRTF	FIRST		

[a] Docked to MIR Space Station [b] Attached Shuttle Mission [c] International Space Year

Acronyms :

AXAF	Advanced X-ray Astrophysics Facility	IUE	International Ultraviolet Explorer
COBE	Cosmic Background Explorer	ROSAT	Röntgensatellit
EUVE	Extreme Ultra-Violet Explorer	SAX	Satellite per Astronomia X
FIRST	Far Infrared and Sub-millimetre Space Telescope	SHEAL	Shuttle High Energy Astrophysics Laboratory
GRO	Gamma Ray Observatory	SIRTF	Space Infrared Telescope Facility
HST	Hubble Space Telescope	XMM	X-ray Multi-Mirror Mission
IRTS	Infrared Telescope in Space	XTE	X-ray Timing Explorer
ISO	Infrared Space Observatory		

and in addition, the Australia Telescope will be the prime southern hemisphere component of the ground-based VLBI network. Other contributors include Poland, Europe and the USA.

Given the ~10-fold increase in angular resolution over terrestrial VLBI networks, Radioastron will have a fundamental impact on mapping and dynamical studies of galactic and extra-galactic radio sources. A key objective is the imaging of nuclei and relativistic jets in AGN at a resolution approaching the scale of the accretion disks that are believed to surround the massive black holes in these systems. Other objectives concern the determinination of fundamental cosmological constants, probing of the environments of galactic neutron stars and black holes, the physics of stellar and interstellar masers, star and planetary system formation, investigations of flare and mass-loss stars, the structure of interstellar plasma, and proper motion and distance measurements. A more detailed discussion of Radioastron and the astrophysical objectives can be found in Jauncey (1988).

Plans are already well advanced for further missions in the Radioastron series, although these are not yet formally approved by the Soviet government. Later missions will emphasize millimetre wavelengths, and will also provide a capability for orbital aperture synthesis using a system of three antennae in widely disparate orbits. A continued Australian role in these later missions seems assured, given the unique capabilities of the Australia Telescope for ground-based VLBI support.

3.2 Cosmic Background Explorer

The Cosmic Background Explorer (COBE) is scheduled for a Delta launch by NASA in May 1989, and is intended to map the large scale distribution of the 2.7 K cosmic background at sub-millimetre wavelengths, and to search for evidence of a diffuse extragalactic infrared background (e.g. from primeval galaxies). The COBE spacecraft is thus dedicated entirely to cosmology, with the emphasis being on extremely sensitive intensity and spectral measurements in view of the very small deviations from isotropy and black-body behaviour that are expected. Orders of magnitude improvements in sensitivity and accuracy are anticipated over previous investigations.

COBE will be injected into a 900 km altitude, sun-synchronous polar orbit that precesses by 360° during the one year mission (the lifetime is limited by the onboard cryogen supply). Thus as the spacecraft slowly rotates at ~ 1 rpm, all-sky coverage will be achieved over the course of the mission. Three complementary instruments are arranged at various angles to the rotation axis (Mather 1981):

- A set of four ambient-temperature Differential Microwave Radiometers (DMR) operating at frequencies of 23.5, 31.4, 53 and 90 GHz (these frequencies are chosen to minimize interference from known astronomical sources as well as man-made radiation). The radiometers are intended to map the 2.7 K cosmic background and to conduct a sensitive search for intensity variations by rapidly switching (~ 100 Hz) between pairs of antennae separated by 60°. Each antenna has a 7° field of view, equivalent to ~ 1000 pixels on the sky and ~ 25,000 pairs that are 60° apart. An extraordinarily high differential sensitivity is anticipated over the course of one year, corresponding to a temperature difference of 3×10^{-4} K between field pairs.
- A Far Infrared Absolute Spectrometer (FIRAS), which is a cryogenically-cooled Michelson interferometric spectrometer for measurements of the spectrum of the 2.7 K cosmic background, and of interstellar dust and other sources emitting between 100-10,000μ. Deviations of the cosmic background spectrum for a black-body can be measured very accurately by comparison with a precision onboard black-body calibrator. This provides an accuracy of better than 1 part in 1000 at the peak of the 2.7 K spectrum. A parabolic horn antenna defines a beam width of 7°, corresponding to 1000 pixels on the sky. The expected sensitivity in each pixel for a spectral resolution of 5% is 10^{-13} W cm^{-2} sr^{-1} (cf Figure 1, discussed below).
- A cryogenically-cooled Diffuse Infrared Background Experiment (DIRBE), involving an off-axis 20 cm Gregorian telescope and a 10-band filter photometer covering the 1-300μ range. The four shortest wavelength bands are equivalent to J, K, L and M, while the next four are similar to the survey bands used during the IRAS mission. Polarization will be measured in the J-L bands. The main objective of DIRBE is to separate a possible extragalactic IR background from foreground sources such as starlight, sunlight reflected and re-radiated from interplanetary dust, and thermal emission from interstellar dust heated by starlight. Discrimination between these components will be based on their spectral and spatial characteristics. The DIRBE field of view is 1° × 1°, and the sensitivity is expected to be better than 2×10^{-12} W cm^{-2} sr^{-1} Hz$^{-1/2}$ between J-L, and $\sim 6 \times 10^{-13}$ W cm^{-2} sr^{-1} Hz$^{-1/2}$ in the IRAS bands.

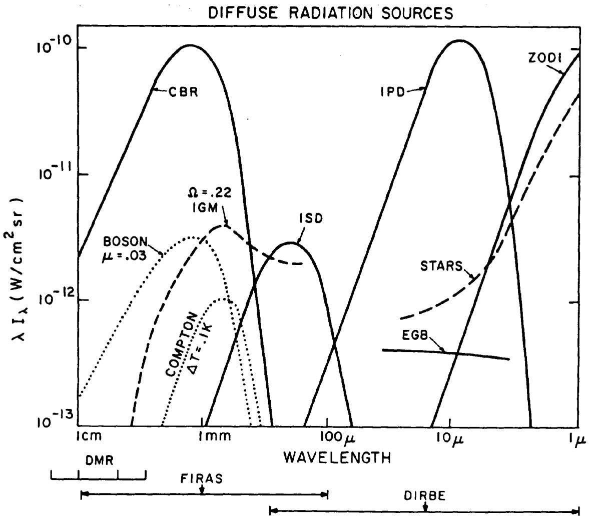

Figure 1 – Predicted brightness of various sources of diffuse radiation in the COBE wavelength range. The abbreviations are as follows: CBR = Cosmic background radiation, IGM = Intergalactic medium, ISD = Interstellar dust, IPD = Interplanetary dust, EGB = Extragalactic background, ZODI = Zodiacal light. The curves labelled Compton, Boson and IGM refer to possible distortions of the blackbody CBR spectrum caused by postulated energy release mechanisms in the early Universe (Mather 1981).

The astrophysical potential and wavelength coverage of the three COBE instruments are graphically summarized in Figure 1, reproduced from Mather (1981). This figure shows the brightness of several cosmological and local sources of diffuse radiation, with the 2.7 K cosmic background radiation (CBR) dominating at long wavelengths (dotted and dashed lines in this region refer to predicted deviations from a black-body for possible energy release mechanisms at early epochs). At shorter wavelengths, Figure 1 shows the spectra of interstellar dust (ISD), interplanetary dust (IPD), zodiacal light (ZODI), and the hypothesized IR extragalactic background (EGB) based on models of primeval galaxies. Separation of this latter component clearly requires precise measurement and modelling of the IPD, zodiacal, and starlight contributions.

There will be no Guest Investigator opportunities for COBE due to the survey nature of the mission and the short lifetime. However, fully reduced data in the form of all-sky maps of brightness at ~ 100 wavelengths between 1-13,000μ will become available in digital format approximately one year after the completion of the mission. Mather (1981) points out that at wavelengths where the 2.7 K background is dominant, *these maps will be the equivalent of a photograph of the inside of the Big Bang.*

3.3 Infrared Space Observatory

The Infrared Space Observatory (ISO) represents the next major step in infrared astronomy, and offers an unprecedented opportunity for Australian participation. It is scheduled for

TABLE 2

Description of the ISO Instruments *

	Main Function	Wavelength (microns)	Spectral Resolution	Spatial Resolution	Outline Description
ISOCAM	Camera and Polarimetry	3 - 17	Broad, narrow and Circular Variable Filters	Pixel FOVs of 1, 3, 6 and 12 arcseconds	Two channels each with a 32 x 32 element detector array
ISOPHOT	Imaging Photo-polarimeter	3 - 200	Broad & Narrow band filters Near IR Grating Spectrometer with R=100	Variable from diffraction limited to wide beam	Four sub-systems : • Multi-band, Multi-aperture photo-polarimeter (3 - 30 μ) • Far-Infrared Camera (30-200 μ) • Spectrophotometer (3-16 μ) • Mapping Arrays (3 bands, 4-22 μ)
SWS	Short Wavelength Spectrometer	3 - 45	1000 across wavelength range & 3 x 10^4 from 15-30 μ	14 and 20 arcseconds	Two gratings and two Fabry-Pérot Interferometers
LWS	Long Wavelength Spectrometer	45 - 180	200 and 10^4 across wave-length range	1.65 arcmins	Grating and two Fabry-Pérot Interferometers

* from Kessler (1986)

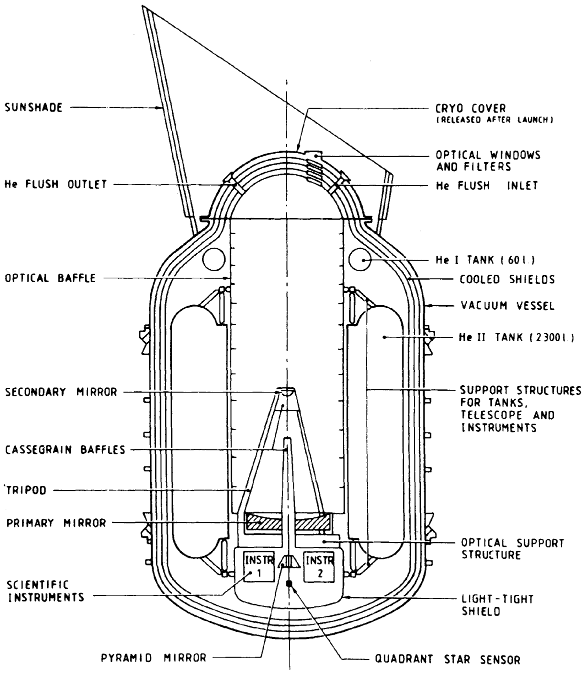

Figure 2 – A schematic of the ISO payload module under construction by ESA. It is essentially an orbiting thermos bottle containing a 60 cm cryogenically-cooled telescope, with a field of view that is split between four focal plane instruments using a pyramid mirror (Kessler 1986).

launch by ESA in 1993, and will build upon the pioneering all-sky survey conducted by the Infrared Astronomical Satellite (IRAS) in 1983. ISO is an Observatory-class mission, and comprises a cryogenically cooled 60 cm Ritchey-Chrétien telescope (Figure 2) with four focal plane instruments that collectively cover the 3-200 micron bandpass:

- ISOCAM for imagery and polarimetry between 3-17 microns.
- ISOPHOT for imaging photometry and polarimetry between 3-200 microns.
- SWS for Short Wavelength Spectroscopy between 3-45 microns.
- LWS for Long Wavelength Spectroscopy between 45-180 microns.

Specific details of the ISO instruments and their sensitivities are discussed by Kessler (1986), Mandolesi (1987), Saraceno (1987), and Ferrari-Toniolo (1987). A summary of the instrument characteristics is reproduced in Table 2. The four instruments view adjacent regions of the sky, with instrument selection being accomplished by fine pointing of the spacecraft. Thus, only one instrument will be operational at a time, although some serendipitous measurements can be undertaken using ISOCAM. Approximately 30% of the observing time will be reserved for the European groups providing the four focal plane instruments, and also for the Mission Scientists and the ESA Observatory Team who will operate the facility. Most of the remaining time will be available to competitive Guest Investigator proposals from the European (and international)

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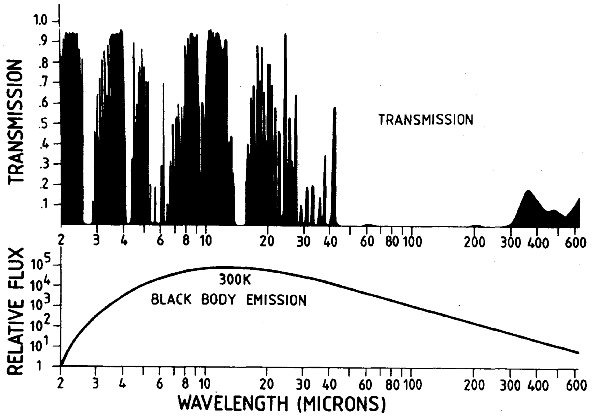

Figure 3—The infrared transparency of the atmosphere in the wavelength regime of ISO. For comparison, the blackbody curve of an object at a termperature of 300 K is shown (Kessler 1986).

