SUPPORT TOOLS FOR NEO OBSERVERS

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ABSTRACT

Modern IT solutions have the potential to prove very useful in many areas of science. In particular, leading space agencies, including European Space Agency (ESA), promote their application in the domain of Near Earth Objects (NEOs), where they can enhance collaboration of observers, consolidate resources, simplify observations planning and analyse the obtained results. Here we present four services for NEO researchers available on-line, developed by ITTI, SME from Poland cooperating with ESA: NEODECS – system for telescope sharing and observational campaign organizations; SANORDA – lightcurve analysis and historical orbital data service; NEO tools – set of seven tools dedicated for studying asteroid; and NOAS – a tool supporting automatization of telescope control. They are just a probe of ITTI solutions in the SSA area.

1 INTRODUCTION

The growing knowledge about Earth's near-space environment has brought out the need for an extensive space situational awareness programs. This task has been recently undertaken by space agencies and governments, who increasingly focus on space debris and Near-Earth Objects (NEO) research. New space probes are planned and built, new ground-based and space detectors are being designed, and ambitious space exploration plans are announced [1]. The involvement of so called citizen science is also growing [2]. The collaboration and communication within the research community in these domains became substantial, and modern technologies can play a crucial role in their development. From data sharing to communication facilitation to the support of solving complex scientific problems, IT solutions have more and more to offer to the science community. The new services are usually created in a process involving active researchers from the applicable domains, and their organization and management under the flag of space agencies (e.g. European Space Agency, ESA) help improve their accessibility and distribution.

In this article, we would like to present four of such services, developed for ESA by the Polish company ITTI Sp. z o. o. in cooperation with Astronomical Observatory of Adam Mickiewicz University of Poznań. All of them are relevant for research in NEO domain, and are built upon the ideas of collaboration enhancement and observation facilitation. They have a potential of being highly beneficial to the observations and research of the asteroids.

2 SOFTWARE DEVELOPMENT APPROACH

ITTI was established in 1996 in Poznan, Poland. The IT staff is grouped in two business areas (Space – solutions for space sector and Perpixel – solutions for business and public). The ITTI's mission is to develop and provide innovative applications and dedicated software solutions adjusted to customer needs. In the software development process ITTI uses agile methodologies and SCRUM framework.

ITTI is involved in research and development projects funded by European Commission, European Defense Agency and European Space Agency. The SPACE department is an important and continuously developing part of the company, with a growing staff and an increasing number of projects. Up to now ITTI has performed over 30 projects for space industry, designing and developing numerous software solutions. We describe four of them in the following chapters, while others are listed in chapter 7.

3 NEODECS – NEO DATA EXCHANGE AND COLABORATION SERVICE

In the changing world of social relations, networking contacts are becoming more and more intense, and cooperation between researchers takes place on many levels. The growing idea of civic science also enables amateur scientists to participate in research, often on a voluntary basis. This is largely due to technical progress and the fall in prices of observation equipment. In a short time, this leads to an explosion in the amount and variety of astronomical information, which in turn creates the risk of increase in information noise. Information appears in many places (social networks, original websites, mailing lists, etc.). The development of tools for managing such information is therefore

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inevitable.

NEODECS is an application designed for asteroid observers. With the focus on NEOs, its main objective is to reinforce the cooperation between scientists worldwide through coordination of observations and sharing telescope resources. Its features allow the expansion of the observing time of specific objects, raising the chances of obtaining substantial results in shorter time, as well as optimizing the telescope usage. The service is also equipped with a repository of on-line asteroid databases and resources, to which the user can contribute [3].

3.1 Telescope sharing

Astronomical observations very often depend on local weather conditions, and the observing time window depends on geographical location. Due to these factors, some important observational opportunities may be missed.

The risk may be mitigated by using equipment of other observers from the world. In the NEODECS Telescope sharing option (Fig. 1), the observers can provide information about their telescopes and then offer them to the community. They specify the days of availability and give the additional information, useful to assess suitability for potential future observations (geographic coordinates, equipment parameters, available observation types, magnitude limits etc.). Specific conditions of sharing can be defined. The list of available telescopes can be searched by other NEODECS users based on detailed criteria. Upon finding an appropriate offer, the researcher can contact telescope's supervisors and initiate communication with them.

