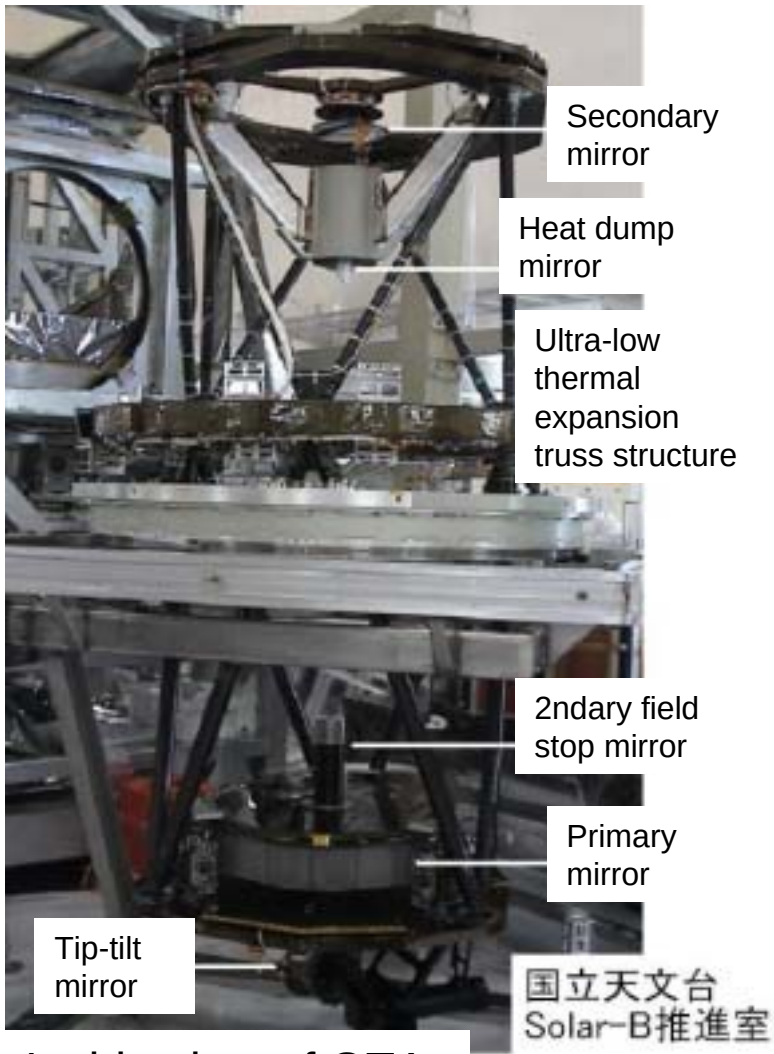
# Optical Performance of OTA: Wavefront Error Measurements

Y. Suematsu (NAOJ) and OTA team

# OTA Structure

Aplanatic Gregorian with heat dump mirror and collimator lens unit




Inside view of OTA

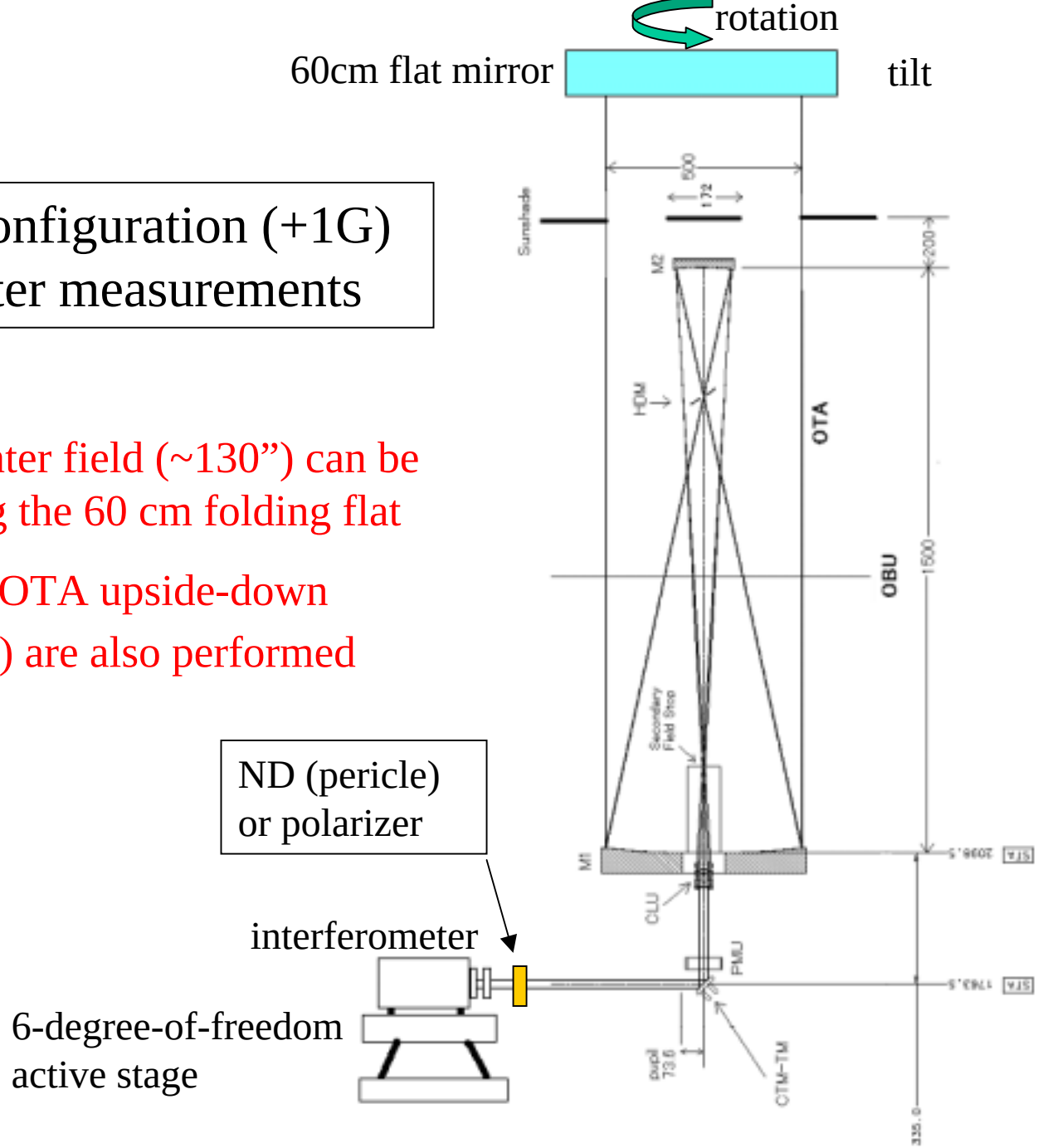
- Low-expansion CFRP honeycomb panels and pipes (0.1ppm/K) are used for mirror cell, center section, ring plate, top ring, upper truss and lower truss.
- High thermal conductive CFRP is used to alleviate hot temperature spot caused by oblique incidence of solar light.
- Panels and pipes are adhesively bonded instead of connection by flange for weight saving and to avoid differential CTE.