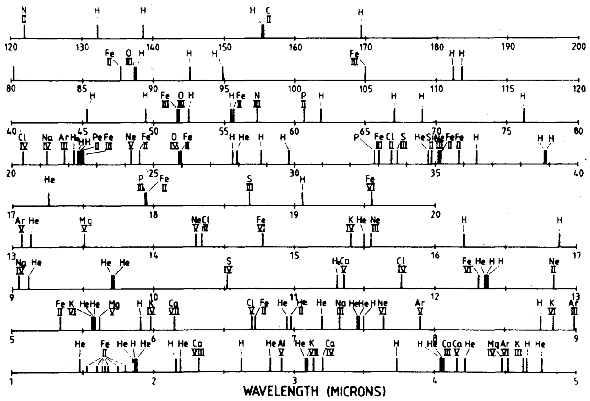

Figure 4—A schematic showing some of the numerous infrared emission lines accessible to ISO. The diagram is reproduced from the ESA Phase-A Study Report for ISO.

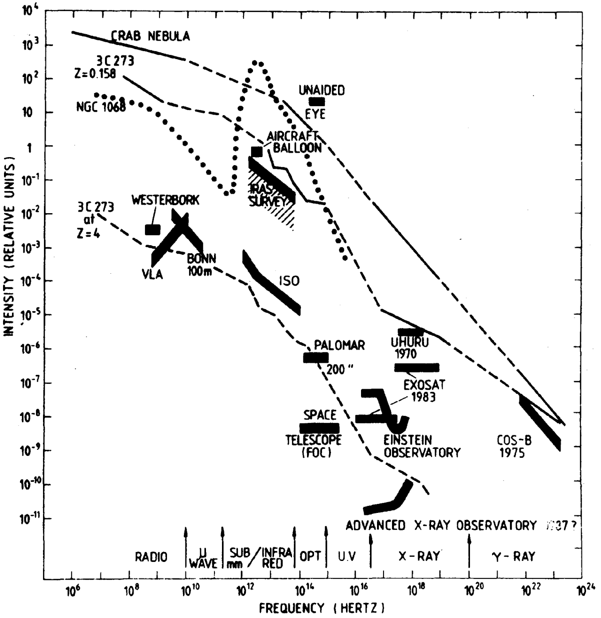

Figure 5—The sensitivity of the ISO mission compared with other major space and ground-based astronomical facilities. Broadband spectra for the Crab Nebula, NGC1068, and 3C 273 are included for comparison. ISO will achieve a sensitivity increase over the IRAS survey mission by ~3 orders of magnitude. The diagram is reproduced from the ESA Phase-A Study Report for ISO.

community. The ISO mission duration will be at least 18 months and most probably 2 years, depending on the lifetime of the superfluid helium coolant.

Figures 3-5 collectively summarize the potential of ISO in regard to the accessible wavelength range, key emission lines, and the sensitivity compared to other ground-based and space observatories. The scientific objectives of the mission are very broad, ranging from Solar System studies to cosmology (Kessler 1986). In the latter area, the high sensitivity of ISO will permit deep searches for galaxies forming from primeval material, while a study of the evolution of infrared galaxies may help to resolve whether the Universe is open or closed, as well as contribute to measurements of the distance scale. Spectroscopy of the exceedingly luminous infrared galaxies discovered by IRAS will provide details on stellar populations and evolution as a function of redshift. ISO is also especially well suited to the study of star formation processes in our Galaxy and in nearby galaxies. Infrared mapping of molecular clouds and galaxies will clarify the processes that trigger star formation and elucidate the role played by density waves. Near infrared spectroscopy will provide information on the gas dynamics of star forming regions, allowing the study of collapse, fragmentation, and shocks. Spectroscopic studies of more evolved objects, ranging from cool giant stars and planetary nebulae to globular clusters, will contribute significantly to our knowledge of the chemical abundances and the dynamical evolution of these objects.

ISO was originally intended for launch into a 12 hour elliptical orbit as one of two payloads on a shared Ariane vehicle. However, in 1987 it was decided instead to place ISO into a lower background, higher altitude 24 hour orbit using a dedicated Ariane-4 launcher. This orbit, measuring 70,000 × 1000 km, provides significantly more observing time amounting to ~22 hours of useful data per day. However, the additional cost of a full Ariane-4 launch has forced the ISO project to accept single ground station coverage from Villafranca in Spain, and as a result, approximately 8 hours of good quality data cannot be received. Thus ESA is presently soliciting an international collaboration to recover the lost data at no cost to ESA in return for a share of the ISO observing time. Australia is an ideal country in view of the longitude complementarity with Villafranca. In fact, a study of potential antenna sites (Tuohy 1988) shows that except for a brief ~1 hour period near perigee when the spacecraft is in a very high radiation environment, complete coverage of the ISO orbit can be provided by stations as far apart as Gnangara (Perth) or Mount Pleasant (Hobart), in combination with the prime ESA receiving station at Villafranca.

A formal invitation from ESA in July 1987 for Australia to provide an S-band relay station for ISO has recently received strong endorsement from the Australian Space Board, which provides executive guidance to the Australian Space Office. Accordingly, the Space Office has submitted a firm proposal to ESA based on Australia funding the operation of the ESA tracking facility at Gnangara. This is the cheapest and most attractive option, given the obvious compartibility with the ESA network. In support of these developments, an Australian ISO Science Working Group was formed in September 1988 to coordinate astronimcal input at a national level, and to liaise with the Space Office. It is noted that the Australian proposal to ESA is in competition with a joint U.S./Japanese submission which also seeks lucrative ISO observing time.

Access to the ISO mission would clearly provide a major boost to Australian astronomy. ISO offers a performance leap of several orders of magnitude over IRAS, and for the first time, will bring infrared sensitivity close to that achieved at optical and other wavelengths. In fact the ISO sensitivity approaches the fundamental limit set by the natural IR background due to zodiacal light. At the same time, ISO observations would both complement and drive research using our major ground-based facilities; ie the Australia Telescope, the AAT, and the ANU 2.3 metre telescope. More competitive access to other facilities such as the United Kingdom Infrared Telescope and the Hubble Space Telescope may also follow as a consequence of discoveries made with ISO. Finally it is noted that cooperation with ESA in the tracking of ISO could well pave the way for similar participation in future ESA space astronomy missions such as XMM (see section 3.21 below).

3.4 Infrared Telescope in Space

The Infrared Telescope in Space (IRTS) is one of several experiments planned for launch in early 1993 on a Japanese orbital platform known as the Space Flier Unit (SFU). The SFU is a retrievable multi-purpose carrier which is designed for launch on the new H-2 rocket and for recovery by the NASA Space Shuttle. The IRTS experiment involves US collaboration and is described by Okuda (1987). It is a small cryogenically cooled telescope of aperture 15 cm intended for studies of the cosmic background radiation and Galactic infrared sources. In this regard, IRTS is intended to bridge the gap between the IRAS and COBE survey missions, and Observatory-class spacecraft such as ISO and SIRTF. A star sensor and four instruments share the focal plane of the Ritchey-Chrétien telescope:

- A Near Infrared Spectrometer covering the range 1.2-4.1μ with a spectral resolution of 0.15μ and a beam size of $0.14 \times 0.14°$.
- A Middle Infrared Spectrometer covering the range 5-13.5μ with a spectral resolution of 0.26μ and a beam size of $0.14 \times 0.14°$.
- A Far Infrared Line Mapper for high resolution spectroscopy of the OIλ63.2μ line (R = 450; 5th order) and the CIIλ157.7μ line (R = 420; 2nd order). The field of view is 8×20 arcmins.
- A Far Infrared Photometer for simultaneous measurements in seven bands between 60-1000μ using dichroic beam-splitters. The field of view is 0.5°, corresponding to the central region of the telescope beam (the three preceding instruments and the star sensor access the outer periphery of the beam using diagonal mirrors).

IRTS will operate in a scanning mode by rotation around an axis along the Earth-Sun line. Thus great circle scans will progress through the sky at 1° per day. Due to the limited capacity of superfluid helium coolant ($\sim$ 1 month supply), only about one sixth of the sky will be surveyed. Nevertheless, IRTS will provide important new input for the contemporaneous ISO mission, and is aimed at some key areas of infrared astrophysics, as discussed by Okuda (1987):

- Medium resolution spectroscopy of the cosmic background, and especially of an IR excess between 2-3μ found from rocket observations. The improved spatial and spectral resolution of IRTS over IRAS should enable separation of the cosmic component from Earth-related background, as well as from field stars. This investigation is directed towards the early history of the Universe, corresponding to $z = 3 \sim 100$.
- Mapping of the Galactic plane in the CII and OI fine structure lines. the CII line in particular is thought to be a dominant cooling line of interstellar gas, and therefore a good tracer of low energy ionization and shock phenomena. The OI line is sensitive to denser regions, and thus the ratio of the two lines provides information on the density and temperature of the gas.
- Spectral features in the emission from cosmic dust. This survey is aimed at unambiguous identification of contraversial infrared band structures that hold the clue to the origin and evolution of cosmic dust particles.

3.5 Space Infrared Telescope Facility

The Space Infrared Telescope Facility (SIRTF; Werner and Eisenhardt 1988) is one of four missions in the NASA 'Great Observatories' series, and was identified by the Field Committee as the cornerstone for future infrared astronomy in the United States (Field *et al.* 1982). SIRTF is intended for launch by the Space Shuttle in the late 1990's, and in constrast to the IRAS and ISO missions, will have a long mission lifetime of 5-10 years as a result of replenishment of the superfluid helium coolant every 2-3 years. The mission is conceived as primarily a Guest Investigator facility open to scientific proposals from all countries.

The SIRTF telescope will have an aperture of 85 cm diameter, and will operate over a very broad bandpass of 2-700 microns using cooled ($<$7K) optics and detectors. Special emphasis is being given to image quality, with 1 arcsec diffraction-limited images expected at the shortest wavelengths (more than a hundred-fold sharper than IRAS). This excellent imaging performance will be particularly beneficial for high resolution mapping, and accordingly, SIRTF will take advantage of the rapid developments in monolithic infrared arrays. The intrinsic angular resolution may be further enhanced by the application of 'super-resolution' image processing techniques on high signal-to-noise data, especially near 100 microns where ground-based telescopes have been limited to $\sim$30 arcsec resolution.

Three focal plane instruments are under development for SIRTF:

- An Infrared Array Camera having a wide field ($\sim$5 arcmins), diffraction-limited imaging capability in the 2-30 micron range. Arrays of up to 128×128 pixels will be used, and simultaneous observing will be possible in three selectable bands. A polarimetric capability will be provided.
- An Infrared Spectrometer covering the 2-200 micron regime with Low and High resolution options which provide resolving powers from 50 to $>$1000. Detector arrays will be used to permit long slit spectroscopy of extended objects.
- A Multiband Imaging Photometer which employs small arrays and pixels to fully sample the Airy disk in the 3-200 micron range. In addition, the instrument will permit wide field, high resolution imaging between 60-120 microns, and broad-band photometry and mapping between 200-700 microns. A polarimetric capability is also included.

SIRTF will be launched initially into a low Shuttle orbit and then boosted by a propulsion system to a 700-900 km operational altitude. This orbit provides a benign environment for cooled telescopes, and also a long lifetime. As with other cooled space infrared telescopes, the background level will be some 6-7 orders of magnitude lower than that for ground-based telescopes, with the residual background being dominated by thermal emission from zodiacal dust grains (Figure 6). A huge increase in sensitivity over the IRAS mission is anticipated,

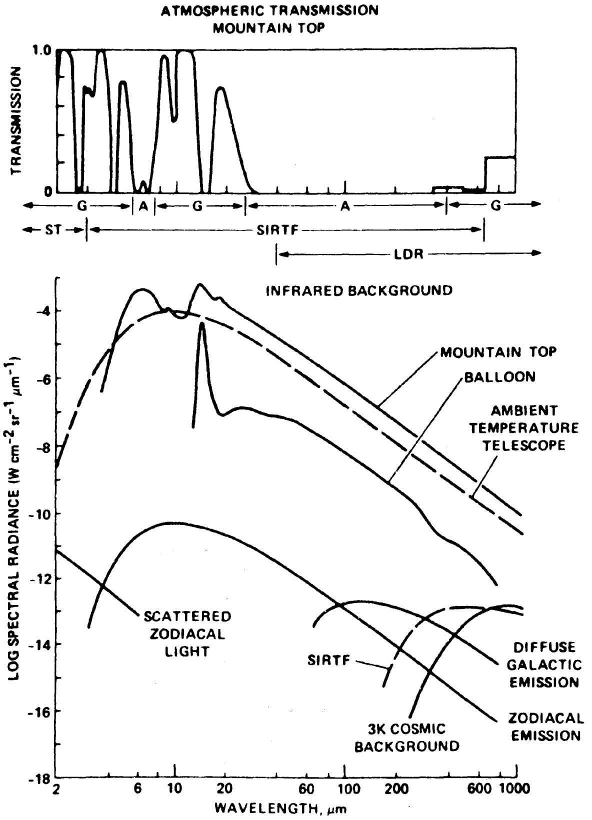

Figure 6—This diagram highlights the dramatic reduction in background infrared radiation between the best terrestrial sites and the SIRTF environment. The dashed line indicates the expected SIRTF instrumental background, which is comparable to the limit set by natural background sources. The upper panel shows atmospheric transmission over the SIRTF regime (Werner and Willoughby 1988).

amounting to a factor 10^{3-4}. Thus SIRTF will be able to acquire high quality spectra of any IRAS source in a very short timescale.

