The scientific results of the optional laser tracking campaigns to the defunct satellites Envisat and Topex

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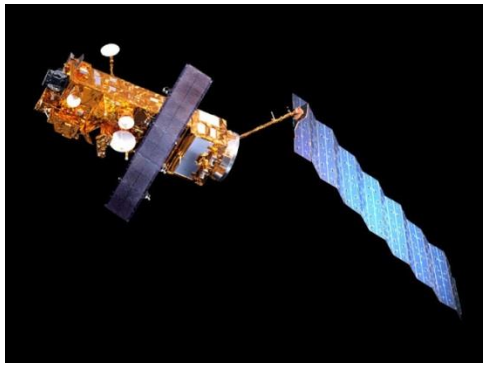
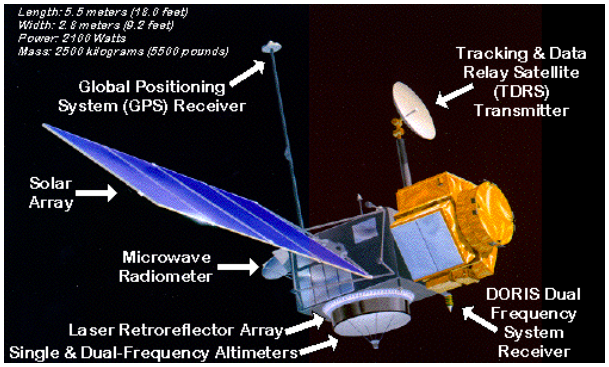
Optional tracking campaigns to the cooperative space debris objects

Defunct satellite	Inclination	Altitude	Mission end	Campaign duration
Envisat (ESA)	98.5°	796 km	April 2012	May 2013 – Dec 2013…
Topex (NASA / CNES)	66.0°	1340 km	Oct 2005	Nov 2015 – Sept 2016
OICETS (JAXA)	97.8°	610 km	June 2006	Sept 2016 – (Feb 2017)

new

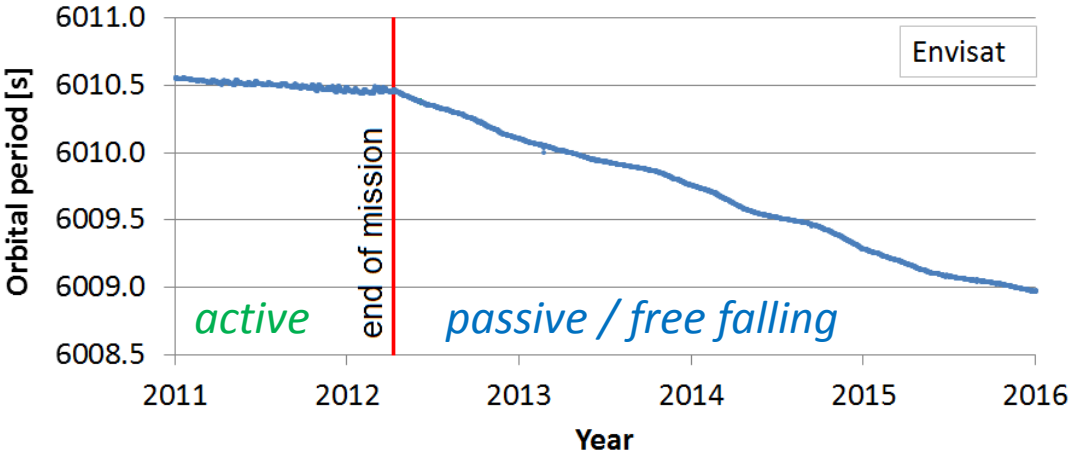
15 SLR stations participate in the optional campaigns organized by the ILRS Space Debris Study Group
http://ilrs.gsfc.nasa.gov/network/newg/sdsg/index.html





Orbit decay of defunct satellites

Satellite	Mission start	Active phase end	Inclination	Altitude	Mass
Envisat	Mar 2002	Apr 2012	98.5°	796 km	8200 kg
Topex	Aug 1992	Oct 2005	66.0°	1340 km	2400 kg

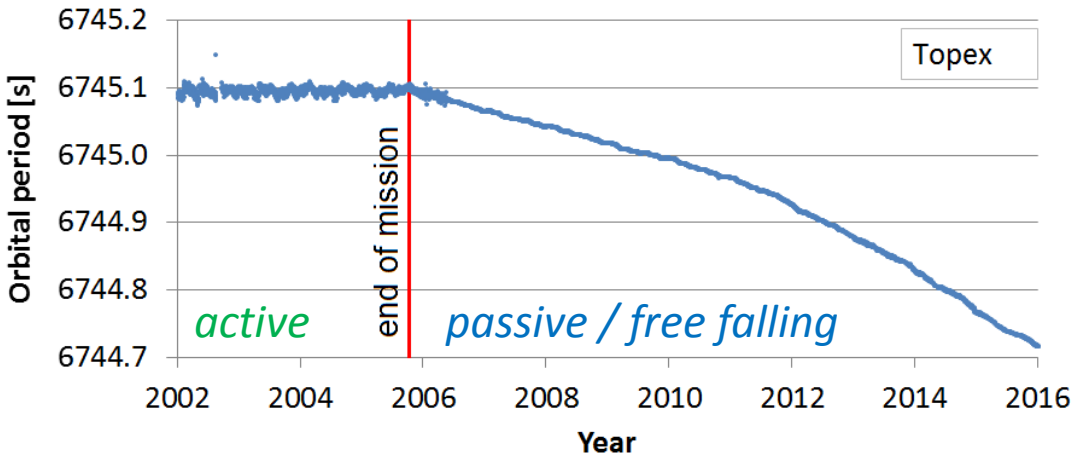


active phase

- orbit and attitude maintained through active maneuvers

passive phase

- orbit decays
- unstable attitude (spin/orientation)

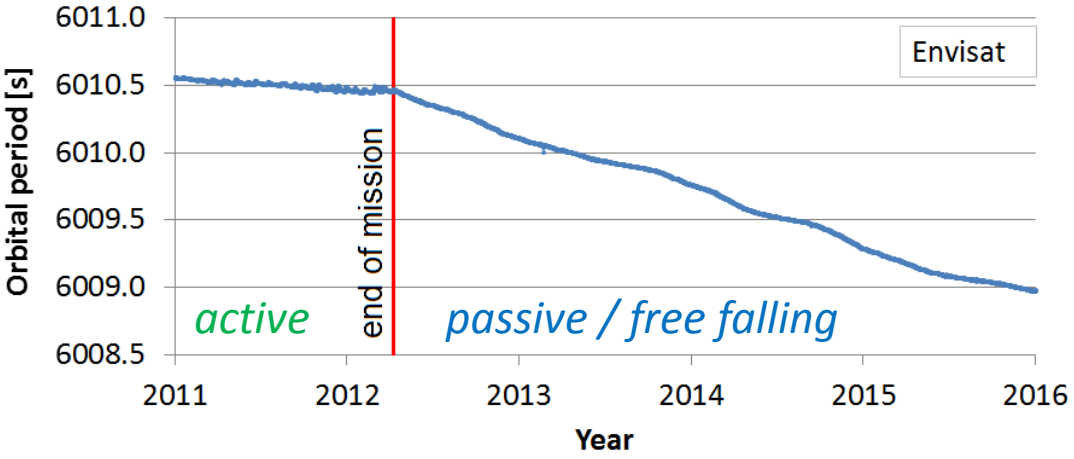


The atmospheric drag is the most significant effect responsible for the orbit decay of LEO satellites.
The solar radiation pressure also contributes to this process.

