THE PHOTOMETRIC MODEL OF ARTIFICIAL SATELLITE AJISAI AND DETERMINATION OF ITS ROTATION PERIOD

E. Korobeynikova, N. Koshkin, S. Shakun, N. Burlak, S. Melikyants, S. Terpan, S. Strakhova

Astronomical Observatory, Odessa National University, Odessa, Ukraine
nikkoshkin@yahoo.com

ABSTRACT. Photometry is used to make remote diagnostics of an artificial satellite's motion around its centre of mass. Experimental satellite Ajisai was designed to explore the effects of the space factors, such as gravitation and magnetic fields, solar radiation and others, on its orbital motion and rotation. In the present study we consider the use of peculiar light curves of Ajisai, exhibiting a complex sequence of momentary flashes, for precise determination of the rotation period and velocity variations. For the first time, on the basis of the high-speed photometry, the model of placement of mirrors on the satellite's surface was designed to carry out further analysis of its kinematics.

Introduction

Geodesic artificial satellite Ajisai of mass 685 kg has a near-spherical shape (with radius 1.075 m). On its surface there are 120 laser corner reflectors and 318 quasi-flat mirrors (spherical in fact – the radius of curvature of the mirrors is 8.4÷8.7 m, and the size $\leq$ 0.25 m) (Sasaki & Hashimoto, 1987). Both types of reflectors are placed in 12 latitudinal rings and two polar caps on the satellite's surface. The mirrors are additionally inclined at different angles to the central latitude of their rings so that while the satellite is rotating around the axis of symmetry any three of them with the same inclination could always reflect the light towards the observer during one revolution. In the literature we have not found information on the actual placement of the whole set of mirrors. However, such data available can be used to estimate the precise rotation period and orientation of the artificial satellite according to the results of the photometric observations (Koshkin et al., 2009/2010).

Right after the launching the satellite rotated with the velocity of 40 revolutions per minute around the axis almost parallel to the Earth's axis of rotation. By the results of many years' laser ranging observations it is known that the rotational velocity slowly decreases with time. In so doing, the axis of rotation slowly oscillates in space, deviating from the celestial pole at the angle of $\approx$ 0÷3° (Kucharski et al., 2010). The current rotation period is about 2.2 sec, and, according to our estimates, the duration of satellite flashes does not exceed 0.006 sec.

There are two purposes that we pursue by using the photometric timing of moments of flashes when reflecting the sunlight from the mirrors of the fast-rotating satellite. At first, the interval between individual flashes along with the "fitted" rotation period allows us of developing the simulation model of Ajisai – the model of its mirrors' placement and orientation. And further that model is applied to compute the phase shift between far distant in time flashes from two (and more) mirrors that makes possible to considerably improve the accuracy of estimation of the current value of the sideric rotation period.