The science objectives of SIRTF are discussed in considerable detail by Rieke *et al.* (1986) and by Werner and Willoughby (1987). Many of the objectives parallel those of the ISO mission discussed above, but SIRTF will offer significantly improved image quality and sensitivity, as well as wider spectral coverage. Thus SIRTF will be especially suited to high resolution mapping of star-forming, dense cloud regions in the solar neighbourhood, with a goal being to acquire a complete sequence of images and spectra covering all stages of star formation. Similarly, SIRTF will probe star formation regions in local galaxies in order to reveal patterns of star formation and to investigate the influence of environment. SIRTF will be able to detect protostars of one solar mass or more in the LMC, and in fact, could study star formation in the LMC with comparable detail to that currently achieved in the Galaxy. The high angular resolution of SIRTF will also permit direct detection of Jupiter-size planets in orbit around nearby stars; for instance, a search of the regions outside 15 AU from the 50 nearest stars would detect any planets of three Jupiter masses or more. Deep surveys by SIRTF will have the capability to detect several hundred brown dwarfs in a few square degrees of sky. Such studies, apart from contributing to our understanding of dark matter in the Galaxy, will also determine empirically the threshold mass for the initiation of nuclear burning in stars.

Beyond the Galaxy, SIRTF will have unique capabilities for discovering proto-galaxies, especially since the peak luminosity associated with star formation in these objects will be redshifted well into the infrared band; eg. to ~15 microns for a look-back time equivalent to 10% of the age of the Universe. The sensitivity of SIRTF imaging will be such that a galaxy comparable to our own could be detected at 4% of the age of the Universe. A minimum surface density of one proto-galaxy per square arcminute is foreseen in deep surveys, and identification of candidate objects will be achieved through the detection of diagnostic spectral features associated with star formation. SIRTF will clearly contribute to broadband spectral measurements of quasars and other AGN, especially studies of emission regions that are obscured at other wavelengths. More specific details of SIRTF science objectives can be found in a special issue of Astrophysical Letters & Communications (Volume 27, Number 2, 1988).

3.6 Far Infrared and Sub-millimetre Space Telescope

The Far Infrared and Sub-millimetre Space Telescope (FIRST) is a Cornerstone mission in the ESA Horizon 2000 program (Bonnet 1989), and is intended to provide a very powerful complement to the IRAS, ISO and SIRTF missions through superior spatial and spectral resolution. SIRTF will be ideally suited to the study of cool material at temperatures between 10-3000 K, corresponding to continuum radiation from dust, and atomic and molecular spectral lines. The mission is presently in an extended technology development phase, with a projected launch on an Ariane-5 vehicle in 2002.

FIRST is an exceedingly ambitious project, requiring a deployable, large aperture telescope (~8 metres diameter) having a high surface quality (8-10 microns) and diffraction limited performance down to 150 microns. The passively cooled telescope will have a >3 arcminute field of view and a chopping secondary reflector with a beam throw of 10 arcminutes. The following instruments are presently envisaged to be contained in a cryostat at the Cassegrain focus:

- A set of coherent tunable receivers for very high resolution ($R \sim 10^6$) heterodyne spectroscopy between 400-2000 GHz (down to the CII line at 157.7 microns). The instantaneous bandwidth will be ~1% (i.e. a few GHz), and the sensitivity will be $0.5\nu_{GHz}$K. This advanced technology incorporates super-conducting mixers and lasers for local oscillators.
- An incoherent imaging spectrophotometer providing modest resolution ($R \sim 10^4$) between 2000-3000 GHz (50-350 microns) and a wideband sensitivity of 1 mJy. The spectrograph will be based on a Fabry-Pérot étalon, a grating order-sorter, and an array of Blocked Impurity Band detectors (~30×30 pixels).
- A chopping photometer to provide high resolution imaging (3.5 arcsec at 100 microns) between 50-350 microns, and high throughput photometry at wavelengths longward of 350 microns. The detector consists of a combination of photo-conductors and Ge-Ga bolometers operating at 300mK.

The high spectral resolution capability of FIRST is illustrated in Figure 7 which shows that very narrow maser line sources and a wide range of other astrophysical phenomena will be accessible for study. In particular, the dramatic gain over ISO and ground-based spectroscopy is indicated on the right hand axis. The following areas have been identified as being critically

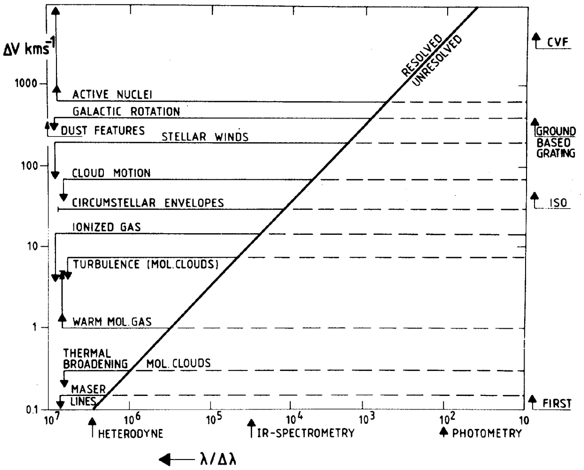

Figure 7 – Typical velocities associated with astrophysical phenomena plotted as a function of spectral resolution (ESA SP-1098). It is clear that the very high resolution of FIRST will permit resolved studies of nearly all astrophysical phenomena, from narrow maser lines to broad line regions in AGN.

dependent on major progress in sub-millimetre astrophysics through the FIRST mission (Bonnet 1989).

- The physics of the interstellar medium and its fragmentation into protostellar clouds:
  - determination of the physical conditions and chemical composition of dense clumps through high excitation, rotation-vibration transitions.
  - the energy balance of the various phases of the interstellar gas, including shocks (role of hydrogen, hydrides, fine-structure lines, etc).
  - mapping of star-forming regions in external galaxies with much better angular resolution to investigate triggering mechanisms, and to search for low mass stars and protostars in molecular clouds.
- The physics of star formation:
  - the dynamics and physical conditions (through studies of high excitation transitions) in accretion discs and bipolar flows as clues to the main problem of star formation; the mechanism that allows the gas of a protostellar cloud to lose angular momentum and be accreted to the protostar.
- Cosmological studies. Deep continuum surveys at $\lambda > 350$ microns for:
  - the detection of star-burst galaxies at large redshifts (such surveys will be confusion-limited with telescopes smaller than 8 metres).
  - the search for small angular scale (~10 arcmin) fluctuations of the cosmological background, which will provide the main observational constraints on galaxy formation models and, in conjunction with the Sunyaev-Zel'dovich effect, will yield a new method of determining the Hubble constant and the absolute velocity of clusters with respect to the microwave background.
- Properties of primitive solar system material through molecular (especially H_2O) studies of comets.

FIRST will be operated as a real-time observatory with substantial Guest Investigator participation. The mission lifetime will be at least two years, and perhaps longer if replenishment of the cryogenic coolant is feasible. This latter aspect depends critically on the choice of orbit – present studies are examining orbits ranging from low earth, to geostationary, to highly elliptical (the latter is currently baselined).

3.7 Hipparcos

Hipparcos is a unique spacecraft which will make an unprecedented contribution to the fundamental science of astrometry. Due for Ariane launch by ESA in 1989, Hipparcos will measure the precise positions and parallaxes of ~120,000 program stars brighter than $B = 13^m$. The typical accuracy in stellar positions and parallaxes will be 2 milli-arcseconds, while proper motion components will be determined to ~2 milli-arcseconds per year. Stellar parallaxes will be absolute, rather than relative, and will be a factor 5 better than achieved through ground-based measurements. In addition, Hipparcos will greatly extend the volume of space containing stars for which accurate distances are known. This will be especially important for improving the cosmic distance scale, and in particular, for overcoming present selection effects involving very close, high proper motion stars, and dwarf stars later than spectral type A0.

The most important product of the 2.5 year mission will be the Hipparcos Catalog which will constitute a basic stellar reference frame having *homogenous* sky coverage, and against which all objects observed in other wavebands (e.g. radio) can be related and identified. The catalog will also be of enormous value for the determination of stellar luminosities, and for dynamical studies of the Galaxy through proper motion and distance measurements. In this regard, a serious limitation of the present FK4 proper motion system is the lack of homogeneity which hinders a full understanding of the kinematic structure of the Galaxy in the vicinity of the Solar System. Hipparcos will also provide substantial data concerning stellar multiplicity, much of which will be of a serendipitous nature.

Hipparcos will be launched into a 24 hour geostationary orbit, and will slowly rotate at a rate of ~11 revolutions per orbit. The instrumentation comprises a 29 cm diameter all-reflective, folded Schmidt telescope which views two 0.9° square regions of sky through an aspheric beam combiner/corrector. Star images from both fields of view, which are separated by 58°, are focussed on to a finely spaced grid, and as the spacecraft rotates about the orthogonal axis, modulated signals are recorded by an image dissector tube. Individual stars will pass through the two fields of view at a time separation of ~20 minutes, and will be scanned several times during any one epoch. Angular information is derived from the phase differences of the modulated signals in the combined scans. An important limitation of the instrument operation is that precise positional data are not recorded for *all* bright stars that pass through the field of view; rather, it is necessary to uplink prior information concerning program stars so that they can be tracked by the detector during transit across the focal surface. This necessitates the generation of an Input Catalog, which is the responsibility of a consortium of ~100 scientists from many astronomical institutions in Europe and elsewhere (including Australia).

The analysis of the primary data from the Hipparcos mission will be a massive task, and will be undertaken by two scientific consortia so that the validity of the results can be assured. It is anticipated that the two consortia will converge upon the Hipparcos Catalog of astrometric parameters approximately three years after the completion of the mission. This catalog of ~120,000 stars will be rigid in the sense that all stars are measured relative to one another. Zero points for the positional and proper motion reference frames will be established by several methods (for instance, by observations of radio stars, or stars near quasars which can be observed by the Hubble Space Telescope). In addition to the Hipparcos Catalog, a separate consortium will produce the Tycho Catalog of ~500,000 stars brighter than B~11 for which uniforn two-colour (B & V) magnitudes and less precise positions will be available from the star mapper (which is used primarily for attitude determination). Both catalogs will eventually be released in optical disk format.

It is clear that the Hipparcos and Tycho Catalogs will be unique and fundamental resources that will be in great demand for research and applications purposes. The European Space Agency and participating institutions are to be commended for providing this service to the worldwide community.

3.8 Hubble Space Telescope

The long-awaited Hubble Space Telescope (HST) is currently scheduled for Shuttle launch in February 1990 (IAU Circular #4651). This major new mission has been reviewed in numerous papers over the past decade (e.g. NASA CP-2244 and references therein), but for completeness, will be outlined here. HST is a joint NASA+ESA (15%) mission intended to have a lifetime of >15 years through orbital refurbishment. The telescope is based on a f/24 Ritchey-Chrétien configuration, with a 2.4 metre primary mirror having diffraction-limited performance (≤0.1 arcsec) over most of the 1150-11000Å bandpass. Five primary instruments and a Fine Guidance System share the focal plane:

- A Wide Field and Planetary Camera (WFPC) which operates in two modes corresponding to f/12.8 and f/30. The respective fields of view and pixel sizes are: (2.6 × 2.6 arcmins, 0.10 arcsec) and (1.1 × 1.1 arcmins, 0.043 arcsec). The detector is a mosaic of 4 CCDs, each having 800 × 800 pixels and sensitive between 1150-11,000Å. A large selection of filters, provides a capability for broadband and emission line imagery over a very wide dynamic range of $8.5 \leq V \leq 28$. Polarizers and gratings are also included for polarimetry and slit-less spectroscopy (R~100).
- A Faint Object Camera (FOC) which provides high resolution photon-counting imagery in several formats between 1150-6500Å. These include fields of view and pixel sizes of: (11 × 11 arcsecs, 0.022 arcsec), (22 × 22 arcsecs, 0.043 arcsec), and (44 × 44 arcsecs, 0.086 × 0.043 arcsec). The instrument also incorporates capabilities for very high resolution speckle imagery, polarimetry, coronography, objective prism spectroscopy, and long-slit (0.1 × 20 arcsec) spectroscopy (R~2000). The dynamic range is $\sim 21 \leq V \leq 28$.
- A Faint Object Spectrograph (FOS) intended for medium resolution spectroscopy at resolutions of R=250 and R=1300 between 1150-8500Å using photon-counting digicon detectors. The respective dynamic ranges for the two resolution modes are $\sim 22 \leq V \leq 26$ and $\sim 19 \leq V \leq 22$. Linear and circular polarization can be measured over the entire pass band.
- A High Resolution Spectrograph (HRS) covering the 1150-3200Å bandpass at resolutions of $R = 2 \times 10^3$, $R = 2 \times 10^4$ and $R = 10^5$ using a combination of first order and échelle gratings, and digicon detectors. The overall dynamic range is $\sim 11 \leq V \leq 19$ for the three resolution modes.
- A High Speed Photometer (HSP) for high time resolution photometry between 1200-8000Å to a limiting magnitude of $V \leq 24$. The instrument incorporates various filters and apertures, and has a polarimetric mode.
- A Fine Guidance System (FGS), which incorporates three sensors, two of which are needed for precise tracking of target objects, while the third is available for astrometric measurements. Relative positions can be measured to a precision of 0.0016 arcsec for objects as faint as V=17. An extensive Guide Star Catalog has been compiled, itself a major resource of astrometric positions (Lasker *et al.* 1988).

