The SOLAR-C mission: study status update

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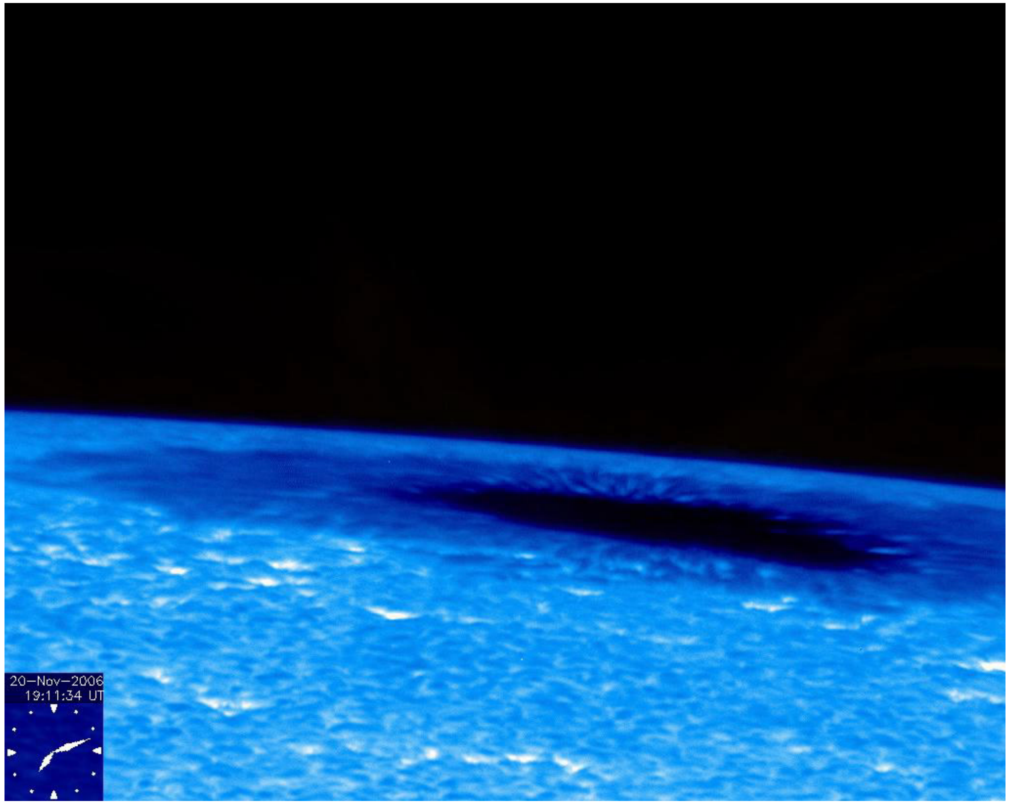
New solar physics opened with Hinode

324 referred papers (as of 28 June 2010)

More dynamic chromosphere!

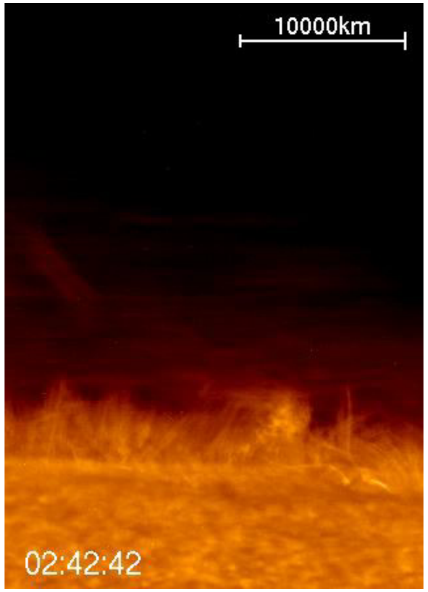


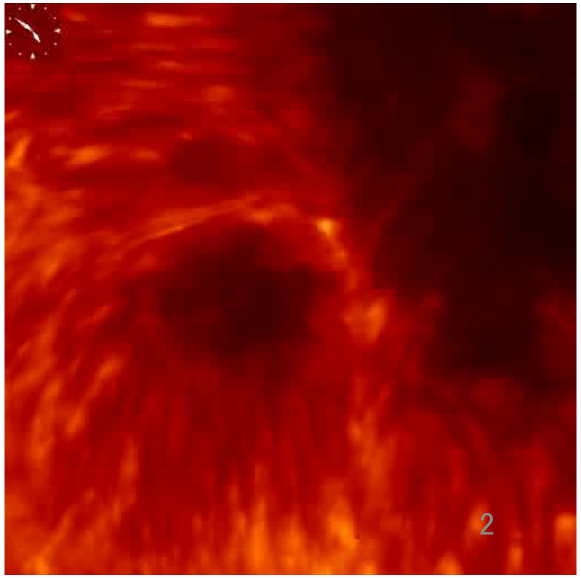
Ginant jet (Nishizuka+08, Liu+09)

Spicules (DePontieu+07)

Anemone jets (Shibata+07)

Penumbral micro-jets (Katsukawa+07)





