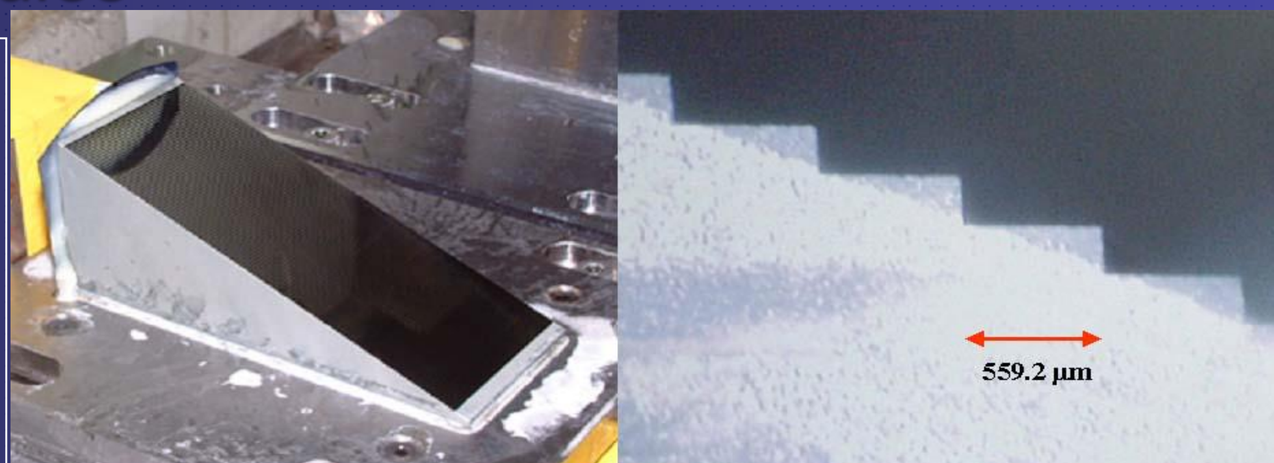
中間赤外線高分散分光観測装置の開発

GIGMICS(Germanium Immersion Grating Mid-Infrared Cryogenic Spectrograph)

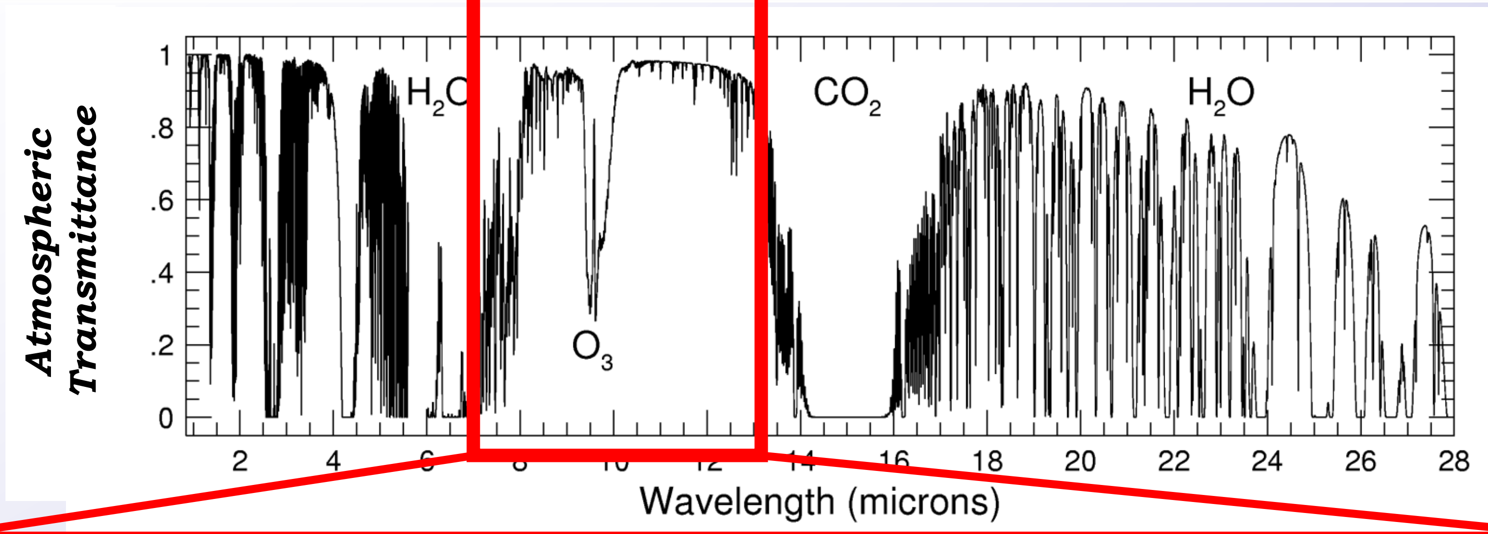
Wide coverage: 7.5<λ<13.5um, High dispersion: R～40,000, Designed for line survey and search for interstellar molecules

echelle grating
groove interval : 0.6 mm
blaze angle : 68.75 deg.
order : 344 – 560 th
size : 30 × 30 × 72 mm
Surface roughness: ~3nm



名古屋大学環境学研究科/地球惑星科学教室
平原　靖大

Spectroscopic observation in the Astronomical "N-Band" : 8~13 μm



- "All molecules have Vibrational transition": $n = \frac{1}{2p}\sqrt{k/m}$
- <u>Fingerprint region（指紋領域）for Organic molecules</u>

