SOLAR-C Plan-B
Mission Description

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SOLAR-C WG

SOLAR-C Plan-B

- Understanding coupling between chromosphere and corona through observations by combination of spectroscopic (and polarimetric) and imaging instruments.
- Fundamental mechanism in MHD and plasma physics: waves, turbulence, and magnetic reconnection, i.e. *dissipation of magnetic energies*

- To achieve them,
  - From imaging to spectroscopy (+polarimetry): obtain precise information on dynamics such as waves and magnetic reconnection, and on magnetic fields in the entire solar atmosphere.
  - Extend the wavelength coverage: cover the entire solar atmosphere from photosphere to corona through chromosphere and transition region.

Mission-wide science goals

1. Understand elementary structures of the magnetic atmosphere and determine how they are created and evolve.

2. Trace energy and mass flows from the photosphere through the chromosphere into the corona.

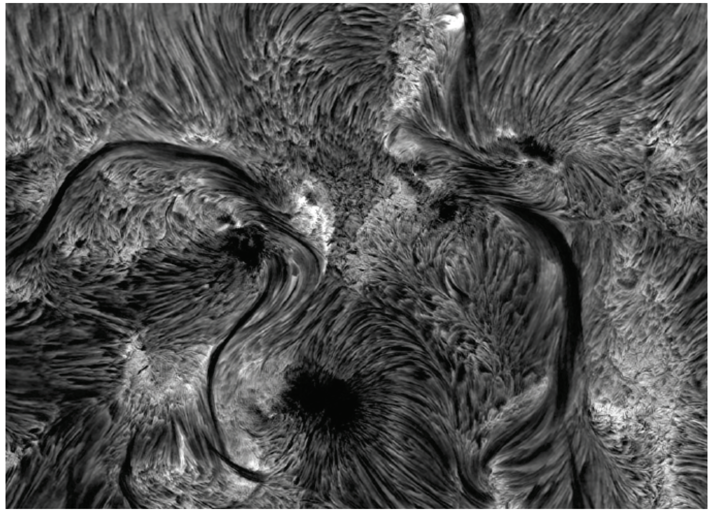
3. Understand how small-scale physical processes initiate large scale dynamic phenomena creating space weather.

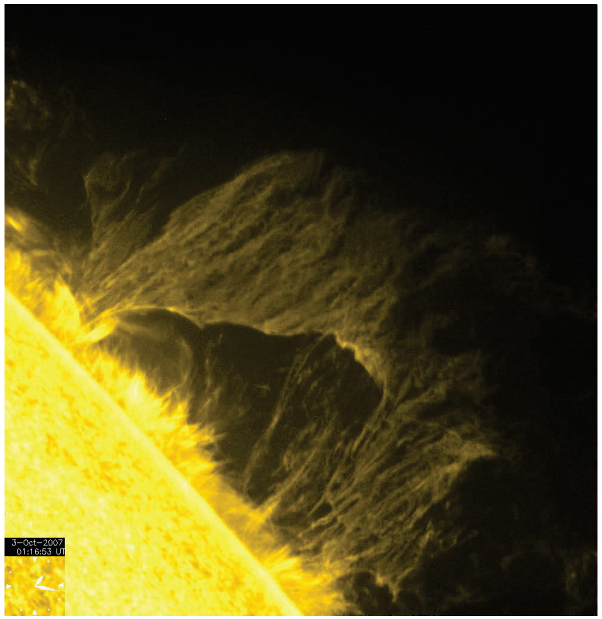
4. Understand physical processes responsible for magnetic dissipation in astrophysical plasmas.

These are still preliminary. *It is important to combine science goals raised by each subWG.*

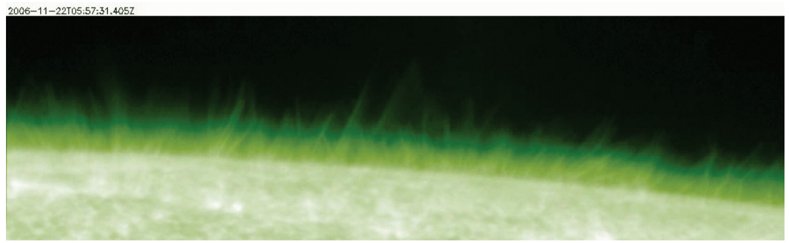
Understand elementary structures of the magnetic atmosphere and determine how they are created and evolve (1)

- How magnetic solar atmospheres are created and evolve.
  - Emergence and evolution of magnetic fields in QS and AR from the photosphere through the chromosphere into the corona.
  - Structures and dynamics in prominences





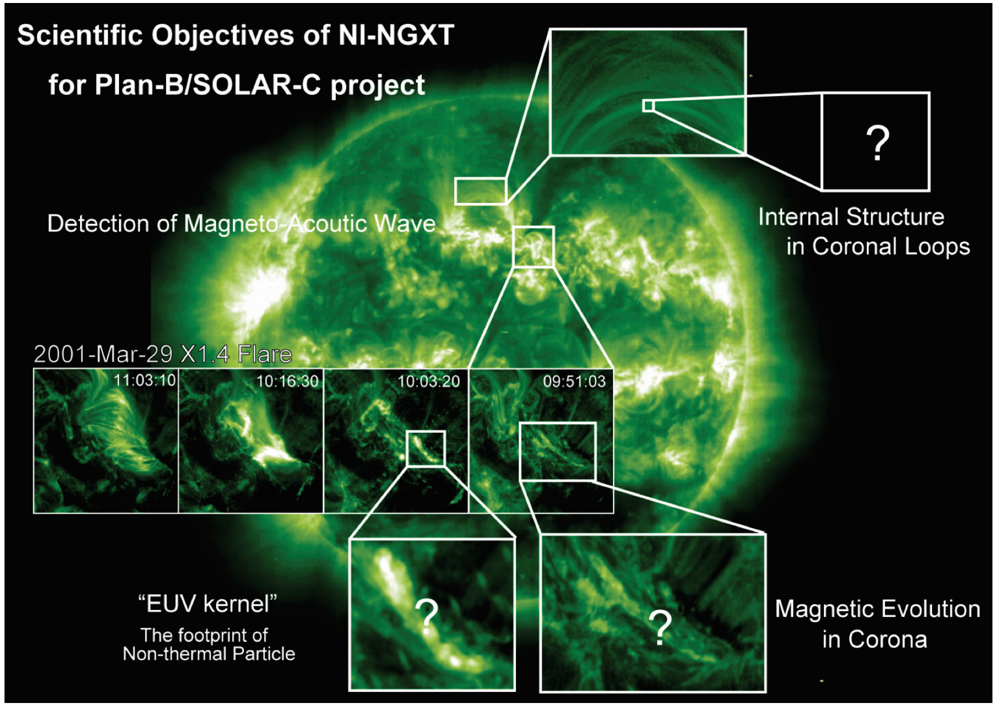
It is still poorly known how cool materials are sustained in the upper atmosphere. Little observational knowledge on magnetic field configuration.



