The next-generation space solar observatory: The SOLAR-C Mission

K. Watanabe & H. Hara
ISAS/JAXA & NAOJ
SOLAR-C WG
2015 Feb 27

ISSI Coronal Rain
Basic Problems in Helio-Physics

1. Origin of large-scale explosion

2. Heating of chromosphere and corona, Solar wind acceleration

3. Magnetic cycle

First determines 3D magnetic structures from unprecedented observations for elucidating basic problems in Helio-Phys.

Keywords:
- Chromospheric $B$ measurements
- $0.1'' - 0.3''$ spatial resolution ($0.1'' = 70$ km)
- $\sim 1$s high-cadence observations
- high resolution spectroscopy
Science Objectives

Observations of All from photosphere to corona seamlessly as a system

SOLAR-C will determine

- Physical origin of explosions that drive short-time geo-space variability
- Mechanisms responsible for
  - heating and dynamics of chromosphere & corona
  - acceleration of solar wind
- Fundamental physical processes
  - Magnetic reconnection, MHD waves, shocks, etc.
- Fine-scale magnetism and associated solar spectral irradiance
SOLAR-C Spacecraft

EUVST (EUV Spectroscopic Telescope)

- EUVST
- Telemetry Antenna

- Startracker
- SUVIT/TA
- Ultrafine Sun Sensor
- Telescope Door
- HCI
- SUVIT/IU
- SUVIT/UBIS
- SUVIT/SP
- SUVIT/FG

50cm dia. telescope

Hinode

SUVIT TA

1.4 m diameter telescope

Chromospheric magnetic fields measurements

SUVIT: Solar UV-Visible-IR Telescope

<table>
<thead>
<tr>
<th>Weight</th>
<th>2300 kg (w/o fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>3.7m x 3.2m x 7.1m</td>
</tr>
<tr>
<td>Power</td>
<td>5 kW generation @EOL</td>
</tr>
<tr>
<td>Data rate and DR volume</td>
<td>Average: 8 Mbps (×20 of Hinode)</td>
</tr>
<tr>
<td></td>
<td>DR volume: 100GB</td>
</tr>
<tr>
<td>Attitude control</td>
<td>3-axis attitude control</td>
</tr>
<tr>
<td>Orbit</td>
<td>a geosynchronous orbit</td>
</tr>
</tbody>
</table>
3.4 High Resolution Coronal Imager (HCI)

The HCI is a normal-incidence EUV telescope consisting of primary and secondary mirrors in Ritchey-Chrétien configuration. It will perform high-resolution imaging in the EUV pass-bands described in Section 2.4: 30.4 nm containing the He II resonance line as diagnostic of the transition region, 17.1 nm containing lines of Fe IX and Fe X showing 1 MK coronal structures at high contrast, and 9.4 nm containing Fe XVIII with emission in very hot outburst features.

Table 5 summarises key design features of HCI. The primary and secondary mirrors are both divided into three sectors, with each sector coated with different multi-layer coatings for high reflectance in the pertinent passband. The sectors have different areas to accommodate expected count rates (17.1 nm 33%, 30.4 nm 17%, 9.4 nm 50%, respectively).

The primary mirror will have a clear aperture of 32 cm diameter. Wavelength selection will be done with a filter wheel as in SDO/AIA.

The optics will give an effective focal length of 20 m. Combined with a 10 $\mu$m pixel back-thinned CCD (4k $\times$ 4k format) this gives 0.1000/pixel sampling.

The secondary mirror will have an active mount that is actuated to remove instrument pointing errors and focus the system, as in TRACE and SDO/AIA. As in these instruments, HCI will have a guide telescope for Sun-tracking to feed the image stabiliser. This system will incorporate spacecraft pointing information to achieve the required pointing accuracy and stability.

Entrance filters will reject visible light. An aperture door protects them during launch, as in TRACE and SDO/AIA. A mechanical shutter near the focal plane controls the exposure time. Typical exposure times (as for the comparable channels of SDO/AIA) will range from 0.1 s for flares to 100 s for dark quiet-Sun targets.

The analog output from the single CCD will be converted into 14 bits. In standard observing, the readout area will cover only one quarter of the full FOV (2k $\times$ 2k pixels or 205000 $\times$ 205000) at an exposure cadence of 10 s.

The planned data rates for normal-cadence observations are 5.9 Mbps (raw), 2.9 Mbps (lossless) and 1.3 Mbps (lossy). In lossless compression each pixel value corresponds to 7 bits; in lossy compression only 3 bits. In fast small-area sampling 1024 $\times$ 1024 pixels (100000 $\times$ 100000) readout can reach 1 s cadence with lossy compression.

