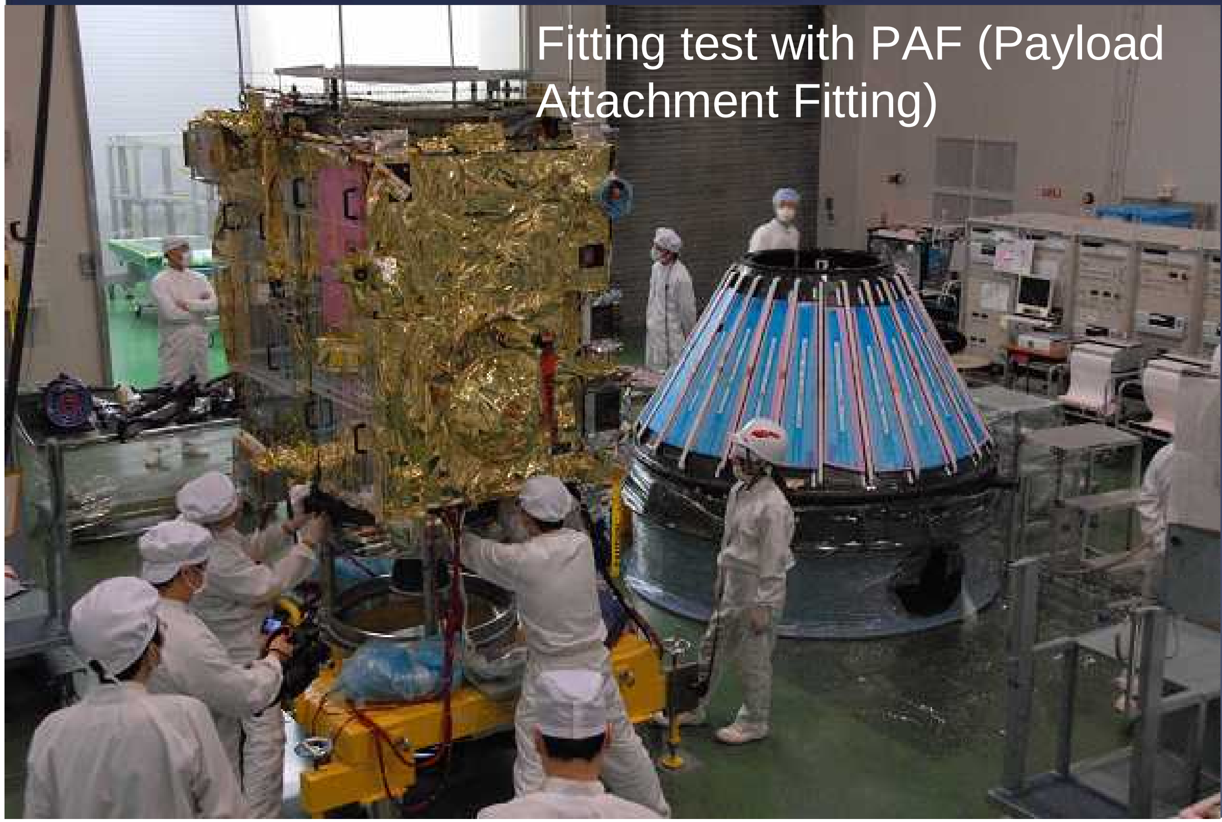
Planned Observation by Venus Climate Orbiter

Takeshi Imamura
Japan Aerospace Exploration Agency

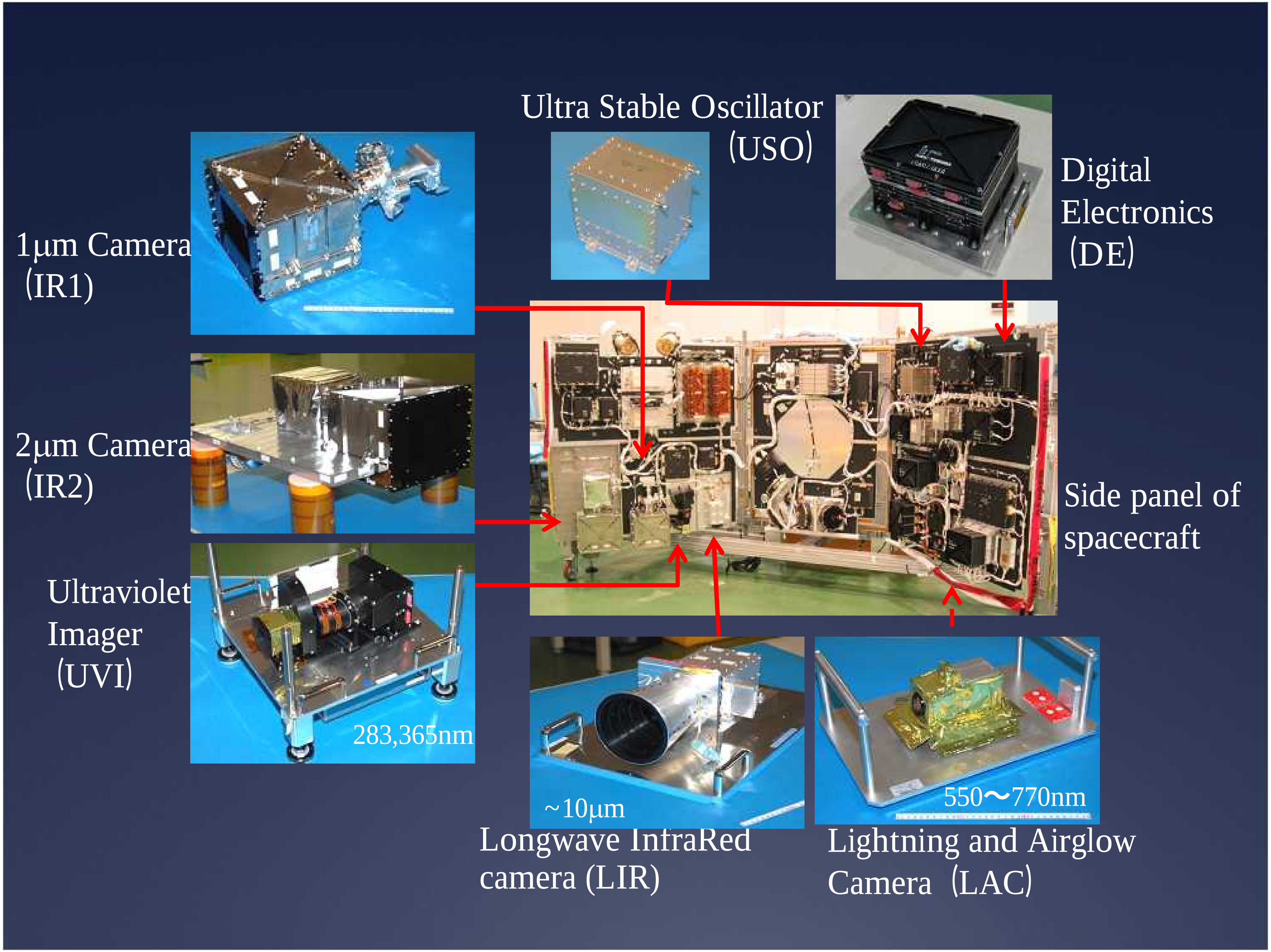
Current status

* Flight model integration test is being conducted. Vibration test and electrical performance tests have been completed successfully. Thermal vacuum test is planed this month.
* The spacecraft will be shipped to the launch site in March.



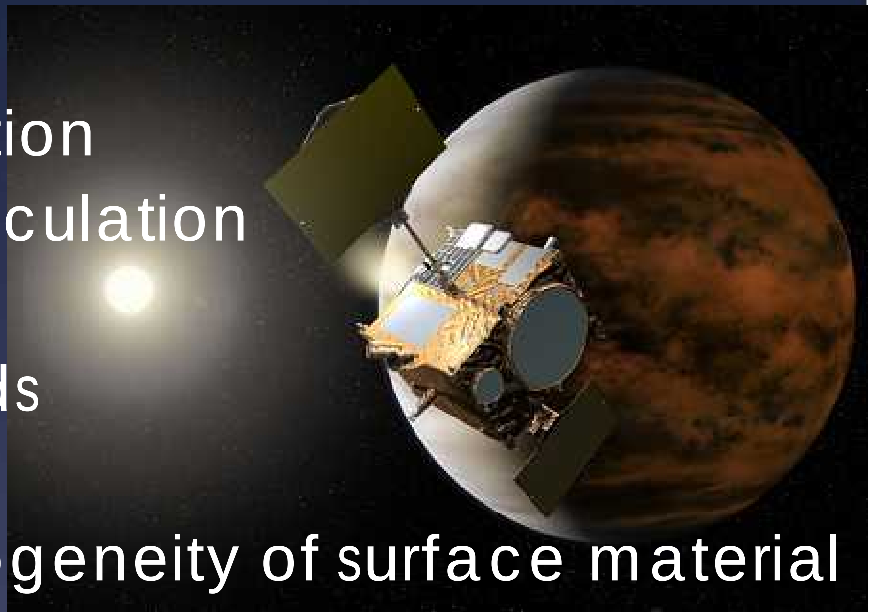
Fitting test with PAF (Payload Attachment Fitting)

