Simultaneous Multi-Color Photometric Observations of Tumbling GLONASS Satellites

Thomas Schildknecht[(1)], A. Brönnimann[(1)], A. Vananti[(1)], J. Rodriguez[(1)]

[(1)]Astronomical Institute, University of Bern, Sidlerstr. 5, CH-3012 Bern, Switzerland
thomas.schildknecht@unibe.ch

ABSTRACT

The population of space debris increased drastically during the last years. Collisions involving massive objects may produce large number of fragments leading to significantly growth of the space debris population. An effective remediation measure in order to stabilize the population in LEO is therefore the active removal of large, massive space debris. In order to design missions to remove such objects, detailed information about their attitude states is required. One important property of an object targeted for removal is its spin period and spin axis orientation in a body-fixed frame. The same holds for missions intended to service uncontrolled spacecraft.

Non-resolving optical observations of the magnitude variations, so-called light curves, are a promising technique to determine rotation or tumbling rates and the orientations of the actual rotation axis of objects, as well as their temporal changes. Acquiring such observations as well as extracting attitude states from these measurements is challenging and requires sophisticated observations and processing techniques.

Over the past years, photometric observations of more than 60 decommissioned GLONASS satellites were acquired at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald, Switzerland. The tumbling rates derived from these measurements show complex behaviour over time. Determining the spin axis orientation in the body fixed and inertial frame turned out to be difficult without additional information. Simultaneous multi-colour observations performed with the Zimmerwald twin wide-field instrument ZimTWIN contain very promising complementary information. The paper will review the temporal evolution of the spin rates and will particularly focus on the new type of colour observations.

1 INTRODUCTION

The temporal variation of the magnitude of an object, the so-called light curve, is a traditional technique to determine the attitude motion of space objects. Light curves are commonly used in the astronomical community to determine physical characteristics of minor planets, namely their rotation rate, spin axis direction, shape, and surface properties. Artificial objects, on the other hand, have more complex shapes and a large variety of surface materials as compared to asteroids. Deriving the full attitude state of artificial objects from light curves, i.e., the orientation of the rotation axis and the spin rate in a body-fixed and in the inertial frame, is thus not a trivial task. In general, it is even impossible to derive these quantities from light curve data of a single observing site. Color information tuned out to be promising to solve some of the ambiguities related to the attitude determination [1].

The Astronomical Institute of the University of Bern (AIUB) is acquiring light curve observations since more than 25 years. Currently the data base contains 6740 light curves from 632 objects. Most of the observations were acquired with sensors of the Swiss Optical Ground Station and Geodynamics Observatory (SwissOGS) (see Fig. 1).

