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OBSERVATIONS OF ASTEROID MAGNITUDE-PHASE RELATIONS AT THE KHARADZE ABASTUMANI ASTROPHYSICAL OBSERVATORY

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Abstract

In the scope of the cooperative program studying asteroids between the Kharadze Abastumani Astrophysical Observatory and the Astronomical Institute of V.N. Karazin Kharkiv National University, the observations of five main-belt asteroids were performed to obtain their magnitude-phase relations and other physical characteristics. The paper presents the preliminary results of the photometrical observations for large dark asteroid (1390) Abastumani.

Key words: asteroids, CCD-observations, light curves, magnitude-phase relations

1. Introduction

The magnitude-phase relation is one of the main physical characteristics of asteroids obtained through observations. First of all, it allows obtaining the absolute magnitude of an asteroid, which on the one hand, is the basis for determining the albedo and the diameter, and is the basis for ephemerid computations of apparent magnitudes on the other hand. The magnitude-phase relation contains information about the physical properties of the asteroid's surface layer (i.e. light scattering mechanisms, albedo, roughness, porosity and refractive index of material). It is also used to determine the value of the phase integral to calculate albedo and diameters of asteroids from the emissivity in the infrared wavelength region (Masiero et al. 2011; Usui et al. 2011). All three areas differ for asteroids with different reflectivity and are formed in different scale structures of the surface: microrelief (scale up to hundreds of microns), mesorelief (up to tens of centimeters) and macrorelief (up to tenths of the average radius of an asteroid).The magnitude-phase dependence can be conventionally divided into three sections: the region of the opposition effect, which usually shows the magnitude surge at the smallest phase angles (0÷7 deg), the linear region (7÷80deg) and the nonlinear decrease region of brightness at largest phase angles (80÷180 deg). For the main belt asteroids, whose phase angles are typically less than 25-30 deg, the magnitude-phase dependence is linear down to 5-7 deg (described with a linear phase coefficient), and has the opposition effect (OE), that is nonlinear brightness increasing near opposition, usually at phase angles less than 5-7 deg. The asteroids with different albedo show distinct differences in the linear slopes and the OE amplitudes (Belskaya, Shevchenko 2000). Most of asteroids show evident of the OE, but some of low albedo asteroids do not show the OE (Shevchenko et al. 2012, 2014b; Slyusarev et al. 2014). A lack of the OE in asteroid phase dependences may indicate that these asteroids are the darkest objects in the Solar System. There is a relationship of the linear phase coefficient with a geometric albedo (Belskaya, Shevchenko 2000, 2018). This relationship is very important because it allows evaluating the asteroid albedo using photometric measurements only.

Practically, all observations of asteroids are carried out at nonzero phase angles and their absolute magnitudes can be obtained by using the special function. This function (i.e. a magnitude-phase function) can be also used in ephemeris computation of the apparent magnitude. Incorrect values of absolute magnitudes result in wrong values of albedos obtained from the data of infrared surveys (WISE, AKARI, IRAS, etc.) what were demonstrated by Pravec et al. (2012) and Shevchenko et al. (2014a). To present, a two parameter *HG*-function was used to determine an asteroid absolute magnitude (Bowell et al. 1989). But this function fits poorly the magnitude-phase relations of high- and low-albedo asteroids (Belskaya, Shevchenko 2000; Shevchenko et al. 2008, 2012). Recently, a new three parameter HG_1G_2-function has been proposed and actively used (Muinonen et al. 2010; Pentilla et al. 2016; Shevchenko et al. 2016). High-quality data on magnitude-phase relations in the wide phase angle range were obtained for less than hundred main-belt asteroids. New high-quality magnitude-phase relations for a large number of asteroids of different taxonomic classes are needed to provide a thorough check of this function.

Preliminary asteroid taxonomical classification can also be made using their magnitude-phase dependences. By measuring the slope of the magnitude-phase dependence, it is possible to distinguish between low, moderate and high albedo surfaces (Belskaya, Shevchenko 2000; Carbognani et al. 2019; Mahlke et al. 2021; Oszkiewicz et al. 2012, 2021; Shevchenko et al. 2021). The main asteroid compositional types are well distinguished in the relationship of the OE amplitude and the linear slope (see Fig. 1).

