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Investigation of the Surface Features of the Jupiter's Galilean Moons

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***Abstract*—**The purpose of the research is to investigate the surfaces of Jupiter's Galilean moons (satellites), namely to identify which moon has the most uniform surface among them, what is the difference between the front (in the direction of motion) and the back sides of each moon's surface, as well as the temporal variations of the moons. Since 1981, the E. Kharadze Georgian National Astrophysical Observatory has been conducting polarimetric (P) and photometric (M) observations of Jupiter's Galilean moons with telescopes of different diameters (40-cm and 125-cm), as well as polarimeter Automatic Scanning Electron Polarimeter (ASEP)-78, the latest generation photometer with polarimeter and modern light receiver Santana Barbara Instrument Group (SBIG). As it turns out from the analysis of the observed material, parameters P and M depend on: α, the phase angle of the moon (satellite); L, the orbital latitude of the moon (satellite); λ, the wavelength, and t, the period of observation, i.e., P = P (α, L, λ, t), and similarly: M = M (α, L, λ, t). Based on the analysis of the obtained results, we get: The magnitude of the degree of polarization of Jupiter's Galilean moons near the opposition significantly differs from zero. Europa appears to have the most uniform surface, and Callisto has the least. Time variations are most characteristic of Io, which confirms the presence of volcanic activity on its surface. Based on the observed materials, it can be seen that the intensity of light reflected from the front hemisphere of the first three moons: Io, Europa, and Ganymede, is less than the intensity of light reflected from the rear hemisphere, while the picture with Callisto is opposite. The paper provides an explanation of this fact.

***Keywords*—**Galilean moons, polarization, degree of polarization, photometry, front and rear hemispheres.

I. Introduction

LONG-term photometric and polarimetric observations of the surfaces of Jupiter's Galilean moons (Io, Europa, Ganymede, and Callisto) have shown that their surfaces differ from each other. I will refer to the drawing to show this.

For more clarity, we refer to the schematic image in Fig. 1, where: P depending on α –phase angle, L - orbital longitude, λ - wave length and t - observation period, or P = P (α, L, λ, t) and similarly: M = M (α, L, λ, t).

II. Observations

From the analysis of the results obtained, the following conclusions can be drawn:

1. Polarization degree of Jupiter's Galilean satellites near the opposition significantly differs from zero [1], [3]. This is confirmed by the analysis of the observed material, which is given in the form of a table (Table I), where L is the orbital longitude, and P is the linear polarization.

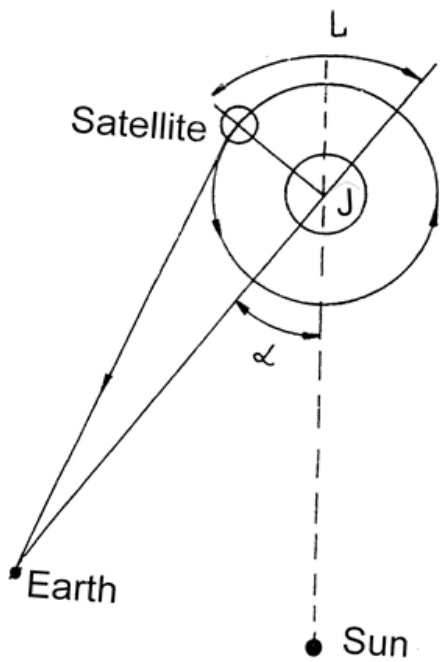

Fig. 1 Schematic picture

TABLE I
Polarization Degree of Jupiter's Galilean Satellites (Moons) near the Opposition

Galilean moons	Orbital longitude (L^0)	Linear polarization (P%)
Io	93	-0.35
	275	-0.41
Europa	269	-0.27
	95	-0.22
Ganymede	90	-0.35
	277	-0.27
Callisto	276	-0,26
	76	-0.15

In the presented work, the mean square error of one measurement does not exceed 0.05% of the measured value.

2. The dependence of the degree of polarization and phase angle, α (inv) is the angle at which the sign of polarization changes.
3. Figs. 3-8 show the orbital changes of the Galilean moons of Jupiter.

When (ΔP) and (ΔM) are small, the surface is uniform.

