
Determination of AJISAI spin parameters using Graz kHz SLR data

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Abstract

Using the Graz full rate kHz SLR data, we determined the spin rate and spin direction of the satellite AJISAI as well as its slow down between 2003/10 and 2005/06. The high density of the kHz data results in a precise scanning of the satellite's retro-reflector panel orientation during the spin motion. Applying spectral analysis methods, the resulting frequencies allow identification of the arrangement of the involved laser retroreflector panels at any instant in time during the pass. Using this method, we calculated the spin rate with a high accuracy (RMS of 4.03×10^{-4} Hz), and the slow down of the spin rate during the investigated period with a magnitude of 0.0077497 Hz/year. We obtained these results from routine SLR tracking data, i.e. day and night observation, without any additional hardware.

Introduction

The Japanese geodetic satellite AJISAI, launched on August 13, 1986 into a 1500 km circular orbit with a 50° inclination, is a passive sphere with a diameter of 2.15 m [1]. The surface is covered with 318 sunlight reflection mirrors for visual tracking and 120 laser retro reflector (LRR) panels each carrying 12 corner cube reflectors for SLR [2] (see Fig. 1). The satellite's axial rotation causes the mirrors to produce visible flashes of reflected sunlight, which are observable on Earth [4]. This in principle allows a precise determination of the spin rate, but, however, requires dedicated photometric equipment at the ground station. Furthermore, these observations can only be made during night time, and for limited time spans where the satellite is illuminated by the Sun. This method was applied for AJISAI in Japan only in the frame of a few campaigns.

AJISAI was put into orbit with an initial spin rate of 40 rpm, and with the spin axis parallel to the Earth's rotation axis. With the method of photometric timing an axial rotation of 0.67 Hz was measured after launch [5], slowing down to 0.57 Hz by October 1997 [2].

In the present study AJISAI's spin rate has been investigated using the full rate kHz SLR observations of the Graz laser station and was determined to be 0.5064 Hz in July 2005. The main reason for this slowdown is the eddy current resulting from an interaction between the satellite's metallic parts and the Earth's magnetic field [2].

While standard SLR measurements are usually done at a 5 or 10 Hz repetition rate, the SLR station Graz was upgraded and is operating a 2 kHz laser system since October 2003. Due to the capability of detecting return pulses with as few as a single photon, the return rate from AJISAI comes close to 100 %, even with the low energy per shot 400 μ J) of the Graz SLR system. The 2 kHz repetition rate produces up to 1 million measurements per AJISAI pass, which has a duration of typically 16 minutes. This amount of data represents a very dense temporal sampling of the satellite's rotating surface, which allows an accurate determination of the spin parameters.



Fig. 1. Geodetic satellite AJISAI.

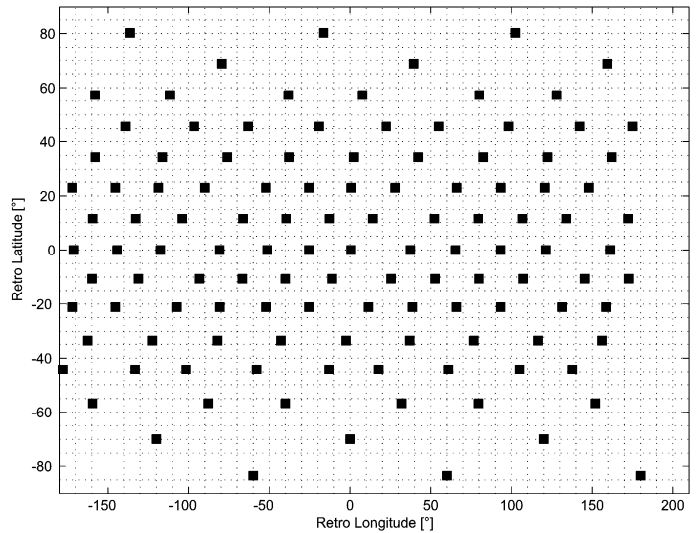


Fig. 2. Schematic distribution of the LRR panels

The LRR panels are almost uniformly distributed over the surface, arranged in 15 latitudinal rings [2]. There are 5 rings with 12 LRR's, 4 rings with 9 LRR's, 2 rings with 6 LRR's, and 4 rings with 3 LRR's each. The schematic distribution of these LRR panels in terms of latitude and longitude is shown in Fig. 2.

