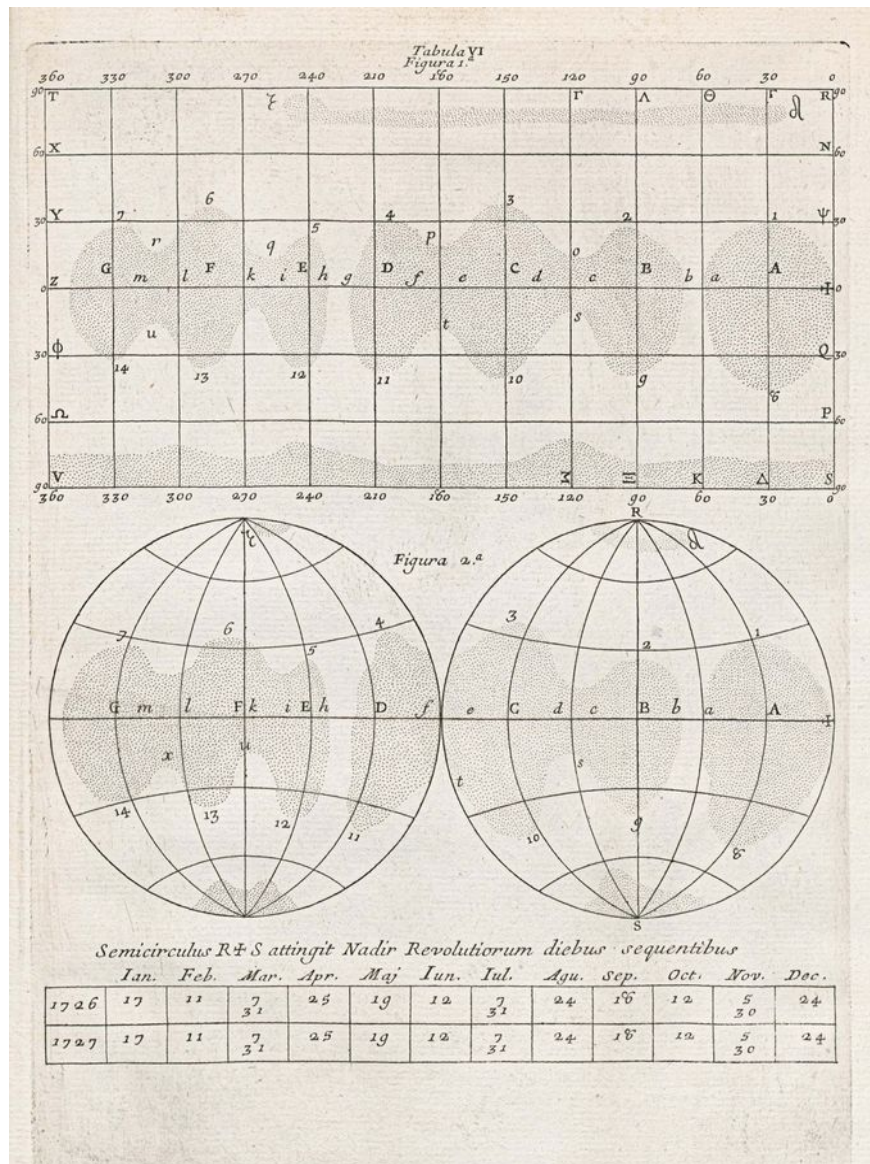
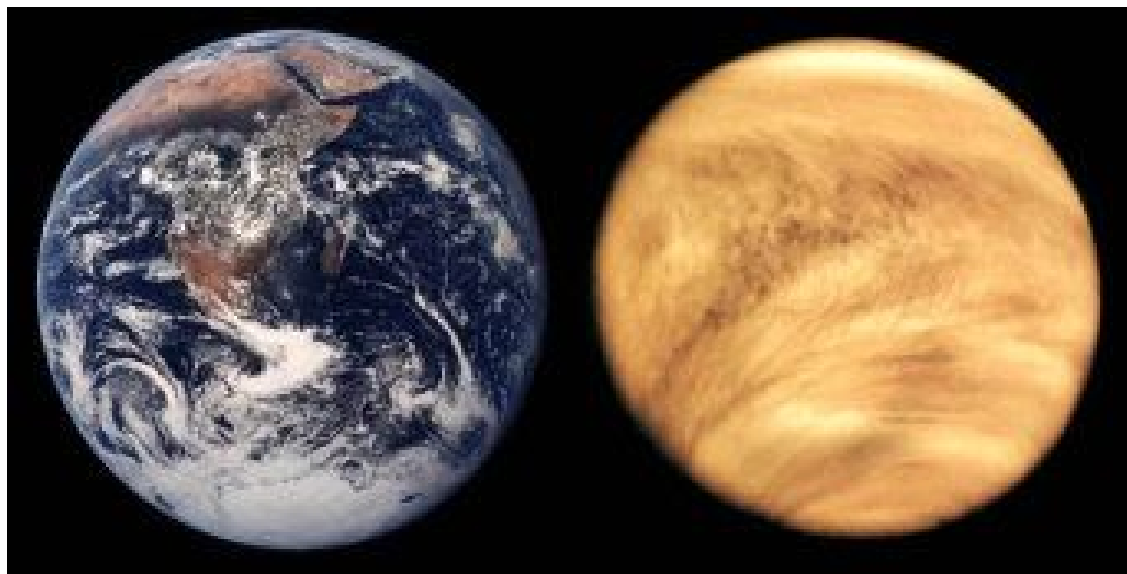


金星大気温故知新セミナー

「金星の雲」

あかつき
佐藤 毅彦 (ISAS)



F. Bianchini (1726)による初めての金星地図

全体の構成(寄せ集め)

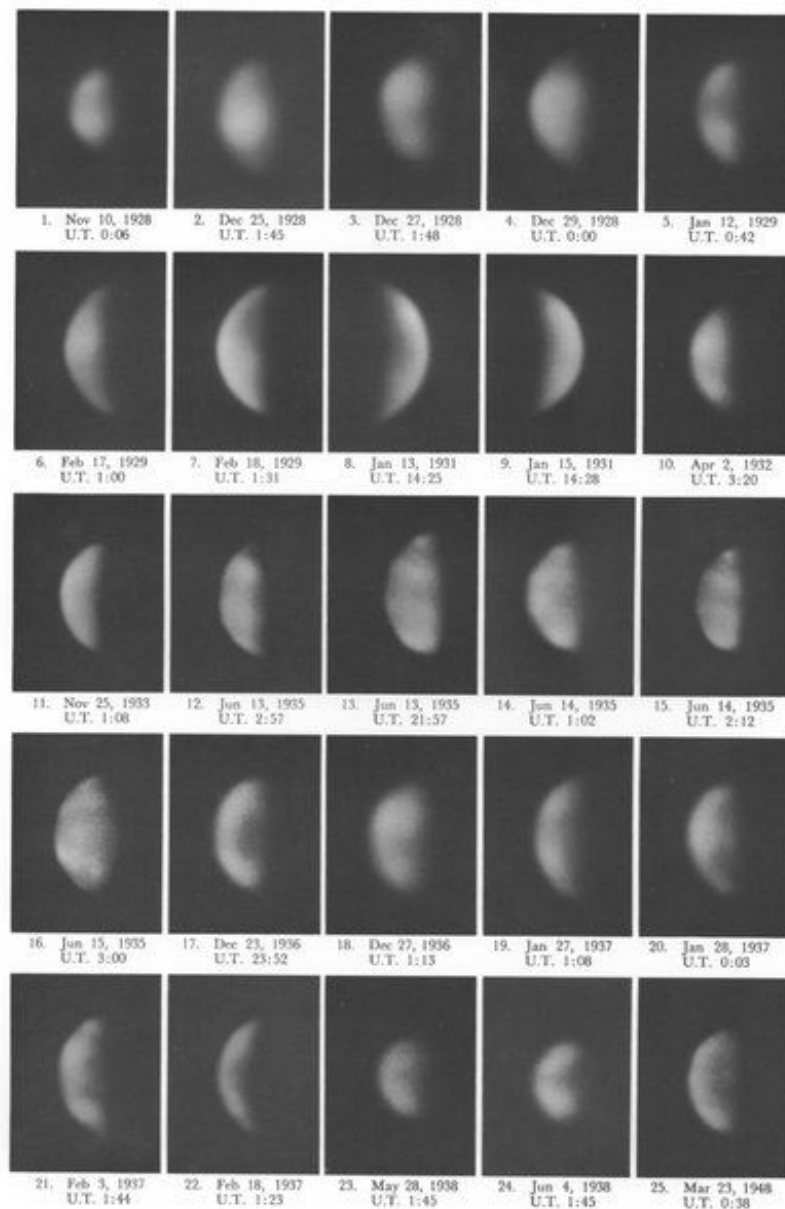
- このイントロダクション(素材0)
- IR2の開発(素材1)と、
それに起因するデータ特性(素材2)
- IR2夜面データの補正と、CALMの発見(素材3)
- Enormous Cloud Cover (ECC)を研究中(素材4)

模様に見える金星雲層

- 紫外線で観測すると、何らかの(未知)吸収物質による模様が見られる。
 - 4日循環(スーパーローテーション)の発見
- 本日は、吸収物質には触れません。化学にも運動学にも立ち入りません。
- どのような雲がどこにどれだけあるか、それを観測的にいかにして明らかにしてゆくか、が主題となります。

Slipher, E.C. "A Photographic Study of the Brighter Planets"
(Lowell Observatory, 1964)

PLATE VII
TYPICAL ULTRAVIOLET PHOTOGRAPHS (λ3650 TO 4000) TAKEN FROM 1927 TO 1948
DISPLAYING VARIATIONS IN THE CLOUD COVER ON VENUS



金星「雲」研究の歴史

- 金星の雲に対する理解は、おおまかに言えば
- 偏光(地上観測、Pioneer Venus Orbiter/OCPP)
 - Hansen, J.E., Hovenier, J.W., JAS 31, 1137-1160, 1974.
- 降下プローブ(Pioneer Venus Probe/LCPS)
 - Knollenberg, R.G., Huntten, D.M., JGR 85, A13, 8039-8058, 1980.
- 近赤外線「窓」によるリモセン(地上観測、Galileo/NIMS)
 - Allen, D.A., Crawford, J.W., Nature 307, 222-224, 1984.
 - Carlson, R.W., et al., PSS 41, 7, 477-485, 1993.
- によって大きく進展した。

Interpretation of the Polarization of Venus

JAMES E. HANSEN

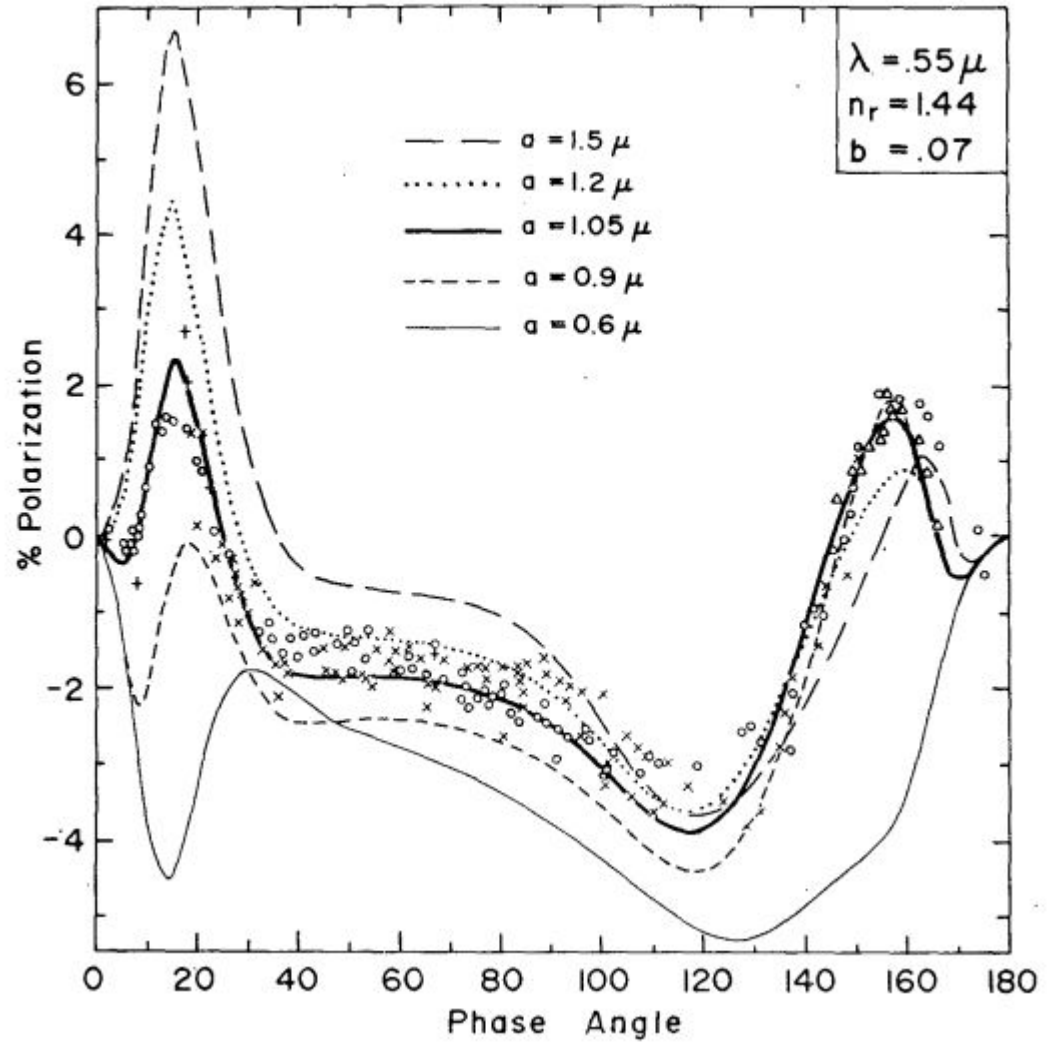
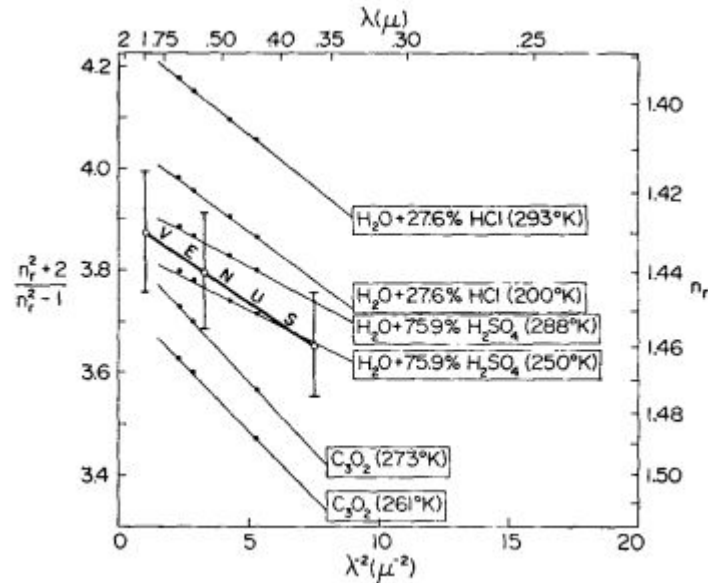
Goddard Institute for Space Studies, New York, N. Y. 10025

J. W. HOVENIER

Dept. of Physics and Astronomy, Free University, Amsterdam, Netherlands

(Manuscript received 20 November 1973, in revised form 15 January 1974)

硫酸液滴(75%)の雲粒子
有効半径 1.05 μm , 有効分散 0.07



金星偏光観測の歴史

- Lyot (1929)による広い位相角をカバーした精度の高い観測
- Dollfus (1955)以来、多くの観測
- Coffeen & Gehrels (1969)が偏光データから雲粒子のサイズ・屈折率を推定
- Hansen & Hovenier (1974)による多重散乱を考慮した解析
- Pioneer Venus Orbiter OCPP
- Venus Express SPICAV

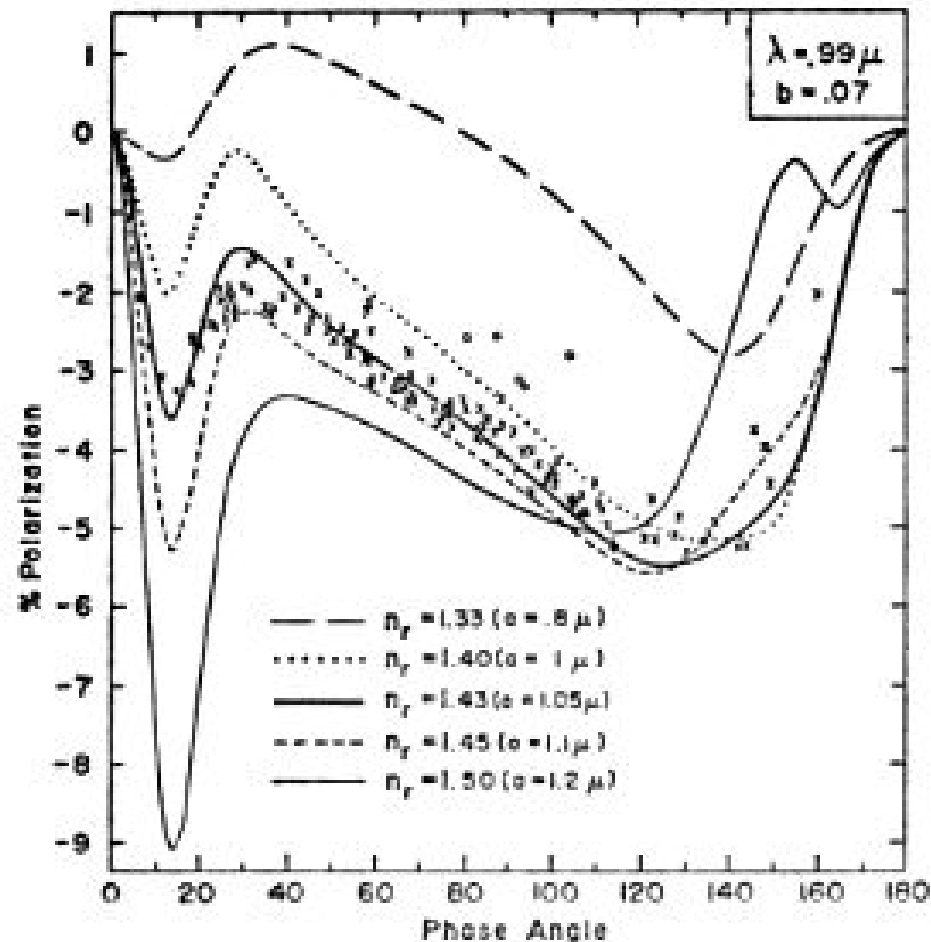


図 8 ミー粒子による多重散乱モデルと金星偏光度の観測データの比較。各屈折率に対して、観測値との一致が最良となる半径を選んでいる (Hansen and Hovenier, 1974)。

PV Orbiter/OCPPによる偏光観測

- Kawabata, K., et al. JGR 85, A13, 8129-8140, 1980.

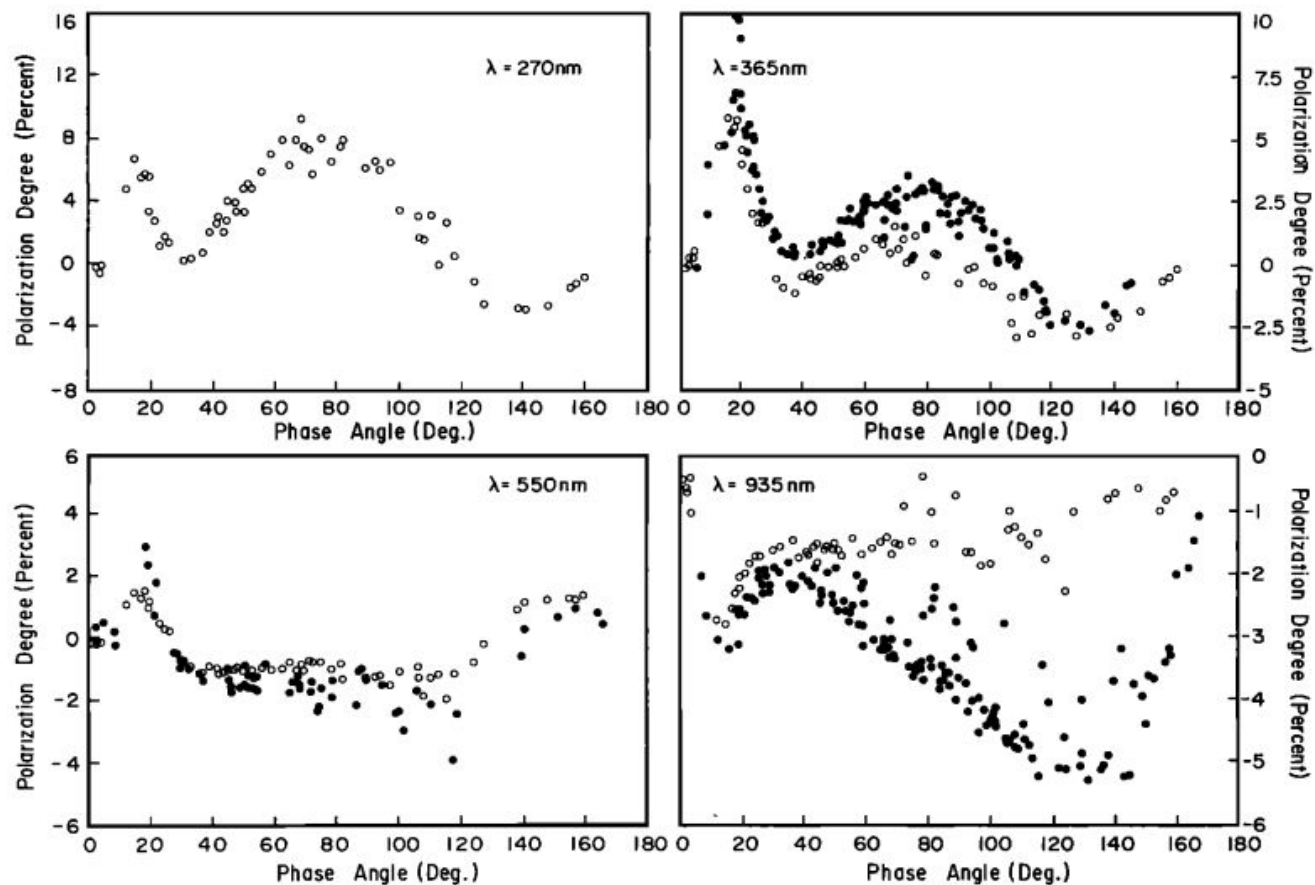
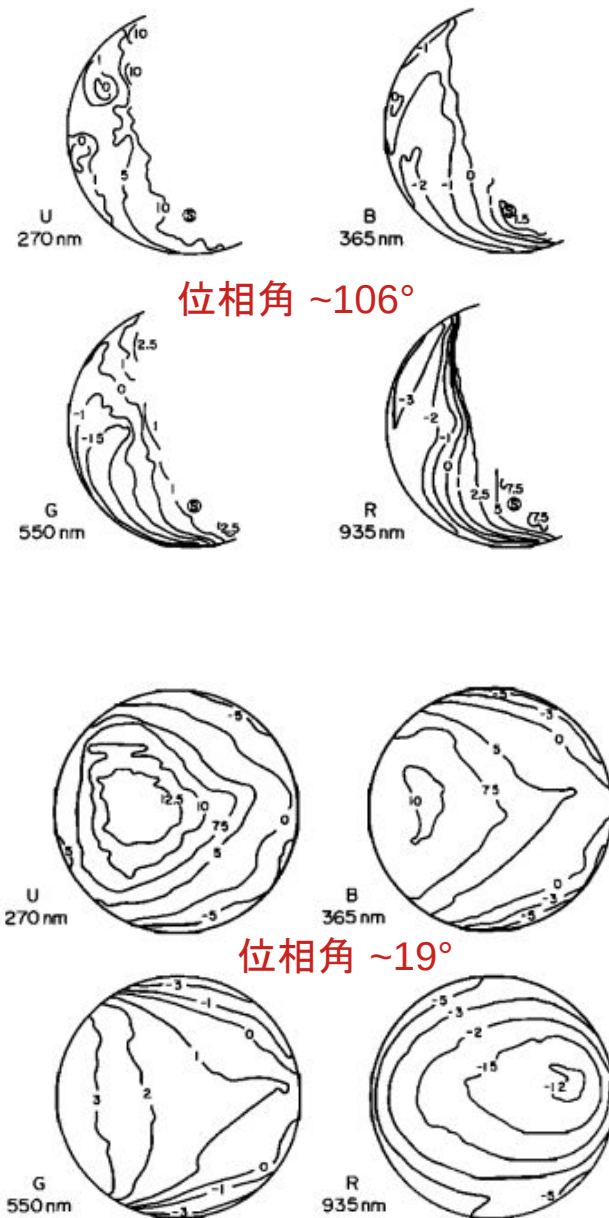


Fig. 2. Disk-integrated OCPP polarimetric data (open circles) compared with ground-based observations (solid circles) by Coffeen and Gehrels [1969], Coffeen [Dollfus and Coffeen, 1970], and Gehrels et al. [1979].





