IAC-18-A6.3

Analysis of Temporal Evolution of Debris Objects' Rotation Rates inside AIUB Light Curve Database

Abdul Rachman[a]*, Thomas Schildknecht[a], Alessandro Vananti[a]

[a] *Astronomical Institute University of Bern (AIUB), Switzerland, abdul.rachman@aiub.unibe.ch*
* Corresponding Author

Abstract

The Astronomical Institute of the University of Bern (AIUB) maintains a light curve database of debris objects in various orbital regions. Currently the database contains more than 3,000 light curves from more than 500 objects. All the light curves were obtained using the 1-meter telescope ZIMLAT which is located at Zimmerwald Observatory in Switzerland through non-resolving optical observations. The database also contains apparent rotation periods and phase diagrams for most of the objects. In this paper we discuss our analysis of the temporal evolution of the rotation rates and of the signatures in the light curves for different types of objects and orbital regions in the database. The information resulted from the analysis could be useful for the future active debris removal missions and to understand the intricate relationship between natural forces and satellites attitude in space.
Keywords: space debris, optical observation, light curve database, rotation rate evolution

1. Introduction

The risk from space debris keeps growing as their number continues to grow. More than 18,900 space objects consist mostly of debris are currently encircling the Earth pose danger to operational satellites [1]. The solution requires the stabilization of the population in part with Active Debris Removal (ADR) by nudging the large debris into a safer orbit or forcing it to prematurely reenter the atmosphere.

For the ADR mission to be successful, sufficient knowledge about the attitude of the debris is mandatory. One method to obtain this is by observing debris using optical telescopes to get their light curves. Routine and careful observations can reveal the temporal evolution of the attitude properties such as rotational periods (or the equivalent rotational rates).

Astronomical Institute University of Bern (AIUB) has observed space debris and collected their light curves since January 2007 using optical telescopes. More than 3,000 light curves from more than 500 space objects have been obtained by the system so far. The objects include payloads, rocket bodies, debris, and a group of objects discovered during ESA's GEO, GTO, and Molniya surveys which is called DIS objects. Origin of DIS objects is unknown. Temporal evolution analysis can be performed using the database that spans for more than 10 years now.

Previous studies of space debris' evolution have been performed for example by using PPAS database [2] or for GEO satellites [3]. The first aforementioned study used a database which is naturally different with the AIUB database and was conducted 20 years ago. The second study was performed on GEO satellites not on MEO satellites especially GLONASS satellites which happened to be the class that seems the most suitable for a study of temporal evolution using the AIUB database [4].

This paper will explain how we analyse the temporal evolution of the apparent rotation rates possessed by objects registered in the AIUB light curve database with more emphasize is given on the GLONASS satellites.

2. Data and methods

We used the collection of light curves inside the AIUB light curve database. In the database, no image calibration is performed in acquiring the images which are used to get the objects' apparent periods [5].

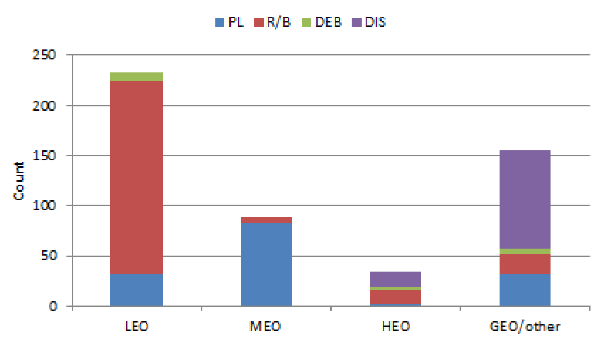

Fig. 1. Number of objects in the AIUB light curve database as a function of orbital type and object type.

LEO objects are the biggest constituent followed by GEO/other object then MEO and HEO objects as Fig. 1 shows. The figure also shows that most of the observed objects are rocket bodies followed by payloads, discovered objects, and debris. Indeed, most of the LEO objects are rocket bodies (around 80%) while most of MEO objects are payloads (around 90%), most of HEO objects are shared roughly equally by rocket bodies

(40.0%) and discovered objects (45%), and most of GEO/other objects are discovered objects (around 63%).

