NASA

National Aeronautics and
Space Administration

Washington, D.C.
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Reply to Attn of: SZ

MAY 31 1990

TO: Distribution

FROM: S/Associate Administrator for Space Science and Applications

SUBJECT: Roentgen Satellite (ROSAT) Prelaunch Mission Operation Report (MOR)

The Prelaunch Mission Operation Report (MOR) for the Roentgen Satellite (ROSAT) is enclosed for your information.

ROSAT is a large, 5333 lb., Explorer class scientific satellite configured to accommodate a large x-ray telescope, the most powerful one ever built, for the measurement of soft x-ray emissions from celestial objects. A secondary telescope, the Wide Field Camera, is also carried to extend the spectra measured into the extreme ultraviolet band. ROSAT's science mission is scheduled in two phases: (a) a 6 months survey phase, conducted by German scientists, to produce an all-sky map and catalog of x-ray sources, and (b) a pointed phase, lasting at least 12 months, during which the telescopes are pointed at pre-selected individual x-ray sources designated by Guest Observers.

This MOR: (a) describes the objectives of the ROSAT mission; (b) provides brief descriptions of the spacecraft and its scientific instruments; (c) provides a chronology of launch, deployment, and acquisition events; and (d) describes the ground operation elements that support the mission.

The ROSAT mission is an international collaboration between NASA, the Federal Ministry for Research and Technology in the Federal Republic of Germany, and the Science and Engineering Research Council in the United Kingdom. NASA is providing the Delta II launch and the High Resolution Imaging detector at the focal plane of the x-ray telescope. The NASA Guest Observer program is allocated 50% of the observing time in the pointing phase of the mission. The ROSAT observations will provide the astrophysics community with the only x-ray astronomical imaging data between the High Energy Astronomy Observatory (HEAO-2) whose mission ended in 1981, and the Advanced X-ray Astrophysics Facility (AXAF), whose mission is to start in 1997.

L A Fisk

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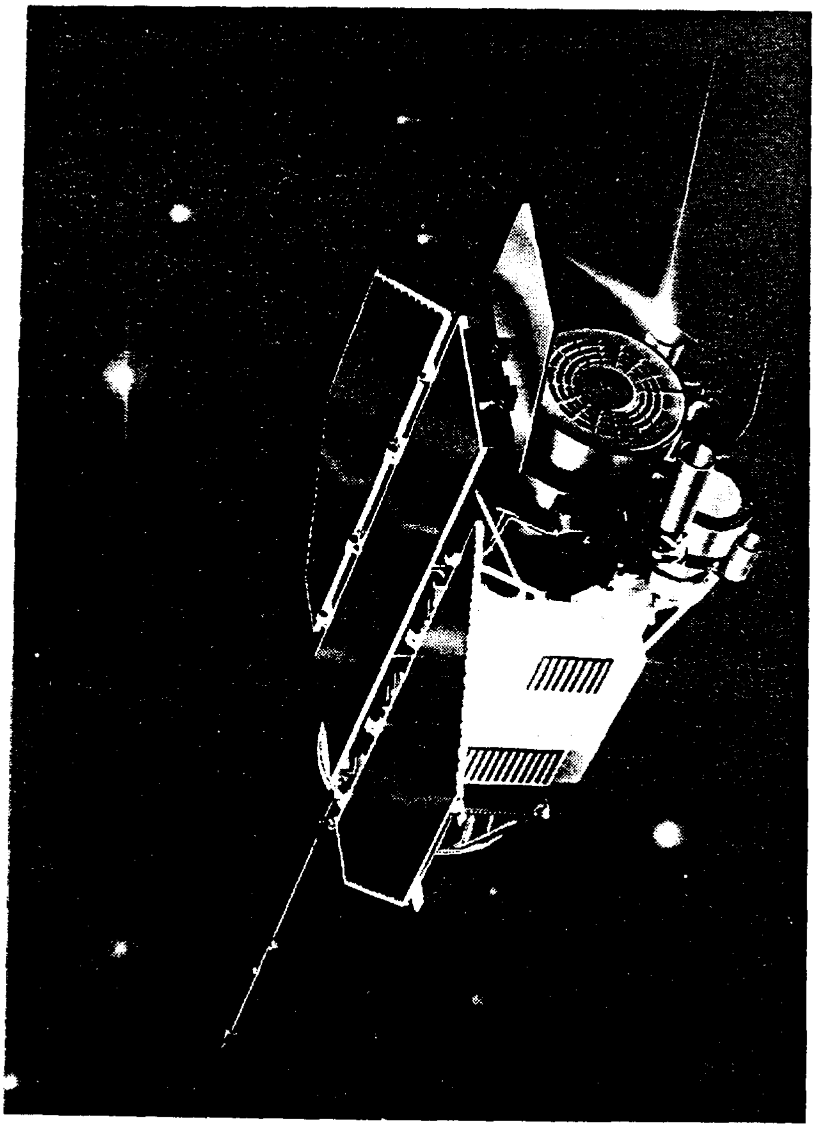
Enclosure

National Aeronautics and
Space Administration

Mission Operation Report

OFFICE OF SPACE SCIENCE AND APPLICATIONS REPORT NO. E-876-90-03



ROENTGENSATELLIT

(ROSAT)

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FOREWORD

MISSION OPERATION REPORTS are published expressly for the use of NASA senior management, as required by the Administrator in NASA Management Instruction NMI 8610.3D, dated May 13, 1982. The purpose of these reports is to provide NASA senior management with timely, complete, and definitive information on flight mission plans, and to establish official mission objectives which provide the basis for assessment of mission accomplishment.

Reports are prepared and issued for each flight project just prior to launch. Following launch, updating reports for each mission are issued to keep management currently informed of definitive mission results as provided in NASA Management Instruction HQMI 8610.1B.

These reports are sometimes highly technical and are for personnel having program/project management responsibilities. The Public Affairs Division publishes a comprehensive series of reports on NASA flight missions which are available for dissemination to the news media.

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ROSAT PROGRAM OVERVIEW

The NASA Astrophysics Program seeks: to understand the origin and fate of the universe; to understand the birth and evolution of the large variety of objects in the universe, from the most benign to the most violent; and to probe the fundamental laws of physics by examining their behavior under extreme physical conditions. These goals are pursued by means of observations across the entire electromagnetic spectrum, and through theoretical interpretation of radiations and fields associated with astrophysical systems.

Astrophysics orbital flight programs are structured under one of two operational objectives: (1) the establishment of permanent "Great Observatories" for viewing the universe in four major wavelength regions of the electromagnetic spectrum (infrared/submillimeter radio, ultraviolet/visible, X-ray, and gamma ray bands), and (2) the obtainment of crucial bridging and supporting measurements via missions with directed objectives of intermediate or small scope conducted within the Explorer and Spacelab programs. Under (2) in this context, ROSAT is a large Explorer class mission which will provide the United States astrophysics community with the only X-ray astronomical imaging data available between the High Energy Astronomy Observatory (HEAO-2), whose mission ended in 1981, and the Advanced X-ray Astrophysics Facility (AXAF), whose mission is to start in the mid-1990's.

ROSAT's specific mission is to advance the science of astrophysics through the study of X-ray emissions from non-solar celestial objects with an X-ray observatory which will both survey the sky for X-ray sources and also point at specific, selected sources for extended periods of time. Following an eight week in-orbit turn-on and check-out period, the "survey" phase of the mission is expected to last approximately 6 months. The subsequent "pointed" phase is expected to last one full year but could possibly extend to 2.5 years. ROSAT will allow the logical and timely continuation of data-gathering along the directions indicated by the highly successful HEAO-2 mission, and will be a key link in preparing for the AXAF observation program. With several times the sensitivity and resolution of HEAO-2, ROSAT will provide a bridge in capabilities as well as time.

ROSAT is an international cooperative project between NASA, the Federal Ministry for Research and Technology (BMFT) of the Federal Republic of Germany (FRG), and the Science and Engineering Research Council (SERC) of the United Kingdom (UK). The Memorandum of Understanding (MOU) between NASA and BMFT was signed by NASA Administrator James M. Beggs and BMFT State Secretary Hans-Hilger Haunschild in 1982. The MOU between BMFT and SERC was signed in 1983. In accord with these MOU's: Germany developed and is providing the spacecraft, the X-ray telescope, and the two Position Sensitive Proportional Counters (PSPCs) at the focal plane of the telescope; NASA is providing the High Resolution X-ray Imager (HRI) at the focal plane of the telescope and the Delta II launch; and SERC is providing the stand-alone extreme ultraviolet (XUV) Wide Field Camera (WFC).

The ROSAT spacecraft is a 3-axis stabilized, 5333 lb.(2424 kg) satellite designed for pointing at celestial targets, for slewing between targets, and for performing scanning observations on great circles perpendicular to the plane of the ecliptic. The scientific payload, which utilizes about two-thirds of the total weight, is based on two, coaligned imaging telescopes. The primary telescope is the large X-ray telescope (XRT) designed for measuring "soft" X-rays over the energy range 0.1 to 2 keV, which corresponds to wavelengths 100 Å to 6 Å. The secondary telescope is the Wide Field Camera (WFC) which extends the measuring range to the extreme ultraviolet region by covering the energy range 0.04 to 0.2 keV (300 Å to 60Å).

ROSAT, in circular orbit (580 km altitude, 53° inclination), will be operated by the German Space Operations Center (GSOC) in Oberpfaffenhofen, West Germany using the German Deep Space Station near Weilheim, West Germany for command functions and the receipt of data from the tape recorders on-board the spacecraft. NASA tracking station support is to be limited to launch preparations, early mission operations, and subsequent back-up in case of emergencies. BMFT will be responsible for the processing and analysis of X-ray data acquired during the survey mode for the purpose of compiling an X-ray source catalog. Responsibilities for the processing and analysis of X-ray data acquired in the pointing mode are to be shared between NASA and BMFT. Observing time in the pointed mode is to be entirely available to scientific Guest Investigators. The scientific community accordingly responded to the first Announcement of Opportunity with a large number of proposals for observations and analyses. These proposals, applicable to the first six months of observations in the pointed mode, were submitted concurrently to NASA, BMFT, and SERC. In accord with the MOU, the U.S. will receive, as its share of the ROSAT observations, 50% of the observing time during the pointed phase. Detailed timelines (i.e., observing schedules), taking into account each countries share and observing priorities, have been established for the first six months in the pointed mode. A second Announcement of Opportunity, soliciting proposals for observations during the second six months of operation in the pointed mode, is to be issued after launch following confirmation of operational performance.

At the inception of the ROSAT project, ROSAT was to be launched by NASA's Space Shuttle in 1987. However, due to delays caused by the Challenger accident, NASA and BMFT jointly decided in 1987 to launch ROSAT on a Delta II vehicle with a February 1990 launch schedule. Germany subsequently modified and tested the ROSAT spacecraft to be compatible with the Delta II vehicle and the U.S. developed a new (10 foot diameter) nose section fairing for the Delta II to accommodate ROSAT's dimensions. Schedule evaluations in October 1989, centering on the fabrication and test program for the new Delta II fairing and the queue for Delta launches from the Cape Canaveral Air Force Station, prompted a change in launch schedule to May 1990.

Report No. E-876-90-03

NASA OBJECTIVES FOR THE ROENTGENSATELLITE (ROSAT) MISSION

The ROENTGENSATELLIT (ROSAT) mission is a cooperative program involving the United States, Federal Republic of Germany (FRG), and the United Kingdom (UK). The FRG is providing the spacecraft, X-ray telescope, and two moderate-resolution Position-Sensitive Proportional Counter (PSPC) focal plane detectors. The US is providing launch of the spacecraft, tracking and ground support during the initial operations phase, and a High Resolution Imager (HRI) focal plane detector. The UK is providing an Extreme Ultraviolet (EUV) telescope and associated focal plane detectors. Following an initial turn-on and calibration phase, a six-month X-ray and EUV all-sky survey will be performed by the FRG and UK. Subsequently, pointed observations of selected cosmic EUV and X-ray sources will be conducted for a period of one year (nominal mission). Subject to the sustained nominal performance of the observatory, an extended phase of pointed observations of selected targets will continue until the end of the useful mission life.

The Goals of NASA's participation in the ROSAT mission are to:

- ensure the successful execution of the X-ray and EUV all-sky surveys by delivering the spacecraft into the proper orbit and providing tracking and ground support during the initial operations phase

- elucidate the nature of cosmic astrophysical sources via imaging, spectroscopic, and temporal observations of their associated X-ray emission

The Objectives of NASA's participation in the ROSAT mission are to:

- measure the spatial, spectral, and temporal characteristics of discrete cosmic sources including normal stars, collapsed stellar objects, and active galactic nuclei

- perform spectroscopic mapping of extended X-ray sources including supernova remnants, galaxies, and clusters of galaxies

- conduct the above observations of cosmic sources with unprecedented sensitivity and spatial resolution over the 0.1 - 2.0 keV energy band

These objectives will be accomplished by:

- launching the ROSAT spacecraft into a nearly circular orbit with an altitude of 580 km and inclination of 53 degrees

- performing pointed observations of selected targets using the X-ray telescope and High Resolution Imager (HRI) focal plane detector. The objectives of the HRI observations include obtaining source positions with an accuracy of 6 arcseconds, mapping multiple source fields and extended emission features with a spatial resolution of 6 arcseconds, measuring flux variations with a temporal resolution of 61 microseconds, and, achieving a limiting sensitivity of 5×10^{-15} ergs-cm^{-2}-sec^{-1} over the 0.1 - 2.0 keV energy range.

- performing pointed observations of selected targets using the X-ray telescope and Position-Sensitive Proportional Counter (PSPC) focal plane detectors. The objectives of the PSPC observations include obtaining source positions with an accuracy of 10 arcseconds, mapping multiple source fields and extended emission features with a spatial resolution of 30 arcseconds, measuring flux variations with a temporal resolution of 130 microseconds, determining source spectra with a resolution of 0.13 keV and 0.3 keV at energies of 0.1 keV and 2.0 keV, respectively, and, achieving a limiting sensitivity of 3 x 10^{-15} ergs-cm^{-2}-sec^{-1} over the 0.1 - 2.0 keV energy range.

- ensuring the ready access of the international scientific community (excluding investigators from the FRG and UK per the ROSAT MOU) to the US share of pointed observing time (50% following the all-sky survey phase) made available through a competitive review process. The US goal is to perform a total of more than 500 observations per year (assuming an average observing time of 10,000 seconds per target).

- making the pointed data available to the scientific community in a timely manner and providing adequate support of their data analysis requirements through the US ROSAT Science Data Center (RSDC) facilities at the Goddard Space Flight Center (GSFC) and Harvard/Smithsonian Astrophysical Observatory (SAO). Mission goals are to deliver the corrected data to observers within 2 weeks of receipt of data at the RSDC and for data to be deposited in the High Energy Astrophysics Science Archival Research Center (HEASARC) at the GSFC within one year after receipt by the original investigator in final form.

C. J. Pellerin, Jr., Director
Astrophysics Division,
Office of Space Science &
Applications

Date: 5/6/90

L. A. Fisk, Associate Administrator
Office of Space Science &
Applications

Date: 5/27/90

J. A. Lintott, Program Manager

Date: 4/12/90

Alan N. Bunner, Program Scientist

Date: 12 Apr '90

MISSION HISTORY

The ROSAT (German acronym for "Roentgensatellit") project originated from a 1975 proposal to the Bundeministerium fuer Forschung und Technologie (BMFT) from scientists at the Max Planck Institut fuer Extraterrestrische Physik (MPE) in Garching, FRG. The original objective was to conduct an all-sky survey with an imaging X-ray telescope (XRT) of moderate (≤ 1 arcmin) angular resolution. Between 1977 and 1982, extensive prephase A and phase A studies were carried out by German space companies. Simultaneously, the development of a large X-ray mirror system was initiated in Germany by the Carl Zeiss Company and MPE began to develop the focal plane instrumentation.

In 1979, following the regulations of the European Space Agency (ESA) convention, BMFT announced the opportunity for ESA member states to participate by offering the possibility of flying a small autonomous experiment together with the large X-ray telescope. In response to this announcement a consortium of United Kingdom (UK) institutes led by Leicester University proposed an extreme ultraviolet (XUV) Wide Field Camera (WFC) to extend the spectral band measured by the XRT to longer wavelengths. This experiment was subsequently approved by the British Science and Engineering Research Council (SERC) and in 1983 the Memorandum of Understanding (MOU) between BMFT and SERC was signed.

In 1981/82, NASA and BMFT conducted negotiations for U.S. participation in the ROSAT mission and the resulting MOU was signed in 1982. Under this MOU, NASA agreed to provide the ROSAT launch with the STS Space Shuttle and a High Resolution Imager (HRI) X-ray detector to be placed at the focal plane of the X-ray telescope. BMFT's obligations included: the design, fabrication, test, and integration of the spacecraft, mission control, tracking, and data acquisition after separation from the shuttle, and the initial reduction and distribution of data. NASA's approach for the focal plane HRI was to provide (with minimum change) a flight model copy of the HRI previously flown successfully on the HEAO-2 (Einstein) mission. In 1983 NASA Headquarters issued a sole source contract to the Smithsonian Astrophysical Observatory (SAO) to build flight and engineering model HRI's and provide integration and launch support. An HRI engineering test unit built in 1984 was essential to satisfy a German need for a structural, electrical, thermal, and mass model. In May 1985 this contract was transferred to the Goddard Space Flight Center (GSFC) for administration and implementation.

