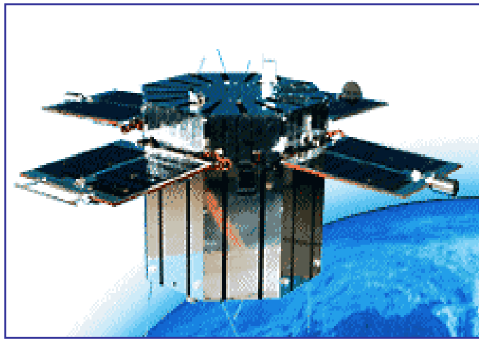
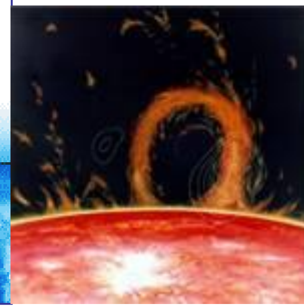
SOLAR-C Mission: Science Objectives and Current Status

Y. Suematsu and SOLAR-C WG

CSPM 2015, 5-9 Oct. 2015

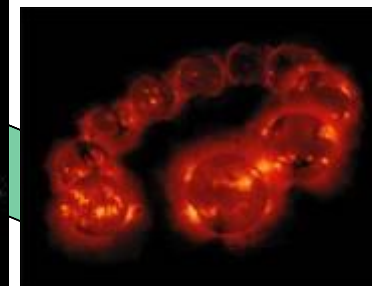
Solar physics mission from space in Japan

HINOTORI/ASTRO-A（1981–1982）

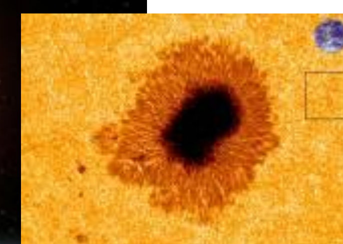
Solar flare
X-ray, γ-ray (E >10 keV)

YOHKOH/SOLAR-A（1991–

Flare, Corona
X-ray, γ-ray (E >0.1 keV)

HINODE/SOLAR-B（2006–）

Photosphere, chromosphere, transition region, corona, flare, Visible, EUV, X-ray

Plan-A
vs.
Plan-B

Higher resolution,
intense spectroscopy
SOLAR-C
2019 (FY)

Proposed to JAXA,
ESA/M4
~2023 launch
Not successful

Will re-propose
for next chance
~2025 launch

SDO (2010-
IRIS (2012-
Solar Orbiter (2018-
Solar Probe Plus (2018-

Science Objectives

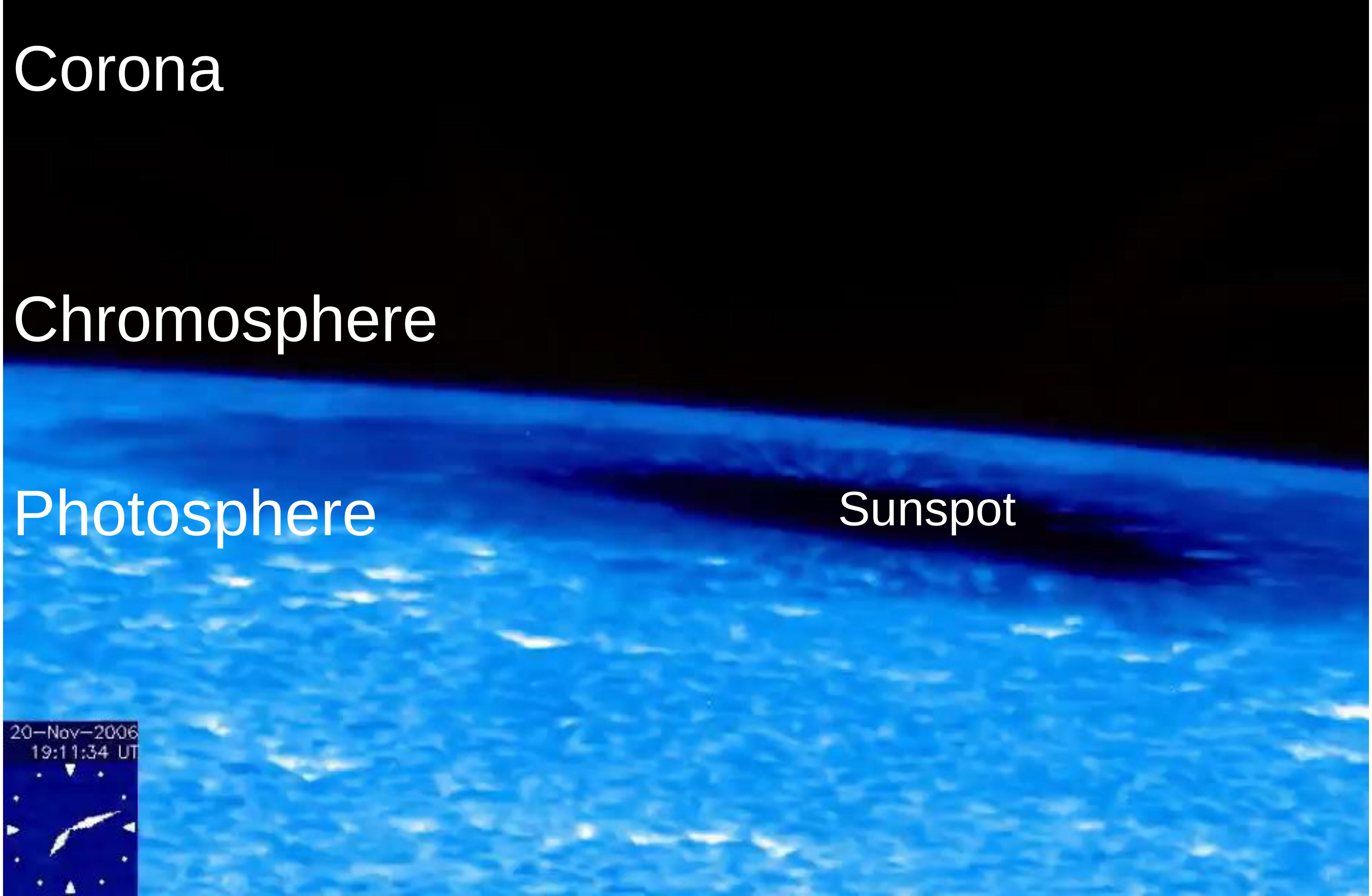
SOLAR-C

Current understandings and next steps for SOLAR-C

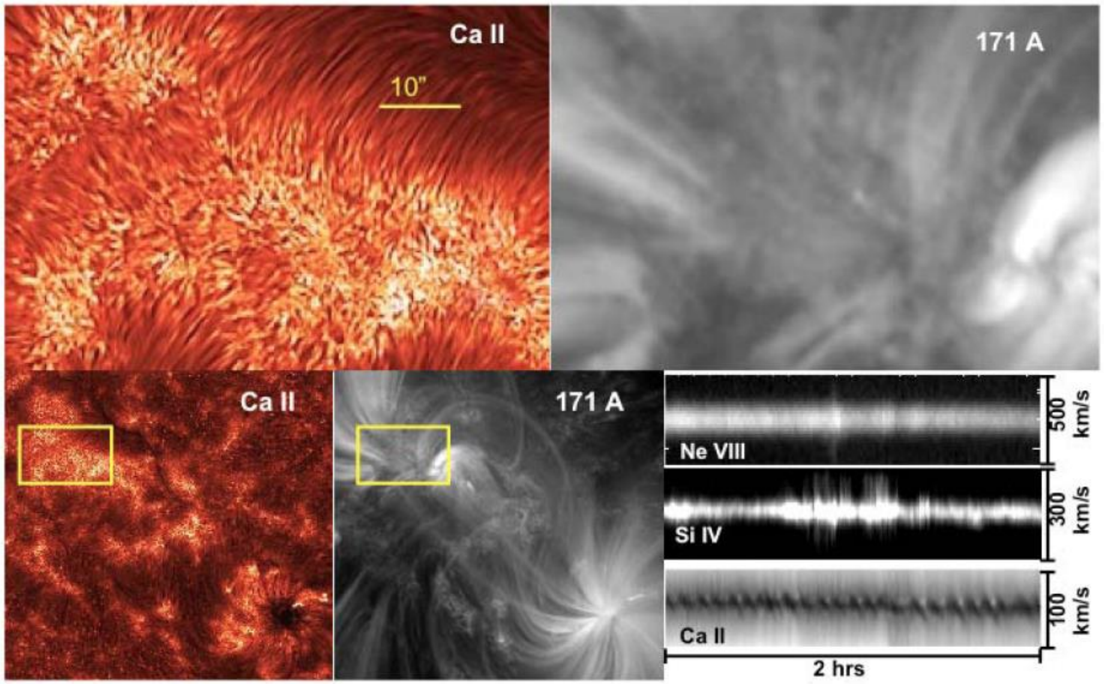
Tackled with utilizing advantages in space observation

- diffraction-limited performance for large FOV for connection between small and large-scale phenomena
- high-precision polarimetry (eg. Hinode SP) thanks to stable PSF
- access vacuum UV and shorter wavelengths for high T plasma diagnostics
- continuous observation for long-term evolution without day-night interruption