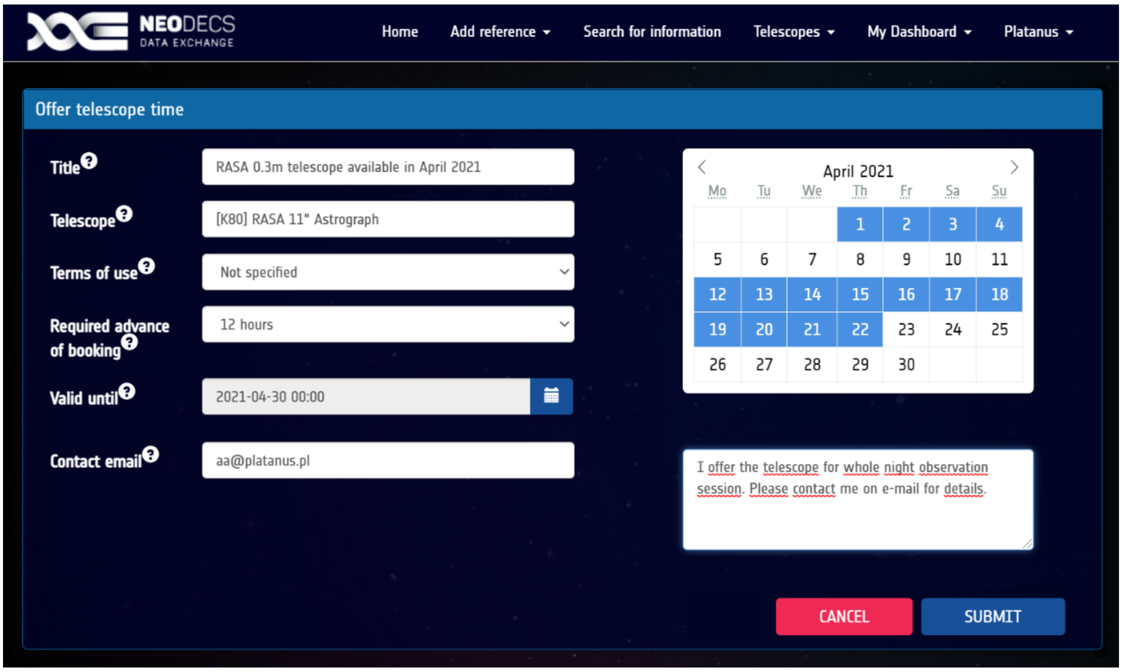

Figure 1. Sharing a telescope time in NEODECS tool.

3.2 Planning observation campaign

The second tool supporting observers cooperation, dedicated especially to NEO researchers, is the tool for planning observation campaigns.

The uniqueness of the NEO observations, even compared to other astronomical applications (as mentioned above), is that:

- new NEOs appear unexpectedly,
- due to the usually small size and distance to the Earth, the observation window usually lasts no more than a few days,
- the observations are urgent – accurate orbit determination needs sufficient amount of position measurements from different locations; there is a risk of losing the object tracking, if they are not provided.

All this means that observational campaigns - especially of newly discovered NEOs - have to be organized and carried out efficiently. With the use of NEODECS service, a worldwide network of observers can be set up promptly. Using the "campaign request" feature, an user can quickly define a campaign, specifying its desired duration, observation conditions and indicating the object to be observed. The campaign can have different accessibility restrictions: it can either be open to all NEODECS users (and will therefore appear in the general search results) or have a "private" status - it is visible only to the specific followers. Regardless of the campaign status, the creator can invite individual observers using the "Invite members" function.

3.3 Information cataloging

The aforementioned rapid growth of scientific communication – formal and (especially) informal – appearing on experts discussion groups or researchers' websites, creates an unprecedented possibility of their reuse in other, parallel research. The increase in data volume is inevitably accompanied by the problem of cataloging and efficient retrieval. NEODECS proposes a solution by offering a reference adding tool (Fig. 2). References are stored in the metadata repository. NEODECS users can contribute to the repository development by adding appropriate entries to the database. It should be emphasized here that NEODECS does not collect the data itself, but the metadata describing the sources.

By "reference" we mean one of the 4 data categories:

- Resource,
- Data request,
- Campaign request,
- Announcement.

Each of the references present in the system can be tagged with one or more asteroid designation tags, which makes searching easier. It can also have a validity period – this reflects the dynamic nature of on-line resources.

Resource

Resource is the most general category of information. It refers to any information available on-line. This could be an on-line publication from a scientific journal, a researcher's website, an ephemeris site, a light curve database, etc. A special form of resource are posts from the Minor Planet Mailing List – a discussion group of asteroid researchers [4]. The posts are automatically imported and tagged by the application.

