公募型小型衛星搭載
高感度EUV/UV分光望遠鏡
SOLAR-C_EUVST

渡邊 鉄哉(国立天文台), 清水 敏文 (JAXA), 今田 晋亮 (名大), 川手 朋子 (JAXA), 原 弘久 (国立天文台), 一本 潔 (京大), 末松 芳法 (国立天文台), 勝川 行雄 (国立天文台), 鹿野 良平 (国立天文台), 久保 雅仁 (国立天文台), 石川 遼子 (国立天文台), 関井 隆 (国立天文台), 鳥海 森 (国立天文台), 渡邉 恭子 (防大), 永田 伸一 (京大), 阿南 徹 (U. Hawaii), 草野 完也 (名大), Quintero Noda, Carlos (JAXA) 他 **SOLAR-C WG** (JAXA)

Solanki, S. K. (MPS), Harra, L. K. (MSSL), Fludra, A. (RAL), Auchère, F. (IAS), Andretta, V. (INAF), Naletto, G. (UNIPD), Korendyke, C. (NRL), Tarbell, T. D. (LMSAL)

Solar-C WG Activity in 2017

- Final Report of <u>NGSPM – SOT</u> (Next Generation Solar Physics Mission – Science Objective Team) endorsed by the Heliophysics Divisions of JAXA/NASA/ESA

↓

- Proposing of Solar-C EUV/UV High-Throughput Spectroscopic Telescope; **高感度EUV/UV分光望遠鏡** (*Solar-C_EUVST*)

NGSPM-SOT membership

PARTICIPANTS:

- Co-Chairs
  - Masaki Fujimoto – ISAS/JAXA
  - Luigi Colangeli – ESA
  - Steve Clarke – NASA

- NASA appointed Members
  - David McKenzie, NASA, Marshall Space Flight Center
  - Ted Tarbell, Lockheed Martin Solar and Astrophysics Laboratory
  - John Raymond, Smithsonian Astrophysical Observatory
  - Sara Gibson, High-Altitude Observatory

- ESA appointed Members
  - Louis Ramon Bellot Rubio - Instituto de Astrofisica de Andalucia, Spain
  - Mats Carlsson - UiO Institute of Theoretical Astrophysics, Norway
  - Lyndsay Fletcher - University of Glasgow, UK
  - Sami Solanki - Max-Planck-Institut für Sonnensystemforschung, Göttingen

NGSPM-SOT membership

PARTICIPANTS:

- JAXA / National Astronomical Observatory of Japan (NAOJ) appointed Members
  - Kiyoshi Ichimoto, Kyoto University/NAOJ
  - Kanya Kusano, Nagoya University
  - Toshifumi Shimuzu, ISAS/JAXA
  - Hirohisa Hara, NAOJ

- National Astronomical Observatory of Japan (NAOJ) Observer
  - Tetsuya Watanabe, Solar-C Chair, Hinode Science Center, Prof., Solar & Plasma Astrophysics

- NASA OIIR (Office of International and Interagency Relations)
  - Jacob Parsley, International Program Specialist

Final Report of NGSPM

- Prioritization of Scientific Objectives for Next-Generation Mission (mid. 2020es)
- Pick up of Nortional Strawman Instruments
- Mission Concept & Implementation
- Recommendations

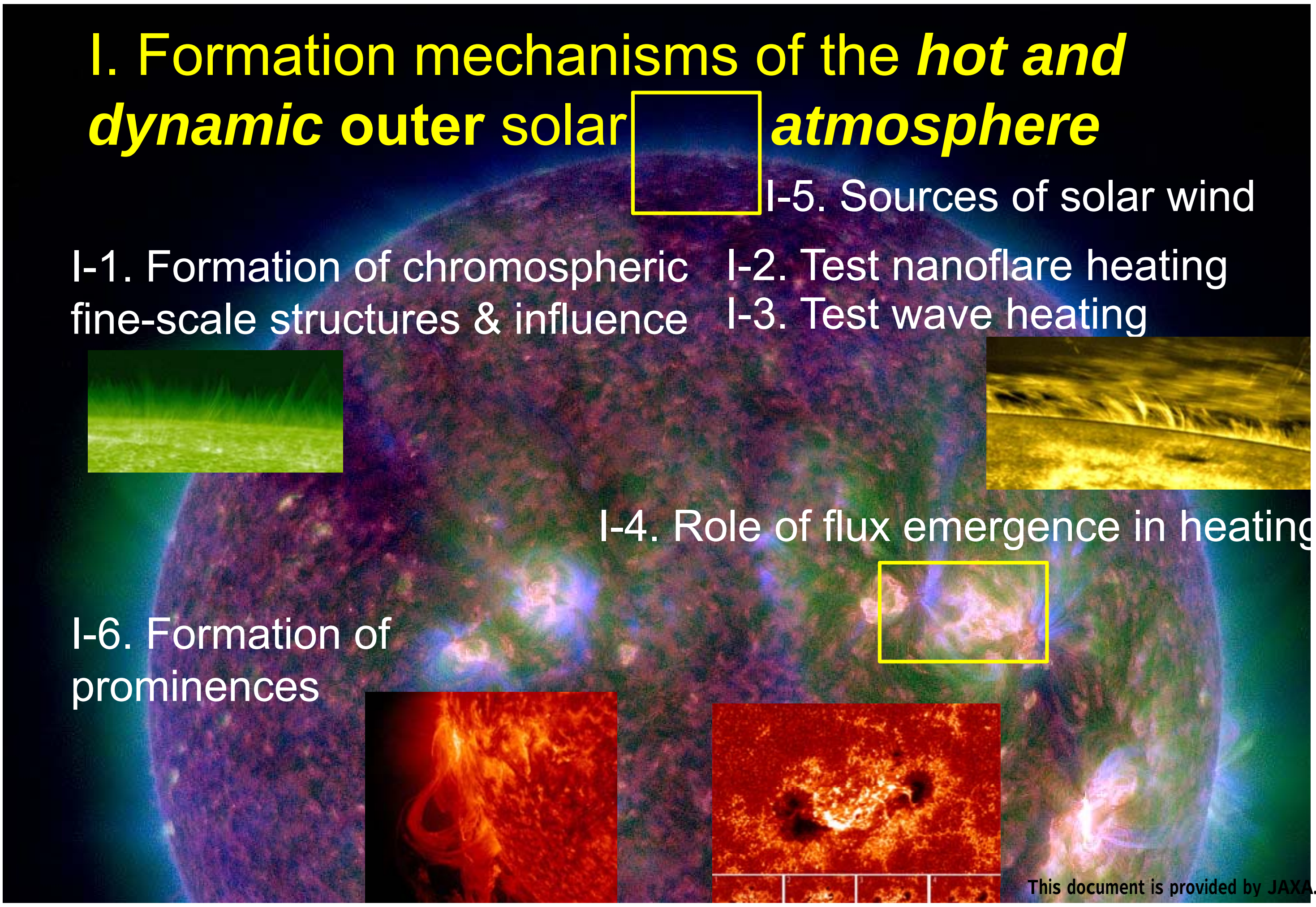
Science Objectives: *Priority* for Next-Generation mission

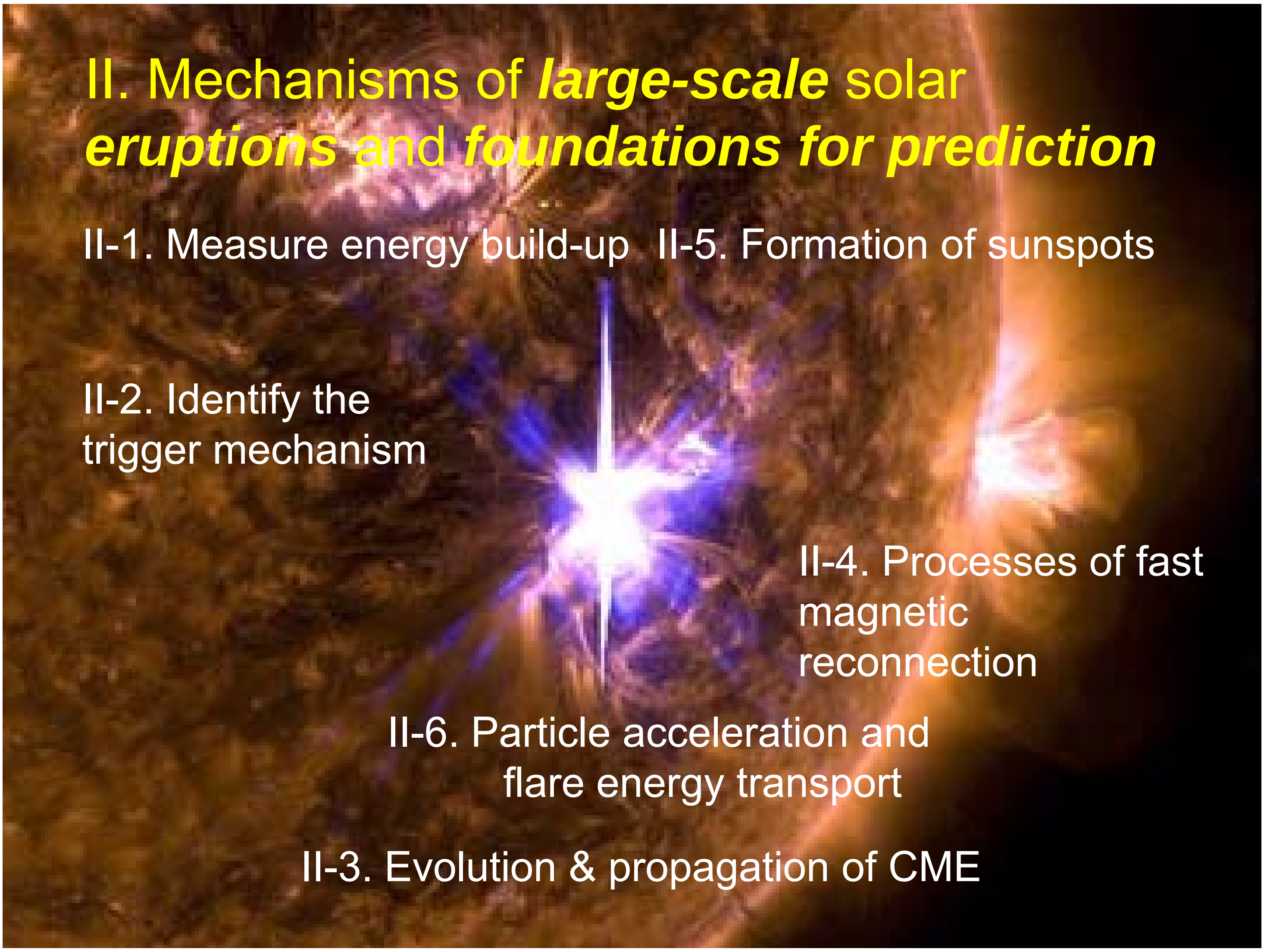
- Starting point, Solar-C (2015) proposed objectives
- White paper inputs → additions, augmentations
- Team discussions, with specific criteria:
  - A) Relevance to NASA/JAXA/ESA objectives (++)
  - B) Scientific impact on solar physics (++)
  - C) Scientific impact on other disciplines (+)
  - D) Inability of current/planned missions and facilities to accomplish (++)
  - E) Need for space observations (++)
  - F) Maturity of technology: measurements can be made (+)
  - G) Maturity of methodology: data can be inverted (+)
  - H) Widespread interest within the solar physics community

Science Objectives (revised from 2015 Solar-C)

