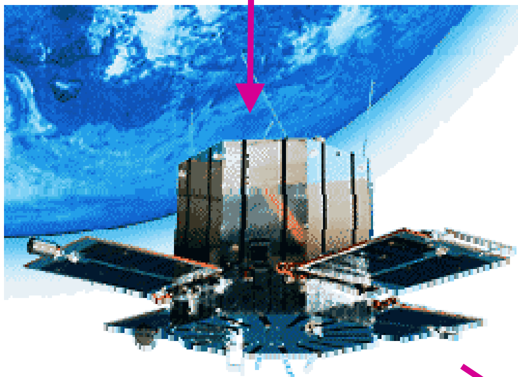
International SOLAR-C science definition meeting

November 18-21 2008 JAXA/ISAS-JSPEC

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

Solar physics from space in Japan

Tansei
(Path finder mission)

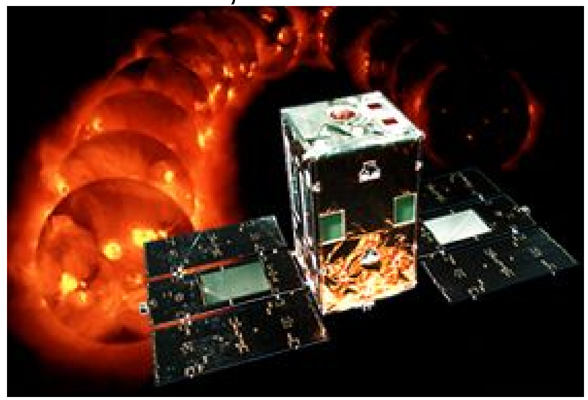


Hinotori (ASTRO-A)
188 kg, 1981

Non-thermal acceleration

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

With NASA, UK

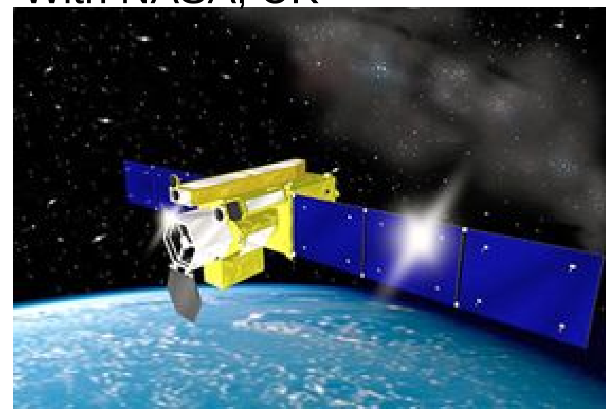


Yohkoh (SOLAR-A)
390 kg, 1991

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

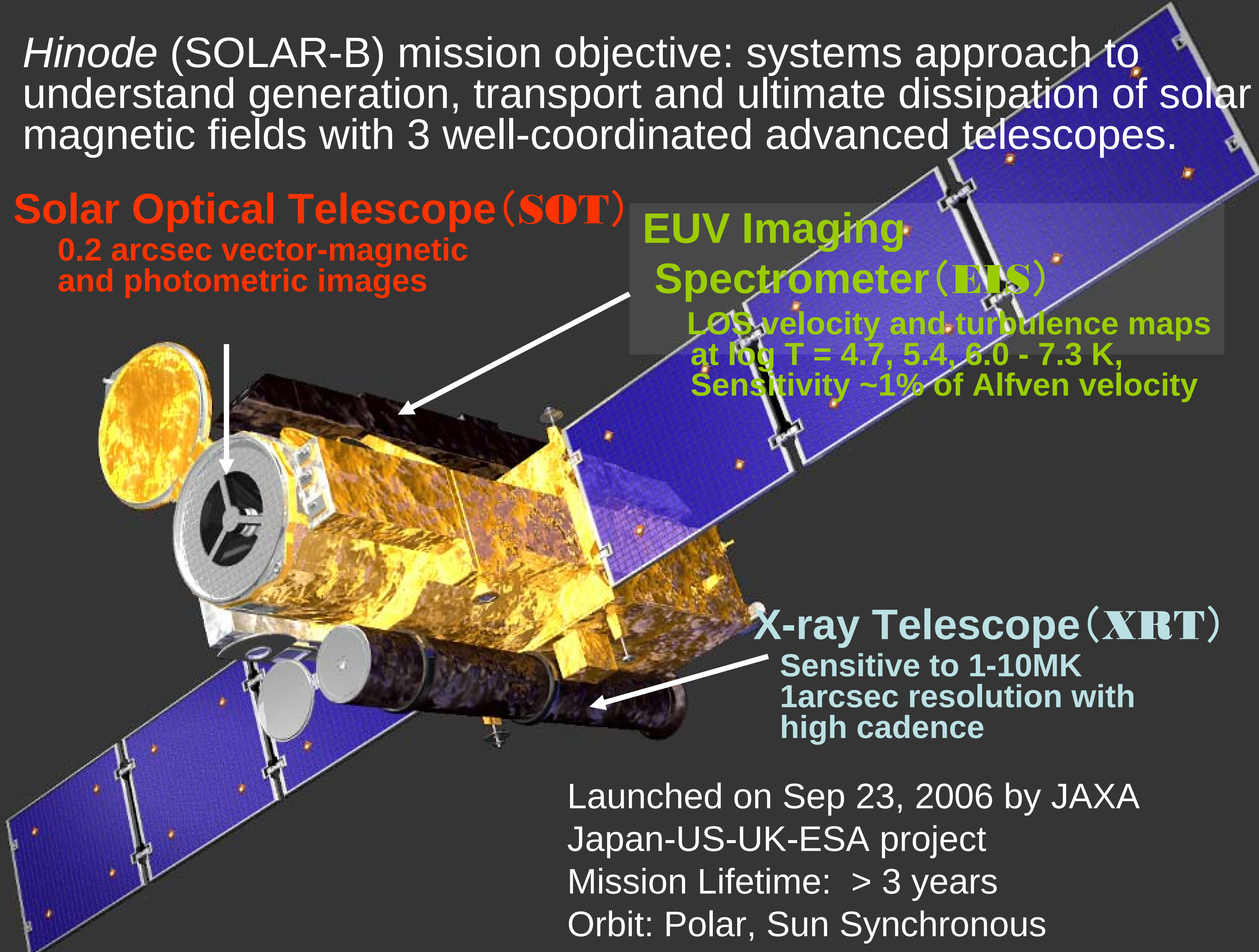


Hinode (SOLAR-B)
~ 900kg, 2006

Magnetic fields with corona

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

