P-CG18-P05

PLANETS 望遠鏡の開発 能動主鏡支持機構などを用いた最終研磨量削減の試み

Development of PLANETS telescope: An attempt to reduce polishing volume in final polishing process by using an active mirror support

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関連投稿：P-CG18-P03
High dynamic range observation using a 1.8-m off-axis telescope PLANETS: feasibility study and telescope assembly

Summary

Background : PLANETS is 1.85m telescope with **off-axis parabola (OAP)** for the observation of the planetary faint atmosphere and plasma

The final polishing process of the primary mirror (M1) will be held in June 2021

Purpose : In the final polishing process, small polishing volume is desirable.

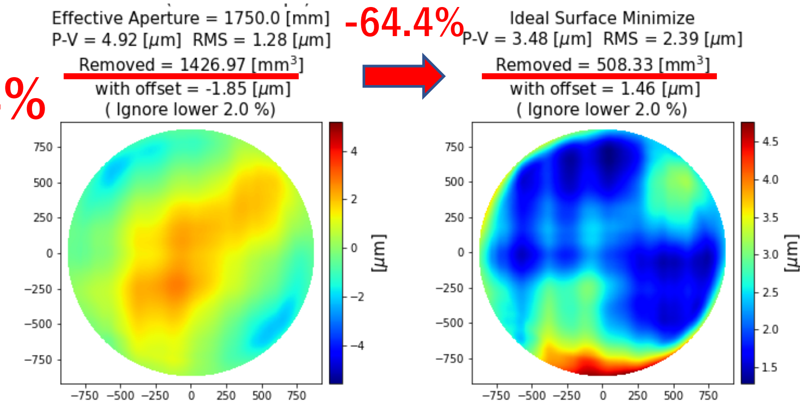
Method : A : Tuning OAP parameters to find best-fit parameters

B : Correcting the surface figure error with the active support mechanism

Result : With only A method, **polishing volume is reduced 64.4%**

With combination of A and B method, reduced 67.5%

FEM model doesn't simulate actual surface accurately



Discussion : **It is effective to reduce polishing volume by tuning the OAP parameters**

For current M1 surface error, we will only use method A

PLANETS (Polarized Light from Atmosphere of Nearby Extra-Terrestrial Systems)

Key technology

- 1.85m telescope with **off-axis parabola (OAP)**
- The primary mirror (M1) is mounted on the active support system
- Various observation equipment : coronagraph, polarimetry, and high-resolution spectroscopy
- Will be installed at the **Haleakala observatory**, Hawaii in collaboration with Japan, USA, Germany, and Brazil

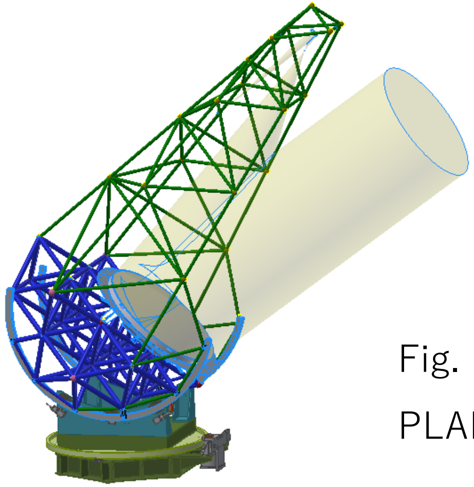


Fig. 1 : PLANETS overview

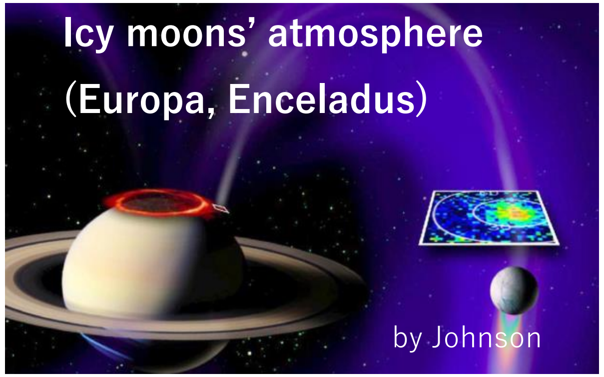
Strength

- Low-scattered optics
- High-dynamic range (HDR) observation
- Long-term continuous observations

Scientific targets

Faint atmosphere and plasma emission near bright body

- Icy moons' atmosphere (Europa, Enceladus)
- Magnetospheric plasma (Io plasma torus, etc.)
- Escaping plasma and neutrals (Mars, Venus)



