Advances in Astronomy and Space Physics, **2**, 177-179 (2012)

Polarimetric observations of the Galilean satellites near opposition in 2011

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We present results of the new polarimetric observations of the Galilean satellites Io, Ganymede, Europe, and Callisto carried out on October 21 – November 1, 2011. We used 1.25m telescope equipped with the UBVRI double image chopping photoelectric polarimeter, 2.6m Shain telescope equipped with a one-channel photoelectric photometer-polarimeter, 1m RCC telescope equipped with a one-channel photoelectric photometer-polarimeter (Crimean Astrophysical Observatory, Ukraine), and 0.7m telescope equipped with a one-channel photoelectric photometer-polarimeter (Chuguev Observational Station of Astronomical Institute of Karazin Kharkiv National University, Ukraine). The measurements were performed at phase angles ranging from 0.34° to 2.12°. Our new observations fully confirmed the presence of the polarization opposition effect for high-albedo satellites Io, Europa, and Ganymede at phase angles less than 2°. Within the accuracy of the measurements we did not detect the polarization opposition effect for moderate-albedo satellite Callisto.

Key words: polarization, planets and satellites: surfaces

INTRODUCTION

Polarimetry is a very powerful method for studying distant atmosphereless Solar System Bodies (ASSBs), such as asteroids, planetary satellites, planetary rings. The characteristics of phase-angle dependence of polarization for these bodies are very sensitive to the mechanisms of the light scattering as well as to the albedo, composition, and structure of the particular surface. The phase-angle dependence of polarization near the opposition for different ASSBs is still in the focus of attention because the behaviour of polarization at small phase angles is a key test for alternative models of light scattering by regolith surfaces [13]. High-albedo Jovian satellites Io, Europa, and Ganymede are among the ASSBs exhibiting narrow, asymmetric spike of negative polarization at small phase angles, namely, a secondary minimum superimposed upon the negative polarization branch (the so-called polarization opposition effect) [11]. Its appearance was theoretically predicted by Mishchenko [5] as manifestation of coherent backscattering as the primary mechanism to explain the observed opposition effects for high-albedo ASSBs. Measurements of the degree of linear polarization of the Galilean satellites at different phase angles were started in 1960s [2], but so far the available polarimetric data are still not enough to trace the behaviour of polarization at small phase angles in details. Moreover, according to Chigladze [1] for Jupiter satellites there are the secondary points of inversion at phase angles about 0.5°. We present results of new polarimetric observations of the Galilean satellites at small phase angles in 2011 as well as the results of observations obtained in 1988 – 2010.

OBSERVATIONS

Polarimetric observations of the Galilean satellites Io, Ganymede, Europa, and Callisto were carried out on October 21 – November 1, 2011. We used 1.25m telescope equipped with the UBVRI double image chopping photoelectric polarimeter [7], 2.6m Shain telescope equipped with a one-channel photoelectric photometer-polarimeter, 1m RCC telescope equipped with a one-channel photoelectric photometer-polarimeter [14] (Crimean Astrophysical Observatory, Ukraine), and 0.7m telescope equipped with a one-channel photoelectric photometer-polarimeter [14] (Chuguev Observational Station of Astronomical Institute of Karazin Kharkiv National University, Ukraine). Observations were carried out in the U, B, V, R, I bands. The measurements were performed at phase angles ranging from 0.34° to 2.12°.

The data of the highest accuracy were obtained

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in the V and R spectral bands. Fig. 1 shows the phase-angle dependencies of linear polarization for the Galilean satellites in the V and R bands at phase angles less than 7° according to this work (filled symbols) and previous studies (open symbols) – Rosenbush et al. [8], Rosenbush and Kiselev [9], Kiselev et al. [4], Zaitsev et al. (unpublished). Circles represent the data for leading hemispheres, and diamonds for trailing hemispheres. For Europa and Ganymede solid lines show the regular negative branches of polarization. For Io and Callisto solid and dashed lines correspond to the regular negative branches of polarization for the leading and trailing hemispheres, respectively [9].

The Stokes parameters u and q were determined from observations, and then the degree of linear polarization P and the position angle of the polarization plane θ were calculated, using the following expressions:

$$P = \sqrt{u^2 + q^2}, \tag{1}$$

$$\theta = \frac{1}{2}\arctan\left(\frac{u}{q}\right). \tag{2}$$

The random errors σ_p were calculated in two ways. The first one uses the statistics of recorded photons from the object n_o and from the sky background n_s according to the expression

$$\sigma_p = \sqrt{\frac{1}{n_o}\left(1 + \frac{1+\tau}{R}\right)}, \tag{3}$$

where τ is a ratio of the measurement durations for object and the sky background, and R is a ratio of the recorded photons n_o and n_s for the same period [12]. Another method lies in using the expression

$$\sigma_p = \sqrt{\frac{1}{2}\left(\sigma_u^2 + \sigma_q^2\right)}, \tag{4}$$

where σ_u and σ_q are the mean square root errors of the individual measurements of parameters u and q, respectively [12]. The larger of these two errors σ_p was adopted as a measurement accuracy of the weighted mean values of polarization parameters P for night. The errors σ_θ in the position angle measurements were determined using the standard relation

$$\sigma_\theta = 28.65\frac{\sigma_p}{P}. \tag{5}$$

Instrumental polarization u and q in the V and R spectral bands determined from the observations of unpolarized standard stars do not exceed 0.4% for 1.25m telescope, 0.2% for 1m RCC telescope, 0.06% for 2.6m Shain telescope (Crimean Astrophysical Observatory), and 0.1% for 0.7m telescope (Chuguev Observational Station of Astronomical Institute of Karazin Kharkiv National University, Ukraine) with errors of about 0.02%. This was carefully taken into