Model of Ajisai satellite

As is known, at least three flashes are observed during each revolution of Ajisai. That occurs on conditions that the declination of the phase angle bisector almost equals to the latitude of the normal of three mirrors (to simplify the description we use the concept of "normal" as for the flat mirror). In so doing, we neglect the deviation of the satellite's rotation axis from the celestial pole, as well as possible little deviation of the rotation axis from the Ajisai axis of symmetry. The central latitude of each ring with reflectors and the number of mirrors in the ring are known (Kucharski et al., 2010; Kucharski et al., 2009; Kucharski et al., 2010a; Kirchner et al., 2007). The techniques to proceed are as follows. Let us examine an individual light curve of Ajisai for its pass when the declination of the phase angle bisector varied rather widely. The flashes that follow each other with the time close to the current value of the rotation period stand out on the local section of the light curve. Usually, there can be three such sequences (the so-called "chains"), and it is necessary to determine the averaged time intervals between them as the portion of period. As the bisector declination changing (and the "plash of sunlight" shifting on the satellite's surface) the amplitude of certain chains is abruptly reduced; meanwhile, three other chains appear, and their amplitude is rapidly growing up to the optimum. Thereby passing from a certain chain of flashes to the next one, we restore the phase shift between them and the difference of longitudes between the respective mirrors. However, using inaccurate value of the rotation period leads to the error accumulation while shifting along the model's meridian. That is why that procedure demands successive accurate determination. The positions of the central "normal" of the mirrors in the most worked out in detail part of our model are shown in Figure 1.
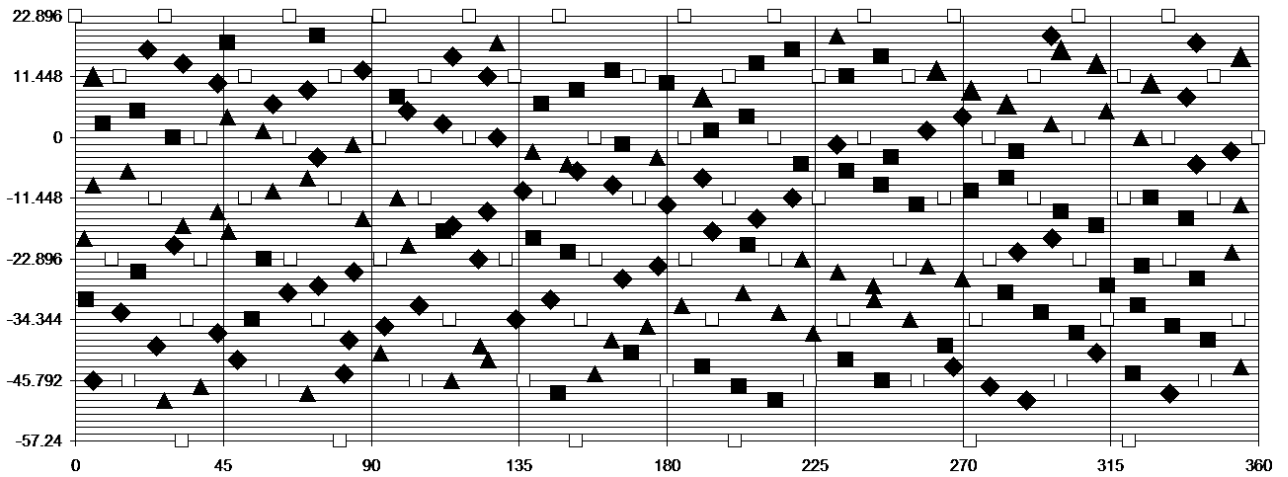
Figure 1. The model of artificial satellite Ajisai: the diagram of the mirrors' positions on its surface. The longitude is plotted on the X-axis, the latitude of the reflector is plotted on the Y-axis. The corner reflectors are marked as blank squares.

Rotation period determination

Neglecting little deviation of the rotation pole of Ajisai from the celestial pole, it is possible to calculate its sideric rotation period. Synodic period, determined by two flashes from the same mirror, equals to $P_{syn} = (t_2-t_1)/n$, where t_1 and t_2 – is moments of the flashes, n – the number of the satellite's complete revolutions around fixed coordinate frame. The sideric period P_{sid} can be determined by the formula: $P_{sid} = (t_2-t_1)/(n - \Delta\alpha'/2\pi)$, where $\Delta\alpha'$ – the change in the bisector's right ascension for the time t_2-t_1. When using flashes from different mirrors (not only from the same one), t_2-t_1 interval is to expand considerably, and the formula looks as follows: $P_{sid} = (t_2-t_1)/(n - \Delta\alpha'/2\pi + \Delta\lambda/2\pi)$, where $\Delta\lambda$ – the difference between longitudes of any two mirrors on the satellite. The averaging by many pairs of flashes allows us of appreciably improving the accuracy of estimation of the sideric period during one pass of the satellite over the observation point.

The change in the sideric rotation period of Ajisai for almost three years according to the photometric observations in Odessa using telescope KT-50 with TV CCD-camera is shown in Figure 2. For such an interval it is still possible to approximate the period change by the linear formula. The average daily increase of the period is 0.000088 sec.

When using the whole period of observations of Ajisai from the moment of its launching in 1986, the change in its sideric rotation period should be approximated by the exponent, whose parameters are determined by joint examination of the satellite laser ranging data (Kucharski et al., 2010) and our photometric observations:

$$P_{sid} = 1.485802 \cdot Exp(0.0150114 \cdot T),$$

where T – the time interval in years from August 12, 1986 (since launching).

Deviations of the determined individual values of the rotation period from the approximation by the above indicated exponential formula are shown in Figure 3. It is obvious that those observations are not enough, and they cluster near the so-called "periods of observability" of the satellite from this site. However, those deviations are not random and they are within the same span ±8 msec, wherein their variations were found out by other researchers on the basis of the laser ranging data (Kucharski et al., 2010).