HOPS

A New Imaging Polarimetry Instrument

T. Satoh, Faculty of Educ., Kumamoto Univ.

tsatoh@educ.kumamoto-u.ac.jp

K. Kawabata & N. Yamamoto, Faculty of Sci., Science U of Tokyo

T. Tenma, New Mexico State University

T. Akabane, Hida Observatory, Kyoto University

Presented at Jupiter Meeting in Boulder, CO (June 2001).

The Microphysics of the Clouds of Venus: Results of the Pioneer Venus Particle Size Spectrometer Experiment

R. G. KNOLLENBERG

Particle Measuring Systems, Inc., Boulder, Colorado 80301

D. M. HUNTEN

University of Arizona, Tucson, Arizona 85724

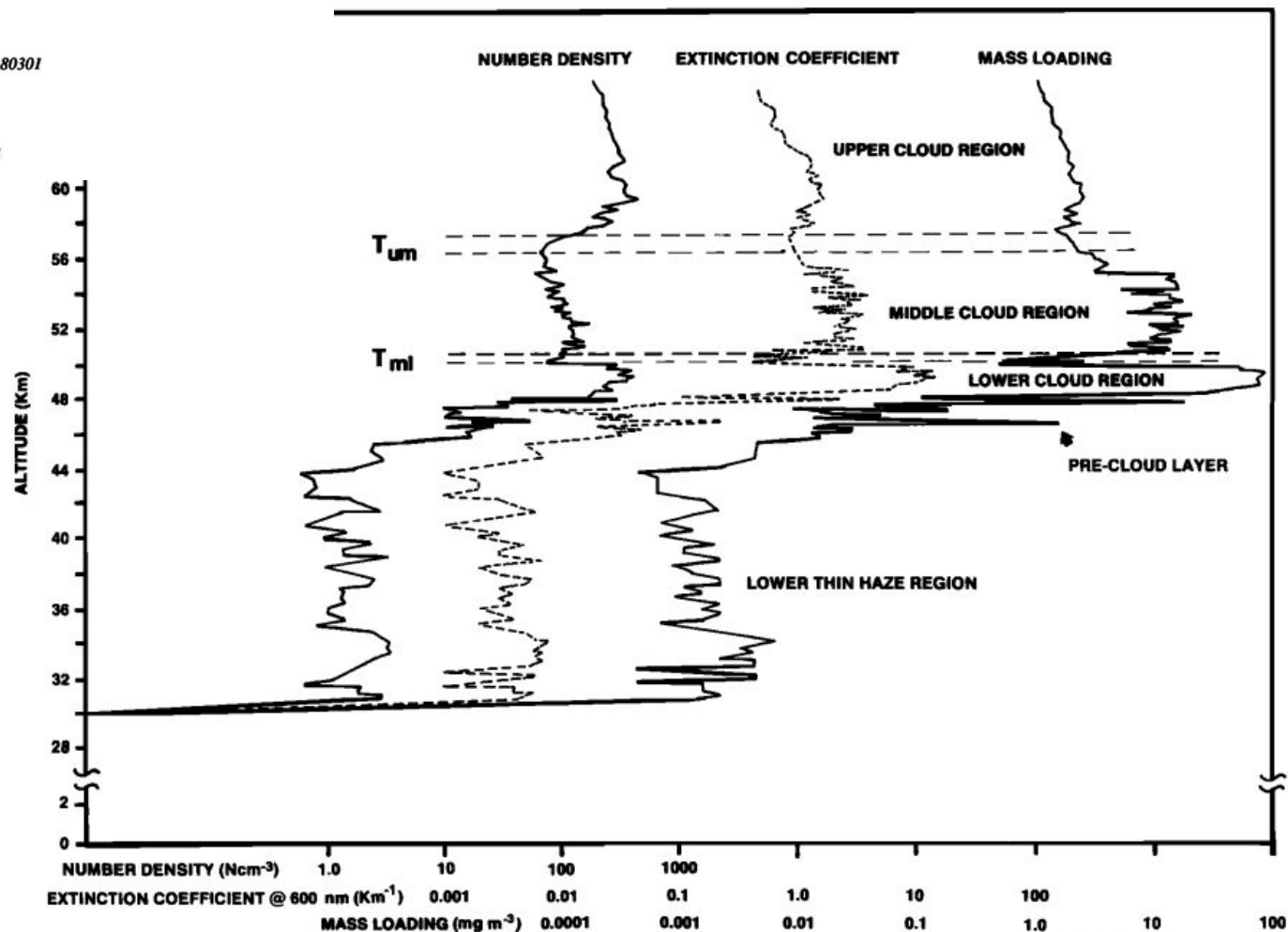


Fig. 4. Vertical structure of Venus cloud system. The above data represent direct computations from the LCPS data. No allowance has been made for particles smaller than the 0.6 μm lower limit of size sensitivity or above the largest sizes actually measured. A density of 2 g cm^{-3} was assumed for mass loading computations. The thickness of T_{um} is about 1 km while T_{mi} is several hundred meters thick.

PV Probe/LCPSの観測

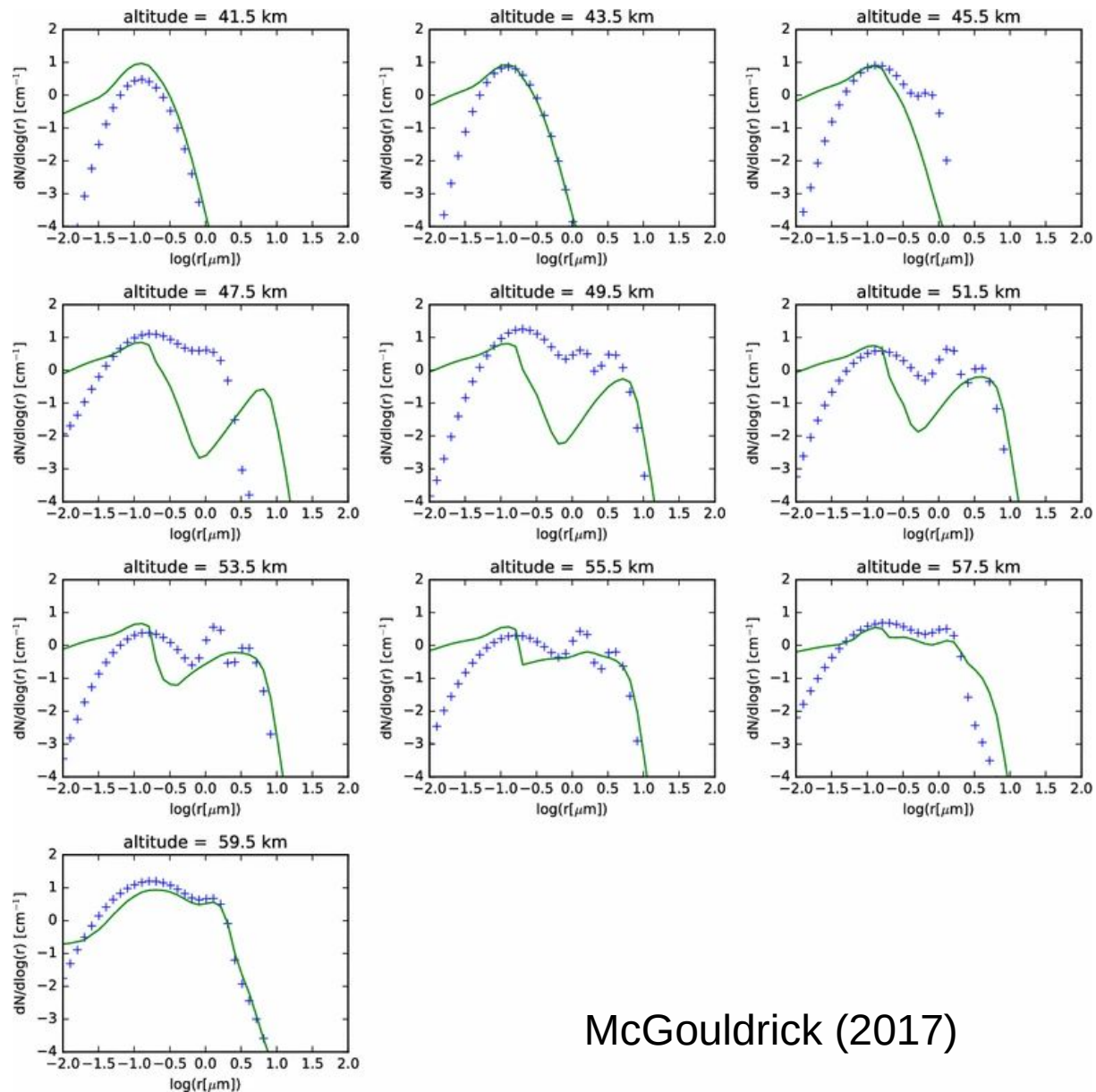
TABLE 4. Mode 1, 2, and 3 Size Distribution Parameters for LCPS Data

	Altitude Range	Log Normal Distribution			Gaussian Distribution			Log Normal Distribution		
		Mode 1			Mode 2			Mode 3		
		N_T, ncm^{-3}	σ_g	$\bar{d}_g, \mu\text{m}$	N_T, ncm^{-3}	$\sigma, \mu\text{m}$	$\bar{d}, \mu\text{m}$	N_T, ncm^{-3}	σ_g	$\bar{d}_g, \mu\text{m}$
Upper cloud	66.10–65.20	181	2.16	0.35	9	0.50	1.33			
	65.20–63.80	211	2.16	0.35	22	0.68	2.38			
	63.80–62.50	336	2.16	0.35	41	0.68	2.20			
	62.50–61.25	521	2.16	0.35	53	0.80	2.20			
	61.25–60.20	544	2.16	0.35	64	0.69	2.32			
	60.20–59.00	608	2.16	0.35	71	0.84	2.28			
	59.00–58.15	348	2.16	0.35	63	0.91	2.26			
	58.15–57.10	197	2.16	0.35	58	0.87	2.12			
T_{um}	57.10–56.20	54	2.16	0.35	29	0.82	2.38			
Middle cloud	56.20–55.40	69	2.16	0.35	30	0.74	2.54	17	1.25	7.40
	55.40–54.80	69	1.9	0.30	31	0.44	2.83	30	1.25	7.40
	54.80–54.30	69	1.9	0.30	30	0.49	2.73	37	1.25	7.40
	54.30–53.90	86	1.9	0.30	32	0.48	2.80	32	1.25	7.40
	53.90–53.25	72	1.9	0.30	38	0.55	2.70	50	1.26	7.28
	53.25–52.80	99	1.9	0.30	37	0.55	2.80	38	1.26	7.28
	52.80–51.30	112	1.9	0.30	44	0.65	2.73	35	1.26	7.28
	51.30–52.70	122	1.9	0.30	54	0.59	2.73	48	1.26	7.28
	52.70–51.10	110	1.9	0.30	56	0.63	2.70	40	1.27	7.41
	51.10–50.60	121	1.9	0.30	52	0.68	2.70	39	1.27	7.41
T_{mi}	50.60–50.10	93	1.9	0.30	46	0.63	2.45	14	1.27	7.41
Lower cloud	50.10–49.70	144	1.80	0.35	14	0.60	1.70	15	1.27	7.41
	49.70–49.25	528	1.80	0.4	57	0.75	2.58	126	1.29	7.20
	49.25–48.75	563	1.80	0.4	71	0.60	2.73	177	1.29	7.20
	48.75–48.30	404	1.80	0.4	75	0.55	2.60	72	1.29	7.20
	48.30–47.75	233	1.80	0.4	59	0.66	2.14	33	1.29	7.20
Upper precloud	47.75–47.50	474	2.02	0.35	111	1.25	2.10			
Lower haze	47.50–46.45	128	1.70	0.28						
Lower precloud	46.45–46.30	179	1.80	0.30	34	0.85	2.90			
Lower haze	46.30–43.25	218	1.57	0.25						
	43.25–38.70	41	1.57	0.25						
	38.70–31.00	46	1.57	0.25						

雲微物理モデル

- LCPS観測結果を再現

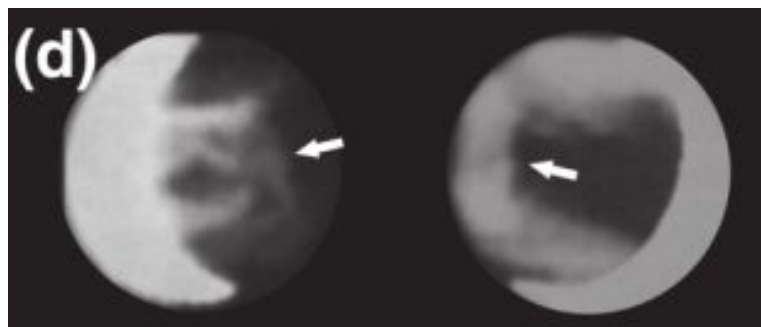
- 一次元大気柱モデル(水平面方向の輸送を含まない)
- 比較に際して、LCPSプロファイルのモード3を、全高度にわたり 1/3 に減らしている。
- Nephelometerによる後方散乱観測と合わないから、らしい(Pollack et al., 1980)。



McGouldrick (2017)

近赤外「窓」の発見

- 1983年に地上観測により発見
 - CO₂吸収が相対的に弱く、下層からの熱放射が宇宙空間へ逃げ出すことができる波長



左) Allen&Crawford (1984), 右) Crisp et al. (1991)

<u>Window Region</u> (microns)	<u>Approximate Depth Probed</u>
1.01	Surface (>90%)
1.10	Surface (~60%) plus 0 to 15 km
1.18	surface (~40%) plus 0 to 15 km
1.27	15 to 30 km
1.31	30 to 50 km
1.74	15 to 30 km
2.3	45 to 26 km

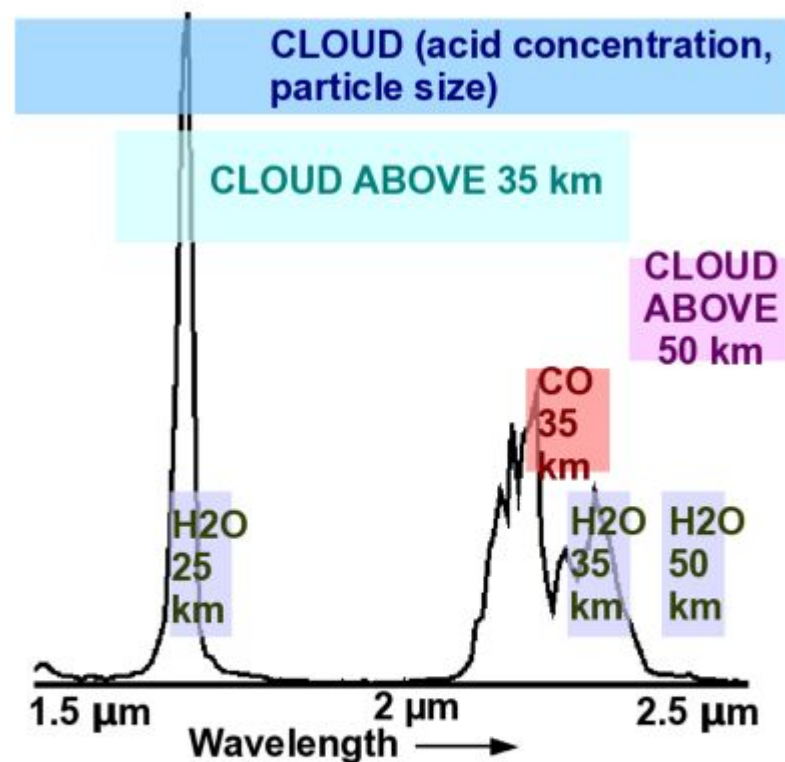


Figure 1: VIRTIS-M-IR spectrum with sensitivity to the acid concentration, mode 3 abundance, base altitude and CO and H₂O between 1.6 and 2.6 μm .

Barstow et al. (2010)

Variations in Venus cloud particle properties: a new view of Venus's cloud morphology as observed by the *Galileo* Near-infrared Mapping Spectrometer

R. W. Carlson,¹ L. W. Kamp,¹ K. H. Baines,¹ J. B. Pollack,² D. H. Grinspoon,³ Th. Encrenaz,⁴ P. Drossart⁴ and F. W. Taylor⁵

¹Jet Propulsion Laboratory, Pasadena, CA 91109, U.S.A.

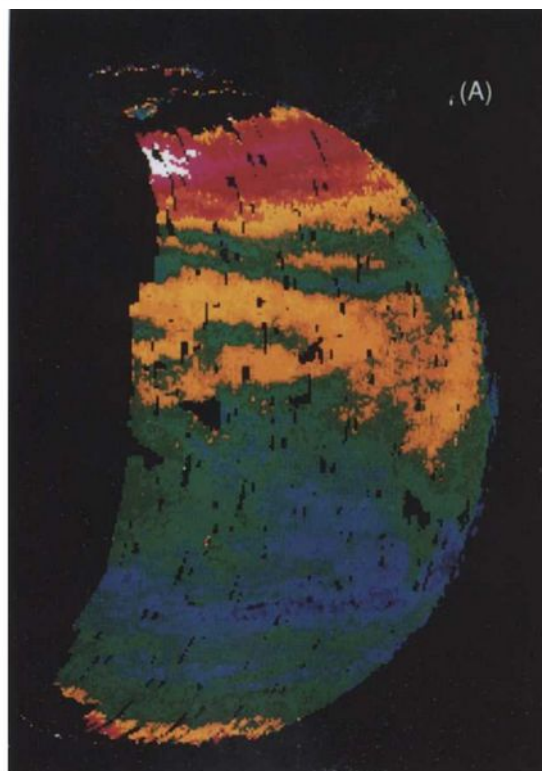
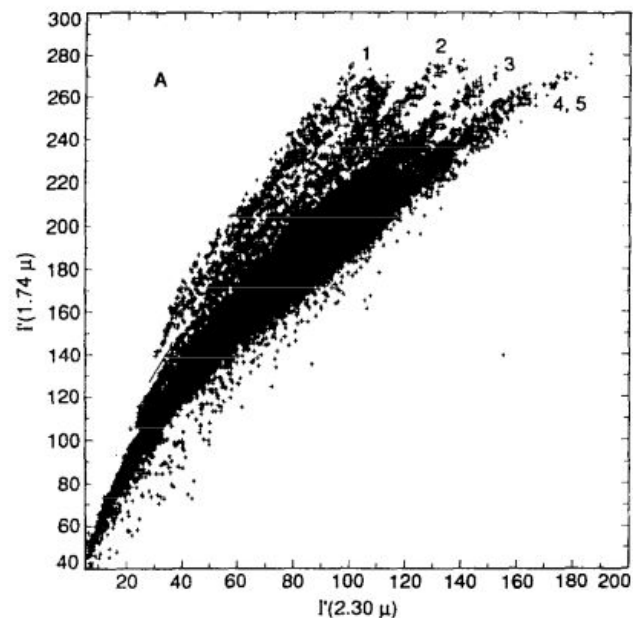
²NASA Ames Research Center, Moffet Field, CA 94035, U.S.A.

³University of Colorado, Boulder, CO 80309, U.S.A.

⁴DESPA (CNRS-URA 264), Observatoire de Paris, F-92195 Meudon, France

⁵Clarendon Laboratory, Oxford University, Parks Road, Oxford OX1 3PU, U.K.

