INFLUENCE OF THE PHASE OF A SPHERICAL PLANET ON DETERMINATION OF COORDINATES OF ALBEDO FEATURES ON THE PLANET'S SURFACE FROM GROUND-BASED OBSERVATIONS

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A new method of determination of planetocentric coordinates of albedo features on the visible disc of a spherical planet is offered under various conditions of its illumination. The method is aimed for processing the images of planets received with ground-based telescopes. The position of a detail on the image of a planet is determined not concerning center of a geometric planetary disc, and concerning center of the illuminated part of its visible disc, that allows excluding influence of a phase of a planet. The auxiliary coordinate system connected to equator of intensity is applied for determination of a position of points on the illuminated part of a visible planetary disc. The formulae for transition from auxiliary coordinate system to planetocentric coordinate system are received. The particular cases of determination of planetocentric coordinates of basic points of the illuminated part of the visible disc of a spherical planet from the formulae, which are not requiring of attraction of auxiliary coordinate system, are considered. The method is checked up on an example of processing of the images of a Mercury and Mars.

INTRODUCTION

By mapping of albedo details on surfaces of planets of the Solar System and their natural satellites using ground telescopic observations, there is a problem to determine planetographic coordinates of details on the images of their visible discs. For the terrestrial planets, it is possible to consider their shape in the first approximation as spherical. But this problem becomes difficult due to phases causing appreciable damages on the visible disc, that does not allow one to apply the certain methods for determination of coordinates of observable details [2–4, 9]. The paper [7] is devoted to the finding solution of this problem. In this article a method for determination of planetocentric coordinates of any point, observable on the illuminated part of the visible disc of a spherical planet is described.

From ground observations the equatorial planetocentric coordinate system, which determines the position of each point on the surface of the planet is observed on its visible disc in an 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 disc of the planet with planetocentric coordinates (l_p, b_p), where l_p is longitude of the central meridian passing through the center of the disc, b_p is latitude of the center of the geometric disc. The latitude b_p is equal to planetocentric declination of the Earth $D_\oplus$.

The present contribution is the further development and generalization of the method [5] for any point of the visible disc of a spherical planet in consideration of a phase by determination of planetographic coordinates of albedo details on images of spherical planets received from ground-based observations.

INFLUENCE OF THE PHASE ANGLE ON THE CALCULATION OF THE PLANETOCENTRIC COORDINATES

The methods [2–4, 9] for determination of planetocentric coordinates (l, b) of a detail on the visible planetary disc are fair only in that specific case, when the disc is completely illuminated, *i.e.*, the phase angle Φ is equal to zero. If the phase angle Φ differs from zero, the center of the illuminated part of the visible planetary disc does not coincide the geometric center of the planet's disc. The limitations of the applicability of those methods result in the necessity to develop a new method, which allows, without a loss for the accuracy, to exclude the influence of the phase.

Let us consider the visible disc of a spherical planet illuminated by the Sun at a phase angle Φ (Fig. 1). Let us introduce O as the geometric center of the planetary disc, E as the subsolar point (pole of illumination),

C as the center of the illuminated part of the planet's visible disc, T as the visible center of the orthographic terminator, A and B as orthographic horns of the disc, M as a point on the planet's surface.

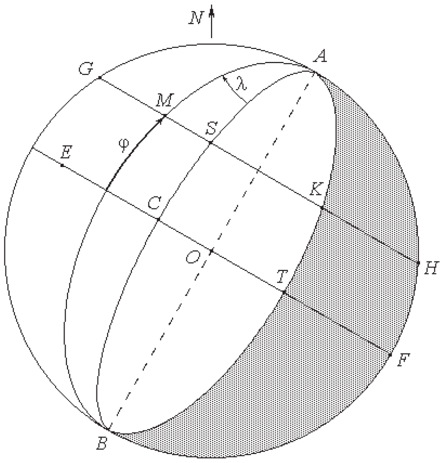


Figure 1. The auxiliary coordinate system (the transverse orthographic projection)

We introduce an auxiliary spherical coordinate system (λ, φ) on the planet's surface, in which the plane of equator of intensity is considered as the basic plane, and poles are the orthographic horn of the disc [7]. Origin of the auxiliary system is the point C, which always is on the illuminated part of the visible planetary disc. Then, the position of each point on the surface of the illuminated part of the visible planetary disc will be determined by latitude φ, which is measured from the equator of intensity, and longitude λ, which is measured from the mean meridian (it is passing through the point C) westward of the planet. As described in [7], it is possible to find the auxiliary spherical coordinates (λ, φ) of any point on the planet's surface from its relative coordinates (ξ, η).

