NEW VISIBLE-RANGE SPECTRAL FEATURES OF GALILEAN ICY SATELLITES.

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Summary: Some weak absorption bands (the relative intensity ~1-10%) are found for the first time in the visible-range reflectance spectra of Galilean icy satellites of Jupiter, Europa, Ganymede and Callisto. It seems seven of them are common for the bodies and could be manifestations of the adsorbed O_2 because of radiation implantation of O^+ ions into the satellites' surface substance in the magnetosphere of Jupiter. Specific spectral features are probably created by iron ions (Fe^{2+} and Fe^{3+}) on Ganymede and Callisto and by methane (probably in an adsorbed state) on Europa.

Briefly on previous results: As is known, Europa, Ganymede and Callisto have predominant or considerable water-ice component of the surface [1-4]. Sings of internal water oceans on the satellites were found by the NASA's spacecrafts Voyager and Galileo. The space images of Europa discovered an extremely low crater density for an atmosphereless body and formations of the «iceberg»-type going on its surface in the relatively recent past (e. g., [5, 6]). Spectral data showed that non-icy materials on the surface of Europa are mostly represented by $MgSO_4$, Na_2SO_4, H_2SO_4 and their hydrates [7-11] filling the numerous intersecting cracks on the ice surface of the satellite [11, 12]. As follows from modeling based on reflectance spectra (RS), shares of water ice may be ~50% on Ganymede and up to 10% on the surface of Callisto [9]. Their non-icy materials are similar to carbonaceous chondrites, though they could have more organics and hydrated silicates of serpentine type [15]. Small amounts of SO_2 [14], CO_2, H_2S and H_2O_2 [15, 16] as well as hydrates of sulfuric acid (H_2SO_4•$8H_2O$, H_2SO_4•6, $5H_2O$, H_2SO_4•$4H_2O$) [7] are discovered on the surface of the satellites as possible products of sulfur and other ions implanted from Jovian magnetosphere. It leads to emergence of anions (SO_4^{2-}, HSO_3^-, and HSO_4^-) and cations (H_3O^+ and H_5O^+) having spectral details in the infra red (IR) range [17]. A radiolysis product on the surface of icy Galilean satellites is also molecular oxygen (O_2 and/or O_3) originated from O^+ which may be in an adsorbed state in the water ice [18-21].

Results of observations and their interpretation: The observations were performed at 1.25-m telescope with a spectrograph (CCD SBIG ST-6) of the SAI Crimean Observatory in the range of 0.40-0.92 µm with a spectral resolution of ~8Å [22]. The star HD101177 was used as a standard and a solar analog. To exclude a noise component emerging in the RS they were smoothed by the method of "a running box average". The methods are similar to those that were used at processing of spectral data of asteroids [22]. The relative errors (RMSD) in the central part of the visible range of the RS are not more on the average than 1-2% and rise up to 5-7% near the borders of the used spectral range. The phase-angles of the Galilean satellites at the observations were small and changing from 3.8 to 4.3º.

Fig. 1.

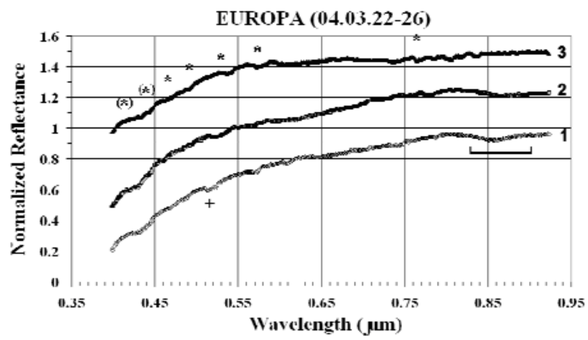


Fig. 2.

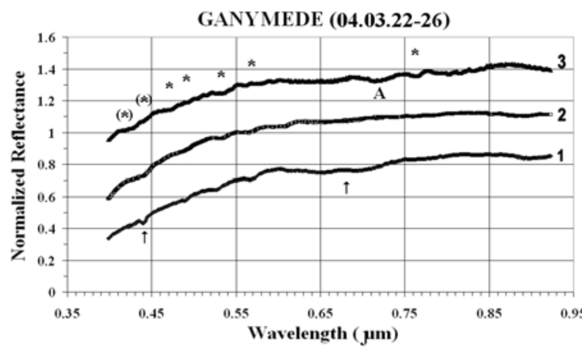
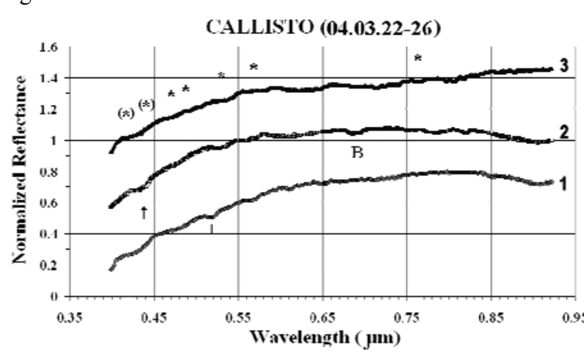


Fig. 3.



