REDUCED IRON GRAINS FROM NANO- TO MICRON SIZES IN LUNAR AND MERCURIAN REGOLITHS: CALCULATION OF SPECTRAL EFFECTS WITH MIE THEORY. L. V. Starukhina and Yu. G. Shkuratov, Astronomical Institute of Kharkov University, Sumskaya 35, Kharkov, 61022. Ukraine, starukhina@astron.kharkov.ua

Introduction: Studies of lunar soils showed that space weathering of silicates results in reduction of iron and formation of metallic iron grains ranging from nano- (nFe^0) to submicron and micron (μFe^0) scale [1]. In immature soils, nFe^0 is dispersed in the 100-200 nm-thick rims of regolith particles, typical diameter of nFe^0-grains being 3nm [2]. Mature soils contain both nFe^0 and μFe^0 all over the particle volumes, Fe^0 in agglutinitic glasses averaging up to 0.17μm in diameter [3].

μFe^0 forms in so called ripening process, when the larger grains grow at the expense of the smaller ones. The process occurs at high temperatures, most quickly in impact melt. Lunar soil particles with embedded μFe^0 were melted for short times and still contain much nFe^0 that is an effective light absorber. This makes lunar soil particles with μFe^0 too dark to enable μFe^0 to control the optical properties of the Moon. On Mercury, more intensive meteoritic bombardment may convert nFe^0 to μFe^0 more efficiently, enabling μFe^0 to become significant for optical properties of the surface.

Spectral effects of growth of Fe^0-grains embedded into transparent powders were studied experimentally in [4]. Laboratory measurements show variations in reflectance and spectral shapes as a function of size. However, the size distributions are difficult to control and they are likely to be bimodal. Large Fe^0-grains formed mostly at the surfaces of pores that are paths of enhanced diffusion. Thus the experiments give mostly qualitative information.

In the presents study, spectral effects of Fe^0-grains in size range from nm to μm are simulated with Mie theory and modified version of the model of spectral albedo for regolith-like surfaces [5].

Calculation of optical spectra of powders with embedded Fe^0 grains: Fe^0–grains in regolith particles are known to be spherical. Absorption and scattering coefficients of particles with such grains can be calculated with Mie theory provided that complex refractive indices n of Fe^0–grains are known. To avoid resonance effects, size distribution of ripening grains [6] was taken into account (Fig.1).

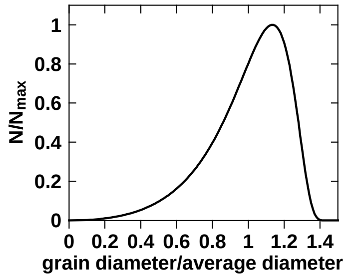

Fig.1. Size distribution of ripening Fe^0-grains according to ripening theory [6].

The spectral model [5] was modified to take internal scatterers into account. Since the absorption coefficients α of regolith particles are proportional to volume fraction c of the embedded Fe^0-grains, the optical density of the soil particles $\tau = \alpha l \propto lc$, l being particle size, so reflectance R of a soil and the shape of spectral curves are controlled by the value of lc.

Fig.2 shows calculated optical characteristics of regolith particles with embedded Fe^0 as functions of grain diameter d at different wavelengths λ. At a given λ, α first grows with d, then decreases (Fig. 2*a*), because large grains ($d >> \lambda/4\pi|n|$) are opaque and strong light absorption changes to light scattering (Fig.2*b*). Such behavior was qualitatively described in [7] and called "overmaturation". The maxima on α(d) curves correspond to minima on R(d) curves (Fig.2*c*,*d*) that shift to larger d at longer λ.

