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THE SOLAR-B MISSION

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ABSTRACT

The Solar-B is the third Japanese spacecraft dedicated for solar physics to be launched in summer of 2006. The spacecraft carries a coordinated set of optical, EUV and X-ray instruments that will allow a systematic study of the interaction between the Sun's magnetic field and its high temperature, ionized atmosphere. The Solar Optical Telescope (SOT) consists of a 50cm aperture diffraction limited Gregorian telescope and a focal plane package, and provides quantitative measurements of full vector magnetic fields at the photosphere with spatial resolution of 0.2-0.3 arcsec in a condition free from terrestrial atmospheric seeing. The X-ray telescope (XRT) images the high temperature (0.5 to 10 MK) corona with improved spatial resolution of approximately 1 arcsec. The Extreme Ultraviolet Imaging Spectrometer (EIS) aims to determine velocity fields and other plasma parameters in the corona and the transition region. The Solar-B telescopes, as a whole, will enable us to explore the origins of the outer solar atmosphere, the corona, and the coupling between the fine magnetic structure at the photosphere and the dynamic processes occurring in the corona. The mission instruments (SOT/EIS/XRT) are joint effort of Japan (JAXA/NAO), the United States (NASA), and the United Kingdom (PPARC). An overview of the spacecraft and its mission instruments are presented.

Key words : space telescope — solar:corona — magnetograph — instrument

I. INTRODUCTION

Recent observations of the sun from space revealed the dynamic nature of the solar corona; it is hot, highly structured, and changes with time yielding occasional explosions such as solar flare. From the recent progress of ground based solar polarimetries, it is believed that the dynamic processes occurring in the solar corona are ultimately driven by the ensemble of fine scale magnetic fields at the photosphere. Its detailed mechanisms are still unknown due to limitations of spatial resolution and accuracy of magnetic field measurements, and also due to limited diagnostic performance of current coronal observations. Continuous and high precision magnetic field observations with high spatial resolution, together with simultaneous coronal observations taken with advanced X-ray/EUV instruments, are of crucial importance for better understanding the dynamics of the Sun and the fundamental mechanisms governing the cosmic plasma dynamics.

The Solar-B is a follow-up of the most successful YOHKOH spacecraft (1991 - 2001) and the third Japanese spacecraft for solar physics. One of the advantageous characteristics of the Solar-B mission is to realize the coordinated and simultaneous observation of the photosphere, the transition region and the corona, which will enable us to explore the nature of sun's dynamic phenomena, with special attention paid to the connection between changing photospheric magnetic fields and dynamic responses of the coronal plasma.

In this paper, we briefly describe the Solar-B spacecraft and its mission instruments.

II. SPACECRAFT OVERVIEW

Fig. 1 shows a schematic view of the Solar-B spacecraft. The Solar-B is an orbiting solar observatory with a coordinated set of optical, EUV and X-ray instruments.

The Solar Optical Telescope (SOT), which is placed at the center of spacecraft, consists of a 50cm aperture diffraction limited Gregorian telescope (optical telescope assembly; OTA) and a focal plane package (FPP), and provides quantitative measurements of full vector magnetic fields at the photosphere with spatial resolution of 0.2-0.3 arcsec. The X-Ray Telescope (XRT) images the high temperature (0.5 to 10 MK) corona with improved spatial resolution of approximately 1 arcsec. The Extreme ultraviolet Imaging Spectrometer (EIS) aims at determining velocity fields and other plasma parameters in the corona and the transition region. These telescopes are mounted on a cylindrical structure of the spacecraft which serves as an optical bench to maintain a precise alignment of the three telescopes. The Solar-B spacecraft weights about 900kg including thruster gas for maintaining the orbit.

The launch is scheduled in summer of 2006, from the Uchinoura Space Center of JAXA using a M-V rocket. The orbit is a polar, sun synchronous one with a height

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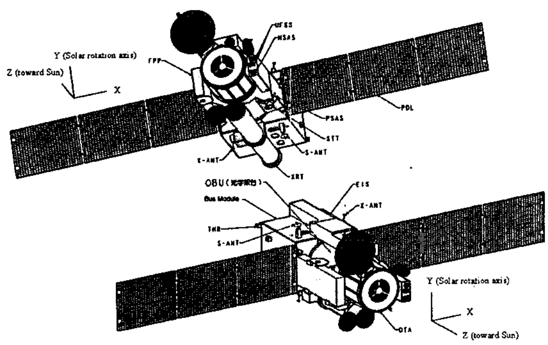

Fig. 1.— The SOLAR-B spacecraft.

