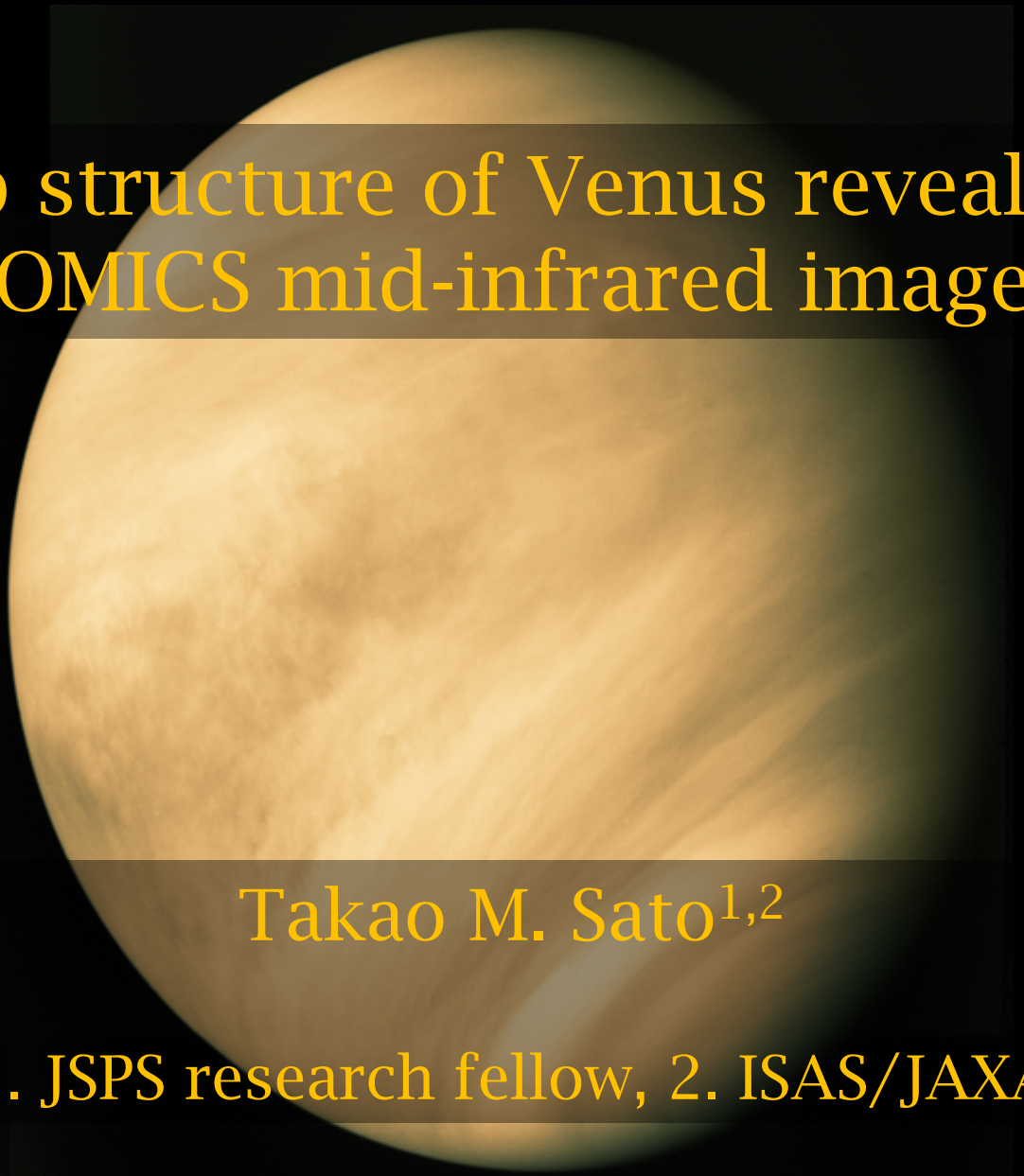
Subaru Users' Meeting FY2015
(Wed) Jan 20, 2016, 17:40-18:00

Cloud top structure of Venus revealed by Subaru/COMICS mid-infrared images



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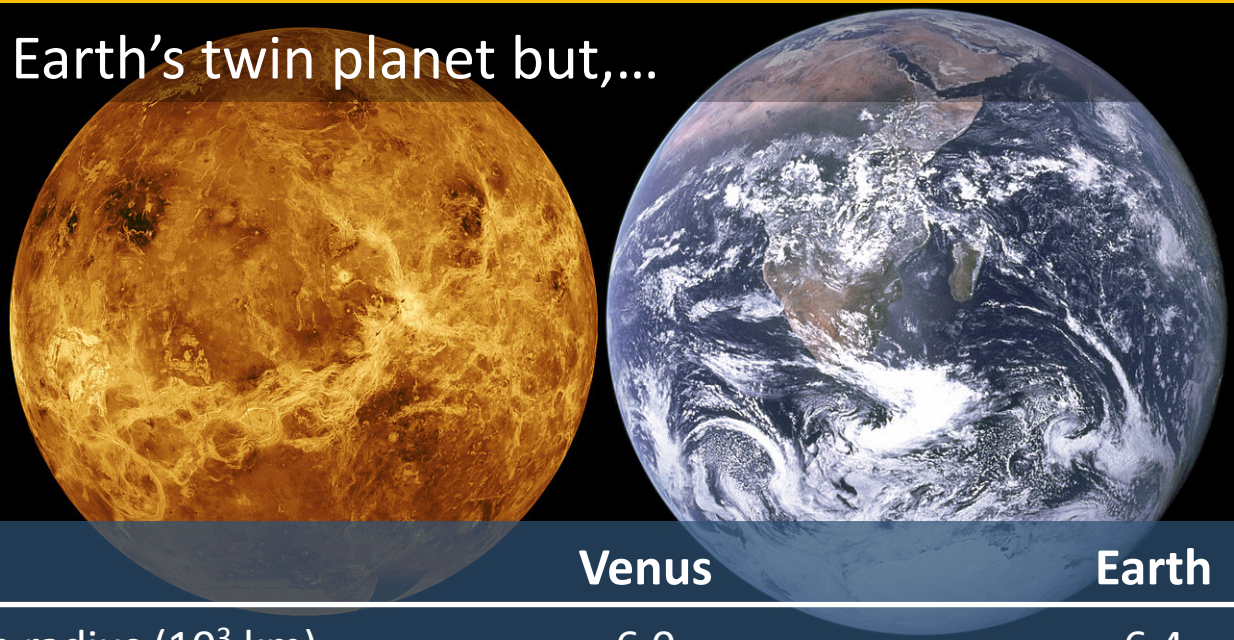
Introduction

