ESA Optical Surveys to Characterize Recent Fragmentation Events in GEO and HEO

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ABSTRACT

Two major fragmentation events in GEO and HEO were observed in 2018. Based on measurements of the International Scientific Optical Network (ISON) and the Roscosmos Automated Warning System on Hazardous Situations in Outer Space (ASPOS OKP) a fragmentation of the Titan 3C Transtage 1969-013B, SSN #3692 on February 28, 2018 was identified. More than 100 objects detected by optical instruments operated by ASPOS OKP, the Astronomical Scientific Center, ISON, ISTP RAS and other Russian scientific and research organizations could be clearly identified as fragmentation debris related to this event. Another massive fragmentation event in HEO related to the Atlas Centaur upper stage 2014-055B, SSN #40209, which occurred on August 30, was identified based on the same data sources. Many of the fragment of this event are crossing the operational GEO region. In March and April 2019 two additional breakup events of Atlas Centaur upper stages took place.

Since October 2018 ESA is performing a coordinated survey campaign using its 1-m telescope at the OGS, Tenerife, complemented by sensors of the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald, Switzerland. The paper will describe the development of the survey strategy to search for additional fragments of the two mentioned events, the execution of the actual observation campaign including the handover of newly discovered objects to other sensors and the subsequent follow-up observations, and the main results of and lessons learned from this campaign.

1. INTRODUCTION

Since more than 20 years ESA is performing regular and ad hoc optical survey and tracking campaigns to detect and characterize space debris in high-altitude orbits. The main objectives of this program are to:

- maintain and validate space debris environment models, in particular ESA's Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) model [1];
- support resolving spacecraft contingencies, requiring analysis of physical integrity, orbit and attitude of the object;
- provide independent tracking and orbit improvement for conjunction assessment, for both objects involved in a predicted close conjunction;
- support tracking during re-entry of risk object, in particular for objects on highly elliptical orbits.

The Astronomical Institute of the University of Bern (AIUB) is executing this observation program on behalf of ESA by regularly conducting survey observations with ESA's 1m telescope at the OGS in Tenerife, Spain, by performing follow-up observation to establish 6-parameter orbits of debris objects, and by dedicated tracking campaigns to improve the orbits for different purposes including the estimation of area-to-mass rations. The latter two task are supported by observations from sensors of the Swiss Optical Ground Station and Geodynamics Observatory (SwissOGS) (see Figure 1).

A typical result from the monitoring observations at the OGS are discoveries of objects, which do not correlate with the ESA DISCOS system. For these objects near real-time follow-up observations are performed allowing to determine 6-parameter orbits. A subset of these objects is then maintained in a catalogue by regularly tracking them. An example of these results used to validate the MASTER model is provide in Figure 2 and Figure 3. The "clouds" seen in Figure 3 are actually indicating fragmentation events.

Figure 1: Sensors used in ESA/AIUB space debris observation campaigns. Clockwise from top left: ESA 1m telescope at the OGS in Tenerife, 0.2m ZimSMART telescope, 2x0.4m wide field ZimTWIN, 0.8m ZimMAIN, and 1m ZIMLAT telescope. The latter four are located at the SwissOGS.

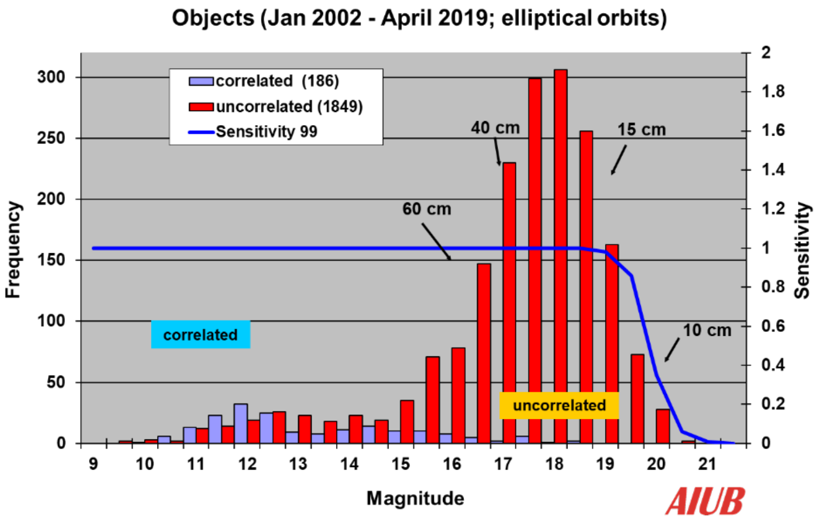


Figure 2: Magnitude Histogram of objects discovered during ESA statistical surveys of the GEO region (correlation was performed with the TLEs from ESA's DISCOS).

