

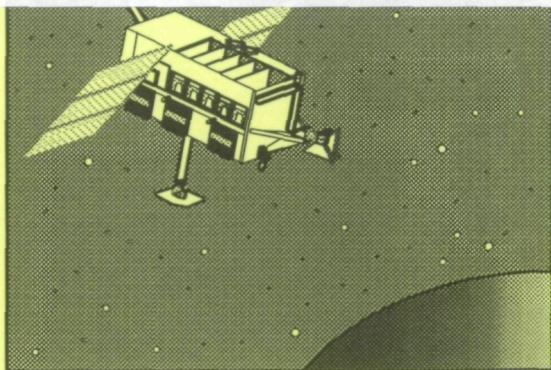
Explorer Program

(NASA-TM-111083) EXPLORER PROGRAM:
X-RAY TIMING EXPLORER (NASA,
Goddard Space Flight Center) 37 p

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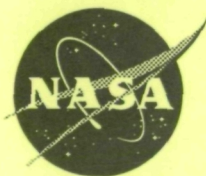
X-ray Timing Explorer

National Aeronautics and Space Administration

Goddard Space Flight Center

XTE Project Office

Greenbelt, Maryland



VITAL STATISTICS

LAUNCH:

Target Date: August 31, 1995
Launch System: Delta II (Model 7920-10) expendable launch vehicle
Launch Site: Cape Canaveral Air Force Station, Florida

ORBIT:

Altitude: 580-km (360-miles) circular
Inclination: 23 degrees
Period: 96 minutes

OBSERVATORY:

Size: 3.9 m (20 ft) by 1.8 m (6 ft) square
Mass: 3045 kg (6700 lbs)
Power: 800-watts minimum (orbital average)
Telemetry: 96-kbps nominal
1056-kbps optional
Attitude Control: 3-axis inertially stabilized

INSTRUMENT COMPLEMENT:

Proportional Counter Array (PCA)
High-Energy X-ray Timing Experiment (HEXTE)
All-Sky Monitor (ASM)

OPERATIONS CENTERS:

Mission Operations: NASA Goddard Space Flight Center
Science Operations: NASA Goddard Space Flight Center

MISSION LIFE: 2-year minimum

AB-57 = ① - ②

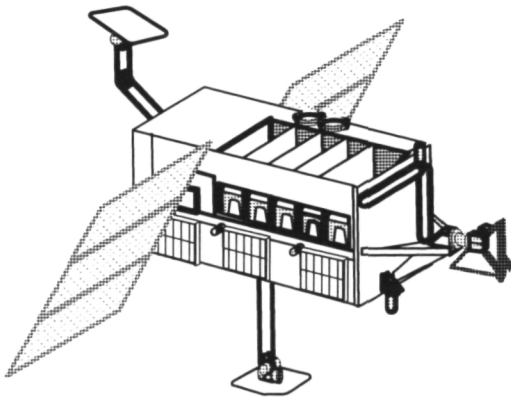
INTRODUCTION

This booklet describes the X-ray Timing Explorer (XTE), one in a series of Explorer missions administered by the National Aeronautics and Space Administration's (NASA) Office of Space Science and managed by the NASA Goddard Space Flight Center (GSFC).

The X-ray astronomy observatory is scheduled for launch into low-Earth orbit by a Delta II expendable launch vehicle in late summer of 1995. Launch is from the Cape Canaveral Air Force Station, Florida. The mission is expected to operate for at least 2 years and will carry out in-depth timing and spectral studies of the X-ray sources in the 2 to 200 kilo-electron Volt (keV) range. XTE is intended to study the temporal and broad-band spectral phenomena associated with stellar and galactic systems containing compact objects, including neutron stars, white dwarfs, and black holes.

Observing time is devoted solely to guest observers; there is no guaranteed Principal Investigator (PI) observing time. Observations using the XTE observatory will be chosen from proposals submitted by scientists from around the world.

The science instruments were provided by the Massachusetts Institute of Technology (MIT), the University of California in San Diego (UCSD), and GSFC. GSFC also developed, integrated, and tested the observatory and will operate the mission.



MISSION BACKGROUND

Over the past half century, scientists have come to realize that the visible light that is observed from astronomical objects represents only a small fraction of their total radiation output. The scientific field of *high-energy astrophysics*, so named because the radiation has a much higher energy content per photon than visible light, represents the study of the X-rays and gamma-rays emitted by cosmic sources. As a result of the higher energy, X- and gamma radiation allows observation of higher temperature regions closer to the energy sources of astronomical objects than is possible with visible light. And, because it is readily absorbed by the Earth's atmosphere, this high-energy radiation can only be observed with instruments flown above this obscuring layer. This may be accomplished by deploying payloads for short periods on sounding rockets or high altitude balloons, and for longer periods on orbiting satellites.

With the advent of the Space Age, a new window was opened on the universe. In 1962, a sounding rocket flight of an experiment designed to search for solar X-rays reflected off the moon accidentally scanned across an intense source of X-rays of unknown origin. This source was subsequently identified with an X-ray star beyond the solar system, and the field of X-ray astronomy was born. Subsequent observations conducted with modest payloads flown on sounding rockets suggested that the X-ray emission from cosmic sources was highly variable. Launched in 1970, the first satellite mission designed to survey the sky in X-rays, *UHURU*, revealed a dazzling array of sources that appeared to vary dramatically in their X-ray brightness on virtually all time scales – pulsations with periods as short as seconds, eclipses occurring on time scales of hours to days, and spectacular outbursts from previously undetected sources lasting for several months and rivaling the optical supernovae in the violence of their emissions. The majority of the new sources shared another common characteristic – many of them could be traced to binary star systems in which a "normal" star is transferring material to an extremely compact companion star. It was quickly realized that the gravitational

energy lost by the material as it spirals down into a disk of hot gas circling the compact object, and ultimately onto the object itself, provides the source of the prodigious energy output of these systems. Largely due to studies of their temporal variations, the latter were hypothesized to be exotic objects whose existence had previously only been theorized – *neutron stars*, the rapidly spinning remnant of an exploded star that has collapsed to a radius of only 6 miles or so, and *black holes*, the remnants of massive stars that have collapsed so far that they cannot be seen directly because the radiation cannot escape.

Since *UHURU*, a number of missions designed to study cosmic X-ray sources have been flown, both by the U.S. and other countries. In 1975, the third in a series of Small Astronomy Satellite (SAS) missions, SAS-3, was launched to perform intensive studies of selected variable sources. In 1977, the U.S. launched the first High-Energy Astronomy Observatory (HEAO-1) to conduct a much more sensitive sky survey than that conducted by *UHURU* 7-years earlier. A year later, the second High-Energy Astronomy Observatory (HEAO-2) was launched and revealed that, in addition to the exotic objects discovered earlier, virtually every class of object known to traditional optical astronomy emits X-rays at some level.

With the end of the HEAO-2 mission in 1981, the U.S. entered a hiatus in cosmic X-ray astronomy. Although several fruitful collaborations with other countries have been carried out over this period, the U.S. has not launched a mission of its own. The launch of the XTE marks the end of this hiatus in U.S. leadership of the field pioneered by this country. It is specifically designed to perform the most comprehensive and detailed studies of the enigmatic objects discovered by the *UHURU*, SAS-3, HEAO-1, and subsequent international missions. With its unprecedented combination of capabilities in collecting area, temporal resolution, spectral response, and rapid reaction to transient phenomena, XTE promises to provide a wealth of new information on the most chaotic and energetic objects in the universe. And, as with all missions, it is perhaps the unpredictable new discoveries and scientific surprises that await which generate the greatest sense of anticipation of the launch of XTE.

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SCIENCE OBJECTIVES

The primary goal of XTE is to study X-rays, including their origin and emission mechanisms, and the physical conditions and evolution of compact X-ray sources within the Milky Way Galaxy and in the nuclei of other galaxies. These systems include accreting white dwarfs, neutron stars, and stellar-mass black holes in orbit with a normal stellar companion and the nuclei of active galaxies, which may harbor supermassive black holes. XTE is designed to perform the most sensitive observations to date of temporal variations of the X-ray intensity and broad-band spectrum of these objects over timescales down to a few microseconds and over baselines of up to several years. The detailed scientific objectives include:

- Determine the physical properties of stellar-mass compact objects (e.g., masses, moments of inertia, and magnetic field strength)
- Investigate fundamental physical problems associated with matter at the extremes of density, temperature, and magnetic field (i.e., equation of state of nuclear matter, mass transfer processes and accretion disks, and physics of black holes and their environs)
- Study the dynamics of accretion from disks, magnetospheres, and stellar winds
- Investigate the structure (i.e., geometry, density, temperature, and stability) of the X-ray emitting regions
- Study the evolution of the normal stellar companions in compact X-ray binaries
- Determine the origin of outbursts in X-ray novae
- Determine the physical parameters and emission mechanisms of active galactic nuclei (AGN) (e.g., Quasar, Seyfert galaxies, and BL Lac objects are particular types of AGNs)

To address these objectives, the following capabilities were built into the mission:

- To provide a capability for performing broad-band (2 to 200 keV) observations of cosmic X-ray sources down to a limiting sensitivity of approximately $1/10,000$ th of the Crab Nebula with a limiting temporal resolution of 2 microseconds
- To provide a record of sources brighter than $1/100$ th of the Crab Nebula (on the average) with a time resolution of 90 minutes for sources brighter than $1/50$ th of the Crab Nebula
- To be able to detect the onset of new sources (called X-ray novae) or sudden changes in the intensity of known sources and redirect the observatory within a period of less than 10 hours after onset.

THE COSMOS, X-RAYS, AND XTE

Astronomers have long studied the sky in order to determine the nature of celestial objects. In the past century, the use of powerful telescopes and advanced instrumentation have led to great strides in understanding the cosmos. Studies have shown that the Sun is only one of 100 billion stars that make up the Milky Way Galaxy and that this galaxy is only one of billions of galaxies in an expanding universe. Moreover, astronomers have learned much about the life histories of stars, galaxies, and even of the universe itself.

