SOLAR-C PLAN-B: Mission Concept

Y. Katsukawa and SOLAR-C WG

SOLAR-C SDM

2008.11.18-21

Outline

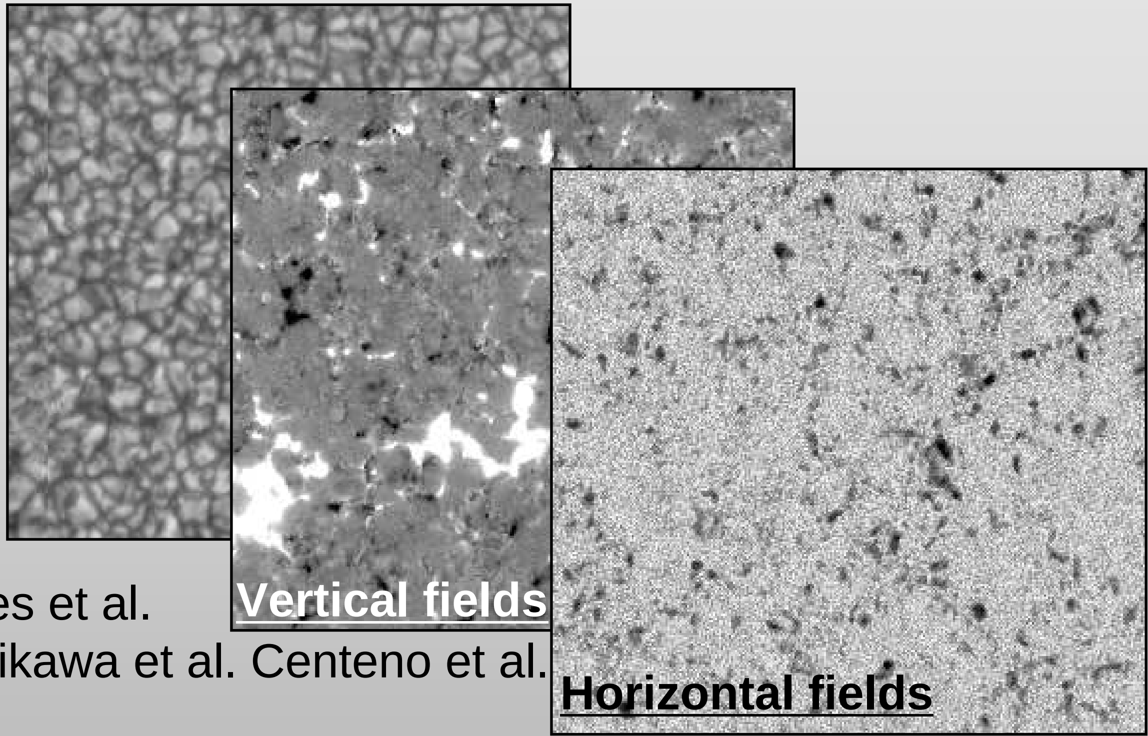
1. Beyond HINODE
    - Highlights of HINODE discoveries
    - Beyond HINODE
2. SOLAR-C Plan B mission concept
    - Mission instruments
    - System requirements
3. Key items addressed in the meeting

SOLAR-C Plan B

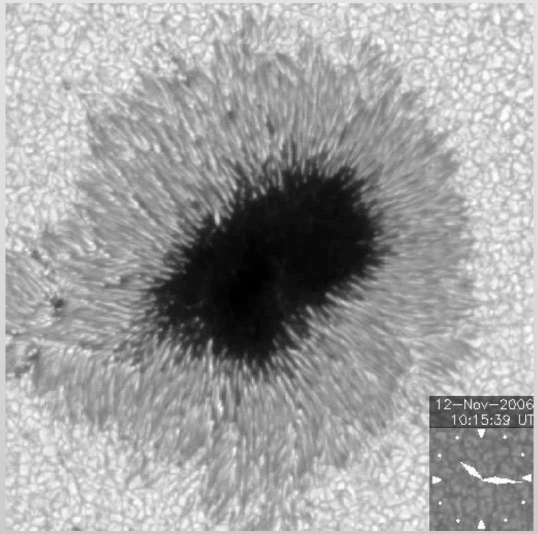
- Pursues high resolutional observations with enhanced spectroscopic capability from photosphere to corona to investigate magnetism of the Sun and its role in heating and dynamics of the solar atmosphere.

- Advantages of SOLAR-C
  - *Enhanced spectroscopic (+polarimetric) capability*
    - Use the solar atmosphere as laboratory plasma by the powerful diagnostic capability
  - *High time resolution, high throughput spectrometer*
    - Catch elemental processes of the solar plasma such as waves and reconnection
  - *Complete coverage of the solar atmosphere through photosphere, chromosphere, TR, and corona*

Magnetic field dynamics in the photosphere

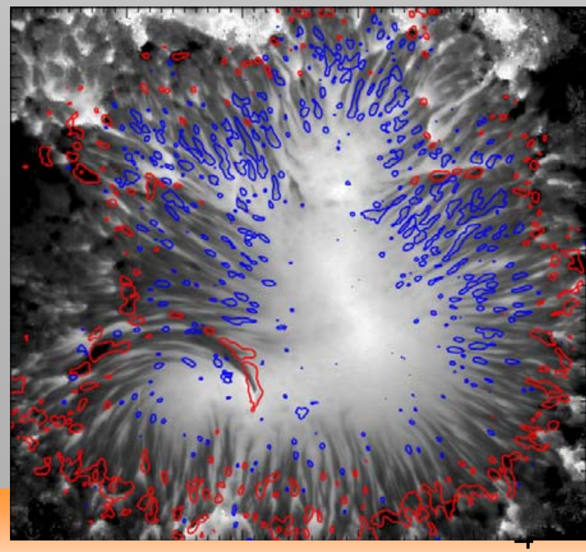


Lites et al.
Ishikawa et al. Centeno et al.