AIUB has long-standing scientific collaborations with the International Scientific Optical Network (ISON) operated by the Keldysh Institute of Applied Mathematics, Moscow and the Astronomical Scientific Center, Moscow, and is regularly sharing observation data with them. Russian colleagues timely informed AIUB/ESA after the following two events:

- a fragmentation of the Titan 3C Transtage 1969-013B, SSN #3692 on February 28, 2018, and
- a massive fragmentation event in HEO related to the Atlas Centaur upper stage 2014-055B, SSN #40209, which occurred on August 30.

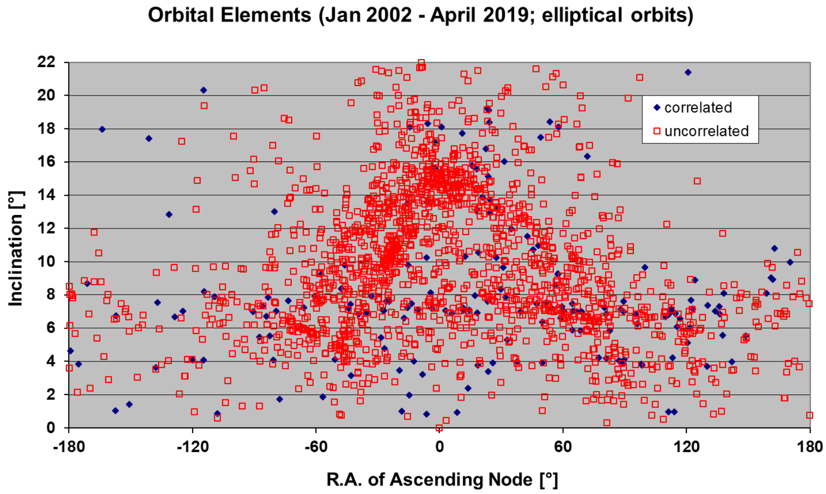


Figure 3: Orbital planes of objects discovered during ESA statistical surveys of the GEO region (correlation was performed with the DISCOS TLE catalogue).

The events were identified in the data collected by optical sensors operated by ASPOS OKP [2], the Astronomical Scientific Center, ISON, ISTP RAS and other Russian scientific and research organizations. By the end of September 2018, there were more than 150 fragments with well determined orbits from the Transtage breakup recorded. 65% of these objects are crossing the protected GEO region. At this time almost 500 fragments from the Centaur upper stage were tracked by the Russian sensors, which corresponded to an 25% increase of the population of objects tracked in this orbital region.

At this point ESA decided to perform dedicated campaigns to search for fragments of these two breakup events and dedicated 13 observation nights of the OGS telescope in October 2018 for this purpose.

On March 26, 2019, Vladimir Agapov from the Astronomical Scientific Center informed the community about another fragmentation event of an Atlas Centaur upper stage (2009-047B, SSN #35816) discovered the night before. Two weeks later the Russian collogues discovered fragments, which they could associate with even another Atlas V Centaur upper stage (2018-079B, SSN #43652). Table 1 provides the main characteristics of the 4 mentioned breakup events.

	Titan 3C Transtage 17 1969-013B	Centaur upper stage 2014-055B	Centaur upper stage 2009-047B	Centaur upper stage 2018-079B
Orbit region	GEO	HEO	HEO	HEO
Date of fragmentation	Feb 28, 2018	Aug 30, 2018	Mar 24, 2019	Apr 6, 2019
Time in space	49 years	4 years	8.5 years	5 months
Fragments detected (June 2019)	>150	>590	>250	>250
Crossing GEO protected region	~65%	~27%	<<1%	~26%
dispersion in orbital period (min-max)	>600min	>500min	~3min	~280min

Table 1: Main Characteristics of the 4 fragmentation events discovered in GEO and HEO in 2018 and 2019.

2. PREPARATION OF OBSERVATION CAMPAIGN

The observation campaign was planned to consist primarily of survey observations at the OGS telescope combined with real-time follow-up observations with the same sensor and complemented by additional follow-up measurements using the 1m ZIMLAT telescope at the SwissOGS.

