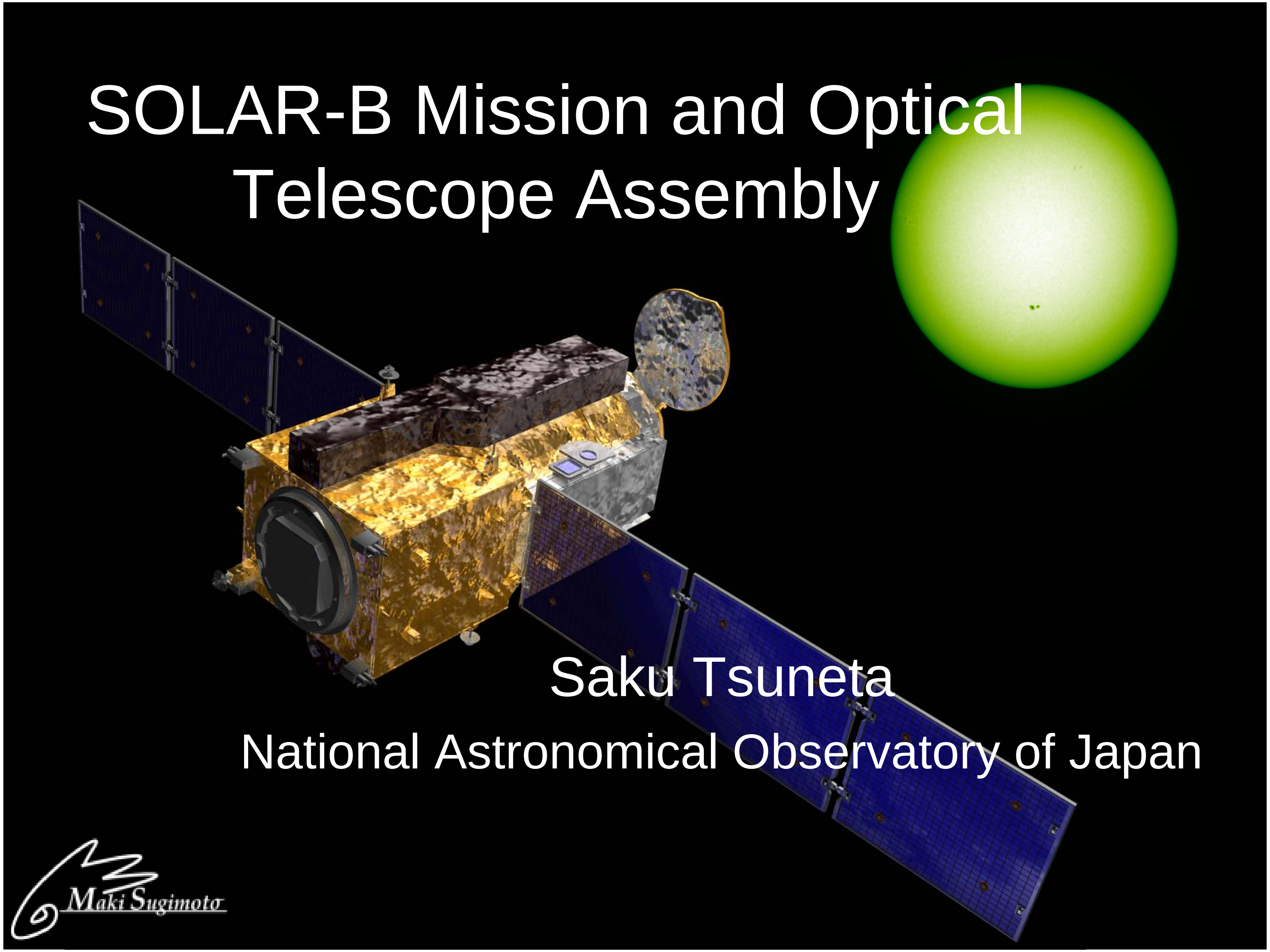
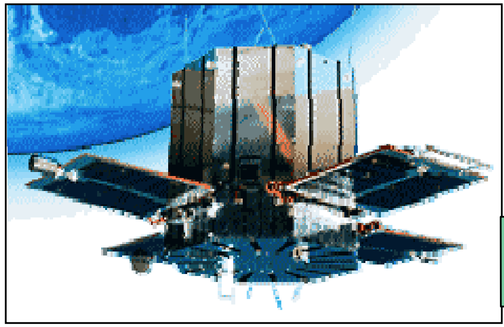
SOLAR-B Mission and Optical Telescope Assembly



Saku Tsuneta

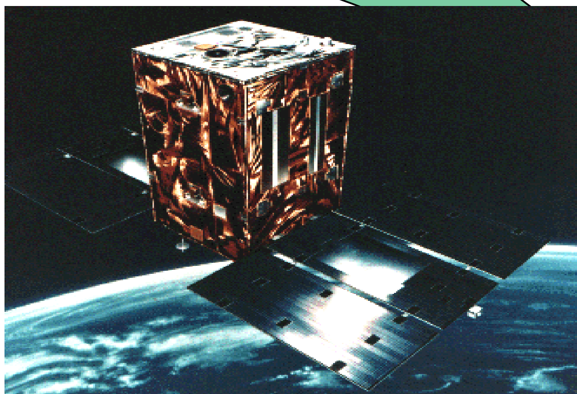
National Astronomical Observatory of Japan

Solar Physics from Space in Japan



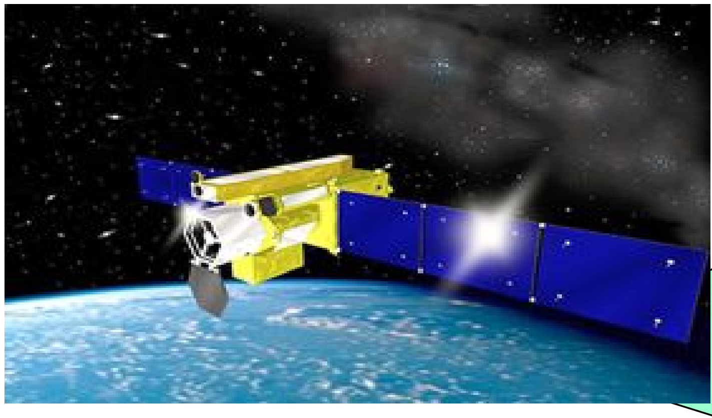
Hionotori (1981-1982)

Yohkoh (1991- 2001)



With NASA and UK

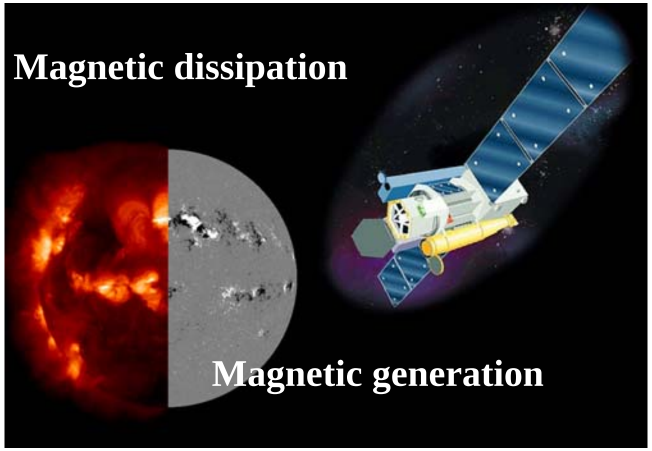
SOLAR-B (2006)

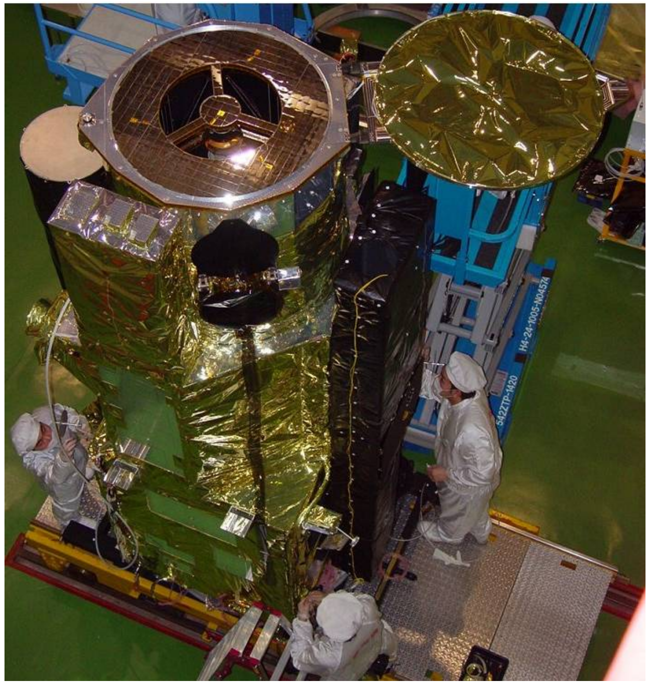


With NASA and UK

Solar-B

- Japan-US-UK solar observation satellite following highly successful Yohkoh (1991-2001)
- Primary mission: systems approach to understand generation/transport and ultimate dissipation of solar magnetic fields with 3 well-coordinated advanced telescopes.
- Onboard instruments
  - Solar Optical Telescope (Japan, US)
  - X-ray Telescope (US, Japan)
  - EUV Imaging Spectrometer (UK, US, Japan)
  - Spacecraft and launch (Japan)
- Versatile onboard data compression (JPGEG, and DPCM)
- Post compression rate approx. 500 kbps
- Launch on summer 2006 with ISAS M-V-7
- Orbit: Sun synchronous, Altitude: ~ 600 km, Weight: ~ 900 Kg
- ESA provides downlink service with Norway station, resulting in substantial increase in data rate.

