

# THE SOLAR-A MISSION: AN OVERVIEW\*

Y. OGAWARA, T. TAKANO, T. KATO

*Institute of Space and Astronautical Science, Sagami-hara, Kanagawa 229, Japan*

T. KOSUGI, S. TSUNETA

*Institute of Astronomy, University of Tokyo, Mitaka, Tokyo 181, Japan*

T. WATANABE

*National Astronomical Observatory, Mitaka, Tokyo 181, Japan*

I. KONDO

*Faculty of Systems Engineering, Shibaura Institute of Technology, Tameihara, Fukasaku, Omiya, Saitama 330, Japan*

and

Y. UCHIDA

*Department of Astronomy, Faculty of Science, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan*

(Received 10 April, 1991; in revised form 17 June, 1991)

**Abstract.** The SOLAR-A spacecraft is to be launched by the Institute of Space and Astronautical Science, Japan (ISAS) in August, 1991. As a successor of HINOTORI, this mission is dedicated principally to the study of solar flares, especially of high-energy phenomena observed in the X- and gamma-ray ranges. The SOLAR-A will be the unique space solar observatory during the current activity maximum period (1989–1992). With a coordinated set of instruments including hard X-ray and soft X-ray imaging telescopes as well as spectrometers with advanced capabilities, it will reveal many new aspects of flares and help better understand their physics, supporting international collaborations with ground-based observatories as well as theoretical investigations. An overview of this mission, including the satellite, its scientific instruments, and its operation, is given in this paper. Also the scientific objectives are briefly discussed.

## 1. Introduction

The SOLAR-A spacecraft is scheduled to be launched by the Institute of Space and Astronautical Science, Japan (ISAS) in August 1991 from the Kagoshima Space Center. The main goal of this spacecraft is to observe energetic phenomena related to solar flares in X- and gamma-rays with a coordinated set of instruments.

The first Japanese spacecraft dedicated to flare studies, HINOTORI, was launched close to the previous solar activity maximum in February 1981. At that time the Solar Maximum Mission (SMM) had been in operation for about a year, pursuing almost the same objectives as HINOTORI. The two missions successfully revealed new aspects of solar flares in X- and gamma-rays (e.g., Kundu and Woodgate, 1986; Tanaka, 1987).

The hard X-ray imagers on board the two spacecraft, for the first time, made images of flares in the hard X-ray range above a few keV. These novel observations showed

\* After the launch the name of SOLAR-A has been changed to YOHKOH.

that in impulsive flares (type B of Tanaka, 1987) two or more separate sources brighten almost simultaneously in hard X-rays, and that extended hard X-ray sources (type C) are located high in the corona at altitudes of a few times  $10^4$  km above the photosphere in gradual X-ray flares.

The production and evolution of high-temperature plasmas in flares has been systematically studied via soft X-ray emission lines observed with high-resolution Bragg crystal spectrometers on board the P78-1, Tansei IV, SMM, and HINOTORI spacecraft. The precise diagnostics obtainable from various high-temperature emission lines revealed the dynamics of plasmas trapped in flaring loops; these include the violent heating of the transition region and the chromosphere due to precipitation of energetic electrons, turbulent motions, and evaporation (ablation) of the chromospheric material seen as blue-shifted components of emission lines in the initial phase of flares. A group of flares (type A) showed prominent hydrogen-like iron emissions from 'superhot' ( $T > 3 \times 10^7$  K) thermal plasmas.

A number of gamma-ray-producing flares were also detected. It was found that ions can be accelerated to few-MeV energies within a few seconds and simultaneously with electrons at the flare onset. This has put strong constraints on theories of acceleration mechanisms. Gamma-ray events were preferentially observed near the solar limb, which suggests anisotropy of gamma-ray radiation and particle motions.

These discoveries from the last activity maximum, and their tantalizing physical interpretations, demanded further investigations. The images taken with the hard X-ray imagers had relatively low spatial resolution and their energy range was below about 30 keV so that the 'hard' X-ray images could be contaminated by X-rays from thermal sources. Another deficiency was the lack of reflecting telescopes for the soft X-ray wavelengths, where one can almost directly see the coronal magnetic structures in which flares occur. Such reflecting telescopes were flown previously only on SKYLAB in 1973-1974. The Bragg crystal spectrometers showed vividly the existence of chromospheric evaporation owing to high spectral resolution, but due to low sensitivities no clean data could be obtained at the very onset of a flare. Most gamma-ray flares were observed without simultaneous imaging at hard X-ray energies.

Based upon this scientific motivation, SOLAR-A was planned and constructed as an international collaborative project including many institutions in Japan, in the United States, and in the United Kingdom. The participating institutions and their responsibilities are summarized in Table I. In the present paper, we will give an overview of the SOLAR-A mission from the viewpoints of the scientific instruments in Section 2, the spacecraft design in Section 3, and the flight operations in Section 4. The scientific objectives will be briefly discussed in Section 5. *In this paper, as well as in the following series of papers in this Solar Physics issue, we will call this mission by its development name SOLAR-A, but it is to be noted that the mission will be formally given a new name after launch according to the ISAS tradition.*

TABLE I  
The SOLAR-A mission

Mission objectives	Investigation of high-energy phenomena on the Sun	
Launch	August 1991	
Mission life	$\gtrsim 2$ years (orbital life $\gtrsim 3-4$ years)	
Organization		
Project manager	Yoshiaki Ogawara (ISAS)	
Project scientist	Yutaka Uchida (Univ. of Tokyo)	
Principal investigators		
Hard X-ray Telescope (HXT)	Keizo Kai <sup>a</sup> (NAOJ) and Kazuo Makishima (Univ. of Tokyo)	
Soft X-ray Telescope (SXT)	Tadashi Hirayama (NAOJ) and Loren W. Acton (LPARL; U.S. PI to NASA)	
Wide Band Spectrometer (WBS)	Jun Nishimura (ISAS)	
Bragg Crystal Spectrometer (BCS)	Eijiro Hiei (NAOJ) and J. Leonard Culhane (MSSL; U.K. PI to SERC)	
Major participating institutions		
Japan: ISAS, National Astronomical Observatory (NAOJ), Univ. of Tokyo, Rikkyo Univ., Kyoto Univ., Nagoya Univ., etc.		
U.S. SXT team: Lockheed Palo Alto Research Laboratory (LPARL), Stanford Univ., U. California at Berkeley, and Univ. Hawaii		
U.K. and U.S. BCS team: Mullard Space Science Lab. (MSSL), Rutherford Appleton Lab., E.O. Hulburt Center for Space Research, and the National Institute of Standards and Technology		

<sup>a</sup> Deceased 1991 March 11.

