DO TROJAN ASTEROIDS HAVE THE BRIGHTNESS OPPOSITION EFFECT? V. G. Shevchenko[1], Yu. N. Krugly[1], I. N. Belskaya[1], V. G. Chiorny[1], N. M. Gaftonyuk[2], I. G. Slyusarev[1], I. A. Tereschenko[1], Z. Donchev[3], V. Ivanova[3], G. Borisov[3], M. A. Ibrahimov[4], A. L. Marshalkina[4], I. E. Molotov[5], [1]Astronomical Institute of Kharkiv Karazin National University, Sumska Str. 35, Kharkiv 61022, Ukraine, shevchenko@astron.kharkov.ua, [2]Crimean Astrophysical Observatory, Crimea, Simeiz 98680, Ukraine, [3]Rozhen Astrophysical Observatory, Rozhen, Bulgaria, [4]Ulugh Beg Astronomical Institute, Uzbek Academy of Sciences, Astronomicheskaya 33, Tashkent 100052, Uzbekistan, [5]Keldysh Institute of Applied Mathematics, RAS, Miusskaya sq. 4, Moscow 125047, Russia.

Introduction: The majority of atmosphereless celestial bodies shows the brightness opposition effect (OE), i.e. a considerable increase of surface brightness as the phase angle decreases to zero. The amplitude of the OE defined as the relative increase in magnitude compared to the extrapolation of the linear part of phase dependence was shown to be different for objects with different surface albedo [1, 2, 3].The objects of low albedo surfaces usually display the smallest OE amplitudes [4]. Moreover, a few low-albedo asteroids were found which had not revealed an opposition surge as all [5, 6]. French [7] pointed out a possible absence of the opposition surges for Trojan asteroids 1173 Anchises and 2674 Pandarus, however these observations were rather scarce to define the OE amplitudes with confidence. To obtain detailed magnitude-phase dependences with maximal possible phase angle coverage for Trojan asteroids we have initiated a wide observational program joined efforts of four observatories. As a result of the program, we present new data on the asteroid 588 Achilles.

Observations: Asteroid 588 Achilles is a very dark object that moves around the Sun in Jupiter Langrangian point L_4 and was classified as D-type asteroid characterized by a steep red slope spectrum [8]. Its diameter and albedo were obtained from IRAS and MSX satellite data [9, 10] and equal to 135.5 km, 0.033, and 140.8 km, 0.031, respectively. The Earth-based observations in the infrared bands with the KECK telescope [11] pointed out an albedo of 0.038-0.051 and a diameter of 138.6-160.8 km depending on assumed thermal model parameters. Previous photometric observations of 588 Achilles were performed by [12, 13], however the full lightcurve was not measured. The rotation period was estimated to be equal 7 hours [13].

Our CCD- observations of 588 Achilles were carried out from July to October in 2007 and in September 2008. To decrease an influence of weather conditions and to obtain comprehensive data on the asteroid magnitude-phase dependence we performed coordinated observations from four observatories, namely Kharkiv Observatory (KhO) at the 70-cm reflector, Simeiz Observatory (SO) at the1-m reflector, Rozhen Observatory (RO) at the 2-m reflector, and Maidanak Observatory (MO) at the 1.5-m reflector. Aspect data of the observations are presented in the Table, which contains the UT date of observation, distances to the Sun and to the Earth, phase angle and observatory. The observations were carried out mainly in two spectral bands, V and R. Several observations were also performed in B and I bands to define broad-band colors of the asteroid surface. Long-term observations allowed us to obtain detailed lightcurve coverage and to determine the rotation period of 588 Achilles equal to 7.306 ± 0.002 hours. The composite lightcurve in the R band for the 2007 opposition constructed with this period is presented in Fig. 1. The maximal lightcurve amplitude is equal to 0.11 mag with about 0.04 mag difference seen between the primary and secondary maxima. We have not found any difference between lightcurves obtained in the V and R bands exceeding observational errors. Average color indexes for the 2007 opposition are found to be: B - V = 0.70 ± 0.03, V - R = 0.44 ± 0.03, R - I = 0.47 ± 0.04 mag. Observations in the 2008 opposition have shown a decrease in the lightcurve amplitude to 0.05 mag.