The Challenger accident in January 1986 led to a reconsideration of schedules and the examination of launch alternatives. In 1987 NASA and BMFT jointly decided to launch ROSAT in February 1990 with a Delta II vehicle and the MOU was appropriately modified in an exchange of letters. Germany subsequently modified the spacecraft design and test and integration procedures to be compatible with the Delta II vehicle. The U.S., in turn, undertook the development of a new (10 foot diameter) fairing for the Delta II nose section to accommodate ROSAT's maximum cross-sectional dimension which is determined by the offset mounting of the WFC (see Figures 1 and 2).

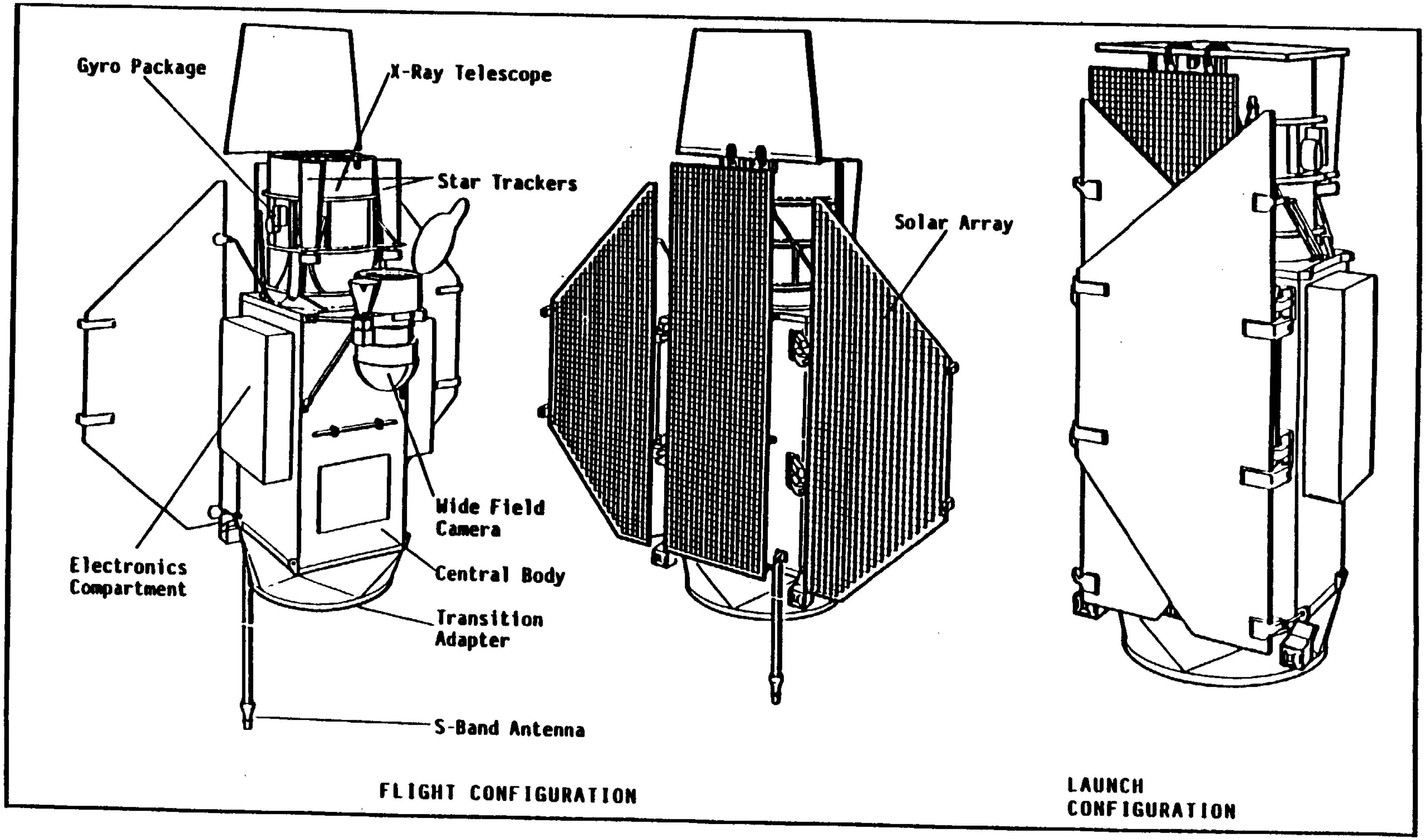


Figure 1. ROSAT Flight and Launch Configurations

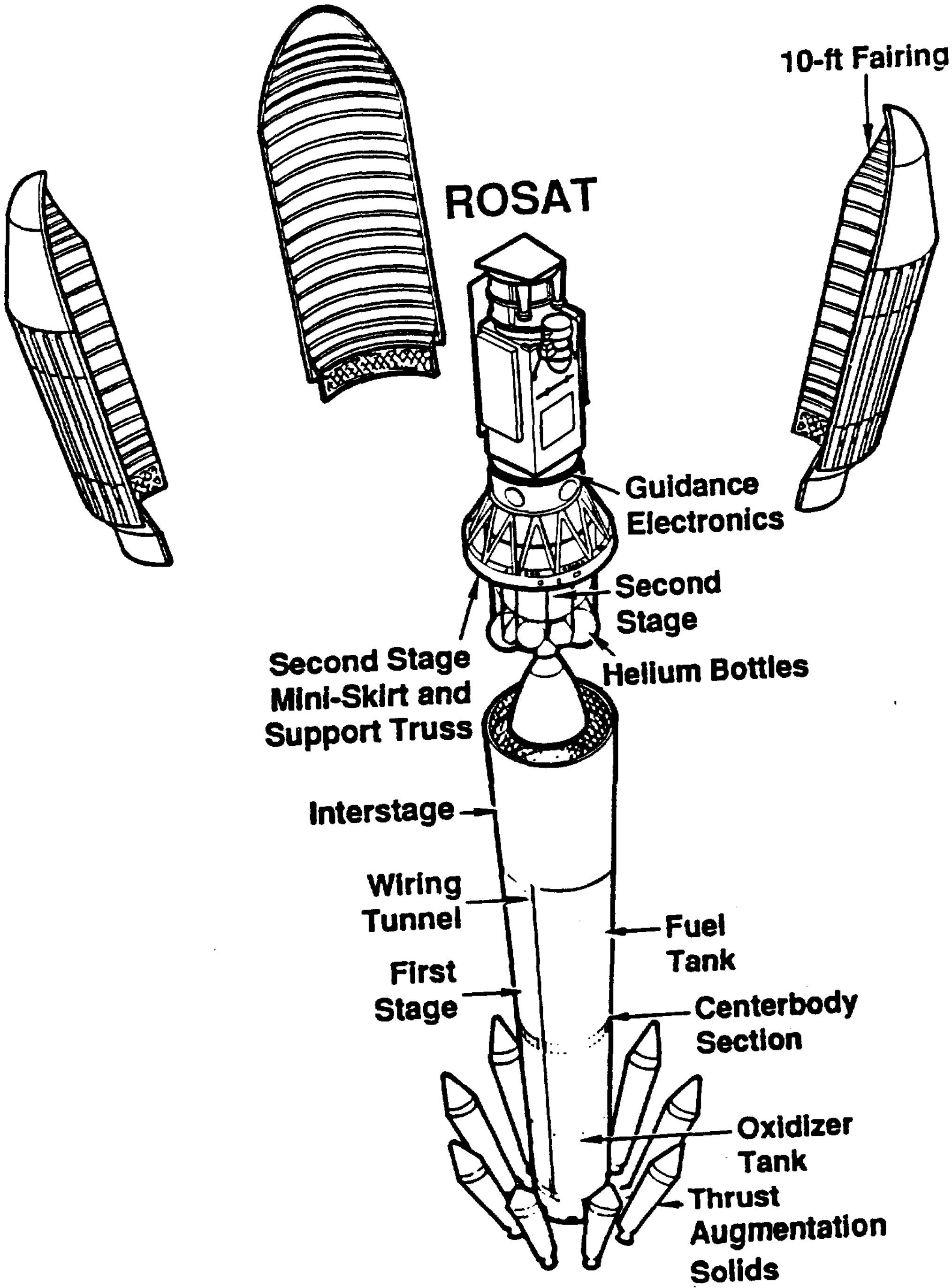


Figure 2. Launch Vehicle Schematic

MISSION PHASES

ROSAT's mission is to be carried out in two phases: an all-sky survey phase and a pointed phase. Distinctly different science programs and modes of spacecraft operation are associated with each phase. Prior to both mission phases there are three preparatory periods: a 13-day premeasurement phase, a 24-day calibration phase, and a 19-day verification phase. The principal functions for each phase are summarized in Table 1. The mission performance of all ROSAT subsystems, nominal observing modes, and ground operations, including the quality of ground systems software and data analysis, will be tested during the verification phase. It is also anticipated that data acquired during the verification phase will be of sufficient quality for immediate scientific publication. Accordingly, the target selection for the verification phase includes targets proposed by Guest Observers.

The All-Sky Survey Phase

The all-sky survey phase is to be performed first during a continuous six month observing period in the scan mode of operation. In the scan mode the telescopes are pointed away from the earth and 90° from the sun-spacecraft line. By maintaining this orientation relative to the earth and sun throughout an orbit, the spacecraft synchronously rotates around the sun-spacecraft line once each orbit and the telescopes scan a great circle band on the celestial sphere whose width is determined by the field of view. When this rotation is combined with the earth's rotation about the sun (about 1° per day or 4 arcmin per orbit) the complete sky is scanned in 180 days. With its 2° field of view the X-ray telescope (XRT) scans each specific source once each orbit for a period of two days (see Figure 3).

The all-sky survey is to be performed with one of the two redundant Position Sensitive Proportional Counters (PSPCs) supplied by the Max Planck Institut fuer Extraterrestrische Physik (MPE) at the focus of the XRT (i.e., the HRI is not used during this phase). The analysis of X-ray data acquired during this phase is the sole responsibility of BMFT and the German investigator team and rights to this data will remain with BMFT. BMFT will compile an X-ray source catalog from the survey observations and make this catalog available in the open scientific literature.

The Pointed Phase

The pointed phase could also be named the "Guest Observer Phase" in that the entire observing time is allocated to observations proposed to the three partner agencies, NASA, BMFT, and SERC, which will share XRT observing time in the ratio 50:38:12, respectively. During this phase, which follows the survey phase, ROSAT will point continuously at selected individual X-ray sources for variable lengths of time which depend on the intensity of the source. For example, a total of more than several thousand seconds of observation might be required to acquire sufficient data for analysis of a single weak X-ray source. When the required time exceeds about 3 ksec the total observing time will in many cases have to be obtained from more than one contiguous observation. The pointed phase is, in effect, made up of multiple six month phases in that the capability to point at any one location in the sky appears at least once each six months for a variable number of days. The number of opportunity days (or orbits) and the time intervals potentially available for continuous observation of a pre-selected source are determined by constraints on the spacecraft's orientation. Current plans are based on 12 months (i.e., two six month phases) of operation in the pointed mode. The anticipated lifetime of the satellite is, however, much longer, providing the possibility of carrying out an extended observing program.

Either the High Resolution Imager (HRI) or one of the PSPCs may be used as the XRT focal plane detector for a pointed observation. This choice depends on the scientific requirement expressed by the Guest Observer for the proposed study.

Table 1. Mission Phases

PHASE	DURATION	FUNCTION
Launch to Separation	2510 sec.	Injection in orbit
Premeasurement Phase	13 days	Exercise spacecraft subsystems. Purge PSPC gas. Map particle belts with SAAD. Stepped turn-on of PSPC high voltage.
Calibration Phase	24 days	Calibrate science instruments in sequence PSPC, WFC, HRI.
Verification Phase	19 days	5-day mini sky survey (WFC/PSPC). Pointing verification on well-known X-ray targets in sequence PSPC/WFC followed by HRI/WFC.
Survey Phase	6 months	Scan complete sky with PSPC at focus of XRT. BMFT survey science.
First Pointed Phase	6 months	Point at selected targets with either HRI or PSPC at focus of XRT. Guest Observer science.
Second Pointed Phase	6 months	Point at selected targets with either HRI or PSPC at focus of XRT. Guest Observer science.
"N" Pointed Phase	Indefinite	Extended operations with either HRI or PSPC at focus of XRT. Guest Observer science.

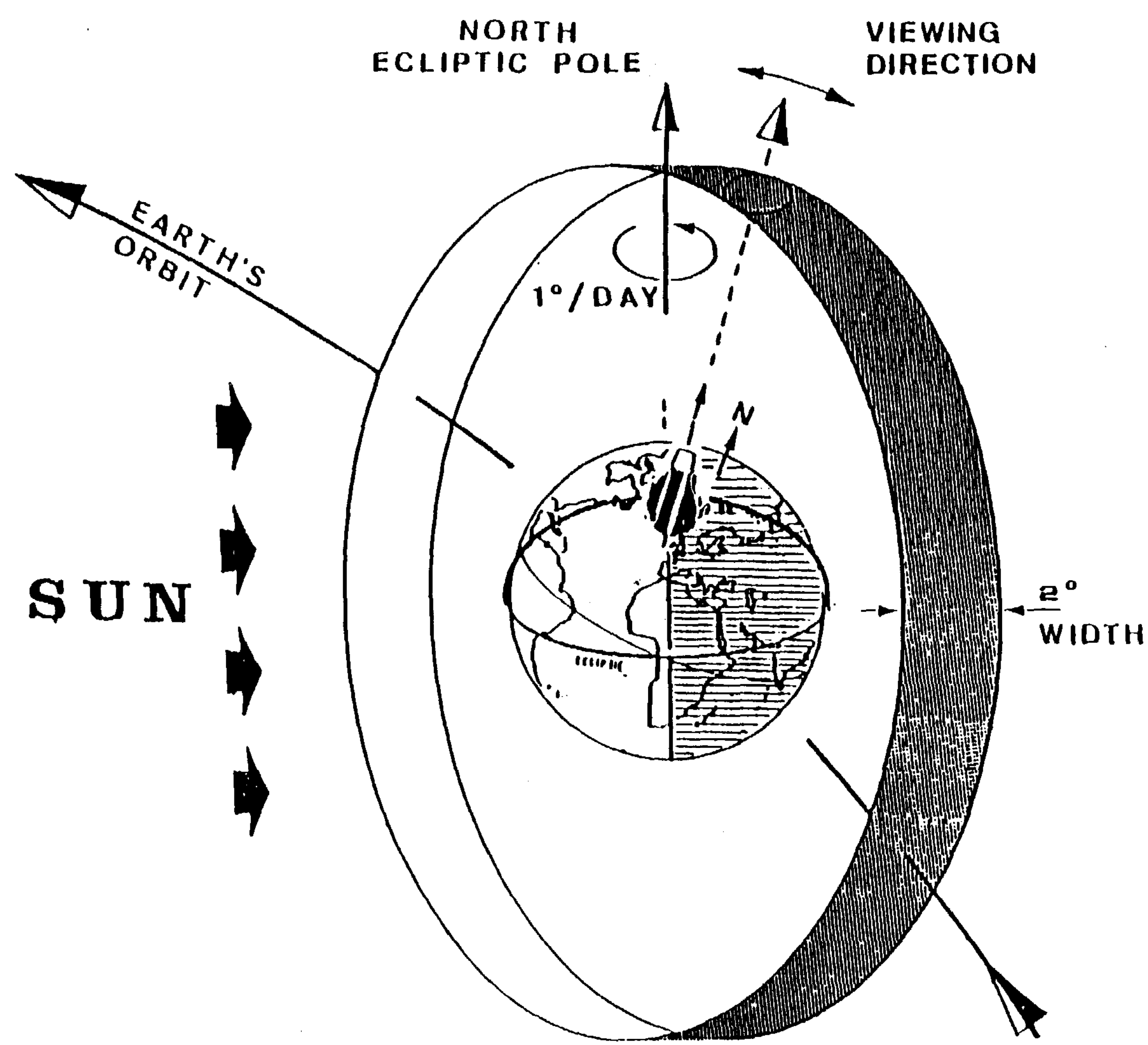


Figure 3. Scan Profile for the All-sky Survey

SCIENTIFIC OBJECTIVES

The astrophysical importance of X-ray astronomy is now recognized as being comparable to that of optical and radio astronomy. Thirty years ago, prior to the first detection of a cosmic X-ray source in 1962, there was little, if any, expectation that X-ray observations would lead to a major new field of astronomical endeavor. X-ray astronomy is, however, still a frontier science with each new project and advance in mirror systems and detector technology leading to new discoveries. ROSAT's scientific objectives are accordingly a follow-on and expansion of the objectives previously pursued with the SAS-1 (Uhuru) and HEAO-2 (Einstein) missions. The expansion of objectives results from the dual (scan and pointed) modes for ROSAT operations, the synergy of X-ray and XUV simultaneous and co-pointing observations, and improvements in instrumentation. The X-ray instrumentation improvements are characterized by a factor of one thousand in sensitivity for the all-sky survey relative to SAS-1, and factors of 5 and 3 in sensitivity and angular resolution, respectively, for pointed observations relative to HEAO-2. In the extreme ultraviolet the WFC sensitivity represents an improvement of at least two orders of magnitude over previous measurements, which have been limited to only a small fraction of the celestial sphere.