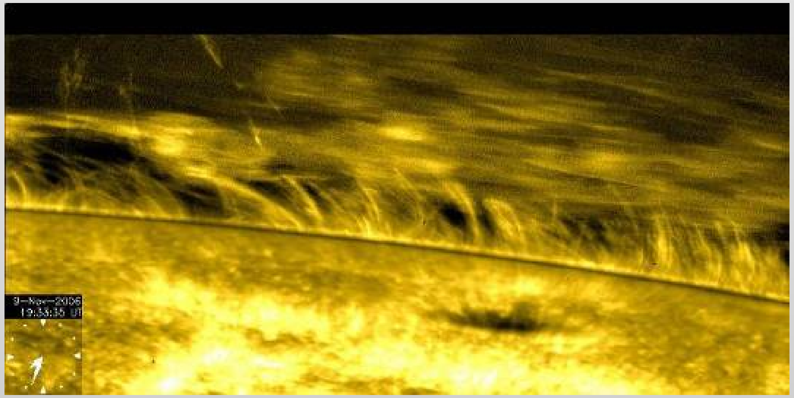
Katsukawa et al.

Ichimoto et al.

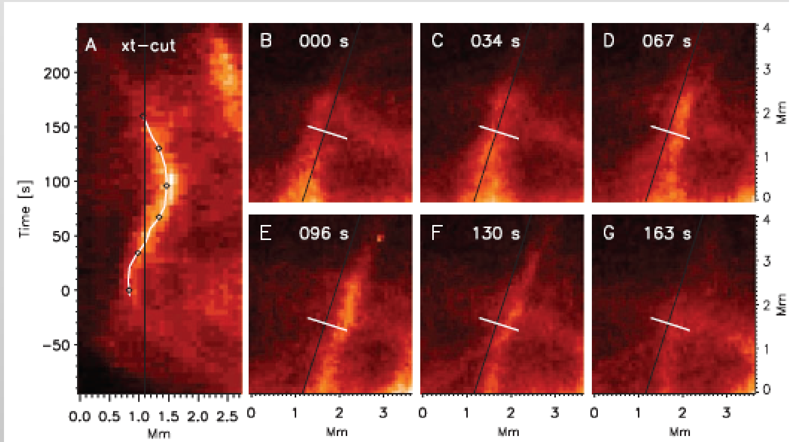


- QS photospheric magnetic fields
  - Formation of flux tubes, ubiquitous horizontal fields
- Sunspot structures
  - Penumbral filaments and Evershed flow
  - Umbral dots, light bridges, MMFs etc.

Waves/oscillations in chromosphers/coronae

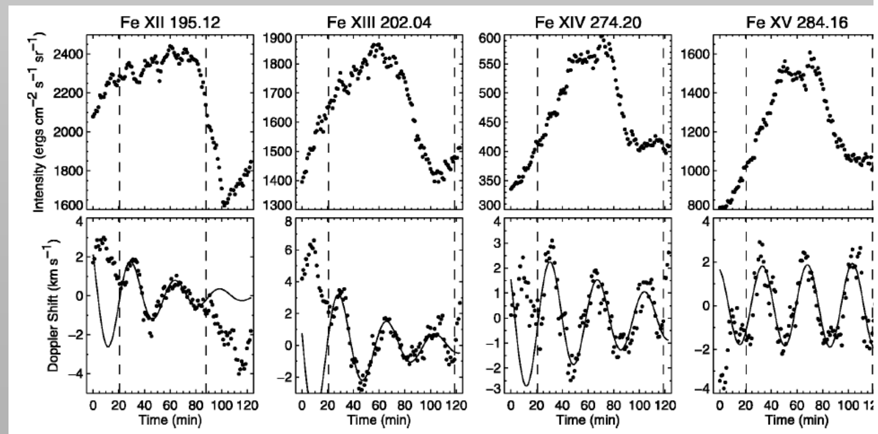


Okamoto et al.



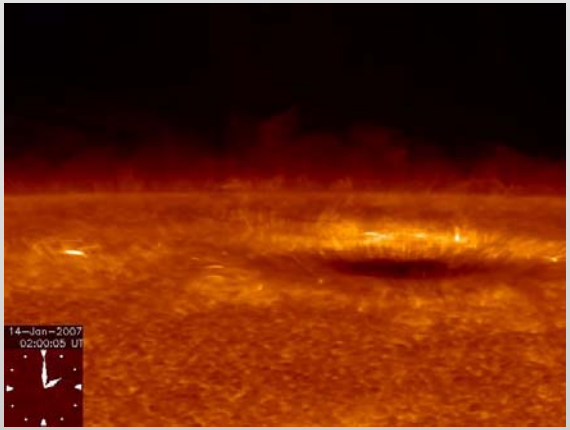
De Pontieu et al.

- Oscillations/waves are observed everywhere in the solar atmosphere, which may be important in energy transfer to heat the atmosphere.
  - Period: 2 - 5mins or longer
  - Oscillation amplitude: ~1000km
  - Velocity amplitude: 10 – 20 km/s

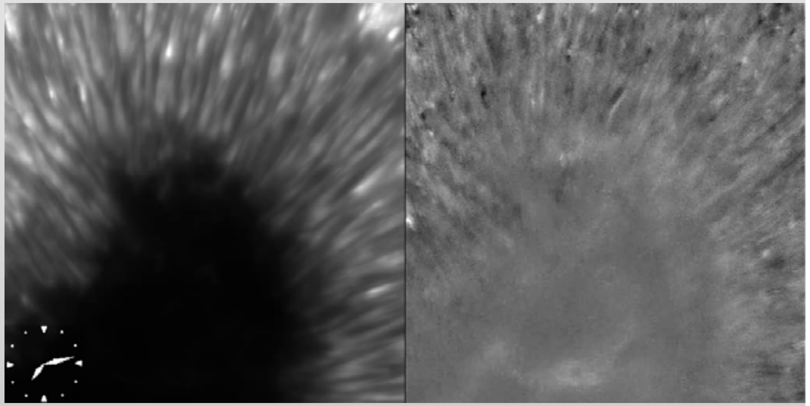


Mariska et al.

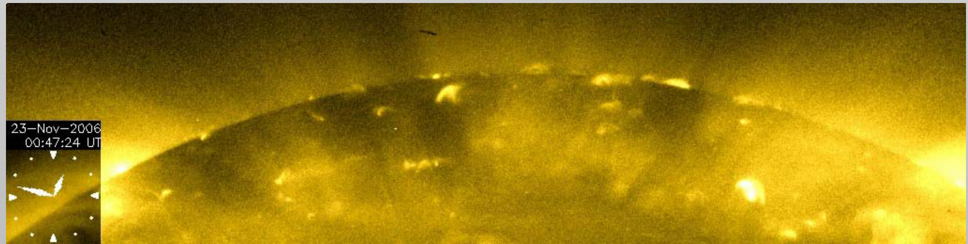
Chromospheric/X-ray jets driven by magnetic reconnection



Shibata et al.