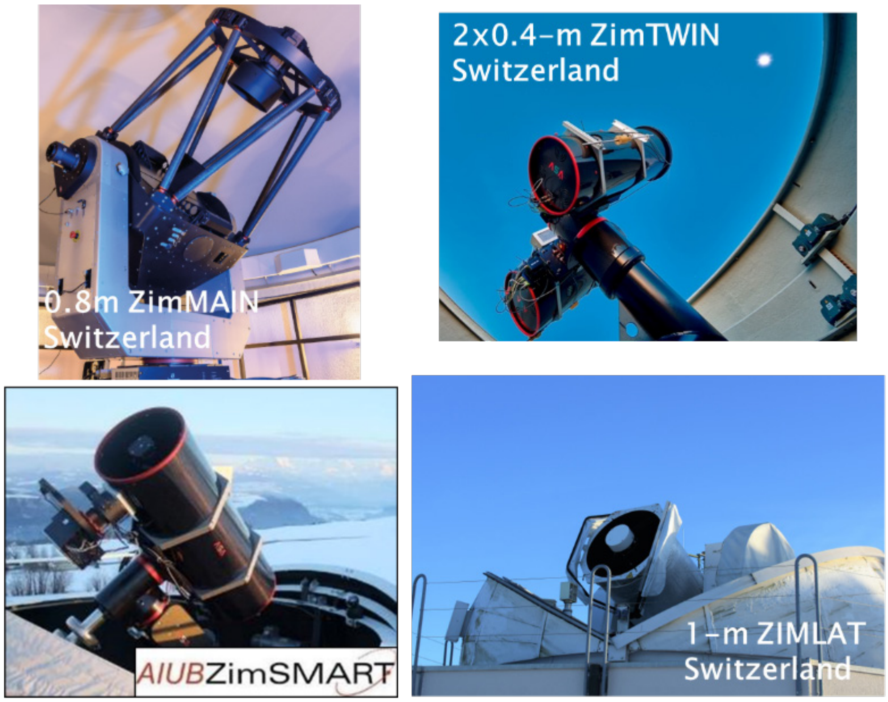


Fig. 1: Sensors of the SwissOGS used to acquire light curves. Clockwise from top left: 0.8m ZimMAIN, 2x0.4m wide field ZimTWIN, 1m ZIMLAT telescope, and 0.2m ZimSMART telescope.

Over the past years, photometric observations of more than 60 decommissioned GLONASS satellites were acquired on a regular basis. Most of these inactive satellites are rotating with periods ranging from a few seconds to a few minutes and 27 show oscillating patterns in their spin period evolution [2], [3], [4]. In order to model this evolution, which is driven by solar radiation pressure, a better understanding of the attitude state (rotation axis) is required.

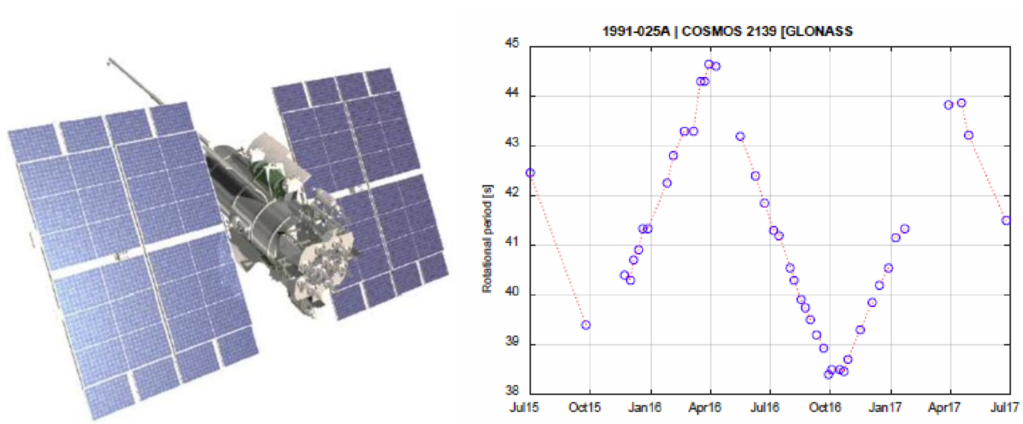


Fig. 2: Fist-generation GLONASS "Uragan" Satellite (left), spin period evolution of COSMOS 2139 (right).

2 SIMULTANEOUS MULTI-COLOR LIGHT CURVE OBSERVATIONS

Observations were conducted with the ZimTWIN telescope allowing to observe the same object simultaneously in two color bands. The telescopes are equipped with FLI Proline PL16803 cameras with KAF-16803 CCD detectors and a set of high-transmission Bessel BVR filters (Fig. 3). The red (R) and blue (B) filters are placed in tube 1, and the visual (V) filter in tube 2. A particular challenge was to make sure that the exposures are taken quasi-simultaneously and that the reference clocks for the time tagging of the two cameras were synchronized to much better than one second.

