CISCO : A Cooled Infrared Spectrograph and Camera for OHS

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ABSTRACT

CISCO is an infrared camera and spectrograph based on a single 1024×1024 HgCdTe array detector (HAWAII), which has been developed as a back-end spectrograph of OHS (OH-airglow Suppressor). It is also designed to be mounted on the Cassegrain or Nasmyth focus directly as an independent instrument. In addition to the normal imaging and spectroscopy modes, CISCO has a slitless prism spectroscopy mode at resolving power of ∼30. This mode is primarily aimed at detecting the Hα emission line of forming galaxy at z=2.05–2.65. The development of CISCO is in near completion, showing results of test observations carried out using a 1.5m telescope.

Keywords: infrared, instrument, spectra, spectroscopy, imaging, infrared array

1. INTRODUCTION

We have been developing one of the near-infrared spectrograph for Subaru Telescope, OHS(**OH**-airglow **S**uppressor), which achieves highest sensitivity among the low to medium resolution infrared spectrographs for 8-10 m telescopes. OHS is capable of suppressing sky background emission by a factor of 20 to 40 in the J- and H- bands respectively with a special spectroscopic filter system. It is expected to extend the limiting magnitudes by about 1.5 to 2 mag.[1]

CISCO(**C**ooled **I**nfrared **S**pectrograph and **C**amera for **O**HS) is a back-end camera and spectrograph system for OHS, and it can also be mounted on the Cassegrain or Nasmyth focus serving as an independent general-use infrared camera/spectrograph. As one of the first instruments of the Subaru telescope, it will be utilized as a test observing system in the near-infrared. CISCO has following observing modes:

- Direct imaging
- Long-slit spectroscopy
- Slitless prism spectroscopy

The whole system of CISCO has already been assembled, and test observations using a 1.5m telescope are in progress to check its performance. After the last test observations which is scheduled in April 1998, CISCO is shipped to Subaru observatory on Mauna Kea.

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2. LAYOUT OF THE INSTRUMENT

2.1. Optics

Figure 1 shows a layout of optics. It consists of 9 lenses made of material of CaF_2, SiO_2 and MgO. All of the surfaces are spherical and anti-reflection coated. The transmittance per surface is 98 % and the overall throughput of the optics including a dewar window and a broad-band filter is estimated to be 56% at the K band.

An image of object is focused on the aperture with focal ratio of $f/12.2$(Cassegrain focus) or 13.6(Nasmyth focus). The first 4 lenses serves as a collimator, which produces a cold stop, where two filter wheels are located. The other lens system made of 5 lenses gives an image on the detector with $f/4.1$(Cassegrain) or 4.5(Nasmyth),where the pixel scale is $0.12''$/pix.

A 2-D slit assembly with two pairs of movable slit plates is furnished behind the entrance window. We can select the aperture of any slit size in the spectroscopic mode, or square aperture from full detector view ($2' \times 2'$ FOV) to pinhole size continuously. The two filter wheels are supposed to accommodate 7 filters/dispersing-elements as shown in Table 1.

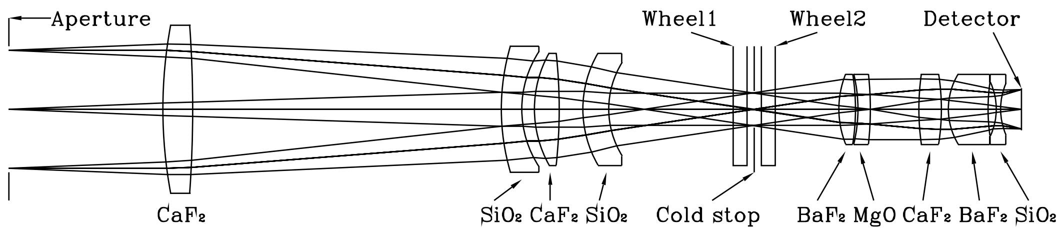

Figure 1. Optical layout of CISCO.

