LABORATORY MEASUREMENT OF THE PHASE FUNCTION OF NATRITE. Jian-Yang Li[1], R. M. Nelson[1,2], J. C. Castillo-Rogez[3], M. D. Boryta[2], K. S. Manatt[3], C. L. Vides[2,4], J. Quinones[2,5], C. T. Russell[6], C. A. Raymond[3], [1]Planetary Science Institute (jyli@psi.edu), [2]Mt. San Antonio College, [3]California Institute of Technology, Jet Propulsion Laboratory, [4]California Polytechnic State University at Pomona, [5]California State University at Los Angeles, [6]University of California at Los Angeles.

Introduction: Spectroscopic observations of Ceres by the VIR instrument onboard the Dawn spacecraft revealed bright carbonate deposits as a major mineralogical component of the Cerealia Facula, the extremely bright spot inside the Occator crater [1]. The carbonate spectral absorption center positions of the facula agree with those of natrite (Na_2CO_3) [1]. The Cerealia Facula and Occator crater region has been suggested to be associated with water outgassing [2], and haze has been suspected to exist above the bright region [3], although others argued that the photometric behavior of the facula is not unusual for high-albedo material [4]. In order to clearly characterize the photometric behavior and the physical and mechanical properties of the bright materials inside the Cerealia Facula, Dawn performed observations very close to the opposition geometry, with a minimum phase angle of <1º [5]. In order to help interpret the low-phase observational data of the bright deposit on Ceres, we measured the phase functions of natrite of various grain sizes in laboratory with a goniometer, and analyzed the photometric behavior of the samples, in particular the dependence of the opposition surge with respect to grain size.

Data: The data were taken on the goniometric photopolarimeter located at the Department of Earth Science and Astronomy at Mount San Antonio College, Walnut CA. The wavelength of the incident radiation is 0.635 μm. The instrument and methods of data acquisition are described in [6]. The measured phase functions of natrite are shown in Fig. 1.

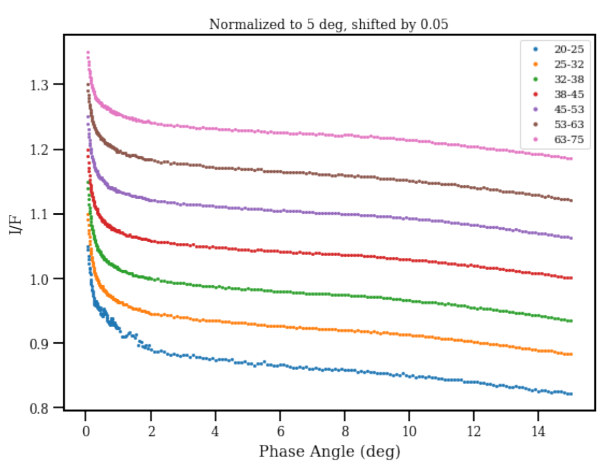

Figure 1. The lab measured phase functions of natrite with in 7 size bins from 20 μm to 75 μm. The y-scale is arbitrary, and phase functions are shifted vertically for clarity. Phase functions change with grain size systematically.

Empirical Modeling: We fitted the phase function with two empirical models. The first empirical model is based on the observations that the measured phase functions appear to contain four components: two linear segments at 4º-8º and 10º-15º phase angle ranges with different slopes, and two exponential segments at 0.5º-2º and at <0.5º phase angle ranges. Therefore, we decide to use the following form of model to fit the data at phase angles <10º,

$$f(\alpha) = A_1 \exp\left(-\frac{\alpha}{\alpha_1}\right) + A_2 \exp\left(-\frac{\alpha}{\alpha_2}\right) + B_0 + B_1\alpha,$$

where α is phase angle, A_1, α_1, A_2, α_2, B_0, and B_1 are constant model parameters. We call this model "double-exponential-linear model" or "DEL model". The only purpose of this model is to describe and characterize the measured phase functions, without any physical rationales, although the parameters may reveal some physical implications. It may be reasonable to regard the two exponential terms might represent two components of opposition surge from shadow-hiding and from coherent backscattering.

The second empirical model is referred to as PSIMTSAC1 function as adopted by Nelson et al. in their most recent work [6], and takes the form

$$f(\alpha) = \cos\left(\frac{\alpha}{2}\right)[a\exp(b\alpha) + c\exp(d\alpha)],$$

where a, b, c, and d are model parameters. This model contains two exponential components, one to describe the opposition and the other to describe the overall shape of phase function.

We fitted the phase functions to both models, and used the results to study the dependence of phase function on grain size, or the size parameter $2\pi r/\lambda$, where r is the grain size of samples, and λ is wavelength, which is 0.635 μm for our experiment. Overall the DEL model describes the data better than the second one. This is simply because the DEL model contains more components and parameters that are specifically designed to describe the measured phase function than the second model. The results about the grain size dependence on the phase functions as derived from both models are consistent with each other.

