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Using *UBVRI*-photometry to detect signs of asteroid activity

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Abstract. This paper focuses on the application of *UBVRI*-photometry to detect signs of sublimation-dust activity in Main Belt asteroids. Survey observations have been conducted at the Caucasian Mountain Observatory of Moscow State University since 2021, using the RC600 telescope, which has provided data for 133 asteroids. Special attention is given to primitive-type asteroids (with low-temperature mineralogy), many of which may still retain water ice in their interiors. Numerical models of light reflection by active C-type asteroids with a dust exosphere have confirmed spectral differences depending on particle composition. A qualitative criterion for the activity of a primitive asteroid was established, based on the occurrence of a negative gradient in its reflection spectrum in an active state due to ice sublimation and the formation of a dust exosphere. As a result of observations and data analysis, spectral signs of dust activity were detected in 14 primitive asteroids, confirming the effectiveness of the method used.

Keywords: methods: observational; techniques: photometric; asteroids: active asteroids

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1 Active asteroids: relevance of research

In recent years, the distinctions between comets and asteroids have blurred, complicating their identification. Although sublimation activity is a traditional feature of comets, they can appear like asteroids as their volatile compounds are depleted or an insulating crust forms (Rickman et al. 1990). Conversely, asteroids can show comet-like activity, though the mechanism is debated. An example is 133P/Elst-Pizarro, discovered in 1996 and classified as a Main Belt comet (Elst et al. 1996). The concept of the "asteroid-comet continuum" suggests no rigid boundaries between these objects.

Active asteroids are bodies that have shown pronounced activity, such as coma or tail formation, at least once. The causes are not specified, as activity can arise from various mechanisms. The main mechanisms for Main Belt asteroids are ice sublimation (mainly water ice) and impact events. Sublimation requires ice near the surface to absorb solar energy. Primitive-type asteroids, likely formed near the early Solar System's water ice condensation boundary, are prime candidates for active asteroids.

2 Object selection criteria

For the phenomenon of sublimation activity to occur, the bodies must contain reserves of water ice. Therefore, when designing the observation program, special attention is given to low-temperature asteroids that have not undergone significant heating throughout their existence. These asteroids exhibit absorption bands in their reflection spectra characteristic of hydrosilicates (Busarev et al. 2015). Such spectral types of asteroids include C, B, F, G according to Tholen's classification, as well as B, C, and subgroups Cb, Cg, Ch, Cgh according to the SMASS II classification by Bus-Binzel. The taxonomic class X is also promising, as the asteroids within it generally exhibit characteristics similar to those mentioned above.

Ice does not necessarily need to be on the surface of a solid, airless body to sublimate; however, for remote detection, it must be present on the surface. Ice reservoirs may be located just below the surface or deeper, with the most well-preserved reservoirs likely found in larger asteroids.

Sublimation requires the presence of radiant energy, the source of which is the Sun. Many periodically active objects, particularly comets, become more active as they approach the Sun. Therefore, the observation program includes asteroids that are at minimal perihelion distances (Shcherbina et al. 2022).

3 *UBVRI*-photometric observations: observatory, methodology, and data processing

Since 2021, studies of Main Belt and near-Earth asteroids have been conducted at the Caucasian Mountain Observatory of Moscow State University (CMO MSU; elevation 2112 m) to detect signs of activity. *UBVRI*-photometric data are obtained using the semi-automatic RC600 telescope (0.6 m). The photometric system's characteristics are detailed in Petrova & Busarev (2023). Two observational programs from December 2021 to March 2022 and November 2022 to February 2023 yielded *UBVRI* data for 133 asteroids (Petrova & Busarev 2023; Busarev et al. 2024).

The method for calculating approximated reflection spectra involves dividing the integral light intensity at the effective wavelength in each photometric band (registered by the CCD from the asteroid) by the same value from a solar-analog star, considering the difference in air masses and the spectral transparency function of the atmosphere. The reflectance values are normalized to the V-band. Each asteroid was observed in three series (passes through *UBVRI* filters within a few minutes to ∼10–15 minutes, depending on brightness), compiling individual reflectance values into a single spectrum. Solar control stars (non-variable stars close to the asteroid in magnitude and coordinates on the same CCD-frame) ensured atmospheric stability. Consistent data from the three series indicated good atmospheric conditions during measurements.