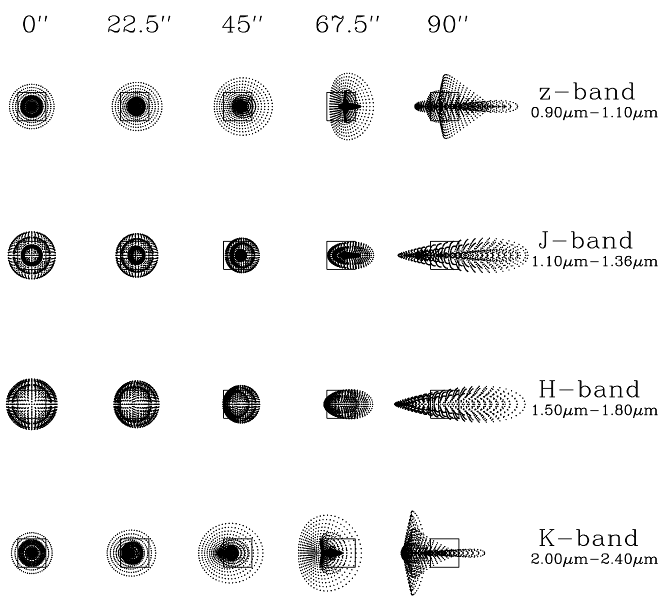

Figure 2. Spot diagrams of the optics. Small squares indicate the pixel size.

Wheel 1:	z, J, H, K′, K, two narrow-band filters
Wheel 2:	K grism, zJ grism, JH grism, prism, three narrow-band filters

Table 1. Filters, grisms and a prism stored in filter wheels.

CISCO has three operation modes. Any of the modes is selected from the workstation by setting the aperture, and by choosing a filter, grism or prism.

Direct Imaging

An image of $2' \times 2'$ FOV is acquired in this mode. Figure 2 shows the spot diagrams calculated for the fixed focus of telescope in the respective wavebands.

Although the image size elongates to about 4 pixels($0.5''$) in the corner of the detector, it is typically less than 1.5 pixels ($0.18''$) or smaller so that it is comparable to the expected stellar image size with the tip-tilt compensation.

Longslit Spectroscopy

3 grisms for the z&J, J&H and K bands, are used for long-slit spectroscopy mode. Resolving power are 300(z&J), 280(J&H) and 400(K) with slit width of $1''$ and higher resolution can be achieved with narrower widths. It is expected to achieve a $0.3''$ image size by the tip-tilt in the K band, and a resolving power of 1200 is achieved in this case.

Slitless Prism Spectroscopy

This is a unique observation mode aimed at detecting Hα emission line from star-forming galaxies in the redshift range of $z = 2.0 - 2.6$. A Zenger prism made of SiO_2 and BaF_2 gives resolving power of 30 at the K band when the image size is $0.3''$. The limiting magnitude is larger by only about 1 mag compared with direct imaging. It is estimated that with the 6 hours integration, the Hα line of $\sim 10^{-16}$ erg/s/cm^2 will be detected at S/N=5, which corresponds to the rest frame equivalent width of 100$\AA$ for a K$\sim$22 mag object.

2.2. Mechanics

The cryostat of CISCO, which was fabricated by Infrared Laboratories, Inc., is 400mm in diameter and 1370mm in length. The overall weight is 150kg together with two electronics boxes for array-readout and AD conversion. Figure 3 shows the schematic of the cross-section of the cryostat.

The optical system is mounted on a base plate which is enclosed by an aluminum "inner shield". The base plate is connected to a cold stage of a closed cycle cooler (CTI model 1020) at the bottom of the cryostat. A detector

