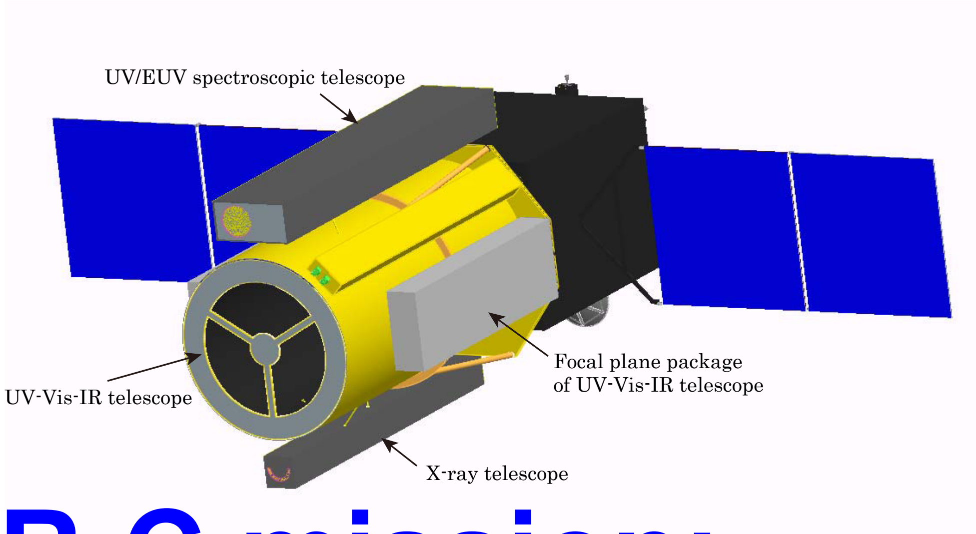
3rd Solar-C Science Definition
Meeting at Palermo, Italy



The SOLAR-C mission: Plan B

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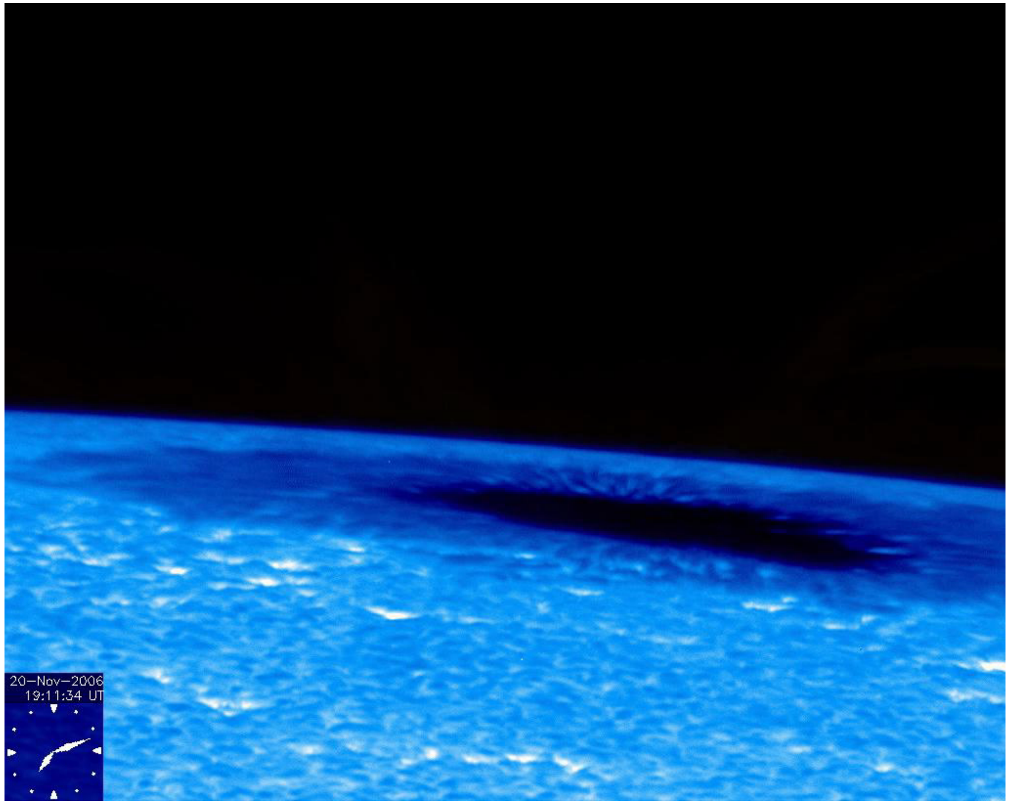
New solar physics opened with Hinode

324 referred papers (as of 28 June 2010)

More dynamic chromosphere!

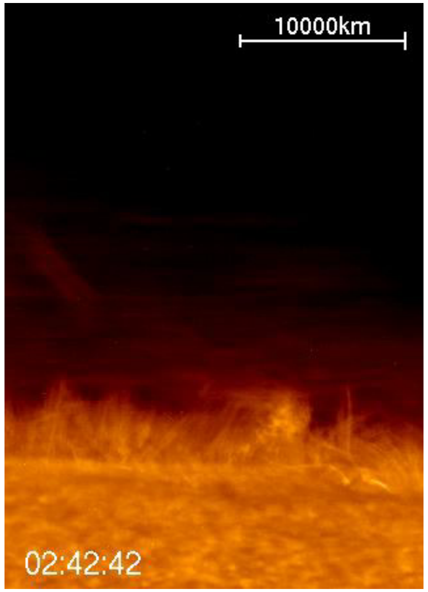


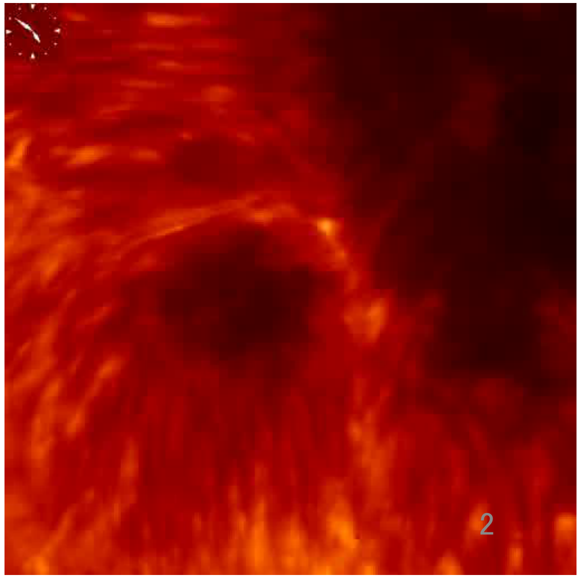
Ginant jet (Nishizuka+08, Liu+09)

Spicules (DePontieu+07)

Anemone jets (Shibata+07)

Penumbral micro-jets (Katsukawa+07)





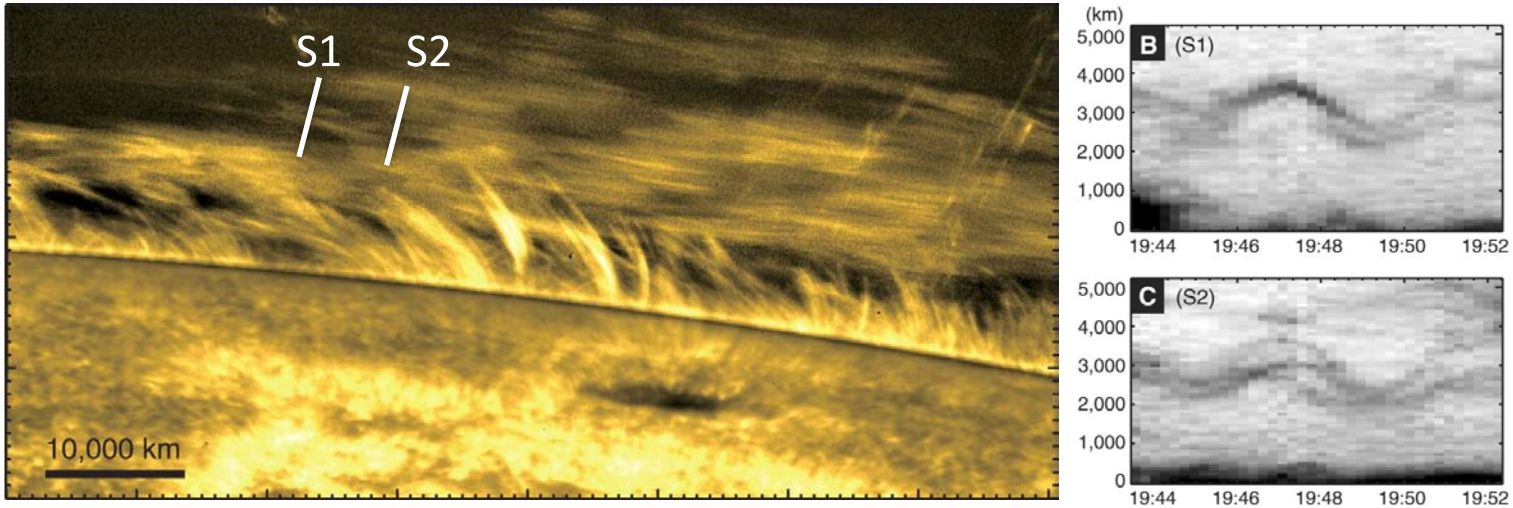
A variety of jets

- Signatures of transient magnetic energy releases
- Apparently playing an important role in the energy, momentum and mass balance of the atmosphere

Light bridge jets (Shimizu+09)

New solar physics opened with Hinode

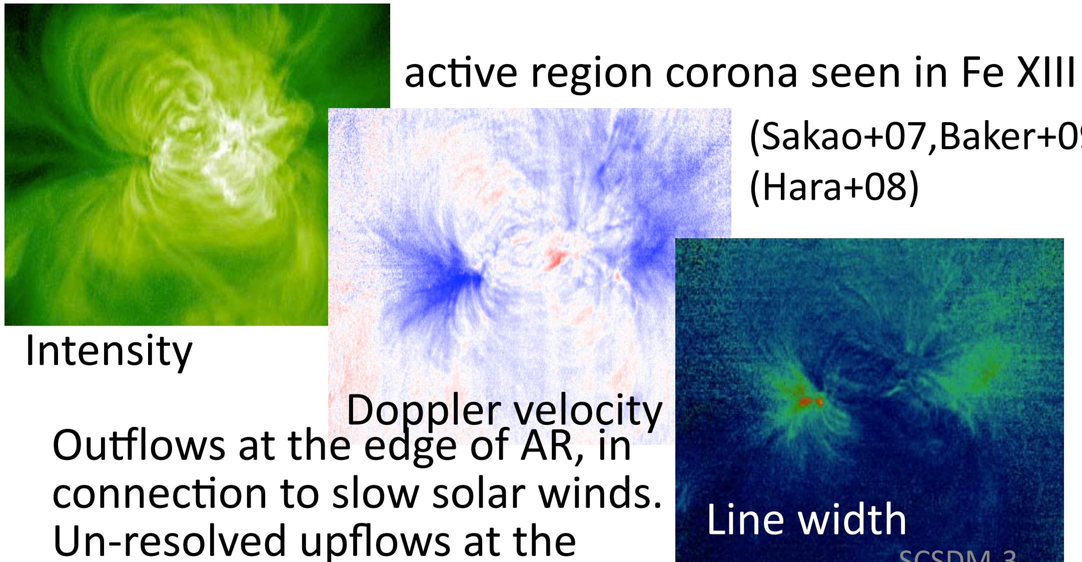
Waves!: signatures of energy transport and release



Transverse oscillations of prominence threads that trace the B field (Okamoto+07)

Alfven waves

- Can carry an energy flux into the corona or solar wind.

