Ground-based observations of the cyclic nature and temporal variability of planetary scale UV-features on Venus

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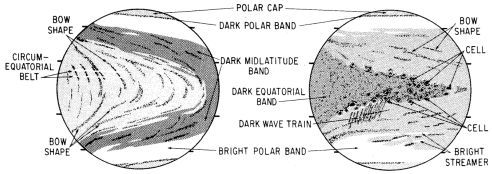
Planetary scale UV feature

- There is planetary scale dark feature = Y-feature
- The Y-feature can be used as a reference for monitoring atmospheric motions

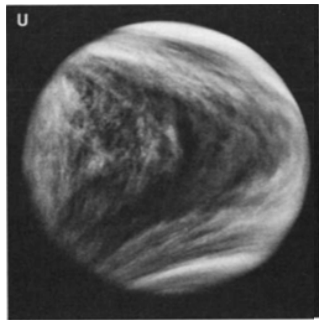


[Rossow et al., 1980]

These features were explored by esp.
Pioneer Venus Orbiter (PVO) by NASA
1978–1992
Venus Express (VEX) by ESA
2006–2014

Pioneer Venus 365 nm images

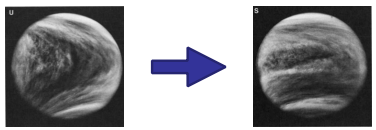
~4 days circulation

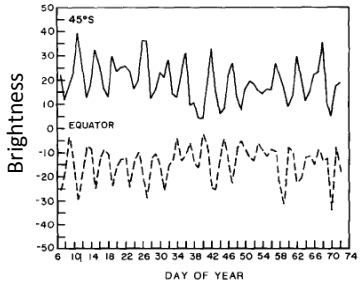


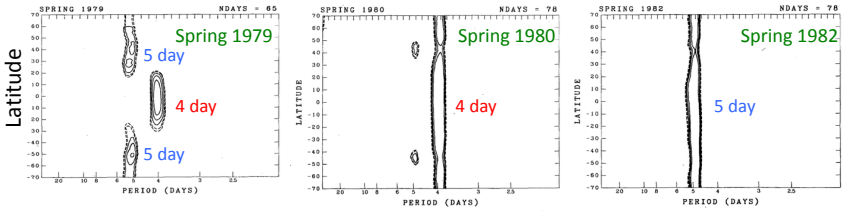
[Del Genio and Rossow, 1982]

Observed variabilities of the SR

- PVO observations suggested the existence of planetary waves



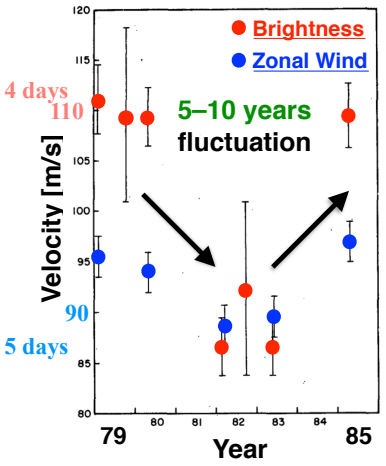




[Del Genio and Rossow, 1990]

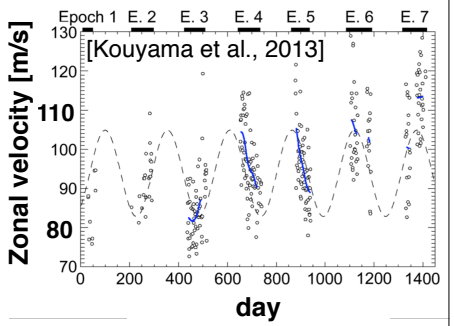
Long-term fluctuation of the SR period

- These fluctuation are not well considered in past numerical models



[Del Genio and Rossow, 1990]

Zonal winds fluctuation with ~255 days periodicity



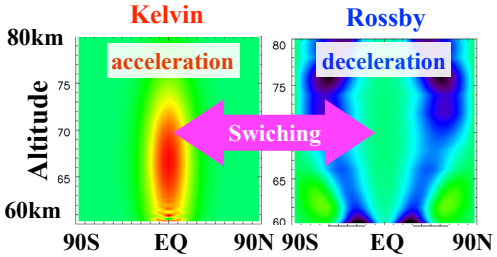
Is there any seasonal variation in SR?

e.g., Rotation = 243 d
Revolution = 224 d
Solar day = 117 d

Purpose

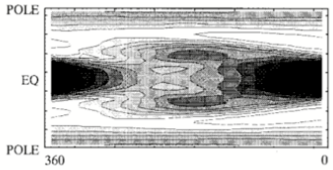
- Planetary-scale waves are considered forming the SR and the Y-feature

However, time evolution of these waves are not well understood.



