SSA at ITTI — From observation planning to data sharing

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ABSTRACT

For six years ITTI Sp. z o. o. – an SME from Poland – has been running projects for European Space Agency in the scope of the Space Situational Awareness programme. They are mostly software development projects in near-Earth objects (NEOs) and satellite surveillance and tracing (SST) activity areas.

Within these project various software applications have been developed e.g. calculating tools for astronomers and observers, 3D realistic models visualisations, a data format editor, web portals for data sharing and cooperation, applications for data processing, and web services for access to databases and catalogues. This software covers some of important needs of asteroid and satellites observations. Its elements can be ordered according to the stages of a typical observation cycle.

1 ORIGINS

Seven years ago Poland joined European Space Agency and the Polish Industry Incentive Scheme (PLIIS) was signed for 5 years. It offered Poland special conditions for space-related projects and initiatives aiming at supporting of developing Polish space industry. In 2017 the PLIIS was extended until 2019. Thus this year programme terminates. ITTI intensively benefited of the Polish Industry Incentive Scheme and realised many interesting projects also in Space Situational Awareness programme. It is a good moment to summarise undertaken efforts and measurable achievements.

2 Gaia-GOSA

Everything began when the Gaia-Groundbased Observational Service for Asteroids (Gaia-GOSA) has been built in 2015 and delivered in 2016. Since then the programme is in continuous operation and provides services not only for NEOs but also for the Main Belt Asteroids. The main goal of Gaia-GOSA is to encourage observers to make photometric observations of asteroids at the same time when they are observed from space by the Gaia spacecraft. Since Gaia makes only a single photometric measurement of a target which transits its field of view, simultaneous photometric observations from the Earth, covering a whole or a substantial part of the asteroid rotation (usually several hours), are of great importance. Gaia-GOSA is an interactive tool which helps observers in planning such observations. It uses the ESA developed transit prediction algorithm to forecast which asteroids will be observed by Gaia in the near future and combines it with the ephemerides of asteroids downloaded from the Minor Planet Center. Until now the service has over 130 active users who made over 450 observations.

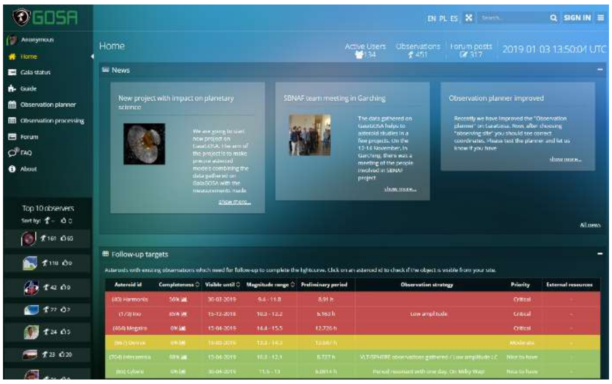

Figure 1. Gaia-GOSA Internet Service main page

Thanks to Gaia-GOSA not only professionals but also the advanced amateur astronomers are able to start collaborating with a real space mission.

Proc. 1st NEO and Debris Detection Conference, Darmstadt, Germany, 22-24 January 2019, published by the ESA Space Safety Programme Office
Ed. T. Flohrer, R. Jehn, F. Schmitz (http://neo-sst-conference.sdo.esoc.esa.int, January 2019)

3 Feasibility Study to setup a Polish Component to SSA

This project started in 2016 aimed at create a roadmap of the future Polish component to SSA in Poland. It was the only non-development project devoted to SSA at ITTI.

One of the product of the project presents the results of activities performed in the first stage of Feasibility Study for SSA in Poland which was to gather information on the existing infrastructure and capacity inventory of Poland within the three areas of the ESA Space Situational Awareness (SSA) Programme.

Project shows also the high-level requirements and identifies services of the segment as a baseline for SST system design and its further development in Poland.

Finally deliverables discusses briefly the existing PL SST infrastructure, namely sensors and software. The most important part is the proposal of the Polish SST structure, development plan and upgrade requirements. This document provides also information about the needs for new sensors for Polish SST. The final part of the document presents the PL SST system architecture, possible administrative solutions, a proposal for National Operation Centre (NOC), sensor and other components. The authors' recommendations were also included in this deliverable.

