RECENT DEVELOPMENTS AT THE SWISS OPTICAL GROUND STATION AND GEODYNAMICS OBSERVATORY ZIMMERWALD

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ABSTRACT

One of the main aim of the scientific research in the space debris field is the characterization of the space debris population. Questions like: how many debris objects are there, where are they, how big are they, what are they made of, and therefore how their population will evolve with time could not be answered without the help of measurements acquired with ground-based sensors.
The Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald (SwissOGS), owned and operated by the Astronomical Institute of the University of Bern (AIUB), has performed astronomical observations over the last 60 years. First, performing "classical" astronomical observations focusing on sky surveys to detect supernovae, minor planets, and comets; then, especially in the last 40 years, also performing satellite laser ranging measurements and passive optical observations to discover and characterize space debris.
In order to be autonomous in the discovery, the cataloguing, and the characterization of the space debris and to still fulfill the duties within the satellite laser ranging community, substantial extension of the SwissOGS sensor suite was needed. First, the historical Schmidt-Cassegrain telescope was substituted with the new 0.8-meter Zimmerwald Multiple Applications Instrument (ZimMAIN); then, two new domes were built and equipped with state of the art telescopes: the Zimmerwald Twin Widefield Instrument and the Zimmerwald Network Telescope (ZimTWIN and ZimNET, respectively). Nonetheless, the capabilities of the "old" telescopes are still under development and improvement.
In this paper, we will present the new capabilities of the SwissOGS for both, space debris and NEO research, showing the main aims and activities which can be performed through the use of the newly implemented telescope systems. Then first results and performance figures of the new telescopes will be shown and finally, we will report on the current status and the recent improvements of the existing telescopes.

1 INTRODUCTION

In the space debris research, scientists try to find answers to questions like: how many space debris objects are there, where they are, how are they made of, and how their population will evolve with time. To answer this kind of questions a fundamental three step approach has to be performed. First, one has to discover space debris, then one has to know precisely where they are, and finally one has to characterize them. All these steps are actually performed by employing ground-based sensors such as optical telescopes. The Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald (SwissOGS) operated by the Astronomical Institute of the University of Bern (AIUB) has a world leading position in the space debris field of research. In particular, the AIUB is discovering, cataloguing, and characterizing space debris objects. Due to the high number of space debris objects, and to other projects which are employing the telescopes time, an improvement of the infrastructure was needed.
In this paper, we will present the current activities and projects running, in the space debris and Near-Earth Objects (NEO) fields, on the SwissOGS telescopes both the "old" and the newly installed ones. We will show the performances of all telescopes. First, we will describe the achievements obtained with the Zimmerwald Laser and Astrometry Telescope (ZIMLAT) focusing on all steps of space debris research and on the fusion of different observation techniques as fast imaging and satellite laser ranging (SLR). We will then show the performance of the Zimmerwald Small Aperture Robotic Telescope (ZimSMART) which built a huge portion of the GEO space debris catalog of AIUB. We will finally describe the newly implemented instruments, their capabilities, their contributions to the space debris results, and the preliminary results obtained during the first months of the test phase.

2 ZIMLAT

The Zimmerwald Laser and Astrometry Telescope (ZIMLAT, in Figure 1) is today the oldest telescope of the SwissOGS. It was installed in 1997. Nevertheless, it is the most versatile instrument of the SwissOGS, its development is still ongoing and, as shown in paragraph 2.3 and extensively discussed in [1], was recently equipped with a tracking camera which can be used both for SLR and space debris observations.
This telescope is operated on a 24/7 basis and different projects are related to it. This telescope hosts both the satellite laser ranging (SLR) system and the astrometric equipment. The equipment of the SLR system is in the Coudé focus of the telescope; while the astrometric equipment, as can be seen in Figure 2, is hosted in the

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)

Nasmyth platform that contains both sCMOS and CCD cameras. These different camera types are employed in the different projects described in the following sections (2.1, 2.2, and 2.3).


Figure 1 The ZIMLAT Telescope.

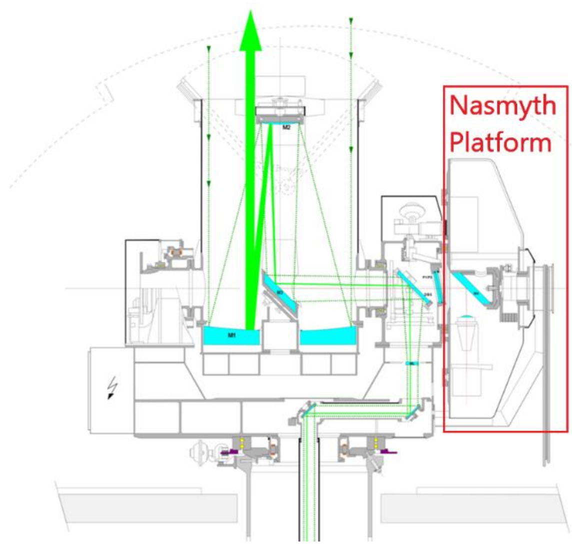

Figure 2 Sketch of ZIMLAT Telescope.