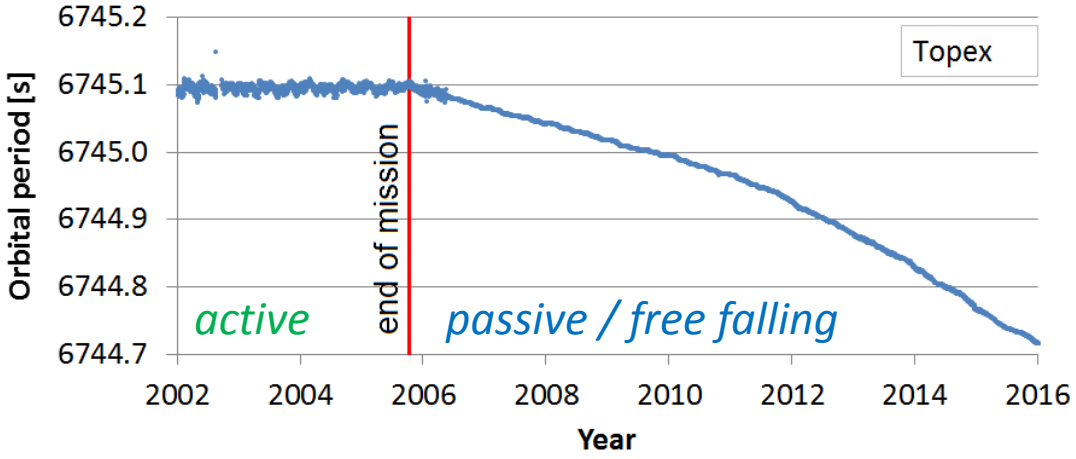
Orbit decay of defunct satellites

The CCR panel is the only instrument that works throughout the entire lifetime of the satellites, thus SLR makes it possible to perform research on the passive phase of the missions:

- orbit decay analysis
- re-entry predictions (of the large box-wing satellites)



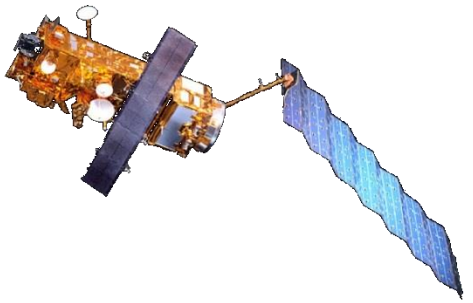
Envisat RRA / Alcatel Space Industries

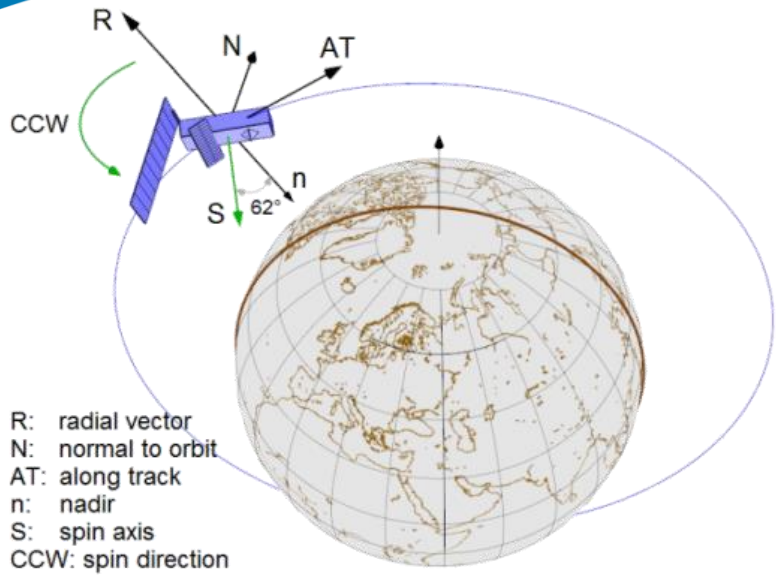


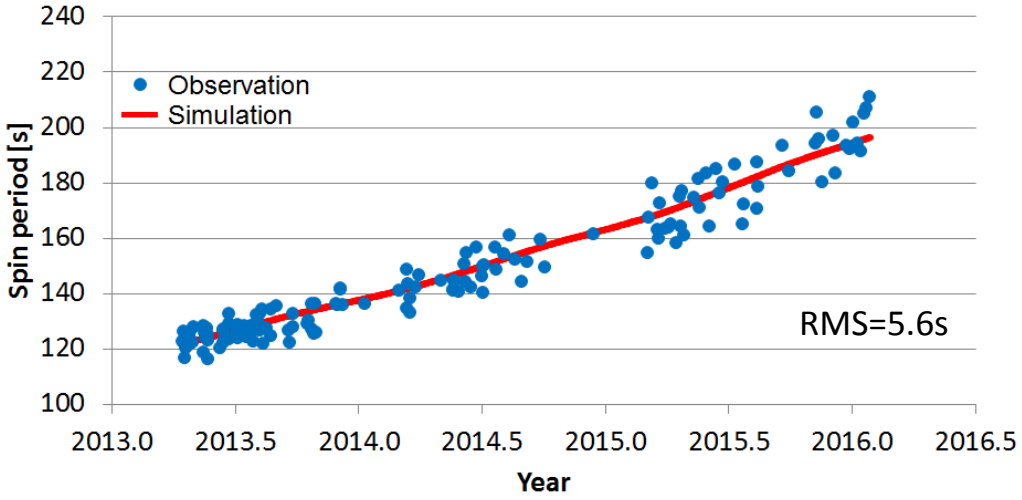
During the passive phase of the mission the laser range data can be used for:

- precise orbit determination
- spin / attitude parameters determination for drag estimation
  (cross sectional area in AT/Sun directions)

Spin of defunct Envisat





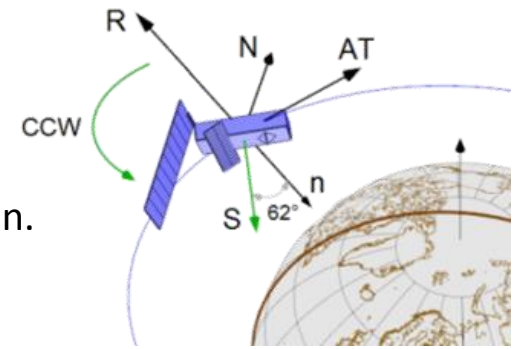


The loss of the rotational energy caused by the interaction with the Earth's magnetic field.
The flow of the induced eddy currents in the metallic elements of the spacecraft acts against the spin and dissipates the rotational energy.

The spin period of Envisat:
- increases by 72 ms/day
- doubles every 4 years
- will become equal to the orbital period (6000 s) in year 2032

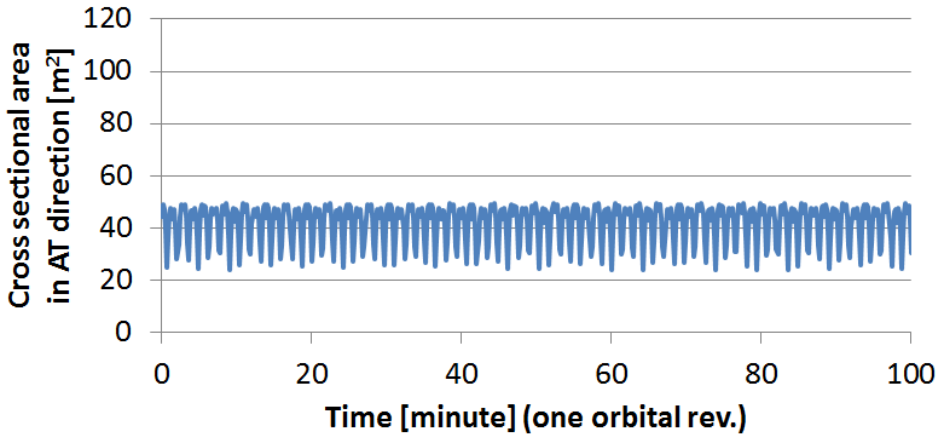
Published in:
Attitude and spin period of space debris Envisat measured by Satellite Laser Ranging. IEEE TGRS, doi:10.1109/TGRS.2014.2316138