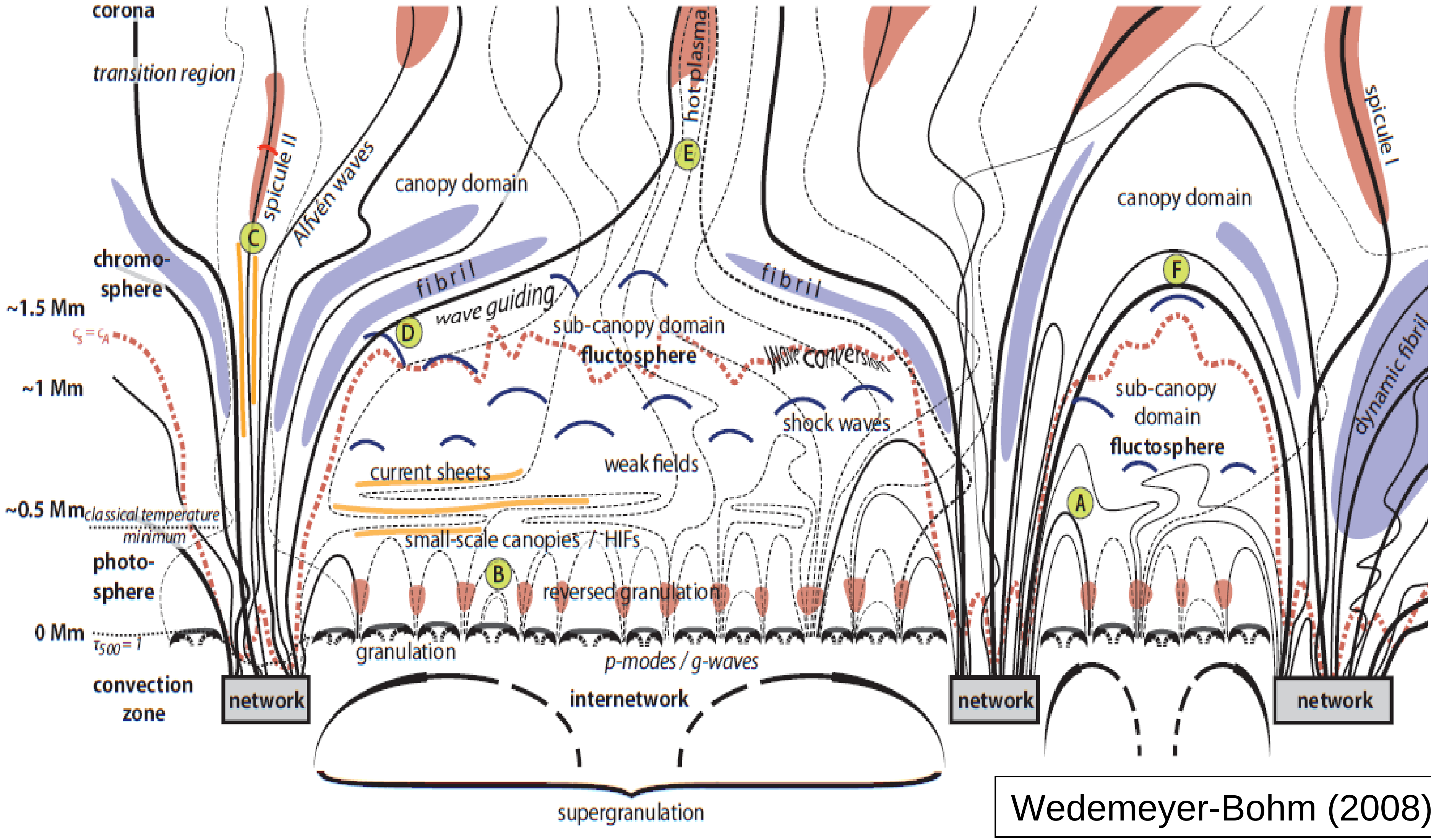


Katsukawa et al.



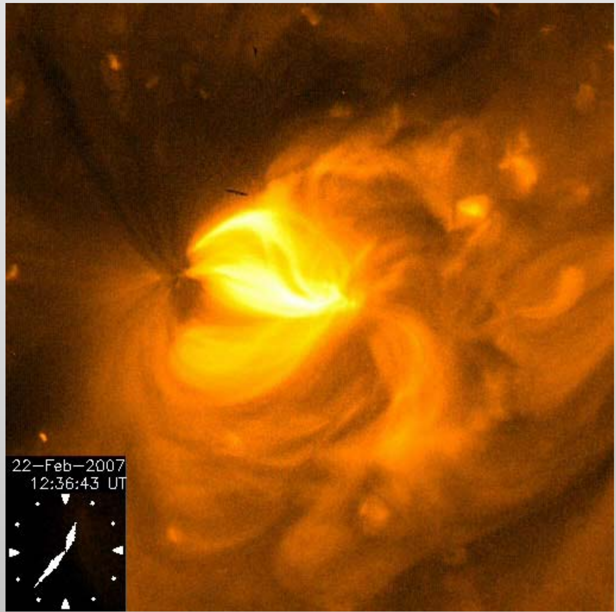
Cirtain et al.