CFRP= Carbon Fiber Reinforced Plastics

# OTA upward configuration (+1G) for interferometer measurements

WFE in off the center field (~130”) can be measured by tilting the 60 cm folding flat

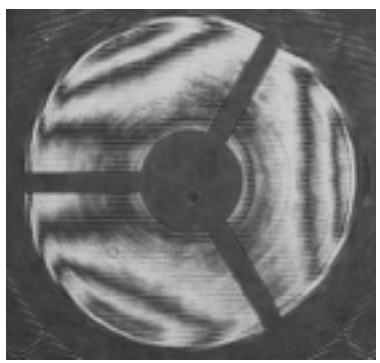
Measurements for OTA upside-down configuration (-1G) are also performed



# FM-OTA Interferometer Measurements

Method

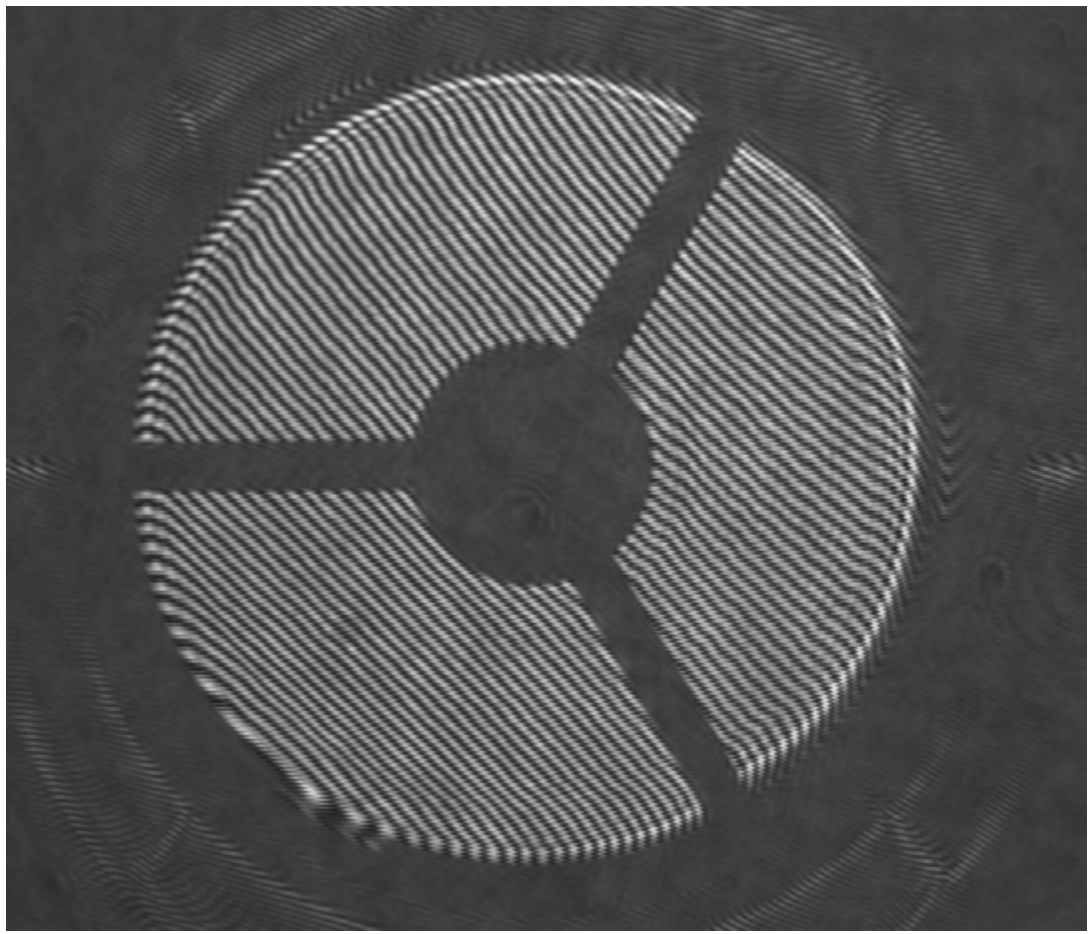
- usage of high-speed interferometer and phase map construction by spatial heterodyning method tolerant of vibration and seeing effect
- selection of good fringe map and average over 30-40 phase maps (FLIP bitmap mode)
- Consideration of air-flow system to make air temperature in optical pass uniform
- Zero-G optical performance is evaluated by an average of OTA upward and upside-down WFE measurements
- Usage of polarizer or ND in front of interferometer or off-axis measurement for rejection of ghost fringe from PMU
- Calibration of polarizer and ND WFE
- Calibration of 60cm folding flat mirror; non-axially symmetric component of WFE was removed by an average of 90 degs step rotation



