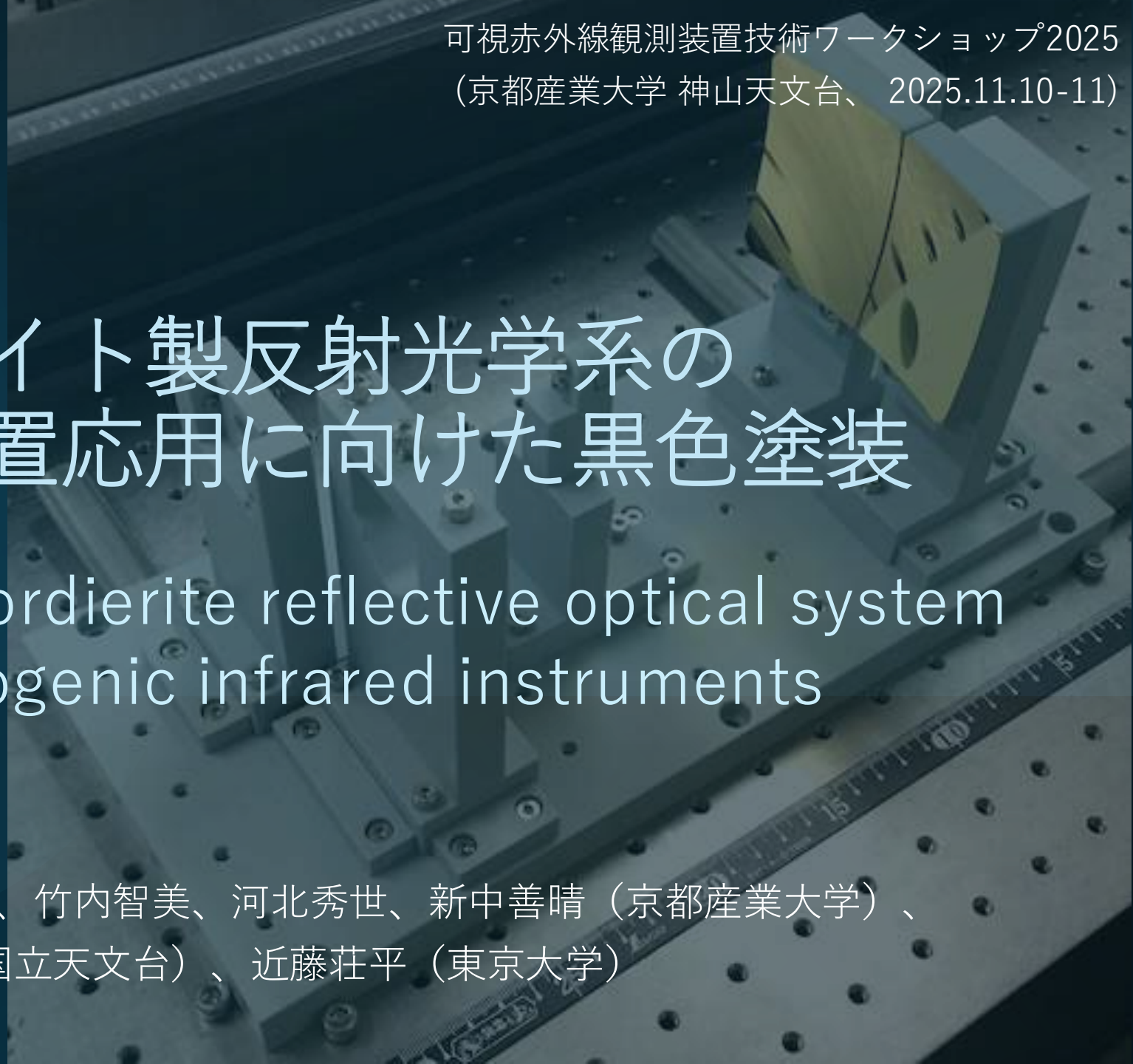
可視赤外線観測装置技術ワークショップ2025
（京都産業大学 神山天文台、 2025.11.10-11）



コージライト製反射光学系の冷却赤外線装置応用に向けた黒色塗装

Black paint for all-cordierite reflective optical system applied to cryogenic infrared instruments

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Background

Advantages of reflective optical system

- No chromatic aberration
- Wide wavelength coverage obtained with metal coatings
- Compact optical layouts realized by folded optical path designs
- High-order aberration correction using nonspherical (freeform) surfaces
- Availability of large (>1 m) optical systems
- Athermal optics employing the same material for optical and structural components

Reflective optical system can theoretically realize ideal optical designs.