Four classifications are available in the database: very low quality (only few measurement points are available), stable (the light curves only resemble the change in phase angles during the passes), slow rotator (complex signals present in the data set indicating objects' own rotations), and rotator (clear periodic variation of signals over time). In the case of a rotator, the apparent rotation period and phase diagram are also available. These are obtained through a period extraction process which begins with the estimation of the initial period and is finalized by using the phase reconstruction method [6]. Rotators can be found in all orbital regions as seen in Fig. 2.

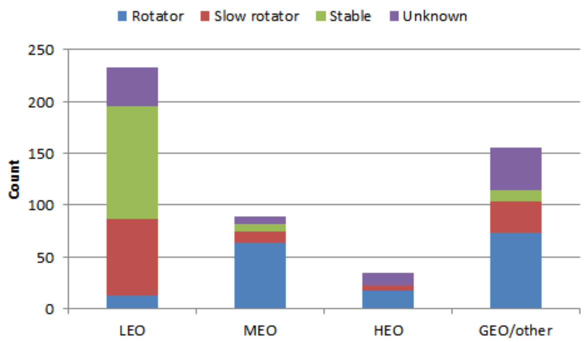

Fig. 2. Number of objects in the AIUB light curve database as a function of orbital type and attitude group.

In the database, rotators (objects with clear periodic variation of signals over time) are divided (based on the pattern of their historical periods) into oscillating, increasing, decreasing, and common rotators [4]. Oscillating rotator appears to display a similar pattern of linear segments and abrupt changes in its historical rotational periods as shown in Fig. 3. Increasing or decreasing rotators only display simple trends as shown in Fig 4. Common rotators do not demonstrate any special pattern in their historical periods.

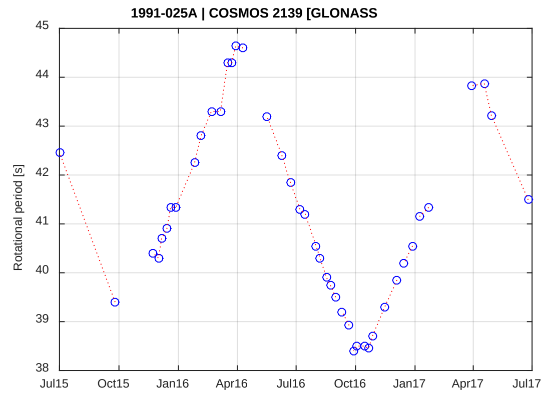

Fig. 3. Rotational periods evolution of one of the oscillating rotators in the AIUB light curve database.

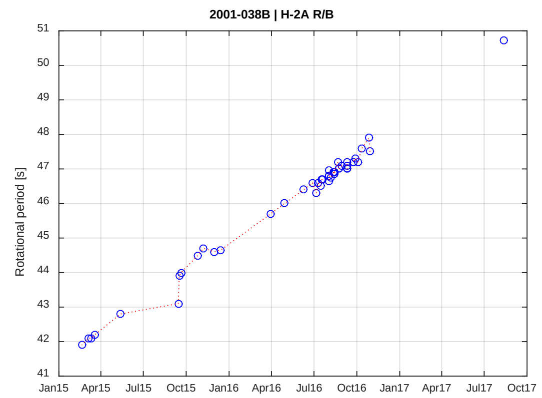

Fig. 4. Rotational periods evolution of one of the increasing rotators in the AIUB light curve database.

After selecting rotators with enough data points and clear trends, we measured the linear trend in unit of degrees per second. In addition, we also measured the average of periods. One trend is enough for the case of simple increasing or decreasing rotators unlike oscillating rotators where we also measured the segment's slope besides the amplitude of the oscillation.

For measurement of the oscillating rotators, we need to identify the peaks of the oscillation. These are located at the intersection between two adjacent segments. We define the amplitude of oscillation by measuring the distance between all peaks to the trend line of the center of the segments as shown in Fig. 5. We calculated the average periods using only the peaks instead of all the data points which are the case for simple increasing or decreasing rotators. Sometimes the segments are not clear enough for an oscillating rotator. For these cases, we treated them as simple increasing or decreasing rotators.

