Investigation on Envisat attitude motion

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e.Deorbit Workshop, 06/05/2014

Summary

1. Available surveillance data
2. Data analysis after Envisat failure
3. Simulation of Envisat attitude
4. MOWA (Models on Orbit With an Attitude): analysis of ISAR images
5. Recent observations of Envisat

Available surveillance data: Laser

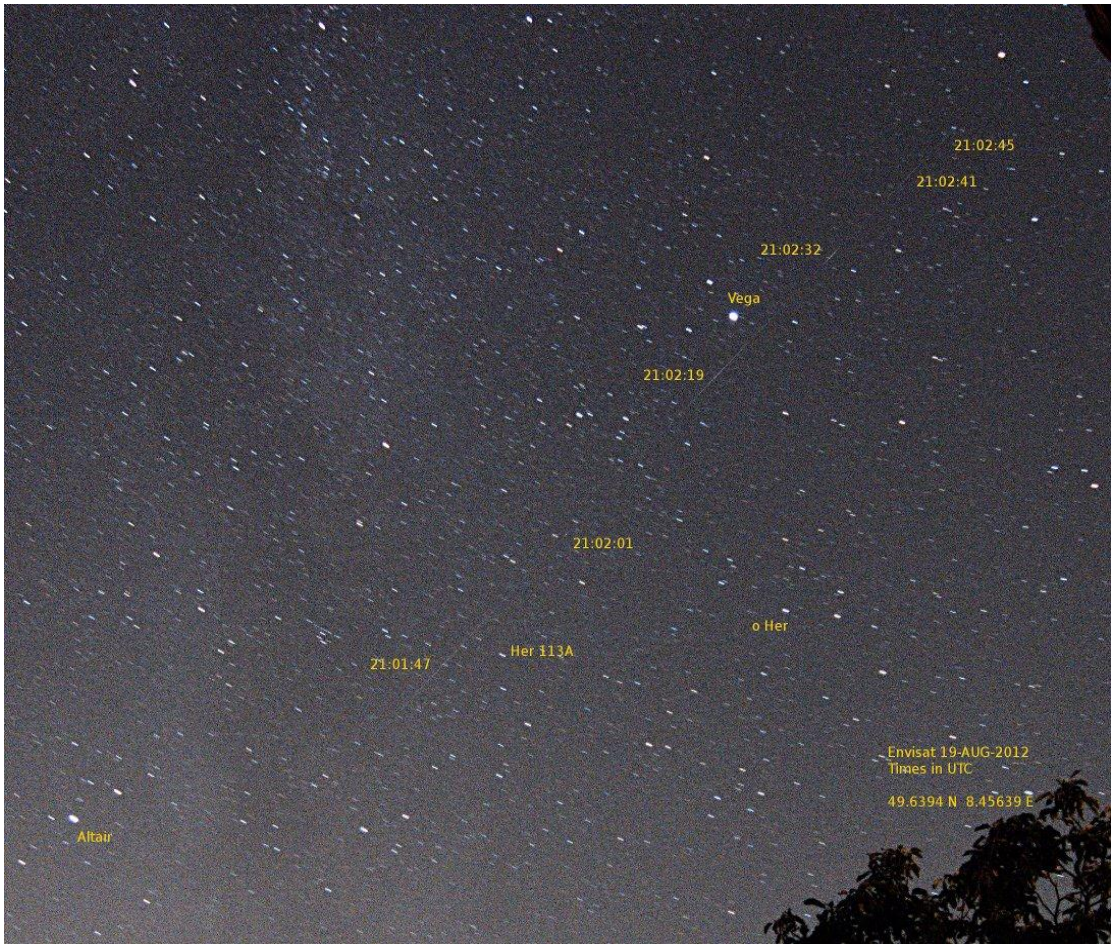
- The International Laser Ranging Service (ILRS) has supported the ESA Envisat mission with an high priority from Phase E1 (commissioning phase) to Phase E2 (exploitation phase), with the delivery of valuable & continuous laser acquisition. This allowed ESA to generate high-quality orbit products.