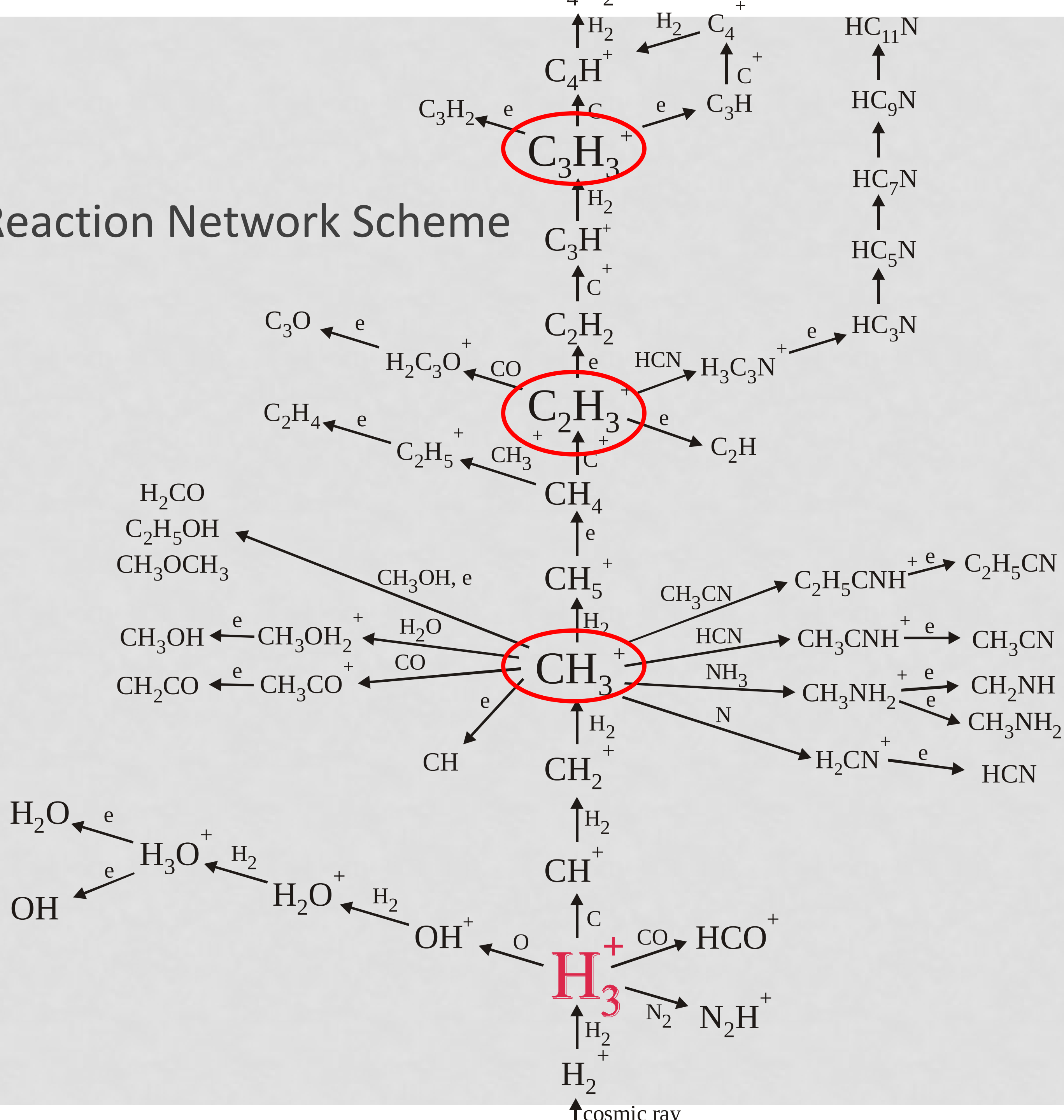
  e.g. streching of C-C C-O C-N, Bending of C-C-C

- vibration-rotation transitions of Methane, Ethane, Ammonia, N_2O, O_3, SO_2, H_2O, CO_2, SO_2, H_2S, NOx, Halogen Oxides, etc.

High dispersion: R>30,000→Vib.Rot. Transitions resolvable for various "tri-atomic" molecules: $C_nH_m^{(+,-)}$

==Key species in Astrochemistry

Chemical Reaction Network Scheme In ISM



Interstellar Molecules Detected in IR Only(≒Nonpolar)

○Simple Hydrides, inorganic species：

H_2, HF, HCl, H_2O, NH_3, C_2, O_2, CH_4, CO, CO_2, N_2O, H_2S, CS, SO_2, OCS, SiH_4, SiO, SiS, NaCl, KCl, AlCl, AlF, PN, HCP

○molecules in cyclic (AROMATIC) form：

c-C_3H, c-C_3H_2, c-$(CH_2)_2O$, c-C_3H_2O(cycloprpenone), C_6H_6 (benzene), c- SiC_2, c- SiC_3, C_{60}, C_{70} (Spitzer)

○"Cyanopollynes, polyacetylenes and related "LINEAR Carbon chains"：

C_3, C_5, C_3O, C_3S, C_3O, C_3S, H_2C_3, H_2C_4, H_2C_6, C_2H_2, HC_4H(diacetylene）, HC_6H(triacetylene), C_2H_4, C_4Si, HCN, HNC, HC_3N, HNCCC, HCCNC, HC_5N, HC_7N, HC_9N, $HC_{11}N$, CH_3CN, CH_3NC, CH_3CH_2CN, CH_3C_3N, CH_3C_5N, CH_3CCH, CH_3C_4H, CH_3C_6H, C_2H_5CN, C_2H_3CN, C_2H_5CN

○Ions：

H_3^+, CH+(OPT), CO^+, SO^+, CF^+, HCO^+, HOC^+, HN_2^+, HCS^+, H_3O^+, H_2COH^+, $HOCO^+$, $HCNH^+$, HC_3NH^+, C_4H^-, C_6H^-, C_8H^-, C_3N^-, C_5N^-, H_2O^+, H_3O^+, OH^+, SH^+, H_2Cl^+(Herschel)

○Radicals：

CH, CH_2, CH_3, OH, NH, NH_2, SH, HNO, SO, NS, NO, SiC, SiN, NaCN, MgCN, MgNC, AlNC, SiCN, SiNC, NH_2CH, HCO, CCH, C_3H, C_4H, C_5H, C_6H, C_7H, C_8H, CN, C_3N, C_5N,

H_2CN, HCCN, HC_4N, CH_2CN, CCO, CCS, CP, PO

○Aldehydes, Alchoholes, Ethers, Ketons, Amides and related species(<u>"Pre-Biotic" molecules</u>)：H_2CO, H_2CS, CH_3CHO, HNCO, HNCS, NH_2CHO, HC_2CHO, CH_2OHCHO, CH_3OH, C_2H_5OH, CH_2CHOH, CH_3SH, $(CH_3)_2O$, $(CH_3)_2CO$, HCOOH, $HCOOCH_3$, CH_3COOH, H_2CCO, CH_2CCHCN, CH_2NH, CH_3NH_2, NH_2CN, CH_3CONH_2

