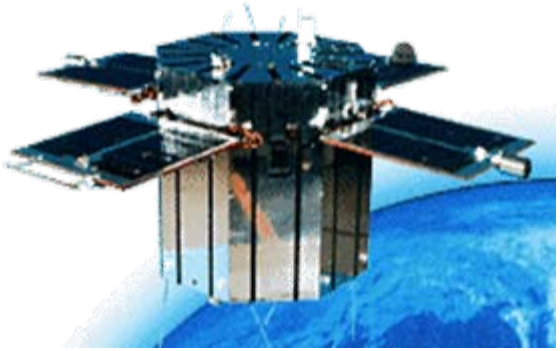
SOLAR-C mission

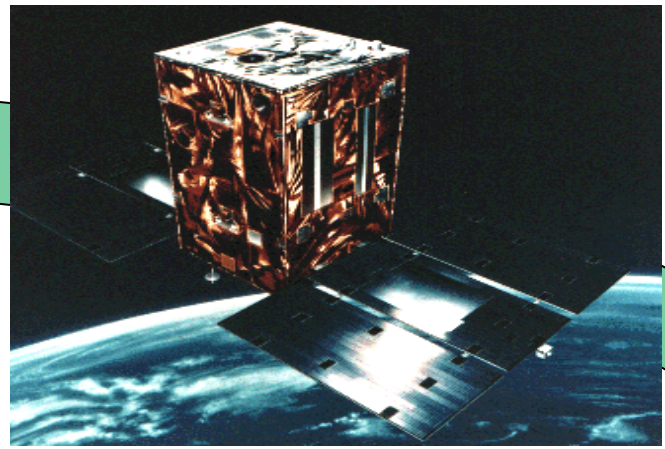
Saku Tsuneta (NAOJ/JAXA)
SOLAR-C working group
January 31, 2008

Solar physics from space in Japan



Hinotori(1981-1982)

Yohkoh (1991- 2001)
With NASA/PPARC

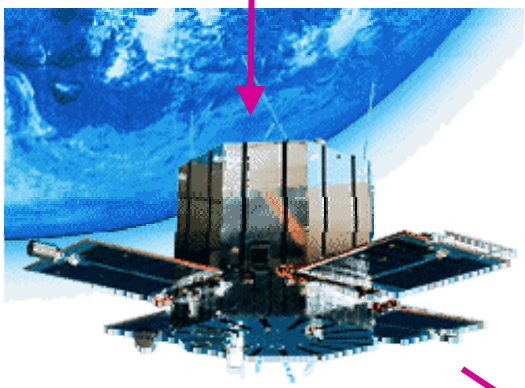


Hinode (2006-) with NASA/STFC/ESA

SOLAR-C
2010-19

Solar physics from space in Japan

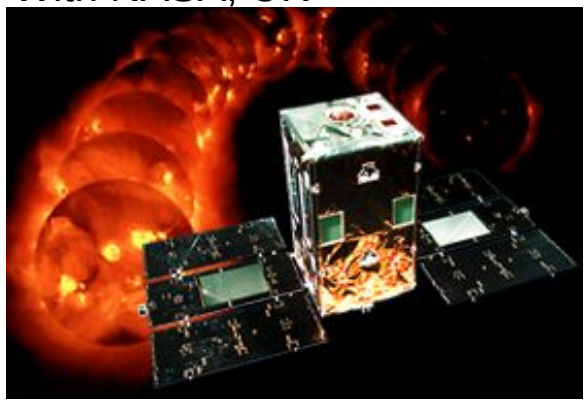
Tansei
(Pathfinder mission)