2.1 SPACE DEBRIS FOLLOW-UP & CHARACTERIZATION

While during daytime the telescope is totally employed for SLR observations, during the night time, the telescope time is shared equally between SLR and, what we generally call, CCD observations. The switch between SLR and CCD operations is completely automatic and it is handled by the telescope observation software, only the acquisition of the light curves is done manually by the night observer. In the automatic mode, the telescope acquires follow-ups of the target objects. These are categorized in campaigns which differ by priority and observation settings. The observation software of the telescope schedules automatically the object to be observed taking into account priorities, visibilities, and observations previously performed. A summary of the observations performed by the ZIMLAT telescope is shown in Figure 3 and Figure 4. In the first we have a summary of the number of pictures acquired by the telescope and the consequent number of extracted tracklets (series of triplets which contain observation epoch, right ascension, and declination). It must be said that this statistic does not take into account the pictures acquired during photometric series.

The main targets of the ZIMLAT telescope are faint high area to mass ratio (HAMR) space debris objects belonging to the AIUB internal space debris catalog which contains 85 objects (December 2018). We focus on this kind of targets because we want to exploit the 1m aperture of the telescope and since the telescope time, for space debris observation, is limited. As confirmed in Figure 4 the cutoff of the telescope using 12 seconds of exposure time is magnitude 19. On the other hand, the telescope field of view (FoV) is 26x26 arcmin, which requires accurate ephemeris to ensure the reobservability of the objects. Finally, the maximum in Figure 4 is due essentially to two main reasons: first, to monitor the telescope time bias, GNSS satellites are observed regularly; and second, the telescope is often used to support observation campaigns which focus on defunct satellites.

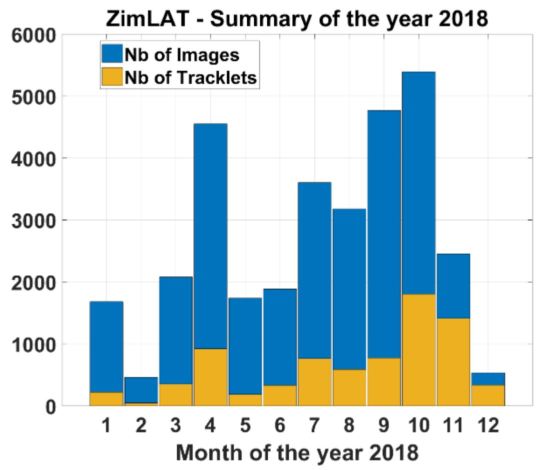

Figure 3 Summary of ZIMLAT observations until 12th December 2018.

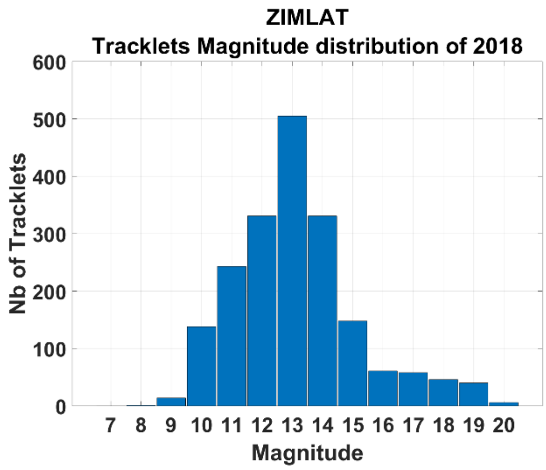

Figure 4 Magnitude distribution of the objects observed by ZIMLAT.

The ZIMLAT telescope is also used for space debris characterization. An average of 2 hours per night is dedicated to the acquisition of light curves. This allowed the AIUB to build a light curve database which contains more than 3500 light curves acquired since January 2007 for more than 520 objects [2]. The CCD camera of the ZIMLAT telescope is equipped with a Johnson-Cousins photometric system which allows us to analyze the "colors" of the observed object. This information can be used to characterize the nature of the objects in terms of material composition and age. The telescope hosts also a sCMOS camera which allows the acquisition of high resolution light curves with up to 30 fps (full frame). We can increase the time resolution of the light curve by using subframes acquisition. An example of a high-resolution light curve is shown in Figure 5 for the N1 LEO rocket stage (cospar 7818B) acquired at 67 fps. The resulting rotation period of the observed object is ~5 seconds.