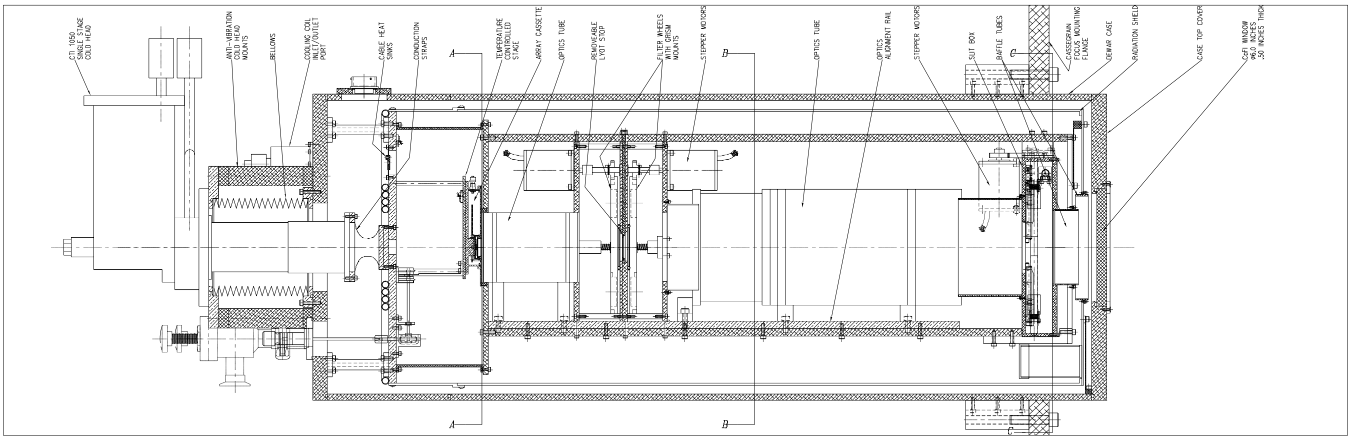

Figure 3. Schematic of the cross-section of the cryostat.

cassette on which a detector array is mounted is also supported on the cold stage, thermally insulated by pillars made of glass-epoxy. The cassette is connected to the stage by a copper wire for cooling, and a heater is equipped to control the detector temperature. This cold stage is cooled down to about 60K while the detector cassette is kept at higher temperature of about 77K. A copper tube circuit is fixed under the cold stage to accelerate cooling by flowing liquid nitrogen. It takes about 72 hours to cool the whole system to operating temperature without using this copper pipe. All these units are enclosed in an "outer shield" which keeps thermal radiation and heat leakage minimum.

Both slit mechanism and filter wheels are driven by cryogenics stepping motors made by Phytron Co.. These motors are controllable from a workstation via a RS-232C board on the VME rack (Figure 4). Four thermometers are furnished at the slit box, the filter mounts, the detector cassette, and the cold head. Each temperature is monitored by a Lakeshore 330 controller which also communicates with the workstation via the RS-232C board.

2.3. Array Readout Electronics and Data Acquisition

2.3.1. Detector Array and Readout Electronics

Two different types of 1024×1024 infrared array detectors are available today, one is HgCdTe "HAWAII" and the other is InSb "Aladdin". Because OHS reduces the natural background to a great extent and its detectivity is no more background-limited, small readout noise and low dark current are required for a detector to make use of the