## 2. Scientific Instruments

SOLAR-A carries the following scientific instruments: the Hard X-ray Telescope (HXT), the Soft X-ray Telescope (SXT), the Wide Band Spectrometer (WBS), and the Bragg Crystal Spectrometer (BCS). As the technical details of these instruments are described in separate papers, only a brief summary is given below and in Table II.

### 2.1. HARD X-RAY TELESCOPE (HXT)

The HXT (Kosugi *et al.*, 1991) is a Fourier synthesis telescope. It consists of 64 bigrid modulation collimators, each with  $2.3 \times 2.3$  cm cross-section and a 0.5 cm thick NaI(Tl) crystal attached to a 1-inch square phototube. The individual subcollimators measure spatially-modulated photon counts, thus providing 32 complex 'Fourier' components at appropriate position angles and wave numbers in the  $(u, v)$ -plane. The field of view covers the whole Sun, while the synthesis aperture, determined by the grid pitch corresponding to the fundamental wave number, is about  $2 \times 2$  arc min. The angular resolution is about 5 arc sec. Images in four energy bands (15–24–35–57–100 keV) will be obtained simultaneously with a temporal resolution up to 0.5 s.

### 2.2. SOFT X-RAY TELESCOPE (SXT)

The SXT (Tsuneta *et al.*, 1991) is a grazing-incidence reflecting telescope in the soft X-ray band (3–60 Å) with a CCD detector of  $1024 \times 1024$  pixels. Its field of view covers

TABLE II  
SOLAR-A scientific instruments

<b>Hard X-ray Telescope (HXT)</b>	
Instrument	Fourier-synthesis type collimator (64 elements)
Energy bands	15–24–35–57–100 keV (4 bands)
Angular resolution	~5 arc sec
Field of view	Full solar disk
Effective area	~70 cm <sup>2</sup>
Time resolution	0.5 s
<b>Soft X-ray Telescope (SXT)</b>	
Instrument	Modified Wolter type I grazing incident mirror + CCD with coaligned optical telescope
Wavelength range (X-ray)	3–60 Å (selectable with filters)
(optical)	4600–4800 Å or 4293–4323 Å
Angular resolution	~2.5 arc sec
Field of view	Full solar disk
Time resolution	up to 0.5 s
<b>Wide Band Spectrometer (WBS)</b>	
Detectors	Gas proportional counter (soft X-rays; 2–30 keV) NaI scintillation counter (hard X-rays; 20–400 keV) BGO scintillation counter (gamma-rays; 0.2–100 MeV)
Time resolution	(count-rate data) 0.125, 0.25, or 0.5 s (pulse-height spectrum data) 1, 2, or 4 s
<b>Bragg Crystal Spectrometer (BCS)</b>	
Instruments	Bent crystal spectrometers
Spectral lines and resolutions	
S XV (5.0385 Å)	5.0160–5.1143 Å with 3.232 mÅ resolution
Ca XIX (3.1769 Å)	3.1631–3.1912 Å with 0.918 mÅ resolution
Fe XXV (1.8509 Å)	1.8298–1.8942 Å with 0.710 mÅ resolution
Fe XXVI (1.7780 Å)	1.7636–1.8044 Å with 0.565 mÅ resolution
Time resolution	up to 0.125 s

the whole Sun. The angular resolution of the optical system of SXT is on the order of 2 arc sec across the solar disk, slightly better than that determined by the CCD pixel size (2.4 arc sec). Two filter wheels and a shutter device are placed in front of the CCD detector to choose energy band and exposure time properly. Filter and exposure selection as well as data acquisition are controlled by a dedicated microprocessor, following the commands dispatched by the main data processor on board the spacecraft. When the Sun is quiet, whole-Sun images are taken together with up to four bright active regions which are monitored at a moderate rate. When a flare occurs, the observation will be concentrated on the brightest region by taking ‘partial-frame’ images with up to 0.5 s time resolution.

### 2.3. WIDE BAND SPECTROMETER (WBS)

The WBS (Yoshimori *et al.*, 1991) consists of four types of detectors: the Soft X-ray Spectrometer (SXS), the Hard X-ray Spectrometer (HXS), the Gamma-Ray Spec-

trometer (GRS), and the Radiation Belt Monitor (RBM). The SXS, HXS, and GRS detectors observe the Sun, while RBM views perpendicular to the solar direction in order to monitor the radiation-belt environment of the spacecraft.

The SXS, a gas proportional counter filled with xenon, detects soft X-rays in the 2–30 keV band. Count-rate data are taken in two channels every 0.25 s and in a 128-channel pulse-height spectrum every 2 s. The HXS, a NaI(Tl) scintillation counter, detects 20–400 keV X-rays. Two-channel counting rates are taken every 0.125 s and 32-channel pulse-height spectrum every second. The GRS consists of two identical bismuth germanate (BGO) scintillators and detects 0.2–100 MeV gamma-rays, each producing six-channel count-rate data every 0.25 or 0.5 s and also a 128-channel pulse-height spectrum data every 4 s.

