NASA
National Aeronautics and
Space Administration
Washington, D.C.
20546

AUG 22 1991

Reply to Attn of: SZ

TO: Distribution

FROM: S/Associate Administrator for Space Science and Applications

SUBJECT: Solar-A Prelaunch Mission Operation Report (MOR)

The Prelaunch Mission Operation Report (MOR) for the Solar-A mission is enclosed for your information.

Solar-A is a Japanese-led program involving the United States and the United Kingdom as participating partners. The Japanese Institute of Space and Astronautical Science (ISAS) provides overall program management, the launch vehicle, the spacecraft, and two science instruments--a Hard X-ray Telescope and a Wide Band Spectrometer. NASA is providing one of the primary science instruments on the mission, the Soft X-ray Telescope. NASA also provides tracking support using the Deep Space Network (DSN) ground stations. The United Kingdom is providing a Bragg Crystal Spectrometer.

The participating U. S. scientists will have access to the data from all four mission instruments. The use of the Soft X-ray Telescope in conjunction with the ISAS-provided Hard X-ray Telescope will provide the first simultaneous images of the Sun in both soft and hard x-rays. These measurements will constitute an important new tool to further our understanding of solar flare plasma physics, including energy storage and release, particle acceleration, and solar-terrestrial effects.

Launch is scheduled for late August from the ISAS launch center near Kagoshima in southern Japan.

This MOR: (a) describes the NASA objectives for the Solar-A mission; (b) provides brief descriptions of the spacecraft and its scientific instruments; (c) provides a chronology of launch and deployment; and (d) describes the ground operation elements that support the mission.

L. A. Fisk

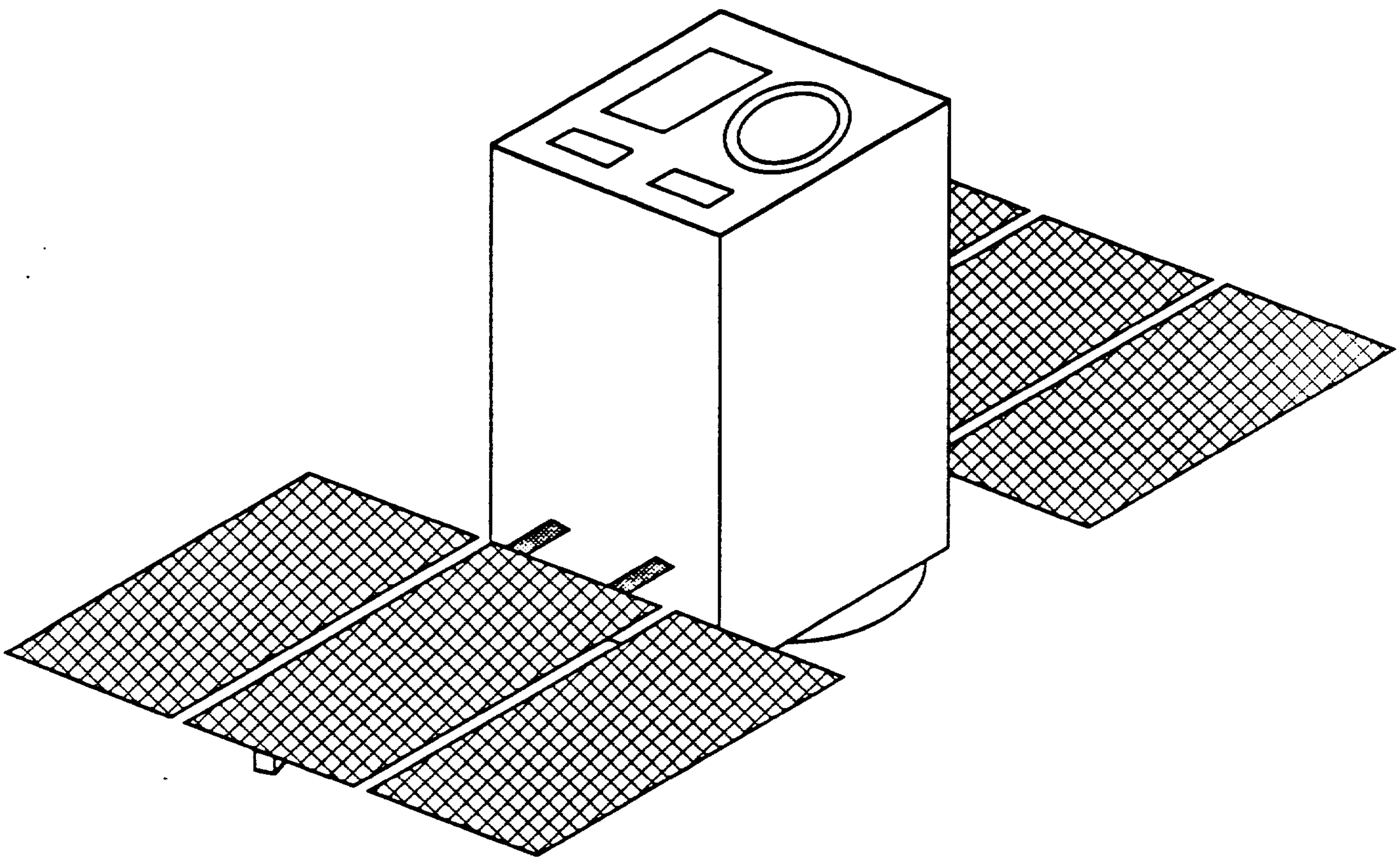
Enclosure

National Aeronautics and
Space Administration

Mission Operation Report

OFFICE OF SPACE SCIENCE AND APPLICATIONS

REPORT NO. S-416-91-01



SOLAR-A

TABLE OF CONTENTS

Foreword 1

Solar-A Program Overview 2

Mission Objectives 4

Mission History 6

Mission Phases 7

Scientific Objectives 8
General Goals and Objectives 8

Science Instruments 10
Soft X-ray Telescope (SXT) 10
Hard X-ray Telescope (HXT) 14
Wide-Band Spectrometer (WBS) 14
Bragg Crystal Spectrometer (BCS) 15

Spacecraft Description 16

Mission Sequence 18
Vehicle and Launch Site 18
Launch Sequence 18
Orbital Operations 18
Launch Window 19

Mission Support 20
Mission Control 20
Tracking and Data Acquisition 20
Data Management 23

Mission Management 25

Project Acronyms 27

LIST OF FIGURES

Figure 1.	Solar-A Mission Instrument Characteristics	10
Figure 2.	Schematic of SXT Optical System	11
Figure 3.	Calculated X-ray imaging performance	12
Figure 4.	Solar-A/SXT Instrument Assembly	13
Figure 5.	Solar-A spacecraft structure	16
Figure 6.	Cutaway view of the M-3SII and Performance Table	19
Figure 7.	The orbit ground tracks, on a Mercator projection map	21
Figure 8.	Soft X-ray Telescope/Solar-A Data Flow	22

FOREWORD

MISSION OPERATION REPORTS are published for the use of NASA senior management. 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 program 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 mission which are available for dissemination to the news media.

Published and Distributed by the
OFFICE OF HEADQUARTERS OPERATIONS
NASA HEADQUARTERS

SOLAR-A PROGRAM OVERVIEW

The Solar-A mission is a Japanese-led program with the participation of the United States and the United Kingdom. The Japanese Institute of Space and Astronautical Science (ISAS) is providing the Solar-A spacecraft, two of the four science instruments, the launch vehicle and launch support, and the principal ground station with Operational Control Center. NASA is providing a science instrument, the Soft X-ray Telescope (SXT)and tracking support using the Deep Space Network (DSN) ground stations. The United Kingdom's Science and Engineering Research Council (SERC) provides the Bragg Crystal Spectrometer.

The Solar-A mission will study solar flares using a cluster of instruments on a satellite in a 600 km altitude, 31° inclination circular orbit. The emphasis of the mission is on imaging and spectroscopy of hard and soft X-rays.

The principal instruments are a pair of X-ray imaging instruments, one for the hard X-ray range and one for the soft X-ray range. The Hard X-Ray Telescope (HXT), provided by ISAS, operates in the energy range of 10-100 keV and uses an array of modulation collimators to record Fourier transform images of the non-thermal and hot plasmas that are formed during the early phases of a flare. These images are thought to be intimately associated with the sites of primary energy release.

The Soft X-Ray Telescope (SXT), jointly provided by NASA and ISAS, operates in the wavelength range of 3-50 Angstroms and uses a grazing incidence mirror to form direct images of the lower temperature (but still very hot) plasmas that form as the solar atmosphere responds to the injection of energy. The SXT instrument is a joint development effort between the Lockheed Palo Alto Research Laboratory and the National Astronomical Observatory of Japan. The U.S. effort also involves Stanford University, the University of California at Berkeley and the University of Hawaii, who provide support in the areas of theory, data analysis and interpretation, and ground-based observations. The hard and soft X-ray telescopes both have an alignment sensor, operating in the visual region of the spectrum, to provide co-alignment information.

