A trial production of the image slicer unit for next generation infrared instruments and the assembly of the evaluation system of the pseudo slit image quality

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ABSTRACT

We have carried out the trial production of small format (n=5) image slicer aiming to obtain the technical verification of the Integral Field Unit (IFU) that can be equipped to the next generation infrared instruments such as TMT/MICHI and SPICA/SMI. Our goal is to achieve stable pseudo slit image with high efficiency. Here we report the results of the assembly of the image slicer unit and the non-cryogenic evaluation system of the pseudo slit image quality in the infrared.

Keywords: Integral Field Unit, infrared, image slicer

1. INTRODUCTION

Integral Field Unit (IFU) spectroscopy is one of the unique primary functions that should be requested in next generation mid-infrared instruments, such as TMT/MICHI (Okamoto et al. 2010; Packham et al. 2012) and SPICA/SMI (Nakagawa et al. 2014). Spatially resolved dusty circumstellar structures around stellar sources of various stellar evolutionary stages and of various main sequence masses will be valuable laboratories in space that allow us to examine the chemical and mineralogical evolution processes of dust grains. Those targets will be much more efficiently observed with an IFU spectroscopy rather than with a long slit spectroscopy.

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Our initial attempt to develop an image slicer for mid-infrared instruments has been made for MIRSIS (Okamoto et al. 2008). The slicing mirrors installed in MIRSIS's Image Slicer were designed and produced by piling up aluminum plates with a thickness of 300μm. This design requests somehow complicated the alignment process to make the pseudo slit images of different slice channels placed straightly in a line. Then we have started the examinations to develop a new image slicer that adopts monolithic slicing mirrors, monolithic pupil mirrors and monolithic pseudo slit mirrors. The trial production of the test pieces of monolithic slicing mirrors, monolithic pupil mirrors and monolithic pseudo slit mirrors have been made based on the specification designed for SPICA/MCS (Kataza et al. 2012) by making use of the super precision cutting techniques (see Sakon et al. 2013). This paper reports the results of the assembly of the small format (n=5) image slicer unit using our trial production elements and the non-cryogenic measurement system of the pseudo slit image in the mid-infrared.

2. ASSEMBLY OF THE IMAGE SLICER UNIT

2.1 Monolithic slicing mirrors, monolithic pupil mirrors and monolithic pseudo slit mirrors

The details on our trial production of monolithic slicing mirrors, monolithic pupil mirrors and monolithic pseudo slit mirrors are given in Sakon et al. (2013).

2.2 Two free-form mirrors

Two free-form surface mirrors (COL3 and COL4) that take the role to refocus the incident collimated beam on the slicing mirrors are produced with Nanoform 700 at Crystal Optics Ltd (see Figure 1). Based on the shape precision measurement of each spherical pupil mirror with Ultrahigh Accurate 3-D Profilometer (UA3P), r.m.s.<0.095 μm and P-V<0.54μm for COL3 and r.m.s.<0.063 μm and P-V<0.33μm for COL4 were achieved. From the measurements with Zygo NewView 7200 Optical Profilers, nice surface roughness Ra<5nm is achieved at any positions of COL3 and COL4.

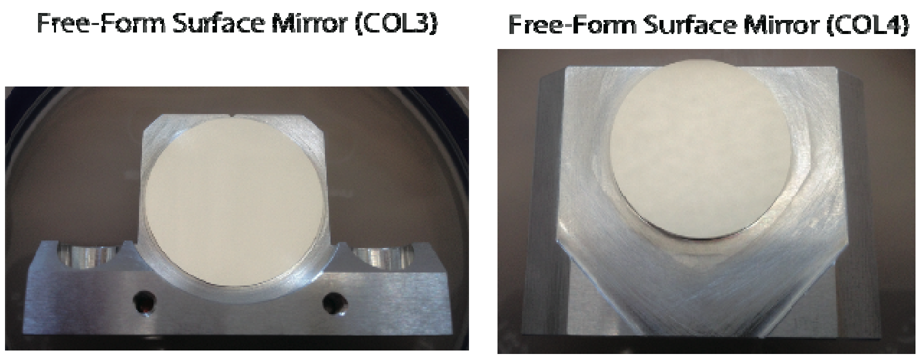

Figure 1. Produced samples of two free-form surface mirrors (COL3 and COL4).

2.3 Assembly of the small format (n=5) image slicer unit

The trial production pieces of the unified monolithic slice mirrors and monolithic pseudo slit mirrors (Sakon et al. 2013), the monolithic pupil mirrors and two free-form surface mirrors, COL3 and COL4, are mounted on the aluminum surface plate (see Figure 2).

