PHOTOMETRY OF HIGH ALBEDO OUTER-BELT ASTEROIDS: THE CASE OF (665) SABINE AND (863) BENKOELA. V. G. Shevchenko[1,2], O. I. Mikhalchenko[1,2], I. N. Belskaya[1,2], V. G. Chiorny[1], I. G. Slyusarev[1,2], Yu. N. Krugly[1], A. N. Rublevsky[3], E. A. Sergeeva[3], N. N. Kiselev[3], A. Novichonok[4], A. V. Kusakin[5], I. V. Rewa[5], I. E. Molotov[6], [1]Astronomical Institute of V. N. Karazin Kharkiv National University, Sumska Str. 35, Kharkiv 61058, Ukraine, [2]Department of Astronomy and Space Informatics of V. N. Karazin Kharkiv National University, Svobody sq. 4, Kharkiv 61022, Ukraine, [3]Crimean Astrophysical Observatory, Nauchnij, Crimea, [4]Petrozavodsk State University, Lenin Str. 33, 185910, Petrozavodsk, Republic of Karelia, Russia, [5]Fesenkov Astrophysical Institute, Observatory 23, 050020 Almaty, Kazakhstan, [6]Keldysh Institute of Applied Mathematics, RAS, Miusskaya sq.4, Moscow 125047, Russia, shevchenko@astron.kharkov.ua.

Introduction: Some asteroids orbited in the outer part of the main belt, where majority of dark asteroids are present, show moderate and high albedo surfaces according to radiometric data [1-4]. Knowledge of the fraction of such asteroids in the outer belt is very important for understanding formation and evolution of our Solar system. However, radiometric albedos may have rather large observational errors due to non-simultaneous visible and infrared measurements (e.g. [5, 6]). As it was shown in [7, 8], a complimentary information on albedo and composition type of asteroids can be obtained from their phase angle dependences of brightness. We initiated an observational program aimed to provide an independent check of the taxonomic type and albedo of the selected outer-belt asteroids using their magnitude-phase dependences. For our observational program we have chosen asteroids with orbital semimajor axis in the range of 2.99-3.39 AU, which belong to moderate/high albedo compositional classes or have albedos >0.1 according to the IRAS, WISE and AKARI IR-surveys [1-4]. The first preliminary results of our photometric observations of the asteroids (152) Atala, (723) Hammonia and some others were presented in [8-10]. In this work we present new measurements of the magnitude-phase dependence of the outer-belt asteroids (665) Sabine and (863) Benkoela.

Observations: *(665) Sabine*. The asteroid has an orbit with a semi-major axis of 3.14 AU, an eccentricity of 0.17, and an inclination of 14.8°. The asteroid is non-family object, but in the proper element space, it is very close to Tirela family. According to the IRAS data, its albedo is equal to 0.39 with a diameter of about 51 km [3]. The high albedo is confirmed by the of the AKARI data (0.36) [2]. The data of the WISE satellite give even higher albedo value of 0.49 [1]. In addition, the spectral reflectance of the surface of this asteroid has a slope of only 2.5% / 10^3 Å in the visual region of the spectrum without absorption bands, also inherent to high albedo E-type asteroids [11-13]. Previous photometric observations of this asteroid were carried out to determine its rotational characteristics and shape [14], but no magnitude-phase dependence was previously obtained. The absolute magnitude H of this asteroid is 8.60 mag according to the MPC.

Our observations were performed in January-May 2018 for 18 nights in the *BVR* bands and covered both the linear region and the area of the opposition effect down to phase angle of 1°. We have obtained the average values of the color indices B-V = 0.691 and V-R=0.40 mag. The maximal amplitude of the lightcurve is found to be 0.35 mag. The lightcurve variations were taken into account in the phase dependence of brightness.

The phase dependence for the maximum brightness of Sabine in the V band is shown in Figure 1. The dashed line indicates the approximation of the phase dependence of HG_1G_2-function [15, 16] with the parameters: H = 8.481 ± 0.048 mag, G_1 = 0.51 ± 0.07, G_2 = 0.18 ± 0.04.