Results and discussion

The photometric timing is a useful instrument (Cusumano et al., 2012) to study variations of the rotation period of artificial satellite Ajisai. With actual time resolution (δt) of measurements equal 0.02 sec, on the observation interval of 7 minutes and more, the error of the period estimate is ≤ 0.0001 sec. And that makes possible to expand the analysed time span, for instance by two consecutive passes of the satellite, i.e. up to 120 minutes, thereby decreasing the total period error by one more order (Koshkin et al., 2009/2010). With such accuracies of period, begin to count the errors in the above indicated model of the Ajisai mirrors' placement, making about 3° and more in longitude. According to (Sasaki & Hashimoto, 1987) their structural accuracy in longitude does not exceed ±0.5-0.8°. To check the precision of the model when estimating the sideric period, several times
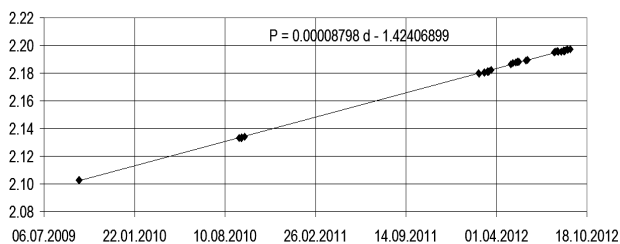

Figure 2. The change in the sideric rotation period of Ajisai according to the some photometric observations in Odessa in 2009-2012. The parameters of the linear approximation are presented.
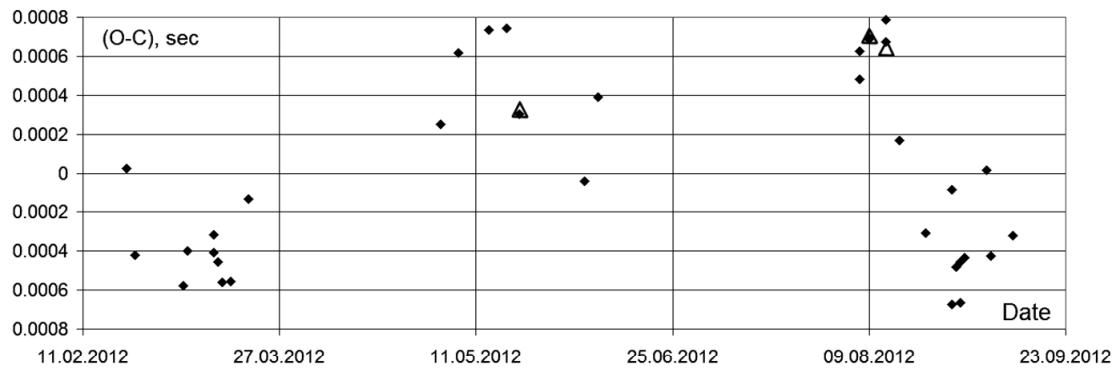
Figure 3. Deviations (O-C) of individual values of the rotation period in 2012 from the approximation by the exponential formula.

we used flashes from the same (!) mirrors in the beginning and in the end of the light curve. That is possible when the geometry of the satellite path relative to the observer is so that the bisector declination in the beginning and in the end of the pass assumes the same values (the patch of the reflected sunlight is shifting on the satellite's surface firstly down and then up the latitude). In that case the effects of the errors in the model on the period values are entirely eliminated (result is marked as blank triangles in the Fig. 3). Nevertheless, the rotation period values slightly differ from the values obtained with the model in that case too, and that is indicative of the model's adequacy.

There may be several components in the total error of the obtained values of the rotation period. First of all, those are local distortions of the model kind of "torsions" that arise due to inaccuracy of the period value, applied when developing the model; and also that can be the finite exposure time that considerably exceeds the flash duration. A small summand of the error is due to the disregard of the deviation of the satellite's axis of rotation from the celestial pole. And finally, it is not certain that the axis of rotation in the satellite's body coincides with the axis of symmetry. Quite the contrary, when observing the light reflection from the low-latitude mirrors additional chains of flashes appeared in very close longitudes; that is impossible for the mirrors of the same

ring, but can be caused by some oscillating of the satellite and "engaging" of the mirrors of the adjacent ring.

However, the possibility to apply the developed model discovers new perspectives. At the new stage it is planned to improve and expand the model, as well use as to substantiate the hypotheses on the precession of the Ajisai axis of rotation. To do that thorough series of the photometric observations of the satellite from different sites, including the Southern hemisphere, are essential.

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