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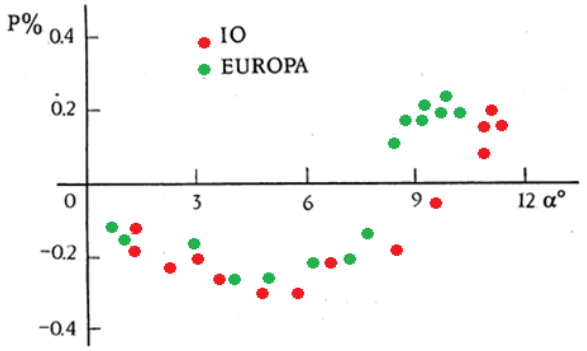

Fig. 2 For Io, α (inv) ≈ 10^0; for Europa, α (inv) ≈ 8^0

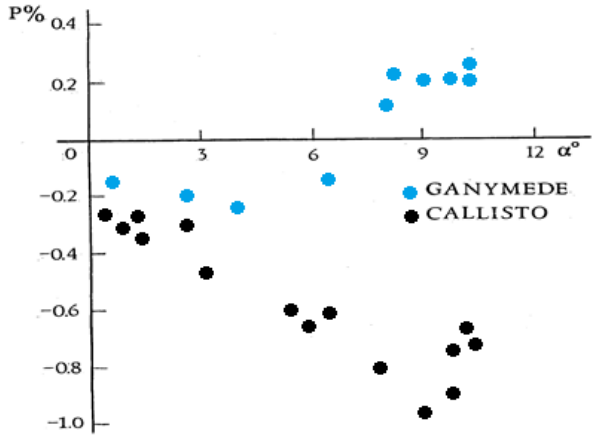

Fig. 3 For Ganimede, α (inv) ≈ 8^0; for Callisto, α (inv) > 11^0

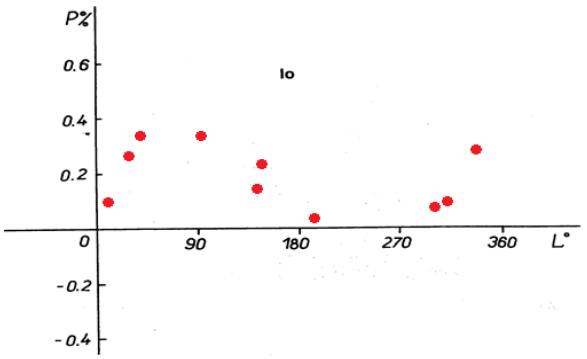

Fig. 4 Dependence of the Degree of Polarization and Orbital Longitude

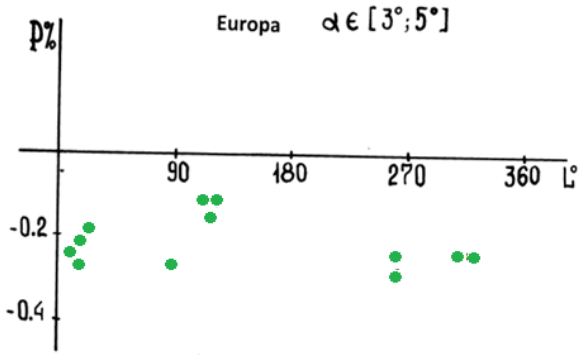

Fig. 5 Dependence of the Degree of Polarization and Orbital Longitude

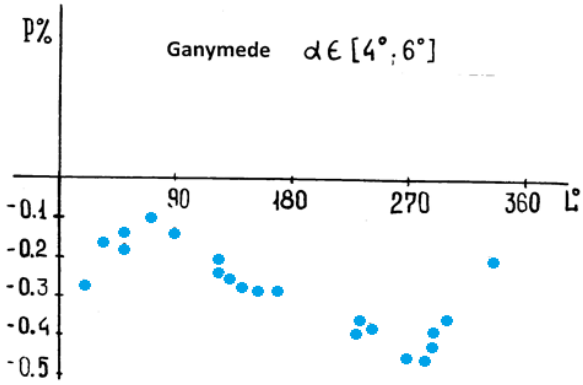

Fig. 6 Dependence of the Degree of Polarization and Orbital Longitude

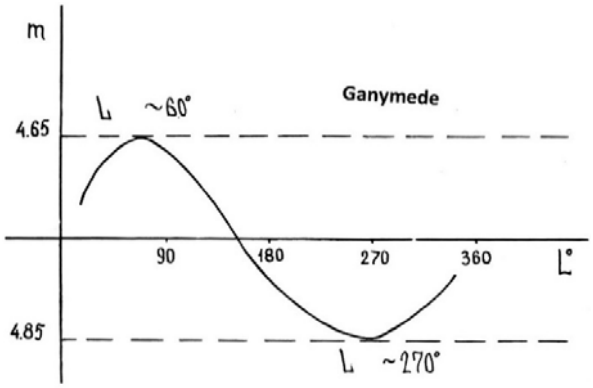

Fig. 7 Dependence of Visual Magnitude (m) on Orbital Longitude [4]

