Lightning on Venus

Searching for optical evidence with VIRTIS on Venus Express

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Lightning in the Solar System

Lightning detected on Earth, Jupiter, Saturn, Uranus, Neptune

Practically, observed on most planetary atmospheres…

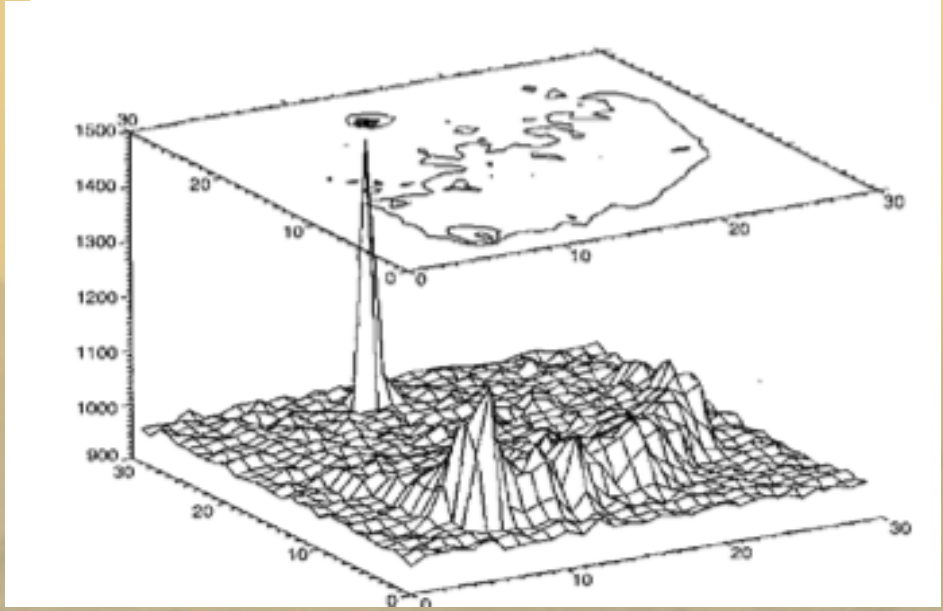
So we should expect it to occur on Venus, right?

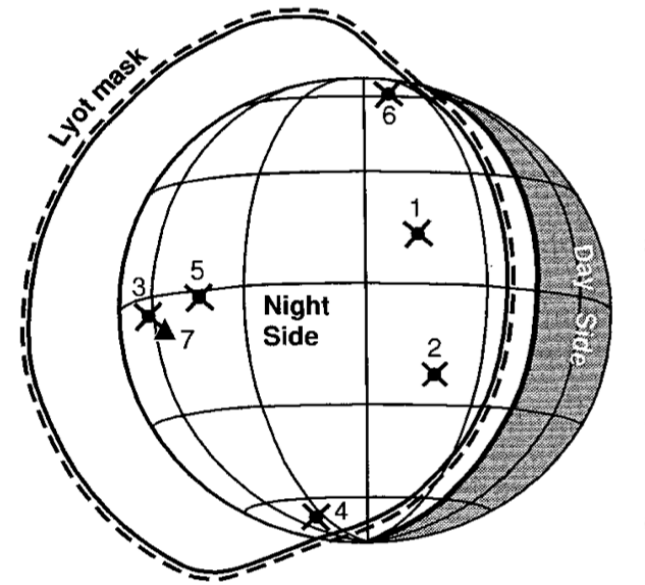
Lightning on Venus
Electromagnetic Evidence

- Venera 11-14 (10-80 kHz),
  generated by the craft?
- PVO (0.1-30 kHz) @ 100 Hz (whistler modes?),
  correlation with topography?
- Galileo (0.1-5.7 MHz),
  too remote observation?
- *Cassini flybys (0.125-16 MHz): no detection*
  but detection at Earth
- VEx magnetometer: '*clear*' evidence, terrestrial frequency, high dayside activity, whistler modes,…
  still controversial though...

Lightning on Venus
Optical Evidence?

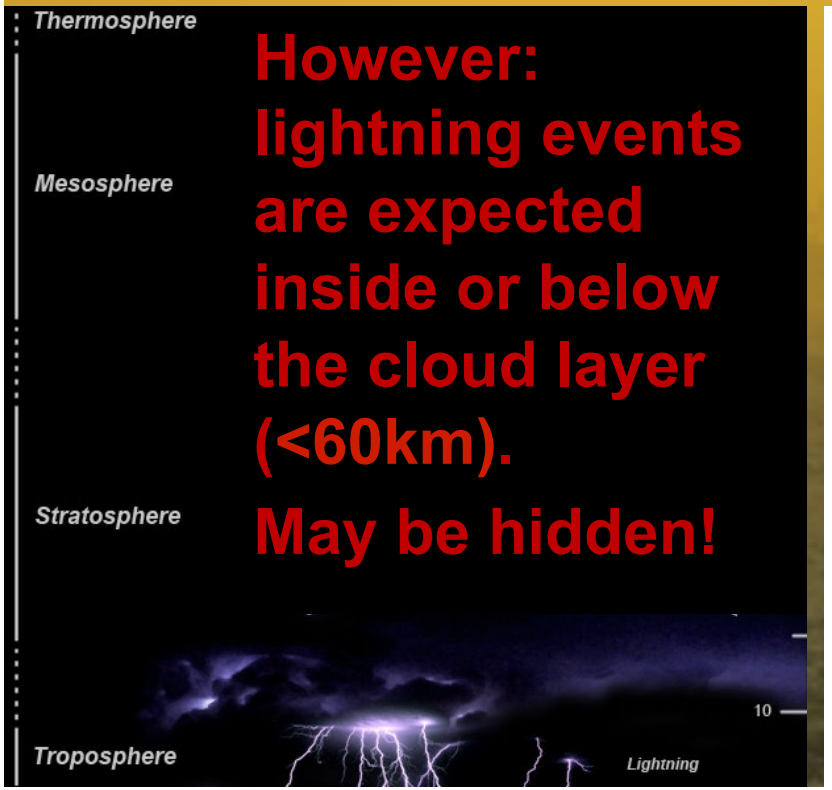
- Venera 9-10
- PVO Star Tracker broad band photometry
- Ground based observations: Hansell et al. 1995
- A. Garcia Muñoz at Calar Alto & La Palma

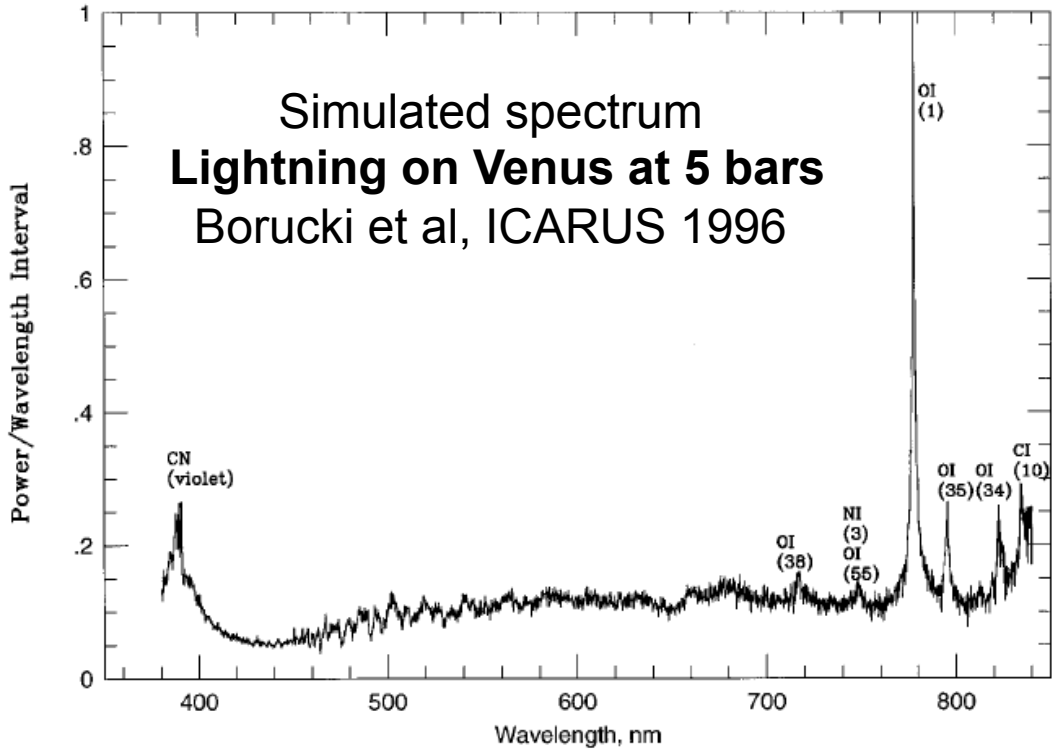




Lightning on Venus
What can we expect?

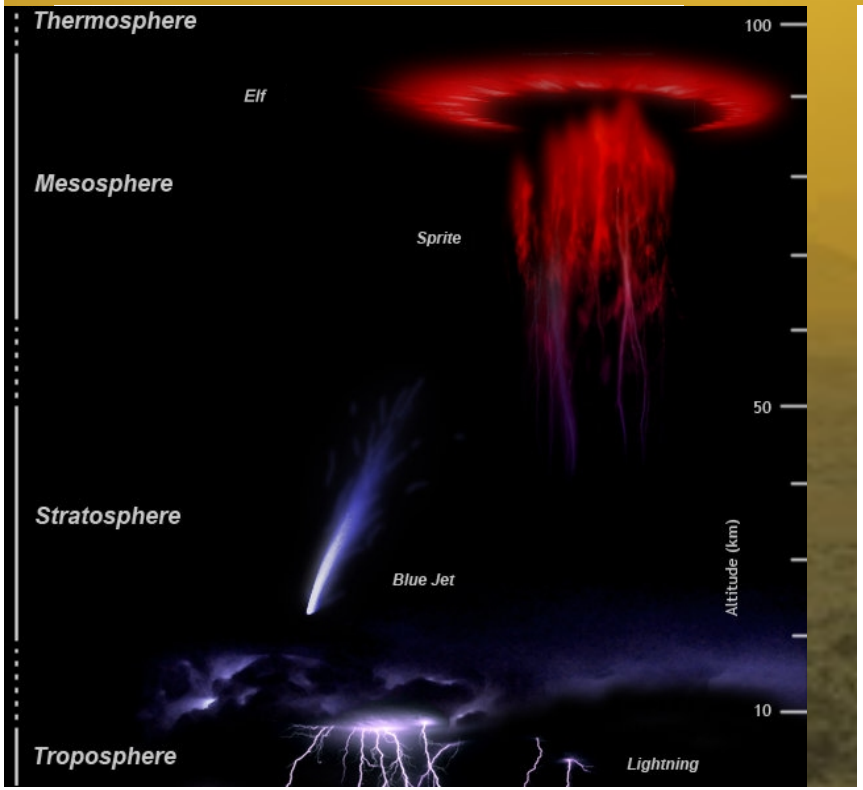
- **Lightnings on Earth have the strongest emission lines at 777.3nm and 844.6nm**, corresponding to atomic oxygen
- Laboratory measurements at higher pressures predict that the **dominant line at 777.3nm should be present on Venus**

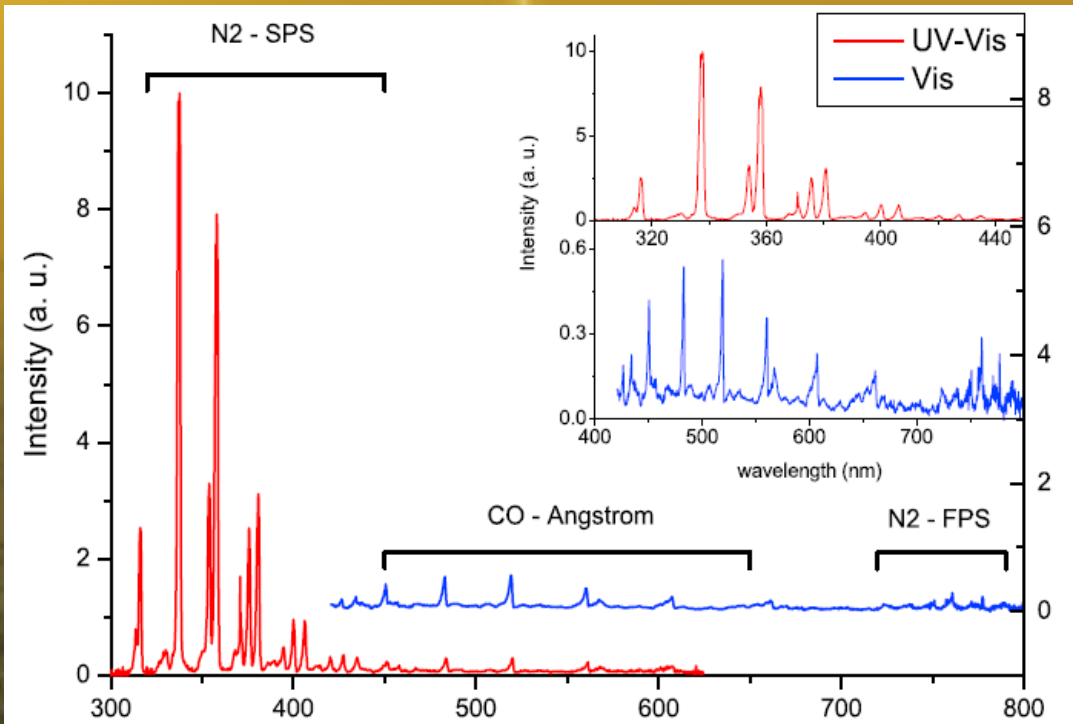




Lightning on Venus
What can we expect?

- **Transient Luminous Events** (TLEs): **Sprites, Halos, Elves**, are likely to appear **at higher altitudes** (50~90km)
- **Dominant emission around 280-420nm, peak at 337nm,** (2nd positive band of N_2) No presence of oxygen emissions

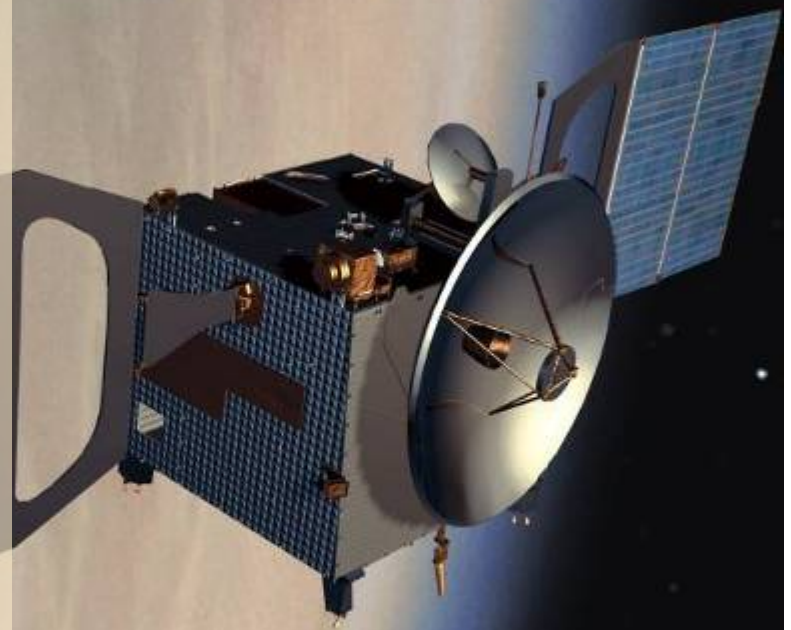




Dubrovin et al, JGR 2010

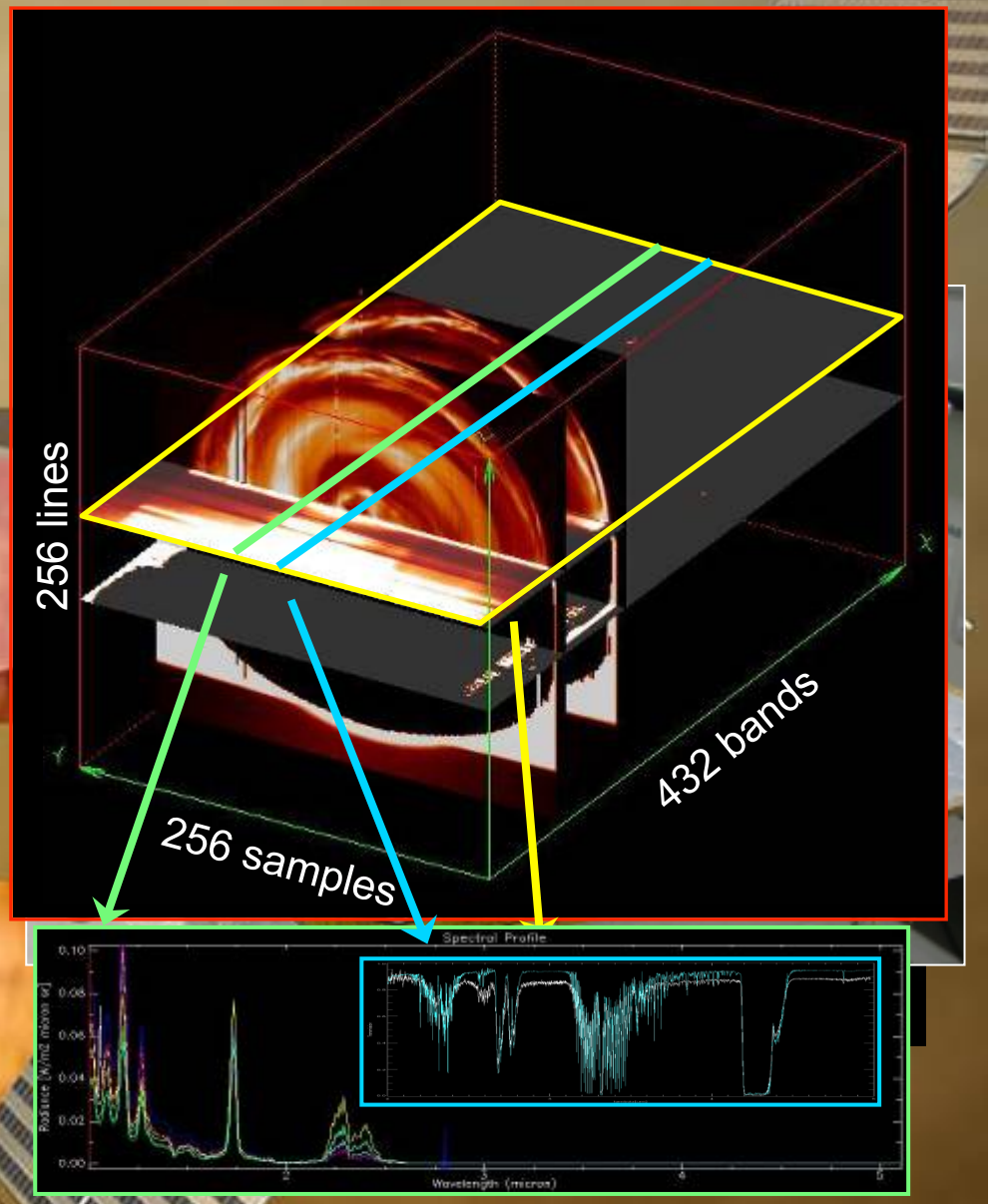
Venus Express Contribution

- **Huge data set**
  (7 years of observations)
- **Full atmosphere coverage**
  (all latitudes, longitudes, local times, …)
- **Multi-spectral information**
  (UV, Visible and Near Infrared)
- **Images covering wide areas**
  (Large FOV: 3.3 VIRTIS, 20 deg VMC)
- **”Enough” sensitivity**
  (theoretically able to capture flashes)