3. ASSEMBLY OF NON-CRYOGENIC MEASUREMENT SYSTEM OF PSEUDO SLIT IMAGE

The non-cryogenic measurement system of pseudo slit image has been assembled using the image slicer unit described in section 2 and the standard blackbody furnace (See Figure 3). The blackbody radiation from the standard blackbody furnace (LS1350-200; Electro Optical Instrument Ltd.) is collimated by the infrared collimator (LS-03; Electro Optical Instrument Ltd.). Double Filter Wheels mechanics are placed between the standard blackbody furnace and the Infrared collimator tube. Three band-pass filters (N8.6, N11.7, N14.1) are installed in the filter slots of Filter Wheel #1. The specifications of the band-pass filters in Filter Wheel #1 are given in Table 1. Aperture masks with different aperture

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radius (0.0125inch—0.5 inch) are installed in the filter slots of Filter Wheel #2. The specifications of the aperture masks in Filter Wheel #2 are given in Table 1. The smallest aperture "A1" is used to simulate the point source and "A4" is used to simulate a fully extended source. "BLANK" is used for the background measurement. The collimated beam is refocused on the slice mirrors by means of two free-form surface mirrors (COL3 and COL4). The field of view on the refocused plane is divided into 5 slitlets by means of the monolithic slice mirrors. Their pupil images are produced on the spherical pupil mirrors, which are place independently on the output pupil positions. The images of the slitlets refocused by the 5 spherical pupil mirrors are aligned on the pseudo slit mirrors. The pseudo slit image is refocused on the infrared bolometer array (C200C-N008N; Nippon Avionics Co. Ltd.) through the F/1.0 f=8mm Ge lens. Note that the longest wavelength covered in our non-cryogenic system is constrained by this Ge lens to be <14μm.