Issues

- High accuracy is required for surface shape and alignment
- Considerable effort is required for the alignment of off-axis systems

Those issues tend to be serious, in particular, for cryogenic optics used for infrared and space instruments.

All-cordierite reflective optical system

Cordierite (a ceramic material with a very low CTE)

- Some commercial products are available for optical mirrors (e.g., Kyocera CO-720).
- Ceramics can form a complex 3D shape easily.
- Cordierite parts can be shaped as precisely as typical metal parts.
- Very low thermal expansion coefficient.

Apply to reflective optical system

- All components can be made of the same material.
- Precise alignment can be realized by only mechanical assembly.
- Dimensional change is small when cooled.
- Monolithic (i.e., seamless) optical systems are expected to be ultimately fabricated.

	Glass (normal)	Glass (low CTE)	Aluminum	S-SiC	CVD-SiC	Cordierite (CO-220)	Cordierite (CO-720)
Polishability	○	○	×	△	△	○	○
Voidless	○	○	○	△	○	△	○
Structural material	×	△	○	○	△	○	○
Precise 3D shaping	×	×	△	○	△	○	○
Low thermal expansion	×	○	×	△	△	○	○

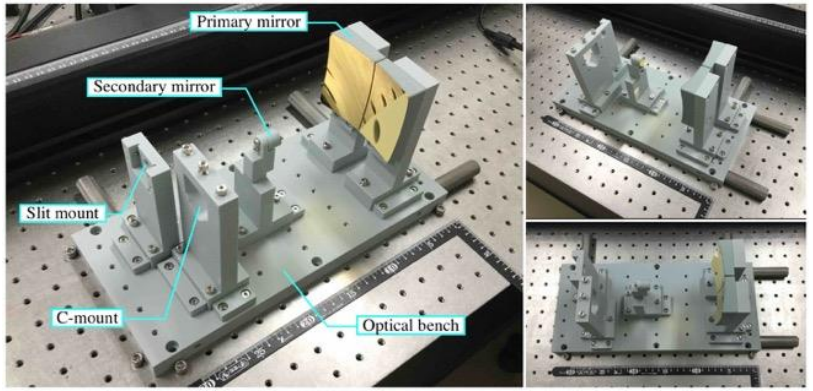
Cordierite can maximize the advantages of reflective optical system.

A significant breakthrough is expected in cryogenic infrared optics.

Experiment and Application

✓ Experimental all-cordierite optical system

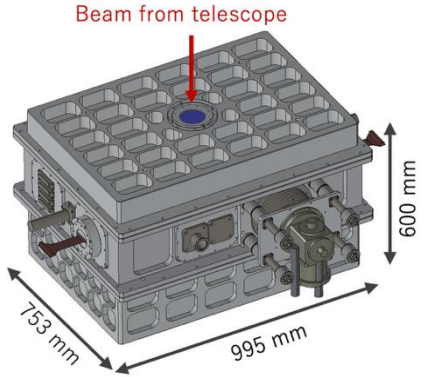
- Optical system consisting three spherical mirros
- Diffraction-limited optical performance can be achieved in the visible wavelength range using only mechanical assembly.
- The diffraction-limited optical performance is maintained even after cooling to 80 K.
  (Sarugaku et al. 2023)

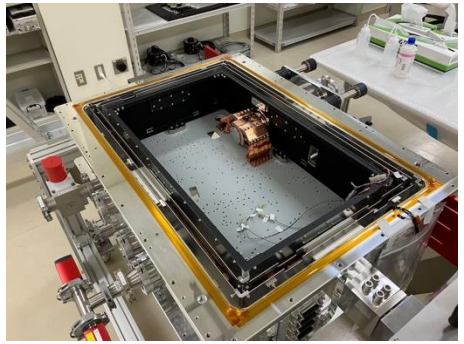


Black painting (or coating) to reduce stray light

✓ GARNET

- NIR high-resolution spectrograph
  - K-, L-bands
  - R = 200,000
- Very compact (for 1-m class telescopes)
- New technologies
  - High efficiency Ge immersion grating
  - All-cordierite reflective optical system





Araki telescope (D=1.3 m)