This article presents new observations of several main belt asteroids obtained in a wide range of phase angles and aimed at determining their magnitude-phase relations.

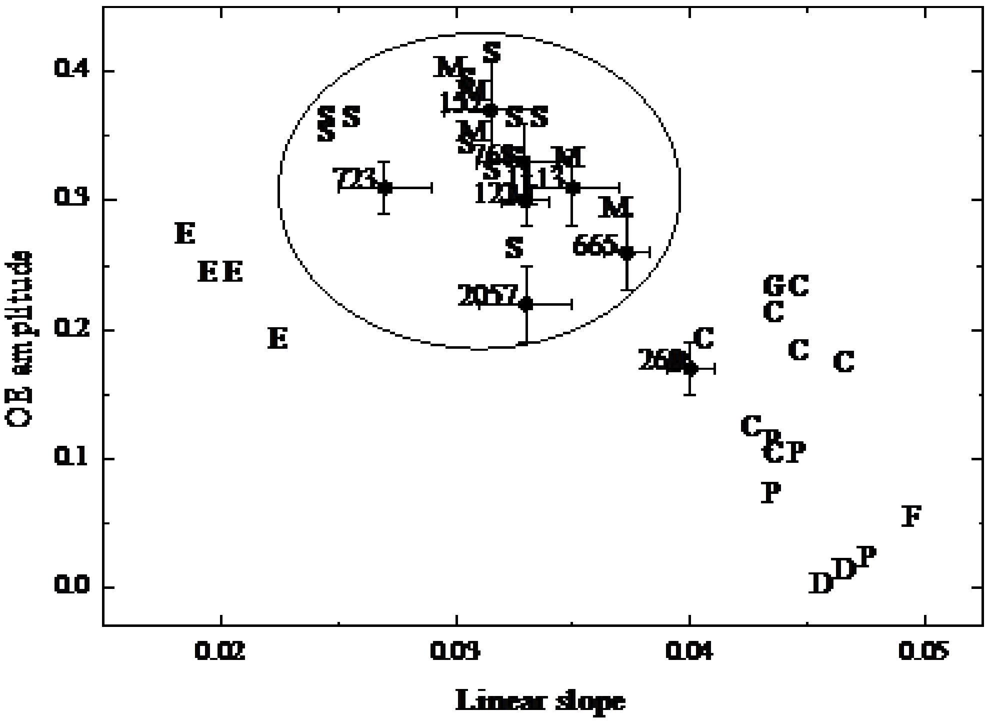

Fig. 1. Diagram of the OE amplitudes versus the linear slopes for asteroids of the main spectral classes (data taken from Belskaya, Shevchenko 2000; Shevchenko et al. 2021).

2. Observations and Results

The observations of magnitude-phase relations started at the Kharadze Abastumani Astrophysical Observatory within the scope of cooperation with the Institute of Astronomy of V.N. Karazin Kharkiv National University. The observations of magnitude-phase relations of the selected asteroids were performed in several directions: a) the study of the opposition effect of low-albedo asteroids; b) the study of the phase curves of the V-asteroids; and c) the observations of the M-asteroids. The cooperative observations were performed from October 2018 to February, 2021 for five asteroids during 62 nights. The following physical characteristics of the observed asteroids (spectral class taken from Tholen (1989); albedo and diameter taken from Masiero et al. (2011, 2012) and Usui et al. (2011) obtained in this work: rotation period, color indices *B-V* and *V-R*, and absolute magnitude) are listed in Table 1.

