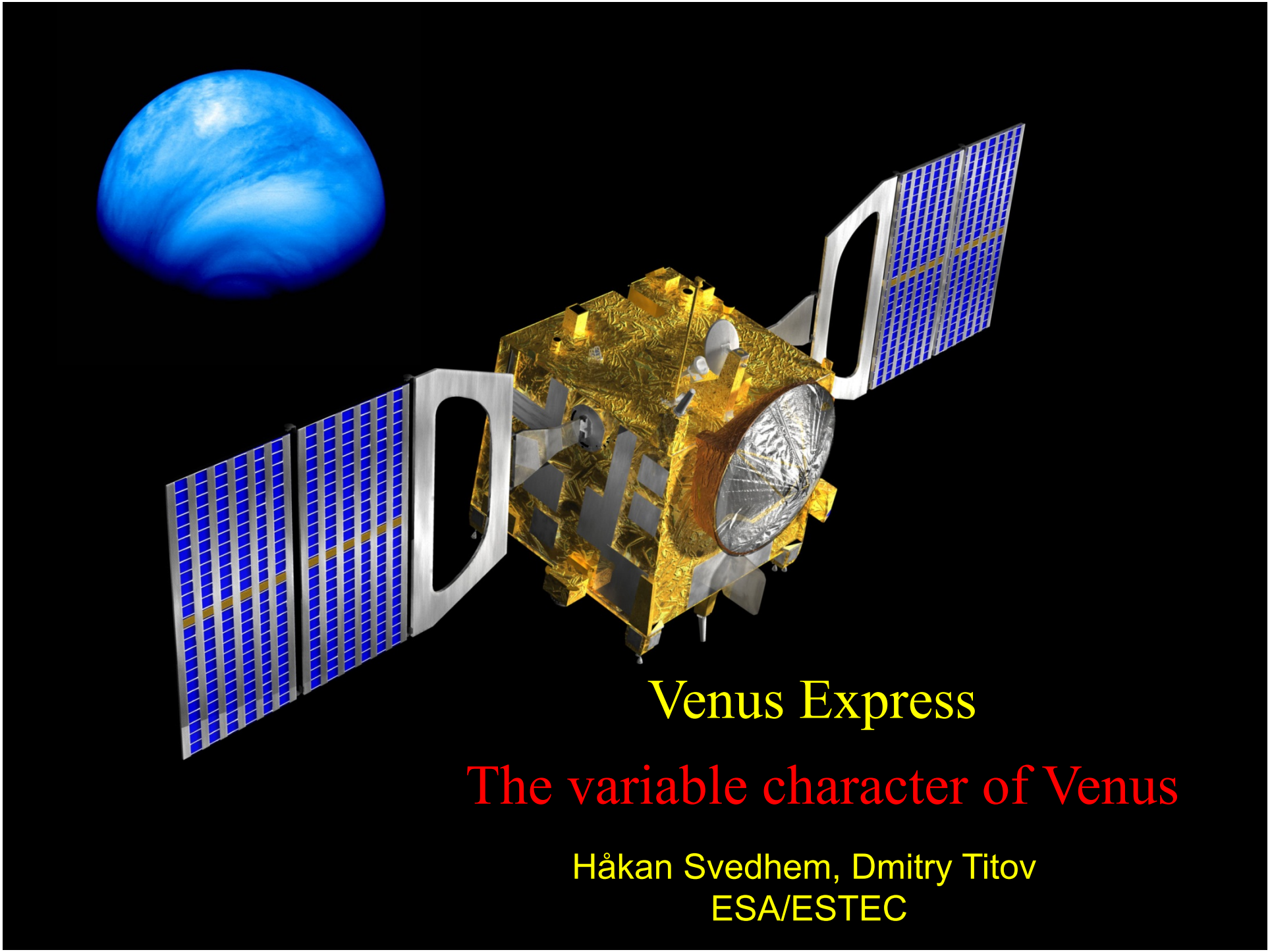


Venus Express

The variable character of Venus

Håkan Svedhem, Dmitry Titov
ESA/ESTEC

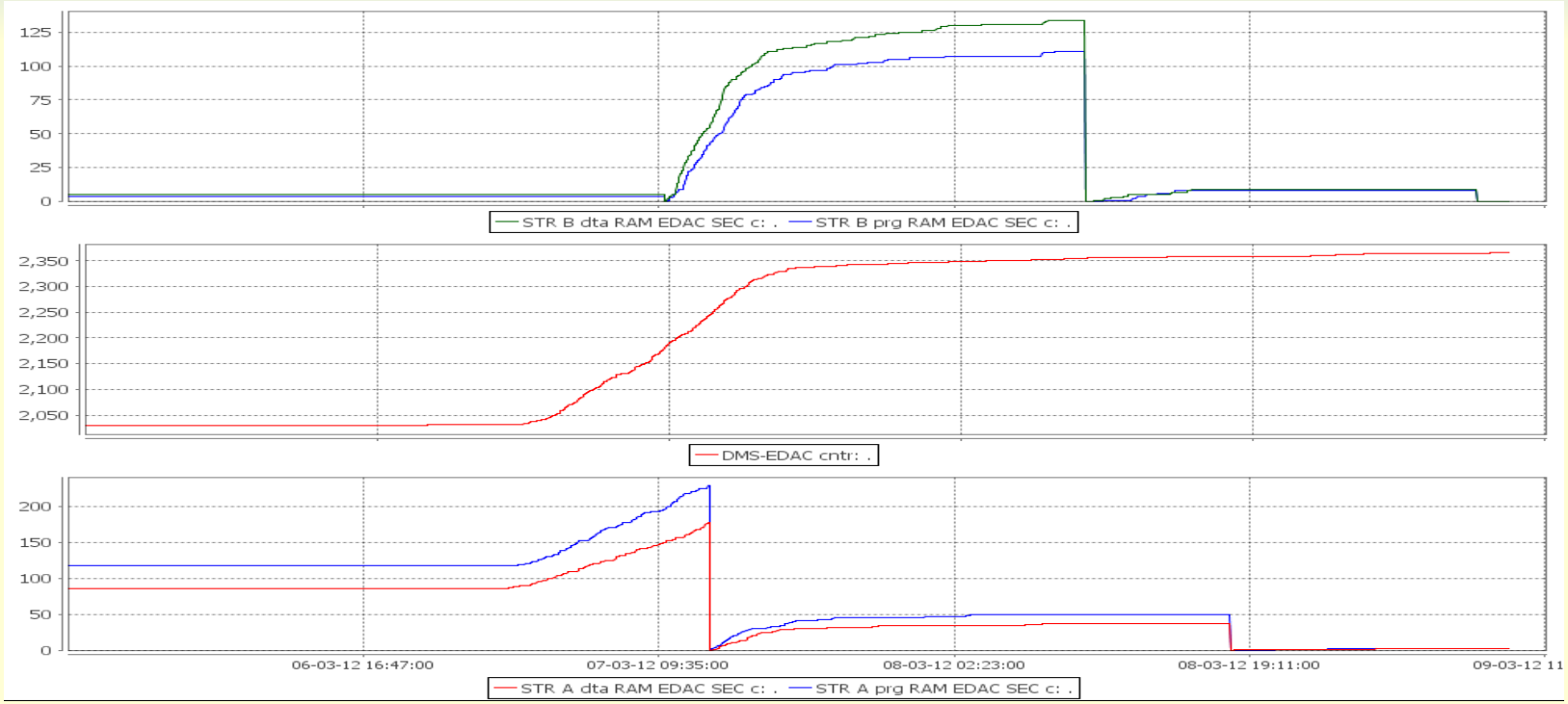
Mission Status (1)

- The spacecraft is in an excellent condition and the fuel and power situation is very good, even after over six years in orbit.
  - Amount of remaining fuel somewhat uncertain as it is inherently difficult to measure. A novel method of estimating fuel will be tried next spring. Best (conservative) estimate today predicts end of fuel in 2015.
- On 7 March a strong flux of high energy protons originating from a solar flare reached the spacecraft. This resulted in a temporary blinding of both star trackers for a duration of about 50 hours.
- Occasional anomalies have occurred but these are normally solved and understood very quickly. They mostly relate to data transmission and the SSMM.
- Well over 4000 Gbit of science data has now been downloaded to ground.
- 12 earth occultation season have taken place so far. Typically radio science observations have been carried out every 1-3 orbits. More than atmospheric 500 profiles have been collected.

Mission Status (2)

- 9 atmospheric drag campaign have been performed. About 100 measurements down to an altitude of 165km has been collected.
- A major orbit control manoeuvre (8.5 m/s) was carried out successfully on 23 January, rising the pericentre altitude138 km to 314 km. The rate of the downward drift in altitude is increasing with time
- A study of the feasibility of reducing the orbital periods by aero-braking has been conducted by the s/c manufacturer, Astrium. A feasible case, with adequate margins, to go to 0.3-0.4 N/m2 has been identified. It is intended to carry out aerobraking as a science and technology experiment in 2015.
- The data archive (PSA) is in a good state, with all but one investigation archived and up to date. The radio science data is lagging behind but we are working on a solution for this. See: www.rssd.esa.int/psa
- Data workshops for new users of data from the missions are organized at ESAC, Spain. Next one will tentatively take place in spring 2013 and will be specially intended for users of Virtis data.

Solar flare and CME



On 7 March a strong flux of high energy protons originating from a solar flare reached the spacecraft. This resulted in a temporary blinding of both star trackers for a duration of about 50 hours.

Mission operations funding

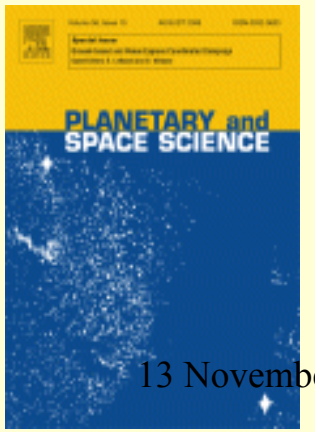
- Venus Express is presently funded for operations until end 2012
  - Funding until end 2014 is preliminary given and funding is allocated. Confirmation by the Science Programme Committee is expected 15-16 November 2012
  - Extension until end 2015 has been requested and has been evaluated positivey by the ESA advisory groups. However as the full budget envelop still is uncertain a descision by SPC is not expected before June 2013.
  - An ESA council meeting on ministerial level end November 2012 will determine the over all ESA budget for the next 3-5 years.

