# Vertical propagation of planetary scale waves in variable background zonal winds

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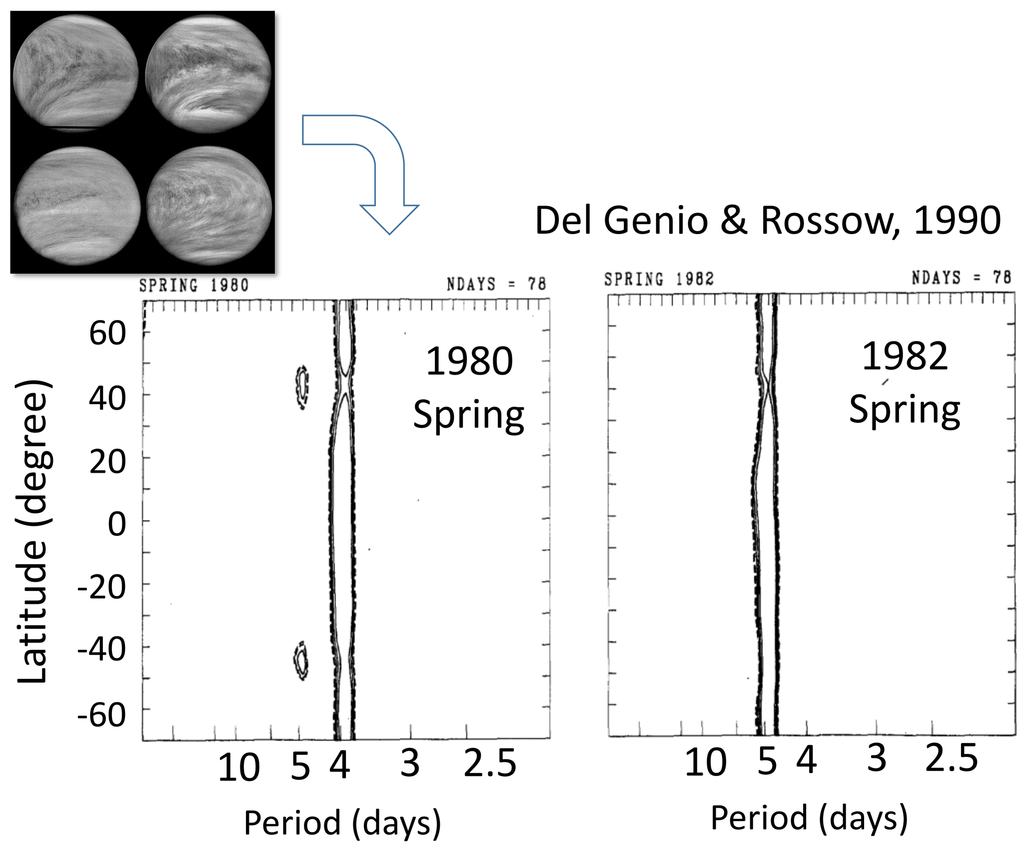
## Planetary-scale Waves in Venus atmosphere

