16 years of LAGEOS-2 Spin Data - from launch to present

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Abstract

Satellite Laser Ranging (SLR) stations measure distance to the satellites equipped with Corner Cube Reflectors (CCRs). These range measurements contain information about spin parameters of the spacecraft. We present 15 years of LAGEOS-2 (15580 values) spin period determination. The measurements have been made by standard 10 Hz SLR systems and the first 2 kHz SLR system from Graz (Austria). The obtained data allowed calculation of the initial spin period of the satellite: 0.906 s. Long time series of the spin period values show that the satellite's slowing down rate is not constant but is oscillating with a period of 578 days. The results presented here definitely prove that the SLR is a very efficient technique able to measure spin period of the geodetic satellites.

1. Introduction

LAGEOS-1 (L1) and LAGEOS-2 (L2) are spherical, passive geodynamic satellites. They are identical in construction: spheres of 60 cm radius, equipped with 426 corner cube reflectors (CCRs). The parameters of the missions are presented in table 1.

Table 1. Mission parameters.

	LAGEOS-1	LAGEOS-2
Sponsor	United States	United States and Italy
COSPAR ID	7603901	9207002
Launch Date	May 4, 1976	October 22, 1992
Inclination	109.84 degrees	52.64 degrees
Eccentricity	0.0045	0.0135
Perigee	5,860 km	5,620 km
Weight	406.965 kg	405.38 kg

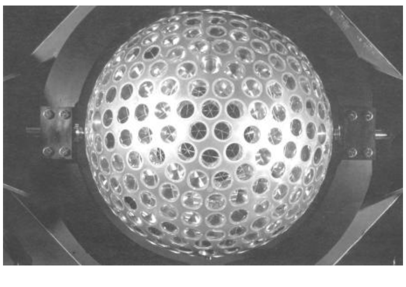

Figure 1. LAGEOS-2 (Courtesy of Italian Space Agency).

The spin parameters of these satellites were investigated using photometric (Bertotti and Iess, 1991, Otsubo et al., 2004) and SLR (Satellite Laser Ranging) measurements (Otsubo et al., 2000b, Bianco et al., 2001, Kucharski et al., 2007), however only for a certain epoch time or for very short time periods. These results then have been used for the mathematical model LOSSAM (LAGEOS Spin Axis Model) (Andrés et al., 2004), which describes and predicts the spin parameters of L1 and L2. Information about spin period value and spin axis orientation helps to verify and improve models of the orbital perturbations (Andrés et al., 2004). Better models can improve the accuracy of the orbital analysis, which in turn results in more accurate investigation of the geodynamical parameters of the Earth (geocenter position, polar motion etc.).

2. Satellite spin measure techniques

Spin parameters of the passive satellites can be investigated with 2 techniques: photometry and SLR. The photometry determines epoch times of flashes caused by sunlight, and reflected from the outer surfaces of the CCRs. This technique works only at night, with the satellite illuminated by the sun, and only with spin periods below about 100 s for LAGEOS type satellites.

The second technique measures the distance to the satellites with laser. The laser pulses transmitted from the SLR station are reflected by the CCRs back to the receiver telescope at the SLR system. The spinning satellite frequently shows the same pattern of the CCRs to the station, thus engraving a frequency signal on the SLR data. This signal can be obtained by spectral analysis (Lomb 1976) of the unequally spaced range residuals (measured – predicted satellite range) data (Otsubo et al., 2000a). The resulting spectra contain frequency peaks with values depending on the spin rate of the satellite and the number of CCRs involved.

SLR can measure spin periods of satellites during day and night, regardless to the Sun – satellite – station geometry (as it is with photometry), and without any additional equipment. With the kHz SLR system it is possible to measure spin parameters from LEO (Low Earth Orbit), like Gravity Probe - B (Kirchner et al., 2008) to HEO (High Earth Orbit), like ETALONs (Kucharski et al., 2008), from very slow spinning objects like LAGEOS-1 (Kucharski et al., 2007) to fast spinning like AJISAI (Kirchner et al., 2007). Table 2 shows the main differences between the previous Graz 10 Hz and the new Graz 2 kHz SLR system. This new system is able to detect return pulses with single or multiple photons, resulting in up to > 1 million measurements per pass of LAGEOS-2, even with its low energy per laser shot (400 μJ).

