18th International Workshop on Laser Ranging, Japan

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

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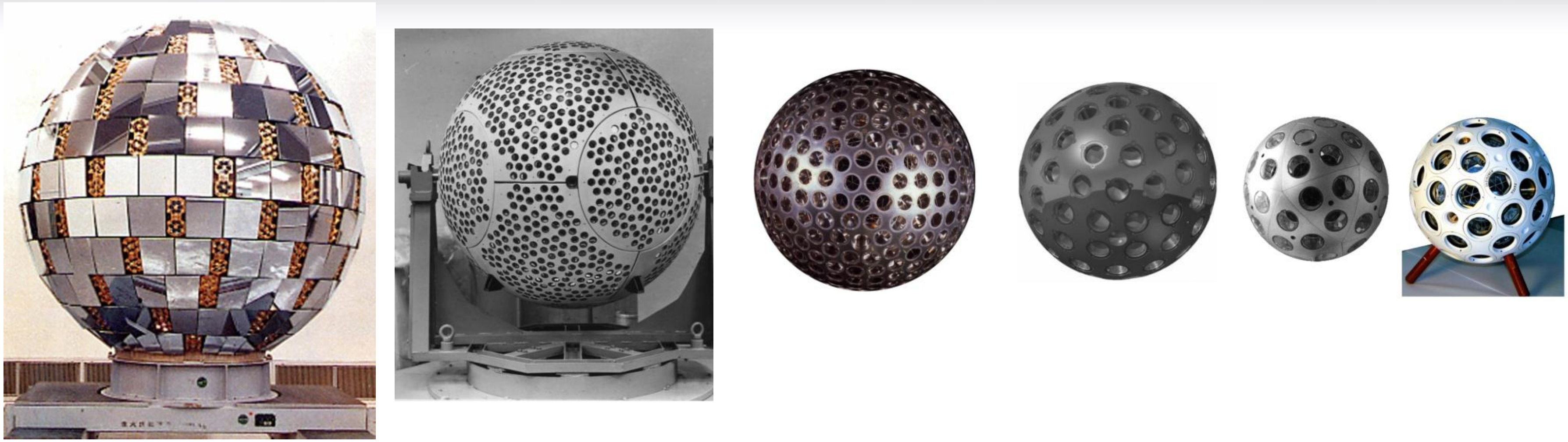
13-0304. November 13, 2013

Spinning geodetic satellites



Ajisai ETALON-1/2 LAGEOS-1/2 LARES Stella Larets

	Launch date	Perigee [km]	Mass [kg]	Radius [m]	Initial spin period [s]
Ajisai	August 12, 1986	1485	685.0	1.075	1.49
Etalon-1	January 10, 1989	19105	1415.0	0.647	60.20
Etalon-2	May 31, 1989	19135	1415.0	0.647	59.40
LAGEOS-1	May 4, 1976	5850	407.0	0.300	0.43
LAGEOS-2	October 22, 1992	5625	405.4	0.300	0.98
LARES	February 13, 2012	1450	386.8	0.182	11.80
Larets	September 27, 2003	691	23.3	0.120	0.82
Stella	September 26, 1993	815	48.0	0.120	13.20

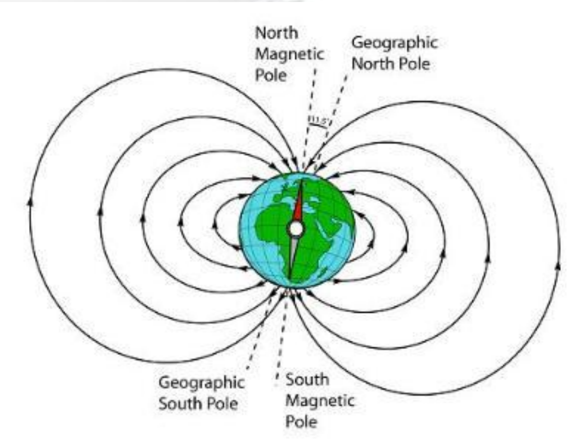
Spin measurement and motivation

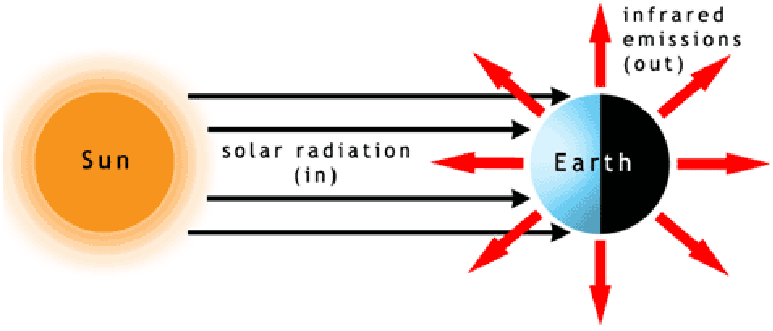
- Spin parameters of the passive, geodetic satellites can be measured by photometry and SLR.

-SLR can measure spin of the fully passive satellites during day and night, without any additional equipment. SLR delivers long data spans (many years of continues observation).

- The geodetic satellites are launched with an initial spin, which helps to stabilize the spacecraft in the inertial space.