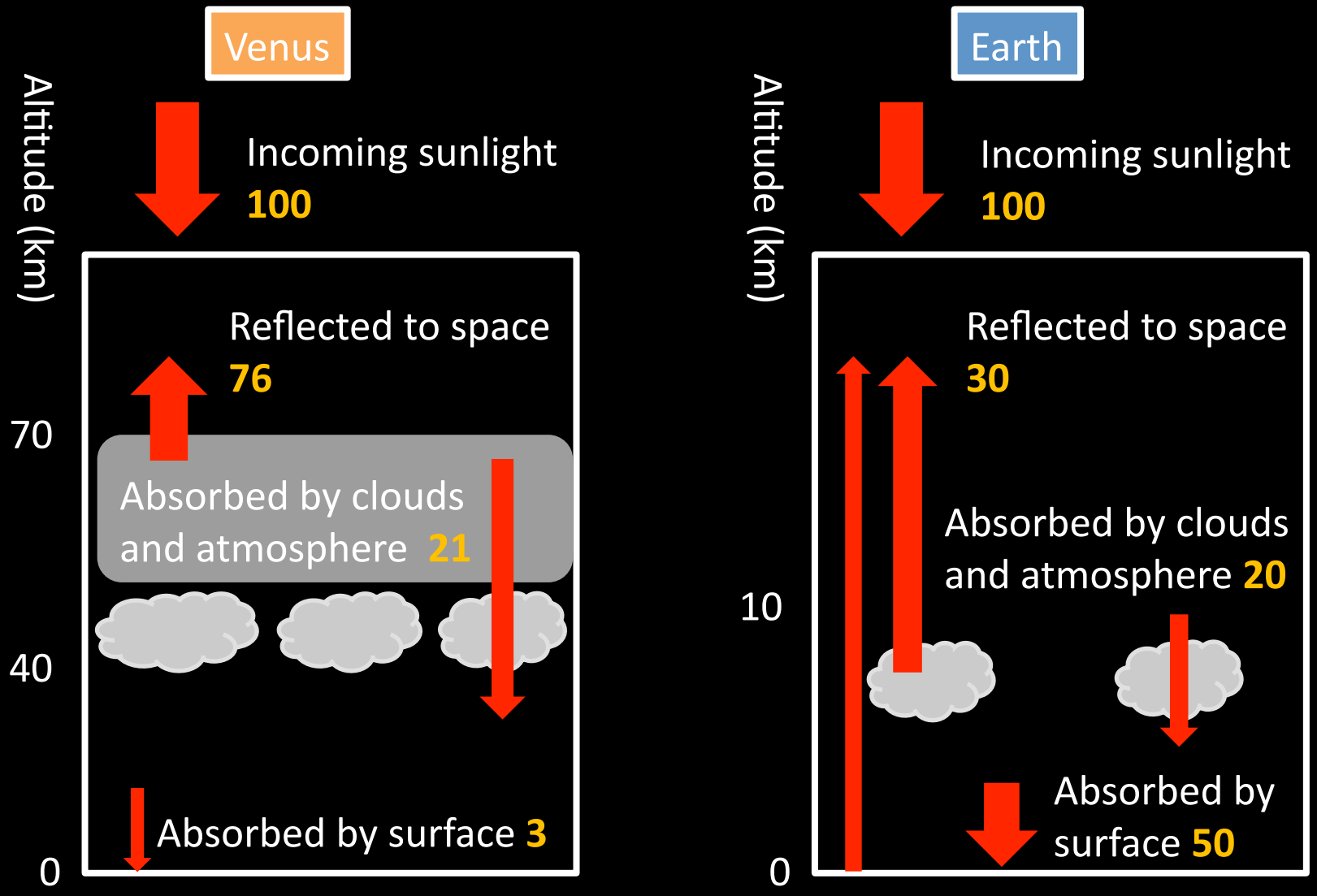
Venus is the Earth's twin planet but,…



	Venus	Earth
Mean radius (10^3 km)	6.0	6.4
Mass (10^{24} kg)	4.9	6.0
Density (g cm^{-3})	5.2	5.5
Gravity (m s^{-2})	8.9	9.8
Sidereal rotation period	-243 days	23.9 hours
Surface pressure (bar)	92	1
Surface temperature (K)	737	288
Composition (%)	CO_2 (96.5), N_2 (3.5)	N_2 (78.08), O_2 (20.95)

Credit: NASA (Venus from Magellan, Earth from Apollo 17) [de Pater and Lissauer]

Introduction: radiative energy budgets



For Venus, optically thick clouds control solar input and impact on the climate system.

UV observations probe the cloud top

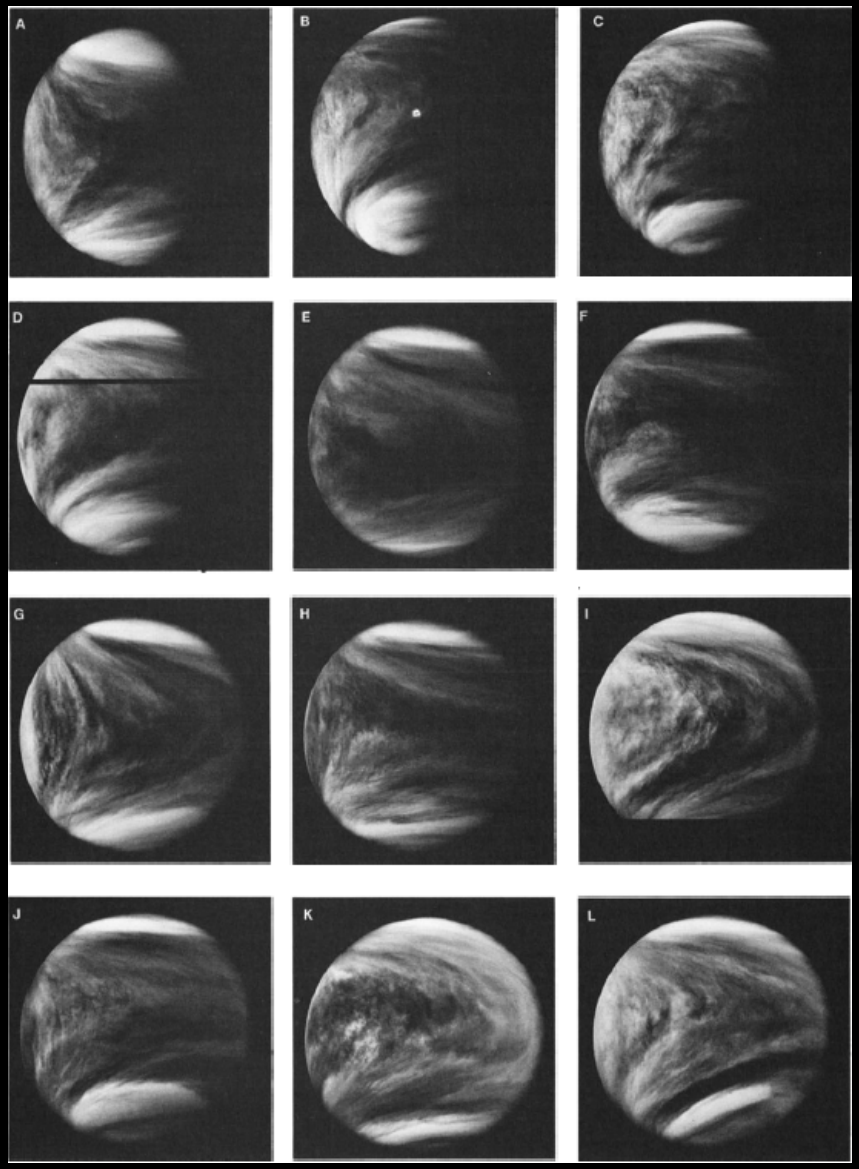


Fig. Consecutive images at UV (365 nm) from PVO/OCPP [Rossow et al., 1980].

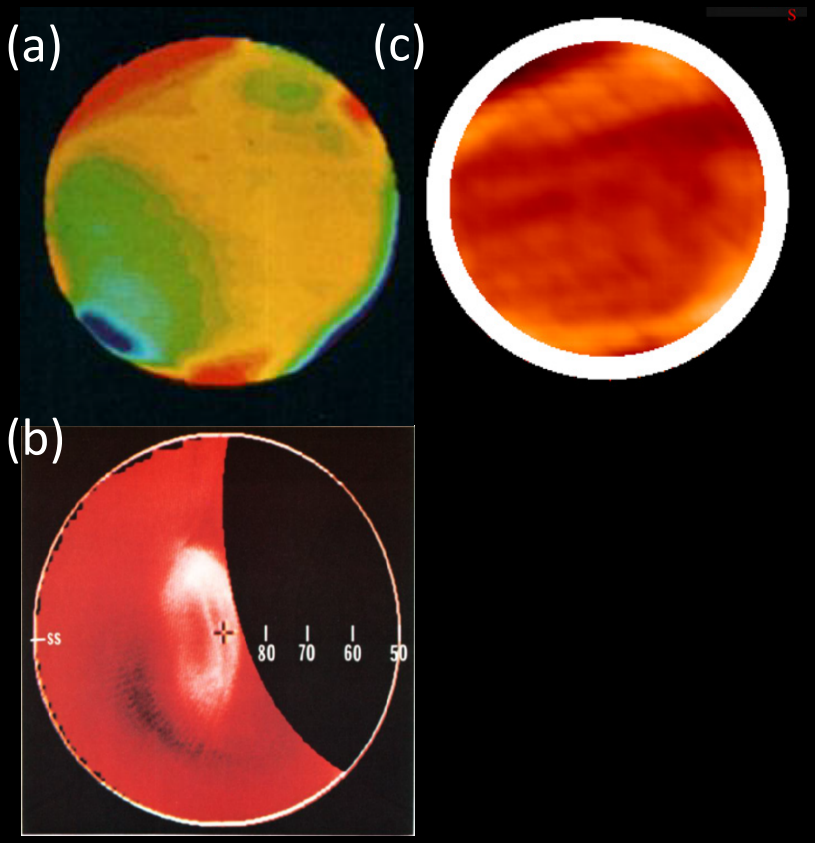
- ☐ UV wavelengths
- reflected sunlight attenuated by not-identified UV absorbers in clouds

- horizontal wind vectors near the cloud top (~70 km) by tracking features

- ✓ Atmospheric super-rotation
- The entire atmosphere near the cloud top circulates 60 times faster than the planet's rotation.

