MIMIZUKU

Challenging the difficulties in ground-based MIR observations: The case of TAO/MIMIZUKU

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TAO PROJECT The University of Tokyo Atacama Observatory

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Assigned topic: High Backgroud?

Asked to talk on:

High Background to provide a summary on the current and/or projected state of that field and identify potential synergies with JWST.

What's the High Background?

Inami-san said 'High background' includes:

Observations of IR-bright sources.

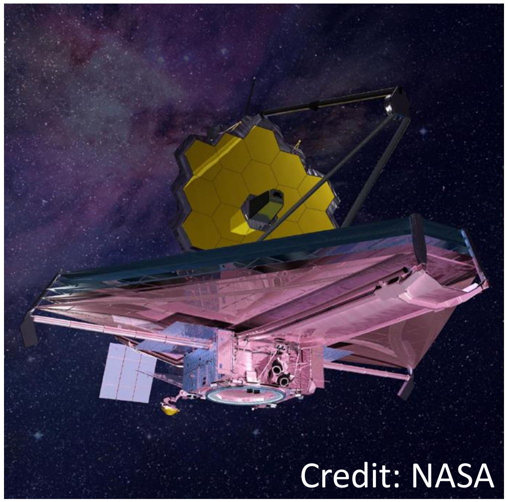
Treatment of high background in ground-based observations.

I will talk about:

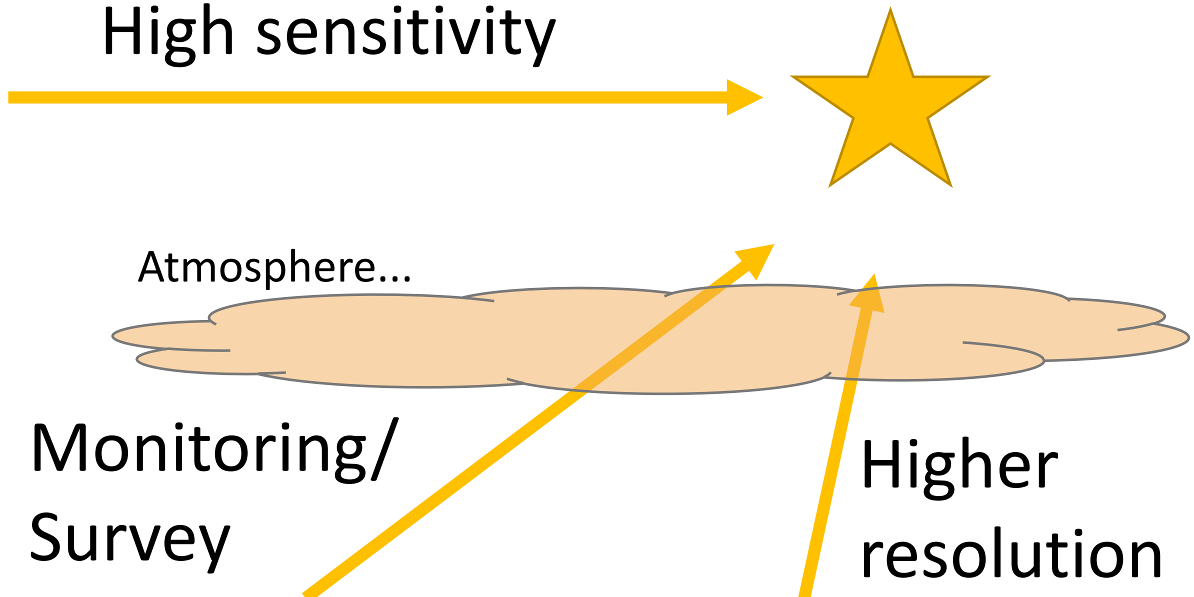
Our challenges to the annoying atmospheric HIGH BACKGROUND (& absorption) for realizing MIR monitoring of BRIGHT SOURCES.

Ground-based MIR observations in the JWST era

JWST



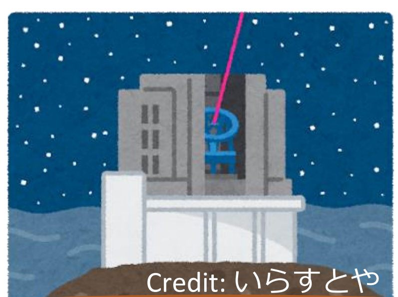
High resolution &
High sensitivity



Monitoring/
Survey

Higher
resolution

<10-m class



30-m class

JWST is the best in sensitivity.
Ground-based observations
complement the JWST.

Annoying atmosphere

Variable Bright Emission:

Orders of magnitude brighter than objects.

Varies in <1 seconds.

→ Accurate removal is needed.

Variable Strong Absorption:

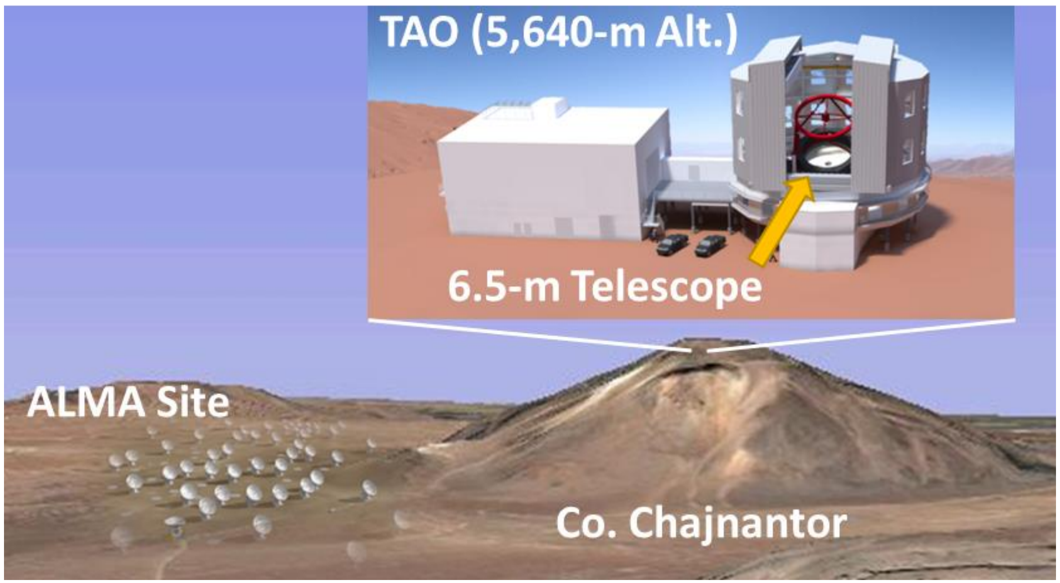
Miscorrection for it leads to errors in photometry and spectroscopy.

→ Difficulty for time-domain astronomy.

We are challenging to overcome these difficulties in our instrument TAO/MIMIZUKU.

TAO/MIMIZUKU

The University of Tokyo Atacama Observatory (TAO)



Observatory location.

