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SPECTROPHOTOMETRIC STUDIES OF ASTEROIDS II: TAXONOMIC TYPE

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Abstract. *Analysis of spectral observations of a number of Main Belt asteroids, the Apollo family asteroid (NEO) 30825 (1990 TG1), and the rare asteroid 1951 Lick was used to determine their taxonomic types. The observations were carried out in 2023-2024 at the Assy-Turgen Observatory on the AZT-20 telescope equipped with a spectrograph using a volume-phase holographic dispersive element with 360 lines per millimeter in low-resolution mode (R=600). We use the "template" method proposed in (Savelova A.A. et al., 2022) and the visual albedo values. An analysis was carried out for S-type asteroids (107) Arachne and (482) Petrina and the Apollo family asteroid (NEO) 30825 (1990 TG1), which have minerals formed under high-temperature conditions, as well as asteroid (97) Klotho, belonging to the M class, which includes asteroids with an increased metal content. Class A asteroids are characterized by high albedo and a marked increase in reflectance at longer wavelengths. These features indicate the presence of high-temperature olivine or mixtures of olivine with metals, mainly iron and nickel. The presented results show that asteroids (366) Vincentina and (1951) Lick belong to this class. The analysis showed that the normalized reflectance spectrum of (47) Aglaja corresponds to asteroids of spectral class B, the main components of the surface of which are probably anhydrous silicates, hydrated clay minerals, organic polymers, magnetite, and sulfides. According to the authors' results, the normalized reflectance spectrum of asteroid (718) Erida corresponds to the spectral corridor for the T-class template with an albedo ranging from 0.04 to 0.042.*

Keywords: spectrophotometry, asteroids; taxonomic type; reflective spectroscopy;

1. Introduction

Asteroids, as the closest bodies to the Earth, can be considered as possible sources of extraterrestrial natural resources (Board et al., 2010; Lewis, 1996) [1-2], and as relevant technologies are developing, the classification of the asteroids according to certain features of the presence of various minerals for their mining is becoming increasingly in demand). The taxonomic classification of asteroids is a crucial tool in planetology, Earth protection, resource exploration, and understanding the evolution of the Solar System. It is employed in both global space security initiatives and fundamental scientific research, particularly as numerous missions target small celestial bodies. The relevance of asteroid taxonomic classification encompasses scientific, applied, and strategic dimensions. From a scientific perspective, it enhances our comprehension of the Solar System's origin and evolution. In applied contexts, accurate determination of taxonomic type is essential for selecting targets for space missions (e.g., OSIRIS-REx, Hayabusa2, DESTINY+), given that different types exhibit distinct compositions, densities, surface structures, and volatile content.

The observation-based classification of small Solar System bodies has been continuously developed and updated over the last 40 years. While previous iterations of methodology development followed either the availability of large observational campaigns or new instrumental capabilities opening up new dimensions of observation, we see an opportunity to improve, first and foremost, the established methodology.

Taxonomy is the classification of asteroids into categories (classes, taxa) using certain parameters without any a priori rules. The main goal is to identify groups of asteroids that share similar characteristics of their surface composition. Classification into taxa is the first step for further studies in comparative planetology. In the case of asteroids, a precise taxonomic system makes it possible to approach the specific mineralogy for each of the defined classes. Taxonomic systems of asteroids were originally based on broadband colors (Chapman et al. 1971), which made it possible to distinguish two separate types of objects - "S" (rocky) and "C" (carbonaceous). With the increasing amount of information from different types of observations, new taxonomic classes were identified. Historically, the most widely used taxonomies are Tholen (1984) [3] and Barucci et al. (1987) [4], which used data from the Eight-Color Asteroid Survey (Zellner et al. 1985) [5]; Bus & Binzel (2002a) [6], which used SMASSII data, and DeMeo et al. (2009) [7], which is an extension of the previous taxonomy scheme into the near infrared range of the spectrum.

The Tholen classification (Tholen, 1984) [3] is based on photometric studies and offers a method for approximating average reflectance spectra for different classes of asteroids, and also determines their generalized chemical and mineralogical composition. The use of albedo data helped to identify individual classes in this system, which includes 14 spectral classes. In 2002, S. Bus and R. Binzel proposed an expanded version of the classification based on data from the SMASS project, which studied the reflectance spectra of small Main Belt asteroids in the 0.4-1.0 μm wavelength range (Bus and Binzel, 2002) [6]. Unlike the Tholen method, this approach has a much higher spectral resolution and allows for additional details to be considered, which led to the development of a new classification. This system, inheriting the principles of the Tholen classification, expands the number of classes to 24, without taking into account the albedo of asteroids. The Bus-DeMeo classification, proposed later, expanded the methodology for features detected in reflectance spectra up to 2.45 μm wavelength (DeMeo et al., 2009) [7].