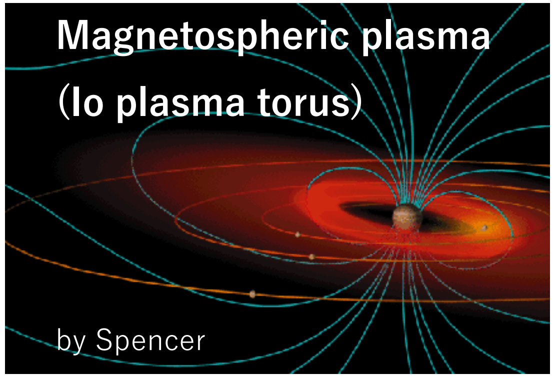


Fig. 2 : Scientific targets

Previous study of active support structure

TMT (Thirty Meter Telescope)

- 30m telescope with segmented mirrors
  - To compensate for residual polishing errors, installation errors, gravity effects and parasitic forces in the whiffletree support, each segment is equipped with 21 warping harness mechanisms
  - The WH mechanism consists of a Linear Actuator, Ball Link and a Leaf Spring with strain gauge sensor
  - With active support, measured Zernike modes were within 4% of commanded modes

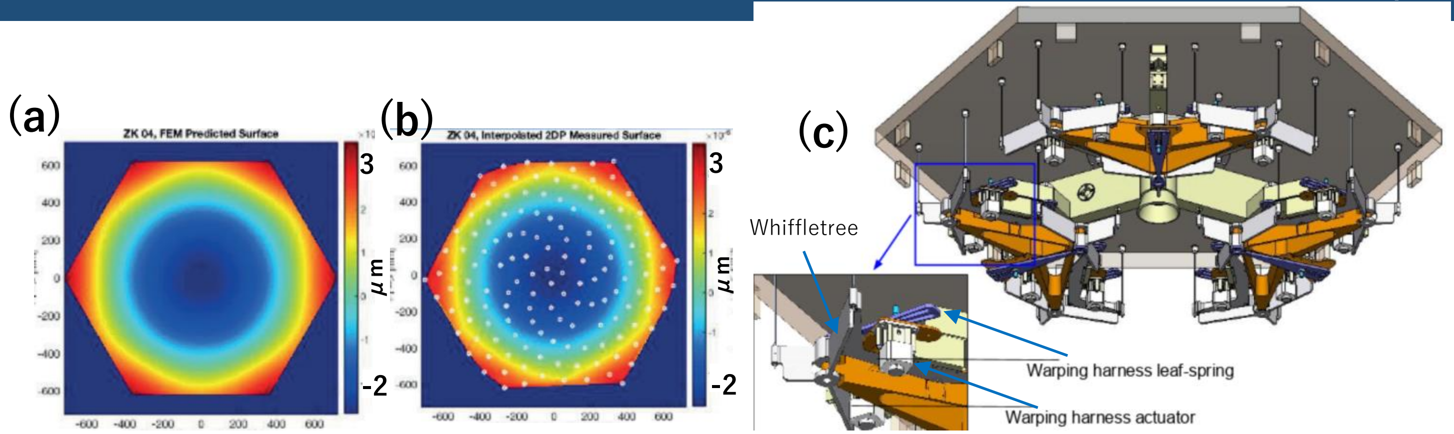


Fig. 3 : TMT warping harness and whiffletree (Visser et al. 2017)

(a) Predicted surface in FEM (Zernike 4th) (PV=6.276um, RMS=1.597um)

(b) Interpolated 2D profilometry measured surface (PV=1.663um, RMS=5.549um)

(c) Leaf springs are used to apply a moment to the whiffletree

DKIST(Daniel K. Inouye Solar Telescope)

- 4.2m off-axis solar telescope
  - Consists of 118 axial actuators and 24 lateral actuators, and each axial support force is about 220~280N
  - Uses active support in polishing and metrology process, but the adjustment for each actuators is about -2.5~+2.5N (only 1% of the support force)