Stars are known to be spheres of gas held together by gravity and powered by thermonuclear burning in their centers. When the nuclear fuel is exhausted, a star changes size and color several times and finally collapses to become a compact *white dwarf*, or a very compact neutron star, or possibly a black hole. Our Sun will become a white dwarf, about the size of the Earth and a million times more dense. A neutron star is about 100 trillion times more dense than the Earth; it is like packing almost one million Earths into a sphere the size of Manhattan Island. Magnetic fields on the surface of a neutron star can be one trillion times stronger than the Earth's magnetic field. A black hole results when the entire mass of a star collapses until the gravitational field is so strong that even light beams cannot escape from its immediate vicinity.

Some of these compact stars are accompanied by a "normal" gaseous star in an accreting *binary system*. If two stars of the binary are sufficiently close to one another, gas from the surface of the "normal" star is attracted by gravity toward the compact star (see Figure 1). As the gas falls toward the compact star, it gains so much energy that it becomes hot enough (~10 million degrees Kelvin) to emit X-rays (see Figure 2). This radiation provides astronomers with detailed information about conditions in the environment of incredibly strong gravitational and magnetic fields near a compact star. Studies of these stars are in the domain of *high-energy astrophysics*.

High-energy radiation is also seen from distant galaxies (collections of billions of stars) that lie well beyond the Milky Way Galaxy. Some of these exhibit an intense point of light at the center, known as the *active galactic nucleus*. In some cases, the nucleus is so bright that it can be seen at great distances when the light from the surrounding stars would be nearly undetectable; quasars are this type of AGN.

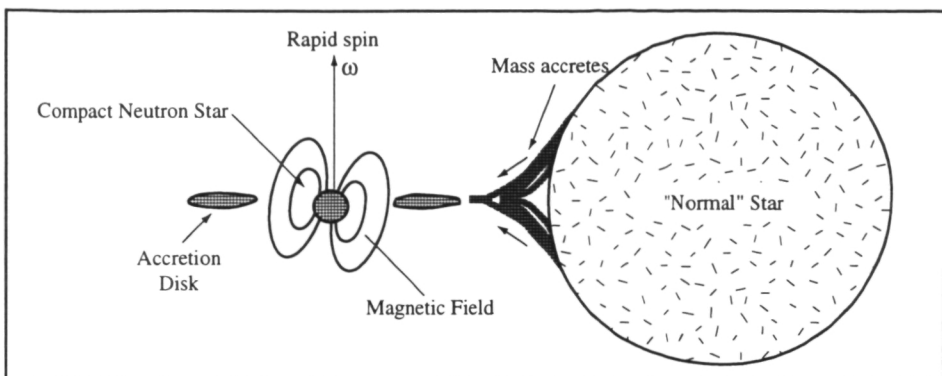


Figure 1. Accreting Binary – A normal gaseous star may find itself in a bound orbit with a compact neutron star or white dwarf. Gas from the "normal" star escapes its gravity and falls toward a neutron star. The gas may form an accretion disk (shown in cross section), and the magnetic field may guide the gas toward the pole of the compact neutron star where X-rays are emitted.

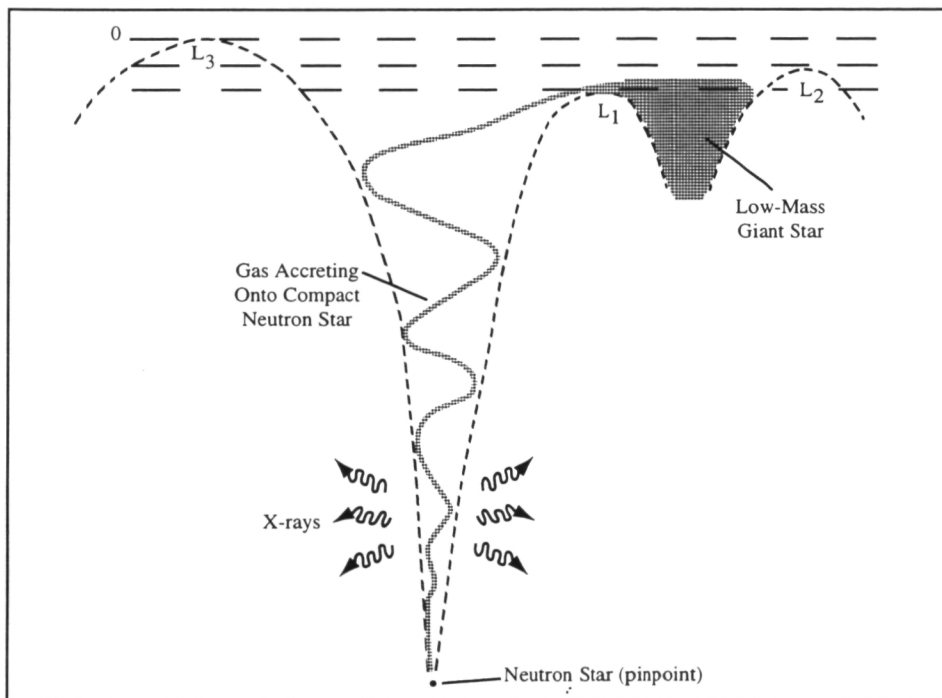


Figure 2. Potential Wells – The pseudo-potential of the accreting binary system illustrates the deep potential well of the compact neutron star into which gas from a star can fall.

These nuclear regions can emit more light than all the stars in a galaxy. They often exhibit rapid variations of light indicating they are very small in size, possibly of a size comparable to the solar system. Also, these galaxies often show immense *jets* of particles and radiation emanating from the nucleus.

The most likely explanation of AGN is that the nucleus is a black hole 10 to 100 million times more massive than the Sun. Surrounding matter is pulled by gravity into the black hole's deep potential well with the attendant emission of radiation at many wavelengths (see Figure 3). The X-rays and gamma rays will come from the innermost and hottest regions close to the massive black hole. A full understanding of these objects is greatly aided by concurrent observations from radio waves to the X-ray and gamma ray portion of the electromagnetic spectrum.

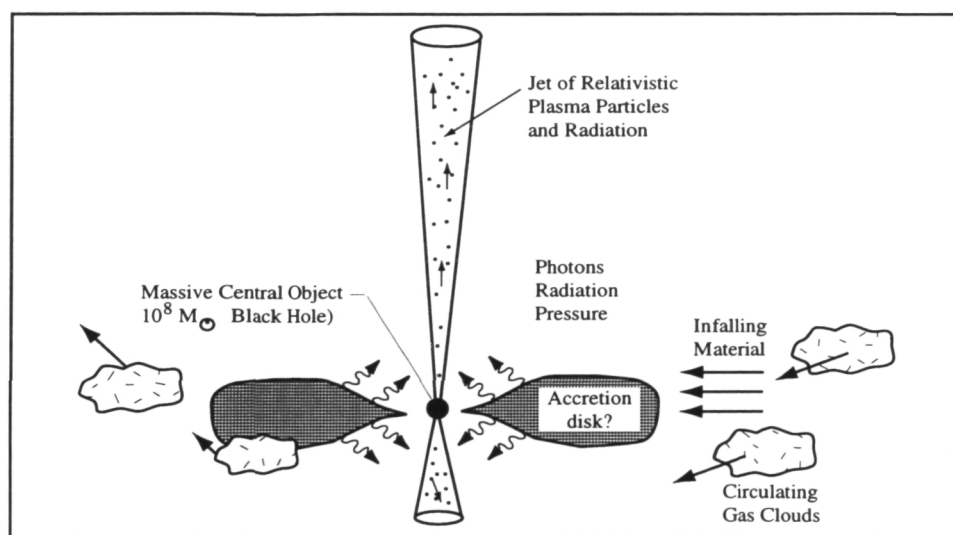


Figure 3. AGN – One view [not to scale] of an AGN is shown here. The energy source of this luminosity is thought to be the gravity of a massive black hole about 10 to 100 million times more massive than the Sun. Jets of particles and radiation may be formed, and massive clouds of gas orbit the center.

ASTRONOMY WITH X-RAYS

In the last half century, many new spectral windows on the cosmos have opened: radio, infrared, ultraviolet (UV), X-rays, and gamma rays. With the exception of the radio band and parts of the infrared band, these radiation measurements have been made from orbiting satellites because radiation is absorbed into the Earth's atmosphere.

X-rays are one of several types of radiation that are part of the electromagnetic spectrum (Figure 4). They are characterized by a short wavelength and a high photon energy of 0.2 to about 200 keV. These photons can be emitted by gases of very high temperature (~ 10 million degrees Kelvin) or by very energetic non-thermal particles. The high penetrating power of X-rays allows them to escape from the hot gaseous environs of a compact object and to travel through the diffuse gases of interstellar space so that astronomers on Earth may observe them directly. X-rays are an ideal probe of the innermost regions near compact objects.

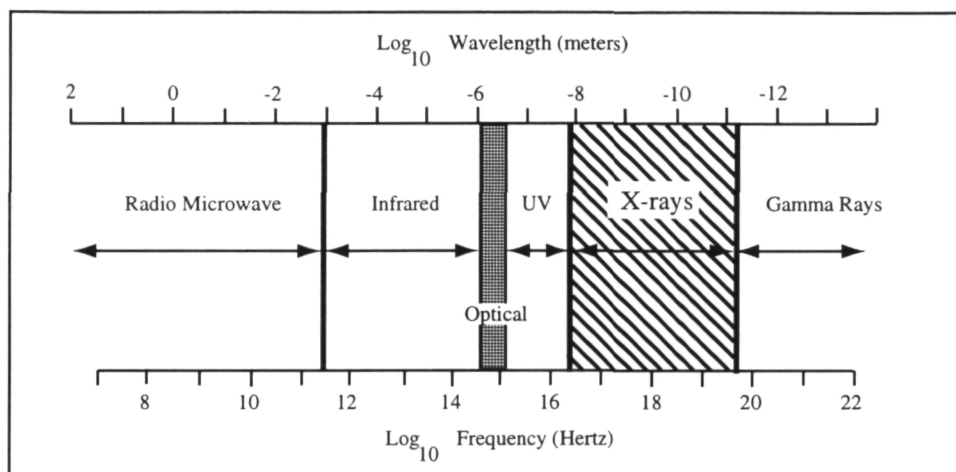


Figure 4. Frequency Bands – X-rays are one of the several bands of frequencies that make up the electromagnetic spectrum. X-rays and gamma rays have the highest-energy photons and hence typically emerge from the hottest regions or from the most energetic particles in celestial sources. Often data from all the bands are required to properly understand a celestial object.

