SURVEY AND FOLLOW-UP STRATEGIES USED IN OPERATION OF ASPOS OKP TO GATHER OBSERVATION DATA ON GEO, HEO AND MEO OBJECTS

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ABSTRACT

Improvement of situation awareness for near-Earth space is essential for safety of space operations in the crowded environment. To deal with this issue the State Space Corporation Roscosmos has ordered development of the Automated Warning System on Hazardous Situations in Outer Space (ASPOS OKP). ASPOS OKP is operated since Jan 1, 2016 by Astronomical Scientific Center (ASC) under the contract with Roscosmos. ASC has developed and implemented various observation strategies used for routine surveys and tasking, detection and immediate follow-up of new objects and observation of 'clouds' of debris formed as the result of a fragmentation. The paper will discuss these strategies and will provide various examples of their implementation.

1 ISSUES OF MONITORING DEEP SPACE ORBITS

At present the number of objects (nearly 7600) tracked by ASPOS OKP in high near-Earth orbits (or so called 'deep space orbits') have exceeded more than 2.1 times the quantity of the same kind of objects with orbital data being providing at SpaceTrack. Absolute majority of these objects is represented by previously unknown faint space debris and by previously discovered but then lost fragments.

Operation of dedicated optical observation facilities that provide functional support to the ASPOS OKP (Fig. 1) has already resulted in discovery of nearly 2800 new objects in GEO region and at various HEOs (GTO, Molniya) during 2016-2018 of which only 267 ones relate to the new launches. Two major fragmentations have occurred in GEO and GTO in 2018. The overall number of detected and tracked debris objects released only in these two events exceeds 700. Therefore, the contribution of these events was almost half to the total number of 1570 objects discovered in deep space orbits in 2018 by dedicated and contributing sensors of ASPOS OKP.

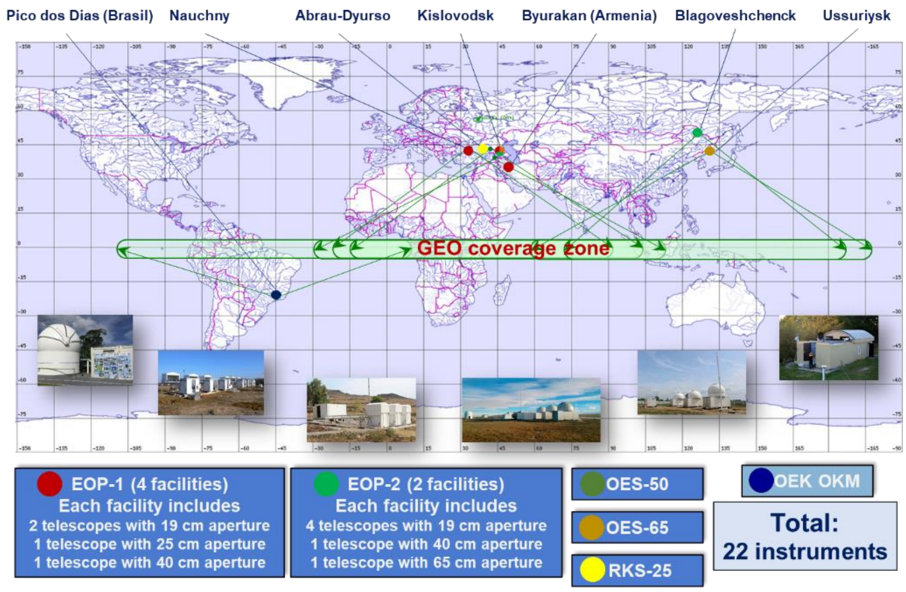


Figure 1. Operational network of optical facilities of ASPOS OKP (ROSCOSMOS)

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)

Considering that there were no new sensors put into operation in 2018 such a significant increase of the number of tracked objects was achieved only thanks to continuous improvement of observation strategies. At the same time, the increasing number of detected objects requiring regular monitoring on the one hand and fixed capacity of the observation network on the other hand leads to the decrease, in average, of accuracy of orbits maintained in the catalogue since the observation time which can be spent per object is decreasing and gaps between sequential observations of the same object are increasing. Thus, it is important to build up observation strategies that take into account requirements by the catalogue maintenance task along with requirements by other tasks such as observation of objects predicted to encounter at close distance, monitoring manoeuvrable spacecraft or faint objects with strong variation of brightness etc.

