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UKRAINIAN DATABASE AND ATLAS OF LIGHT CURVES OF ARTIFICIAL SPACE OBJECTS

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ABSTRACT. This paper describes the Ukrainian database of long-term photometric observations of resident space objects (RSO). For the purpose of using this database for the outer space monitoring and space situational awareness (SSA) the open internet resource has been developed. The paper shows examples of using the Atlas of light curves of RSO's for analyzing the state of rotation around the center of mass of several active and non-functioning satellites in orbit.

Key words: Database, space object, photometry, light curve, rotation period.

1. Introduction to the problem

The significance and functions of resident space objects in near-Earth orbits is continuously growing. In the same time the debris of outer space is also increasing. Especially dangerous collisions involve large massive objects that can produce a large number of fragments. An effective way to prevent this is removing the most dangerous space debris (SD) from the Earth's orbit. Removing an object from the orbit requires an accurate prediction of its motion and RSO orientation parameters. The important characteristics of the removing object are the period of its rotation and orientation in space at any moment in time. Rotating objects periodically change their brightness. So, the photometric monitoring is a real approach for remote diagnostics of satellite rotation around its center of mass. This information is also very useful, for example, in emergency cases when operating spacecraft is involved. Also in the numerical integration of non-spherical bodie's moving it's important to take into account their orientation (for example, for large defunct RSO) especially in case of predicting close approaches with other RSO.

There are several centers that carry out photometric monitoring of near-Earth RSOs in Ukraine. These are several university observatories of MOSU (first of all the Astronomical Observatory of Odessa National University) and Space control centers of State Space Agency of Ukraine (now located in Mukachevo and Dunaevtsi). The database of light curves of AO ONU contains results of more than 10-years monitoring of the satellites functioning and large space debris objects in near-Earth orbits. The KT-50 telescope (main mirror diameter of 500 mm) is used to track of RSOs on low Earth orbit (Shakun & Koshkin, 2014). High-orbit RSOs have been observed using automated OMT-800 telescope (with main mirror diameter of 800 mm) at the observation station in Mayaki (Andrievsky et al., 2013).

2. Ukrainian Database and Atlas on-line

In 2016, AO ONU and the Space control center (SCC) created Ukrainian "Photometric Data Storage Portal for RSOs" as the specialized part of the Ukrainian Virtual Observatory (UkrVO). The results of RSOs photometric observations provided by the national optical observation devices are coming for storing and online access to the "Portal", and are used by the SCC to perform it tasks.

The software complex is intended to store photometric data and includes function of accumulation and archiving of light curves and other priori RSOs information. Uploading and viewing of existing data is carried out using an interactive web interface (Fig. 1-2). Due to the large amount of data, the interface provides filtering and searching features by all the most important criteria. The results of the RSO brightness measurements are available both as text file and as an interactive light curve chart with zooming features (Fig. 3). The available opportunities allow conducting preliminary expert evaluation of the RSOs behavior based not only on the latest observations results, but also on retrospective data. This is very important feature for SCC because it allows determining RSO type (spacecraft, rocket carrier, SD or its fragment, etc.) as well as identifying the spacecraft activity periods and making conclusions about their functional purposes and statuses.

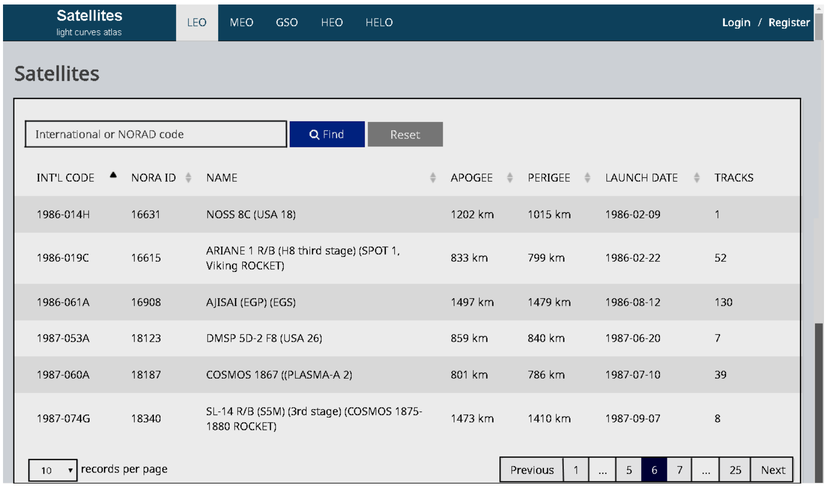

Figure 1: Ukrainian Database and Atlas of light curves of artificial space objects (RSO selection window).