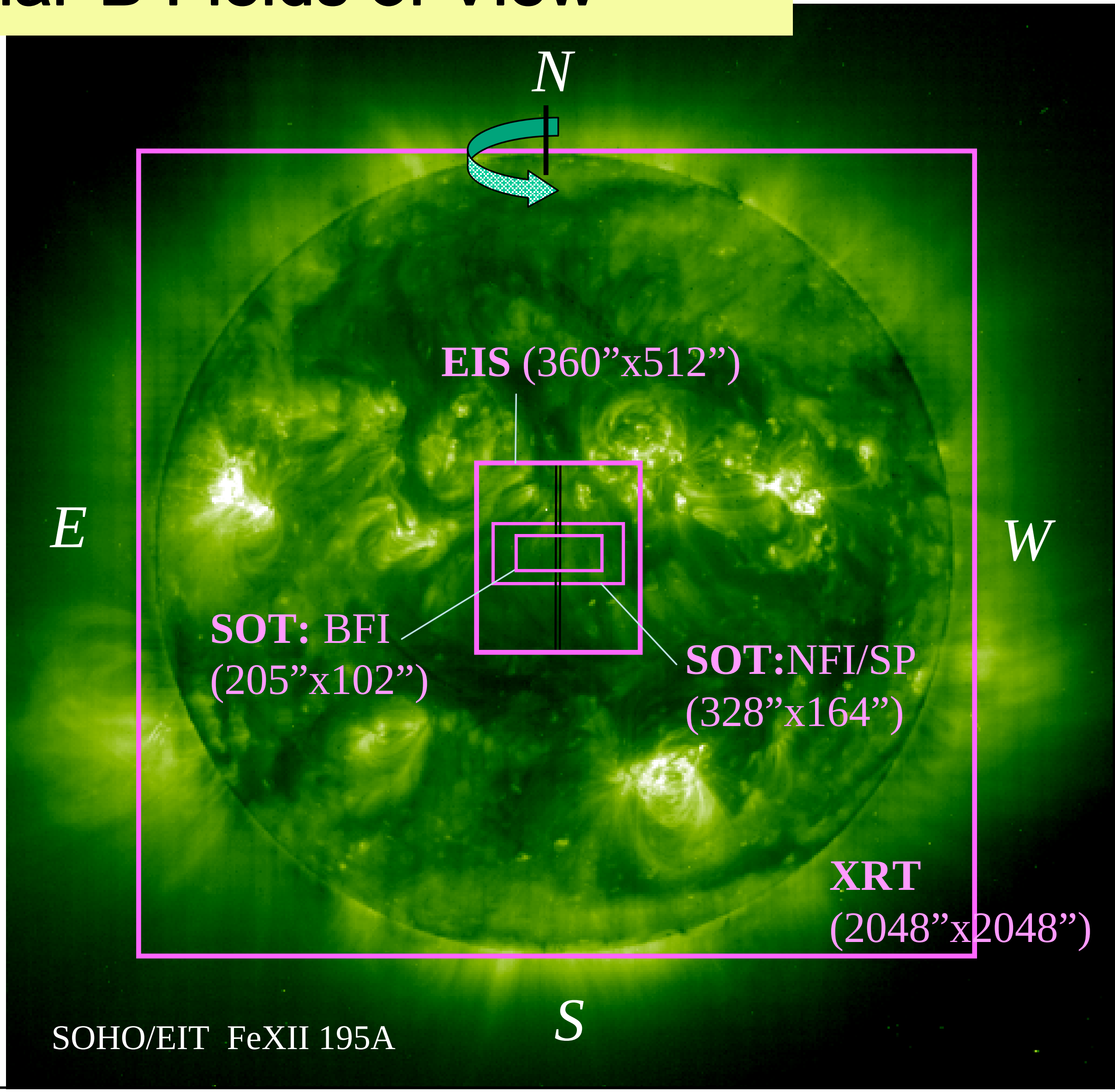




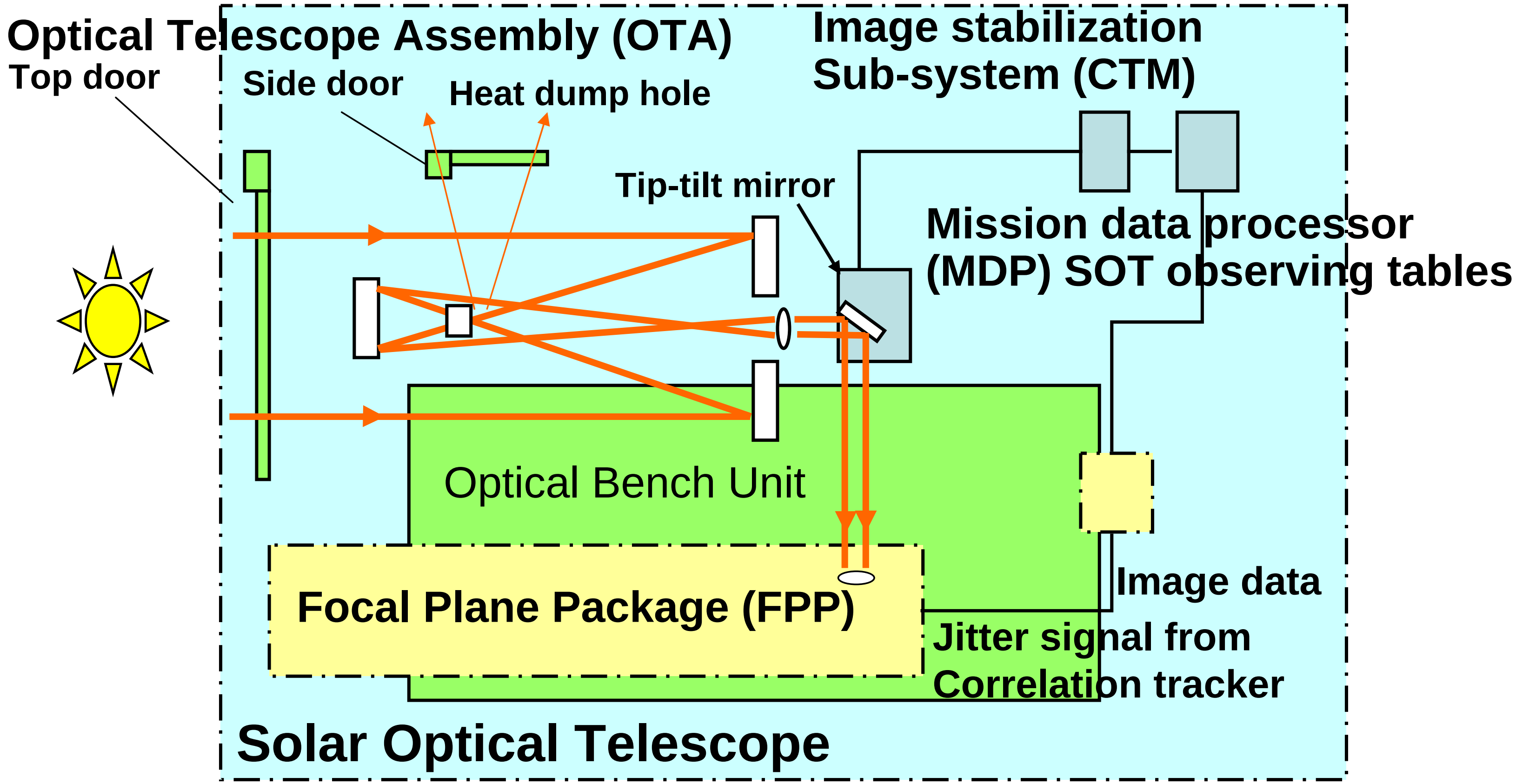
X-ray & EUV Telescopes aboard SOLAR-B

- XRT
  - We chose grazing-incidence after extensive tradeoff
  - 1 arcsec resolution/1 arcsec pixel, >x3 better than Yohkoh
  - FOV: 30arcmin squares
  - Sensitive to 0.5MK-10MK(20MK)
  - Filter choice provides SXT and TRACE-like images.
  - Filter-ratio: powerful tool for T- diagnostics
  - Visible light imaging for alignment purpose
- EIS
  - EUV emission line spectroscopy
  - Two EUV bands: 170-210 Å and 250-290 Å, log T = 4.7, 5.4, 6.0 - 7.3 K
  - X 10 more sensitive than CDS
  - 1 arcsec/pixels, Field of View： 6 arcmin × 8.5 arcmin
  - Selectable Slit & Slot: 1”, 2”, 40” and 250” width at primary focus
  - Single line: Doppler motion, non-thermal width
    - ~ 25 km/s pixel sampling, a few km/sec sensitivity
  - Line pair ratio: Temperature, density diagnostics
  - Multiple lines: Differential emission measure