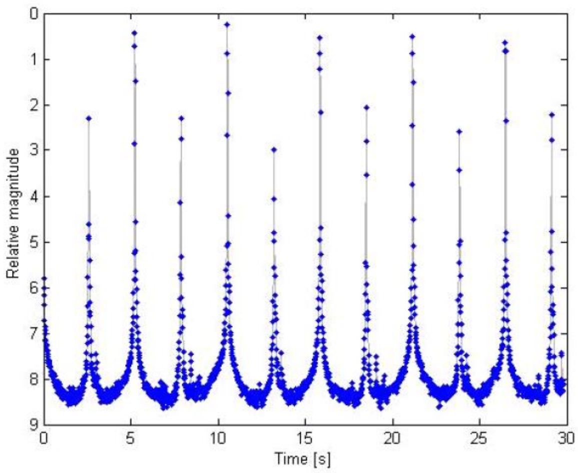

Figure 5 Light curve of N1 (78018B) rocket stage acquired by ZIMLAT.

2.2 NEO OBSERVATIONS

The ZIMLAT telescope is not only dedicated to SLR and space debris observations but also for "classical" astronomical observations. Observation campaigns were conducted on supernovae, double stars and near Earth objects (NEO). Figure 6shows a picture acquired during a special observation campaign carried out the night of the 11th October 2018 on the asteroid 2012 TC4 during its close approach to the Earth. 7 series of observations were performed over the 140 minutes of asteroid visibility window over the SwissOGS. For each observation series we extracted a light curve (summarized in Figure 7), which were then processed together to extract the rotation period of the asteroid. As for the space debris, we applied the phase reconstruction method [3] to reconstruct the phase of the fragmented light curve. The phase-reconstructed diagram of the 2012 TC4 is shown in Figure 8, both the extracted period of 735 ± 5 seconds (0.204 ± 0.001 hour), and the phase-reconstructed diagram are consistent with the values reported in [4, 5, 6].

Figure 6 Picture of the asteroid 2012 TC4 acquired with ZIMLAT.

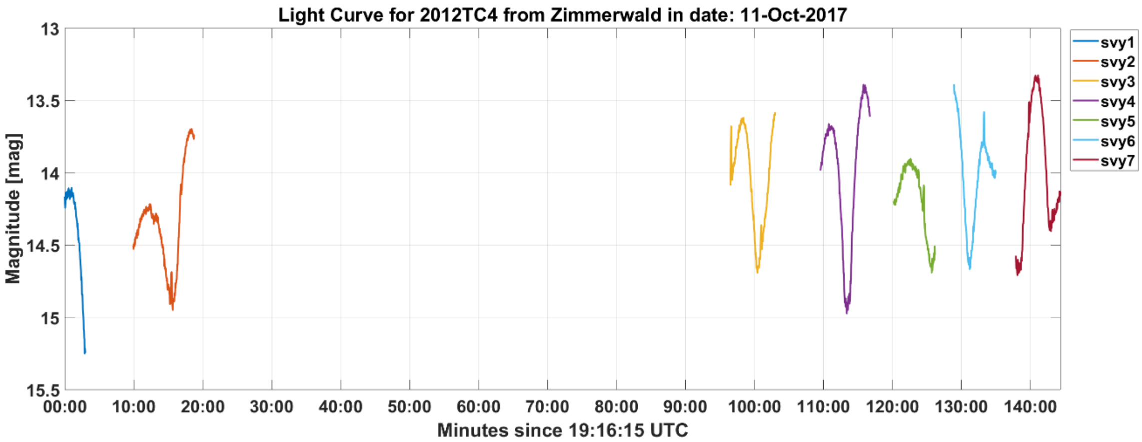

Figure 7Light curve of the asteroid 2012 TC4 observed with ZIMLAT the night of October 11th, 2017.

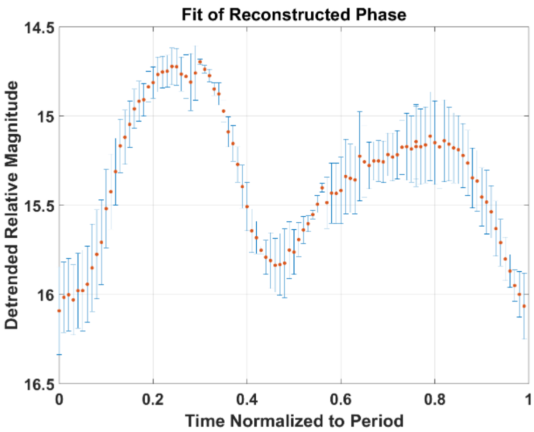

Figure 8 Reconstructed phase of the asteroid 2012 TC4.

