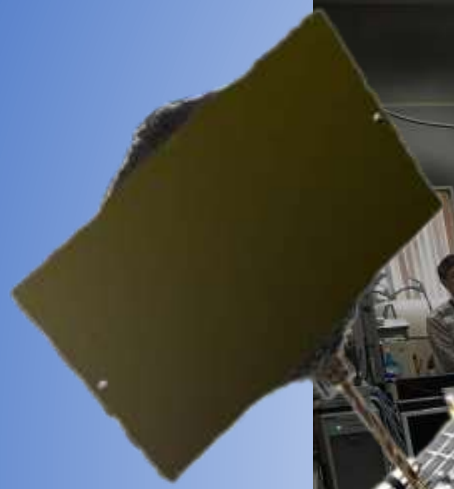
AKATSUKI Now
~ Status, Achievements, and Future ~



Takehiko Satoh (ISAS/JAXA)

Project Scientist, AKATSUKI

Science Objectives of Akatsuki

- Understand in detail the atmospheric dynamics, by drawing 3-D views of wind fields, with multi-wavelength imaging observations (5 onboard cameras). Particular interest is in the “super rotation”.

Dynamics

- Describe spatial and temporal variabilities of clouds (**UVI, IR1, IR2, LIR**), to understand how the massive clouds are maintained and what the roles of clouds are in dynamics and the current environment.

Clouds

- Coordinated imaging and radio occultation measurements (**RS**) will allow us to study relationship between cloud morphology/dynamics and vertical profiles of the temperature (stability of the atmosphere) and the H_2SO_4 vapor.

Structure

- The ground surface is studied for mineralogy and volcanism (**IR1**).

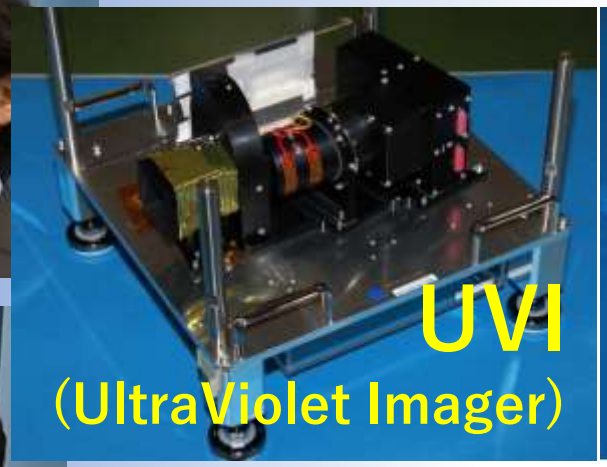
Surface

- To answer the long-time controversy of Venus lightning with an “optimized” high-speed sampling sensor (**LAC**).

Lightning

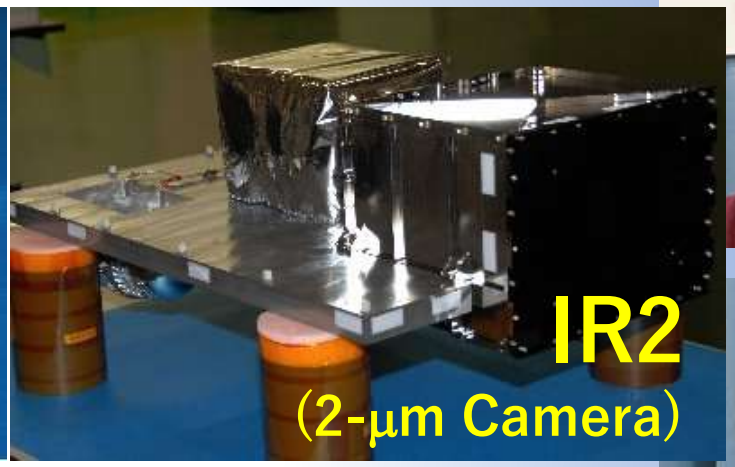
JAXA 宇宙航空研究開発機構
Japan Aerospace Exploration Agency

Science Instruments onboard Akatsuki

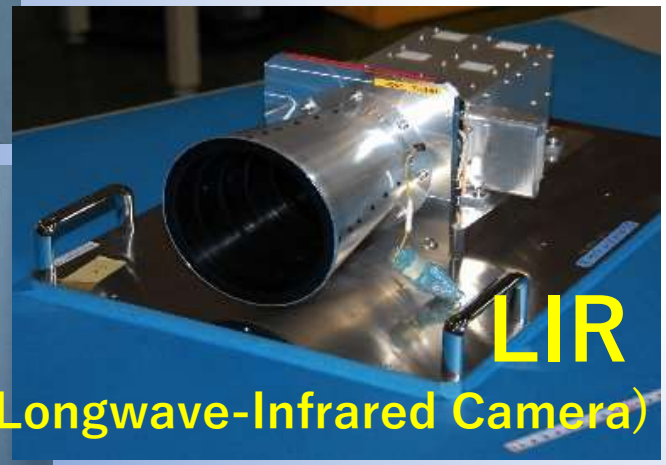


UVI
(UltraViolet Imager)

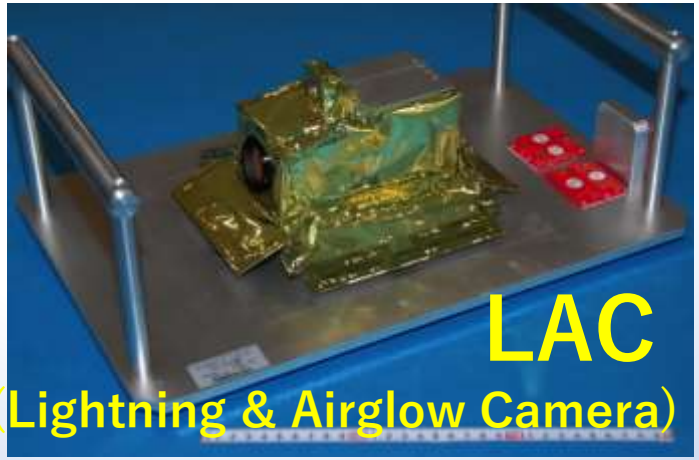
IR1
(1-μm Camera)



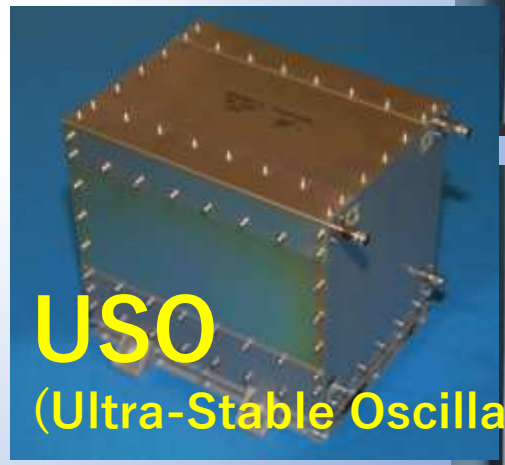
IR2
(2-μm Camera)



LIR
(Longwave-Infrared Camera)



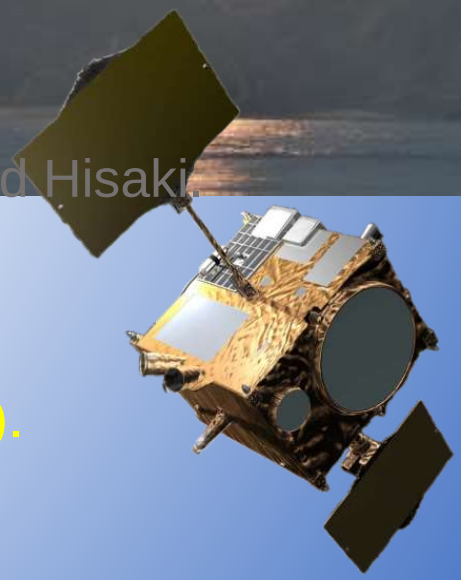
LAC
(Lightning & Airglow Camera)



USO
(Ultra-Stable Oscillator)

Venus Climate Orbiter (VCO), Akatsuki chronology

- Mission approved in **2001** (officially named PLANET-C).
- Launched on 21 May **2010** from TNSC by H-IIA F17 (with IKAROS and 4 small satellites).
- VOI-1 attempted on 7 Dec **2010** but failed.
- Successful VOI-R1 on 7 Dec **2015** (followed by VOI-R2 on 20th) to orbit Venus with an orbital period of ~10.5 Earth days (different from what was originally planned).
  - Slight orbit adjustment (PC1) on 4 Apr **2016** to orbit with P ~10.8 Earth days.
- IR1 & IR2 stopped working due to malfunction of IR-AE (Dec **2016**).
- First extended mission since April **2018.**
  - Slight orbit adjustment (PC2) on 7 Oct **2020** to avoid extremely long umbrae.
- Tri-spacecraft Venus campaign with BepiColombo (flyby on 15 Oct **2020**) and Hisaki.
- Second extended mission since April **2021.**
- Eleven (13) Venusian years in the Venus' orbit (Dec **2023**).
- *A new and final* mission extension (until Mar 2029) just approved (Feb **2024**).



