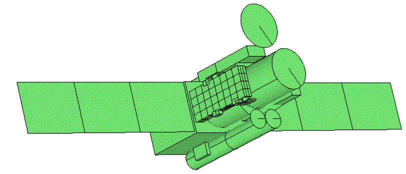

High Resolution Observatories in the Coming Decade

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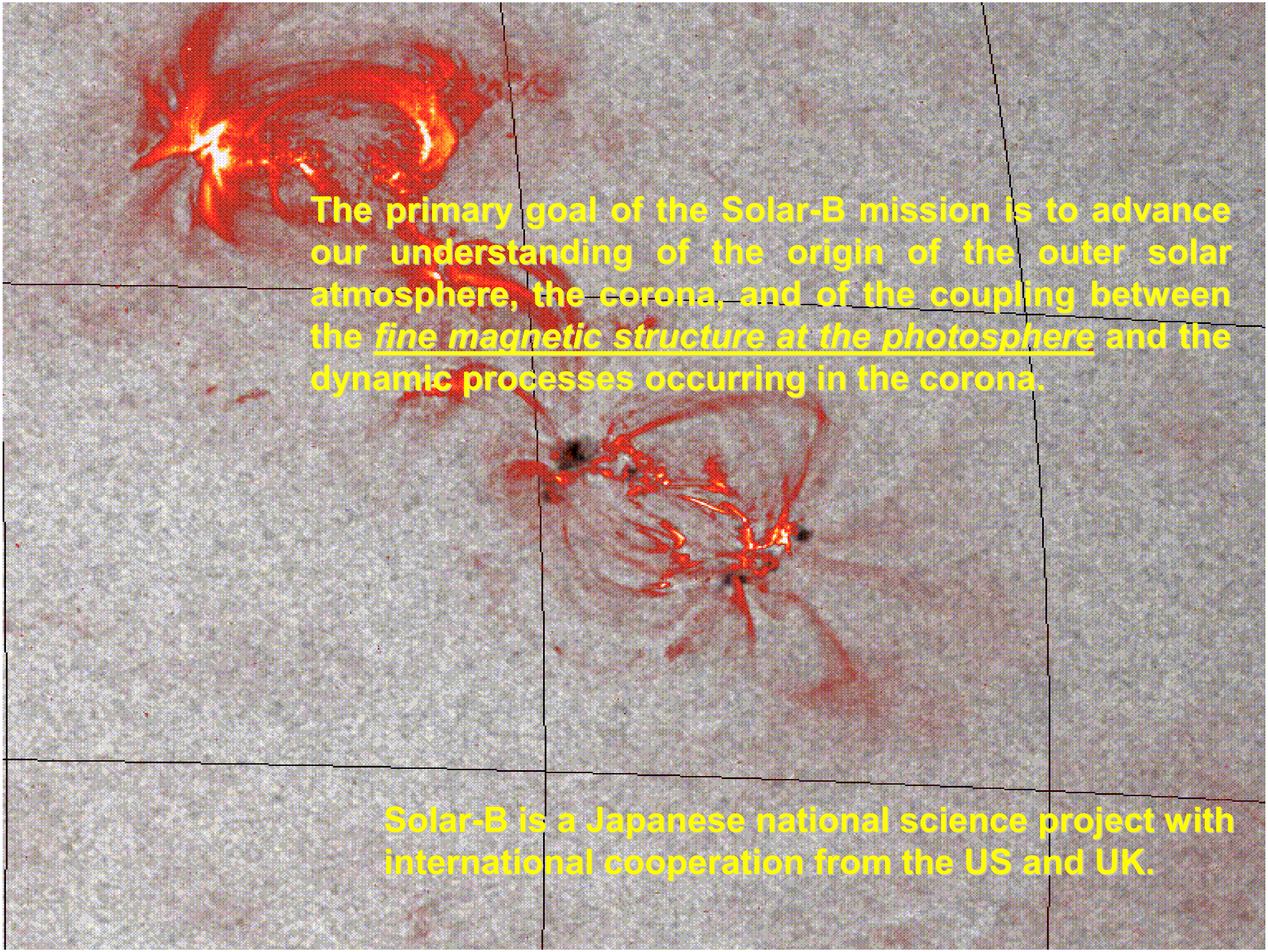
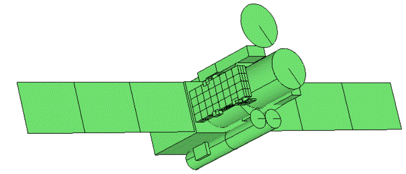
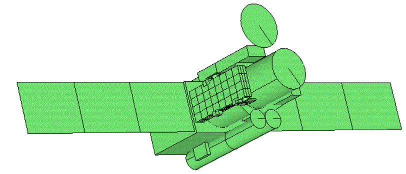

The primary goal of the Solar-B mission is to advance our understanding of the origin of the outer solar atmosphere, the corona, and of the coupling between the *fine magnetic structure at the photosphere* and the dynamic processes occurring in the corona.
Solar-B is a Japanese national science project with international cooperation from the US and UK.

Solar-B Overview



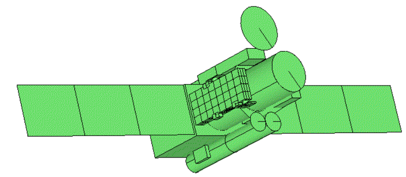
- Solar-B will be launched from Japan in summer, 2005
  - **Prof. Takeo Kosugi of ISAS is the Solar-B Project Manager and PI**
- Solar Optical Telescope (SOT) -- 50 cm Gregorian Telescope provided by ISAS
  - **Built by Mitsubishi Electronics Company for ISAS & NAOJ**
  - **Japanese PI Prof. Saku Tsuneta**
- Focal Plane Package (FPP) -- Spectropolarimeter and Filtergraph Instrument provided by NASA
  - **Built at LMSAL in collaboration with HAO**
  - **US PI Alan Title**
- Other Solar-B Instruments
  - **X-Ray Telescope (XRT), by ISAS and NASA (SAO, Leon Golub is US PI)**
  - **EUV Imaging Spectrometer (EIS), by UK, ISAS, and NASA (NRL, George Doschek)**

Solar-B Spacecraft



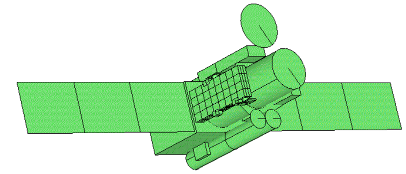
- Launch: August or September, 2005, on ISAS M-V rocket
- Orbit: 625 km Sun-synchronous polar orbit
- Lifetime: >3 years
- Mass: ~900 kg (including propellant)
- Power: ~1000 Watts
- Attitude control: 3-axis stabilized body control (< 1 arcsec stability) with tip-tilt mirror for optical telescope (0.02 arcsec)
- Science data rate (after JPEG/DPCM compression): average 300~500Kbps, maximum 2Mbps
- Telemetry: ~ 4 Gbit onboard storage, playback at 4 Mbps over Kagoshima and overseas sations (including NASA)

SOT/FPP Requirements



- **Spatial Resolution < 0.25 arcseconds**
  - Preserve imaging quality of SOT from 3880 — 6600 Å.
- **Field of view > 200 x 100 arcseconds**
  - Capture entire active region and significant portions of surrounding quiet network.
- **Image stabilization system < 0.02 arcseconds**
  - Stabilize S/C jitter to < 0.02 arcsec over range of 2 — 20 Hz.
- **Science Instruments**
  - Narrowband Tunable Filter: better than 1% precision magnetograms
  - Broadband Filter Instrument: 0.2 arcseconds 3880Å
  - Spectro-Polarimeter: better than 0.1% precision Stokes vector measurements.

FPP Major Components



- **FPP: <u>Focal Plane Package</u>**

➔ NFI: Narrowband Filter Imager

Tunable Birefringent filter: ~ 0.1 Å bandwidth, vector magnetograph.
Data similar to the SOUP filter images from La Palma, with higher sensitivity and spatial resolution.

➔BFI: Broadband Filter Imager

Interference filters for short exposures and highest image quality.
Data similar to G- band movies from La Palma, with perfect seeing.