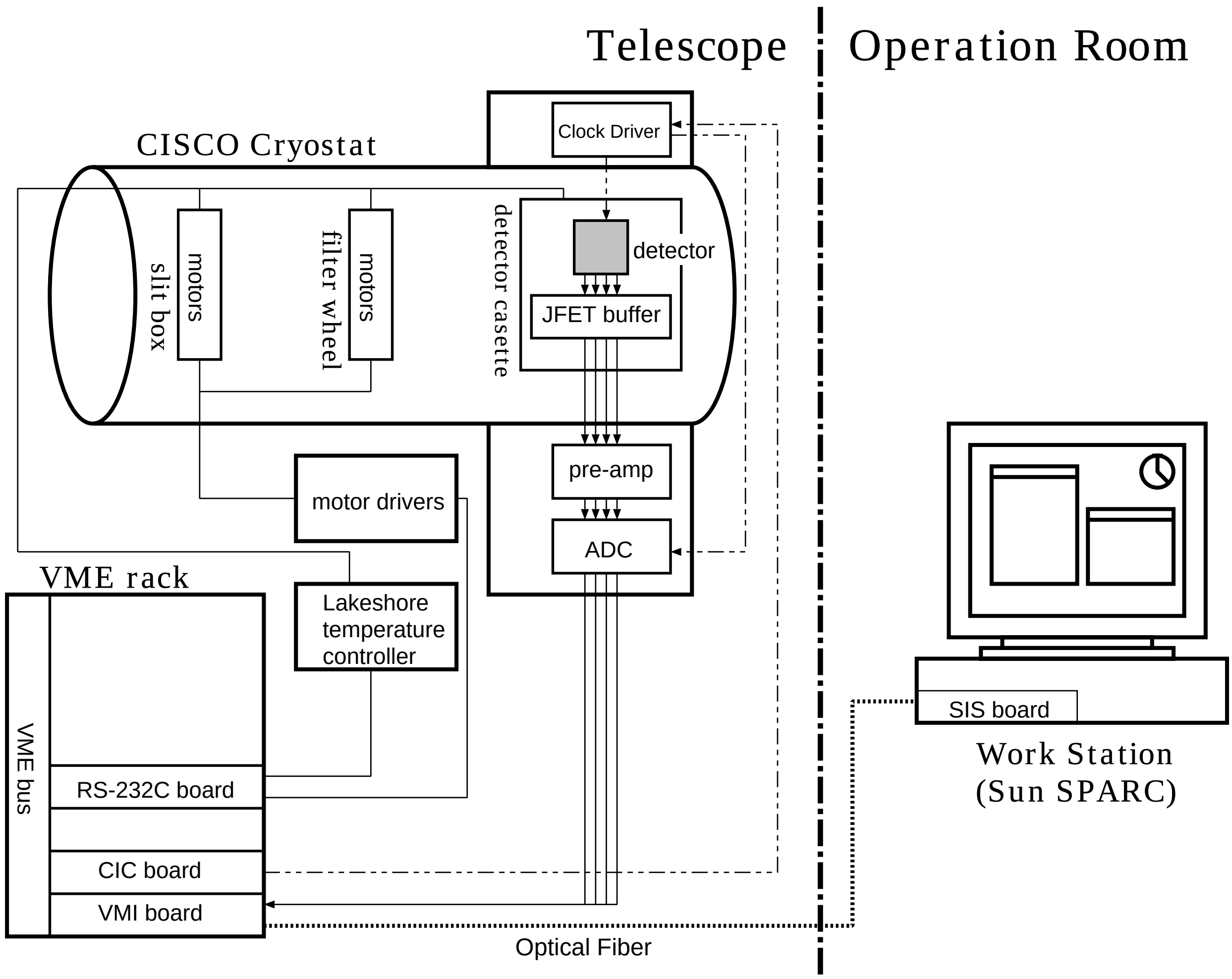

Figure 4. Block diagram of overall electronics of CISCO.

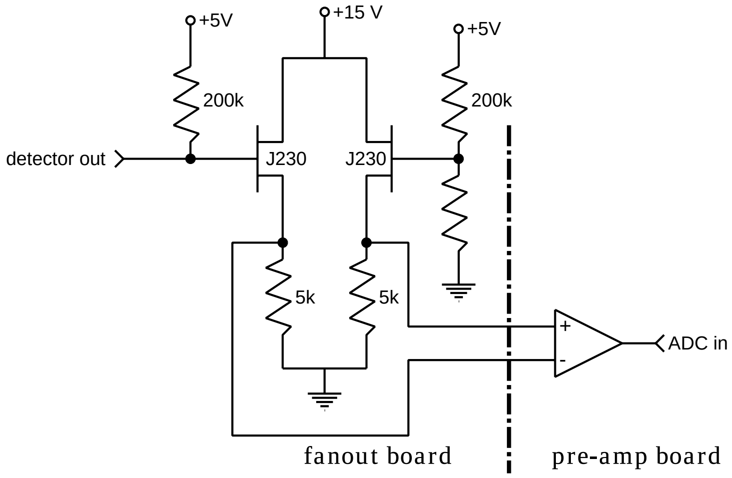

Figure 5. Schematic of a paired FETs amp on the detector fanout board.

full potential of OHS . In this context, we employed HAWAII in view of excellent features such as low dark current level($< 0.1e^-/s/pix$) and small readout noise($< 6e^-$r.m.s./pix/readout)[2] * .