### Planetary-scale wave signatures

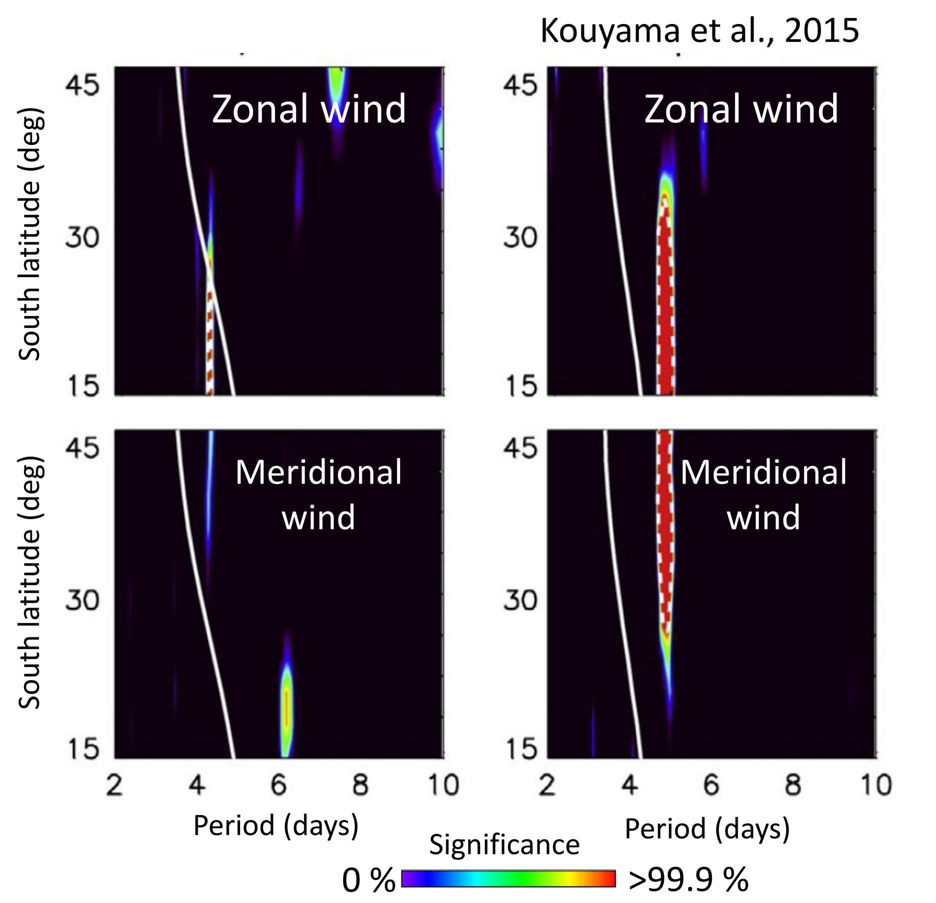
- 4 and 5-day periodical variations in UV brightness [Del Genio & Rossow, 1990]
- 4 and 5-day periodical perturbations in zonal and meridional wind speed [Kouyama et al., 2013, 2015]

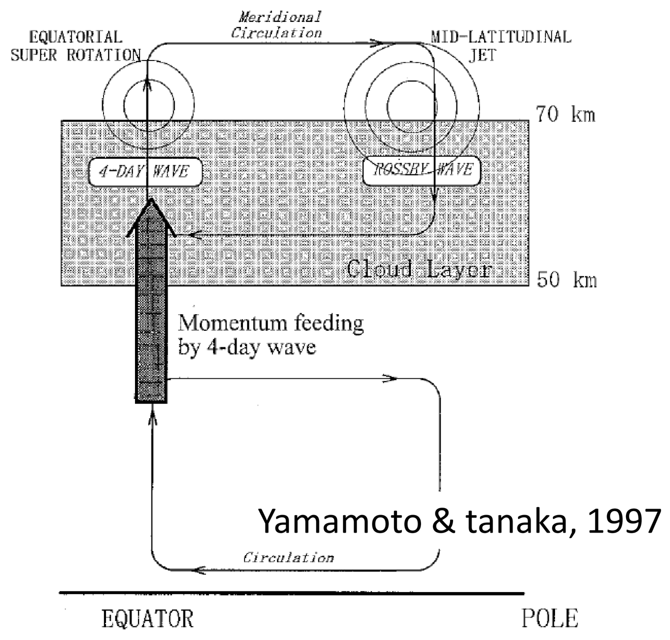
-> Wave propagation relates to brightness variation and wind perturbations

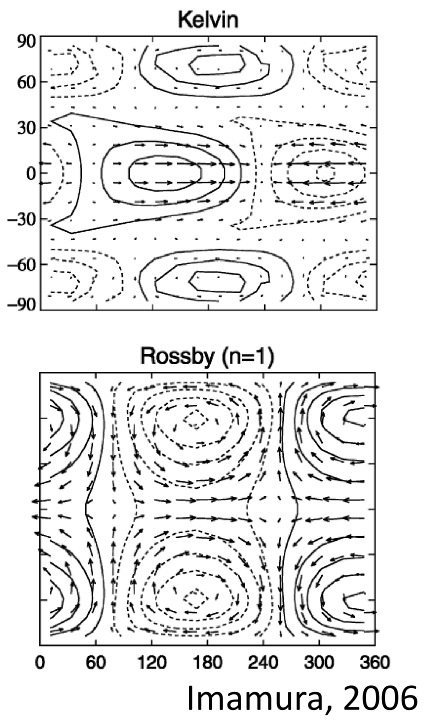



### Importance of the waves

- Vertical propagation of waves transport atmospheric momentum vertically, so that they can accelerate/decelerate the zonal wind speed. [cf. Rossow et al., 1990 Yamamoto & Tanaka, 1997; Imamura, 2006]
- Waves affect global distribution of UV absorbers -> Somewhat controlling thermal input at cloud level?




