高感度太陽紫外線分光観測衛星　SOLAR-C

The SOLAR-C Mission

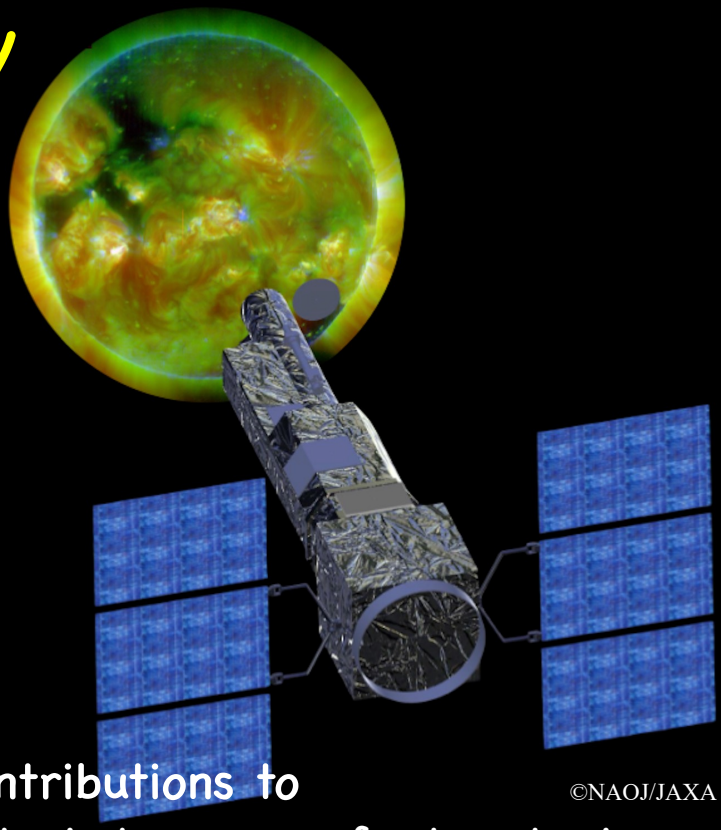
a satellite mission for a high-throughput EUV Imaging Spectroscopy of the Sun

H. Hara
National Astronomical Observatory of Japan
and JAXA

and the SOLAR-C Team

Project Summary

- SOLAR-C has become a JAXA Project. (Mar 2024)
  (a competitively-chosen M-class mission)
- The launch with Epsilon-S rocket is scheduled for FY2028. Orbit: sun-synchronous polar orbit of 600 km altitude
- Science Objectives: to understand
  - how fundamental processes lead to the formation of the solar atmosphere and the solar wind.
  - how the Sun influences the Earth and other planets in our solar system



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- SOLAR-C payload:
  - EUVST (0.4" resolution, 1s cadence, wide EUV λ coverage)
    - EUV imaging spectrometer [17-125 nm]
    - UV slit-jaw imager [280nm band]
  - EUV solar spectral irradiance monitor

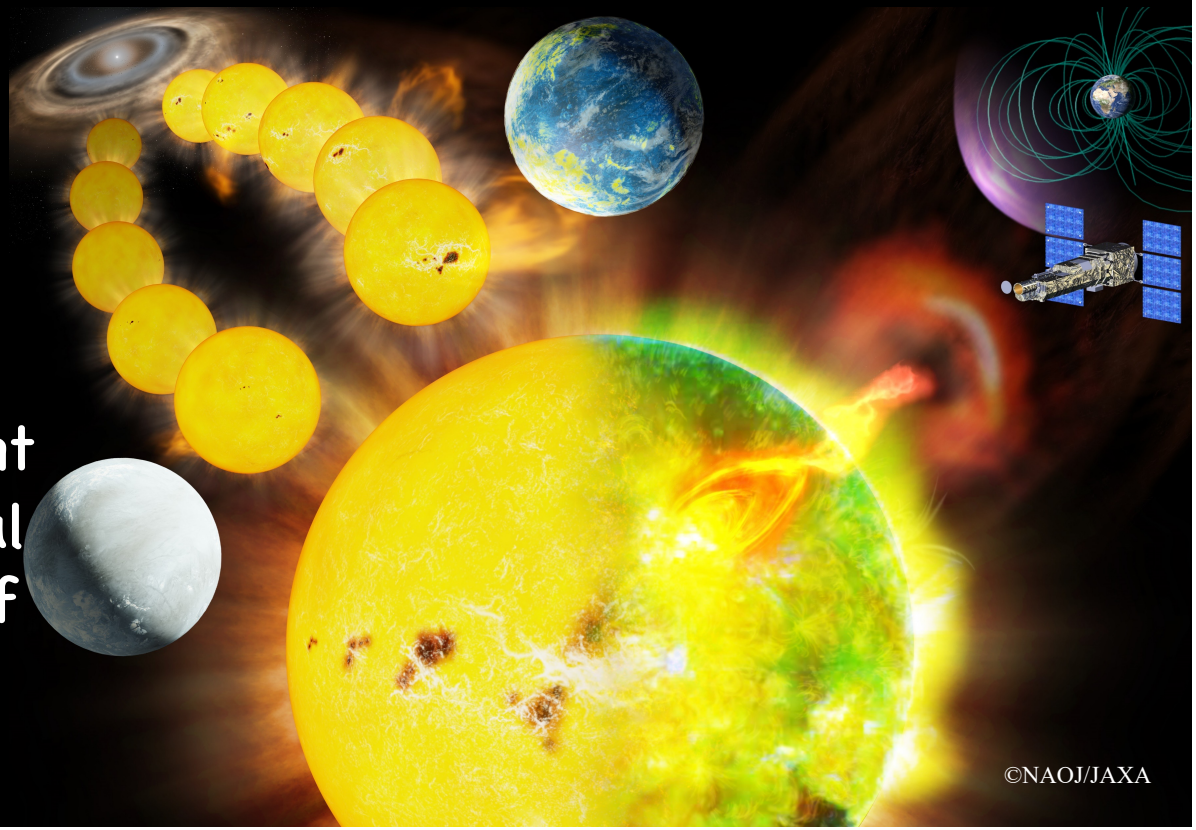
- Outcomes: contributions to
  1. Fundamental physical processes for target science
  2. Space weather prediction
  3. Plasma/atomic physics
  4. Past space climate, and
  5. Developing key technology in space instrumentation

Science Goals

for understanding the physical processes

- how the plasma universe is created and evolves
- how the Sun influences the Earth and other planets in our solar system

The resultant plasma environment in the heliosphere may be pivotal for establishing the conditions of our life and habitability.



