Mapping the surface composition of Venus in the near infrared. J. Helbert[1] , N. Müller[1], S. Ferrari[1], D. Dyar[2], S. Smrekar[3], J. W. Head[4] and L. Elkins-Tanton[5], [1]Institute for Planetary Research, DLR, Rutherfordstrasse 2, 12489 Berlin, Germany (joern.helbert@dlr.de), [2]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075, [3]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA, 91109, [4]Department of Geological Sciences, Brown University, Providence RI 02912 USA, [5]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5251 Broad Branch Road, Washington, DC 20015, USA.

The permanent cloud cover of Venus prohibits observation of the surface with traditional imaging techniques over most of the visible spectral range. Fortunately, Venus' CO_2 atmosphere is transparent in small spectral windows near 1 µm. These have been successfully used by ground observers, during the flyby of the Galileo mission at Jupiter, and most recently by the VMC and VIRTIS instruments on the ESA VenusExpress spacecraft. Observations have revealed compositional variations correlated with geological features.

Studying surface composition based on only a small number of spectral channels in a narrow spectral range is very challenging. The task is further complicated by the fact that Venus has an average surface temperature of 460°C. Spectral signatures of minerals are affected by temperature, so comparisons with mineral spectra obtained at room temperature can be misleading. Based on experience gained from using the VIRTIS instrument to observe the surface of Venus and new high temperature laboratory experiments, we have developed the concept for the Venus Emissivity Mapper (VEM). VEM is a multi-spectral mapper dedicated to the surface of Venus. VEM imposes minimal requirements on the spacecraft and mission design and can therefore be added to any future Venus mission. Ideally the VEM instrument is combined with a high-resolution radar mapper to provide accurate topographic information.

Surface mapping by VIRTIS on VEX: The VIRTIS on the ESA mission VenusExpress (VEX) was the first instrument to routinely map the surface of Venus using the near-infrared windows from orbit [1,2,3]. The instrument is the flight spare of the VIRTIS instrument on the ESA Rosetta comet encounter mission[4]. Originally designed to observe a very cold target far from the Sun, it was adapted to work in the Venus environment. The instrument's main purpose on VEX was to study the structure, dynamics and composition of the atmosphere in three dimensions. However, the idea of surface studies was introduced very late in the mission planning and VIRTIS was never specifically adapted for this purpose. For example, the wavelength coverage was not optimal and only the long wavelength flank of the main atmospheric window at 1.02µm could be imaged. Despite these issues, VIRTIS was an excellent proof-of-concept experiment and far exceeded our expectations. It provided significant new scientific results and could show, for example, that Venus had volcanic activity in the very recent geological past [5].

Target: A global discussion of emissivity variations seen by VIRTIS is given by [1]. With the currently available data from VIRTIS on VenusExpress [1,2,5] the whole southern hemisphere is a target area. With a future mission carrying a follow-up instrument like VEM this can be extended to global coverage.

We discuss here, as an example of a target area, the Quetzalpetlatl Corona in the Lada Terra region [2] (Figure 1). This area is a showcase for the type of surface emissivity anomalies seen by VIRTIS and their correlation with geological units.

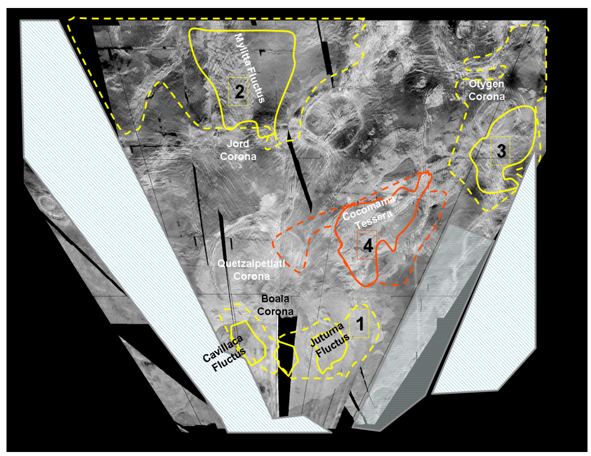

Figure 1. The areas mapped from the VIRTIS data as anomalies have been overlaid on the Magellan SAR images of the area around Quetzalpetlatl Corona. Yellow denotes positive anomalies, red negative. For further details, see [2].