Hinotori (ASTRO-A)
188 kg, 1981

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

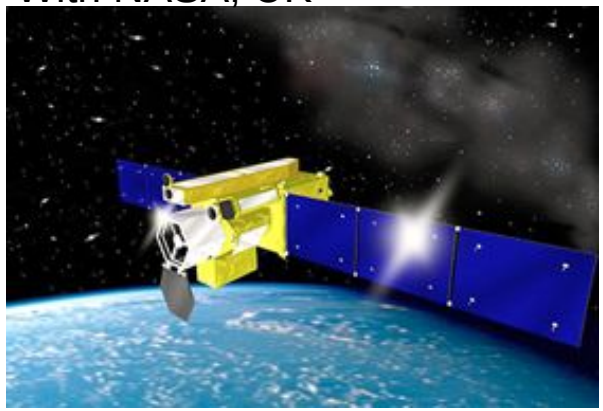
With NASA, UK



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



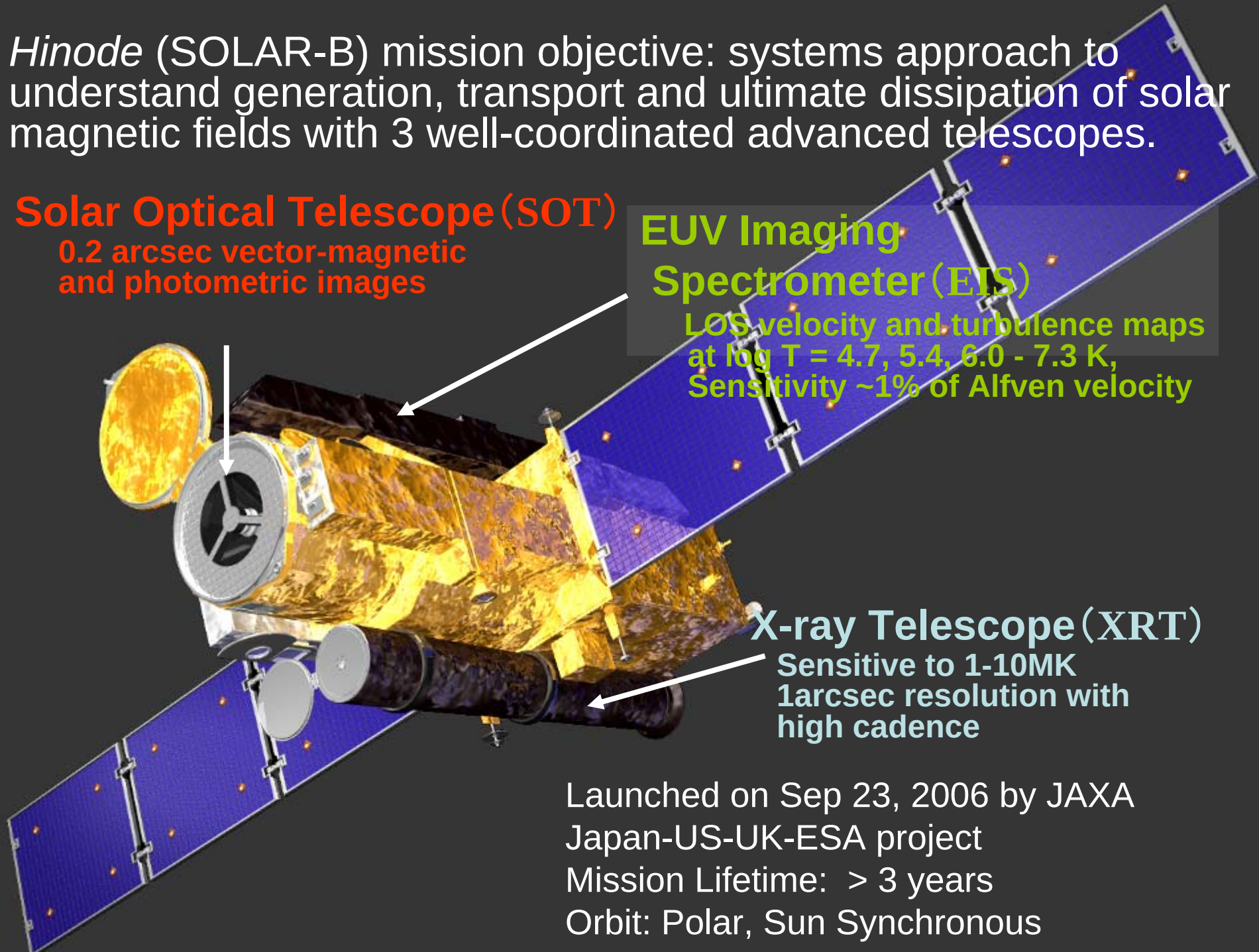
Hinode (SOLAR-B)
~ 900kg, 2006

Magnetic fields with corona
- SOT (Japan, US) 0.2 arcsec
- XRT (US, Japan) 2arcsec
- EIS (UK, US, Japan) 2arcsec

Solar Physics from Space in Japan

- Strong support from X-ray astronomers in Hinotori and Yohkoh missions
- Heritage of suborbital (sounding rocket and balloon) programs at NAOJ (U. Tokyo)
- Merge space and ground-based optical people to form one team for SOLAR-B
- With successful completion of SOLAR-B, solar physics reached critical mass to implement a major mission in stand-alone mode if with international collaboration.

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



Solar Optical Telescope（SOT）
0.2 arcsec vector-magnetic and photometric images

EUV Imaging Spectrometer（EIS）
LOS velocity and turbulence maps at log T = 4.7, 5.4, 6.0 - 7.3 K, Sensitivity ~1% of Alfven velocity

X-ray Telescope（XRT）
Sensitive to 1-10MK 1arcsec resolution with high cadence

Launched on Sep 23, 2006 by JAXA
Japan-US-UK-ESA project
Mission Lifetime: > 3 years
Orbit: Polar, Sun Synchronous

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==

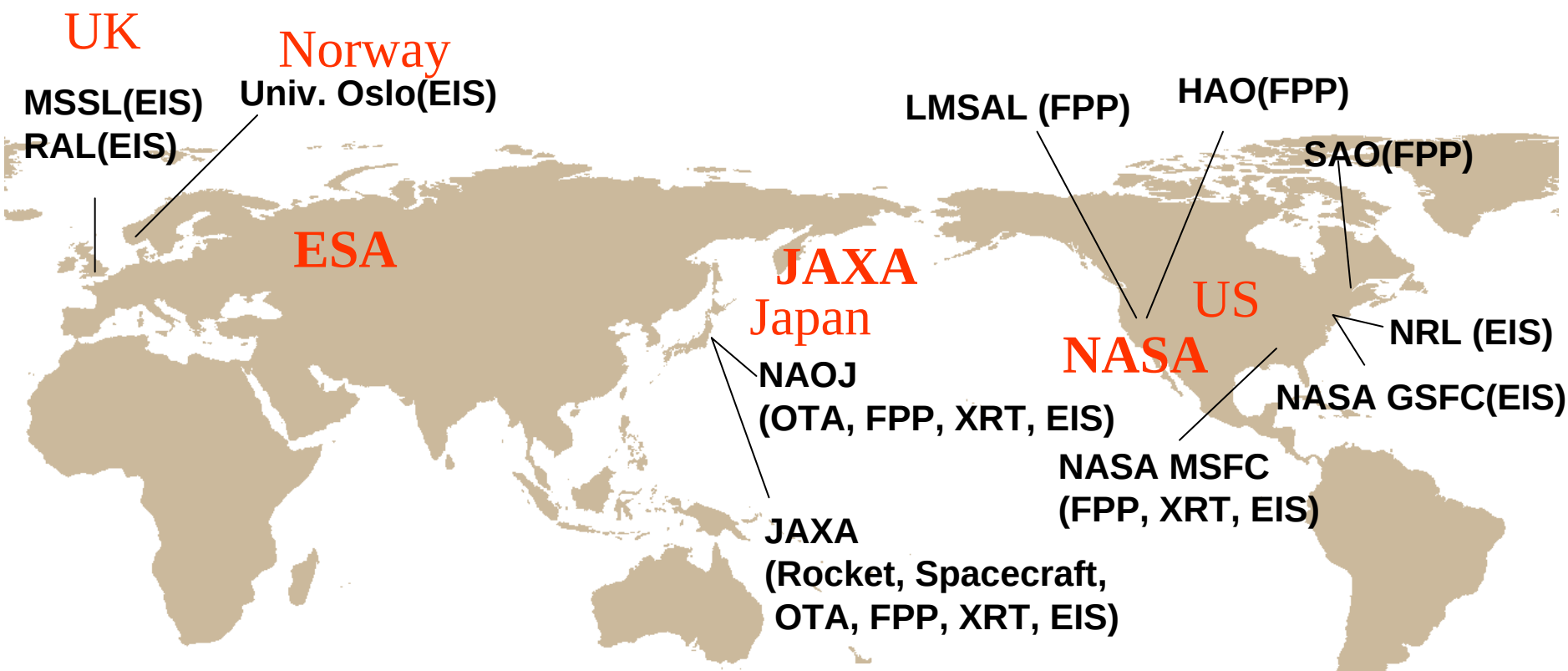
- 1998 New start with basic research ¥
- 1999-2001 Proto-model design/fab./test
- 2001-2004 Flight-model design/fab./test
- 2005-2006 Final test/launch
- 2006 PV Observations start