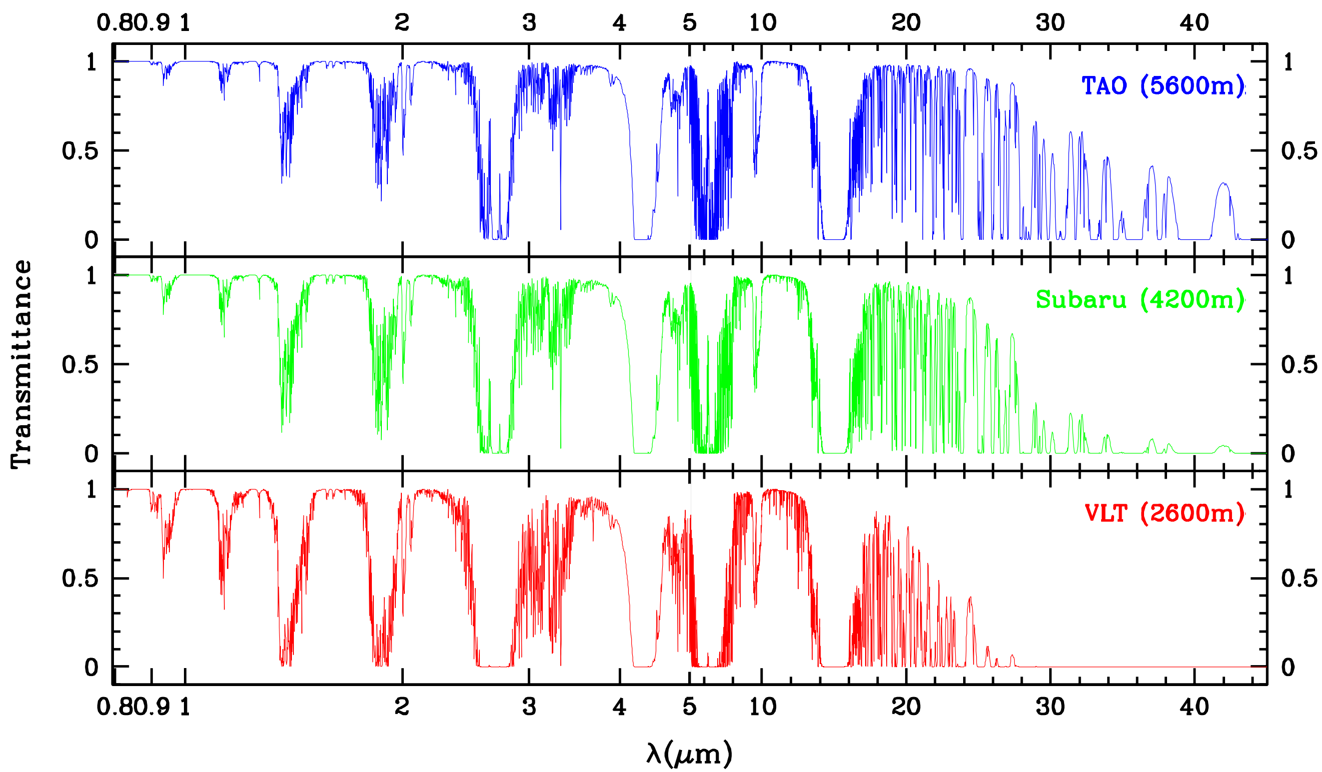
Telescope frame.

An observatory being constructed by the Univ. of Tokyo (P.I.: Y. Yoshii)

- Equipped with a 6.5-m telescope.
- Located at the summit of Co. Chajnantor in the Atacama Desert (5640-m alt.).

➔ Large university's telescope at a site ideal for ground-based MIR observations.

The University of Tokyo Atacama Observatory (TAO)

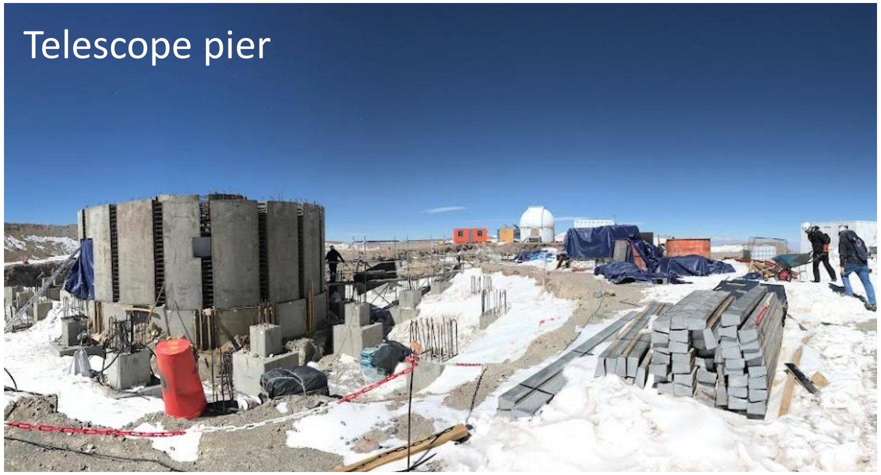


Atmospheric transmittance calculated by ATRAN.

High altitude + Desert climate → Low atmospheric water vapor

→ Transparent atmosphere in the MIR!!

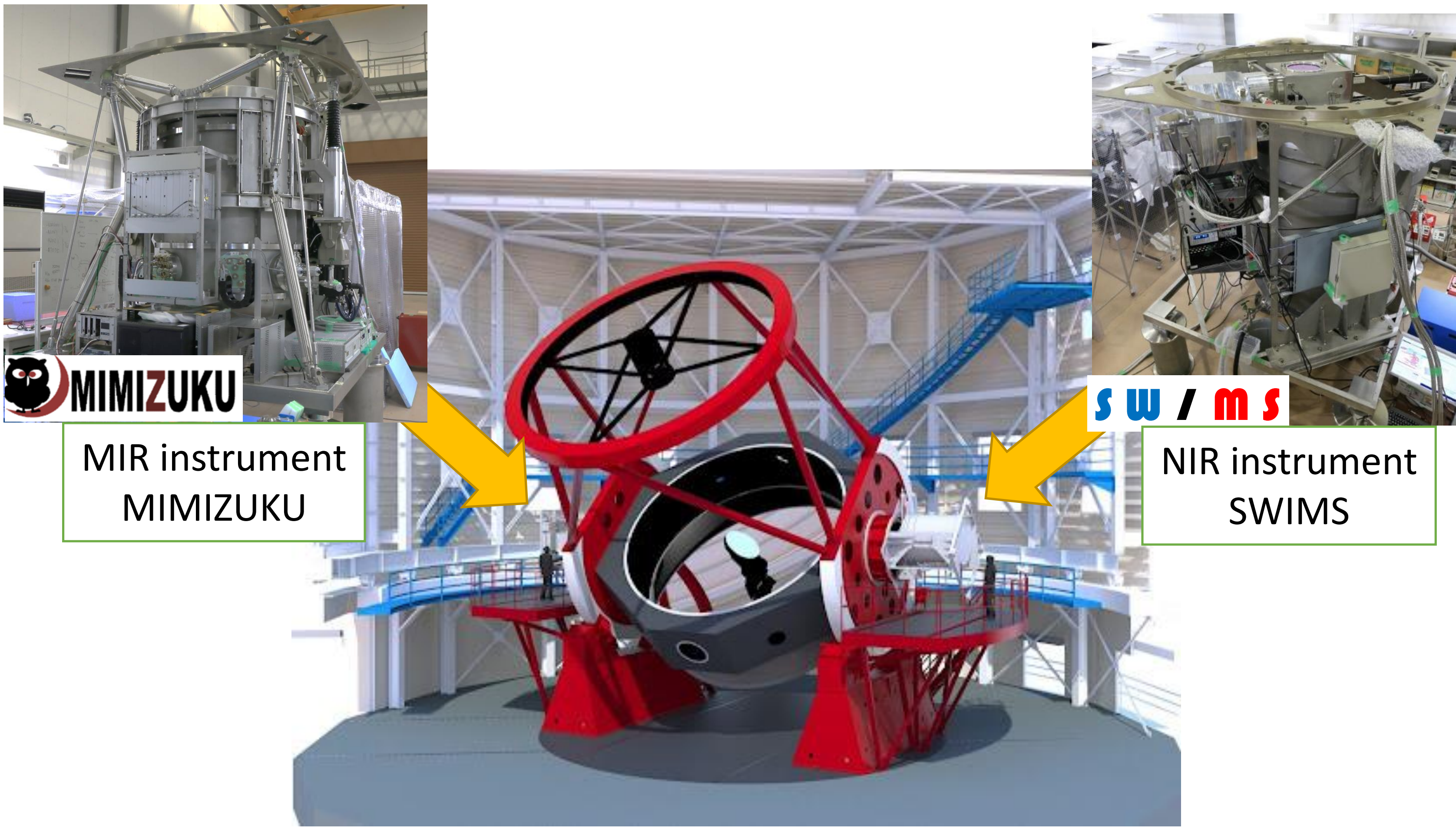
The University of Tokyo Atacama Observatory (TAO)



We resumed construction disturbed by COVID-19.