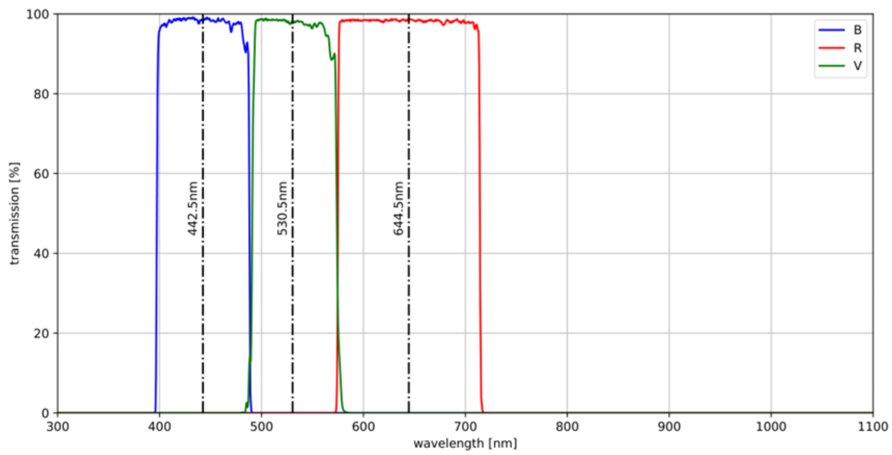


Fig. 3: Transmission spectrum of the B-, R-, and V-Bessel filters.

3 DATA REDUCTION

The classical image reduction steps were performed using master frames for the bias, the dark and the flatfield. Instrumental brightness of the target objects was derived by means of aperture photometry. The resulting light curves show some trends which may stem from properties of the objects, changing illumination conditions, varying distance between the objects and the observer, and atmospheric extinction (Fig. 4). Remaining trends after the correction for the extinction and the changing distance were fitted with a straight line and corrected for each color separately. No correction for the changing illumination conditions (phase angle) was applied as this would require a priori knowledge of the spin axis orientation and detailed information on the surface characteristics.

The detrended data is then used to estimate the rotation period and generate phase-folded phase diagrams using a phase-dispersion minimization algorithm (Fig. 5). Fig. 6 shows the final phase diagrams for all three colors for object 00063A on February 13, 2023.

