VIRTIS for Venus Express

Pierre Drossart[#] and Giuseppe Piccioni[&], December 2002
[#]LESIA, Obs. Paris and [&]IASF,Rome

VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) is a complex instrument initially devoted to the remote sensing study of comet Wirtanen on the Rosetta mission, at wavelengths between 0.3 and 5 µm. The focal planes, with state of the art CCD and infrared detectors achieve high sensitivity for low emissivity sources. Due to the high flexibility of the operational modes of VIRTIS, these performances are also ideally adapted for the study of Venus atmosphere, both on night and day sides. VIRTIS is therefore aimed to provide a 4-dimensional study of Venus atmosphere (2D imaging + spectral dimension + temporal variations), the spectral variations permitting a sounding at different levels of the atmosphere, from the ground up to the thermosphere. The infrared capability of VIRTIS is especially well fitted to the thermal sounding of the night side atmosphere (Taylor et al, 1997), which give a tomography of the atmosphere down to the surface.

Precursors: First attempts of imaging spectrometry on the Venus night side from space in the near infrared were made by NIMS/Galileo (Figure 1) in 1990 (Carlson et al, 1990) and VIMS/Cassini in 1999 (Baines et al, 2000). These fast fly-bys gave an idea of how powerful this method of investigation could be at Venus. Unfortunately, the limited duration of the fly-bys allowed only limited investigations, in particular on the meteorological evolution of the clouds. Observation of Venus with a new generation imaging spectrometer like VIRTIS would provide a unique opportunity to continue these investigations on an extended basis.

General description: VIRTIS is a sophisticated imaging spectrometer that combines three unique data channels in one compact instrument. Two of the data channels are committed to spectral mapping and are housed in the Mapper (-M) optical subsystem. One frame records a spectral image, and the second image dimension is obtained through a scanning mirror, to be combined with S/C motion. The third channel is devoted solely to spectroscopy and is housed in the High resolution (-H) optical subsystem. Both channels operate simultaneously, or separately, depending on observing modes. They are boresighted, and combined operations therefore provide a spectral image of 64 mrad from the 2 VIRTIS-M channels, associated with one spectral image. In Figure 2, a simple graphic representation of the output data is given.

Figure 1:

Image of Venus (night side) at 2.3µm, taken by Galileo (Carlson et al, 1990). The thermal emission from the deep atmosphere is modulated by the cloud structure of the deeper atmosphere. Cloudy regions appear in blue (lower emission), when bright regions (in red) correspond to less cloudy regions.