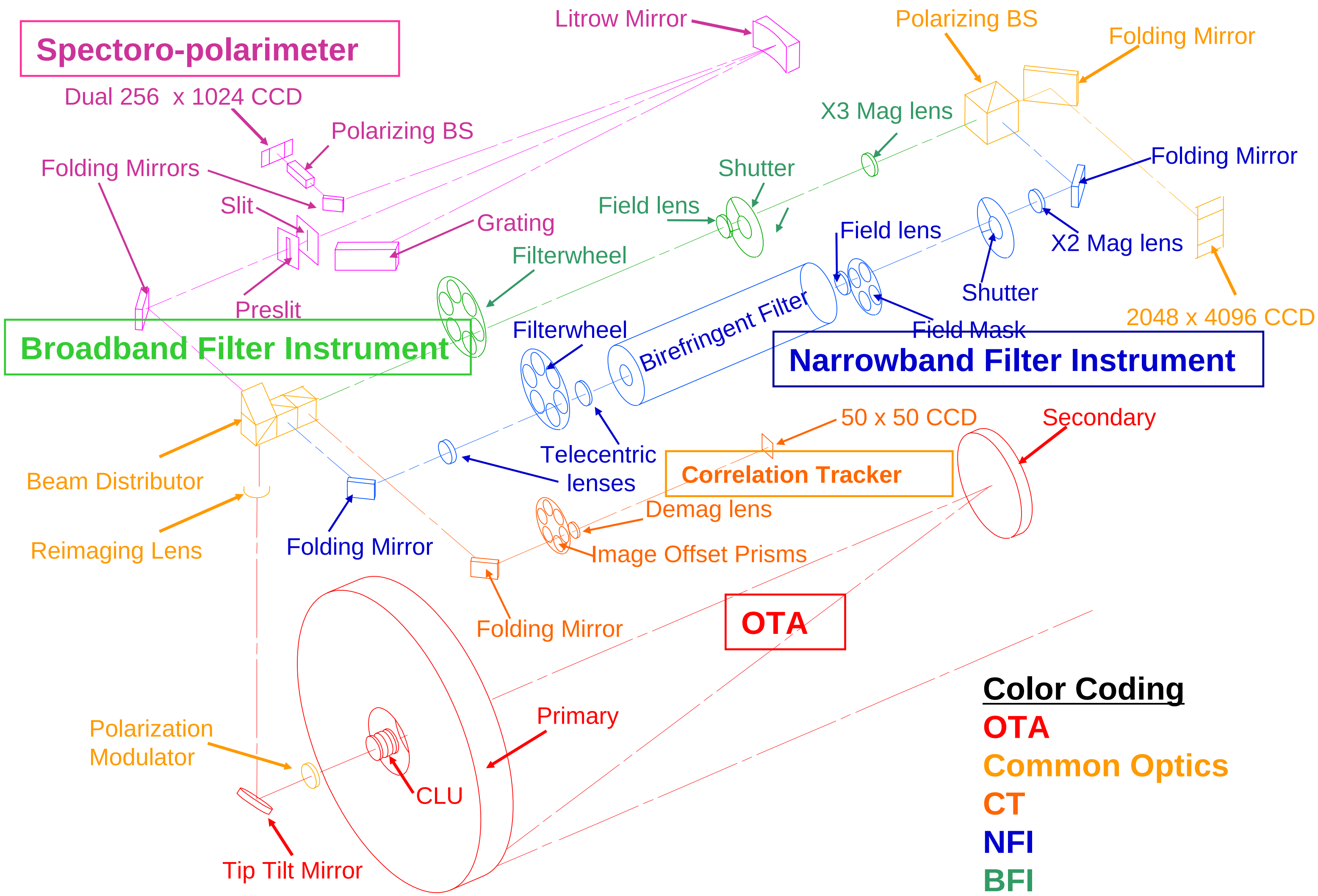
Solar-B Fields of View



Optical and control interface of SOT



Optical layout of SOT



Color Coding

OTA

Common Optics

CT

NFI

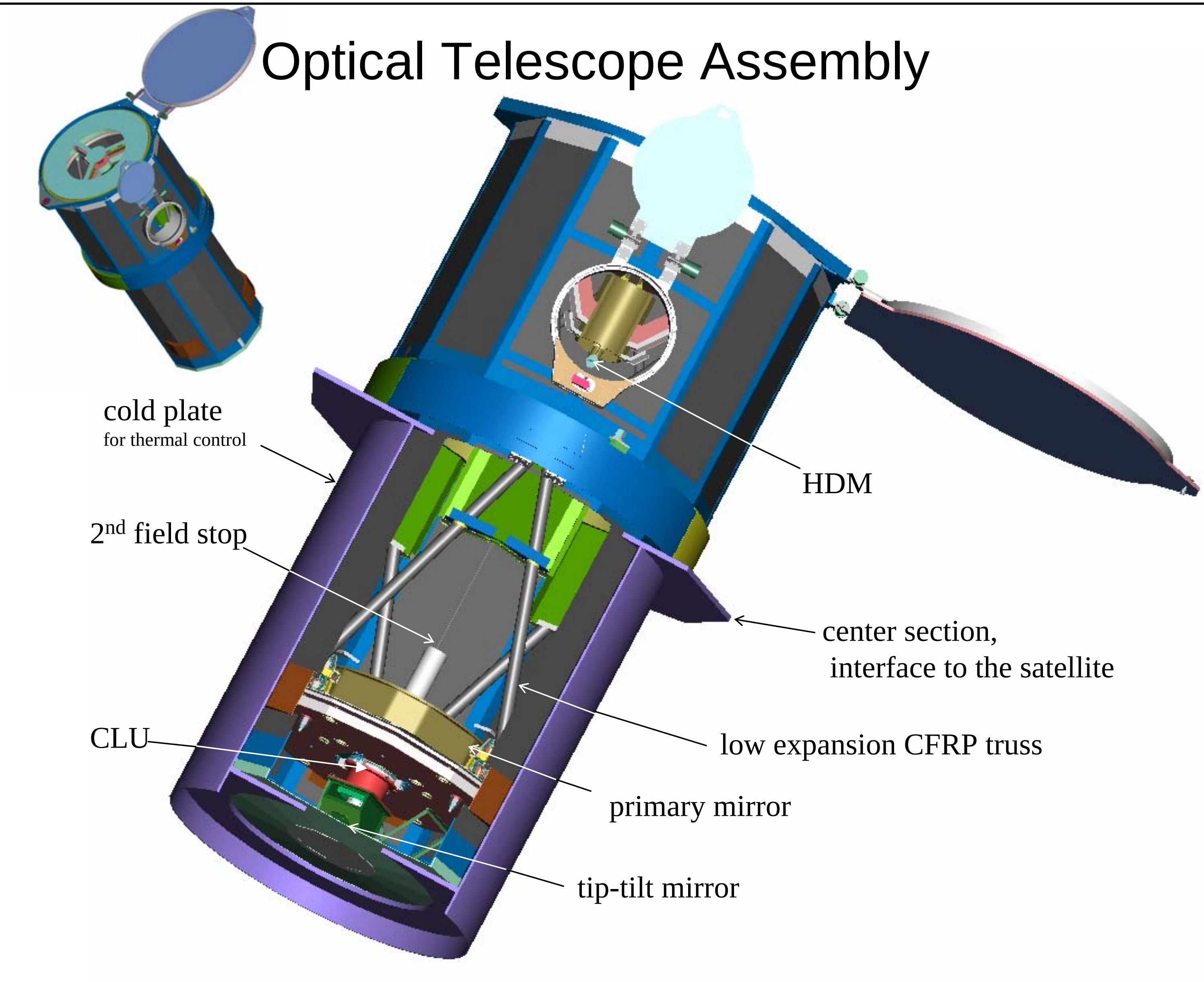
BFI

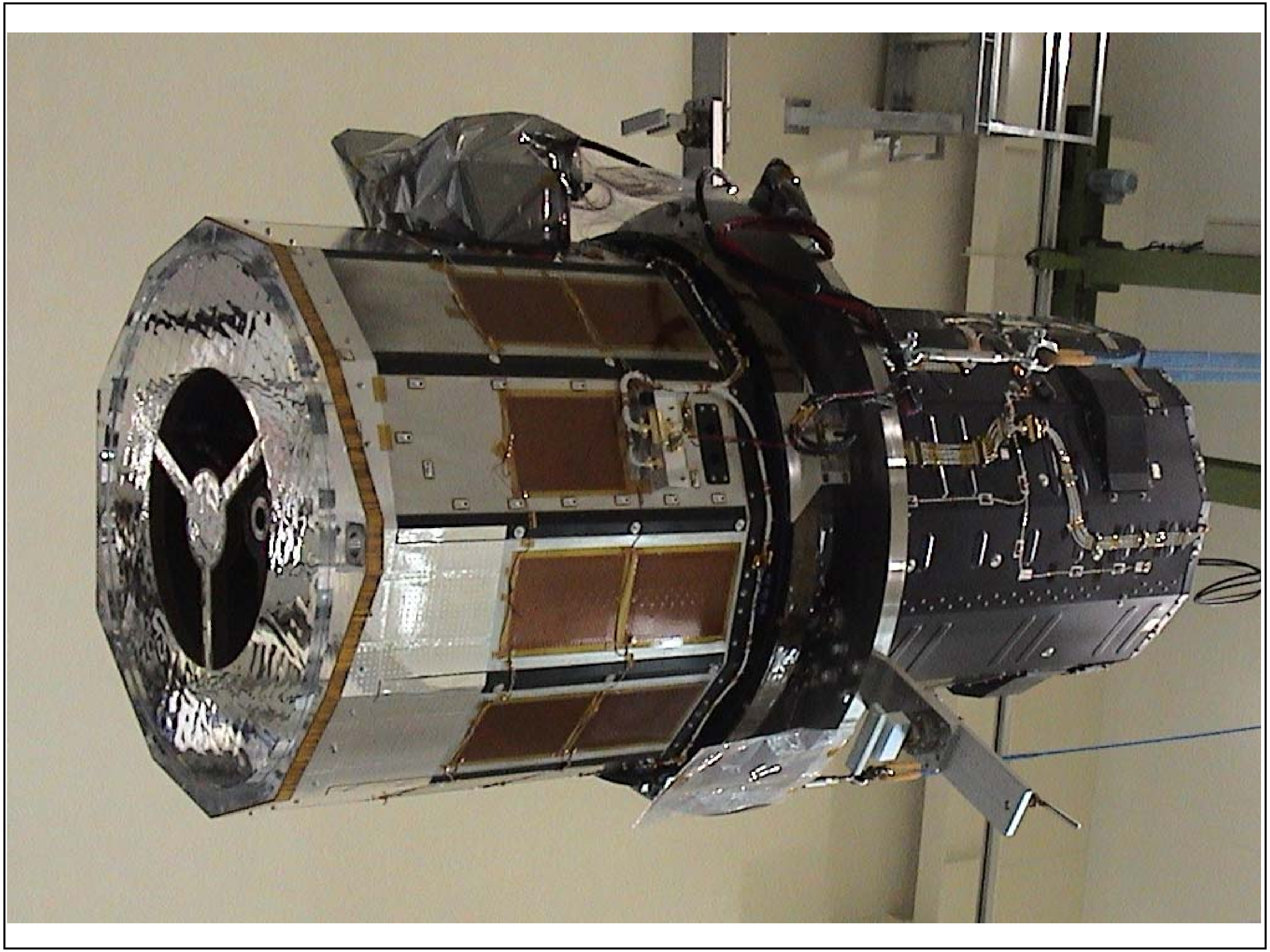
SP

SOT Observables

Broadband Filtergraph Dt : 2s	wavelengths	388.3 CN molecular bandhead: chrom. network 396.8 Ca II H-line: magnetic elements in low chrom 430.5 G-band CH bandhead: magnetic elements 450.5/555.0/668.4 continuum.
	FOV / pix scale	218 × 109 / 0.054 arcsec
Narrowband filtergraph Dt : 3s~30s	wavelengths	FeI 525.0 Photospheric magnetograms Mg Ib 517.3 Low chromosphere mag./dopplergrams Fe I 557.6 Photospheric dopplergrams Na D 589.6 Chromospheric magnetic fields Fe I 630.2 Photospheric magnetograms H I 656.3 H-alpha chromospheric image and Dopp
	FOV / pix scale	328 × 164 / 0.08 arcsec
	Polarization	IQUV, ~0.5% accuracy
Spectro-polarimeter Dt : 3s~1hr	wavelengths	630.2 nm (high precision vector mag. Fields)
	FOV / pix scale	164 x 324 (full scan) / 0.16 arcsec
	Polarization	IQUV full profile, 0.1% accuracy
Correlation tracker, 580Hz	wavelengths	629-634 nm
	FOV	11 × 11 arcsec

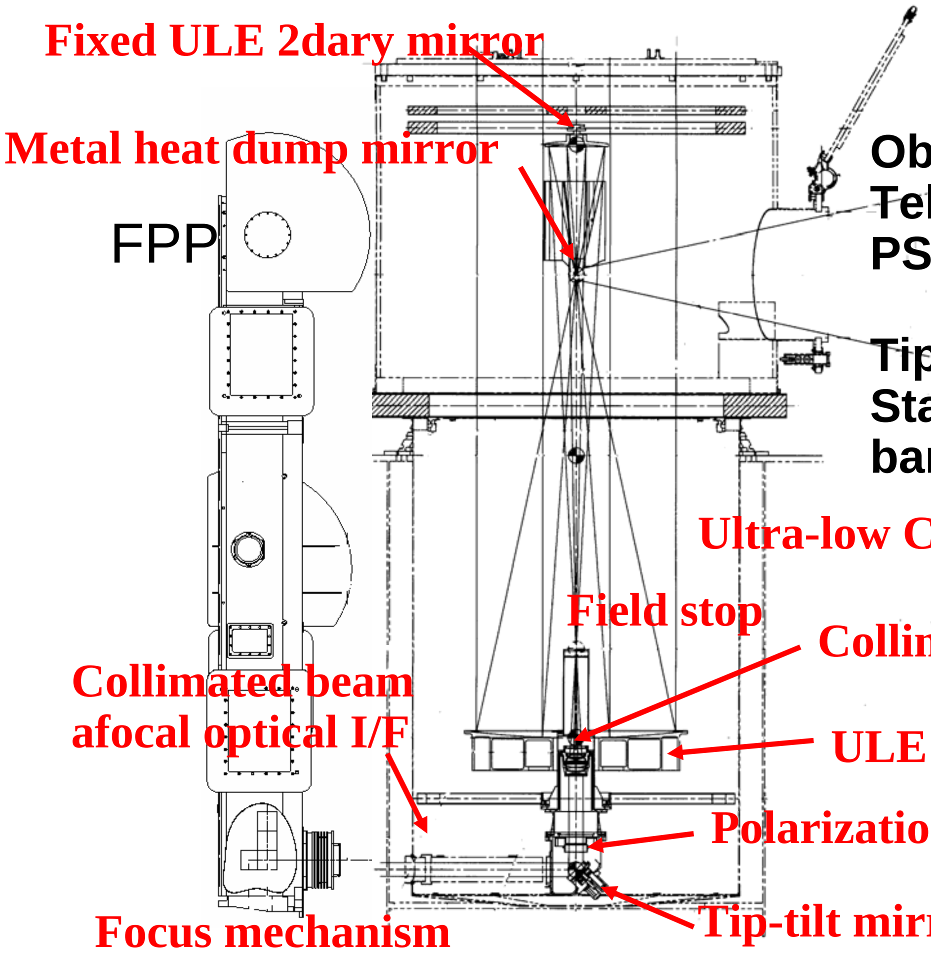
Optical Telescope Assembly





SOT (Solar Optical Telescope)