Another recent classification of asteroids is based on studies using visible and near-infrared spectrophotometry, as well as on the study of the albedo of these objects (Mahlke et al., 2022) [8]. This classification seems to be quite complete and justified, while maintaining continuity with respect to the two previous ones. The paper presents the transition from one classification to another. Dimensionality reduction and clustering revealed three main complexes: the well-established C- and S-complexes and the restructured M-complex. Spectral classes for all three classifications (Tholen, Bus-DeMeo, Malkhe) [8] are given on the internet resource.

In general, three large complexes can be distinguished: asteroids with low-temperature mineralogy, i.e., not subjected to significant heating during their evolution, the so-called primitive types, or C-complex (C-class); high-temperature asteroids - S-complex asteroids (S-class); and the M(X) complex, which includes asteroids with an increased metal content. The evolution of the X-complex between taxonomies is unclear, since the visual albedo is unknown. In our opinion, the introduction of visual albedo into the analysis of the taxonomic type of asteroid is a justified step, since this characteristic indicates the chemical and mineralogical features of the asteroid's surface.

The obtained results hold both theoretical and practical significance for solar system astrophysics. Determining the taxonomic type of asteroids is crucial for understanding the evolution of the Solar System, the composition of celestial bodies, and assessing potential threats from near-Earth objects. This is particularly relevant for Main Belt asteroids and the Apollo family (Apollo NEOs), especially 30825 (1990 TG1) and the rare asteroid (1951) Lick, which cross Earth's orbit and are of interest for both scientific research and planetary defense. Apollo asteroids constitute the largest subclass of potentially hazardous objects by number, and their taxonomy is vital due to their proximity to Earth and the associated collision risk.

2. Observations

Observations were conducted at the AZT-20 telescope of the Assy-Turgen Observatory using a long-slit spectrograph. A low-resolution mode (R=600) was employed, achieving a dispersion of 4.25 Å per pixel. An EMCCD operating with a gain factor of 5 was used as the detector. The exposure time was 10 seconds, and the spectrograph slit width was 9 arcseconds. To calibrate the wavelengths, the spectra of a standard source -

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a He-Ne-Ar lamp - were taken. The spectrum of the asteroids was measured using the differential method by comparing the fluxes from the object and a standard star. Stars analogous to the Sun (spectral class G) were used as standards. Analysis is based on reflectivity spectra obtained on 2024-02-22, 2023-11-03, 2023-11-04, and 2023-11-21 at the Assy-Turgen Observatory and comparison with reflective spectra of these asteroids based on INASAN observations performed in 2013–2017 and model spectra obtained from Gaia DR observations. Taxonomic classes were estimated according to the Tholen classification, without taking into account the albedo of the asteroids.

3. Method of analysis

To analyze the reflectance spectra of asteroids, the "template" method proposed in (Savelova et al., 2022) [9] was utilized. The authors propose using templates that are the general spectral boundaries of a taxonomic class, calculated using all normalized reflectance spectra of asteroids of a particular taxonomic class from the SMASSII database (Bus and Binzel, 2020) [10], including visual albedo in the analysis, since this characteristic indicates the chemical and mineralogical features of the surface of asteroids. The template is an area within which the reflectance spectrum of an asteroid belonging to a given taxonomic class is likely to be located.

Template selection was based on asteroid albedos categorized by class, as established in Tholen's seminal work (Tholen, 1984) [3]. Asteroids with numbers up to 2000 from the SMASSII database were selected to compile the database. Based on the SMASS II data, the highest and lowest values of the normalized intensity were determined depending on the wavelength. (The "spectral corridor" of the template). For asteroids of class A, 4 spectra were selected, for class B - 5 spectra, for class C - 74 spectra, for class D - 5 spectra, for class E - 8 spectra, for class F - 7 spectra, for class G - 7 spectra, for class M - 23 spectra, for class P - 11 spectra, for class S - 112 spectra, and for class T - 5 spectra. In this way, data were selected for 11 taxonomic classes, taking into account the albedo. The correspondence between the reflectance spectra of the asteroids considered in this work and the templates was checked at wavelengths in the range of 0.44-0.75 µm.