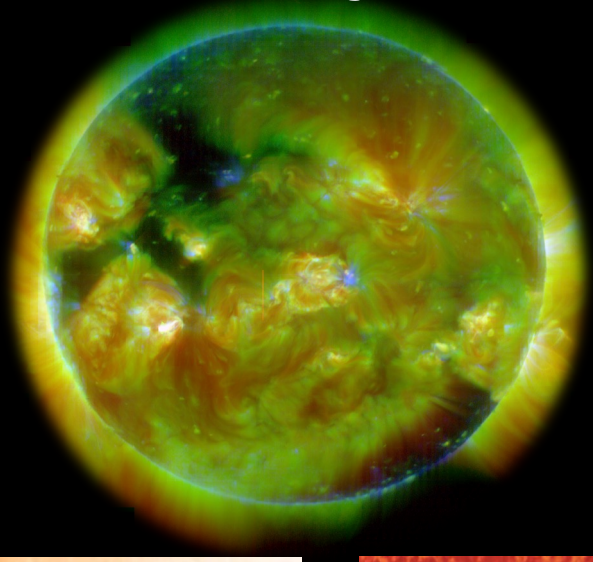
Science Objectives

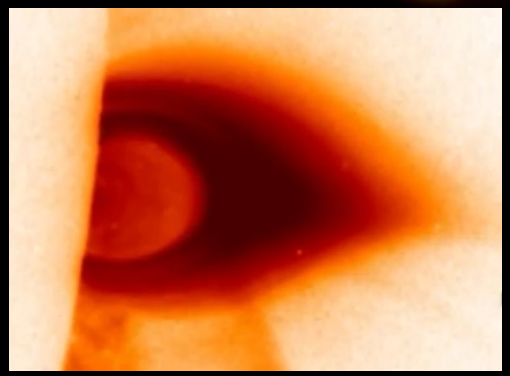
for understanding the physical processes by studying the Sun

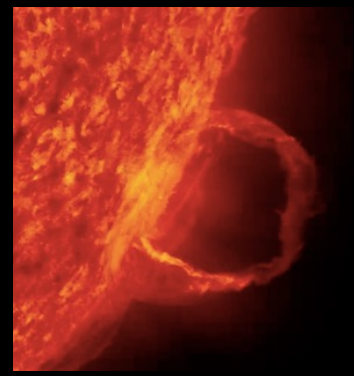
Questions to be answered:

I. how fundamental processes lead to the formation of the solar atmosphere and the solar wind.

II. how the Sun influences the Earth and other planets in our solar system







Science Objectives

for understanding the physical processes by studying the Sun

I. how fundamental processes lead to the formation of the solar atmosphere and the solar wind.

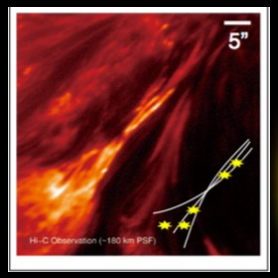
i. Quantify the contribution of Nanoflares to Coronal Heating

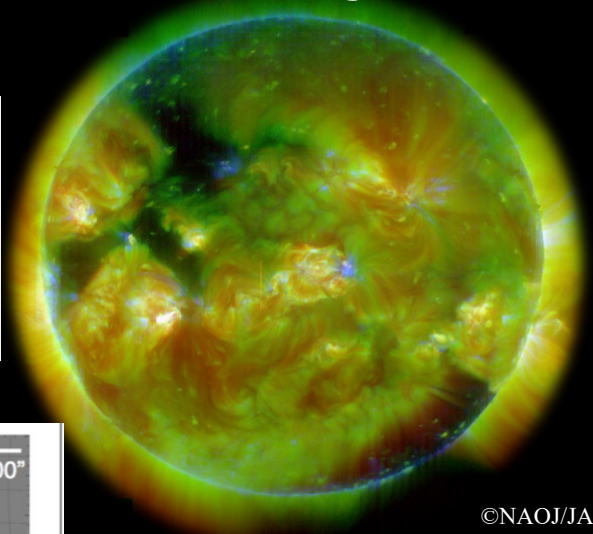
ii. Quantify the contribution of Wave Dissipation to Coronal Heating

iii. Understand the Formation Mechanism of Spicules and quantify their contribution to Coronal Heating

iv. Understand the source regions and the acceleration mechanism of the Solar Wind

(i) Nanoflares





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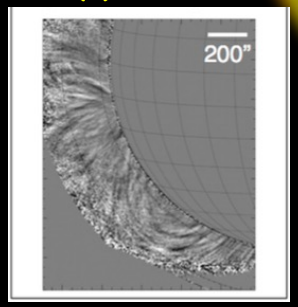
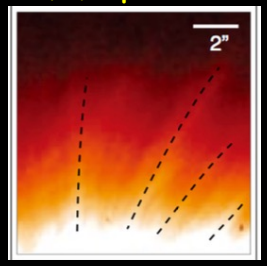
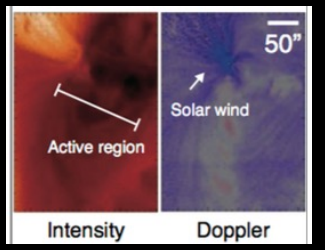
(ii) Waves



(iii) Spicules



(iv) Solar Wind



References:
(i) Cirtain et al. (2013)
(ii) Tomczyk et al. (2007)
(iii) De Pontieu et al. (2007)
(iv) Harra et al. (2008)

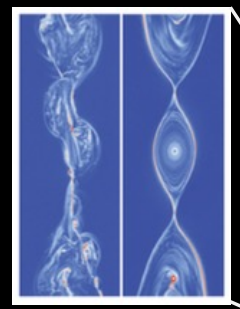
Science Objectives

for understanding the physical processes by studying the Sun

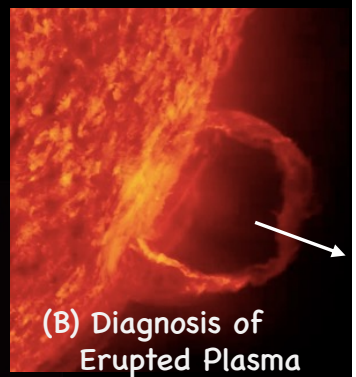
II. how the Sun influences the Earth and other planets in our solar system

i. Understand the Fast Magnetic Reconnection Process (A) and (C)

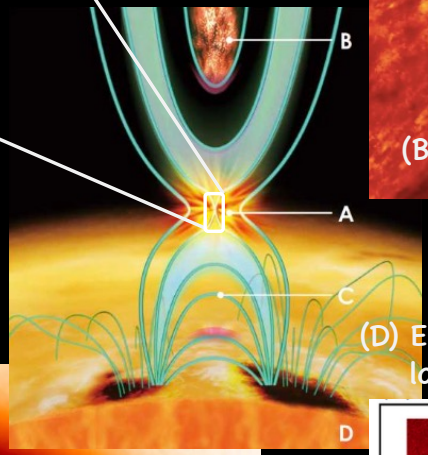
ii. Identify the Signatures of Global Energy Buildup and the Local Triggering of the Flare and Eruption (B) and (D)



