THE OPPOSITION EFFECT OF THE MOON FROM SMART-1 AMIE DATA. ***V. Kaydash***[1], ***M. Kreslavsky***[2], ***Yu. Shkuratov***[1], ***S. Gerasimenko***[1], ***P. Pinet***[3], ***S. Chevrel***[3], ***J.-L. Josset***[4], ***S. Beauvivre***[4], ***B. Foing***[5], *and AMIE Smart-1 team,* [1]Astronomical Institute of Kharkov University, Sumskaya 35, Kharkov, 61022 Ukraine. kvg@vk.kh.ua; [2]University of California, Santa Cruz, CA, USA, [3]UMR 5562/CNRS/ Toulouse III University, Midi-Pyrenees Observatory, 14 Av. E. Belin, 31400 Toulouse, France. [4]Space Exploration Institute (CH-2002 Neuchâtel, Switzerland) [5]ESA/ESTEC (Keplerlaan 1, 2201 Noordwijk, The Netherlands)

Introduction: The opposition effect is a sharp increase of brightness of the lunar surface with the decrease of phase angle from ~10° to 0. Variations of the opposition spike amplitude and width depend on the size of regolith particles and their optical heterogeneity, thus bearing information about the lunar regolith structure in the upper mm-thick layer. Images obtained in 2005-2006 by the Advanced Moon Micro-Imager Experiment (AMIE) camera onboard SMART-1 spacecraft allow access to low phase angle data. In this paper we use AMIE data to study the opposition spike for several sites and estimate the steepness of phase function in the phase angle range $\alpha = 0 - 2.5°$.

AMIE photometric data: During the lunar and extended phase of SMART-1 mission [1], about 32000 of color (750, 915 and 960 nm) and wideband (no-filter) lunar images were obtained with the AMIE micro-imager [2]. Spatial resolution of the images varies from tens to hundreds of meters. The quality of AMIE images is sufficient for estimation of the phase function parameters and search for photometric anomalies [3]. A few images in the whole AMIE dataset contain the zero-phase-angle point. In the images the bright diffuse opposition spot is complicated by albedo variations over the scene. The problem is to separate the opposition brightness variations from the albedo pattern. We apply here the method of phase ratios, which had been successfully applied to the Clementine data [4]. In that method, the ratio of two images of the same scene (one of them contains the zero-phase-angle point, another is taken at a larger phase angle) is used to eliminate albedo pattern on the resulting image.

The absolute photometric calibration of the AMIE data is still under development. Fortunately, using the preliminary calibration [5] with updates based on in-flight data [6] we are able to convert raw counts to the values proportional to the bidirectional reflectance. This is sufficient to make phase-ratios and normalized phase dependence of brightness. The signal-to-noise ratio is higher for the no-filter area than for color-filter data, thus we deal in this study only with the clear filter frames. The latest versions of AMIE SPICE kernels [7] allow calculating the selenographic and photometric coordinates for each pixel in the frames.

Derivation of phase functions: To derive phase functions from image pairs we performed three main steps: (1) coregistering two images of the same scene which were obtained at different phase angles, (2) calculation of the ratio of the coregistered frames, and (3) averaging the ratio image in concentric bins (with the center at the zero phase angle point) to determine the phase curve. We show in Fig. 1 an example of phase ratio processing. Fig. 1a presents the reflectance image 2376/7 (2376 is the SMART-1 orbit number, 7 is the image number within the orbit) with albedo pattern masking the opposition spot. The phase angle ratio 2376/7_2244/6 (phase angles:~0°/~30°) clearly shows the opposition spot with largely removed albedo pattern (Fig. 1b). Ratio also contains differently illuminated topographic features such as crater walls, pits, ridges. These details spoil the phase ratio and were excluded from the averaging. Then we averaged the ratio for a number of concentric zones of constant phase angle in the opposition image (Fig. 1c).