Table 1-7 presents the designation of the asteroid, date and time of observation, exposure time, and air mass. Data format: 1 - Date and time in YYMMDD, 2 - Universal Time in hhmmss, 3 and 4 - right ascension and declination at the time of observation in the J2000, 5 - distance from the observer to the object (in AU), 6 - distance from the Sun to the object (in AU), 7 - solar elongation (in °), 8 - phase angle of the object (in °), 9 - predicted stellar magnitude, 10 - air mass, 11 - exposure time. Columns 3-9 are given according to the Minor Planet Center at the time of observations. The last row of the table contains information on the EMCCD mode used during observations.

4. Results and discussion

Reflectance spectra analysis for each asteroid was performed. In the figures below, the area of the corresponding template of the taxonomic class under consideration to which the asteroid belongs is highlighted in green, and the reflectance spectra of the asteroid itself, obtained by the authors of this work, are shown in colored lines. *(97) Klotho* is a Main Belt asteroid. Its orbital period is 1592.5213 days, and its rotation period is 35.15 hours. Its geometric albedo is 0.128, its diameter is 100.717 km, and its SMASSII spectral type is class M (Small-Body Database Lookup - NASA) [11]. Data on the observation conditions are given in Table 1, and the normalized reflectance spectrum is shown in Figure 1.)

Table 1. Information on observations of (97) Klotho

Date (y m d)	UT (hms)	R.A. (h m)	Decl. (˚ ‘)	Delta (AU)	R (AU)	Elong (˚)	Ph (˚)	$V^{(m)}$	Airmass	Exp Time (s)
1	2	3	4	5	6	7	8	9	10	11
97 Klotho										
2023 11 03	182443	23 33 56.5	-12 48 14	1.437	2.188	127.6	21.0	11.4	2.637	120
2023 11 03	182646	23 33 56.5	-12 48 14	1.437	2.188	127.6	21.0	11.4	2.667	120

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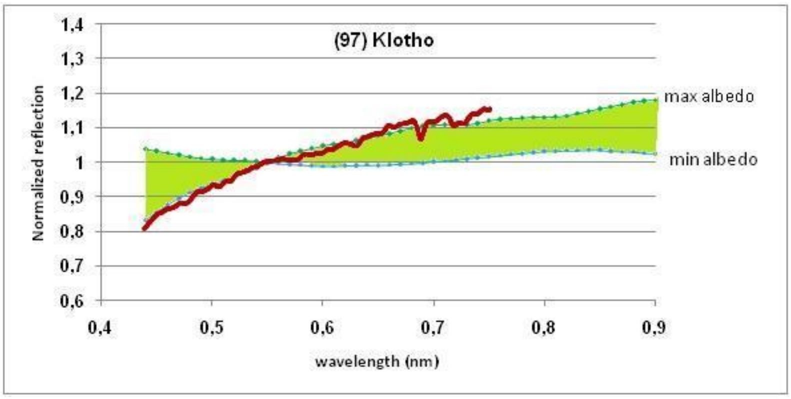

Fig.1. Normalized reflectance spectrum of asteroid (97) Klotho based on FAI observations, green area - spectral corridor corresponding to the taxonomic class M template in the albedo range from 0.072 to 0.203

The results obtained, taking into account the visual albedo, allow classifying (97) Klotho as an M-class asteroid, the third most numerous class of asteroids, the composition of which has been studied rather poorly. It is only known that asteroids of this class have a moderately high albedo (0.1 - 0.2) and contain metals. Some, but not all of them, consist of nickel and iron, with a small admixture of rocks. These asteroids are probably the remains of the metal cores of larger planetesimal asteroids, which were destroyed as a result of mutual collisions in the early stages of the formation of the Solar System. They may be the main source of metal meteorites. *(107) Arachne and (482) Petrina* asteroids, according to our results, can be classified as class S. The information about observations is presented in Table 2, and the normalized reflectance spectra are shown in Figure 2.