HCI will use large heritage from the comparable EUV imagers on-board TRACE and SDO/AIA. However, as the instrument will have 5–6 times better angular resolution, the following issues will be assessed during the definition phase:

- mirror micro-roughness, i.e., optimising multi-layer reflectance and minimising wide-angle scattering;
- effect of multi-layer coatings on effective area after masking;
- stabilisation at twice the resolution of IRIS;
- vibration from moving elements (as the filter wheel);
- effect of hits by energetic particles.
Fine-scale coronal structures inferred from Hinode

Fine-scale chromospheric structures observed by Hinode & GBO

Fine-scale kG photospheric structures inferred from Hinode

Wavelength (nm)

Spatial Resolution (arcsec)

Telescope diameter

0.1” = 70 km

SOLAR-C High-resolution Observations

Yohkoh 1991
Corona-imaging

Hinode 2006
Corona-imaging

Hinode 2006
Corona-imaging

Hinode 2006
Corona-imaging

SOHO 1995
Corona-imaging

SOHO 1995
Chrom.-Corona-spectroscopy

SDO 2010
Photospheric mag.

IRIS 2013
Chrom.-TR Spectroscopy

RHESSI 2002
HXR-imaging

Yohkoh 1991
HXR-imaging

FOXl 2012
HXR focusing imaging

SOHO 1995
Chrom.-Corona-spectroscopy

TRACE 1999

HiC 2012
Corona-imaging

SOLAR-C HCl
TR-Corona imaging

EUVST
Chrom-corona spectroscopy

SOLAR-C
SUVIT

W-b imaging
N-b imaging
spectro-polarimetry
(mag. fields)
Fine-scale coronal structures inferred from Hinode
Fine-scale chromospheric structures observed by Hinode & GBO
Fine-scale kG photospheric structures inferred from Hinode
SOLAR-C: Field of View (FOV)

- **SUVIT**: 184” x 184”
- **EUVST**: 280” x 280”
- **HCI**: 410” x 410”
- **SOT**: 320” x 160”

<table>
<thead>
<tr>
<th>SUVIT</th>
<th>FG</th>
<th>SP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WB</td>
<td>NB</td>
</tr>
<tr>
<td>Hi-Res.</td>
<td>61”x61”</td>
<td>90”x90”</td>
</tr>
<tr>
<td>Wide FOV</td>
<td>184”x184”</td>
<td>184”x143”</td>
</tr>
</tbody>
</table>
**SUVIT Filtergraph (FG)**

- **FOV, plate scale (4k x 4k camera):**
  - NB-High Res: 90” x 90”, 0.0225” pixels
  - NB-Wide FOV: 180” x 180”, 0.045” pixels
  - WB-High Res: 60” x 60”, 0.015” pixels
  - WB-Wide FOV: 180” x 180”, 0.045” pixels

### Wide bands

<table>
<thead>
<tr>
<th>Pass-bands</th>
<th>279 nm</th>
<th>380 nm</th>
<th>393 nm</th>
<th>TBD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum lines</td>
<td>Mg II k/h</td>
<td>CN band</td>
<td>Ca II K</td>
<td>continuum</td>
</tr>
</tbody>
</table>

### Narrow bands with a polarimeter

<table>
<thead>
<tr>
<th>Pass-bands</th>
<th>517 nm</th>
<th>525 nm</th>
<th>589 nm</th>
<th>656 nm</th>
<th>854 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum lines</td>
<td>Mg I b</td>
<td>Fe I</td>
<td>Na I D</td>
<td>H I α</td>
<td>Ca II</td>
</tr>
</tbody>
</table>
SUVIT Spectro-polarimeter (SP) to observe photospheric & chromospheric \textit{mag.} fields

0.07” slit width for slit obs.
0.2” slit width for IFU

<table>
<thead>
<tr>
<th>Wavelength bands</th>
<th>1083 nm</th>
<th>854 nm</th>
<th>525 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum lines</td>
<td>He I</td>
<td>Ca II</td>
<td>Fe I</td>
</tr>
<tr>
<td>Order</td>
<td>15</td>
<td>19</td>
<td>31</td>
</tr>
<tr>
<td>Wavelength sampling</td>
<td>45.2 mÅ</td>
<td>35.6 mÅ</td>
<td>21.9 mÅ</td>
</tr>
</tbody>
</table>
EUVST

- Optics: single off-axis mirror (30cmφ, f=360cm) and a grating
- Telescope length: 430cm