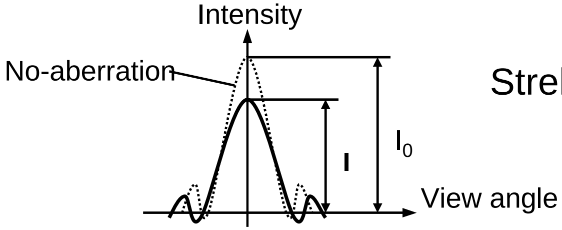
Optical Telescope Assembly (OTA) NAO, Japan
Focal Plane Package (FPP) Lockheed Martin/HAO/NASA with NAO



Observing wavelength: 388 ~ 668nm
Telescope wavefront error ~ 18.2nm
PSF <0.2 arcsec in blue band
>0.2 arcsec in red band
Tip-tilt image stabilization system
Stability ~ 0.002 arcsec rms
bandwidth ~14Hz

Evaluation Method of Image Quality

Specification of Image Quality by Strehl ratio



Point spread function on focal plane

Strehl ratio = $\frac{I}{I_0}$

Diffraction-limited performance
∼0.2” (λ=388 – 670 nm)

SOT target: Strehl ratio (I/I_0) = 0.7 at λ=500nm

Relation between Strehl ratio and rms Wavefront error

Strehl ratio= $e^{-\left(\frac{2\pi\sigma}{\lambda}\right)^2} \geq 0.7$

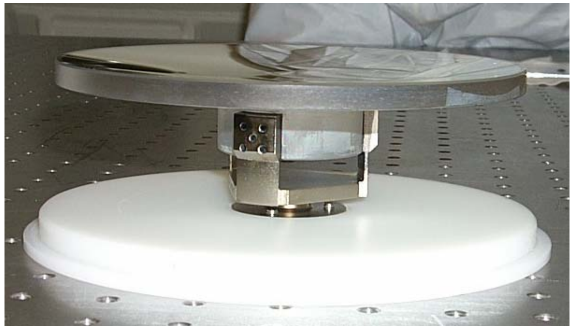
σ: rms Wavefront error
λ: Wavelength = 500 nm

Total rms Wavefront error for OTA-FPP: σ < 47.5 nm
- OTA: 37.8 nm
- FPP: 25.8 nm
- Guidance: 12.8nm

OTA development with budgets

- There are multiple internal and external elements that contribute to error and performance degradation. These have been controlled with strict budget during development.
- WFE budget
- Focus budget
- Pointing budget
- Contamination budget
- Weight budget
- Power budget

OTA Key Components



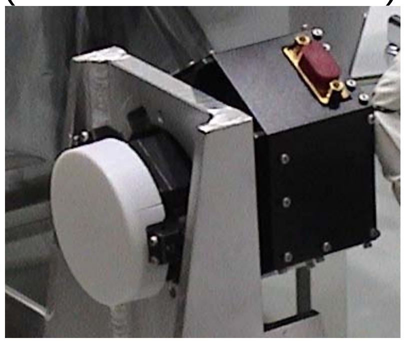
Secondary Mirror

Primary Mirror

Zero-CTE composite structure

Collimator lens unit

Polarization modulator
(Lockheed Martin/HAO)



Tip-tilt mirror

OTA primary secondary mirrors

- ULE with protected Ag coat
- M1～11Kg
- WFE for M1-M2 combination
  18nm (rms)

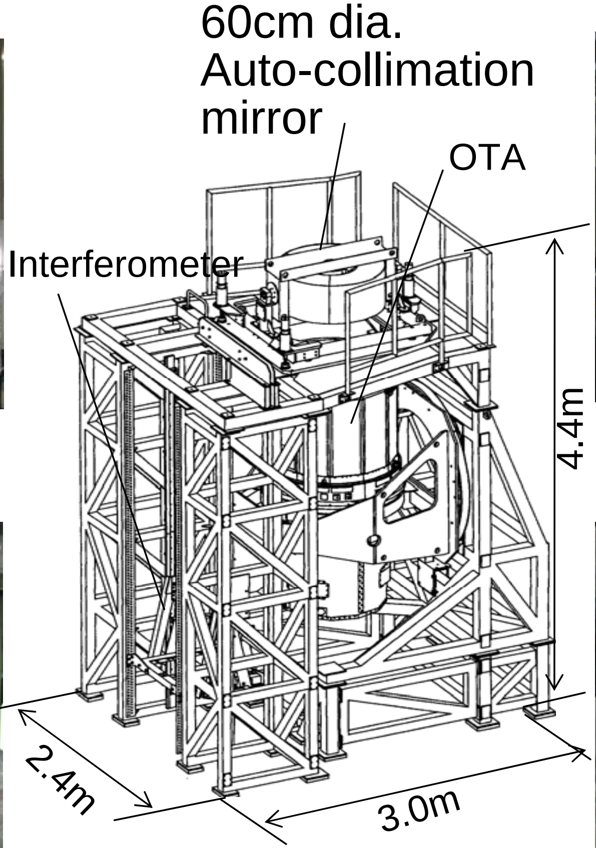
Collimator lens unit requirements

- 388-690nm
- F/9
- Achromatic focus shift < 35micron
- WFE < 17nm (rms)
- No retardance/no di-attenuation
- Orbital temperature range: 20±10 degree C

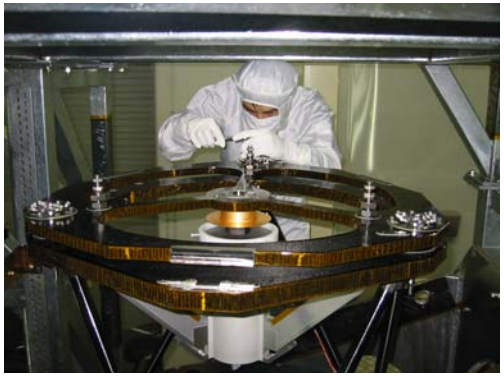
Optical IT&T

OTA assembly in the Class-10 clean tent

M1 alignment



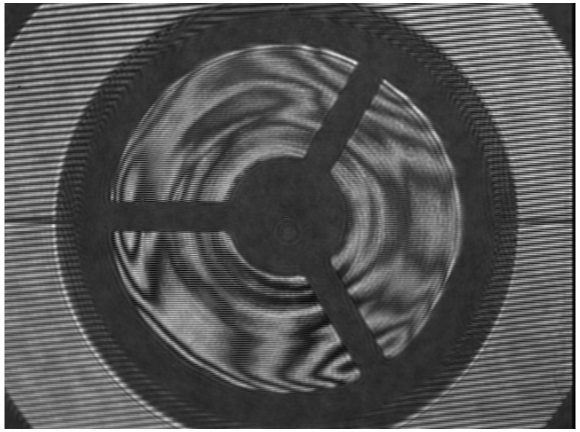
Dedicated Optical Test Tower for IT&T at NAOJ



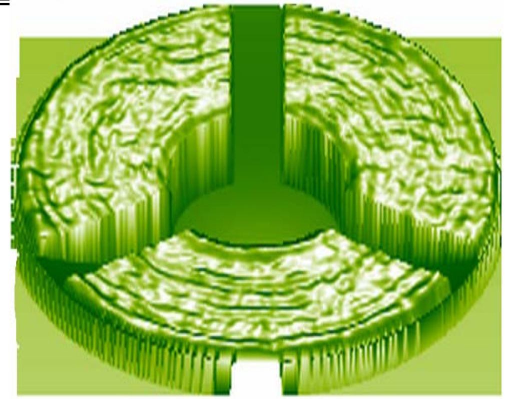
M2 alignment

Interferometric test

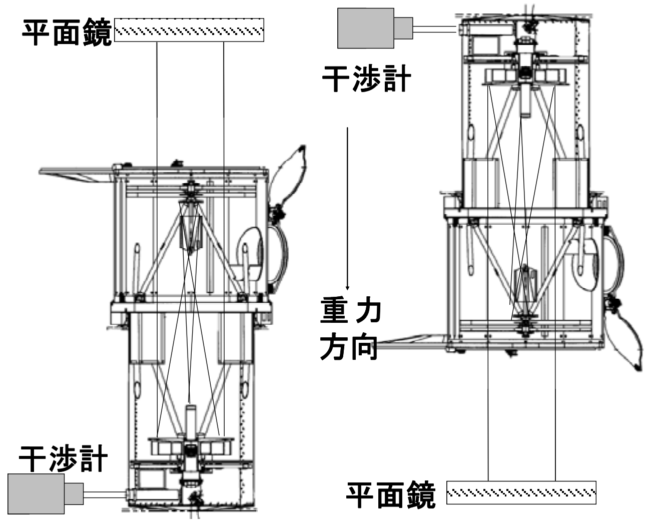
END-TO-END WFE measurement with 60cm dia. auto-collimation mirror



