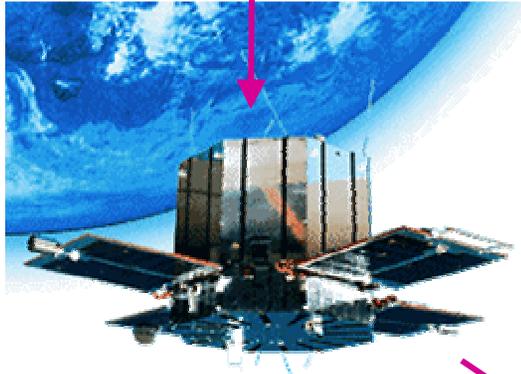


JAXA *SOLAR-C* mission

JAXA *SOLAR-C* Working Group
Saku Tsuneta (WG chair)

Solar physics from space in Japan

Tansei
(Path finder mission)



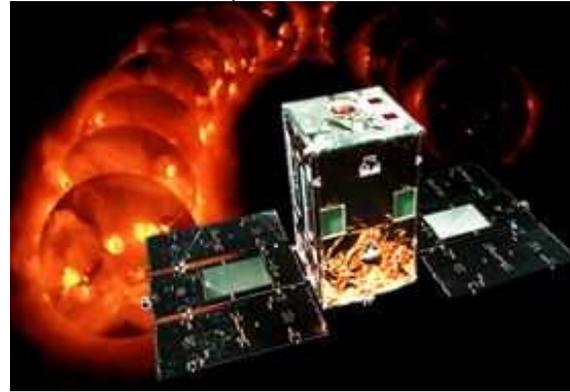
Hinotori (ASTRO-A)

188 kg, 1981

Non-thermal acceleration

- Hard-Xray imaging with rotation modulation collimator **10 arcsec**
- Bragg crystal spectrometer
- SXS, HXS

With NASA, UK



Yohkoh (SOLAR-A)

390 kg, 1991

Non-thermal acceleration and plasma heating

- HXR Fourier telescope (J) **7 arcsec**
- Soft X-ray telescope (J/US) **5arcsec**
- Bragg spectrometer (J, US, UK)
- WBS

With NASA, UK



Hinode (SOLAR-B)

~ 900kg, 2006

Magnetic fields with corona

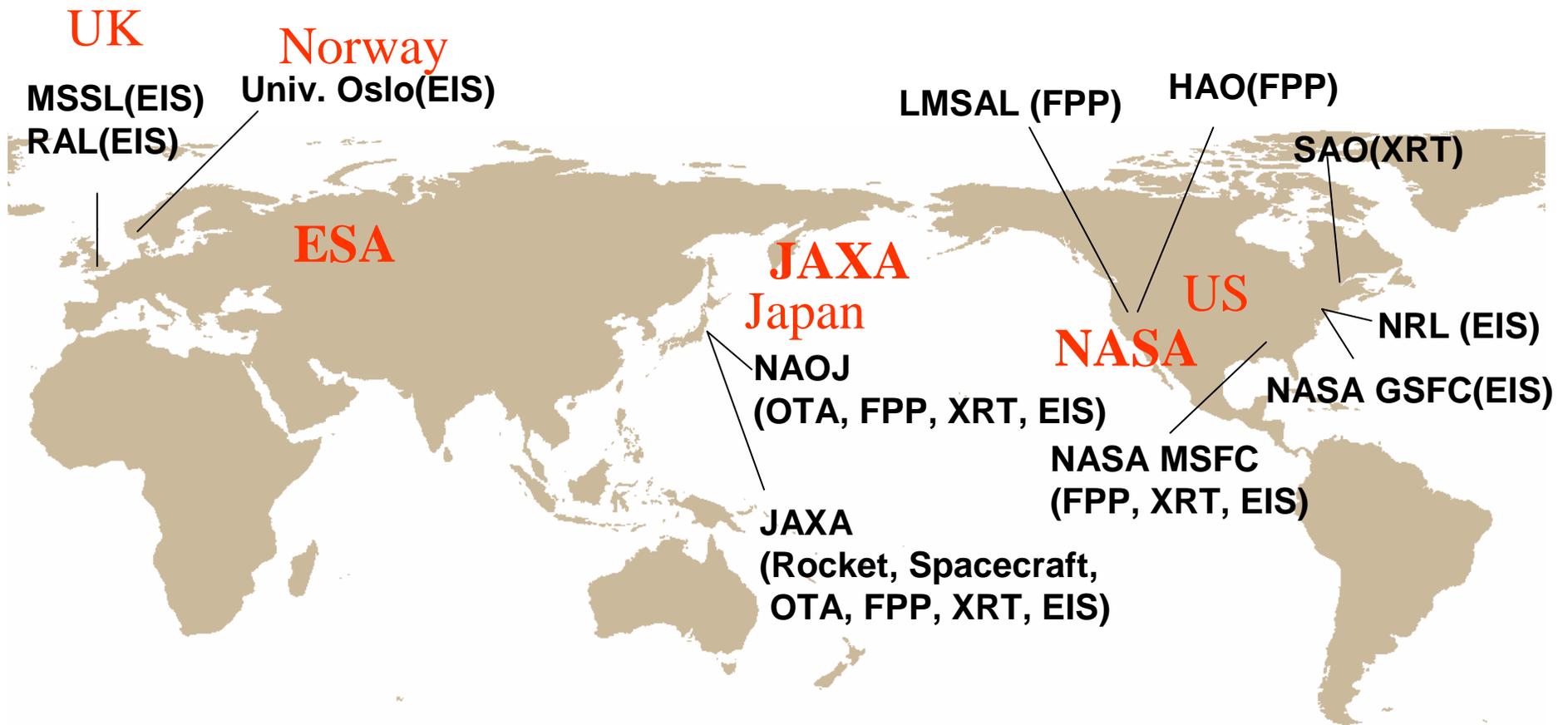
- SOT (Japan, US) **0.2 arcsec**
- XRT (US, Japan) **2arcsec**
- EIS (UK, US, Japan) **2arcsec**

