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First reported observation of asteroids 2017 AB8, 2017 QX33, and 2017 RV12

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Abstract. In this paper, we show the result of the joint use of the OMT-800 telescope, the CoLiTec software, and the Väisälä method. The paper considers in detail several of the discovered (rediscovered) asteroids: 2017 AB8, 2017 QX33, and 2017 RV12 from a long list of small bodies of the Solar System.

Key words: Minor planets, asteroids: general – Methods: observational, numerical

1. Introduction

The Odesa Astronomical Observatory (OAO) has a long history of patrol observations as well as targeted observation campaigns. During the implementation of various observational programs, a large amount of scientific value information has been accumulated in the observatory archive.

Against the backdrop of constant interest in the search and study of Solar System objects, we strive to extract the maximum additional information from the observations obtained, using the modern processing tools at our disposal. We will talk about the search for moving objects in a series of panoramic images of the starry sky, which were obtained earlier in the course of observing a particular object with the OMT-800 telescope (Andrievsky et al., 2013). The method of storage of observational information and the organization of access to it is an independent task; however, in the case of CCD images, as a rule, we conduct additional research in hot pursuit. The research resource is thousands of images with a penetrating power of up to 20 magnitude obtained during the observational season, covering tens of square degrees of the sky. At the time of writing this manuscript, the number of registered small bodies of the Solar System, according to the Minor Planet Center[1] (MPC), is almost 1.3 million and continues to grow every week, thanks to the efforts of search groups (asteroid surveys). The overwhelming majority of known small bodies belong to the main asteroid belt, and it should be expected that their number in the field of view will be greater when the field of view is close to the ecliptic zone.

OMT-800 telescope targets are often just asteroids, which increases our chances of finding and measuring other small bodies in the telescope's field of view. With the help of specialized software for searching for asteroids and comets CoLiTec (Khlamov et al., 2018) introduced at OAO in 2017, we are able to detect the trajectories of objects relative to fixed stars in the OMT-800 telescope field of view in one series of frames. Once the MPC has been identified, the detected objects may contain previously unknown objects. The search for unknown small bodies of the Solar System as an accompanying result (a byproduct) is the goal of our work.

2. Observations and data reduction

All the source material for our work was obtained at the OMT-800 telescope (0.8-m main mirror) during the Solar System object astrometric and photometric compaignes in 2017. The telescope was installed at the suburban observation station Astronomical Observatory of Odesa I. I. Mechnykov National University, in Mayaky village in the Odesa region, with coordinates: latitude $+46°23'49.1''$, longitude $+30°16'16.6''$ E, altitude 19 meters; and has code: 583 Odesa-Mayaky, (Kashuba et al., 2015). To obtain images of observed objects, the telescope is equipped with a FLI ML09000 camera, which, together with a field corrector, provides a field of view of $59' \times 59'$ and an image scale of 1.15 arcsec/pixel. A detailed description of the optical scheme of the telescope and additional equipment is given by Andrievsky et al. (2013).

Note that since the launch in 2012, the objects of observation on the OMT-800 telescope for astrometry and photometry have been: 1) asteroids and comets (Kleschonok et al., 2018; Troianskyi et al., 2019; Carry et al., 2021; Kwiatkowski et al., 2021; Kleshchonok et al., 2022; Oszkiewicz et al., 2020, 2021, 2023); 2)

[1] `https://minorplanetcenter.net`

artificial Earth satellites, including space debris (Bazyey, 2014; Romanyuk et al., 2021); 3) variable stars (Pavlenko et al., 2019; Simon et al., 2019); and 4) stellar occultation by asteroids (Santos-Sanz et al., 2022; Rommel et al., 2023). The field of view, the penetrating ability of the telescope depending on the duration of exposure and a series of images over a time interval of more than 1 hour allow us to hope for related results. In our publication, we present the most interesting of them, since they led to the discovery of previously unknown asteroids among dozens of other numbered objects detected during the observing season.

We did standard data reduction (i.e., dark subtracting and flat-fielding); for details, see Oszkiewicz et al. (2019, 2020, 2021, 2023). After that, we used frame summation (see details in Sec. 3) to detect objects of lower magnitude (Troianskyi et al., 2014b).