The CCD-observations of these asteroids were carried with a 70 cm Maksutov meniscus telescope AC-32 at the Kharadze Abastumani Astrophysical Observatory. The telescope is equipped with a FLI PL4240 Peltier-cooled CCD camera (2048×2048 pixels with size 13.5×13.5 μm). At the Institute of Astronomy of V.N. Karazin Kharkiv National University, the CCD-observations were performed at Chuguev Observation Station using a 0.7-m reflector AZT-8. The telescope is equipped with a FLI ML4710 Peltier-cooled CCD camera (1056×1027 pixels with size 13×13 μm). The images were taken in *B*, *V* and *R* bands of the Johnson–Cousins photometric system. Original CCD-frames were reduced for dark current and flat field in the standard manner. The CCD-observations and data reduction methods were explained by Krugly et al. (2002, 2016). The brightness measurements of stars on CCD-images were done using the aperture photometry package ASTPHOT developed by Mottola et al. (1995). The absolute calibrations of the magnitudes were performed with standard star sequences taken from Landolt (1992) and Skiff (2007). In some cases, for the calibration of the comparison stars, we used their magnitudes in the SDSS (*ugriz*) photometric system, taken from the APASS DR9 (Henden et al. 2012) and Pan-STARRS DR1 (Chambers et al. 2016) catalogs. To transform them to the Johnson-Cousins (*UBVRI*) photometric system, we used the corresponding equations given in Fukugita et al. (1996), and in Tonry et al. (2012). The accuracy of the resultant absolute photometry is within 0.01-0.03 mag. In the next section, we present the obtained results of the photometrical observations for large dark main-belt asteroid (1390) Abastumani.

Table 1. Physical characteristics of the observed asteroids

Asteroid	Sp. class	p_v	D km	P, hours	B-V mag	V-R mag	H mag
(439)Ohio	P	0.037	75.6	37.489±0.005	0.72 ± 0.02	0.41 ± 0.02	10.03± 0.02
(863) Benkoela	A	0.44	31.5	-	1.06 ± 0.04	0.56 ± 0.03	9.16± 0.02
(1390) Abastumani	P	0.033	98.3	13.164±0.001	0.71 ± 0.02	0.40 ± 0.02	9.42± 0.02
(2263) Shaanxi	M	0.16	22.3	-	0.81 ± 0.02	0.42 ± 0.02	12.20± 0.02
(2763) Jeans	V	0.41	7.5	7.80±0.02	0.82 ± 0.02	0.49 ± 0.02	12.38± 0.02

2.1. (1390) Abastumani

The asteroid was discovered on 3 October, 1935 by Soviet astronomer Pelageya Shajnat at the Simeiz Observatory in the Crimea. It was given the name after the Abastumani Astrophysical Observatory began working in Georgia in 1932. The asteroid is located in the outer part of the main belt with the following orbital parameters: semi-major axis of 3.438 AU, eccentricity of 0.03 and inclination of 20 deg. The asteroid is big of about 100 km, it has low albedo of the surface equal to 0.033 (Masiero et al. 2011; Usui et al. 2011), and it was classified as a rare P-type asteroid (Tholen 1989). An estimation of the rotation period (17.1 hour) was obtained by Gross (2003) using observations of April, 2002. Durech et al. (2018) using the Lowell Photometric Database reconstructed shape model of this asteroid and obtained the rotation period equal to 13.16482 hours. Besides, there are estimations of the absolute magnitude *H* from Minor Planet Center (MPC) to be 9.19 mag and those obtained by Veres et al. (2015) (*H*=9.15) from Pan-STARRS survey.

Our observations of this asteroid were carried out from October to December of 2018 and in January, 2019, for twelve nights in *B*, *V* and *R* bands of the Johnson–Cousins photometric system. The aspect data of the asteroid are presented in the Table 2. The columns present the observation data, ecliptic coordinates at epoch 2000.0, the distances from the asteroid to the Sun and to the Earth in an astronomical unit (AU), the phase angle, the reduced *R* magnitude corrected for distances from the Earth and the Sun and corresponding to the primary maxima of the asteroid light curves, and their errors. We have determined the rotation period to be 13.164±0.001 that is close to those determined by Durech et al. (2018). The composite light curve constructed with this period is pictured in Fig. 2. The maximal amplitude of the light curves is about 0.35 mag. As Fig. 2 shows, the light curve amplitude changes with an increasing phase angle. We obtained also the color indices *B-V* and *V-R*, which are given in Table 1.