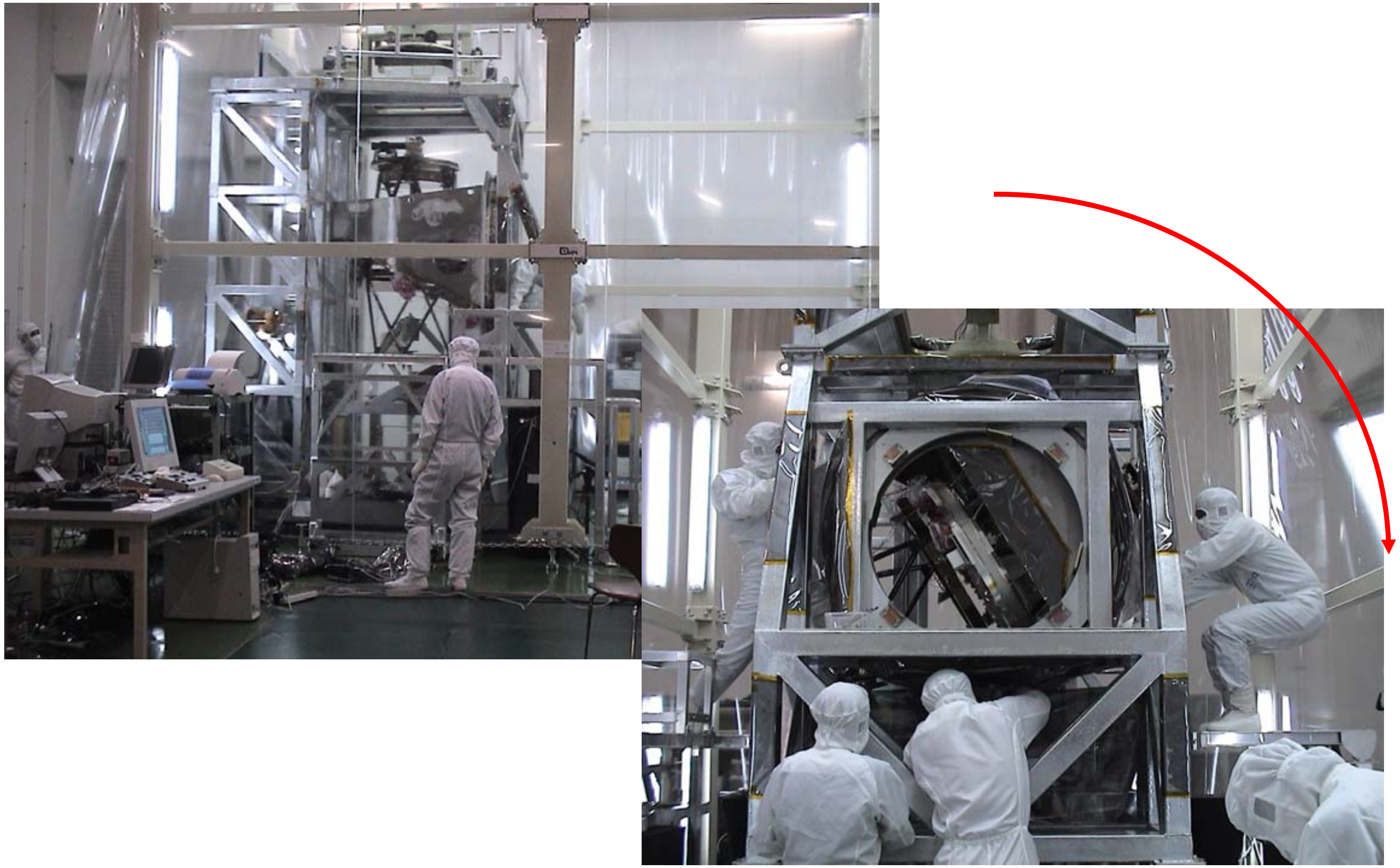
Measured wavefront error 18.2nm



- **Telescope configuration for WFE measurement: vertical (nominal and upside-down)**
- **Telescope is deformed under 1-G condition. 0-G WFE is obtained by averaging data taken with nominal and upside-down configurations.**
- **WFE (rms) is 0.0288 lambda at 632.8nm, and is 18.2nm (0.0182micron).**
- **WFE (RMS) at short-end of the observing band (388nm) is 0.0469 lambda. Telescope is diffraction-limited (<0.071 lambda) for all observing bands.**



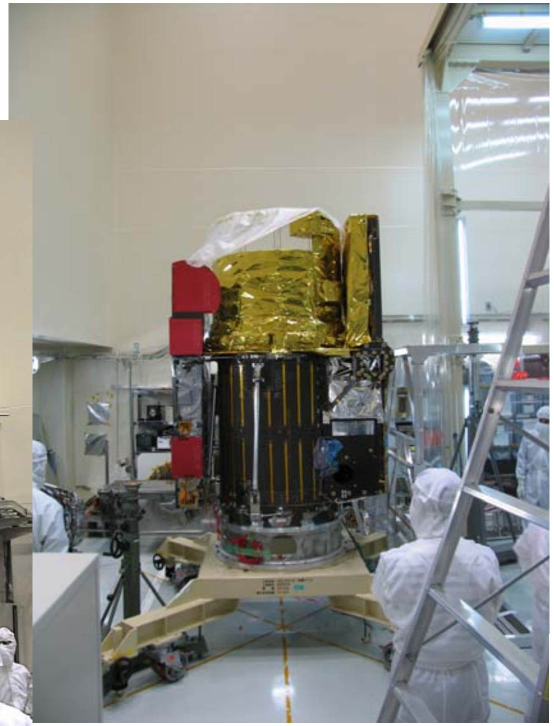
Gravity cancellation by overturning OTA for WFE measurement



Telescope IT&T

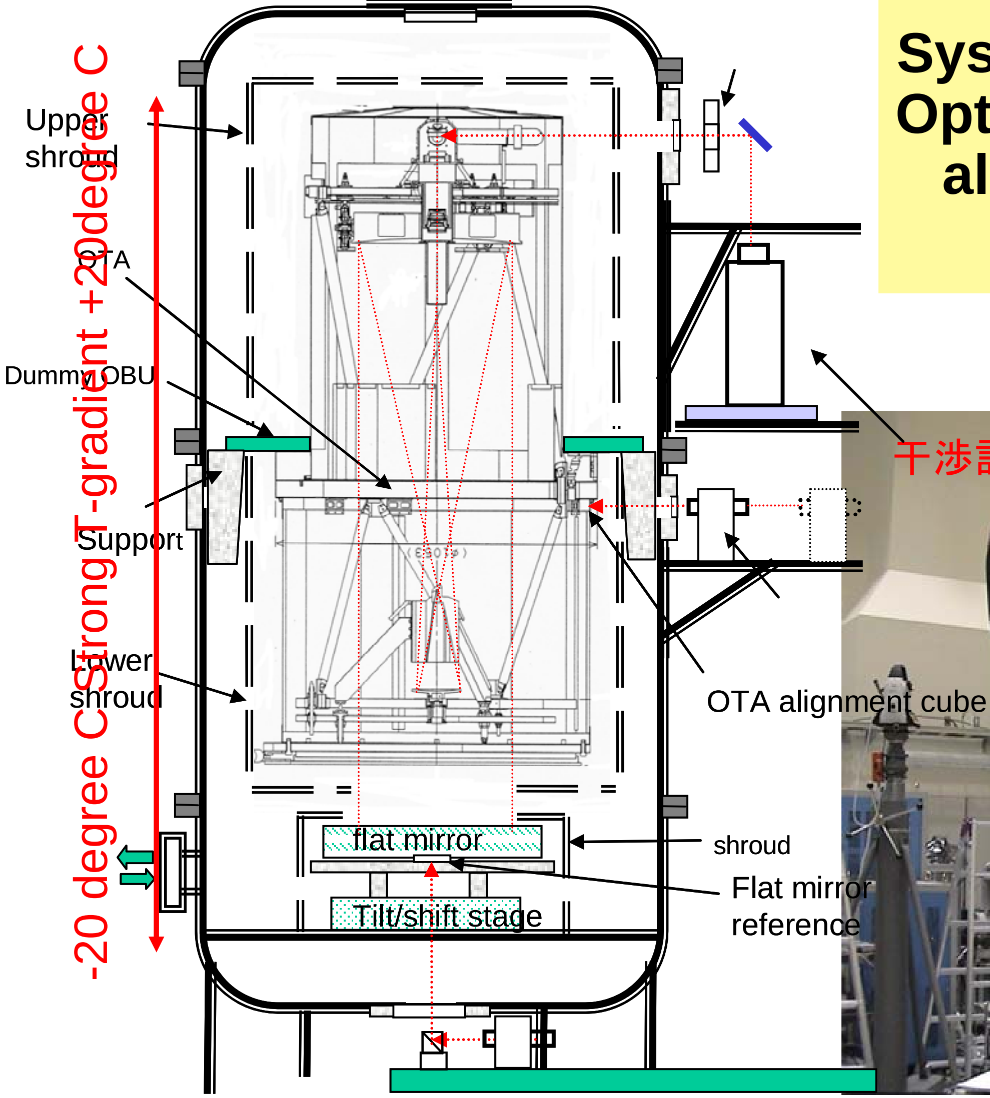
Assembly

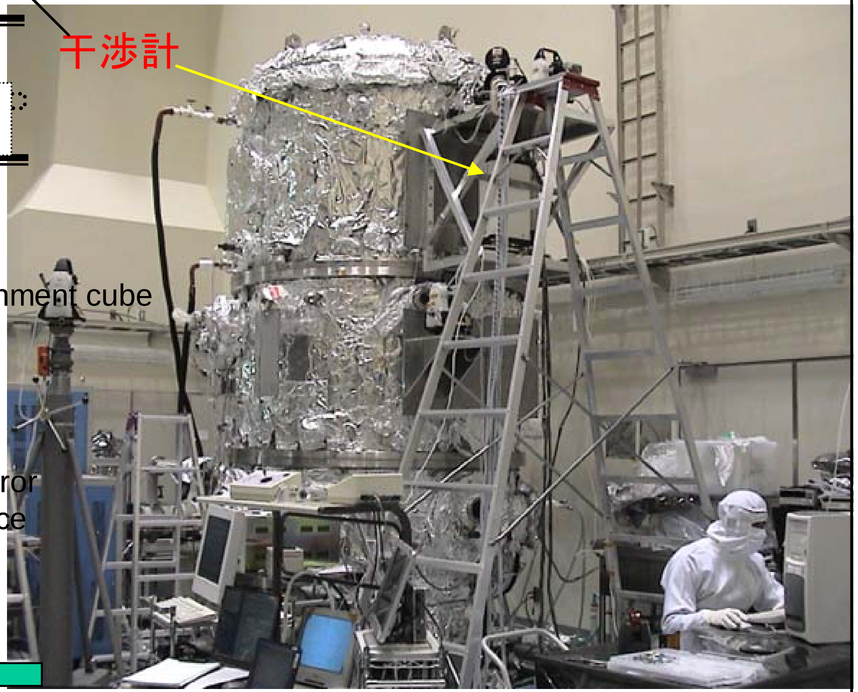
Preparation for
Opto-thermal-vacuum test



OTA&FPP
Integrated to S/C
Optical bench

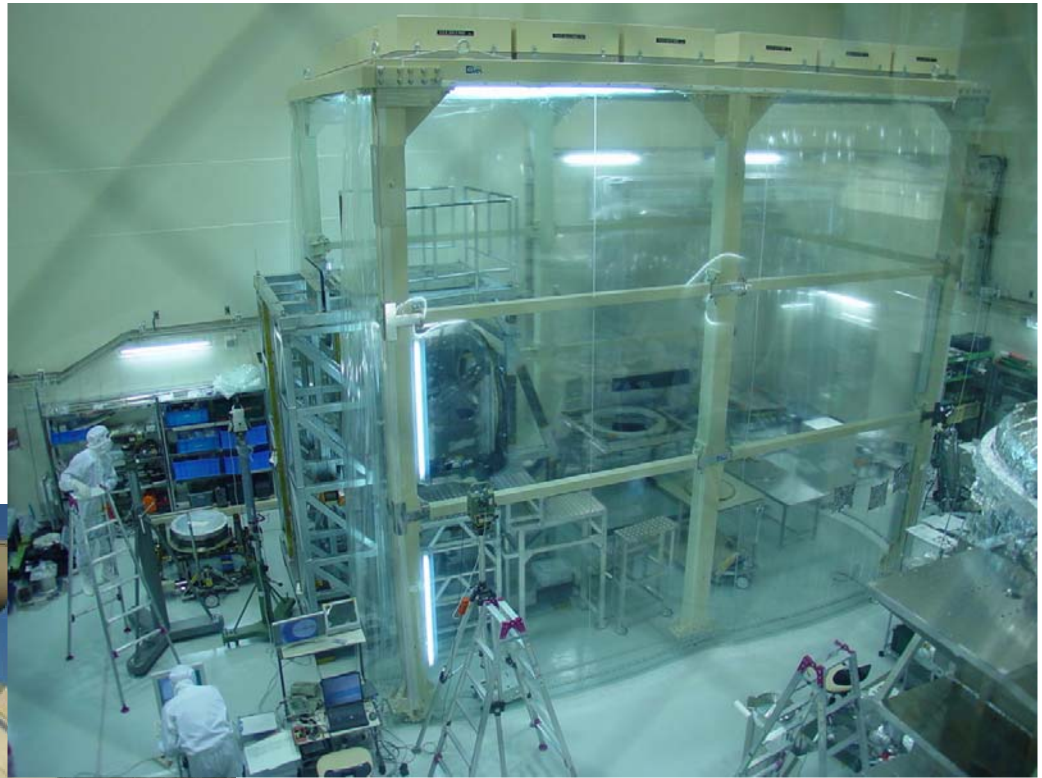
System level optical test (1)
Opto-thermal test for WFE& alignment measurement in orbit environment