3. CoLiTec software

The CoLiTec[2] (Collection Light Technology) software is a widely used astronomical package, which implements the different mathematical methods for the series of frames processing in real-time (Savanevych et al., 2023). This is a complex system for astronomical data processing, which includes user-friendly tools for processing control, results reviewing, integration with online catalogs, and a lot of different computational modules that are based on the developed mathematical computational methods.

The main functional features of the CoLiTec software are described below:

- working with a very wide field of view (up to 10 square degrees);
- automated calibration and cosmetic correction;
- frame summation or track-and-stack;
- brightness equalization and background alignment;
- automated rejection of the worst observations;
- fully automatic robust algorithm of astrometric and photometric reduction;
- automated objects rejection with bad or unclear measurements;
- automated detection of faint moving objects (SNR > 2.5);
- automated detection of very slow and very fast objects (from 0.7 to 40.0 pixels/frame);
- multi-threaded processing support;

[2] https://colitec.space

– multi-core systems support with the ability to manage individual treatment processes;

– processing pipeline managed by On-Line Data Analysis System (OLDAS).

More detailed information on the CoLiTec software and its comparison with other astronomical software packages is described in Savanevych et al. (2022).

4. Väisälä method

The Väisälä method can be extremely useful in many cases (Väisälä, 1940). It comes into wide use when you have a very short observing arc, not long enough to determine the "real" orbit and predict the object's position within the next week or so. Also, the method allows to obtain a sufficiently good primary orbit for further refinement by one of the iterative methods. This method is actively used to search for the primary orbit of small bodies of the Solar System in a short observation arc at the MPC.

4.1. Orbit determination

Since observations are made from the Earth, it is obvious that

$$\vec{\rho_i} = \vec{r_i} + \vec{R_i}, \tag{1}$$

where ρ_i are the geocentric distances of the object, r_i are the heliocentric distances of the object and R_i are the geocentric distances of the Sun.

Each observation of an object gives topocentric directions to this object. After reduction to the center of the Earth, we get right ascension (α_i) and declination (δ_i) for a certain moment (t_i) and this allows us to write three connected equations:

$$\begin{cases} \rho_i \cos\alpha_i \cos\delta_i = x_i + X_i, \\ \rho_i \sin\alpha_i \cos\delta_i = y_i + Y_i, \\ \rho_i \sin\delta_i = z_i + Z_i, \end{cases} \tag{2}$$

where X_i, Y_i, Z_i are the rectangular geocentric equatorial coordinates of the Sun and x_i, y_i, z_i are the rectangular heliocentric equatorial coordinates of the object.

The geocentric coordinates of the Sun are known from any model of the Solar System, and the unknown quantities in Equations 2 are the geocentric distances (ρ_i) and the heliocentric coordinates (x_i, y_i, z_i) of the object.

4.2. Method

The classic Väisälä method (Gingrich, 1951) assumes that you have two observations of an object at times t_1 and t_2. A Väisälä orbit is the one that satisfies both viewpoints and the object is on the apsidal axis at time t_2, at the perihelion or aphelion of its orbit. Mathematically, it looks like this:

$$\left.\frac{dr}{dt}\right|_2 = 0. \tag{3}$$

The essence of the classical Väisälä method is that we find the primary orbit from two close observations $(t_1, \alpha_1, \delta_1, t_2, \alpha_2, \delta_2)$. In this case, we choose so that the inequality is true (orbit closer to circular):

$$0 < a - r_2 < 0.5, \tag{4}$$

where a is the semi-major axis of the object's orbit. After that, we write an expression for finding the geocentric rectangular coordinates of the object:

$$\begin{cases} x_2 = \Delta_2 \cos\alpha_2 + X_2, \\ y_2 = \Delta_2 \sin\alpha_2 + Y_2, \\ z_2 = \Delta_2 \tan\delta_2 + Z_2, \end{cases} \tag{5}$$

where $\Delta_2 = \rho_2 \cos\delta_2$. Thus, we found $\overrightarrow{r_2}$.