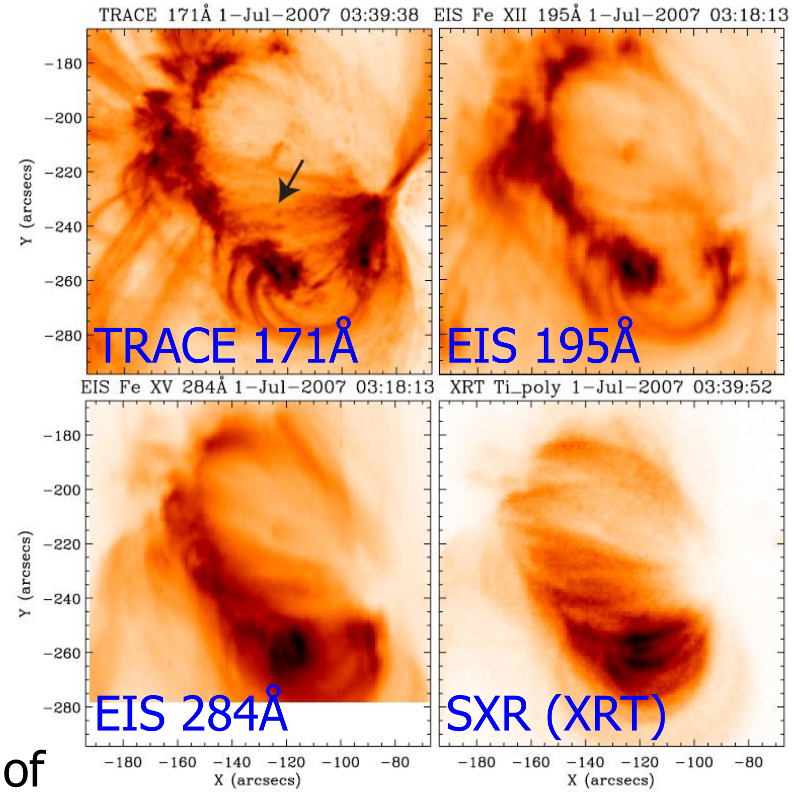
Chromospheric Dynamics revealed with Hinode



Coronal heating



Phenomenological "connectivity" between the base of the corona and the chromosphere/transition region with EUV-line images



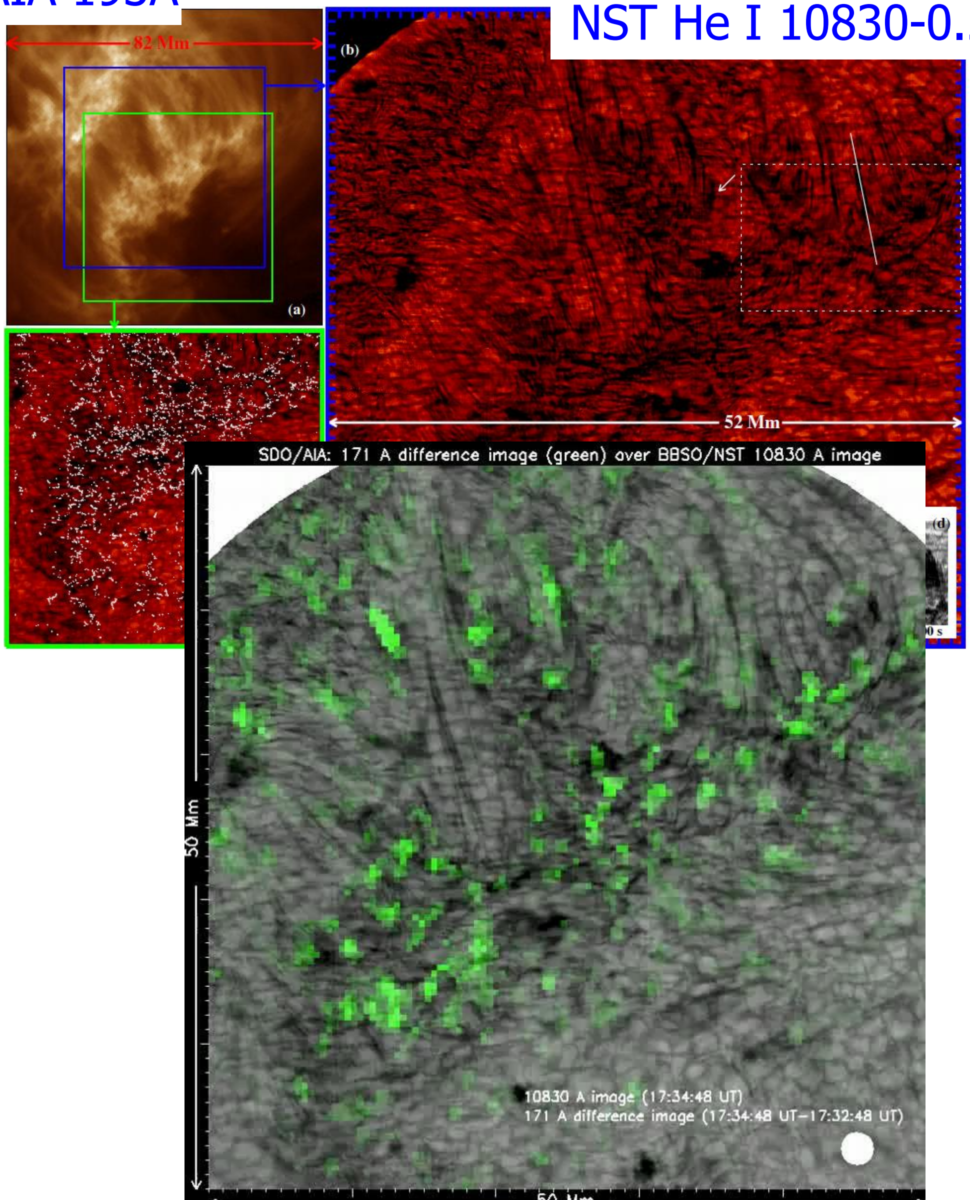
Heating and activities of hot loop with broad-band soft X-ray image

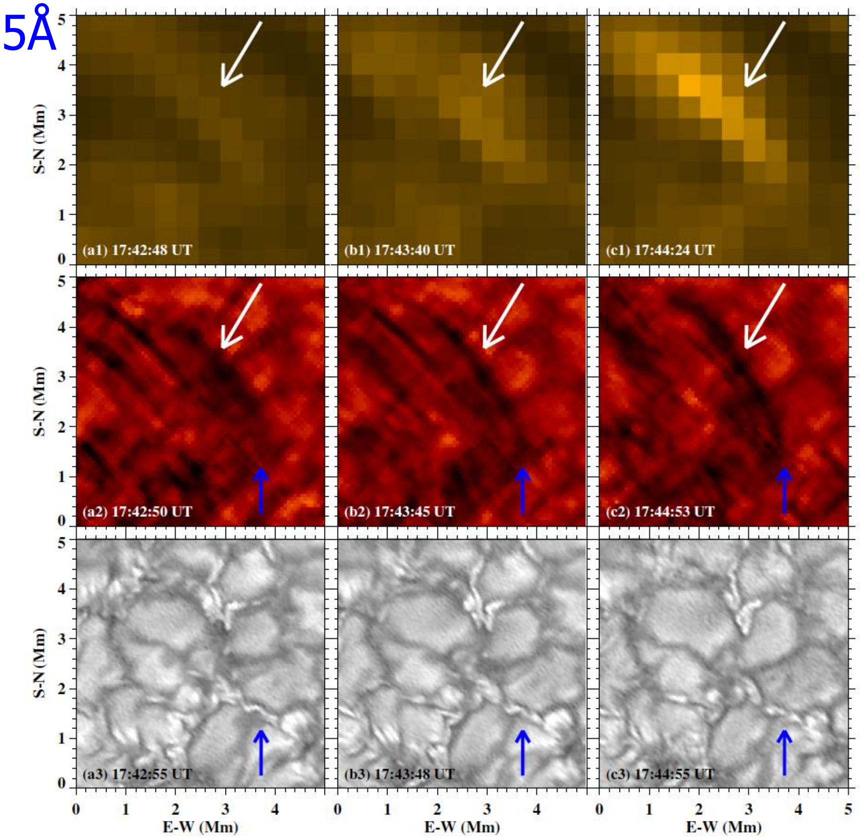
"What corona do we want to see?"