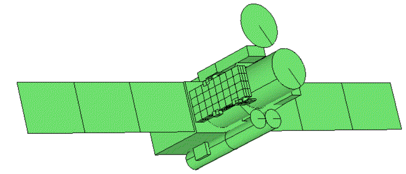
➔SP: Spectro-Polarimeter

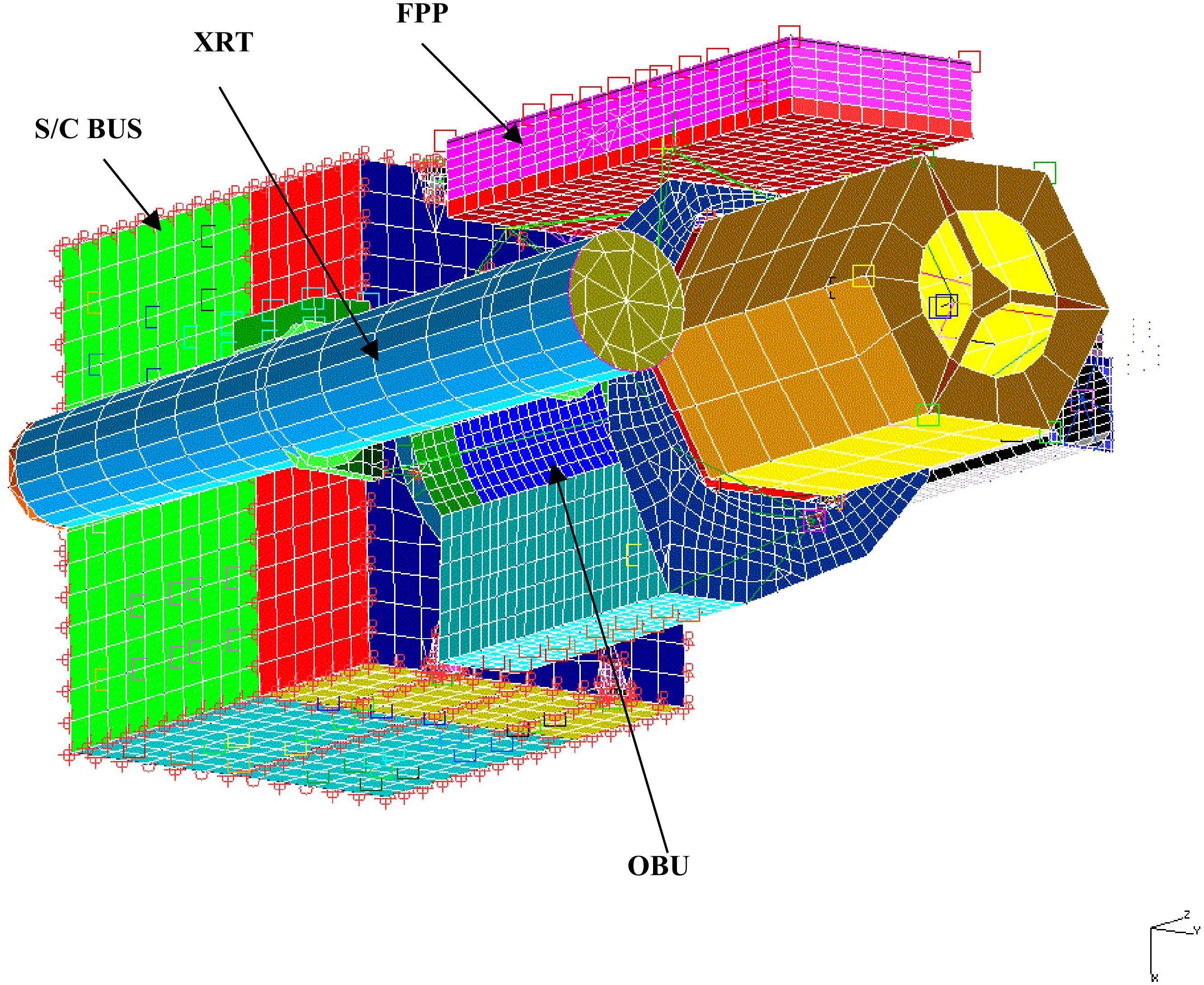
Fe I 6301/2Å lines: dual-line dual-polarization spectra for high precision Stokes polarimetry.
Data similar to HAO Advanced Stokes Polarimeter, with much higher spatial resolution.

➔CT: Correlation Tracker

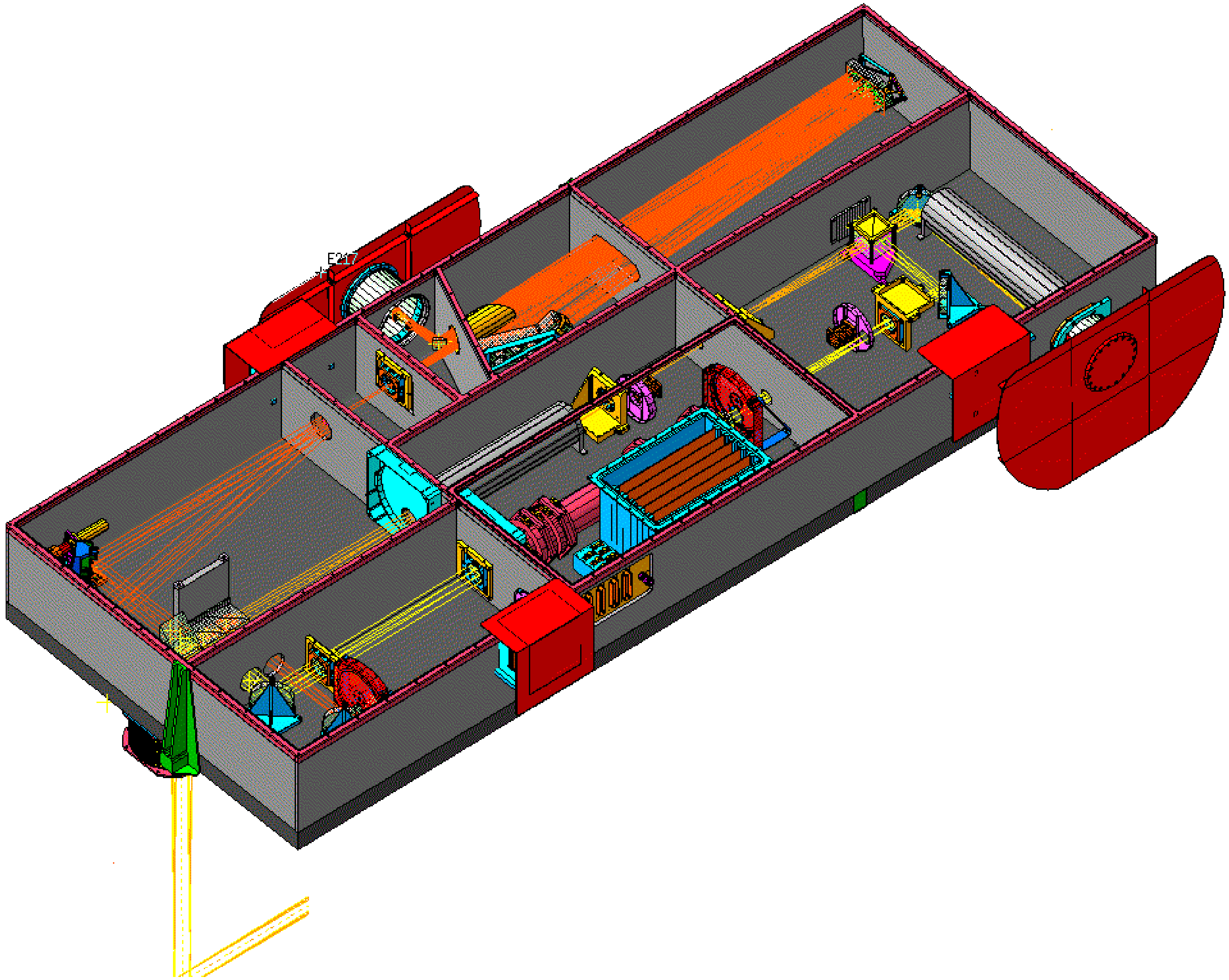
Jitter sensor for image stabilization with tip/tilt mirror.