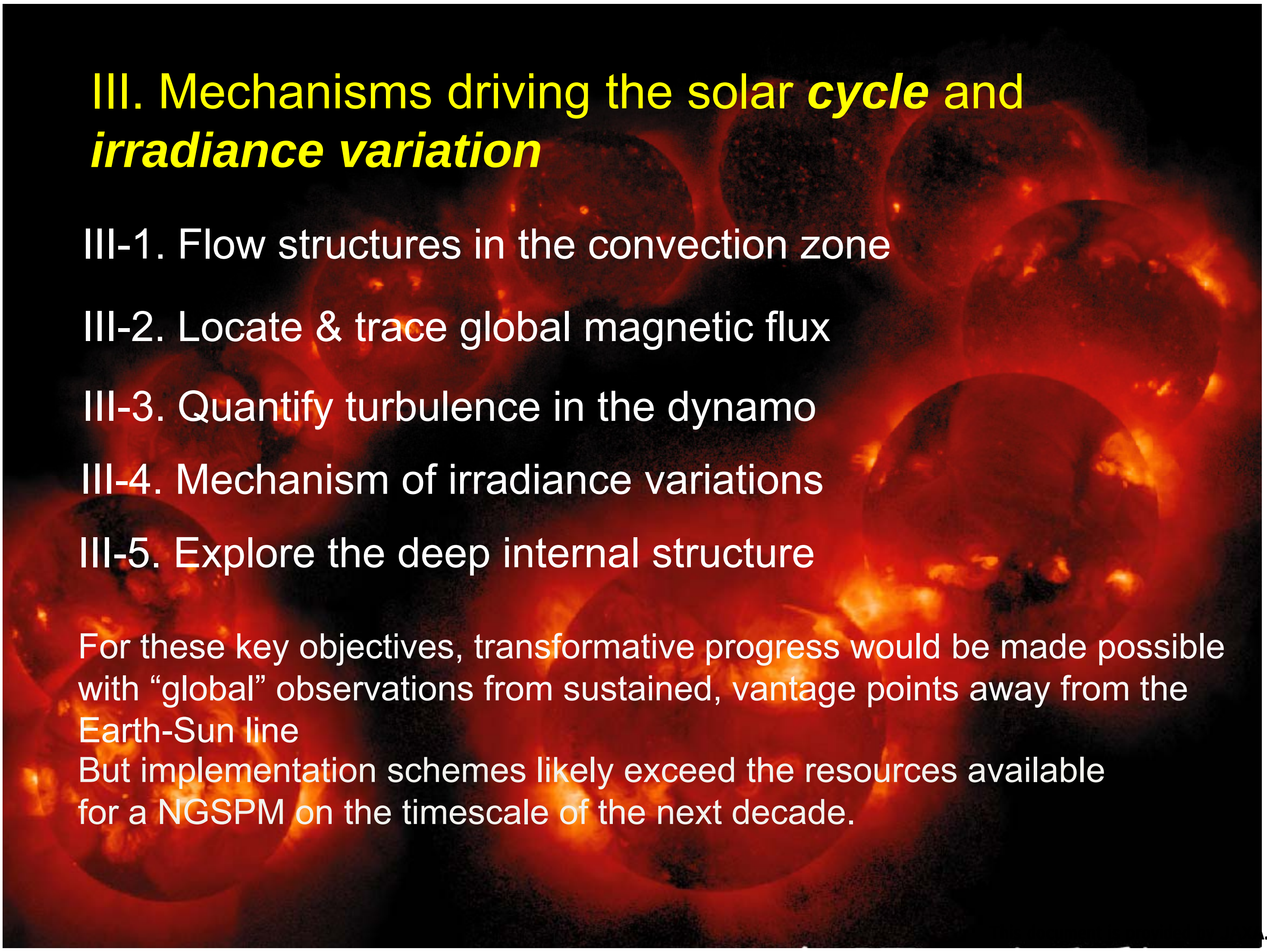
I: Formation mechanism of the *hot and dynamic outer solar atmosphere*		
I-1	chromospheric fine scale structures	Foot point B topology, shock, twist,,
I-2	Nano-flare heating	Tiny brightening, non-thermal plasma
I-3	Wave heating	Wave mode, energy flux, dissipation
I-4	Flux emergence	Evolution of 3D vector magnetic field
I-5	Solar wind acceleration	B topology in CH, Alfven wave in corona
I-6	prominence	B field structure, mass circulation
II: Mechanism of *large-scale solar eruptions* and algorithm for prediction		
II-1	Energy storage	Photo./chrom. B field maps
II-2	Trigger mechanism	Emerging flux, interaction with chrom.B
II-3	Evolution and propagation of CME	Large scale coronal dynamics
II-4	Physics of fast reconnection	Current sheet, plasmoid, shock
II-5	Formation mechanism of δ sunspots	Flux tube & flow in convection zone,
II-6	Particle acceleration & energy transp.	electron & ion distribution, response of chrom.
III: Mechanism of *solar cycle and irradiance variation*		
III-1	Flow structures in convection zone	Global flows in the sun
III-2	Magnetic flux in the sun	Flux tube at tachocline, polar field reversal
III-3	Role of turbulence in dynamo	Small scale helicity & α effect, local dynamo
III-4	solar irradiance variations	Fine structure of UV source, TSI & SSI model
III-5	Deep interior	G-mode

Green – new sub-objectives from the Solar-C mission proposal 2015





II. Mechanisms of *large-scale* solar *eruptions* and *foundations for prediction*
II-1. Measure energy build-up
II-5. Formation of sunspots
II-2. Identify the trigger mechanism
II-4. Processes of fast magnetic reconnection
II-6. Particle acceleration and flare energy transport
II-3. Evolution & propagation of CME



III. Mechanisms driving the solar *cycle* and *irradiance variation*
III-1. Flow structures in the convection zone
III-2. Locate & trace global magnetic flux
III-3. Quantify turbulence in the dynamo
III-4. Mechanism of irradiance variations
III-5. Explore the deep internal structure
For these key objectives, transformative progress would be made possible with "global" observations from sustained, vantage points away from the Earth-Sun line
But implementation schemes likely exceed the resources available for a NGSPM on the timescale of the next decade.

Notional strawman instruments

- With 17 sub-objectives, each having ~3 required measurements, certain observational capabilities are needed.
- There are common threads, so that we can identify the types of instruments we should hope to develop.

Notional strawman instruments

T-01: 0.1” photospheric magnetograph
T-02: 0.2”-0.5” photospheric & chromospheric imaging magnetograph
T-03: Full-disk photospheric magnetograph
T-04: 0.1” — 0.3” chromospheric imager and magnetograph
T-05: 0.1” chromospheric spectrograph
T-06: Full-disk chromospheric imager
T-07: 0.2” ” — 0.6” coronal imager
T-08: Full-disk coronal imager
T-09: 0.3” coronal/TR spectrograph
T-10: High-energy spectroscopic imager
T-11: Large-scale coronagraph
T-12: Coronagraphic polarimeter
T-13: Coronagraphic spectrograph
T-14: Heliospheric imager
T-15: Total Solar Irradiance & Solar Spectral Irradiance monitors

Notional instrument set for elemental science

- A minimum set of instruments with which NGSPM can address the greatest number of sub-objectives and maximize the science return of the mission.

Higher priority of instruments in order from the top

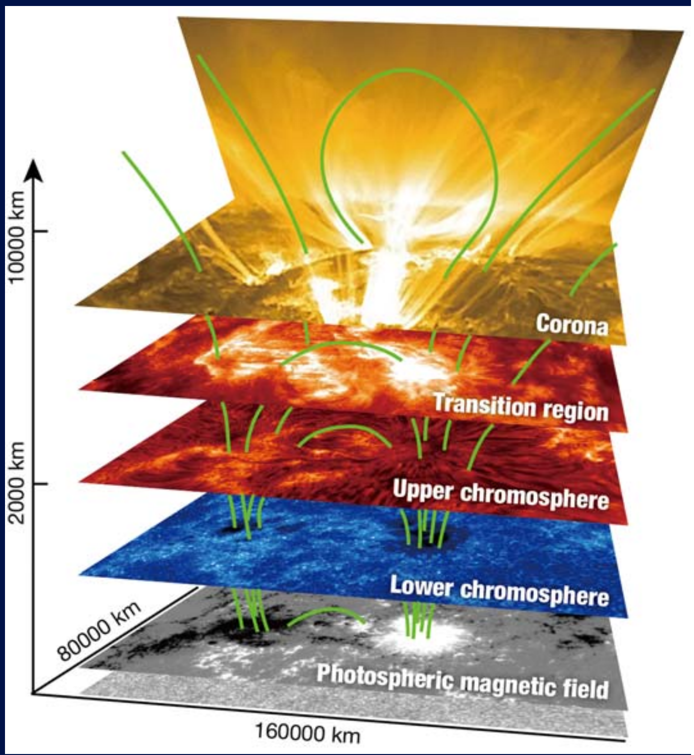
0.3” coronal/TR spectrograph (T-9)

seamless plasma diagnostics through the atmosphere

0.2”-0.6” coronal imager (T-7)

0.1” – 0.3” chromospheric imager and magnetograph (T-4)
0.1” photospheric magnetograph (T-1)
0.1” chromospheric spectrograph (T-5)

Magnetic and velocity fields at chromosphere



Notional Instrument Set for Elemental Science

- Using the strawman instrument list from above, we searched for the combination that would address a high number of the sub-objectives and maximize the science return of the mission.
- The combination of these five instruments will address well over half of the required measurements:

① 0.3” coronal/TR spectrograph (T-9)
② 0.2” – 0.6” coronal imager (T-7)
③ 0.1” – 0.3” chromospheric imager and magnetograph (T-4)
0.1” photospheric magnetograph (T-1)
0.1” chromospheric spectrograph (T-5)

(Top-level priority of instruments)

Mission concepts

1. Large mission design

- 3 instruments (T-09, T07, and T-01/04/05) on a single platform.
- Opportunity: JAXA strategic large mission (戦略的中型)
- Significant scientific and operational advantages: launch & operations simultaneously and integrated, instrument design optimized, save the total costs
- Smaller, less complex, and less expensive than 2015 Solar-C

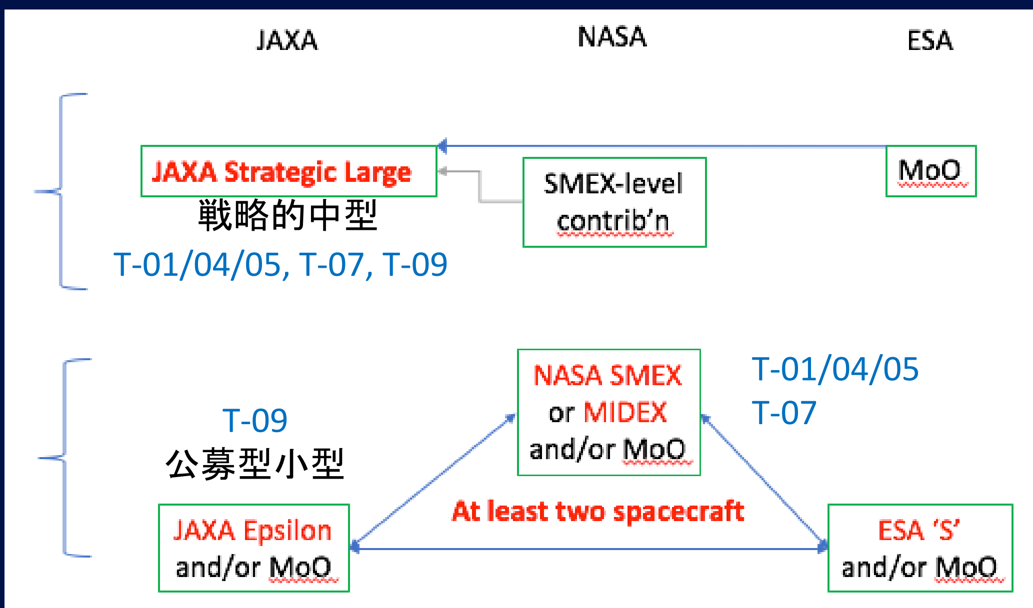
2. Constellation of small/med-class missions

- To form a constellation of satellites to realize 3 instruments (T-09, T07, and T-01/04/05).
- Opportunity: JAXA Epsilon (公募型小型), NASA SMEX/MIDEX
- Increase the possibility that some of the instruments are launched as early as possible.
- Scientific synergy limited unless significant overlap in observing time of the missions

Possible Collaborative Configuration

SOT's highest priority recommendation

Epsilon (T-09) on board
Epsilon paired with T-02 & T-07 (SMEX, MIDEX)



Recommendations (1/2)

- The science focus of NGSPM be the investigation of physical mechanisms on the smallest resolvable time- and length-scales, at all temperature domains in the solar atmosphere.
- *Instruments with the capabilities represented by T-09, T-07, T-04, T-01, and T-05 are the highest priority for advancing the science objectives mentioned above within the next decade.*
- NGSPM be realized with *a single platform*, as a JAXA Strategic Large mission with contributions from NASA (SMEX-level), ESA (MoO), and ESA member states. If the single-platform approach is not possible or available, a combination of two or three spacecraft can achieve many of the NGSPM objectives, with some loss of capability and at increased risk.