- The spin parameters, are changing over time. This is caused by the influence of the Earth's gravity and magnetic fields, and the solar irradiation. We need to study this phenomenon in order to better understand the dynamics of the artificial satellites.





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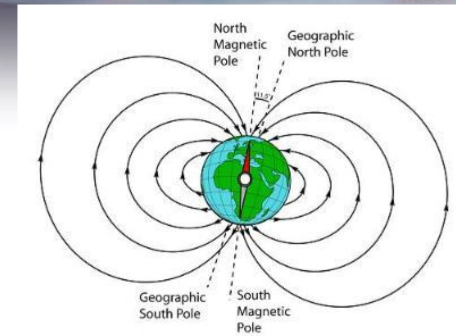
Spin measurement and motivation

The theory background

The magnetic torque (Bertotti and Iess, 1991)

$$\Gamma_{magnetic} = V\alpha'\varpi \times B(\varpi \cdot B) - V\alpha''(B \times \varpi) \times B$$

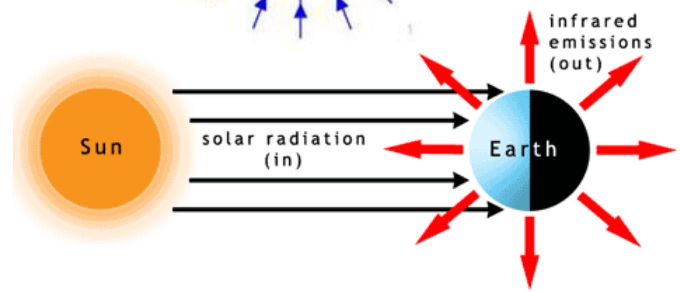


The gravitational torque (Farinella et al., 1996)

$$\Gamma_{gravitational} = -\frac{3m^2}{4L^2}(C - A)(3\cos^2\vartheta - 1)(n \cdot L)(n \times L)$$

Solar radiation pressure causes a torque (Vokrouhlicky, 1996)

$$\Gamma_{offset} = \frac{I_0 h C_R A_{cross}}{c}(s \times r_{sun})$$

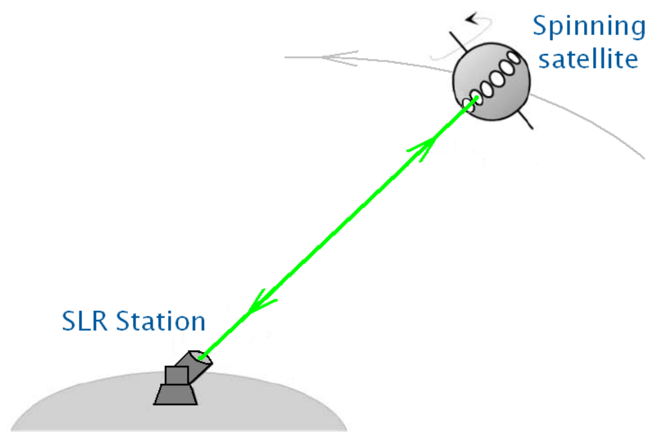


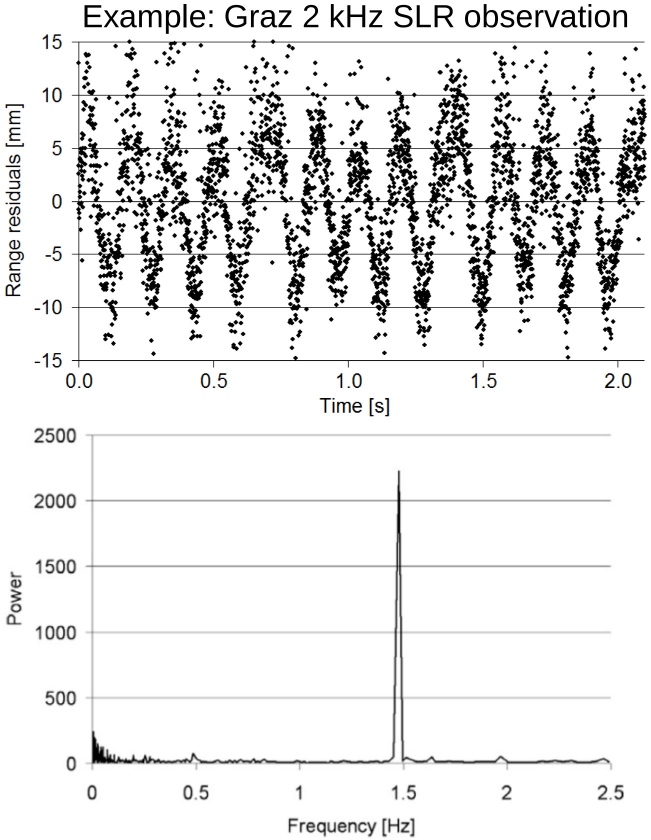
LOSSAM – Spin model for LAGEOS (Andrés et al., 2004)