The six instruments share the ~28 arcmin diameter field of view, with the WFPC in an axial location, the FOC, FOS, HRS and HSP each viewing a radial quadrant, and the FGS sensors distributed around the outer periphery. Normally only one of the four radial instruments will be operational at a time, but serendipitous imagery can be acquired with the axial WFPC instrument. The five primary instruments are all designed for replacement in orbit, and plans are well advanced for second generation instruments which will eventually supersede the first series. In addition to an improved version of the WFPC already under construction, three Advanced Scientific Instruments are presently being studied: the Space Telescope Imaging Spectrograph, the Imaging Michelson Spectrometer, and the Near Infrared Camera and Multi-Object Spectrometer (the latter instrument will extend the HST spectral coverage to 2.5 microns).

The science objectives of the HST mission have been extensively reviewed over the past decade (e.g., Longair 1979, Leckrone 1980, Bahcall and O'Dell 1980, NASA CP-2111, NASA CP-2244) and are also described in the accompanying paper by Norman (1988). They will therefore not be repeated here, but instead, the key issue of access to HST data by Australian astronomers will be highlighted in two areas:

First, Australian astronomers are eligible to apply for Guest Investigator time on HST, and accordingly, proposals have been submitted in response to the first NASA Announcement of Opportunity (AO) which closed on October1, 1988 (for HST observations starting 7 months after launch and continuing for one year). The second AO is expected to be released after launch, and will be followed by regular opportunities throughout the lifetime of the observatory. However, HST will in all probability be the most heavily over-subscribed astronomical facility of all time. Thus, while Australian astronomers will undoubtedly benefit from the NASA program through the scientific excellence of proposals and linkage with Australian ground-based facilities, the nett amount of observing time and data that can be expected as Guest Investigators is very small.

The second method of gaining access to HST data concerns archival research. In this regard, the case for an *Australian Space Astronomy Data Centre*, which would be established primarily to support HST archival research, is addressed in some detail by Tuohy (1987). It is argued that such a facility is essential for providing Australian astronomers with efficient access to the unique HST database that will become available on an expanding basis after a proprietary data period of approximately one year. The proposed facility would maintain the HST archive (on optical disks), and provide the staff expertise, catalogs, and computational resources for data processing, either locally or via remote access. A minimum staff level of 2 astronomers and ~2 computer/programming specialists is envisaged.

An important consideration is that it is already clear that the facilities of the Space Telescope Science Institute (STScI) will be stretched to the limit once HST becomes operational, and that opportunities for archival research by foreign investigators will be severely restricted (and in any event, subject to competitive proposals from the community at large). Thus, the STScI is encouraging the formation of a limited number of regional facilities, and in this regard, the Canadian astronomical community acted in 1985 by initiating the *Canadian Space Astronomy Data Center*, attached to the Dominion Astrophysical Observatory. This facility was established specifically to support HST data analysis, but the potential for also supporting ground-based archival research (e.g. CCD imagery from the Canada France Hawaii Telescope) has recently led to the word 'space' being dropped from the title. The Canadian Astronomy Data Centre (CADC) is now providing a service that is extremely similar to that foreseen for the proposed Australian facility, and is gearing up to handle the flow of HST archival data. The remotely accessible services presently provided by the CADC are described in a user manual (Justice, Durand, and Crabtree 1988), and include access to a wide range of astronomical catalogs and archival data. It is understood that a comparable HST regional facility in England is under consideration, and a major establishment, the Space Telescope European Coordinating Facility, is operational at the European Southern Observatory to support the 15% ESA share of the mission.

It is apparent that Australian astronomers will be at a significant disadvantage without similar access to HST archival data. Thus the Australian astronomical community needs to act urgently in a coordinated and collaborative manner to implement a national facility that would be established with HST archival research as a driving motivation, but which could also provide various other services on an on-line basis (Tuohy 1987). These include access to data from other space astronomy missions (e.g. IUE, IRAS, EXOSAT, etc) and to major astronomical catalogs (e.g. the SIMBAD catalog in Strasbourg, the HST Guide Star Catalog, Hipparcos catalogs, etc). It is clear that a national facility would greatly complement our ground-based telescopes, as well as opening up new fields of research that would be accessible to even small astronomical groups. Ideally, the proposed national facility should be hosted by a major astronomical institution, as is the case overseas. The Canadian facility could provide a valuable model for an Australian centre, particularly in view of the rather similar requirements of the astronomical communities in the two countries.

3.9 The ASTRO Observatory

ASTRO is an attached Space Shuttle payload that was originally due to be flown on the flight following Challenger. It is presently manifested for launch in March 1990. The payload comprises three ultraviolet telescopes, all coaligned and mounted to an Instrument Pointing System:

- The Hopkins Ultraviolet Telescope which consists of a 0.9 metre f/2 telescope with a prime focus Rowland-circle spectrograph sensitive between 420-1850Å. The resolution is ~3Å in first order, and ~1.5Å in second order. A sensitivity equivalent to an un-reddened B star of magnitude V = 17 is anticipated.
- An Ultraviolet Imaging Telescope, consisting of a 0.38 metre Cassegrain telescope having a 40 arcmin field of view and sensitive between 1200-3200Å. Ultraviolet images with a resolution of ~2 arcsec will be recorded through 11 selectable filters using an image intensifier and 70 mm film. A 30 minute exposure under dark orbital conditions will reach a magnitude equivalent to a V = 25 un-reddened B star.
- The Wisconsin Ultraviolet Photo-Polarimeter Experiment comprising a 0.5 metre Cassegrain telescope and a low resolution spectrometer equipped with polarimetric analysers to measure the four Stokes parameters in ~40Å bands covering the range 1400-3300Å. A sensitivity down to an ultraviolet magnitude of ~16 is expected.

In addition to the above UV package, a powerful X-ray telescope with a separate pointing system has been added to the ASTRO-1 mission in the aftermath of the Challenger accident. Known as the Broad Band X-ray Telescope (BBXRT), this instrument features a tightly nested set of 118 grazing incidence foils which permit efficient X-ray imaging to appreciably higher energies (>10 keV) than conventional soft X-ray telescopes (Serlemitsos 1981). Two mirror assemblies of diameter 100 cm are used, each with a cooled Si(Li) spectrometer in the focal plane. The resolving power ranges between 3-60 over 0.3-12 keV.

The ASTRO-1 mission will be under the control of Payload Specialists, and although it will only last ~10 days, the observatory will have a significant impact on UV and X-ray astrophysics. Several of the capabilities of the UV package complement those of HST, which is scheduled for launch just ahead of ASTRO-1. These include extreme ultraviolet spectroscopy, wide field UV imaging, and UV polarimetry (and the ability to gather imaging, spectroscopic and polarimetric data from the same target on a simultaneous basis). At X-ray wavelengths, BBXRT will be the first facility capable of undertaking imaging spectroscopy over a very broad energy range that includes the diagnostic iron line emission complex between 6-7 keV.

The first ASTRO mission is not open to Guest Investigator opportunities, although archival data will become available after a proprietary period. However, the ASTRO-2 mission in ~1992 will be suported by NASA on a full Guest Investigator basis.

3.10 Extreme Ultra-Violet Explorer

The NASA Extreme Ultra-Violet Explorer (EUVE; Bowyer 1983) will be one of two missions in 1990-91 (with ROSAT, discussed below) to conduct the first all-sky surveys in the EUV regime (100-1000Å). This spectral band has been neglected in the past because of pessimistic predictions concerning the severity of interstellar absorption in the solar neighbourhood. It is now recognized however that the local interstellar medium is very patchy, and that the Sun lies in a low density cavity having high EUV transparency. Accordingly, it should be possible to observe at 200Å to a distance of ~100 parsecs in many directions, and perhaps completely out of the Galaxy in some directions at 100Å.

EUVE will be the first payload to be installed on the new multi-purpose NASA Explorer Platform (which is compatible with either a Delta or Shuttle launch). It will operate initially in a spin-stabilized mode to facilitate an all-sky survey during the first six months of the mission. This survey will be performed with an angular resolution of ~0.1° by three 40 cm diameter grazing incidence telescopes viewing orthogonally to the spin axis of the spacecraft. Thus, an annular band of sky is scanned as the spacecraft rotates, and the complete sky is surveyed in 6 months by keeping the spin axis aligned with the Sun. The three telescopes and associated micro-channel plate detectors will have different filter transmissions, giving bandpasses of 80-190Å, 170-300Å, and 350-540Å or 500-750Å. The survey sensitivities in these bands are estimated to be 0.003, 0.3, 0.1

and 0.1 mJy respectively. In addition to the three survey telescopes, a fourth grazing incidence telescope with a bandpass of 80-350 Å is aligned along the spin-axis in the anti-solar direction to take advantage of the greatly reduced background arising from resonantly scattered solar HeIIλ304 Å emission. Although this telescope will only examine a narrow band of sky in the ecliptic plane, the sensitivity will be up to two orders of magnitude deeper than for the survey telescopes.

Following the completion of the survey phase of EUVE, the spin-axis telescope will be used in a *spectroscopic* mode to observe targets within 45° of the ecliptic plane (Hettrick *et al.* 1985). Light in the telescope focal plane is shared between three slit-less spectrometers which incorporate variable line space gratings and microchannel plate detectors. The three spectrographs have the following bandpasses, spectral resolutions, and peak effective areas: (70-190 Å, $\Delta\lambda \sim 0.5$ Å, 1.2 cm^2 at 100 Å), (140-380 Å, $\Delta\lambda \sim 1.0$ Å, 0.5 cm^2 at 200 Å), and (280-760 Å, $\Delta\lambda \sim 2.0$ Å, 0.6 cm^2 at 400 Å). Of special interest is the fact that the spectroscopic phase of EUVE will be dedicated entire to Guest Investigator observations under a peer review panel to be appointed by NASA. This phase is expected to last at least one year, subject to current NASA planning to replace EUVE with XTE (section 3.14) on the Explorer Platform after an 18 month mission.

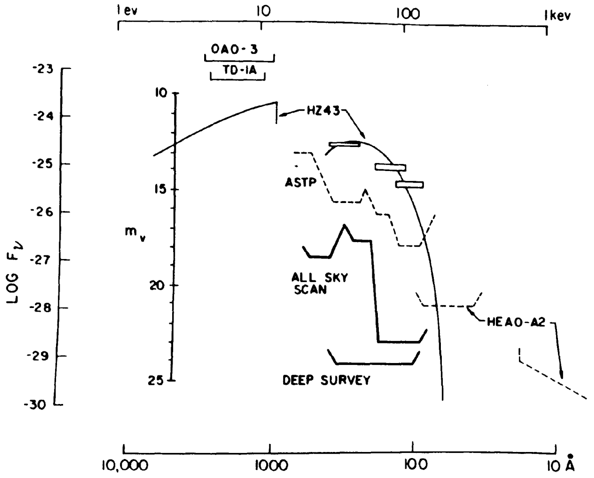

Figure 8—The sensivity of the EUVE survey compared with four previous missions (OAO-3 = Copernicus, TD-1A, ASTP = Apollo-Soyuz Telescope Project, and HEAO-A2). The spectrum of the hot white dwarf HZ 43 is also shown. The EUVE deep survey in the ecliptic plane will have a sensitivity ~10 magnitudes fainter than HZ43 (Bowyer and Malina 1981).

The all-sky survey by EUVE will have a sensitivity that exceeds that of previous pointed experiments on the Apollo-Soyuz and Voyager missions by a factor 10-100 (Figure 8). In fact these latter experiments have detected EUV emission from only ~10 celestial sources and these were chosen in a highly biased manner (e.g. Bowyer 1983). Thus the potential for discovering new objects and phenomena with EUVE is enormous. A primary goal will be to identify classes of EUV sources and to determine their space densities and luminosity functions. It is clear from earlier results that several calsses of galactic sources will be prominent at EUV wavelengths, namely hot white dwards, cataclysmic variables, flare stars, and late-type stellar coronae. In the case of hot white dwarfs, the observable numbers will be dependent on surface helium abundances, given the strong attenuation below the HeII edge at 228 Å for n(He)/n(H) ~ 10^{-3}. The spectroscopic mode of EUVE will actually allow direct measurement of this edge in hot white dwarfs. Many stellar coronae should be visible to EUVE, particularly M dwarfs because of their high space densities. Spectroscopic measurements of the continuum and line complexes will enable plasma temperatures, densities, and volume filling factors to be determined. The detection of nearby cataclysmic variables by EUVE would be especially important since most of the accretion luminosity is believed to released at EUV wavelengths, at least for non-magnetic systems with accretion disks.

3.11 ROSAT

ROSAT (Röntgensatellit) is primarily a German mission, but has substantial U.S. and British participation (Trümper 1984, 1988). It was originally due for launch into low earth orbit by the Space Shuttle in 1987, but has now been rescheduled for a Delta-2 launch by NASA in early 1990. The basic objective of the mission is to undertake exceedingly sensitive all-sky surveys at soft X-ray and EUV wavelengths. These surveys will be performed by two imaging telescopes, rather than by collimated detectors as used in the past (e.g. Uhuru, HEAO-1).