Correspondence of low corona and chromosphere at ultra-fine scales

AIA 193Å

NST He I 10830-0.25Å





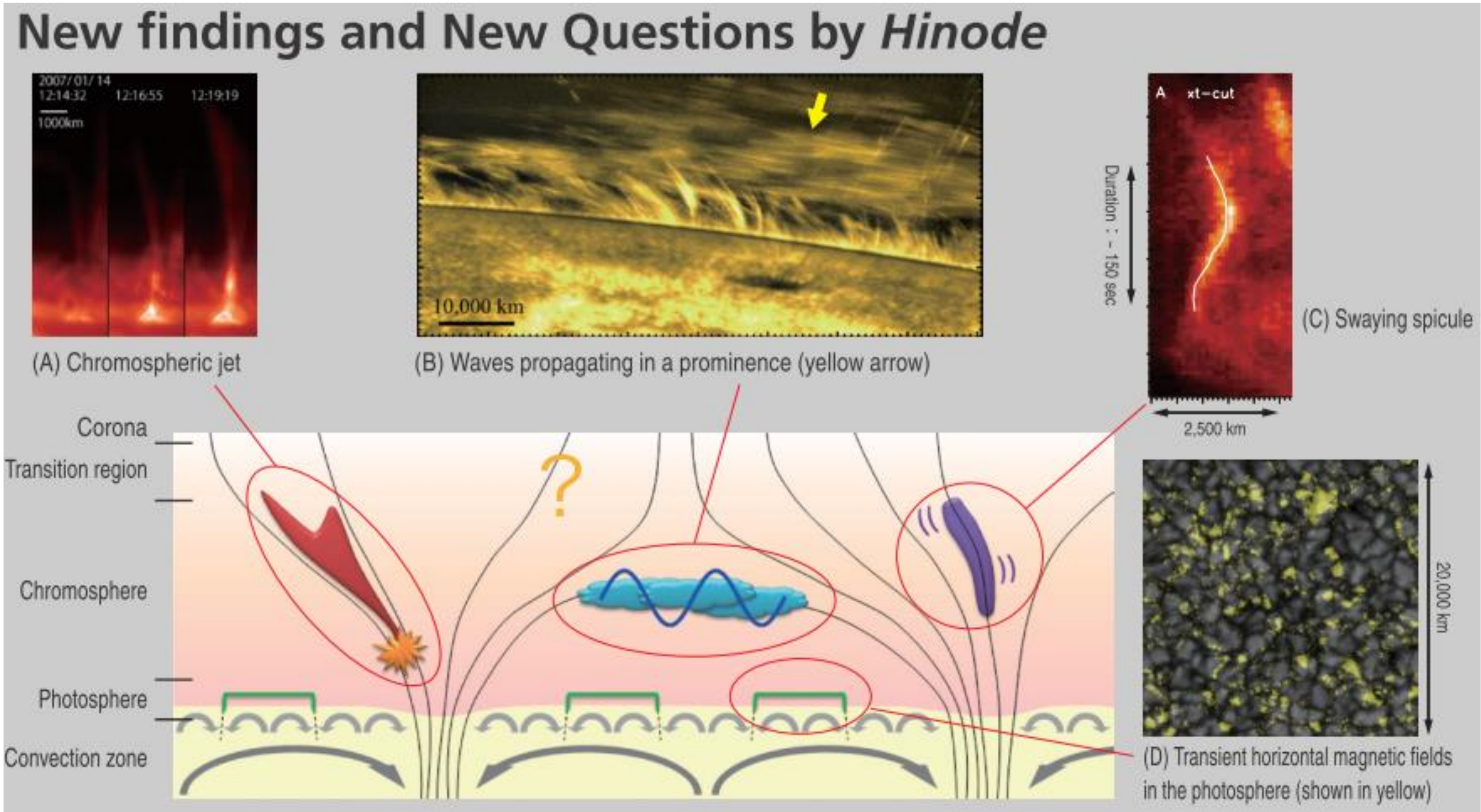
Ji, Cao, and Goode 2012, ApJ

- BBSO/NST He I 10830Å
- SDO/AIA 171 Å

Structure with diameter ~100 km

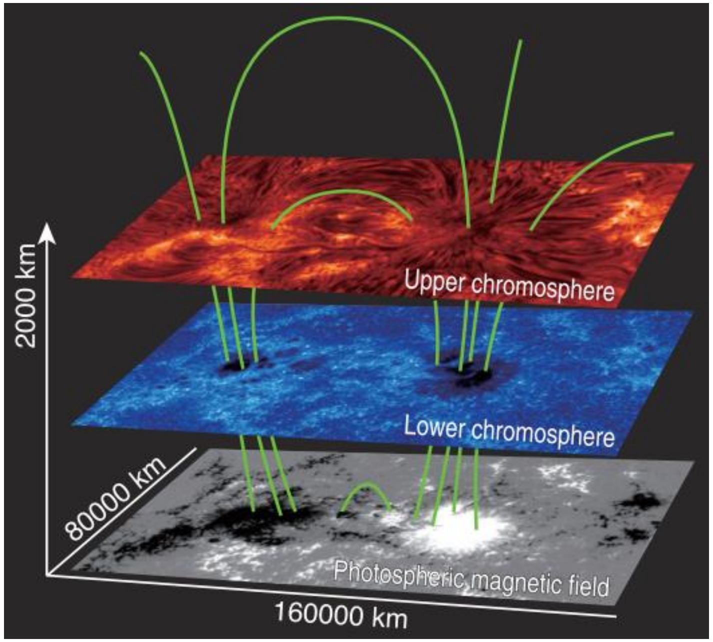
Science from Hinode to SOLAR-C

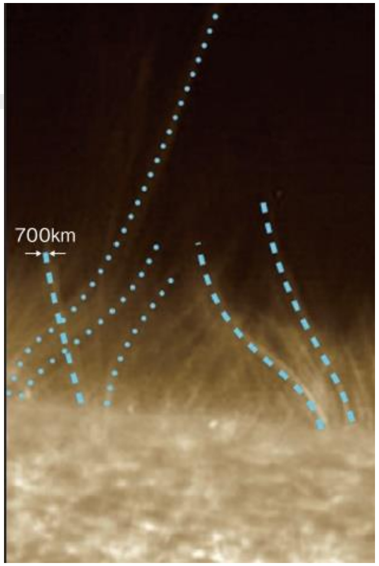
Hinode: 50 cm Optical telescope, EIS, and XRT



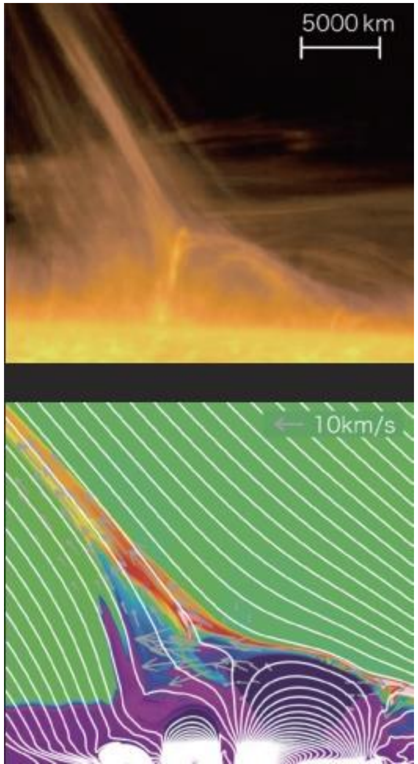
Magnetic fields dominate the dynamics in the chromosphere, transition region and the corona, and likely play a central role in the heating mechanisms. For understanding the heating mechanisms it is essential to carry out high accuracy and high spatial-resolution observations of magnetic fields from the photosphere to the corona, including the chromosphere.

SOLAR-C Science





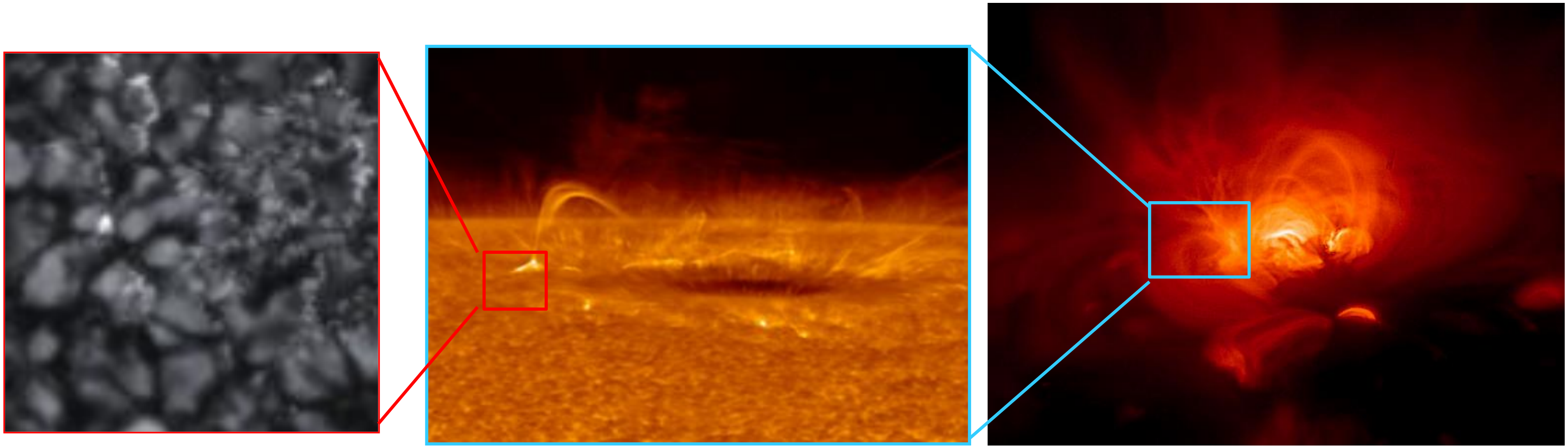
To clarify the nature of these waves from the photosphere and chromosphere, and determine whether they are responsible for coronal heating and solar wind acceleration.



Determining the three-dimensional structure of the solar magnetic field from the photosphere to the corona will be necessary for clarifying the many different phenomena associated with those magnetic fields

to make seamless observations across the solar atmosphere, at various temperatures, of reconnection-induced plasma flows, MHD waves, and shock waves.

How do we observationally connect these regions with such different appearances?



