Determination of LAGEOS Spin Motion from Photometric Observation

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1. Introduction

The attitude of geodetic satellites is now a key parameter when we precisely analyse their orbits. It is now well known that thermal thrust and anisotropic emissivity significantly perturb the orbit of geodetic satellites such as LAGEOS [1-3], ETALON [4] and AJISAI [5-6].

There are currently three methods available to determine the spin motion of these satellites:

(a) timing measurement of flashes

(b) spectral analysis of SLR full-rate data

(c) residual analysis of along-track acceleration

Approach (a) involves the timing of flashes that are caused by sunlight reflected by the satellite. We can use flashes reflected by curved mirrors in the case of AJISAI [7], but the reflection from the surface of a corner cube reflector (CCR) is the only observable from the LAGEOS satellites. The observation chance is therefore significantly limited because the satellites do not flash continuously.

Method (b) is to apply spectral analysis to SLR full-rate data, as has been demonstrated for AJISAI [8] and LAGEOS [9]. The spin rate derived by this approach has been less precise than the flash observation, but it has an advantage in that no special observation facilities are required except the laser ranging system itself. It therefore maximises the time and spatial coverage although at the moment the method is not sensitive to the spin axis direction.

The last option (c) is rather an indirect method. Analysing the residual variation of empirically solved along-track acceleration, some physical parameters of LAGEOS were adjusted and the equation of motion of a rigid body was solved at the same time [10][11]. We believe this method is meaningful in terms of the direct relation with the satellite orbit, but there is a significant risk of confusing the spin-related modelled forces with other non-graviational forces.

This paper describes our attempt to determine the spin rate and the spin axis of two LAGEOS satellites, but mainly focusing on LAGEOS-2, using the approach of (a). A similar attempt has already been made for LAGEOS-1. Astro-metrology group at University of Maryland had coordinated the flash observation from world-wide stations until mid-90's [3], but no data has been obtained since 1996 probably because the spin rate is now so slow that very few flashes occur.

2. Observation system at Herstmonceux

We developed a photometric observation system at the UK laser ranging facility at Herstmonceux. Non-green signal rejected by a dichroic mirror is guided to a photomultiplier Hamamatsu H7155 whose outputs per a certain time is counted by a universal counter Stanford Research SR620. Fig 1 shows the signal processing scheme.

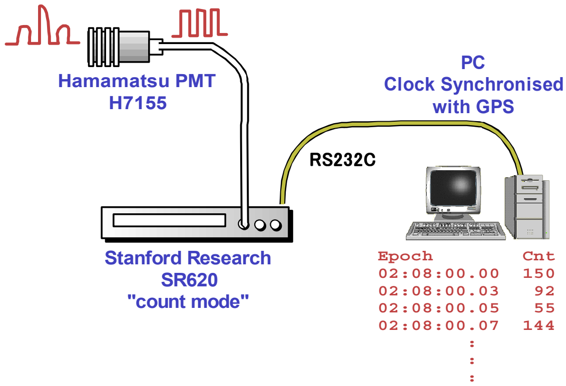

Fig. 1: The Photometer and event counting system at Herstmonceux.

As the timing measurement in this system relies on the RS232C communication, the time duration to count the number of events is set to a minimum of 20 ms at the moment. We also need to stop firing the laser because its light sometimes looks like the flash signal.

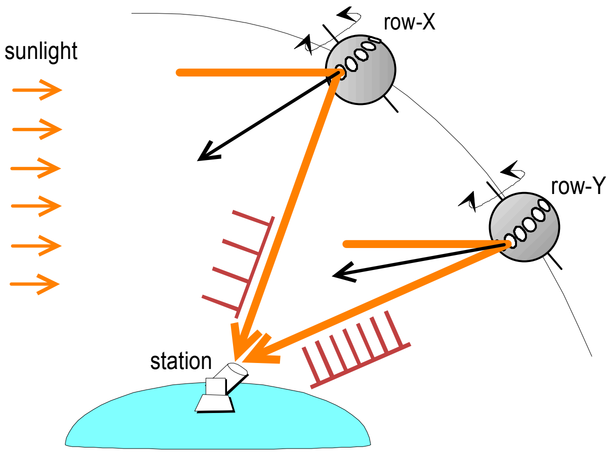

Fig. 2: Flashes from LAGEOS satellites.

