I've looked at clouds from both sides now
From up and down and still somehow
It's cloud's illusions I recall
I really don't know clouds at all

- Joni Mitchell

Puzzling Cloud cover of Venus

THE MYSTERIES IT COVERS HOLD CLUES TO ITS EVOLUTION

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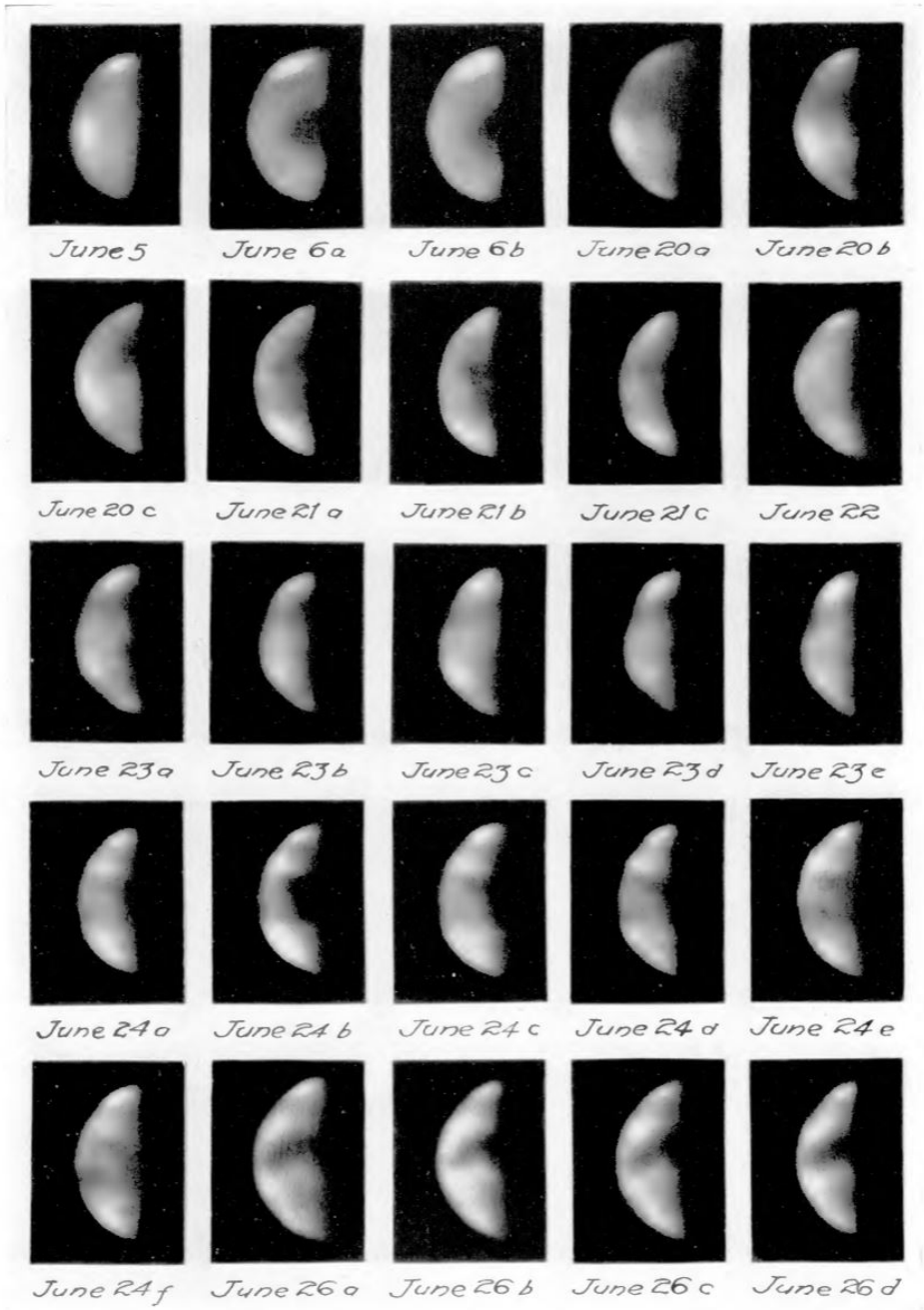
UNIVERSITY OF WISCONSIN

INTERNATIONAL VENUS CONFERENCE, NISEKO, HOKKAIDO, JAPAN, 31 MAY-3 JUNE 2019

PLATE I



PHOTOGRAPHS OF VENUS, IN ULTRA-VIOLET LIGHT, TAKEN WITH 60-INCH REFLECTOR, JUNE 1927

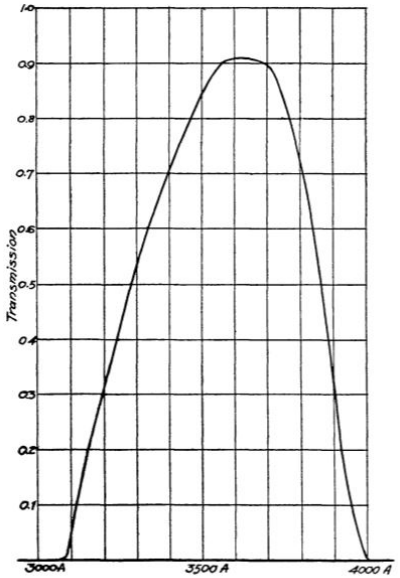
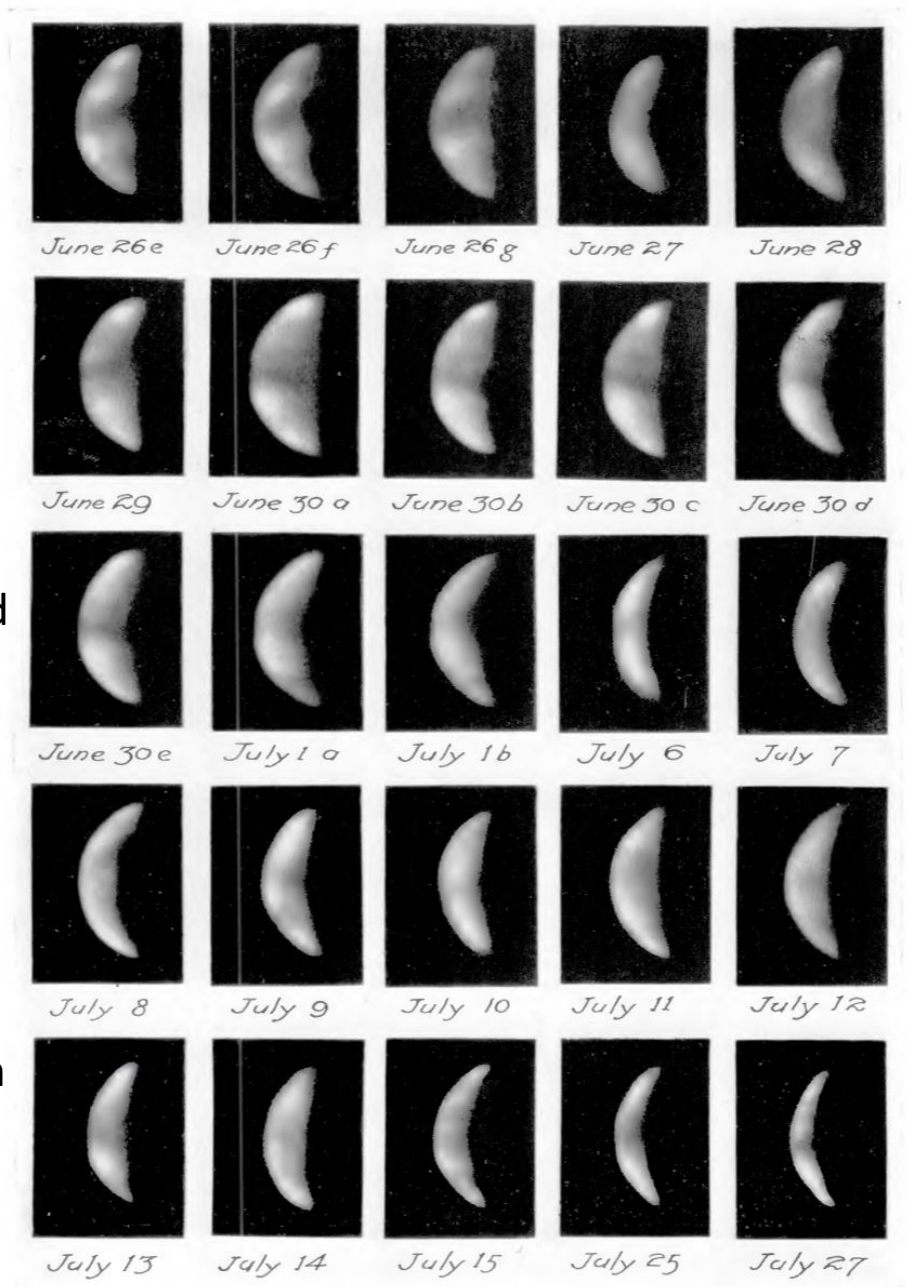


FIG. 2.—Spectral transmission of ultra-violet filter No. 18A.