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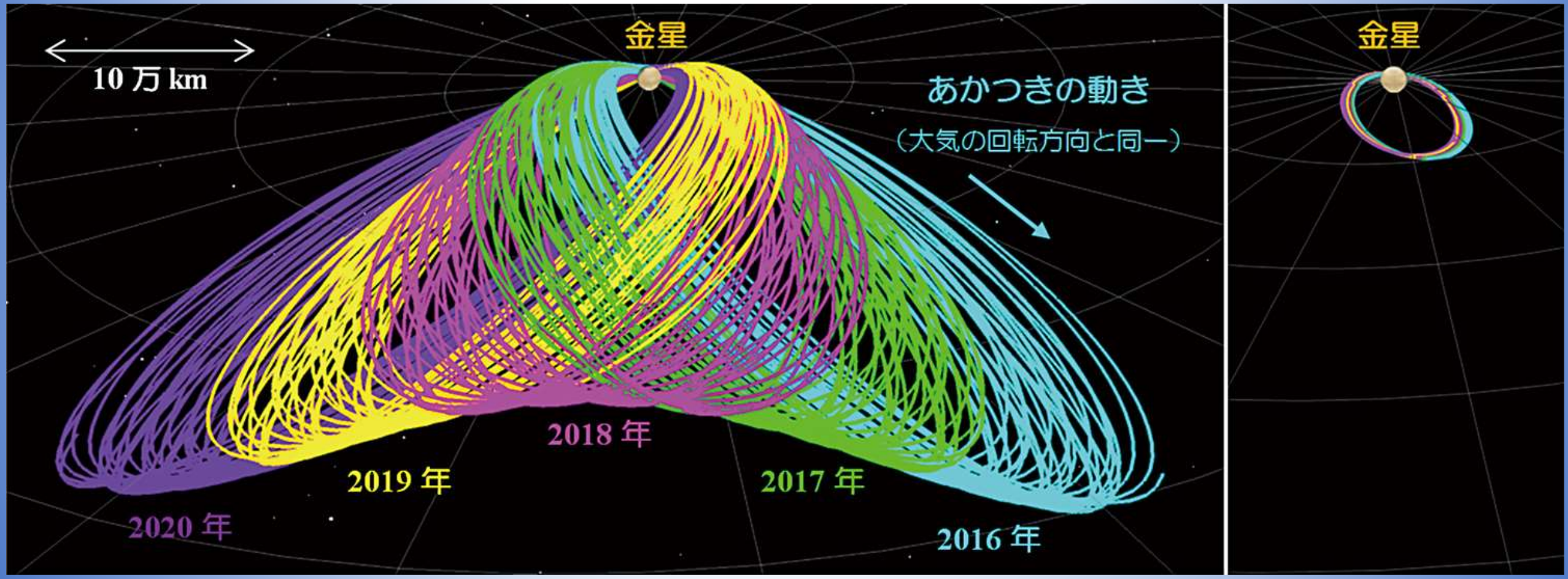
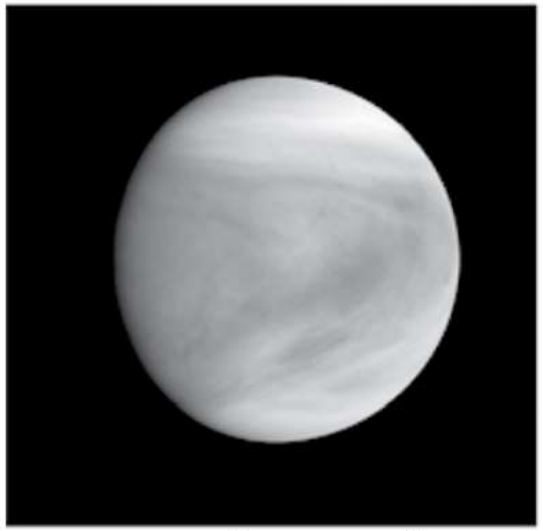
Japan Aerospace Exploration Agency

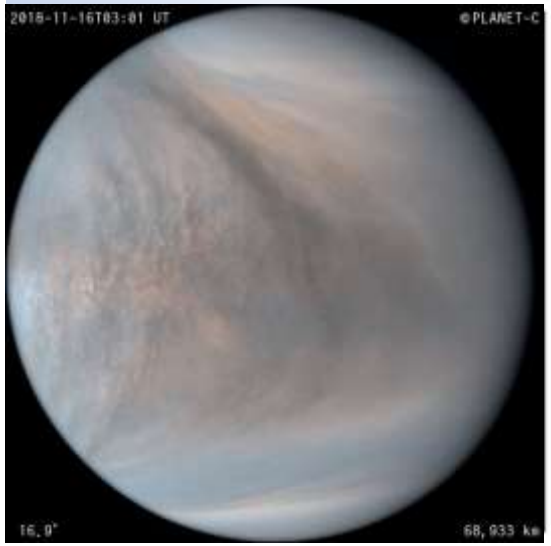
Akatsuki's orbit around Venus (planned vs actual)

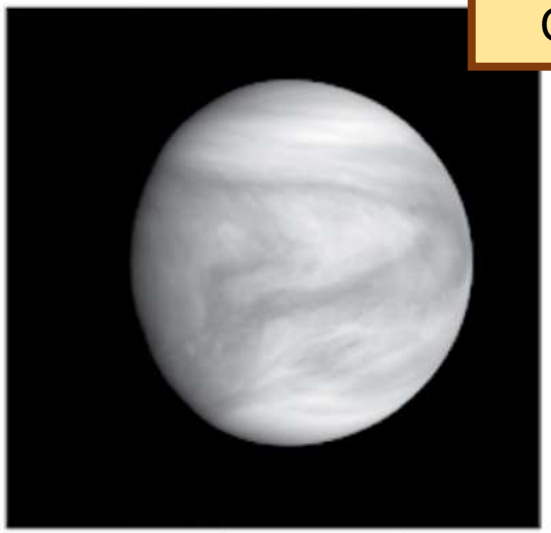


Akatsuki Image Gallery (Day & Night)



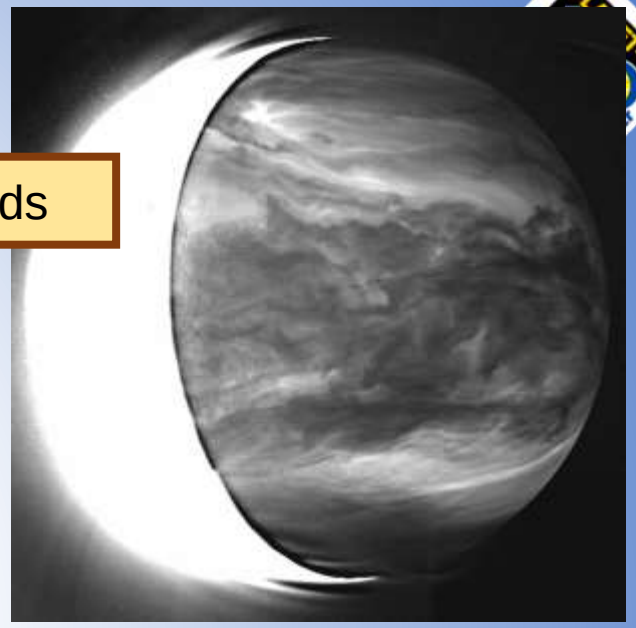
UVI (283 nm)





UVI (365 nm)

Clouds



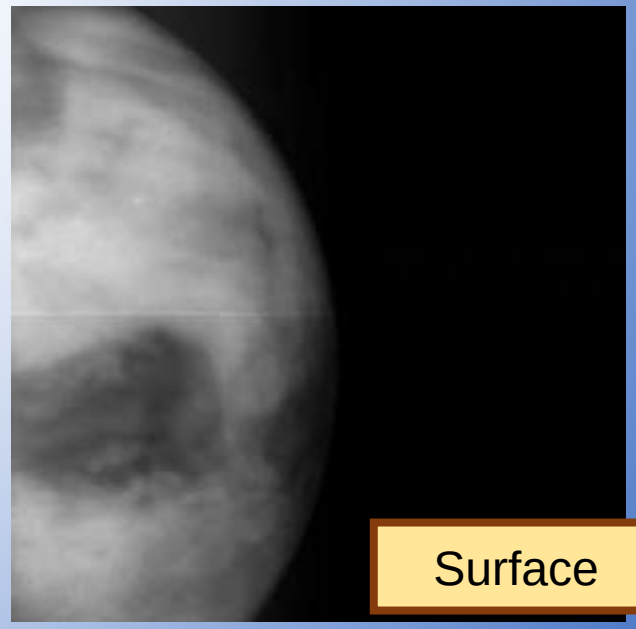
IR2 (2.26 μm)
IR1 (1.01 μm)

Dynamics

IR1 (0.90 μm)