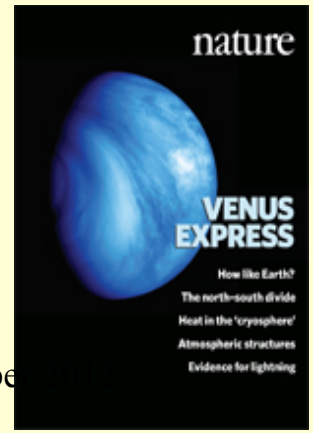
Future operations

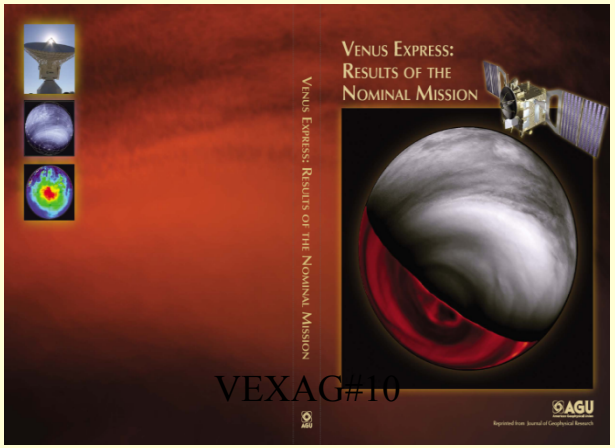
- 2013 -2014 operations will focus on a number of topics following recent findings and will be executed as campaigns of up to two months duration
  - Atmospheric changes
    - SO2 variations
    - NO variations
    - Superrotation
  - South Pole dynamics
  - Thermal structure, waves
  - Surface changes and anomalies
- 2015 will focus on aerobraking and low altitude in situ measurements and imaging

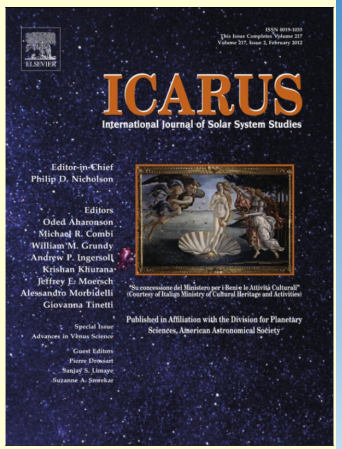
Major publications

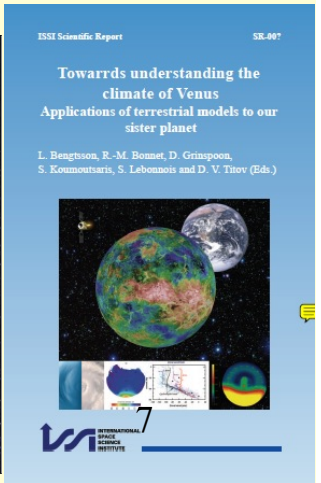
- Over 300 refereed publications related to Venus Express
- Planetary & Space Science, double issue on Venus Express (2006-07)
- Special section of Nature (2007)
- Planetary & Space Science, special issue on coordinated ground and space based observation campaign (2008)
- Journal of Geophysical Research, special issue on Venus Express (2009)
- Planetary & Space Science, special issue on comparative planetology (2010)
- Icarus, special issue on Venus (2012)
- ISSI Book “Towards understanding the climate of Venus” (2012)











Venus Science conference 2013

- We are organising a scientific conference in late May or June 2013
- The format will be similar to the format in La Thuile (2007, 2008) and Aussois (2010)
- The Venus will be on the Italian islands of Sicily or Vulcano
- Preliminary dates: 27-31 May OR 10-14 June
- Local Organiser: Giuseppe Piccioni

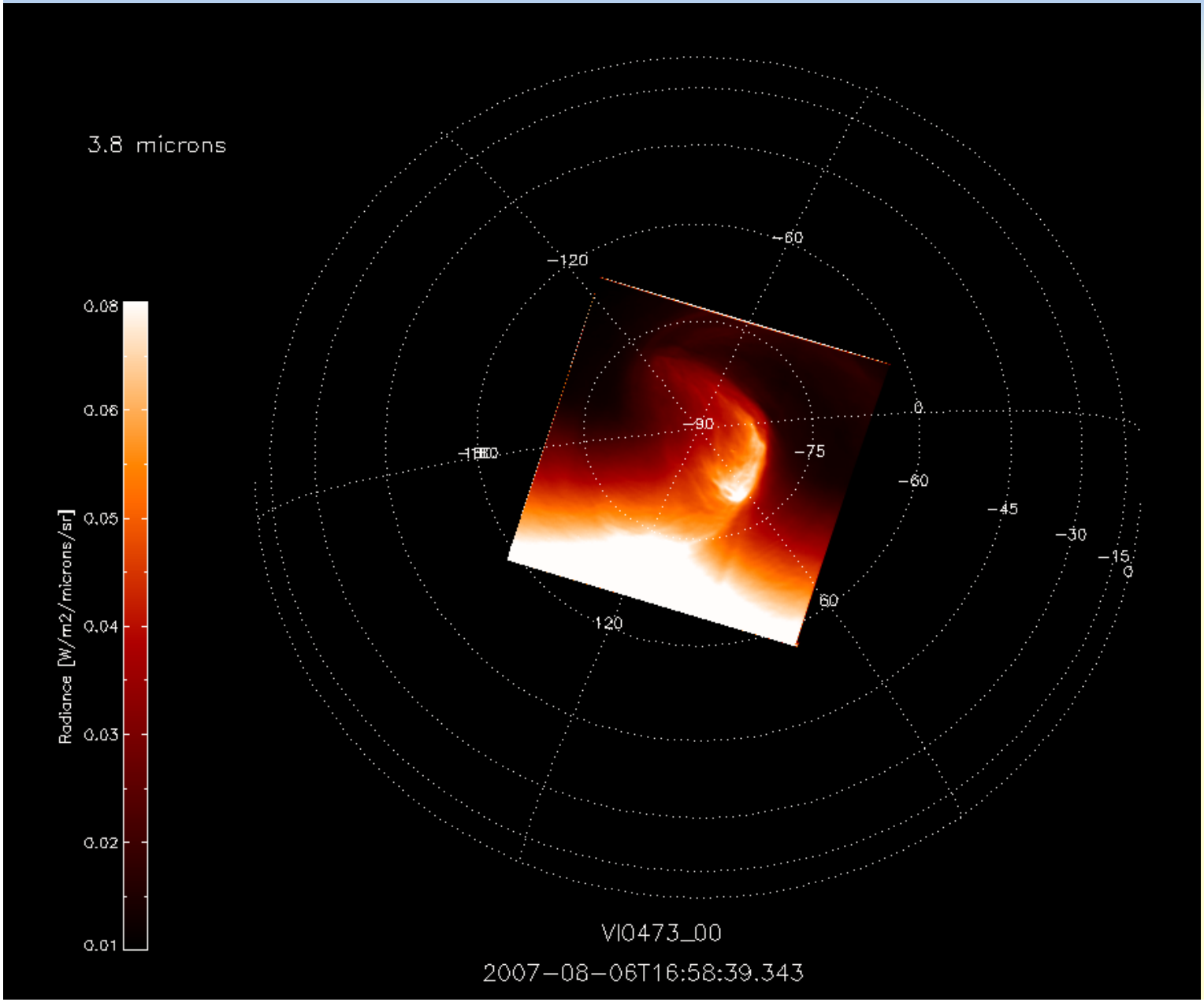
Some Results

- New and Old
- Major results in relation to original mission objectives
- What is solved, what remains to be studied

Mission Objectives

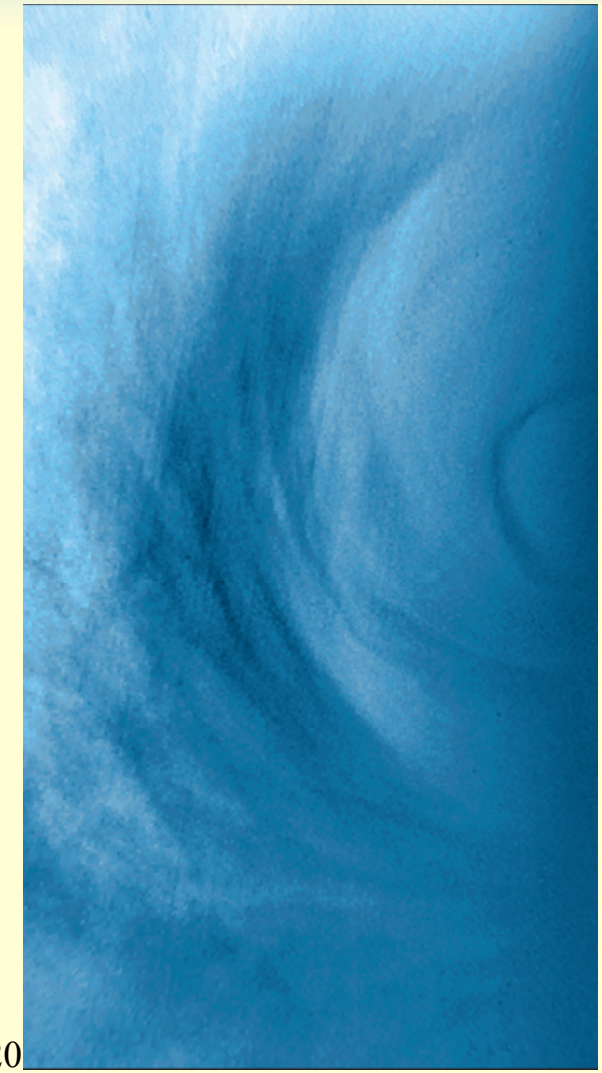
- Science Themes
  - Atmospheric Dynamics
    - Global Dynamics mechanisms, Super-rotation, Double Polar Vortex
  - Atmospheric Structure
    - Density and Temperature in three dimensions
  - Atmospheric Composition and Chemistry
    - Processes and species in the different regions
  - Cloud Layer and Hazes
    - Behaviour and characteristics, UV absorber
  - Radiative Balance and Greenhouse effect
    - Global thermal balance, Greenhouse in past, present and future
  - Surface Properties and Geology
    - Volcanic and seismic activity, highly radar reflective areas
  - Plasma Environment and Escape processes
    - Evolution of the atmosphere, water, escape history