X-rays have been detected from essentially every type of astronomical object: black holes, accreting white dwarfs and neutron stars, supernovae, coronal active stars, active galactic nuclei (e.g., quasars) and clusters of galaxies. There is also a diffuse background of X-rays from the entire sky.

A major characteristic of X-radiation from compact objects is the variability of the intensity. Examples are pulses of X-rays at regular intervals from magnetized spinning neutron stars (*X-ray pulsars*; see Figure 5), *X-ray bursts* from thermonuclear explosions on neutron-star surfaces, the sudden emergence of X-ray novae, and rapid (~ 100 second) flaring in AGN and distant quasars.

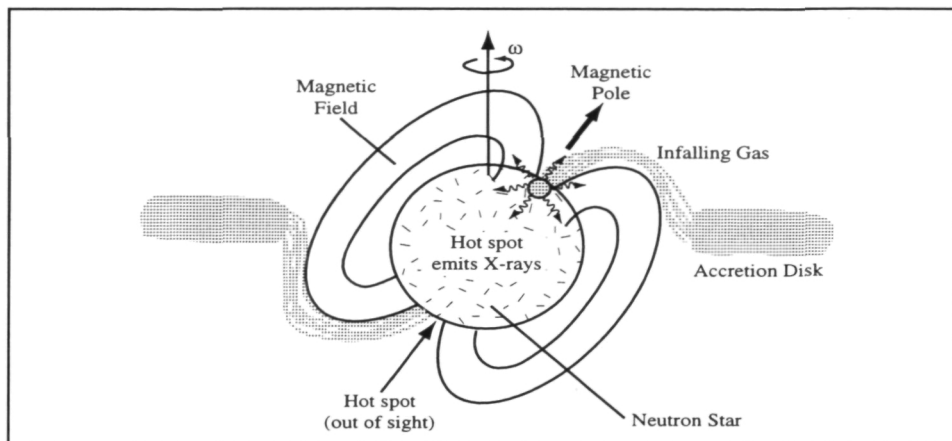


Figure 5. X-Ray Pulsar – Close-up view of an accreting neutron star or white dwarf. The accreting gas can be guided to the magnetic pole of the compact object where it creates a hot spot that rotates into and out of sight as the compact star rotates. Radiation from the hot spot can depart only in certain directions because of the infalling gas and strong magnetic fields. The result is an X-ray "pulsar."

As with all types of astronomy, spectral information is very important for the diagnosis of the underlying processes. For example, an excess of power at a specific frequency (a spectral line) can indicate the presence of iron atoms in the object. Simultaneous observations from different observatories (radio waves to gamma rays), known as *multifrequency studies*, are now recognized as an important tool in astronomy. The XTE observation planning system can accommodate coordinated observations.

Studies of the character of X-ray sources by past space missions have led to a broad understanding of the emitting systems. Temporal and broad-band spectral studies in X-ray astronomy in the medium-to-hard X-ray energy band (1 to 200 keV) have been conducted with a series of satellites including the U.S. HEAO-1, the European EXOSAT, the Japanese *Ginga*, and the Soviet/European Granat missions. Imaging and high-resolution spectral studies at lower X-ray energies (0.1 to 4 keV) have been carried out with the U.S. *Einstein* and the German *ROSAT* missions. Each of these missions has made vital new contributions to our knowledge of emitting systems.

XTE MISSION

Much more remains to be learned about X-ray emitting systems. It is not known how plasmas behave on time scales comparable to their free-fall time (~100

microseconds) near a neutron star or a black hole. It is not known if there is a fast rotating pulsar or a black hole left over from the recent supernova SN1987A. While much is understood about the internal structure of "normal" stars, little is known about the interior of neutron stars. Nor is it known if black holes are truly black. The interior regions of AGN which generate large amounts of X-ray and gamma-ray radiation are still an enigma. It has not yet been shown which type of object is responsible for having filled the sky with a background of X-ray energy.

XTE will address these and other fundamental questions about the nature of the cosmos. The large effective area ($\sim 0.8 \text{ m}^2$ total) and broad band of sensitivity (2 to 200 keV) of its three instruments make it especially valuable for timing of intensity variations and for the determination of broad-band spectra from high-energy sources. For the first time, studies of variability ranging from about 1 microsecond to several years will be carried out. XTE's design and flexibility of operations will allow it to respond rapidly to changes in the X-ray sky (within hours) and facilitate multifrequency observations. XTE can study more than a thousand of the brightest X-ray sources in the sky (see Figure 6). These represent a diverse set of objects and physical processes.

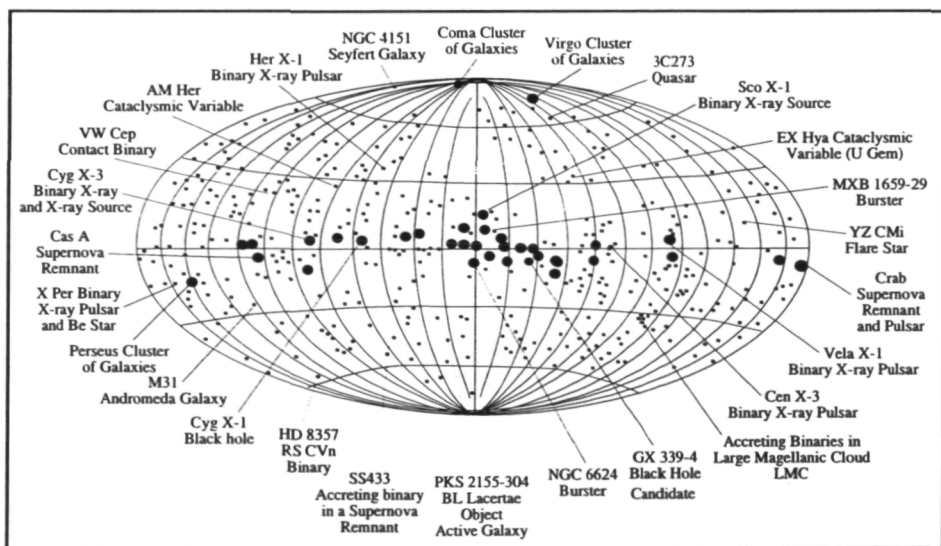


Figure 6. The HEAO-1 satellite surveyed the sky in 1977-79 and detected the 842 X-ray sources shown here. These represent a wide variety of high-energy phenomena. These sources will be the prime targets of XTE, though fainter objects and previously unknown transient or nova sources can also be studied.

THE XTE OBSERVATORY

The XTE observatory has been designed as an integral unit consisting of a complement of science instruments and supporting systems and subsystems. The observatory is shown in Figure 7.

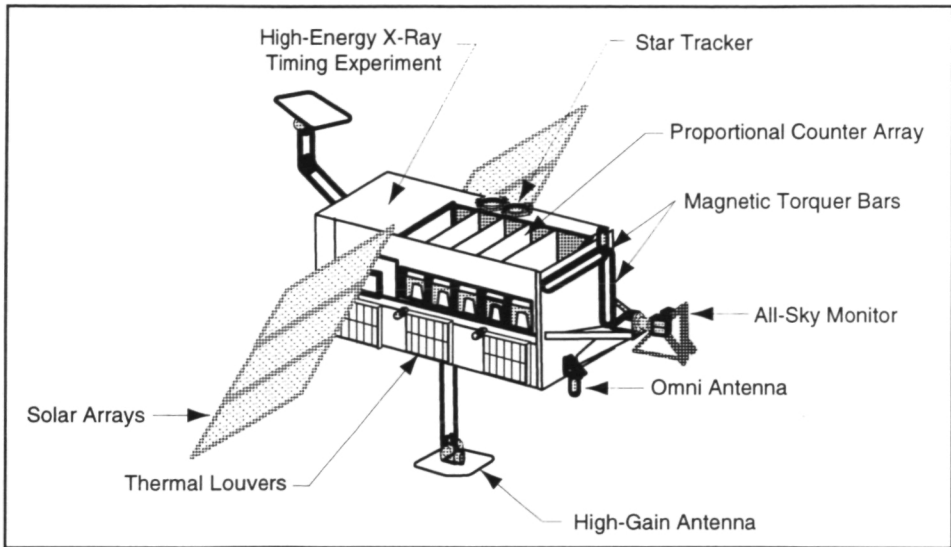


Figure 7. X-ray Timing Explorer (XTE) Observatory

THE XTE INSTRUMENTS

The XTE will carry out its studies with the three instruments listed in Table 1. A Proportional Counter Array (PCA) with a large collecting area (7000 cm^2) will be sensitive to X-rays from 2 to 60 keV. This instrument is supported by a powerful microprocessor-driven flight data system with multiple analysis channels capable of processing high rates (up to about 500,000 X-rays per second) with a minimum loss of information. The PCA will work in parallel with the High-Energy X-ray Timing Experiment (HEXTE), which consists of crystal scintillator detectors (1600 cm^2) that extend the XTE energy sensitivity up to 200 keV.