We write the geocentric velocity components in the following form:

$$\begin{cases} \dot{x}_2 = \frac{\Delta_1 \cos\alpha_1 - F_1 x_2 + X_1}{G_1}, \\ \dot{y}_2 = \frac{\Delta_1 \sin\alpha_1 - F_1 y_2 + Y_1}{G_1}, \\ \dot{z}_2 = \frac{\Delta_1 \tan\delta_1 - F_1 z_2 + Z_1}{G_1}, \end{cases} \tag{6}$$

where $\Delta_1 = \frac{F_1 r_2 + X_1 x_1 + Y_1 y_1 + Z_1 z_1}{x_2 \cos\alpha_1 + y_2 \sin\alpha_1 + z_2 \tan\delta_1}$, $F_1 = 1 - A\tau^2$, $G_1 = \tau - B\tau^3$, $A = \frac{r^3}{2}$, $B = \frac{A}{3}$, $\tau = k(t_1 - t_2)$ is the time interval between observations, and k is the gravitational constant. Thus, we found $\overrightarrow{v_2}$.

The results obtained $(x_2, y_2, z_2, \dot{x}_2, \dot{y}_2, \dot{z}_2)$ can be applied to find the Keplerian elements of the object's orbit at time t_2.

5. Results

Discoverers will be defined by the MPC only when an object is numbered. At that time, the time tags on all the observations included in the solution will be examined. The discovery observation will be that observation which is the earliest-reported observation at the opposition with the earliest-reported second-night observation (M.P.E.C. 2010-U20).

The OMT-800 is one of 27 telescopes in the Gaia Follow-Up Network for Solar System Objects[3] (Gaia-FUN-SSO; Troianskyi et al. (2014a); Carry et al. (2021)). The Gaia-FUN-SSO is to coordinate ground-based observations on alert triggered by the data processing system during the mission for the confirmation

[3] https://gaiafunsso.imcce.fr/index.php

of newly detected moving objects or for the improvement of orbits of some critical targets. Gaia scans the sky following a predefined scanning law, and such ground-based observations are required to avoid the loss of newly detected Solar System objects and to facilitate their subsequent identification by the probe.

5.1. Main-belt asteroid 2017 AB8 (2014 OD380)

On 3 January 2017, we observed one of Gaia Alert (*g16347*; Tab. 1), as a result we managed to find another candidate for a discovery object (using CoLiTec software). Using the Väisälä method, we determined the preliminary orbit of the new object and then calculated its position for the next weeks. As a result, on January 26 we again observed our object, which subsequently received the name 2017 AB8 (MPS 762342).

Table 1. Our observations of asteroid 2017 AB8.

Date	J2000 RA, field center	J2000 Dec, field center	Obs. object	Exp. time	Series duration	Num. of frames
2017-01-03	09 31 25.4	+02 44 17.3	*g16347*	30 sec	$1^h\ 03^{min}$	50
2017-01-26	09 14 45.1	+01 20 27.1	*2017 AB8*	30 sec	$1^h\ 04^{min}$	60
2017-02-19	08 53 41.5	+01 41 35.4	*2017 AB8*	30 sec	$1^h\ 25^{min}$	55

Based on our Tab. 4 and colleagues' observations from other observatories, it turned out that the asteroid 2017 AB8 (MPS 768338) is the previously lost object 2014 OD380 (MPS 525811), and was rediscovered by us.

5.2. Mars-crossing asteroid 2017 QX33

One of the tasks that the OMT-800 telescope performs is photometric observations. On 25 July 2017, we observed the 2014 YC15 asteroid (Troianskyi et al. (2019); Tab. 2) and, at the same time, using CoLiTec software we found a candidate for a new object in the field of view of the OMT-800 telescope.

Table 2. Our observations of asteroid 2017 QX33.