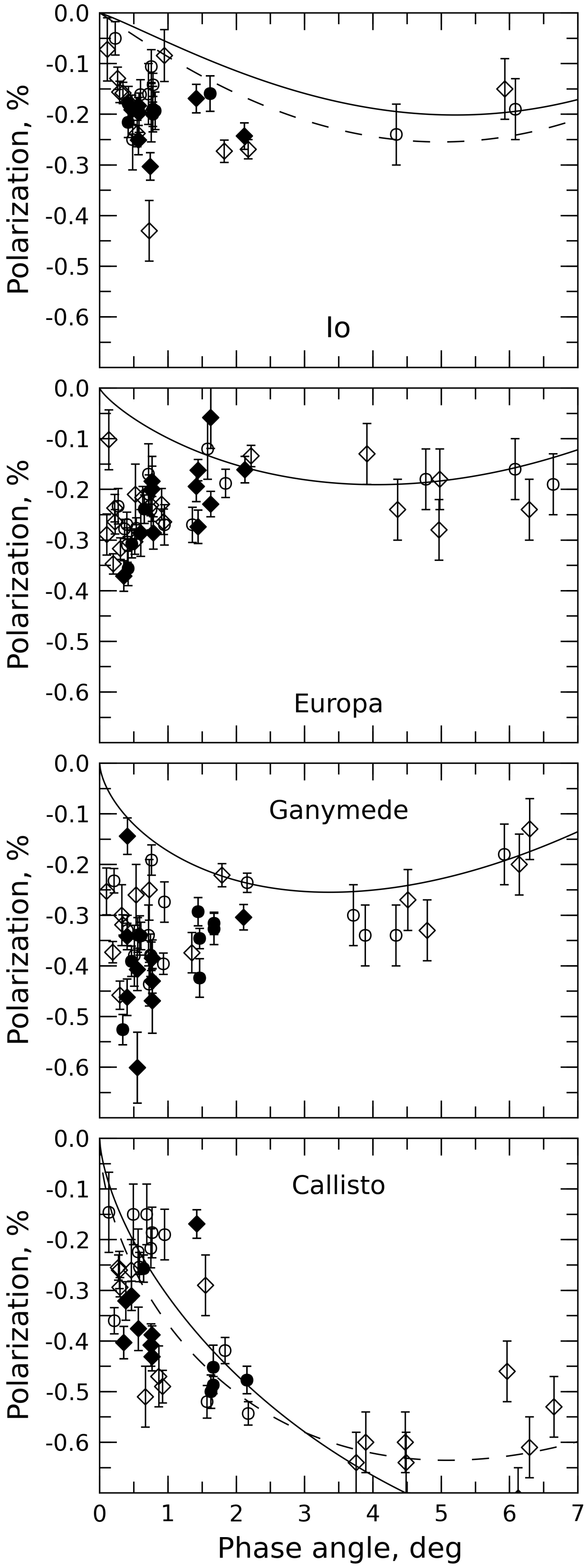

Fig. 1: Phase-angle dependencies of polarization for the Galilean satellites in the V and R bands.

account. The calibration of the position angle of the polarization plane was made using the observations of stars with well-known large interstellar polarization [3]. The angle θ_r between the polarization plane and the plane perpendicular to the scattering plane φ was calculated according to the expression:

$$\theta_r = \theta - (\varphi \pm 90^\circ). \tag{6}$$

In all cases, the angle θ_r is close to 90°, i. e., the degree of polarization is negative, as it is generally agreed.

DISCUSSION

Our new observations fully confirmed the presence of asymmetric secondary minimum of polarization (the polarization opposition effect) superimposed upon the negative polarization branch for high-albedo satellites Io, Europa, and Ganymede [4, 8, 9] at phase angles less than 2°. The shape and amplitude of the polarization opposition effect are slightly different for different satellites. For Europa and Ganymede the polarization peaks are slightly deeper then for previous observations, that confirms that the amplitudes of the polarization peaks are slightly different for different apparitions (the same effect was observed for high-albedo asteroid 64 Angelina [10]). The difference in polarization from apparition to apparition possibly can be explained by longitude dependence of polarization, which is caused by difference in physical properties of the surface layer (surface roughness and single-particle geometrical and optical properties), by systematic errors of the measurements in different sets of observations, and differences in aspects in different apparitions. The significant scatter of polarization data points is mainly the result of local inhomogeneities of the satellites surface, which is superimposed on the global differences of polarimetric properties of the leading and trailing hemispheres. We did not detect the polarization opposition effect for moderate-albedo satellite Callisto. New data for this satellite confirm distinctions of polarimetric properties of the leading and trailing hemispheres [10].

For all Galilean satellites Chigladze [1] found that there are the second inversion points at phase angles about 0.5°. Non-zero degree of polarization (about 0.3%) of the satellites at phase angle about 0.5° was observed by Morozhenko [6]. In addition the angle between the plane of polarization and the scattering plane was close to 45°. The Chigladze's and Morozhenko's data are inconsistent with our present and previous results. Our observations have not revealed the presence of the second points of inversion, and the plane of polarization was always parallel to the scattering plane. The reasons for these differences have been analysed by Kiselev et al. [4]. After correction of Chigladze's and Morozhenko's data the contradiction in results disappears.

CONCLUSION

New polarimetric observations of the Galilean satellites of Jupiter in 2011 are in a good agreement with our previous observations and confirm the presence of the polarization opposition effect for Io, Europa, and Ganymede in the range of phase angles smaller than 2°. Within the accuracy of the measurements we did not detect any polarization opposition effect for the moderate-albedo satellite Callisto.

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