The instrument complement on Solar-A also includes a Bragg Crystal Spectrometer (BCS), developed by the National Astronomical Observatory of Japan in collaboration with the U.K. Science & Engineering Research Council (SERC), the U.S. National Institute of Standards & Technology (NIST) and the U.S. Naval Research Laboratory (NRL), which operates in the wavelength range of 1.8 to 5 Å. A Wide Band Spectrometer (WBS), developed by ISAS, which operates in the energy range of 2 keV to 100 MeV is also included.

The Solar-A spacecraft fits within a launch envelope which is 1.4 meters in diameter by 2.0 meters high, and has a maximum mass of 420 kg. It is stabilized in 3 axes by two momentum wheels and a control moment gyro. Pointing accuracy is 3 arc minutes maximum and short term pointing stability is 5 arc seconds/minute. Orbital average power (generated by solar arrays and stored in batteries) is 200 Watts. Onboard data storage is provided by a bubble memory with an 80 megabit capacity. Engineering and science data will be telemetered to the Kagoshima Space Center in Japan at 1, 4 or 32 kbps real-time or 131/262 kbps playback depending on whether convolutional coding is used. There are 5 contacts per day with Kagoshima which also acts as the spacecraft Operational Control Center. The NASA Deep Space Network provides additional data capture with up to 10 contacts per day.

Solar-A will be launched from the Kagoshima Space Center and will be inserted into orbit by the Japanese M-3SII, 3-stage, solid-propellant launch vehicle. The launch is scheduled for August 26, 1991 and the nominal mission duration is 3 years. The benefits to NASA for participation in this mission include access to the all science data captured by the other instruments in addition to the data captured by the SXT.

NASA OBJECTIVES FOR THE SOLAR-A MISSION

The Solar-A mission is a Japanese program involving the United States and the United Kingdom as participating partners. The Japanese Institute of Space and Astronautical Science (ISAS) provides overall program management, the launch vehicle, the spacecraft, and two science instruments -- a Hard X-Ray Telescope, one of the primary mission instruments, and a Wide Band Spectrometer. NASA is providing in cooperation with ISAS the other primary mission instrument, the Soft X-Ray Telescope. NASA also provides tracking support using the Deep Space Network ground stations. The U.K. is providing a Bragg Crystal Spectrometer.

The primary objectives of NASA's participation in the Solar-A mission are to:

- Obtain simultaneous images of solar flares with high time and spatial resolutions in both the hard and soft x-rays in order that the full morphology of the flare can be observed with sufficient precision to reveal the underlying physical processes.

- Image the solar corona in soft x-rays, with both high time and spatial resolution, to reveal properties of the global coronal magnetic fields.

- Measure variations of photospheric brightness with modest spatial resolution for studies of solar irradiance and global oscillations.

These objectives will be accomplished by:

- Making high energy observations of solar flares with high time, spatial, and spectral resolution using the co-aligned Solar-A instrument complement.

- Acquiring science data using the DSN in addition to the data acquired by the ISAS ground station.

- Making data from all Solar-A instruments available to the U.S. Solar-A investigators in a timely manner and providing adequate support of their data analysis requirements.

- Performing concurrent studies from ground-based telescopes.

CONCURRENCES:

SS/William J. Wagner
Program Scientist

7/19/91
Date

SZ/John Lintott
Program Manager

7/19/91
Date

SS/George L. Withbroe
Director, Space Physics Division

7/22/91
Date

SZ/Charles J. Pellerin, Jr.
Director, Astrophysics Division

Date

OSSA APPROVAL:

L. A. Fisk
Associate Administrator for
Space Science and Applications

8/1/91
Date

MISSION HISTORY

The mission was originally conceived as a purely Japanese national project to study high-energy solar flare emissions during this solar maximum. The Japanese Institute of Space and Astronautical Science (ISAS) initiated the Solar-A mission as a follow on to the ISAS Hinotori mission, which had been launched in 1981. Scientific return from the Hinotori mission had been greatly enhanced by the collaborative study of flares with the NASA Solar Maximum Mission (SMM) and this mission is a natural extension of that joint work.

Japan/U.S. discussions on Solar-A began in 1983 and in 1985 ISAS invited NASA to participate. An Announcement of Opportunity (AO) for a Soft X-Ray Telescope (AO OSSA-86-1) was released in March of 1986. A peer review was conducted in July, 1986. The Lockheed Palo Alto Research Laboratory proposal was selected by NASA and approved by ISAS on October 20, 1986. A letter agreement between ISAS and NASA for the Solar-A/SXT collaborative effort was signed by NASA on August 19, 1987. ISAS formally approved the agreement on March 15, 1990. An amendment to add DSN tracking support for the mission was approved on June 25, 1991.

Solar X-ray imaging dates back to the early 1960's when Richard Blake used a pinhole camera on a sounding rocket. The Orbiting Solar Observatory (OSO) series of satellites, flown during the 1960's and 1970's, conclusively showed that solar flares emitted copious amounts of high energy radiation from ultraviolet to hard X-rays but the imaging capabilities of the science instruments were inadequate or non-existent at these wavelengths. The P78-1 mission, launched by DOD in May 1979 included a coronagraph and a Bragg Crystal Spectrometer. The Solar Maximum Mission (SMM), launched by NASA in 1980, included a Hard X-ray Imaging Spectrometer, but the temporal and spatial resolutions were inadequate to resolve flare structure. The Hinotori mission featured a Hard X-ray Telescope with 15 arc second spatial resolution and 4-6 second temporal resolution that operated in the energy range of 15-40 keV

P78-1, SMM and Hinotori were launched in order to observe solar flares during the previous maximum of solar activity. Bragg Spectrometers on all 3 missions showed that, early in the impulse phase of flares, spectral lines are much wider than expected from thermal broadening. The "turbulent" or non-thermal motions are typically about 160 km/sec when first observed but can be as high as 300 km/sec. By the time peak X-ray flux is reached, and during the decay phase of flares, the non-thermal motions have decreased to somewhere between 0 and 60 km/sec - values that are difficult to measure. According to Antonucci et al (Solar Physics, 78, 107, 1982), there is a correlation between the peak non-thermal motion and the peak flux in the hard X-ray bursts associated with the impulsive phase. However, this conclusion is disputed by the P78-1 investigators and more data is needed for clarification. The instruments on Solar-A can provide this data.

The U.S. SXT was chosen by the Japanese because it was a crucial supporting instrument for their HXT and because the U.S. had already developed precursor instruments. In particular, Lockheed had flown soft X-ray instrumentation on OSO-8 and SMM.

Project responsibility for the SXT was assigned to the Marshall Space Flight Center (MSFC) in February 1987. The SXT X-ray calibration was completed at MSFC in June 1989. The SXT was sent to White Sands, New Mexico, for an end-to-end X-ray focus test during April and May, 1991 and shipped to Japan in May.

Launch is scheduled to take place from the Kagoshima Space Center on August 26, 1991.

MISSION PHASES

The Solar-A mission can be separated into the phases of:

- prelaunch science
- initial on-orbit operations (launch through 30 days)
- mission operations (nominally 3 years duration starting at completion of initial on-orbit operations)
- data reduction and analysis (nominally 4 years duration, concurrent with but extending one year beyond the mission operations phase).

The prelaunch science phase for the SXT includes such activities as:

- spatial resolution performance assessment
- sensitivity calculations
- X-ray filter evaluation
- expected signal calculations
- instrument performance simulations including development of the SXT software simulator, and development of the automatic exposure control procedure, the region of interest selection procedure and test input images for analysis software
- prelaunch operations planning within the Solar-A teams, with ground-based programs and observational sequence planning
- developing objectives and programs with the U.S. CoI's
- the transfer of calibration data and software amongst the U.S. CoI's
- general planning, meetings and papers/presentations

The initial on-orbit operations phase takes place for approximately 30 days after the August 26, 1991 launch and will involve checkout and performance validation of the Solar-A spacecraft, verification of the spacecraft orbit, calibrations of the science instruments, validation of the command & telemetry, data capture and data dissemination functions, and validation of the data reduction and analysis functions.

During mission operations, the instruments are continually pointed at the solar disk (except during periods of earth occultation). The spacecraft has four modes of telemetry operation: Quiet Hi, Quiet Med, Flare Hi and Flare Med, which are characterized by different data rates. Primary data capture (real-time and playback) is performed by the Kagoshima Space Center, which is located at 131° E Longitude and 31° N Latitude. Contact times of 10-12 minutes per orbit for up to 5 orbits a day (out of 15) are possible from this location. The NASA Deep Space Net (DSN) has a capability of up to 10 orbits per day which will be used for capturing playback data only.

Mission operations will also involve ground operations in Japan, coordination with the Max-91 Program, dealing with film from the ground-based H-alpha telescopes and acquisition of National Oceanographic and Atmospheric Administration data.

