The next-generation space solar observatory:

The SOLAR-C Mission

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JAXA SOLAR-C WG
2015 Nov 4

APSPM in Seoul National University
SOLAR-C Proposals 2015

• Assume JAXA + ESA + Europe + USA Collaboration; Target launch year in 2023

• 1\textsuperscript{st} JAXA Strategic Medium Mission:
  – AO: 2014 Dec 26
    (Announcement of Opportunity)
  – Proposed by Solar-C WG (2015 Feb 16)

• 4\textsuperscript{th} ESA Medium-class Mission:
  – AO: 2014 Aug 19
  – Proposed by EPIC consortium (2015 Jan 16)
    • EPIC (European Participation In Solar-C)
Solar-C Project View

1. To understand the plasma dynamics as a system that connects the solar surface to the solar corona and interplanetary space

2. To investigate the elementary processes that take place universally in cosmic plasmas, the both of which also contribute to the comprehension and the prediction of solar activity that could give impact on the earth and the human society.

(C) JAXA, NAOJ
**Science Objectives**

1. Investigate the formation mechanisms of the chromosphere, the corona, and the solar wind
2. Understand the physical origin of large scale solar eruptions to extract the algorithm for prediction
3. Reveal the mechanism of solar spectral irradiance variation of the climate change of the earth
Solar-C Approach

Observations of All from photosphere to corona seamlessly as a system

SOLAR-C will

- Resolve the elemental structures of solar atmospheres and observe their changes with necessary cadences,
- Determine the properties and evolution of the 3D magnetic field $B$, measuring photospheric and chromospheric $B$, and estimating coronal $B$ from the former information,
- Observe all the temperature regimes of the atmosphere seamlessly and simultaneously, and
- Obtain spectroscopic information on dynamics of elementary processes taking place in solar atmosphere.
Solar-C Science Cases:

I: Formation mechanisms of chromosphere, corona, and solar wind

SOLAR-C will

• Understand formation mechanism of spicules and their influence in the corona.

• Verify the nanoflare hypothesis.

• Verify the wave heating.

• Understand the magnetic structure at the source regions of solar winds and their acceleration mechanism.

• Understand the prominence formation mechanism.
Causal linkage in Solar Atmosphere
Observations of All from photosphere to corona seamlessly

Hinode
Cirtain et al. 2012
Solar-C Science Cases:

II: Mechanism of large-scale solar eruptions and algorithm for prediction

SOLAR-C will

• Measure energy buildup processes in flaring and CME regions.
• Identify the trigger mechanism of solar flares and CMEs.
• Clarify the mechanisms of destabilizing and erupting of the entire system.
• Understand the processes of fast magnetic reconnection.
Magnetic Reconnection
Study of a Fundamental Physical Process

Yohkoh

Hinode & SDO

SOLAR-C

- High-resolution (0.3") imaging & spectroscopy in chromosphere-corona
- Higher sensitivity (>×10) than Hinode in spectroscopy
- Growth of sheet structure by high-cadence (>×5) obs.
- MHD shock structure for heating outflows
Solar-C Science Cases:

III. Mechanism of solar spectral irradiance variation that could influence the climate change of the earth

SOLAR-C will

- Understand the UV irradiance in tiny magnetic structures.
- Construct a model capable to reproduce total and spectral solar irradiance by incorporating fine scale magnetic structures.
### Solar-C Science objectives (proposed in 2015)

#### I. Formation mechanism of chromosphere, corona and solar wind

<table>
<thead>
<tr>
<th>I-1</th>
<th>Spicule</th>
<th>Foot point B topology, shock, twist</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-2</td>
<td>Nano-flare heating</td>
<td>Tiny brightening, non-thermal plasma</td>
</tr>
<tr>
<td>I-3</td>
<td>Wave heating</td>
<td>Wave mode, energy flux, dissipation</td>
</tr>
<tr>
<td>I-4</td>
<td>Solar wind acceleration</td>
<td>B topology in CH, Alfvén wave in corona</td>
</tr>
<tr>
<td>I-5</td>
<td>Prominence</td>
<td>B field structure, mass circulation</td>
</tr>
</tbody>
</table>