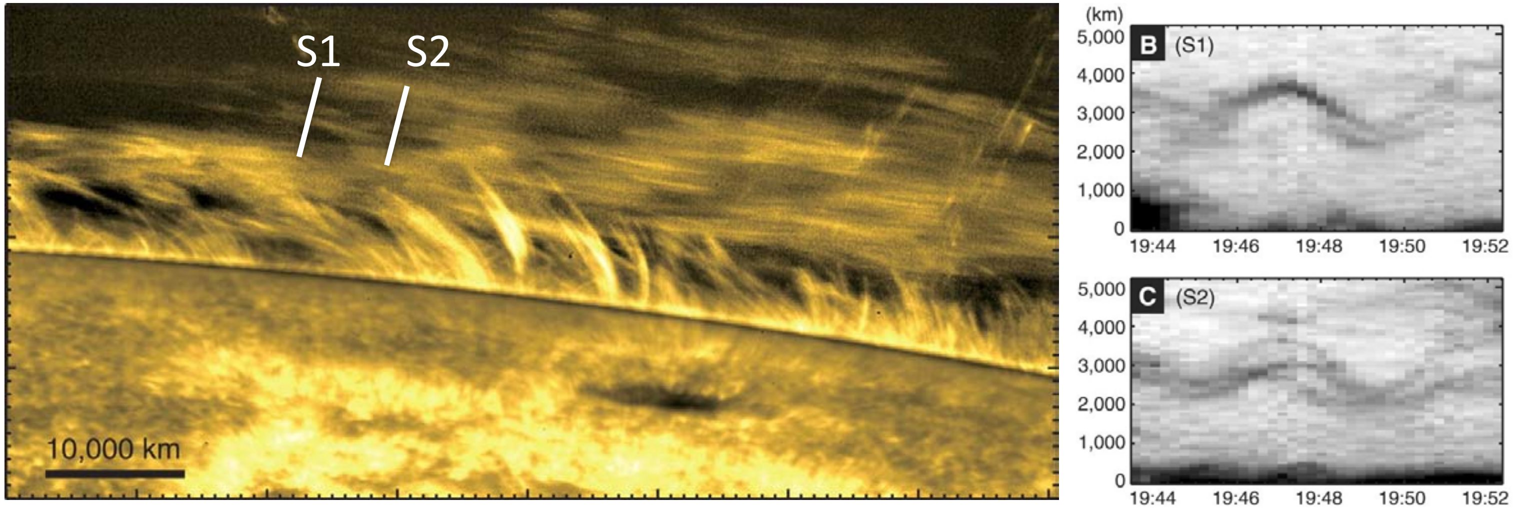
A variety of jets

- 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

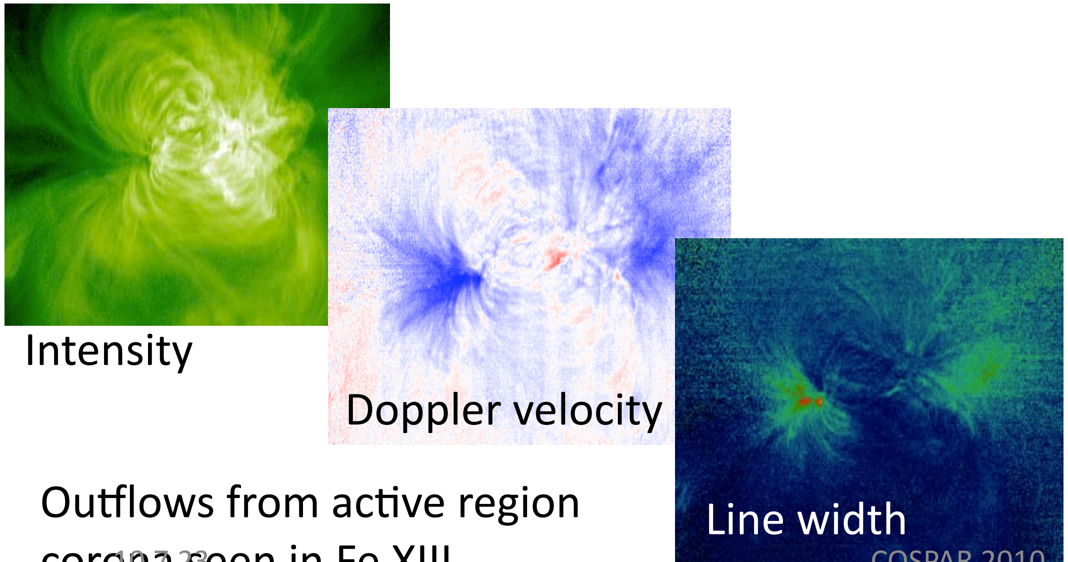
Waves!: signatures of energy transport and release



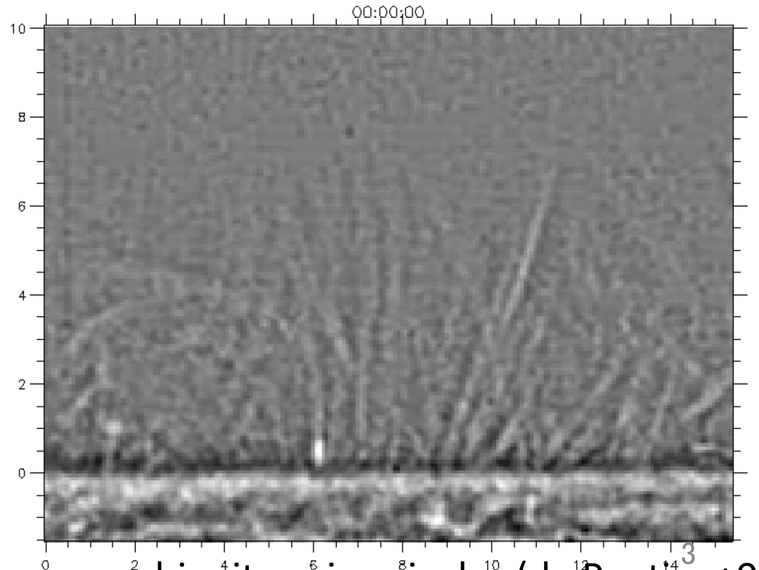
Transverse oscillations of prominence threads that trace the B field (Okamoto+07)

Alfven waves

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



Outflows from active region corona seen in Fe XIII



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

New mission after Hinode: **Two *SOLAR-C* mission concepts**

- ***Plan A***: *Magnetic field, helioseismic and X-ray observations* from an out-of-ecliptic orbit to explore the polar region, internal structure and **solar activity cycle origin** (dynamo).

  <<Toward understanding the solar magnetic activity cycle>>

- ***Plan B*** *:* High spatial resolution, *high throughput, high cadence* spectroscopic and polarimetric observations *seamlessly from photosphere to corona* to investigate magnetism of the Sun and its role in heating and dynamism of solar atmosphere.

  <<Toward understanding the magnetic field dissipation processes and energy transfer in the atmosphere>>

Latest study status (1)

- The Solar-C WG was organized in JAXA in December 2008.
- "***International SOLAR-C Science Definition Meeting***" was held twice at ISAS/JAXA with participation of many scientists from European countries and US.
  - 18-21 November, 2008
  - 9-12 March, 2010

- Since March 2009, 4 sub WGs have been working to polish up sciences and payload concepts.

4 Sub WGs for studying specific topics

- **Helioseismology and the Solar Dynamo**
  - T. Sekii (chair), T. Appourchaux (co-chair), H. Hara, T. Yokoyama, L. Gizon, M. Rempel, M. Miesch, S. Kosovichev, J. Zhao
  - Establish science cases for the Plan A mission in terms of helioseismology

- **Chromospheric/Corona Field Measurements**
  - Y. Katsukawa (chair), B. Lites (co-chair), T. Okamoto, D. Orozco-Suarez, S. Nagata, R. Casini, H. Uitenbroek, H. Lin, T. Wiegelmann, J. Trujillo-Bueno, H. Socas-Navarro, M. Carlsson
  - Establish science caeses for the Plan B mission especially in terms of chromospheric and coronal magnetometry and extrapolation

- **UV/EUV High-throughput Spectrometry**
  - T. Shimizu (chair), G. Doschek (co-chair), H. Hara, T. Watanabe, S. Imada, H. Isobe, L. Harra, L. Teriace, U. Schuehle, C. Korendyke, J. Davila, T. Tarbell
  - Establish science cases for the UV/EUV range with high-throughput, high-cadence, high-resolution spectroscopy.

- **Next Generation X-ray Telescope**
  - T. Sakao (chair), E. DeLuca (co-chair), N.Narukage, K.Watanabe, M.Shimojo, K.Ishibashi, L.Golub, K.Reeves, K.Korreck, J.Cirtain, J.Lemen, D.McKenzie
  - Establish science cases and investigate technical feasibility for X-ray imaging observations with photon-counting spectroscopy

Latest study status (2)

- The Solar-C mission proposal will be submitted to ISAS/JAXA, when the AO of the next JAXA mission comes out in 2011.
- The draft of the mission proposal will be prepared for both Plan A and Plan B by October 2010.