Together the PCA/HEXTE instruments are a powerful "telescope." The large areas and low backgrounds provide high sensitivity to weak X-ray sources. They can view a single source in their common 1-degree field of view (FOV). The third

Table 1. XTE Instruments

Instruments		Detectors	Net Area Geom. (cm ²)	Bandwidth (keV)	Field of View (FWHM)	Time Resolution	Telemetry Rates (kbps)	Sensitivity (milli-Crab)
PCA	Proportional Counter Array	5 Xenon Proportional Counters	7000	2-60	1°	1 μs	18 avg 300 max	0.1 (600s)
HEXTE	High-Energy X-ray Timing Experiment	8 Sodium Iodide Cesium Iodide	1600	20 - 200	1°	10 μs	5 avg 26 max	1 (10 ⁵ s)
ASM	All-Sky Monitor	3 Xenon Proportional counters	90	2-10	6° x 90°	1.5 h	3	20 (1.5h) ^a
a 10 mCrab in 1 day								

instrument is an All-Sky Monitor (ASM) that scans most of the sky every 1.5 hours in order to monitor the intensities and spectra of the brightest ~75 sources in the sky. It will explore the long-term behavior of these sources and will provide timely information on any large changes of intensity and spectral shape. The observatory permits rapid pointing of the XTE instruments to almost any point in the sky for studies with great sensitivity.

The power and uniqueness of XTE comes in large part from the natural synergism of the three instruments and the versatile observatory (Figure 8). These address a single well-defined objective: the timing and broad-band spectra of X-ray sources from 2 to 200 keV. The PCA/HEXTE measures short-term variability to microsecond levels while the ASM measures long-term (hours to months) light curves of bright sources. Long-term variability of faint sources may be monitored with repeated brief PCA/HEXTE observations.

PROPORTIONAL COUNTER ARRAY (PCA)

The PCA consists of five large detectors with a total net area of 7000 cm² (Figure 9). Each detector is filled with xenon gas. Low background is achieved through efficient anti-coincidence schemes including side and rear chambers and a propane top layer. The xenon of the three signal detection layers is 3.6-cm thick at one atmosphere. The front window and a window separating the propane and the xenon chambers are both aluminized mylar of 25-μm thickness. The propane layer may also be used as a signal layer in the energy range of 1 to 3 keV.

SYNERGISM OF XTE CAPABILITIES

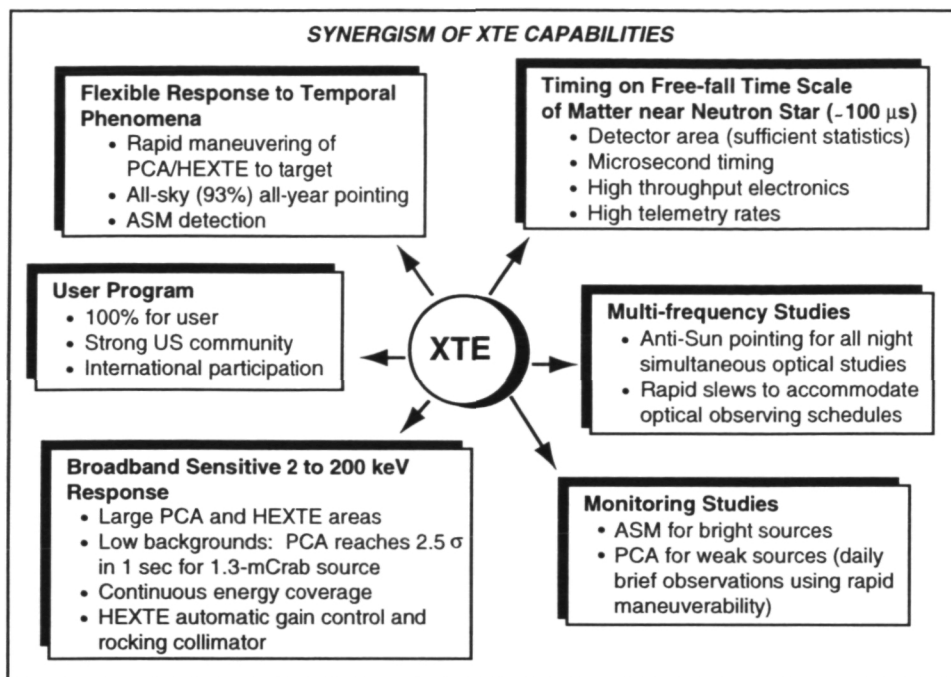


Figure 8. Synergism – The ability of XTE to effectively study systems containing compact objects is based in large part on the synergism of its capabilities.

X-rays in the 2- to 60-keV band are photoelectrically absorbed by the xenon gas. The amount of electric charge so created is proportional to the X-ray energy (thus, the name "proportional counter") and is further multiplied in the high electric fields near the signal anodes inside the detector. The resulting charge signal is digitized by the PCA electronics and transferred to an Experiment Data System (EDS) for compression, storage, and eventual telemetry downlink.

The PCA has a 1° FOV full width half max (FWHM) defined by hexagonal collimators. The faintest detectable source is limited not by counting statistics but by variations in the diffuse, cosmic X-ray background. This so-called "confusion limit" is equivalent to about 0.1 mCrab (1/10,000 the intensity of the Crab Nebula). Active galaxies at 1 mCrab provide statistically significant numbers of counts in a few seconds.

The PCA electronics provides digital pulse-height data to the EDS for binning and onboard analyses. The PCA is provided by GSFC.

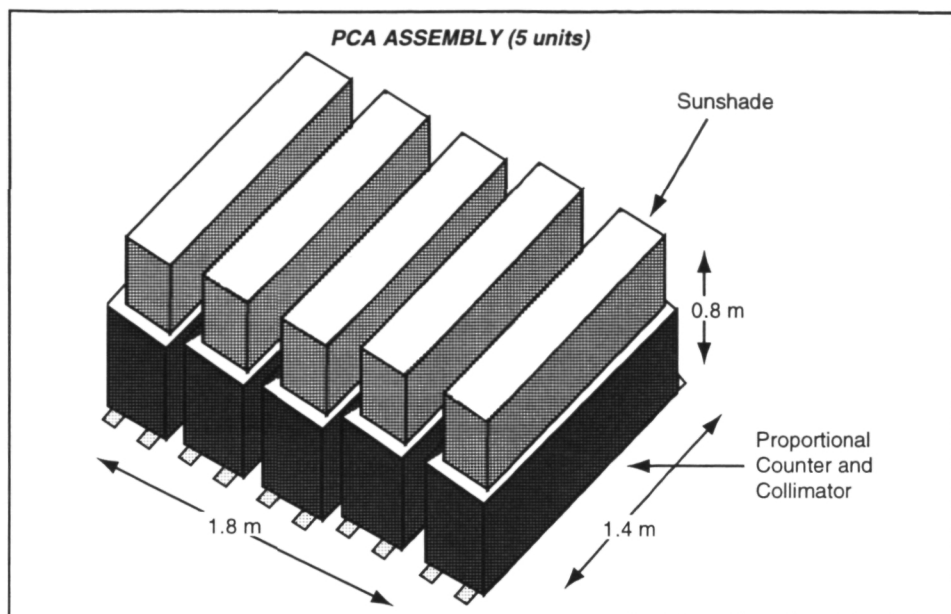


Figure 9. The Proportional Counter Array measures X-rays in the 2 to 60 keV region and has an exceptionally large collecting area (7000 cm²). It consists of five separate gas-filled X-ray detectors, each with a collimator and Sun shade. The background is kept very low by means of anti-coincidence chambers on four sides of the detection chamber. A radioactive source provides in-flight energy calibration.

EXPERIMENT DATA SYSTEM (EDS) FOR THE PCA AND ASM

The EDS is a microprocessor-driven data system used for onboard processing of the PCA and ASM data. The system will process count rates from the PCA up to $\geq 500,000$ cs⁻¹ (Sco X-1, the brightest persistent source yields $\sim 160,000$ cs⁻¹) and will be able to time photon arrivals to ~ 1 μ s. The PCA data stream can be binned and telemetered in six different modes simultaneously by six independent Event Analyzers (EAs) which operate in parallel, each analyzing the total PCA data stream. For example, a pulsar fold, a high-resolution spectrum, a low-resolution spectrum, and Fourier transform with 1- μ s bins could all be carried out simultaneously.

Each EA includes a Digital Signal Processor (DSP) chip that will rapidly bin the individual events according to highly flexible criteria (e.g., non-uniform pulse height bin widths and arbitrarily chosen timing bin widths), which may be specified for each observation. The DSP is used in conjunction with a table-lookup scheme

to provide the required speed of classification for each event (i.e., the tables hold the binning criteria for a given observation). An additional microprocessor in each EA serves as the EA manager.

The EAs will create data packets for transfer to the observatory memory from which they will be transmitted via a telemetry stream to the ground at a time average rate of 21 kbps for the PCA and 5 kbps for the ASM. In addition, a data burst of 300 kbps for up to 30 minutes a day can be accommodated to view bright X-ray sources. The EDS is provided by MIT.

HIGH-ENERGY X-RAY TIMING EXPERIMENT (HEXTE)

The HEXTE consists of two independent "clusters" (see Figure 10) of four detectors each (called "phoswiches") that are sensitive to X-rays from 15 to 250 keV. These detectors are improved and much larger versions of the detectors that formed part of the HEAO-1 mission in 1978 -- the previous NASA mission to cover XTE's broad range in energy.

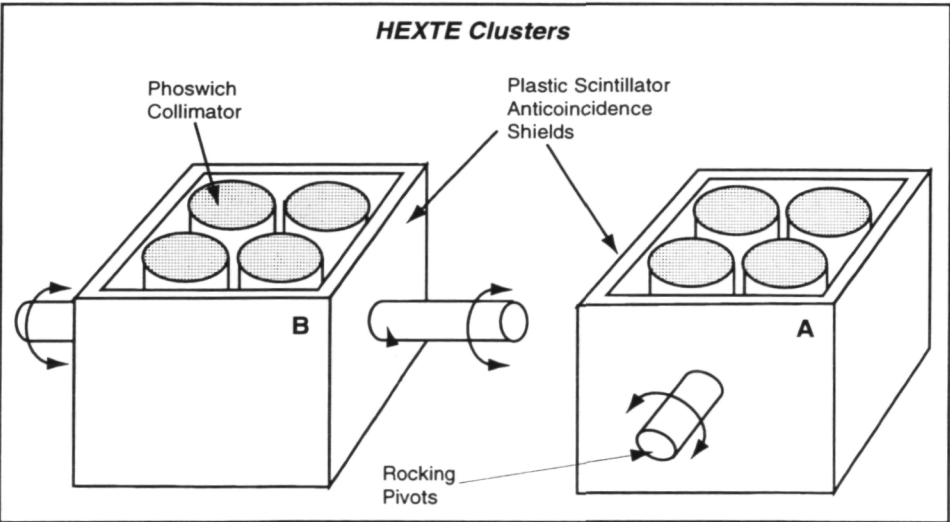


Figure 10. The HEXTE system is sensitive to higher energy X-rays (20 to 200 keV) than the PCA. There are two rocking clusters, each with four "phoswich" detectors that lie inside a 5-sided plastic scintillator anticoincidence shield (box). Magnetic shielding (partially shown) surrounds the photomultiplier tube and collimator. A radioactive source provides a signal for stabilization of the detector gain. The rocking allows the detectors to sample blank sky every ~32 seconds in order to measure background.