Fonte: ESA, 2007.

Available surveillance data: Optical

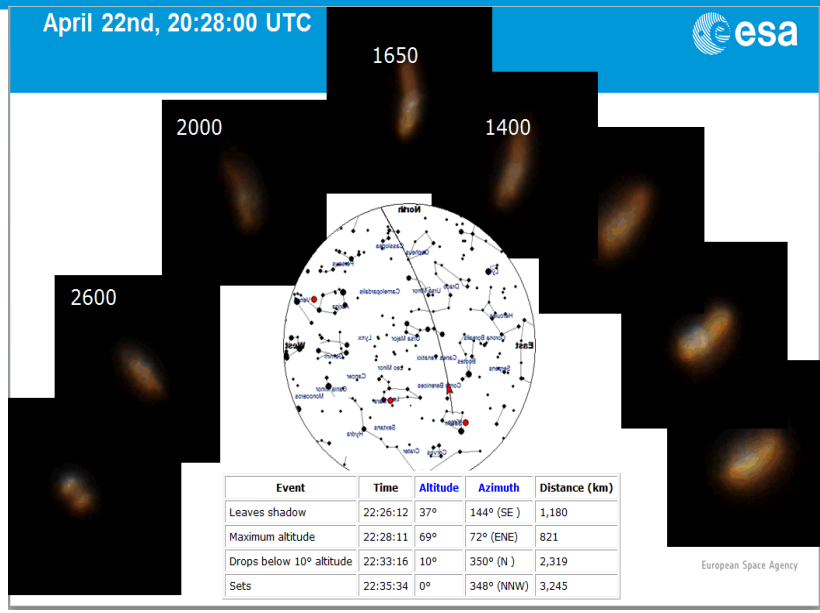
- Light curve observations made by an amateur astronomer on August 2012 in Germany.

- Flares, variation in the apparent brightness of the object, are an indication for attitude dynamics but might also be caused by surface features under varying illumination conditions.

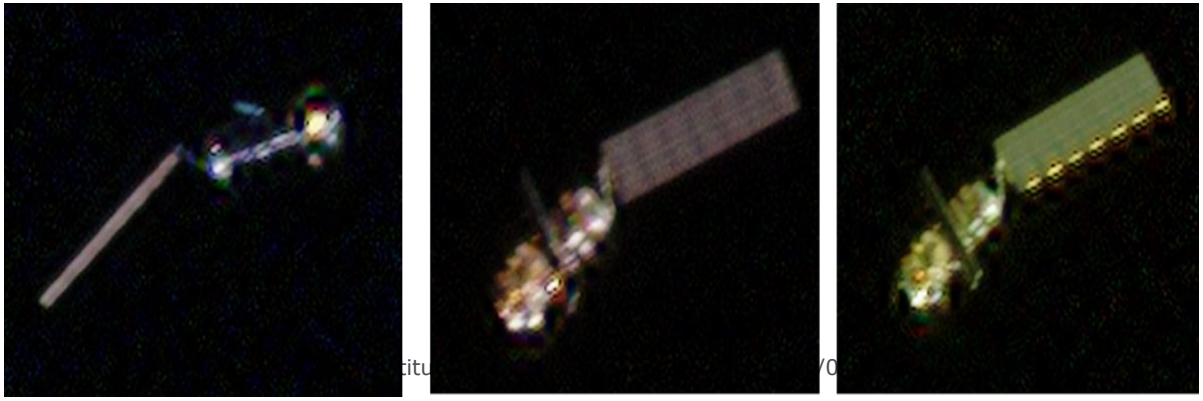


Available surveillance data: Optical

- Volkssternwarte Munich (private initiative with three experienced observers) use of EL/AZ-mounted 80cm f/10 Dobson telescope
- Envisat observations on Apr 2012.