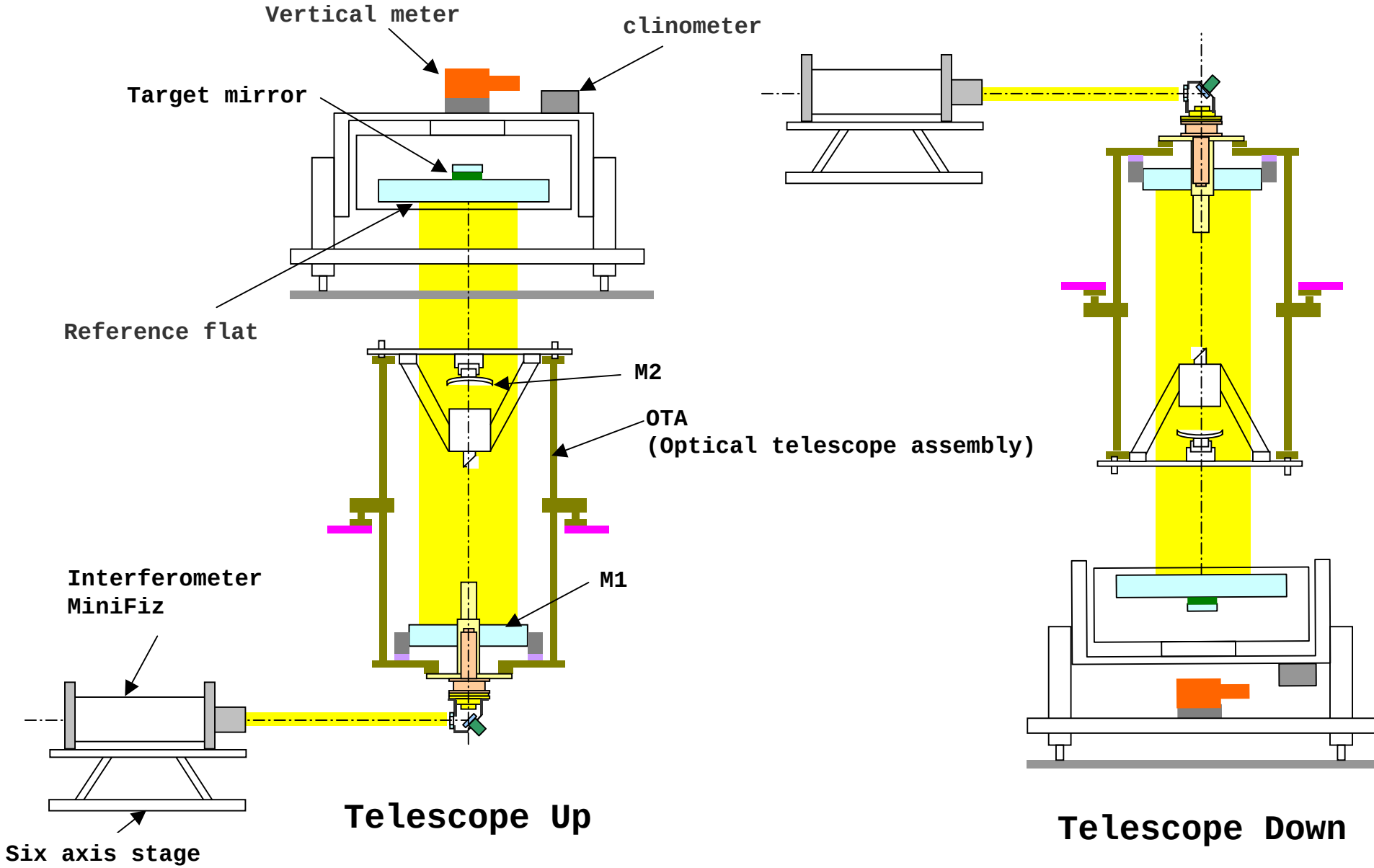
Null fringe map. Tri-angular astigmatism due to gravity is prominent.

Measurements in upward (+1G) configuration

# Sample of fringe for phase map derivation



# OTA 0-G Test Configuration




## OTA Optical Test Configuration

# Gravity deforms OTA primary mirror and CFRP truss!

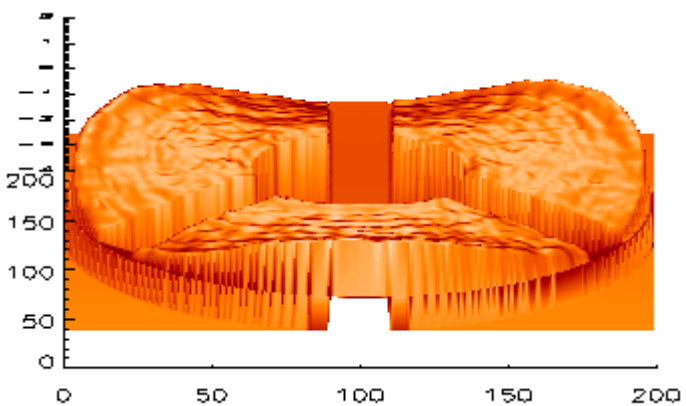
Solar-B/SOT NAOJ

OPD

uppl−ref
26/04/05, 11:25:46
(unit: λ)
max = 1.2293
min = −2.3812
mean= −0.0132
PV = 3.6105
RMS = 0.7434

