A new mid-infrared camera for ground-based 30 micron observations: MAX38

Takashi Miyata [a], Shigeyuki Sako[a], Tomohiko Nakamura [a,b], Takashi Onaka [b], Hirokazu Kataza [c]
[a] Institute of Astronomy, the University of Tokyo, 2-21-1 Osawa, Mitaka, Tokyo, Japan 181-0015;
[b]Department of Astronomy, the University of Tokyo, Bunkyo-ku, Tokyo, Japan 113-0033;
[c]Department of Infrared Astrophysics, Institute of Space and Astronautical Science, Japan Aerospace, Exploration Agency, Yoshinodai 3-1-1, Sagamihara, Kanagawa, Japan 229-8510

ABSTRACT

We are developing a new infrared camera MAX38 (Mid-infrared Astronomical eXplorer) for long mid-infrared (25-40 micron) astronomy for the Univ. of Tokyo Atacama 1.0-meter telescope which is the world highest infrared telescope at 5,640m altitude. Thanks to the high altitude and dry weather condition of the Atacama site we can access the 30-micron wavelength region from ground-based telescopes for the first time in the world. We employ a Si:Sb 128x128 array detector to cover the wide mid-infrared wavelength range from 8 to 38 micron.

The development of the MAX38 has been almost completed. Test observations in N-band wavelength at Hiroshima Kanata telescope (Hiroshima, Japan) was successfully carried out on June 2007 and March 2008. The first 30-micron observation at Atacama is scheduled in the spring of 2009.

Keywords: mid-infrared, ground-based observations, Si:Sb

1. INTRODUCTION

Long mid-infrared (25 - 40 micron) is one of the most important wavelengths for observing dusty astronomical objects such as star forming region, mass losing stars and planetary/debris disks. This wavelength includes a wide variety of dust features in addition to the peak of the blackbody radiation of ~100K, which is comparable to temperature of circumstellar dust shells/disks and dusty galaxies. Observations in this wavelength have been insufficient so far because of the difficulty to access the wavelength from ground-level telescopes. However recent progresses of infrared projects of high-altitude telescopes and space/airborne telescopes make improvement of the situation.

We, institute of astronomy, the University of Tokyo are now constructing an Atacama 1.0-m telescope at the summit of Co. Chajnantor (5,640m) in Atacama, Chile[1]. This will be an optical/infrared telescope at the world's highest site. A perceptible water vapor amount at Chajnantor of 0.4 to 1.3 mm is much below that at Mauna Kea, Hawaii of 0.9 to 2.8 mm and provides excellent atmospheric transmission especially at the mid-infrared range. Figure 1 shows the calculated transmission of the atmosphere at Co. Chajnantor and Mauna Kea. New atmospheric windows appear at the longer wavelength than the 20 micron "Q-band" windows. These windows are clear enough for astronomical observations

For the long mid-infrared observations from the Atacama 1.0-m telescope we are developing a new camera MAX38 (Mid-infrared Astronomical eXplorer). Observations from the ground have an advantage of spatial resolution over space telescopes. The MAX38 has an imaging capability with diffraction limited spatial resolution at wide range of mid-infrared region from 8 to 38 micron. A Si:Sb blocked impurity band (BIB) array detector which has sensitivity at from NIR to 38 micron is employed. In addition to the imaging mode, grism spectroscopic observations at the N-band (7.5-13.5micron) and the longer wavelength range (19-38 micron) with a resolution of 50-100 can be optionally carried out. The specifications of the MAX38 are summarized in Table 1. We note that the MAX38 is a proto type instrument for next coming 6.5-m telescope of Tokyo-university Atacama Observatory (TAO; P.I.: Yuzuru Yoshii) [2].