- Plasma ejections are ubiquitously observed in the wide range of spatial/temporal scales, which are probably driven by magnetic reconnection.
  - Spicules, penumbral microjets, chromospheric jets, explosive events, X-ray jets, etc.
  - Duration: <1min ~ minutes ~ 1 hour
  - Spatial scale: <1000km ~ 5,000km ~ 50,000km



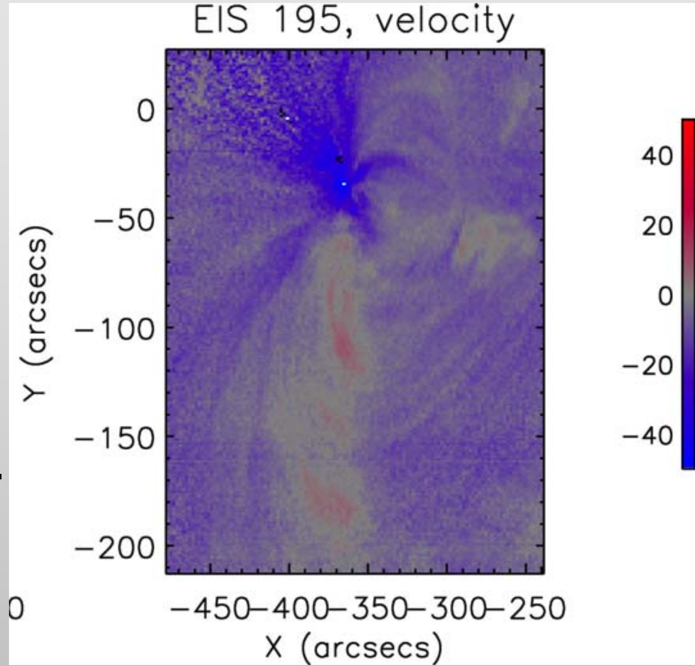
Wedemeyer-Bohm (2008)

Coronal flows, solar wind, and non-therm vel.



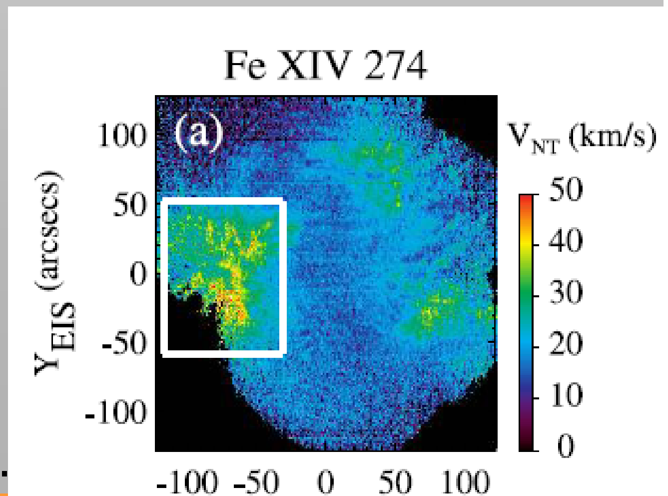
Sakao et al.

Harra et al.

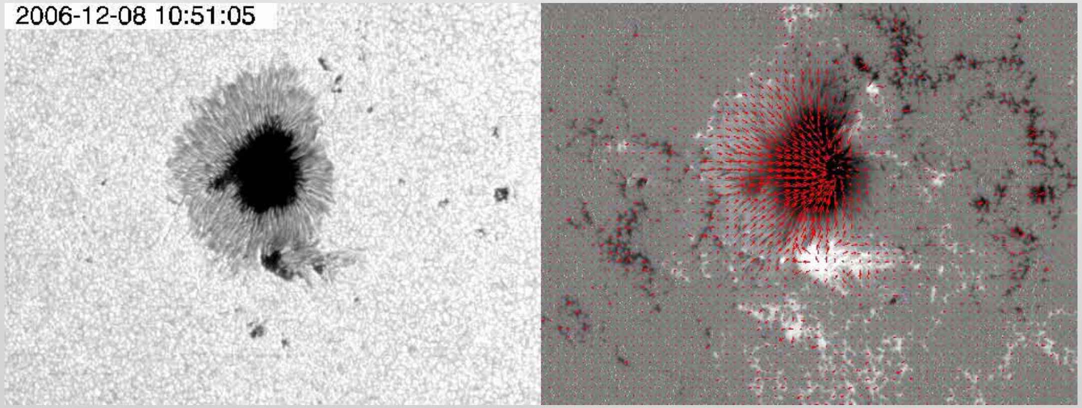


- Outward flow along magnetic field lines in the corona.
  - Velocity ~ 100km/s
  - Source of slow solar wind
- Non-thermal broadening near the footpoints of coronal loops
  - Signature of nanoflares?

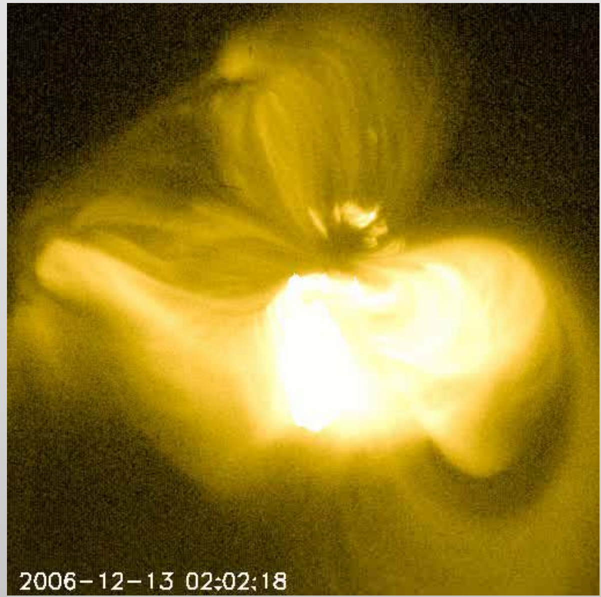
Hara et al.
Doschek et al.