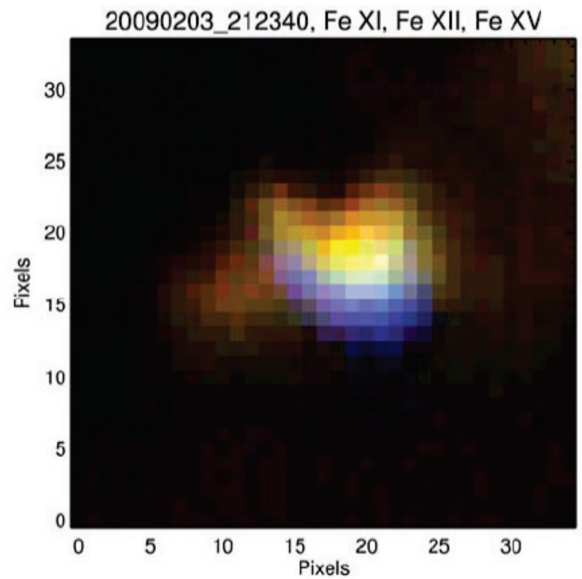
Monochromatic image of the solar chromosphere seen in chromospheres. There are varieties of structures (fibrils, filaments, spicules etc.) regulated by magnetic fields. But the intensity image does not provide any quantitative information on magnetic fields.

Understand elementary structures of the magnetic atmosphere and determine how they are created and evolve (2)

- Elemental structures of coronal fine structures
  - Observations with ~1” resolution indicate that there are sub-arcseconds structures (i.e. filling factor <1).
  - It is essential to have a spatial resolution comparable to observations of photosphere/chromosphere to identify elemental heating events and trace energy flows from feet of coronal structures.



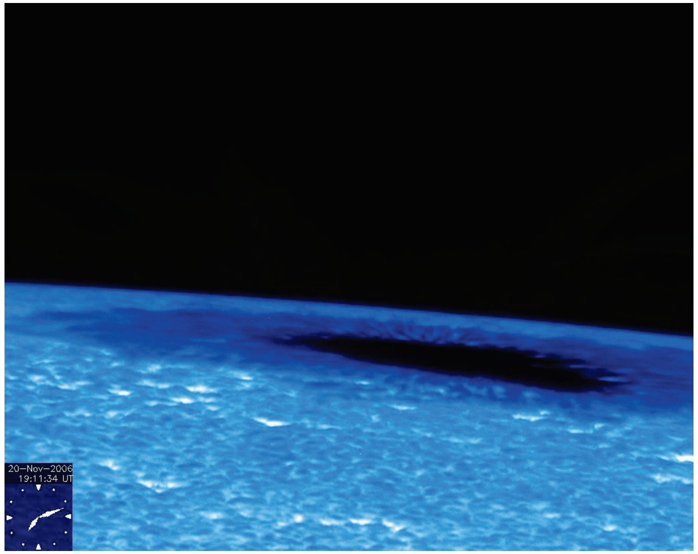
Targets of high resolution X-ray imaging telescope

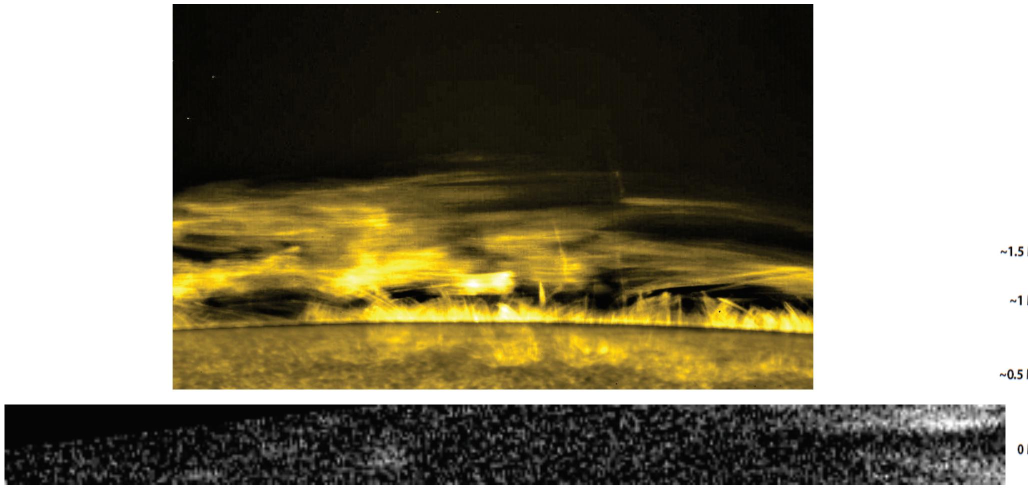


Bright point in a polar coronal hole. Elementary heating events are not resolved with the 1” resolution.