In section 2, the optics, cryogenics, detector, and electronics of the MAX38 are described. Test observations on the Kanata 1.5-m telescope are briefly reported in section 3. Section 4 is a summary

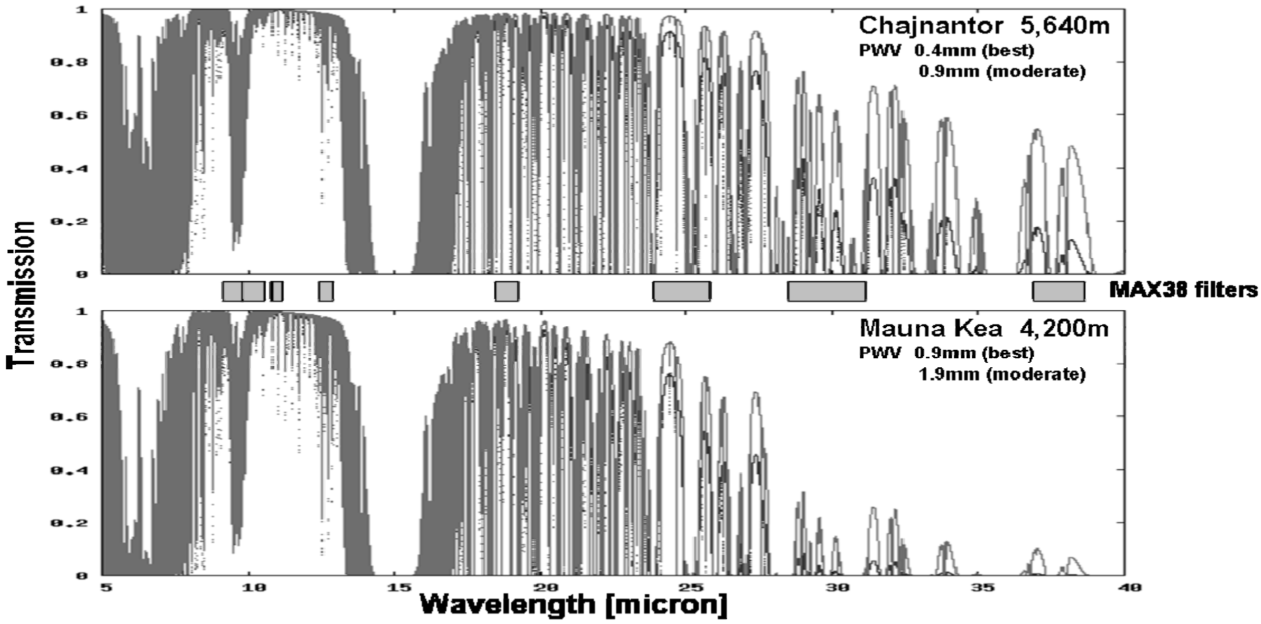

Fig. 1. A plot of atmospheric tramsmission calculated with ATRAN[3]. Upper panel shows transmission at the sumiit of Chajnantor (5,640m), and lower shows at Mauna Kea (4,200m). Thin lines and dotted lines indicate the transmission of best 10% (PWV of 0.4mm at Chajnantor and 0.9mm at Mauna Kea) and median condition (PWV of 0.9mm at Chajnantor and 1.9mm at Mauna Kea), respectively. Bars between the panels indicate the wavelength coverage of the MAX38 filters (see Table 2).

Table 1. MAX38 specifications on the Atacama 1.0-m telescope

Parameters	Value	Notes
Detector	Si:Sb BIB array	manufactured by DRS
Array format	128x128	
Pixel scale	1.26 arcsec/pix	
Field of View	161arcsec x 79arcsec	for imaging
Wavelength coverage	8-38 micron	see Table 2
Throughput	6% at 10 micron	including the optics,
	30% at 30 micron	the filter, and the detector
Sensitivity	~2Jy at 10micron	
	~8Jy at 30micron	see Table 2
N-band Spectroscopy mode	(optional)	
Resolving power ($\lambda / \Delta \lambda$)	~100	
Wavelength Coverage	7.5 – 13.5 micron	

2. INSTRUMENT DESIGN

2.1. Optics

The optical layout of MAX38 is shown in Figure 1. It consists of two 1:1 relay optics; the former one is for the internal cold chopping system, and the latter is a camera which has a filter wheel and a stop. All optical components except for an entrance window are gold-coated reflective optics to achieve high throughput whole the wavelength coverage of the MAX38 (8-38 micron). The window is a 40mm diameter chemical vapor deposition (CVD) diamond which has a high transmittance of 70% from NIR to FIR. Mirrors with power (two collimator mirrors and two camera mirrors) and a flat mirror in the cold chopping system are diamond-tuned aluminum alloy developed by the advanced technology center of the national astronomical observatory of Japan. The r.m.s. surface roughness of the mirror is below 0.1 micron, so they are perfect mirrors for mid-infrared wavelength. Since the optical bench on which all optical parts mount is the same kind of aluminum alloy, we can align and focus the optical system at room temperature and cool to the operating temperature without misalignment and focus shifts.