South polar vortex at 3.8 µm



Venus polar vortex vs Earth hurricanes

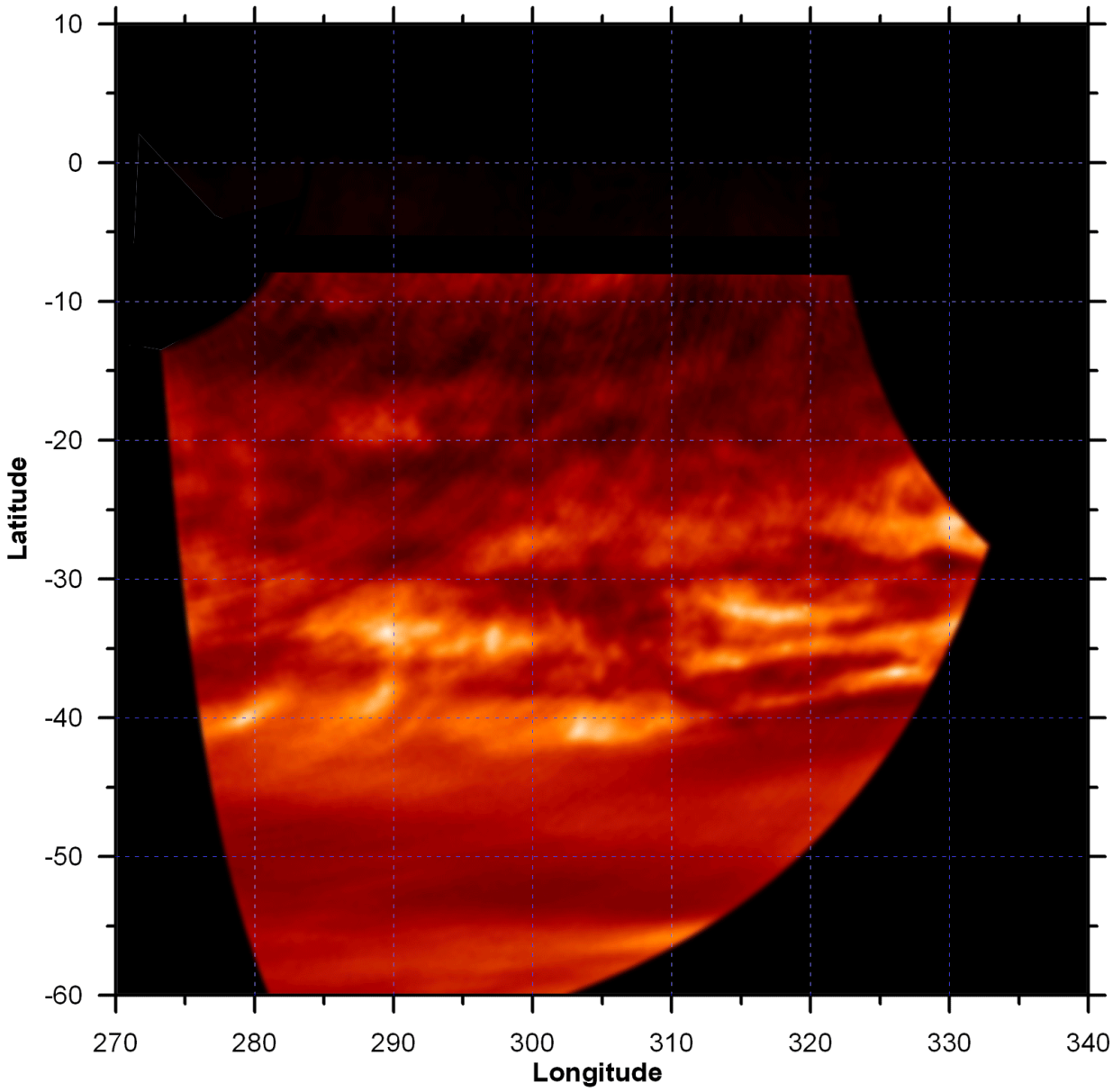
Venus S-Pole Frances



S. Limaye et al. 2010

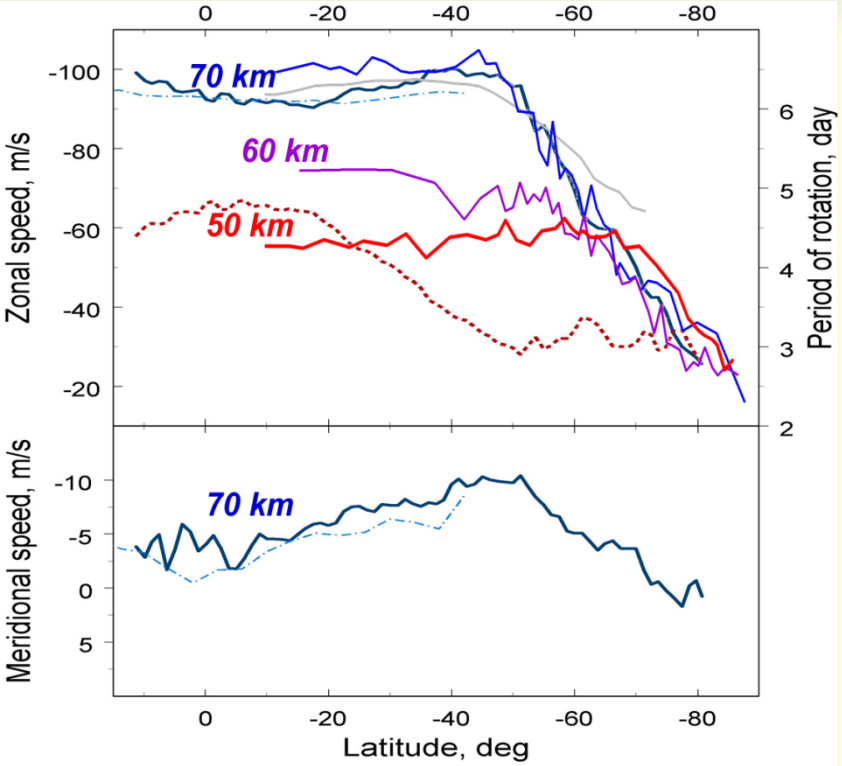
Atmospheric dynamics and wave phenomena

VIRTIS near-IR movie

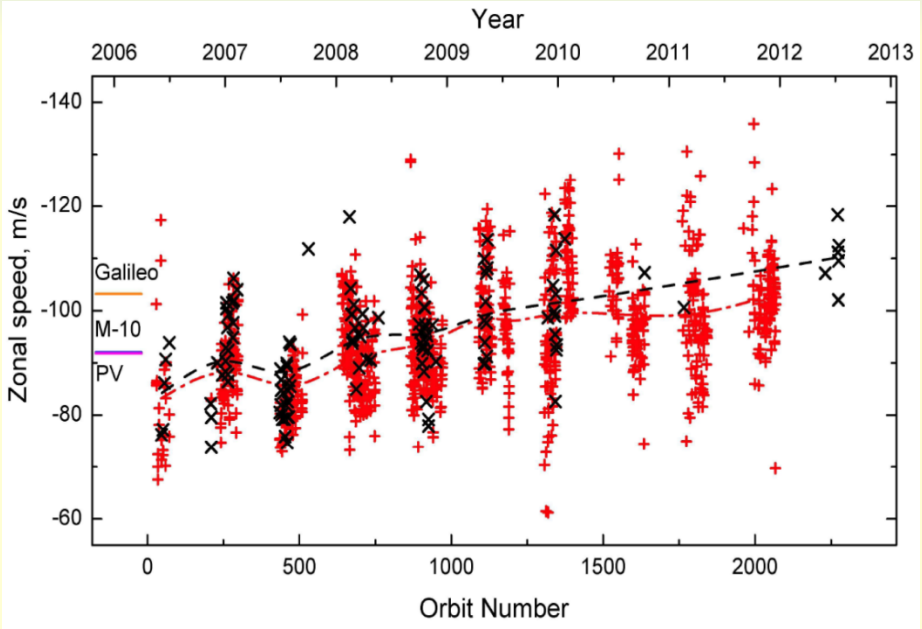


13 November 2012

Winds at the cloud level



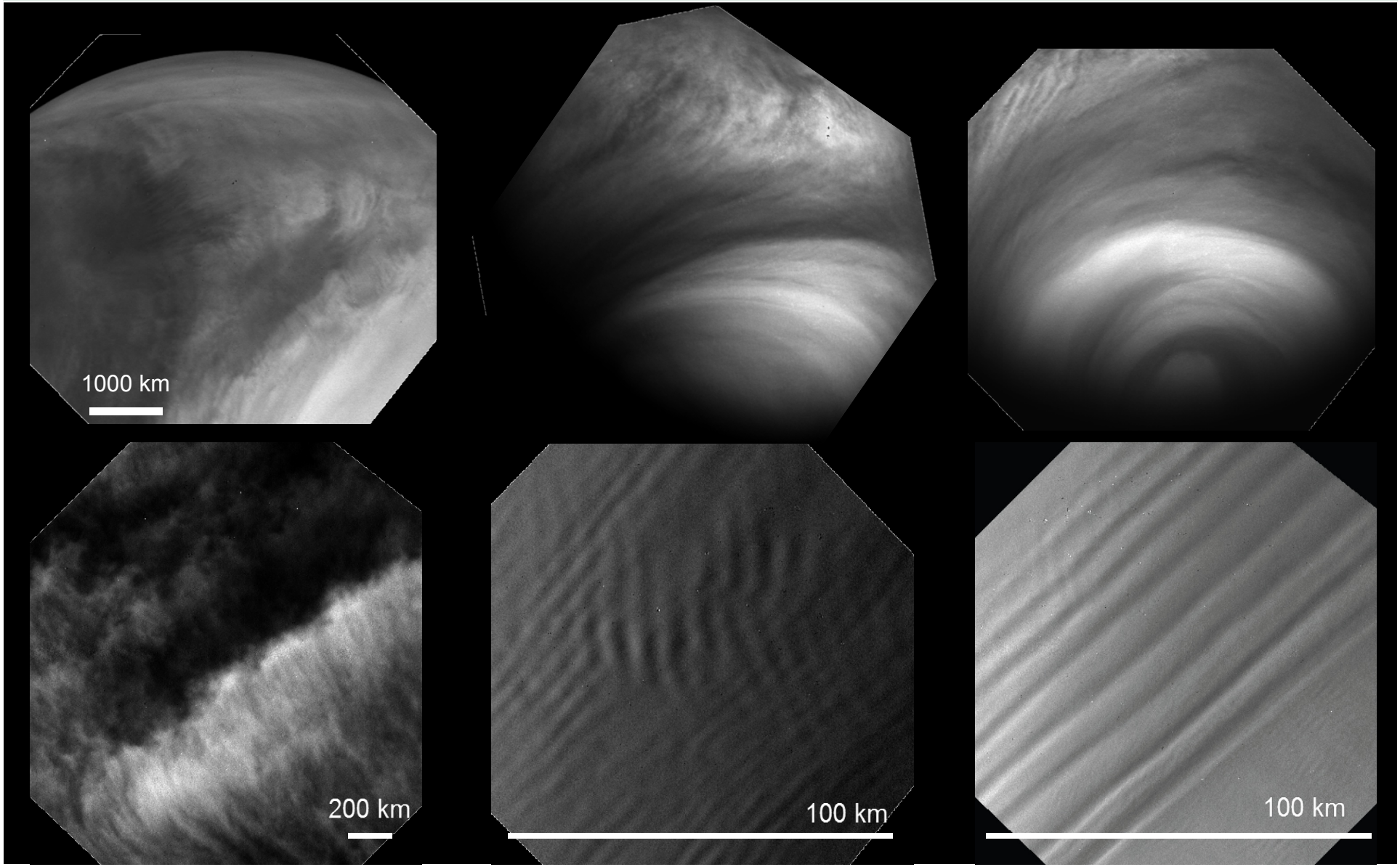
Khatuntsev et al., Sanches-Lavega et al.