Andrés J. I., et. al. Spin axis behavior of the LAGEOS satellites. J. Geophys. Res., 109 (B6), B06403, 2004
Bertotti, B., and Iess, L. The rotation of LAGEOS, J. Geophys. Res., 96 (B1), 2431-2440, 1991
Farinella, P., et al. The rotation of LAGEOS and ist long-term semimajor axis decay, J. Geophys. Res., 101 (B8), 17,861-17,892, 1996
Vokrouhlicky, D. Non-gravitational effects on LAGEOS' rotation. Geophys. Res. Lett., 23, 3079-3082, 1996

Spin determination

In order to determine the spin rate of the satellite we apply frequency analysis to the full rate range residuals data. This method has been demonstrated by T. Otsubo et al. – Ajisai, LAGEOS-2, G. Bianco et al. – LAGEOS-2, G. Kirchner et al. – Ajisai, D. Kucharski et al. – Ajisai, Etalon-1/2, LAGEOS-1/2, LARES, Larets, Stella.

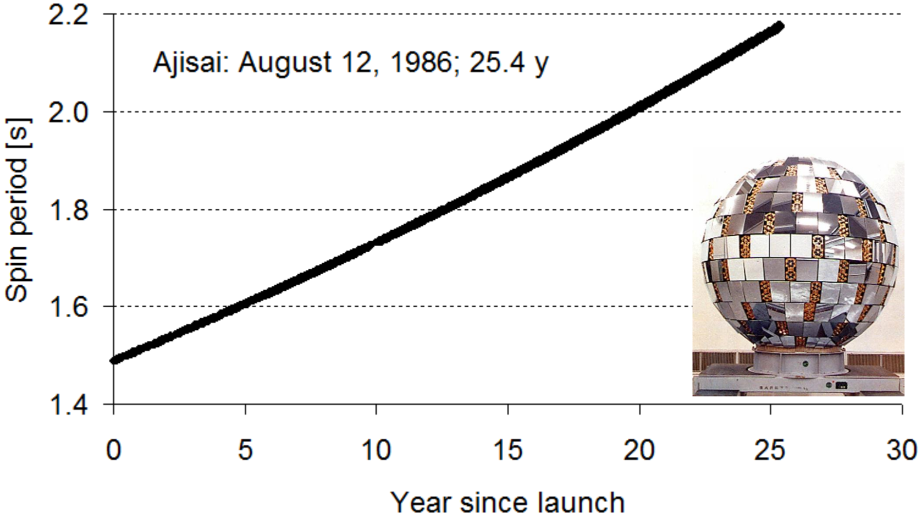


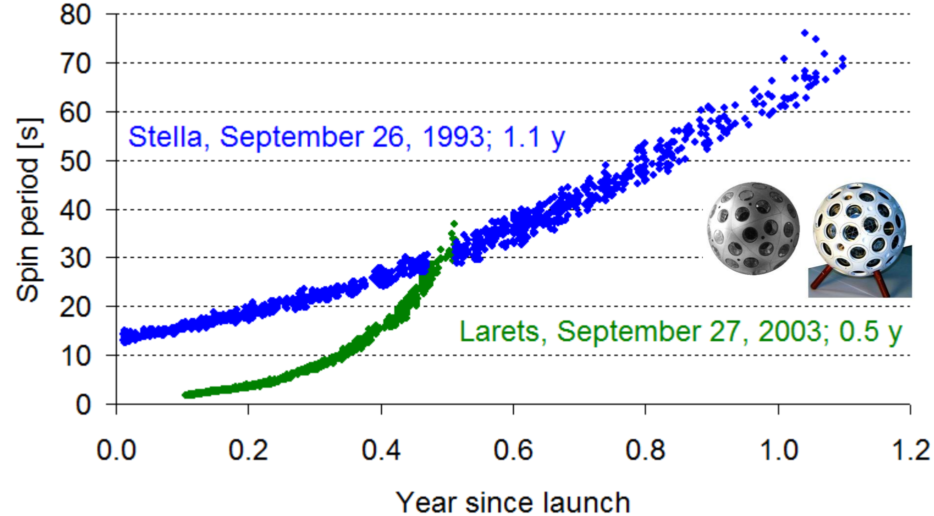


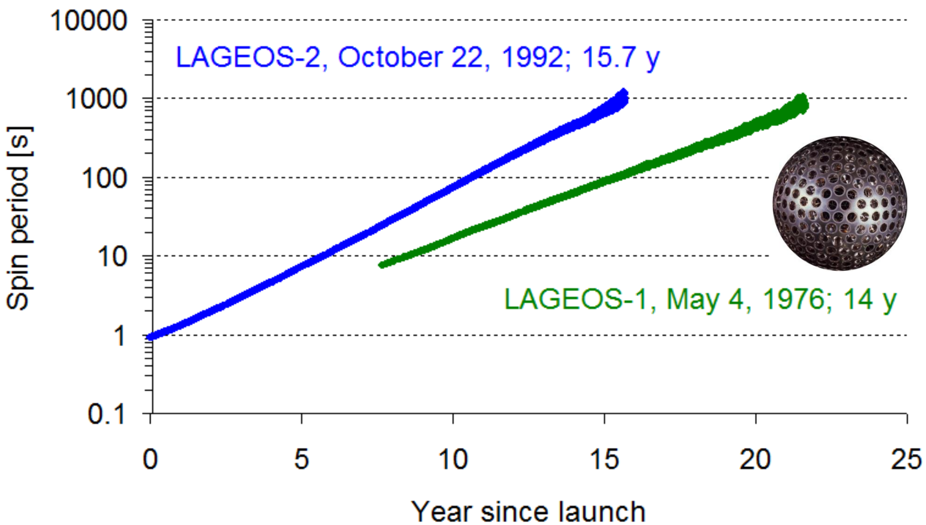
The High Repetition Rate SLR data significantly improves the accuracy of the spin determination, and makes possible to investigate spin of the slowly rotating satellites (not possible with 10 Hz systems).