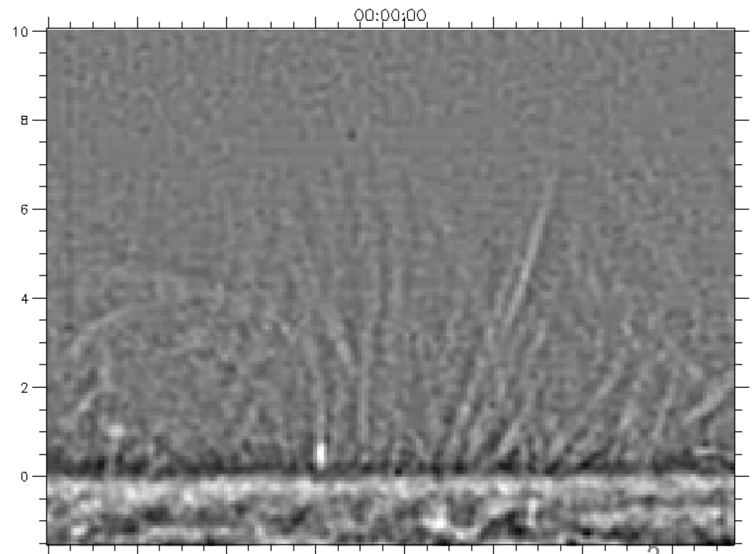


Intensity

active region corona seen in Fe XIII

(Sakao+07,Baker+09)
(Hara+08)

Outflows at the edge of AR, in connection to slow solar winds.
Un-resolved upflows at the bases of coronal loops.



Transverse oscillations are ubiquitous in spicules (de Pontieu+07)

Plan B: High^3 (spatial resolution, throughput, cadence) **Imaging-Spectroscopic Observations**

- At the core of all the questions related to how the Sun floods the heliosphere with hot plasma, radiation, particles, and magnetic fields is the need to **understand <u>the elementary structures and fundamental physical principles</u> that govern a magnetized plasma**.
  - Our guiding principle is that important physics is located in small scales

- **Powerful combination of ① high resolution and ② spectro-polarimetric capabilities for ③ seamless observation of the entire solar atmosphere**

Plan B: top-level science goals

For exploring important physics in small scales

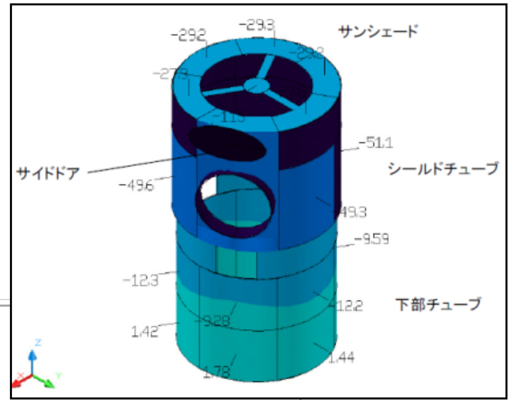
1. How **elementary structures** of the magnetic atmosphere **are created and evolve** over each temperature domain of the atmosphere?
2. How the energy that sustains the atmospheric structure is **transported through small elementary structures** into large-scale corona and **energizes the solar wind**?
3. How **the magnetic energy is dissipated** in the astrophysical plasma?

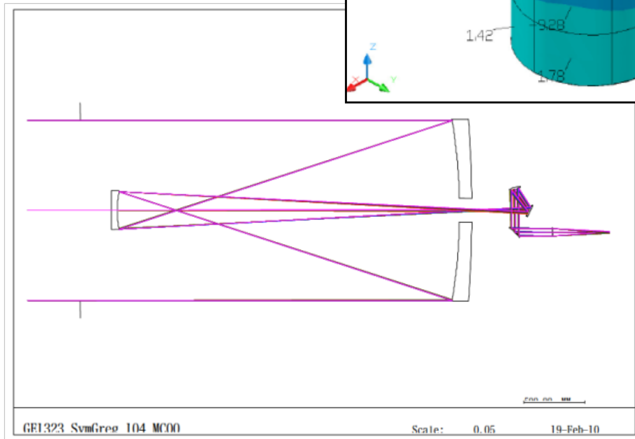
For relating small-scale physics to large-scale phenomena

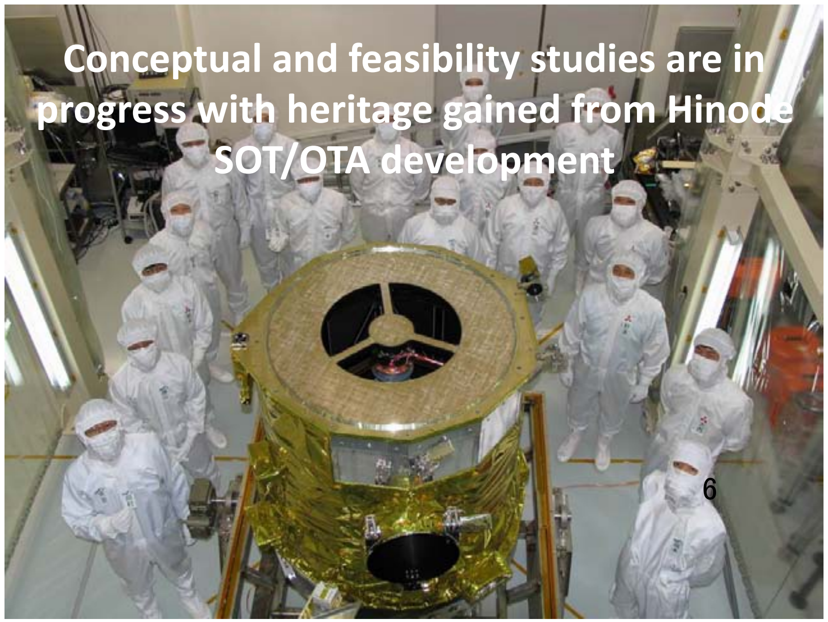
4. How **small-scale physical processes initiate** large scale dynamic phenomena creating space weather

Solar-C Plan B payloads (1)

- UV-Visible-Near IR telescope
  - The aperture size under study is 1.5 meter in diameter, which can accumulate one order of magnitude larger number of photons in an exposure time than Hinode SOT.
  - Spectro-polarimetric and imaging measurements of magnetic field and dynamics with chromospheric spectral lines
    - He 1083nm and Ca II IR(854nm) with Zeeman + Hanle effect sensitivity
    - Mg II k/h (280nm) most suitable for dynamics.
  - Variety of spectral lines available for diagnosing the wide range of the lower atmosphere from photosphere to chromosphere.



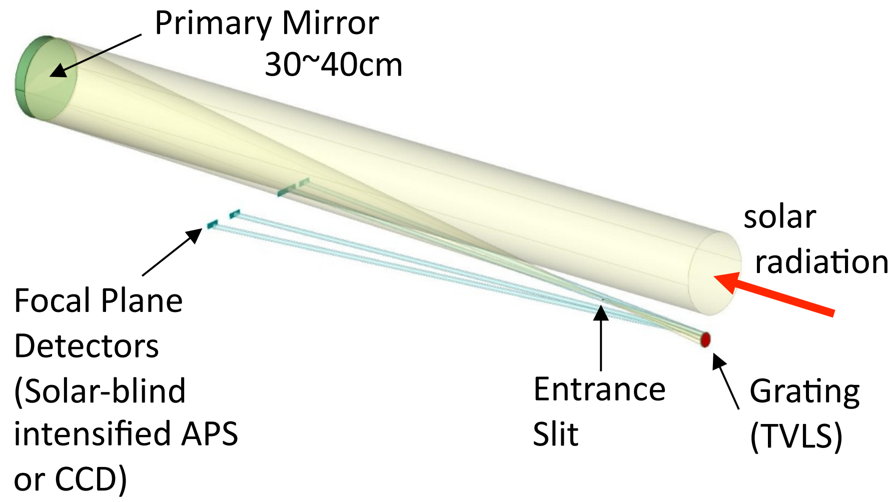




Solar-C Plan B payloads (2)

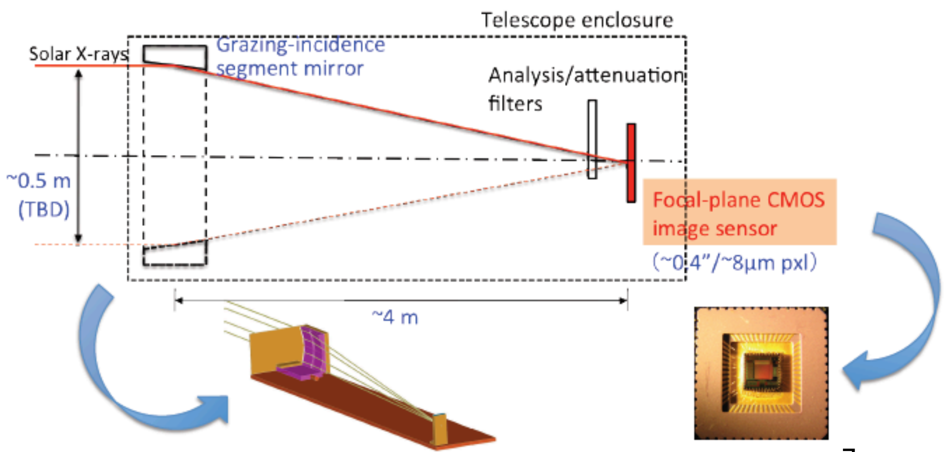
- UV/EUV high-throughput spectrometer
  - High throughput to increase high temporal cadence
  - High spatial resolution better than ~ 0.5”
  - The entire coverage of plasma temperature from the chromosphere, transition region to the corona and flare.