Data request

Data request is a request made by a user to the community about the need of information - including unpublished ones. Asteroid studies are sometimes long-term projects. Precise determination of orbital parameters or physical properties often requires asteroid observation during several oppositions or close-ups. During this time, not all the results of partial studies are published. Data request can increase their availability.

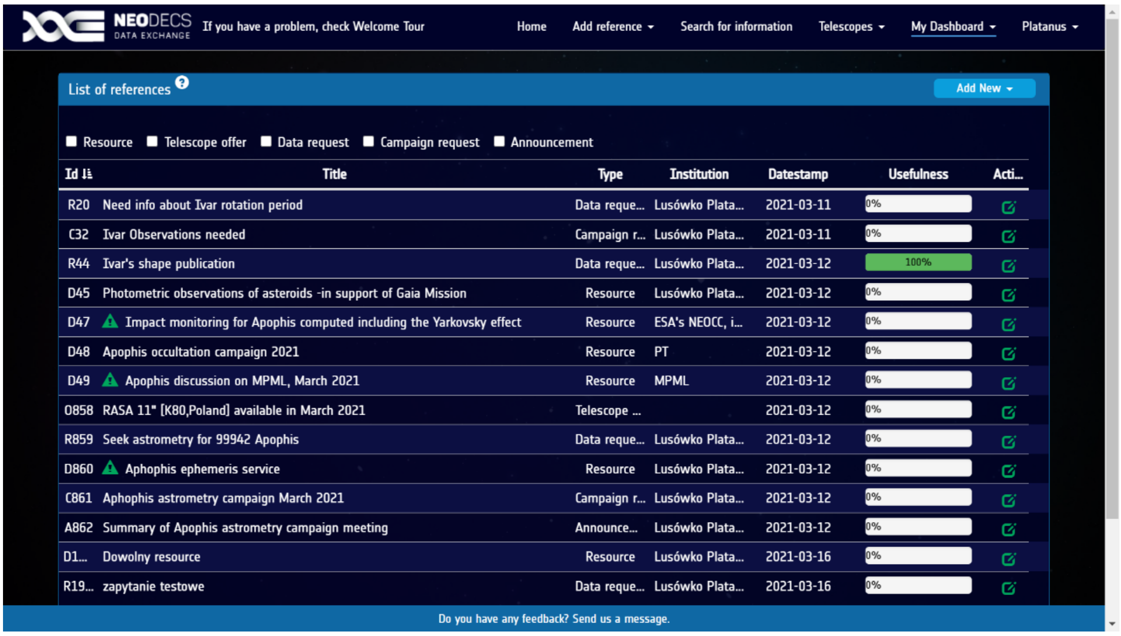

Figure 2. User dashboard lists all user's references.

Announcement

In the 21st century, thanks to technological progress, organizing conferences, seminars or other forms of exchanging research results, meetings and live discussions is much easier. In particular, on-line conferences and webinars, which are cost effective and convenient for participants, are becoming more and more popular. Also, the increasing involvement of citizens in the science contributes to the organization of many new popularizing events (for instance the worldwide Asteroid Day celebrations [5]). The "Announcement" function can be used to inform the community about these types of events.

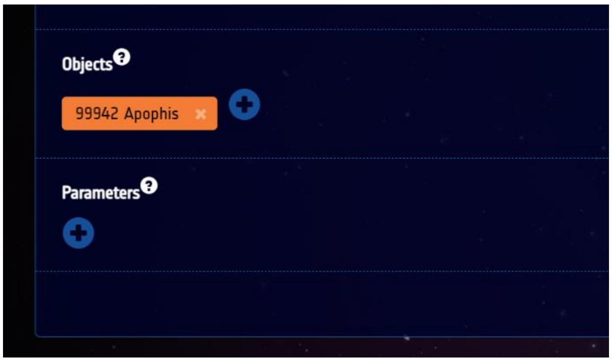

Figure 3. In NEODECS each resource can be tagged with the asteroid designation. It improves search results then.

3.4 Searching for information

The NEODECS has an built-in engine that enables searching for information in references (see 3.3). In a world dominated by global, efficient search engines, creating a domain search engine seems unjustified at first glance. However, it is known that the global search engines have different goals and use algorithms optimized to achieve these goals. The NEODECS directory stores information about resources verified for scientific value by the community, and every individual resource can be tagged with an asteroid designation (Fig. 3). This ensures quick and adequate access to the requested, professional information. Additionally, the user can ask the community for additional resources that he or she did not find with the search engine, using “Data request” functionality described above.

