Development of the Mid-Infrared High Dispersion Spectrograph (IRHS)

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High-dispersion infrared observations are useful for the definite identification of molecular species in the interstellar medium (ISM) by their vibration-rotation transitions. According to radio wavelength observations, molecular transitions in the ISM are Doppler-broadened, with line widths of 2~20 km/s in typical high-mass star forming regions and circumstellar envelopes of late type stars. Due to these broadenings, the wavelength resolving power R= $\lambda / \Delta \lambda$ =15,000~150,000 is required for sensitive detection of the spectra. In order to achieve such a high resolution in infrared region, Fourier transform spectroscopy (FTS) has usually been employed. In the mid-infrared region (8~13 μm), however, the dominant noise source is the background blackbody radiation, so multiplex property of FTS is no longer advantageous toward fainter astronomical sources.

Recently, we have developed the “mid-InfraRed High dispersion Spectrograph” (IRHS), a cryogenic échelle spectrometer designed for Nasmyth focus stage of NAOJ Subaru 8.2m telescope, which operates at 8-13 μm in wavelength with the resolving power $\lambda / \Delta \lambda$ of >50,000 at 10 μm. To reduce thermal radiation of the instrument, all optics of IRHS is arranged on the cold optical base plate (~30K) of the cryostat with the diameter of 80cm. In order to achieve high dispersion, broad bandwidth, and high sensitivity, two key devices are employed: a single crystal germanium immersion echelle grating (30×30×72mm) and a Si:As IBC (Impurity Band Conductor) focal plane array (FPA) detector (412×512 pixels, unit pixel size 30 μm) operated at 5 K[1]. The most important key device, germanium immersion échelle grating for collimated beam size of 28mmϕ was fabricated by utilizing ultra precision micro-grinding method coupled with “ELectrolytic In-process Dressing” (ELID) technique[2]. The immersion grating has 600 μm groove spacing with a 68.75° blaze angle. It is used in very high order, ranging from 332 at 13.5 μm to 597 at 7.5 μm. In order to separate the échelle orders by ~10 pixels on the Si:As array detector, the cross-disperser wheel employs two first-order echelette gratings: a 100 grooves/mm with a 26.7° blaze angle for short wavelength (7.5–10 μm) and a 61.97 grooves/mm with a 18.1° blaze angle for long (10–13.5 μm). The spectral coverage is typically λ/15, which includes 32–56 échelle orders, depending on wavelength. Eight cross-disperser position angles give full continuous coverage throughout 7.5–13.5 μm.

The optics on the spectrometer was aligned by using an attenuated CO_2 laser as a light source. In the alignment procedures at room temperature condition, an infrared bolometer camera was replaced with the Si:As IBC FPA detector. Since the CO_2 laser was operated in multi-mode oscillation, simultaneous observation by using the FT-IR spectrometer (BioRad FTS-6000) was necessary to assign the laser transitions. After the alignment, placing Si:As IBC array back to the original position, we examined the sensitivity tests of IRHS by recording the blackbody radiation around the 10.6 μm wavelength region at the room temperature (~300 K). It took approximately 3 seconds to saturate the Si:As IBC detector, which is well compared with our design specification and the full-well capacity of the detector. For the check of the wavelength resolution, we observed the spacially diffracted light from the CO_2 laser source by the #3000 sandpaper. Figure 1 shows the échelle image thus obtained of IRHS in the region of 904 – 967 cm^{-1} (10.3-11.1 μm in wavelength). The HWHM linewidth for the most faintly observed P(20) laser transition to 0.018 cm^{-1}, assuming that one pixel corresponds to 0.0052 cm^{-1}. The currently derived resolving power, ~50,000, is in an excellent agreement with a design specification of our spectrograph.