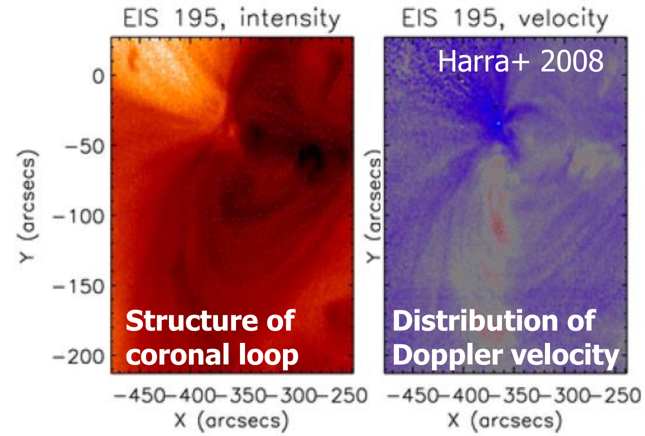
Photosphere **Interface region Chromosphere** **2-5MK corona**

Questions to determine model instrument specifications

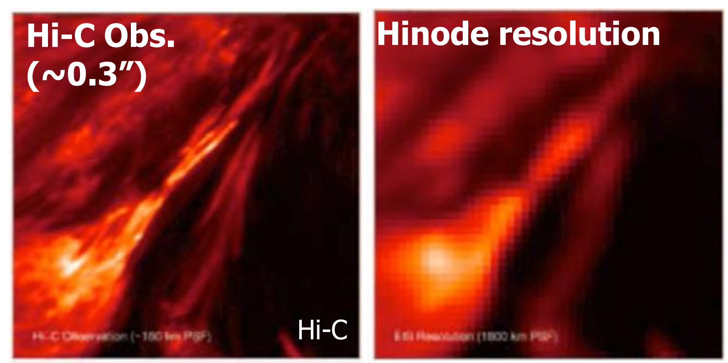
- ***How do we determine chromospheric magnetic structure?***
- ***How do we determine coronal magnetic structure?***
- ***Can we identify neutral sheet structures?***
- ***Can we identify waves in chormosphere?***
- ***What is the smallest scale size inferred from filling factors in all layers?***
- ***What is the source of EIS line broadening; flows or turbulence or waves?***
- ***How do we confirm or reject the Parker and type-II spicule conjectures on coronal heating?***

Current achievements and next steps

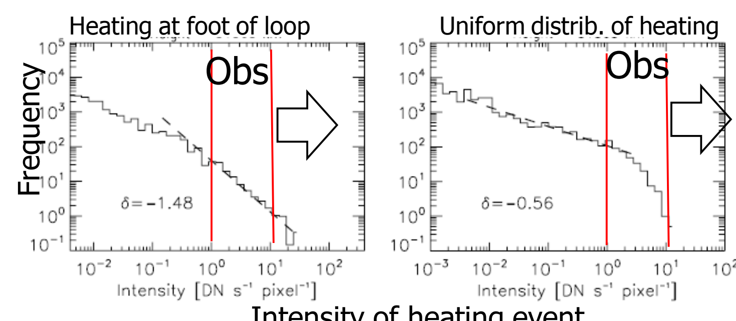
- Corona： derived plasma parameters of heated regions but not yet resolved the two hypotheses



- Subject： resolve fine-scale structure along magnetic fields and study spatial relation between input flux and dissipation
  (implication from latest obs -> 0.3”)



- Subject： differentiate the hypotheses using frequency statics of resolved nano-scale heating events
  (need 10 times higher sensitivity)
- Subject： detect supra-thermal plasma ($T \sim 10^7$K) for nano-flare hypothesis
- （need high throughput EUV spectroscopy：
  10 times higher han Hinode/EIS)



Freq distribution of heating events predicted by 1.5D MHD simulation (Antolin+2008)

Understaning complicated solar atmospheric Structures

SOLAR-C

- <u>Acceleration mechanism of fast solar wind</u>

Momentum transport by Alfven waves

Measure wave motion, energy/mass flux, and turbulence along magnetic field lines connecting polar CH region with interplanetary space
⇒Need high-precision spectroscopy

- <u>Formation mechanism of prominence</u>

Material circulation in dynamically and thermally balanced circumstance

⇒measure magnetic fields of prominence

Sunspot formation and dynamics

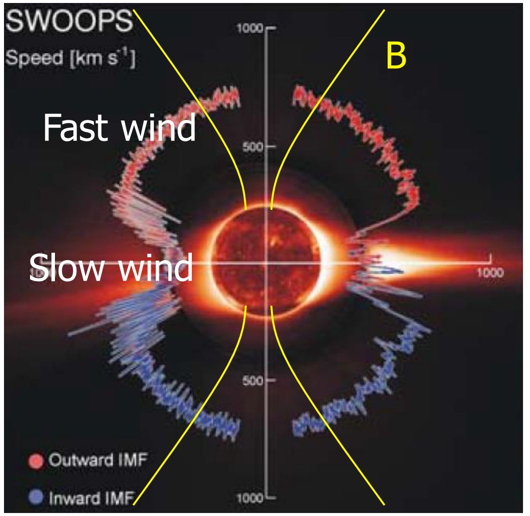


Fig. 1.4: 太陽極小期における太陽風の速度構造（McComas et al. 2003より）。

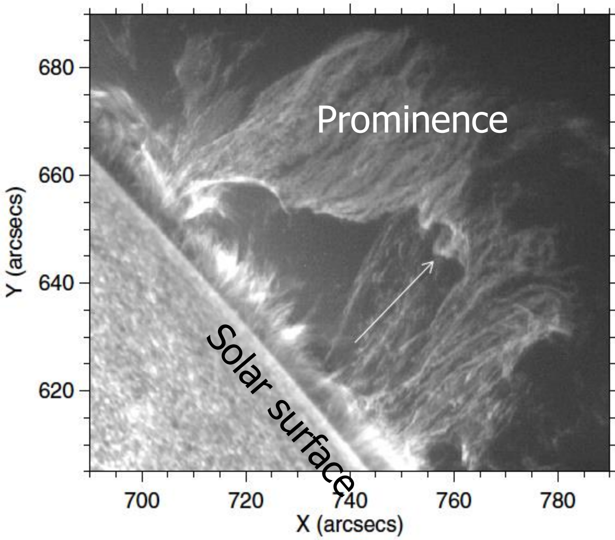
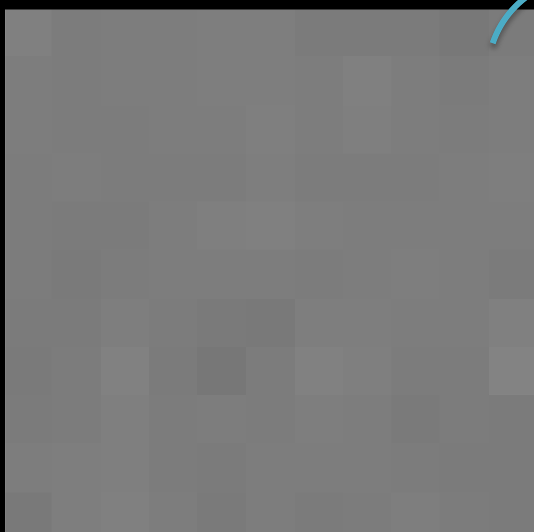


Fig. 1.5: 「ひので」で観測されたコロナ中に浮かぶ10^4 Kのプロミネンス構造（Hillier et al. 2012より）。

Necessity of high-resolution observation for magnetic field

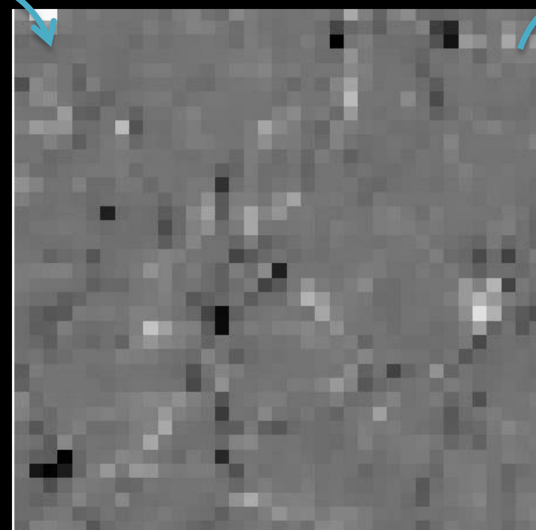
~ photon meanfree path

Res 1” (typial ground)



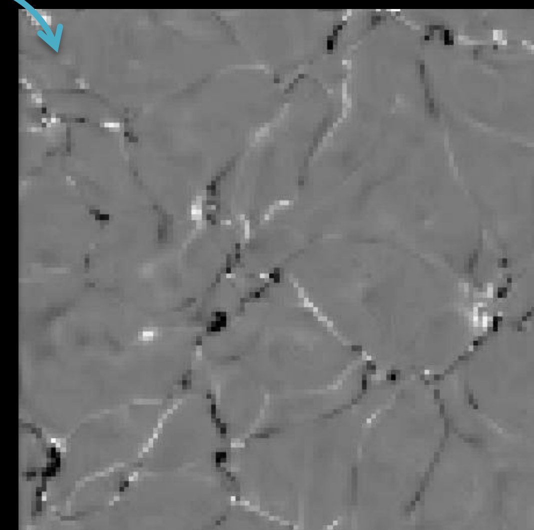
- Indirect evidence of kG flux tubes

Res 0.3” (Hinode)



- Detection and tracking of kG flux tubes
- Missing 80% of flux

Res 0.1” (SOLAR-C)



- Resolve kG flux tubes
- Interaction between tubes ➔ 50 times larger than Hinode
- Detect micro-vortex and derivation of currents