Table 2. The information about observations of (107) Arachne and (482) Petrina

Date (y m d)	UT (hms)	R.A. (h m)	Decl. (° ')	Delta (AU)	R (AU)	Elong (°)	Ph (°)	V(m)	Airmass	Exp Time (s)
1	2	3	4	5	6	7	8	9	10	11
407 Arachne										
2023 11 21	162505	05 54 52.6	+30 29 09	1.627	2.526	149.1	11.6	13.0	1.640	240
2023 11 21	162913	05 54 52.4	+30 29 09	1.627	2.526	149.1	11.6	13.0	1.613	240
482 Petrina										
2023 11 03	144726	21 57 53.3	-08 33 51	2.458	2.921	108.0	18.9	14.2	1.652	120
2023 11 03	144931	21 57 53.3	-08 33 51	2.458	2.921	108.0	18.9	14.2	1.656	

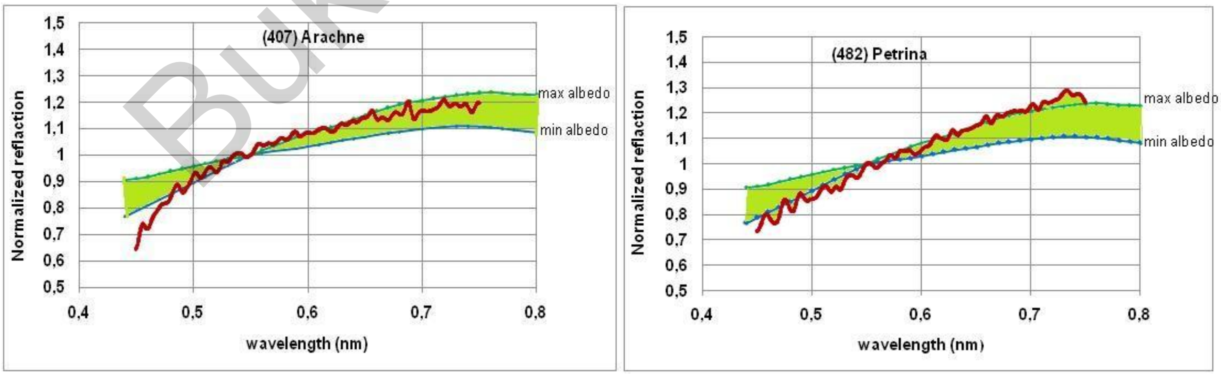

Fig.2. Normalized reflectance spectra of asteroids (407) Arachne and (482) Petrina based on FAI observations, green area - spectral corridor corresponding to the taxonomic class S template in the albedo range from 0.082 to 0.244

(407) Arachne is a Main Belt asteroid. Its orbital period is 1552.6650 days, and the rotation period is 22.627 hours. The geometric albedo is 0.0548, the diameter is 95.07 km, the spectral type according to Tholen is class C, and according to SMASSII its class is Ch (Small-Body Database Lookup NASA) [11].

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(482) Petrina is a Main Belt asteroid. Its orbital period is 1897.5417 days, and its rotation period is 11.7922 hours. Its geometric albedo is 0.246, its diameter is 45.751 km (Small-Body Database Lookup - NASA) [11]. Similar to INASAN observations, the reflectance spectrum has an increase in the long-wavelength region and, according to (Shcherbina et al., 2019) [12], corresponds to high-temperature silicate assemblages and belongs to the Tholen class S. The spectral class S indicates a siliceous (rocky) mineralogy. They have a relatively high density. About 17% of asteroids belong to this class, making it the second most common after the carbonaceous C-type.

(718) Erida is a Main Belt asteroid. Its orbital period is 1954.9347 days, and its rotation period is 17.447 hours. Its geometric albedo is 0.042, its diameter is 70.911 km, and its SMASSII spectral type is class X (Small-Body Database Lookup - NASA) [11]. The information about the observations is given in Table 3, and the normalized reflectance spectrum is shown in Figure 3.

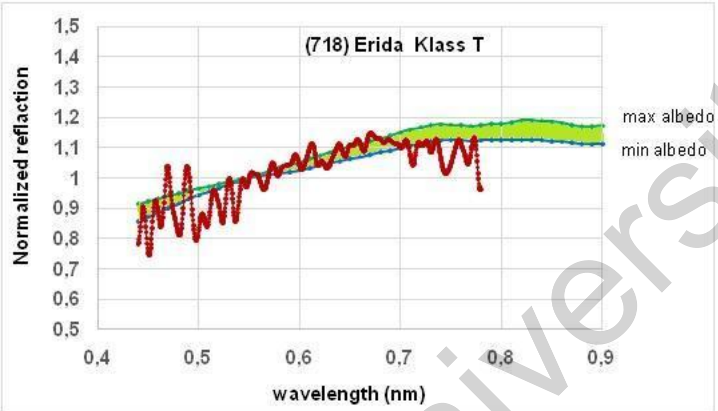

Fig.3. Normalized reflectance spectrum of asteroid (718) Erida based on FAI observations, green area - spectral corridor corresponding to the taxonomic class T template in the albedo range from 0.04 to 0.042

