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NOAP — SCRIPT PACKAGE FOR PLANNING AND ANALYSIS OF NEO OBSERVATIONS

We present a package of Python scripts NOAP (NEO Observations Analyzer and Planner) designed for the automatic planning of NEO observations, as well as analysis of already existing observations in the NEODyS-2 database.

The package is divided into two parts: analyzer and planner. The analyzer automatically downloads data from the NEODyS-2 database, converts them by adding additional information, including the apparent speed of objects and observation errors along and across the track, and also provides a large amount of statistical data and graphs for the selected period. It can be done for several observatories at once.

The planner also selects the objects of observation for the upcoming night and calculates their ephemeris with a given step in a fully automatic mode. The output data format of the scheduler allows its use both on semi-automatic telescopes and for fully robotic observations. NOAP has been successfully used for more than a year for planning and analysis of NEO observations by optical sensors of the National Space Facilities Control and Test Center of the State Space Agency of Ukraine.

Keywords: NEO, optical observations.

INTRODUCTION

At the end of the 20th century, the danger of asteroids and comets falling to Earth became clear. In July 1981, the United States of America National Administration for Space Research held a Working Meeting on "Asteroid and Comet Collisions with the Earth: Physical Consequences and Humanity". An overview of the main decisions of the conference was given in [4].

At the beginning of the 21st century, the problem was acknowledged as important even at the level of the United Nations (UN), when in 2007, according to UN General Assembly resolution 61/111, a temporary working group of Near-Earth Objects (NEO) was created as part of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space [41].

Special telescopes with large fields of view, such as the Panoramic Survey Telescope And Rapid Response System (Pan-STARRS) [32] or the Asteroid Terrestrial-impact Last Alert System (ATLAS) [1] and Lincoln Near-Earth Asteroid Research (LIN-

EAR) [49, 50] are used to detect the NEOs, including small ones. But such discoveries require quick confirmations, or these new objects will be lost. Such confirmations are crucial for NEOs discovered at relatively small distances from the Earth. In such cases, the confirmation time is significantly limited by high speeds of apparent movement (20 arcsec/min and more).

Telescopes with significantly lower capabilities compared to the telescopes mentioned above can be applied using appropriate image processing techniques for similar confirmations.

Also, similar telescopes can be used during campaigns of massive observations of individual NEOs during their approach to the Earth. Such observations, for example, were done for the asteroid Apophis in 2013 [18, 56] and 2012 TS4 in 2017 [39].

A software blink comparator implemented, for example, in the Astrometrica [2] program, is the simplest method of NEO detecting. In this case, the object moving against the background of stationary stars is discovered by the observer when viewing a series of changing images (frames). This method gives acceptable results, but it cannot be used for rapid processing of a large number of frames.

At present, there is a huge number of algorithms for the automatic detection of small bodies of the Solar System on CCD (CMOS) images. Most of them can be considered as detection options based on multiple hypothesis testing (MHT) [20].

Depending on the specifics of MHT implementation, several groups of methods can be distinguished. The first group includes the methods that implement the detect-before-track technology (DBT). First, they identify and form a list of detected images of objects (detections) on each frame of the studied series. Then, for all pairs of detections on the two selected frames, the parameters of possible trajectories are estimated, gates (trust regions) are built for all other frames, and the presence of detections confirming the presence of objects is checked. Determining the prior trajectory parameters is necessary for reducing the number of tested hypotheses. It is preferable for the primary analysis to choose the first and last frame of the series as the primary pair because this approach allows for reducing the maximum possible sizes of the trust region.

Similar techniques are implemented in the software used in the LINEAR project [49, 50] and the Moving Objects Processing System (MOPS) of the Pan-STARRS [9, 19] and others. With a huge number of analyzed detections (which is practically inevitable with relatively low detection thresholds or with large fields of view of survey telescopes), such methods can have significant computational complexity. Various search optimization algorithms can be used to reduce it, for example, the organization of a hierarchical classifier based on k-dimensional trees [9, 19].

More complex implementations of MHT are different variants of matched filtering (MF) in the space-time domain. The methods of this group are based on the formation of all possible hypotheses about the parameters of moving objects' trajectories on the series of frames under consideration. For each hypothesis, according to certain rules, it can determined its weight (maximum likelihood function, posterior probability, etc.). Hypotheses with a weight higher than the given one are recognized as valid, and the corresponding conditional estimates of the trajectory parameters are issued to the consumer. This approach, with the development of computer technology, made it possible to increase the number of detected faint objects. The first work that described a similar method was presented by Mohanty [24]. Then, the number of similar works only increased. A large amount of early papers on this topic are presented in [11], a more modern overview can be found, for example, in [27]. The work [23] can be included in the same group.

As a separate variant of MF, it is worth mentioning the methods based on the "shift-and-add" ("shift-and-stack") technology or methods of incoherent post-threshold accumulation with a zero threshold. As an example of such methods, we can cite [13, 38, 60, 61]. Hypotheses about the presence of a moving object are verified by adding CCD (CMOS) images of one part of the celestial sphere with displacement along possible object trajectories. In [60], in order to reduce the computational complexity, it is proposed to check hypothetical asteroid trajectories by stacking with a shift using median filtering of only the frame area around each image inhomogeneity energetically slightly exceeds the background. In a later work [59], the accumulation of binary images, which are formed

using a primary non-zero threshold, is used to increase performance. Another option to reduce the computational complexity is to choose a slightly larger offset step of the frames to be added [11]. It leads to a certain decrease in the number of detected objects compared to the optimal step size. A priori information about the speed and direction of object movement also significantly reduces the calculation complexity [13].

The disadvantages of this group of methods include the need for a large number of sequentially formed frames, which significantly reduces the search potential of telescopes. On the other hand, it has the advantage of detecting objects with a weak light in a high quality. Both MF and "shift-and-stack" methods can be classified as track-before-detect (TBD) methods. The most accessible implementation of shift-and-stack is used in [2] (only for asteroids with known apparent motion parameters). A more advanced version, with the possibility of detecting unknown objects, is implemented, for example, in [34], but it requires much more powerful computing equipment.

There is another TBD method of detecting moving objects — the virtual tabulation method. Its essence is to tabulate the weights of hypotheses about the number and parameters of the movement of objects on the set of all such hypotheses (set of states). The likelihood function (criterion of maximum likelihood) can be used as a weight. Physically, this method corresponds to the accumulation of image statistics (for example, the amplitude of detections or the brightness of individual pixels) along the possible object trajectories. A moving object is considered detected if the accumulated statistics in any gate exceeds the threshold. The initial parameters of the object's movement are the average values for the given gate and can be refined later.

The tabulation method often uses the Radon [37] or Hough [15] transforms. For example, the paper [43], and the Ukrainian CoLiTec automated asteroid detection program [44—48]. In this case, a virtual tabulation of detections obtained at the stage of interframe processing is used. Thus, the detection method used in CoLiTec is a mix of DBT and TBD approaches.

All the methods mentioned above use a linear model of the movement of a celestial object on a series of frames. More complex movement models are used only when combining observations for several nights — inter-night linking, e.g., MOPS [9].