We have successfully observed many bursts of flashes in 23 LAGEOS-2 passes and possible flashes in 9 LAGEOS-1 passes since Jan 2000. The duration of the LAGEOS-2 flash is considered to be about 15 ms, i.e. shorter than the time resolution of our system, and it continuously happens for a few tens of seconds. All flashes in a "burst" are reflected by the CCRs located in the same row at an equal longitudinal interval. A few bursts from different rows are usually observable per pass. On the other hand, from only 0 to 2 flashes per pass were observable from LAGEOS-1 due to its slow spin rate, but with a much longer flash duration of from one to two seconds. According to the prelaunch report of LAGEOS-2 [12], the two satellites identically have 20 rows of CCRs, each row having different number of CCRs, namely 32, 32, 31, 31, 27, 23, 18, 12, 6 and 1 running from the equator to the pole in each hemisphere.

3. Data analysis (LAGEOS-2)

(a) Spin rate

A number of LAGEOS-2 flashes in three bursts obtained on 4 Mar 2000 are plotted in Fig 3. Spike pulses are the reflection from the satellite and the base is the background noise. As it is close to the dawn, the background noise rose but the satellite signal remained visible. The mean time intervals between two adjacent pulses are different; 0.654 s for the first case, 0.673 s for the second and 0.772 s for the last. We found the ratio between the three very close to the inverse of 32:31:27 each of which is the actual number of CCRs per row. Multiplying the mean intervals by the estimated number of CCRs, therefore, the spin period and the trend can be obtained. In the case of Fig. 3 (4 Mar 2000), the spin period was about 20.9 s.

50 such bursts have been observed between March and July 2000. The spin period has increased