SOLAR-B science mission design（1995-1997）

- 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.*

Strong international collaboration for SOLAR-B

3 space agencies, 11 organizations in 4 countries



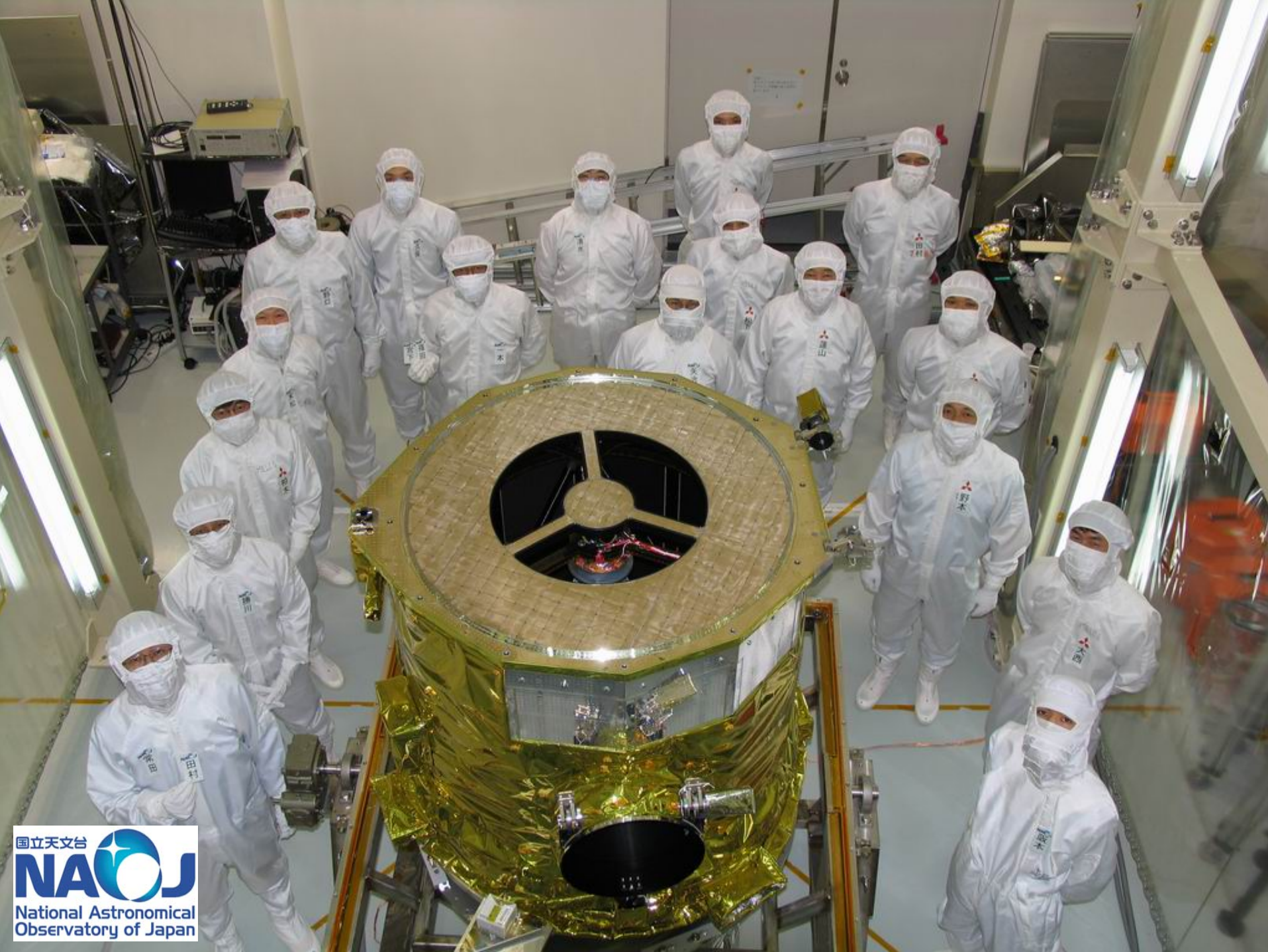
JAXA 宇宙航空研究開発機構 Japan Aerospace Exploration Agency