Strawman spectrometer



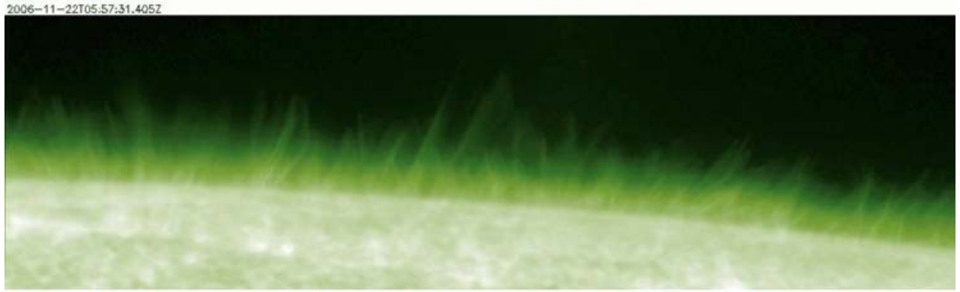
- Photon counting X-ray telescope
  - Imaging emissions from <1MK to 20 MK coronal plasma
  - Photon counting capability for spectroscopy with grazing incidence telescope with 0.5 arcsec
  - Option 2) Ultra-high spatial resolution (~ 0.1arcsec) for normal incidence telescope

Photon-counting X-ray telescope

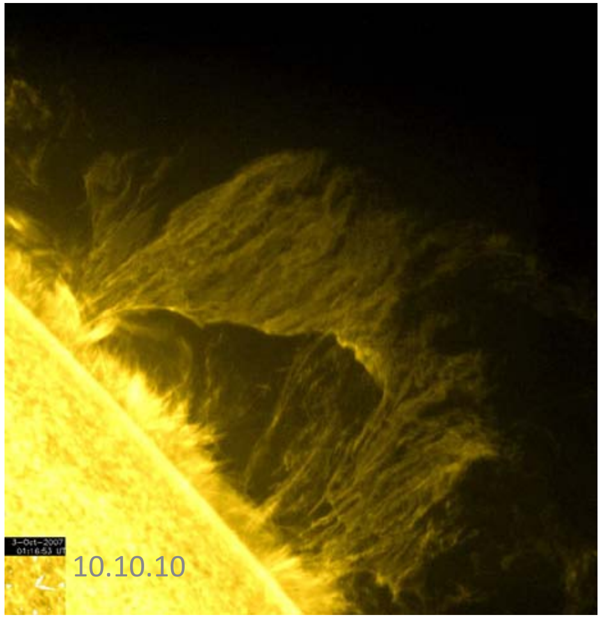


How magnetic elementary structures are created and evolve (1)

- Hinode provides much improvements on the processes by which the magntic flux interacts with the convective flows in the photosphere.
  - Ubiquitous horizontal fields and their dynamics (Lites+07,Ishikawa+08…)
- Resolve the evolution and dynamics of elementary structures in the complicated photosphere-chromosphere-corona system.



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.



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

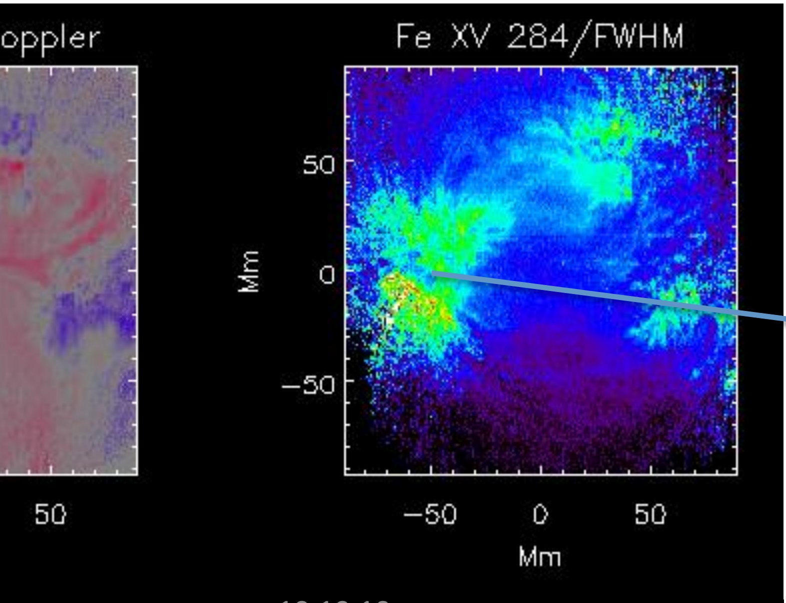
- Dynamical nature of elementary structures in upper atmosphere is directly connected with the formation of global structures, heating, dynamics, and flares.

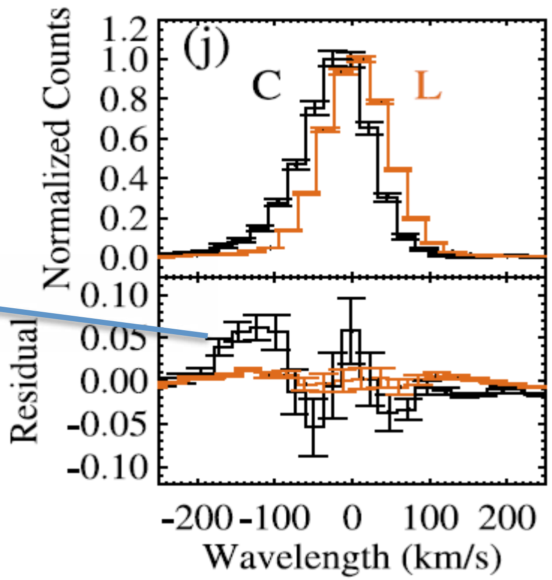
e.g.,

- Emergence and evolution of magnetic fields in QS and AR from the photosphere through the chromosphere into the corona.
- Magnetic field structures and dynamics in prominences

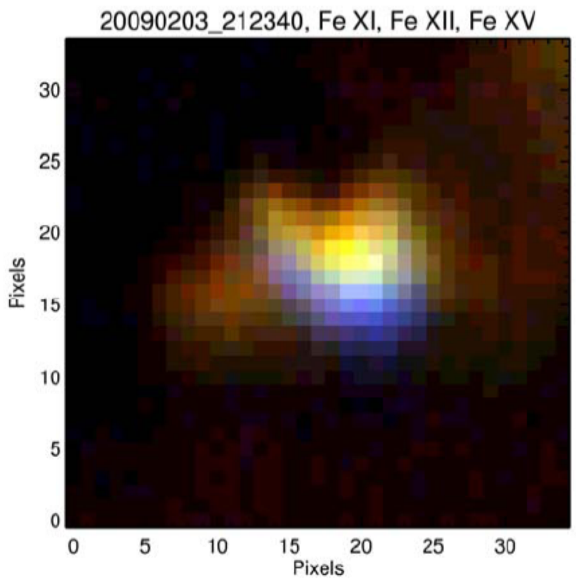
How magnetic elementary structures are created and evolve (2)

- Understand elementary structures of coronal loops for the heating issue
  - EIS spectroscopic observations suggest that only 10% of the volume in coronal loops is filled with hot plasma (Warren+08).
  - EIS observations suggest that high-speed upward flows of the plasma exist at the base of coronal loops and they are not resolved (Hara+08).
  - Such fine structures reflect the source of energy inputs and their understanding is the way to understand the coronal heating.





(Hara+08)

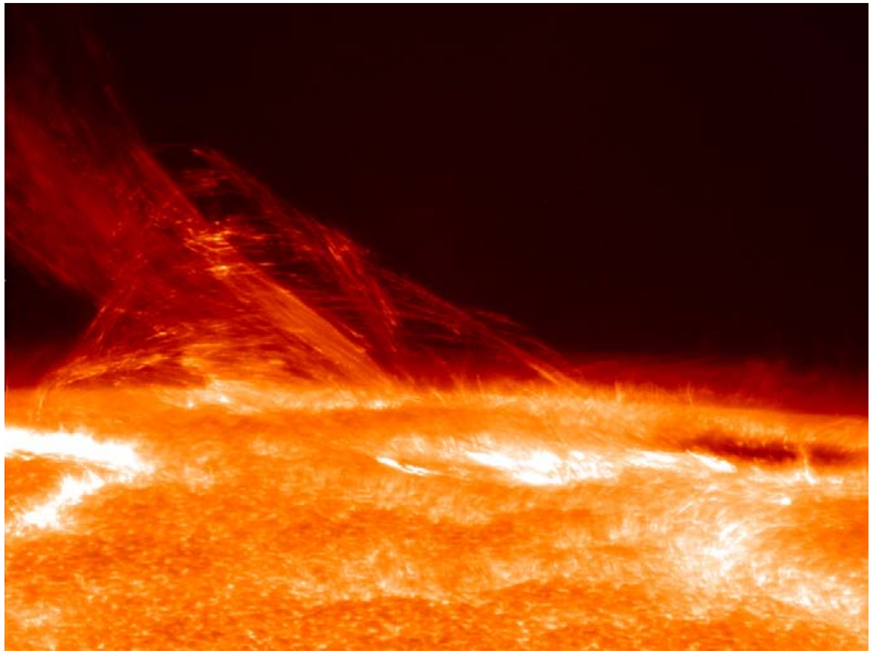


Bright point in a polar coronal hole. Elementary heating events are not resolved with the EIS resolution.

(Doschek+10)

Energy transport through elementary structures (1)

- Energy and mass are transferred from photosphere to the corona through the chromosphere.
  - Dominant physics changes from hydrodynamic (β >1) to magnetic forces (β <1). The region where most of the non-radiative heating take place.
  - Full of small-scale dyamics, far from hydrostatic equilibrium.



