SOLAR-C mission

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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)
With NASA, UK

Hinotori (ASTRO-A)
188 kg, 1981

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

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

Hinode (SOLAR-B)
~ 900kg, 2006

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

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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 $T = 4.7, 5.4, 6.0 - 7.3 \, \text{K}$, Sensitivity $\sim 1\%$ of Alfvén 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
NAOJ/ATC Clean Room for space optics

190m², 10m High
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 assembly

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 monochromator

EUV monochromator

SSD

$^{55}$Fe

Shutter
SOLAR-B Flight model at ISAS
SOLAR-C mission
Parallel investigation

- **Plan A**: Out-of-ecliptic magnetic and helioseismic 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

Chromospheric jets due to reconnection
Waves along spicules
Penumbral micro-jets
Magnetic velocity fluctuation

Waves in prominence
Convective collapse
Supersonic downflow
Slow solar wind
High coronal turbulence
Ubiquitous horizontal fields
Polar kG fields

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 (1300-8500 Å) > 50 cm diffraction-limited telescope (<0.1-0.3 arcsec) with advanced imaging and spectroscopic instruments
  - Ultra-high resolution EUV/X-ray telescope (100-1000 Å)
  - 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 >50 cm 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.

Spectroscopic observations with SOLAR-C

Hinode imaging observations

XRT

EIS
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**
  - A case: 2015 Feb. (Orbit trans)

- **SOLAR-C**
  - 2014

- **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. 35 degree

**Notes**:

1. Plan A orbit trans. period not accurate, being studied.
2. NASA decadal plan beyond SDO not available.
3. 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  Launch [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