Solar-B chronology

- 1994-1995 Ad-hoc working group at NAOJ
- 1995 Mission proposal (MUSES-C)
- 1996 Mission proposal² (IR-mission)
- 1997 Mission proposal³ (finally won)
==parallel activity in US and UK==
- 1998 New start with basic research \
- 1999-2001 Proto-model design/fab./test
- 2001-2004 Flight-model design/fab./test
- 2005-2006 Final test/launch
- 2006 PV Observations start

Strong international collaboration for SOLAR-B over 8 years

3 space agencies, 11 organizations in 4 countries



Solar physics from space in Japan

Yohkoh (1991- 2001)
With NASA/PPARC

Open issues in solar physics
Global and local dynamo
Coronal and chromospheric heating

Hinode (1991-1992)

Hinode (2006-) with NASA/STFC/ESA

SOLAR-C
J-FY2016
(provisional)



Two SOLAR-C mission concepts under study

- *Plan A: Out-of-ecliptic magnetic/X-ray and helioseismic observations* of the polar and the equatorial regions to investigate properties of the polar region, meridional flow and magnetic structure inside the Sun to the base of the convection zone.
- *Plan B:* High spatial resolution, *high throughput, high cadence* spectroscopic (polarimetric) and X-ray observations *seamlessly from photosphere to corona* to investigate magnetism of the Sun and its role in heating and dynamism of solar atmosphere.
- *Launch Date:* Japanese fiscal year *2016 (provisional)*
 - Expects joint observations with highly complementary missions
 - *NASA SDO* (whole sun field of view)
 - *ESA&NASA Solar Orbiter* (Insitu and stereo obs with SOLAR-C)
 - *NASA Solar probe* (In-situ)

What is going on in polar region ?

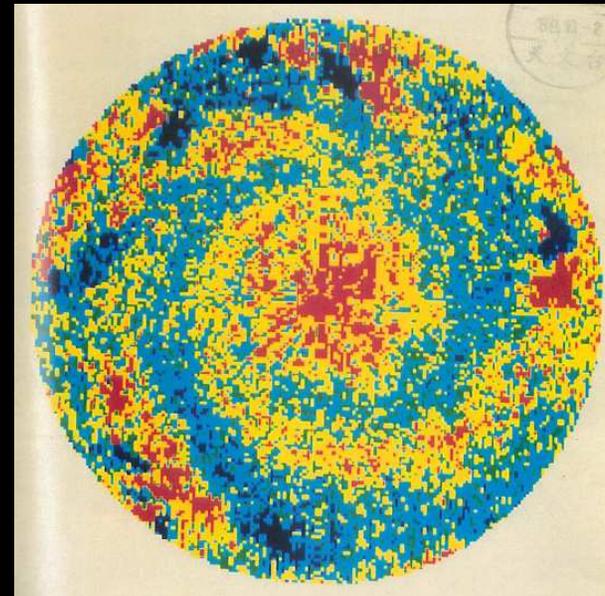
Source of fast solar wind
Location of global poloidal fields
sink of meridional flow

High speed solar wind

Ulysses
(McComas
etal 2000)



Kitt Peak
(Wang et al)