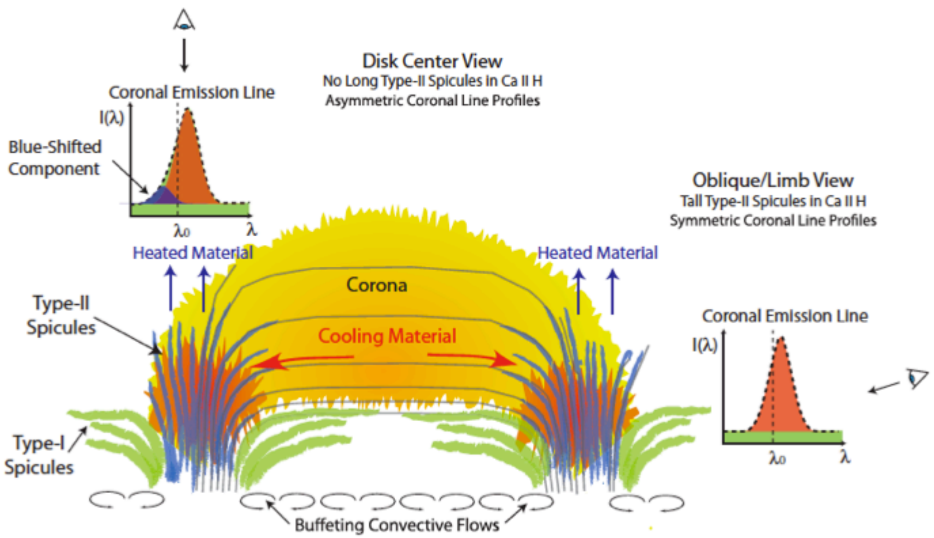


Figure 5. Mass and energy transport between the chromosphere, TR, and corona, as deduced from SOT and EIS observations. See Section 4 for details.

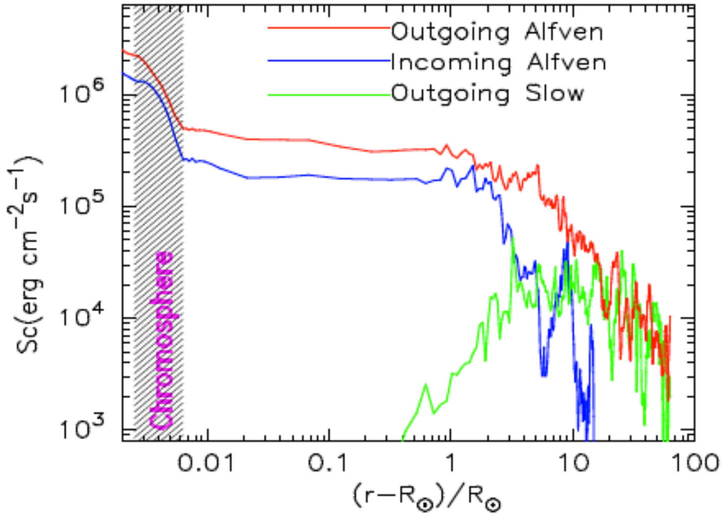
(De Pontieu+09)

- A blue-red asymmetry in TR lines, suggesting mass upward transport by type-II spicules (De Pontieu+09)
- Indication of highly blue-shifted (100km/s) structures at the base of coronal loops (Hara+08)
- How are energy transported through elementary structures?

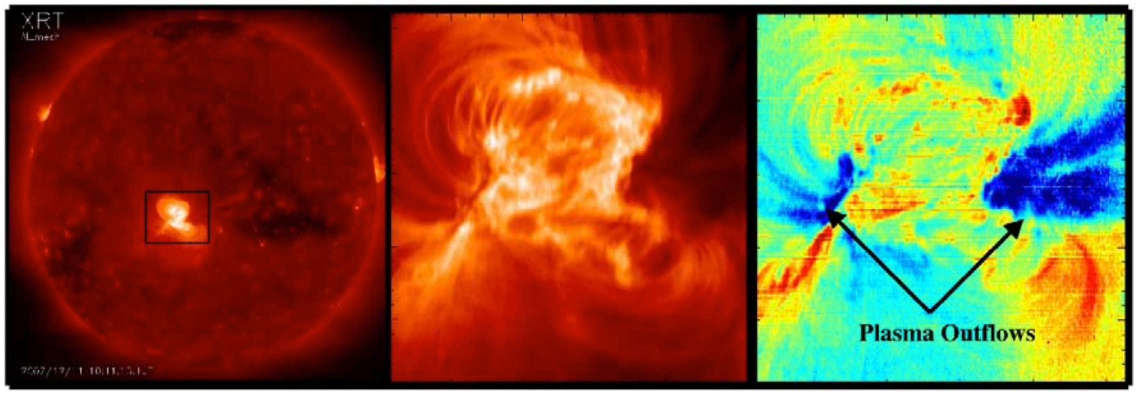
Energy transport through elementary structures (2)

- Determine the relevance of the observed waves for chromospheric and coronal energy budget

- Low-freq (<5mHz) magneto-acoustic waves propagating in the chromosphere may steep into shocks to heat the chromosphere (Carlsson+10). They should be verified.
- Alfven wave may heat and accelerate plasma as a result of nonlinear generation of compressive waves and shocks (Suzuki+05)



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).



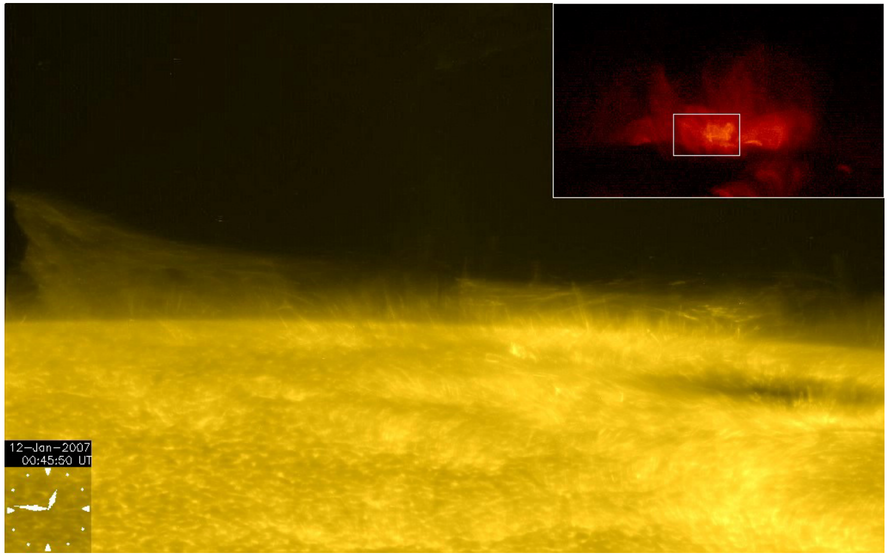
Outflows identified in a HINODE EUV spectroscopic observation. A driving mechanism is still an open question.

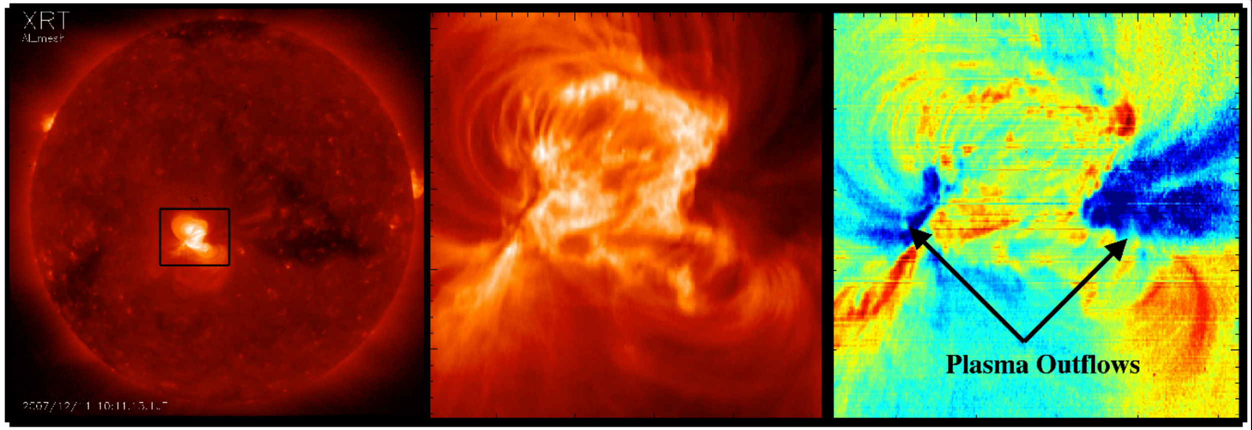
- Sufficient energy remain in the observed waves?
- Crucially important to measure B-field fluctuation simultaneously with velocity & intensity fluctuation. Possible up to chromosphere.

Magnetic Reconnection as a key process in solar dynamical nature

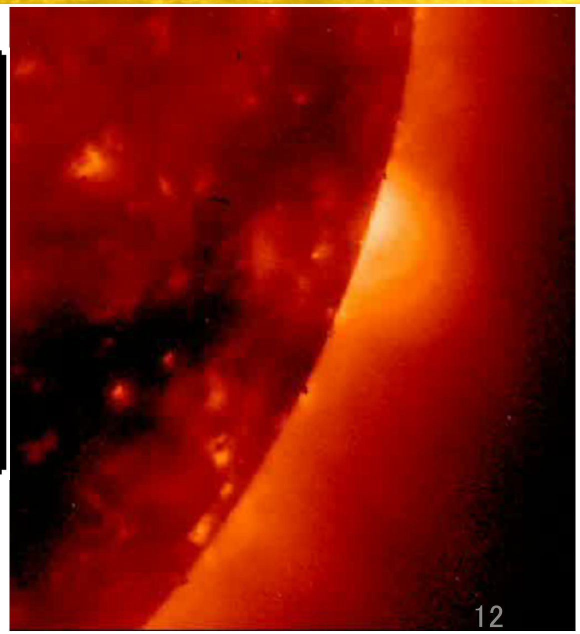
- A central engine for
  - Dynamical nature of atmosphere
  - Energy release in solar flares and initiation of CMEs
- May be a central engine for
  - the heating of the atmosphere
  - the acceleration of solar winds