2.3 NIGHT TRACKING CAMERA

The ZIMLAT telescope was recently equipped with a night-tracking camera. The main aim of the tracking camera is the correction of the offset in the pointing of the telescope given by ephemeris with poor accuracy. This correction is needed if we want to exploit the SLR system, which has a small FoV (~30 arcsec), to range to orbiting objects, either active satellites or space debris. For details about the integration of the tracking camera in the ZIMLAT system please refer to [7]. An example of the successful tracking of TOPEX satellite with the night-tracking camera is shown in Figure 9. The red cross represents the laser pointing direction, we can see how the correction given to the pointing direction of the telescope allowed to range successfully to the object.

The main advantage of the tracking camera is the possibility to perform both the orbit and the attitude determination of the object with a single observation session. In particular, as shown in Figure 10 and extensively discussed in [1], the outputs of the tracking camera include the angular position of the object in the sky, its distance, and its brightness. The azimuth and elevation, together with the ranges provided by SLR system, are for orbit determination purposes. While, the ranges and the light curve, extracted from the images stored by the camera, are for the attitude determination of the object. Figure 11 shows the phase reconstructed light curve and the estimated rotation period for TOPEX using the measurements provided by the tracking camera. Another advantage related to the employment of the tracking camera is the high temporal resolution of the measurements. In fact, the measurement rate given by the SLR system is 100 Hz; while the measurement rate of the angular and brightness observations is given by the frame rate of the camera which, being a CMOS sensor, provides up to 30 Hz full frame images. Finally, the tracking camera allows the extraction of angular measurements for the observed objects without performing an astrometric data reduction, which is very important when dealing with fast LEO objects and the FoV of the instrument is relatively small.

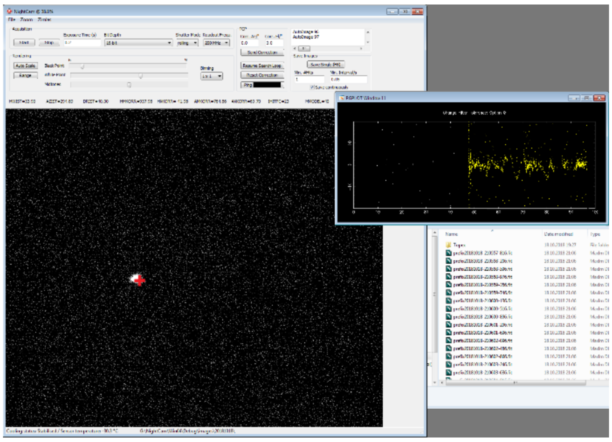

Figure 9 Screenshot of the night-tracking camera at work showing the successful range to TOPEX satellite.

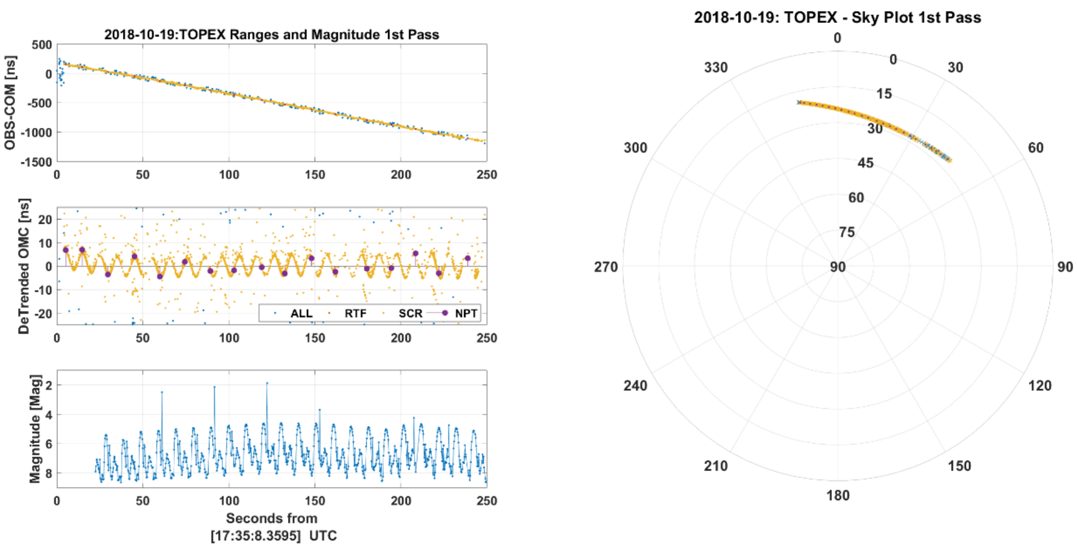

Figure 10 Output of a night-tracking camera observation session.