The data reduction and analysis phase will include the revision and extension of reduction software, revisions and extensions of analysis software, data transfer amongst the U.S. CoI's, data analysis and presentation of results, and Guest Investigator Program support.

SCIENTIFIC OBJECTIVES

General Goals and Objectives

The Solar-A mission is designed to answer many questions in solar flare physics that have been raised by the highly successful Hinotori and SMM missions. The analysis of observations with these satellites has revealed that the most important direction for future flare observation lies in high resolution imaging in both soft and hard X-ray bands and in precise wide-band spectrometry in the soft X-ray to the gamma-ray regime. The simultaneous imaging of flares in both hard and soft X-rays is regarded as imperative if the full morphology of the flare is to be understood with sufficient precision to test the theoretical models. Wide band spectral observation provides the key to understanding plasma heating, electron and ion acceleration and high energy photon emission at the flare site. Solar-A will be the only spacecraft designed for flare studies that will be in orbit at the time of this current solar maximum.

The HXT and SXT are powerful imaging instruments with better spatial resolution, photon energy coverage and time resolution than were available with SMM. HXT has a spatial resolution of better than 8" and SXT has a spatial resolution of 2" over 60% of its FOV. The temporal resolution of both instruments is approximately 1 second. The energy ranges of SXT and HXT are 0.25-4 keV and 10-100 keV respectively. The Wide Band Spectrometer covers the energy range 2 keV to 50 MeV in three separate instruments. The Bragg Crystal Spectrometer is designed to measure electron temperatures in four spectral lines around 1.5-5 A of specific interest for solar flare studies.

No previous solar mission has had available such a potent combination of hard and soft X-ray imaging and spectrometry instruments operating over such a wide energy band and with adequate dynamic range and time resolution to study even the brightest flares. Together, they will allow studies of the pre-flare coronal structures immediately prior to energetic flares, the physical processes that are responsible for energy release, the nature of the particle acceleration processes that occur during the flare impulsive phase, and the means by which energy is transported away from the primary release site to other parts of the solar atmosphere.

The BCS will greatly enlarge our understanding of the flare energy release mechanism and the interaction of that energy with the lower solar atmosphere. In addition, given the substantial increase in sensitivity over the SMM spectrometers, there is a high probability of achieving unexpected discoveries of the kind made with the SMM instruments.

The hard X-ray and gamma-ray spectrometers of the WBS will allow studies of the electron, proton and nuclear acceleration processes that operate during flares. Comparison of the hard X-ray spectral data with images from the Fourier Synthesis telescope (HXT) will enable detailed studies of the electron acceleration to be undertaken. Gamma-ray and neutron detection will provide information on the nuclear processes that follow the acceleration of high energy protons. In addition, the extended high energy response (as compared to the SMM spectrometers) will permit the detection of new gamma-ray lines and the measurement of element abundances under the extreme conditions that prevail in solar flares.

A correlated study of the observations made with all the Solar-A instruments and the simultaneous observations made with ground-based solar radio and optical telescopes will help answer the following specific questions about solar flares:

- What are the pre-flare conditions immediately prior to an energetic flare? What are the fundamental physical differences between flares with strong nonthermal effects such as high energy particle acceleration and mass ejection and those that appear to be primarily thermal in nature?

- What physical processes are responsible for the energy release? Is the energy released continuously or in discrete pulses (elementary flares)?

- What are the conditions under which the energy released during the impulsive phase will drive the entire flare? What determines if additional energy is to be released during the gradual phase?

- What is the rate of energy release? How does it vary during the flare?

- What is the characteristic time for the acceleration process?

- Are electrons and ions accelerated simultaneously by the same process? Are there multiple phases or steps in the acceleration process to cover the wide range of energy (non-relativistic to relativistic) and mass (electrons, protons and heavier ions)?

- Where does the acceleration occur in relation to the magnetic field structure in the vicinity of the optical flare? What are the dimensions of the acceleration region? Is the acceleration region spatially coincident with the sources of hard X-ray and gamma-ray emission?

- How do the energetic particles propagate from the acceleration region to these sources? Do they diffuse or propagate in well collimated beams?

- What is the relationship between the energetic particles which escape from the sun into interplanetary space and those which remain in the sun and produce hard X-ray, gamma-ray, radio, and other emissions?

- How is the energy transported from the site of primary energy release to the sources of soft X-rays, extreme ultraviolet, and optical emissions? Do the energetic particles play a major role in the energy transport to the chromosphere, especially during the impulsive phase?

SCIENCE INSTRUMENTS

The science instrument complement of Solar-A consists of four instruments: SXT, HXT, BCS, and WBS. The characteristics and capabilities of the science instruments are summarized in Figure 1. More complete descriptions are as follows:

	SXT	HXT	BCS	WBS
Spatial Resolution	< 2"/60% FOV	<8" FWHM	N/A	N/A
Energy Range	0.24-4 KeV	10-100 KeV	2.5-6.9 KeV	0.002-100 MeV
Time Resolution	~ 1 sec	~ 1 sec	~ 1 sec	2 sec (100 ms HXS)
Energy Resolution	N/A	N/A	4 spectral lines	128 channels (32 for HXS)
Field of View	42' x 42' (FSD)	40' x 40' (FSD)	full solar disc	full solar disc
Spectral Resolution	N/A	N/A	$\lambda/\Delta\lambda$= 3000 - 6000	same as energy resolution
Optics	Nariai-Werner	Fourier Synth	4 bent crystals	
Detector	CCD	Scintillation. Det.	1 - d	

Figure 1. Solar-A Mission Instrument Characteristics

Soft X-ray Telescope (SXT)

SXT uses grazing incidence optics to form direct images on a CCD detector. The optical system, shown schematically in Figure 2, includes an entrance aperture filter, the X-ray mirror, a filter wheel assembly, a rotating shutter, and the CCD camera. A coaxially mounted objective lens assembly allows visible light images to be made on the same CCD detector for aspect determination. The separation of the objectives and the focal plane is maintained by a metering tube of carbon fiber-epoxy composite designed to compensate for thermal expansion in other parts of the instrument over the expected range of operating temperatures. The X-ray passband of the SXT instrument is determined by the entrance aperture filter, the reflectivity of the mirror, the spectral response of the CCD detector, and by the choice of one of several thin metallic film analysis filters. These filters block the visible light from the aspect telescope aperture so that it does not contaminate the X-ray images. The filter wheel also contains two glass filters that can be used to observe visible images for aspect determination. These filters are opaque to soft X-rays, so that there is no X-ray component in the visible images.

The CCD is cooled to about -20° C in order to reduce the effect of dark spikes (pixels with abnormally high dark current levels). Exposure times are controlled by a rotary shutter mounted just in front of the focal plane. The CCD camera, built by the NASA Jet Propulsion Laboratory, can also be operated in a pseudo frame transfer mode in the event of problems with the mechanical shutter. A partial frame readout mode is provided to allow rapid exposure sequences to be made and to reduce the amount of data that must be handled by the spacecraft image processing system.

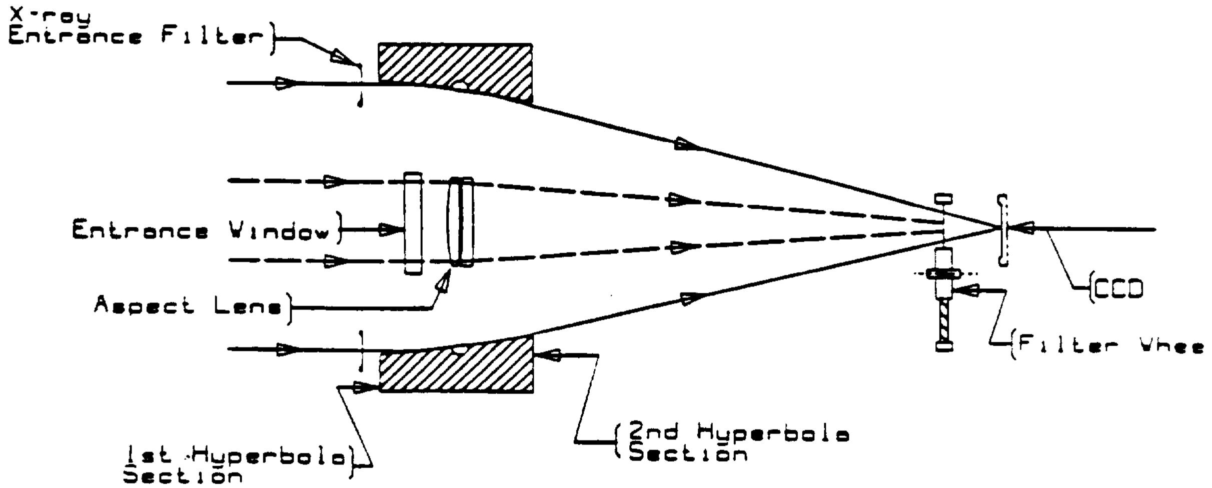


Figure 2. Schematic of SXT optical System. The X-ray and visible light objectives have equal focal lengths and are coaxially mounted. The setting of the filter wheel determines which image reaches the CCD detector.