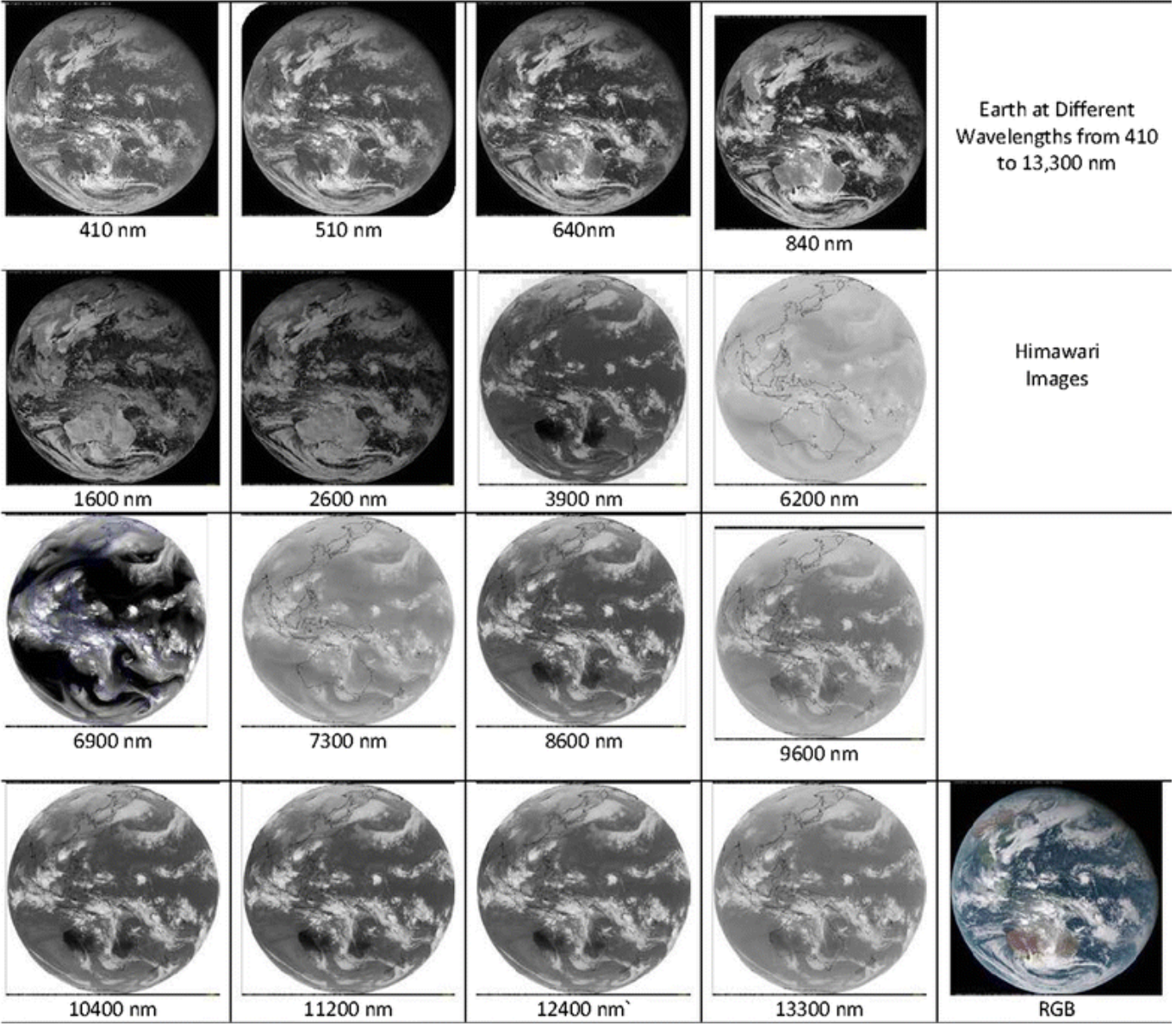
Venus contrasts were observed and photographed in ultraviolet about a century ago, long after the presence of the atmosphere was discovered in 1761.

These images from Yerkes and Wilson Observatories by Ross in 1927 show the dark patches which are still baffling

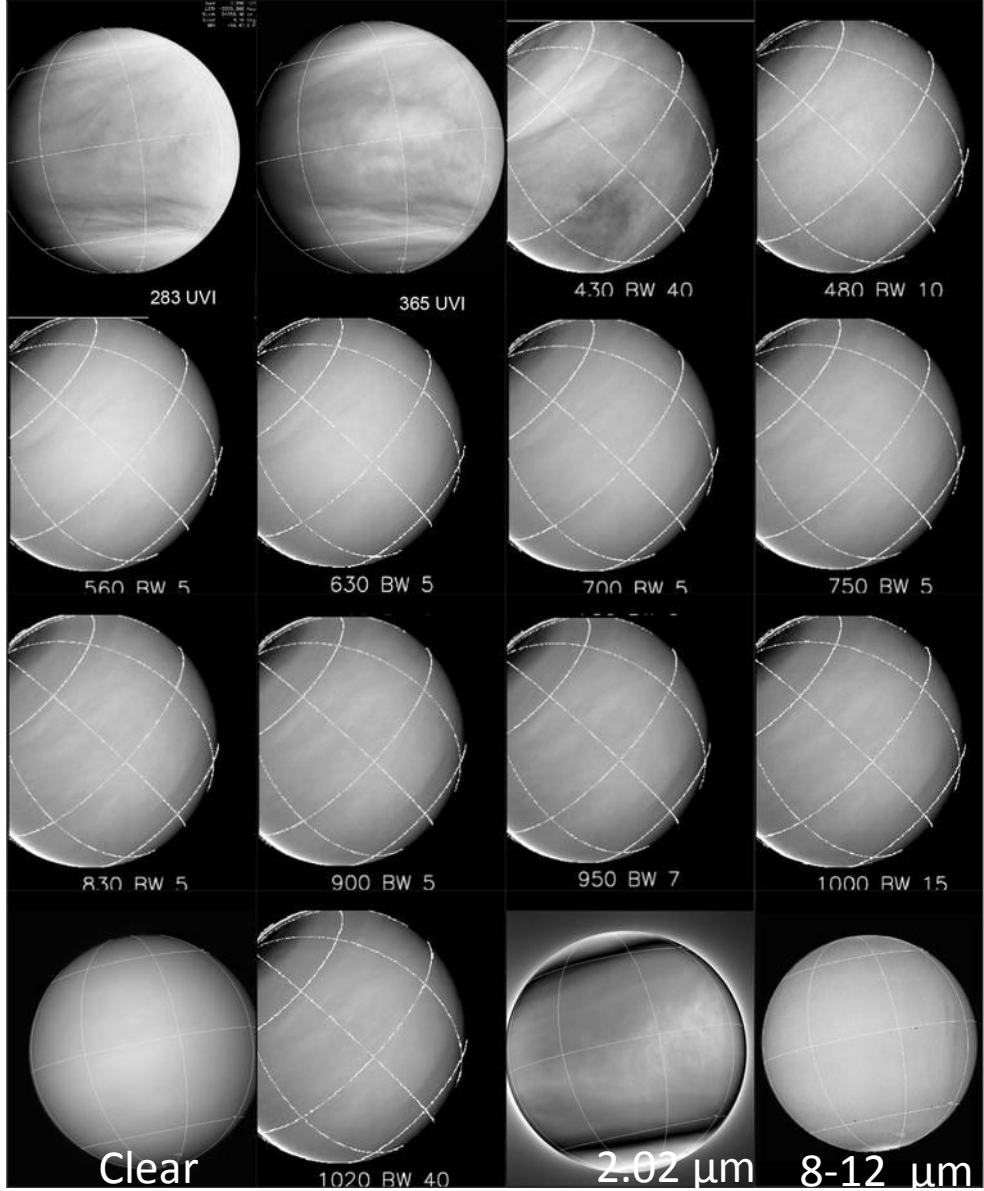
PLATE II



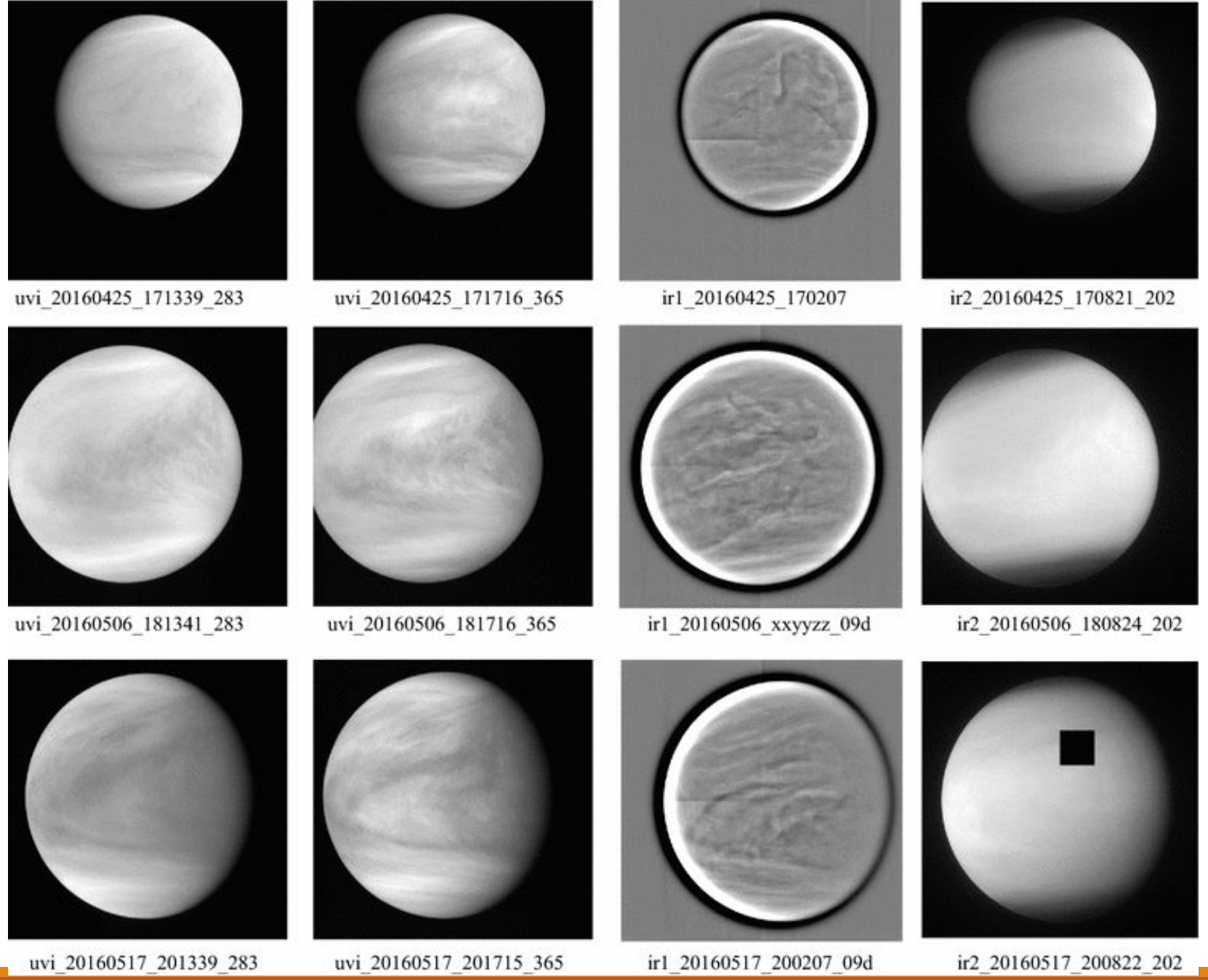
PHOTOGRAPHS OF VENUS, IN ULTRA-VIOLET LIGHT, TAKEN WITH 60-INCH AND 100-INCH REFLECTORS, JUNE-JULY 1927