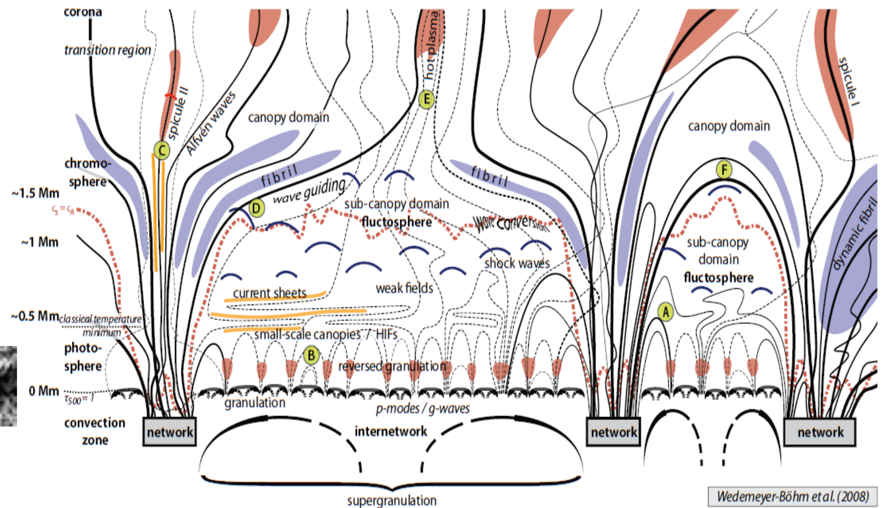
Trace energy and mass flows from the photosphere through the chromosphere into the corona (1)

- Chromosphere
  - Dominant physics changes from hydrodynamic (β >1) to magnetic forces (β <1). Most of the non thermal heating take place.
  - Energy transfer and mode conversion by MHD waves.
  - Liberation of magnetic energies through magnetic reconnection.





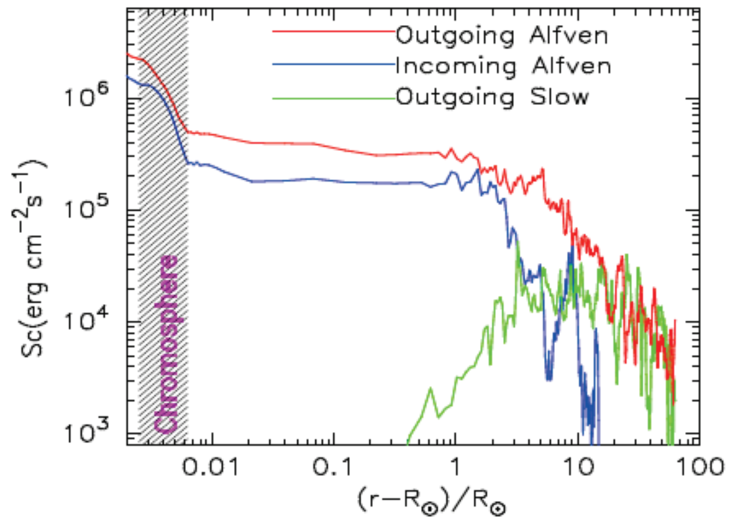
Oscillation of threads in a prominences (Okamoto et al. 2007). Quantitative measurements of magnetic fields are crucial for identifying wave modes.



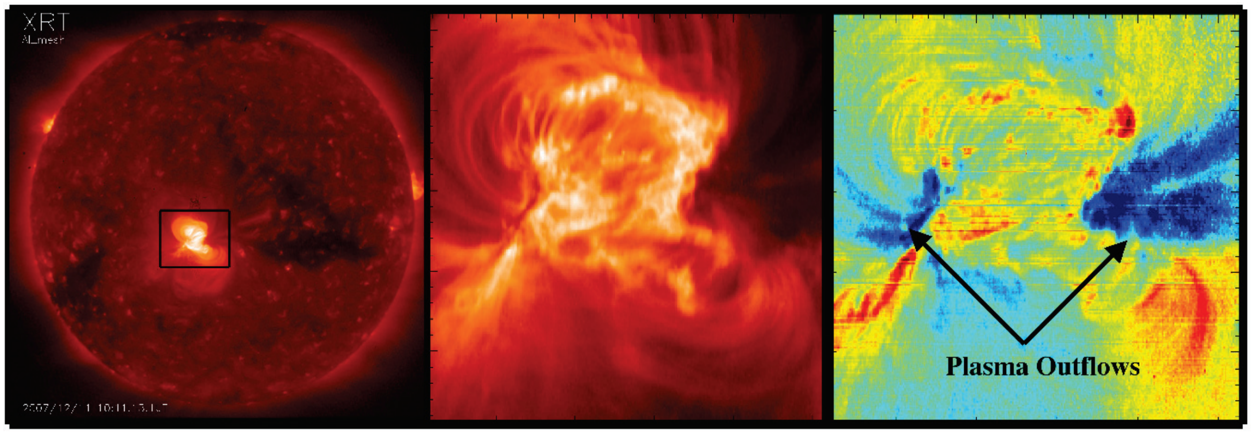
Wedemeyer-Bohm et al. (2009)

Trace energy and mass flows from the photosphere through the chromosphere into the corona (2)

- Where are coronal plasmas heated and accelerated and how?
  – How much energies can propagate through the chromosphere.
  – Where are magnetic energies converted into thermal and kinetic energies?
  – It is critically important to have a spatial resolution comparable to the observation of photosphere and chromosphere with coverage from chromosphere, TR, to corona.



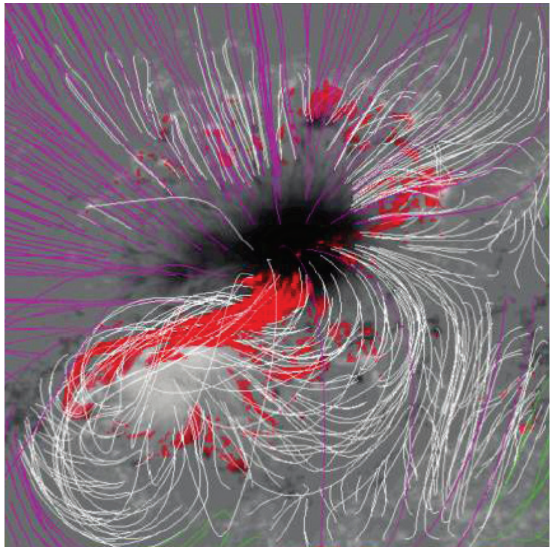
Most of the Alfvenic energies dump in the chromosphere. It is demanded to observe magnitude of energy transfer in the upper chromosphere and TR (Suzuki et al. 2005).