Attitude model of Envisat



Cross sectional area in the Sun direction changes from 24-115 m^2 due to the spin.
Simulations for <u>one orbital revolution</u> (at epoch 2015.25):

A)



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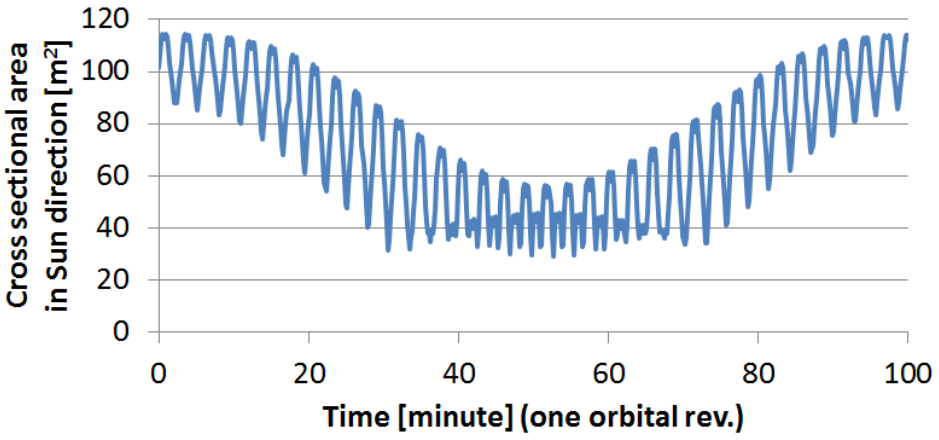
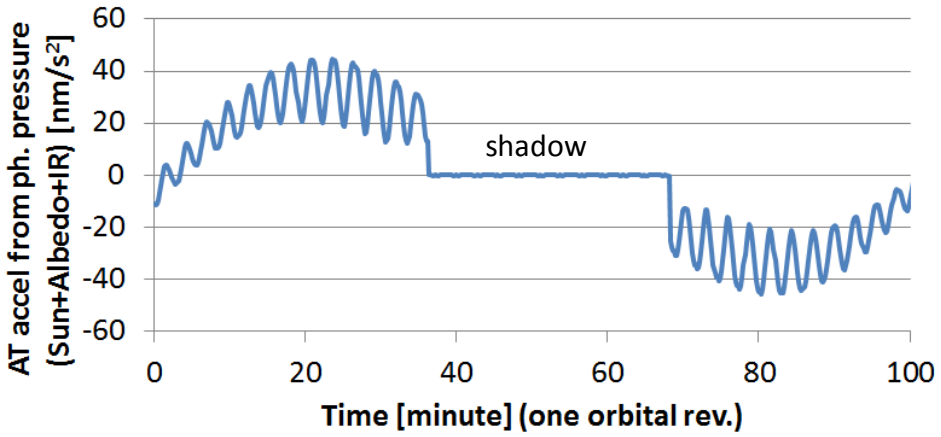


Along track acceleration depends on the cross sectional area

C)



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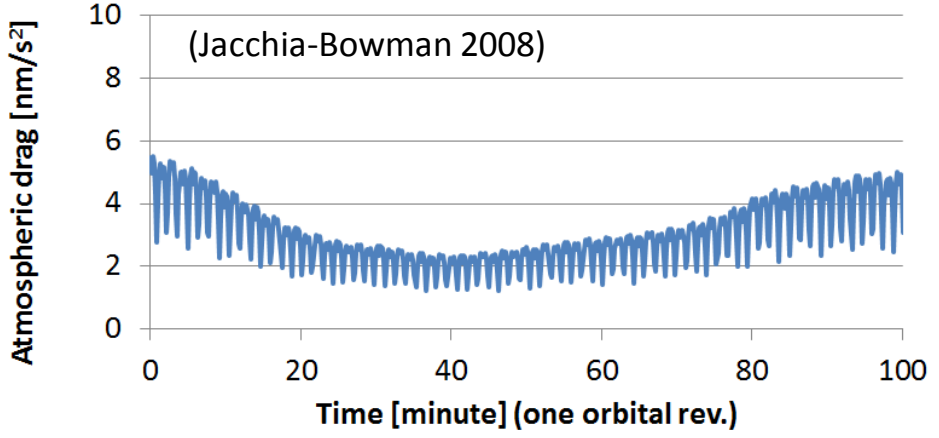
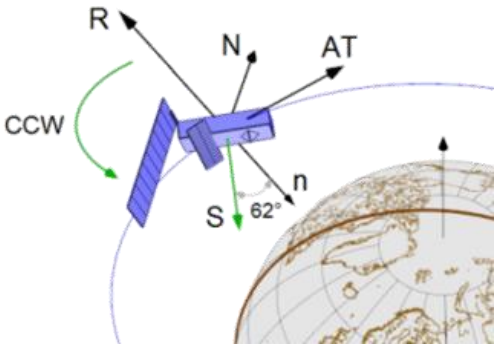
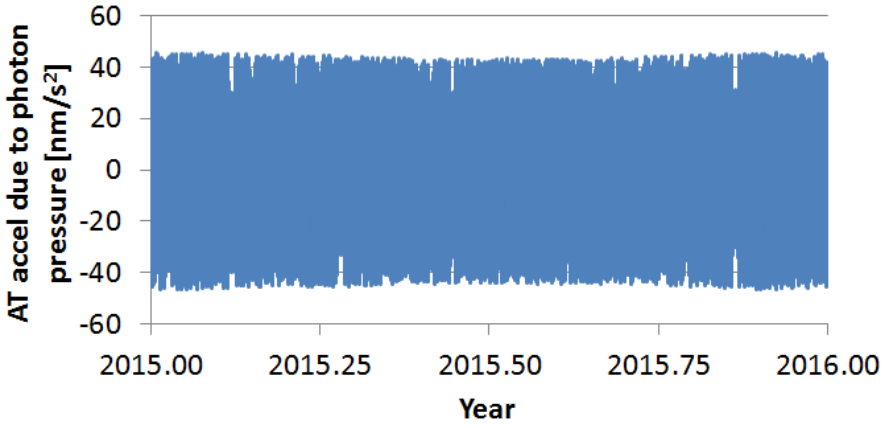


Attitude model of Envisat



One year simulations:

A)



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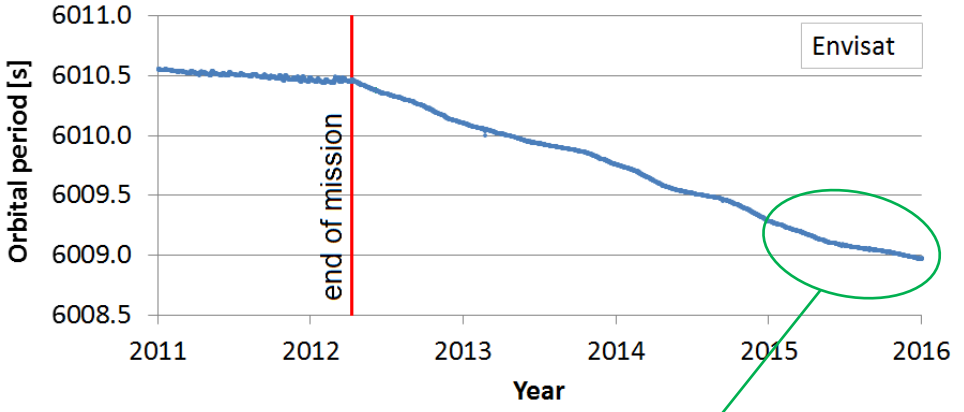