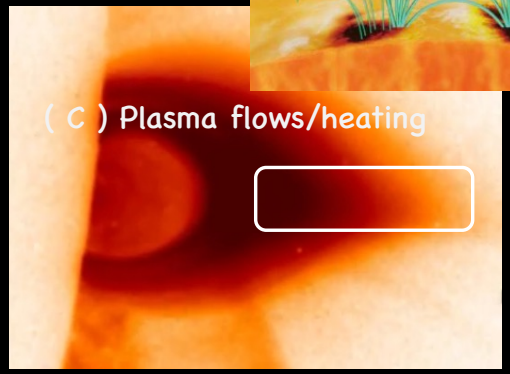
(A) Diagnosis of MR Process



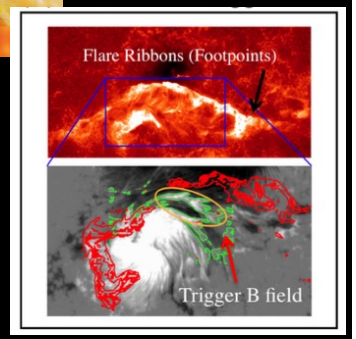
(B) Diagnosis of Erupted Plasma



(D) Energy Buildup and local triggering



(C) Plasma flows/heating



References

A) Daughton et al. **(2011)**

B) Data from NASA SDO

C) Data from JAXA Hinode

D) Bamba et al. (2013)

SOLAR-C approach and science instruments

- SOLAR-C tackles the following observations:
  - **Wide temperature coverage:** (log T_e [K] = 4.3-7.2)
    To seamlessly observe all the temperature regimes of the atmosphere from the chromosphere to the corona simultaneously,
  - **High resolution (0.4") & high throughput (~1s):**
    To resolve elemental structures of the solar atmosphere and track their changes with sufficient cadence, and,
  - **Spectral diagnosis: (Te / Ne / V_D / abundance)**
    To obtain spectroscopic information on the dynamics of elementary processes taking place in the solar atmosphere.

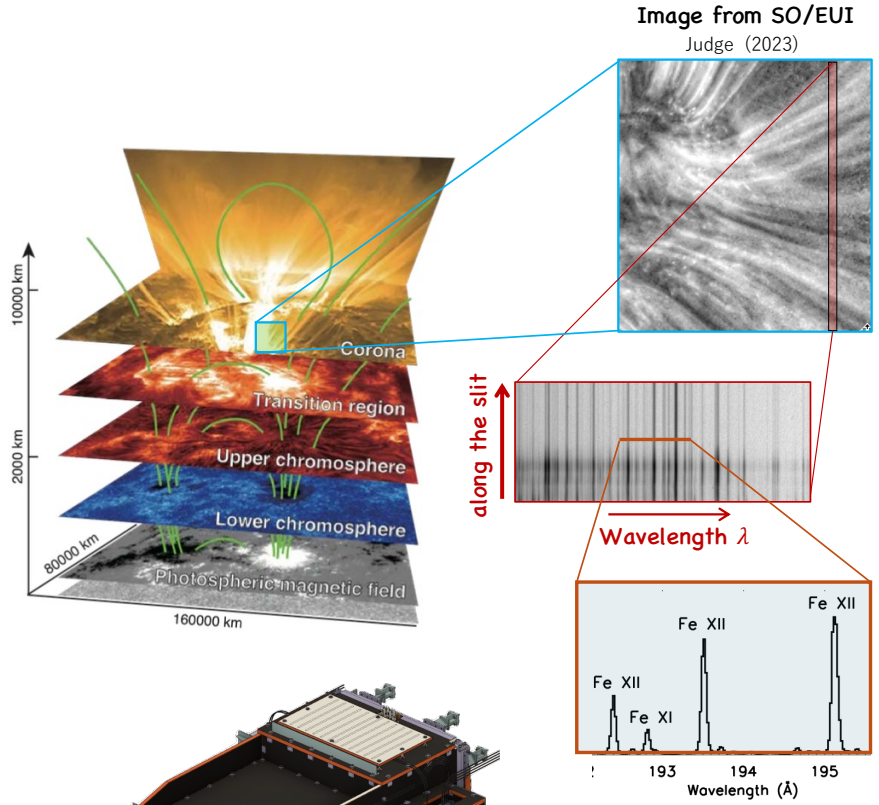
- SOLAR-C Science Payload

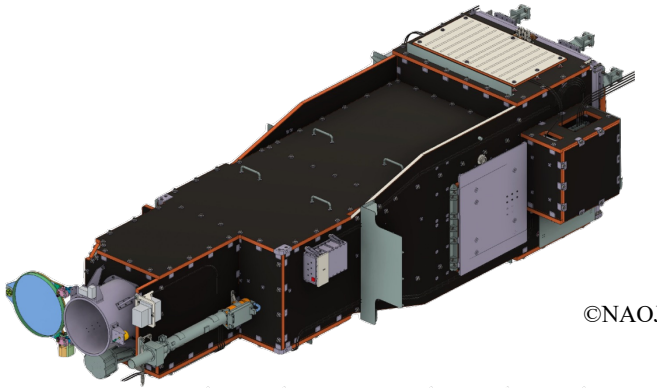
  EUVST (EUV high-throughput Spectroscopic Telescope)

  Imaging Spectrometer in EUV

  Slit-Jaw Imager in UV

  Solar Spectral Irradiance Monitor in EUV





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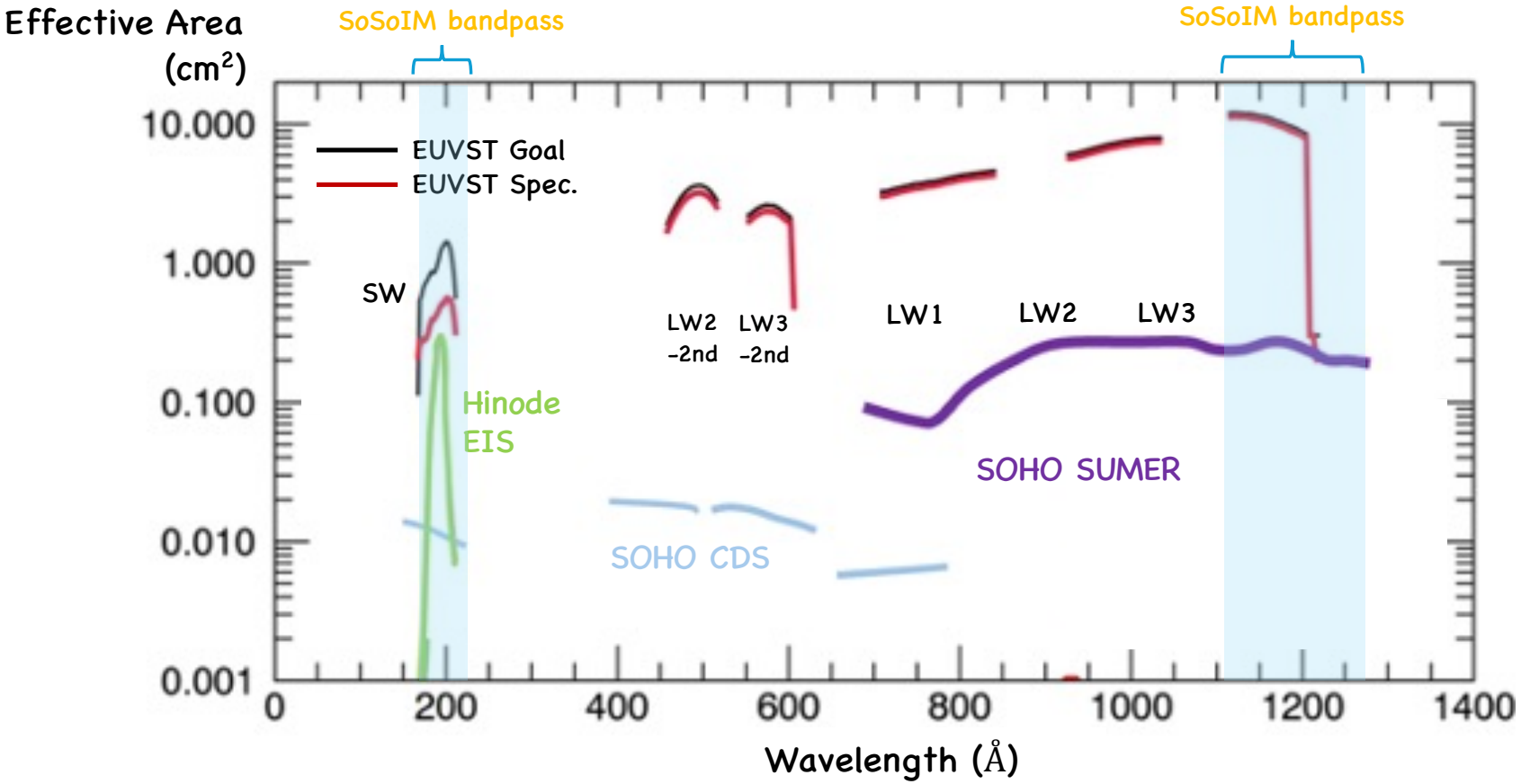
EUVST Sensitivity
in Spectrometer's Working Wavelengths