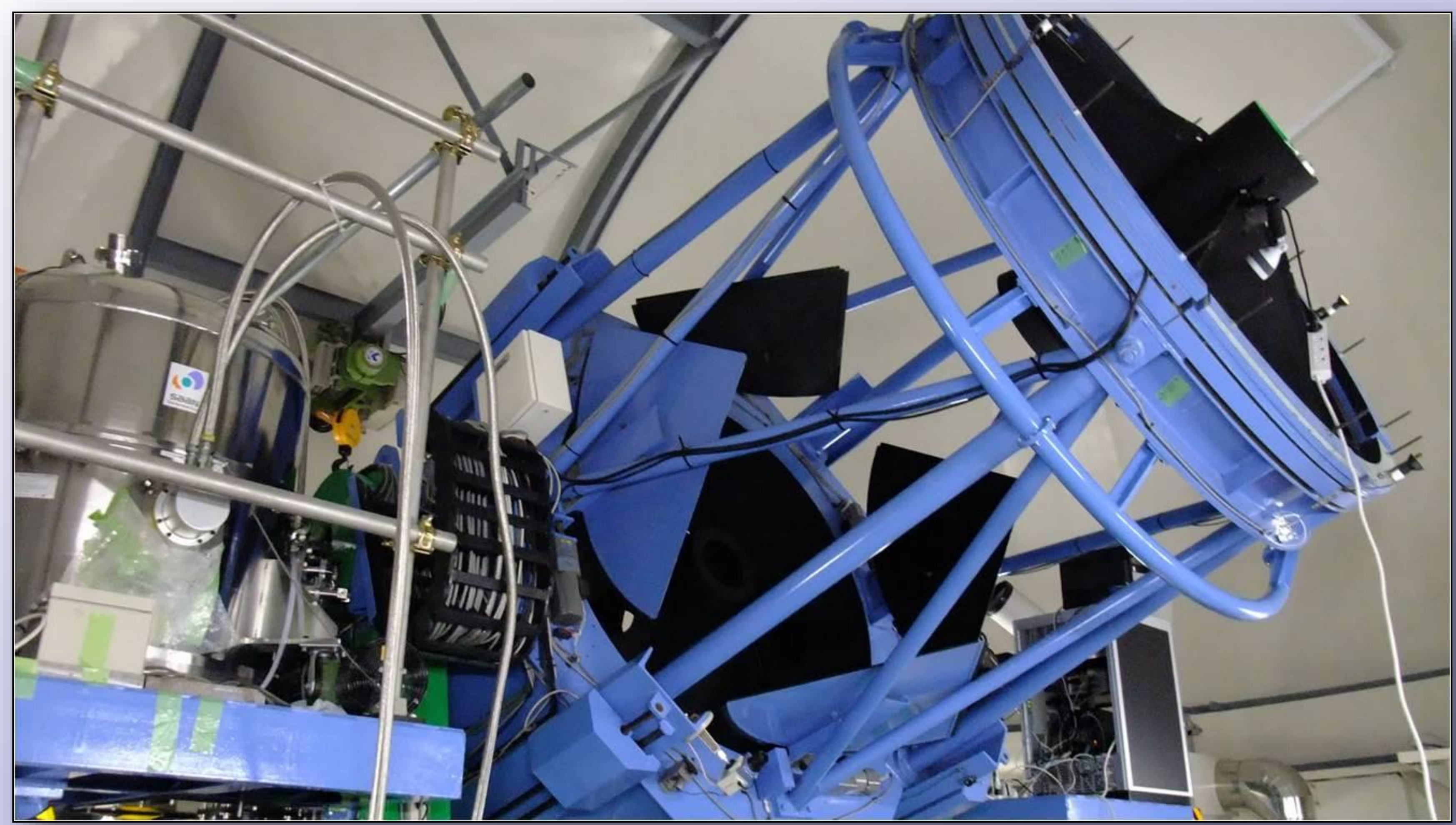
Few IR "line survey" in IR, "No" laboratory IR data

The Mid-Infrared bands toward the new detection by GIGMICS/SUBARU

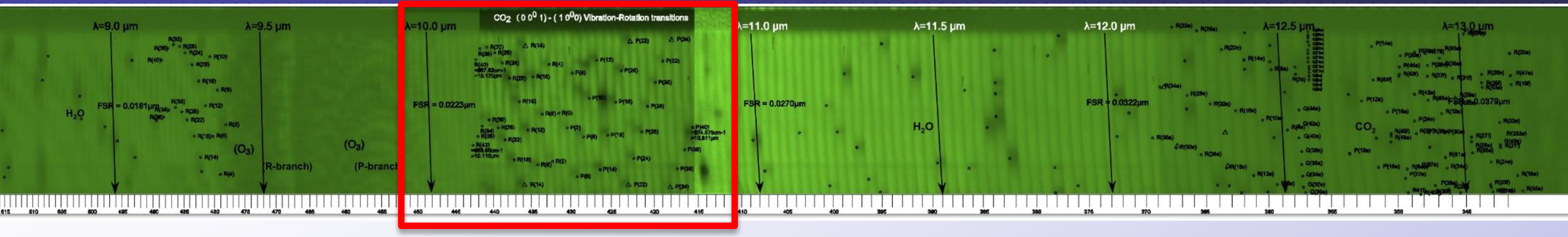
Species (electronic state)	Vibration Mode	Transition frequency (cm^{-1})		
		ab initio calculation	Matrix spectrum	Gas-phase spectrum
CH_3^+	ν_1	2942[)]		–no data–
	ν_2	1377[67)]		–no data–
	ν_3	3090[)], 3108[67)]		3108[)]
	ν_4	1387[67)]		–no data–
$C_2H_2^+(^2\Pi_u)$	ν_3	3340 [)]		3136[)] (IR difference Laser spectroscopy)
	ν_4	741[70)]		754[71),)] (Laser Induced Reaction+ion trap)
$C_2H_3^+$	ν_6	3159[)]		3136, 3142[)] (IR difference Laser spectroscopy)
(Non-classical)	ν_2	2456[73)]		2217[)] (IR laser photodissociation spectroscopy)
	ν_9	845[73)]		–no data–
linear–$C_3H(^2\Pi)$	ν_3	1151[)]	1159.8[76)]	–no data–
cyclic–$C_3H(^2B_1)$	ν_3	1332[76)]		–no data–
	ν_4	940[76)]		–no data–
linear–C_3H_2	ν_4, ν_5	1051, 1080[)]	1003, 999.2[)]	–no data–
cyclic–C_3H_2	ν_3	1316[)]	1279[78)]	1277[)] (FTIR absorption spectroscopy)
	ν_4	913[79)]	886[78)]	–no data–
	ν_6	798[79)]	788[78)]	776[79)] (FTIR absorption spectroscopy)
	ν_8	1089[79)]	1062[78)]	–no data–
cyclic-$C_3H_3^+$	ν_4	3206[)]	3130.4[)]	3182[81)] (IR laser photodissociation spectroscopy)
	ν_5	1315, 1318[81)]	1276[)]	1293[81)] (IR laser photodissociation spectroscopy)
	ν_6	939[81)]	908[83)]	–no data¬–
$HCCCH_2^+$	$\nu_{6(1)}$	1127[81)]		1111[81)] (IR laser photodissociation spectroscopy)
	$\nu_{6(2)}$	1150[81)]		1222[81)] (IR laser photodissociation spectroscopy)
linear–$C_2N(^2\Pi)$	ν_3		1066[)]	1046[)] (FTIR emission spectroscopy)
linear–NCO^-	ν_1	1130[)]		1210[)] (IR Laser spectroscopy, by hot band)
	ν_3		2156[)]	2182, 2124[87)] (IR Laser spectroscopy, by hot band)

2011:First Light Observation of GIGMICS

Kanata 1.5-m telescope at HASC, Hiroshima Univ., Altitude: 503m
=“Subaru simulator” at Mitaka, NAOJ, until 2005
2011: Jan-Apr, Target: Moon, Proto-Planetary Nebula, and Venus, etc.