The normalized (at 0.55 µm) RS 1-3 of Europa, Ganymede and Callisto obtained on three nights, 22/23 (1), 23/24 (2) and 25/26 (3), of March 2004 are shown in figs 1-3. The curves are offset vertically for clarity. The RS of Europa (T_{rot}= 3. 551^d, D = 3121.6 km) span a time interval close to the rotational period of the body and, therefore, represent its surface as a whole (Fig. 1). The spectra 1-3 of Ganymede (T_{rot}= 7.155^d, D = 5262.4 km) cover a time close to a half of its rotational period (Fig. 2). The spectra 1-3 of Callisto (T_{rot}= 16. 689^d, D = 4820.6 km) were obtained during a quarter of its rotational period (Fig. 3).

Some weak absorption bands indicated by marks were registered for the first time in the RS of Europa, Ganymede and Callisto (see figs 1-3). We are interpreting them with regard to found materials on the surfaces of the satellites. As follows from measurements (e. g., [23, 24, 25]), only molecular oxygen and silicates and/or hydrated silicates have noticeable absorption bands in the visible range among the listed compounds. For instance, there are absorption bands of solid O_2 at <u>0.420</u>, 0.445, <u>0.446</u>, 0.448, <u>0.475</u>, 0.479, 0.494, 0.532, 0.574, 0.575, <u>0.576</u>, <u>0.623</u>, <u>0.627</u>, <u>0.751</u>, <u>0.756</u>, 0.760, and 0.915 μm (the underlined values refer to more intense bands of solid O_2) [23]. At least seven of the bands or their signs at 0.420, 0.446, 0.475, 0.494, 0.532, 0.576, and 0.760 μm (indicated by asterisks or asterisks in brackets if the feature is overlapping with another one) are distinguished in the RS of Jovian satellites in question (figs 1-3). It can be considered as a confirmation of O_2 previous discovery on the bodies based on absorption bands at 0.577 and 0.628 μm [18, 20]. There is a considerable discrepancy between the temperature of solid O_2 (<54 K [23]) and daytime temperatures on the bodies ~120-170 K (e. g., [26, 27]). Nevertheless, one should have in mind that wavelength positions of absorption bands of solid, liquid and condensed states of O_2 remains roughly the same (e. g., [23, 28]). Thus, the found absorption features could be attributed to O_2 on the satellites' surface in an adsorbed state as a type of condensed one.

Two or three of the mentioned absorption bands of O_2 in the RS (figs 1-3) overlap possibly with an absorption feature of Fe^{3+} at 0.44 μm [24] found by us on many asteroids and considered as an indicator of serpentine-type hydrosilicates [22]. Such a supposition is corroborated by the spectrum 1 of Ganymede (fig. 2) with a more narrow absorption feature at 0.44 μm of Fe^{3+} and a wide absorption band of hydrated silicates at 0.67 μm arising probably due to electronic charge-transfere transitions $Fe^{2+} \rightarrow Fe^{3+}$ [25] (indicated by a vertical arrow). The spectrum could be attributed to a side of Ganymede which contains a considerable proportion of hydrated silicates and less water-ice. Prevalence of silicates on the surface of Callisto is probably confirmed not only a narrow absorption band at 0.44 μm (Fe^{3+}) [24] (indicated by a vertical arrow, spectrum 2, fig. 3) but also relatively intense absorption features at 0.90 μm (Fe^{2+}, similar to orthopyroxenic one) [25] in the spectra 1 and 2 (fig. 3). A subtle absorption feature at 0.52 μm in the reflectance spectra of Europa (fig. 1, curve 1) and Callisto (fig. 3, curve 1) (inducated by "+") could be ascribed to electronic transitions in Fe^{2+} [25] in salts and/or minerals. Letters "A" and "B" in the RS of Ganymede and Callisto (figs 2 and 3) designate residual telluric absorption bands of O_2.

There is a probability that hydrated silicates were delivered to the surfaces of Europa, Ganymede and Callisto at magmatic and/or fluvial processes connected with tidal deformations of the bodies by Jupiter. However, taking into account large exposure ages of Ganymede's and Callisto's surfaces (e. g. [12]), a lot of hydrated materials could be brought to them at the fall of asteroids and/or meteoroids.

There is another absorption band in the spectral range 0.84-0.90 μm of two RS of Europa marked by a horizontal bracket (curves 1 and 2, fig. 1). Its existence cannot be explained by the presence of oxygen or iron ions. Sulphur compounds found on the surface of Europa have noticeable absorption features only in the IR region (e.g., [6, 17]). Besides, the range of 0.80-0.90 μm is almost free of telluric absorption bands (e. g., [29]). As follows from laboratory data, the observed feature at 0.84-0.90 μm coincides with position of a pair of overlapping absorption bands of liquid and solid methane (CH_4) [30, 31]. Because of temperature differences between these states of methane (91-112 K) [31] and Europa's daytime surface (120-150 K) [27], CH_4 could be there only in a condenced state (e. g., adsorbed in water ice, similarly to O_2). Problematical character of methane on Europa's surface can be overcome, if there is some way of its replenishment. For example, endogenous flow of CH_4 (due to geological or biological processes in interiors) could lead to its partial accumulation in the regolith layer of Europa.

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