Vibration test


Ultra Stable Oscillator (USO)
Digital Electronics (DE)
1μm Camera (IR1)
2μm Camera (IR2)
Ultraviolet Imager (UVI)
283,365nm
Side panel of spacecraft
~10μm
Longwave InfraRed camera (LIR)
550〜770nm
Lightning and Airglow Camera (LAC)

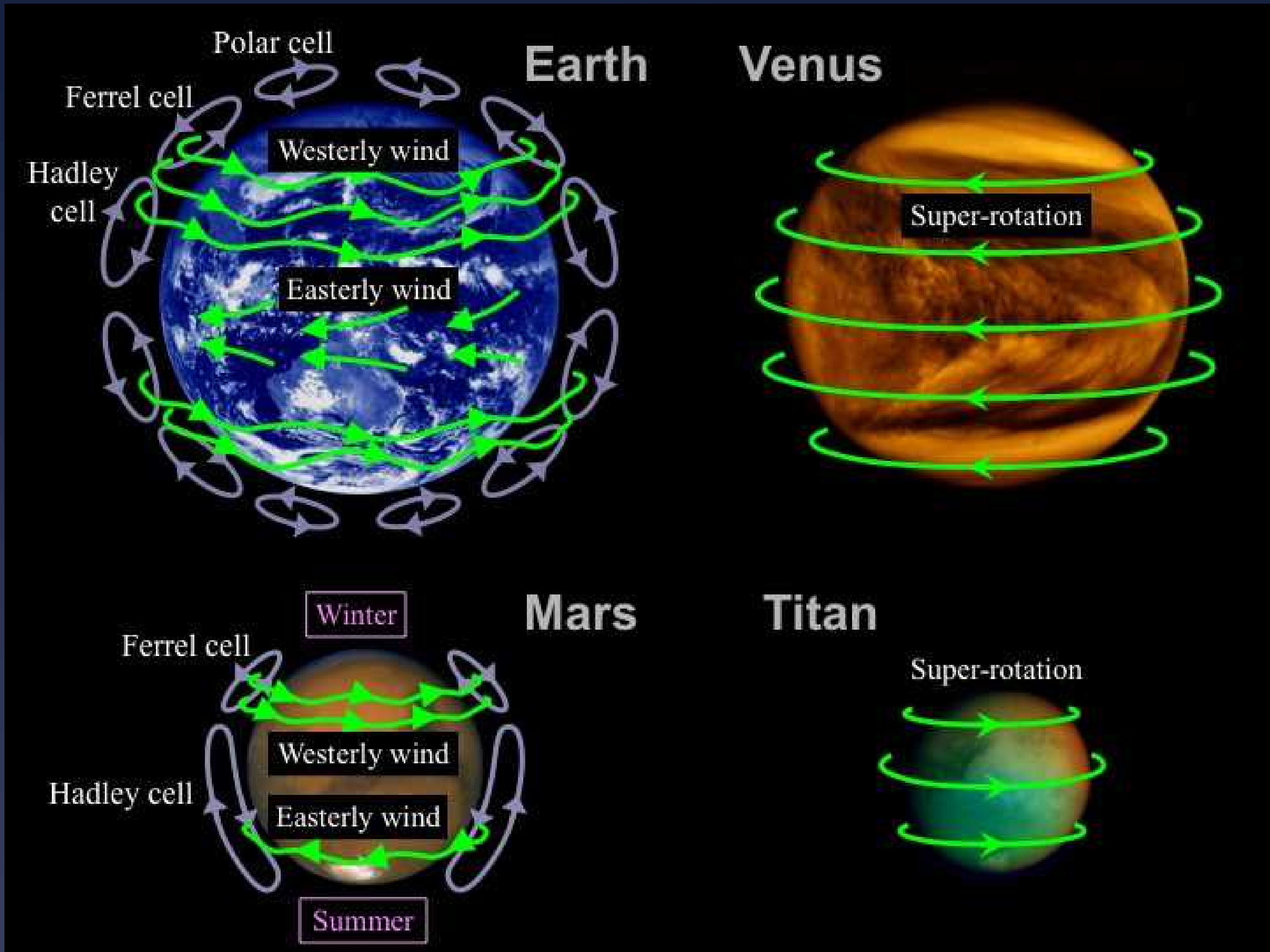
Venus Climate Orbiter/Akatsuki
(PLANET-C project)

- First Japanese Venus mission
- Science target :
  - Mechanism of super-rotation
  - Structure of meridional circulation
  - Meso-scale processes
  - Formation of H_2SO_4 clouds
  - Lightning
  - Active volcanism, inhomogeneity of surface material
  - Zodiacal light (during cruise)

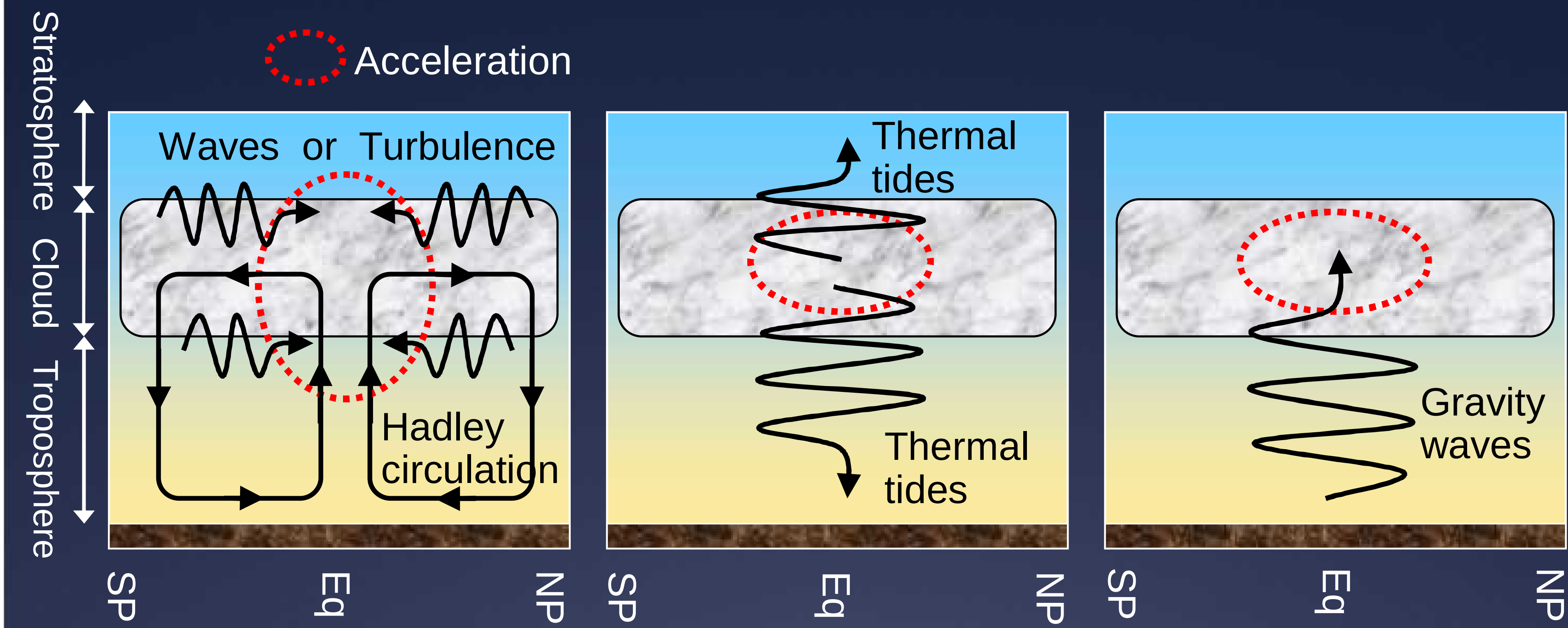


- Launch : May 2010 → Arrival: December 2010
- Mission life :More than 2 Earth years

