Science Application of MICHI's IFU

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Science Application of MICHI's IFU

The mid-infrared instruments onboard future space missions (e.g., JWST and SPICA)
- will achieve the highest sensitivity observations
- can target the faintest dusty structures extended more than an arcminute's spatial scale

TMT/MICHI
- excellent spatial resolution in the mid-infrared
- opens up a new window to investigate the spectral variations among sub-arcsecond scale's dusty structures within a relatively compact source in the mid-infrared.

- *Galactic nearby (< a few kpc) stellar sources of various stellar evolutionary stages and of various main sequence masses* offer unique laboratories to test the formation and denaturing process of dust in circumstellar environments.

- *Extragalactic dusty sources*, which have never been sufficiently resolved by MIR instruments onboard 8m class telescopes, will also be important targets for TMT/MICHI.

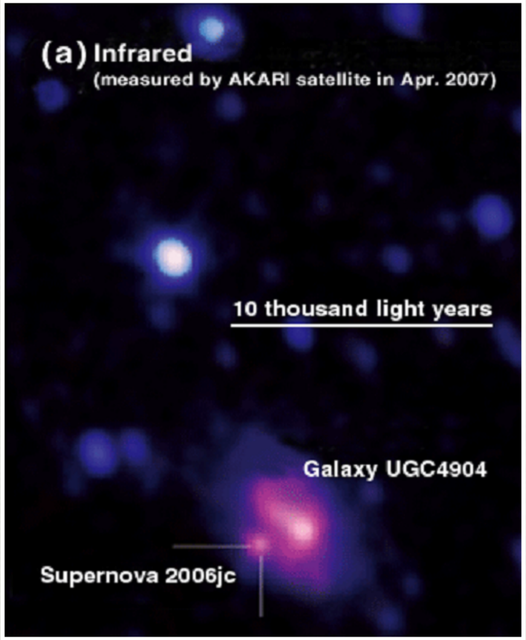
Those targets will be much more efficiently observed with *the IFU spectroscopy having the FOV size of a few arcsec by a few arcsec* rather than with *the long slit spectroscopy having a few tens arcsecond's slit length.*

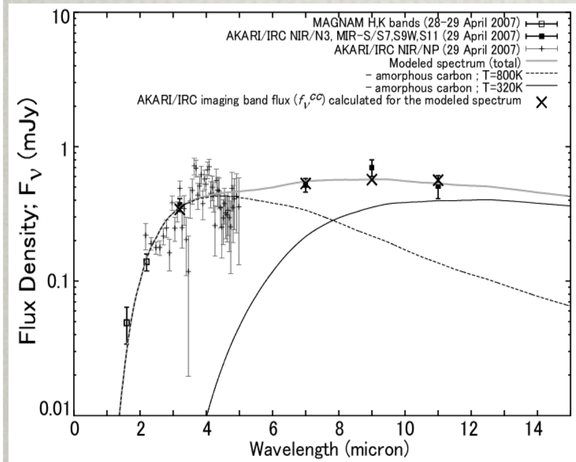
Can Massive Stars be Dust Budget in the Early Universe?

The amount of Dust supplied by SNe

Theory; ~0.1-1$M_\odot$/SN is needed to explain the dust content in the early universe

Observations; much smaller amount of dust formation (10^{-3}-$10^{-5}M_\odot$)



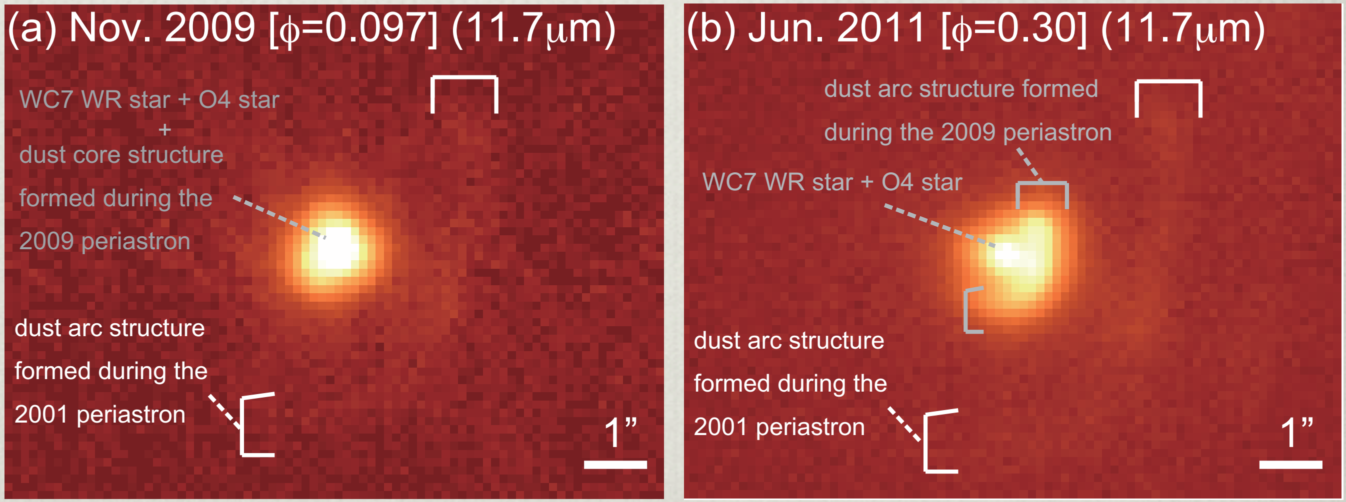


Sakon et al. (2009)