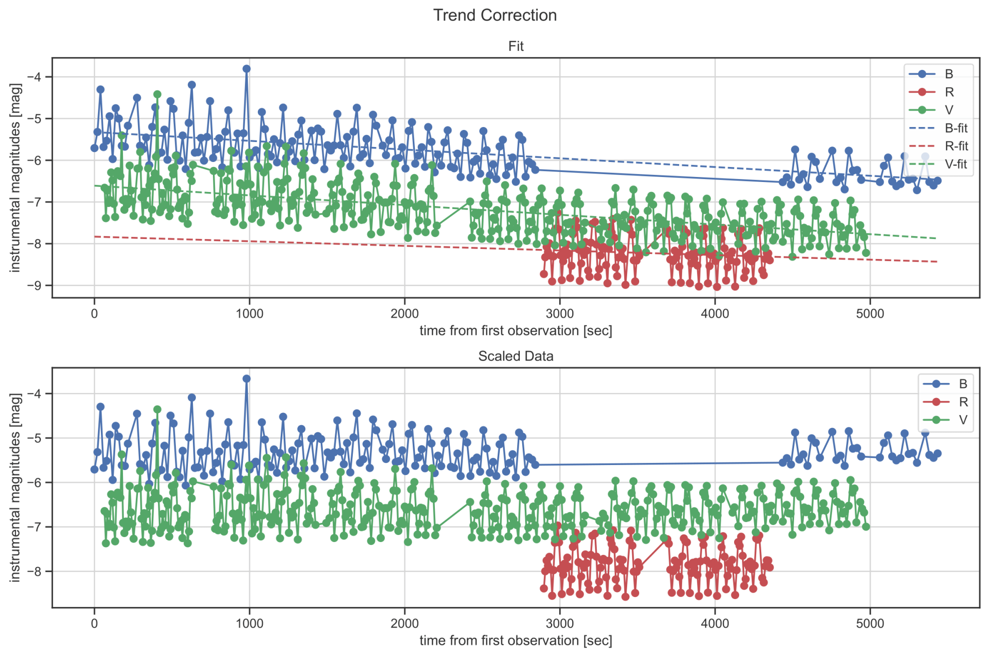


Fig. 4: Light curve measurements for three colors of the target object 00063A on November 10, 2022 (top). B and R were measured consecutively (filters in the same tube) while V is measured throughout the entire pass. Remaining trends after the correction for the extinction and the changing distance were fitted with a straight line and corrected for each color separately (bottom).

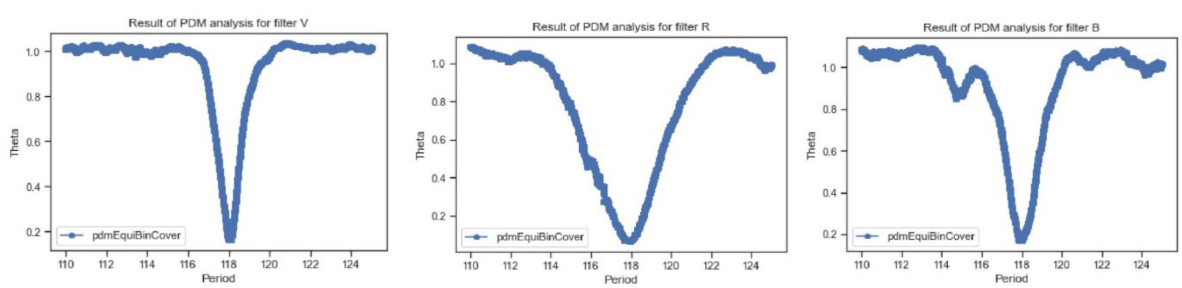


Fig. 5: Example of the phase dispersion θ for different rotation periods of the target object 00063A on November 10, 2022.

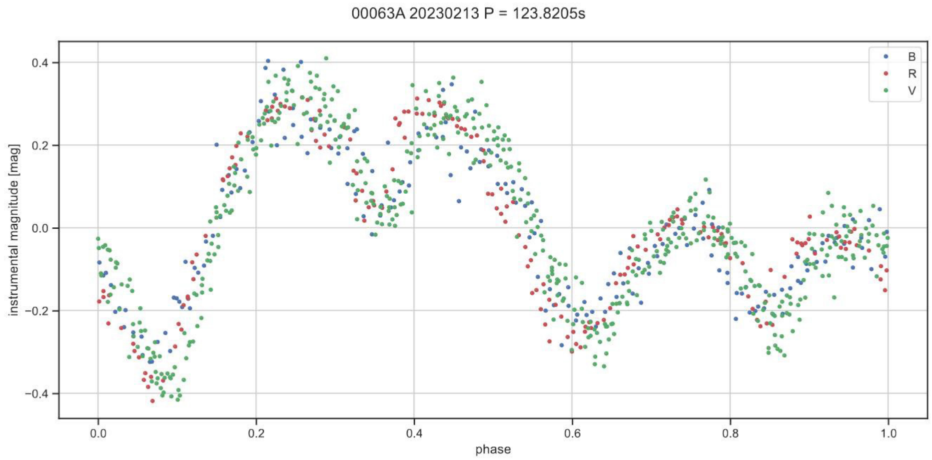


Fig. 6: Example of the phase diagrams of the target object 00063A on February 13, 2023.

