The scientific results of the optional laser tracking campaigns to defunct satellites Envisat and TOPEX/Poseidon

Daniel Kucharski[1*], Georg Kirchner[2], James C. Bennett[1], Franz Koidl[2]

1. Space Environment Research Centre, SERC, Mount Stromlo, Australia
   *) danielkucharski@serc.org.au
2. Space Research Institute, Austrian Academy of Sciences, Graz, Austria

Abstract

The inactive satellites Envisat and TOPEX/Poseidon (T/P) are tracked by a number of SLR systems supporting the analysis of the space debris dynamics. The collected laser range measurements are used to determine the spin parameters of the defunct satellites and analyze their interaction with the space environment. The SLR data indicates that the orientation of Envisat is stable within the orbital coordinate system (stable offset from nadir) while the T/P spin axis points in the direction of the orbital perigee vector. The laser data reveals different development of the spin rates of the two satellites: Envisat loses its rotational energy due to the strong interaction with the Earth's magnetic field, while the spin rate of T/P slowly increases due to the solar radiation pressure.

1. Introduction

The environmental satellites TOPEX/Poseidon (T/P) and Envisat have been decommissioned in 2006 and 2012 respectively. During the active period of the mission the satellites were nadir-stabilized, and the attitude perturbations were regularly compensated for. After the end of the mission the satellites became passive space debris objects with the attitude dynamics governed by the forces and torques from the environment. The satellites are equipped with the retroreflector arrays which enable the SLR systems to measure their inertial orientation and the spin periods. The orbiting satellites experience a continuous drag force in the along-track direction which causes the orbits to decay. This process is reflected in the shortening of the orbital period duration presented on Fig. 1 and 2.

Table 1. TOPEX/Poseidon and Envisat SLR campaign duration

Defunct satellite	Inclination	Altitude	Mission end	Campaign duration
TOPEX/Poseidon (NASA/CNES)	66.0°	1340 km	Oct 2005	Nov 2015 – Sept 2016
Envisat (ESA)	98.5°	796 km	April 2012	May 2013 – Dec 2013

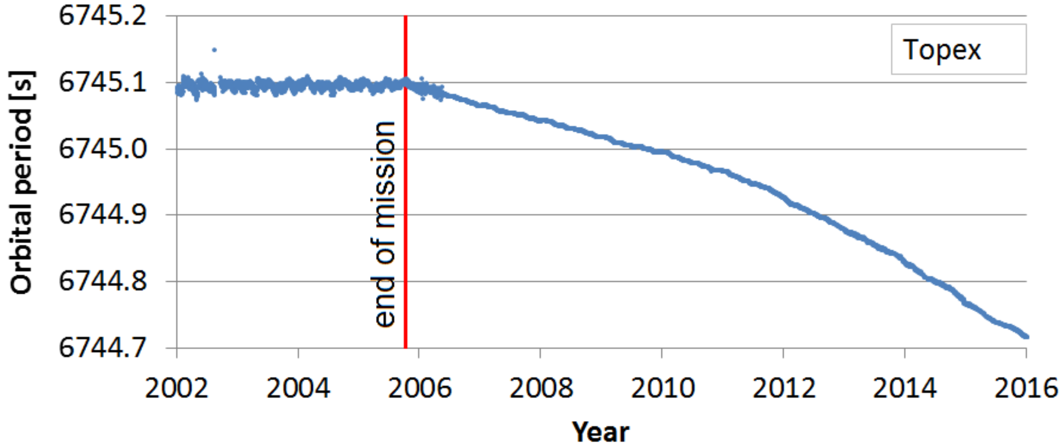


Fig 1. Change of the orbital period of T/P after end of the mission.

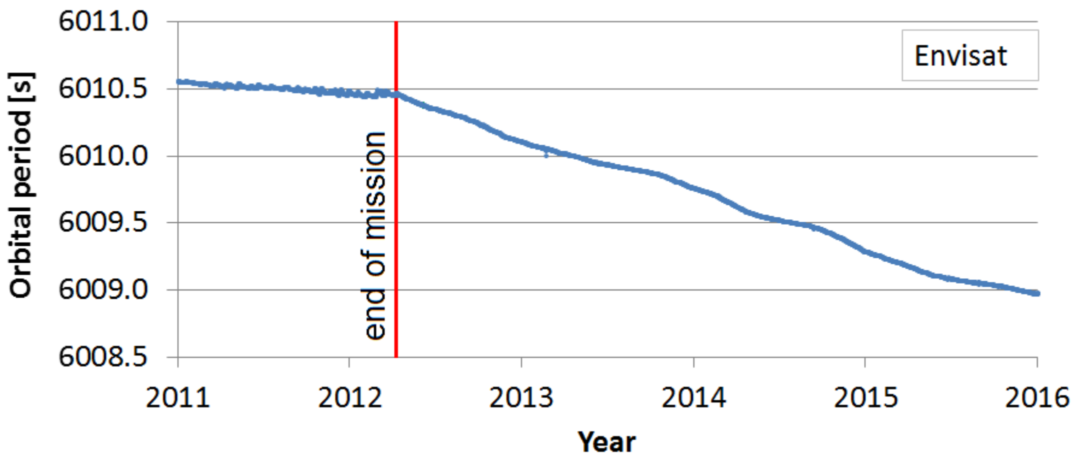


Fig 2. Change of the orbital period of Envisat after end of the mission.

