DETERMINATION OF PLANETOCENTRIC COORDINATES OF ALBEDO DETAILS ON SURFACE OF THE SPHERICAL PLANET AND SOME POINTS OF THE ILLUMINATED PART OF PLANET'S VISIBLE DISK UNDER VARIOUS PHASE ANGLES FROM GROUND TELESCOPIC OBSERVATIONS

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ABSTRACT. The method of processing of the images of planets is based on use of auxiliary coordinate system connected with equator of intensity, is applied for determination of planetocentric coordinates of albedo details on the visible disk of the spherical planet under various conditions of its illumination. The position of a detail on the planet image is determined not relative to the center of the planet geometric disk, but relative to the center of an illuminated part of its visible disk, which permits the planetary phase influence to be excluded. By means of the given method the planetocentric coordinates of albedo details on the images of a Mercury and Mars derived from ground telescopic observations were determined.

The formulae for determination of planetocentric coordinates of some basic points of the illuminated part of the visible disk of a spherical planet, in projection onto the plane of the sky, are derived. The formulae do not require attraction of auxiliary coordinate system, in spite of the fact that they are deduced from general expressions using this coordinate system.

1. Introduction

At drawing up of maps of details of an albedo on the surface of the terrestrial planets, what their shape is spherical at first approximation, the problem of determination of planetographic coordinates of details on the images of their visible disks becomes complicated through influence of the phase, causing to appreciable damage on the visible disk. The article (Mikhalchuk, 2004a) is devoted to the solution of a considered problem. In this article the method of determination of planetocentric coordinates of any point, observable on a illuminated part of the visible disk of a spherical planet is offered.

At ground observations the equatorial planetocentric coordinate system determining a position of each point of a surface of a planet is observed on its visible disk in orthographic projection. In this coordinate system, the position of each point on the planet's surface is specified by the planetocentric latitude b and longitude l. The basic reference point is the center of the geometric disk of the planet.

The method of determination of planetocentric coordinates of center of the illuminated part of the visible disk of a spherical planet is described in article (Mikhalchuk, 2001a). From set of the points located on a illuminated part of a visible planetary disc also the greatest value for determination of planetocentric coordinates of details and for photometric measurements have some basic points located on equator of intensity (the pole of illumination, the pole of the phase, the visible center of the orthographic terminator and the mirror point), in the projection to the plane of the sky. In the contribution (Mikhalchuk, 2004b) the capability of the simplified solution of a problem about determination of planetocentric coordinates (l, b) these points is described. Let's consider the solution for two basic points: the pole of illumination and the visible center of the terminator.

2. The exception of influence of the phase angle through the auxiliary coordinate system

Let's consider the visible disk of the spherical planet illuminated by the Sun under any phase angle Φ (Figure 1). Let O is the geometric center of the planetary disk; E is the subsolar point (the pole of illumination); C is the center of the illuminated part of the planet's visible disk; F is the point of the least illumination of the disk; T is the point of intercerption direct OF with the orthographic terminator (the visible center of the orthographic terminator); the arch of the large circle passing through the points E, C, O, T and F is the equator of intensity of the planet.

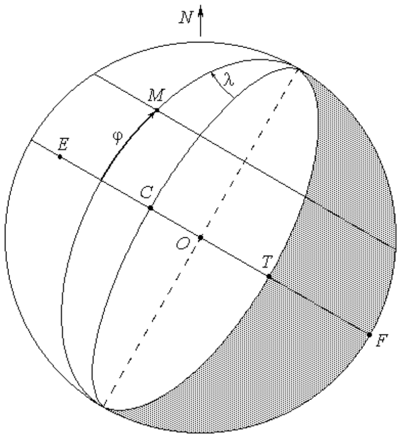


Figure 1: The auxiliary coordinate system.

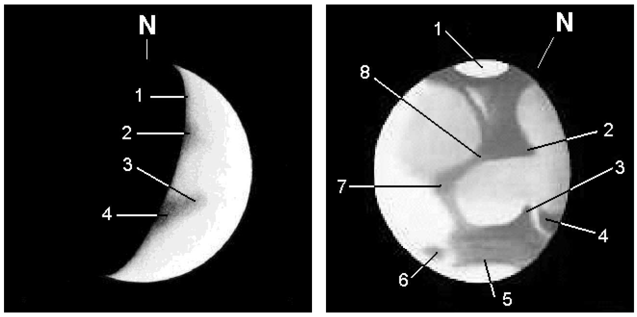
In the papers (Mikhalchuk, 2004a; Mikhalchuk, 2004b) for exception of influence of a phase angle at determination of planetocentric coordinates of albedo details on surface of the planet the auxiliary spherical coordinate system (λ, φ), in which for a basic plane is adopted the plane of equator of intensity, and the poles are the orthographic horns of the disk. Origin of an auxiliary system is the the point C, which always is on the illumunated part of visible planetary disk. The arc of a large circle, passing through the orthographic horns and the point C, (mean meridian of the illuminated part of the visible disk) we shall take as an initial meridian of auxiliary coordinate system. Then the position of each point on a surface of the illuminated part of visible planetary disk will be determined by an latitude φ, is measured from the equator of intensity, and longitude λ, is measured from mean meridian westward of the planet. How is described in article (Mikhalchuk, 2004a), it is possible to find the auxiliary spherical coordinates (λ, φ) of any point on a surface of the planet (of the point M) from its relative coordinats (ξ, η).

