Laser de-spin maneuver for an active debris removal mission
- a realistic scenario for Envisat

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ABSTRACT

The defunct satellite Envisat is considered to be a potential target for a future de-orbit mission (ESA's e.Deorbit). Before the removal from orbit, the massive satellite has to lose its rotational energy to present a stable attitude in the space. The laser tracking and optical observations reveal that the satellite's spin energy decays according to an exponential trend and will dissipate by 2032. This loss of the spin energy is caused by the interaction between the metallic spacecraft and the Earth's magnetic field and the de-spin process can be accelerated if an additional laser photon pressure is applied on the spacecraft's body. The simulations performed with the macromodel of Envisat indicate that a global network of ten high power laser systems (20 kW each) has the potential to exert a significant laser photon pressure force and de-spin the spacecraft 11 years earlier than it would occur naturally.

1. INTRODUCTION

The environmental satellites Envisat and Topex (Table 1) were nadir stabilized during the active time of the mission. After the end of life the satellites became passive space debris objects and lost their attitude stabilization. The lack of the active maneuvers resulted in the slow orbit decay which can be observed as a decrease of the orbital period (Fig. 1).

Table 1. Mission parameters of Envisat and Topex

Satellite	NORAD	Sponsor	Mission start	Mission end	Inclination	Eccentricity	Altitude	Mass
Envisat	27386	ESA	March 2002	April 2012	98.5°	0.001	796 km	8200 kg
Topex	22076	NASA and CNES	August 1992	October 2005	66°	0.000	1340 km	2400 kg

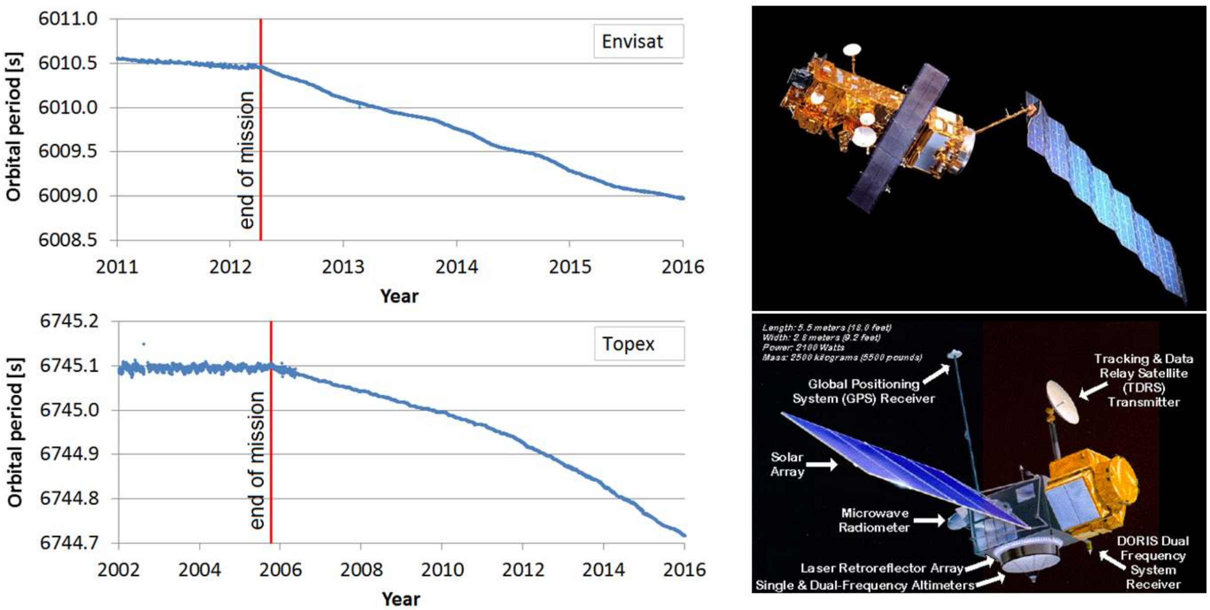

Fig 1. Envisat and Topex orbit decay after the end of the mission. Image credit: ESA, NASA

The large, passive satellites interact with the space environment and change their attitude mostly under the influence of the Earth's gravity and magnetic fields and solar radiation pressure. Envisat and Topex reveal a very interesting spin dynamics which can be measured by the laser ranging and optical systems. In order to determine the spin rates of the satellites we use the laser range observations collected by the SLR systems from Graz (major participant) and other participants organized within the Space Debris Study Group of International Laser Ranging Service [3].

