CALCULATIONS OF OPTICAL EFFECTS OF THE LASER EXPERIMENT IMITATING SPACE WEATHERING OF THE COSMIC BODY SURFACES. D.Shestopalov[1] and S.Sasaki[2], [1]Shemakha Astrophysical Observatory, Shemakha, Azerbaijan 373243 (shestopalov_d@mail.ru). [2]Department of Earth and Planetary Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan (sho@eps.s.u-tokyo.ac.jp).

Optical features of the material forming surfaces of atmosphereless celestial bodies withered with age by reason of space weathering process. To accurately interpret the reflectance spectra of these kinds of planets there is need of the correct laboratory experiments simulating optical maturation of their surfaces and acceptable theoretical models of light scattering. In this work we decided to test the agreement between the results of the laser experiments simulating micrometeorite bombardment of the planetary surface [1] and the predictions of the model of spectral albedo of regolith-like surface [4].

Experiments. Pulse laser irradiation of the pyroxene and olivine samples under a vacuum makes for formation of the submicroscopic reduced iron inclusions (SMFe) in the particle rims [3]. In turn, these iron inclusions (space-weathering product on real planetary surfaces) affect the reflectance spectra of mineral samples [1,2]. To calculate correctly this effect it is important to take into account the conditions of the experiment. Mineral samples were ground and separated to a particle size < 75 µm. Then the powdered samples were packed into dense pellets and exposed to laser treatments under various energy of 1, 15, 30, 30×5, and 30×10 mJ. Bidirectional reflectance spectra of the pellets before and after laser treatment in the wavelength region from 250 to 2500 nm were recorded at every 10 nm. Observational geometry was set up to simulate that of telescopic asteroid observations: an incidence angle of 30° and an emission angle of 0°. Below we confined ourselves to spectral data for San Carlos Olivine (Fo_{91}) as far as its spectral properties are more sensitive to laser treatment than pyroxene ones.

Theory. The geometrical-optics model [4] establishes simple link between albedo A and optical density τ of the powdered surface. The model parameters are: l – average optical pathlength in the material, n – imaginary part of the complex refractive index of the particle, q – volume part of the material, filled by particles. Basing on laboratory spectral and photometric measurements authors [4] conclude that brightness coefficient (reflectance) at arbitrary phase angle γ is $R=A\times f(\gamma)$, where phase function $f(\gamma)$ is normalized at 5°.

Calculations. Taking into account the conditions of experiment we believe that reflectance law of olivine samples is very intimate to Lambert's law ($f(\gamma)$ is practically constant at γ from 30° to 5° and $\lambda \geq 350$ nm), q = 1 for the pellets and n = 1.6 for olivine for $350 \leq \lambda \leq 2500$ nm. SMFe inclusions are situated near the surface of the olivine particle within a layer having thickness t. Let Δs be the portion of the area of particle occupied by this layer and c_1 - volume concentration of SMFe in the layer. According to [4,5] optical density of such particle is $\tau_w = \tau_h + \tau_{Fe}$ or $\tau_w = \alpha_h l + \beta_{Fe} c_1 \Delta s\ 2t$, α_h being absorption coefficient of host material (olivine in our case) and β_{Fe} - specific (per unit of SMFe volume concentration) iron absorption coefficient and l – approximately average particle size.

At first optical constants n_{Fe} and k_{Fe} from [6] and the formula for β_{Fe} from [5] were employed to calculate the spectra of the irradiated olivine pellets. We calculated τ_h by olivine spectrum and attempted to approximate spectra of the altered olivine pellets varying $b = 2c_1\Delta s\ t$. However unsatisfactory results have been obtained since difference between the calculated and measured spectra proved too large. We supposed that either calculations with the expression for β_{Fe} obtained in [5] within in framework of Maxwell-Garnett theory are not quite precise or there is some effect that has been not taken into consideration.

To study the form of SMFe absorption coefficient function the differences $\Delta\tau^i = \tau^i_w - \tau_h = \beta_{Fe} b^i$ were obtained, where τ^i_w were calculated by the altered olivine spectra (i=15, 30, 30×5, and 30×10 mJ). These curves shown in Fig.1 change position with respect to each other because b^i increases together with growth of the laser irradiation energy.

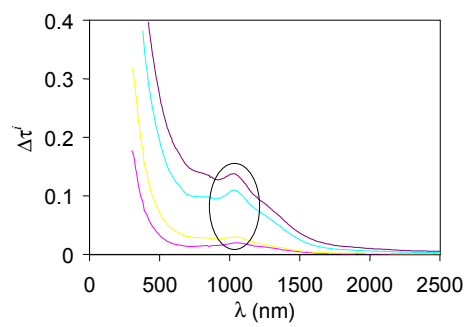

Fig.1. $\beta_{Fe} b^i$ curves were calculated by the altered olivine spectra. Oval marks the detail of olivine spectrum (residue of 1000 nm absorption band) that distorts these curves.

Besides, the curves contain the details of olivine spectrum (the rest of 1000 nm absorption band, for example). Hence, ordinary differences as $\tau^i_w - \tau_h$ do not allow calculating $\beta_{Fe} b^i$ values with acceptable accuracy.