Hinode (SOLAR-B) mission objective: systems approach to understand generation, transport and ultimate dissipation of solar magnetic fields with 3 well-coordinated advanced telescopes.



Launched on Sep 23, 2006 by JAXA

Japan-US-UK-ESA project

Mission Lifetime: > 3 years

Orbit: Polar, Sun Synchronous

Results *from Hinode* should be the basis for *SOLAR-C*

Hinode discoveries

Waves in prominence

Slow solar wind

Chromospheric transition region jets due to reconnection

Polar kG fields

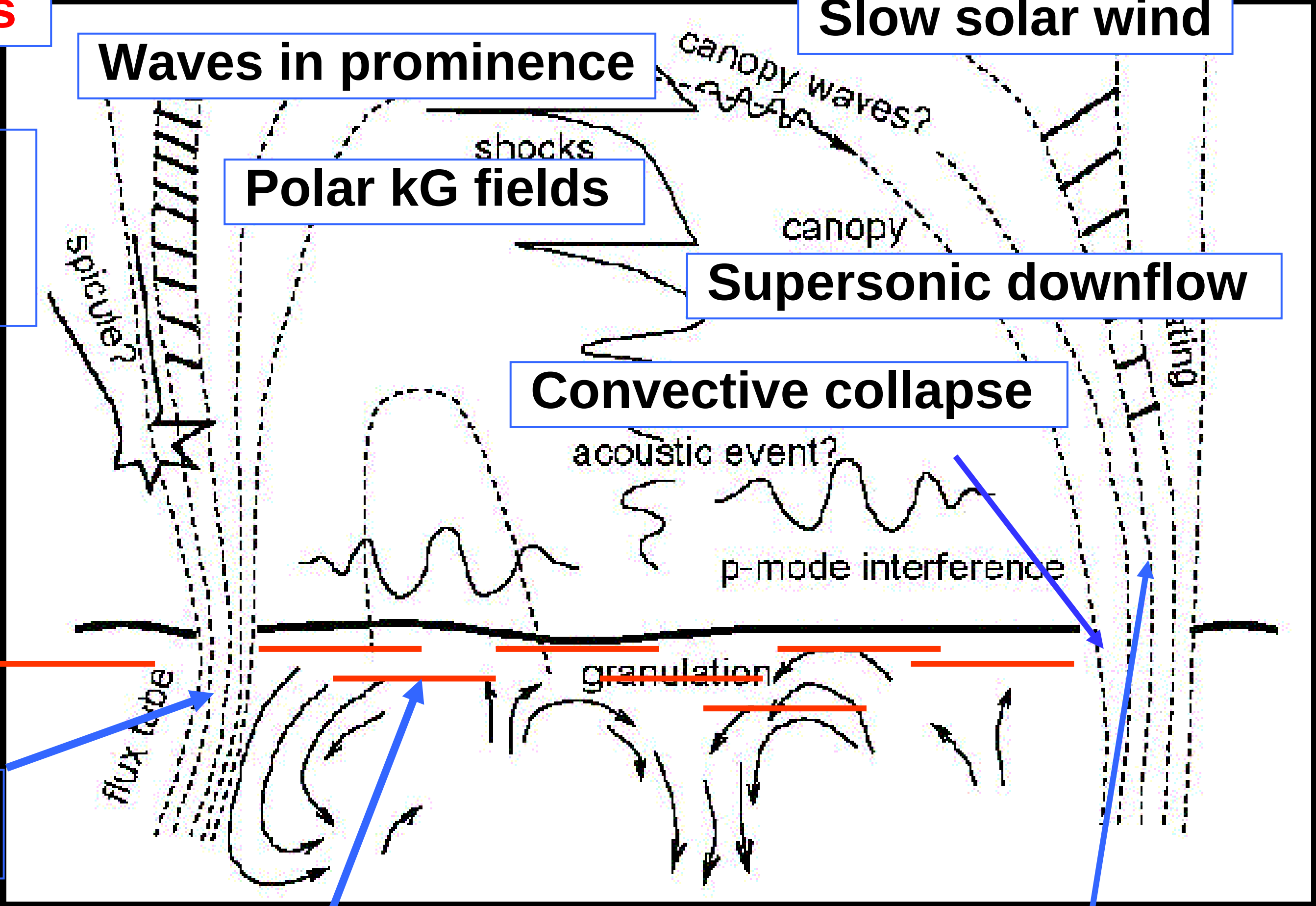
Supersonic downflow

Waves along spicules

Convective collapse

Penumbral micro-jets

Magnetic velocity Fluctuation



Local dynamo process

Ubiquitous Horizontal fields

High coronal turbulence

Rutten, R., ASP-CS, 184, 181, 1999

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)