### Observed timing of 4-day and 5-day waves

Usually dominant wave is only one (4 or 5 day wave) at a certain period.

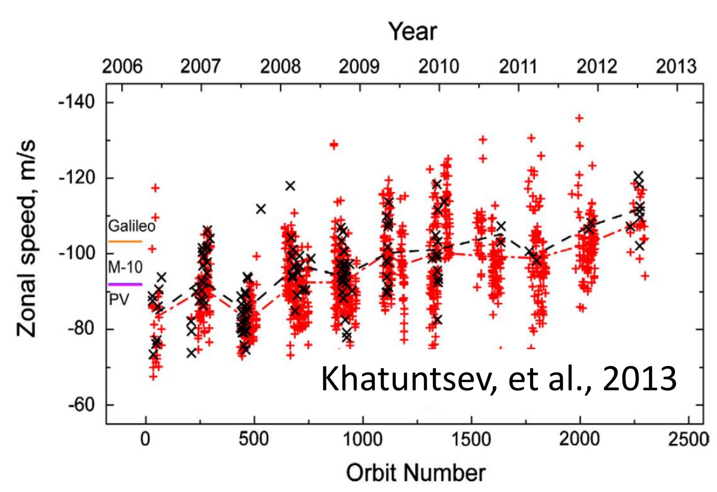
- Slow background zonal speed -> 4-day (Kelvin) wave
- Fast background zonal speed -> 5-day (Rossby) wave

Filtering mechanism?
Condition for exciting waves?

### Purpose of this study

Investigating vertical wave propagations using numerical calculation in variable and realistic background zonal winds for understanding wave appearances at the cloud top in the realistic condition.

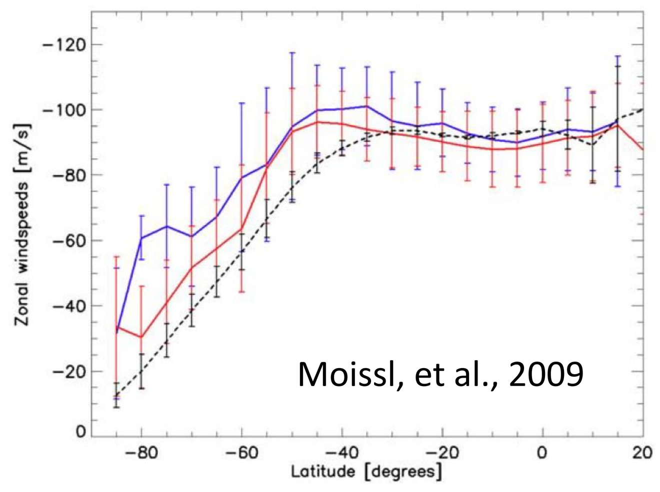
## Observed zonal wind profiles




### Temporary variation:

- Gradual acceleration of zonal wind speed (up to 30 $ms^{-1}$) in Venus Express observation [Khatuntsev, et al., 2013] with relatively short term variation (~20 $ms^{-1}$ within 100 days) [Kouyama et al., 2013].

➡ Intrinsic phase speed of each waves should vary with time, affecting vertical propagation behaviors of each waves

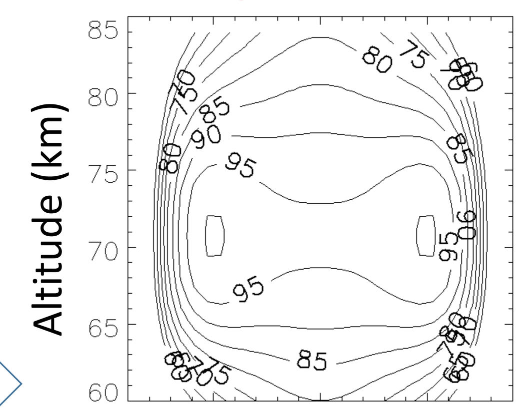



### Non-solid body rotation:

- Latitudinal zonal wind profiles from cloud tracking results show flat distributions.
- In previous work (Kouyma et al., 2015), solid body rotation profile (= non-realistic) was adopted to simplify the calculation.