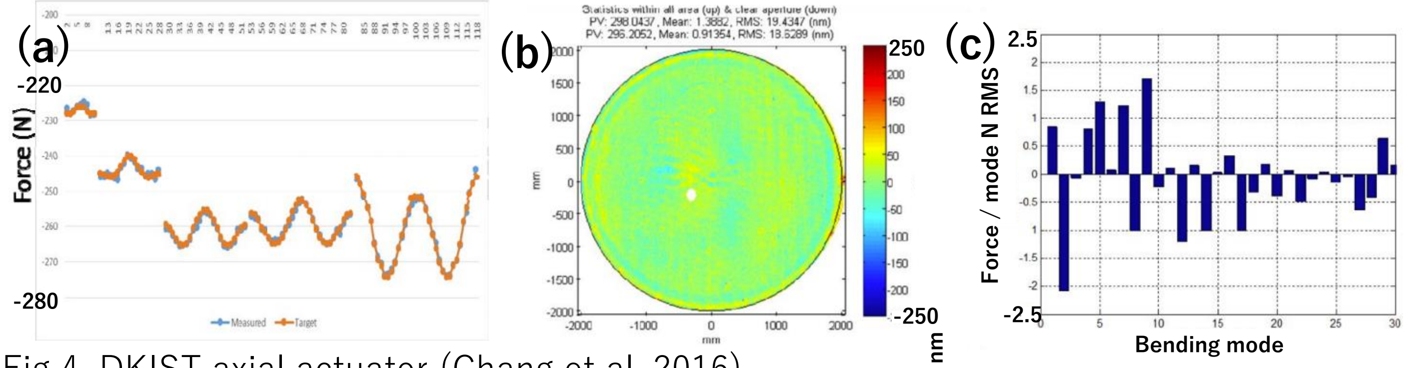


Fig 4. DKIST axial actuator (Chang et al. 2016)

(a) Targeted supported force distribution and measured force in each axial actuator

(b) Surface measurement from CGH null interferometry (PV=296.2nm, RMS=18.63nm)

(c) Modal correction force

Purpose

Surface measurement and polishing of OAP

- In order to compensate for several surface errors in observation, PLANETS adopts whiffletree and active support (warping harness), and they can also be applied to the final measurement and polishing process
- Large volume of mirror material to be removed by polishing (polishing volume) leads to an increase in the time and cost required.

➢ **Purpose : To reduce polishing volume**

We will reduce the polishing volume by using both of the following two methods.

A) Tuning off-axis paraboloid parameters

B) Correcting the surface figure error with the active support mechanism

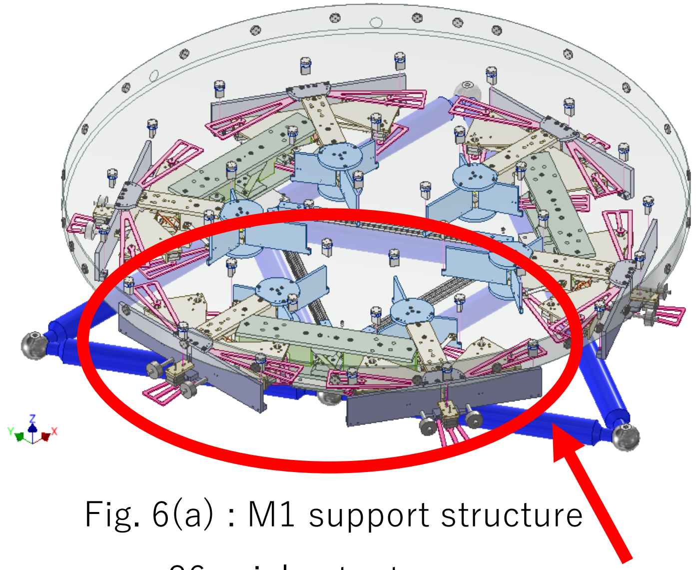


Fig. 6(a) : M1 support structure uses 36 axial actuators

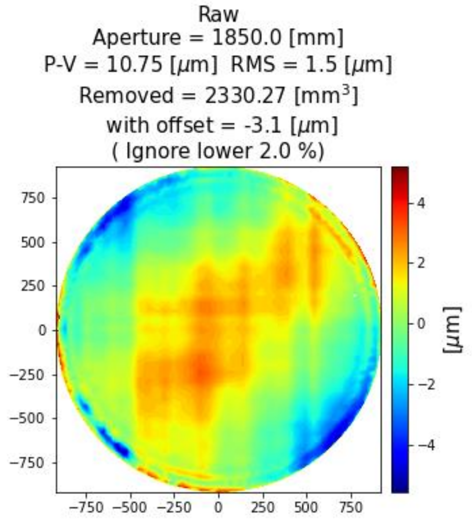


Fig. 5 : Current M1 surface error

The final polishing aims to achieve the surface error < 20 nm RMS for 30-cm spatial scale.