Hinode XRT
High coronal
Activity in polar
region

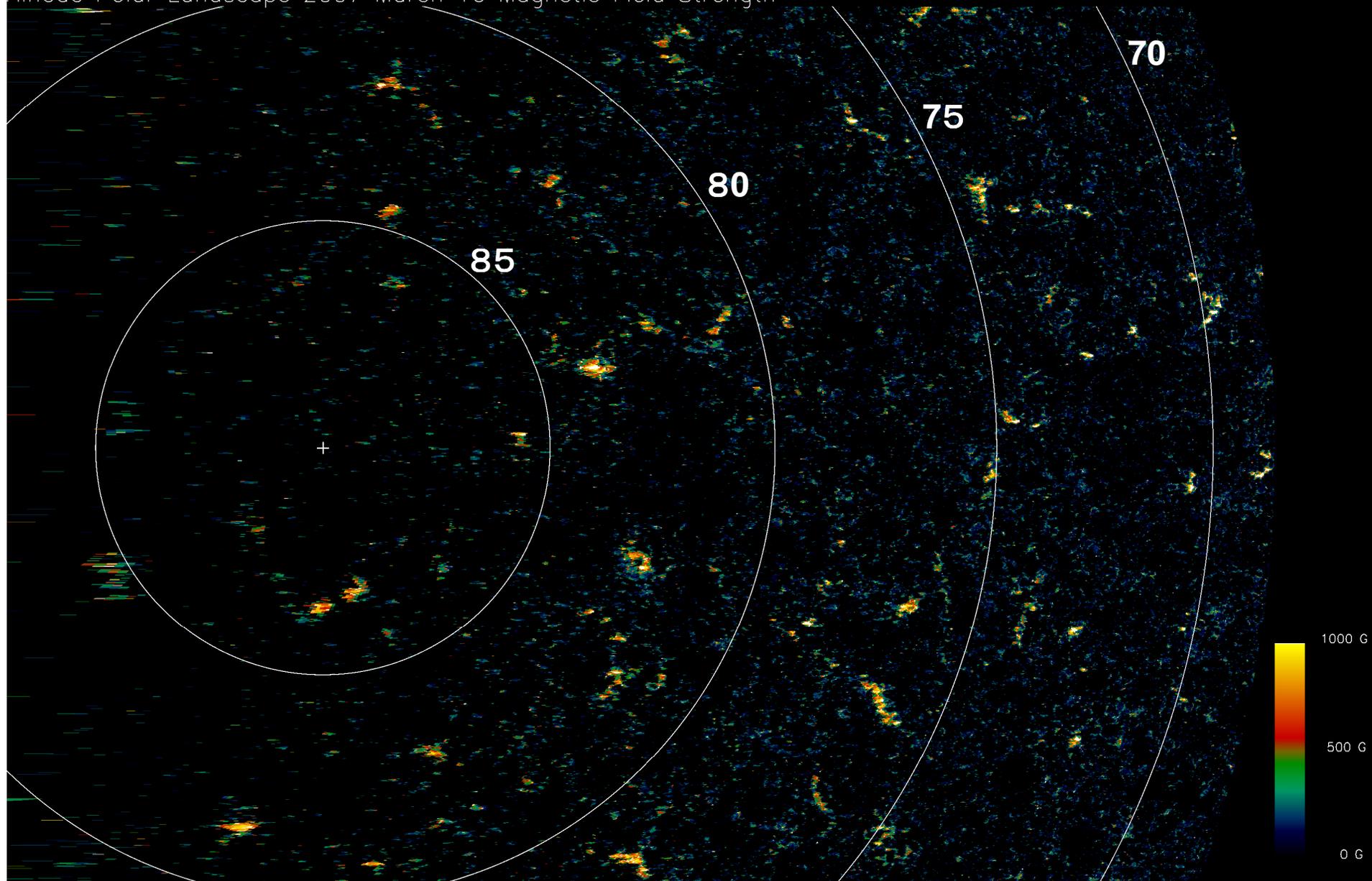


2006/11/23 00:47:25
XRT Al_poly filter exp. 16385msec

Cirtain etal 2007

Polar landscape kG field

Hinode Polar Landscape 2007 March 16 Magnetic Field Strength



Plan-A: Exploration of polar region, internal structure and solar dynamo

The Sun as a star

- *Scientific objective*

- Measure meridional flow at high latitudes, and see where it turns downwards
- Detect magneto-sound speed anomaly located in the tachocline region (*flux tube/sheet imaging in tachocline*)
- Observe the vector magnetic fields of photosphere and chromosphere and coronal imaging in X-ray/EUV
- Obtain acoustic speed and angular rotation speed distribution in the polar region
- Understand acceleration mechanism of fast solar wind
- Monitor total irradiance (optional)
- Study influence of the Sun to heliosphere

- *Model payload*

- Photospheric and chromospheric dopplergram
- Stokes-polarimeter for photosphere and chromosphere
- X-ray/EUV imager
- Optional: total irradiance monitor, in-site instruments, and coronagraph