Date	J2000 RA, field center	J2000 Dec, field center	Obs. object	Exp. time	Series duration	Num. of frames
2017-08-25	23 12 11.7	+06 19 21.5	*2014 YC15*	120 sec	$3^h\ 53^{min}$	72
2017-08-29	23 10 03.8	+05 58 12.1	*2017 QX33*	120 sec	$0^h\ 47^{min}$	24
2017-09-16	23 03 14.0	+02 16 20.6	*2017 QX33*	60 sec	$2^h\ 12^{min}$	50

Using the Väisälä method, we determined the preliminary orbit of the new object and then calculated its position for the next days. On 29 July we again observed a candidate for a new object, which as a result was named 2017 QX33 (MPS 813479). On 16 August, we again observed the 2017 QX33 asteroid with the OMT-800 telescope (MPS 81712; Tab. 5).

At the time of writing this manuscript, asteroid 2017 QX33 was listed in the MPC as: "First reported observation by Odesa-Mayaky on 2017-08-25".

5.3. Main-belt asteroid 2017 RV12

One of the main objects of observation at the OMT-800 telescope are artificial Earth satellites and space debris. On 14 September 2017, while observing satellite OSIRIS-REx[4], by using CoLiTec software we found another candidate for a new object in the field of view of the telescope.

Table 3. Our observations of asteroid 2017 RV12.

Date	J2000 RA, field center	J2000 Dec, field center	Obs. object	Exp. time	Series duration	Num. of frames
2017-09-14	00 22 17.7	+02 35 15.8	*OSIRIS-REx*	60 sec	$2^h\ 00^{min}$	56
2017-09-16	00 19 52.0	+02 43 03.9	*2017 RV12*	60 sec	$2^h\ 05^{min}$	50

Using the Väisälä method, we determined the preliminary orbit of the new object and then calculated its position for the next days. On 16 September we again observed a candidate for a new object, which as a result was named 2017 RV12 (MPS 1152157; Tab. 6).

At the time of writing this manuscript, asteroid 2017 RV12 was listed in the MPC as: "First reported observation by Odesa-Mayaky on 2017-09-14".

6. Summary

The CoLiTec software (Khlamov & Savanevych, 2020) is a suitable and convenient tool for identifying new small bodies in the Solar System. The Väisälä method is very stable for determining a preliminary orbit of new small bodies of the Solar System.

The combined use of the OMT-800 telescope, CoLiTec software, and the Väisälä method showed good results in the search for small bodies in the Solar System (2017 AB8, 2017 QX33, 2017 RV12).

Astrometric observations are very important for further research (numerical integration of orbits) of small bodies of the Solar System (Troianskyi & Bazyey, 2018; Troianskyi et al., 2023).

[4] https://www.nasa.gov/osiris-rex

Table 4. Our observations in MPC of asteroid 2017 AB8. Where: RA is astrometric right ascension and DEC is declination of the target center with respect to the observing site (Location); Mag. - asteroid approximate magnitude and references (Ref.) in Minor Planet Electronic Circulars.

Date (UT)	J2000 RA	J2000 Dec	Mag.	Location	Ref.
2017 01 03.96407	09 31 25.01	+02 48 39.6	20.2	Odesa-Mayaky	MPS 757613
2017 01 04.00278	09 31 23.90	+02 48 27.2	19.5	Odesa-Mayaky	MPS 757613
2017 01 04.02108	09 31 23.38	+02 48 20.1	20.1	Odesa-Mayaky	MPS 757613
2017 01 04.04478	09 31 22.71	+02 48 11.9	19.1	Odesa-Mayaky	MPS 757613
2017 01 26.94419	09 15 09.20	+01 28 04.4	19.4	Odesa-Mayaky	MPS 762342
2017 01 26.95308	09 15 08.76	+01 28 04.8	19.0	Odesa-Mayaky	MPS 767286
2017 01 26.95556	09 15 08.57	+01 28 03.5	20.1	Odesa-Mayaky	MPS 762342
2017 01 26.96395	09 15 08.14	+01 28 02.0	19.4	Odesa-Mayaky	MPS 762342
2017 01 26.96641	09 15 07.98	+01 28 01.6	20.4	Odesa-Mayaky	MPS 762342
2017 01 26.97541	09 15 07.46	+01 28 02.3	18.6	Odesa-Mayaky	MPS 767286
2017 01 26.97792	09 15 07.31	+01 28 01.2	18.7	Odesa-Mayaky	MPS 767286
2017 01 26.98663	09 15 06.86	+01 28 00.5	19.1	Odesa-Mayaky	MPS 762342
2017 01 26.98914	09 15 06.71	+01 28 00.4	19.1	Odesa-Mayaky	MPS 762342
2017 02 19.84208	08 53 19.87	+01 41 33.1	19.3	Odesa-Mayaky	MPS 768338
2017 02 19.85598	08 53 19.20	+01 41 34.8	19.3	Odesa-Mayaky	MPS 768338
2017 02 19.86955	08 53 18.48	+01 41 37.2	19.7	Odesa-Mayaky	MPS 768338
2017 02 19.88564	08 53 17.68	+01 41 39.5	19.0	Odesa-Mayaky	MPS 768338

