MONITORING OF THE INOPERATIVE ENVISAT SATELLITE'S BEHAVIOUR

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ABSTRACT. New positions data and light curves were received for the inoperative Envisat spacecraft still in orbit. The satellite pole and sidereal rotation period were determined on the base of the photometric data for the period from April to August 2013. The presence of a precession of the Envisat rotation axis was deduced.

Introduction

Optical tracking techniques based on the sunlight reflection by the space craft (SC) surface are used to provide remote sensing of the Earth-orbiting satellite's motion. In Odessa Astronomical Observatory we use a satellite tracking technique that enables to obtain characteristics of a satellite's orbital motion and rotation around its centre of mass. That technique is based on two principles: tracking of the apparent moving of a satellite by telescope and acquisition of its images against the background stars with maximum possible frame rate. The latter objective is ensued principally from the high-speed satellite photometry requirements. The indicated method enables to remotely determine parameters of the satellite self-rotation around its centre of mass. With the high-speed photometric techniques it is possible not only to record, for example, an occurred flash, but also to estimate the time profile of that flash, and hence, the indicatrix of light reflection from the corresponding surface of the satellite. That is a fundamental quality change of photometry, and sometimes it enables to distinguish specularly reflecting surfaces even when observing in a single spectral range. It should be noted that the accuracy of the time reference of all light curve features is critical for interpretation of the recorded satellite brightness variations.

A television camera WATEC-902H2 Supreme with the interlaced mode that works well in practice is used as the high-speed panoramic light receiver. The camera is installed in the focal plane of the 50-cm tube of the tracking telescope KT-50. The actual temporal resolution (Δt) is about 0.02 sec. To provide a reliable, stable and OS-independent time reference, the hardware introduction of the converted pps-pulses from the GPS receiver was applied (Dragomiretsky et al., 2013).

The EnviSat satellite monitoring

EnviSat is a satellite designed to capture high-resolution images of the Earth's surface. It was launched in 2002 into the polar orbit altitude of 777 km with inclination i = 98.4°. The main objective of EnviSat was to conduct altimetry of oceans and ice cover, as well as other monitoring of the Earth. On April 8, 2012, EnviSat unexpectedly shut down, and the contact with the satellite was lost rendering it inoperative. All efforts to re-establish contact with the satellite failed. As can be seen from the images received from Pleiades and Spot spacecrafts, EnviSat is fully intact, and its solar arrays are deployed.

In case of the EnviSat failure in-orbit, it is likely to collide with other operative satellites as it has a 26-meter cross section and weighs some 8000 kilograms. EnviSat is "a bomb", which poses an immense danger to the heavily crowded corridor in the polar orbit at altitude of 780 km. Its estimated lifetime is 100 years! The remaining fuel and energy reserves can only make it more hazardous.

Therefore, it is necessary to oversee the EnviSat orbital motion. However, the atmospheric drag at the given altitude is an important factor. To reliably predict the satellite's motion in the upper atmosphere of the Earth (below 1000 km), it is necessary to take into account the orientation of a complex-shaped body, i.e. rotation. At any moment it is essential to know not only cross-sectional areas of large satellite, but also its actual tilt and physical characteristics of surfaces, which interact with impinging atmospheric molecules.

The erroneous prediction of EnviSat's position in orbit in May 2013 is shown in Figure 1. The residuals between prediction (Kara I.V., 2009/2010) and actual position of the satellite reach 0.5° along its orbit (while 1″ corresponds to ~5 m at a distance of 1000 km). As soon as the satellite monitoring by the International Laser Ranging Service (ILRS) and Ukrainian Network of Optical stations (UMOS) was resumed, the residual errors decreased to units of arcseconds.

The photometric observations (monitoring) started by Odessa Astronomical Observatory and the UMOS network in April 2013 enabled to gather plenty information to analyse. The results of simultaneous measurements of the EnviSat's brightness obtained on July 11, 2013 in Odessa and Yevpatoria are shown in Figure 2. The presence of bright flashes of the satellite allows of estimating the synodic period of its rotation in the given trajectory segment. The variation in the estimated synodic period values within 4 months of monitoring is presented in Figure 3.

