# SPIN-UP OF SPACE DEBRIS CAUSED BY SOLAR RADIATION PRESSURE

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## ABSTRACT

The dynamics of the space debris objects undergoes perturbations under the influence of the environmental forces and torques. The Earth's gravity field affects the orientation of the satellites while the magnetic field dissipates the spin energy by inducing eddy currents in the conductive elements of the orbiting objects. The solar photon pressure produces force on the exposed surface area of the satellite and generates a small torque which has the potential to spin up the illuminated object. One of the best examples of debris spin-up is TOPEX/Poseidon with the spin parameters observed since it was decommissioned in January 2006. The solar radiation pressure exerts force on the inclined solar panel and produces a small torque with the magnitude below 1 mNm. Over the period of 11 years the solar radiation torque increased the spin rate of the satellite from 0 to 5.7 rotations-per-minute.

## 1 INTRODUCTION

The large, defunct satellites interact with the space environment and change their attitude under the influence of the Earth's gravity and magnetic fields and solar radiation pressure [3]. The large box-wing type satellites of the Earth-observing or telecommunication missions are nadir stabilized during the operation. After the end of the mission the on-board systems are switched off and the satellite becomes a passive object with the dynamics governed by the environmental forces. Observation of the spin parameters development, allows for the modelling of the forces and torques acting on the satellites. The spin measurements are performed by the globally distributed Satellite Laser Ranging [2, 4] and photometric systems.

## 2 SPIN ANALYSIS

TOPEX/Poseidon satellite (NORAD 22076, Figure 1) has been decommissioned in January 2006, and the spin parameters of the satellite are measured since that time. The satellite occupies a circular orbit with a perigee of 1340 km and an inclination of 66°. The photometric observations collected by Odessa observatory and the satellite laser ranging (SLR) data from the stations of the ILRS network [2, 4] allowed for the spin parameters determination of TOPEX/Poseidon over the time span of 10 years.

The light curves collected by a photometric system can be processed with the phase dispersion minimization method, PDM which finds the periodic variation in the time series by minimizing the dispersion of the folded data set. Unlike frequency analysis, PDM allows for the determination of the long spin periods in relation to the pass duration. Figure 2 presents a folded light curve of T/P (observed by Odessa on May 13, 2008) with the determined spin period of 28.6 s.

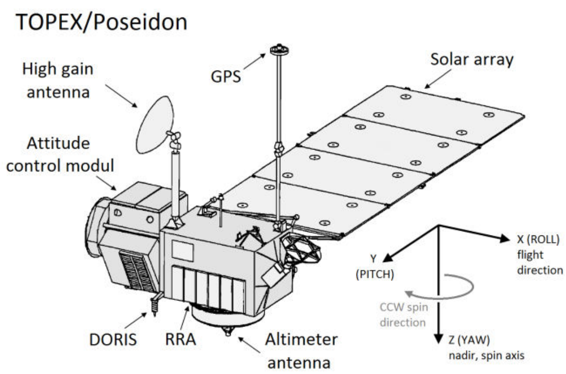


*Figure 1. TOPEX/Poseidon satellite*

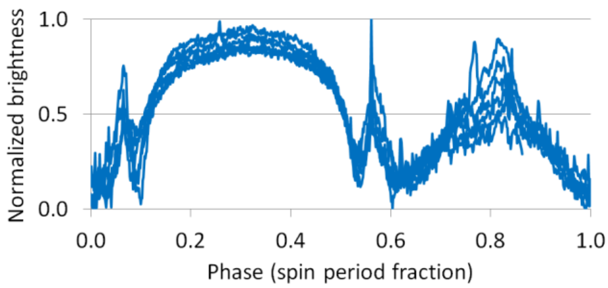


*Figure 2. Example of TOPEX/Poseidon light curve measured by Odessa Observatory on May 13, 2008 and folded into spin period bin. The duration of the pass is 2m:45; the spin period determined with PDM is 28.6 s.*

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An example of a TOPEX/Poseidon pass measured by the Graz high repetition rate SLR system is presented in Figure 3. The range residuals are computed as the difference between the measured and calculated ranges to the satellite – the zero level indicates the reference orbit. The range residuals oscillate with a stable period during the pass due to the rotation of the retroreflector array about the spin axis of the satellite. In the case of the SLR data, the spin period is determined with a frequency analysis of the range residual oscillations. The analysis uses Lomb algorithm which estimates a frequency spectrum of an unequally spaced data, based on the least squares fit of sinusoids to the data samples.