2 GENERAL APPROACHES TO THE OBSERVATION STRATEGIES

There are three general kinds of the telescope tasking used in ASPOS OKP: surveying the wide areas of the sky (surveys), search in a local zone with immediate follow-up upon object of interest detection (search and track) and follow-up without search.

Survey is a widely used strategy in deep space objects monitoring especially the GEO region or Molniya-type orbits apogees region. Such strategies are using knowledge on certain peculiarities of the evolution of corresponding groups of orbits which results in forming quite compact regions on celestial sphere where visible passes of objects one and the same group are concentrated. The core of the strategy is to find the optimal balance between the number of repeated observations of each field in the selected portion of the region of interest, the average cumulative observation arc length per night for each field and the area of the entire region of interest covered without gaps during one night taking into account such constraints as average angular motion rate of objects belonging to the group, the telescope IFOV size, effective exposure time, dynamical characteristics of the telescope mount, the Milky Way and the Moon position as well as, at certain conditions, proximity of the observed field to the anti-Sun direction.

Search in a local zone with immediate follow-up upon detection of a supposed object of interest is a strategy which applies to monitoring of objects with large uncertainties in predicted position or of a group consisting of unknown number of objects with similar visible trajectories, for example, in case of launch of multiple objects. The key difference of this strategy comparing to the ‘classical’ survey one is the requirement that the entire area of searching should be covered within limited period of time determined by the characteristics of visible motion of the searched object(s). Simultaneously the task of association of observations obtained for every detected object to the orbits in the catalogue should be solved in order to select the object(s) of interest and to start follow-up tracking of the object(s) as soon as it possible.

Follow-up without search is the simplest strategy because it requires just proper pointing the telescope to the predicted visible position of an object and keep tracking the object with its angular velocity or observe even with the optical axis pointed towards the fixed specific direction.

3 FRAGMENTATION DEBRIS DETECTION AND TRACKING AS A SPECIAL CASE OF OBSERVATION STRATEGY

The likelihood of the situation that an object in deep space orbit being observed directly at the moment of its fragmentation is very low unless the object is not being monitored continuously. Usually the assumption that an object possibly fragmented is based on a combination of several facts. First, processing of observations indicates that the motion of the objects center of mass experienced unexpected disturbance which cannot be caused by natural perturbations. Second, new unknown objects moving in a close vicinity to the observed one are detected. By the moment when these two facts are established possible fragments may already dispersed in a large volume of space. Since neither time of the fragmentation (and therefore the position of the object at that time) nor characteristics of the event (number of fragments, their size, distribution of their velocity vectors at the moment of the fragmentation etc.) are known a-priori then it is virtually not possible to properly constrain the portion of space which should be scanned in order to find the fragments.

The simplest approach in this case is to organize quick search in a local zone which is build up along the visible trajectory of the fragmented object with the width across the trajectory equal to a few IFOV of the telescope used.

As soon as reliable orbital parameters are determined for the major remained piece of the fragmented object or for several fragments it becomes possible to make the next step in order to improve the effectiveness of the search strategy. Based on analysis of the determined orbits it is required to assess the point of fragmentation. Importance of knowing the position of the object at the moment of fragmentation is obvious. All fragment’s trajectories start at this point in space that is why it is widely known as a ‘pinch point’. Therefore, during certain (sometimes – quite long) period of time concentration of visible passes of the fragments will be maximal in a local zone around the pinch point that in turn makes it possible to organize very effective search of the fragments in this local zone.

4 THE SEARCH STRATEGY APPLIED TO THE CASE OF THE CENTAUR R/B (2014-055B, SSN #40209) FRAGMENTATION

The fragmentation of the Centaur R/B (2014-055B, SSN #40209) occurred on Aug 30, 2018 at 22:03:49 UTC. This event was a good stress test for the optical observation scheduling algorithms developed and implemented by ASC.

Last observation prior to the detection of an anomaly in orbital motion was obtained on Aug 30 at 2020 UT. Orbit determination (OD) fit span which included the last observation was equal to 59.8 days. 950 measured positions from 31 telescopes were used for the OD. First observation that lead to the detection an anomaly in orbital motion was obtained on Aug 30 at 2346 UT (i.e. 3 hours 26 min after the prior observation). Large residuals of new measurements with respect to the propagated orbit from the last OD revealed: -392 arcsec along track (equivalent to -14.2 sec of time) and -221 arcsec cross-track. These values significantly exceeded the expected 0.3 arcsec position uncertainty calculated from the last OD covariance.