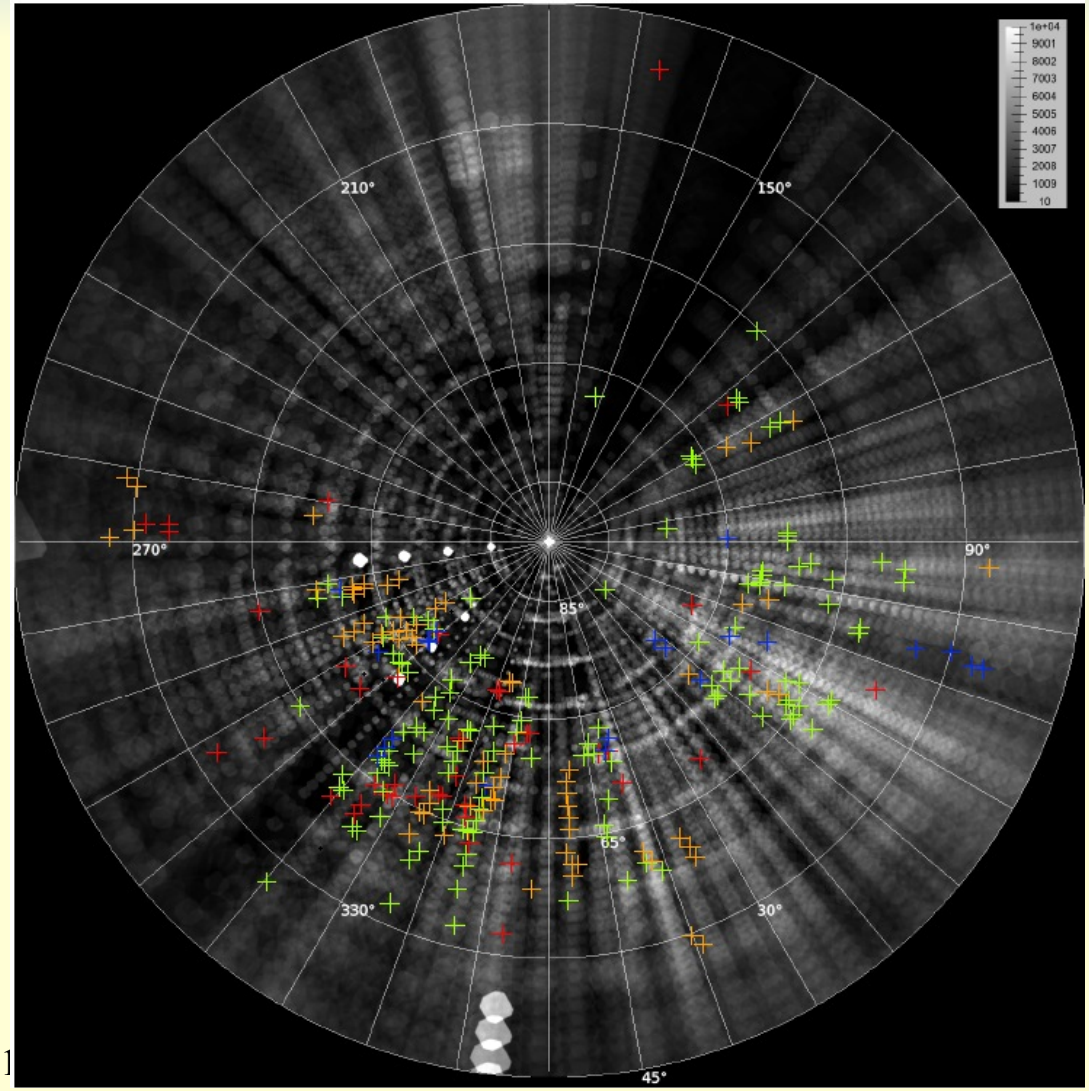
Khatuntsev 2012

Now wind data over six years reveal a dramatic 30% increase in super-rotation rate!

Cloud top morphology and small scale structures



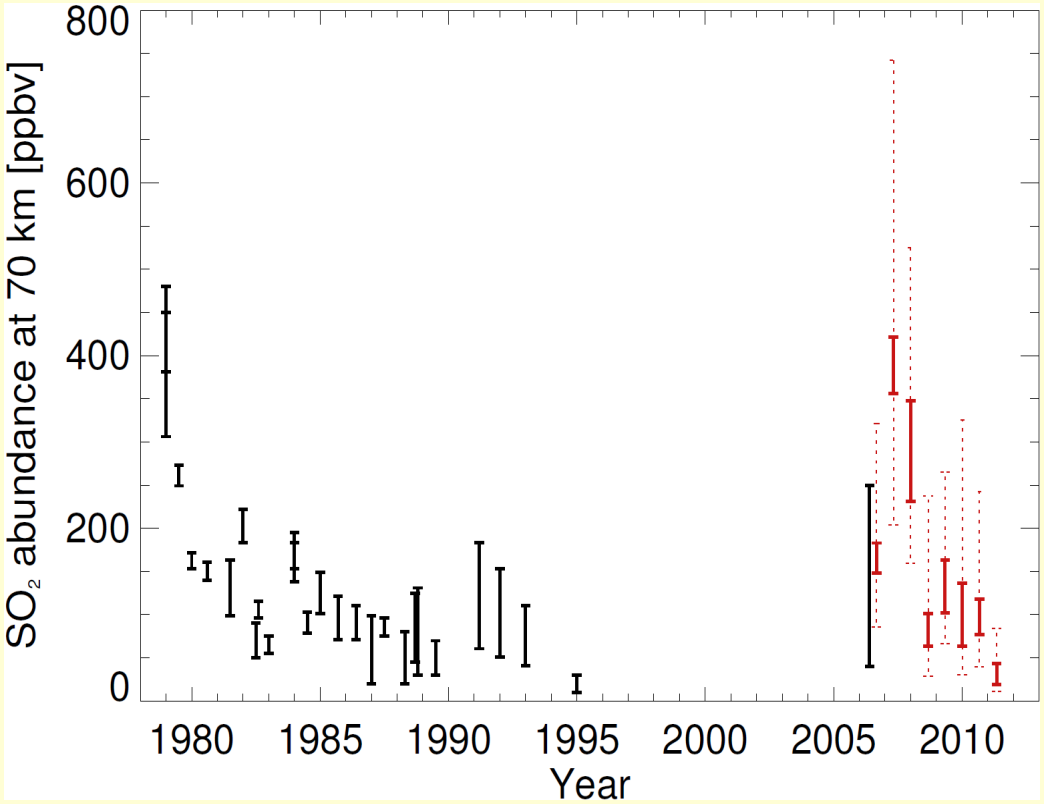
Location of detected horizontal gravity waves



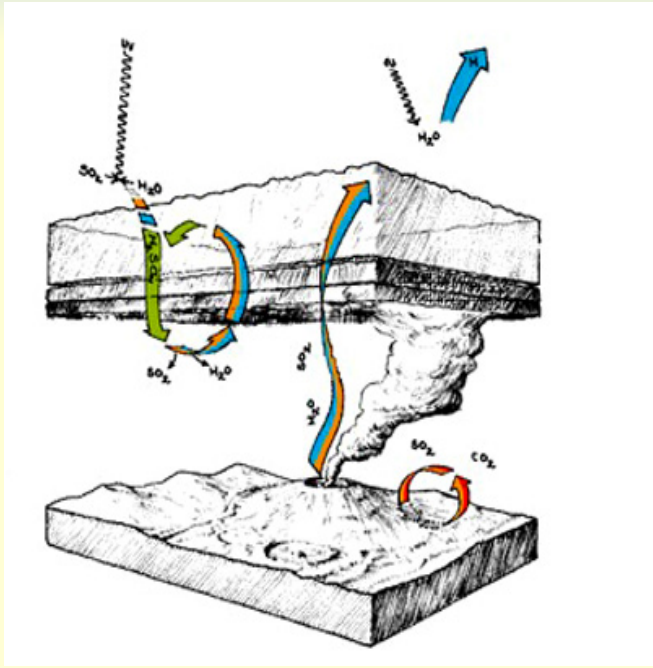
Northern hemisphere. To be interpreted with care as strong biases in the data set do exist.

[A. Piccialli, 2012]