<table>
<thead>
<tr>
<th>Field</th>
<th>Required value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial resolution</td>
<td>≤0.28″</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>λ/Δλ 17 000 to 32 000</td>
</tr>
<tr>
<td>Doppler shift accuracy</td>
<td>≤ 2 km s⁻¹</td>
</tr>
<tr>
<td>Doppler width accuracy</td>
<td>≤ 5 km s⁻¹</td>
</tr>
<tr>
<td>Temperature coverage</td>
<td>0.01 to 20 MK</td>
</tr>
<tr>
<td>Field-of-view</td>
<td>slit length 280″</td>
</tr>
<tr>
<td>raster coverage</td>
<td>300″ (w/o re-pointing)</td>
</tr>
<tr>
<td>Exposure times</td>
<td>≤ 10 s (0.28″ sampling)</td>
</tr>
<tr>
<td>Mirror micro-roughness</td>
<td>about 3 Å rms or better</td>
</tr>
</tbody>
</table>

With low scattering optics, for exploring low EM regions (MR and CH).
EUVST

- Optics: single off-axis mirror (30cmφ, f=360cm) and a grating
- Telescope length: 430cm

With low scattering optics, for exploring low EM regions (MR and CH).
3.4 High Resolution Coronal Imager (HCI)

The HCI is a normal-incidence EUV telescope consisting of primary and secondary mirrors in Ritchey-Chrétien configuration. It will perform high-resolution imaging in the EUV pass-bands described in Section 2.4: 30.4 nm containing the He II resonance line as diagnostic of the transition region, 17.1 nm containing lines of Fe IX and Fe X showing 1 MK coronal structures at high contrast, and 9.4 nm containing Fe XVIII with emission in very hot outburst features.

Table 5 summarises key design features of HCI.

<table>
<thead>
<tr>
<th></th>
<th>HCI</th>
<th>SDO/AIA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optics</strong></td>
<td>EUV normal-incidence</td>
<td>EUV normal-incidence</td>
</tr>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>0.2”-0.3”</td>
<td>1.2”</td>
</tr>
<tr>
<td><strong>Cadence</strong></td>
<td>~&lt;2.0 s (typ. 10 s)</td>
<td>12 s</td>
</tr>
<tr>
<td><strong>Field of view</strong></td>
<td>~400” x 400”</td>
<td>full Sun</td>
</tr>
</tbody>
</table>
| **Temperature coverage** | \(5 \times 10^4\) K (He II 304Å)  \\
|                  | 6.3 \times 10^5\) K (Fe IX 171Å)   \\
|                  | 6.4 \times 10^6\) K (Fe XVIII 94Å) | 5 \times 10^4 \) K to \\
|                  | \(2.0 \times 10^7\) K in | Table 4.4-3                             |

The entrance filters will reject visible light. An aperture door protects them during launch, as in TRACE and SDO/AIA. A mechanical shutter near the focal plane controls the exposure time. Typical exposure times (as for the comparable channels of SDO/AIA) will range from 0.1 s for flares to 100 s for dark quiet-Sun targets. The analog output from the single CCD will be converted into 14 bits. In standard observing, the readout area will cover only one quarter of the full FOV (2k \(\times\) 2k pixels or 205,000 \(\times\) 205,000) at an exposure cadence of 10 s.
International Collaboration
A planned case of task share that world-wide solar physicists desire

EUVST (EUV Spectrograph)
ESA &
EUVST consortium

Launch vehicle: JAXA
Spacecraft: JAXA

- Proposed to US Heliophysics Decadal Survey
- EUVST: proposed to ESA Cosmic Vision II
- Submitted to JAXA-AO

**International Collaboration Table**

<table>
<thead>
<tr>
<th>Weight</th>
<th>2300 kg (w/o fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>3.7m x 3.2m x 7.1m</td>
</tr>
<tr>
<td>Power</td>
<td>5 kW generation @EOL</td>
</tr>
<tr>
<td>Data rate and DR volume</td>
<td>Average: 8 Mbps (×20 of Hinode)</td>
</tr>
<tr>
<td>Attitude control</td>
<td>3-axis attitude control</td>
</tr>
<tr>
<td>Orbit</td>
<td>a geosynchronous orbit</td>
</tr>
</tbody>
</table>

- Proposed to US Heliophysics Decadal Survey
- EUVST: proposed to ESA Cosmic Vision II
- Submitted to JAXA-AO
Coordinated Observations

Solar Orbiter

Credit: ESA/AOES

Solar Probe Plus

Credit: NASA/JHU APL

Solar Dynamic Observatory or a mission of full-disk observations

SOLAR-C
Summary

- SOLAR-C is a mission to understand the causal linkage between solar magnetic fields and active phenomena on the Sun and in the heliosphere.

- SOLAR-C equips three major payloads to elucidate fundamental problems in Helio-physics by high-resolution (0.1”–0.3”) imaging & spectroscopy with temporally stable chromospheric magnetometry.

- All telescopes of the SOLAR-C have capability to observe coronal rains with enough spatial resolution, enough cadence, and enough coverage of temperature.