For implementation of transition from auxiliary spherical coordinates (λ, φ) to planetocentric coordinates (l, b) we shall consider a projection of the visible disk of the spherical planet to the plane of the sky. Let $D_\oplus$ is the planetocentric declination of the Earth, P is the angle of position of the axis of rotation of the planet on the geocentric celestial sphere, Q is the angle of position of the point of the least illumination of the disk (Abalakin, 1979). The planetocentric coordinates of the point O are known and are equal (l_p, b_p), where l_p is longitude of a central meridian what is passing through center of the disk; b_p is latitude of center of the geometric disk, and $b_p = D_\oplus$. The planetocentric coordinates of the point C are equal (l_0, b_0) and are determined on the method (Mikhalchuk, 2001a). Then it is possible to determine the planetocentric coordinates (l, b) of the any point of the illuminated part of a visible planetary disk on auxiliary spherical coordinates (λ, φ) of this point through the formulae obtained in the article (Mikhalchuk, 2004a). These formulae contain the longitude $\lambda_0 = \lambda + \gamma$, where γ is the phase shift of the center of the planetary disk. The longitude λ_0 of the point M is measured from a line of the horns passing through the point O.

3. Application of the method of determination of planetocentric coordinates to drawing up of maps of the details of an albedo of the spherical planets

The planetocentric coordinates of some details of an albedo on surfaces of Mercury and Mars under their images received at ground telescopic observations (Anderson, 1997; Melillo, 2004) were determined. For processing the images of planets were taken only those, which were received at considerable phase angles.

The image of Mercury (Figure 2a) represents drawing (Melillo, 2004), received at visual observations (observer M. Frassati, telescope of diameter 203 mm). The image of Mars (Figure 2b) also represents drawing (Anderson, 1997), received at visual observations (observer Carlos E. Hernandez, telescope of diameter 200 mm). For both images the resolution equal $0.6''$.



a. Mercury. b. Mars.

Figure 2: The images of visible disks of the planets.

For calculation of physical ephemerides of Mercury and Mars the elements of rotation of planets were used from article (Seidelmann et al., 2002). The visible radiuses r of planets and their the physical ephemerides at moments of observations, which are calculated on the programs of a batch (Mikhalchuk, 2001b), are given in Table 1.

On the measured relative coordinates ξ and η the auxiliary spherical coordinates λ and φ were determined through the formulae (Mikhalchuk, 2004a). During calculations the phase shift of centres of disks of planets were obtained: for Mercury $\gamma = -42.2°$ and for Mars $\gamma = +5.1°$. The coordinates of details on the surfaces of planets, are found as the result of application of the method (Mikhalchuk, 2004a), are listed in

Table 1: The physical ephemerides of planets

Planet	UT	r	Φ	$D_\oplus$	P	Q	l_p
Mercury	$05/05/2002, 18^{\mathrm{h}}15^{\mathrm{m}}$	$4''.14$	$110^\circ.02$	$-0^\circ.51$	$343^\circ.03$	$72^\circ.86$	$303^\circ.53$
Mars	$06/01/1997, 10^{\mathrm{h}}10^{\mathrm{m}}$	4.22	34.79	+23.68	27.41	292.70	35.89

Table 2: The coordinates of details on the surfaces of planets

Planet	Detail	ξ	η	λ_0	φ	l	b	The name of region on the map
Mercury	1	+0.95	+0.75	$-21^\circ.0$	$+48^\circ.6$	$282^\circ.5$	$+48^\circ.1$	Apollonia
	2	+0.80	+0.45	-24.1	+26.7	279.5	+26.2	Solitudio Aphrodites
	3	+0.25	-0.10	-36.1	-5.7	267.4	-6.3	Solitudio Criophori
	4	+0.75	-0.30	-25.1	-17.5	278.4	-18.0	Solitudio Alarum
Mars	1	-0.10	+0.91	+10.4	+65.5	34.5	+89.6	The North polar cap
	2	-0.50	+0.20	-21.5	+11.5	9.9	+31.5	Deuteronilus
	3	-0.49	-0.33	-20.9	-19.3	17.9	+1.6	Margaritifer Sinus
	4	-0.80	-0.40	-39.7	-23.6	2.2	-7.2	Sinus Meridiani
	5	-0.10	-0.85	-0.1	-58.2	40.7	-34.4	Vulcani Pelagus
	6	+0.72	-0.70	+48.2	-44.4	76.0	-24.1	Nectar
	7	+0.37	-0.10	+25.2	-5.7	62.8	+17.6	Lunae Palus
	8	0.00	+0.10	+5.1	+5.7	41.2	+29.7	Niliacus Lacus

Table 2.