The X-ray telescope on ROSAT comprises a set of four nested Wolter Type I grazing incidence X-ray mirrors (37-83 cm diameter) having excellent imaging performance (3 arcsec Half Energy Width at 1.5 keV; Aschenbach 1988 and private communication). The relatively large grazing angles (~2°) define a high energy reflection cut-off near 2 keV, while a low energy limit of ~0.1 keV is set by the detectors. Three detectors are mounted on a carousel in the focal plane (Pfeffermann *et al.* 1986):

- Two Position Sensitive Proportional Counters (PSPC) providing a field of view of 2°, an angular resolution of 30 arcsec FWHM on axis, an modest energy resolution (45% FWHM at 1 keV, equivalent to ~4 independent colours between 0.1-2 keV). One of these detectors will be used throughout the survey phase of the mission, with the other providing redundancy. The peak effective area of the PSPC is ~200 cm^2 at 1 keV.
- A High Resolution Imager (HRI) based on a microchannel plate, and nearly identical to the instrument flown on the Einstein Observatory. This detector has lower quantum efficiency and a smaller field of view than the PSPC, but much better angular resolution (~3 arcsec).

A smaller coaligned EUV telescope, known as the Wide Field Camera (WFC), will also be carried as part of the ROSAT payload (Pye *et al.* 1984). This telescope consists of a nested set of three grazing incidence mirrors having a 5° field of view. Two curved microchannel plate detectors are located on a carousel in the focal plane, and selectable filters define several spectral bands between 70-1750 Å (but note that the survey phase will be limited to ~70-130 Å; Barstow *et al.* 1985). The peak effective area of the WFC using a Beryllium/Lexan filter is ~30 cm^2 at 125 Å.

The ROSAT survey will be executed by a continuous and over-lapping sequence of great circle scans perpendicular to the Earth-Sun line, such that the entire sky will be covered in 6 months. A novel aspect of this mode of operation is that the satellite spin period will be set to the orbital period (~90 minutes) so that Earth-occultation is completely avoided and a high observing efficiency achieved.

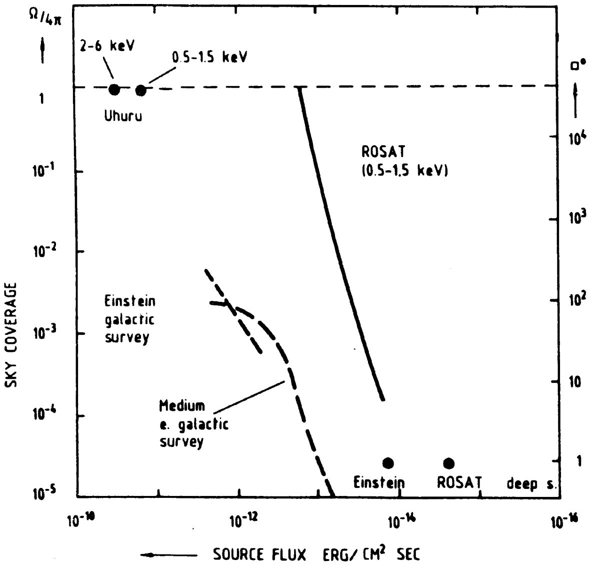

Figure 9—Sky coverage versus sensitivity for the soft X-ray telescope on ROSAT compared with the Uhuru all-sky survey, and selected regions surveyed by the Einstein Observatory. ROSAT will achieve a sensitivity comparable to the Einstein Medium Sensitivity Survey, but over the *entire* sky. During the pointed phase, ROSAT will reach flux levels ~10 times fainter than those of the Einstein Deep Surveys (Trümper 1983).

The imaging nature of the ROSAT survey will result in a dramatic increase in the number of cataloged sources at both soft X-ray and EUV wavelengths. For instance, the HEAO-1 all-sky X-ray catalog (Wood *et al.* 1984) contains 842 sources in the 1.5-20 keV band, compared with ~100,000 objects anticipated from the ROSAT soft X-ray survey. The potential of the ROSAT survey is further emphasized by Figure 9 which shows the sky coverage as a function of sensitivity, compared with other X-ray missions. The key difference is that very high sensitivity will be achieved over the *entire* sky. Thus ROSAT has enormous potential for significantly improving the number counts (i.e. Log N vs Log S) for various classes of sources, as well as extending these relationships to fainter flux levels. The sensitivity of the survey will be a function of ecliptic latitude, given that the rotation axis of the spacecraft will follow the Sun during the course of the six month survey. The 5σ sensitivity at the ecliptic equator will be ~2×10^{-13} erg cm^{-2} s^{-1} (0.1-2 keV), rising to ~2×10^{-14} erg cm^{-2} s^{-1} at the ecliptic poles. This latter figure is comparable to that achieved by the Einstein Observatory during a few long duration 'deep surveys'. Variability studies of sources close to the ecliptic poles will be possible since these regions will be scanned every orbit. The bulk of the $\geq 10^4$ galactic X-ray sources expected in the survey will correspond to coronal emission from nearby stars, while the ~10^5 extra-galactic sources will be dominated by active galactic nuclei, followed by clusters of galaxies. Sources will be located to <1 arcmin, rendering optical identificcation reasonably tractable, at least away from the Galactic Plane (arcsecond positions for selected sources can be obtained by follow-up observations using the HRI).

The number of sources to be detected during the WFC survey is more difficult to predict because of the uncertainty in the global EUV opacity, but is estimated to be 10^3-10^4 (Pye *et al.* 1984). Locational uncertainties will range from ~15 arcsec for strong sources to ~1 arcmin near the threshold sensitivity. The WFC is sensitive to plasma temperatures between 10^5-10^6K, and as with EUVE discussed above, most sources will correspond to late-type stellar coronae (normal main sequence stars, RS CVn binaries, and flare stars), isolated hot white dwarfs, cataclysmic variables, and supernova remnants. Given the wide field of view, the WFC will be especially well suited to mapping the EUV background and large scale structures in the Galaxy.

It is apparent that substantial optical and radio telescope time will be required to adequately exploit the ROSAT soft X-ray and EUV surveys. Australian telescopes can clearly play a major role in the identification and follow-up investigation of southern sources found in the surveys; these observations could be directed towards detailed studies of individual sources, or to statistical studies of large samples of objects.

Following the survey phase, the ROSAT mission will be devoted to *pointed* soft X-ray and EUV observations under a Guest Investigator program. It is understood that this program will only be open to astronomers in Germany, England, and the U.S.A., but no doubt collaborative observations involving Australian astronomers will be possible, especially if linked with observations at optical or radio wavelengths. It is anticipated that the lifetime of ROSAT will be ~3 years.

A follow-up spectroscopic mission to ROSAT has been proposed, and is known as SPEKTROSAT (Trümper 1988). This second mission would be a duplicate in essence, but with the addition of objective gratings behind the grazing incidence X-ray mirrors to enable high resolution imaging spectroscopy. The transmission gratings will have a spacing of 1000 lines mm^{-1}, and using an HRI as a detector, the resolving power will range from ~20 at 2 keV to ~200 at 0.2 keV (Predehl *et al.* 1988). The mission is presently aimed for launch in 1996, and will clearly have great diagnostic power in following up the results of the initial ROSAT survey.

3.12 SAX

The *Satellite Scientifico Italiano per Astronomia X*, SAX, is the first X-ray astronomy mission under the Italian National Space Plan, and includes participation by the Netherlands and ESA. A driving motivation, apart from the science objectives, is to stimulate the Italian space industry. Originally due for launch in 1989 on the Space Shuttle, SAX has been rescheduled for launch in late 1992 on an Atlas-Centaur vehicle. The mission has been described in considerable detail by Perola (1983), Spada (1983), Bevilacqua and Barraco (1983), Scarsi (1986), and Perola (1988). A comprehensive selection of X-ray instruments spanning the 0.1-200 keV regime is presently under construction:

- A Concentrator/Spectrometer system comprising an assembly of four grazing incidence telescopes (each with 30 tightly nested conical reflectors) with position-sensitive, gas scintillation proportional counters in their focal planes. The bandpass is very wide, 0.1-10 keV, thus providing sensitivity to X-ray plasmas at temperatures between 10^6-10^8K. The instrument has a total effective area of ~200 cm^2 at 7 keV, a field of view of 0.5°, a spatial resolution of ~1 arcmin, and an energy resolution of ~9% FWHM near 6 keV. This latter capability is particularly important for diagnostic measurements of highly ionized iron lines between 6-7 keV.
- A Phoswich Detector System (PDS) which provides low resolution broad band spectroscopy at hard X-ray energies between 15-200 keV. The effective area is ~800 cm^2 and the field of view of the rocking collimator is 1.5°. An anti-coincidence shield around the detector provides both charged particle rejection and sensitivity to gamma-ray bursts above a threshold of ~10^{-6} erg cm^{-2} s^{-1}.

- A High Pressure Gas Scintillation Proportional Counter for medium resolution spectroscopy between 3-120 keV. The energy resolution of 3% at 60 keV is a factor 6 better than the PDS, which is of prime importance for the study of high energy cyclotron lines in magnetic neutron stars. The effective area is $\sim$450 cm^2, and the field of view of the instrument is 1°. A rocking collimator permits measurement of the particle induced background.
- Two Wide Field Cameras, each having a 20° square field of view, an effective area of 250 cm^2, and a Dicke mask providing a spatial resolution of $\sim$5 arcmins in the range 2-30 keV. The two cameras point in opposite directions, perpendicular to the above three coaligned instruments. As well as providing simultaneous monitoring of sky regions during observations by the prime instruments, the two cameras will undertake high sensitivity scans of the galactic plane on a regular basis.

SAX will be launched into a circular 600 km orbit having a low inclination of 2°; such a near-equatorial orbit minimizes charged particle background, especially that due to the South Atlantic Anomaly. A Scientific Data Centre in Italy will operate the facility (via a satellite link and tracking facility in Malindi, Kenya) and also manage a Guest Investigator program. The minimum lifetime of the mission is 2 years, but an appreciably longer duration is anticipated.

The astrophysical objectives of the SAX mission have been reviewed in great detail by Perola (1983, 1988). These objectives encompass all classes of X-ray sources spanning 20 orders of magnitude in luminosity from nearby stellar coronae ($L_x \sim 10^{27}$ erg s^{-1}) to exceedingly luminous quasars ($L_x \sim 10^{47}$ erg s^{-1}). While many of the objectives parallel those of other X-ray missions, SAX offers the capability for very sensitive spectroscopy over more than three decades in energy. Thus, modelling of continuum processes should be especially fruitful (e.g. spectral breaks in stellar black hole systems and AGN). SAX will also be a powerful tool for imaging spectroscopy of supernova remnants and clusters of galaxies, and for broad-band pulse-phase spectroscopy of X-ray pulsars (and in particular, the umambiguous resolution of cyclotron emission/absorption features). Finally, regular monitoring by the wide field cameras will enable transient and known X-ray sources to be studied in exceptional detail at critical phases of activity.

3.13 ASTRO-D

ASTRO-D is the fourth in the ASTRO series of Japanese X-ray astronomy missions and will maintain continuity following the present Ginga spacecraft. The four missions have been characterized by a progressive increase in performance, and in this regard, ASTRO-D will be the first to have an imaging capability. The mission will emphasize high-throughout X-ray spectroscopy over a wide energy range (> 10 keV), together with a spatial resolution comparable to the Imaging Proportional Counter on the Einstein Observatory (Tanaka 1987c). ASTRO-D is in a conceptual design phase, but is intended to carry U.S. supplied multi-foil telescopes based on the BBXRT concept (Serlemitsos 1981; see also section 3.9 above). The payload will consist of four sets of grazing incidence mirrors, with a design goal being to achieve effective areas of ≥ 1000 cm^2 below 2 keV and ≥ 500 cm^2 between 6-7 keV (i.e. the energy range of highly ionized iron). The field of view will be 30 × 30 arcmin, and the spatial resolution will be < 1 arcmin (the pointing direction can be determined to ≤ 0.1 arcmin). Two types of imaging detectors are expected to be split between the focal planes of the four telescopes, with both types emphasizing good spectroscopic performance. These are Imaging Gas Scintillation Proportional Counters, and cooled CCD Cameras, providing high quantum efficiencies and spectral resolutions of $\leq 8\%$ and $\leq 2\%$ at 6 keV respectively. A comparison of the effective area versus energy for the Einstein Observatory, AXAF, and ASTRO-D is shown in Figure 10.

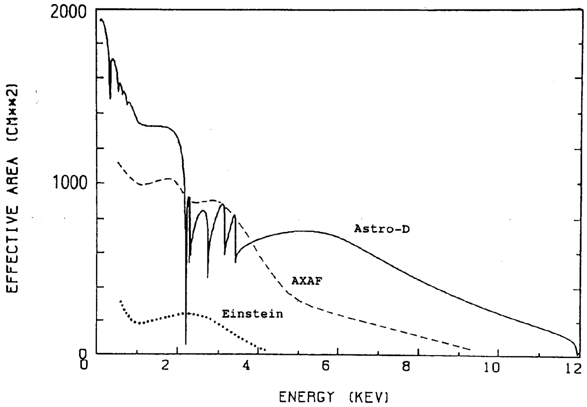

Figure 10 – The Effective area of ASTRO-D compared with the Einstein Observatory and the planned AXAF mission (Tanaka 1988, private communication). Note the significantly larger area below and above 2-4 keV; this will be especially important for plasma spectroscopy near the Oxygen ($\sim$0.5 keV) and Iron (6-7 keV) K-lines.

