THE SOFT X-RAY TELESCOPE FOR SOLAR-A

W.A. Brown, L.W. Acton, M.E. Bruner, J.R. Lemen, K.T. Strong (Lockheed Palo Alto Research Lab.)

ABSTRACT

The Solar-A satellite being prepared by the Institute for Space and Astronautical Sciences (ISAS) in Japan is dedicated to high energy observations of solar flares. In collaboration with investigators at the National Astronomical Observatory of Japan (NAOJ) and the Institute for Astronomy of the University of Tokyo, we are preparing the Soft X-Ray Telescope (SXT) to provide filtered images in the 2 to 60Å interval. Prof. T. Hirayama of NAOJ is the SXT principal investigator.

The flight model is now undergoing tests in the 1000 foot tunnel at MSFC. Launch will be in September 1991. Earlier resolution and efficiency tests on the grazing incidence mirror have established its performance in soft x-rays. The unique one-piece, two mirror grazing incidence telescope is supported in a strain free mount separated from the focal plane assembly by a carbon-epoxy metering tube whose windings and filler are chosen to minimize thermal and hygroscopic effects. The CCD detector images both the x-ray and the concentric visible light aspect telescope. Optical filters provide images at 4308(fwhm30)Å and 4700(fwhm200)Å.

The SXT will be capable of producing over 8000 of the smallest partial frame images per day (64 × 64 pixels or 2.5 × 2.5 arcmin), or fewer but larger images, up to 1024×1024 pixel images. Image sequences with two or more of the five x-ray analysis filters, with automatic exposure compensation to optimize the charge collection by the CCD detector, will be used to provide plasma diagnostics. Calculations using a differential emission measure code were used to optimize filter selection over the range of emission measure variations and to avoid redundancy, but the filters were chosen primarily to give ratios that are monotonic in plasma temperature. Practical exposure times and counting statistics were included in the selection process.

Science planning in collaboration with NOAJ, U. Tokyo, ISAS, and US co-investigators at UC Berkeley, Stanford, and U of Hawaii has been underway for two years, and detailed plans for organization of data acquisition and eventual archiving are being developed. The LPARL work is supported by NASA under contract NAS8-37334.
Objectives of SXT Science

- Magnetic Structures and energy release
- Location of Particle acceleration and precipitation regions
- Electron Beams and heating of low atmosphere by energetic particles
- Superhot thermal plasma
- Plasma and magnetic parameters during flare energy build up
- Waves and moving fronts in the corona
- Flare periodicity and hot spots
- Electrical current systems and flaring
- Explosive chromospheric evaporation
- Coronal holes, x-ray bright points and global magnetic evolution
- Helioseismology

INSTITUTIONS AND NAMES OF SXT AND SOLAR-A PARTICIPANTS

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>ACRONYM</th>
<th>PRINCIPAL INVESTIGATOR</th>
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<tbody>
<tr>
<td>Hard X-Ray Imager</td>
<td>HXT</td>
<td>K. Kai NOAJ</td>
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<tr>
<td>Soft X-Ray Telescope</td>
<td>SXT</td>
<td>T. Hirayama, NOAJ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L. Acton , LPARL</td>
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<tr>
<td>Wide Band Spectrometer</td>
<td>WBS</td>
<td>J. Nishimura NOAJ</td>
</tr>
<tr>
<td>Bragg x-tal Spectrometer</td>
<td>BCS</td>
<td>E. Hiei NOAJ</td>
</tr>
<tr>
<td></td>
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<td>L. Culhane, MSSL</td>
</tr>
</tbody>
</table>

SOFT X-RAY TELESCOPE TEAM

T. Hirayama, T. Sakurai, T. Watanabe, NAOJ, S. Tsuneta, U. of Tokyo
Y. Ogawara, ISAS
M.E. Bruner, J.W. Lemen LPARL Coinvestigators
R. Canfield, U.Haw., P. Sturrock, Stanford, S. Kane, UC, Coinvestigators

Relation of Solar-A to Max-91

The Solar-A spacecraft will be operated by scientists at the Institute of
Space and Astronautical Science at Sagamihara, near Tokyo, Japan. As a
mission primarily devoted to the study of high energy solar physics it
is expected that the Solar-A team will choose to participate in most Max
'91 and FLARES 22 campaigns. A scientist at ISAS will be designated to
facilitate this coordination and it is anticipated that Solar-A x-ray
images will be made available to the Boulder forecast center in
support of coordinated observing.
The Solar-A Soft X-Ray Telescope Program (SXT)