VIRTIS - Visible Infra-Red Thermal Imaging Spectrometer

- **Instrument with two channels:**
  - VIRTIS-M (Mapping):
    - Visible 0.25-1μm
    - Infrared 1-5μm
    - 256 x 432 bands (δλ 1~10nm)
  - VIRTIS-H (High Resolution):
    - Infrared 2-5μm
    - 3452 bands (δλ ~1nm @ 3μm)
- **3-Dimensional data cubes**
  - 2 spatial dimensions (VIRTIS-M)
  - 1 spectral dimension
- **Scientific Objectives**
  - Global study of the atmosphere
  - Thermal mapping of the surface
  - Cloud Dynamics, Composition,...
  - But not designed for lightnings ☹

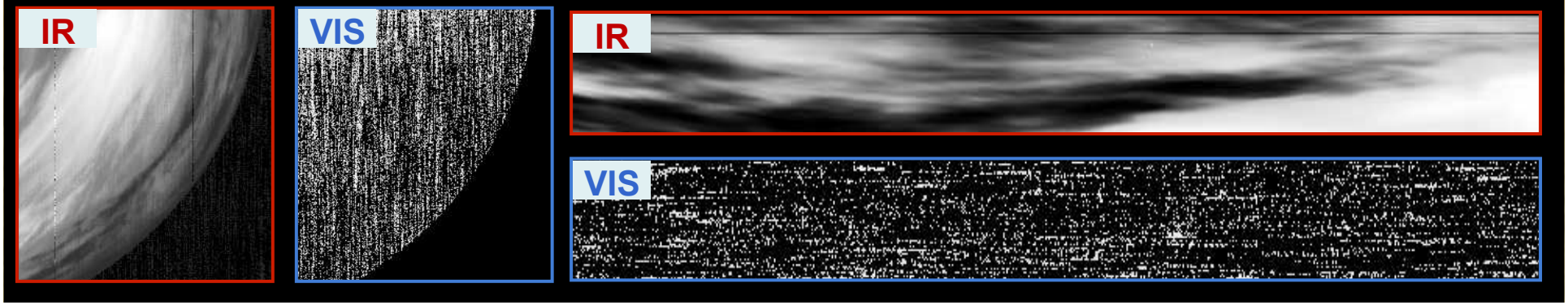


Lightning & Transient Events on VIRTIS data

- Frame/Line scanner: **not designed for lightning search**.
- Transient events cause **signal variation in a single frame/line**
- Effects can be filtered out by calibration, **need to analyze raw data**

- Both **Infrared and Visible data** with same geometry
- **Visible signal from nigthside atmosphere is almost negligible**

- We then use **Visible Nightside Long Exposure Nadir Images**



Analysis of the VIRTIS Archive
Visible Images in the Nightside

Algorithm to search for signal:

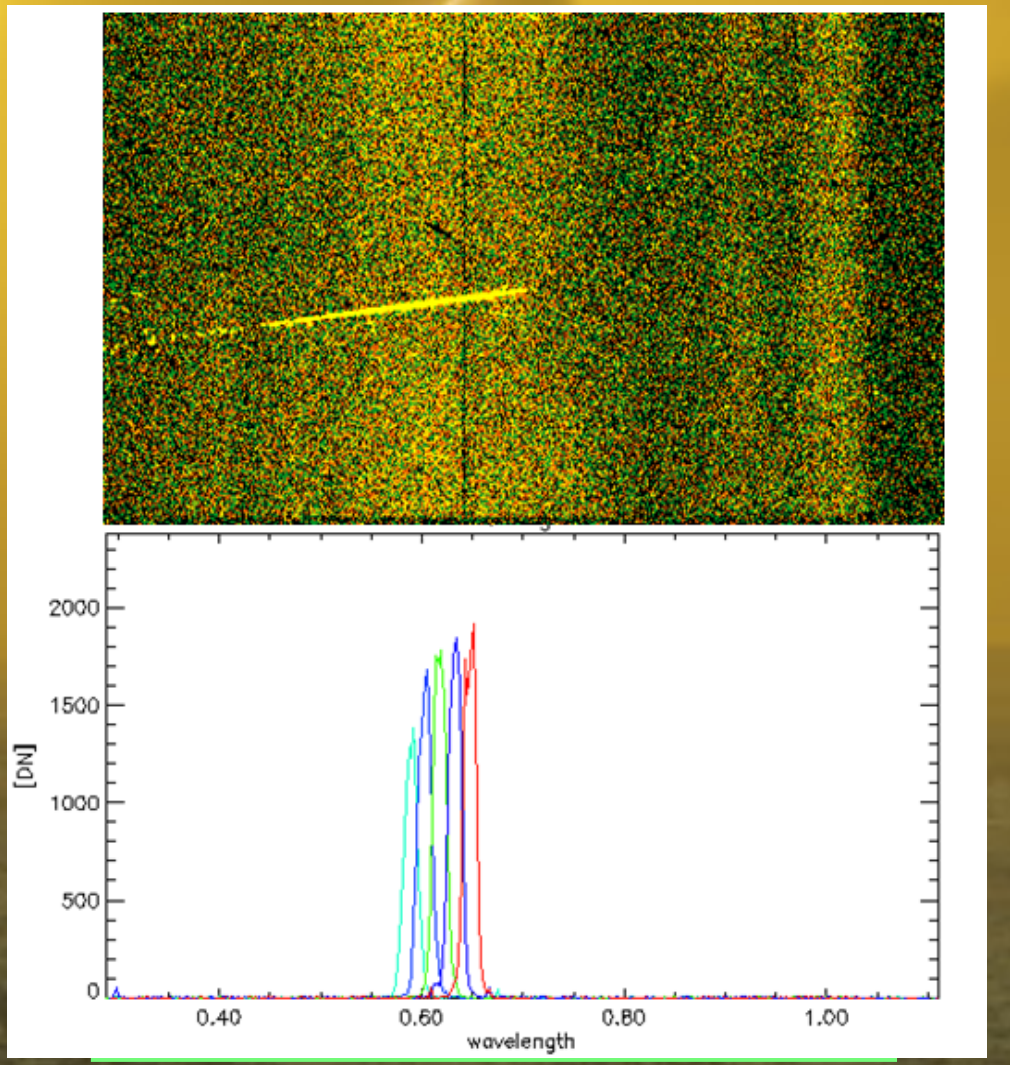
- Of **"a few" digital counts**
- In **"a few" bands**
- Of **"a few" pixels**
- In a **single line/frame**

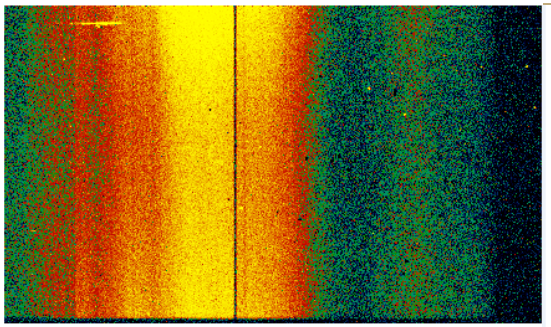
No assumption on emission bands.

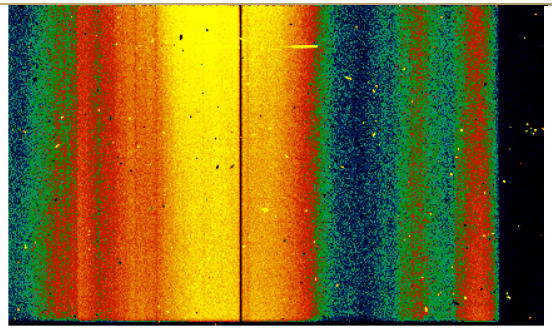
All wavelengths are considered.

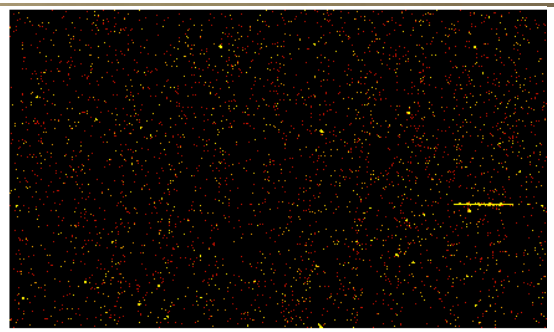
We can detect transient events!

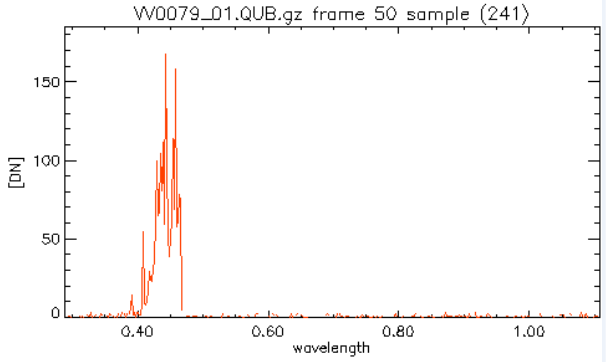
But we also detect all the spikes!

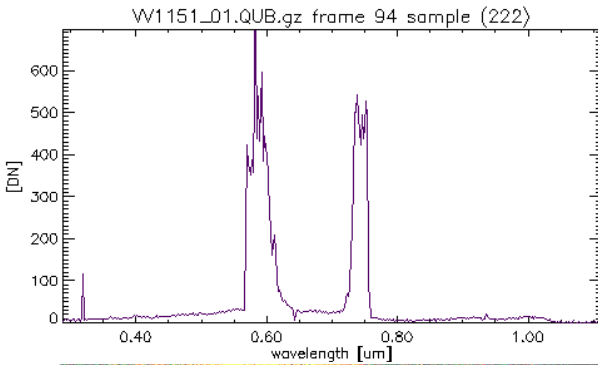


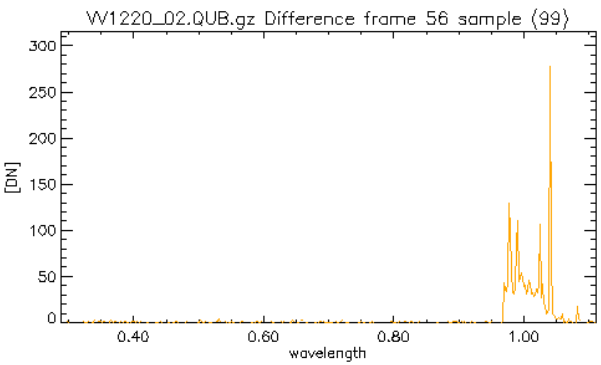


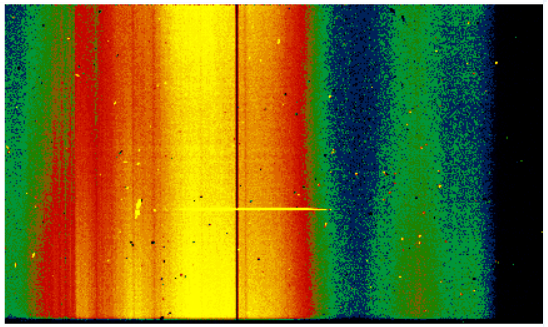


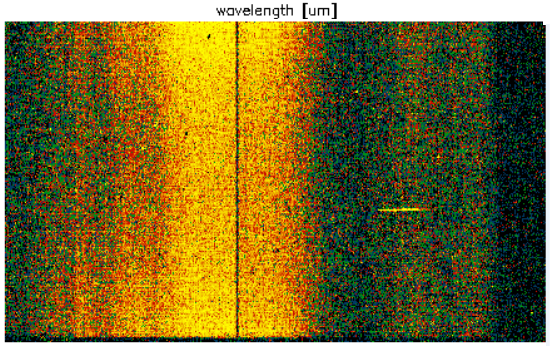


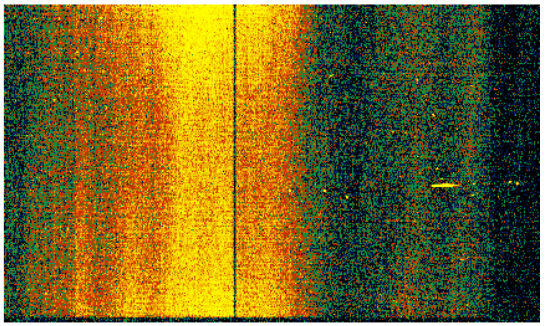

W0079_01.QUB.gz frame 50 sample (241)
[DN]
wavelength

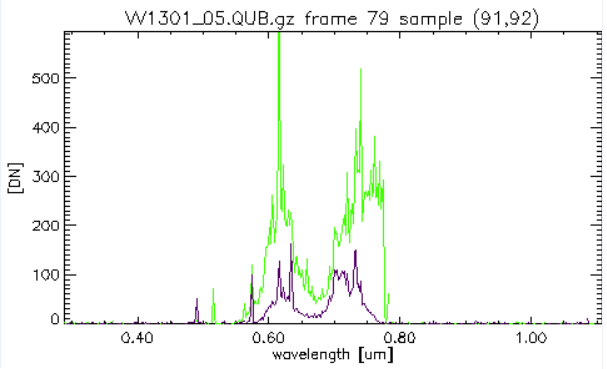

W1151_01.QUB.gz frame 94 sample (222)
[DN]
wavelength [um]

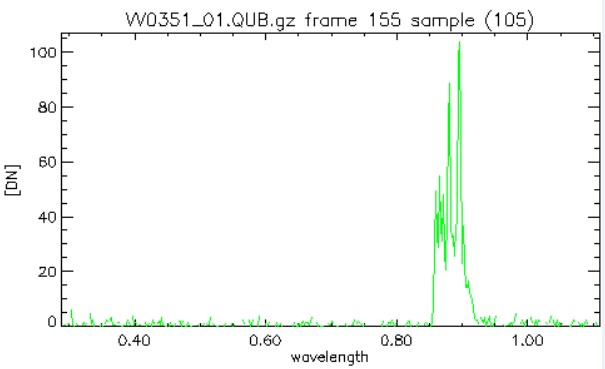

W1220_02.QUB.gz Difference frame 56 sample (99)
[DN]
wavelength

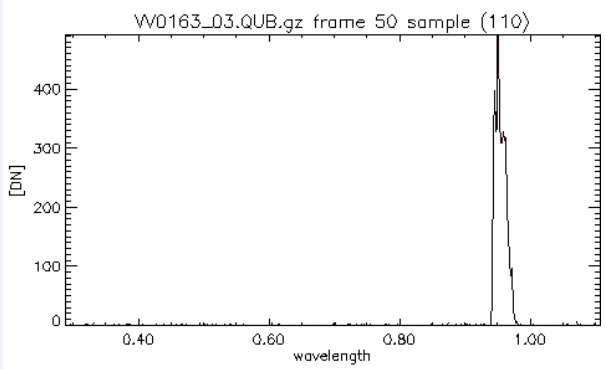







W1301_05.QUB.gz frame 79 sample (91,92)
[DN]
wavelength [um]