Earth views from 410 nm to 13.3 µm



Venus views from 283 nm to 12 µm



Concurrent view of Venus from Akatsuki at 283, 365, 900 nm and 2.02µm

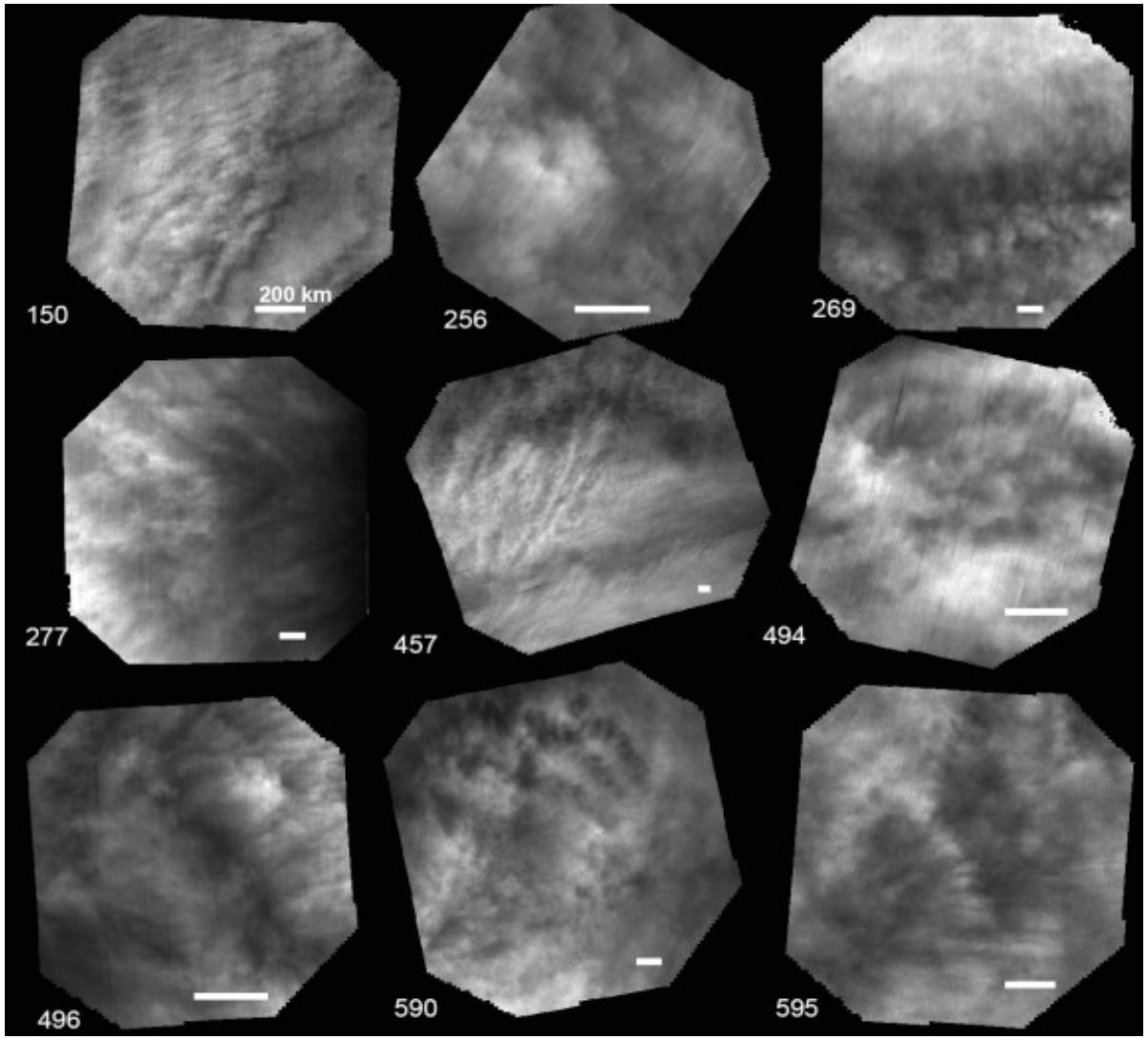
900 nm images have been contrast enhanced to bring out detail

A much larger range of morphologies is seen in IR1 (day) and IR2 (day and night side) images compared to the UV images

Some of the Venus Cloud Cover Puzzles

1. Why are any contrasts seen at different wavelengths on the day and night side? *What properties of the absorbers/cloud particles are responsible?*
2. What are the different absorbers that cause reflectance or opacity variations?
3. What determines the spatial scale of the contrasts?
4. What controls the temporal evolution on different time scales?
5. What is responsible for sharp boundaries seen in the night side NIR images? *Different air masses?*
6. What causes the meso-scale vortices seen in Akatsuki day and night side images?
7. Occasionally, the cloud cover patterns are not symmetric about the equator.

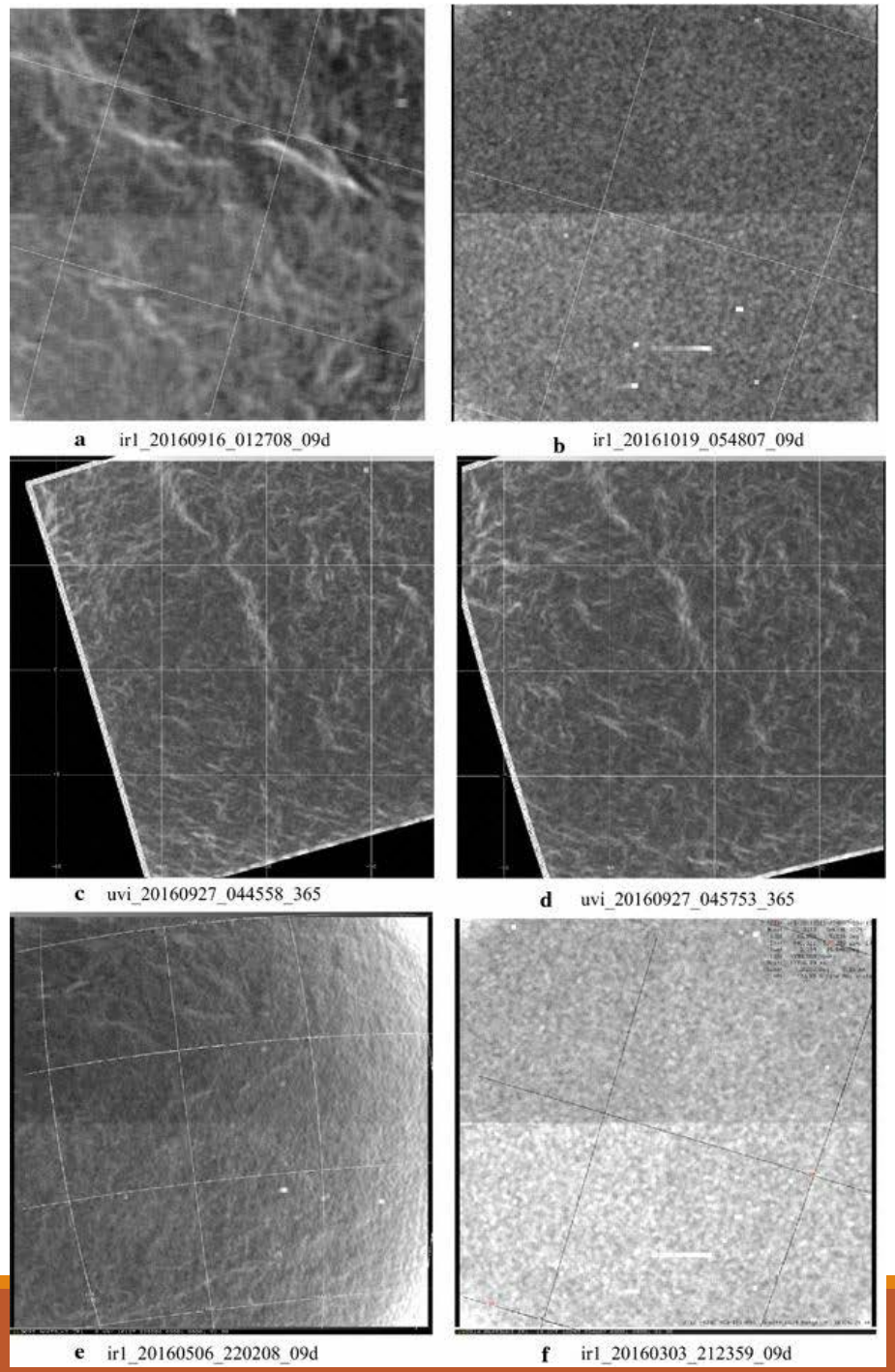
TEMPORAL CHANGES



- Equatorial region 365 nm images
- Contrasts are dynamic and scale dependent
- Timescales are minutes to weeks!
  - Minutes: ~10 km distances…
  - Weeks: ~2000 km distances…

What properties of the absorbers are changing?