Ranging Simulations

Due to the axial rotation of AJISAI and the well separated reflector panels, the distance from the observer to each panel varies periodically. The periods are given by the spin rate of the satellite and the number of panels of the involved ring. The amplitudes depend on the dimension of the sphere, the distance between the panels and on the incidence angle of the laser beam. Based on the known location of each reflector panel on AJISAI [6], a ranging simulation was made which clearly shows the expected periodic distance variation.

Fig. 3 shows a full 360° rotation viewing with an incident angle of -18.125° from the satellite's equator, which contains 12 reflector panels, consisting of 3 groups with 4 panels each. The distances between these 3 groups are slightly larger than the distances between the panels within each group (Fig. 2). The resulting pattern shows the corresponding peaks, with 3 larger gaps (at 100°, 220° and 340° longitude) in between.

Spectral analysis of kHz data

In order to verify these simulation results, using the Graz kHz SLR measurements, we calculated a reference orbit from the standard SLR predictions and subtracted the calculated value from the measured distance. A low order polynomial was approximated and subtracted from the residuals in order to remove the remaining low-frequency part (approx. a few minutes in time) of the observations, but keeping the high-frequency variations (less than a few seconds) originating from the rotating reflector panels.

Fig. 4 shows range residuals for a 2 s interval (1 full revolution) of a routinely observed AJISAI pass.. The residual plot clearly shows the bigger gaps (longer ranges) due to the larger distances between the 3 groups as well as small variations in

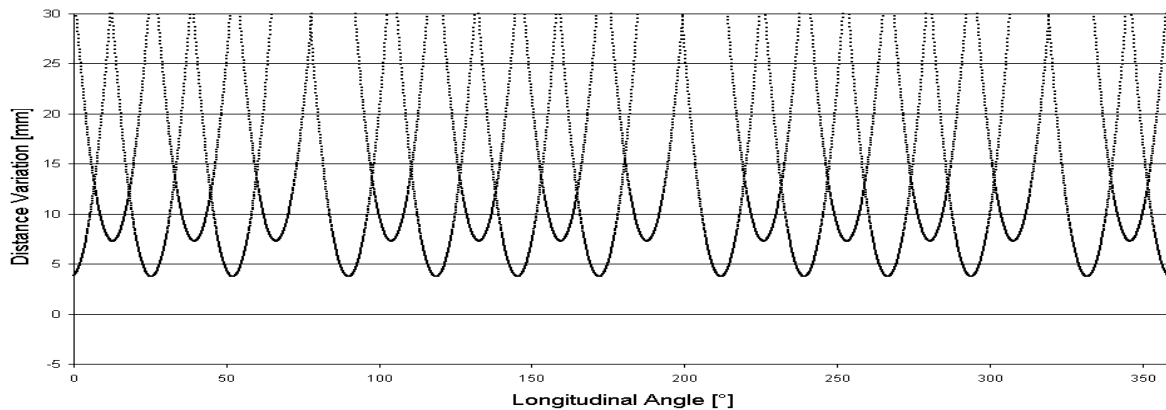


Fig. 3. Simulated distance variations of LRR panels at a laser beam incidence angle of -18.125° latitude. The non-symmetric LRR arrangement (Fig. 2) causes the slightly irregular distribution in both the simulation (Fig. 3) and in the ranging residuals (Fig. 4).