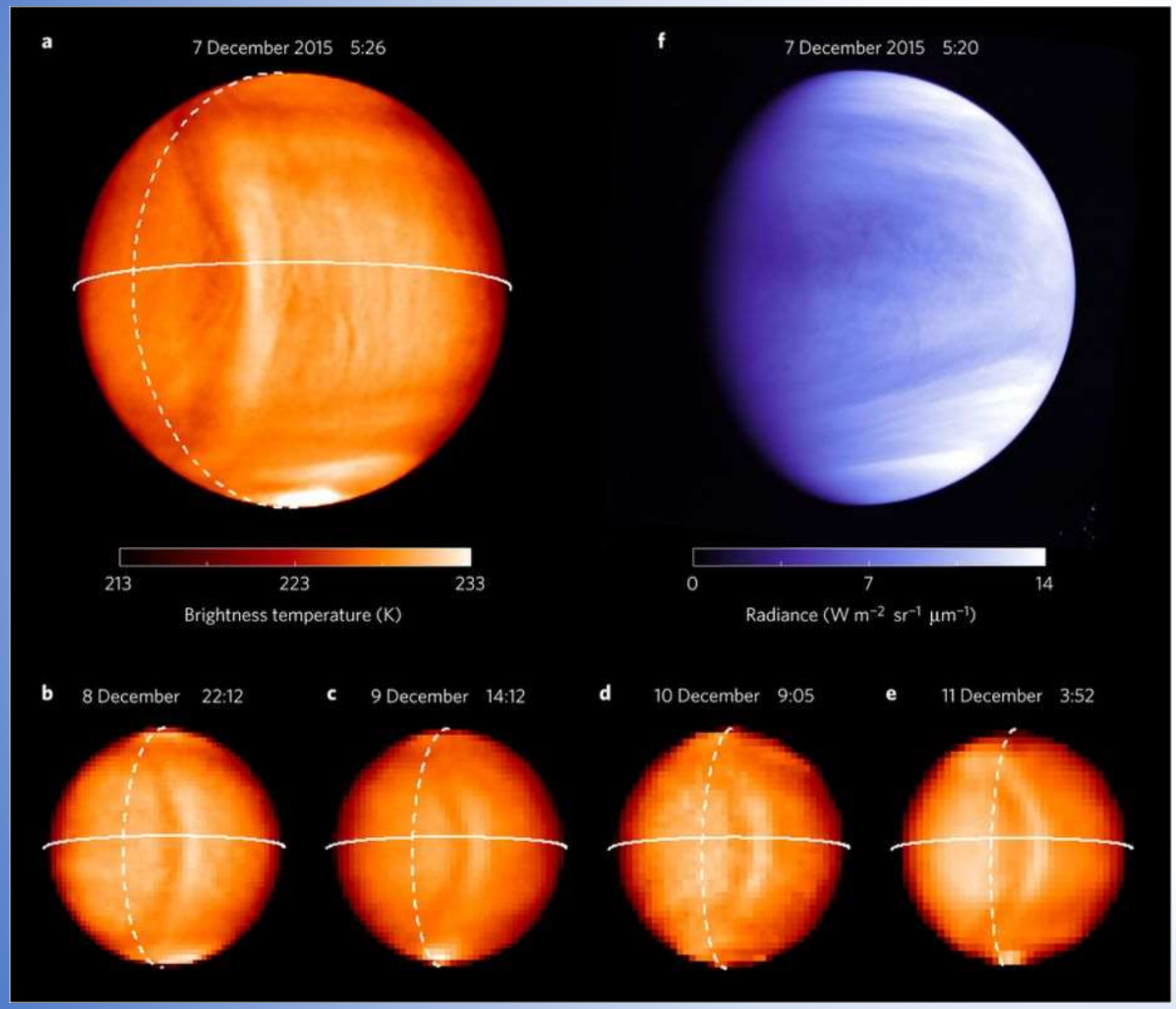
IR2 (2.02 μm)

LIR (10 μm)



Surface

Discovery of Stationary Gravity-Wave Features

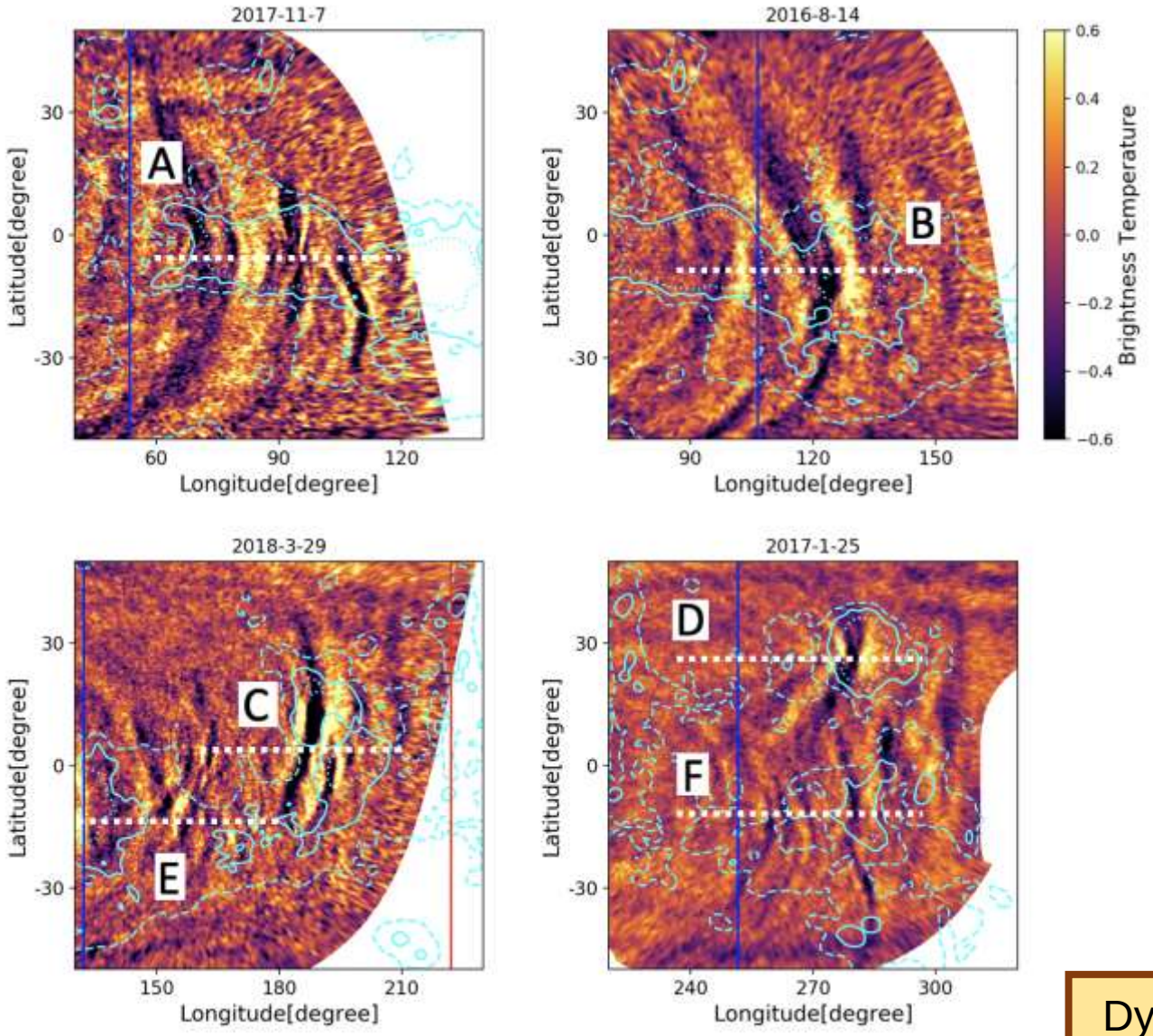


- The LIR thermal maps right after the successful VOI-R1 revealed a striking bow-shaped feature, which was observed until Dec 11 but disappeared when observation resumed in mid-January 2016. The amplitude of temperature variation is ±3 K.
  - The project had to prepare for VOI-R2 (20 Dec 2016) so the scientific observations paused for about a month.
- The feature was not moving at a speed of the super-rotation but appeared rather stational. Later analysis showed it was caused by gravity wave originating from Aphrodite Tera, the largest highland near the Venus equator.