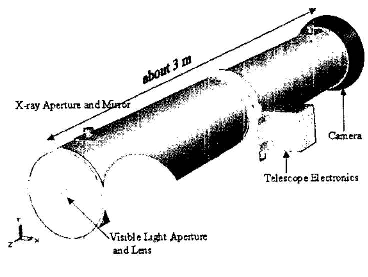

Fig. 2.— The structure of XRT.

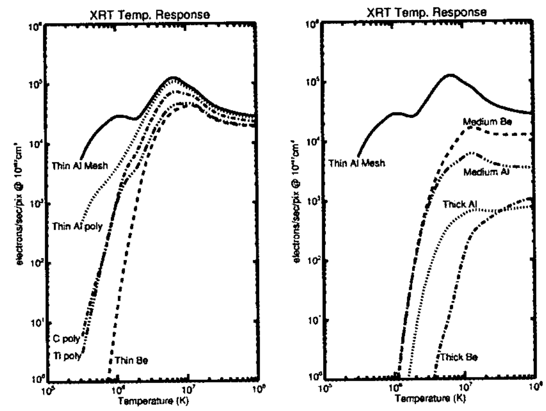

Fig. 3.— Temperature response functions of XRT with the transmissivity of the entrance filter and the X-ray analysis filters, the effective area of the X-ray mirror, and QE of the CCD taken into account.

of about 600km, which enables a 10 month a year, continuous observation of the sun without interruption due to satellite nights. The attitude control system will keep the pointing axes of the three telescopes towards a selected target region on the sun by following the predicted trajectory of solar rotation.

The mission instruments are developed under international collaboration among the three space agencies in Japan (JAXA), US (NASA) and UK (PPARC), with many academic and industrial partners involved in each country; SOT is mainly developed by JAXA-NAOJ (for OTA) and Lochkeed Martin (for FPP), XRT by Smithsonian Astrophysical Observatory (for telescope) and JAXA/NAOJ (for CCD camera), EIS by Mullard Space Science Laboratory of University College London and other UK institutions and US Naval Research Laboratory.

III. MISSION INSTRUMENTS

(a) X-ray Telescope

XRT is an optimized Wolter-I Grazing incidence telescope with an annular aperture of 340mm diameter and a focal length of 2708mm (Fig. 2). XRT provides images of the high temperature corona with spatial resolution of approximately 1 arcsec/pixel. A back illuminated CCD camera (2048×2048) (Sakao et al. 2004) has a field of view of 34×34 arcmin, thus covering the full Sun. XRT can take partial frame images of various sizes. On-chip pixel summing by 2×2, 4×4, 8×8 is also available. With 9 different X-ray analysis filters, whose temperature response functions are shown in Fig. 3, XRT can diagnose the coronal temperature in a range of 0.5 to 10 MK. XRT has a capability of taking a 4305Å visible light images for the purpose of coalignment with images taken with other instruments. The Mission Data Processor (MDP) enables the following functions of XRT; 1) Automatic Exposure Control (AEC) to enable a dynamic adjustment of exposure length against the temporal change of brightness of the target region, 2) Automatic Region Selection (ARS) to enable the partial field of view of XRT to truck the brightest region(s), 3) Flare Detection (FLD) to detect the onset of flare and trigger the transition to the flare observing mode, and 4) Pre-Flare Buffer to retrieve pre-flare data in case of the flare occurrence (see Kano et al, 2004).