The magnitude-phase relation for the maximum brightness of (1390) Abastumani in the *R* band is shown in Fig. 2. The maximum of brightness was used to consider the brightness variations of the asteroid with rotation and to build the magnitude-phase relation correctly. The absolute magnitudes of the asteroid were estimated by us by using the new HG_1G_2– magnitude system proposed by Muinonen et al. (2010), with some modifications presented by Penttila et al. (2016). For actual computations, the online calculator of the *H*, G_1 and G_2 photometric parameters (http://h152.it.helsinki.fi/HG1G2/) was used. The dashed line in Fig. 3 indicates the approximation of the phase curve by HG_1G_2-function with parameters: H_R = 8.85 ± 0.02 mag, G_1 = 0.97 ± 0.06, G_2 = 0.00 ± 0.05. The obtained values of G_1 and G_2 parameters are close to average values for the low albedo asteroids of D spectral class (Shevchenko et al. 2016). The magnitude-phase relation does not show an oppositional brightening and is linear in all ranges of observed phase angles with the linear phase coefficient equal to 0.046 ± 0.001 mag/deg. It points out very dark surface of this asteroid.

Table 2. Aspect data and measured magnitudes of asteroid (1390) Abastumani

UT Date day	λ_{2000} deg	β_{2000} deg	r AU	Δ AU	α deg	$R_o(1,\alpha)$ mag	
2018 10 05.81	32.423	-1.244	3.327	2.371	5.96	9.147	0.022
2018 10 12.81	31.119	-0.699	3.328	2.346	3.57	9.043	0.019
2018 10 14.87	30.717	-0.537	3.329	2.341	2.84	9.016	0.018
2018 10 18.04	30.082	-0.283	3.329	2.336	1.72	8.987	0.018
2018 10 19.03	29.882	-0.204	3.329	2.335	1.36	8.947	0.019
2018 10 20.84	29.517	-0.060	3.330	2.335	0.71	8.909	0.020
2018 10 29.69	27.730	0.647	3.331	2.345	2.45	9.020	0.020
2018 11 14.69	24.868	1.860	3.334	2.423	7.79	9.220	0.019
2019 01 12.70	24.626	4.892	3.345	3.151	17.08	9.688	0.020
2019 01 21.69	26.052	5.189	3.347	3.286	17.03	9.659	0.029
2019 01 23.80	26.428	5.254	3.348	3.318	16.98	9.677	0.020
2019 01 26.72	26.978	5.344	3.348	3.361	16.88	9.667	0.020

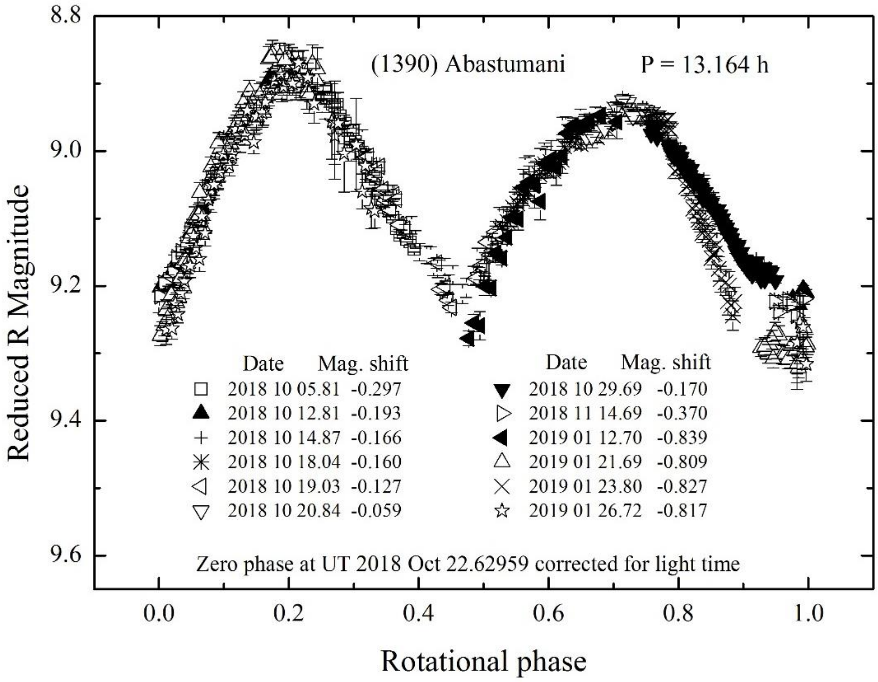

Fig. 2. Composite light curve of asteroid (1390) Abastumani

By considering the light curve amplitude and color index *V*-*R* = 0.40 mag, our estimate of the absolute magnitude in *V* band is 9.42 mag. It should be noted that our estimation of the absolute magnitude has a difference similar to those that given by the MPC (*H*=9.19) and obtained by Veres et al. (2015) (*H*=9.15).