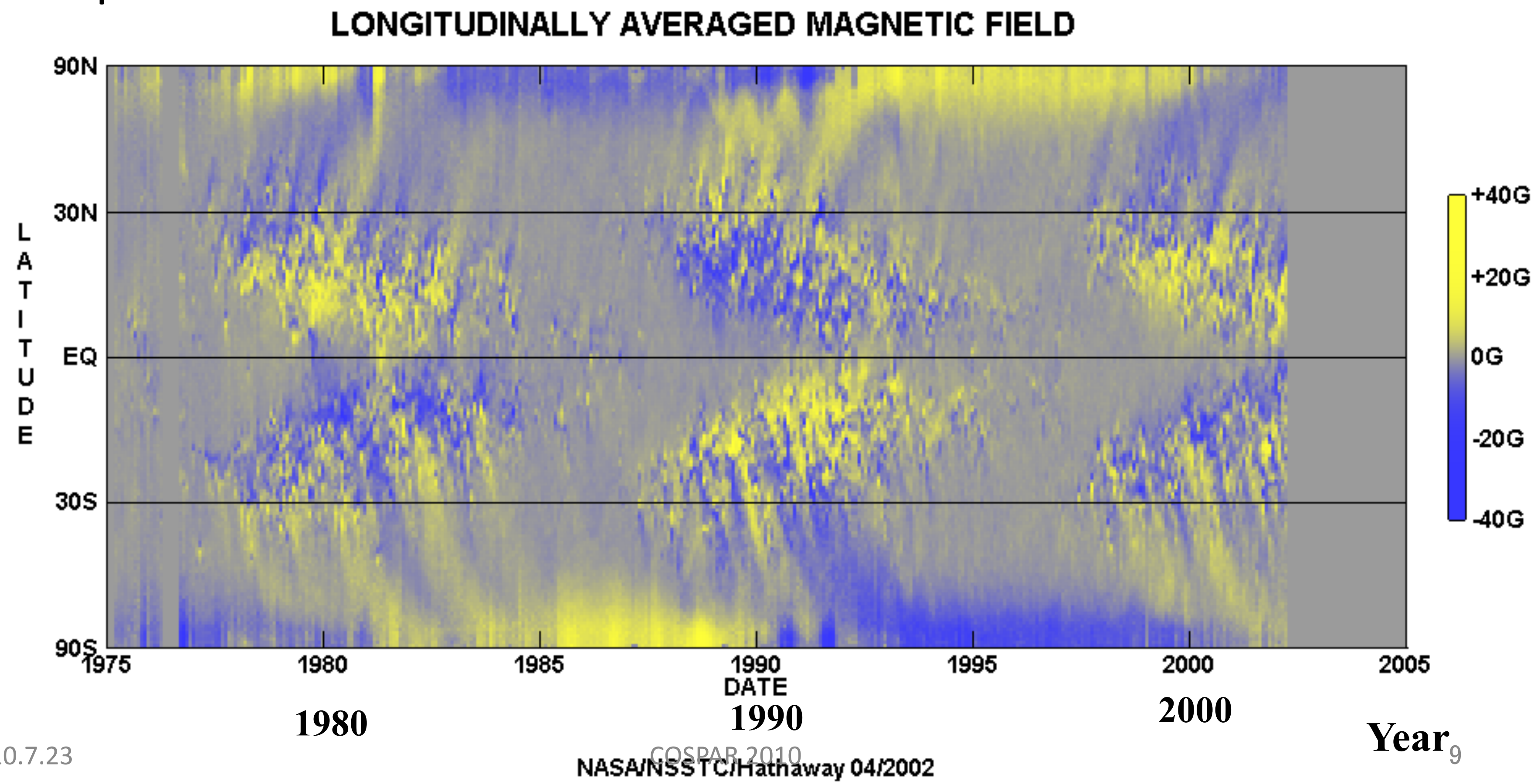
- For building international collaboration
  – Dialogs with NASA and ESA
  – A JAXA-NASA Joint WG will be formed soon to evaluate science goals of Solar-C. The outputs from the JWG will be used for evaluation and inclusion in the NASA Heliophysics Decadal Survey.

This presentation

- Briefly describes two mission concepts.
  – No intent to compare the two concepts.
- Focus on magnetic reconnection studies expected with the Plan B mission.

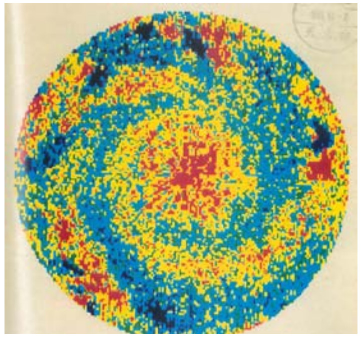
Plan-A: Solar Magnetic Activity Cycle

- **How are magnetic fields created in the sun?** (Dynamo)
- Internal flows, behavior of polar magnetic fields, and polarity reversal at poles from out-of-ecliptic observations may be important.



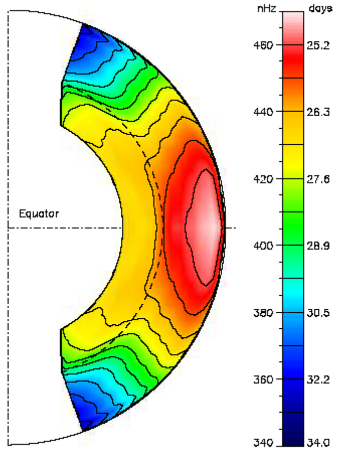
Plan-A:

Exploration from out-of-ecliptic orbit



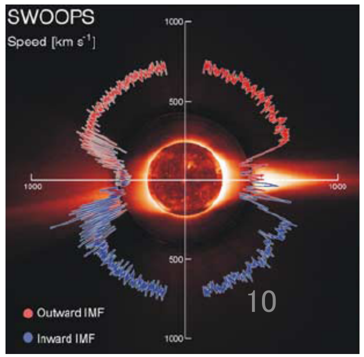
＜Toward understanding the solar dynamo＞

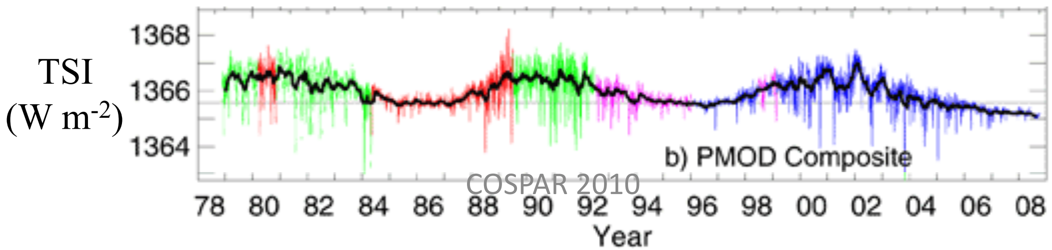
- Surface/internal flow fields in polar regions
- Search for strong magnetic fields in the tachocline at the base of the convection zone
- Surface magnetic activity in polar regions



＜Exploration from Vantage Point＞

- Identify the solar wind origins in polar coronal holes
- Total irradiance measurements from out-of-ecliptic orbit; The Sun as a star
- Imaging of CMEs and solar wind/CIR shock structures