In recent years, the National Space Facilities Control and Test Center (NSFCTC, State Space Agency of Ukraine) has begun to pay attention to the expansion of participation in international activities to solve the global problem of the asteroid-comet hazard. This activity was reflected in the transition from participation in individual observation campaigns [17, 18, 56] and separate new NEO confirmations [25, 26] to regular observations, indicated as a separate item in the plans of scientific and scientific-technical activities. The optical instruments of observation, which are part of NSFCTC, have already obtained 3 codes from the Minor Planet Center of the International Astronomical Union (IAU MPC).

The main technical problem of observation planning for NEO at the NSFCTC was the lack of specialized software and technical complex for solving such problems. In fact, planning is carried out almost in manual mode. The operator engaged in planning has to visit several websites, form a list of NEOs that can potentially be observed, calculate the ephemeris, and final sorting of objects for observation. The result of this activity is a list of ephemerides. The planning process takes a long time and, thus, significantly reduces the efficiency and frequency (number) of observations, especially in the case when it is necessary to use several means of observation.

When planning in manual mode, it is practically impossible to assign a differentiated priority to different NEOs depending on the importance of their observations (it is only possible to give maximum priority to new NEOs that require confirmation of discovery). Another disadvantage of this planning method is the actual impossibility of obtaining the ephemeris in a standardized format and determining the parameters of the observation mode (number of frames and exposure of the frame). All this significantly complicates the potential possibility of NEO automating observations.

To improve the accuracy of the NEO coordinates measurements, it is necessary to conduct constant monitoring and analysis of the quality of the observations received.

This can be done using information that is publicly available on the Internet.

With large volumes of data (several observatories, thousands of observations, hundreds of objects), it is very time-consuming to perform such analysis manually.

At the same time, the use of an already existing software product for such observation planning [12] looks quite difficult. It is based on the requirements and the peculiarities of the optical sensors' operation of the NSFCTC

Thus, the task to make the planning and analysis of the observations of NEO automatic is relevant, and this led to the creation of NOAP.

1. THE NOAP PACKAGE STRUCTURE AND IMPLEMENTATION FEATURES

1.1. *General features of the NOAP package.* NOAP consists of two software pipelines: "Planner" and "Analyzer" (Figure 1). They perform operations for planning observations and analyzing their quality, respectively.

The package is designed in the Python 3 programming language [36]. The choice of the programming language is due to the absence of license terms of use and the presence of a large number of developed application libraries and packages.

The software uses the concept of ETL (Extract, Transform, Load).

A significant number of external units and libraries were used while designing the package: Configparser — unite that operates with configuration files [7], Sys — a unite that provides access to variables and functions that interact with the Python interpreter [51], Requests — a unite that operates with the HTTP requests [40], BeautifulSoup — a unite that analyses the HTML and XML documents [3], Datetime — A unite that operates with date and time [8], Re — a unite that operates with regular expressions [38], Math — a unite that operates with mathematical functions [21], Pandas — a unit for data processing and analysis [31], Numpy — a unit for operating with arrays and matrices [28], Jdutil — a unit that operates with modified Julian dates [33], Matplotlib — data visualization unit [16], Astropy — operates with astronomical data [52—54], Skyfield — astronomical calculations [42].

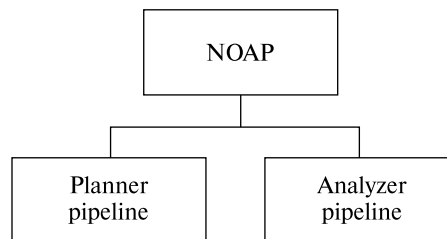These ready-made products made it possible to shorten the development time of NOAP.

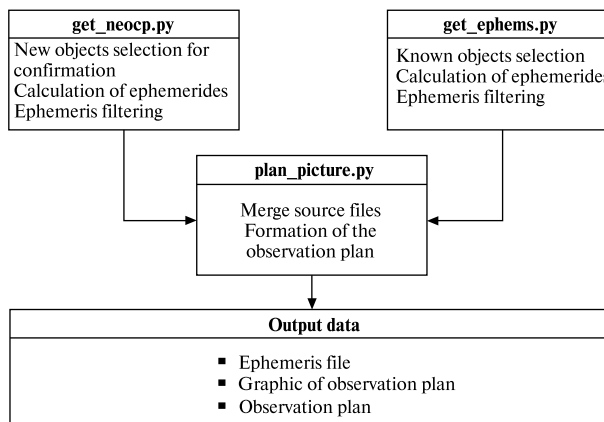

Figure 1. Structure of NOAP

Figure 2. Structure of Planner pipeline

1.2. *Planner pipeline.* The pipeline «Planner» consists of three scripts (Figure 2) and a configuration file.

The *get_neocp* script is responsible for generating a list of ephemerides of new NEOs requiring confirmation of discovery, their calculation, and filtering (subject to constraints, see 1.2.1). The main source of data is the new NEOs confirmation page on the MPC website [55].

The *get_ephems* script is responsible for the list formation, calculation, and filtering of the ephemerides of already known NEOs and for the calculation of their observation priority. To fulfill this task a number of online sources are used:

— lists of close approaches from the websites of European Space Agency (ESA) [5] and NEODyS-2 [6],

— lists of priority objects from websites of ESA [35] and NEODyS-2 [57],

— lists of objects that can be observed by this observatory with given constraints, which are formed on the MPC website [29] and NEODyS-2 [30].

All the lists are combined, and then the ephemerides are calculated with the help of the MPC Ephemeris Service [22] and their filtration according to constraints (see 1.2.1).

The *plan_picture* script combines the ephemeris generated by the two previous scripts into one file for each observatory and generates an observation plan in graphic and textual forms (see 1.2.3).

1.2.1. Input data. In addition to the of web page addresses that are necessary for the pipeline operation, the output data includes: MPC observatory code (planning is done only for those optical sensors that have this code), the range of visible brightness of the observed NEOs (in magnitudes), the range of permissible declinations of the observed NEO (in degrees), the speed range of visible movement of the observed NEOs (in degrees per day), the image scale formed by the corresponding telescope (″/pix), the ephemerides calculation step for NEO (in minutes).

In addition, the initial data should include additional restrictions that are taken into account when calculating and filtering ephemerides: the maximum angle of the Sun (as a rule, no more than $-16°...-18°$), the maximum zenith angle of the observed NEO (usually no more than 70°), the minimum angular distance to the Moon when it is close to the full (typically at least 30° for a Moon phase of 0.88 to 1.0 and a Moon elevation of at least 10°).

The pipeline is able to take into account the complex maximum zenith angles of observations with additional closure. To do this, a suitable mask of closure angles is included in the input data. A primary closure angle file is required for mask calcula-

tion. Such a file is a set of points in a horizontal topocentric coordinate system, where each point has an azimuth and its corresponding maximum working zenith angle (or minimum working elevation angle). For better formation of the working angles mask, it is desirable that there should be at least three points for each "unevenness" of the closing line, while the minimum number of points to create a mask is 4.

1.2.2. Priority. The priority is determined by the importance of a given NEO observations during the night of the observations. The maximum priority is given to new NEO that require the confirmation of discovery. Higher priority is given to NEOs from the ESA priority list, potentially dangerous asteroids (PHA), and NEOs that will have a close approach to the Earth in the coming days.