We hope to start observations in 2023.

TAO/MIMIZUKU



There are two first-generation instruments attached to the two Nasmyth foci.

Mid-Infrared Multi-field Imager for gaZing at the UnKnown Universe (MIMIZUKU)

Wide band coverage:

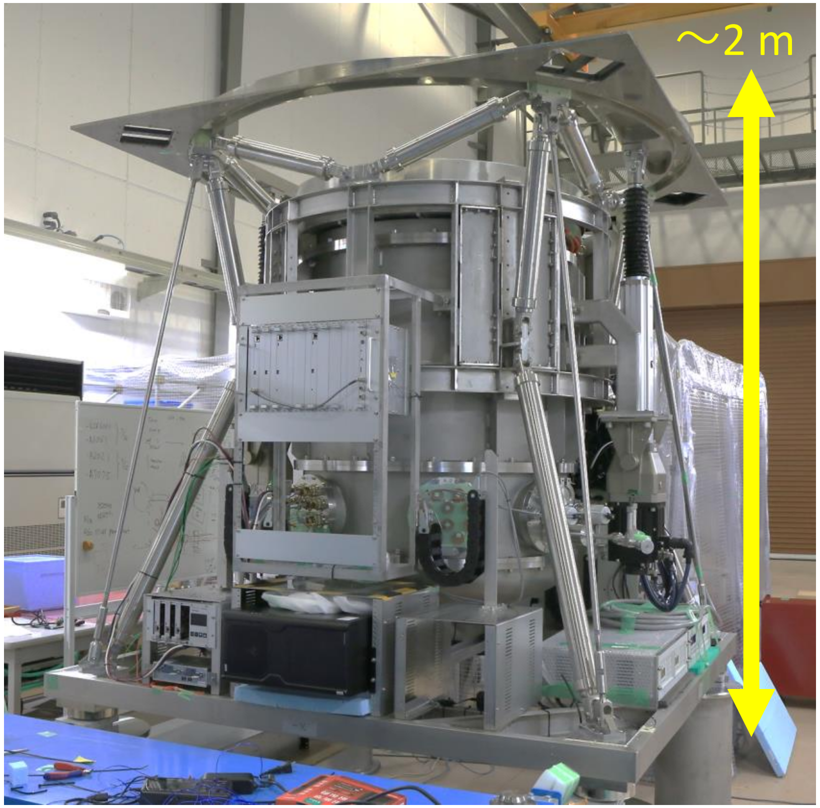
NIR ch : 2.0 – 5.3 μm
MIR-S ch : 7.0 – 26 μm
MIR-L ch : 24 – 38 μm

Imaging & Low-res. spec. (R~60-600) in 2 – 38 μm.

Good spatial resolution:

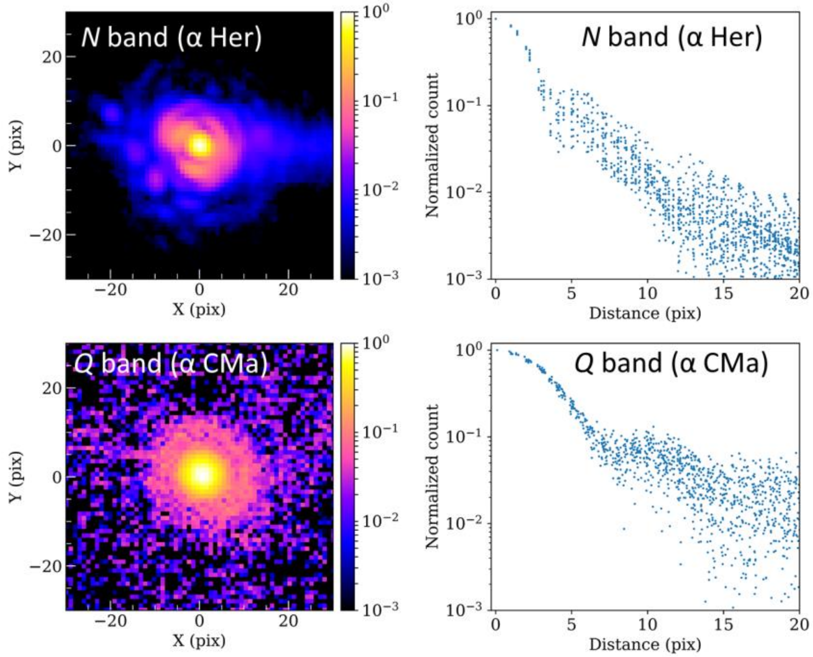
NIR : ~0.5 arcsec (seeing lim.)
10-μm band : ~0.6 arcsec (~diffraction lim.)
20-μm band : ~0.8 arcsec (diffraction lim.)
30-μm band : ~1.2 arcsec (diffraction lim.)

Development since 2009.
MIR-S ch achieved First light in 2018 at Subaru.



Appearance of MIMIZUKU (2m×2m×2.1m; 2.5 t).

MIR-S ch imaging mode in FL



Point source image and radial profile (Kamizuka et al. 2020).

Imaging properties of MIR-S ch.

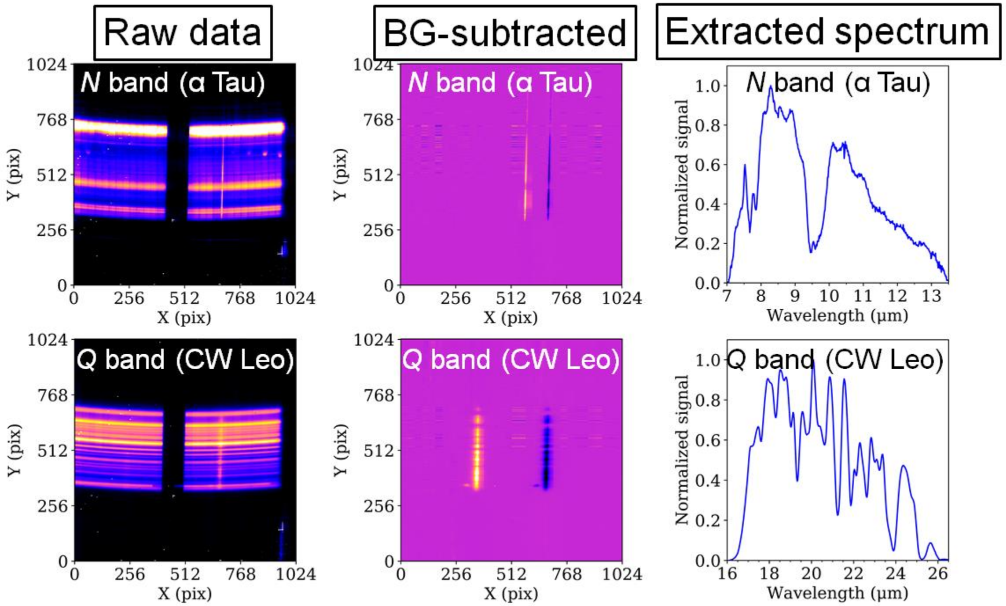
Band name	Spatial resolution	System Efficiency†
11.6-μm	0.37''×0.32''	20.8%
20.8-μm	0.65''×0.57''	4.8%

†: including atmosphere

We confirmed in the FL observations that:

- Diffraction-limited resolution is achieved.
- *N*-band efficiency is as expected from design.
- *Q*-band efficiency is slightly low, but acceptable.