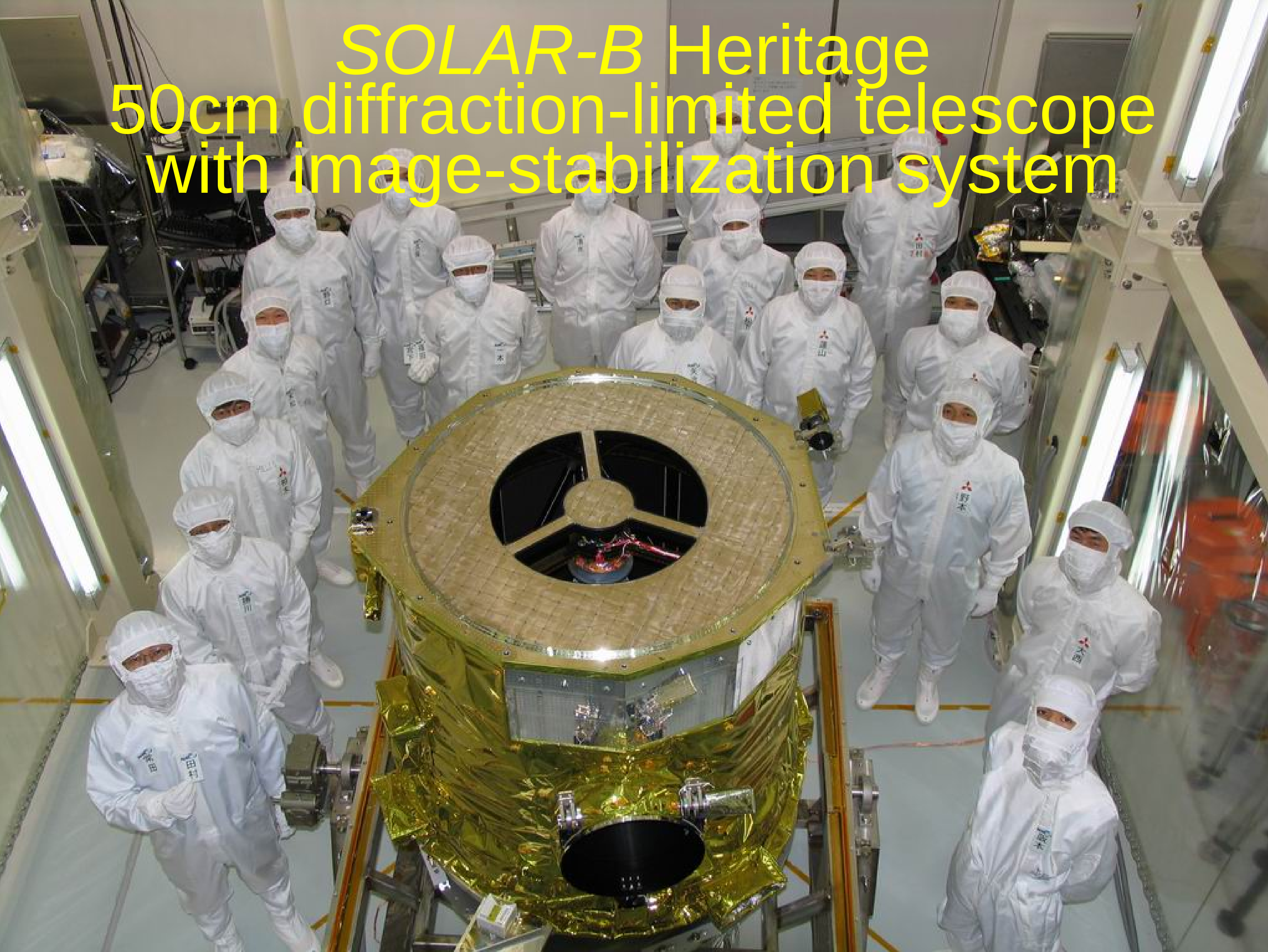
  ==parallel activity in US and UK==
- 1998 New start with basic research ¥
- 1999-2001 Proto-model design/fab./test
- 2001-2004 Flight-model design/fab./test
- 2005-2006 Final test/launch
- 2006 PV Observations start

SOLAR-B science mission design（1995-1997）

What are the lessons learned from SOLAR-B?