2. SPIN ANALYSIS

Envisat and Topex are equipped with the retro-reflector arrays for the satellite laser ranging (SLR) observations. The SLR data can be also used to determine the inertial orientation and the spin rates of such objects. The laser observations delivered by the global ILRS stations indicate an opposite spin behavior of the analyzed satellites: the spin period of Envisat is increasing over time (Fig. 2), while the spin period of Topex is decreasing (Fig. 3).

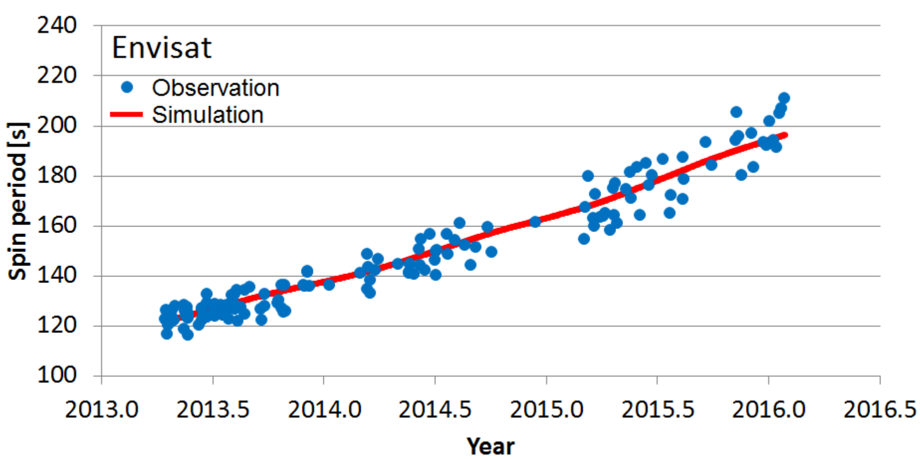

Fig 2. Spin period of Envisat determined from SLR data. RMS of the spin period residuals calculated to the trend function is 5.6 s.

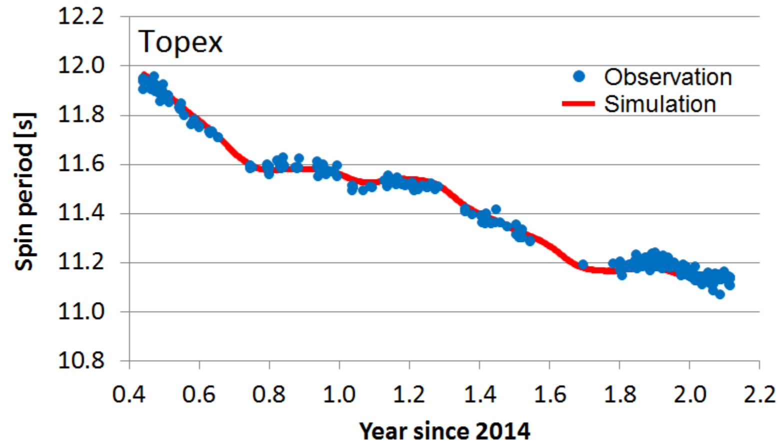

Fig 3. Spin period of Topex determined from the SLR data. RMS of the spin period residuals calculated to the trend function is 21 ms.

The decrease in the spin period observed in the case of Topex is caused by the solar radiation pressure. The force exerted by sunlight on the large solar panel causes the spacecraft to gain the rotational energy over time – the spin period decreases at the rate of 44.3 ms/year. The physical simulations performed with the macromodel of Topex indicate that the modulation of the spin period trend is the result of the change of incident angle between the normal vector to the solar panel surface and the direction to the Sun. The torque produced on the satellite by the solar radiation pressure varies over time, but remains below 1 mNm – Fig. 4.