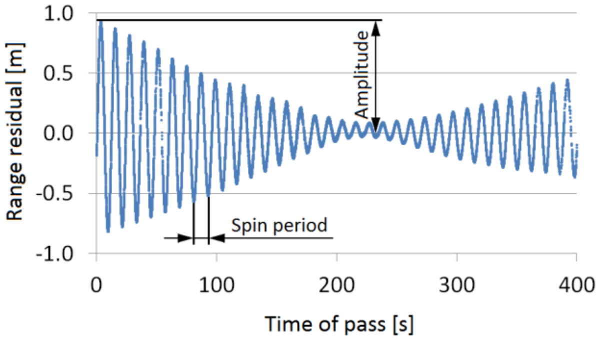


*Figure 3. Example TOPEX/Poseidon SLR pass: range residuals (observed minus calculated range) measured by Graz SLR station on June 18, 2014. The period and the amplitude of the oscillations are indicated.*

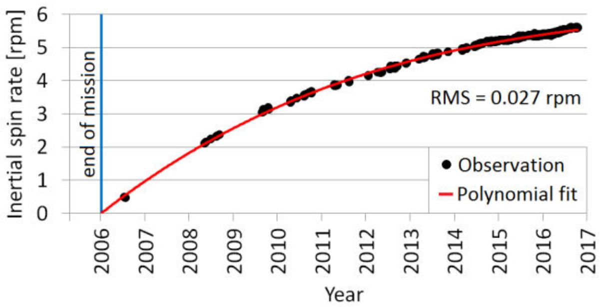


*Figure 4. The history of TOPEX/Poseidon inertial spin rate*

Figure 4 presents the obtained spin trend of the satellite. TOPEX/Poseidon slowly, but continuously gains the rotational energy since it was decommissioned.

The geostationary Engineering Test Satellite-8 (ETS-8, NORAD 29656, perigee of 36000 km, Figure 5) has been decommissioned in January 2017 and relocated to graveyard orbit. The former telecommunication satellite is equipped with two large-scale antennas and has been nadir pointing during the active phase of the mission. The very large area-to-mass ratio makes the dynamics of this object sensitive to the non-gravitational forces produced by the solar radiation pressure.

The light curves collected at Mount Stromlo station in March 2017 indicate spin of defunct ETS-8 with a period of 10.6 minutes. An example light curve measured on March 8, 2017 is presented in Figure 6.

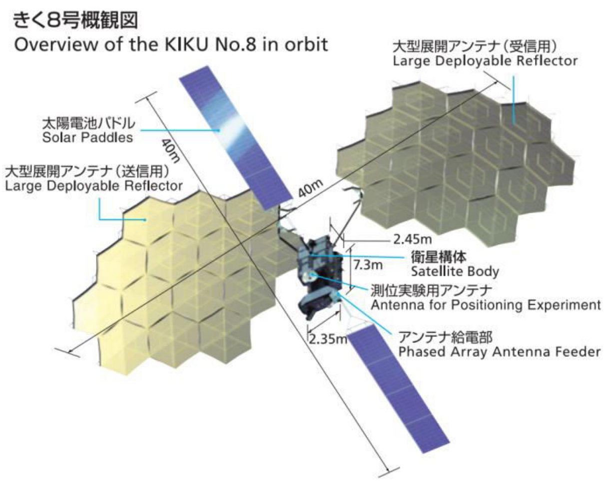


*Figure 5. ETS-8 is one of the largest objects in graveyard orbit (courtesy of JAXA).*

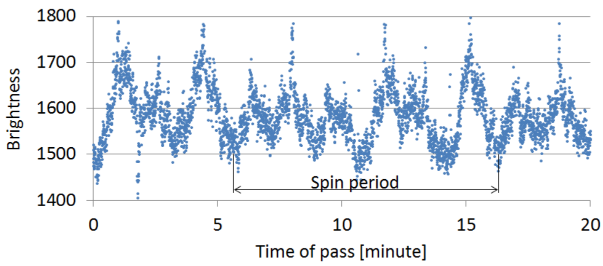


*Figure 6. Light curve of ETS-8 measured by EOS Mount Stromlo station on March 8, 2017.*