Recommendations (2/2)

- The agencies form a unified Science Definition Team for NGSPM as soon as possible to define the agencies' respective contributions in more detail.
- JAXA allow for the possibility of moving an instrument proposed for an Epsilon mission into a Strategic Large mission at a later time.
- ESA support European contributions to NGSPM in the form of a Mission of Opportunity.
- NASA support contributions by US scientists to all instruments of NGSPM.
  - The NASA contribution to a JAXA Strategic Large mission should be at least the size of a SMEX mission.
  - For a constellation configuration, the NASA contribution should be as large as a MIDEX.
  - NASA have a proposal opportunity dedicated to NGSPM

SOLAR-C_EUVST Proposal

for competitive M-class (ε) missions

Trade off study for selection of instruments

	0.3" coronal/TR spectrograph (T-09)	0.2"-0.6" coronal imager (T-07)	0.1" chrom./photo. magnetograph/spectrograph (T-01/04/05).	0.2"-0.5" photo./chrom. magnetograph (T-02)	Solar-C large mission (T-09+ T-01/04/05 + T-07)
Science return, achievement level of scientific objectives	○	△	○	△	◎
Uniqueness / synergy with other telescopes	◎ Significant advantage from others	○	○ some overlap w/ 4m ground telescope	△ moderate jump from SOT/Hinode	◎
Cost (fit to epsilon)	○	○	× high	△ high	× Very high
size/weight (fit to epsilon)	○	○	×	○	×
Technical and programatic risks	○ No serious risk	○ No serious risk	△ Big & high precision optics	○ No serious risk	△ Big & high precision optics
capabilities of domestic and international communities	◎ World-wide support	△ limited domestic interests	△ Need large resources	○	△ Need large resources
data volume, data rate, and size of post analysis	○ High but treatable	○ 〃	○ 〃	○ 〃	○ 〃

Science Objectives (revised from 2015 Solar-C)

I: Formation mechanism of the *hot and dynamic outer solar atmosphere*		
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III-5	Deep interior	G-mode

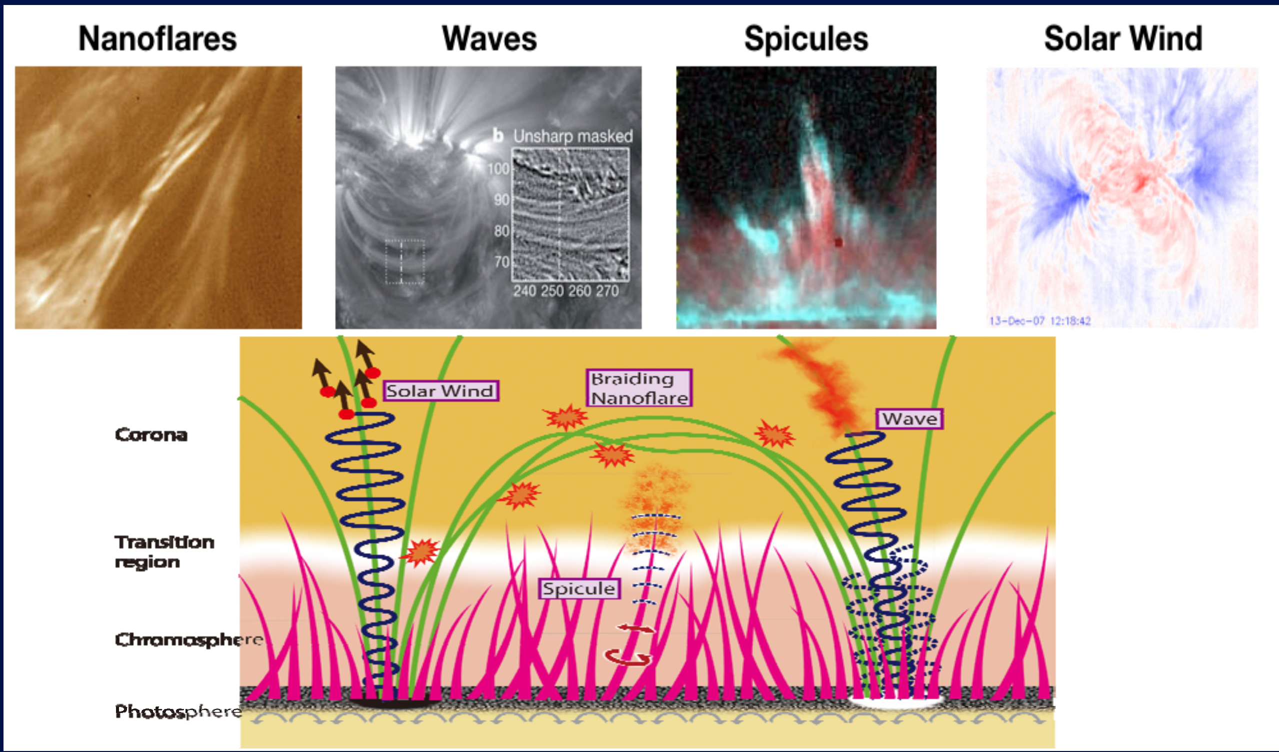
Green – new sub-objectives from the Solar-C mission proposal 2015

Science objectives of Solar-C EUVST

I: Understand How Fundamental Processes Lead to the *Formation of the Solar Atmosphere* （P-125: 今田他）	
I-1	Quantify the Contribution of Nanoflares to Coronal Heating
I-2	Quantify the Contribution of Wave Dissipation to Coronal Heating
I-3	Understand the Formation Mechanism of Spicules and Quantify Their Contribution to Coronal Heating
I-4	Understand the Source Regions and the Acceleration Mechanism of the Solar Wind

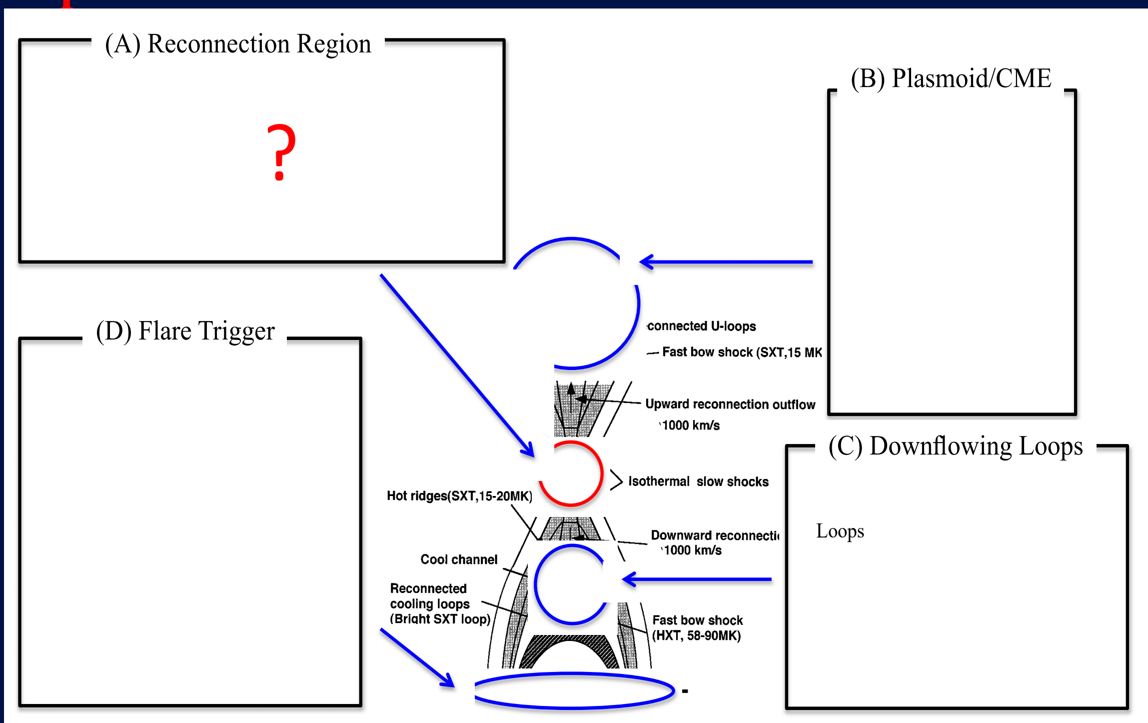
II: Understand How the Solar Atmosphere Becomes Unstable, Releasing the Energy that Drives *Solar Flares and Eruptions* （P-126： 鳥海他）	
II-1	Understand the Fast Magnetic Reconnection Process
II-2	Identify the Signatures of Global Energy Buildup and the Local Triggering of the Flare and Eruption

I: Understand How Fundamental Processes Lead to the Formation of the Solar Atmosphere



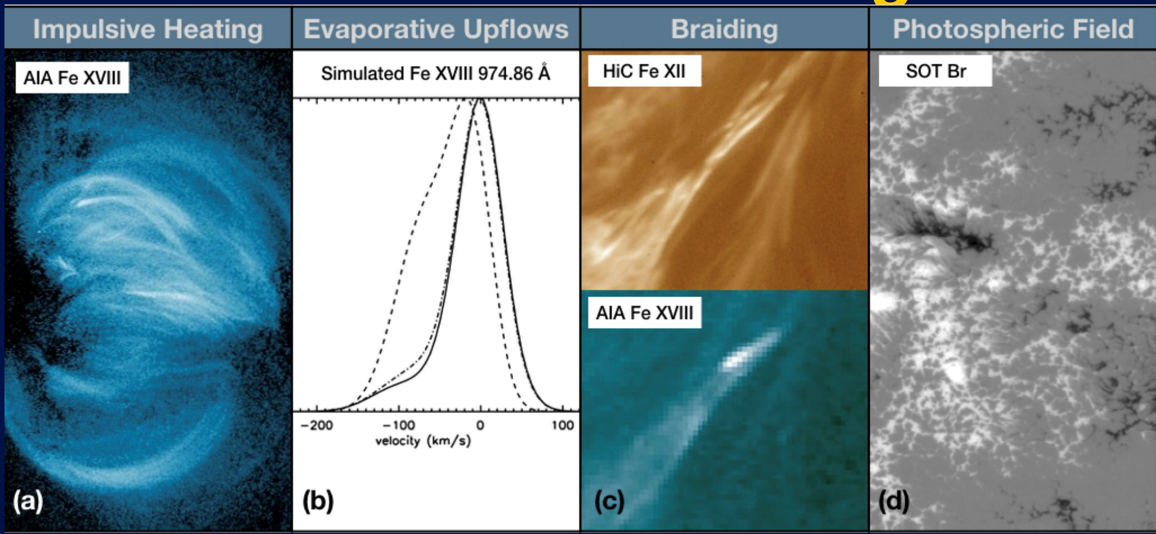
Collage made with the myriad of phenomena described in point I). The events presented in the different panels are thought to be directly related to the heating of the corona. Central part displays a cartoon where the different interaction of magnetic fields (thin lines) that gives birth to different solar structures.

II: Understand How the Solar Atmosphere Becomes Unstable, Releasing the Energy that Drives Solar Flares and Eruptions



Standard flare model with observed behaviors and numerical simulations in each sight. (A) Numerical simulation of reconnection region (Daughton et al., 2011). (B) Erupting plasmoid and reconnecting current sheet observed by AIA (Liu et al., 2013). (C) Downward flowing loops signatures above the flare loop (Imada et al., 2013). (D) Snap shot of flare ribbons (footpoints) and photospheric magnetic fields with flare trigger (Bamba et al., 2013).

