KLET OBSERVATORY PREPAREDNESS AND PLANS FOR PLANETARY DEFENCE

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ABSTRACT

Klet Observatory has been discovering and tracking asteroids since 1992, employing a 1.06-m KLENOT Telescope for the task since 2002. The KLENOT Project resulted in nearly 100 000 astrometric measurement up till now. Priority is given to Virtual Impactors, newly discovered Near Earth Objects (NEOs) and NEOs with uncertain orbits. Both hardware and software has been continuously upgraded to stay competitive in the field and more enhancements are planned. Moreover an attention has been given to educate the public and the media on impact hazards. The observatory is ready to participate in European Planetary Defence activities.

1 INTRODUCTION

After several decades of increasing effort to understand Near Earth Objects (NEOs) population as well as asteroid hazard studies we realize that humankind is living on a cosmic shooting-range where the target is Earth. An ability to track and compute position of NEOs ahead of time gives us unprecedented opportunity to mitigate or avoid this natural hazard.

2 KLET OBSERVATORY

Klet Observatory team entered an international effort of discovering and tracking NEOs early after its beginning in a collaboration with the Minor Planet Center (MPC). The observatory is situated in the southern part of the Czech Republic near Austrian and Bavarian borders. Klet night skies are still reasonably dark due to its position 500 meters above the nearest town as well as its location in the centre of the Natural Protected Area.

The first NEO astrometric follow-up from Kleť was made photographically using 0.63-m Maksutov camera in 1992. In 1994 we started CCD measurements using 0.57-m reflector. In 2002, a new 1-m class telescope called KLENOT, was built and put into operation at Klet Observatory and became the main device of the project. It has been used for confirmation of the NEOCP objects, early astrometric follow-up of confirmed NEOs, NEO recoveries, follow-up astrometry of radar targets and targets of space missions. After the first successful and prolific phase of the KLENOT Project (2002-2008), new computer-controlled paralactic mount was built for the KLENOT Telescope. More advanced CCD camera was installed in 2013.

KLENOT Telescope specifications:

- 1.06-m f/2.7 optical system: Zeiss parabolic mirror + 4-lenses optical corrector
- field of View 0.63 x 0.63 degrees
- CCD ProLine 230, chip e2v 2048x2048 pixels, pixel size 15 microns, electronic cooling

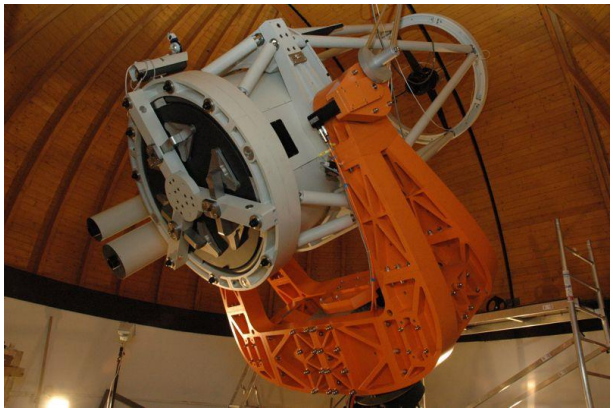

Figure 1. KLENOT Telescope

The KLENOT Project uses its own software package developed by the team and optimized for its needs. It contains tools for observation planning, data-acquisition, camera control, data processing and orbit calculation. The tools are linked in between each other and our SQL database and they leave our servers to do most of the processing. KLENOT image processing is made almost in real time. All obtained image sequences are checked visually by an observer experienced in image processing, and precise astrometric positions are produced within minutes of the image acquisition. All astrometric positions are compared to their on-site computed positions to ensure only the most precise data are sent to the MPC. Images are catalogued and archived to be available at any time.

Since 2014 Klet Observatory has served as one of several national cooperating sensors in the framework of ESA SSA NEO segment.