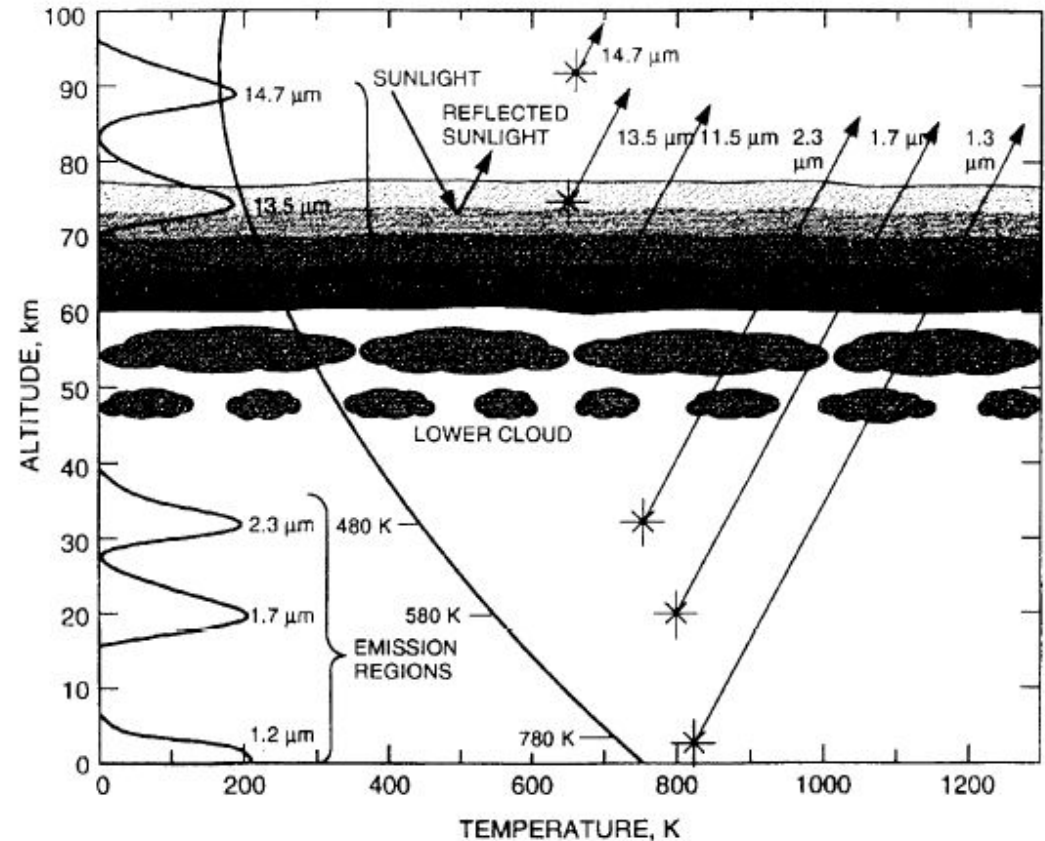
480



481

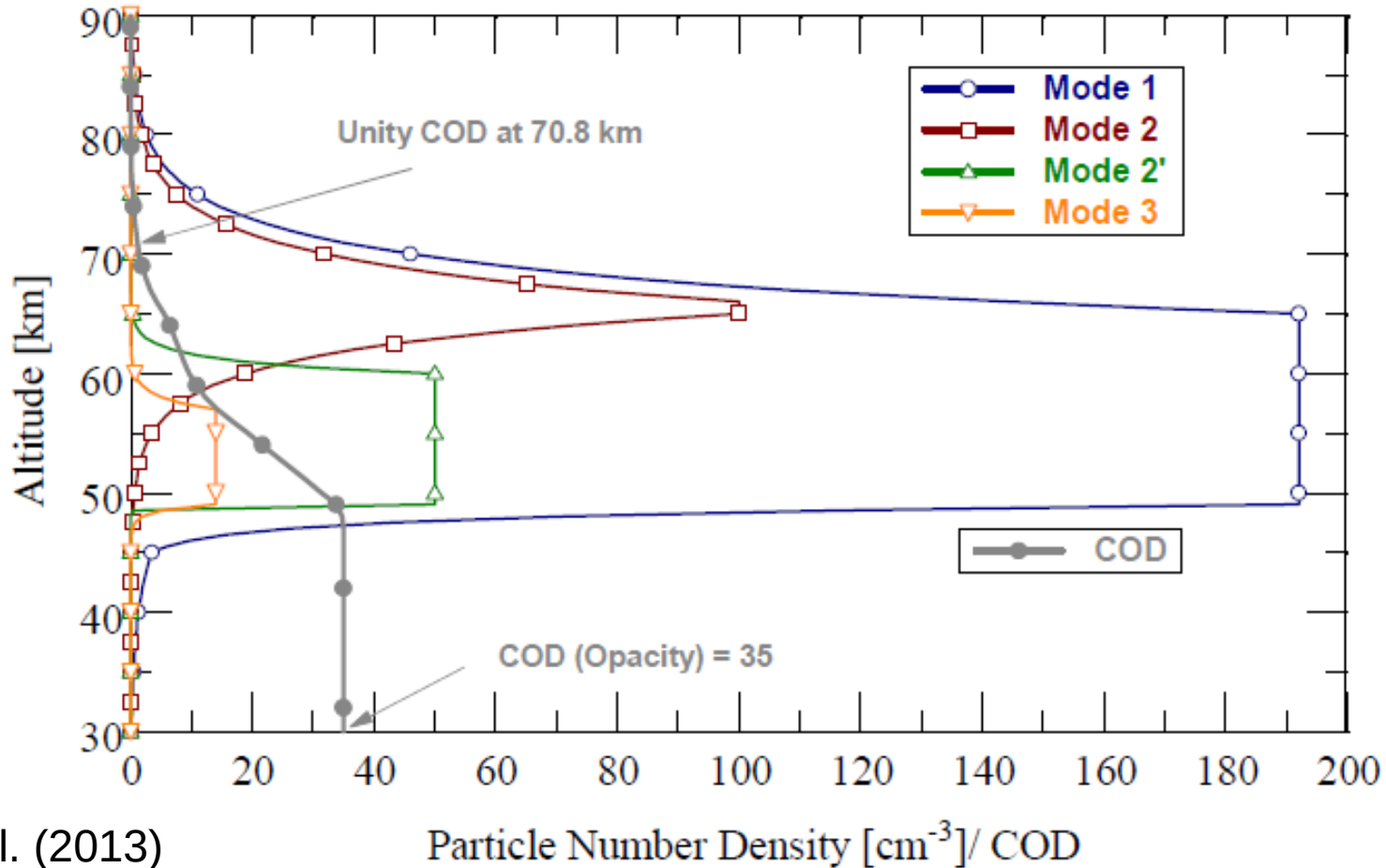
近赤外「窓」における放射(観測量)

- 代表高度からの熱放射
 - CO₂吸収により決まる(熱放射と吸収による寄与関数)
- 雲による減光
 - 散乱、吸収: 一次散乱アルベドはかなり高い
 - 吸収された分は、熱放射に
 - 上層雲は比較的一様
 - 下層雲は濃淡ムラが大きい (Grinspoon et al., 1993)



Hausらの雲モデル(複数「窓」解析)

- 近年の放射伝達計算で最もよく使われている(と思われる)。



Haus et al. (2013)

すべて硫酸の雲なのか？

- 分かりません！分光データから硫酸「濃度」解析の例はあり。

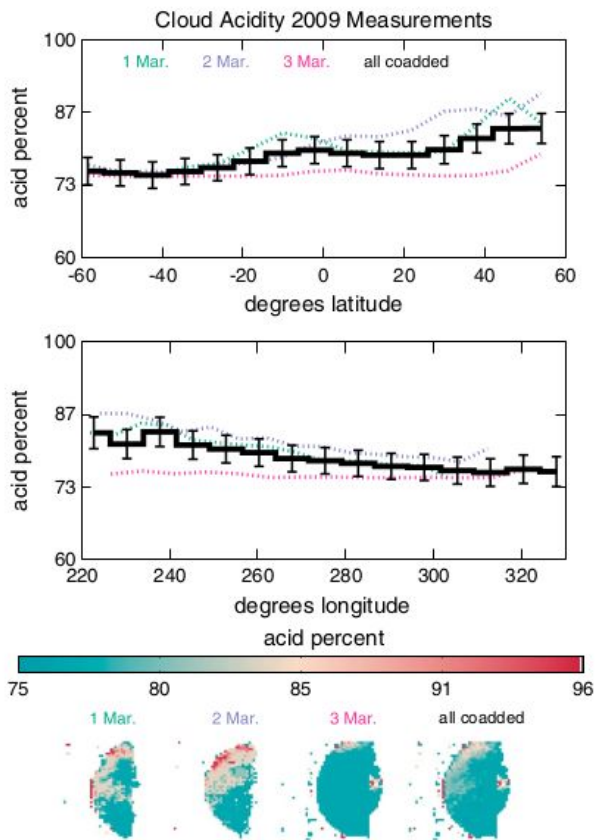


Figure 10. Acid concentration maps from 2009. Note the hemispherical dichotomy of higher H_2SO_4 concentration in the north.

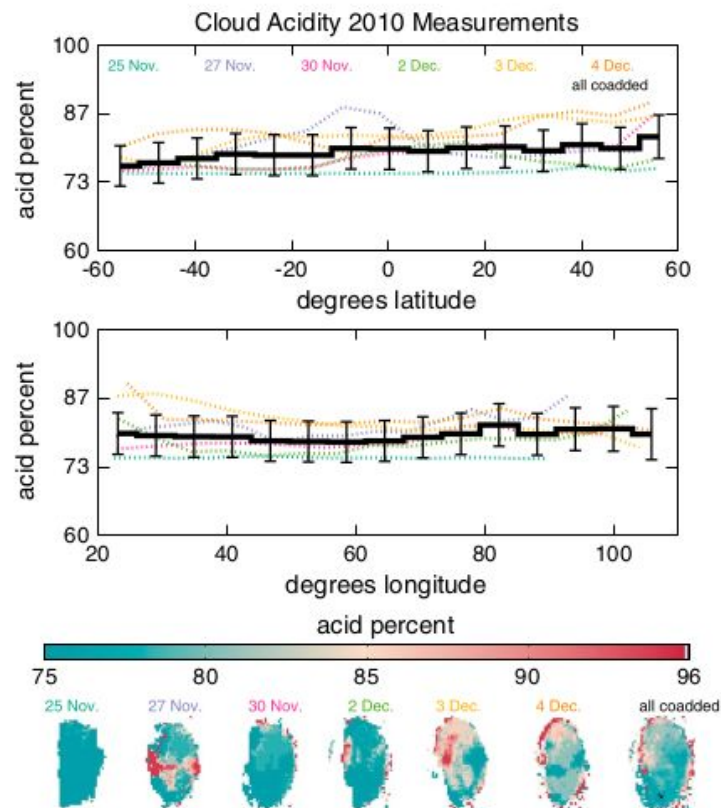
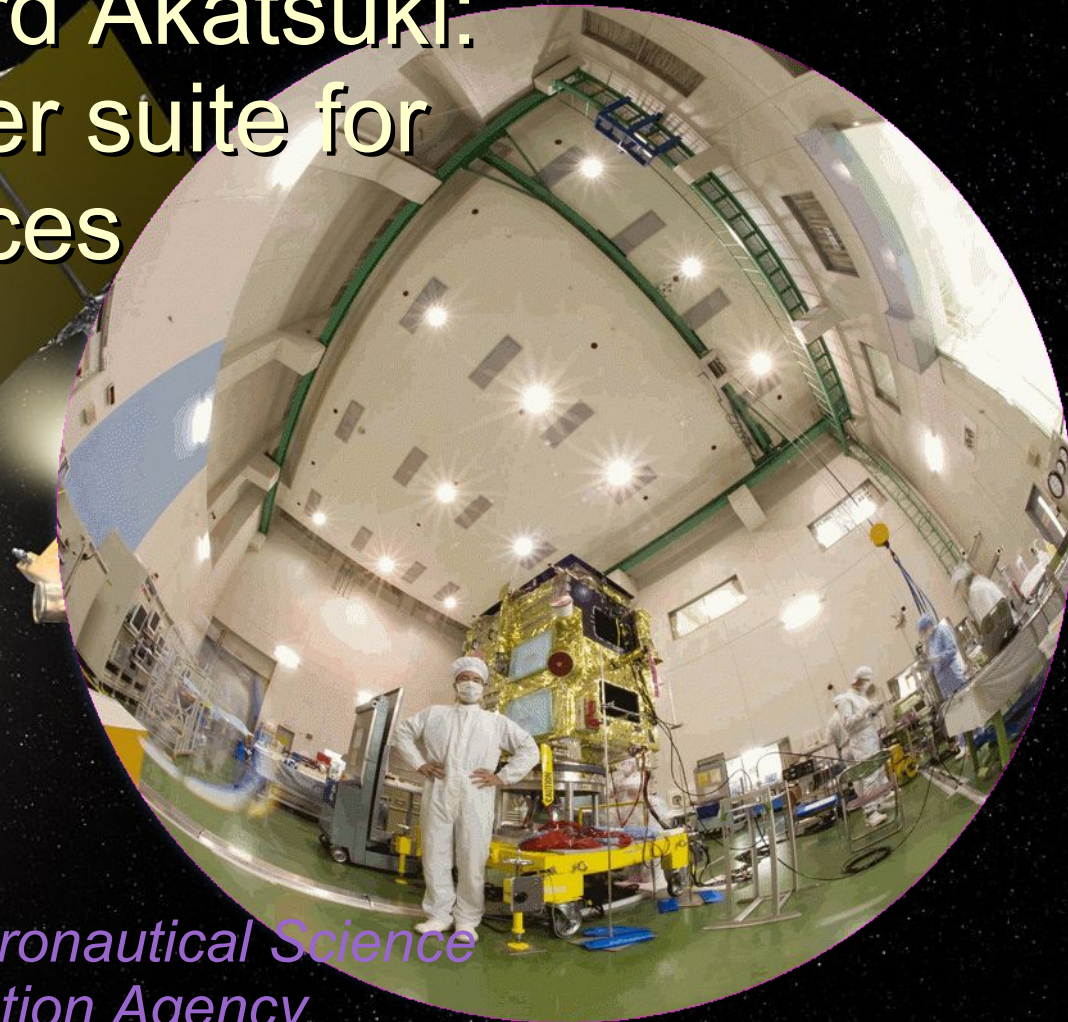


Figure 11. Acid concentration maps from 2010. There may be a hemispherical dichotomy with more H_2SO_4 concentration in the north.

IR1+IR2 onboard Akatsuki: A near-IR imager suite for planetary sciences



Takehiko Satoh

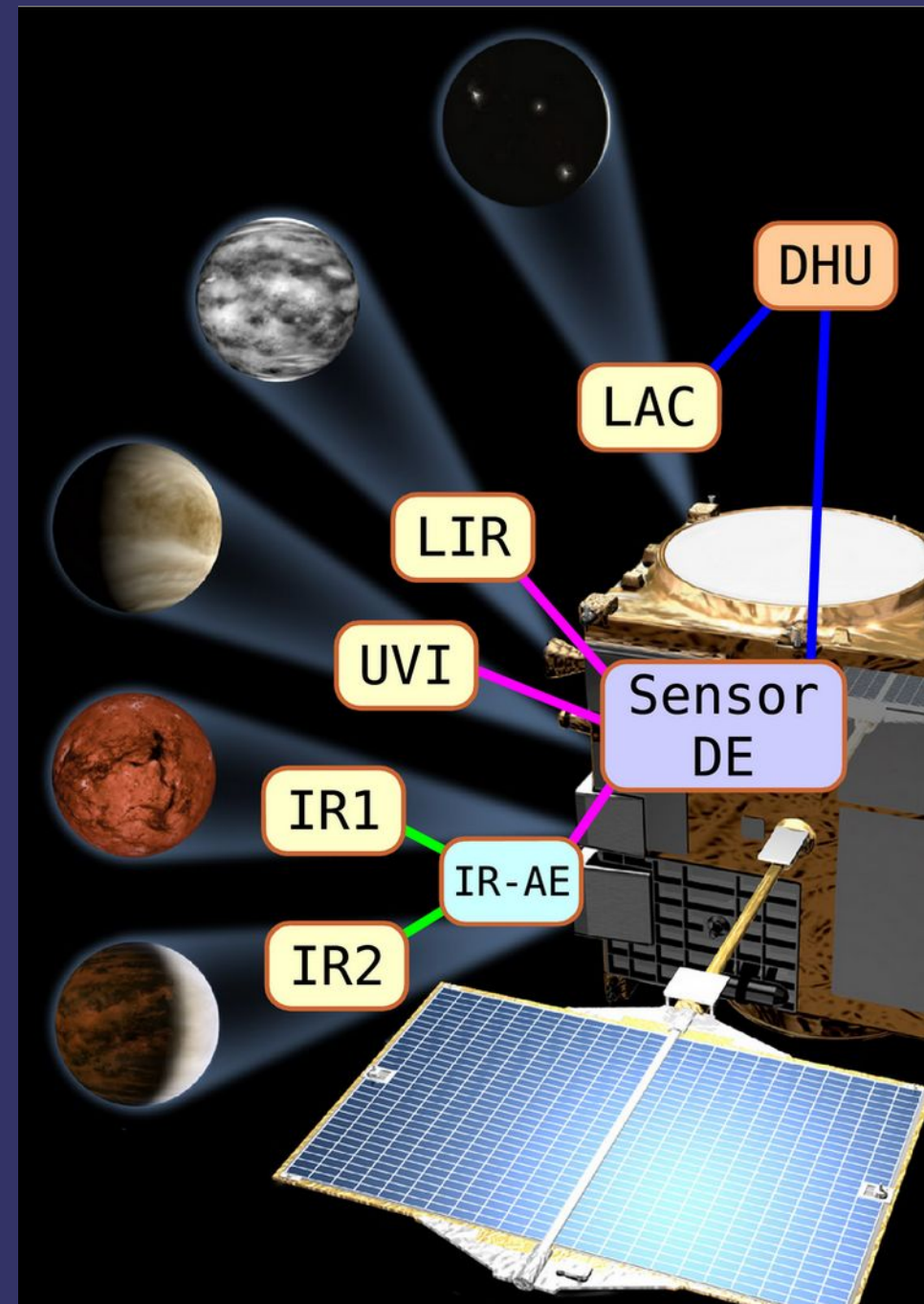
*Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency*

Takehiko Satoh

IR1+IR2 on Akatsuki

	Scientific targets	Wavelengths
LAC	Lightning and airglow	777 nm (lightning), 480-605, 558 nm (airglow), 545 nm (background)
LIR	Cloud-top temperature	9-11 um
UVI	Cloud motion, UV absorber and SO2 distribution	283 nm, 365 nm
IR1	Surface temp. , minerals and clouds	0.90, 0.97, 1.01 um (night), 0.90 um (day)
IR2	Mid to lower cloud motion, CO, cloud-top alt., and zodiacal light	1.735, 2.26, 2.32 um (night), 2.02 um (day), 1.65 um (zodiacal light)

- IR1 and IR2 shares IR-AE
- Data from Sensor DE goes to DHU
- Data stored on DR (in DE)



IR1 (1- μm Infrared Camera)

“Cloud Tracking” for dynamics

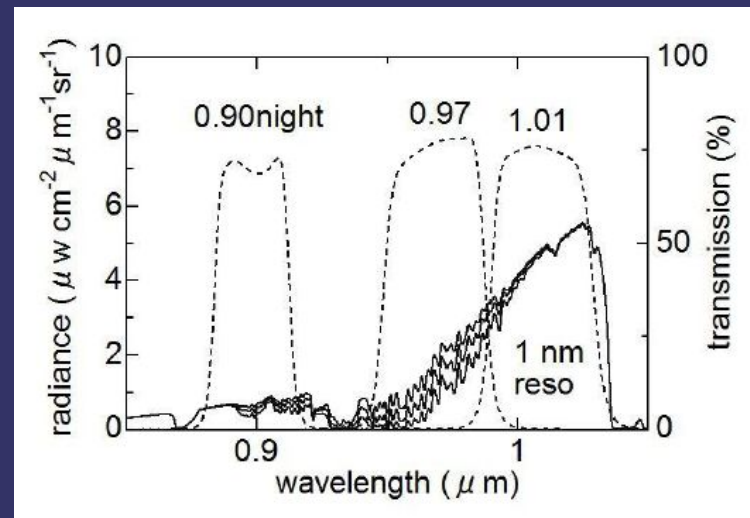
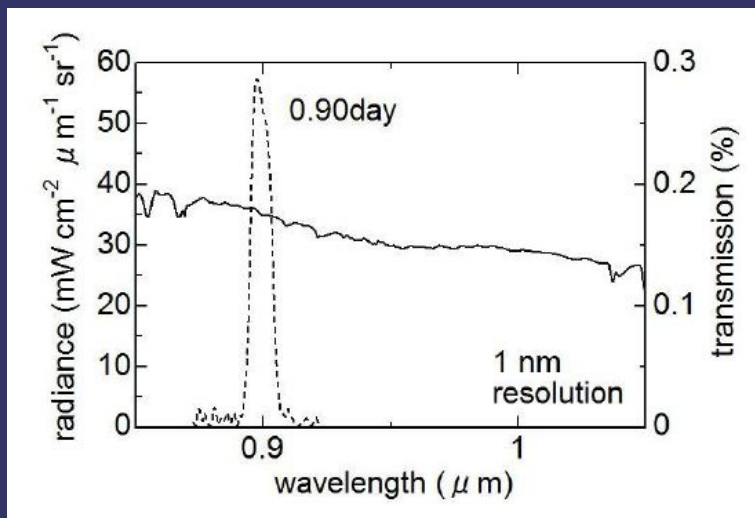
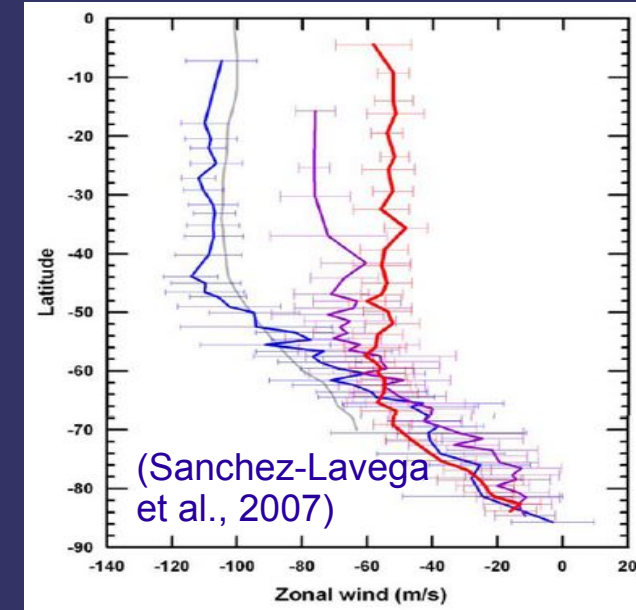
Day side (0.90 μm): winds within clouds