- A highly improved sensitivity from the EUV spectrometers so far developed

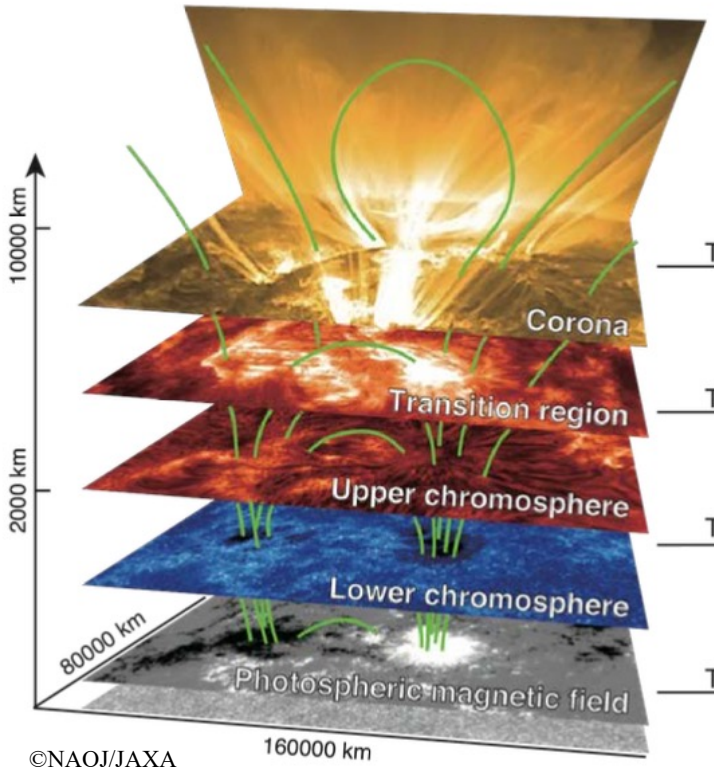


Temperature Coverage in EUV Observations

Spectral lines observed with spectrometers

Spatial resolution 3 arcsec 0.4 arcsec

Low count rate high count rate from the same area



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	Hinode/EIS	SOLAR-C/EUVST
10^7 K	Fe XXIV ($T\sim10^{7.2}$) Fe XXIII ($T\sim10^{7.1}$)	Fe XXIV ($T\sim10^{7.2}$) Fe XXII ($T\sim10^{7.1}$) Fe XXI ($T\sim10^{7.1}$) Fe XX ($T\sim10^{7.0}$) Fe XIX ($T\sim10^{7.0}$) Fe XVIII ($T\sim10^{6.8}$)
	N/A	
	Ca XVII ($T\sim10^{6.7}$)	Ca XVII ($T\sim10^{6.7}$) Ca XVI ($T\sim10^{6.7}$) Ca XV ($T\sim10^{6.7}$) Ca XIV ($T\sim10^{6.6}$)
	Fe XVI ($T\sim10^{6.4}$) Fe XV ($T\sim10^{6.3}$) Fe XIV ($T\sim10^{6.3}$) Fe XIII ($T\sim10^{6.2}$) Fe XII ($T\sim10^{6.1}$)	Fe XIV ($T\sim10^{6.3}$) Fe XIII ($T\sim10^{6.2}$) Fe XII ($T\sim10^{6.1}$)
10^6 K $T\sim10^6$ - 10^7 K	Fe XI ($T\sim10^{6.1}$)	Fe XI ($T\sim10^{6.1}$)
	Fe X ($T\sim10^{6.0}$) Fe VIII ($T\sim10^{5.8}$)	Fe X ($T\sim10^{6.0}$) Fe IX ($T\sim10^{5.9}$) Ne VII ($T\sim10^{5.8}$)
10^5 K $T\sim10^5$ K	N/A	
	He II ($T\sim10^{4.7}$)	O VI ($T\sim10^{5.5}$) S V ($T\sim10^{5.2}$) O IV ($T\sim10^{5.2}$) N IV ($T\sim10^{5.1}$) C III ($T\sim10^{4.8}$) C II ($T\sim10^{4.6}$) Si III ($T\sim10^{4.5}$) N IV ($T\sim10^{5.1}$) He I ($T\sim10^{4.3}$)
10^4 K $T\sim10^4$ K	N/A	H I ($T\sim10^{4.3}$)
		Mg II k (SJI)
		Mg I (SJI)
$T\sim6000$ K		continuum (SJI)