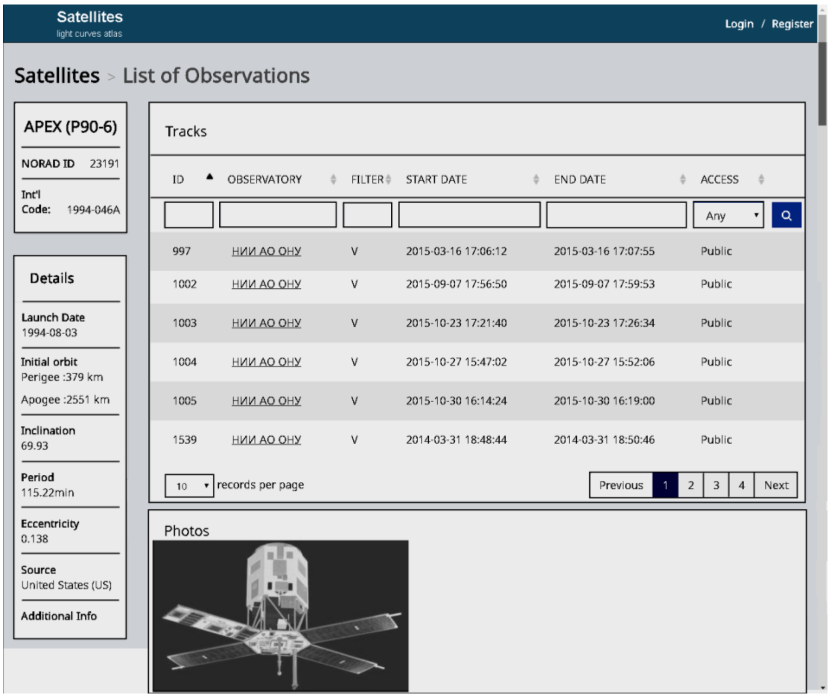

Figure 2: Ukrainian Database and Atlas (Track selection window).

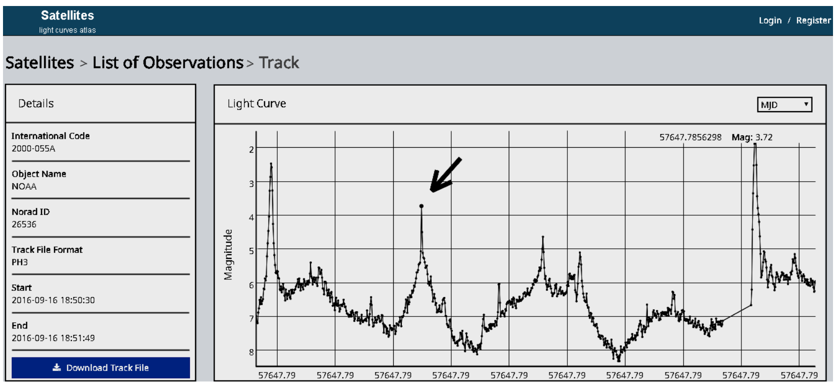

Figure 3: Ukrainian Database and Atlas (Light curve presentation window).

Based on the "Portal" data specialists have possibility to make conclusion about the stabilization and spatial orientation of the spacecraft, to assume the geometric shape, the presence and location of external antennas, optics and other equipment. Analysis results are used by SCC to track and regular update actual RSO classifiers that incorporate the signs confirmed or refined based on latest photometric measurements. Processed data are than passed to NCSFCT.

We can conclude that the creation of the "Photometric Data Storage Portal for RSOs" and its using for space surveillance purposes made it possible to significantly expand the functional capabilities of the SCC and provided possibility to online access data in cooperative mode.

3. Usage of database

As an example of the analysis of photometric material from the AO ONU database let's consider the brightness variations of two Cosmos satellites. The first one (Kondor-E, 2013-032A) is launched into low Earth orbit on June 27, 2013, the second (Kondor-E2, 2014-084A) on December 19, 2014. Both satellites are intended for obtaining images of the Earth's surface and oceans monitoring. They have an orbit height of about 500 km above the ground, inclination of 74.75° and their planned operation time is 5 years. The Kondor-E satellites are equipped with a large parabolic antenna measuring 6 × 7 m in the S-band synthetic aperture radar (SAR), which can perform both survey in strip mode and detailed selective spot surveys. We do not know about any serious problems with these satellites. However, analysis of the light curves of these RSOs shows a different character of their motion about center of mass. Fig. 4,a shows the light curve of the 2013-032A RSO, obtained on May 29, 2017 using the telescope KT-50 in Odessa. Changes in the brightness of the satellite have a pronounced periodic nature, which may indicate its rotation. The apparent rotation period in this case is approximately 8.7 seconds.