Fig.3 shows calculated reflectance spectra of bright material with embedded Fe^0-grains of different sizes d for all range of lc typical of lunar soils. The change of spectral shapes with grain size is the same as observed in experiments [4] (here UV

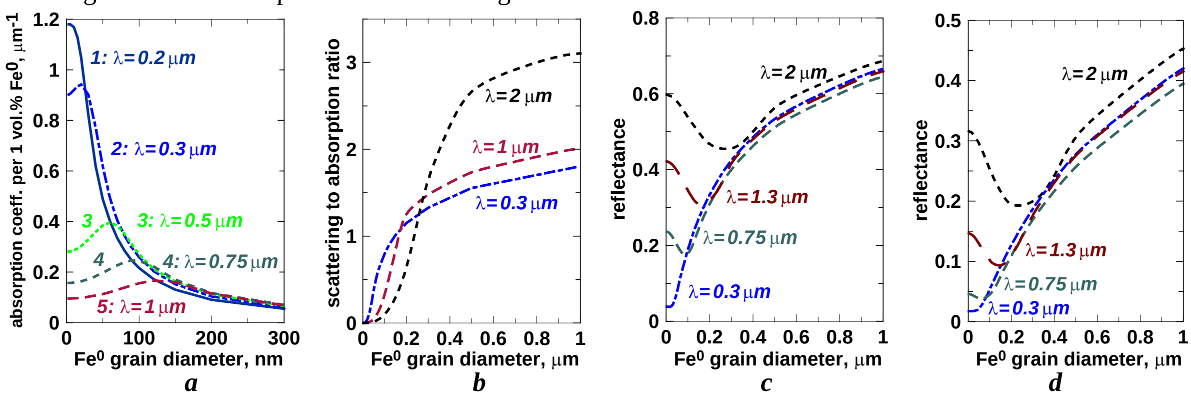

Fig.2 Grain size dependence of optical properties of regolith particles with embedded Fe^0-grains at selected wavelength λ: absorption coefficient at 0.1 vol.% Fe^0 (*a*), scattering to absorption ratio (*b*), reflectance at lc =1 (*c*) and 5 (*d*) μm·vol.% Fe^0.

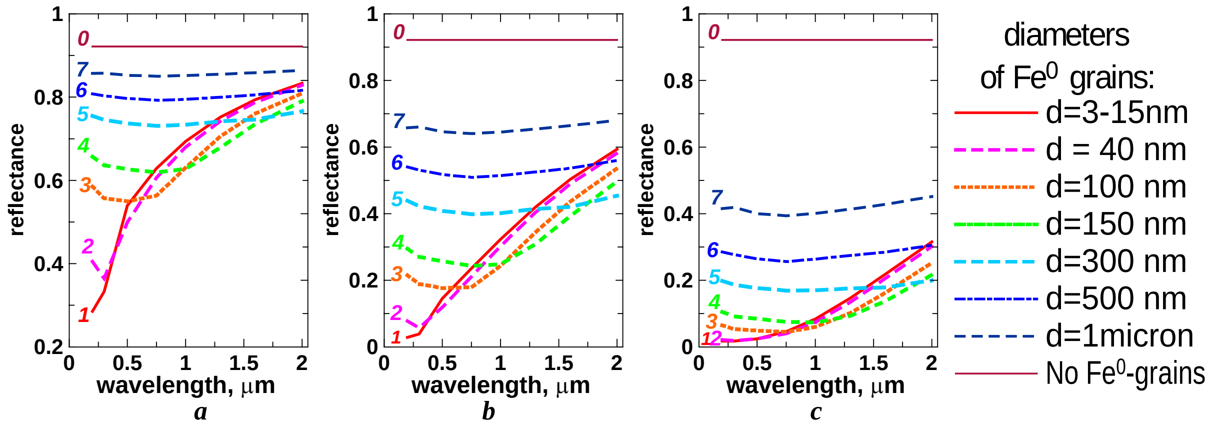

Fig.3 Calculated reflectance spectra of Fe^{2+}-free featureless bright material with embedded Fe^0-grains of different sizes; values of *lc* being 0.1 (*a*), 1 (*b*), and 5 (*c*) μm·vol.% Fe^0.

range 0.2-0.3μm is added). Calculations enables us to determine more exactly the critical sizes *d** of Fe^0-grains above which regolith becomes brighter compared to that with nFe^0-grains. For typical *l* and *c*, *d**= 30, 40, 100, 250, and 750 nm at λ = 0.2, 0.3, 0.5, 1 and 2 μm, respectively.

In Fig.4 the effect of addition of Fe^0 of various sizes for Fe^{2+}-bearing lunar-like material is presented. As shown, the growth of nFe^0 to 0.1μm crucially changes the spectra in the visible range; and >1μm grains do not essentially affect the spectra in 0.3-2μm range.