4 Criteria for detecting sublimation-dust activity

After obtaining the approximated reflection spectra, an analysis identified signs of sublimation-dust activity. A clear indicator is a significant deviation from the "canonical" reflection spectrum from the SMASS II database. Figure 1 shows examples for asteroids 145 Adeona (a) and 322 Phaeo (b). Thus, a qualitative criterion was established: a significant negative gradient in the reflection spectrum of an active asteroid compared to its "classical" spectrum from the SMASSII database.

For interpreting the obtained reflection spectra of active asteroids, numerical modeling of light scattering in the exosphere of a hypothetical low-albedo (geometric albedo $A_g = 0.072$) C-type asteroid with a dust exosphere was conducted. Figure 2 shows examples of normalized reflection spectra calculated for such an asteroid, normalized to the value at $\lambda = 0.55$ μm. The optical thickness of the exosphere (τ), sizes of individual particles ($R_{\rm eff}$), and monomers in aggregates (r), as well as substance designations, are indicated on the graphs and captions.

From Fig. 2b, it is evident how different the reflection spectrum of an active asteroid can be depending on the exosphere particle composition. Non-absorbing

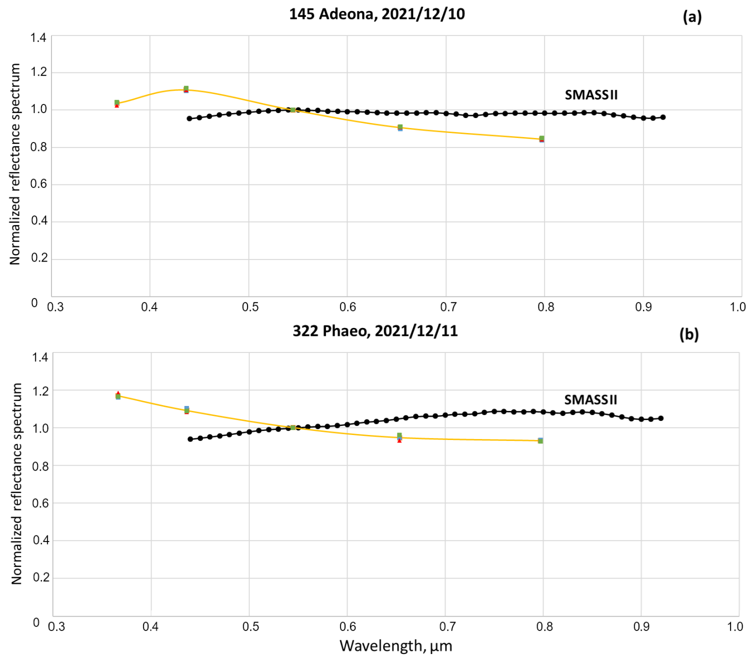

Fig. 1. Approximated normalized to 0.55 μm reflection spectra (at the effective wavelengths of $UBVRI$-photometric bands) of asteroids showing signs of activity: 145 Adeona (a); 322 Phaeo (b). Their reflection spectra from the SMASS II database are shown in black.

ice or weakly absorbing silicates significantly elevate the short-wavelength part of the spectrum, whereas submicron particles that absorb short wavelengths have the opposite effect.

To accurately determine the sublimation-dust activity of a specific asteroid, a quantitative criterion was introduced. This criterion compares the standard error of the mean intensity of light flux in the U-band from the active asteroid and a non-variable control star. According to model calculations, the U-band is the most informative for detecting asteroid activity, exhibiting the largest amplitude of short-period variations in light flux intensity caused by the solar wind (Busarev et al. 2024). The control star on the same CCD-frame, with a similar magnitude, should not show such strong variations.

5 Results

Since 2021, spectral-dust activity of varying degrees has been detected in 14 asteroids, with some objects showing repeated signs of activity. The physical parameters of these asteroids are presented in Table 1.

Table 1. Physical parameters and family affiliation (if applicable) of asteroids showing signs of activity. Note: The source of the information is indicated by superscript letters: [a] https://ssd.jpl.nasa.gov/; [b] https://www.minorplanet.info/. Classification is indicated by superscript numbers: [1] according to Tholen classification; [2] according to SMASS II classification.