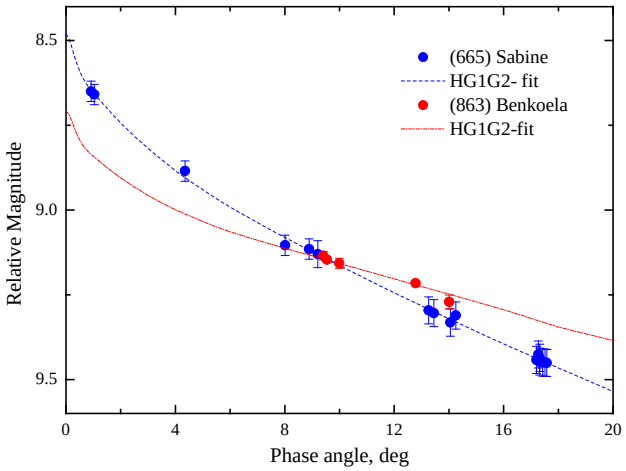

Fig. 1. Magnitude-phase dependences of (665) Sabine and (863) Benkoela in the V band. Data of (863) Benkoela were shifted on 0.68 mag at phase angle of 9.4 deg for a coincidence with the magnitude-phase dependence of (665) Sabine.

It should be noted that our estimates of absolute magnitude are close to the value given in the MPC. The linear phase coefficient β for the V band is equal to 0.032 ± 0.002 mag/deg, and the amplitude of the OE is about 0.36 mag. Using the value of the linear coefficient and the new calibrated relation between linear

coefficients and albedo [7], we estimate that the geometric albedo of asteroid (665) Sabine should be 0.19 ± 0.05. These values are typical for a moderate albedo surface and contradicts to the E-type classification.

(863) Benkoela. The asteroid has nearly circular (e=0.029) and highly inclined (i=25.4°) orbit with semi-major axis of 3.20 AU and it does not belong to any asteroid families. In the proper element space, its position is in low asteroid density region at smaller inclinations than Euphrosyne family. Morrison & Chapman [17] made the first albedo estimation (0.26) from ground-based radiometric measurements and found its similarity to moderate albedo asteroids. Other data on albedo obtained from infrared satellites IRAS (0.60, [3]), WISE (0.11, 0.79, 0.29 [1, 4]) and AKARI (0.44, [2]) pointed out a probable high albedo surface of this asteroid. The visible spectra of this asteroid has a slope of 23.3 %/10^3 Å and an absorption band at a wavelength of about 1.0 μm, that is characterized a substance consisting predominantly with olivine, so it was classified as the A-type asteroid [11-13]. It should be noted that the asteroids of A-type have typically moderate albedo. The polarimetric properties of (863) Benkoela are also close to the A-type [18] and the estimated polarimetric albedo is 0.32±0.12 [19]. Benkoela is the only one known member of this type in the outer part of main belt. Previous photometric observations of (863) Benkoela [20, 21] were performed for determination its rotational properties.

We made new photometric observations of the asteroid in October-November 2018 during five nights in the *BVR* bands to measure the magnitude-phase dependence. At present, we were able to cover only the linear region of the magnitude phase dependence down to 9.4 degree of the phase angle. The lightcurve variations did not exceed 0.05 mag. We have not confirmed the rotation periods found in [20, 21]. Further observations at other apparition are needed to determine accurate rotation period of this asteroid. We have obtained the average values of the color indices B-V = 1.11 and V-R=0.56 mag that pointed a very high spectral slope.

Since the lightcurve amplitude is small, we used an average magnitude over night to construct the magnitude phase dependence (Figure 1). The dashed red line represents the approximation of the phase dependence of HG_1G_2-function [15, 16] with the parameters: H = 9.372 ± 0.055 mag, G_1 = 0.15 ± 0.10, G_2 = 0.60 ± 0.15. These parameters are rather typical for high albedo asteroids [22]. Using correlations between parameters of G_1, G_2 and albedo [22], an estimation of albedo was done that is equal to 0.59 ± 0.20. The linear slope β of magnitude-phase dependence of (863) Benkoela is found to be β = 0.023 ± 0.003 mag/deg which similar to the phase slopes of high albedo asteroids such as (44) Nysa [23], (214) Aschera [22], and (2836) Steins [24]. Using the value of the linear coefficient and the new calibrated relation between linear coefficients and albedo [7], we estimate that the geometric albedo of asteroid (863) Benkoela should be 0.48 ± 0.10. This is in favor of high albedo surface of this asteroid. Up to now any well measured magnitude-phase relations for A-type asteroids are not available. We plan to continue the observations to cover the opposition effect region.

Conclusions: We performed the photometric observations of two outer belt asteroids (665) Sabine and (863) Benkoela and obtained their magnitude-phase angle dependences. Our aim was to check the high radiometric albedos of these asteroids. We found that the phase angle dependences of (665) Sabine and (863) Benkoela are quite different (see Figure 1). The shape and parameters of the phase curve of (665) Sabine are typical for moderate albedo asteroids, fully exclude high-albedo surface, and E-type classification. On the other hand, the slope of the phase curve of (863) Benkoela is typical for high albedo asteroids confirming high-albedo surface of this outer-belt asteroid.

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