I-1: Quantify the Contribution of Nanoflares to Coronal Heating

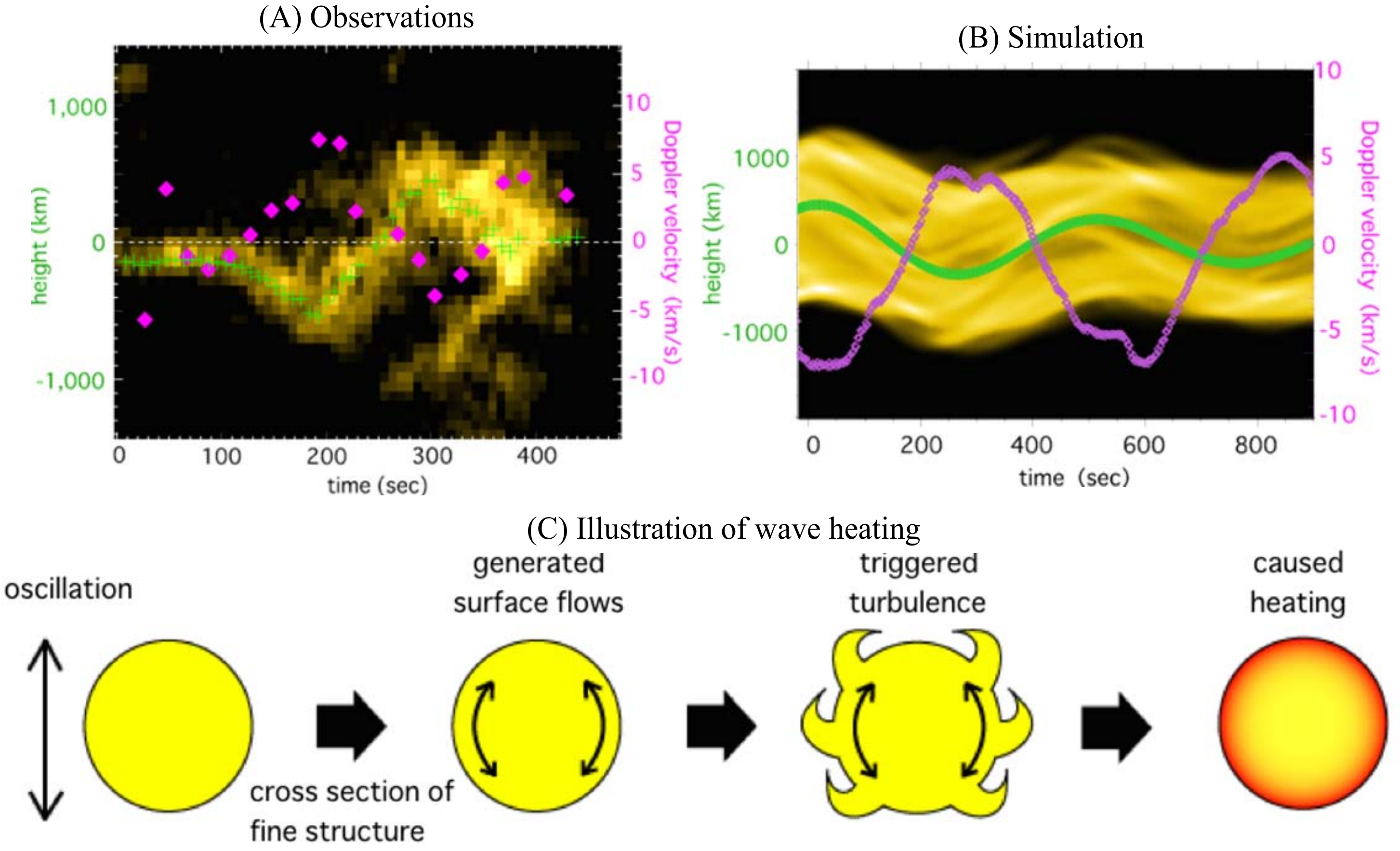


Solar-C_EUVST will revolutionize our understanding of coronal nanoflares. (a) AIA/SDO routinely observes transient heating events in Fe XVIII. EUVST will observe them with much higher spatial resolution and cadence and also provide the temperatures, densities, Doppler shifts, and non-thermal motions that are needed to compare with theory. (b) EUVST will be able to observe the evaporative upflows associated with small scale heating events predicted by nanoflare models. Here we show a simulation for Fe XVIII 974.86 Å. (c) Very high spatial resolution images from Hi-C have detected braided loops in Fe XII. EUVST will observe such events over a very wide range of temperatures. (d) Hinode/SOT observations of the magnetic field at the footprints of Fe XVIII loops. Similar coordinated observations from very high resolution ground based observatories such as DKIST will allow the photospheric changes that drive nanaoflares to be identified.

I-1: Quantify the Contribution of Nanoflares to Coronal Heating

Item	Requirement	Rationale
Temperature coverage	0.8~10MK	To confirm nanoflare evaporation condensation cycle, tenuous and very hot (~7 – 10 MK) component should be observed, simultaneously with behaviors of cool draining plasma (~0.8 – 1 MK).
Spatial resolution	0.4 arecsec	For resolving nanoflare events and subarcsec braiding structures in the corona.
Temporal resolution	5s without scanning 100s scaning	To match the cadence of heating events detected by Hi-C.
FOV	0.4 x 100 40 x 300 (arcsec^2)	Sit-and-stare (events, evaporation); raster 40x300 to observe braiding loops.
Velocity resolution	~10 km/s	Observe the upflows flows associated with nanoflares.
Observation duration	~1 hour	Longer than the evaporation-condensation cycle

I-2. Verification of Wave Heating

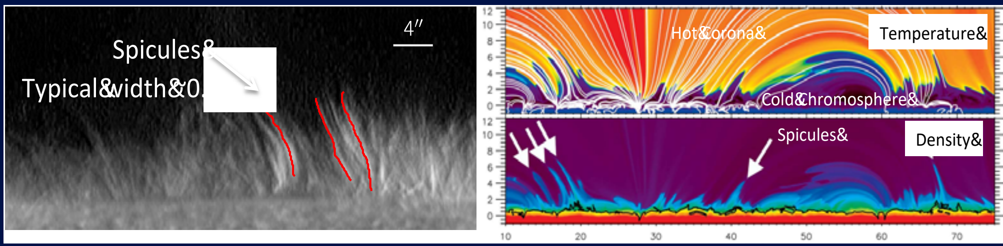


3D dynamics of a prominence fine structure by observation and simulation with the schematic illustration of the heating mechanism (from JAXA/NASA press release).

I-2. Verification of Wave Heating

Item	Requirement	Rationale
Temperature Coverage	0.8-3 MK	For high velocity resolution, it's better to concentrate bright coronal lines, such as Fe IX 171 A.
Spatial resolution	0.4 arecsec	For achieving high S/N and high temporal resolution, 1" is acceptable. For resolving thread-like structures through chromosphere to corona, 0.4" is required.
Temporal resolution	0.3 sec /step in 0.4" step	The scanning speed should be faster than Alfven speed 1000km/s, i.e. 0.3 sec /step in 0.4" step. This is probably difficult. This case, we should make use of a sparse scan to cover the FOV with cadence of <30 sec.
FOV	280 x 280 arcsec^2	It is very difficult to cover the wavelength of such Alfven waves whose period is 300 sec (3mHz). It is marginally possible to cover the wavelength of Alfven waves with a period shorter than 200 sec. 1000 km/s x 200 sec ~ 200 Mm, corresponding to 280".
Velocity resolution	~0.3km/s	<0.3 km/s for accurately measuring coronal Alfven waves discovered by CoMP. 1-2 km/s for measuring transverse oscillations responsible for energy transfer.
Photometric accuracy	~1%	To be discussed
Observation duration	~1 hour	Longer than the typical transient phenomena in AR/QS (e.g., jets)

I-3. Understand the formation mechanism of spicules and quantify their contribution to coronal heating



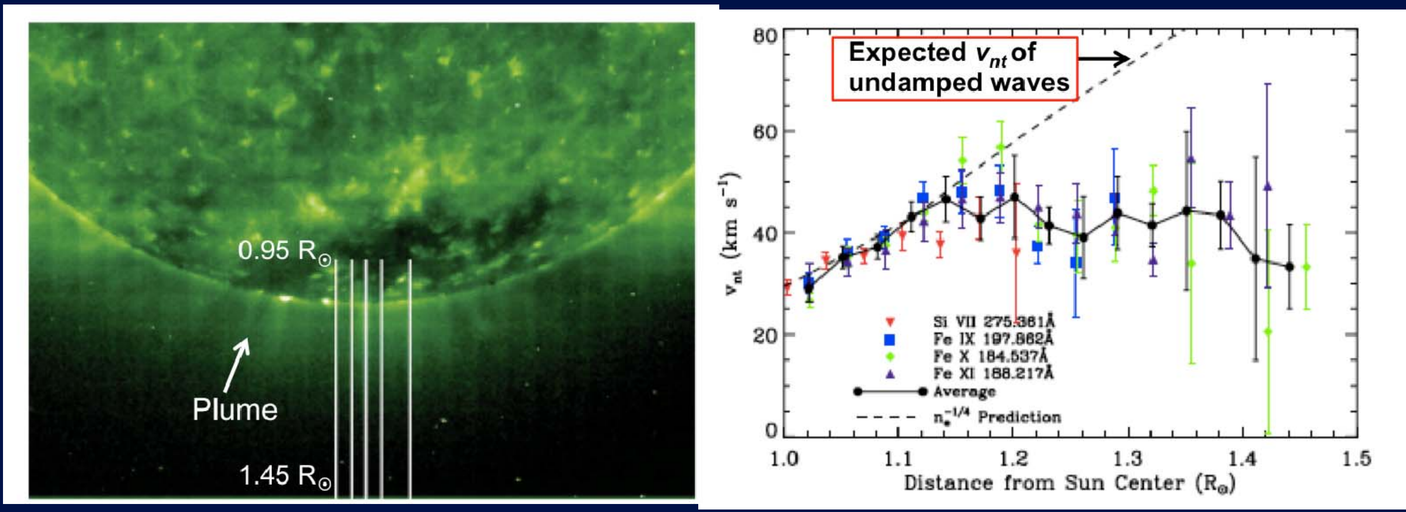
Left) Sample spicule Ca II H image observed by Hinode SOT (Pereira et al. 2012). The typical spicule width can be estimated to ~0.4 arcsec. Right) Spicule-like features in radiative MHD simulateon. We can clearly see the cold spicules penetrate into the hot corona.

	Region	Diagnostic	Lifetime (s)	v_{up} (km s^{-1})	l_{max} (Mm)	w (km)	v_t (km s^{-1})	abs(θ) (deg)	$-a$ (m s^{-2})
Beckers (1972)	. . .	Hα	250	25	6.5–9.5	400–1500	<5	15–20[a]	. . .
De Pontieu et al. (2007b)	CH	Ca II H	20–90	50–150	1.0–7.0	120–720	0–30[b]	. . .	. . .
De Pontieu et al. (2007b)	AR	Ca II H	180–420	. . .	. . .	120–720	. . .	. . .	50–400
Pasachoff et al. (2009)	QS	Hα	288–564	9–45	5.2–9.2	460–860	. . .	8.4–38.4	. . .
Anan et al. (2010)	AR	Ca II H	179	34	1.3	. . .	. . .	. . .	510
Zhang et al. (2012)	CH	Ca II H	112	41	9.6	≈200	. . .	. . .	1040
Zhang et al. (2012)	AR[c]	Ca II H	176	16	5.0	≈200	. . .	. . .	130
This work	QS	Ca II H	57–165	37–83	3.7–7.3	226–382	5–27	3.1–22.6	. . .
This work	CH	Ca II H	45–125	42–100	4.5–8.6	219–417	8–32	2.9–22.4	. . .
This work	AR	Ca II H	182–343	22–39	5.3–8.5	267–428	3–25	4.2–26.4	182–343

I-3. Understand the formation mechanism of spicules and quantify their contribution to coronal heating

Item	Requirement	Rationale
Temperature coverage	0.01 - 3 MK	For observing the chromosphere, transition region, and corona simultaneously.
Spatial resolution	0.4 arcsec	For resolving sub-arcsec spicule structures in the chromosphere and their counterparts in transition region and corona.
Temporal resolution	0.5 - 2 sec / 0.4” step	For scanning a 5.6” wide area within 10 sec in active regions and 30 sec in quiet regions.
FOV	5 x 20 arcsec^2	The entire structure of spicules and chromospheric jets should be observed.
Velocity resolution	2-5 km/s in chromosphere and TR 10 km/s in the corona	Enough to resolve upward speed of spicules.
Observation duration	~1 hour	Longer than the typical transient phenomena in chromosphere (e.g., jets)

I-4. Understand the Source Regions and the Acceleration Mechanism of the Solar Wind

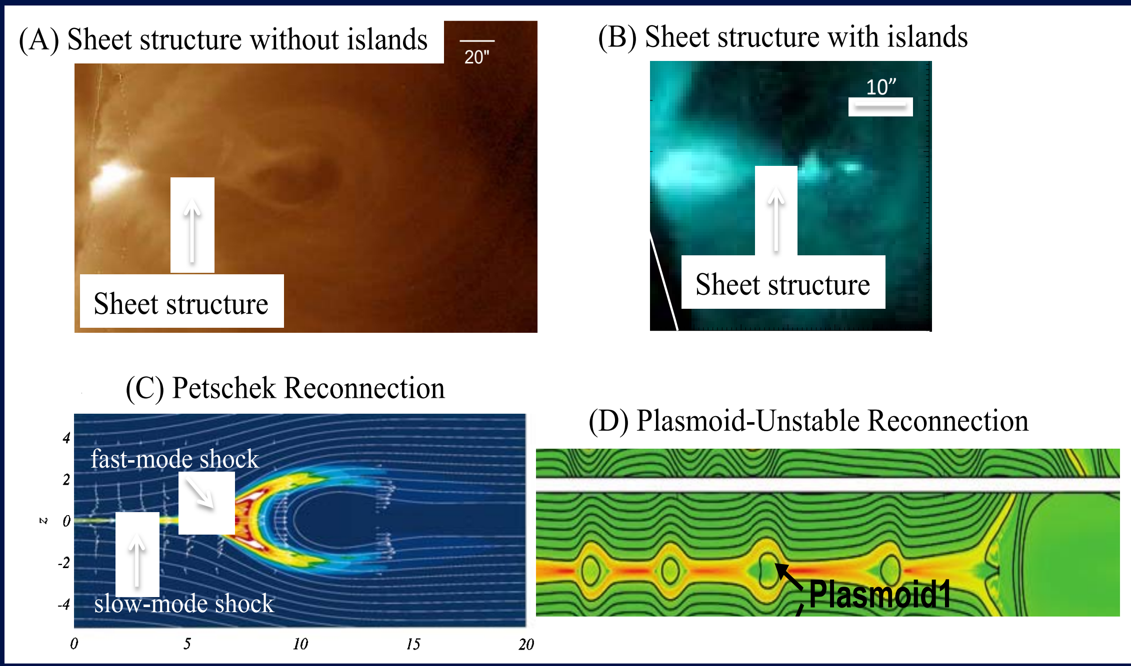


Left: slit positions of the EIS observations are illustrated overlaid on an SOHO/EIT image in the 195Å band. Right: the off-limb observation (in the left panel) of the non-thermal velocity (v_{nt}) from the strongest observed lines (symbols). The dashed line gives the predicted trend, proportional to the electron density n as $n^{-1/4}$, for undamped waves, and the observed behavior of v_{nt} may be considered as a dumping signature of Alfven waves. Hahn and Savin (2013)