Comparative planetary meteorology



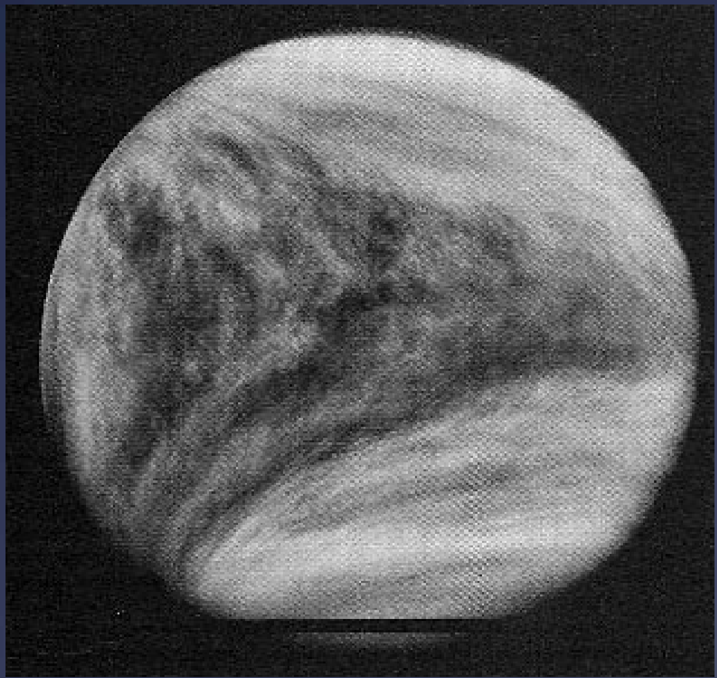
Hypotheses of super-rotation



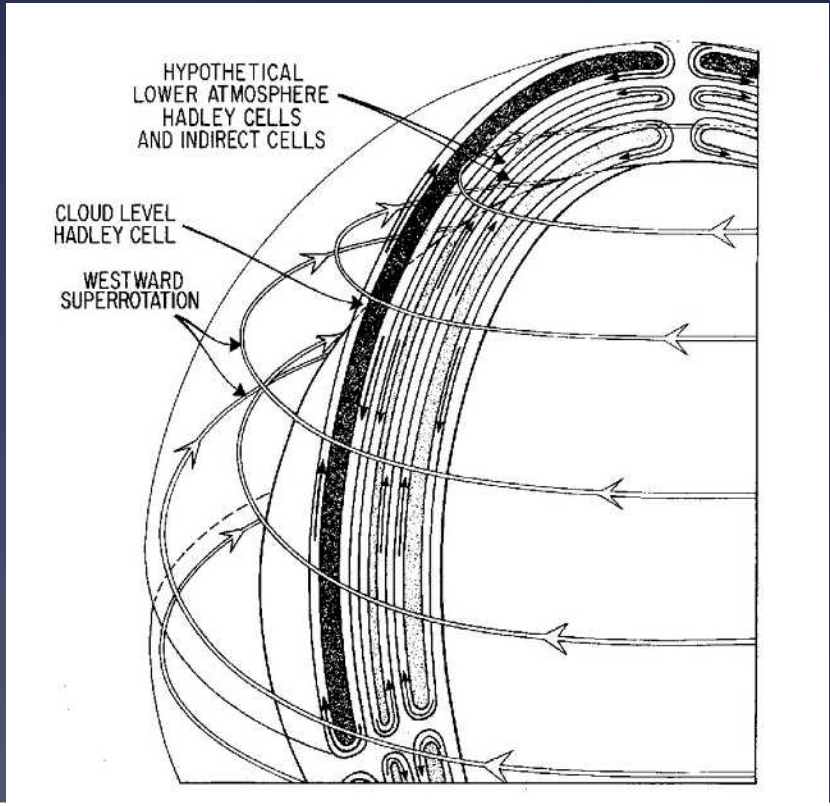
- Which is working? Any other mechanisms?
- Key parameters: Planetary-scale waves, Meridional circulation, Large-scale turbulence

Cloud processes

- Dynamics of cloud formation, role of meridional circulation in transporting cloud-related species
- Origin of UV markings
- Whether lightening occurs or not



Left: Knollenberg et al. (1980), J. Geophys. Res.



Concept of meteorological satellite

* Capturing global structures with emphasis on the low latitude
  → Wide FOV imaging from equatorial orbit

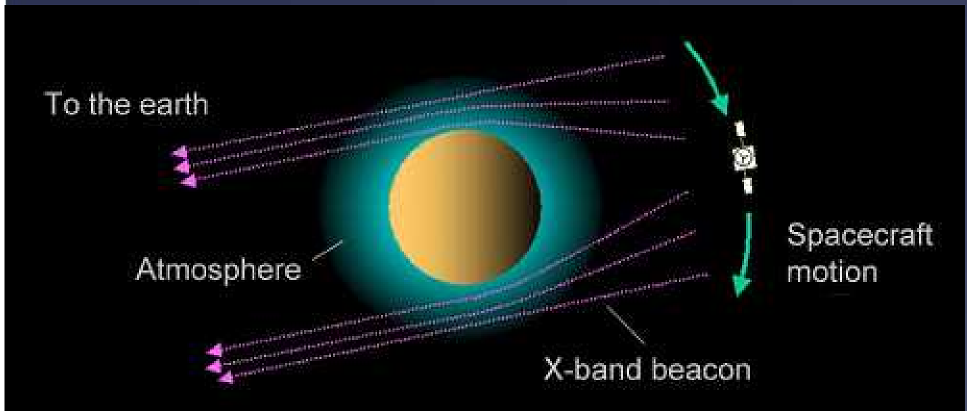
* Covering spatial scales from meso to global
  → Large-format 2D detectors

* Covering time scales from hours to months
  → Continuous sampling, repeating for all orbits

* Studying vertical structures
  → Multi-wavelength imaging + radio science

Observation from an orbiter

- 4 cameras sounding different altitudes, a high-speed lightning detector, and an ultra-stable oscillator for radio science
- Constructing 3-D model of atmospheric dynamics

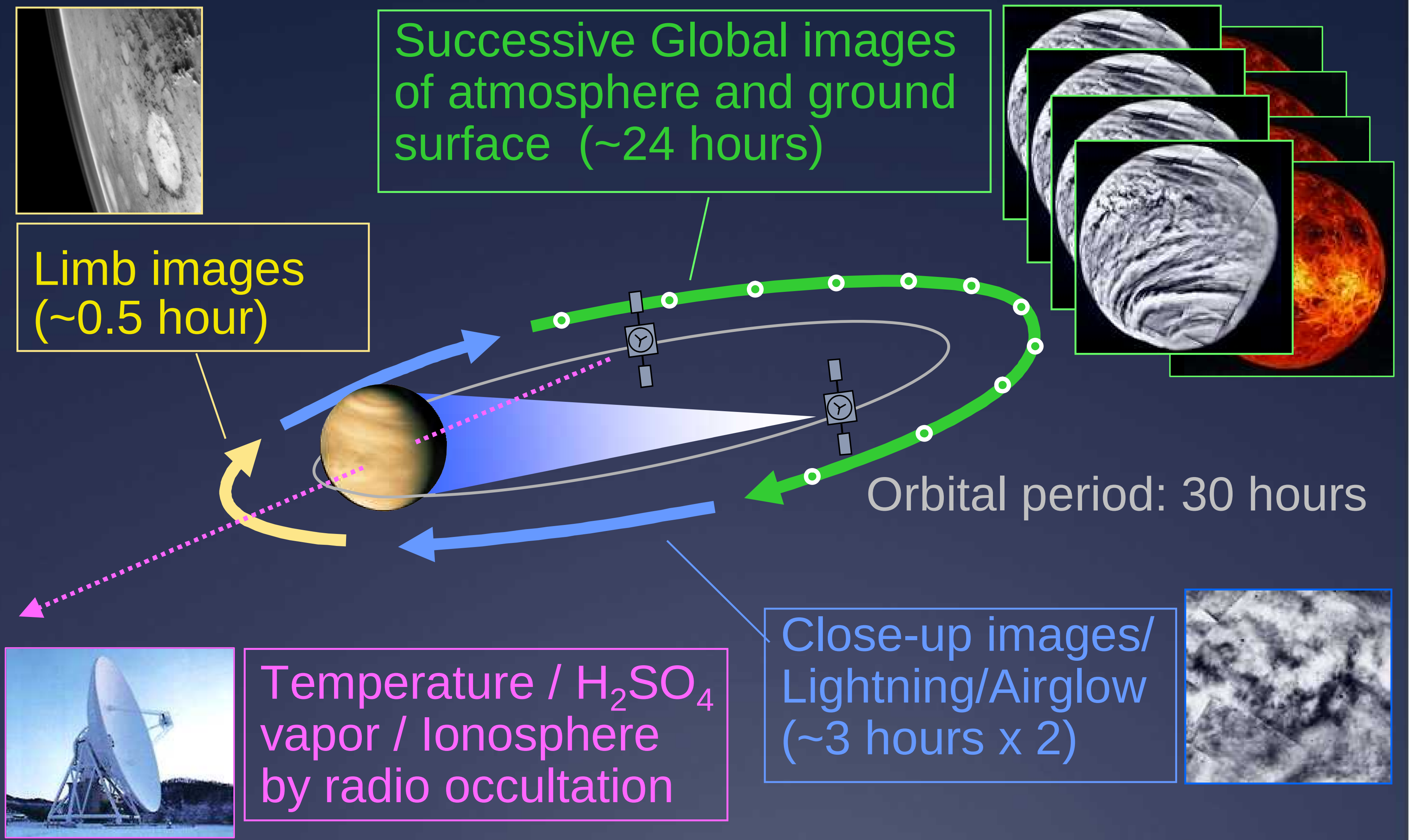


Radio science (vertical structure)