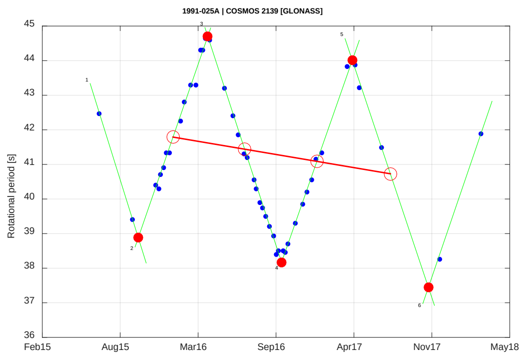

Fig. 5. Measurement of the secular trend for one of the GLONASS satellites. Red dots are the identified peaks, red circles are the measured center of the segments, and the red line is the measured trend.

3. Results

We found 26 of oscillating rotators with clear segments, 25 of decreasing rotators, and 13 of increasing rotators for the total of 64 objects. Generally, the change in rotational rate ranged from -1 to 1 °/s after one year as can be seen in Fig. 6 and Fig. 7. Visual inspection indicates there was no correlation between the change of rotational rate and average of periods.

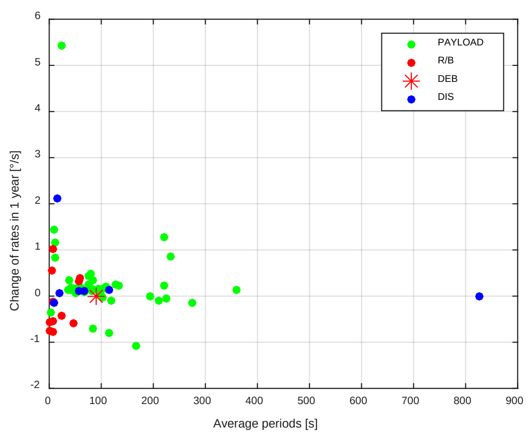

Fig. 6. Rotation rates vs average periods for the 64 objects in this study grouped according to their orbital region.

"Yearly" variation can be easily seen in the historical periods of oscillating rotators. We found that these variations or periodicities ranged from 253.28 to 549.71 days. Their median is 365.05 days which is very close to 1 sidereal year (365.25 days).

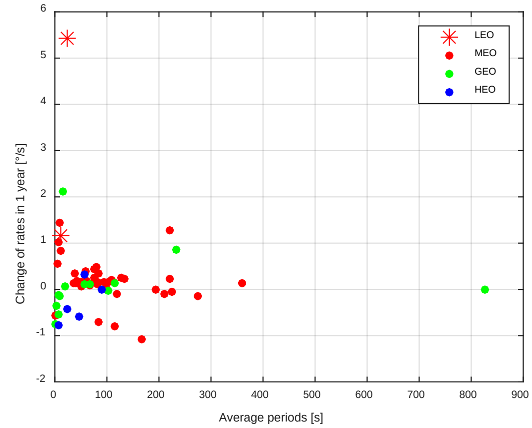

Fig. 7. Rotation rates vs average periods for the 64 objects in this study grouped according to their objects type.

Concerning extremities, we found that the highest change of rotational rates per year belongs to TELKOM 3 satellite (COSPAR number 2012-044A) with 5.4337 °/s while the lowest belongs to a ZMD Object (ID E09287A) with 0.0026 °/s. E09287A also has the lowest average rate which is 0.4356 °/s (average period equals to 826.45 s). Within GLONASS satellites, the highest change of rotational rates per year is 1.44 °/s while the lowest is 0.0075 °/s. Still within this group, the highest change of rates for the segments per year is 30.9290 °/s while the lowest is 0.2127 °/s.

Typically four peaks appear in a phase diagram of GLONASS satellites which resemble their four sides. Most of the time, they come in 2 pairs although not exactly the same in shape as can be seen in Fig. 8 and Fig. 9. Also, shape of phase diagrams for one object may significantly change with time as can be seen in Fig 8 and Fig. 10.

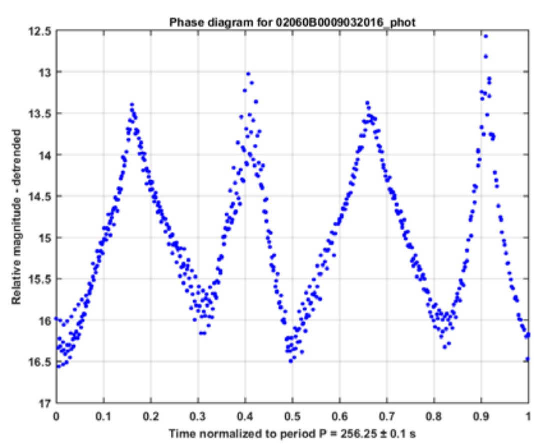

Fig. 8. Phase diagram for COSMOS 2396 [GLONASS] observed on 09.03.2016.