Venus Express VMC 365 nm images. Numbers indicate orbit number



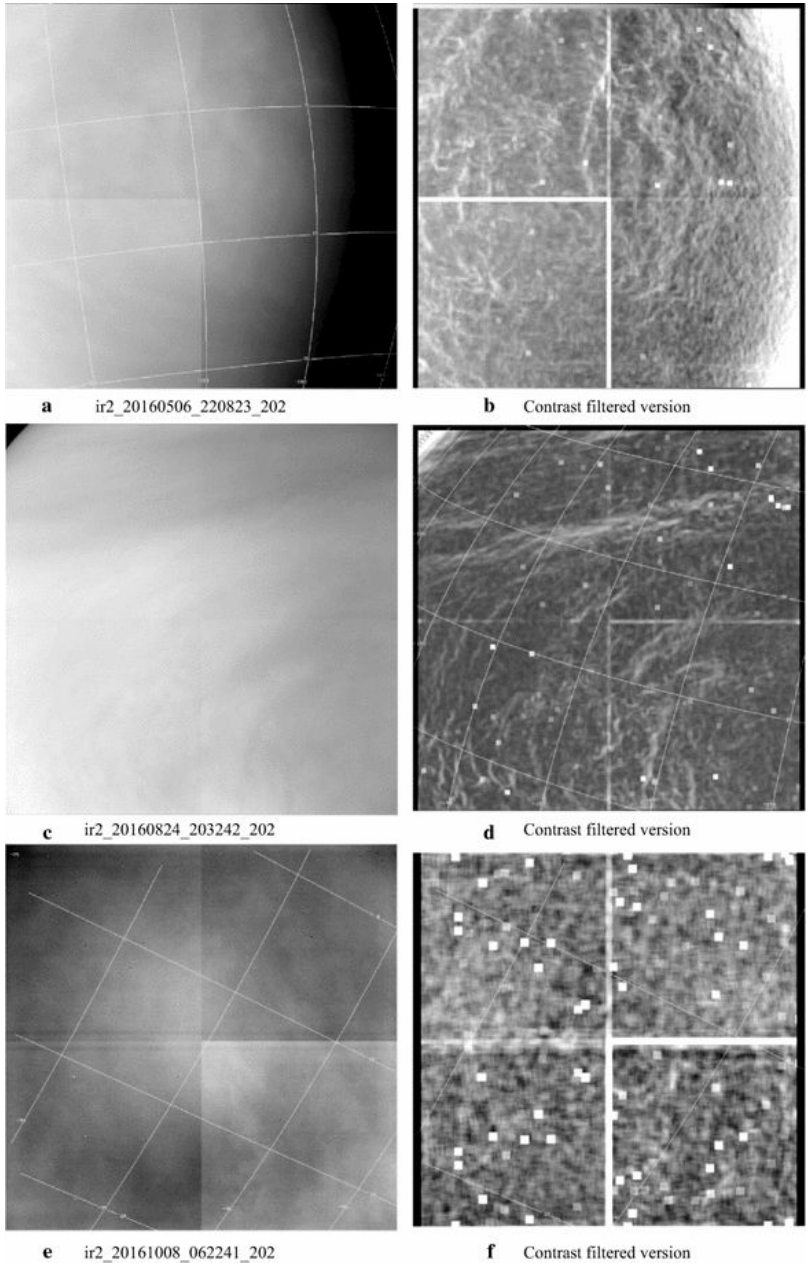
IR1 900 nm

UIV 365 nm

IR1 900 nm

High-resolution images from the IR1 camera (top and bottom rows) in the 09d filter and two UVI images taken through the 365-nm filter (c and d, middle row). Only contrast filtered images are shown to emphasize the details.
The UVI images are taken about 12 min apart and are shown as rectilinear maps to show the rapid changes that can take place in the appearance of the wavy features.

In the 0.9-µm images a, e wavy and curved patterns are also seen; however, the slightly higher-resolution images b, f do not show such details. It is not known whether this is due to the transient nature of the patterns or due to spatial-scale dependence of contrasts



ORIGINAL CONTRAST FILTERED

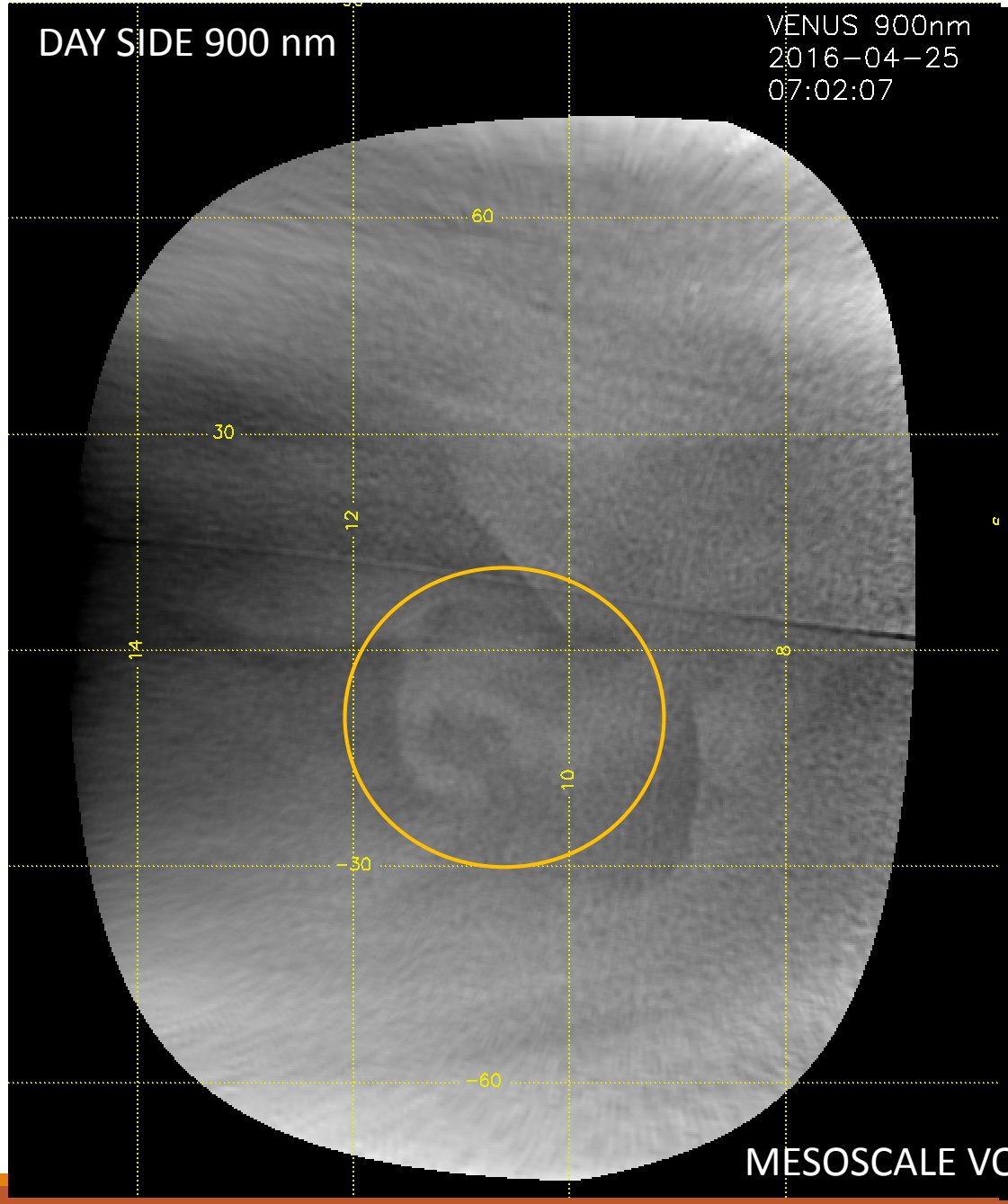
IR2 2.02 µm

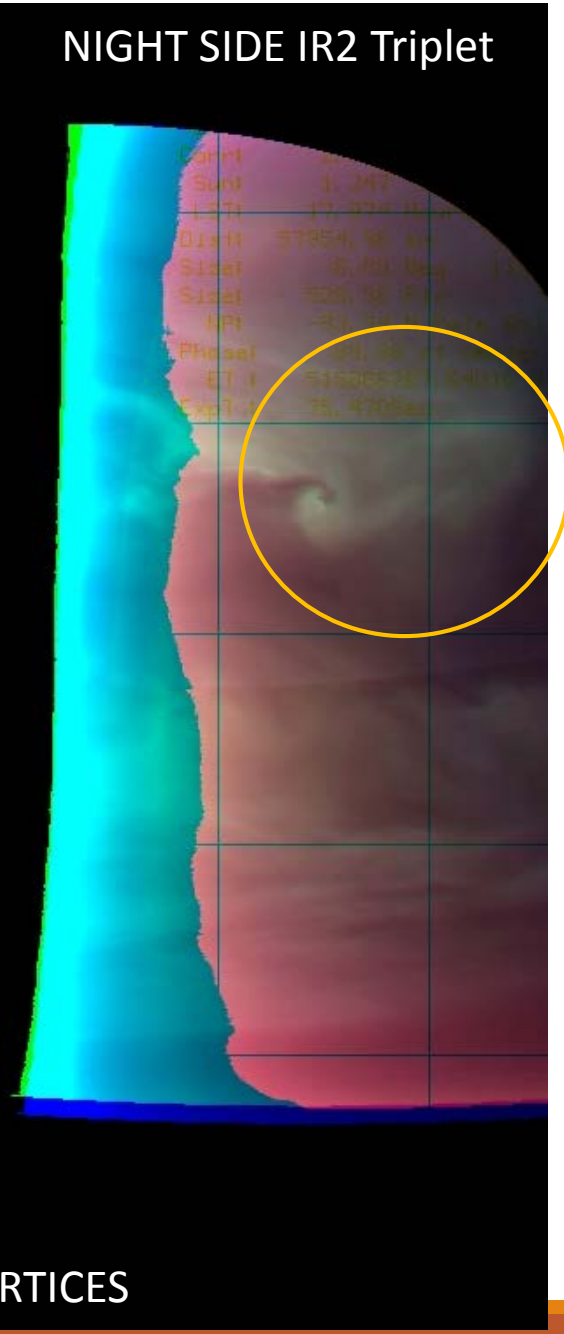
~ 5km/pixel

A sample of high spatial resolution dayside 2.02-µm images from the IR2 camera, each at a pixel scale of approximately 5 km in the calibrated (left column, a, c, e) and contrast filtered versions (right column, b, d, f).