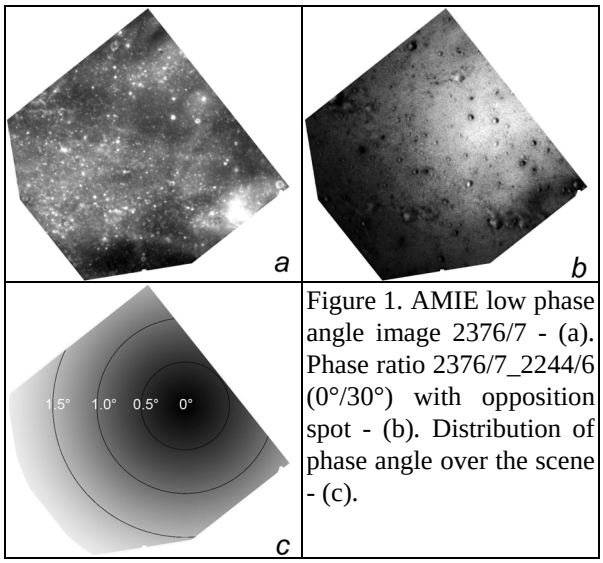

Figure 1. AMIE low phase angle image 2376/7 - (a). Phase ratio 2376/7_2244/6 (0°/30°) with opposition spot - (b). Distribution of phase angle over the scene - (c).

This method demands the position of the zero-phase-angle point in the frames to be known with accuracy higher than can be derived from the available positioning and orientation data. Following [4], we calculated the zero-phase-angle point position as the most probable center of symmetry of the ratio image and used the coordinates derived to find the phase function.

We considered two orbits in the AMIE dataset (2363 and 2376) containing frames with zero phase angle and corresponding to larger phase angles. First

area we studied is a mare region in western Procellarum west to the Reiner Gamma Swirl (RGS). This area [8] includes "pure" mare basalt surface, portions of south-western "tail" of RGS, and ejecta from the nearby highland crater Cavalerius (Fig. 2a). Second area also belongs to the mare surface type (north of Montes Carpatus and west of Pytheas crater, Fig. 2b) with distinct markings of distal Copernicus ejecta.