Light rays from the telescope enter the cryostat through the CVD diamond window and make 90-degree turn on the first folding mirror (upper left of Figure 2). The telescope focus is located between the window and the folding mirror. The light rays go parallel to the optical bench and are collimated by the 1st collimator mirror. This makes an image of the secondary mirror of the telescope on a cold chopping mirror. This is a wobbling mirror system operated below 10K and provides chopping observations without chopping secondary system on the telescope. Details of the cold chopper are discussed in Nakamura et al. [4] in this conference.

The light rays reflect on the 1st camera mirror (which is the same mirror of the 1st collimator mirror) and make an image of a star on the field stop. The field stop has a rectangular hole for imaging field (161"x79") and a slit for grism spectroscopy (width 2.5"). The rays passed through the field stop go to the 2nd collimator and make a pupil again. We put the Lyot stop on the 2nd pupil to suppress unwanted thermal radiation from the telescope and the cold chopping system. Diameter of the collimated beam on the 2nd pupil is 9mm. Finally the rays reflect on the 2nd camera mirror and the folding mirror, and make an image of a star again on the detector (lower left of Figure 2).

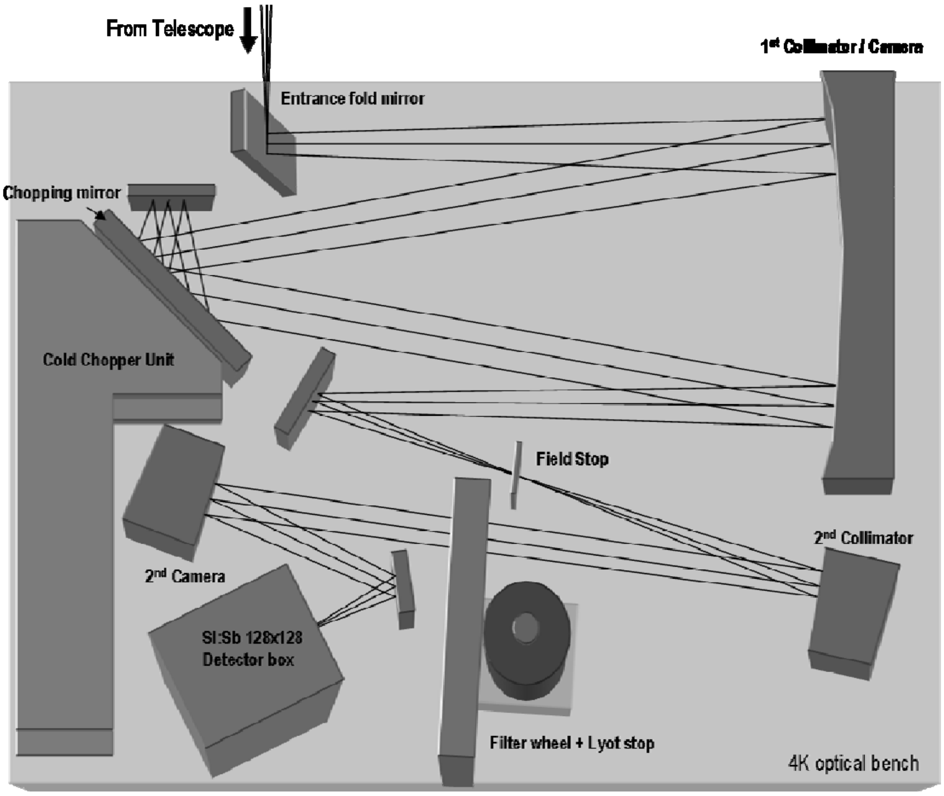

Fig. 2. Schematic drawing of the MAX38 optics. All components are mounted on the optical bench and cooled below 8K.