Numerous bright (of 15th magnitude or brighter) fragments were detected on tracks similar to the 2014-055B during the routine observations of the Centaur R/B at 2346 UTC on Aug 30, 2018. Two dozen of new debris-like objects were detected on the pass at 0118-0121 UTC on Aug 31. Therefore, collected information clearly indicated that the Centaur R/B have fragmented into numerous pieces.

Additional measurements collected for the major observed piece of the Centaur R/B were used to determine its orbit and estimate time when anomaly in the orbital motion have occurred. Following estimation was obtained:

Time: Aug 30, 2018 at 22:03:49 UT

Place: longitude 8.504 E, latitude 22.189 S, altitude 29017 km

dV: 9.3 m/s with components dVr +5.7 m/s, dVt -6.1 m/s, dVz -4.0 m/s

Therefore, position of the pinch point was determined and sufficient amount of information to build up effective observation strategy accumulated.

Fig. 2 illustrates the developed and implemented observation strategy.

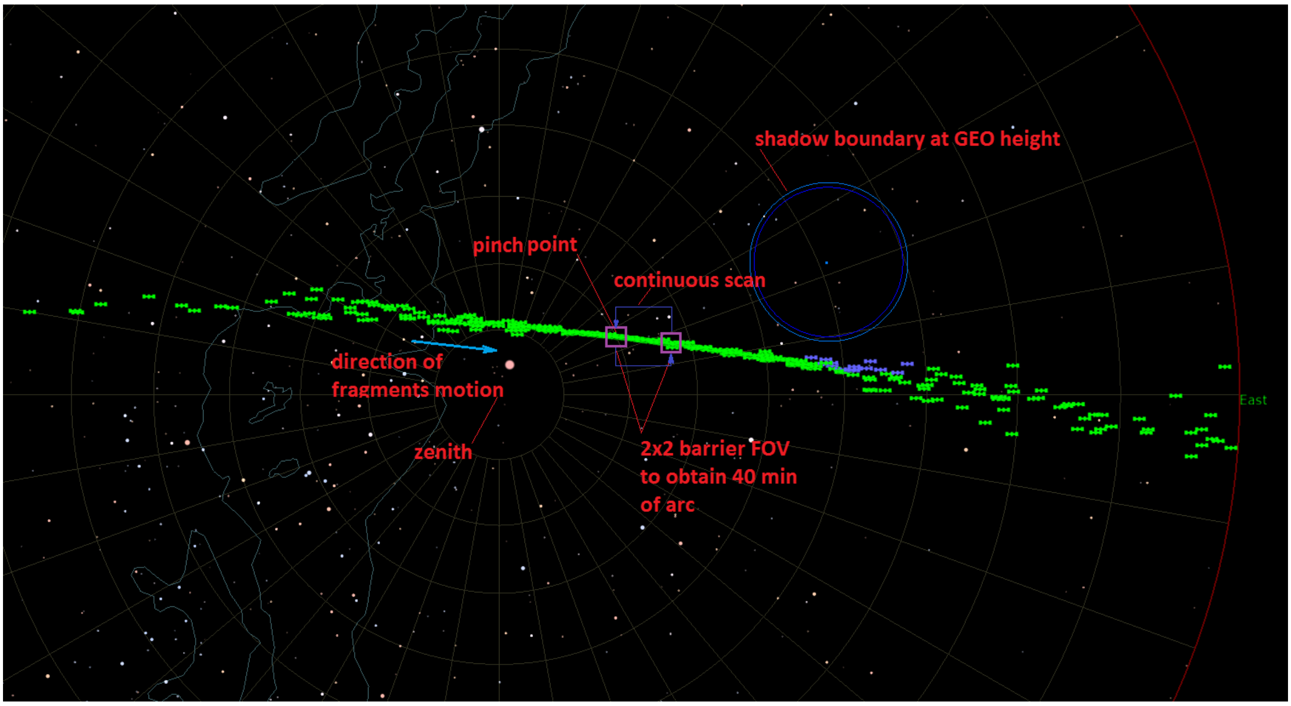


Figure 2. Illustration of the observation strategy applied at the ASC facility in Chile to detect and track fragmentation debris of the Centaur R/B (2014-055B)

Starting Aug 31, 2018 the observation strategy was applied at different sensors. This approach resulted in quick establishing reliable orbits for large number of fragments. By Sep 25, 2018 (i.e. less than 1 month after the fragmentation time) there were already 440 debris objects with well-established orbits (i.e. orbits determined from measurements collected at least at 3 different nights) catalogued by ASPOS OKP. This was an absolute record for the deep space fragmentations observed ever. Figure 3 shows rate of discovery of the fragments.