The many facets of ROSAT's scientific mission are evident from the receipt of 729 Guest Observer proposals in response to the solicitation for the first six months of pointed observations. The scope is too extensive for full representation here. For brevity, "general" and "typical specific" objectives are outlined below.

<u>General Goals and Objectives</u>, include:

- perform the first high resolution, high sensitivity, soft X-ray survey of the complete sky with an imaging telescope
- perform the first survey of the complete sky in the extreme ultraviolet wavelength band, 60 to 300 Å
- obtain high resolution images of a variety of selected X-ray sources (e.g., stars, supernovas, galaxies, clusters of galaxies, quasars) to determine characteristics such as spatial extent, temporal variability, and spectral properties
- perform "deep surveys" to search for and characterize sources contributing to the X-ray background

<u>Typical Specific Objectives</u>, include:

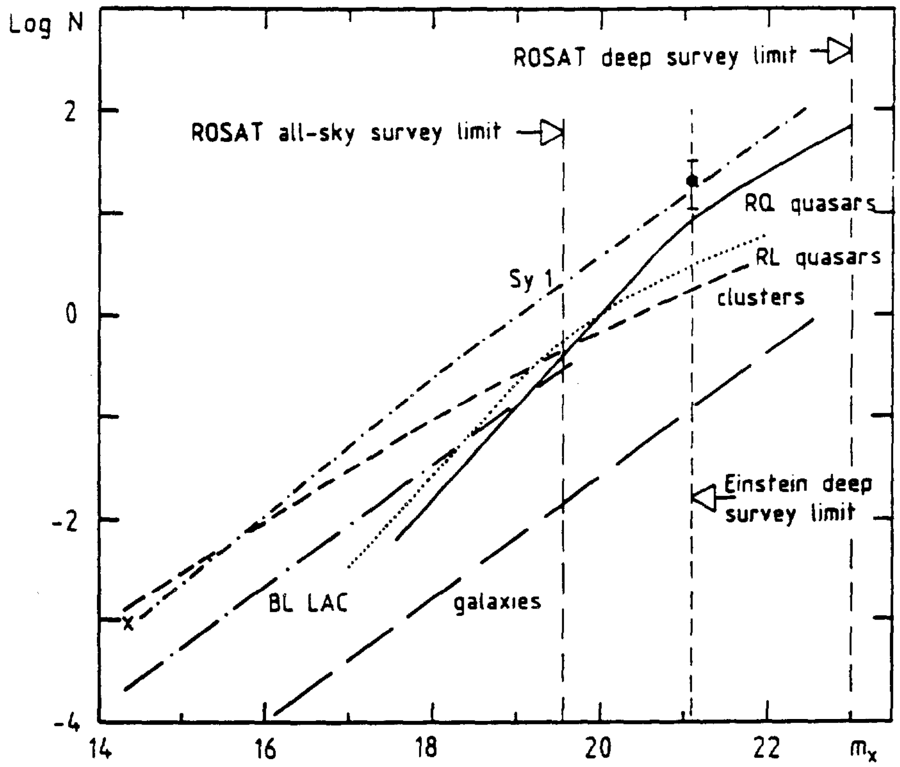
- the study of coronal X-ray emissions from stars of all spectral types
- the detection and mapping of X-ray emissions from galactic supernova remnants
- evaluating the overall spatial and source count distributions for various types of X-ray sources in our galaxy
- obtaining a detailed XUV mapping of the local interstellar medium
- obtaining a detailed X-ray mapping of the distant interstellar medium

- the detailed study of various populations of active galaxy sources (i.e., Seyferts, QSO's, BL Lacs, etc.)

- the morphological study of X-ray emitting clusters of galaxies

Figure 4 provides one illustration of the importance of the increase in sensitivity provided by ROSAT. There is a long standing controversial question regarding the origin of the diffuse X-ray background. Does the background come from a very high energy gas left over from the early formation of the universe, or is it made-up of millions of weak, unresolved X-ray sources, such as distant quasars? ROSAT's deep survey measurements, conducted by pointing at "dark" regions of space for long time intervals, will penetrate much deeper than previous observations to detect the presence of weak individual X-ray sources, if they are present. Relative to the HEAO-2 (Einstein) observations the difference in detectability shown in Figure 4 is approximately a factor of five, almost two X-ray magnitudes. By helping to resolve the origin of the X-ray background ROSAT, will contribute to understanding cosmic structure on a large scale.

ROSAT's contributions to astrophysics will extend beyond its direct scientific findings. An immediate benefit will be the identification of sources for supplementary studies in the visible and UV bands with the Hubble Space Telescope (HST). Later (1996), it's survey mappings will be of particular value in the planning of X-ray observations to be conducted by NASA's Advanced X-Ray Astrophysics Facility (AXAF) with a future generation of improvements in sensitivity and resolution.



Sensitivity of the ROSAT X-ray all-sky and deep surveys in comparison with the sensitivity of the deep surveys of the Einstein observatory. The curves represent integral source counts for various classes of extragalactic X-ray sources. N is the number of objects/deg^2, m_x is the X-ray magnitude: $m_x = -2.5 \log f_x$ (2 keV) + 8.38, where f_x is the observed flux at 2 keV in units of keV/cm^2 sec keV corrected for interstellar absorption (curves from Setti and Woltjer 1982 (5)).

Figure 4. Sensitivity of ROSAT for X-ray Deep Surveys Compared with the Deep Survey Sensitivity of the Einstein Observatory

SCIENCE INSTRUMENTS

Two imaging telescopes constitute the scientific payload of ROSAT. The main telescope is the large X-Ray Telescope (XRT) which is designed for imaging measurements of soft X-rays within the energy range 0.1 keV to 2.0 keV (equivalent to wavelengths 100 Å to 6 Å). The secondary telescope is the Wide Field Camera (WFC) which is designed to extend the imaging measurements to the extreme ultraviolet (XUV) energy range 0.04 keV to 0.2 keV (equivalent to wavelengths 300 Å to 60 Å).

The X-Ray Telescope (XRT)

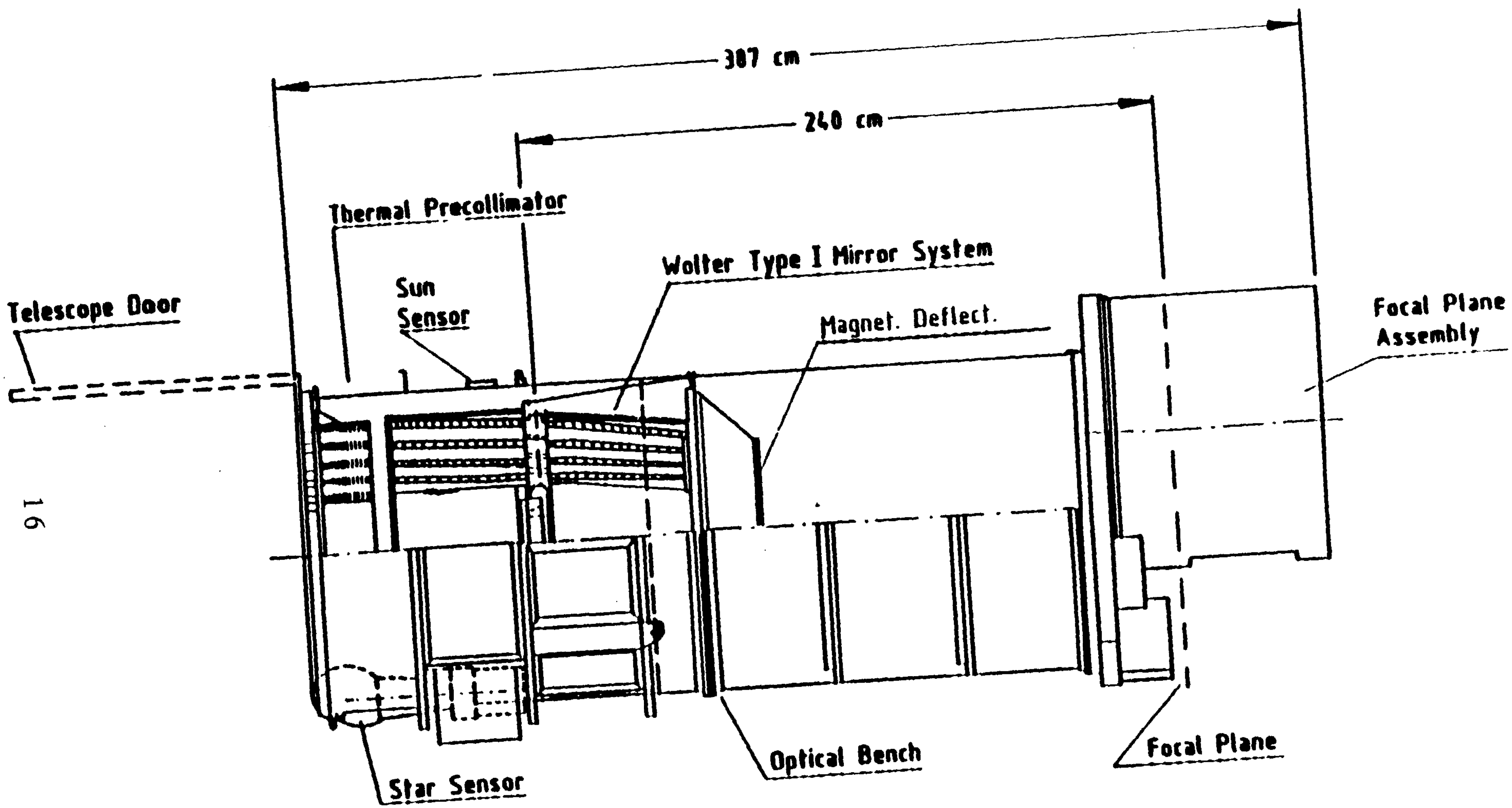
The principal subsystems of the X-ray telescope are: (a) the X-Ray Mirror Assembly (XMA) and the focal plane detector instruments, consisting of (b) two redundant Position Sensitive Proportional Counters (PSPCs) and (c) a High Resolution Imager (HRI). These subsystems are described below in sections (a), (b), and (c).

Figures 5 and 6 illustrate the dimensions and structural layout of the XRT assembly. The hinged door at the front of the telescope protects both the telescope and star trackers against contamination during launch and while on the ground; in orbit, it serves as a sunshade. Thermal baffling in front of the mirror assembly limits the heat loss through the telescope aperture and serves as a straylight shield. A magnetic deflector behind the mirror assembly diverts background electrons away from the aperture of the focal plane detectors. The two star trackers and the gyro package, the vitally important units for attitude measurement, are structurally mounted to the telescope housing such that they will experience the same deformations as the telescope. To identify and measure any misalignment due to thermal distortions of the telescope or any displacement of the X-ray detector after a detector change, the assembly contains a fiducial light system. For this function, light from an LED source in the focal plane instrument section is collimated by a lens in the center of the mirror assembly and gets reflected to the star trackers by one, axially located, prism assembly and two outer prism assemblies (Note: the location of the prism assemblies is illustrated in Figure 6).

The focal plane instrument section which is mounted at the rear of the optical bench of the mirror system, as shown in Figures 5 and 6, houses all of the science instrumentation associated with the X-ray detectors. Within this section, the two redundant PSPCs and the HRI are mounted on a turret (or "carrousel") which positions the desired detector at the focus of the telescope. Front-end electronics, some supporting electronic elements, and the gas supply system for the PSPCs are also mounted on the turret. Other electronic elements associated with the X-ray detectors are located on a fixed platform around the turret housing.

The support electronics in the focal plane assembly control the science instruments and their subsystems and organize the scientific and housekeeping data for transmission to the spacecraft data handling system. All functions are controlled by a dedicated onboard computer, the "central data electronics" (ZDE), based on a Motorola 68000 microprocessor. Most of the components of the ZDE are redundant and can be switched by command. Special routines have been included in the ZDE software which allow the execution of long and complex actions of the focal plane instrumentation by means of a single command. Also, commands can be added, or their sequence can be changed during the mission, by software reconfiguration using telecommands.

The instrument assembly also includes a charged particle monitor (an n-type silicon semiconductor) called the South Atlantic Anomaly Detector (SAAD) which is used to put the imaging detectors in a safe mode (by reducing the high voltage) during passage through



Cross section of the ROSAT telescope tube housing the fourfold nested 80 cm Wolter type I mirror system and the focal plane turret containing two position sensitive proportional counters with filter wheels and one HRI.

Figure 5. X-ray Telescope Cross-section Layout and Dimensions

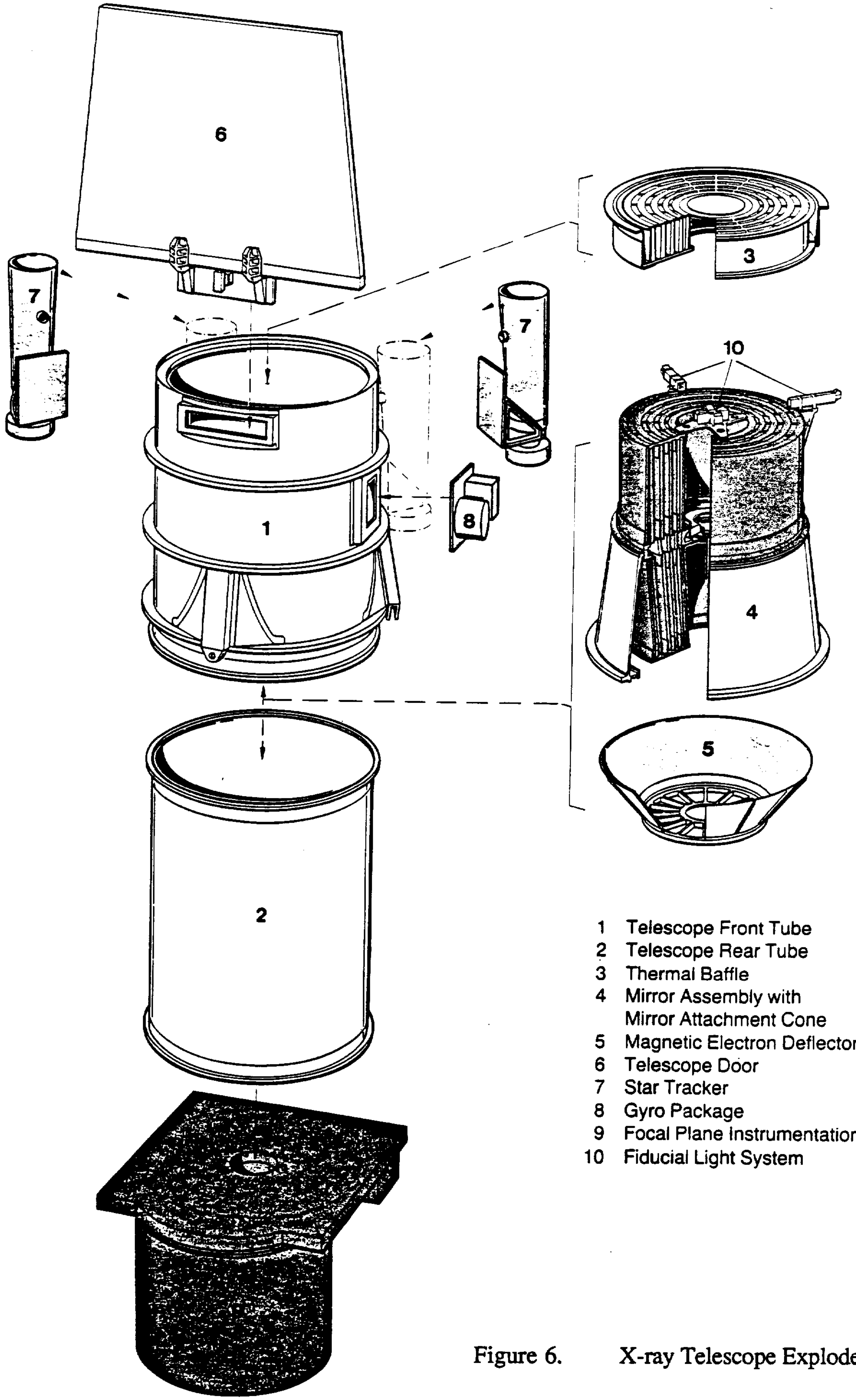


Figure 6. X-ray Telescope Exploded View

regions where the particle background is intense (e.g., the south Atlantic magnetic anomaly, auroral zone contacts, etc.). In the case of the south Atlantic anomaly, where high backgrounds are predictable, this is a backup to time-tagged commands. Two independent units are provided for redundancy.