Dynamics in CaIIH and X-ray



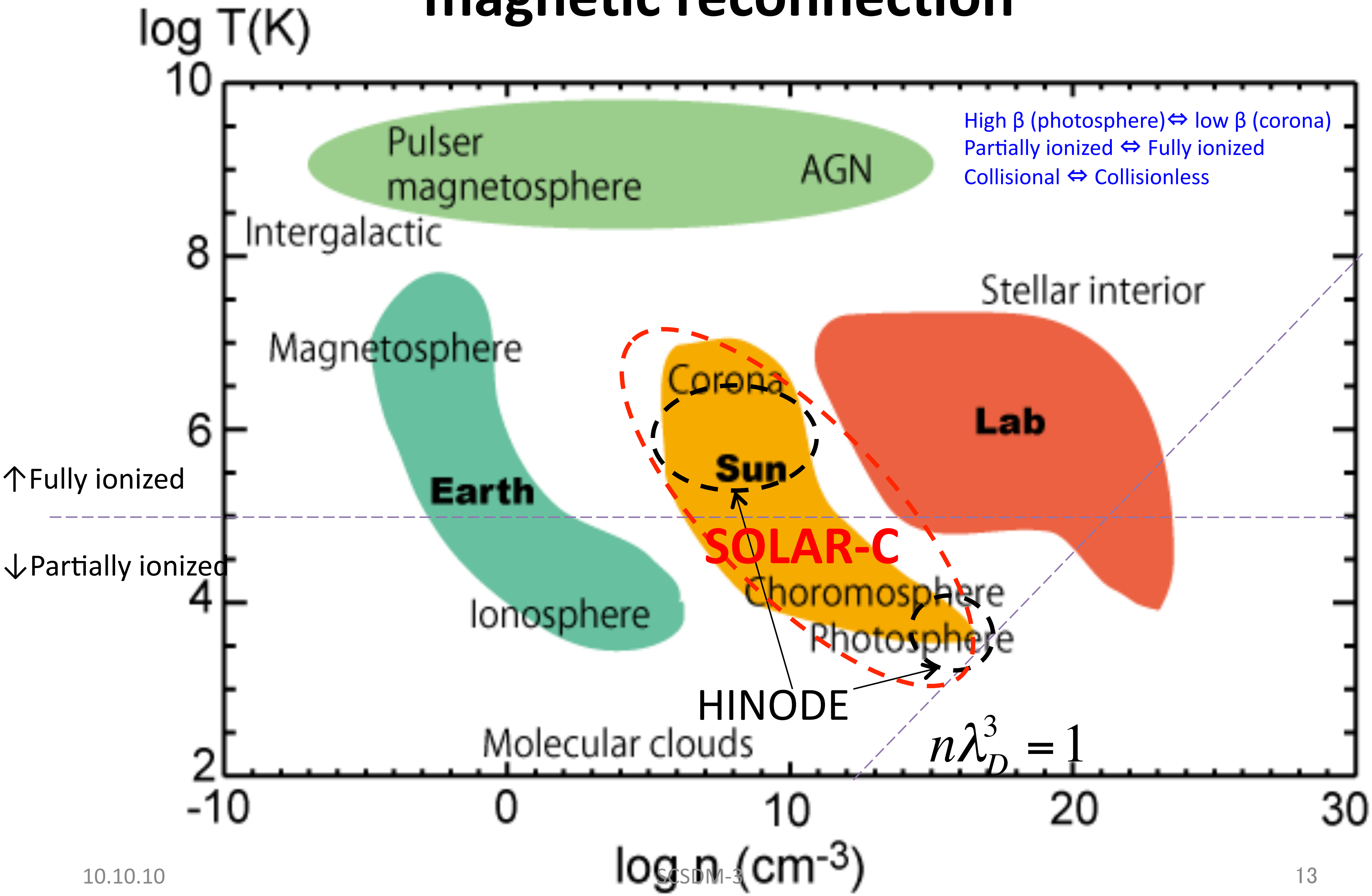


Outflows are found at active region edge as a possible source of slow solar wind (Sakao et al. 2007). Outflows identified in a HINODE EUV spectroscopic observation (e.g., Baker et al. 2009). A driving mechanism is still an open question. Reconnection??



X-ray: 2008 April 9 "Cartwheel CME" Flare

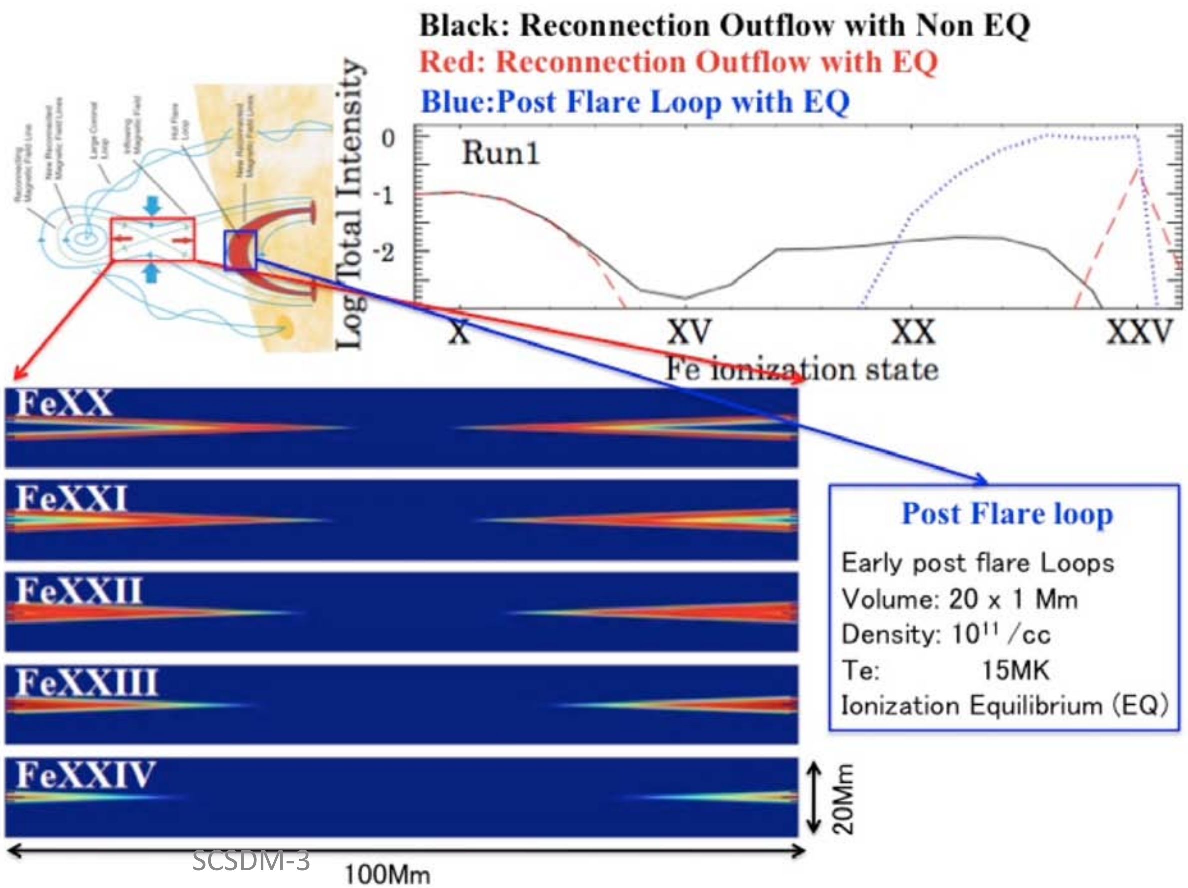
Solar atmosphere as a plasma laboratory for magnetic reconnection



Magnetic reconnection in collisionless plasma (corona & TR)

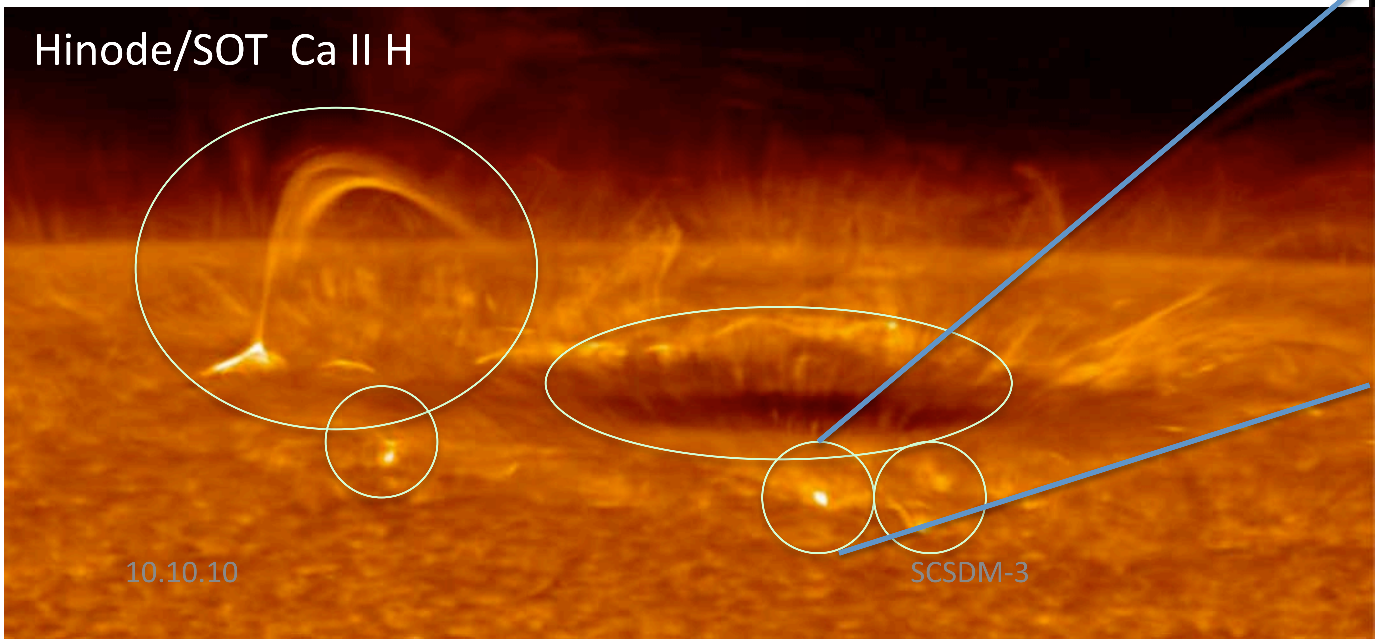
- Poor knowledge on plasma conditions in reconnection region because of its faintness.
- What controls the energy population, i.e, the ratio of conversion from magnetic energy to kinetic, thermal, non-thermal energy, or wave/turbulence?

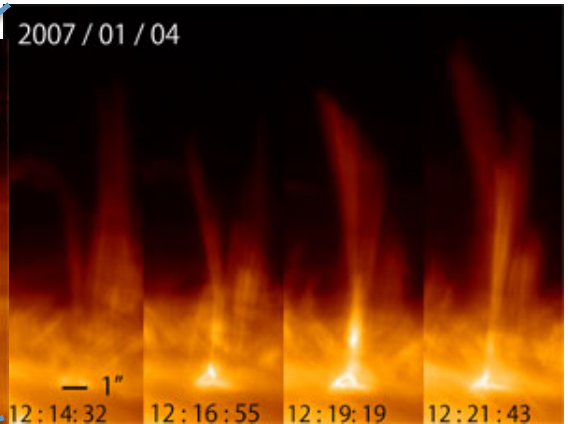
- Ionization non-equillibrium and thermal non-equillibrium
  - EUV line spectroscopy with different ionization states can diagnose conditions of the plasma just after rapid heating in reconnection region.