[Kouyama et al., 2014]

Couple of two waves are considered to form Y-feature



[Yamamoto and Tanaka, 1997b]

Previous spacecrafts observation were not enough since its orbital plane were nearly fixed in the internal reference frame.

→ Investigate the variabilities of the Superstation in one Venus year with the information of the Y-feature shape.

Ground-based Observation with Pirka Telescope

- Realize the long-term Venus monitoring resolving one Venus year. (Synodic period ~584 days)

Wavelength
: 365 nm (+/- 10 nm)
Exposure time
: ~ 0.3 s
Spatial Resorution
: > 10° (latitude)
Typical seeing size
: ~ 2.3″

Obs. Period	Days	%	Dia. [″ (pix)]	STO angle [°]
2013/8/19 - 8/29	10 d	91%	14.1 (36)	58.4
2013/9/23 - 10/8	18 d	71%	18.6 (49)	75.2
2013/10/18 - 11/8	21 d	73%	23.8 (61)	88.2
2014/2/25 - 3/28	31 d	65%	34.7-23.2 (89-60)	109.3 - 87.5
2014/5/6 - 6/1	27 d	70%	15.3 (40)	63.8
2014/6/19 - 6/30	12 d	66%	12.4 (32)	47.8

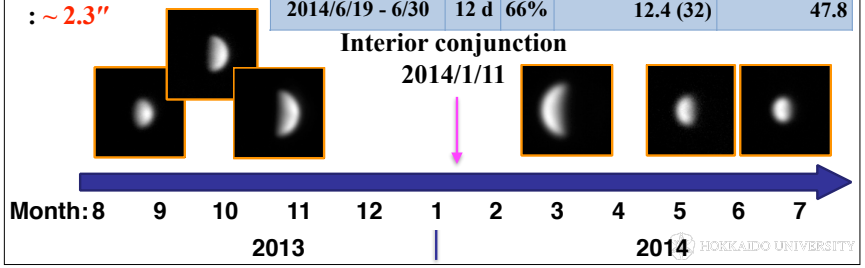
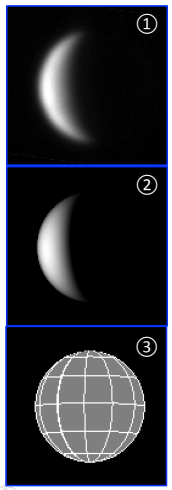


Image analysis

①: Observational image (after redacting bias, flat and sky)
②: Simulated image (using NASA: HORAIZONS)
③: Graticule image



Simulated images were calculated using the empirical equation from Belton et al. (1991).

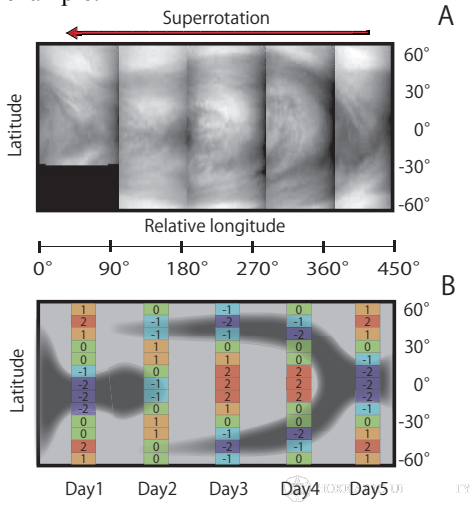
$$I = B\frac{F_\odot}{\pi\mu}(\mu\mu_\odot)^k\frac{1-\exp(-\mu_\odot/a)}{1-\exp(-\mu/b)}$$

I is the simulated brightness of Venus at each pixel (x, y), μ_s and μ denote the cosines of the solar incidence angle
The constants a, b and c were set to 0.0547, 0.0039 and 0.9.
Set $F_s = 1$.

Relative brightness measurement for the Y-feature

- Illustration the scheme for measuring the relative latitudinal brightness variation with 5 levels simplified example.