- limited to dayside

MIR observations also probe the cloud top



Figs. (a) False color images from the ground [Apt et al., 1984];
(b) Polar stereographic image by PVO/OIR [Taylor et al., 1980];
(c) Equatorial image by AKATSUKI/LIR [Taguchi et al., 2012].

- ☐ Mid-infrared wavelengths (8-12 μm)
- thermal radiation attenuated mainly by clouds and CO_2
- cloud top temperature, cloud top altitude, and cloud scale height
- enable to observe dayside and nightside equally

- ◆ Previous observations (1970s and 1980s)
- ground-based telescopes
- ✓ single pixel detector with raster scanning

- spacecraft [Pioneer Venus & Venera 15]
- ✓ single pixel detector
- ✓ view from the polar orbit

Objectives of this study

- Venus has optically thick clouds (40-70 km) which control solar input and impact on the climate system.

- MIR observations enable to probe the cloud top altitudes (~70 km) regardless of dayside or nightside.

- Previous MIR observations had several limitations

✓ ground-based: low spatial resolution

✓ spacecraft: large gap in the coverage, especially in the equatorial region

To investigate the spatiotemporal variations of cloud top morphology, we conducted MIR observations of Venus with Subaru/COMICS in 2007.

[Details are described by Sato et al., 2014. Cloud top structure of Venus revealed by Subaru/COMICS mid-infrared images, Icarus 243, 386-399.]

Observations

- October 25-29, 2007
- COMICS mounted on the Subaru Telescope
- Imaging observations: 8.66 μm and 11.34 μm

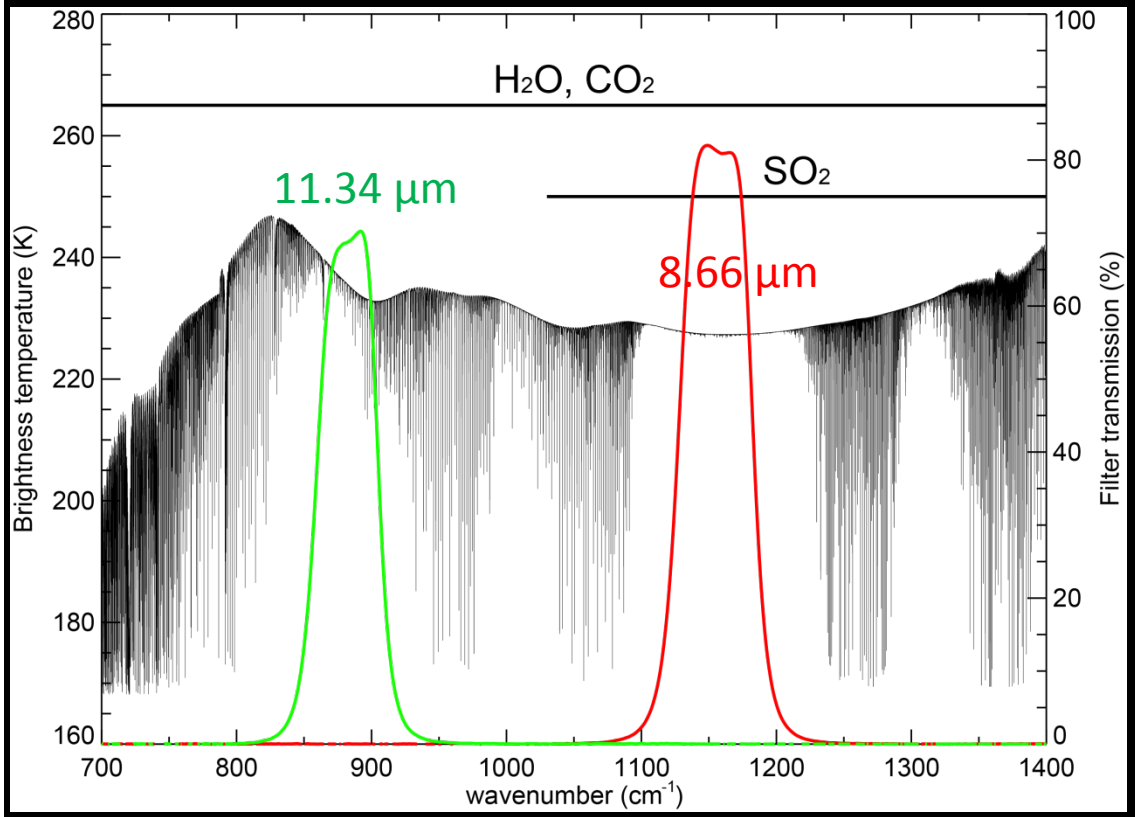


Fig. Simulated spectra obtained from a radiative transfer model with two filter transmission curves.

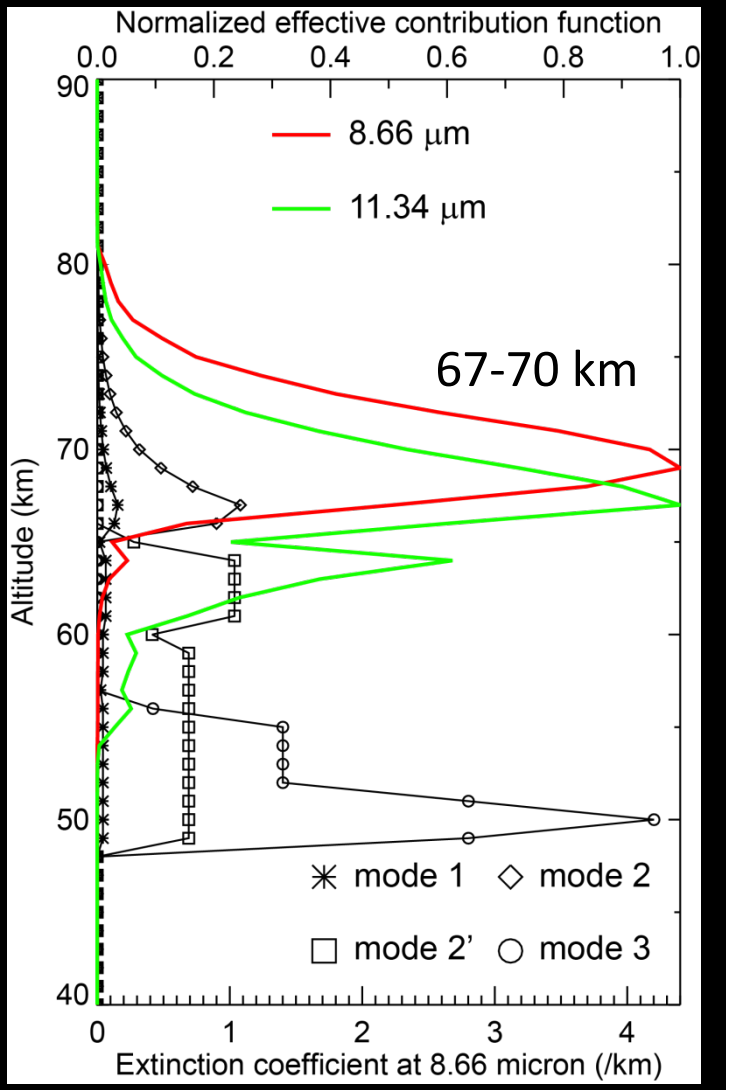


Fig. Contribution functions of two wavelengths with vertical profiles of extinction coefficients for clouds.