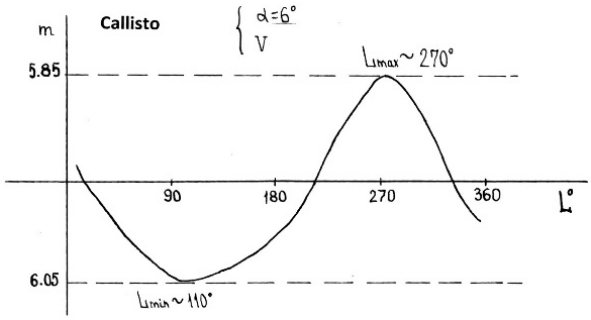

Fig. 8 Dependence of Visual Magnitude (m) on Orbital Longitude [4]

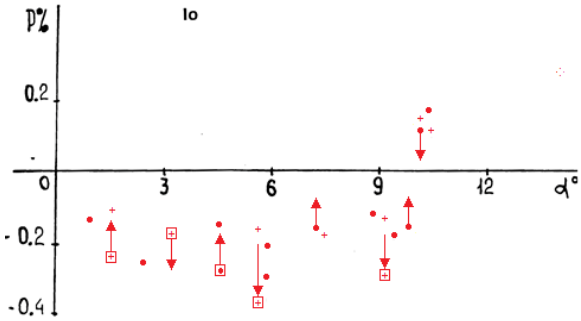

Fig. 9 Time Variations of Io

4. Time variations are most characteristic of Io, what evidences the existence of the volcanic activity on its

surface.

5. Figs. 10-13 show the change in the degree of polarization of light reflected from the surfaces of the Galilean moons of Jupiter depending on the wave length.

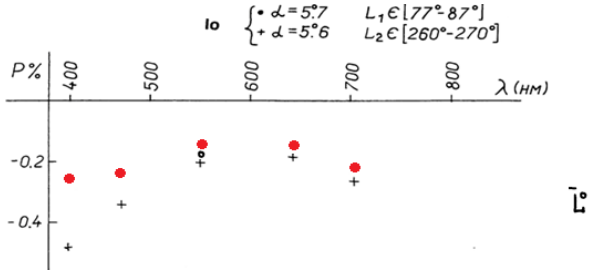

Fig. 10 Dependence of Polarization and Wave Length for Io (Black circle – the observation of Dolfus [5]

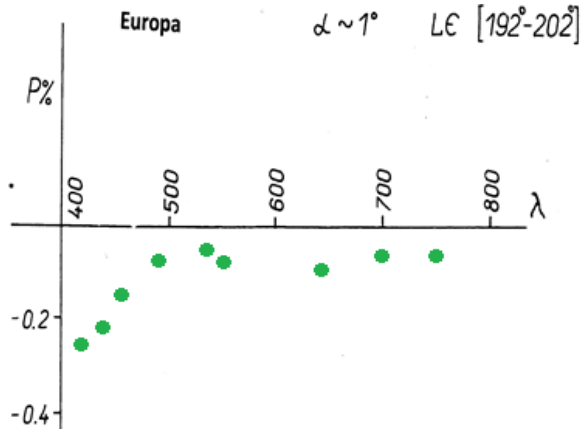

Fig. 11 Dependence of Polarization and Wave Length for Europa

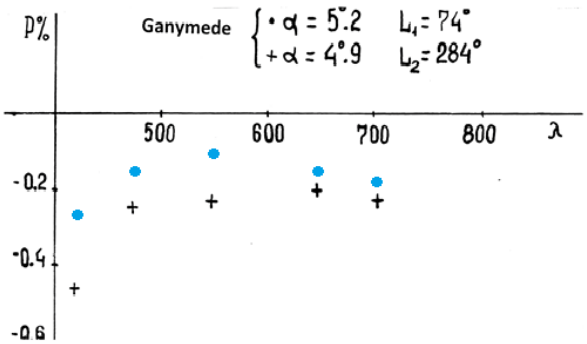

Fig. 12 Dependence of Polarization and Wave Length for Ganymede

III. Results and Conclusions

1. As the drawings show, the most homogeneous surface is typical to the Europa, and the least homogeneous surface is typical to the Callisto: $(\Delta P)_{Europa} < (\Delta P)_{Io} < (\Delta P)_{Ganymede} < (\Delta P)_{Callisto}$.