An additional priority is calculated for known NEOs. It is formed by analyzing the line of the need for additional observations based on the MPC data. The line is formed by the MPC website for each NEO and begins with the words "*Further observations?*"

The priority is increased if the line contains one of the line constants listed in the Table 1.

1.2.3. Output data. The pipeline output data is the NEO ephemeris file and the observation plan. The ephemeris file is almost identical to the ephemerides in the MPC Ephemeris Service [22] format, with some differences (Appendix 1). First, the ephemeris title for each object consists of only two lines: packed designation of the NEO (permanent number or provisional) and the final priority of this NEO. Secondly, each line of the ephemerides corresponds to specific observation mode values (exposure and number of frames), which are indicated at the end of the line. At present, the observations are carried out in the mode of sidereal tracking, and their processing is carried out by one of the options of the "shift-and-stack" method.

Therefore, the exposure is calculated as follows:

$$\exp = \frac{motion_{\max}}{60 \cdot scale},$$

where exp — exposure, sec; $motion_{\max}$ — the maximum velocity of the NEO visible movement during the survey according to the ephemeris, arcsec/min; *scale* — the scale of the image, arcsec/pix.

So, the observed NEO should pass no more than one pixel of the image registered by the telescope during the exposure.

Table 1. **Priority gain depending on the string constant**

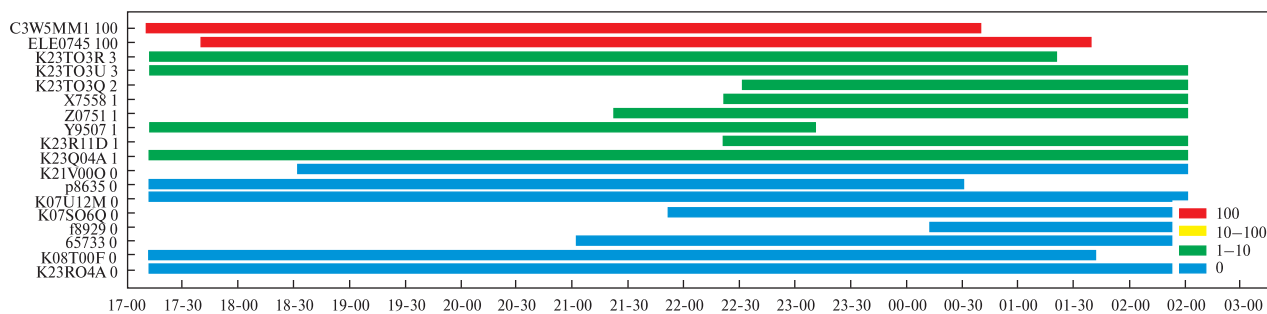| String constant	Priority increasing
Useful for orbit improvement (based on orbit uncertainty)	1
Not necessary this month for numbering	1
[PHA]	1
Desirable as radar target	1
Useful for orbit improvement (based on orbit uncertainty)	1
Useful for numbering	2
[VI]	1

Figure 3. Graphic version of the observation plan

The estimation of the number of frames necessary to obtain the appropriate number of measurements after their assembly is carried out according to the heuristic technique outlined in [12].

It should be mentioned that the blocks of individual NEO ephemerides are located at the same distance from each other. It will simplify the reading of such a file using a personal computer (PC) when organizing fully automatic observations of NEOs.

In addition to the main file from the ephemerides, a plan for future observations is also formed. The plan is formed in the text (Appendix 2) and graphic (Figure 3) form. The plan indicates the NEO designation, its priority, the start time, and the end time of the NEO visibility for a given observatory.

Having such a plan makes it much easier for the operator to make a decision about the sequence in which to observe the NEO.

1.3. *Analyzer pipeline.* Structurally, the "Analyzer" consists of 6 scripts (Figure 4). The *raw_table* script is responsible for obtaining information about the NEO observations from the NEODyS-2 website that creates tables of «raw» observations (coordinates (RA, Dec) and brightness, errors of the coordinates and brightness according to NEODyS-2 data for each given observatory.

The *mod_data* script is designed to add the additional data to the tables of «raw» observations, namely: the predicted velocity of the apparent motion, the position angle, the predicted brightness of the observed NEOs, and the measurement errors along (dL/AT) and across (dN/CT) the trajectory of the object apparent motion. The ephemeris calculation service of the NASA Jet Propulsion Laboratory (JPL) HORIZONS [14] is used to obtain these data (Fig. 5).
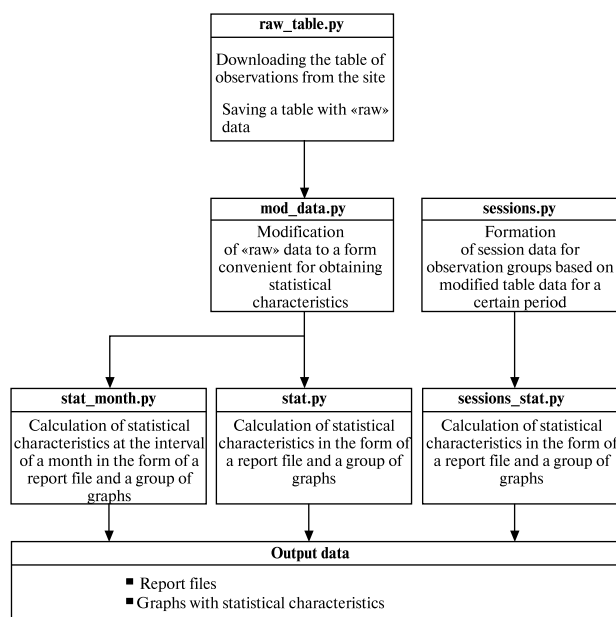

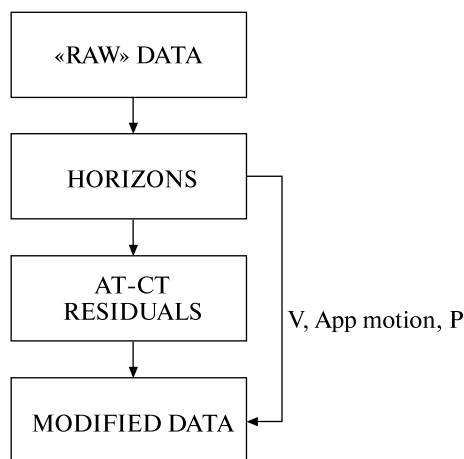**Figure 4.** Structure of Analyzer pipeline