GIGMICS with KANATA: 8-13 μm Echellegram toward the moon



- 412×4260 mosaic image, Diffration order 420<m<520

Ref: Grating equation: $m\lambda$ = “n”×d[sin(β) + sin(γ)]

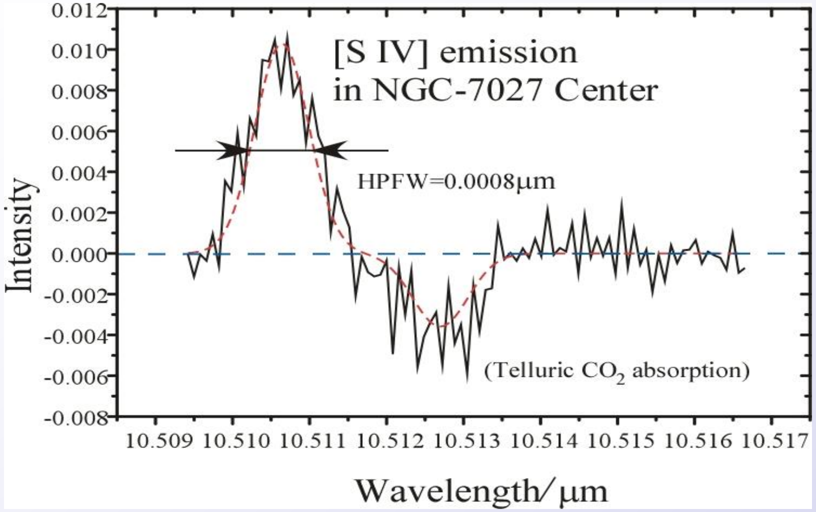
- Assignment of the absorption “spot” by the HITRAN database
- →vibration-rotation transition for
- CO_2:167、H_2O 107、O_3 78、N_2O 78 lines, 377 in total.
- Least squares fit :$\lambda_i=\lambda_i(m, x)$

$$x_{obs} = -Xc + \frac{192.0}{0.03}\tan\left[\arcsin\left[n\sin\left\{\arcsin\left(\frac{m\lambda_{obs}}{n} - \sin\alpha\right) - \alpha\right\}\right]\right]$$

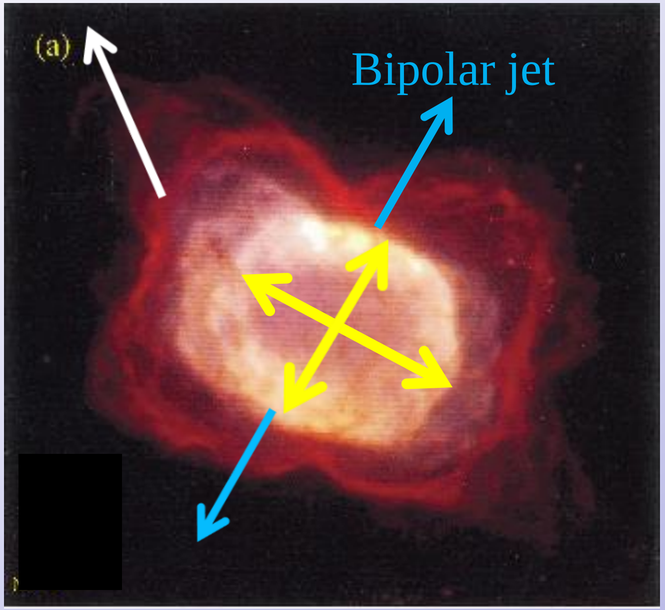
→fitting rediuals (σ) : 3.96 pixel

Definite assignment of m → daviated +1

初期成果I:惑星状星雲NGC7027での[S IV]輝線のマッピング (M2 青木)



- *Flux* : 中心部を極大とする強度勾配あり
  - Total Flux 1503Jy from 10″x4″ 長円形
  - Total throughput of Kanata-GIGMICS: ~15%
- 中心観測点での観測波長 λ_{center}=10.51130 (μm)
  - 赤方偏移 (*ref.* λ_{rest}=10.5105μm)
- V_{LSR} ~22km/s
  - 観測点間での速度差は少ない(σV < 4km/s)
    - 双極ジェットとは独立
- ΔV_{FWHM} ~40km/s resolved → T~1,000,000K :

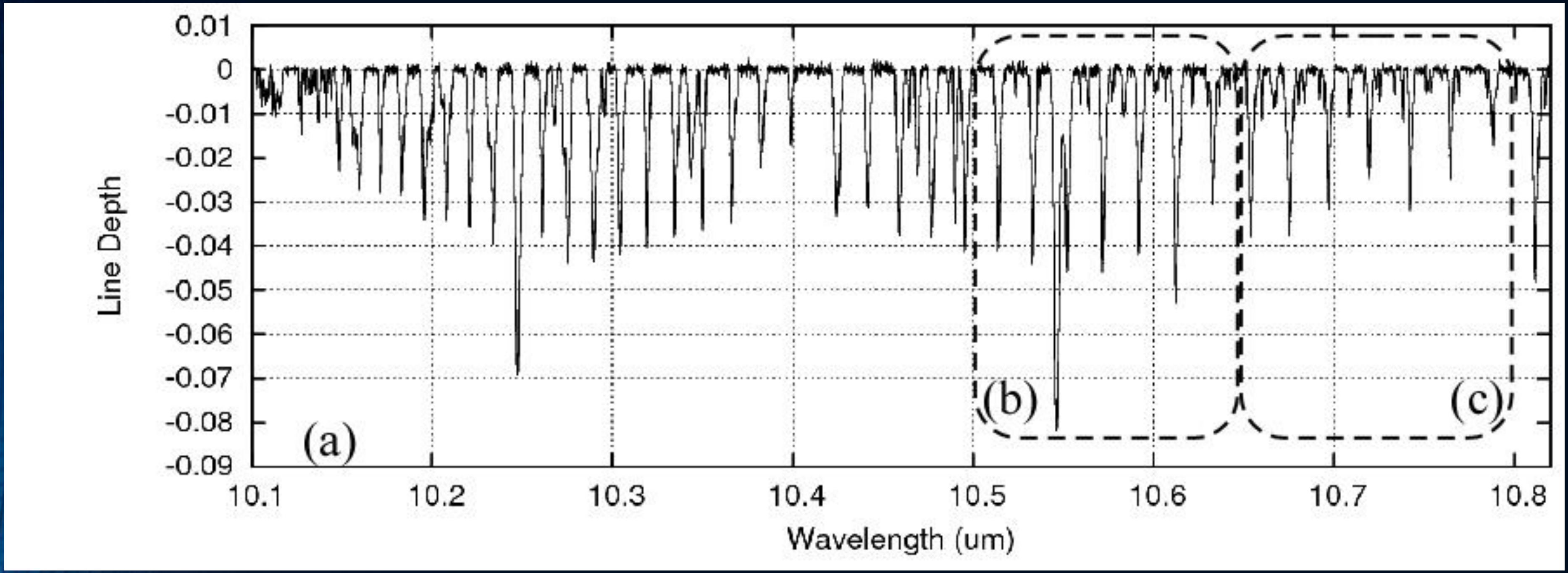


HST/NICMOS (Latter *et al.*, 2000)

<u>Rest Frequency of [SIV] transition</u>

	***λ* (μm)**	***R*$_{obs}$**	***Reference***
Lab. (λ_{rest})	10.5105(1)	100,000	Martin *et al.* (1990)
ISO-SWS	10.510(5)	2,000	Bernard-Salas *et al.* (2000)
GIGMICS	$10.51130(58)_{1\sigma}$	35,000	*(ΔV~7.5 km/s)*

金星大気雲頂領域におけるCO_2の観測(M2 柴田)



- 東広島天文台 かなた望遠鏡
- GIGMICS (Germanium Immersion Grating Mid-Infrared Cryogenic Spectrograph)
- 2011年4月6日 AM5:50 明けの明星
- 観測波数: 924 ~ 988 cm^{-1}