(a) The X-Ray Mirror Assembly (XMA)

The ROSAT grazing incidence X-ray mirror assembly utilizes four nested Wolter type 1 mirrors. This type of mirror has two focusing surfaces in series, one parabolic and one hyperbolic, to focus incoming X-rays at the detectors. The nesting of several mirrors inside each other increases the sensitivity and energy range relative to a single mirror. All of the mirror shells are made out of Zerodur, a glass ceramic with an almost negligible thermal expansion coefficient, and are coated with a thin layer of gold to increase X-ray reflectivity. Dimensionally, the mirror system has a focal length of 240.0 cm, a maximum reflecting diameter of 83.5 cm, a minimum reflecting diameter of 36.7 cm, and an unobscured geometrical collecting area of 1141 cm^2. The field of view, 2° in diameter, was selected, in part, from predictions of background rates likely to be encountered by the PSPCs. Each of the eight (4 parabolic and 4 hyperbolic) mirrors is 50.0 cm long. As illustrated by the cut-away drawing in Figure 6, the four parabolic mirrors are cantilevered at one end from a central supporting flange which carries the four hyperbolic shells on its opposite side. The center supporting flange, which is 7.8 cm thick, is made of Invar. Thinner flanges of similar shape stabilize the mirror shells at the entrance and exit planes of the assembly.

The above, and other, characteristics of the XMA are tabulated in Table 2. The achievement of an angular resolution (HEW) < 5 arcsec and scattering powers < 3% at 1.5 keV and < 1% below one keV represents a considerable improvement over previously available X-ray mirrors and allows very high contrast imaging. Extremely precise alignments and extensive efforts in the polishing, and other production processes, were required. The XMA is the product of a joint endeavor between the Max Planck Institut fur Extraterrestrische Physik (MPE) and the Carl Zeiss Co., FRG.

(b) The Position Sensitive Proportional Counters (PSPCs)

ROSAT's, two identical, PSPCs are enlarged and improved versions of position sensitive multiwire proportional counters developed and flown on sounding rockets by MPE. They operate in the energy range 0.1 to 2.0 keV and have a sensitive area 8 cm in diameter. Performance characteristics are tabulated in Table 3.

Figure 7 is a schematic diagram of a PSPC. It essentially consists of two separate counters: the position sensitive counter formed by anode A1 with cathodes K1 and K2, and an anticoincidence counter for background rejection formed by anode A2 and cathode K3. The electrodes are wire grids wound on glass ceramic frames. The anode grids have gold-plated tungsten wires 10 μm in diameter with spacings of 1.5 mm (A1) and 2 mm (A2). The cathode grids are platinum iridium wires 50 μm in diameter with spacings of 0.5 mm. The 1 μ polypropylene entrance window is coated with carbon and lexan to decrease UV transmission. The grid system is contained in a counter housing filled with a gas mixture.

For the PSPC to record an incoming X-ray photon as an event, the photon must first be transmitted through the entrance window, and second, be absorbed by the counter gas to

Table 2. ROSAT Mirrors

	X-RAY MIRROR	WFC MIRROR
Mirror type	Wolter I	Wolter-Schwarzschild I
Mirror material	Zerodur	Ni plated Aluminum
Reflective coaring	Gold	Gold
Number of shells	4 paraboloid & hyperboloid pairs	3
Field of view	2° (diameter)	5° (diameter)
Geometric area	1141 cm^2	465 cm^2
Aperture diameter	84 cm	57.6 cm
Focal length	240 cm	52.5 cm
Focal Plane Scale Factor	11.64 µm = 1 arcsec	160 µm = 1 arcmin
High energy cutoff	~ 2 keV	0.21 keV (10% of peak)
Angular resolution	≤ 5 arcsec half energy width (HEW)	1.7 arcmin half energy width at 0.04 keV
Scattered power	< 3 percent at 1.5 keV (for single reflection)	N/A

Table 3. ROSAT Instrument Characteristics

	PSPC	HRI
Field of view	2 degrees	32 arc minutes
Spatial resolution	25 arc seconds	1.7 arc seconds
Energy resolution	0.43 (E/.93 keV)$^{-0.5}$	N/A
Temporal resolution	130 μs	61 μs
Dead time	170-280 μs	0.36-1.35 ms
Quantum Efficiency		
0.28 keV	50%	40%
1.0 keV	60%	40%
1.5 keV	70%	23%
Background	(cts/s/arcmin^2)	(cts/s/arcsec^2)
Internal	0	3-4x10^{-7}
Particle	2-4x10^{-4}	1-5x10^{-7}
X-ray	0.45-1.8x10^{-3}*	1x10^{-7}
Total	0.65-2.2x10^{-3}	5-10x10^{-7}
Einstein Comparison	3x10^{-3}	1.4x10^{-6}

* predominately in C-band (<0.28 keV)

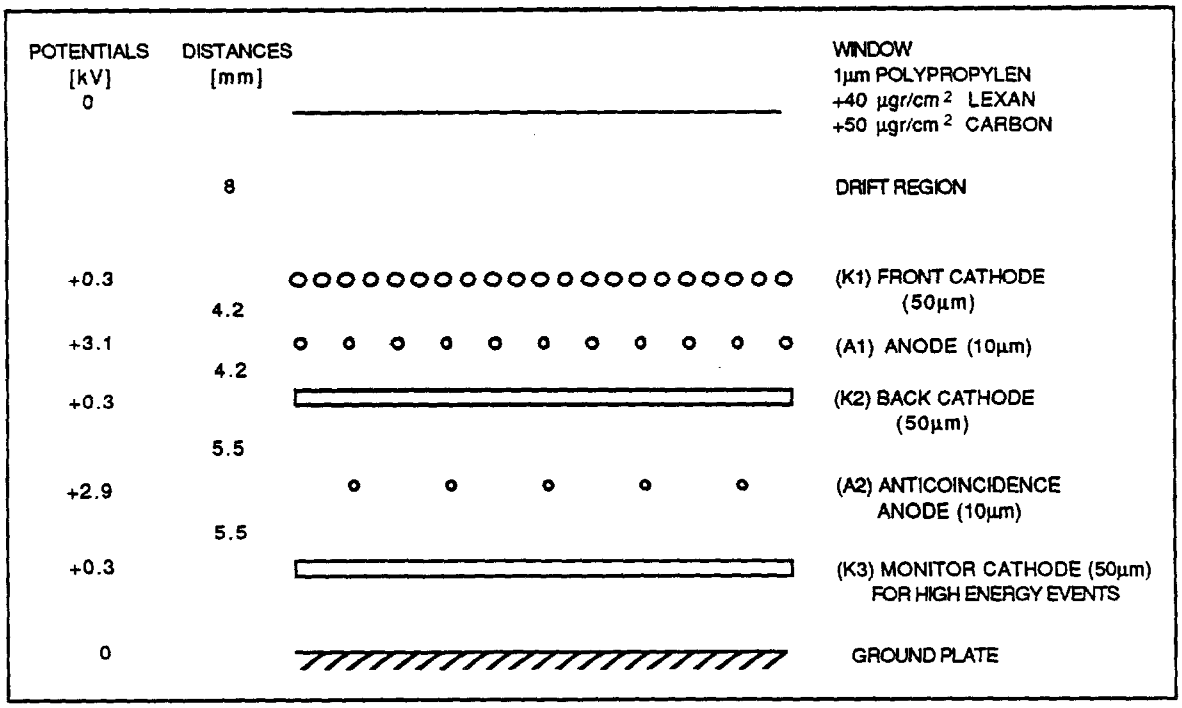


Figure 7. Schematic Diagram of the PSPC

produce a photoelectron which in turn produces the primary electron cloud. This cloud drifts through the cathode K1 towards anode A1. Near A1 the electric field strength is so high that the charge cloud gets amplified like an avalanche. Typically, the counter is operated with a gas gain of about 5×10^4. This leads to a charge signal at the anode and an induced signal at the cathodes, which is sensed by charge-sensitive preamplifiers. The A1 anode signal is used to trigger the electronics and to determine the energy of the X-ray event. The cathode grids are divided into strips 3.5 mm in width. Each strip has a separate preamplifier and the induced charge of an X-ray event is usually distributed over 3 to 5 strips. The position of the event is determined from the cathode strip signals by a center of mass calculation. K1 and K2 are mounted orthogonal to each other to get both coordinates.

As the gain of the PSPC is highly dependent on the gas density, the density of the gas mixture (65% Ar, 20% Xe, 15% methane) is controlled by regulating the pressure (~ 1.5 bar) in the counter relative to a sealed reference volume. The gas mixture is maintained constant by controlled flow rates which are about 10 to 70 times the rate of diffusion through the PSPC window.

A four position filter wheel in front of the window is attached to the housing of each PSPC (see Figure 8). The different positions have the following functions: (1) vacuum tight door closed (with calibration sources), (2) door open (free field of view), (3) field of view closed (without calibration sources), and (4) Boron filter in front of the window. Position (2) is the normal operating position. Position (3) is to be used for some orbits to monitor the particle background. The boron filter in position (4) is used to improve the energy resolution at low energies and will only be used for selected observations in the pointed phases of the mission.

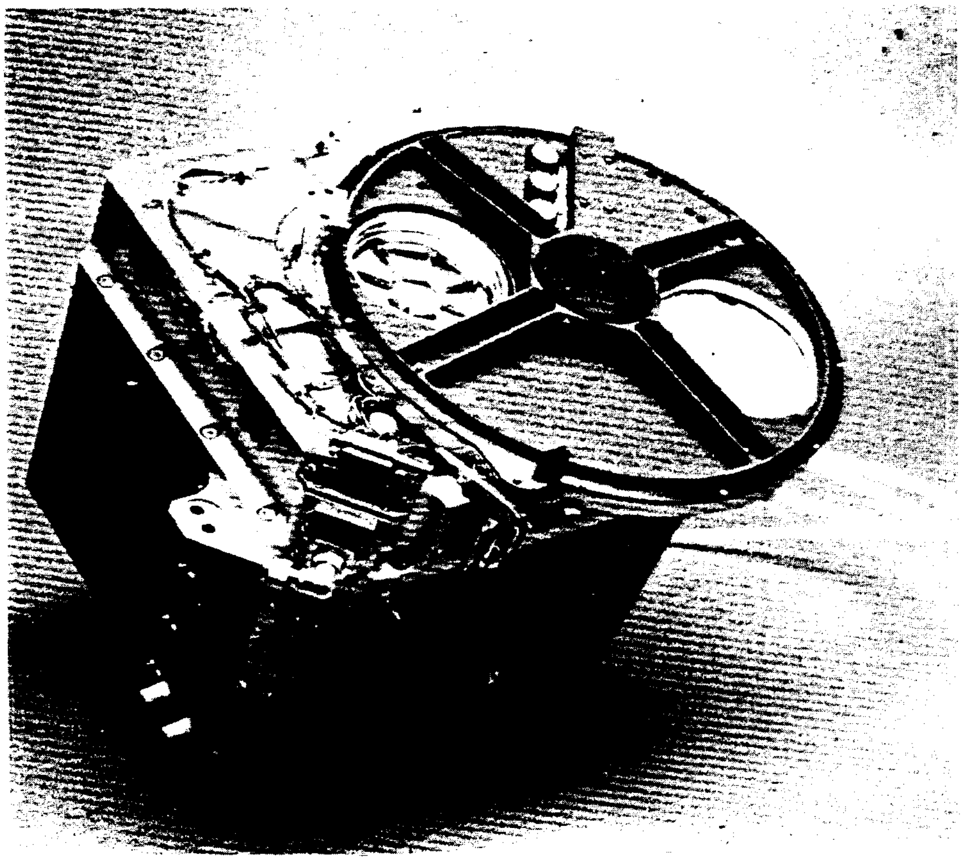


Figure 8. PSPC with Filter Wheel

The electronics for the PSPCs perform the following functions: recognition of an X-ray event, measurement of pulse heights for the different electrodes, determination of the event time, determination of the event energy, and calculation of the event position (or formatting of the raw data). Also, events are rejected when the event: produces a simultaneous signal in the anticoincidence counter, falls outside the energy range, excites cathode strips which are not adjacent, or excites more than five cathode strips. Digital data are routed to the microprocessor system which calculates the position of the X-ray event.

(c) The High Resolution Imager (HRI)

The ROSAT High Resolution Imager (HRI), developed for NASA by the Smithsonian Astrophysical Observatory (SAO), is almost identical to the HRI flown successfully on HEAO-2, the Einstein Observatory. The principal difference is that cesium iodide (CsI) has been substituted for magnesium fluoride as the detector photocathode (to increase the quantum efficiency) and an additional conductive "ion shield" has been placed in front of the multichannel plates (MCPs) very close to the photocathode input face (to reduce background levels). Minor changes, not affecting performance, have been made in the mechanical configuration to have the same mounting arrangement as the PSPCs.

Performance characteristics of the HRI are tabulated in Table 3 where they can be compared with the PSPC characteristics. The HRI does not provide any energy resolution but has a much higher spatial resolution (1.7 arc seconds vs. 25 arc seconds). The HRI is, accordingly, much better for precisely locating X-ray sources and for separating sources in regions where the sources are closer together than the resolving power of the PSPC.

The HRI is contained in two assemblies, shown in Figures 9 and 10: a Detector Assembly (DA) and a Command and Data Electronics Assembly (CDEA). Both of these assemblies are mounted on the turret in the focal plane instrument section. The DA, weighing 31 kg, contains the MCP detector with its associated grid readout and initial processing electronics, a UV/ion shield, a UV calibration system, a fiducial light assembly, a sliding vacuum door with an X-ray source for ground checkout, an ion pump for maintaining vacuum while on the ground, and a bias voltage supply. The CDEA, weighing 8 kg, contains signal processing electronics, low voltage power supplies, and electronics for command, clocks, telemetry, and power control.

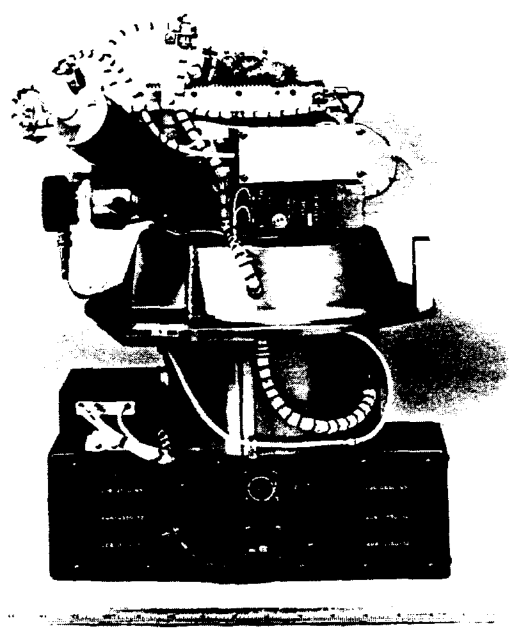


Figure 9. HRI Detector Assembly

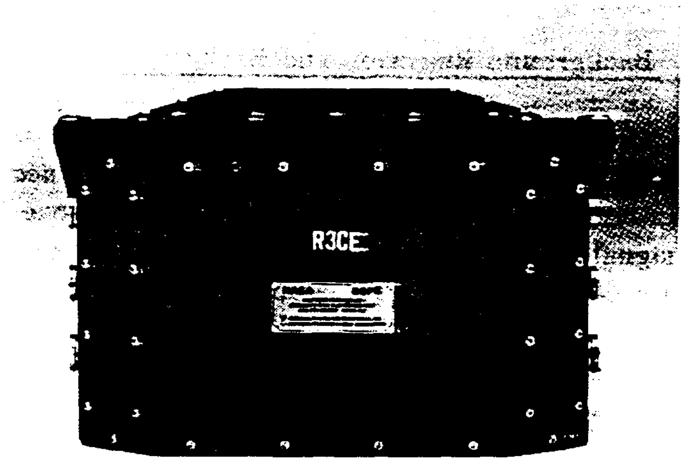
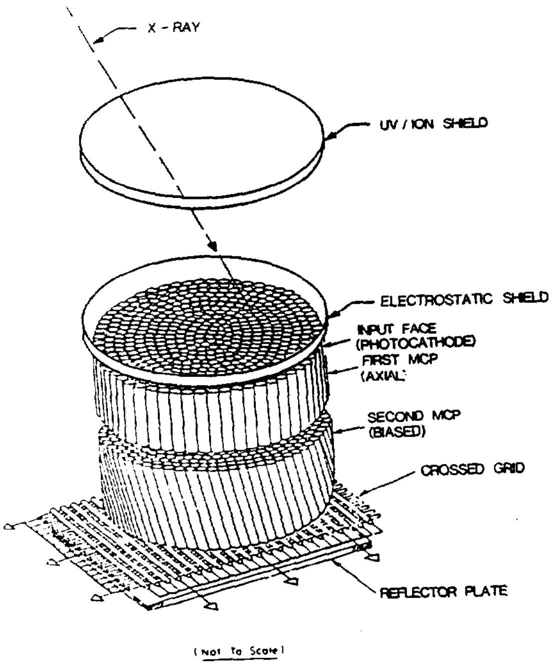


Figure 10. HRI Command/Data Electronics Assembly

The principle of two-dimensional X-ray detection by the HRI is illustrated schematically in Figure 11. The detector basically consists of two microchannel plates (MCPs) in a cascade configuration and a crossed grid for electronic readout. The input surface of the first MCP is coated with cesium iodide (the photocathode) over a circular area 25 mm in diameter (36 arc minutes for the focal plane scale of ROSAT). The front MCP has a tube length-to-diameter ratio (L/D) of 80 and a bias angle of 0° (i.e., the microchannel tubes are perpendicular to the face). The second MCP also has an L/D of 80 but has a bias angle of 13° to prevent ion feedback. The inside diameters and the center-to-center spacings of the channels are 12.5 μm and 15 μm, respectively, for both MCPs. A dc voltage, which is programmable between -4 kV and -2 kV, is applied to the front surface of the first MCP relative to the rear surface of the second MCP. This adjustable voltage range is sufficient to accommodate the drop in gain of the MCPs that will occur over the lifetime of the mission. The potential drop is divided equally across each MCP. The "Crossed Grid Charge Detector" (CGCD) which provides the electronic readout consists of two crossed planes of parallel wires (see Figures 11 and 12). The wire-to-wire spacing is 0.2 mm and adjacent wires are connected with resistors. There are 129 wires in each plane and every eighth wire is connected to a low noise preamplifier for a total of 17 preamplifiers for each axis. The measurement of the position of an incident X-ray photon that produces a photoelectron at the photocathode is accomplished by determining the centroid of the burst of electrons emerging from the second MCP. The XY coordinates of the centroid of the charge cloud is determined from the charge division on two orthogonal, X and Y, axes corresponding to the two crossed planes of parallel wires. A block diagram of the processing electronics for one axis is shown in Figure 12.