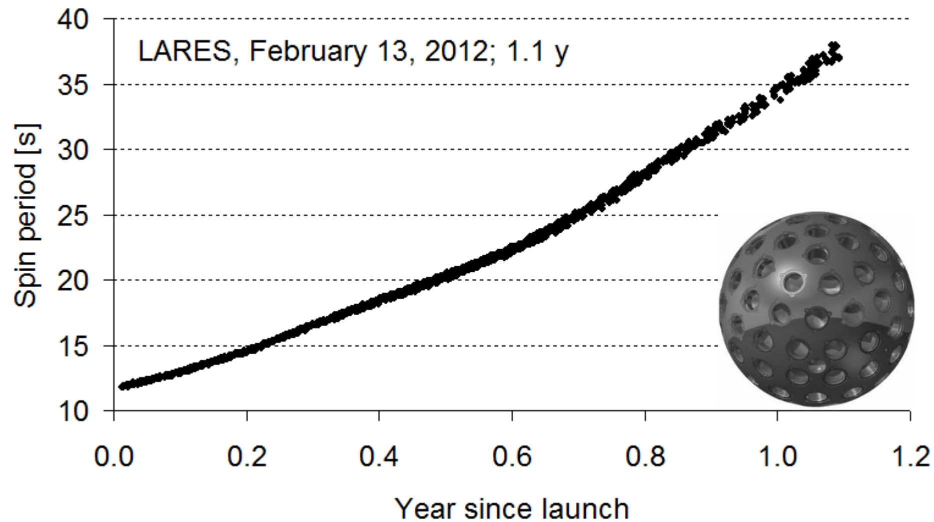
Spin determination

The exponential lose of rotational energy is caused by the Earth’s magnetic field – eddy currents.



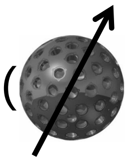




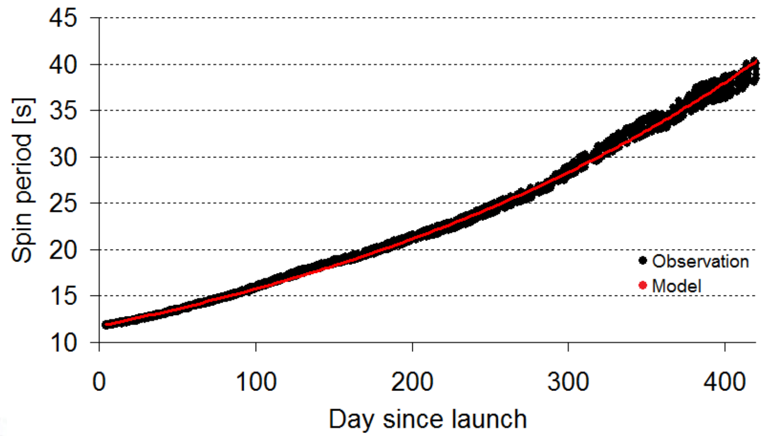


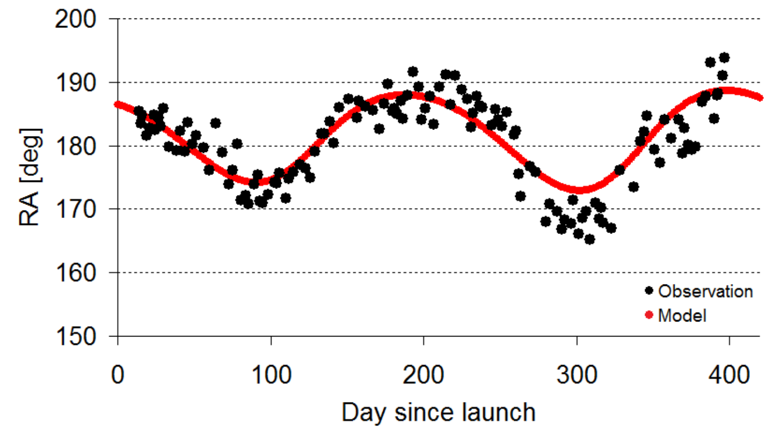
Analysis of the spin trends – spin models