Number and Name	Diameter (Effective) km	Class[a]	Geometric Albedo	Family[b]
145 Adeona	127.78[a]	C[1]	0.06[a]	Adeona
	150.95[b]	Ch[2]	0.05[b]	
164 Eva	100.25[a]	CX[1]	0.03[a]	–
	73.03[b]	X[2]	0.10[b]	
322 Phaeo	69.86[a]	X[1]	0.09[a]	Phaeo
	73.14[b]	X[2],D[2]	0.08[b]	
360 Carlova	129.13[a]	C[1]	0.04[a]	–
	115.62[b]	C[2]	0.05[b]	
521 Brixia	107.23[a]	C[1]	0.07[a]	–
	115.78[b]	Ch[2]	0.04[b]	
629 Bernardina	35.09[a]		0.14[a]	–
	29.97[b]	X[2]	0.18[b]	
750 Oskar	22.53[a]	F[1], C[1]	0.06[a]	Nysa-Polana
	20.51[b]		0.05[b]	
751 Faina	113.70[a]	C[1]	0.03[a]	Faina
	110.18[b]	Ch[2]	0.04[b]	
757 Porthlandia	32.89[a,b]	XF[1]	0.22[a]	Athor
		Xk[2]	0.16[b]	
762 Pulcova	147.34[a]	F[1], C[1]	0.04[a,b]	–
	136.88[b]	Cb[2]		
778 Theobalda	55.32[a]	F[1]	0.08[a]	Athor
	63.88[b]		0.05[b]	
779 Nina	80.57[a]		0.16[a]	–
	77.45[b]	X[2]	0.17[b]	
1121 Natascha	12.86[a]		0.29[a]	Theobalda
	12.41[b]		0.27[b]	
1687 Glarone	37.85[a]		0.14[a]	Theobalda
	33.66[b]		0.08[b]	Themis

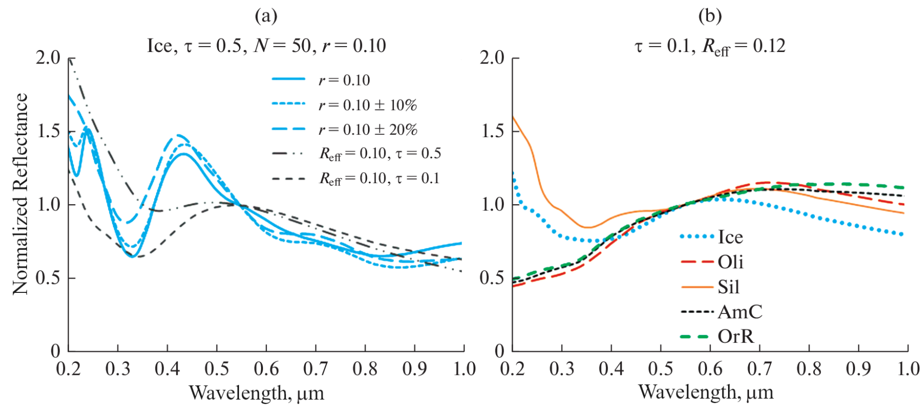

Fig. 2. Normalized reflectance spectra for a hypothetical low-albedo C-type asteroid with a dust exosphere. Numerical modeling by E.V. Petrova (Petrova & Busarev 2023). (a) The spectra for the exosphere ($\tau = 0.5$) composed of ice aggregates, with particle radii $r = 0.10$ μm or within specified limits, or homogeneous particles at specified $R_{\rm eff}$ and τ. (b) The exosphere with $\tau = 0.1$ contains homogeneous particles of different composition ($R_{\rm eff} = 0.12$ μm). "Ice" – H_2O ice, "Oli" – olivines, "Sil" – astronomical silicates, "AmC" – amorphous carbon, "OrR" – refractory organic.

Therefore, based on the presented observational and modeling results, it can be asserted that *UBVRI*-photometric survey observations are a highly sensitive and reliable method for detecting signs of sublimation-dust activity in primitive-type asteroids, likely containing water ice.

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