ASTRO-D is planned for launch into a 550 km circular orbit using a Japanese M-3SII rocket in early 1993. The mission will thus partly pre-empt the AXAF and XMM missions later in the decade, at least in the area of medium resolution imaging spectroscopy. For example, studies of supernova remnants will resolve the K-lines corresponding to O, Si, S, Ar, Ca, and Fe, and allow temperature and abundances to be investigated as a function of location in the remnants. The CCD Cameras will permit the K_α and K_β components to be separated, as well as the detection of Doppler shifts of ≥ 1000 km s^{-1} in young remnants. Other examples of ASTRO-D science are listed by Tanaka (1987c), and cover most classes of galactic and extra-galactic X-ray sources. These include spectral measurements of AGN that are a factor 10 fainter than previously detectable, compositional studies of the cosmic X-ray background beyond the limit of the Einstein Observatory, and measurements of the temperature and abundance structure of clusters of galaxies up to $z = 1$.

3.14 X-ray Timing Explorer

The NASA X-ray Timing Explorer (XTE; Bradt 1983, Bradt and Swank 1988) has been in a study phase for many years and is presently scheduled for Shuttle launch and in-orbit installation on the Explorer Platform in 1994 (replacing EUVE, according to present NASA planning). As the name suggests, the primary purpose of the mission is to undertake timing studies of galactic and extra-galactic X-ray sources on time scales ranging from micro-seconds to months. The instrumentation for XTE has been driven by three main considerations: a broadband wavelength coverage, the need to obtain high statistical precision on sub-millisecond timescales, and the capability to detect and respond rapidly to transient phenomena. These requirements are satisfied by the following three instruments:

- A very large area Proportional Counter Array (PCA) sensitive to X-rays between 2-60 keV. The net effective area is 6000 cm^2 at 10 keV, providing a 2-10 keV confusion-limited sensitivity of 0.1μJy in a timescale of minutes. The detectors have a 1° FWHM circular field of view, with two of the array modules being offset from the pointing axis to continuously monitor the background. The time resolution of the PCA is 5μsec.

- A High Energy X-ray Timing Experiment (HEXTE) based on NaI/CsI phoswhich scintillation detectors operating between 15-200 keV. The instrument modules have a 1° FWHM circular field of view (coaligned with the PCA) and are gimballed to permit chopping measurements of the target object and four surrounding background regions. HEXTE has an effective area of 1100 cm^2 at 100 keV, a sensitivity of 1μJy in 10^5 seconds, and a time resolution of 5μsec.
- An All-Sky Monitor (ASM) which is a 2-10 keV position-sensitive proportional counter based on a scanning Dicke camera. The ASM has one-dimensional angular resolution, and thus scans slowly in the second dimension around an axis which is inclined at 45° to the pointing axis defined by the PCA and HEXTE. In this manner, 80% of the celestial sphere is surveyed during a satellite orbit (90 minutes) at a sensitivity of 30μJy per orbit (or 10μJy per day). In addition to patrolling the sky for sudden X-ray transients, the ASM can also monitor the long term variability of numerous catalogued sources with a time resolution of 90 minutes over the entire mission.

A further key feature of XTE is unsurpassed operational flexibility. In contrast to all previous X-ray missions, the entire sky will be accessible on any day except for a ~15% area around the Sun. In particular, anti-Sun pointing is a design feature which will permit *all-night* coordinated optical studies from ground-based observatories, instead of the present short overlap periods that are a consequence of strict satellite sun-angle constraints. Similarly, all transient X-ray sources detected by the ASM will be accessible for rapid follow-up studies by the PCA and HEXTE within hours of discovery. The fast slew rate of the spacecraft (6° per minute) will also permit weak sources to be monitored efficiently by brief PCA observations on a daily basis.

The primary science goals of XTE concern compact objects (white dwarfs, neutron stars, and black holes), and especially the evolution of these systems, and the physical parameters of their environments under extreme conditions of gravity, temperature, and magnetic field. Very high time resolution is mandatory for such studies, given that the free-fall timescale of accreting material in the vicinity of a neutron star or stellar black hole is 0.1-1 millisecond. The mission is aimed at the brightest ~1000 X-ray sources in the sky, ranging from isolated X-ray pulsars, to binary X-ray systems, to AGN containing massive black holes. In the case of neutron stars, precise timing measurements of pulsation and binary periods will provide direct information on their equations of state, accretion torques, emission geometries, and magnetic fields. XTE is also especially well suited to the investigation of Quasi-Perodic Oscillation (QPO) behaviour in low mass X-ray binaries containing neutron stars (believed to be the pre-cursors of millisecond radio pulsars). Other examples of XTE science are provided by Bradt and Swank (1988).

XTE has great potential for participation by the Australian astronomical community. First, the mission will be entirely dedicated to *Guest Investigator* observations following an initial check-out and calibration period. Second, the mission is essentially the first for which *multi-wavelength* observations have been a design driver. Such measurements have been notoriously difficult in the past due to the difficulties of coordinating satellite observations sufficiently in advance to match ground-based schedules on the one hand, and the small degree of simultaneous overlap for optical measurements on the other. The first of these problems will be alleviated by a positive XTE policy to encourage and support multi-wavelength observations in recognition of the projected scientific return, while the latter situation will not arise because of the anti-sun pointing capability of XTE. Thus Australian astronomers will be exceptionally well placed to take advantage of the opportunities for correlated observations of southern sources, which in many cases could include the application of even small telescopes equipped with CCDs.

3.15 Gamma-1

Gamma-1 is a joint U.S.S.R.-France-Poland mission due for launch in late 1988 into a low earth orbit of altitude ~400 km and inclination ~51°. The Salyut-type spacecraft will carry 2000 kilograms of scientific instrumentation, and will have 3-axis stabilization to a precision of ~30 arcminutes, with a star sensor providing aspect determination to ~2 arcminutes. Gamma-1 will be tracked only from the Soviet Union, and thus data will be stored in a large memory (~100 Megabits) and down-linked twice per day. Three instruments cover the γ-ray and X-ray regimes:

- GAMMA-1: A 50-500 MeV gamma-ray detector involving a 12-layer spark chamber, a Cerenkov gas counter, two time-of-flight scintillators, and a 4-layer scintillation calorimeter for energy measurement (Akimov *et al.* 1985, 1987). The instrument has a field of view of 20°, an effective area of 250 cm^2 at 500 MeV, an energy resolution of 30% at 300 MeV, and an angular resolution of 1.2° at 300 MeV. Increased angular resolution (≤ 20 arcmin) can be obtained by moving a pair of tungsten coded-masks in front of the aperture. Both the effective area and the angular resolution are 2-4 times better than those of the COS-B mission. A sensitivity in COS-B units of ~10^{-7} counts cm^{-2} s^{-1} is anticipated, and sources that are a factor ~10 brighter will be localized to a precision of a few arcminutes (thereby greatly improving the prospects for optical and/or radio identification).
- DISK: A NaI scintillator experiment covering the 20 keV-5 MeV range. The overall field of view is 20°, but a rocking collimator provides an instantaneous field of ~3° for source localization and background determination. The sensitivity for a one hour observation is ~10^{-4} counts cm^{-2} s^{-1} keV^{-1} at 200 keV, and $\sim 2\times10^{-6}$ counts $cm^{-2}s^{-1}$ keV^{-1} at 2 MeV. The instrument will be especially suitable for gamma-ray line emission studies.
- PULSAR X-2: An array of four proportional counters with offset collimators to study X-ray pulsar and bursting phenomena between 2-25 keV.

The Gamma-1 science program will clearly give primary emphasis to detailed studies of the 25 γ-ray sources catalogued during the COS-B all-sky survey (Swanenburg *et al.* 1981). An important aspect is the capability of performing simultaneous γ-ray and X-ray observations for the first time. Akimov *et al.* (1987) present simulations showing the expected results for an observation of the Vela pulsar lasting 6 days; other observations could last as long as a month, given the faintness of the COS-B sources. Last, it is noted that Soviet astronomers have expressed a strong desire for coordinated and follow-up observations by

Australian observatories (such measurements will be particularly important for determining the nature of the mostly un-identified COS-B sources).

3.16 Granat

GRANAT is a high orbit (200,000 × 2,000 km) observatory being prepared for launch in 1989 by the U.S.S.R., France, Denmark and Bulgaria. It has 3-axis stabilization to a precision of ~20 arcminutes over 24 hours and will be capable of continuous operation for three days out of the four day orbit (i.e. above the radiation belts). The following comprehensive suite of instruments will be flown on GRANAT:

- ART-P: Four coaligned coded-mask proportional counters for Positional measurements between 3-100 keV. The field of view is 1.8° square, and the angular resolution is 5 arcminutes. The total sensitive area is 2400 cm^2.
- ART-S: Two pairs of conventional proportional counters with a rocking collimator for Spectroscopic measurements between 3-150 keV. The field of view is 2° square, and the combined sensitive area is 2400 cm^2.
- SIGMA: A coded-mask NaI scintillator comprising four modules of effective area ~400 cm^2 for studies of X-ray sources and gamma-ray bursts in the energy range 50 keV-2 MeV. The field of view is 10° square and the angular resolution is 16 arcmins. The experiment incorporates two star sensors, one of which provides optical imaging during gamma-ray bursts.
- KONUS: An array of seven NaI detectors for gamma-ray burst studies in 40 spectral channels between 20 keV-4 MeV. Localization accuracy for bursts is 1-5°.
- PODSOLNUKH (Sunflower): Two proportional counters (2-25 keV) on a steerable platform which can be manoeuvred rapidly (~1 second) to point towards a burst source detected by KONUS. A coaligned 6 cm refractive telescope with a CCD array provides optical imaging of burst sources.
- PHEBUS: An array of six bismuth germanate detectors (100 keV-100 MeV) for spectral studies of gamma-ray bursts over 4π steradians. The burst sensitivity ranges from 2×10^{-6} to 4×10^{-7} erg cm^{-2}.
- WATCH: A mosaic of NaI and CsI scintillators and a rotating modulation collimator to localize rapidly varying X-ray sources in the range 5-120 keV. Four modules with an effective area of 45 cm^2 provide 4π coverage and an angular resolution of ~0.1°.

Data from Granat will be transmitted in real-time during ~4 hour periods of visibility to U.S.S.R. ground stations, and also stored in onboard bubble memories and a tape recorder for subsequent dumping once per day. Due to the evolution of the orbit, tracking support from a station(s) outside the U.S.S.R. is desirable in later years of the mission (e.g. Australia?). Support of the mission by ground-based optical and radio observatories in Australia has been encouraged by the U.S.S.R. under the U.S.S.R.-Australia Space Research Agreement.

3.17 Spectrum-X-Gamma

Two spacecraft are envisaged in the new-generation U.S.S.R. Spectrum-X-Gamma series, each having wide international collaboration. The first is an approved mission planned for launch during 1993 into a high apogee orbit of altitude 200,000 km and period 4 days. The U.S.S.R. is providing the spacecraft, the ground segment, and part of the ~2500 kilogram instrumentation. The spacecraft will have a pointing accuracy of 2 arcminutes, and stabilization within 30 arcseconds over 24 hours. Data will be transmitted in real-time when the spacecraft is visible to ground stations, and also dumped for one hour per day from onboard memories for each instrument (total capacity $1\text{-}5 \times 10^{10}$ bits). The payload is in a final definition phase, but the following coaligned, multi-national instruments are planned or are under consideration:

- X-SPECT: Two identical multi-foil (>100 nested conical surfaces) telescopes having deployable focal lengths of 8 metres, a peak effective area of ~4000 cm^2 between 0.2-20 keV, a ~1° field of view, and an angular resolution of ~2 arcmins. The focal plane detectors are not yet defined, but a Bragg crystal spectrometer is incorporated to provide an energy resolution of R~500. A 5σ sensitivity of 3×10^{-14} erg cm^{-2} s^{-1} between 0.5-10 keV will be achieved in 2000 seconds.
- JET-X: A Wolter imaging X-ray telescope incorporating a cooled CCD in the focal plane, and having a bandpass of 0.2-10 keV with an effective area of 350 cm^2 at 1 keV. The field of view is 40 × 40 arcmins, and the angular resolution is 10-30 arcsecs. The 5σ sensitivity is 3×10^{-15} erg cm^{-2} s^{-1} between 0.5-10 keV for a 10^5 second exposure.
- MART: A coded-mask hard X-ray (4-100 keV) telescope similar to ART-P on the Granat spacecraft. It has an 8 × 8° field of view, a spatial resolution of ~6 arcmins, and an effective area of 650 cm^2.
- EUVITA: Two extreme ultraviolet, normal-incidence telescopes with multi-layer coatings providing bandpasses between 100-400 Å. Microchannel plate detectors give an angular resolution of ~10 arcsecs over a 1° field of view.
- FOURPI: A coded-mask all-sky X-ray monitor (2-15 keV) consisting of four wide-field, cylindrical, position-sensitive proportional counters having a total effective area of 3500 cm^2. Transient X-ray sources can be located to a precision of a few arcminutes by combining data acquired at different alignment angles.
- SPIN: An array of gamma-ray burst detectors having 4π coverage and an energy range of 10 keV to 10 MeV. Burst events above can be located to 0.5°.