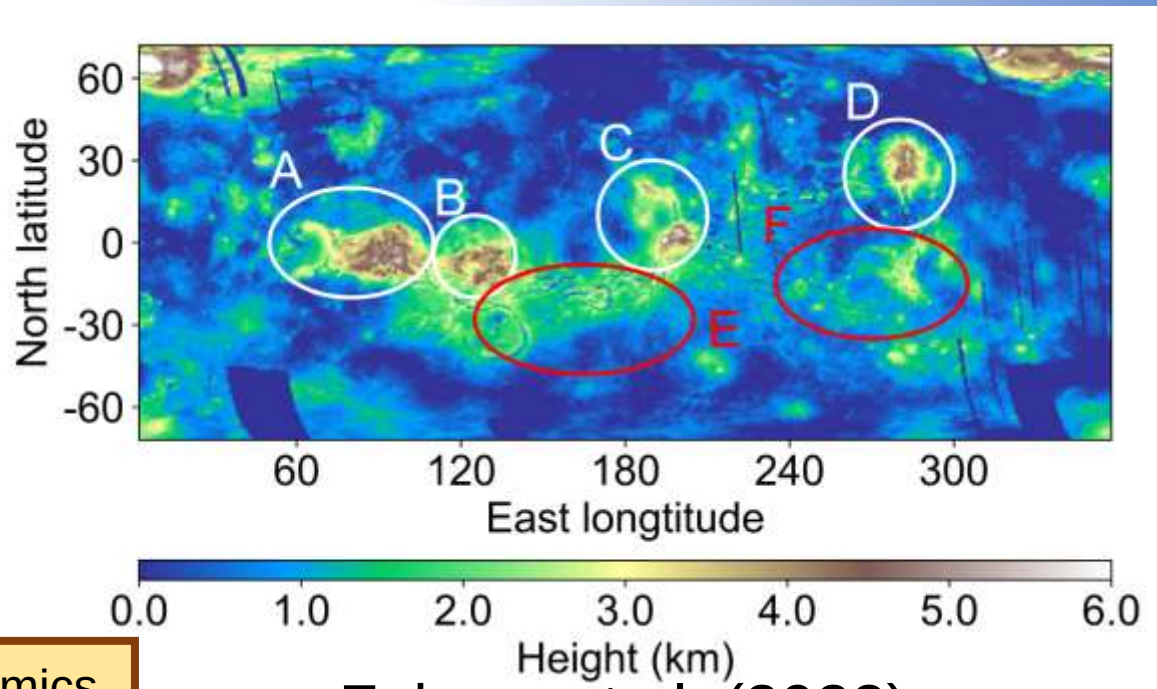
Dynamics

Fukuhara et al., 2017

Finer Structures of Stationary Gravity Waves



Owing to improved image processing techniques, not only lager scale waves, but also rather small-scale can successfully be identified in the data.
Surprising enough, there are so many waves above all highlands in the low latitudes.



Dynamics

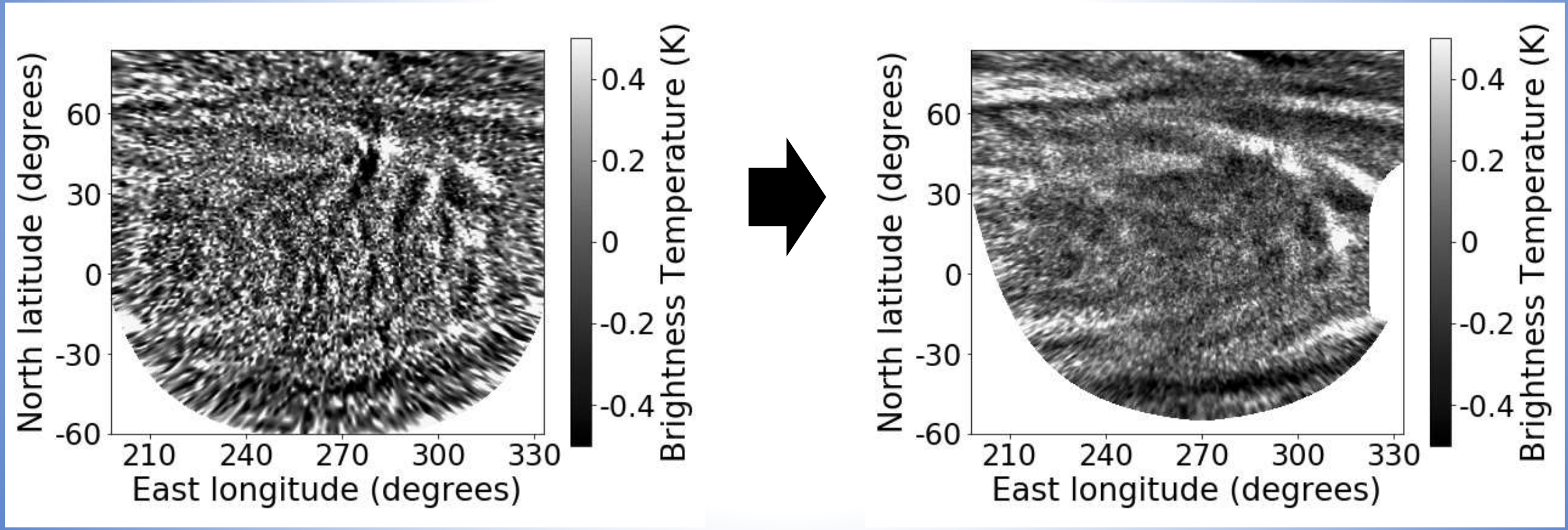
Fukuya et al. (2022)

Thermal Features Moving *with* Super-Rotation

Dynamics

High-pass filtered map without averaging

Averaging images on a coordinate system moving with the background atmosphere (SR)

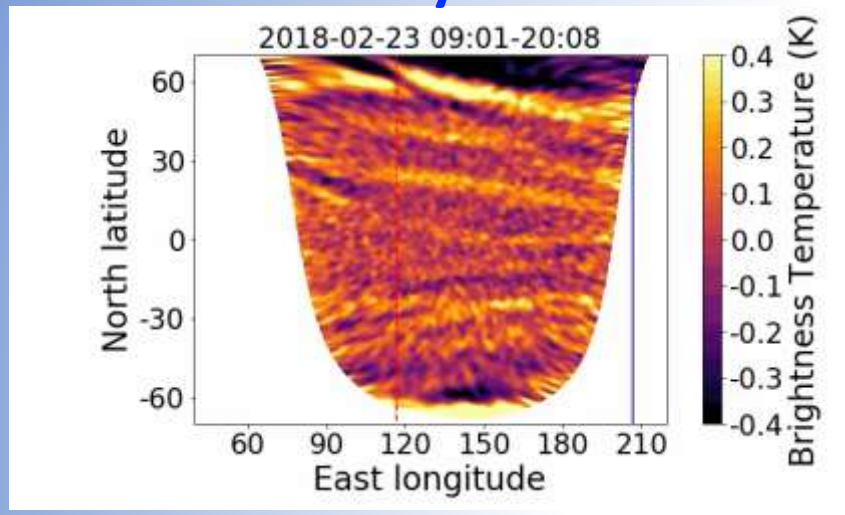


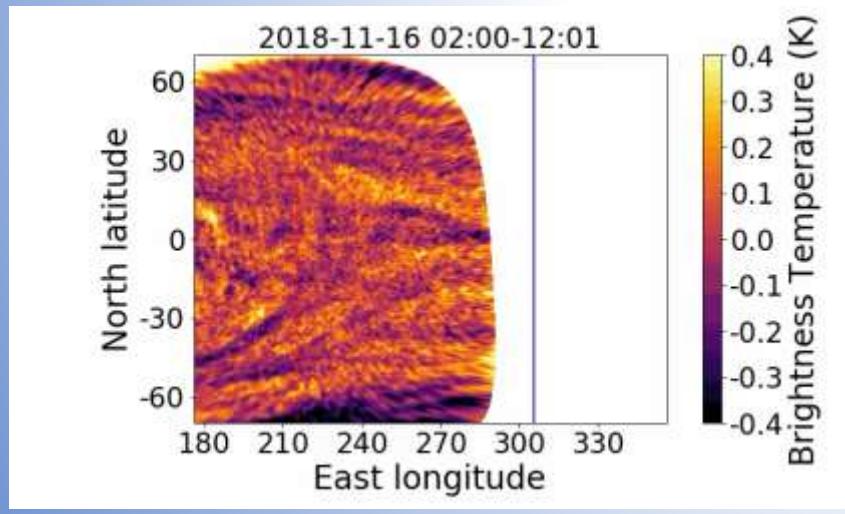
Random noise reduced and stationary features averaged out.