Fig. 4,b shows the light curve of RSO 2014-084A, obtained also on May 29, 2017 using the telescope KT-50. The changes in the satellite brightness have an aperiodic showing (although in two zones of the light curve we can see a repeat of a short-term increase in brightness at an interval of about 6 sec. The may be caused by the design element movement, for instance, by the movement of scanning antenna) In general, this light curve is usual for stabilized spacecraft on its orbit.

In some cases, long-term photometric monitoring of RSO's orbital behavior makes it possible to reveal the evolution of its rotation. Fig. 5,a shows the light curve of the US weather satellite 1994-089A NOAA-14 (on orbit since December 1994, orbit altitude of about 850 km, inclination is 98.7°), obtained on May 17, 2017. Fig. 5,b shows light curve of the satellite 2000-055A NOAA-16 (on orbit since September 21, 2000, orbit altitude of about 840 km, inclination - 98.8°), received on August 1, 2017. Both spacecraft are inactive, so it's actually space debris. The light curves are similar in character, periodic and display the rotation of the satellites. For now, NOAA-14 shows a rotation with a visible period of about 19.4 seconds (4 peaks per full revolution). The NOAA-16 spacecraft seems to be rotating faster – the full synodic period at the beginning of August 2017 was about 7.6 seconds.

It is known that around November 25, 2015 NOAA-16 collided with another body in orbit, that is caused the formation of 136 new small fragments, including the main body of the satellite.

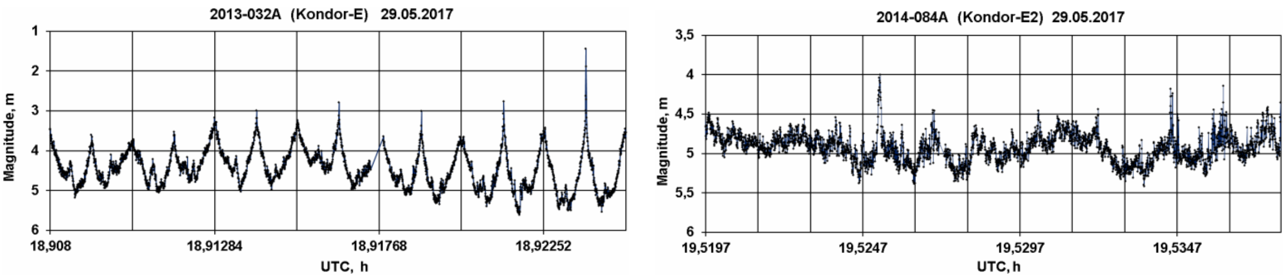

Figure 4: (a) The light curve of the RSO 2013-032A (Kondor-E). Vertical lines correspond to a time interval of 8.7 s. (b) The light curve of RSO 2014-084A (Kondor-E2). Vertical lines correspond to a time interval of 6 s. Both light curves obtained on May 29, 2017 with using the telescope KT-50 in Odessa.