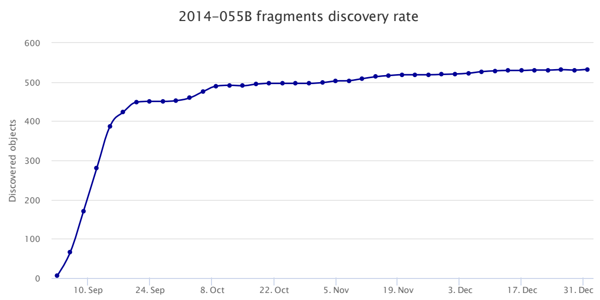


Figure 3. Rate of discovery of fragments of the Centaur R/B

It is interesting that some of fragments were observed with time intervals up to a few weeks. Nevertheless, the processing algorithm has merged appropriate separate tracks into individual orbits. Fig. 4 illustrates distribution of time intervals between the earliest and the latest measurement used in the OD after which object was declared as catalogued. Note that some objects were declared as catalogued after merging measurements at intervals of 2-3 months.

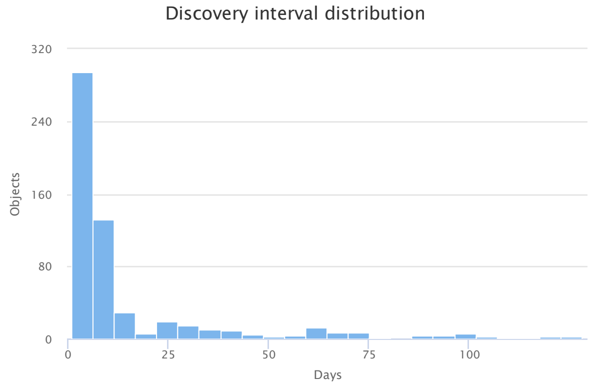
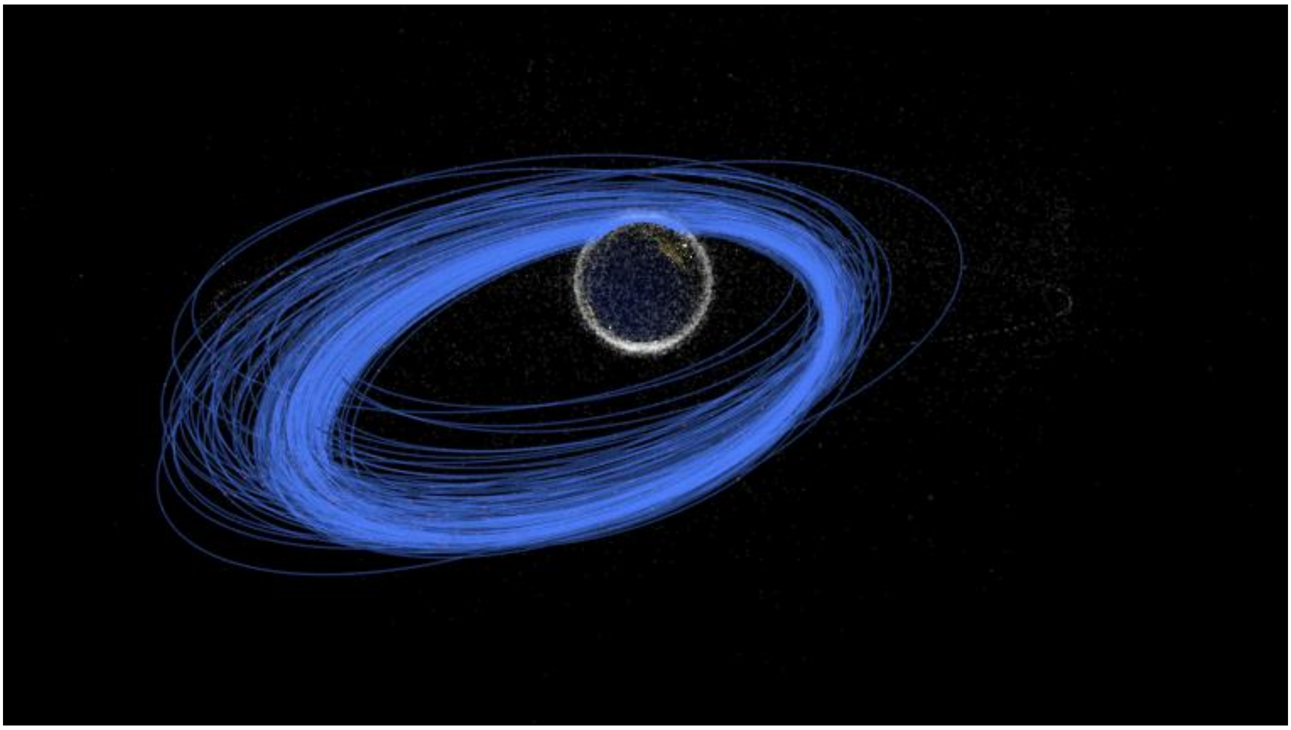