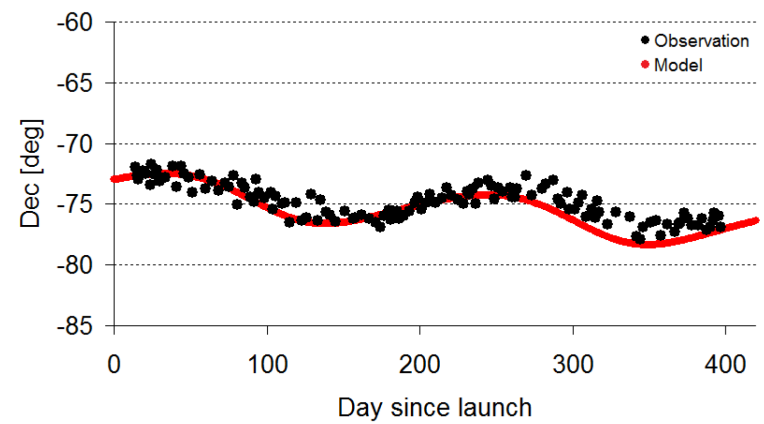
Spectral analysis of SLR data gives an apparent spin of a satellite.

$f_{apparent} = f_{inertial} + \text{ApparentCorrection}($  $)$

LARES







-Analysis of the apparent effect allows to find orientation of the spin axis

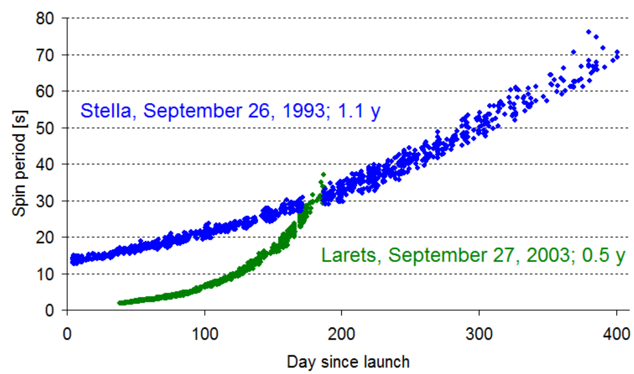
-Observed spin parameters make possible to model the spin dynamics of LARES (initial spin conditions required) [Bertotti, Iess, Farinella, Vokrouhlicky, Andrés]

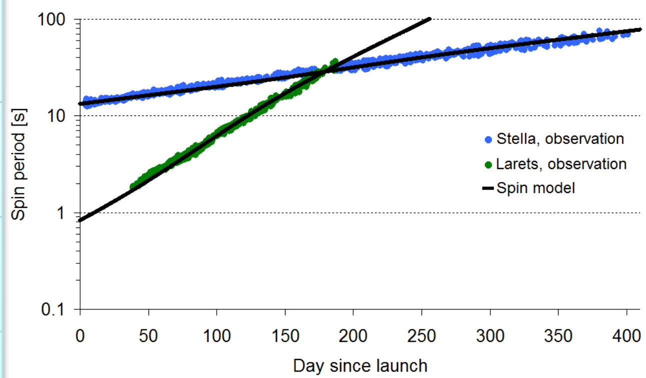
Kucharski et al. Spin axis precession of LARES measured by Satellite Laser Ranging. IEEE Geosci. Remote Sens. Letters, vol. 11 (2), doi:10.1109/LGRS.2013.2273561, in press (2013).

Analysis of the spin trends – spin models

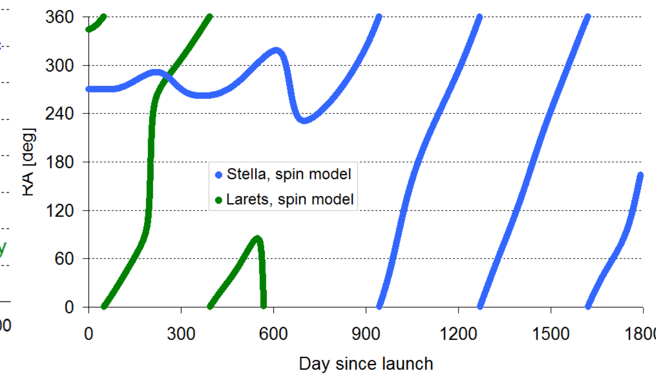
Low Earth Orbit geodetic satellites

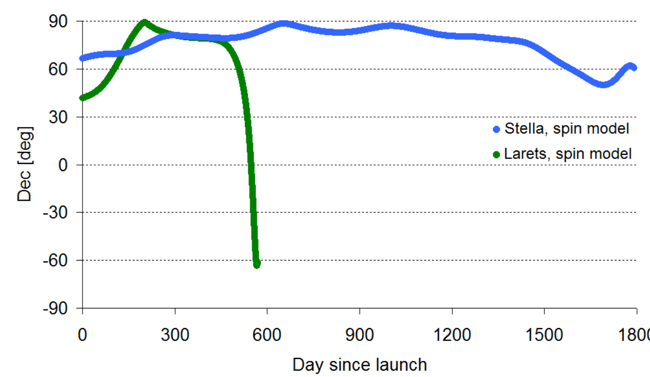
	Launch date	Perigee [km]	Orbital period [s]	Orbit in Sun [%]	Weight [kg]	Dia. [cm]
GFZ-1	Apr 1995	398 (initial)	5539	61-100	20.63	21.5
Larets	Sept 2003	691	5911	65.4-66.9	23.28	24.5
Starlette	Feb 1975	812	6257	66.1-100	47.29	24
Stella	Sept 1993	800	6058	65.9-67.3	48	24
WESTPAC	July 1998	835	6078	66.2-67.8	23.76	24.5