MIR-S ch spectroscopic mode in FL



Spectroscopic data (Kamizuka et al. 2020).

We confirmed in the FL observations that:

- Wavelength coverage, resolution are as expected.
- *N*-band efficiency is good.
- *Q*-band efficiency is slightly lower than expected.

Properties of spectroscopic mode.

Band name	Wavelength coverage	Wavelength resolution	Spectral resolution
N band	7.0–13.5 μm	0.01574 μm pix^{-1}	170
Q band	16.5–26.0 μm	0.0240 μm pix^{-1}	110

MIR-S ch was confirmed to be working as designed.

Other two channels are being developed in Japan.

Instrument features and Science cases

Each ch. has characteristic observables & related sciences.

Examples are:

NIR ch : 2.7-μm feature from hydrous minerals on asteroids.
→ Origin of water; Thermal history of asteroids.

MIR-S ch : Dust features. Temperature of warm dust.
→ Mineralogy; Dust formation around evolved stars.

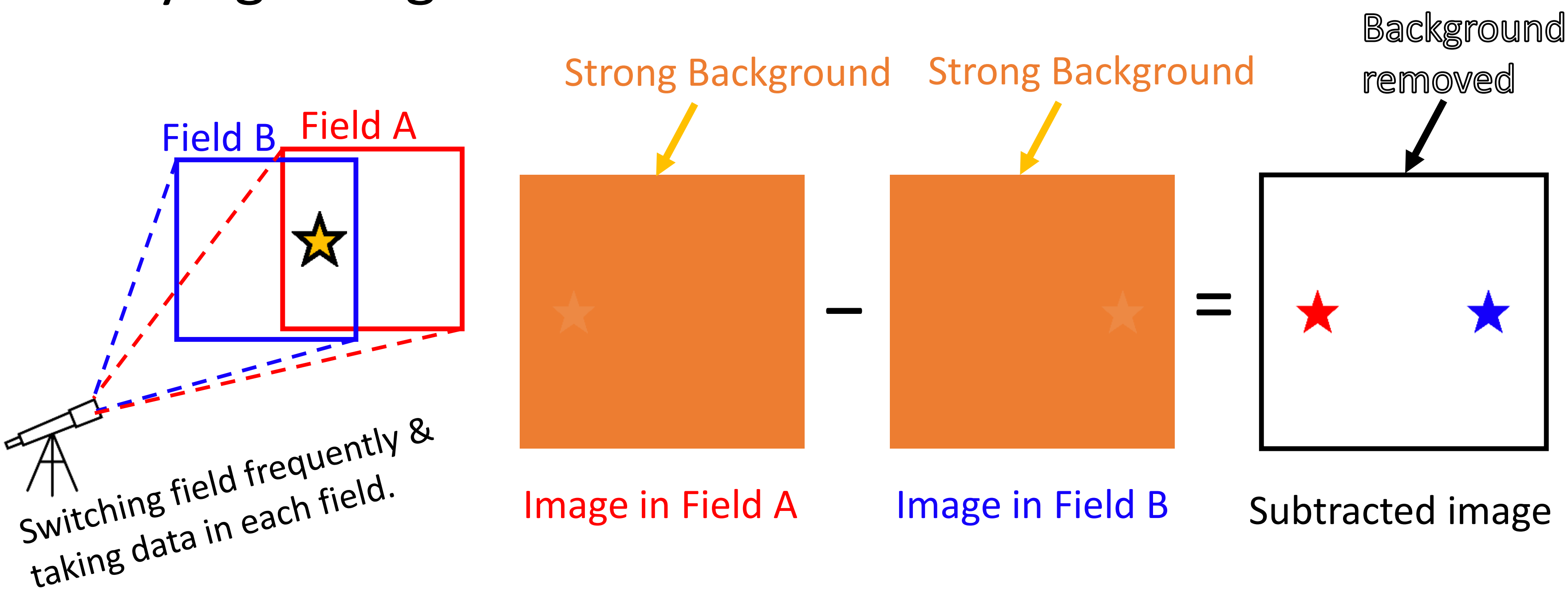
MIR-L ch : Cold dust distributions.
→ Mass ejection history of evolved stars.

Survey or monitoring studies are important for these science cases.
We are making challenges to overcome the difficulties to realize them.

Our challenge
– Removal of background –

Removal of background: Chopping method

'Chopping' method is widely used for removing the varying background emission.



If we take data in different fields before the background changes and subtract each other, we can remove the background emission and observe targets.

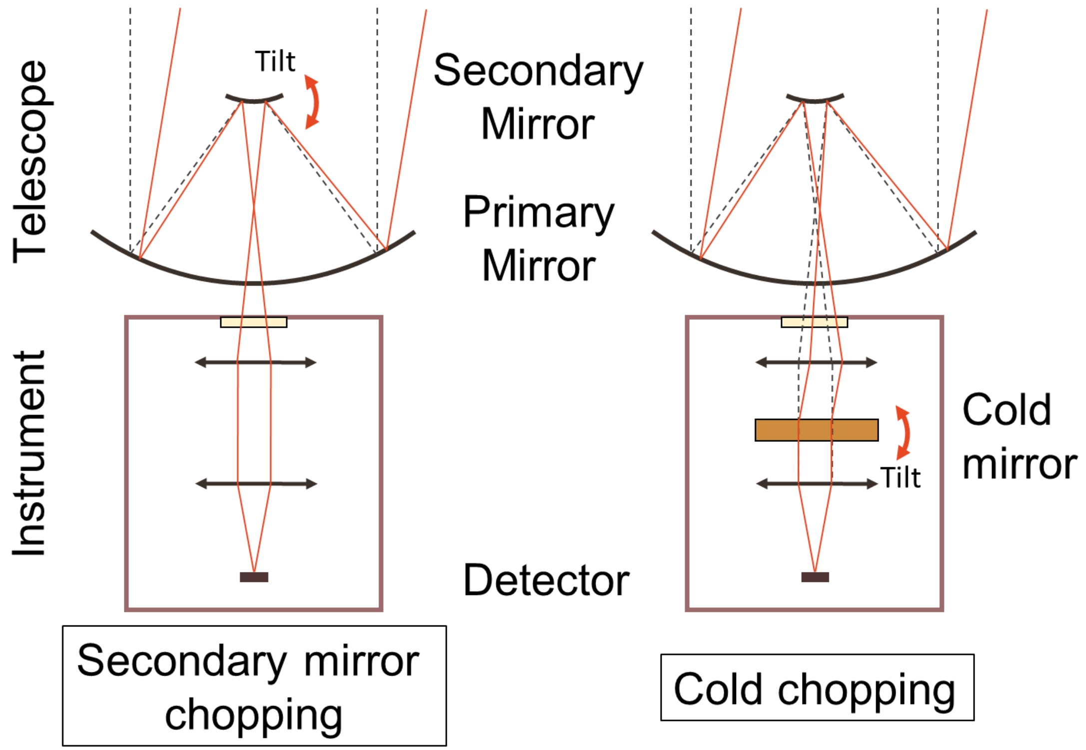
Removal of background: Cold chopping

Evolving from secondary mirror chopping to cold chopping.

