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Comparison of ground-based and VIRTIS-M/ROSETTA reflectance spectra of asteroid 2867 Šteins with laboratory reflectance spectra in the VIS and IR

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Asteroid 2867 Šteins was encountered by Rosetta on September 5, 2008. During this close encounter the VIRTIS spectrometer aboard Rosetta acquired spectra of Šteins in the wavelength range from 0.2 μm to 5 μm [1]. We compare ground-based VIS and NIR reflectance spectra of Šteins [2, 3, 4, 5, 6, 7] with the reflectance spectra obtained by OSIRIS [8] and VIRTIS-M during the fly-by and laboratory reflectance spectra of enstatite achondrites (aubrites) and minerals (enstatite, oldhamite, albite).

Ground-based and fly-by observations show an overall flat spectrum with the typical E[II]-type absorptions bands at 0.49 μm and $\sim$0.9 μm. E-type asteroids have been associated to aubrites in view of their large reflectance and overall featureless spectrum. Compared to the ground-based observations the VIRTIS spectrum shows an additional absorption feature at 0.6 μm. The lack of absorption bands at 1 μm and 2 μm indicates that Šteins' surface has no Fe-bearing pyroxenes or olivines. At wavelengths $<$1 μm ground-based and fly-by spectra show slight reddening, whereas the spectra at wavelengths $>$1 μm are flat and featureless. At wavelengths $>$2.5 μm, only covered by VIRTIS, the spectrum is also flat and featureless, except for wavelengths $>$3.5 μm that are affected by thermal emission which contributes significantly to the detected radiation.

Our laboratory reflectance spectra of aubrites fit the overall characteristics of the Šteins spectrum, but are unable to reproduce the prominent 0.49 μm absorption band. The amount of oldhamite, showing a band at 0.49 μm and thus considered as a possible component of the surface material [9], needed to reproduce the 0.49 μm absorption band in ground-based spectra [3, 6] is $>$40% and is not consistent with the composition of aubrites. Oldhamite is only an accessory phase with abundances usually $<$1 vol% [10]. Nevertheless individual oldhamite-rich clasts have been described for the several aubrites [11, 12, 13]. This implies that the formation of very oldhamite-rich lithologies is possible and that these lithologies exist on the aubrite parent body. Furthermore, it cannot be ruled out, that Ti-rich pyroxenes instead of oldhamite are the source of the 0.49 μm absorption feature [14]. Ti-rich and Fe-poor pyroxenes associated with Fe-poor material are up to now only found in calcium- and aluminum-rich inclusion (CAIs). Pyroxenes in type B CAIs in Allende are characterized by a high amount of TiO_2 (up to 17.5%), Al_2O_3 (up to 21.4%) and low FeO ($<$1%) abundances [15]. Spectra of type B CAIs extracted from Allende show an absorption feature around $\sim$0.48 μm and a weaker feature at $\sim$0.66 μm [16]. Šteins and other E[II]-type asteroids could therefore also represent Fe-poor lithologies with significant amounts of type B CAIs. This indicates two completely different formation scenarios for Šteins: Either Šteins was formed under reducing conditions, preventing Fe to be incorporated into the silicates (i.e., Šteins is an evolved differentiated body composed of oldhamite with aubrites or enstatite) or Šteins was formed before Fe-bearing phases condensated from the solar nebula (i.e., Šteins resembles a primordial undifferentiated body composed of CAIs).

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