Modeled spin axis orientation up to the 'resonance condition'



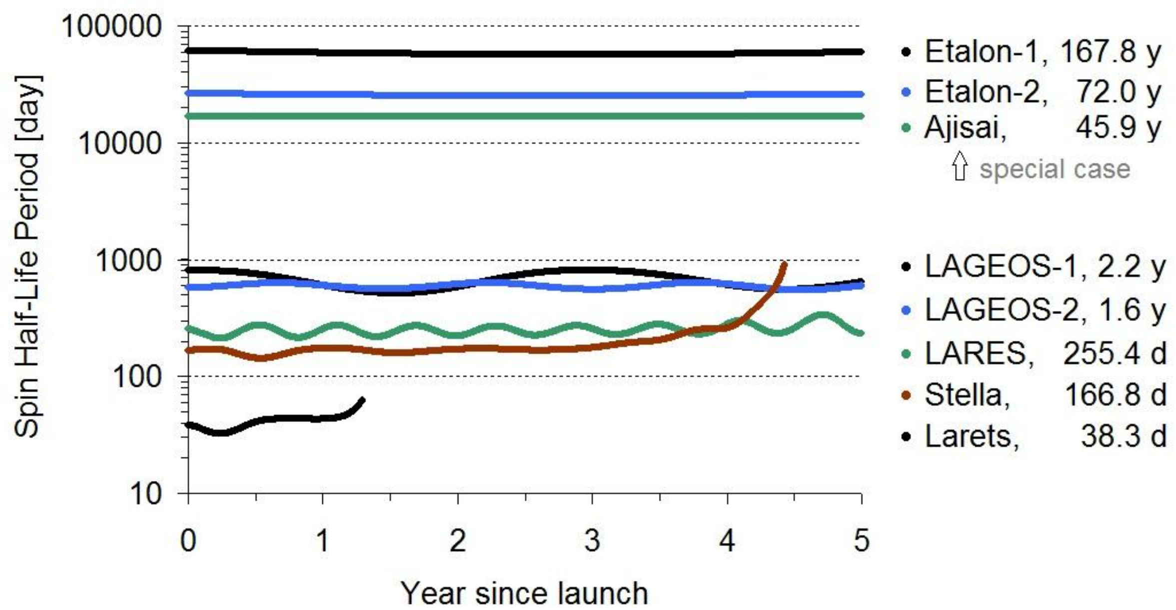


The long data span of the spin period observation and the initial spin axis orientation allow to model precession of the satellite's spin axis.

Analysis of the spin models

-The spin models allow to investigate evolution of the satellite's spin parameters (up to the 'resonance condition')

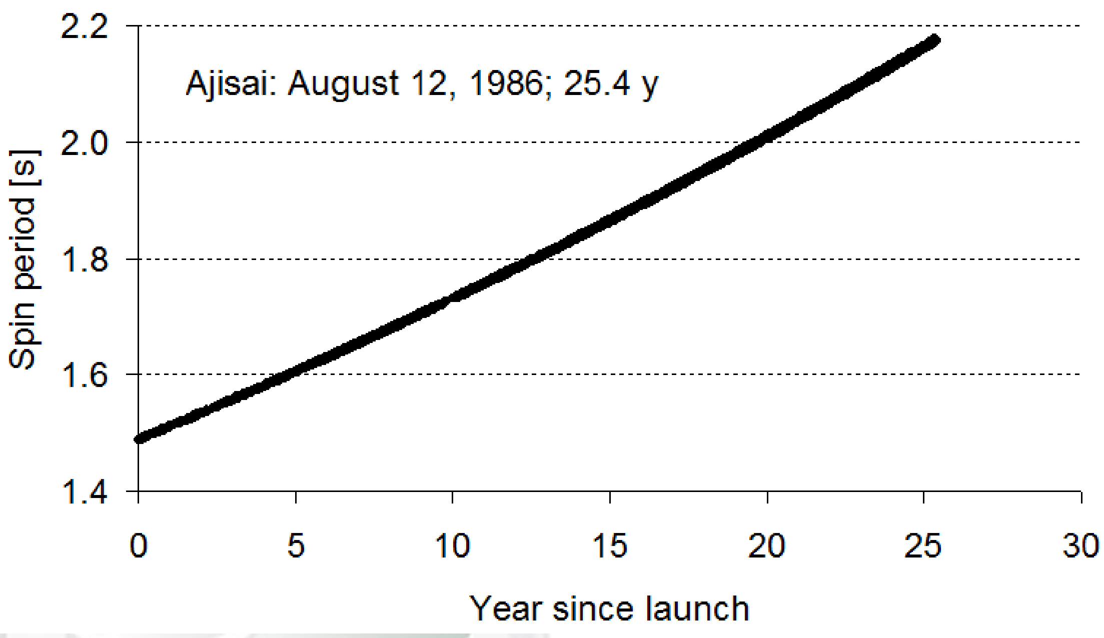
- The rate of the de-spin process can be described by the Spin Half-Life Period: this is time after which the satellite's rotational period has doubled