NAO Clean room for space optics

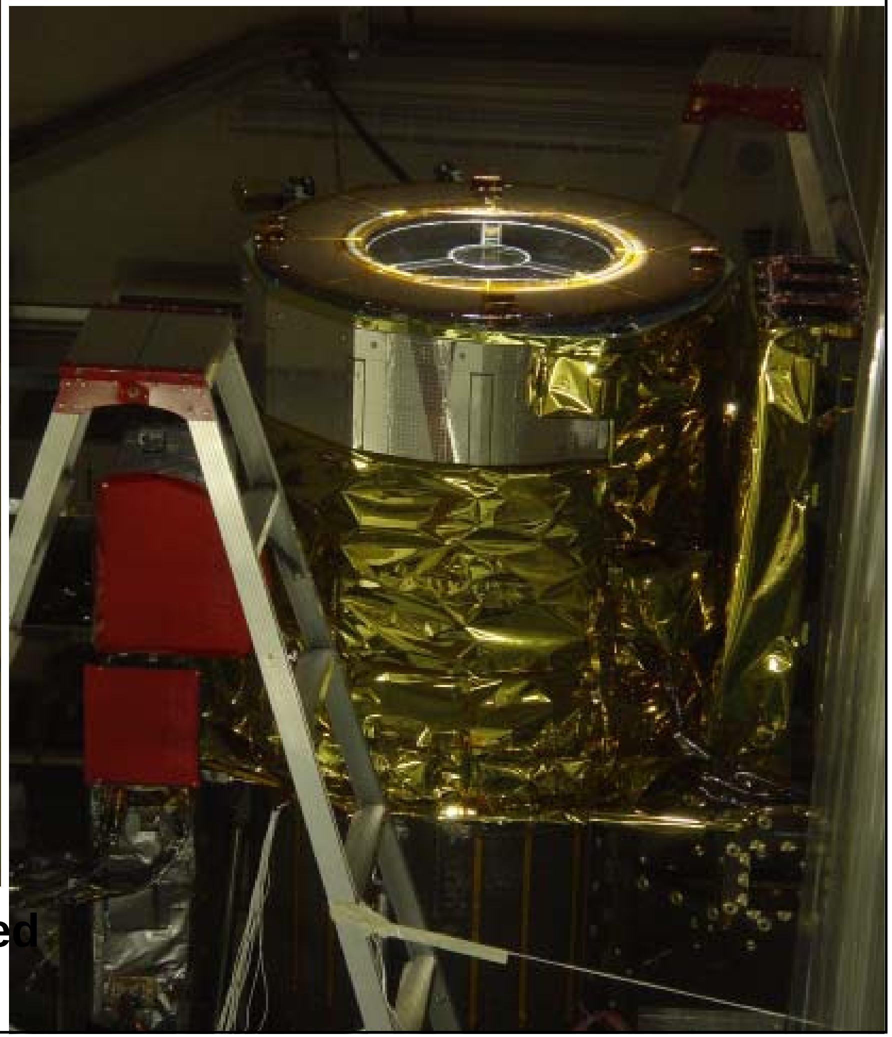
190m^2 ,10mHigh
Class 100
Class 0-10 in the booth
Space-chamber, large optical flat, fast interferometer, large Newport table



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

System level optical test (2)
Natural sun-light test
at NAO clean room

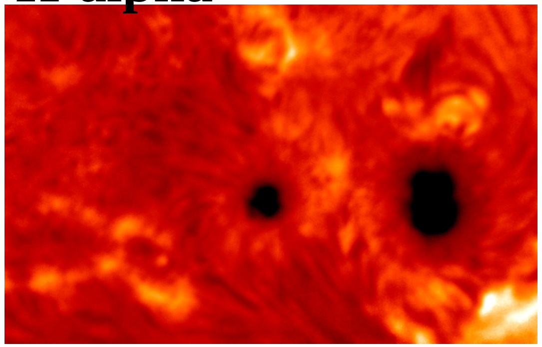
Telescope in clean room illuminated with 50cm sun beam

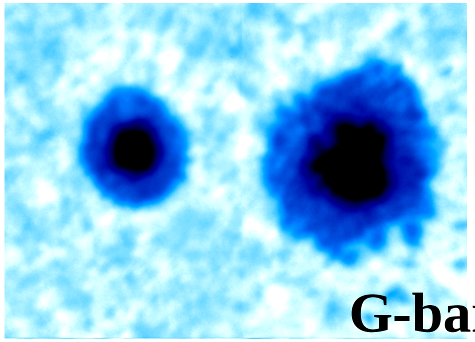


Natural sun-light test Engineering first light with full flight model 2004 August

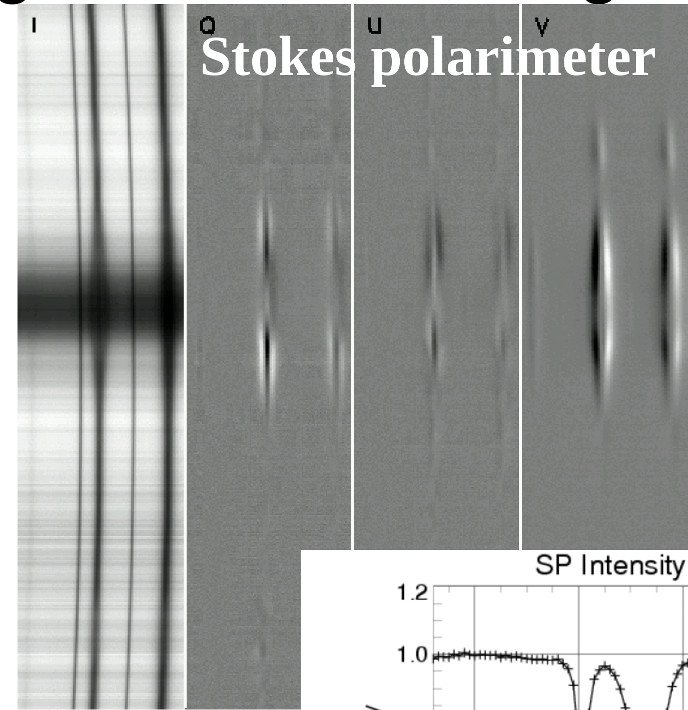
Note
- **Bad seeing in Tokyo**
- **Under 1-G**

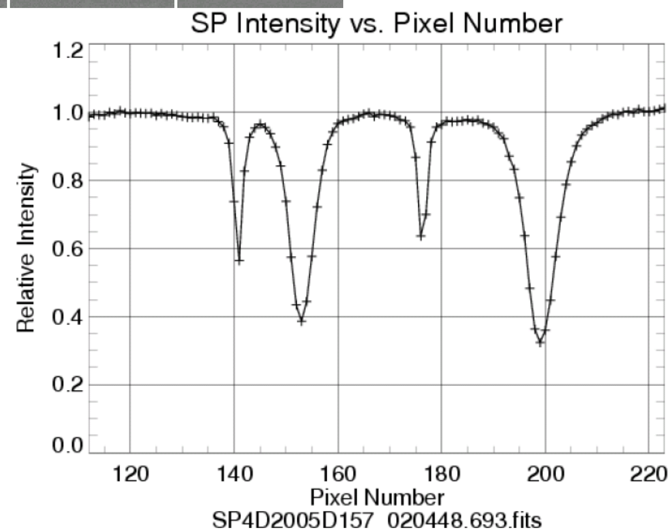
H-alpha





G-band

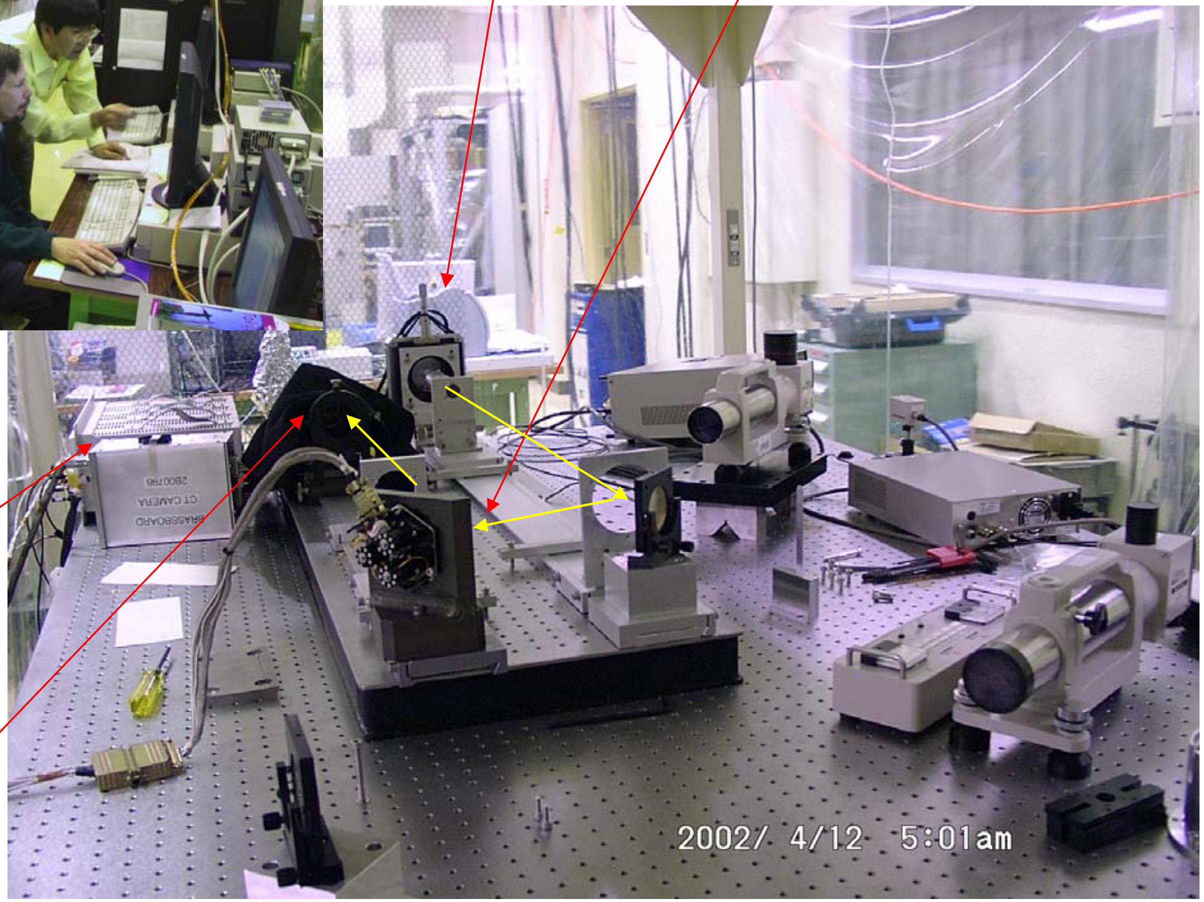




1. Test items of Sunlight test **ALL DONE**

item	purpose (possible source of error)	Methodology	goal
1. Vignetting	OTA-FPP alignment	DC exposure by NFI	No 2FS edge,
2. Ghost	Possible sources: CLU filter, PMU, as correction lens	Limb exposures	$I < 10^{-3}$
3. Scatter light	Edge of sunshade, HDM, 2FS FPP returned light into OTA	Pupil image ?	< 0.02
4. Focus	Confirmation of overall setting Initial setup for Sun test	Reimaging lens scan	Prediction ± 5mm
5. Throughput	Filter design, etc.	Guide sensor signal → absolute intensity	Prediction ±30%
6. Polarization (SP&FG)	Determine the sign of V Evaluate V→Q,U crosstalk map	Sheet polarizer on heliostat window	
7. End-to-end performance as a magnetograph	Start scientific data analysis Practice of polarization calibration using solar data	'Observing mode' is described in this document	
8. Tunable filter property	Check the uniformity of filter property.	Scan tunable filter WL at DC.	
9. Other engineering 1)HDM &OTA side window clearance	HDM/shield tube alignment	Limb pointing, visual inspection	Clearance > 3mm