Separation of dust emission into newly formed dust and pre-existing dust components is always difficult…

→ high-spatial resolution observations of Galactic evolved massive stars (e.g., Wolf-Rayet stars, LBVs) offer unique opportunity to demonstrate the geometry and physical/chemical properties of circumstellar dust present around the SN progenitor

Periodic Dust Formation by WR+O-type Binary WR140 observed with Subaru/COMICS (period; 7.93y)

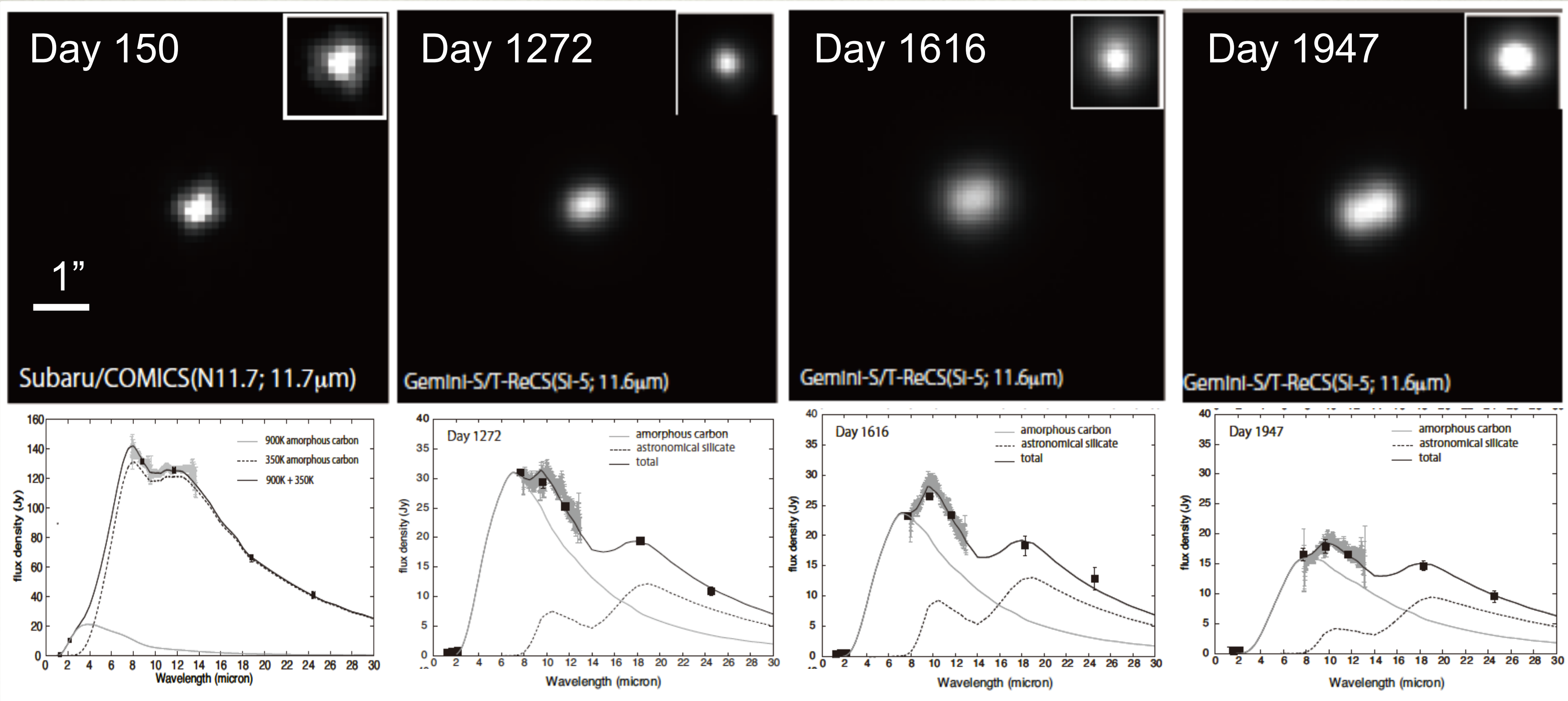


Dust forming region is located *a few hundreds mas* from the WR+O core

→ Imaging and IFU Spectroscopic capability of TMT/MICHI with excellent spatial resolution in the mid-infrared are indispensable to resolve the dust forming region.