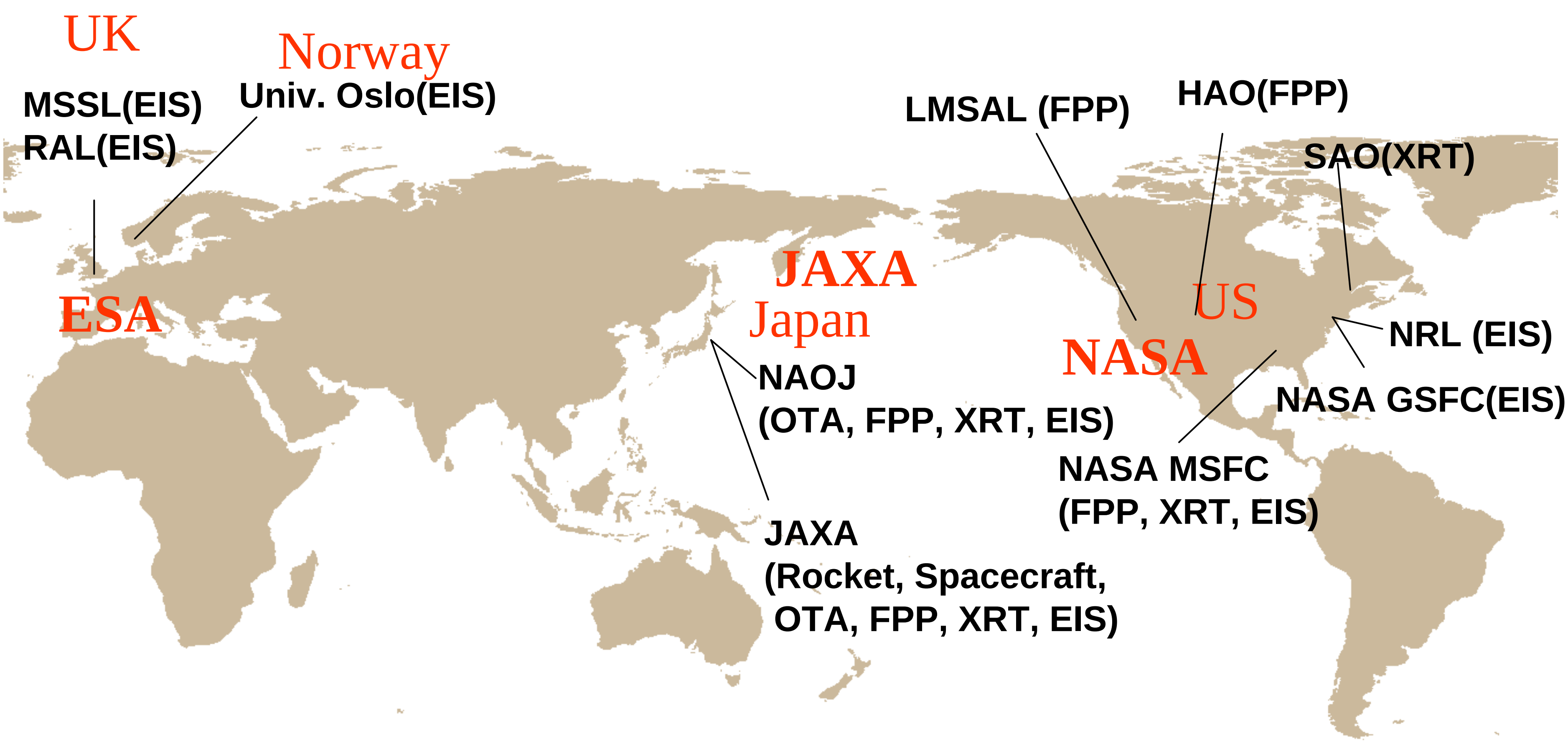
- SOT：Modest 50cm diffraction-limited telescope, considering science requirement, technical and cost reality.
- Stokes polarimeter is a must instrument (can not fly only with filter instrument)
- Needs velocity maps with EUV imaging spectrometer
- Simultaneous observations with high co-alignment accuracy
- XRT: Choice of grazing incidence optics to have temperature sensitivity in 1-20 MK, while maintaining high spatial resolution
- *Once the concept was established, there has been no compromise during the development.*

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



Strong international collaboration for SOLAR-B over 8 years

3 space agencies, 11 organizations in 4 countries



What is next?

Hinotori(1981-1982)

Yohkoh (1991- 2001)
With NASA/PPARC

Open issues in solar physics
Global and local dynamo
Chromospheric and coronal activity and heating

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 ?

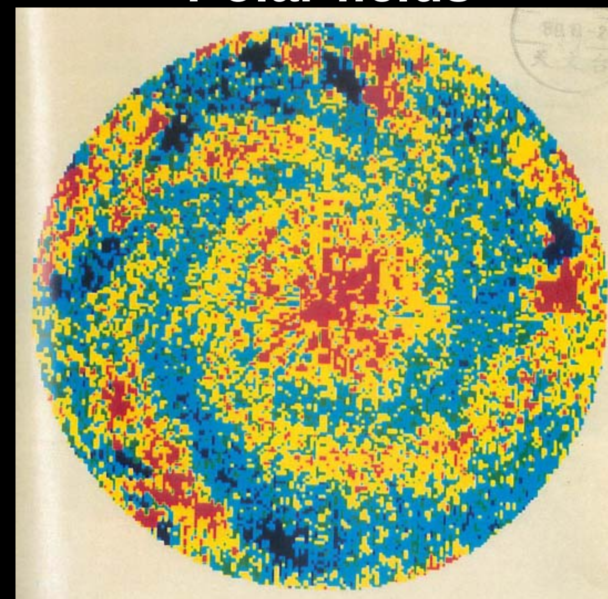
Source of fast solar wind
Location of global poloidal fields
sink of meridional flow

High speed solar wind

Ulysses
(McComas etal 2000)