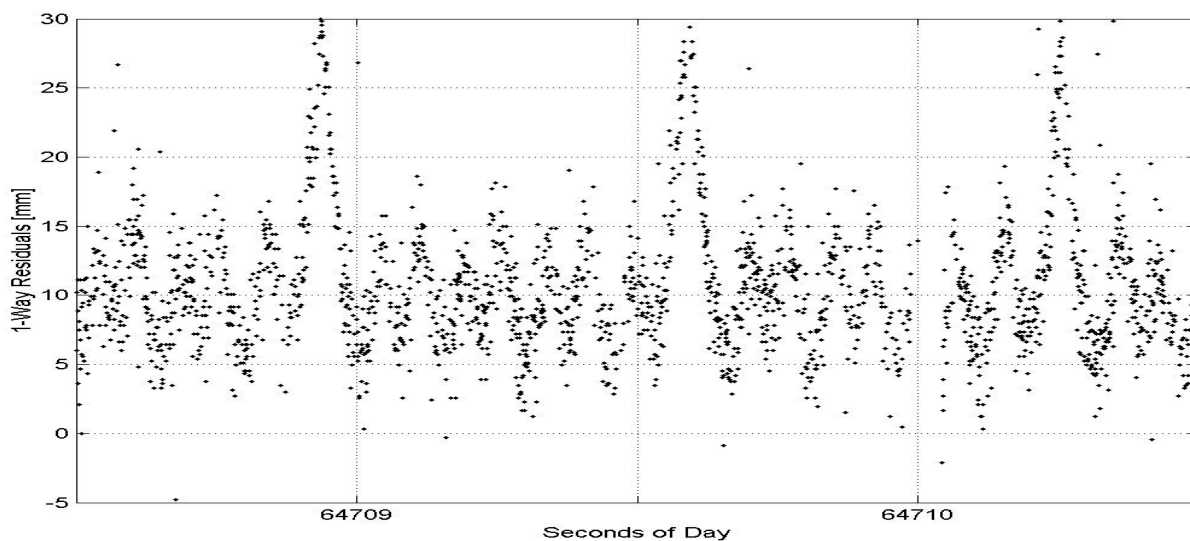


Fig. 4. Full rate 1-way range residuals during one full rotation of AJISAI (DOY 122/2005) for comparison with the simulation shown in Fig. 3

between due to 2 different rings. This residual analysis coincides well with the corresponding simulation shown in Fig. 3.

Frequency Analysis using FFT versus Lomb

Usually, SLR systems do not reach a 100 % return rate, even in good weather conditions. Due to the resulting gaps, the measurements are in general not equidistant in time and therefore the Fast Fourier Transform (FFT) method cannot be directly applied for a frequency analysis. In order to use FFT for the given AJISAI range residuals, the data gaps may be interpolated, but, however, this may induce new frequencies and decrease the accuracy of the results [8]. In [2], the Lomb method for spectral analysis of non-uniformly distributed data was suggested as a useful alternative. This method can handle non-equally spaced data and provides an approximation of the spectrum using the least-squares method.

Connecting Frequencies with AJISAI Geometry

Applying the Lomb method to the residuals of a 10 seconds interval of an AJISAI pass (see Fig. 5), a number of spectral peaks due to the distance variations can be seen clearly. The frequencies of 1.5, 3.1, 4.6 and 6.1 Hz are multiples of AJISAI's basic

spin rate of about 0.5105 Hz in January 2005, and the number of LRR panels (3, 6, 9 or 12) of the involved ring. The higher frequencies of 7.57, 9.09, 10.60 and 12.12 Hz are generated by simultaneous contributions of LRR of two or more adjacent rings. For instance, the clear spectral peak at 12.12 Hz in Fig. 5 cannot be associated with any single ring, but is produced by the combination of two 12-retro rings.