**OVERVIEW**

The SOLAR-A Mission is a program of the Institute of Space and Astronautical Science (ISAS), the Japanese agency for scientific space activity. The SOLAR-A satellite will be launched in August 1991 from Kagoshima Space Center (KSC) in Japan. It will be on board an M-3S three stage solid fuel vehicle. The purpose of this mission is to study high energy phenomena in solar flares. Under an international cooperative agreement between ISAS and NASA, Lockheed will provide a scientific investigation including manufacture of a Soft X-Ray Telescope (SXT), one of the primary experiments of the mission.

**Key Technologies**

- Spacecraft (SXT)
- Constant Temperature (CST)
- High absorption geometry
- Internal expansion (SXT)
- Theory (Solar Flares)

**Launch Date August 1991**

*NASA*  
*Lockheed*  
*Research & Development Division*  
*SXT*  
*National Astronomical Observatory of Japan*
SOLAR IMAGE ON SXT CCD

Arrangement of the solar image on the CCD. The partial frame image (64 x 64) pixels may be taken anywhere in the 1024 x 1024 pixel area while the full width image (1024 x 512 pixels) may be placed anywhere in the N-S direction.

### SXT Image Parameters

<table>
<thead>
<tr>
<th>Type</th>
<th>No. Pixels</th>
<th>Pixel Sum</th>
<th>Field-of-View</th>
<th>Time resol.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWI</td>
<td>1024 x 512</td>
<td>1 x 1</td>
<td>41.6' x 20.8'</td>
<td>256 s</td>
</tr>
<tr>
<td></td>
<td>512 x 512</td>
<td>2 x 2</td>
<td>41.6' x 41.6'</td>
<td>128 s</td>
</tr>
<tr>
<td></td>
<td>256 x 256</td>
<td>4 x 4</td>
<td>41.6' x 41.6'</td>
<td>32 s</td>
</tr>
<tr>
<td>PFI</td>
<td>64 x 64</td>
<td>1 x 1</td>
<td>2.6' x 2.6'</td>
<td>2 s</td>
</tr>
<tr>
<td></td>
<td>64 x 64</td>
<td>2 x 2</td>
<td>5.2' x 5.2'</td>
<td>2 s</td>
</tr>
<tr>
<td></td>
<td>64 x 64</td>
<td>4 x 4</td>
<td>10.4' x 10.4'</td>
<td>2 s</td>
</tr>
</tbody>
</table>
**SXT IMAGE CADENCE**

Valid Partial Frame Image Mosaics:

- 64 x 64 pixels
- 128 x 128 pixels
- 256 x 256 pixels

**Time (secs) to complete Partial Frame Images (64 x 64) and Mosaics**

<table>
<thead>
<tr>
<th>Image Size (arcmin)</th>
<th>Pixel Size (arcsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>2.5 x 2.5</td>
<td>2/8/16</td>
</tr>
<tr>
<td>5 x 5</td>
<td>8/32/64</td>
</tr>
<tr>
<td>10 x 10</td>
<td>32/128/256</td>
</tr>
</tbody>
</table>

**Time (secs) to complete Full Width Images (1024 x 512)**

<table>
<thead>
<tr>
<th>Image Size (arcmin)</th>
<th>Pixel Size (arcsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>40 x 20</td>
<td>256/1024/2048</td>
</tr>
<tr>
<td>40 x 40</td>
<td>-</td>
</tr>
</tbody>
</table>

(3 TELEMETRY RATES: 2048/512/256 PIXELS/SEC)
SOLAR-A TELEMETRY AND DATA RATES

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telemetary Data Rate</td>
<td>32 Kbytes/s</td>
</tr>
<tr>
<td>Orbits per day</td>
<td>5*</td>
</tr>
<tr>
<td>Recorder Data Capacity</td>
<td>10.5 Mbytes</td>
</tr>
<tr>
<td>Total Daily Accumulated Data</td>
<td>52.5 Mbytes*</td>
</tr>
<tr>
<td>SXT partial frame images per day (64 x 64 pixels)</td>
<td>≥ 8000*</td>
</tr>
<tr>
<td>SXT full width images per day (1028 x 512 pixels)</td>
<td>≥ 5*</td>
</tr>
</tbody>
</table>

Quiet Mode Telemetry (60% SXT)