W0351_01.QUB.gz frame 155 sample (105)
[DN]
wavelength

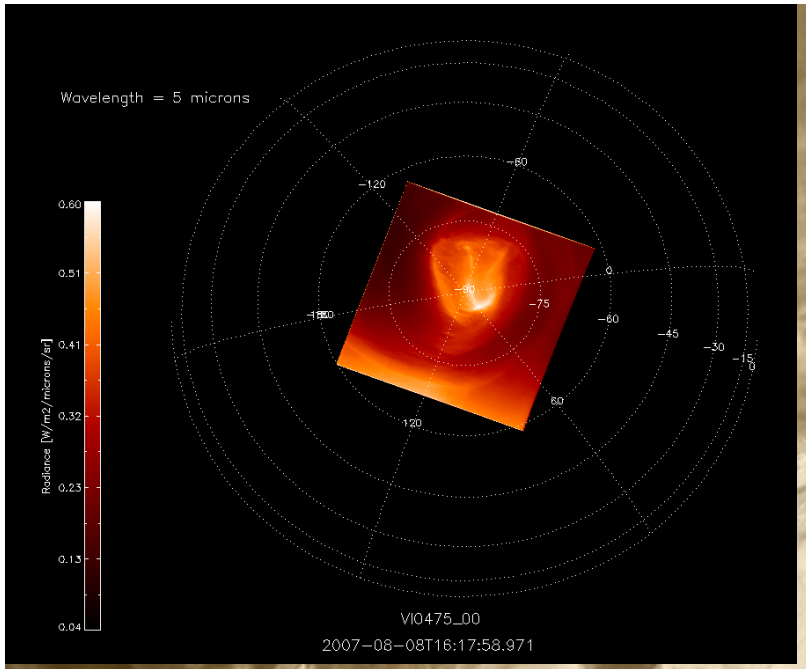

W0163_03.QUB.gz frame 50 sample (110)
[DN]
wavelength

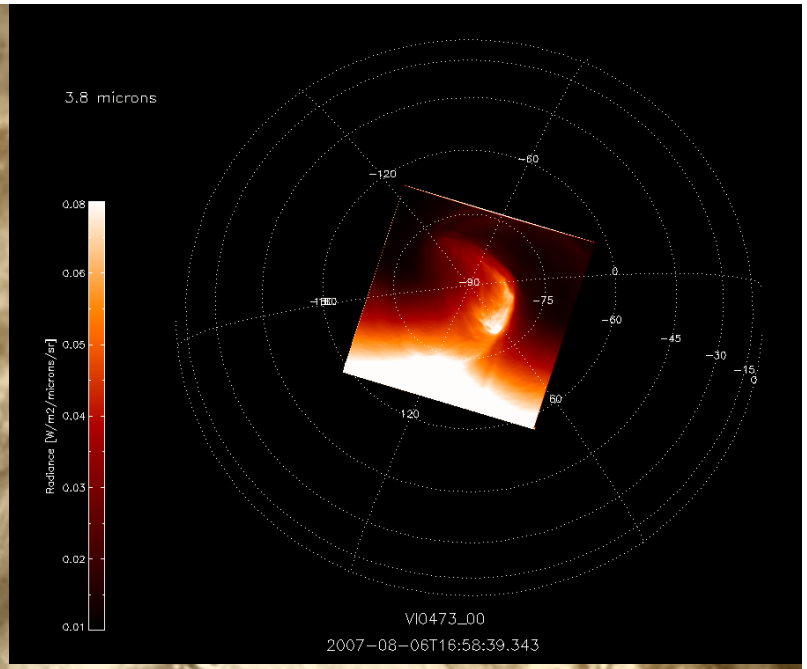
ID

Future Work

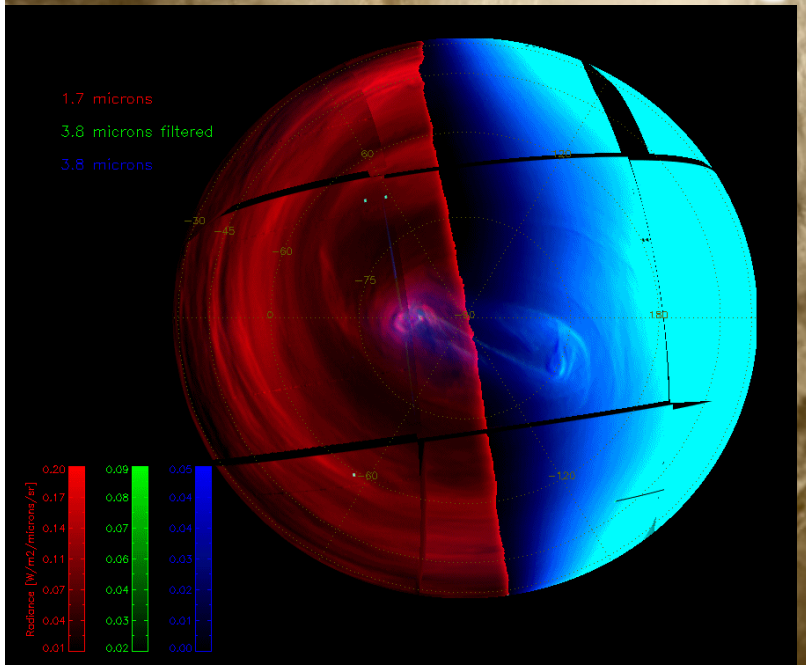
- Optimize search algorithm / parameters
- Image pattern recognition
- Analysis of limb data
- Analysis of Infrared data
- Statistics of detection / non-detection

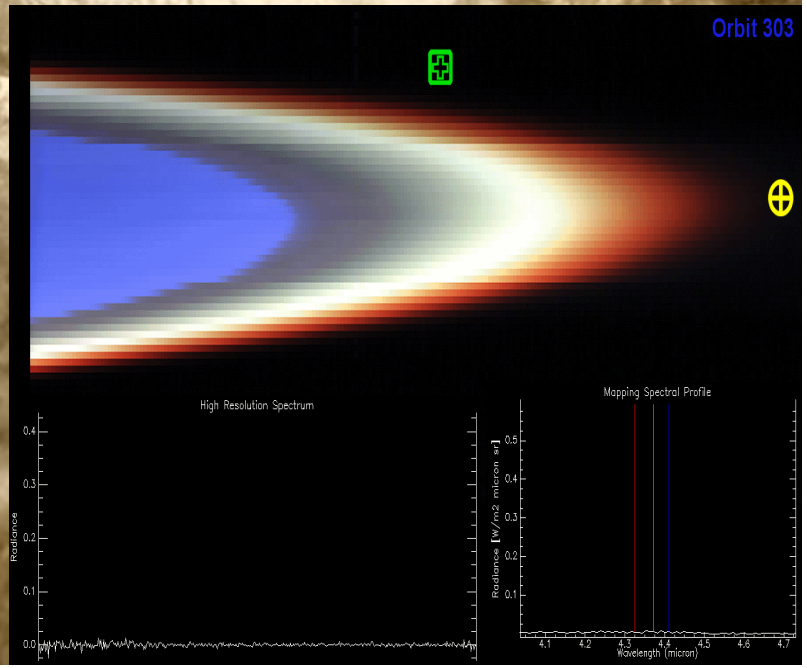
- Hopefully all this can be done with the help of a student trainee in 2014…


Wavelength = 5 microns
Radiance [W/m2/microns/sr]
VI0475_00
2007-08-08T16:17:58.971

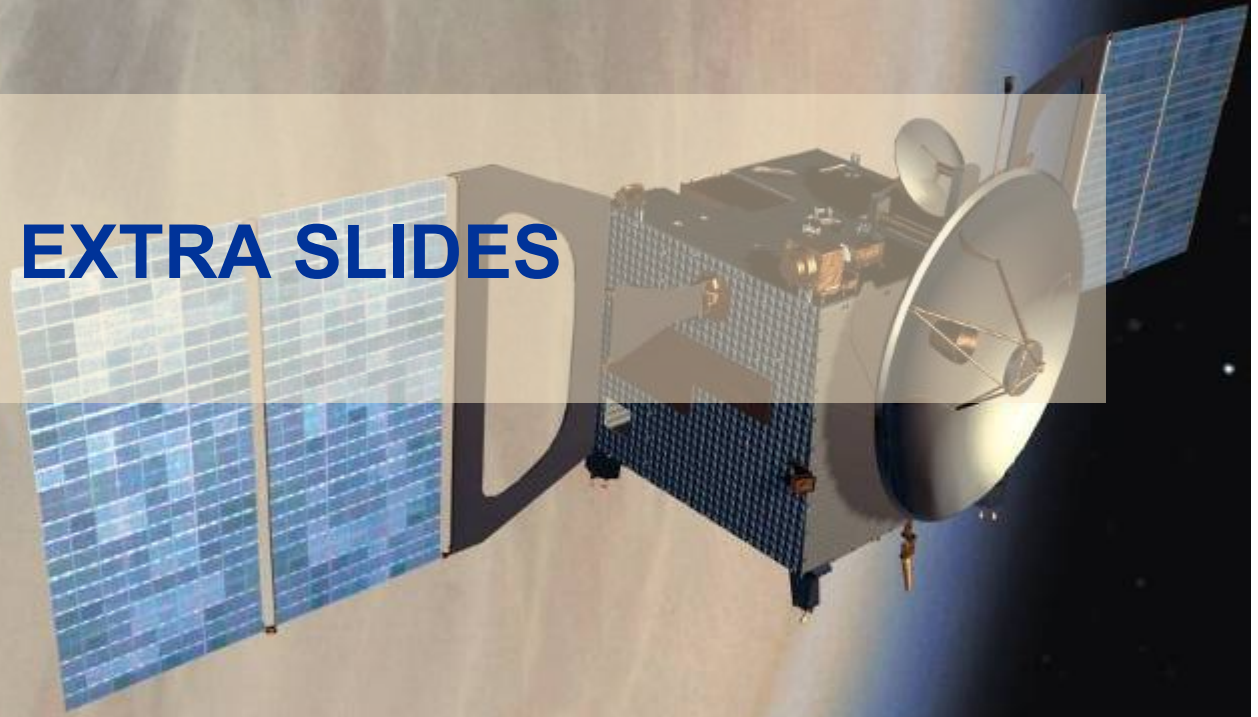

3.8 microns
Radiance [W/m2/microns/sr]
VI0473_00
2007-08-06T16:58:39.343

Questions?

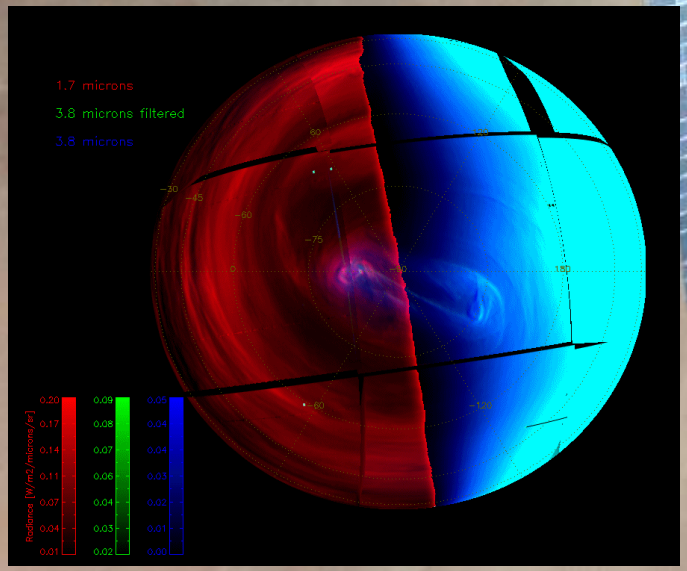

1.7 microns
3.8 microns filtered
3.8 microns
Radiance [W/m2/microns/sr]

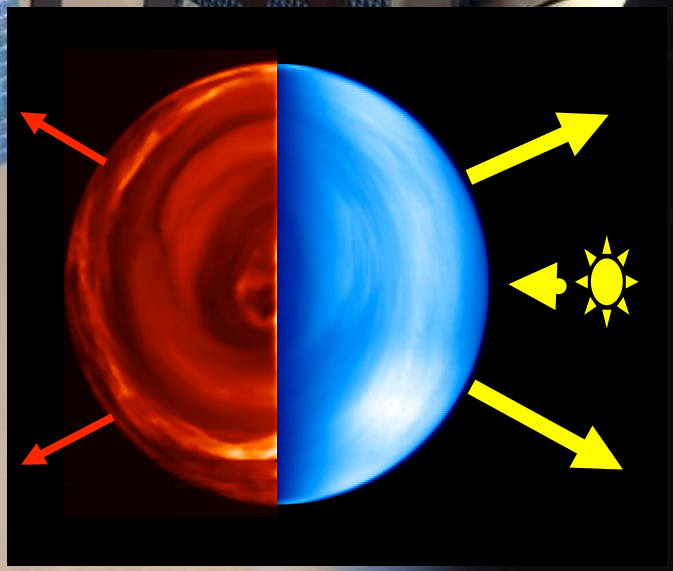

Orbit 303
High Resolution Spectrum
Radiance
Mapping Spectral Profile
Radiance [W/m2 micron sr]
Wavelength (micron)

EXTRA SLIDES

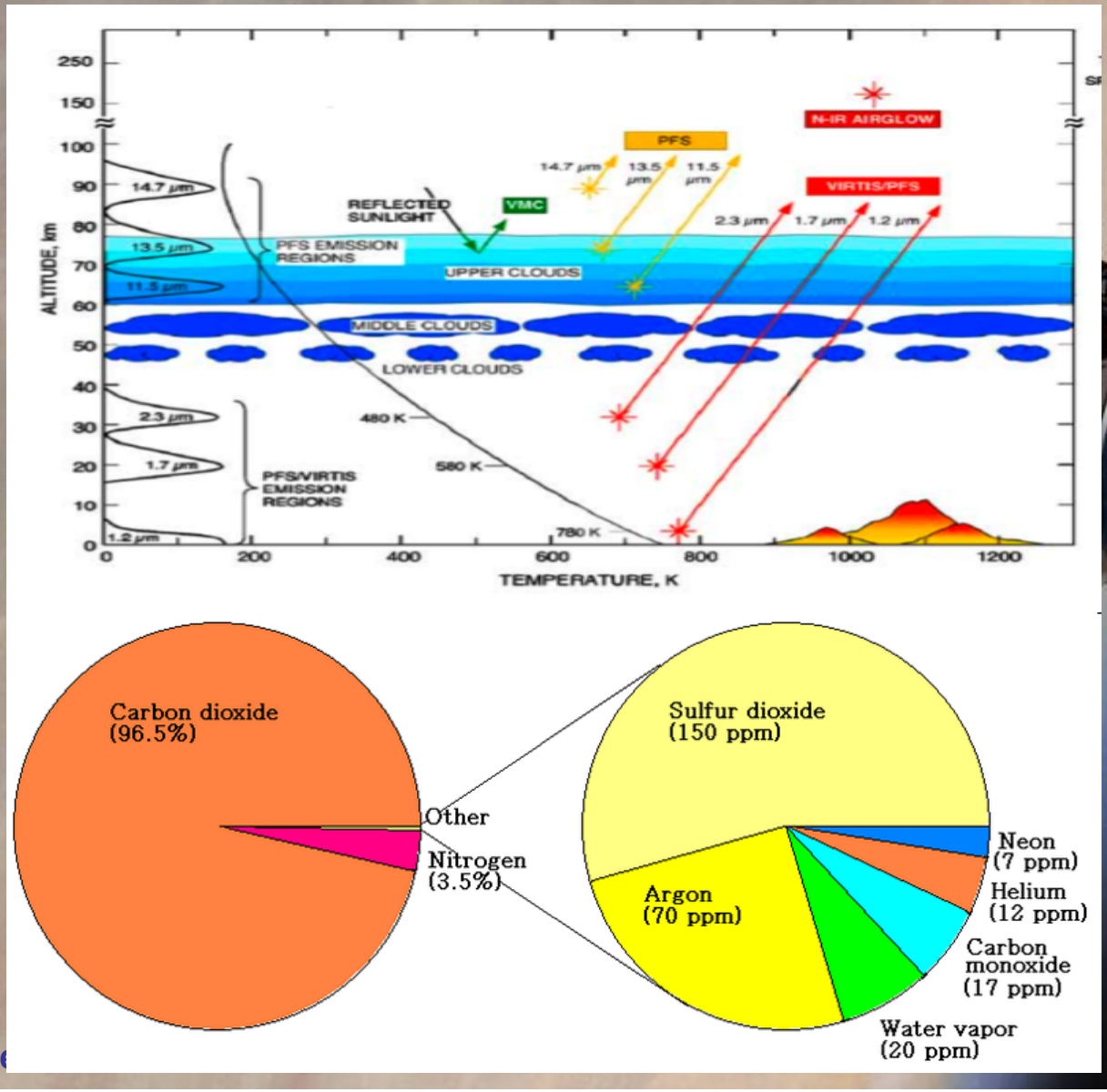


Venus



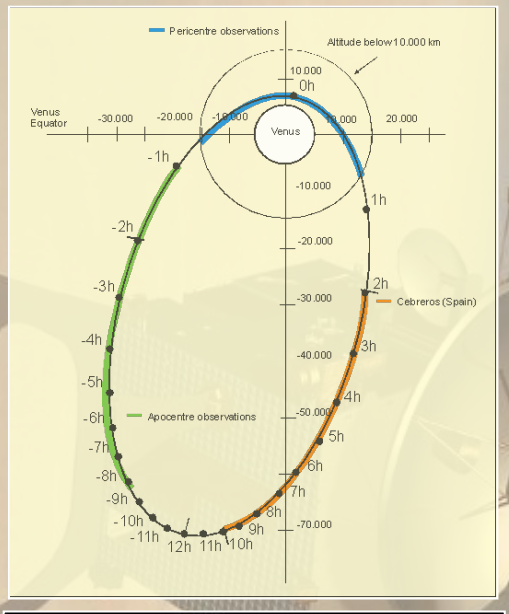


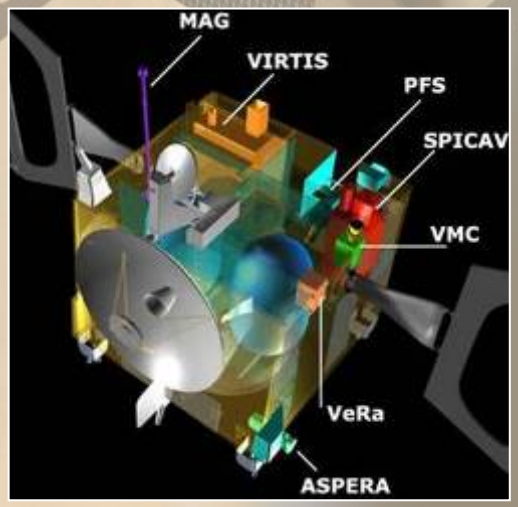
Venus Atmosphere

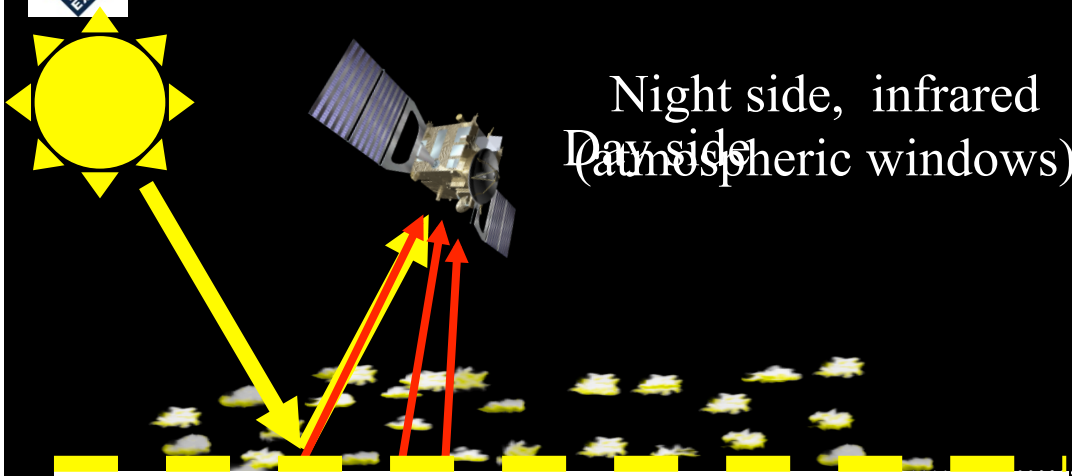


Venus Express

- Launch 09 November 2005 04:43 UTC
  - Venus Orbit Insertion 11th April 2006
- Polar elliptical orbit
  - Pericentre ~250 km
  - Apocentre ~66.000 km
  - Period ~24 hours
- Scientific Objectives
  - Atmosphere composition
  - Cloud morphology and structure
  - Atmosphere/surface interaction
  - Thermal mapping (and vulcanism)
- Instrumentation
  - VIRTIS (Imaging Spectrometer IR-VIS)
  - PFS (IR Spectrometer)
  - SPICAV (UV Spectrometer)
  - VMC (VIS-UV Camera)
  - ASPERA (Plasma science)
  - MAG (Magnetometer)