Earth's atmospheric extinction

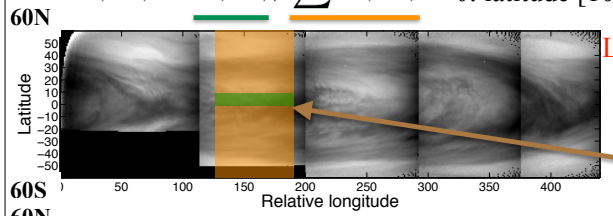


Test analysis for Galileo violet images

- Measure the relative brightness and investigate the time variation.

$$R(\theta,t) = B(\theta,t) / \sum B(\theta,t)$$

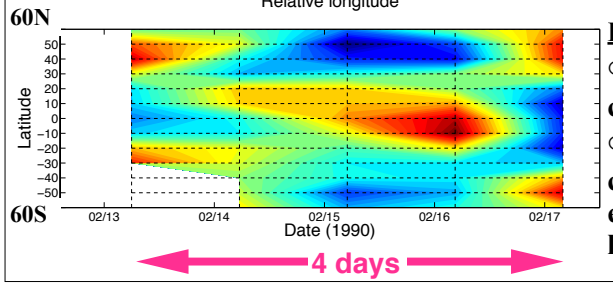
θ: latitude [10°], t: time [day]



Local time: 9 or 17-hr (day side)

Area size

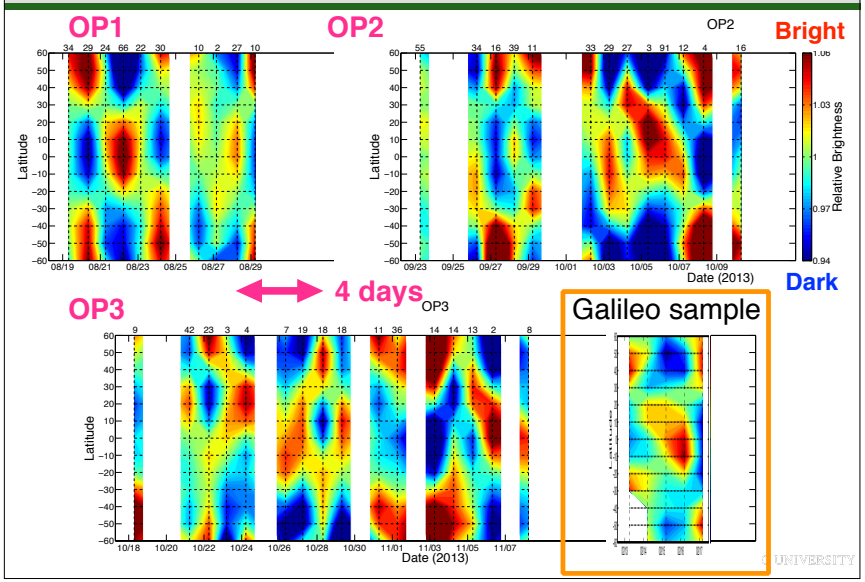
60° × 10°



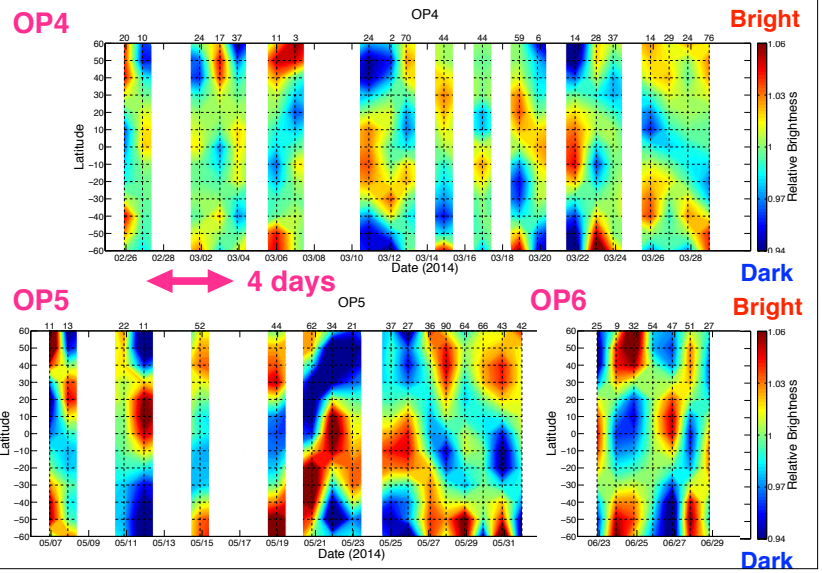
If the Y-feature exist,

- **Bright and Dark cyclic pattern**
- **Inverse correlation between equatorial and mid-latitudinal region**

Periodical Brightness variation ("Y-feature")