3. Conclusions

Following the implementation of the proposed cooperative program, we performed the photometric observations of five asteroids during 62 nights. Some main physical characteristics of the observed asteroids (rotation periods, color indices *B*-*V* and *V*-*R*, and absolute magnitudes) were gained. In the given paper, we present the preliminary results of the photometrical observations of large dark asteroid (1390) Abastumani. We obtained the magnitude-phase relation for this asteroid, which did not show oppositional brightening. This is another asteroid without the oppositional effect. So far, about ten of low-albedo asteroids without nonlinear increasing of brightness down to subdegree phase angles have been detected among outer belt asteroids, Hildas and Jupiter Trojans (Shevchenko et al. 2014b; Slyusarev et al. 2014). These asteroids have a range of diameters from 50 to 200 km, and their magnitude-phase dependences are practically similar to small differences in linear slopes compared to uncertainties of measurements. All these asteroids belong mainly to the P and D spectral classes that have featureless spectra with moderate to high slope in the visual and near-infrared wavelengths. It is necessary to obtain the spectrum of (1390) Abastumani for an unambiguous classification of this asteroid.

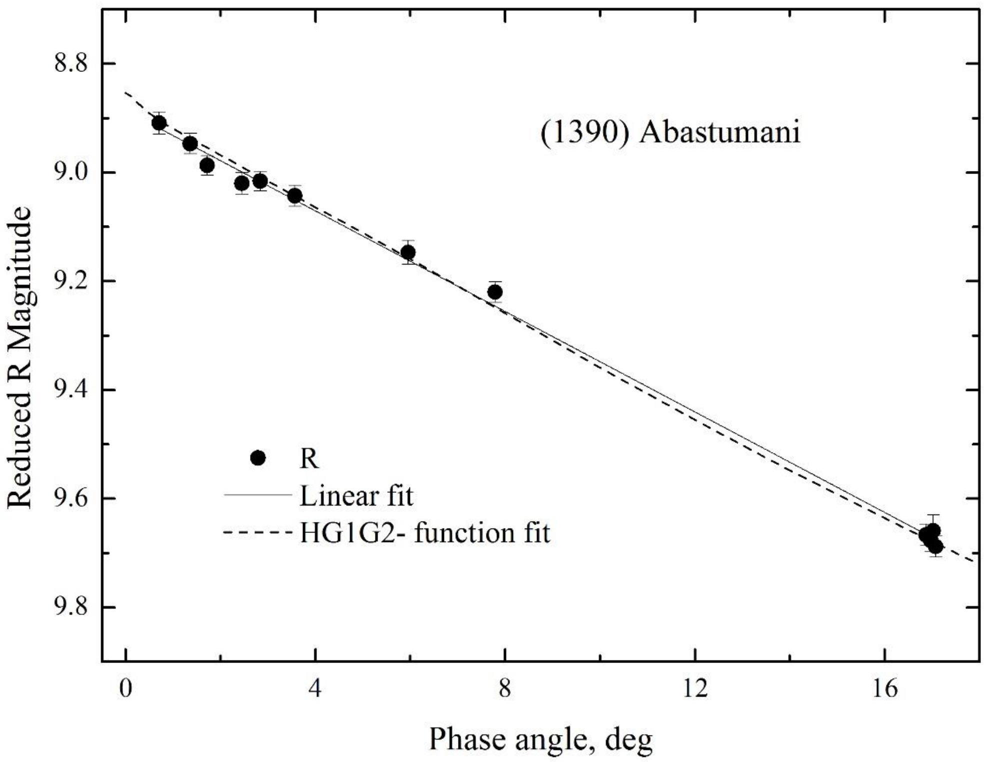

Fig. 3. Magnitude-phase relation of asteroid (1390) Abastumani

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References

Belskaya, I. N., Shevchenko, V. G. 2000, Icarus, 146, 490.
Belskaya, I. N., Shevchenko, V. G. 2018, EPSC2018-730-1.
Bowell, E., Hapke, B., Domingue, D., et al. 1989, In Asteroids II, ed. R. P. Binzel, T. Gehrels, & M. S. Matthews, 524.
Chambers, K. C., Magnier, E. A., Metcalfe, N., et al. 2016, arXiv:1612.05560, 38 pp.
Durech, J., Hanus, J., Ali-Lagoa, V. 2018, Astron. Astrophys., 617, A57.
Gross, J. 2003, Minor Planet Bull., 30, 44.
Henden, A. A., Smith, T. C., Levine, S. E., Terrell, D., 2012, AAS Meeting #220,id. 133.06.
Fukugita, M., Ichikawa, T., Gunn, J. E. et al. 1996, Astron. J., 111, 1748.