Dust Forming Novae as the laboratory in situ to measure the dust properties

TMT/MICHI will spatially resolve the on-going dust forming sites around Galactic Novae (~a few kpc)
- Obtaining obvious information on the dust geometry
- Determining the physical conditions that governs the formation of carbonaceous dust and silicate dust
- Understanding the mixed chemistry around novae



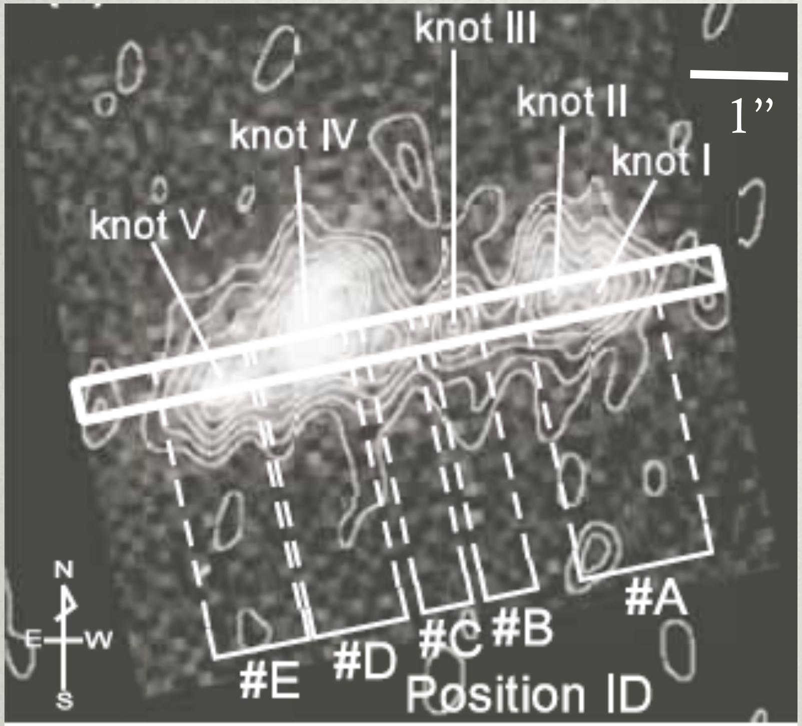
Expanding Nova Dust Structures around V1280Sco (d~1.1kpc; v_d=350km/s) and its SED Evolution observed with Subaru/COMICS and Gemini-S/TReCS (Sakon et al., in prep.)

Unveiling the Nature of Extremely Massive Star-forming Site in Blue Compact Dwarf Galaxies

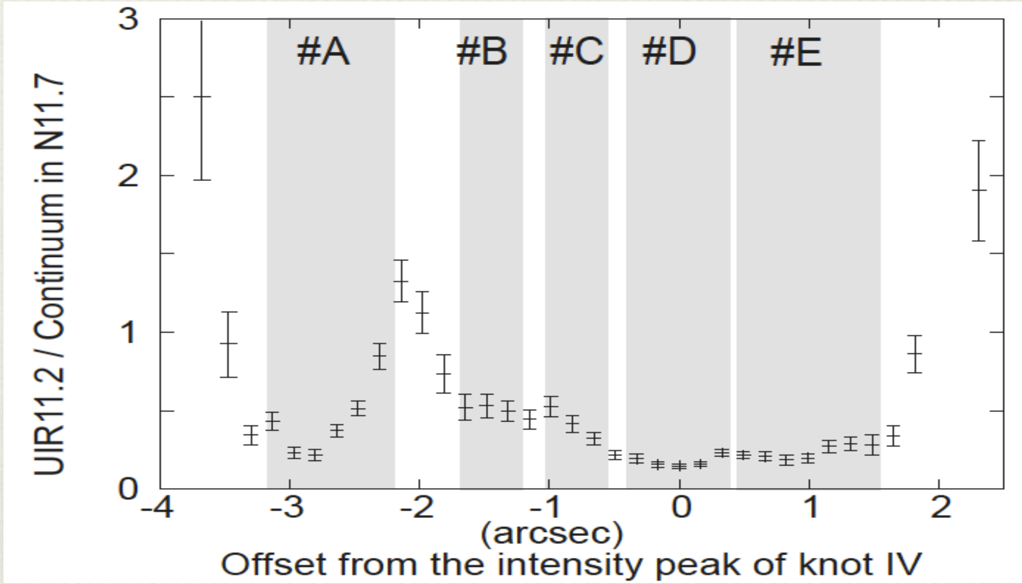
Blue Compact Dwarf Galaxies
- immature system with low metallicity
- presence of super star clusters (SSCs)
-thousands of O-type stars in each SSC

→ The stellar evolutionary cycles have not been accumulated many times

→ ISM produced by those cycles has not been well mixed within a galaxy



11.7μm image of SSCs in Henize 2-10 obtained with Subaru/COMICS



Low PAH-to-hot dust continuum ratios at SSCs

Analyses on the distributions of dust of different compositions within a BCD will provide us important clue to understand the life cycle of dust in galaxies.