Mesospheric SO_2 changes



Marcq, 2012

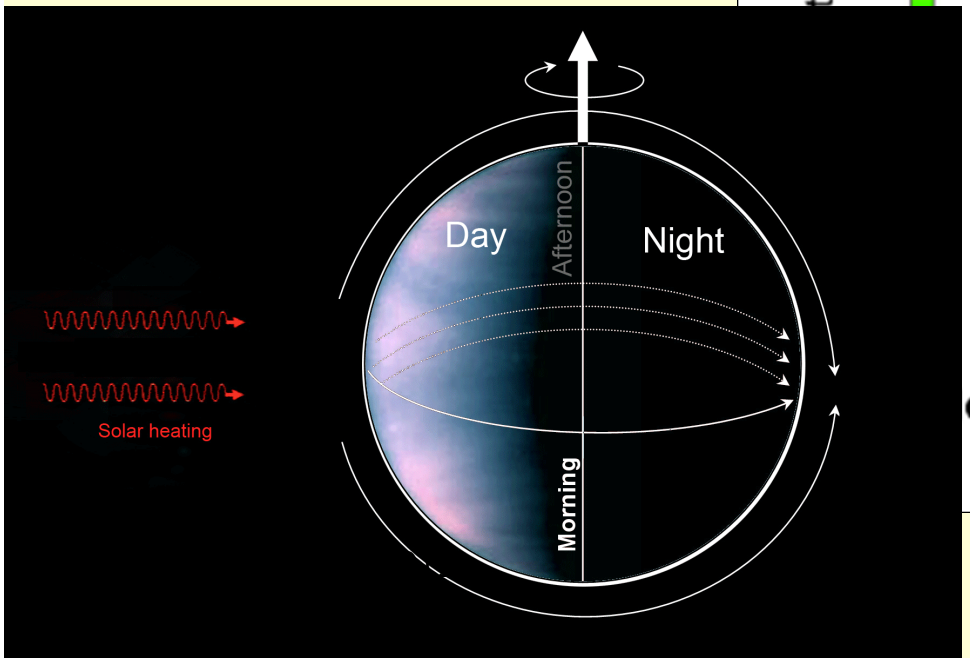


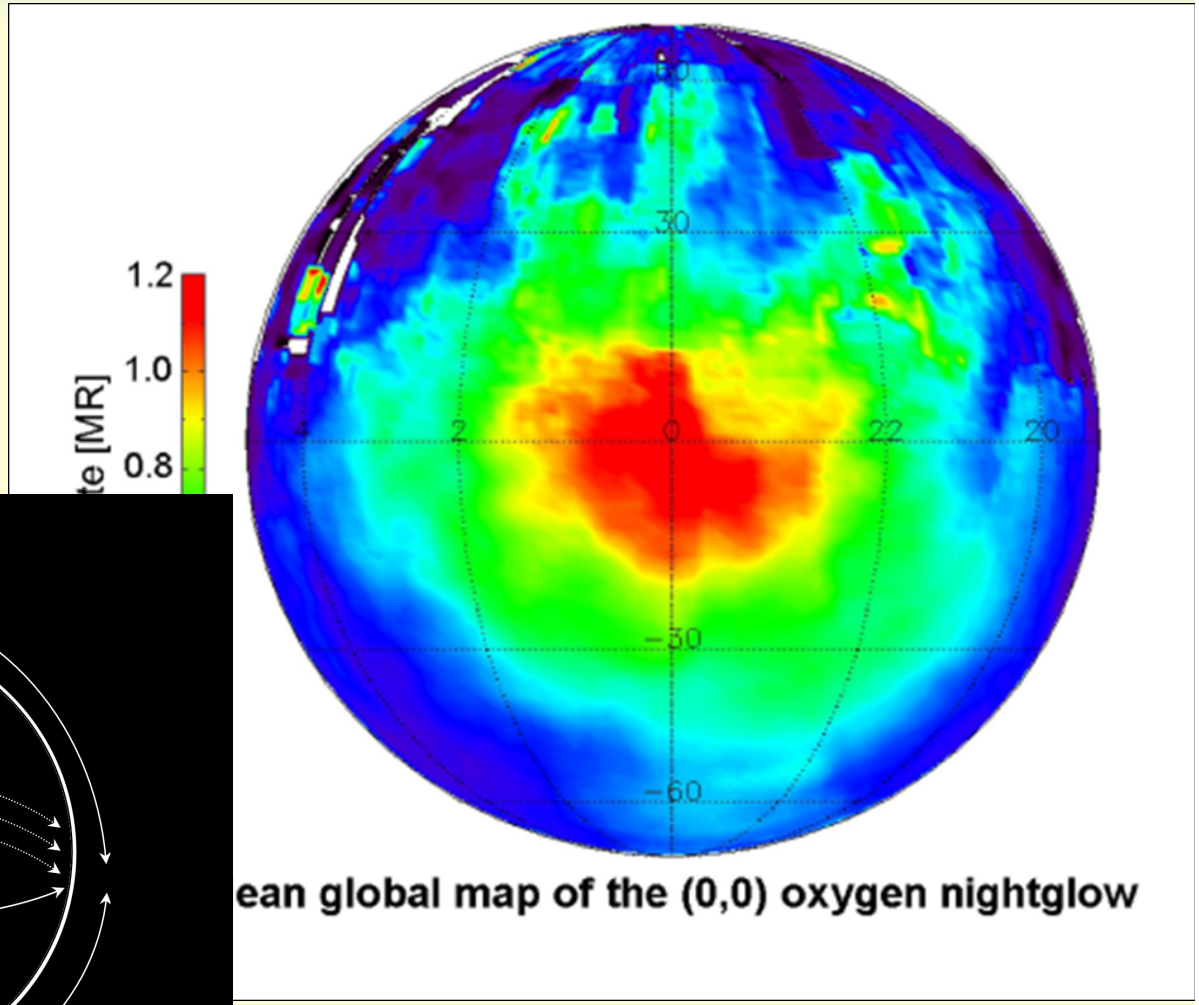
Venus Express shows episodic injection of SO_2 into mesosphere.

- Is this an connected with volcanic activity (like Pinatubo)?
- Or is it simply atmospheric variability (like El Niño / La Niña)?

Upper Atmosphere Dynamics

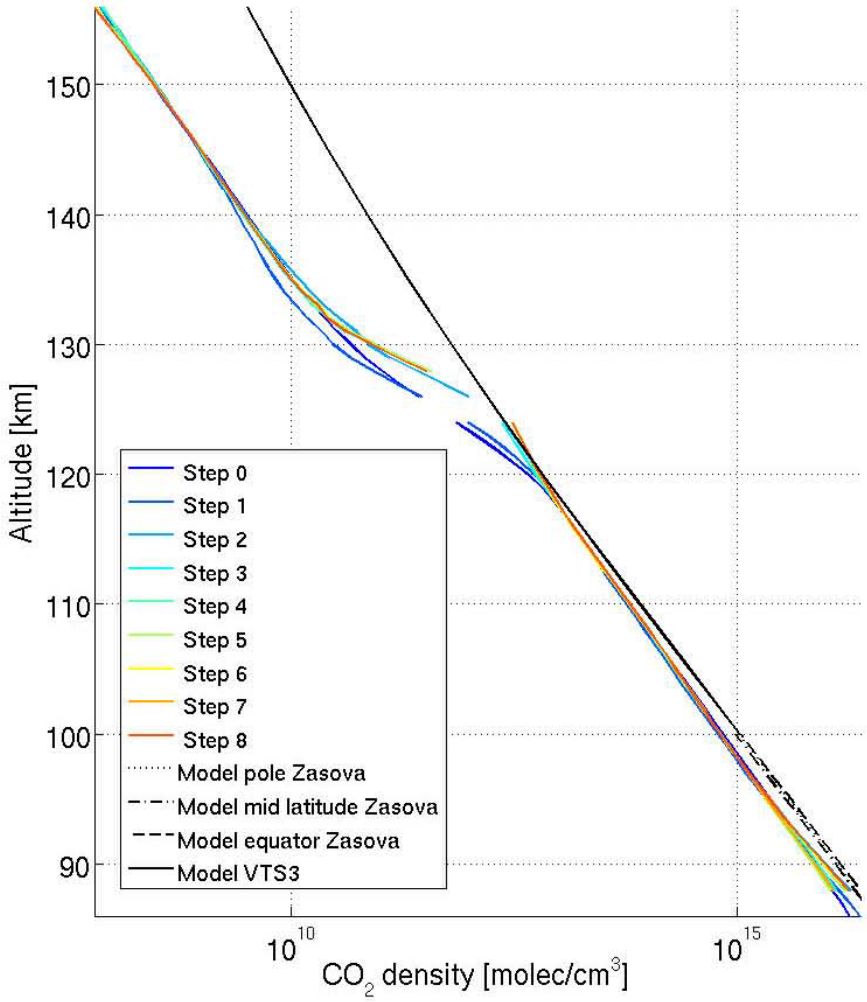
- Evidence of Solar to anti-solar circulation in the upper atmosphere by oxygen glow at and around the anti-solar point from recombination of oxygen atoms

