PHOTOMETRIC STUDIES OF EROS FROM NEAR DATA. Jianyang Li, M. F. A'Hearn, L. A. McFadden, *Department of Astronomy, University of Maryland, College Park MD 20742, USA, (jyli@astro.umd.edu).*

Introduction: Phase functions of small bodies are related to their surface physical properties and are of importance in establishing thermal balance. However, for asteroids, the irregular shapes make it ambiguous in defining their phase functions. Previous studies [1,2] showed that, without the knowledge of their shapes, the most common way of constructing phase functions from the means or the maxima of lightcurves could lead to errors if the phase function is fitted by a disk-integrated Hapke phase function [3] assuming a spherical shape.

The NEAR mission provided us with tremendously detailed data with very high resolution. The multispectral imager (MSI) onboard the NEAR spacecraft acquired images covering phase angles between 50° and 120° from visible wavelengths through near-infrared, with resolution less than 20 m/pix. From these images, the shape model of Eros was obtained [4]. Then using the shape model, the geometric effect could be separated from photometric properties with very high accuracy [5,6]. In this paper, the MSI images taken through the F1 filter centered at 550nm have been used, combined with earlier ground based photometric data at phase angles <60° [7,8], to construct an improved photometric model for Eros.

Simulation Results: Eros has a very irregular shape at all scales from craters as small as several meters to the global deviation from a sphere. Using Eros's published shape model [4] and photometric parameters [5], we calculated theoretical rotational lightcurves at solar phase angles <60°. Then the phase functions constructed from the theoretical lightcurve maxima and lightcurve means were fitted, with a spherical shape and smooth surface assumed, to see how well the original photometric parameters could be recovered. Simulations indicated that if the lightcurve maxima were used, the single-scattering albedo (SSA) would be overestimated by more than 40%, and the asymmetry factor g in the one-term Henyey-Greenstein single-particle phase function could be more forward-scattering by a comparable amount as well. If the lightcurve means were used, the resultant SSA and g will still be biased by small amounts. However, it is surprising that the opposition effect amplitude B_0 and width h could be recovered very accurately, with less than 3% and 10% error, respectively, from the phase function constructed from the lightcurve maxima. These results from simulations are of importance in indicating how we should use the ground-based lightcurves in photometric analysis.

Photometric Results: According to Hapke's theory [3], if the 5-parameter form of the bidirectional reflectance function is used, then photometric data at various phase angles will make different contributions in fitting those parameters [1]. For Eros's published photometric model, the photometric data around 60° phase angle contribute the least in fitting the g factor. Their contribution to fitting the opposition effect parameters is also negligible. Therefore the MSI images taken between phase angles 55° and 65° and at about 10 m/pix resolutions were used to fit the SSA and global roughness parameter $\bar{\theta}$. The resultant SSA of 0.33 is much smaller than the the published value 0.43 at this wavelength [5]. The global roughness parameter was estimated to be 27°, comparable with Clark's result of 24° [6], but different from Domingue's result of 36° [5].

Within the phase angle range covered by NEAR MSI F1 filter images, the contribution of the opposition effect is negligible. Therefore, once an accurate SSA and global roughness parameter were obtained, the next step was to estimate the asymmetry factor of the single particle scattering function. We found a g factor of -0.28, which is comparable with the published result of -0.29 [5].

The opposition effect parameters had to be fitted using photometric data at low phase angles, where there was no coverage by the NEAR MSI images. The ground based observations [7,8] were then used. The lightcurve maxima were used to construct a phase function as indicated from the simulations. In response to recent evidence that Eros's opposition effect includes both the shadow hiding component (SHOE) and coherent backscattering component (CBOE) [9, 6], the amplitude of opposition surge was allowed to exceed unity in the fit. We obtained an estimate of B_0=1.38, and h=0.015. These photometric parameters in turn yielded a geometric albedo of 0.25, and a Bond albedo of 0.097, compared to 0.29 and 0.12, respectively, from the previous study [5].

Discussion: The photometric properties of Eros were previously studied by Domingue et al. at 550nm [5], and in the near-IR through 2.2μm by Clark et al. [6]. Our results can be compared with Domingue's directly, and compared with Clark's through the slope of the reflectivity. Our value of the SSA is less than the value Domingue et al. found. Considering the result of our simulations that the real SSA should be slightly smaller than the one fitted from the mean of lightcurves, a smaller SSA is more acceptable. The smaller SSA, and the corresponding smaller geometric albedo and Bond albedo, also move Eros closer to the values of average S-type asteroids [1,10]. It is consistent with the red slope shown in Eros's spectrum from the visible wavelength to near-IR as well [6].