国立天文台 NAOJ National Astronomical Observatory of Japan

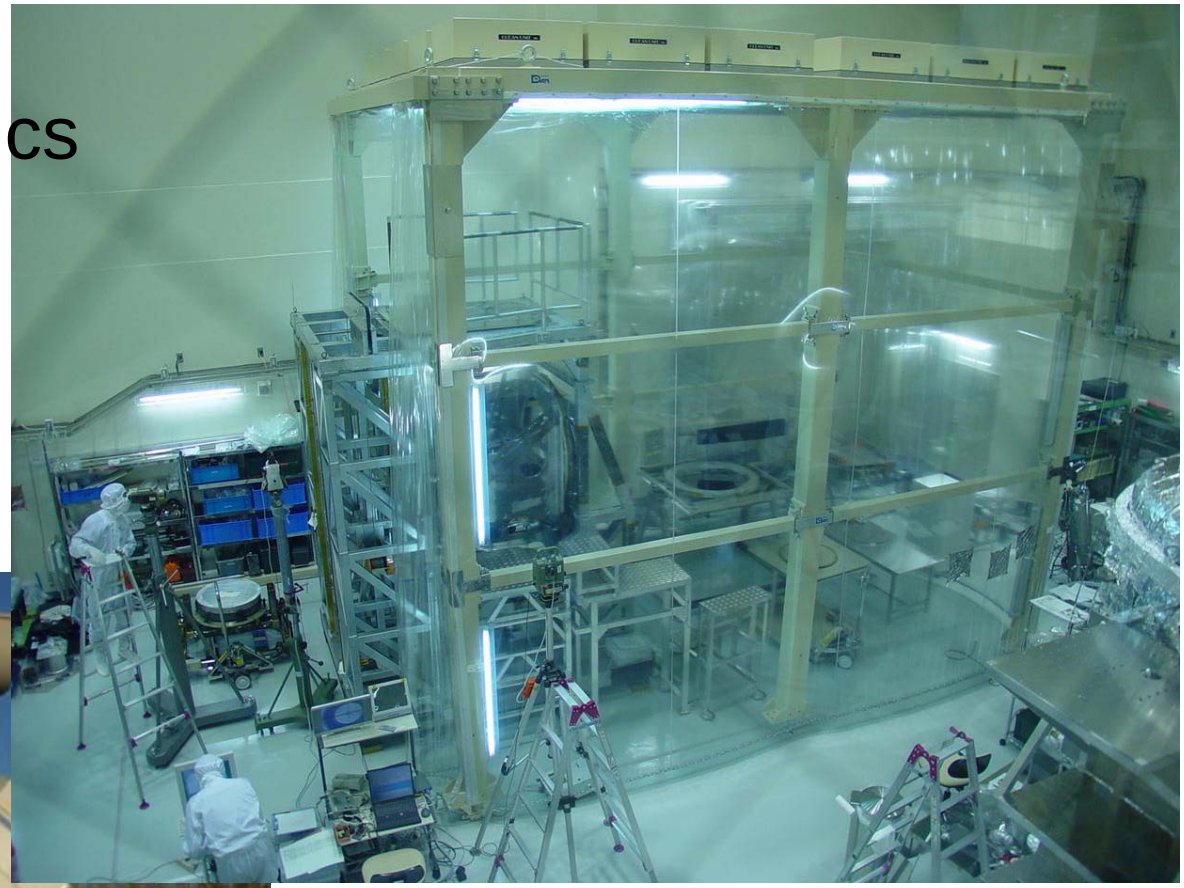
NASA

Science & Technology Facilities Council

esa

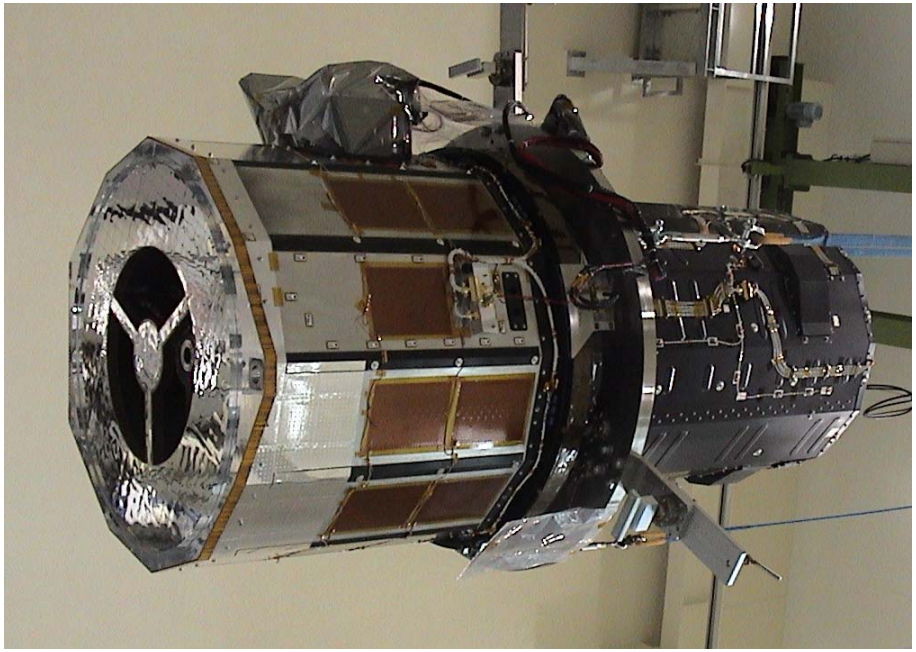

国立天文台
NAOJ
National Astronomical
Observatory of Japan

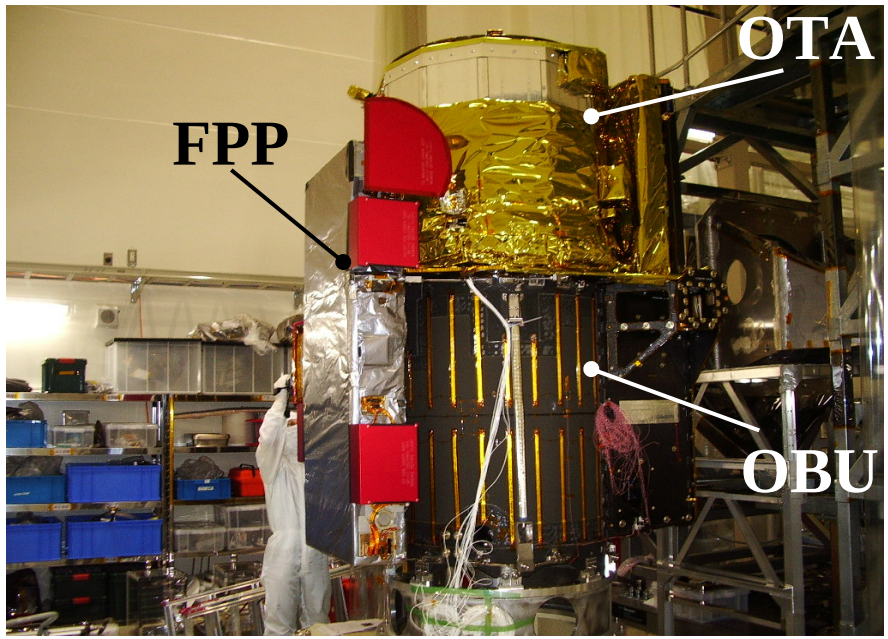
NAOJ/ATC Clean Room for space optics



190m^2 ,10mHigh
Class 100
Class 0-10 in the booth
Space-chamber, large optical flat, fast interferometer, large Newport table

Heliostat to introduce natural star and sun light: Beam size 55 cm dia.

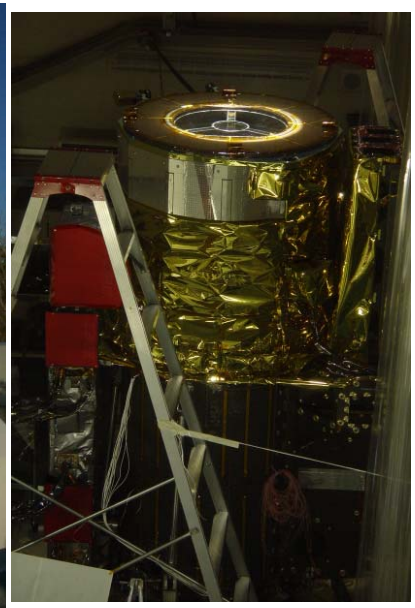


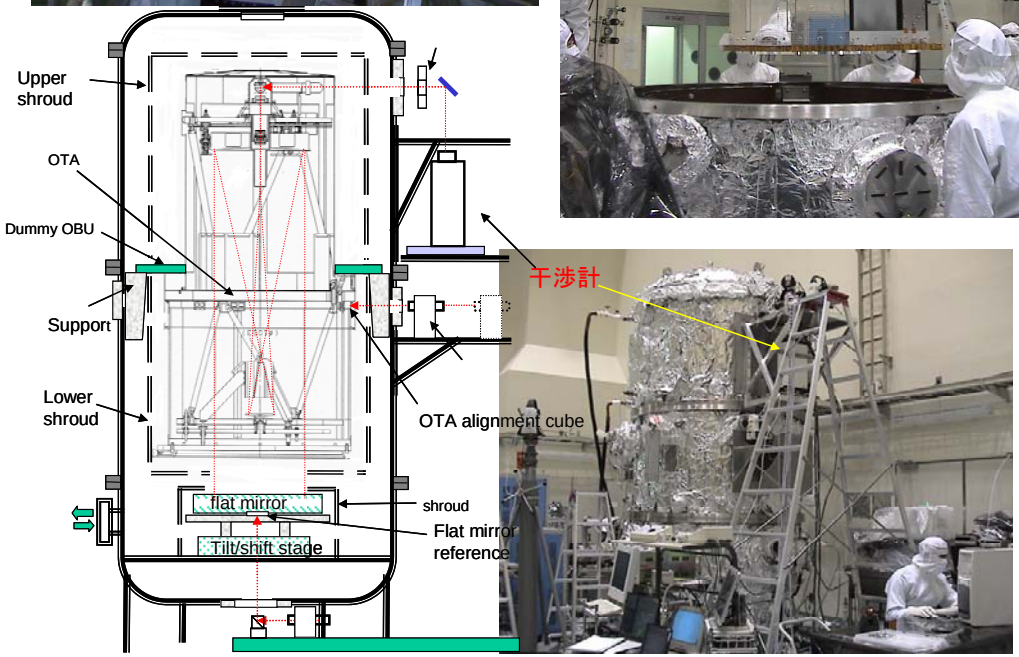


SOT assembly and test at NAOJ/ATC

Telescope integration and test at NAOJ/ATC clean room

Thermal vacuum test





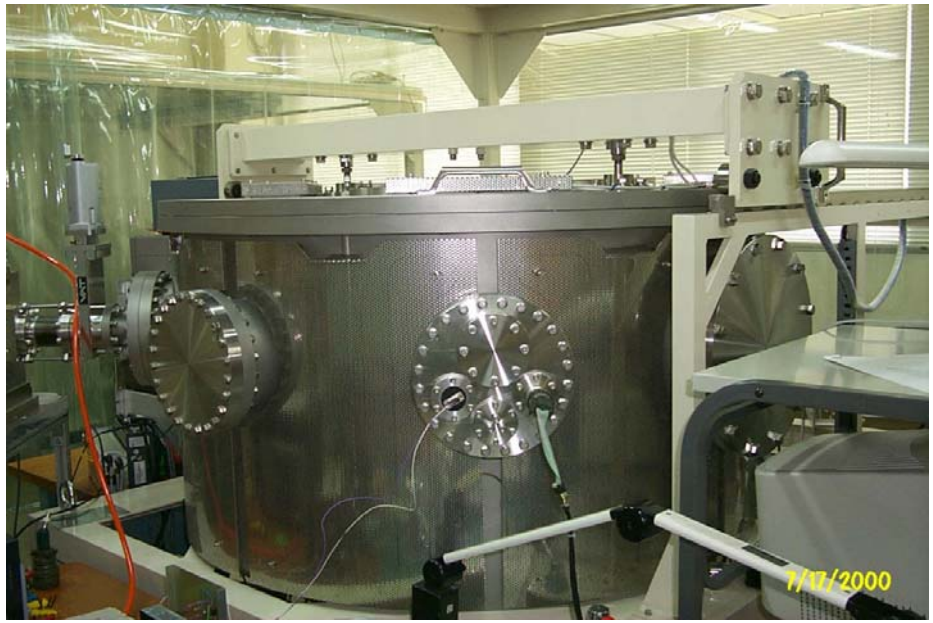
Telescope in clean room illuminated with 50cm sun beam

