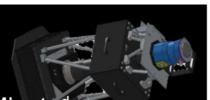
Development of Nayoro Optical Camera and Spectrograph for 1.6-m Pirka telescope of Hokkaido University



Hikaru Nakao[a], Makoto Watanabe[a], Kazuo Sorai[a], Mahiro Yamada[b], Yoichi itoh[c], Shigeyuki[d] Sako, Takashi Miyata[d]

[a]Department of Cosmosciences, Hokkaido University, Kita 10, Nishi 8, Kita-ku, Sapporo Hokkaido, 060-0810, Japan;
[b]Graduate School of Science, Kobe university, 1-1 Rokkodai, Nada, Kobe 657-8501, Japan;
[c]Nishi-Harima Astronomical Observatory, Center for Astronomy, University of Hyogo, 407-2 Nishigaichi, Sayo, Hyogo 679-5313, Japan;
[d]Institute of Astronomy, School of Science, the University of Tokyo, 2-21-1 Osawa, Mitaka, 181-0015 Tokyo, Japan

ABSTRACT

We have developed a visible imager and spectrograph, Nayoro Optical Camera and Spectrograph (NaCS), installed at the Nasmyth focus of the 1.6-m Pirka telescope of the Hokkaido University in Hokkaido, Japan. The optical and mechanical design is similar to that of WFGS2 of the University of Hawaii 2.2-m telescope (UH88), however the camera is newly designed. The spectral coverage is 380–970 nm. The SDSS (g′, r′, i′, z′) filters, Johnson (B, V) filters and a replica grism (R ~300 at 650 nm) are equipped. We selected a 2k×1k fully-depleted back-illuminated Hamamatsu CCD as a detector. The Kiso Array Controller (KAC) is used as a CCD controller. The first light observation was done on November 2011. We present the design, construction, and performance of this instrument.

INTRODUCTION

Long-term monitoring of active galactic nuclei (AGNs) is a way to investigate the spatially unresolved structure of AGNs. We built a visible imager and spectrograph for AGN monitoring. To resolve broad line profiles of AGN, requirement of spectroscopy is spectral resolution R≧300 (at 656 nm). To monitor the luminosity of AGN as compared with field star, requirement of a field of view is about 10 arcmin. Our main targets are the LINERs and the radio-loud AGNs with about r’≦15 mag.

Major specification

Table 1: Major specification of NaCS

Spectral coverage	**380 — 970 nm (Imaging), 435 — 820 nm (Spectroscopy)**
Field of view	**8.4 × 4.7 arcmin**
CCD	**Hamamatsu 2k × 1k (pixel scale : 0.247 arcsec pixel^{-1})**
Array format	**2048 × 1104 pixel (pixel size : 15 μm)**
Broad-band filters	**SDSS (g’,r’,i’,z’), Johnson (B,V)**
Order-cut filter	**GG435**
Replica grism	**300 gr mm^{-1}**
Spectral Resolution	**R ~ 300@656 nm (slit width = 3.0 arcsec)**
Size	**560 mm × 560 mm × 1130 mm**
Weight	**75 kg**

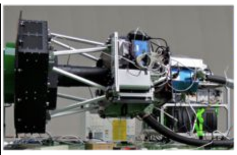


Figure 1: Picture of NaCS

Optics

We selected a similar optical design of WFGS2 because of

- Wide field of view (~10 arcmin)
- Wide spectral coverage (380 — 970 nm)
- Imaging mode and Spectroscopy mode can be swiched quickly.

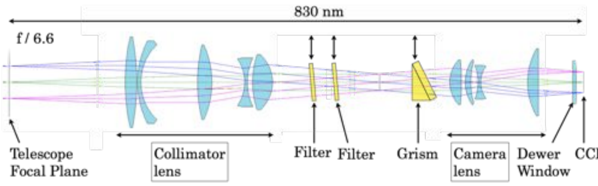


Figure 2: Optical layout of NaCS

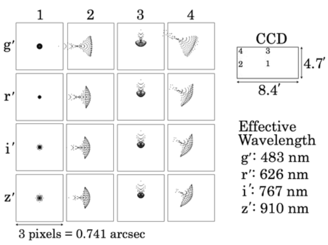


Figure 3: The spot diagram of NaCS (imaging mode). These diagrams are optimized for each band. These spot are within 1/3 of the typical seeing size (~1.8'') at the Nayoro Observatory.

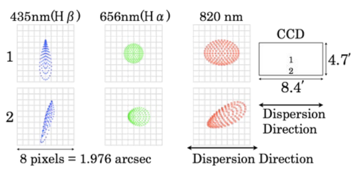


Figure 4: The spot diagram of NaCS (spectroscopic mode). These spots are within the typical seeing size at the Nayoro Observatory.

Mechanics

- To reduced the weight, a truss structure with a wheel box.
- Mounted on the Nasmyth instrument rotator.

