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Modeling spin parameters of Ajisai, LARES and the other geodetic satellites with SLR data

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Abstract. *The Satellite Laser Ranging (SLR) data allows for the spin parameters determination of the fully passive, geodetic satellites. We have spectrally analyzed the long time series of the Full Rate SLR data delivered by the global network of the SLR stations and obtained information on the spin parameters, and the spin evolution, of the following satellites: Ajisai, LAGEOS-1, LAGEOS-2, LARES, Larets, Stella. The satellites made of the conducting materials are exponentially losing the rotational energy over time with the rate depending on the intensity of the Earth's magnetic field at the altitude of an orbit. The Low Earth Orbiting satellites Larets and Stella lose spin with the fastest rate - it takes only 38.3 days for the spin period of Larets to double, while for Ajisai - 45.9 years.*

Introduction

The spherical, geodetic satellites dedicated to Satellite Laser Ranging (SLR) are equipped with corner cube reflectors (CCRs). The initial spin parameters are usually set during the injection of the satellite into an orbit in order to stabilize the inertial attitude of the spacecraft. The spin parameters (spin axis orientation and spin rate) of the passive, conductive bodies are changing under influence of the forces and torques caused by the Earth's magnetic and gravitational fields, and the solar activity (Andrés et al., 2004).

During a pass of a satellite over an SLR station, the laser pulses transmitted from the ground system are reflected by the CCRs back to the receiver telescope. The spinning array of the CCRs causes a mm-scale modulation of the range measurements what engraves a frequency signal on the SLR data. The

spin frequency can be obtained by spectral analysis of the unequally spaced data (Lomb algorithm; Lomb, 1976) as it was demonstrated in (Bianco et al., 2001, Kucharski et al., 2012, 2013a, Otsubo et al., 2000).

Spin determination of the geodetic satellites with SLR

In order to determine the spin rate of the geodetic satellites we used the SLR data delivered by the stations of the ILRS network (Pearlman et al., 2002). The full rate data of every pass is processed and the range residuals are calculated (with respect to predicted orbits). As the next step the frequency analysis is performed and the spectral signal is obtained.

The determined spin trends of Ajisai, LAGEOS-1, LAGEOS-2, LARES, Larets, Stella indicate an exponential lose of the rotational energy, and the rate of the de-spin process depends mainly on the altitude of an orbit. The magnetic field of the Earth induces eddy currents in the metallic satellites, and generates forces and torques which affect the spin dynamics of the artificial satellites. This effect depends on the magnetic properties of the spinning satellites, and on the strength on the external field. Figures 1-4 present spin period trends determined from the SLR data of the geodetic satellites: Ajisai (Fig. 1; Kucharski et al., 2009), LAGEOS-1 and LAGEOS-2 (Fig. 2; Kucharski et al., 2013b), LARES (Fig. 3; Kucharski et al., 2014b), Larets and Stella (Fig. 4; Kucharski et al., 2014a).