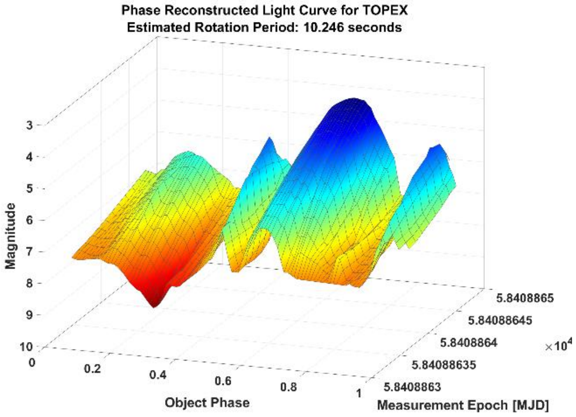

Figure 11TOPEX phase reconstructed light curve with measurements provided by the tracking camera.

3 ZIMSMART

The second oldest telescope is the Zimmerwald Small Aperture Robotic Telescope (ZimSMART, visible in Figure 12). This is a Newtonian astrograph of 20 cm aperture with a resulting 3.6x3.6 degree FoV. Due to the wide FoV, the main purpose of this telescope is the discovery of space debris in the GEO region. One of its main achievements is the buildup and the maintenance of the GEO space debris AIUB internal catalog. This telescope produces an average of ~1300 images and ~400 tracklets over 8 hours of observation time (based on September 2018 data). For this telescope a refurbishment of the mount is planned within the first quarter of 2019; this will allow us to increase the amount of measurements provided by the telescope. The observation summary for the year 2018 of this telescope is shown in Figure 13. Figure 14 shows the magnitude distribution of the object observed by the telescope. The cut off at 16 magnitude (1 meter-size object at GEO altitude) is due to the aperture size of the telescope and the standard exposure time used for the actual survey campaign, which is only 8 seconds. As for ZIMLAT, and all the other telescopes, also ZimSMART is acquiring regularly GNSS satellites which are used to estimate the telescope time bias and monitor the astrometric accuracy of the extracted tracklets.

Figure 12 The ZimSMART telescope.

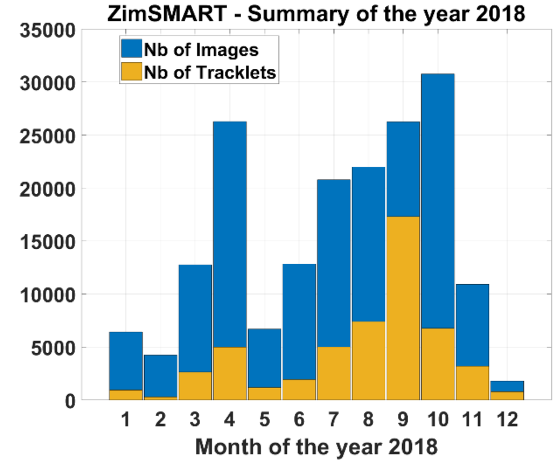

Figure 13 Summary of ZimSMART observations until 12th December 2018.

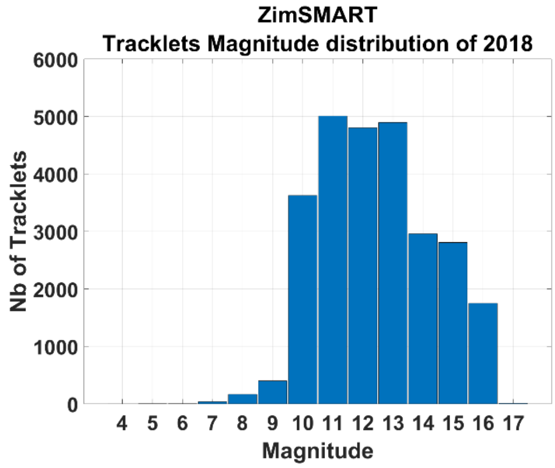

Figure 14 Magnitude distribution of the objects observed by ZimSMART.

4 ZIMMAIN

The Zimmerwald Multiple Applications Instrument (ZimMAIN, visible in Figure 15) is the first of the newly installed telescopes.