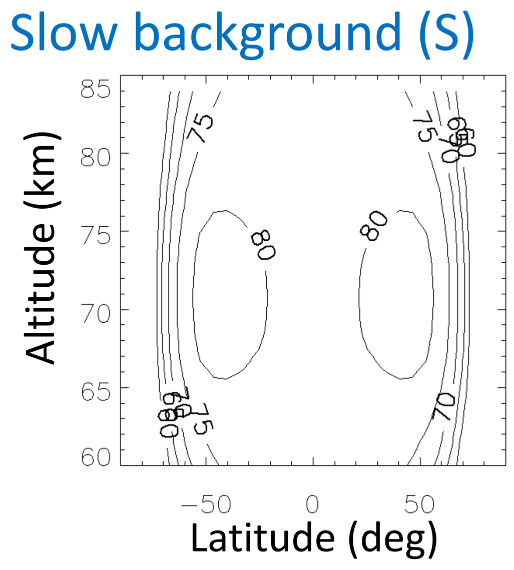
## Model description

Fast background (F)

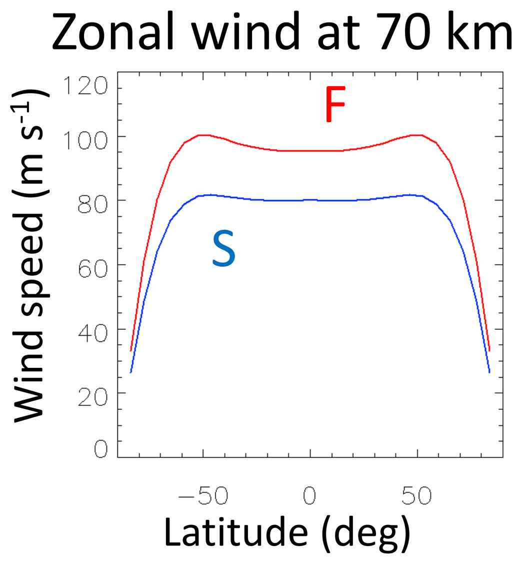



- Linearized primitive equation model based on Imamura (2006) calculation
- Fast and slow background zonal wind profiles with the consideration of non-solid body rotation
- Strong radiative cooling based on Crisp (1997)
- Kelvin (~115 m $s^{-1}$) and Rossby (~79 m $s^{-1}$) waves are induced at 60 km altitude.

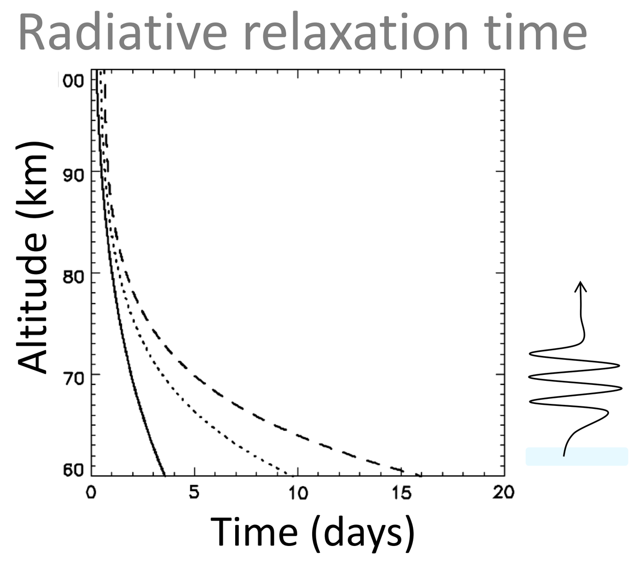
Slow background (S)