Table 2. Key parameters of Graz SLR system.

Graz Laser System	10 Hz Laser before 2003/10/9	2 kHz Laser after 2003/10/9
Wavelength	532 nm	532 nm
Repetition rate	10 Hz	2 kHz
Energy/Pulse	30 mJ	400 μJ
Pulse width	35 ps	10 ps

3. Spin period determination

Since the beginning of SLR measurements to LAGEOS-2, many stations send full rate data to the International Laser Ranging Service (ILRS) Data Centers (Pearlman et al., 2002). We spectrally analyzed all available data sets, and got frequency spectra for all of the passes. Only spectra with visible signal peaks of power more than 10 were accepted for further processing. This criterion allowed calculating spin period since 23rd of October 1992 (1 day after launch). The 426 CCRs on the satellite are arranged in 20 rings (with different number of prisms). The different rings are the source of multiple frequency signals (spectral peaks; fig. 2), detectable with Lomb analysis. The values of these peaks are a result of the number of CCRs on the corresponding ring and the spin rate of the satellite; additional peaks can be caused by superposition of a signal produced by two neighboring rings.

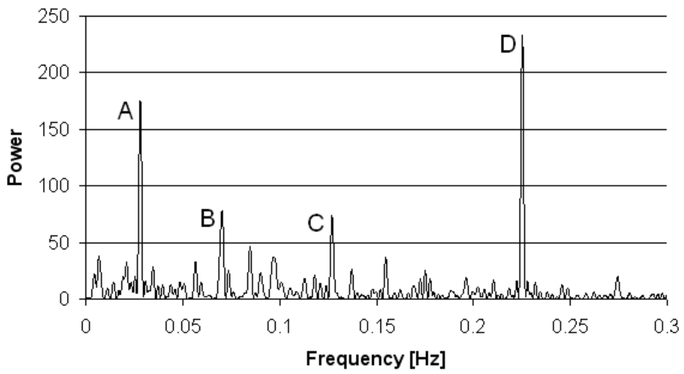

Figure 2. Result of spectral analysis of a kHz pass: LA2 of 15th March 2004.

Fig. 2 presents spectral peaks of a Graz kHz SLR observation of L2, taken on 15th of March 2004. The signal peaks can be recalculated into spin period by formula period = N / frequency, where N is a multiplication factor. In order to obtain the period of the body we were changing the N factor (from 3 to 32) and comparing the result value with LOSSAM predictions. The best agreement criterion allowed us to find out that the D peak is generated by the ring or rings equipped with 32 CCRs (142.3 s = 32 / 0.2249 Hz). The most powerful peak of each single pass – together with its correlated number of CCRs – was used to determine the spin period. However, it must be emphasized that the detected frequency signal is an apparent one; the changing station - satellite geometry during the pass is influencing the detected signal. This work thus presents apparent spin period values as detected by each SLR station. Without knowing the satellite's spin axis orientation it is not possible to properly correct the measured apparent spin period value and get a true spin period of the satellite. However, over a large number of passes, this effect may be considered to average out and should not affect our conclusions regarding long-term spin period behavior.

Fig. 3 shows spin period of L2 (from 1992-10-23 to 2007-08-15, 15580 points) derived from the global SLR full rate data. The resulting spin period data series were divided into time slots of 0.25 years. Spin period values within the slots were approximated with linear function, and spin period residuals to this function were obtained. The RMS of the residuals of every time slot is presented on fig. 4.