Table 3. The information about observations of (718) Erida

Date (y m d)	UT (hms)	R.A. (h m)	Decl. (˚ ‘)	Delta (AU)	R (AU)	Elong (˚)	Ph (˚)	V(m)	Airmass	Exp Time (s)
1	2	3	4	5	6	7	8	9	10	11
718 Erida										
2023 11 03	171341	23 24 44.0	-09 30 56	2.837	3.527	127.3	12.9	15.5	1.885	240
2023 11 03	171747	23 24 44.0	-09 30 56	2.837	3.527	127.3	12.9	15.5	1.906	240

According to the Bus-Binzel (SMASS) classification, (718) Erida is an X-type asteroid with featureless spectra and a wide range of albedo, suggesting a variety of surface compositions. X-type spectra typically show low curvature or nearly flat spectral regions. According to Tholen, these are asteroids of unknown composition with dark and moderately red spectra and moderate absorption bands below 0.85 µm.

According to our results, the normalized reflectance spectrum of asteroid (718) Erida falls within a spectral corridor corresponding to the T-type template with an albedo in the range from 0.04 to 0.042. T-type asteroids are rare asteroids of the inner Main Belt. They may be related to P- or D-type asteroids, or possibly highly modified C-type objects. Asteroids of this class were originally thought to be anhydrous, but new spectroscopic data indicate the presence of hydration features. (Hiroi & Hasegawa, 2003) [13] found that asteroid 308 Polyxo has spectral characteristics similar to the Tagish Lake meteorite, which contains signs of hydration. In addition, new spectroscopic observations of T-type asteroids such as (96) Aegle and (570) Kythera also revealed hydration signatures, confirming the presence of water or hydrated minerals on their surfaces (Kwon et al., 2022) [14]. Future study of asteroid (718) Erida will be important to study this rare spectral class and detect signs of hydration.

(47) Aglaja is a Main Belt asteroid with an orbital period of 1787.1149 days, and the rotation period of 13.178 hours. Its geometric albedo is 0.082, the diameter is 168.174 km, the spectral type according to SMASSII is class B, and according to Tholen it is class C. The information regarding the observations is given in Table 4, and the normalized reflectance spectrum is shown in Figure 4.

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Table 4. The information about observations of (47) Aglaja

Date (y m d)	UT (hms)	R.A. (h m)	Decl. (˚ ‘)	Delta (AU)	R (AU)	Elong (˚)	Ph (˚)	$V^{(m)}$	Airmass	Exp Time (s)
1	2	3	4	5	6	7	8	9	10	11
47 Aglaja										
2023 11 03	151112	22 03 42.0	-13 22 29	2.067	2.549	107.7	21.8	12.9	1.907	120
2023 11 03	151316	22 03 42.0	-13 22 28	2.067	2.549	107.7	21.8	12.9	1.903	120

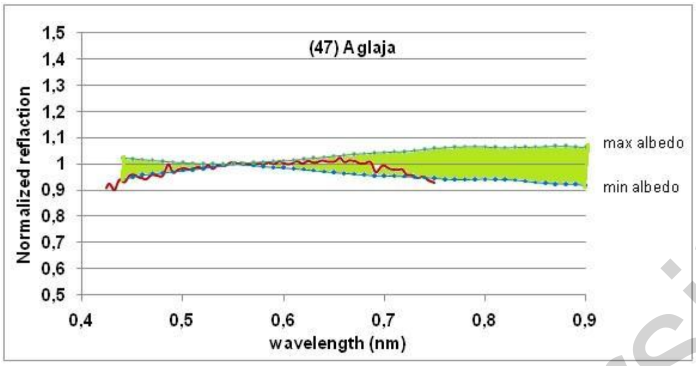

Fig.4. Normalized reflectance spectrum of asteroid (47) Aglaja based on FAI observations, green area - spectral corridor corresponding to the taxonomic class B template in the albedo range from 0.066 to 0.129

Results presented in this study indicate that this asteroid is of class B in accordance with SMASSII classification. Asteroids of this class have a nearly linear spectrum and are distinguished only by spectral tilt. The main constituents of the surface are probably anhydrous silicates, hydrated clay minerals, organic polymers, magnetite, and sulfides. *(366) Vincentina* is a Main Belt asteroid. Its orbital period is 2037.5442 days, and its rotation period is 12.7365 hours. Its geometric albedo is 0.091, its diameter is 86.368 km, and its SMASSII spectral type is of class A (Small-Body Database Lookup - NASA) [11]. The information regarding the observations is given in Table 5, and the normalized reflectance spectrum is shown in Figure 5