4 RESULTS

Finally, differences between two passband, so-called color indices, can be formed. Light curves of these color indices directly show the change in colors during the rotation of the object. Fig. 7 shows light curves for the color indices B-V, V-R, B-R for object 00063A on February 13, 2023 (cf. Fig. 6). Negative color indices indicate blue and positive color indices red colors, respectively. Analyzing, e.g., the B-V color light curve shows, that magnitude maxima (i.e., brightness minima) in the phase-folded light curve (Fig. 6) correspond to maxima in the color index (i.e., red color). This result is consistent with the hypothesis that the brightness maxima in the light curve are produced by the large solar cells, which are expected to be rather blue, and that the minima correspond to situations where we see mostly the bus (rather red). The fact that all brightness maxima are blue would indicate that both, the front, and the back sides of the solar panels are rather blue. Although this is the case for most observations, there are cases where only two out of the four maxima are blue. Fig. 8 shows an example where only the first and the third brightness maximum are blue. This underlines the difficulty to assign light curve features to features of the object. In some cases all four brightness peaks might be produced by the solar panels, e.g. if we assume that the two panels are not any more aligned with each other. In other cases two of the maxima may stem from bright features of the spacecraft bus (thermal radiator doors? cf. Fig. 2).

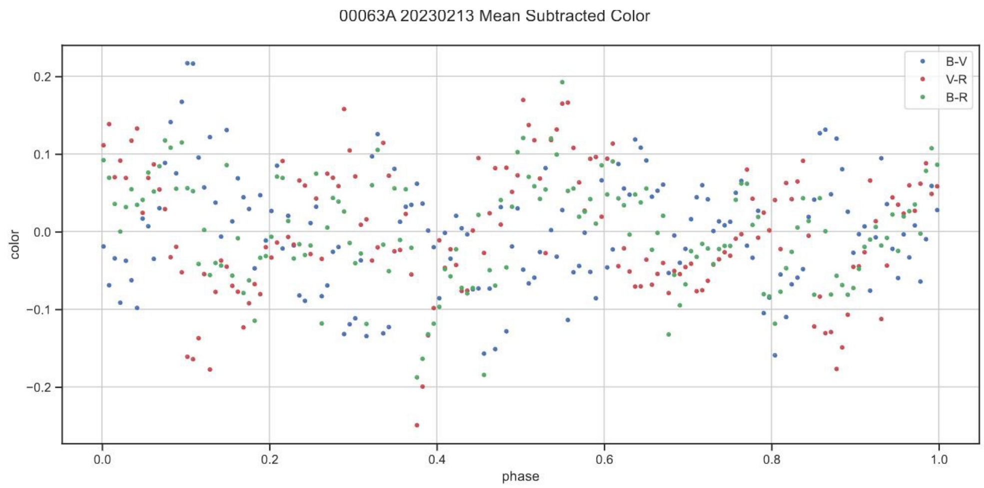


Fig. 7: Light curves for the color indices B-V, V-R, B-R for object 00063A on February 13, 2023.