→Excellent spatial resolution in the mid-infrared with TMT/MICHI is indispensable
- to characterize the properties of dust associated with such active star clusters
- to illustrate the material evolution within a galaxy that might have taken place in the early universe.

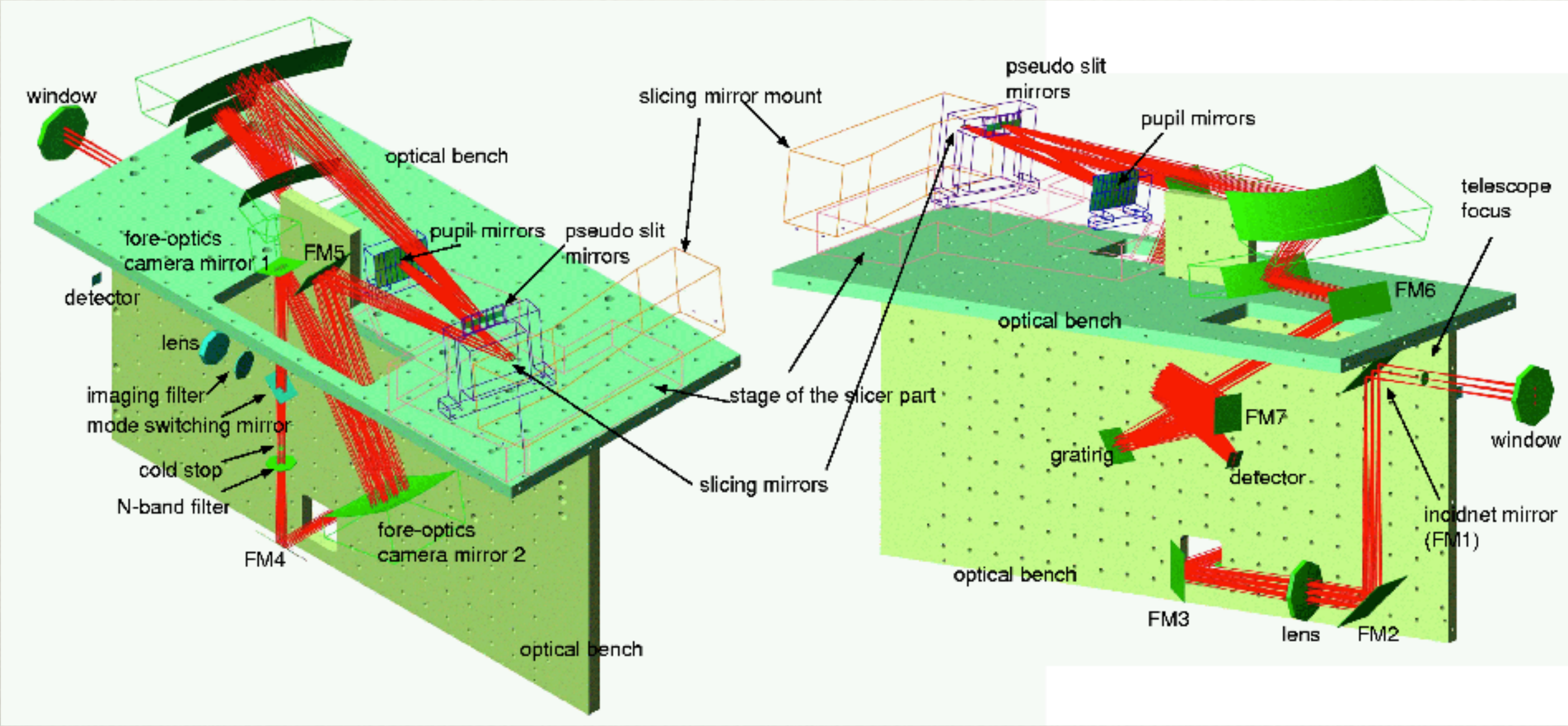
Mid-InfraRed Spectrometer with an Image Slicer (MIRSIS)

MIRSIS (Okamoto et al. 2008);
-- our initial attempt of an image slicer development for mid-infrared instruments

The slicing mirrors installed in MIRSIS's Image Slicer were designed and produced by piling up aluminum plates with 300μm thickness.

MIRSIS is ready to be onboard some appropriate telescopes (IRTF, Subaru etc).