A filter wheel is located near the 2nd pupil. It has six one inch holes (with clear apertures of 11mm) for standard filters, two grism holders, and two 12mm x 12mm holes for metal mesh filters. The metal mesh filters are our newly developed band-pass filters for long mid-infrared observations. Details are described in Sako et al.[5] at this conference. The filters are summarized in Table 2.

A combination of the telescope and the MAX38 optical system provides a pixel scale of 1.26 arcsecs. This is consistent with the Nyquist sampling of diffraction limited image sizes at 12.6 micron. Oversampling the point spread function at longer wavelength will be helpful to improve the spatial resolution with software image reconstruction method

Table 2. Filter list of the MAX38

Type	Name	Center [micron]	Width [micron]	Expected sensitivity 1sigma 1sec	Notes
Normal	J089W08	8.9	0.8	1.5Jy	
	J098W09	9.8	0.9	1.5Jy	
	J106W04	10.6	0.4	2.0Jy	
	J122W05	12.2	0.5	1.5Jy	
	C187W09	18.7	0.9	2.5Jy	not yet installed
	C245W22	24.5	2.2	5.4Jy	
Film	MMMF-30	30.0	3.0	7.4Jy	now under development
	MMMF-37	37.0	2.0	25Jy	now under development
Grism	G30	19.0 – 38.0	(19.0)	----	only for measurements of atmosphere
	G10	7.5 – 13.5	(6.0)	10Jy	not yet installed

2.2. Cryogenics and mechanics

All the optical components including the filter wheel and the detector are mounted on the base plate and attached to a cryocooler manufactured by Sumitomo Heavy Industry. The cooler has a cooling capability of 1 Watt at 4.2K. The temperature of the optics and the chopping system reaches to below 8K, which is enough to avoid excess noise by thermal radiation from the optical components. Operating temperature of the detector is approximately 7K. It is slightly higher than the expectation, but does not cause serious effects on the sensitivity for imaging and low-resolution spectroscopy. We need 24 hours for cooling time

There is one motor for the filter wheel inside the cryostat. We use a regular stepping motor whose bearing was exchanged to molybdenum-coated one for cooling operation. This type of cryomotors was originally developed by Z-laboratory of Nagoya University and also used for Atacama Near-IR camera (ANIR)[6]. Heat generated by the motor rotation was measured as ~ 100mW. It raises the optics temperature ~0.1K if the motor was continuously rotated. This effect is not negligible, but acceptable for typical operations since the rotation time is shorter than total observing time.

2.3. Detector and electronics

For the observation at the long mid-infrared range the MAX38 employs Si:Sb BIB array detector manufactured by DRS sensor and targeting system, Inc. The array format is 128x128 with a pixel size of 75 micron. It is designed for moderate flux and has enough well capacity (10^7 e-) for ground-based observations. Typical background flux of the imaging is expected as $3x10^8$ e-/pixel/sec. To avoid saturation of the pixels we adopt 50 Hz as the typical frame rate. The detector is operated with exposure-during-readout mode.