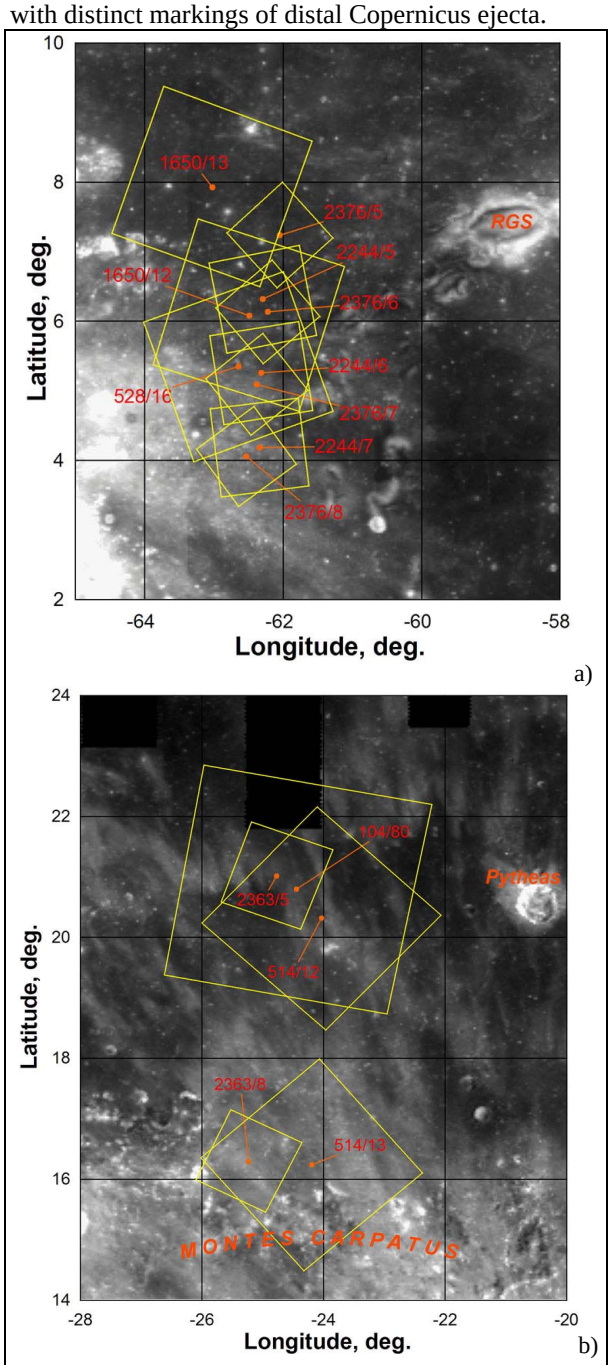

Figure 2. Selenographic reference for AMIE frames (yellow squares) used in current study. Orbit/image numbers are shown. (a): western Procellarum region. (b): area northern Carpathian Mountains.

Resulting phase functions are presented in Fig. 3. The data are less reliable at the phase angles <0.2° and >2°, where statistics is poor. Curves show a monotonic increase from 2.5° to 0 with some diversity of slopes. We believe this diversity is a real effect and reflects variations of amount of craters ejecta material in the scenes.

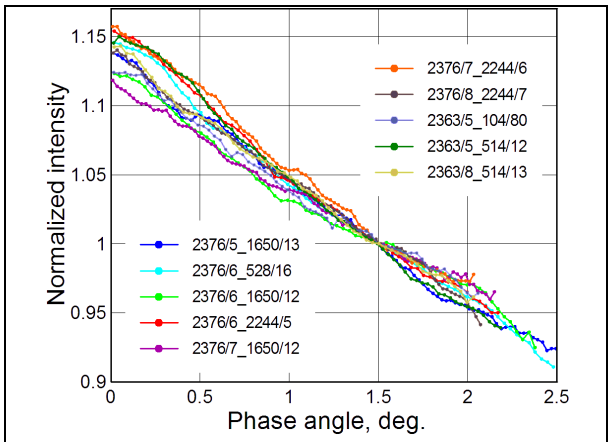

Figure 3. Phase functions derived for areas shown in Fig. 2. The source phase ratios for each curve are presented in upper and lower insets. Each curve is normalized at 1.5° phase.

In this work we dealt with wide-band filter images, thus we cannot estimate spectral dependence of opposition spike parameters. Nevertheless the average phase slope of 13-14% at 0 - 1.5° phase angle range is in quantitative agreement with previous opposition spike studies using Clementine data [4]. We averaged all curves presented in Fig. 3 and show the values of the averaged phase function F(α) in table below.

α,°	0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0
F (α)	1.119	1.093	1.067	1.043	1.021	1.00	0.98	0.964

Conclusions: AMIE photometric data allow studying the lunar opposition effect for a limited number of sites and estimate the phase function slope at phase angles in 0°-2.5° range. The value of the slope of average phase function derived from SMART-1 AMIE data is in agreement with previous Clementine opposition spike data. Joint analysis of Clementine UVVIS and AMIE data [9] give an opportunity to increase amount of data suitable to study the opposition spike.

References:[1] Foing B.H., et al. (2006) *Advances in Space Res.*, 37, 6–13. [2] Pinet P., et al. (2005) *Planet. Space Sci.* 53, 1309. [3] Kaydash V., et al. (2007) *LPSC* XXXVIII, Abstract # 1535. [4] Kreslavsky M. A., et al. (2000) *JGR*, 105, 20281. [5] Koschny D., et al (2003) S1-AMIE-RSSD-RP-001. [6] Grieger B., (2007) ESA tech. note S1-AMIE-SGS-TN-011. [7] Dougnac V., (2007), AMIE Sci. Meeting, Rome, 31 May - 1 June. [8] Pinet P. et al. (2000) *J. Geophys. Res.*, 105, E4, 9457-9475. [9] Shkuratov Y. et al., (2003) *Sol. Sys. Res.*, Vol. 37, No. 4, pp. 251–259.