Table 5. The information about observations of (366) Vincentina

Date (y m d)	UT (hms)	R.A. (h m)	Decl. (˚ ‘)	Delta (AU)	R (AU)	Elong (˚)	Ph (˚)	$V^{(m)}$	Airmass	Exp Time (s)
1	2	3	4	5	6	7	8	9	10	11
366 Vincentina										
2023 11 03	155150	22 33 43.9	-07 04 42	2.411	2.992	116.8	17.2	13.9	1.661	120
2023 11 03	155356	22 33 43.9	-07 04 42	2.411	2.992	116.8	17.2	13.9	1.667	120

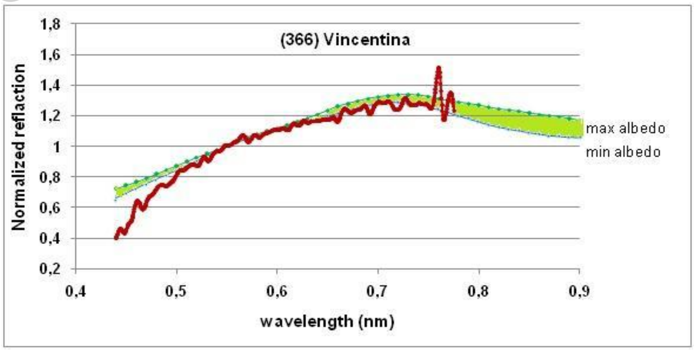

Fig.5. Normalized reflectance spectrum of asteroid (366) Vincentina based on FAI observations, green area - spectral corridor corresponding to the taxonomic class A template in the albedo range from 0.122 to 0.29

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The obtained results indicate that this asteroid corresponds to the spectral class A according to the SMASSII classification. This is a rare class of asteroids (since 2005, only 17 asteroids of this class have been discovered), which are characterized by a fairly high albedo (between 0.17 and 0.35) and a reddish color in the visible part of the spectrum, which is determined by a significant increase in the reflectivity of asteroids of this class towards long wavelengths.

Asteroids of this class show strong absorption in the UV region of the spectrum, as well as at wavelengths of 0.7 and 1.05 μm in the IR region, while there are no absorption bands at a wavelength of 2 μm, which indicates the presence of high-temperature olivine or a mixture of olivine with metals, mainly iron and nickel. The discovery of olivine in asteroids is significant, as olivine is typically formed only under high temperatures, ranging from 1100 °C to 1900 °C. This, in turn, suggests that asteroids of this class are fragments of intermediate silicate shells from larger asteroids, which, at an early stage in their history, were in a partially or completely molten state and underwent stratification (differentiation) of magma. Asteroids of class A predominate mainly in the inner part of the Main Asteroid Belt.

(1951) Lick is a rare type of Mars-crossing asteroid with a diameter of approximately 5.6 kilometers. In the SMASS taxonomic classification, Lick's spectral corresponds to a rare A-type asteroid (Small-Body Database Lookup - NASA) [11] with a surface consisting of almost pure olivine (J. de León et al., 2004) [15]. Its orbital period is 598.8541 days. The most recent observation by Michael Lucas in February 2011 yielded a rotation period of 5.317 hours with an amplitude of 0.33 magnitudes (Lucas et al., 2001) [16]

According to three observations made by the infrared astronomical satellite IRAS, the diameter of the asteroid is 5.57 kilometers and its albedo is 0.09 (Tedesco et al., 2004) [17]. The information regarding the observations is given in Table 6, and the normalized reflectance spectrum is shown in Figure 6.

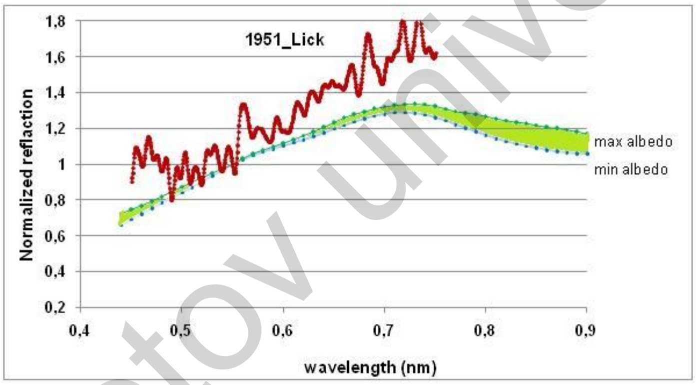

Fig.6. Normalized reflectance spectrum of asteroid (1951) Lick based on FAI observations, green area - spectral corridor corresponding to the taxonomic class A template in the albedo range from 0.122 to 0.29