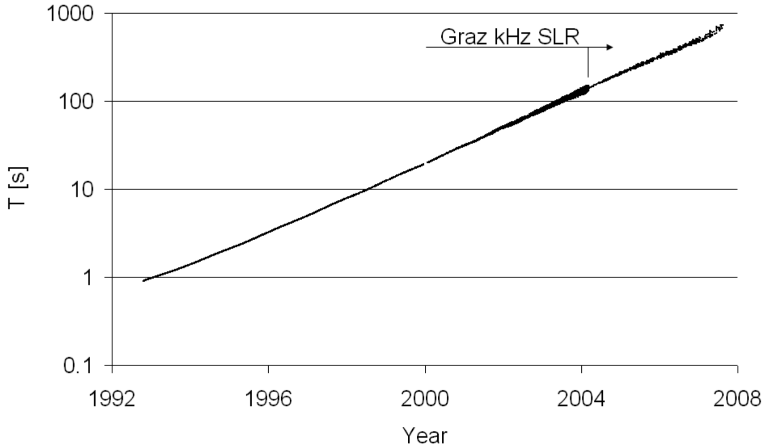

Figure 3. Spin period of L2 (logarithmic scale) derived from SLR data.

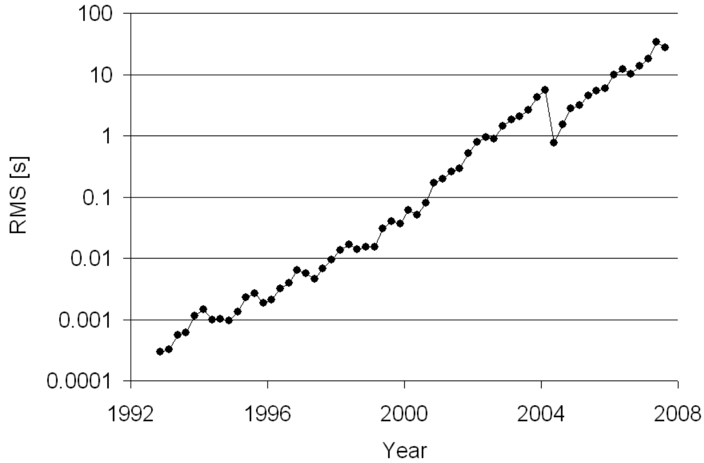

Figure 4. RMS of spin period residuals calculated with a quarter of a year step.

With a slowing down of the satellite the RMS of spin period residuals is increasing with an exponential trend. The number of full rotations of the satellite per pass is decreasing with an exponential trend, thus the frequency signal detected by SLR station gets poorer from pass to pass. The significant improvement of the RMS occurs when the Graz kHz data started to be used. Two hundred times more measurements per pass allow calculation of spin period values with an order of magnitude better accuracy than the 10 Hz SLR systems can give. The Graz kHz SLR data allowed extension of the investigated period for L2 for another 4 years, from 2003 to 2007. While spectral analysis of L2 passes failed for 10-Hz-stations after 2003 (spin period significantly above 100s), the last spin period value for L2 using Graz kHz data was 721 s (15^{th} of August 2007).

4. Determination of initial spin period

Such a long time trend of spin period data allow determination of initial spin period value T_0. We used 137 spin period values measured during the first 30 days after the launch. These values were approximated with a linear function $T = 0.00089012Y + 0.90604$ [s]. The function points to an initial spin period value of $T_0 = 0.906$ s; the spread of the spin period points around the linear trend function is RMS = 0.000228 s.

5. Slowing down of LAGEOS-2

To investigate the continuity of the spin period increase, we calculated the differences between the values separated by given number of days D (±1%) and plotted them as percentage of actual spin period dT. We have processed a set of investigations with increasing the D number from 10 to 500 with a step of about 10%. The result for D = 500 and 90 days are presented on fig. 5 and 6. The results obtained for every D value were spectrally analyzed. By setting D = 500 days it is possible to investigate the main trend of the spin period changes. Graz kHz SLR data (visible at the end of the chart) allowed to complete the trend function (2nd degree polynomial) and to calculate its maximum (at about 2002.5). For D = 90 days (fig. 6) spectral analysis gives a peak which is indicating a period of T_{90} = 578 days.