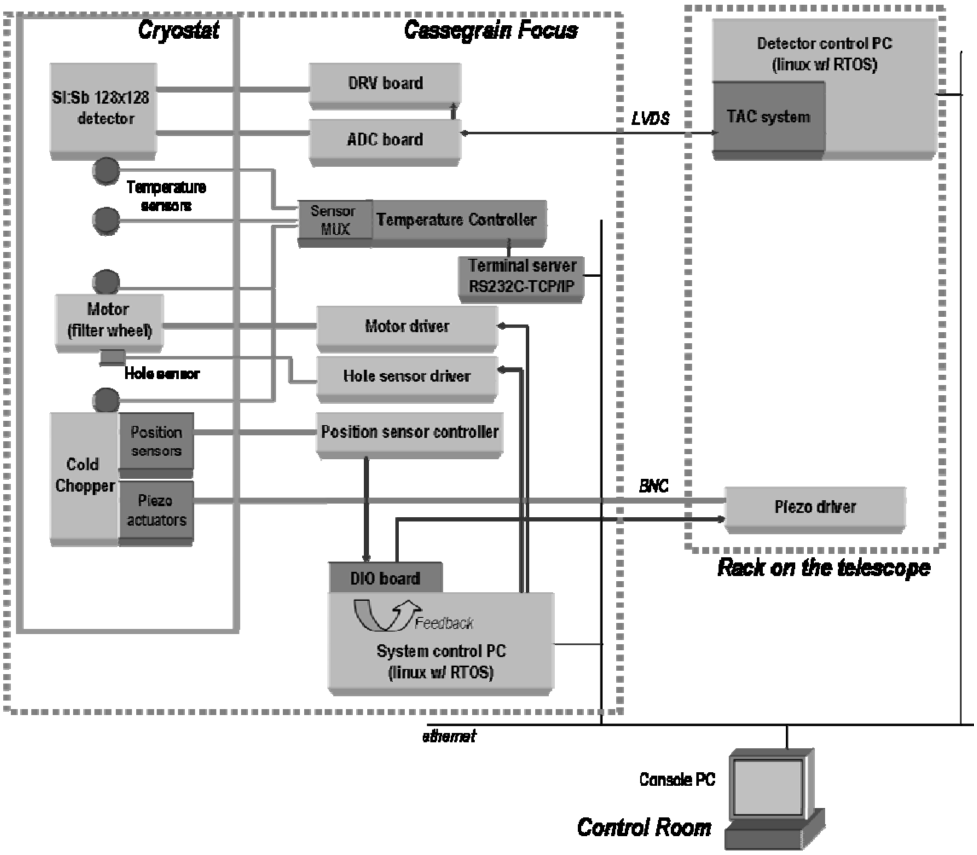

Fig. 3 Block diagram of the MAX38 control system. Components in the dotted box labeled "Cassegrain Focus" are mounted in the instrument carry and attached at the Cassegrain focus of the telescope. The detector control PC and the piezo driver are put in the computer rack attached on the telescope. All systems can be operated from console computer(s) via Ethernet.

A schematic drawing of the MAX38 control system is shown in Figure 3. The detector requires 4 clocks and 16 DC levels to operate. The clocks are generated in the TAO array controller (TAC) system[7] running in a detector controller computer, and sent to the driver board (DRV). On the DRV the voltages of the clocks are shifted to the suitable level of the detector. The DRV also generates the low drift, low noise DC biases for the detector.

The detector has four outputs in parallel. Signal from each output is led into each preamplifier, and digitized by each 16-bit A/D convertor on the analog-digital convertor board (ADC). Digitized data are sent to the memory of the TAC system via low voltage differential signaling (LVDS) line, and read by the detector control computer. When integration is completed, the data is stored as a FITS data file.

3. TEST OBSERVATIONS AT KANATA TELESCOPE

In order to evaluate the system performance of the MAX38, we carried out test observations with Kanata 1.5-m telescope at Higashi Hiroshima Observatory (Hiroshima, Japan) in June 2007 and in March 2008. Although the weather condition was unfortunately poor and the water vapor was high for mid-infrared observations, we successfully achieved the first light observation in the N-band.