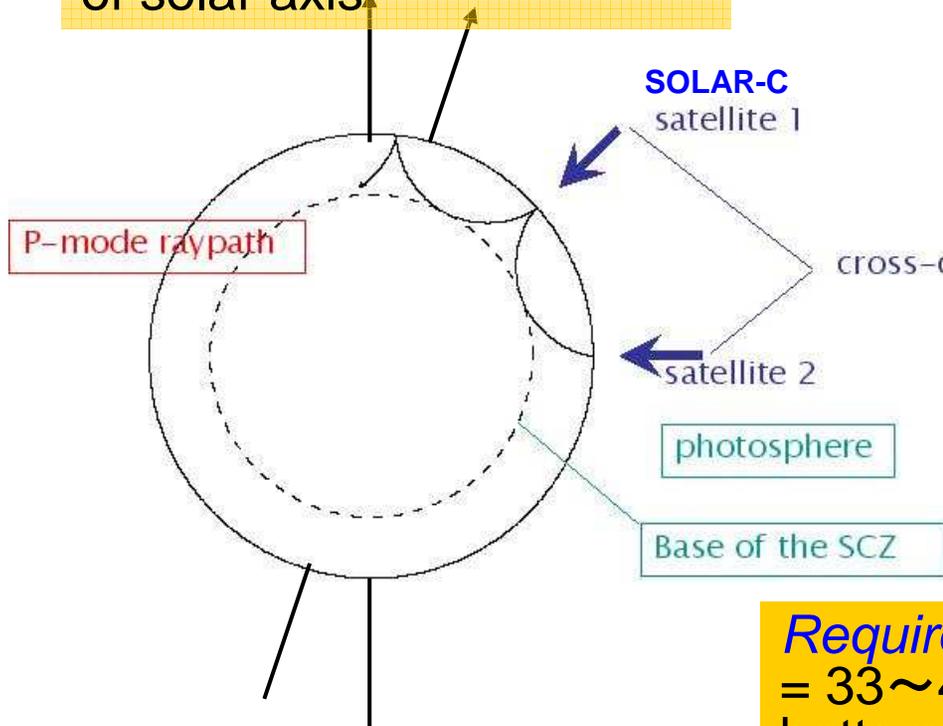
Plan-A: A new possibility

Imaging of flux tubes in tachocline

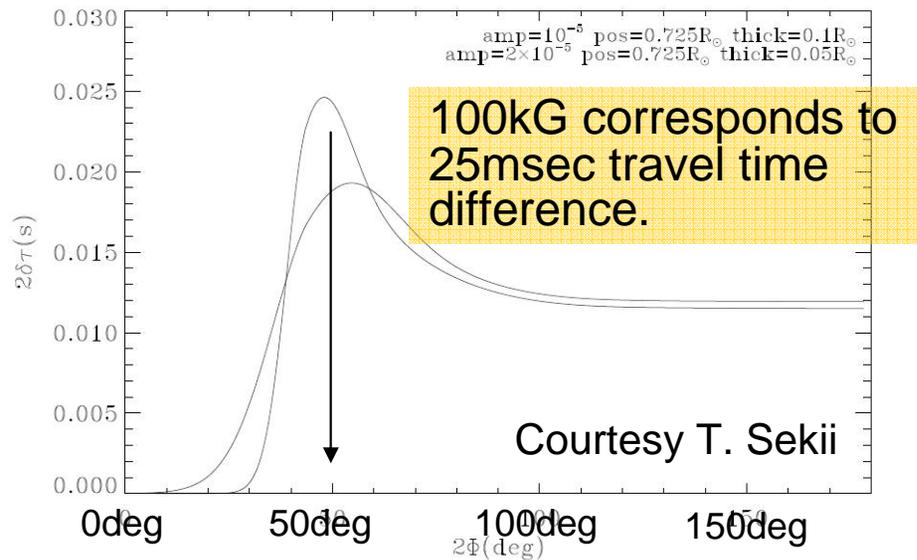
A high-inclination orbit and dual observations

- Observe Doppler velocity at high latitudes without undesired projection
- Observe waves penetrating deep into the sun with dual stations.

By choosing launch timing, use precious 7 degree tilt of solar axis



Skip angle versus travel-time perturbation due to flux sheet at tachocline



Required inclination : 40 ~ 50 minus 7 degree = 33 ~ 43 degree: Optimum angle to reach bottom of CZ

Plan A Orbit and Engine Trade-off

Case 1: Ion engine + Earth swing-by

Case 2: Ion engine + Earth swing-by + Venus swing-by

Case 3: Chemical engine + Jupiter swing-by

Case 4: Chemical engine + Jupiter swing-by + Earth swing-by

<Trade-off items>

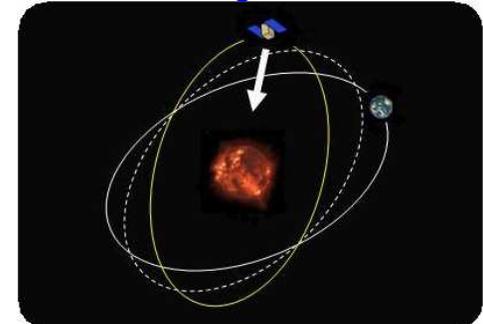
flight time until starting observation, achievable inclination, observational timing, payload mass, thermal design, tele-communication link, etc.

ex.) One possible solution of Case 1 assumes,

- JAXA H2A launch
- Initial mass = 1200kg.
- Payload mass = 100kg.

Achieves Inclination (to the Solar equator) of
30 deg. in 2 years from the launch,
45 deg. in 5 years from the launch.

*Observe both polar and equatorial
Regions maintaining ~1AU distance*



Plan-B brings new discovery space though enhanced spectroscopic capability *seamlessly covering entire atmosphere*