In addition to the above instruments, a further set of detectors will be mounted on a *steerable* platform (similar to the Sunflower facility on Granat) which can be slewed rapidly (~1.5 seconds) to enable viewing of gamma-ray burst sources and other objects simultaneously with the fixed, coaligned instruments:

- ART-SP: A 2.5-35 keV coded-mask telescope with a 7.3° square field of view and a ~7 arcmin spatial resolution.
- GITA: A doubly-nested Wolter-I grazing incidence telescope sensitive between 0.5-2 keV. The effective area is 30 cm^2 at 1 keV, and the angular resolution is ~20 arcsecs over the 2° field.
- Two EUVITA-type extreme ultraviolet telescopes.
- An Optical Monitor/Star Tracker with a 3 × 3° field of view and sensitive down to $\sim 13^m$.

The Spectrum-X-Gamma mission is clearly destined to have a major impact on X-ray Astronomy, ranking with the Observatory-class missions of other countries. It will benefit from the sensitive all-sky X-ray survey to be undertaken during the forthcoming ROSAT mission, and will precede AXAF and XMM in the late 1990s. The broad objectives include high resolution spectroscopy and imaging of faint sources, timing studies, and the determination of the redshifts of distant clusters of galaxies via their iron line emission.

While the first Spectrum-X-Gamma mission is largely defined, a narrow window of opportunity for participation by Australia has arisen under the U.S.S.R.-Australia Space Research Agreement signed in December 1987. In particular, during a visit by an Australian Space Office delegation to Moscow in June 1988, an invitation was extended by the U.S.S.R. for Australia to supply the FOURPI X-ray monitor in collaboration with the University of Birmingham who first proposed the instrument. Funding is being actively sought for FOURPI which provides an outstanding opportunity to apply Australian rocket and balloon X-ray expertise in an orbital environment, with far greater scientific return. FOURPI offers a factor of 10 increase in sensitivity over previous all-sky X-ray monitors, and for the first time, will enable the entire sky to be imaged on an essentially continuous basis as a result of the deep orbit. The instrument will allow simultaneous monitoring of hundreds of X-ray sources (including X-ray binaries, new transient objects, flaring events, and AGN) on timescales ranging from minutes to months (and even years). Such studies constitute a largely unexplored regime of parameter space, and thus fundamentally new results can be anticipated. It is noted that FOURPI measurements would provide significant opportunities for participation by the Australian astronomy community, especially through correlated and follow-up optical/radio observations.

The second spacecraft in the Spectrum-X-Gamma series is still under discussion for possible launch no earlier than 1995 (it is not yet approved under the USSR five year plan). This mission will emphasize X-ray timing and hard X-ray/γ-ray astronomy, and is presently intended for low Earth orbit at an altitude of ~ 400 km. As with the first mission, there will be substantial opportunities for international participation.

3.18 Indian X-ray Astronomy Satellite

In August 1987, funding approval was granted by the Indian Space Research Organization for an Indian X-ray Astronomy Satellite (IXAS; Agrawal *et al.* 1985) which will build on experience gained in previous X-ray missions (e.g. Bhaskara; Manchanda *et al.* 1980). IXAS will use a 150 kg class, spin-stabilized, Rohini satellite, and will be launched into a ~ 500 km orbit using an Indian ASLV rocket in ~ 1992. The satellite spin axis can be pointed to a precision of $1°$, and the payload comprises:

- Three collimated proportional counters sensitive between 2-20 keV, each having effective areas of ~ 200 cm^2 and fields of view of $3° \times 3°$ FWHM. Two of the proportional counters view along the satellite spin axis, while the third is offset by $6°$ to provide simultaneous monitoring of the background.
- A Monitor Proportional Counter having an effective area of ~ 60 cm^2 and a fan beam field of view measuring $1° \times 6°$ FWHM. This detector will be offset by $30°$ from the spin axis so that a $360° \times 60°$ region of the sky will be surveyed every spin cycle. The primary purpose is to detect new transient or flaring X-ray sources.

Clearly, the IXAS capabilities will be limited compared with other planned X-ray facilities in the next decade. Nevertheless, IXAS will be able to undertake valuable timing and spectroscopic studies, especially in view of the great demands that will be placed on the limited number of X-ray observatories that are available at any one time. The observing program will emphasize periodic and aperiodic variations in weak galactic X-ray sources, changes in the pulsation and orbital periods of X-ray pulsars and binaries, long term variability in AGN, the light curves and spectral evolution of transient and flaring X-ray sources, and correlated X-ray and optical investigations. It is expected that 30-50 X-ray sources can be studied in detail during the ~ 2 year mission.

3.19 Shuttle High Energy Astrophysics Laboratory

The NASA Shuttle High Energy Astrophysics Laboratory (SHEAL-2) is an attached Shuttle payload similar in concept to the ASTRO mission described earlier. It is scheduled for a ~ 7 day flight in late 1992, and comprises two separate experiments:

- A Diffuse X-ray Spectrometer (DXS) which will conduct the first high resolution spectroscopy of the diffuse soft X-ray background between 0.15-0.30 keV. DXS consists of a pair of identical Bragg reflection spectrometers mounted on opposite sides of the Shuttle cargo bay. Both detectors rotate in order to measure the background over a $\pm 75° \times \pm 15°$ band of sky. The spectral resolution is < 0.01 keV which is sufficient to resolve various silicon, sulphur and magnesium lines which are expected to be present in the 0.15-0.30 keV background spectrum, depending on the origin of the radiation. In particular, the prime objective of DXS is to confirm that the soft X-ray background arises from $\sim 10^6$ K plasma produced by ancient supernovae within a few hundred light years of the Solar System. The emission line spectra measured over selected regions of the sky will enable the temperature, composition and ionization state of the emitting plasma to be ascertained.
- A Broad-Band X-ray Telescope (BBXRT) similar to that to be flown during the ASTRO mission (see section 3.9 and Serlemitsos 1981). It consists of two 100 cm diameter coaligned telescopes, each comprising 118 nested reflecting surfaces which focus X-rays on to Si(Li) detectors. The detectors are cooled using solid argon, and have a small degree of spatial resolution (a central pixel for point sources, and four surrounding pixels for background and/or extended source measurements over 4 arcminutes). Effective areas of 765 cm^2 at 1.5 keV and 300 cm^2 at 7 keV will be achieved, together with a resolving power of 3-60 between 0.3-12 keV. BBXRT will be mounted to a Two-Axis Pointing System to permit precise target acquisition largely independent of Shuttle orientation and motion. Most of the observing time will be devoted to measuring the X-ray spectra of AGN, although clusters of galaxies, young supernova remnants, and X-ray binaries will also be observed. As indicated previously, the BBXRT spectra will be of far higher quality than past measurements, especially in the vicinity of the diagnostic iron line complex between 6-7 keV.

Subsequent Shuttle flights with an evolving complement of instrumentation are envisaged in the SHEAL series. These later missions are expected to provide opportunities for Guest Investigator observations.

3.20 Advanced X-ray Astrophysics Facility

The Advanced X-ray Astrophysics Facility (AXAF) is the long-awaited successor to the NASA Einstein Observatory (HEAO-2) which undertook the first X-ray imaging observations of celestial X-ray sources between 1978-81. Extensive technological studies of the mission have been underway in recent years, and construction of the telescope and instrumentation is expected to begin in 1989, leading to a Shuttle launch in ~1996 and a planned mission lifetime of ~15 years. AXAF will be the third in the NASA 'Great Observatories' series, after HST and GRO, and the overlap with these latter two facilities will greatly add to the astrophysical potential of the mission. The scientific importance of AXAF is underscored by the fact that in 1982 it received the number one priority in the Field Committee ranking of all major new programs in both space *and* ground-based astronomy (Field *et al.* 1982). Australian astronomers will be eligible to apply for observing time on AXAF under an international Guest Investigator program to be administered by NASA.

AXAF will comprise a set of six nested pairs of grazing incidence mirrors with diameters between 0.6 to 1.2 metres and focal lengths of 10 metres (Weisskopf 1987). The mirror assembly has four times the collecting area (~1700 cm^2) of the Einstein Observatory and eight times better angular resolution (~0.5 arcsec). Also, the image degradation caused by mirror scattering in the wings of the point response function will be markedly reduced. Arguably the most important improvement however is the broad bandwidth (0.1-10 keV) achieved with the long focal length and shallow grazing angles. This bandwidth is twice that of the Einstein Observatory and four times that of the impending ROSAT mission. Apart from permitting more precise spectral determinations of source continua, the wide bandwidth encompasses the cirtical emission line complex between 6-7 keV due to highly ionized iron—a pervasive feature of X-ray emitting plasmas, and of great diagnostic value.

The improvements in X-ray mirror technology for AXAF are combined with four advanced focal plane instruments:

- A High Resolution Camera (HRC; Murray *et al.* 1987) having a 32 arcminute square field of view and an angular resolution of 0.5 arcsec between 0.1 to 8 keV. This microchannel plate detector has excellent imaging qualities but very little energy resolution.
- A CCD Imaging Spectrometer (ACIS; Nousek *et al.* 1987) comprising an array of CCD chips combining subarcsecond resolution, significant energy resolution (~150 eV), and a quantum efficiency of ~30% over most of the 0.1-10 keV bandwidth.
- An X-ray Calorimeter (Holt 1987) offering an exceptional spectroscopic performance of 10 eV resolution and very high quantum efficiency over the entire AXAF bandpass.
- A Bragg Crystal Spectrometer (BCS; Canizares *et al.* 1987) incorporating a variety of reflective crystals for dispersive spectrosccopy at resolving powers of 50 to 2000 in strategic energy intervals within the AXAF bandpass. This instrument offers unsurpassed spectral resolution at the expense of lower effective area and a wavelength-scanning mode of operation.

Both the X-ray Calorimeter and ACIS represent new X-ray technologies, while the HRC and the BCS are greatly improved versions of instruments flown on the Einstein Observatory. In addition to the four focal plane detectors, AXAF includes two sets of objective gratings which diffract the X-ray spectrum on to either the HRC or ACIS; the Low Energy X-ray Transmission Grating Spectrometer (Brinkman *et al.* 1987) covers the wavelength region between 2-140Å with a spectral resolution of 0.05Å, while the High Energy Transmissions Grating (Canizares *et al.* 1987) operates over the energy range of 0.4-8 keV and provides resolving powers of 200-2000.

Given the huge gain in senstivity relative to the Einstein Observatory (e.g. Figure 5), the science objectives of AXAF give greatest emphasis to extragalactic studies. For instance, it is expected that AXAF will have the capability to settle the long-running uncertainty in the origin and composition of the diffuse X-ray background once and for all (Giacconi 1987). Also in the area of cosmology, AXAF should permit the first determination of the Hubble constant (to precision of ~10%) using the Sunyaev-Zel'dovich effect in distant clusters of galaxies (van Speybroeck 1987). Exceptionally sensitive imaging and spectroscopic studies of AGN, normal galaxies and clusters of galaxies will also lead to improved temperature, luminosity, mass and distance measurements. Further details of these and other examples of the power of AXAF can be found in a special issue of Astrophysical Letters and Communications (Volume 26, Numbers 1-2, 1987).

3.21 X-ray Multi-Mirror Mission

The X-ray Multi-Mirror Mission (XMM; Peacock and Ellwood 1988, Ellwood and Peacock 1988), alternatively known as the High Throughput X-ray Spectroscopy Mission, is the second Cornerstone facility in the ESA Horizon 2000 program (Bonnet 1989). It will be the first ESA follow-up X-ray mission to the outstandingly successful Exosat spacecraft which operated between 1983-86, and amongst other achievements, pioneered the application of a high altitude orbit for X-ray Astronomy to great scientific gain.

XMM is presently in a technology development phase leading up to anticipated construction beginning in ~1992 and launch in ~1998. The driving philosophy of XMM is to achieve unprecedented sensitivity for the spectroscopic diagnosis of galactic and extragalactic X-ray plasmas (particularly for the oxygen and iron K-lines). To this end, the major elements of the facility are a set of three very large area X-ray mirror modules and a suite of advanced focal plane detectors for imaging spectroscopy. Each mirror module comprises a set of 58 nested grazing incidence mirrors which provide an X-ray bandpass up to 10 keV, and modest imaging capability (~30 arcsec resolution) within a 30 arcminute field of view. The dramatic gain in effective area and bandwidth of XMM over other X-ray missions is highlighted in Figure 11.

The three X-ray telescopes will each have a CCD camera at their prime foci to provide a capability for broad-band imaging spectrophotometry with a resolving power of 10-50 between 1-7 keV. In addition, two of the modules will be equipped with reflection gratings which will disperse 40% of the photons to CCD strip detectors at off-axis secondary foci. The latter combination will permit medium resolution spectroscopy with a resolving power of 200-400 in the waveband 4-50Å. Most of the photons (50%) that are not intercepted by the reflection gratings will be transmitted directly to the CCD cameras at the prime foci, thereby permitting images of the entire field to be acquired simultaneously with the dispersive spectroscopy. XMM will also carry an Optical Monitor that will provide simultaneous coverage of the entire field down to a limiting magnitude of 24.5 between 2000-6000Å. This concept, the first such inclusion of a sensitive optical telescope on an X-ray mission, will greatly extend the potential of the mission for multi-wavelength studies, while eliminating the difficulties of coordinating space-borne and ground-based optical measurements (and weather problems). The Optical Monitor will also provide positional calibration for the X-ray telescopes.