Implication to spectral variations on Mercury: We modeled spectral variations on Mercury in the same way as those for particle size fractions of lunar soils [5]. Spectrum of mature soil is calculated from that of immature one by decreasing particle size and adding Fe^0-grains. For lunar spectra, this is possible by adding nFe^0 only [5]. To reproduce the spectra [10] of dark areas on Mercury starting from those of overlaying crater rays, presence of μFe^0 is required.

Conclusions: Modification of the model of spectral albedo [5] and Mie theory enabled us:

(1) to determine "overmaturation" sizes of Fe^0-grains embedded into regolith for different wavelengths,

(2) to estimate $\mu Fe^0/nFe^0$ ratio from the optical spectra of particulate surface,

(3) to find spectral evidence for the dominance of μFe^0 over nFe^0 on Mercury.

Acknowledgment: I thank M. A. Kreslavsky and L. V. Moroz for discussions. This study was supported by CRDF grant UKP2-2897-KK-07.

References: [1] McKay D. S. et al. In: Lunar sourcebook. Eds. Heiken G. H. et al. N. Y., 1991, p.285-356. [2] Keller, L. P., Clemett, S. J. (2001) *Lunar and Planet. Sci. 32th* Abstr.#2097. [3] James C. et al. (2002) *Lunar and Planet. Sci. 33th* Abstr. #1827. [4] Noble S. K. et al. (2007) *Icarus 192*, 629-641. [5] Shkuratov Yu. G. and Starukhina L. V. (1999) *Icarus 137*, 235-246. [6] Lifshitz I. M. and Slyozov V. V. (1961). *J. Phys. Chem. Solids 19*, 35-50. [7] Starukhina L. V. and Shkuratov Yu. G. (2003) *Lunar and Planet. Sci. 34th*, 2003. Abstr. #1224. [8] Pieters, C. et al. (1993) *J. Geoph. Res. 98*, 20817-20824. [9] Warell, J., and D. T. Blewett (2004). *Icarus 168*, 257-276. [10] McClintock W. E. et al., *Science 321*, 62-65.

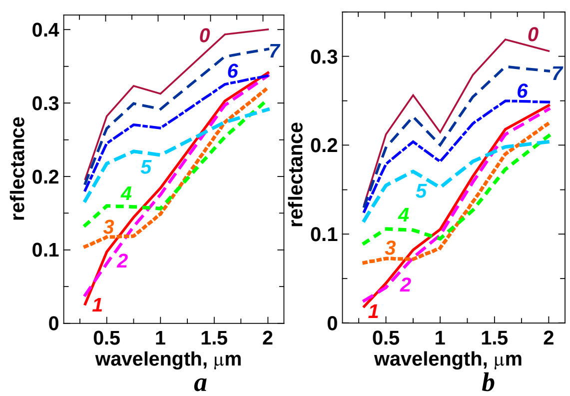

Fig.4 Theoretical simulation of adding 0.1 vol.% of Fe^0-grains of different sizes (see Fig. 3 for the legend) to immature lunar highland (*a*) and mare (*b*) soil particles; spectra of the initial material (0) were calculated from those of 45-95μm size fractions [8] at particle sizes *l* = 22μm.

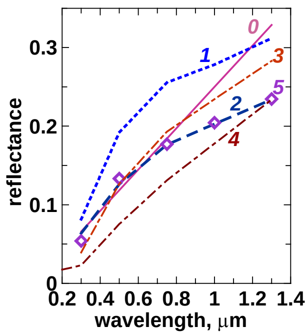

Fig.5. Simulation of spectrum of a dark area on Mercury (2) (scaled to Warell spectrum [9] (*0*) at 0.4μm) starting from spectrum of overlaying bright ray (1) [10]. For lines (3), (4) only nFe^0-grains were added (*c*·= 0.5 and 1.2 vol.% Fe^0, respectively); diamonds (5) show the result of addition of both nFe^0 (0.4 vol.%) and μFe^0 (>1 vol.% of 0.2 to 0.5μm grains); particle sizes was decreased by 10% for all model curves.