Optical performance test in orbit environment

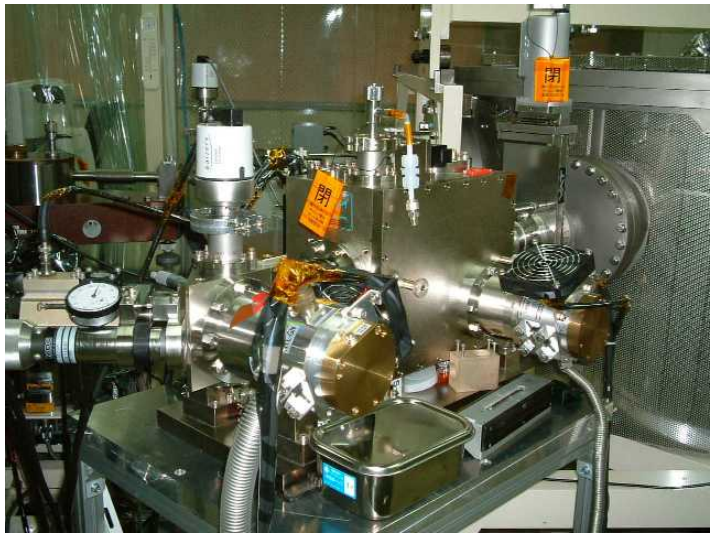
XRT Camera Calibration Facility at NAOJ/ATC