The survey fields were selected in a way to maximize the number of fragments in a specific orbital plane covered by the fields, and the tracking parameters were set to match the expected angular velocities of the objects (for details of the survey technique see [3]). The baseline for this selection were sets of orbital elements of fragments from both events provided by Vladimir Agapov.

Figure 4 shows, as an example, the geocentric apparent ephereides of 252 fragments of the Centaur upper stage breakup event. The pinch-point visible from the OGS is located at RA=20h48m / DE=-21°48', only 26° away from the perigee (20181001). The apparent velocities in right ascension of 252 fragments of the Centaur upper stage breakup event, defining the optimum tracking during the survey, are given in Figure 5. The red circle at about 15 arcseconds per second motion in RA indicates the search field position.

The selection of the survey fields for the fragments of the Transtage event was done by optimizing the coverage of the orbital poles of the fragment orbits by the survey field. Figure 6 shows a polar plot (RA/DEC) of debris orbits and the search field (03:45.0/+05:00) for the Transtage fragment survey (the field is covering all poles within the stripe indicated in the figure). The Transtage fragment cloud is indicated by the red ellipse.

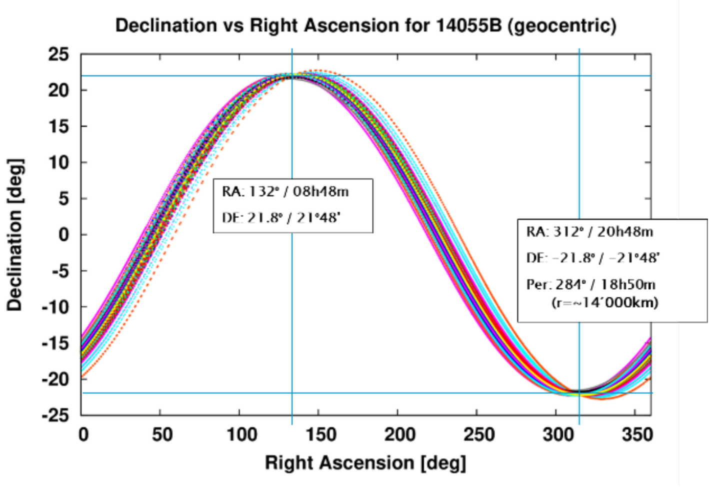


Figure 4: Geocentric apparent ephemerides of 252 fragments of the Centaur upper stage breakup event.

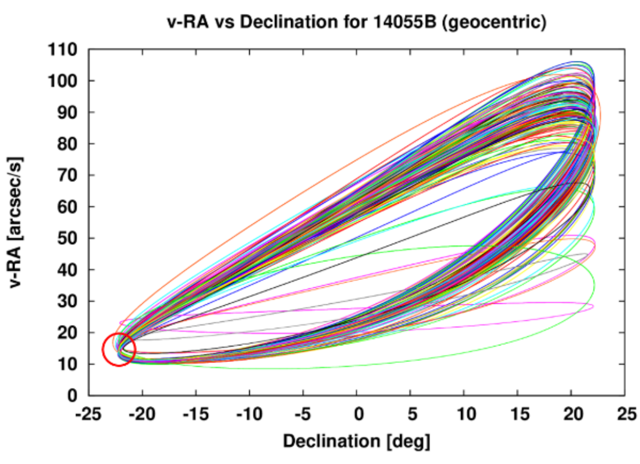


Figure 5: Apparent velocities in right ascension of 252 fragments of the Centaur upper stage breakup event. The red circle indicates the search field position.

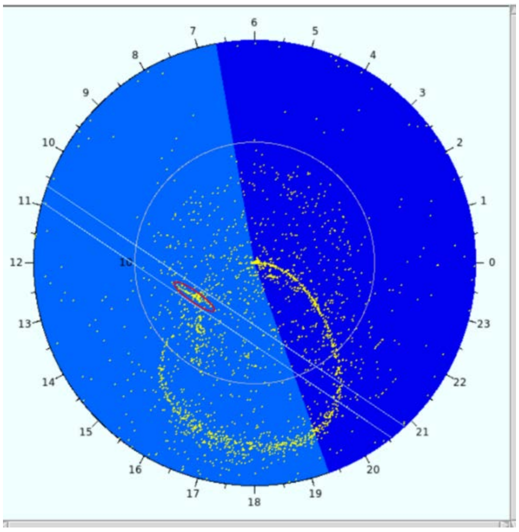


Figure 6: Polar plot (RA/DEC) of debris orbits and search field (03:45.0/+05:00) for the Transtage fragment survey (the field is covering all poles within the stripe indicated in the figure). The Transtage fragment cloud is indicated by the red ellipse.