(b) EUV Imaging Spectrometer

EIS is a normal incidence telescope with a grating spectrometer (Fig. 4). The primary mirror is an off-axis paraboloid with a high-reflectance Mo/Si multilayer coating on it and a focal length of 1934mm. The aperture diameter is 150mm. The spectrometer utilizes a toroidal diffraction grating with the multilayer coating in a normal incidence optical layout. The multilayer coating has high reflectance in two wavelength ranges, 170–210 Åand 250–290 Å, and these wavelength ranges are simultaneously observed with two large back-illuminated CCDs. Many EUV emission lines from the transition region, the corona, and flares are contained in the wavelength ranges and observers

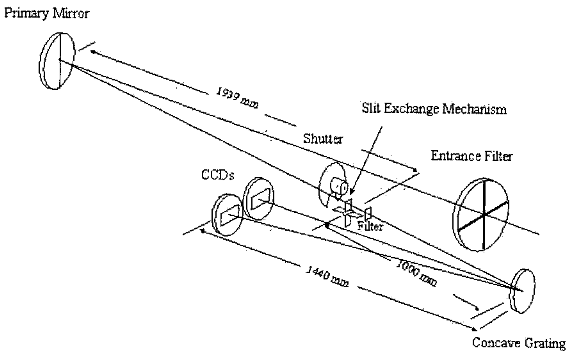

Fig. 4.— Optical layout of EIS.

can select spectral windows up to 25 in the imaging area of two CCDs. There is a slit/slot exchanger that contains two narrow slits (1" and 2" width) and two wide slits (40" and 250" width) at the focus of the primary mirror. Two dimensional EUV images are obtained with one of the narrow slits in a raster observation by a pivot rotation of the primary mirror in the east-west direction. In a slot observation using one of the wide slits, two dimensional images of the sun in multiple emission lines are taken at once without the primary-mirror motion, though the velocity information is convolved in this case. See also Hara et al. (2004). Table 1 summarizes the basic parameters of EIS.

TABLE 1.
CAPTIONBASIC PARAMETERS OF EIS

Telescope	
aperture diameter	150mm
focal length	1934mm
Spectrograph	
Slit/Slot width	1", 2", 40", and 250"
" length	512"
mirror scan range	± 3arcmin in EW direction
Wavelength range	170–210Å, 250–290Å
Dispersion	1.65 Å/mm
CCD format	1024 × 2048 pixels
Pixel scale	
wavelength	0.0223Å/pix
spatial	1.0 arcsec/pix
Effective Area	$0.5cm^2$ @195Å
	$0.2cm^2$ @270Å

(c) Solar Optical Telescope

Fig. 5 shows the optical layout of SOT. OTA is a diffraction limited (Strehl > 0.8 at 500nm) Gregorian telescope with an aperture of 500mm. The distance between primary and secondary mirrors is 1500mm. A heat dump mirror located at the primary focus reflects unnecessary lights (out of the field of view, about 88%

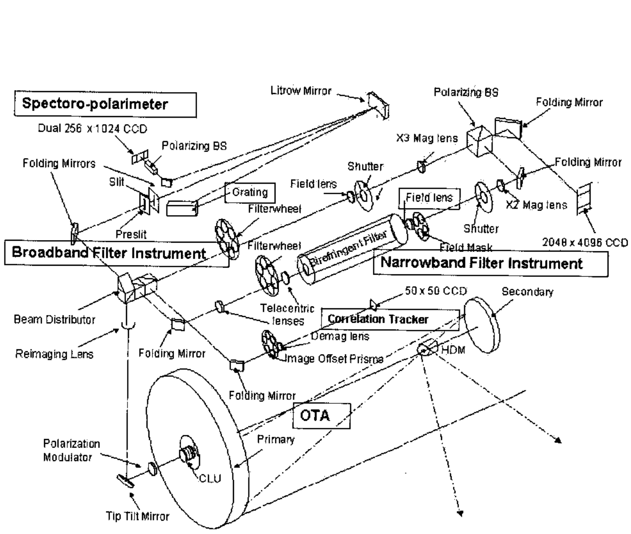

Fig. 5.— Optical layout of SOT.

of incident energy) out to the space to reduce the heat load on the succeeding optics. With a collimating lens unit (CLU) at the center of the primary mirror and a tip-tilt mirror beneath it, OTA provides a collimated, pointing-stabilized beam to the FPP. Polarization modulator unit (PMU) (a rotating waveplate) is located in the collimated beam near the pupil image.