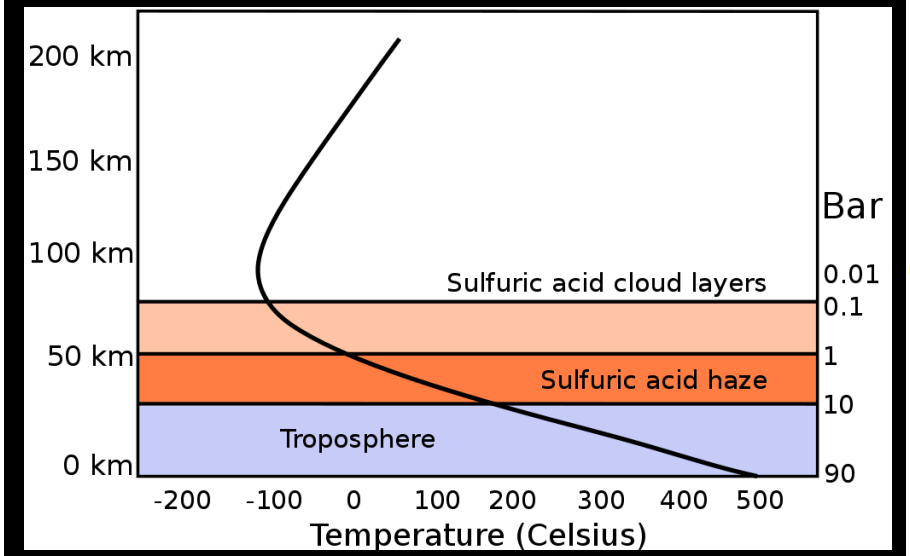
Clouds layers

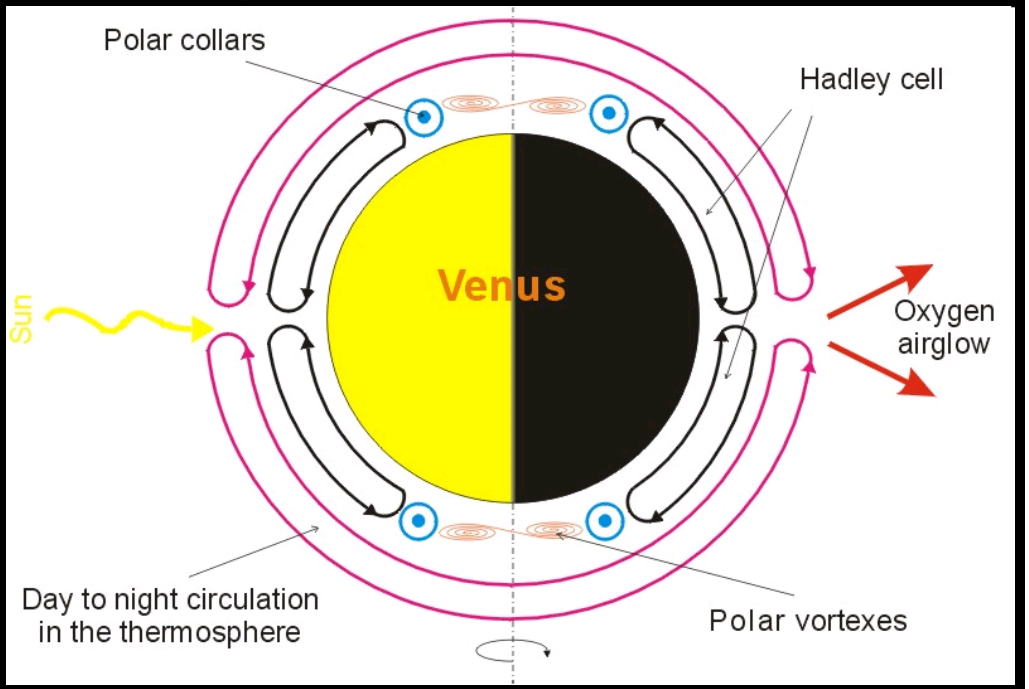
Layer	90 km	Particle size [micron]
Haze	↑	
	68	<0.5
Upper		
	57	2.7-3.2
Medium		
	51	3.2-3.8
Lower		
	48	1.8-32
Haze	↓	
	32-10	<0.5

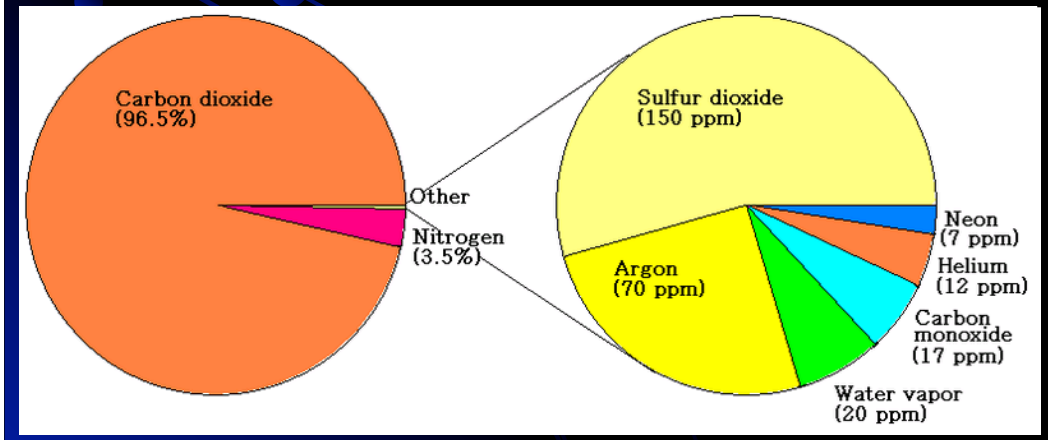
This part is not accessible by visible light neither for day time nor for night time !

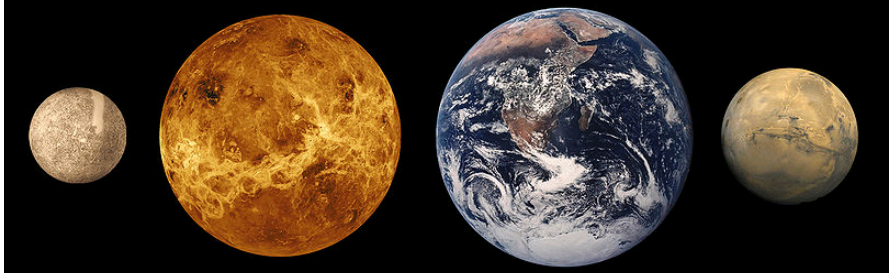
We need the infrared light and only in night time !

Venus Atmosphere

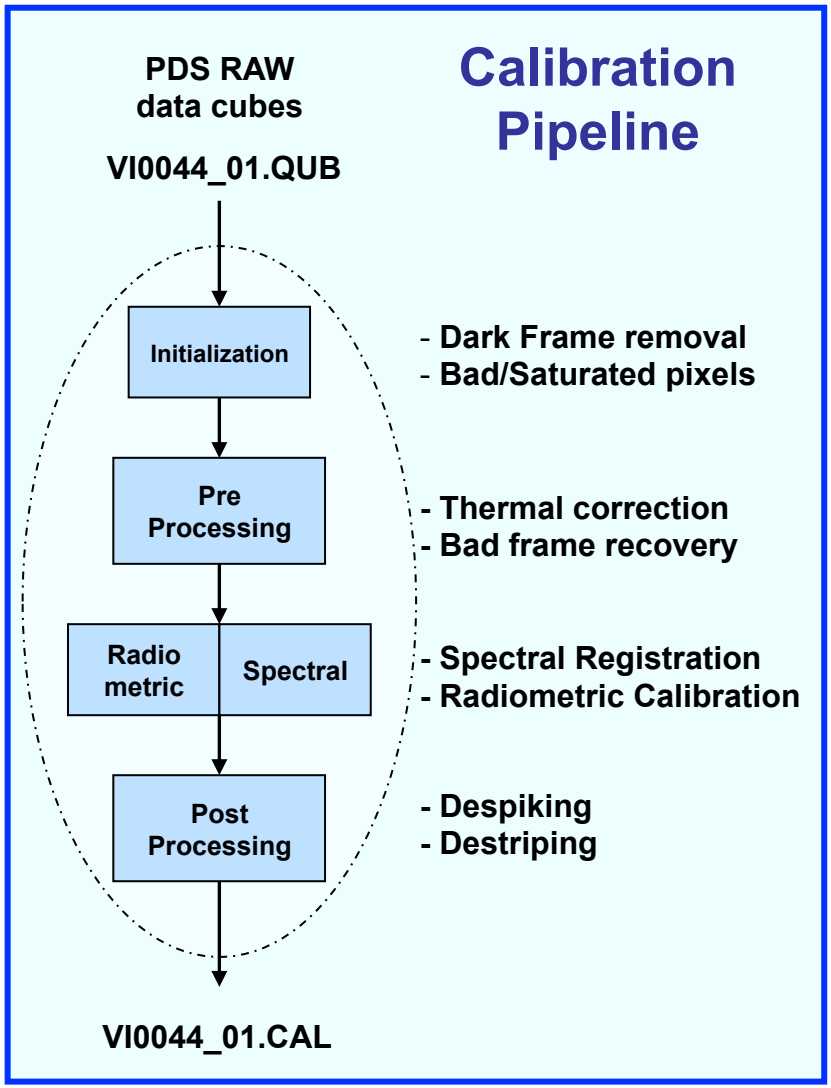


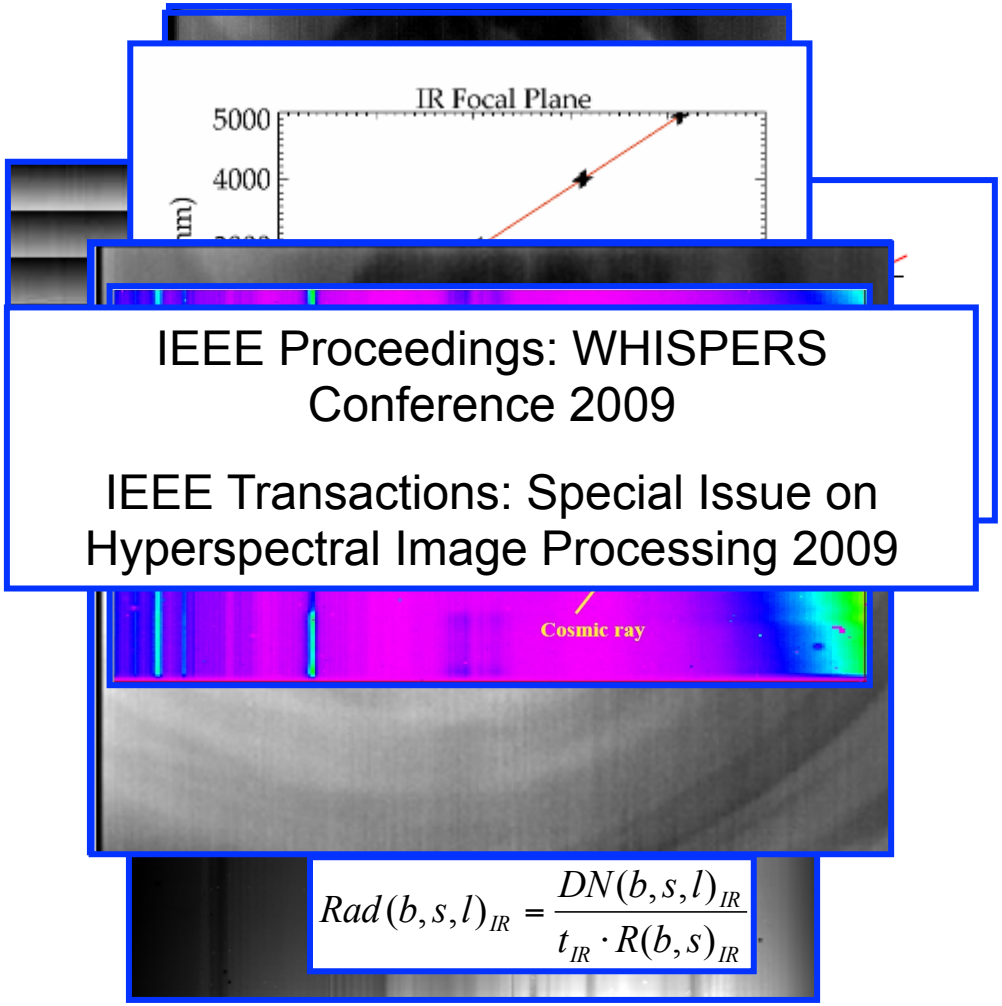






Data Calibration pipeline - Summary

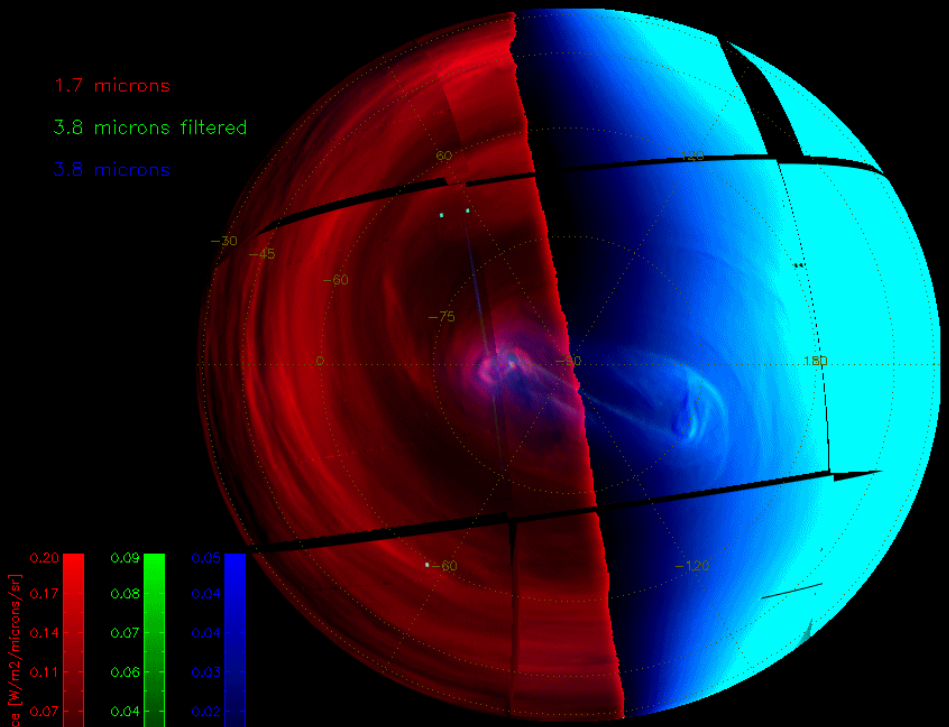


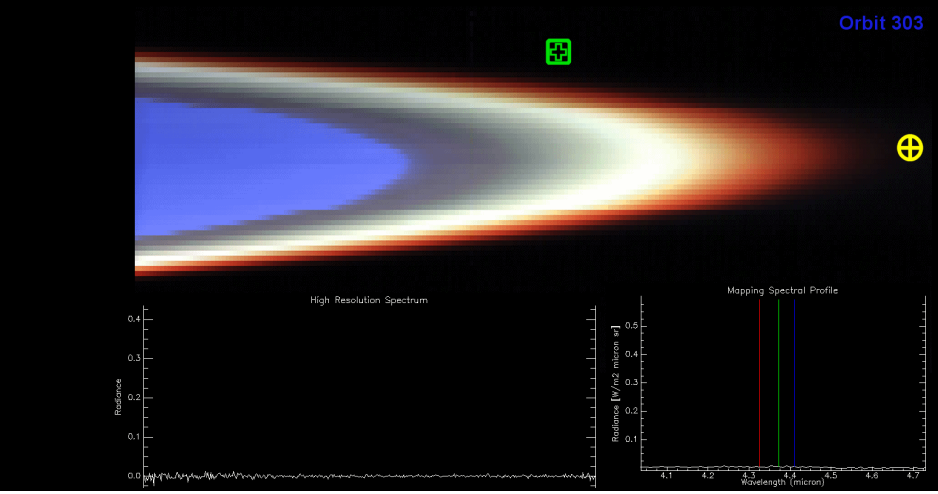


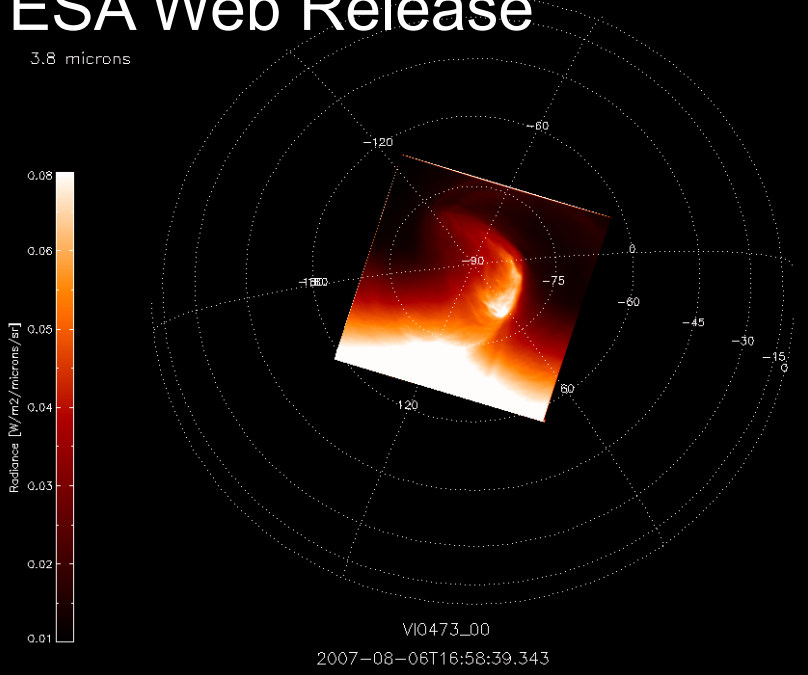
IEEE Proceedings: WHISPERS Conference 2009