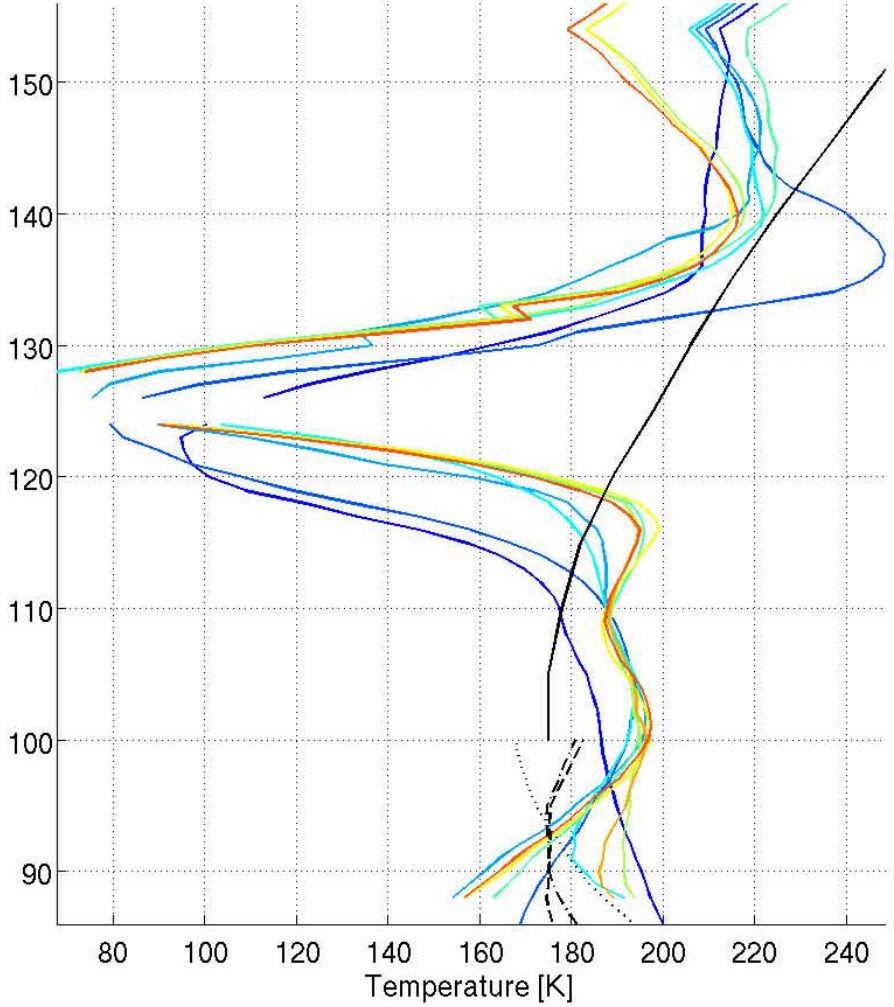




ean global map of the (0,0) oxygen nightglow

A very cold layer at 125km, from solar occultations

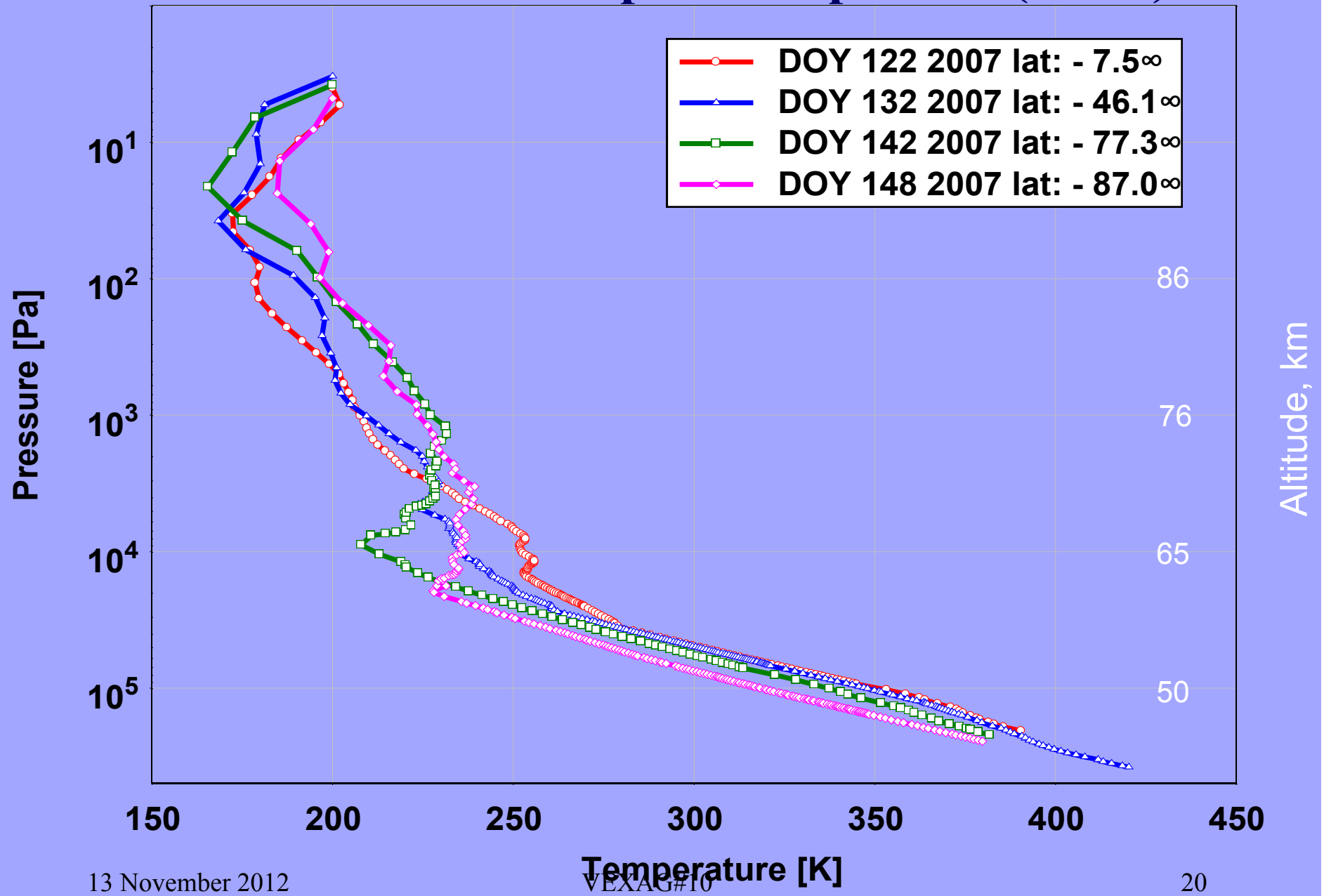




Mahieux 2012

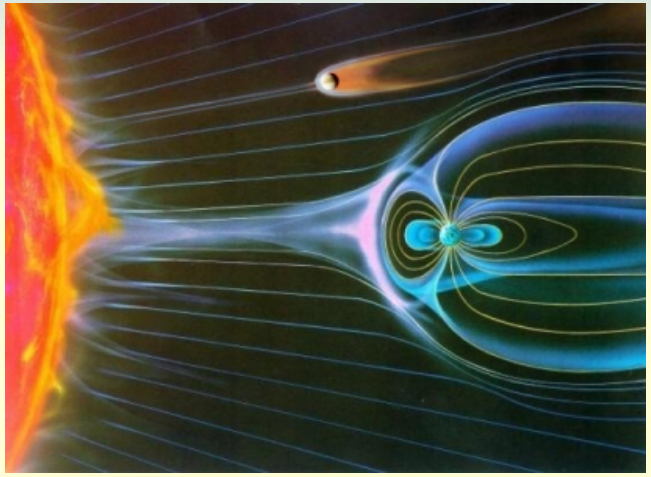
Mahieux, 2012

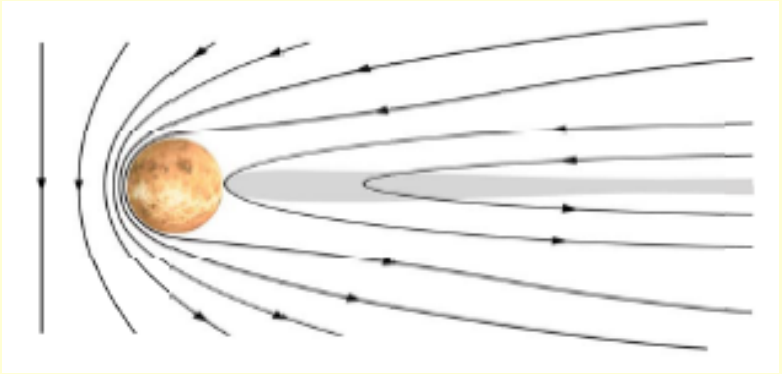
Radio-occultation temperature profiles (VeRa)

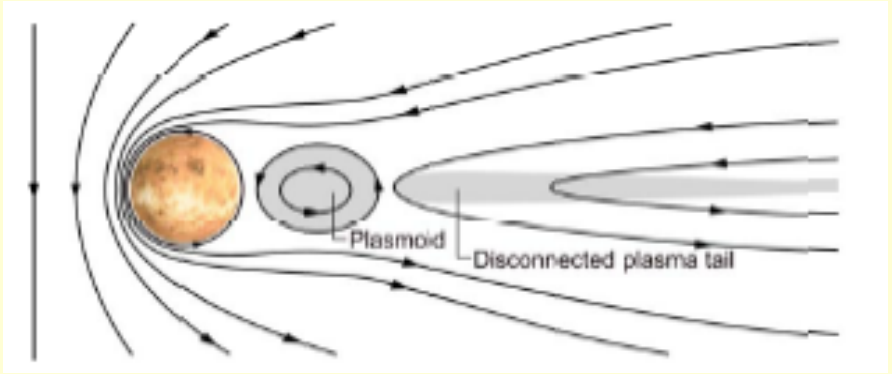


Recent MAG results

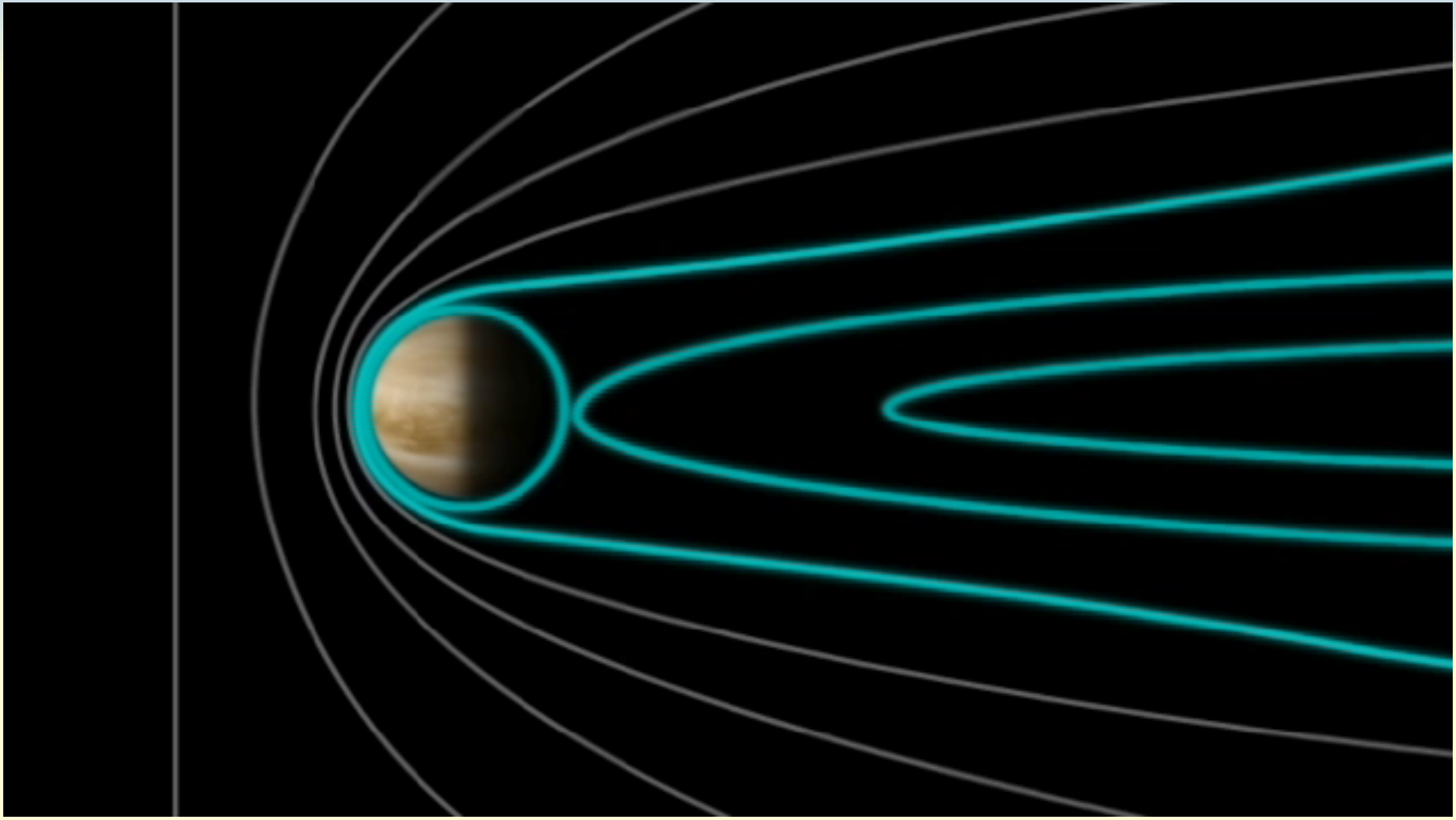
- Indications of an intrinsic dipolar field of 10 nT. (Luhmann, DPS 2012)
- Detection of magnetic reconnection in the magnetotail. Observed at several occasions.(Zhang, 2012)
- Demonstrates similarities with the Earth in spite of large differences in type and size of magnetosphere
- Provides a possibly important escape mechanism not yet well quantified