Suppose, l increases with the irradiation treatment. The reason (as observed in SEM images [2]) lies in that smaller grains are preferentially lost from the altered surface by evaporation and scattering. Apparently the larger irradiation energy is, the more intensive process runs. In that case it is necessary to subtract some value of $\alpha_h lk$ ($k > 0$) from difference $\tau^i_w - \alpha_h l$. So, $\tau^i_w - \tau_h(1+k) = \beta_{Fe} b^i$. Changing k, one may attempt to put olivine spectrum details out of $\beta_{Fe} b^i$ curves. To exclude b^i from these curves the normalized values $\beta^0_{Fe} = \beta_{Fe}(\lambda)/\beta_{Fe}(\lambda_0)$ at λ_0=550 nm are used. Black curves in Fig.2 show that one may find such k in order that to exclude the residues of olivine spectrum from SMFe scaled absorption coefficient. Moreover, k is equal for spectra of the altered samples, which were

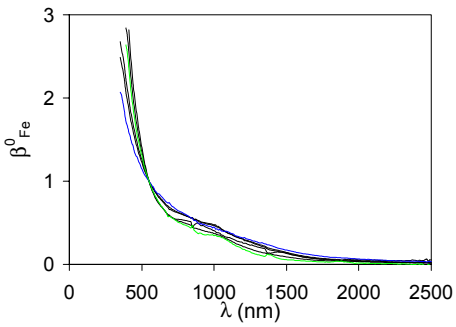

Fig.2. Scaled absorption coefficient of iron inclusions without details of olivine specrtum; k=0.46 for the samples obtained by laser irradiation of 15 and 30 mJ and k = 1.7 for 30x5 and 30x10 mJ. Color marks curves calculated by close olivine spectra.

obtained at near energy of laser treatment. Therefore we have additional opportunity to obtain two new estimations of β^0_{Fe} not using parameter k. These results (blue curve and green) are shown in Fig.2, too.

Then we calculated average of β^0_{Fe} using individual curves presented in Fig.2. To exclude the occasional oscillations of the points of the average curve, it was smoothed by the polynomial of degree 5 starting with λ = 1360 nm. This result is shown in Fig.3 together with analogous data from [5].

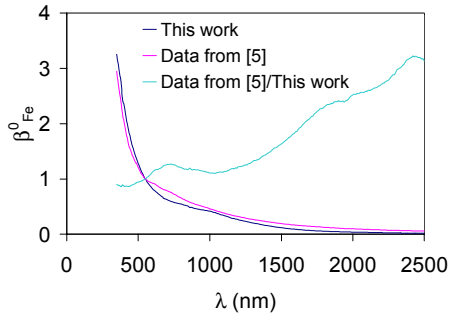

Fig.3. Average scaled absorption coefficient of iron inclusions, which was obtained in this work and according to [5]. Ratio of the curves is shown in ordinate axis, too.

We see strong growth of ratio "β^0_{Fe}[our work]/β^0_{Fe}[5]" at λ > 1200 nm, but apparently it is ordinary picture at comparison of experimental and theoretical SMFe scaled absorption coefficients (see Fig.10 in [5]).

Now, it makes sense to return to the altered olivine spectra simulation. To calculate the nonscaled absorption coefficient of the iron inclusions let β^0_{Fe} be equal 22.3 at λ = 550 nm in accordance with Hapke [2]. Results of simulation are shown in Fig.4. The calculated altered olivine spectra are in satisfactory accordance with

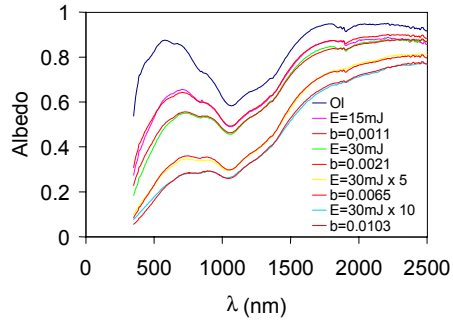

Fig.4.The measured and calculated spectra of the olivine at various values b=2$tc_1\Delta s$ and SMFe absorption coefficient from this work; k = 0.4 for spectra obtained at E = 15 mJ and 30 mJ; k = 2 for spectra obtained at E = 30 mJ×5 and 30 mJ×10.

measured ones. The change of the olivine spectra with growth of the irradiation time connected with laser irradiation is conditioned by increasing both SMFe concentrations in the particle rims and average particle sizes.

References: [1] Yamada M, et al. (1998) *Antarctic Meteorites 23*, 173-176. [2] Yamada M, et al. (1999) *Earth, Planets, and Space 51*, 1255-1265. [3] Sasaki S., et al. (2001) *Nature 410*, 555-557. [4] Shkuratov Yu., et.al (1999) *Icarus*, *137*, 235-246. [5] Hapke B. (2001) *JGR*, *106*, 10039-10073. [6] Johnson P.V. and Christy R.W. (1974) *Phys. Rev.B, 9,* 5056-5070.