Comparison the planetocentric coordinates of the basic details at the images of visible disks of the Mercury and Mars, which are obtained as a result of the given method, with coordinates of the same details, which have been taken from maps of an albedo of planets of epoch 2000 (Melillo, 2004; Troiani et al., 2004), has allowed to establish, that the calculated coordinates of albedo details coincide their coordinates, which have been taken from the map, within errors of the initial images and the map.

4. Determination of planetocentric coordinates of the pole of illumination and the visible center of the terminator of the spherical planet

The formulae for determination of planetocentric coordinates of considered points should be similar to expressions for coordinates of the point C, which are obtained in articles (Mikhalchuk, 2001a; Mikhalchuk, 2004a). For points, located on equator of intensity, the latitude $\varphi = 0$. In this case from the formulae (Mikhalchuk, 2004a) we shall obtain more simplified expressions:

$$\sin b = \cos\lambda_0 \sin D_\oplus \mp \sin\lambda_0 \cos D_\oplus \cos(P-Q), \tag{1}$$

$$\mathrm{tg}(l-l_p) = \frac{\pm\sin\lambda_0 \sin(P-Q)}{\cos\lambda_0\cos D_\oplus \pm \sin D_\oplus \sin\lambda_0 \cos(P-Q)}, \tag{2}$$

where the signs of the numerator and denominator in expression (2) coincide with the signs of $\sin(l-l_p)$ and $\cos(l-l_p)$ respectively. The formulae (1) and (2) allow to obtain the planetocentric coordinates (l, b) any point of the illuminated part of the equator of intensity.

The pole of illumination (the point E) is located on the visible planetary disk, if $\Phi < 90^\circ$, and is on the invisible part of the planet otherwise. The longitudes of the pole of illumination are equal $\lambda = \pm\Phi - \gamma$ and $\lambda_0 = \pm\Phi$. The visible center of the orthographic terminator (the point T) has longitudes $\lambda = \pm(\Phi - 90^\circ) - \gamma$ and $\lambda_0 = \pm(\Phi - 90^\circ)$. Then from the formulae (1) and (2), taking into account the rule of the signs (Mikhalchuk, 2004a), and also taking into account values of longitudes λ_0, we shall obtain for the planetocentric coordinates of the pole of illumination (of the point E)

$$\sin b = \cos\Phi \sin D_\oplus - \sin\Phi\cos D_\oplus \cos(P-Q), \tag{3}$$

$$\mathrm{tg}(l-l_p) = \frac{\sin\Phi\sin(P-Q)}{\cos\Phi\cos D_\oplus + \sin\Phi\sin D_\oplus\cos(P-Q)}. \tag{4}$$

Similarly, for the planetocentric coordinates of the visible center of the orthographic terminator (of the point T), we shall obtain

$$\sin b = \sin\Phi \sin D_\oplus + \cos\Phi\cos D_\oplus \cos(P-Q), \tag{5}$$

$$\mathrm{tg}(l-l_p) = \frac{-\cos\Phi\sin(P-Q)}{\sin\Phi\cos D_\oplus - \cos\Phi\sin D_\oplus\cos(P-Q)}. \tag{6}$$

The signs of the numerator and denominator in the formulae (4) and (6) coincide with the signs of $\sin(l-l_p)$ and $\cos(l-l_p)$ respectively.

Table 3: The planetocentric coordinates of some basic points of the visible disks of planets

Planet	The point C		The point E		The point T	
	l_0	b_0	l	b	l	b
Mercury	$261^\circ.37$	$-0^\circ.49$	$193^\circ.51$	$0^\circ.00$	$283^\circ.51$	$-0^\circ.54$
Mars	41.49	+24.00	73.68	+21.88	339.77	+9.64

The obtained formulae (3)-(6) were applied to determination of planetocentric coordinates of the considered points of the illuminated part of the visible disks of Mercury and Mars. The results of calculations are listed in Table 3.

Because for Mercury $\Phi > 90^\circ$, then its pole of illumination (the point E) is located on the invisible part of the planet. For Mars $\Phi < 90^\circ$, hence, pole of illumination is on its visible disk. From Table 3 follows, what the planetocentric longitudes of the pole of illumination and the visible center of the orthographic terminator of Mercury differ exactly on 90°. It follows from what the planetocentric latitude of the pole of illumination of Mercury is always equal zero, i.e. the Sun always is positioned in the equatorial plane of the planet.

5. Conclusion

The basic results obtained in this contribution, allow us to draw the following conclusions:

1. The method of determination of the planetocentric coordinates of details on the visible disk of the spherical planet, which is allowing to exclude influence of the phase, is applied to the images of Mercury and Mars.

2. The formulae for determination of planetocentric coordinates of some basic points of the illuminated part of the visible disk of the spherical planet, lying on the illuminated part of the equator of intensity, is obtained.

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