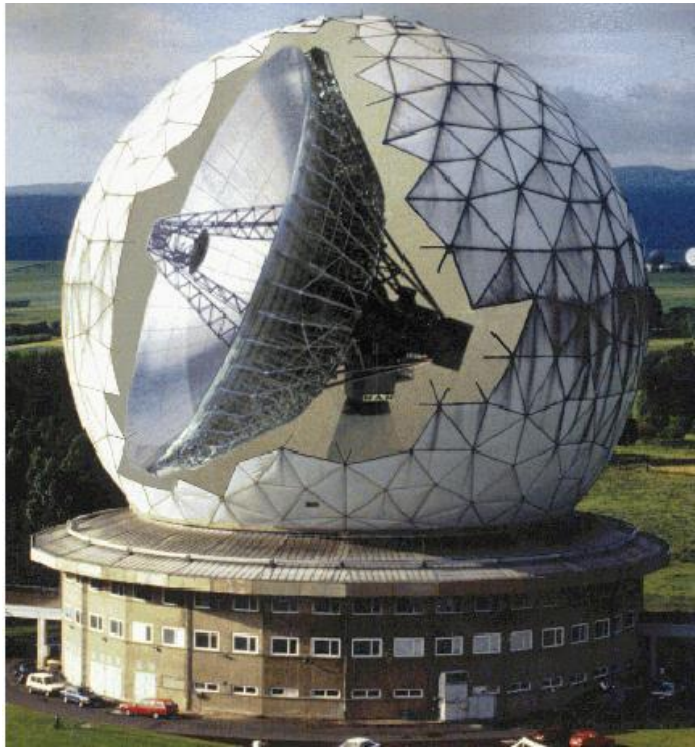


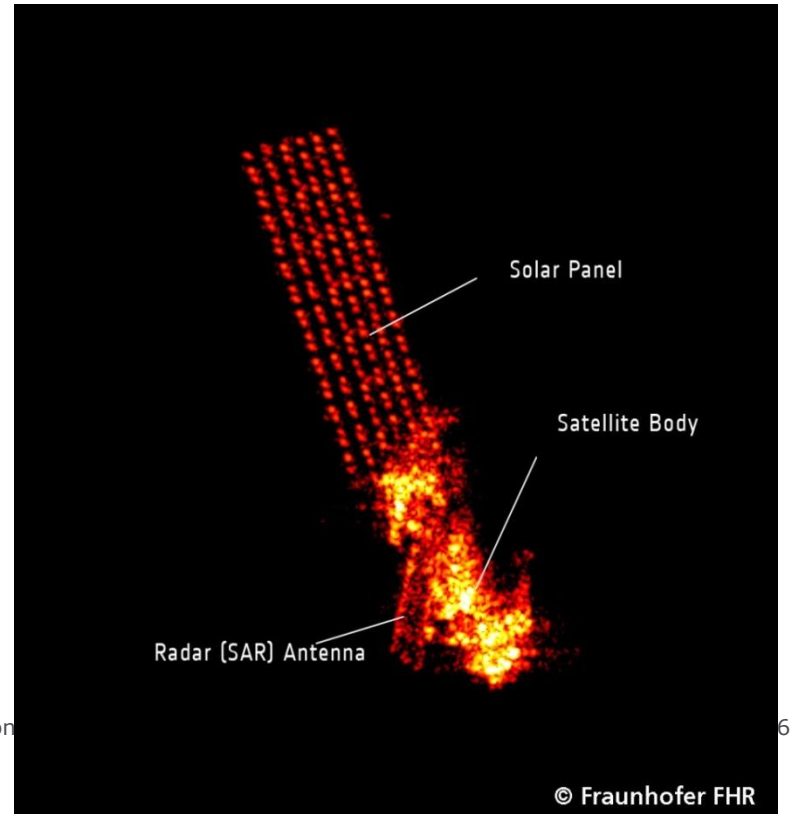
- Pleiades satellite observations of Envisat on Apr 2012.