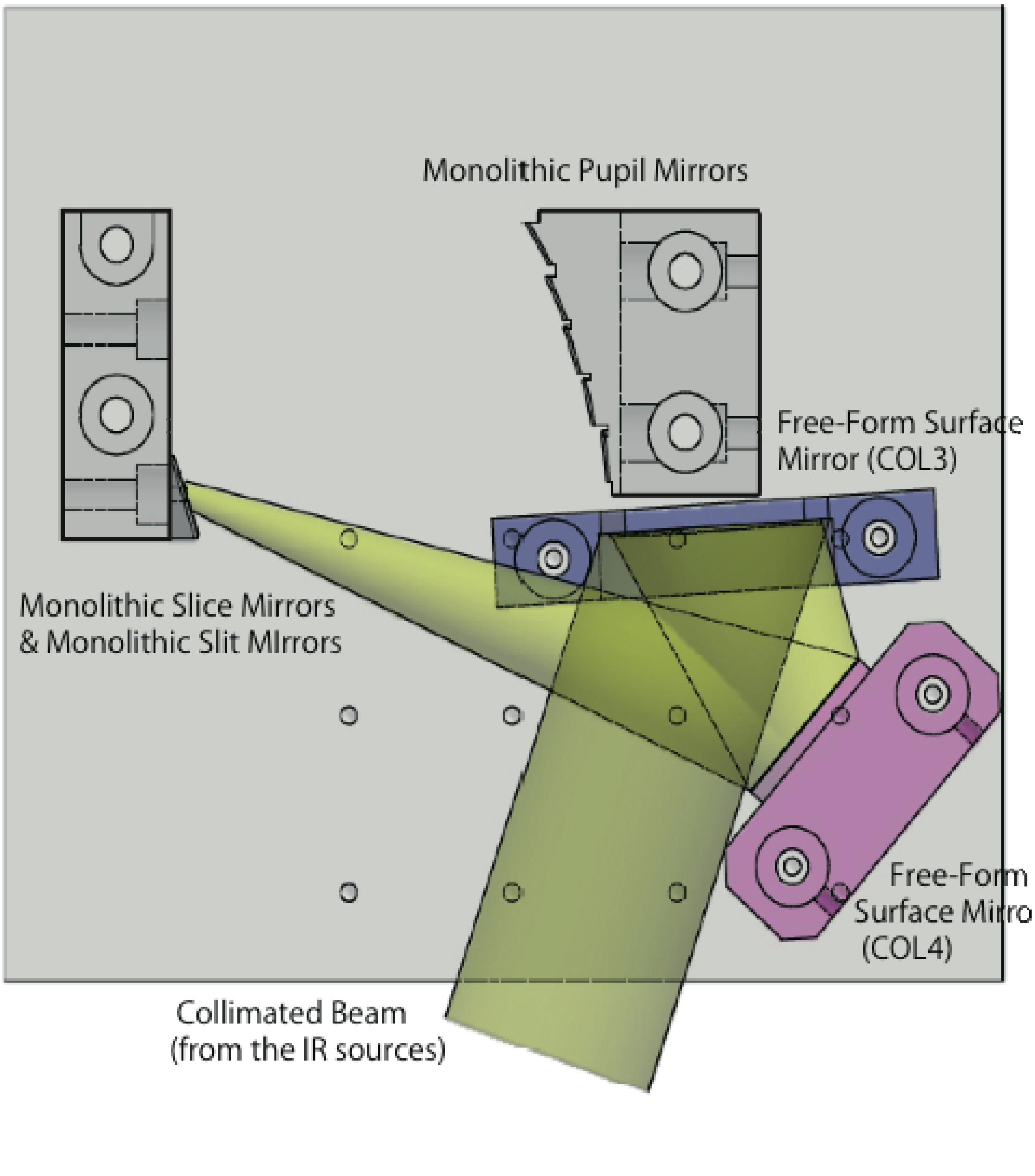

Figure 2. The layout of the small format (n=5) image slicer unit assembled on the Aluminum surface plates

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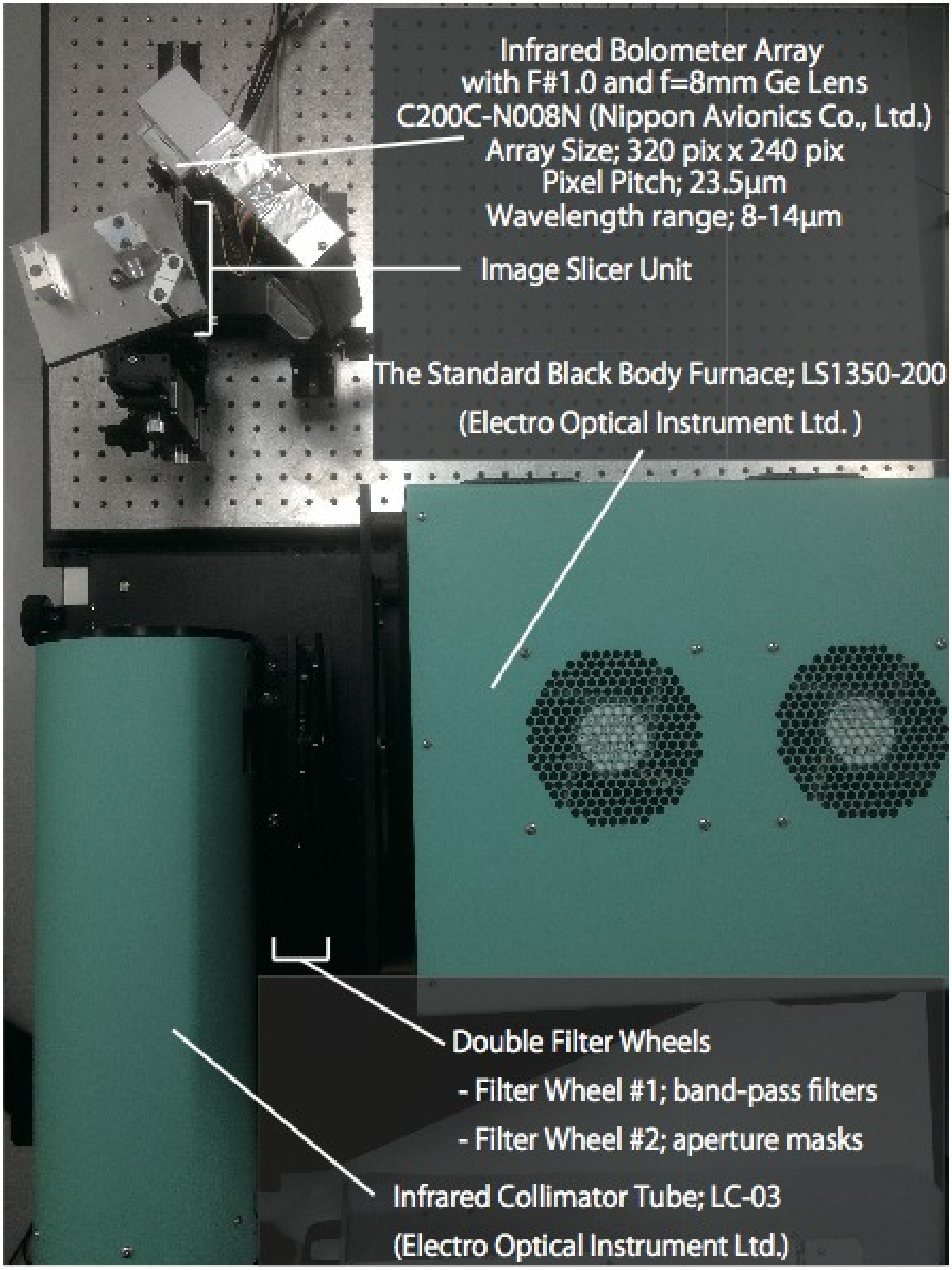