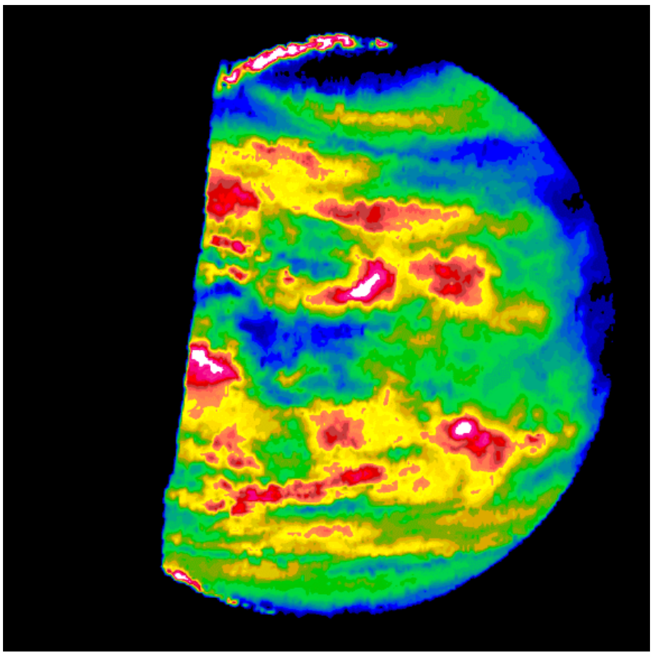
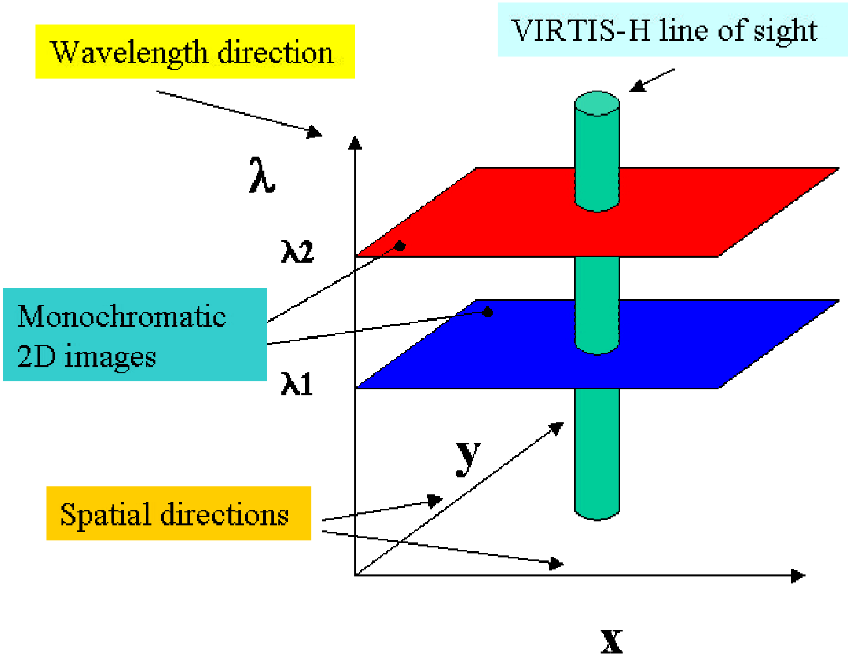


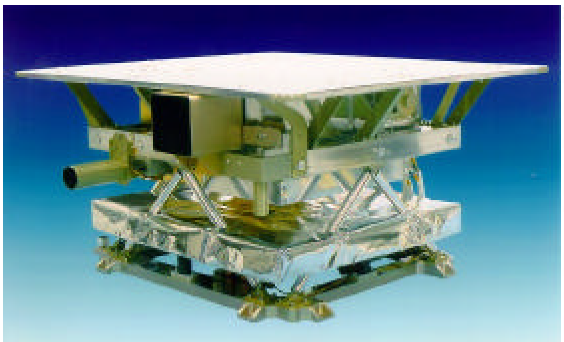
Figure 2:

The output from VIRTIS-M can be considered to be a large set of stacked monochromatic two-dimensional images in the range between 0.25 to 5 µm, at moderate spectral resolution. The field of view of VIRTIS-H centered in the middle of the –M image provides spectra at high spectral resolution in this small portion of the frame.



<u>HARDWARE DESCRIPTION</u> : VIRTIS is an imaging spectrometer combining three data channels in one compact instrument. Two of them are devoted to spectral mapping (Mapper optical subsystem: -M). The third channel is devoted to spectroscopy (High resolution optical subsystem: -H). The Optics Module is electrically connected by the Inter-Unit Harness to the -M and -H Proximity Electronics Modules and to the Main Electronics Module, which are internally mounted to the spacecraft.