Figure 4. Discovery interval distribution

As of Jan 20, 2019, there were 572 fragments of the Centaur R/B (2014-055B) catalogued by ASPOS OKP. Neither of fragments were catalogued (at least, officially at SpaceTrack web-site) by the U.S. SSN. Trajectories of all catalogued fragments, as of Jan 20, 2019, are shown at Fig. 5.



Fiure. 5. Trajectories of fragments as of Jan 20, 2019

Due to evolution of orbits of fragments conditions of visibility of the near-apogee pinch point were changing continuously. Therefore, different portions of the ‘belt’ formed by the orbits of fragments in the inertial space were observed. Fig. 5-8 illustrate which parts of the ‘belt’ were observed in Sep, Oct, Nov and Dec.

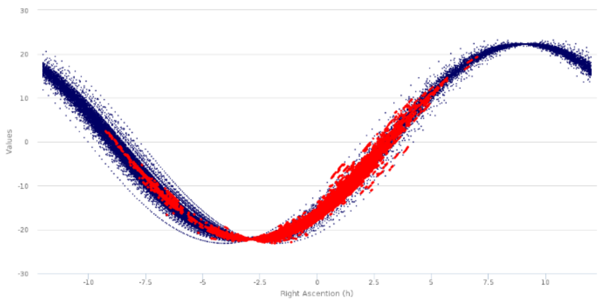


Figure 6. Observed parts (red dots) of the fragment's trajectories in Sep 2018

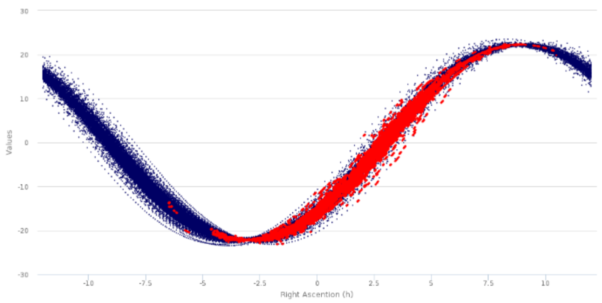


Figure 7. Observed parts (red dots) of the fragment's trajectories in Oct 2018

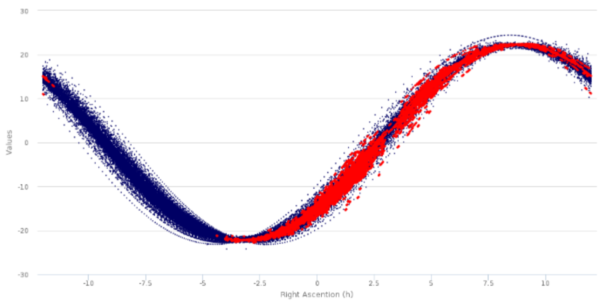


Figure. 8. Observed parts (red dots) of the fragment's trajectories in Nov 2018

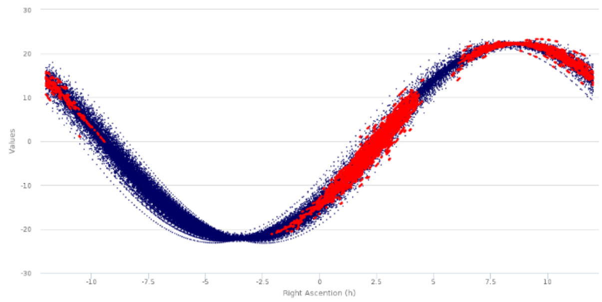


Figure 9. Observed parts (red dots) of the fragment's trajectories in Dec 2018

It should be noticed that there are two pinch points: one at near-apogee area (low declination) and other at near-perigee area (high declination). The first one is better for the purposes of conducting survey in local zone due to much smaller