Hinode discoveries

Slow solar wind

Waves in prominence

Chromospheric transition region jets due to reconnection

Waves along spicules

Penumbral micro-jets

Magnetic velocity fluctuation

Local dynamo process

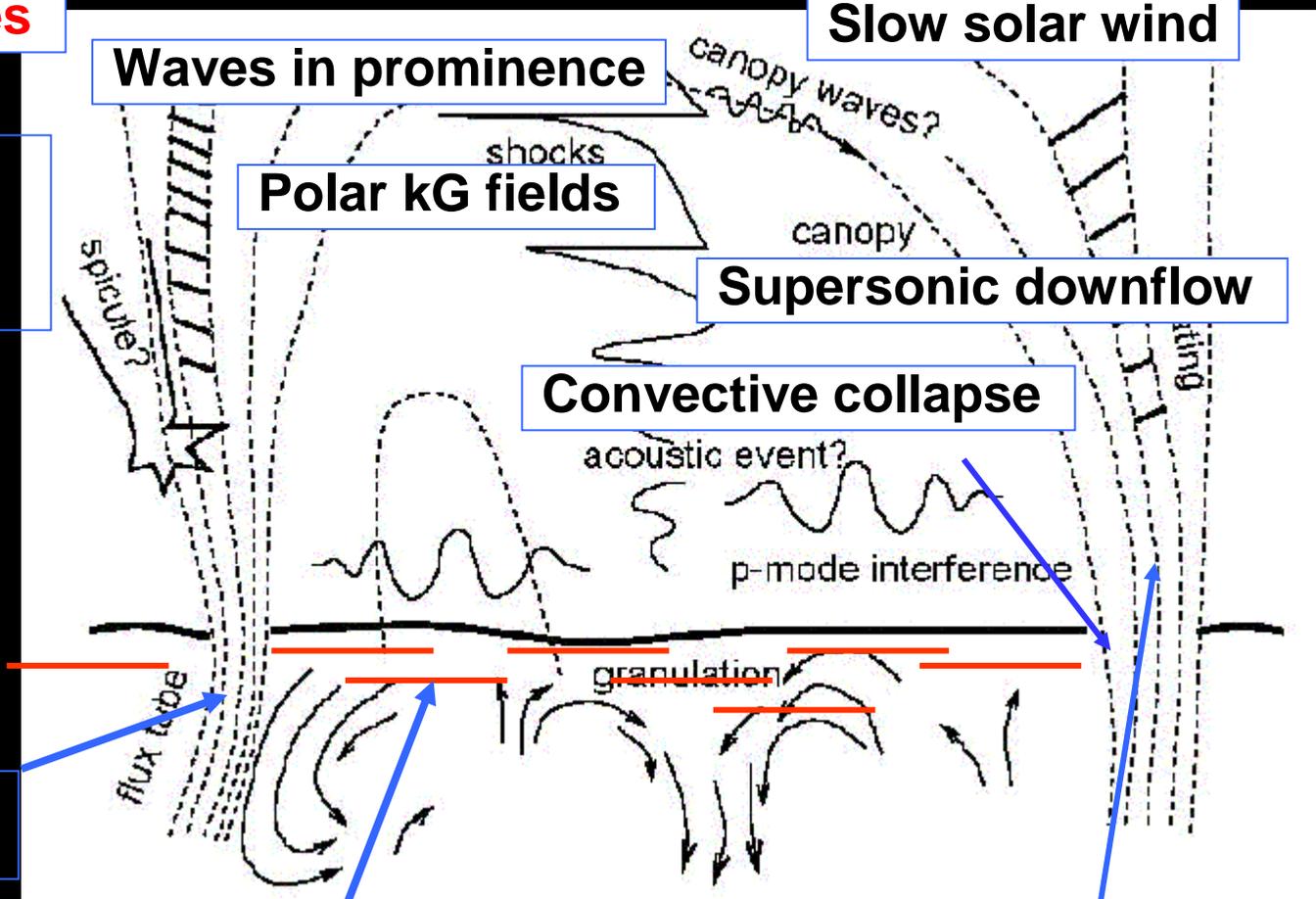
Polar kG fields

Supersonic downflow

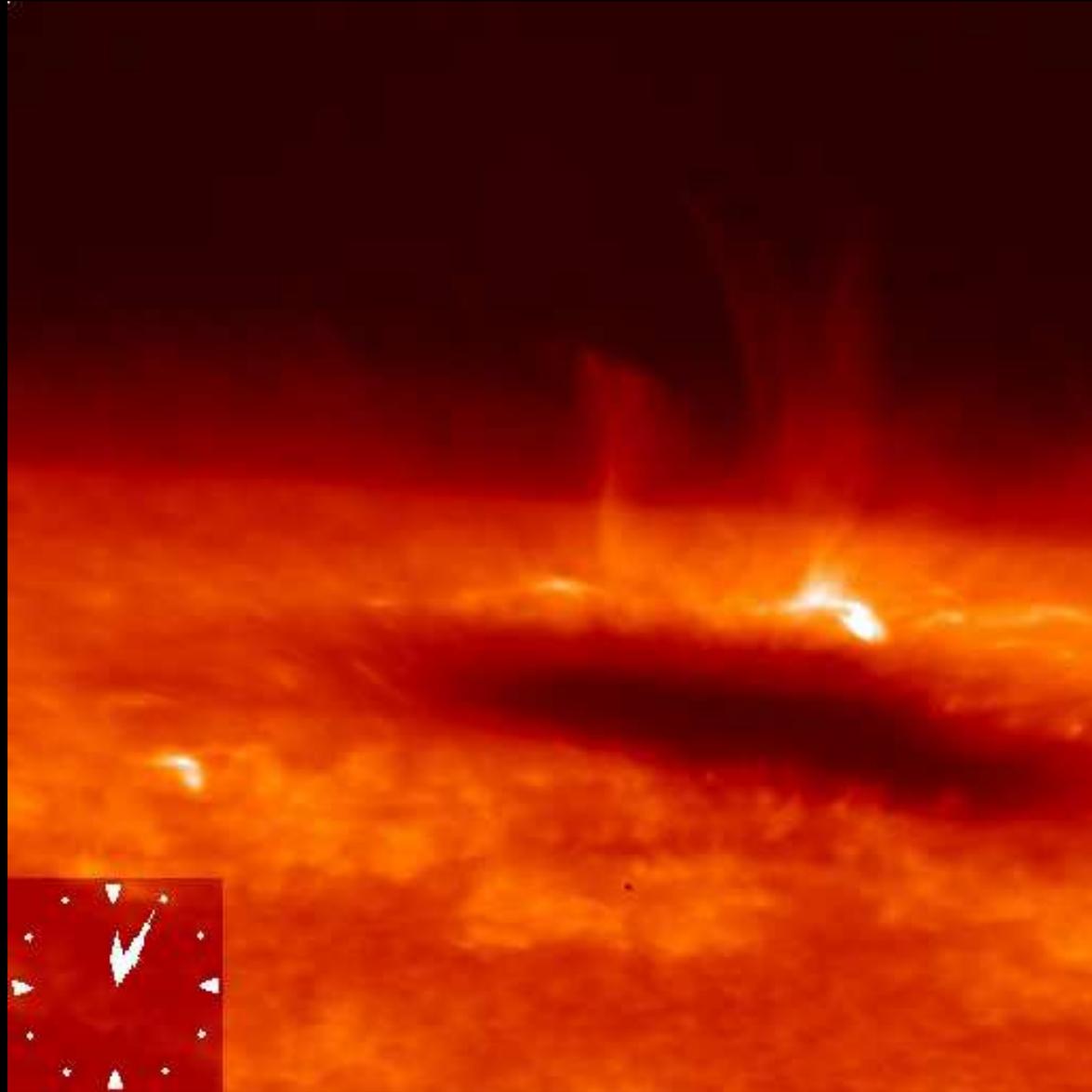
Convective collapse

Ubiquitous Horizontal fields

High coronal turbulence