SOLAR-B SYSTEM FINITE ELEMENT MODEL



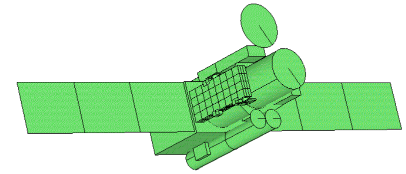


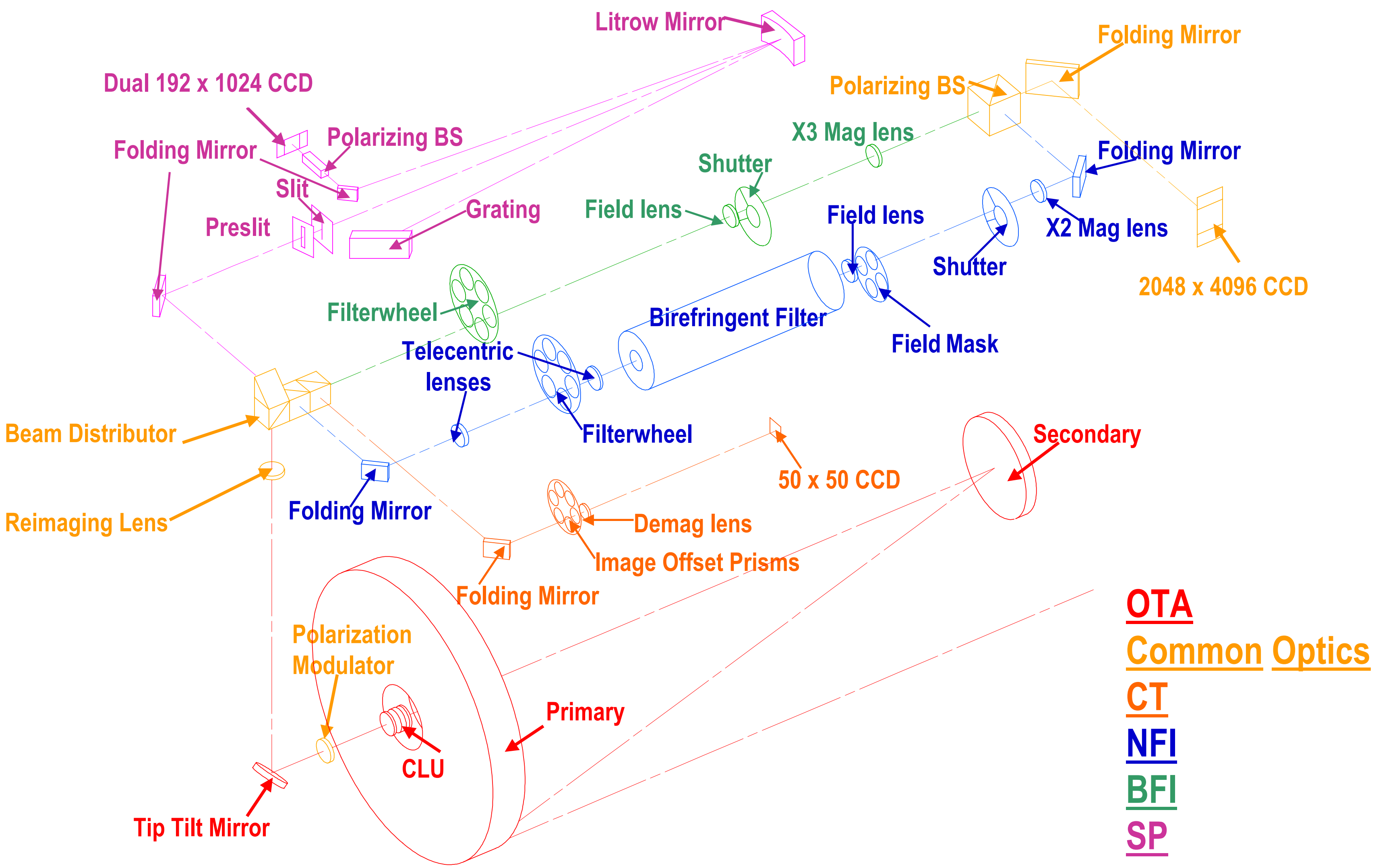
FPP Instrument - Y Side



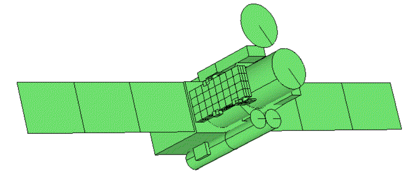
Beyond Solar-B

Optical Schematic of SOT/FPP





Cast of (New) Characters



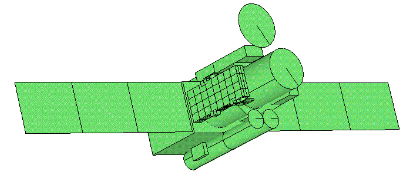
- **Ground Based Observatories**
  - Dutch Open Telescope (DOT), New Swedish Solar Telescope (NSST), GREGOR, Advanced Technology Solar Telescope (ATST)
  - Plus our old friends at Sacramento Peak, Big Bear, Tenerife, etc. with new technology (adaptive optics, image reconstruction, new detectors, etc.)
- **Balloon Missions**
  - Flare Genesis Experiment (FGE), SUNRISE
- **Space Missions**
  - Solar-B, Solar Orbiter, Chinese Space Solar Telescope
  - Solar Lite, Solar Probe, Super-X, HIREX, DEUCE
  - SEC Roadmap Missions: High Resolution Solar Optical Telescope (HRSOT), Reconnection and Micro-Scale Probe (RAM)
- **Moderate Resolution (Full Disk) Observatories**
  - Solar Dynamics Observatory (SDO), SOLIS

Beyond Solar-B

Dutch Open Telescope

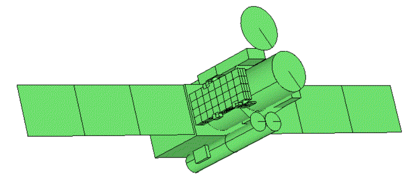
- Open tower telescope on La Palma, next to Swedish Tower
- 45 cm Primary mirror (tower can accomodate 1 meter)
- Cameras & data acquisition system for very high resolution multi-wavelength speckle imaging
- Pathfinder for new open telescopes (GREGOR, ATST)
- See http://dot.astro.uu.nl

New Swedish Solar Telescope (NSST)



- Upgrade of La Palma Swedish Vacuum Solar Telescope
- 1 meter Objective Lens, Vacuum Tower design similar to SVST
- Two secondary optical systems, both with Adaptive Optics
  - Monochromatic imaging or polarimetry with best possible image quality
  - Achromatic imaging using Schuppmann corrector
- In construction now, possible first light late summer, 2001
- See http://www.astro.su.se/groups/solar/NSST/nsst.html

GREGOR



- New 1.5-meter telescope on the Gregory Tower in Tenerife
- In development by a consortium of German solar physics research institutes
- Lightweight Silicon Carbide mirrors and stiff, open structure
- Optimized for spectro-polarimetry: POLIS
- See http://gregor.kis.uni-freiburg.de/

Open Telescope

GREGOR is designed as a completely open telescope with a retractable dome, to avoid internal seeing. This design allows for a lightweight and very stiff construction. Care will to be taken to protect the telescope from dust and from strong wind.