Issues in black painting

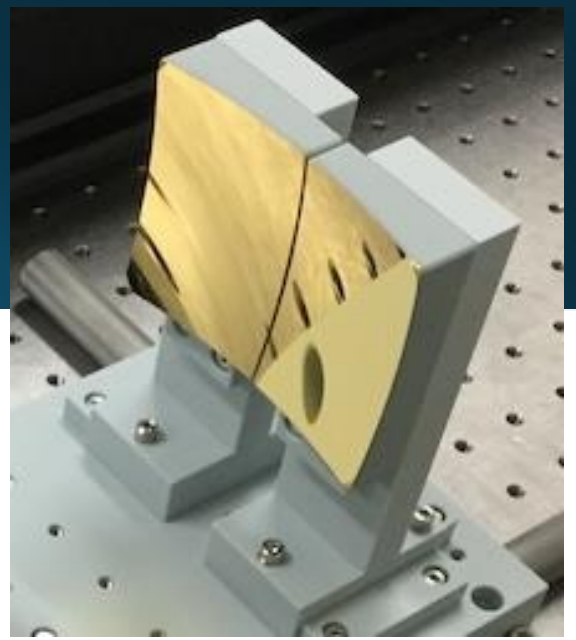
- Selection of paint
  - Low reflectance at the target wavelength range (~ 2 – 4 um)
  - Adhesion to a cordierite substrate
  - Resistance to low temperature and thermal cycling

    ＊Baking is not allowed for mirror components.

  → Aeroglaze Z306

- Procedure to paint
  - Method to prevent fouling of mirror surfaces during painting and drying

Painting on mirror components



- Constraints
  - Black painting after mirror surface coating
    → ambient drying
  - Time from painting to drying: ~ 2 weeks
    - under coat ~ 1 week, finish coat (and touch up) ~ 1week

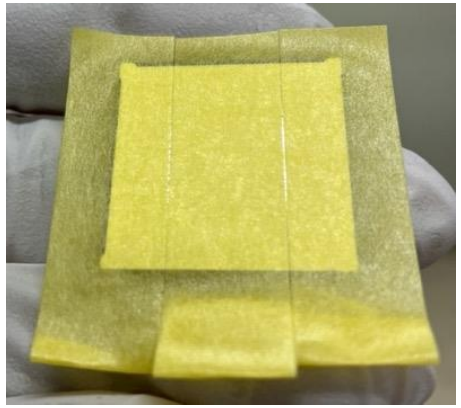
- Need to protect mirror surfaces during painting and drying

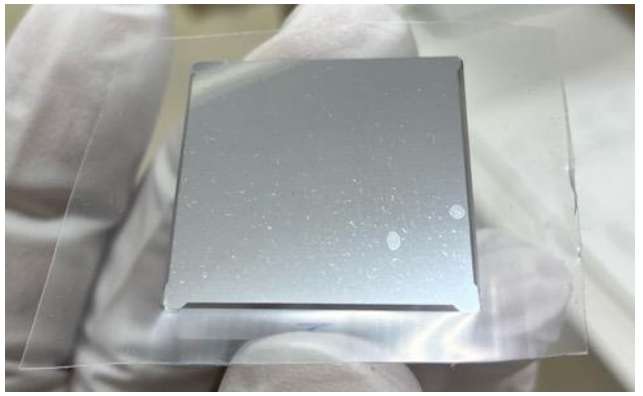
- Approach: attach tapes or films on mirror surfaces (protective coating)

- Selection and evaluation of tapes and films
  - effect on a mirror surface (optical performance)
  - resistance to the solvents in a paint

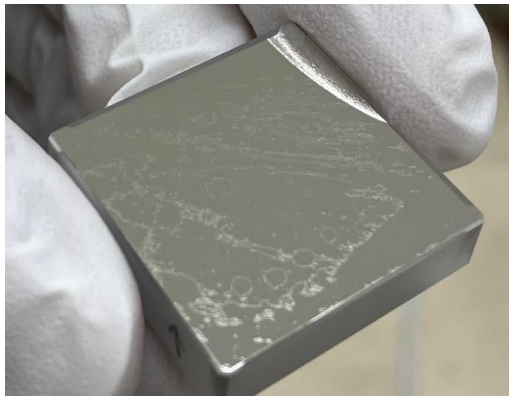
Selection and evaluation of tapes/films

- Sample
  - 1. マスキングテープ
  - 2. 光学部品用表面保護フィルム
  - 3. 表面保護フィルム
  - 4. カラー鋼板用表面保護フィルム