To summarize, the purpose of the project was to discuss the plan for enhancement and exploitation of the existing Polish SSA elements and national activities on research and R&D that could be used as SSA infrastructure. These included space debris and satellite optical observation of objects laser ranging measurements, and radar sensors used for low Earth orbit (LEO) space debris surveillance and tracking. Furthermore, the needs in terms of new sensors for SSA activities taking into account innovative approaches were also presented.

The concept of the SSA activities in Poland was developed in accordance with several aspects: existing and proposed SST infrastructure, civilian, governmental and industrial requirements, the decision No 541/2014/EU of the European Parliament and of the Council of 16 April 2014 establishing the Framework for Space Surveillance and Tracking Support. The plan was also based on the information and data from all civilian institutions involved in the Polish SSA system.

4 P2-NEO-VI User support Tools

A milestone was a project P2-NEO-VI User support tools started in 2015. It was an open call project realised according to the specification of work prepared by ESA. The final product delivered in 2017 consisted of seven different tools allowing for NEO observation planning, visualisation and learning:

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

In the following subchapters the above-mentioned tools are described.

4.1 Observation Planning Tool

Observation Planning Tool assists users with NEO observation planning process. It helps to select target objects from the following catalogues: NeoDyS-2, ESA Primary List and MPC Confirmation Page.

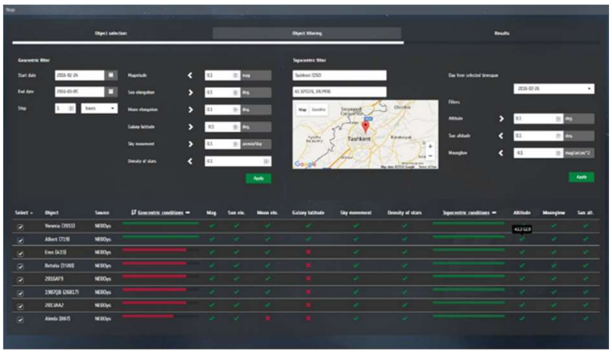

Figure 2. Observation Planning Tool

Once the user set the observation time window, the candidate objects may be filtered by their geocentric (e.g. magnitude, Sun and Moon elongation, Galactic latitude, sky movement, density of stars in a FOV) and topocentric visibility conditions (e.g. object altitude, Sun altitude, moon glow). The tool produces a forecast plots of their long-term and short-term visibility and the ephemerides tables. On the short-term plot the tool provides a link to previous observation of each object.

4.2 Sky Coverage Reporting Tool

In a semi-automatic process, Sky Coverage Reporting Tool provides information about the observational sky coverage basing on the information contained in the FITs headers to the Minor Planet Center.

The tool consist of standalone downloadable analytical program extracting information from FITs headers and window for uploading the extracted information to the NEODECS server. A user can add further metadata and send the report. The uploaded report is available at MPC Sky Coverage Diagram.

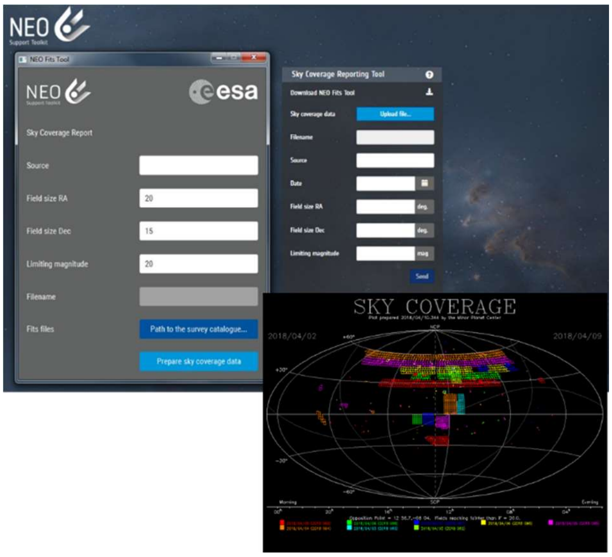

Figure 3. Sky Coverage Reporting Tool

4.3 Sky Chart Displaying Tool

Sky Chart Displaying Tool generates a sky chart for the specific observation in two modes. In the scientific mode the sky chart presents a target object track against the background stars. Apart of the location on the sky, it provides the information on the magnitude of the object, sky movement near the object and proximity of the bright stars which may dim (interfere) the observation.