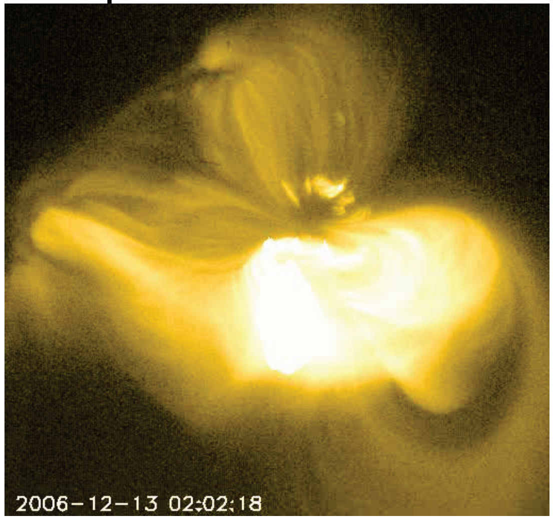
Outflows identified in a HINODE EUV spectroscopic observation. A driving mechanism is still an open question.

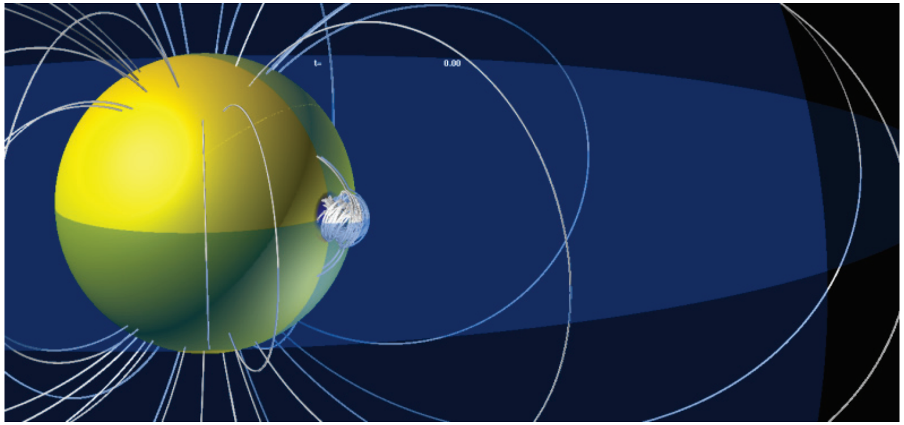
Understand how small-scale physical processes initiate large scale dynamic phenomena creating space weather.

- High resolutional and detailed observations combined with large-FOV obs are a powerful tool to study initiation of big explosions affecting space weather.
  - NLFFF and possibly MHDS modeling and extrapolation using photospheric and chromospheric magnetic fields.
  - Small scale phenomena may be responsible for triggering massive explosions.



NLFFF extrapolation (Schrijver et al. 2008)

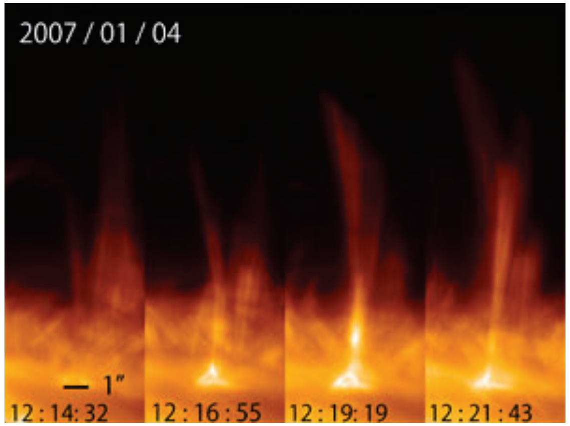




Coronal mass ejection, shock propagation and particle acceleration are sources of the space weather (Shiota et al. 2009).

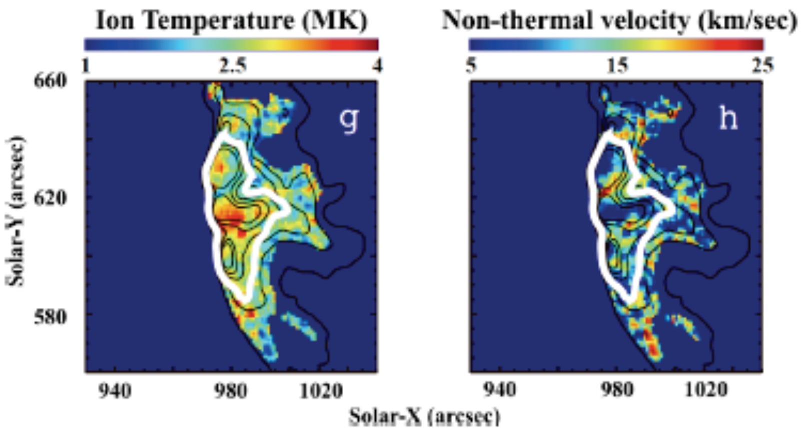
Understand physical processes responsible for magnetic dissipation in astrophysical plasmas

- The solar atmosphere as a plasma laboratory with varieties of conditions.
  - High β (photosphere)⇔ low β (corona)
  - Partially ionized ⇔ Fully ionized
  - Collisional ⇔ Collisionless