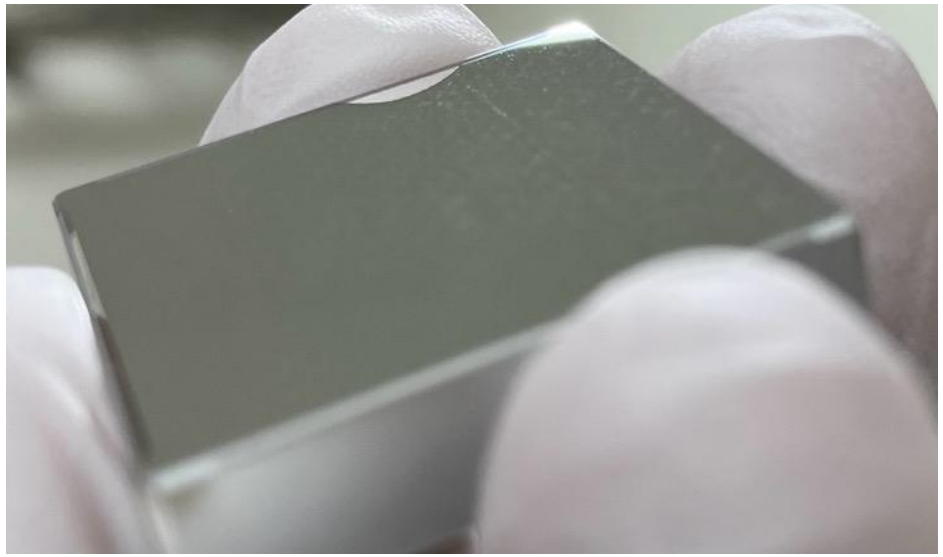
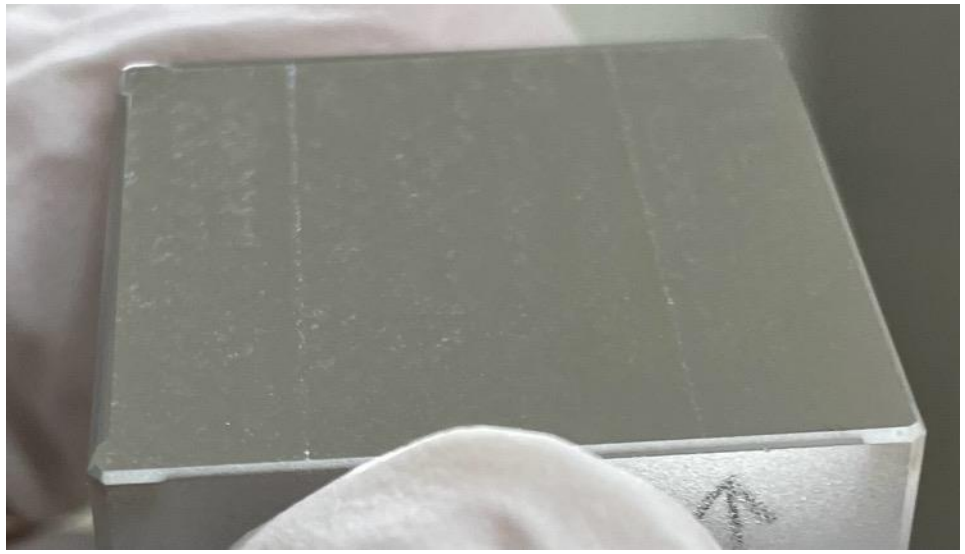




- Evaluation of mirror surfaces after attaching tapes/films
  - Period of attachment (put on – peel off)
    - few hours
    - ~ 1 month
  - Evaluation
    - visual inspection
    - reflectance (specular reflection) measured with FTIR



Evaluation: sample 1

Period of attachment: **few hours**	Period of attachment: **~ 1 month**
• ノリ跡が目視で確認された。 • シルボン紙とエタノールを使ったドラッグ法での拭き取り(縦横、計2回)でノリ跡は無くなった（目視）。 • 反射率(拭き取り後)に有意な変化は見られなかった(図は後のページ)。	• ノリ跡が目視で確認された。 • シルボン紙とエタノールを使ったドラッグ法での拭き取り(縦横、計4回)ではノリ跡が残る。 • レンズペーパーにエタノールを含ませて**しっかりめ**に2回拭いたらノリ跡は無くなった（目視）。 • 溶剤後が残らないように(念のため)、さらにドラッグ法での拭き取り（縦横、計2回）を実施。 • 反射率(拭き取り後)に有意な変化は見られなかった(図は後のページ)。
	