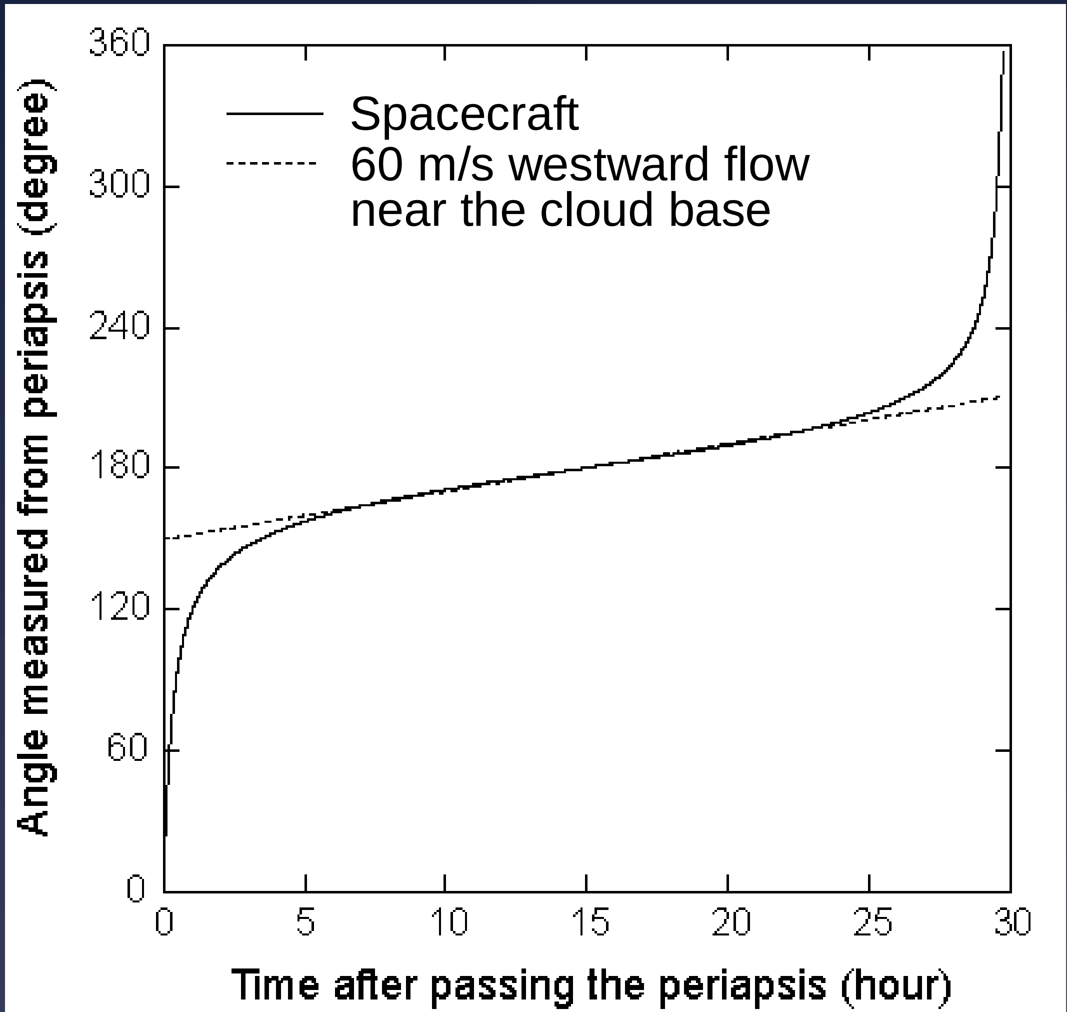
Onboard instruments

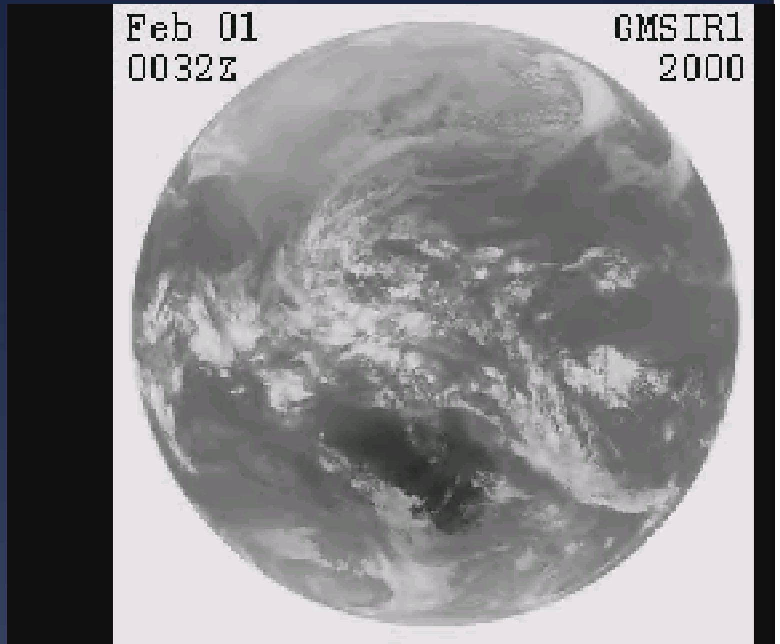
Instrument	FOV	Detector	Filters	Width	Targets
1-μm Camera **IR1**	12 °	Si-CSD/CCD 1024 x 1024 pix	1.01 μm (night)	0.04 μm	Surface, Clouds
			0.97 μm (night)	0.04 μm	H_2O vapor
			0.90 μm (night)	0.03 μm	Surface, Clouds
			0.90 μm (day)	0.01 μm	Clouds
2-μm Camera **IR2**	12 °	PtSi-CSD/CCD 1024 x 1024 pix	1.735 μm (night)	0.04 μm	Clouds, Particle size
			2.26 μm (night)	0.06 μm	
			2.32 μm (night)	0.04 μm	CO below clouds
			2.02 μm (day)	0.04 μm	Cloud-top height
			1.65 μm (cruise)	0.3 μm	Zodiacal light
UltraViolet Imager **UVI**	12 °	Si-CCD 1024 x 1024 pix	283 nm (day)	15 nm	SO_2 at cloud top
			365 nm (day)	15 nm	Unknown absorber
Longwave IR Camera **LIR**	12 °	Bolometer 240 x 320 pix	10 μm (day/night)	4 μm	Cloud-top temperature
Lightning & Airglow Camera **LAC**	16 °	8 x 8 APD (50kHz sampling in lightning mode)	777.4 nm (night)	4.2 nm	OI lightning
			552.5 nm (night)	4.7 nm	O_2 HerzbergII ariglow
			557.7 nm (night)	3.1 nm	OI airglow
			630.0 nm (night)	3.5 nm	OI airglow
Ultra-stable oscillator for Radio Science **RS**			X-band (8.4GHz)		Vertical prifiles of T, H_2SO_4 (g), Ne

Observations to be conducted during one orbital revolution



Orbital motion synchronized with the super-rotation





A concept similar to geostationary meteorological satellite

(movie provided by M. Odaka)

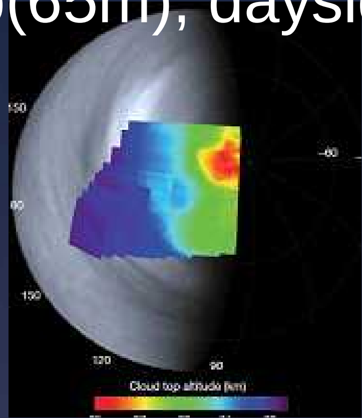
Wavelengths for cloud-tracking

365nm, cloud top (65km), dayside

365 nm image taken by PVO/OCPP

Knollenberg et al. (1980): J. Geophys. Res.

2.02μm, cloud top(65m), dayside



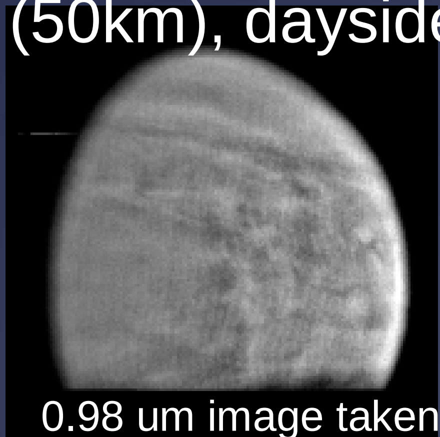
Cloud altimetry by VenusExpress/VIRTIS

Titov et al. (2008): Nature.

10μm, cloud top (65km), dayside & nightside

8.6 um image taken by Subaru telescope, high-pass filtered

0.9μm, lower cloud (50km), dayside



0.98 um image taken by Galileo/SSI

Belton et al. (1991): Science .

* Cloud top and bottom will be covered on both dayside and nightside.