The -M utilizes a silicon charge coupled device (CCD) to image from 0.25 µm to 1 µm and a mercury cadmium telluride infrared focal plane array (IRFPA) to image from 1 µm to 5 µm. The -H employes the same HgCdTe IRFPA to perform spectroscopy from 2 µm to 5 µm. The electronics to drive the CCD and the two IRFPAs are housed inside the Proximity Electronics Modules, while the remaining electronics boards are housed inside the Main Electronics Module. Both IRFPAs require active cooling to minimize the detector dark current (thermally generated Johnson noise). To minimize the thermal background radiation seen by these two



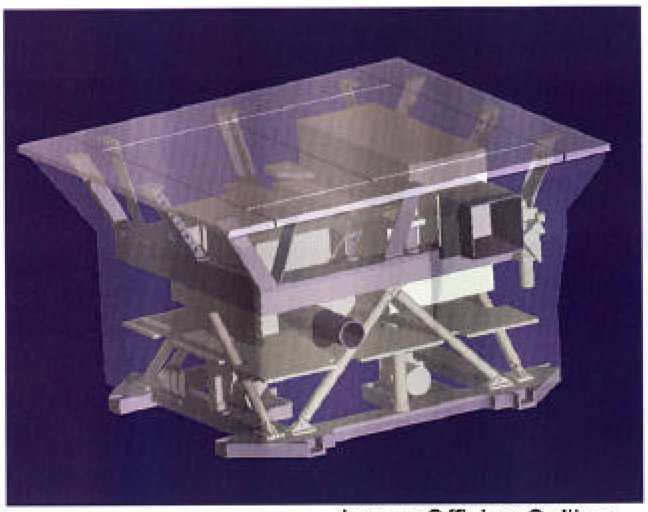


Image Officine Galileo

IRFPAs, the Cold Box must be passively cooled to less than 130 K by radiating one of its surfaces toward cold space. While the coolers are housed inside the Optics Module Pallet, which directly interfaces with the warm spacecraft, the cold detectors and optical systems are housed in a cold structure that must be rigidly mounted to the much warmer Pallet while remaining thermally insulated from it. The structure of VIRTIS/Rosetta will be adapted to the Venus Express spacecraft, with different conditions from the Rosetta mission. Models show that for temperatures of the optics module lower than 150 K, scientific specifications for Venus atmospheric studies should still be guaranteed. The team intends to work closely with the spacecraft engineers to ensure that the interface to the spacecraft is likewise kept simple and straightforward.

VIRTIS technical specifications:

VIRTIS/M channel: mapping spectrometer with moderate spectral resolution (R ~ 200) and high spatial resolution of 0.25 mrad (250m at 1000 km altitude), which uses two detectors (1) CCD (0.25 - 1 µm) and (2) IR FPA (1-5µm);

VIRTIS/H - echelle high resolution spectrometer (R ~ 1200) using an IR FPA detector (2-5µm).

Table 1. Expected parameters of the measurements of the atmospheric composition below the clouds by VIRTIS-H and -M (for wavelength shorter than 2µm)

Trace gas	**Wavelength, µm**	**Altitude,km**
H_2O	1.1- 1.18 1.74 2.40-2.43	0-12 20 33
HDO	2.38-2.46	33
CO	2.3	30-40
COS	2.43	30-40
SO_2	2.46	40

The IR/FPA are high sensitivity detectors (HgCdTe arrays of 270 x 438 pixels) specially designed to provide high sensitivity and low dark current (10 fA at 80 K), with a read noise lower than 500 e^-. For 1 sec integration, the noise equivalent spectral radiance is of the order of $5\ 10^{-5}$ W $m^{-2}sr^{-1}\mu m^{-1}$ for both Virtis H and M at 2.3 µm. According to the Figure 3 above, the maximum expected flux on Venus on the night side in this window is as high as 0.15 W $m^{-2}sr^{-1}\mu m^{-1}$, ensuring a S/N higher than 100, even for colder area. The FPA of both channels is actively cooled by cryocoolers down to the operating temperature of 80 K. On Rosetta, the spectrometer is passively cooled down to T= 130 K by the radiator on the cold panel pointing to the deep space. Due to the thermal constraints on Venus Express, and the comfortable Signal to Noise ratio expected on Venus, the specification on the Optical Module temperature can be relaxed. Simulations on Virtis H show that a temperature of T=150 K on the optical module still provide a S/N higher than 100 for a 1 sec integration time. The spectrum expected from VIRTIS/H is shown in Figure 3 while VIRTIS-M will systematically obtain maps of surface brightness distribution similar to that shown in Figure 1.