Evaluation: sample 2

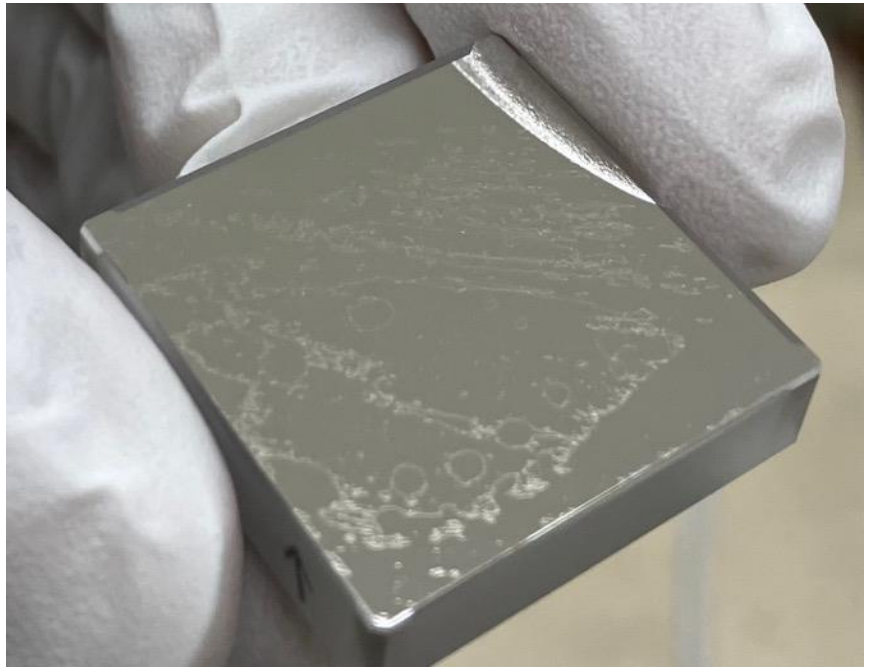
Period of attachment: **few hours**	Period of attachment: **~ 1 month**
• ノリ跡は目視で確認されなかった。 • シルボン紙とエタノールを使ったドラッグ法での拭き取り（縦横、計2回）を実施。 • 反射率(拭き取り後)に有意な変化は見られなかった(図は後のページ)。	• ノリ跡は目視で確認されなかった。 • シルボン紙とエタノールを使ったドラッグ法での拭き取り（縦横、計2回）を実施。 • 反射率(拭き取り後)に有意な変化は見られなかった(図は後のページ)。

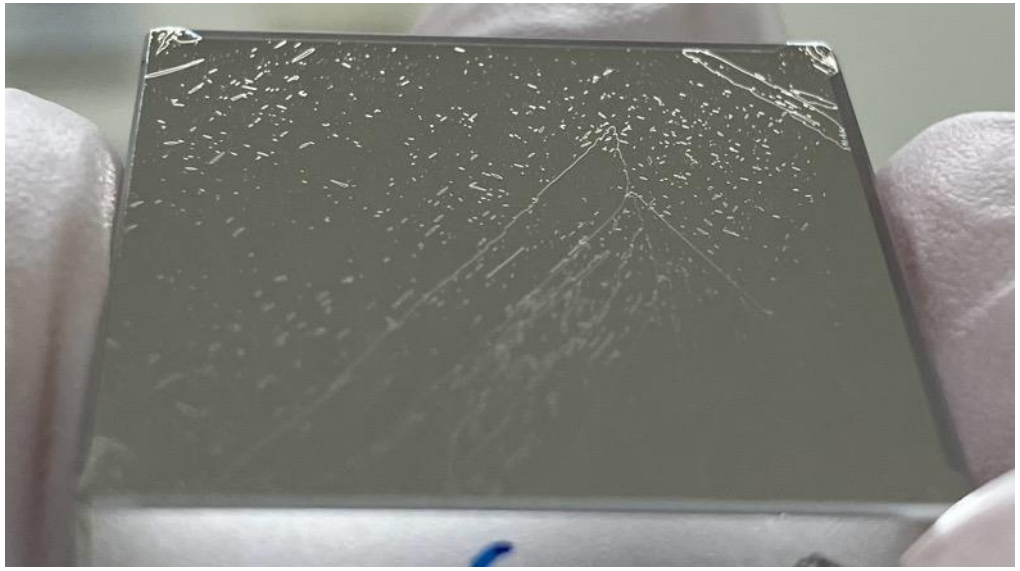
Evaluation: sample 3

Period of attachment: **few hours**	Period of attachment: **~ 1 month**
• ノリ跡は目視で確認されなかった。 • シルボン紙とエタノールを使ったドラッグ法での拭き取り（縦横、計2回）を実施。 • 反射率(拭き取り後)に有意な変化は見られなかった(図は後のページ)。	• ノリ跡が目視で確認された。 • シルボン紙とエタノールを使ったドラッグ法での拭き取り(縦横、計4回)ではノリ跡が残る。 • レンズペーパーにエタノールを含ませて**軽め**に2回拭いたらノリ跡は無くなった（目視）。 • 溶剤後が残らないように(念のため)、さらにドラッグ法での拭き取り（縦横、計2回）を実施。 • 反射率(拭き取り後)に有意な変化は見られなかった(図は後のページ)。 