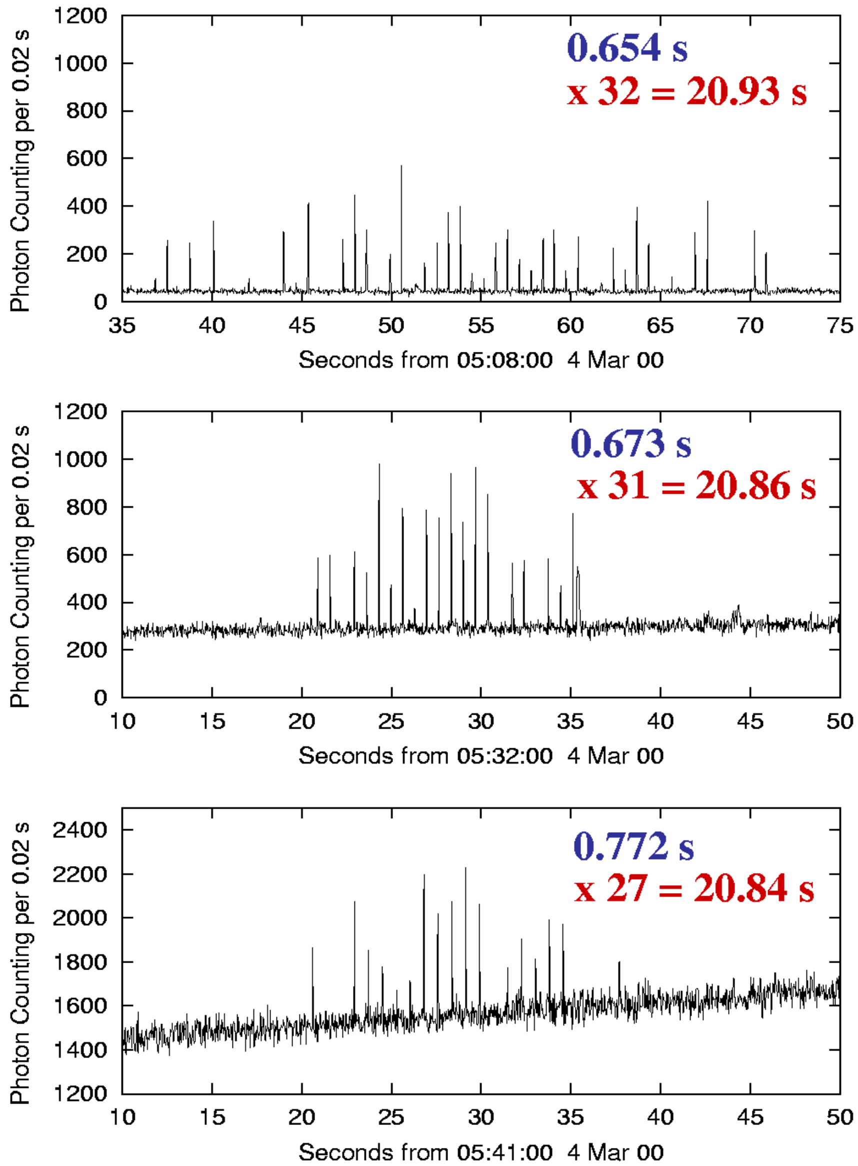

Fig. 3: LAGEOS-2 photocounting around three flash bursts observed at Herstmonceux on 4 Mar 2000.

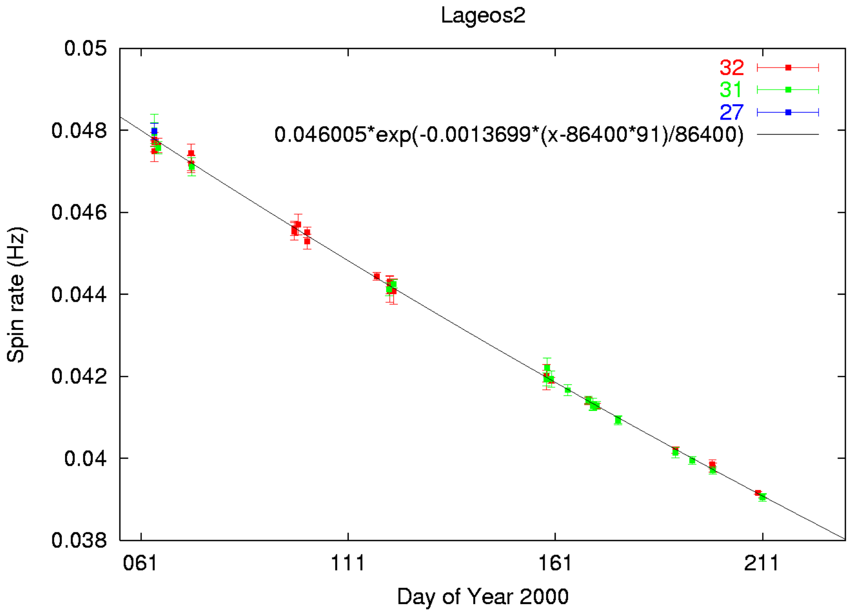

Fig. 4: Estimated spin rates of LAGEOS-2 in 2000. The red points are from 32 CCR row, the green points from 31, and the blue points from 27.

during these four months, reaching 25.6 s on 29 July 2000. The best-fit exponential curve (Fig. 4) indicates that the spin rates (=reciprocal of spin period) is decreasing by 40% per year.

(b) Spin axis

Now the number of CCRs can be identified, but an ambiguity problem must be solved. Any of 2 or 4 possible rows contributes to a flashing burst because there are 2 or 4 rows whose number of CCRs are the same. For instance, when a burst is identified as being generated by a 31-CCR row, it must be one of either the third or fourth rows in the upper hemisphere, or the third or fourth rows in the lower hemisphere.