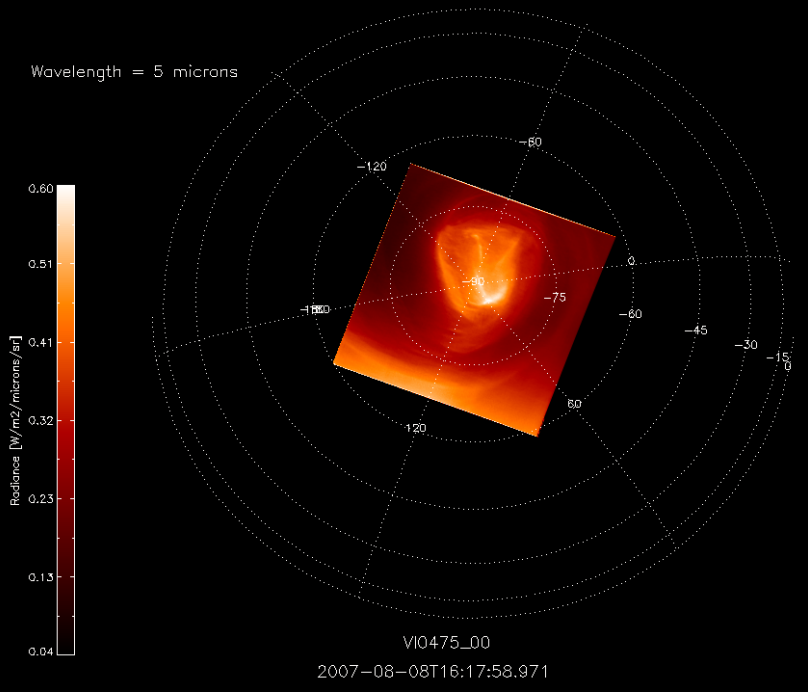
IEEE Transactions: Special Issue on Hyperspectral Image Processing 2009

First results 2008 : Nature – ESA Web Release



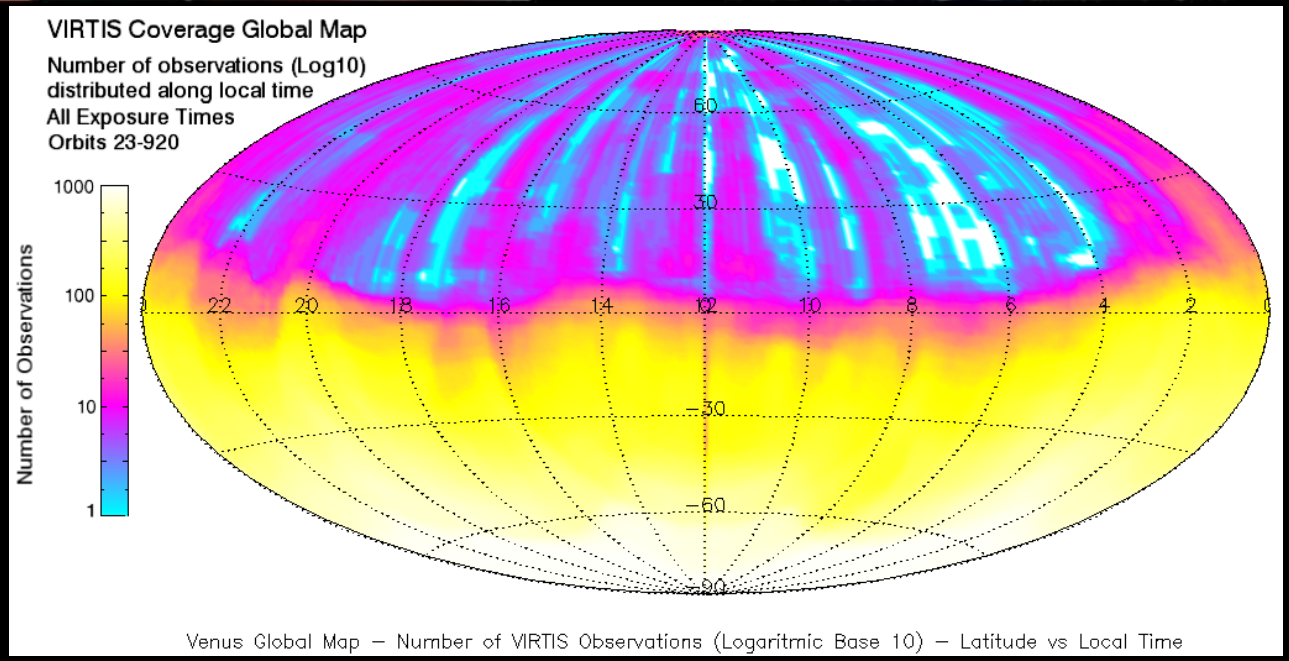


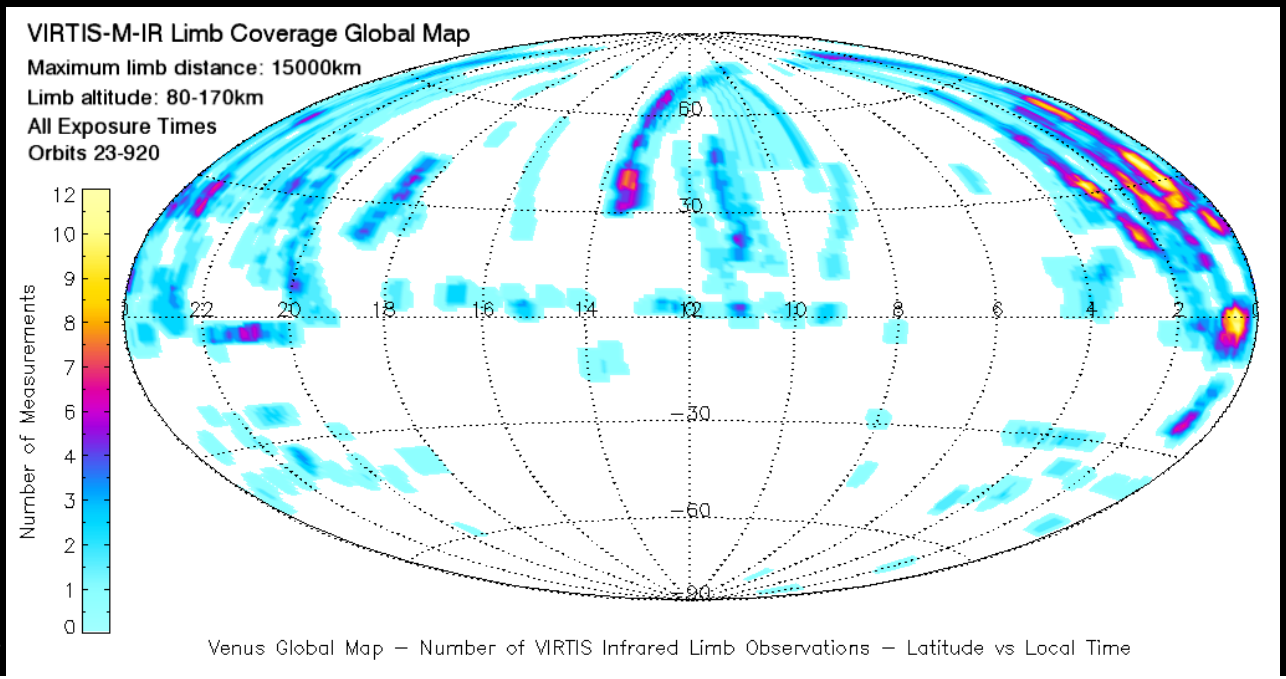




SPACE OPS 2010

VIRTIS Observation Coverage Maps





Frew et al.

SOLAR SYSTEM

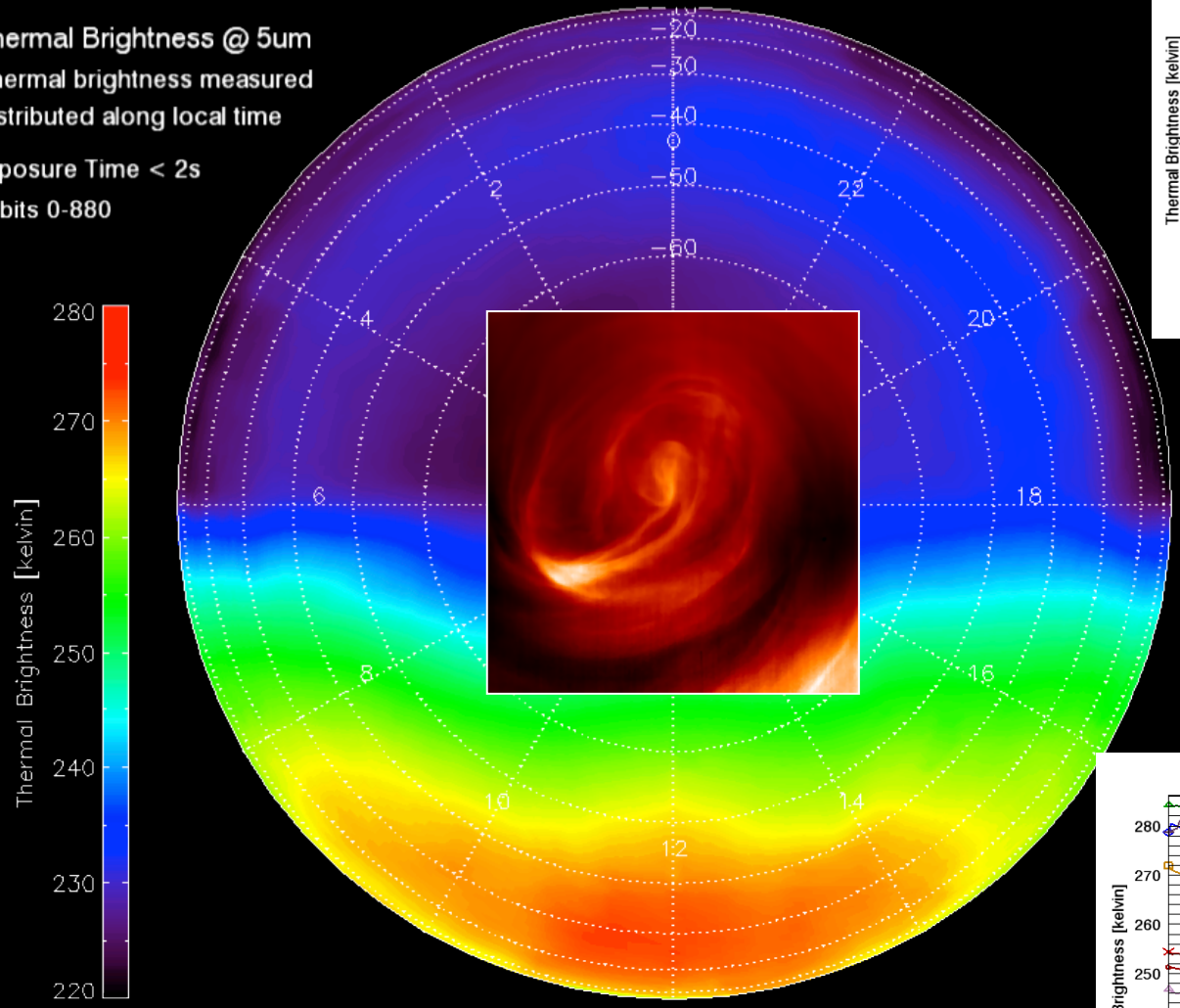
ESA – RSSD Science Newsletter 2009

Thermal Brightness @ 5um

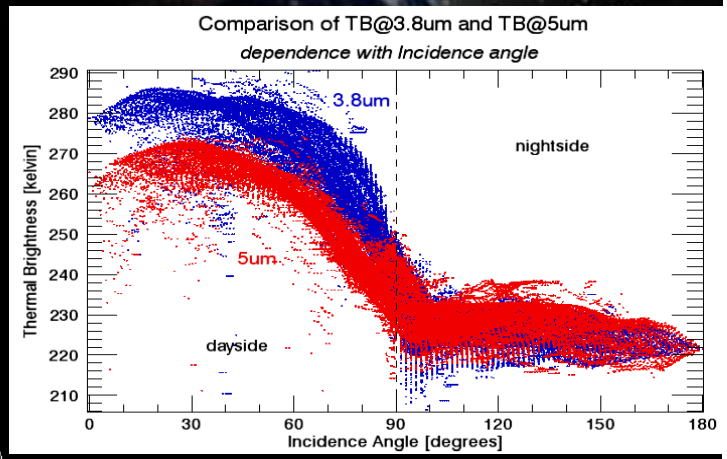
Thermal brightness measured distributed along local time

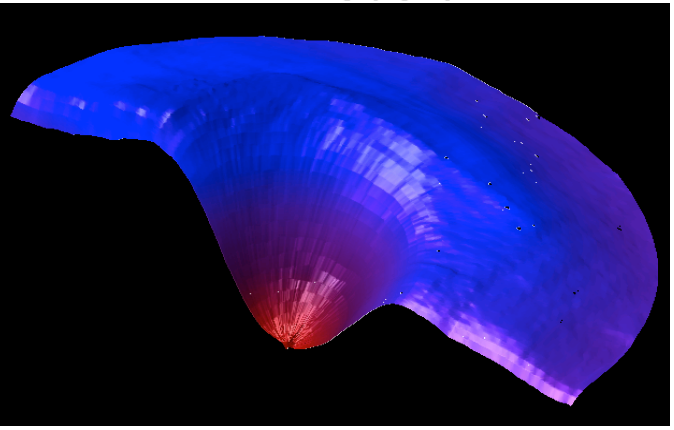
Exposure Time < 2s

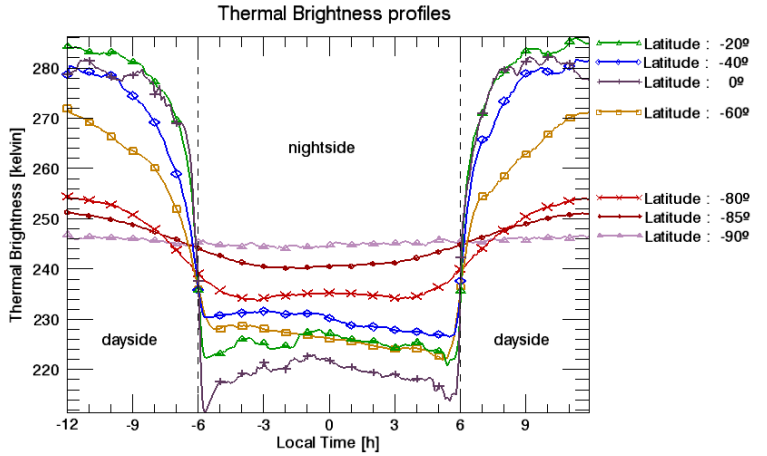
Orbits 0-880



VIRTIS Venus Express South Pole – Latitude vs Local Time







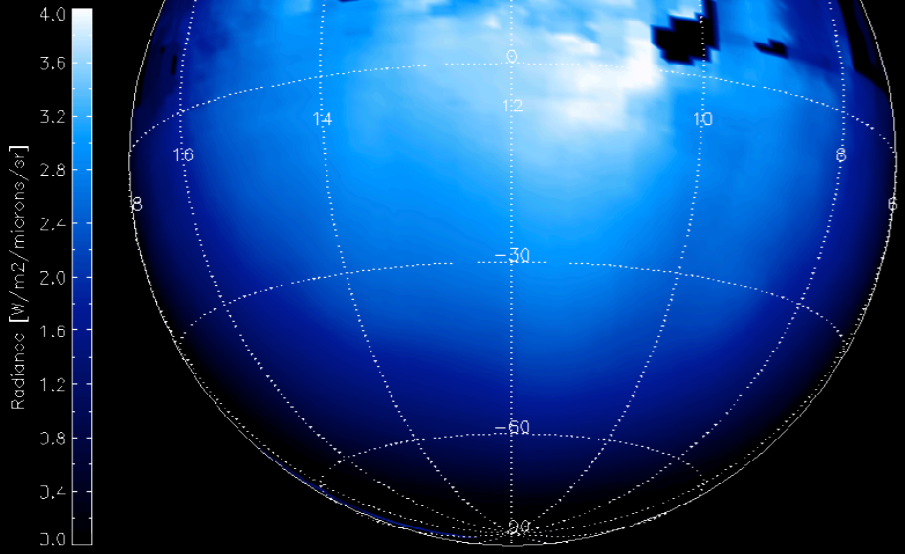
A.Cardesín Moinelo, G. Piccioni

SOLAR SYSTEM

AGU Fall Meeting – JGR 2009

CO2 Non-LTE Emission @ ~4.3um

Not corrected for emission angle
Not corrected for flat field
Emission Angle < 80°
Exposure time < 2s
Orbits 23-920