Cloud tracking using mid-IR (10 μm) images taken by LIR

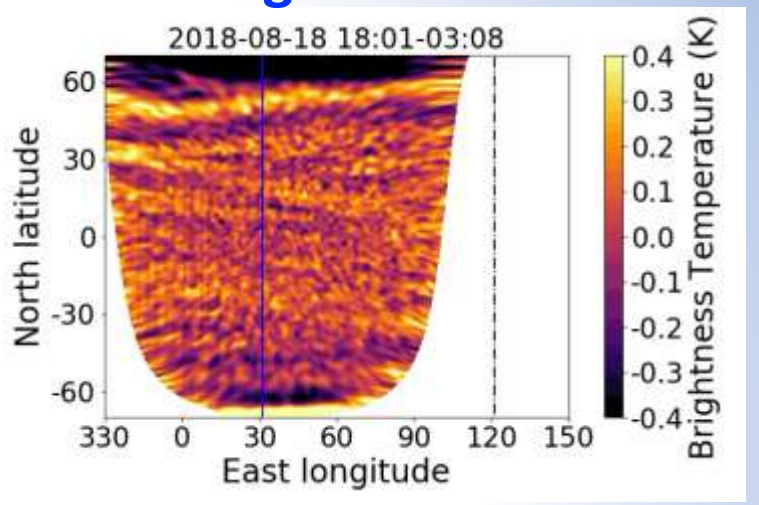
terminator

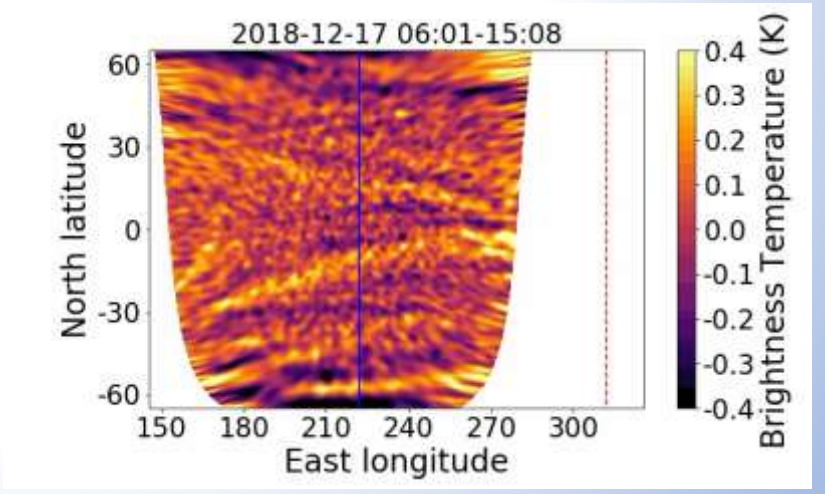
Dayside





Nightside



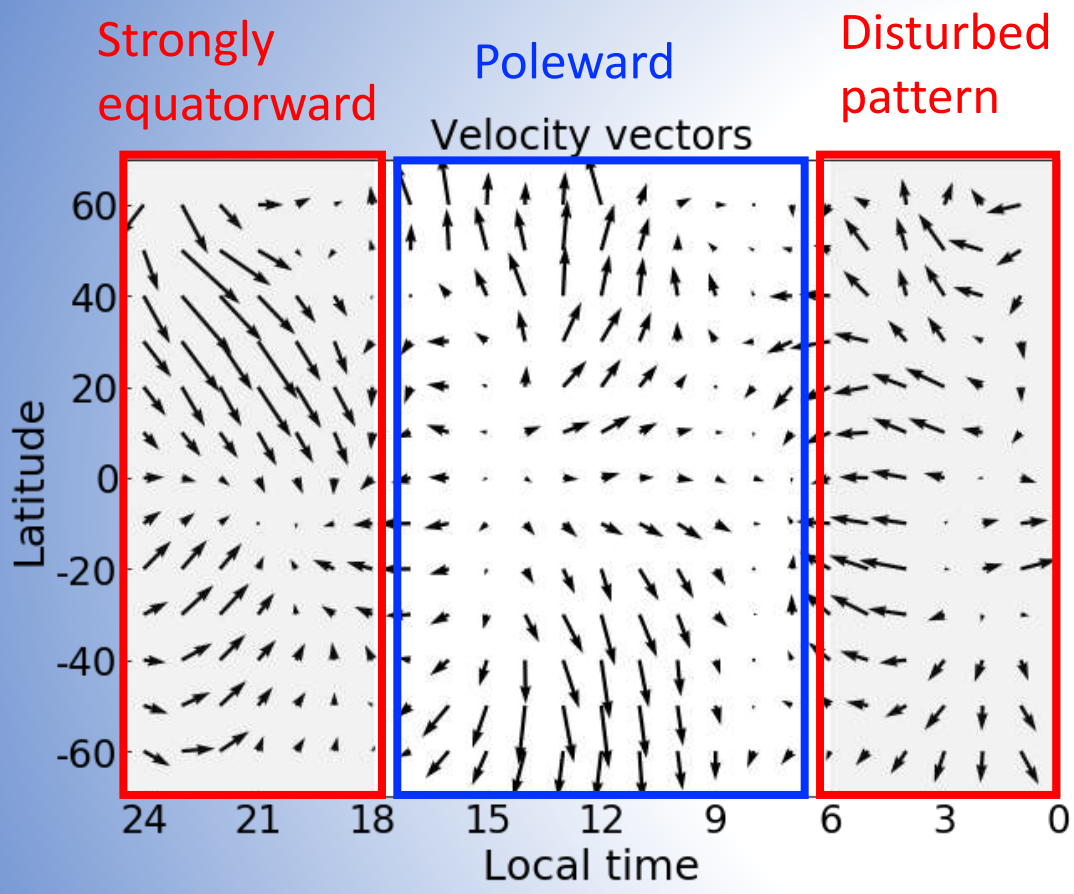


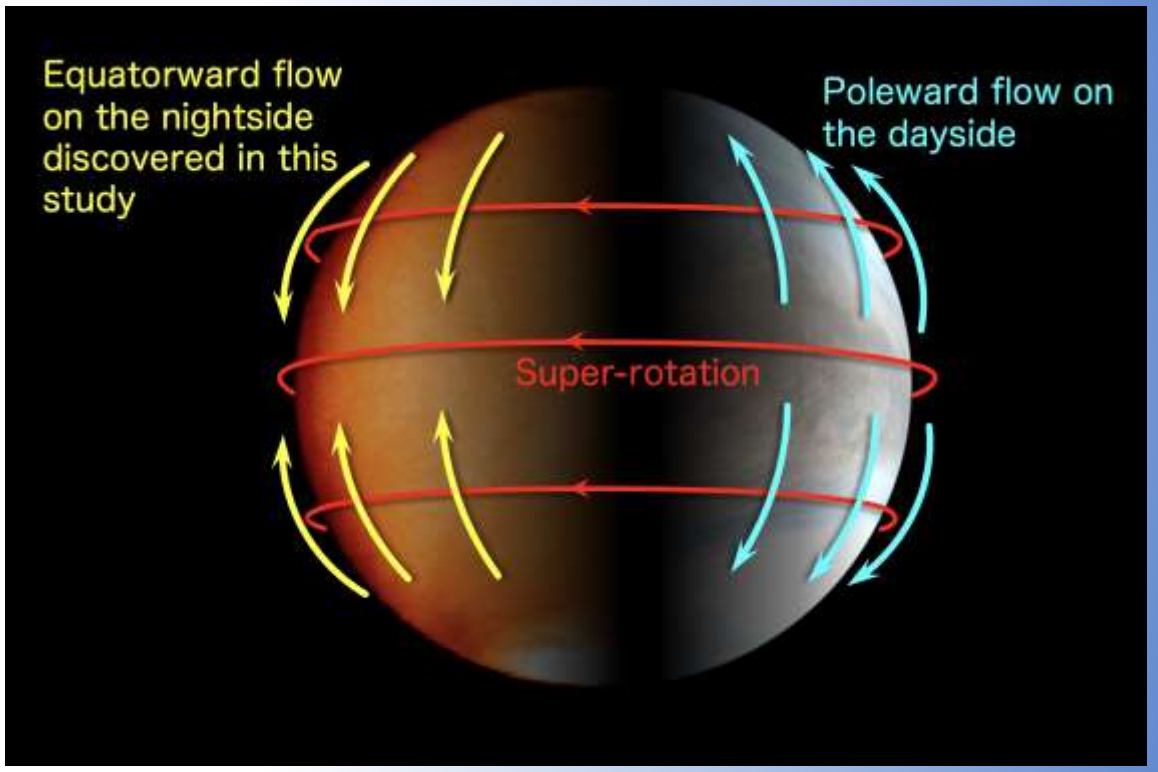
Dynamics

Fukuya et al., 2021

- Nightside cloud-top winds were observed for the first time

Wind field covering both dayside and nightside



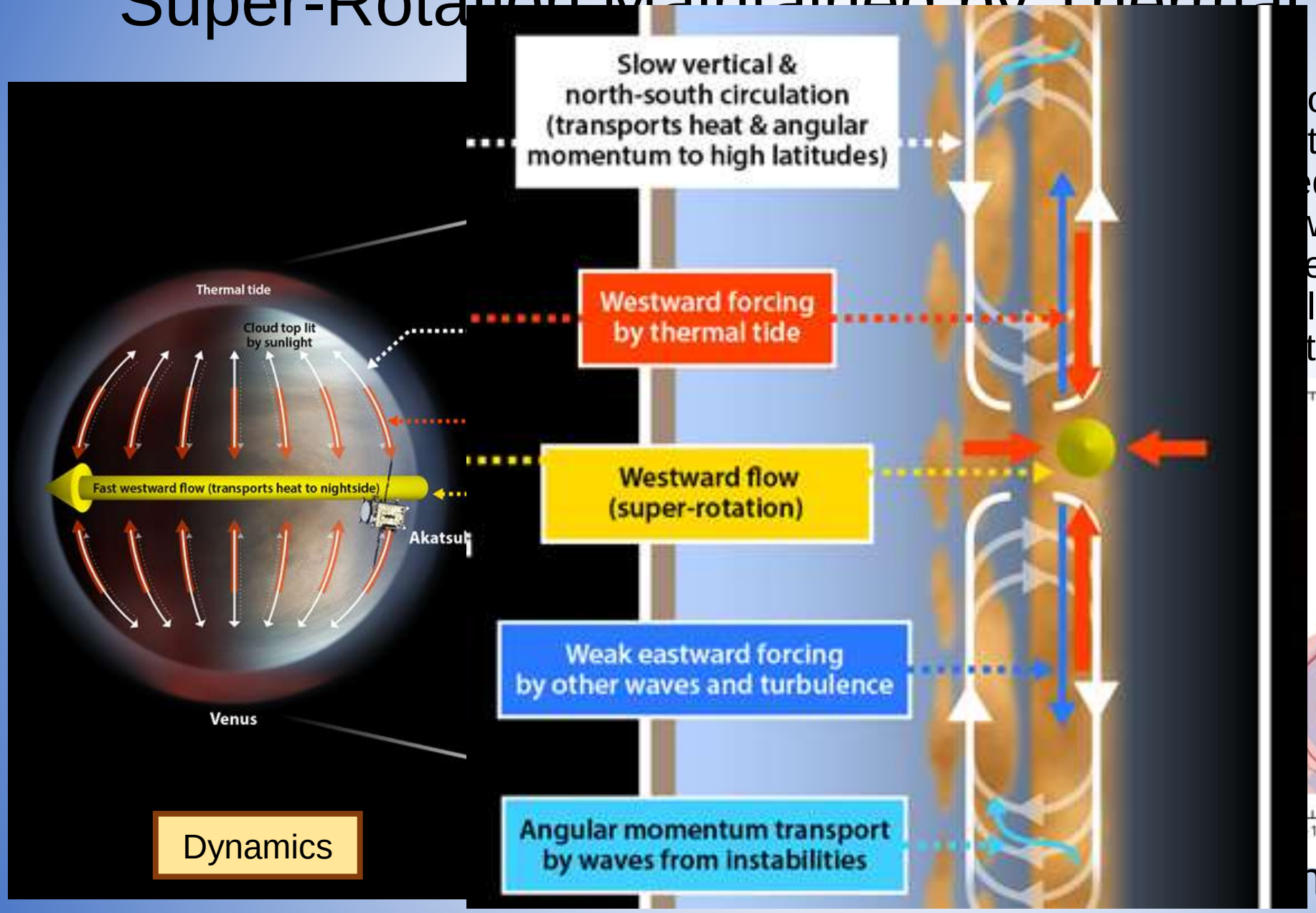


Fukuya et al., 2021

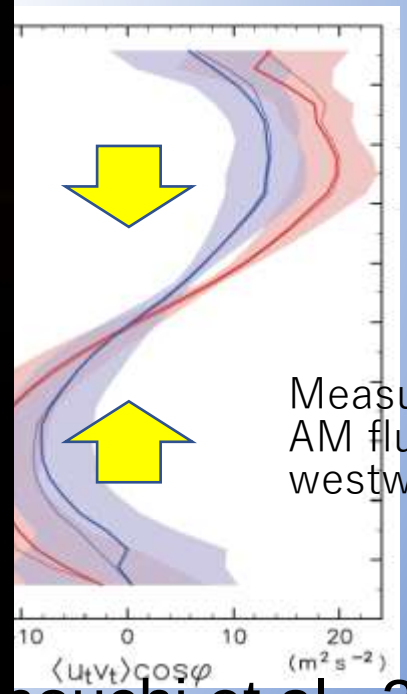
Dynamics

- Equatorward circulation was discovered on the nightside
- Dayside poleward flow and the nightside equatorward flow cancel each other