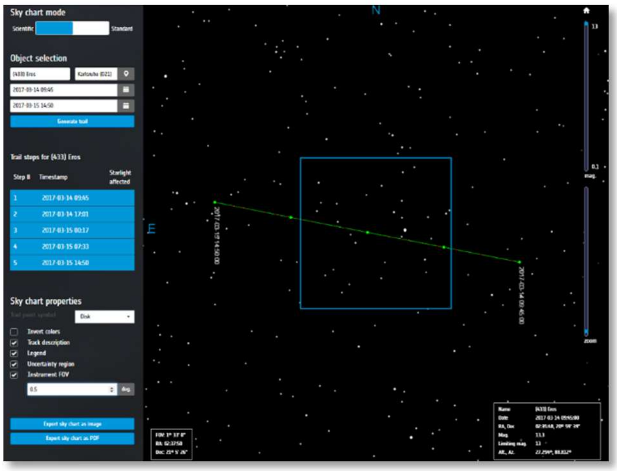

Figure 4. Sky Chart Displaying Tool

In the standard mode the sky chart simulates the observation on the night sky showing the object position on the naked-eye visible stars with the photorealistic horizon line. Lastly the user can print the sky chart report.

4.4 Sky Calculator

Sky Calculator tool supports observer in dates and coordinates calculation, asteroid diameter determination (out of its magnitude and albedo) and sky observation parallax between two different places on the Earth (e.g. observatories).

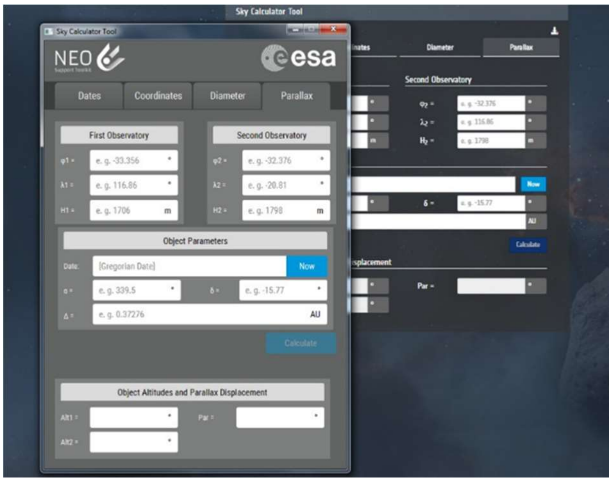

Figure 5. Sky Calculator

It supports Gregorian, fractions of years, months, days, minutes, Julian and modified Julian dates. It is able to convert to various coordinates systems, such as equatorial (α, δ) and (t, d), horizontal (A, h), Galactic (l, b), and ecliptic (λ, β).

For magnitude-albedo for diameter calculation a user can choose one of three typical parameters for C-type, S-type and V-type objects. The sky calculator may be used as a web tool as well as a standalone application.

4.5 Orbit 3D Visualiser

NEO Orbit Visualisation tool displays orbital model of the Solar System with orbits and positions of planets together with the selected asteroids.

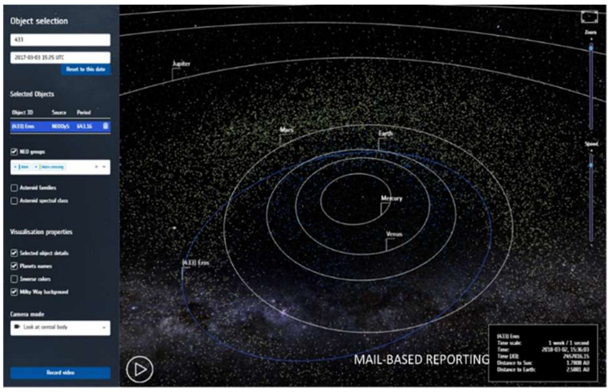

Figure 6. Orbit 3D Visualiser

A user can switch on and off the view of indicated groups, families and spectral classes of known objects.

The model shows all bodies in motion in a given time scale. The perspective: the direction of view, the speed of motion and the zoom are controlled by a user. The "camera" may look to the centre of the Solar System or trace the given object.

The tool provides also basic information about the objects e.g. distances to the Sun and the Moon. Finally the whole view may be recorded in a downloadable video file for further presentations.

4.6 Earth and Mars Flyby Visualiser

Earth and Mars Flyby Visualiser allows a user to search for NEOs flybys close to the Earth or Mars in the given time span. The tool calculates the close encounters with catalogued NEOs.

