## 2. X-RAY ASTRONOMY

### K A Pounds

A. INTRODUCTION

       The period leading up to the last IAU General Assembly was dominated in X-
ray Astronomy by the results from the Einstein Observatory. This first
application of a large, satellite-borne, high resolution X-ray telescope to the
study of cosmic sources had led, by the end of orbital operation in April 1981,
to the detection of X-ray fluxes from a wide variety of astronomical objects and
the full maturing of X-ray Astronomy. During the past three years a strong
scientific output has continued to flow from the analysis of the more than 5600
separate Einstein observations, many of which are now widely available via the
Einstein Data Bank. In sharp contrast, the peak of activity and scientific
output from Einstein will apparently be followed, in the United States, by
almost a decade with no new X-ray satellite. Fortunately, successful launches
have been achieved in both the Japanese and European programmes, with Tenma
launched in February 1983 (to join Hakucho in orbit) followed by EXOSAT three
months later. Both these new missions have attracted world-wide interest and
observing time on both is at a premium. Of a range of instruments on board the
Tenma satellite the most productive is proving to be the large ($\sim 800$ cm$^2$) array
of gas scintillation proportional counters. These detectors, flown for the
first time on Tenma (and EXOSAT), provide a factor-of-two increase in spectral
resolution over the more conventional proportional counters, an advantage which
is particularly valuable in resolving the key emission line and absorption
features associated with the K-shell of iron, near $\sim 7$ keV. One particularly
exciting result reported from this Tenma instrument was an apparent absorption
feature at $\sim 4.1$ keV in X-ray burst spectra from the source 2S 1636-536 (later
supported by EXOSAT observations), the feature being attributed to red-shifted
iron absorption in the strong gravitational field close to the neutron star
burst source! At the time of writing (December 1984) a power storage problem is
limiting the operational efficiency of Tenma, but the scientific payload
continues to function well.

       The unique orbit of EXOSAT is proving to be a major asset, with continuous
observations of more than 70 hours being possible, uninterrupted by Earth
eclipse. In addition, the apogee over N. Europe allows real-time operation of
EXOSAT, analogous to observations with a ground-based telescope. The scientific
payload consists of an array of proportional counters (effective area $\sim 1600$
cm$^2$), a small gas scintillation proportional counter ($\sim 90$ cm$^2$) and 2 imaging
telescopes. Good data have been obtained from all the EXOSAT instruments, but
problems with some of the focal plane detectors and the mechanical drive are
currently preventing the use of the second telescope and of either transmission
grating. Given the considerable scientific potential and current scarcity of X-
ray spectra of corresponding resolution the latter is particularly
disappointing. Nevertheless, to date over 1500 EXOSAT observations have been
carried out, the programme continues to be heavily over-subscribed and it is
hoped to continue full operation until satellite re-entry in 1987.

       An expanding effort in X-ray astronomy is also reported from the Soviet
Union with the Salyut-7 orbital station carrying several experiments for X-ray
astronomy. Of particular interest is the RT-4M instrument, a grazing incidence
telescope with a non-imaging flow gas proportional counter as focal plane
detector. The telescope optics are of two-fold nested Wolter type I design,
with a maximum entrance aperture 24 cm wide and a focal length of 66 cm. The
reflecting surfaces are coated with gold (outer mirror) and nickel (inner

mirror) to provide an operating wavelength band between 44 A and 100 A over a
field of view of 45' by 3°.  The detector entrance aperture is divided into
three parallel sectors, viewing different fields (Mandelstam et al, 1983).
Results from this and other Salyut instruments are eagerly awaited.  In the
following section, a (necessarily personal and incomplete) review is made of
progress in X-ray astronomy over the period since the Commission's 1982 report.