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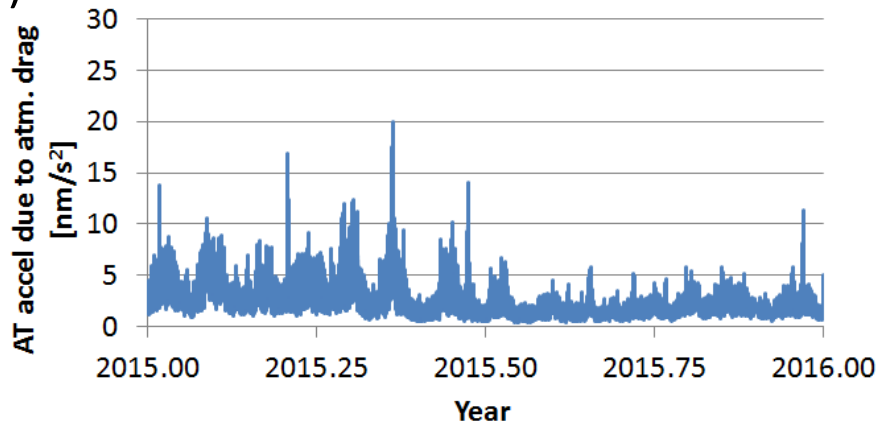

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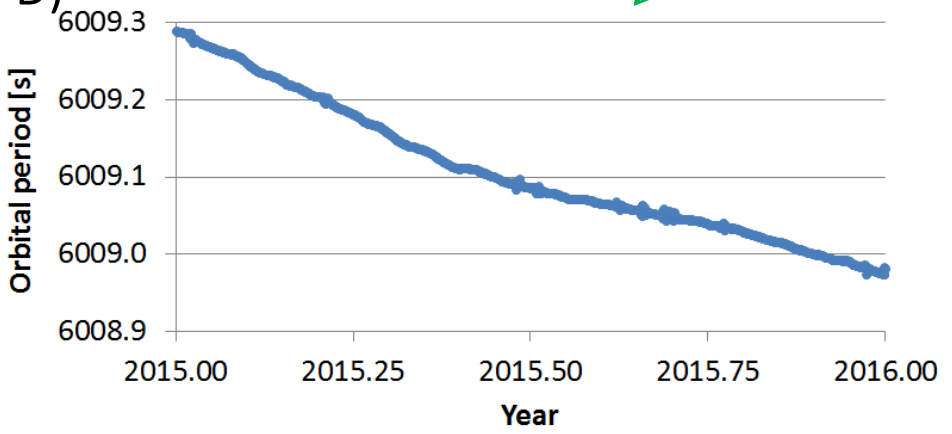
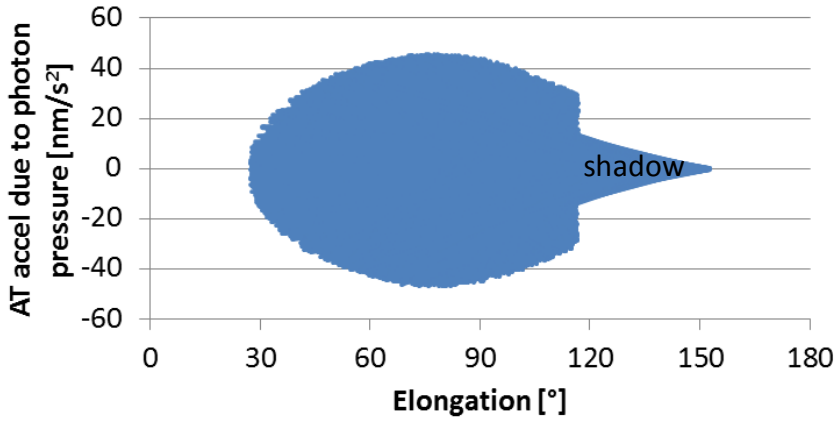
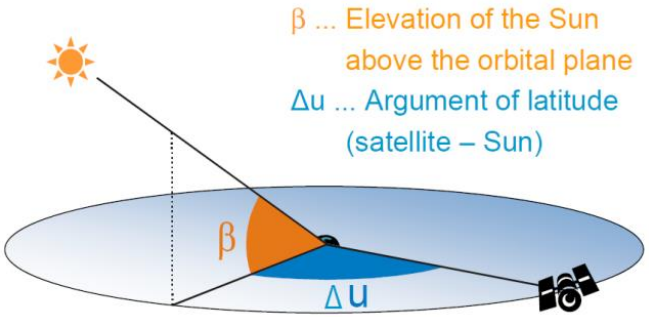


Attitude model of Envisat

A)





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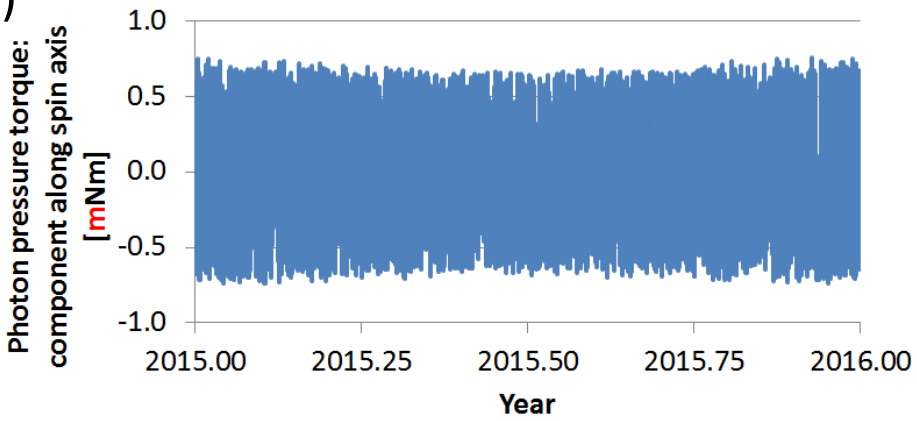