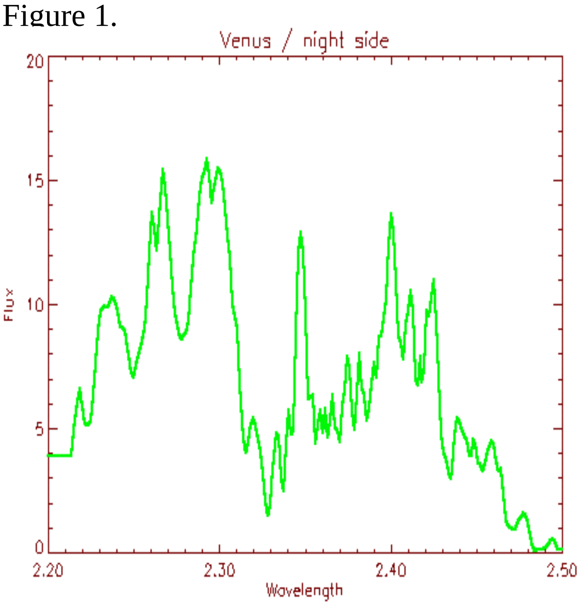


Figure 3:

Synthetic spectrum of Venus night Side at the spectral resolution of VIRTIS-H. Spectral features absorb the themal emission of the surface, with absorptions of CO_2, H_2O, CO, OCS and SO_2. The unit of radiance is in $\mu W cm^{-2} sr^{-1} \mu m^{-1}$

Scientific goals: The main scientific goals of VIRTIS at Venus are the following:

Study of the lower atmosphere composition below the clouds and its variations (CO, OCS, SO_2, H_2O) (see Table 1) from night side observations (Collard et al., 1993; Drossart et al., 1993);

Study of the cloud structure, composition, and scattering properties (day side observations) (Roos et al., 1993);

Cloud tracking in the UV (~70 km, day side) and IR (~50 km, night side);

Measurements of the temperature field with subsequent determination of the zonal wind in the altitude range 60-100km (night side);

Lightning search (night side);

Mesospheric sounding: understanding the transition region between troposphere and thermosphere

(1) non-LTE O_2 emission (night/day side) at 1.27 μm (95-110 km) (Drossart et al., 1993);

(2) CO_2 fluorescence (day side): non LTE emissions at 4.3μm (>80km) (Roldan et al., 2001)

(3) limb observations (CO, CO_2): atmospheric vertical structure (> 60 km) (day/night side);

Search for variations related to surface/atmosphere interaction, dynamics, meteorology, and volcanism;

Temperature mapping of the surface, search for hot spots related to volcanic activity;

Search for seismic waves from propagation of acoustic waves amplified in the mesosphere: search for high altitude variations of pressure/temperature in CO_2 4.3 μm band (Artru et al, 2001).

VIRTIS will also provide true colour high definition images of Venus that are of great value for public outreach programme.

<u>**Observation strategy for VIRTIS:**</u> To achieve the scientific objectives, VIRTIS must observe both day and night side, and to work with full imaging spectroscopy capabilities, VIRTIS must be able to reconstruct spectral images from the orbit of Venus Express. With the orbit of Venus express (24h/400-66000 km), the spatial resolution of VIRTIS is always better than 20 km at apoapsis. This spatial resolution is consistent with the science objectives of cloud structure (Galileo/Venus global observations had a 15-30 km resolution). It is also consistent with surface studies in the IR, because the scattering in the Venus clouds blurs the thermal flux coming from the surface over a scale range comparable to the cloud height (30 km). Therefore, the altitude of the S/C is not a limiting factor for VIRTIS observations.