[Basic Specification; Number of slicers (n=5), Width of the slitlet mirror; 300μm]



A schematic view of the optical and structural design of MIRSIS

A Trial Production of an Small Format monolithic Image Slicer Unit

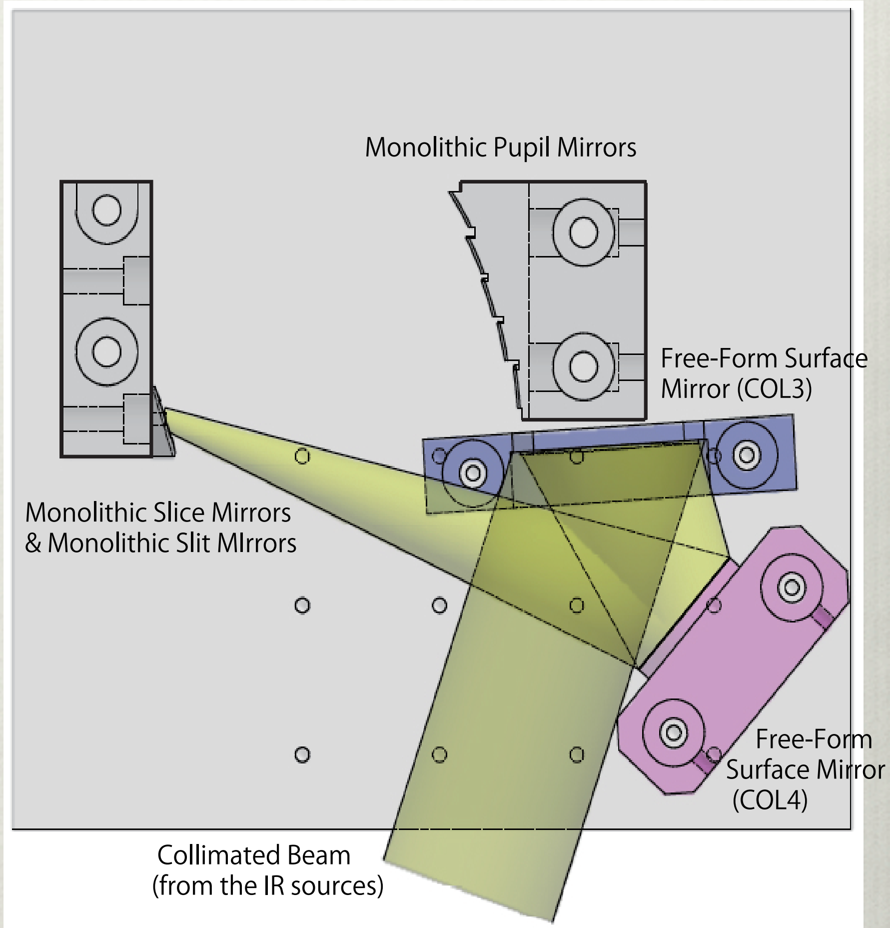
Simplicity for the optical alignment process is crucial for the success of developing a larger-format Image slicer (cf. n=22 for TMT/MICHI)

The development of an image slicer with
- monolithic slicing mirrors
- monolithic pupil mirrors
- monolithic pseudo slit mirrors
has been started.

A trial production of the test pieces of those three key elements have been made based on the specification of the IFU designed for SPICA/MCS (Kataza et al.2012)

- Number of slicers (n=5)
- Width of the slitlet mirror; 184μm

→ Ultra high-precision cutting technologies are useful for those trial productions