#### II. Physical origin of large-scale eruptions and algorithm for prediction

<table>
<thead>
<tr>
<th>II-1</th>
<th>Energy storage</th>
<th>Photo./chrom. B field maps</th>
</tr>
</thead>
<tbody>
<tr>
<td>II-2</td>
<td>Trigger mechanism</td>
<td>Emerging flux, interaction with chrom. B</td>
</tr>
<tr>
<td>II-3</td>
<td>Mechanism of explosion</td>
<td>Large scale dynamics, current system</td>
</tr>
<tr>
<td>II-4</td>
<td>Physics of fast reconnection</td>
<td>Current sheet, plasmoid, shock</td>
</tr>
</tbody>
</table>

#### III. Mechanism of solar spectral irradiance variation

<table>
<thead>
<tr>
<th>III-1</th>
<th>Mechanism of UV emission</th>
<th>UV emissions at fine scale B structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>III-2</td>
<td>TSS/SSI modeling</td>
<td>TSI/SSI, full-disk B map</td>
</tr>
</tbody>
</table>
Requirements  
(not all shown)

- **Spatial resolution**: Photosphere (Ph.) / Chromosphere (Ch.): 0.1”, Ch. B: 0.3”, Transition Region (TR)/Corona: 0.3”
- **Temporal resolution**: 1.0 sec
- **FOV**: Ph./Ch.: >40”×40” for 0.1” resol., >160”×130” for 0.2” resol.  
  TR/Corona: >240” ×240”
- **Photometric sensitivity**: Ph./Ch.: < 1%, TR/Corona: < 5%
- **Line of sight V**: < 0.1 km/s for Ph./Ch., < 1 km/s for TR/Corona
- **Mag. Fields B**: Photosphere  \( B_L < 2 \) G, \( B_T < 70 \) G  
  Chromosphere: \( B_L < 10 \) G
- **Simultaneous observations of photosphere to corona for targets**
- **Continuity of observations**: > 3hr for fine scale, < 2 weeks for AR
- **Mission life**: > 3 yrs near solar activity maximum
SOLAR-C Spacecraft

EUVST (EUV Spectrograph)

Hinode
50cm dia. telescope

SUVIT/TA
1.4m diameter telescope

SUVIT/FG

SUVIT/UBIS

SUVIT/SP

SUVIT/IU

Sun Sensor

HINODE

Weight | 2300 kg (w/o fuel)
Size    | 3.7m x 3.2m x 7.1m
Power   | 5 kW generation @EOL
Data rate and DR volume | Average: 8 Mbps (×20 of Hinode)
                     | DR volume: 100GB
Attitude control | 3-axis attitude control
Orbit     | a geosynchronous orbit
SOLAR-C payload

1.4 m diameter telescope

SUVIT
Solar UV-Visible-IR Telescope

UBIS
Ultraviolet Broadband Imager

Spectro-polarimeter (SP)

HCl (High Resolution Coronal Imager)

EUVST (EUV Spectrograph) + IM (Irradiance Monitor)
Regions to be observed by SOLAR-C

- Corona
- Chromosphere
- Photosphere

SOLAR-C

HINODE

- Plasma β
- Temperature

- Photosphere
- Chromosphere
- Transition Region
- Corona

Height (km) from photosphere

Temperature

plasma β

$10^6$ K

$10^3$ K

$10^4$ K

$10^{-4}$

$10^{-3}$

$10^{-2}$

$10^{-1}$

$10^1$

$10^2$

$10^3$
SOLAR-C: Field of View (FOV)

**SUVIT**
- 0.1” res.
- 184” x 184”

**EUVST**
- 0.3” res.
- 280” x 280”

**HCl**
- 0.3” res.
- 410” x 410”

**SOT 320”x160”**

<table>
<thead>
<tr>
<th><strong>SUVIT</strong></th>
<th><strong>UBIS</strong></th>
<th><strong>FG</strong></th>
<th><strong>SP</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hi-Res.</td>
<td>USP</td>
<td>61”x61”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70”x70”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide FOV</td>
<td>UBI</td>
<td></td>
<td>184”x184”</td>
</tr>
<tr>
<td></td>
<td>120”x120”</td>
<td></td>
<td>184”x143”</td>
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</tbody>
</table>