I-4. Understand the Source Regions and the Acceleration Mechanism of the Solar Wind

Item	Requirement	Rationale
Temperature coverage	0.7~3 MK	Plumes (0.7~0.9 MK) and inter-plumes (1~1.3MK) in coronal holes and the edges of active regions (~ 3MK). Chemical abundance, electron density and temperature diagnostic capability.
Spatial resolution	~2 arecsec	For distinguishing fine structures in solar wind source regions, e.g. polar plumes (width ~ 30 arcsec) and inter-plumes in polar coronal holes.
Temporal resolution	~3 minutes in off-limb regions	The scanning time should be close to the timescales for the evolution of the structures (few to several minutes) to cover them.
FOV	280 x 280 arcsec^2 Off-limb obs. up to 1.4 solar radii	Entire active region size. To follow plumes and interplumes and study their structure and dynamics with height. For measuring the fluctuation (wave) with height, off-limb observation is needed up to 1.4 solar radii.
Observational mode	Roll observation	For observing streamers or spicules near the equatorial limb with height, a roll observation is needed.
Velocity resolution	Vd ~ 2km/s Vnt ~ 4km/sec	To observe a few 10 km/sec velocity signal. To observe height dependence for the non-thermal velocity (typically ~40 km/sec)
Observation duration	~1 hour	Longer than the typical transient phenomena in AR/QS (e.g., jets)

II-1: Understanding of the Processes in Fast Magnetic Reconnection

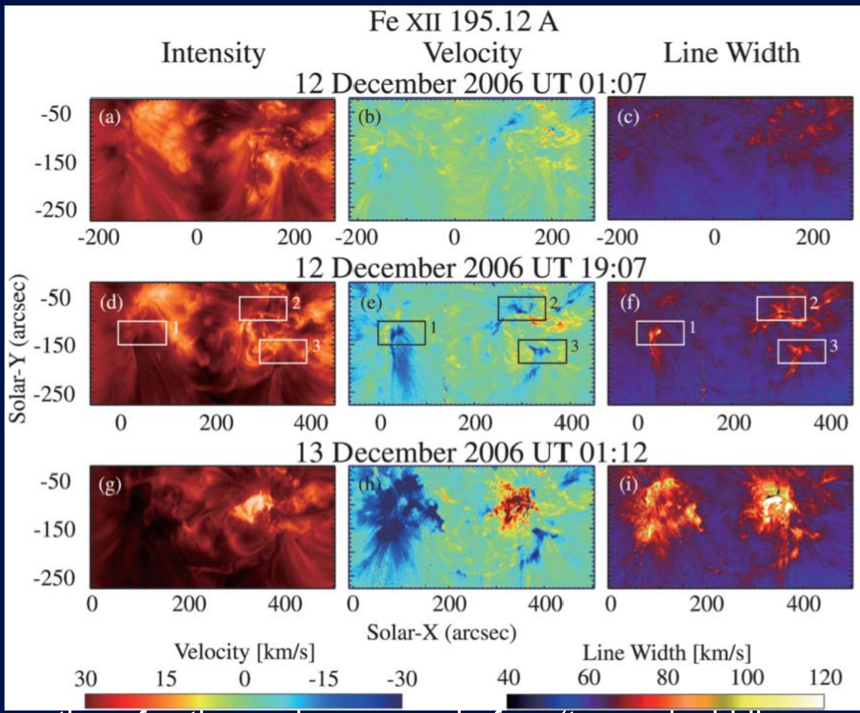


SDO/AIA observations showing a reconnecting current sheet structure (A) without islands (Warren et al., 2018) and (B) with islands (Takasao et al. 2012). Numerical simulations of magnetic reconnection (C) Petschek reconnection (Yokoyama & Shibata, 1997), (D) plasmoid-unstable reconnection (Shibayama et al., 2015).

II-1: Understanding of the Processes in Fast Magnetic Reconnection

Item	Requirement	Rationale
Temperature coverage	0.01-10 MK	To observe the site of magnetic reconnection and chromospheric evaporation in the chromosphere, transition region, and corona simultaneously. Non-equilibrium ionization diagnostic capability.
Spatial resolution	~1 arecsec	For resolving magnetic islands during the flare (~1”), kernels of chromospheric evaporation (~1”), and magnetic reconnection in the chromosphere (~1”).
Temporal resolution	~1 sec /step in 1” step 0.1 sec without scan	The scanning speed should be faster than Alfven speed 1000km/s, i.e. 1 sec /step in 1” step. This is probably difficult. This case, we should make use of a sparse scan to cover the FOV. <30 sec. Evolution timescale for the kernels of chromospheric evaporation (0.1 sec).
FOV	20 x 280 arcsec^2	Entire reconnection region in the corona should be observed (20” x 280”). To observe flare ribbons evolution (1” x 280”). Entire reconnection region in the chromosphere should be observed (20” x 100”).
Velocity resolution	~2 km/s for Doppler a few km/s for non-thermal width	A few km/s to observe the reconnection related flows. To discuss the non-thermal velocity variation, a few km/s is needed.
Observational mode	Roll observation	For observing flare near the equatorial limb with height, a roll observation is needed.
Observation duration	A few days	~ a few days to catch at least one flare

II-2. Identify the Signatures of Global Energy Buildup and the Local Triggering of the Flare and Eruption



Hinode/EIS observation of active region corona before (top and middle rows) and after (bottom row) the flare event at 02:14 UT, 2006 December 13 (Imada et al. 2014). Upflows of 30 km/s with line broadening are seen one day prior to the occurrence of the flare (panels e and f).

II-2. Identify the Signatures of Global Energy Buildup and the Local Triggering of the Flare and Eruption

	Requirements	Reasons
Temperature coverage	0.1-10 MK	(1) A broad temperature range of log(T [K])=3.8-7.3 should be covered to monitor pre-flare phenomena. (2) Lower temperature ranges, log(T [K])=3.8-4.0 and 4.8-6.0, should be covered to reveal the dynamics of the lower atmosphere.
Spatial resolution	~1 arcsec	(1) Resolution better than or similar to AIA (~1.2") is needed. (2) High resolution observations (0.8") should be conducted to resolve the flare-triggering fields (~10").
Temporal resolution	~1 minute	(1) About or less than 1 hour is needed. Constant, continuous monitoring is crucial for this observation. (2) Less than 10 minutes (preferably about 1 minute) to monitor the dynamics of trigger fields.
FOV	280 x 280 arcsec^2	(1) The entire AR should be covered (e.g. 280"x280"). (2) A FOV similar to II-1 (e.g. 25" x 100") is requested.
Velocity resolution	~1 km/sec for Doppler ~10 km/sec for non-thermal width	(1) For the coronal measurements, a few km/s for the Doppler velocity and ~10 km/s for the turbulence velocity are requested to resolve, e.g., the pre-flare dynamics and non-thermal broadening. (2) For the chromospheric measurements, ~1 km/s for the Doppler velocity is desirable so that the Alfven and acoustic velocities (a few 10 km/s) are resolved.
Observation duration	a few days (up to 2 weeks)	A few days are requested to catch at least one flare event (up to 2 weeks for the whole disk passage).

Performance required for Observation

ID	mission requirement (goal) item	requirement		reason	justification of the value	Study-I I-1	I-2	I-3	I-4	Study-II II-1	II-2
MR-01	temperature range	log T [K] =	3.8 – 4.0	observe chromosphere	temperature range of chromosphere		A	A	B	A	A
			4.0 – 6.0	observe transition region	temperature range of transition region	B	A	A	A	A	A
			6.0 – 7.3	observe corona	temperature range of corona including flares	A	A	A	A	A	A
MR-02	spatial resolution	chromospheric intensity, velocity	0.5″ (0.4″)	resolve fine scale density structures in chromosphere	same size as chromospheric structures (e.g., spicules, current sheet)		A	A	B	A	B
		transition region and corona	0.5″ (0.4″)	resolve fine structures in transition region and corona	estimation from Hinode EUV spectroscopy fine structures observed by HiC rocket	B	A	A	B	B	B
MR-03	time resolution	imaging observation	1.0 s (0.1 s)	resolve time variation of Alfvenic phenomena	time scale of Alfven time, and or non-thermal phenomena	A	A			A	
			10-60 s	resolve time variation of fine structures	time scale of fine structure evolution			A	B		B
MR-04	field of view	High cadence observation for small region: 28″ x 280″		capture dynamics in flaring current sheet	size of currentsheet			A		A	
		corona obs : ＞240″x 240″		observe active region corona	size of corona influenced by active region	A	A		A		A
MR-05	time span of continuous obs	high cadence obs of fine structures 3 hr (max)		observe entire history of process starting in photosphere and propagete into chromosphere and coronal	life time of phoitospheric/chromospheric dynamic structures 1min〜1hr response time of corona 1min〜1hr	A	A	A	A		
		continuous obs. Of active region etc. 2 weeks (max)		observe formation and evolution of AR and flares	half period of solar rotation					A	A
MR-06	photometric accuracy	chromosphere	$\delta I/I_{(\mathrm{Disk})} < 0.01$	detect small heating process	observe small brightening (energy event) with 10 times higher sensitivity than Hinode		B	A	A	A	B
		transition region and corona	$\delta I/I_{(\mathrm{Active\ Region})} < 0.05$	detect faint structures	detect small plasmoids and shock frontstructures in magnetic reconnection	A	A	A	A	A	A
MR-07	accuracy for velocity	LOS V: chrom.	$\delta V_{\mathrm{D}} \leq 0.1$ km/s	observe motions in photo./chrom.	detect amplitude of 5min oscillation (〜0.5km/s)		B	A	B	A	B
		LOS V: TR / corona	$\delta V_{\mathrm{D}} \leq 1$ km/s	observe motions in corona	turbulent motions in corona /10	B	A	A	A	A	B
		Turbulent V : chrom.	$\xi \leq 3$ km/s	Observe plasma dynamics and kinetic energy	typical width of spectral lines as known in each region		B	A	B	A	A
		Turbulent V: TR, corona	$\xi \leq 10$ km/s			A	A	A	A	A	A
MR-08	mission life	longer than 1 years including solar maximum (>3yr)		observe large number of flares	flare occurrence ingreases around solar maximum					A	A

T: temperature, I: intensity, B_{L}: line of sight component of magnetic field , B_{T}: transversal component of magnetic field , V_{D}: line of sight velocity , V_{H}: horizontal velocity ξ: turbulent velocity (nonthermal velocity)
LOS: line of sight,