3. OBSERVATION RESULTS

A first intense observation campaign was conducted at the OGS and at the Swiss OGS in October 2018. Out of the 13 planned observation nights, one was completely clouded and four had less than 4 hours of observations due to bad weather conditions.

The campaign resulted in 159 tracklets of "new" objects, i.e. tracklets that could not be correlated with orbits of known objects. All of these tracklets consist of two observations only. This is characteristic for tracklets stemming from survey observations of the OGS telescope and is due to the small field of view of the sensor. For most of the discovery tracklets real-time follow-up observations were attempted. These observations are planned based on circular orbits determined from the discovery tracklets (which corresponds mostly to a linear extrapolation of the apparent motion of the object) and the first follow-up executed about 15 minutes after discovery.

After being informed by Vladimir Agapov on the fragmentation event of 2009-047B on March 26, 2019, observations were scheduled for sensors at the SwissOGS the same day. Fist successful observations of dozens of fragments were acquired with ZimSMART and ZimMAIN in the evening of March 26. Figure 7 shows a frame taken by ZimTWIN on March 27 with dozens of fragments visible in the vicinity of the parent body.

A fragment survey at the OGS was scheduled for the nights from April 2 to 4 (note that the OGS is used by many different projects and thus only a few nights could be made available for this survey). As the fragments of this event showed very low dispersion in mean motion, we expected them still to be in close vicinity of the parent object and therefore decided to do an along-track survey (see Figure 8). From the three observation nights one was completely clouded and visibility constraints for the mentioned search region eventually resulted in one hour of survey for each of the remaining nights. The results of this campaign are provided in Table 2.

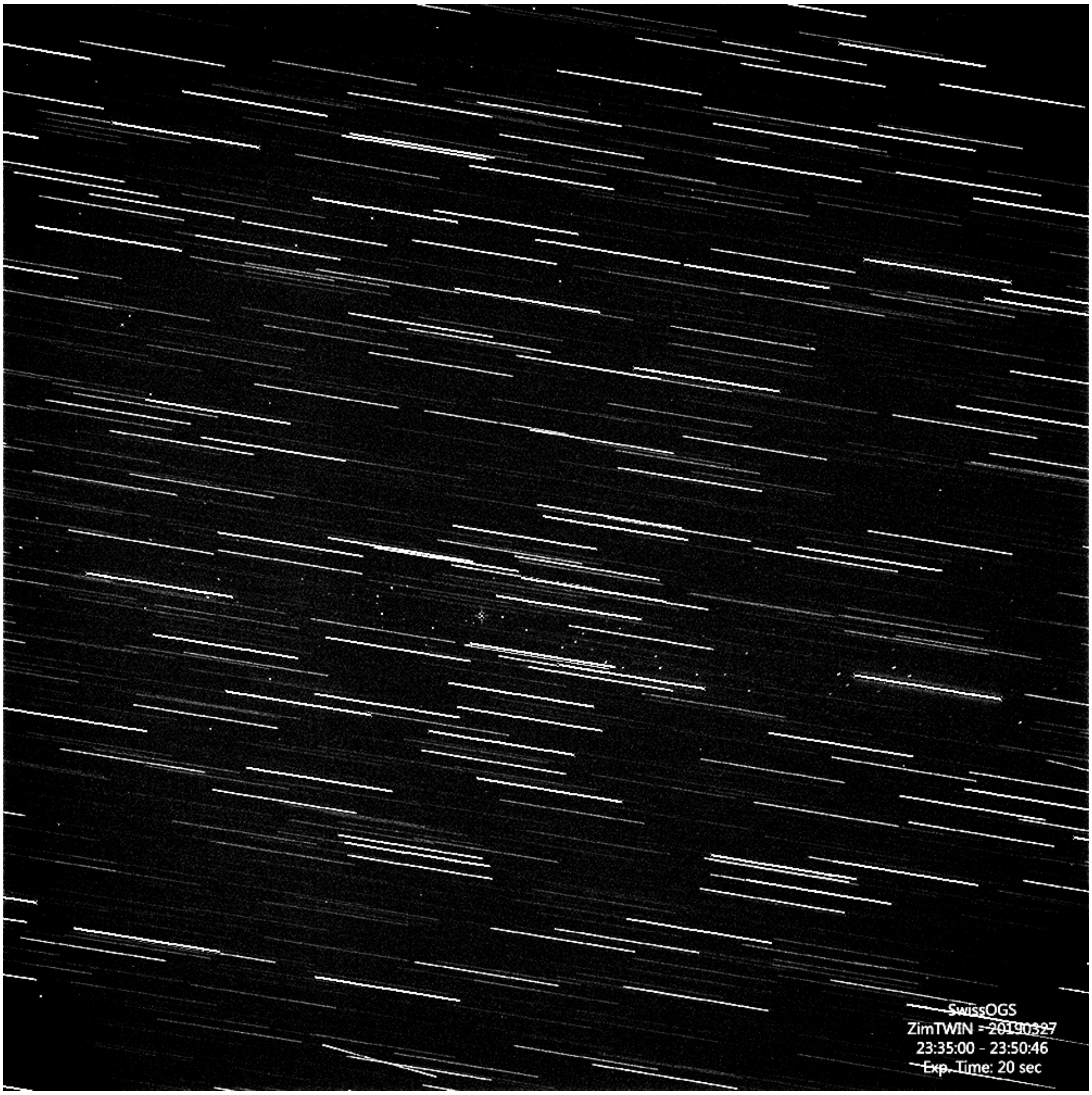
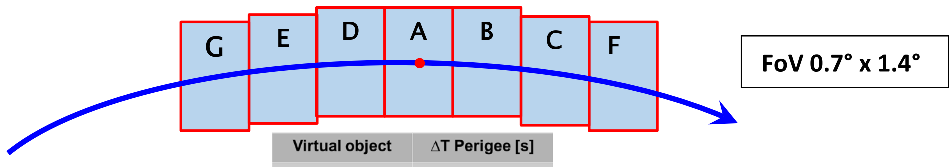