Table 6.The information about observations of (1951) Lick

Date (y m d)	UT (hms)	R.A. (h m)	Decl. (˚ ‘)	Delta (AU)	R (AU)	Elong (˚)	Ph (˚)	V$^{(m)}$	Airmass	Exp Time (s)
1	2	3	4	5	6	7	8	9	10	11
1951 (Lick)										
2024 02 22	142710	04 51 11,4	+02 42 01	0.958	1.471	98.1	41.7	16.5	1.34	60
2024 02 22	142824	04 51 11,5	+02 42 03	0,958	1,471	98,1	41,7	16,5	1.34	60
2024 02 22	142958	04 51 11,5	+02 42 05	0,958	1,471	98,1	41,7	16,5	1.35	120
2024 02 22	143230	04 51 11,6	+02 42 06	0,958	1,471	98,1	41,7	16,5	1.35	240

It was not possible to figure out a taxonomic class taking into account the albedo using the “template” method, using observations presented in this study. Based on the visual albedo (1951) Lick fits into the spectral corridors of classes M (in the albedo range from 0.072 to 0.203) and S (in the albedo range from 0.081 to 0.244), but does not fit into the spectral corridor of templates for these classes at all and has a significant increase in reflectivity in the visible spectrum, similar to class A asteroids

This increase in reflectivity, the “reddening” of the reflectance spectrum, according to [Brunetto, R., de León, J., & Licandro, J. (2007) [18] was caused by space weathering. The researchers compared the spectrum of (1951) Lick with laser ablation experiments on silicate olivine to determine the effect of space

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weathering on its surface. The results showed that the asteroid's surface is heavily weathered, and the saturation level of weathering is similar to laboratory experiments, indicating an age of the surface of the order of 10^7-10^8 years Figure 7. Observations obtained in this work confirm the large value of the spectral slope at the level of 1.9 μm^{-1}.

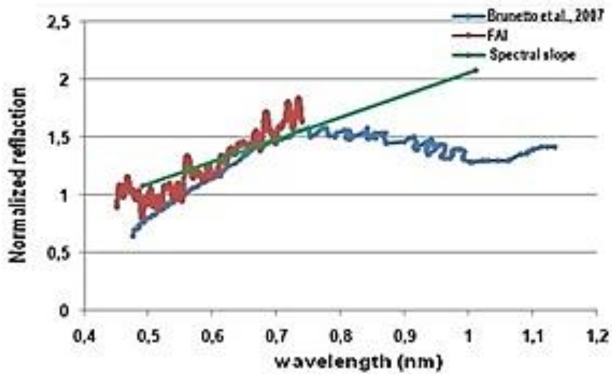

Fig.7. The FAI spectrum of Lick (red) compared with the spectra of San Carlos olivine (blue line) scaled at 0.55 μm, and the line represents the spectral slope

Apollo 30825 (1990 TG1) is an Apollo-family (NEO) Earth-crossing asteroid with an orbital semi-major axis greater than Earth's (> 1 AU), but a perihelion distance less than Earth's aphelion (q < 1.017 AU), and a minimum distance from Earth of 0.06912 AU. The orbital period is 1388 days; the rotation period of the asteroid is 2.62428 hours. The geometric albedo is 0.262, the diameter is 5.6 ± 2.1 km [11]. Its spectral class S [2] indicates that this is a "rocky" asteroid composed mainly of silicates, iron, and magnesium. The information regarding the observations is given in Table 7, and the normalized reflectance spectrum is shown in Figure 8.

Table 7. The information about observations of 30825 (1990 TG1)

Date (y m d)	UT (hms)	R.A. (h m)	Decl. (° ')	Delta (AU)	R (AU)	Elong (°)	Ph (°)	$V^{(m)}$	Airmass	Exp Time (s)
1	2	3	4	5	6	7	8	9	10	11
30825 (1990 TG1)										
2024 02 22	150513	07 50 47,2	-01 57 22	0,494	1,407	140,8	26,4	15,2	1.54	60
2024 02 22	150621	07 50 47,1	-01 57 22	0,494	1,407	140,8	26,4	15,2	1.54	60
2024 02 22	150812	07 50 46,9	-01 57 21	0,494	1,407	140,8	26,4	15,2	1.53	120
2024 02 22	151032	07 50 46,7	-01 57 20	0,494	1,407	140,8	26,4	15,2	0.52	240