## B. SCIENTIFIC ACHIEVEMENT

### (i) Stellar emission.

Einstein observations have provided an outline of the X-ray emission
properties of stars throughout the H-R diagram (e.g. Vaiana et al, 1981; Swank
et al, 1981; Caillault and Helfand, 1982; Montmerle et al, 1983), but a detailed
understanding has so far been limited by the small sample of higher resolution
spectra obtained with the Einstein grating or crystal spectrometers (e.g. Mewe
et al, 1981; *Swank and Cassinelli, 1983; Swank and Johnson, 1982; Vedder and
Canizares, 1983).*  Evidence that stellar surface activity (as an effect of
surface convection) does indeed cease along the main sequence is provided by the
discovery that the X-ray luminosity decreases from a mean of $10^{29}$ erg s$^{-1}$ at F5
to upper limits of $\sim 10^{27}$ erg s$^{-1}$ at AO (Schmitt et al, 1985).  Early type stars
*are readily detectable as X-ray sources but it is not yet clear whether the*
emission is from coronae, shocked winds, or some other cause.  Recent models
have been discussed by Waldron 1981), Lucy and White (1980) and Lucy (1982),
among others.  Of particular value in determining the evolution of stellar X-ray
emission is the study of star clusters (of common age), such as those in the
Hyades (*Stern et al, 1981*) and Pleiades (Caillault and Helfand, 1985) Clusters.
Preliminary indications are that for solar type stars the fall in X-ray output
(at least up to $\sim 10^{9}$ yr) is slower than $t^{-0.5}$.

The significance of RS CVn stars as highly variable X-ray sources was
*underlined in an analysis of short-lived Ariel-5 transients (Pye and McHardy,
1983),* who found 6 of 11 optically identified X-ray transients to be RS CVn
systems.  The long EXOSAT observing time is well matched to the study of such
systems.  For example, Barstow (1985) has observed the RS CVn binary HR1099,
during which an X-ray outburst was followed through a peak (of 3 x $10^{34.5}$erg s$^{-1}$,
2 - 6 keV) and subsequent decay over $\sim$ 2 hours.  *Interesting, non-periodic
modulations were also clearly seen.*  Other recent EXOSAT stellar observations
have covered the contact binary VW Cephei, revealing a structured corona (Vilhu
and Heise, 1985), the 12 day rotating K2 V star $\in$ Eri (Horstman et al, 1985),
and the nearby triple star system Algol.  Observations of Algol during the
*secondary optical eclipse (B star in front of K Companion) have provided lower*
limits to the size of the K star's X-ray corona, while ME and grating spectra
revealed a thermal spectrum with Fe XVII and XVIII emission lines and a
continuum temperature of  2.4 x $10^{7}$ K (Culhane et al, 1985).  A large X-ray
flare was also seen, with an effective temperature of 6 x $10^{7}$ K and iron
*emission up to Fe XXV (Parmar et al., 1985). Further detections of soft X-rays*
from hot white dwarf stars have been reported from Einstein observations (Kahn
et al, 1984).  EG 187, Gr 288, Gr 289 and LB 1663 have spectra consistent with
DA white dwarf photospheric temperatures in the range 3 - 6 x $10^{4}$ K.
Complementary IUE data show the need for some atmospheric opacity, with a H:He
*ratio in the range (2-600) x $10^{-5}$.  The implication of these detections is that*
many more white dwarf stars should be available for study in future XUV surveys.

### (ii)  Supernova remnants.

The Einstein Observatory has successfully mapped more than 40 galactic
supernova remnants and has detected 25 and 6, respectively, in the Large and
Small Magellanic Clouds (Mathewson et al, 1983 and references therein).  The