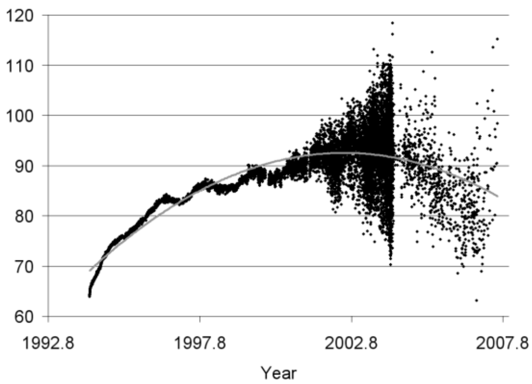

Figure 5. L2 spin period changes: percent of change between points separated by 500 days and 2nd degree polynomial main trend function.

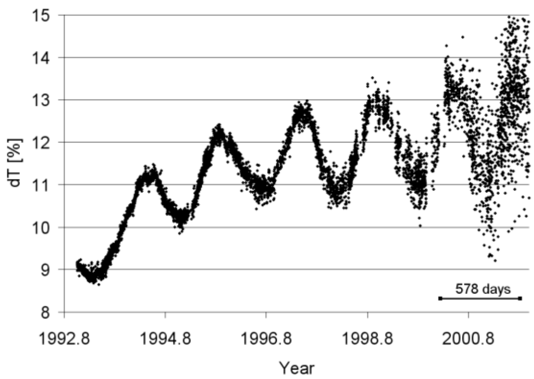

Figure 6. L2 spin period changes: percent of change between points separated by 90 days. Oscillation period: 578 days.

Spectral analysis of dT gives also a good signal for D = 30 days (fig. 7) of a value T_{30} = 103 days. These oscillations are visible up to 2 years after launch.

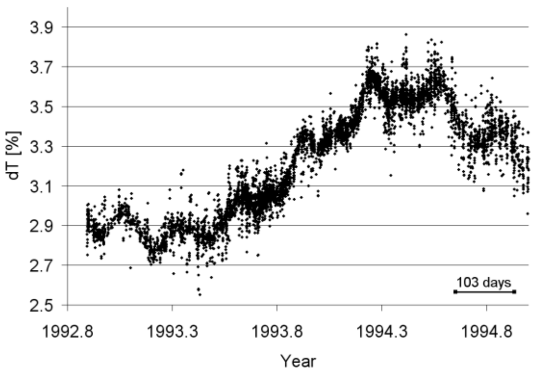

Figure 7. L2 spin period changes: percent of change between points separated by 30 days Oscillation period: 103 days.

6. Conclusions

Satellite Laser Ranging allows determination of spin period of a passive satellite LAGEOS-2. In this paper we used all available laser measurements of all SLR stations to derive spin period values of 15 years for L2 (15580 points). Due to the increasing L2 spin period, only Graz kHz SLR data - with its high repetition rate and 10 ps pulse width - permitted calculation of L2 spin period after 2003; this kHz data also yields an order of magnitude higher accuracy. The values presented here are in very good agreement with the LOSSAM model. Up to now, only 463 spin rate measurements of L2 have been made by photometry, until this technique had to be stopped at the end of 2002 for L2, because of too long spin periods of the both satellites.

The accuracy of spin period determination depends on the number of satellite's full revolution during the single pass and it is decreasing with en exponential trend. However, it is good enough to process detailed analysis of the satellite's slowing down rate. The oscillations of the slowing down rate can be caused by gravitational torque acting on the satellite. The period of the oscillations depends on an angle between the angular velocity vector and the spin axis vector of the satellite.

The evolution of satellite spin periods gives information about forces acting on the spacecraft, and causing perturbation of its orbit. The first-time accurate determination of long series of such spin period values can be used to upgrade models of all those forces.

7. References

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