SXT uses a Nariai-Werner mirror design which differs from the more commonly used Wolter Type I, in that both mirror segments have been made hyperbolic (as opposed to one parabolic and one hyperbolic) in order to gain better off-axis performance at the expense of a slight loss of on-axis resolution. The Nariai-Werner design has a lower field curvature than the Wolter Type I design, a helpful feature when a flat detector such as the CCD must be used. Resolution is expected to be limited by the CCD pixel size out to about 15 arc min from the axis, and to be no worse than 4 arc sec at the solar limb. The RMS blur diameter vs off-axis angle characteristic is shown by Figure 3.

The mechanical design of the SXT mirror system is also somewhat unusual. The mirror system, procured from United Technology Optical Systems, is a one-piece design with both optical surfaces formed on the same piece of material. The mirror is made of Zerodur and is insensitive to temperature gradients and fluctuations. The X-ray mirror is mechanically supported by a set of 6 titanium fingers that extend forward from a common mounting ring. The mirror support fingers are provided with small invar pads which are bonded to the mirror with epoxy. This ring, in turn, is fastened in 3 places to the telescope structure. The symmetry properties of this design assure that the mirror will remain centered with respect to the mechanical structure at all temperatures. Lengths and cross sections of the support fingers have been chosen such that the natural frequency of the mirror system avoids known resonances in the instrument, the spacecraft, and the launch vehicle. An exploded view of the SXT instrument is given by Figure 4. The SXT is 170 cm (67 inches) long and has a 30 cm (11.8 inch) square cross-section. The overall mass of the instrument is 30 kg (66 lbs).

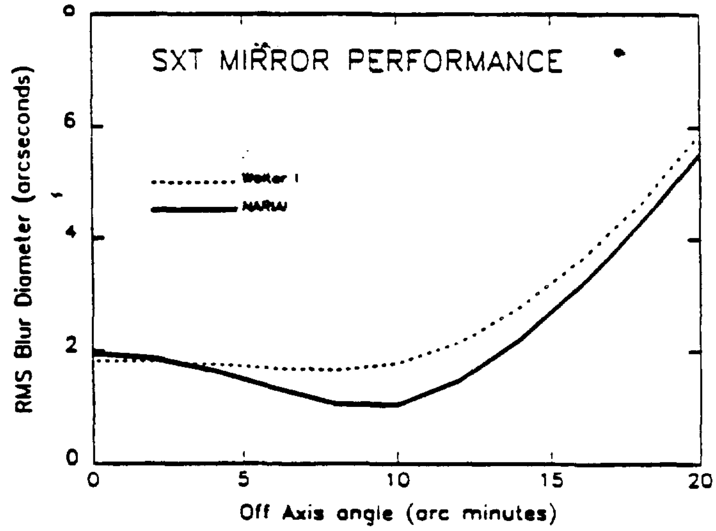


Figure 3. Calculated X-ray imaging performance. The solid curve shows the expected rms spot diameter as a function of field angle for the Nariai-Werner double hyperboloid mirror system. The focal position has been chosen for optimum performance of an equivalent Wolter I design focussed for the same axial spot size.

In comparison to the X-ray telescopes on Skylab (which used film), the SXT has a high photometric sensitivity because of the high quantum efficiency of the CCD (typically 30% or higher). The geometric aperture of the X-ray mirror is of the order of 2 sq cm. After accounting for the transmission of the entrance filter, the reflectivity of the X-ray mirror, and the quantum efficiency of the CCD, the effective area of the telescope still approaches 1 sq. cm. at 10 Å. The useful range of sensitivity is 4 to 50 Å.

The operation of the SXT instrument and the handling of science data is under the control of electronics and software in the Solar-A data processor (computer). This processor has the ability to examine SXT image data to select regions of interest and to adjust the length of the SXT exposure. It can also monitor data from the hard or soft X-ray spectrometers and issue a flare flag to alter the telemetry mode and SXT observing sequence. In order to maintain the required time resolution for studies of solar activity with the SXT, it is normally necessary to transmit only a subsection of the full 1024 x 1024 CCD array. As implemented for the SXT such a subsection is limited to a 64 x 64 pixel size and is referred to as a partial frame image (PFI). Flare observations, especially observations of large flares, have priority. Flare alerts are derived from the signals of the non-imaging HXS, SXS, or both instruments through an "or" gate.

During non-flare periods the SXT data rate will be as given in Quiet-Hi or Quiet-Med as indicated by the following table:

Telemetry mode	Rate	Image Transfer Time: Full Frame Image (FFI)	Image Transfer Time: Partial Frame Image (PFI)
Quiet (Hi - sect 1)	512	1024	8
Quiet (Hi - sect 1)	2048	256	2
Quiet (Med)	256	2048	16
Flare (Hi)	2048	256	2
Flare (Med)	256	2048	16

FFI = 1024 X 512 pixels; PFI = 64 x 64 pixels

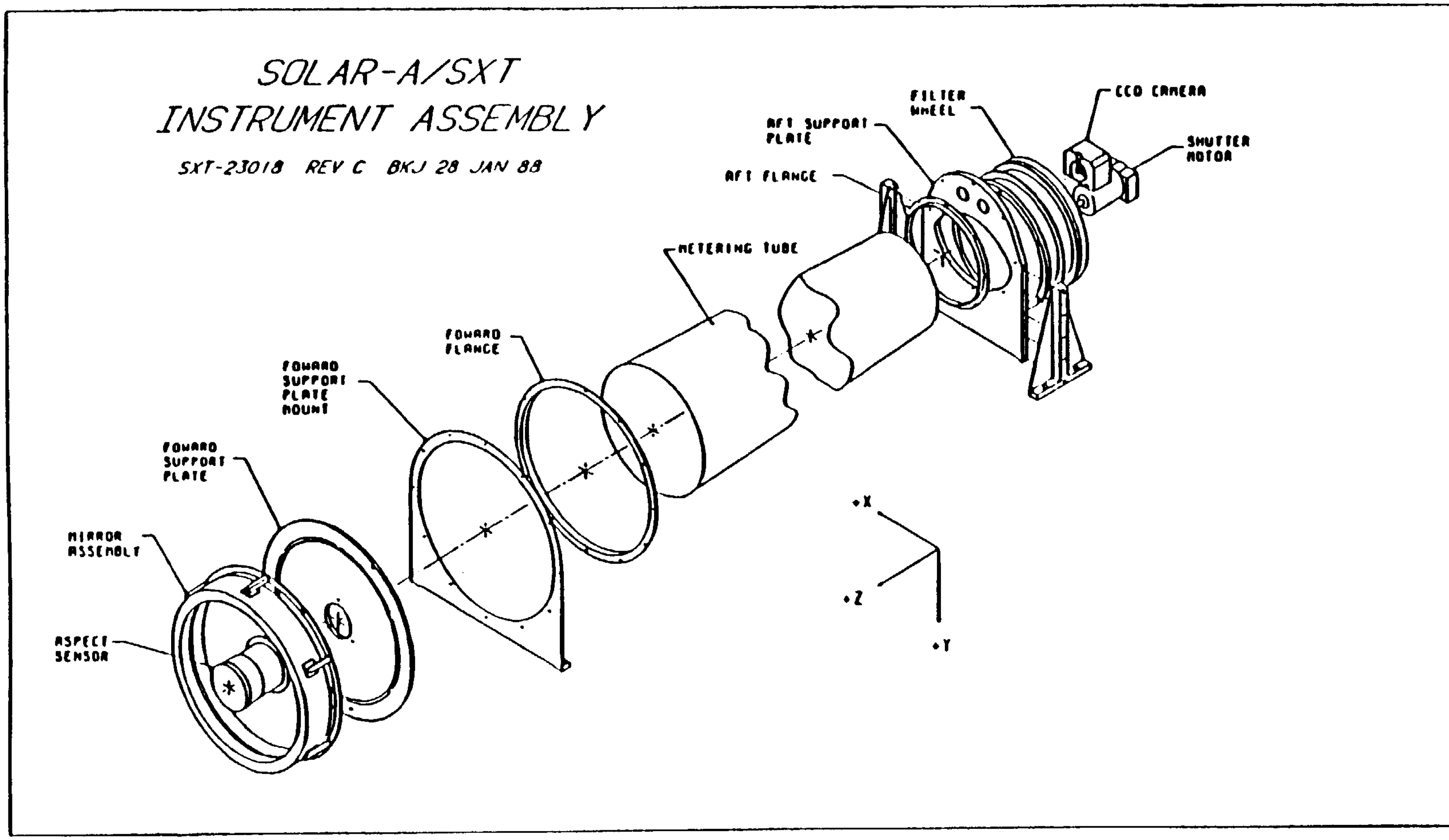


Figure 4. Solar-A/SXT Instrument Assembly

If the bubble data recorder fills up, flare data can overwrite quiet mode data except for the pre-flare interval specified by the pre-flare data saver. Flares that exceed the high flare threshold have the highest priority; high flare data can overwrite low flare data. This data priority scheme is based on that used on the Hinotori mission which was very successful in capturing data on large flares.