The RBM consists of a silicon diode detector and a NaI scintillator. The silicon detector measures counting rates of charged particles above about 20 keV every 0.25 s, while the NaI detector records counting rates in two channels every 0.25 s and 32-channel pulse-height data every second. In addition to solar flare observations, HXS and the NaI/bursts detector of RBM are used to detect cosmic gamma-ray burst during quiet periods of the Sun and during spacecraft night.

#### 2.4. BRAGG CRYSTAL SPECTROMETER (BCS)

The BCS (Culhane *et al.*, 1991) consists of four bent-crystal spectrometers with position-sensitive proportional counters. The wavelength bands covering S XV, Ca XIX, Fe XXV, and Fe XXVI lines are chosen to get information about the temperature and motion of hot plasmas produced in solar flares. Each energy band has up to 256 spectral bins. The BCS is equipped with its own queue memory (384 kbytes) to store the initial-phase data with high time resolution (up to 0.125 s). The data accumulation of BCS is controlled by a dedicated microprocessor to accommodate the maximum possible number of data with suitable time resolution during a flare. Data temporarily stored in the queue memory are read out at a fixed rate by the main data processor.

### 3. The Spacecraft

#### 3.1. GENERAL

The SOLAR-A is to be launched in August 1991 from the Kagoshima Space Center at latitude 31 N, longitude 131 E, by an M-3S-II launcher, into a nearly circular orbit of about 600 km altitude, 31 deg inclination, and 97 min period.

The spacecraft, schematically shown in Figure 1, has dimensions of approximately  $100 \times 100 \times 200$  cm with two external solar panels ( $150 \times 200$  cm each) outside, and weighs about 400 kg. The spacecraft body is made up of seven panels, i.e., one center panel and six surrounding panels. The center panel and two side panels form an H-shaped structure, the mechanical backbone of the spacecraft. The center panel holds the two large telescopes (SXT and HXT), as well as BCS, and plays the role of optical bench for them. The top panel facing the Sun holds the WBS detectors and also has



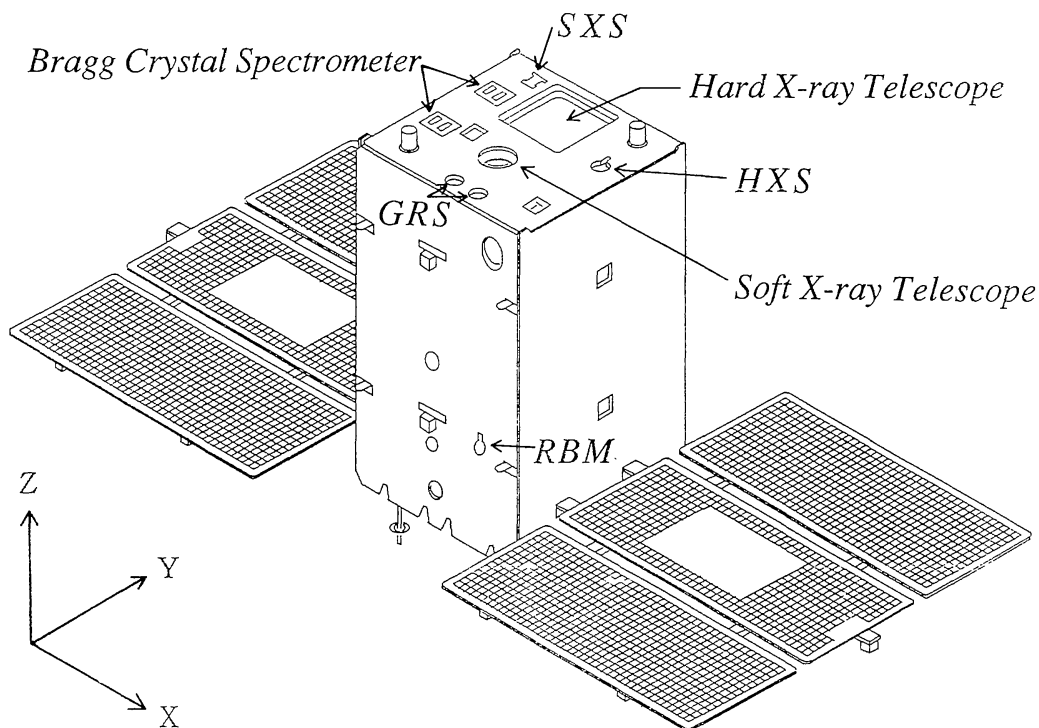


Fig. 1. The SOLAR-A spacecraft and its scientific instruments. The abbreviations used are: SXS, Soft X-ray Spectrometer; HXS, Hard X-ray Spectrometer; GRS, Gamma-Ray Spectrometer; and RBM, Radiation Belt Monitor. The spacecraft coordinates are given at the bottom left.

aperture windows for SXT, HXT, and BCS. Most of the electronics units are attached to the four side panels and the bottom panel.

Two solar cell panels are to supply about 570 W during spacecraft day. Excess power in daytime is stored into NiCd batteries for the power required during night. By this arrangement, about 220 W of power during day and 180 W during night are available.

The major parameters of the spacecraft are summarized in Table III.

### 3.2. ATTITUDE CONTROL

Since the SOLAR-A spacecraft is to take high spatial resolution images as well as spectra, precise control of the attitude is crucially essential. Thus it is stabilized in all three axes and its  $Z$ -axis (cf. Figure 1) is pointed at the center of the Sun with a stability of the order of  $1 \text{ arc sec s}^{-1}$  and several  $\text{arc sec min}^{-1}$ . The  $Y$ -axis is directed toward celestial north.