SoSpIM irradiance

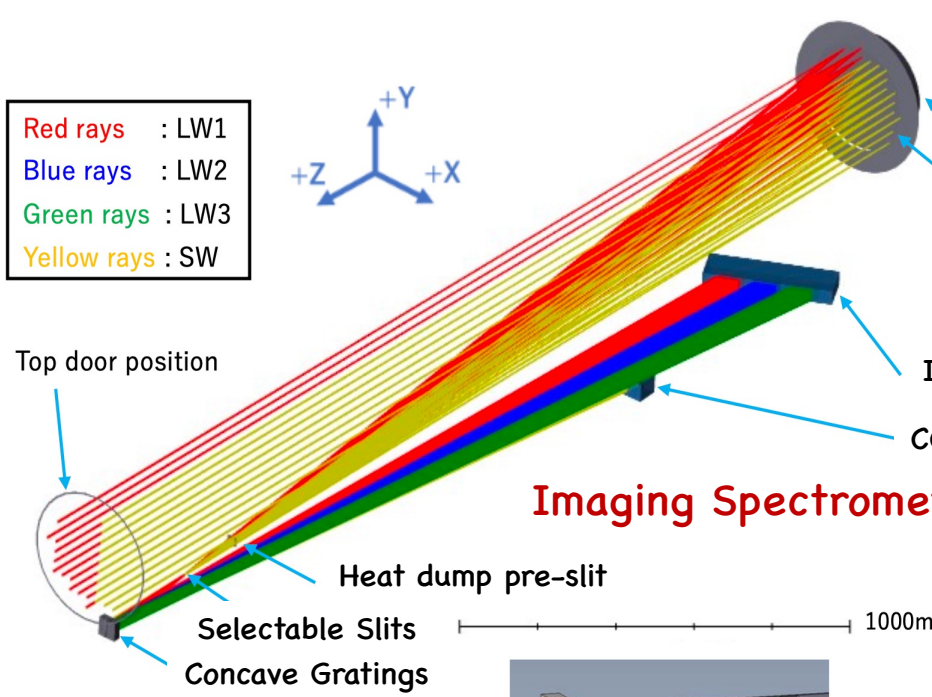
Imaging Spectrometer

SoSpIM irradiance

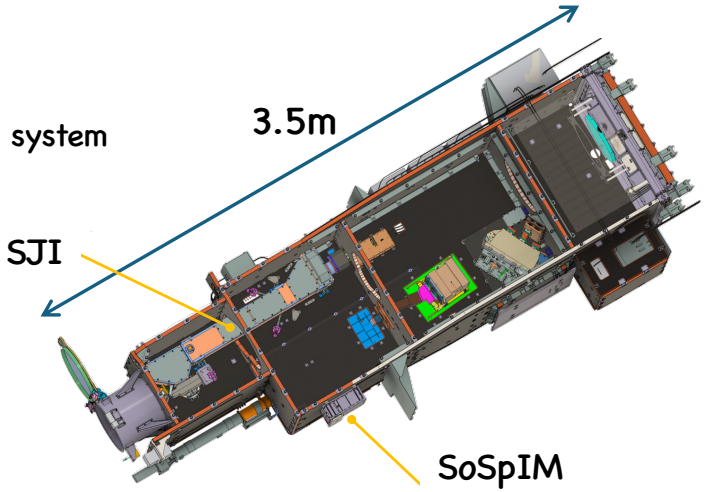
Slit-Jaw Imager

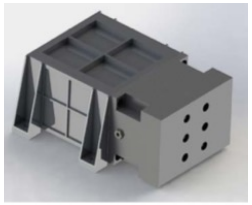
Te / Ne / V_D / abundance

SOLAR-C Payload & Optical Layout

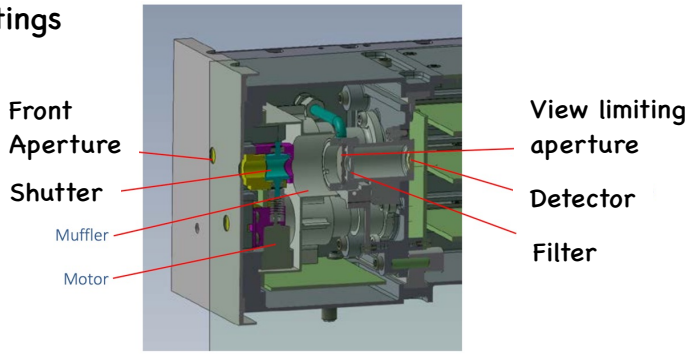


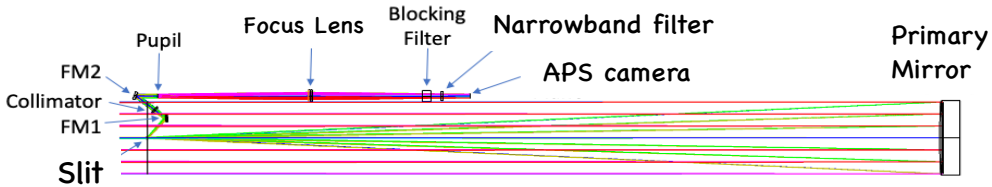
Imaging Spectrometer



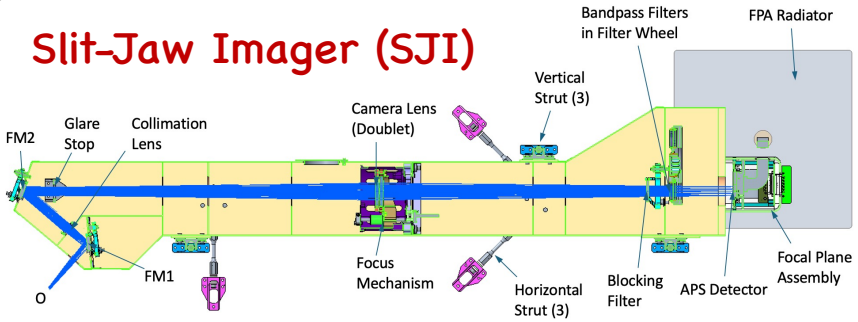


SoSpIM



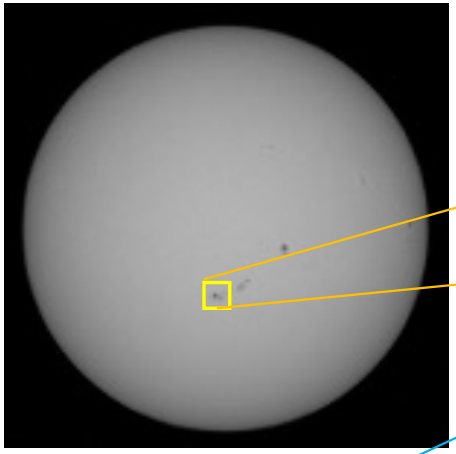


Slit-Jaw Imager (SJI)