The UV/ion shield shown schematically in Figure 11 is located far enough in front of the MCPs to permit a UV (1850Å) source, located as a side appendage, to project a pattern of dots on the photocathode from an acute angle that does not pass through the filter. When used on the ground or in-flight, the pattern provides a monitor on the stability of the position readout system. The UV/ion shield, an aluminized plastic membrane, has two functions: it attenuates UV photons from the geocorona or high temperature stars in the field of view, and it prevents low energy ions from reaching the detector. The ROSAT HRI contains an additional electrostatic shield, not used on HEAO-2, to greatly reduce the higher background levels that accompanied the change from a magnesium fluoride to a cesium iodide photocathode. This ion shield, an aluminum coated polypropolene membrane designed to pass the 1850Å dot pattern, is positioned in front of, and very close to, the photocathode input face to form a conductive barrier at the same potential as the input face.



HIGH RESOLUTION X - RAY IMAGER

DETECTOR CONCEPT

Figure 11. HRI Detector Schematic

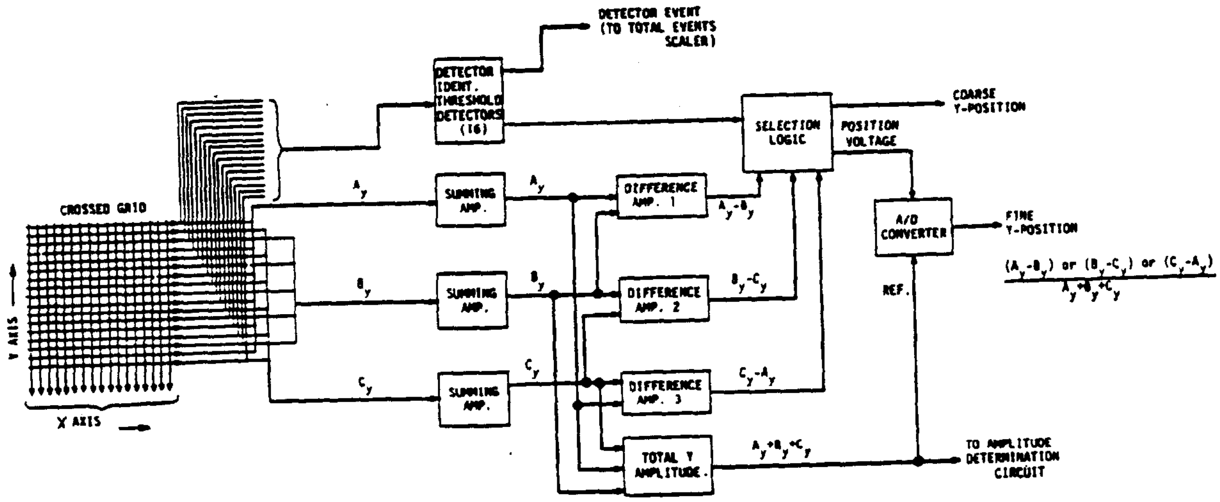


Figure 12. HRI Image Processing Electronics

The Wide Field Camera (WFC)

The Wide Field Camera (WFC), developed and supplied by Leicester University in the UK, complements the ROSAT X-ray telescope by extending the spectral coverage into the extreme ultraviolet (XUV) band, 0.21 to 0.041 keV (60 to 300 Å). The WFC is an autonomous instrument with its own star tracker for aspect information, thermal control system, and command and data handling system (CDHS). It relies on the ROSAT spacecraft for power, on-board data storage, command reception, and telemetry. As illustrated by its location and fixed orientation, shown in Figure 1, it always points at the same area of the sky as the XRT but with a larger (5° circular diameter) field of view.

The schematic cross-section in Figure 13 illustrates the principal components. The WFC optics consist of a nested set of 3 Wolter-Schwarzschild Type 1 grazing incidence mirrors, fabricated from nickel plated aluminum and coated with gold for maximum reflectance. The WFC-XUV mirror parameters are summarized in Table 2 where they can be compared with the X-ray mirror.

Two identical detector assemblies are mounted on a focal plane turntable such that either one can be selected for use. Both use paired, front and rear, microchannel plates (MCPs) with bias angles of 0° and 13°, respectively. The length-to-diameter (L/D) ratio of the MCP channels is 120. A cesium iodide (CsI) photocathode is deposited on the front (i.e., input) face of the front MCP to increase the XUV quantum efficiency. To take full advantage of the telescope resolution the MCP surfaces, both front and rear, and the resistive anode readout system are all curved (i.e., like a watchglass) to match the optimum focal surface (see Figure 13). The detector resolution is a factor >2 better than that of the mirror nest and thus does not contribute significantly to the net performance of the WFC.

A filter wheel assembly containing eight filters is located in front of the detectors (Figure 13). Six of these filters are science filters which can be selected to define selected XUV wavelength bands and suppress geocoronal background radiation which might otherwise saturate the detectors. One of the remaining two filters is a narrow-band UV interference filter used only for calibration purposes. The other remaining filter is opaque to photons but has a sensitivity to the particle background similar to that of the science filters. It is used to determine the particle component of the WFC background. Because the WFC is particularly sensitive to soft electrons a magnetic electron diverter (Figure 13) is incorporated to divert a high percentage of the incident electrons away from the detector aperture. The remaining particle flux can, however, still present a significant problem. Thus, two particle detectors, a Geiger tube and a channel electron multiplier, are included to monitor this background. They also provide a signal to switch off the MCP detector during passage through high background regions such as the South Atlantic magnetic anomaly or contacts with the auroral zones when they extend to middle latitudes.

The WFC has several operational modes which can be selected by the operational staff. The ZOOM mode is of particular interest to guest observers as it permits a reduction of the field to a 2.5° x 2.5° region when pointed mode filters are used. The on-board storage rate is normally restricted to 200 counts/sec, which fills the WFC allocation on the on-board tape recorder in 24 hours. A higher data rate of 400 counts/sec can, however, be used for limited time periods by taking advantage of off-times (e.g., during passage through the South Atlantic anomaly, etc.).

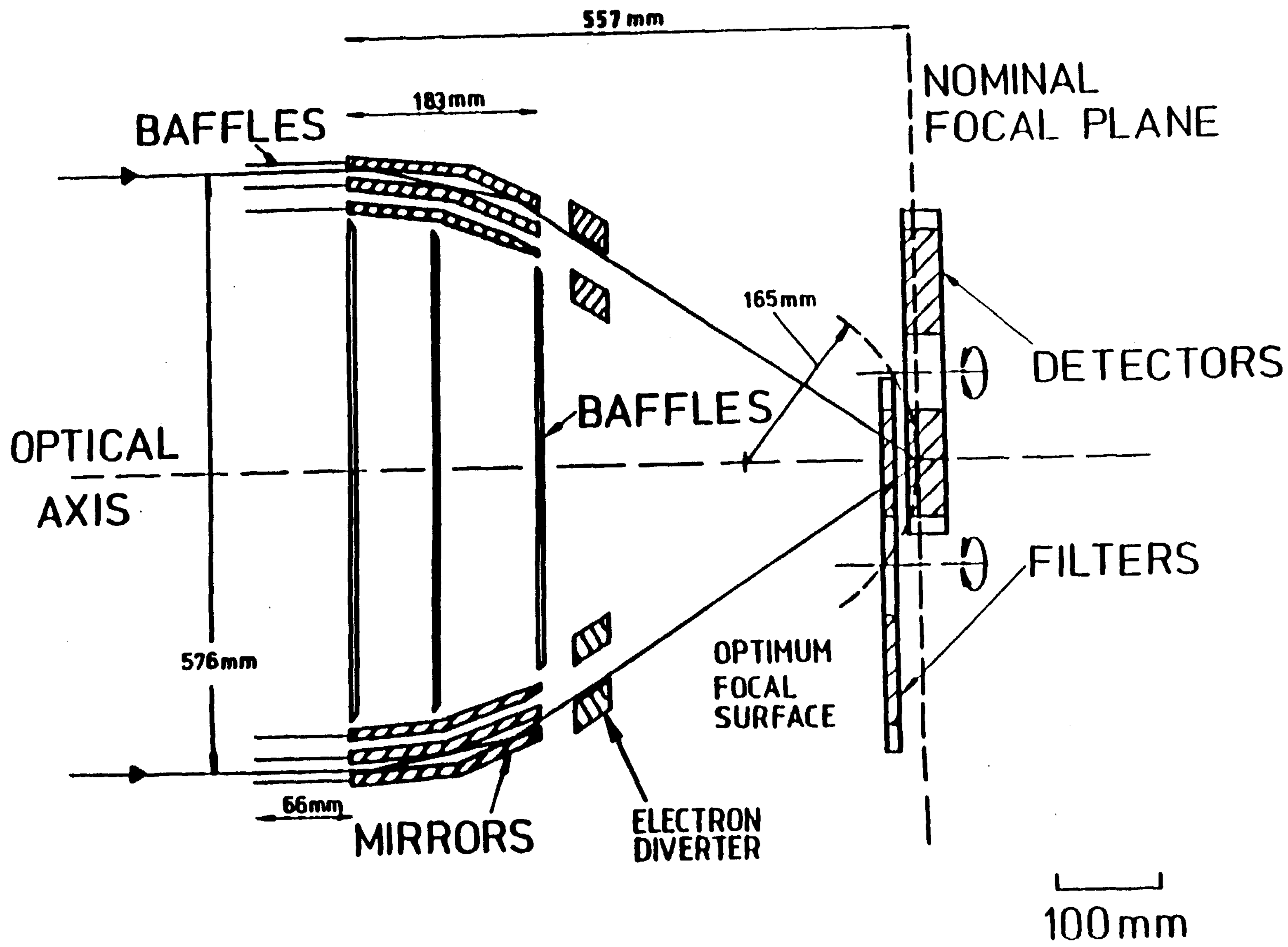


Figure 13. Wide Field Camera Cross-section Layout and Dimensions

SPACECRAFT DESCRIPTION

ROSAT was originally configured in accord with two primary considerations: the size and configuration of the large X-ray telescope (XRT), and the requirements for installation in the cargo bay of the space shuttle. With the removal of shuttle support structures, and the development of a 10 foot fairing for the Delta II vehicle, only minor changes in the configuration, dimensions, and mass resulted from the switch to a Delta II launch. Shuttle launch dimensions (4.46 m x 2.25 m) and mass (2570 kg) can be compared with the launch configuration dimensions (4.5 m x 2.2 m x 2.4 m) and mass (2424 kg) for the Delta II launch. These and other system parameters are tabulated in Table 4. Subsystem descriptions, supplementing Table 4, are given below.

Table 4. Spacecraft Characteristics

Dimensions	Launch Deployed	2.2 m x 2.4 m x 4.5 m 4.6 m x 2.4 m x 8.9 m
Mass	Total Science Instruments S/C Bus	2424 Kg (5333 lbs) 1520 Kg (3344 lbs) 904 Kg (1989 lbs)
Power	Available Solar Array Battery Consumption Main Solar Array Charge Solar Array Battery	 1000 W 400 W 556 W 350 W 336 W
Communications	Frequency Uplink Frequency Downlink Transmitting Power	2096.2771 MHz 2276.5 MHz 2 W (nominal)
Commands (available)	Low Power On/Off High Power On/Off 16 Bit Serial Load Bit Rate	128 128 256 1 KBit/s
Data/Telemetry	Real Time Tape Dump Tape Recorder Capacity (each)	8 KBit/s 1 MBit/s 700 MBit (21 hours)
Attitude	Measurement Accuracy Scan Mode Pointing Mode	 ≤ 16 arcsec ≤ 3 arcsec

Figure 1 schematically illustrates ROSAT in launch and flight configurations. Figure 14 identifies major spacecraft components in an exploded view. The XRT, except for the front mirror assembly (XMA) section shown in Figure 6, is encased inside the square shaped central body (1 in Figure 14) with mountings that decouple the XRT from thermal/mechanical distortions of the spacecraft structure. Two compartments (5 in Figure 14) located on both sides of the central body contain most of the electronic subsystems. Solar panels and the antenna boom (8 in Figure 14) are deployed during the launch sequence, within several minutes following spacecraft separation. Telescope doors are opened much later, during checkouts. The antenna boom with the S-band antenna located at its tip also carries the magnetometer used for coarse attitude measurements.

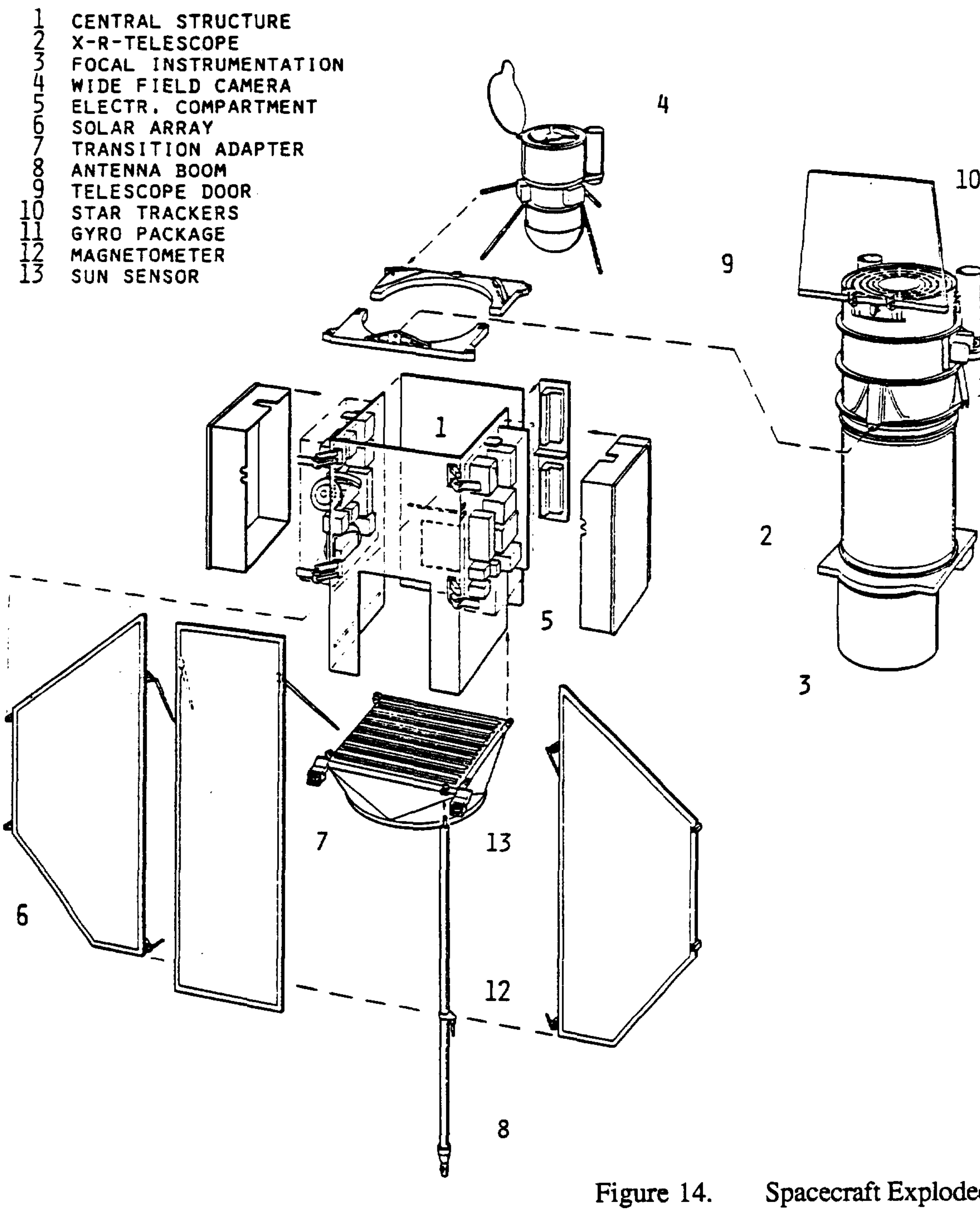


Figure 14. Spacecraft Exploded View

The power subsystem consists of three solar arrays, a 26 cell (24 AH, 26 - 32.5 V unregulated) Ni-Cd battery pack, and associated distribution and control units. The total solar array area is about 12 square meters. The large, unobstructed rear surface of the arrays will dissipate excess heat into space. Pre-ship measurements show an actual available solar array power of 1100 watts and an average consumption of 917 watts for a margin of 183 watts. For operations in eclipse, the available battery power (400 watts) provides a 64 watt margin above the average consumption level of 336 watts. Thermistors and heaters (182 watts, nominal) provide active thermal control during sun phases; passive controls with radiators, insulation, and surface finishes maintain temperatures during eclipse phases. The most important temperature requirements are noted in Figure 15.