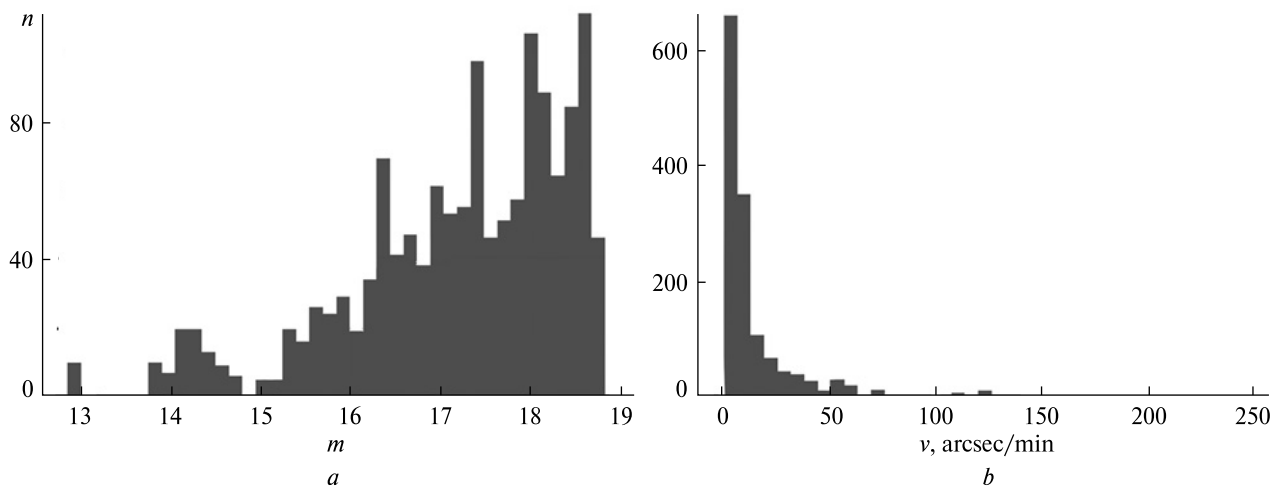**Figure. 5.** Data modification in *mod_data* script

Figure 6. An example of observations distribution by predicted brightness (*a*) and predicted apparent velocity (*b*)
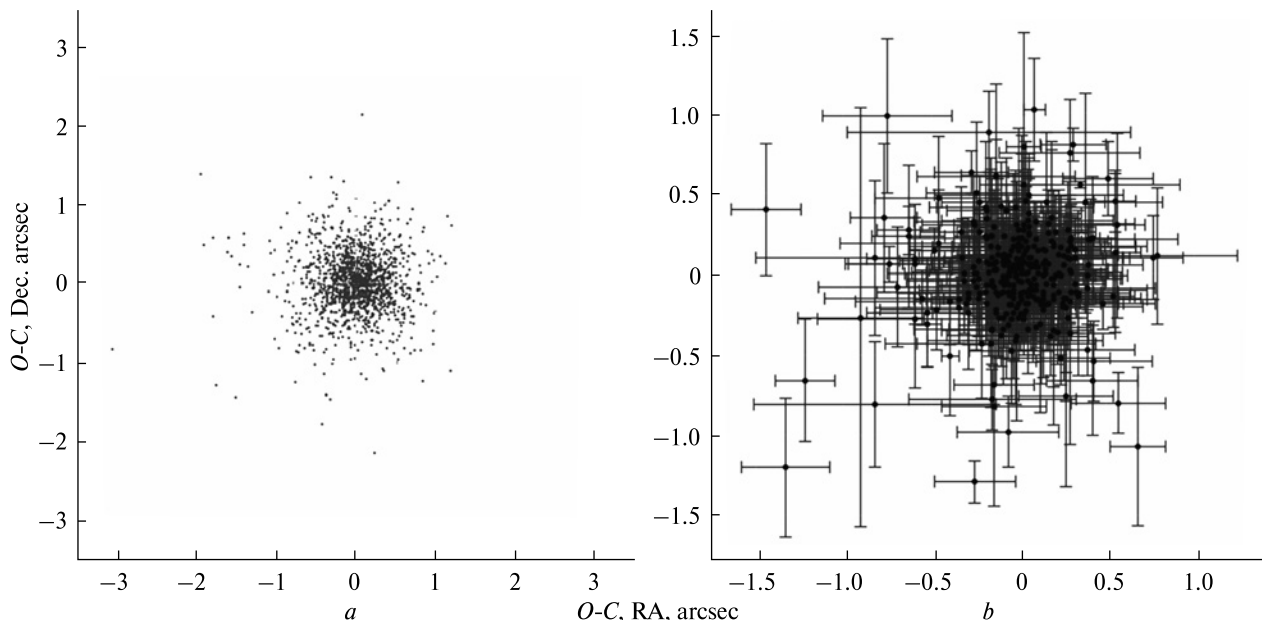
Figure 7. An example of the mutual distribution of errors in the RA — Dec coordinates for observations (*a*) and sessions (*b*)

The service is accessed using the external Astroquery library [10]. The script results are saved in tables with modified data for each observatory.

The *sessions* script is responsible for the formation of observation sessions. A session is a set of observations of one NEO by one observatory during one night. The use of sessions makes it possible to avoid a greater influence on the statistical characteristics of a potentially larger number of the brighter NEO observations.

The script results are saved in a table with data for each session. In addition to the data stored in the modified observation tables, they indicate the values of the standard deviations of the observation errors that are part of the session in two coordinate systems (RA — Dec and AT — CT).