Basic Mechanism of Erupsions

Explosive growing by nonlinear feedback process

Ideal MHD Instability

(torus insta./loss-of-equilibrium)

simple eruption

Current status

- Resolving basic mechanisms of explosions but far from prediction of onset where and when and magnitude (unknown trigerring)
- Very poor and unreliable prediction for explosions

non-eruptive flare

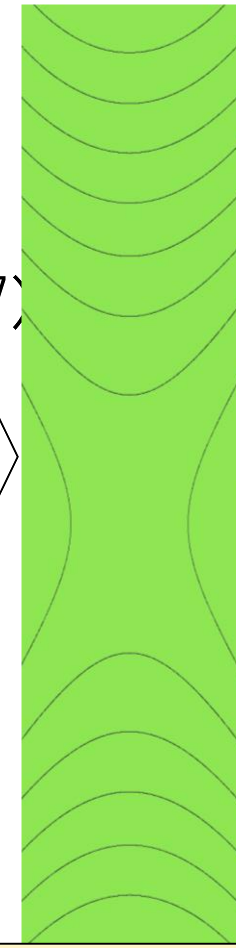
Magnetic reconnection

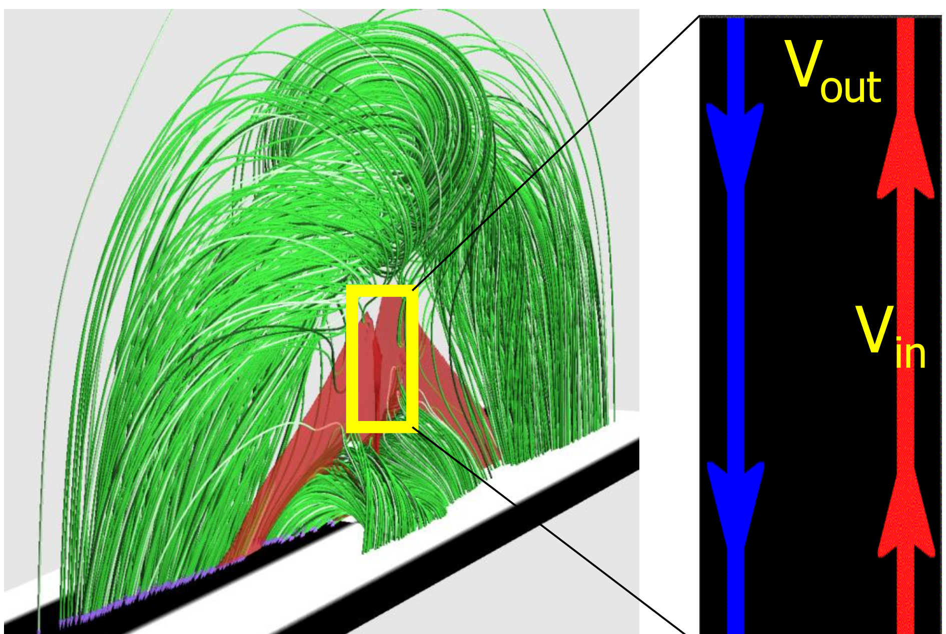
Magnetic reconnection

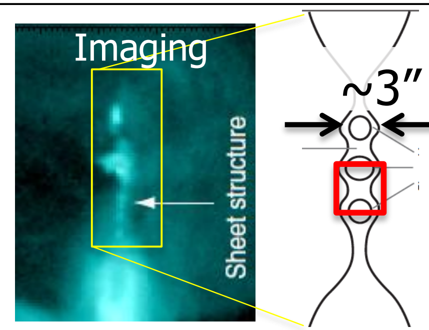
- Magnetic energy release by reconnection
- Subject：solve mechanism or fast reconnection rate (V_{in}/V_A)

~observations $(10^{-2\pm1}) \gg$ theoretical model $(S^{-1/2} \sim 10^{-7})$

Formation of small-scale structure inside current sheet may acceleration of reconnection







Plasmoids found by SDO/AIA (Takasao et al. 2012)

Observe the growth of fine-scale structure in the current sheet and study its relation to the acceleration of reconnection

Variation of Solar Spectral Irradiation

SOLAR-C

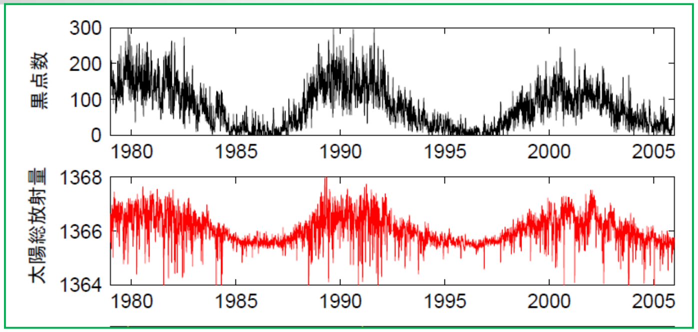
- Current status: good correlation between sunspot number and irradiation whose variability mostly comes from UV variation but its origin is not known

Solar UV radiation affects the atmospheric convection through the heating of ozone layer of stratosphere (Kodera+2002)

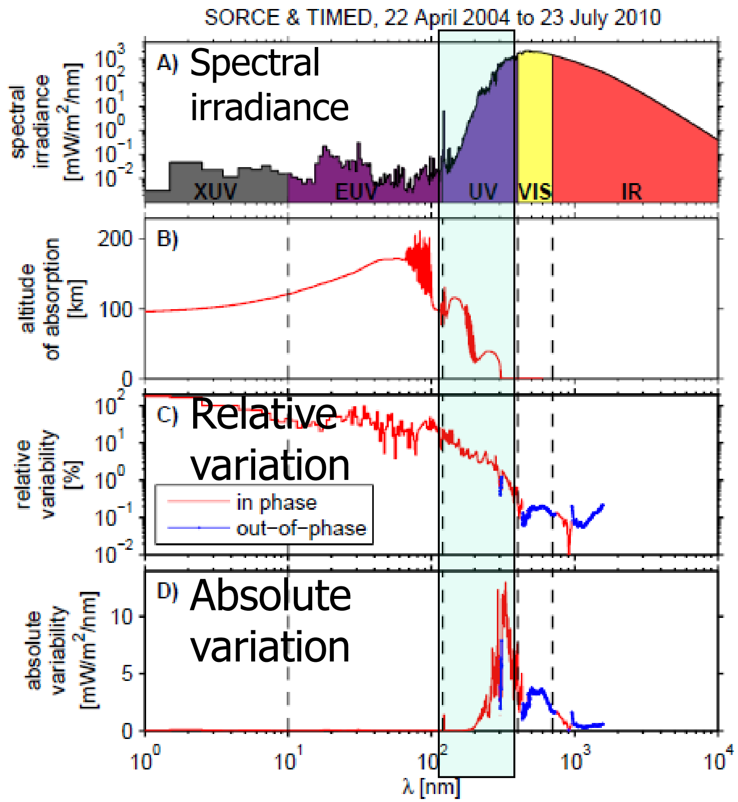
- Subject: resolve the relation between the UV radiation from photospheric and chromospheric elements and magnetic structures

⇒ UV narrow band (200-300 nm) imaging observations resolving magnetic elements

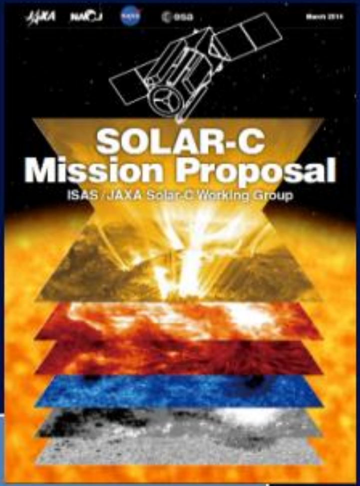
Need to realize a model for accurately reconstructing spectral irradiance



Total solar irradiance



Scientific Objectives



Description of Main Scientific Objectives
Understand the plasma dynamics as a system that connects the solar surface to the solar corona and interplanetary space
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.

	Three Scientific Objectives for Study
I	Investigate the formation mechanisms of the chromosphere, the corona, and the solar wind
II	Understand the physical origin of largescale solar eruptions to extract the algorithm for prediction
III	Reveal the mechanism of solar spectral irradiance variation that could influence the climate change of the earth.

Scientific Goals and Detailed Scientific Cases

I: Formation mechanisms of chromosphere, corona, and solar wind	
I-1	Understand the formation mechanism of spicules and their influence in the corona
I-2	Verify the Nanoflare* hypothesis *tiny events that have nano-level energy (10^{23} erg) of the

II : Mechanism of large-scale solar eruptions and algorithm for prediction	
II-1	Measure the energy build-up processes in flaring and CME regions
II-2	Identify the trigger mechanism of solar flares and CMEs
II-3	Clarify the mechanisms of destabilizing and erupting of the entire system
II-4	Understand the processes of fast magnetic reconnection