Figure 7: Observation of fragments from Atlas V Centaur upper stage 2009-047B (SSN #35816) by ZimTWIN on March 27. Stars are trailed as the tracking was optimized for the parent body. Dozens of fragments, still in the vicinity of the parent body, can be seen in this frame (field of view is about 4°x4°).



Virtual object	∆T Perigee [s]
09047AA (parent)	0
09047AB	61.55
09047AC	123.10
09047AD	-61.55
09047AE	-123.10
09047AF	184.65
09047AG	-184.65

Figure 8: "Along-track" search strategy for fragments of 2009-047B adopted in April 2019 campaign.

Virtual object	# of objects observed		
	2019.04.02 (1.2h)	2019.04.03	2019.04.04 (1h)
09047BG (behind)	31	Bad Night	15
09047BE	16		0
09047BD	0		2
09047BA (parent)	41		0
09047BB	36		6
09047BC	23		0
09047BF (in front)	26		Not observed

Table 2: Fragments observed during the April survey campaign at the OGS. The "virtual object correspond to the survey fields shown in Figure 8.

All objects discovered were handed over to the sensors at the SwissOGS, where follow-up observations were taken in order to determine and maintain their orbits. During the subsequent months these objects and additional fragments for which the orbits were provided by Vladimir Agapov were regularly observed by the SwissOGS and the results shared with our Russian partners. It is worth noting that the fragmentation of 2009-047B shows very unique characteristic. The delta-velocities of the fragments with respect to the parent object are extremely low and the magnitude distribution shows a distinct decrease for magnitudes fainter than 18mag (see Figure 9). The decrease is well below the sensitivity limit of the used sensor (blue line in Figure 9) and indicates that only a few very small fragments were produced during this event. This is in contradiction with all existing fragmentation models. Figure 10 shows the fragment clouds of the three breakup events in HEO as of June 2019. A comparison of the debris population in the public US TLE catalogue as of June 2019 with the same population augmented by the fragments from the three breakup events in HEO is given in Figure 11).