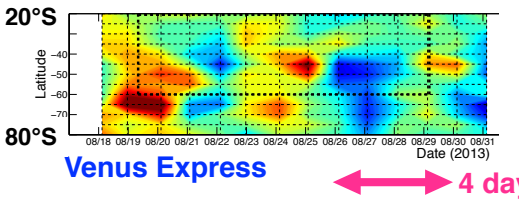


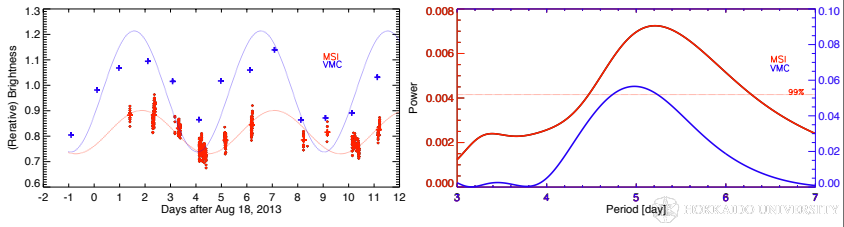
Another type of brightness variation



Comparison of periodic analysis result with VMC

- Comparison in the area of equatorial region. (10°N – 10°S)
- Phase and periodicities are well corresponds.



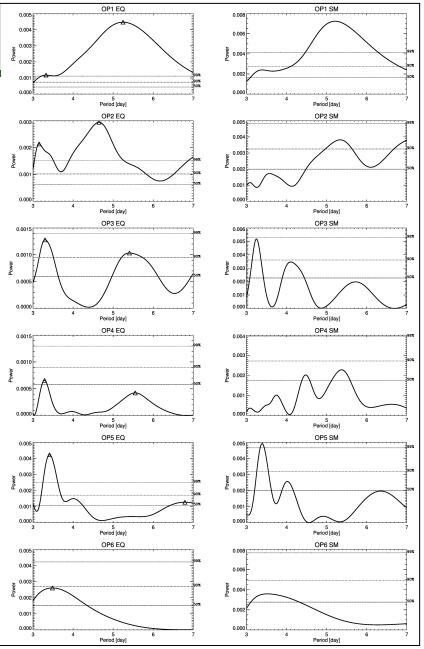


Periodical analysis results

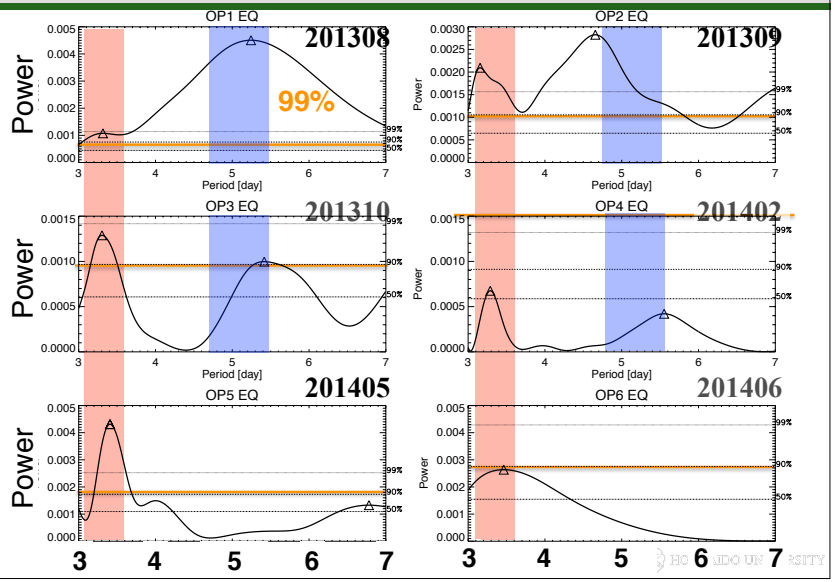
- Periodicities were calculated using Lomb-Scargle periodgram.
  [Lomb, 1976; Scargle, 1982]

This analysis extracts the power spectra from unevenly sampled data, equivalent to fitting sinusoidal waves to the data by the least-squares method.

	First significant	Second significant
OP1	5.2 days	(3.3 days)
OP2	4.7 days	3.2 days
OP3	3.3 days	5.4 days
OP4	3.3 days	5.6 days
OP5	3.4 days	6.8 days
OP6	3.5 days	-

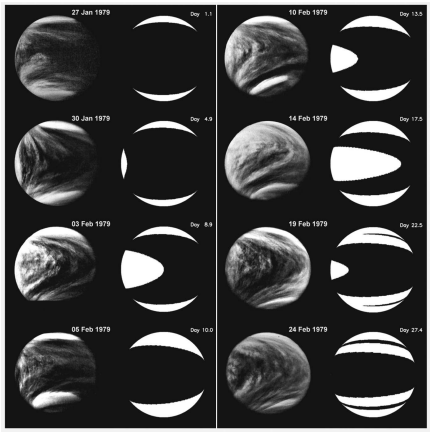


Periodicity of the variation (Equator)