The overall array readout system is illustrated in Figure 4. The multiplexer of HAWAII has four outputs which corresponds to four quadrants on the array. Each output has two pins; one is buffered by a built-in FET on the multiplexer and the other is unbuffered. Hodapp et al.(1996)[2] reported the strong glow of built-in FETs when they are activated, and so we chose unbuffered outputs. Each output is sent to paired JFETs on the fanout board inside the detector cassette, as illustrated in Figure5. The signals are then fed to amplifiers with a gain of 10.0, filtered by low-pass filters with a gain of 1.27 and a cutoff frequency of 1.25 MHz, and sent to 16-bit AD converters.

Clocks to drive the array and AD converters are generated at the CIC board on the VME rack and converted to C-MOS level(0–5V) clock by clock drivers. The pixel rate is currently set to 5.2μsec, which corresponds to the frame rate of 1.4sec. We employ a combination of clocks including dummy read sequence to secure stable image frames.It is also possible to readout a portion of the array with a high frame rate. For example, if we readout only 32 lines, the frame rate is 84 msec.

2.3.2. Data Acquisition

The data acquisition system is based on the VME subsystem called MESSIA III(**M**odulated **E**xpandable **S**y**S**tem for **I**mage **A**cquisition) developed by Sekiguchi et al..[3] It consists of clock generators(CIC board), frame memories(VMI board), interface with S-bus(SIF board), and a software package to control these boards with Tcl/Tk.

The digitized pixel data are first sent to the VMI board and stored in its two 16MB SIMM memories that can hold 12 raw frames. The data are then transferred to the memory on workstation via the fiber cable by Direct Memory Accessing(DMA). Because pixel data of four quadrants are sent out in parallel, the raw image data on memory is a mixture of four quadrants. We rearrange it to produce a final image in a FITS format. It takes about 2sec for data transfer and 12sec for rearrangement. However, the latter can be performed as a background process without taking extra time.

3. PERFORMANCE OF CISCO

Expected performance of CISCO is shown in Table 2.

Minimizing the readout noise of the electronics is essential to make use of the full potential of OHS. For example, limiting magnitude will become worse by 0.5 mag in the H band and by 1 mag in the J band if the readout

*Using 128 samples of multi-sampling.

noise increases from 10 to 30e^-r.m.s./pix/frame-read†. Laboratory tests have so far shown that the system gain of electronics is 3 ADU/e^- and that readout noise is 17 e^- r.m.s./pixel/frame-read for correlated double sampling. Using moderate(< 12) times of multi-sampling, we expect to reduce this noise to less than 10e^- r.m.s./pixel/frame-read.

	CISCO only	OHS+CISCO
Field of View	$2' \times 2'$	$20'' \times 20''$ (suppressed area: $1'' \times 20''$)
Pixel Scale	$0.12''$/pix	
Readout noise	$< 10e^-$/pix/readout (using multi-sampling)	
Resolving Power ($1''$ slit)	zJ : 300 JH : 280 K : 400	zJ : 300 JH : 280
Limiting Magnitude(H band) (3600sec, $0.6''\phi$, S/N=10)	22.7mag(imaging) 20.5mag(spectroscopy)	24.2mag (slit imaging) 22.0mag (spectroscopy)

Table 2. Expected performance of CISCO

4. TEST OBSERVATIONS

To demonstrate the performance of CISCO and also to check out both hardware and software systems,we have carried out test observations at the 1.5m "Infrared Simulator" telescope located in the campus of National Astronomical Observatory in Tokyo, Japan.

The first observing run was carried out from 17 to 27 of November, 1997 and the second run was from Jan 24 to February 2, 1998. Due to saturation of the background level, the short integration time is inevitable to get K$'$-band image frames and the typical exposure was 40 sec. When we took a frame of a QSO field by the total integration of 1600 sec(Figure 8), the efficiency of observation in terms of net exposure time relative to total observing time was ∼89%. It was found that readout noise increased to 45e^- r.m.s./pix/frame-read when mounted on the telescope. Major noise sources were,

- High frequency noise caused by the switching regulator-based power supply for cryogenic stepping motors.
- Line-induced noise picked up through flexure tubes of the closed-cycle cooler yielding a huge "ground loop" which also act as an antenna to receive electro-magnetic noise.