Zernike coefficient:

| | | |
|---|---|---|
| A00= 0.0619 | A11= 0.0759 | B11= 0.0334 |
| A20= −1.4300 | A22= 0.0397 | B22= 0.0110 |
| A31= 0.0545 | B31= −0.0017 | A40= 0.1122 |
| A33= −0.0155 | B33= 1.1246 | A42= −0.0291 |
| B42= 0.0144 | A51= −0.0117 | B51= 0.0351 |
| A60= 0.0696 | | |




WFE for OTA upward configuration (+1G) (average of 4 data from 90 degs step rotation of 60 cm flat after calibration)

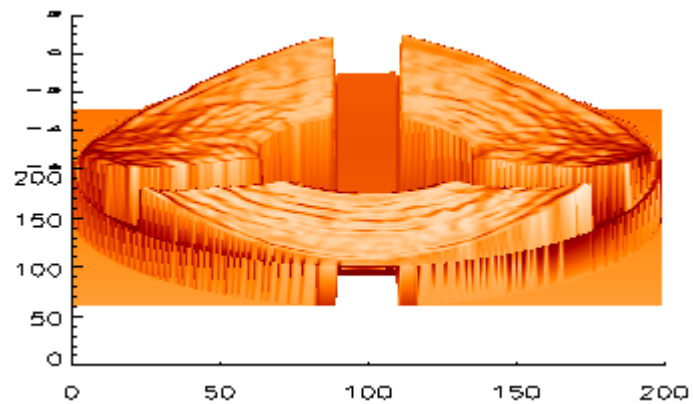
Solar-B/SOT NAOJ

OPD

sh_dwpl−ref
00/00/00, 00:00:00
(unit: λ)
max = 1.8159
min = −2.7468
mean= 0.0013
PV = 4.5627
RMS = 1.0685

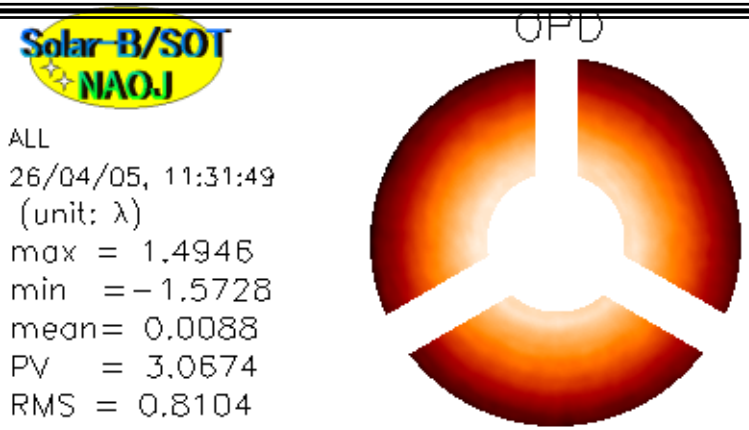
Zernike coefficient:

| | | |
|---|---|---|
| A00= 0.2411 | A11= −0.0865 | B11= 0.0534 |
| A20= −2.0624 | A22= −0.0126 | B22= −0.0262 |
| A31= 0.0780 | B31= −0.0617 | A40= −0.0478 |
| A33= −0.0412 | B33= −1.2193 | A42= −0.0262 |
| B42= 0.0122 | A51= 0.0028 | B51= 0.0241 |
| A60= 0.0712 | | |

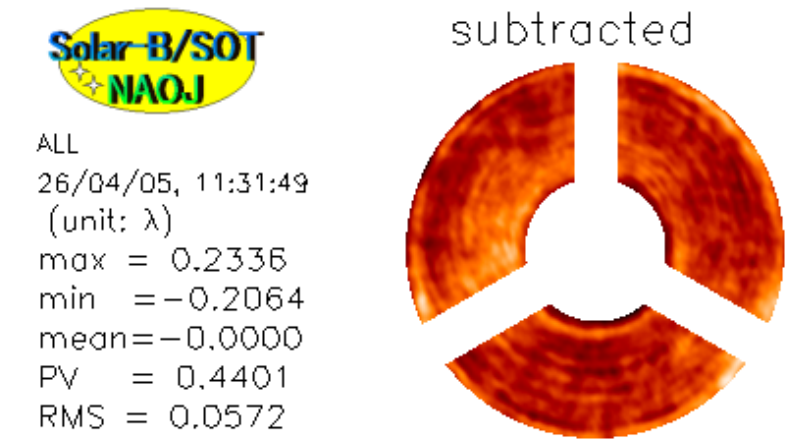



WFE for OTA downward configuration (-1G) (average of 4 data from 90 degs step rotation of 60 cm flat after calibration)

