Discovery of Near-Earth Objects at Venus

T. Widemann [(1)], P. Tanga [(2)], E. Perozzi [(3)]

1 - LESIA – Observatoire de Paris, CNRS, 5 place Jules-Janssen, 92190 Meudon, France – thomas.widemann@obspm.fr
2 -Observatoire de la Côte d'Azur/LAGRANGE CNRS UMR 7293, Nice, France
3 - Deimos Space, Strada Buchesti 75-77, Bucharest, Romania

The population of asteroids orbiting at the interior of the Earth is currently very poorly known. Only 14 “Atiras” have been discovered, 3 of which in the ~1 km class. However, past studies showed that this population, potentially harboring hazardous objects, could be as much as half the number of Atens (~900 known) [1].
Mission concepts such as Sentinel [2] or EUNEOS [3] have proposed in the past to observe from Venus’ orbit, or even closer to the Sun, for a more efficient NEO detection. However, we believe that a Venus-orbiting mission could be an outstanding platform capable of coupling NEO discovery with Venus exploration.
The first phase of Venus spacecraft exploration by the Venera, Pioneer Venus, and Vega missions (1962-1992). It established a basic description of the physical and chemical conditions prevailing in the atmosphere and at the surface of the planet. ESA’s Venus Express has provided global long-term remote sensing observations [4]. Today, several future plans to explore the planet focus on the geology and interior of the planet [5,6]. This orbit can be considered as a unique vantage point to investigate near-earth objects and potentially hazardous objects (PHOs) at Venus.
From a Venus orbiter quasi-circular polar orbit, based on the EuNEOS study [3] a typical astrometry instrument would use a very large FOV (3.0° x 3.0°) and small pixel angular size. EuNEOS and Sentinel have explored different options for NEO detection from the inner Solar System. Polarimetry measurements, providing clues on the albedo of the observed object, could also be an option. In order to avoid moving parts and also conflicting observational requirements, we propose a continuously scanning telescope optimized for moving object detection. The simple rotation of the probe(e.g. around the optical axis of the Venus-pointing camera) could produce the scanning motion needed to observe NEOs. There's a wide choice of geometric configurations (angle of the NEO telescope in respect to the rotation axis, orbit constraints…), to be taken into account and optimized by numerical simulation.

Science Objectives : Venus science

Lightning and airglow camera (LAC)

Table 3 Optical performances of LAC

Parameter	Value
Wavelengths	777.4 nm (lightning)
	480-605 nm (O_2 Herzberg II band airglow)
	557.7 nm (O_2 line airglow)
	545.0 nm (airglow-free background image)
Interference filter	Array bandpass filter
Image sensor	Hamamatsu Si APD (Avalanche photodiode) 4461
Pixel size	2.0 mm × 2.0 mm
	Gap between pixels: 0.20 mm
Image sensor format	8 pixels × 8 pixels
Field of view	16.0 degrees × 16 degrees
	(2ω = 23.3 degrees)
Angular resolution	1.84 degrees/pixel
Spatial resolution	32 km @1,000 km
	580 km @38Rv
Optics	Image-side telecentric
Objective lens	Aspheric lens
Entrance pupil (diaphragm)	25.0 mm dia
Focal length (F number)	61.9 mm (F/~2.5)

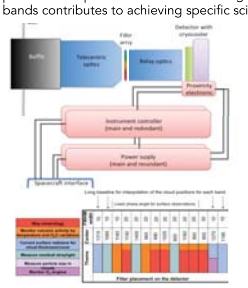
LAC on board JAXA's VCO/Akatsuki is designed to detect lightning flashes with an intensity of 1/100 of standard lightning on the Earth when viewed from 1000 km altitude and to measure 100-R night airglow with a signal-to-noise ratio more than 10. LAC has a field-of-view of 16 degrees, and as the detector it uses a multi-anode avalanche photo-diode (APD) that has 8 x 8 matrix of 2-mm square pixels [7]

