Spectrophotometry of Asteroids and Other Small Bodies with the 6-m, 2.5-m, and 2.0-m Russian Telescopes

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Abstract. This is a briefly review of some important results of spectrophotometry of some asteroids and Galilean satellites of Jupiter, Europa and Callisto with the 6-m telescope of SAO RAS, 2.5-m telescope of the Caucasus Mountain Observatory of SAI MSU, and 2-m telescope of the Terskol observatory of IA RAS in the 21st century.

Keywords: telescopes; minor planets, asteroids: general; planets and satellites: general

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1 Introduction

The study of asteroids and moons of planets in the Solar system is becoming more and more popular, as their research reveals new important evidence confirming close connection of the bodies with the cosmogony of the early Solar system and the processes of formation of the primary life. On the other hand, the earth-approaching asteroids, which could be a threat to the earth's civilization, are considered as sources of valuable extraterrestrial resources. For the reasons, the largest telescopes and the best scientific equipment are used to study these celestial bodies in many countries, including Russia.

2 Spectroscopy of Asteroids with the 6-m Telescope

Spectrophotometric observations of main-belt asteroid 3045 Alois (V=17.2m on March 29/30 and 30/31, 2001) and centaur 10199 Chariklo (V=18.1m on March

31 -April 1, 2001) were performed with 6-m telescope of SAO RAS to study the composition of the bodies. The spectrograph UAGS with a R325/4 diffraction grating and Photometrics CCD camera (1024x1024 px, 24x24 microns/px) operating in the range of 0.360-0.800 μm with a resolution of $R \sim 300$ and a slit width of 2" were also used. Along asteroids, a solar analog star HD 105633 was observed to calculate asteroid reflectance spectra (RS). Despite the presence of high thin clouds in our time, a high optical power of the telescope and a special method of asteroid reflectance spectrum calculation allowed us to obtain scientifically significant results.

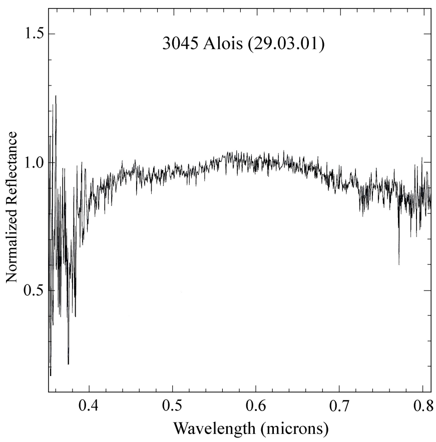

Fig. 1. Normalized (at 0.55 μm) RS of asteroid 3045 Alois on Mar 29, 2001

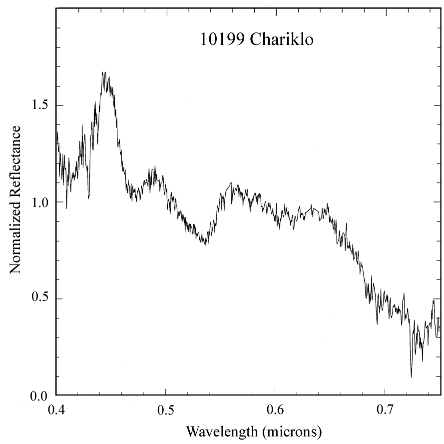

Fig. 2. Normalized RS of Centaur 10199 Chariklo on Mar 31, 2001

3045 Alois is a small (D = 27.5 km) and relatively fast rotating asteroid (P = 3.75 h), moving on the periphery of the main asteroid belt (JPL data). RS measured for the opposite sides of the body show that it has a primitive and heterogeneous composition of matter. The spectrum of one side of it (Fig. 1) corresponds to C taxonomic type and that of another with a positive slope (not shown here) – to D-type (e.g., Bus & Binzel, 2002). The resulting RS of Centaur 10199 Chariklo (Fig. 2) corresponds to its perihelion distance of 13.216 AU exceeding the radius of Saturn's orbit. Taking into account its geometric albedo

(0.045) and eccentricity of orbit (e = 0.169256) (JPL, Accessed September 15, 2020), we calculated Chariklo's subsolar temperature to be equal to $\sim$ 110 K at perihelion and to $\sim$ 90 K at aphelion. Thus, near perihelion, the subsolar temperature reaches the triple points of the NH_3 and CO_2 (e.g. Luna et al., 2014). It should lead to sublimation of the ices of these compounds and the formation of a temporary $NH_3 - CO_2$ gaseous exosphere or coma around the asteroid. This is confirmed by the overall profile of Chariklo's RS which grows to the short-wavelengths according to the Rayleigh law of reflected light scattering $\sim 1/\lambda^4$ (Fig. 2).

3 Spectrophotometry of Asteroids with 2-m Telescope

Regular spectrophotometric observations of asteroids with the 2-m of Terskol Observatory of IA RAS were started in 2012, since commissioning on this telescope a suspended prismatic CCD-spectrograph of low resolution ($R \sim 100$), operating in the range of 0.35-0.92 μm. To date, observations and analysis of more than fifty RS of main-belt asteroids (MBAs) and near-earth asteroids (NEAs) up to 17^m allowed us to study composition and other properties of these bodies. New results obtained with the 2-m telescope include: (1) registration and study of the uncovered short-wavelength part of these asteroid RS ($\sim 0.35-0.45 \mu m$) in data of other authors (Busarev et al., 2015); (2) detection of some specific spectral features of the NEAs (Busarev et al., 2015); (3) discovering spectral features of simultaneous sublimation activity at perihelion of four primitive ice-content asteroids 145 Adeona, 704 interamnia, 779 Nina and 1474 Beira in September 2012 (Busarev et al., 2015, 2016); (4) confirmation of the periodic nature of the activity on three of the asteroids at perihelion (Busarev et al., 2018a); (6) first registration of spectral signs of solar activity influence to the sublimation activity of primitive-type MBAs (Busarev et al., 2019). Examples of the averaged RS of four primitive MBAs at perihelion (145, 704, 779, and 1774) with signs of simultaneous sublimation activity in September 2012 – maxima of reflected solar light scattered in sublimation exospheres of these asteroids at 0.40-0.55 μm and/or 0.60-0.70 μm - and "canonical" spectra of these asteroids (without signs activity) from SMASSII data base are shown in Figs. 3 and 4.