best data naturally arise for the relatively young galactic remnants and detailed studies have been reported on a number, including Tycho's SNR (Seward et al, 1983), SN 1006 (Pye et al, 1981), Cas A (Stewart et al, 1983) and most recently RCW 86 (=SN185A.D.), observed with Einstein by Pisarski et al (1984). Other high quality X-ray maps have been obtained with Einstein for several older, but bright, remnants, in particular Puppis A (Petre et al., 1982) and Cygnus Loop (Ku et al., 1984). These observations have generally supported the view that the X-ray emission from these remnants is thermal, from shock heated gas (of the supernova itself and the surrounding interstellar medium) at temperatures $\sim$ 1 - 10 keV. Spatial structures have been compared with radio and optical features. X-ray spectra taken with the Einstein solid state spectrometer (see review by Holt, 1983) have been analysed in terms of thermal models, but, in general, the lack of spatial resolution and uncertainties as to the state of equilibrium of the emitting plasma have limited the reliability of the deduced mass and element abundance distributions. The high resolution crystal spectrometer data from Puppis A (Winkler et al, 1981) have shown the great promise of future, more sensitive observations. EXOSAT X-ray maps of Puppis A (Aschenbach et al, 1985), SN 1006 at higher resolution (Jones et al, 1984) and Cygnus Loop (Arnaud et al, 1985) are now adding to this field.

An increasing number of core-halo remnants have been reported, some with an associated neutron star. Four pulsars have been found in SNR to date, while Einstein observations have added a further six with point sources too weak to allow pulsations to be detected (Seward, 1983). In addition to the Crab Nebula, MSH15-52 has been found to contain an X-ray/radio pulsar with the highest known rotational energy loss rate (Seward and Harnden, 1982) and a further Einstein observation showed CTB109 to contain a long period ($\sim$7 sec) X-ray pulsar (Fahlman and Gregory, 1983). Other remnants found from Einstein observations to have weak point X-ray sources include RCW103, 3C58, CTB80 and W28 (Tuohy and Garmire, 1980; Becker et al, 1982; Andrews et al, 1983). A recent EXOSAT addition to this sub-group is the southern SNR PKS1209-52 (Kellett, 1985).

(iii) Galactic X-ray binaries with compact components.

By their nature, both Tenma and EXOSAT are well suited to detailed study of the bright X-ray binaries containing white dwarf, neutron star or (possibly) black hole components. Over 100 of these sources now have identified optical counterparts (Bradt and McClintock, 1983) and it is conventional to divide them according to system mass, nature of the compact component, or location (e.g. globular cluster). An excellent review of this broad field is now publishd in Lewin and van den Heuvel (1983) while other reviews may be found in a special volume of Physica Scripta (vol. T7, 1984).

Recent progress in the study of massive X-ray binaries (sometimes called class I) where the components are an early type star of $M > 10M_\odot$ and a neutron star has concentrated on the details of mass loss, stellar wind opacity, pulse structure etc., since this class is basically better understood than the low mass systems (most of which are not yet actually established to be binary). Continuing Hakucho and Tenma observations of Vela X-1 have now shown the spin-down, noted in the Commissions's report 3 years ago, to have again reversed, indicating a complex interaction between the accreting material and the neutron star (Nagase et al, 1984 and references therein). The rate of change of the pulsar period in LMC X-4 is also in strong discord with a simple accretion torque model (Keller et al., 1983). Two of the best candidate X-ray binaries to contain a black hole, Cygnus X-1 and GX 339-4 remain 'unproven', though new high quality data has been obtained on the short term X-ray variability (e.g. Maejima et al, 1984; for GX339-4 and Meekins et al, 1984 and Page, 1985; for Cyg X-1). In addition, the analysis of SAS-3 data has revealed an intriguing series of intensity 'dips' generally occurring near superior conjunction of the X-ray

source (Remillard and Canizares, 1984). Identification of several 'classical'
X-ray transient sources with Be stars (Warwick et al, 1981; Rappaport and van
den Heuvel, 1982; Steiner et al, 1984) has been followed by further detailed
optical and X-ray studies and it now seems likely that it is the strong
equatorial mass loss of the Be star that fuels the neutron star accretion over
the large (and probably eccentric) orbits of such long period binaries as 1145-
61 (187d; Watson et al., 1981), 4U0115+63 (24d) and the highly luminous LMC
transient A0538-66 (16.6d; Charles et al, 1983).