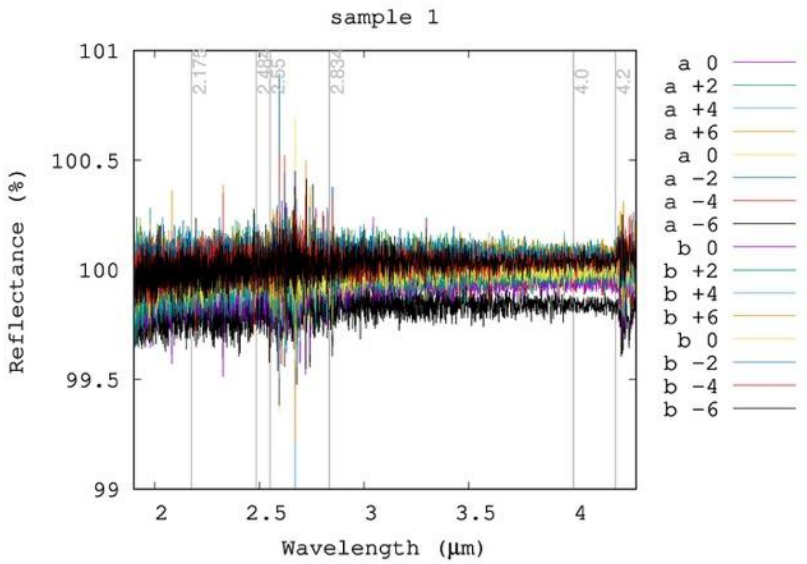
Evaluation: sample 4

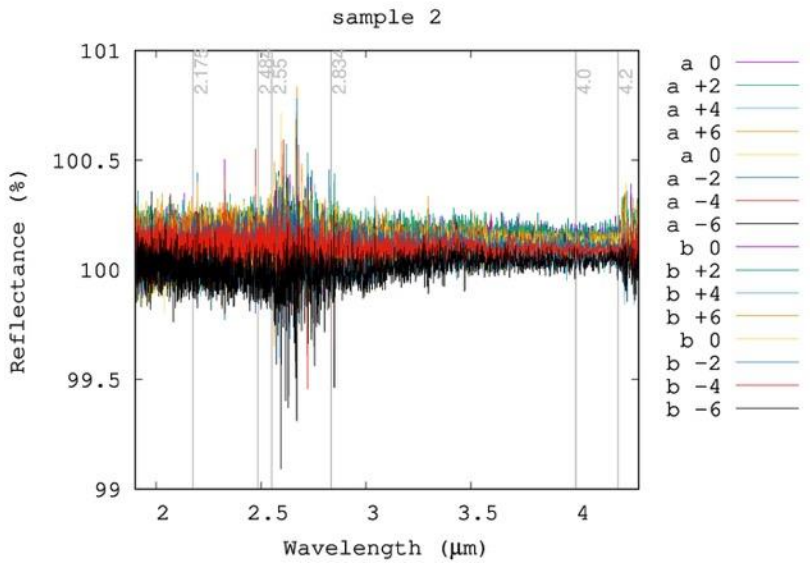
Period of attachment: **few hours**	Period of attachment: **~ 1 month**
• 貼り直しをする際に不用意に剥がしてしまい、ミラーのコーティングが剥がれた。 • 反射率の測定は行なっていない。	• 気をつけながら剥がしたが、ミラーのコーティングが剥がれた。 • 反射率の測定は行なっていない。