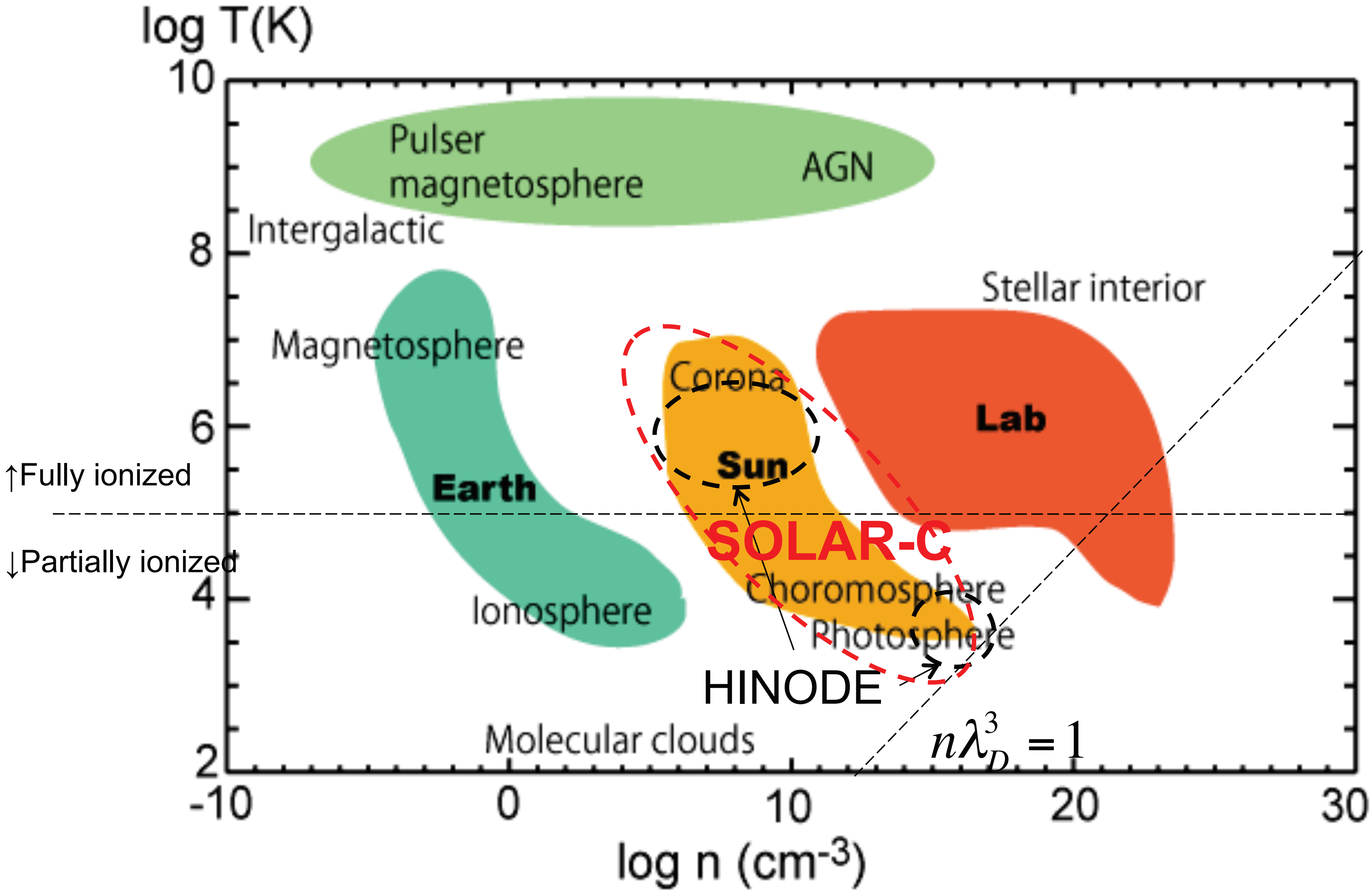
We know that rapid liberation of magnetic energies happens even in the collisional and partial ionized plasma. Measurements of physical parameters around a reconnection site may provide us a breakthrough.

- Measure how fast magnetic fields dissipate in the solar atmosphere
  - What plasma parameters determine a reconnection rate
  - Shocks and particle acceleration
  - Non-thermal equilibrium, non-ionization equilibrium



Ion temperature distribution (Imada et al. 2009) High throughput and high temporal cadence essential to resolve evolution of ionization.

Solar atmosphere as a plasma laboratory



Plan-B: Concepts of mission instruments

- Advanced instruments to explore the solar magnetic atmosphere:
  - Precise spectroscopic & polarimetric observations for understanding nature of magnetic fields, especially in the chromosphere
  - High time resolution, high throughput spectroscopic observations for understanding nature of dynamics
  - Seamless observations over the entire atmosphere, i.e., from photosphere to corona, for understanding the entire pictures of heating and dynamics
  - High spatial resolution observations for resolving elementary physical processes