4 Spectrophotometry of Jupiter's Moons Europa and Callisto with the 2.5-m Telescope

We conducted spectrophotometric observations of the leading and trailing hemispheres of Europa and Callisto in the near-infrared range (1.0-2.5 μm) using the

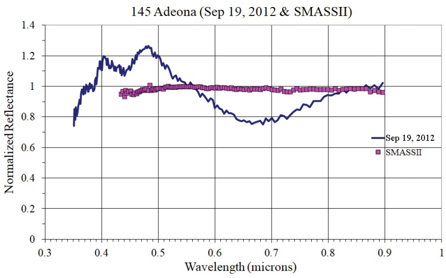

Fig. 3. Averaged and normalized (at 0.55 μm) RS of active asteroid 145 Adeona and its "canonical" spectrum without signs of activity from SMASSII database

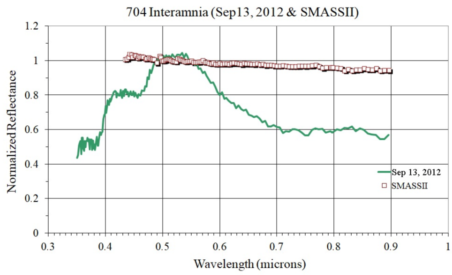

Fig. 4. Averaged and normalized RS of active asteroid 704 Interamnia and its "canonical" spectrum without signs of activity from SMASSII database

2.5-m telescope of the Caucasus Mountain Observatory SAI MSU in 2016-2017 (Busarev et al., 2018b). The observations were made also with the ASTRON-IRCAM infrared camera-spectrograph installed on the 2.5-m telescope (Nadjip et al., 2017). The spectrograph operates in the mode of crossed dispersion with a slit of 10" long and 1.8" wide. In this mode, the spectrum recorded in the Y-J range (1.0-1.5 μm) and separately in the H-K band range (1.5-2.5 μm) with a slit width of 1.8" has a spectral resolution of $R \sim 1000$.

The spectra of Europa and Callisto were calibrated (corrected for atmospheric absorption) with the use of telluric standards. As such standards, we took the stars of early spectral types with a small number of lines in the near-IR range (the stars of A–B types) and G-type stars (with the energy distribution close to solar) to calculate the satellites' RS (Busarev et al., 2018b). The averaged RS (normalized at 1.5 μm and shifted arbitrary for clarity) of Europa's leading (1) and trailing (2) hemispheres are presented in Fig. 5. Importantly, the spectra are in a good agreement with the spectra of H_2O ice–reach (1) and sulfur acid hydrate–reach (2) formations on the surface of Europa obtained with the NIMS spectrograph of Galileo SC of NASA (Carlson et al., 1999) (Fig. 6). Thus, as first found, the obtained RS of the whole trailing hemisphere of Europa point to the predominance of sulfuric acid hydrates in the surface matter and on the leading hemisphere – water ice and clathrate compounds. The vertical arrow indicates the position of the absorption band of methane clathrate (i. e., CH_4 including molecules of H_2O) at 1.67 μm (Fig. 5, the both spectra), identified by us (Busarev et al., 2018b) using previous laboratory data (Smythe, 1975). The

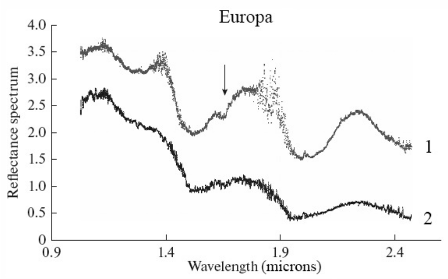

Fig. 5. Averaged and normalized (at 1.5 μm) RS of the leading (1) and trailing (2) hemispheres of Europa. Spectrum 1 is arbitrary shifted for clarity along the vertical axis. The vertical arrow shows the position of assumed weak methane clathrate absorption band at 1.67 μm

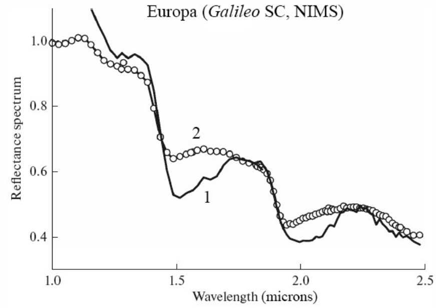

Fig. 6. Normalized (at 1.0 μm) RS of H_2O ice–reach (1) and sulfur acid hydrate–reach (2) local formations on the surface of Europa obtained with the NIMS spectrograph of Galileo SC of NASA (Carlson et al., 1999)

same weak absorption band is seen also in the spectrum registered by Galileo SC (Fig. 6, spectrum 1). There are also similar but very weak signs of the band on the spectra of Callisto obtained closer to its trailing hemisphere. The overall shape of obtained Callisto's spectra (not shown here) turned to be similar to the spectrum of Europa's trailing hemisphere spectrum (Fig. 5, spectrum 2). It points probably to existence in Jupiter's magnetosphere common mechanisms of transfer of sulfuric compounds erupting from volcanoes of Io satellite and their implantation on trailing hemispheres of Europa and Callisto.

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