# New Optical Sensors Cluster for Efficient Space Surveillance and Tracking

**Krzysztof Kamiński, Edwin Wnuk, Justyna Gołębiewska,**
**Mikołaj Krużyński, Monika K. Kamińska**
*Astronomical Observatory Institute, Faculty of Physics, Adam Mickiewicz University,*
*Słoneczna 36, 60-286 Poznań, Poland.*
**Michał Żołnowski, Marcin Gędek**
*6 Remote Observatories for Asteroids and Debris Searching,*
*ul. Godebskiego 55a, 31-999 Kraków, Poland*
**Jacek Pala**
*ScopeDome, Poland*

## ABSTRACT

We present the most advanced Polish project for optical satellite tracking and survey. The new cluster of robotic sensors, under development since 2017 by the Astronomical Observatory of Adam Mickiewicz University, will be composed of 5 independent telescopes located at the same site. Two of them will be dedicated to surveys, and therefore equipped with 30cm f/1.0 prime focus optical tubes. Two additional will be dedicated to tracking and equipped with 32cm f/5.3 optical tubes. The largest 0.7m f/4.5 telescope will be dedicated to the most demanding tasks and faintest targets. Each of these telescopes will be installed on an independent direct-drive mount with satellite tracking capabilities and less than 10s all-sky slewing time. The cluster will be controlled with dedicated software capable of autonomous decision making based on priorities, current weather conditions, new object detections and observing data quality assessment. Its features will include dynamic task allocation for each telescope, automatic targets identification, immediate follow-up for new objects and local orbital catalog updated after each observation. This technology demonstration project will initially be located in Poland and is aimed at testing currently available solutions in highly demanding SST observations regime. Validation of the prototype SST sensor cluster will be the first step in creating the concept of future global network of such clusters that could potentially track all LEO satellites and space debris above 5cm. The project is based on our experience in remote and automatic SST observations with our Global Astrophysical Telescope System – an intercontinental pair of 0.5m and 0.7m optical telescopes. We present the basic concept of the SST cluster hardware and software design and the results of numerical simulations conducted to evaluate its future performance as a single cluster and a possible global network of similar clusters.

## INTRODUCTION

Optical SST sensing is the cheapest technique used for survey and tracking of Earth's artificial satellites. The main limitation of optical sensors is the fact that they can only be used at night (although event-based sensors might change that in the near future [1]) and when the observed target is outside the Earth's shadow. These limitations can be mitigated to some degree by creating a global network of optical telescopes located in areas with good weather conditions. In existing networks (for example ISON [2]) the usual strategy is to use a single optical sensor at each site and utilize as many sites as possible. Such approach has the advantage of making the weather less likely to interfere with the observing plan of the global network, but it has the disadvantage of under-utilizing sites with predominantly good weather conditions. This is prominent when looking at Fig. 1, where we present the typical numbers of TLE catalog targets visible simultaneously from a single site during a typical night. In our simulations of a typical SST sensor site it is clear that over 7000 satellites are available for observations during a clear night, which significantly exceeds the capabilities of a single optical sensor. In Fig. 2 we present the minimum number of satellite tracking observations (tracklets) that are required every minute to record all targets appearing above the selected site during a whole night. On average 9.5 are necessary, but during dusk and dawn 20 is more representative, with occasional peaks reaching the level of 25. These results suggest that adding new optical sensors to existing sites can significantly increase the output of a global network and can be regarded as an effective strategy of development.

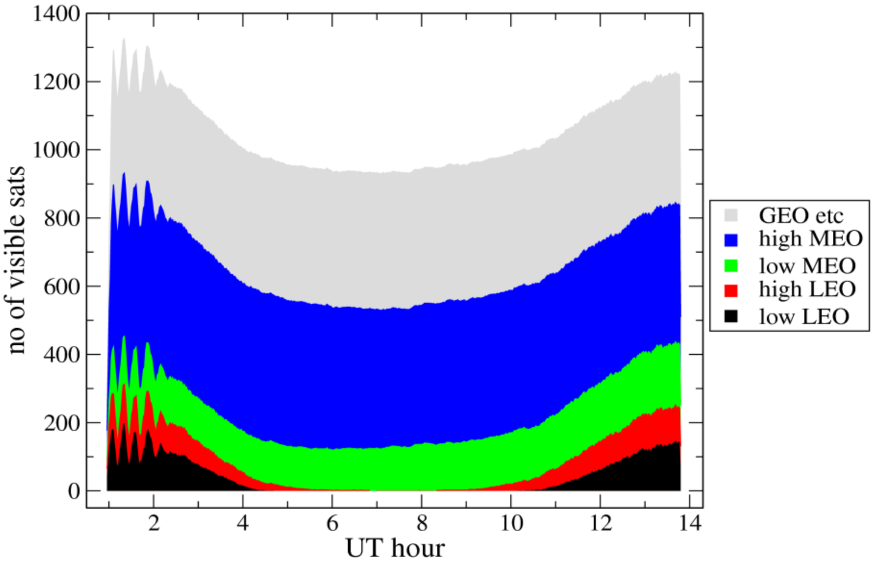

Fig. 1. The average number of satellites simultaneously visible, and therefore available for observation, from a site at latitude 40° N in January 2018. On average, one can observe about 1100 targets of all types at least 15° above the horizon each moment during a night. Typical flyby time for low LEOs is of the order of 4 minutes and for high LEOs is of the order of 9 minutes.
A total number of unique objects observable during a single night in this example is around 7300.