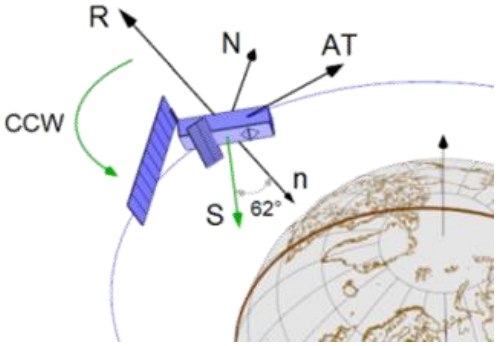

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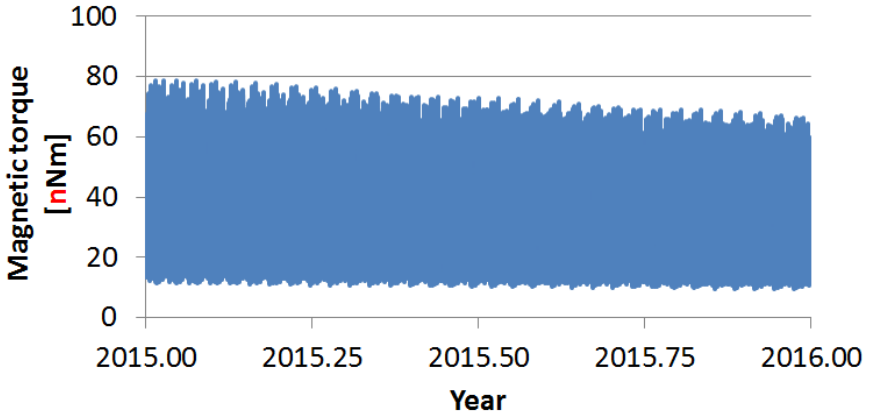
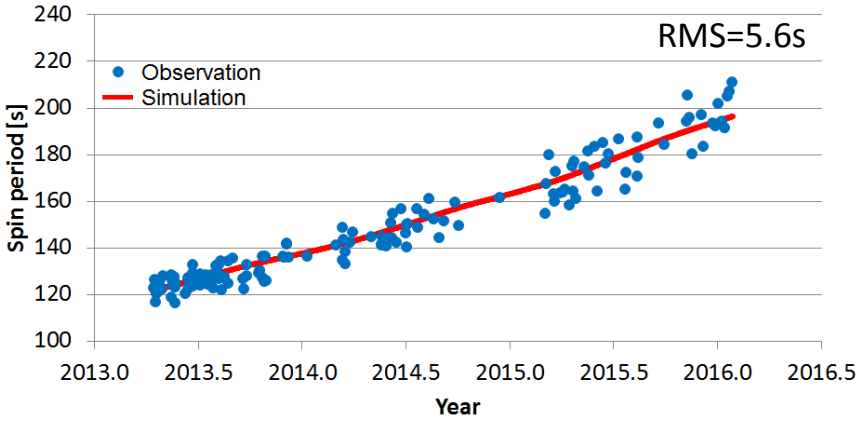
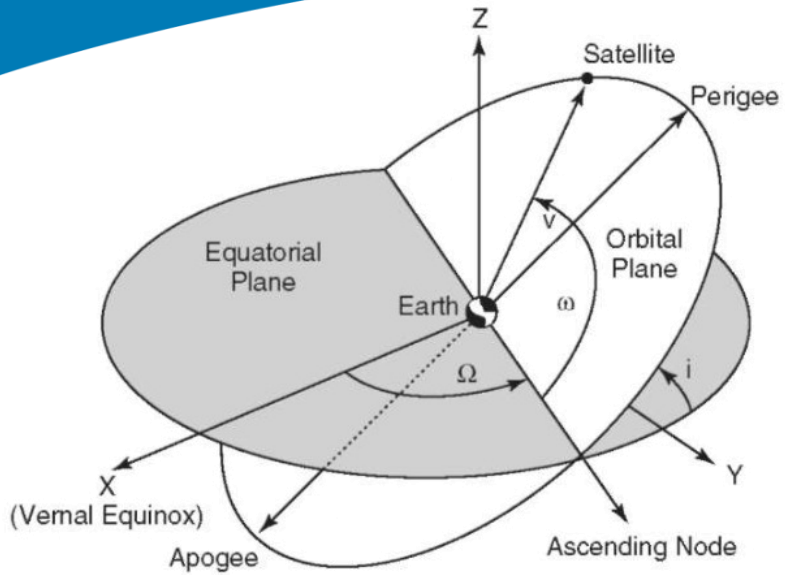


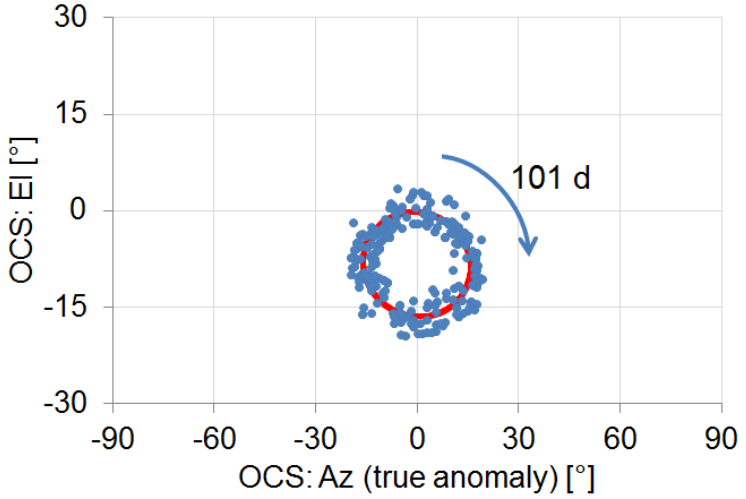
Torques causes de-spin at the rate of 72ms/day



Spin of defunct TOPEX



Spin axis in Orbital Coordinate System



Orbital Coordinate System:

Right handed, Cartesian system

+X: Perigee axis (~270°)

+Z: normal vector to the orbital plane

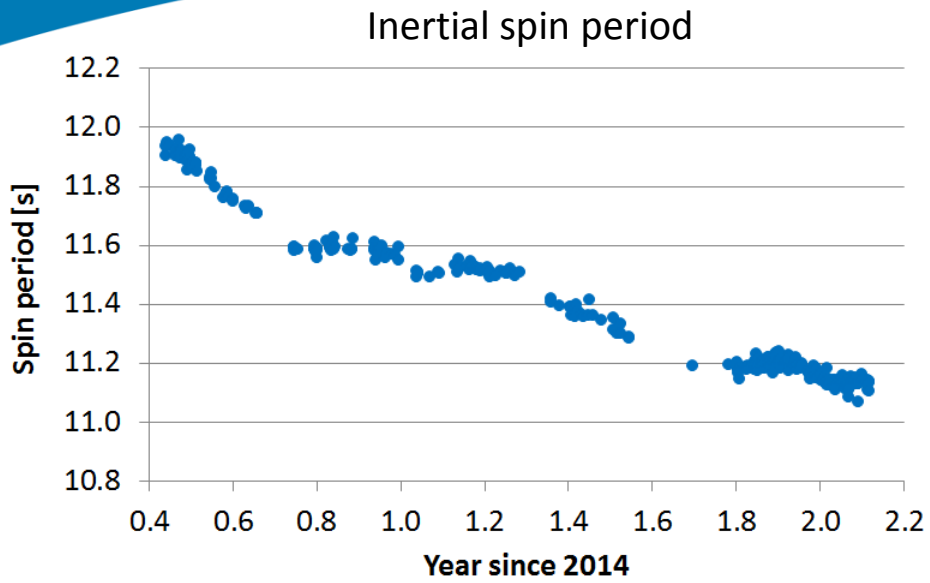
+Y: complementary axis

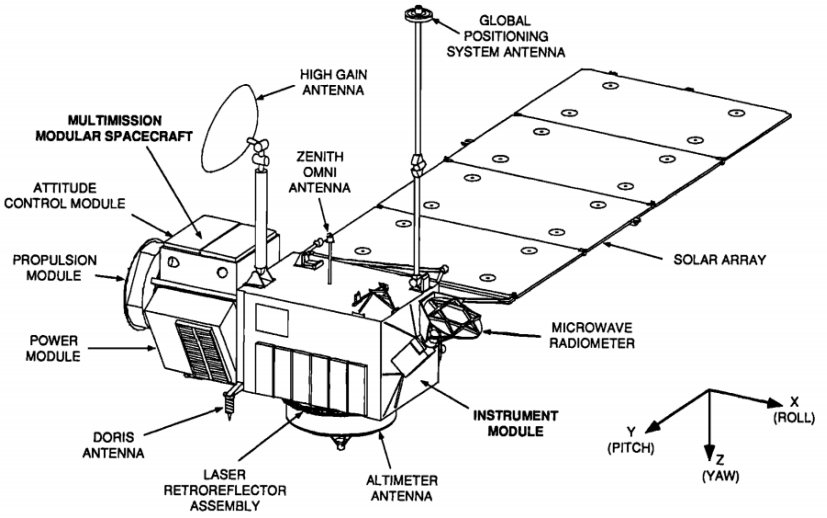
[0°,0°] is the perigee

[0°, -8.4°] is the cone center

Spin axis of Topex oscillates in Orbital Coordinate System near perigee, with a period of 101 days. (the period of orbital precession is 173 days)