The last three scripts (*stat*, *session_stat*, *stat_month*) are responsible for generating output data for a given observatory and a given time interval: for
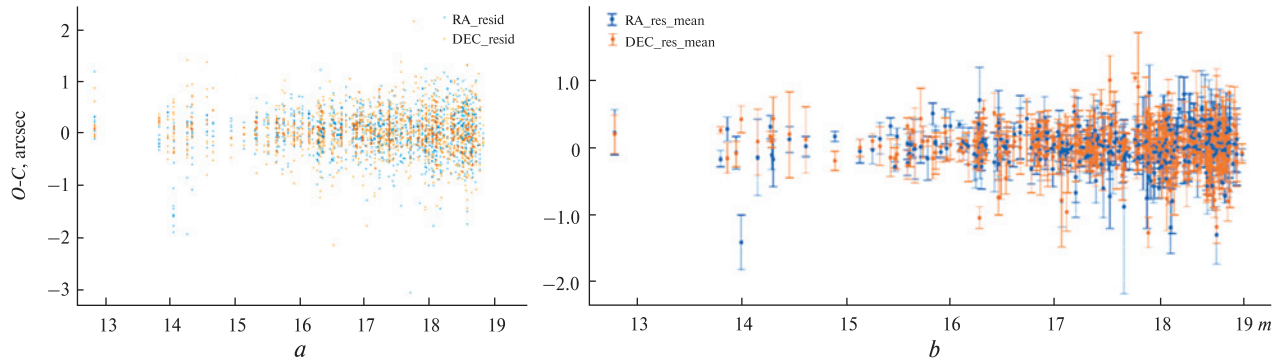
Figure 8. An example of the dependence of the errors in the RA — Dec coordinates on the visible brightness of the observed NEO for observations (*a*) and sessions (*b*)
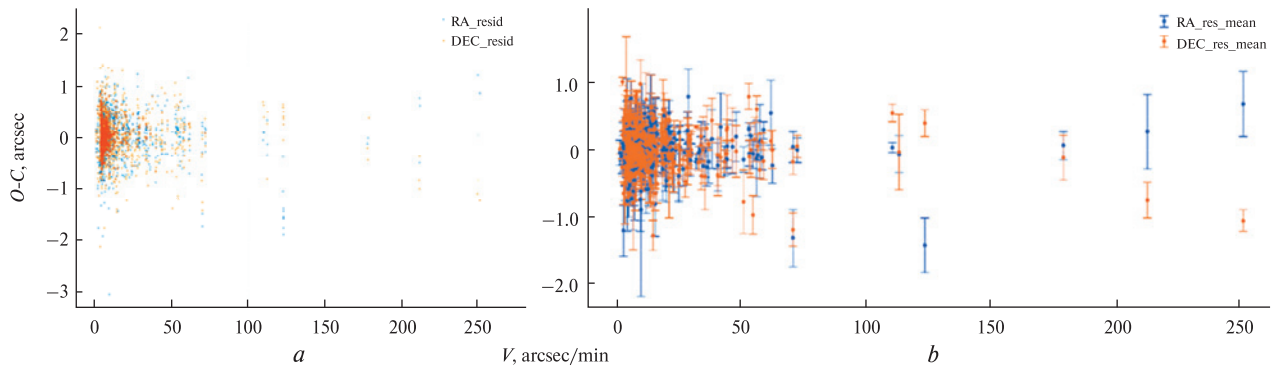
Figure 9. An example of the dependence of the errors in the RA — Dec coordinates on the speed of the apparent movement of the observed NEO for observations (*a*) and sessions (*b*)
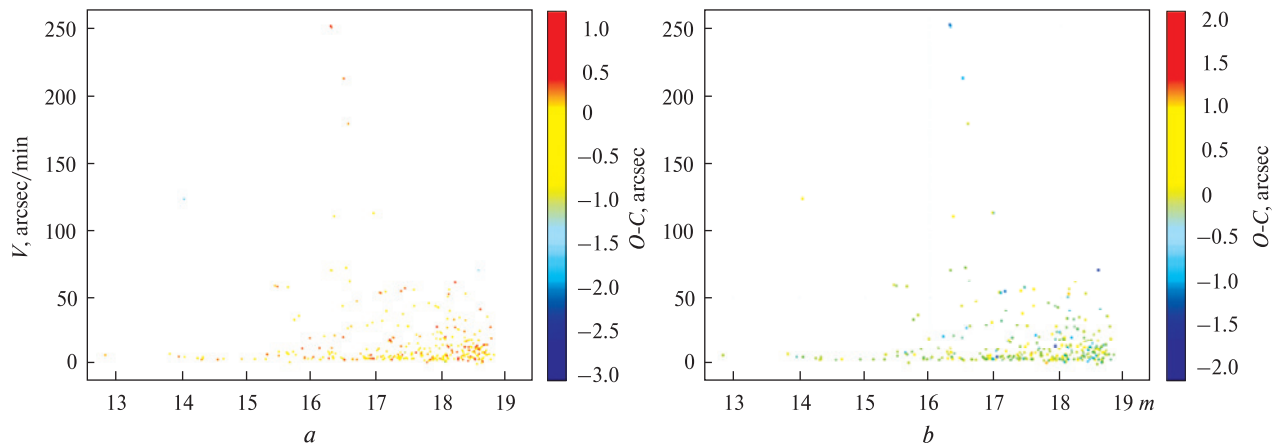
Figure 10. An example of heat maps of the observational residuals dependence on the apparent brightness and the visible movement velocity of the observed NEO for RA (*a*) and Dec (*b*)

observations, sessions, and observations by month, respectively.

These six scripts can work in a batch mode, that is, for a list of observatories at once.

The input data for the pipeline is the list of MPC codes of the observatories for which calculations are to be performed and the time interval for which statistics are to be obtained.

The NOAP package produces a report containing observational data, point and interval estimates of the apparent brightness distribution, and observational residuals of NEO in the graphic form and the form of charts.

Their examples are shown in Figures 6—10. The graphics from Figure 7—10 are also formed for residuals in AT — CT coordinates.

2. RESULTS OF USING AND PLANS FOR THE FUTURE

At the moment, NOAP capabilities are fully used by the NSFCTC for planning and analysis of the results of their NEO observations. In addition, the *raw table* script from the "Analyzer" pipeline is used in the Mykolaiv Astronomical Observatory. As you can see, the list is not very long, but we hope that this work will increase it.

While using the scripts, the performance of analysis and planning tasks was optimized. In addition, the script functionality is planned to be expanded.

The list of script improvements is quite long.

For the "Planner" pipeline:

• batch calculation of ephemeris and observation plans for several observatories,

• changing the algorithm for obtaining data from the NEOCP webpage for more prompt detection of the appearance of new objects that require confirmation,

• an adaptive algorithm for filtering NEOs that can be observed on the given telescope, taking into account both the velocity of their visible movement and the predicted brightness. This will allow to increase the limiting magnitude for slower NEOs, increase the time of NEOs in sight, reject NEOs that cannot be observed on the given telescope according to the "brightness — velocity" ratio,

• the introduction of a graphical user interface,

• integration of the "Planner" pipeline with the "Analyzer" pipeline for priority calculation.

For the "Analyzer" pipeline:

• calculation of the compatible statistics for several observatories,

• quality assessment of NEOCP object observations,

• checking the accuracy of the observations before they are sent to the MPC,

• the optimization of additional calculations, especially those associated with data modification,

• tracking of observations that have disappeared from the NEODyS-2 database.

CONCLUSION

1. A technique for automatic planning of NEO observations has been developed. It was implemented in an early release of the "Planner" scripting pipeline in the Python 3 programming language.

2. The set of scripts significantly increased the speed and quality of planning observations of NEO by the optical means of observation of the NSFCTC, and also simplified their implementation.

3. The "Planner" pipeline is ready to be used in an automatic mode. It may require minimal adjustments.

4. The "Analyzer" pipeline allows us to obtain information automatically from the database of the NEO observations. It also adds the information about the velocity and predicted brightness of the NEO and calculates the observation errors along and across the trajectory. This significantly expands the script's capabilities.

5. "Analyzer" also automatically calculates a large number of statistical indicators, which significantly speeds up their further analysis.

6. Further work should be focused on the following: software code optimization, correction of errors that were detected when using NOAP, improvement of algorithms, integration of two pipelines.

7. We are ready to work with anyone who wants to try NOAP.

Appendix 1

Part of the ephemeris file for NEO observations, generated by the "Planner"