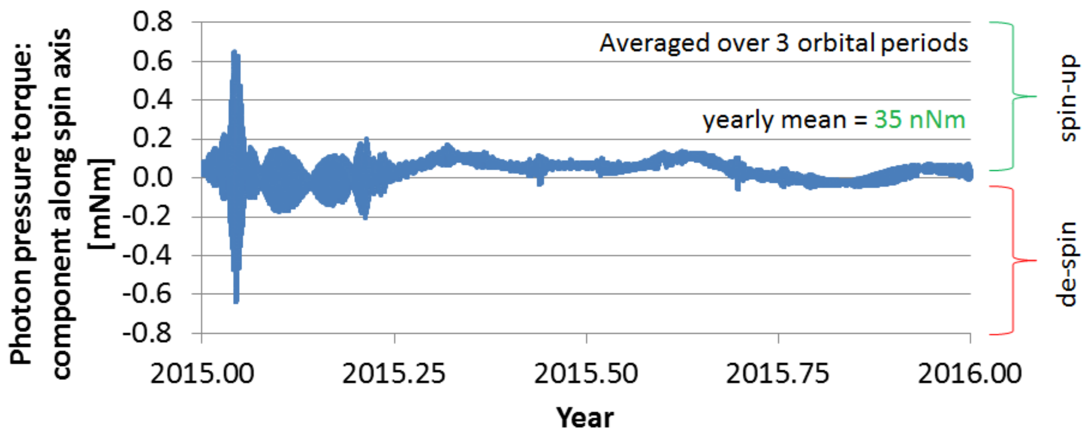

Fig 4. Solar photon pressure torque on Topex. Values averaged over 3 orbital periods.

The observed increase of the spin period of Envisat is caused by the strong interaction between the spacecraft and the external magnetic field. The flow of the eddy currents in the metallic elements of the body dissipates the rotational energy according to an exponential trend. Fig. 5 presents the modeled magnetic torque on Envisat during year 2015. The torque has a magnitude of a few tens of nNm and always acts against the spin of the satellite – the flowing eddy currents convert the spin energy into heat. Due to the sun-synchronous orbit of Envisat the solar radiation pressure torque averages out and does not cause any long term perturbations of the spin rate.

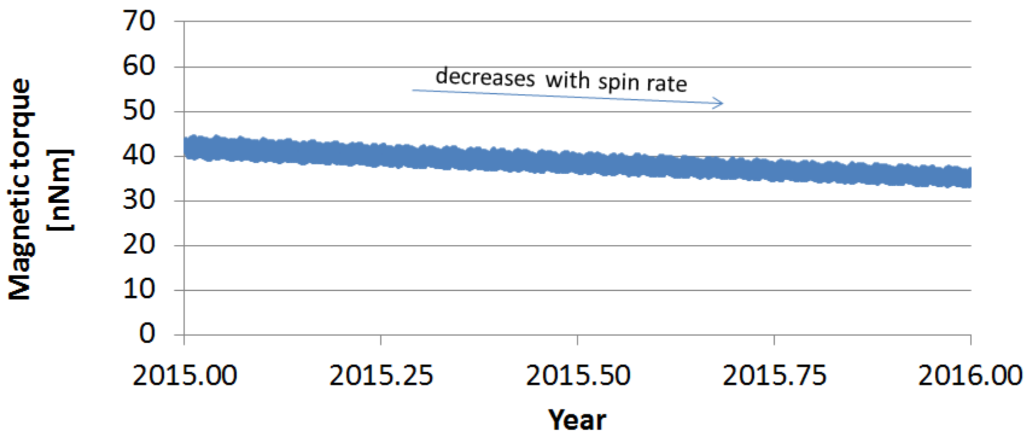

Fig 5. Magnetic torque on Envisat. Values averaged over one orbital period.

3. LASER FORCE FOR DE-SPIN MANEUVER

Defunct Envisat occupies a crowded polar orbit and it is a potential candidate for the active debris removal mission e.Deorbit (ESA's Clean Space program). The risk of the debris removal maneuver can be minimized if the spin energy of Envisat is dissipated before a close contact with the robotic spacecraft. We propose the use of the high power laser systems to produce a negative torque on the spacecraft and stabilize its attitude for the active removal mission. The proposed idea is investigated with the simulated network of 10 globally distributed high power laser systems (wavelength 532 nm) - Fig. 6 – which can observe Envisat whenever it is above 10 degrees of elevation.