The quadrant boundaries of the CCD can be faintly seen in the calibrated version due to slightly different gains of the readout electronics. Very bright pixels in the contrast filtered versions represent noise pixels. Very subtle sinuous or string-like structures are seen with widths of about 20–40 km and with variable lengths and inclinations to latitude circles as seen in a and b. Image b shows bow-like waves also seen at ultraviolet wavelengths. Image e is devoid of such patterns, but instead shows a bright area surrounded by a poorly defined dark ring, which results from low-frequency electronic noise due to the cross talk between the readout electronics of the four quadrants of the image.

This pattern disappears in the contrast filtered version (f). It is interesting that the thin wavy streaks seen in b and d are absent in f which has almost twice the spatial resolution, similar to the difference at the shorter wavelengths (images b and f)



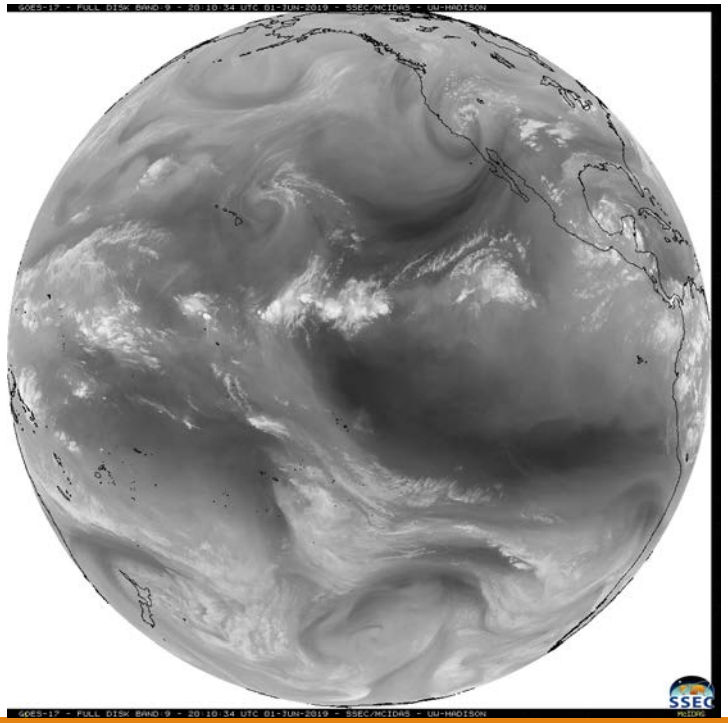


MESOSCALE VORTICES

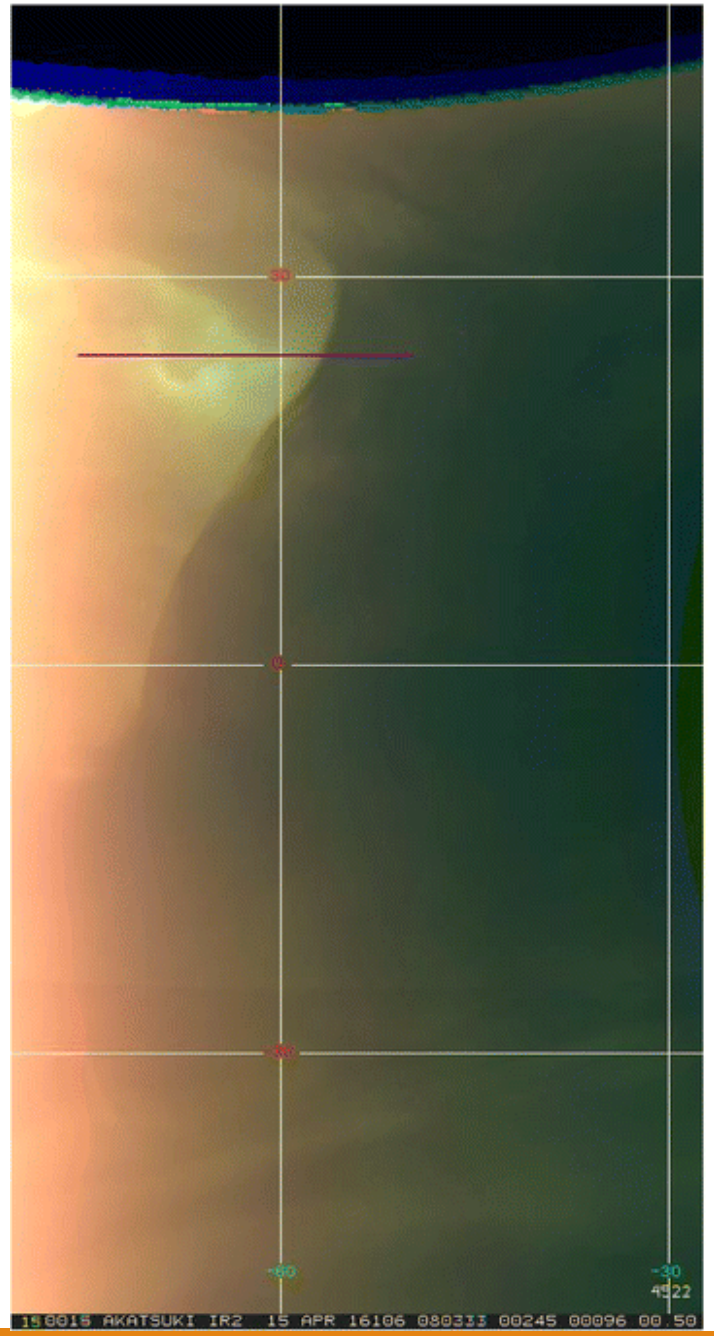
The occurrence of mesoscale vortex circulations in IR1 and IR2 images from Akatsuki has been one of the major surprises.

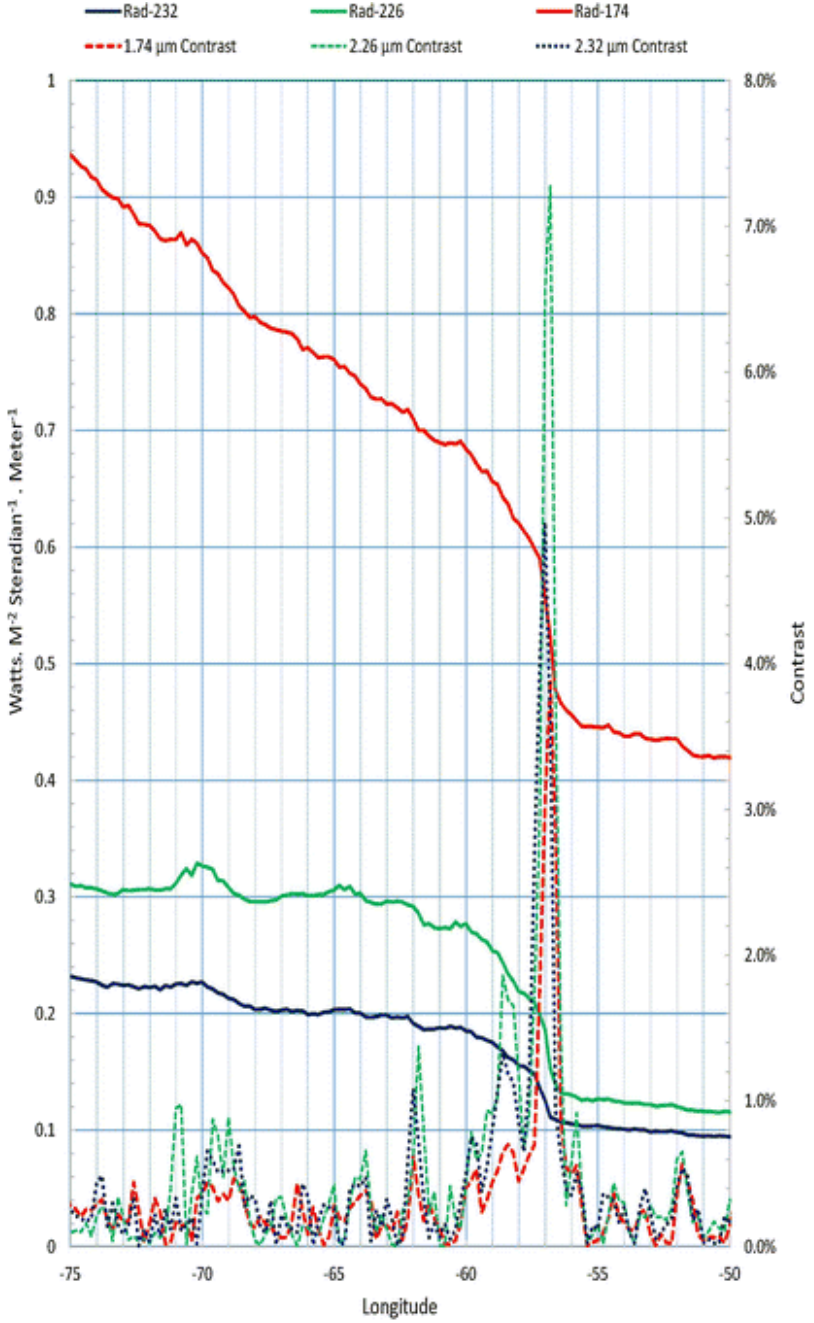
These feturres reveal deformation zones and revela cylocnic and anticyclonic circulations

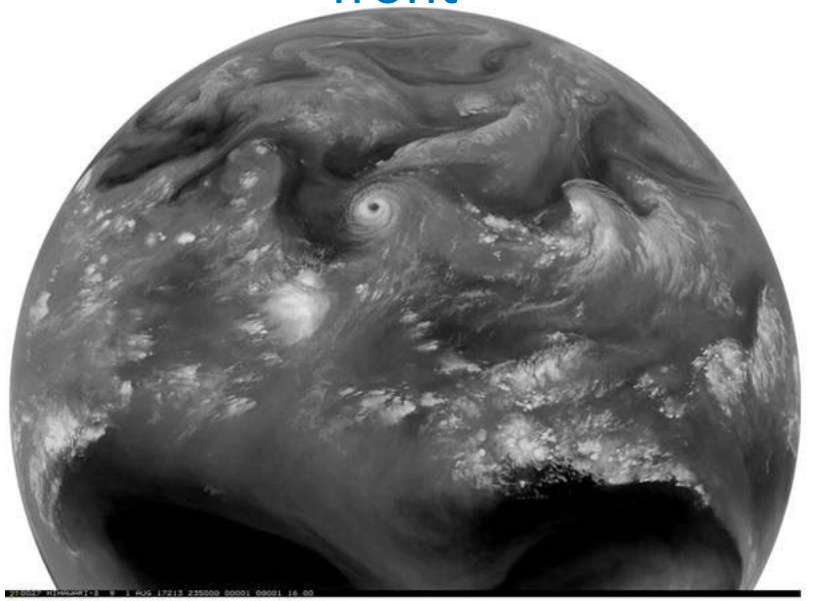
What makes them visible is not known.