We are now planning to replace the power supply of a switching type by that of a dissipative type. It is also intended to put insulating couplers between the cold head and flexure tubes.

Figure 7 is the K$'$ band image of the QSO [HB89]1225+317 field, while Figure 8 is the slitless spectroscopic image of the same field. 1225+315 is a QSO at z=2.219 whose K magnitude is 13.4 mag,[4] with the Hα emission line in the middle of the K band. Its rest frame equivalent width is known to be 166$\mathring{A}$,[5] which is detected as shown in Figure 9.

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†500sec integration/frame, $1''$ slit, dark current=0.1e^-/sec/pix.

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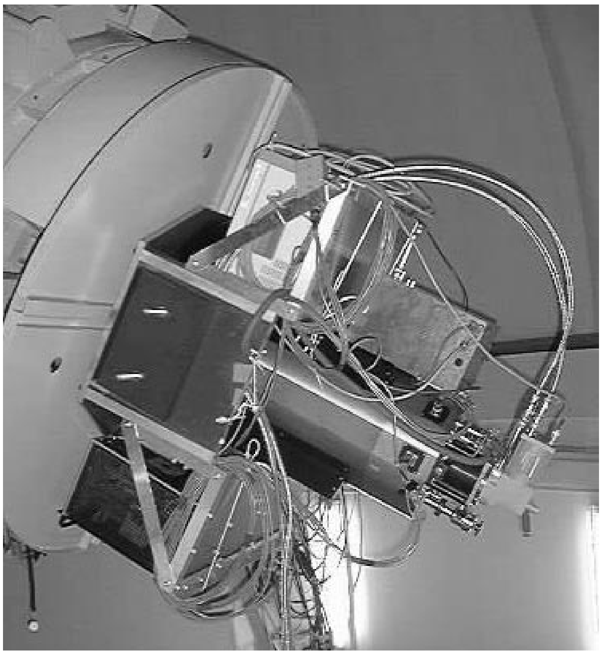

Figure 6. CISCO mounted on a Cassegrain focus of NAO 1.5m telescope.

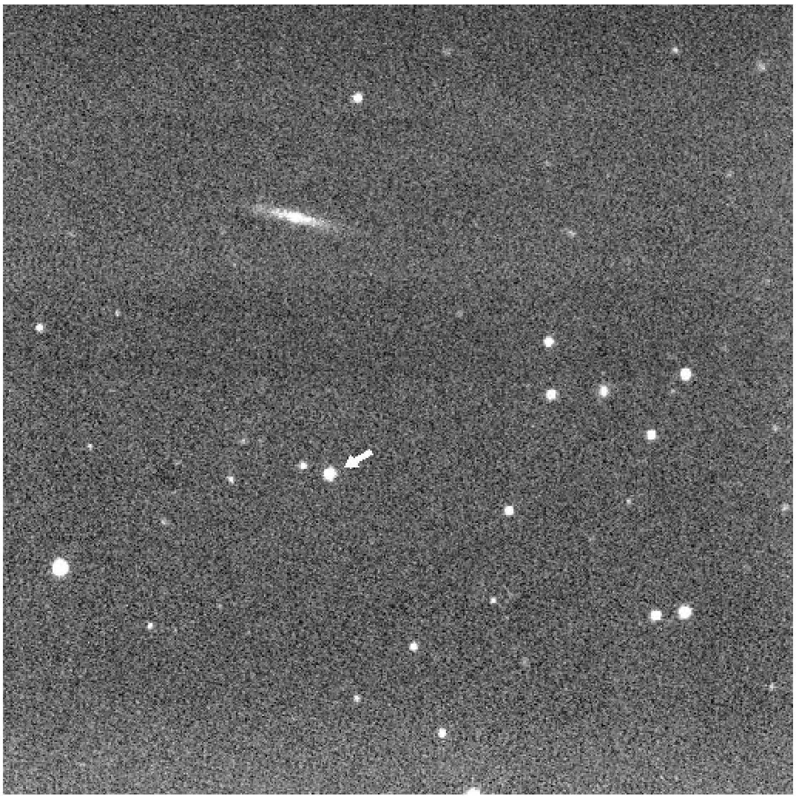

Figure 7. K$'$ band image of the field of [HB89]1225+317(arrowed). Integration time is 1600 sec.