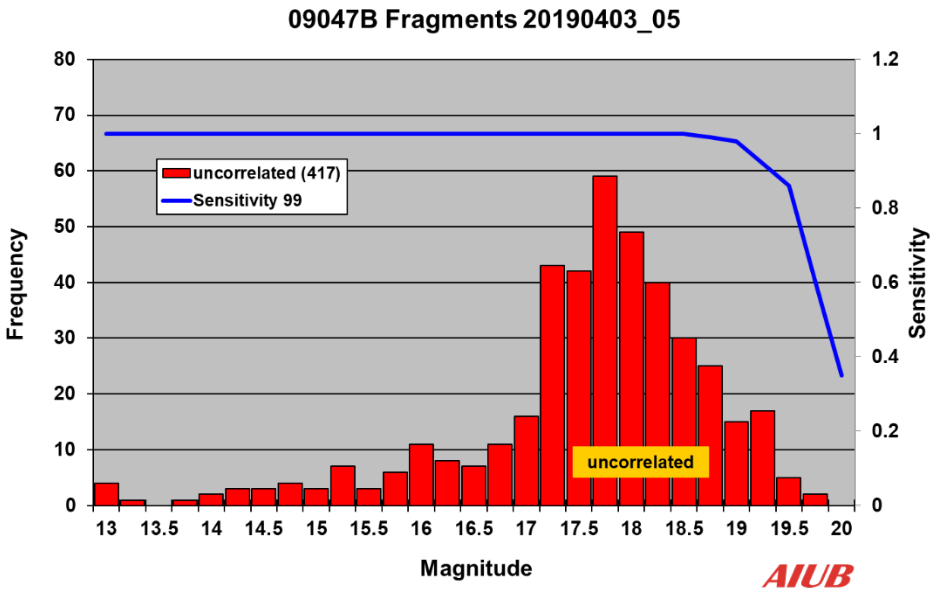


Figure 9: Magnitude distribution of the fragments of 2009-047B discovered in the April campaign at the OGS. The blue line indicates the sensitivity limit of the sensor.

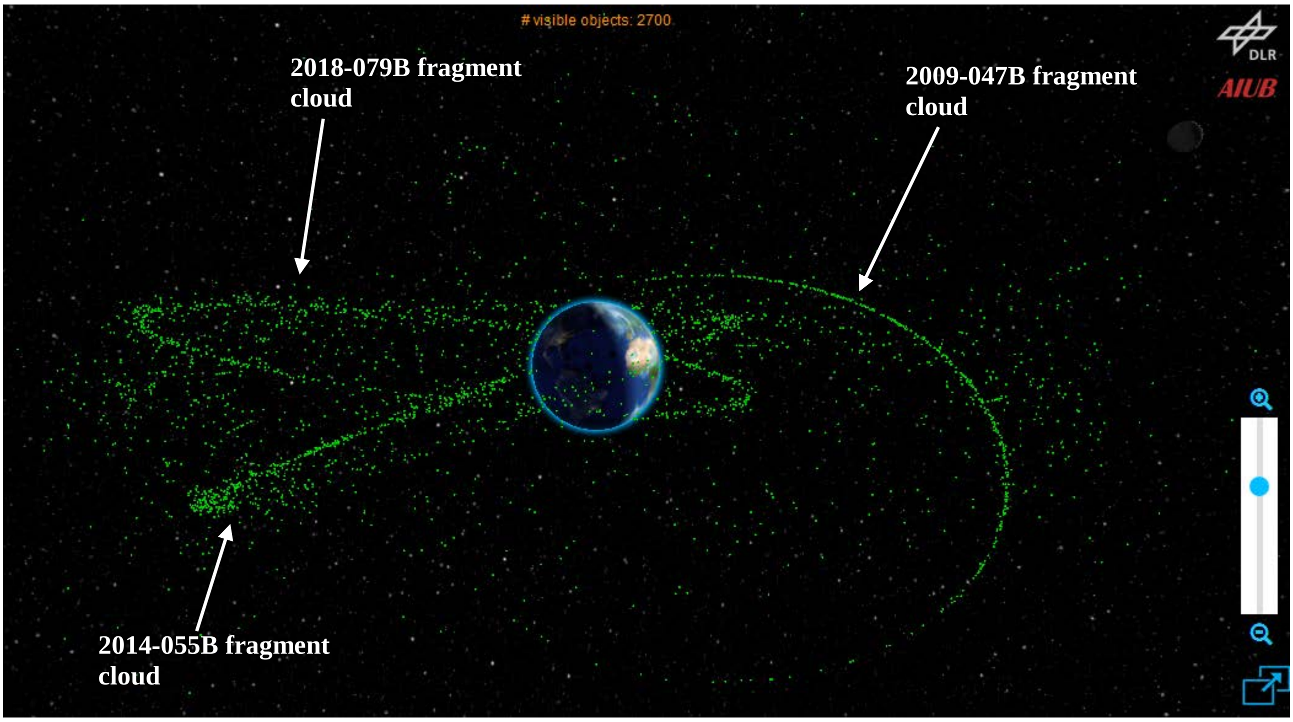


Figure 10: Fragments from the three break-up events in HEO orbits (as June 2019).