Brightness temperature (BT) distributions

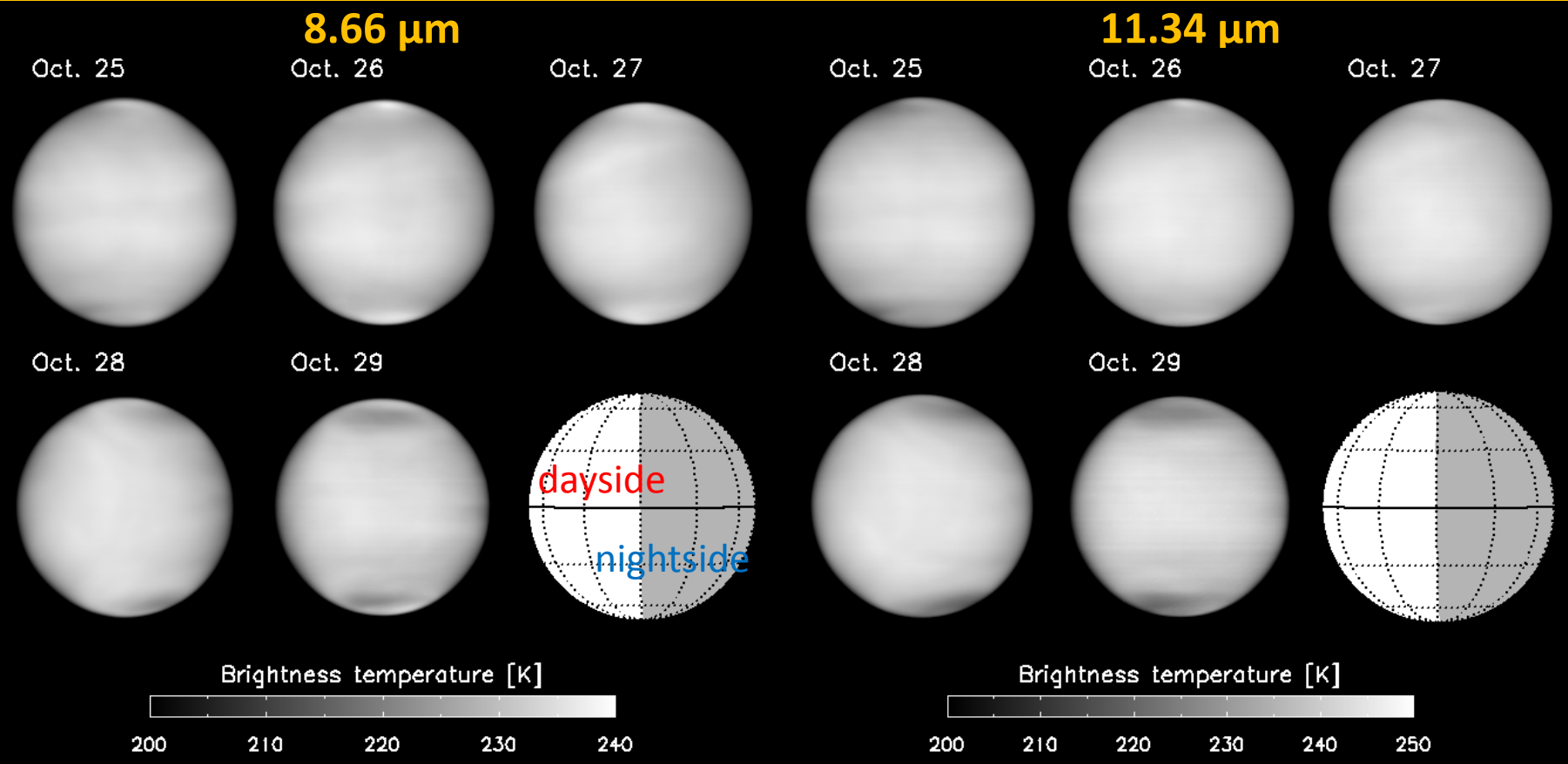
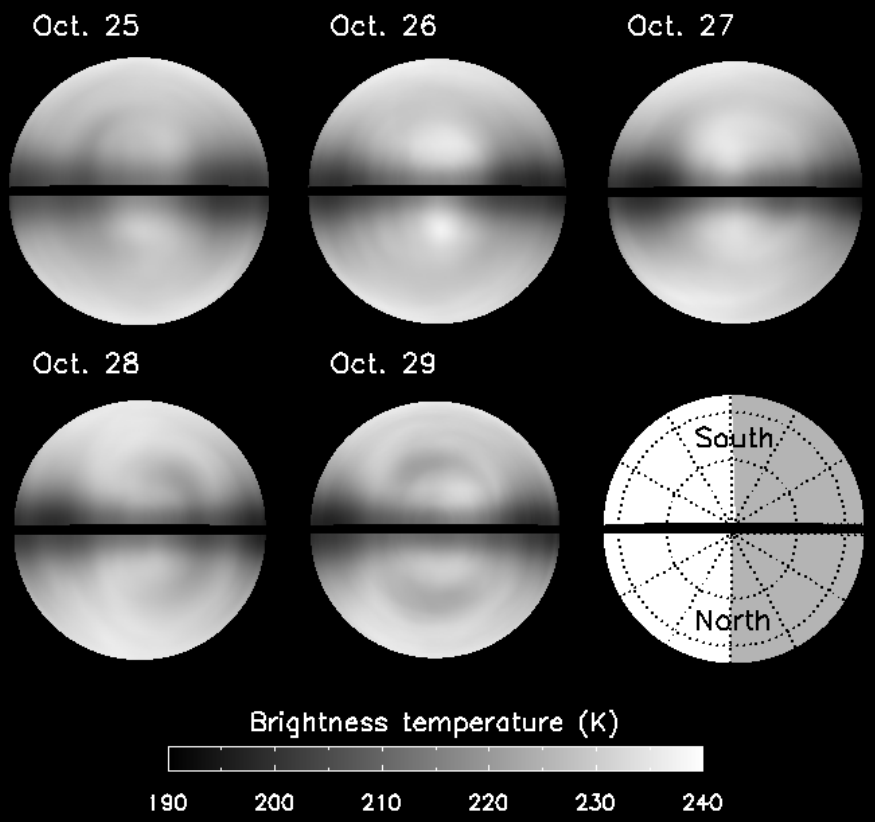


Fig. Calibrated Venus images during 5-day observations.

- Clearly visible features in MIR: Hot polar spots and cold collars in both hemispheres
- No significant day-to-day variations of disk-averaged BT are seen from our data.
- Disk-averaged BT during the period: ~230 K (8.66 µm), ~238 K (11.34 µm)

✓ Disk-averaged BT from AKATSUKI/LIR (8-12 µm) data: ~236 K (accuracy of ~3K)

Synchronization of northern and southern polar features



Direction of atmospheric rotation

Fig. Polar stereographic images at 8.66 μm.

- A possibility that the westward rotation of the polar features is synchronized between the northern and southern hemispheres.
- ➢ The first time to show an observational evidence of such possibility in Venus.