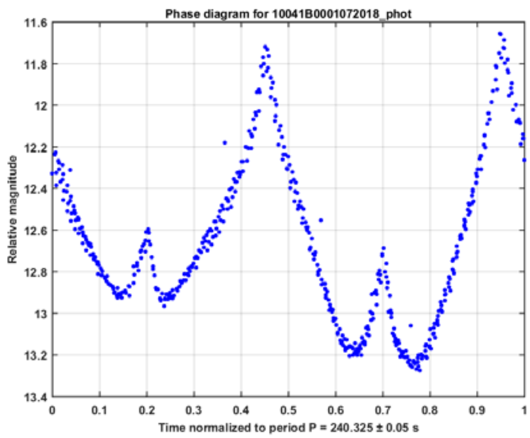

Fig. 9. Phase diagram for COSMOS 2465 [GLONASS] observed on 01.07.2018.

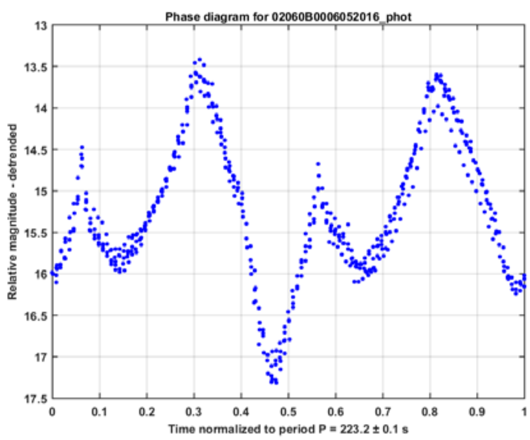

Fig. 10. Phase diagram for COSMOS 2396 [GLONASS] observed on 06.05.2016.

Rocket bodies also display changes in their phase diagram throughout their lives. Different number of peaks and shapes can be obtained from this class of object.

5. Discussion

The fact that the segments of historical periods of GLONASS satellites are linear most of the time can be used to easily predict other values by interpolation or extrapolation. Furthermore, during the measurements we found out that the absolute value for the slopes for all the segments of an oscillating rotator were pretty much the same (see Fig. 11). This fact seems always present no matter the trend or shape of the historical periods. This made us possible to construct other segments and estimate other peaks which their identifications are not possible due to lack of data points (see Fig. 12). This made us possible to predict other values of rotational periods or rotational rates much farther by assuming no significant changes in the pattern.

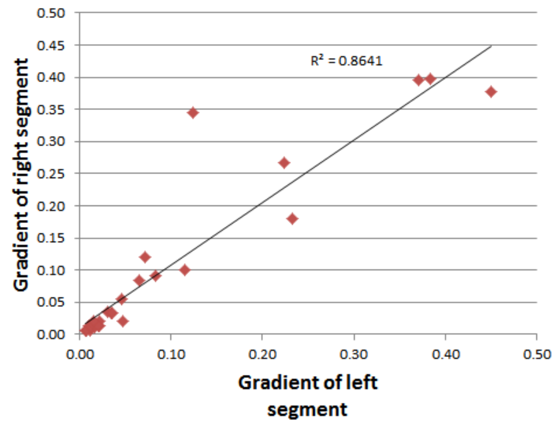

Fig. 11. Relationship between the slopes of left segments and right segments of the 26 oscillating GLONASS satellites in this study.

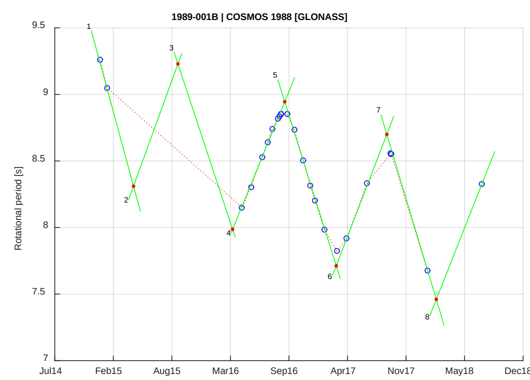

Fig. 12. The estimation of peaks number 2, 3, 4, and 8 for COSMOS 1988 using limited available data points.