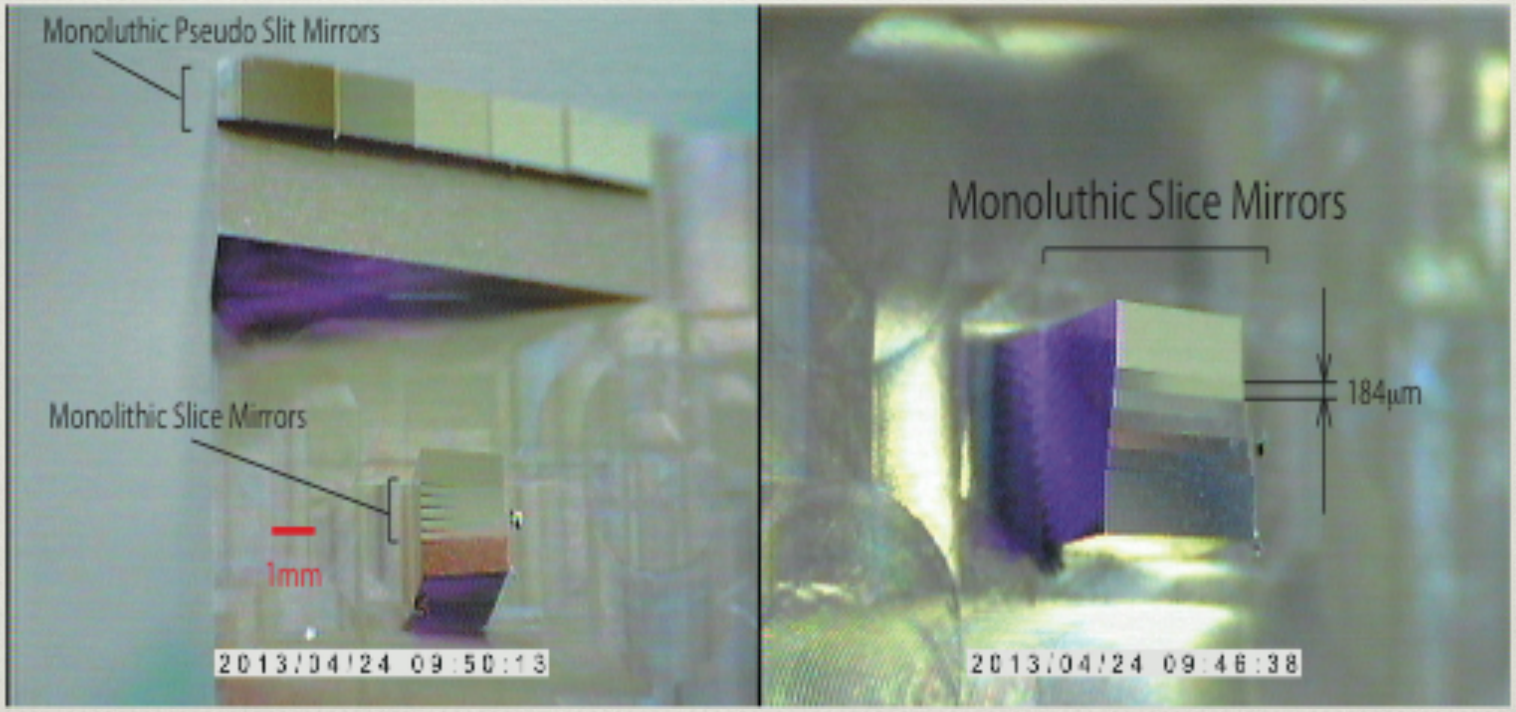


A schematic view of the optical and structural design of the trial production monolithic image slicer unit

A Trial Production of an Small Format monolithic Image Slicer Unit

1. Trial Production of Monolithic Slice Mirrors and Monolithic Pseudo Slit Mirrors

The monolithic slice mirrors and the monolithic pesudo slit mirrors are made from a single aluminum block. A test piece of the monoluthic slice mirrors was produced by ultra high-precision machine with a single crystal diamond bite (Slice Format; n=5, The width of each slice mirror; 184μm).

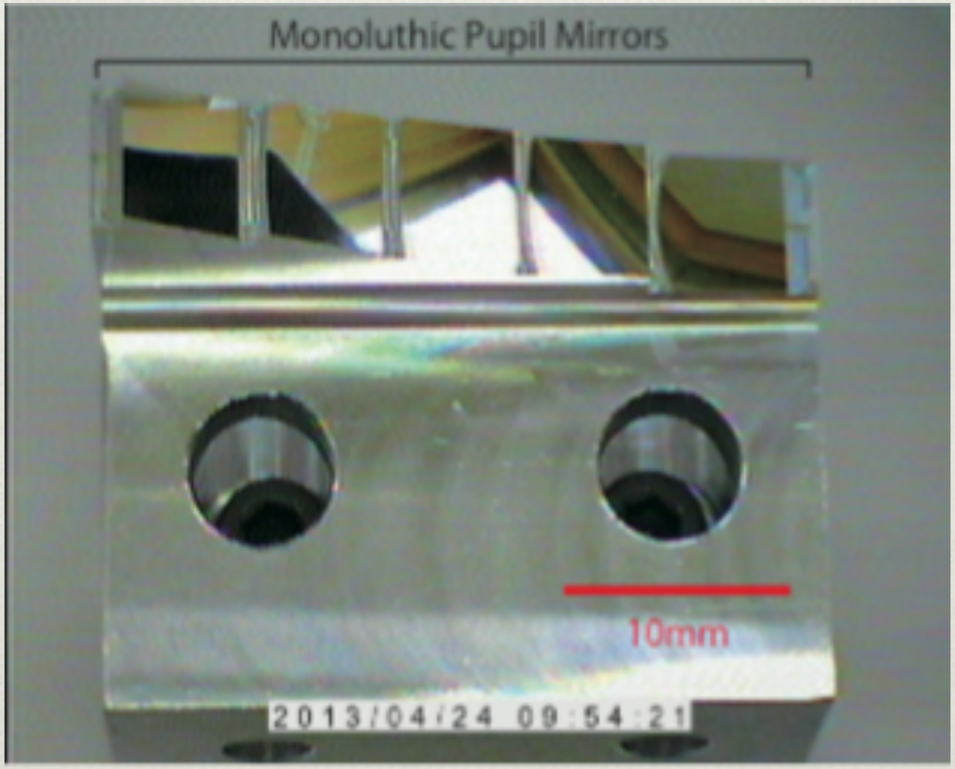


The results of the Surface roughness (Ra) measurements;
- Ra<50nm is achieved at any positions of the slice mirrors
- Ra<20nm is achieved at any positions of the pseudo slit mirrors.