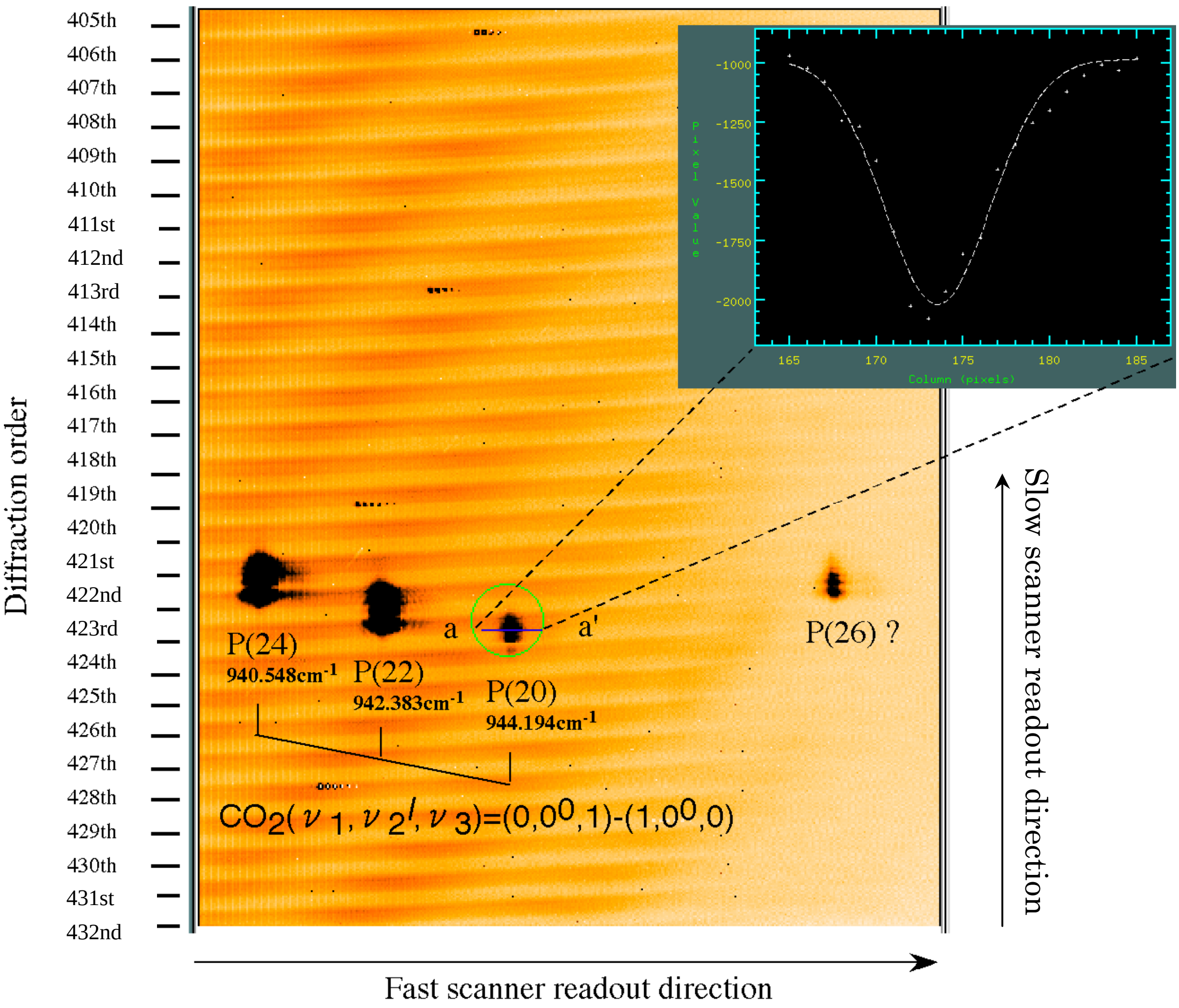

Figure 1: The first échelle image of IRHS for the the CO_2 laser, taken with Si:As IBC 512 x 412 FPA detector cooled to 5.7K. The exposure time for each pixel is uniformly 0.17 second. The abscissa for the image (412 pixels) represents direction for the fast scanner readout of the detector. The ordinate for the image (512 pixels) represents the direction for slow scanner readout, and that for dispersion for the cross-disperser. Diffraction orders for the Ge immersion grating separated by the cross-disperser are also shown. The assignments for the dark spots for the CO_2 laser are shown on the image. The background stripes are due to the thermal emission on the room temperature. Note that the laser spots except for P(20) and probably P(26) are heavily saturated and the spot sizes for the laser lines are significantly larger than the intrinsic resolution of the spectrograph, since the laser power during the measurement is stiil very high.

References

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