When the flash is observed, the direction of the normal vector of the CCR surface in the J2000.0 inertial reference frame can be calculated from the geometry between the sun, the satellite and the Herstmonceux station.

For example, let us discuss the acutal data set on 6 June 2000 (Fig. 5). The first burst was from a row with 31 CCRs and the normal vector is computed to be directed towards a Right Ascention of 2.087 hours and a Declination of 3.411 degrees. When only the first burst is available, the spin axis can lie anywhere on the four red curves. With the second burst, the ambiguity is reduced to several crossing points of any of four red and any of four green curves. Usually three or four bursts are needed to remove the ambiguity and find the solution. In this case, the third (blue curves) burst determined the unique solution, which was confirmed by the fourth one (purple curves). Strictly speaking, the four

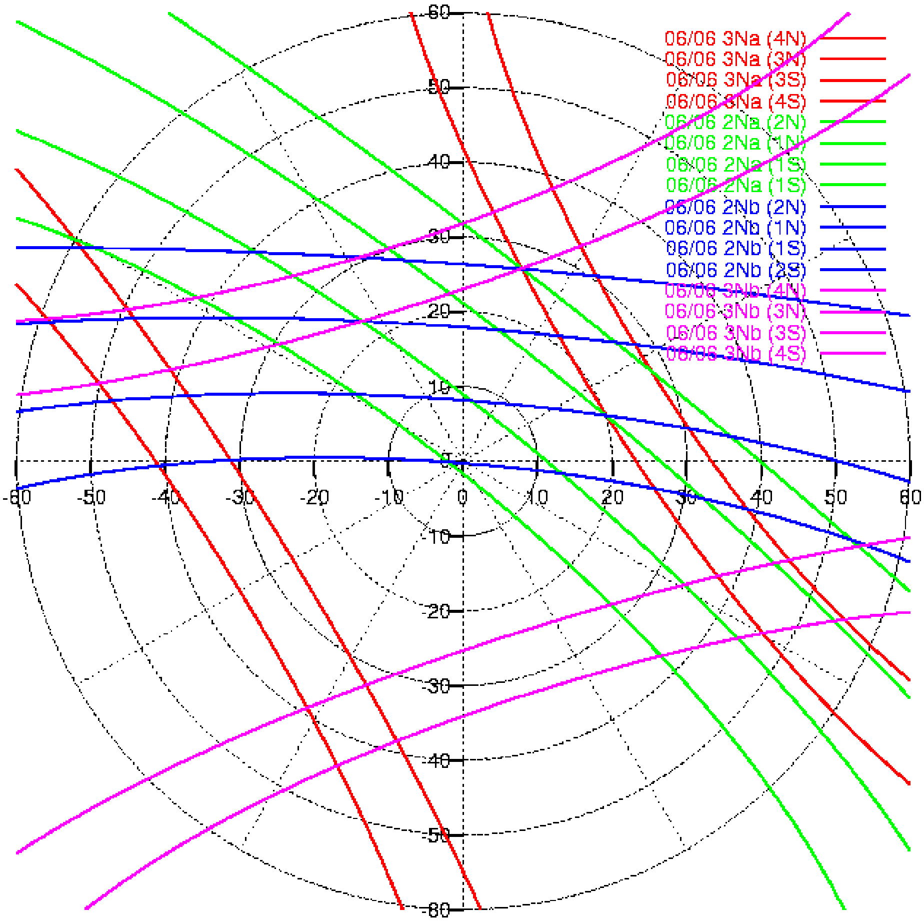

Fig. 5: The algorithm to determine the spin axis direction. The solution is at the point where all of four coloured curves cross.

curves did not cross exactly but passed around a point due to the observation error, but it was as close as 0.25 degrees.