An important feature of XMM is that it will be launched into a highly eccentric 24 hour orbit in order to provide high observing efficiency by minimizing Earth occultations, and to

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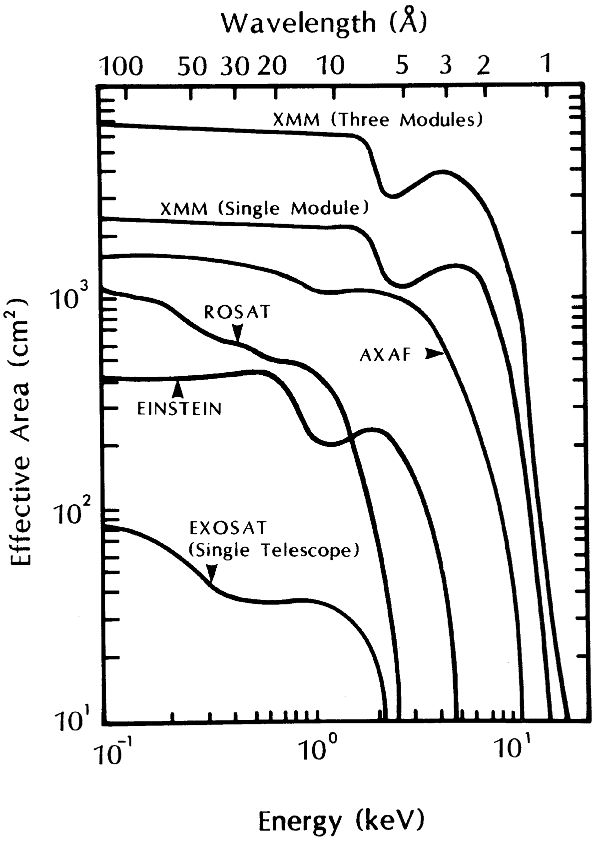

Figure 11—The effective area of the XMM High Throughput Spectroscopy mission compared with previous and planned X-ray observatories. In addition to having superior collecting area, XMM will have the widest X-ray bandpass (ESA SP-1097).

enable uninterrupted monitoring of X-ray sources that vary on timescales of less than 1 day. It is pointed out that the apogee must be in the Southern Hemisphere, and accordingly, an Australian ground station is deemed essential (Peacock and Ellwood 1988). The ESA tracking facility at Gnangara (near Perth) is presently baselined; it is thus conceivable that an Australian scientific role in XMM could be negotiated with ESA on a similar basis to that proposed for the Infrared Space Observatory (section 3.3).

XMM will be operated from a single control centre on a near-real time basis, and although the 'high reliability design lifetime' is 2 years, the onboard consumables will permit a mission duration in excess of 10 years. Observing time will become available under a world-wide Guest Investigator basis beginning ~6 months after launch, and will reach a level of 100% after 2 years. XMM is therefore destined to be a major new astronomical tool, and together with the contemporaneous AXAF mission, will dominate X-ray Astrophysics at the turn of the century.

XMM will permit high quality spectral measurements to be undertaken for sources as faint as 10^{-14} erg cm^{-2} s^{-1}. For many targets, simultaneous UV/optical monitoring will be feasible, and in addition, the imaging optical monitor will enable immediate identification of many of the X-ray field sources. The science potential of XMM is described in considerable detail in the Mission Science Report for XMM (ESA SP-1097). Amongst the prime scientific objectives are the following:

- Understanding the origin and composition of the diffuse X-ray background.
- Mapping of the temperature and elemental abundances in clusters of galaxies.
- The determination of cluster evolution with redshift.
- An unbiased spectral survey of a large number of elliptical and spiral galaxies.
- Understanding the detailed temporal and spectral characteristics of active galactic nuclei and their dependence on redshift.
- Studies of accreting X-ray binaries in nearby galaxies.
- Detailed temporal and plasma diagnostic studies of accreting binaries in our own Galaxy.
- A complete and unbiased stellar X-ray spectral survey.
- Studies of the timescales and physics of stellar flares.
- Spectral studies of supernova remnants in nearby galaxies.

3.22 Gamma Ray Observatory

The Gamma-Ray Observatory (GRO) is the second in the series of 'Great Observatories' planned by NASA. GRO is presently scheduled for Shuttle launch in 1990, and will offer a sensitivity an order of magnitude better than any previous gamma-ray mission. There are four separate instruments covering an exceptionally broad wavelength range of $0.05-3\times10^4$MeV:

- EGRET, the Energetic Gamma-Ray Telescope, is a wide field of view telescope based on a spark chamber, a total absorption scintillator counter, and a time-of-flight coincidence system. It has a maximum effective area of 2000 cm^2 and is sensitive to gamma-rays from 20 to 3×10^4MeV. The energy resolution is ~15% in the centre of this range, and the point source sensitivity is $\sim5\times10^{-8}$ photons cm^{-2} s^{-1} above 100 MeV. Sources can be located to an accuracy of 0.5-1°.
- COMPTEL, the Imaging Compton Telescope, is a wide field of view (1 steradian) double-Compton telescope spanning the 1-30 MeV range and providing an energy resolution of 5-8% and a positional accuracy 7.5 arcminutes for strong sources. The maximum effective area is 50 cm^2, and the point source sensitivity is 3×10^{-5} to 3×10^{-6} photons cm^{-2} s^{-1} for line emission, and 5×10^{-5} photons cm^{-2} s^{-1} for continuum emission ($E>1$ MeV).
- OSSE, the Oriented Scintillation Spectrometer Experiment, consists of four identical Phoswich scintillation detectors, each of which is mounted on a gimbal allowing rotation through 180° in a single plane. The detectors have a field of view of 3.8° × 10° and are sensitive to gamma-rays between 0.1 to 10 MeV with an energy resolution of 8% at 0.66 MeV. The maximum total effective area is 2310 cm^2, and the predicted sensitivity for line emission is 2×10^{-5} photons cm^{-2} s^{-1}, and 3×10^{-5} photons cm^{-2} s^{-1} for continuum emission between 0.1 to 10 MeV.
- BATSE, the Burst and Transient Source Experiment, is composed of four detectors designed to continuously monitor a large segment of the sky for the occurrence of gamma-ray bursts. For burst *monitoring*, it has an energy range of 0.05 to 1.0 MeV, a time resolution of <1 millisecond, and a maximum effective geometric factor of 15,000 cm^2 sr. For burst *spectroscopy*, it has an energy range of 0.05 to 20 MeV, a resolution of 7.3% at 0.66 MeV, and a maximum effective area of 127 cm^2 on each of the four detectors.

The Science Plan for GRO is presented in considerable detail by Kniffen *et al.* (1988). Prime objectives include:

- The nature of the un-identified COS-B sources. Only a handful of the 25 sources in the COS-B catalog are identified (Swanenburg *et al.* 1981), and the lack of bright X-ray or radio counterparts implies that their peak luminosities occur in the gamma-ray regime. Thus the question arises as to whether these sources belong to a new class of energetic object. The improved sensitivity and angular resolution of GRO will be crucial for addressing this question via reliable identifications.
- Nucleosynthesis processes through the study of gamma-ray line emission (e.g. silicon, sodium and nickel lines, π^0 decay lines near 68 MeV, and the 511 keV positron annihilation line). Silicon emission from extragalactic supernovae should be detectable at distances of up to 10 Mpc.
- Gamma-ray emission processes near neutron stars and black holes. This includes the mechanism responsible for the high luminosity ($L_\gamma \sim 10^{33\text{-}34}$ erg s^{-1}) pulsed emission from radio pulsars, and a search for similar pulsations from SN 1987A. Also, the study of quantized cyclotron emission from strongly magnetized neutron stars ($B \sim 10^{12\text{-}13}$ G), gamma-ray bursts from accreting neutron stars, and red-shifted emission lines (e.g. 511 keV) from both neutron stars and black holes.
- The structure and dynamics of the Galaxy through a study of diffuse gamma-ray emission. Essential requirements for this study are good angular resolution to resolve discrete sources, and spectral measurements in the few MeV region to separate nucleonic emission from that of cosmic ray electrons. GRO will provide independent information on the density distributions of both the cosmic ray nucleons and the cosmic ray electrons in the Galaxy.
- Extragalactic gamma-ray emission, covering radio galaxies, AGN, diffuse processes, and cosmology. A key factor here is the transparency of the Universe to gamma-rays, allowing early epoch cosmological studies to redshifts of $Z \geq 100$. Studies of the spectrum and degree of isotropy of the diffuse gamma-ray emission are vital for testing cosmological models, while the sensitivity and broadband coverage of GRO will be fundamental for continuum spectroscopy of luminous extragalactic sources.

GRO will have a formal Guest Investigator program that will provide opportunities for Australian astronomers. Given the complexity of the detectors and their data analysis, collaboration with the instrument groups will frequently be the most efficient method of GRO access, although research as an independent investigator will be feasible for some programs. Follow-up optical and radio observations to identify and study the counterparts of gamma-ray sources will be particularly important.

4. CONCLUDING REMARKS

The main objective of this paper has been to provide an overview of all approved space astronomy missions, and where appropriate, to draw attention to opportunities for participation by Australian astronomers. To facilitate follow-up of such opportunities and for further information, readers are invited to contact the author for a list of scientists and institutions responsible for the individual missions surveyed in this review.

While an attempt has been made to make the survey complete and free of selection effects, it has not been practical to include the large number of additional missions that are in a proposal phase, or are undergoing feasibility studies ahead of possible selection for flight. In the United States, such missions include two Explorer-class spacecraft (the Far Ultraviolet Spectroscopic Explorer; i.e FUSE/Lyman, and a gamma-ray satellite), as well as various proposed facilities for the Space Station era (e.g. the X-ray Large Array). Within ESA, a planetary mission (Cassini) was selected in October 1988 ahead of three astronomical missions (Lyman, Quasat and Grasp) that were also in contention. However, the flexibility inherent in the ESA Horizon 2000 Space Science Plan will provide opportunities for these and other space astronomy missions in later selection cycles. In the U.S.S.R., an impressive and ambitious program of future missions is foreseen, principally through the Space Research Institute (IKI) and Interkosmos. The U.S.S.R. program will continue to give greatest emphasis to high energy astrophysics and space VLBI. In Japan, the Space VLBI Observatory Program (VSOP!), is likely to be approved in due course (Morimoto *et al.* 1988, Nishimura and Hirabayashi 1988), and there will undoubtedly be continuity in the very successful series of Japanese ASTRO X-ray missions. In addition, an infrared facility based on the experience with IRTS is anticipated. It is noted that space astronomy programs are being initiated in other countries not featured in this review. For instance, Chinese astronomers are anxious to exploit the very powerful capabilities of the Long March launch vehicles by orbiting a collaborative X-ray astronomy mission (e.g. a proposed Anglo-Chinese mission known as 'Chixsat', or IXTO, an International X-ray Timing Observatory).

Australian efforts to gain a foothold in spaceborne UV and X-ray astronomy since 1980 have mostly led to disappointment, despite the wealth of expertise that has been developed and the enthusiasm that lingers. After far-sighted, vigorous, and ultimately frustrating participation in Starlab (Mathewson 1984, Tuohy 1986), Mirrabooka (Greenhill *et al.* 1986), and Lyman (Tuohy and Dopita 1987, Dopita *et al.* 1988), the recent Radioastron involvement represents the only space astronomy facility in which we presently have a secure role (and this was funded for political reasons, rather than the science potential). At the same time, the invitation by ESA to provide a ground station for the Infrared Space Observatory (ISO) represents a golden opportunity which is being negotiated as a high priority by the Australian Space Board and Space Office. Success in this endeavour will not only provide access to a state-of-the-art facility, but will result in close cooperation with ESA that can only be beneficial to future collaboration in space projects (including a potential data reception role in subsequent ESA space astronomy missions). In a similar vein, the U.S.S.R-Australia Space Research Agreement, our only such government-level agreement covering space science, provides very real opportunities for flying Australian instrumentation on Soviet missions (e.g. Spectrum-X-Gamma). Such opportunities are especially important, given the clear Soviet desire to give substance to the Agreement, and the fact that the prospects appear bleak for similar hardware participation in the space astronomy programs of other agencies.

An over-riding impediment to the provision of Australian instrumentation for space astronomy missions remains the lack of a clear avenue, or indeed a policy regarding space science funding – a situation exacerbated by the abolishment of the federal Department of Science in 1987. While earlier space initiatives met with significant funding success through their impact on developing a space industry capability, this argument is no longer effective at government level, even though the linkage between space science projects and industrial spin-off remains demonstrable. On a positive note, an Academy of Science committee has been commissioned by the Australian Space Office to produce recommendations and priorities pertaining to Australian space science. In addition, the embryonic Australian Research Council has been asked to consider the support of space projects in coordination with the Australian Space Office. Hopefully these initiatives, coupled eventually to the formation of a statutory Australian Space Agency, will lead to a long over-due mechanism for the funding of space science, and space astronomy in particular. At the same time, it is clear that astronomical institutions will also need to commit some of their own resources to maximize involvement in space astronomy; this is especially true in regard to the proposed Australian Space Astronomy Data Centre.

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