***Chromosphere more dynamic
than expected!***

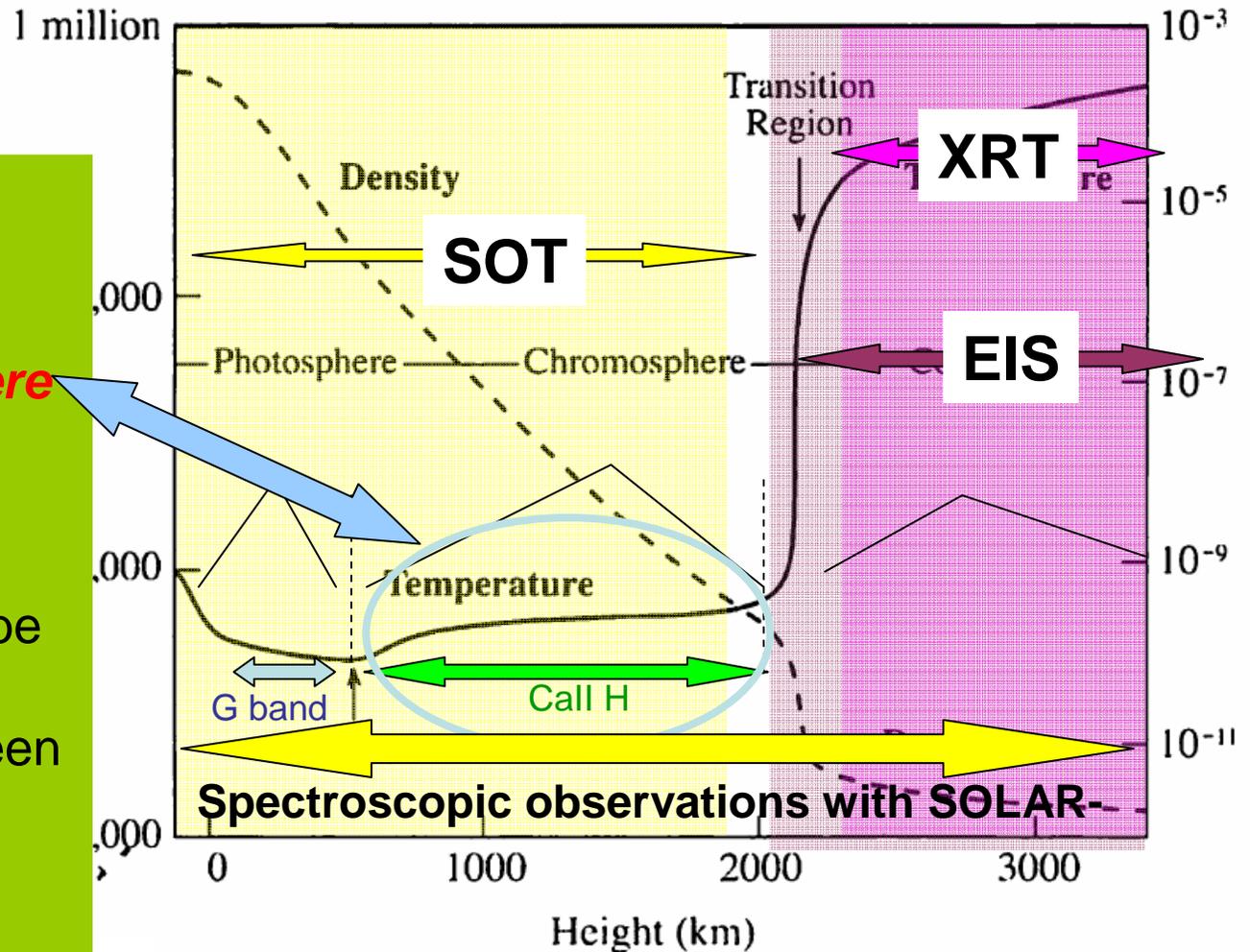


SOLAR-C *Plan B*

From imaging to spectroscopy
From visible to UV-visible-IR

Hinode imaging observations reveal unexpected **highly dynamic chromosphere**

- Chromosphere needs x10 heating energy.
- Not static atmosphere
- Coronal heating may be closely related to the interface region between the magnetic photosphere and the dissipative corona.