The major recent advance in the understanding of low mass (or class II)
systems has been the establishment of a binary period for several cases,
typically of a few hours (though there are notable exceptions, e.g. Cygnus X-2
at 9.8 days). Thus 2A 1822-371 has been found to have a binary period of 5.6 h
(Cowley et al, 1982 and references therein) and 2A 2129+470 one of 5.2 h
(McClintock et al, 1982). The proposition that X-ray bursters are a sub-class
of low mass binaries (having a lower mean accretion rate or weaker neutron star
magnetic field?) has been justified by the identification of binary periods for
1636-53 (~4h, from optical photometry; Pedersen et al., 1981), 1915-05 (~50m,
from X-ray dips; White and Swank, 1982), 1755-33 (4.4h, from X-ray dips; White
et al., 1984), 1659-29 (7.1h, from X-ray dips; Cominsky and Wood, 1984) and
1254-69 (~3.9h). The latter result is perhaps the most interesting in that the
period is found from both optical photometry (Motch et al., 1984) and X-ray dips
(Courvoisier et al., 1985). X-ray burst sources have continued to receive
attention in the Tenma and EXOSAT programmes. Use of large detector arrays,
with improved spectral and timing resolution, are yielding high quality data
which are helping to clarify details of the mechanism and geometry of the
emission region. The previously established model for the more common type I
bursts, involving thermonuclear fusion on the surface of an accreting neutron
star, remains intact, but only now are first attempts being made to calculate
the radiation transfer properties in the neutron star photosphere. The
intriguing detection of an apparently red-shifted absorption line by Tenma (Waki
et al, 1984) and EXOSAT observers (Turner et al, 1984) has been mentioned
previously. Correlated optical and X-ray bursts have been detected for 1735-44
(Grindlay et al., 1978), 1636-536 (Matsuoka et al., 1984) and - most recently -
for MXB1659-29 (Matsuoka et al, 1984).

Probably the most significant progress in the study of X-ray binaries
during the past 3 or 4 years has been of those systems involving accretion onto
a white dwarf star, the cataclysmic variables. Because of their proximity (~50-
500 pc) cataclysmic variables are excellent objects in which to study the
physics of accretion onto a compact object. They are also readily studied by X-
ray techniques and some 50 have now been so detected (see review by Cordova and
Mason, 1983). Ariel-5, HEAO-1 and Einstein observations have been actively
followed up in the EXOSAT programme. An important variable in such systems,
which are believed to involve a low mass star and a white dwarf, is the magnetic
field strength of the dwarf star. Twenty or so AM Her (or polar) and DQ Her
(intermediate polar) type stars have strong fields which, in the former case,
lock the white dwarf rotation to the binary period. Most cataclysmics, such as
SS Cyg and U Gem, however, show no evidence of magnetic fields. One of the
earliest EXOSAT observations showed GK Persei to have a strongly modulated X-ray
flux, establishing 351 sec as the white dwarf rotation period and GK Per as the
sixth known 'intermediate polar'. Extended observations further showed the
depth of modulation to be independent of mean flux (accretion rate), indicating
an extended, thin polar cap emission region (Watson et al, 1985a). Repeated
EXOSAT observations of SS Cygni between and during optical outbursts have
confirmed the anti-correlation of hard and soft X-ray flux (Watson et al, 1985)
and are providing detailed information on the emission in such a non-magnetic
white dwarf system, which appears to involve thermal radiation (of the soft
component) from the surface of the white dwarf and a (harder) component from an

overlying hot corona (King, 1985). Rapid variability of the quiescent flux
(~10 sec) was seen during quiescence, consistent with the earlier HEAO-1
observations of SS Cyg and U Gem (Cordova et al, 1984).