Available surveillance data: Radar

- TIRA Tracking and Imaging Radar (34m antenna, with L-band tracking and Ku-band imaging) of Fraunhofer/FHR, at Wachtberg, near Bonn, Germany
- ISAR-Image of ENVISAT on Apr 2012



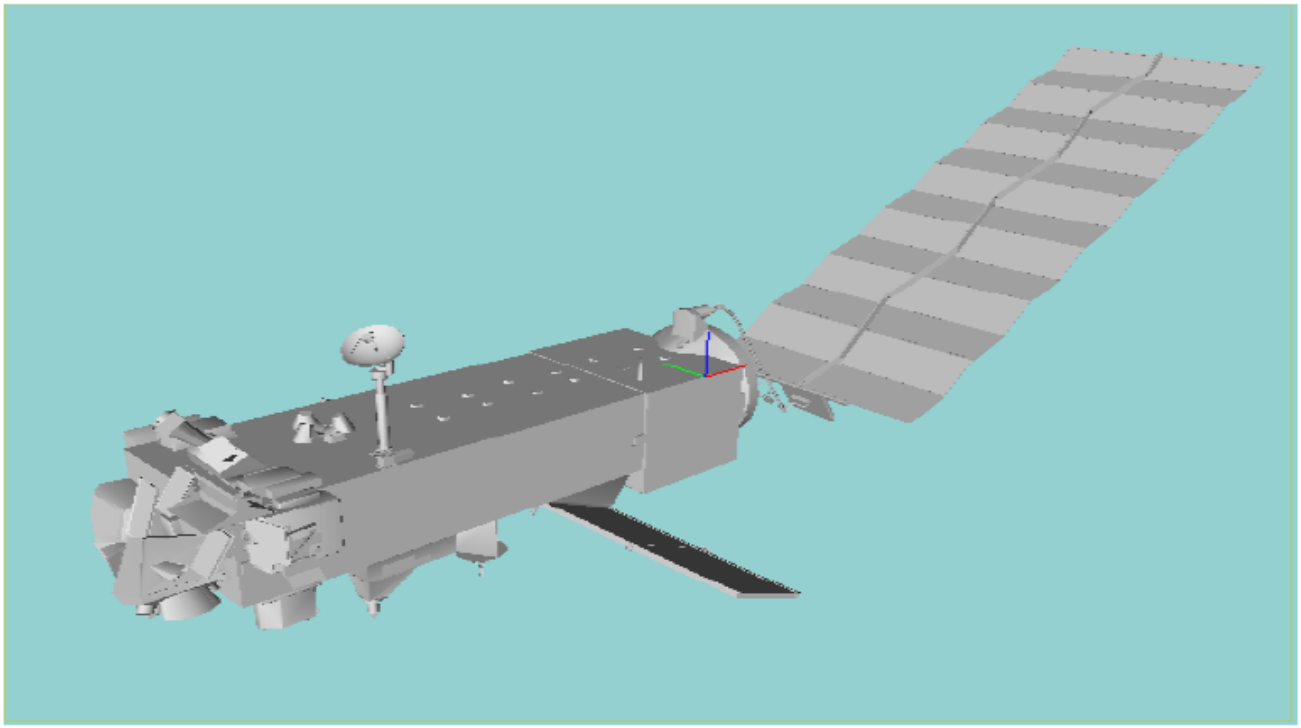


Data analysis after Envisat failure

- After the loss of contact with Envisat, a wealth of observation data concerning the attitude was collected for processing (optical, radar images, laser ranging, radar tracks, light tracks).
- Interpretation of optical data :
  - The spacecraft body axis (X axis) is not inertially fixed but changes from observation to observation (period > 1 orbit revolution).
  - The solar panel is locked close to the anti-canonical position since April 11.
  - The rotation around the X-axis is small, perhaps less than a few degrees per minute, but definitely less than 12 degrees per minute.
  - The question whether these motions are regular or irregular cannot be answered from the limited observation periods.
- Interpretation of radar data :
  - Many observation passes resulted in rates of ca. 0.4°/s; changing rotation axis; initial passes: 0.1°/s, afterwards slow increase to 0.4°/s.
  - Rotation from pass to pass, resulted often in similar rotation axis, the rate can only be assessed modulo 0.06°/s (N full rotations in 1 orbit).