Table. Observational circumstances

Date	r	Δ	α	Obs.
2007 07 06.99	5.646	4.812	6.39	KhO
07 07.97	5.645	4.802	6.25	KhO
07 15.97	5.638	4.727	4.99	SO
07 17.95	5.637	4.711	4.66	KhO
08 03.99	5.622	4.617	1.54	KhO
08 05.00	5.622	4.614	1.34	KhO
08 06.01	5.621	4.611	1.14	KhO
08 10.01	5.617	4.604	0.37	KhO
08 10.95	5.617	4.603	0.20	KhO
08 11.89	5.616	4.602	0.08	KhO, RO
08 13.04	5.616	4.603	0.26	RO
08 13.95	5.615	4.602	0.43	RO
08 14.93	5.613	4.602	0.61	KhO, MO
08 15.95	5.612	4.602	0.81	KhO, MO
08 16.89	5.612	4.603	0.99	KhO
08 17.90	5.611	4.604	1.19	KhO
08 18.88	5.610	4.605	1.38	KhO, MO
08 19.89	5.609	4.607	1.57	KhO, MO
08 20.92	5.608	4.608	1.77	KhO, MO
09 14.84	5.587	4.748	6.18	KhO
10 10.75	5.564	5.044	9.23	KhO
10 17.76	5.557	5.142	9.72	KhO
2008 09 22.86	5.206	4.231	2.87	SO
09 28.85	5.200	4.253	3.99	SO

The obtained observational data let us to exclude an influence of the lightcurve on magnitude phase angle behavior and to obtain comprehensive phase curve of 588 Achilles. The phase dependences of brightness in the V and R bands are shown in Fig. 2. They cover the phase angle range from 0.08 to 9.7 deg. One can see that the magnitude linearly increases with phase angle. It can be well-fitted by linear fit with the phase coefficients of 0.045±0.001 and 0.043±0.001 mag/deg for the V and R bands, respectively. Any evidence of the opposition surge toward small phase angles has not been found down to the phase angle as low as 0.08 deg.

Conclusion: As a result of our long-term observations we have determined the rotation period and have obtained the detailed magnitude phase relations for 588 Achilles in two spectral bands. The magnitude phase dependence is found to be linear down to 0.1 deg of phase angle. We have not revealed any noticeable opposition brightening nor in the V neither in the R spectral bands. An absence of opposition surge puts constraints on the surface properties of the asteroid. Such behavior is inherent for very dark surfaces where single scattering plays dominating role. Moreover, it also excludes a fluffy structure of the surface layer of Achilles.

Recently new observations of phase curves of Trojan asteroids have been announced [14, 15] which also revealed an absence of opposition surge.

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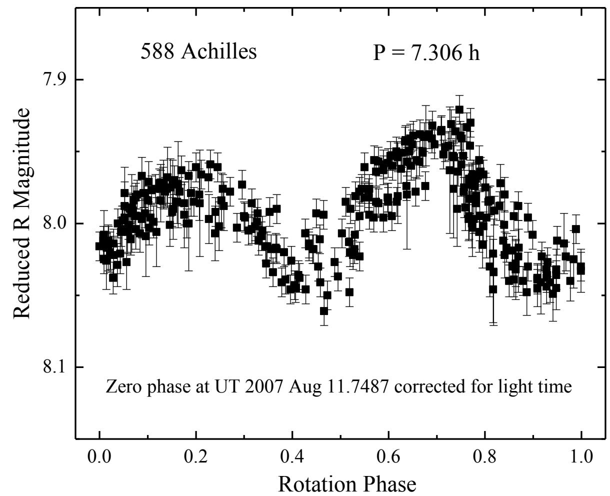

Fig. 1. Composite lightcurve of 588 Achilles

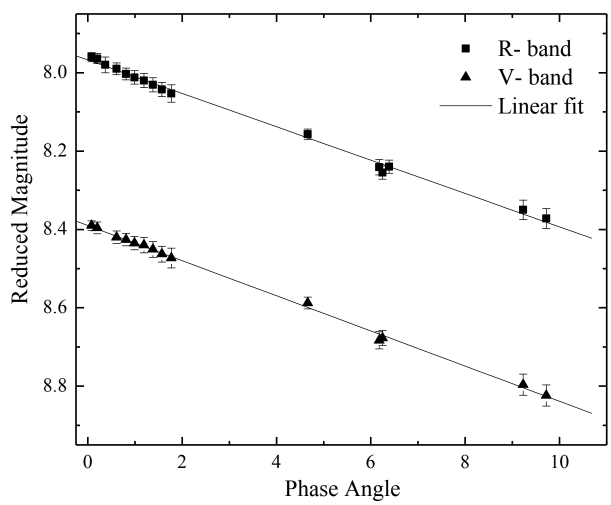

Fig. 2. Magnitude-phase dependence of 588 Achilles