Night side (0.90 μm): winds at cloud base

“Surface & H₂O” study

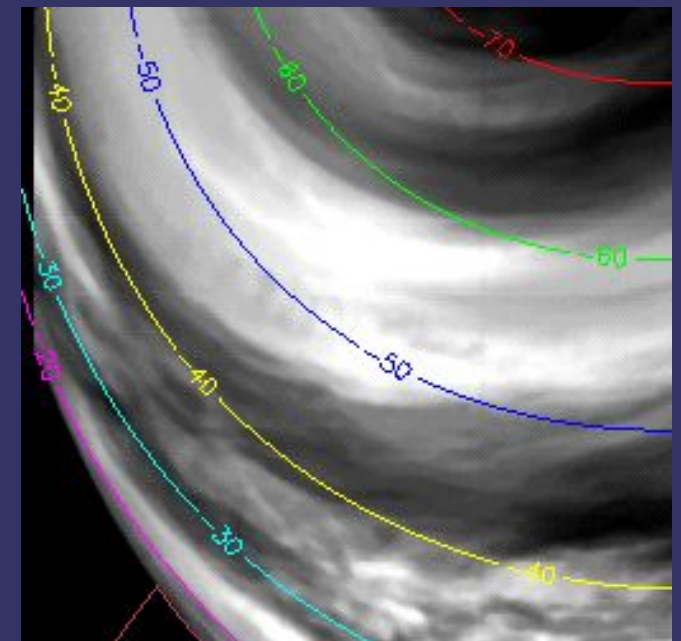
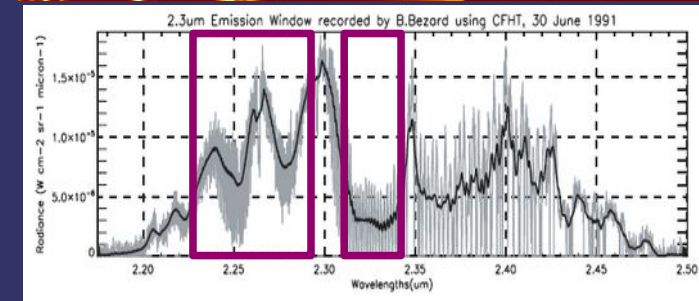
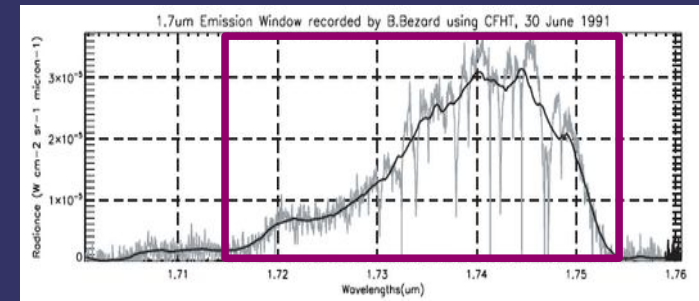
1.01 or 0.90 μm for surface emissivity

0.97 μm for H₂O absorption

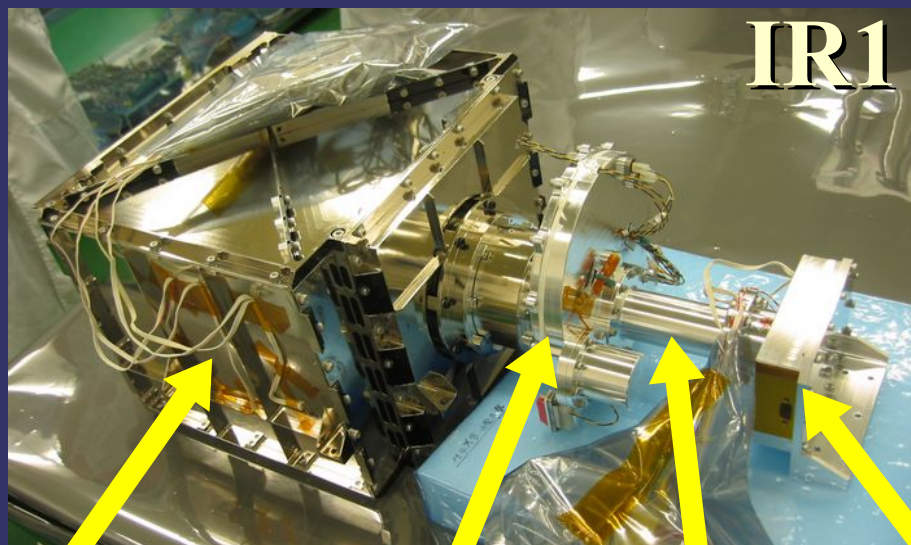


Science Targets of IR2

- Venus Night (un-illuminated) Side
 - Imaging in 1.735 μm , 2.26 μm , 2.32 μm windows
 - Motion in the mid-to-low atmosphere
 - 1.735 μm , 2.26 μm combination
→ physical properties of aerosols
 - 2.26 μm , 2.32 μm combination
→ spatial & temporal variability of CO
- Venus Day (illuminated) Side
 - Imaging in 2.02 μm CO₂ absorption band
 - Peaks and dips in pixel-to-pixel photometry
→ complements cloud-top temperature measurements with 10- μm camera (LIR)
- Zodiacal Light (while cruising)
 - Imaging in 1.65 μm (Astronomical H band)
 - Map interplanetary dust distribution in the region 0.7 – 1.0 AU for the first time



Outlook of IR1~IR2~IR-AE~DE



Box-shape
light baffle

6-position filter
wheel

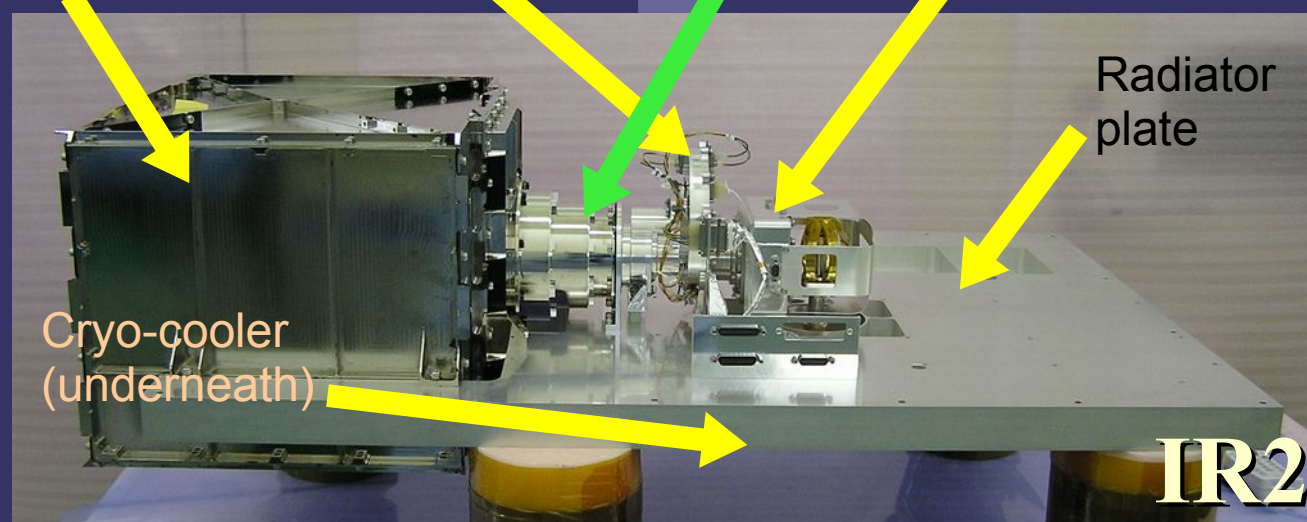
Lens &
housing

Detector
housing

Flow of data
& command



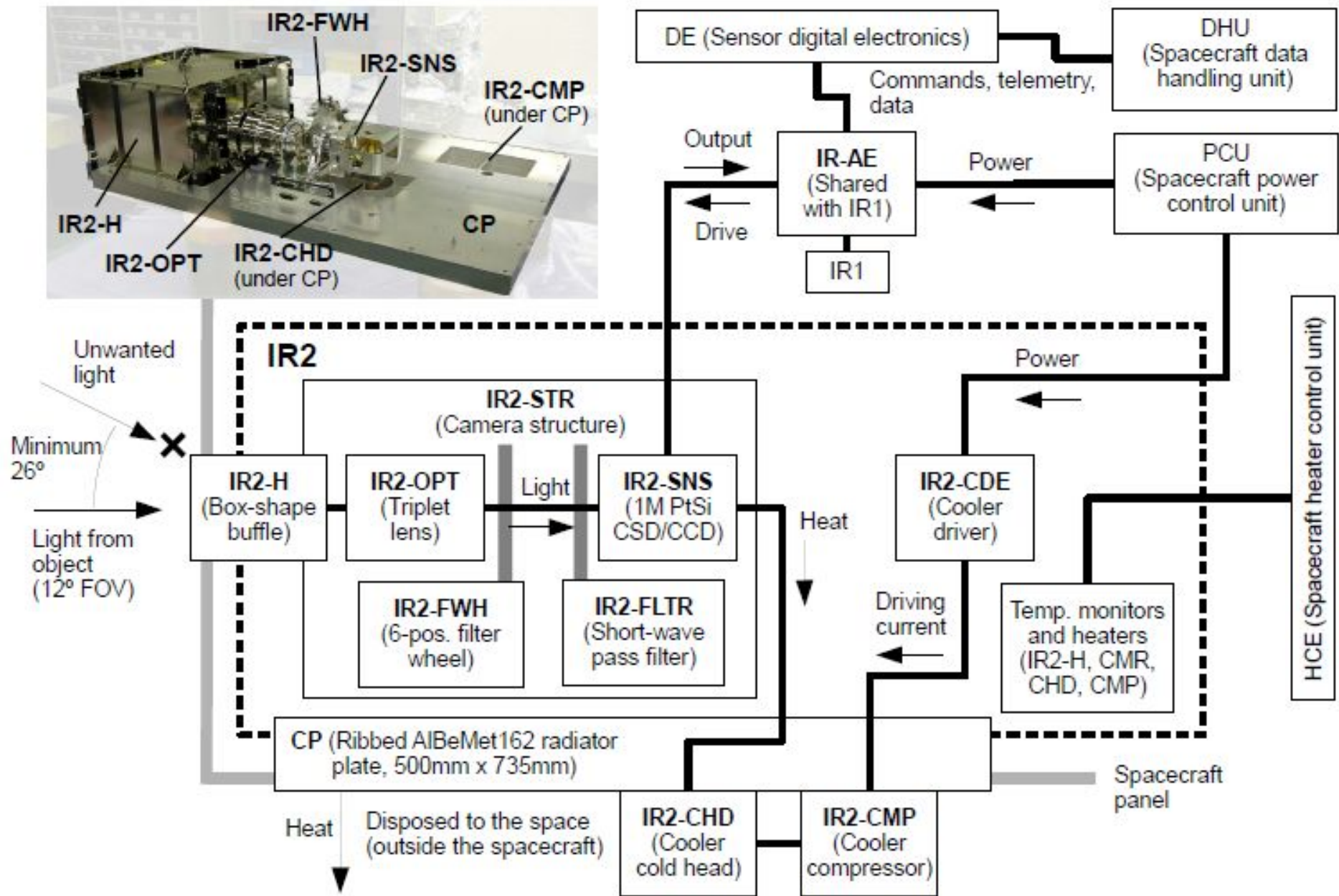
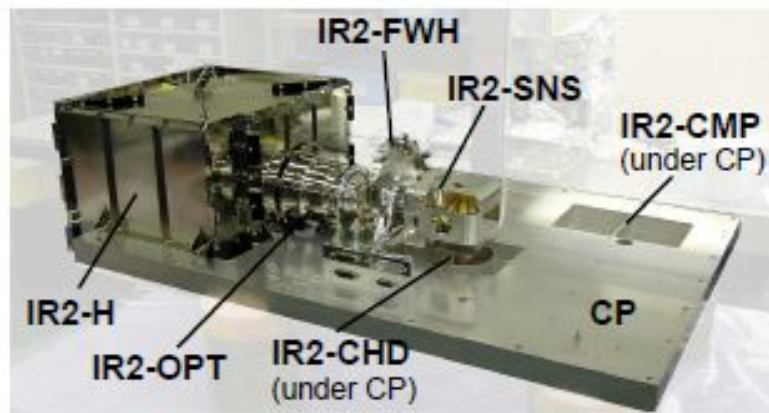
Flow of data
& command



Radiator
plate

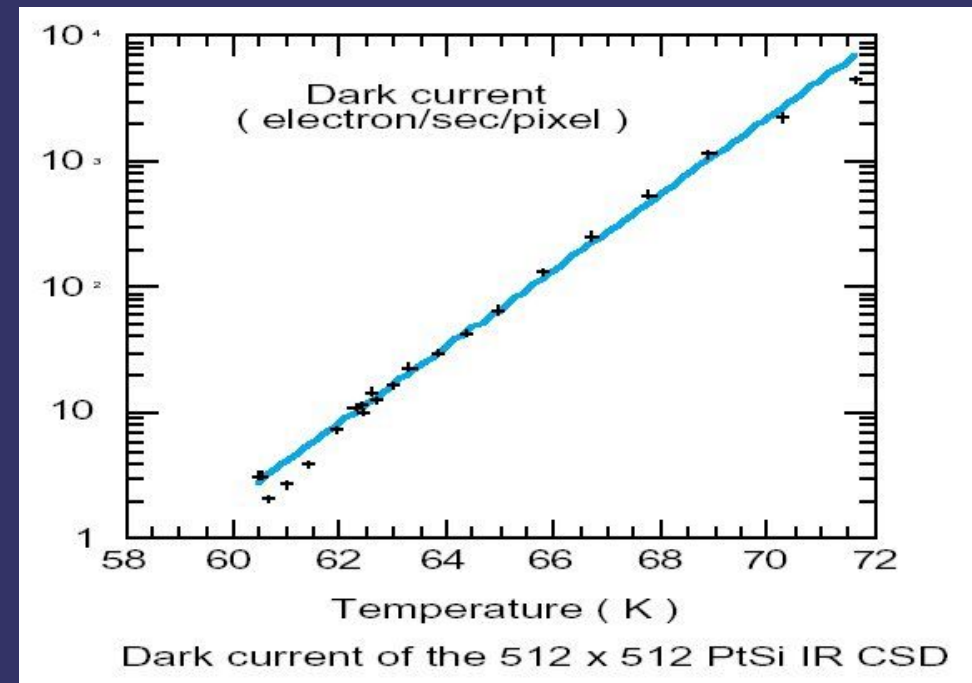
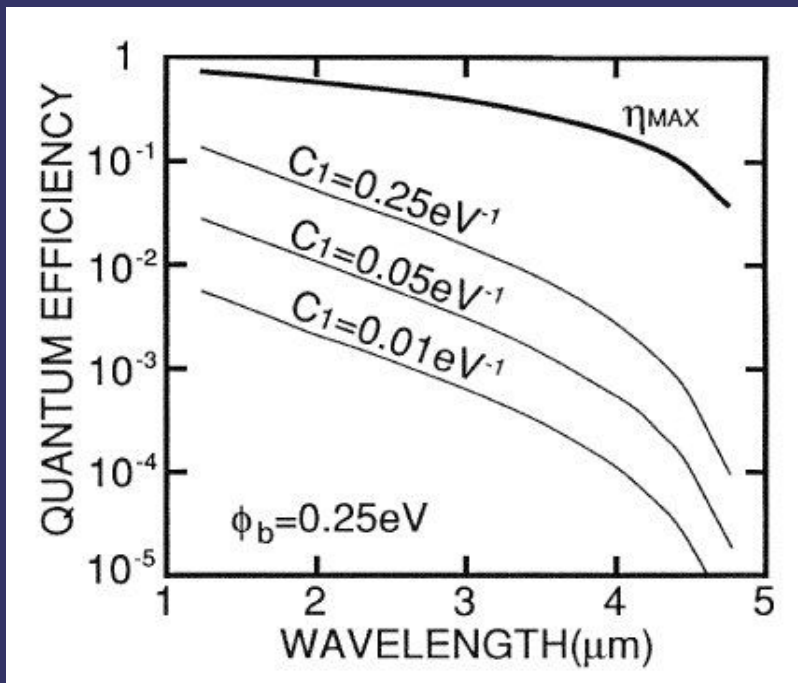
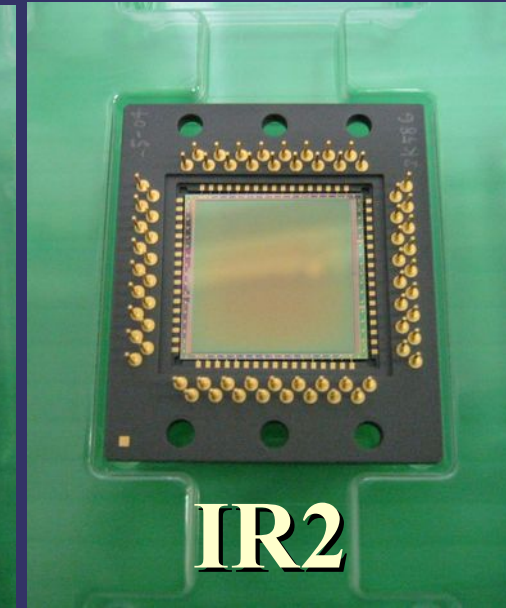
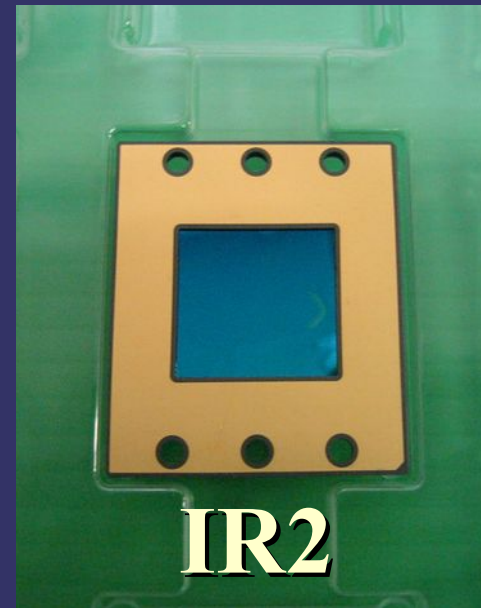
Cryo-cooler
(underneath)





PtSi Detector on IR2

- Domestic sensor (MELCO)
 - 1024x1024 pixels with 17 μ m pitch + 8-lines OB area (1040x1040 total)
 - QE *not* very high (~4% @ 2 μ m) but uniformity and stability superb
 - CSD (Charge-Sweep Device) transfer in vertical lines, achieving a good fill factor (59 %) w/o micro lenses



How CSD/CCD works

- ◆ CSD (Charge-Sweep Device) transfers electrons in vertical.
- ◆ CCD (Charge-Coupled Device) transfers electrons in horizontal.

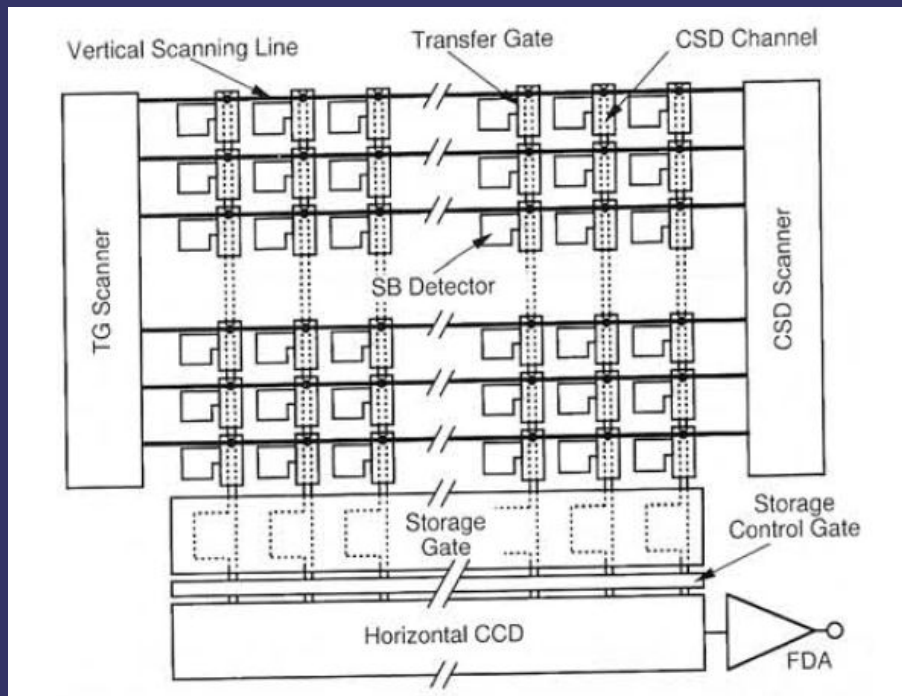


Fig. 3. Block diagram of Schottky-barrier FPA with Charge Sweep Device (CSD) readout architecture.

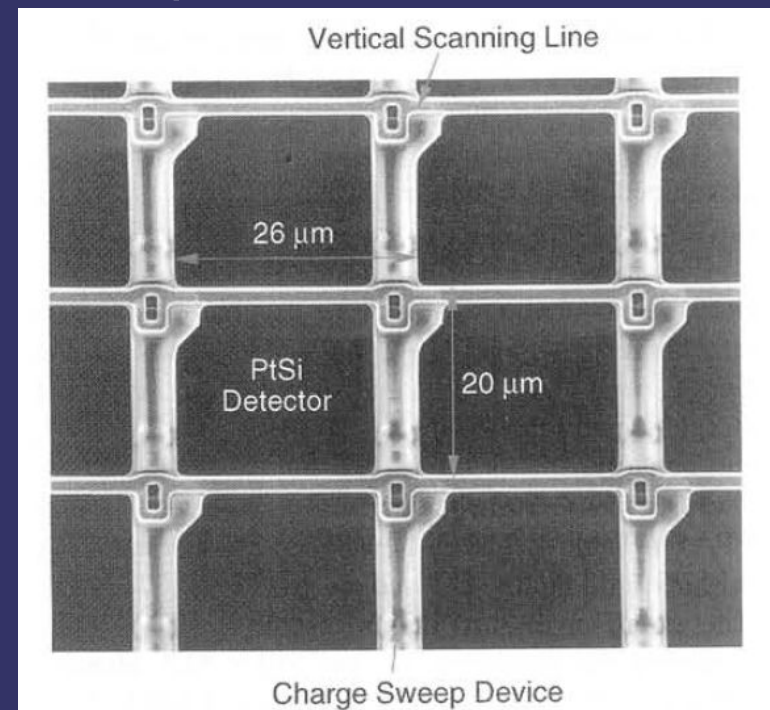
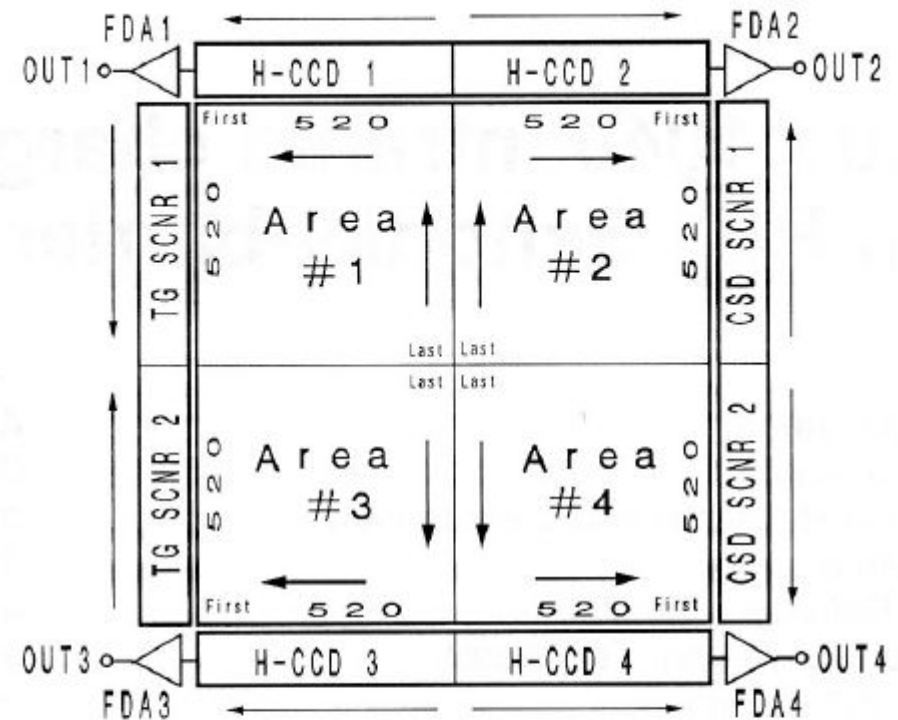


Fig. 6. Pixel photograph of 512 × 512 element PtSi Schottky-barrier FPA designed with CSD readout architecture. The photograph was taken just before the Al reflector formation. The pixel size and fill factor are 26 × 20 μm² and 71%, respectively.