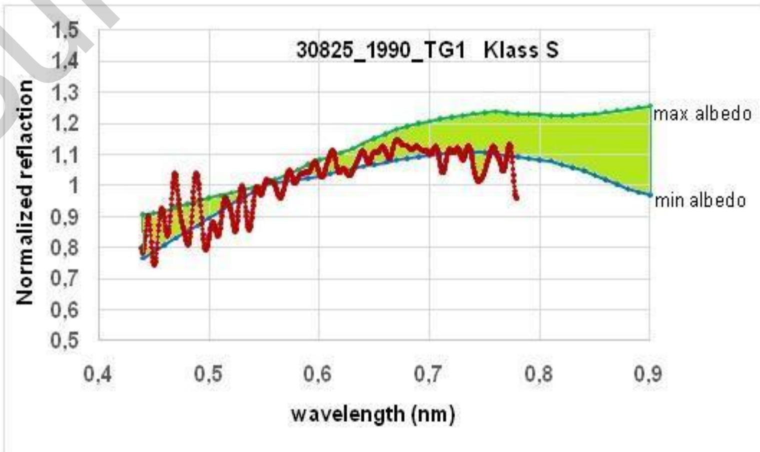

Fig.8. Normalized reflectance spectrum of asteroid 30825 (1990 TG1) based on FAI observations, green area - spectral corridor corresponding to the taxonomic class S template in the albedo range from 0.081 to 0.244

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The template analysis shows that the albedo of asteroid 1990 TG1 fits into the spectral class A, which has an albedo range from 0.081 to 0.29. However, its spectrum is more consistent with the S class (Figure 7). The asteroids are of the silicate type, quite bright (albedo from 0.10 to 0.22). They are rich in metals: iron, nickel, and magnesium. Their spectrum is enhanced at long wavelengths, similar to the spectrum of iron meteorites. According to (Benner et al., 2008) [2], asteroid 30825 (1990 TG1) has a circular polarization ratio (SC/OC) of 0.27 ± 0.03, indicating a moderately rough surface on centimeter-to-decimeter scales. The moderate roughness may be the result of micrometeorite bombardment and other processes, such as space weathering, that have altered the asteroid's surface over time. These processes include surface color change (reddening), decreased albedo, and weakening of spectral lines.

5. Conclusion

In this paper, spectral observations of several Main Belt asteroids, the Apollo family asteroid (NEO) 30825 (1990 TG1), and the rare asteroid 1951 Lick were analyzed to determine their taxonomic classes. In general, the results obtained correspond to the generally accepted large taxonomic classes. Asteroids (107) Arachne and (482) Petrina can be classified as S-class asteroids with minerals formed under high-temperature conditions. The Apollo family asteroid (NEO) 30825 (1990 TG1) was also included in this class. (97) Klotho belongs to the M-class asteroids, which include asteroids with an increased metal content. Asteroids with a fairly high albedo and a significant increase in reflectivity in the long-wavelength part of the spectrum of class A include asteroids (366) Vincentina and (1951) Lick, which indicates the presence of high-temperature olivine or a mixture of olivine with metals, mainly iron and nickel, in their composition. The normalized reflectance spectrum of (47) Aglaja corresponds to asteroids of the spectral class B, the main components of the surface of which are possibly anhydrous silicates, hydrated clay minerals, organic polymers, magnetite, and sulfides. According to results presented in this study, the normalized reflectance spectrum of asteroid (718) Erida corresponds to the spectral corridor of the template for class T asteroids, with an albedo range from 0.04 to 0.042. Class T are rare asteroids of the inner part of the Main Belt. According to the SMASSII classification, without taking into account the albedo, asteroid (718) Erida belongs to class X.

It should be noted that the "template" method used is empirical: spectral "corridors" are derived statistically, without direct physical modeling of mineralogy. Its reliability is limited by the relatively low spectral resolution of the data (R ≈ 600) and the uncertainty of albedo measurements, which can reach 20–30%. Thus, the method is suitable for first-order taxonomic classification but cannot provide an unambiguous mineralogical interpretation, especially for rare classes such as A and T. These limitations and the quality of the observational material obtained prevented a definitive conclusion regarding their classification and taxonomic type. Further observations of the corresponding asteroids with higher resolution or in the near-infrared range are necessary.

Conflict of interest statement.
The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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