Polarimetry and the Solar-C Mission

Kiyoshi Ichimoto (Kyoto Univ.)
Y.Suematsu, Y.Katsukawa, H.Hara (NAOJ),
T.Shimizu (JAXA)
and
JAXA SOLAR-C WG

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Many *Hinode* results are related to fundamental MHD processes.

- Waves
- Magnetic reconnection
- Local dynamo
- Flows
- Turbulence
- Instability
- Magneto-convection
But, they are not yet contributed to our full understanding of the solar magnetism

What we learned from *Hinode*;
- Many features are unresolved.
  > 80% of flux is invisible to Hinode/SP (Pietarila Graham+. 2010)
- Large mismatch in spatial resolution in the coronal (~2") and photospheric (~0.3") observations
- Blind to chromosphere in terms of physical diagnostics
- Blind to transition region
- Insufficient time resolution of spectroscopic observations
The unique approach of the Solar-C
Observations of All from photosphere to corona seamlessly as a system

- **Resolve** sun’s elementary structures in space and in time.
- Determine **3D magnetic field** from photosphere to corona.
- Observe the **entire temperature regime** seamlessly \((3 \cdot 10^3 - 10^7 \text{ K})\)
- Determine **physical quantities** of plasma before and after thermalization
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**Need**

→ **Large aperture telescopes**

→ **High precision spectro-polarimetry in Vis/NIR**
→ **Coordinated set of telescopes to cover from IR to EUV**
→ **High resolution EUV spectroscopy**
Critical scales

Spatial scale; (1” ~ 720km on the sun)
- 0.1” photospheric magnetic field \(\leftarrow\) kG B, photon mean free path
- chromospheric density structure \(\leftarrow\) recent ground obs.
- 0.3” chromospheric magnetic field \(\leftarrow\) expansion from photo.
- coronal density structures \(\leftarrow\) EIS/Hinode fill factor, HI-C obs.
- ~200” AR size \(\rightarrow\) FOV

Time scale;
- ~1sec flares, high energy events
- ~10sec dynamics of fine scale structures
- ~10min active region evolution, energy storage
SOLAR-C spacecraft

**Mission goal:**
To understand how the Sun sustains its dynamic atmosphere that governs our space environment and the physics of fundamental processes of magnetized plasma in the Universe.

**EUVST:**
High throughput EUV spectrograph
- ~0.3” spatial resolution
- Wide temperature coverage
- High temporal cadence

**SUVIT:**
1.3~1.4m UV-visible-NIR telescope
- 0.1” spatial resolution
- High precision spectro-polarimetry

**HCI:**
High resolution Corona Imager
- 0.2~0.3” spatial resolution

International project led by JAXA, ESA and NASA aiming for the launch in 2023
JAXA Mission proposal by 16 Feb. 2015
ESA M4 proposal by 15 Jan. 2015

<table>
<thead>
<tr>
<th>Weight:</th>
<th>2300kg (w/o fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size:</td>
<td>3.7m x 3.2m x 7.1m</td>
</tr>
<tr>
<td>Orbit:</td>
<td>Geosynchronous</td>
</tr>
<tr>
<td>Power:</td>
<td>5 kW (EOL)</td>
</tr>
<tr>
<td>Data rate:</td>
<td>Av. &gt;8Mbps (&gt; x20 of Hinode)</td>
</tr>
</tbody>
</table>
SUVIT (Solar UV-Vis.-IR Telescope)

Aplanatic Gregorian telescope with a polarization modulator and collimator
Focal plane instruments

- Spectro-polarimeter (SP)
  - 525, 854, 1083nm
- Narrowband Filter Imager (NFI)
  - 500 ~ 1083nm
- Blue Channel (BC)
  - 280 ~ 450nm
- Broadband Filter Imager (BFI)
- UV Spectro-polarimeter (USP; option)
Focal plane instruments

Interface Unit (IU)

~1500

High reso.

wide

shutter

Filterwheel

Tunable filter

camera

280nm spectro-polarimeter (optional)

grating

Broad-band imager

Inspection ports
Plate scales (not final)

<table>
<thead>
<tr>
<th></th>
<th>SOT/Hinode</th>
<th>SUVIT/Solar-C</th>
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<tbody>
<tr>
<td><strong>BC</strong></td>
<td>Spatial sampling 0.054”</td>
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<td>10⁻³</td>
<td>10⁻³ - 10⁻⁴</td>
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# SUVIT wavelength (candidates)