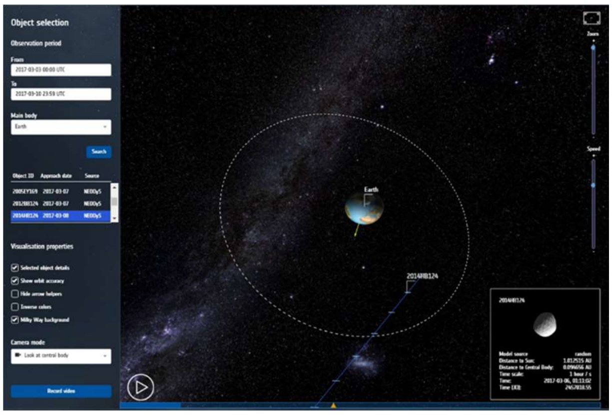

Figure 7. Earth and Mars Flyby Visualiser

When the user chooses the particular flyby from the default list, the tool displays a fragment of the NEO orbit in the proximity of the central body e.g. the Earth. It also presents a geostationary orbit and the Moon's orbit as a distance reference. The model shows all bodies in motion in a given time scale. For easy handling, a timeline of the event is shown at the bottom of the screen with a marking indicating the moment of perigee. The perspective: the direction of view, the speed and the zoom are controlled by a user.

The tool displays also estimated shape of the body. The more information about the surface of the body is collected, the better accuracy of the shape can be simulated. It displays also the basic temporal information of the object e.g. distance to the Sun, distance to the Earth. Finally the whole view may be recorded in a downloadable video file for further presentations.

4.7 NEO Educational Tool

This tool presents a hypothetical NEO Earth impact threat situation in the form of a game. The narrations go from one stage to another letting the player solve the relevant problems.

There are six stages from object detection and follow-up observations, through determination of size and impact risk assessment, to potential impact effects and conclusions. Sometimes to answer the question the user needs to use a tool from the NEO support toolkit.

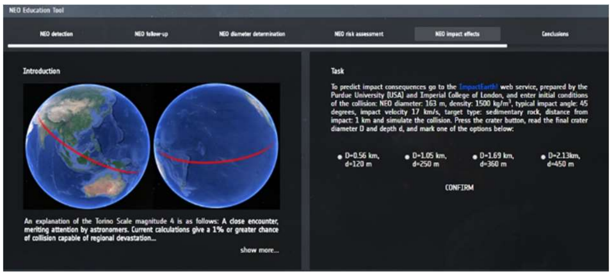

Figure 8. NEO Educational Tool

The developed tools use of course data from external sources e.g. NEO catalogues (NeoDyS-2, ESA Primary List and MPC Confirmation Page), referencing star catalogues (USNO-B1, BSC).

The internet service with all these tools is supposed to be established on ESA SSA Portal.

5 NEODECS

Then, in 2016, there came NEO Data Exchange and Collaboration Service (NEODECS) as one of the first projects financed in the Polish Industry Incentive Scheme. Now the development stage of the project is closed. It is available on internet for testing and promotion.

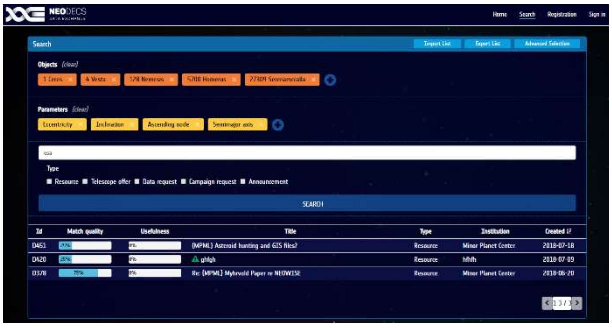

Figure 9. NEODECS

The main function of NEODECS is publishing and searching for different information sources about data concerning: Near-Earth Objects (NEOs), Trans-Neptunian Objects (TNOs), and Main Belt Asteroids (MBAs).

These data source indication is called reference. There are the following types of references:

- Resource – data sets promoted by users or acquired from MPML (Minor Plane Mailing List),
- Request – a need of particular information (submitted by users),
- Observation – a telescope time slots (offered by users),
- Campaign – a group of observations of the same objects/type (run by users),
- Announcement – any other information (input

by users).