Takahashi et al. 2008 [7]

Venus Emissivity Mapper

The Venus Emissivity Mapper (VEM) observes the surface of Venus in parts of the near-IR spectrum (“atmospheric windows”) that penetrate the atmosphere with minimal absorption. It builds on experience gained by VIRTIS on Venus Express, to characterize Venus’s surface geology and monitor volcanic activity. While VEM is a new instrument, it uses well-established concepts. It is a multi-spectral, push-frame imager with no moving parts [8]

VEM is focused mainly on observing the surface. It maps the surface in all near-IR atmospheric windows, using filters with spectral characteristics optimized for the wavelengths and widths of those windows. It also observes bands necessary for correcting atmospheric effects; these bands also provide valuable scientific data on cloud thickness, cloud opacity variations, and H_2O abundance variations in the lowest 15 km of the atmosphere.
A filter array is placed directly on the entrance window of the space-qualified SOFRADIR HgCdTe detector. The filters are placed above the detector in a pattern that optimizes science return. Figure 4 indicates how each of the filters/bands contributes to achieving specific science goals.



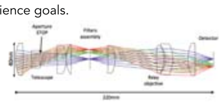
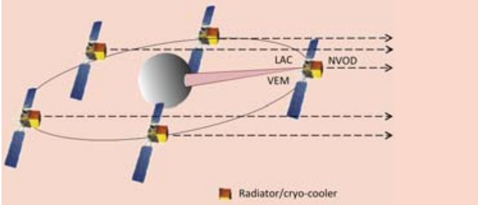


Figure 2 Optical layout of VEM-M

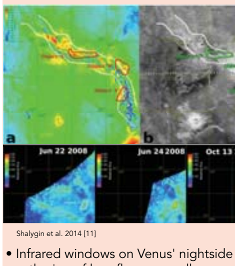
To split the light into several bands, VEM uses a multilayered dielectric-coating ultranarrow-band filter array (made by Balzer Optics) instead of a grating to maximize the signal to the FPA. The filter array is located at an intermediary focus of the optical path. We image each band onto the 17 512-pixel rows of the FPA. The surface bands are spatially sandwiched between the cloud bands to provide calibration before and after each surface data acquisition.

The space-qualified FPA is a SOFRADIR Neptune 256×500 HgCdTe detector array operating at <200 K. IFOV is 0.06 deg with each 30-µm-pitch pixel covering 225 m on the surface from an altitude of 215 km. A filter on the detector blocks radiation longward of 1.5µm. The space-qualified Ricor K508 cooler has a mean time to failure of 8,000 hours.
VEM provides great flexibility in achieving the required spatial resolution of 60×60 km at the surface and 10×10 km for clouds. The instantaneous FOV of the FPA is 30×30°, while that of a single pixel is 0.06×0.06°. For an altitude of 215 km, this provides a swath width of about 113 km with a single pixel resolution of 225 m and the nadir ground speed is about 7 km/s so the integration time of 90 ms corresponds to about 1 km smear. One pixel with 90 ms integration time corresponds to 225 m×1000 m. In addition, each ultra-narrow-band filters covers 17 rows of pixels. Hence, the required 10×10 km spatial resolution corresponds to binning 445 pixels in each band while 60×60 km resolution co-adds 36 10×10 km bins.



Two goals coupled – Venus nightside and asteroids

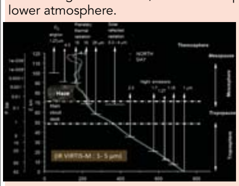
- Vantage point for the monitoring of the inner Solar System
- Possibility to measure the meteor(ite) flux at Venus along with the local NVO (Near Venus Objects) population
  - Important constraints to models of dynamic transport of small asteroids toward the terrestrial planets
  - Constraints on the survival rate of meteoroids in the inner Solar System

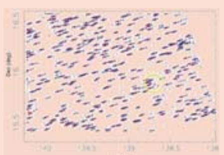


Shalygin et al. 2014 [11]

ESA's Venus Express/VIRTIS-M [9,10] has demonstrated the feasability of mapping the heated surface thermal emission through infrared atmospheric windows located between 0.8 and 1.18µm. Observations have revealed anomalies in this emission, in particular on geologically recent lava flows, interpreted as terrain emissivity variations. Surface thermal emission, strongly anti-correlated to existing radar altimetry, is constrained by emissivity which reflects mineralogy and contributions by volcanism, surface wheathering chemistry and past tectonic activity.