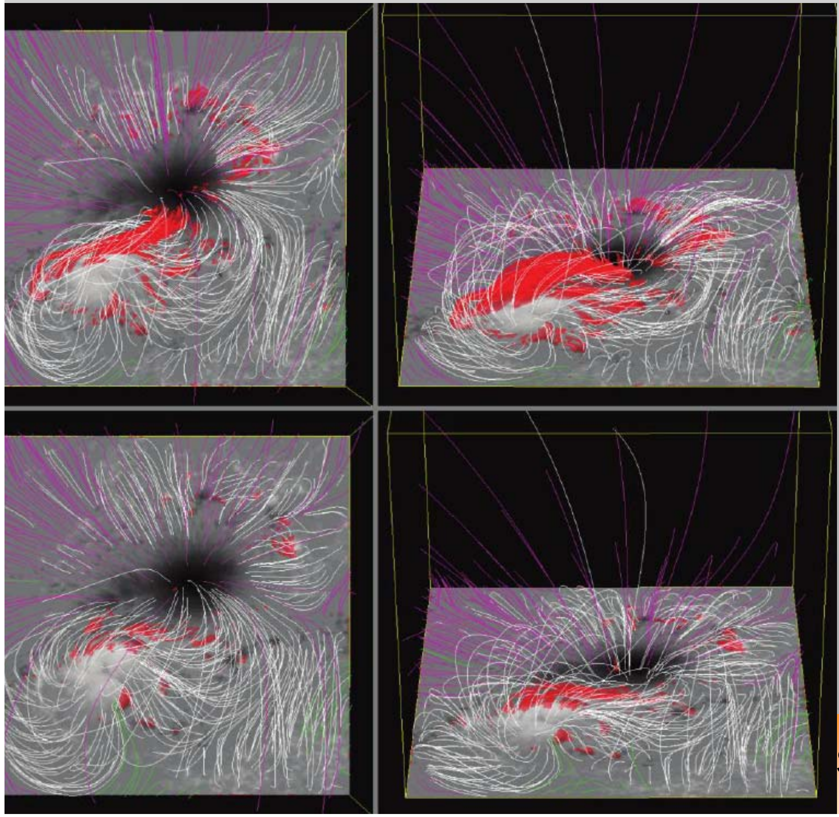


AR evolution, flare onset



Kubo et al.





Schrijver et al.

- Continuous observations of vector fields in the photosphere together with observations of the corona has provided unprecedented information about flare onset.
  - NLFFF extrapolation from vector fields in the photosphere to the corona

- Elemental MHD processes started to appear by high resolutional observations.
- We are still in the middle of studies using HINODE and other existing instruments. We are sure that we are on a path toward solving major problems in solar physics.
  - Chromosphere and corona heating
  - Flares/CMEs onset
- It is also true that we are not satisfied with the current instruments. We have to think about what we should do next, beyond HINODE.

Beyond HINODE

- *Spectroscopic capability of chromospheric and TR lines*
  - HINODE/SOT has a capability to observe only photospheric lines of Fe I. Only imaging observations of chromospheres are available.
  - HINODE/EIS observes mainly coronal plasma > 10^6K.
  - There is a gap between the photospheres and the coronae, which make it difficult to understand energy transfer and dissipation between them.

⇒

- Extend the observing wavelength range to fill the gap between the photosphere and the corona.
- Capability of spectroscopic(+polarimetric) observations in both photospheric and chromospheric lines to enable quantitative diagnostics

Beyond HINODE (cont'd)

- *Temporal cadence in spectroscopic observations*
  - It takes very long time (longer than 1 hour) to get spectral observations over a wide area.
  - We have to reduce FOV if we like to achieve the high temporal cadence. This prevents us from studying dynamical phenomena by spectroscopic observations.

- High throughput telescope to increase the temporal cadence in spectroscopic observations (for EUV obs)
- Instruments to use photons efficiently in spectroscopy (for Vis/NIR obs)
  - Multi-slit or multi-object spectroscopy
  - Narrow-band filter imager with rapid wavelength scanning

Beyond HINODE (cont'd)

- *Spatial resolution to resolve elemental physical processes*
  - Is 0.2"-0.3" resolution enough to resolve magnetic field and convection dynamics in the photosphere, waves and magnetic reconnection occurring in the chromosphere?
  - It is not easy to connect fine scale structures (<1") seen in the photosphere/chromosphere to coronal structures because of lack of spatial resolution (>1") in coronal observations.

- Increase the spatial resolution in coronal observations.
- We have to discuss how critical improving spatial resolution is in observations of photosphere and chromosphere.

SOLAR-C Plan B

- Pursues high resolutional observations with enhanced spectroscopic capability from photosphere to corona to investigate magnetism of the Sun and its role in heating and dynamics of the solar atmosphere.

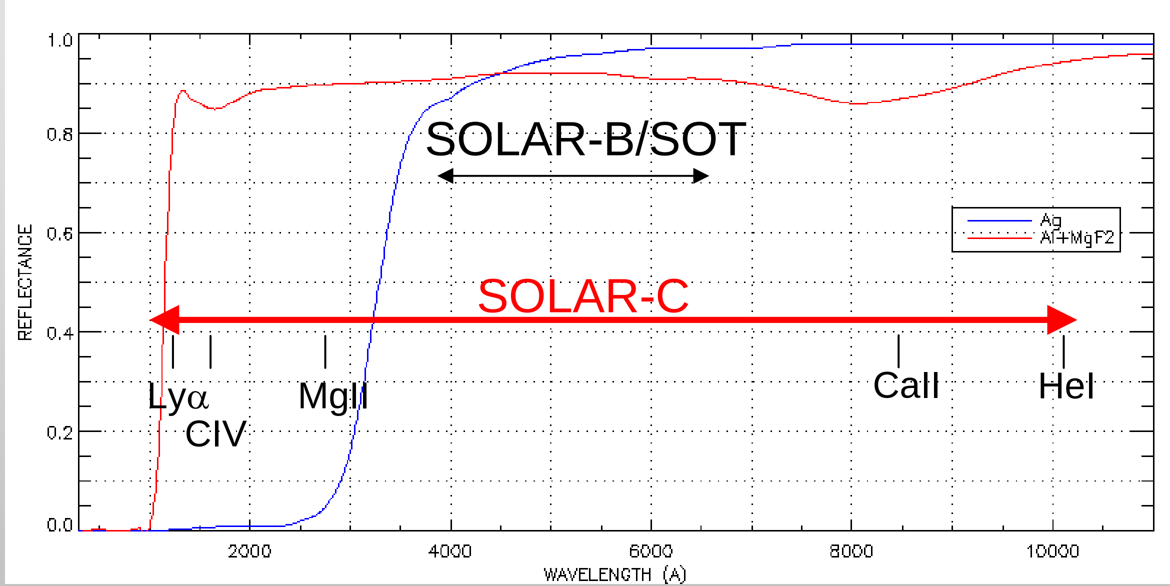
- Advantages of SOLAR-C
  - *Demonstrates power of spectro-polarimetry*
    - Use the solar atmosphere as laboratory plasma by the powerful diagnostic capability
  - *High time resolution, high throughput spectrometer*
    - Catch elemental processes of the solar plasma such as waves and reconnection
  - *Complete coverage of the solar atmosphere, photosphere, chromosphere, TR, and corona*