The advanced search for objects is based on constraints on their properties. The following orbital properties are used:

- Semi-major axis
- Inclination
- Eccentricity
- Argument of perihelion
- Ascending node
- Mean anomaly
- Orbital period
- Mean motion
- Perihelion distance
- Aphelion distance
- MOID
- Orbit type

A user is able to select objects also by the following physical properties:

- Size, Albedo, H, G1, G2
- Mass, Density, Porosity
- Taxonomic type
- Colour index
- Rotation period
- Quality code U
- Light curve amplitude
- Sense of rotation
- Spin vector

NEODECS employs a social network paradigm for data indexing and sharing. The service performs periodical automatic data loading, validation of links by checking their availability, change of file size and content. The caching of the linked webpages is performed to enable full text search capability. To inform users directly an email notification mechanism (e.g. reminders, informing messages) is employed.

The idea is to create a NEO observers community and facilitate access to observation outcomes.

6 NOAS

NEO and SST Observation Assistant Service (NOAS) was another project in the PLIIS. It began in 2017 and currently is about to end.

NOAS concept supports the whole cycle from observation planning to acquiring data at the telescope. The observing plan for the night is encoded in the XML file based on the SCM (Scheduling and Commanding Message) standard, established and promoted by ESA. It includes information about the observing system (parameters of the telescope, filters, CCD camera) as well as a list of objects (usually NEOs, artificial satellites and space debris) to be observed.

The goal of the project was twofold: to create an application making it easy to prepare the SCM files for observations, and to demonstrate the usage of SCM files in practice by preparing tasking functions for two telescopes. Since currently not all robotic telescopes "understand" the SCM standard, the so called "tasking functions" will be prepared to translate the SM file to the internal language used by the observing system to operate the telescope during the observations. The main software product of NOAS is a stand-alone SCM Editor written in java.

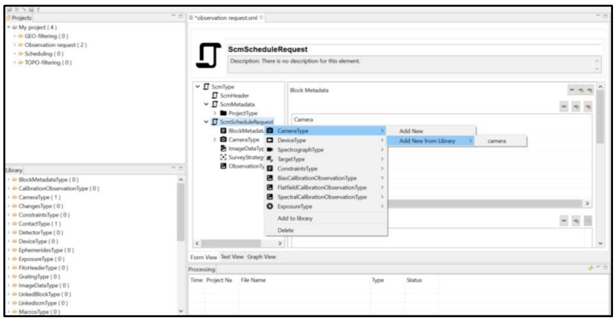

Figure 10. SCM Editor

The SCM Editor uses the following back-end modules & processes:

- NEOLib: asteroids ephemerides computation
- SatLib: SST ephemerides computation
- Sched: a scheduling program to create an optimal sequence of observations of NEOs and SST objects for a given night based on different constraints set by the observer
- Translation of SCM files into telescope native commands (handled by the tasking function)

All those modules are run on the server which is queried by the stand-alone SCM editor when needed. The information is exchanged in the SCM format which makes it possible to end the process at the intermediate stage and use the resulting SCM file for the observer's own programs. This can be useful, for example, if the there is no tasking function prepared for a given instrument. In such case the observer can view the final schedule for the night in the SCM editor and copy and paste the data to his own program controlling the telescope.

The final version of the SCM editor is now being delivered.

7 SANORDA

Service for Archival NEO Orbital and Rotational Data Analysis (SANORDA) is one of the last projects realised thanks to PLIIS. It was started in 2017.

SANORDA provides databases and tools to analyse the accuracy of NEO orbits determination, derivation of their rotation periods and phase curves. It consist of four modules:

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

They are described below.

7.1 NEO Historical Orbits Database

In the project the evolution of orbital uncertainties for near-Earth objects (NEOs) were reproduced and collected in a database accessible to researchers. The database might help to better understand evolution of collision probabilities, biases in the data, as well as plan for more efficient NEO follow-up.

Orbits for NEOs are routinely computed by services such as NEODyS or MPC. The most up to date orbits are then stored overwriting the previous orbital solution. In NHOD database the temporary orbits are recovered (by re-computing) and stored, so that the whole evolution of orbital uncertainties with the increasing number of observations and the length of observing arc can be viewed.

All asteroids discovered in the years 2004-2017 were processed. This sort of large scale processing have not been attempted before and required several tenths to hundreds of orbit computations per object for the 18000 NEOs. For every such orbit a set of clones had to be created to estimate the accuracy of the solution. This was computationally a very demanding task and it was achieved with the AO AMU and AMU Quantum Physics group computer clusters. Cases where the orbit computation failed (e.g. no unique solution, clear outliers, etc.) were flagged as difficult and left for later analysis for interested researchers. The end result is a database of temporary orbital elements and orbital uncertainties for known NEOs.