Scarab model for attitude simulation (1/2)

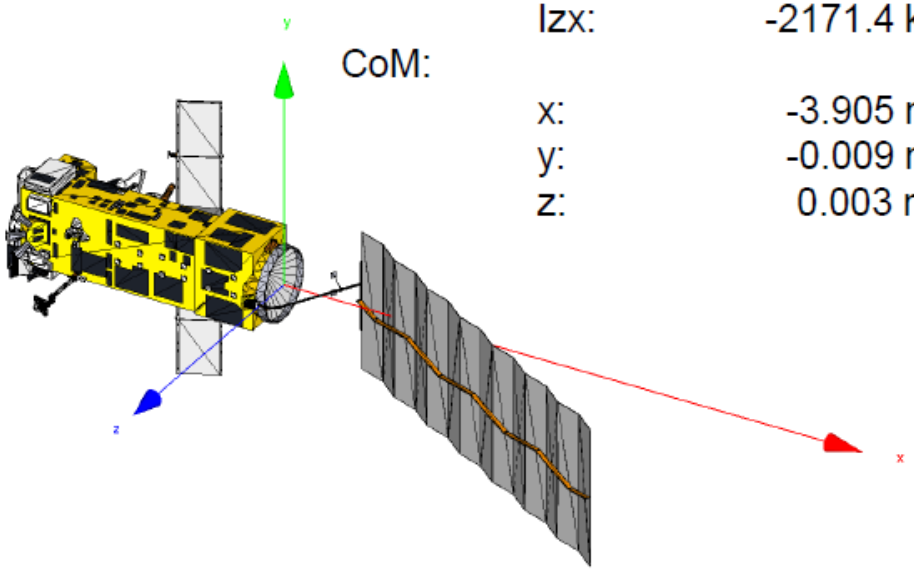
- Envisat modeled with sufficient detail, a 6DOF simulator used to propagate attitude states a decade forward, in order to assess the stability of the motion.
- First model based on mass and moments of inertia, as well as *.wrl and *.obj files for the geometry (that were used in the CDF e.Deorbit study)
- One-sided panel model, no mass-summation, no thermal analysis.

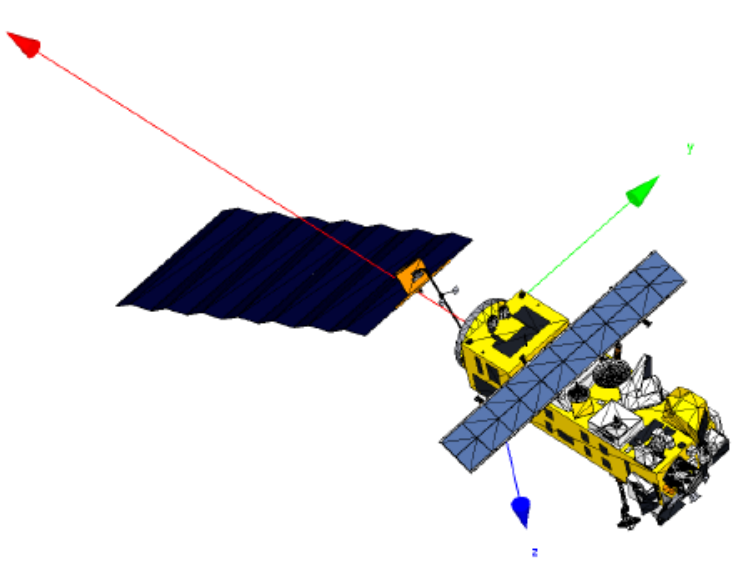


Modeling detail: Primitives: 30, Panels: 12034

Scarab model for attitude simulation (2/2)