2. Spin parameters measured by SLR

The accurate range measurements to the retroreflector arrays of the satellites are used to determine the spin parameters of T/P and Envisat. The orientation of the T/P spin axis vector oscillates in the vicinity of the orbital perigee vector and can be presented in the orbital coordinate system – OCS. The OCS is defined as a right-handed Cartesian system with +X axis oriented as perigee and +Z being the normal vector of the orbital plane. Fig. 3 shows the clockwise oscillation of T/P spin axis vector with respect to the location of the orbital perigee at azimuth = 0° and elevation = 0°. The spin axis oscillates with a period of 101 days. The spin period of T/P determined from the global SLR data is presented on Fig. 4. The decrease of the period indicates that the satellite gains the rotational energy from the space environment.

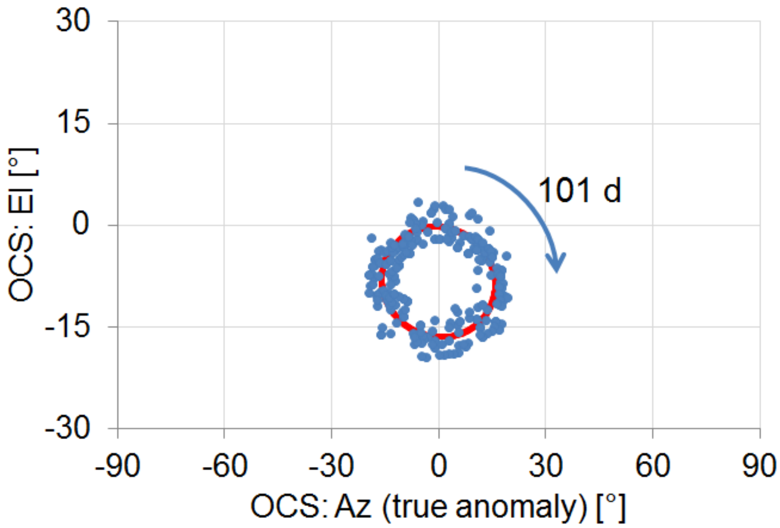


Fig 3. Motion of T/P spin axis vector in orbital coordinate system.

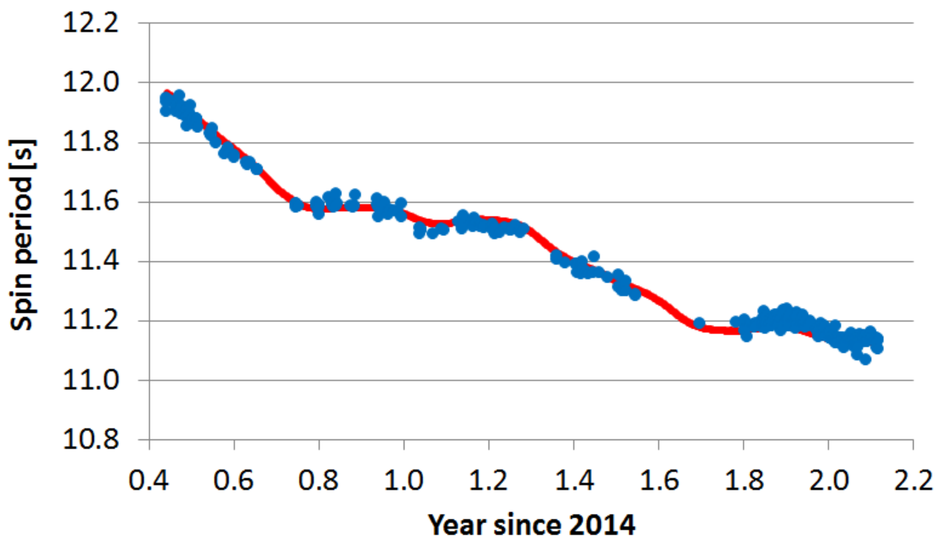
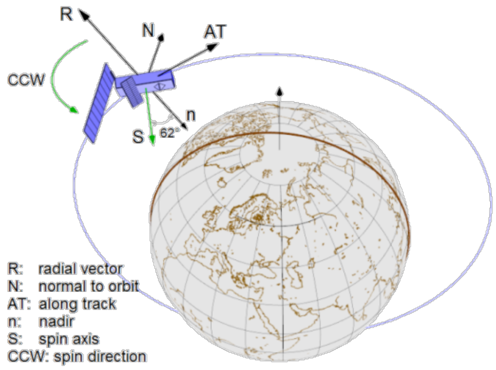


Fig 4. Inertial spin period of T/P determined from SLR data. The RMS of the spin period residuals calculated to the trend function is RMS = 21 ms.