Small-amplitude features

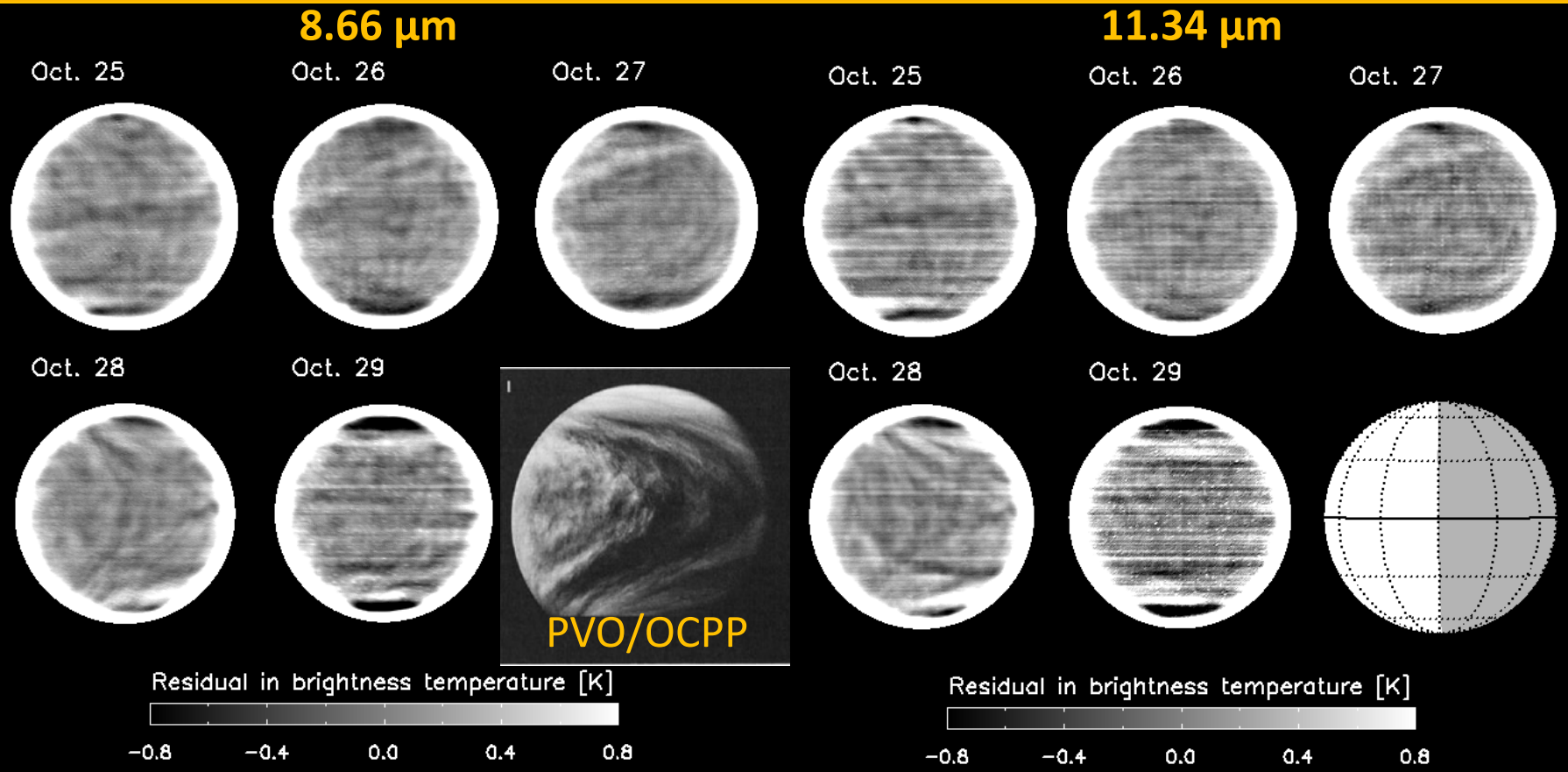


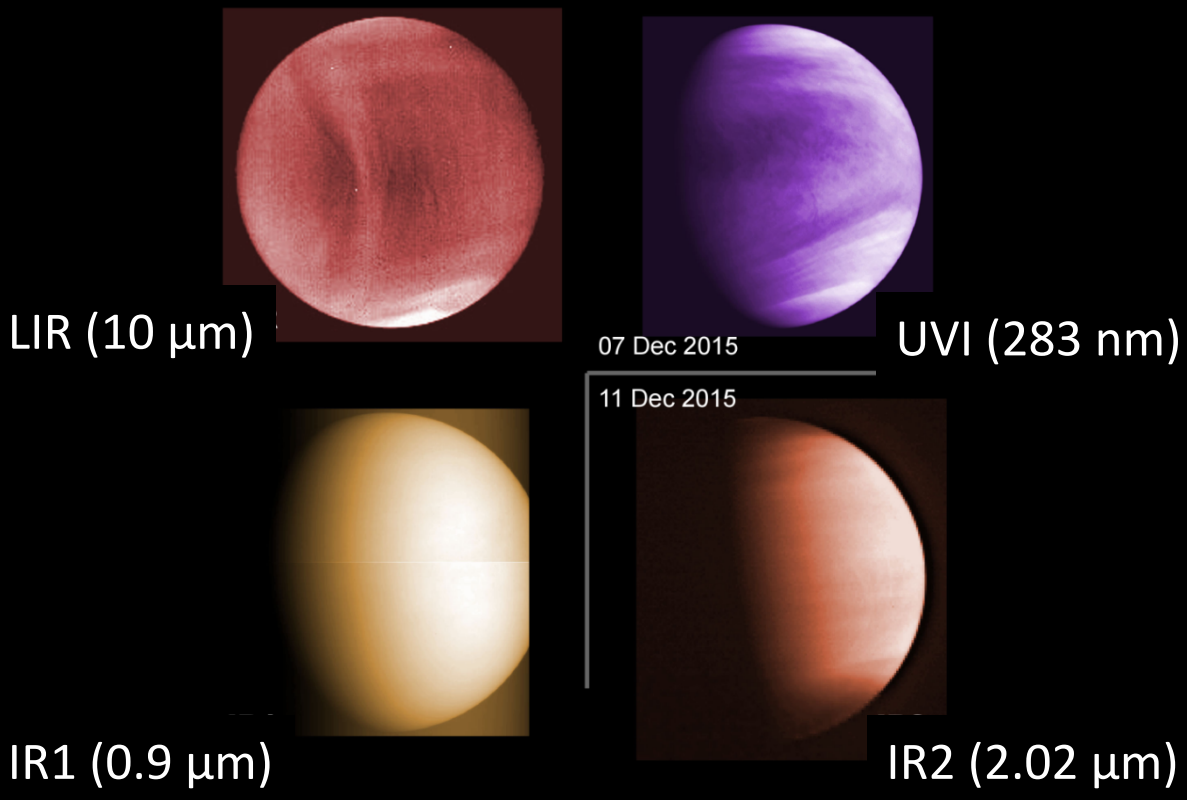
Fig. Day-to-day variations of residual patterns after high-pass filtering.

- Streaks and mottled and patchy patterns (~0.5 K) in the entire disk.
- The patterns varying from day to day are independent of wavelengths.
- The patterns would result from the inhomogeneities of both the temperature and the cloud top altitude.

Further studies with AKATSUKI and COMICS

AKATSUKI, the Japanese spacecraft carrying five cameras to investigate the climate system of Venus

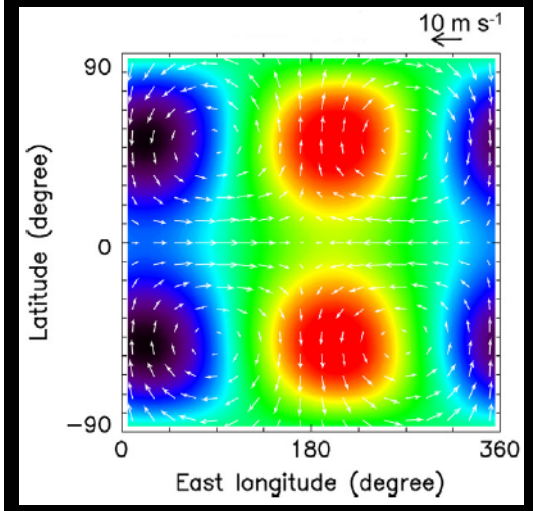
First in-orbit Venus images from AKATSUKI [JAXA web]



- Dec. 7, 2015 Entered a Venus orbit
- Jan. 15, 2016 Started continuous observations by the four cameras with checkout

➢ Unprecedented opportunity to conduct coordinated observations of AKATSUKI and COMICS!

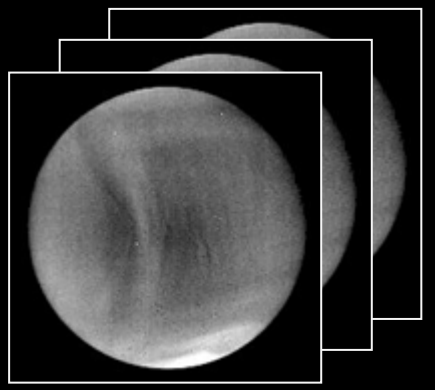
Strategy of our proposal for S16B (Jan., 2017)



Simulation

Propose a candidate for explaining the observed synchronization

- Several planetary-scale waves excited in the equatorial regions can spread poleward with keeping the phase of waves [Kouyama et al., 2015].



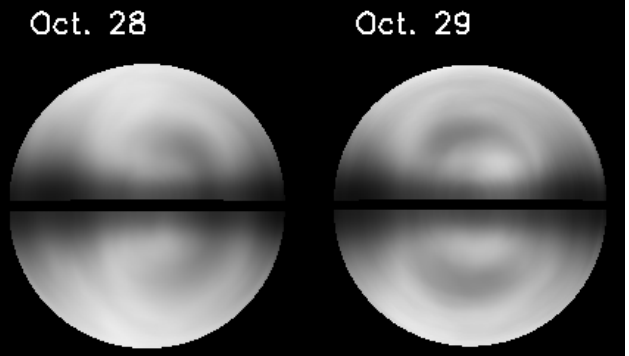
AKATSUKI/LIR (imaging)

- Only LIR enables to observe temperature disturbance continuously.
  - ➢ Derive the physical characteristics of the planetary-scale waves mentioned above.