A10KrbW
Priority: 100

Date	UT	R.A. (J2000) h m s	Decl.	Elong.	V	Motion "/min	P.A.	Object Azi.	Alt.	Sun Alt.	Moon Phase	Dist.	Alt.	Uncertainty	Exp, s	Frames
2022 09 30	1730	17 40 06.1	+25 52 18	80.8	18.6	10.85	062.3	061	+55	-17	0.25	053	+03	Map/Offsets	9.4	110
2022 09 30	1740	17 40 13.2	+25 53 08	80.9	18.6	10.85	062.4	064	+54	-18	0.25	053	+02	Map/Offsets	9.4	110
2022 09 30	1750	17 40 20.4	+25 53 59	80.9	18.5	10.86	062.4	067	+52	-20	0.25	053	+01	Map/Offsets	9.4	100
2022 09 30	1800	17 40 27.5	+25 54 49	80.9	18.5	10.86	062.4	070	+51	-21	0.26	053	+00	Map/Offsets	9.4	100
2022 09 30	1810	17 40 34.6	+25 55 39	80.9	18.5	10.86	062.5	072	+49	-23	0.26	053	-02	Map/Offsets	9.4	100
2022 09 30	1820	17 40 41.8	+25 56 29	81.0	18.5	10.87	062.5	074	+48	-24	0.26	053	-03	Map/Offsets	9.4	100
2022 09 30	1830	17 40 48.9	+25 57 19	81.0	18.5	10.87	062.6	077	+46	-26	0.26	053	-04	Map/Offsets	9.4	100
2022 09 30	1840	17 40 56.1	+25 58 09	81.0	18.5	10.87	062.6	079	+45	-27	0.26	053	-06	Map/Offsets	9.4	100
2022 09 30	1850	17 41 03.2	+25 59 00	81.0	18.5	10.88	062.6	081	+43	-29	0.26	053	-07	Map/Offsets	9.4	100
2022 09 30	1900	17 41 10.4	+25 59 49	81.1	18.5	10.88	062.7	083	+41	-30	0.26	053	-08	Map/Offsets	9.4	100
2022 09 30	1910	17 41 17.6	+26 00 39	81.1	18.5	10.89	062.7	085	+40	-31	0.26	053	-10	Map/Offsets	9.4	100
2022 09 30	1920	17 41 24.8	+26 01 29	81.1	18.5	10.89	062.7	087	+38	-33	0.26	053	-11	Map/Offsets	9.4	100
2022 09 30	1930	17 41 32.0	+26 02 19	81.1	18.5	10.90	062.8	089	+37	-34	0.26	053	-13	Map/Offsets	9.4	100
2022 09 30	1940	17 41 39.2	+26 03 09	81.2	18.5	10.90	062.8	091	+35	-35	0.26	053	-14	Map/Offsets	9.4	100
2022 09 30	1950	17 41 46.4	+26 03 59	81.2	18.5	10.91	062.9	093	+33	-36	0.26	053	-16	Map/Offsets	9.4	100
2022 09 30	2000	17 41 53.6	+26 04 49	81.2	18.5	10.92	062.9	095	+32	-37	0.26	053	-17	Map/Offsets	9.3	100
2022 09 30	2010	17 42 00.8	+26 05 38	81.2	18.5	10.92	062.9	096	+30	-38	0.26	053	-19	Map/Offsets	9.3	100
2022 09 30	2020	17 42 08.0	+26 06 28	81.3	18.5	10.93	063.0	098	+28	-39	0.27	053	-20	Map/Offsets	9.3	100

K22S09B
Priority: 5

Date	UT	R.A. (J2000) h m s	Decl.	Delta	r	El.	Ph.	V	Sky Motion "/min	P.A.	Object Azi.	Alt.	Sun Alt.	Moon Phase	Dist.	Alt.	Uncertainty info 3-sig/" / Map / Offsets	P.A.	Exp, s	Frames
2022 09 30	213000	00 50 20.4	-19 40 54	0.014	1.015	156.7	23.0	18.1	45.07	23.0	346	+21	-44	0.27	091.7	-32	4 077.6 / Map / Offsets	111	2.3	285
2022 09 30	214000	00 50 52.3	-19 41 07	0.014	1.015	156.6	23.0	18.1	45.14	23.0	349	+21	-44	0.27	091.6	-34	4 077.8 / Map / Offsets	111	2.3	285
2022 09 30	215000	00 51 24.3	-19 41 19	0.014	1.015	156.6	23.1	18.1	45.20	23.1	351	+21	-44	0.27	091.5	-35	4 078.1 / Map / Offsets	111	2.3	290
2022 09 30	220000	00 51 56.3	-19 41 30	0.014	1.015	156.5	23.1	18.1	45.27	23.1	353	+21	-44	0.27	091.4	-37	4 078.4 / Map / Offsets	111	2.2	290
2022 09 30	221000	00 52 28.4	-19 41 41	0.014	1.015	156.5	23.1	18.1	45.34	23.1	356	+21	-44	0.27	091.3	-38	4 078.7 / Map / Offsets	111	2.2	290
2022 09 30	222000	00 53 00.5	-19 41 52	0.014	1.015	156.5	23.1	18.1	45.42	23.2	358	+21	-44	0.27	091.3	-40	5 079.0 / Map / Offsets	111	2.2	290
2022 09 30	223000	00 53 32.7	-19 42 01	0.014	1.015	156.4	23.2	18.1	45.50	23.2	000	+22	-44	0.27	091.2	-41	5 079.3 / Map / Offsets	111	2.2	290
2022 09 30	224000	00 54 04.9	-19 42 10	0.014	1.015	156.4	23.2	18.1	45.58	23.3	003	+22	-44	0.27	091.1	-43	5 079.6 / Map / Offsets	111	2.2	290
2022 09 30	225000	00 54 37.2	-19 42 19	0.014	1.015	156.4	23.3	18.1	45.66	23.3	005	+22	-43	0.28	091.0	-45	5 079.9 / Map / Offsets	111	2.2	290
2022 09 30	230000	00 55 09.6	-19 42 27	0.014	1.015	156.3	23.3	18.1	45.75	23.3	008	+21	-43	0.28	091.0	-46	5 080.2 / Map / Offsets	111	2.2	290
2022 09 30	231000	00 55 42.0	-19 42 34	0.014	1.014	156.3	23.4	18.1	45.84	23.4	010	+21	-42	0.28	090.9	-48	5 080.5 / Map / Offsets	111	2.2	290
2022 09 30	232000	00 56 14.5	-19 42 41	0.014	1.014	156.2	23.4	18.1	45.93	23.4	012	+21	-41	0.28	090.8	-49	5 080.9 / Map / Offsets	111	2.2	290

Appendix 2

Observation plan — text form

obj_name	obj_prior	obj_start	obj_stop
A10KrbW	100	2022-09-30 17:30:00	2022-09-30 20:10:00
K22S09B	5	2022-09-30 21:30:00	2022-09-30 23:10:00
K16W55N	8	2022-09-30 20:10:00	2022-10-01 02:30:00
K22R05B	3	2022-09-30 19:00:00	2022-10-01 02:30:00
K11T02G	1	2022-09-30 20:50:00	2022-10-01 02:30:00
i3880	0	2022-09-30 17:30:00	2022-09-30 22:00:00
f0088	0	2022-10-01 00:40:00	2022-10-01 02:30:00
z2143	0	2022-09-30 17:30:00	2022-09-30 22:50:00
P4417	0	2022-09-30 17:30:00	2022-09-30 18:20:00
K11G62D	1	2022-09-30 17:30:00	2022-09-30 19:50:00
K22R03X	1	2022-10-01 01:40:00	2022-10-01 02:30:00
z2443	0	2022-09-30 17:30:00	2022-10-01 02:30:00
J98S04S	1	2022-09-30 20:30:00	2022-10-01 02:30:00
e9836	0	2022-10-01 01:30:00	2022-10-01 02:30:00
p6428	0	2022-09-30 17:30:00	2022-10-01 02:30:00
53429	1	2022-09-30 17:30:00	2022-10-01 00:20:00
X8292	0	2022-09-30 17:30:00	2022-10-01 02:40:00