## 3 SPIN SIMULATION

The major forces affecting spin dynamics of the passive satellites are produced by the Earth's gravity and magnetic fields and solar radiation pressure. The gravitational torque acts on the dynamical oblateness of the spacecraft and causes a low-frequency change of its orientation. The magnetic field generates eddy currents in the spinning metallic objects. The flow of the induced currents converts the rotational energy into heat and de-spins the spacecraft. The major factor which can cause the spin-up of the satellites is solar radiation pressure.

In the spin simulation process we use realistic macromodels of the satellites including the optical properties (in visible and IR light) of the body surface. The simulated photon pressure on the satellite comes from direct solar radiation, Earth's albedo and IR emissivity of Earth surface. The photon pressure force depends on the area and orientation of surface exposed to the photon flux. Since the end-of-life orientation of the TOPEX/Poseidon solar panel is not known, the set of simulations have been generated for various pitch angle of the solar panel (orientation of the panel about the Y/pitch axis of the platform coordinate system).

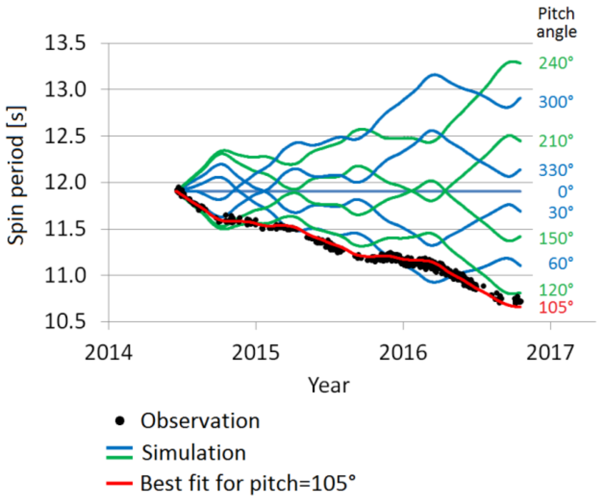


*Figure 7. Spin period of TOPEX/Poseidon measured by SLR (black points) and simulated trends for different pitch angles of the solar panel.*

The observed and simulated spin period trends for TOPEX/Poseidon are presented in Figure 7. The observed trend (black dots) is determined from the accurate SLR measurements, and indicates spin-up of the satellite with a modulated rate. The simulated spin trends have been obtained for different orientations of the solar panel with respect to the satellite body (pitch angle about the platform Y axis). The solar photon pressure force produced on the satellite depends on the orientation of the solar panel towards the Sun – for certain orientations of the panel the photon pressure produces positive torque that spins up the satellite. The orientation of the solar panel is assumed to be fixed with the body, but can change in the inertial frame due to the precession of the satellite's spin axis – the coordinates of spin axis are presented in Figure 8.

The spin-up rate of TOPEX/Poseidon depends on the incident angle between the satellite's spin axis and the solar flux vector. The satellite gains more rotational energy when the incident angle is larger than 90° (Figure 9).