It is also accepted that:

$(\Delta M)Europa < (\Delta M)Io < (\Delta M)Ganymede < (\Delta M)Callisto$ [4]

2. The empirical formulas for each object are as follows:

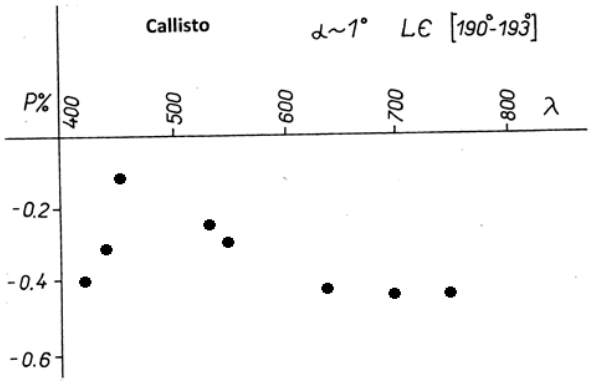

Fig. 13 Dependence of Polarization and Wave Length for Calisto

For Io:

$$P(\alpha) = 20.31\ \alpha^2 - 3.72\alpha - 0.07$$
$$M(\alpha) = -0.001\alpha^2 + 0.046\alpha + 4^{m}.80$$

The relationship between them is as follows:

$$P(\alpha) = M(\alpha) - 4^{m}.8 + 20.311\alpha^2 - 3.766\alpha - 0.07.$$

For Europa:

$$M(\alpha) = -0.00125\alpha^2 + 0.0312\alpha + 5^{m}.17$$
$$P(\alpha) = 54.55\alpha^2 - 6.57\alpha - 0.05$$

The relationship between them is as follows:

$$P(\alpha) = M(\alpha) - 5^{m}.17 + 54.55\alpha^2 - 6.60\alpha - 0.05.$$

For Ganymede:

$$P(\alpha) = 72.33\ \alpha^2 - 10.09\alpha - 0.04$$
$$M(\alpha) - 0.00066\alpha^2 + 0.323\alpha + 4^{m}.54$$

The relationship between them is as follows:

$$P(\alpha) = M(\alpha) - 4^{m}.54 + 72.33\alpha^2 - 10.41\alpha - 0.04.$$

For Callisto:

$$P(\alpha) = 62.39\ \alpha^2 - 13.07\alpha - 0.03$$
$$M(\alpha) = -20.00274\alpha^2 + 0.078\alpha + 5^{m}.5$$

The relationship between them is as follows:

$$P(\alpha) = M(\alpha) - 5^{m}.5 + 82.4\alpha^2 - 13.14\alpha - 0.03.$$

3. The value of the degree of polarization of the light reflected from the front hemisphere of Io (in the direction of movement) is 0.27% lower the value of the degree of polarization of the light reflected from the back hemisphere.
4. The value of the degree of polarization of the light reflected from the front hemisphere of Europa is 0.15% lower than the value of the degree of polarization of the light reflected

from the back hemisphere.

5. The value of the degree of polarization of the light reflected from the front hemisphere of Ganymede is 0.35% lower than the value of the degree of polarization of the light reflected from the back hemisphere.
6. The value of the degree of polarization of the light reflected from the front hemisphere of Callisto is 0.67% higher than the value of the degree of polarization of the light reflected from the rear hemisphere.

IV. Analysis

It is evident that the magnitude of the degree of polarization of the light reflected from the front hemisphere of the first three satellites (Io, Europa, Ganymede) is less than the degree of polarization of the light reflected from the rear hemisphere, while the picture is opposite with the satellite Callisto.