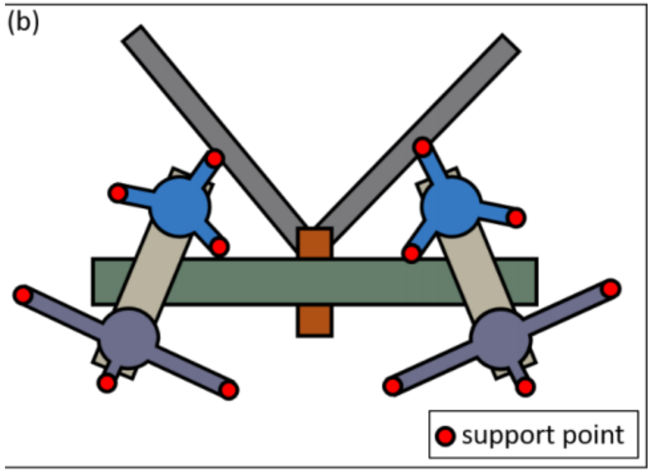


Fig. 6(b) : Enlarged view

Support structure is 120° symmetric

A : Tuning off-axis paraboloid (OAP) parameters

Original OAP

- p = 8667 mm :
  Radius of curvature
- q = 1800 mm :
  Off-axis distance
- Φ = 0 mrad :
  Rotation angle
  on the support structure

Tuning params

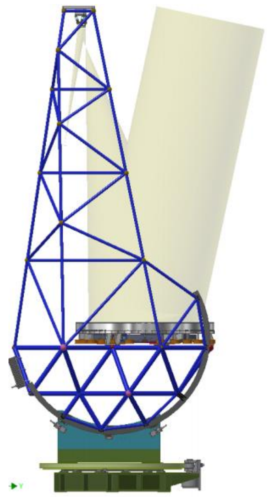
p = 8667 ± 100 mm

q = 1800 ± 100 mm

Φ = 0 ± 10 mrad

Tuned OAP

- Change of parameters (p, q, ϕ)
  deform surface figure
- ➢ Polishing volume is minimized with best-fit parameters



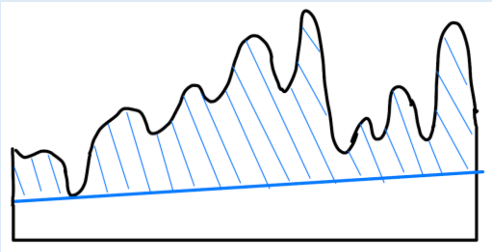


Fig.7 : original OAP

(Large polishing volume)

e.g.) make tilt smaller using longer q

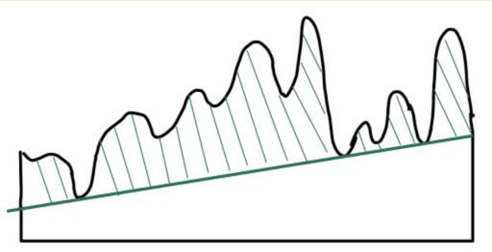


Fig.8 : Tuned OAP

(Small polishing volume)

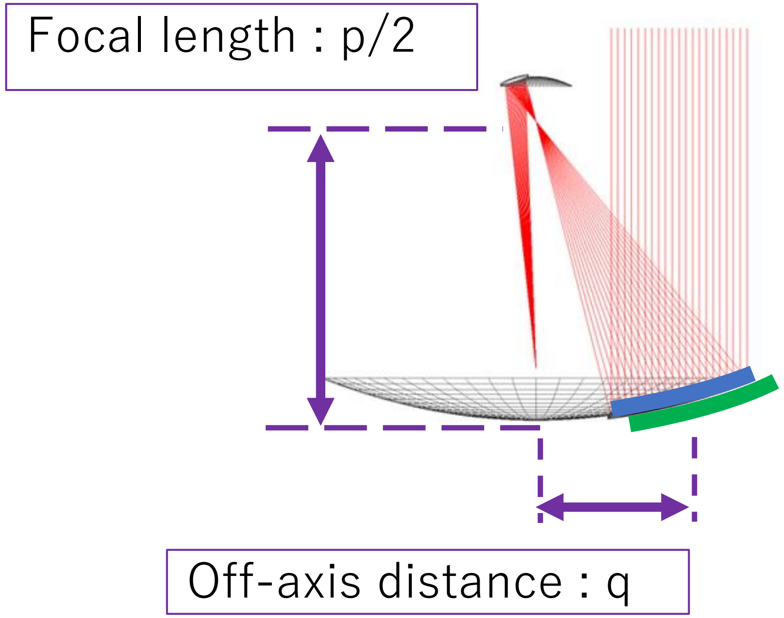


Fig. 9 : each parameters

B : Correcting the surface figure error with the active support

◆ Active support in general telescope

➢ Adjust mirror surface error due to posture change and manufacturing error of support structure in observation