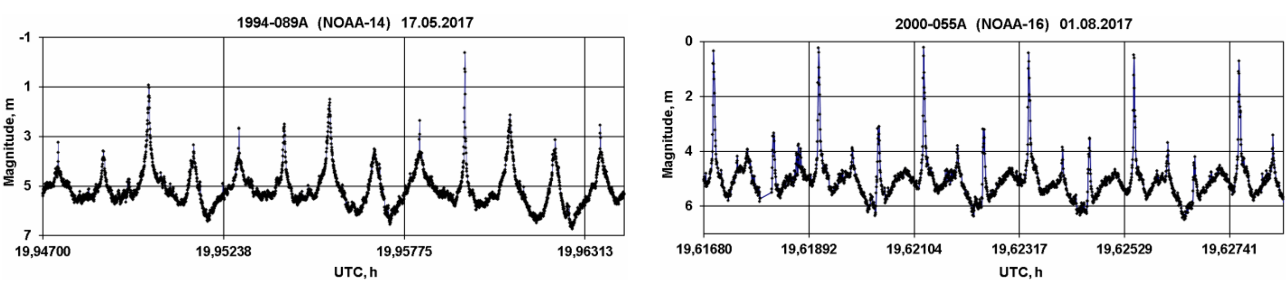

Figure 5: (a) The light curve of NOAA-14 (1994-089A), obtained on May 17, 2017. Vertical lines correspond to a time interval of 19.4 seconds. (b) The light curve of NOAA-16 (2000-055A), obtained on August 1, 2017. Vertical lines correspond to a time interval of 7.6 seconds. Both light curves obtained with using the telescope KT-50 in Odessa.

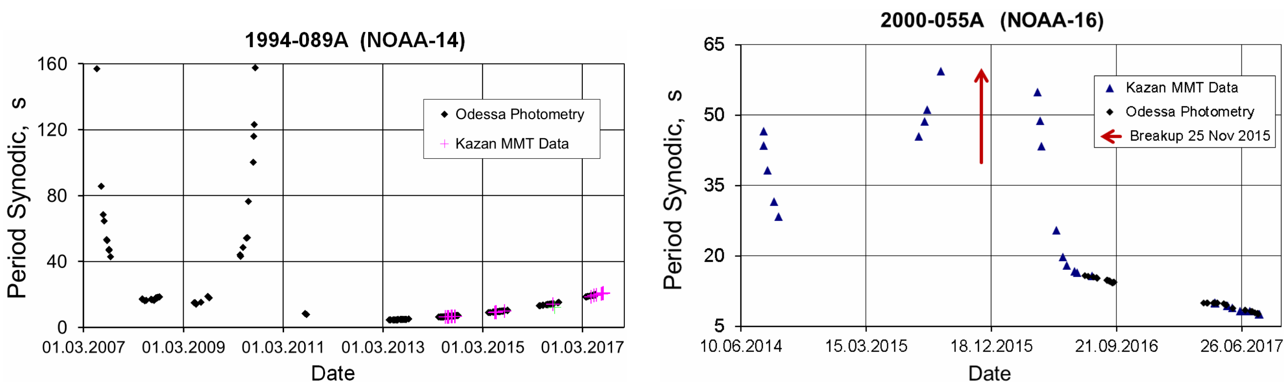

Figure 6: Change in the observed synodic rotation period of two non-functioning RSO: (a) NOAA-14; (b) NOAA-16.

Rotational speed of NOAA-14 did not remain constant. Fig. 6,a shows a complex history of the rotation period evolution of this RSO during 2007 - 2017 according to our measurements obtained with the telescope KT-50 and the Russian MMT project (Biryukov et al., 2015). However, starting from 2013 the satellite slows down in a stable mode. Fig. 6,b shows the change in the rotation period of NOAA-16 at different times in the interval from 2014 to 2017 according to MMT and our measurements on the KT-50. It's obvious that the angular velocity of rotation also experienced great changes and after a catastrophic collision on the orbit the rotation has accelerated. During 2016-2017 the period of rotation of this satellite monotonously decreased with small variations which are typical for objects of space debris. These objects are subjected, for example, to the pressure of solar radiation (Kucharski et al., 2017).

4. Conclusion

Last years, interest in studying the rotation of satellites has been continuously growing (primarily, defunct satellites, i.e. space debris). The Multichannel monitoring telescope (MMT, Kazan, Russia) has been active since 2014 (Biryukov et al., 2015). ESA runs the "Debris Attitude Motion Measurements and Modeling" project, led by the Astronomical Institute of the University Bern (AIUB) (Kanzler et al., 2015). The Space Research Institute of Austrian Academy of Sciences (Graz, Austria) in cooperation with Space Environment Research Centre (SERC, Australia) and a number of other centers of Satellite Laser Ranging (SLR) perform a large program to determine the satellites attitude and their spin properties (Kucharski et al., 2017).

The Ukrainian Light Curves database will be contain results of more than 10-year monitoring (now is added data only by the AO ONU) of the behavior of functioning satellites and large objects of space debris in orbit. Some of this data is already available on-line within digital Atlas of light curves and they continue to grow. The functioning of the database is supported by the program of the Ukrainian space agency for ensure of the space situational awareness. The paper describes the database structure and capabilities of working with it. The example of four RSOs demonstrates the use of photometric data for a preliminary analysis of the state and evolution of their rotation around center of mass.

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