One of the possible hypotheses for explaining this phenomenon is as follows: as it is known, there is a shower of a group of meteorites, moving both on circular and elliptic orbits. The showers of meteors, moving on elliptic orbits in the direction coinciding with the satellites' direction must be the reason for the above-mentioned exposed difference. These showers are falling asymmetrically upon the satellites' front and rear hemispheres.

In order to facilitate our calculations, let us review the meteor showers, the pericenter of which is ≈ $6R_J$ close to the satellite (specifically Io) orbit, located near the planet, and the apocenter ≈ $26R_J$ close to the satellite Callisto orbit.

In such case, as it is well-known from celestial mechanics, the velocity of a body movement in pericenter and apocenter is calculated using the following formulae: $V^2 = V^2_c\,(1+e)/(1-e)$ (in pericenter), $V^2 = V^2_c\,(1-e)/(1+e)$ (in apocenter), where V_c is the main velocity of the object moving on the orbit, and e is the orbit eccentricity [6]. On the one hand, it may be easily obtained that the velocity of meteoric bodies with the above-mentioned properties will be: V = 22.7 km/s in pericenter and V = 5.1 km/s in apocenter [4]. On the other hand, optimum velocities of Galilean satellites moving on circular orbits are: 17.1 km/s for Io, 13.5 km/s for Europa, 11.2 km/s for Ganymede, and 8.3 km/s for Callisto.

Evidently, the indicated meteoric bodies are falling upon Io from the rear side ($V_{Meteors} > V_{Io;Eur;Gan}$), while the picture in the case of Gallisto ($V_{Cal.} > V_{Meteors}$) is the opposite.

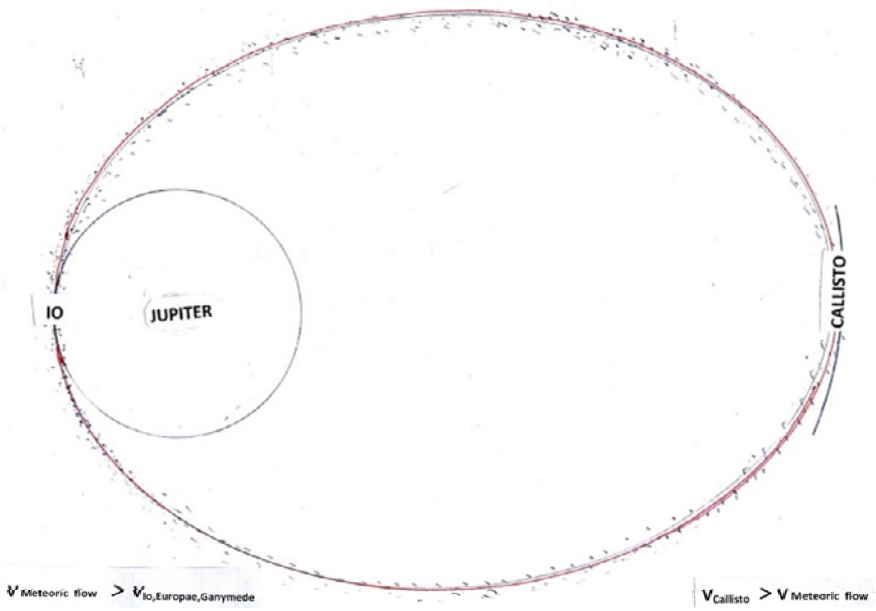

Fig. 14 Schematic picture

Callisto is gathering on and overtaking meteor showers, which bombard it from the front side due to the fact that the majority of meteoric bodies are dark (have less albedo and a high degree of polarization).

Consequently, the light, reflected from the satellite's indicated side corresponds to the higher degree of polarization. As the mentioned effect lasts for billions of years, the satellite's front and rear sides differ from each other.

V. Conclusion

The obtained results confirm that the surfaces of the Galilean moons moving synchronously around Jupiter are non-uniform, among them Europa has a relatively uniform surface, while Callisto has the most non-uniform surface, Io's surface undergoes the most changes over time.

Based on the analysis of the observed material, we are also convinced that the front hemispheres of the Galilean moons (Io, Europa, Ganymede) that are relatively close to Jupiter (due to their movement) have the ability to reflect the light falling on them more than the rear hemispheres, and Callisto, which is far from Jupiter, on the contrary, is one of the reasons for this fact. - One explanation is given in the presented work.

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