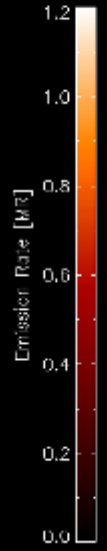


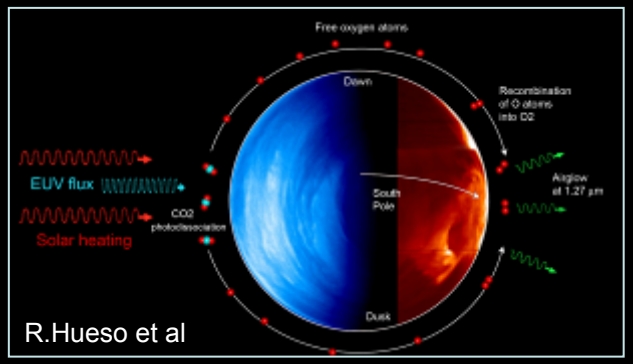
Oxygen Airglow @ ~1.27um

Corrected for emission angle
and for thermal contribution

Exposure time > 0.1s

Orbits 0-880



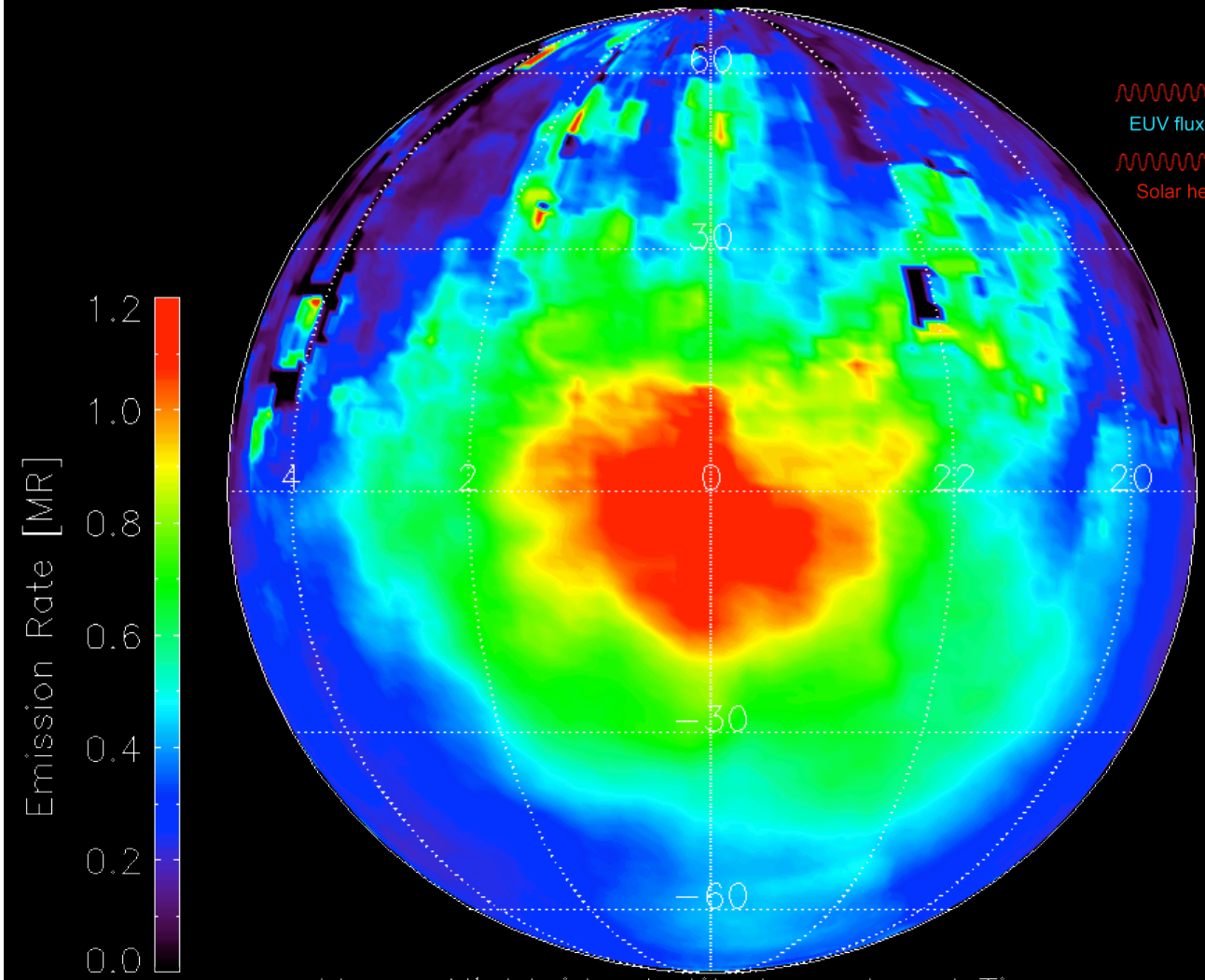


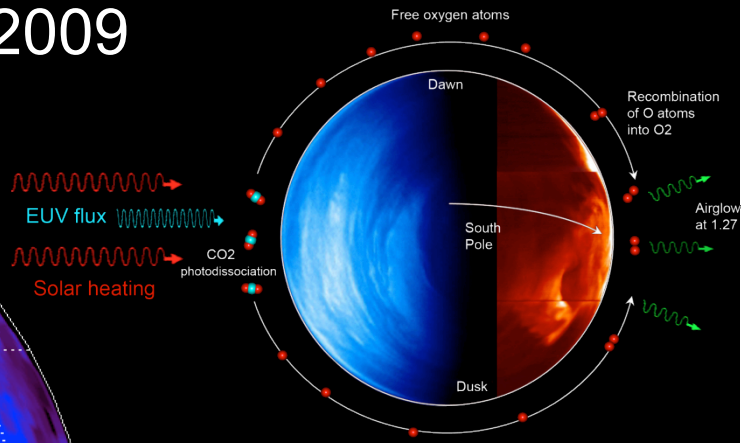
R.Hueso et al

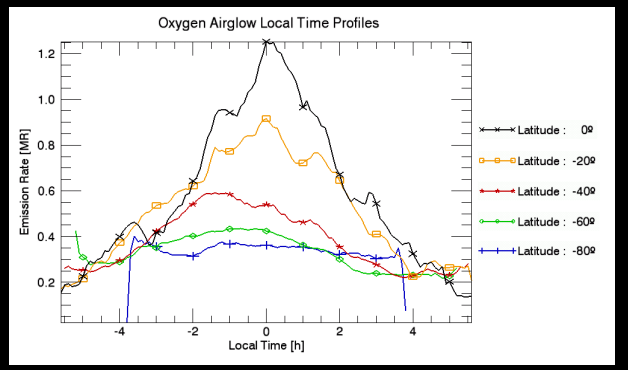
VENUS EXPRESS

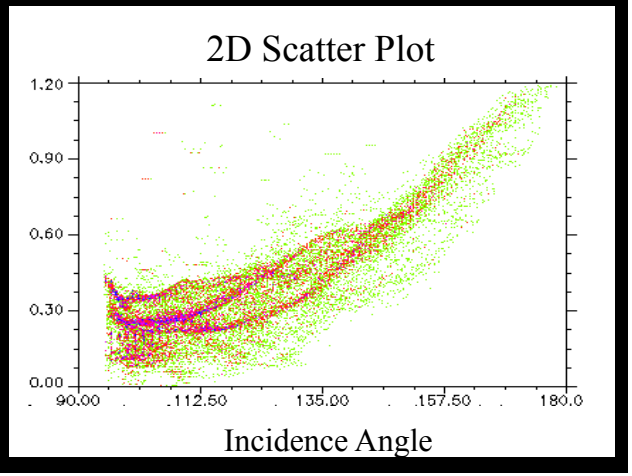
esa SCIENCE

Journal of Geophysical Research, 2009





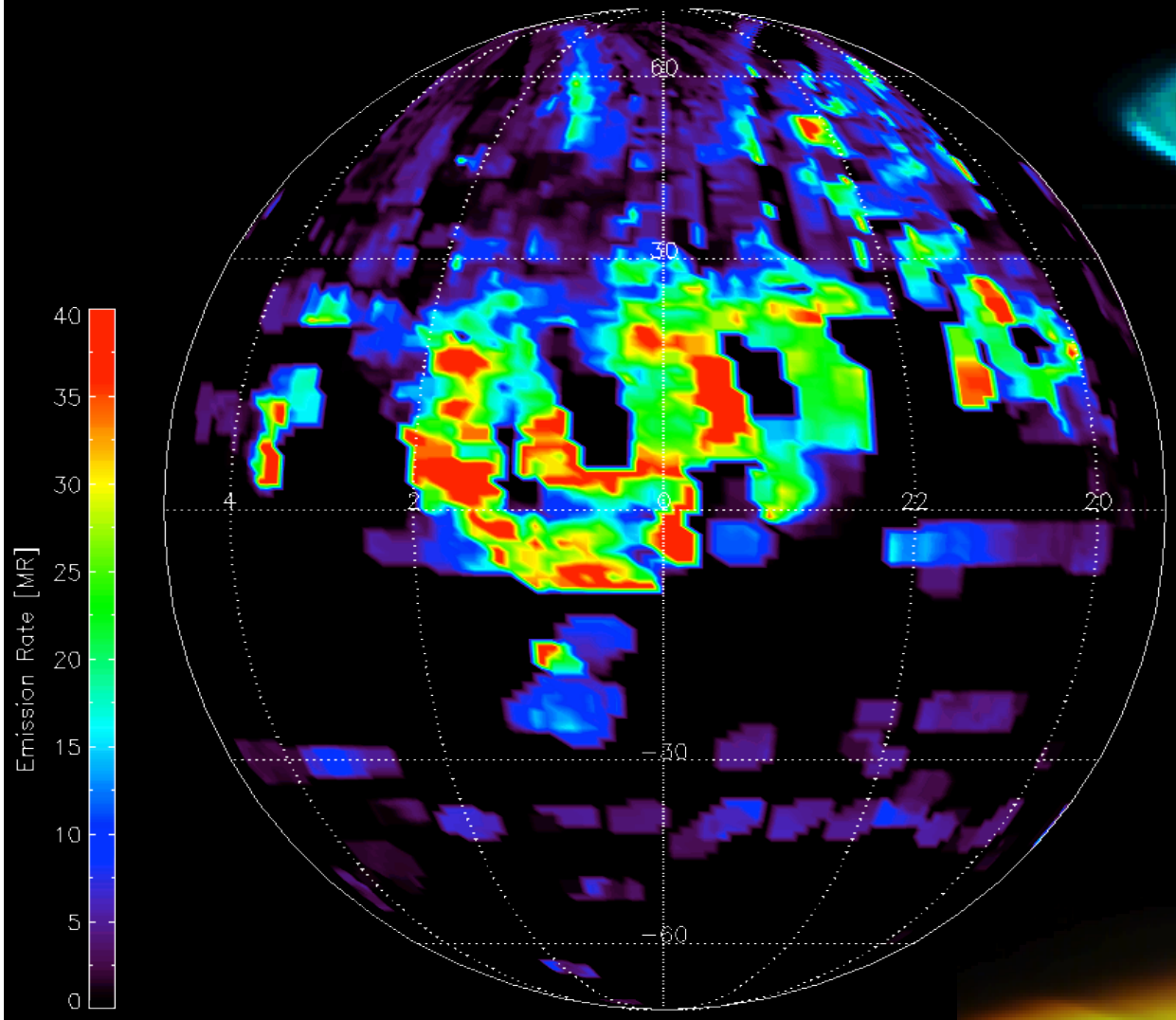


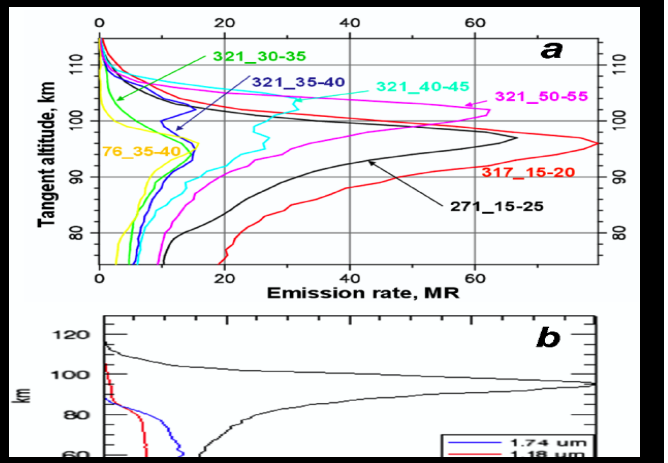


G. Piccioni et al.

SOLAR SYSTEM

Planetary & Space Sciences 2010





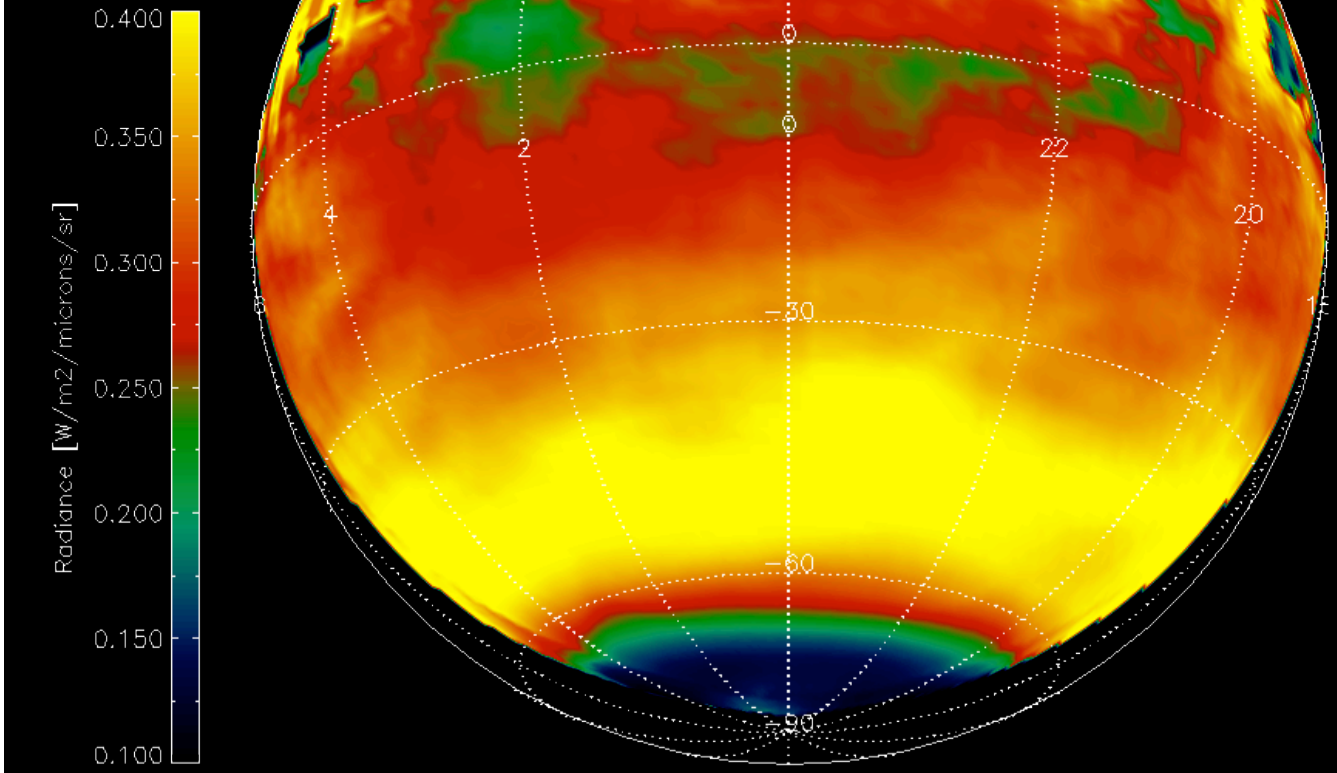
Migliorini et al.