This is an 80 cm aperture Ritchey-Chrétien telescope with a resulting FoV of 22.5x22.5 arcmin, which make it suitable for follow-up observations. The follow-up observations, as for the ZIMLAT telescope, are used to improve and maintain the orbit of catalogued objects. The telescope is still under testing phase. The preliminary results, whose summary is reported in Figure 16, show that the telescope acquires an average of ~2200 images over 9.5 hours of observation time (based on October 2018 data). Figure 17 shows the magnitude distribution of the objects observed by ZimMAIN which is comparable to that of ZIMLAT visible in Figure 4. The center of the distribution is still ~13.5 magnitude because, being in test phase, we focus essentially on GNSS satellites to evaluate the pointing, the time offset and the astrometric accuracy of the telescope. Nevertheless, we have already employed it for follow-up of faint objects (18-19 magnitude) belonging to the AIUB space debris internal catalog. We expect an improvement of the sensitiveness and the performances in terms of number of tracklets in the first half of 2019 when we are going to substitute the actual camera with a more sensitive and larger CCD which will allow us to double the effective FoV.

Figure 15 The ZimMAIN telescope.

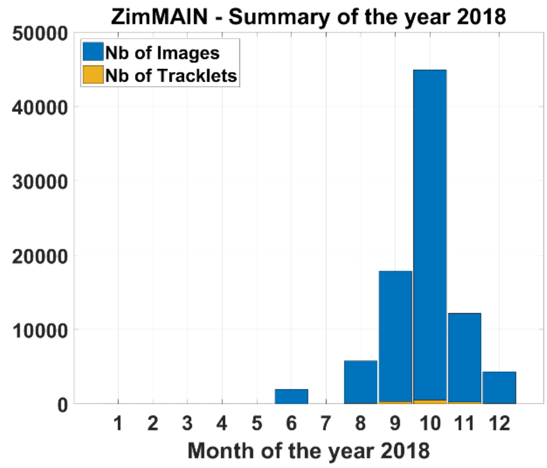

Figure 16 Summary of ZimMAIN observations until 12th December 2018.

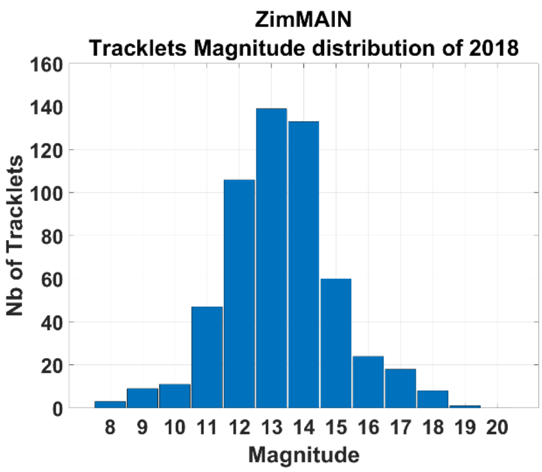

Figure 17 Magnitude distribution of the objects observed by ZimMAIN.

5 ZIMTWIN

Almost at the same time as the ZimMAIN, also the Zimmerwald Twin Wide-field Instrument (ZimTWIN, visible in Figure 18) was installed. The instrument consists of two ASA 16 inch f2.4 primary focus telescopes on the same mount. The primary focus system allows us to obtain a big FoV, which makes the telescope suitable for the discovery of space debris, and NEO. At the same time, the telescopes have also a filter unit which enables us to carry out even some characterization studies. Both kinds of activities will be described in the following paragraphs. Furthermore, the relative pointing of the two tubes can be adjusted according to the intended observations. Finally, it must be said that also this telescope is still in test phase, so the presented results are preliminary and will not show the full performance of this instrument.

Figure 18 The ZimTWIN telescope.

5.1 SURVEY

The primary focus system produces a FoV of 2.14x2.14 degree for each tube. The relative pointing of the tubes can be adjusted such that the cameras see a contiguous portion of the sky. This will produce a total FoV of 4.28x2.14 degree which is optimal for sky survey both for space debris and NEO. Being still in test phase, this telescope is currently used for GEO survey. The results reported in Figure 19 and Figure 20 refer to a GEO survey campaign performed using only one of the two tubes. One single tube produces ~1765 images every 9.5 hours of observations in survey mode (based on October 2018 data). For the moment, the main advantage w.r.t. the ZimSMART telescope is the increase of sensitiveness that allows the discovery of smaller objects. Figure 20 shows the classical peak at ~13 magnitude characteristic of satellite-dimension objects; at the same time, another peak is visible for ~17 magnitude characteristic of 0.4÷0.5 meter size objects at GEO altitude. Also for this telescope the standard exposure time used in survey mode is 8 seconds. It must be said that the “fall-off” of the telescope at 17 magnitude is due to the sensitivity limit given by the 40 cm aperture of the telescope for the used exposure time.