According to the simulations with the shape model, our resultant g factor should be a little more back-scattering than that in [5] because of the different techniques used. However, we found that when the phase function was constructed in [5], the phase angles of the reflectance data between 65° and 90° for the NEAR MSI images were possibly underestimated, meaning that the small reflectance values at phase angles >90° were moved to this range in the fit. With the correct reflectance data at phase angles <60° from ground based observations, the consequence was that the phase function used in [5] to fit photometric parameters became more back-scattering than it would have been if all phase angles had been calculated correctly, which then cancelled the underestimate of back-scattering introduced by the method of fit as shown by the simulations. By coincidence, this left no bias in the fitted g factor.

The opposition parameters have greater uncertainties than the other parameters, because of both the lack of photometric data near opposition and the exclusion of CBOE in the currently used model. Physically, the amplitude parameter for either SHOE or CBOE should not exceed unity [3,5]. The published B_0=1 [5,6] reflects this physical constraint. However, more and more evidence shows that there exists a strong CBOE component in Eros's opposition effect [6]. The simplest way to include this effect is to allow B_0 to exceed unity, while keeping everything else unchanged. This resulted in an estimate of B_0 greater than 1, which confirmed the existence of CBOE as well. A narrower width parameter was derived to compensate for the increase of the estimated B_0.

The global roughness parameter $\bar{\theta}$ is an average of the unresolved surface slope variations, thus it is strongly influenced by the sizes of areas over which the bidirectional reflectance were averaged. In our study, the image footprint size was comparable to what was used in [6]. While in [5], the whole-disk averaged reflectance was used to construct a phase function. This makes a reasonable explanation of the comparison of our result with previous ones in [5,6]. The different global roughness parameters at different scales may be an indicator that the distribution of slope varies on the surface of Eros as the scale size of interest changes.

Conclusions: To summarize, we have done the photometric analysis of Eros at 550nm. The single scattering albedo, asymmetry factor of the single-particle scattering function, and global roughness parameter were estimated from NEAR images acquired in the orbital phase. The opposition parameters were fitted from ground-based observations, and analyzed and evaluated by theoretical simulations. We found a geometric albedo of 0.25 and a Bond albedo of 0.097, slightly smaller than previous results, which makes Eros more similar to a typical S-type asteroid. The fitted amplitude of the opposition effect is greater than 1, which is consistent with the existence of the coherent backscattering opposition effect. With the estimate of all photometric parameters and the high resolution images from NEAR, a full albedo map of Eros's surface can be constructed, which is now in progress.

References: [1] Helfenstein et al. (1989) Asteroid II, 557-593; [2] Li et al. (2003), 35th DPS meeting, 24.04; [3] Hapke (1993) Theory of Reflectance and Emittance Spectroscopy, Cambridge University Press; [4] Thomas et al . (2002) *Icarus*, **155**, 18-37; [5] Domingue et al. (2002) *Icarus*, **155**, 205-219; [6] Clark et al. (2002) *Icarus*, **155**, 189-204; [7] Harris et al. (1995) 26th LPSC, 553; [8] Krugly et al. (1999) 30th LPSC, 1595; [9] Hapke (2002) *Icarus*, **157**, 523-534; [10] Helfenstein et al. (1996) *Icarus*, **120**, 48-65; [11] Helfenstein et al. (1994) *Icarus*, **107**, 37-60.

Table Caption: Photometric parameters for Comparable Objects. These parameters were derived for different wavelengths: Eros in this paper and [5] 550nm, Eros in [6] 950nm, Gaspra and Ida 560nm, S-type average V-band.

	w	B_0	h	g	$\bar{\theta}$	$A_{geometric}$	A_{Bond}	Ref
Eros	0.33	1.38	0.015	-0.28	27	0.25	0.098	This paper
Eros	0.43	1.0	0.022	-0.29	36	0.29	0.12	[5]
Eros	0.42	1.0	0.022	-0.26	24	0.26	0.13	[6]
Gaspra	0.36	1.63	0.06	-0.18	29	0.22	0.11	[11]
Ida	0.22	1.53	0.020	-0.33	18	0.21	0.071	[10]
Avg S-type	0.23	1.32	0.02	-0.35	20	0.22	0.084	[1,10]