	Launch date	Perigee [km]	Orbital period [s]	Mass [kg]	Radius [m]	Moment of Inertia [kgm2]	Initial Magnetic torque [nNm]	Initial Spin Period [s]	Initial Spin HLP
Ajisai	Aug 12, 1986	1485	6960	685.0	1.075	527.735	1080.65	1.49	45.9 y
Etalon-1	Jan 10, 1989	19105	40560	1415.0	0.647	236.933	3.16	60.20	167.8 y
Etalon-2	May 31, 1989	19135	40500	1415.0	0.647	236.933	7.83	59.40	72.0 y
LAGEOS-1	May 4, 1976	5850	13528	407.0	0.300	12.905	1944.37	0.43	2.2 y
LAGEOS-2	Oct 22, 1992	5625	13348	405.4	0.300	11.225	1048.49	0.98	1.6 y
LARES	Feb 13, 2012	1450	6885	386.8	0.182	5.125	80.70	11.80	255.4 d
Larets	Sept 27, 2003	691	5906	23.3	0.120	0.134	209.84	0.82	38.3 d
Stella	Sept 26, 1993	815	6053	48.0	0.120	0.365	8.51	13.20	166.8 d

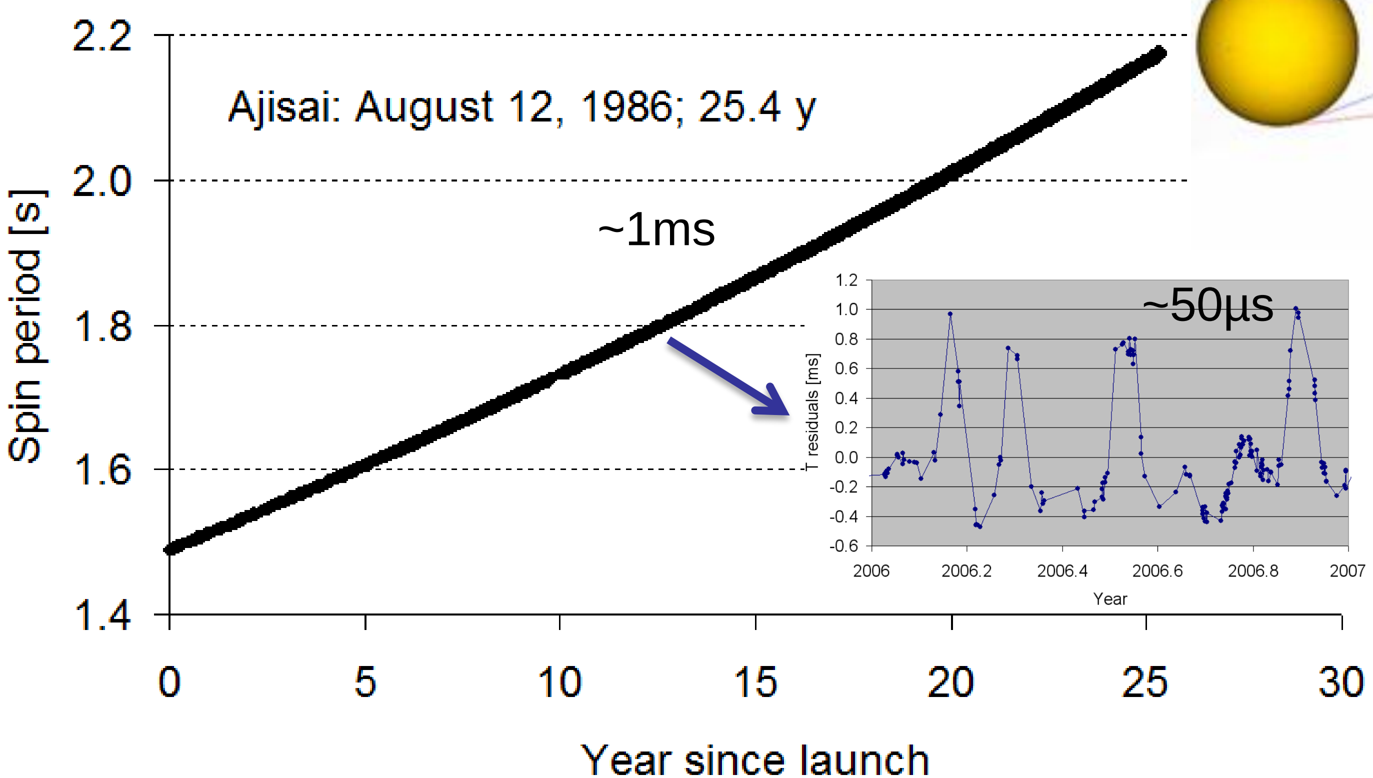
Analysis of the spin trends: Ajisai

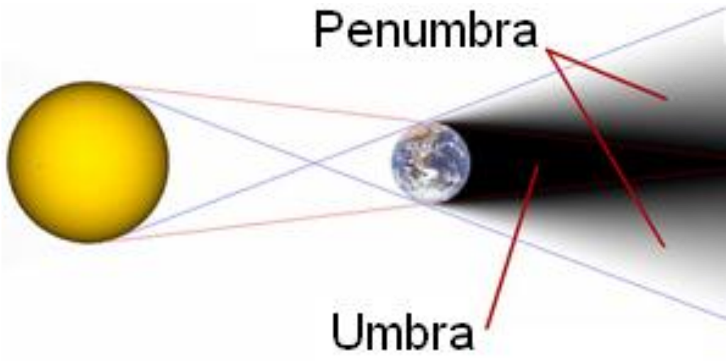
- Ajisai presents special spin behavior among the geodetic satellites.
- Ajisai is losing rotational energy very slowly - it takes about 46 years for the spin period to double.
- This property has been achieved by composing the surface of the body from several thin layers of aluminum separated by a dielectric film.
- The structure of Ajisai minimizes the possibility of conducting the eddy currents by the Earth's magnetic field, prevents lose of the rotational energy and stabilizes the attitude of the spacecraft



Analysis of the spin trends: Ajisai

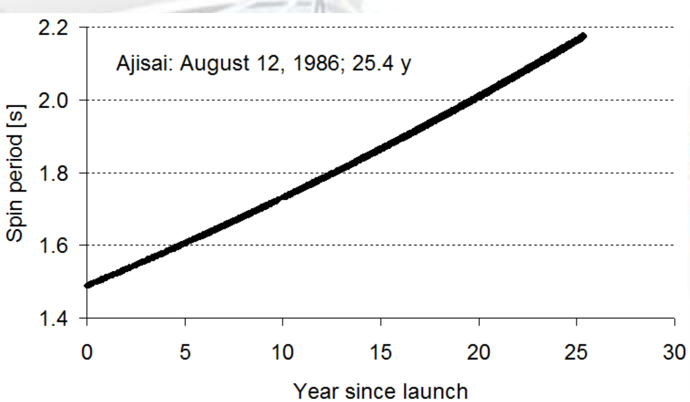
- The fast spin and the slow de-spin process of Ajisai allow to study the tiny spin perturbations (at µs level) caused by the solar irradiation.
- Ajisai is changing its temperature as it travels through the shadow of the Earth.

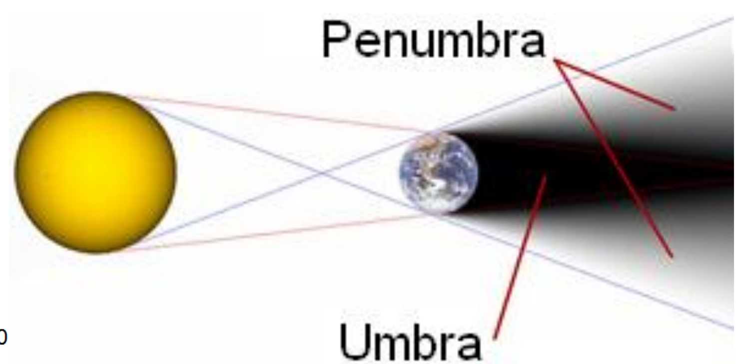