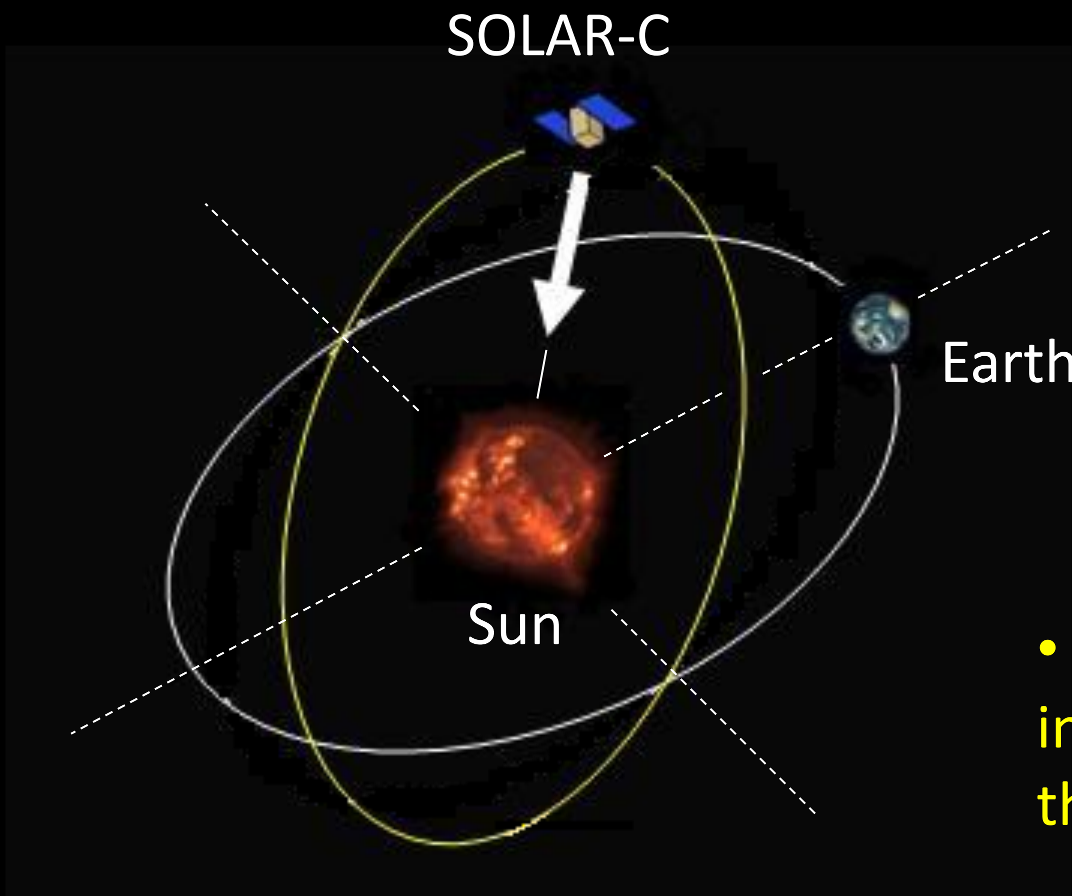
Plan-A : Model Payloads

Total mass **130 kg** (tentative allocation for design activity)
Data recording rate: **> 100 kbps on average**

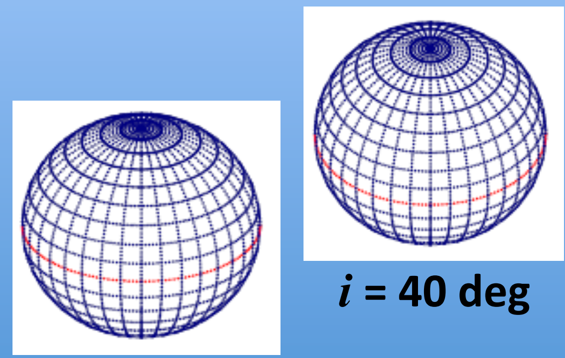
Each has a space heritage/a slightly modified version in the missions that have been already flown.

- **Visible-light Magnetic-field and Doppler imager**
  - full-disk observations
  - Internal flow structures, mag. fields, convection, .. in polar regions
- X-ray/EUV telescope
  - Coronal dynamics in polar regions, synergy with coronal imagers, observing the sun around the earth, in stereo-scopic views
- EUV imaging spectrometer
  - Flow/wave structures in polar regions (plume, solar wind)
- Total irradiance monitor
  - Latitudinal distribution of surface irradiance
- Others (Options at present)
  - Heliospheric imager: CME imaging, solar wind/CIR shock structures
  - Zodiacal-light photometer: distribution of interplanetary dust
  - In-situ instruments (magnetometer, dust counter, …., etc.)

Plan-A: Target Final Orbit



Polar view from the out-of-ecliptic orbit



i = 30 deg

i = 40 deg

- The final orbit's inclination is ~40 deg from the equatorial plane

- The final orbit is at ~1 AU, orbital period of 1 yr, synchronized with Earth
- Cruise period ~5 years

Orbit and Spacecraft design is the most critical area

Two candidates to install the spacecraft into the final orbit

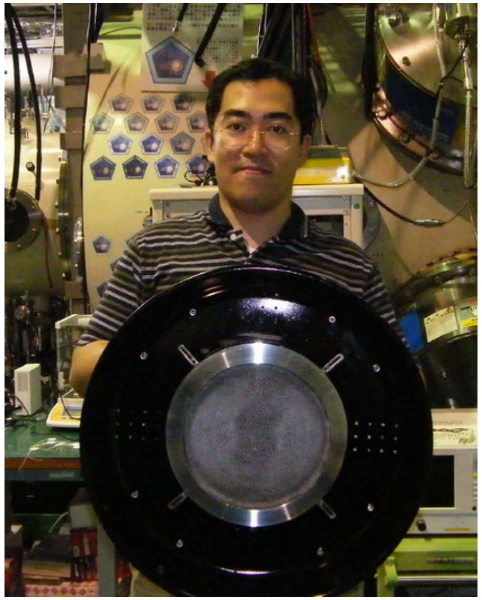
- *Near-earth orbit with increasing the inclination by Ion engine and earth swing-by*
- Ballistic orbit with Jupiter swing-by and earth swing-by

Heritage:

Ion Engine

Ion Engine μ10

HAYABUSA



Bigger ion engine μ20 under development

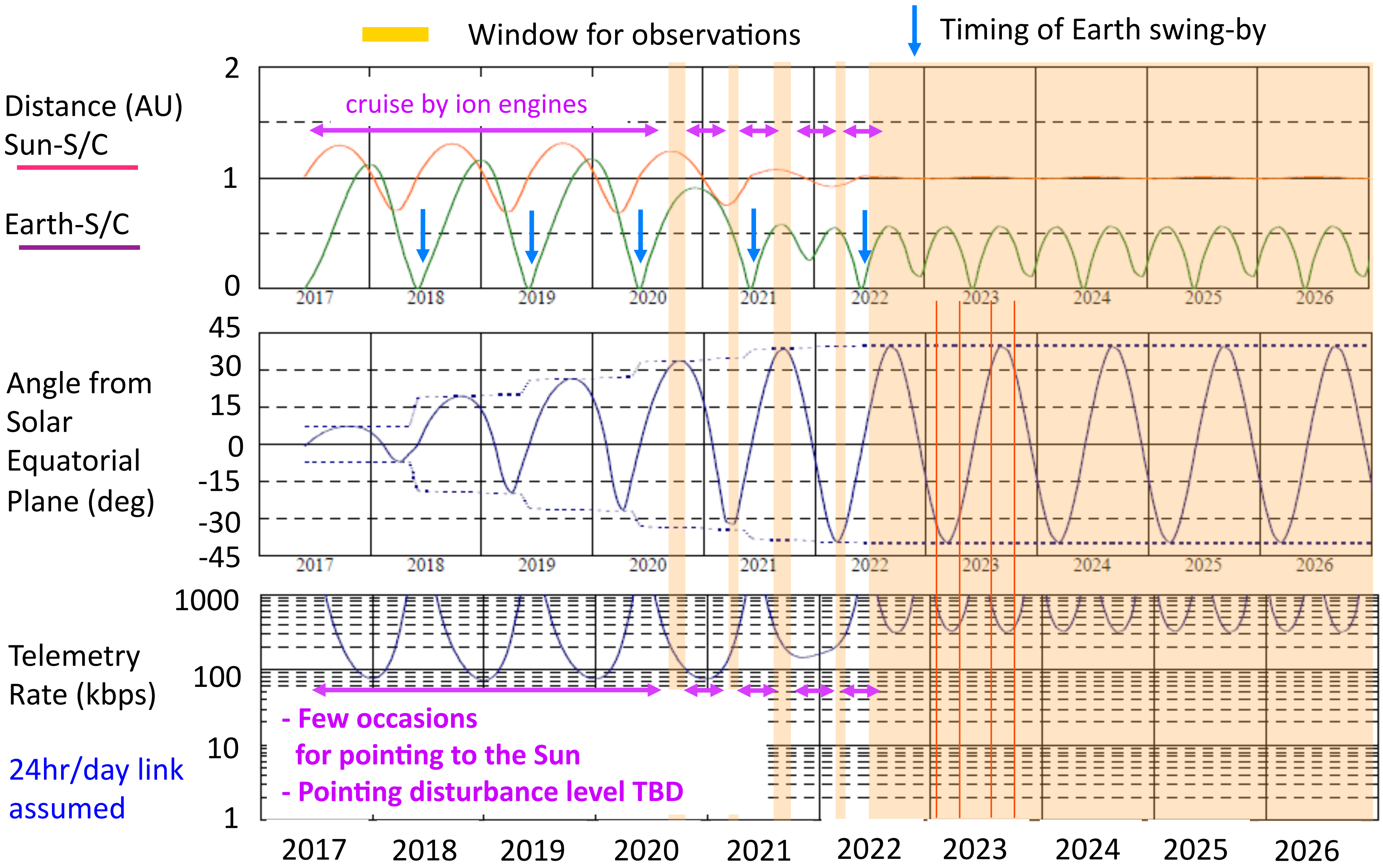
Asteroid 'Itokawa'

Plan A is a good plan in terms of scientific and orbital considerations.