Spin of defunct TOPEX

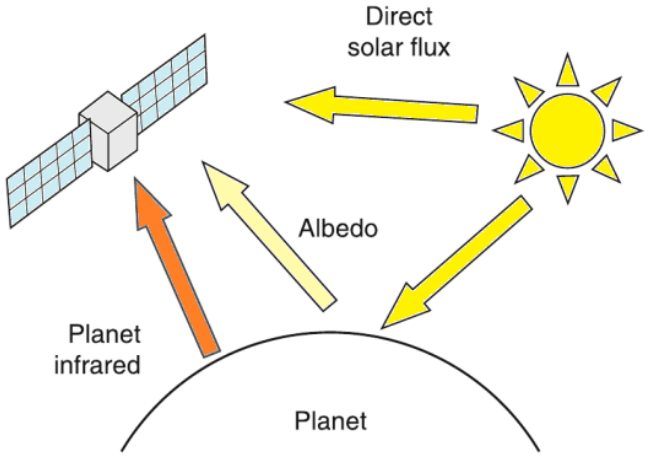




Solar photon pressure force

$$\overline{F} = \frac{I}{c}\sum_{i=0}^{n} A_i(\overline{u}\cdot\overline{n}_i)\left[2K_i^s(\overline{u}\cdot\overline{n}_i)\overline{n}_i + K_i^d\left(\overline{u}-\frac{2}{3}\overline{n}_i\right) + K_i^a\overline{u}\right]$$

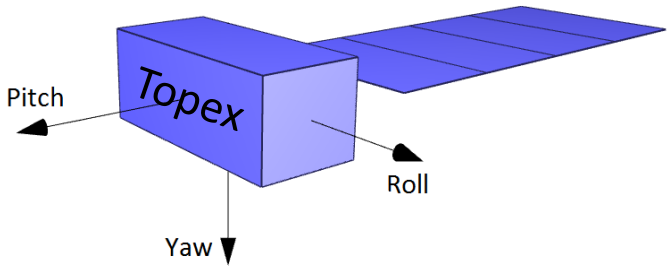
I: power of radiation flux
A_i: exposed surface area
$\overline{u}, \overline{n}_i$: direction of the incident flux and normal vector to the surface
K_i^s, K_i^d, K_i^a: coefficients of specular, diffused and absorbed portion of the received power



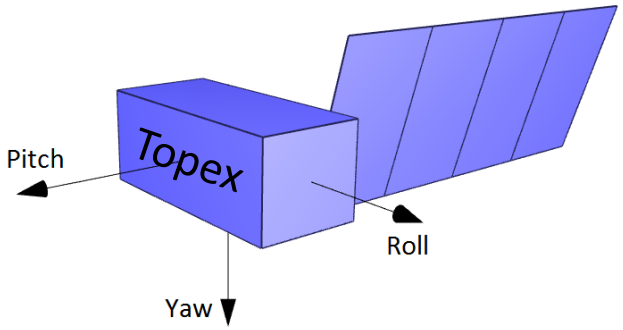
Spin of defunct TOPEX

Satellite macromodel

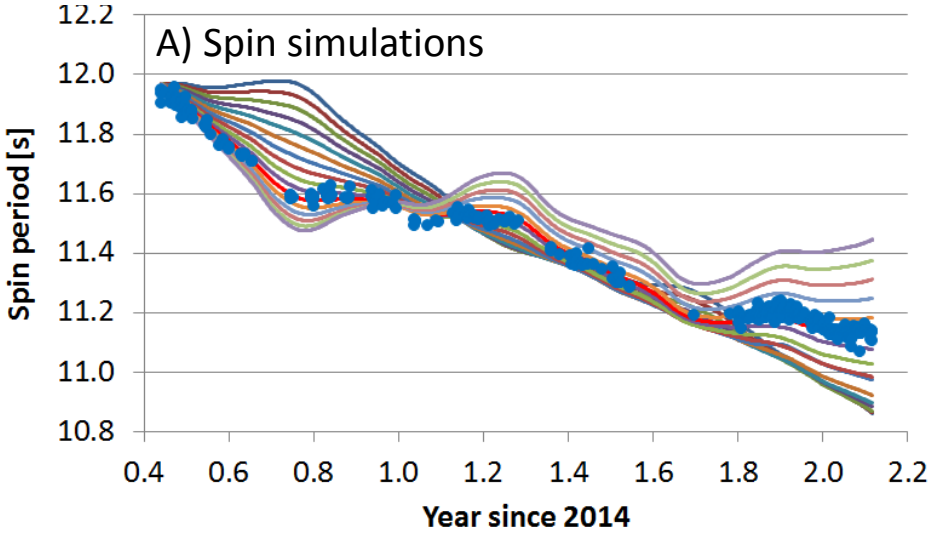
solar panel pitch angle 0°



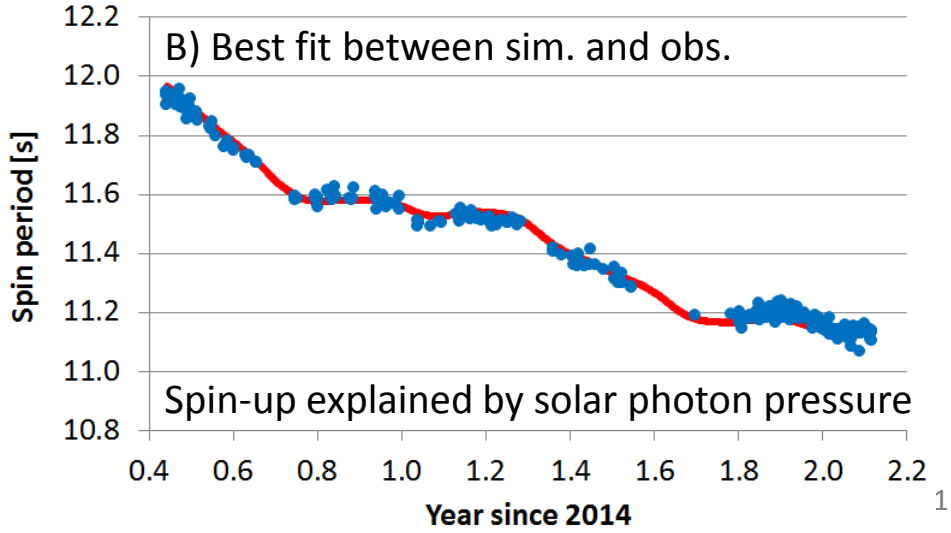
solar panel pitch angle 105°



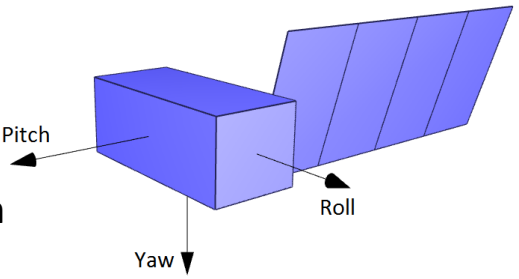
Solar panel pitch angle changed from 75°-120° with 3° step