◆ Active support in PLANETS

➢ Also used in the final polishing process

- Active support consists of 36-point whiffletree and 33 warping harness (leaf springs and linear motors to control the support force at each support point)
- We also use the active support to reduce polishing volume by decreasing the surface figure error on large spatial scale
- Active support is mainly used in observation, so small motor drive amount is desirable in polishing process.

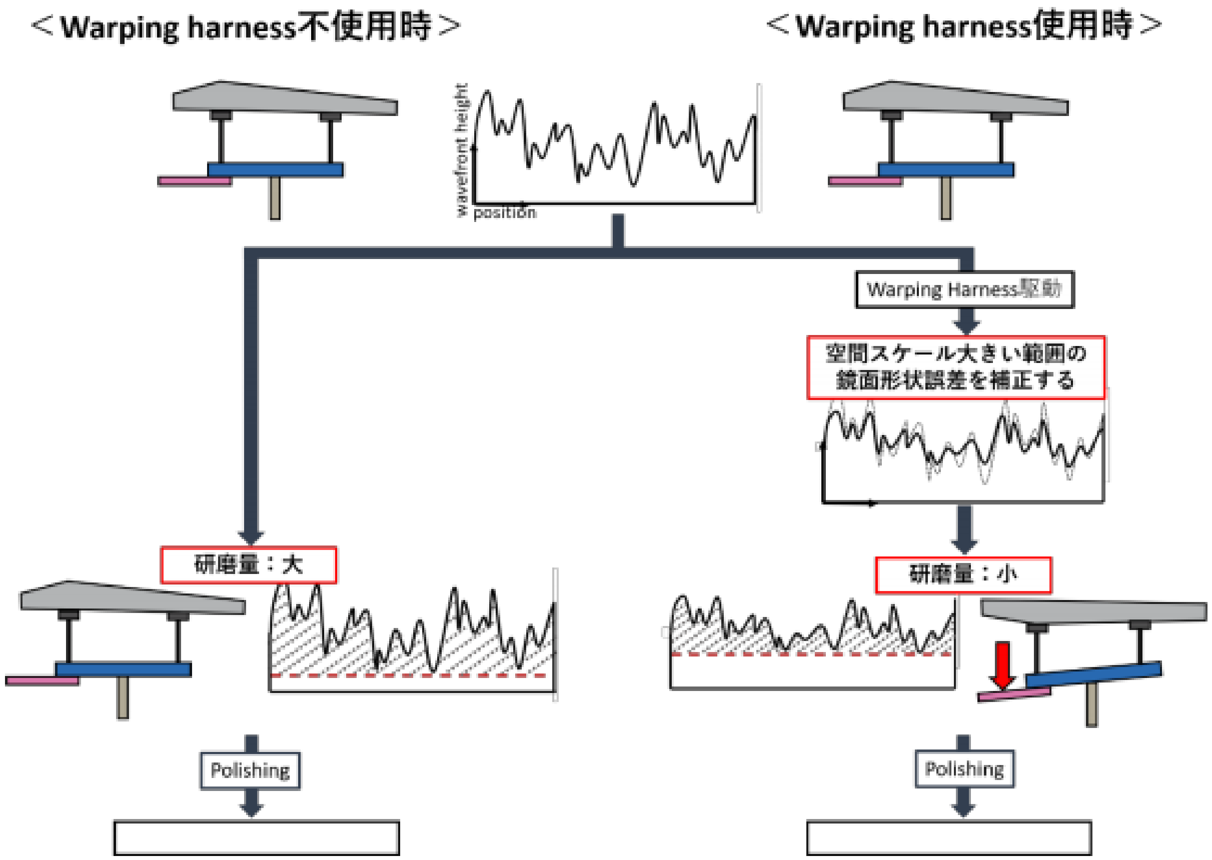


Fig. 10 : Reduce polishing volume with active support (Suzuki 2019)