Issues:

- Assessment on the reliability of the bigger ion engines
- Relationship to the Solar Orbiter and Solar Probe Plus; Need a real story for synergy
- Domestic continuation of science

Ion engine + Earth swing-by



Priority in this case: reach max inclination as soon as possible

Plan-B: Spectroscopic & Polarimetric Observations

- *Mission*
  - *Quantitatively investigate fundamental physical processes in variety of solar plasma; roles of magnetic reconnection and MHD waves*
  - *How are fundamental processes linked to large-scale structures, dynamics, and heating?*

- New observational tools with ***SOLAR-C***
  - ***From imaging to spectroscopy: Significantly enhance spectroscopic & polarimetric capabilities to UV and near-IR***
  - ***High time resolution, high throughput spectrometer***
  - ***Seamless observations from photosphere to corona***

These powerful diagnostic capabilities can give new scientific gains or discovery space.

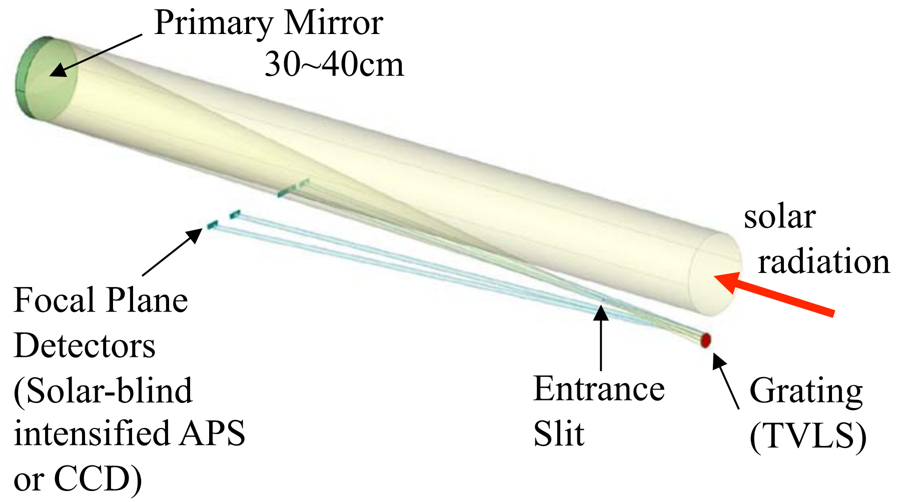
Plan B: model payloads (1)

- ***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.

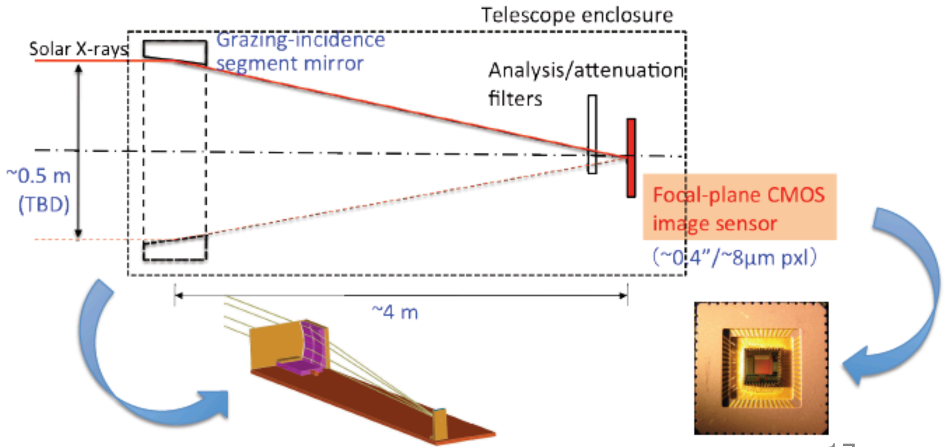
Plan B: model payloads (2)

- ***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.
- ***X-ray imaging (spectroscopic) telescope***
  - Imaging emissions from >1MK coronal plasma
  - Option 1) Photon counting, i.e., spectroscopic capability for grazing incidence telescope with 0.5 arcsec
  - Option 2) Ultra-high spatial resolution (0.1arcsec) for normal incidence telescope

Strawman spectrometer



Photon-counting X-ray telescope



Plan B: science goals and issues

1. Energy and mass flows through the chromosphere from the photosphere into the corona.
2. Magnetic dissipation in astrophysical plasmas; magnetic reconnection and particle acceleration
3. Origins and roles of MHD waves
4. Elementary structures of the magnetic atmosphere; how they are created and evolved.
5. How small-scale physical processes initiate large scale dynamic phenomena creating space weather

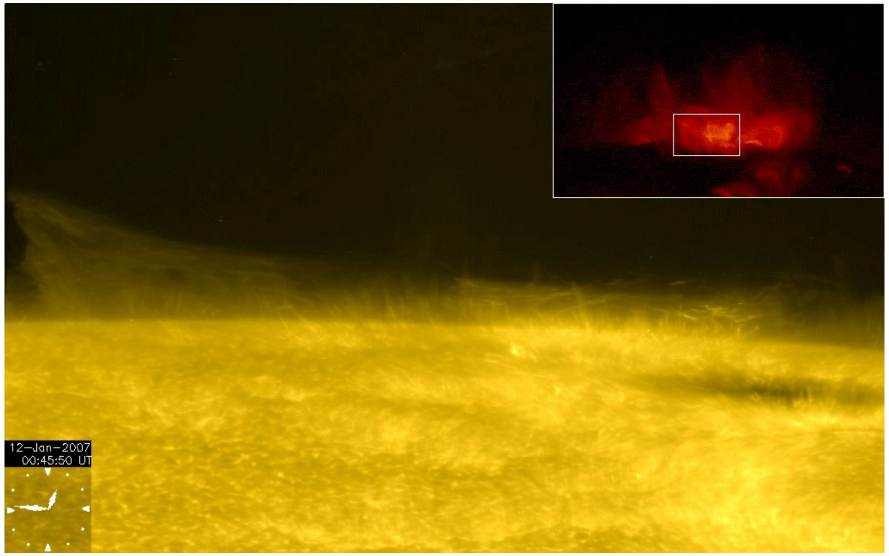
Plan B is a unique mission aiming MHD-scale physics in solar plasma

Issues:

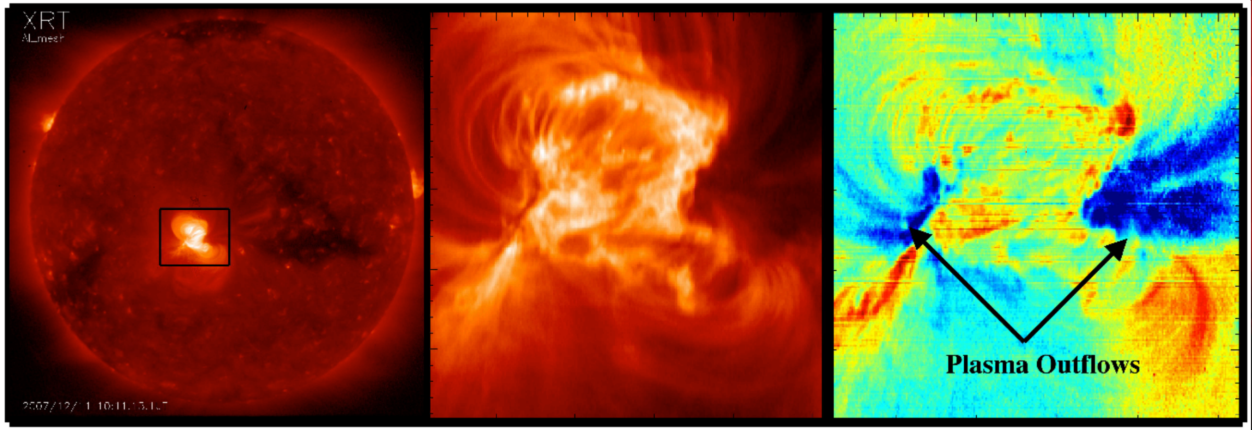
- Appealing science goals ?
- Telescopes too expensive?