Actual MELCO sensor

- Full frame (1040x1040 pixels) is electronically divided to 4 quadrants.
 - PtSi formed in the inner 1024x1024-pix region, leaving IR non-sensitive margin of 8 pixels wide
- Each quad is read via a FDA on the corner after CSD/CCD transfer of electrons from pixels.



FDA : Floating Diffusion Amp.

H-CCD : Horizontal CCD

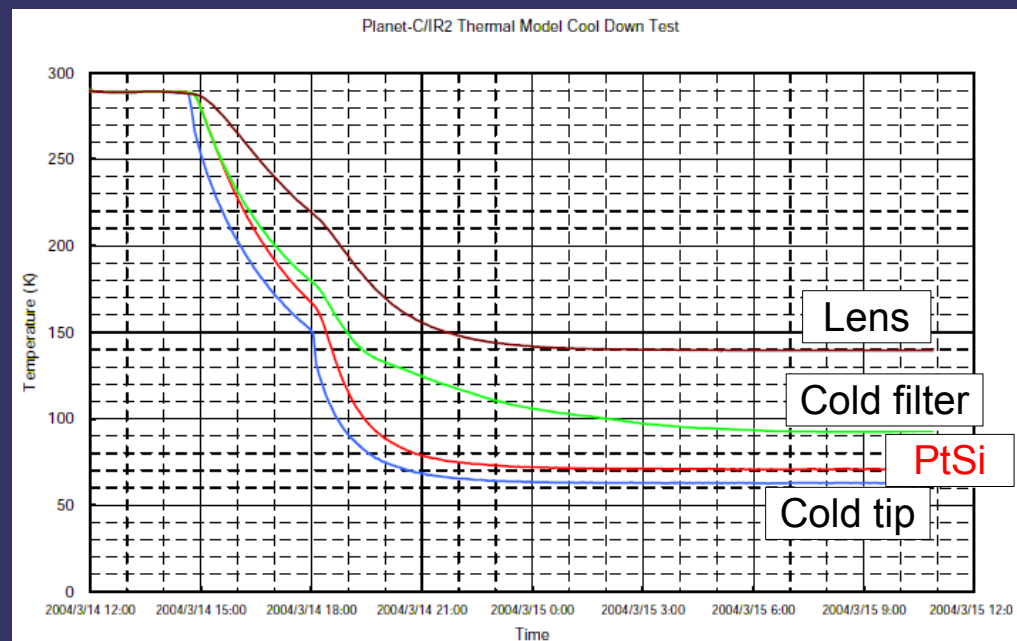
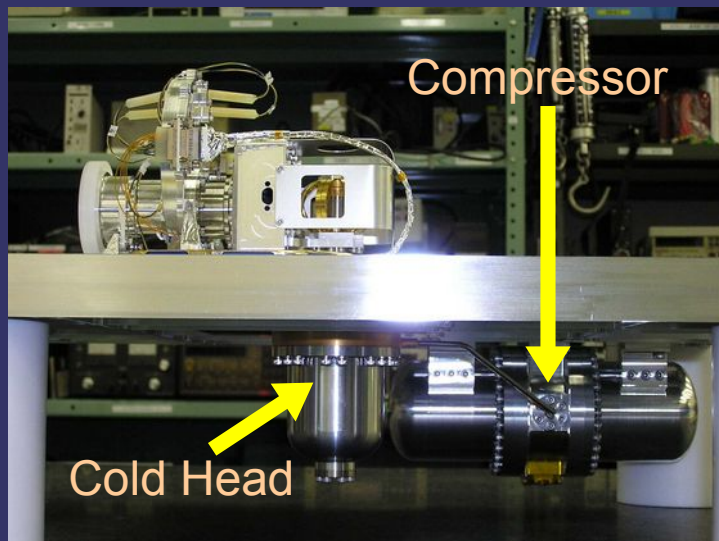
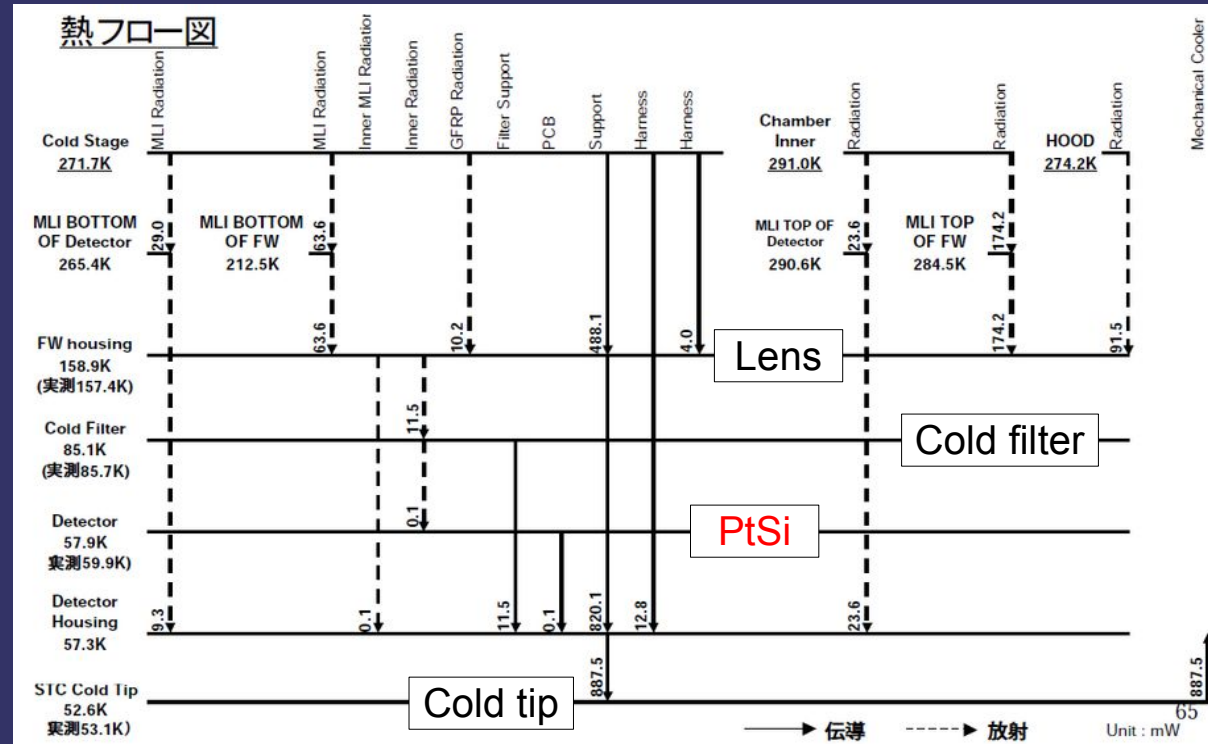
TG SCNR : Transfer Gate
Scanner

CSD SCNR : CSD Scanner

Fig. 3 Block diagram of 1040×1040 IRCSD.

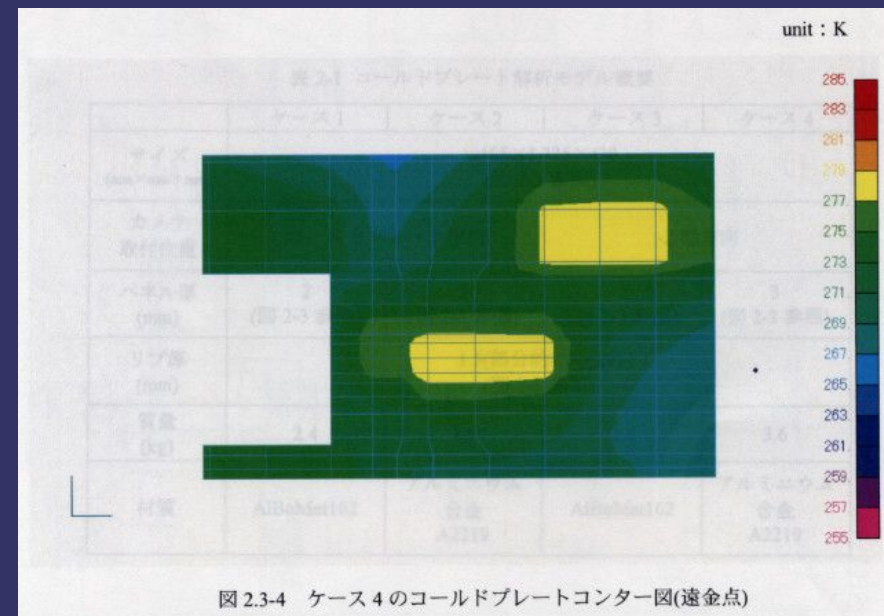
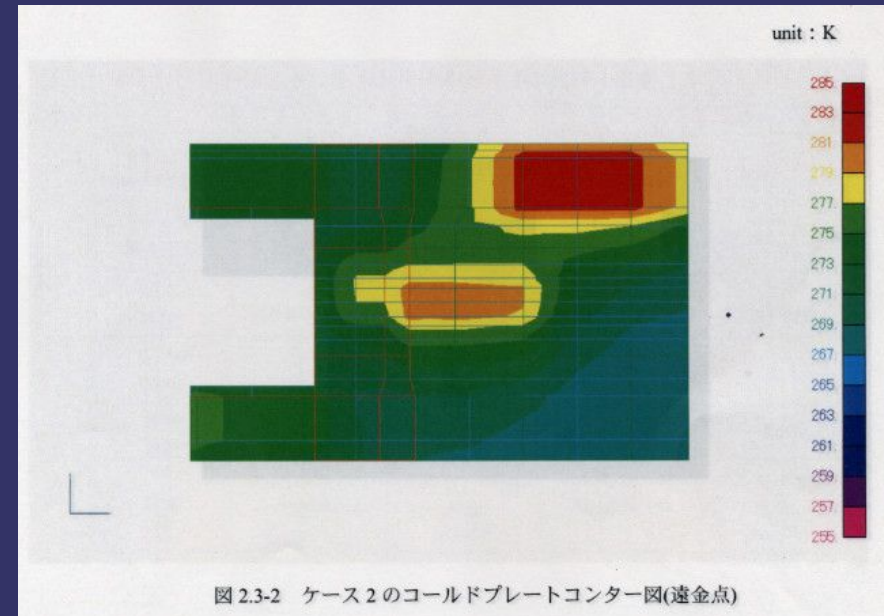
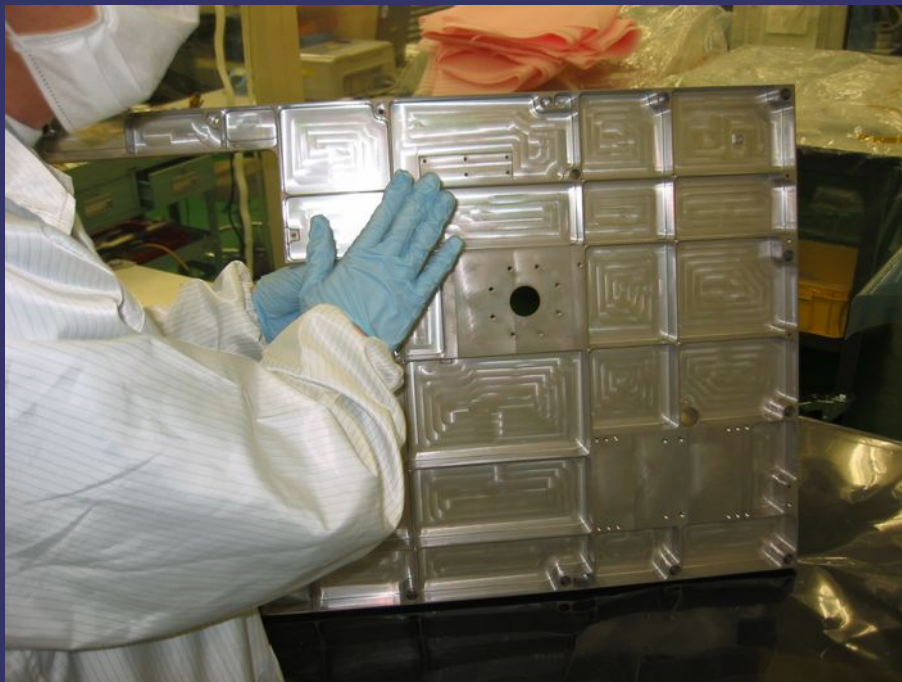
IR2 Cooling System

- Cryo-cooler for IR2's PtSi CCD
 - A single-stage Stirling-cycle cryocooler (SHI) cools the detector down to desired temperature (**65K**)
 - Removed heat is disposed to the space through an AlBeMet-alloy radiator plate with sufficient area (500x735 mm²)



Cooling was *not* all that straightforward!

- Two major components generate heat
 - The IR2 Compressor
 - The IR2 Cold Head
- Their locations on the radiator plate are very important, affecting the heat distribution & utilization of the available surface area for heat disposal.



Optics of IR1/IR2

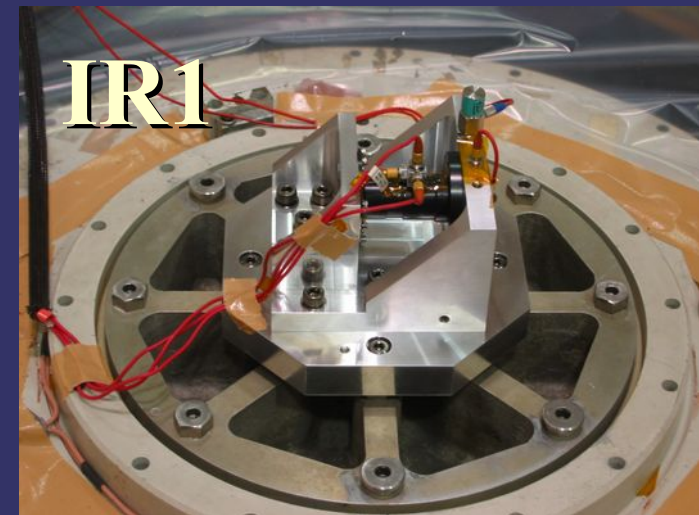
Designed & manufactured by Nikon
Common spec: $f = 84.2 \text{ mm}$ Triplet optics
(Glass materials are different, of course)

For IR1

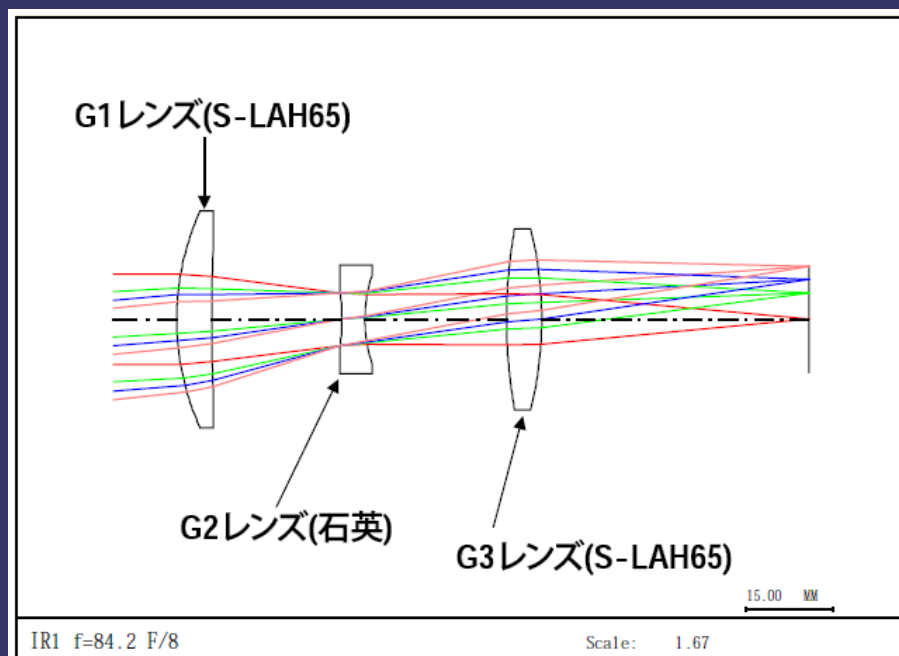
F/8、Nikon provided the lens assembly

For IR2

F/4、Nikon provided shaped glasses, and
SHI manufactured the low-temperature holder

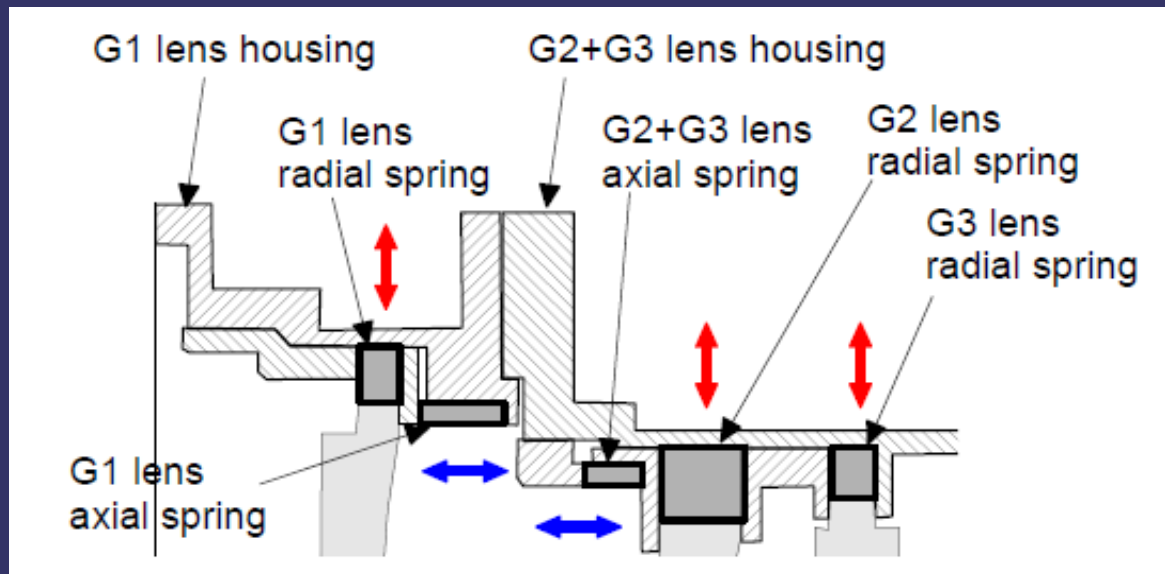


Photos of IR1 lens assembly tests (top: vibration test, bottom: optical performance test)



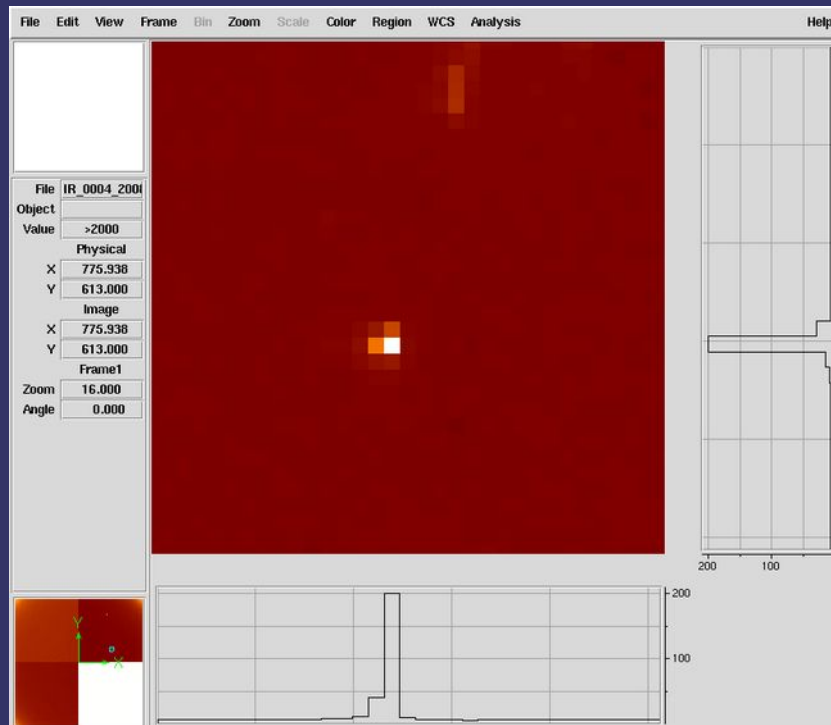
Low-Temp Lens Holder

- Two conflicting requirements:
 - At the time of *launch*: the lens, at normal temp, needs to be tightly held to survive vibration.
 - But, the lens should not be held too tight, when it is cooled to operation temp, to avoid excessive stress which could damage the glass.
- Satisfied with carefully-designed spring mechanism in both axial and radial directions.



Optical Performance of IR2

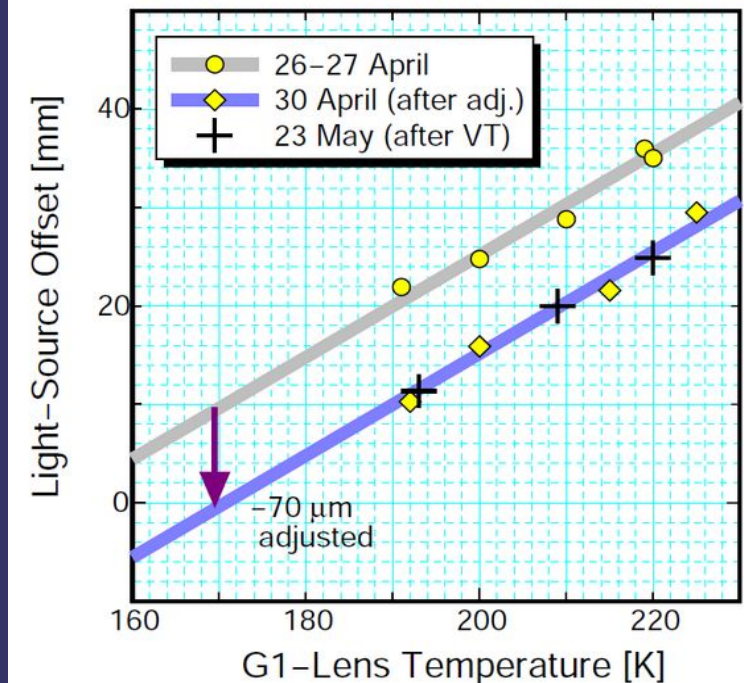
- Low-temp focus tests in a space chamber
 - Focus shift: $4.5 \mu\text{m} / \text{K}$
Operation temp (optics): $162 \text{ K} \pm 10 \text{ K}$
 - The best focus is $\text{FWHM} \sim 1 \text{ pixel}$
Degradation of optical performance in $\pm 10 \text{ K}$ is acceptable (F/4 lens with $17\text{-}\mu\text{m}$ pitch pixel)
- High-performance optics successfully been made.