REFERENCES

1. Asteroid Terrestrial-impact Last Alert System. URL: https://atlas.fallingstar.com/home.php (Last accessed: 15 October 2023).
2. Astrometrica. URL: http://www.astrometrica.at/ (Last accessed: 15 October 2023).
3. Beautiful Soup Documentation. URL: https://beautiful-soup-4.readthedocs.io/en/latest/ (Last accessed: 15 October 2023).
4. Chapman C. R., Morrison D. (1989). *Cosmic Catastrophes.* New York: Plenum Press.
5. CLOSE APPROACHES. URL: https://neo.ssa.esa.int/close-approaches (Last accessed: 15 October 2023).
6. CLOSE APPROACHES. URL: https://newton.spacedys.com/index.php?pc=3.3 (Last accessed: 15 October 2023).
7. Configparser 6.0.0. URL: https://pypi.org/project/configparser/ (Last accessed: 15 October 2023).
8. datetime — Basic date and time types. URL: https://docs.python.org/3/library/datetime.html (Last accessed: 15 October 2023).
9. Denneau L., Jedicke R., Grav T. (2013). The Pan-STARRS Moving Object Processing System. *Publ. Astron. Soc. Pacif.*, **125**, 357—395.
10. Ginsburg A., Sipőcz B. M., Brasseur C. E., et al. (2019). astroquery: An Astronomical Web-querying Package in Python. *Astron. J.*, **157**, 98. DOI: 10.3847/1538-3881/aafc33
11. Gural P. S., Larsen J. A., Gleason A. E. (2005.) Matched Filter Processing for Asteroid Detection. *Astron. J.*, **130**, 1951—1960.
12. Haeusler B. (2023). NEO Planner V4.6 — CCD/CMOS Parameters — Explanations. URL: https://www.b82maidbronn.de/neoplanner_CCDParameters.htm (Last accessed: 15 October 2023).
13. Heinze A. N., Metchev S., Trollo J. (2015). Digital Tracking Observations can Discover Asteroids 10 Times Fainter than Conventional Searches. *Astron. J.*, **150**, 125. DOI: https://doi.org/10.1088/0004-6256/150/4/125
14. Horizons System. URL: https://ssd.jpl.nasa.gov/horizons/ (Last accessed: 15 October 2023).
15. Hough P. V. C. (1962). Method and means for recognizing complex patterns. Pat. 3069354 USA.
16. Hunter J. D. (2007). Matplotlib: A 2D Graphics Environment. *Comp. Sci. & Engineering*, **9**, 3, 90—95. DOI: https://doi.org/10.1109/MCSE.2007.55
17. Kozhukhov O., Maigurova N., Pomazan A. (2017). Results from optical CCD observations of asteroid 2014 JO25 during its close approach to the Earth on April 19 2017. *Bull. Taras Shevchenko Nat. Univ. of Kyiv. Astron., 56*, 22—25. DOI: https://doi.org/10.17721/btsnua.2017.56.22-25
18. Kozhukhov A. M., Maigurova N. V., Pomazan A. V., Kryuchkovskiy V. F. (2013). Observations of Apophis in NSFCTC (Yevpatoria) and RI NAO (Mykolaiv). *Odessa Astron. Publs*, **26** (1), 70—72.
19. Kubica J., Denneau L., Grav T., et al. (2007). Efficient intra- and inter-night linking of asteroid detections using kd-trees. *Icarus*, **189**, 1, 151—168.
20. Lee J., Zubair L., Virani S., Murphy T., Holzinger M. J. Hardware-in-the-Loop Comparison of Space Object Detection and Tracking Methodologies. AAS 16-266.

21. math — Mathematical functions. URL: https://docs.python.org/3/library/math.html (Last accessed: 15 October 2023).

22. Minor Planet & Comet Ephemeris Service. URL: https://minorplanetcenter.net/iau/MPEph/MPEph.html (Last accessed: 15 October 2023).

23. Miura N., Itagaki K., Baba N. (2005). Likelihood-Based Method for Detecting Faint Moving Objects. *Astron. J.*, **130**, 1278—1285.

24. Mohanty N. C. (1981). Computer Tracking of Moving Point Targets in Space. *IEEE Transactions on Pattern Analysis & Machine Intelligence*, **3**, 606—611.

25. MPEC 2017-X85: 2017 XS. URL: https://www.minorplanetcenter.net/mpec/K17/K17X85.html (Last accessed: 15 October 2023).

26. MPEC 2018-C14: 2018 BA7. URL: https://www.minorplanetcenter.net/mpec/K18/K18C14.html (Last accessed: 15 October 2023).

27. Murphy T. S., Holzinger M. J. (2016). Uncued Low SNR Detection with Likelihood from Image Multi Bernoulli Filter. URL: https://amostech.com/TechnicalPapers/2016/SSA-Algorithms/Murphy.pdf (Last accessed: 15 October 2023).

28. NumPy. URL: https://numpy.org/ (Last accessed: 15 October 2023).

29. Observable-Object List Customizer. URL: https://minorplanetcenter.net/iau/lists/Customize.html (Last accessed: 15 October 2023).

30. OBSERVATIONAL QUERY. URL: https://newton.spacedys.com/index.php?pc=3.2 (Last accessed: 15 October 2023).

31. pandas. URL: https://pandas.pydata.org/ (Last accessed: 15 October 2023).

32. Pan-STARRS. URL: http://legacy.ifa.hawaii.edu/research/Pan-STARRS.shtml (Last accessed: 15 October 2023).

33. parhamfh/jdutil.py. URL: https://gist.github.com/parhamfh/0b9b3116296fa1a944a1 (Last accessed: 15 October 2023).

34. Parrot D. Tycho Tracker: A New Tool to Facilitate the Discovery and Recovery of Asteroids Using Synthetic Tracking and Modern GPU Hardware. URL: https://drive.google.com/file/d/1ApjYChayGpL9Y9H85wQBjel3n9z0UT2B/view (Last accessed: 15 October 2023).

35. PRIORITY LIST. URL: https://neo.ssa.esa.int/priority-list (Last accessed: 15 October 2023).

36. Python. URL: https://www.python.org (Last accessed: 15 October 2023).

37. Radon, J. (1917). Berichte ber die Verhandlungen der Kniglich-Schsischen Akademie der Wissenschaften zu Leipzig, Mathematisch-Physische Klasse, **262** translated by Parks, P. C. (1986). *IEEE Transactions on Medical Imaging*, **5**, 170 .

38. re — Regular expression operations. URL: https://docs.python.org/3/library/re.html (Last accessed: 15 October 2023).

39. Reddy V., Kelley M. S., Farnocchia D., et al. (2019). Near-Earth asteroid 2012 TC4 observing campaign: Results from a global planetary defense exercise. *Icarus*, **326**, 133—150. DOI: https://doi.org/10.1016/j.icarus.2019.02.018

40. Requests: HTTP for Humans™. URL: https://requests.readthedocs.io/en/latest/ (Last accessed: 15 October 2023).

41. Report of the Scientific and Technical Subcommittee on its forty-fourth session, held in Vienna from 12 to 23 February 2007 - United Nations, General Assembly, Committee on the Peaceful Uses of Outer Space Fiftieth session Vienna, 6—15 June 2007. URL: https://www.unoosa.org/pdf/reports/ac105/AC105_890E.pdf (Last accessed: 15 October 2023).