SOLAR-C S/C and Strawman Payloads

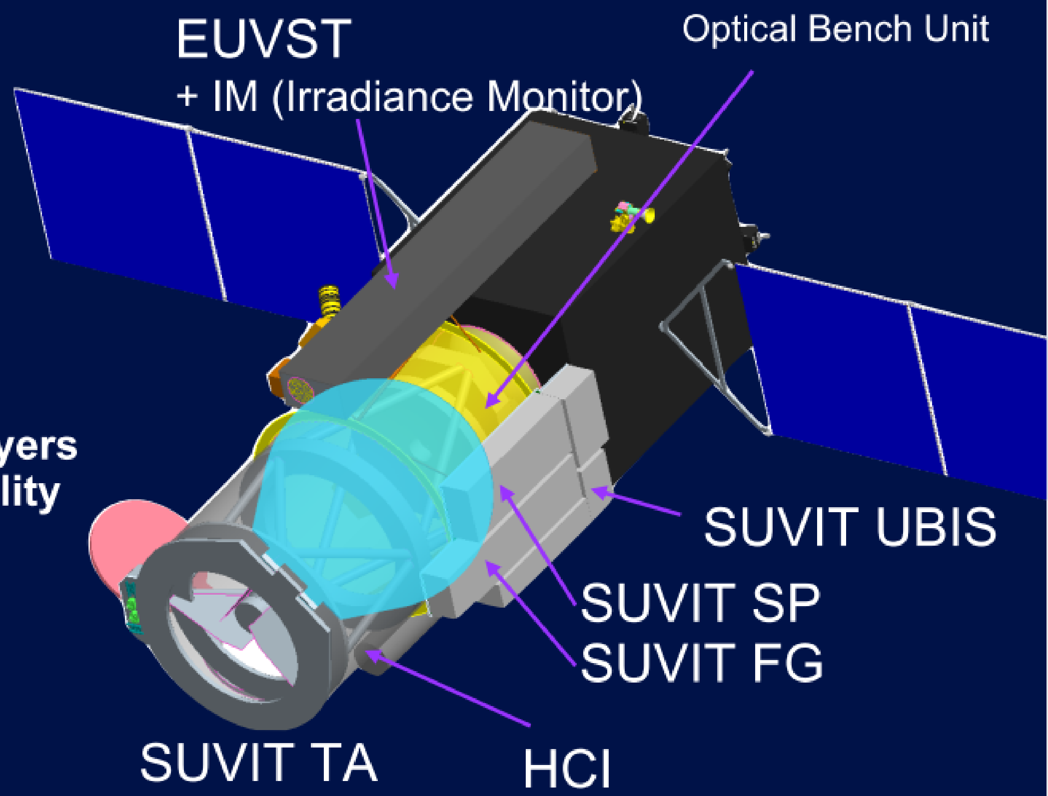
Three advanced telescopes

•SUVIT (Solar UV-Vis-IR Telescope)
Spectropolarimetry for photospheric & chromospheric magnetic fields with spatial resolution of 0.1"~0.2"
Aperture: ~1.4m (Hinode×3)

•EUVST (EUV Spectroscopic Telescope)
Spectroscopy for upper atomospheric layers with increased plasma diagnostic capability
Spatial resolution: Hinode×5
Sensitivity: Hinode×10

•HCI (High resolution Corona Imager)
Wide FOV coronal imaging
with spatial resolution of 0.3"
Spatial resolution: Hinode×10

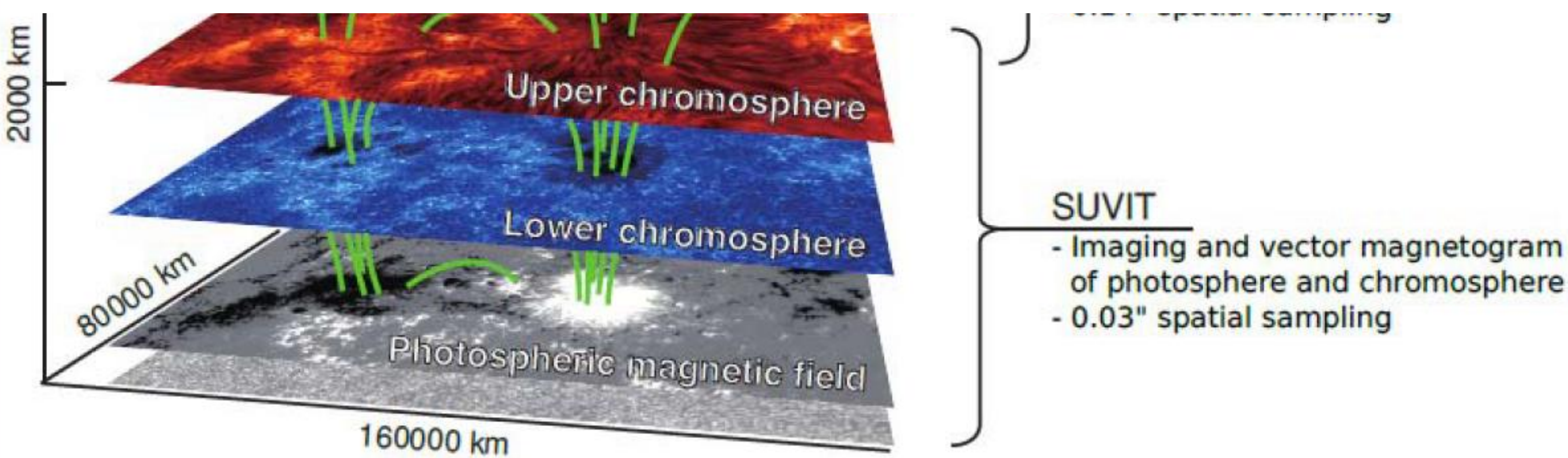
･IM (Irradiance Monitor)
Total & UV spectral irradiance monitor



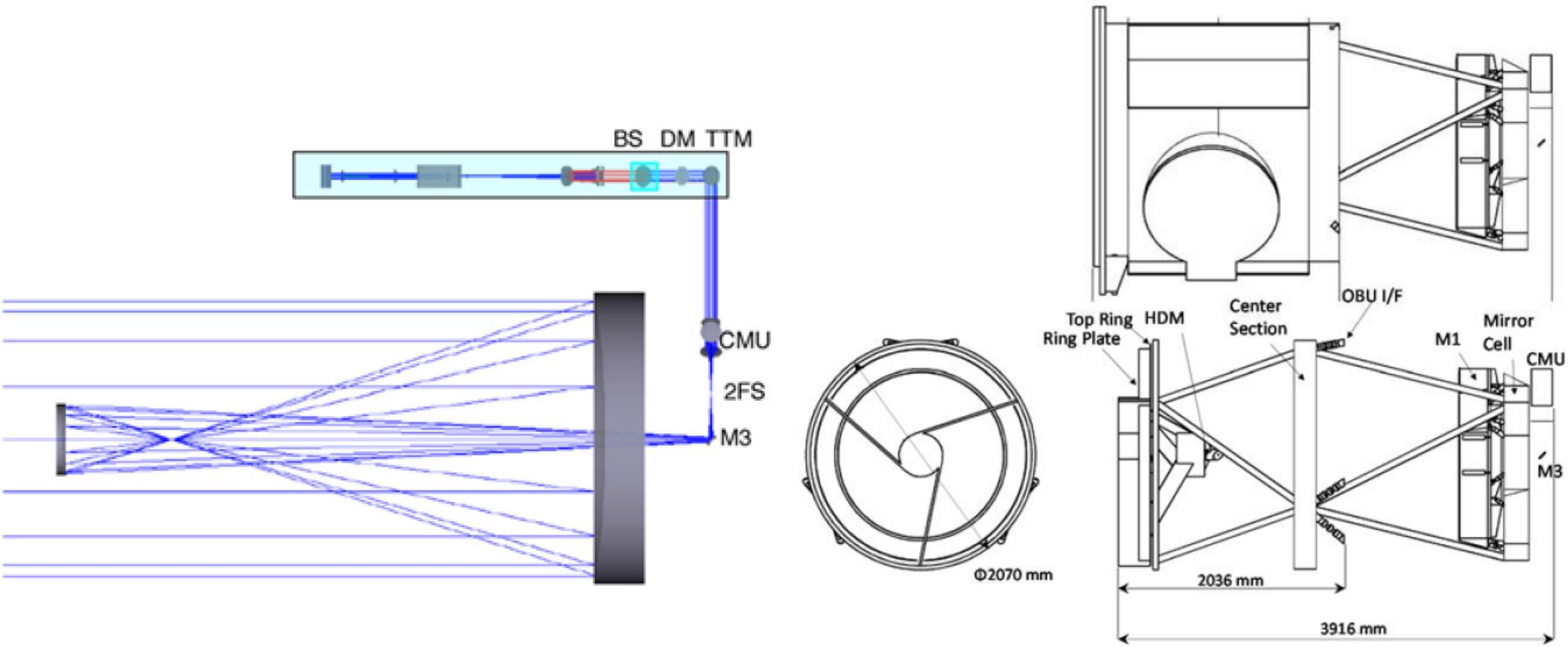
weight	2300 kg (w/o fuel)
size	3.5 m x 3.0 m x 7.3 m
Data rate & Data volume	8 Mbps (ave) (Hinode×20) DR ～200 GB
Orbit	Geo-synchronous