KLENOT Project resulted in 94 028 astrometric measurements of 11 173 objects between 2002 and 2018, which include:

- astrometry of about 200 Virtual Impactors (CLOMON, SENTRY)
- confirmation and astrometry of 1092 NEAs from NEOCP list
- recovery of 16 NEAs and 4 comets
- 25 015 astrometric positions of 2444 NEAs
- discovery of 776 new asteroids, incl. 3 NEAs

3 OBSERVATION PLANNING

Flexibility in observing plan is crucial. Smaller NEOs are often discovered when passing close to the Earth and failure in promptly obtaining enough quality data to determine their orbit results in inevitable loss of the object. Early follow-up is thus crucial step in planetary defence.

Klet Observatory developed its own flexible observation planning tool, supplying its observers with the most current object lists and data and letting the experienced observer choose the targets on the go. Together with custom astrometric processing producing precise astrometric measurements of NEOs within minutes of the image acquisition, and large field of view of the KLENOT Telescope, Klet Observatory is especially suitable for rapid response astrometric observations.

The observing targets in our custom list are sorted by Right Ascension, highlighted by type of the target and properties useful for the decision are listed.

The priority is given to, from top to bottom:

- Virtual Impactors, NEOCPs (listed at MPC NEO Confirmation Page), targets of radar observations and space missions in need of astrometry
- objects on ESA's Priority List, early astrometric follow-up of confirmed NEOs
- NEOs with lower precision of the computed orbit, expressed in uncertainty parameter U listed by orbital parameters of MPC

NEA recoveries are also performed thanks to the large field of view of the KLENOT Telescope.

4 KLEŤ PROGRESS AND PLANS

Klet Observatory constantly pushes to upgrade its equipment and enhance its software to stay competitive in the field. This part lists and describes both existing and planned progress of Klet Observatory within a scope of few years.

4.1 KLENOT Telescope Mount

In order to increase tracking accuracy of the KLENOT telescope the main gearbox of the KLENOT mount was upgraded. The mount uses epicyclic gearing, which was furnished with optoelectronic sensor to provide higher accuracy of tracking.

4.2 Star Catalogue

Quality catalogue is essential for high precision astrometry. GAIA DR2 catalogue is the most precise astrometric catalogue to date. It is recommended by MPC for observers to employ. We have incorporated GAIA DR2 astrometric catalogue into our workflow and started to produce astrometric measurements using GAIA DR2 just two weeks after the catalogue's publishing.

4.3 Artificial Flatfield

We are working on artificial flatfield created as a background estimate of the image to improve signal to noise ratio and measurements precision of our astrometry. For an image series, kappa-sigma clipping is used on each pixel of the serie to create the artificial flatfield, while for a single image, a filter based off SMIN algorithm can be used to obtain nearly as good flatfield estimate. The methods can be applied also on images from our vast archive for precovery purposes. They were developed and tested in [1] and resulted in obtaining astrometric measurements of the first interstellar body 1I/'Oumuamua [2] and will be accessible as routine part of our processing workflow soon.

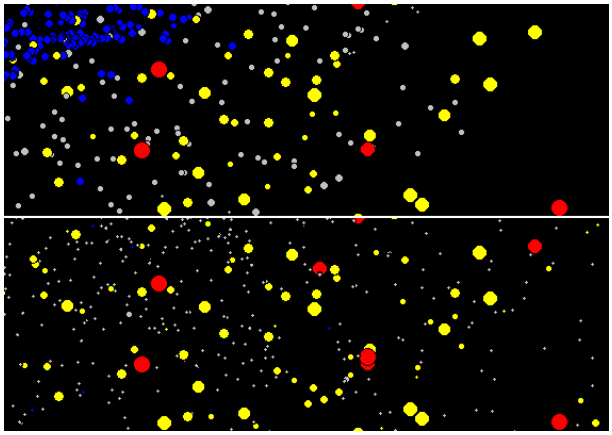

Figure 2. Object detection cutouts. On top before, and to the bottom after an artificial flatfield was applied.

4.4 Object Predictor

We have augmented our custom observer's tool with minor planets and comets predictor, which is taking ephemeris of known objects and marks them on viewed image. That simplifies searching for the observer.