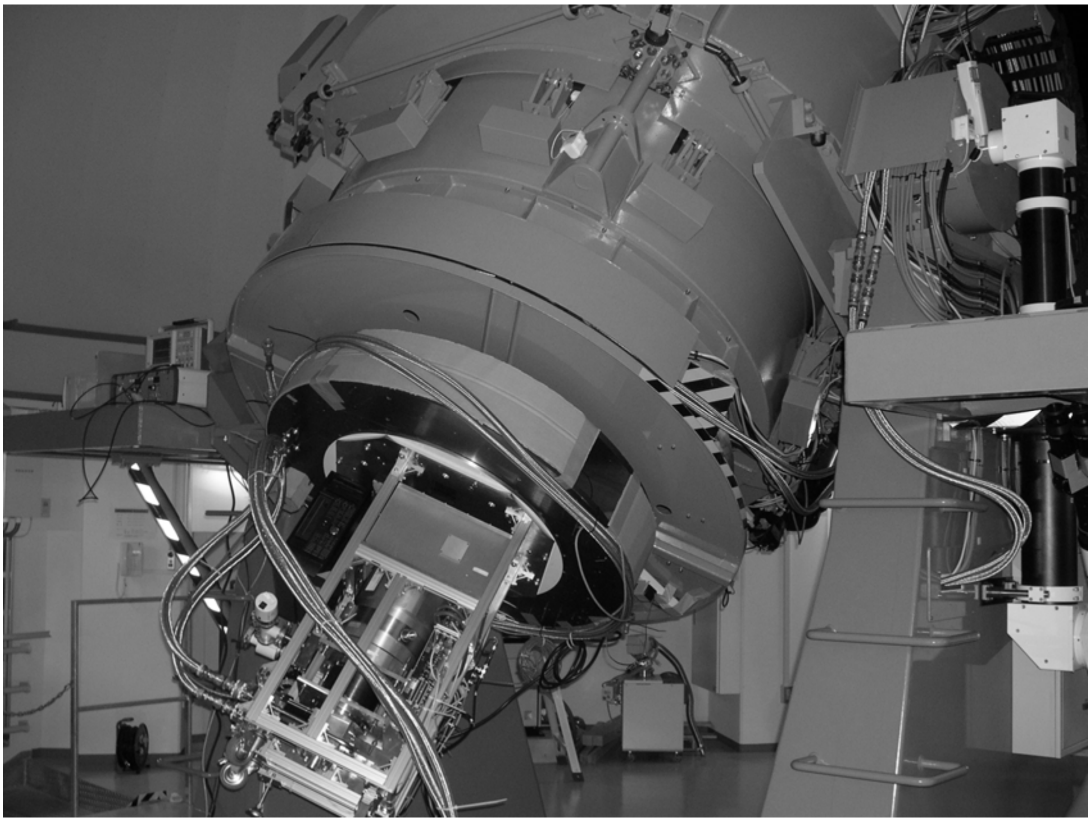

Fig. 4 The MAX38 mounted on the Kanata 1.5-m telescope at the Higashi Hiroshima Observatory (Hiroshima, Japan)

- Cold Chopping

The Kanata telescope did not have a secondary chopping system, so the internal cold chopping system was used for the observations. Figure 5 displays a mid-infrared image of Orion BN/KL nebula taken by the MAX38 with cold chopper. Chop and Nod technique was adopted, so two positive images and two negative images can be seen in the image. The throw of the chopping was 17 arcseconds and the frequency of the chopping was 1.9 Hz. It clearly demonstrates that the internal cold chopping was enough speed and throw for mid-infrared observations.