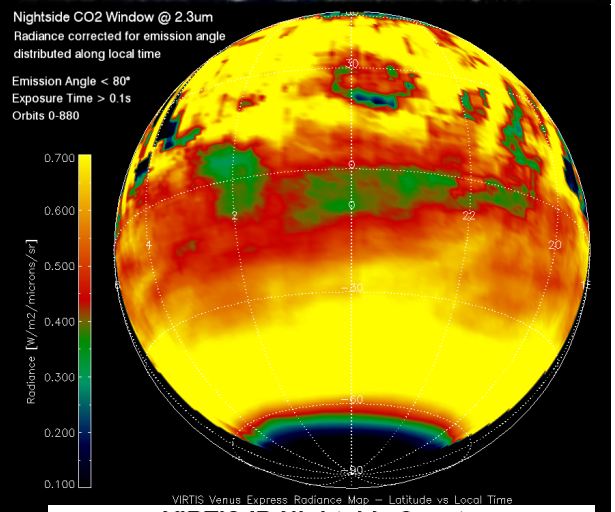
SOLAR SYSTEM

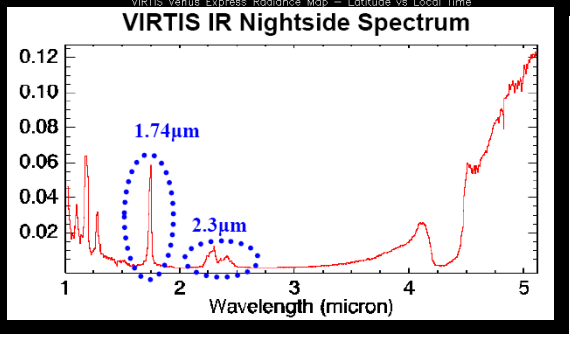
AGU Fall Meeting 2009

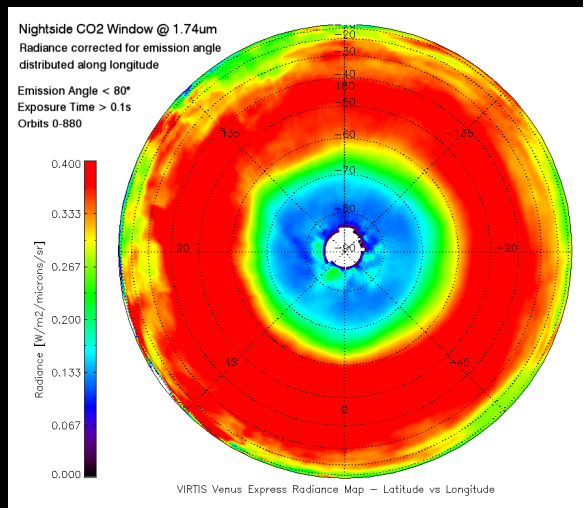
Nightside CO2 Window @ 1.74um
Radiance corrected for emission angle
distributed along local time

Emission Angle < 80°
Exposure Time > 0.1s
Orbits 0-880

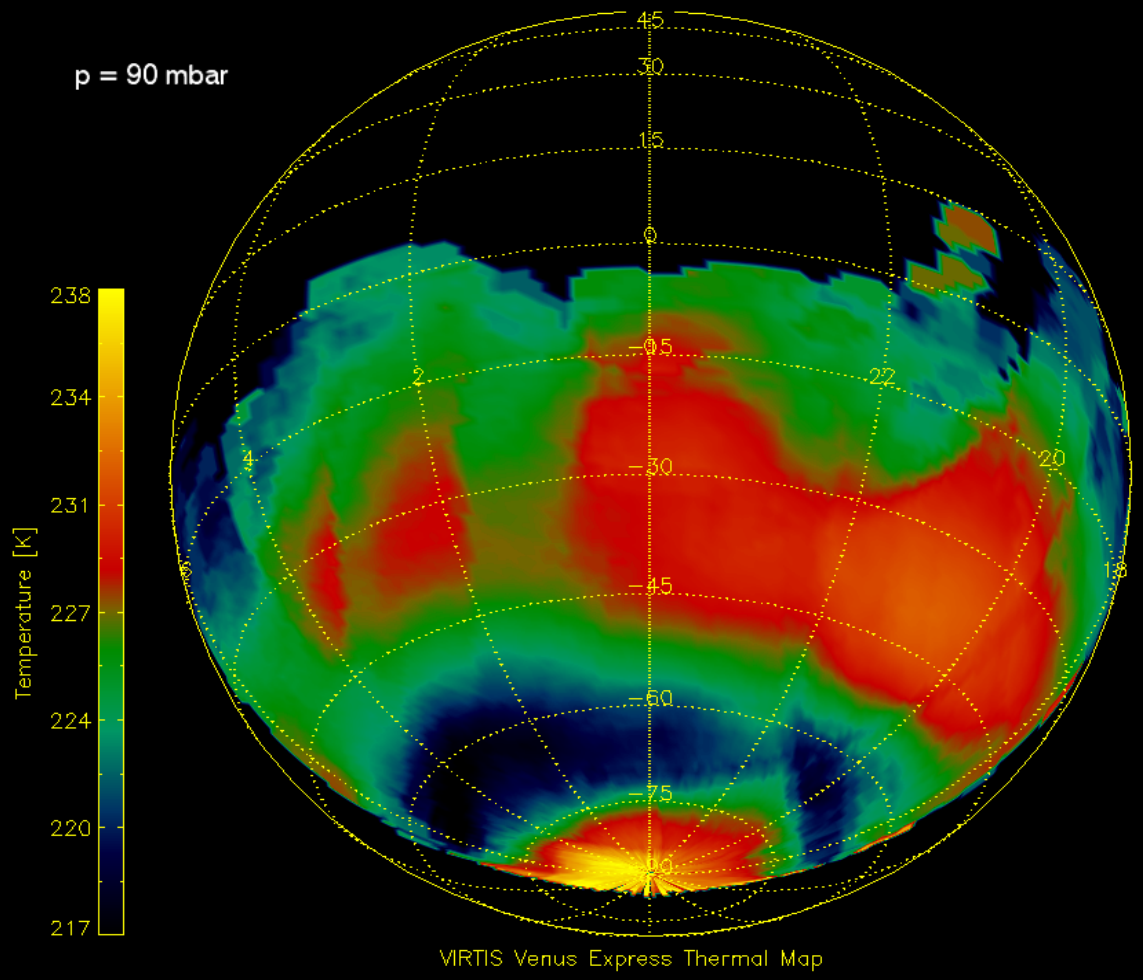


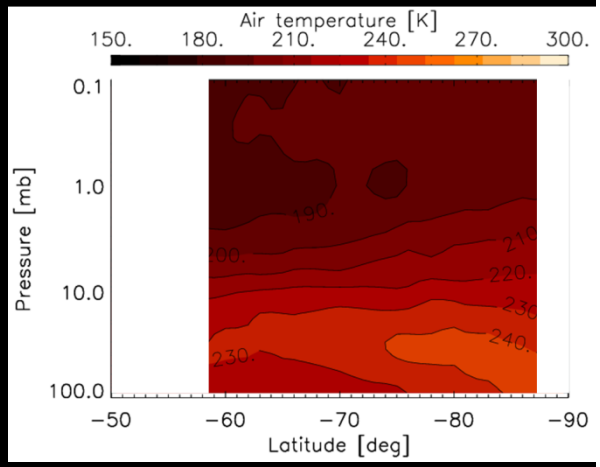


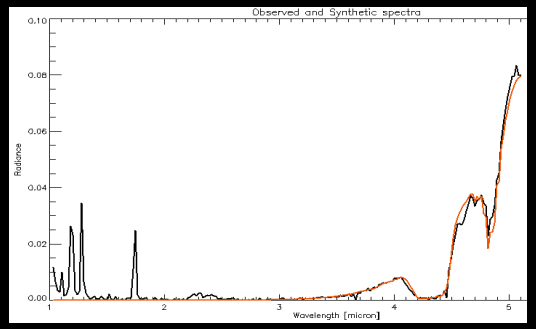


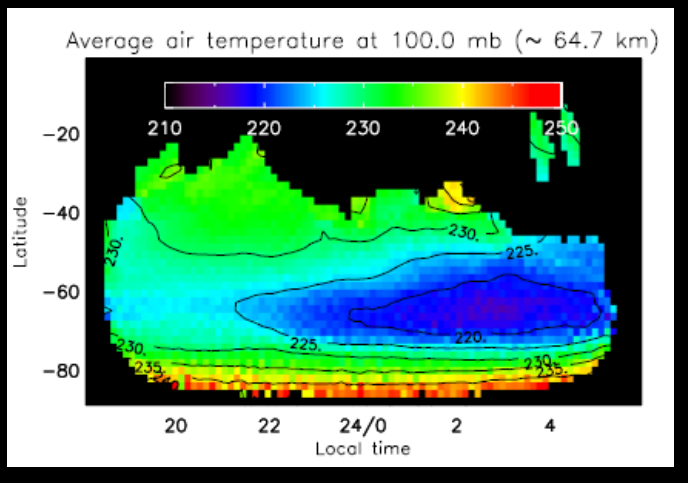


Journal of Geophysical Research 2010









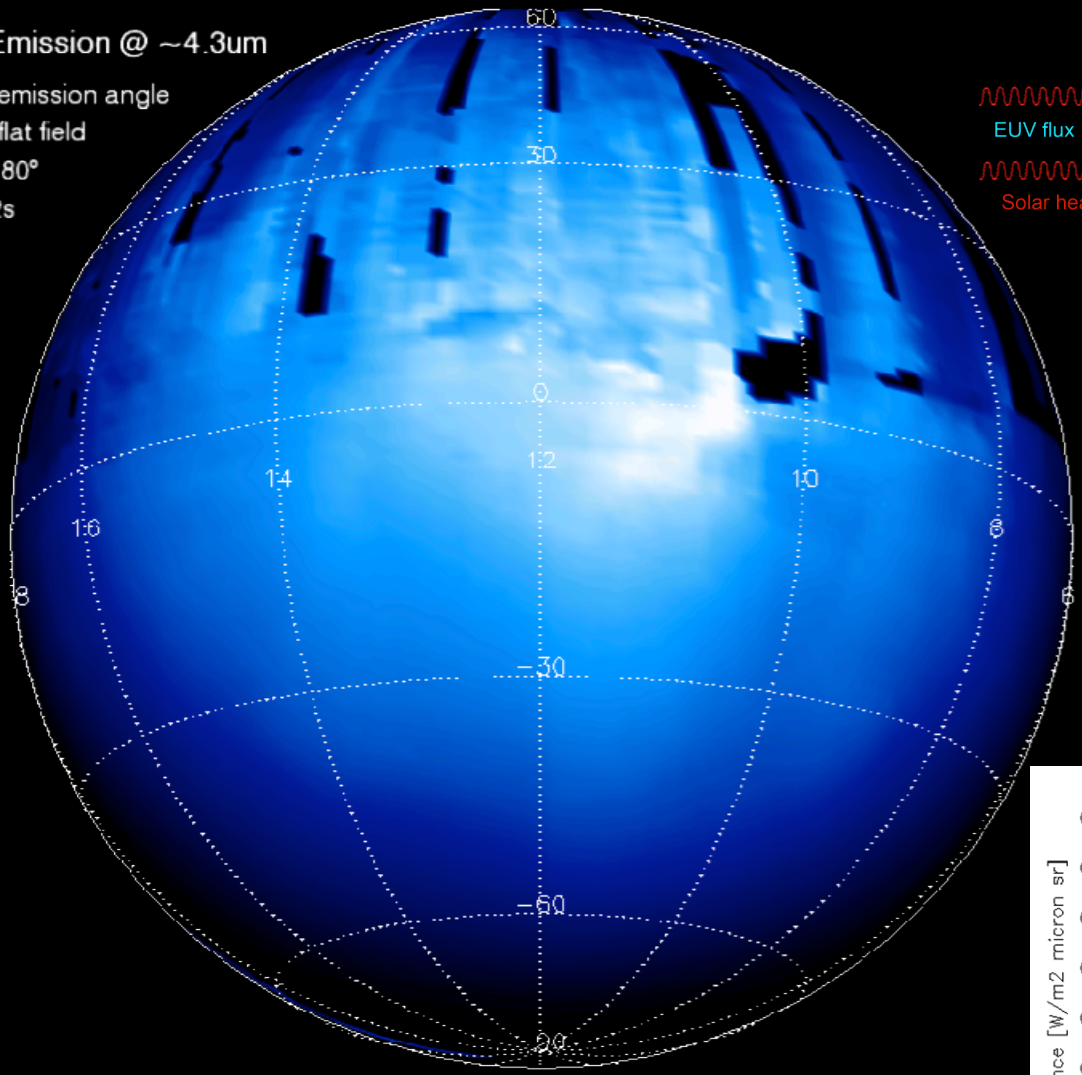
D. Grassi et al.

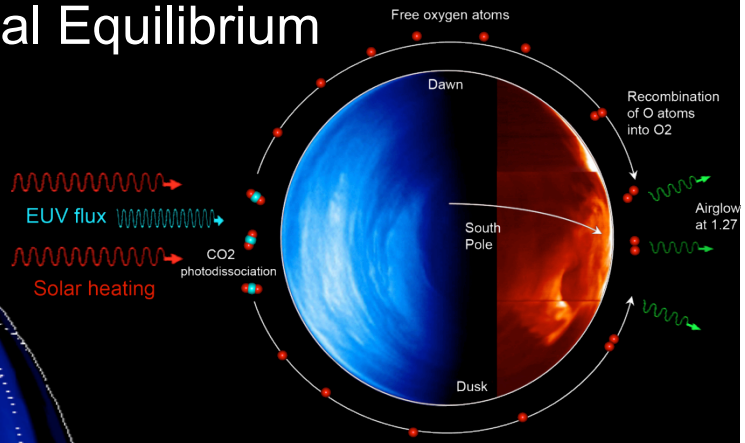
SOLAR SYSTEM

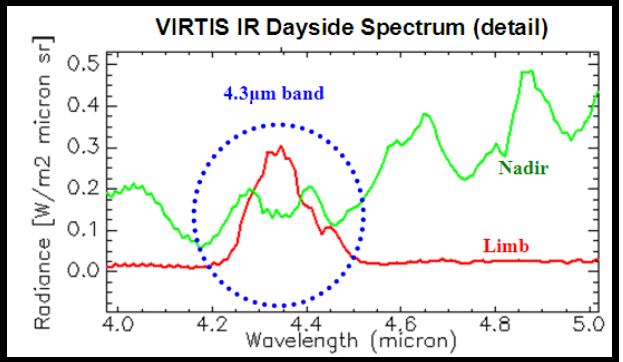
Current Study on Non Local Thermo-Dynamical Equilibrium

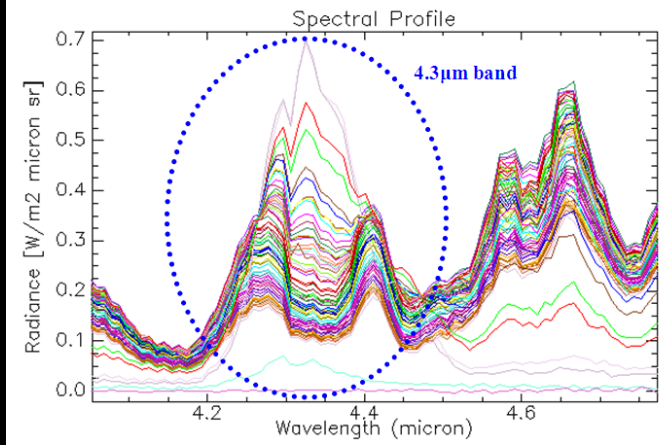
CO2 Non-LTE Emission @ ~4.3um

Not corrected for emission angle
Not corrected for flat field
Emission Angle < 80°
Exposure time < 2s
Orbits 23-920



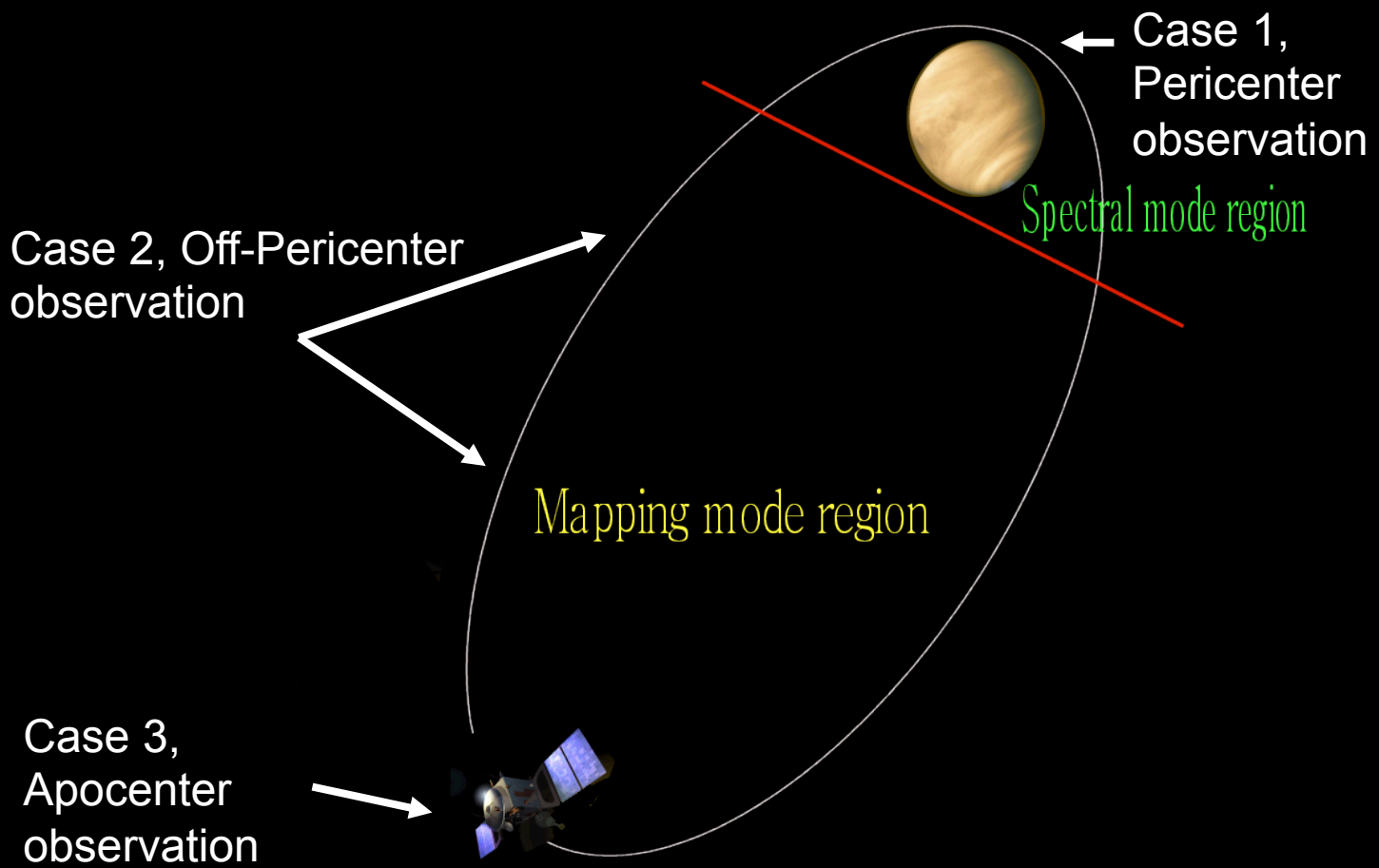






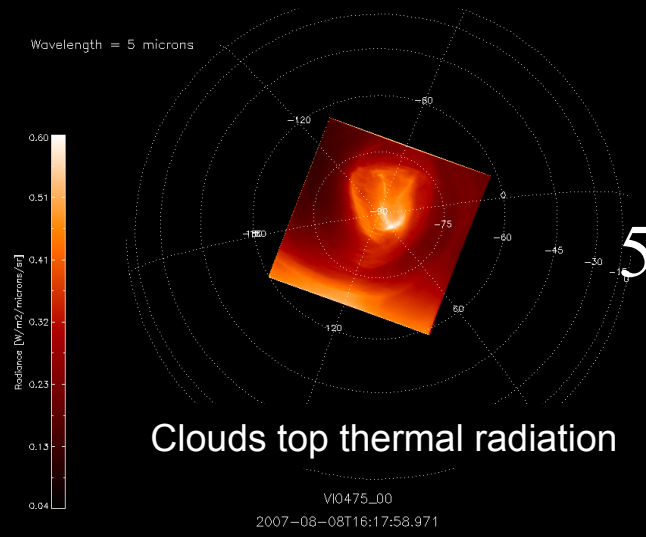
A. Cardesin et al.