SOLAR-C

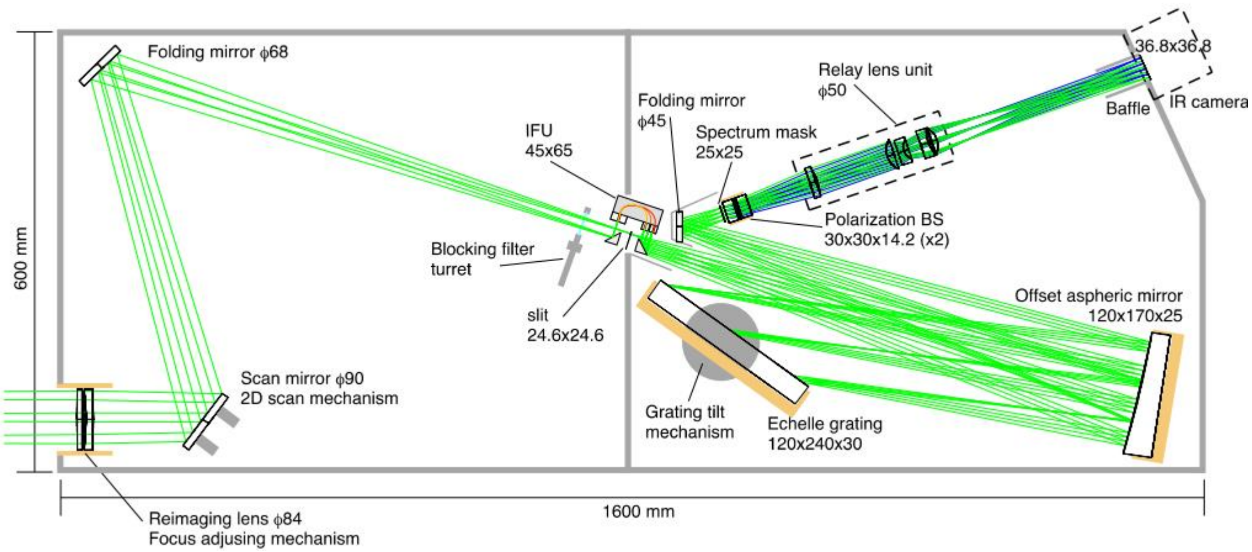
- Resolve elementary structures in space and time
- Measure 3D magnetic fields from the photosphere through the chromosphere
- Seamlessly observe whole observable temperature range (4·10^3-10^7K)
- Measure plasma parameters before and after energy dissipation



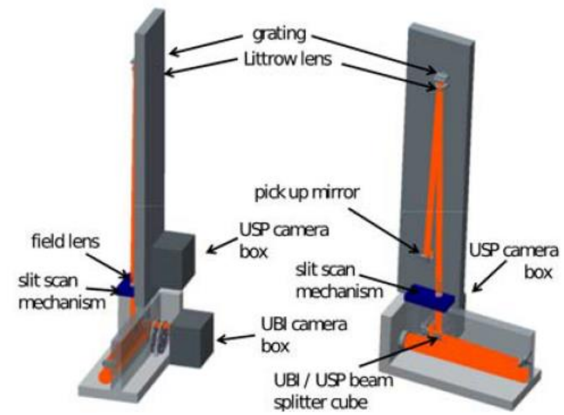
SUVIT/TA (Telescope Assembly)