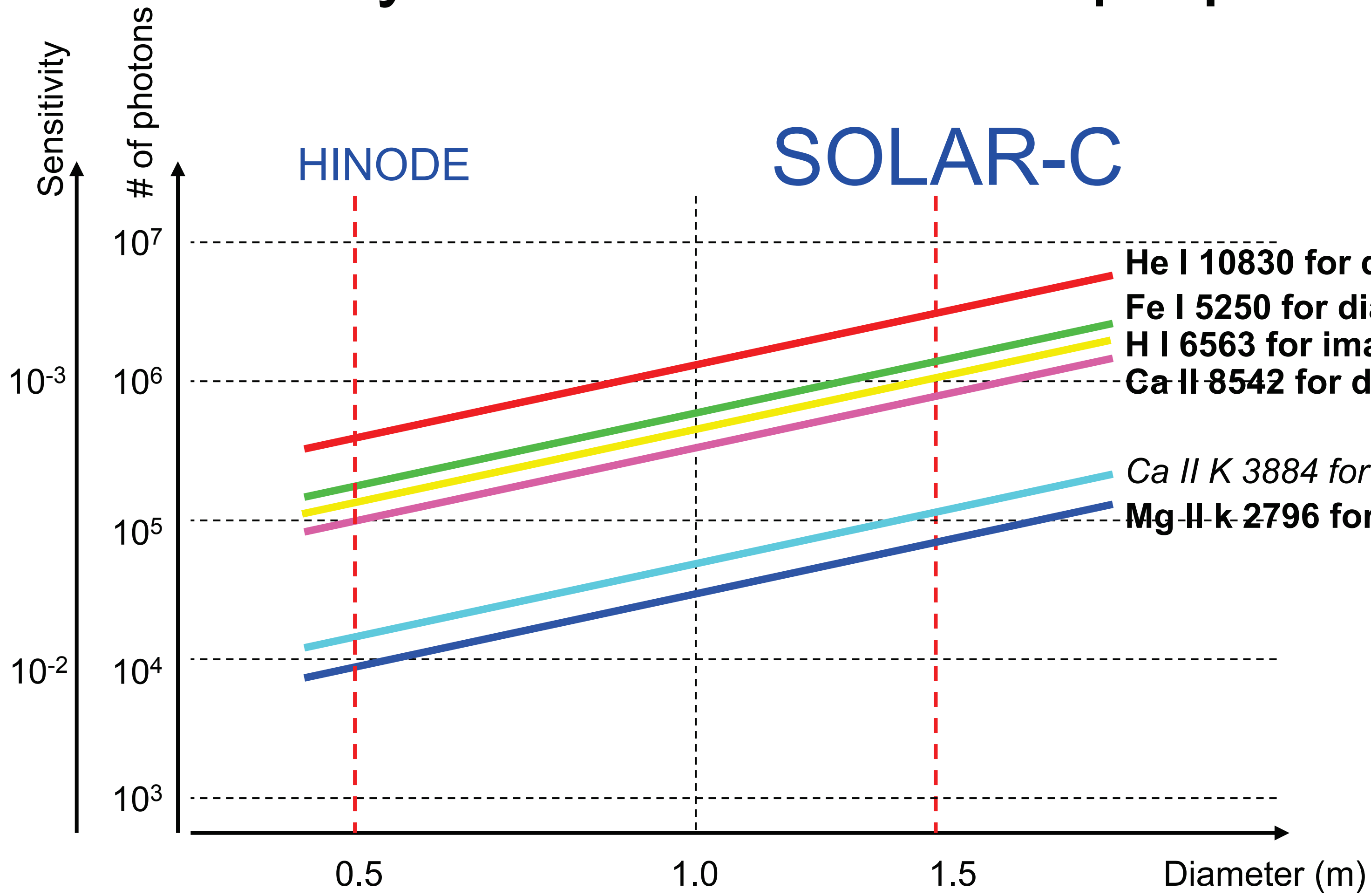
Mission Instruments

- *UV-Visible-NIR telescope*
  - 1.5mφ diffraction-limited telescope with advanced imaging and spectro-polarimetric instruments
  - Wide wavelength coverage with capabilities of observing spectral lines useful for diagnosing the solar atmosphere from photosphere to the upper chromosphere (and transition region)

- *High throughput UV/EUV spectrograph*
  - High throughput to achieve high temporal cadence
  - High spatial resolution (better than 0.5")
  - Wide temperature coverage from the chromosphere, the transition region, low corona and flare temperatures.

- *Next generation X-Ray imaging (spectroscopic) telescope*
  - Imaging of emissions from >1MK coronal plasma
  - ***Grazing incidence telescope*** with 0.5" resolution with the spectroscopic (photon counting) capability
  - ***Normal incidence telescope*** with ultra-high resolution of 0.1"

Why we need the 1.5mϕ aperture



- Based on preliminary design of the telescope
  - 4 mirrors coated with Al+MgF_2
  - Spectrograph efficiency 0.2
- Sampling
  - Spatial: 0.06"/pix
  - Temporal : 1sec
  - Wavelength: $\lambda/\Delta\lambda=2\times10^5$

Why we need the 1.5mϕ aperture

- S/N~10^4 for high precision spectro-polarimetry
  - He I 10830Å & Ca II 8542Å: 0.18"/pix, 10sec integration

    We can temporally and spatially resolve dynamical phenomena in the chromosphere (spicules, jets, etc.) with magnetic field diagnostics.

- S/N~10^2 for high-speed spectroscopy
  - Mg II k 2796Å: 0.06"/pix, <0.5sec integration

    We can achieve the highest spatial and temporal resolution in spectroscopic diagnostics of the chromosphere.

Sub WG activities in FY 2009

- International sub-WGs are established to investigate specific scientific and technical items for each mission instrument.

- Chromospheric/coronal magnetic field measurements
  - 1st meeting at HAO on 5-6 Apr.
  - 2nd meeting at IAC on 5-6 Oct.

- High throughput UV/EUV spectroscopy
  - 1st meeting at GMU on 20-21 Mar.
  - 2nd meeting at MPS on 29-30 Jun.

- Next generation X-Ray telescope
  - 1st meeting at SAO on 12-13 Mar.
  - 2nd meeting at SAO on 10-12 Aug.

- Science cases and specifications of each instrument become much clearer through the discussion in the subWG.
- The subWG have compiled documents reporting what they discussed in terms of scientific and technical points of view. The documents are groundwork for making a mission proposal.

Basic specifications of the three telescopes

Pixel size and FOV

			FOV	Pixel size	Exposure	Note.
UV-Vis-NIR telescope		Broadband	164" x 164"	0.04"	< 1sec	• 2.5 pix sampling of **0.1"** res. • 4Kx4K detector
		Narrowband	246" x 246"	0.06"	< 1sec	• 2.5 pix sampling of **0.16"** res. • 4Kx4K detector
		Spectrometer	246" x 246"	0.06"	1sec (S/N~1600)	• 2.5 pix sampling of **0.16"** res. • 4K pix along slit
				0.12"	10sec (S/N~10^4)	
UV/EUV imaging spectrometer		Spectrometer	1024"x 1024"	0.5"	0.5sec (AR) 5sec(QS)	• **0.5"**pixel size • 2Kx2K MCP+CMOS detector
X-ray telescope	NI	Imaging	410"x410"	0.1"	1sec (AR) 10sec (QS)	• High res imaging with NI telescope • 4Kx4K detector
	GI	Imaging	1024"x1024"	0.5"	1sec	• Imaging spectroscopy with GI • 2Kx2K CMOS detector
		Photon count	1024"x1024"	2.0"	60sec	

Size

	Size (mm)	Weight (kg)
UV-Vis-NIR telescope (telescope)	ϕ2300x4300	500
UV-Vis-NIR telescope (focal plane instruments)	2500x400x3000	200
UV/EUV imaging spectrometer	400x800x4000	120
X-ray telescope	400x400x4000	100

Engineering study for SOLAR-C

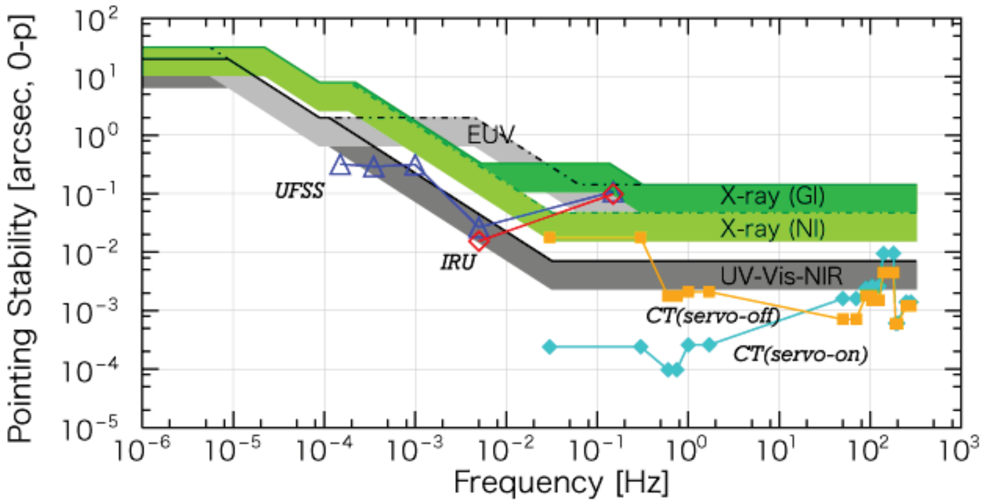
- SOLAR-C WG has started to investigate engineering issues of the1.5mϕ telescope based on the design concept of HINODE/SOT to clarify what major technical differences are in the bigger telescope.
- Telescope
  - Optical design of the 1.5mϕ telescope
  - Thermal issues
- Focal-plane instrument
  - Conceptual studies on the instrument configuration
  - Narrow-band tunable filter (Lyot filter or Fabry-Perot)
  - Mechanisms with high reliability