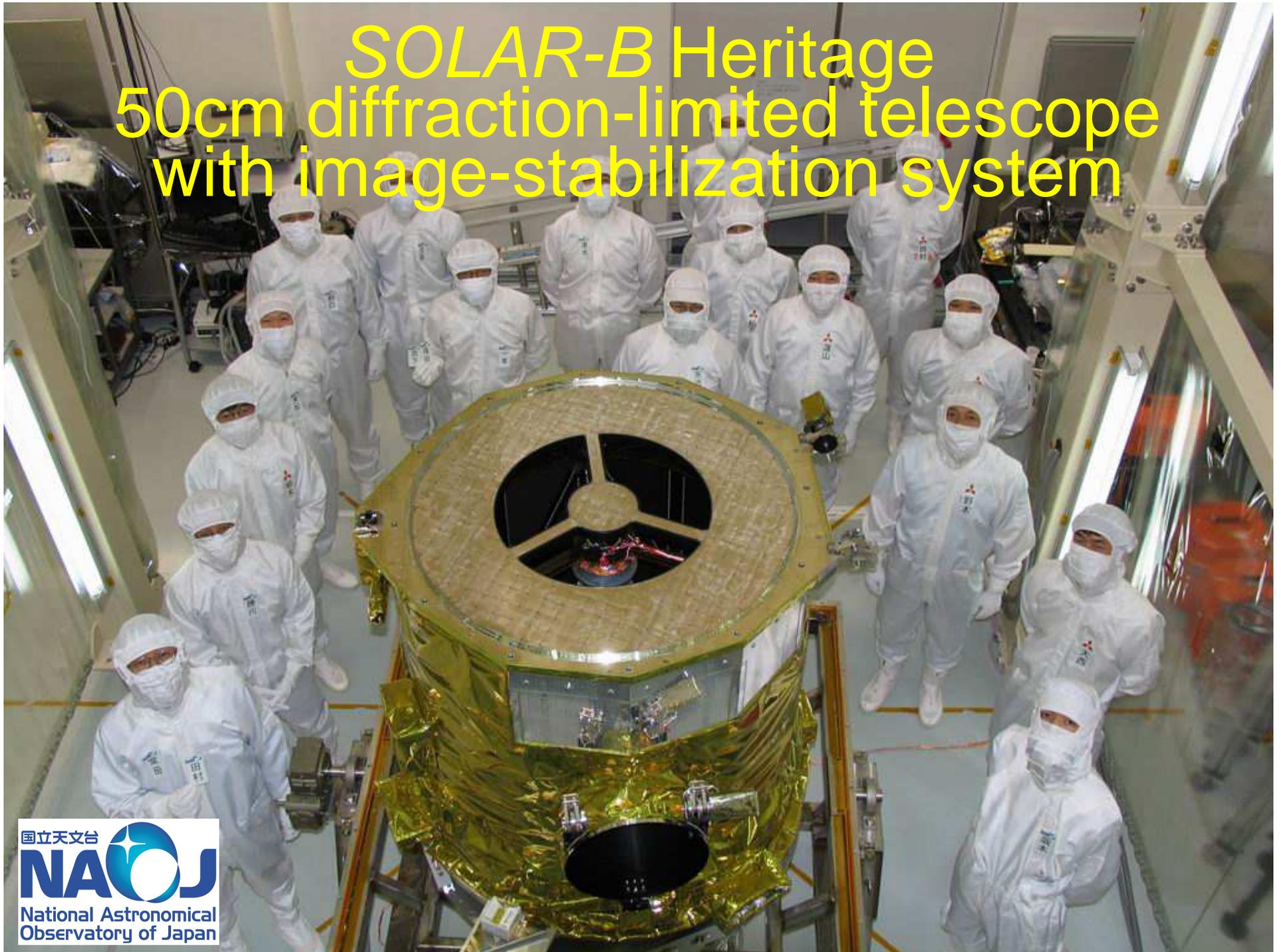
Hinode and *SOLAR-C Plan-B*

- Hinode/*SOLAR-C*
 - Demonstrates power of spectro-polarimetry from space
 - *Significantly enhance spectro-polarimetric capabilities to UV and near-IR*
 - Dynamism of chromosphere is a major Hinode discovery. Chromospheric dynamics may generate disturbance to corona: new implication to coronal heating (Isobe et al 2008)
 - *High time resolution, high throughput spectrometer*
 - Little diagnostic capability for chromosphere and transition regions
 - *Seamless observations from photosphere to corona*
- *Scientific Objective*
 - Obtain precise *chromospheric* and, if possible, *coronal vector magnetic field* maps in addition to photospheric magnetic maps with high spatial and temporal resolution
 - Obtain *coronal 3-D magnetic field* map from chromospheric vector field, predict location and evolution of *neutral-sheets, discontinuities* for transient and stationary coronal heating and eruption
 - Reveal *causal relationship* of photosphere-chromosphere-transition region-corona to understand coronal/chromospheric heating and dynamism
 - Understand the nature of *hidden magnetism*: Is the observed B tip of the iceberg?
 - Deepen Hinode discoveries with quantitative analysis: *waves, turbulence, magnetic reconnection*
 - Study influence of the Sun to heliosphere