Conventional secondary mirror chopping is difficult for large telescopes.

Placing a fast tip-tilt mirror at the place conjugate with the secondary inside instrument.

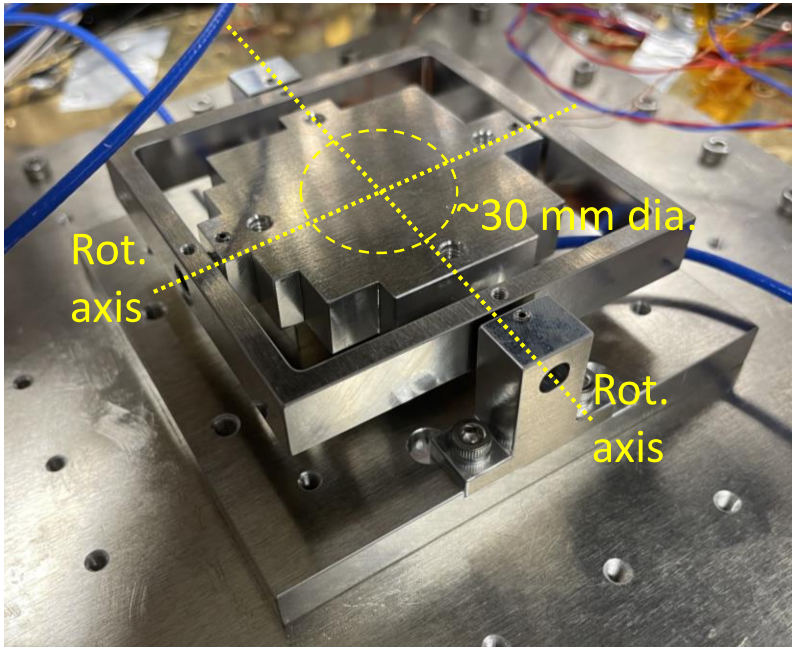
We call the fast tip-tilt mirror in the cold optical system ‘cold chopper’.



Secondary mirror chopping and cold chopping (Honda et al. 2020).

Removal of background: Cold chopper system

We are developing a cold chopper system for TAO/MIMIZUKU, because the secondary mirror cannot quickly move.



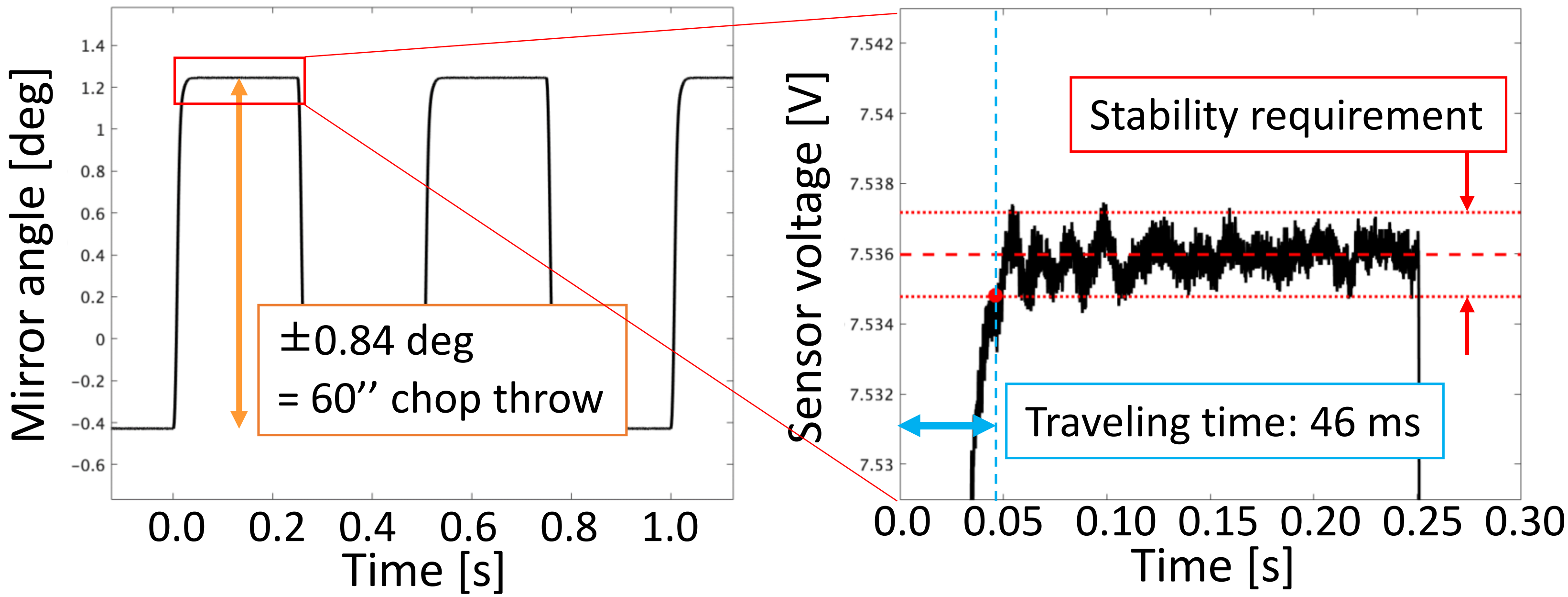
Prototype of our cold chopper (Michifuji-san's master thesis).

Fast, large amplitude, stable, and low heat cold chopper is required.

Requirements:

- Operating temperature: ≦30 K
- Frequency: ≧2 Hz
- Traveling time: <50 ms
- Chop throw: >30'' (>±0.42 deg in tilt angle)
- Stability: 0.02'' RMS on sky (6×10^{-4} deg in tilt angle)
- Heat dissipation: <100 mW

Removal of background: Cold chopper cryogenic test



Chopper movement with a frequency of 2 Hz at 20 K (Michifuji-san’s master thesis).

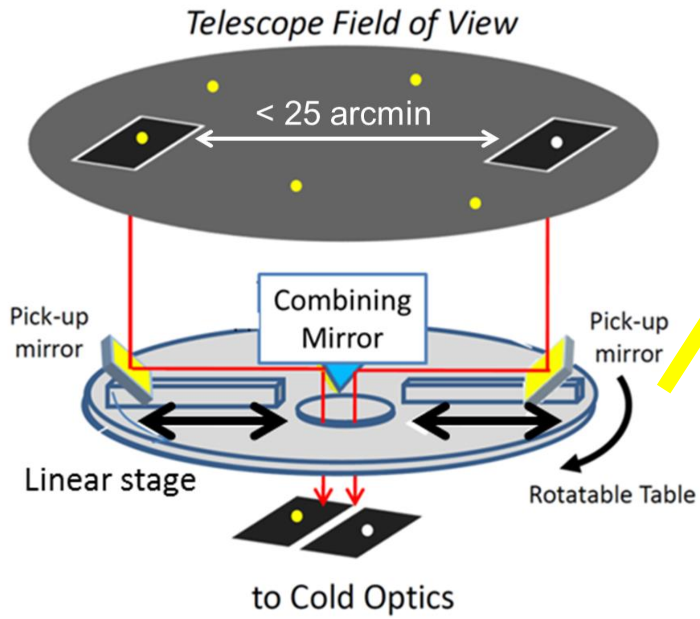
In cryogenic tests at 20 K, our chopper achieved:

