First light observation of GIGMICS

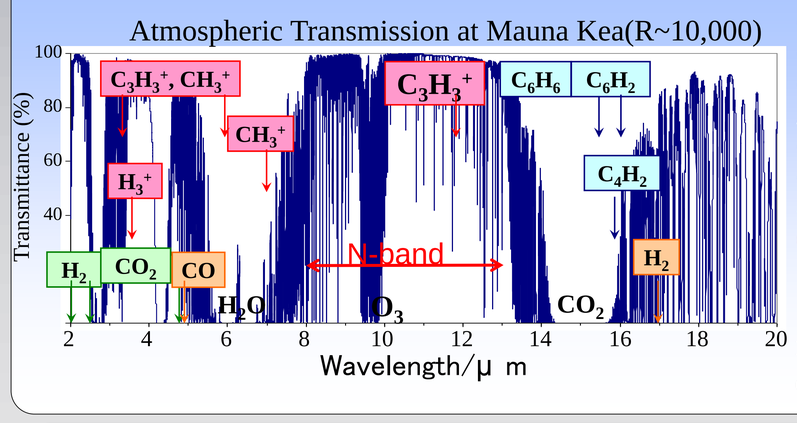
(Germanium Immersion Grating Mid-Infrared Cryogenic Spectrograph)

by Kanata 1.5-m telescope at Higashi-Hiroshima Observatory

Yasuhiro HIRAHARA (Nagoya University), *yasu@nagoya-u.jp,* & GIGMICS team:
Yoshio TATAMITANI, Keishin AOKI, Kanako OTA, Sho SHIBATA,
Tsuyoshi HIRAO, Noboru EBIZUKA(Nagoya University)
Michitoshi YOSHIDA, Koji KAWABATA, Makoto UEMURA, Takashi OOSUGI(Hiroshima Univ.)
Ryuji FUJIMORI, Hiroki OHIWA, Hisayuki NAGAHIRO, Kentarou KAWAGUCHI(OkayamaUniv.)

Abstract: We have developed a germanium immersion grating mid-infrared cryogenic spectrograph (GIGMICS) designed for the Nasmyth focus stage of NAOJ Subaru 8.2-m telescope, which operates at N-band (8-13 μm) in wavelength (λ) with maximum resolving power R(≡λ/Δλ) ~ 50,000. A single crystal germanium echelle immersion grating (30 × 30 × 72 mm) for collimated beam size of 28 mmφ was fabricated by utilizing ultra precision micro-grinding method coupled with the ELID (ELectrolytic In-process Dressing) technique (Ohmori, H. 1992, Ebizuka et al. 2003). After the critical test for the application to the laboratory gas-phase IR high-resolution spectroscopy(Hirahara et al. 2010), we have conducted the "first light" astronomical observation of GIGMICS by the Kanata 1.5-m telescope at Higashi-Hiroshima Observatory from Jan. to Apr., 2011. Toward many astronomical objects such as the Moon, Venus, Jupiter, circumstellar envelopes of late-type stars, proto-planetary nebulae, and interstellar molecular clouds in the vicinity of star-forming regions, we conducted spectroscopic observations in the N-band region.

I: Scientific Objective



Importance of Mid-IR High-resolution Observations

Chemistry:
- All molecules have vibrational transitions, especially for "non-polar" molecules & ions.
- Mid-IR region is a "Fingerprint Region" for Organic Compounds.
- High-resolution ro-vibration spectra make definite identification for gas phase species.

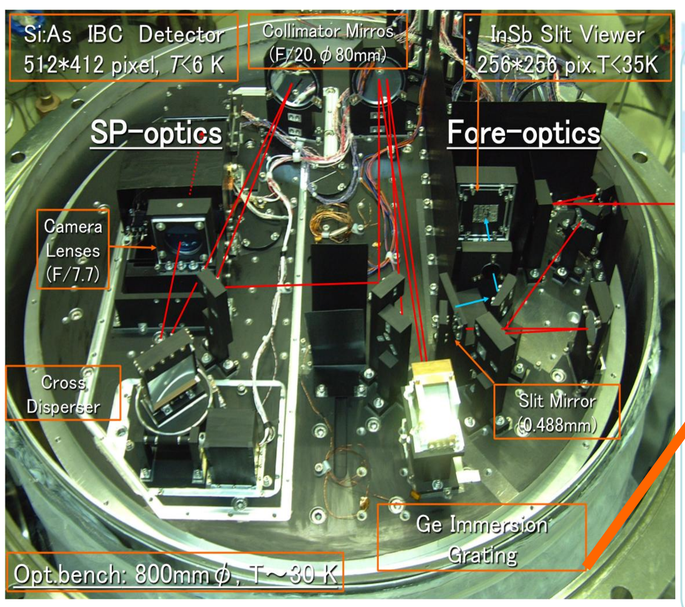
Astronomy:
- N-band is an "open window" to the atmosphere.
- High-resolution observations of interstellar molecules give information for kinematics.