In this way, 8 effective solutions were obtained as shown in Fig. 6 although not all passes have plenty of bursts. The spin axis is seen to be inclined from the Earth's rotation axis at approximately 25 degrees, and to be precessing clockwise. The time span of our solution so far is too short to compare with the solution of Farinella [11].

4. Data analysis (LAGEOS-1)

The LAGEOS-1 satellite does not flash as frequently as LAGEOS-2. The spin period had increased from 0.6 s just after its launch in 1976 to 490 s in 1996, the final observation available at a website of Univ of Maryland [13]. From the exponential curve fitted to their observations, the period is expected to be close to one hour in 2000.

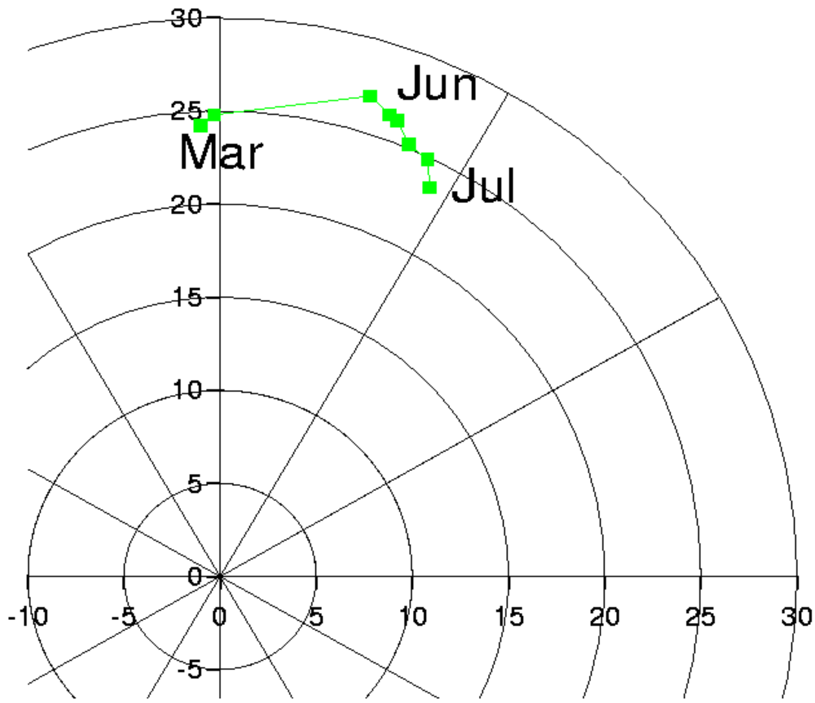

Fig. 6: The precessing motion of the LAGEOS-2 spin axis from March to July 2000.

The Herstmonceux photometry system has observed a few tens of LAGEOS-1 passes most of which are fruitless. However, some passes include one or two wide pulses. After rejecting ones that matched bright stars listed in star catalogues, we found 8 possible flashes whose pulse durations were 1.2 to 2.6 s, the only information we can use now. The angular diameter of the sun is about 0.5 degrees and the duration of the reflected flash should be eqivalent to a 0.25-degree rotation of the satellite, assuming that it swept the full diameter of the sun. Using the longest duration of 2.6 s among our obsesrvations, the spin period is approximated at one hour.

5. Conclusions and future studies

The spin motion of LAGEOS-2 was precisely monitored using the newly developed photometry system at Herstmonceux, UK. The slowdown of its spin rate was estimated at 40% per year and its spin axis precessed through tens of degrees just in four months. The spin behaviour of LAGEOS-1 is now difficult to be monitored because of its very slow spin rate, but the observed flash duration suggested a spin period of approxmately 60 minutes. We need more observations, although the chances of obtaining them are getting slimmer.

We are going to enhance the time resolution of the photometry system. With one-ms time resolution we will be able to monitor the direction of the spin axis as well as carry out a more precise determination of the spin rate, and in addition we will not have to stop the laser ranging operation. This photometry system would be useful in monitoring the orientation of other satellites.

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