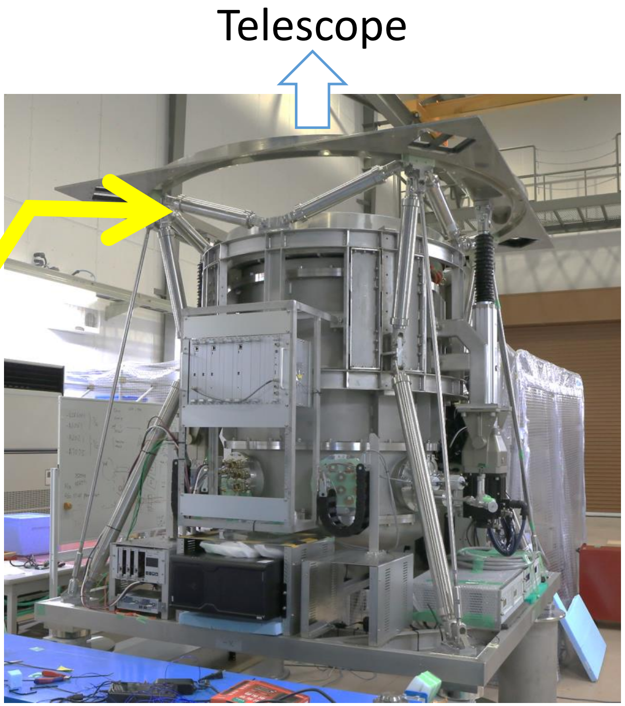
- ○ 2 – 5 Hz chopping frequency.
- ○ 60’’ chop throw.
- ○ <50 ms traveling time.
- △ 5×10^{-4} deg RMS stability.
- ○ 5 mW heat dissipation.

We are preparing to install this system on MIMIZUKU.

Our challenge
– Atmospheric correction –

Atmospheric correction: Field stacker

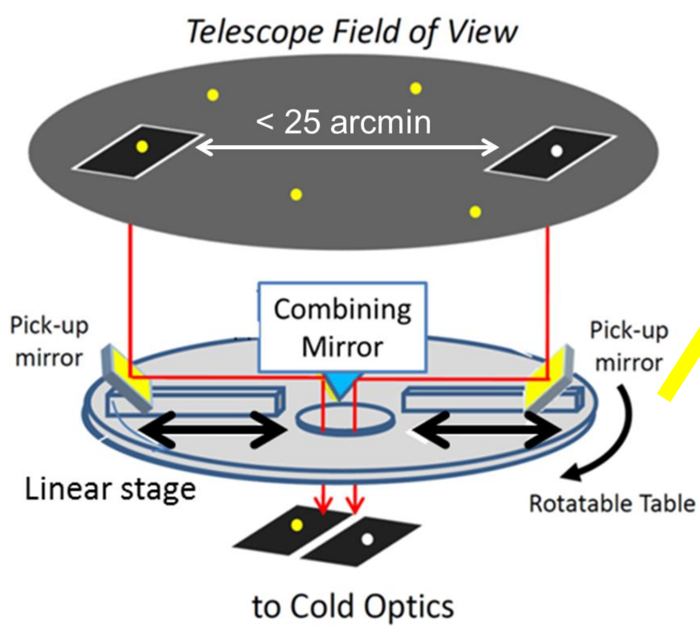




Field stacker mechanism on MIMIZUKU.

FS picks two observation fields off and combines them into one beam.
→Observe an object and a reference star simultaneously.
→Accurate atmospheric correction!!

Atmospheric correction: Field stacker



Telescope

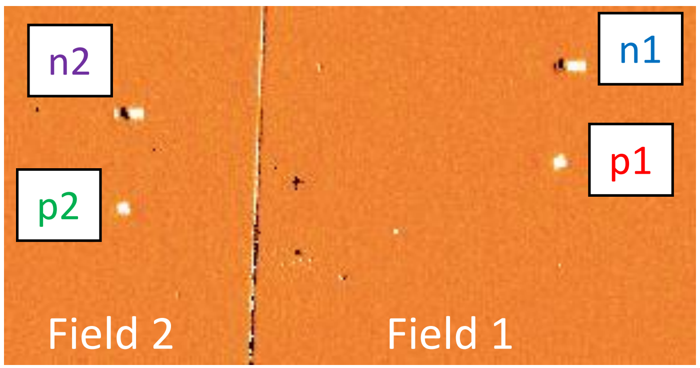
Field stacker mechanism on MIMIZUKU.

FS picks two observation fields off and combines them into one beam.

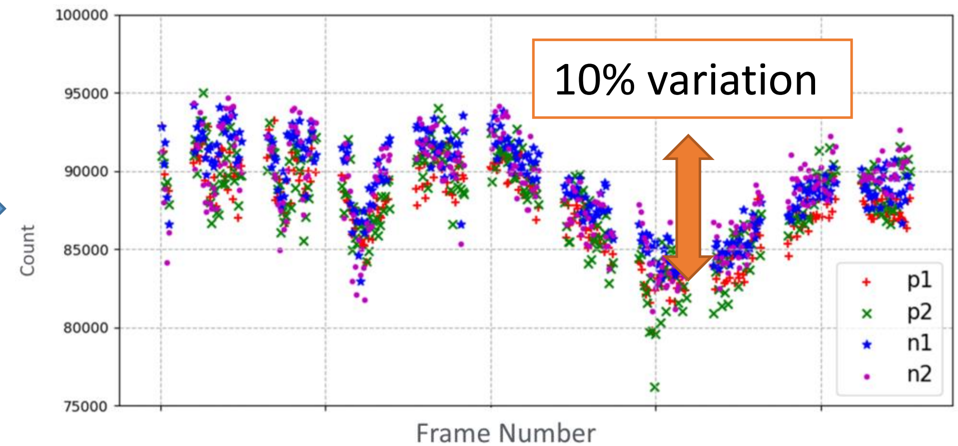
→Observe an object and a reference star simultaneously.

→Accurate atmospheric correction!!

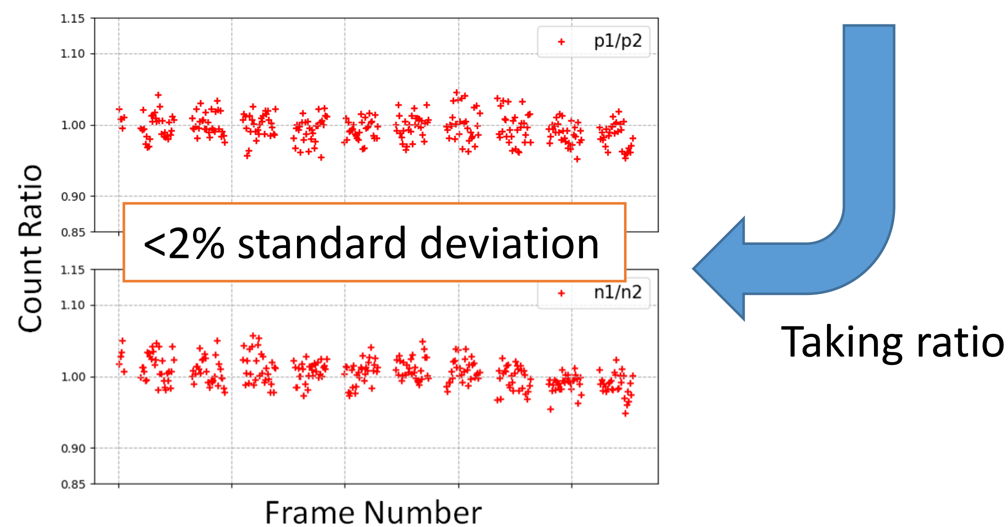
Atmospheric correction: Field stacker imaging test



Chopping-subtracted image in FS imaging mode (11.6 μm).