Magnetic reconnection in weakly ionized plasma (chromosphere)

- Hinode revealed that the chromospheric events are fast. Why the energy release in chromosphere so fast?
  - Evaluate the reconnection rate and compare with Spitzer resistivity, with measurements of physical parameters (density, magnetic field, speed) by the UV-visible-NIR telescope.
  - Ion-neutral collision causes ambipolar diffusion. A current sheet can be thinner due to the ambipolar diffusion effect (Isobe+10). Relate the reconnection locations with the plasma condition where ambipolar diffusion can effectively work.



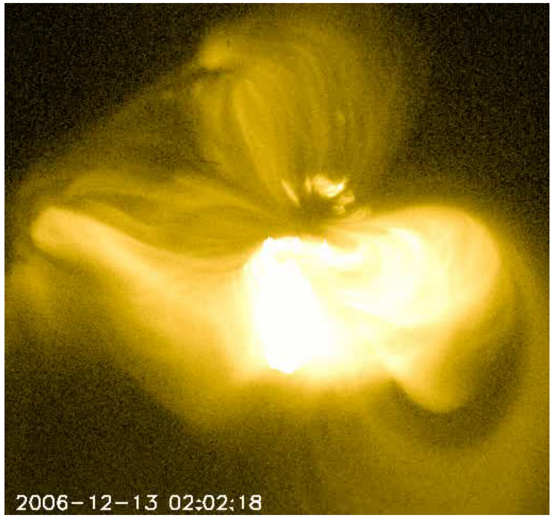


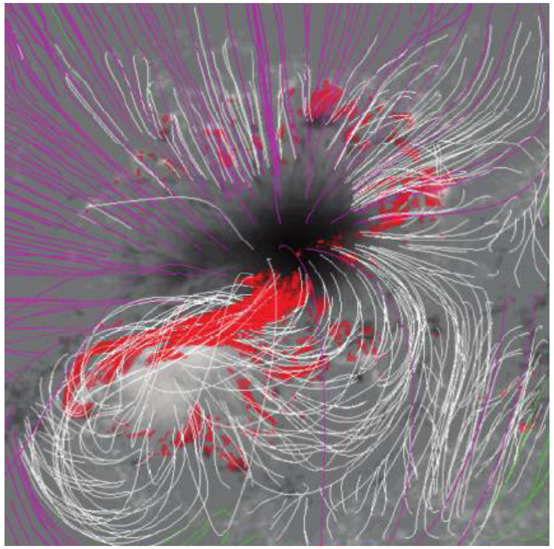
We know that rapid liberation of magnetic energy happens even in the collisional and partial ionized plasma. Measurements of physical parameters around a reconnection site may provide us a breakthrough.

Implication to space weather

- Space weather origins on the Sun

  Flares and CMEs, fast and slow solar winds
- High resolution and spectroscopic observations combined with other large-FOV obs (e.g., SDO) are a powerful tool to study initiation of large scale dynamic phenomena creating space weather.
  - Small scale phenomena may be responsible for triggering massive explosions.
  - Spectroscopic observations to understand details of the mass motion at the event initiation.
  - Data driven simulation with NLFFF and possibly MHDS modeling based on combination of photospheric and chromospheric magnetic field measurements.

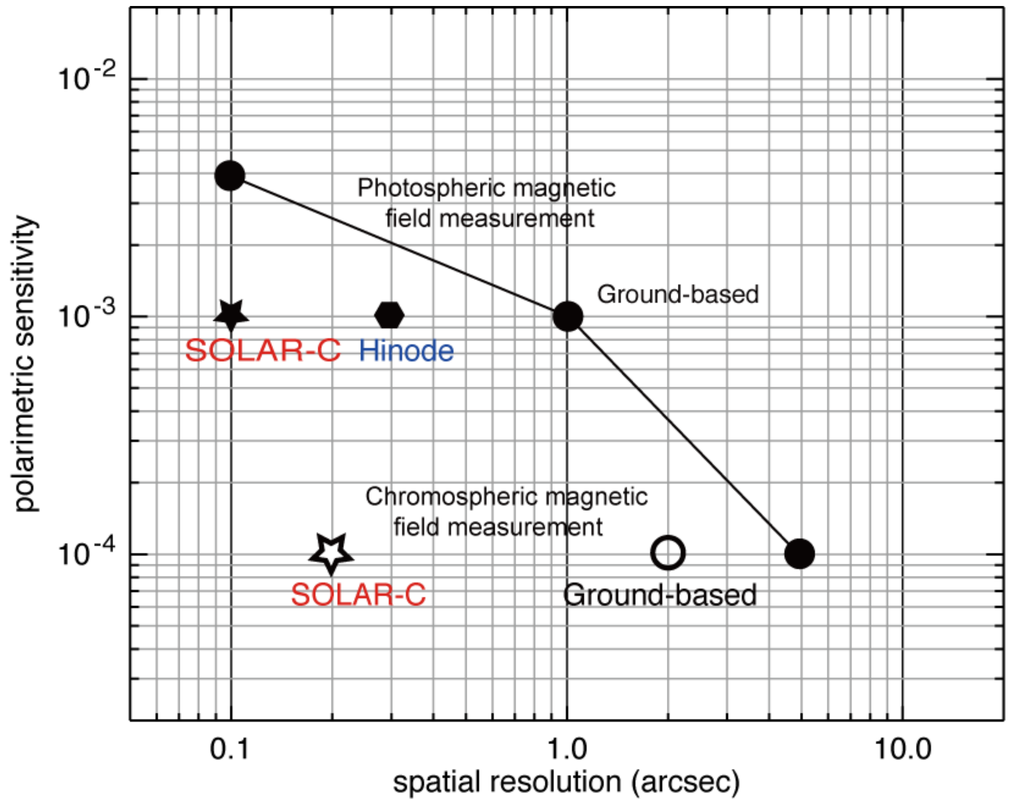




NLFFF extrapolation (Schrijver et al. 2008)

Discovery spaces by the 1.5m telescope

- ***Chromospheric magentic fields diagnostics with Hanle+Zeeman***
  - S/N~10^4 for ~10G detection in chromosphere
    - He I 10830Å & Ca II 8542Å: 0.18"/pix, 10sec integration
  - S/N~10^2 for high-speed spectroscopy
    - Mg II k 2796Å: 0.06"/pix, <0.5sec integration
    - highest spatial and temporal resolution



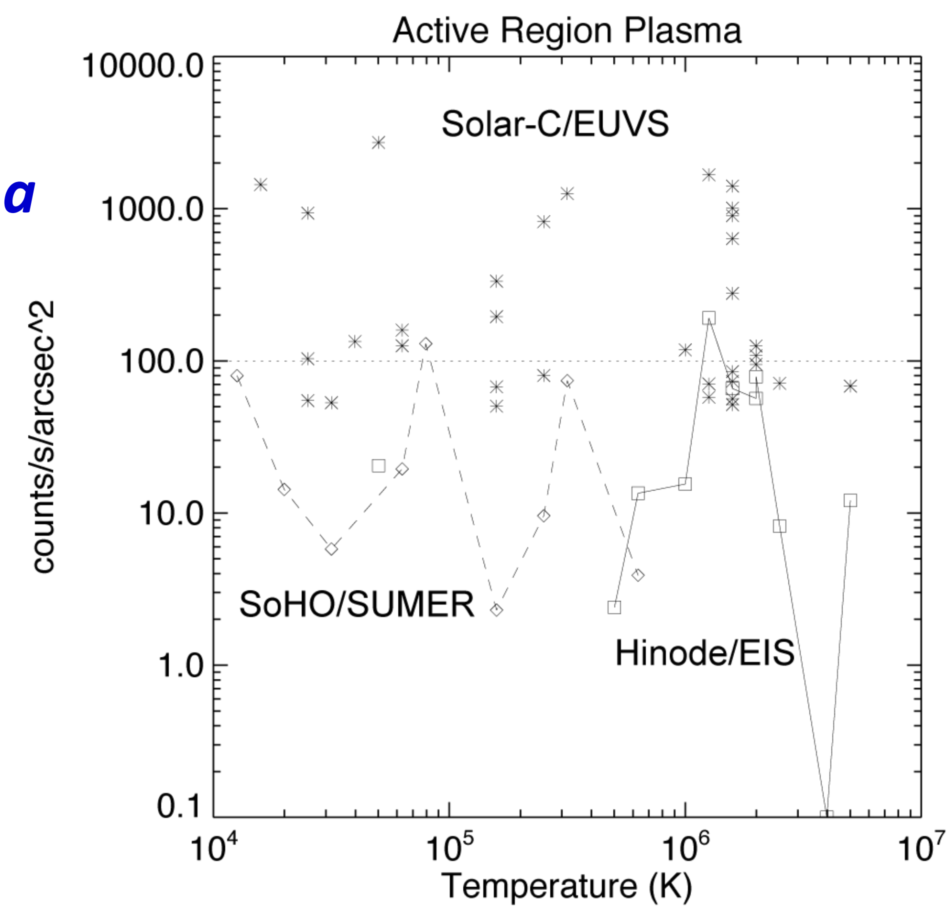
- ***Long-duration continuous observations with super high resolution***
  - How elementary structures are created and evolve? Filament etc.
- ***Low instrument scattering***
  - Off-limb fine structures, spicules and prominences

Discovery spaces by UV/EUV spectrometer

- ***High throughput, high cadence***
  - About one order of magnitude higher throughput
  - Physics of dynamical phenomena
- ***Seamless coverage from ch., TR, to corona and flare plasma***
  - Track the flow of energy from chromosphere into the corona.
  - Simultaneous measurement to match the propagation speed.
  - Combined EIS + SUMER
- ***Spatial resolution 0.5" or better***
  - Spectroscopic trace with spicule width (0.3")

