Development of the near-infrared spectrometer for the IRSF telescope

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ABSTRACT

IRSF (InfraRed Survey Facility) consisits of a 1.4 m telescope and the near-infrared (NIR) camera SIRIUS, which is located in South Africa. We are developing a new NIR spectrometer for the IRSF telescope. The spectrometer covers the wavelength range of 1.0–1.6 μm with a high optical throughput ($\approx$ 70%) owing to a small number of optical surfaces to reduce reflection losses. NIR photons from the telescope are dispersed by a sapphire prism and are focused on a 640×512 InGaAs detector; the spectral resolution of the instrument is designed to be 230 at 1.2 μm and 310 at 1.6 μm. The spectrometer is also equipped with a NIR slit viewer with a $3' \times 4'$ field of view, which enables us to perform very precise spectral monitoring and mapping. We introduce the status of the development and synergy with *AKARI*.

Keywords: near-infrared, spectrometer, IRSF

1. INTRODUCTION

IRSF is a facility with a 1.4 m telescope located at South African Astronomical Observatory (SAAO) and operated by Nagoya University and SAAO. The current main instrument on IRSF is the near-infrared (NIR) camera SIRIUS (Nagayama et al. 2003) which enables observations in the J, H, and K_S bands in a $7.'7 \times 7.'7$ field simultaneously. With IRSF/SIRIUS, we have performed surveys of the Magellanic Clouds (Kato et al. 2007) and the Galactic Center (Nishiyama et al. 2010), as well as other interesting regions. We have also performed line mapping observations of star forming regions and supernova remnants with the narrow-band filters tuned for Paβ, Brγ, [Fe II] and H_2 (Kokusho et al. 2015). We can measure linear or circular polarization with SIRPOL, which is an additional unit for SIRIUS (Kandori et al. 2006). In order to perform follow-up spectroscopy of interesting objects we have found so far, we are developing a new spectrometer for the IRSF telescope (Nagayama et al. 2012).

2. SPECIFICATIONS AND FEATURES OF THE SPECTROMETER

Figure 1 shows the optical layout of the spectrometer. The concept of the spectrometer is the effective use of photons. We can observe NIR and optical wavelengths simultaneously with a high optical throughput owing to a small number of optical surfaces. Photons from the telescope are separated into NIR and optical channels by a dichroic window. A slit with a size of 12 mm $\times$ 70 μm, corresponding to 180$''$ and 1$''$, respectively, is placed at the telescope focal plane. The slit width of 1$''$ is comparable to the typical seeing size at the Sutherland observatory where IRSF is located.

In the NIR channel, light passing through the slit is collimated by a spherical mirror. The collimated light then goes through a sapphire prism, which disperses the light along the direction perpendicular to the optical base plate. The far side of the prism is coated by aluminum to reflect the light to the spherical mirror which refocuses the light onto a 640×512 InGaAs detector. A camera lens in front of the detector reduces the telescope F ratio of 9.9 to 6.9 in order to measure unresolved sources by 3×3 pixels. A NIR slit viewer with a $3' \times 4'$ field of view is implemented in the NIR channel, and we use another 640×512 InGaAs detector for the slit viewer. This slit viewer is very useful to quickly introduce targets into the slit and to estimate the slit-loss correction factor.

In the optical channel, the light is collimated and refocused by a parabolic mirror. The light is dispersed by a diffraction grating and focused on a 1024×250 Si detector. The specifications of the spectrometer and its expected performance are summarized in Table 1. The NIR optical system is installed in a cryostat with a size of 554 mm $\times$ 384 mm $\times$ 300 mm. We use a refrigerator to cool the entire NIR optical system down to 100 K.

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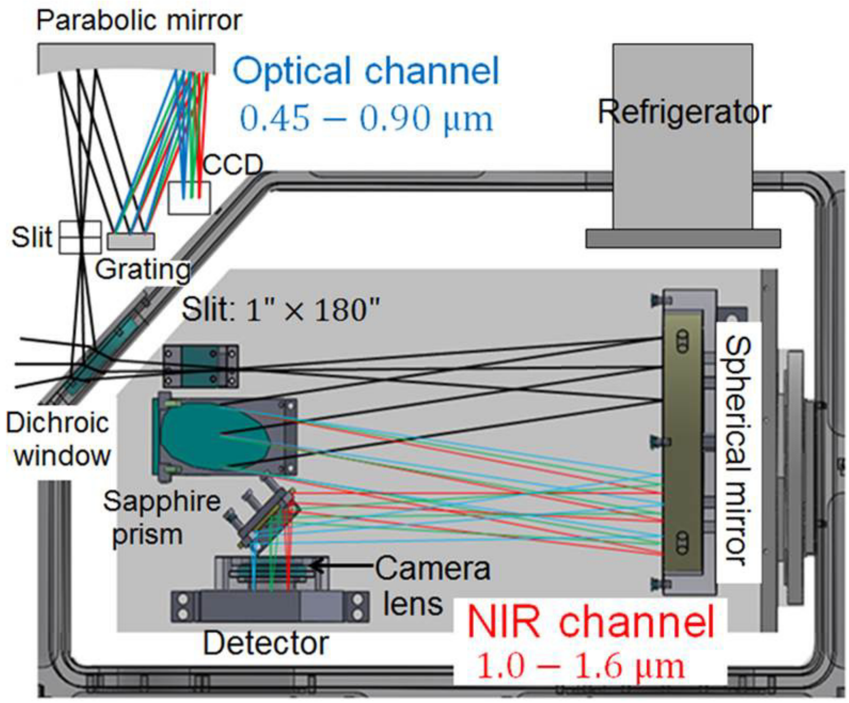

Figure 1. Optical layout of the NIR and optical spectrometer for the IRSF telescope.