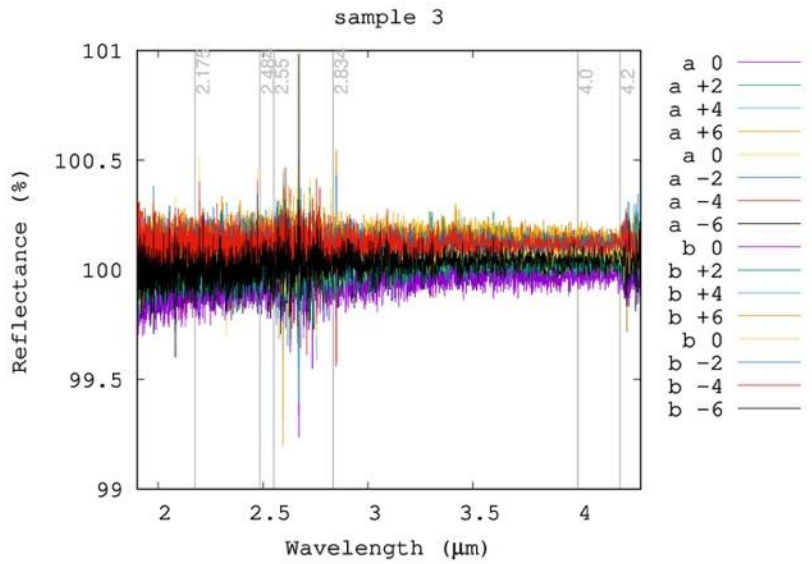


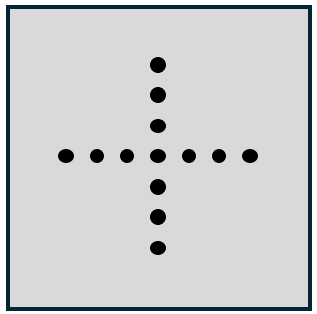


The ratio of reflectances after/before attachment (few hours)