Not-so-different spatial resolution

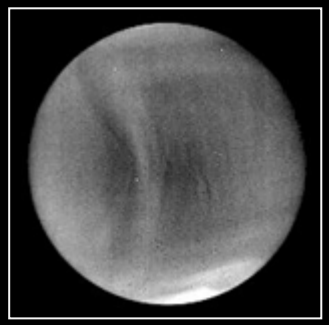
COMICS (imaging)

- Only COMICS enables to monitor the features in both polar regions simultaneously.
  - ➢ Reconfirm the existence of synchronization



Strategy of our proposal for S16B (Jan., 2017)

AKATSUKI/LIR (imaging)

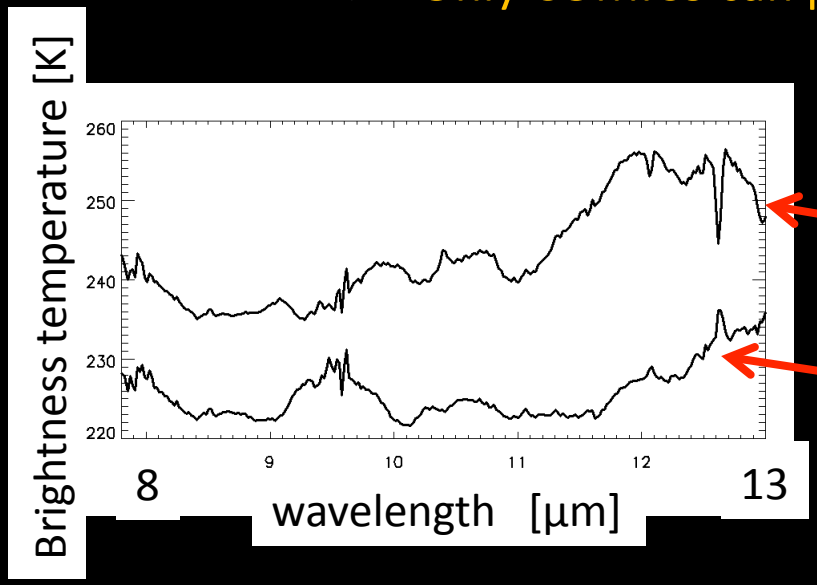


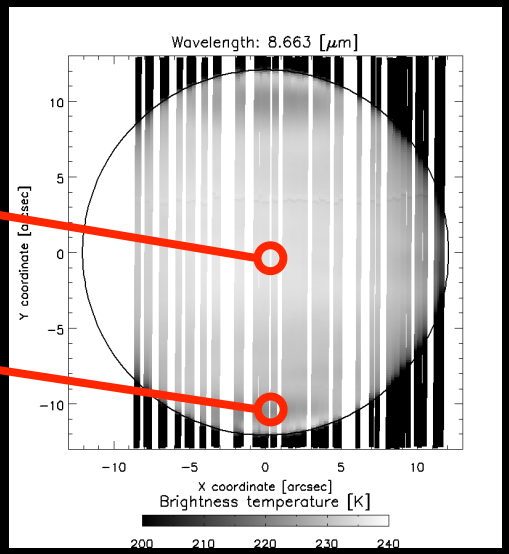
- hard to study what atmospheric parameters are responsible for the observed radiance only from single-channel data.

COMICS (spectroscopy)

- Atmospheric parameters (cloud top altitude, cloud top temperature, and cloud scale height) can be retrieved from ground-based spectra [Sato et al., in prep.]

➢ Only COMICS can provide unique information to LIR data.





Figs. (left) Two obtained spectra (right) A slit-scan image at 8.663 μm.

COMICS is essential not only for Venus but for Jupiter

In Oct. 2016, NASA/Juno spacecraft will observe…

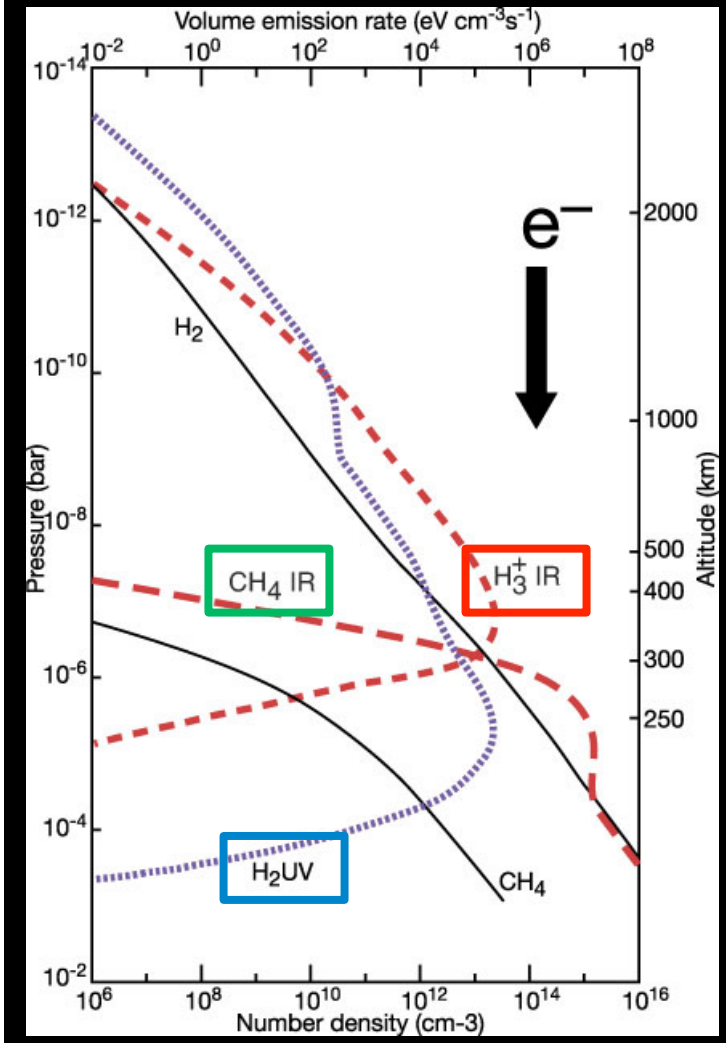


Fig. the altitudes where multi-wavelength aurora are excited in Jupiter [Clarke et al., 2004].

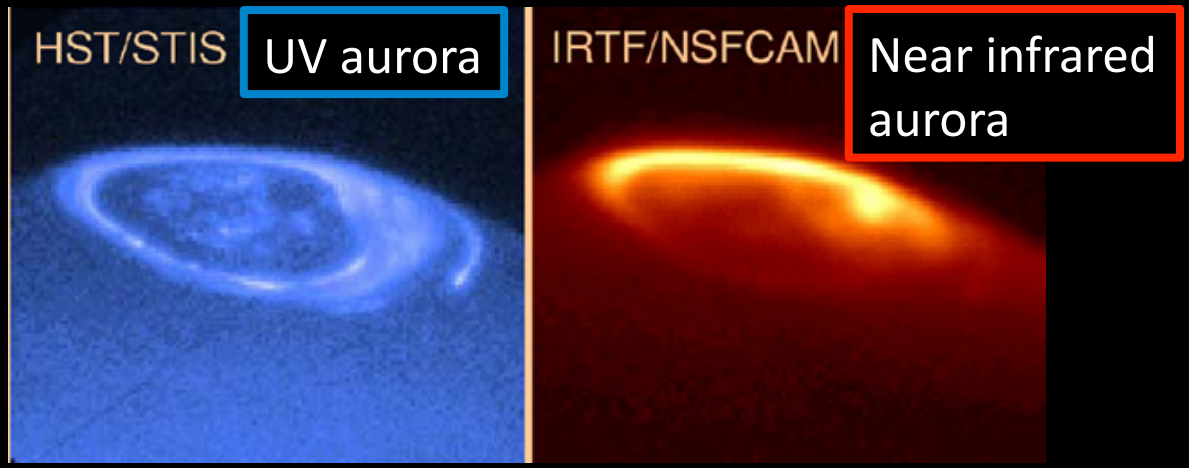


Fig. UV and near-infrared aurora obtained by HST/STIS and IRTF/NSFCAM, respectively [Clarke et al., 2004].

Missing MIR observations should be…

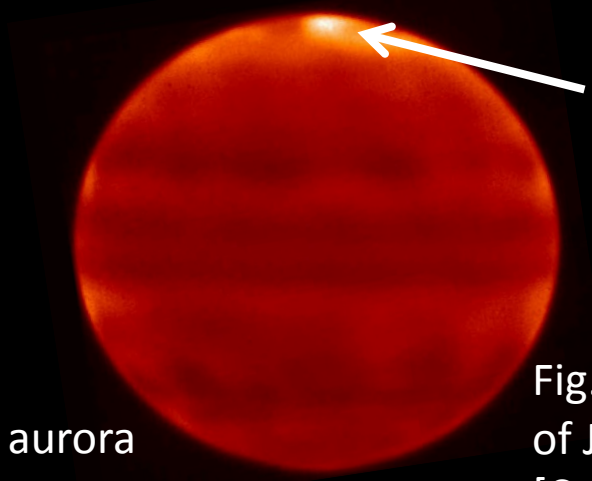


Fig. 7.9-μm image of Jupiter by COMICS [Courtesy of Glenn Orton].