- Infrared windows on Venus' nightside allow to study ground emissivity and weathering of lava flows, as well as map water vapor traces and variability in the lower atmosphere.





Mainzer et al. 2015 [12]

Pointing/FOV constraints

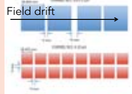
- Rotating synchronous to orbit
  - no star tracking (less power/”fuel” consumption/smaller reservoirs)
  - approx. equatorial orbit
  - pointing is thus drifting in the direction of NEO proper motion

➔ All stars are trailed – NEOs and NVOs less trailed = easier identification

- Orbit of 4 days = 3.75 arcsec/sec
  - Exposure 180 s (M2015) ➔ ~10 arcmin
  - Rate can be tuned to average drift rate expected for IEOs (20-50 mas/s)

Cf. Mainzer et al. 2015 [12] :

- Active cooling is required up to 5 µm (MCT detector)
- Telemetry rate restricted : on-board windowing around sources
- Two arrays of “N” HgTdCe detectors, optimized for 5 and 10 µm
- Both arrays image the same field (beam splitter required)
- Same field is seen “N” times, according to the following cycle :



Science Objectives : NEO science

Near-Venus Objects Detection

Requirement	Venus-trailing
Telescope aperture (m)	0.5
Wavelengths (µm)	4 - 5.2; 6 - 10
Field of view (°)	1.85 x 7.77
Slew time (s)	30
Dwell time (s)	180
Minimum background current (electrons/s	~300
Detector format	1x4 2048^2 mosaic;
	2x8 1024^2 mosaic
Detector type	HgCdTe
Pixel size (µm)	18; 18
Image FWHM (arcsec)	3; 4
Dark current (electrons/s)	<5; <200
Read noise (CDS)	15; <30
Quantum efficiency (%)	>60; >60
Point Source Sensitivity* (µJy, 5-σ)	50; 150
Viewing zones (solar elongation)	180±75°
Viewing zones (ecliptic latitude)	±41.9°

Mainzer et al. 2015 [12]

-A telescope at Venus has the potential of characterizing the whole NEO population, thus contributing to the census of potentially hazardous asteroids. However, following Mainzer et al. 2015 no specific advantage is present, relative to a space telescope on Earth-like orbit.

While this is true in general, a telescope orbiting Venus can much more easily detect and characterize the Atiras (or IEO), asteroids that are orbiting entirely inside the Earth’s orbit.

The Atiras constitute a very poorly known population (22 known at March 2015). Following the models of this population, their number can reach 50% of the Atens (currently 900 Atens are known).

A more complete census of the Atiras can bring important constraints on the mechanisms of transport of small asteroids toward the terrestrial planet region, and on their survival time scales in the inner Solar System.

By coupling asteroid discoveries to the observation of impact flashes on the Venus night-side, using a LAC-type camera, a large size range of objects in the circum-cytherean space can be characterized.