### (iv) Globular clusters

An important advance in the study of globular clusters has been made using
Einstein data which have shown diffuse X-ray emission in the clusters W Cen, M22
and 47 Tuc (Hartwick et al, 1982). The presence of diffuse gas has previously
been looked for without success in optical and radio searches, and probably
arises from the winds of red giant stars. In the continuing effort to
understand the nature of the well established luminous X-ray components,
presumably due to intrinsic variability and - in part - to the 'softer' response
of the EXOSAT telescopes. Although few sources have been optically identified,
the high X-ray luminosities strongly suggest a population of X-ray binaries and
supernova remnants, as dominate our own Galaxy. The Large and Small Magellanic
Clouds were well mapped by Einstein and a programme of source identification in
the SMC, based on precise Einstein HRI positions, has now been extended with
EXOSAT, with preliminary results yielding 2 foreground stars, an HII nebula, the
SNR N 76 and a (background) Seyfert galaxy (Jones et al., 1985). Although the
mean X-ray luminosity of the LMC sources is significantly higher than for the
Galaxy, the number of luminous stellar X-ray systems per unit mass is similar.
Other nearby galaxies which have now been well studied include M82 and M81.
Watson et al (1984) found an extended region of emission in M82 with a bright
component centred on the nucleus, together with a broader region correlated with
Hα filaments and the optical halo, interpreted by the authors in terms of a
starburst model. The main X-ray feature of M81 is a luminous X-ray nucleus, a
property shared with other nearby spirals M100, M83 and M33 and, as recently
reported, M51 (Fabbiano et al, 1985). In summary, the observations of a sample
of nearby spiral galaxies suggests a base level of X-ray emission similar to our
own Galaxy, probably due to 'classical' X-ray binaries and supernova remnants,
but with a level of nuclear activity varying by up to 1000 times that of the
Galaxy. Elliptical and lenticular galaxies reveal a greater spread of extra-
nuclear X-ray luminosity, with evidence for extended (thermal) emission in some
cases, particularly NGC 4636 (Stanger, 1985) and M86. The suspected high mass
loss of stars in early-type galaxies and the possibility that this gas is then
expelled by galactic winds are fundamental ideas given support by recent
detections of hot coronae around galaxies both inside and out of clusters
(Nulsen et al, 1984; Forman et al, 1984). In addition, nine extended sources
were detected around mainly early-type galaxies in the core of A1367 (Bechtold
et al, 1983), the measured temperatures of ~ 1 keV suggesting the ejected gas
may have been heated by supernova explosions. More detailed X-ray mapping and
spectroscopic observations of early-type ellipticals will be of great interest

the most probable masses in 8 globular clusters to be ~ 1.5 $M_\odot$, consistent with
them being accreting neutron star binaries. More recently a survey of 71
galactic globular clusters (Hertz and Grindlay, 1983) has revealed a bimodal X-
ray luminosity function, with a fainter group of sources (< 10    erg s$^{-1}$),
believed to be cataclysmic variables (but see Verbunt et al, 1984). The fact
that the presence of both high and low luminosity X-ray sources is correlated
with the timescale for binary formation by tidal capture is interpreted as
evidence for the importance of this process in globular clusters.

### (v) Normal galaxies

The Einstein map of M31 contained ~ 100 discrete sources and was able to
distinguish between the X-ray emission from the nucleus, from a bulge population
and from a disc population (e.g. Crampton et al, 1984). Repeated observations
with EXOSAT have shown substantial changes in the source distribution,

accurate (~ 1 arc sec) positions have allowed Grindlay et al (1984) to determine

in determining the amount of hot gas, the heating mechanism, extension, and confining medium (dark halo?) and whether or not (as seems likely in NGC 4636) cooling flows are important in the central regions of the galaxy. On this topic, also see Nulsen et al. (1984).

### (vi)  Active galactic nuclei (AGN)

Substantial progress in analysing well-exposed Einstein fields (the Medium Deep Survey) has been made and Gioia et al (1984) recently reported the results from 150 fields covering $\sim$40 square degrees of sky. Approximately half of the 112 new X-ray sources are identified with AGN. The rapidly increasing number of AGN identifications will be of great value in improving both the AGN luminosity function(s) and estimates of their contributions to the X-ray background.