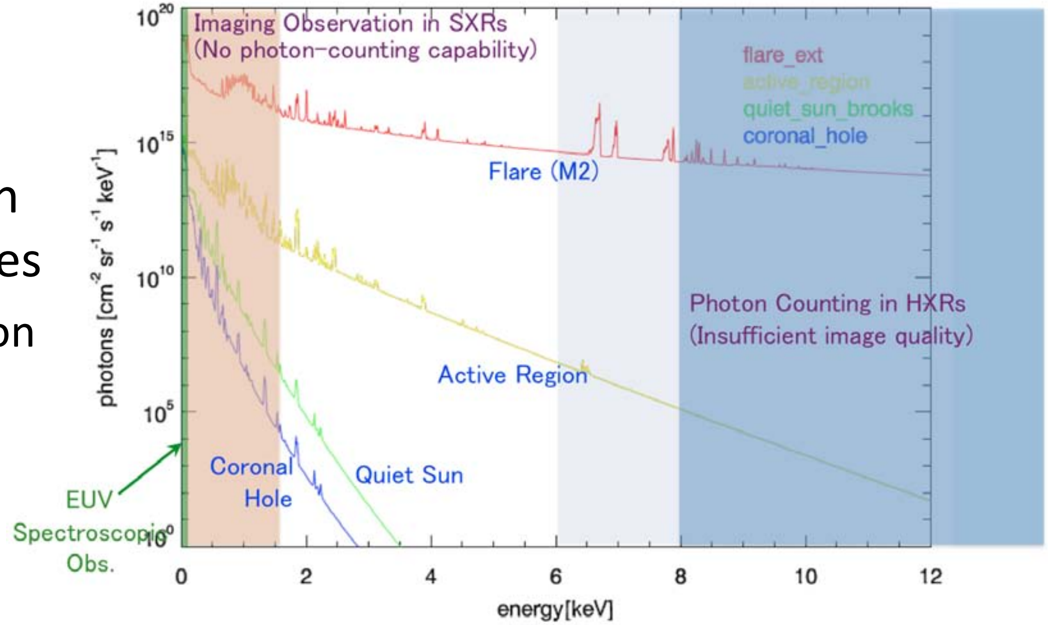
  cf. 2-3" by EIS, SUMER
- ***Low scattering performance to allow to investigate faint regions.***

<u>Intensity of spectral lines observed</u>

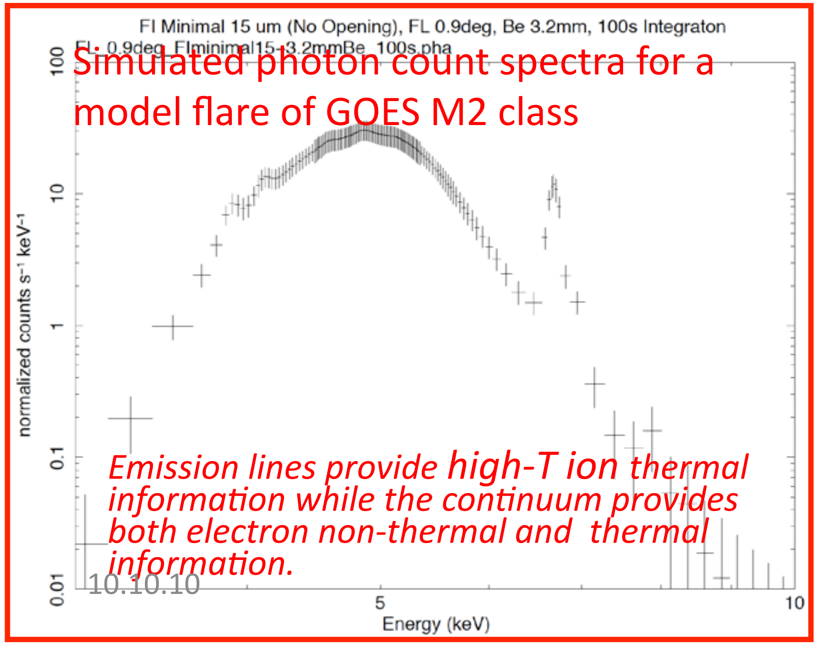


Discovery spaces by photon-counting X-ray telescope

- ***First attempt of imaging spectroscopy in 1-10keV***
  - High-T ion thermal, and electron thermal and non-thermal sources
  - Electron property compared with ion property from EUV spectroscopy
- ***Dynamic range ~ 1000 (previous~10)***



- Faint reconnection region
- 4arcsec, 3sec for M2 flares



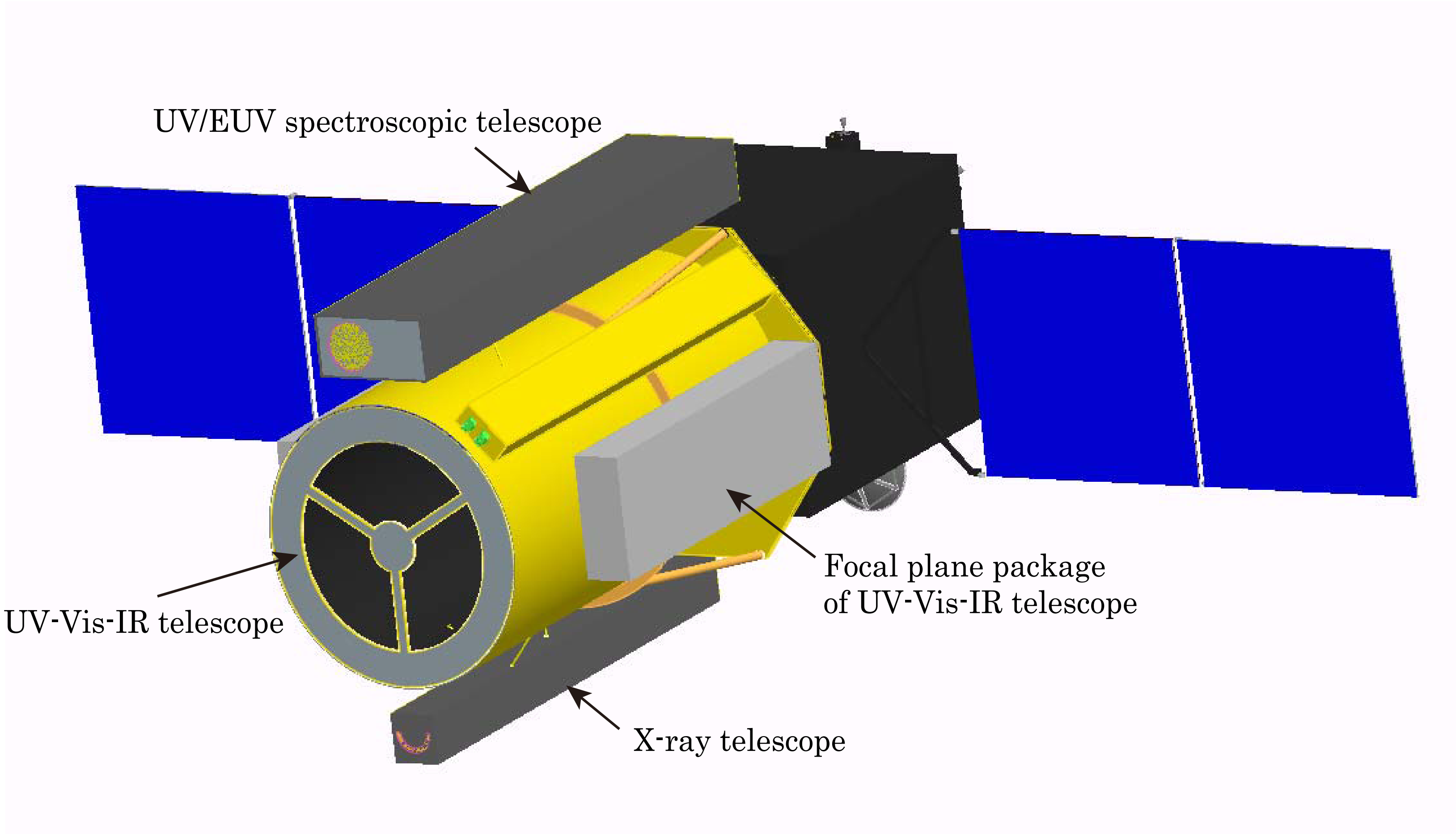
Simulated photon count spectra for a model flare of GOES M2 class

Emission lines provide high-T ion thermal information while the continuum provides both electron non-thermal and thermal information.

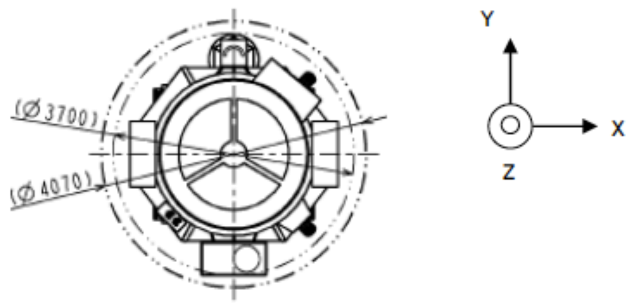
Diagnostics of >5MK plasma and non-thermal plasma, especially at initial phase of flares

- Physics of magnetic reconnection with its possible role in particle acceleration
- Forms of dissipation of the energy that was transferred upwards

Plan-B Spacecraft layout concept



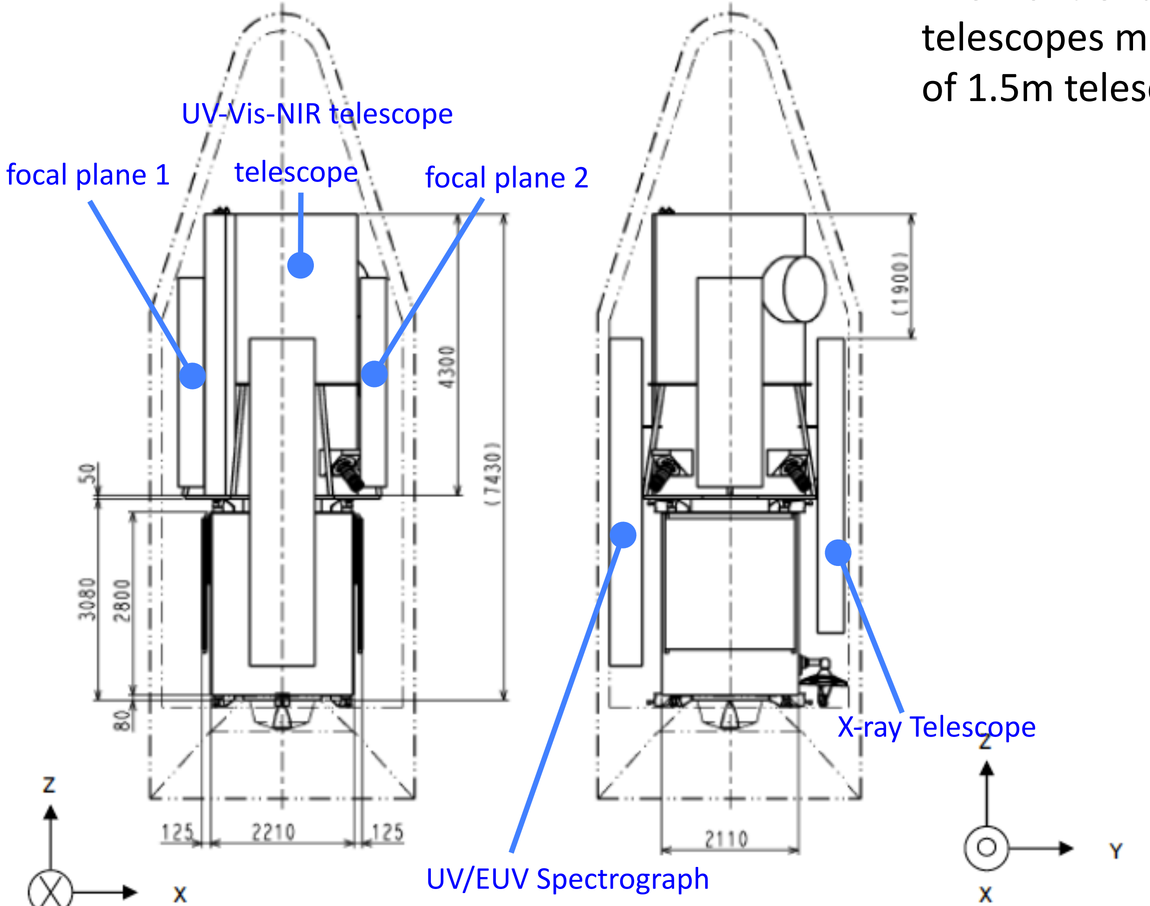
Maximum usage of Hinode technical heritage, such as the spacecraft structural design.
Telescopes are mounted with mounting legs on the spacecraft OBU (Optical bench).