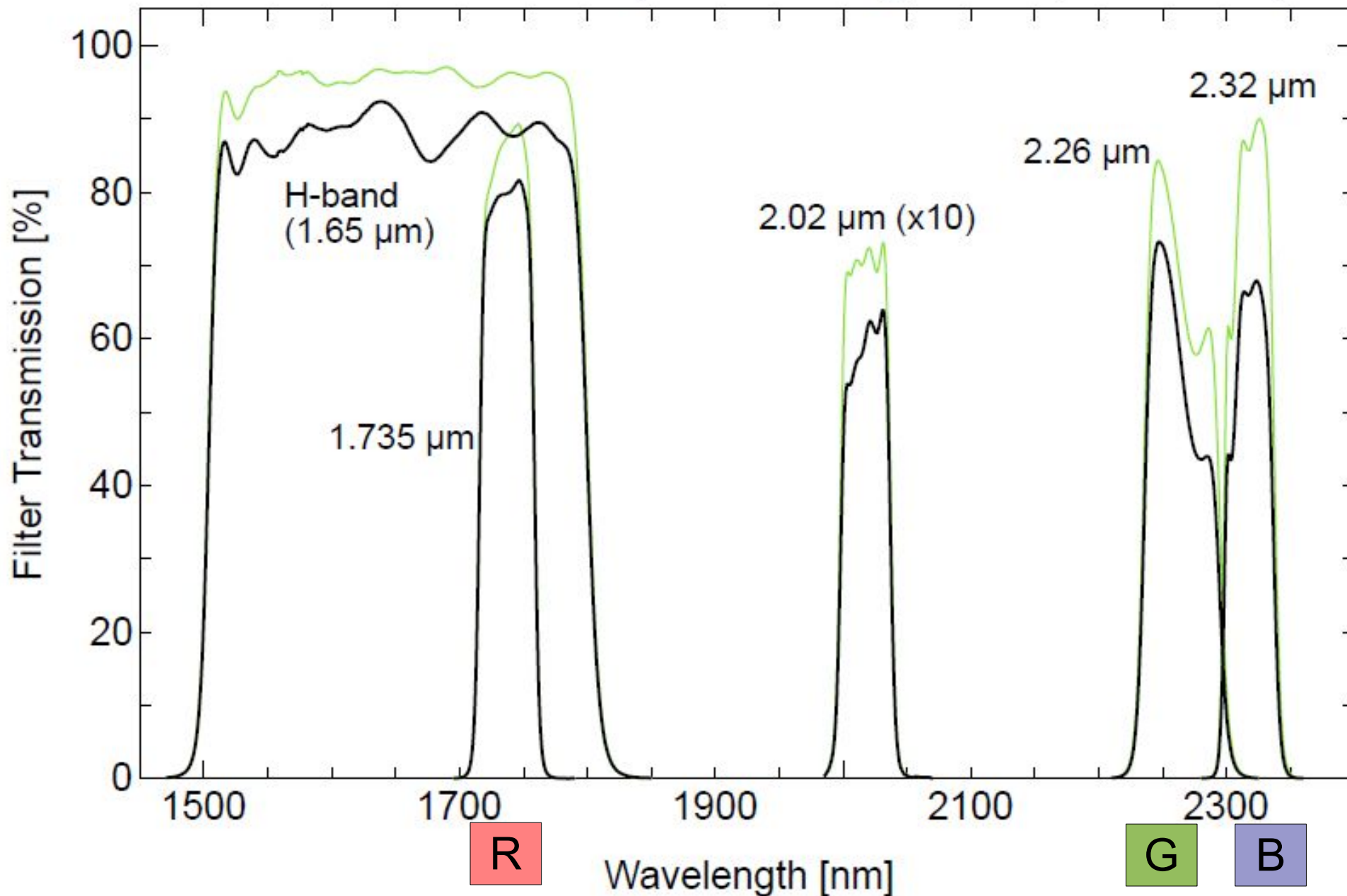
LEFT: The spot image at IR2's best focus. Most of light is in one center pixel with only little in adjacent pixels.

RIGHT: Temp-dependent focus of IR2. A 10-mm light source offset translates to 90 μm offset at the focus.

Temperature-Dependent Focus of IR2



IR2 filter transmission (Half-cone angle = 15° , $T = 298$ K)



IR2 images Sagamihara



IR2 Data “How To”



Observation



Restoration



Takehiko Satoh, and IR2 Team

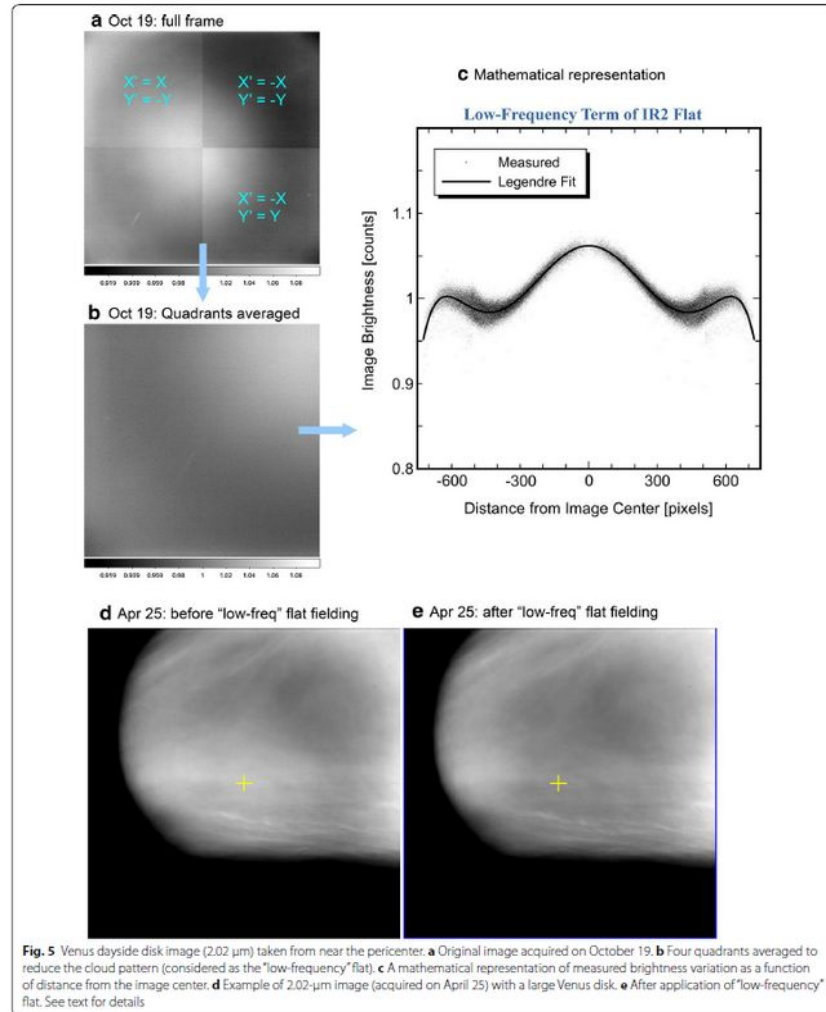
Pre-Optics	Optics	Camera	Filters	Detector	Electronics
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Low-frequency flat-field pattern

- Equation published
 - Sato et al. (2017)
 - May be applied AFTER corrected for PSF

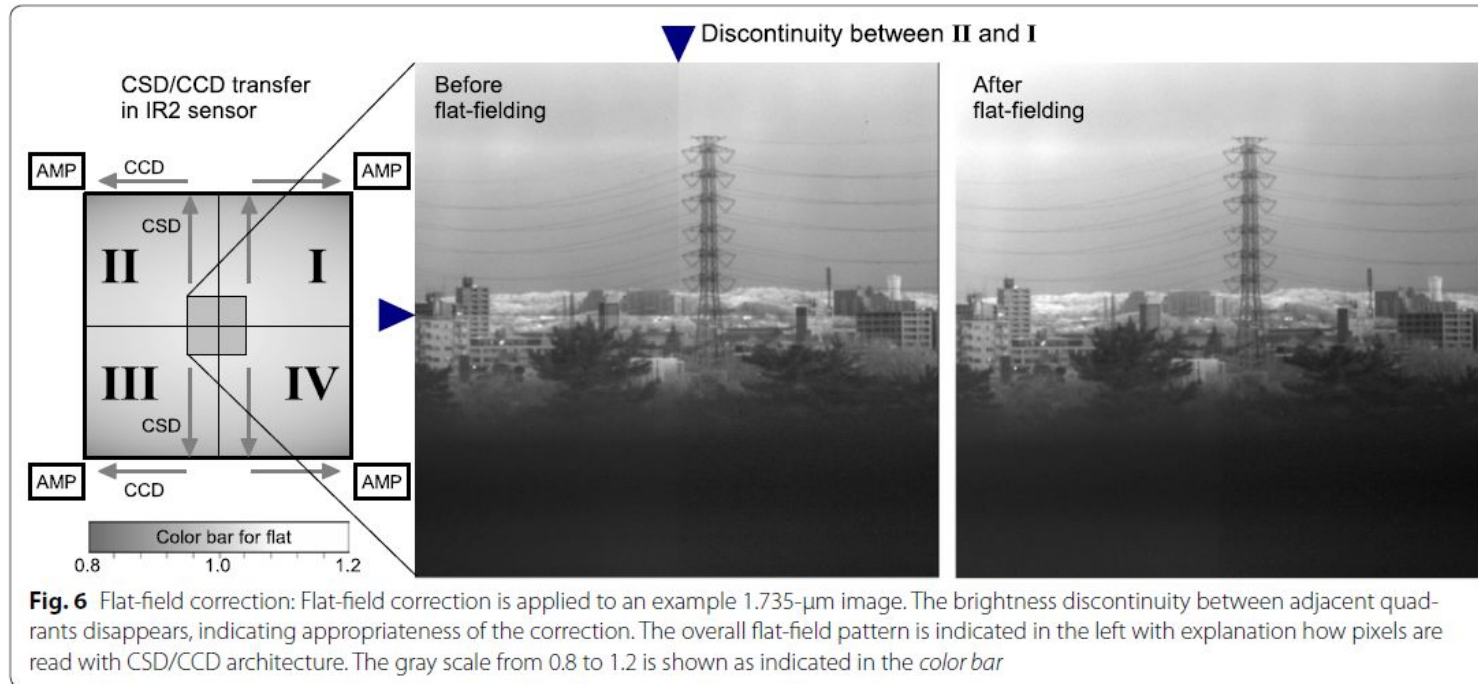
Table 5 Coefficients for “low-frequency” flat

Order i	Coefficient for $P_i(t)$	Order i	Coefficient for $P_i(t)$
0	1.009934	6	-0.049436
2	-0.045019	8	-0.002947
4	0.038583		



High-frequency flat-field pattern

- Pre-launch measurements (Sato et al., 2016)
 - Corrected in L2B



Pre-Optics

Optics

Camera

Filters

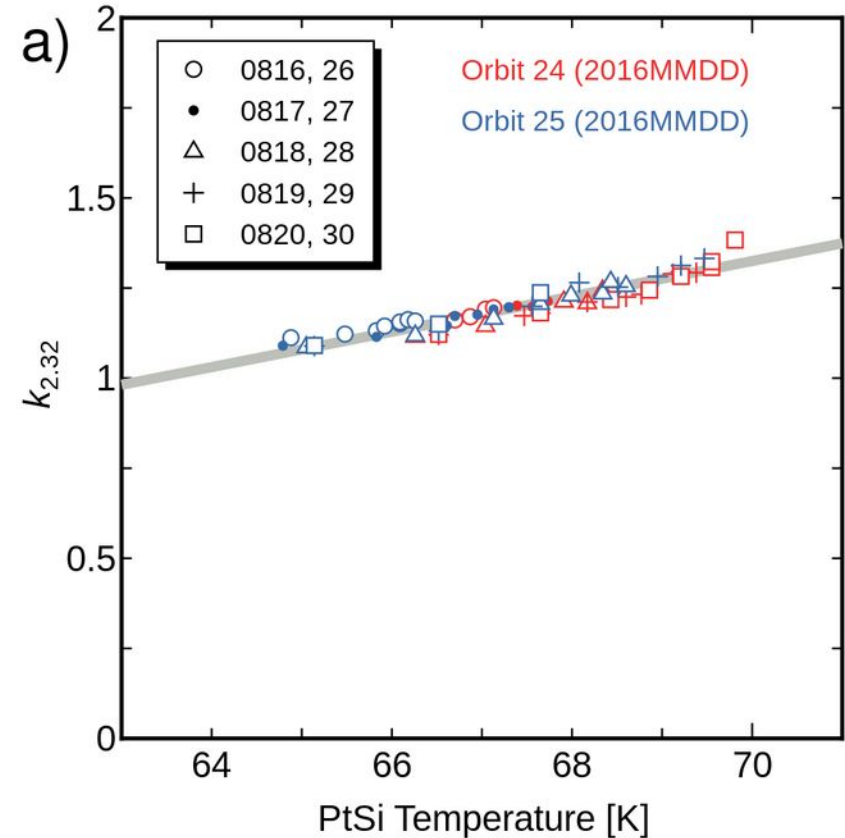
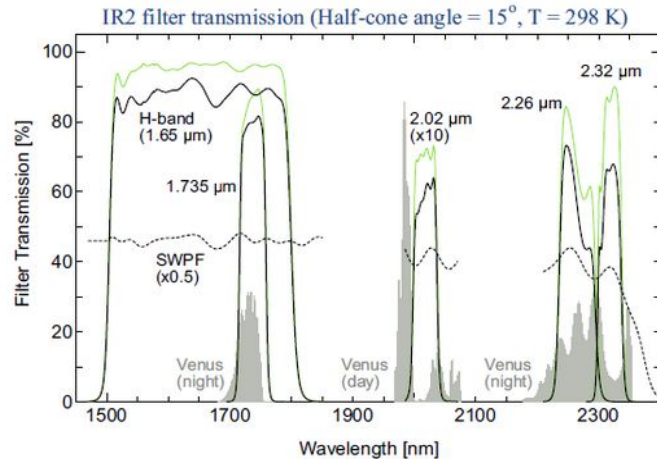
Detector

Electronics

Slight changes of inter-band sensitivity

- Equation published
 - Satoh et al. (2021)
 - Noticeable for 2.26/2.32
 - Not noticeable for 1.735/2.26

$$k_{2,32} = 0.0491 T - 2.11$$



Pre-Optics

Optics

Camera

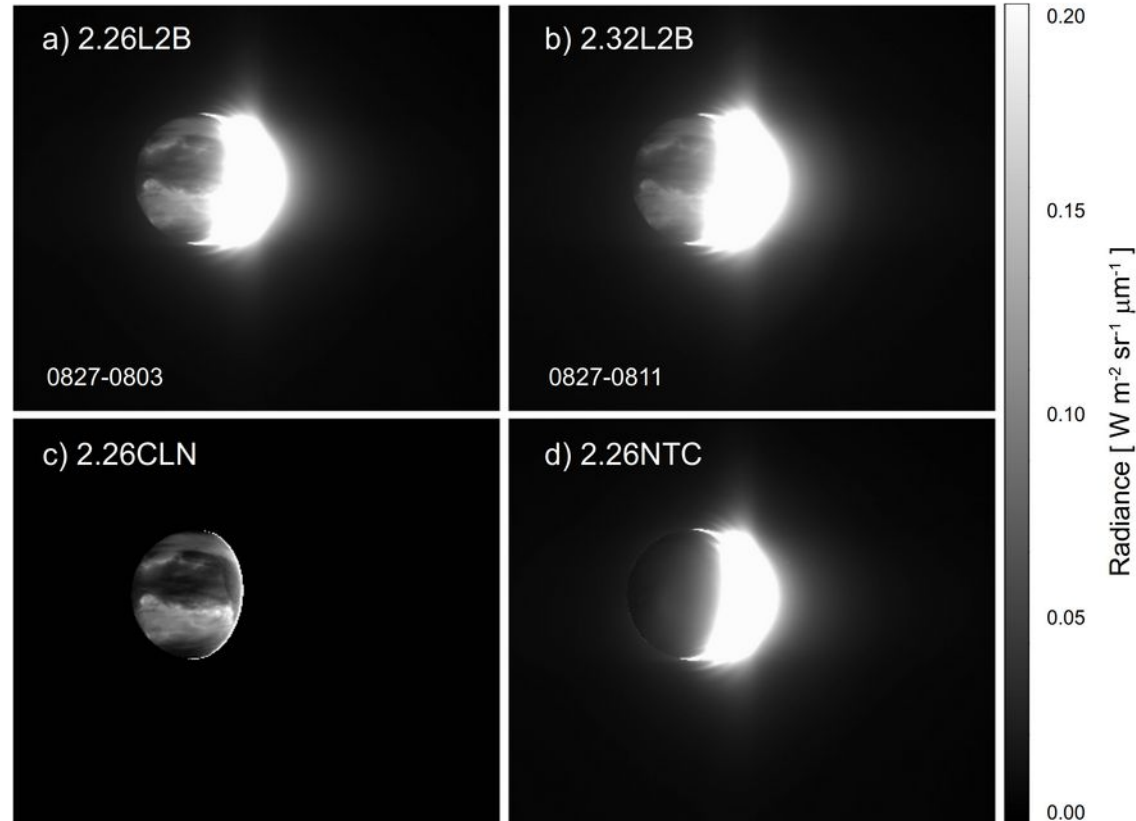
Filters

Detector

Electronics

Multiple reflection in Si substrate (an extended PSF)

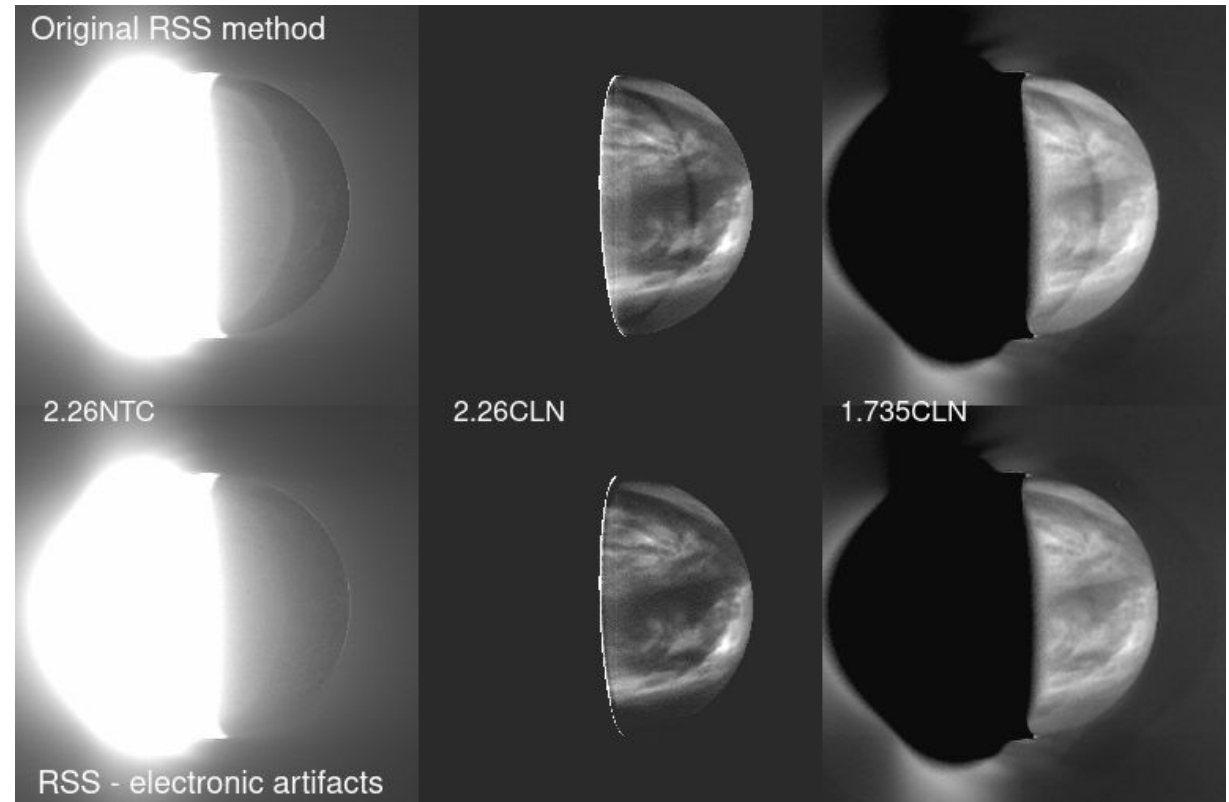
- Can be reduced by
 - Subtraction (RSS)
L2S datasets will be shared
Sato et al. (2021)
 - Deconvolution (RD)
L2D datasets will be shared
Sato et al. (2020)
- Leave it as is
 - Okay for cloud tracking or morphological studies
(image enhancement would be applied any way)



Pre-Optics	Optics	Camera	Filters	Detector	Electronics
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Mirror-symmetric repetitions

- Reported by Satoh et al. (2017)
 - Can be corrected for only very limited cases