Each detector consists of a sandwich of sodium iodide (NaI) and cesium iodide (CsI) crystal layers, which produce tiny flashes of light in response to incident X-rays; these so-called "scintillations" are then picked up and amplified by a photomultiplier tube. In order to intercept as many X-rays as possible from faint sources, each cluster has a total detector area of 800 cm².

Such detectors are also sensitive to the high-energy particles that the HEXTE will encounter in its orbit. Therefore, each HEXTE cluster of detectors is surrounded by active "shield" detectors that register such particles as they fly through the instrument, and signal the electronics to reject the scintillations they produce in the detectors. This "anti-coincidence" shielding technique reduces the background noise by over 1000 percent.

To measure and subtract the residual background due to cosmic ray particles and X-rays not originating from the source, each HEXTE cluster will "rock" on- and off-source every 32 seconds to measure this background on either side of the source. The rocking of the two clusters is synchronized so that the source is always in the field of view of one of them.

Another important innovation is the Automatic Gain Control (AGC) system. A small Americium radioactive source provides X-rays at a fixed energy that can be monitored by each detector. Using this information, the AGC system works in a feedback loop to compensate for variations of detector voltages throughout the XTE orbit, and provides scientists with a reference signal for monitoring any long-term changes in detector performance. While the HEXTE is able to perform timing studies down to 8 microseconds, this gain stability will also enable astronomers to make accurate comparisons between observations taken months or even years apart.

Like the PCA, the HEXTE has a 1-degree field of view of the sky. It is able to provide users with a large number of data modes, either signaling every X-ray photon (event mode), or accumulating them to produce light curves or spectra (binned modes), as well as providing a "trigger" for detecting rapid bursts of X-rays. The data rate from the HEXTE will be about 5 kbps. The HEXTE is provided by the University of California at San Diego.

ALL-SKY MONITOR (ASM)

The ASM consists of three Scanning Shadow Cameras (SSCs) on one rotating boom with a total net effective area of 90 cm^2 (180 cm^2 without masks, see Figure 11). Each SSC is a one-dimensional "Dicke camera" consisting of a one-dimensional mask and a one-dimensional, position-sensitive proportional counter. The gross field of view of a single SSC is $6^\circ \times 90^\circ$ FWHM, and the angular resolution in the narrow (imaging) direction is 0.2° . An approximately 5σ detection provides a single line of position of $3' \times 90^\circ$. Two of the units view perpendicular to the rotation axis in nearly the same direction except that two detectors are each rotated by $\pm 12^\circ$ about the view direction so that they serve as "crossed-slat collimators". The crossed fields provide a positional error region of $0.2^\circ \times 1^\circ$ for a weak source and $3' \times 15'$ for a $\sim 5\sigma$ detection. An observatory maneuver could reduce this to $3' \times 3'$. With high-statistics detections, precisions $< 1'$ should be attainable. The third SSC unit views along the axis of rotation. It serves in part as a "rotation modulation collimator" and surveys one of the two poles not scanned by the other two SSCs.

Each SSC detector is a sealed proportional counter filled to 1.2 atm with xenon- CO_2 , and has a sensitivity depth of 1.3 cm. It has eight position-sensitive anodes, a $50\text{-}\mu\text{m}$ beryllium window, a sensitive area of 60 cm^2 of which only $1/2$ can view a given celestial position through the mask at a given time, anticoincidence chambers on the sides and rear, and sensitivity to 2 to 10 keV X-rays with three energy channels. The one-dimensional design of the SSCs greatly minimizes the required telemetry rate compared to two-dimensional systems. The data is telemetered in a spatial-image mode and in a time-series mode.

A motorized drive will rotate the three SSC's from field to field in 6° steps. At each resting position, a ~ 100 second exposure of the X-ray sky will be made; a complete rotation is thus completed in ~ 100 minutes. Since the "crossed-field detectors" are stepped by only the 6° FWHM angle, each source is viewed twice. In this manner, each source gives rise to the entire mask pattern in the accumulated data, thus minimizing aliasing and side bands in the deconvolved results. During each rotation, ~ 80 percent of the sky will be surveyed to a depth of $\sim 20\text{-mCrab}$ (about 50 sources). Frequent observatory maneuvers will make it likely that 100 percent of the sky is surveyed each day. In one day, the limiting sensitivity becomes $\leq 10 \text{ mCrab}$ (~ 75 sources). The drive can be commanded to stop for an extended observation of a given source to obtain a precise position of a nova. The drive has a total rotation angle of $\sim 500^\circ$ before it must be rewound. It can be stepped or moved rapidly in either direction.

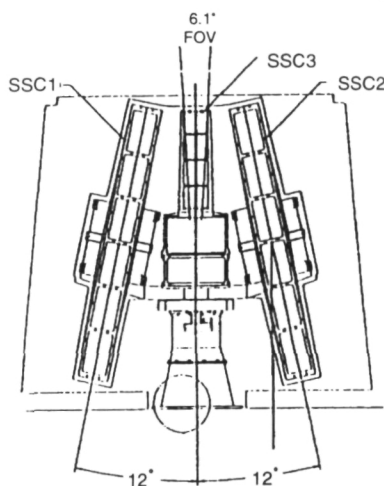
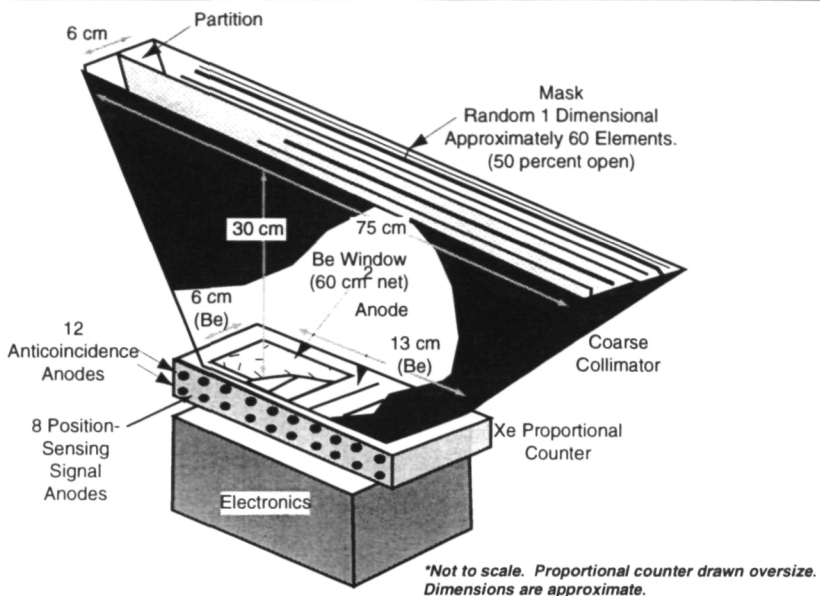


Figure 11. ASM – The All-Sky Monitor scans 80 percent of the sky every ~100 minutes to monitor the intensity of the brightest ~75 X-ray sources and to provide an alert if a source changes state or brightens suddenly. This allows the observatory to be maneuvered so the powerful PCA/HEXTE instruments can study the event. There are three SSCs that survey the sky in 6° steps by means of the motorized drive upon which they are mounted. The system will yield the celestial position of a previously unknown source with a precision of ~3' x 15'.

The intensities and other basic results derived from the data will be made available in the XTE Science Operations Center (SOC). The results will make possible rapid acquisition by the PCA/HEXTE of sources when they undergo a change of state (e.g., when a transient appears or when a source changes its characteristic spectrum). The ASM is provided by MIT.

THE XTE SPACECRAFT

The spacecraft is made up of the systems and subsystems necessary to provide structural integrity of the observatory during launch and ascent, precise alignment and pointing of the science instruments in orbit, maintenance of the observatory within acceptable temperature limits, electrical power, and two-way communications with the ground. The spacecraft was developed by GSFC and the completed observatory was also integrated and tested at GSFC.

The following is a description of the spacecraft subsystems.

STRUCTURAL

The XTE structure, composed of riveted assemblies of machined aluminum beams and honeycomb panels that provides accommodation for eight instrument components and approximately 63 spacecraft electronic components and boxes. Secondary structures are used to mount the Power Control Units (PCUs), star trackers, Inertial Reference Units (IRUs), Reaction Wheels, and the ASM. The spacecraft is designed such that a clear field of view is maintained for the instruments and star trackers. The ASM is mounted at one end of the spacecraft to provide nearly 85-percent sky coverage. The instruments are mounted such that boresights of PCU/HEXTE are aligned and remain within 0.1 degree. The structure is electrically conductive to avoid static charge build-up and is designed to withstand the Delta II launch environments. The interface to the launch vehicle is accomplished through a payload attachment fitting (PAF).

THERMAL CONTROL

The XTE Thermal Control Subsystem uses both passive and active methods to keep the instruments and the spacecraft components within acceptable temperature ranges during all phases of the mission. Deployable mechanism temperatures are maintained within their limits before and during deployment. Passive thermal

control is provided by louvers, thermal paints, coatings, and multilayers of thermal insulation. Active control is provided by electronically-controlled heaters to control the temperature of more critical components such as instruments in which temperatures must be controlled continuously. Temperature sensing is provided by various thermistors in the vicinity of components to adequately measure the component temperatures.