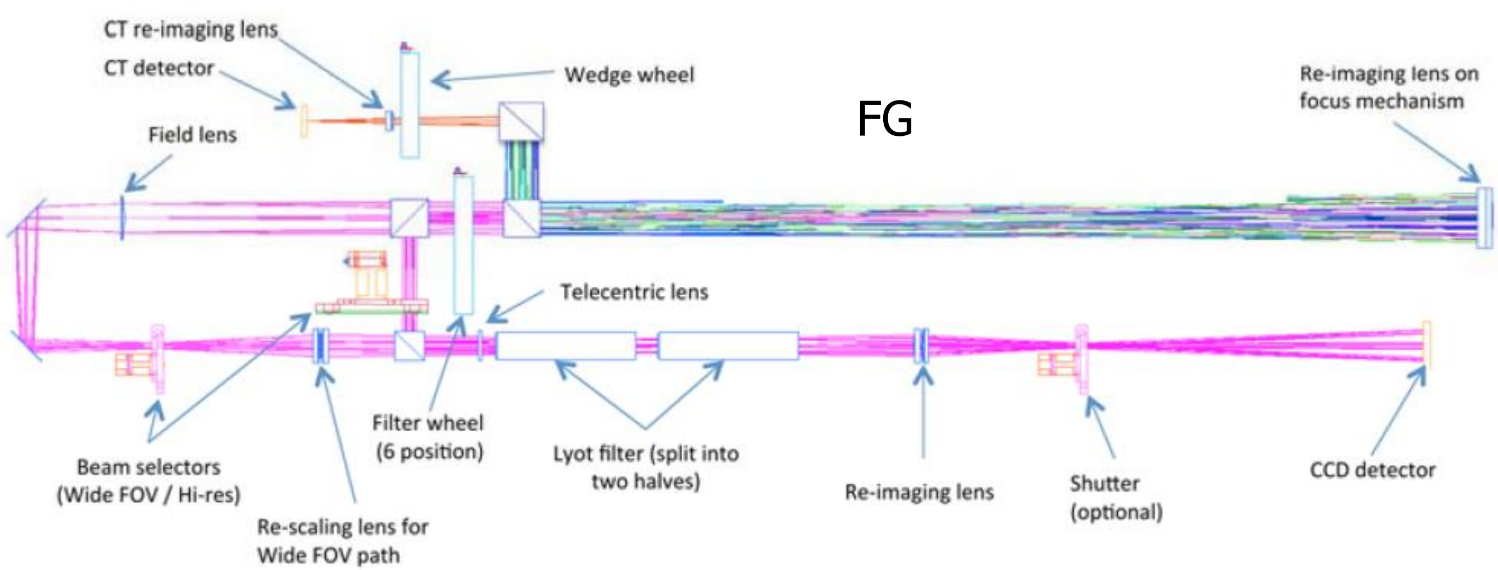
SUVIT/Focal Plane Instruments



SP



UBIS

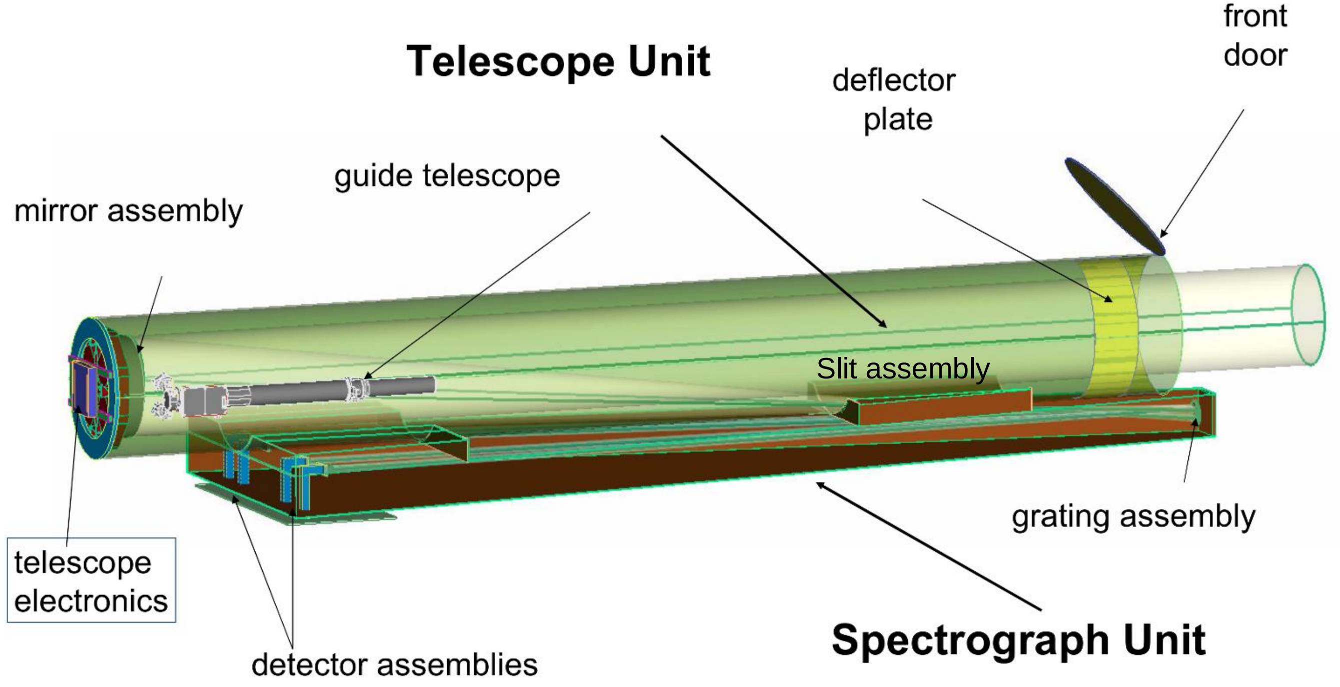


FG

EUVST(LEMUR): layout

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

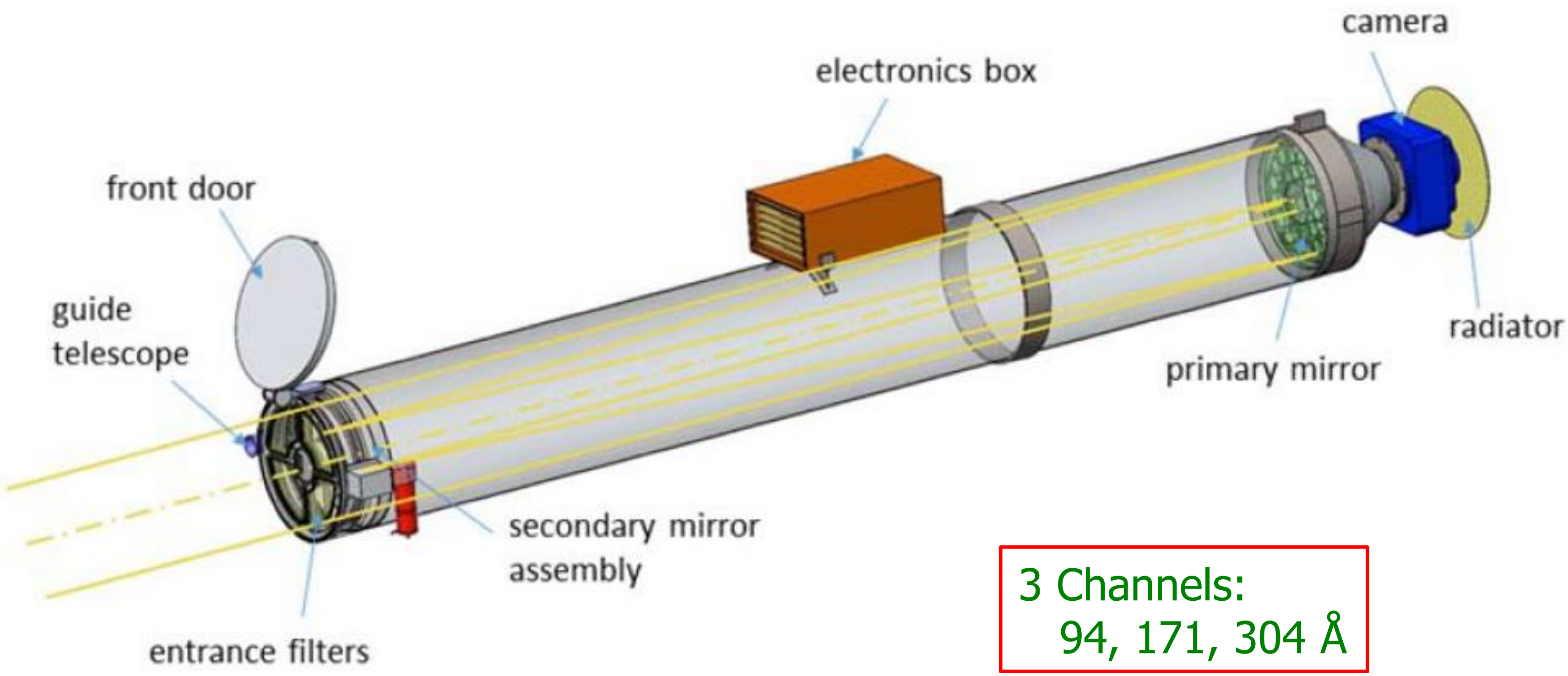
Field	Required value
Spatial resolution	$\leq 0.28''$
Spectral resolution	$\lambda/\Delta\lambda$ 17 000 to 32 000
Doppler shift accuracy	$\lesssim 2$ km s^{-1}
Doppler width accuracy	$\lesssim 5$ km s^{-1}
Temperature coverage	0.01 to 20 MK
Field-of-view	slit length $280''$
raster coverage	$300''$ (w/o re-pointing)
Exposure times	$\lesssim 10$ s ($0.28''$ sampling)
	$\lesssim 1$ s ($1''$ sampling)
Mirror micro-roughness	about 3 Å rms or better



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

22

HCI (High Resolution Coronal Imager)



3 Channels:
94, 171, 304 Å

Current Status

Proposed in early 2015

Spacecraft Bus (Japan, ESA)
- 0.02″ pointing stability

SUVIT-TA (Japan, mirrors from E
- Φ1.4m, all reflective (λλ200-

SUVIT-FPP
- SP (Japan, ESA)
  - slit and IFU (Fe I 525, Ca
- FG (NASA?)
  - NFI with high res mode (λ
- UBIS (ESA)
  - UBI (λλ220-435, FOV 120
  - USP (optional, Mg II k pol

EUVST (ESA+)
- Φ30cm, res 0.28″, T 4000 –
- 1st order：17.0-21.5nm, 69.0
- 2nd order: 46.3-54.2nm, 55.

IM (ESA)

HCI (NASA?)
- Φ32cm, f20m, res 0.2″-0.3″
- He II 30.4 nm、Fe IX 17.1 nr

Need descope, simpler I/F, less internl' corabolatins

Spacecraft Bus (Japan)
- 0.04″? pointing stability

SUVIT-TA (Japan, (ESA))
- Φ~1m, all reflective (λλ200-1100)

SUVIT-FPP
- one package? (NASA?, (Japan))
- either SP (Ca II 854 or He I 1083) or FG with BFI(λλ?)

EUVST (ESA+) with slit-jaw HCI?
- Φ30cm?, res 0.4″?, T 4000 – $2x10^7$K

Synergies with
- SDO
- Solar Orbiter
- DKIST, EST
- other new missions, etc.

Future course of Actions

Solar-C Science Meeting

☆ Early Preparation of "*Nominal*" Plan

Nominal: [JAXA – Str. Med (L)

+ ESA & NASA – MoOs levels]

Cost reduction with Focused science

Synergy with other missions/facilities (SOLO, DKIST, …)

☆ Promotion of International Collaboration

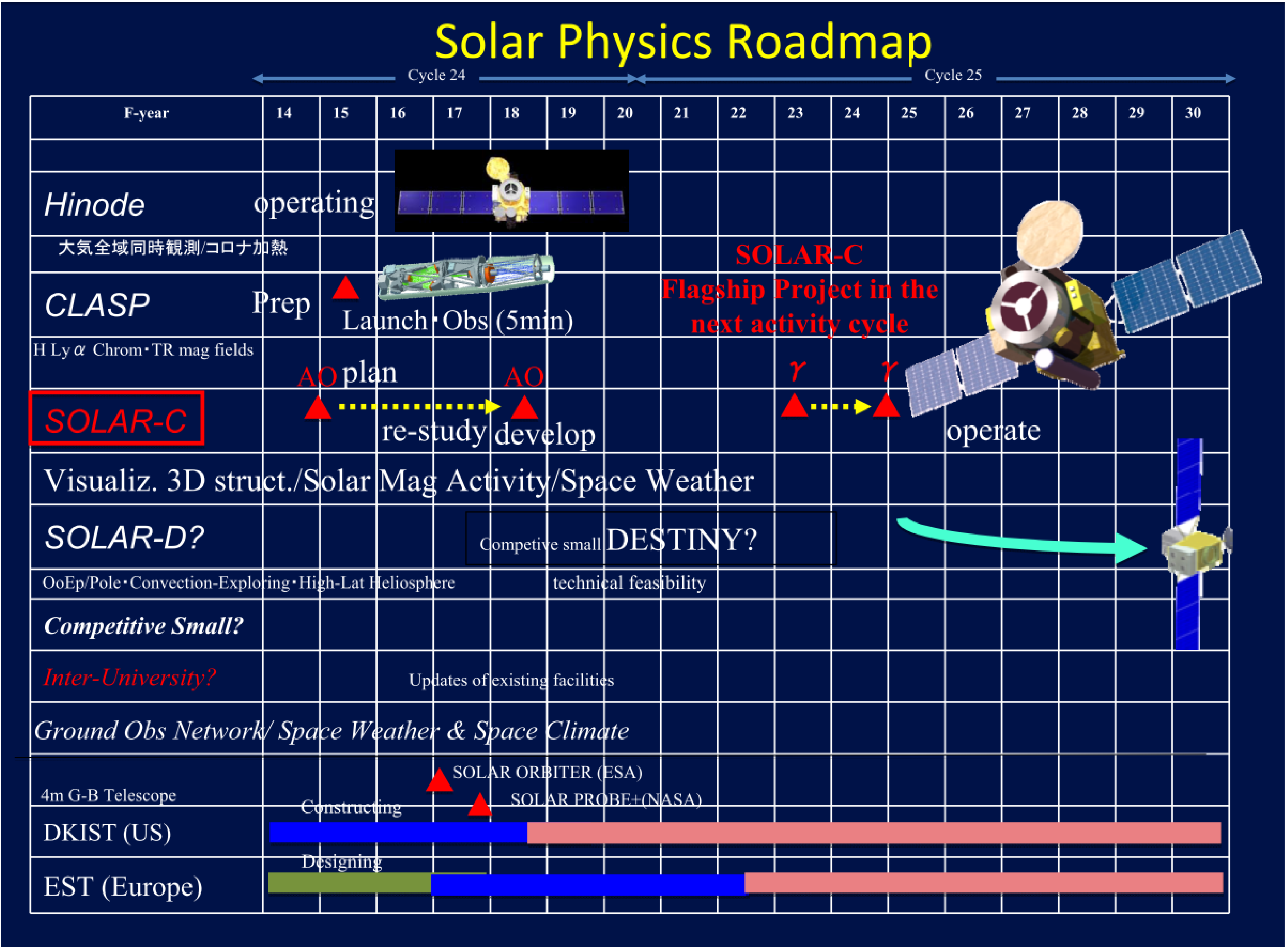
more feasible/affordable

NASA: Setup of STDT

ESA: Seek for MoOs

JAXA/Strategic Med
ESA MoO
NASA…

☆ Δ MDR (mission definition re-review)


Solar Physics Roadmap
Cycle 24
Cycle 25
F-year
14
15
16
17
18
19
20
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22
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25
26
27
28
29
30
Hinode
operating
大気全域同時観測/コロナ加熱
CLASP
Prep
Launch･Obs (5min)
H Ly α Chrom･TR mag fields
SOLAR-C
Flagship Project in the
next activity cycle
AO
plan
AO
γ
γ
SOLAR-C
re-study
develop
operate
Visualiz. 3D struct./Solar Mag Activity/Space Weather
SOLAR-D?
Competive small
DESTINY?
OoEp/Pole･Convection-Exploring･High-Lat Heliosphere
technical feasibility
Competitive Small?
Inter-University?
Updates of existing facilities
Ground Obs Network/ Space Weather & Space Climate
SOLAR ORBITER (ESA)
SOLAR PROBE+(NASA)
4m G-B Telescope
Constructing
DKIST (US)
Designing
EST (Europe)

Thank you for your attention