2.3μm, lower cloud (50km), nightside

2.3 um image taken by Galileo/NIMS

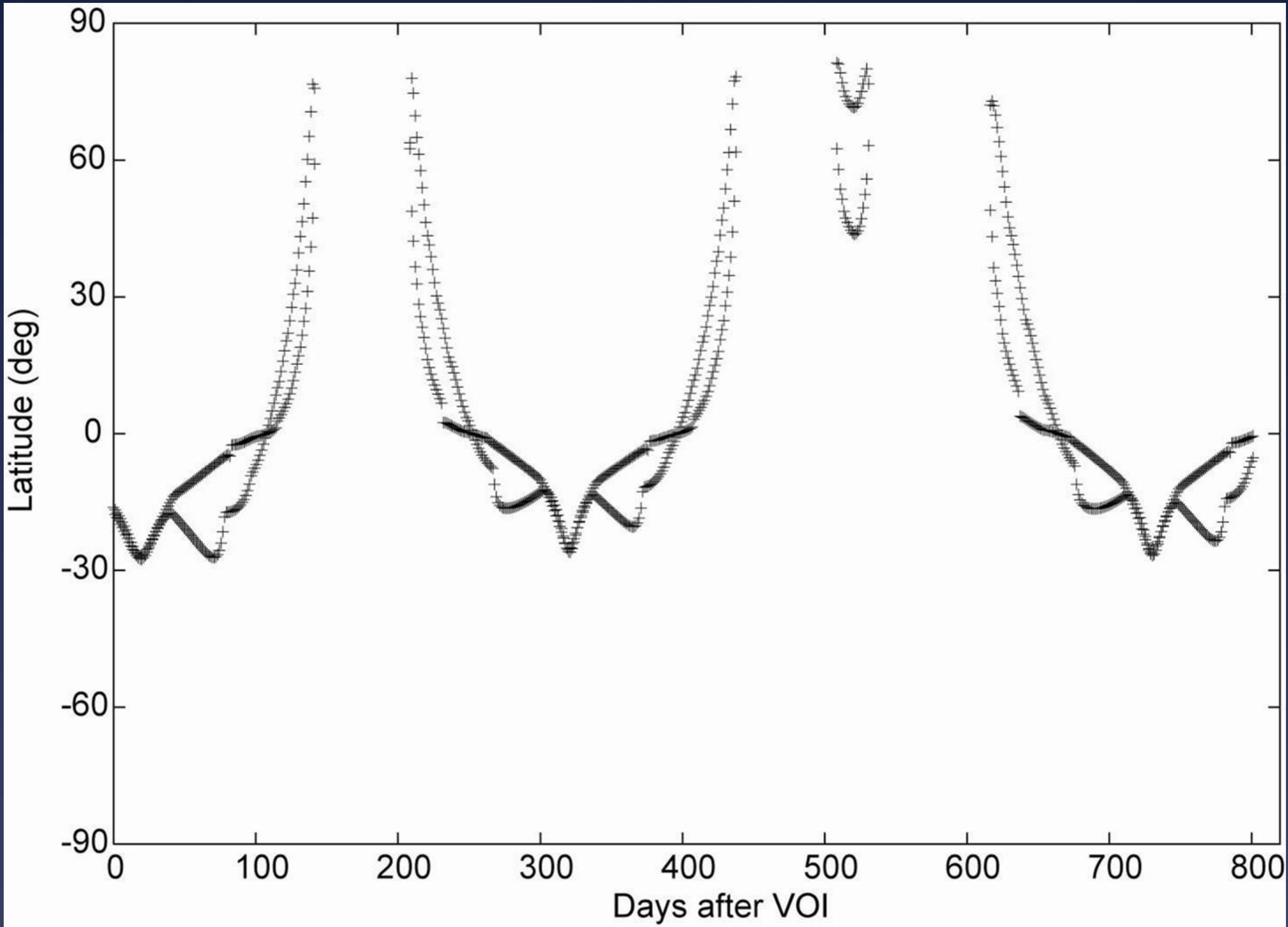
Carlson et al. (1991): Science.

Accuracy of wind velocity measurement

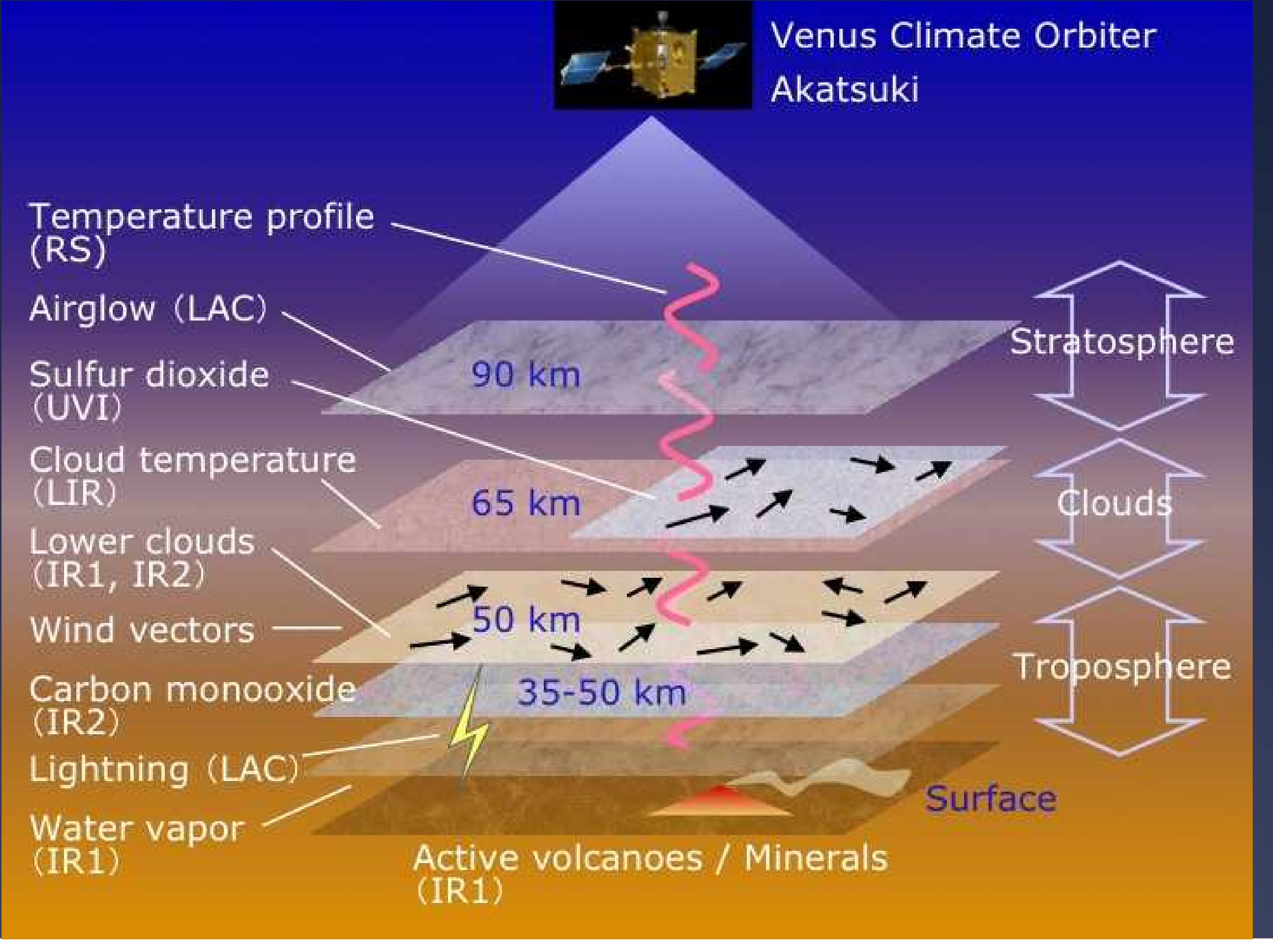
	Individual vectors using images separated by 2 hours (5° x 5° resolution)	After smoothing to 30° x 30° resolution	Individual vectors obtained by tracking long-lived clouds for 10 hours
UVI IR1 IR2	12 km/2h＝1.7 m/s	0.28 m/s	12km/10h＝0.33 m/s
LIR	53 km/2h＝7.3 m/s	1.2 m/s	53km/10h＝1.5 m/s

* **Cloud position accuracy is assumed to be 1 pixel.**
* **Mean meridional circulation is obtained by averaging large number of vectors and will be determined with much higher accuracy than above estimates.**

Latitudinal coverage of radio occultation

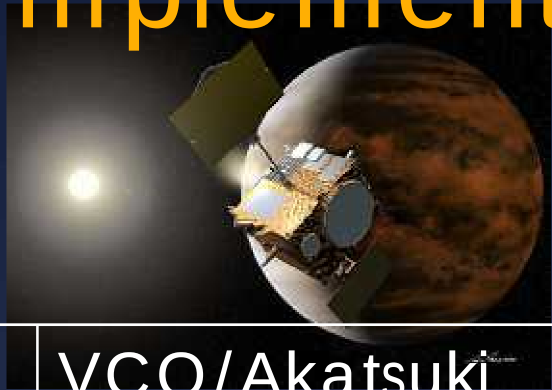


3-D sounding



Venus Climate Orbiter
Akatsuki
Temperature profile
(RS)
Airglow (LAC)
Sulfur dioxide
(UVI)
Cloud temperature
(LIR)
Lower clouds
(IR1, IR2)
Wind vectors
Carbon monooxide
(IR2)
Lightning (LAC)
Water vapor
(IR1)
90 km
65 km
50 km
35-50 km
Stratosphere
Clouds
Troposphere
Surface
Active volcanoes / Minerals
(IR1)

Complementary missions



	VCO/Akatsuki	Venus Express
Instruments	5 cameras Radio science	3 spectrometers 1 camera Plasma analyzer Magnetometer Radio science
Target	Atmospheric dynamics	Atmospheric chemistry and dynamics, Surface processes, Plasma environment
Orbit	Equatorial	Polar

Coordinated observations are being planned.