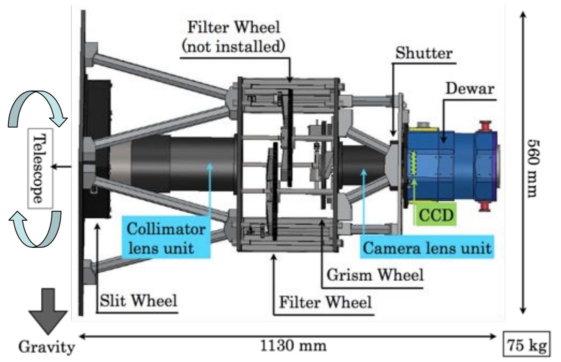


Figure 5: Mechanical layout of NaCS

CCD and readout system

2k×1k Hamamatsu CCD

- Same type of 2k×4k Hamamatsu CCDs used by HSC of Subaru telescope, but image area is a quarter of them.
- Fully-depleted back-illuminated CCD.
- High quantum efficiency (≧80%) over optical wavelength (440 — 920 nm).
- Four readout channels.
- 1104 ×512 pixels (with 15 μm-square pixel) + 48×512 extra pixels (with smaller size) per channel.

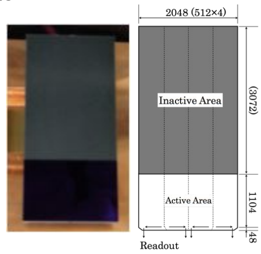


Figure 6: (left) Picture of 2k×1k CCD, (right) overview of 2k×1k CCD

Kiso Array Controller (KAC)

Figure 7: Picture of KAC of NaCS. The outside dimension is 160 mm ×100 mm.

- Designed for MIT CCDs and SITe CCDs with 16 readout channels originally
- Compact and low-cost readout system
- The analog circuit of KAC newly is designed for Hamamatsu CCD.

Table 2: readout time and readout noise of KAC

Number of sampling	Readout noise (e^{-1})	Readout time (s)		
		1×1	2×2	4×4
1	5.2	5.3	3.7	2.9
2	4.0	8.7	5.4	3.8
4	3.8	12	7.1	4.7

readout mode

- Multiply-sampling (readout reduces the readout noise by sampling each pixel multiply)
- 2×2 and 4×4 pixel binning

Performances and examples of observations

To observe several AGNs in a night, we confirmed that the total observation time per one AGN (r’=15 mag, S/N =100) is about 20 min (photometry) and about 90 min (spectroscopy).

Table 3: Limiting magnitude (S/N = 10) for broad-band imaging

	B	V	g′	r′	i′	z′
Effective wavelength (nm)	438	545	483	626	767	910
Effective bandwidth (nm)	94	87	138	138	154	137
Sky bightness (mag arcsec^{-2})	21.3	20.5	21.4	21.1	19.9	19.1
Overall efficiency	0.094	0.306	0.237	0.385	0.250	0.195
Limiting magnitude *						
t = 5 s	18.4	18.5	19.0	19.1	18.3	17.8
t = 60 s	20.3	20.1	20.8	20.8	19.9	19.3
t = 300 s	21.3	21.1	21.7	21.7	20.8	20.2

*4 arcsec diameter aperture and 2 arcsec seeing are assumed. Magnitude of B and V are Vega magnitude and of g’, r’, i’, and z’ are AB magnitude.

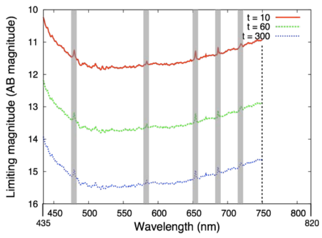


Figure 8: Limiting magnitude (S/N = 10) for slit spectroscopy (slit width = 3 arcsec). The gray regions cannot be used for estimate limiting magnitude.

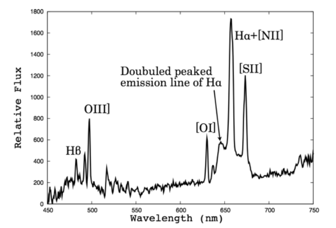


Figure 9: The observed spectrum of Arp102B with 3 arcsec slit width. The flux of [OI] emission line was normalized to 1000. The S/N @600 nm amounted to 80(exposure time is 75 min).

Figure 9: The pseudo-collar image of M88(g′: blue, r′: green, i′: red). The angular size of M88 is 7×4 arcsec. The whole galaxy is contained.

Conclusions

We have developed a visible imager and spectrograph, NaCS for long-term spectroscopic monitor of AGNs. We confirmed that NaCS has the performance required for AGN monitoring which observe several AGNs in a night. NaCS is also used for other astronomical observations such as pre-main-sequence stars, brown dwarfs, asteroids and galactic disks.