ASTEROID HAZARD AND INSTRUMENTAL CAPABILITIES OF THE SHAMAKHY ASTROPHYSICAL OBSERVATORY

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The 'ability of' Shamakhy Astrophysical Observatory's 'telescopes' to detect 'near Earth' astreroids and comets in the sky-monitoring mode is considered. It is shown Maksutov's mirror-lens telescope AST-452 fits for this aim the best of all.

Keywords: asteroids hazard– sky monitoring–telescope

1. INTRODUCTION

The main belt of asteroids is located between the orbits of Jupiter and Mars, but some asteroids move on very elongated elliptic orbits and can reach the terrestrial planets. Astronomers have long realized a hazard to humanity in the Earth's collision with asteroids. The catastrophe scale depends on the size, velocity, and composition of the matter of the celestial body [1, 2].

The smaller the size of the bodies crossing the Earth's orbit, the larger there are, and the greater their collision probability with the Earth. According to current estimates, the number of near-Earth asteroids (NEAs) with diameters less than 0.5 km is approximately 100,000, of which 22,261 objects are known at the beginning of March 2020 [3]. The problem is that the orbits of the NEAs are constantly changing due to close conjunctions with the terrestrial planets, which significantly complicates long-term predictions of these bodies' potential hazard. Besides, there are significant gaps in our knowledge of NEA's physical properties (size, mass, composition of matter).

The potential hazard posed by near-Earth asteroids is crucial to our civilization's future; in this regard, the UN established International Asteroid Day (30

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June annually) to draw the public, scientists, and government's attention to this problem. The first link in the protection system against probable collisions with asteroids - the patrol of the celestial sphere to detect asteroids approaching the Earth and determine their orbits. Let us consider in this respect the capabilities of the telescopes of the Shamakhy Astrophysical Observatory, operating in the sky-monitoring mode (sky scanners).

2. THE EFFECTIVENESS OF THE PATROL-TELESCOPE

According to [4], the effectiveness of the telescope operating in the sky-monitoring mode should be directly proportional to the path S that the scanner covers in the celestial sphere during operation Q and inversely proportional to the limited illumination n [photon$\times sm^{-2} \times s^{-1}$], which is capable of registering a light detector on a telescope of these sizes. Thus, Eff ∞ S/n.

Let us choose the norming constant in the form N/2π, where N [photon$\times$ $ster^{-1}$ $\times sm^{-2}\times$ s^{-1}] - illumination from the sky in a unit solid angle, 2π - solid angle of the hemisphere. Then, as follows from work [4],

$$Eff\infty(N/n) \times (1/2\pi) \times (Ld_{px}V_5Q/F \quad ,$$

Or in the stellar magnitude scale

$$-m_{Eff} = 2.5lgEff = m - M + 2.5lg(Ld_{px}V_s/F) + Const \qquad (1)$$

Here m - the stellar magnitude of the object or star in the bandwidth of the telescope optical system; M - the stellar magnitude of the sky background in a unit solid angle in the same wavelength interval; L - the size of the side of the CCD-matrix (number of pixels); d_{px} - the linear size of the element of the CCD-matrix; V_s - the velocity of the diurnal motion of the stars; F - the effective focus of the telescope; Const - normalization constant. Earlier in work [4], two modes of operation of the patrol-telescope were considered. In continuous mode, the telescope is stationary, but sky-monitoring in the camera's field of view occurs due to the diurnal rotation of the celestial sphere. Telescope exposes a selected sky region, participating in the diurnal rotation of the celestial sphere at quasi-continuous sky-monitoring mode (S.N Blazhko's method [5]). Then the telescope's field of view is shifted under one of the coordinates on the slight angle, and the neighboring sky region is exposed. The penetrating power of the telescope in this method is turn out to be more significant since short-term exposures give dot-matrix images of both stars and fast-moving objects. As shown in [4], under the condition of quasi-continuous sky-monitoring mode, formula (1) is transformed as follows:

$$-m_{Eff} = Const - 1.25lg(k_1^2 i) + 1.25lg(D^2/F) + 2.5lg[L^{3/2}(d_{px}V_s)^{1/2}] \qquad (2)$$

Where $k_1 d_{px}$ - linear size of the star image or object on the matrix, i - the number of exposures of given sky region, D – aperture, and other designations are the same as in formula (1). It is convenient to compare the effectiveness of operation of the telescope under sky-monitoring mode with some "ideal scanner," equipped with the same receiving equipment and directed to the same region of the celestial sphere.