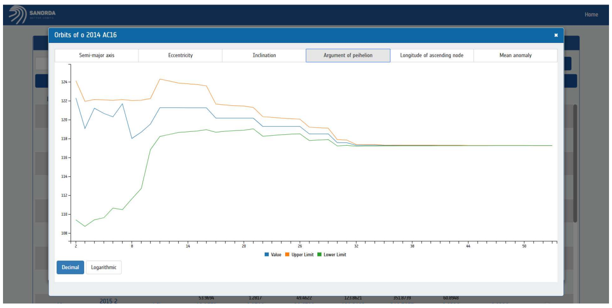

Figure 11. A plot of the evolution of the argument of perihelion of the orbit of 2014 AC16. The horizontal axis shows a number of days after discovery.

The computations were performed at two computer clusters and lasted around 1.5 year. Each asteroid was observed from a few to thousands of times resulting in a few to thousands of asteroid orbit computations per object. The fully completed computations can now be used by researchers for analysis of important problems such as phase transition and efficient observation planning. Number of computations indicated possible outliers or problematic cases. We encourage the researchers to explore those cases separately and identify possible sources of problems (i.e. long gaps in follow up observations) and possible solutions (i.e. weighting schema).

7.2 NEO Light Curve Database

This functional module collects the photometric lightcurves of asteroids and enables to translate them between the ALCDEF and ATLAS6 formats doing parameters calculations basing on the NASA JPL service. Furthermore this component also provides possibility to visualize those curves using charts and tables.

Figure 12. A table presenting the details on the lightcurves of asteroid Honoria, present in the NLCD. After clicking on a table row a plot of the selected lightcurve is shown at the right.

Finally user is able to download them in the all of the previously mentioned formats.

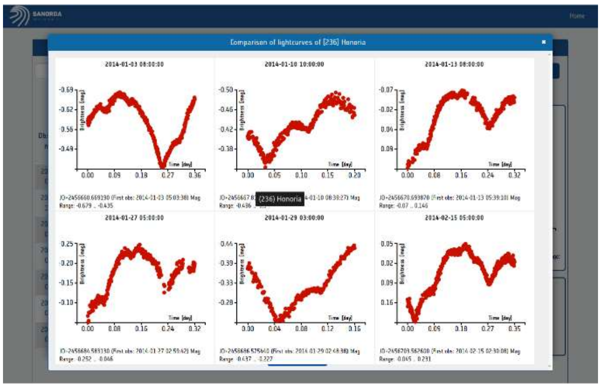

Figure 13. Comparison of user selected lightcurves of Honoria.

The collection of those light curves is enabled by the automatic import mechanisms tied to the data sources.

7.3 NEO Period Determination Tool

This module uses the lightcurves from the database to search for the synodic period of an asteroid. This is done by a least-squares fitting of a Fourier series to the data and finding the period for which the data scatter is minimal. The uncertainties of the obtained solution are then estimated by the Monte Carlo simulation.

The analysis is started by selection of a set of lightcurves of sufficient quality, setting up an interval for period search, the order of the Fourier series fit, etc. After that a plot of the Chi2 value of the fit versus o trial period is displayed showing the global, and local, minima (Fig. 14).

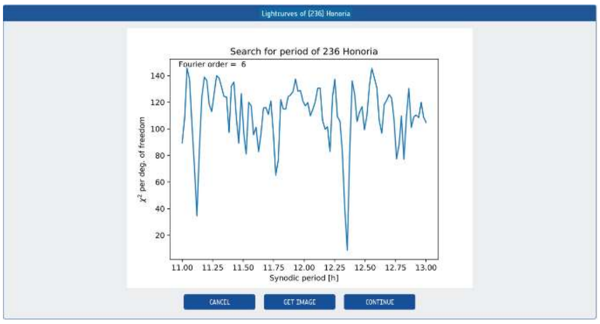

Figure 14. A Chi2 plot showing a global minimum at P=12.34 h..