The SXT is constrained to operate in synchronism with the readout of image data, which is done at a fixed rate. That is, during the daylight portion of each orbit the image buffer is always being read out and operation of the SXT is slaved to this readout rate. It is not possible to take pictures faster than this rate allows; exposures too infrequent or too long to sustain this rate can only be made at the expense of retransmitting old image data.

The spacecraft telemetry operates with 3 basic data rates: high (32 kbps), medium (4 kbps), and low (1 kbps). The low rate is for night use and contains no scientific data. HXT does not produce data in the quiet mode. In this mode the SXT image buffer control permits telemetry to be shared between 2 separate images with interleaved data streams. Typically, the full frame image (FFI) would be read out of section 2 with a 4-minute time resolution, while PFI's utilize section 1 with 8-second time resolution. In the flare mode, initiated by the internal flare flag or by command, a portion of the data stream is assigned to the HXT. Flare (Med) is used to observe flare decay during orbits with no ground station contact.

The readout time for a FFI at full resolution is 4 sec and the time for a PFI is 0.5 sec. The shortest exposure time in all cases is 1 ms.

Hard X-ray Telescope (HXT)

The Solar-A Hard X-ray Telescope (HXT) is designed to image solar flare X-radiation in the 20-80 keV range, with an angular resolution of better than 8 arc seconds (FWHM) and a time resolution of 0.5 to 2 seconds. Used in conjunction with SXT, HXT will study hard X-ray emissions from solar flares and active regions with considerably better resolution at higher energies than its predecessors on the SMM and Hinotori missions.

The HXT imager consists of 64 photomultiplier tubes, each with its own thallium-doped sodium iodide (NaI(Tl)) scintillation crystal, using 64 independent collimators in a "push-pull" Fourier transform system, yielding a set of 32 visibility functions covering about 10% of the U-V plane.

Wide-Band Spectrometer (WBS)

The Wide-band Spectrometer (WBS) consists of four subsystems: the Soft X-ray Spectrometer (SXS), the Hard X-ray Spectrometer (HXS), the Gamma-ray Spectrometer (GRS) and the Radiation Belt Monitor (RBM). The SXS, HXS and GRS are used to observe solar flares, while the RBM serves as an alarm for the South Atlantic Anomaly passage.

The Soft X-ray Spectrometer detects soft X rays from 2 to 30 keV. Its proportional counter has three wire anodes, for the detection of small flares and large flares, and for in-flight energy calibration, respectively. The energy resolution (FWHM) of the SXS is 1.5 keV at 5.9 keV. The field of view of the proportional counter is limited to 10° by a slat collimator.

The Hard X-ray Spectrometer detects hard X rays from 20 to 400 keV. This spectrometer has no collimator; the scintillator is covered by an iron absorber to suppress the lower energy X-ray events. The HXS also is used as the cosmic gamma-ray burst detector.

The Gamma-ray Spectrometer detects gamma-rays in the energy range of 0.2 to 100 MeV. The energy resolution (FWHM) is 82 keV at 662 keV. The GRS can also detect neutrons and cosmic gamma-ray bursts.

The Radiation Belt Monitor (RBM) consists of two detectors oriented in a direction perpendicular to the Sun. The RBM is thus insensitive to solar flares, and serves as an alarm for the South Atlantic Anomaly passage of Solar-A. Both detectors are sensitive to radiation belt particles of energies greater than 20 keV; the NaI(Tl) scintillator can detect particles with energies up to 400 keV.

Bragg Crystal Spectrometer (BCS)

The primary function of the BCS is to study plasma heating and dynamics during the impulsive phase of solar flares. A bent crystal approach is used; the wavelength range is determined by bending the crystals. There are no moving parts; the crystals are set before launch. BCS uses four crystals to cover X-ray line groups of diagnostic importance, indicating the progressive heating of plasma before and during the flare impulsive phase, as well as certain transient effects. The groups are near the resonance lines of S XV (5.0160-5.1143), Ca XIX (3.1631-3.1912), Fe XXV (1.8298-1.8942), and Fe XXVI (1.7636-1.8044).

Unlike the SMM bent crystal spectrometers, the Solar-A BCS has no collimator. This not only reduces size and weight, but ensures that flares will be observed no matter where they occur, whether on the solar disk or close to the limb. Because collimators reduce transmission, eliminating the collimator increases sensitivity by a factor of about three. Because only four groups of lines are observed, the sensitivity of each channel has been improved at least fivefold compared to the SMM-BCS. The detectors are sealed proportional counters. One innovation is that each detector contains two windows and two anode wires, which can be used with two crystals, saving both weight and power. The instrument is split into two spectrometers mounted on either side of the main spacecraft bulkhead.

SPACECRAFT DESCRIPTION

The Solar-A spacecraft fits within an envelope 1.4 meters in diameter by 2.0 meters high and has a maximum mass of 420 kgm. It is inertially stabilized in 3 axes. Pointing accuracy is 3 arc minutes maximum and short term pointing stability is 5 arc seconds/minute. Orbital average power (provided by solar arrays) is 200 Watts. Onboard data storage is provided by a bubble memory with a capacity of 80 megabits.

The spacecraft structure consists of a main body and six solar panels as indicated by Figure 5. The main body is a rectangular box, the structural members of which have an 'H' shaped cross-section.

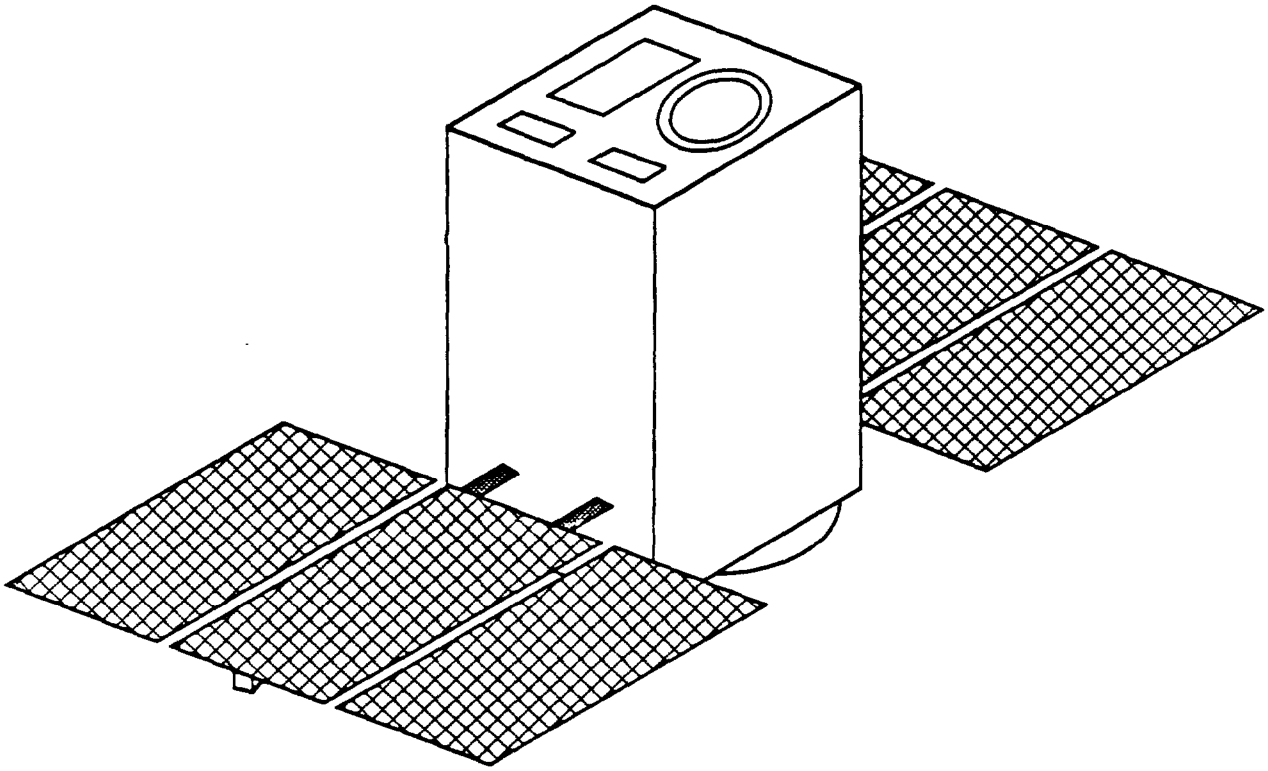


Figure 5. Solar-A spacecraft structure

Spacecraft attitude is determined by a Star Tracker, a two-axis Fine Sun Sensor, a non-spin type Sun Aspect Sensor, a pair of Geomagnetic Aspect Sensors and an Inertial Reference Unit. Attitude is controlled by a pair of Momentum Wheels, a Control Moment Gyro and three Magnetic Torquers. The attitude sensors and attitude actuators are connected by Attitude Control Electronics and Attitude Control Processor Units.