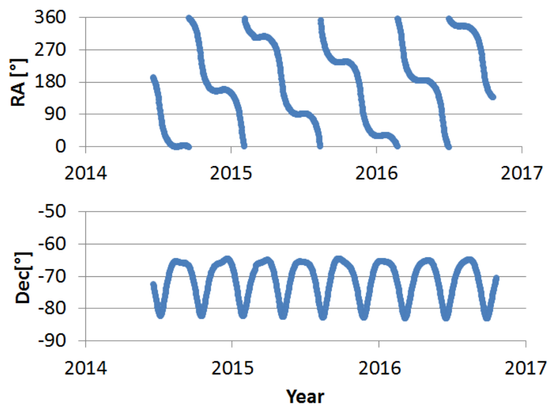


*Figure 8. Spin axis of TOPEX/Poseidon in J2000 inertial reference frame.*

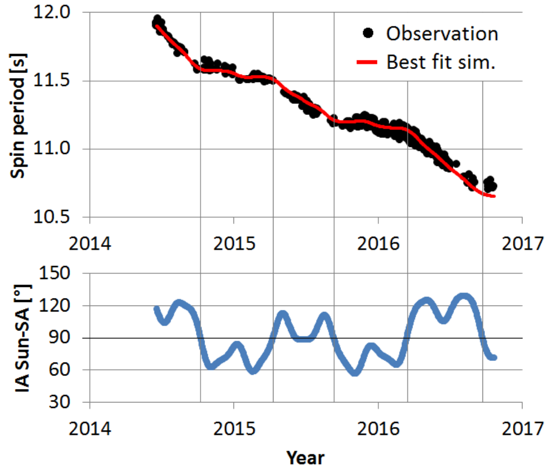


*Figure 9. The decrease of the spin period in relation to the incident angle between the spin axis and the satellite-Sun direction.*

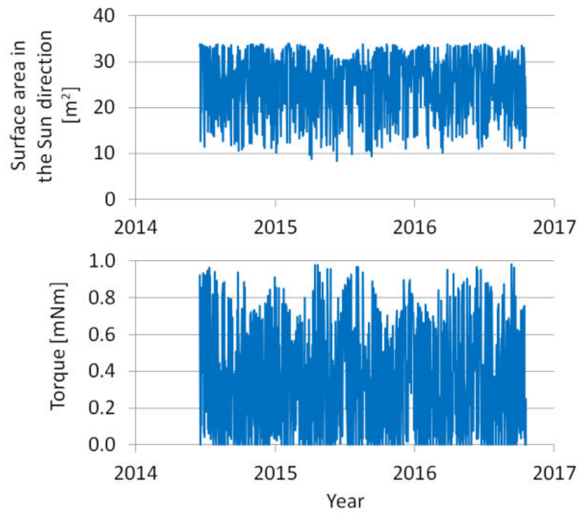


*Figure 10. TOPEX/Poseidon surface area exposed to the Sun, and the torque on the satellite produced by the direct solar radiation.*

The surface area of TOPEX/Poseidon exposed to the Sun changes between 10-34 $m^2$ due to the orbital motion and the spin of the spacecraft. The magnitude of the direct solar radiation torque exerted on the spinning body remains below 1 mNm – Figure 10. The torques produced by the Earth's albedo and the IR emission are about an order of magnitude lower that the direct solar effect.

The developed macromodel of ETS-8 (Figure 11) will help to analyse the spin dynamics of the objects from the (near) geostationary, graveyard orbit.

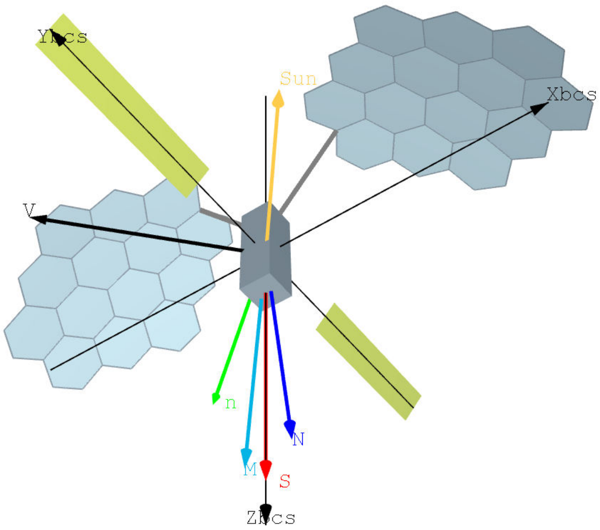


*Figure 11. Macromodel of defunct ETS-8 for the spin simulations.*

The long term spin observations and model-fitting will allow estimation of the solar radiation pressure force acting on this object, and predict its spin behaviour in the future.

## 4 CONCLUSIONS

The dynamics of the passive satellites are governed by the environmental forces and can be measured by SLR and photometric systems. Analysis of the observed spin parameters and the comparison with the simulation models allows for the estimation of the external forces and torques acting on the objects. The complete spin models of the space debris allow for the reliable prediction of the perturbations acting on the orbital motion [1]. The realistic attitude modelling supports design of the future Active Debris Removal missions.

## 5 ACKNOWLEDGEMENT

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