How to extract Fourier components

* Zonal-mean
* Solar-fixed components
* Traveling planetary-scale waves
* Meso-scale disturbances

→Continuous, regular sampling is a key to distinguish these components.

Zonal-mean

- Major axis of the orbit is nearly fixed with respect to the inertial frame. Then, averaging the data obtained during one Venus year (imaging) or half year (radio occultation) gives a zonal-mean on the assumption that the atmospheric state is stable and the dependence on the longitude is negligible.

Solar-fixed components

- The mean state for each local time is obtained by averaging data in a local time-latitude coordinate, and then the zonal-mean is subtracted from it.

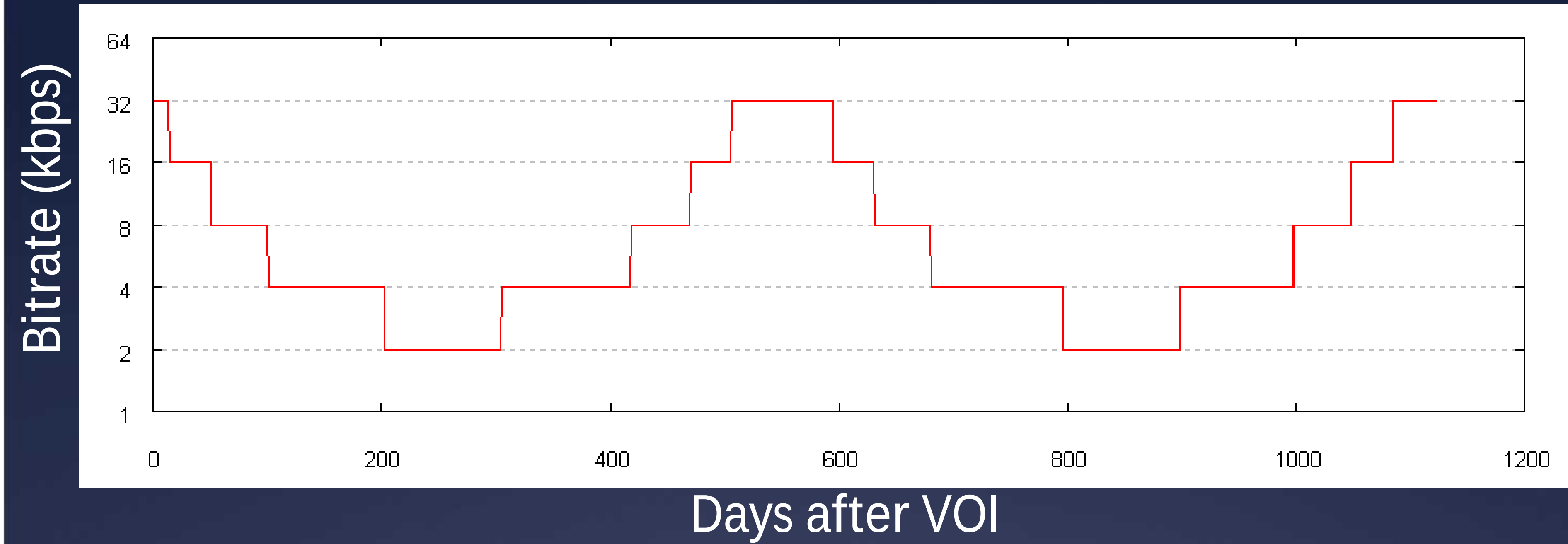
Traveling planetary-scale waves

- Subtraction of the local time-fixed structure from individual observations gives traveling components. Amplitudes of waves will be extracted by convolving (in longitude and time) the data with sine waves of varying zonal wavenumber and phase speed.
- Fourier analysis of variables at a specific local time regularly sampled once per orbital revolution also gives temporal spectra.

Meso-scale eddies

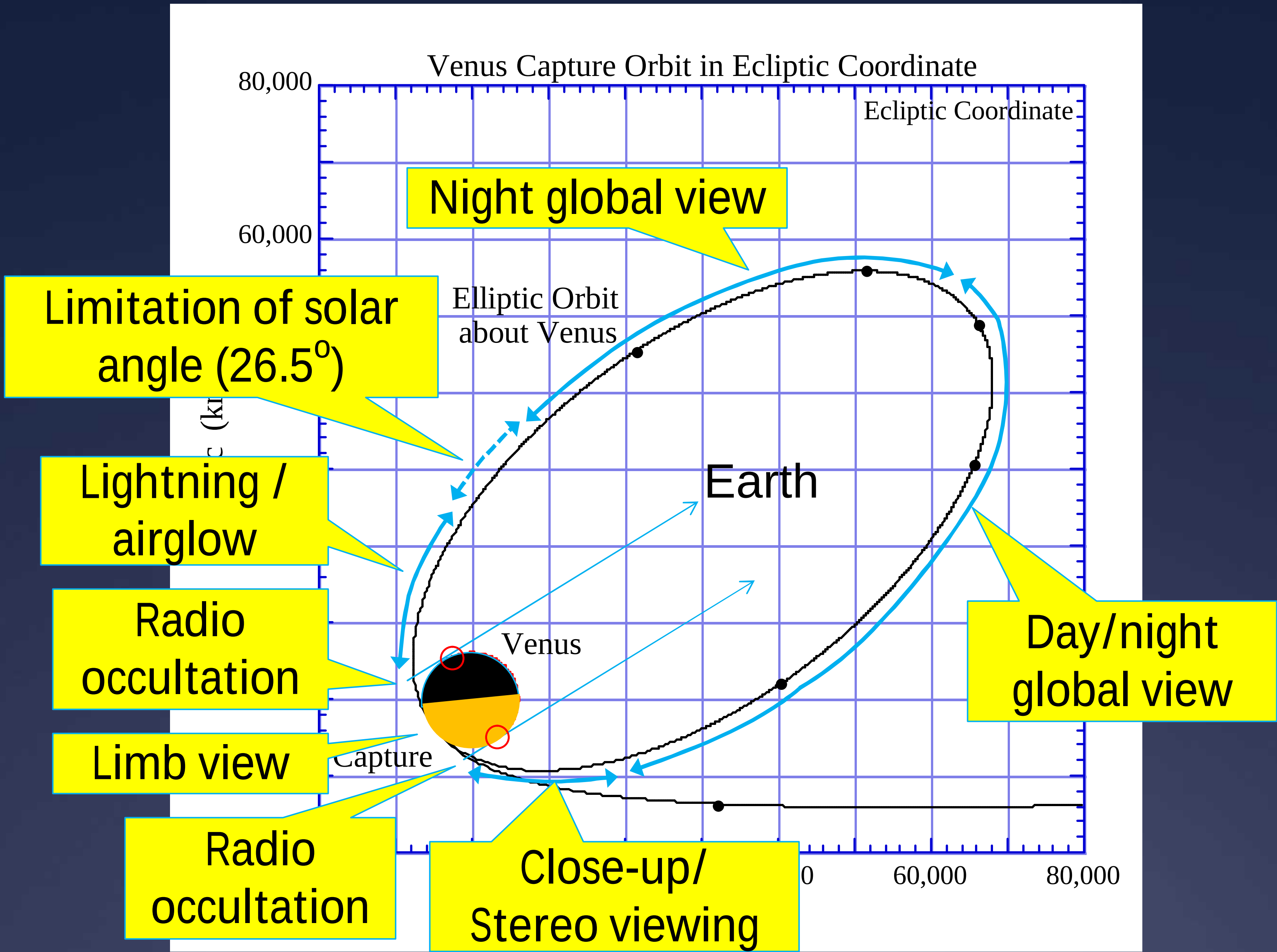
- In addition to close-up images near periapsis, development of meso-scale eddies over 1 Earth day can be observed. Distribution of meso-scale structures over the entire cloud layer is obtained by combining data over one super-rotation period.