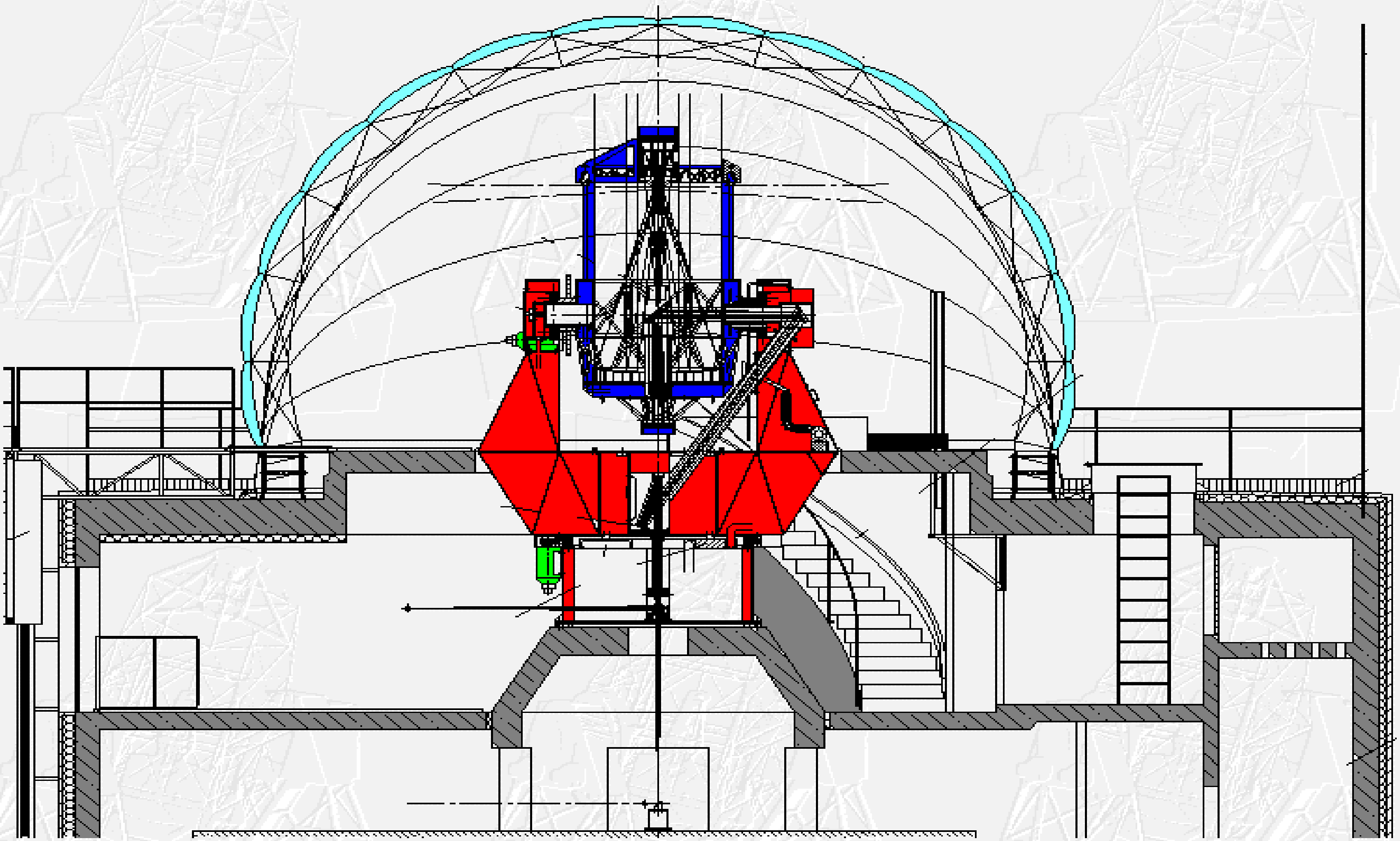
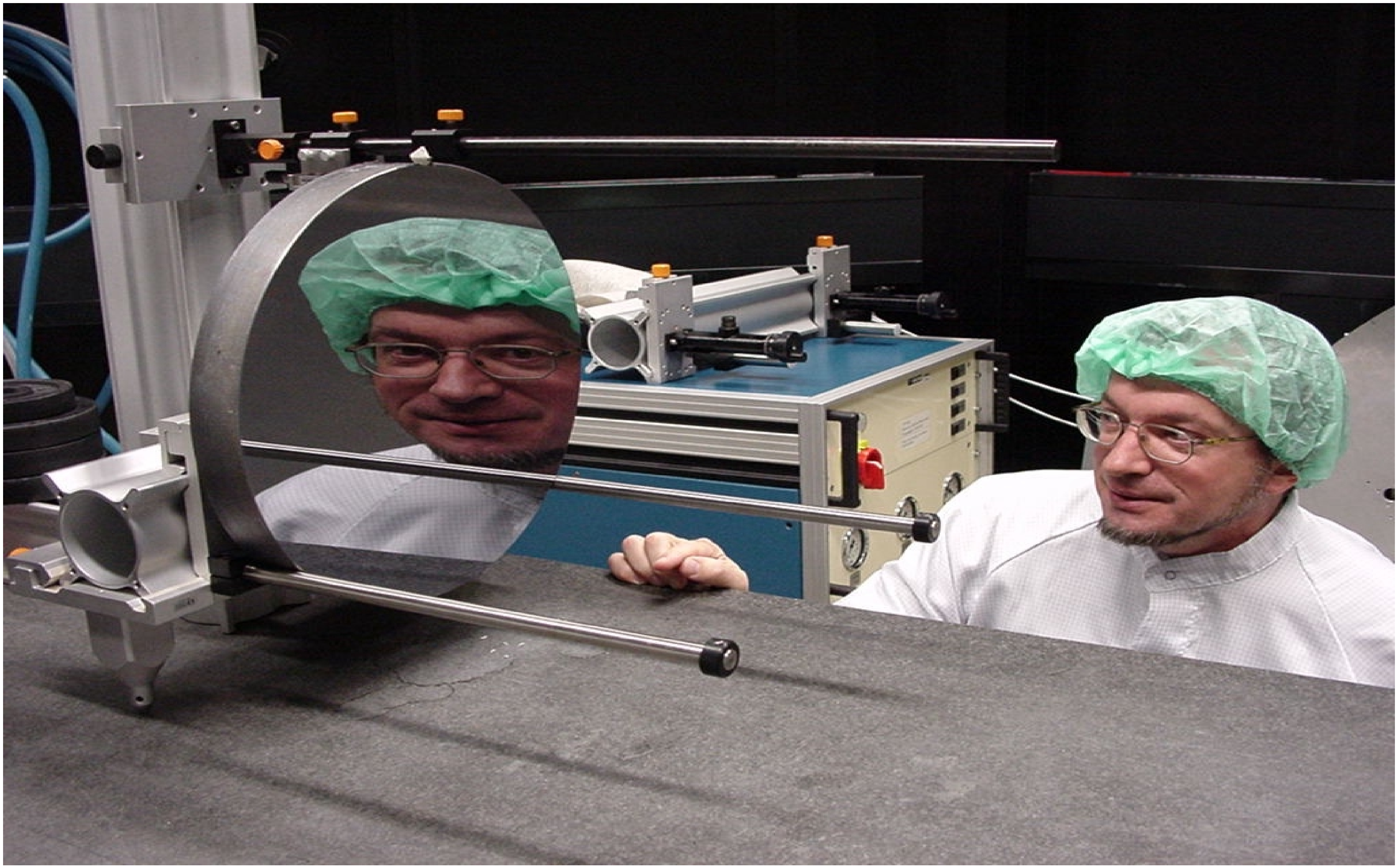
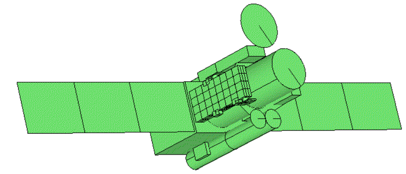


Fig. 8: sketch of the GREGOR telescope in the GCT building and the two observing floors. Instruments can be located in the upper floor on optical benches and on the existing spectrograph table in the lower floor.

GREGOR SiC Tertiary Mirror

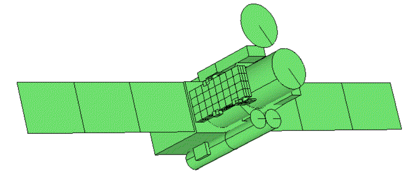


Advanced Technology Solar Telescope (ATST)



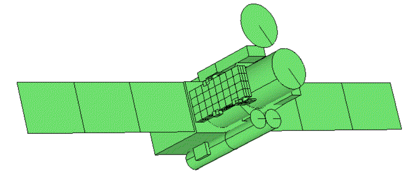
- **Proposal to NSF by NSO (on behalf of the entire US solar community) for a 4-meter visible/IR telescope facility**
- **Present concept is a large-aperture, open-air, all-reflecting telescope with adaptive optics**
  - **Very high spatial resolution: 0.1 arcsec or better**
  - **Large photon flux for sensitive polarimetry**
  - **High-resolution access to the near and thermal IR, for chromospheric and coronal observations**
- **Proposal has been approved**
  - **3.5 Year Design & Development Phase about to begin**
  - **Includes site survey, high order adaptive optics demo, detailed ATST design**
  - **D & D phase funding being negotiated, ~ $ 10 M**
- **See http://www.sunspot.noao.edu/ATST/index.html**

ATST baseline parameters and their science drivers (1 of 2)



- **Sensitivity: 4 meter photon collection aperture**
  - to study the ubiquitous weak magnetic field and test models of turbulent dynamo in the upper convection zone
  - to measure waves in flux tubes and test models of chromospheric and coronal heating
  - to measure magnetic fields in the corona
- **Field of view: 5 arc minutes**
  - to test models of the eruption of flux from active regions from the strong-field dynamo in the lower boundary layer of the convection zone
  - to test models of large-scale coherent processes that lead to flares and CME's
  - to observe large-scale oscillations in prominences and compare with models
- **Wavelength range: 0.3 to 35 μm**
  - to observe the widest variety of diagnostic spectral lines and spectral regions
  - to constrain atmospheric properties from photosphere to the corona