<table>
<thead>
<tr>
<th>Basic Data</th>
<th>WBS</th>
<th>BCS</th>
<th>SXT 1</th>
<th>SXT 2</th>
</tr>
</thead>
</table>

Flare Mode Telemetry (50% SXT)

<table>
<thead>
<tr>
<th>Basic Data</th>
<th>WBS</th>
<th>BCS</th>
<th>HXT</th>
<th>SXT</th>
</tr>
</thead>
</table>

* If Deep Space Network available increase by factor of about 2
ILLUSTRATION OF SXT SELECTION OF A REGION OF INTEREST (ROI)


b. Divided into zones representing 64x64 SXT pixels.

c. Automatic selection algorithm chooses 4 brightest locations.

d. Original image with selected ROI's superimposed.
Log scale, Cu-L (13.3 Å)
SXT Mirror Test, On-axis
16 Nov 1989

Linear scale, Cu-L (13.3 Å)
40x40 pixels
2.5 arcsec/pixel

Comparison of Encircled Energy Versus Image Diameter for Selected X-ray Telescope

Test of Point Spread Function of the X-ray Telescope. The plots show log and linear signals collected on the CCD pixel array and the encircled energy. This data taken at the best focus obtained in MSFC Tunnel.
Entrance Filter, sample #1

Composite Al/Mg/Mn

Al 1200 A + 300 A Carbon

OBSERVED AND CALCULATED TRANSMISSIONS OF 3 SXT FILTERS
SXT Characteristics

X-RAY TELESCOPE:
- Mirror: Nariai-Werner Double Hyperboloid, Gold on Fused Quartz
- Focal Length: 154 cm
- Thermal Filter: 1800 A Lexan + 800 A Al + 900 A Titanium (Doubled)
- Metering Tube: Tapered epoxy-carbon fiber
- Filter Wheels: Two 6 position wheels in tandem
- X-Ray Analysis Filters:
  - 1200 Angstrom Aluminum (2 each, one in each wheel)
  - 3 micron Magnesium
  - Al/Mg/Mn 3000/2000/600 Angstrom
  - 12 micron Aluminum
  - 100 micron Beryllium
- Detector: CCD 1024x1024 18.3 micron pixels
  - Front illuminated virtual phase
  - Resolution < 4 arcseconds over sun's diameter from geometric, diffraction, and mirror surface

ASPECT TELESCOPE:
- Lens: Achromatic doublet with .008" spacing, consisting of radiation-resistant crown and flint spherical elements
- Clear Aperture: 50 mm
- Focal Length: Matched to X-ray mirror effec foc len to 0.2%
- Filters:
  - Entrance filter: 4250-4800 A fwhm
    - Al attenuator layer, IR blocking substrate, dielectric films for out-of-band reflection, + dielectric passband filter 0.001 peak transmission to match X-ray responsivity
  - Narrow band filter: Interference filter
    - 30 A fwhm bandpass centered at 4308 A
      - CH bandhead, plage and active region sensitive 0.1 +/− 0.05 peak transmission
  - Wide band filter: Opal glass,
    - 200 A fwhm bandpass centered at 4700 A
      - Flat field diffuser for radiometric calibration
- Detector: Shares the same CCD as x-ray telescope

ACCOMMODATION:
- Weight: 29 kg
- Power: 18 watt average 29 watts peak
- Envelope: 50 x 30 x 200 cm + Electronics Boxes
The finished SXT x-ray mirror mounted in its flight support fixture. The two hyperboloids of revolution are polished into a single piece of Zerodur. (Mirror made by UTOS)

In the center is the support for the Aspect telescope.
SXT Response Function including Mirror, Detector, and Entrance Filters
SXT SIGNALS FOR CONSTANT EMISSION MEASURE.

RATIOS OF SIGNALS ILLUSTRATING THE TEMPERATURE SENSITIVITY WITH FOUR PAIRS OF FILTERS
SIMULATIONS OF THE ABILITY OF THE SXT TO REPRODUCE A DIFFERENTIAL EMISSION MEASURE CURVE.

a. INPUT DEM CURVE INFERRED FROM SMM XRP DATA. VARYING PHOTON NOISE ADDED TO EACH DEMON RUN. NOTE THAT IN PRACTICE BCS DATA WILL BE USED TO IMPROVE HIGH ENERGY FIT.

b. INPUT ISOTHERMAL SPECTRA AT 1 AND 10 MILLION DEGREES. NO NOISE ADDED.