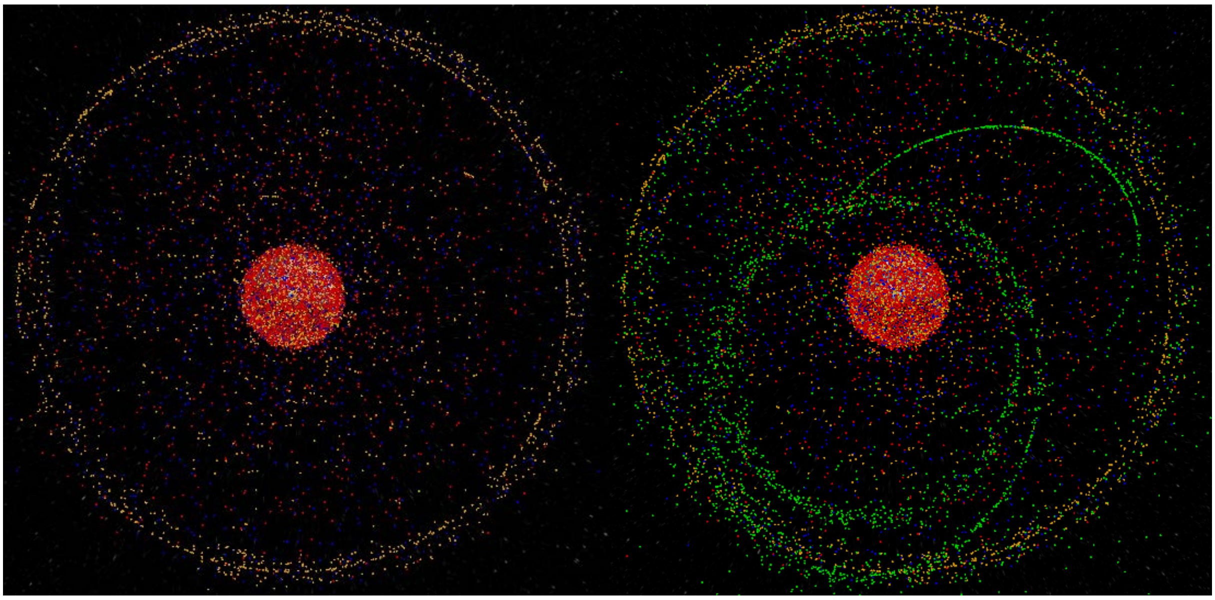


Figure 11: Debris population in the public US TLE catalogue as of June 2019 (left), and augmented by the fragments from the three breakup events in HEO (right).

4. SUMMARY

AIUB on behalf of ESA is performing regular optical surveys at the ESA OGS in Tenerife to monitor the space debris environment in high-altitude orbit regions. The resulting statistical data is used to validate models and to maintain a catalogue of high A/m-ratio objects. During 2018, two major breakup-events occurred in GEO and HEO. On February 28 a Titan 3C Transtage (1969-013B, SSN #3692) in GEO fragmented resulting in more than 150 debris pieces tracked by optical sensors operated by various Russian scientific and research organizations. The second event was a breakup of an Atlas V Centaur upper stage (2014-055B, SSN #40209) in HEO with more than 500 fragments tracked by the Russian sensors. In 2019 two additional Centaur upper stages in HEO suffered serious fragmentations resulting in more than 250 fragments tracked in both cases (2009-047B, SSN #35816 on March 24, 2018-079B, SSN #43652 on April 6). ESA performed dedicated survey and tracking campaigns to search for fragments of these events using the ESA OGS telescope supported by sensors of the SwissOGS. The surveys were planned based on information provided by Vladimir Agapov from the Astronomical Scientific Center in Moscow and the results shared with the Russian colleagues. The four fragmentation events increased the number of known fragments in GEO and HEO by more than 1000 with many of them crossing the GEO protected region.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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