Strawman Mission Instruments

- NIR-Visible-UV telescope
  - >50cmϕ diffraction-limited telescope (0.1- 0.4arcsec resolution) with advanced imaging and spectroscopic instruments
  - Wide wavelength coverage with capabilities of observing spectral lines useful for diagnosing the solar atmosphere from photosphere to transition region
- EUV spectroscopic telescope
  - Wide wavelength coverage to see solar atmosphere from transition region to corona.
  - High spatial resolution (better than 0.5")
  - High throughput to achieve high cadence.
- Ultra-high resolution EUV/X-Ray imaging telescope
  - Imaging of emission from coronal plasma.
  - High spatial resolution (better than 0.5")

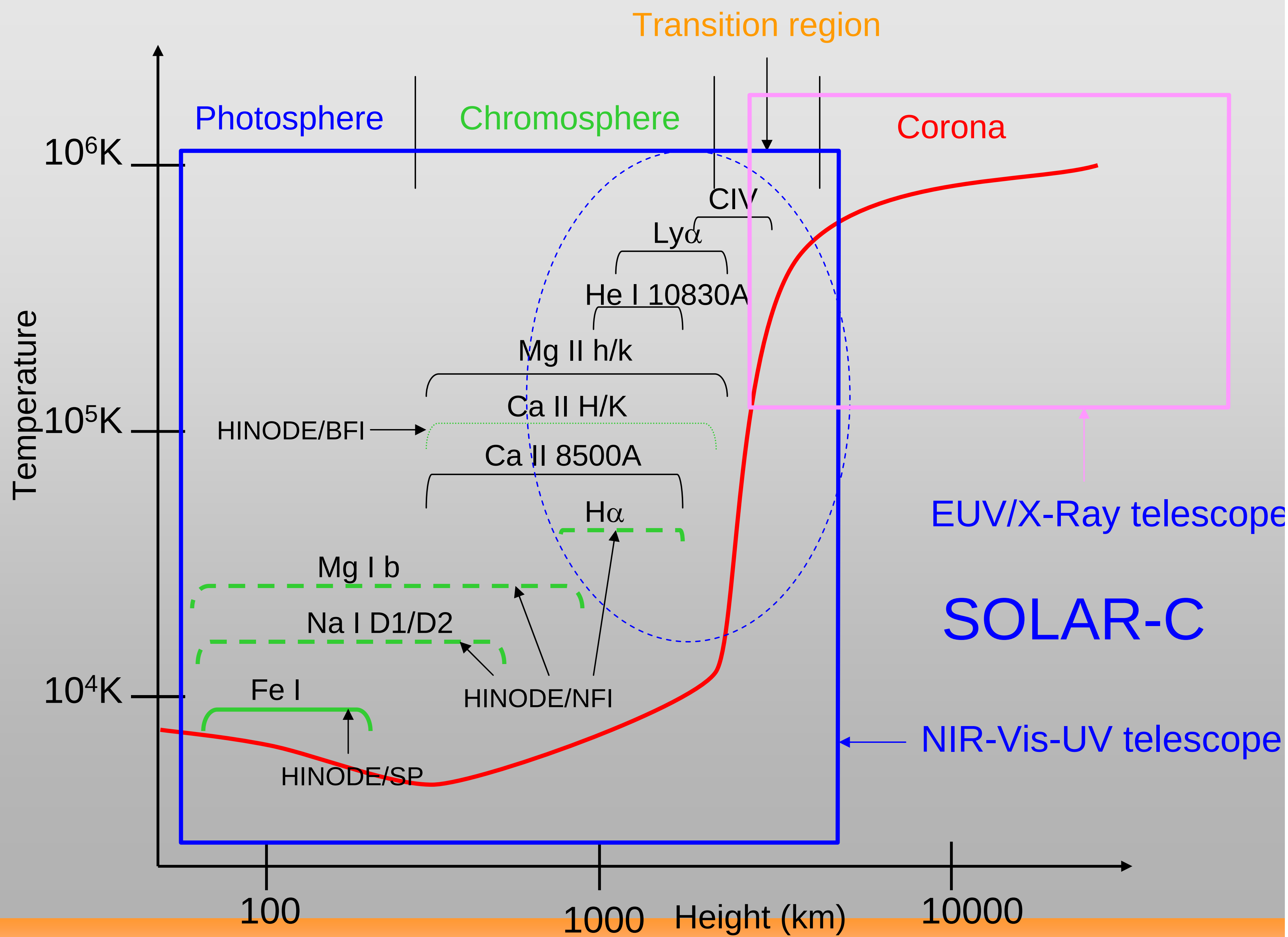
NIR-Vis-UV telescope

- Extend the observing wavelength range to UV and NIR in order to see the upper chromospheres/TR.
- The mirror coating is changed to Al+MgF_2 from Ag for UV observations.



- High throughput by >50cm ϕ allows us to perform high resolutional spectroscopic observation

- Eff. area 30-200 cm^2 in 120-300nm (ref. 0.01 ~ 0.3 cm^2 for SUMER)
  100- 400 cm^2 in > 400 nm (ref. 100 ~ 200 cm^2 for HINODE/SOT)