ELECTRICAL POWER

The XTE Electrical Power Subsystem provides the observatory electrical power. It provides a minimum of 800 watts of continuous electrical power during the mission lifetime of two years and maintains the bus voltage at approximately 28 volts. It includes 192 square feet of solar arrays, two 50 ampere-hour advanced nickel-cadmium batteries, Power Signal and Control Unit (PSCU), Power Source Interface Unit (PSIU), and Power Bus Interface Unit (PBIU). The power is distributed via three busses: essential bus, non-essential bus, and pyrotechnic bus.

Silicon cells are mounted on planar-deployable solar arrays. They provide power during the sunlit portion of the orbit. The power generated is supplied to the instruments and the spacecraft subsystems and is also used to charge the batteries. The batteries supply power during the eclipse period of the orbit.

The PSCU performs the battery charge control function and provides a command and telemetry interface. The PBIU interfaces directly with the batteries through a relay while the PSIU interfaces with the solar arrays.

The Power Switching and Distribution Units (PSDUs) distribute power to the observatory loads through fuses and switches.

ATTITUDE CONTROL SYSTEM

The Attitude Control Subsystem (ACS) maneuvers the XTE observatory through space at a rate greater than 6 degrees/minute and points the PCA/HEXTE instruments to any position in the sky on any day of the year except for pointing within 30 degrees of the Sun. The ACS commands the solar array drives so that the solar arrays can track the Sun during all phases of the mission. The ACS also commands the High-Gain Antenna (HGA) pointing system to track a Tracking and Data Relay Satellite (TDRS). The XTE ACS is a 3 axis stabilized, zero momentum

system that employs a complement of sensors and actuators to measure and control spacecraft attitude. As XTE moves through space, external forces (e.g., Earth's magnetic and electrical fields, aerodynamic drag, and solar radiation) can induce attitude perturbation. The ACS is used to perform all attitude corrections required to maintain the observatory position. Figure 12 shows ACS hardware and Table 2 provides the attitude control and determination performance of the observatory.

Table 2. Observatory Attitude Control and Determination.

Attitude Control and Determination	Performance
Target Observation	Point PCA/HEXTE line-of-sight anywhere in the celestial sphere except for pointing within 30 degrees of the Sun.
Observatory Maneuvering Capability	> 6 degrees/minute
Instrument Pointing Accuracy	Point the instrument detectors to within 0.1 degree of a commanded target
Instrument Pointing Knowledge	Maximum allowable pointing error knowledge is 0.05 degrees
ACS Attitude Determination	Accuracy better than 0.02 degrees

RF COMMUNICATIONS

The RF Communication System (RFCS) receives commands sent to the XTE observatory from the ground and transmits subsystem status and science data to the ground network. During deployment and normal operations, communications between the XTE observatory and the ground takes place via a TDRS. In the event of an emergency the TDRS or the Deep Space Network (DSN) is used to communicate with the XTE observatory. Figure 13 illustrates the XTE communications links.

The RFCS consists of two transponders, two deployable HGAs, two omni-antennas, three transfer switches, two diplexers, and an RF combiner box.

The two computer-controlled HGAs provide an RF interface with the space network (SN) that decouples network scheduling from science planning.

The RFCS command characteristics are:

- Carrier Frequency: 2106.4 MHz

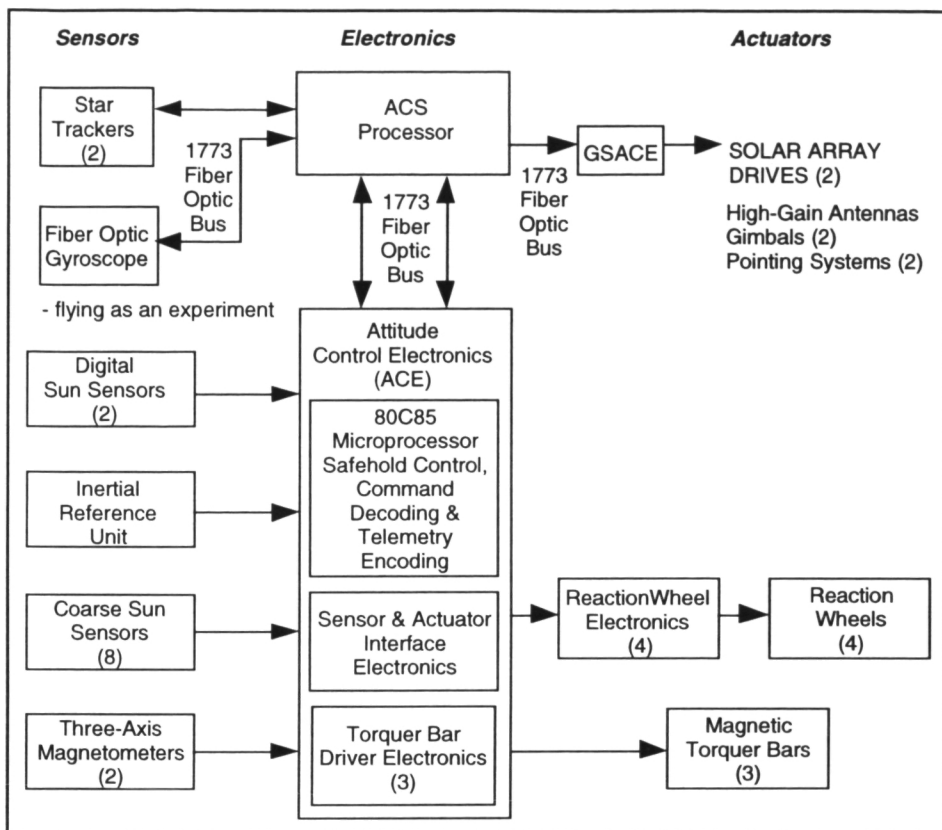


Figure 12. ACS hardware and their relationships.

- Command Rate: 1 kbps through HGA during normal operations
- Emergency commanding through the omni-antennas at 125 bps using TDRS or 2 kbps using the DSN

The RFCS telemetry characteristics are as listed below:

- Carrier Frequency: 2287.5 MHz
- Normal Operations Data Rate:
 - Multiple-Access Mode:
 - Observatory Status Data: 16 or 32 kbps
 - Science Data: 32 or 64 kbps

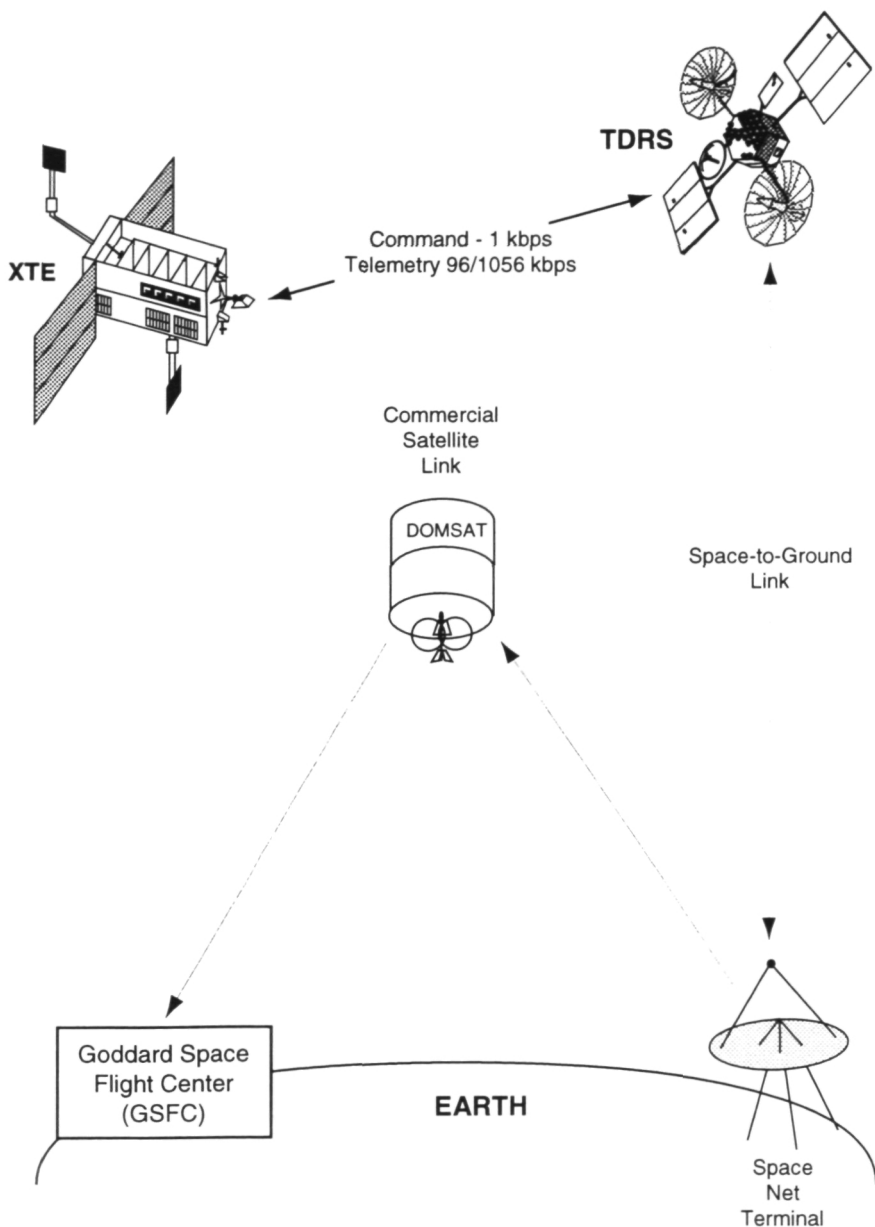


Figure 13. XTE Command and Telemetry Communication Links.

- Single-Access Mode:
 - Observatory Status Data: 16 or 32 kbps
 - Solid State Recorder Dump (Science Data): 512 or 1024 kbps
- Emergency telemetry through the omni-antennas at 2 kbps using TDRS or 1024 kbps using the DSN.