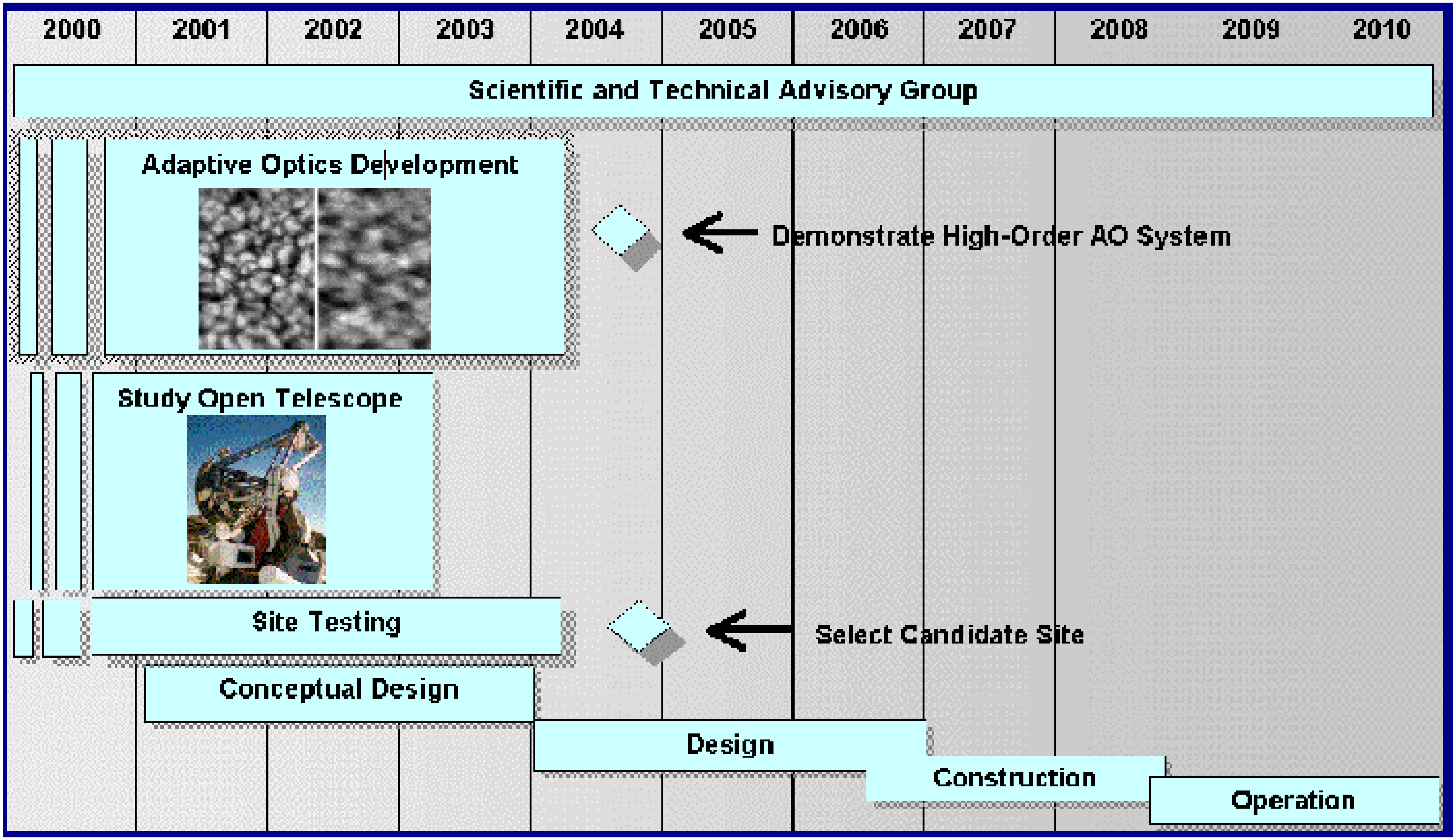
ATST baseline parameters and their science drivers (2 of 2)



- **Spatial resolution: >~ 0.1arcsec using adaptive optics**
  - to resolve the photon mean free path and the pressure scale height in the photosphere
  - to probe IR signature of cool clouds in the chromosphere and test models of their radiative cooling
- **Polarization accuracy: 10-4 of intensity**
  - to precisely measure the magnetic field vector and test models of wave generation in magnetic flux tubes by surrounding granulation
  - to test models of extremely weak magnetic fields in the photosphere, chromosphere, and in prominences using Hanle effect
- **Scattered light: <10% in sunspots, coronagraphic in thermal IR**
  - to test models of magneto-convection in the darkest parts of sunspots
  - to measure properties of coronal magnetic fields and test models of coronal heating
- **Location: best possible site in terms of seeing and sunshine hours**
  - to maximize the telescope performance and minimize the cost of adaptive optics