Time variability of the photometric counts.



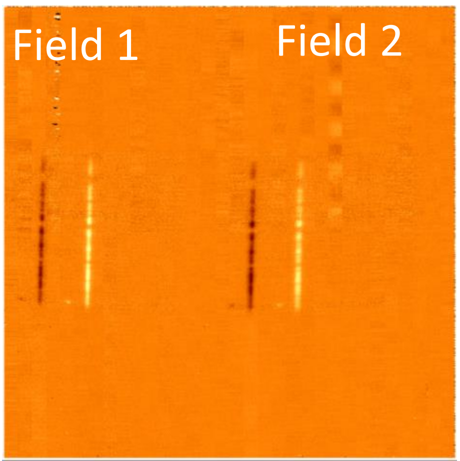
Time variability of the count ratio.

Photometric counts showed a 10% variation due to weather condition.

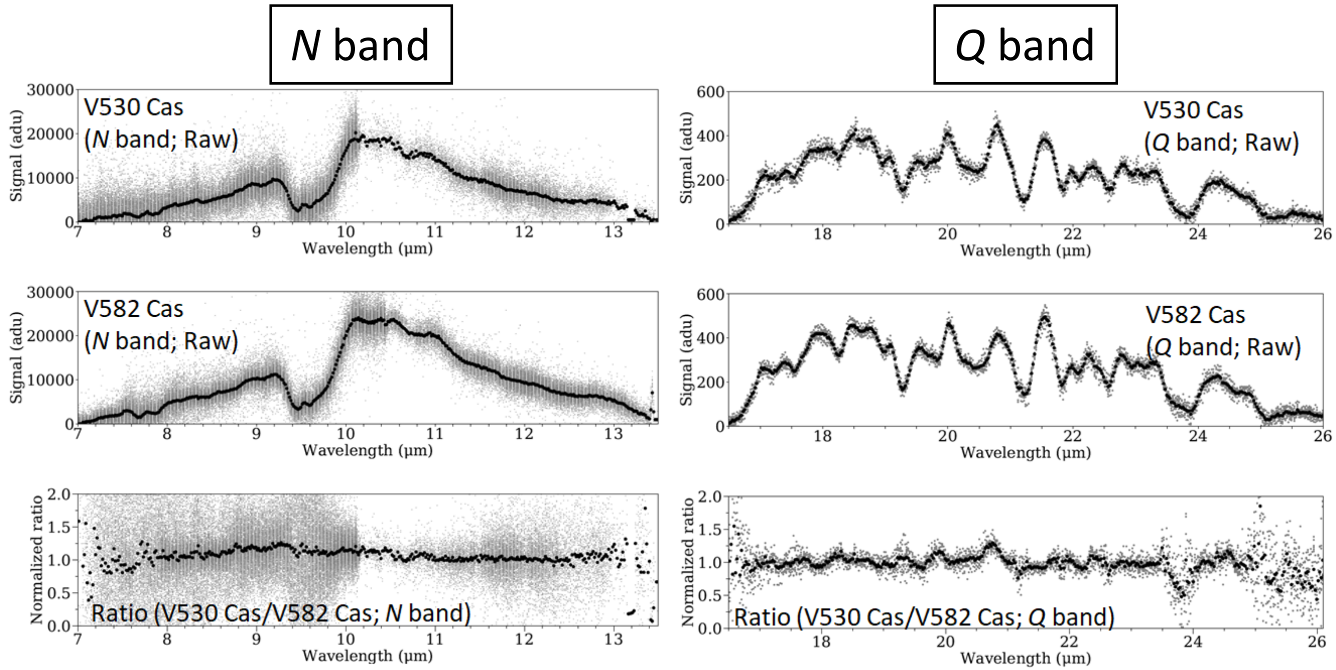
On the other hand, the count ratio of the two objects showed only <2% stddev.

➔ FS improves atmospheric correction.

Atmospheric correction: Field stacker spectroscopy test



Chopping-subtracted image in FS Q-band spc. mode.



Raw spectra of the two objects and their ratio (Kamizuka et al. 2020).

By taking ratio, the atmospheric features seen in the two row spectra are compensated even in the *Q* band.

➔ Ground-based *Q*-band spectroscopy is enabled by Field stacker.

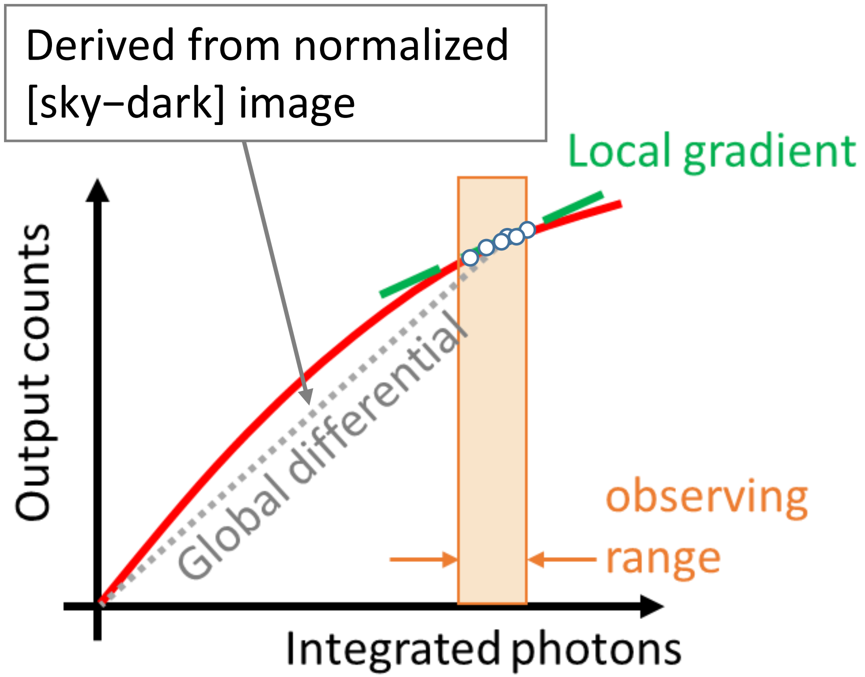
Our challenge
– Flat correction –

Improving flat correction

Flat fielding is also important for monitoring.

We must consider both optical flat & <u>detector flat</u>.

Non-linearity must be considered.

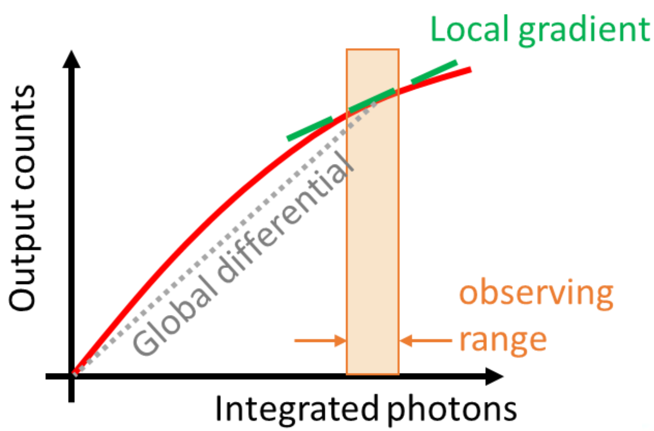


Non-linear detector response.