X-ray Monochrometer

Vacuum Chamber

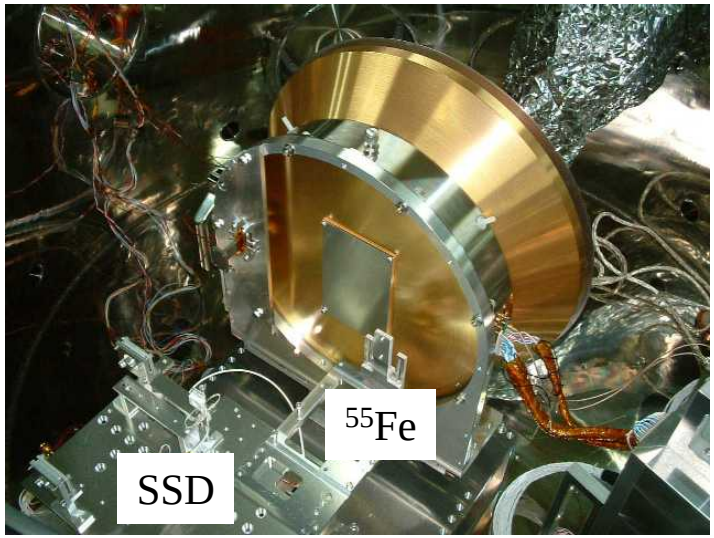


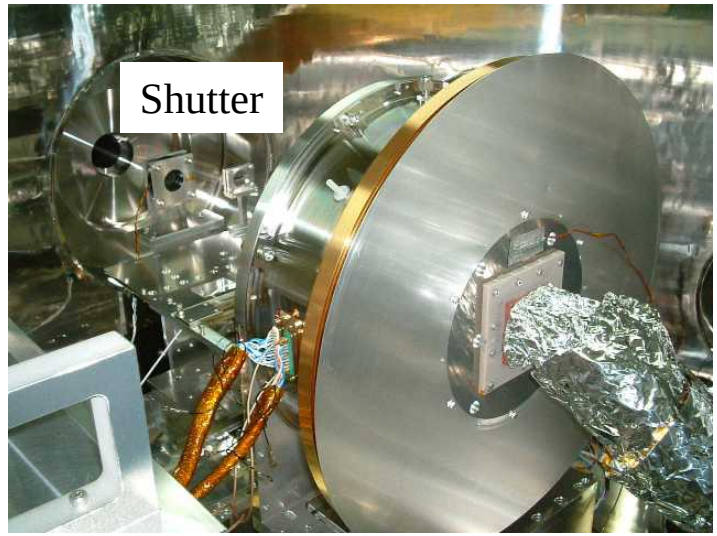
XRT Camera Calibration Facility



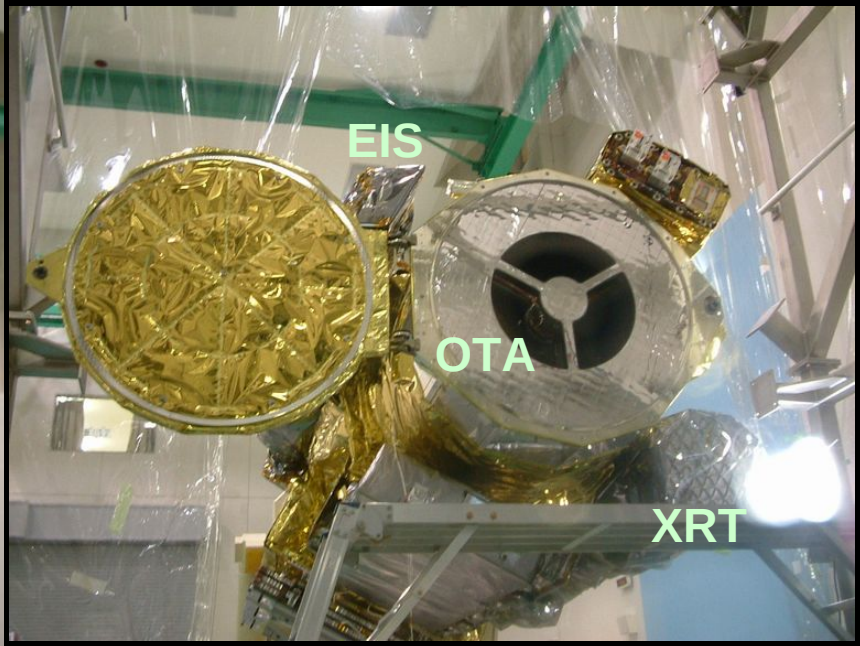
X-ray monochrometer

EUV monochrometer





SOLAR-B Flight model at ISAS



SOLAR-C mission

Parallel investigation

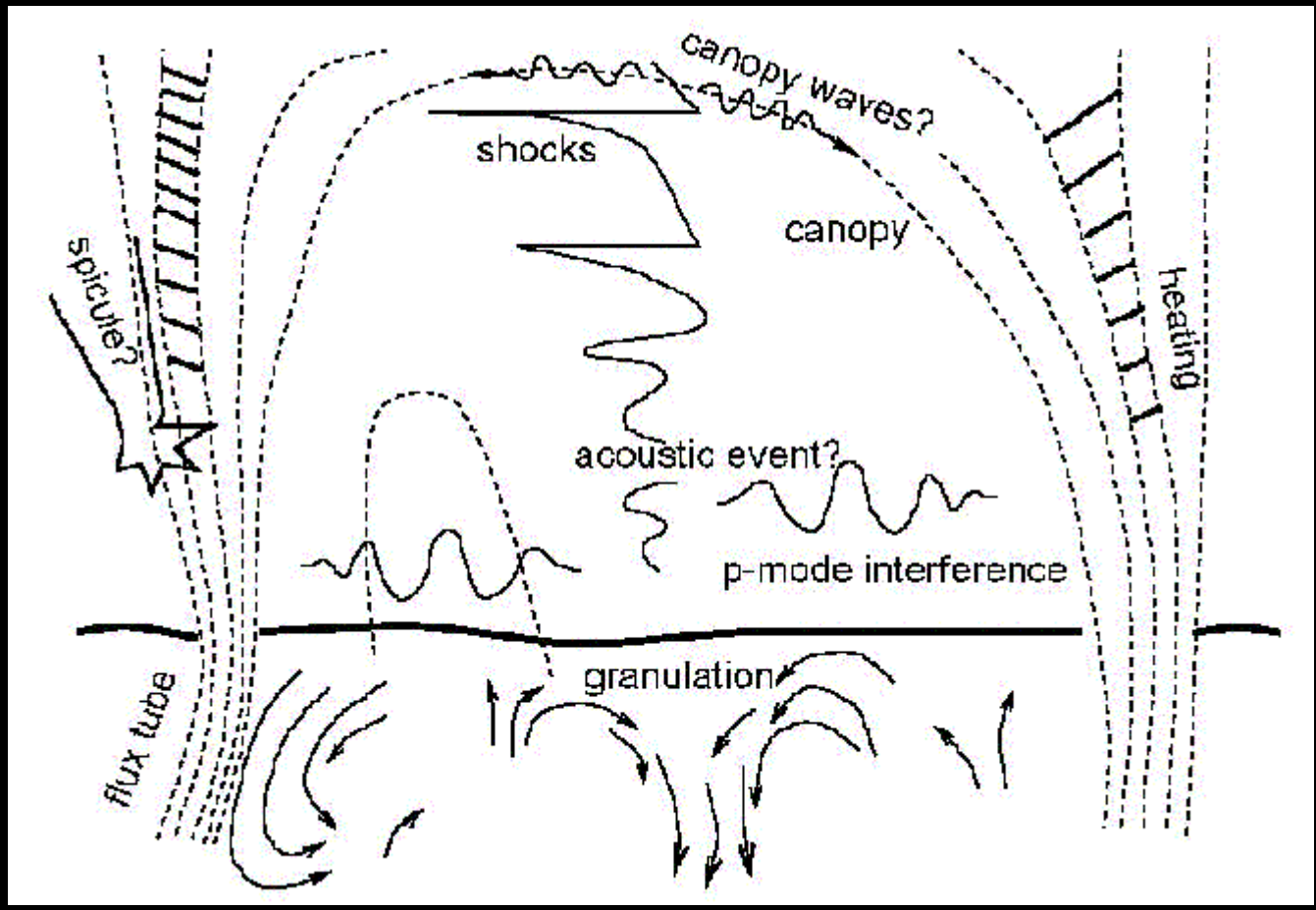
- Plan A: Out-of-ecliptic magnetic and helio-seismic observations of solar polar region to investigate the internal structure and dynamo mechanism of the Sun.
- Plan B : Higher resolution observations to investigate heating and dynamics of solar atmosphere with UV-enhanced Hinode SOT plus advanced spectroscopic capabilities
- Request mid-2010 launch.
- Launch vehicle JAXA H-IIA.

Plan A: Investigate the sun as a star through exploration of polar regions

- Out-of-ecliptic observations on solar polar regions have never been performed.
- Hinode is providing unprecedented view on the magnetic landscape of the solar polar regions.
- Observing target includes
  - Helio-seismic observations on internal acoustic speed, angular rotation speed, meridional flow, and flux tube imaging
  - Magnetic observations on surface magnetic and velocity fields
  - Option: reach deep convection zone and tachocline with dual satellite observations, using the methodology of local helio-seismology.
  - Option: in-site instruments

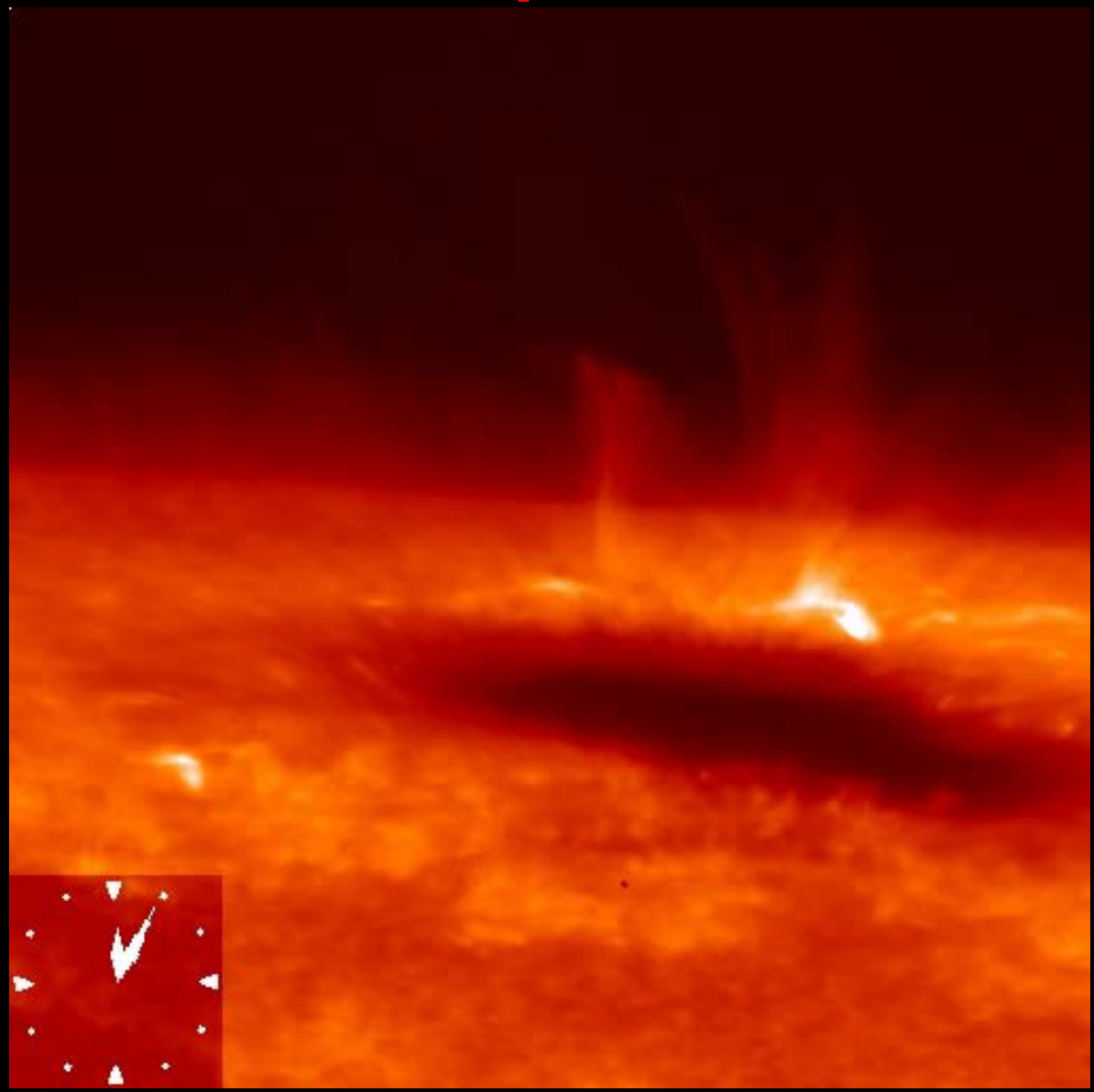
Magnetic and velocity fluctuations in the Solar Atmosphere