The attitude control system uses momentum wheels, magnetic torquers, and control-moment gyros as the actuators. As the attitude sensors, two Sun sensors and a star tracker, as well as geomagnetic sensors, are available for determining the spacecraft pointing relative to the direction of the Sun and to the ecliptic plane, respectively, while an inertial reference unit comprising four gyros detects changes of attitude with time. As a whole, the attitude system, using elaborate control programs with microprocessors, keeps the three axes well inside the requirements specified in Table III. The accuracy of  $Z$ -axis determination is estimated to be about 1 arc sec, disregarding bias error due

TABLE III  
Major parameters of SOLAR-A

Size	~ 100 cm (L), 100 cm (W), 200 cm (H)	
Weight	~ 400 kg	
Power	~ 570 W (maximum; supply from solar cells)	
Data recorder	10 Mbytes (magnetic bubble memory)	
Data rate	32, 4, or 1 kbps	
Telemetry rate	32, 4, or 1 kbps (real-time data) 262 kbps (reproduced data from the data recorder)	
Orbit		
Altitude	~ 600 km (nearly circular)	
Inclination	~ 31 deg	
Period	~ 97 min	
Attitude control (requirement)		
Absolute pointing	a few arc min	
Stability	around <i>X/Y</i> -axes (origin of image)	< 36 arc sec hr <sup>-1</sup> < 7 arc sec min <sup>-1</sup> < 1.2 arc sec s <sup>-1</sup>
	around <i>Z</i> -axis (rotation of image)	< 5 arc min min <sup>-1</sup> < 20 arc sec s <sup>-1</sup>
<i>Z</i> -axis pointing determination	≤ 1 arc sec	
Offset pointing	capable, up to 45 arc min from the Sun center	
Ground stations		
Commanding and downlink	Kagoshima Space Center (131 E, 31 N)	
Downlink only	NASA stations at Goldstone, Madrid, and Canberra	

to misalignment of the fine Sun sensor. Note that the two imaging telescopes have their own aspect sensors.

### 3.3. ONBOARD DATA PROCESSING

The scientific instruments of SOLAR-A, especially SXT, require sophisticated control of flight operations to exploit their capabilities within the constraints of the telemetry data rate and the capacity of the data recorder (cf. Table III). This is achieved by the 'data processor' (DP) unit.

The DP consists of dual redundant microcomputer systems. Further, the most essential parts of the DP functionality can also be achieved by hardwired logic if both of the microcomputer systems should fail to operate.

The fundamental functions of DP are as follows:

- (1) Data gathering from all the instruments.
- (2) Data processing and editing into the telemetry stream.
- (3) Data recording to and data dump from the data recorder, including complicated control of the data recorder (cf. Section 4.3).

(4) Automated control of observing mode, the data rate, and the operation of the scientific instruments, especially SXT. The mode and rate are switched by DP depending on conditions such as occurrence of flares, spacecraft sunrise/sunset, etc.

The data can be telemetered to the ground in real time, with data rates of 32, 4, or 1 kbps, depending on the observation conditions. Since contacts with downlink stations are limited, the data are also stored in an on-board recorder, and dumped during ground-station contacts. The recorder is a magnetic bubble data recorder with 10-Mbyte capacity. Unfortunately this capacity is not sufficient for recording data continuously at the high rate (32 kbps) for a full orbital period, so that sophisticated control algorithms are required. Such operations-related items, together with data processing and editing, will be further discussed in Section 4.

### 3.4. COMMAND SYSTEM

An uplink commanding system controls the operation of all the instruments on the spacecraft. Commands from the ground are to be sent only from the Kagoshima Space Center, during contacts of about 10 min duration each for 5 orbits day<sup>-1</sup>. Each command is distributed by the telemetry command control unit to the instrument specified by the instrument code included in the command.

In addition, the control unit can coordinate sequences of commands. First, it can store up to 128 sets of 'organized commands' (OG's), each being a set of up to 32 commands. An OG can be launched by an 'OG start command' from the ground. Also several OG's can be automatically triggered to start at the times of interruption messages issued by specific on-board instruments. Such interruptions include sunrise/sunset (from a Sun sensor), occurrence of a flare (from DP), and emergencies in the power control system or the attitude control system. Second, a series of OG's can be dispatched sequentially with specified time intervals. Such a command series is called an 'operation program (OP)', and is controlled by a program which contains a sequence of 128 OG addresses and intervals stored in the program memory. The operation program is initiated by an 'OP start command' and can last for up to about 10 days, so that the operator can easily program several days' spacecraft operation beforehand.

### 3.5. TELEMETRY

Data acquired with the instruments on board SOLAR-A can be telemetered to three Deep Space Network stations at Goldstone, Madrid, and Canberra, as well as to the Kagoshima Space Center station. Two telemetry channels are used, one at S-band (2.2 GHz) and the other at X-band (8.4 GHz). At Kagoshima, the two channels are received simultaneously; the S-band channel transmits 'real-time data', while the X-band transmits 'reproduced data' from the bubble data recorder at 262 kbps. The 10-Mbyte data stored in the data recorder can be sent in about 5 min well within the 10-min contact duration. On the other hand, at the other stations only reproduced data are transmitted via the S-band and no real-time data are available.

Real-time data downlinked at Kagoshima are sent to ISAS at Sagami-hara, near Tokyo, via a real-time data link. Reproduced data are also sent to ISAS within 30 min from downlink. Data taken at the Deep Space Network stations are brought first to the Jet Propulsion Laboratory and then transferred to ISAS through a NASA Communication (NASCOM) line in less than a few days. For archiving and scientific analysis



all of the data are finally stored and maintained in a database system at ISAS. For more information the reader should refer to the article by Morrison *et al.* (1991).