The telecommunication subsystem consists of two, redundant S-band transceivers, command decoders, and an antenna with a cardioid pattern. The basic characteristics are listed in Table 4. Tests, relative to the Weilheim station, showed an uplink command margin ranging from 17.9 dB (worst case and 5° elevation) to 78.0 dB (best case and 90° elevation). Downlink real time telemetry margins ranged from 6.8 dB (worst case and 5° elevation) to 32.5 dB (best case and 90° elevation). Corresponding downlink tape transmission margins ranged from 1.9 dB (worst case and 10° elevation) to 32.0 dB (best case and 90° elevation).

Hardware for data handling consists primarily of two subsystems: a data processing system and tape recorders. Processing is achieved with Dornier's "Modular Universal Data Acquisition and Control System" (MUDAS) based on an INTEL 8086 microprocessor. Reconfiguration of software in orbit is possible using several load commands. Telemetry frames consist of 128 8-bit words. Input data channels are of four types: analog conditioned, analog from active sources, parallel digital, and serial digital-word/block transfer. Two, redundant tape recorders are used for data storage; each has a 700 Mbit capacity permitting 20 to 21 hours of recording.

The Attitude Measurement and Control System (AMCS) provides 3-axis stabilization and highly accurate attitude measurements (Table 4). Three axis stabilized pointing is achieved using gyros, four reaction (i.e., momentum) wheels, and three magnetic torquers for desaturating the reaction wheels. The reaction wheels are designed for fast slews (180° in ~ 15 minutes) to make it possible to observe two targets on opposite hemispheres during each ROSAT orbit. Attitude is sensed by two star trackers, three coarse sun sensors, the gyro package, and the magnetometer. The two, highly accurate CCD star sensors with overlapping fields of view provide position sensing of guide stars. The AMCS's pointing accuracy (i.e., the distance between the "actual" and "requested" pointing direction) is specified to be 3 arcminutes at the 3σ confidence level. The pointing stability (i.e., the movement of the optical axis of the XRT while on target) is specified to be < 5 arcsec/s but it is likely that actual movements will be substantially smaller (~ 1 arcsec/s) with a jitter radius of ~ 30 arcsec. The anticipated attitude measurement accuracy, determined ex post facto on the ground by GSOC, is given in Table 4 for both the scan and pointing modes. The operational modes include a special "wobble" mode, which is a modification of the pointing mode, to be used when a PSPC is located at the XRT focus for pointing mode observations. The purpose is to prevent shadowing of X-ray sources by the PSPC support grids. In this modified pointing mode the telescope's pointing direction is slowly rocked back and forth with a small amplitude at a low frequency (e.g., 3 arcminutes in 1 minute of time). Selected amplitudes and frequencies for the wobble are implemented by commandable software reconfigurations.

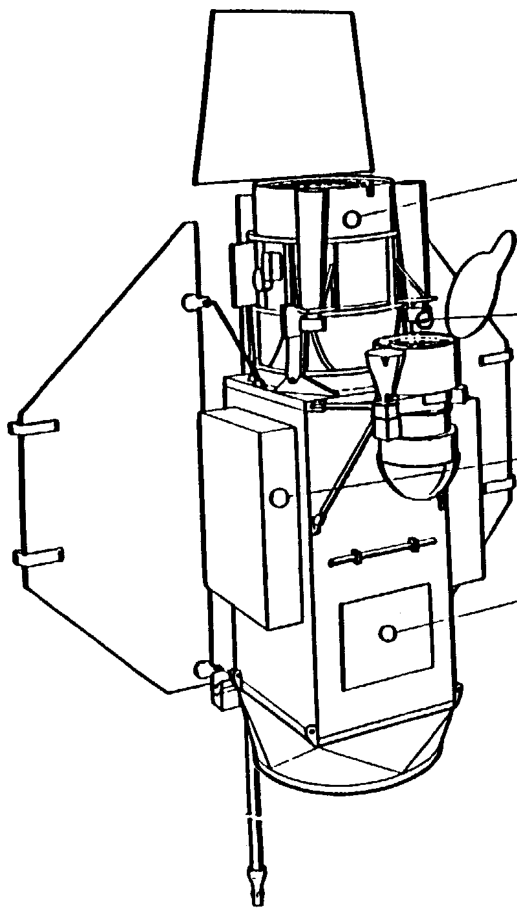


Figure 15. Temperature Requirements

MISSION SEQUENCE

Vehicle and Launch Site

The ROSAT spacecraft is to be launched into a 53° inclination, circular orbit at an altitude of 580 km by a two-stage Delta 6920-10 vehicle. The Delta designator "6" specifies a first stage with an extra extended long tank and a RS-27 engine, augmented by Castor IVA solid motors. The designator "9" specifies 9 solid motors. The designator "2" specifies an upgraded second stage, and the designator "0" specifies "no third stage." The added number "-10" specifies a nose (i.e., payload) section fairing with a 10 foot diameter. The 10 ft., 3 section fairing, shown schematically in Figure 2, will be flown for the first time with the launch of ROSAT. It represents a new development undertaken by NASA to accommodate the transverse dimensions of ROSAT and future spacecraft (e.g., EUVE).

The ROSAT launch is to take place from the Eastern Test Range (ETR), Cape Canaveral Air Force Station (CCAFS), Launch Complex 17, under the management and direction of the US Air Force as authorized by the NASA Mixed Fleet Manifest. Vehicle preparations are the responsibility of a USAF/McDonnell Douglas Space Systems Company launch team. Payload preparations are to be conducted in NASA/KSC facilities located within the CCAFS.

Launch Sequence

Tables 5 and 6 list the time sequence of major events following vehicle lift-off. Figure 16 schematically illustrates the boost profile and supplements Table 5 with altitude and velocity information through the first cut-off of the 2nd stage (SECO 1). Figure 17 illustrates the orbital path and ground station contacts well into the second orbit. Additional characteristics of the launch profile are described below.

At lift-off the vehicle is boosted by the main engine and 6 of the 9 solid motors. The remaining 3 solid motors are ignited at 60.5 sec --- between burnout (55.5 sec) and jettisoning (61.6 and 62.5 sec) of the first 6 motors. One roll maneuver and a series of pitch maneuvers are executed prior to 70 sec. During this phase the vehicle is on a flight azimuth of 65° to satisfy range safety requirements relative to local facilities. First stage yaw (i.e., "dog-leg") maneuvers to achieve the desired 53° orbital inclination are initiated at 70 sec. The final yaw maneuver, establishing the 53° inclination, is executed by the 2nd stage between 292 and 302 sec. At SECO 1, 669.7 sec, (Figure 16) the vehicle has achieved a transfer orbit at the required 53° inclination.

(Note: pre-1989 mission parameters specified a 57° inclination. The change to a 53° inclination was made primarily to reduce the amount of time spent in contact with auroral regions giving a high background count. Secondary benefits from this change include: a small increase in signal acquisition time from the Weilheim station, a considerable increase in vehicle performance margins, and a significant increase in the distance between Newfoundland and the zone of booster and fairing impact, shown in Figure 18.)

Roll and pitch maneuvers during the coast phase following SECO-1 provide the required attitude for the second burn of the 2nd stage which results in the desired altitude, 580 km (313 nmi). As illustrated by the coincidence between "acquisition of signal" (AOS) at the Indian Ocean Station (IOS) and ignition of the second burn of the 2nd stage, the flight profile is designed for orbital insertion over the Indian Ocean Station. Pre-separation maneuvers, ROSAT separation, and 2nd stage cold gas retro maneuvers are completed within r-f view of the IOS. The separation operation is initiated by an electroexplosive release of the clamp assembly at 2550 sec (Table 5). ROSAT is, however, still attached to

Table 5. Sequence of Events (Vehicle)

ROSAT LAUNCH

Event	Time (sec)
Liftoff	0.0
6 Solid Motors Burnout	55.5
3 Solid Motors Ignited	60.5
Jettison 3 Solid Motors	61.6
Jettison 3 Solid Motors	62.5
3 Solid Motors Burnout	116.1
Jettison 3 Solid Motors	122.0
Main Engine cutoff (MECO)	264.5
First/Second Stage Separation	272.5
Second Stage Ignition	278.0
Jettison Fairing	283.0
Second Stage Engine Cutoff (SECO 1)	669.7
Begin Coast Phase Maneuvers	720.0
End Coast Phase Maneuvers	2170.0
AOS at IOS (5°)	2282.2
Restart Second Stage	2282.2
Second Stage Engine Cutoff (SECO 2)	2294.1
Begin Maneuver to Separation Attitude	2300.0
Separation Attitude Achieved	2490.0
Inhibit Second Stage Attitude Control	2549.5
Release Clamp Band	2550.0
ROSAT Separation (Latch Release)	2580.0
Initiate Second Stage Retro	2580.5
Enable Second Stage Attitude Control	2587.5
End Second Stage Retro	2622.0
LOS at IOS (5°)	2689.1
Second Stage Evasive Burn Ignition	5950.0
Second Stage Evasive Burn Cutoff	5955.0
Second Stage Depletion Burn Ignition	6610.0
Second Stage Depletion Burn Cutoff	6631.6

Table 6. Sequence of Events (Spacecraft)

ROSAT LAUNCH

ROSAT Sequencer Functions	Time
Sequencer Initiation To = 2550 sec	To
Pyro Power ON	To + 15 sec
Solar Panel 3 Deployment	To + 75 sec
Solar Panel 1 Deployment	To + 165 sec
Antenna Boom Deployment	To + 225 sec
Gyro 1-4 ON	To + 285 sec
Solar Power to Main Bus	To + 315 sec
Reaction Wheels 1-4 ON	To + 465 sec
Transmitter 1 ON	To + 32 min
Star Tracker 1-2 ON (thermal reasons)	To + 96 min
Premeasurement Phase: Major Events*	**Day**
Activate FI electronics, open HRI door, switch-on SAAD-B, test carousel, Turn-on WFC	2
PSPC-A moved to focus, start gas purge, switch-on SAAD-A	3
Experiment electronic checkouts	4 - 5
Open WFC door, test WFC star tracker	5
PSPC-A high voltage iteratively stepped, checkouts of WFC focal plane mechanisms	6 - 7
PSPC-A calibration with radioactive source	8
PSPC-A particle background measurements	9
WFC high voltage switch-on	12
Start PSPC calibration phase	13

* Preliminary, subject to change

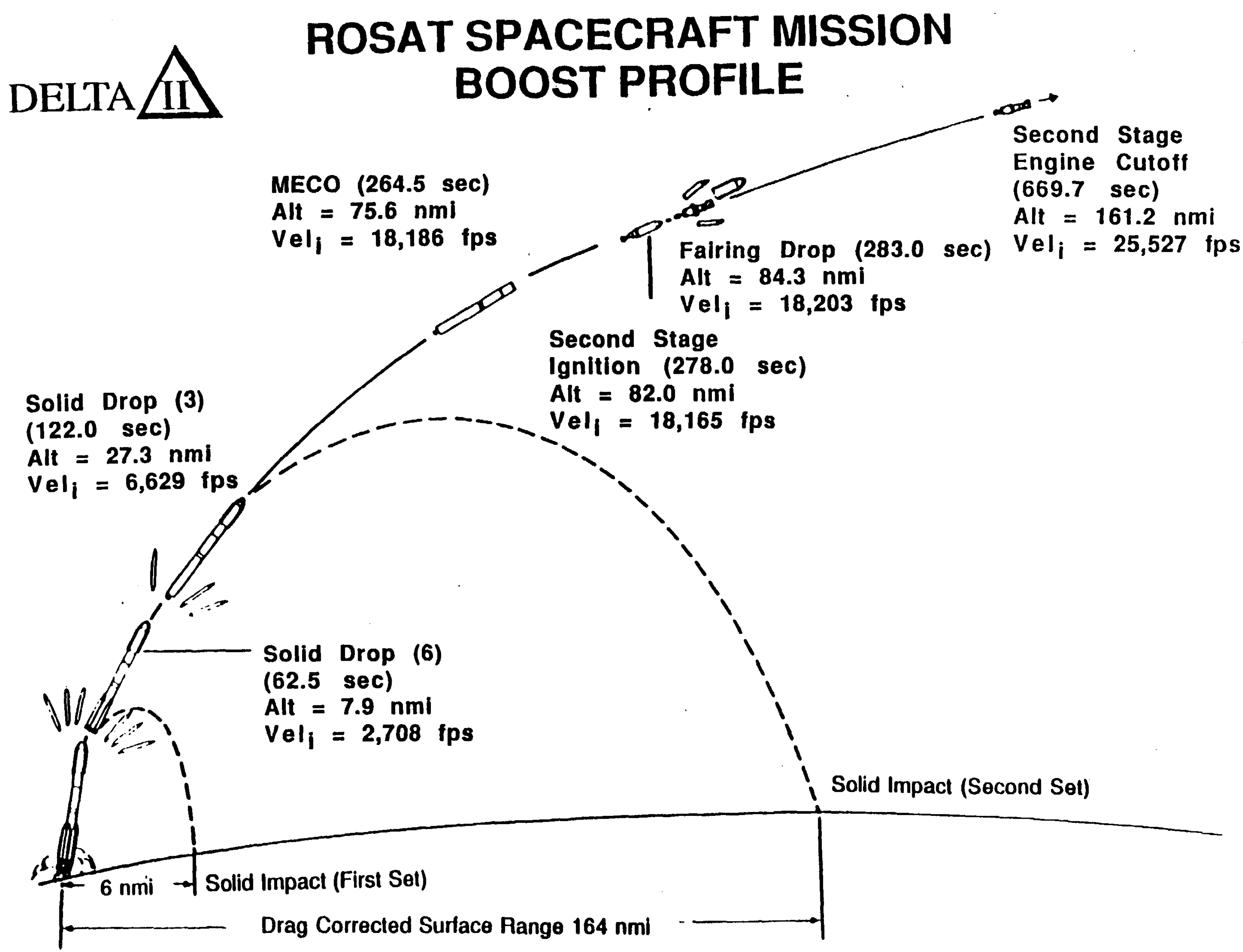
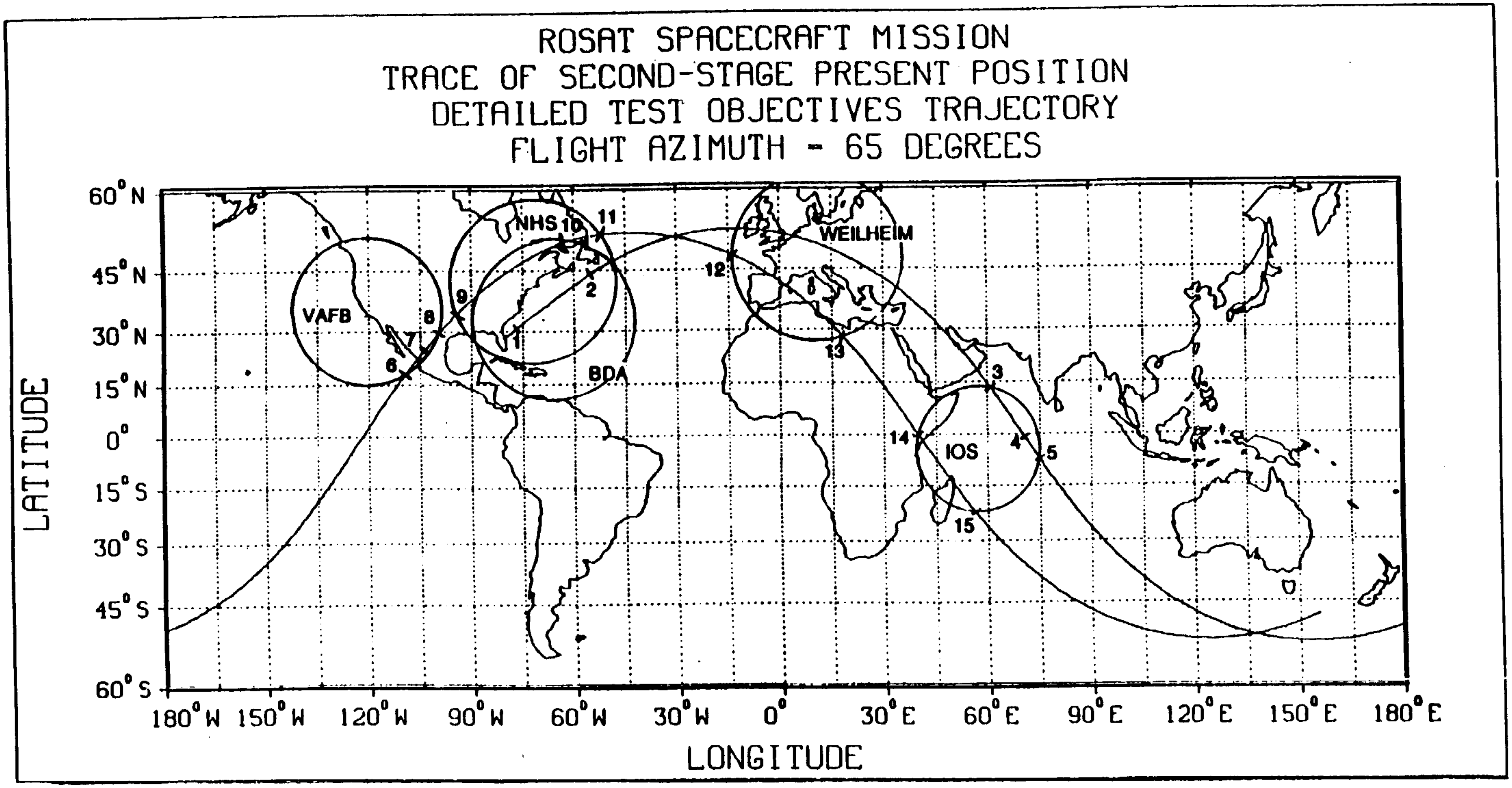