Telescopes' size used in the layout

Instruments		Size (mm)	Weight (kg)
UV-Vis-IR telescope	Telescope	ϕ2300 x 4300	500
	Spectrograph	1000 x 400 x 3200	100
	Imager	1000 x 400 x 3200	100
UV/EUV spectroscopic telescope		1000 x 500 x 5000	150
X-ray telescope (photon counting)		400 x 400 x 4500	150
Total			1000

The front-end position of the X-ray and UV/EUV telescopes may be located below the front position of 1.5m telescope, if 4S type fairing is used.



H-IIA 4S fairing envelopes

An initial rough estimate (2.3 ton, without propellant mass 2.3 ton) significantly over ~1.8 ton, which H-IIA202 rocket can carry into geo-synchronous transfer orbit. Note that H-IIA204 can carry ~6 ton into the same orbit, although much more expensive. Need further evaluation on both spacecraft and telescope portions.

Plan B Telemetry and Orbit (1)

- High rate science telemetry is required to acquire spectroscopic/polarimetric data with high cadence and resolution. The current design target is the average data output of about 10Mbps from the onboard telescopes.
  - Data volume: 700 Gbits in a day with 8Mbps average output
    c.f., Hinode ~36Gbits

Data rate estimate

Instruments		data rate (Mbps)		
		no comp.	lossless comp.	lossy comp.
Solar UV-Vis-IR telescope	standard	14.4	6.1	2.5
	burst	320	128	48
UV/EUV spectroscopic telescope	standard	7.0	3.0	1.5
	burst	140	60	30
X-ray telescope (photon counting)	standard	6.9	3.5	
	burst	110	55	
Total	**standard**	28.3	12.6	**7.5**
	burst	570	243	**143**

- Data compression is assumed at the telescope side. Data line accommodating the burst data rate is needed. Onboard recorder is needed, because of no 24 hrs continuous link.

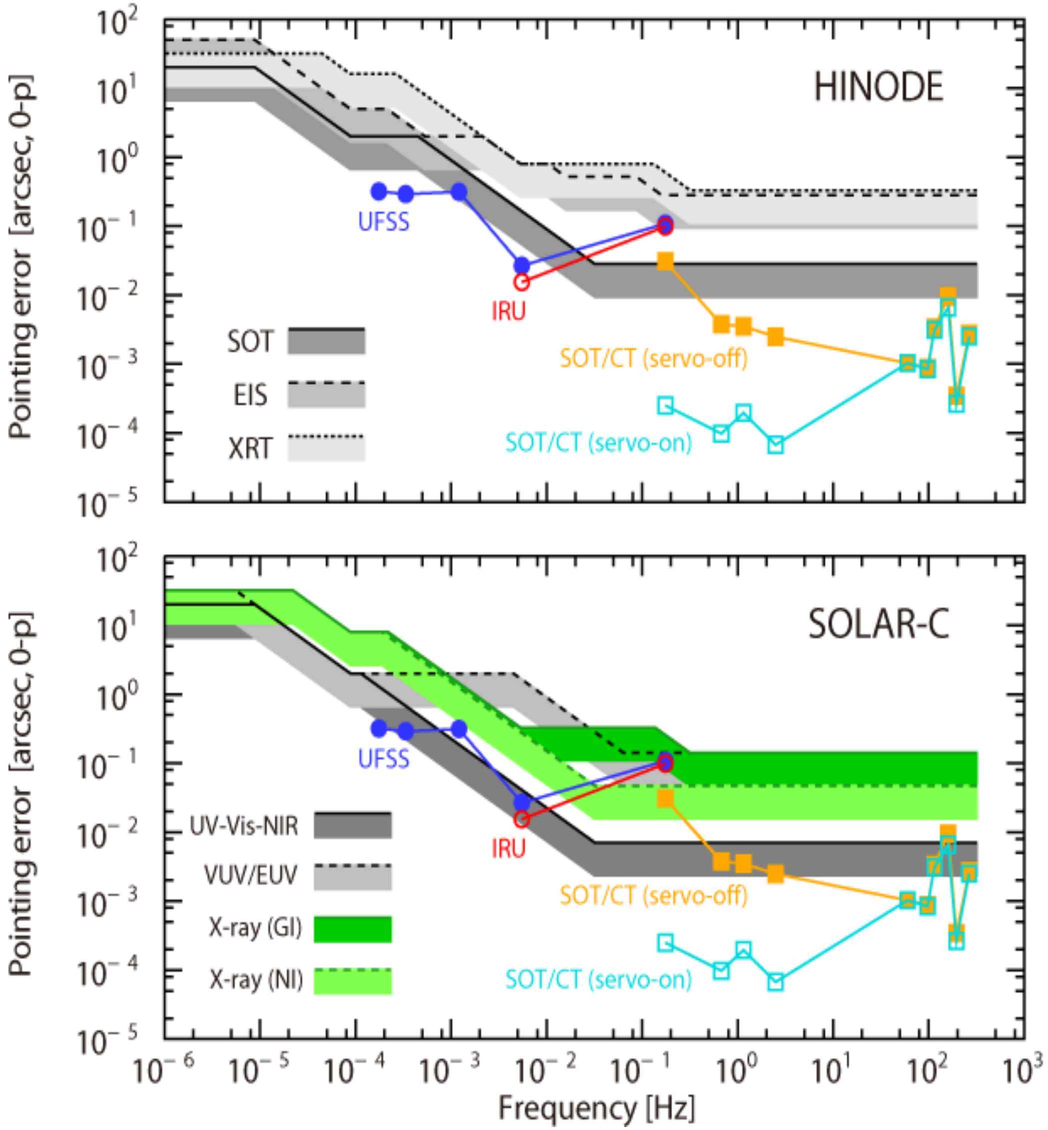
Plan B Telemetry and Orbit (2)

- A conceptual study suggests an inclined geosynchronous orbit, similar to NASA SDO orbit, for the Plan B orbit.
- An X-band system (16Mbps, 16-QAM, occupied bandwidth<10Mhz) meets the requirement with the continuous link for >12 hours in each day.
  - USC 34m is the primary antenna. < 8 hrs per day, considering other S/C operations.
  - Need to explore additional downlinks on NASA and ESA stations.
- Another candidate is to use higher telemetry rate system available in Ka band. Note no heritage in Japanese science satellites to use Ka band for this kind of science data downlinks.

Plan B Science Operations

- The operation scheme used in Hinode is the starting point for designing operations.
- But since we have a long communication period each day, in addition to the standard operation scheme like Hinode, we can have a special effort, i.e., monitor data → revise plan (especially, select target exactly) → uplink/restart observation, in the communication period, if observers want in advance.
- This would be a strong function for researches of emergence and dynamics with the narrow FOV spectrometer.

Plan B Pointing Stability



- We evaluated Hinode and SOT stability performance carefully and identified the three areas to be improved.
  - Orbital variation (10^{-3}-10^{-5}Hz)
  - Degradation of the pointing stability seen around 0.1Hz
  - High-frequency micro-vibration (>100Hz)
- We have been studying how to improve the performance in these frequencies.

Plan B Pointing Stability: requirements

Instruments		Time scale	Requirements (θx/θy)	Unit
Solar UV-Vis-IR telescope (*)		1 sec	0.015	arcsec 3σ
		10 sec	0.015	arcsec 3σ
		1 hour	2	arcsec 0-p
		Mission life	20	arcsec 0-p
UV/EUV spectroscopic telescope		0.5 sec	0.3	arcsec 3σ
		5 sec	0.3	arcsec 3σ
		1 hour	2	arcsec 0-p
		Mission life	32	arcsec 0-p
X-ray telescope	Normal incidence (*)	1 sec	0.1	arcsec 3σ
		10 sec	0.1	arcsec 3σ
	Grazing incidence	1 sec	0.3	arcsec 3σ
		1 min	0.7	arcsec 3σ
		1 hour	8	arcsec 0-p
		Mission life	32	arcsec 0-p

Instruments		Time scale	Requirements (θz)	Unit
Solar UV-Vis-IR Telescope		1 hour	50	arcsec 0-p
UV/EUV spectroscopic telescope		1 hour	100	arcsec 0-p
X-ray telescope	Normal incidence	1 hour	50	arcsec 0-p
	Grazing incidence	1 hour	100	arcsec 0-p

(*) The pointing stabilities are to be achieved with the usage of an image stabilization system inside the telescopes.

Summary

- The Plan B mission concept was briefly described.
- **With powerful combination of ① high resolution and ② spectro-polarimetric capabilities for ③ seamless observation of the entire solar atmosphere, the mission will**
  - **identify the dynamical nature of magnetic elementary structures and**
  - **understand the energy transfer and dissipation in the solar plasma**

  , which are keys for understanding corona/chromospheric heating, wind acceleration, and flares.
- The telescopes can provide significant discovery spaces.
- The latest spacecraft design concept is also described.