Beyond Solar-B

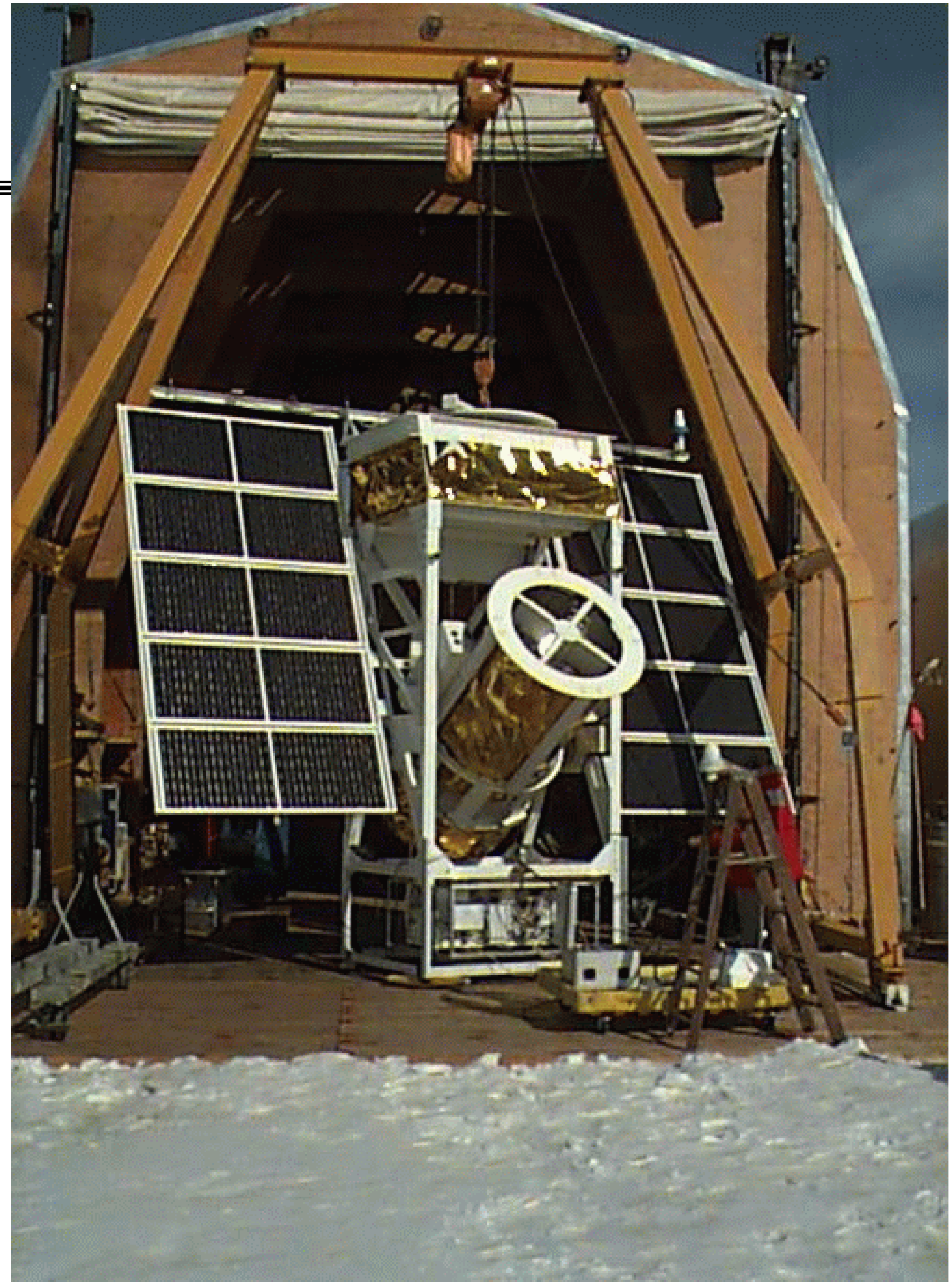
ATST Schedule



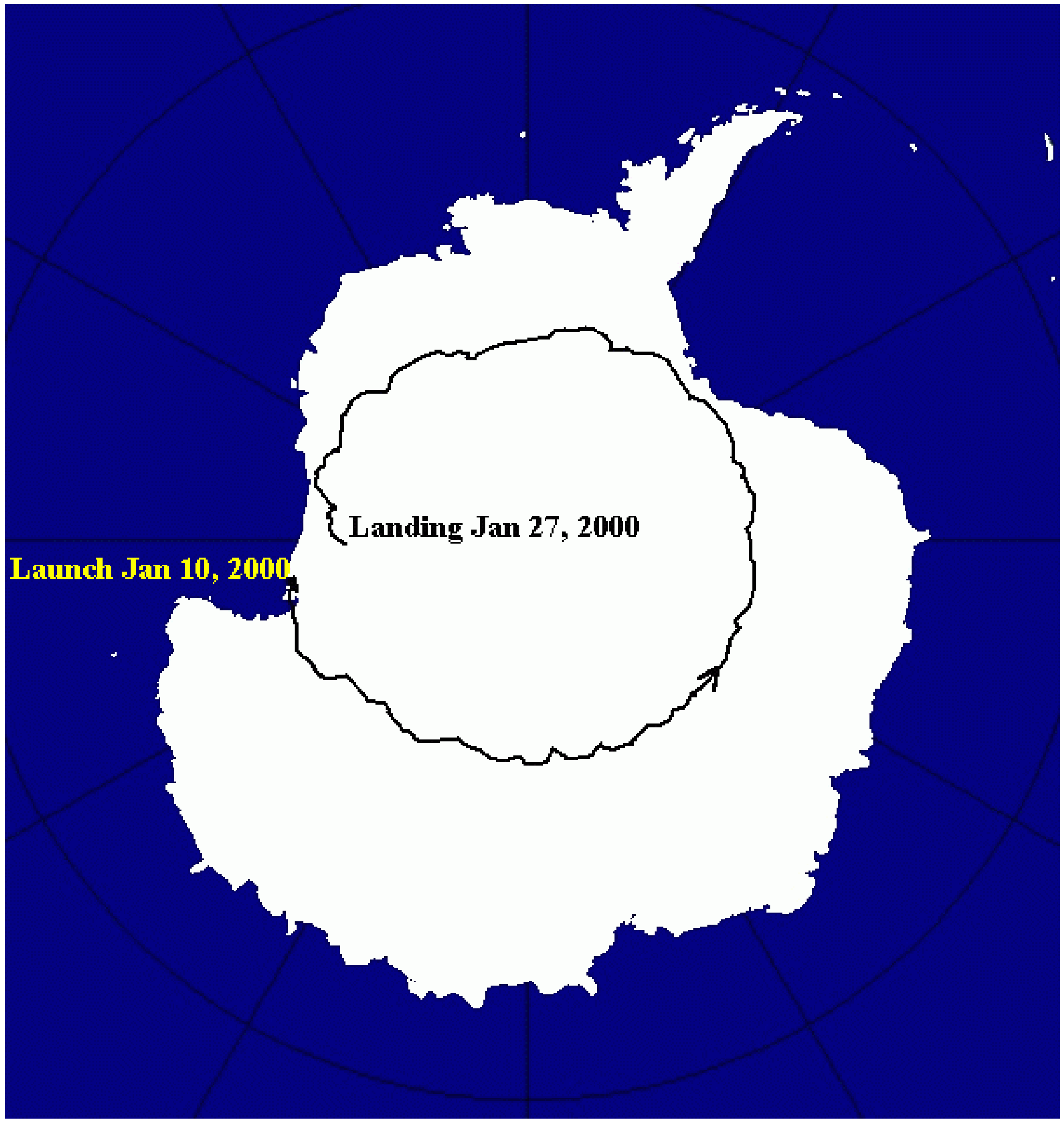
Beyond Solar-B

Flare Genesis

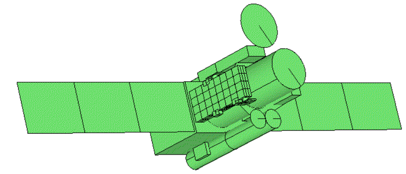
- **Antarctic long duration ballon mission with 1-meter telescope and tunable Fabry-Perot vector magnetograph**
- **January 2000 flight was quite successful**
  - 17- day duration
  - Good data on an active region with emerging flux
  - Telescope recovered and on its way home for refurbishment
- **See Dave Rust's poster or http://sd-www.jhuapl.edu/ FlareGenesis/**