The power system consists of silicon solar cells, mounted on the six solar panels, a Power Control Unit and two sets of 19 ampere-hour NiCd Battery cells.

Spacecraft thermal control is provided by a combination of passive and active methods. Multilayer thermal blankets and thermal radiators are used for passive control. Heaters (with thermostats) are used to control the temperature of the NiCd Batteries, the Star Tracker and the Soft X-ray Telescope.

Scientific data, housekeeping data and status data are formatted into a Pulse Code Modulation (PCM) data stream by a Data Processor which also generates timing signals for each instrument. A Bubble Data Recorder has 80 megabits of data storage capacity and the recording and dumping operations are controlled by the Data Processor.

The telemetry subsystem consists of an S-band Transmitter capable of transmitting realtime PCM data and a range measurement signal simultaneously as well as the PCM data dumped from the Bubble Data Recorder. There is also an x-band transmitter which is used with Japanese ground stations.

The command subsystem consists of an S-band Receiver and a Command Decoder (CMD). The CMD demodulates the command codes which are in the form of a pseudo-noise (PN) sequence and feeds the decoded command data to a Telemetry and Command Unit (TCU). The TCU is capable of storing programmed commands and distributing both programmed and realtime commands to each subsystem or instrument.

MISSION SEQUENCE

Vehicle and Launch Site

Solar-A will be launched by the ISAS M-3SII launch vehicle from the Kagoshima Space Center into a 600 km altitude, 31° inclination circular orbit. Nominal orbital period is 97 minutes. Since the inclination of the orbit is the same as the Latitude of the launch site, the launch direction will be due East.

The M-3SII is a solid propellant, three-stage booster system with an optional 4th stage Kick Motor. The 4th stage Kick Motor is not required for Solar-A. It has a payload capability of approximately 770 kg into low earth orbit and approximately 170 kg into solar orbit. Previous launches have included SAKIGAKE (Pioneer) in January, 1985; SUISEI (Comet) in August, 1985; GINGA (Galaxy) in February, 1987; and AKEBONO (Dawn) in February, 1989. A cutaway view of the M-3SII is provided by Figure 6 which also includes a performance table showing the characteristics of the various stages and the Strap On Boosters.

Launch Sequence

The exact launch sequence is not yet available but is expected to be similar to that of the SUISEI mission with separation of the Strap On Boosters occurring 40 seconds after liftoff, 1st stage separation at 84 seconds, ignition of the 2nd stage at 86 seconds, jettison of the nose fairing at 155 seconds, and separation of the 2nd stage at 240 seconds.

Stage III, with the Solar-A spacecraft still attached, would coast to operational altitude, at which time stage III would be ignited. The time between stage II-III separation and the ignition of stage III for orbit circularization is expected to be approximately 7 minutes at which time stage III and the Solar-A spacecraft would be at an altitude of 600 km and approximately 1300 km down range.

Prior to the ignition of the third stage motor, the spacecraft is spun up to a nominal spin rate of 2 revolutions per second. The spacecraft retains this spin rate until the deployment of a set of yo-yo masses which are wound around the spacecraft body. The deployment of the yo-yo despinner is initiated by the spacecraft timer at third stage separation plus 20 seconds.

Orbital Operations

ISAS has full responsibility for the conduct of the Solar-A mission operations and the Kagoshima Control Center will provide the realtime computational facilities, spacecraft data displays, etc., during all mission phases as well as telemetry data acquisition and spacecraft commanding throughout the mission.

Lockheed will be providing two scientists and other personnel to support Solar-A operations in Japan. Their responsibilities will include coordinating ground-based solar observations with data from SXT, performing initial processing of SXT data, supporting visiting SXT personnel and collaborating with Japanese Solar-A colleagues.

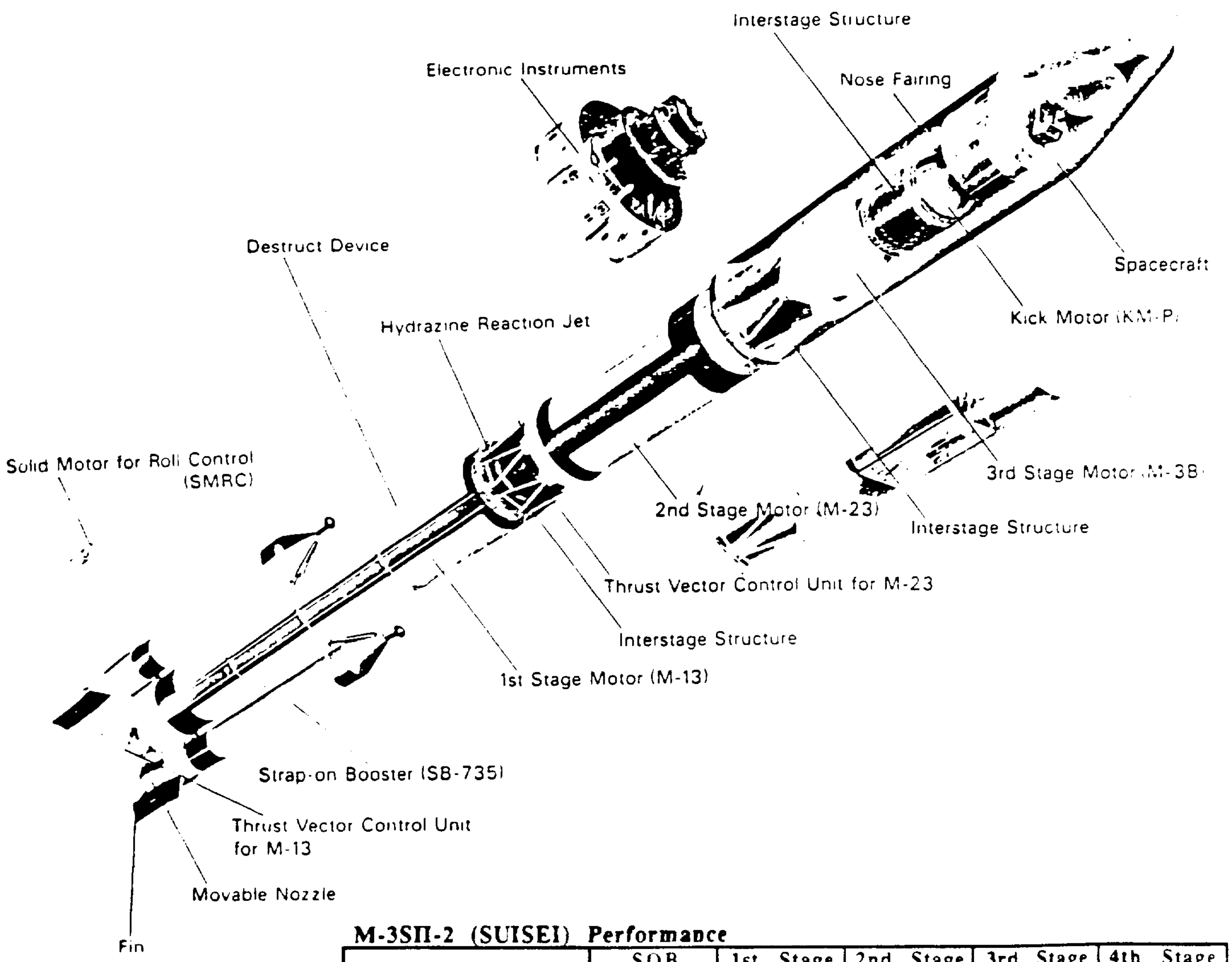
NASA will be providing data capture support to the Solar-A mission through its Deep Space Network (DSN) ground stations at Goldstone, California, Canberra, Australia, and Madrid, Spain.

U.S. SXT Co-Investigators will be providing supporting ground observations from the Mees Solar Observatory at the University of Hawaii.

Lockheed is responsible for implementing the SXT program in the U.S., developing data analysis software for SXT, analyzing SXT data, preparing Solar-A data for NSSDC, supporting Co-Investigators and, subsequently, supporting Guest Investigators.

Launch Window

The Solar-A launch window occurs through August and September, 1991. This window is not a scientific or engineering requirement but is due to a Japanese government policy to refrain from Kagoshima launches during fishing seasons.



M-3SII-2 (SUISEI) Performance

	SOB	1st Stage	2nd Stage	3rd Stage	4th Stage
Designation	SB-735	M-13	M-23	M-3B	KM-P
Total Weight (ton)	62.0	52.0	17.3	4.20	0.61
Stage Weight (ton)	10.0	34.7	13.1	3.59	0.47
Propellant Weight (ton)	8.0	27.1	10.4	3.28	0.42
Average Thrust (ton)	67	129	53.4	13.5	3.3

Figure 6. Cutaway view of the M-3SII and Performance Table

MISSION SUPPORT

Mission Control

Mission control is performed at the ISAS Kagoshima Space Center which also provides the facilities for spacecraft command and telemetry. The Sagamihara Space Operation Center provides communications support and interface to the JPL Network Operations Control Center for DSN support. Orbit determination is provided by the Tsukuba Space Center of the Japanese National Space Development Agency (NASDA).