4 SANORDA – SERVICE FOR ARCHIVAL NEO ORBITAL AND ROTATIONAL DATA ANALYSIS

Service for Archival NEO Orbital and Rotational Data Analysis started in 2017. Its goal was to provide databases and tools, tied up with a web interface, to analyse the accuracy of NEO orbit determination and derivation of their spin rates and phase curves [6]. Four modules have been developed in the project:

- NEO Historical Orbits Database,
- NEO Light Curve Database,
- NEO Period Determination Tool,
- NEO Phase-curve Analysis Tool.

4.1 NEO Historical Orbits Database

This module was created in order to facilitate the analysis of historical evolution of NEO orbits models [7].

The main orbits computing services, like NEODyS [8] or MPC [9], routinely compute parameters basing on updated observation database, however store the current results only. The historical data, e.g. orbit prediction when a lower number of observations was available and observation arc-time was shorter, are not archived. From the other hand, understanding how our knowledge about asteroid orbits evolves might result in deeper understanding of the evolution of impact probabilities, biases in the data as well as improve NEO follow-up plan.

A set of 18000 NEOs was selected for the project. It covers all asteroids discovered in the years 2004-2017. The starting point was chosen based on the shift to the use of CCD frames in astrometric measurements. Before, when the traditional photography still played an important role, the accuracy of observations was significantly lower (also due to the accuracy of the star catalogues at that time). Tenths to hundreds orbits have been calculated for every object, reflecting changing amount of astrometry available historically. Orbit elements uncertainties have been estimated based on Monte Carlo statistical ranging method (when number of observations was low) or linear covariance mapping (when number of observations was sufficient). Due to nature and volume of the data, the computations lasted around one year on a computer cluster. The end result is a database of historical orbital elements and orbital uncertainties for known NEOs. It can be used for analysis of problems, such as phase transition and efficient observation planning.

4.2 NEO Light Curve Database

The Light Curve Database module collects information about asteroids light curves together with their position in space. The database was loaded initially with Asteroid Lightcurve Photometry Database [10] data. In the developed ATLAS6 format, common light curve parameters are stored along with asteroid-centric observer’s and Sun’s positions for each single observation. This feature facilitates further data analysis and is especially significant for a NEO, when its position changes rapidly during observation night. Additionally, NEO LCD interface provides tool to transform data format between ATLAS6 and the ALCDEF format developed by Brian D. Warner under NASA contract [11]. Furthermore, this component provides possibility to visualize these curves using charts and tables, and download them in a required format (Fig. 4).

4.3 NEO Period Determination Tool

This module implements a method of light curve analysis for synodic rotation period determination. The analysis is based on Fourier series approximation, and the uncertainty is estimated by the Monte Carlo method. User defines initial, assumed range of the potential period and then the periodogram (period vs. Chi^2) is calculated. The actual period usually correspond to one of the minima of the periodogram. The periodogram as