The spin axis orientation of Envisat measured by the SLR systems remains stable within the radial coordinate system RCS [1]. The retroreflector panel points in the direction opposite to the normal vector of the orbital plane in such a way that the spin axis makes an angle of 61.86° with the nadir vector and 90.69° with the along track vector (Fig. 5-Left). The spin period of Envisat increases over time due to the strong interaction between the satellite and the Earth's magnetic field – Fig. 5-Right.



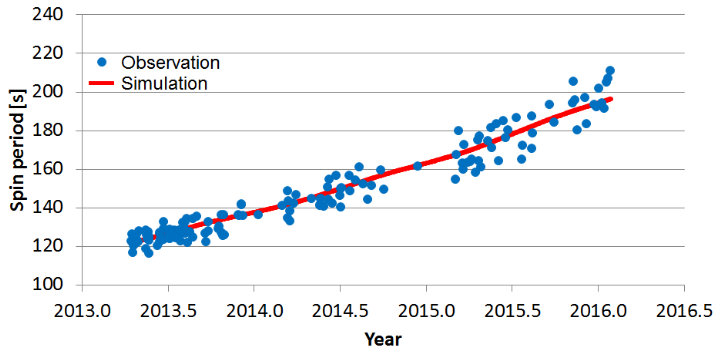


Fig 5. Left: Orientation of Envisat; Right: spin period trend, the RMS of the spin period residuals calculated to the trend function is RMS = 5.6 s.

3. Along-track accelerations

The inertial attitude of the satellites plays an important role in the estimation of the forces acting on the orbiting bodies:

- the atmospheric drag depends on the cross-sectional area of the satellite in the direction of motion

- the solar radiation pressure depends on the area and orientation of the surface exposed to the solar flux.

The complete attitude models developed with the SLR data allow for a realistic estimation of the along-track accelerations experienced by the satellites. Fig. 6 and 7 present the along-track accelerations on T/P caused by the photon pressure (direct solar radiation, Earth albedo and IR emissivity). The high modulation of the perturbations is caused by the fast change of the satellite cross-sectional area in the range of 10-35 m^2 in the direction of motion and to the Sun due to the spin.

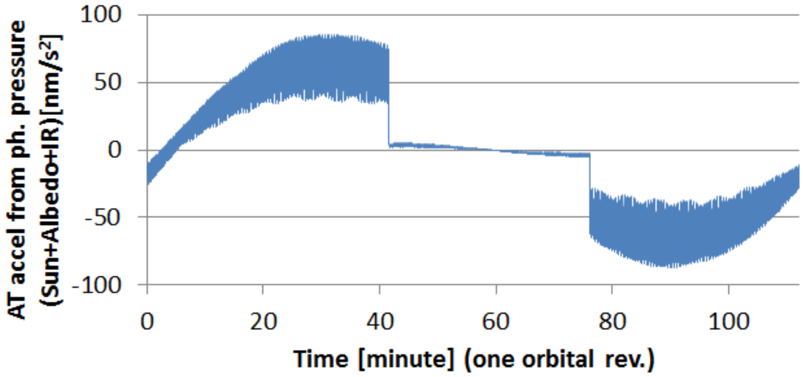


Fig 6. Along-track acceleration on T/P due to the photon pressure during one orbital revolution at epoch 2015.25. The central part represents the orbital eclipse.

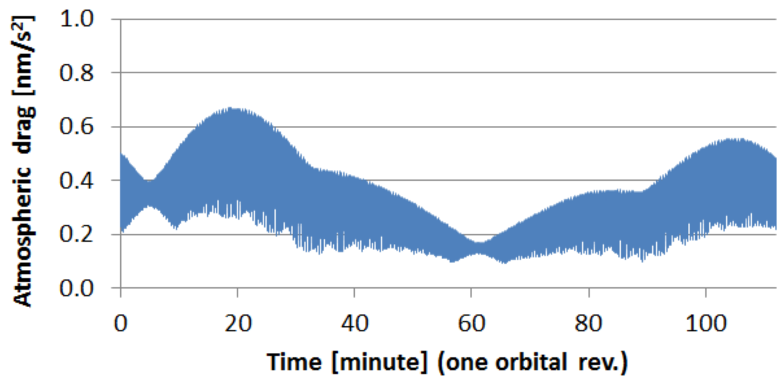


Fig 7. The atmospheric (JB2008) drag on T/P during one orbital revolution at epoch 2015.25.