Figure 3. The non-cryogenic system assembled to measure the pseudo lit image

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Table 1. The filters and aperture masks settings in Filter Wheels #1 and #2

Filter Wheel #1				Filter Wheel #2		
Filter Wheel Pos.	Filter ID.	λ^{center}_{band} (μm)	$\Delta\lambda_{band}$ (μm)	Filter Wheel Pos.	Mask ID.	Aperture diameter (inch)
#1-1	N14.1	14.14±0.16	1.06±0.16	#2-1	A1	0.0125
#1-2	hole	--	--	#2-2	A2	0.0251
#1-3	N8.6	8.64±0.08	1.13±0.08	#2-3	A3	0.0501
#1-4	N11.7	11.66±0.08	0.81±0.08	#2-3	BLANK	--
				#2-4	A4	0.2561
				#2-5	A5	0.4996

4. THE PSEUDO SLIT IMAGES TAKEN WITH THE NON-CRYOGENIC SYSTEM

The blackbody source temperature was set to 700℃ in the following measurements. The images at N8.6, N11.7 and N14.1 bands were taken with the aperture masks of "A1", "A2" and "A4". The ones at N8.6, N11.7 and N14.1 bands taken with the "BLANK" mask were subtracted from the corresponding band images taken with "A1", "A2" and "A4" masks to remove the ambient infrared background radiation (see Figure 4).

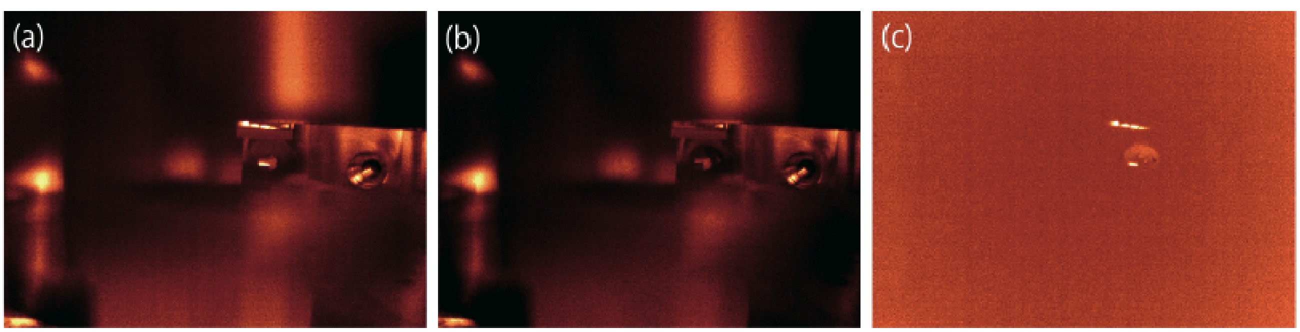

Figure 4. (a) An image taken at N14.1 band with "A4" mask. (b) An image taken at N14.1 band with "BLANK" mask to measure the background radiation. (c) The pseudo slit image at N14.1 for a fully extended source obtained as a result of (a) – (b).

The obtained pseudo slit images at N8.6, N11.7 and N14.1 bands with "A1", "A2" and "A4" aperture masks are shown in Figure 5. The point source represented by the "A1" aperture mask is set to fall on the Ch.2 slit mirror. The extended source represented by the "A4" aperture mask is intended to fall entirely on the Ch.1 – Ch.5 slit mirrors. The intensities of the pseudo slit image of each channel relative to that of Ch.2 are summarized in Table 2. The values obtained for Ch.1 are significantly larger than 100% at any wavelength bands. This should be due to the larger effective area size of Ch.1 pseudo slit mirror than that of Ch.2 mirror by a factor of ~1.15 (Sakon et al. 2013). The pseudo slit images for the extended source 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 mirror areas of the Ch.4 and Ch.5 pseudo slit mirrors (see Table 2) due to the production errors in the angle of the mirror axis of each pupil mirror and/or the alignment errors.