Granular motion
Elemental flux tube
Acoustic waves
Hot corona
Spicules
etc etc….



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

Chromosphere more dynamic than expected!



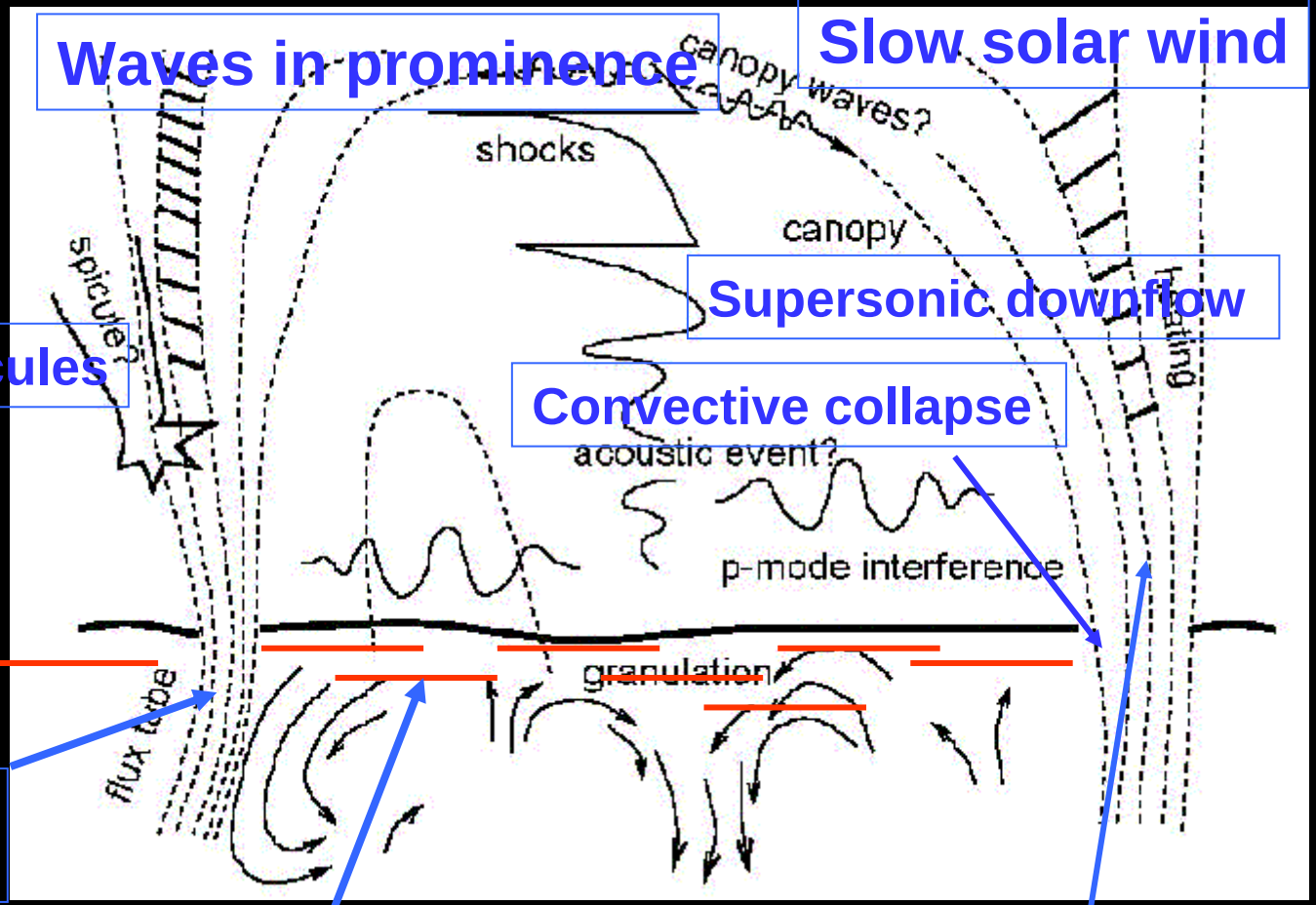
Post-Hinode understanding on solar atmosphere