To transform the auxiliary spherical coordinates (λ, φ) into the planetocentric coordinates (l, b), we shall consider a projection of the visible disc of spherical planet on the plane of the sky. Let P be the angle of position of the rotation axis of the planet on the geocentric celestial sphere, let Q be the angle of position of point F as the least illuminated on the disc [1]. The planetocentric coordinates of the point O (l_p, b_p) are known and $b_p = D_\oplus$. The planetocentric coordinates of the point C are (l_0, b_0) and can be determined using the method [5]. The auxiliary coordinates (λ, φ) of the point M are also known. Then, it is possible to determine the planetocentric coordinates (l, b) of any point of the illuminated part of the visible planetary disc from the auxiliary spherical coordinates (λ, φ) of this point using the equations obtained in [7]:

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

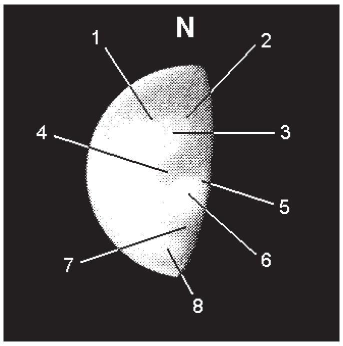
$$\tan(l - l_p) = \frac{\pm[\cos\varphi \sin\lambda_0 \sin(P-Q) + \sin\varphi\cos(P-Q)]}{\cos\varphi\cos\lambda_0\cos D_\oplus \mp \sin D_\oplus[\sin\varphi\sin(P-Q) - \cos\varphi\sin\lambda_0\cos(P-Q)]}, \tag{2}$$

where $\lambda_0 = \lambda + \gamma$, γ is the phase shift of the center of the planetary disc, and the signs of numerator and denominator in (2) coincide with the signs of $\sin(P-Q)$ and $\cos(P-Q)$, respectively. The selection of a sign in expressions (1) and (2) is defined by the rule: the upper sign concerns the case, when $\sin(P-Q) > 0$, and the lower sign – the case, when $\sin(P-Q) < 0$.

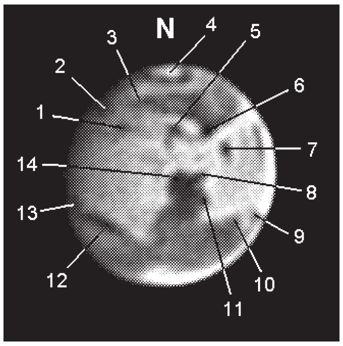
APPLICATION OF THE METHOD OF DETERMINATION OF PLANETOCENTRIC COORDINATES TO MAPPING ALBEDO DETAILS OF SPHERICAL PLANETS

The planetocentric coordinates of some albedo features on surfaces of Mercury and Mars were determined using their images received from ground-based observations. Photos and CCD-images of visible discs of planets were processed (Internet Web site ALPO: the Mars Watch, 1999; the Mercury Watch, 2003). For processing only those images were used, which were received at considerable phase angles.

The image of Mercury (Fig. 2a) represents drawing, received from visual observations (Internet Web site ALPO, observer M. Frassati, telescope with diameter of 203 mm and resolution of 0.6″). The image of Mars (Fig. 2b) was received using a CCD (Internet Web site ALPO, observers S. Buda and B. Curcic, telescope with diameter of 254 mm and resolution of 0.5″).



a) Mercury



b) Mars

Figure 2. The images of visible discs of the planets

To calculate physical ephemerides of Mercury and Mars, the elements of rotation of planets were used from [8]. Physical ephemerides of planets at moments of observations, which were calculated using programs from [6], are given in Table 1.