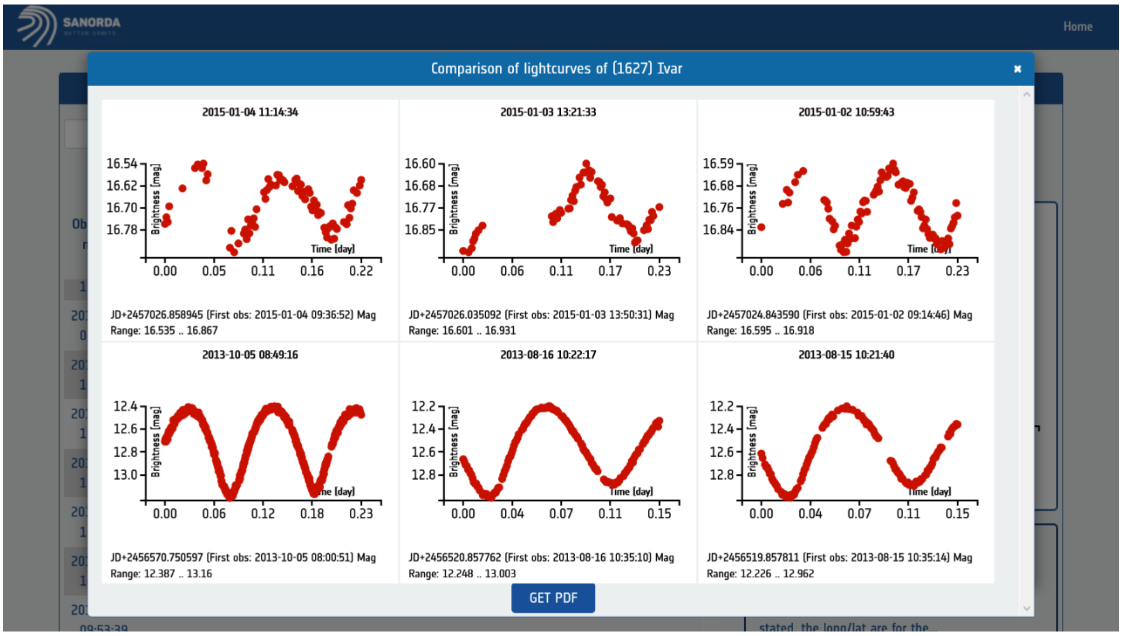

Figure 4. With SANORDA Light Curve Database the user can visualise and compare asteroid lightcurves.

well as the composite light curve created on the selected minimum can be viewed and downloaded as PDF vector graphics for further use.

4.4 NEO Phase-curve Analysis Tool

Asteroid photometry parameters: absolute magnitude H and slope parameters G, G12, G1, G2 are subject of study to clue them with physical properties of the celestial body. NEO PAT allows the user to perform an analysis of their own lightcurves (Fig. 5). Three different phase function models can be fitted: (H, G), (H, G12) and (H, G1, G2). The uncertainty of the derived parameters is estimated by the Monte Carlo method. The uncertainty of the derived parameters is estimated by the Monte Carlo method.

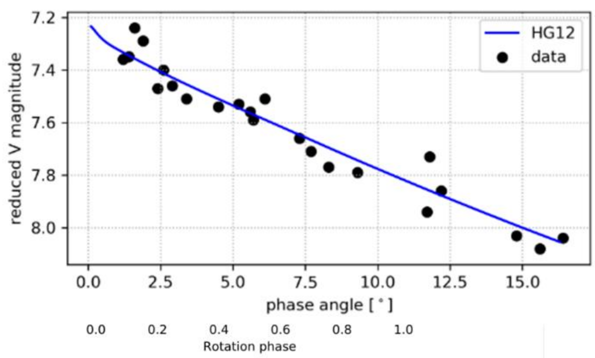

Figure 5. The visualization of brightness data fit to H-G model, generated in SANORDA NEO Phase-curve Analysis Tool (curtesy of Tomasz Kwiatkowski).

5 NEO USER SUPPORT TOOLS

The NEO User Support Tools project started in 2015 and was delivered in 2017. It consists of 7 separate tools that help planning, conducting and analysing NEO observations [6]. They can be used for scientific research and for educational purposes. The system modules are:

- Observation Planning Tool,
- Sky Coverage Reporting Tool,
- Sky Chart Displaying Tool,
- Sky Calculator,
- Orbit 3D Visualiser,
- Earth and Mars Flyby Visualiser,
- NEO Educational Tool.

5.1 Observation Planning Tool

In this day and age with a million of known asteroids, a tool to plan an observation session may be needed. The Observation Planning Tool serves to select objects with favorable observing conditions at the specified location. The potential targets can be filtered by observer location, time window, topocentric (Sun, Moon horizon position, object visibility) and geocentric (magnitude, Sun, Moon elongation, sky motion, Galactic latitude, star density) conditions. The results are plotted in the visibility and ephemeris tables.

5.2 Sky Coverage Reporting Tool

To maximise sky coverage with NEO observations, Minor Planet Center (MPC) maintains a Sky Coverage Diagram [12]. NEO observers are encouraged to send information about the region of the sky they inspected. The tool supports the process of extracting all necessary information from the FITS files created during observations. The user can then add additional metadata and send the report to MPC.

5.3 Sky Chart Displaying Tool

The purpose of the tool is to visualize asteroid and its movement through the stars. It can operate in two modes: scientific and educational. In scientific mode system provides information about object's position, brightness and proximity to bright stars (to assess its impact on asteroid light). The educational mode visualizes the asteroid position against the background of a realistic virtual horizon and naked-eye visible stars.

5.4 Sky calculator

This module provides a toolkit to easily carry out useful observational calculations such as dates calculations (Gregorian, Julian, modified Julian calendar) and coordinates (equatorials, horizontal, galactic and ecliptic), asteroid diameter determination (based on absolute magnitude, assumed albedo or spectral class) and the sky parallax as seen from two distant observers.