- High throughput UV/EUV spectroscopic telescope
  Next Generation X-ray telescope
  - International subWGs are studying strawman configuration of the telescope.

- Spacecraft system
  - Spacecraft configuration
  - High data rate telemetry (X-band or Ka-band) to achieve the average telemetry amount of >10Mbps
  - Orbit (Sun-synchronous orbit, Geostationary orbit)
  - Attitude control system and for high pointing stability

Hinode heritage: space craft system

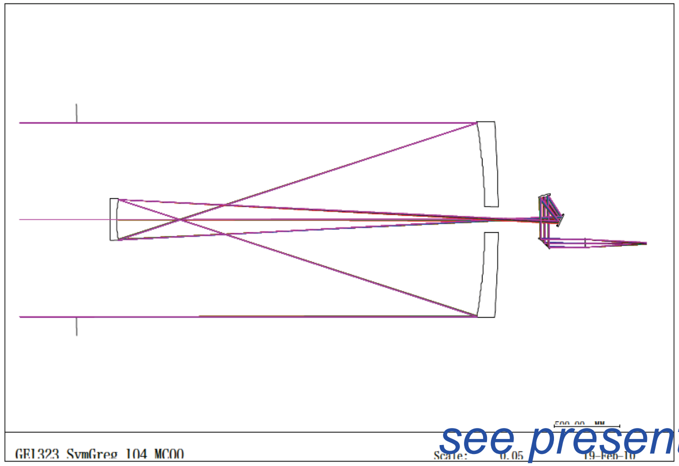
- Spacecraft design, including S/C attitude control, micro-vibration control technique

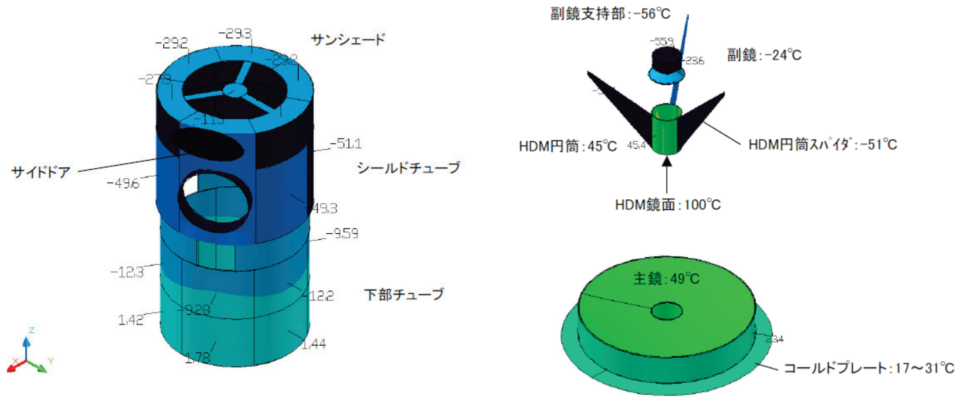


Requirements of pointing stability compared with Hinode achievements (see presentation by Y. Masada)

Hinode heritage: optical telescope

- Optical and thermal designs



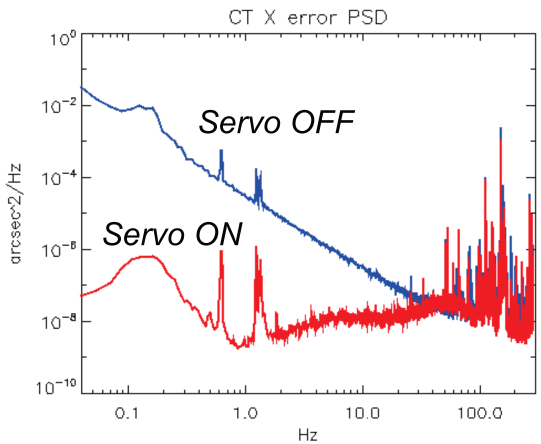


see presentation by Y. Suematsu

Preliminary optical design of the telescope 1.5mϕ aplanatic Gregorian with a heat dump mirror at the primary focus.

Thermal study of the telescope. Large heat load at the primary mirror is one of the critical technical items to be solved.