Table 2. The intensity of pseudo slit image of each channel relative to that of Ch.2 measured at N8.6, N11.7 and N14.1 bands

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

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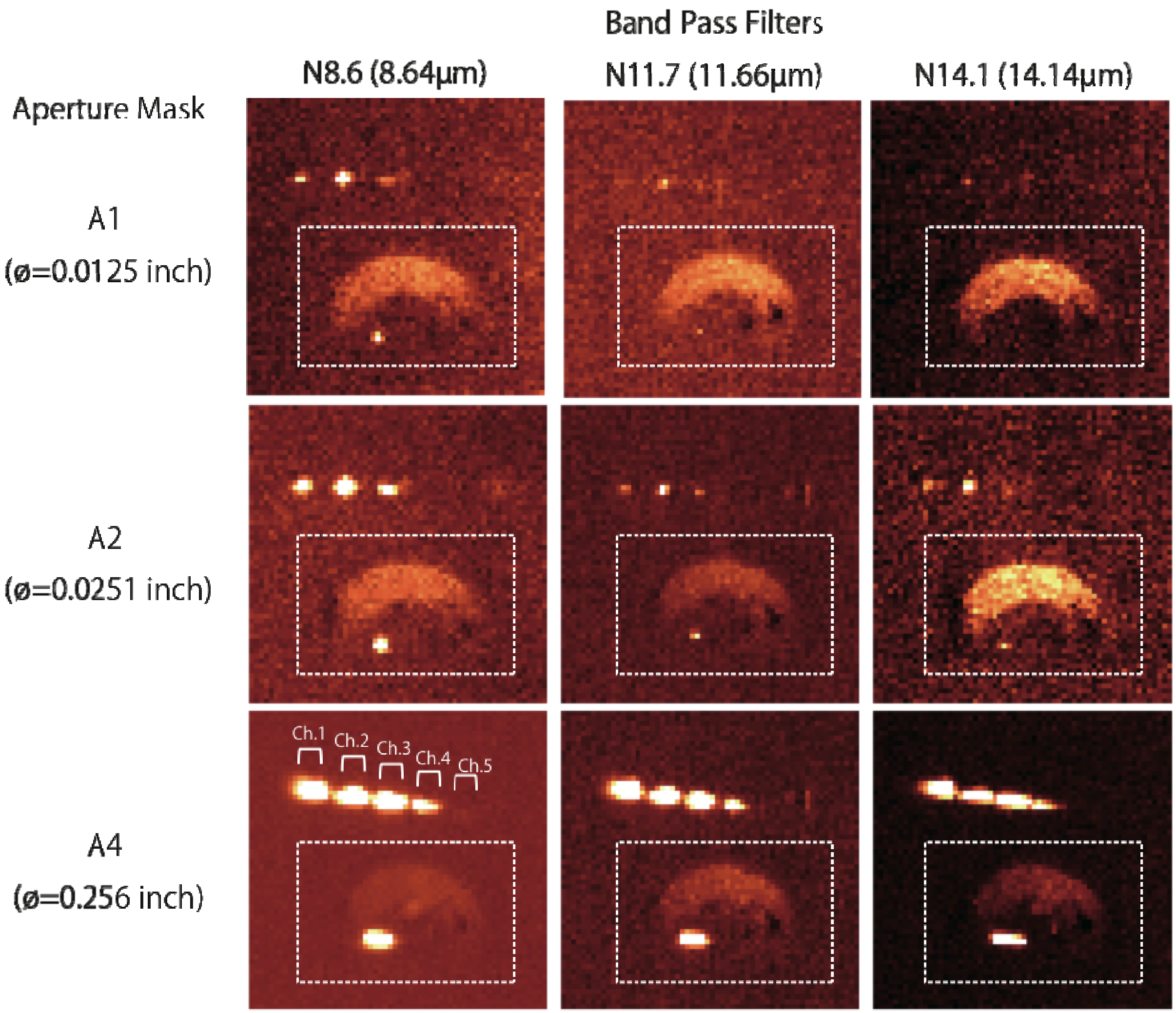

Figure 5. The pseudo slit images taken at N8.6, N11.7 and N14.1 bands with "A1", "A2" and "A4" aperture masks. The scattered light caused by the slice mirrors is seen in the pixel areas enclosed by white dotted boxes.

Based on the measurements with the current optical and structural design of our image slicer trial production module, the primary source of scattered light that may affect the pseudo slit images at any wavelength bands is the one originating from the slice mirrors' structure. This scattered light component appears in the pixel areas that are located somewhat apart from the pseudo slit images (see the pixel regions enclosed by the white dotted boxes in Figure 5) and, therefore, will not have a serious effect on the following optics if the structural distance between the slice mirrors and the pseudo slit mirrors is set longer than that of the current design.

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