Polar fields

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

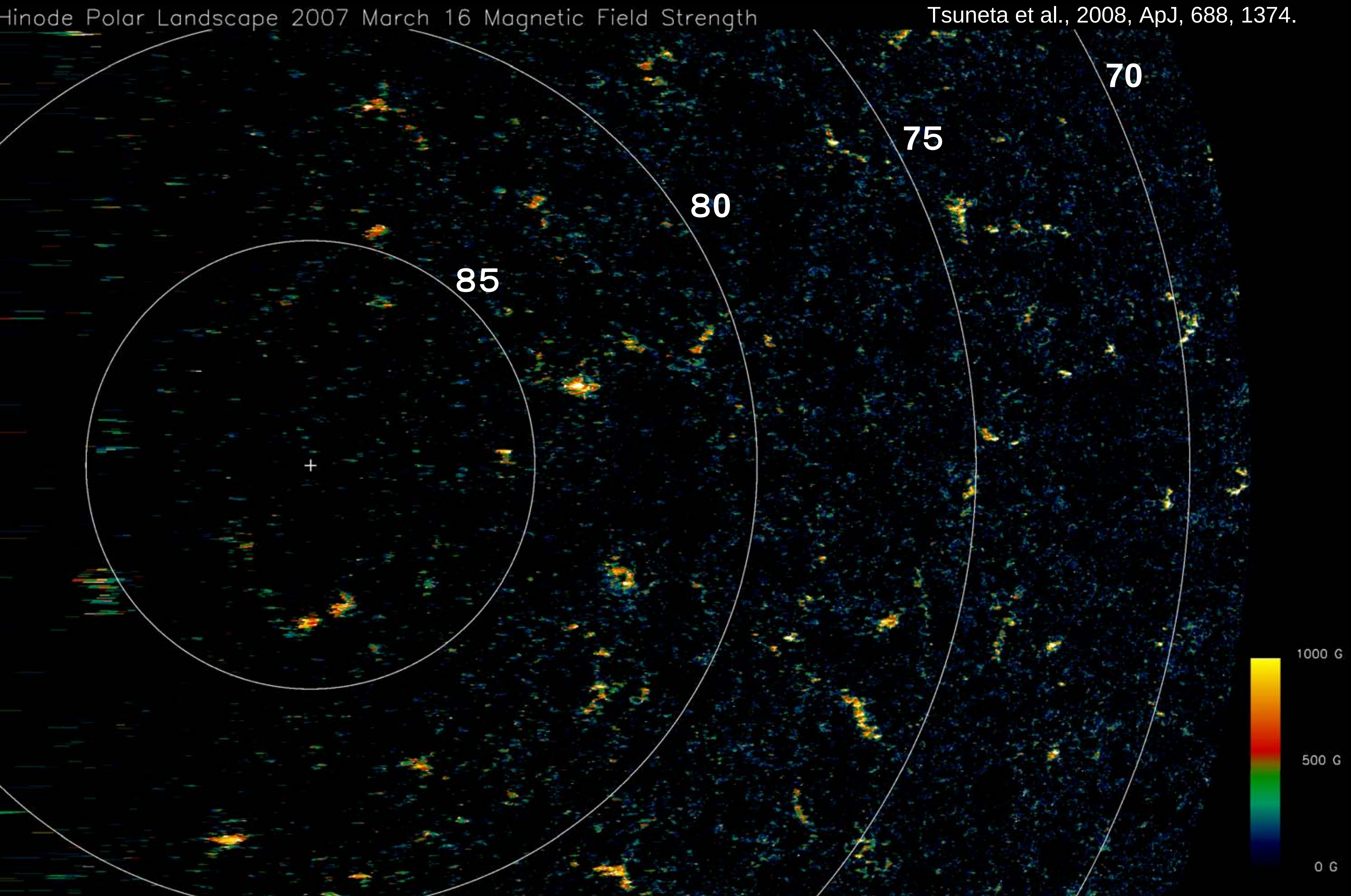
Cirtain etal 2007

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*)
  - Detect toroidal flows driven by Coriolis force
  - 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

Polar landscape kG field

Tsuneta et al., 2008, ApJ, 688, 1374.