Flare Genesis Flight Path

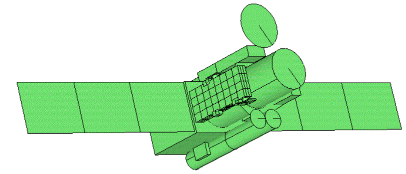


SUNRISE

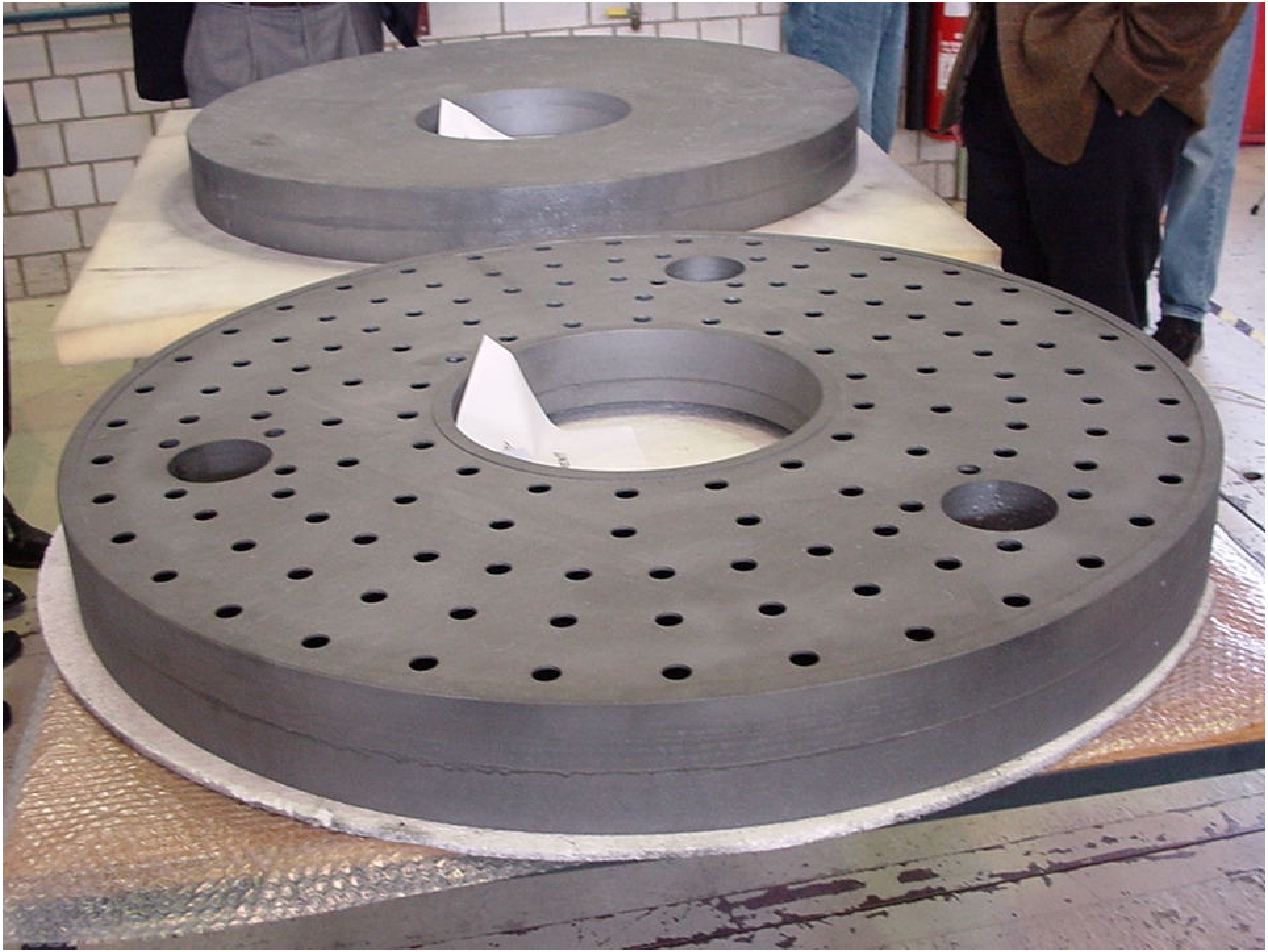


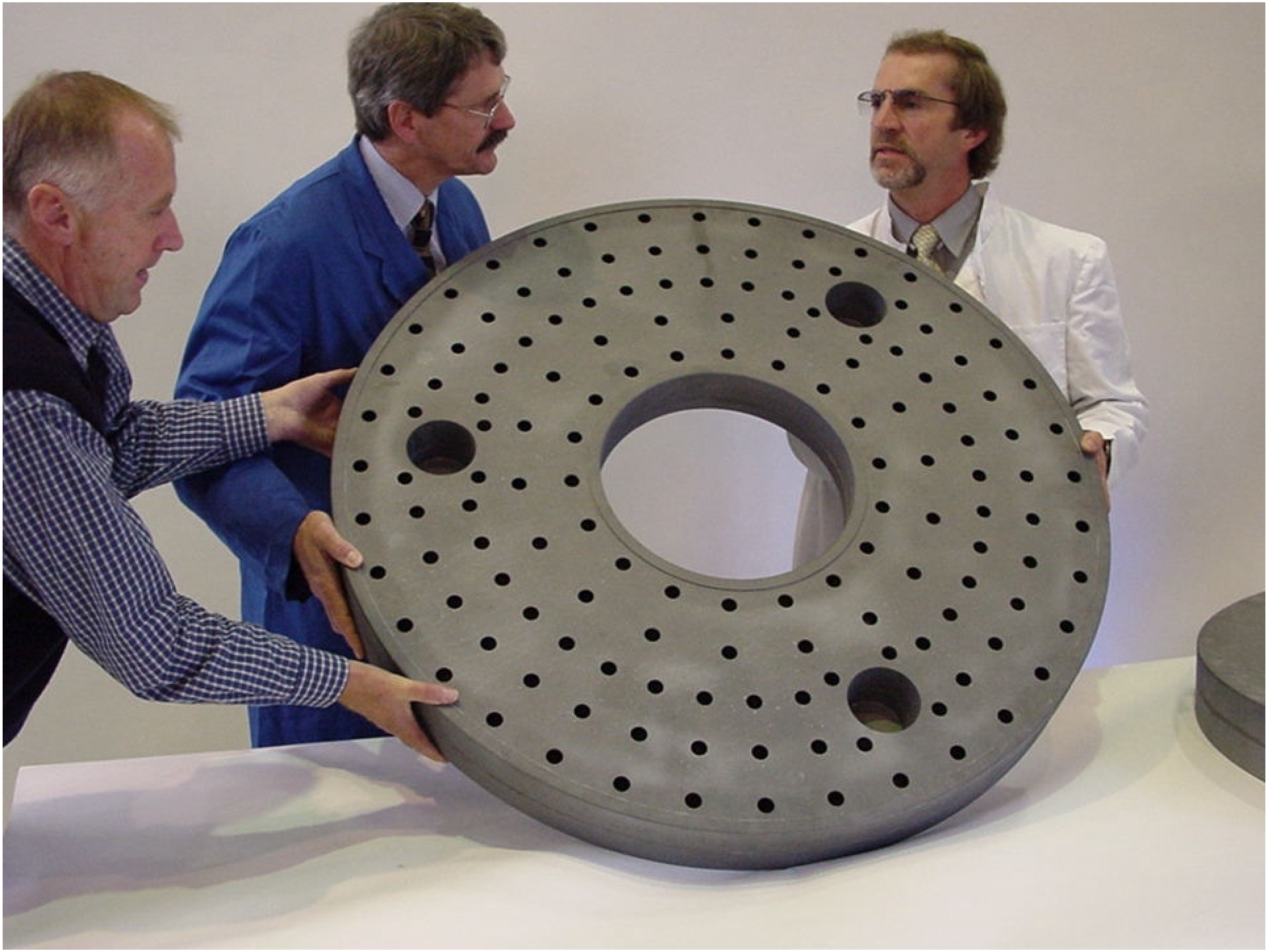
- **Proposal to the German space agency DLR for a long duration balloon mission with 1-meter telescope and very complex payload**
  - Design studies this summer
  - Revised proposal to be submitted in late 2001
- **UV & Visible Spectrograph & Polarimeter**
- **Broadband UV & Visible filtergraph**
- **Fabry-Perot Filter Magnetograph**
- **Correlation Tracker & Adaptive Optics**
- **MPI/Lindau is lead institute; KIS, HAO & LMSAL collaborators**

Solar Lite

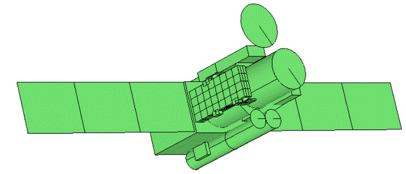


- **Started as a proposal for a Russian-made 1-meter telescope with Silicon Carbide mirrors, to fly on an Explorer or Spartan mission**
- **Became a technology experiment, with mirrors being made by a German firm, Astrium, after several unsuccesful attempts in Russia**
  - **Managed by Lockheed Martin, with collaborators at MSFC, GSFC & KIS**
- **Silicon Carbide is promising for reducing mass and cost of space telescopes**
  - **Low density, high stiffness, high thermal conductivity**
  - **Solar Lite prototype mirror has 2x aperture of Solar-B, only 3x the weight: 43 kg**
- **Astrium SiC mirrors developed by Solar Lite are baselined for SUNRISE, same technology to be used by GREGOR**



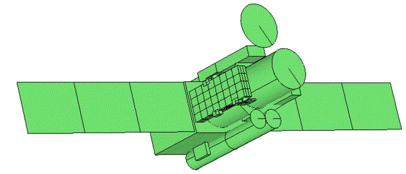


Chinese Space Solar Telescope



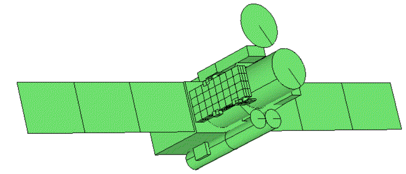
- **Project at Beijing Astronomical Observatory, Chinese Academy of Sciences (Ai Guo Xiang, Director)**
- **Phase A study completed in 1998, funding approved in 1999**
- **1-meter optical telescope with spectrograph, small WL, H-alpha and EUV imagers**
- **As of early 2000, the published schedule showed:**
  - Engineering model (EM) telescope for ground testing complete in late 2000
  - EM electronics model complete in late 2001
  - Flight model development in 2002 - 2004
  - Launch in 2005
- **Present status unknown, but will not launch even close to this schedule**

Solar Probe



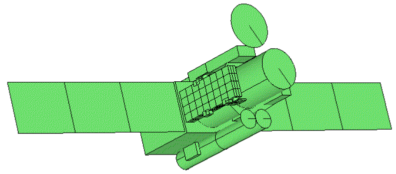
- Perihelion encounter would permit ~12 hours of imaging with resolution of ~50 km or better on the Sun
- Science Definition Team recommended a Visible Magnetograph to address several of the highest priority mission science objectives
- Despite technical difficulties and resource limitations, two credible proposals for imaging instruments including magnetographs were submitted in response to the AO in mid-2000
- Solar Probe has been removed from the President's 2001 budget (along with Pluto Express)
- Fate of the mission is uncertain

Solar Orbiter

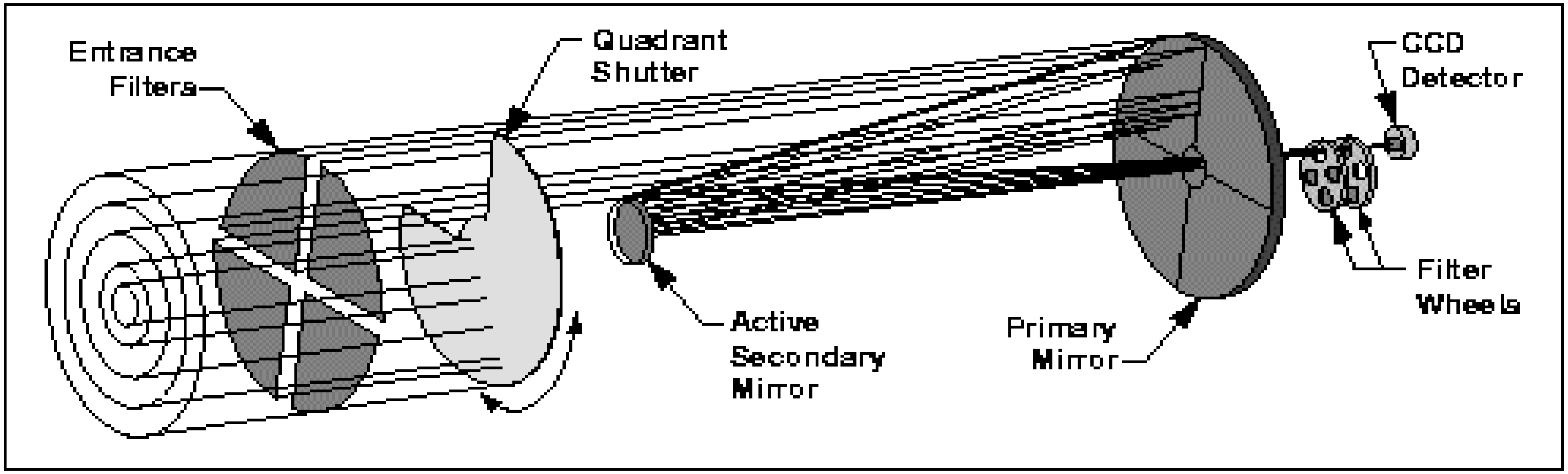


- Approved ESA Mission to study the sun & solar wind from 0.21 AU
- Launch Windows every 19 months, in Jan 2009, Aug 2010, etc.
- 1.9 year Cruise Phase, 3 year Nominal Mission (7 orbits)
- Visible Imager & Magnetograph: 75 km resolution
- EUV Imager: 25 km resolution
- EUV Spectrometer & UV/Visible Coronagraph
- See separate presentation by B. Fleck (ESA Study Scientist)

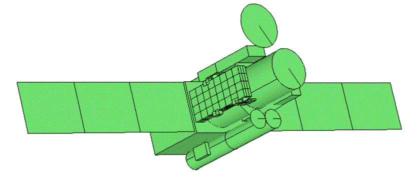
Super-X



- Solar-B proposal (unsuccessful) for a high resolution imager of transition region & coronal plasma
- Cassegrain telescope with normal incidence multi-layer optics
  - Straightforward evolution of TRACE design: 3.5 times higher resolution
- Resolution of 0.27 arcsec (0.135 arcsec pixels)