Magnetic Reconnection as a key process in solar dynamical nature

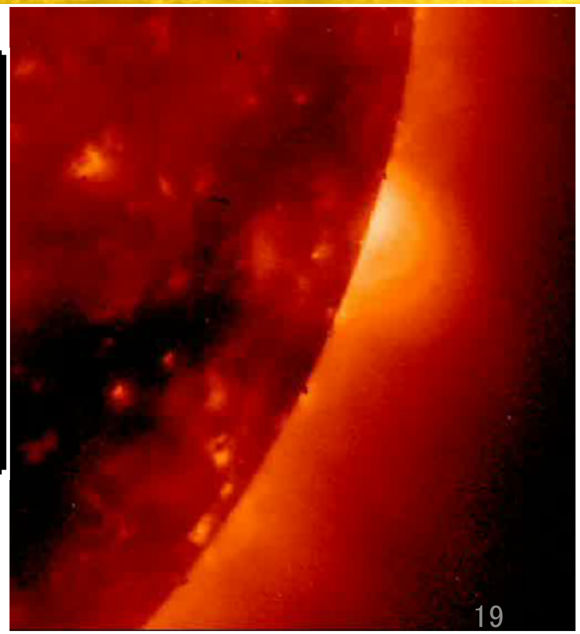
Dynamics in CaIIH and X-ray



- The solar atmosphere is full of dynamical nature.
- Quantitative observations to understand elementary structures of the magnetic atmosphere; how are they created and evolve?
- How small-scale physical processes initiate large scale dynamic phenomena creating space weather.

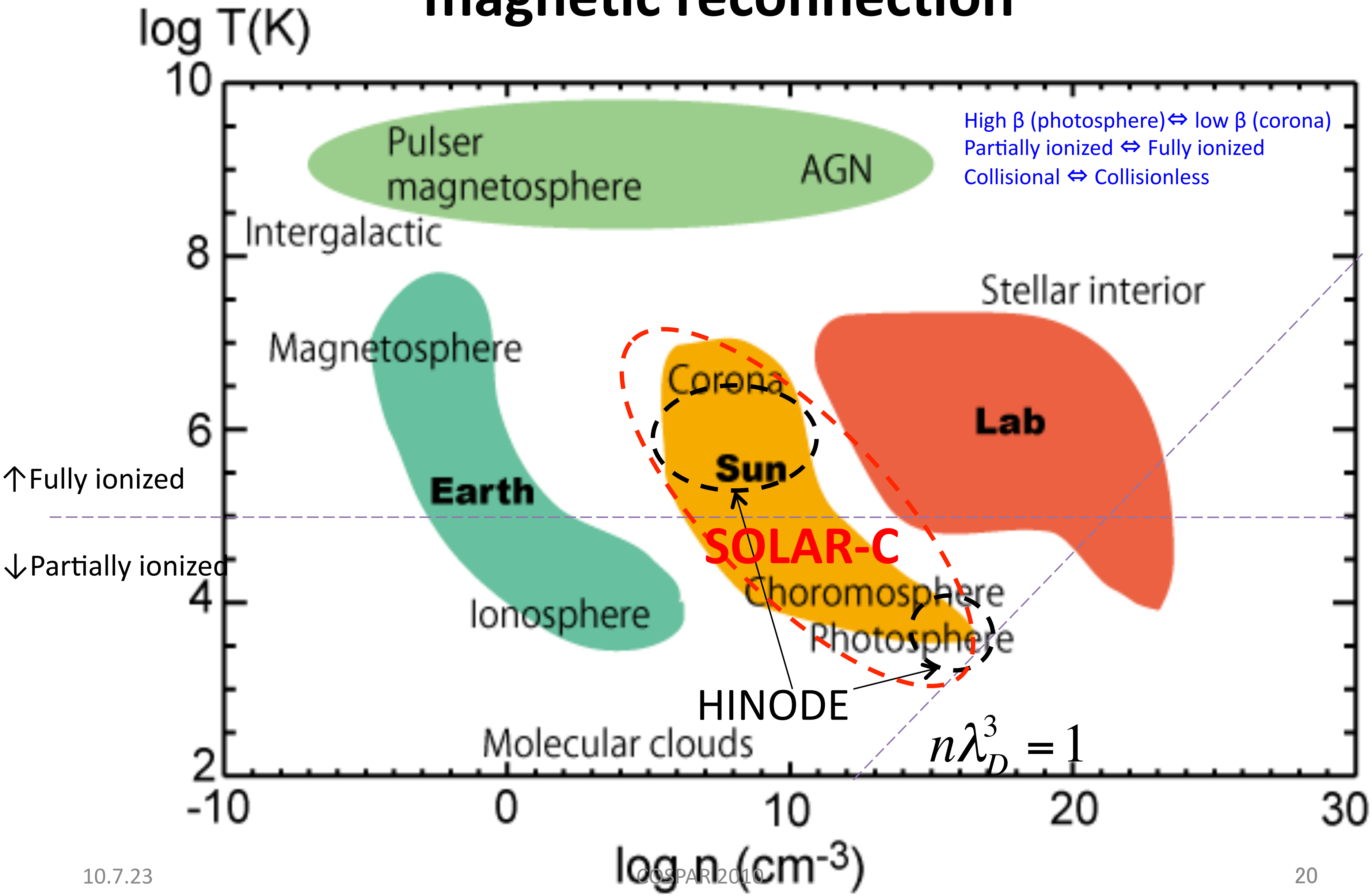


Outflows are found at active region edge as a possible source of slow solar wind (Sakao et al. 2007). Outflows identified in a HINODE EUV spectroscopic observation (e.g., Baker et al. 2009). A driving mechanism is still an open question. Reconnection??