angular velocities of the fragments. But the visibility conditions of the near-apogee pinch point were getting worse with time due to two circumstances. The first one was shifting the near-apogee pinch point area towards the daylight time and thus increasing the phase angle (Fig. 10) that were making observation of very faint objects problematic and even not possible at all. The second one was increasing dispersion of trajectories in cross-track direction (Fig. 11) that required to cover larger areas of the celestial sphere. Considering this situation, the only option was to organize surveys and follow-up observations in the vicinity of the near-perigee pinch point. In general, it required involvement either telescopes of the same aperture that were used for initial detection of fragments but with larger field of view in order to provide for possibility of covering larger fields or telescopes with larger aperture in order to minimize required exposure time.

Due to very dense flux of the fragmentation debris through the telescope FOV (Fig. 12) the observation strategy was combining follow-up tracking and local zone survey techniques.

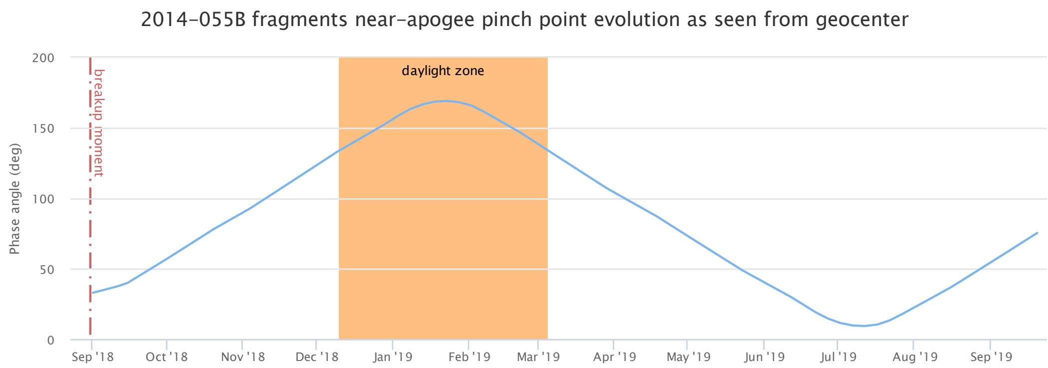


Figure 10. Changing the phase angle in the vicinity of the near-apogee pinch point.

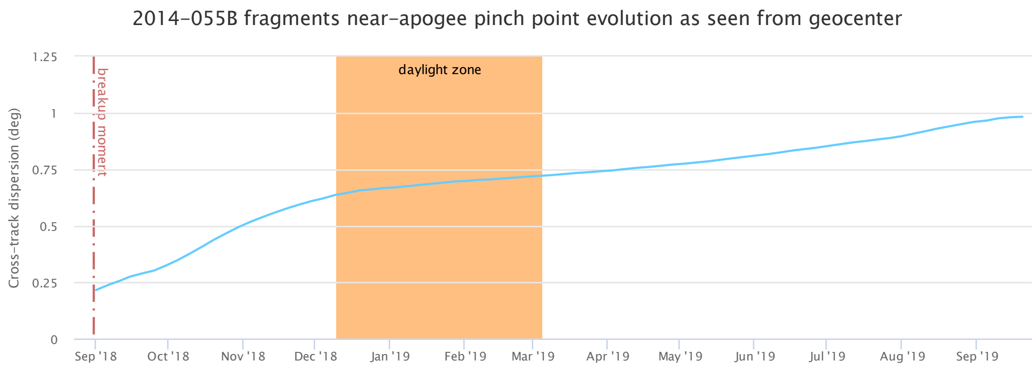


Figure 11. Changing the cross-track dispersion of trajectories of fragments in the vicinity of the near-apogee pinch point.