Broad-band X-ray spectra have been reported for a sample of the brighter AGN, covering a wide range of luminosity ($\sim 10^{42}$ - $10^{46}$ erg s$^{-1}$) and morphological type and Mushotzky (1984), in reviewing these mainly HEAO-1 and Einstein MPC and SSS data, reports a remarkable uniformity of spectral slope. New EXOSAT spectra, reviewed by Pounds et al. (1985), confirm many of these 'canonical' spectra (photon number index $\sim$ 1.7) but also provide evidence for several steeper spectra and for spectral variability. Two particularly interesting results from this EXOSAT study are the discovery of a soft spectrum and marked variability (on a timescale $\sim$ 1 hour) for the nearby Seyfert galaxy NGC 4051. The EXOSAT observations of steep, soft X-ray components in several AGN conforms with a result from the re-analysis of Einstein IPC spectra of the brighter QSOs (Elvis, private communication) and may correspond to the spectral break 'required' to join the X-ray and UVOIR continua of AGN. Einstein (Holt et al, 1980) and EXOSAT (Pounds, 1985) observations of NGC 4151 have shown the potential of X-ray spectra for studying the environment of AGN, both analyses providing evidence for a complex absorbing structure in the surrounding gas. A particularly interesting spectral feature was detected in the Einstein OGS observation of the BL Lac object PKS 2155-304. An absorption edge or trough at $\sim$ 600 eV, probably attributable to ionised oxygen in the vicinity of the AGN or in an (hypothesised) intervening intergalactic medium (Canizares and Kruper, 1984).

### (vii) Clusters of galaxies

Analysis of the rich Einstein data base has continued, extending the range of cluster morphologies and demonstrating a continuous distribution of loose groupings to highly evolved clusters (Jones and Forman, 1984). The Einstein observations also show that many of the clusters with a dominant central galaxy probably have central cooling flows, which could contribute substantially to the growth of this central galaxy. From a determination of the central density and temperature of 36 clusters of galaxies, Stewart et al. (1984) estimated cooling times less than the Hubble time and derived mass inflow rates of between 2 and 400 $M_\odot$ yr$^{-1}$. The search for distant clusters (Z > 0.5) is important in relation to the fundamental questions of cluster formation and evolution. X-ray observations should prove an effective way of discovering very distant clusters, due to their characteristic extended emission and lower confusion level (than in the optical or radio bands). McHardy and Cooke at Leicester have been using Einstein and EXOSAT to search for X-ray emission from suspected distant clusters, selected from a sample of $\sim$ 150 steep spectrum radio sources with deep CCD optical follow-up, while Harris (CFA) is studying serendipitous Einstein sources for the same purpose.

### (viii) Gamma ray bursts

Identification and understanding of the intense (but rare) $\gamma$-ray bursts has

been brought closer by the determination of several relatively precise source
positions. Cline et al (1984) have reported positions accurate to a few (arc
min) for the moderately intense bursts of 1978 Nov 24 and 1979 Nov 5 and 16,
from the interplanetary network of Soviet, US and European spacecraft. Although
all 3 locations are at high galactic latitude none have an obvious steady
optical counterpart; however, a search of archived data produced a coincident
optical event, confirming the previous $\gamma$-ray burst/optical transient association
discovered by Schaefer (Schaefer, 1981). Barat et al (1984) report the precise
location of the intense 1979 January 13 $\gamma$-ray burst, probably coincident with a
second of the Schaefer et al (1984) optical flashes and with a possible faint
($m_v \sim 23$) quiescent optical counterpart. A quasi-periodic repetition of $\gamma$-ray
pulses makes this observation different to most previous detections. On the
basis of a total of 3 optical flashes seen near $\gamma$-ray burst locations, Schaefer
et al (1984) conclude an average recurrence timescale of $\sim 1$ year and a ratio of
$\gamma$-ray to optical flux of $\sim 900$. Although the $\gamma$-rays burst sources remain an
unsolved puzzle, these new data appear to support the view that they originate
within the magnetosphere or at the surface of an isolated or weakly accreting
neutron star.