Krugly, Yu. N., Belskaya, I. N., Shevchenko, V. G., et al. 2002, Icarus, 158, 294.
Krugly, Yu. N., Ayvazian, V.V., Inasaridze, R. Ya., et al. 2016, Astron. Astrophys. (Caucasus), 1, 38.
Landolt, A. U. 1992, Astron. J., 104, 340.
Mahlke, M., Carry, B., Denneau, L. 2021,Icarus, 354, article id. 114094.
Masiero, J. R., Mainzer, A. K., Grav, T., et al. 2011. Astroph. J., 741, id. 68, 20 pp.
Masiero, J. R., Mainzer, A.K., Grav, T., et al. 2012. Astroph. J., 759, L8, 5 pp.
Mottola, S., de Angelis, G., di Martino, M., et al. 1995, Icarus, 117, 62.
Muinonen, K., Belskaya, I. N., Cellino, A., et al. 2010, Icarus, 209, 542.
Penttilä, A., Shevchenko, V. G., Wilkman, O., Muinonen, K. 2016, Planet. Space Sci.,123, 117.
Pravec, P., Harris, A. W., Kušnirak,P., et al. 2012, Icarus, 221, 365.
Oszkiewicz, D. A., Bowell, E., Wasserman, L. H., et al. 2012, Icarus, 219, 283.
Oszkiewicz, D., Wilawer, E., Podlewska-Gaca, E., et al., 2021,Icarus, 357, id. 114158.
Shevchenko,V.G., Chiorny, V.G., Gaftonyuk, N.M., et al.2008,Icarus,196, 601.
Shevchenko, V. G., Belskaya, I. N., Slyusarev, I. G., et al.2012,Icarus,217, 202.
Shevchenko, V. G., Slyusarev, I. G., Belskaya, I. N. 2014a, Meteor. Planet. Sci., 49,103.
Shevchenko, V. G., Belskaya, I. N., Slyusarev, I. G. 2014b, In Asteroids, Comets, Meteors, Helsinki, Finland, 510. ISBN 978-952-10-8962-6.
Shevchenko, V. G., Belskaya, I. N., Muinonen,K.,et al.2016,Planet. Space Sci.,123, 101.
Shevchenko, V. G., Mikhalchenko, O. I., Belskaya, I. N., et al., 2021, submitted to Planet. Space Sci.
Skiff, B. A. 2007.VizieRon-linedatacatalog:II/ 277.Originallypublished in Lowell Observatory.
Slyusarev, I. G., Shevchenko, V. G., Belskaya, I. N. 2014,In Asteroids, Comets, Meteors, Helsinki, Finland, 518. ISBN 978-952-10-8962-6.
Tholen, D. J., 1989,In Asteroids II, ed. R. P. Binzel,T. Gehrels, & M. S. Matthews, 1139-1150.
Tonry, J. L., Stubbs, C. W., Lykke, K. R. et al. 2012,Astrophys. J., 750, id. 99, 14 pp.
Usui F., Kuroda D., Muller T. G., et al. 2011, Publ. Astron. Soc. Japan, 63,1117.
Veres, P., Jedicke, R., Firzsimmons, A., Denneau, L., et al. 2015, Icarus, 261, 34.