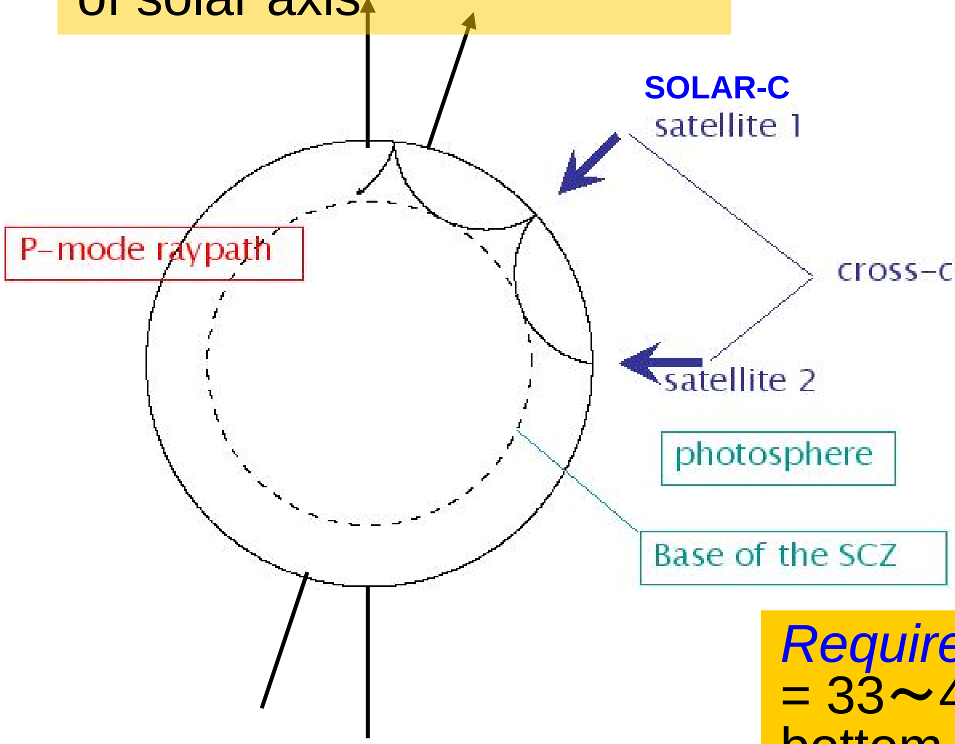


Plan A: what is required inclination angle? An exercise

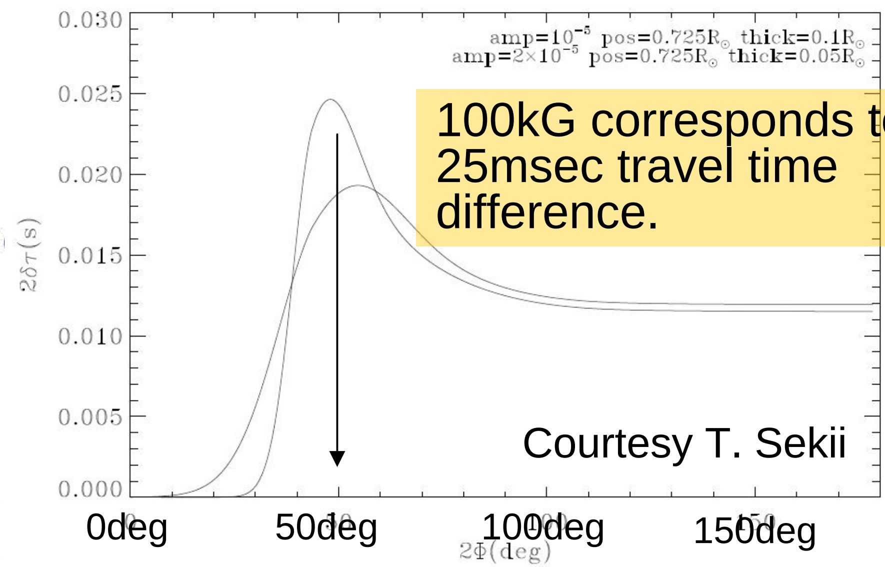
A high-inclination orbit and dual observations

- 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



100kG corresponds to 25msec travel time difference.

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

Key parameters such as payload mass, telemetry, inclination, flight time have to be clarified beforeha

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.

To be revised today

ex.) One possible solution of *Case 1* assumes,

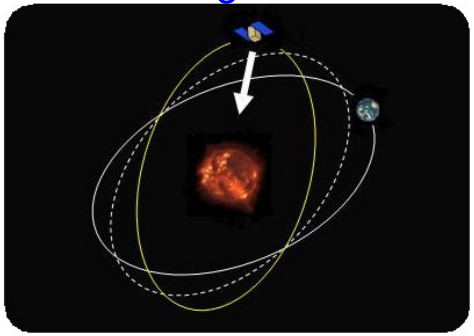
- JAXA H2A launch
- Initial mass = 1200kg.
- Payload mass = 100kg.