Super-Rotation Maintained by Thermal Tides



oud-tracking analysis
that the super-rotation is
d by the thermal tides (red
while other waves and
es actually work to weaken
lue arrows) in the equator
tudes.



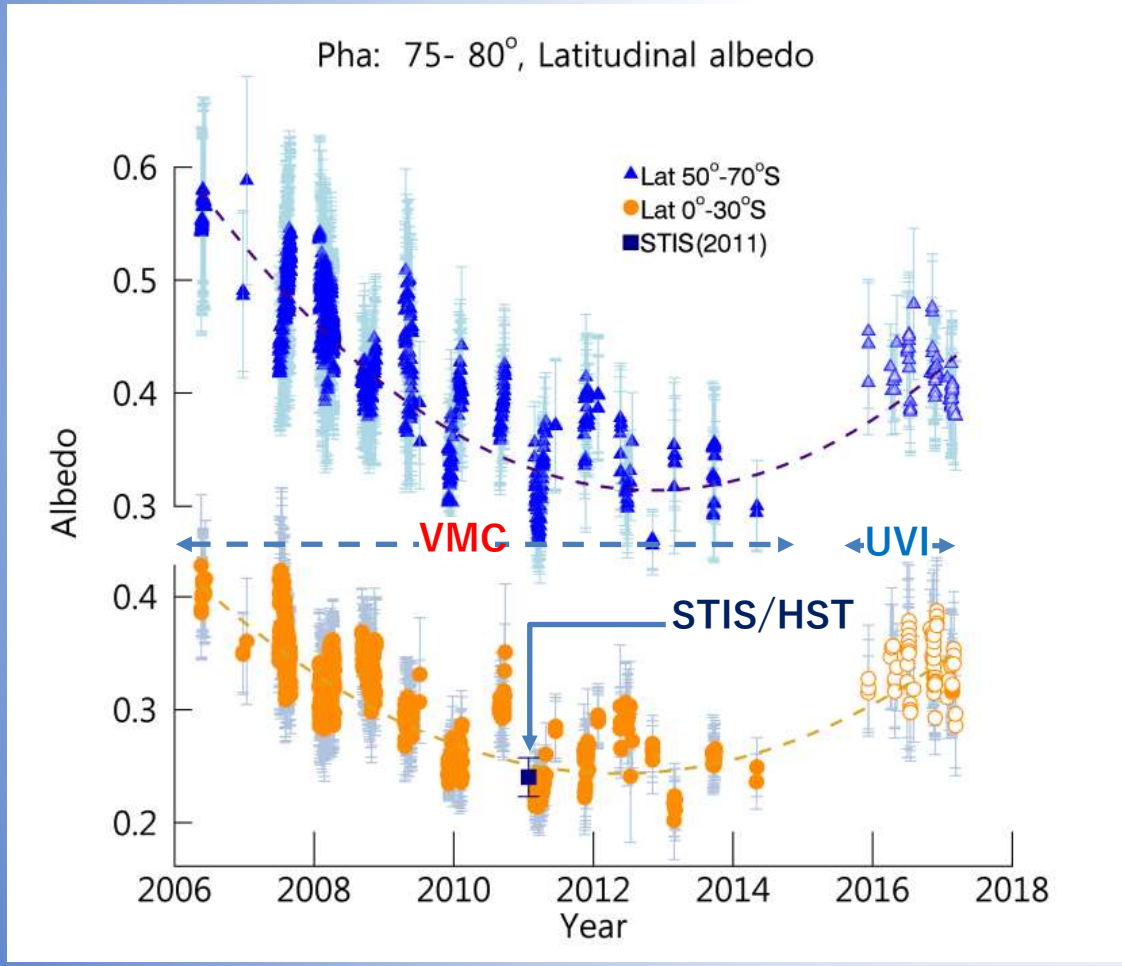
Measured poleward AM flux forcing the westward flow

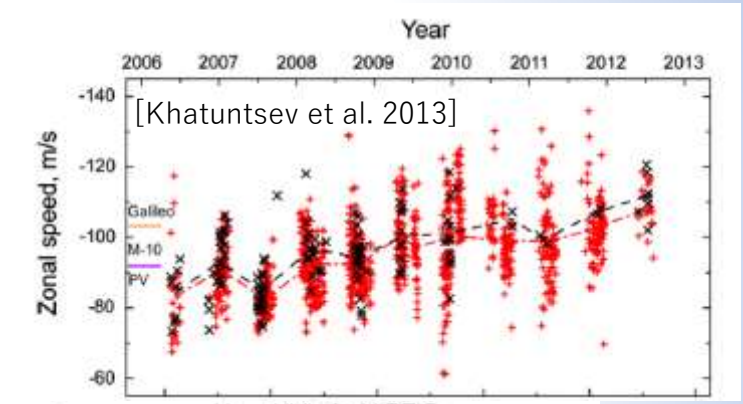
nouchi et al., 2020

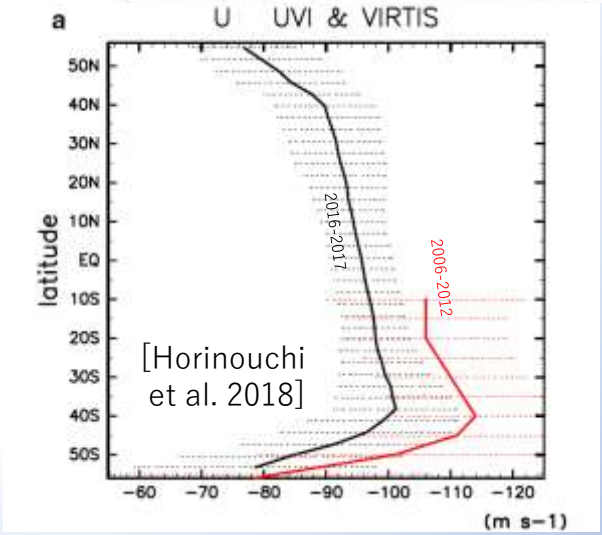
Dynamics

Long-term variation: UV albedo

365-nm albedo has changed by a factor of 2 in the recent decade. This can directly control the solar heating rate around the cloud-top level. This may possibly affect the zonal wind speed.