Vortex pairs and an example of a front







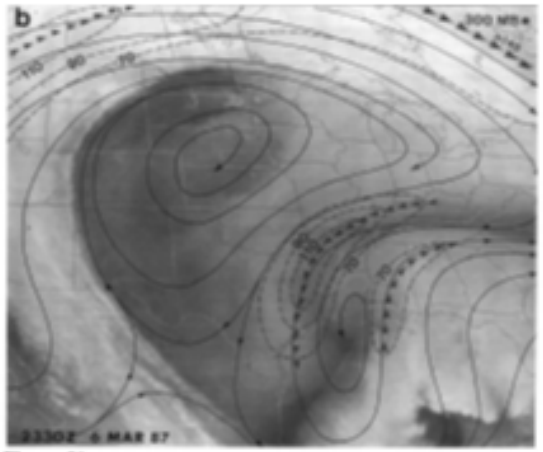
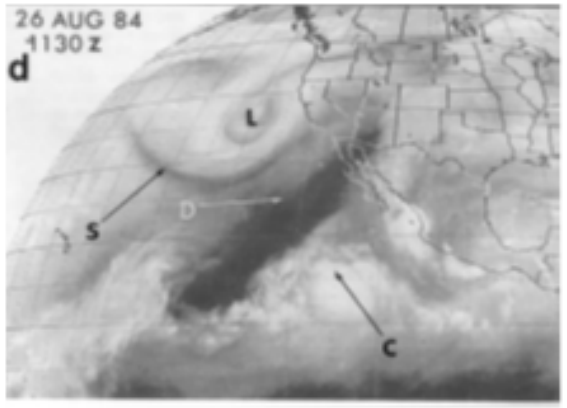


Figure 21



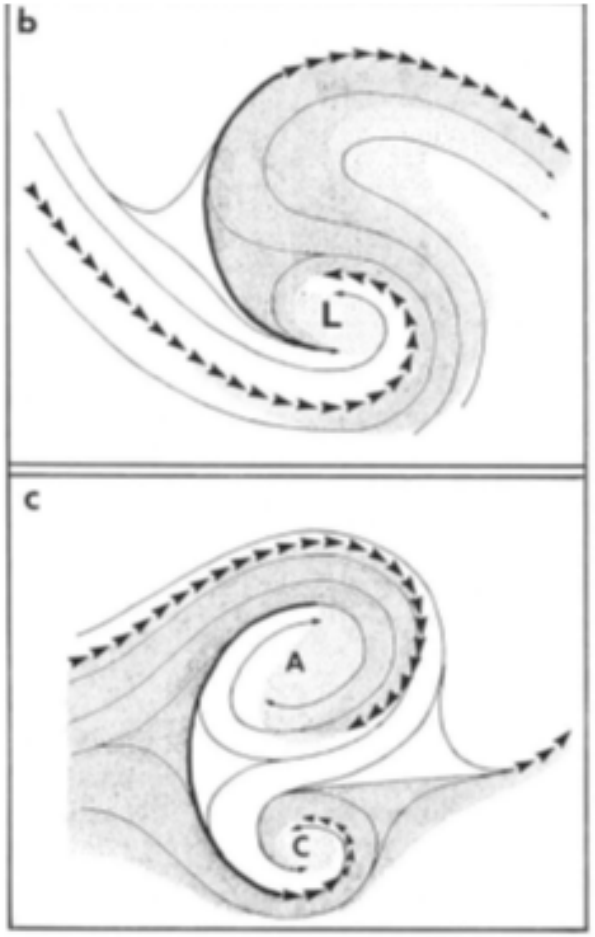
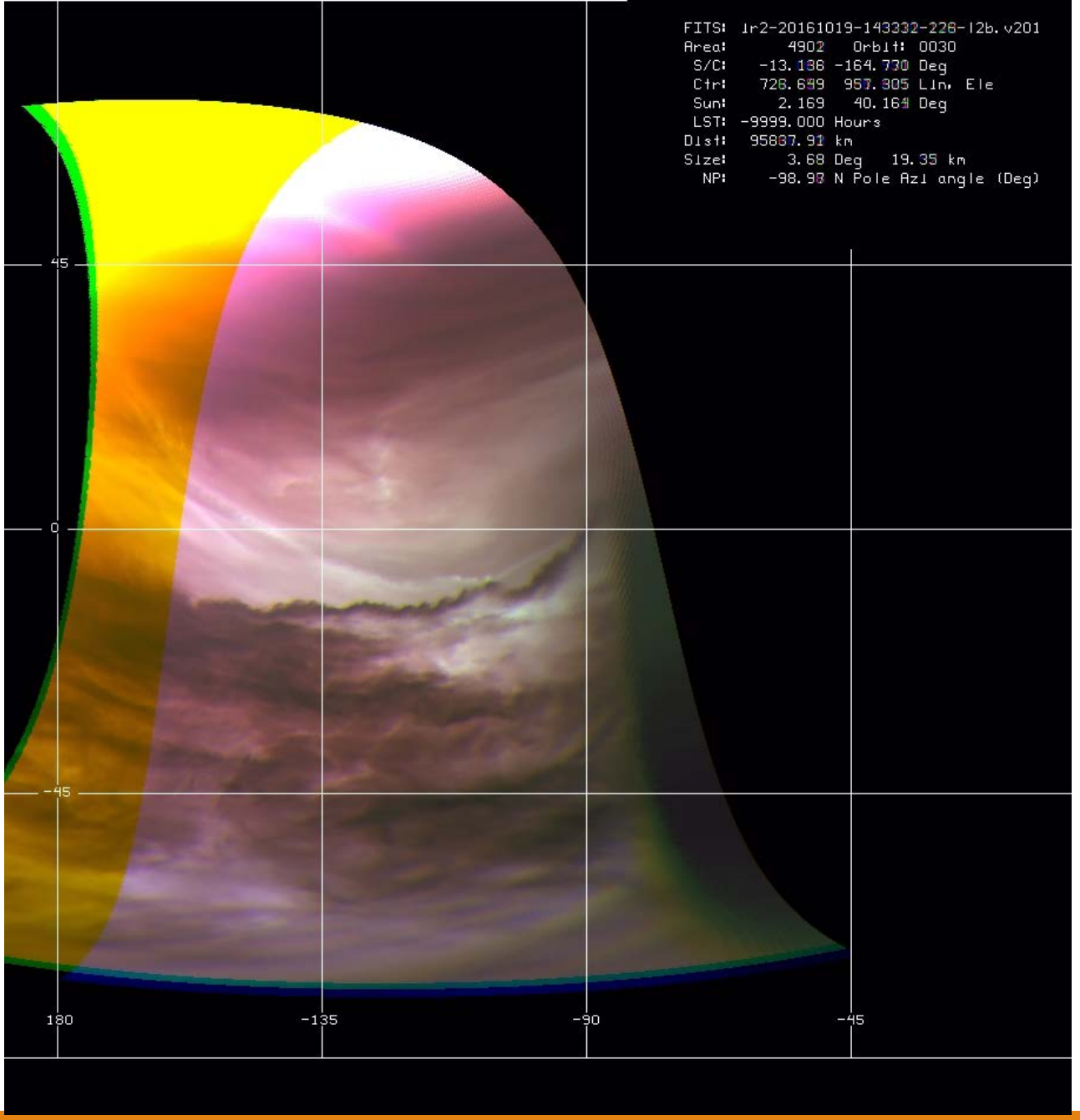
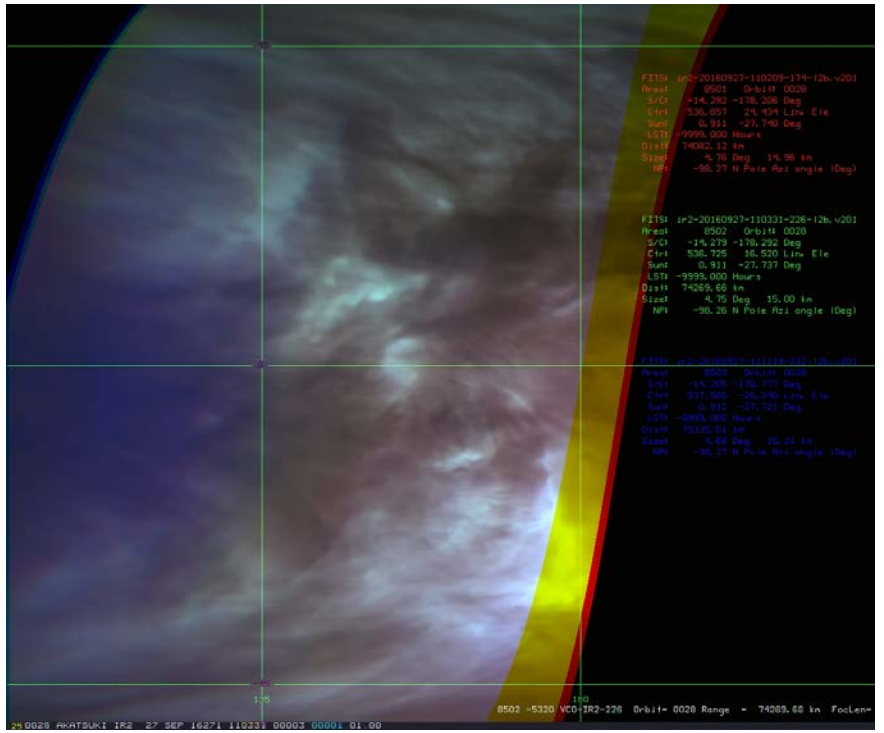


Figure 5. Examples of Inside and Head Boundary formations seen in water vapor images of Earth shown as images on the left and as schematic showing streamlines on the right. The top row represents the Inside Boundary Formation due to Anti-cyclogenesis leading to a drier "mushroom" pattern while the bottom represents a bright (cloudy) formation of a Head Boundary due to cyclogenesis. Credit – Weldon and Holmes (1991).