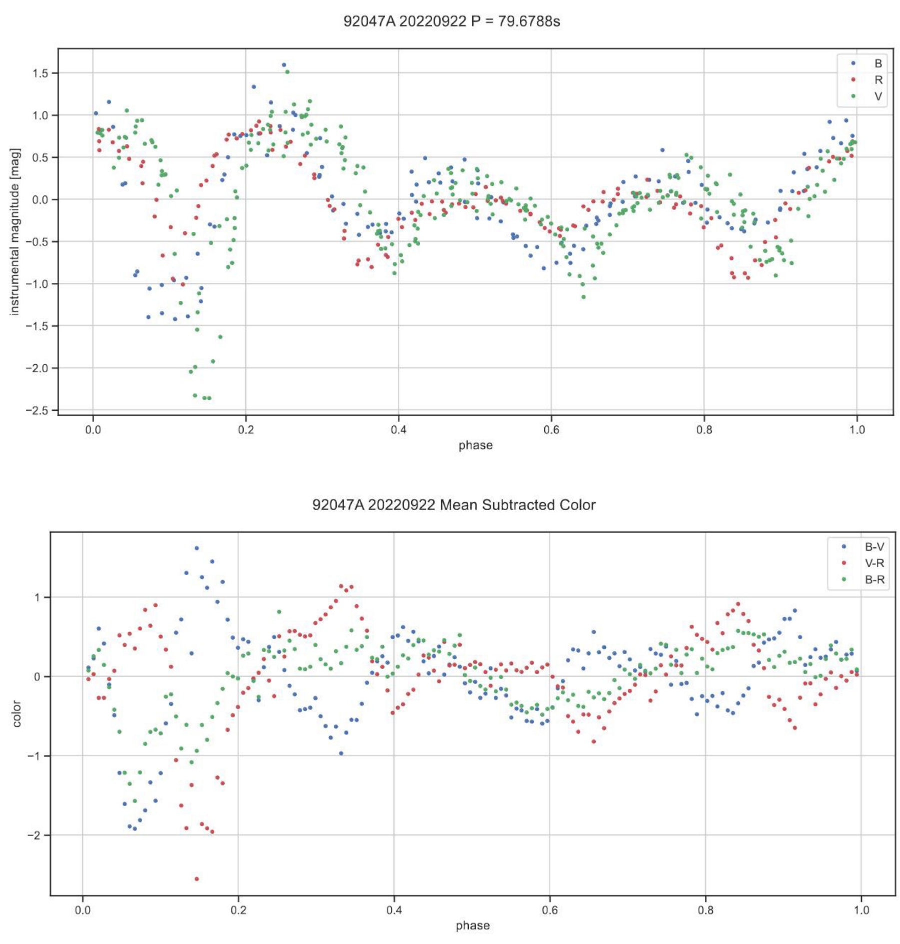


Fig. 8: Light curves (top) and light curves for the color indices B-V, V-R, B-R (bottom) for object 92047A on September 22, 2022.

Some of the light curves of object 00063A show a phase shift between the V and the other passbands. An example is given in Fig. 9. The obvious suspicion would be that the camera used to acquire the V measurements had a time offset with respect to the other camera. Dedicated experiments were conducted to check for such time biases, but none could be discovered. Assuming that the phase shift is real, this would provide additional information for the attitude modelling.

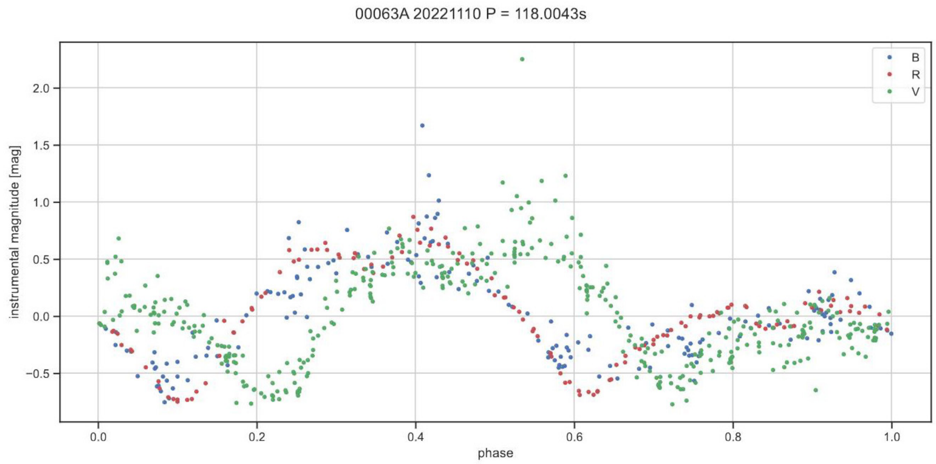
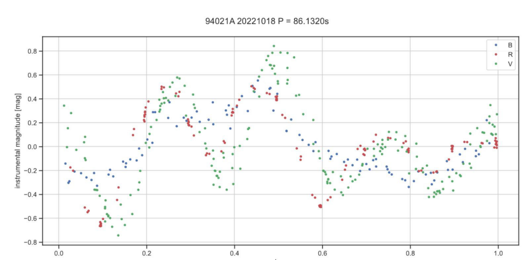


Fig. 9: Phase diagrams for the three colors of the target object 00063A on November 10, 2022. The V-band shows a phase shift with respect to the other passbands.