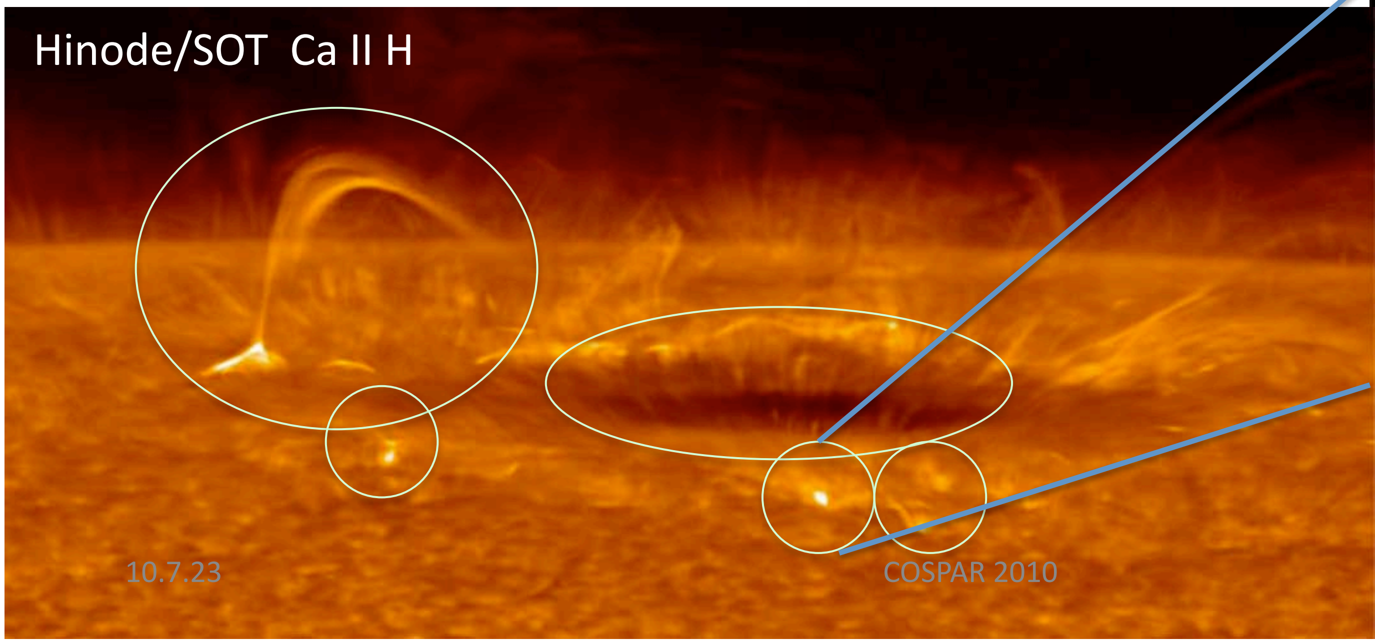
X-ray: 2008 April 9 "Cartwheel CME" Flare

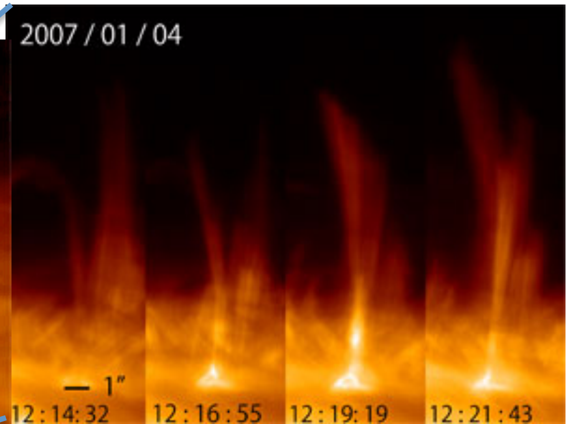
Solar atmosphere as a plasma laboratory for magnetic reconnection



Magnetic reconnection in weakly ionized plasma (chromosphere)

- Is magnetic reconnection in chromosphere really 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+2010).
  - Relate the reconnection locations with the plasma condition where ambipolar diffusion can effectively work.
- How much energy can be converted in weakly ionized plasma?

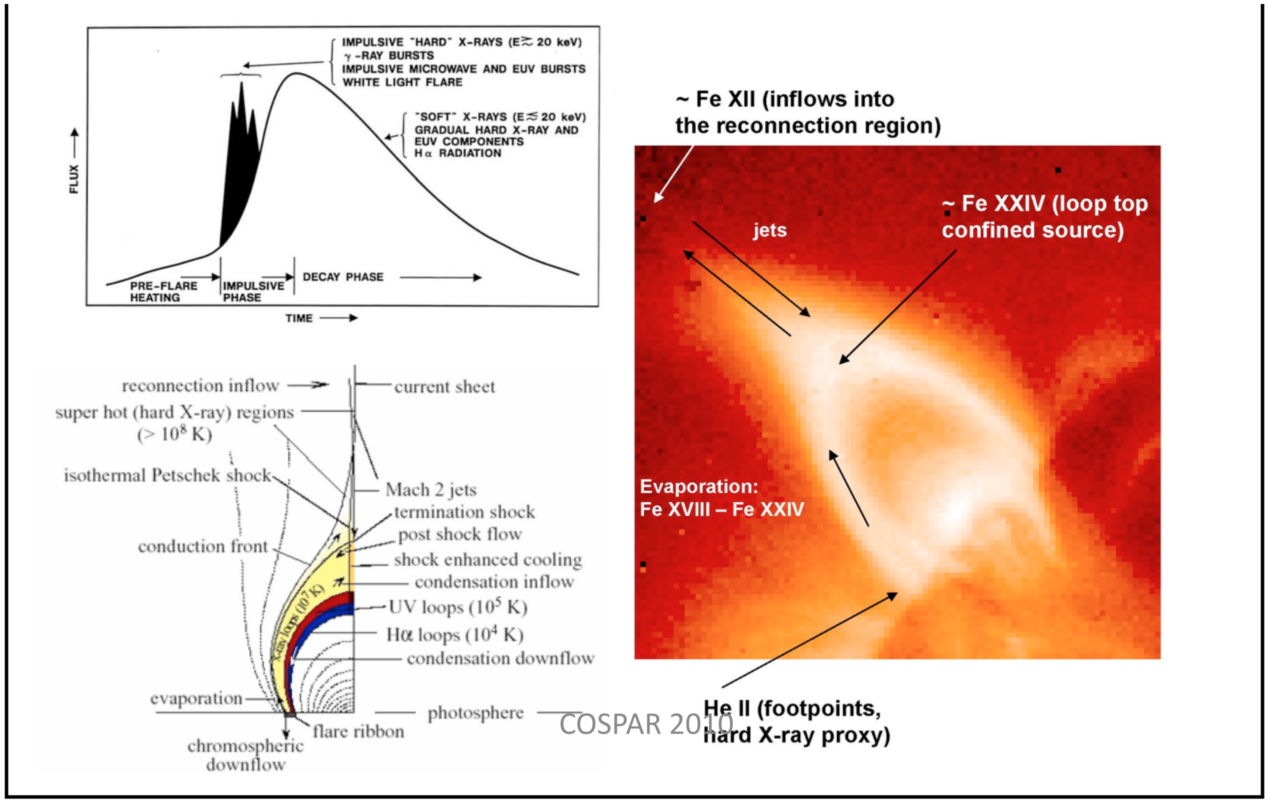




We know that rapid liberation of magnetic energy happens even in the collisional and partial ionized plasma. Measurements of physical parameters around a reconnection site may provide us a breakthrough.

Magnetic reconnection in collisionless plasma (corona & TR)

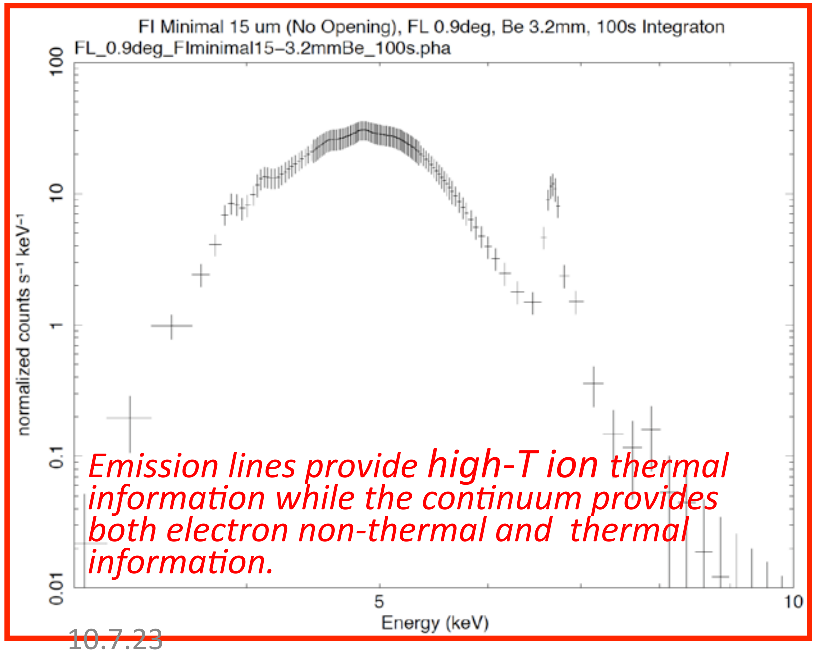
- Poor knowledge on plasma conditions in reconnection region because of its faintness.
- What controls the energy population, i.e, the ratio of conversion from magnetic energy to kinetic, thermal, non-thermal energy, or wave/ turbulence?
- Why non-thermal energy, i.e., particle acceleration, is different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