Combination result of A and B

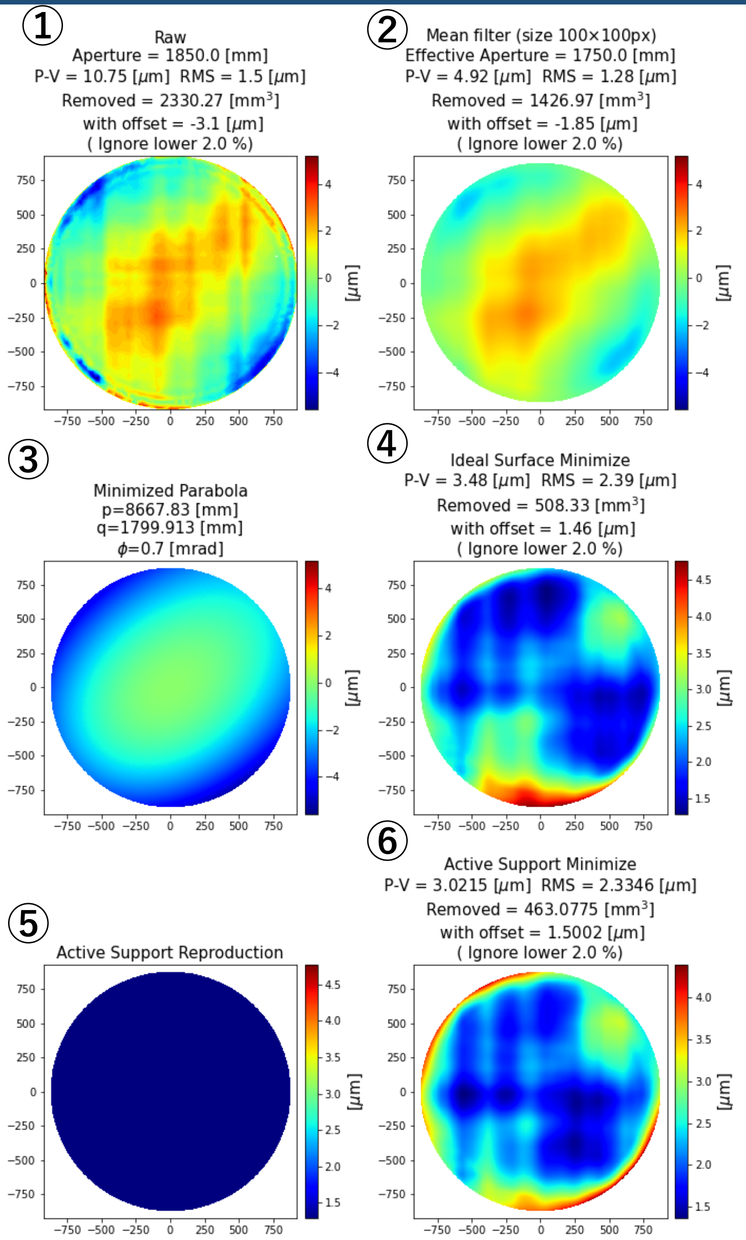
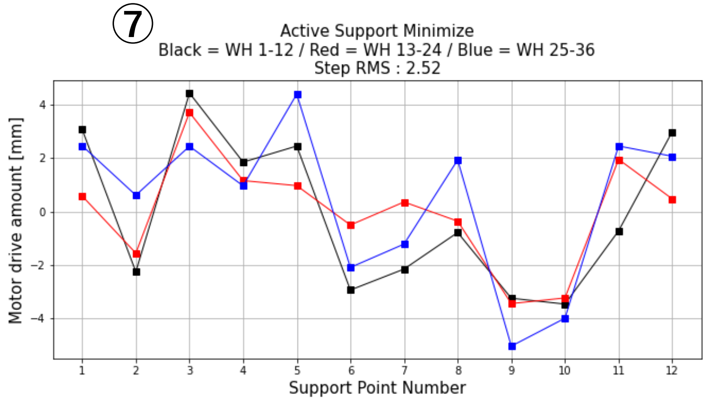


Fig. 11 : Procedure of minimization

1. ① Current M1 surface error
2. ② Smoothing for ① (to exclude outliers)
3. ③ Best-fit OAP for ②
4. ④ Residual from ② to ③
5. ⑤ Reproduction by active support to ④ simulated in finite element method (FEM)
6. ⑥ Residual from ④ to ⑤ (Removed in final polishing)
7. ⑦ Motor drive amount for ⑤ (plotted every 120 degrees)