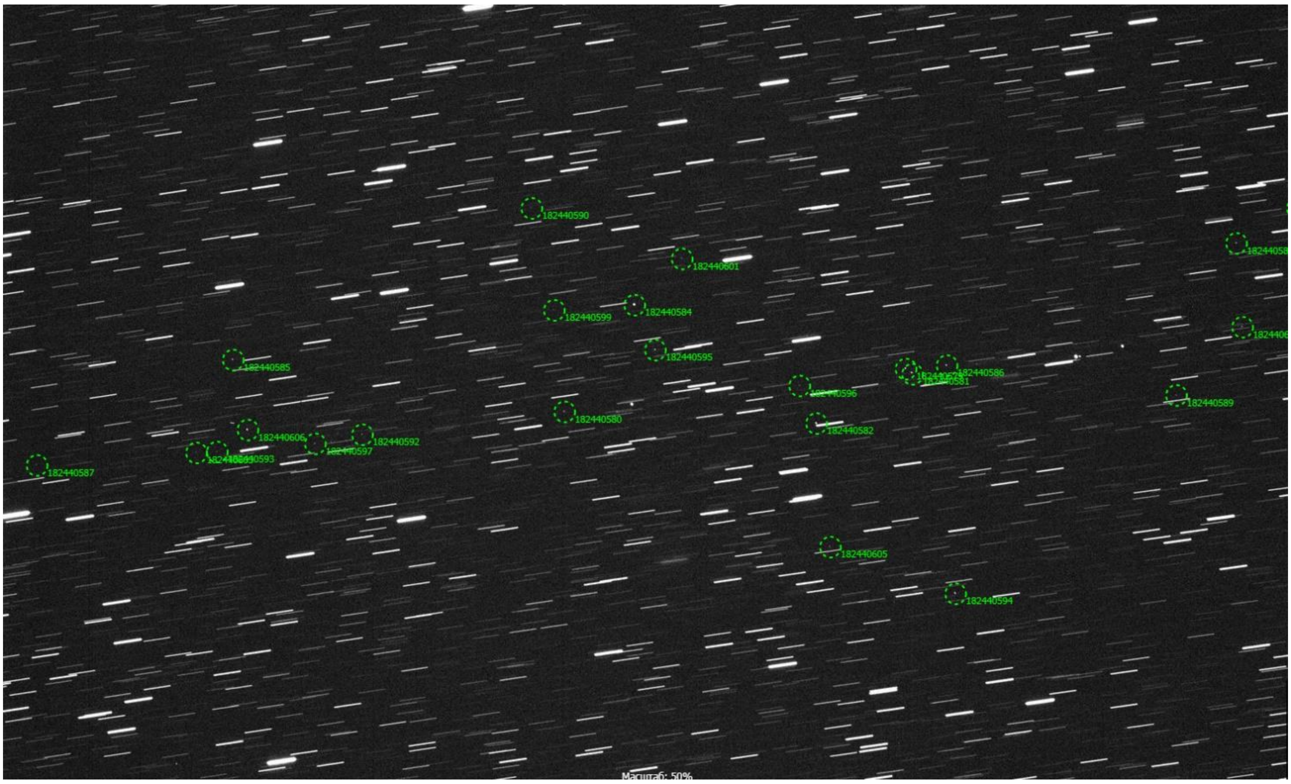


Figure 12. Typical field with numerous fragmentation debris as seen early days after the event

5 CONCLUSION

Since Jan 1, 2016 when ASPOS OKP was put in a full operation mode Astronomical Scientific Center continuously works on improvement of algorithms for building up efficient observation strategies at various situations. Thanks to these efforts the number of newly detected objects is growing fast as well as the number of objects recovered after they are being lost. Dedicated ASPOS OKP optical facilities and contributing facilities by ASC were able to catalogue several hundred fragmentation debris in GTO during period of just 1 month after the fragmentation of the Centaur R/B (2014-055B) on Aug 30, 2018. Such result is achieved for the first time in the history of monitoring deep space objects.

Continuously growing number of discovered space debris objects at high geocentric orbits requires thorough analysis of the ways of the future development both observation instruments and algorithms of observation scheduling and measurements processing.