C.    FUTURE PROSPECTS

By its nature, the Einstein Observatory examined only a small fraction of
the whole sky, an aspect in common with most large ground-based telescopes. The
German ROSAT mission, due for launch on the US Space Shuttle in late 1987, will
carry a somewhat larger Wolter I telescope, of similar properties to Einstein
(see Table), which will be used in the first $\sim 6$ months in orbit to conduct an
all-sky survey with a sensitivity at least comparable to the Einstein medium-
deep survey (Trumper 1984). More than $10^5$ sources of all astronomical types are
anticipated from this survey, greatly increasing the statistical power of many
varied studies and - potentially - uncovering major new phenomena. Alongside
the ROSAT X-ray telescope will be flown the UK Wide Field Camera, a telescope
optimised for the extreme ultraviolet waveband (Pye, 1984). Following a
simultaneous all-sky survey (probably the first in the XUV band), the WFC and
ROSAT X-ray telescopes will then embark on a programme of observations of
selected fields, in the manner of the Einstein Observatory. US astronomers will
participate strongly in this phase of the mission.

Several months before the launch of ROSAT, the successor to Tenma is due to
be placed in orbit by the Institute of Space and Astronautical Science. This
Japanese satellite, ASTRO-C, will carry a 0.5 square metre array of proportional
counter detectors, to conduct detailed timing and spectral studies of a wide
range of galactic and extragalactic sources. UK astronomers are collaborating
with ISAS on the payload development and will share in the scientific operation
of ASTRO-C. This mission, complementary in its capabilities to ROSAT, will
provide a powerful extension to the studies now being conducted with Tenma and
EXOSAT (due to re-enter the atmosphere in mid-1987).

Beyond 1987, NASA plan to fly two satellites in the Explorer programme
which cover this field of astronomy. The Extreme Ultra Violet Explorer (EUVE)
will carry out a sky survey in the XUV band, similar to the ROSAT WFC, and may
also have some additional spectroscopic capability. Later on, the X-ray Timing
Explorer (XTE) is due for launch, carrying a powerful array of detectors,
including a 1 square metre proportional counter array, for timing and spectral
studies of the brighter galactic and extragalactic sources. In Italy, approval
has recently been obtained for the SAX mission, an X-ray satellite to be
launched on the US Space Shuttle towards the end of the 1980s and designed to
carry out a range of spectroscopic and hard X-ray mapping studies.
Collaboration of Dutch astronomers is proposed for SAX. Finally, in the present
decade, it is hoped that a small Indian X-ray payload will be launched, while

further experiments are planned in the Russian programme (though details are not yet known).  In summary, it appears that the 1980s should see a total, world-wide activity in X-ray astronomy similar to that of the previous decade, but with a much broader international spread.

TABLE          Characteristics of some recent and planned X-ray telescopes

| Telescope | Einstein | EXOSAT | ROSAT XRT | ROSAT WFC | AXAF |
|---|---|---|---|---|---|
| Type | Wolter I | Wolter I | Wolter I | Wolter-Schwarzschild I | Wolter I |
| Nested shells | 4 | 2 | 4 | 3 | 6 |
| Focal length (cm) | 344 | 109 | 240 | 52 | 1000 |
| Max. diameter(cm) | 58 | 28 | 83 | 58 | 120 |
| Geom. area (cm ) | 350 | 89 | 1150 | 511 | 1500 |
| Energy range(keV) | 0.2-4 | 0.04-1.5 | 0.1-2 | 0.015-0.2 | 0.1-10 |
| On-axis resolution (arc sec) | | | | | |
| FWHM | 3 | 5 | 5 | 30 | 0.5 |
| HER (44 A) | 4 | 10 | 2.5 | 60 | 0.5 |
| HER (8 A) | 5 | 15 | 2.5 | 60 | 0.5 |

In the 1990s, further Japanese and European X-ray missions (ASTRO-D and XMM, respectively) are firmly planned, very probably with an emphasis on realising the great scientific potential of moderate-to-high resolution X-ray spectroscopy.  A major focus will be on the NASA AXAF mission.  This natural (US) successor to the Einstein Observatory, with a nested Wolter I telescope of maximum mirror diameter 1.2 metres and sub-arc second resolution, is seen as the X-ray counterpart to the Hubble Space Telescope and will be the most powerful X-ray mission yet conceived.

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