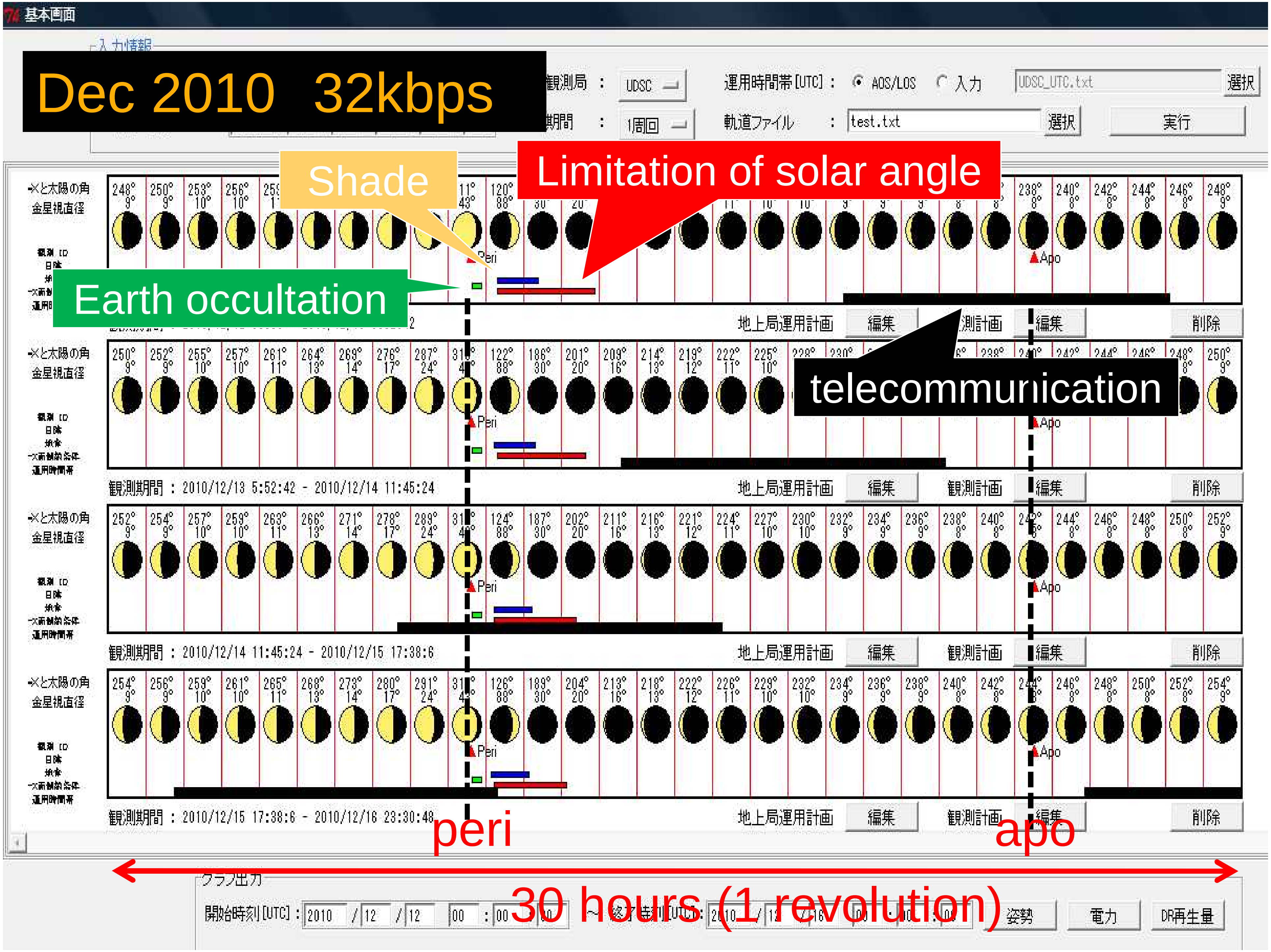
Telemetry rate



- Bit rate is relatively high during the 1-2 months following VOI (Venus Orbit Insertion).
- Well-laid observation plan is needed to reduce the data volume.

Orbit just after VOI





Dec 2010 32kbps
Shade
Limitation of solar angle
Earth occultation
telecommunication
peri
apo
30 hours (1 revolution)
基本画面
観測期間 : 2010/12/13 5:52:42 - 2010/12/14 11:45:24
観測期間 : 2010/12/14 11:45:24 - 2010/12/15 17:38:6
観測期間 : 2010/12/15 17:38:6 - 2010/12/16 23:30:48
地上局運用計画
観測計画
編集
削除

Observation programs to be installed in the Sensor DE

Obs program	Channels	Volume (MB)
night-nominal	IR2 1.73, 2.26, 2.32um, LIR	6.18
night-short	IR2 2.26um, LIR	2.28
IR1-night-nominal	IR1 0.9um(night), 0.97um, 1.01um	6
IR1-night-short	IR1 1.01um	2
day-nominal	IR1 0.9um(day), IR2 2.02um, UVI 283, 365nm, LIR	8.18
day-short	IR1 0.9um(day), IR2 2.02um, UVI 365nm, LIR	6.18
day-closeup-nominal	UVI 283nm, 365nm, LIR	4.18
day-closeup-short-2times	UVI 365nm, LIR x 2times	10.9
day-closeup-short-7times	UVI 365nm, LIR x 7 times	15.8
limb	IR1 0.9um(day), UVI 365nm	4
…		

Dec 2010

Time from apo (h)	Obs. program
0	IR1-night-nominal night-nominal
2	IR1-night-nominal night-nominal
4	IR1-night-nominal night-nominal
6	IR1-night-nominal night-nominal day-nominal
8	IR1-night-nominal night-nominal day-nominal
10	IR1-night-nominal night-nominal day-nominal
12	IR1-night-nominal night-nominal day-nominal
13.5	day-closeup-short-7times
14.5	day-closeup-short-2times
15	limb
16	LAC
18	IR1-night-nominal night-nominal
20	IR1-night-nominal night-nominal
22	IR1-night-nominal night-nominal
24	IR1-night-nominal night-nominal
26	IR1-night-nominal night-nominal
28	IR1-night-nominal night-nominal

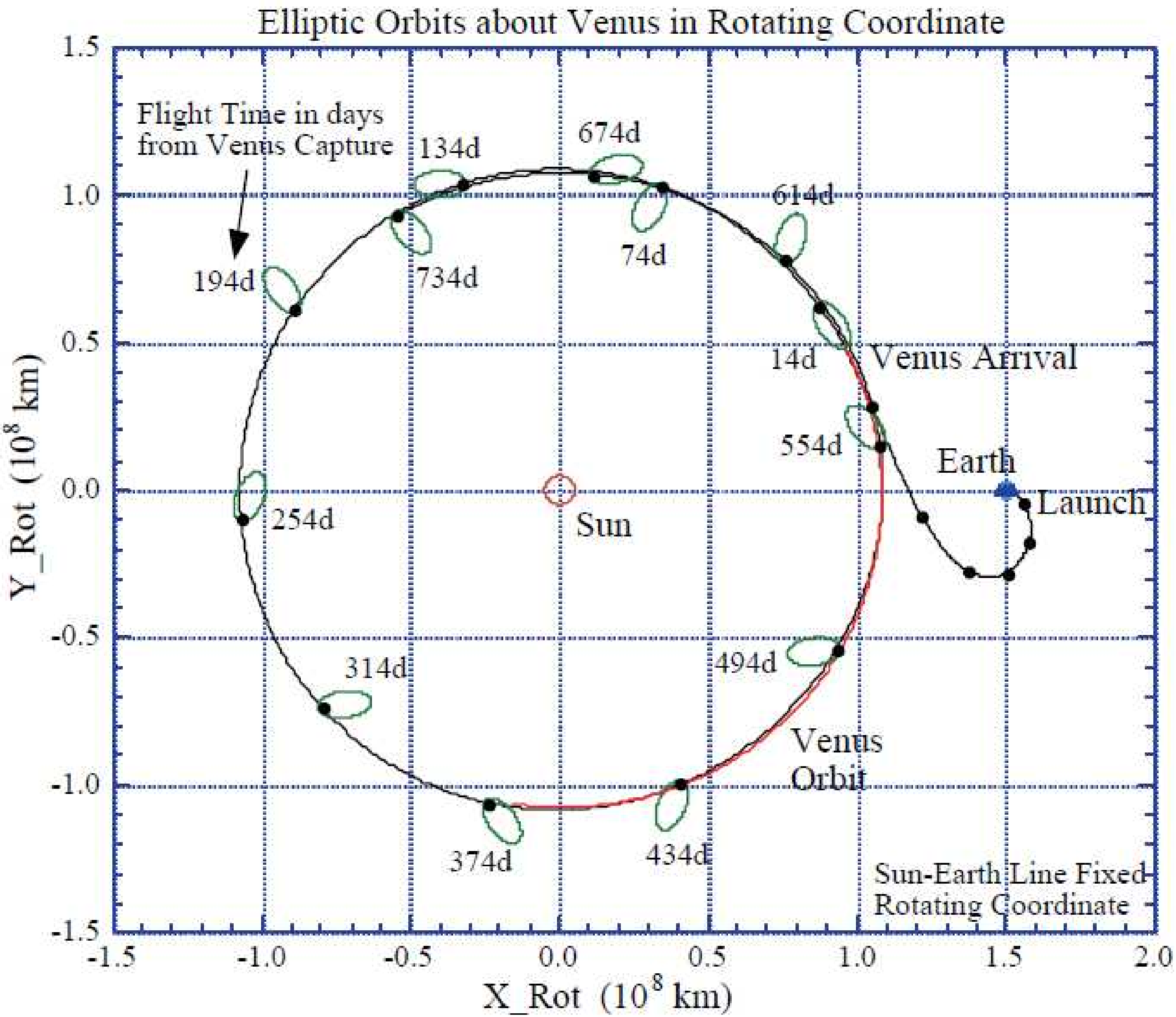
Night viewing

Day viewing

Day viewing

Night viewing

Total volume : 226MB (130 images)
After compression (x1/3) : 75MB
Obs time factor (x3/4) : 55MB
< Telemetry rate of 72MB/day