Analysis of the spin trends: Ajisai

- the general spin model allows to predict the exponential slowing down of Ajisai (due to the interaction with the Earth's magnetic field) with ~1 ms accuracy (RMS of the spin period residuals; 25 years of data); it is not possible to achieve this accuracy with regular exp functions / polynomials.
- including the model of the Sun-related effects (heat) allows to achieve ~50 µs accuracy of the spin period prediction.
- we plan to upgrade the spin model (the first half of 2014) and predict the spin period of Ajisai with accuracy better than 10 µs (new penumbra model – ASI/Matera, Earth's albedo model).
- analysis of Ajisai's spin perturbations caused by the Sun-related effects will help to model the spin dynamics of the geodetic satellites during the slow regimes (LAGEOS-1/2, LARES, Starlette/Stella).



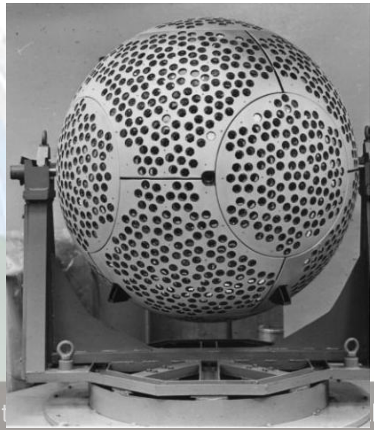


Conclusions and future plans

- SLR is the perfect technology for the spin observation of the fully passive satellites
- The long, continuous time spans of the SLR data allow to study the de-spin process of the artificial satellites
- We want to use the spin models of Ajisai, ETALON-1/2, LAGEOS-1/2, LARES, Larets, Stella, to understand the connection between the rotational dynamics and the orbital motion of the satellites (possible way to improve POD?)

Future plans:

- Improvement of the spin model of Ajisai; understanding perturbations of its spin period at a few µs level (~2 ppm)
- Modeling the spin vector orientation of the geodetic satellites during the slow regimes: LAGEOS-1/2, LARES (measured by kHz stations from the beginning), Starlette/Stella.



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Thank you!