Summary and conclusions

- We found several interesting features from Subaru/COMICS images.

[Polar regions: Polar hot spots, cold collar]

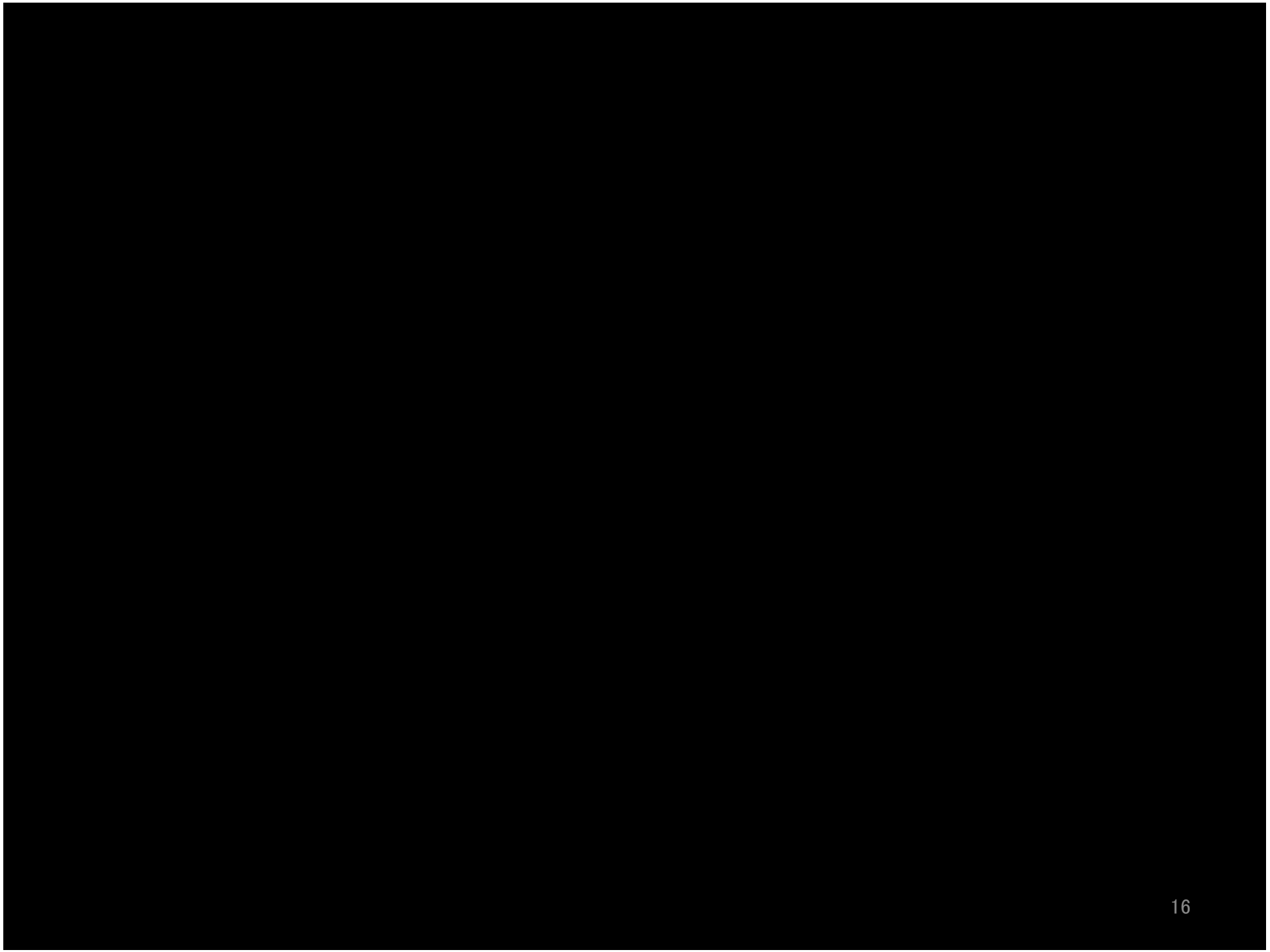
- A possibility that westward rotation of the polar features are synchronized between the northern and southern hemispheres.
  - ➢ This is the first time to present an observational evidence of the possibility in Venus.

[Entire disk: Small-amplitude non-solar-fixed features]

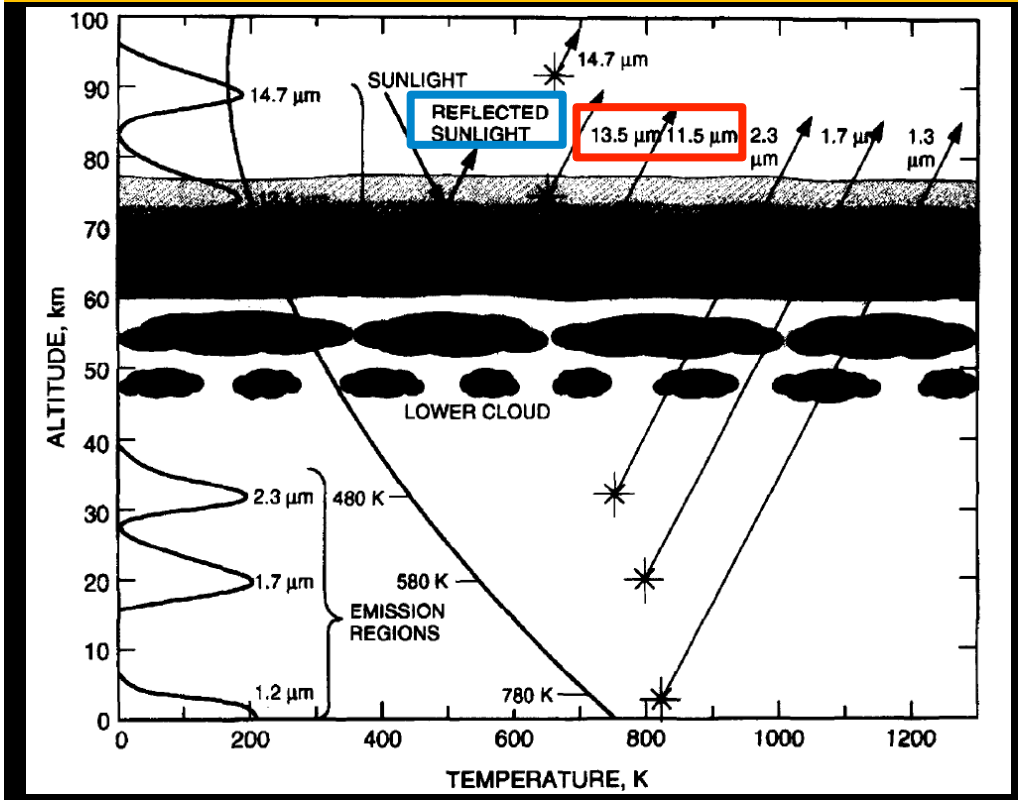
- The images after high-pass filtering revealed some streaks and mottled and patchy patterns (~0.5 K) over the entire disk as can be seen in UV images. Such patterns vary from day to day.
  - ➢ These patterns would result from the inhomogeneities of cloud top temperature and/or cloud top altitude unlike the origin (unknown absorbers) of UV patterns.

- We have a plan for further studies through joint observations of COMICS and AKATSUKI.

- In the field of planetary science, COMICS is still an essential instrument which enables to support several on-going space missions (AKATSUKI and Juno).