Figure 16. L: Boost Profile



1 MECO: 264.54 sec	**6 AOS AT VAFB: 5817.3**	**11 LOS at NHS: 6789.5 sec**
2 SECO 1: 669.70 sec	**7 Stage 2 Evasive Burn: 5950.00 sec**	**12 AOS at Wellhelm: 7112.5 sec**
3 AOS at IOS & Restart Stage 2: 2282.21 sec	**8 LOS at VAFB: 6073.6 sec**	**13 LOS at Wellhelm: 7636.4 sec**
4 Separate Spacecraft: 2580.0 sec	**9 AOS at NHS: 6167.6 sec**	**14 2nd AOS at IOS: 8226.5 sec**
5 LOS at IOS: 2689.1 sec	**10 Stage 2 Depletion Burn: 6610 sec**	**15 2nd LOS at IOS: 8693.6 sec**

Figure 17. ROSAT/2nd Stage Initial Orbit and Signal Acquisition

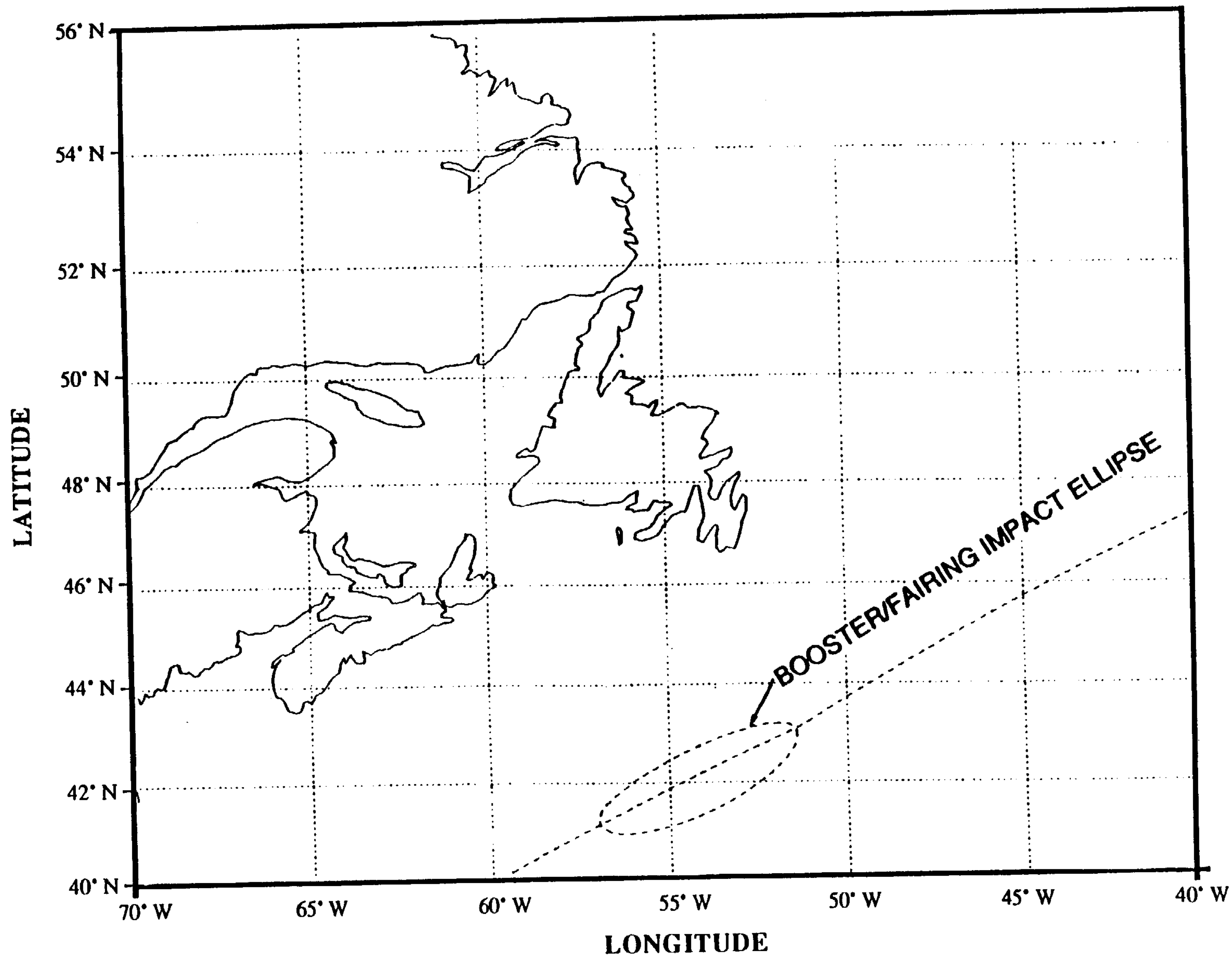


Figure 18. Location of Main Engine and Fairing Impact

the 2nd stage by means of a latching system for another 30 seconds. The latching system permits a small movement between ROSAT and the attach fitting such that separation switches will initiate the ROSAT "sequencer" (Table 6) prior to the latch release (2580 sec) that completes the mechanical separation. The ROSAT sequencer automatically performs the spacecraft turn-on and deployment functions listed in Table 6. The 2nd stage cold gas (helium) retro system, initiated at 2580.5 sec, produces a translational drift of the 2nd stage away from ROSAT.

VAFB, California acquires signals on the ascending leg of the first orbit (Figure 17) and is used for observations of the 3rd burn (the "evasive" burn) of the 2nd stage at 5950 sec (Table 5). The purpose of this burn is to greatly increase the separation of 2nd stage and ROSAT orbits, thus eliminating the possibility of future collision or spacecraft contamination from the subsequent depletion burn. The depletion burn, 11 minutes later, is a safeguard against future debris-generating explosions of the vehicle.

Premeasurement Phase

Following termination of the sequencer events (Table 6) the premeasurement phase (Table 1) is initiated under ground station control, primarily from the German Deep Space Station near Weilheim, FRG. The premeasurement phase encompasses the switch-on procedures and testing of subsystems, the installation of a controlled satellite attitude with inertial reference, and the outgassing of the telescopes. Some of the main events involving the scientific instrumentation are highlighted in the bottom half of Table 6.

Relative to detailed planning of subsequent observations, an important activity in the premeasurement phase is the mapping of radiation belt particle flux contours using the south Atlantic anomaly detectors (SAADs). The maps acquired will supplement particle background models to predict zones of high particle flux where the high voltages of the PSPC and HRI have to be switched off to avoid damage.

Launch Windows

ROSAT can be launched on any day of the year. The duration of daily launch windows has been specified as one hour. The nominal (i.e., reference) orbit for launch has been chosen such that spacecraft separation occurs 10 minutes before orbital dawn. Accordingly, the launch times tabulated in Table 7 are selected such that orbital dawn occurs at 3180 sec (i.e., separation at 2580 sec + 600 sec). The launch window is then specified as opening 15 minutes before, and 45 minutes after, the tabulated launch time.

Table 7. ROSAT Launch Windows

NOTE: The launch window opens 15 minutes before, and closes 45 minutes after, the listed launch time.

Launch Date		Launch Time (GMT)
Month	Day	HR: MIN: SEC
May	15	21:41:48.88
	16	21:42:17.63
	17	21:42:46.21
	18	21:43:14.64
	19	21:43:42.92
	20	21:44:11.02
	21	21:44:38.95
	22	21:45:06.67
	23	21:45:34.20
	24	21:46:01.51
	25	21:46:28.58
	26	21:46:55.40
	27	21:47:21.96
	28	21:47:48.23
	29	21:48:14.21
	30	21:48:39.86
	31	21:49:05.19
June	1	21:49:30.15
	2	21:49:54.74
	3	21:50:18.94
	4	21:50:42.72
	5	21:51:06.06
	6	21:51:28.94
	7	21:51:51.34
	8	21:52:13.24
	9	21:52:34.61
	10	21:52:55.43
	11	21:53:15.68
	12	21:53:35.33
	13	21:53:54.36
	14	21:54:12.74
	15	21:54:30.45
	16	21:54:47.47

MISSION SUPPORT

Mission Control

The ROSAT Operations Control Center (ROCC) located at the German Space Operations Center (GSOC) in Oberpfaffenhofen, Germany is the Mission Control Center (MCC) for ROSAT. ROCC/GSOC is solely responsible for the initial processing of all spacecraft and instrument data for real-time operational purposes. The principal operational functions and interfaces are shown in Figure 19.

Tracking and Data Acquisition

(a) General

The prime tracking and data acquisition station for ROSAT will be the German 15-meter tracking station at Weilheim, Germany. The Weilheim station will be in contact with ROSAT for periods of 6 to 9 minutes for each of 5 or 6 consecutive orbits per day. The operationally useful contact time for sending commands will average about 39 minutes/day. Because the contact times are short, spacecraft operations are primarily based on time tagged commands. Between 2000 and 6000 commands/day are anticipated. The operationally useful contact time for receiving tape dumps at 1 Mbit/s (Table 4) averages about 35 minutes/day. Approximately 1000 Mbits/day of taped data are anticipated. Because there is an operational need for fast access to the data, tape dumps will only be executed over the Weilheim station. As indicated in Figure 19, operational planning and the generation of timelines for selected observations are joint, iterative efforts between ROCC/GSOC and the ROSAT Science Data Center (RSDC) located at the Max Planck Institut fur Extraterrestrische Physik (MPE), Garching, FRG. The MPE-RSDC has sole responsibility for coordinating the inputs from the science community in accord with the guidelines provided by the ROSAT International User Committee (IUC).

Tracking data for orbit determinations consists only of angle data from both the Weilheim and NASA DSN stations. One week, definitive and three week, predict orbits will be produced using GSOC's orbit determination system (GODS). The development and operational use of attitude control and attitude determination systems are also a ROCC/GSOC responsibility.

(b) NASA Role

NASA will: assist ROSAT operations with prelaunch testing, provide ground station support for up to four weeks after spacecraft separation from the launch vehicle, and back-up the German ground tracking and data system during the remainder of primary mission operations. During launch activities 8 Kbit/s telemetry, command, and voice communications will link ROCC/GSOC to launch area facilities. The GSFC Wallops Island tracking station will provide support during the initial acquisition phase. The Goldstone, Canberra, and Madrid Deep Space Network (DSN) will provide 26-meter telemetry, command, radio metric data, and voice communication support throughout the initial 28 days following launch. As drawn in Figure 20, NASA facilities will communicate with GSOC via the Madrid NASCOM Switching Center (MNSC). Circuits from MNSC to GSOC will be a German responsibility.

Following the initial 28 day phase, the 26-meter DSN stations will be available for spacecraft emergencies and/or unexpected mission-critical system malfunctions. Monthly

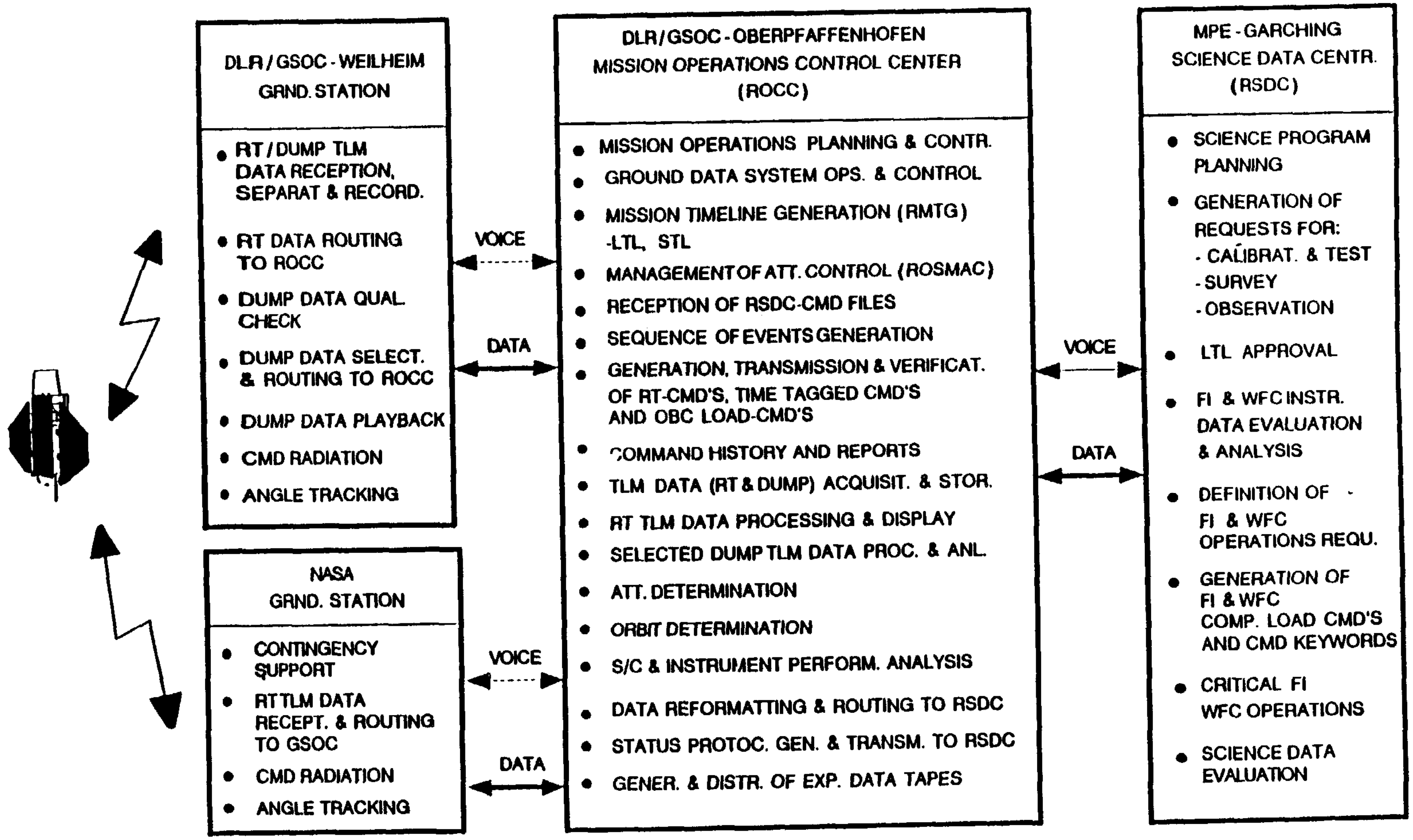
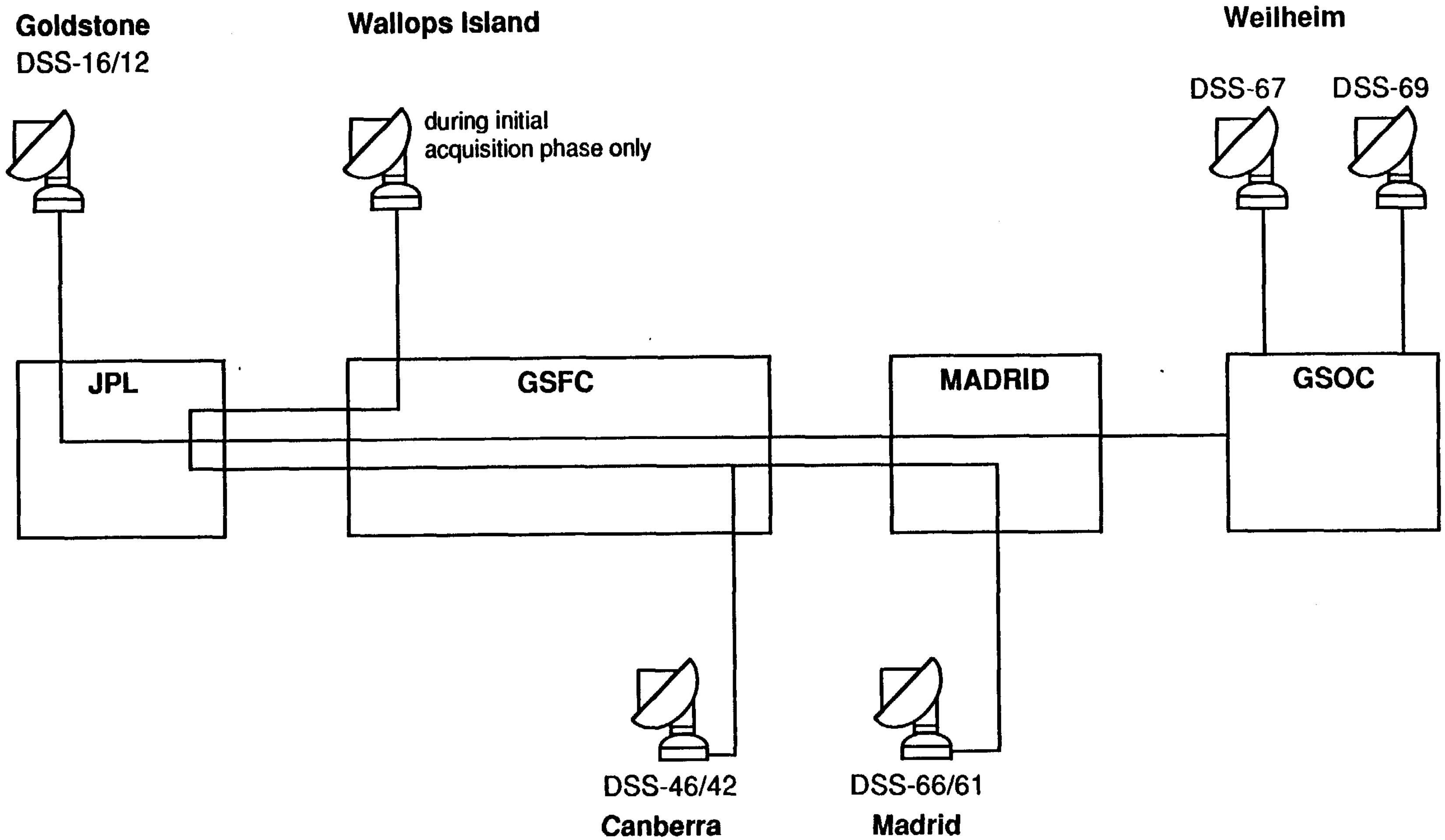