# Optical Performance of OTA in 0-G



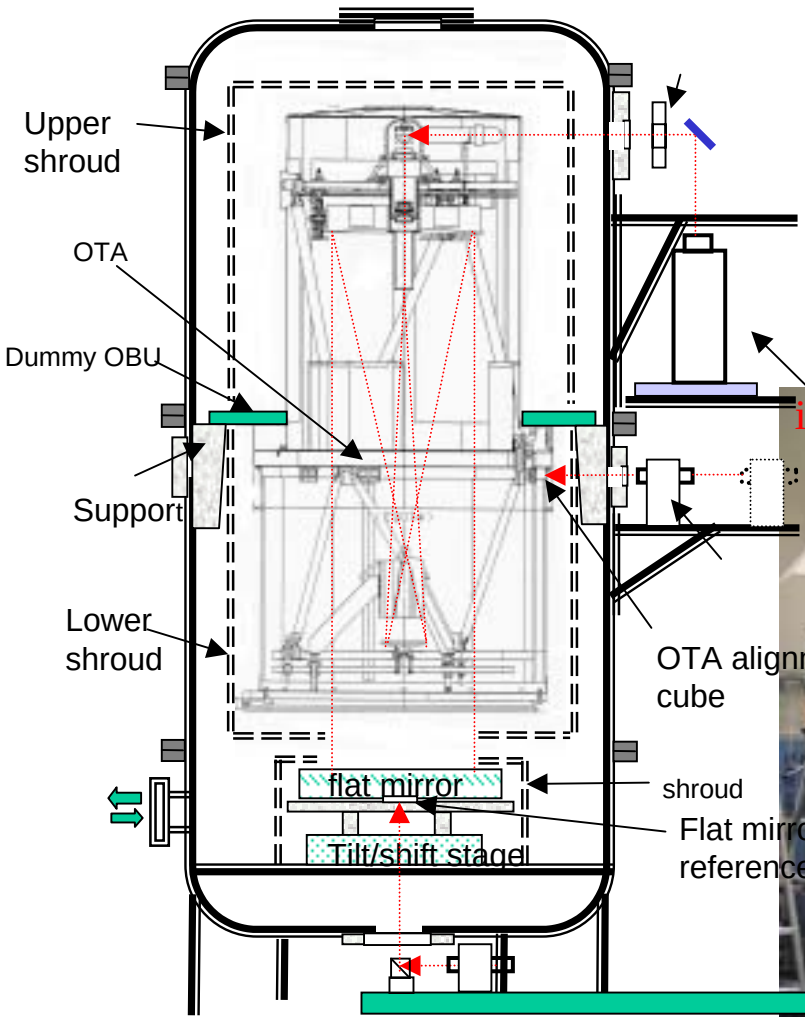

Average WFE of upward and downward OTA




tilt and focus term removed.

**OTA WFE map for zero-gravity condition.** **This was obtained by averaging upward and downward OTA WFE. Then, rms WFE gives 0.0288 waves (18.1nm, λ/35) when focus error which can be corrected on-orbit are removed. This indicates that the rms WFE in the shortest observable wavelength 388 nm is 0.0469 waves and OTA WFE satisfies diffraction-limited condition (less than 0.071 waves, λ/14) in all the SOT observable wavelengths.**

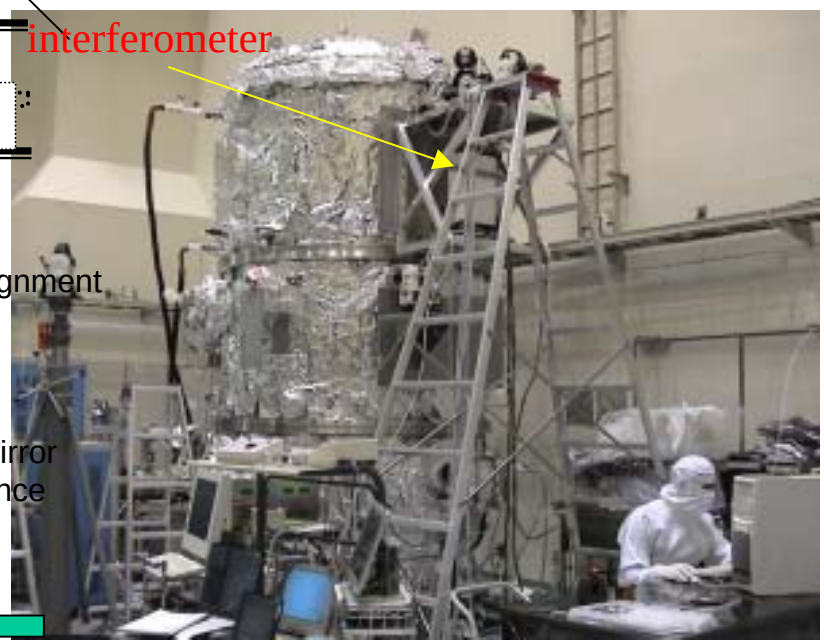
# OTA Opto-Thermal Test for On-Orbit Performance



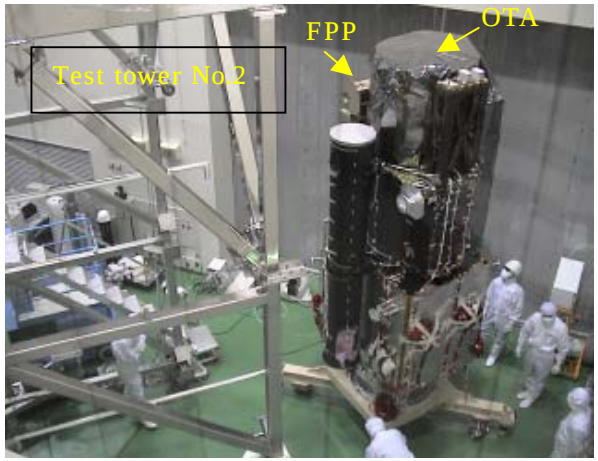

**OTA WFE's were measured with an interferometer for cases that OTA had temperature distribution (−30℃～+40℃) predicted for on-orbit condition.**