- He II 30.4
- Fe IX 17.1
- Fe XVIII 9.4

<table>
<thead>
<tr>
<th>1st order band</th>
<th>λ1: 17 – 22nm</th>
</tr>
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<tbody>
<tr>
<td>λ2: 69 – 85nm</td>
<td></td>
</tr>
<tr>
<td>λ3: 92 – 109nm</td>
<td></td>
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<tr>
<td>λ4: 112–128nm</td>
<td></td>
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</tbody>
</table>

- Mg II 280
- Ca II 393
- CN 388
- CH 430
- Cont.432 225, 260
- Fe I 525
- Na I 589
- Fe I 617
- H I 656
- Ca II 854
- He I 1083

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- Na I 589
- Fe I 617
- H I 656
- Ca II 854
- He I 1083
Proposed International Task Share

- EUVST (ESA) + IM (Irradiance Monitor)
- SUVIT-TA (JAXA, ESA)
- SUVIT-UBIS (ESA)
- SUVIT-SP (JAXA, ESA)
- SUVIT-FG (NASA)
- HCI (NASA)
- JAXA strategic medium mission
- ESA Cosmic Vision II, M4
- US Heliophysics Decadal Survey

Launcher: JAXA
S/C bus: JAXA, ESA
Coordinated Observations

Solar Orbiter
Credit: ESA/AOES

Solar Probe Plus
A NASA Mission to Touch the Sun
Credit: NASA/JHU APL

(Daniel K. Inouye Solar Telescope)
DKIST

Solar Dynamic Observatory
or a mission of full-disk observations

SOLAR-C
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Phase of JAXA Science Project

- **Pre Phase A**
- **WG**
- **Pre-Project 1**
- **Pre-Project 2**
- **Phase A-1**
- **Phase A-2**
- **Phase B/C/D/E**

**Time Flow:***
- **MDR** (Mission Definition Review)
- **AO** (Announcement of Opportunity)
- **Reviews**
MDR Results

• EPIC: not selected by ESA (2015 Jun 5).
• SOLAR-C Proposal to JAXA
  – Five missions (three Science and two Engineering missions) proposed for the JAXA 1st Strategic Mission
  – 1st priority recommendation among three Science missions under a condition (= visibility for international task share) by Science Advisory Committee.
  – None among five was selected. Sample return from Mars satellite has selected as Candidate for 1st Strategic Mission.
  – did not pass MDR (2015 Sep) because
    • the condition of international task share is not satisfied.
    • some science/technical feasibility is not well verified.
  – Assessment of Evaluation Committee (EC):
    • Re-study by WG with careful consideration of mission size
Japanese Space Solar Observations

**SOLAR MAX**
- 1980
- 1990
- 2000
- 2010
- 2020
- 2030

**Spacecraft**
- **Hinotori**
  - (Hard X-rays, γ-rays)
- **Yohkoh**
  - (SXR, HXR, γ-rays)
- **Hinode**
  - (Visible, EUV, soft X-rays)
- **SOLAR-C**
  - (UV, Visible, NIR, EUV)

**Launches**
- Sounding Rocket (since late 1960’s)
  - S520-5CN
  - S520-22CN
- **CLASP**
- **SOLAR MAX**
- **SOLAR MAX**
- **SOLAR MAX**
- **SOLAR MAX**
- **SOLAR MAX**

**Phases**
- Planning
- Development
- Operation
- Launch
Toward Updated Proposal

• Target Mission Size:
  – Cost Reduction with Focused Science
  ➔ Smaller SUVIT with band selections, simpler EUVST, low-cost coronal imager
  – Affordable size: JAXA + Europe + ESA MoO + NASA MoO:
  – Synergy with other mission/facility (SOLO, DKIST,..)

• Promotion of international collaboration:
  – Set up Science and Technology Definition Team in NASA
  – Seek for ESA MoO

• Effort on moving from WG to Pre-Project
  – Re-definition of Solar-C science targets
  – Improve science and technical feasibility by further studies
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.

• JAXA SOLAR-C WG is updating the SOLAR-C mission proposal with more focused science for a coming opportunity (2\textsuperscript{nd} Strategic Mission) with US and European institutes.