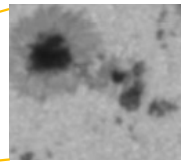


Expected Data from SOLAR-C

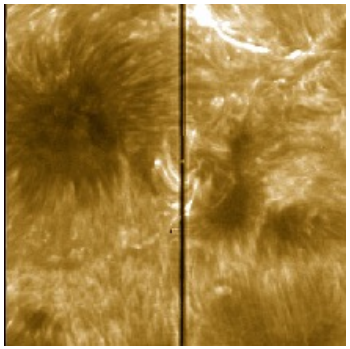
Visible Sun



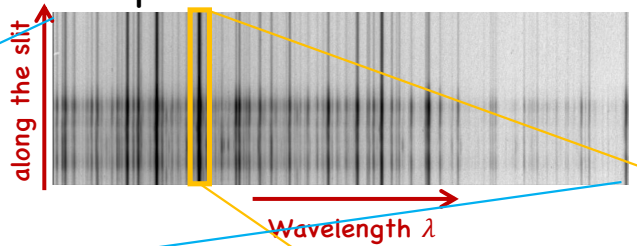
Solar image on the EUVST slit



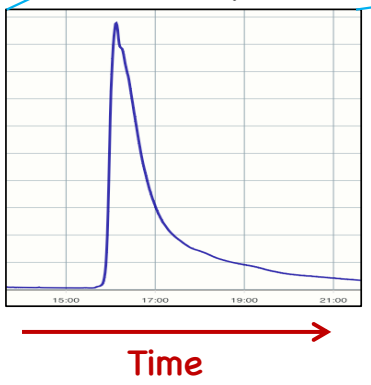
Slit-jaw image 280nm



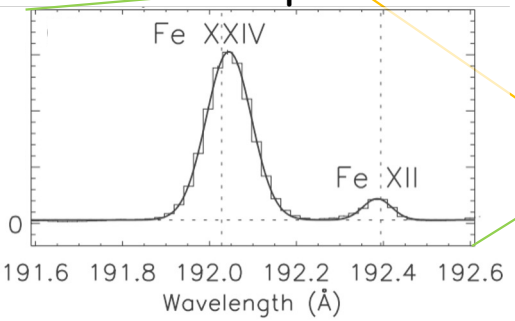
EUV spectrum on the SW detector



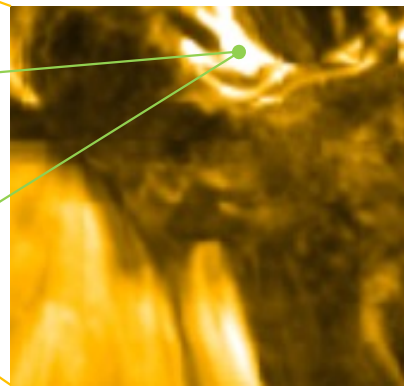
EUV band irradiance from SoSpIM



EUV line spectra

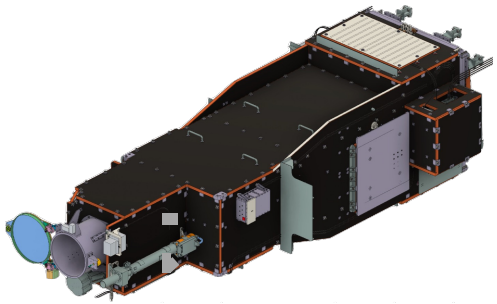


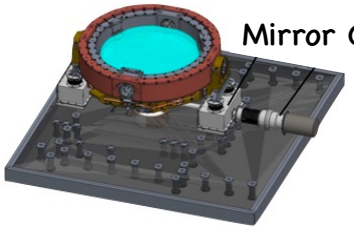
Raster scan data from an emission line



Figures: ©JAXA/NASA

SOLAR-C Science payload





Mirror Coating

EUVST Controller: SEB

Structure

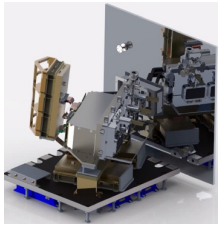
Primary Mirror Assy

Slit Jaw Imager

TEB

Slit Assy

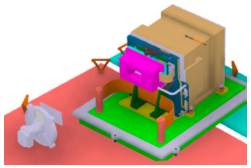
Pre-slit



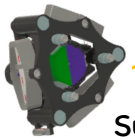
LW IAPS camera

Aperture Door

SW CCD camera



Grating Assy

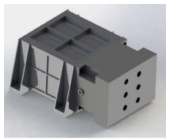


Rotary shutter

Sun Sensor UFSS

Guide Telescope

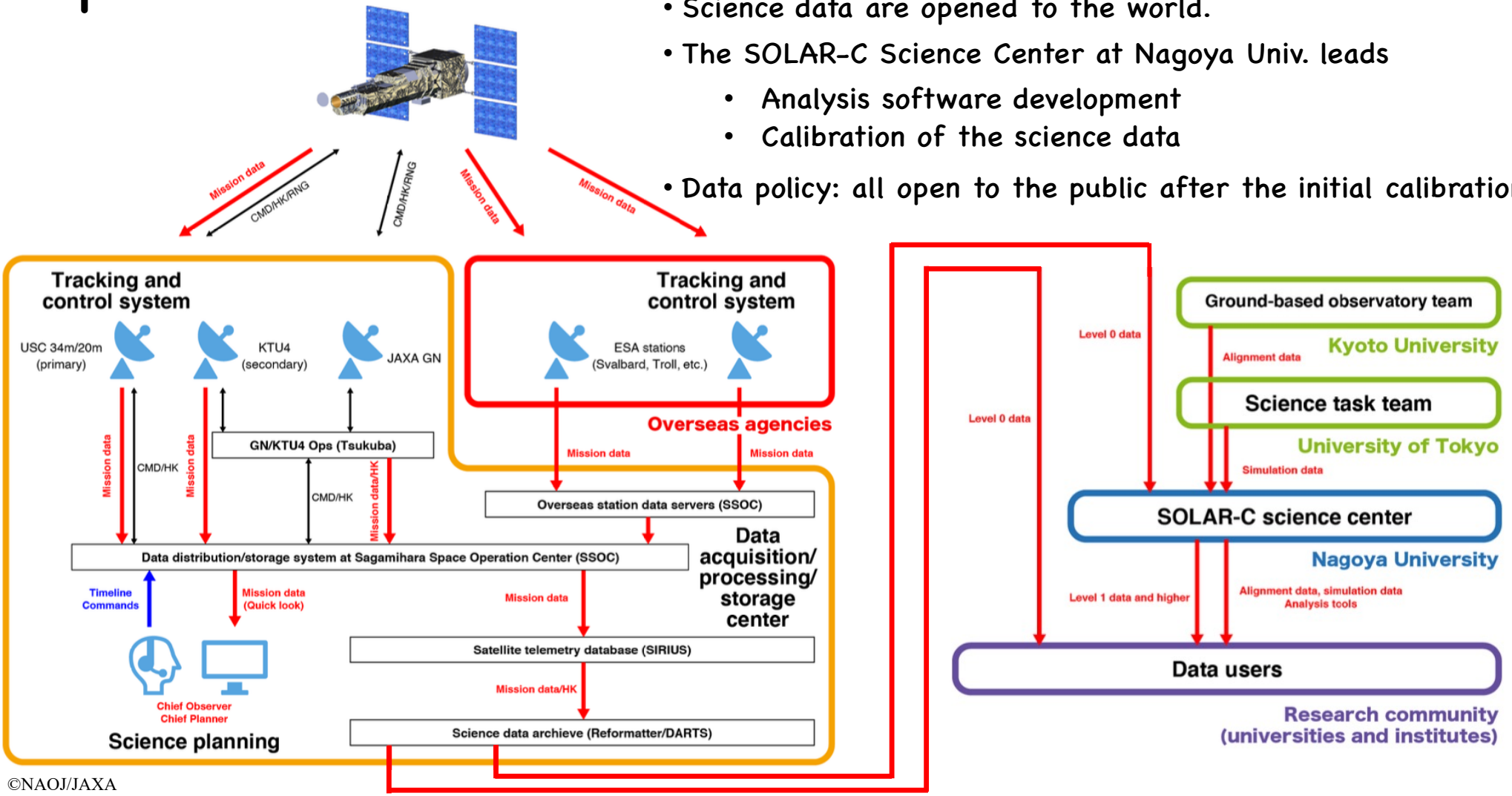
Solar Spectral Irradiance Monitor



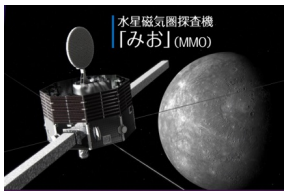
- STR, PMA, TEB assembled and tested in Japan
- Others are assembled and aligned in US
- Mechanical & electrical tests in US
- Thermal test & radiometric calibration in Germany