- Image stabilization system, correlation tracker

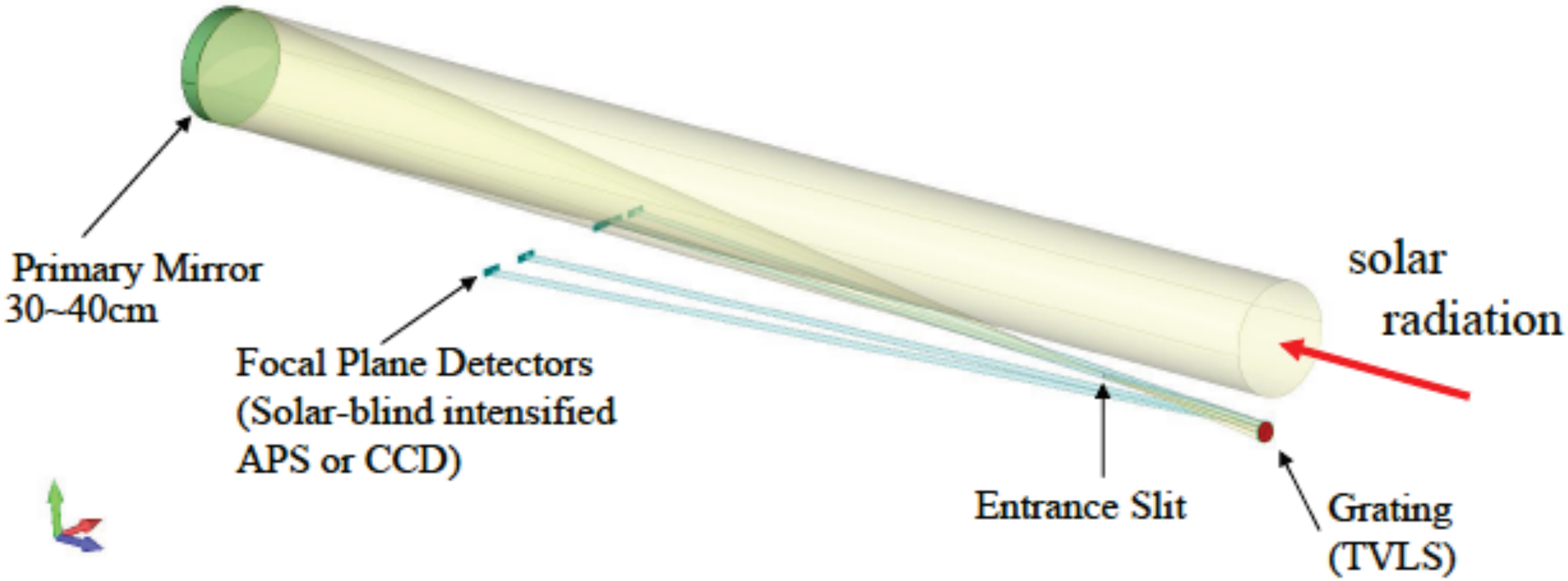


Performance of the image stabilization system

High throughput UV/EUV spectrograph

Performance much improved from previous instruments

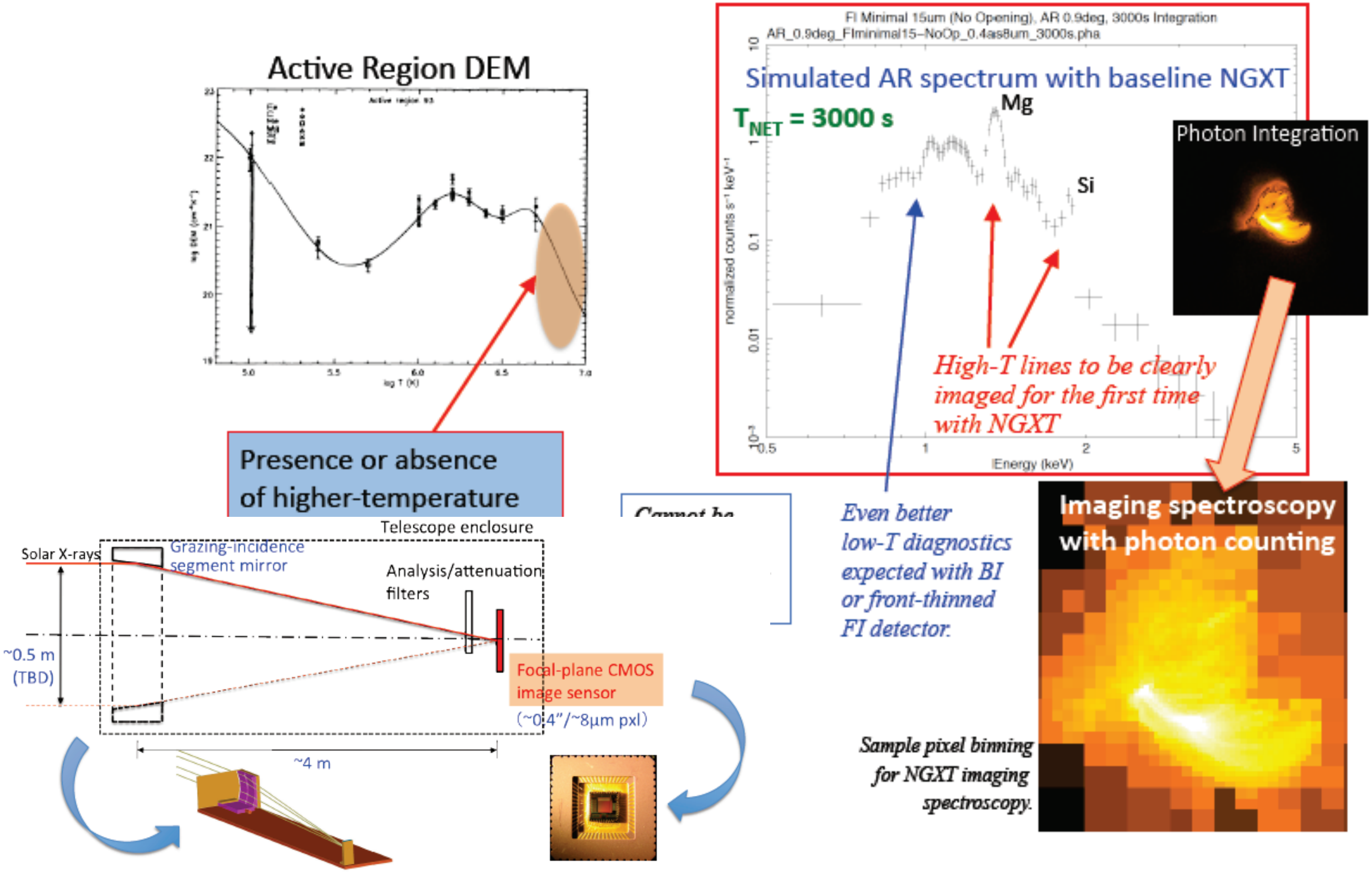
大型分光望遠鏡の雛形概念図



- By removing metal filters with solar-blind intensified detector, having minimum numbers of optics and ~30cm aperture, we expect >10 improvement in effective area from EIS and SUMER.

Next Generation X-ray Telescope

Exploring Active Regions with NGXT: Science Cases



Summary

- SOLAR-C Plan-B: Mission to investigate dissipation of magnetic energies in astrophysical plasmas with spectroscopic (+polarimetric) instruments

- Science targets are begin clarified through the discussion in each subWG.

  (We may need more discussion to define mission wide science goals.)

- We have now conceptual designs of the spacecraft and the mission instruments.