Achieves Inclination (to the Solar equator) of

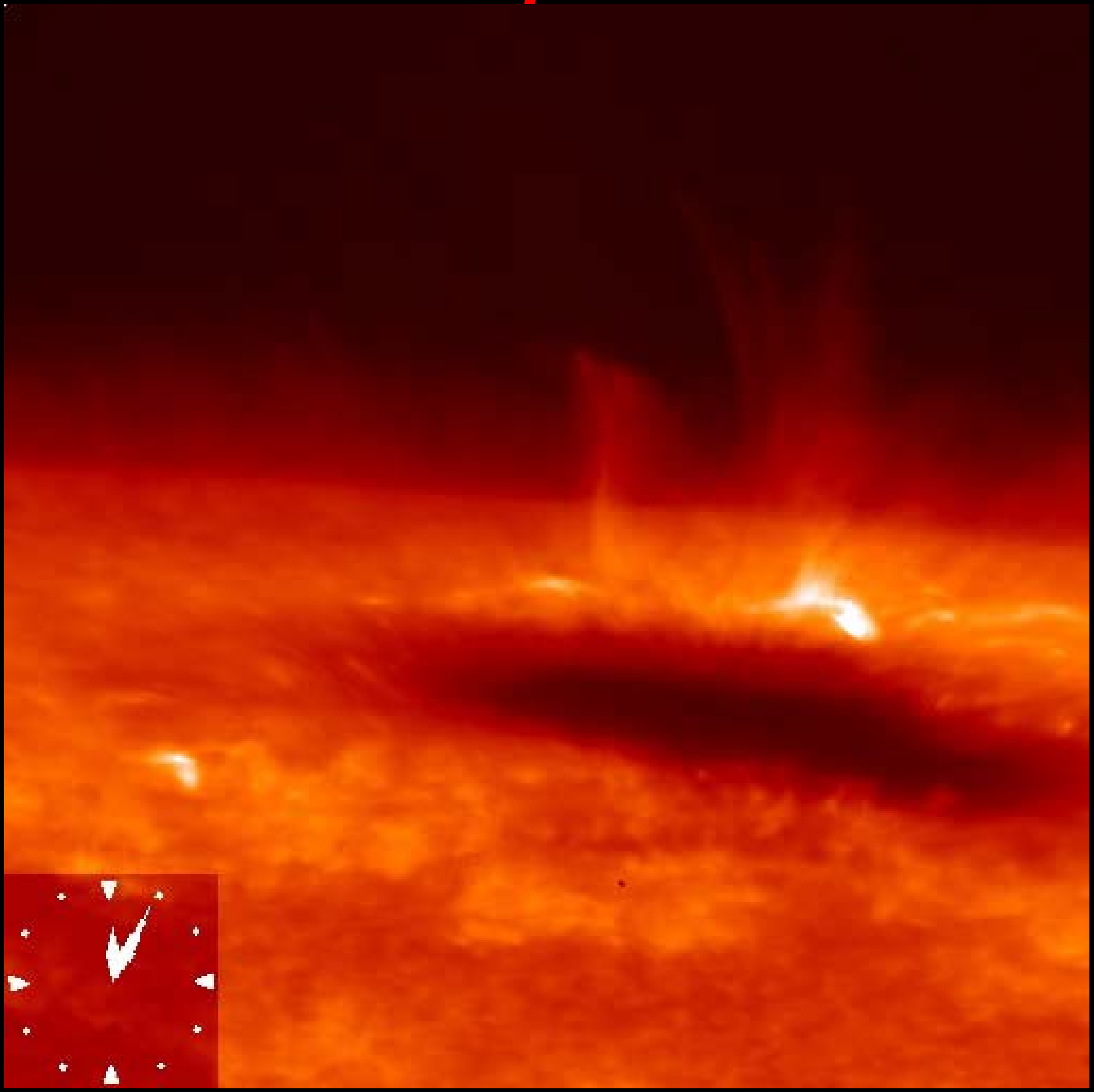
30 deg. in 2 years from the launch,

45 deg. in 5 years from the launch.

Observe both polar and equatorial Regions maintaining ～1AU distance



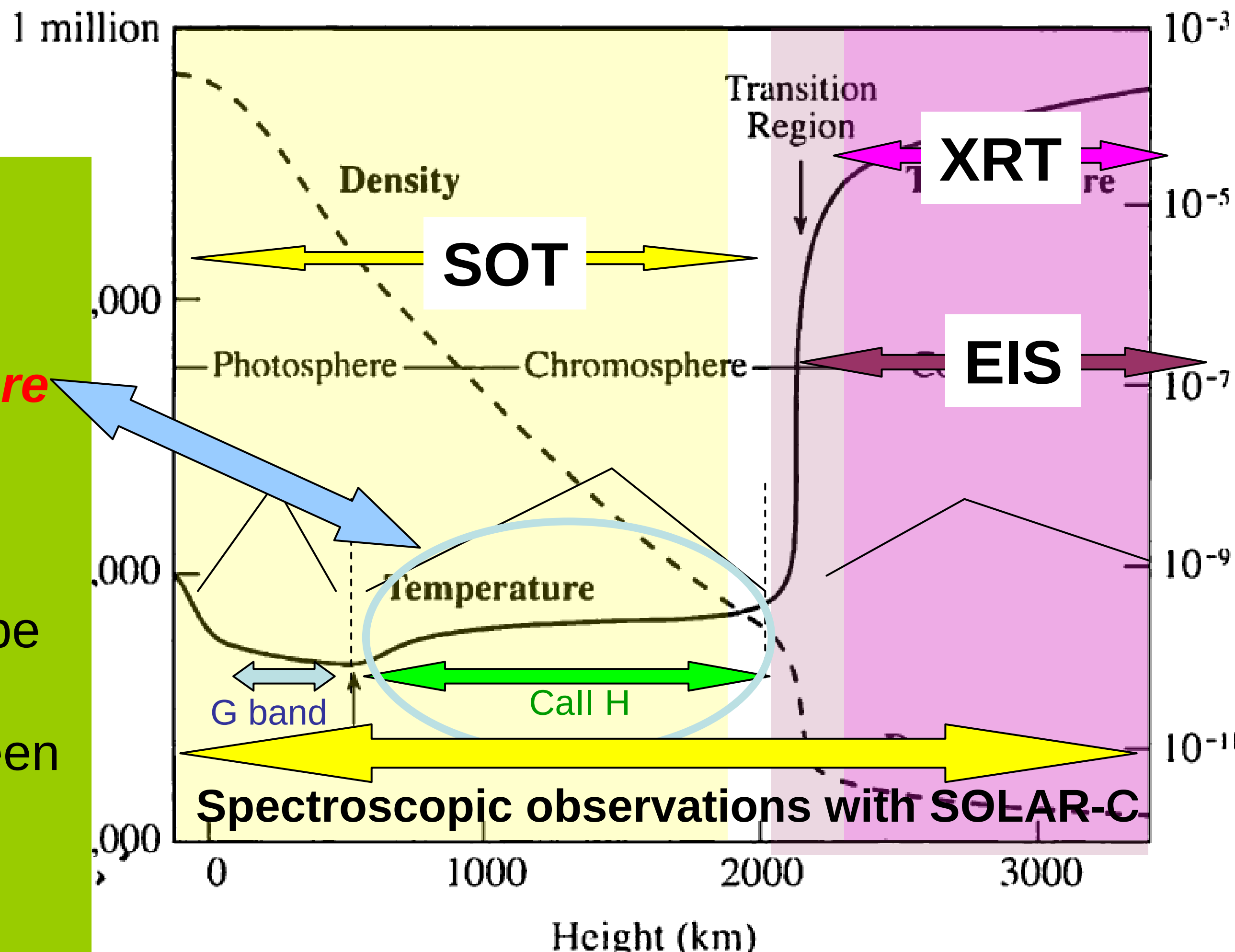
Chromosphere more dynamic than expected!