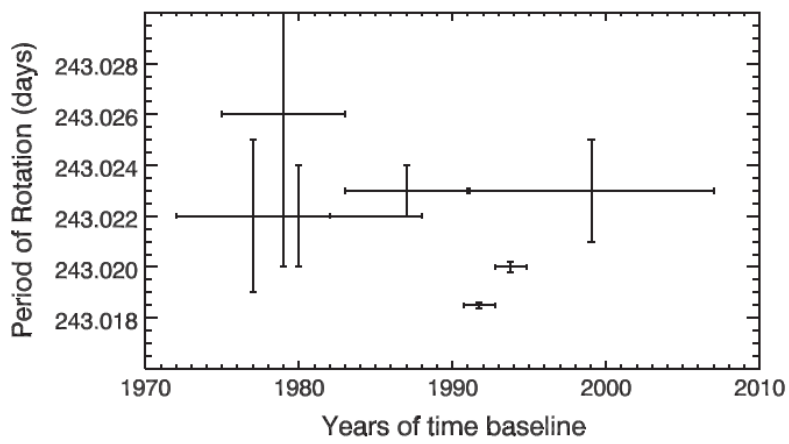


Zhang, 2012

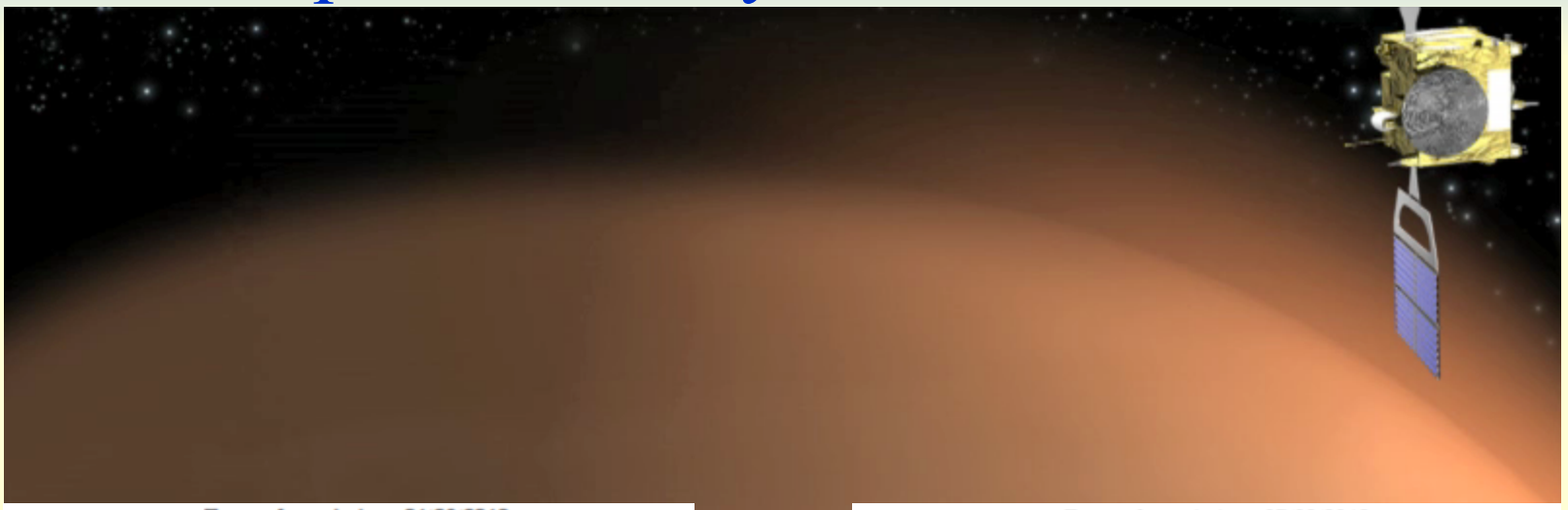


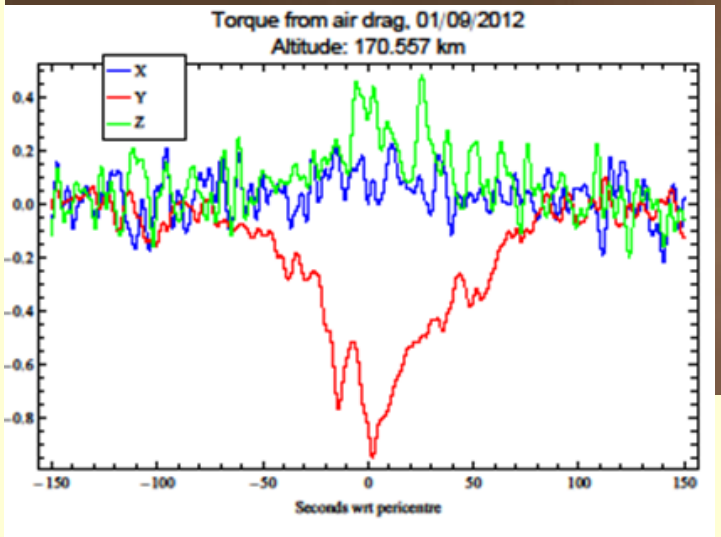
Venus rotation rate

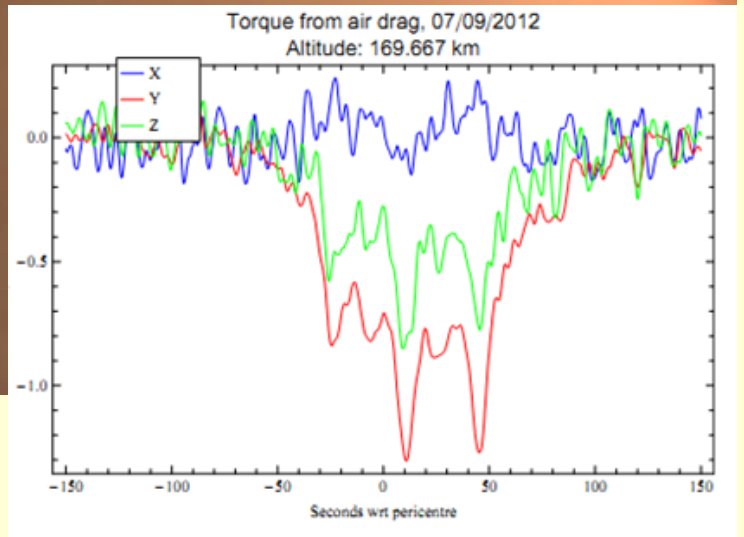
- Imaging by Virtis determines a surface shift since Magellan by 0.15 degrees in longitude, indicating an increase in the length of day (LOD).
- This corresponds to an average length of day of 243.023 ± 0.002 days
- The corresponding Magellan value is 243.0185 ± 0.0001 days
- Is the Magellan value an effect of a short term variation on the LOD, or is there a secular increase in the LOD?
- Momentum transfer
  solid planet ↔ atmospshere?
- Note the increase in superrotation since 2006.