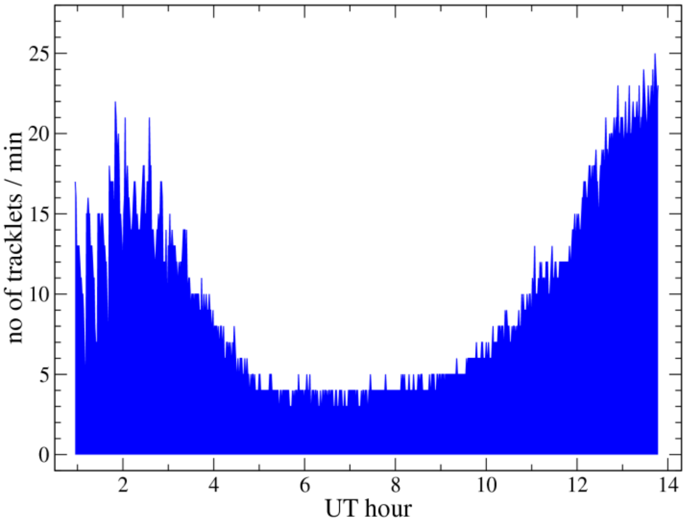

Fig. 2. Minimum number of satellites necessary to be tracked each minute of a night for the purpose of tracking all 7300 visible targets.
The same parameters were assumed as in Fig. 1.

## DESIGN

PST3 (Poznań SST Telescope 3) is designed as a universal and efficient instrument for tracking and survey tasks. Its name refers to two historical designs in 60's and 70's, when photographic cameras: 10cm PO-1 and 15cm PO-2 have been created and utilized for many years at Poznań Astronomical Observatory. The PST3 cluster will be composed of two 30cm survey sensors, two 32cm tracking sensors and one 70cm tracking sensor. The basic specification of all sensors is presented in table 1.

Table 1. Specification of PST3 sensors.

| Sensor designation | PST3a | PST3b, PST3c | PST3d, PST3e |
|---|---|---|---|
| Primary assignment | tracking | tracking | survey |
| No of sensors within the cluster | 1 | 2 | 2 |
| Aperture | 0.7m | 0.32m | 0.3m |
| Focal ratio | f/4.5 | f/5.3 | f/1.0 |
| Mount | Planewave CDK700 | Planewave L-500 | Planewave L-500 |
| Max slewing speed | 30°/sec | 60°/sec | 60°/sec |
| Camera | Andor Zyla 5.5 | Andor Zyla 5.5 | Andor Zyla 5.5 |
| FoV with 16.6mm sensor | 0.3° × 0.3° | 0.56° × 0.56° | 3.17° × 3.17° |
| Pixel scale | 0.43"/pix | 0.8"/pix | 4.5"/pix |

The optical design of tracking sensors is a Planewave's modified Dall-Kirkham with a lens group near the focal plane. The survey sensors feature a prime focus design with dual, full aperture correction plates, Mangin mirror and a lens group near the focal plane. The design of all sensors is optimized for large chips (diagonal of 52mm) and will be initially only partially utilized because of relatively small CMOS detectors used. The Andor Zyla 5.5 camera was selected primarily because of its true electronic global shutter and low readout noise < 3e$^-$/pix. It will be directly connected to a GNSS receiver for accurate, sub-millisecond timing.

Fig. 3. PST3 will be housed in one regular and 3 ScopeDome clam-shell domes.
The central dome will house a control centre.

For the purpose of efficient operation, on-site and on-line data analysis, a small computer cluster will be installed inside the PST3 central dome, and all 5 optical sensors will be housed in three clam-shell domes located around it (Fig. 3).

## EXPECTED EFFICIENCY

The PST3 cluster is going to be operated primarily in a combined survey/tracking mode. This means that some sensors will be assigned for survey and some for tracking, depending on the schedule and user requirements, but also on results from on-line analysis of recorded images. Such a dynamic assignment will allow to react on detection of a new, unidentified target by a survey sensor and within a few seconds modify the schedule of a tracking sensor for immediate follow up. On the other hand, if a tracking sensor will fail to detect a known, pre-scheduled object, the survey sensor will be immediately assigned to verify the target's absence with its much larger field of view. Alternatively, a larger aperture sensor might also be assigned if a smaller one will not detect a satellite that might be too faint for it. An internal database of satellite absolute magnitudes and brightness variability will be maintained and used for observation scheduling.