Elliptic Orbits about Venus in Rotating Coordinate
Flight Time in days from Venus Capture
134d
674d
614d
74d
734d
194d
14d
Venus Arrival
554d
Earth
Launch
Sun
254d
494d
314d
Venus Orbit
374d
434d
Sun-Earth Line Fixed Rotating Coordinate
Y_Rot (10^8 km)
X_Rot (10^8 km)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0

Policy of data reduction

* Frequent sampling is required for wavelengths used for cloud tracking, while it can be relatively sparse for wavelengths used for observing trace gases, cloud microphysical parameters and surface properties
* Dark frame is subtracted from Venus frames by onboard data processing, and dark frames are not transmitted in the nominal operation phase.
* Lossless compression is the nominal, but lossy compression might also be considered depending on the telemetry rate (under discussion).

Data processing pipeline

Level 0 : Uncompressed images

↓

Level 1 : Calibrated images with FITS header

↓

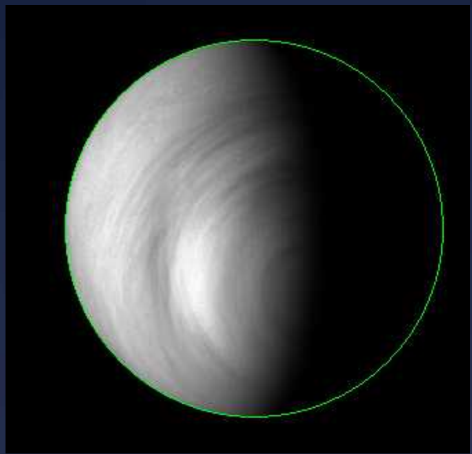
Level 2 : Calibrated images with FITS header, including geometry information

↓

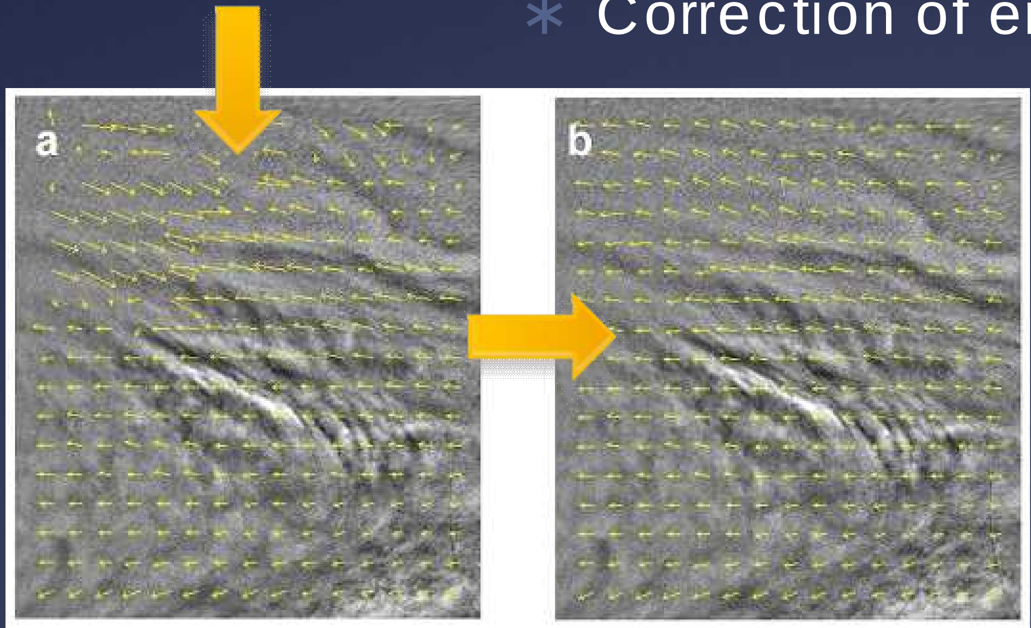
Level 3 : Wind vectors and other higher-level products on longitude-latitude grids in NetCDF format

* Level 2 and Level 3 data will be released to the public with PDS-like label files.

Automatic Level 3 processing



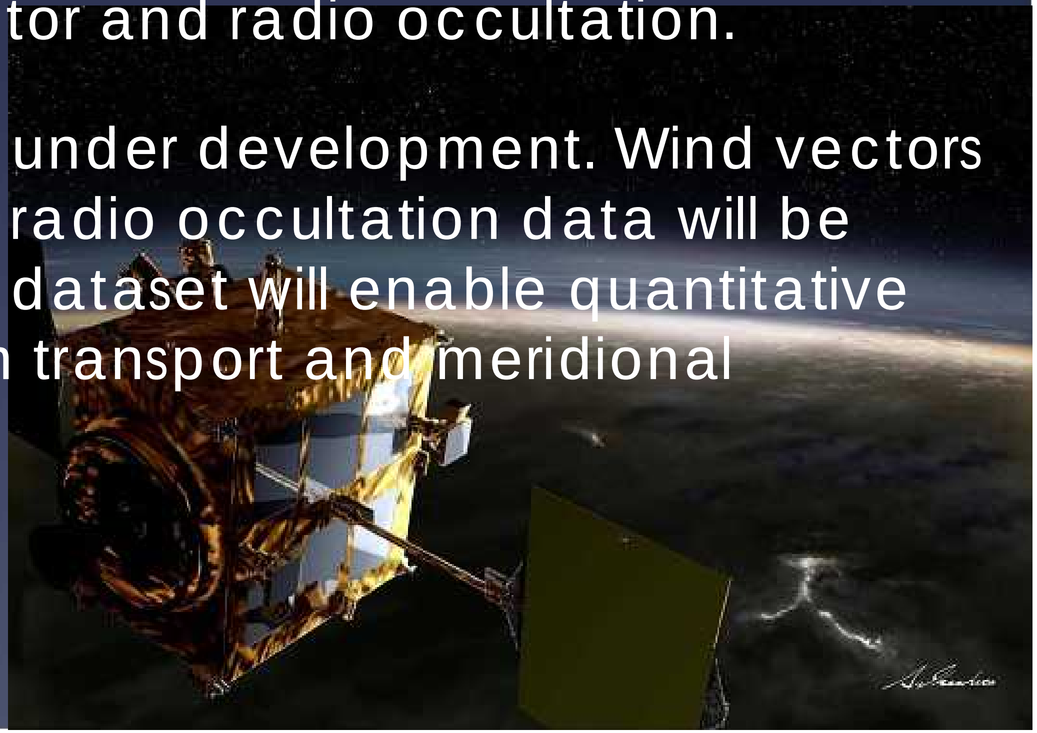
- Limb fitting to precisely determine the direction of camera FOV
- Projection onto longitude-latitude grids assuming typical cloud height (2 levels)
- Cloud tracking by cross correlation method
- Correction of erroneous vectors



(Method developed by Toru Kouyama at U. Tokyo/ISAS)

Summary

* VCO/Akatsuki will address the unique dynamical state of the Venus atmosphere with systematic sampling of meteorological variables from equatorial orbit.
* Three-dimensional structure of the atmosphere and its temporal variation will be observed by using 4 cameras, a high-speed lightning detector and radio occultation.
* Data processing pipeline is under development. Wind vectors as well as image data and radio occultation data will be released to the public. The dataset will enable quantitative studies of eddy momentum transport and meridional circulation.



VCO/Akatsuki message campaign

* The message sheet is put on a table outside of the lecture room.
* Don’t miss it ! Only names (without messages) are ok.

references

* Belton et al., 1991: Images from Galileo of the Venus cloud deck, Science 253, 1531-1536.
* Carlson et al., 1991: Galileo Infrared Imaging Spectroscopy Measurements at Venus, Science 253, 1541-1548.
* Knollenberg et al., 1980: The clouds of Venus: A synthesis report, J. Geophys. Res. 85(A13), 8059-8081.
* Schubert, 1983: Venus, University of Arizona Press, 681-765.
* Titov et al., 2008: Atmospheric structure and dynamics as the cause of ultraviolet markings in the clouds of Venus, Nature 456, 620-623.