VENUS GLORY AND THE UNKNOWN UV ABSORBER. W.J. Markiewicz[1], E. Petrova[2], O. Shalygina[1], M. Almeida[3], D.V. Titov[4,1], S.S. Limaye[5] and N. Ignatiev[2]; [1]Max-Planck-Institut für Sonnensystemforschung, Max-Planck-Str 2, 37191 Katlenburg-Lindau, Germany; [2]Space Research Institute, Moscow, Russia; [3]ESA-ESAC, Villanueva de la Cañada, Madrid, Spain; [4]ESA-ESTEC, SRE-SM, Noordwijk ZH, The Netherlands; [5]Space Science and Engineering Centre, University of Wisconsin-Madison, Madison, Wisconsin, USA.

We report on the first observation of a complete glory on top of the Venus clouds captured with the Venus Monitoring Camera (VMC) [1] when the Sun was almost directly behind the Venus Express spacecraft [2]. The wavelengths dependence of the position of the glory is consistent with clouds being composed of spherical droplets of sulphuric acid with radius of 1.2 micron, the so called mode-2 particles [3]. The ratio of backscattering (zero phase angle) to maximum intensity of the glory as well the slope of the observed intensity at larger phase angles cannot be explained by the sulphuric acid droplets alone suggesting a need of an additional component. We investigated several possibilities and argue that one good explanation is that the acid droplets nucleate on small inner cores composed of iron chloride. Iron chloride is one candidate for the so-called unknown absorber in the ultraviolet wavelengths range [4, 5]. An alternate explanation could be that the sulphuric acid droplets are coated with a thin layer of sulphur.

Data: During the past year we have been able to observe Venus with VMC in backscattering viewing geometry. First such observations were made on 4th of April, 2011 (orbit 1809). Subsequently we repeated this type of imaging on more than a dozen of other orbits. As an example, data taken in orbit 1920 (July 24th, 2011) are shown the Figure 1. In all cases the observed intensity exhibits a characteristic circular pattern centered on zero phase angle. This rainbow like pattern known as glory is often observed on Earth but to date has never been seen on any another planet. Glory is a different phenomenon from rainbow as it is produced by diffraction of light rather than refraction. Glory can only be produced by spherical particles with a narrow size distribution. The intensity profiles shown in the left panels of Figure 1 are averages over concentric rings of pixels with the same phase angle from a serious of images. These curves exhibit two relative maxima, one minimum and fairly fast decrease with increasing phase angle. Since the VMC frame angular width is about 15° in terms of a phase angle, and the angular positions of the maximum and minimum in brightness are closer in shorter wavelengths, the complete glory pattern can be seen within a single image only in UV filter.

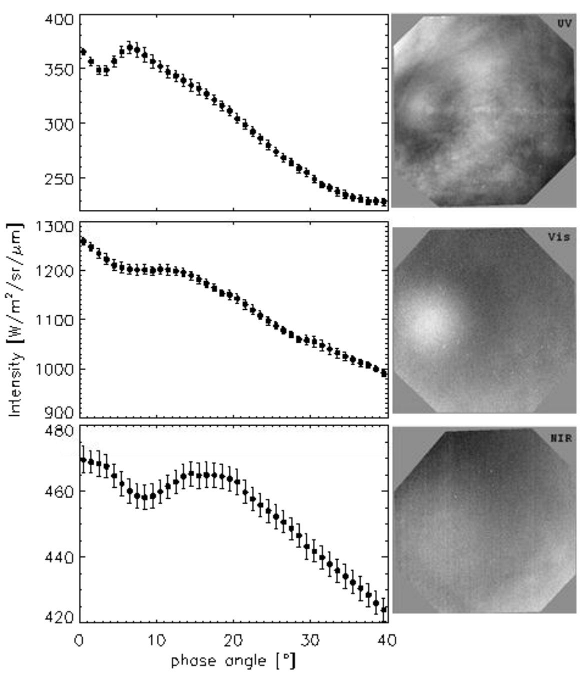

Figure 1. Venus glory as observed in three of the VMC channels (UV – 365 nm, Vis – 513 nm and NIR – 965 nm).

Analysis: From sets of successive images acquired in each of the channels, the phase dependences of brightness were retrieved in a phase range from 0° to 60° (Fig. 1 shows only the range 0°-40°). The angular positions of maximum and minimum in the glory can be confidently determined for each of the wavelengths, and they well agree with those peculiar to sulphuric acid droplets (75% concentration) with an effective radius 1.2 µm and an effective variance of 0.07, i.e. the particles of the so called mode 2 known to be present in the upper clouds of Venus [3]. This is well seen from the comparison of the measured phase profiles with the single scattering phase functions calculated for such particles. Their behavior in the backscattering domain is shown in Figure 2. Thus, we can conclude that the main contributors to the scattering at the cloud layers sounded by VMC channels, at least in the region observed during orbit 1809 (an equatorial region, close to the local noon), are the mode-2 particles.