42. Rhodes B. (2019). Skyfield: High precision research-grade positions for planets and Earth satellites generator. *Astrophys. Source Code Library*, record ascl: 1907.024. URL: https://ascl.net/1907.024 (Last accessed: 15 October 2023).

43. Richards G. (1996). Application of the Hough transform as a track-before-detect method. *IEE Colloquium on Target Tracking and Data Fusion*, 2/1—2/3. DOI: https://doi.org/10.1049/ic:19961349

44. Savanevych V. E., Briukhovetskyi A. B., Ivashchenko Yu. N., et al. (2015). Comparative analysis of the positional accuracy of CCD measurements of small bodies in the solar system: software CoLiTec and Astrometrica. *Kinematics and Physics of Celestial Bodies*, **31**, 302—313. DOI: https://doi.org/10.3103/S0884591315060045

45. Savanevich V. E., Bryukhovetskiy A. B., Kozhukhov A. M., Dikov E. N., Vlasenko V. P. (2012). The Program CoLiTec for Automated Detection of Faint Celestial Bodies. *Space Science and Technology*, **18**, 1, 39—46 [in Russian].

46. Savanevich V. E., Bryukhovetskiy A. B., Kozhukhov A. M., Dikov E. N. (2011). The Method of Asteroid Detection, Based on After-Treshold Accumulation of Signal Statistic In Space of Asteroid Trajectory Parameters. *Systemy Obrobky Inform.*, **2(92)**, 137—144 [in Russian].

47. Savanevych V. E., Briukhovetskyi O. B., Sokovikova N. S., et al. (2015). A new method based on the subpixel Gaussian model for accurate estimation of asteroid coordinates. *Mon. Notic. Roy. Astron. Soc.*, **451**, 3287—3298. DOI: https://doi.org/10.1093/mnras/stv1124

48. Savanevych V. E., Khlamov S. V., Vavilova I. B., et. al. (2018). A method of immediate detection of objects with a near-zero apparent motion in series of CCD-frames. *Astron. and Astrophys.*, **609**, A54. DOI: https://doi.org/10.1051/0004-6361/201630323

49. Stokes G. H., Evans J. B., Viggh H. E. M., Shelly F. C., Pearce E. C. (2000) Lincoln Near-Earth Asteroid Program (LINEAR). *Icarus*, **148**, 21—28.

50. Stokes G. H., Shelly F., Viggh H. E. M., et al. (1998). The Lincoln Near-Earth Asteroid Research (LINEAR) Program. *Lincoln Lab. J.,* **11**, 1, 27—40.

51. sys — System-specific parameters and functions. URL: https://docs.python.org/3/library/sys.html (Last accessed: 15 October 2023).

52. The Astropy Collaboration, Price-Whelan A. M., Lim P. L., et al. (2022). The Astropy Project: Sustaining and Growing a Community-oriented Open-source Project and the Latest Major Release (v5.0) of the Core Package. *Astrophys. J.*, **935**, 167. DOI: 10.3847/1538-4357/ac7c74

53. The Astropy Collaboration, Price-Whelan A. M., Sipőcz B. M., et al. (2018). The Astropy Project: Building an Open-science Project and Status of the v2.0 Core Package. *Astron. J.,* **156**, 123. DOI: 10.3847/1538-3881/aabc4f

54. The Astropy Collaboration, Robitaille T. P., Tollerud E. J., et al. (2013). Astropy: A community Python package for astronomy. *Astron. and Astrophys.*, **558**, A33. DOI: 10.1051/0004-6361/201322068

55. The NEO Confirmation Page. URL: https://minorplanetcenter.net/iau/NEO/toconfirm_tabular.html (Last accessed: 15 October 2023).

56. Thuillot W., Bancelin D., Ivantsov A., et al. (2015). The astrometric Gaia-FUN-SSO observation campaign of 99 942 Apophis. *Astron. & Astrophys.*, **583**, A59. DOI: https://doi.org/10.1051/0004-6361/201425603

57. NEODyS-2. URL: https://newton.spacedys.com/priority_list/PLfile.txt (Last accessed: 15 October 2023).

58. Wang B., Zhao H. B., Li B. (2017). Detection of Faint Asteroids Based on Image Shifting and Stacking Method. *Acta Astron. Sinica*, **58**, 5, 49.

59. Yanagisawa T., Kurosaki H. (2012). Detection of Faint GEO Objects Using JAXA's Fast Analysis Methods. *Trans. JSASS Aerospace Tech. Jap.,* **10**, ists28, Pr_29—Pr_35.

60. Yanagisawa T., Nakajima A., Kadota K., et al. (2005). Automatic Detection Algorithm for Small Moving Objects. *Publs Astron Soc Jap.*, **57**, 399—408.

61. Zhai C., Shao M., Nemati B., et al. (2014). Detection of a Faint Fast-Moving Near-Earth Asteroid Using the Synthetic Tracking Technique. *Astrophys. J.*, **792**, 60. DOI: https://doi.org/10.1088/0004-637X/792/1/60

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NOAP — ПАКЕТ СКРИПТІВ ДЛЯ ПЛАНУВАННЯ ТА АНАЛІЗУ СПОСТЕРЕЖЕНЬ НАВКОЛОЗЕМНИХ ОБ'ЄКТІВ

Ми презентуємо новий інструмент для науковців та астрономів у сфері космічної безпеки та астрономії — пакет Python-скриптів NOAP (NEO Observations Analyzer and Planner). Цей пакет розроблено для автоматичного планування спостережень за об'єктами, що наближаються до Землі (ОНЗ), а також для аналізу спостережних даних у базі даних NEODyS-2.

NOAP поділено на дві основні частини: Аналізатор та Планувальник. Аналізатор автоматично завантажує дані з бази даних NEODyS-2, а потім розширює їх, додаючи важливу додаткову інформацію. Ця інформація включає в себе дані про видиму швидкість і напрямок руху об'єктів та помилки спостереження, обрані вздовж та поперек їхнього шляху. Крім того, аналізатор генерує велику кількість статистичних даних та графіків, що дозволяє отримати більше інформації про ОНЗ протягом обраного періоду. Ця операція може проводитися одночасно для декількох обсерваторій. Планувальник, з іншого боку, вибирає об'єкти для спостереження на найближчу ніч та розраховує їхні ефемериди з заданим кроком у повністю автоматичному режимі. Формат виведених даних планувальника дозволяє використовувати його як на напівавтоматичних телескопах, так і для повністю роботизованих спостережень.

Крім того, NOAP може легко інтегруватися з різними типами телескопів і астрономічного обладнання, що робить його універсальним рішенням для науковців та астрономів. Він також надає можливість генерувати звіти та візуалізації результатів спостережень, що сприяє покращенню розуміння та аналізу даних про ОНЗ. Пакет NOAP успішно використовується для планування і аналізу спостережень НЕО за допомогою оптичних засобів Національного центру управління та випробувань космічних об'єктів Державного космічного агентства України. Цей інструмент допомагає зрозуміти і краще вивчати об'єкти, що знаходяться недалеко від нашої планети, і відіграє важливу роль у забезпеченні безпеки космічного простору та в астрономічних дослідженнях.

Ключові слова: навколоземні об'єкти, оптичні спостереження.