- **Current M1 status :**
  - P-V : 4.92 μm
  - RMS : 1.28 μm
  - polishing volume : 1426.97 mm³

➢ **Only by tuning OAP parameters :**
  - P-V : 3.48 μm
  - RMS : 2.39 μm
  - polishing volume : 508.33 mm³
  - **Reduced : 64.4%**

➢ **If B is also used (combination of A and B):**
  - P-V : 3.02 μm
  - RMS : 2.33 μm
  - polishing volume : 463.08 mm³
  - **Reduced : 67.5%**
  - The maximum motor drive amount of +-5mm is almost used up (e.g. WH03, 29, 33)

Control repeatability and stability of active support

- Give a drive amount for each actuator and measure local tilt in M1 with autocollimator
  - Measure local tilt in the center of M1 and 40mm from the edge
  - Calculate the difference of local tilt (edge - center) and compare with the result of FEM model
  - ➢ Check the control repeatability and stability of active support structure
  - ➢ Update FEM model

- Repeatability and stability
  - Currently being analyzed.
    (Please check the additional resources)

- FEM model

➢ doesn't simulate actual surface accurately
  - Not a perfect reproduction of the whiffletree structure
  - In the final measurement process, we use three-probe method with robot-arm. Spatial distribution smaller than the spatial resolution of the method can't measure
  - Necessary to consider the stability when combined with the Optical support structure in the future