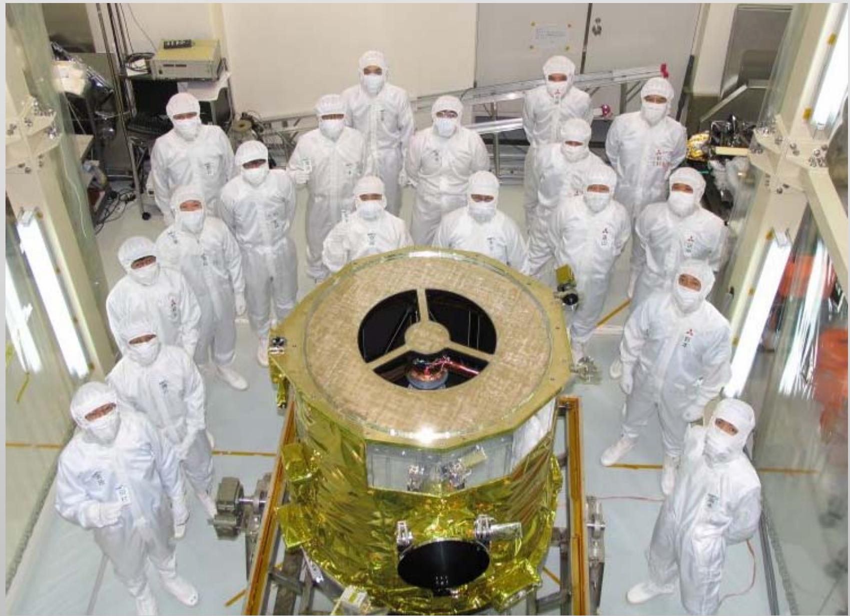


Transition region
Photosphere
Chromosphere
Corona
10^6K
10^5K
10^4K
Temperature
CIV
Lyα
He I 10830A
Mg II h/k
Ca II H/K
HINODE/BFI
Ca II 8500A
Hα
Mg I b
Na I D1/D2
Fe I
HINODE/NFI
HINODE/SP
EUV/X-Ray telescope
SOLAR-C
NIR-Vis-UV telescope
100
1000
Height (km)
10000

Candidates of spectrum lines

- Chromospheric and transition region dynamics
  - *Lyα 1216A*
  - *CIV 1550A*
  - *Other chromospheric and transition region lines at <2000A*
  - Mg II h/k 2800A
  - Ca II H/K 3900A
- Chromospheric vector magnetic fields
  - He I 10830A
  - Ca II 8500A IR triplet
  - MgIb 5172A
- Photospheric vector magnetic fields
  - FeI 5247A/5250A etc.
- Photospheric/lower chromospheric imaging
  - CN band (3883A)
  - Vis/UV continuum

Optical performance in UV



HINODE Optical Telescope Assembly (OTA)

- 50cmϕ diffraction-limited telescope achieved by HINODE SOT
  - STR ~ 0.8 @ 500nm
    (diffraction limit: 0.25")
    STR ~ 0.5 @ 300nm
    (diffraction limit: 0.15")
  - We can achieve at least the same spatial resolution 0.2" in VUV as HINODE SOT in Vis.
- Micro-roughness
  - Minimum requirement 1nmRMS is already achieved by OTA.
- Key technical items
  - Contamination control for UV observations (*preliminary study is reported by Dr. Urayama*)
  - Higher heat absorption by the Al mirror coating
  - Image stabilization for UV obs

Characteristics of NIR-Vis-UV telescope

- Throughput and spatial resolution (50cmϕ aperture)

  S/N ~ 50~200 in Lyα and MgII h/k

  (0.1"pixel (0.2"res), 1sec exp, $\lambda/\Delta\lambda$ = 2x10^4)

  S/N ~ 20~50 in CIV and other VUV lines

  (0.1"pixel (0.2"res), 10sec exp, $\lambda/\Delta\lambda$ = 2x10^4)

  S/N ~ 2x10^3 in FeI 5250A

  (0.1"pixel (0.2"res), 1sec exp, $\lambda/\Delta\lambda$ = 1x10^5)

  S/N ~ 10^4 in CaII 8500A and He10830A

  (0.2"pixel (0.4"res), 6 sec exp, $\lambda/\Delta\lambda$ = 1x10^5)

NIR-Vis-UV telescope
Focal plane instruments (very preliminary)

	Aperture	Wavelength	Focal plane instruments
(1)	>50 cm (VUV-Vis-NIR) utilizing UV/Vis dichroic mirror	120nm< λ <1μm	(1) UV package • UV spectrometer • UV Imager (2) Vis/NIR package • Multi-spectral line spectro-polarimeter • Narrow-band imager
(2)	30 ~ 50 cm (VUV telescope)	120nm< λ <200nm (TBD)	(1) UV package • UV spectrometer • UV imager
	>50 cm (NUV-Vis-NIR)	280nm< λ <1μm (TBD)	(1) Vis/NIR package • Multi-spectral line spectro-polarimeter • Narrow-band imager

UV package

- UV Spectrometer
  - Spatial resolution: better than 0.2"/pixel
  - Spectral resolution: $\lambda/\Delta\lambda > 4\times10^4$ (~ 50mÅ @ 2000A)
  - Spectrum lines, possible candidates
    - Ly α , Si II, Si IV, CIV, Mg II h/k etc.
  - (Optional) Polarimeter for Zeema/Hanle diagnostics

- UV Imager
  - Slit jaw camera to know the slit location
  - Spatial resolution: better than 0.1"/pixel
  - Observing wavelengths
    - UV continuum for the low chromosphere
    - Imaging of bright lines (Lyα, CIV, MgII h/k) if a narrow-band filter (~1A pass-band) is available

NIR-Vis package

- Multi-spectral line spectro-polarimeter
  - At least two spectral lines can be observed simultaneously or by switching pre-filters.
  - Spatial resolution: ~ 0.1"/pixel
  - Spectral resolution: ~20mA/pixel
  - Candidates of spectrum lines
    - He I 10830A (Chromospheric magnetic fields)
    - Ca II 8500A (Chromospheric magnetic fields)
    - Fe I 5250A (Photospheric magnetic fields)