Plan B model payload

- *General*
 - From imaging to spectroscopy
 - *Concentrate best possible lines to represent each layer of atmosphere*
 - High resolution, high S/N, and high time resolution
 - *High throughput multi-object-spectrograph or equivalent needed*
 - From visible to visible+UV+near IR
 - *Seamless coverage of photosphere, chromosphere, TR and corona*
- *Model payload*
 - *Near IR-Visible-UV* telescope TBD-1.1 micron
 - 50cm diffraction-limited telescope 0.1-0.4arcsec
 - *Ultra-high resolution* EUV/X-ray telescope
 - High resolution high throughput coronal spectroscopic capability
- ***Key point1 : Chromospheric, and if possible coronal spectropolarimetry for vector magnetic field observations***
 - Needs He10830 or equivalent with *Zeeman+Hanle* sensitivity
 - Evaluate potentiality of UV and EUV lines for *Hanle-effect* diagnostics of chromosphere and corona
 - Closer to force-free layer: provide better BC for coronal field extrapolation: concern on the adequacy on photospheric BC
- ***Key point 2: High spatial and temporal resolution chromospheric and transition region spectroscopy for dynamics***

SOLAR-B Heritage 50cm diffraction-limited telescope with image-stabilization system



Development of *SOLAR-C* concept

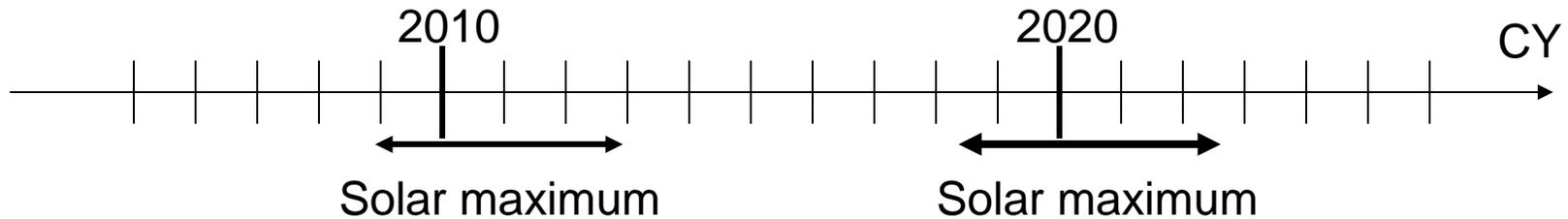
- JAXA *SOLAR-C* WG refines both plans, compare science, technology, and other constraints, and prioritize the two plans with international partners.
- ***International SOLAR-C science definition meeting***
 - week of November 10 2008 at JAXA/ISAS-JSPEC
- **Purpose of meeting**
 - Refine science cases for plans A and B
 - Determine option for Plan-A orbit and engine for further study
 - Propose model science instruments and identify key technology issues
 - Discuss consistency and synergy with NASA and ESA plans
 - Form international sub working groups for specific critical issues
 - Establish connection with space weather

SOLAR C development schedule (provisional)

- FY2016 Launch
- FY2015 S/C tests
- FY2011~14 Flight and proto model
- FY2010 Phase-A
- FY2008~9 Concept study
- FY2007 JAXA SOLAR-C WG

(FY: Japan fiscal year starting April 1.)

SOLAR-C and other ongoing missions



Hinode



SOLAR-C

Plan B 2016 Aug. 

Plan A 2016 Aug. 

ATST (NSF)

2014 

SDO (NASA)

 2008 Dec 08.

Solar Orbiter (ESA&NASA)

2015 May 

2018 summer reach obs-deck 2021 summer Helio-lat. 15 degree 2022-23 Helio-lat. 35degree

Note : Plan A orbit trans. period not accurate, being studied.

Note : NASA decadal plan beyond SDO not available.

Note : ESA SOLAR ORBITER reach 0.22AU on summer of 2018.

Justification for mid-2010s launch

- Plan A satellite has to reach an observing point around 2020 to be ready for the solar maximum and polar field reversal.
- *Joint observations with highly complementary missions*
 - *NASA SDO (whole sun field of view)*
 - *ESA Solar Orbiter*
 - *NASA Solar Probe*
- Continuity in solar physics research in Japan requires mission approximately every 10 years
 - Hinode launched in 2006.
 - Hinode provides new data on the solar maximum Sun around 2010.
- Avoid vacuum in solar physics.

Summary

- Solar physics community in Japan has so far developed 3 solar missions over past 25 years.
- We recognize that success of Hinode and Yohkoh is due to strong international support.
- Solar physics community and related-disciplines in Japan strongly desire and endorse one of the SOLAR-C mission concept to be realized in mid-2010s.
- *The JAXA SOLAR-C working group invites US and European participation to the SOLAR-C program, following our remarkable history of collaboration.*

SOLAR-C web site

- http://hinode.nao.ac.jp/SOLAR-C/index_e.html