CONDENSATE DEPOSITS OF $npFe^0$ AROUND FRESHEST LUNAR CRATERS? V. G. Kaydash[1], Y. G. Shkuratov[1], G. Videen[2], and V. V. Korokhin[1], [1]Institute of Astronomy, V.N. Karazin National University, 35 Sumskaya St, Kharkiv, 61022, Ukraine, vgkaydash@gmail.com, [2]Space Science Institute, 4750 Walnut St. Suite 205, Boulder CO 80301, USA.

Introduction: Lunar craters with sizes on the order of 10-100 m may reveal bright halos and rays that are the result of excavation of subsurface materials. Since fresh materials ejected from craters consist of immature soils, they are generally brighter than the surrounding region. A smaller number of dark-haloed and dark-rayed small craters on the Moon also have been observed. It is considered that these may relate to the excavation of dark subsurface materials [1] and/or high roughness of the ejecta blanket surface [2]. We here suggest an additional explanation of this feature, considering dark halos as a manifestation of thin layers of nanophase iron ($npFe^0$) condensates forming in impact processes. We study this scenario using LROC NAC images of 0.5 m resolution [3] for several fresh craters that have been formed on March 17 and September 11, 2013. In our analysis, we also include a crater created by the impact of the Ranger-9 spacecraft [4].

Data and processing: There are several suitable images acquired by the LROC NAC before and after impacts, making possible a photometric investigation of fresh craters and their halos and ray systems. We process the selected NAC images by converting raw data into radiance factor, making selenographic reference and calculation of photometric angles for each pixel in the frames. All the frames are mapped into a common cartographic projection with an effective spatial resolution of 1 m/pix. To derive temporal ratio images, we use an image acquired after impact, dividing it by an image obtained before crater formation. That is we perform coregistering of two suitable images with sub-pixel accuracy and obtain the ratio image by dividing their corresponding pixels [5]. This procedure demands a preliminary unification of source images, and it is desirable to use components with the same phase angle α.

Results and Discussion: Temporal-ratio imaging may allow elimination of the albedo surface variations, providing high-contrast differences of two images. This technique works well when the component images are taken at similar illumination geometries, i.e. incidence and azimuth angles. Using pre-impact M183689789L and post-impact M1129645568L images, we have calculated a temporal ratio (after/before) using images acquired at α~40° for a scene including the crater formed on March 17, 2013 (Fig. 1). We note the following characteristics: the high-reflectance zone at radial distance <20 m, then the dark-halo mostly extends in the north-east direction up to 50-80 m beyond the inner high-reflectance zone. The next high-reflectance zone consists of separate bright rays distributed on average almost homogeneously in azimuth and extends up to several hundreds of meters. The dark halo can be interpreted as an effect of high roughness of the ejecta blanket surface [2], since the phase angle is rather large. However, we also see the dark halo in the temporal-ratio images obtained at α=20º.

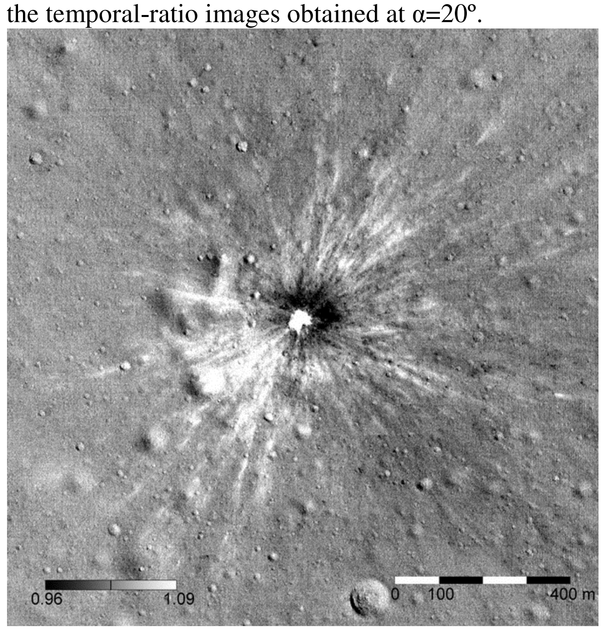

Figure 1. Temporal ratio image of a crater created on March 17, 2013 at α=40°.

The same result with dark halo and rays has been obtained for the crater with a diameter of 34 m created on September 11, 2013. The distribution of the temporal ratio was calculated using images acquired at α=22° (before) and 25° (after). We may interpret the image shown in Fig. 2 as the temporal ratio, since the difference between α of the components is only 3º.

The Ranger-9 impact created a 15-m crater with dark rays; the craters from Apollo 13 and Ranger-6 reveal analogous features [4]. The brightness image from LROC NAC shown in Fig. 3 corresponds to α = 39°. This crater reveals dark rays. The inset shows this site before the impact, which was acquired by the Ranger-9 camera P4 on March 24, 1965 from a height of 1.67 km. In this case, unfortunately, there are no suitable components to calculate a temporal ratio.

Nevertheless, we consider the dark features around craters shown in Figs. 1-3 as a manifestation of the same processes of crater formation.