5.5 Orbit 3D Visualiser

The tool visualizes asteroids motion on their orbits. The user can select an asteroid and display its orbital motion along with Solar System planets and defined asteroid groups, families or spectral classes. The view perspective can be placed on the Sun or follow an object. At the same time, basic information about the object is displayed (Fig. 6). The entire view can be recorded and downloaded as a video file for further presentations.

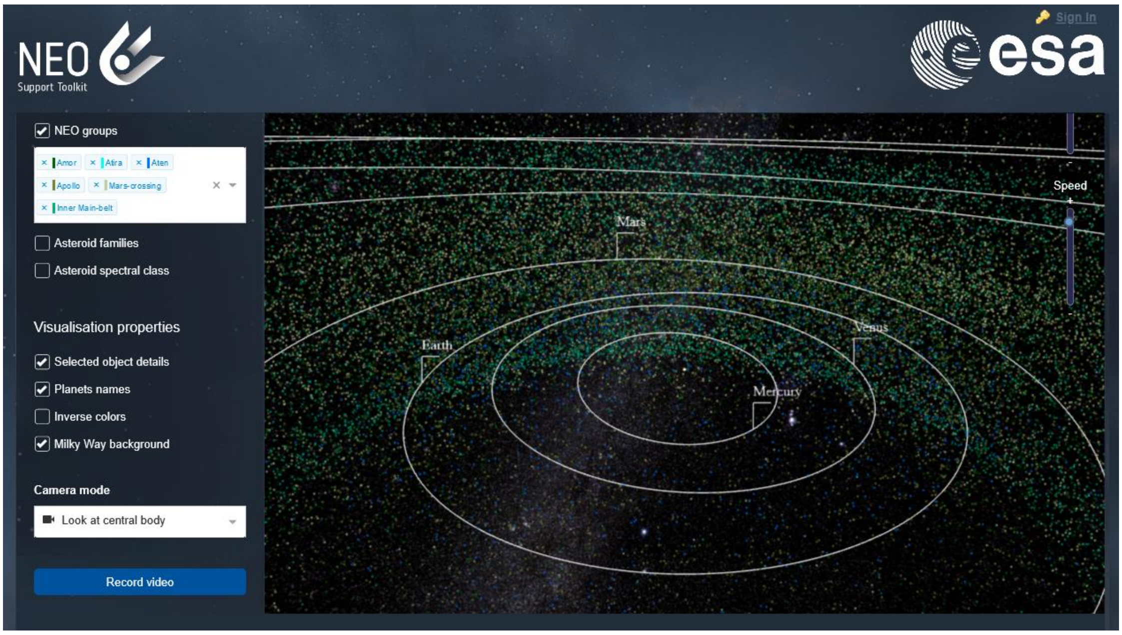

Figure 6. In Orbit 3D Visualiser of NEO User Support Tools, the user has a full control over the perspective parameters and objects display.

5.6 Earth and Mars Flyby Visualiser

The Flyby Visualiser Tool calculates catalogued NEO close approaches to Earth and Mars over a given time period. Then, the list of flybys is presented and the user can select one for visualisation. The part of the body's orbit near the planet (e.g. Earth or Mars) is displayed together with Earth (or Mars) and Moon position and with geostationary orbit for distance reference. The user can select the viewing direction, speed and zoom. The model show all bodies in motion and the scene can be recorded and downloaded as a video file for further use (Fig. 7).

5.7 NEO Educational Tool

This tool is used to visualise the NEO-Earth impact threat situation in the form of a game. A user has to follow six steps to detect, follow-up, size, asses the risk and impact effects, and draw the conclusions. The answers can be given by using other NEO Observer Support Tools.