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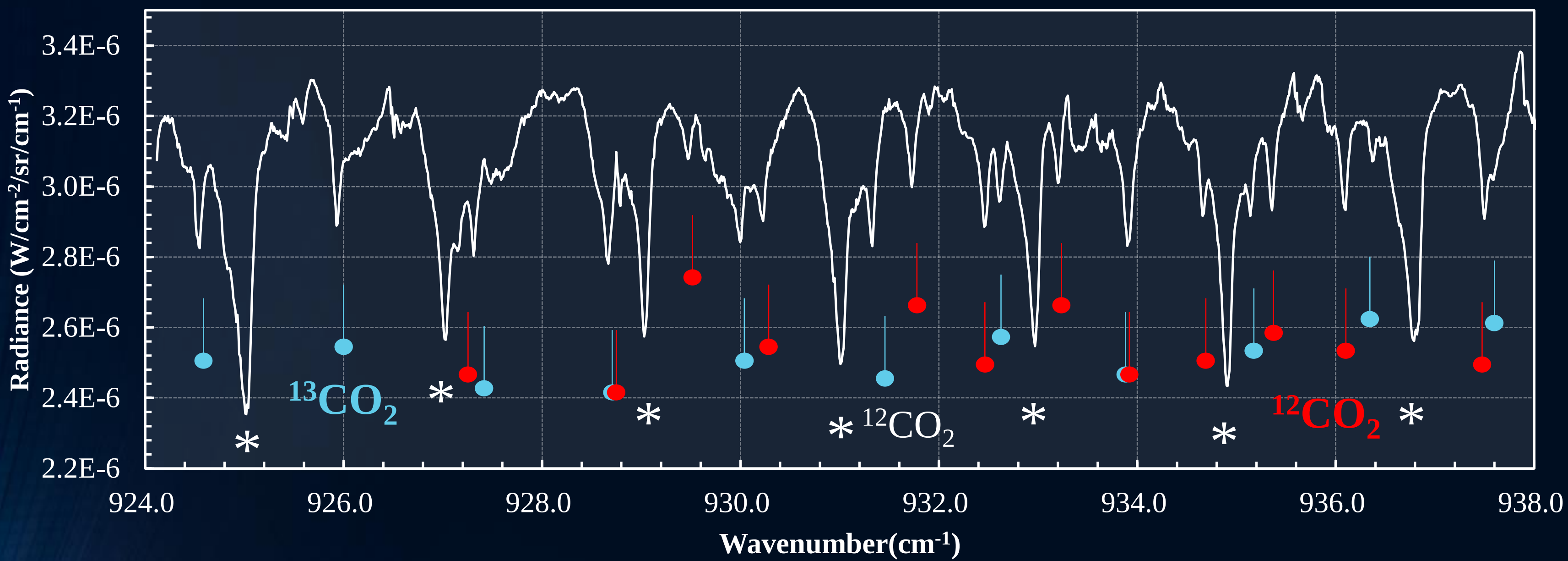

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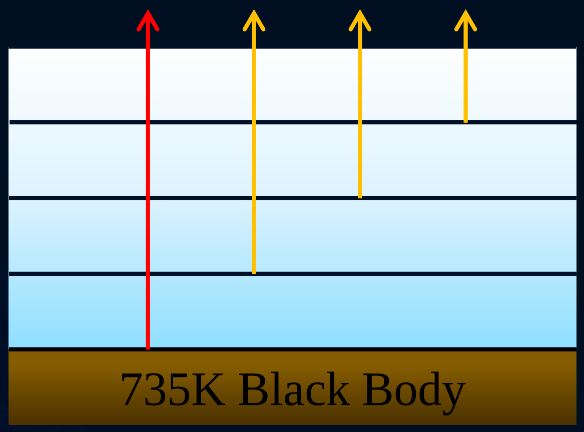
金星大気の放射伝達

- 平行平面大気モデル
- 中間赤外線領域であるため散乱の効果は無視し，
  大気分子，雲粒子による吸収のみを考慮

$$I_{\tilde{\nu}} = B_{\tilde{\nu}}(T_{surf})\, exp(-\tau_{surf,\tilde{\nu}}) + \int_0^{\tau_{surf,\tilde{\nu}}} B_{\tilde{\nu}}(T(\tau_{\tilde{\nu}}'))\, exp(-\tau'_{\tilde{\nu}})\, d\tau_{\tilde{\nu}}$$

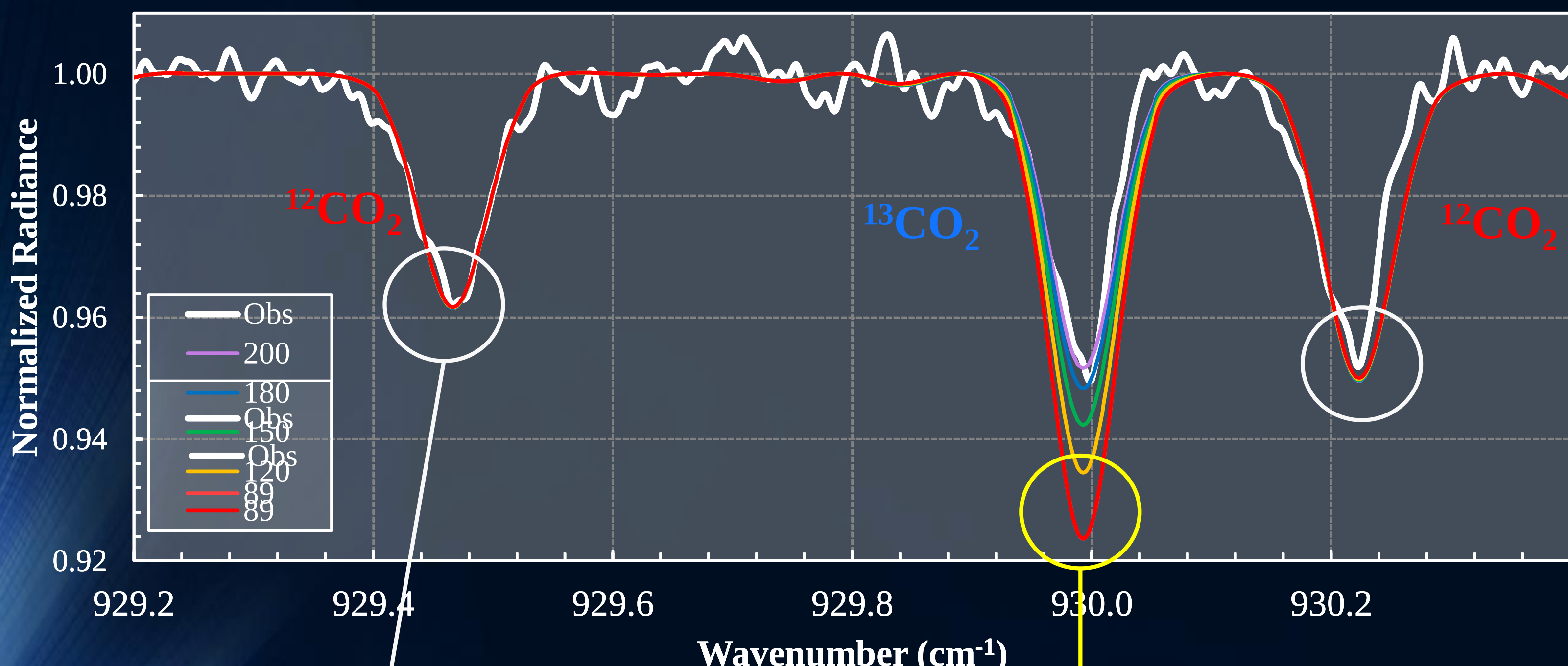
地表面の放射　透過率　大気の放射　透過率

- 光学的厚さ … Line-by-Line法により算出
- 標準大気モデル（VIRA），雲モデル
- 吸収線パラメータ：HITRAN 2008
  （CO_2，H_2O，OCS，SO_2）