A Trial Production of an Small Format monolithic Image Slicer Unit

2. Trial Production of Monolithic Pupil Mirrors

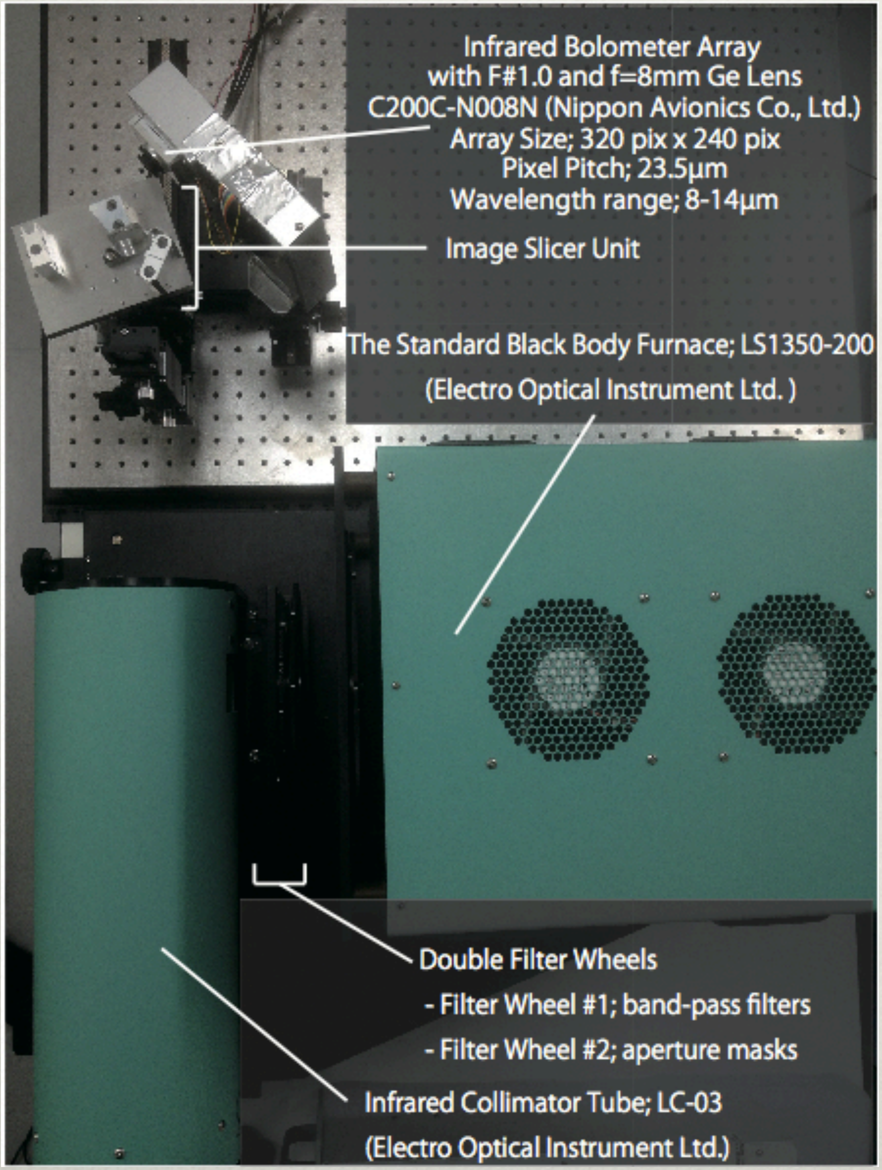
A test piece of monoluthic pupil mirrors was produced at Crystal Optics Ltd., Japan



The results of the shape precision measurement
- r.m.s.<0.034 μm and P-V<0.19μm were achieved for each pupil mirror

The results of the Surface roughness (Ra) measurement
- Ra<20nm is achieved at any positions of the pupil mirrors.

Optical Alignment Via Mechanical Metrology



The non-cryogenic measurement system of pseudo slit image has been assembled using the image slicer unit and the standard blackbody furnace.

The blackbody radiation from the standard blackbody furnace is collimated by the infrared collimator.

The pseudo slit image is refocused on the infrared bolometer array through the Ge lens.