Tracking and Data Acquisition

(a) General

The prime tracking and data acquisition station for Solar-A will be the station at Kagoshima (131° E. Long. & 31° N. Lat.) which will be in contact with the spacecraft for 5 consecutive orbits per day. The orbit ground tracks, on a Mercator projection map, are indicated by Figure 7. Five consecutive-orbit contacts are unusual; they are possible with Solar-A because of the relatively high orbit altitude (600 km) and the fact that orbit inclination equals the latitude of the ground station.

Contact duration is approximately 10 minutes, during which real-time and/or stored commands will be relayed to the spacecraft, and real-time and playback telemetry data will be received. Because the contact times are short, spacecraft operations are primarily based on time tagged commands. A diagram showing the Solar-A data interchange is provided by Figure 8.

The Tsukaba Space Center receives tracking data acquired by the Japanese space tracking network which consists of four stations located at Tanegashima, Okinawa, Katsuura and Uchinoura.

The ISAS will provide prelaunch orbital elements (state vectors) to JPL for each DSN station data acquisition sufficiently in advance of the launch date and will continue to provide updated state vectors to JPL throughout the mission, as applicable. The DSN stations involved are Goldstone, Madrid and Canberra. These stations are only used for data acquisition.

(b) NASA Role

NASA is required to provide pre-mission test support and mission support. A DSN/Solar-A test has been conducted to demonstrate the spacecraft transmitter radio frequency and telemetry format compatibility with the DSN 26-meter station telemetry data systems. Since the transponder and telemetry data system for Solar-A are the same as for the ISAS Astro-C and EXOS-D spacecraft, these on-orbit, operating spacecraft were used in the test. The DSN station readiness testing included Ground Data System data flow tests.

The DSN will provide data capture support for the Solar-A mission for a period of three years during which time there will be up to 10 DSN station contacts per day.

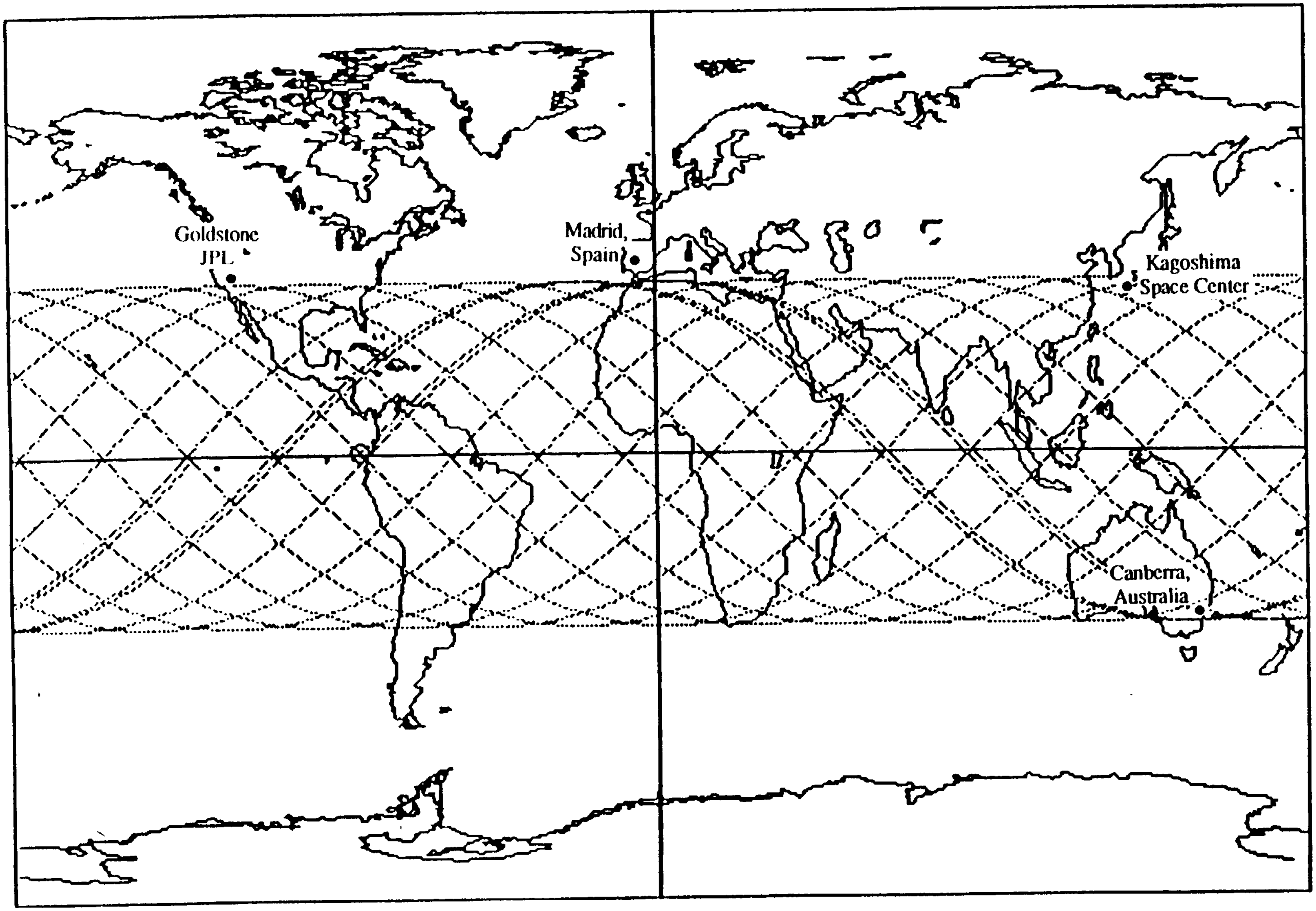


Figure 7. The orbit ground tracks, on a Mercator projection map.