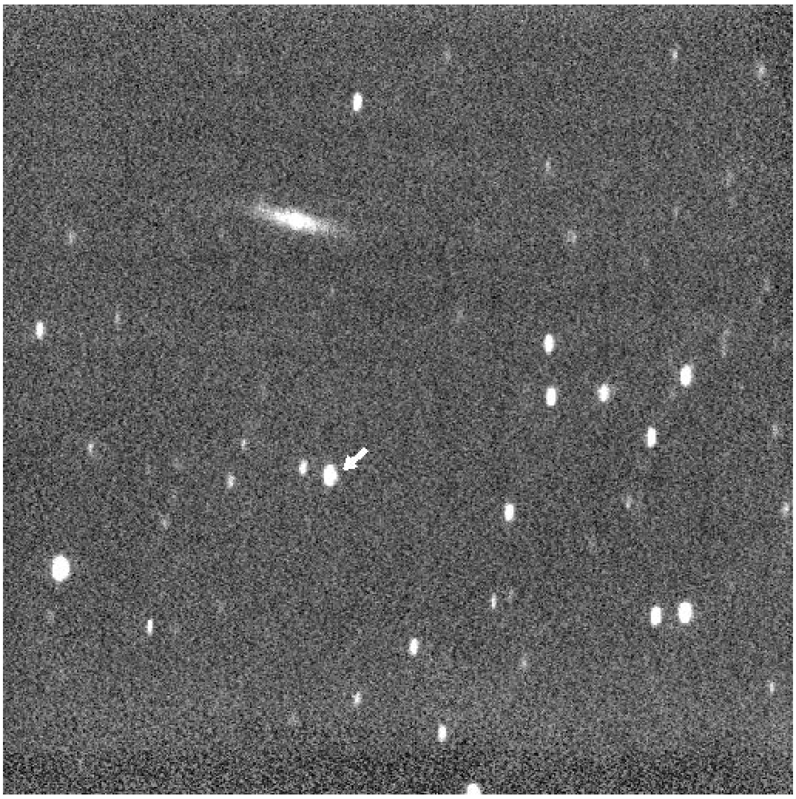

Figure 8. Slitless prism spectroscopy image of [HB89]1225+317(arrowed) at the K$'$ band. Integration time is 6400 sec.

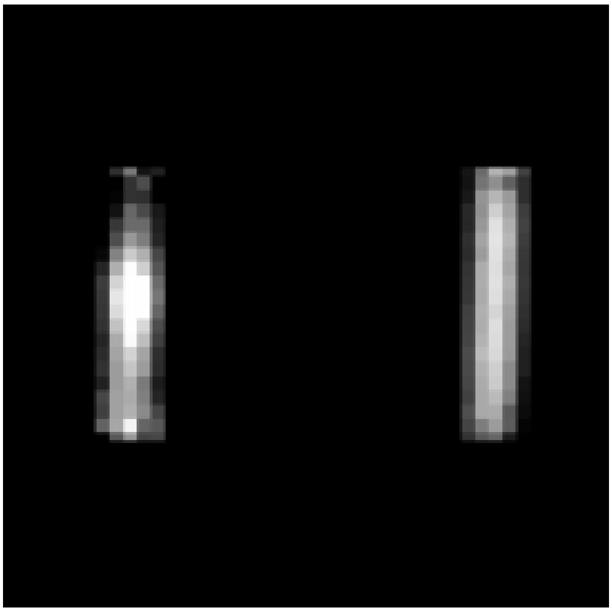

Figure 9. Spectrum images of QSO [HB89]1225+317(left) and the brightest star in the same field(right). Hα emission line is clearly seen.