In an example cutout on Fig. 3, the magenta objects are expected ephemerides from MpcOrb catalogue, and green objects were measured by the observer.

Since the field of view of KLENOT telescope usually contains several mainbelt asteroids in addition to the observed object, in the next step we plan to automatize the astrometry of these low priority, well-determined

objects.

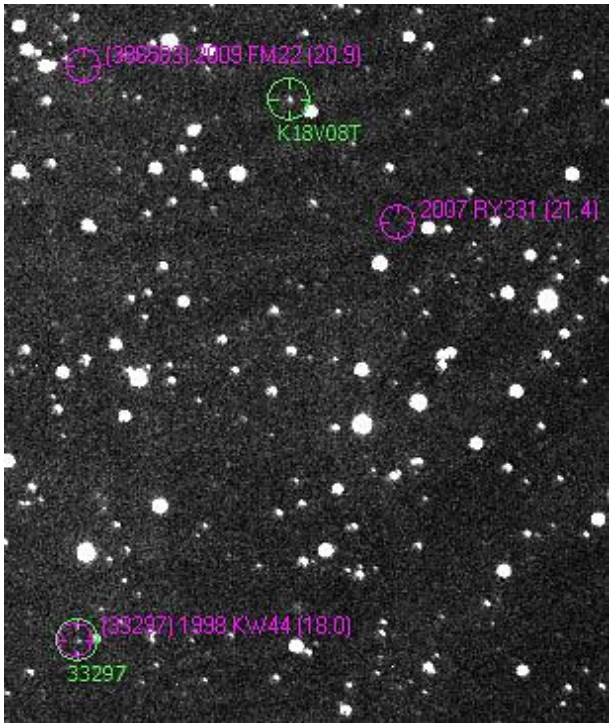

Figure 3. Klet Observatory's Astrometry cutout.

4.5 ADES format

An availability of useful informations of astrometric measurements were until recently limited by the precision of values recorded in the 80 characters long Minor Planet Center (MPC) format. Therefore the MPC started to allow submission of astrometric measurements in ADES (Astrometry Data Exchange Standard) format, approved by the International Astronomical Union in 2015 [5]. ADES format provides new features and higher precision of recorded values. We are ready to make transition of our astrometry to ADES format to take advantage of these changes.

4.6 ESA Priority List

We are going to improve Klet observation planning tool towards higher importance given to the ESA priority list.

5 PUBLIC RELATIONS AND OUTREACH

Our institution represents an unique liaison of the small professional research institution Klet Observatory and the educational and public outreach branch Ceske Budejovice Planetarium. It has been giving us an excellent opportunity for bringing NEO information to a wide audience. An asteroid hazard has become a popular subject of both media and catastrophic movies and stories. It poses an opportunity for scientists and research institutions to educate the public and the media on the matter of detection, impact effects, mitigation missions, impact warning and other related subjects. On the other hand it is necessary to bring clear, comprehensive, relevant and up-to-date information to avoid misunderstanding and sensations or fear among the wide public. We use educational multimedia presentations, summer excursions to Klet Observatory, public lectures, exhibitions and discussions, and last but not least, through social media and special on-line web magazines (e-zins). An important part of NEO public outreach consists of continuous contact with journalists and media. We also search for good opportunities to communicate NEO hazard towards civil authorities and decision makers of various levels in the Czech Republic [6].

6 COOPERATION

The astrometric observations of minor bodies including NEOs are collected and processed by MPC, which operates at the Smithsonian Astrophysical Observatory, under International Astronomical Union. MPC is also responsible for computation, checking and dissemination of astrometric observations and orbits of minor planets and comets including NEOs.

The current European road map towards a Planetary Defence System under ESA leadership becomes the first Europe-wide initiative in tracking and characterization of NEOs. We are ready to cooperate in this field and are open to further improvement and deeper coordination in the framework of European Planetary Defence activities.

7 ACKNOWLEDGEMENT

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