Polar kG fields

Slow solar wind

Waves in prominence

Chromospheric jets due to reconnection



Supersonic downflow

Waves along spicules

Convective collapse

Penumbral micro-jets

Magnetic velocity Fluctuation

Ubiquitous Horizontal fields

High coronal turbulence

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

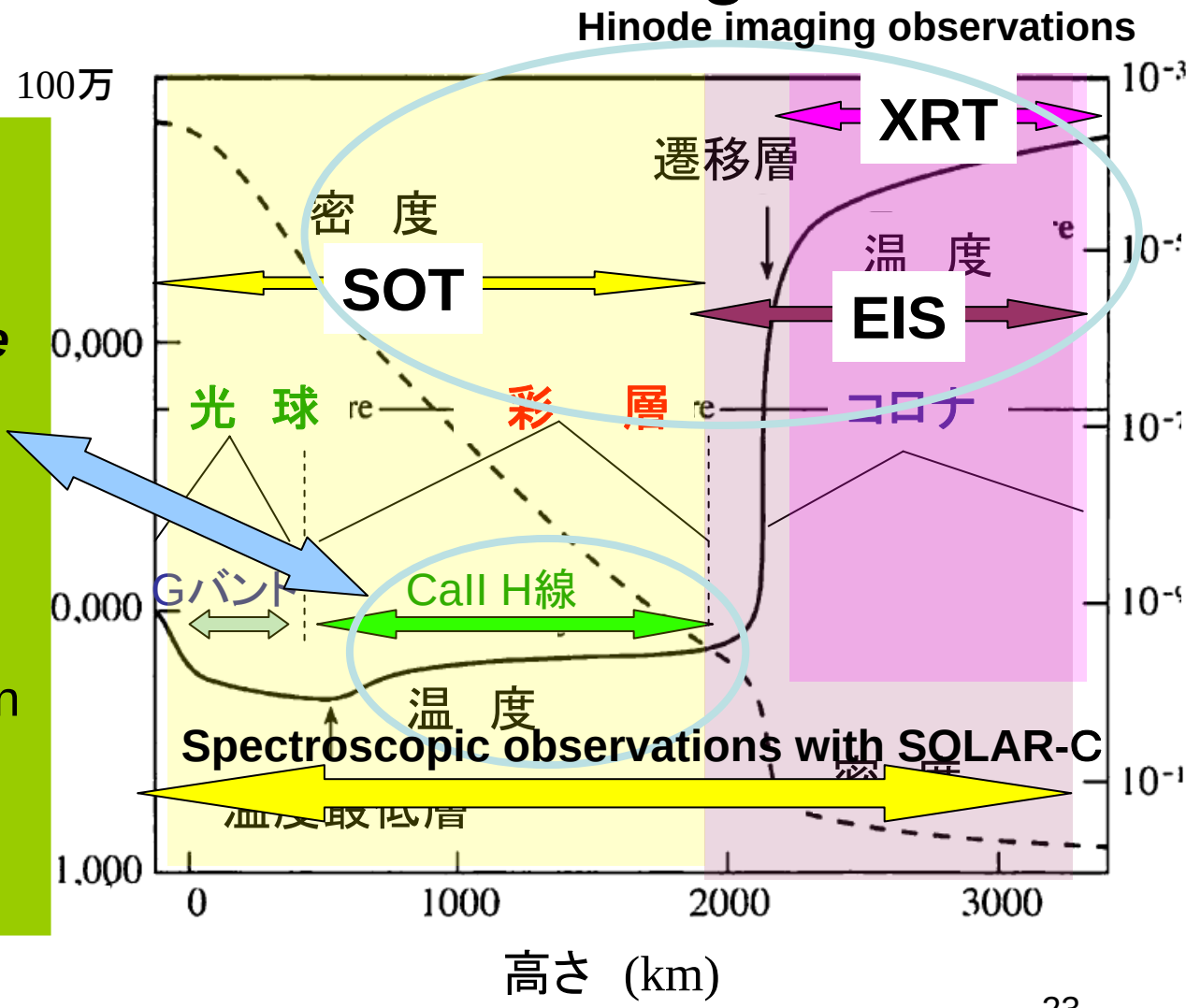
Plan B：High resolution observations from photosphere to corona through interface region of chromosphere and transition region

- From imaging to spectroscopy: obtain precise information on dynamics such as waves, thermal and MHD instabilities, reconnection and on magnetic fields
- From visible to UV: cover the entire solar atmosphere from photosphere to corona through chromosphere and transition region
- Strawman instruments
  - Visible-UV telescope（1300-8500Å）＞50cm diffraction-limited telescope（＜0.1-0.3arcsec）with advanced imaging and spectoscopic instruments
  - Ultra-high resolution EUV/X-ray telescope（100-1000Å）
  - Enhance high-resolution spectroscopic capability as compared with Hinode.
- Understanding on coronal and chromospheric heating and dynamics through observations by combination of spectroscopic and imaging instruments
  - Magnetic and velocity fields of photosphere and chromosphere
  - Wave, turbulence, magnetic reconnection, mode coupling of waves at $\beta \sim 1$ layer
- Progress on Hinode data analysis would affect the mission concept.
  - For instance, remarkable dynamical phenomena of the chromosphere revealed by Hinode intensify interests on the plan B mission.
- Key technology for >50cm diffraction-limited telescope available due to Hinode heritage

End-to-end observations on 5000km-thick layer exhibiting 4000K-to-a few MK change

Hinode imaging observations reveal unexpected highly dynamic chromosphere

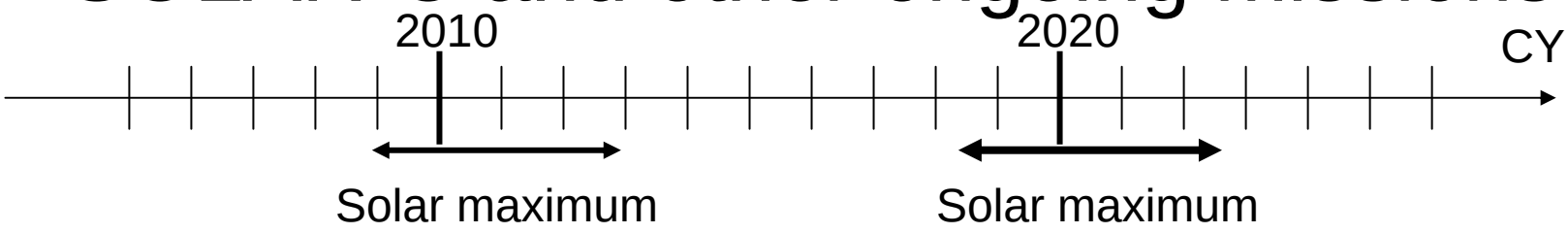
- Chromosphere needs x10 heating energy.
- Not static atmosphere
- Coronal heating may be closely related to the interface region between the magnetic photosphere and the dissipative corona.



Plans A and B

- JAXA SOLAR-C WG investigates science, technology, and other constraints with international teams for decision.
- Tradeoff and figure-of-merit for decision making
  - Science merit is always the major driver.
    - Importance of deepening the Hinode science analysis
  - Feasibility of plan-A spacecraft and orbit critical
  - Technical feasibility for science instruments under constraints
  - Consistency and synergy with NASA and ESA plans

SOLAR-C and other ongoing missions



HINODE

SOLAR-C

B案 2015 Feb.

A案 2015 Feb. Orbit trans

ATST（NSF） 2014

SDO（NASA） 2008 Dec 08.

Solar Orbiter（ESA） 2015 May

2018 summer reach obs-deck

2021 summer Helio-lat. 15 degree

2022-23 Helio-lat. 35degree

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.

SOLAR-C launch opportunity (Not authorized by JAXA)

- PLANET-C 2010
- HAYABUSA-II 2011
- ASTRO-G 2012
- NEXT 2013
- SOLAR-C 2014

Justification for mid-2010 launch

- Plan A satellite has to reach a observing point around 2018 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
- Continuity in solar physics research in Japan requires mission approximately every 10 years
  - Hinode launched in 2006.
  - Hinode science and data continue to be first grade upto solar maximum around 2011.
- Avoid vacuum in solar physics: No similar mission yet defined in NASA and ESA(?)

SOLAR－C development schedule
(under review by SOLAR-C WG and not authorized by JAXA)

- FY2014　　Lauch〔2015 February〕
- FY2014　　S/C tests
- FY2012～13　　Flight model
- FY2010～11　　Proto model
- FY2009　　JAXA phase-A
- FY2008　　Select plan A or B
- FY2007　　JAXA SOLAR-C　WG

SOLAR-C near-term calendar

- 2007 October 16
  - Meeting with NASA HQ personnel (Washington D.C.)
- 2007 December 18
  - Meeting with NASA HQ delegation led by Dr. Alan Stern (ISAS).
- 2007 December 27
  - SOLAR-C working group approved at ISAS space science steering committee with recommendation to present one mission again in one year
- 2008 Jan 30—Feb 1
  - SOLAR-C—ESA Solar Orbiter science meeting in Lindau

SOLAR-C Summary

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

SOLAR-C organization

- JAXA/ISAS working group
  - Chair Tsuneta
  - Vice chair Sakao, Shimizu, Watanabe
- NAOJ SOLAR-C project office (proposed)
  - Head Hara
  - Vice head Katsukawa