Torque technique for measuring atmospheric density

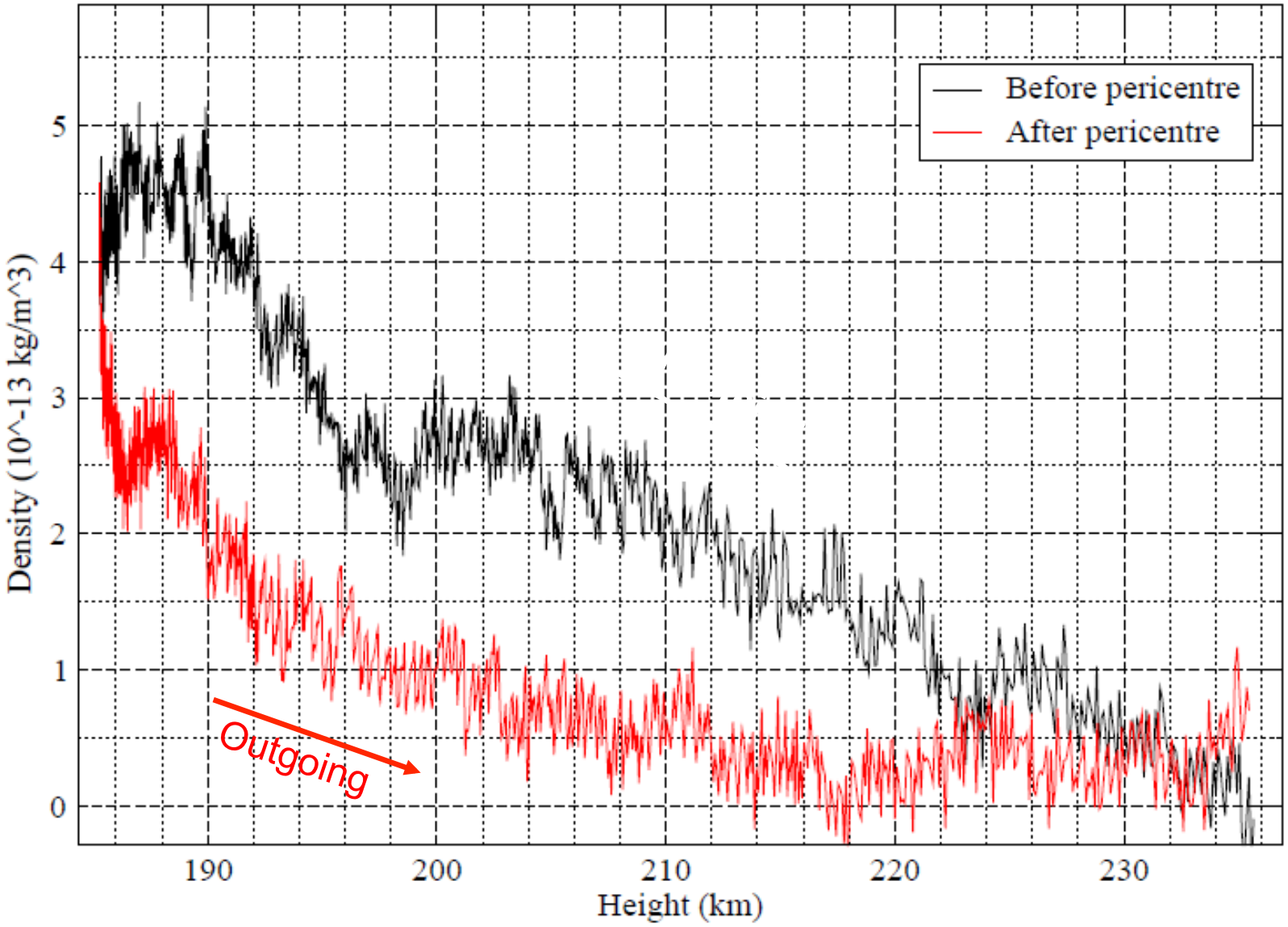




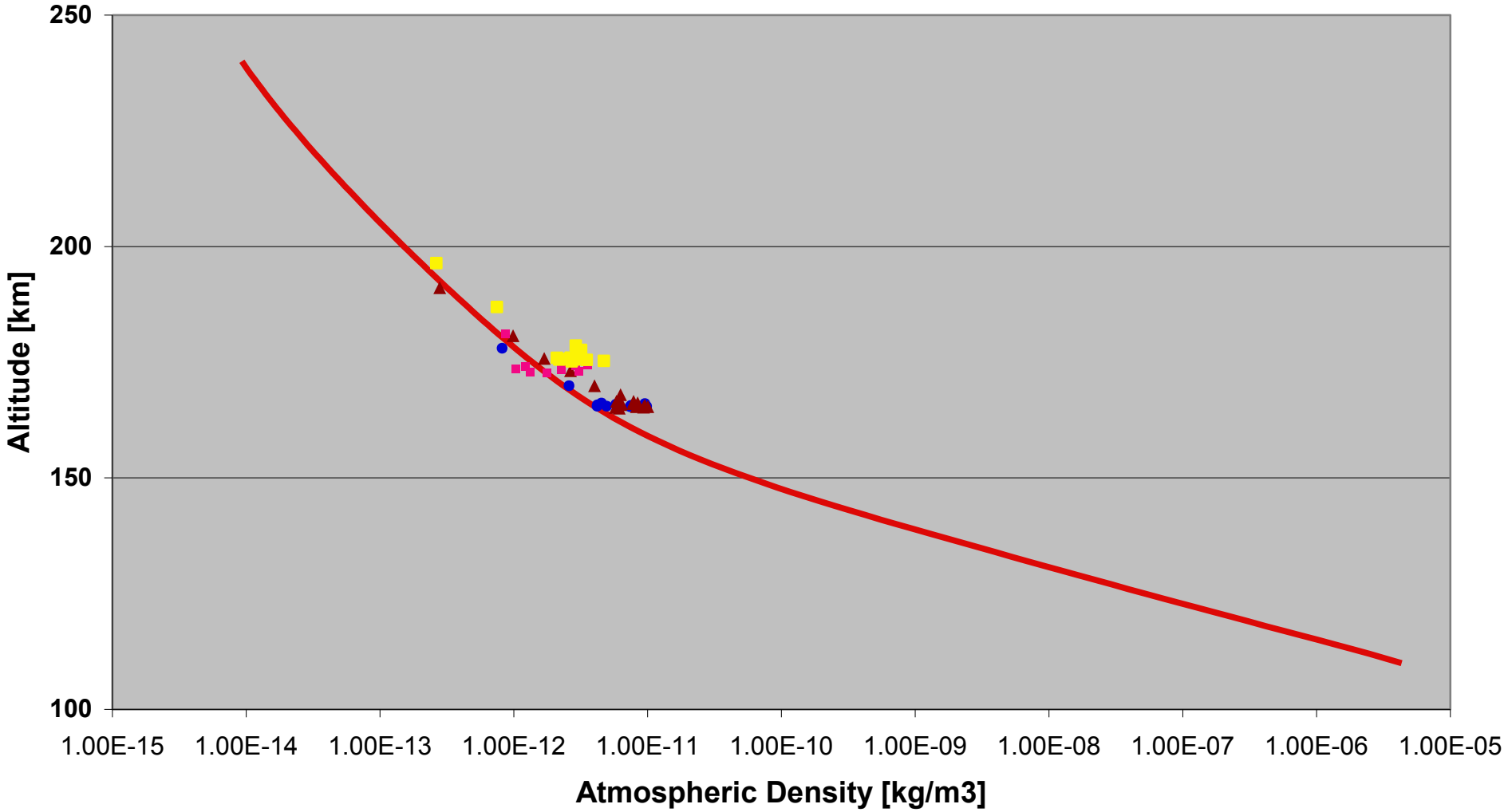


Venus Atmosphere Density

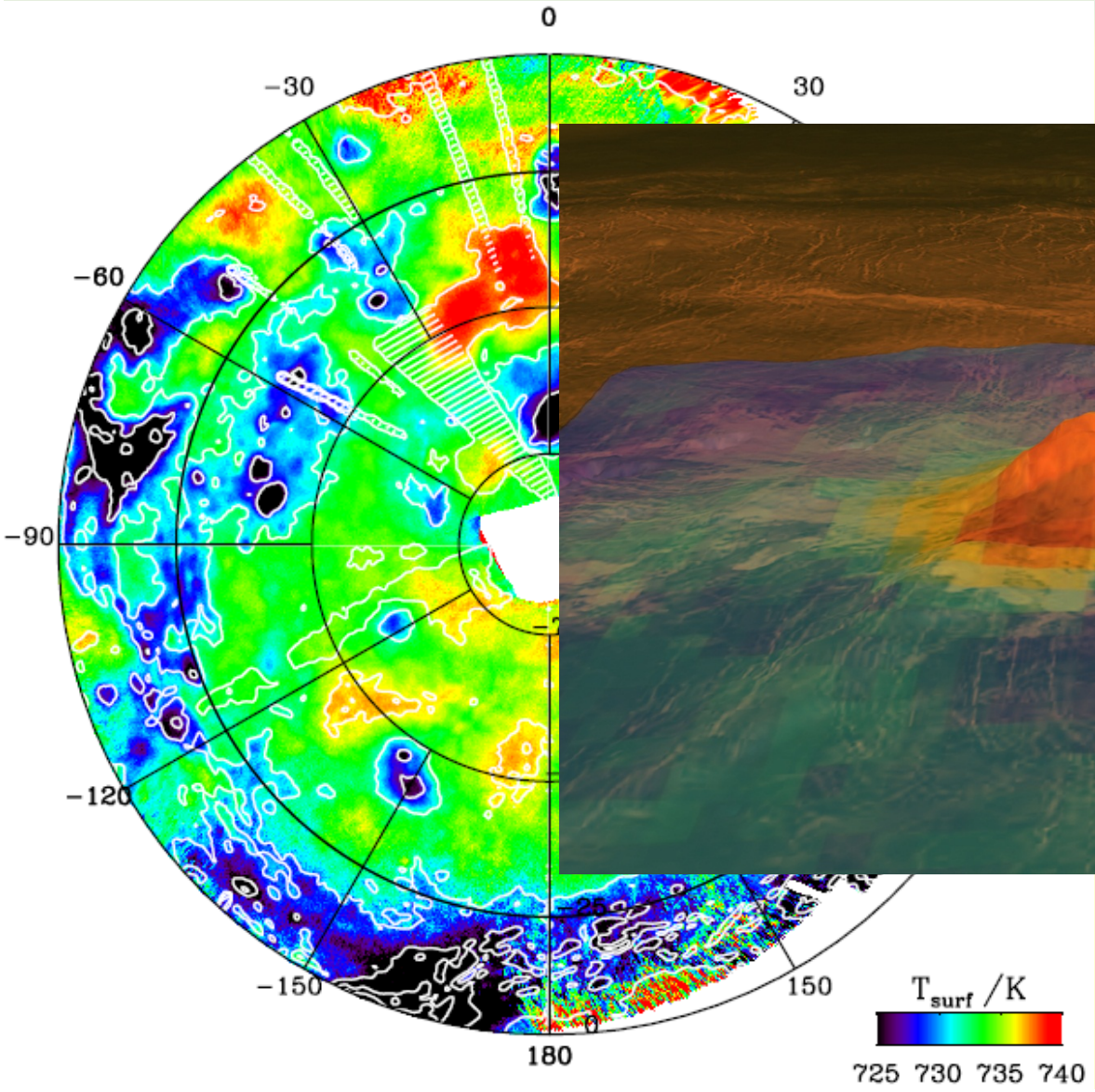
SA Tilt on 25/02/2010

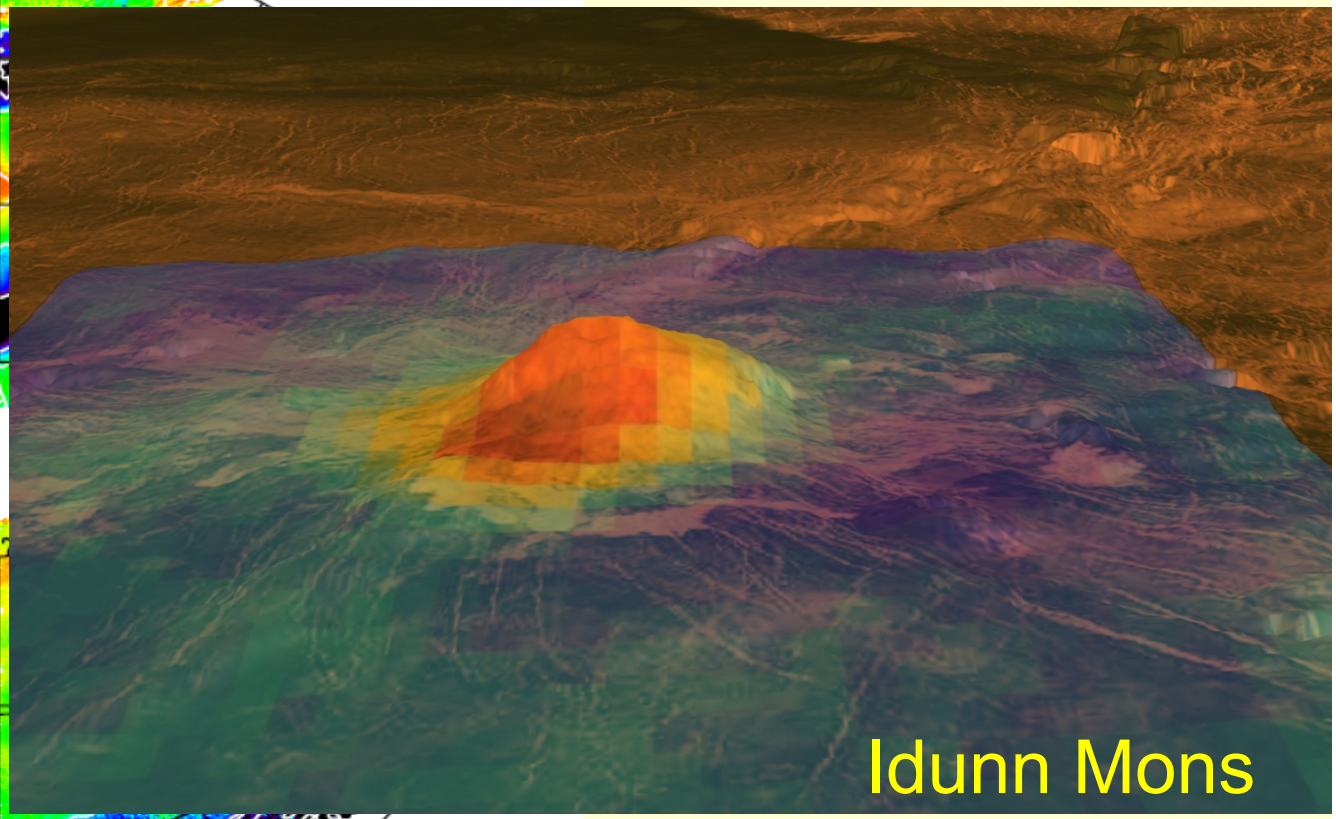


Polar density, normalised to 90 deg SZA



Surface emissivity and recent volcanism





Mueller et al., Smrekar et al.

Some additional major results

- First global scale surface temperature map
- Thermal profiles throughout the atmosphere from SpicaV/ SOIR, VeRa and Virtis
- Profiles of chemical composition CO, SO2, OCS, D/H
- Discovery of new atmospheric species: Ozone, Hydroxyl
- Electron density profiles in the ionosphere, meteor layer
- First detection of ionospheric photoelectrons
- Lightning inferred from whistler waves
- Detection of upstream plasma waves

Venus Express keeps its promises

✓ *First global monitoring of the composition of the lower atmosphere in the near IR transparency "windows"*

✓ *First coherent study of the atmospheric temperature and dynamics at different levels*

✓ *First measurements of global surface temperature distribution from orbit*

✓ *First study of the middle and upper atmosphere dynamics from O_2, O, and NO emissions*

✓ *First measurements of the non-thermal atmospheric escape*

✓ *First coherent observations of Venus in the spectral range from UV to thermal infrared*

✓ *First application of the solar/stellar occultation technique at Venus*

✓ *First use of 3D ion mass analyzer, high energy resolution electron spectrometer, and energetic neutral atom imager*

Conclusions on recent results

- Venus is much more dynamic than perhaps thought until now, evidence is found for significant variability on long and short time scales for,
  - Rotation rate
  - Superrotation
  - Atmospheric structure
  - Atmospheric waves
- A cold layer at the terminator at 125-130 km has been found, with temperatures near or even below the freezing point of CO2
- Magnetic field measurements show that magnetic reconnection occurs in the magnetotail in a similar way as on Earth
- Future operations will focus on further investigation of discovered and yet unexplained features

Mission Objectives

- Science Themes — my rating
  - Atmospheric Dynamics
    - Global Dynamics mechanisms, Super-rotation, Double Polar Vortex — +++
  - Atmospheric Structure
    - Density and Temperature in three dimensions — ++
  - Atmospheric Composition and Chemistry
    - Processes and species in the different regions — ++
  - Cloud Layer and Hazes
    - Behaviour and characteristics, UV absorber — +(+)
  - Radiative Balance and Greenhouse effect
    - Global thermal balance, Greenhouse in past, present and future — +
  - Surface Properties and Geology
    - Volcanic and seismic activity, highly radar reflective areas — +
  - Plasma Environment and Escape processes
    - Evolution of the atmosphere, water, escape history — ++

Conclusions over the mission

- What have we learned so far?
  - Enhanced knowledge in all fields of the defined Science Themes
  - Particular progress in atmospheric dynamics and thermal structure
  - Improved knowledge in cloud structure and chemistry
  - Surface: active on geologic timescales, possibly even today
  - Escape rates, processes and plasma environment
- In spite of the apparent large differences in the conditions, the processes on Venus shows many similarities to those on the Earth
- It is essential to understand Venus in order to understand how the terrestrial planets work, including the Earth.
- But we will need more missions, in particularly to study the lower atmosphere, surface geology and to better understand the planetary evolution (isotopic ratio and noble gasses…) and the radiation balance. - Who will be next?

Need More Missions

Parallax of Venus at transit 2012