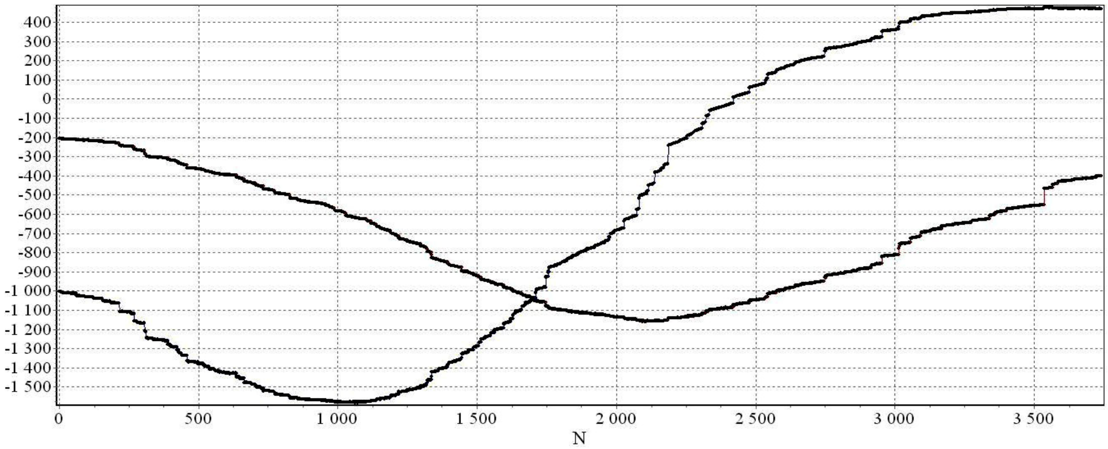

Figure 1: The EnviSat's positions predicted as of the start of its monitoring: an example of residual errors in the predicted equatorial coordinates and astrometric observation data obtained on May 27, 2013 in Odessa using KT-50.

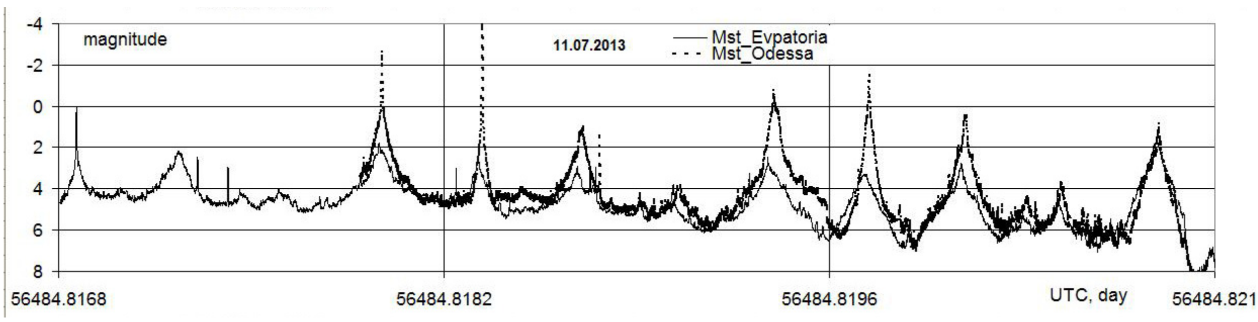

Figure 2: Simultaneous measurements of the satellite brightness from two UMOS observation points. The data received on July 11, 2013 in Odessa and Yevpatoria. Vertical lines correspond to the satellite's rotation period.

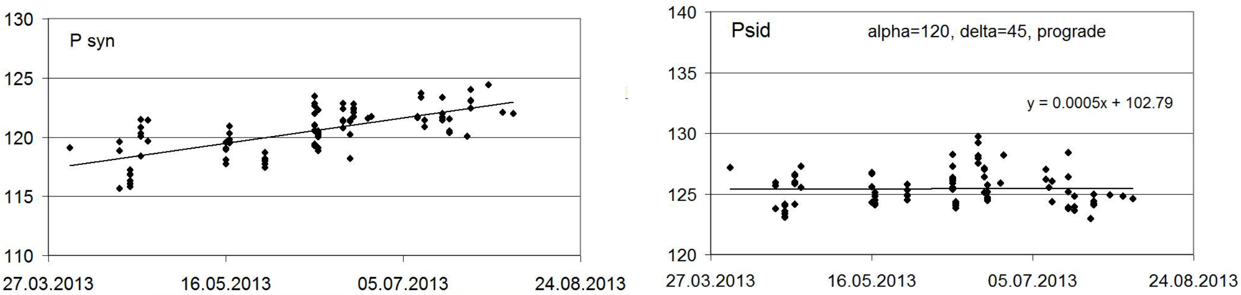

Figure 3: a) the measured values of the EnviSat space craft synodic rotation period; b) the optimal solution for the rotation pole (α_p = 120°, δ_p= 45°, the prograde rotation), deduced by the method accounting for parallactic shift of flashes on the light curve. At that, the average sidereal rotation period within 4 months is almost constant and equals to 125.6 sec.