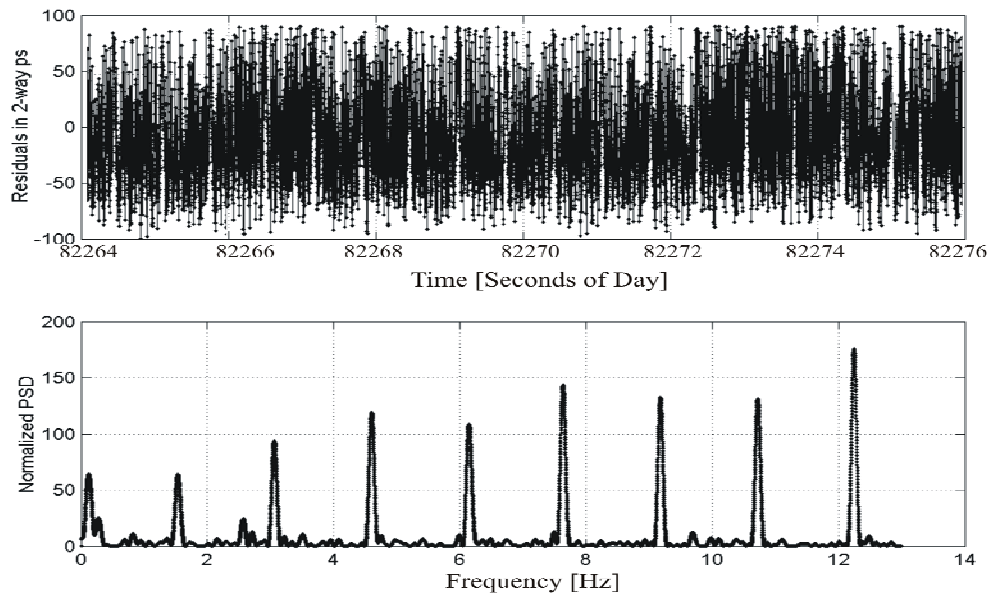


Fig. 5. *Twelve seconds interval of 2-way residuals in time and frequency domain (DOY 019/2005, multiple rings visible).*

Spin rate slow down

It was shown that each calculated frequency corresponds to a specific number of LRR panels. The ratio between frequency and the number of panels of the corresponding ring gives the exact spin rate of AJISAI. The frequency generated by the 3 LRR rings was not used for spin rate calculations, because they generate lower spectral power and lower resolution than the 6, 9 or 12 LRR rings.

For the frequency analysis we selected only passes with high data density (> 300 k returns) observed between 2003/10 and 2005/06. From these passes we used only data of a 1.5 minutes interval centered at the closest approach, containing more than 40 k returns, in order to keep the computation time within reasonable limits (a 3 GHz PC still needed 5 days to analyze the 195 selected passes).

Because the measured spin rate is an apparent spin rate it was corrected for the apparent effect in order to get the sidereal spin rate (see details below). The resulting spin rates for this time span show a well defined slow down rate of 0.0077497 Hz / year (Fig. 6), coinciding well with AJISAI's spin rate slow down calculated for 1997-1999 [2].

Apparent Spin and Spin Direction

The apparent spin rate of a satellite observed at any site on Earth is affected by the axial spin as well as by its orbit around the Earth and by the Earth rotation itself. Therefore the apparently measured spin has to be corrected for these effects, in order to obtain the sidereal spin of AJISAI.