The estimated along track accelerations on Envisat are presented on Fig. 8 and 9. The satellite changes the cross-sectional area in the direction of motion and to the Sun due to the spin.

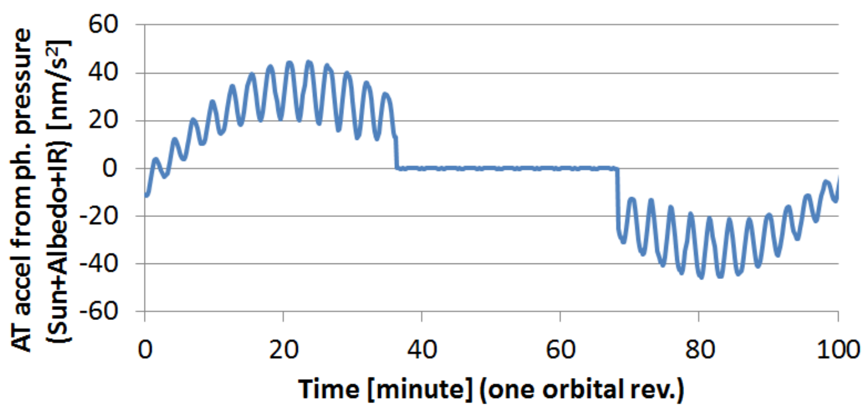


Fig 8. Along-track acceleration on Envisat due to the photon pressure during one orbital revolution at epoch 2015.25. The central part represents the orbital eclipse.

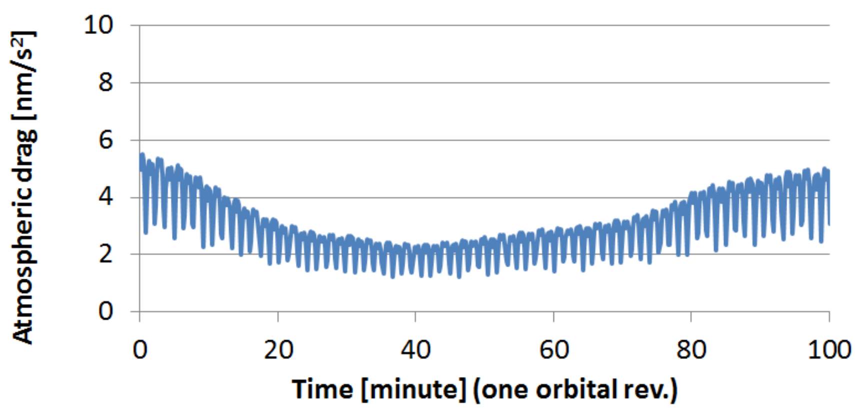


Fig 9. The atmospheric (JB2008) drag on Envisat during one orbital revolution at epoch 2015.25.

4. Conclusions

The SLR can efficiently measure the spin parameters of the space debris objects equipped with the corner cube reflectors. The analysis of the globally distributed SLR data indicates a different spin dynamics of TOPEX/Poseidon and Envisat – both a box-wing type space debris objects. The spin-up of T/P is caused by the force exerted on the satellite by the solar radiation pressure, while the rotation of Envisat slows down due to the strong interaction between the spacecraft and the external magnetic field. The orientation of the satellites is related to the configuration of the orbital plane – the spin axis of T/P remains in the vicinity of the orbital perigee vector, while the orientation of Envisat is stable within the radial coordinate system.

The complete attitude models of the large space debris objects allow for the reliable estimation of the perturbations acting on their orbital motion. The realistic drag modeling supports the orbit decay and re-entry studies as well as improves accuracy of the conjunction analyses.

Acknowledgment

We acknowledge the use of data provided by Graz SLR station and obtained within the ESA project “Debris Attitude Motion Measurements and Modelling” (Project No. 40000112447), as well as the other SLR systems organized within the International Laser Ranging Service.

This research is supported by the Cooperative Research Centre for Space Environment Management, SERC Limited, through the Australian Government’s Cooperative Research Centre Programme.

References

[1] Kucharski, D., Kirchner, G., Koidl, F., et al. Attitude and spin period of space debris Envisat measured by Satellite Laser Ranging. IEEE Trans. Geosci. Remote Sens., vol. 52 (12), pp. 7651-7657, doi:10.1109/TGRS.2014.2316138, 2014.