HIREX & DEUCE

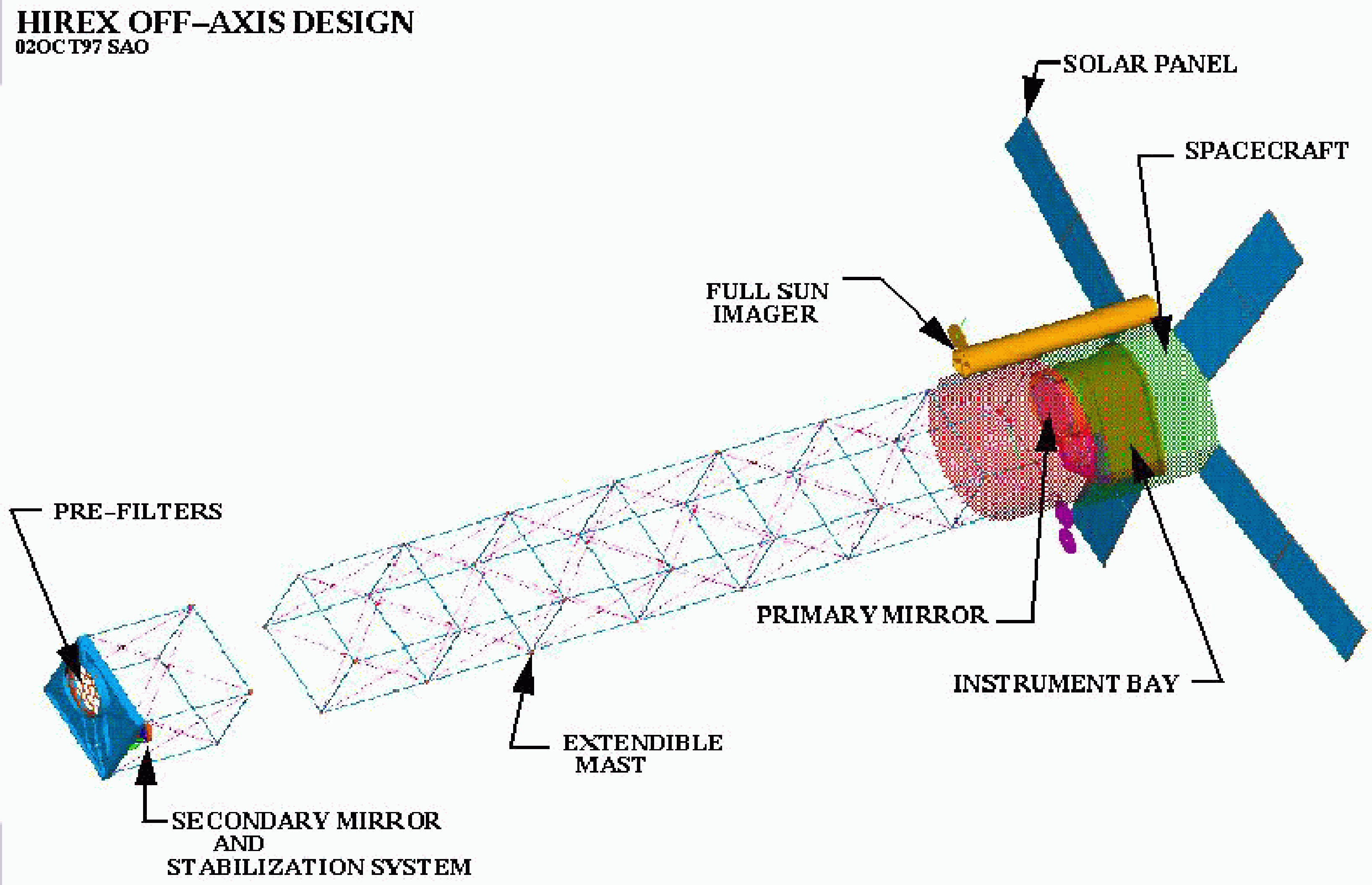


- MIDEX & SMEX proposals (both unsuccessful) for ultra-high resolution EUV imaging telescopes using expandable booms
- HIREX (1998 MIDEX) proposed 0.01 arcsec resolution using a 240-meter focal length off-axis Gregorian telescope with a 35-meter boom
- DEUCE (2000 SMEX) proposed 0.10 arcsec resolution in EUV & UV
- HIREX received funding for a technology study at SAO of mirror fabrication, optical alignment, pointing control, etc.

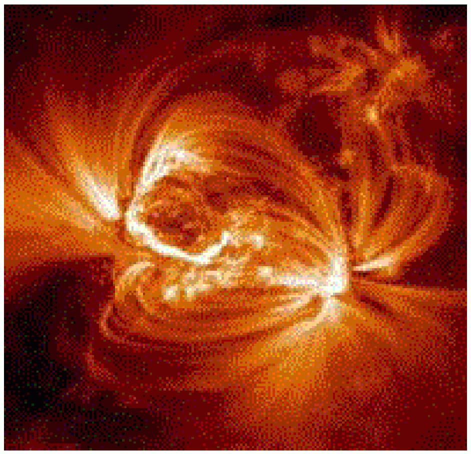
Smithsonian Astrophysical Observatory

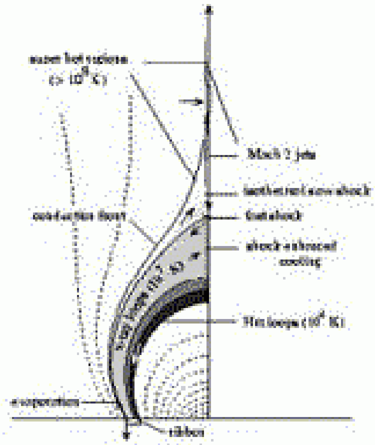
Central Engineering

HIREX Engineering Study



Reconnection and Microscale (RAM) Probe





The RAM Probe will explore and measure the dynamic heating of coronal plasmas.

Technology Requirement:

- Large-format cryogenic imaging detectors
- Diffraction-limited XUV optics
- Large-format, fast-read CCDs
- Onboard AI event processing

Fundamental Question:

- How are coronal plasmas heated during dynamic events?

Science Objectives:

- Study the microscale instabilities that lead to global effects
- Examine the mechanisms contributing to the coronal energy balance
- Determine the conditions leading to flares and CMEs
- Measure the reconnection regions and their topology

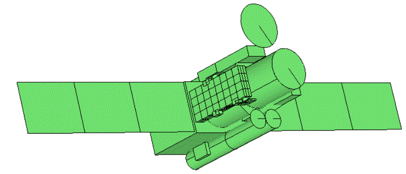
Mission Description:

- Continuous broadband solar observations from L1 or geostationary orbit
- Complementary high-resolution and full-disk imaging
- STP-class mission

Measurement Strategy:

- Ultra-high resolution (0.02 arcsec) coronal imaging
- High-resolution imaging (0.5 arcsec) spectroscopy (4 eV) from 0.25 to 50 keV
- High-resolution EUV spectroscopy
- Full-Sun EUV and white-light context images at 1 arcsec
- High time resolution in all instruments
- Mutual benefit from overlap with, e.g., Solar B and STEREO

What Should be in the Next Roadmap?



High-Resolution Solar Optical Telescope

Understanding flux tube characteristics provides insights about the Sun's magnetic field.

Fundamental Question:

- What are the dynamics of the flux tubes that drive atmospheric heating?

Science Objectives:

- Understand the internal structure, heating, and evolution of the Sun's magnetic flux tubes
- Understand the relationships between fine-scale photospheric magnetic activity and overlying regions
- Understand the changes in magnetic energy, structure, and helicity in active region magnetic fields

Mission Description:

- Sun-synchronous, Earth-orbiting satellite

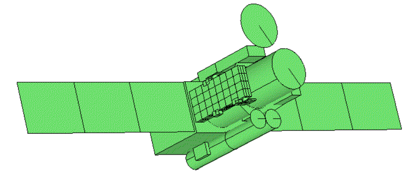
Measurement Strategy:

- Very-high-angular-resolution observations of intensity, velocity, and vector magnetic field
- EUV images of chromospheric and coronal structures

Technology Requirements

- High-data-rate communication
- Large-aperture optics and/or interferometers

Why go into Space?



- **Perfect Seeing over a Large Field of View**
  - Well, not really perfect: but the resolution can be very good and limited only by engineering tradeoffs, not by the sky
- **Excellent Uniformity of Observing Conditions**
  - Really
- **24 Hours of Sunshine and Good Weather every Day**
  - Most of the year, at least
  - Some bad weather during SAA's & proton storms
- **Visible, UV, EUV, X-Ray, IR Instruments in the Same Observatory**
- **It may not be a Zero-Sum Funding Game**