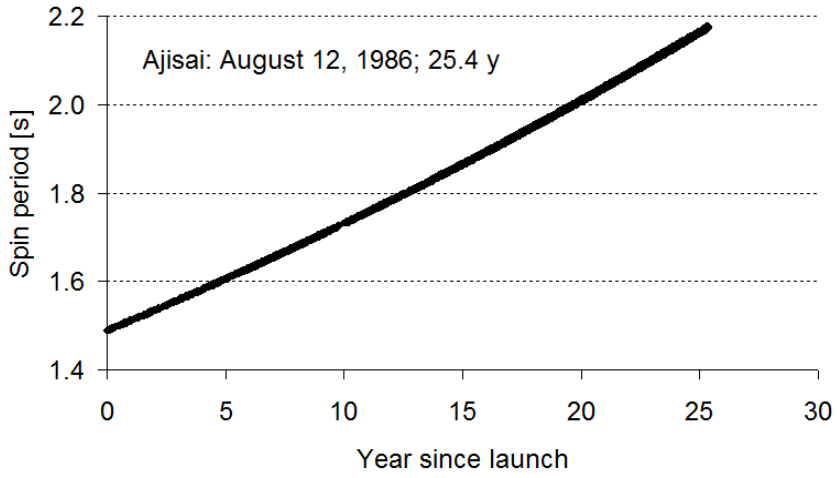

Figure 1. Spin period trend of Ajisai

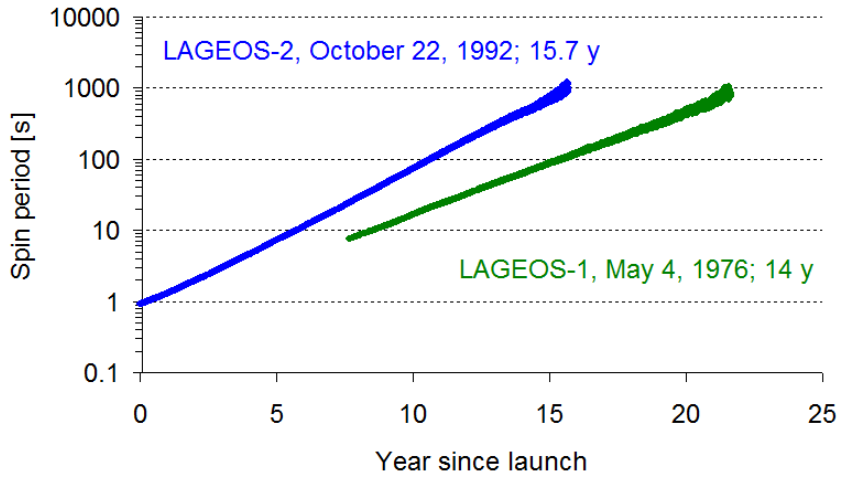

Figure 2. Spin period trend of LAGEOS-1 and LAGEOS-2 (logarithmic scale)

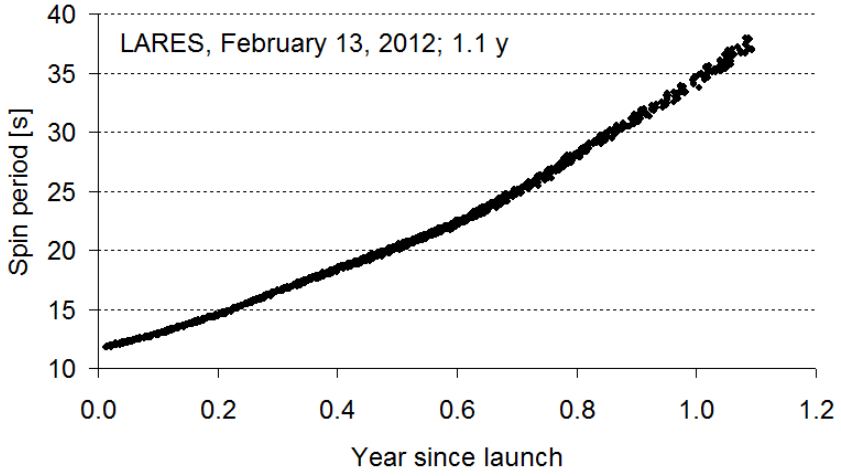

Figure 3. Spin period trend of LARES

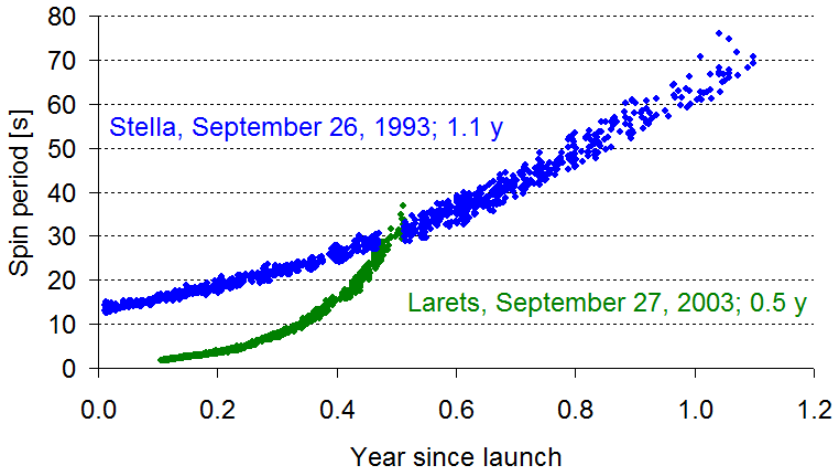

Figure 4. Spin period of Larets and Stella

Spin modeling of the geodetic satellites

The spin trends (Fig. 1-4) can be used for modeling the spin parameters of the observed satellites. The satellite spin model is based on the LOSSAM solution developed for the LAGEOS satellites (Andrés et al., 2004), and can be adopted for another spherical spacecrafts. The best-fitting process of the spin model to the observed spin period values allows to determine parameters related to the spin dynamics of the analyzed satellites (Table 1) such as the initial angular momentum, the initial magnetic torque and the spin half-life period.

Table 1. Parameters of the geodetic satellites

	Ajisai	**LAGEOS-1**	**LAGEOS-2**	**LARES**	**Larets**	**Stella**
Launch date	Aug 12 1986	May 4 1976	Oct 22 1992	Feb 13 2012	Sept 27 2003	Sept 26 1993
Perigee [km]	1485	5850	5625	1450	691	815
Orbital period [h:m]	1:56	3:45	3:42	1:55	1:38	1:41
Mass [kg]	685.0	407.0	405.4	386.8	23.3	48.0
Radius [m]	1.075	0.300	0.300	0.182	0.120	0.120
Moment of inertia [kgm^2]	527.7	12.91	11.23	5.125	0.134	0.365