Figure 19. ROSAT Operational Functions and Interfaces



DSS support: prime 26m station network DSS-16, DSS-46, DSS-66
backup 34m station network DSS-12, DSS-42, DSS-61

Figure 20. ROSAT Tracking Network: Pre-measurement Phase

DSN support passes will be scheduled to verify the GSOC-DSN interfaces. During all DSN support phases the 26-meter stations will supply real-time radio metric angle data at a sample rate of one measurement every 10 seconds while the spacecraft is visible.

Data Management

The German ROSAT Operations Control Center (ROCC/GSOC) and ROSAT Science Data Center (RSDC) have complete responsibility for: (a) the initial (Level 0) processing of all data, and (b) all processing and analysis (Levels 1 and 2) of X-ray data from the all-sky survey phase of the mission. The processing, distribution, analysis, and archiving of XUV data from the UK's wide field camera (WFC) in all mission phases is external to the purview of NASA-BMFT agreements and is treated separately under the SERC(UK) - BMFT memorandum of understanding.

NASA will receive data taken during the 50 percent of X-ray telescope time allocated to NASA during the pointed phases (see Table 1) of the mission. Following initial (Level 0) processing the German RSDC (MPE) will ship video tapes containing master data records to the U.S. ROSAT Science Data Center (USRSDC) located at the Goddard Space Flight Center, Greenbelt, MD. At the USRSDC the ROSAT Standard Data Processing (software) System (SDPS) developed at MPE will be used to process the Level 0 observations to yield a standard data product for each observation. Following verification the data are released to the cognizant observer and archived in the USRSDC (see Figure 21). The ROSAT Data Bank (Figure 21) will be the central location for the storage and distribution of ROSAT data products. At a later date, following the period for which the observer has proprietary rights, the data are to be released to the National Space Science Data Center (NSSDC) for general access.

The USRSDC will provide software to assist observers and data bank users in the analysis of their PSPC or HRI data. This Post Reduction Off-line Software (PROS) is being developed by the Smithsonian Astrophysical Observatory (SAO), Cambridge, Massachusetts in collaboration with GSFC. The PROS system will enable scientists to perform spatial, spectral, and timing analysis of X-ray data.

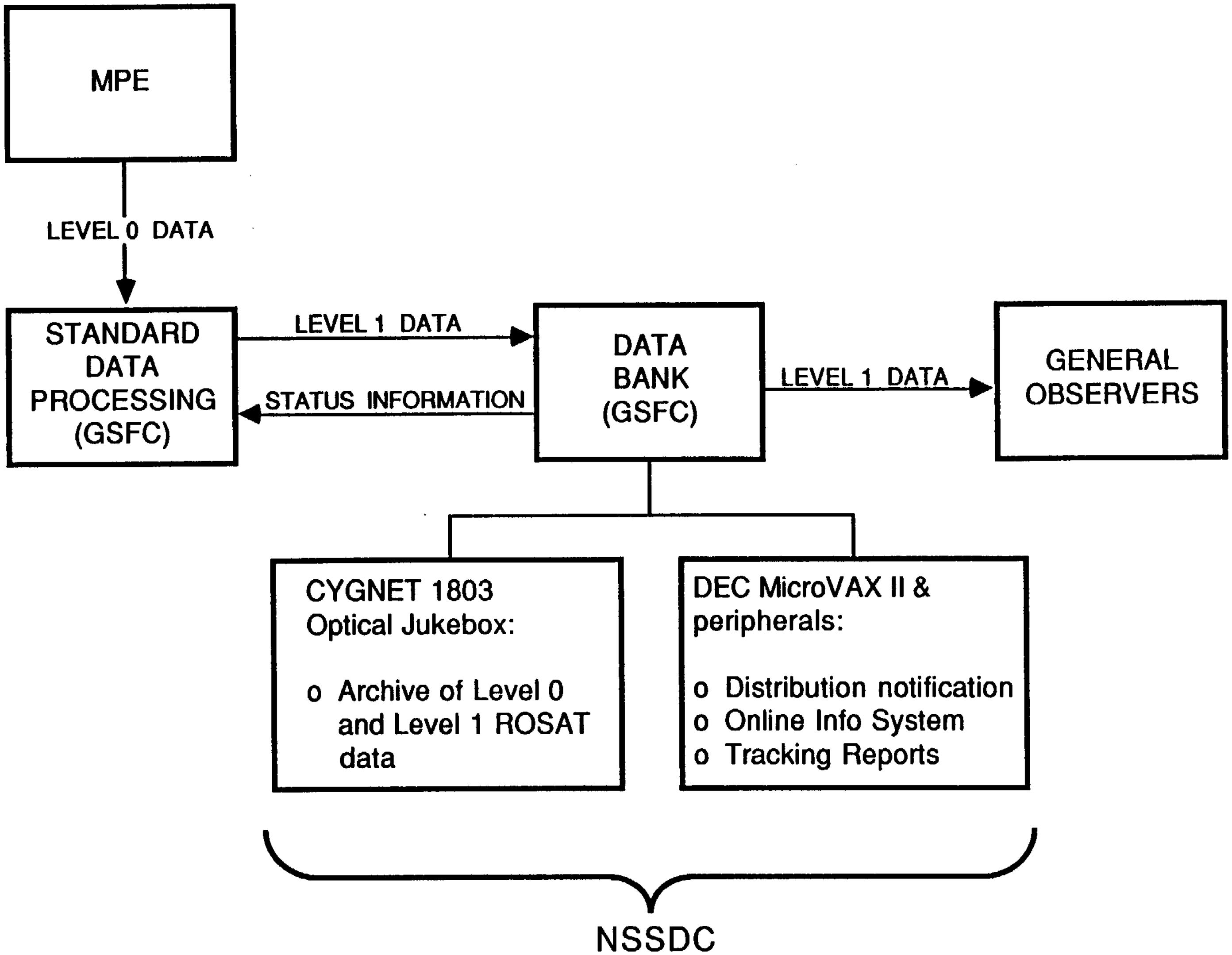


Figure 21. ROSAT X-Ray Data Flow

MISSION MANAGEMENT

The ROSAT project is cooperatively managed by NASA and the Bundesministerium fuer Forschung und Technologie (BMFT). The BMFT has prime management responsibilities for the X-Ray Telescope (XRT), the Position Sensitive Proportional Counters (PSPCs), the ROSAT spacecraft, ROSAT in-orbit operations, and data acquisition. BMFT's responsibilities also include SERC's responsibilities for the Wide Field Camera (WFC) as set forth in the MOU between BMFT and SERC. The NASA has prime management responsibilities for the launch vehicle, launch operations, and the High Resolution Imager (HRI) detector.

Within NASA, the Office of Space Science and Applications (OSSA), NASA Headquarters, is responsible for the overall direction and evaluation of NASA's roles in the ROSAT mission. The Associate Administrator for OSSA has assigned Headquarters responsibility for this Explorer program to the Director of the Astrophysics Division who has designated a NASA Program Manager and a NASA Program Scientist. The Goddard Space Flight Center (GSFC) has been assigned responsibility for project management within NASA. Within GSFC, management is carried out by the ROSAT Project Office in the Flight Projects Directorate and is led by a designated NASA Project Manager and NASA Project Scientist. The Office of Space Operations, NASA Headquarters, is responsible for NASA's role in providing initial, and back-up, tracking support. The Office of Space Flight, NASA Headquarters, is responsible for supporting pre-launch spacecraft activities at the Kennedy Space Center and providing coordination of pre-launch and launch activities between the spacecraft management team and the USAF Cape Canaveral Air Force Station (CCAFS) launch operations team. The ROSAT launch is to be conducted under the management and direction of the USAF with assistance from the McDonnell Douglas Space Systems Company (MDSSC) Delta launch team at CCAFS.

The responsible organizations and personnel are:

<u>NASA Headquarters: Office of Space Science and Applications</u>

Dr. Lennard A. Fisk	Associate Administrator for Space Science and Applications
Alphonso V. Diaz	Deputy Associate Administrator for Space Science and Applications
Dr. Charles J. Pellerin, Jr.	Director of Astrophysics Division ROSAT Program Director
John A. Lintott	ROSAT Program Manager
Dr. Alan N. Bunner	ROSAT Program Scientist

<u>NASA Headquarters: Office of Space Operations</u>

Charles T. Force	Associate Administrator for Space Operations

NASA Headquarters: Office of Space Flight

Dr. William B. Lenoir	Associate Administrator for Space Flight

NASA: Goddard Space Flight Center

Dr. John W. Townsend, Jr.	Director
Dr. James H. Trainor	Associate Director
Peter T. Burr	Director of Flight Projects
Gilbert W. Ousley, Sr.	ROSAT Project Manager
Dr. Stephen S. Holt	ROSAT Project Scientist
John M. Beckham	Delta Project Manager
Dr. Robert D. Price	Manager, U.S. ROSAT Science Data Center

NASA: Kennedy Space Center

James L. Womack	ROSAT Launch Manager

Jet Propulsion Laboratory

Marvin R. Traxler	(NASA) Tracking and Data Systems Manager

Smithsonian Astrophysical Observatory (SAO)

Dr. Harvey D. Tananbaum	Associate Director of High-Energy Astrophysics Division
John Gerdes	HRI Project Manager
Dr. Martin Zombeck	HRI Project Scientist

USAF: Cape Canaveral Air Force Station, 6555th Aerospace Test Group

Lt. Col. Jerry M. Johnson	Commander
Lt. Col. Robert M. Tayloe	Vice Commander
Lt. Col. Harold H. Donald	Chief, Medium Launch Vehicle Division ROSAT Test Director

Bundesministerium fuer Forschung und Technologie (BMFT)

Manfred Otterbein	(BMFT) ROSAT Program Manager and Program Scientist

Max Planck Institut fuer Extraterrestrische Physik (MPE)

Professor Joachim Trumper	(BMFT) ROSAT Project Scientist
Dr. Horst Hippmann	FI Launch Site Support Manager

Deutsche Forschungsanstalt fuer Luft- und Raumfahrt E.V. (DLR)

Wilfried Geist	(DLR) ROSAT Project Manager
Dr. Volker Kaltenbach	(DLR) ROSAT Deputy Project Manager
Friedrich Guckenbiehl	(DLR/GSOC) ROSAT Mission Operations Director

Dornier GmbH

Edgar Bachor	(Dornier) ROSAT Project Manager
Walther Klages	(Dornier) ROSAT Launch Preparation Manager

U.K. Science and Engineering Research Council (SERC)

Dr. G. Martin Courtier (Rutherford Appleton Laboratory)	WFC Program Manager
Dr. Kenneth A. Pounds (University of Leicester)	WFC Project Scientist
Dr. Mark R. Sims (University of Leicester)	WFC Launch Site Support Manager

<u>ROSAT PROJECT ACRONYMS</u>

AMCS	Attitude Measurement and Control System
AO	Announcement of Opportunity
AXAF	Advanced X-ray Astrophysics Facility
AOS	Acquisition of Signal
BMFT	Bundesministerium fuer Forschung und Technologie (Federal Minister for Research and Technology)
CCAFS	Cape Canaveral Air Force Station
CDEA	Command and Data Electronics Assembly
CDHS	Command and Data Handling System
CGCD	Crossed Grid Charge Detector
DA	Detector Assembly
DFVLR (old)	Deutsche Forschungs und Versuchsanstalt fuer Luft und Raumfahrt (German Research and Experiment Facility for Aviation and Space Flight)
DLR (new)	Deutsche Forschungsanstalt fuer Luft und Raumfahrt E. V. (German Research Facility for Aviation and Space Flight E. V.)
DSN	Deep Space Network
ESA	European Space Agency
ETR	Eastern Test Range
EUV	Extreme Ultraviolet
EUVE	Extreme Ultraviolet Explorer
FI	Focal Plane Instrumentation
FRG	Federal Republic of Germany
GODS	GSOC Orbit Determination System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSOC	German Space Operations Center
HEAO	High Energy Astronomy Observatory
HEW	Half Energy Width

HRI	High Resolution Imager
HST	Hubble Space Telescope
IOS	Indian Ocean Station
IUC	International User Committee
JSC	Johnson Space Center
KSC	Kennedy Space Center
MCC	Mission Control Center
MCP	Microchannel Plate
MDSSC	McDonnell Douglas Space Systems Company
MICS	Management Information and Control System
MO&DA	Mission Operations and Data Analysis
MNSC	Madrid NASCOM Switching Center
MOU	Memorandum of Understanding
MPE	Max Planck Institut fuer Extraterrestrische Physik
MUDAS	Modular Universal Data Acquisition and Control System
NSSDC	National Space Science Data Center
OSSA	Office of Space Sciences and Applications
PP	Project Plan
PROS	Post Reduction Off-Line Software
PSPC	Position Sensitive Proportional Counter
ROCC	ROSAT Operations Control Center
ROSAT	Roentgensatellit (Roentgen Satellite)
RSDC	ROSAT Science Data Center
SAAD	South Atlantic Anomaly Detector
SAO	Smithsonian Astrophysical Observatory
SDC	Science Data Center
SDPS	Standard Data Processing System

SECO	Second Engine Cut-Off
SERC	Science and Engineering Research Council
STS	Space Transportation System
UK	United Kingdom
USRSDC	U.S. ROSAT Science Data Center
UV	Ultraviolet
VAFB	Vandenburg Air Force Base
WFC	Wide Field Camera
XMA	X-Ray Mirror Assembly
XRT	X-Ray Telescope
XUV	Extreme Ultraviolet
ZDE	Central Data Electronics