FPP has four observing paths, namely, Narrowband Filter Instrument (NFI), Broadband Filter Instrument (BFI), Spectropolarimeter (SP) and Correlation Tracker (CT). NFI takes vector magnetograms and Dopplergrams in selected spectral lines and Hα images by using a tunable Lyot-type filter with a bandpass of approximately 0.1Å. BFI takes photospheric images in the highest spatial resolution with a spatial sampling of 0.054 arcsec/pixel. A CCD camera is commonly used for NFI and BFI and its format is 4096×2048 pixels. SP takes high precision full Stokes profiles in magnetically sensitive lines of FeI 6302.5Åand FeI 6301.5Å. By tilting a folding mirror in the SP path, the solar image on the slit can be shifted in EW direction in a range of 328 arcsec. CT produces a pointing error signal at 580Hz to control the tip-tilt mirror. By a closed loop control of CT and tip-tilt mirror, the pointing stability of <0.03 arcsec rms will be achieved. A possible defocus due to the change of OTA temperature environment in orbit can be eliminated by adjusting the position of the reimaging lens at the entrance of the FPP.

The basic parameters of SOT instrument and observables are summarized in Tables 2 and 3, respectively. Technical details of OTA and FPP are also found in Ichimoto et al. (2004), Shimizu et al. (2004), and Shimizu (2004).

IV. MISSION DATA AND OPERATION

As described in the previous section, the three instruments of Solar-B have quite high flexibilities in the

TABLE 2.
CAPTIONBASIC PARAMETERS OF SOT

	NFI	BFI	SP	CT
PIXEL SCALE (ARCSEC/PIX)	0.08	0.054	0.16	0.22
MAXIMUM FOV (ARCSEC^2) (EW×NS)	328×164	218×109	328 (SCAN RANGE) ×164 (SLIT LENGTH)	11×11
WAVELENGTH RESOLUTION (Å)	0.1	3∼10	0.02	5
NUMBER OF WAVELENGTH	1∼4	1	244	1
TIME RESOLUTION (TYPICAL)	10∼30S	1∼10S	∼1HR	580Hz
PHOTOMETRIC AQURACY (%)	0.1–0.5	0.5	<0.1	∼0.5

TABLE 3.
CAPTION OBSERVABLES OF SOT

Ion	λ (Å)	purpose	geff	path
CNI	3883.0	mag.network	-	BFI
CaII H	3968.5	Chromos.Heating	1.33	BFI
CHI	4305.0	Mag.Elements	-	BFI
	4504.5	Blue Conti.	-	BFI
MgI b	5172.7	Chrom.Dopp/Mag.	1.75	NFI
FeI	5247.1	Photos.Mag.	2.00	NFI
FeI	5250.2	Photos.Mag.	3.00	NFI
FeI	5250.6	Photos.Mag.	1.50	NFI
	5550.5	Green Conti.	-	BFI
FeI	5576.1	Photos.Dopp.	0.00	NFI
NaI	5895.9	Chrom.Dopp/Mag.	1.33	NFI
FeI	6301.5	Photos.Mag.	1.67	NFI/SP
FeI	6302.5	Photos.Mag.	2.50	NFI/SP
TiI	6303.8	Umbral Mag.	0.92	NFI
	6320.0	Broadband WL	-	CT
H I	6562.8	Chromos.Structure	1.33	NFI
	6684.0	Red Conti.	-	BFI

way of taking data and it is possible to optimize the observing sequence for various kinds of scientific objectives. The three telescopes are controlled by an onboard computer, i.e., the Mission Data Processor (MDP) with sets of parameters named 'observation tables' for each instrument. Good planning of observation is one of the essential issues in operating the Solar-B observatory for fruitful scientific return.

MDP also takes a crucial role in data processing. Most of mission data will be compressed to 10∼50% of the original amount using a bit compression (nonlinear rescaling of data; the quantization unit is so varied as to be roughly equal to or slightly smaller than the Poisson noise), and a successive DPCM or 12bit JPEG image data compression algorithm. The compression mode can be selected for individual data. With the Svalbard station (ESA/Norway) participating as a ground station for Solar-B, more than 16 downlinks are anticipated in a day, and the average data rate will get approximately 500kbps after compression, thus about 5GB of compressed data will be obtained every day.

The Solar-B telescopes, as a whole, will give us unprecedented opportunity to understand generation, emergence, and ultimate dissipation of solar magnetic fields, and enable us to explore the origin of outer solar atmosphere, the corona, and the coupling between fine magnetic structure at the photosphere and dynamic processes occurring in the corona.

International collaboration for data analysis, and observation planning, are highly anticipated for maximizing scientific return from the Solar-B.

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