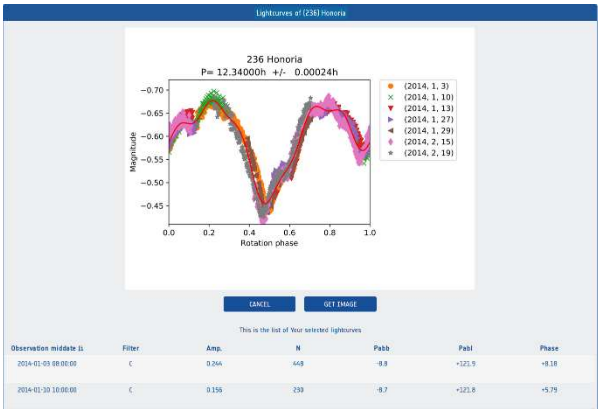

Figure 15. A composite lightcurve of the asteroid Honoria obtained by folding seven lightcurves from the database. A menu at the right shows the dates the individual lightcurves were taken on while the table at the bottom (truncated for this figure) presents the details for each lightcurve (like the filter, peak-to-peak amplitude, number of points, asteroid coordinates during observations, etc.).

The obtained plots can then be saved as PDF vector graphics. The composite lightcurve can also be downloaded in the numerical form for own software analysis.

7.4 NEO Phase-curve Analysis Tool

The aim of this module is to collect observations of the asteroid phase curves and use them to calculate the (H, G), (H, G12) or (H, G1, G2) phase relations. NPAT uses data stored in SANORDA in a simple database to which a user can upload his own measurements. After that the data for a specified object can be displayed both in a tabular form and as a plot of the reduced brightness versus the solar phase angle (Fig. 16).

Figure 16. *Example phase curve data for asteroid 19 Fortuna. The plot at the right shows only the point obtained in the user specified filer.*

In the next step a least-square fit of three photometric models to the data is performed (Fig. 17). The uncertainty of the derived parameters are estimated via the Monte Carlo simulation.

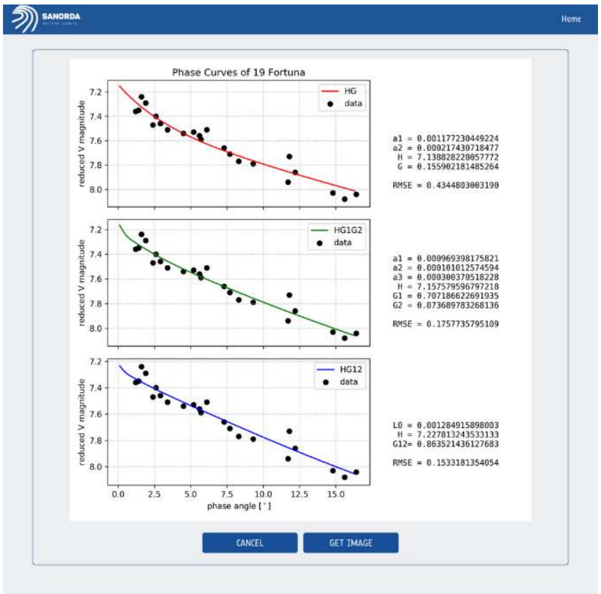

Figure 17. *Plots of the fits of three photometric models to the phase curves of Fortuna.*

8 FOLLOW-UP OBSERVATION CYCLE

As the results of the presented projects 14 different software tools have been developed. They are listed in the Tab. 1.

Table 1. ITTI SSA Tools List

Designation	Tool

Gaia-GOSA	Gaia-GOSA
NOP	Observation Planning Tool
SCR	Sky Coverage Reporting Tool
SCD	Sky Chart Displaying Tool
SCL	Sky Calculator
NOV	Orbit 3D Visualiser
NFV	Earth and Mars Flyby Visualiser
NET	NEO Educational Tool
NEODECS	NEODECS
SCM-E	SCM Editor
HOD	NEO Historical Orbits Database
LCD	NEO Light Curve Database
PDT	NEO Period Determination Tool
PAT	NEO Phase-curve Analysis Tool

The first classification may be made basing on the target objects to which each tool is devoted. The mapping of the tools according to this criterion presents Fig. 18.

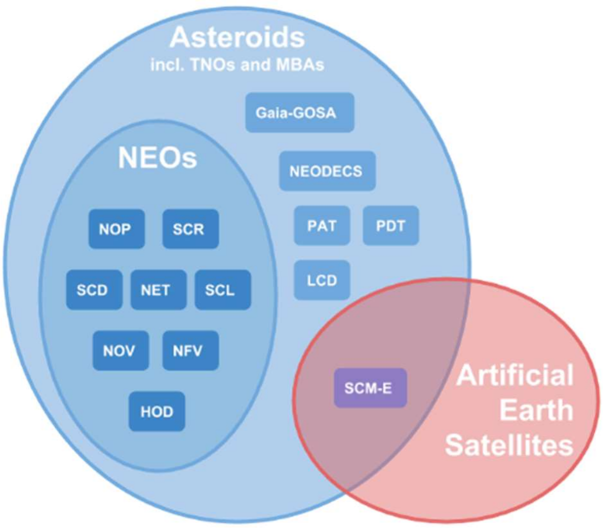

Figure 18. ITTI SSA Tools classification by target objects

As one can see the tools are generally devoted to support observations of asteroids and the most of them concern NEOs. Only SCM Editor developed in the NOAS project can be used also in SST area.