Image stabilizer US-J interface test

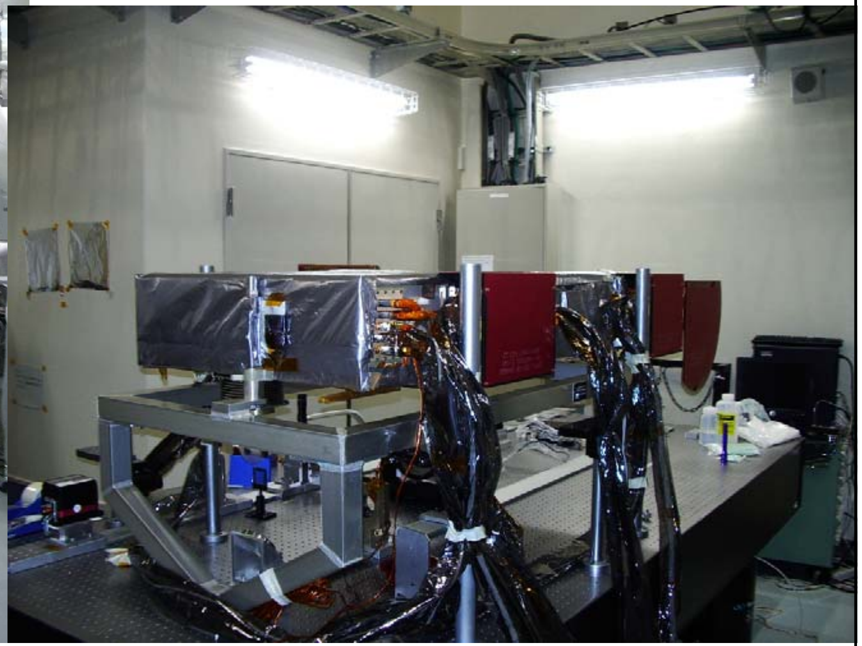


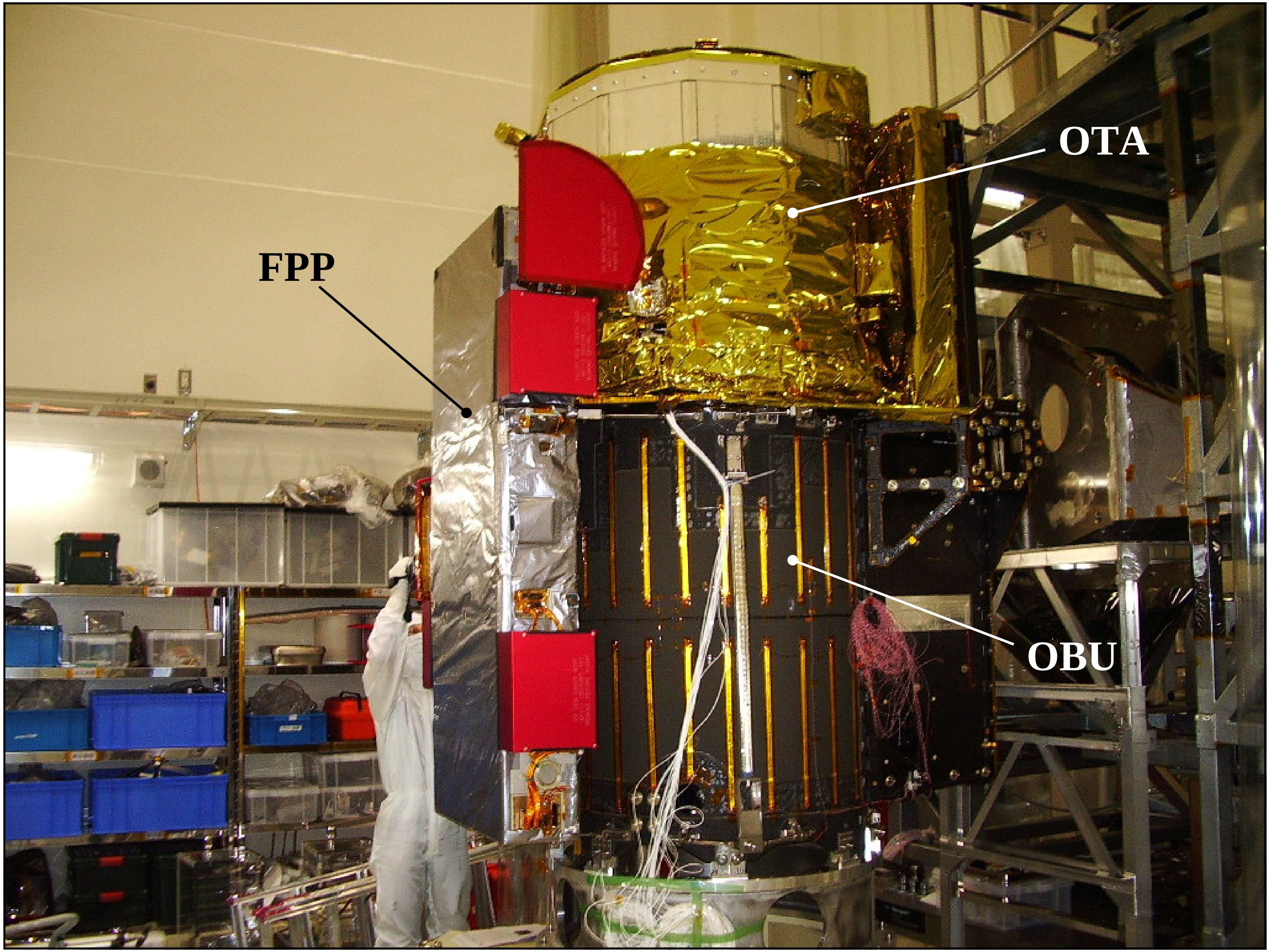
The Team

SOLAR-B可視光望遠鏡完成
国立天文台高度環境試験棟
クリーンルーム2005年4月27日

OTA and FPP at NAOJ

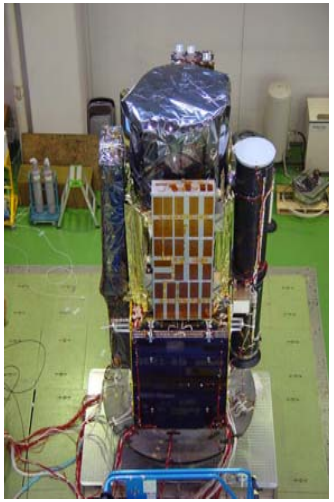
Gregorian heat-dump window




OTA
FPP
OBU

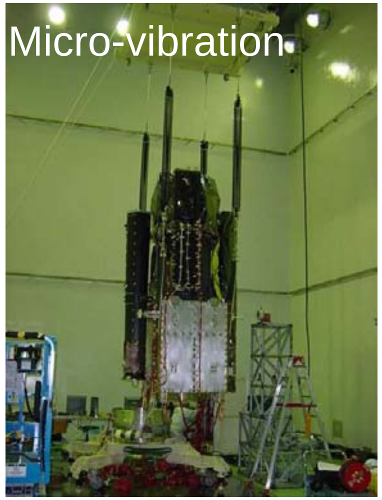
Spacecraft-level testing

Assembly

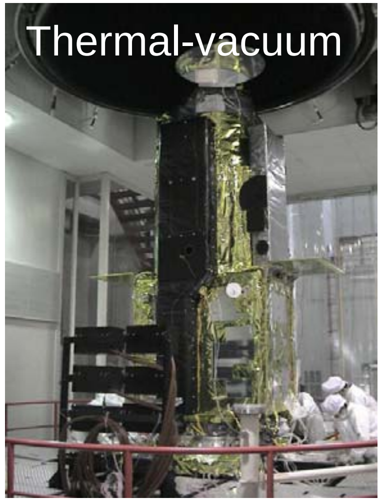


Vibration test

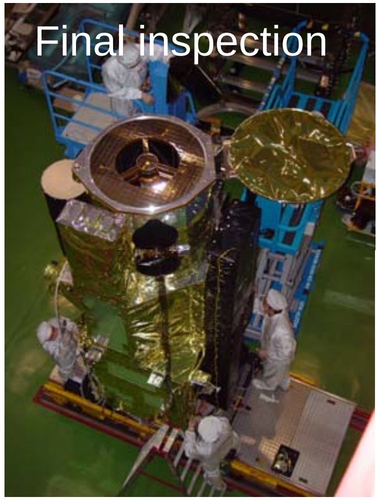
Acoustic test (telescope)



Micro-vibration



Thermal-vacuum



Final inspection

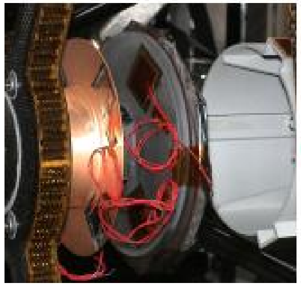
Integration to rocket

Launch

（ASTRO-EII）

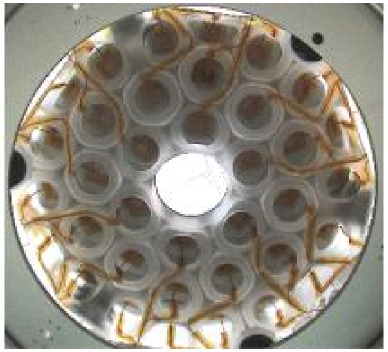
Preparation for S/C thermal vacuum test with OTA thermal model