The opposition surge can be characterized by the model parameters. The strength of the opposition surge can be measured by comparing the actual phase function with a linear phase function extrapolated from outside the opposition (α>4º in our case). We followed the approach adopted by [6], and use the height parameter, which is the excess brightness at 0º phase angle above the linear phase function, and the opposition area, which is the area of the actual phase function above the linear phase function. For the natrite samples that we measured, the strength of opposition surge monotonically decreases with grain size (Fig. 2), consistent with the behaviors of highly reflective samples Al_2O_3 [6].

The width parameter of the opposition effect can be characterized by parameter α_1, α_2 of the DEL model, or the *b* or *d* parameter of the PSIMTSAC1 model that is associated with the narrower exponential term. For the DEL model, the width parameter of the wide surge shows a minimum at medium grain size of 38-45 µm, while that of the narrow surge is almost independent of grain size (Fig. 3). In addition, the linear slope of phase function outside of the surge is probably steeper for smaller grains (longer wavelength). Qualitatively the phase curve behavior of natrite is consistent with that of highly reflective particulate media measured under similar conditions. As particle size decreases, the height and width of the opposition surge increases. The area under the phase curve increases in a similar fashion as that described for Al_2O_3 in [6]. However, the smallest particle size fraction available for natrite is still many times larger than the wavelength of the incident radiation. Smaller particle sizes of natrite were unavailable

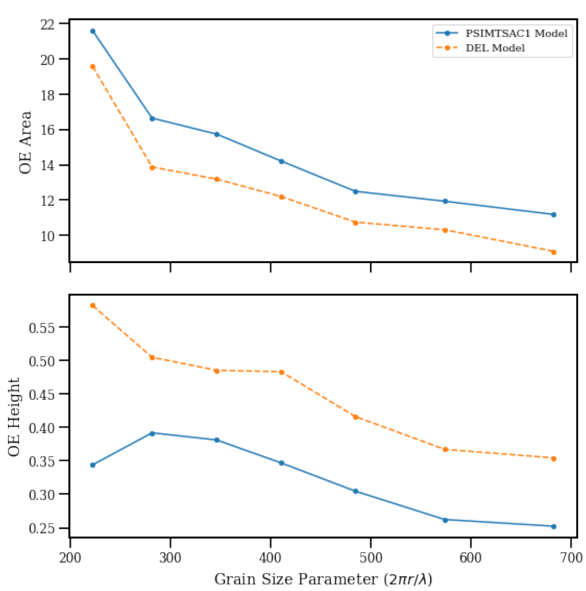

Figure 2. The strength of opposition surge represented by the area (upper) and the height (lower), as described in the text. Both models result in an overall decreasing trend with grain size parameter for the opposition strength.

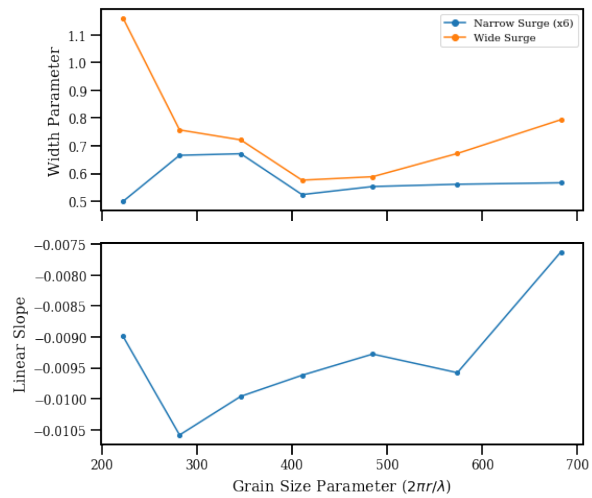

Figure 3. The width of opposition surge (upper) and the linear slope of the phase function outside of opposition surge (lower), based on the DEL model. The width of narrow surge plotted in the upper panel is multiplied by 6 for clarity.

due to the lack of particle sorting capability for particles smaller than 20 µm. Therefore, we are limited to speculating that the phase curve behavior of natrite is similar to that of Al_2O_3 for the particle sizes approximating that of the wavelength of the incident radiation.

Conclusions: The phase functions of natrite of seven grain size bins from 20-75 µm were measured with a laboratory goniometer from 0.05º to 15º phase angle. The phase functions all show two linear segments with two slightly different linear slopes outside of the opposition surge, and a wide exponential component starting from phase angle 2.5º and a narrow exponential component within phase angle 0.5º. The strength of opposition monotonically decreases with grain size, while the width parameter shows a more complicated dependence with grain size. These data will be used to characterize the phase function of the Cerealia Facula near the opposition collected by Dawn camera.

References: [1] De Sanctis, M.C. et al. (2016) *Nature, 536,* 54. [2] Nathues, A. et al. (2015) *Nature, 528,* 237. [3] Thangjam, G. et al. (2016) *ApJL, 833,* 25. [4] Schröder, S.E. et al. (2017) *Icarus, 288,* 201. [5] Schröder, S.E. et al. (2017) *EPSC 2017,* Abstract #866. [6] Nelson, R.M. et al. (2018) *Icarus, 302,* 483.

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