At the same time, there is a noticeable difference in the observed glory features and those modeled for the single scattering by mode-2 droplets. This difference is in the ratio of the two primary and secondary maxima. While the calculated ratio is always significantly greater than unity, the measured values are nearly one for UV and definitely less than one for the other two channels. Radiative transfer calculations confirm that this effect survives the multiple scattering in the layer of an optical depth of 30, expected for the Venus clouds. Figure 3 compares data in NIR channel with radiative transfer models. The positions of the maximum and minimum are well reproduced but the clouds composed of sulphuric acid droplets (dotted curve) fail to provide the substantial increase of brightness at zero phase angle. Since the angular position of the glory features restricts the dominating particle size to that of mode-2, the only parameter that we are free to vary is the real part of the refractive index. Figure 3 shows that increasing refractive index to 1.48, a value significantly greater than that expected for sulphuric acid droplets, allows for a satisfactory fit to the data.

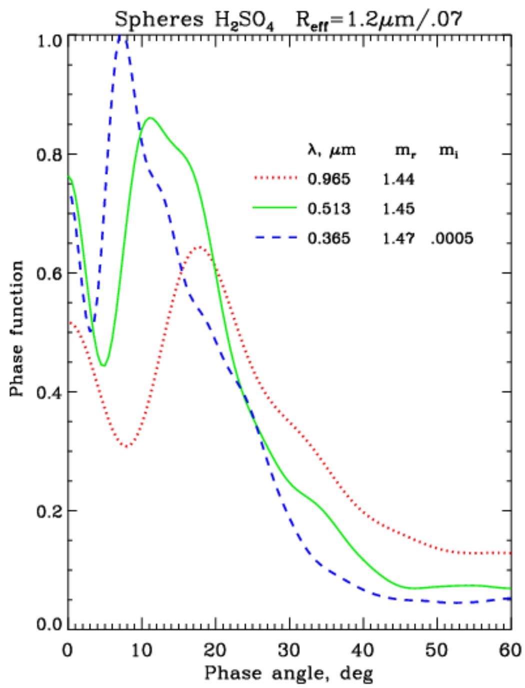

Figure 2. The single scattering phase functions in the backscattering range calculated for the mode-2 particles in three VMC wavelengths.

Discussion: We can think of two ways of increasing the refractive index of the sulphuric acid droplets. One would be to lower the cloud temperature but we estimate this effect to be much too weak. The other is to introduce an admixture of some substance with a high refractive index. This possibility seems quite reasonable, since submicron particles that are ubiquitous in the Venusian clouds and hazes can serve as condensation nuclei for sulphuric acid droplets. The nature of the haze particles is not yet clear, and it likely varies with altitude [3]. Among probable candidates iron chloride and sulphur are worth mentioning, at 0.965 µm their real refractive indices are >1.60 and 1.95, respectively. Moreover, both these materials are often suggested to be the unknown UV absorber (e.g., [4, 5, 6]). The analysis of the phase function of the clouds cannot distinguish between the two possibilities. Nevertheless, it is clear that the refractive index of mode-2 particles should be somehow increased above the standard value of 1.44 (at 250K 0.965 µm) [7] in order to fit the measurements. Our calculations of the single-scattering phase functions of layered spheres composed of sulphuric acid with a sulphur coating showed that a volume fraction of sulphur of 2-3% is sufficient. If iron chloride is added into sulphuric acid droplets, its portion should be larger, since its refractive index is lower than that of sulphur. The used value of 1.60 is however, a lower limit, and the real value could be significantly higher.

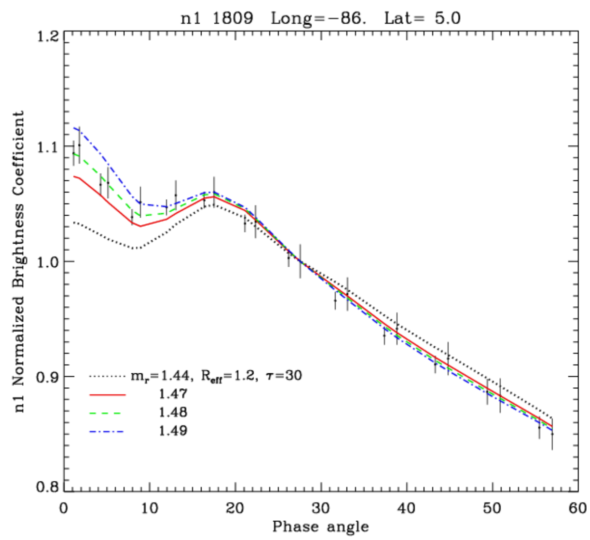

Figure 3. Measured NIR brightness compared with the model of cloud layer composed of mode-2 particles with various values of the refractive index.

References: [1] Markiewicz et al., 2007, PSS, 55, 1701-1711; [2] Svedhem et al., 2007, PSS, 55, 1636-1652; [3] Ragent et al., 1985, Adv. Sp. Res., 5, 11, 85-115; [4] Krasnopolsky, 2006, PPS, 54, 1352-1359; [5] Mills et al., 2007, in Exploring Venus as a Terrestrial Planet, AGU, Washington, USA, 73-100; [6] Toon et al., 1982, Icarus, 51, 358-373; [7] Palmer and Williams, 1975, App. Opt., 14 (1), 208-219.