These are just preliminary results and need further investigations. As soon as we have completed the test phase the usage of the second tube will be implemented, then an optimization of the GEO survey strategy has to be performed in order to exploit the collaboration between ZimTWIN and ZimSMART. Finally, we will employ this telescope also for survey of space debris in the MEO regions mainly in GNSS and Molniya orbits.

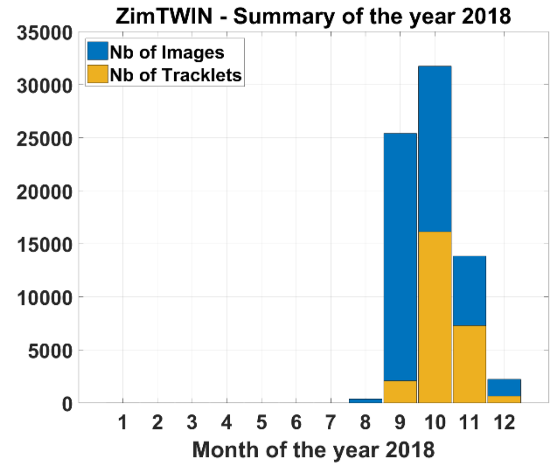

Figure 19 Summary of ZinTWIN observations until 12th December 2018.

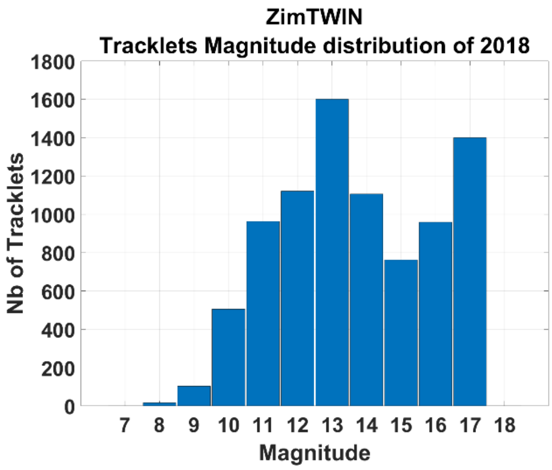

Figure 20 Magnitude distribution of the objects observed by ZimTWIN.

5.2 PHOTOMETRY

The two tubes of the ZimTWIN telescope can also be used to characterize space debris. In particular, by overlapping the FoV of the two tubes and equipping the tubes with different photometric filters, we can not only acquire color light curves, but we can also observe the same object with different filters at the same time under the same observation conditions. This allows us the extraction of the time varying color index which provides interesting information about the attitude of the object and its characterization, for further details please refer to [8]. The first tube of the ZimTWIN is currently equipped with the B and R filter of the Johnson-Cousins photometric system, while the second tube with the V filter. An observation campaign was carried out during the summer of 2018. Several synchronous color light curves were acquired for active satellites in the GEO region, for defunct Glonass satellites and for spent upper stages. An example of the synchronous light curves and the derived color index is reported in Figure 21 for a Delta 4 upper stage. It is very interesting to notice that the color index can be used to solve ambiguities in the light curve. While the light curve shows two brightness minima within one rotation period, the color index shows only one minimum. This could be used to discriminate which end of the rocket stage we are currently observing, either the edge or the nozzle.

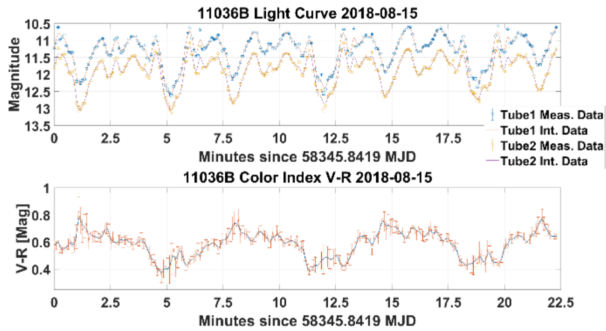

Figure 21 Extracted light curve and corresponding color index obtained for a Delta 4 rocket body (11036B) from ZimTWIN measurements.

6 ZIMNET

The last telescope present at the SwissOGS is the Zimmerwald Network Telescope (ZimNET, visible in Figure 22). This instrument is part of the SMARTnet project between the German Aerospace Center (DLR) and the AIUB. At the moment, it is at the SwissOGS for testing and validation purposes. After the completion of the test phase, the telescope will be shipped to its definitive location in Australia.

It consists of two different tubes, one Dall-Kirkham 50 cm aperture and a Newtonian 30 cm aperture respectively, on the same mount. The two tubes are used for the discovery and the follow-up of space debris objects. For further details about this instrument and the SMARTnet project, please refer to [9].