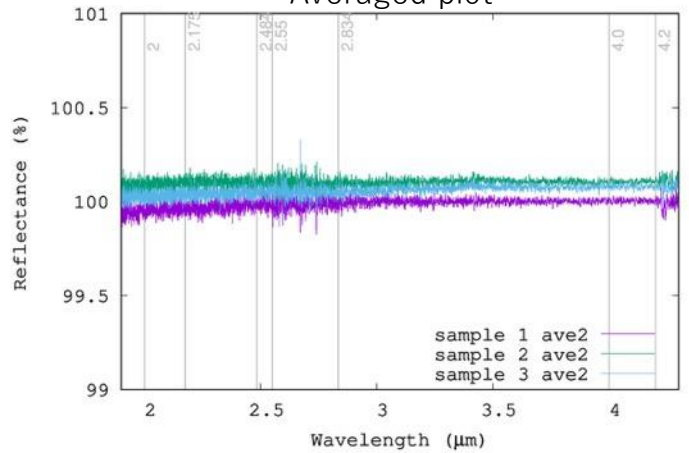




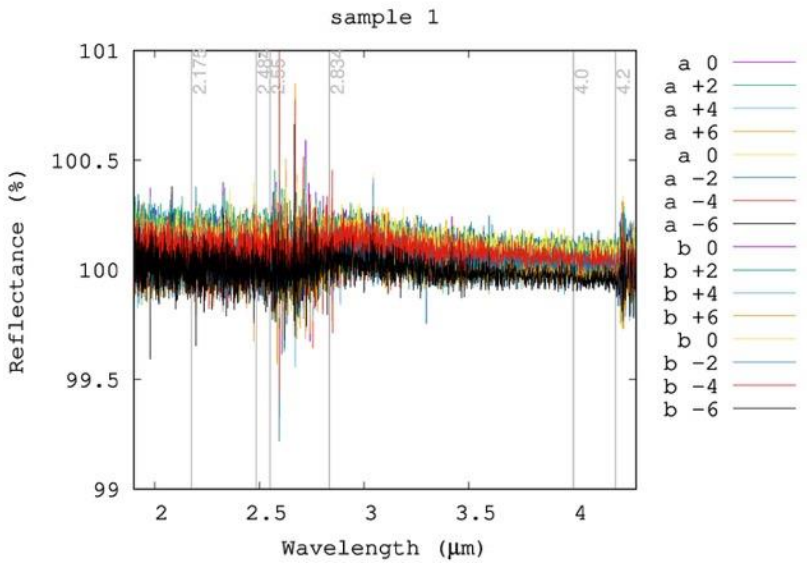


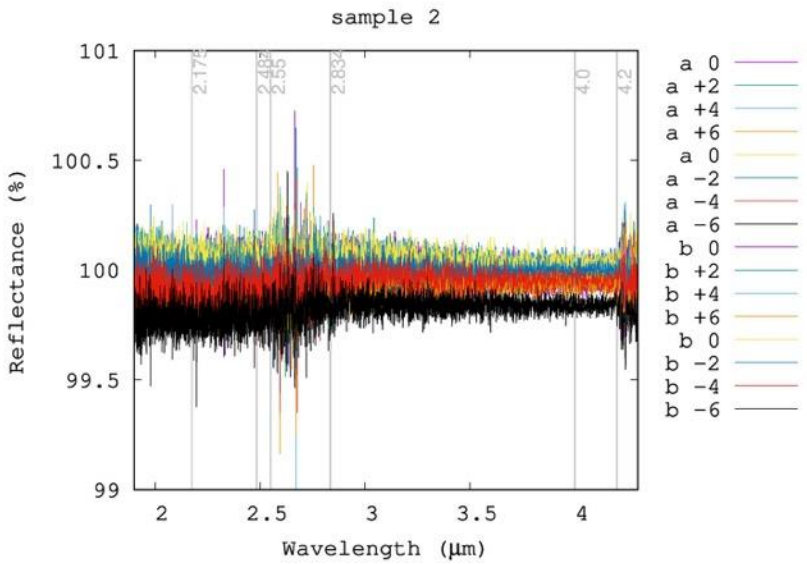
Measuring points

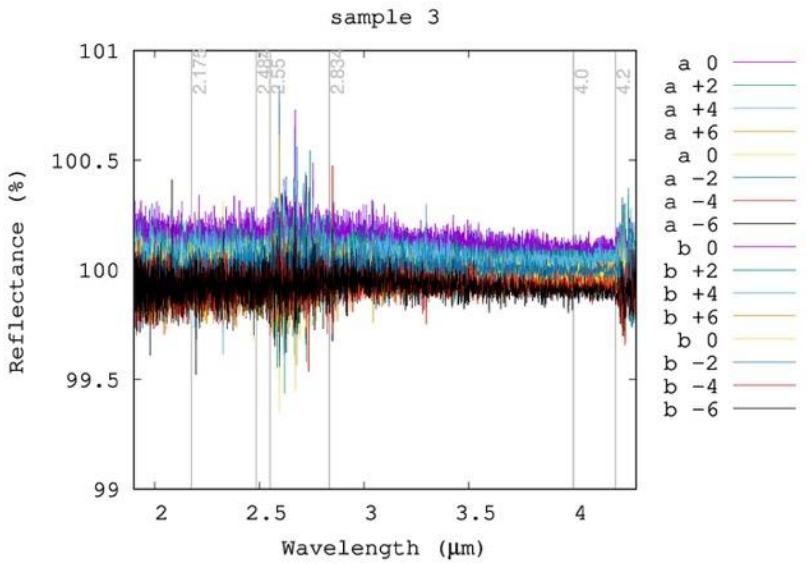
Averaged plot



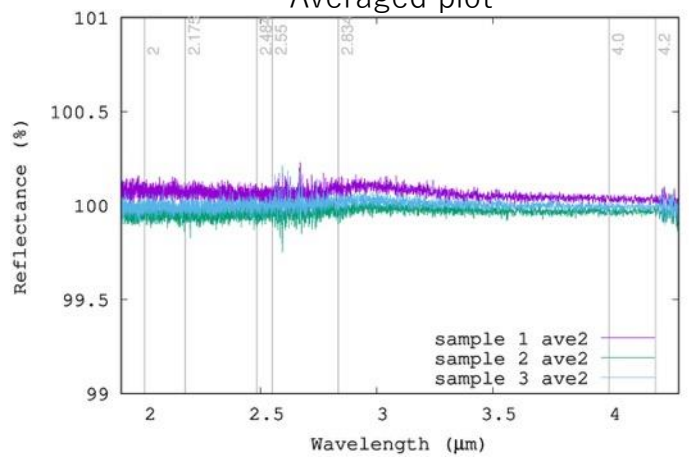
The ratio of reflectances after/before attachment (~ 1 month)







Averaged plot



- No significant change is observed in this test (using commercial mirrors with a protective coating).
  → Candidate = sample 2
  (we also checked the solvent resistance of this sample.)
- “Detailed procedure to protect mirror surfaces according to their actual shapes” is under consideration.

Summary

- An all-cordierite optical system is expected to provide a significant breakthrough in cryogenic optical systems.
- R&D of this system for astronomical applications is in progress.
  - Demonstration of the optical performance at the cryogenic temperature
  - Application to NIR high-resolution spectrograph GARNET
  - Remaining issue: black painting to reduce stray light
- Aeroglaze Z306 was selected as the black painting for GARNET.
  - Low reflectance at K-, L-bans
  - Applicable without baking
  - Adhesion to a cordierite substrate (incl. resistance to low temperature) was confirmed
- Regarding to the black painting on mirror components, we are attempting to protect mirror surfaces by attaching tapes of films on them.
  - A candidate was selected.
  - Detailed procedure adjusted to actual mirror shapes is under consideration.