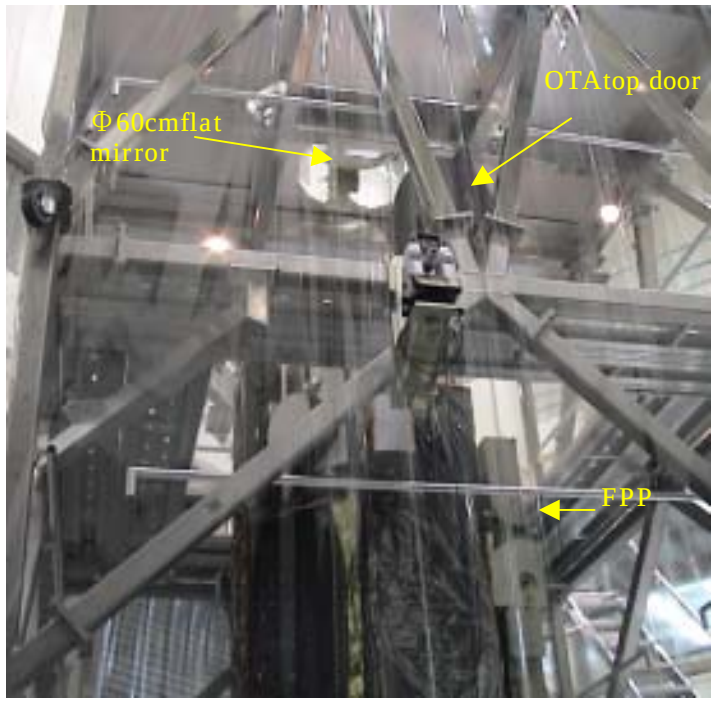
**The test demonstrated that OTA on orbit maintains diffraction limited performance although it was slightly deformed (14.7 nm rms) by the temperature change.**

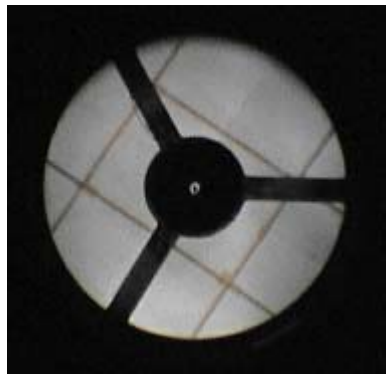
**Duty cycle of operational heaters for M2 and CLU does not affect the optical performance of OTA.**