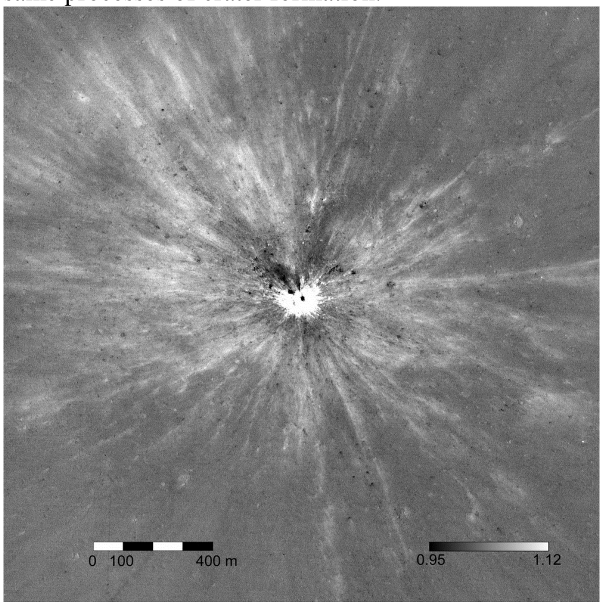

Figure 2. Temporal-ratio image of the crater created on September 11, 2013.

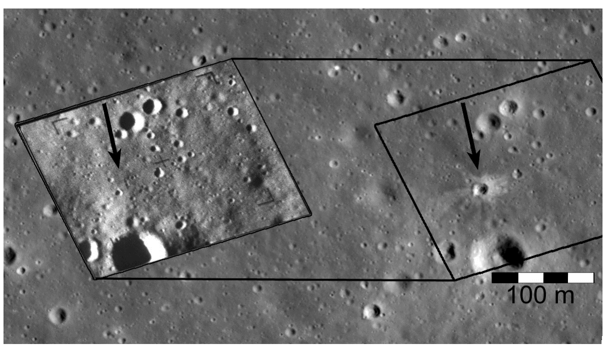

Figure 3. Images of the Ranger-9 impact site before (inset) and after crater formation.

We may assume that the dark halos and rays are deposits of a dark material excavated at the impacts. However, it seems strange that the freshest craters, including those that were formed by spacecraft [4], have a dark material layer beneath the surface. Thus, we may conclude that the dark halos and rays may be formed during the process of crater formation and do not relate to the impact excavation.

Hyper-velocity impacts produce different physical effects such as melting and vaporization of the impactor and target. We suppose that a small portion of this vapor may condensate around craters producing films that ubiquitously can be found on the surface of regolith particles [6]. These films mainly consist of nanophase iron ($npFe^0$) particles of 10 nm size. This iron is an effective chromophore [e.g., 7]; even 4% of such $npFe^0$ globules in a monolayer may provide a noticeable darkening (see Fig. 10 in [8]).

If the mass of an impactor is taken to be 20 kg (i.e. even less than the lower limit of the model assumption of 33 kg [1] for the March 17 crater), then at velocity v = 25-30 km/c, the quantity of vapor can be estimated [9] to be on the order of 100 kg for the studied craters. We assess that the needed amount of $npFe^0$ to generate the optical effect is on the order of 100 g of nanophase iron spread in an area with a radius of 70 m. Thus, only 10^{-3} of the evaporated mass is necessary to produce dark halos; whereas, the precipitated portion of the vapor is estimated for such conditions to be 5 kg [10]. If we assume that iron consists of 10% of the precipitate vapor mass, the 5 times reserve in the estimate still remains. An experiment with ilmenite evaporation has shown that the vapor can permeate many layers in a powdered surface before precipitation [11]. This may significantly increase the optical effectiveness of the condensate coating. Nevertheless, these possible deposits should be very thin, and they should quickly disappear because of micrometeoroid reworking of the regolith. This is why such dark ($npFe^0$) halos can be revealed mainly in the case of very young craters.

Conclusions: We have detected several different photometric features around two new lunar craters formed on March 17 and September 11, 2003. The halos of both studied and spacecraft impact [4] craters are dark. This may relate to condensed thin films from impact vaporization products. Rough estimates suggest that only 100 g of $npFe^0$ is needed to generate the optical effect if the iron is spread in an area with a radius 70 m around a crater in a layer of 10 nm thickness.

References: [1] Robinson M. et al. (2015) *Icarus* 252, 229–235. [2] Kaydash V. G. et al. (2014) *Icarus* 231, 22–33. [3] Robinson M. et al. (2010) *Space Sci. Rev.* 150. 81–124. [4] Kaydash V. G., Shkuratov Y. G. (2012) *Solar Syst. Res.* 46, 108-118. [5] Kaydash V. G. et al. (2012) *J. Quant. Spectrosc. Radiat. Trans.* 113, 2601–2607. [6] Hapke B. (2001) *J. Geophys. Res.* 106, 10,039–10,073. [7] Noble S. et al. (2007) *Icarus* 192, 629–642. [8] Shkuratov Y. G. et al. (1999) *Icarus* 137, 235-246. [9] Melosh H. J. (1989) *Impact cratering. A geologic process.* Oxford University Press, New York. [10] Svetsov, V. (2011). *EPSC* Abstracts, v. 6, EPSC-DPS2011-857. [11] Starukhina L. V. et al. (1999) *Solar Syst. Res.* 33, 212-215.