Pre-Optics	Optics	Camera	Filters	Detector	Electronics
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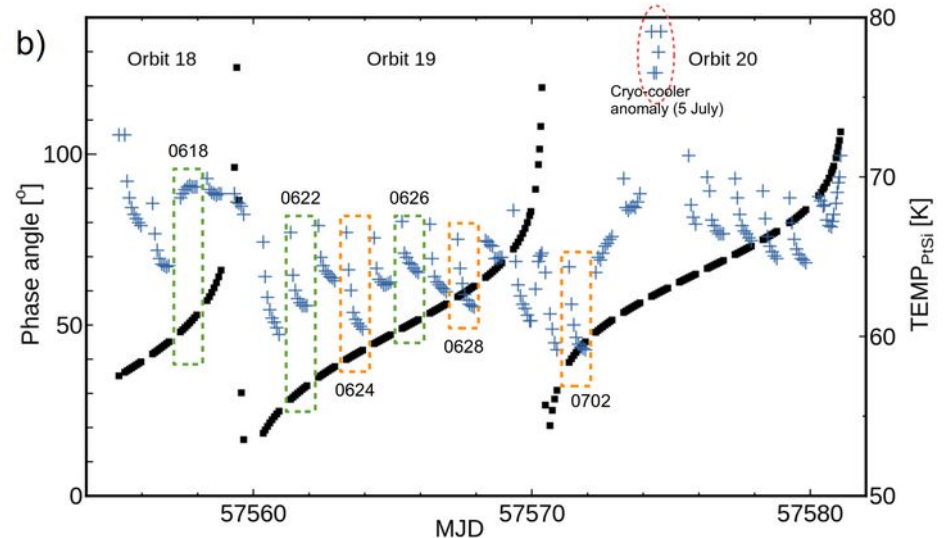
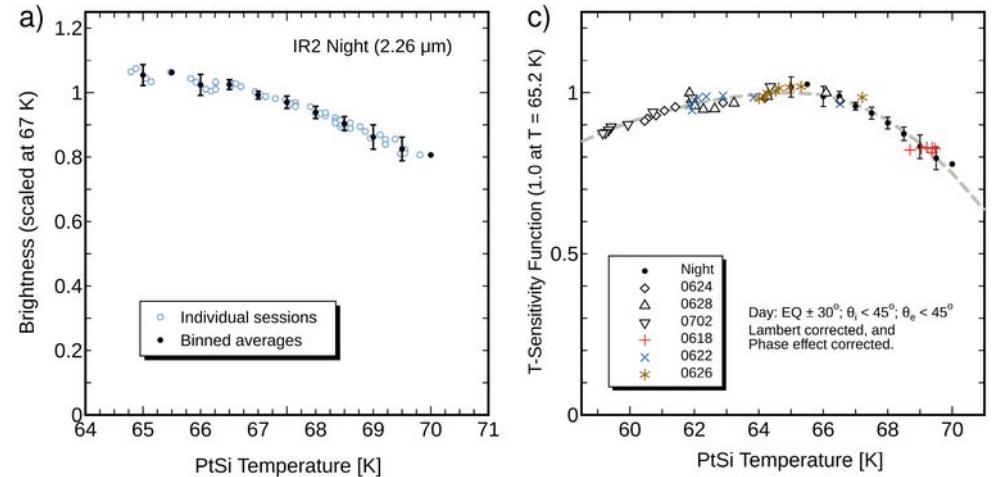
Temperature dependent sensitivity (T-SENS)

- Equation published
 - Sato et al. (2020) (the first use)
 - Sato et al. (2021) (details of derivation)

Low temperature ($T_{\text{PtSi}} < T_0$): $I'_{\text{L2B}} = I_{\text{L2B}} / \left[1.0 - p_{59\text{K}} \times \left(\frac{T_{\text{PtSi}} - T_0}{59 - T_0} \right)^2 \right]$

High temperature ($T_{\text{PtSi}} \geq T_0$): $I'_{\text{L2B}} = I_{\text{L2B}} / \left[1.0 - p_{70\text{K}} \times \left(\frac{T_{\text{PtSi}} - T_0}{70 - T_0} \right)^2 \right]$

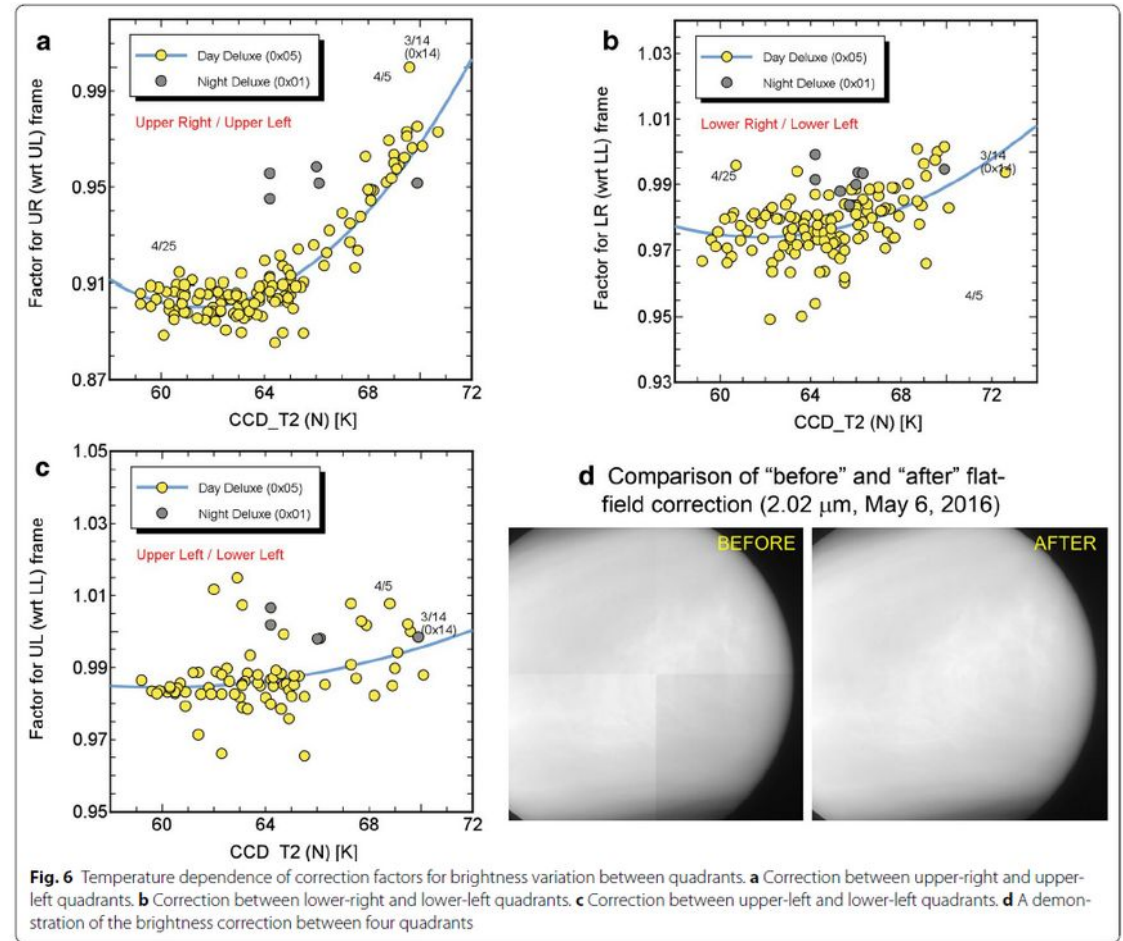
($p_{59\text{K}} = 0.13$, $p_{70\text{K}} = 0.25$, and $T_0 = 65.2$ K)



Pre-Optics	Optics	Camera	Filters	Detector	Electronics
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Brightness variations among quadrants (T-dependent)

- Equation published
 - Satoh et al. (2017)
 - Corrected in L2B (v. 0.5 is the latest)
 - Day-side: full correction
 - Night-side: only upper/lower variations



Pre-Optics

Optics

Camera

Filters

Detector

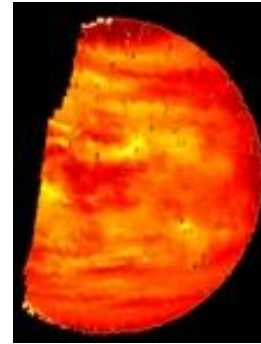
Electronics

あかつきIR2が見つけた 金星夜面における静穏領域

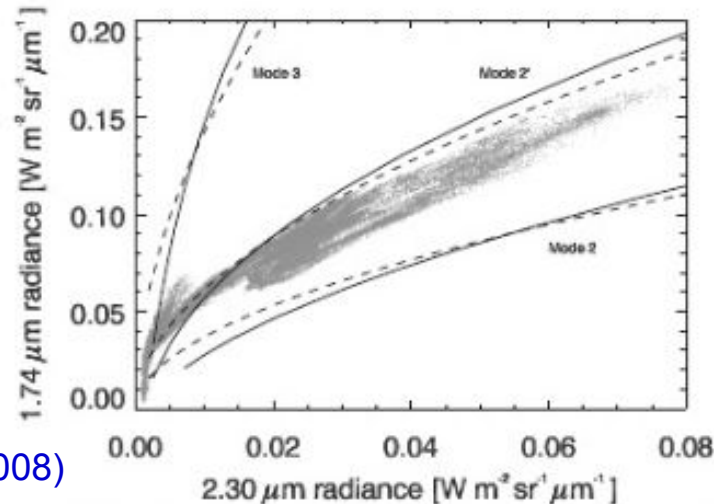
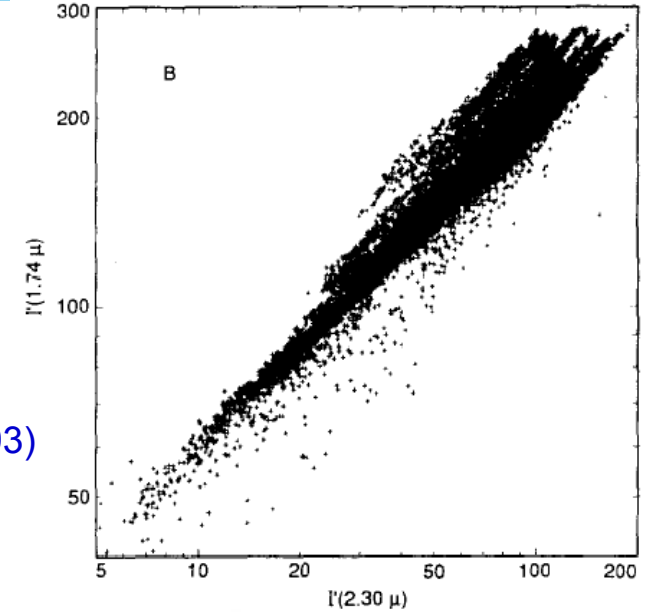
佐藤 毅彦 (ISAS)
佐藤 隆雄 (北海道情報大)
Vun Choon Wei (総研大)
堀之内 武 (北海道大)

イントロ: 夜面2波長データの使い方

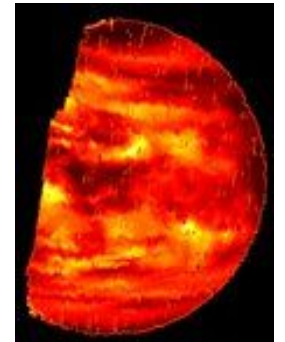
- 金星夜面では、いくつかの「窓」波長において、中下層の雲の濃淡をシルエットとして観測することができる(Allen and Crawford, 1984)。
- Galileo/NIMSデータ解析(Carlson et al., 1993)以来、 $2.3\mu\text{m}$ と $1.74\mu\text{m}$ の相関プロットが、異なる粒子サイズの雲の存在を示すものとして使われてきた。
- Venus Express搭載VIRTISでも同様の手法が適用されている(Wilson et al., 2008)。



Carlson et al. (1993)

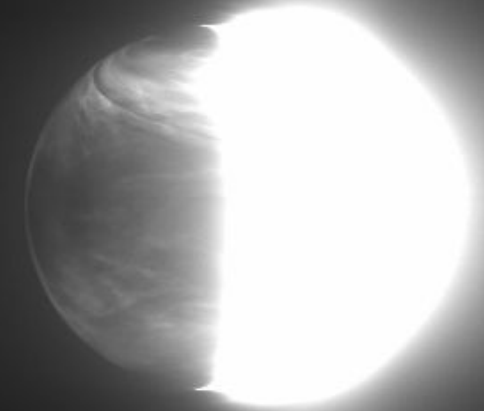
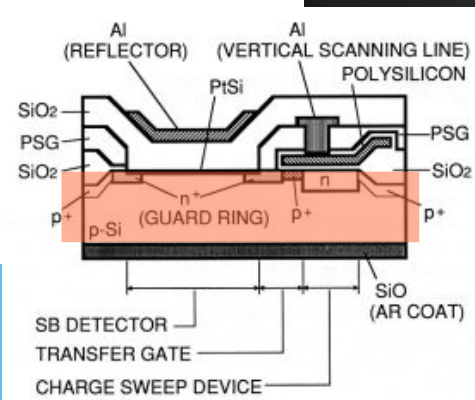
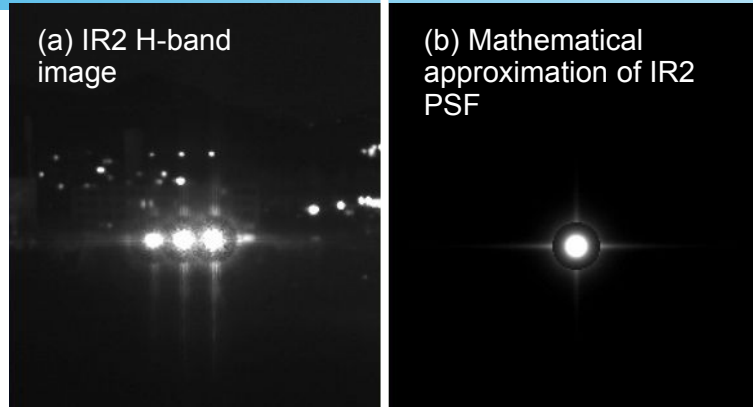


Wilson et al. (2008)



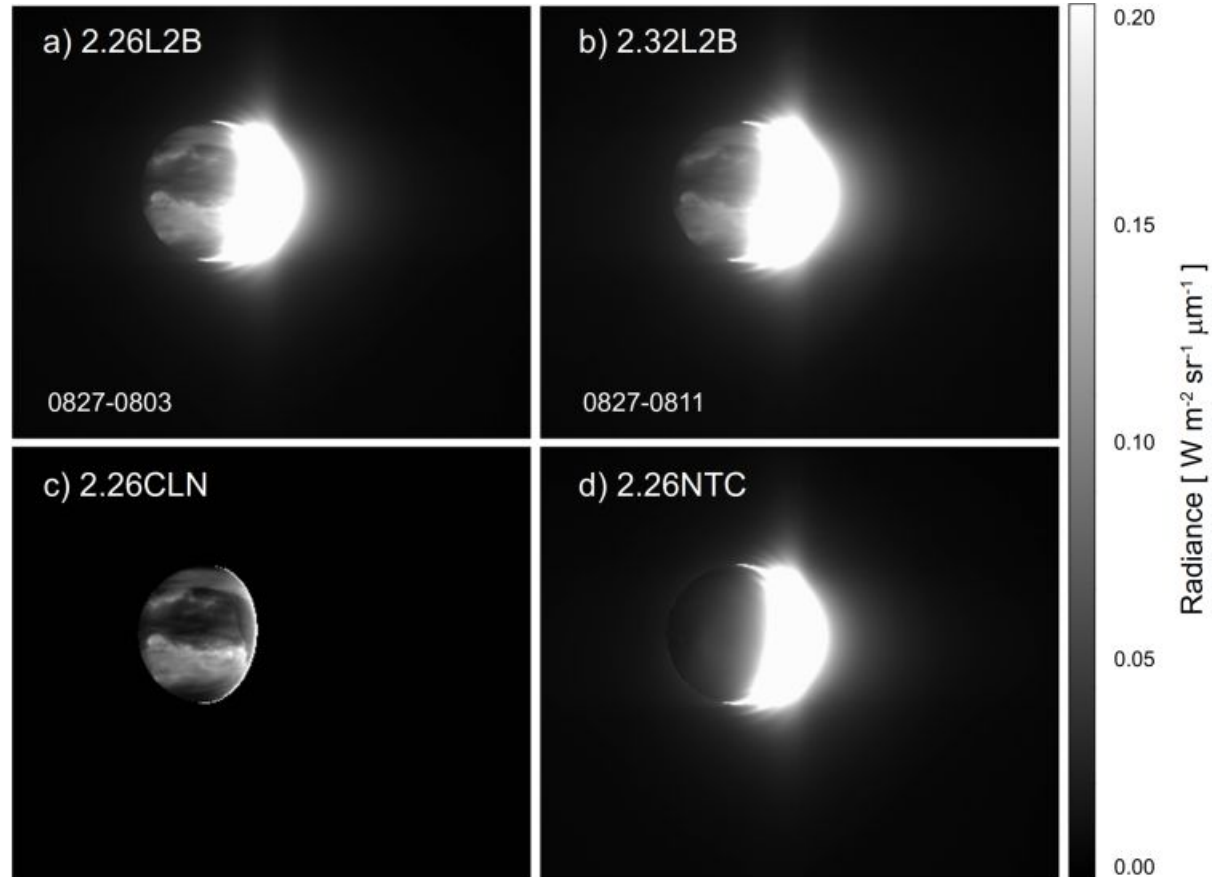
イントロ: あかつきIR2データの問題点

- 検出素子のSi基板内での多重反射に起因する「大きな点広が関数(PSF)」が存在し、昼面からの影響が大きい(Satoh et al., 2017)。
- そのために、運動の研究(雲追跡)や形態の研究は成果を挙げてきたが、測光精度を要求される夜面研究(雲やCO分布)は手つかずであった。
- 2.26 μm , 2.32 μm , 1.735 μm を組み合わせて昼面の影響を軽減する方法(RSS法)を開発して、雲の性質を調べた。

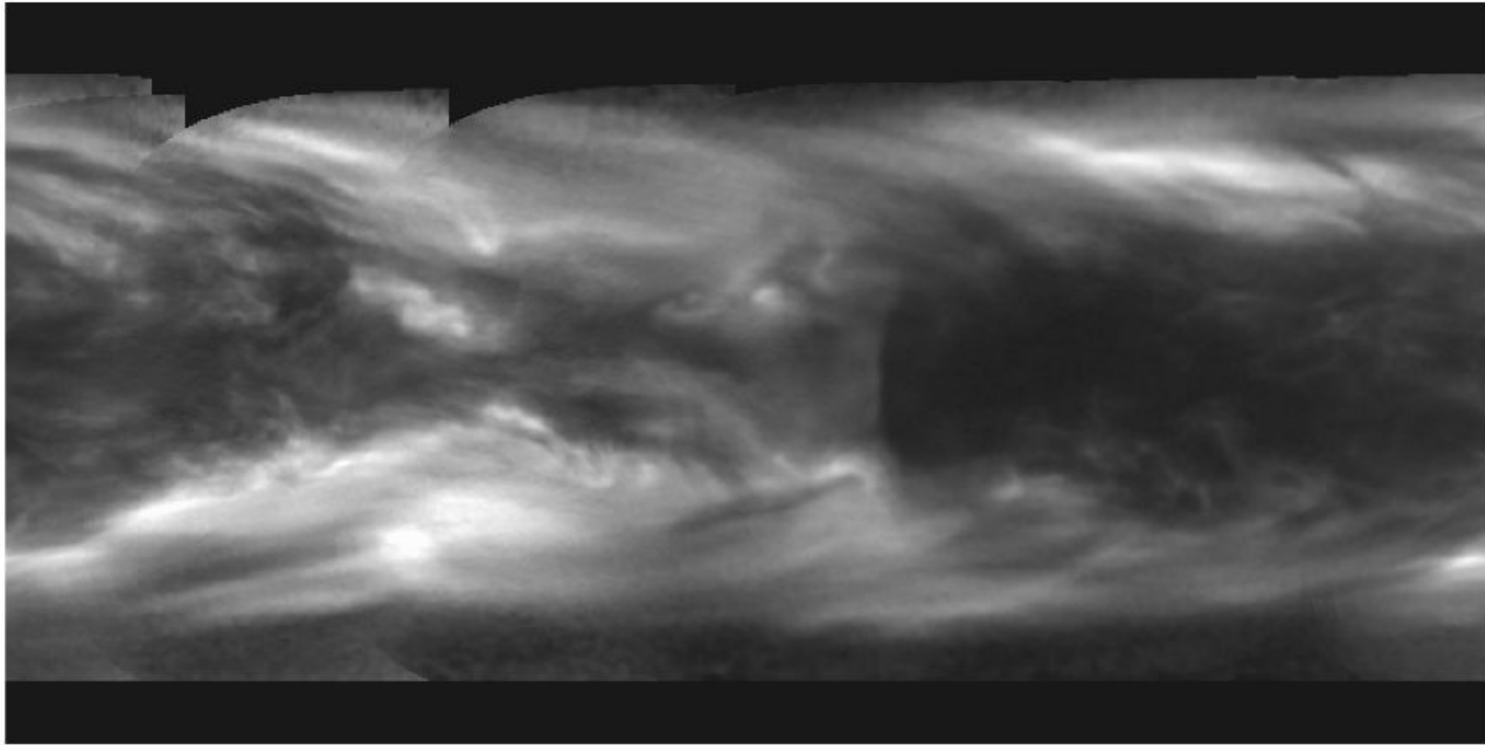


手法: Restoration by Simple Subtraction (RSS)

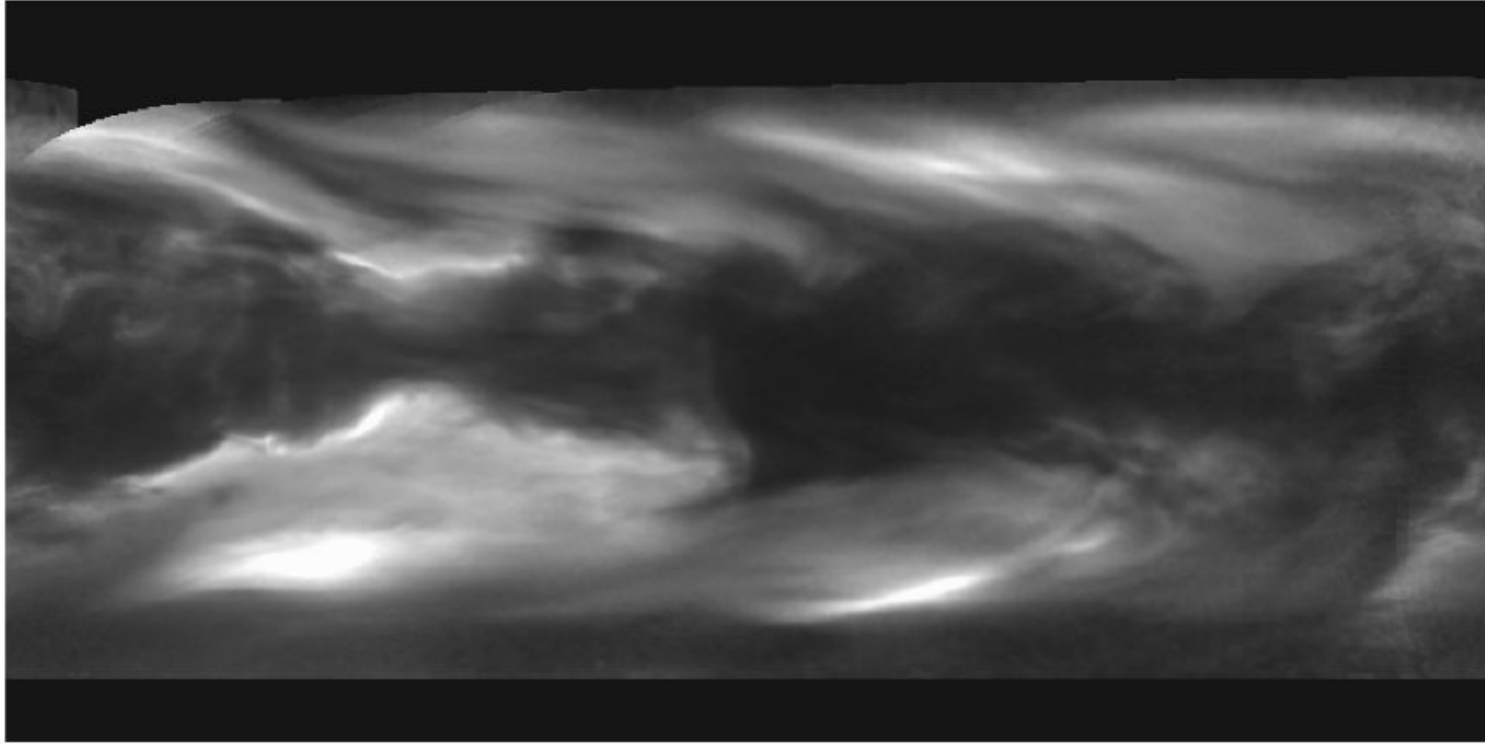
- $2.26\mu\text{m}$ と $2.32\mu\text{m}$ では昼面の明るさはほぼ同じ、夜面は後者が「CO吸収の分だけ暗い」ことを利用し、引き算により昼面の影響を除去する。
- 引き算の結果を、本来の $2.26\mu\text{m}$ の明るさに復元し(2.26CLN)、もと画像から引くと、「昼面からの被り成分」だけ(2.26NTC)を得られる。
- 2.26NTCを係数倍して $1.735\mu\text{m}$ 画像から引くことで、 $1.735\mu\text{m}$ データも復元(1.735CLN)できる。