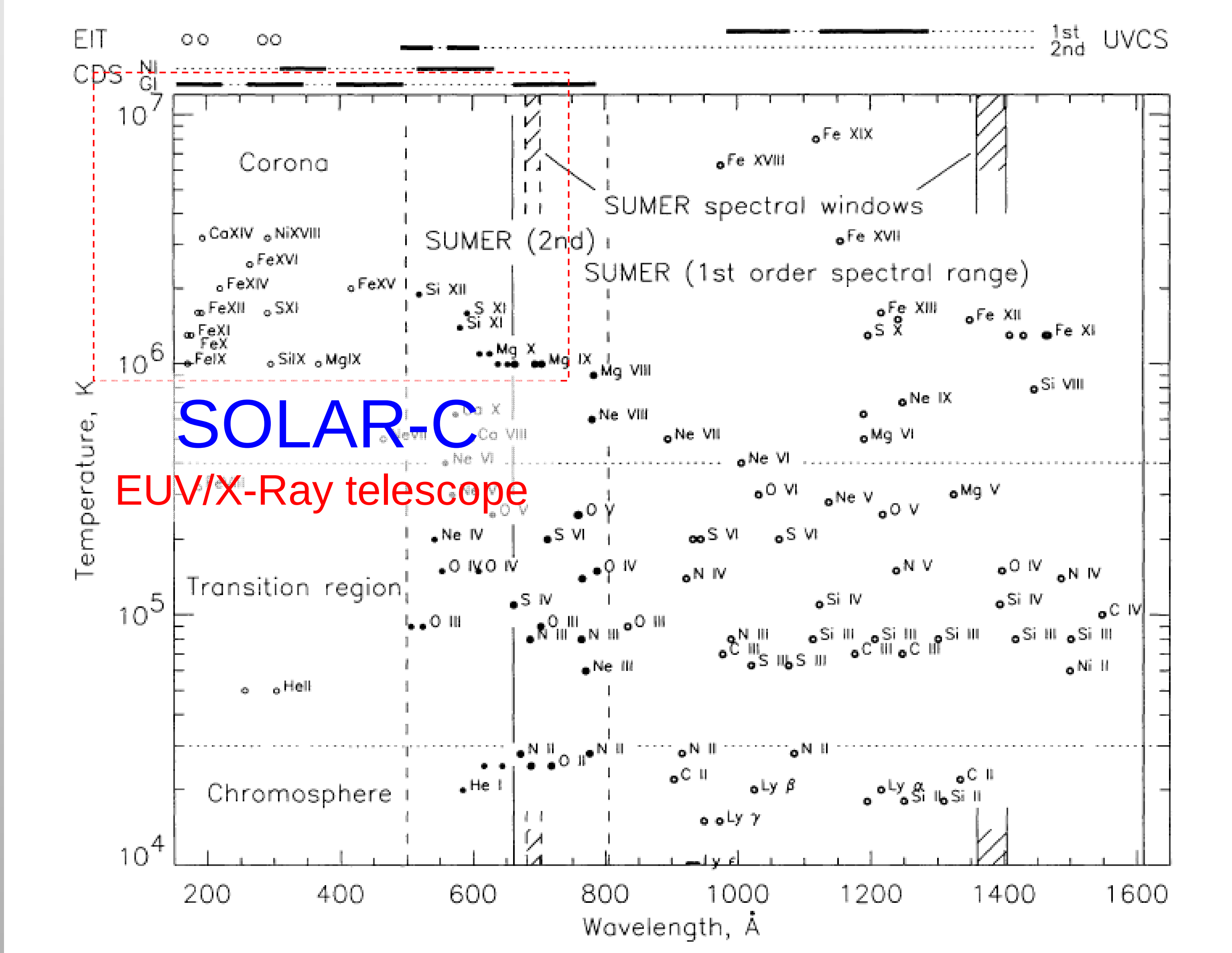
- Narrow-band imager
  - Spatial resolution: better than 0.1"/pixel
  - Spectral resolution: 20 ~ 100mA
  - Rapid wavelength scan by Fabry-Perot or Lyot filter
  - Broadband interference filter for continuum imaging

EUV spectroscopic telescope

- Key performances required
  - High sensitivity, time cadence better than 10 sec even in QS
  - Spatial resolution better than 0.5”
  - Wide temperature coverage from TR to corona, mainly in wide coverage of transition region (some 10, 000 – a few MK)

- To realize high sensitivity telescope, the number of optical elements (filters, mirrors) should be minimized.
  - One optics candidate is off-axis parabola mirror (>20cmϕ) and TVLS grating, and vis. light-blind dector.

Ref: Talks by J. Davila and G. Doschek



Wilhelm et al. (1995)

Ultra-high resolution EUV/X-Ray imaging telescope

- Key performances required
  - Spatial resolution should be better than 0.5"
  - Good throughput to get an image with a reasonable exposure duration

- Normal incidence Cassegrain optics with an large effective area, with multi-layer coating sensitive to EUV emission lines emitting from coronal plasma.

OR

- Grazing incidence optics with an large effective area to cover emissions from coronal plasma with various temperatures. Spectroscopic capability by photon counting detector as an option.

Ref: Talks by L. Golub/E. Deluca, and T. Sakao

Spacecraft system concept

- Utilize high-precision space technologies acquired during the HINODE development, and minimize new developing items for realizing SOLAR-C.
  - Hinode SOT heritage : 50cm diffraction-limited telescope and image stabilization system
  - Spacecraft design, including S/C attitude control, micro-vibration control technique

- Launch vehicle: JAXA H-IIA
  - ~3t for the Sun-synchronous orbit (SSO)
  - ~2t for the Geostationary orbit (GEO)

New items for SOLAR-C

- Ultra-high date rate
  - High temporal cadence spectroscopic observations require very much telemetry. One to two orders of magnitude larger than HINODE.
  - Orbit (SSO or GEO), on-board data processing, and data donwlink are critical in the mission.

- Operate SOLAR-C like a ground-based telescope
  - It's provide a great advantage if we can move the slit on an interesting target with looking at real images.

The details are to be given by T. Shimizu.

Key items addressed in the meeting

- ***Which problems are solved or unsolved ?***
  - Convection, photospheric magnetic field dynamics, local dynamo
  - Sunspot structure, penumbra, magneto convection
  - Chromospheric and coronal heating, solar wind acceleration
  - Prominences, Flare/CME initiation mechanism

Key items addressed in the meeting

- ***What kind of information is missing in understanding the unsolved problems?***
  - Direct measurements of magnetic fields in chromospheres and coronae ?
  - Spatial resolution better than 0.2" to see very small scale waves and reconnection ?
  - High temporal resolution to catch very high frequency waves and dynamics?
  - Spectroscopic and polarimetric accuracy to measure weak magnetic fields and dynamics?
  - Wide FOV to get global magnetic field configuration?

Key items addressed in the meeting

- ***How do we meet the scientific requirements in SOLAR-C?***
  - Spectrum lines most suitable for diagnostics of chromospheres, TR, and coronae
  - What kind of observing instruments are suitable for NIR-Vis-UV telescope. Is 50cmϕ enough?
  - How to build the high resolutional + high throughput X-ray/EUV telescope