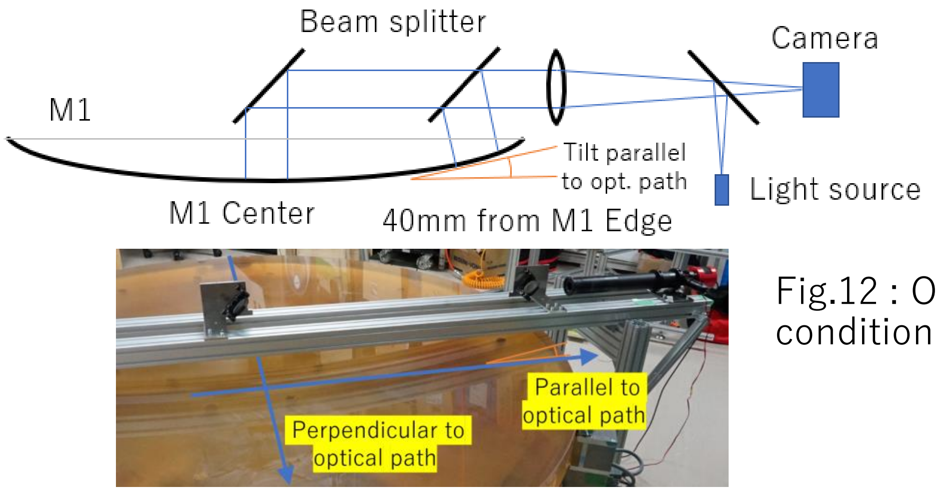


Fig.12 : Optical path and actual condition of the experiment

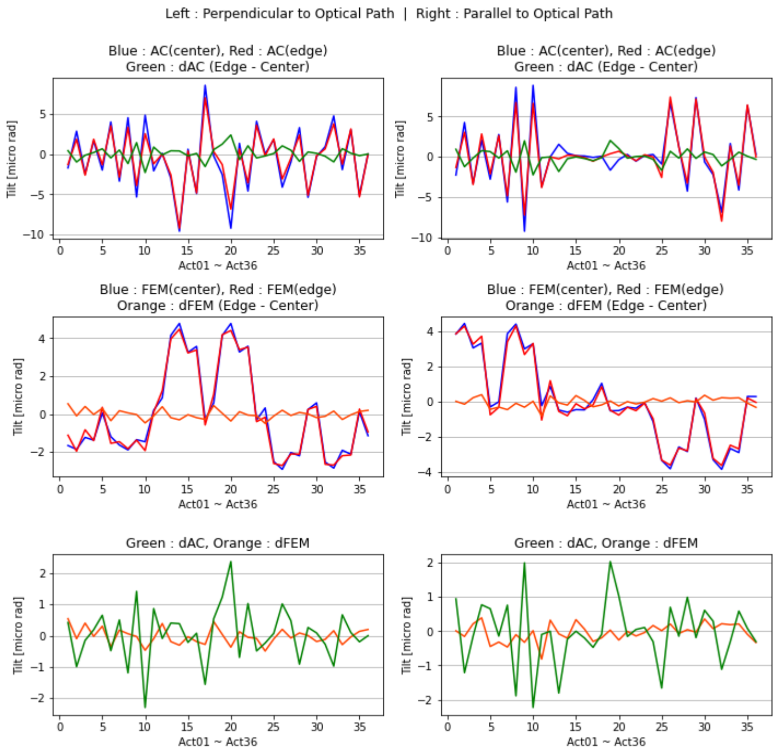
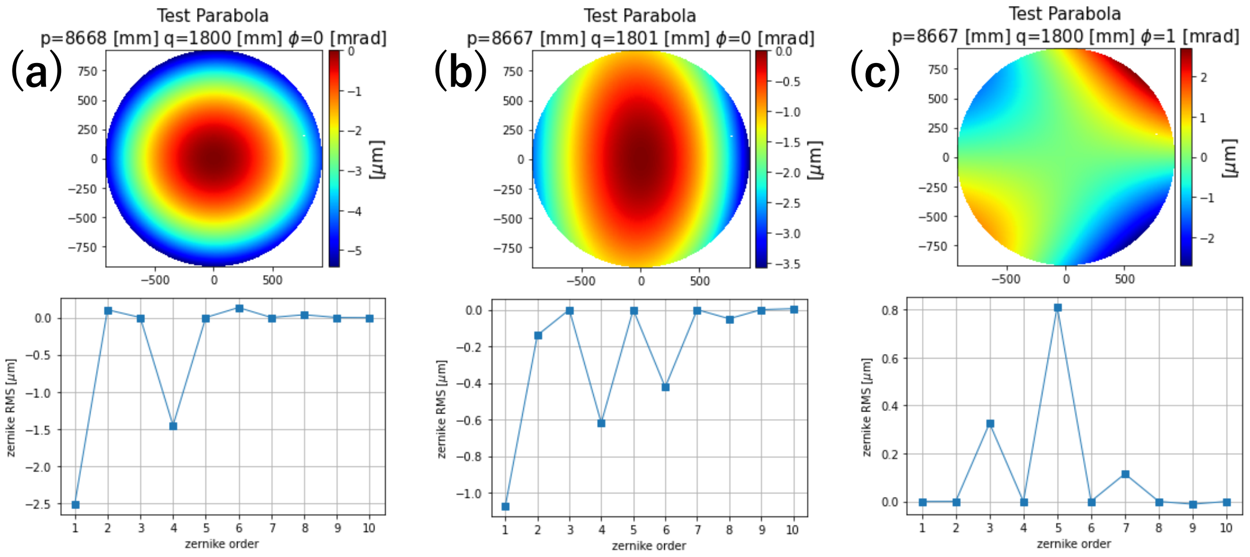


Fig. 13

- By calculating the difference between the tilt of the center and the edge, the influence of entire tilt can be removed.

Discussion

- OAP surface shape is deformed by each parameters (p, q, ϕ) and each minute deformation is a linear superposition
  - Current surface shape can be roughly reproduced by superimposing deformations by p and ϕ
- Depending on the mirror surface error, it is effective to reduce polishing volume by tuning the OAP parameters
- In current surface shape, method B (reduce polishing volume with active support) is unnecessary
  - Only 3% improvement compared to A alone
    (Only A : 64.4% -> A+B : 67.5%)
  - The maximum motor drive amount of +-5mm is almost used up, and leaving no room for correction during observation



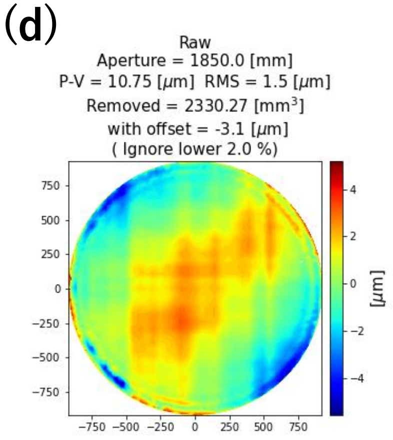


Fig. 14 : Surface deformation by each parameter change and Zernike fitting result

In original OAP, (p, q, ϕ) = (8667, 1800, 0)

(a) p=8667+1 mm

(b) q=1800+1 mm

(c) ϕ =0+1 mrad

(d) Current M1 status

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