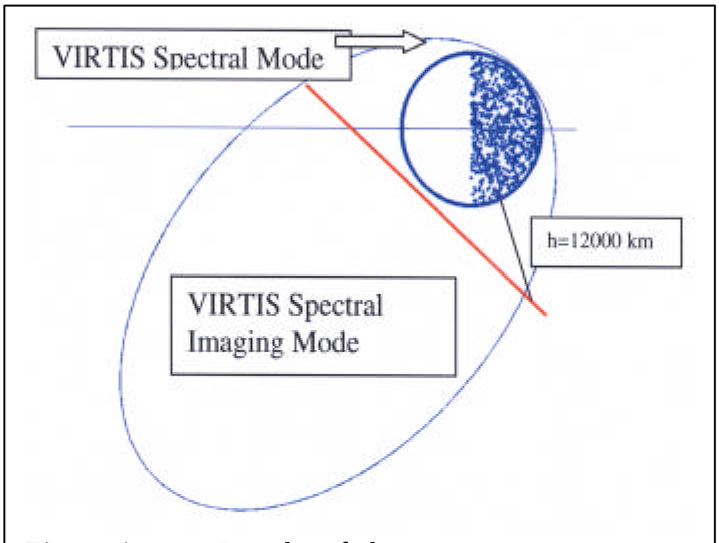


Figure 4 VIRTIS modes of observations.

Due to a minimum repetition time between two VIRTIS spectral images of the order of 2.5 sec, the observation strategy is divided into two parts on the orbit, depending on the dwell time on Venus being shorter than the repetition time (no image reconstruction) or larger (image cubes can be obtained). Therefore, the VIRTIS observations are separated into two categories, corresponding to altitudes lower than 12000 km (spectral mode) or higher (spectral imaging mode) (Figure 4):

Spectral mode (h < ~12000 km): This mode will be used for joint VIRTIS/PFS observations. Only a partial coverage of the surface is obtained in this mode, but the coverage reaches about 15% of the surface after 7 orbits, covering a statistically significant part of the disk. In particular, the cloud variability and related atmospheric composition variability will be tracked, as in the Galileo/NIMS studies (Collard et al, 1993; Drossart et al, 1993). Data volume is of the order of ~ 144 Mbits/hour of observation.

Spectral Imaging mode (h > ~12000 km): cube reconstruction is possible by scanning mirror operations.. Data volume: total amount of 240 to 600 Mbits.

Repetition of observations. Due to the atmospheric rotation in 4 days, an atmospheric program will consist in observation campaigns to cover the time variability in short medium and long term. A definition of science operation strategy will of course need a global discussion between instrument teams and satellite operator, to define the best compromise for science return.

References:

1. Artru J., P. Lognonné, and E. Blanc, Normal modes modeling of post-seismic ionospheric oscillations, Geophys. Res. Letters, 28, 697, 2001
2. Baines et al (2001) (2000). Detection of Sub-micron radiation from the surface of Venus by Cassini/VIMS. *Icarus*, **148,** 307-311.
3. Carlson R.W. et al. (1991)Galileo infrared imaging spectroscopy measurements at Venus. Science, 253, p. 154.
4. Collard et al (1993). Latitudinal distribution of carbon monoxide in the deep atmosphere of Venus, *Planet. Space Sci.* **41**, 487.
5. Drossart et al (1993). Search for spatial variations of the H2O abundance in the lower atmosphere of Venus from NIMS Galileo. *Planet. Space Sci.* **41**, 495.
6. Roldan et al (2000) Non-LTE Infrared Emissions of CO2 in the Atmosphere of Venus. *Icarus*, **147**, 11.
7. Roos et al (1993). The upper clouds of Venus: determination of the scale height from NIMS-Galileo infrared data, *Planet. Space Sci.* **41**, 505.
8. Taylor, F. W., Crisp, D., and B. Bézard (1997) Near-infrared sounding of the lower atmosphere of Venus. In “Venus II”, Univ. of Arizona Press, 325.