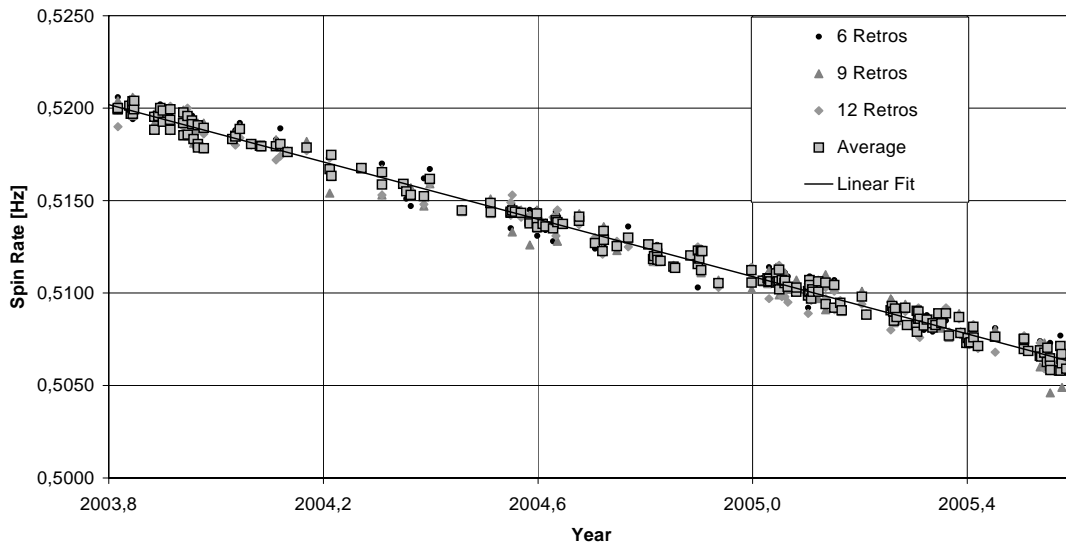


Fig. 6. AJISAI spin rate decrease determined from the averages of 6, 9 and 12 retro ring spin rates for 195 passes between 2003/10 and 2005/06. The linear fit to these average values yields a slow down rate of 0.0077497 Hz / year, with a standard deviation of 0.000403 Hz.

As an example, we calculated the spin rate of an AJISAI pass of 2005/01/19 (again for a period of 1.5 minutes around the closest approach). However, in this case, we selected only short slots of 12 seconds (containing at least 5000 residuals), calculated the spin rate with the same approach as above, then shifted the slot time by 6 seconds, and repeated the procedure.

This results in a clearly visible – apparent – increase of the spin rate near the maximum elevation (71.9° for this pass) as shown in Fig. 7, where the values are given together with the corresponding calculated apparent spin rate. The clearly visible outliers at about 82050, 82150 and 82250 seconds can be correlated with according ring transitions, identifiable by detailed analyses of the residuals. The results confirm the high sensitivity of kHz SLR data for the determination of satellite spin rates.

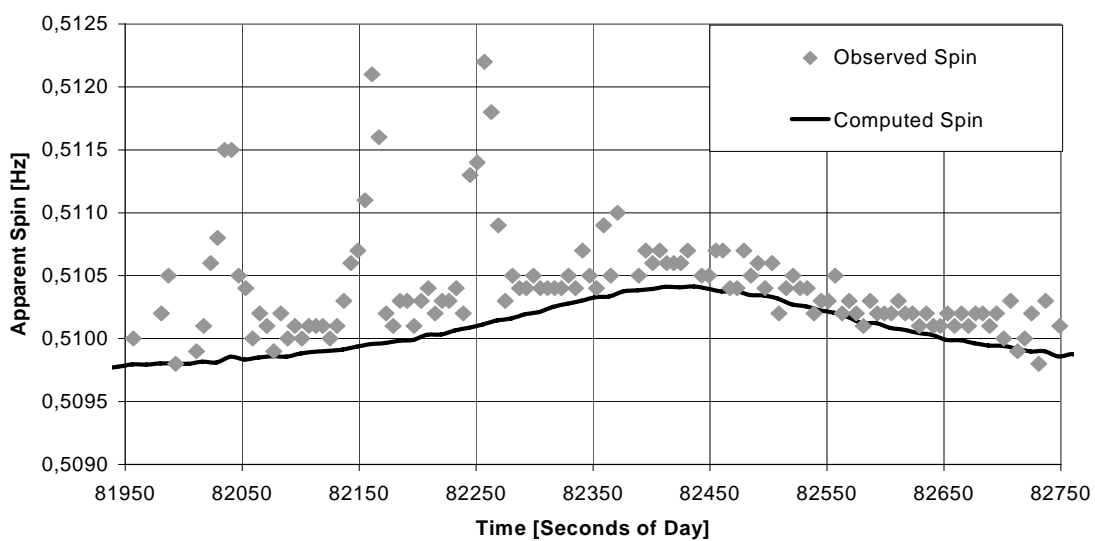


Fig. 7. Apparent spin motion as observed from the SLR site. Measured rates (diamonds) vs computed values (solid line).

We assume that the spin direction of AJISAI a priori is not known. From sequences of observed LRR ring transitions in most passes we have evidence that the spin axis is still at least approximately parallel to the Earth axis. Because the closest approach (CA) of the selected pass was at about $160^\circ / 71.9^\circ$ (as seen from Graz), and the apparent spin shows a slight increase (Fig. 7) at CA, we can conclude that AJISAI is spinning in a clockwise direction.

References

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