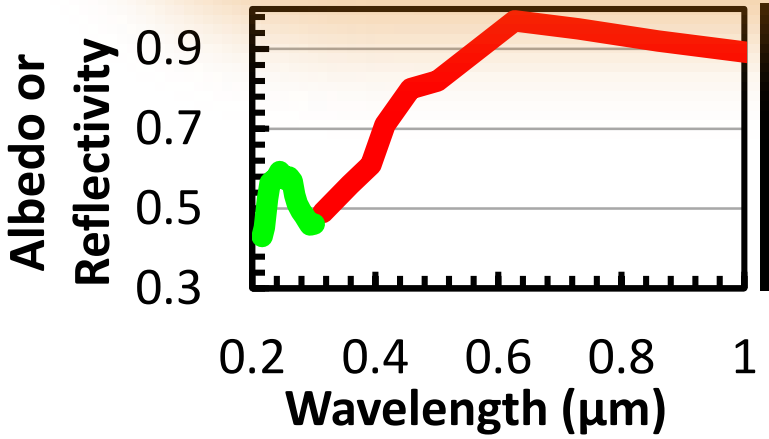


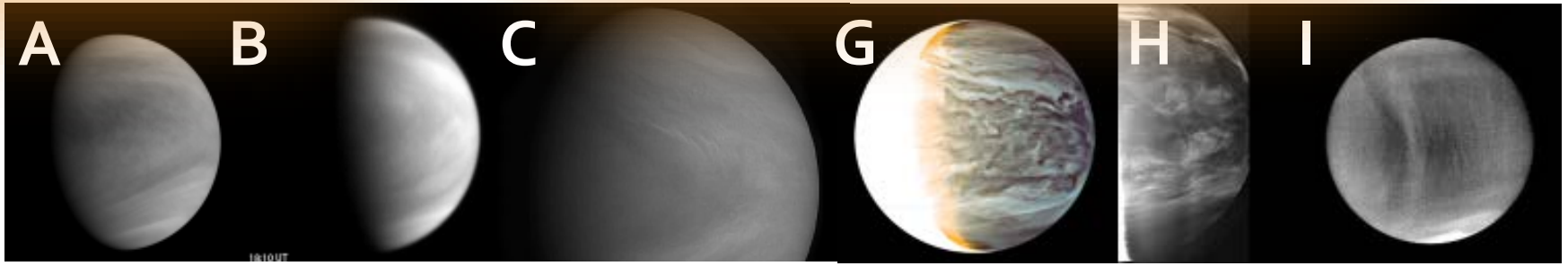
The night side IR2 images at 1.74, 2.26 and 2.32 µm reveal subtle differences in cloud properties/composition.

Can Biology Contribute to the Contrasts?

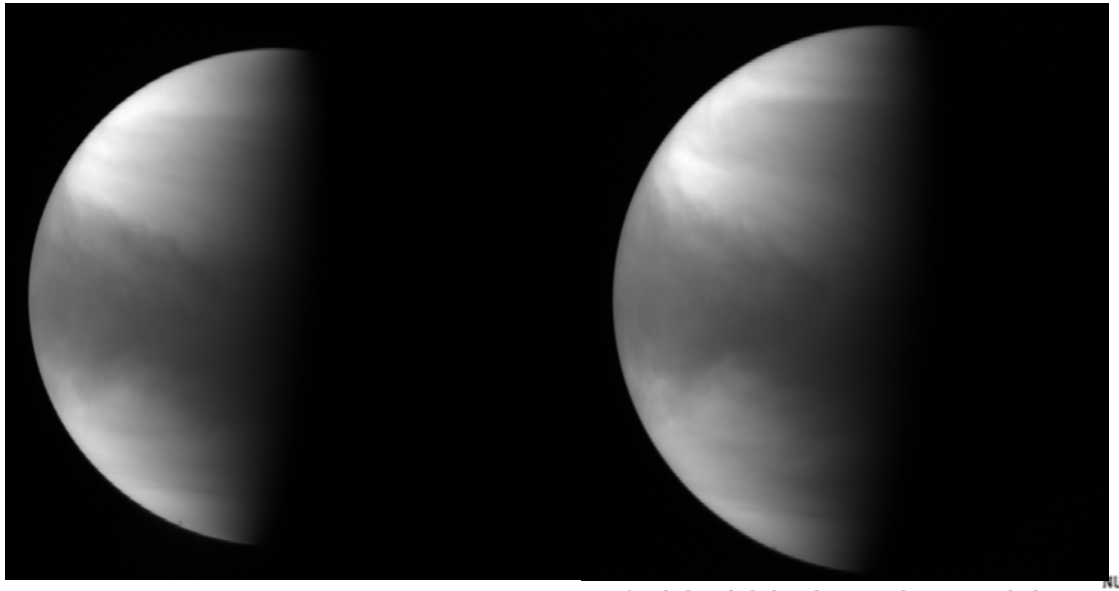
Are Venus' clouds habitable?

Is there sufficient biomass?





283 nm | 365 nm | 410 nm | 1.7 & 2.3 µm | 2.3 µm | 10.0-14.0 µm



uvi_20180819_170111_283

uvi_20180819_170444_365

In UV images, the average reflectance is not symmetric about the equator on a given day and on average over short periods.

Occasional hemispheric brightness asymmetries were reported by Dollfus (1975) on Venus in ultraviolet images from Earth, and have been seen in Venus Express and now in Akatsuki data

Suggests hemispheric circulation/cloud differences rather than external factors for the brightness changes

Dollfus, A. 1975. Venus: Evolution of the upper atmospheric clouds. J. Atmos. Sci. 32:1060-1070

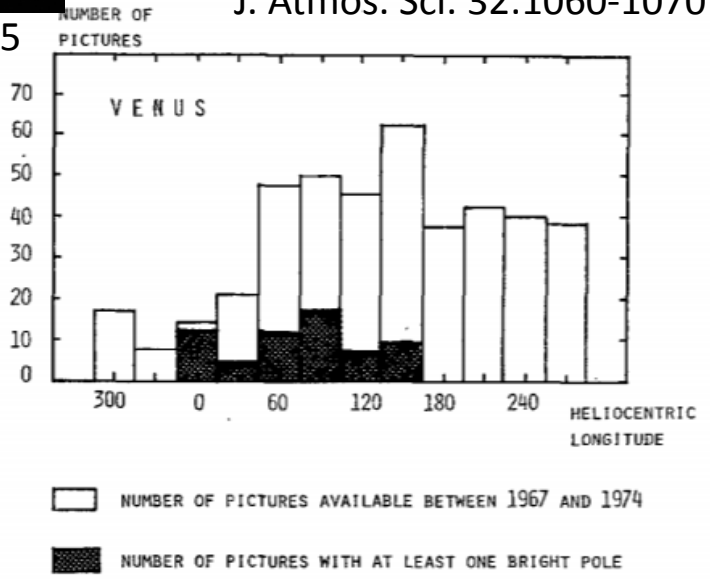


FIG. 11. Histogram of occurrences of white poles as a function of the planet's position on its orbit from 240 plates taken at Pic-du-Midi from 1967 to 1974 and 8 plates from Mariner 10. All bright poles occur when the planet is between 345° and 165° longitude on its orbit.