General VIRTIS Observation Strategy for Nadir or off-Nadir



VIRTIS-M-IR

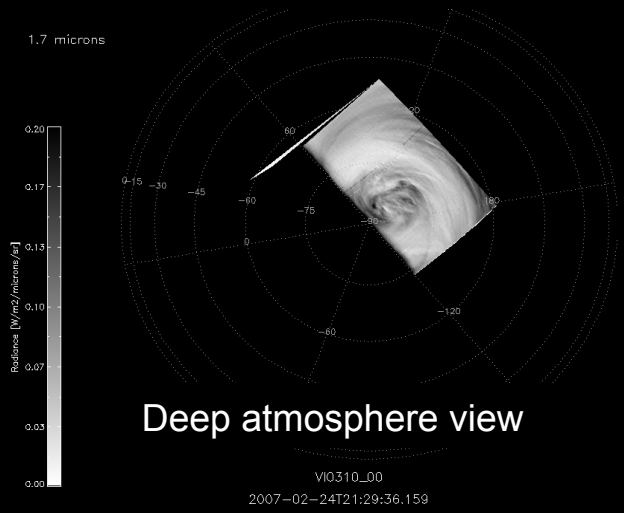
ESA/VIRTIS-VenusX (A. Cardesin Moinelo)



5um

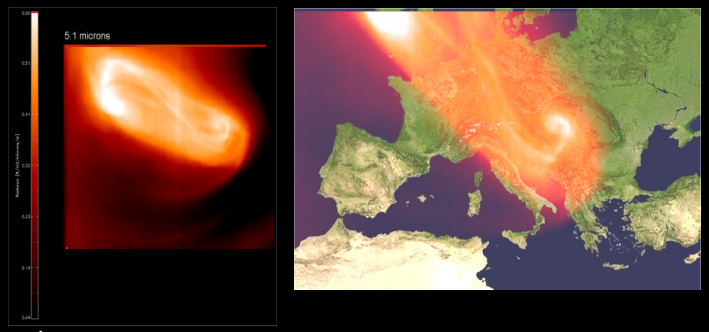
Clouds top thermal radiation

ESA/VIRTIS-VenusX (A. Cardesin Moinelo)



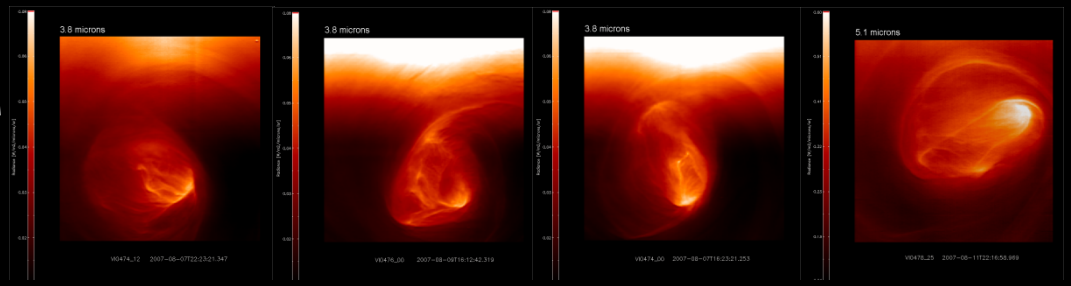
1.7um

Deep atmosphere view

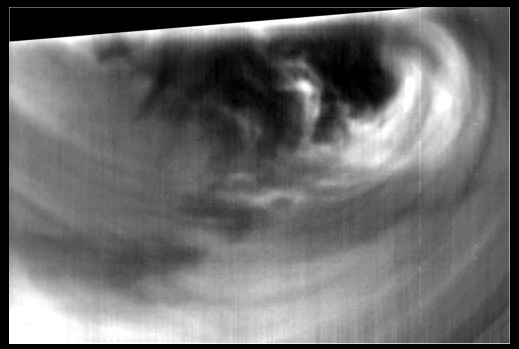


The vortex extends 2700 x 890 km

The vortex shape varies rapidly with time

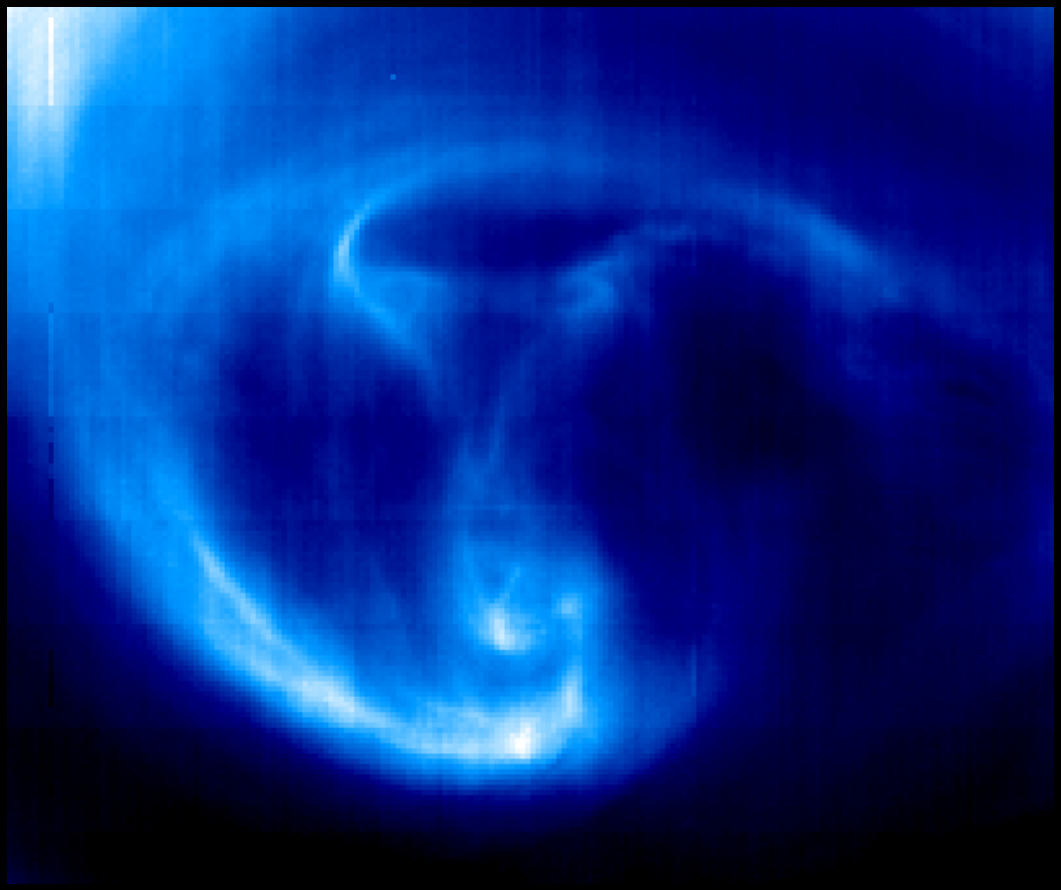


ESA/VIRTIS-VenusX (A. Cardesin Moinelo)



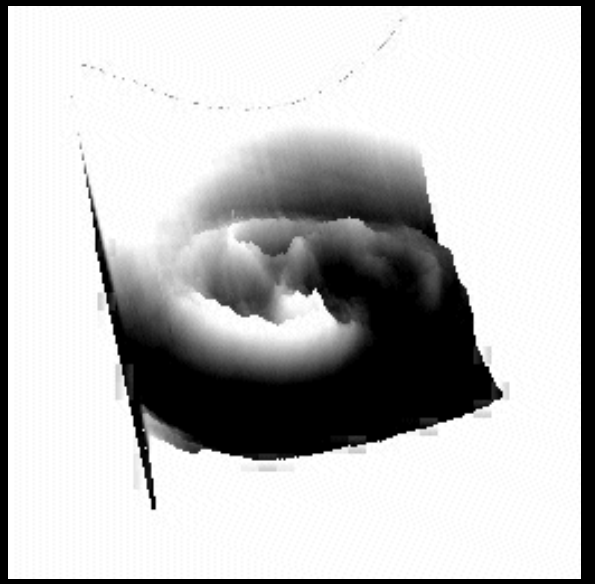
ESA/VIRTIS-VenusX (G. Piccioni)

A new view of the polar vortex: tripole !!!



5.2 microns

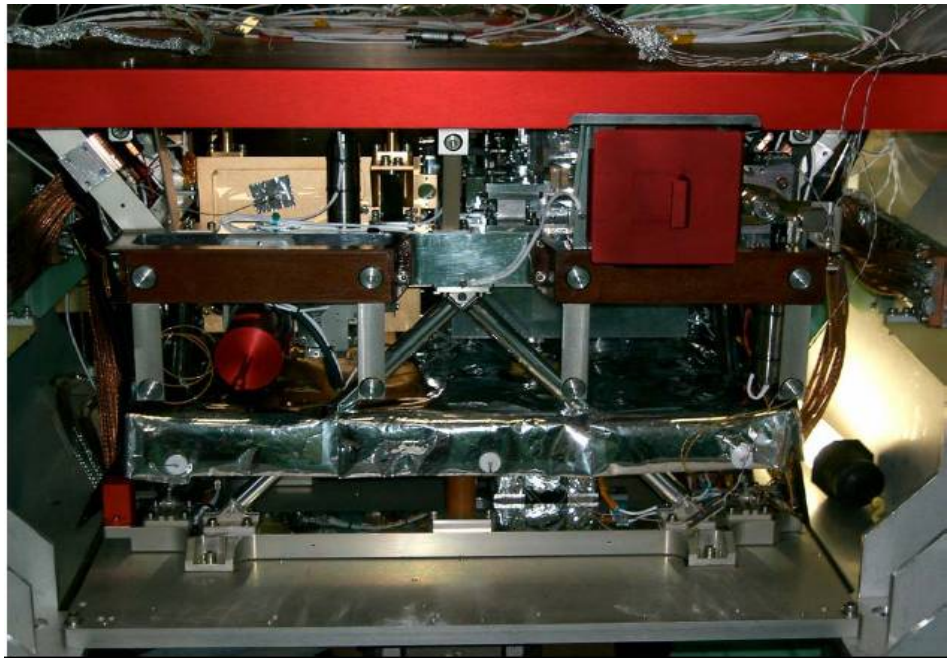
(65 km)

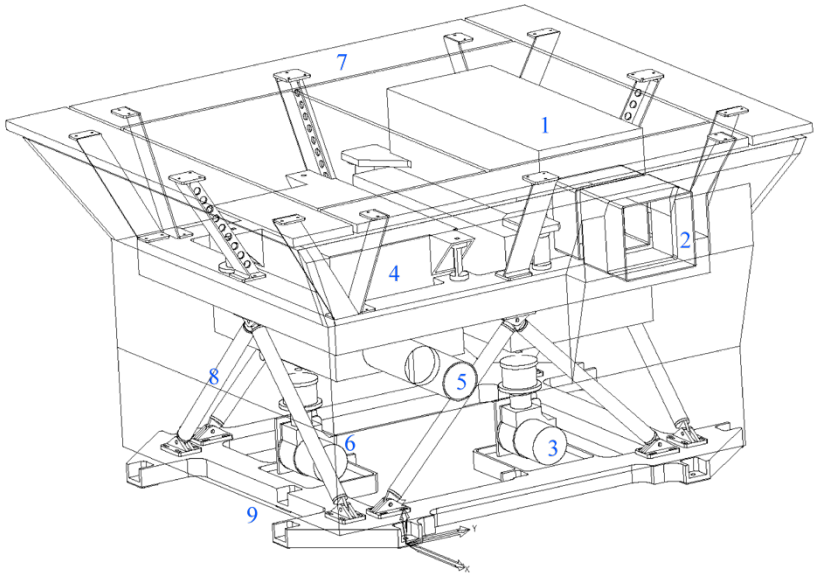


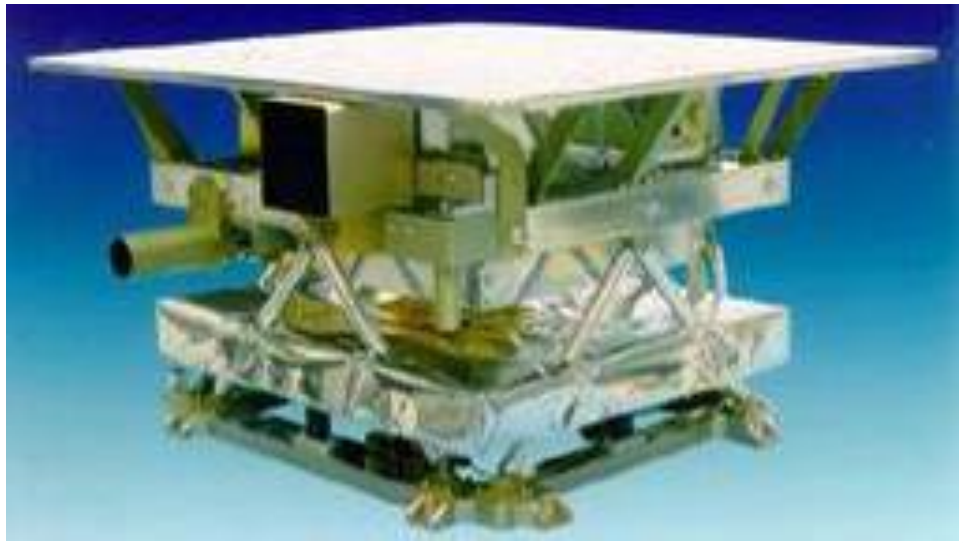
START_TIME = 2008-01-18T17:12:13.719

STOP_TIME = 2008-01-18T17:24:35.740

VIRTIS Instrument







VIRTIS details

	VIRTIS-M Visible	*VIRTIS-M Infrared*	*VIRTIS-H*
Spectral range (nm)	280 – 1100	1050 – 5130	1840 – 4990
Spectral resolution $\lambda/\Delta\lambda$	150 – 500	100 – 500	1300 – 3000
Spectral sampling (nm) [note 1]	1.89	9.47	0.6
Field of view (mrad x mrad)	64 (slit) x 64 (scan)		0.44 x 1.34
Max spatial resolution (μrad)	250 (slit) x 250 (scan)		–
Image size, full FOV high resolution (pixels)	256 x 256		–
noise equivalent spectral radiance (central band, $Wm^{-2}sr^{-1}\mu m^{-1}$)	1.4×10^{-2}	1.2×10^{-4}	1.2×10^{-4}
Telescope	Shafer Telescope	Shafer Telescope	off-axis parabolic mirror
Pupil diameter (mm)	47.5		32
Imaging F#	5.6	3.2	2.04
Etendue (m^2 sr)	4.6×10^{-11}	7.5×10^{-11}	0.8×10^{-9}
Slit dimension (mm)	0.038 x 9.53		0.029 x 0.089
Spectrometer	Offner Relay	Offner Relay	Echelle spectrometer
Detectors	Thomson TH7896 CCD	HgCdTe [note 2]	HgCdTe [note 2]
Sensitivity area format	508 x 1024	270 x 436	270 x 436
Pixel pitch (mm)	19	38	38
Operating temperature (K)	150 – 190	65 – 90	65 – 90
Spectral range (μm)	0.25 – 1.05	0.95 – 5.0	0.95 – 5.0
Mean dark current	< 1 e/s	< 2 fA @ 90K	< 2 fA @ 90K

Notes. 1: depends on selected mode of operation; the maximum value is shown. 2: VIRTIS-M and VIRTIS-H use identical IR detectors.

Venus Express Spacecraft