COMMAND & DATA HANDLING (C&DH)

The C&DH subsystem collects, formats, and records science and engineering data from other subsystems and the instruments for transmission to the Mission Operations Center (MOC) via TDRS. The command equipment will receive, process, and execute real-time commands, as well as execute commands from onboard command storage. The data handling equipment collects the subsystem and instrument data, encodes it, and routes it to the transponders in the RFCS for real-time transmission to the TDRS and to the C&DH solid state recorders for storage that is telemetered at a later time. It utilizes a redundant fiber optic data bus.

The C&DH subsystem provides the following basic functions:

- Receives, decodes, and distributes all commands for XTE operation.
- Collects, formats, and stores status telemetry. Collects and stores instrument science data. The C&DH subsystem can store up to four orbits of observatory and instrument data.
- Provides Convolutional and Reed-Solomon encoding of the real-time data streams; premodulation of the real-time data stream, and formulation of the real-time/playback downlink data stream.
- Generates, distributes, and maintains all timing signals, including the ultra-stable XTE clock.
- Provides onboard missions operations management and health and safety status monitoring.

LAUNCH AND DEPLOYMENT

A Delta II, Model 7920-10 (long-tank, two-stage, nine solids) launch vehicle designed, built, and launched by the McDonnell Douglas Astronautics Company (MDAC) under the technical direction of GSFC, will be used to launch XTE from Cape Canaveral Air Force Station in Florida (see Figure 14).

Besides providing the thrust needed to achieve the desired orbit, the launch vehicle before separation performs a declination maneuver, which places XTE in the attitude required for operation. Figure 15 illustrates the orbit insertion of the XTE observatory.

FIRST STAGE

The Delta first stage is powered by an RS-27 Rocketdyne engine using liquid hydrocarbon propellants and nine strapped-on Hercules graphite-epoxy motors to augment the first-stage performance. Six motors are ignited at liftoff and the remaining three are ignited in flight.

SECOND STAGE

The Delta second stage is powered by an Aerojet AJ10-118K engine using liquid propellants. During powered flight, the second-stage hydraulic system gimbals the engine for pitch and yaw control. A redundant attitude control system (RACS) using nitrogen gas provides roll control. The RACS also provides yaw, roll, and pitch control during unpowered flight. The guidance, control, and navigation system (GC&NS), located in the forward section of the second stage, is operated by a guidance computer to steer the launch vehicle during flight.

A 10-foot (3-meter) diameter fairing, attached to the forward face of the second stage, protects the XTE observatory from aerodynamic heating during the boost flight.

XTE is attached to the launch vehicle through a Model 6915 PAF. It includes a secondary latch system, which holds XTE for a little longer after the separation bolts are fired. It then releases XTE slowly, minimizing observatory motion.

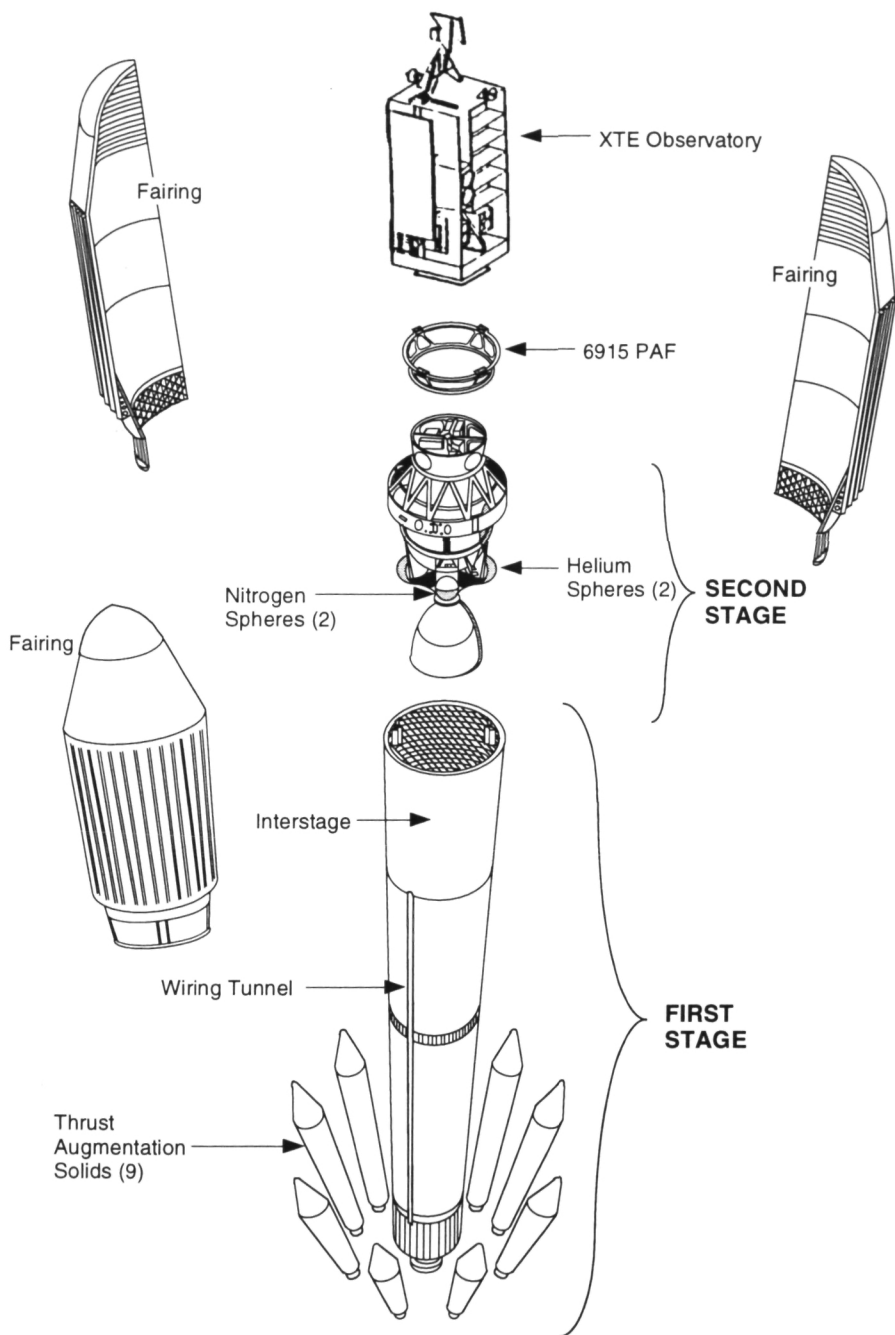
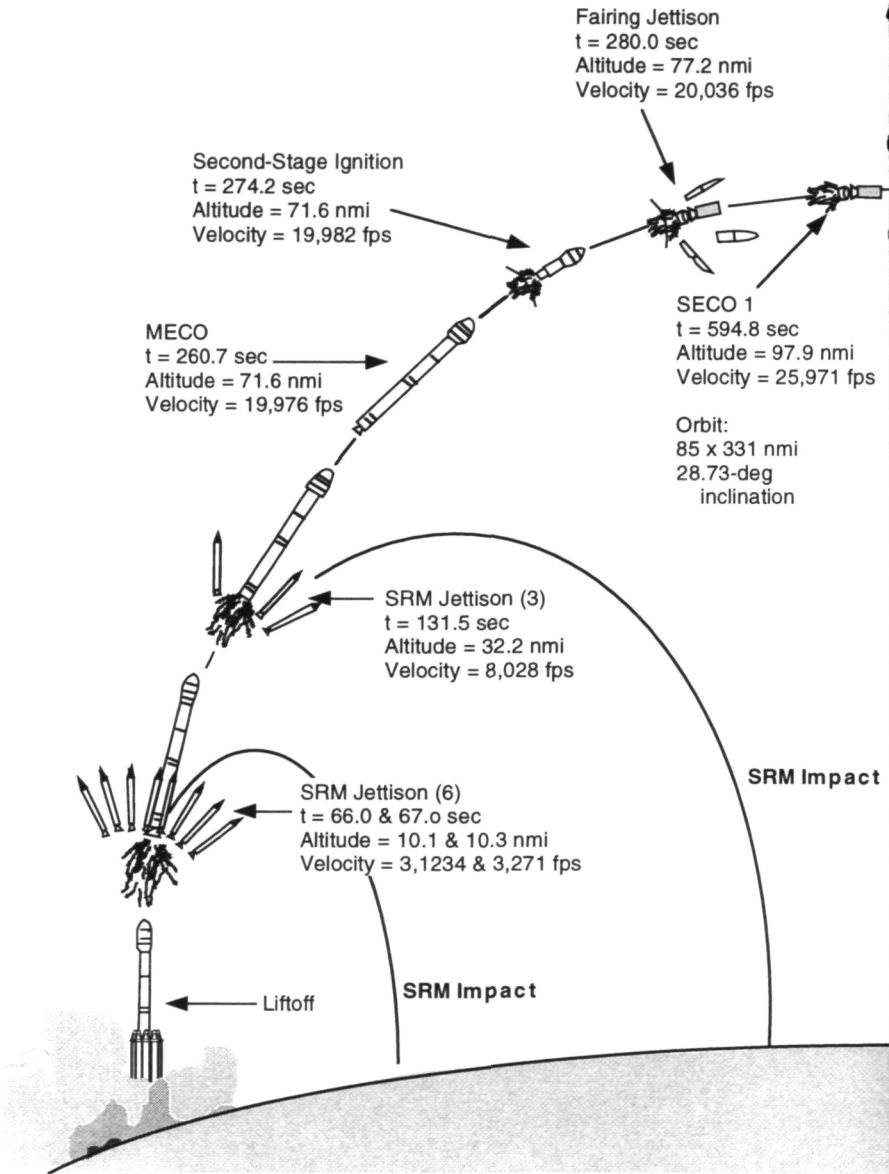
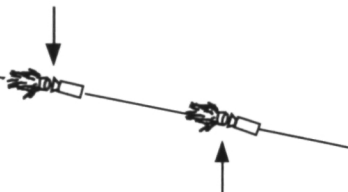


Figure 14. Delta II (Model 7920-10) Launch Vehicle used to place XTE observatory in the desired orbit.