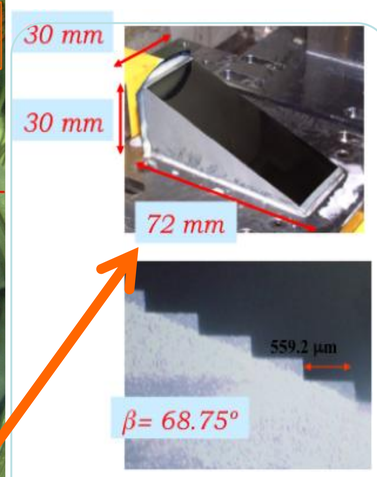
→So far, Only ∽30 molecular species have been identified in IR
Cf: In the radio wavelength region, >140 species identified.

↓

This study: A breakthrough for* the development of high-sensitive and high-resolution spectrometer for the N-band, especially *for the detailed line survey observations, searching for the new interstellar molecules.

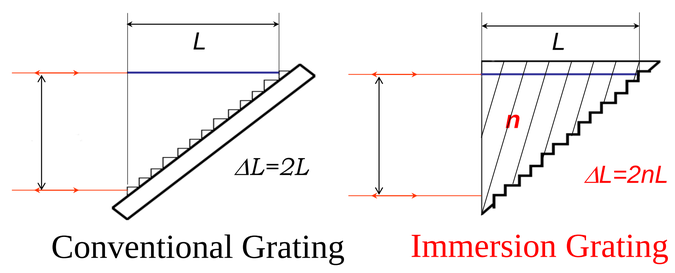
II: Development of GIGMICS





- Surface Roughness:11.5 nm rms
- decrease of *R* by wavefront error: 73 % => real R~38,000

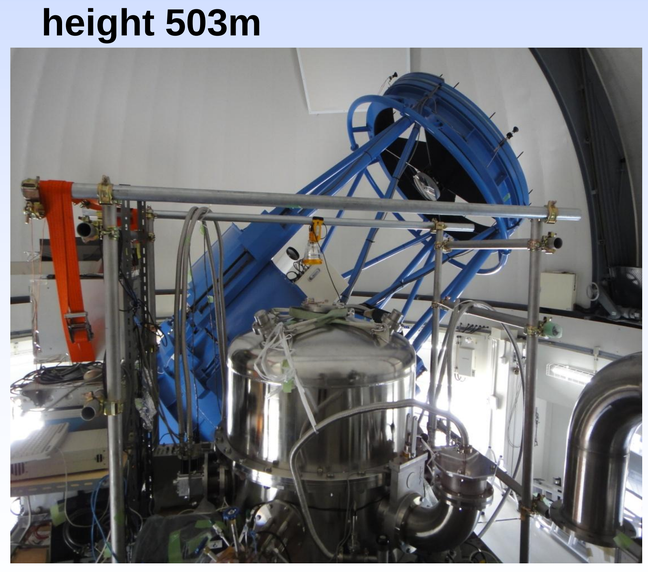
"Key device" : Immersion Grating: is ---
- Diffraction grating with refractive index n>1 material in the optical path.
- Because of the large optical path difference, the size of the spectrograph can be effectively reduced by 1/n for the same $R=\lambda/\Delta\lambda=\Delta L/\lambda$



This study: First fabrication of Germanium* (*n*=4.0) *Immersion Grating by RIKEN's ELID (ELectrolytic In process Dressing) Micro-machining Method (Ebizuka et al., 2003).