There are several examples of positive emissivity anomalies associated with recent flow units (labeled 1,2 and 3 in Figure1). Originally we proposed both an endogenic and an exogenic interpretations for these anomalies. They may either be caused by variations in the surface composition or by a lack of weathering on the younger units. A subsequent study [6] favored the endogenic explanation based on their interpretation that some of the anomalies cover younger and older lava flow units. . In other locations, stratigraphy and context points to a lack of weathering [5]. It seems most likely that we are observing a combination of both effects. They are linked to each other because compositional variations can also result in difference in the weathering rate. More dedicated laboratory work is need to better constrain weathering rates and effects on Venus.

In close proximity, VIRTIS data show a negative emissivity anomaly associated with Coconama Tesserae (labeled 4 in Figure 1). Tesserae are generally associated with negative emissivity anomalies in VIRTIS data. Because tesserae are the oldest surface features on Venus, this correlation might hold clues to the earlier history of Venus. Their age makes it unlikely that we observe here predominantly a weathering effect. In order to attribute this difference only to weathering we would have to assume very slow weathering rates that have weathered the tesserae but not yet the plains. Therefore it seems more likely that we see a compositional difference that might resulting in an additional difference in weathering effects with respect to the surrounding plains. However, it must be recognized that the heavily tectonized surface of the tesserae introduces a larger uncertainty in the altimetric data from Magellan, resulting in a larger uncertainty in the emissivity anomaly determination from VIRTIS data.

Science Goal(s): The example of the area around Quetzalpetlatl Corona shows that near infrared surface observations from orbit can directly address the science goals II.B.1, II.B.2, III.A.2 and III.A.3 as given in Table 2 of the VEXAG Goals, Objectives and Investigations.

Discussion: Near-infrared mapping of the surface of Venus from orbit allows studies of the surface composition on a regional scale to obtain a global picture of surface compositional heterogeneities. Scattering in the clouds limits this to a spatial resolution of about 50km. Placing an infrared mapping instrument on a mobile platform like a balloon or a plane would allow to achieve a higher spatial resolution if the data is obtained below the cloud deck. An aerial platform traverse across the Lada Terra rise with an infrared instrument would allow assessing the mineralogy of recent lava flows, coronae and tesserae.

There are two important points to be considered before selecting targets for near-infrared observations.

Observing the surface of Venus in the near infrared requires a dedicated instrument. VIRTIS observations have successfully demonstrated that important information can be extracted from the windows in the visible portion of the spectrum, but the design of the instrument limited usability for surface investigations. We propose for this type of investigation a new concept. VEM is an instrument concept optimized for observing the surface. It maps the surface in all five of the 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. The design of VEM and the optimizations relative to VIRTIS on VEX would allow mapping the surface in more spectral channels with a higher signal-to-noise ratio and a more compact, less resource-demanding instrument.

Observing the surface of Venus in the near-infrared also requires a dedicated laboratory effort. The atmosphere of Venus dictates which spectral bands the surface can be observed. This places severe constraints on the ability to identify rock-forming minerals. To complicate matters further, we cannot observe reflectance, as would be the standard at 1 μm. Observations are obtained on the nightside where the thermal emission of the surface is measured directly. Finally, high surface temperature can severely affect the spectral characteristics of the minerals observed [7]. Laboratory measurements of emissivity in this wavelength range are virtually non-existent. We have currently undertaken an extensive laboratory campaign addressing these issues, as reported in an accompanying abstract [8].

Conclusions: Observing the surface of Venus in the near-infrared from orbit or from an aerial platform will provide new insights into the mineralogy of Venus. In combination with a high-resolution radar mapper that provides accurate topographic data, this would allow global or regional mapping of the surface composition at a spatial scale of approximately 50km.

In addition to the high scientific value of this data in itself, VEM will also provide important constraints for future landing site selections. Taking again the example of Quetzalpetlatl Corona, the near-infrared data also identify lava flows that show unusual surface composition. Depending on the science strategy for a lander this might be areas to target or to avoid.

Combining the near infrared data with radar derived geological information will allow further conclusions on the evolution of Venus to be drawn.

References: [1] N. Mueller, et al. (2008) *JGR* 113(E5), 1–21, [doi:10.1029/2008JE003118]. [2] J. Helbert et al. (2008) *GRL,* 35, 1–5, [doi:10.1029/2008GL033609]. [3] G. L. Hashimoto, et al. (2008) JGR 113. [4] G. Piccioni, et al. (2007) *ESA Special Publication* 1295 [5] S. Smrekar (2010) *Science* 328 [6] M. Ivanov and J. Head (2010) *PSS*, 58. [7] J. Helbert, et al. (2013) *EPSL*, 369-370. [8] S. Ferrari et al. (2014) this meeting.