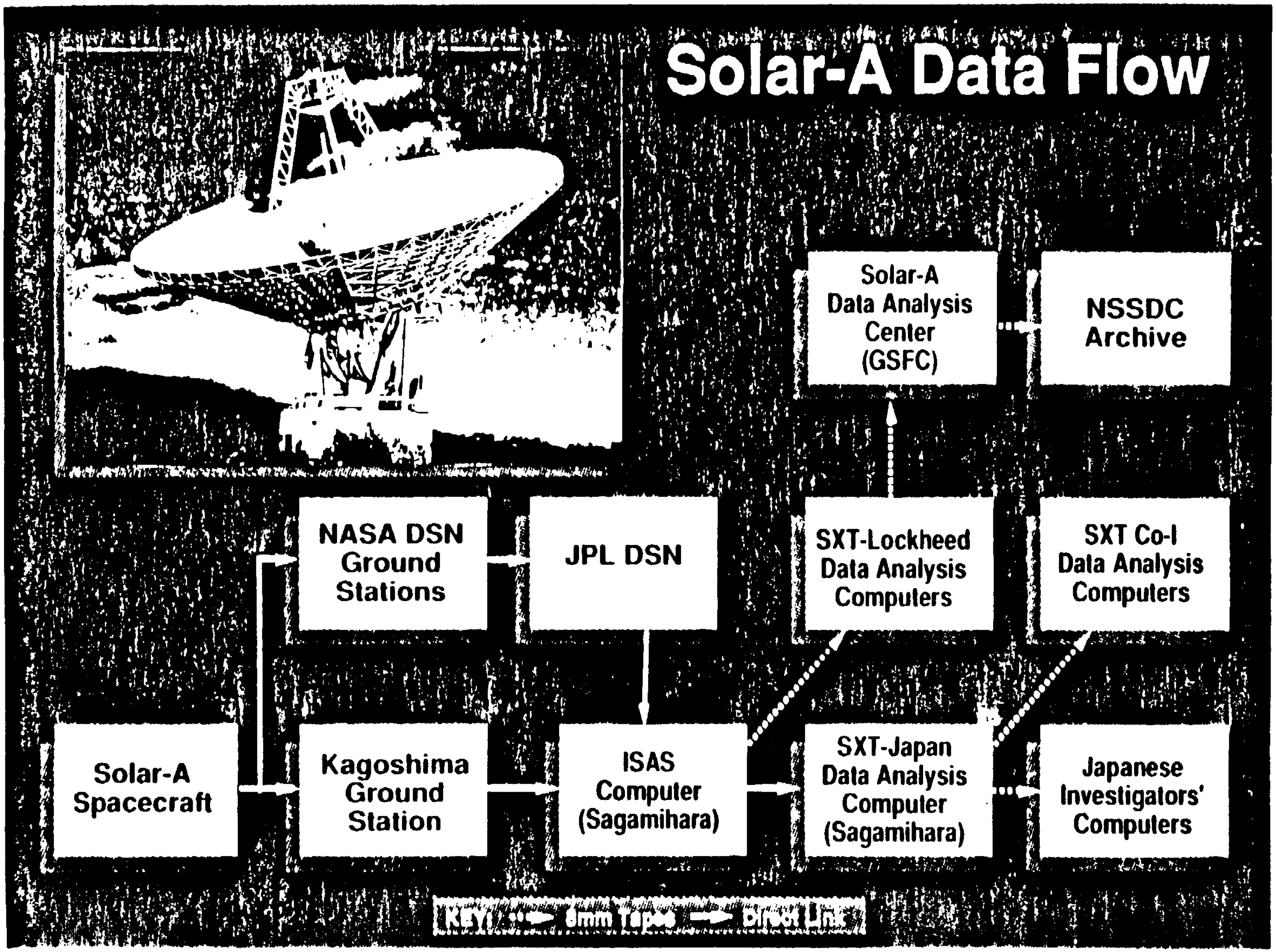


Figure 8. Soft X-ray Telescope/Solar-A Data Flow

All Solar-A telemetry data from the DSN 26-meter subnet will be transmitted non-realtime to the ISAS SSOC via the existing 56 kbps data line in accordance with an agreed-to schedule. The DSN will hold all original digital data tapes at the receive stations for up to 30 days and retransmit data segments to the ISAS SSOC, if requested, during this time period.

The telemetry data stream frequency is 2256.22 MHz and the data formats are PCM (NRZ-S/Conv)-PSK/PM for realtime data at 1.024. 4.096 or 32.768 kbps, and PCM (NRZ-S)-Bi-ϕ-L/PM for Recorder dump data at 131.072 or 262.144 kbps. Convolution coding is $K = 7, R = 1/2$. The frame format is 64 minor frames/major frame and 128, 8-bit words per minor frame. The format is the same for realtime and Recorder data dump.

NASA Communications (NASCOM) support will consist of one voice circuit between JPL and each DSN station for Solar-A operations coordination and one 56 kbps data circuit from JPL to the ISAS SSOC in Japan. The data will be frame synchronized using four frame per NASCOM block (1024 bits per frame).

Data Management

Solar-A data is initially captured by the Kagoshima Space Center (with DSN support) and stored at the ISAS Sagamihara campus. The ISAS computer is the main Solar-A data computer. It stores all Solar-A raw data, reformats this data by time, instrument and image, but stores no formatted data.

The data reduction task will be primarily performed at ISAS, where the reformatted data is stored on (8mm) Exabyte tape. Quick-look processing for operations planning is also performed as well as in depth analysis in selected investigation areas.

A data reduction computer, identical to that used in Japan, and a duplicate version of the reduction software system will also be maintained at Palo Alto to provide redundancy and overflow support. This software will be used to provide initial processing of the SXT images. The (microVax) computer is used to re-expand the SXT images (which are transmitted in compressed format to reduce telemetry requirements) and will apply calibration corrections and register the images to correct the effects of spacecraft attitude drift. The approach is highly modular and consists of a combination of batch and interactive routines.

The reduction software separates SXT data into individual image files and applies various corrections to the images for CCD pixel defects and gain variations. Background subtraction is applied using images obtained with a closed shutter. The images are registered from frame to frame; data from a sensor in the HXT, which indicates the solar limb, is used to remove the effects of spacecraft attitude uncertainty.

The SXT-Japan and the SXR-Lockheed Data Analysis Computers have Silicon Graphics File Servers with 32 megabyte memories, two DEC series 5000 Work Stations, 7 gigabyte hard discs, two Exabyte Tape Drives and miscellaneous peripherals. The SXT CoI's have existing Sun Work Stations or are in the process of acquiring them. A library of low level software modules in Interactive Data Language (IDL) is maintained in the computer. Calls on this library take place in a high level code which can be compiled to run on Sun Work Stations.

The Lockheed Palo Alto Research Laboratory (LPARL) has been designated as the collector and reducer of all Solar-A data for U.S. PI's and CoI's and will be responsible for its dissemination and its delivery to the National Space Science Data center (NSSDC).

MISSION MANAGEMENT

The Solar-A program is managed by the Japanese Institute of Space and Astronautical Science (ISAS). NASA is responsible for the Soft X-ray Telescope hardware, data capture through the Deep Space Network (DSN), and supporting the U.S. Investigation Team.

Within NASA the Office of Space Science and Applications (OSSA), NASA Headquarters is responsible for the overall direction and evaluation of NASA's role in the Solar-A mission. The Associate Administrator for OSSA has assigned Headquarters responsibility to the Directors of the Astrophysics and Space Physics Divisions. The Astrophysics Division provides program management for the development phase. The Space Physics Division provides program management for the mission operations and data analysis phase and the Program Scientist. The Marshall Space Flight Center (MSFC) has been assigned responsibility for project management within NASA. Within MSFC, SXT management is carried out by the Astrophysics and Space Science Project Office of the Payload Projects Directorate and is led by a designated Project Manager and Project Scientist. The Office of Space Operations, NASA Headquarters is responsible for data capture support.

The responsible organizations and personnel are:

<u>ISAS (Japan)</u>

Prof. Yoshiaki Ogawara	Solar-A Program Manager
Prof. Yutaka Uchida (U of Tokyo)	Solar-A Project Scientist

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

Dr. Leonard A. Fisk	Associate Administrator for Space Science and Applications
Alphonso V. Diaz	Deputy Associate Administrator for Space Science and Applications
Dr. George Withbroe	Director, Space Physics Division
Dr. Charles J. Pellerin, Jr.	Director, Astrophysics Division
John Lintott	Solar-A/SXT Program Manager
Dr. William Wagner	Solar-A/SXT Program Scientist

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

Charles T. Force	Associate Administrator for Space Operations

NASA Marshall Space Flight Center

T. J. Lee	Director
Harry G. Craft	Manager, Payload Projects Office
Rein Ise	Manager, Astrophysics & Space Science Projects
John Owens	Solar-A/Project Manager
Dr. John Davis	Solar-A/Project Scientist

Jet Propulsion Laboratory

Dr. Edward C. Stone	Director, Jet Propulsion Laboratory
Larry N. Dumas	Assistant Laboratory Director for TDA
Raymond J. Amorose	TDA Mission Support & DSN Operations
Nick A. Fanelli	TDS Manager for Solar-A

National Astronomical Observatory of Japan

Prof. Tadashi Hirayama	Principal Investigator for SXT
Dr. Saku Tsuneta	Project Manager for SXT

Lockheed Palo Alto Research Laboratory

Dr. Loren W. Acton	U.S. Principal Investigator for SXT
Michael Finch	LPARL Project Manager

PROJECT ACRONYMS

AO	Announcement of Opportunity
BCS	Bragg Crystal Spectrometer
BGO	Bismuth Germanate
C	Celsius
CCD	Charge-coupled Device
Cd	Cadmium
cm	Centimeter
CMD	Command Decoder
Co	Cobalt
CoI	Co-Investigator
DOD	Department of Defense
DSN	Deep Space Network
E	East
Fe	Iron
FFI	Full Frame Image
FOV	Field of View
FWHM	Full Width at Half Maximum
gm	gram
GRS	Gamma Ray Spectrometer
HESP	High Energy Solar Physics
HV	High Voltage
HXS	Hard X-ray Spectrometer
HXT	Hard X-ray Telescope
IDL	Interactive Data Language
ISAS	Japanese Institute of Space and Astronautical Science
JPL	Jet Propulsion Laboratory

K	Kilo
kbps	Kilo bits per second
keV	Kilo electron volts
kgm	kilograms
km	kilometer
LPARL	Lockheed Palo Alto Research Laboratory
MeV	Million Electron Volts
ms	millisecond
MSFC	Marshall Space Flight Center
N/A	Not Applicable
N	North
NaI (Tl)	Thallium-doped sodium iodide
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NASDA	Japanese National Space Development Agency
NiCd	Nickel Cadmium
NIST	United States National Institute of Standards & Technology
NRL	Naval Research Laboratory
NSSDC	National Space Science Data Center
OSO	Orbiting Solar Observatory
OSSA	Office of Space Science and Applications
PCM	Pulse Code Modulation
PFI	Partial Frame Image
PI	Principal Investigator
PN	Pseudo-noise
RBM	Radiation Belt Monitor
RMS	Root Mean Square

rms	root mean square
s	Second
SERC	United Kingdom Science & Engineering Research Council
Si	Silicon
SMM	Solar Maximum Mission
SMM-BCS	Solar Maximum Mission - Bent Crystal Spectrometer
sq	Square
sq cm	Square Centimeter
SSOC	Sagamihara Space Operations Center
SXS	Soft X-ray Spectrometer
SXT	Soft X-ray telescope
TCU	Telemetry and Command Unit
Te	Tellurium
WBS	Wide Band Spectrometer