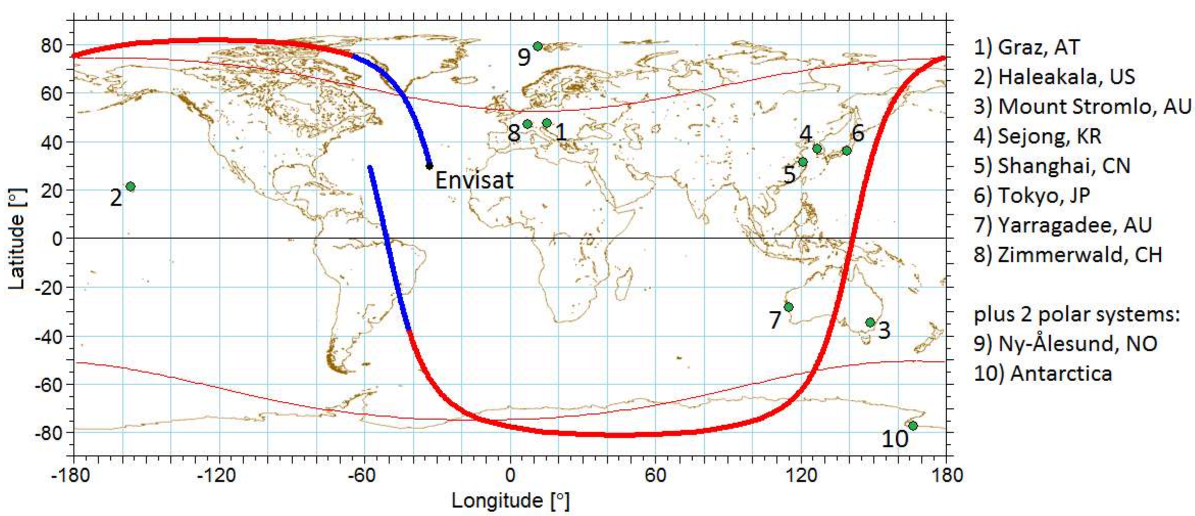

Fig 6. Simulated global distribution of the high power laser systems. An orbital track of Envisat is marked: red line – satellite in Sun, blue line – in shadow. The field of view (at Envisat altitude) of the polar systems is indicated by the red lines.

The orientation of Envisat spin axis is stable in the orbital coordinate system and makes 62° angle with the nadir vector [1]. This information along with the actual (observed) spin period and the spin phase of the body allows prediction of the epoch times when the laser force applied from a defined ground position can produce a negative torque on the spinning satellite.

In order to compute the laser force vector on Envisat we use the standard photon pressure model [2] successfully used to explain the observed spin behavior of Topex (Fig. 3). In the simulations it is assumed that the laser fire times are synchronized with the Envisat spin model in such a way that the torque produced by the laser force acts always against the spin motion.

The observed exponential spin period trend indicates that the satellite will lose the spin energy in April 2032 (spin period equals to orbital period). The spin simulations show that the high power laser network can increase the rate at which the satellite loses the rotational energy: the use of 20 kW lasers can de-spin Envisat by August 2021, while 50 kW – by April 2018 (Fig. 7-A). Fig. 7-B presents the torque (along spin axis component - responsible for the spin rate change) produced by the solar and laser radiation pressure on Envisat: the generation of the laser force is synchronized with the satellite spin model and is applied only when the produced torque acts against the satellite spin.