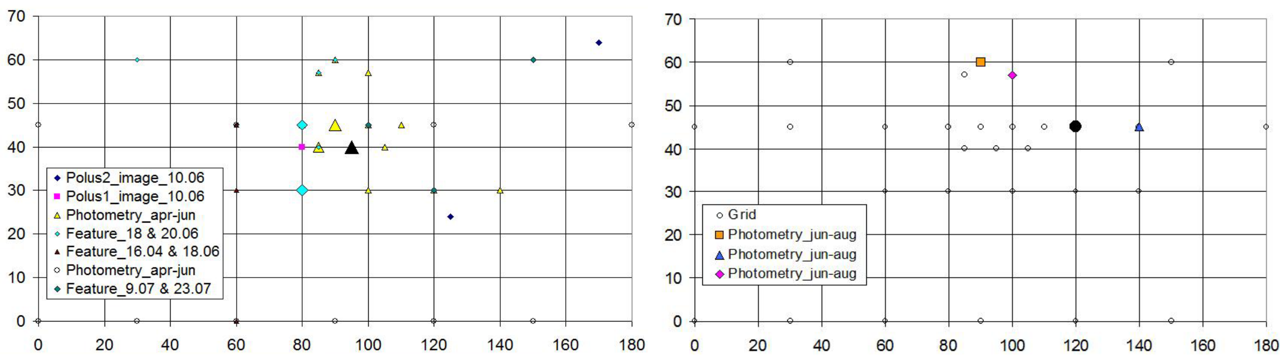

Figure 4: The optimal solution for the EnviSat satellite rotation pole obtained with various techniques for the period from: a) May to June 2013; b) June to August 2013.

There are two factors, which can have impact on the spread of synodic period values. First of all, that is the parallactic shift of the observer-spacecraft line, i.e. orbiting. When the body shape is too asymmetric as is the case with EnviSat, the satellite rotation is quite complicated (Zubov et al., 1968; Beletsky, 1975), and the rotation axis orientation changes during a single satellite's pass over the observer.

To refine the satellite rotation model, we used a classical method of simultaneous selection of the sidereal rotation period and pole position, which is called the method of photometric astrometry (MPA) when applied to asteroids.

Provided steady rotation, the sidereal period is constant only with the right position of the rotation pole. We computed the grid for the rotation axis spatial orientations; the optimal solution in this regard as such the minimum spread (minimum of the mean square error) and constant value of the sidereal period is shown in Figure 3b. However, the residual spread of the sidereal period values can not be explained by the errors of the synodic period measurements. That is definitely indicative of the presence of rapid variations of the instantaneous rotation axis.

Other methods also can be applied to determine the instantaneous rotation pole of the satellite. We analysed the method of similar features applied to the EnviSat light curves measured during different satellite's passes. In this case, the phase angle bisector at the moment of observation has the same latitude relative to the rotation pole, and that enables to select the pole. Our colleagues from the Space Agency of Ukraine estimated the orientation of rotation pole by the analysis of direct images of the satellite received using the long-focal-length telescope (private message). All estimations of EnviSat rotation pole positions are presented in Figure 4.

Apparently, there is no single agreed solution. It can be established that the rotation pole varies within middle latitudes $\delta_p \approx 30$-$60°$. The estimated right ascension of the pole during the period from April to June 2013 was within $\alpha_p \approx 80$-$100°$, and from June to August 2013 - $\alpha_p \approx 90$-$140°$. That drift of the pole corresponds to the precession rate of the satellite's orbital plane.

Conclusions

To continue the in-depth study of the EnviSat satellite light curves, it is necessary to analyse its adequate optical-geometric model. That will allow of identifying all main specific features of the light curves and also accurate computing of instantaneous orientation of the space craft body. On having the model for the satellite's rotation around its centre of mass developed, the satellite body orientation relative to the orbital velocity direction (the flux of impinging atmospheric molecules) at any given moment will be computed. Accounting for the satellite interaction with molecules of the upper atmosphere will further the correct computation of the drag force (slowing down).

References

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