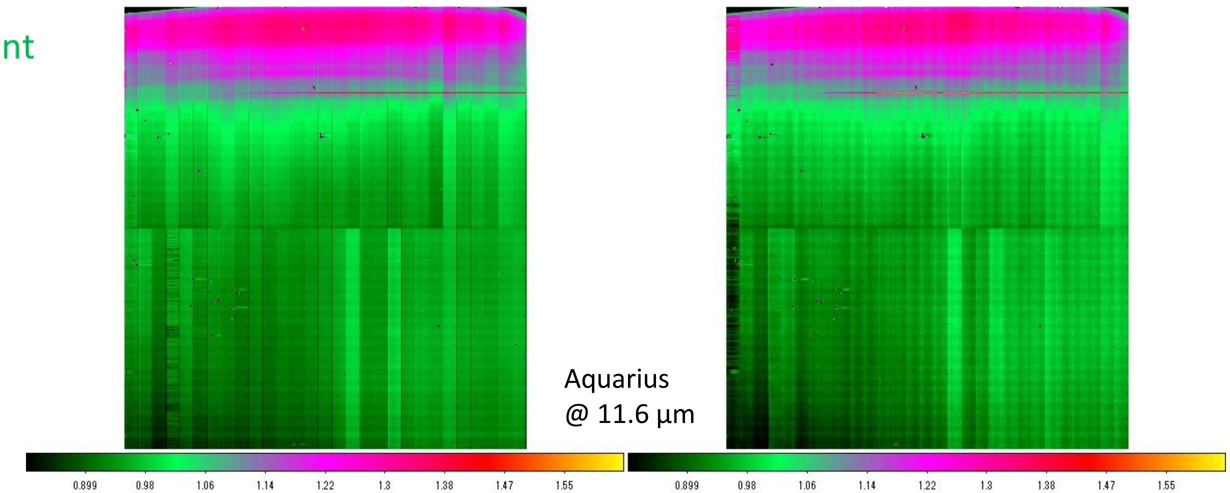
Detector flat is the pixel variety of the local gradient.

We evaluate it by examining the response against a variation of the incoming photon rate.

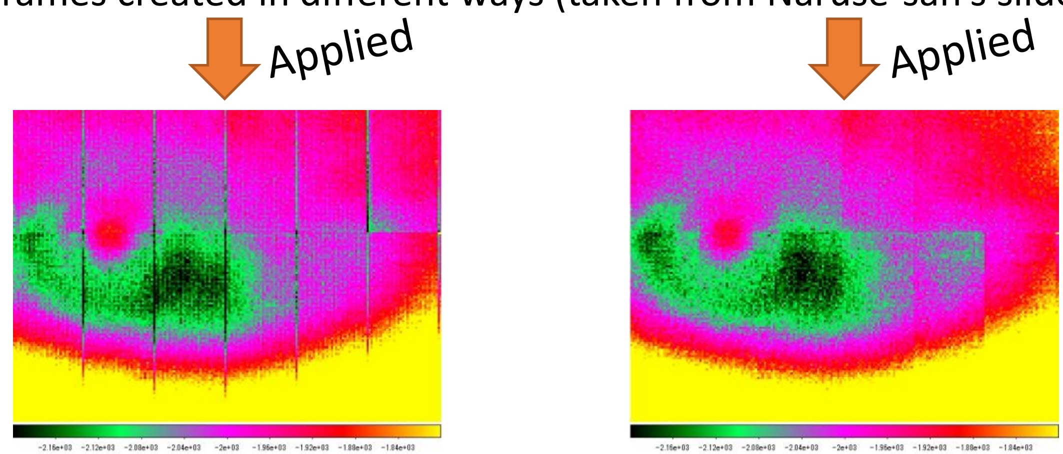
Improving flat correction



Flat using global diff. | Flat using local gradient



Flat frames created in different ways (taken from Naruse-san's slide).

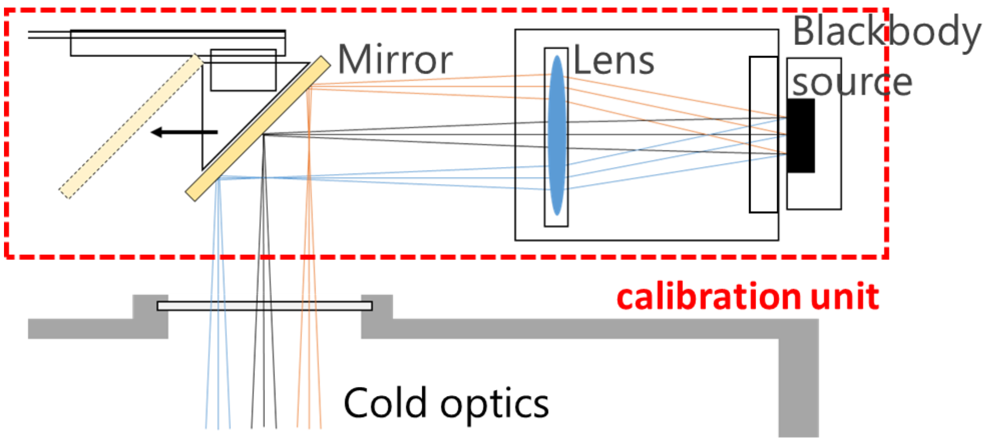


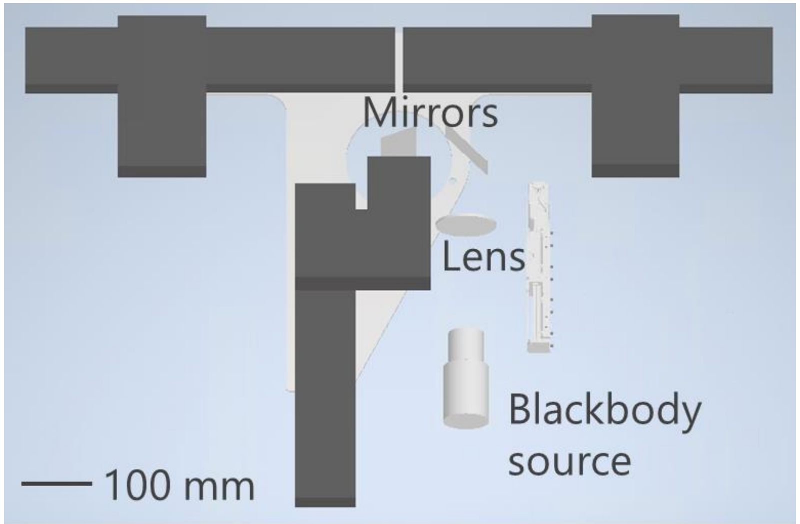
Flat-corrected images (taken from Naruse-san's slide).

Flat frames were created with the two methods and applied to an image to examine the difference.

The local-gradient flat seems to be better (still investigating in detail).

Improving flat correction: on-board calibration unit





Schematic view of the on-board calibration unit (taken from Naruse-san's slide).

We are designing a flat-calibration unit which:

- illuminates the detector uniformly.
- can vary the irradiance in time.
- can be placed in the field stacker unit.

Summary

Summary

Ground-based observations still have missions in the JWST era:

- Advancing science with the JWST.
- Monitoring/Surveying observations with smaller telescopes.
- High-resolution observations with 30-m class telescopes.

➔Technical developments are still important.

In the development of MIMIZUKU, we are making challenges to the difficulties in ground-based MIR observations:

- Cold chopper system for removal of high background.
- Field stacker system for accurate atmospheric correction.
- On-board calibration unit for accurate flat correction.

➔By using these systems, we start surveying or monitoring observations in near future (2023?).