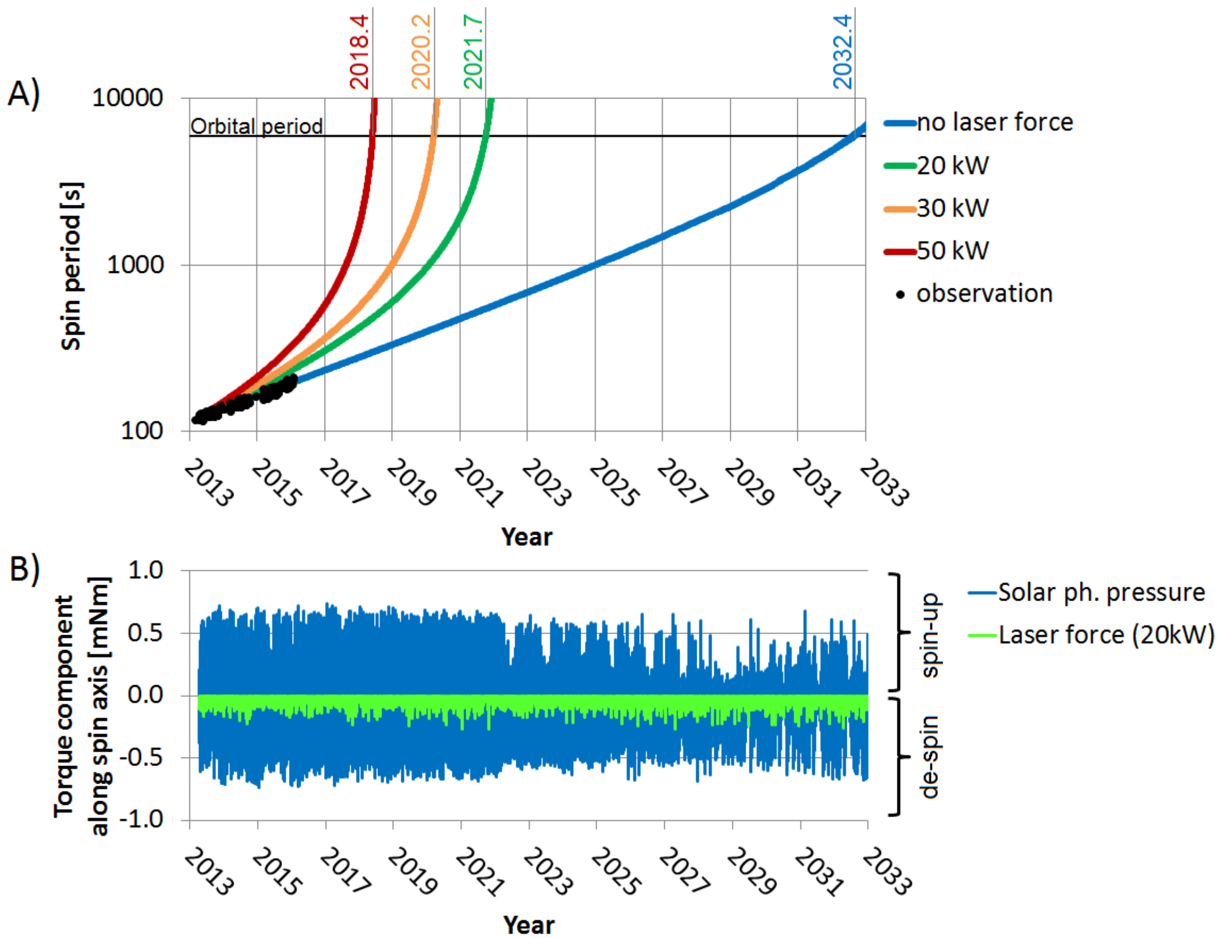

Fig 7. A) The spin period of Envisat: blue – the observed exponential trend; green, orange, red – the simulated trends with the use of the laser force. B) The computed solar and laser photon pressure torque (along spin axis component) – the laser torque remains negative and acts against the satellite spin.

4. CONCLUSIONS

The solar radiation pressure can significantly affect the dynamics of the space debris objects. The spin period of defunct Topex is not stable and changes over time with the rates dependent on the solar photon pressure received by the spacecraft. The spin period of Envisat increases over time due to the magnetic interaction between the satellite and the external field and will become equal to the orbital period in April 2032. The additional photon pressure generated by the ground laser systems can be used to exert a negative torque on Envisat and increase the de-spin rate of the body. The use of the tracking network consisting of ten 20 kW laser systems has the capability to de-spin Envisat by August 2021 and stabilize it for the active debris removal mission.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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