Observed winds:
80-90 m/s in 2006
110 m/s in 2012
~95 m/s in 2016-2017

Ongoing climate change on Venus?

We need continuous observations

[Lee et al. 2019]

The entire mission period and the solar cycles

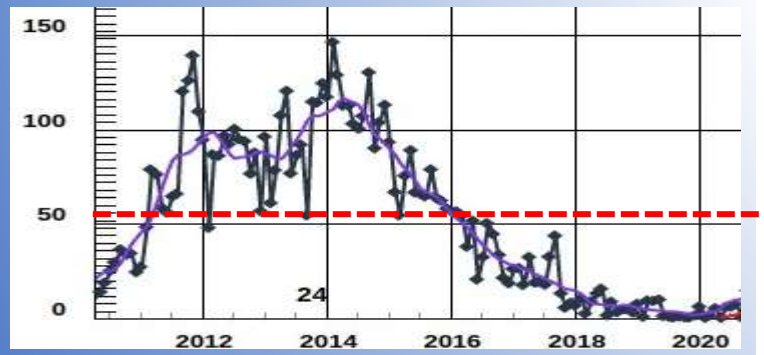
- Nominal mission: May **2010** – March **2018**
  - In Venus' orbit since Dec **2015** (sunspot number ~60 in declining phase)
- First extended mission: April **2018** – March **2021**
- Second extended mission: April **2021** – March **2024**
- Third extended mission: April **2024** – March **2029**
  - The radio emission will be stopped after April **2029** (sunspot number ~60 in declining phase)
  - This allows the Akatsuki data set to cover a complete solar cycle

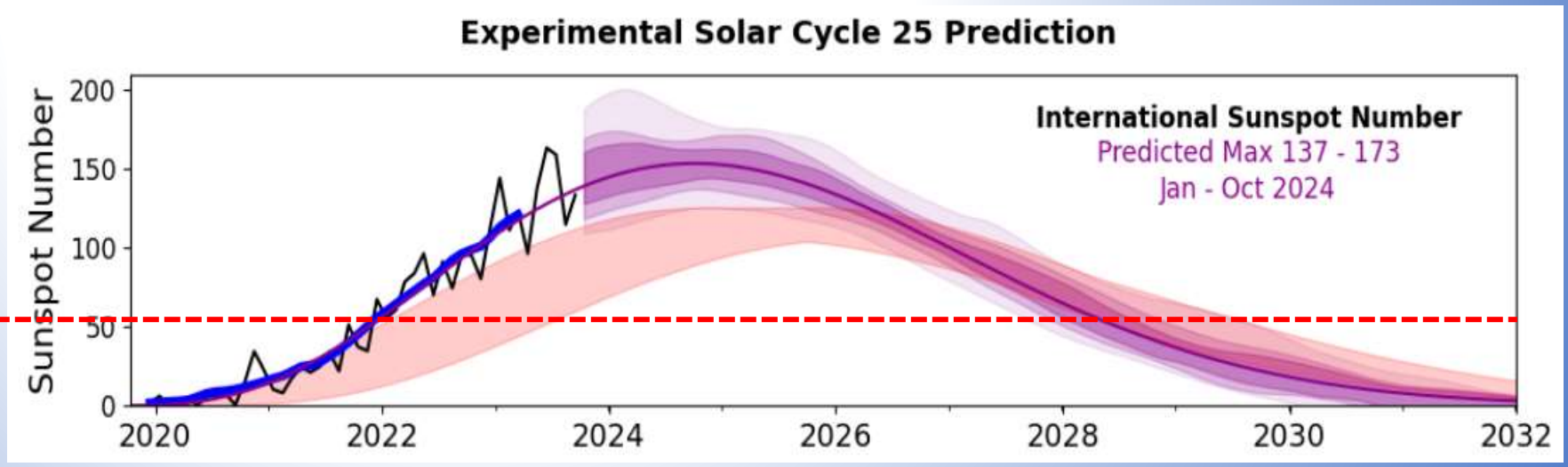
Recovery and Discovery

Identifying/Characterizing long-term variations

Elucidating mechanisms of long-term variations

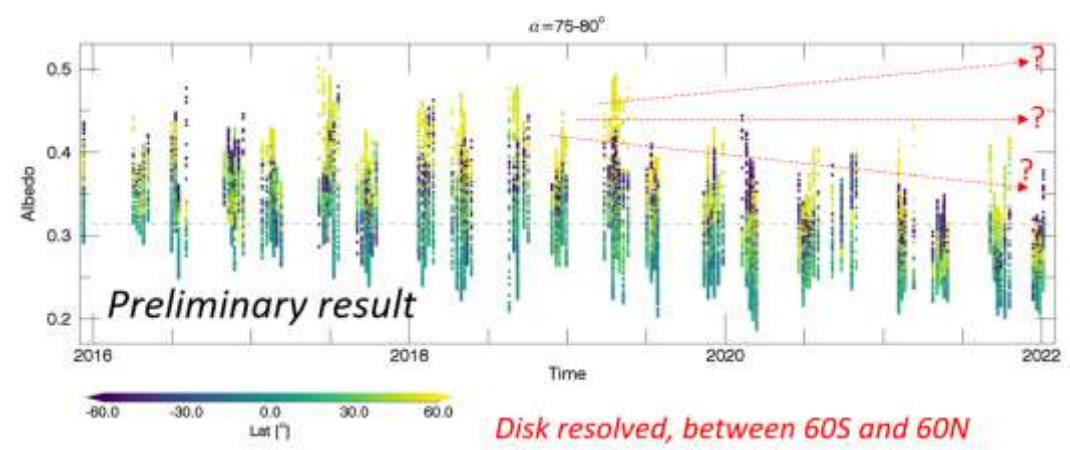
Sunspot numbers in Solar Cycle 24



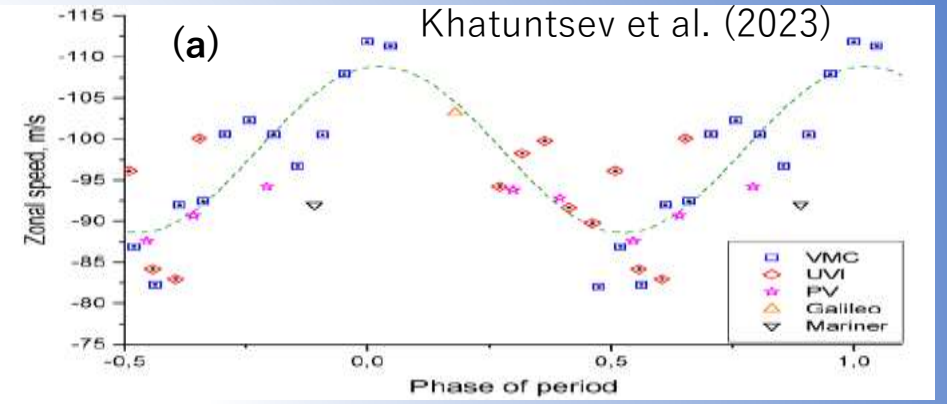


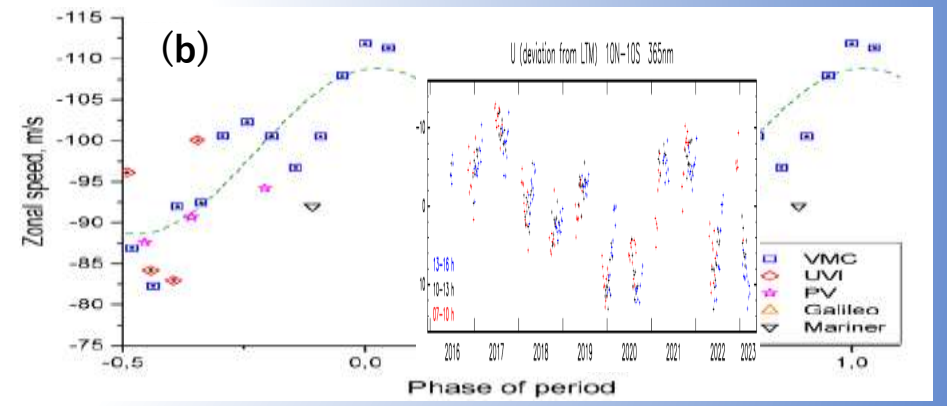
Nominal	First extended mission	Second extended mission	Third extended mission

Example studies we expect to carry out in coming years

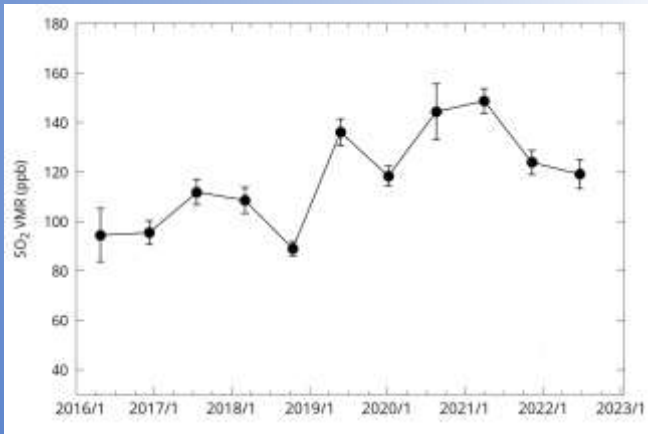


Left) Long-term variation of UV albedo as inferred from Akatsuki UVI data only (Y.J. Lee).
There seems to be a decreasing trend starting in 2019.