観測結果とモデルの比較（1）

- 観測された振動回転スペクトル
  - $^{12}CO_2$ $(v_3+v_2) \leftarrow (v_1+v_2)$　30本
  - $^{13}CO_2$　$v_3 \leftarrow v_1$　13本：すべての吸収が“深い“

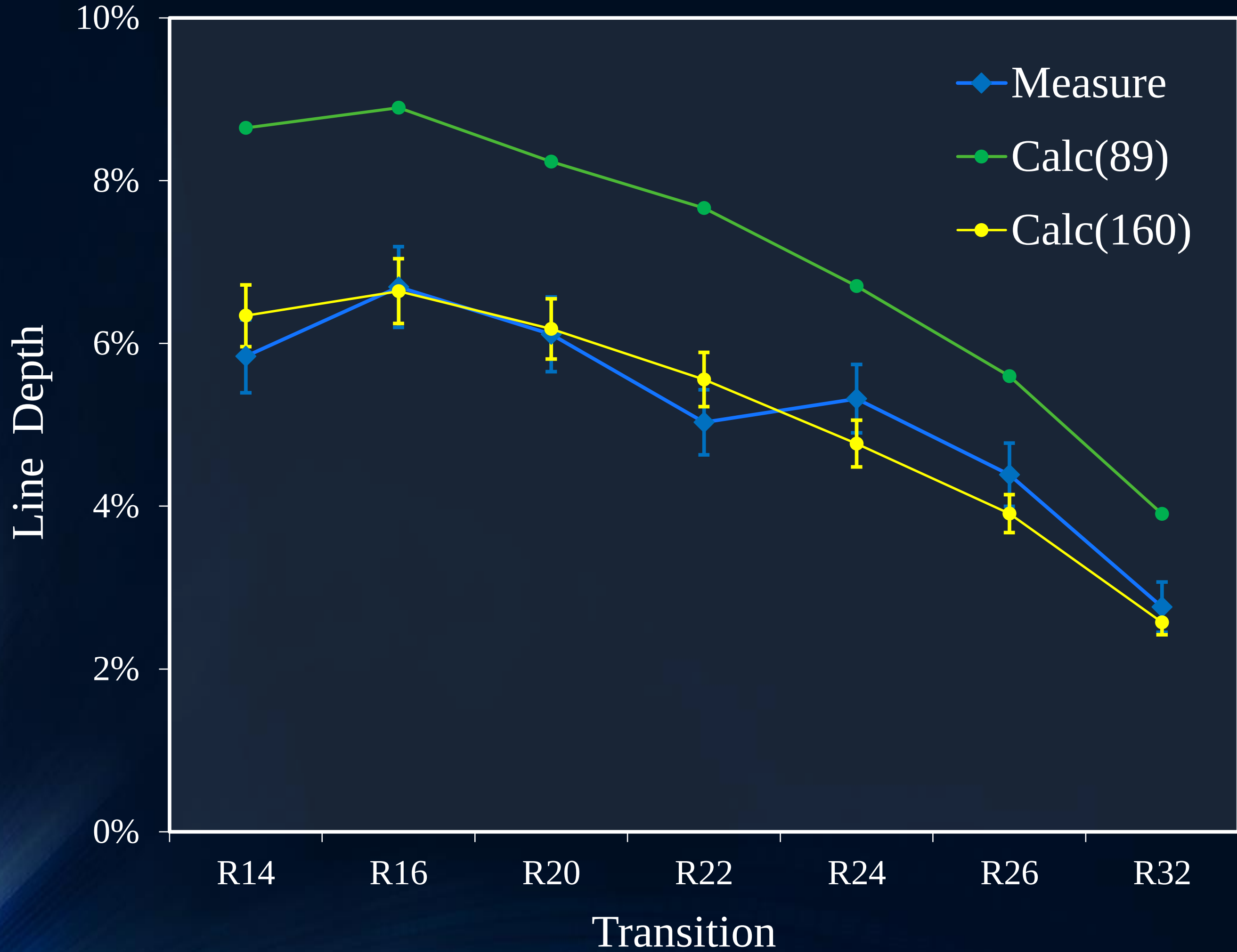


良い一致を示す

ピークの深さ
モデル ＞ 観測

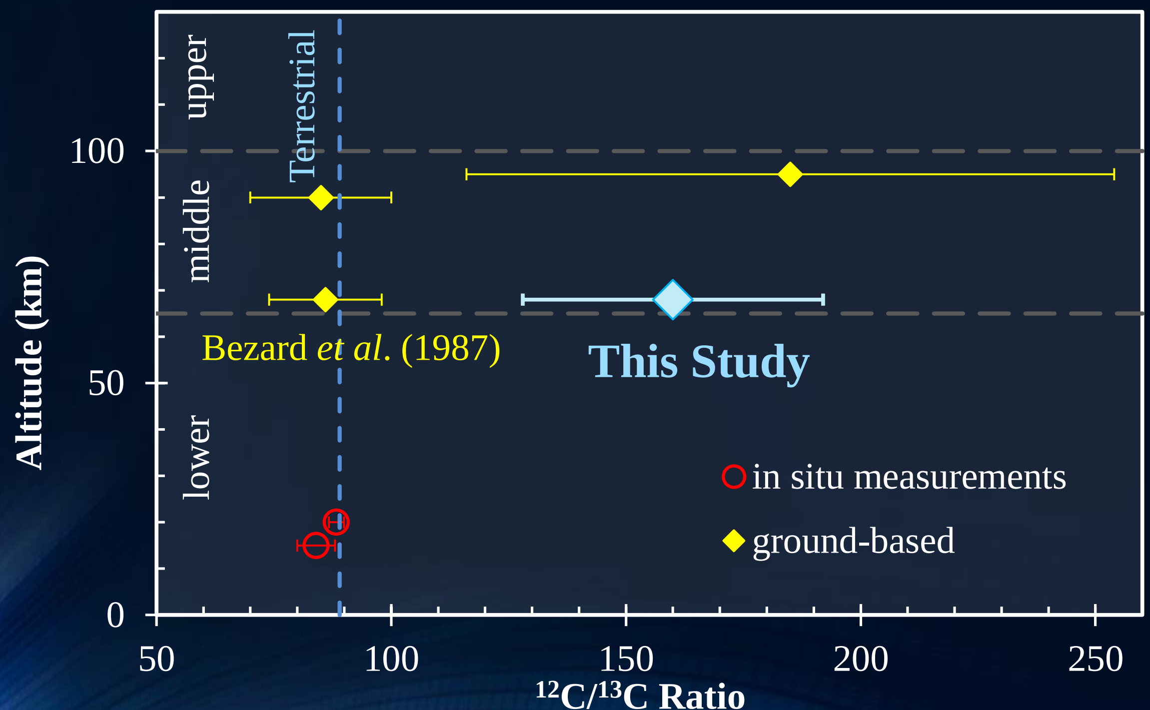
観測結果とモデルの比較(3)