#### 4. Operations

Since the primary objective of SOLAR-A is to understand the high-energy aspects of solar flares, it is of crucial importance to observe as many flares as possible. Major flares are given higher priority, because such flares emit a wide range of radiations from soft X-rays to gamma-ray lines and thus make comprehensive studies possible. At the same time, the mission objectives include understanding of preflare conditions of active regions and also non-flare phenomena such as coronal holes, interconnecting loops, X-ray bright points, etc. The SOLAR-A instruments, especially the Soft X-ray Telescope (SXT), have good capabilities for making such preflare and non-flare observations. In the following we will discuss how the SOLAR-A program has been organized to accomplish these two different (and sometimes mutually contradictory) types of observations in an automated but flexible manner.

##### 4.1. OBSERVING MODES

The spacecraft has four observing modes ('flare', 'quiet', 'night', and 'BCS-out' modes) and three telemetry data rates ('high' 32 kbps, 'medium' 4 kbps, and 'low' 1 kbps). The flare and quiet modes run either at high or medium bit rate. The night mode, used in spacecraft night, runs at low rate. The BCS-out mode at high rate, used specifically for sweeping out the BCS queue memory, is initiated when the spacecraft enters night or just after the flare mode ceases.

Each mode has its own telemetry data format, i.e., the telemetry assignment differs from one mode to another, as shown in Table IV. There is only one significant difference between the quiet mode and the flare mode; the four scientific instruments (HXT, SXT, WBS, and BCS) share the telemetry in flare mode, while HXT yields most of its telemetry assignment to SXT in quiet mode.

TABLE IV  
Mode and telemetry assignment in each 128-byte frame

	Flare mode 32 or 4 kbps	Quiet mode 32 or 4 kbps	BCS-out mode 32 kbps	Night mode 1 kbps
Basic data <sup>a</sup>	32 bytes	32 bytes	32 bytes	32 bytes <sup>b</sup>
HXT	16	–	–	–
SXT	64	64 + 16 <sup>c</sup>	–	–
WBS	8	8	–	–
BCS	8	8	64	–

<sup>a</sup> Contains the spacecraft system information, status and housekeeping data, and some basic monitoring data from the scientific instruments.

<sup>b</sup> Remaining 96 bytes are used for recording cosmic gamma-ray bursts.

<sup>c</sup> Two sections.

In quiet mode the two SXT telemetry sections (64 + 16 bytes) are assigned to obtain 'full frame' images (whole-Sun images) together with what we call 'partial frame' images (images with areas small compared to the whole CCD field of view) in parallel, i.e., one of the two is used for whole-Sun images and the other for partial-frame images. If the 16-byte section is used for whole-Sun images, the image cadence is typically once every 10 min at high data rate (assuming  $2 \times 2$  on-chip summation mode; see Tsuneta *et al.* (1991) for more details). This time resolution can be improved by a factor of 4 by assigning the 64-byte section to whole-Sun images, resulting in a reduced area size and/or reduced time resolution for partial-frame images. In flare mode, on the other hand, only partial-frame images are telemetered, with no whole-Sun images. The time resolution is 2 s if the area size is  $64 \times 64$  pixels (about  $2 \times 2$  arc min) at high data rate.

The 'basic' section of the telemetry data format is not affected by the observing mode. This contains the spacecraft system information (clocks, command answerback, observing mode/data rate, attitude, power supplies, etc.), status and housekeeping data for all of the instruments, and also some basic monitoring data from the scientific instruments. With regard to HXT, data from the lowest-energy band (15–24 keV) are always recorded in this section, so that we can expect to obtain preflare hard X-ray images even before the flare mode is initiated by a flare. Note that at higher energies usually no hard X-rays with intensity high enough to be image-synthesized are emitted without the occurrence of a flare.

The observing modes also affect the control of the instruments. For example, the SXT control in flare mode is completely independent of that in quiet mode (for details see the separate papers in this issue).

#### 4.2. AUTOMATED MODE CONTROL

The logic of the DP software that controls the observing modes is schematically shown in Figures 2 and 3.

At the beginning of each spacecraft day the operating mode is 'quiet' and the data rate is predetermined at 'high' or 'medium'. In this mode SXT takes whole-Sun images to monitor the global structure of the corona together with partial-frame images of active regions to monitor their development. The data taken with HXT are restricted to the lowest energy band.

When DP recognizes flare occurrence by an abrupt increase of counting rate in one of the three sensors (HXS, SXS, and BCS; selectable) above a 'flare threshold', it turns on the flare flag and initiates flare mode at high rate within the next two seconds, provided that there is no simultaneous increase in the RBM counting rates which monitor the particle background environment. In this mode the whole HXT data are sent to the telemetry, while for SXT image-processing software picks out the brightest region and edits partial-frame images for telemetry.

This mode continues unconditionally during a preset 'flare minimum duration'. After this period elapses, two thresholds are applied once every 64 s to determine the mode and data rate. If the counting rates exceed the 'great flare threshold' (case C of Figure 3), the flare mode continues at high rate. If the flare flag turns off due to lower counting