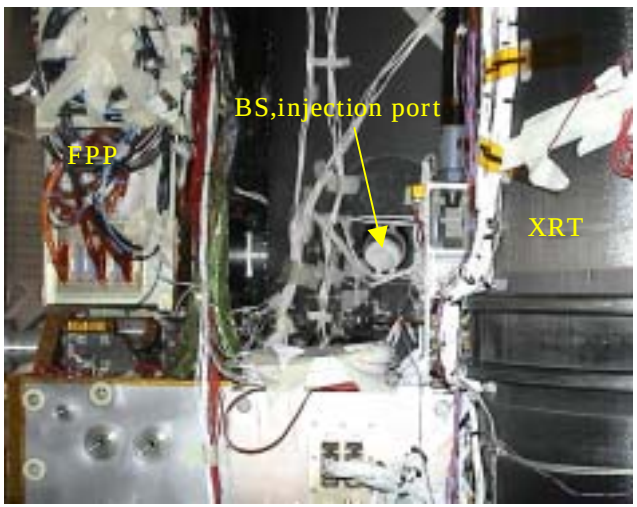
# System-level optical test

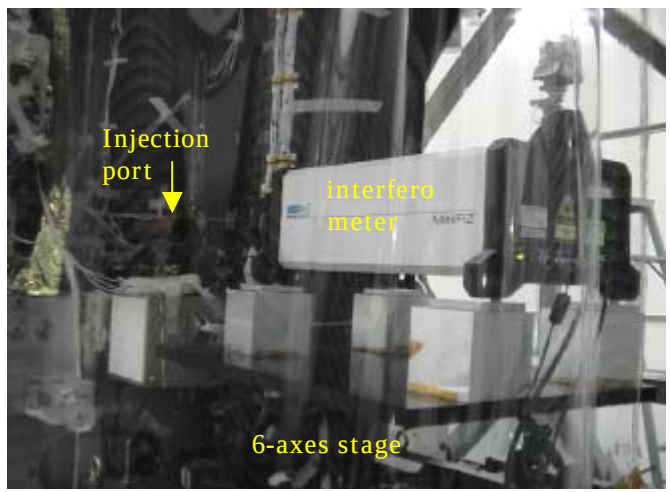


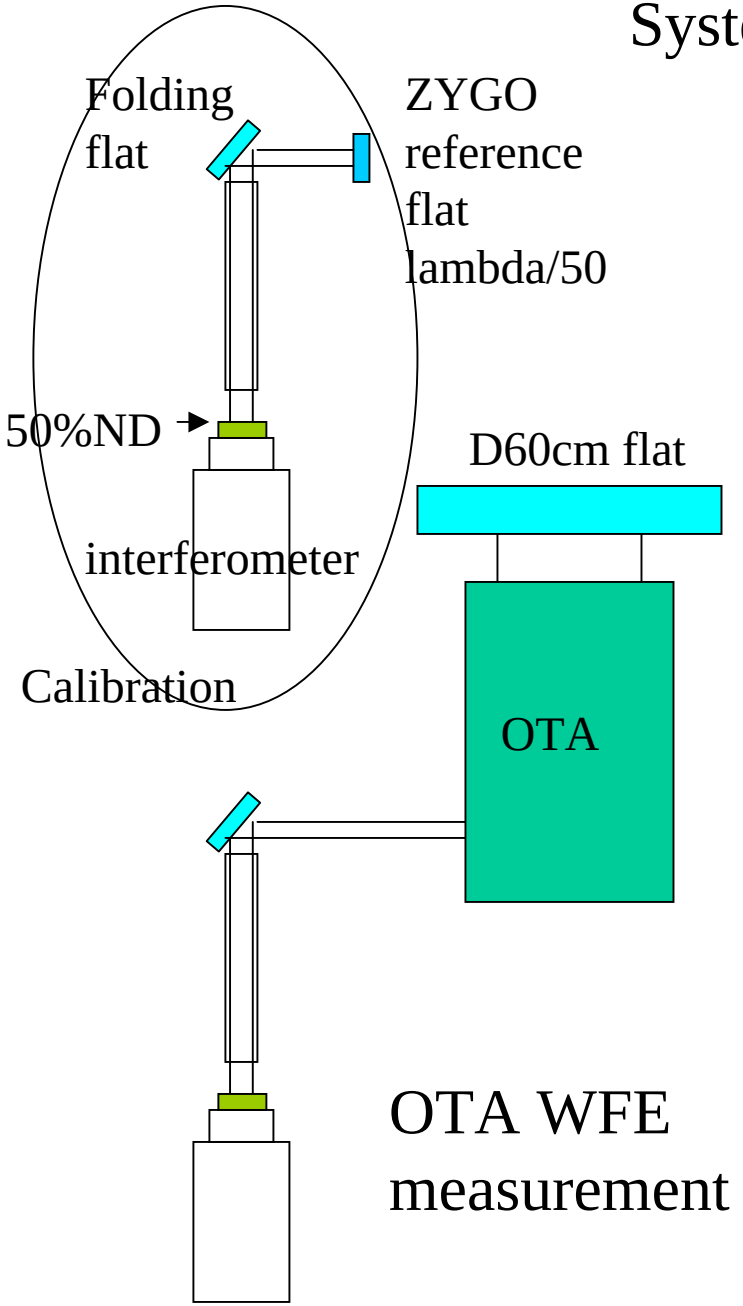



OTA Pupil image

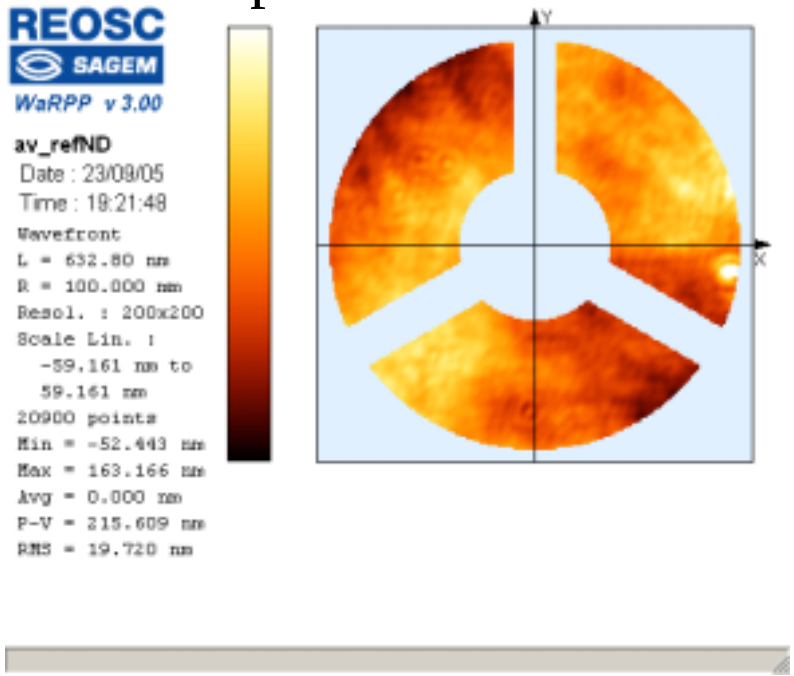


# System-level OTA optical test




OTA WFE measurement




Calibration of 5 cm folding flat WFE

| | | |
|---|---|---|
| // Tilt | -0.004972 | -0.002077 |
| // Focus | -0.005948 | |
| // Astig | 0.017461 | 0.053928 |
| // Coma | 0.026772 | -0.010023 |
| // Sphere 3 | -0.003328 | |
| // Astig Tri | 0.011442 | 0.001463 |
| // Astig 5 | -0.008874 | -0.008480 |
| // Coma5 | -0.012886 | 0.008832 |
| // Sphere 5 | 0.011047 | |