Table 1. Specifications and expected performance of the spectrometer

Parameters	**NIR channel** (1.0–1.6 μm)	**Optical channel** (0.45–0.90 μm)
Focal plane array	InGaAs, 640 × 512	Si, 1024 × 250
Disperser	Sapphire prism	Grating
Optical throughput	70 %	60 %
Spectral resolution ($\lambda/\Delta\lambda$)	220 at 1.0 μm 310 at 1.6 μm	300 at 0.45 μm 600 at 0.90 μm
Sensitivity for point sources (10 min, S/N=10)	16.2 mag at 1.2 μm 15.4 mag at 1.6 μm	18.5 mag at 0.6 μm 17.2 mag at 0.8 μm

3. STATUS OF THE DEVELOPMENT

We are performing optical testing of the NIR channel at the operating temperature of 100 K. We use two laser diodes which have central wavelengths of 1.3 μm and 1.5 μm as light sources and a lens unit to simulate the telescope F/9.9 light. As a result of the optical testing, the measured focus positions at different wavelengths are consistent with those estimated by the optical simulation as shown in Figure 2. However the measured encircled energy is significantly degraded as compared to the simulation shown in Figure 3 where the measured values and simulation results are shown in the red points and green line, respectively. Among several possibilities of reproducing the measured results, we noticed that the degraded encircled energy could be caused by the surface figure error of the camera lens (1.0 μm RMS), which was measured by an interferometer as shown in Figure 4. The blue line in Figure 3 shows the simulation result with the surface figure error of the camera lens taken into account, demonstrating that the simulation indeed reproduces the measured results. Hence we plan to replace the camera lens and conduct the optical testing again.

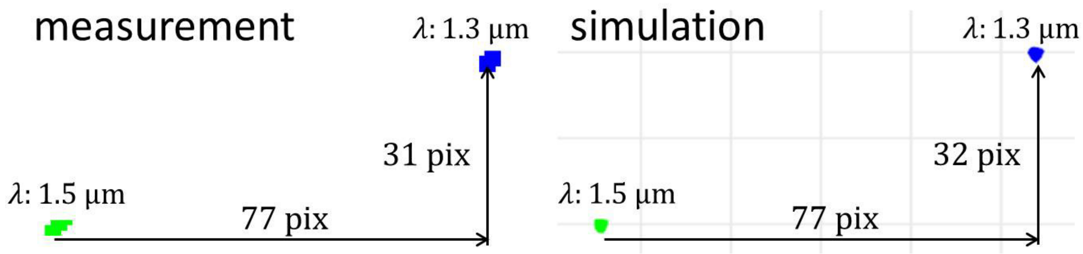

Figure 2. Measured and designed focus positions on the detector array at wavelengths of 1.3 μm (blue) and 1.5 μm (green). Arrows show the distances on the pixel scale.

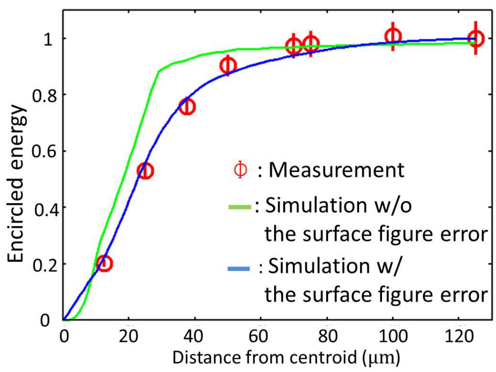

Figure 3. Encircled energies obtained by the optical testing and simulations. Red points show the measurement results, while blue and green lines show the simulation results with and without the surface figure error of the camera lens, respectively.

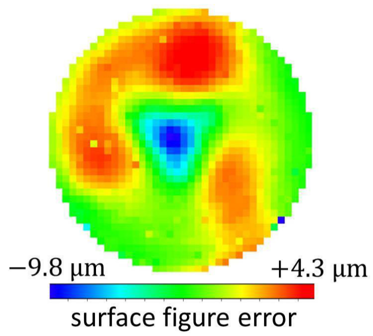

Figure 4. Measured surface figure error of the camera lens. Color bar shows the surface figure error in units of μm.

4. SYNERGY WITH *AKARI*

This spectrometer is useful for follow-up observations of the proto-planetary disks (PPDs) studied with *AKARI*. Tsuzuki et al. (2017, master thesis) have studied the spatial structures of PPDs in Taurus using the *AKARI* all-sky survey data. We expect that the probability of time variation depends on the disk structure. This spectrometer would detect temporal variations of spectra through precise estimation of the slit-loss correction factors with the slit viewer. Simultaneous monitoring of PPDs in the NIR and optical is a powerful tool to investigate the gas accretion and non-uniform dust distribution in PPDs which cause time variability.

5. SUMMARY

We are developing the new spectrometer for the IRSF telescope and performing optical testing of the NIR channel at the operating temperature of 100 K. As a result, we have confirmed that the measured focus positions at different wavelengths are consistent with the designed positions. However the measured encircled energy is degraded due to the surface figure error of the camera lens. We are now planning to replace the camera lens and conduct the optical testing again.

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