<table>
<thead>
<tr>
<th>Spectrum bands</th>
<th>SP</th>
<th>NFI</th>
<th>BFI</th>
<th>USP</th>
<th>Purpose</th>
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<tr>
<td><strong>Continuum</strong></td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>T in the upper photosphere</td>
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<tr>
<td>Mg II k</td>
<td>279 nm</td>
<td>x</td>
<td>x</td>
<td>T and V (and B) in the chromosphere</td>
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<tr>
<td>CN band</td>
<td>388 nm</td>
<td>x</td>
<td></td>
<td>Magnetic elements in the photosphere</td>
<td></td>
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<tr>
<td>Ca II K</td>
<td>393 nm</td>
<td>x</td>
<td></td>
<td>Structures in the chromosphere</td>
<td></td>
</tr>
<tr>
<td>G (CH)</td>
<td>430 nm</td>
<td>TBD</td>
<td></td>
<td>Magnetic elements in the photosphere</td>
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<tr>
<td>Blue cont.</td>
<td>450 nm</td>
<td>x</td>
<td></td>
<td>Imaging and T in the photosphere</td>
<td></td>
</tr>
<tr>
<td>Mg I b</td>
<td>517 nm</td>
<td>x</td>
<td></td>
<td>V and B in the low chromosphere</td>
<td></td>
</tr>
<tr>
<td>Fe I</td>
<td>525 nm</td>
<td>x</td>
<td>x</td>
<td>V and B in the photosphere</td>
<td></td>
</tr>
<tr>
<td>Fe I</td>
<td>557 nm</td>
<td>TBD</td>
<td></td>
<td>V in the photosphere</td>
<td></td>
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<tr>
<td>Na I D</td>
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<td>TBD</td>
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<td>V and B in the low chromosphere</td>
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<tr>
<td>Fe I</td>
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<td>x</td>
<td></td>
<td>V and B in the photosphere</td>
<td></td>
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<tr>
<td>H I α</td>
<td>656 nm</td>
<td>x</td>
<td></td>
<td>Structures in the chromosphere</td>
<td></td>
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<tr>
<td>Ca II</td>
<td>854 nm</td>
<td>x</td>
<td>x</td>
<td>T, V, and B in the chromosphere</td>
<td></td>
</tr>
<tr>
<td>He I</td>
<td>1083 nm</td>
<td>x</td>
<td>(x)</td>
<td>V and B in the chromosphere</td>
<td></td>
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</table>

![Graph showing wavelength bands](image)
Spectro-polarimeter
Coating on mirrors

We selected Ag coating for:
- high throughput in Vis.-IR
- less heat absorption at the primary mirror

For 280nm → a special coating on Ag
Pol. Modulator; Quartz+Sapphire waveplate

Sueoka-san’s data, courtesy D. Elmore

\[
\Delta T = +/- 5C
\]

Good modulation for polarimetry

Tolerance +/- 3.7deg. ~ 0.01wav

Continuous rotation 1rev./sec
Data acquisition for polarimetry

To achieve N/S~ $3 \times 10^{-4}$ within, we need to collect $10^7$ photons or ~1000 frames in 10sec

→ high sensitivity in Vis. & IR
→ fast readout, onboard accumulation

IR/Vis. camera

Teledyne Co.
H2RG FPA, SIDECAR ASIC, HgCdTe, 2k x 2k pixels, 18μm/pix

Space qualified
(TRL-6 for H2RG, TRL-9 for SIDECAR)

Proposed onboard demodulation
→ IQUVR

Readout 64 frames/sec, (WP 1 sec/rot)
& onboard demodulation
SP options under study

**Integral Field Unit;** issue
- optical fiber bundle polarization property, fabrication
- image slicer accommodation, coating on slicer

**Cameras configuration;** 1 camera vs 3 cameras

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**Advantages**
- Simultaneous obs of the three spectrum lines.
- No need of the filter wheel.
- The tilt adjust mechanism of the grating can be simpler.
- The PBS consisting of the calcite blocks can be optimized at each wavelength.
- Optical design of the relay optics becomes easy because there is no chromatic aberration at each optical path.

**Disadvantages**
- Three cameras are necessary (resources).
- Three optical paths are necessary (fabrication and alignment, resources).
Gain from a higher spatial resolution

kG Flux Tube (FT) & Magneto-convection

- Existence of FT predicted from polarimetric obs.
- Existence of FT Proven
- Motion of FT tracked
- 80% FT not resolved
- kG FT mostly resolved
- ~50 times of encounters of opposite polarities
- small-scale vortex & current

In addition, Solar-C will measure magnetic fields in higher layer too.
2D spectro-polarimetry for chromosphere

Mysterious spicule

SUVIT will see fine scale connection between photo. & chrom., current sheets, mag.reconnection, shock,...

What is going on at the foot point of spicules?
- Component reconnection?
- Vortex and twist?
- Emerging flux?
Jump from SOT/Hinode

- Spatial resolution
- Spectro-polarimetry for chromosphere
- Time cadence (especially magnetic field data)

Highly complemental with large ground telescopes

<table>
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<th>DKIST, EST, SUVIT</th>
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| - The highest spatial resolution
  - Developing focal plane instruments and flexible operation
  - Coronagraphic observation |
| - High precision at high spatial resolution
  - Uniform data over wide FOV and time
  - Continuous obs. 24hr/day |
Summary

- Solar-C is an international project led by JAXA, ESA and NASA, and we are about submitting the mission proposals to JAXA and ESA in two month.
- SUVIT is a high precision polarimeter to measure the magnetic fields in solar photosphere and chromosphere at ever highest spatial resolution and precision.
- There still remain undetermined parameters of SUVIT instrument, which will be fixed in a coming year.
- Suggestions and opinions from the community are welcome.
Thank you for listening!
Basic Problems in Helio-Physics to be tackled by Solar-C

1. Formation of the dynamic solar atmosphere; chromosphere, corona and solar wind

   **Steller astronomy**

2. Mechanism of large-scale explosion and its forecast

   **Space weather**

The key is to understand fundamental physical processes of magnetized plasma

**Plasma physics**

3. Origin of magnetic cycle

   **Space climate**

![Sunspot Number vs Time](chart.png)
Fiber IFU experiment

Epoxi glued fiber ribbons
Mueller matrix of fiber ribbon

Ideal Mueller matrix

\[
\begin{pmatrix}
I_{out} \\
Q_{out} \\
U_{out} \\
V_{out}
\end{pmatrix} =
\begin{pmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & x & 0 \\
0 & 0 & 0 & x
\end{pmatrix}
\begin{pmatrix}
I_{in} \\
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Good preservation of the linear polarization (Q).
Science requirements are realized by two complementary instruments; Filtergraph (FG) & Spectro-polarimeter (SP)
### SUVIT basic param’s (not final)

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