III: First Light Observation

"Kanata": "Higashi-Hiroshima Observatory, Hiroshima Astrophysical Science Center Hiroshima University 1.5-m telescope
=Subaru IR Simulator of NAOJ.
height 503m

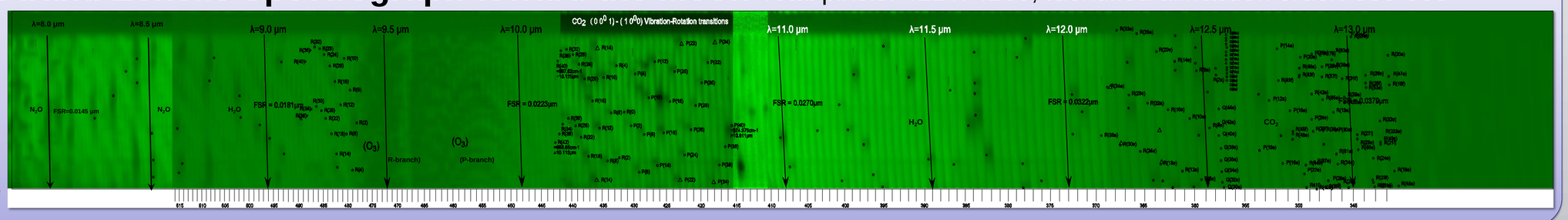


GIGMIGS on Nasmyth Stage of "Kanata"
Jan-Apr of 2011

IV: Result: (I) Full N-band Echelle Spectrograph toward the Moon

Total pixels: 412 x 4260, Identified diffraction order: 330-565

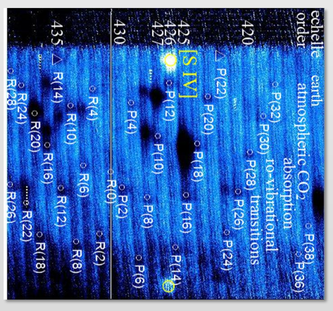
Observation
- Date: Apr. 4, 9, 10, 13,14, 16 2011
- Method: ON/OFF
- Integration time: <50secs.
- Mosaics of 8 echellegrams
- In total, 377 telluric lines are assigned to CO_2, H_2O, O_3, and N_2O
- Definite assignment of diffraction order



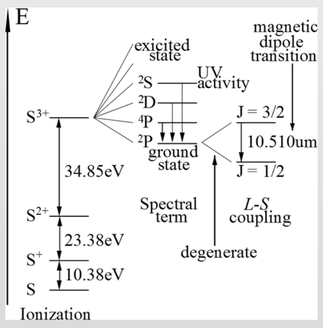
V: Result: (II) Mapping observation of [S IV] in NGC7027

The planetary nebula NGC7027 is one of the most famous stellar object. It has HII region near the central star, and also expanding molecular cloud in the outer envelope. The [S IV] emission is detected by the ISO SWS observation.

Observation
- Date: Apr. 5,13,17 2011
- Method: ON/OFF
- Integration time: 1 min.
- Position: center + outer 14 points
- Spatial resolution: 0.612arcsec



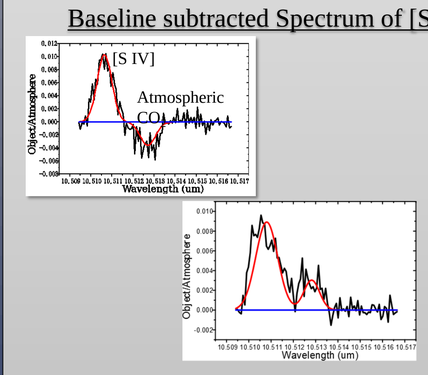
➢Detection of [S IV] on the echellegram



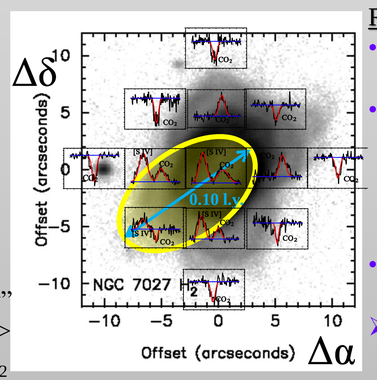
➢Energy level diagram of Sulfur

Detection of strong **[S IV] forbidden emission line ($^2P_{3/2}$→$^2P_{1/2}$: M1)** originated from HII region of NGC7027.