The signatures in the light curves change over time. In particular the relative amplitudes of the minima and maxima are varying. An example of this behavior is given in Fig. 10. The reason for this might be diverse, ranging from a change of the illumination conditions (phase angle) to a change of the spin axis orientation in the inertial frame or in the body-fixed frame. In the case of object 94021A there seems to be a correlation between the shape of the light curve and the phase angle (Fig. 10).



18.10.22	28.12.22	09.02.23
30-40°	45-55°	10-35°

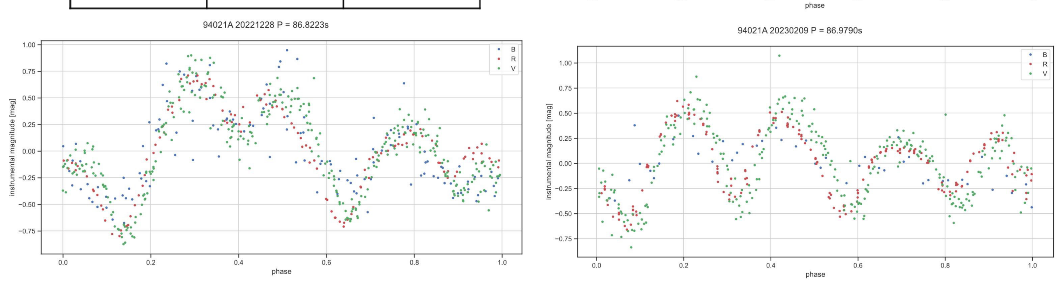


Fig. 10: Light curves of object 94021A for three different epochs and phase angle intervals. The table on the top left shows the phase angle intervals for the three observations.

5 SUMMARY

Most of the decommissioned GLONASS satellites of the first generation are rotating with periods of several seconds to several minutes. In many cases evolution of the rotation periods shows an oscillating pattern and is driven by radiation pressure. In order to understand and model these effects a better knowledge about the orientation of the spin axis in the body-fixed and the inertial frame is needed. In this context simultaneous multi-color photometric observations were acquired and analyzed. Simultaneity was achieved by using the ZimTWIN double 0.4m telescope equipped with two cameras and BVR filter sets.

The resulting phase folded color light curves of 8 GLONASS satellites at different epochs contain a wealth of new information. Correlations between light curve features and colors will help assigning such features to surface parts of the spacecraft. Blue regions in the light curves are likely associated with the solar panels while red parts are expected to be related to the spacecraft body. In some cases, the light curve in the visual passband is systematically phase shifted with respect to the other passbands. This effect has never been seen before and need to be further analyzed. Changes of the light curve features, including the color information, over time are providing additional information to eventually determine the full attitude states of these objects and to allow modelling the evolution of the tumbling motion.

6 REFERENCES

[1] Cordelli, E., P. Schlatter, T. Schildknecht, Simultaneous multi-filter photometric characterization of space debris at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald. Proceedings of AMOS Conference, Maui, Hawaii, 2018.

[2] Rachman, A., T. Schildknecht, J. Silha, J.N. Pittet, A. Vananti, Attitude State Evolution of Space Debris Determined from Optical Light Curve Observations, Proceedings of 68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017.

[3] Rachman, A., T. Schildknecht, A. Vananti, Analysis of Temporal Evolution of Debris Objects' Rotation Rates inside AIUB Light Curve Database. Proceedings of 69th International Astronautical Congress, Bremen, Germany, 2018.

[4] Rachman, A., A. Vananti, T. Schildknecht, Understanding the oscillating pattern in the rotational period evolution of several GLONASS satellites. Proceedings of AMOS Conference (Virtual Conference), 2020.