Operation

- Telemetry is downloaded at domestic/overseas antenna stations.
- Science data are opened to the world.
- The SOLAR-C Science Center at Nagoya Univ. leads
  - Analysis software development
  - Calibration of the science data
- Data policy: all open to the public after the initial calibration

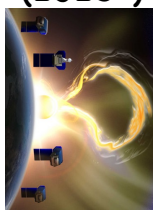


Multi-telescope Collaborations

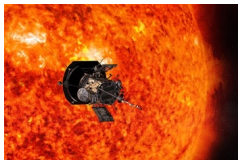


BeppiColombo/Mio
(ESA,JAXA)
In-Situ measurements
65~100 solar radii

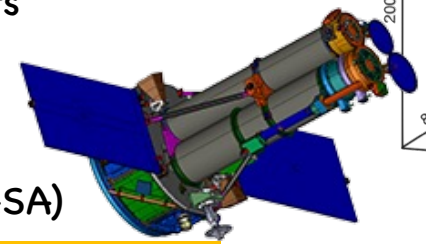
(2025-)



PUNCH (NASA)
Coronal polarimetry
> 5 solar radii



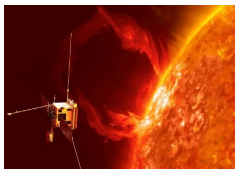
PSP (NASA)
In-Situ measurements
~10 solar radii

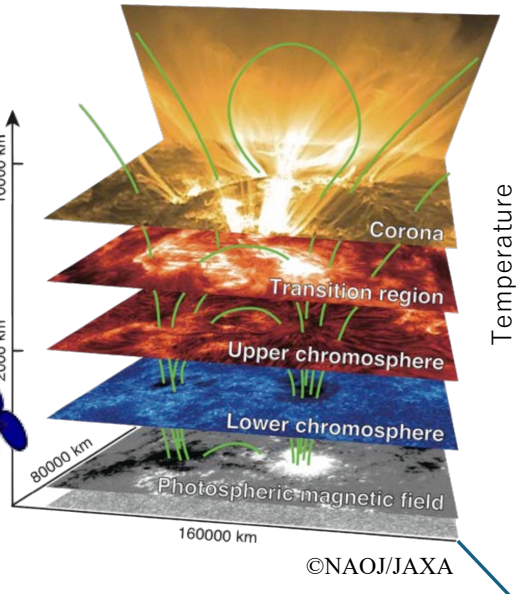


MUSE (NASA)

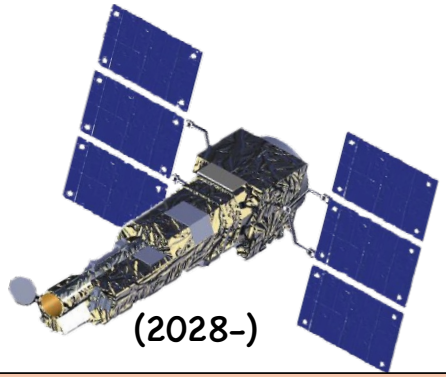
Fast imaging with multi-slit (2027-)

SOLAR Orbiter (ESA)
Stereoscopic views
Out-of-ecliptic observations





SOLAR-C
(JAXA)



(2028-)

Comprehensive spectral investigation of the solar atmosphere

- Intensity
- Doppler velocity & line broadening from line-profile spectroscopy
- Te, Ne from the emission-line ratio
- Abundance

Numerical Tools for Interpretation

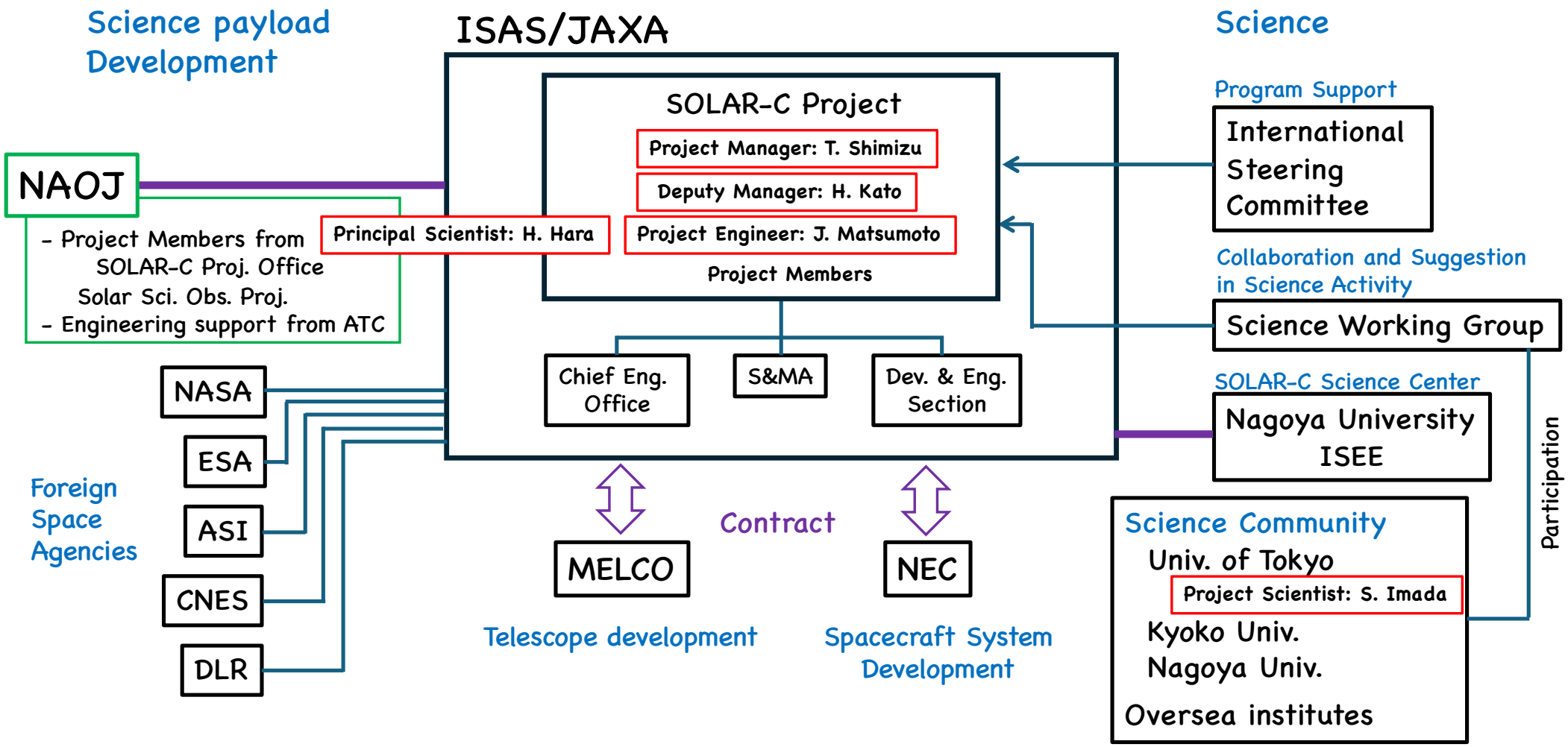
- Numerical models
- Machine learning

DKIST
(NSF)