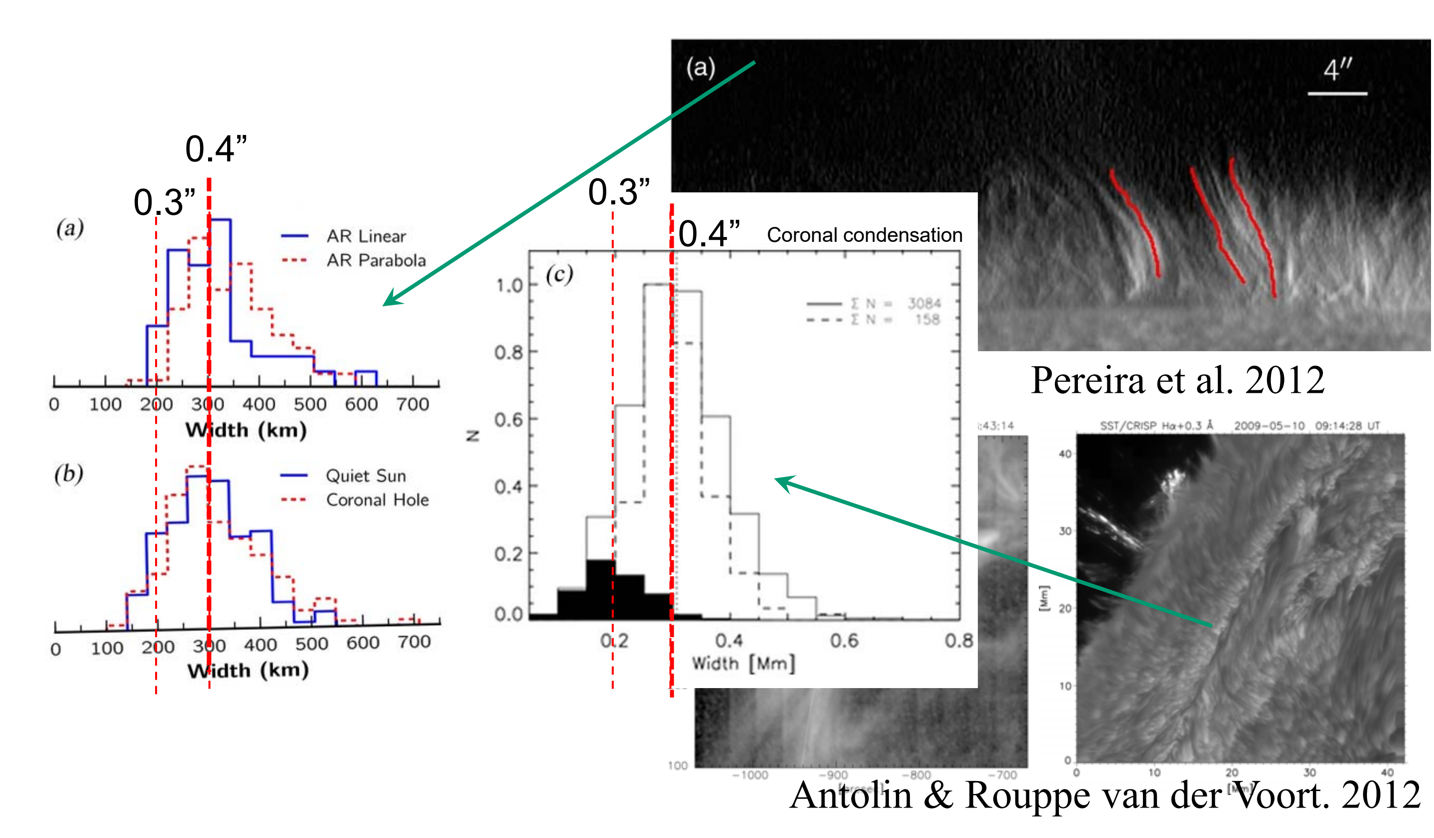
A:High Requirement, B: Middle Requirement

Comparison of possible technologies

	UV spectroscopy (selected technology)	UV imaging	SXR spectroscopy (crystal spectrometer)	SXR imaging spectroscopy (photon counting with CMOS)	SXR imaging	Visible spectroscopy with coronagraph
Temporal resolution (exposure)[sec]	0.1-1	~1	<1	<10	<10	0.25
Spatial resolution [arcsec]	0.4	1.2 (AIA) 0.2 (Hi-C)	N/A	1	1	~10
Spectral resolution [λ/dλ]	~10000	N/A	~5000	5	N/A	~10000
Temperature coverage [K]	6k – 15M	6k – 15M	10M-50M	> 5M	1.3M – 32M	10k, 1.5-2.5M
Temperature resolution [d(logT)]	0.05-0.1	0.2-0.8	0.1	0.1	0.2	N/A
Field of view [arcsec]	200	full disk (AIA) 400 (Hi-C)	1400	<500”	Full disk	>2.8R_sun, only off-limb
Simultaneous measurement (space)	<one exposure (along slit) exposure x step number (along scan)	<one exposure	N/A	< one exposure	< one exposure	< one exposure
Simultaneous measurement (wavelength)	<one exposure	Exposure x wavelengths	< one exposure	< one exposure	Exposure x wavelength	N/A

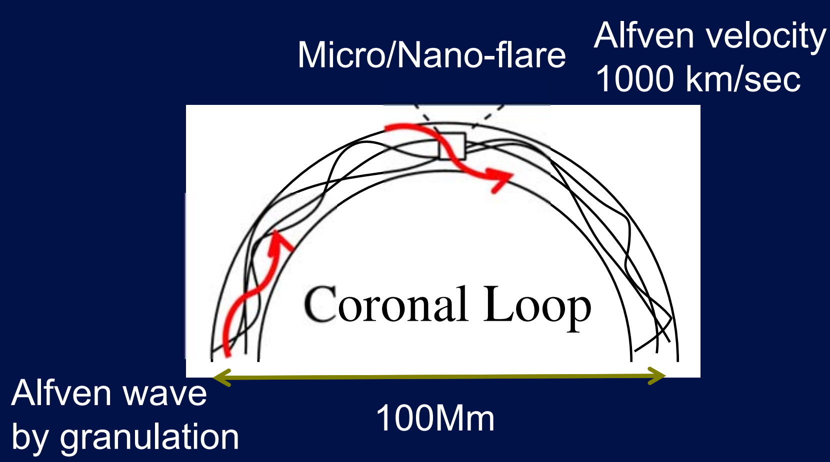
High Spatial resolution

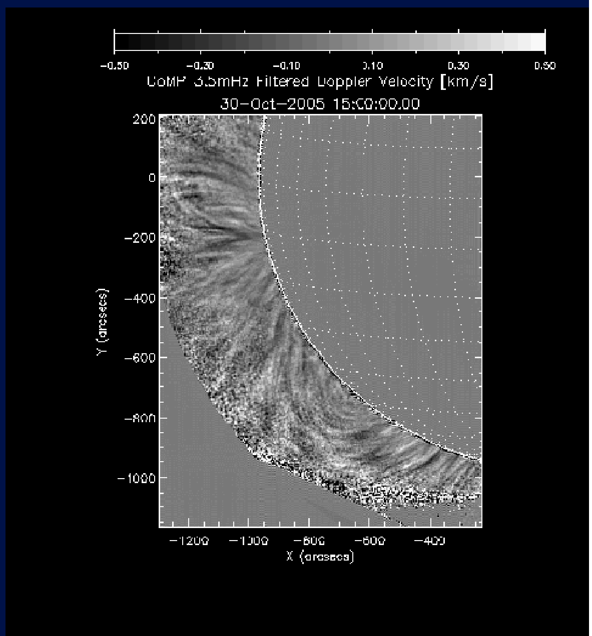
0.4" ~ 300 km on the solar surface



High temporal resolution

- Alfven time ~ 100sec





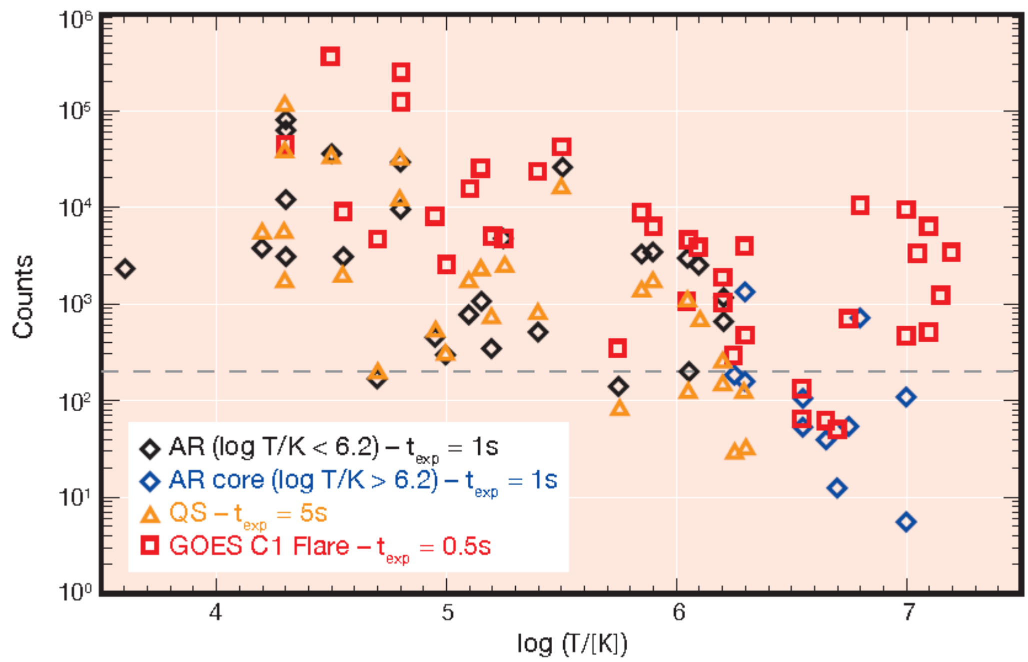
Tomczyk+, Science 2007

- Sound traveling time ~ a few 100 sec
- Ionization time scale ~ 100 sec
- Te ~ Ti time scale ~ 100sec

High Throughput

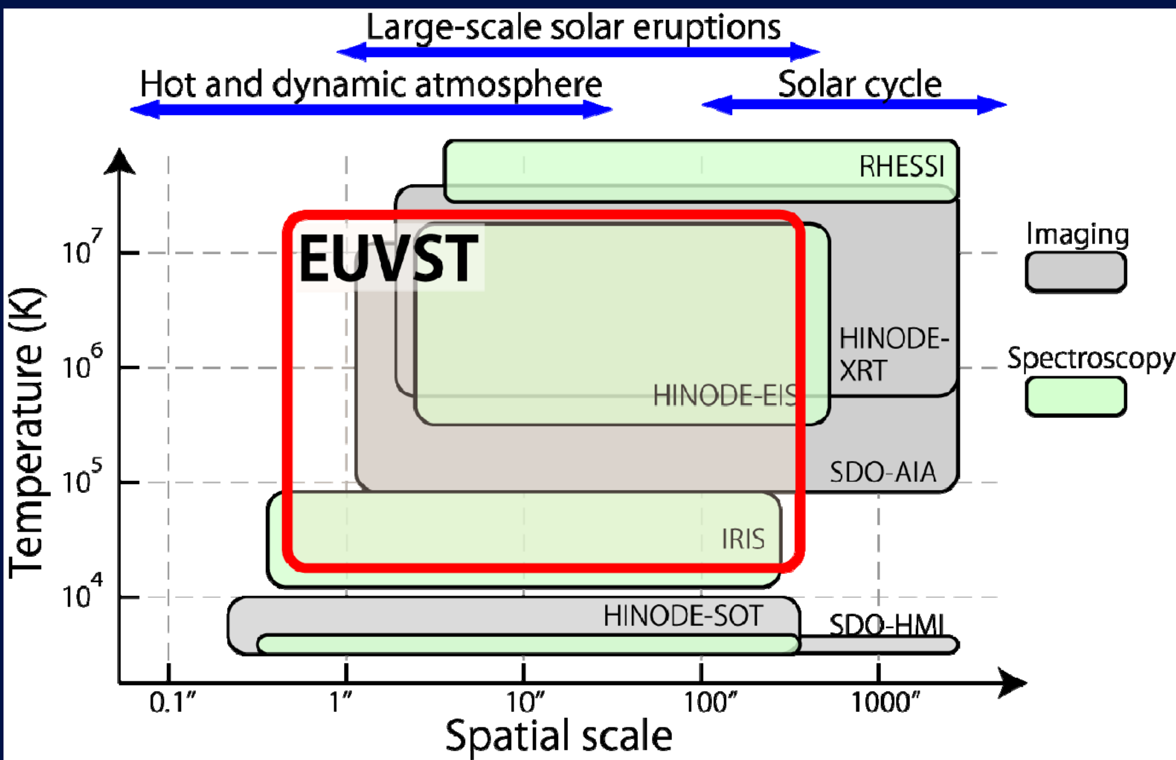
Wide temperature coverage   High spatial resolution   High temporal resolution

Figure 3.8: *EUVST expected count rates (count/arcsec^2) in the indicated exposure times for different solar observational targets (5 s for the quiet Sun, 1 s for active regions, and 0.5 s for a small flare). The horizontal dashed line marks the 200 counts (in the spectral line) level necessary to determine line positions with a ≤ 2 km s^{-1} accuracy.*



Temperature coverage vs Spatial scale

The solar atmosphere is characterized by the continuous exchange of mass and energy through different temperature region, this is arguably the strongest requirement.