Solar panel pitch angle 105°; RMS = 21ms

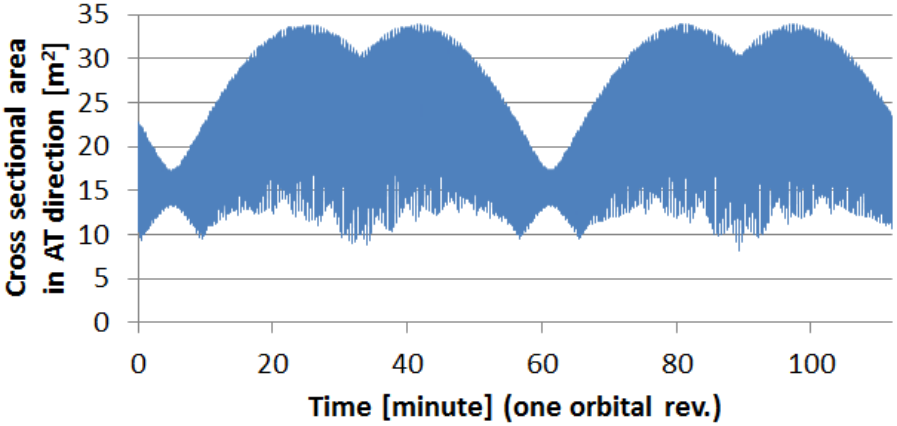


Attitude model of TOPEX

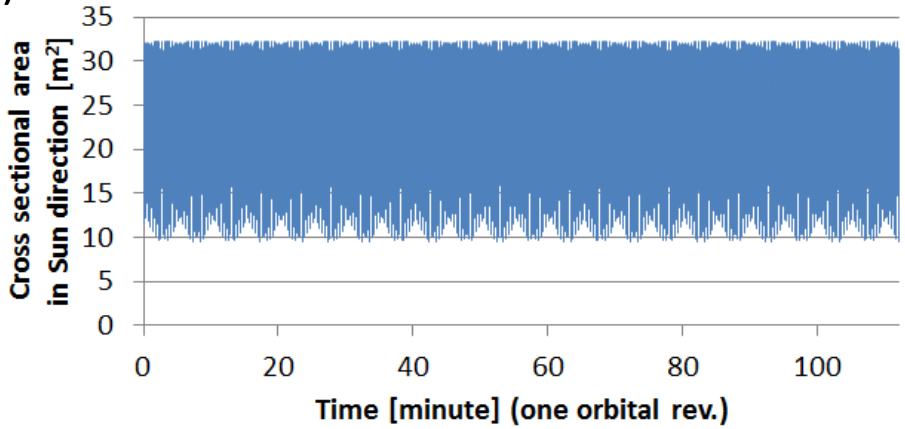


Cross sectional area in the Sun/AT directions changes from 10-35 m^2 due to spin
Simulations for one orbital revolution (at epoch 2015.25).

A)

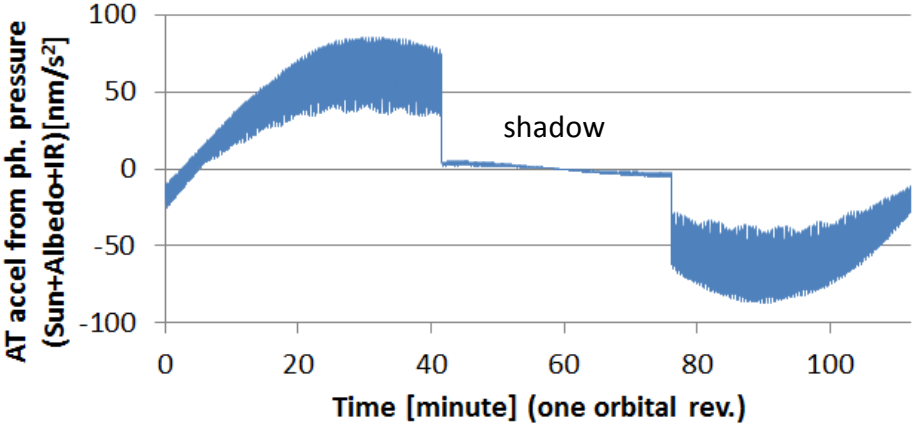


B)

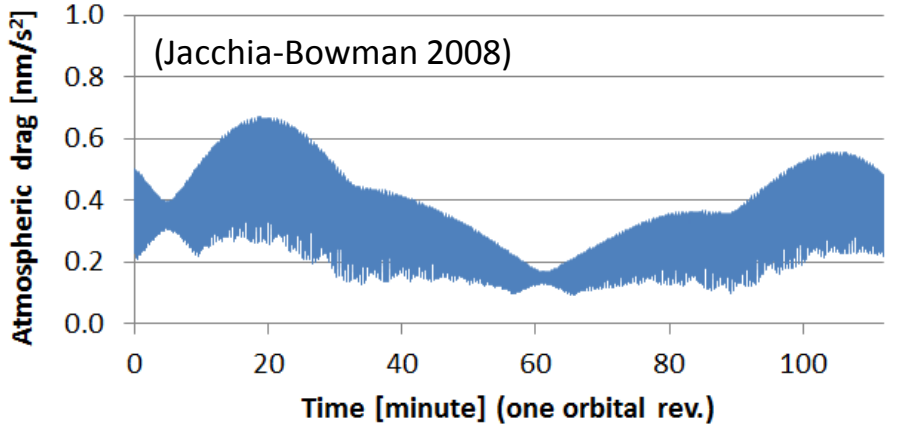


Along track acceleration depends on the cross sectional area

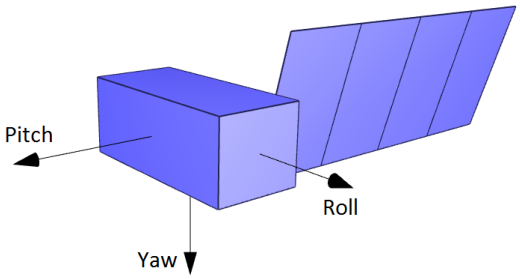
C)



D)

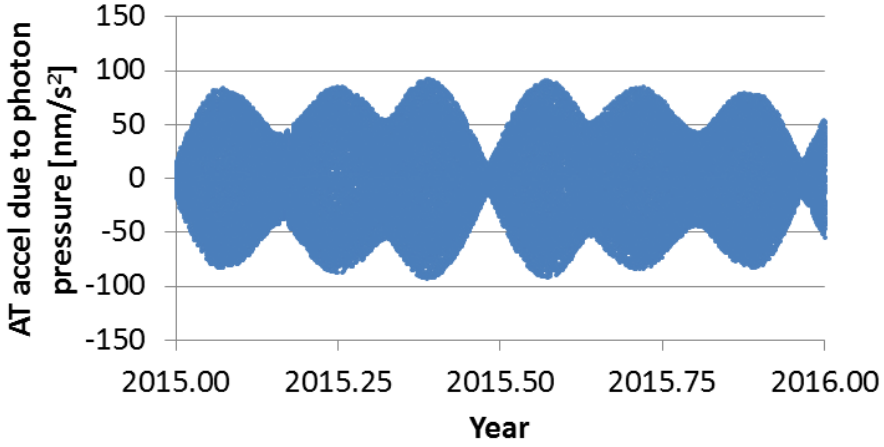


Attitude model of TOPEX

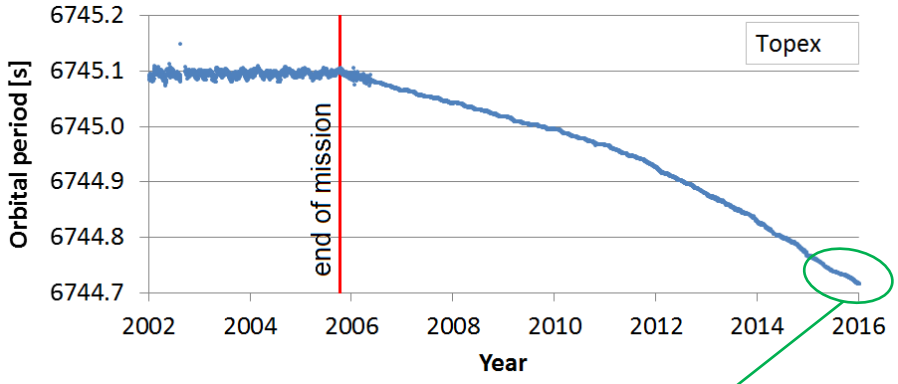


One year simulations:

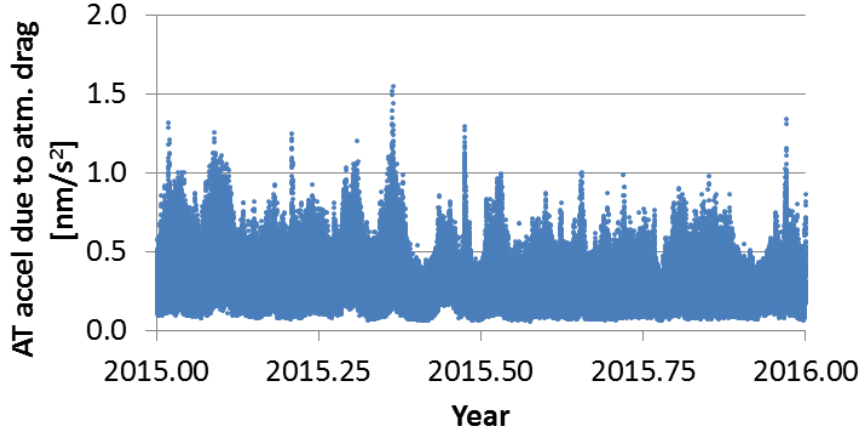
A)



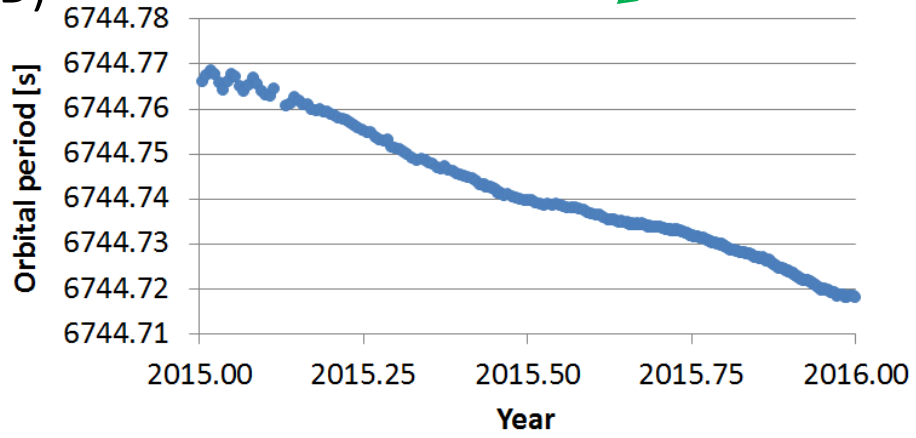
B)



C)

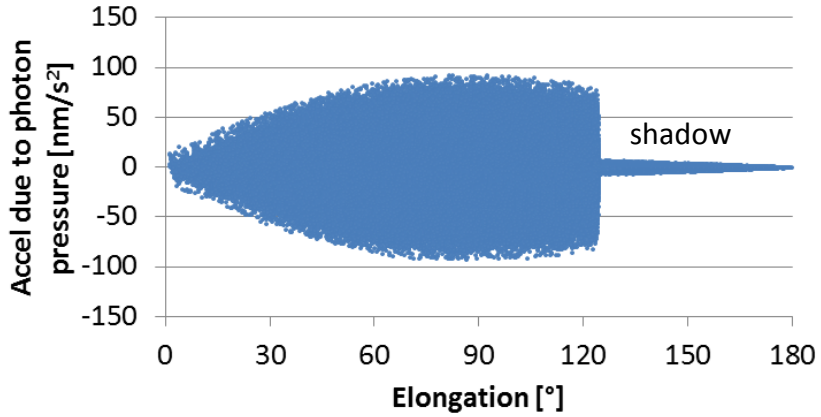


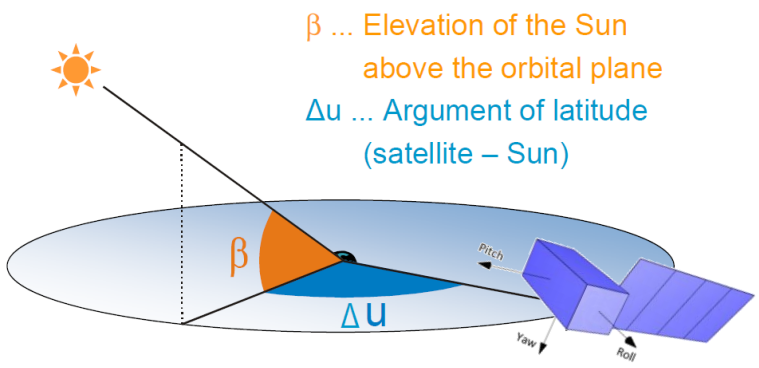
D)



Attitude model of TOPEX

A)





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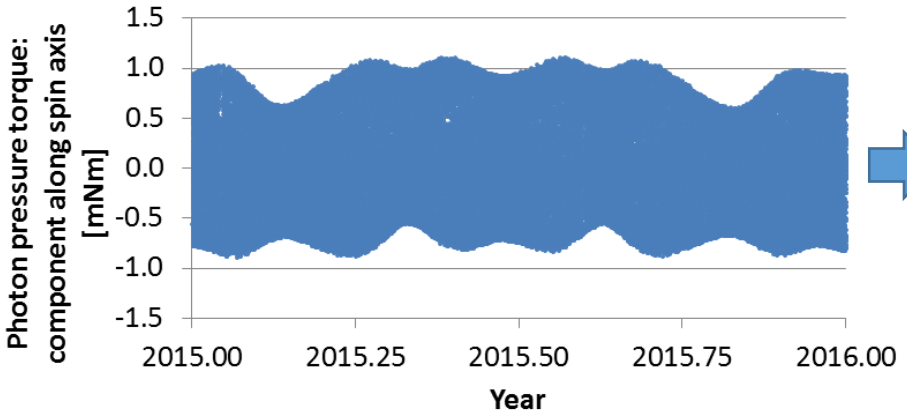
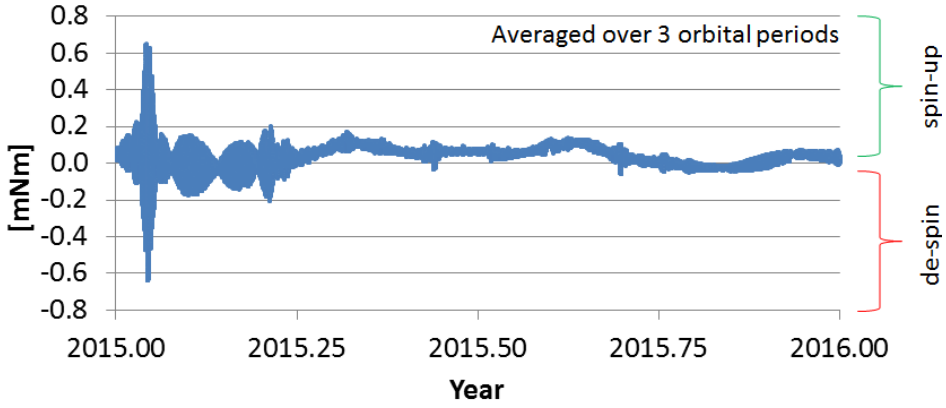


C)



Causes the observed spin-up at the small rate of 0.44 s/year (<4%/year)

Conclusions

- Laser ranging to defunct satellites allows for the accurate spin parameters determination

- The known attitude of the spacecraft gives the cross-sectional area in the along-track and Sun directions for the accurate drag estimation

- The realistic drag modeling on the cooperative space debris objects can improve the orbit decay analysis and re-entry prediction (useful for the future mission planning)

- Please support Space Debris Study Group research and join the current OICETS optional campaign – we need only 1-2 passes weekly from your station.
  See details here: https://lists.nasa.gov/pipermail/ilrs-sdsg/2016-August/000021.html

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.
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SERC SPACE ENVIRONMENT RESEARCH CENTRE

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