The linear segments that form the triangle shapes as we saw in the historical periods of GLONASS satellites could also present in other objects. Among objects under study we only found one case as seen in Fig. 13. The object in the figure is a small GEO rocket body (according to RCS value from Space-Track). It was difficult to find the pattern in the database since usually there are not enough data points to reveal it. However, our result that this pattern only found in the high altitude orbits (MEO and GEO) has stimulated the idea to use the Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect in explaining the observed behaviour. This effect is a torque that is created as a result of thermal energy and sunlight being reemitted and reflected from the surface of an asymmetric body [7]. Future study is necessary to investigate this effect on GLONASS satellites inside AIUB database.

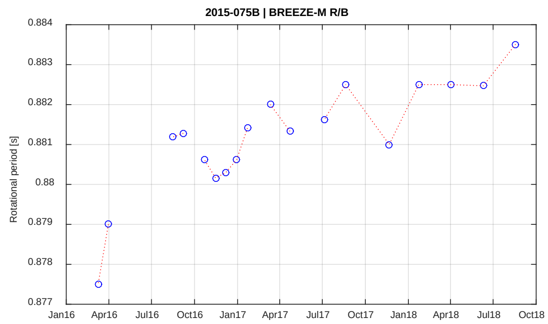

Fig. 13. Rotational periods evolution of one of the rocket bodies in the AIUB light curve database.

6. Conclusions

Sixty four objects inside the AIUB light curve database currently possess historical periods which allow researchers to study the evolutions of their rotational rates through time. Twenty six among these objects are GLONASS satellites which not only display secular linear trends but also yearly (roughly) variations. Twenty five objects display simple decreasing (in terms of rotational periods) increasing while thirteen objects display simple increasing.

Generally, the change in rotational rate ranged from -1 to 1 °/s after one year. Visual inspection indicates there was no correlation between the change of rotational rate and average of periods. For GLONASS satellites, the variations in the group can be modelled by simple triangle shapes with similar slopes for the left and right segments to allow estimation of other period values.

The highest change of rotational rates per year belongs to TELKOM 3 satellite (COSPAR number 2012-044A) with 5.4337 °/s while the lowest belongs to a ZMD Object (ID E09287A) with 0.0026 °/s. E09287A also has the lowest average rate which is 0.4356 °/s (average period equals to 826.45 s). Within GLONASS satellites, the highest change of rotational rates per year is 1.44 °/s while the lowest is 0.0075 °/s. Still within this group, the highest change of rates for the segments per year is 30.9290 °/s while the lowest is 0.2127 °/s.

Typically four peaks appear in a phase diagram of GLONASS satellites which resemble their four sides. Most of the time, they come in 2 pairs although not exactly the same in shape. Also, shape of phase diagrams for one object may significantly change with time.

We thought that Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect is one of the factor that can help us in explaining the behaviour we see in the AIUB light curve database.

References

[1] Orbital Debris Quarterly News, vol. 22, issue 2, p. 8, (2018)

[2] B. De Pontieu, Database of Photometric Periods of Artificial Satellites, Advances in Space Research 19 (1997) 239-232.

[3] P. Papushev, Yu. Karavaev, M. Mishina, Investigations of the evolution of optical characteristics and dynamics of proper rotation of uncontrolled geostationary artificial satellites, Advances in Space Research 43 (2009) 1416–1422.

[4] A. Rachman, T. Schildknecht, J. Silha, J.-N. Pittet, A. Vananti, Attitude State Evolution of Space Debris Determined from Optical Light Curve Observations, IAC-17-F1.2.3, 68th International Astronautical Congress, Adelaide, Australia, 2017, 25–29 September.

[5] J. Silha, J-N. Pittet, M. Hamara, T. Schildknecht, Apparent rotation properties of space debris extracted from photometric measurements, Advances in Space Research 61 (2018) 844–861.

[6] E. Linder, J. Silha, T. Schildknecht, M. Hager, Extraction of Spin Periods of Space Debris from Optical Light Curves, IAC-15.A6.1.2, 66th International Astronautical Congress, Jerusalem, Israel, 12–16 October 2015.

[7] A. A. Albuja, D. J. Scheeres, R. L. Cognion, W. Ryan, E. V. Ryan, The YORP effect on the GOES 8 and GOES 10 satellites: A case study, Advances in Space Research 61 (2018) 122–144.