OTA熱試験モデルI

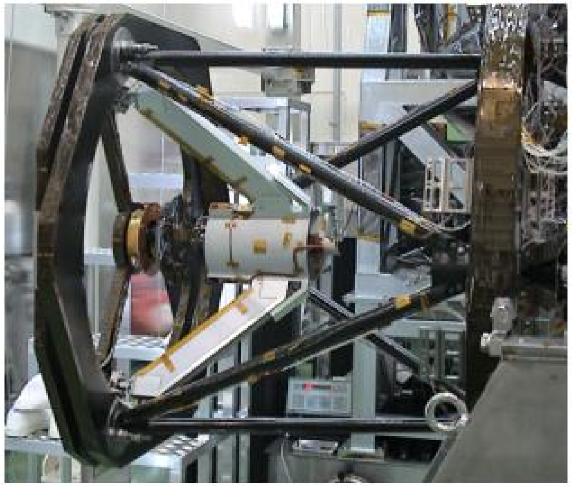


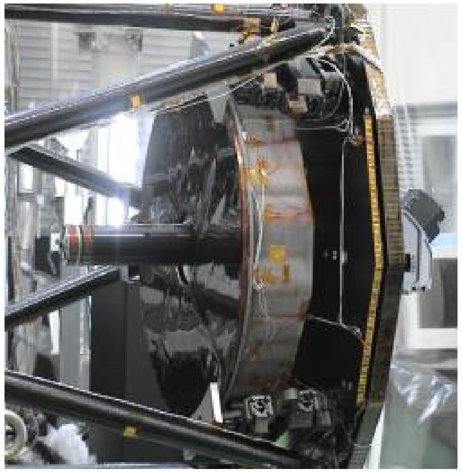
副鏡裏面
のヒーター

太陽光入力を模擬す
る主鏡裏面のヒーター



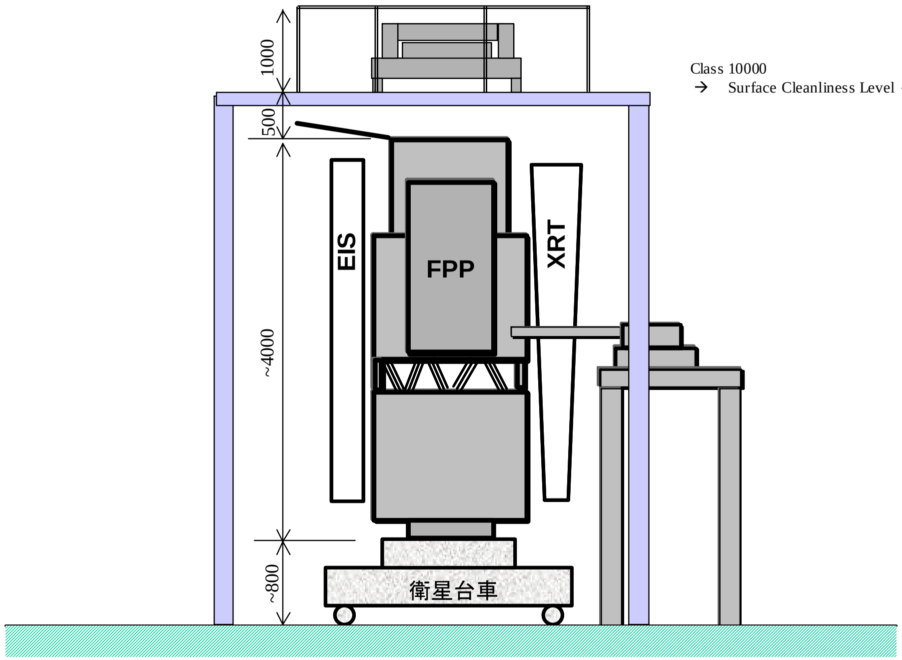
OTAはヒーター
と熱電対の配線





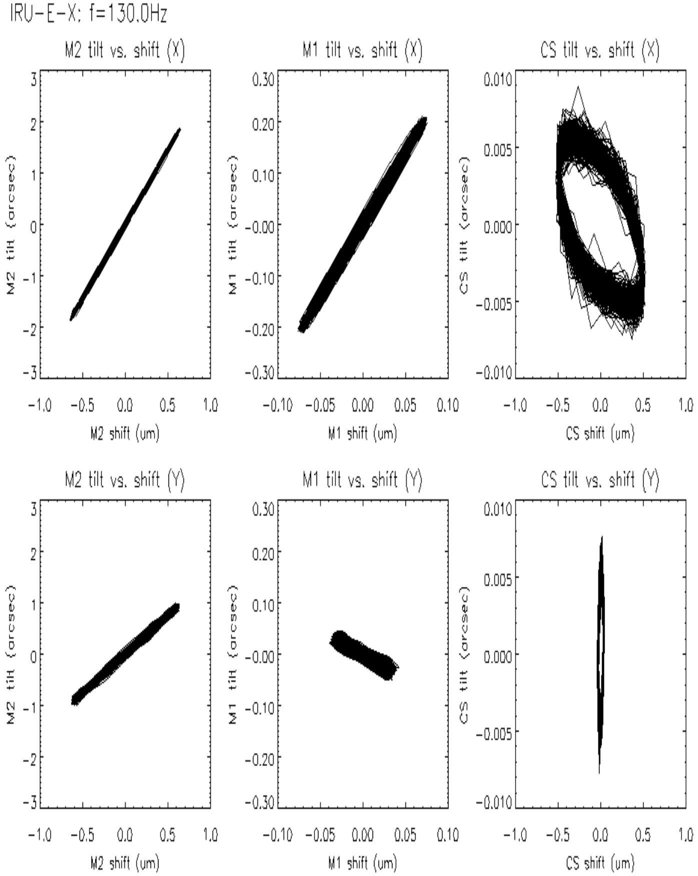
OTA WFE & alignment check as well as FPP optical tests can be done on the spacecraft level after each environment test

OTA optical performance check (measure WFE)
OTA-FPP alignment check

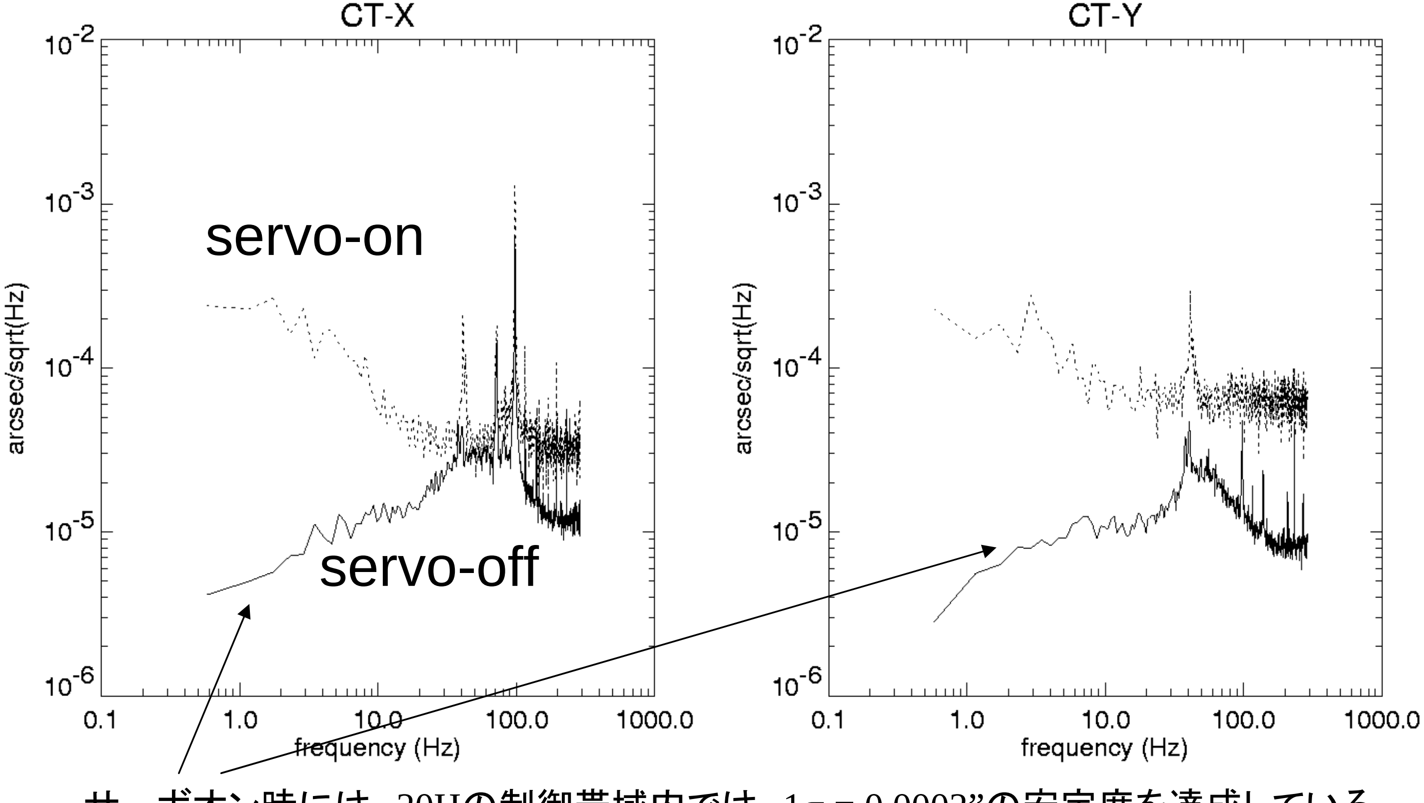


Class 10000
→ Surface Cleanliness Level ~ 250/24hr

Micro-vibration problem
resonance vibration of sensitive optical elements due to moving parts such as gryo-scope and filter wheels



SOT Image stablizer performance



サーボオン時には、20Hの制御帯域内では、1σ = 0.0002"の安定度を達成している（太陽角換算）

実線：サーボオン、破線：制御オフ

Advantage of SOT

- High resolution (0.2arcsec)
- Very stable PSF
  - Only need seasonal focus adjust
- Continuous 24 hours observations
  - Made possible by ESA Norway station
- Both filtergraph and spectro-polarimeter
- Versatile observing modes
- Simultaneous X-ray/EUV observations

Science Topics

- Continuous high resolution observations of elemental flux tube
- Flux emergence and formation of sunspot simultaneous with helio-seismic observations
- Demography of magnetic fields with different origins
- Detection of MHD waves
- Photospheric-chromospheric reconnection
- Pico-flares and Lagrangian tracking of elemental magnetic fields (The Parker concept)
- Magnetic properties of hot and cool loops

OTA current status

- OTA development completed, and integrated to the spacecraft.
- Diffraction limited performance verified.
- Image stabilization system performance with FPP superb
- On-spacecraft WFE/alignment measurements repeatedly done after testing milestones: no change in performance
  - Final test to be done in July

Mission Lifetime

- Desires to observe the sun as close to the next maximum as possible
- Sun-synchronous orbit maintained over > 7 years
- No fuel limit
- Limited-lifetime Gyroscopes fully redundant
- Lifetime for SOT diffraction-limited imaging
  – Contamination of organic materials to M1 increases the heat absorption, resulting in higher M1 temperature.
  – Current best estimate will be presented in this meeting.
  – Prioritization of the science observations important.

Schedule

- 2006 End July: Spacecraft shipped to the launch site
- 2006 September 23: Launch date
- 2006 October: Spacecraft verification and checkout phase
- 2006 November: Instrument Checkout phase (first light phase) for three telescopes
- 2006 December: Performance and Verification (PV) Phase
  - In-orbit calibration and
- 2007 January Initial Observing Phase