Table 1. The physical ephemerides of planets

Planet	UT	r	Φ	$D_\oplus$	P	Q	l_p
Mercury	01/02/2003, $7^{\mathrm{h}}00^{\mathrm{m}}$	3.55″	82.45°	−7.2°	356.6°	265.6°	309.7°
Mars	03/06/1999, $10^{\mathrm{h}}50^{\mathrm{m}}$	7.03	29.28	+22.8	36.3	111.3	303.9

Using equations from [7] and the measured relative coordinates ξ and η, the auxiliary spherical coordinates λ and φ were determined. The coordinates of details on the surfaces of planets, which were found using the method [7], are listed in Table 2.

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

Planet	Detail	ξ	η	λ_0	φ	l	b	Name of region on the map
Mercury	1	0.00	+0.46	+25.7°	+27.4°	333.6°	+21.3°	Solitudio Argiphontae
	2	−0.56	+0.47	+6.7	+28.0	315.6	+21.0	Solitudio Aphrodites
	3	−0.31	+0.27	+15.0	+15.7	324.0	+9.0	Pentas
	4	−0.27	−0.05	+16.4	−2.9	326.3	−9.5	Sinus Argiphontae
	5	−0.92	−0.11	−4.9	−6.3	304.8	−13.6	Solitudio Alarum
	6	−0.63	−0.25	+4.5	−21.3	314.6	−21.6	Pieria
	7	−0.66	−0.56	+3.5	−34.1	314.3	−41.2	Solitudio Criophori
	8	−0.46	−0.75	+10.0	−48.6	322.8	−55.4	Cyllene
Mars	1	+0.56	+0.31	+27.4	+18.1	332.9	+45.0	Ismenius Lacus
	2	+0.86	+0.46	+47.8	+27.4	2.8	+52.9	Mare Acidalium
	3	+0.58	+0.57	+28.6	+34.8	333.4	+61.8	Ortygia
	4	+0.54	+0.90	+26.2	+64.2	219.2	+87.3	The North polar cap
	5	+0.12	+0.41	+2.8	+24.2	298.6	+46.8	Boreosyrtis
	6	−0.24	+0.47	−16.8	+28.0	273.6	+43.3	Casius
	7	−0.44	+0.36	−28.4	+21.1	265.8	+32.2	Nodus Alcyonius
	8	−0.26	+0.10	−17.9	+5.7	283.6	+22.5	Syrtis Major
	9	−0.87	−0.16	−61.4	−9.2	250.1	−9.6	Tritonis Sinus
	10	−0.70	−0.23	−46.0	−13.3	265.6	−6.3	Syrtis Minor
	11	−0.38	−0.14	−24.8	−8.0	282.3	+7.2	Moeris Lacus
	12	+0.52	−0.58	+25.0	−35.5	333.1	−8.5	Sinus Sabaeus
	13	+0.96	−0.44	+56.6	−26.1	0.8	−1.2	Sinus Meridiani
	14	0.00	0.00	−3.7	0.0	300.1	+21.8	Syrtis Major, Aeria

The planetocentric coordinates of the main details on images of visible discs of Mercury and Mars, which were obtained using the above-mentioned method, were compared with coordinates of the same details taken from maps of albedos of the planets for epoch 2000.0 (Internet Web site ALPO). The results shown a good agreement the calculated coordinates of albedo details with the coordinates, which have been taken from the map, within errors of the initial images and the map.

For points located on the equator of intensity, we set φ to 0. In this case, it is possible to obtain from expressions (1) and (2) equations for calculation of planetocentric coordinates (l, b) of any point on the illuminated part of the equator of intensity (the pole of illumination, the pole of phase, the visible center of the orthographic terminator and the mirror point), in the projection on the plane of the sky. The obtained formulae were also applied to the determination of planetocentric coordinates of the aforementioned points on illuminated parts of the visible discs of Mercury and Mars.

CONCLUSION

The main results obtained in this work allow us to draw the following conclusions:

1. The auxiliary spherical coordinate system on the planet's surface is to be introduced to determine positions of details on the illuminated part of planet's visible disc with any values of a phase angle.
2. The method for the determination of the planetocentric coordinates of details on the visible disc of a spherical planet under various conditions of its illumination, which takes into account the influence of a phase, is applied to the processing images of Mercury and Mars.
3. The possibility to derive the formulae for the determination of planetocentric coordinates of basic points on the illuminated part of the visible disc of the spherical planet, which lie on the equator of intensity, is shown.

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