Ground-based Observatories

- Full-disk Magnetic field data
- **Sub-arcsec vector magnetic fields**
- Sub-arcsec obs. of photosphere and chromosphere

Project Organization



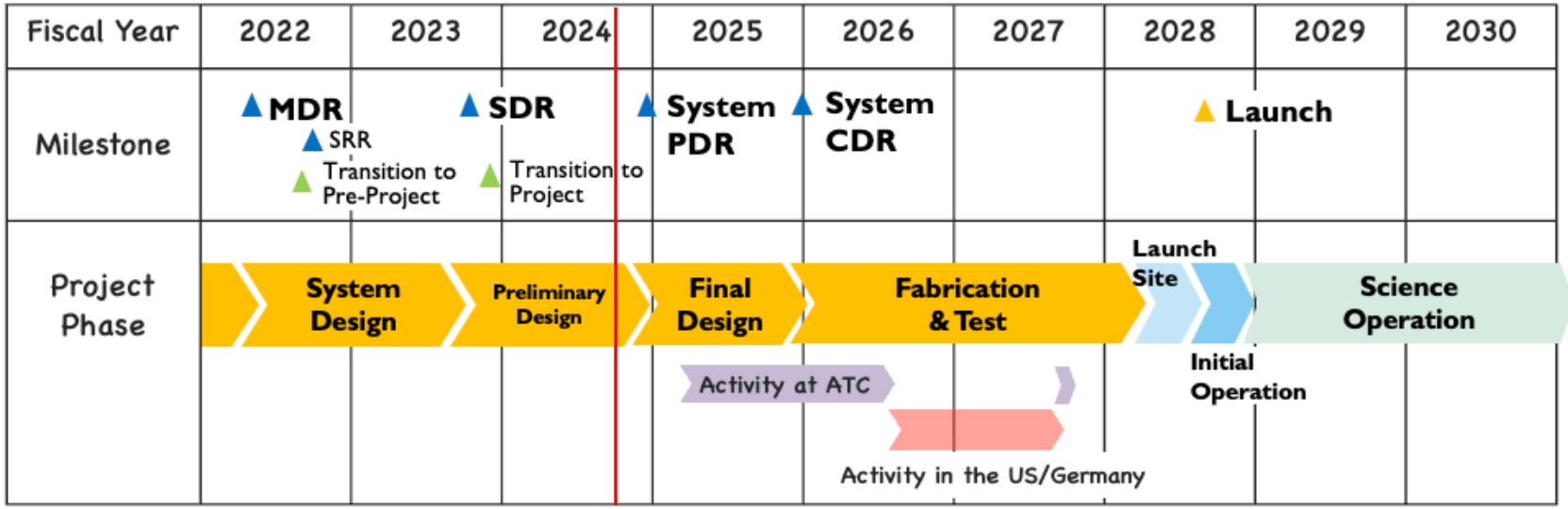
Why NAOJ? (for SOALR-C payload development)

- Long-joint collaborations in the ISAS space science program since the 1960s:
- Institute containing many solar physics scientists who will lead their own science by developing a new space-borne instrument as a team
- Presence of ATC for instrument design capability
- Useful test equipment in the ATC cleanroom for the space-borne telescope development

NAOJ Contribution:

- NAOJ SCP leads the development of the science payload:
  - Drafting of telescope development requirements and specifications
  - Optical design of the imaging spectrometer
  - Support for optical/thermal/structural I/F coordination of equipment in charge overseas
  - Support for telescope satellite system I/F coordination
  - Support for development by the telescope developers
  - Provide clean rooms and auxiliary facilities and help contamination control
  - Assist performance evaluation and confirmation of specifications
  - Operational support to maintain the performance of the EUVST telescope
  - Outreach (HP operation)
- SCP project cost:
  - NAOJ project budget + JAXA funding for NAOJ contribution from SOLAR-C Project Budget
    FY2024: 15.5 → 2025: 14 M-Yen
  - The cost for the ATC cleanroom use has been requested since last year.

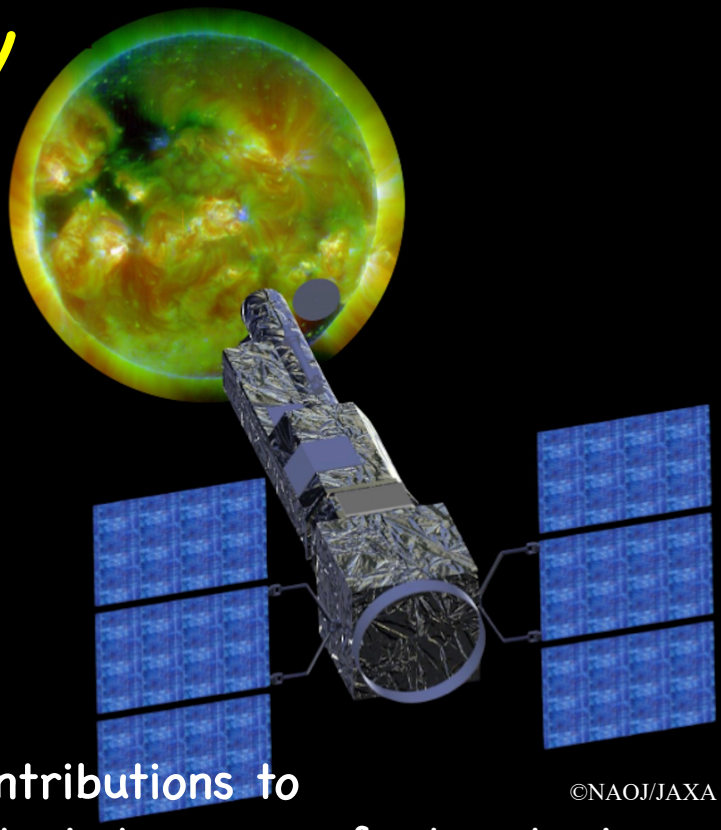
Current Status



- Preliminary design activity is ongoing in general.
- For some long-term delivery products,
  - Science payload EM developments have been carried out ahead of the System schedule by having additional reviews.
    - e.g.: EM primary mirror is being polished for the test in 2025.
  - Procurement of some flight parts has started.

Project Summary

- SOLAR-C has become a JAXA Project. (Mar 2024)
  (a competitively-chosen M-class mission)
- The launch with Epsilon-S rocket is scheduled for FY2028. Orbit: sun-synchronous polar orbit of 600 km altitude
- Science Objectives: to understand
  - how fundamental processes lead to the formation of the solar atmosphere and the solar wind.
  - how the Sun influences the Earth and other planets in our solar system



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- SOLAR-C payload:
  - EUVST (0.4" resolution, 1s cadence, wide EUV λ coverage)
    - EUV imaging spectrometer [17-125 nm]
    - UV slit-jaw imager [280nm band]
  - EUV solar spectral irradiance monitor

- Outcomes: contributions to
  1. Fundamental physical processes for target science
  2. Space weather prediction
  3. Plasma/atomic physics
  4. Past space climate, and
  5. Developing key technology in space instrumentation