Schematic of sounding altitudes for UV and MIR



- UV and MIR observations are complementary approach

UV

- column density of SO_2/unknown absorber, wind velocity
- only dayside with spatial resolution determined by astronomical seeing in the case of using ground-based telescopes

MIR

- temperature/cloud optical thickness
- both dayside and nightside with the diffraction-limited resolution of telescope

Introduction

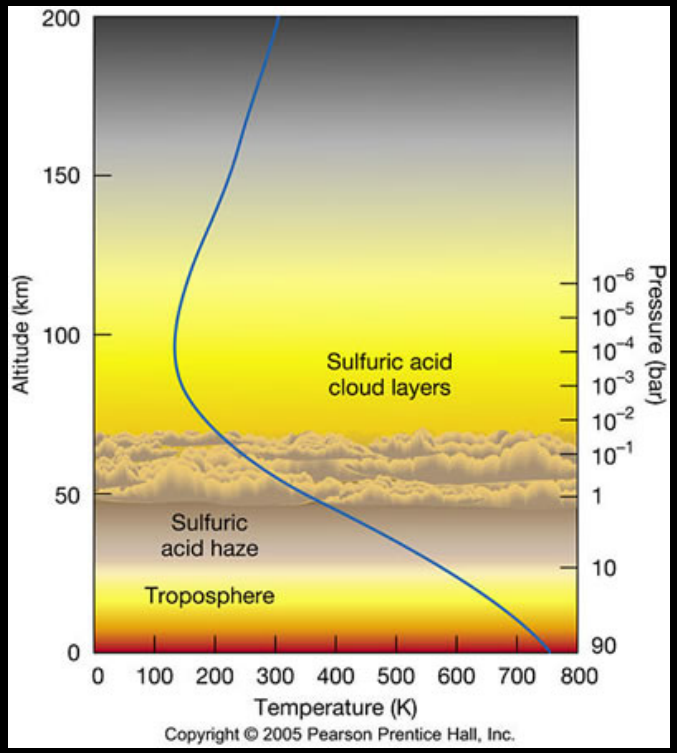


Fig. Venus' atmospheric structure.

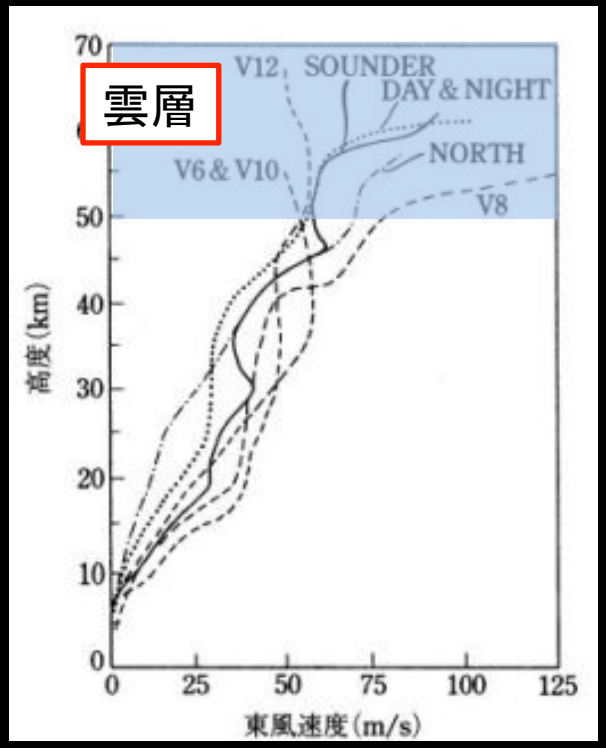


Fig. 探査機プローブによる
風速の直接観測

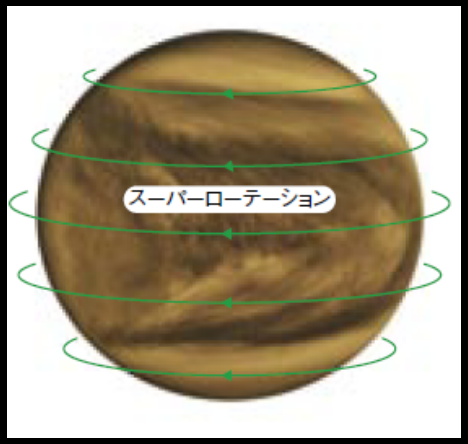


Fig. スーパーローテーション
のイメージ

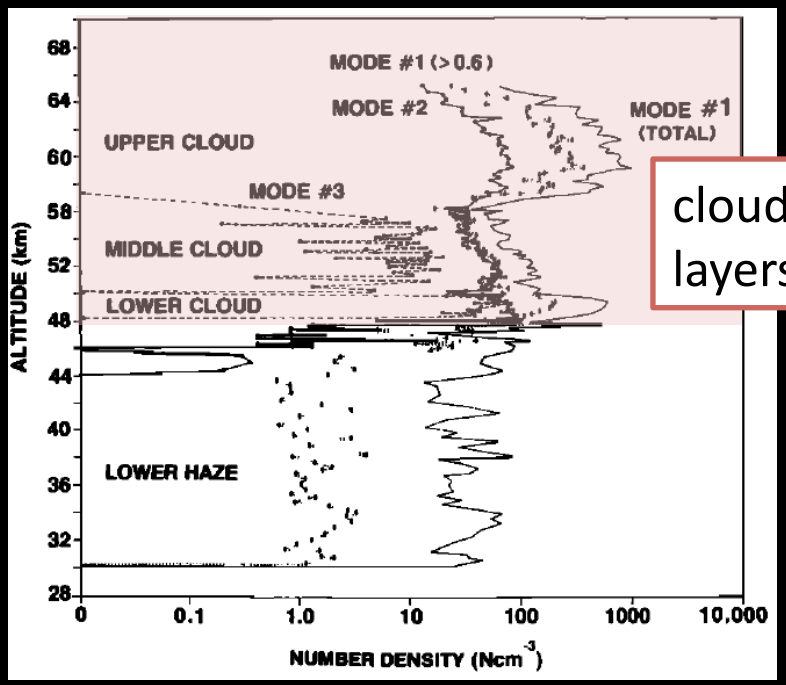
A mysterious phenomenon: atmospheric super-rotation

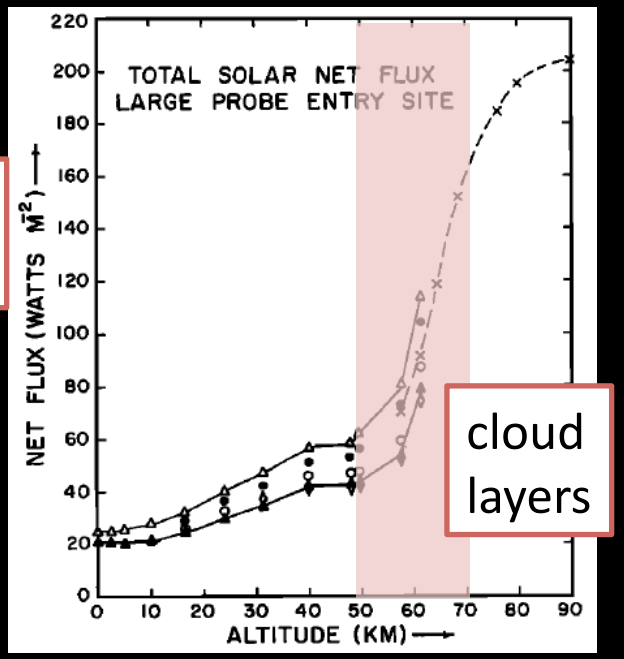
circulate ~60 times as faster than 固体部分の自転が西向きに243地球日 (~1.8 m/s) に対して、
大気は同方向に約60倍の速さで回転する (4-5日で金星を一周) 現象

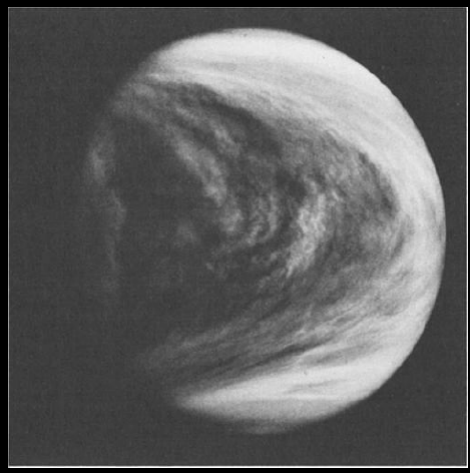
(地球では、自転460m/sに対して、最大でも数十m/sの偏西風程度・しかも局在的)

⇒駆動・維持メカニズムは明らかではない.

Introduction







- Dense H_2SO_4 clouds (50-70 km)
- Upper clouds reflect ~76% of the incident sunlight back to space.
- About 50% of the sunlight absorbed by Venus is deposited at altitudes (>64 km)
- To elucidate the mechanism and maintenance of the super-rotation, the cloud layers, which control the solar input, must be investigated.

maintenance of the super-rotation.