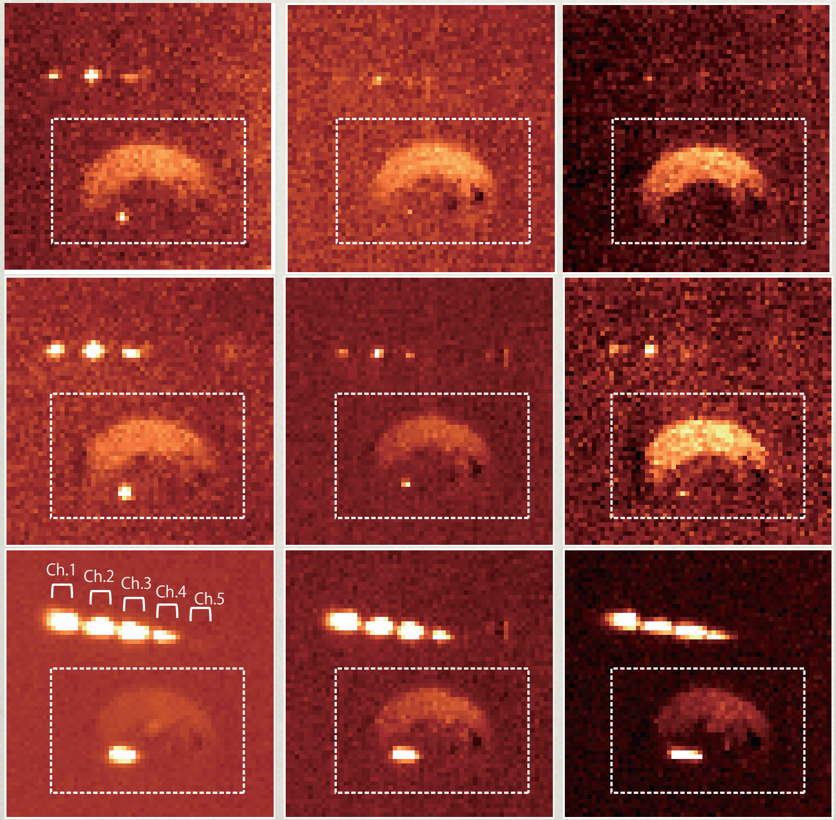
Filter Wheel #1

Filter Wheel Pos.	Filter ID.	λ^{center}_{band} (μm)	$\Delta\lambda_{band}$ (μm)
#1-1	N14.1	14.14±0.16	1.06±0.16
#1-2	hole	--	--
#1-3	N8.6	8.64±0.08	1.13±0.08
#1-4	N11.7	11.66±0.08	0.81±0.08

Filter Wheel #2

Filter Wheel Pos.	Mask ID.	Aperture diameter (inch)
#2-1	A1	0.0125
#2-2	A2	0.0251
#2-3	A3	0.0501
#2-3	BLANK	--
#2-4	A4	0.2561
#2-5	A5	0.4996

Results of the Measurements of the Pseudo Slit Images in the Infrared



The pseudo slit images produced by the extended sources are placed basically in a line on the bolometer array except for those of Ch.4 and Ch.5, which fail to fit in the pseudo slit mirror areas

The primary source of scattered light that affects the pseudo slit images at any wavelength bands is the one originating from the slice mirrors' structure.

This component will not have a serious effect on the following optics if the mechanical distance between the slice mirrors and the pseudo slit mirrors is set longer than that of the current design.

The intensity of pseudo slit image of each channel relative to that of Ch. 2

Filter ID.	λ^{center}_{band} (μm)	Ch.1	Ch.2	Ch.3	Ch. 4	Ch. 5
N8.6	8.64±0.08	118±5%	(100%)	112±4%	30±3%	N/A
N11.7	11.66±0.08	116±4%	(100%)	90±4%	19±3%	N/A
N14.1	14.14±0.16	104±3%	(100%)	105±2%	20±2%	N/A

Development Cost for MICHI's IFU

A trial production of a small format IFU (n=5) ; 40,000 USD

- The monolithic slice mirrors and the monolithic slit mirrors; 20,000 USD
- The monolithic pupil mirrors; 10,000 USD
- Two free form mirrors and others; 10,000 USD

Steps towards the development of the MICHI's IFU

A trial production of of large format IFU(n=22)

- The monolithic slice mirrors and the monolithic slit mirrors; 60,000 USD
- The monolithic pupil mirrors; 40,000 USD
- Two free form mirrors and others; 20,000 USD

Total cost for the development of the MICHI's IFU; 400,000 USD
[120,000 USD x 2 (a factor taking account of the risk and other errors)
 + personnel work within the MICHI team]

Assuming that 8m cost of 1 sec = 1USD, we guess TMT's cost of 1sec will be ~5USD
→ 400,000 USD converts to *only* ~24 hours of TMT's time

Summary

TMT/MICHI opens up, for the first time, a new window to investigate the spectral variations among sub-arcsec scale's dusty, molecular and gaseous structures in the mid-infrared;
- Galactic nearby (< a few kpc) stellar sources of various stellar evolutionary stages and of various main sequence masses
- Extragalactic dusty sources, which have never been sufficiently resolved by MIR instruments onboard 8m class telescopes

will be important targets for TMT/MICHI

Those targets will be much more efficiently observed with the IFU spectroscopy rather than the long slit spectroscopy. *-- "The Universe is not 1 Dimensional", R. Davies*

MICHI's IFU have many advantages including
- observational efficiency
- good matching to the AO observations in the mid-infrared

Based on our trial production of the small format IFU unit, we have demonstrated that MICHI's IFU will be technically feasible after a couple of further trial productions and that IFU capability will greatly elevate the observational efficiency of TMT/MICHI from the development cost's point of view.