Another dimension of classification relates to the types of observations they support. For NET this criterion is not applicable. This classification is presented in Fig. 19.

This proves that the tools are evenly distributed among astrometry, photometric and any other kinds of observations.

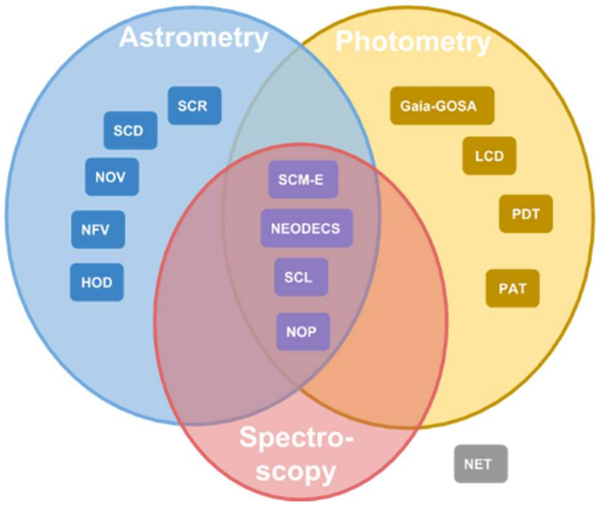

Figure 19. ITTI SSA Tools classification by supported type of observation

The last classification presented in the paper shows the assignment of each tool to the activities within the observation cycle. The observation cycle consists of the following activities:

- New Object Detection (the initiating stage),
- Target Selection and Observation Planning,
- Observations Scheduling and Telescopes Tasking,
- Observations Execution,
- Data Reduction and Analysis,
- Models Improvements and Cataloguing.

Figure 20. ITTI SSA Tools classification in a follow-up observation cycle

The positioning of ITTI SSA tools on the follow-up observation cycle is shown in Fig. 20.

As one can see by completion of 6 years of ITTI projects in SSA the developed tools may cover most of the activities from the asteroids follow-up observation cycle.

9 FUTURE

The Polish Industry Incentive Scheme application period has ended, nevertheless there are still formerly submitted proposals to be realised.

ITTI is running Polish Telescopes Qualification (PolTelSST) project aiming at validation of Polish sensors in use of satellite observations.

This year ITTI will probably begin End-to-End-Procedure for Satellite Orbit Catalogue from Optical Observation (E2EPOC) project.

Last year ITTI has been qualified the second stage of Space Surveillance and Tracking in Observational Network with Event-based Sensors (SPACESTONES) project. It will verify the applicability of event-based cameras in satellite observations.

In 2018 ITTI has applied for Event-based Sensor in Adaptive optics for Telescope Image Correction (ESATIC) project in an European Southern Observatory (ESO) Attract call.

These done and planned activities are accompanied with many other projects and initiatives SSA-related undertaken by ITTI also in the European Commission funding programmes.

10 REFERENCES

1. PC – IAU Minor Planet Center, http://www.minorplanetcenter.net/
2. APC – Asteroid Photometric Catalogue, http://asteroid.astro.helsinki.fi/
3. ALCD – IAU Minor Planet Center Astreoid Light Curve Database, http://www.minorplanetcenter.net/light_curve2/light_curve.php
4. SDC – Centre de Donnees astronomiques de Strasbourg, http://cdsweb.u-strasbg.fr/
5. NEODECS site, http://neodecs.eu
6. Kryszczyńska, A. *NEO Data Exchange and Collaboration Service (NEODECS).* Asteroid, Comets and Meteors 2017, Montevideo, April 2017
7. Kryszczyńska, A, Kwiatkowski, T. *NEO Data Exchange and Collaboration Service (NEODECS)*, European Planetary Science Congress, Berlin, 16-21st September 2018.
8. ALCDEF standard, https://www.minorplanetcenter.net/iau/info/ALCDEF_V109.pdf