Let us determine the optical characteristics of this "ideal scanner" as follows. Since $D^2/F = A^2$F, we choose the relative aperture A = 1. Further, let us choose such effective focus that the size of the dot image in the focal plane to be equal to the matrix element (i.e. k_1 =1).

From the ratio

$$k_1 = \alpha" F/206265 d_{px}$$

Have F = 257.83 sm, if d_{px} = 0.0025 sm and angular size of the star's image $\alpha \approx 2"$ (approximately the average annual image quality in conditions of the astro-climate of the Shamakhy Astrophysical Observatory). It is possible to determine the operating effectiveness of the current patrol-telescope (pt) concerning the "ideal scanner" by using the formula (2):

$$Eff_{pt}/Eff_{is} = 10^{0.4\Delta m_{eff}}$$

where

$$\Delta_{mEff} = 1.25 lg A^2_{pt} F_{pt}/257.83 k^2 pt.$$

Table 1 shows the corresponding calculations for the stellar telescopes of the Shamakhy Astrophysical Observatory. It should be noted that telescopes with a "classical Cassegrain" optical scheme are unsuitable for sky-monitoring. The working effectiveness at the primary focus of the 2-meter Zeiss reflector is 12% relative to the "ideal scanner." The effectiveness is approximately 6 times higher for the telescope AST-452, which is inferior to a 2-meter reflector in penetrating capability but has a large field of view. Therefore, the mirror-lens telescope AST-452 of the Maksutov system is reasonably fit for monitoring the celestial sphere to detect NEO. This telescope has the following characteristics. The aperture - 35 cm, the effective focal length - 85.9 cm, the visual field aperture - 3°, the linear visual field - 6 × 6 cm, which accords to the linear size of the CCD-matrix with the number of elements 6000 × 6000 pixels if the average size of one pixel - 0.001 × 0.001 cm. Accordingly, the smaller the matrix size compared to the linear size of the telescope field of view, the lower the effectiveness of the patrol-telescope. Since the AST-452 telescope has an internal focus, the CCD-photometer must be located inside the telescope tube, which can adversely affect the image quality and reduce positional measurement accuracy. Therefore, we considered the short-focus astrograph RASA 279/620 capabilities as a possible replacement for

Table 1. The efficiency of stellar telescopes while scanning the sky continuously.

Telescope	Aperture (sm)	Focal length (sm)	Effectiveness (%)
AST-452	35	85,9	70.6
Zeiss-600	60	700	5,2
AST-8	70	1100	3,1
Zeiss-2000	200	2900 a)	2,1
Zeiss-2000	200	900 b)	11,9
Astrograph RASA 279/620	27.9	62	91.8

a) Cassegrain focus

b) Primary focus

the telescope AST-452. This astrograph has an external focus and high effectiveness as a patrol-telescope (see table 1). According to the developer's data [6], the optimal aperture of the field of view of the telescope is approximately 4.33 cm, or in an angular measure $\sim 4°$. In order to ensure the calculated effectiveness of sky-monitoring by astrograph RASA 279/620, the size of the CCD-matrix must correspond to the linear size of the telescope's field of view, i.e., approximately 3×3 cm.

3. THE PENETRATING POWER OF THE PATROL-TELESCOPE.

The limiting stellar magnitude that telescope can record, calculated by using Baum's formula [7, 8]:

$$m = 3.75 + 0.5M - 2.15lgK - 2.5lgd/F - 1.25lg(1 + K1) + 1.25lgD^2(1 - K_2)qt \quad (3)$$