Zonal wind at 70 km



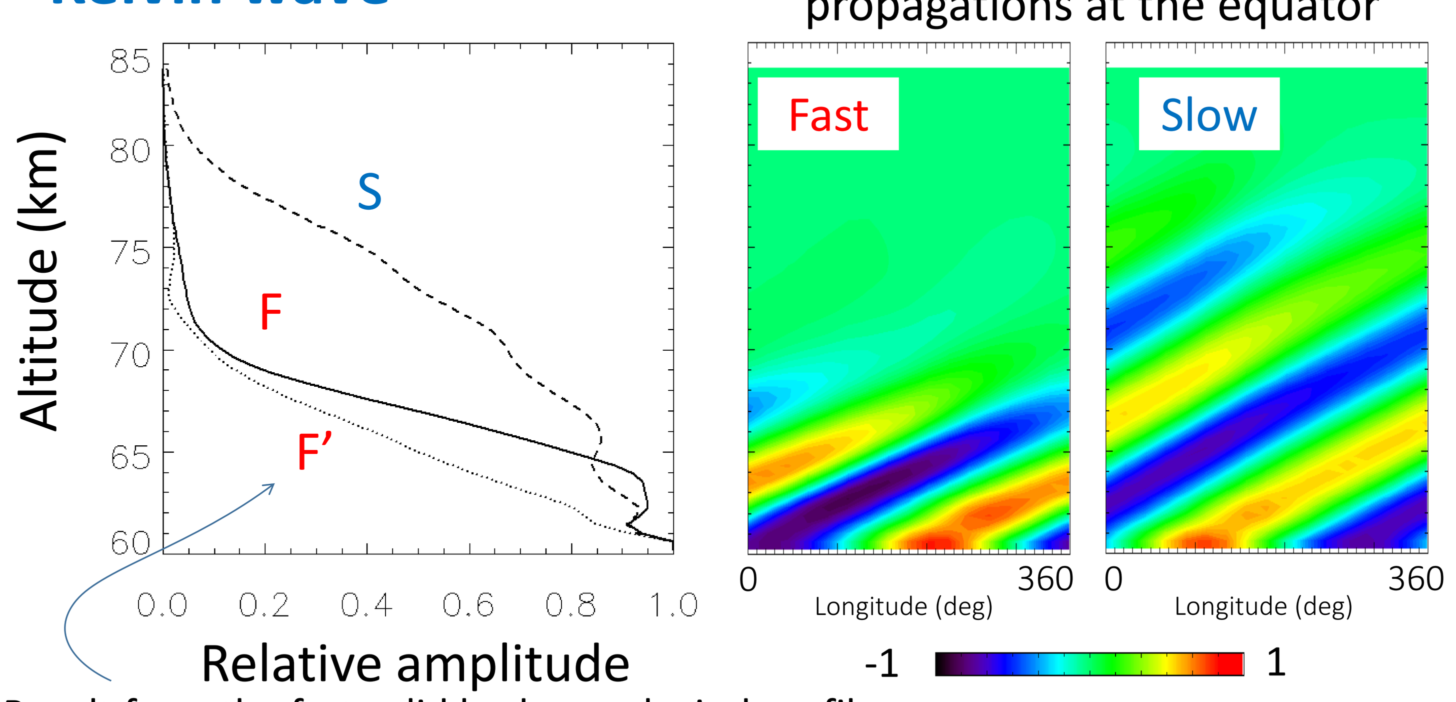

Radiative relaxation time




## Results & Discussion

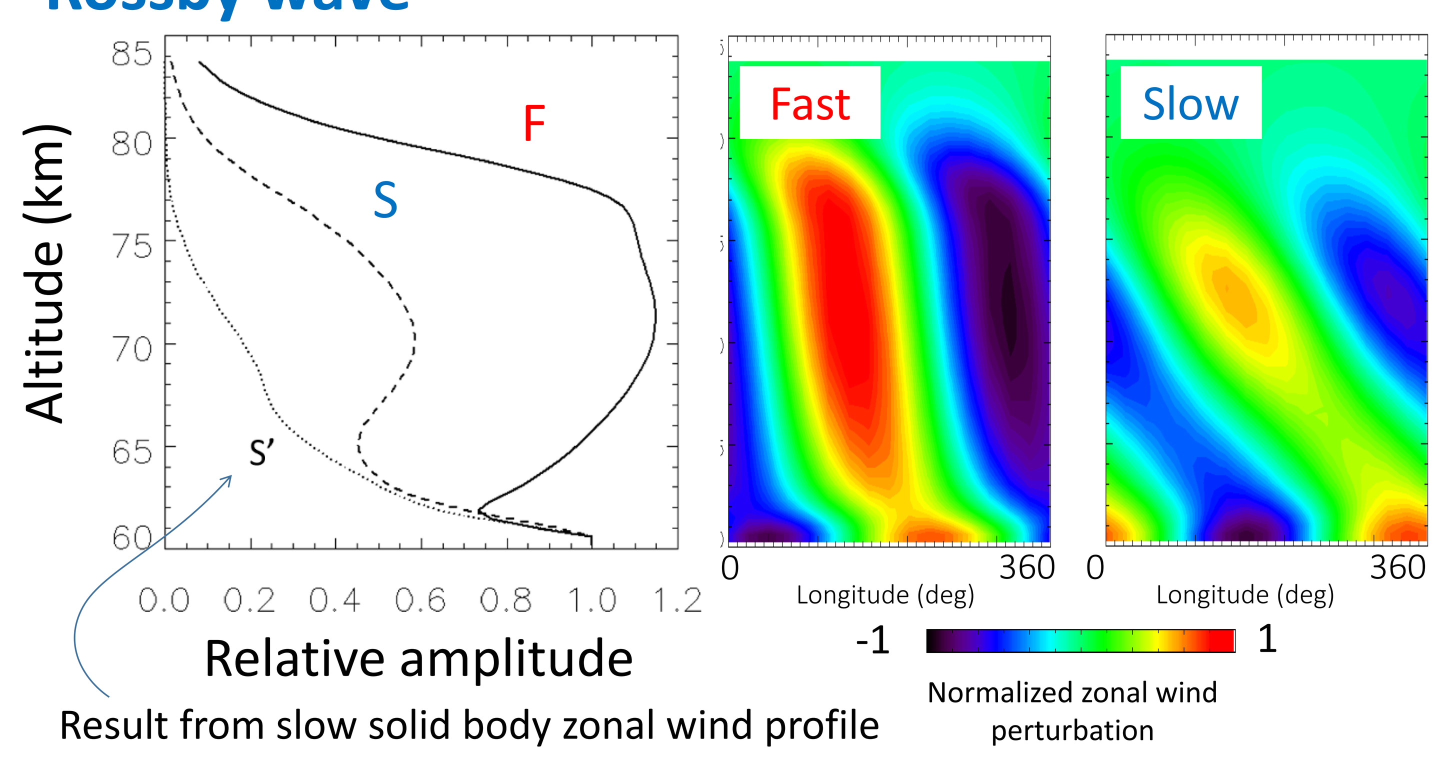
### Kelvin wave

Vertical cross-section of wave propagations at the equator




Result from the fast solid body zonal wind profile

### Rossby wave




Result from slow solid body zonal wind profile

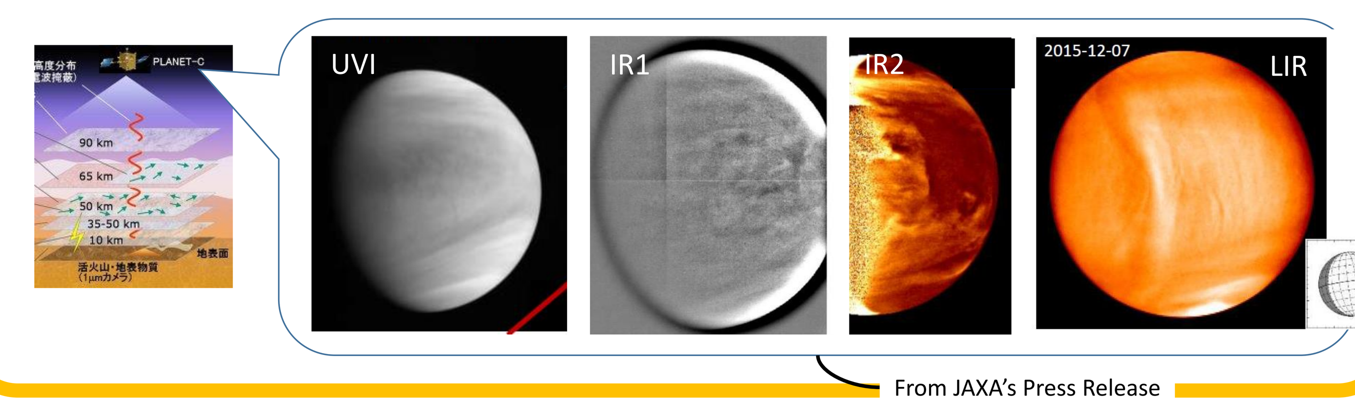
- **Kelvin wave** remains a significant amplitude even above 70 km only in the slow background zonal profile, same as the solid body condition (Kouyama te al., 2015).
- **Rossby wave** remains a significant amplitude in the fast background, and also remains its amplitude some extent in the slow background, which is different from the solid body rotation condition.

-> Flat latitudinal profile of zonal wind may relax the wave attenuation. Thus the reason of less dominance of Rossby wave in the slow zonal wind season is not only the attenuation, but also weak wave excitation at the slow zonal wind season?

## Conclusions

- Vertical propagation of Kelvin and Rossby waves are investigated.
- Both vertical and zonal wind profile can affect the vertical propagation of the waves.
- Since Rossby wave can reach the cloud top level in both fast and slow background zonal profiles, investigation of the condition of the wave excitation should be important to understand the wave dominance at the cloud top.

Multi altitude observations of AKATUSKI should provide essential information for the investigation.




From JAXA's Press Release

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**References:**
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