We estimate PST3 will allow for tracking up to 4000 targets each night, depending on the observing strategy and requirements. Single site data is, of course, insufficient for satellite catalog keeping, but even short, 10-20s tracklets should allow us to correct the orbital parameters from TLE catalog and maintain a sub-catalog with orbital and photometric data for a sample of satellites of interest.

Our experience in SST observations with the existing sensors: RBT/PST2 (Roman Baranowski / Poznań Spectroscopic Telescope 2) – 0.7m Planewave CDK700 equipped with Andor iXon3 electron-multiplying CCD [3] and 6ROADS global network of six remotely controlled and robotic optical telescopes equipped with CCD and CMOS cameras, as well as our simulations, indicate that an aperture of only 0.3m should be adequate for most targets. Estimated minimum diameters of a spherical, Lambertian (diffusely-reflecting) satellite with albedo of 0.1 at different topocentric distances, detectable by 0.32m tracking and 0.3m survey sensors, are presented in Fig. 4 and Fig. 5, respectively. Tracking of 10cm LEO targets should be easily achievable and survey detection of 30cm LEOs should be possible.

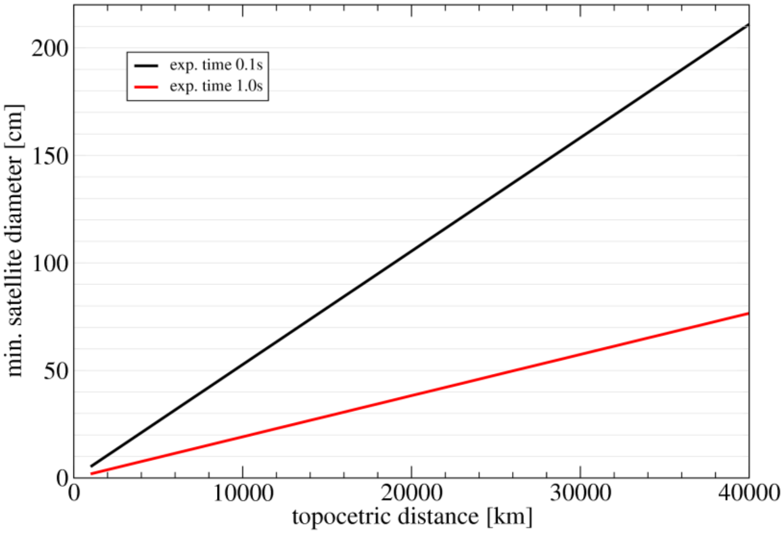

Fig. 4. Estimated minimum diameter of a spherical satellite, which should be optically detectable at SNR=5, using a 0.32m f/5.3 sensor in tracking mode, assuming 0.1s or 1.0s exposure time and corresponding limiting magnitude of V=13.8 and V=16.0, respectively.

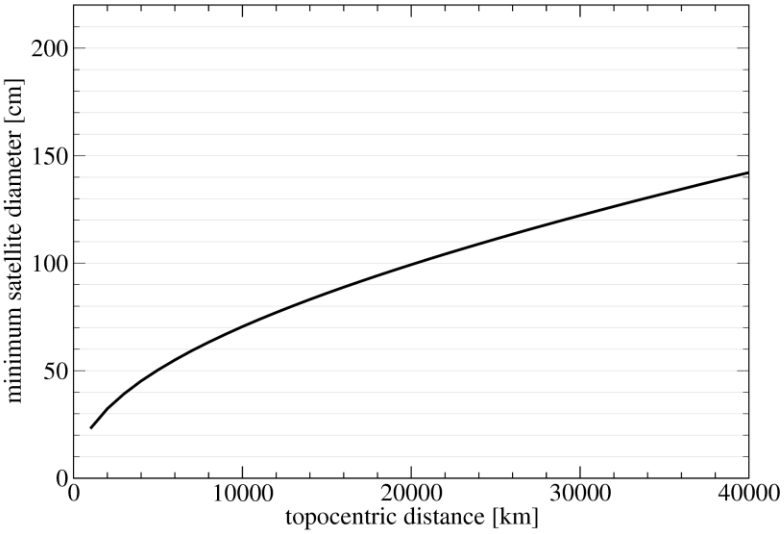

Fig. 5. Estimated minimum diameter of a spherical satellite, which should be optically detectable at SNR=5, with a 0.3m f/1.0 sensor in survey mode, assuming the exposure time of such a length that the satellite trail will be exactly 1 pixel (similar to the sensor's PSF). These results are not applicable for the GEO ring survey, where sensors can blindly track targets without prior knowledge of their orbit.

## SUMMARY

The first light of PST3 sensor cluster is expected in 2019 and the fully autonomous operation level is scheduled for 2020. Its initial location is selected for convenience in western Poland, inside a dark-sky preserve area. This should allow for full evaluation of the efficiency and reliability of its hardware and software. Finishing this part of the project will open the opportunity for relocation into a better site and copying the design for use in a global SST network. We estimate that with roughly 10 such clusters located in sites with good weather conditions around the globe, nearly all TLE catalog targets should be observed daily and such a network could constitute a backbone of a global satellite tracking system.

## REFERENCES

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