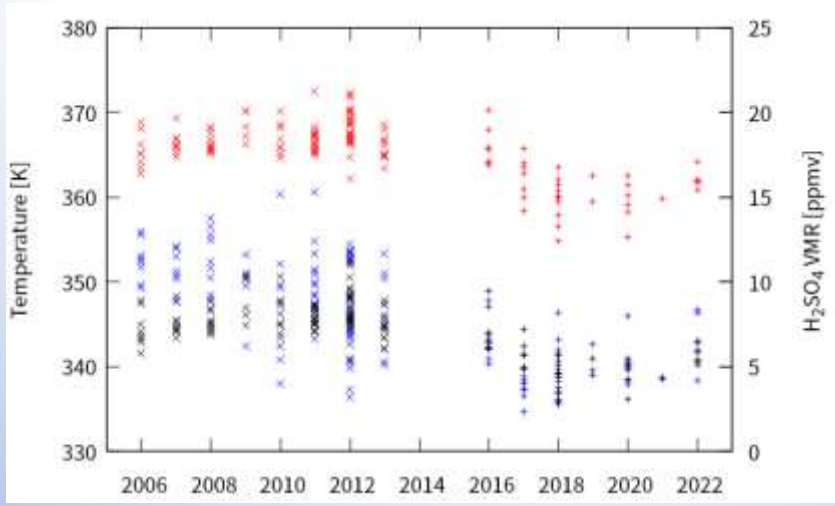


Long-term variation of zonal wind speed measured from Akatsuki data (inset in the bottom panel) is compared with the multi-mission plot compiled by Khatuntsev et al. (2023). Deviations from the sinusoidal periodical curve are suggested for 2022 and 2023 (T. Horinouchi).



Long-term variation of SO_2 VMR at the cloud top as inferred from Akatsuki UVI data (T. Iwanaka).

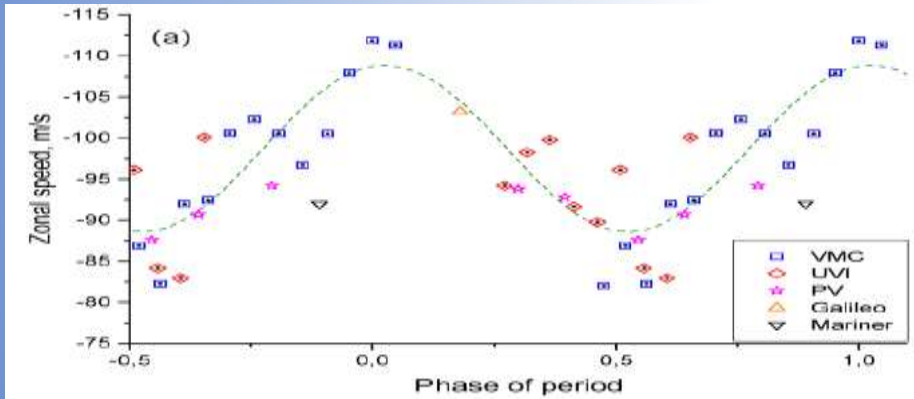
Long-term variation of atmospheric temperature (blue) and of H_2SO_4 vapor VMR (red) near the cloud base. Results from VEx/VERA and Akatsuki/RS (T. Imamura) are combined.



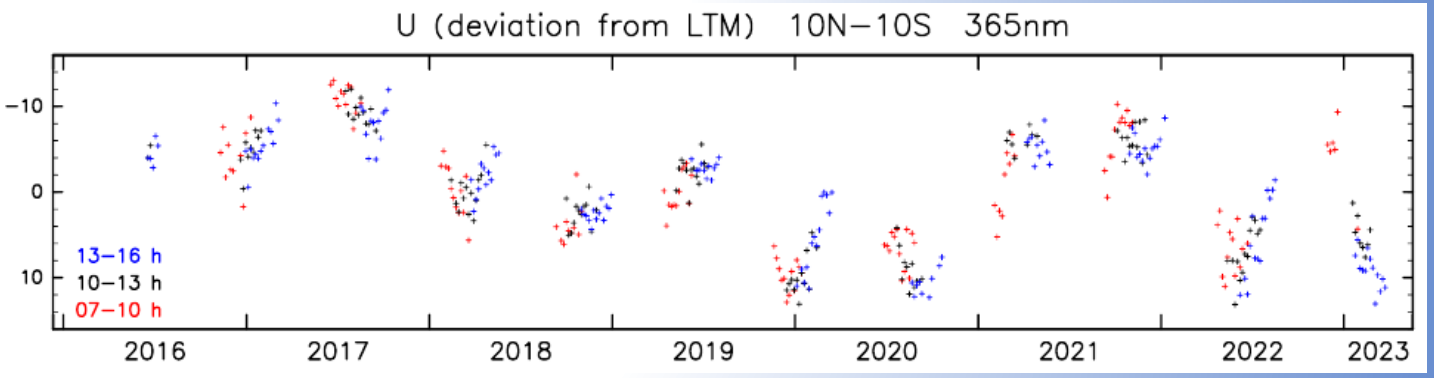
Long-term variation: Zonal wind speed

The way Khatuntsev et al. (2023) presented the data is rather tricky. The data are plotted twice by assuming a periodicity of 12.5 years, and a sinusoidal curve is added. These may altogether enforce the readers to believe the periodic variation.

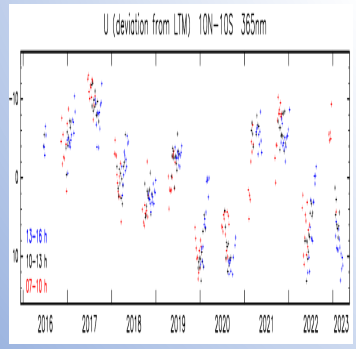
Until the first half of 2021, the variations seem to roughly follow the proposed sinusoidal curve. However, deviations become noticeable for 2022 and 2023 (amplitude of variation is large). Continuing the zonal wind measurement should allow us to conclude if such variations are periodic or random nature.



Khatuntsev et al. (2023)



Courtesy by Horinouchi-san



Summary of Akatsuki Mission (1)

- Proposed as a first "**meteorological**" satellite of a planet other than the earth. Developed to fulfill the requirements, launched and inserted to the Venus orbit successfully in 2015.
- Improved **digital tracking** techniques before successful VOI-R. The L3/CT team benefited from existing VEx/VMC data, enabled high-quality wind measurements even from the actual orbit with distant apocenter.
- **Data archiving** and documentation (in PDS3 and then in PDS4) assisted by NASA Participating Scientists (based on NASA-JAXA LoA).
- **ALL scientific instruments** worked fine for the first year (Dec 2015 to Nov 2016) in the Venus orbit. IR1 and IR2 became in-operational in Dec 2016 due to a failure of the control electronics, IR-AE. UVI, LIR, LAC, and RS continue working to date.
- **Discoveries:** stationary gravity-wave features at the cloud-top levels (suggesting unexpectedly strong coupling between the surface topography and the atmosphere); the equatorial jets in the middle to low cloud layers (requiring some mechanism that accelerates the wind near the equator); the microphysically quiescent regions.

Summary of Akatsuki Mission (2)

- It is identified that **the thermal tides** are the primary agent to maintain the super-rotation in the equator to low latitudes. Other waves work opposite but they may likely work to maintain the SR in the middle to high latitude regions.
- To quantitatively study **the meridional circulation**, more measurements (especially in the nigh-side with higher precision) are definitely needed. The global wind structure derived by averaging LIR images should help this.
- A possible **lightning** event finally (recorded in March 2020).
- Long-term monitoring of **albedos and wind speeds** (and other physical quantities) is of great help to understand the climatology of Venus and other planets + exoplanets.
- **Data assimilation** with Akatsuki data in progress.
- The new and final mission extension is up to March 2029 if the remaining fuel (and other systems of no redundancy, such as RW and IRU) allows. Fingers crossed!