# History of measurements of FM-OTA WFE

| date | 0-G WFE (nm rms, single path) | Focus in 0G: A20 (lambda, double path) | Focus in 1G: A20 (lambda, double path) | Focus in -1G: A20 (lambda, double path) | test |
|---|---|---|---|---|---|
| 2004.Jul.5-7 | 18.2 | -1.29 | -0.98 | -1.63 | FM-OTA initial integration |
| 2004.Jul.14-17 | d(5.2); hot mode –reference | | | -1.60(pre-test)<br>-1.25(post-test) | Opto-thermal test III<br>OTA downward |
| 2004.Aug. | **Note: WFE and focus (Zernike A20 term) given in the table are values measured at field center. WFE for OTA upward or downward configuration is given by a difference from a reference WFE obtained before (d( )).** | | | | Sunlight test I |
| 2004.Sep-Dec | | | | | System EIC/MIC test |
| 2005.Jan.12-14 | d (7.9) ; change by replacement | | -1.78 | OTA upward | Replacement of astig. Corrector |
| 2005.Mar.11-20 | d(14.7); cold obs. mode – reference | | | -2.27(pre-test)<br>-1.43(post-test) | Opto-thermal test IV with thermal cycling test OTA downward |
| 2005.Apr | | | | | Acoustic test |
| 2005.Apr.21-25 | 18.1 | -1.74 | -1.43 | -2.06 | |
| 2005.Jun | | | | | Sunlight test II |
| 2005.Sep.23 | d (7.3) ; change from Apr. | | -2.02 | | System Performance Test OTA upward |

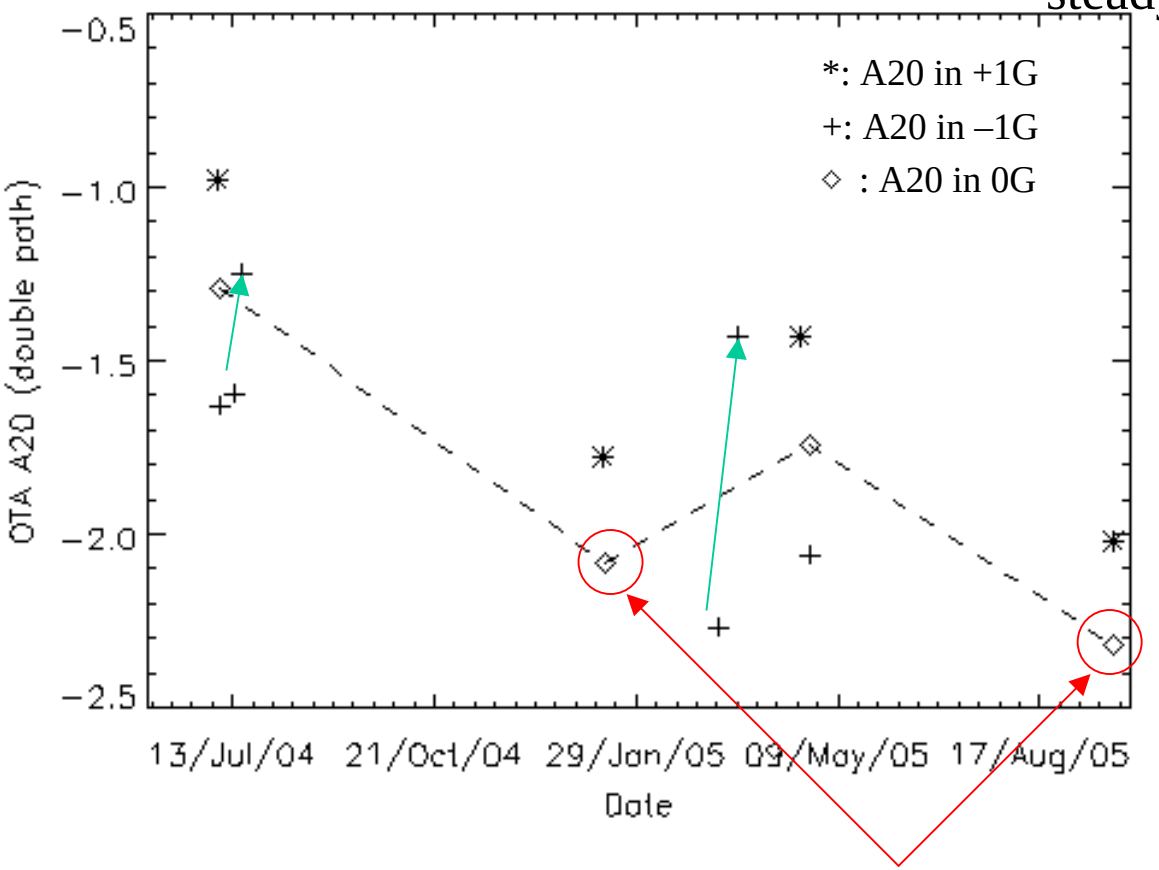
# CFRP truss dehydration Focus Change

Truss contraction due to dehydration in vacuum.

Truss expansion due to moisture absorption in air.

A month after launch, the truss is expected to reaches steady state

Focus change




Truss contraction

Truss expansion

Estimates from +1G measurement

# Summary

**OTA WFE at a room temperature (20 degC) for zero-gravity condition was 18 nm rms when removed tilt and focus term and it did not change after a acoustic test and a thermal cycling test in which OTA experienced the coldest and hottest thermal environment on orbit; the diffraction limited WFE at wavelength of 500 nm is less than 35.7 nm rms.**

**Change in WFE from the room temperature in vacuum to temperature on orbit for cold case observational condition was 14.5 nm rms (BOL) and this indicates total WFE on orbit is 23.1 nm rms, combined with WFE of 18 nm rms for zero-gravity and room temperature condition.**

**The difference in WFE between 130 arcsec off-center and the field center was 13.7 nm rms and hence WFE within 130 arcsec field radius is estimated to be less than 26.9 nm rms including the thermal effect; (max FOV: 160✕320 arcsec^2) .**

**Focus change shown here is due to vapor absorption (in air) or dehydration (in vacuum) effect of CFRP truss and stays in a range corrected on orbit by re-imaging lens of FPP.**

**OTA has a perfect optics!**