6 NOAS – NEO&SST OBSERVATION ASSISTANT SERVICE

The NOAS project goal was to develop a tool to

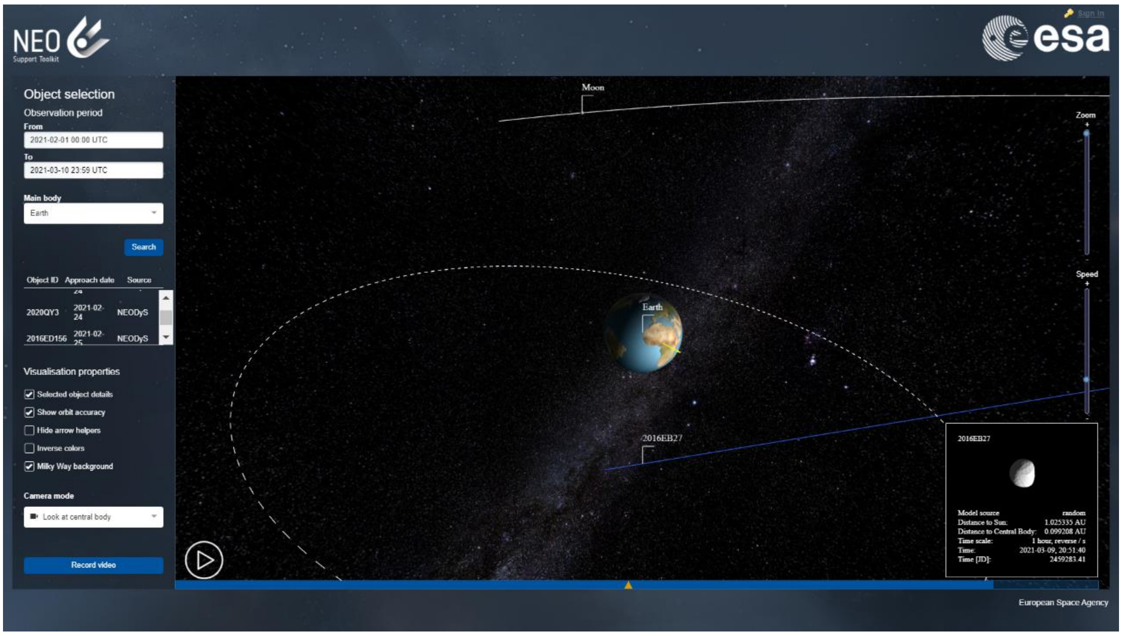

Figure 7. The Earth and Mars Flyby Visualiser of NEO User Support Tools.

facilitate the generation and use of the Scheduling and Commanding Messages (SCM) – a standard file format for observing system commanding and scheduling [13]. SCM was proposed by ESA as a standard for space debris and NEO observations (surveys & follow-ups). It describes observational constraints, target, instrument choices, equatorial coordinates, absolute time etc., and send it to a scheduler. The scheduler collects SCM files for many targets, creates an optimal schedule for the night with absolute times and coordinates, translates it into a sequence of commands for the Telescope Command Language, and sends it to the telescope' computer for execution [14].

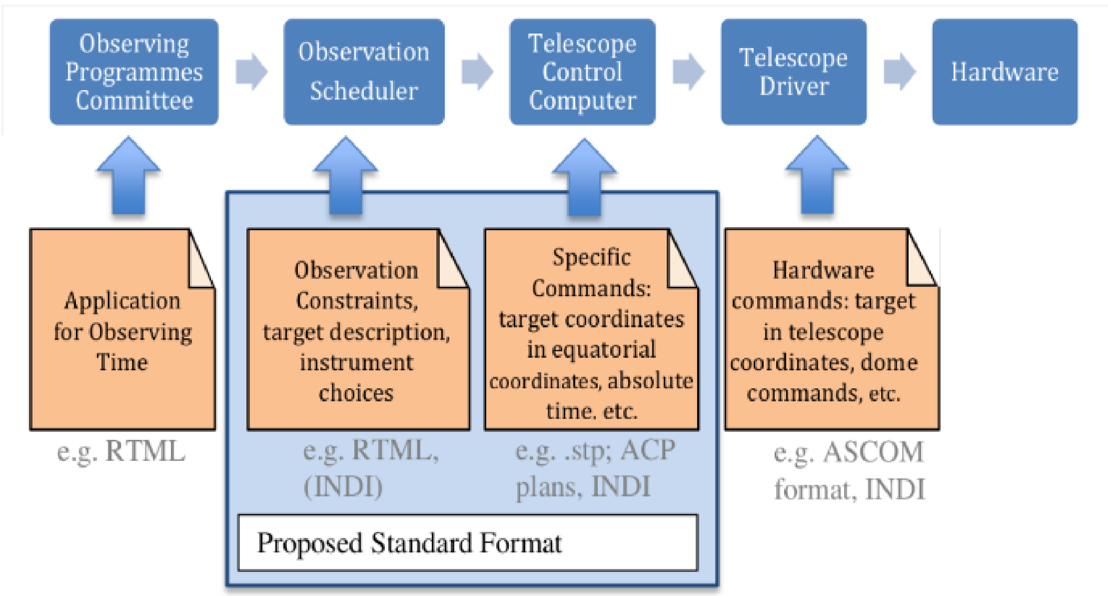

Figure 8. Typical phases of preparation of the observing run at the telescope [13].

can evolve according to processing of the scheduled task (Fig. 8).