Encounter characteristics at Earth and Venus for meteor streams in Rendtel et al. (1995) with $\Delta < 0.02$ AU at Venus*

Designation	Δ_{Earth} (AU)	Δ_{Venus} (AU)	v_{Earth} (km s^{-1})	v_{Venus} (km s^{-1})	$\lambda_{\odot}^{Earth}$ (deg)	$\lambda_{\odot}^{Venus}$ (deg)
Sagittarids	0.0044	0.0061	33	37	43	55
Northern δ Aquarids	0.0092	0.0004	40	47	142	150
α Capricornids	0.0028	0.0080	25	23	128	160
Northern ι Aquarids (1)	0.0122	0.0138	32	35	152	12
Northern ι Aquarids (2)	0.0122	0.0149	32	35	152	168
Piscids	0.0035	0.0176	32	35	182	46
Northern Taurids (1)	0.0039	0.0118	30	31	232	251
Northern Taurids (2)	0.0039	0.0139	30	31	232	72
χ Orionids	0.0000	0.0009	27	27	258	78
Monocerotids	0.0037	0.0045	46	50	254	260

* Quantities given in the Table are minimum orbit distance Δ, impact speed v and solar longitude λ. The three streams with $\Delta_{Venus} < 3 \times 10^{-3}$ AU are highlighted.

Christou 2004 [13]

References

[1] Michel P., Zappalà V., Cellino A., and Tanga P. (2000). "Estimated abundances of Atens and asteroids on orbits between Earth and Sun". Icarus 143 (2): 421–424
[2] http://sentinelmission.org/sentinel-mission/sentinel-data-sheet/
[3] http://www.obs-nice.fr/morby/ESA/esa.htm.
[4] Svedhem, H. Titov, D., Taylor, F. and Witasse, O. (2009), Venus Express mission, J.. Geophys. Res. 114, E00B33, doi:10.1029/2008JE003290, 2009
[5] Hensley, S., Smrekar, S. E., Pollard, B. (2012), P33C-1950: VERITAS: A Mission Concept for the High Resolution Topographic Mapping and Imaging of Venus, AGU Fall Meeting, San Francisco, 3-7 December 2012.
[6] Richard C. Ghail, C. Wilson, M. Galand, D. Hall, C. Cochrane, P. Mason, J. Helbert, F. Montmessin, S. Limaye, M. Patel, N. Bowles, D. Stam, J.-E. Wahlund, Fabio Rocca, David Waltham, Tamsin A. Mather, J. Biggs, M. Genge, P. Paillou, Karl Mitchell, L. Wilson, U. N. Singh (2012), EnVision: taking the pulse of our twin planet, Exp Astron (2012) 33:337–363 DOI 10.1007/s10686-011-9244-3
[7] Y. Takahashi, J. Yoshida, Y. Yair,T. Imamura, M. Nakamura, Lightning Detection by LAC Onboard the Japanese Venus Climate Orbiter, Planet-C, Space Sci Rev (2008) 137: 317–334 DOI 10.1007/s11214-008-9400.
[8] Helbert, J., N. Müller, A. Maturilli, R. Nadalini, S. Smrekar, P.D’Incecco, M. D’Amore 2013, Observing the surface of Venus after VIRTIS on VEX – new concepts and laboratory work, Proc. of SPIE Vol. 8867 88670C-1.
[9] Mueller, N. et al., 2008. Venus surface thermal emission at 1 lm in VIRTIS imaging observations: Evidence for variation of crust and mantle differentiation conditions. J. Geophys. Res. (Planets) 113. doi: 10.1029/2008JE003118.
[10] Mueller et al. 2012, Rotation period of Venus estimated from Venus Express VIRTIS images and Magellan altimetry, Icarus Volume 217, Issue 2, p. 474-483.
[11] Shalygin, E.V. , W.J. Markiewicz, A.T. Basilevsky, D.V. Titov, N.I. Ignatiev, J.W. Head, Bright transient spots in Ganiki Chasma, Venus , 45th Lunar and Planetary Science Conference, 2014.
[12] Mainzer, T. Grav, J. Bauer, T. Conrow, R. M. Cutri, J. Dailey, J. Fowler, J. Giorgini, T. Jarrett, J. Masiero, T. Spahr, T. Statler, E. L. Wright 2015, Survey Simulations of a New Near-Earth Asteroid Detection System, *in press.*
[13] Christou, A.A., Prospects for meteor shower activity in the Venusian atmosphere, Icarus 168 (2004) 23–33.