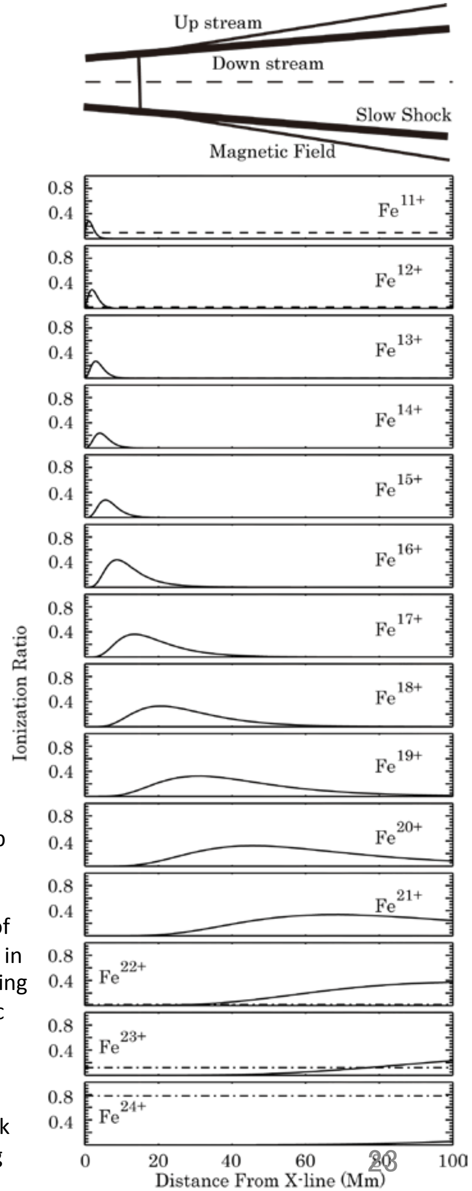


Magnetic reconnection in collisionless plasma (corona & TR)

- Non-ionization equillibrium and non-thermal equillibrium
  - EUV line spectroscopy with different ionization states can diagnose conditions of the plasma just after rapid heating in reconnection region.
- Spatial distribution of thermal and non-thermal sources
  - Photon-counting grazing-incidence X-ray telescope (NGXT)

Simulated Flare spectrum with baseline NGXT



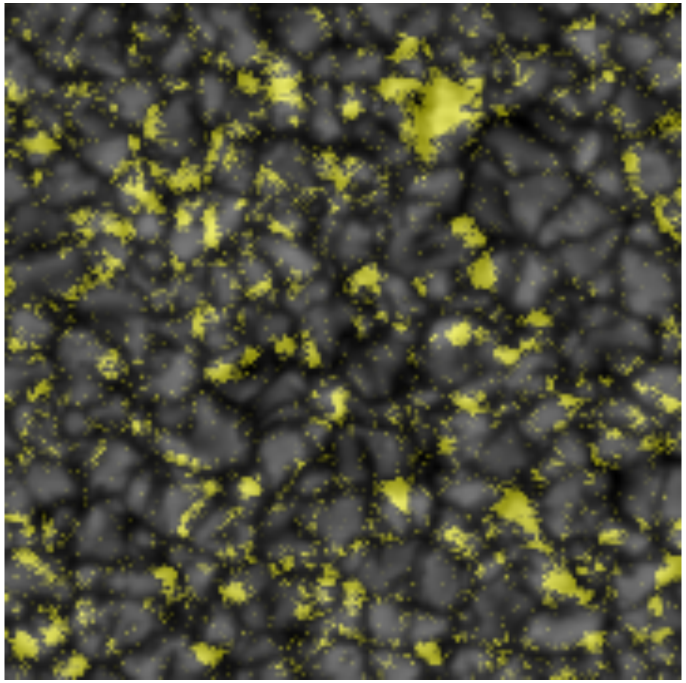


A calculation of non-ionization equilibrium at the down stream of magnetic reconnection region. The top panel shows the schematic picture of the reconnection region. The ionization rate in the center of the reconnection region as a function of distance from an X-type neutral line (dashed line in the top) is plotted from Fe^{+11} to Fe^{+24}. The following parameters are used in this calculation: magnetic field 12 gauss, electon density $4.2 \times 10^{8} cm^{-3}$, temperature 1MK, and plasma β 0.01 at the upstream side of the slow-mode shock and temperature 40MK at the downstream; the shock angle at the upstream and downstream is 85 deg and 2.3 deg, respectively. (Imada et al. 2009)

Roles of hidden magnetism and reconnection generated waves

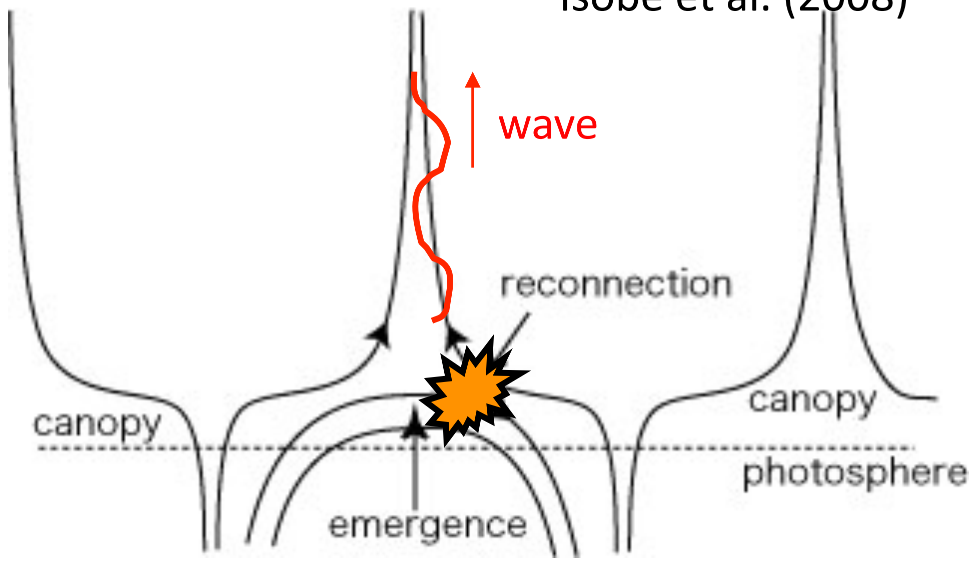
- Ubiquitous small-scale horizontal fields and their temporal dynamical evolution found by SOT (Lites et. al. 2007, Ishikawa et al. 2008)
- Understand the nature of *hidden magnetism and its roles in generation of waves.*
- The heating and dynamics of the upper atmosphere and the solar wind acceleration.

Yellow: distribution of horizontal fields



Ishikawa et al. (2008)

Isobe et al. (2008)



Summary

- Two mission concepts have been studied for SOLAR-C.
- Both two mission concepts challenge to important scientific questions of the Sun.
  - Plan A – the solar magnetic activity cycle.
  - Plan B – the magnetic field dissipation processes and energy transfer in the solar plasma.
  - The both are important for solar physics and related fields.
- The JAXA SOLAR-C WG is now preparing a draft of the mission proposal.
  - The draft is prepared for the both mission concepts.
  - One of the mission will be submitted to JAXA in 2011, after reviewing them in the community.