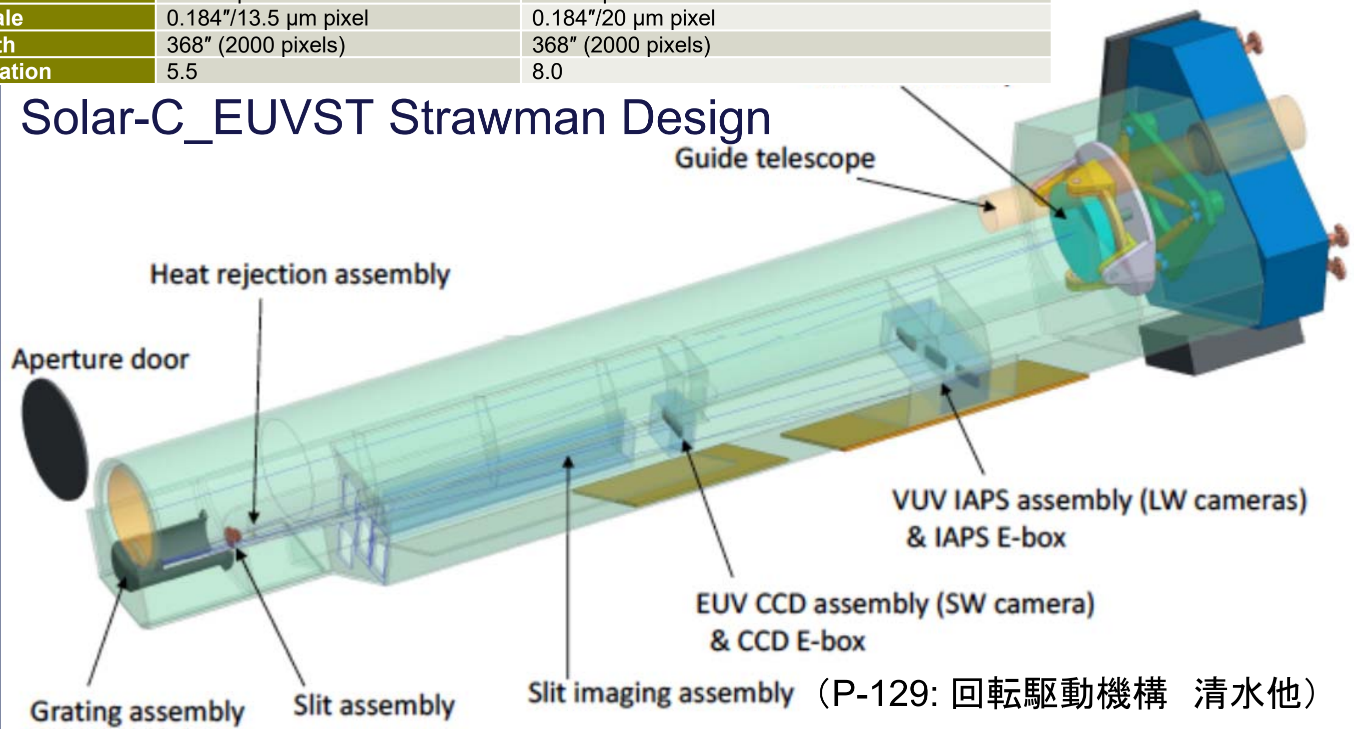


Spatial sampling at CCD	0.184 "/pix	Focal length of the primary mirror	2800 mm
Plate scale at slit	13.57 μm/"	Slit-grating length	300 mm
Mirror diameter	280 mm	Mirror grating length	3100 mm
F/#	10	Grating-CCD length	2400 mm
Grating magnification	8		

	SW waveband	LW wavebands
Spectral ranges	170-215 Å	1st order: 690-850 Å, 925-1085 Å, 1115-1275 Å 2nd order: 463-542 Å, 557-637 Å
Detectors	4096 × 2048 CCD, 13.5 mm pixels	4096 × 2048 intensified APS for 20 mm pixels
Geometry and dispersion	4200 grooves/mm 165 cm grating to detector 20 mÅ/pixel	2000 grooves/mm 240 cm grating to detector 37 mÅ/pixel
Plate scale	0.184″/13.5 μm pixel	0.184″/20 μm pixel
Slit length	368″ (2000 pixels)	368″ (2000 pixels)
Magnification	5.5	8.0

（P-128: 凹面回折格子　川手他）

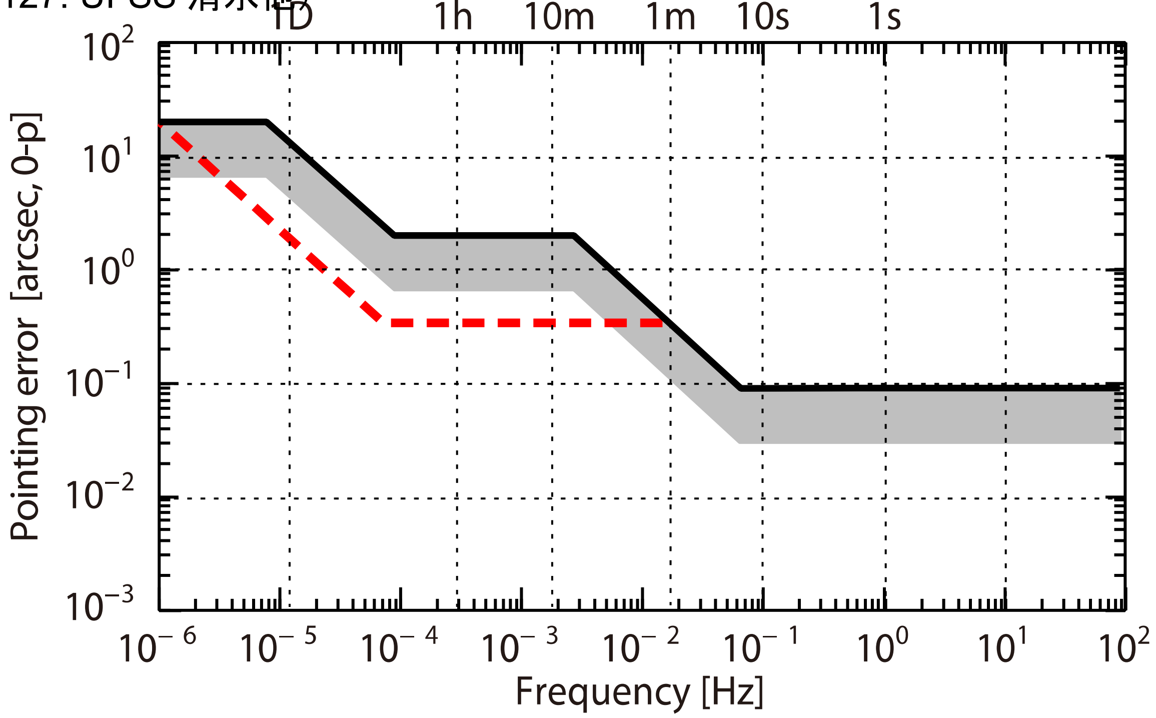
Solar-C_EUVST Strawman Design



（P-129: 回転駆動機構　清水他）

S/C Pointing stability

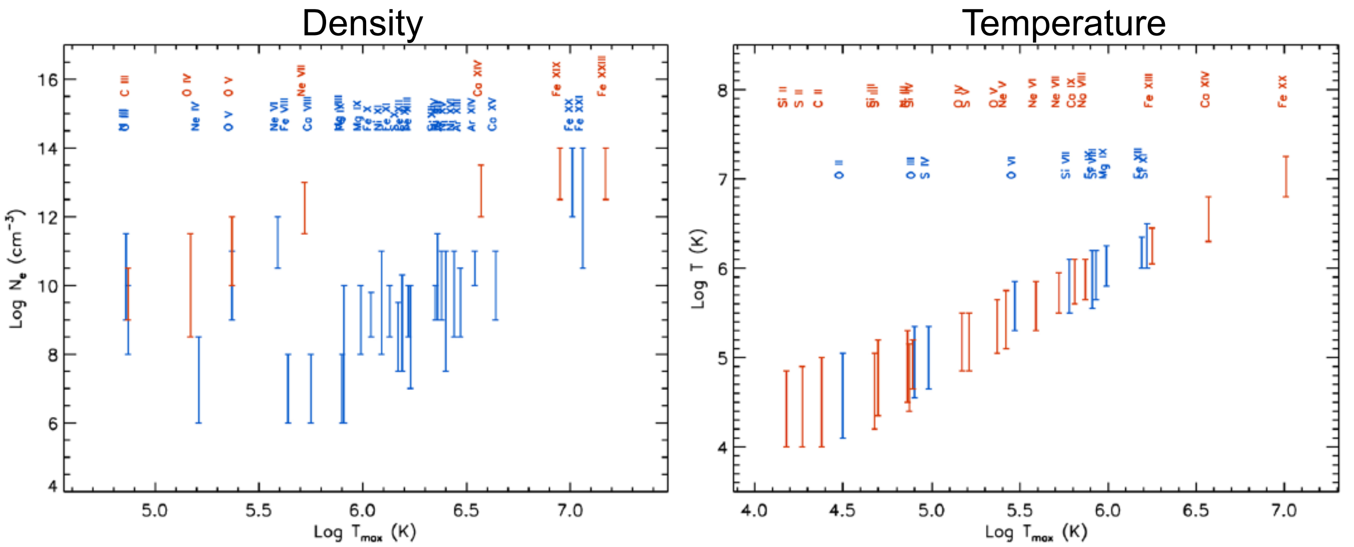
（P-127: UFSS 清水他）



Pointing stability (θ_x, θ_y) requirements in frequency domain. Assuming sine oscillations, $\Delta\theta(0-p) = \sqrt{2}/3\,\theta(3\sigma)$ was used to convert 3σ to 0-p. Pointing may slowly drifts with the orbital phase due to the thermal deformation. Following the IRIS's heritage on the correction by an orbital wobble table (De Pontieu et al. 2014), this orbital drift will be suppressed to the goal level depicted by the red dashed line in the Figure (0.4 arcsec [0-p]) by a look-up table for correcting the tilt of the primary mirror.

Diagnostic Capability

Figure 3.6: *(Left) Electron density range covered by the density-sensitive intensity line ratios available in the EUVST spectral bands as a function of the formation temperature of the line pair. Densities obtained from ratios with all components on the same channel are shown in blue while those having components on different channels are shown in red. For the brightest line systems (e.g., C III 977/1176 or those from Fe X to XIII) densities can be obtained with exposure times down to 1 s. (Right) Electron temperature range covered by the temperature-sensitive intensity line ratios available in the EUVST spectral bands as a function of the formation temperature of the line pair. The best diagnostics (bright or relatively bright lines and good temperature coverage) are shown in blue. Density and temperature ranges are evaluated with CHIANTI 7.1.*



Observing Modes

Obs. mode	FOV	Slit width / exposure	Step size	Cadence	T range	# of lines	Data rate[1]
Context[2]	280″×280″	1.6″ (10 s)	1.6″	1750 s	0.02 – 10 MK	40	0.29 Mbps
QS Context[2]	112″×182″	0.80″ (3 s)	0.80″	420 s	0.02 – 1.5 MK	16	0.51 Mbps
QS Full	112″×182″	0.40″ (2 s)	0.40″	560 s	0.02 – 1.5 MK	8	0.76 Mbps
QS Fast	10″×182″	0.40″ (2 s)	0.40″	50 s	0.02 – 1.5 MK	8	0.76 Mbps
QS Ultra Fast	4.8″×182″	1.6″ (3 s)	1.6″	9 s	0.02 – 1.5 MK	20	0.32 Mbps
Corona Fast	140″×280″	4.0″ (3 s)	4.0″	105 s	0.02 – 10 MK	36	0.35 Mbps
Corona Deep	280″×280″	4.0″ (20 s)	4.0″	1400 s	0.02 – 2.5 MK	Full	0.40 Mbps
SS (sit and stare) Fast	1.6″×280″	1.6″ (3 s)	0″	3 s	0.02 – 2.5 MK	20	0.49 Mbps
SS (sit and stare) Ultra-Fast	0.40″×91″	0.40″ (0.1 s)	0″	0.2 s	0.02 – 20 MK	4	1.91 Mbps
AR Context[2]	280″×280″	0.80″ (1 s)	0.80″	350 s	0.02 – 20 MK	16	2.35 Mbps
AR Full	280″×280″	0.40″ (1 s)	0.40″	700 s	0.02 – 20 MK	8	2.35 Mbps
AR Fast	14″×182″	0.40″ (0.5 s)	0.40″	17.5 s	0.02 – 20 MK	8	3.06 Mbps
AR Ultra Fast	4.8″×280″	1.6″ (1 s)	1.6″	3 s	0.02 – 20 MK	16	1.18 Mbps
Flare	28″×280″	0.80″ (0.5 s)	0.80″	17.5 s	0.02 – 20 MK	12	3.53 Mbps
Dynamics Fast	5.6″×91″	0.40″ (0.5 s)	0.40″	7 s	0.02 – 2 MK	8	1.53 Mbps
Slit camera monitor[2]	30″×150″	(0.2 s)	n/a	7 s	0.01 MK	n/a	0.06 Mbps[3]

(1) Based on 60 pixel wide windows. The number of pixels along the slit is given by the y-size of the FOV divided by the slit width (spatial binning equal to resolution across slit). 14 bits/pixel and lossless compression (factor 2) are assumed. Note that lossless compression of EIS is ~35%, largely depending on the features in the data.