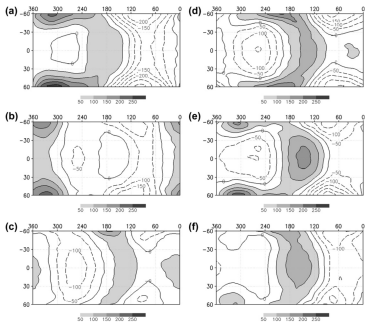


Modulation of the Y-feature

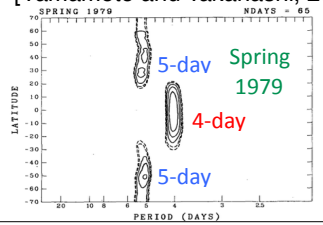
- Deformation of the Y-feature was suggested by some GCM.



[Peralta et al, 2015]



[Yamamoto and Takahashi, 2012]

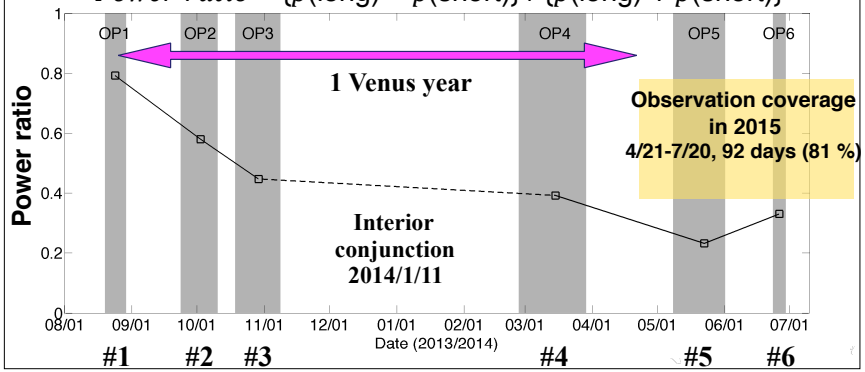


Long-term variation of cyclic nature in our data

- Time evolution of the dominance of the long period (~5 day).

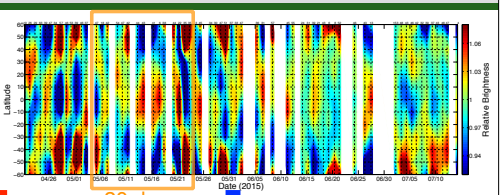
The period changed from 5.2 days to 3.5 days at approximately nine-month intervals, suggesting that the timescales of the periodic variation of the planetary scale waves, but the Venusian year (224 days) do not coincide.

$$Power\ ratio = \{p(\text{long}) - p(\text{short})\} / \{p(\text{long}) + p(\text{short})\}$$

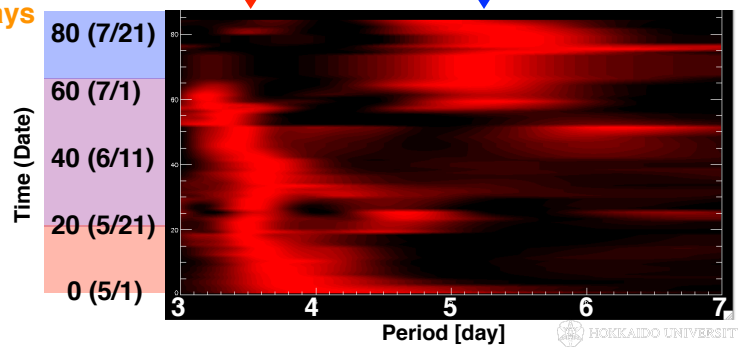


Results of 3 months continuous observation in 2015

- The change of the first significant mode from 3.5-day wave to 5.2-day wave was observed continuously.



Analysis window: ±10 days



Summary

<Results>

- We found two significant periods and a continuous change in their relative strength.
- The amplitude of the relative brightness was not always constant when double periodic waves are dominant, suggesting the Y-feature patterns are deformed like previous GCM results.

- From Aug 2013 to May 2014 (~9 months; > 1 Venus year), phase velocity increase from 85 m/s (5.2-day) to 125 m/s (3.5-day) and 3.5 days variation consecutively more than 2 months from May 2014.
- In 2015, double periodic waves considered to last for 1.5 months.
- The periodicity in the UV brightness variation changes within one Venus year, suggesting it doesn't coincide with one Venus year.

<Future Work>

Compare with the wind velocity data (e.g., Akatsuki cloud tracking) to investigate the acceleration of atmosphere.

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