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, dicontinuities 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 spectro-polarimetry 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***

More on *Plan B* mission

- Sun-synchronous orbit
- Geo-synchronous orbit
  - For quasi-continuous access to the spacecraft
  - Use plan-B spacecraft as ground-based observatory
    - Real-time (more dynamic) response to solar situation

SOLAR －C development schedule (provisional)

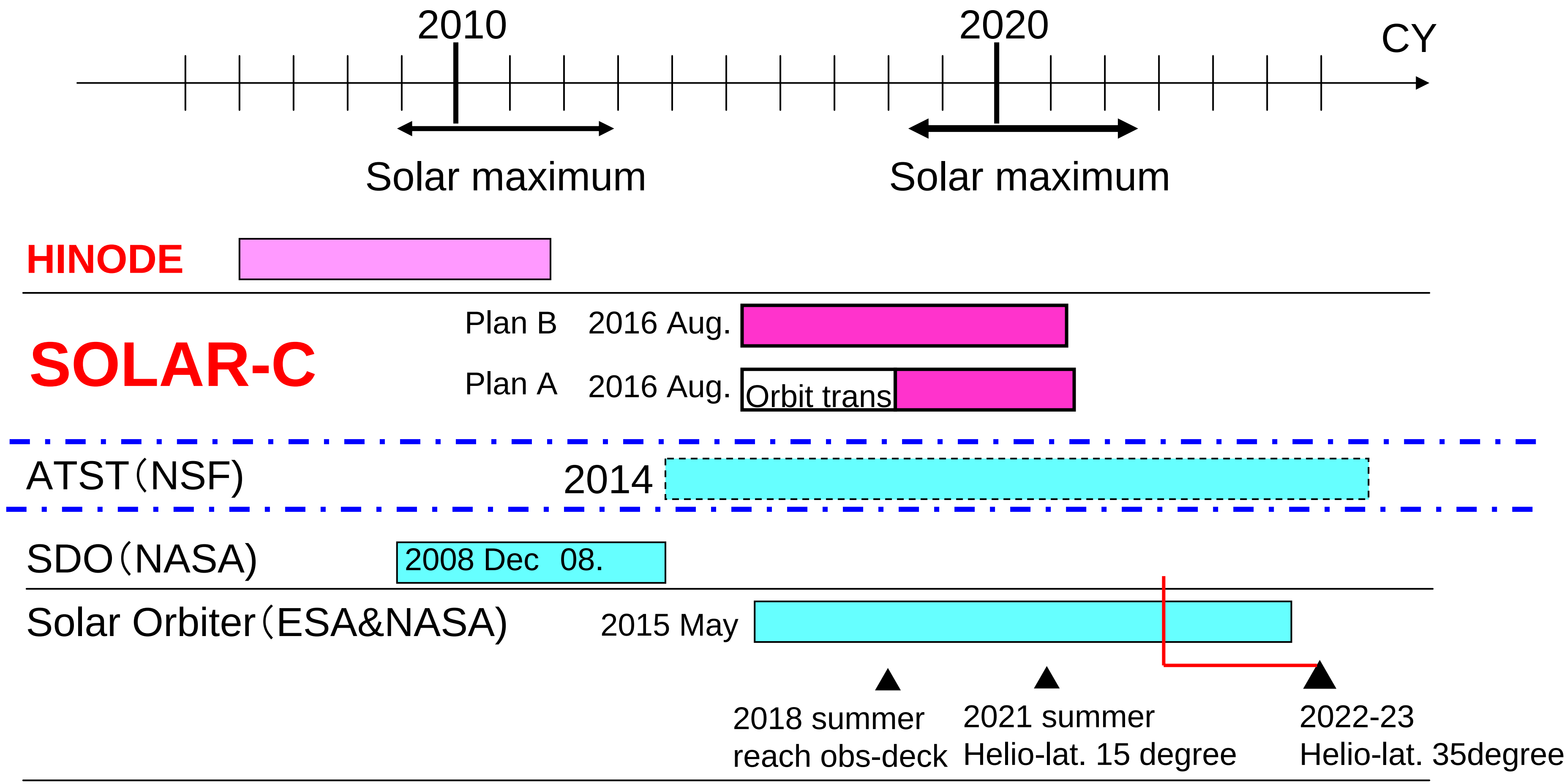
• FY2016	Launch
• FY2015	S/C tests
• FY2011～14	Flight and proto model
• FY2010	Phase-A
• FY2009	Basic development
• FY2008	Concept study
• FY2007	JAXA SOLAR-C WG

(FY: Japan fiscal year starting April 1.)

Prior activities and interactions among space agencies

- October 16 2007 meeting at NASA HQ
- December 15 2007 briefing to NAOJ director in the NAOJ roadmap meeting
- December 18 NASA-JAXA bilateral-meeting at ISAS
- December 27 2007
  - ISAS space science steering committee
  - JAXA SOLAR-C WG approved
- January 30 – February 1 20081
  - SOLAR-C－Solar orbiter information exchange meeting (MPE)
- April 1 2008 NAOJ SOLAR-C preparation office open
- Presentations on SOLAR-C in various international meetings
- August 2008 JAXA president – ESA science director in UK
- November 18-21 2008 JAXA/ISAS-JSPEC

SOLAR-C and other ongoing missions



Note1：Plan A orbit trans. period not accurate, being studied.
Note2：NASA decadal plan beyond SDO not available.
Note3：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.

SOLAR-C mission

- 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.*

Purpose of the Meeting

- Develop science cases for plans A and B
- Identify discovery space for both plans
- Understand Plan-A constraints, and build the plan A mission
- Propose model science instruments
- Solar physics community should reach common understanding on issues related to our future
- Form international sub working groups for specific critical issues if necessary
- Discuss synergy with approved programs

Notes

- S-C scientific design should be based on Hinode results.
- Presentations and discussions should be done purely from scientific point of view. Express your preference on the plan A or B freely.
- Decision-making process and future plan will be discussed at the end of the meeting i.e. after everyone has common base on issues.
- SC-WG will prioritize the two plans as a result of the meeting. SC-WG will discuss programmatic aspects with ESA and NASA.
- ESA officially supports this meeting.