- $^{13}CO_2$ $v_3 \leftarrow v_1$ Measure vs Calculation



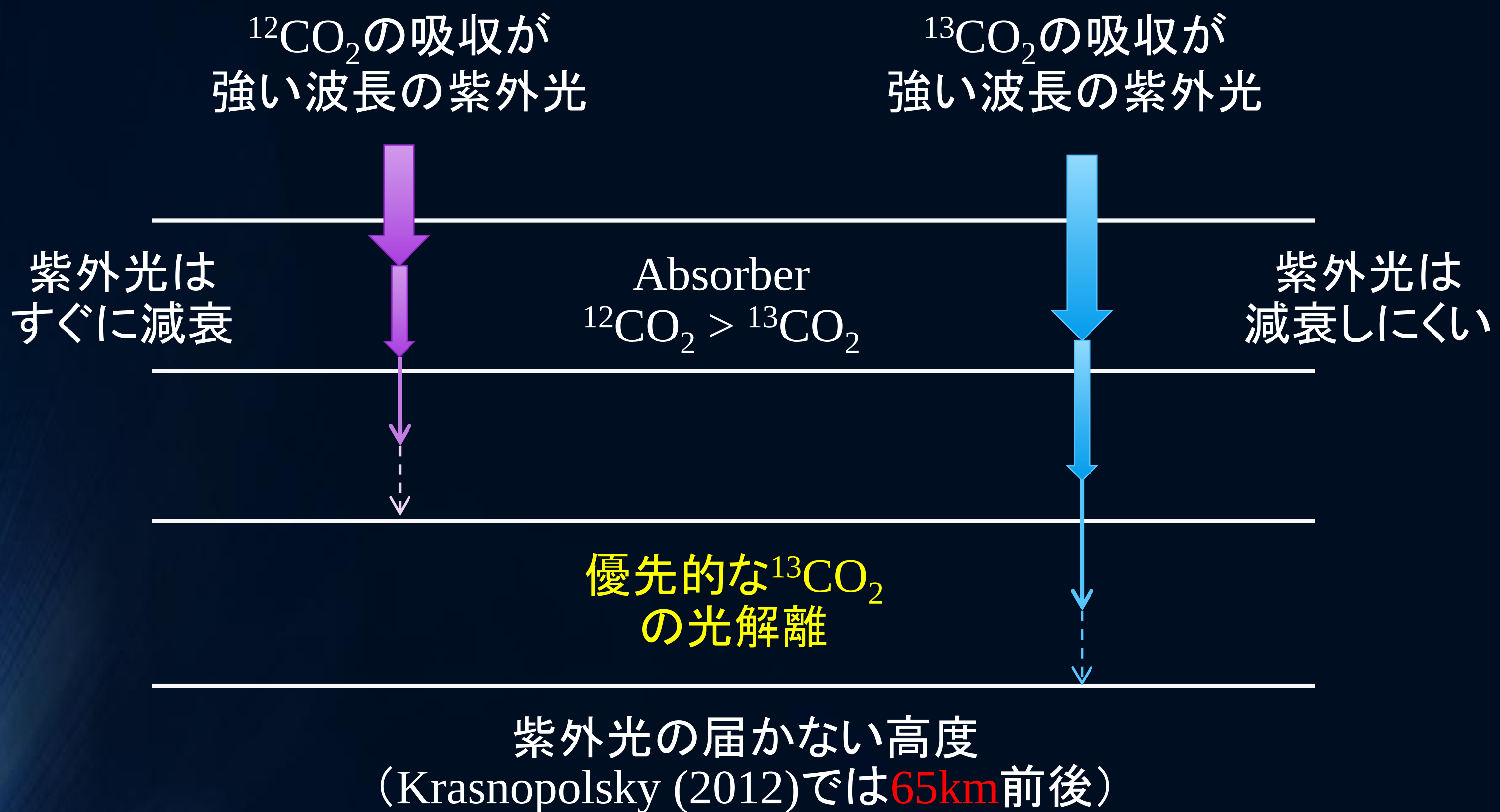
結果

- 雲頂付近の$^{12}CO_2/^{13}CO_2$＝160±32
  - 下層大気（～89）と異なる高い値
  - 同高度領域で異なる$^{12}CO_2/^{13}CO_2$比 (Bezard *et al*. (1987))
  - $^{12}CO_2$と$^{13}CO_2$の**同位体分別**の過程の存在を示唆



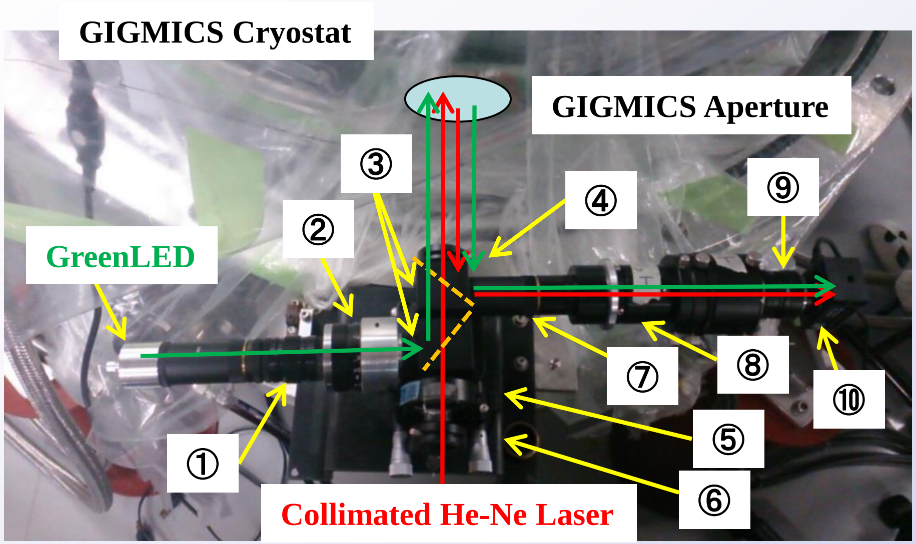
光解離による同位体分別

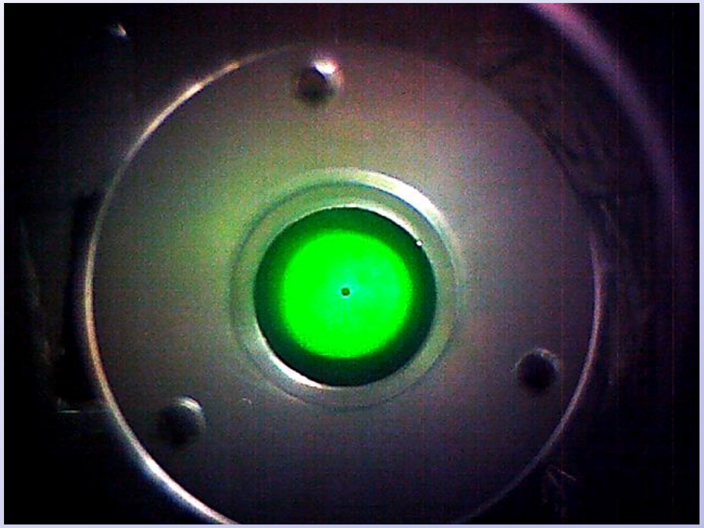
- $^{12}CO_2$と$^{13}CO_2$の光解離波長は厳密には異なる



- 本研究の観測高度域: 65 ~ 71km
- $^{13}CO_2$の光解離が優先 ➡ 高$^{12}CO_2/^{13}CO_2$同位体比

GIGMICS 外部ビューア光学系(海老塚他)