Table 5. Our observations in MPC of asteroid 2017 QX33. Where: RA is astrometric right ascension and DEC is declination of the target center with respect to the observing site (Location); Mag. - asteroid approximate magnitude and references (Ref.) in Minor Planet Electronic Circulars.

Date (UT)	J2000 RA	J2000 Dec	Mag.	Location	Ref.
2017 08 25.90477	23 11 03.83	+06 26 26.1	19.2	Odesa-Mayaky	MPS 813479
2017 08 25.91872	23 11 03.64	+06 26 20.5	18.9	Odesa-Mayaky	MPS 813479
2017 08 25.93113	23 11 03.41	+06 26 15.2	19.7	Odesa-Mayaky	MPS 813479
2017 08 30.01831	23 09 54.28	+05 51 57.4	18.9	Odesa-Mayaky	MPS 813479
2017 08 30.03580	23 09 53.83	+05 51 46.6	19.3	Odesa-Mayaky	MPS 813479
2017 08 30.05153	23 09 53.49	+05 51 38.6	19.3	Odesa-Mayaky	MPS 813479
2017 09 16.85311	23 03 14.03	+02 16 20.6	18.7	Odesa-Mayaky	MPS 817121
2017 09 16.87280	23 03 13.54	+02 16 04.1	18.7	Odesa-Mayaky	MPS 817121
2017 09 16.90047	23 03 12.84	+02 15 40.9	18.7	Odesa-Mayaky	MPS 817121
2017 09 16.91976	23 03 12.33	+02 15 24.3	18.7	Odesa-Mayaky	MPS 817121

Table 6. Our observations in MPC of asteroid 2017 RV12. Where: RA is astrometric right ascension and DEC is declination of the target center with respect to the observing site (Location); Mag. - asteroid approximate magnitude and references (Ref.) in Minor Planet Electronic Circulars.

Date (UT)	J2000 RA	J2000 Dec	Mag.	Location	Ref.
2017 09 14.87524	00 21 11.04	+02 54 14.1	19.8	Odesa-Mayaky	MPS 817137
2017 09 14.88859	00 21 10.48	+02 54 10.1	21.0	Odesa-Mayaky	MPS 817137
2017 09 14.90273	00 21 09.87	+02 54 05.2	20.4	Odesa-Mayaky	MPS 817137
2017 09 14.91764	00 21 09.24	+02 53 59.9	20.9	Odesa-Mayaky	MPS 817137
2017 09 14.93109	00 21 08.75	+02 53 55.7	21.3	Odesa-Mayaky	MPS 817137
2017 09 16.80051	00 19 53.72	+02 43 05.4	20.0	Odesa-Mayaky	MPS 1152157
2017 09 16.81462	00 19 53.15	+02 43 00.7	19.5	Odesa-Mayaky	MPS 1152157
2017 09 16.84238	00 19 51.90	+02 42 50.4	19.6	Odesa-Mayaky	MPS 1152157
2017 09 16.86374	00 19 50.95	+02 42 43.1	19.9	Odesa-Mayaky	MPS 1152157
2017 09 16.88714	00 19 49.90	+02 42 34.5	19.8	Odesa-Mayaky	MPS 1152157

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