データ処理: Orbit 24 (16 - 20 Aug 2016)

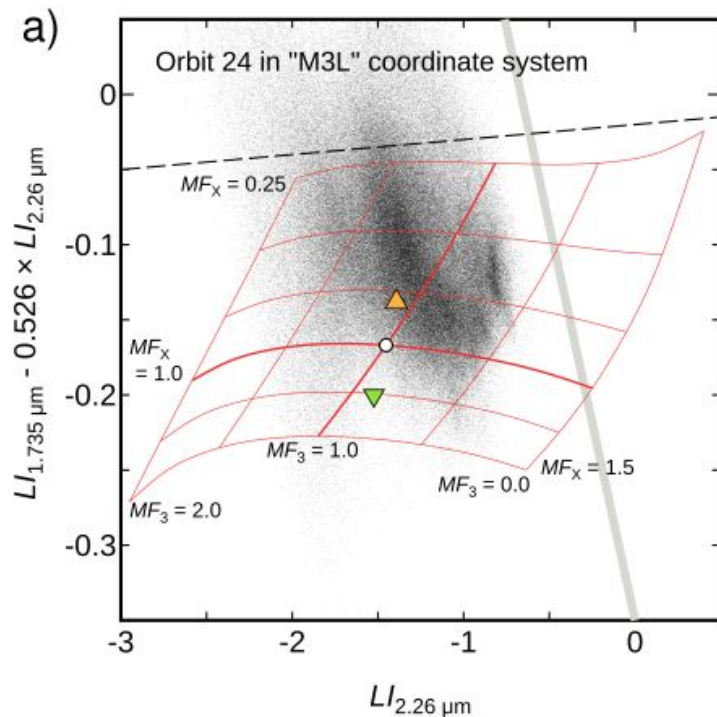
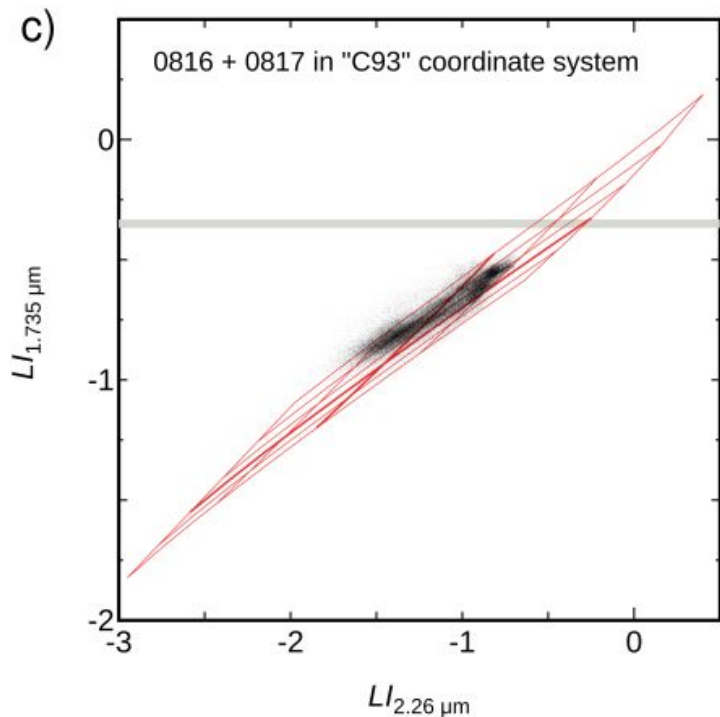


データ処理: Orbit 25 (26 - 30 Aug 2016)



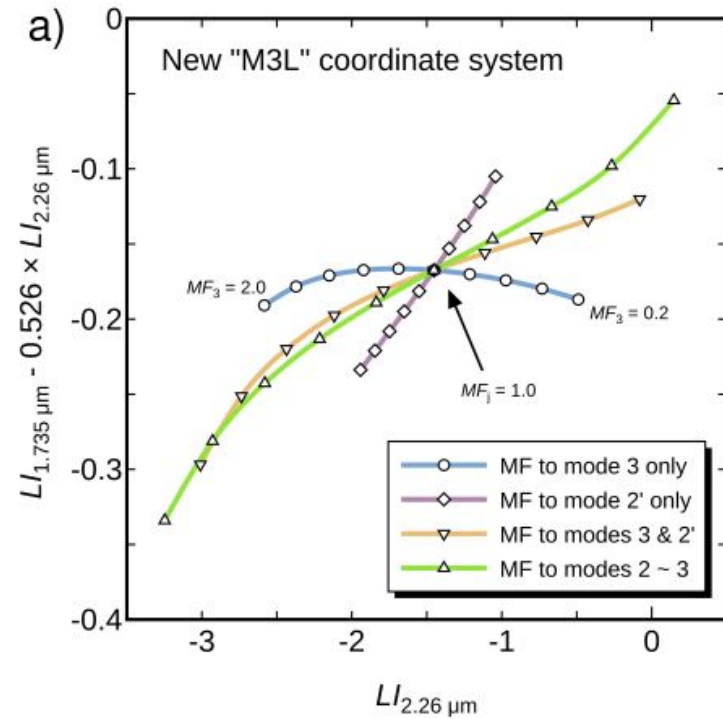
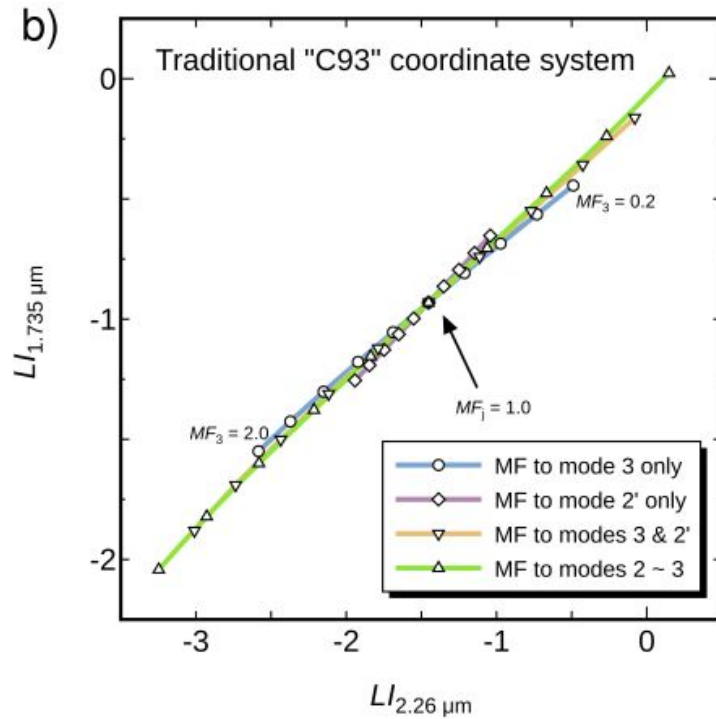
結果: IR2データの2波長相関プロット

- 従来座標 (Carlson et al., 1993) にプロットしたのでは、よく分からない。新しい座標 M3L (次ページでその意味を説明) にプロットすると、何かが見え始める。



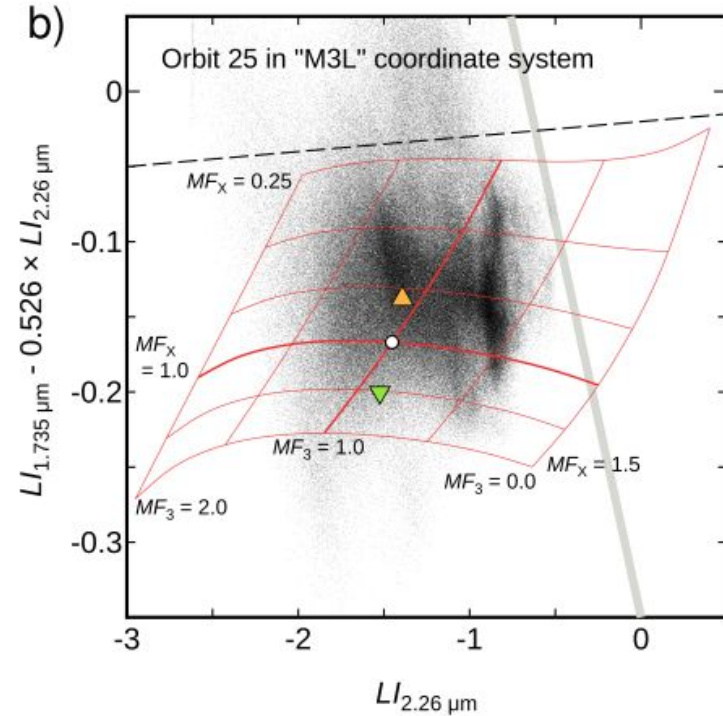
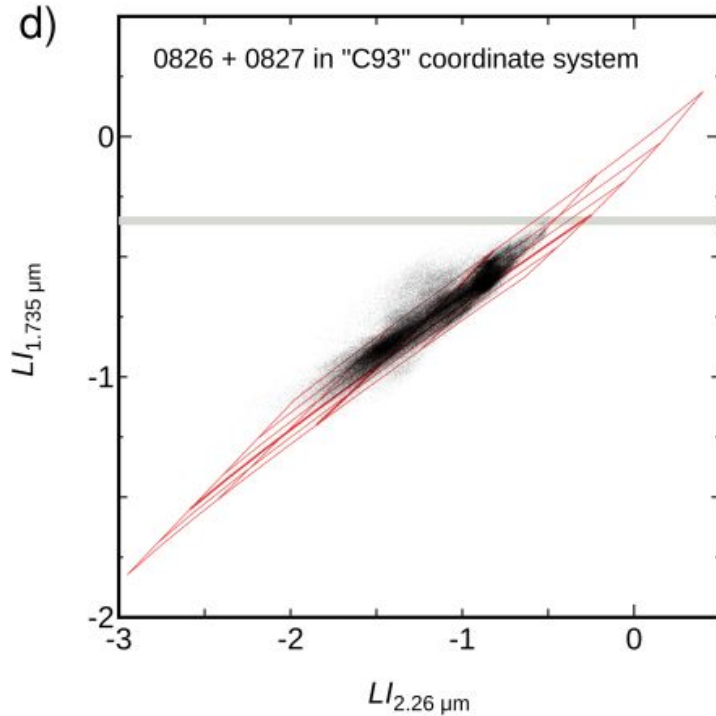
注釈：M3L座標系とは何か

- 大粒子(モード3)の量を増減させ放射をモデル計算したとき、その振る舞いがほぼ水平になるように座標系にシアリングを与えたもの(Mode 3 Levelled)。



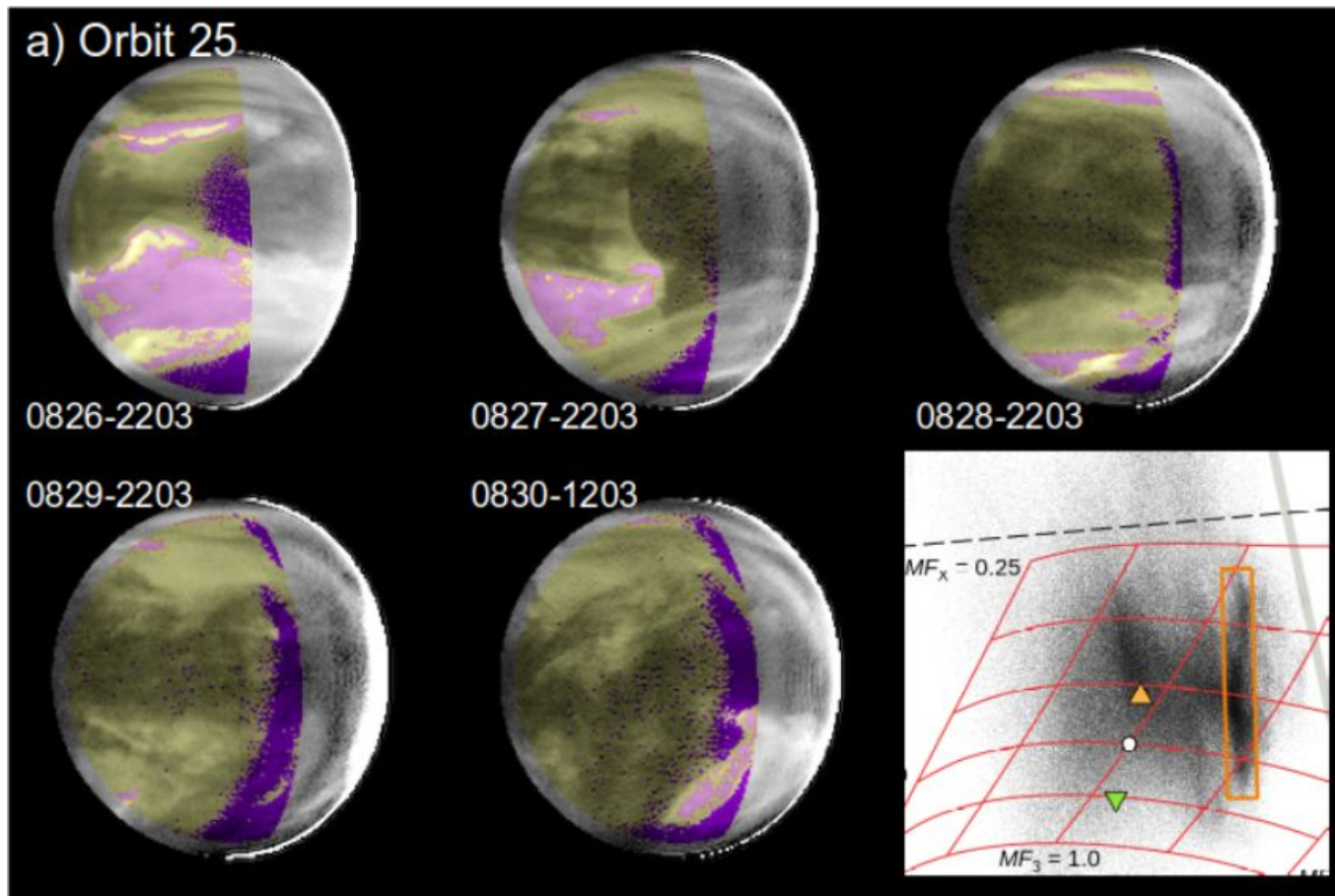
結果: IR2データの2波長相関プロット

- 従来座標 (Carlson et al., 1993) にプロットしたのでは、よく分からない。新しい座標 M3L にプロットすると、特徴的な集団 (パネルbの縦筋) が見えた。



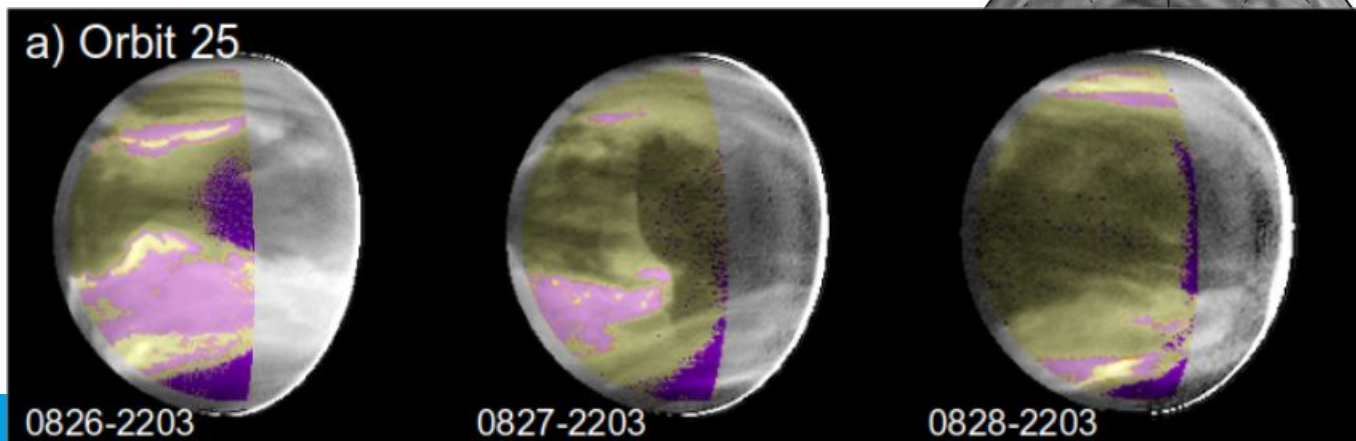
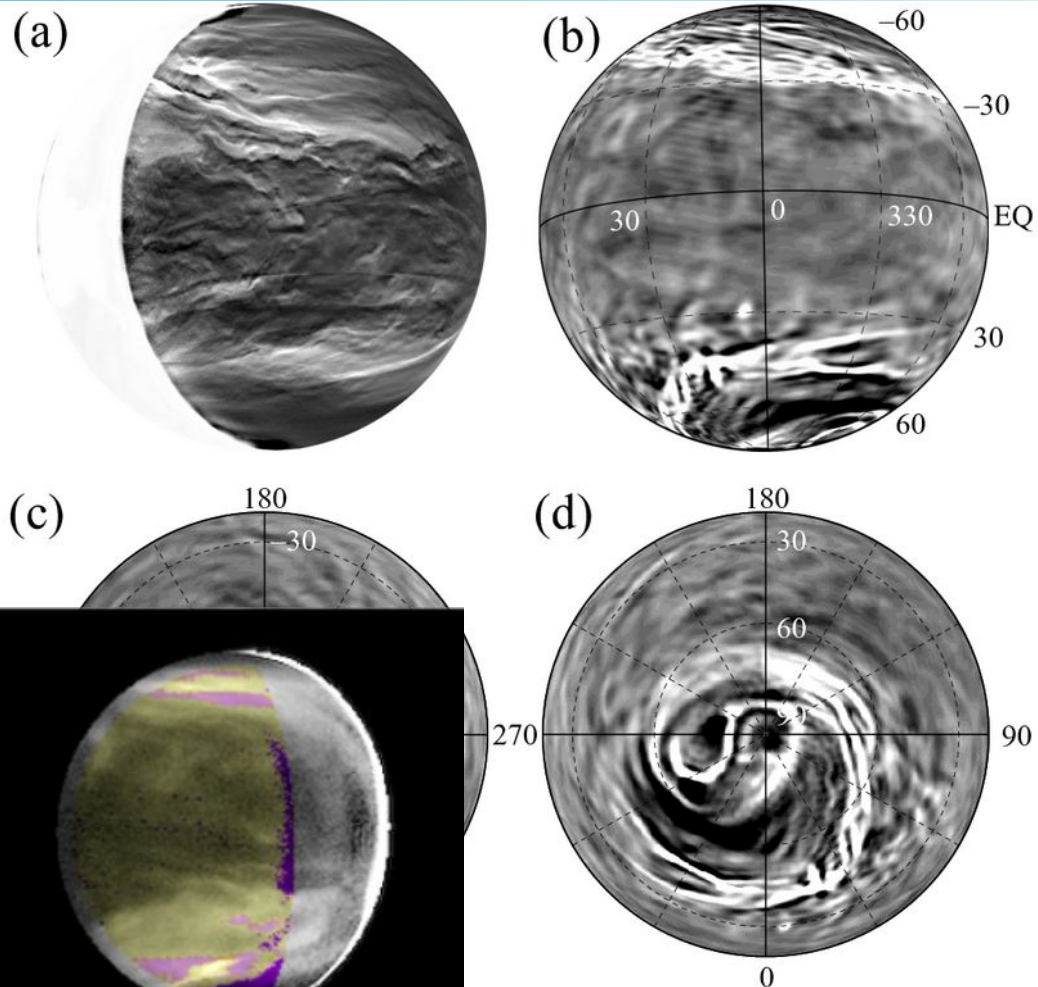
命名 CALM (= **C**louds **A**ligned **L**inearly in **M3L** coordinates)

考察: CALMとはどのような領域か



考察: CALM「ではない」場所

- 数値流体シミュレーションによって、中高緯度の明るいストリークが「下降流の領域」であることが見出されている (Kashimura et al., 2019)。
- ストリークはCALMからはずれた領域であり、非静穏領域であることを観測的に初めて示唆したものである。



まとめ

- データ処理を工夫 (RSS法の開発) することによりついに、あかつきIR2夜面データを測光可能な品質へと高めることができた。
- 新しいM3L座標系を導入して $2.26\mu\text{m}$ vs $1.735\mu\text{m}$ の相関プロットを作成したところ、特徴的な領域CALMを発見することができた。
- CALMの「狭さ」は、そこが静穏な領域で、モード3やその他のサイズの粒子、さらには H_2SO_4 蒸気との間の変化が平衡に近い状態で起きていると考えられる。
- 中高緯度のストリークはCALMからはずれており、そこは「非静穏」な領域であることが予想され、これは数値シミュレーションで示された「下降流」領域であることに整合的である。
- 本研究で得られた結果は、(1)雲微物理に対する新しい制約条件を与えるとともに、(2)リモートセンシングにより大気の運動状態を推測する新たな可能性を与えるものである。
- Satoh et al., *Icarus* **355**, <https://doi.org/10.1016/j.icarus.2020.114134>, 2021.