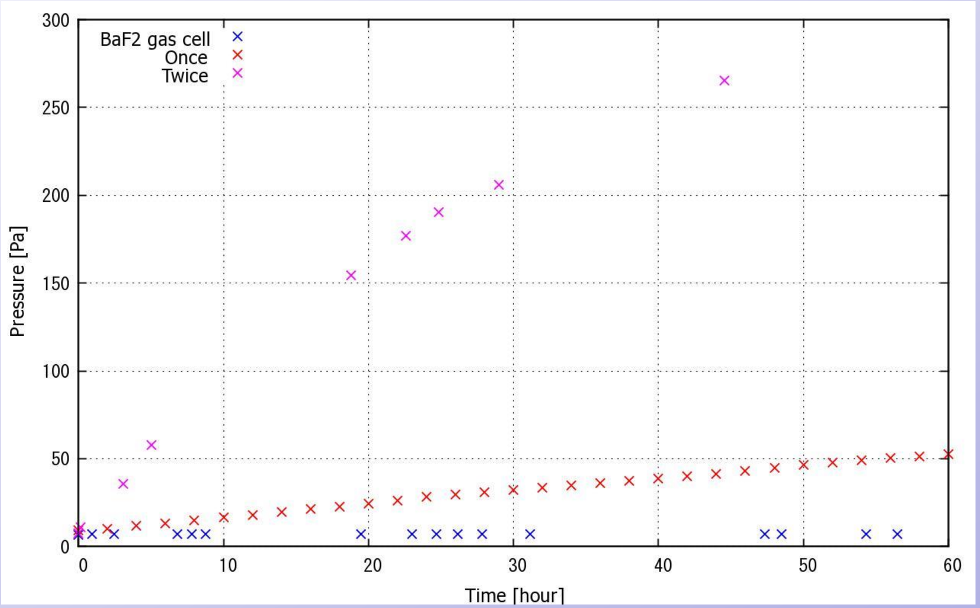


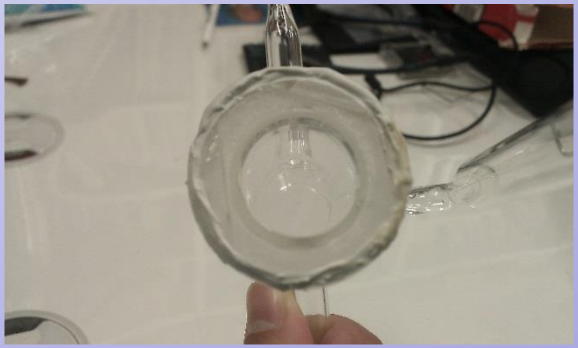


① PCX Lens *f*=6mm *φ*6
② CCTV Lens *f*=50mm *F*/1.4
③ a pair of Half Mirrors
④ 光軸記憶用Iris Diaphragm
⑤ 結像用PCX Lens *f*=250mm *φ*30
⑥ Aperture Stop
⑦ Achromatic Lens *f*=75mm *φ*25
⑧ Plossl　Eyepiece *f*=25mm
⑨ CCTV Lens *f*=12mm *F*/1.2
⑩ CMOS Image Sensor (USBでPCへ)

GIGMICS N-band全域波長校正ガスセル(B4 仲本)

CH4, NH3, C2H4, ~100mmTorr
光路長 100mm, 開口径20mm
Material: Pyrex + BaF2 Window
Torr-Sealによる接着試験中
目標:“メンテナンスフリー“
↓
3つ目:～1週間圧力変化 無
完成か！と思われたが、、、



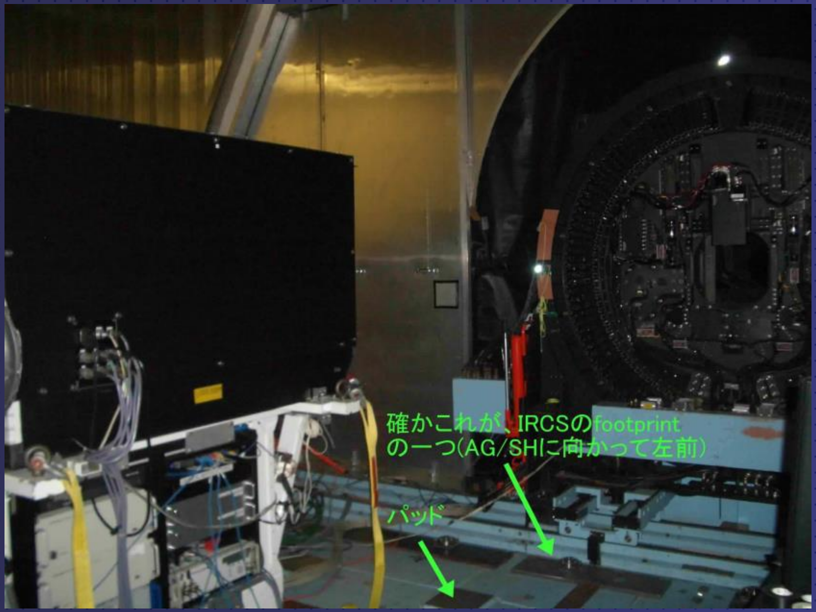


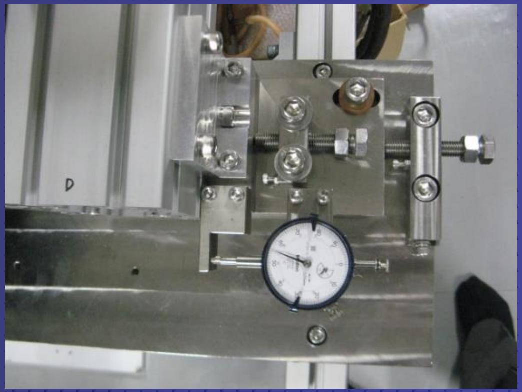
ある朝、窓材亀裂

Last Slide: GIGMICS in future

Carry-in instrument proposal submitted Jan. 2013
→Under Preshippment Review in Nagoya Univ.   Landing: 2015?

Mounting GIGMICS on Nasmith-IR stage: precise and quick alignment necessary





可動域：5mm(XYZ)
0.4deg (φ、θ)独立
組み立て式、
再現可能