Initial spin period [s]	1.49	0.43	0.98	11.8	0.82	13.20
Initial angular momentum [kgm^2/s]	2225	188.6	71.97	2.729	1.027	0.1736
Initial magnetic torque [nNm]	1080.65	1944.37	1048.49	80.70	209.84	8.51
Initial Spin Half-Life period (year / day)	45.9 y	2.2 y	1.6 y	255.4 d	38.3 d	166.8 d

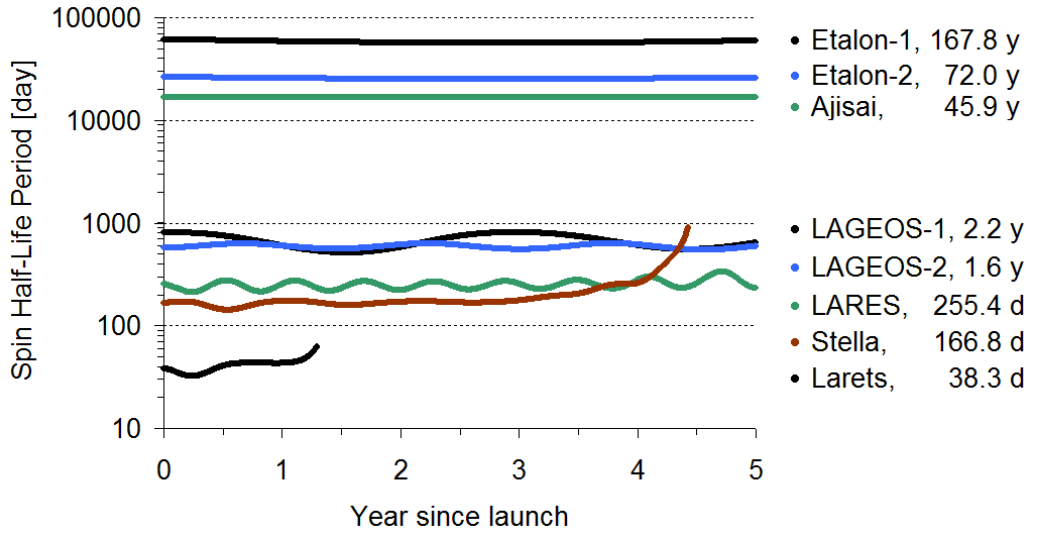

Figure 5. Spin half-life period for the geodetic satellites derived from the spin models - during 5 years from launch (or until the resonance condition in the case of Larets and Stella)

The rate of the de-spin process can be expressed by the spin half-life period - it is time after which the satellite's rotational period has doubled. This parameter can be derived from the spin models; the values for the geodetic satellites are presented on Figure 5. The slow-down rate depends mainly on the altitude of an orbit (strength of the magnetic field). The Low Earth Orbiting satellites demonstrate the fastest degradation of the rotational motion - on the beginning of the lifetime the spin period of Larets doubles every 38.3 days, and every 166.8 days for Stella; the parameter increases for the higher satellites. The change of the de-spin rate during a satellite's lifetime might be caused by the change of the spacecraft's orientation with respect to the Earth's magnetic field. The magnetic torque generated in the satellite's body by the external field depends on the incident angle between the satellite's spin axis and the Earth's magnetic field dipole (Andrés et al., 2004).

The construction of a geodetic satellite can have a crucial impact on the rate of the de-spin process. In the case of Ajisai the spin half-life period is 45.9 years, and it was achieved by composing the surface of the body from several thin layers of aluminum separated by a dielectric film. The sandwich-like structure of the Ajisai's external surface minimizes the possibility of conducting eddy currents by the Earth's magnetic field, prevents lose of the satellites' rotational energy and stabilizes the attitude of the spacecraft (Kucharski et al., 2010).

Conclusions

SLR is the most efficient source of information about the spin dynamics of the geodetic satellites. The SLR systems can measure spin of the fully passive satellites during day and night without any additional equipment. The observed spin period trends are used to find the parameters of the spin model, which help to explain the exponential loss of the satellite's rotational energy. The spin models allow to determine the initial state of the satellite's rotational motion at the launch epoch as well as predict the spin rate and the attitude of the spacecraft until the resonance condition (spin period close to the orbital period).

The spin models indicate large variation of the speed of the de-spin process among the geodetic satellites. The loss of the rotational energy is rapid for the Low Earth Orbiting satellites like Larets and Stella - it takes only 38.3 days for the spin period of Larets to double (at the launch epoch). The very slow degradation of the rotational speed can be observed in the case of the High Earth Orbiting satellites Etalon-1 (167.8 years) and Etalon-2 (72 years). The Etalons are placed on an altitude of 19120 km where the weak magnetic field of the Earth does not affect significantly the spinning spheres with the high angular momentum.

The case of Ajisai proves that the impact of the external magnetic field on the spin dynamics of a geodetic satellite can be limited by the specific design of a spacecraft. Ajisai keeps its high rotational energy, what helps to stabilize orientation of the spacecraft in the inertial space.

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