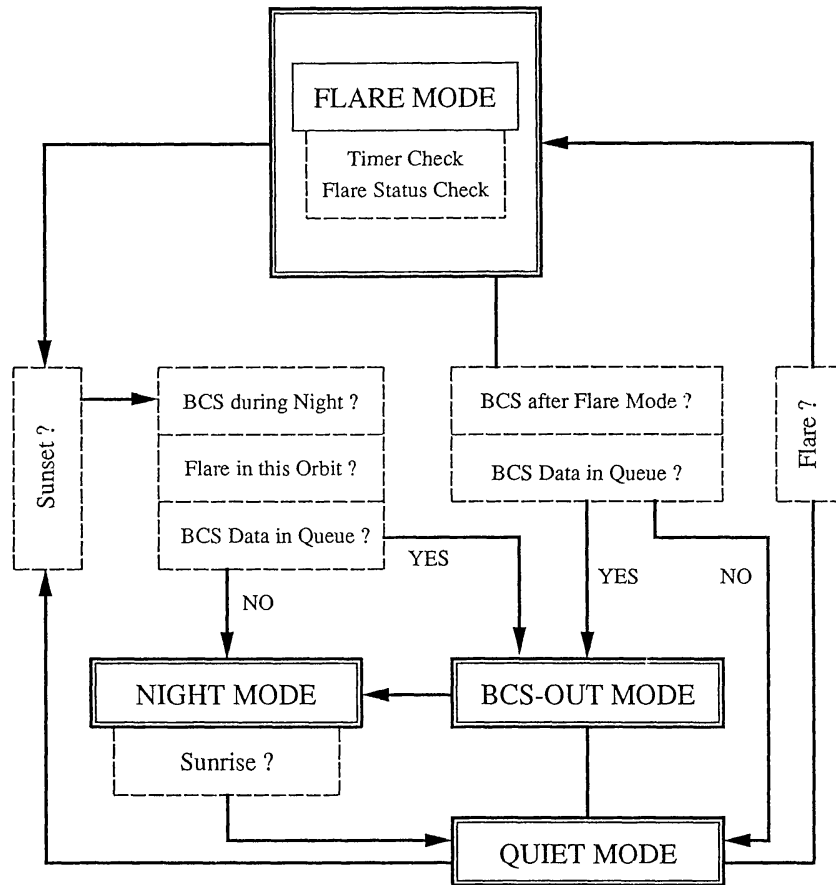


Fig. 2. Diagram showing the logic of automated observing mode control of SOLAR-A. The on-board microcomputer (DP) continuously monitors the day/night signal provided from a Sun sensor, various flare sensor (HXS, SXS, or BCS) counting rates for setting/resetting the flare flag, and the BCS queue memory status. The RBM counting rates are also monitored (not shown) for judging whether an increase of flare sensor counting rate is due to a solar flare or to trapped radiation.

rates than the 'flare end threshold' (case A of Figure 3), the mode is changed to quiet. Otherwise (case B of Figure 3), the flare mode continues but the data rate is changed to medium. This allows recording any long-enduring flare until its end.

When flare mode ends, the observing mode usually returns to quiet. However, if so specified in advance, data stored in the BCS queue memory are swept out (BCS-out mode) before the quiet mode is initiated. When the spacecraft enters into the shadow of the Earth, the mode is changed into night mode, in which data taken with HXS and RBM are recorded to monitor occurrence of cosmic gamma-ray bursts and the particle environment of the spacecraft. The BCS-out mode can be initiated before night mode if its queue memory stores flare data.

Besides this automated operation, it is possible to control the observing mode manually either by directly specifying the mode or by indirectly setting/resetting flags. Such a manual control is initiated and terminated either by commands from the ground (when the spacecraft is within the reach of the Kagoshima Space Center) or by the operation program (see Section 3.4). This manual mode control function will be used, for example, for calibrating the instruments.

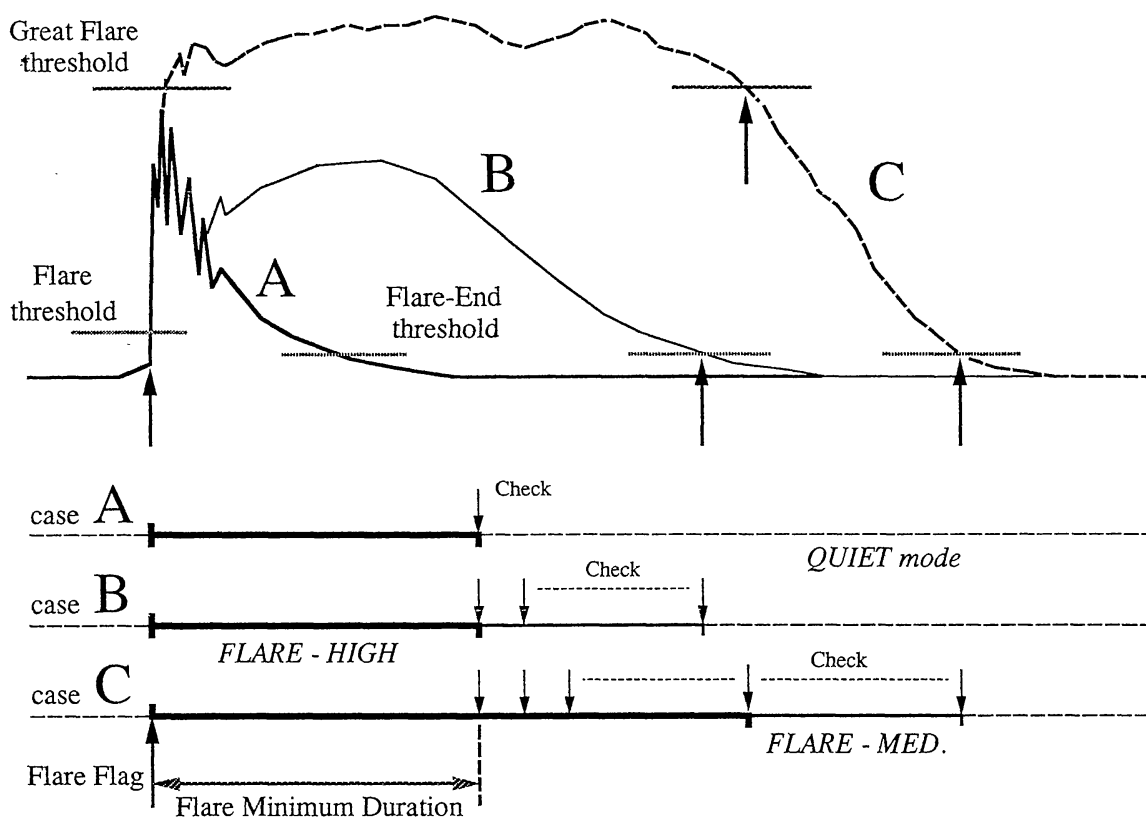


Fig. 3. Three flare thresholds and the control of the flare mode. The flare and flare-end thresholds are used for setting and resetting the flare flag, respectively. The flare mode starts at high data rate. After a specified time elapses, the mode and data rate depend on the flare sensor counting rates. The 'great flare threshold' allows classification of flares into two classes, and determines the data priority against overwrite on the data recorder (see text).