The observer inserts all relevant information about the target and observation conditions into the SCM and

NOAS SCM Editor is a desktop application that realizes comprehensive creation of an observation plan and storing it in an SCM standard file. The file contains all the information necessary to perform the observations.

The tool may work in two modes: a wizard one or as a manual editor. In the wizard mode, the user enters the required information step by step, filling in all the necessary fields. Standard mode is intended for users familiar with SCM structure and provides more flexibility. In both approaches, the application creates a plan that can be reviewed and updated using several tools:

- Edit View – changing a file and update with new content,
- Graphic View – shows observation plan in form of Gantt chart,
- Text View – inspecting contents of SCM XML file.

In addition, NOAS Editor supports the user with validation of the file according to SCM standard, and validates the observational plan (e.g. rejecting targets that are unobservable from a given location at the requested time).

The main functions of the NOAS Editor are (Fig. 9):

- Metadata editing,
- Request editing,
- Request validation,
- Observation scheduling,
- Request translation.

In Metadata editing process, the user provides metadata as dictionaries, indexes and reference information, including telescope parameters and instrument constraints. Request editor creates telescope requests. The user provides basic information and the rest is completed automatically. Request validator checks the formal and the operational correctness. The first deals with the SCM syntax, the later checks if the SCM values match the parameter constraints. Observation scheduling suggests the optimal sequence of observations based on a given location and time window. Request translation converts the SCM file to a format accepted by the given telescope controller.

The SCM standard facilitates cooperation between observation requester and telescope operators and enables the automation of the observation processes. With the support of the NOAS SCM Editor, the standard becomes more accessible to NEO and SST observers.

7 OTHER PROJECTS

In previous chapters we described four projects of about 30 developed by ITTI for space industry so far. Below we list the SSA projects:

- P3-SST-XXVII - Customised SST Software Elements in the SST Core Software and Expert Centre,
- PL_RM22 European F10.7 and F30 Index Monitoring System,
- Debris Mitigation Facility Framework Development (DMF-01),
- P3-COM-VI.1: NEO Data Centre and Applications Maintenance,
- PolTelSST: Polish telescopes qualification for SST,
- SPACETONES: Space surveillance and tracking in observational network with event-based sensors,
- E2EPOC: End-To-End Procedure for satellite Orbit Catalogue from optical observation,
- Gaia GOSA: An interactive service for asteroid follow-up observations,
- SSA PL: Feasibility Study to Setup a Polish Component to SSA.

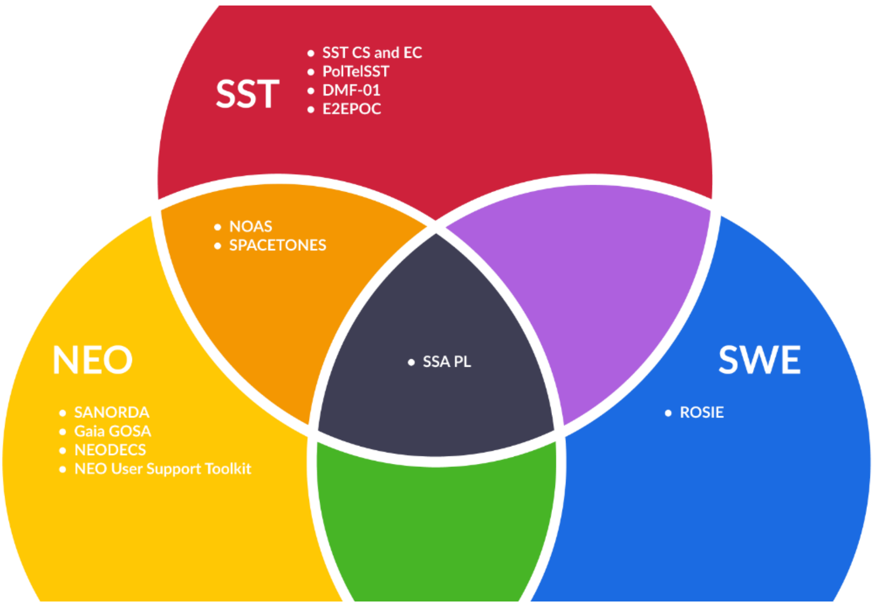

Figure 9. ITTI projects for the ESA SSA programme.

8 CONCLUSION

We believe that the four services presented here have a potential to be of great value to the professional and amateur astronomers in their everyday research. They consist of tools that simplify usual calculations and procedures and help shape the scientific community through promotion of collaboration, resources sharing and standardization.

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