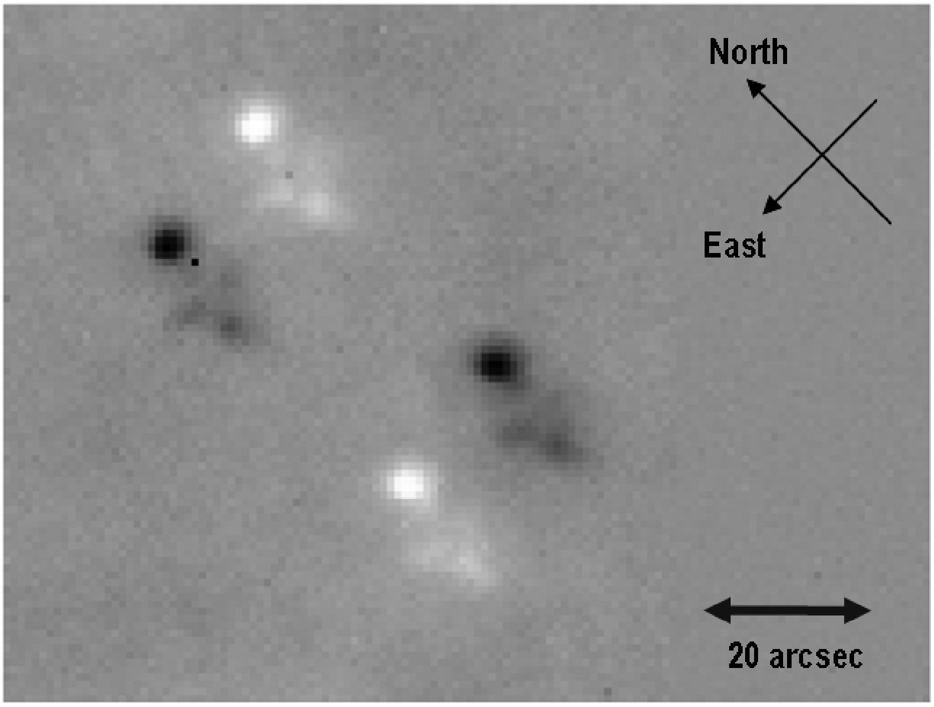

Fig. 5 12.2 micron image of BN/KL nebula taken by the MAX38 on the Kanata telescope. North is upper left and east is lower left. Since chop&nod technique was employed, four images (two positive and two negative) can be seen in the image. Pairs of positive and negative images aligned east-west are itive-and-negative pair at north was taken at the first nodding position, and the pair at south was taken at the other nodding position.

- Image quality

We also verified the image quality of the MAX38. Full width of half maximum of point spread function (PSF) was measured as 2.0 pixels at 12.2 micron filter, which corresponds to the diffraction limited PSF size. Evaluated pixel field of view was 0.86 arcecond which completely agree with the design value. The MAX38 has achieved the diffraction limited spatial resolution of the telescope diameter. No aberration, vignetting, and field curvature were detectable.

- Noise

Read out noise of the MAX38 was measured as 800 e- on the telescope, which was much lower than the Poisson noise come from the background flux. Because of the high temperature of the detector, dark current was high (1.5 x 10^7 e-/sec). This was not negligible, but over one order of magnitude lower than the background photo-current. Therefore we concluded the detector has achieved the background-noise limited performance.

4. SUMMARY

We are developing the new mid-infrared camera MAX38 for the Atacama 1.0-m telescope at Chajnantor site (altitude 5640m), Atacama, Chile. Thanks to the high altitude and dry weather condition of the site we can access the 30-micron wavelength region from ground-based telescopes for the first time in the world. The Si:Sb 128x128 array detector , the reflective optics, and the CVD diamond window were employed to cover a wide mid-infrared wavelength range from 8 to 38 micron. The newly developed cold chopping system operated below 10K was also installed in the MAX38 optical system.

The development of the MAX38 has been almost completed. The first light observation in the N-band at Hiroshima Kanata telescope (Hiroshima, Japan) was successfully carried out. We will atempt the first 30-micron observation at Atacama in the spring of 2009.

We are grateful to all of TAO project members for their support to this project, and to Mr. Okada, Mr. Mitsui, and Mr. Obuchi of the Advanced Technology Center, National Astronomical Observatory of Japan for their helpful support for the development of the aluminum mirrors and the other units. We also acknowledge the staff of the Higashi-Hiroshima Observatory for their kindly help for the test observations. This research was supported by Ministry of Education, Culture, Sports, Science and Technology of Japan, Grant-in-Aid for Scientific Research on Priority Areas, "Development of Extra-solar Planetary Science"

REFERENCES

[1] Sako, S., et al., “The University of Tokyo Atacama 1.0-m Telescope” in this conference
[2] Yoshii, Y., et al., “Tokyo Atacama Observatory Project” Proc. of the IAU 8th Asian-Pacific Regional Meeting, p.35 (2002)
[3] Load et al, Nasa Technical Memo. 103957 (1992)
[4] Nakamura, T., et al., ”Cold Chopper System for Mid-Infrared Instruments” in this conference
[5] Sako, S., et al., “Developing Metal Mesh Filters for Long Mid-Infrared Astronomy” in this conference
[6] Motohara, K., et al., ”ANIR : Atacama Near Infrared Camera for Paschen Alpha Imaging” in this conference
[7] Sako, S., et al., “Developing Infrared Array Controller with Software Real Time Operating System” in this conference