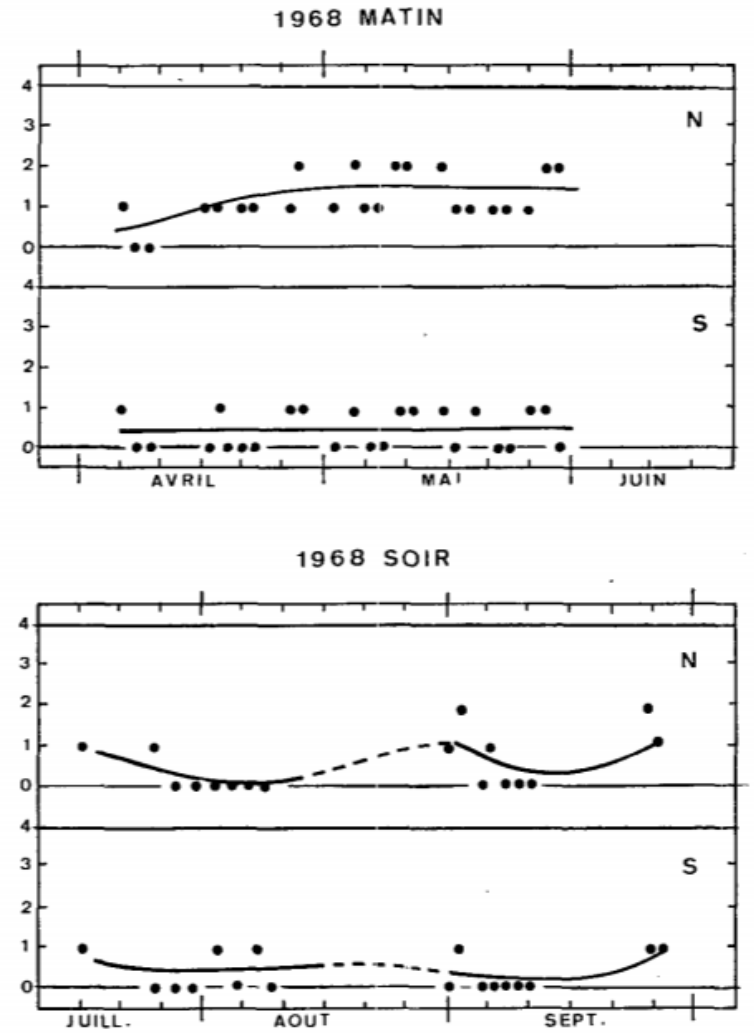
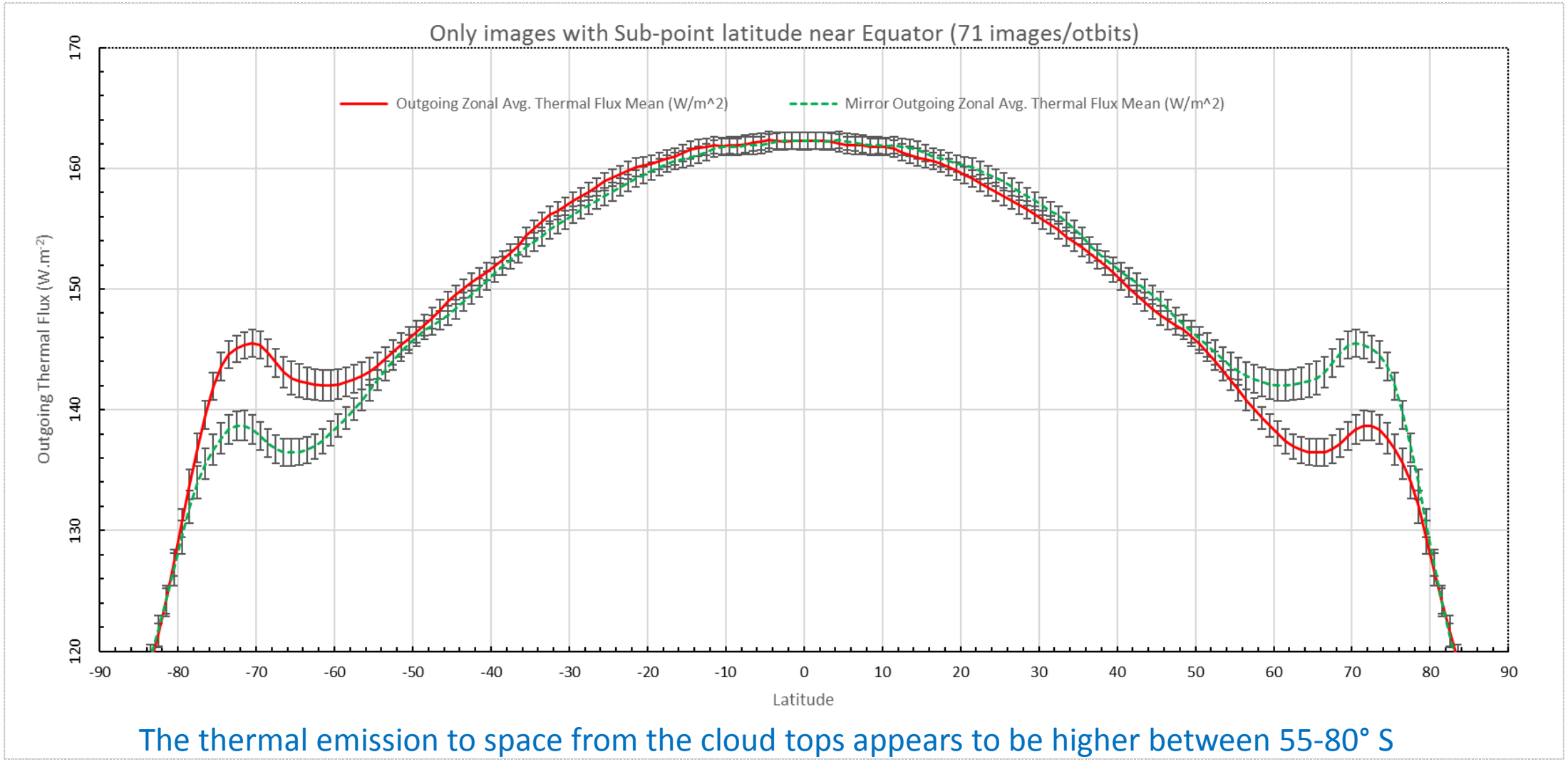


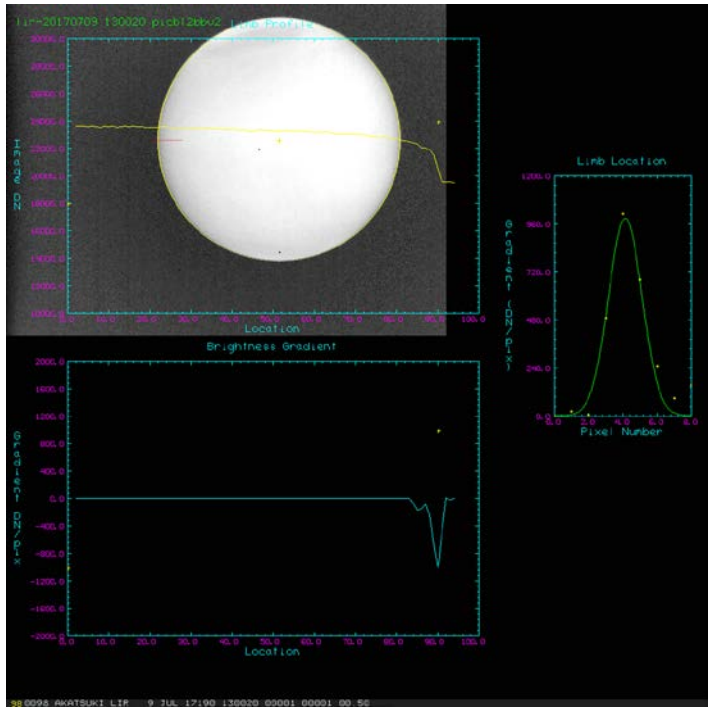
FIG. 12. Brightness variations in the polar areas. The intensities are ranked in five categories with 0=absent (contrast 0.0%) and 5=very bright (contrast 80%).

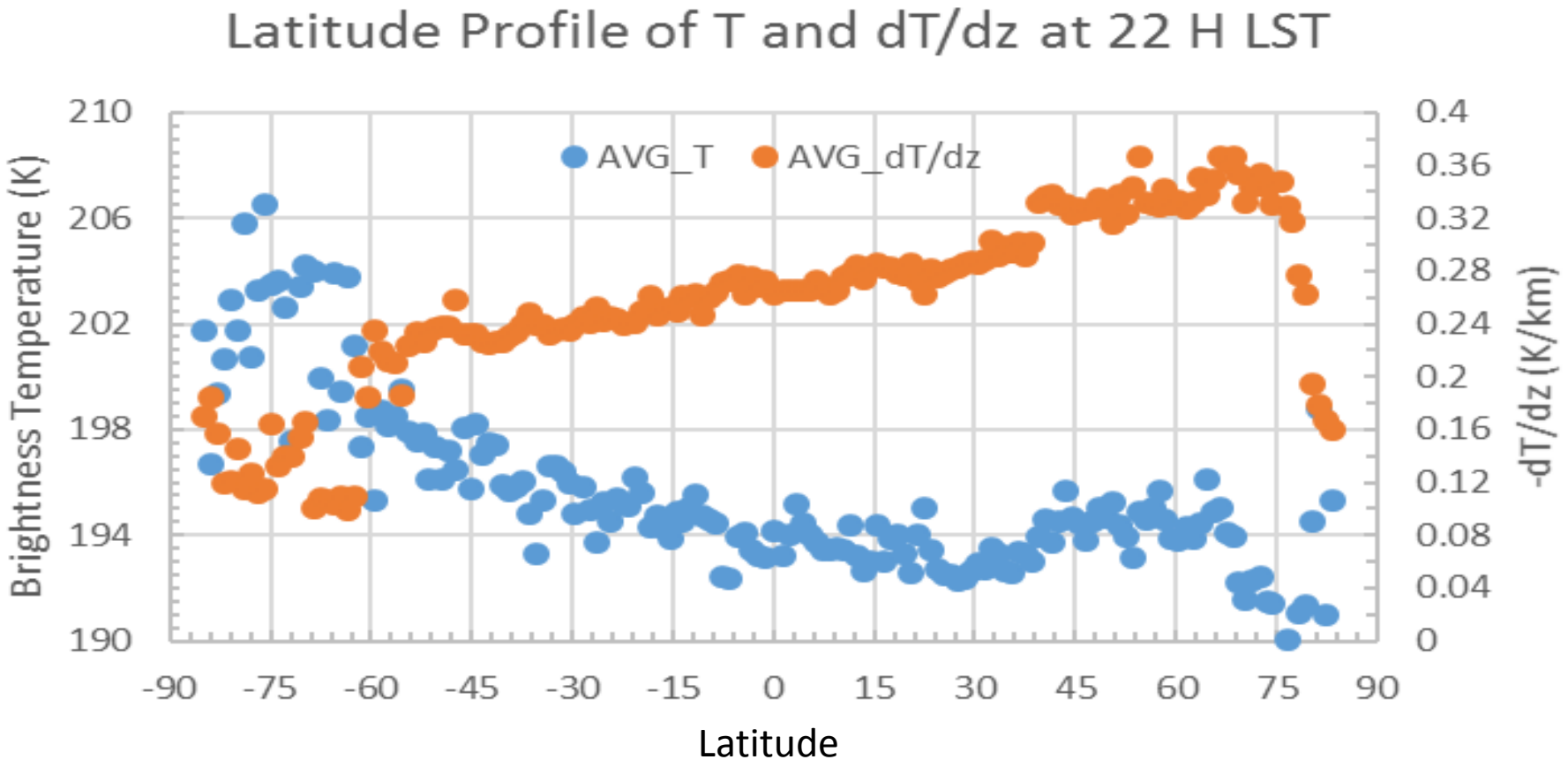
Top: 1968, morning elongation, April-May-June
Bottom: 1968, evening elongation, July-August-September.

Hemispheric Asymmetry in the emitted radiation (8-14 µm) from LIR Data



The thermal emission to space from the cloud tops appears to be higher between 55-80° S compared to the same latitude in the northern hemisphere from a limited sampling of the data





The limb temperature and the lapse rate at the limb determined from LIR data also shows hemispheric asymmetry

Some of the Venus Cloud Cover Puzzles

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5. What is responsible for sharp boundaries seen in the night side NIR images?
6. What causes the meso-scale vortices seen in Akatsuki day and night side images?
7. Cloud cover patterns are not symmetric about the equator

Arigato