(2) EUVST context and Slit camera monitor images are also needed to facilitate alignment with other observations (e.g., DKIST).

(3) Compression to 2.2 bits/pixel is assumed.

EUVST performance in comparison with current & forthcoming spectrometers

	Existing mission			Mission Under Study			
	Hinode/ EIS	SoHO/ SUMER	IRIS	SMEX FOXSI	Solar Orbiter/ SPICE	MUSE	Solar-C EUVST
Temporal resolution for a slit position (1)	10 – 60 s for AR 20 – 120 s for QS	≥15 – 60 s (2)	<10 s for AR 10 s for QS	0.1 s	5 s	1.0 s for AR 0.1 s for flare	0.2(4) – 5 s for AR 0.2 – 20 s for QS
Spatial resolution (1″=725 km on the Sun)	2″ – 3″ 1″ (pixel size)	1.5″ 1″ (pixel size)	0.33″ 0.167″ (pixel size)	8”	1”	0.4”	0.4″ 0.185″ (pixel size)
Field of View (without repointing)	±290″×512″	±1920″×300″	32″×120″	540” x 540”	960”x240”	170”x170”	±150″×280″
Primary temperature coverage ($\log_{10}$ T/[K])	4.9, 5.6 – 7.2	3.6 – 5.8, 6.8 – 7.0(3)	3.7 – 5.2, 7.0	3-50 keV	4.3 – 7.1	5.9, 6.4, 7.0-7.1	4.1 – 7.2
Diagnostics capabilities	LOS Velocity Electron Density Electron/ion Temperature DEM	LOS Velocity Electron Density Electron Temperature	LOS velocity	Electron energy distributio n DEM	LOS Velocity Electron Density Electron/ion Temperature DEM	LOS velocity	LOS Velocity Electron Density Electron/ion Temperature DEM

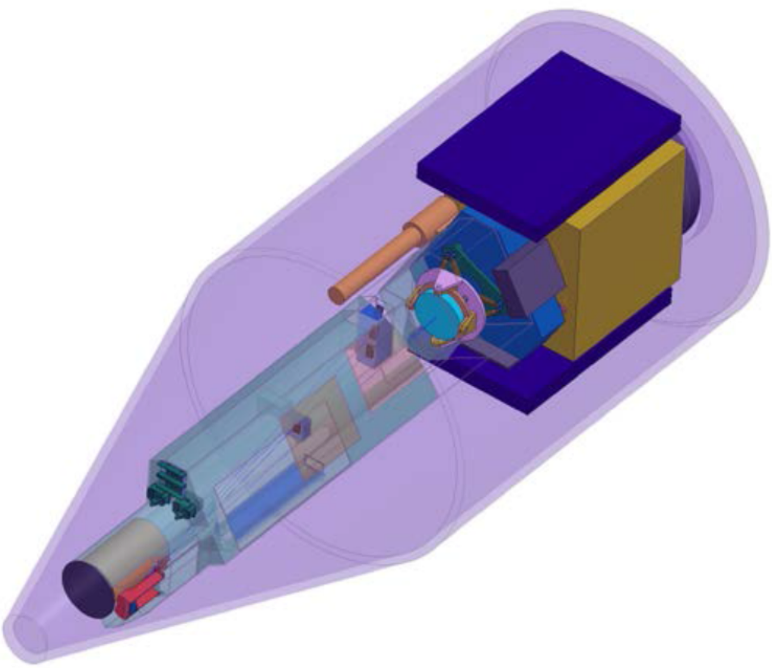
(1) The values given here are typical exposure duration for multiple numbers of spectral lines covering a wide temperature range.

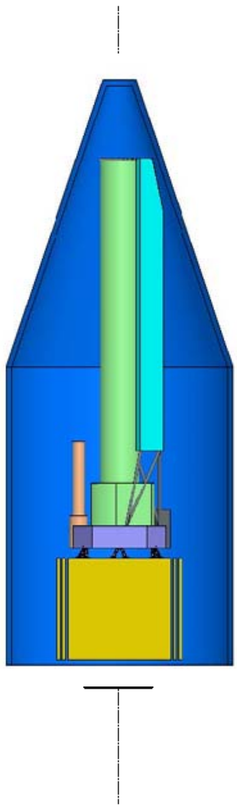
(2) There are several lines in the SUMER range that could actually be recorded at higher cadence even on the quiet Sun but there is neither sufficient telemetry nor on-board storage to allow this. Values given here refer to the time required to transmit just one window of 50 × 300 pixels (300″slit). None of these problems will affect EUVST.

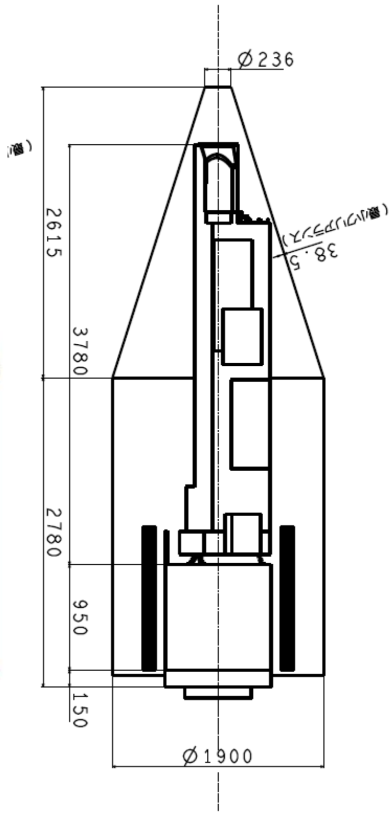
(3) SUMER can record spectral lines in only one spectral window of ≈40 Å at a time. If spectral lines in another spectral window are measured, the spectral window must be changed before the exposure.

(4) Exposure time and time step of 0.2 s is for one line per camera (4 spectral lines).

Epsilon rocket NF







International consortium

Organization		Country	Representative
Max-Planck Institut für Sonnensystemforschung	MPS	Germany	Solanki, Sami, K.
Mullard Space Science Laboratory/ UCL	MSSL	United Kingdom	Harra, Louise, K.
Rutherford Appleton Laboratory	RAL	United Kingdom	Fludra, Andrzej
Institut d'Astrophysique Spatiale	IAS	France	Auchère, Frédéric
Instituto Nazionale di Astrofisica	INAF	Italy	Andretta, Vincenzo
Università Degli Studi Di Padova	UNIPD	Italy	Naletto, Giampiero
Centre Spatiale de Liège	CSL	Belgium	Halain, Jean-Philippe
Royal Observatory of Belgium	ROB	Belgium	Berghmans, David
Naval Research Laboratory	NRL	USA	Korendyke, Clarence
Lockheed Martin Solar & Astrophysics Laboratory	LMSAL	USA	Tarbell, Theodore, D.

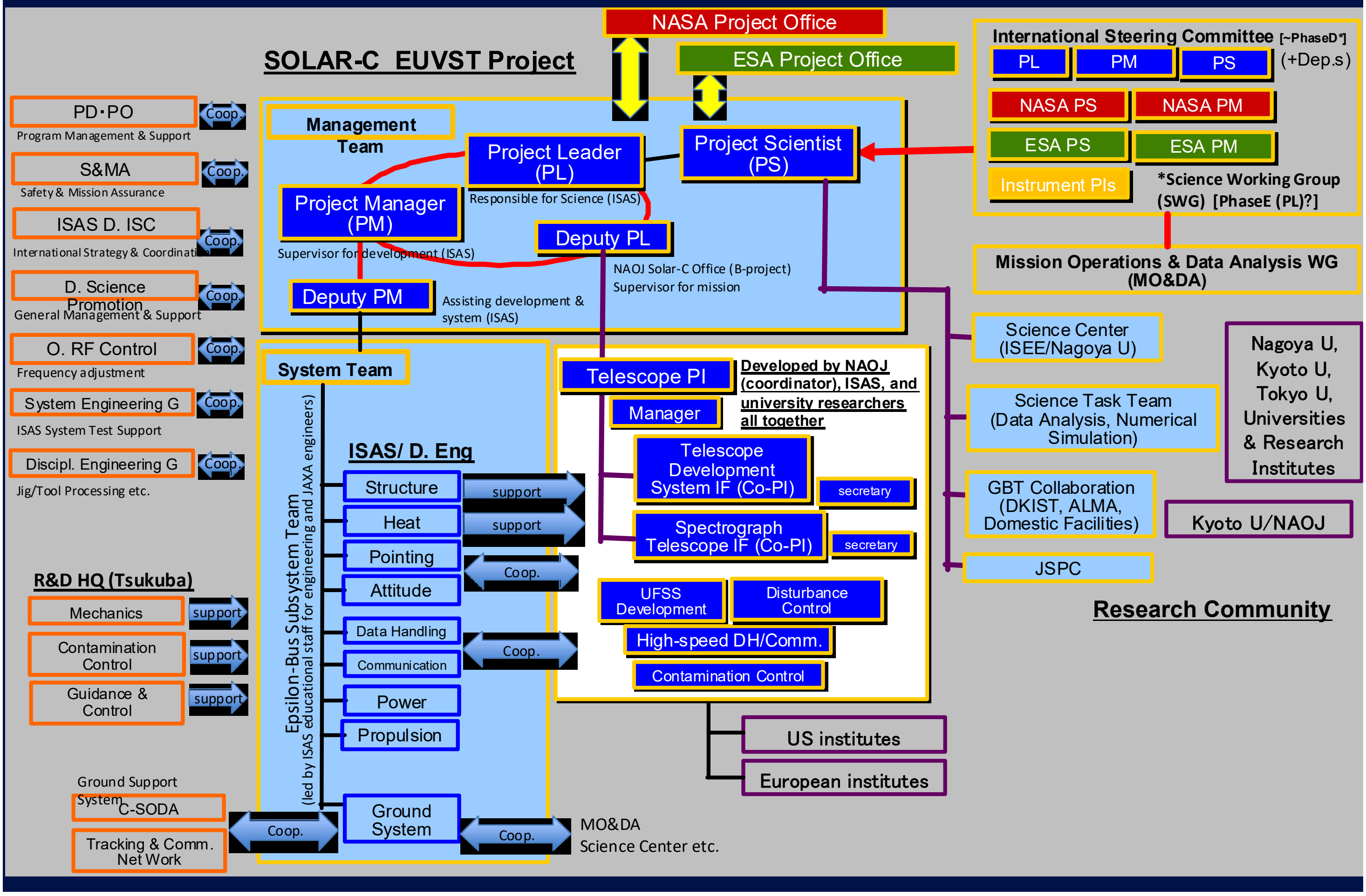
(spectrograph + guide telescope)

Mass & power budgets

Assembly	Mass (kg)	Assembly	Mass (kg)
Telescope unit		**Spectrograph unit**	
Structure	43.4	Structure	31.2
Front door	3.0	Slit assembly	1.5
Deflector plate	1.0	Grating assembly	1.0
Telescope mirror assembly	22.0	CCD focal plane assembly	1.5
Guide telescope	1.7	ICCD focal plane assembly (x3)	7.5
Heat rejection mirror	1.0	CCD electronics box	2.0
Telescope E-box	3.2	ICCD electronics box	4.5
Cables, thermal H/W, misc.	10	Slit imaging assembly	4.0
		Cables, thermal H/W, misc.	8.0
		Spectrograph E-box	8.5
Telescope subtotal	85.3	Spectrograph subtotal	69.7
Total (including 15% reserves)			**155.0**

Electric Power: 161W (including 36W for operational heaters) with an overall maturity contingency of 20%

Project Organization



Ground system/facities + Scientific Operation