MECO	-	MAIN ENGINE CUTOFF
SECO	-	SECOND STAGE ENGINE CUTOFF
SRM	-	SOLID ROCKET MOTOR

Second-Stage Restart
t = 4098.1 sec
Altitude = 315.7 nmi
Velocity = 24,459 fps



SECO 2
t = 4189.2 sec
Altitude = 313.1 nmi
Velocity = 24,832 fps

Orbit:
313.1-nmi circular
23.00-deg inclination

XTE Mission Requirements	
- Orbit criteria - Apogee altitude - Perigee altitude - Inclination - Observatory weight - Launch parameters - Date - Pad - Launch time	560 km 580 km 23 deg 6700 lbs - August 31, 1995 - LC-17CCAFS 10:50 EDT

Figure 15. Mission Flight Profile

DEPLOYMENT

Separation of the XTE observatory from the Delta rocket occurs approximately 78 minutes after lift-off. Communications with the XTE observatory begins approximately 10 minutes before separation. The solar arrays and one of the HGAs are deployed within 15 minutes of separation. Immediately after these deployments, the XTE observatory is stabilized and the solar arrays are pointed at the Sun. During the first orbit the other HGA is deployed.

MISSION OPERATIONS

Mission operations are conducted from GSFC. The MOC is the focal point for flight operations. It provides the hardware and software systems necessary for the real-time and off-line spacecraft support activities. The Flight Operations Team (FOT) in the MOC monitors and controls the spacecraft. They ensure that the science data are transmitted and captured. The FOT schedules use of the TDRSS and provides the interface with all the system support elements. The data are captured by the Sensor Data Processing Facility (SDPF) and provided to the SOC.

SCIENCE PLANNING AND OPERATIONS

The XTE SOC, also located at GSFC, is responsible for science planning, instrument operations, and guest observer support. It is composed of the Science Operations Facility (SOF), the Guest Observer Facility (GOF), and the Data Archive Facility.

The SOF is responsible for implementing the selected observations, that is, scheduling maneuvers that point the PCA and HEXTE at the targets and preparing the commands that put the instruments in the appropriate configurations and rotate the ASM back and forth across the sky. The SOF monitors the instrument diagnostic parameters and the science performance during the observations. It can issue commands (in coordination with the FOT) involving instrument reconfigurations and target adjustments.

The SOF allows guest observers the option to monitor and analyze science data during the actual observations when possible adjustments based on the incoming data could significantly improve the scientific results. After the observation the data collected are sent to the guest observers for detailed analysis. The observer has proprietary rights to the data for 1 year. After that the data are made available to the science community at large.

The instrument teams will maintain the capabilities at MIT, UCSD, and GSFC to look at the data from their instruments remotely. Thus, they will have information needed to advise the SOF on anomalies and reconfigurations. They are responsible for using the data to calibrate the instruments and for recommending special calibration observations as needed.

The GOF is responsible for coordinating the information and software tools that potential guest observers need to propose observations in response to NASA's announcements of opportunities. A large number of observers (326) from the U.S. and abroad proposed for the first 9 months of science observations. The GOF has examined the proposals for feasibility and a panel of 50 scientists has ranked their scientific promise. The highest ranked are being scheduled to start after a month of engineering and instrument checkout operations. The GOF is making available to the observers software to access the data and the calibrations. The GOF also answers observers' questions about the instruments and the software. After the data are captured, they are automatically processed in the Data Archive Facility to repackage it in a more standard form to be readable by a standard type of software and stored in a data base. The data from each observation, together with appropriate calibration information, are sent on 8 mm tapes to the observers at their home institutions. Many observers will analyze the data using their own specialized software at their home institutions.

XTE KEY PERSONNEL

NASA GODDARD SPACE FLIGHT CENTER

- | | |
|------------------------------|--------------------|
| - Project Manager | Mr. Dale Schulz |
| - Project Scientist | Dr. Jean Swank |
| - Spacecraft Manager | Mr. Richard Day |
| - PCA Principal Investigator | Dr. Jean Swank |
| - PCA Project Manager | Mr. Lois Workman |
| - SOC Director | Dr. Frank Marshall |

MASSACHUSETTS INSTITUTE OF TECHNOLOGY CENTER FOR SPACE RESEARCH

- | | |
|------------------------------|-------------------|
| - ASM Principal Investigator | Dr. Hale Bradt |
| - ASM Project Manager | Dr. William Mayer |

UNIVERSITY OF CALIFORNIA AT SAN DIEGO

- | | |
|--------------------------------|------------------------|
| - HEXTE Principal Investigator | Dr. Richard Rothschild |
| - HEXTE Project Manager | Mr. Ed Stephan |

NASA HEADQUARTERS

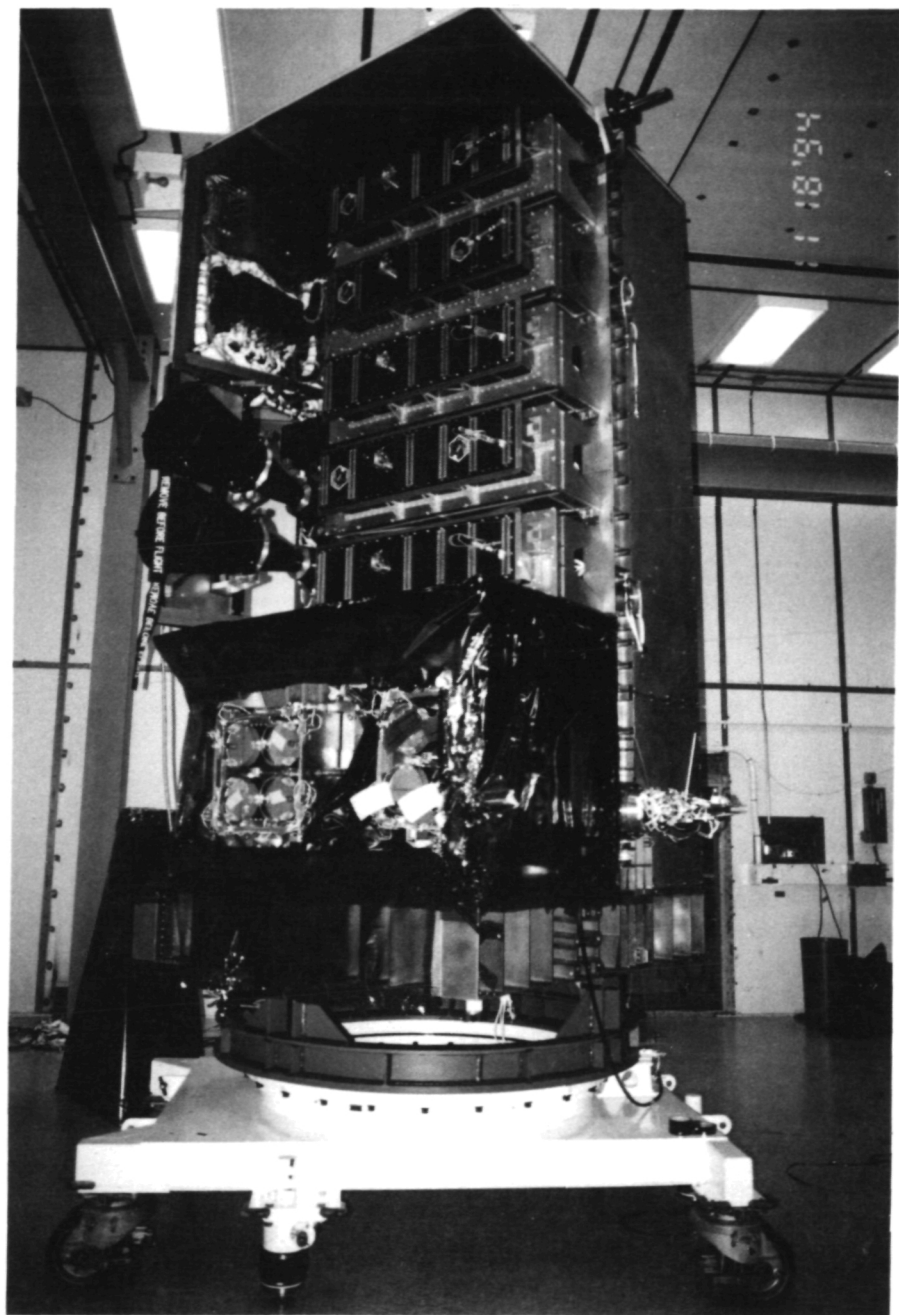
- | | |
|---------------------------------|----------------------|
| - Program Scientist | Dr. Louis Kaluziński |
| - Program Manager (Development) | Mr. John Lintott |
| - Program Manager (Operations) | Dr. Guenter Riegler |

ACRONYMS

ACS	Attitude Control System
AGC	Automatic Gain Control
AGN	Active Galactic Nuclei
ASM	All Sky Monitor
C&DH	Command and Data Handling
EA	Event Analyzer
EDS	Experiment Data System
FOT	Flight Operations Team
FOV	Field of View
FWHM	Full Width Half Max
GOF	Guest Observer Facility
GSFC	Goddard Space Flight Center
HEXTE	High Energy X-ray Timing Experiment
HGA	High Gain Antenna
IRU	Inertial Reference Unit
kbps	kilo bit per second
keV	kilo-electron Volt
MDAC	McDonnell Douglas Astronautics Company
MIT	Massachusetts Institute of Technology
MOC	Mission Operations Center
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications System
PAF	Payload Attachment Fitting
PCA	Proportional Counter Array
PI	Principal Investigator

SADDS	Solar Array Deployment and Drive System
SDPF	Sensor Data Processing Facility
SDVF	Software Development and Verification Facility
SN	Space Network
SOC	Science Operations Center
SOF	Science Operations Facility
SSC	Scanning Shadow Camera
TCS	Thermal Control System
TDRS	Tracking and Data Relay Satellite
UCSD	University of California at San Diego
XTE	X-ray Timing Explorer

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NOTES