Baseline subtracted Spectrum of [S IV]



Severe effect of time variation of "Sky" for the N-band in the observatory site =>
- "Psudo-emission" of the telluric CO_2
- Irregular intensity: line vs. thermal Background component



➢Spatial distribution of [S IV]

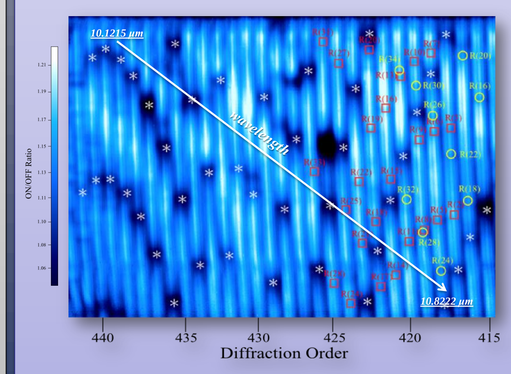
Result
- [S IV] is **spread about 0.10 light years in the southwestern area** of NGC7027.
- The observed wavelength of [S IV]: λ_{center}=**10.51185 (23)μm** (V_{rad}=23km/s), $\Delta\lambda_{HPFW}$=0.001μm
  cf. previous study of [S IV]: R=2,000 (ISO SWS: Bernard-Salas, et al 2001)
- Rest wavelength of [S IV] in laboratory: λ_{lab}=10.5105(1) μm

➢ **V_{LSR} ~ 38km/sec for [S VI], which is comparable to the red-robe outflow for CO_2 (Nakashima et al. 2010)**

VI: Result: (III) Detection of new CO_2 transition in Venus

Venus, the second planet of the solar system, is similar to Earth in terms of size and mass. However, the atmospheric composition and the structure are significantly different. Above all, the atmosphere of Venus is composed dominantly of CO_2.

Observation
- Date: Apr. 2, 6, 10, 13 2011
- LST : AM 5:30 ~ 6:00
- Wavelength: 8.0 ~ 10.8 μm
- Integration time: 200 seconds
- Point : center of Venus

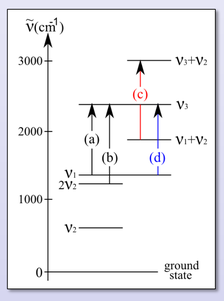


➢Echellegram of Venusian atmosphere at 10.1~10.8 μm
∗ : $^{12}CO_2$ $\nu_3 \leftarrow \nu_1$, □: $^{12}CO_2$ $(\nu_3+\nu_2) \leftarrow (\nu_1+\nu_2)$
○: $^{13}CO_2$ $\nu_3 \leftarrow \nu_1$

CO_2 vibrational-rotational transitions
Spectra detected from Earth and Venus
(a) $^{12}CO_2$ $\nu_3 \leftarrow \nu_1$
(b) $^{12}CO_2$ $\nu_3 \leftarrow 2\nu_2$

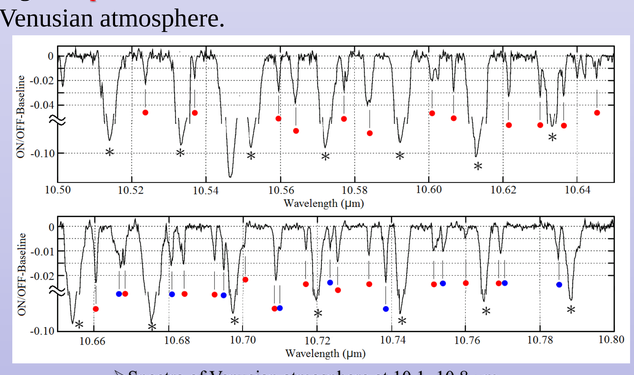
- detected from Venus solely
(c) $^{12}CO_2$ $(\nu_3+\nu_2) \leftarrow (\nu_1+\nu_2)$
(d) $^{13}CO_2$ $\nu_3 \leftarrow \nu_1$

First detection of 11 lines !



➢Vibrational Energy Level Diagram of CO_2

Detection of (c), (d) transitions reflects high temperature and CO_2 abundance of Venusian atmosphere.



➢Spectra of Venusian atmosphere at 10.1~10.8 μm

Parameters
- Doppler shift : $\Delta\lambda=(5.7\pm1.5)\times10^{-4}$ μm
  (Systemic Velocity = 16±4.2 km/s)
- Rotational temperature
  (c) $^{12}CO_2$ $(\nu_3+\nu_2) \leftarrow (\nu_1+\nu_2)$: 292±22 K
  (d) $^{13}CO_2$ $\nu_3 \leftarrow \nu_1$: 373±69 K