#### 4.3. CONTROL OF DATA STORAGE TO THE BUBBLE DATA RECORDER

Because flare occurrence cannot be scheduled, an on-board data recorder is essential. However, the data can consume the bubble data recorder (BDR) capacity of 10 Mbytes in some 40 min at high rate, so that overwriting is inevitable. This causes a serious problem because one orbit day lasts for more than 60 min. This problem would become more serious in cases when some of the downlink stations were not available.

To avoid loss of important data by overwriting with less important data, the DP software is so designed as to compare the importance between the data which DP is going to write and the data which is already stored, and, if necessary, to protect the stored data by skipping.

The priority levels usually used are as follows:

'great flare' data > 'normal flare' data > quiet or night mode data .

Here 'great flares' are flares whose peak counting rates exceed the 'great flare threshold'. This is the same logic as adopted in the HINOTORI mission which resulted in successful observations of many major flares (Kondo, 1983). It is to be noted, however, that in the case of SOLAR-A this overwrite control is executed by the DP software so

that it is more flexible and more powerful. The logic can protect not only flare data but also any associated preflare data. The priority levels are changeable. Further, the observer can unconditionally protect the data taken in a certain period of time by declaring a 'campaign observation'. This campaign observation function will be used to protect, for example, SXT whole-Sun images taken at a regular interval, say once in a few orbits, used for example for a 'synoptic movie' in a given filter. This function will be also useful when the SOLAR-A team makes a short-term, simultaneous observation with certain observatories in which the loss of data by overwriting would be undesirable.

## 5. Scientific Topics

The SOLAR-A mission is a unique space solar observatory accommodating a coordinated set of instruments. The instruments are individually advanced over their predecessors, but there is no doubt that their combination together will make scientific return more fruitful.

For example, the HXT imaging of hard X-ray sources with high time resolution in the four energy bands up to 100 keV will give us information about rapid processes occurring in the impulsive phase of a flare, as well as fainter thin-target sources showing the location of the storage of accelerated particles. Coaligned flare images taken simultaneously with SXT will be of crucial importance to locate the hard X-ray sources on the flaring loop structure seen in soft X-ray images. High-resolution images in the two energy ranges will give much-improved physical interpretations of the energy release and particle acceleration processes in solar flares. In this respect, we note that the two imagers have wide fields of view that cover the whole Sun, which guarantees simultaneous observations for most flares. Similarly the use of BCS together with SXT will allow us to discern the successive brightenings of neighboring points from the true motion of the X-ray emitting plasma.

Another advantage of SOLAR-A is that fainter objects such as loop structures in the quiet corona are expected to be observable with SXT due to its high sensitivity and wide dynamic range. The preflare evolution of active regions is an interesting objective to be examined in detail. Such non-flare objectives may include globally-distributed X-ray bright points, possibly related to the internal dynamo activity of the Sun. Another example would be the morphology of faint coronal loops that we expect to reveal the magnetic connectivity of the outer atmosphere of the Sun and the solar wind.

In the following, we briefly mention possible scientific objectives of SOLAR-A, and give comments from these viewpoints. Since a thorough survey and discussion of the objectives of SOLAR-A are beyond the scope of this introductory overview, we simply make a candidate list and give a very brief discussion of a single topic as an example.

A list of objectives may include:

### (A) *Flare-related phenomena*

- (1) Evolution of active regions, especially their preflare states, in terms of the coronal loop structures that show their magnetic connectivity and its changes.



(2) Flare onset: what happens immediately before and at the very beginning of the impulsive phase?

(3) High-temperature loops and arcades: when and how are they formed and where do the mass and energy come from?

(4) Electron accelerations: where and when exactly?

(5) Ion accelerations and gamma-ray line flares: where and when?

(6) Dynamic behavior of the footpoints of the flaring loops: mass ejection and/or evaporation from the chromosphere.

(7) Flare ejecta, shocks, and plasmoids: are they observable in X-rays?

(8) Relation between the sources of hard X-ray, soft X-ray, optical, and radio emissions.

(9) White-light flares (observable with the SXT aspect sensor).

(B) *Dynamical phenomena not necessarily related to flares*

(1) Surges and Brueckner's jets in X-rays.

(2) Disappearances of quiescent filaments and related phenomena (in some cases, accompanying low-energy two-ribbon flares).

(3) Coronal mass ejections and related phenomena.

(C) *Other forms of activity*

(1) X-ray bright points and their solar-cycle variations.

(2) Micro- and nano-flares.

(3) Formation and evolution of active-region loops.

(D) *Global coronal structure, and others*

(1) Formation and evolution of quiet coronal loops, if possible.

(2) Behavior of coronal holes.

(3) Solar oscillations (observable with the SXT aspect sensor).

(4) Other kinds of simple photospheric imaging.

Here we pick only one example from this list, namely, the problem of what is happening immediately before the 'flare onset'.