Where K determines how many times the desired signal exceeds the noise level; d - the linear size of a star image or object in the focal plane of the telescope; K_1 - the ratio of the instrumental background level to the signal from the sky background; K_2 - light loss in the atmosphere and telescope; q - the quantum output of the light detector; t - the exposure time; M, D, and F determine the same magnitudes as in the formulas above. We used conservative parameter values: K = K_1 = 5; K_2 = 0.4; q = 0.9, in order not to overestimate the capabilities of telescopes, when calculating by formula (3). The diameter of the scattering circle d depends on the image quality and corresponds to 2 arc seconds. The stellar magnitude from the sky background, within the unit solid angle, is accepted $M = -4.6^m$ on the bandwidth V of the Johnson-Morgan system [8]. It should be noted that the exposure time of every star image or object depends on its angular dimensions and displacement velocity over the matrix (see formulas (10) and (11) in [4]). Considering this circumstance, the anticipated limiting stellar magnitude for the telescope AST-452 at the continuous sky-monitoring mode approximately 13.7^m, and at the quasi-continuous sky-monitoring mode, approximately 17.3^m. We obtained practically the same values of the anticipated threshold magnitudes for the astrograph RASA 279/620, at continuous and quasi-continuous sky-monitoring mode: $m = 13.5^m$ and m $= 17.2^m$, respectively. The penetrating power of this telescope turns out to be less than AST-452 due to the smaller aperture, but these differences are more theoretical than practical.

4. ESTIMATION OF THE MINIMUM SIZE OF BODIES THAT CAN BE DETECTED UNDER SKY MONITORING

The diameters of bodies corresponding to the obtained values of the limiting stellar magnitudes can be estimated by the formula:

$$m = Const - 2,5lgpV\pi R^2 f(\gamma)(r_s rE)^{-2} \tag{4}$$

where pV – the visual geometrical albedo of body, 2R – its diameter in km, f(γ) – phase function, γ– phase angle, r_s and rE – heliocentric and geocentric distances of the object in a.u. Const $= 15.5^m$ Const $= 15.5^m$ is calculated from the "Ephemerides of Minor Planets for 1993" for asteroid 8 Flora at $r_s = 2.464$ a.u., rE $= 1.545$ a.u., $2R = 144km, \gamma = 12.8°$ and pV $= 0.23$. Table 2. shows diameters of the bodies calculated by the formula (4) under the condition pV =0.05 – 0.3 and $r_s = 1$a.u.

According to the data in this table, a patrol-telescope based on AST-452 (or RASA 279/620) can register objects about ten kilometers in diameter at a geocentric distance rE $\sim$ 1 a.u. and about several meters in diameter at a distance from the Earth of the order of the first hundred thousand kilometers.

5. CONCLUSION

Let us formulate the main conclusions. AST-452 mirror-lens telescope has the best properties among the stellar telescopes of the Shamakhy Astrophysical Observatory for monitoring the celestial sphere in order to search and detect fast-moving near-Earth objects. It can register objects with a stellar magnitude of $\leq$ 17m, which corresponds to bodies of the order of ten kilometers in diameter at heliocentric distances of $\approxeq$ 1a.u. or bodies several meters in diameter, at a distance of the order of the first hundred thousand kilometers. Astrograph RASA

Table 2. Smallest body sizes with albedo 0.05<pV<0.3 near-Earth (r_s = 1 a.e.).Detected by the telescope AST-452 (or RASA 279/620).

Geocentric Distance (a.u.)	Body diameter (km)	Correction for the phase angle a)
		while scanning the sky continuously
english+russian+russian+		
$r_E = 1.0$	11.5 – 4.7 12.7 – 5.2	’1.8
$r_E = r_{Earth-Moon}$	0.03 – 0.012 0.033 – 0.013	’2.5
$r_E = 0.5\ r_{Earth-Moon}$	0.14 - 0.006 0.016 -0.007	’3.5
		while sky scanning quasi-continuously
english+english+russian+russian+		
$r_E = 1.0$	2.20 – 0.89 2.31 – 0.94	’1.8
$r_E = r_{Earth-Moon}$	0.006 – 0.002 0.006 – 0.002	’2.5
$r_E = 0.5\ r_{Earth-Moon}$	0.003 – 0.001 0.003 -0.001	’3.5

b) The lunar phase law passed. [10]

279/620 does not differ from AST-452 by properties in the sky-monitoring mode. For the full realization of the capabilities of these telescopes as sky monitors, the size of the CCD-matrix must correspond to the linear size of the telescope’s field of view. Small matrixes significantly reduce the efficiency of the patrol-telescope. It should be noted that calculations were fulfilled for ideal astro-climatic conditions, correspond to the natural level of the night sky background. Unfortunately, the sky above the observatory turns out to be overexposed due to numerous hotels, restaurants, and campgrounds surrounding the observatory [9]. This circumstance noticeably affects the penetrating power of telescopes, negatively affects the accuracy of photometric measurements, and creates a real risk of damage to expensive measuring equipment.

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