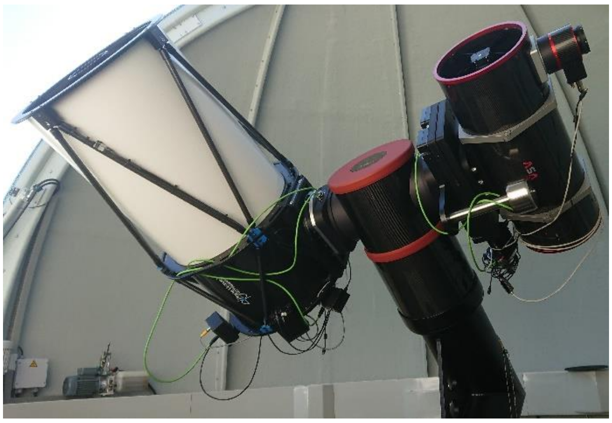

Figure 22 The ZimNET telescope.

7 SUMMARY

In this paper, we have shown the contributions of the telescopes at the SwissOGS in the space debris and NEO research. We proved the capabilities of observing NEO objects, and extracting their rotation period from fragmented light curves. We have shown how the employ of the night-tracking camera allows the real time correction of the a priori ephemeris with the goal of ranging to space debris objects with our SLR system. The tracking camera allows also the simultaneous acquisition of measurements, both for orbit and attitude determination, an example of the obtainable results was also reported. We presented the observation performances of the established telescopes in terms of objects discovery, orbit improvement, and object characterization. We then reported the preliminary results of the newly installed telescope systems. Finally, we have demonstrated the new capability of the SwissOGS connected to objects characterization given by the ZimTWIN telescope. The color index for a spent upper stage, obtained by the simultaneous acquisition of color light curves with different filters, was shown. The information contained in the color index could be used to solve the ambiguities in the light curve analysis, and employed for the attitude determination of a space debris. Although the preliminary results are good, there are several steps to be performed in the near future. First, we will substitute the CCD camera of the ZimMAIN to double the effective FoV on the camera and to increase its sensitiveness. Second, we will put into regular operation the second tube of the ZimTWIN telescope. We will implement the remote control for the relative pointing of the two tubes. Then, after the refurbishment of the mount of ZimSMART we will optimize the survey strategy by the simultaneous employ of the ZimSMART and ZimTWIN telescopes. Finally, we will employ these telescopes also for the discovery of space debris objects in MEO regions.

8 REFERENCES

[1] E. Cordelli, P. Schlatter, P. Lauber and T. Schildknecht, “Use of a night-tracking camera for characterization and orbit improvement of defunct spacecraft,” in *ESA NEO and Debris Detection Conference*, Darmstadt, Germany., 2019.

[2] A. Rachman, T. Schildknecht and A. Vananti, “Analysis of temporal evolution of debris objects rotation rates inside AIUB light curve database,” in *69th International Astronautical Congress (IAC)*, Bremen, Germany, 2018.

[3] E. Linder, J. Silha, T. Schildknecht and M. Hager, “Extraction of spin periods of space debris from optical light curves,” in *66th International Astronautical Congress (IAC)*, Jerusalem, Israel, 2015.

[4] A. B. Sonka, A. I. Gornea, S. Anghel and M. Birlan, “Photometric Observations of Near Earth Asteroid 2012 TC4,” *Romanian Astronomical Journal,* vol. 27, no. 3, pp. 223-231, 12 2017.

[5] C. E. Odden, J. C. Verhaegh, D. G. McCullough and J. W. Briggs, “Lightcurve Analysis for Near-Earth Asteroid 2012 TC4,” *The Minor Planet Bulletin,* vol. 40, no. 3, pp. 176-177, 2013.

[6] D. Polishook, “Fast Rotation of the NEA 2012 TC4 Indicates a Monolithic Structure,” *The Minor Planet Bulletin,* vol. 30, no. 1, pp. 42-43, 2013.

[7] E. Cordelli, P. Schlatter, P. Lauber and T. Schildknecht, “Use of a night-tracking camera for real time correction of the pointing of the SLR system,” in *21st International Workshop on Laser Ranging*, Canberra, Australia, 2018.

[8] E. Cordelli, P. Schlatter and T. Schildknecht, “Simultaneous multi-filter photometric characterization of space debris at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald,” in *Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS)*, Wailea, Hawaii, USA, 2018.

[9] H. Fiedler, J. Herzog, M. Prohaska and T. Schildknecht, “SMARTnet - An Update,” in *ESA NEO and Debris detection Conference*, Darmstadt, Germany, 2019.