HINOTORI and SMM indicated (a) that evidence exists for the presence of a very important stage, in which violent uprising motions with  $300\text{--}400\text{ km s}^{-1}$  were found in FeXXV or CaXIX lines immediately before the flare onset (Tanaka *et al.*, 1983; Antonucci, 1983); (b) that an X-ray source brightens up and is confined at the top of a loop-like structure, already with high temperature when it first appears in X-rays (Tsuneta *et al.*, 1984), without rapid expansion or rapid cooling, requiring special mechanisms of confinement and insulation; and (c) that gamma-ray line emissions appear simultaneously with hard X-ray impulsive bursts (Forrest and Chupp, 1983; Nakajima *et al.*, 1983), requiring almost instantaneous ion acceleration if the impulsive phase is taken to indicate the flare onset. Observations (a) and (b) suggest the possibility that a very important dynamical phase, occurring immediately before the impulsive

phase and possibly carrying mass and energy from below, has escaped our attention thus far (Uchida and Shibata, 1988). If this turns out to be the case by observations with SOLAR-A, it would change our understanding of flares drastically. Note that, in this case, even observation (c) does not necessarily mean any instantaneous acceleration of ions. Instead it would mean the simultaneous release of both electrons and ions accelerated in a dynamical phase before the impulsive phase. The clarification of the processes occurring in this period would be vital for our understanding of flares.

This example shows that an obvious contribution which SOLAR-A can make will be to give a precise answer to the questions regarding where, when, and how mass and energy actually enters a flaring coronal loop. Whether magnetic reconnection really occurs or not can also be examined by SOLAR-A because it can give us the magnetic connectivities and their changes in the flaring locations in terms of coronal loop structures in the preflare and flaring states.

## 6. Concluding Remarks

There will be no other satellite project totally dedicated to solar flare observations during the current maximum period. Only the SOLAR-A mission will provide systematic data covering the broad energy range from soft X-rays to gamma-rays. The coordinated set of instruments on board this mission will provide precious and well-organized data to investigate solar flares and related high-energy phenomena in the corona. The instruments make substantial improvements over those flown earlier on spacecraft such as HINOTORI and SMM.

Although observations in X- and gamma-rays are well established to be very important in the study of solar flares, they still provide only partial information about the flare phenomenon. Solar flares have many aspects, and collaborative observations with ground-based optical and radio telescopes will be extremely important in clarifying the physics of flares and of other active phenomena. In addition, theoretical investigations that can help to synthesize a coherent picture from these complex data will be indispensable. The SOLAR-A will take part in these coordinations and contribute to the investigation of such thorny problems.

We believe that the fruitful scientific return from SOLAR-A will unfold still newer aspects of our understanding of flares and that these new aspects will lead us to develop a more advanced space observatory which, we hope, will be flown as SOLAR-B at some time in the future.

## Acknowledgements

The authors wish to acknowledge the staff of ISAS, and engineers of many companies involved in this project. All the team members express their thanks to the National Aeronautics and Space Agency (NASA) and to the Science and Engineering Research Council (SERC) for their support and contribution to this project. Special thanks are due to Professors Yasuo Tanaka and Minoru Oda, without whose support the

SOLAR-A mission would not have existed. Two important persons passed away during the preparatory stage of this mission. We express our thanks to the late Prof. Katsuo Tanaka, who first proposed the SOLAR-A mission as a successor of HINOTORI, and the late Prof. Keizo Kai, who worked hard until the end as Principal Investigator for HXT. Hugh Hudson and Bob Bentley are acknowledged for their assistance in preparing this manuscript.

### References

- Antonucci, E.: 1983, *Solar Phys.* **86**, 67.
- Culhane, J. L., Hiei, E., Doschek, G., Cruise, A. M., Ogawara, Y., Uchida, Y., Bentley, R. D., Brown, C. M., Lang, J., Watanabe, T., and 17 co-authors: 1991, *Solar Phys.* **136**, 89 (this issue).
- Forrest, D. J. and Chupp, E. L.: 1983, *Nature* **305**, 291.
- Kondo, I.: 1983, in Y. Tanaka *et al.* (eds.), *Proceedings of Hinotori Symposium on Solar Flares*, ISAS, Tokyo, p. 3.
- Kosugi, T., Makishima, K., Murakami, T., Sakao, T., Dotani, T., Inada, M., Kai, K., Masuda, S., Nakajima, H., Ogawara, Y., Sawa, M., and Shibasaki, K.: 1991, *Solar Phys.* **136**, 17 (this issue).
- Kundu, M. R. and Woodgate, B. (eds.): 1986, *Energetic Phenomena on the Sun*, The Solar Maximum Mission Flare Workshop Proceedings, NASA-CP 2439.
- Morrison, M., Lemen, J. R., Acton, L. W., Bentley, R. D., Kosugi, T., Tsuneta, S., Ogawara, Y., and Watanabe, T.: 1991, *Solar Phys.* **136**, 105 (this issue).
- Nakajima, H., Kosugi, T., Kai, K., and Enome, S.: 1983, *Nature* **305**, 292.
- Tanaka, K.: 1987, *Publ. Astron. Soc. Japan* **39**, 1.
- Tanaka, K., Nitta, N., Akita, K., and Watanabe, T.: 1983, *Solar Phys.* **86**, 91.
- Tsuneta, S., Nitta, N., Ohki, K., Takakura, T., Tanaka, K., Makishima, K., Murakami, T., Oda, M., and Ogawara, Y.: 1984, *Astrophys. J.* **284**, 827.
- Tsuneta, S., Acton, L., Bruner, M., Lemen, J., Brown, W., Carvalho, R., Catura, R., Freeland, S., Jurcevic, B., Morrison, M., Ogawara, Y., Hirayama, T., and Owens, J.: 1991, *Solar Phys.* **136**, 37 (this issue).
- Uchida, Y. and Shibata, K.: 1988, *Solar Phys.* **116**, 291.
- Yoshimori, M., Okudaira, K., Hirasima, Y., Igarashi, T., Akasaka, M., Takai, Y., Morimoto, K., Watanabe, T., Ohki, K., Nishimura, J., Yamagami, T., Ogawara, Y., and Kondo, I.: 1991, *Solar Phys.* **136**, 69 (this issue).