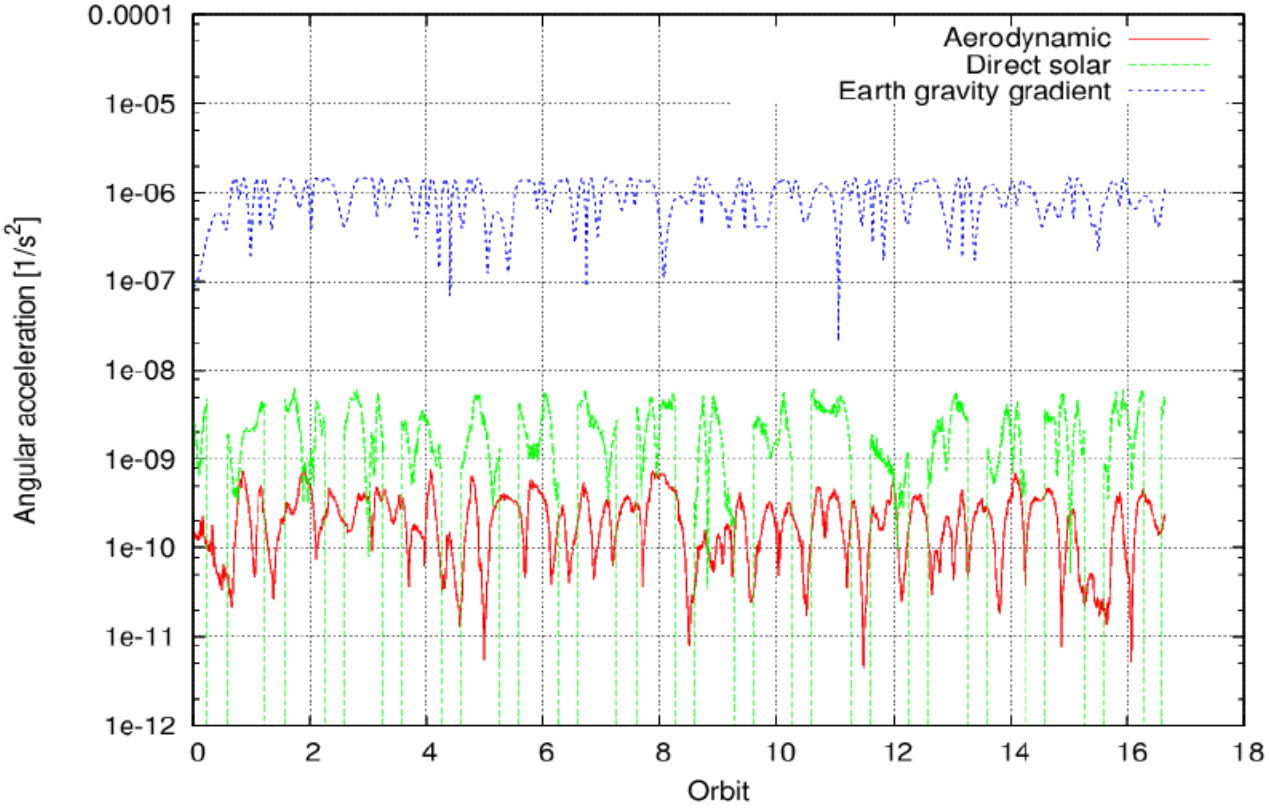
Total mass:		7827.867 kg
MOI:		
	Ixx:	17023.3 kg m²
	Iyy:	124825.7 kg m²
	Izz:	129112.2 kg m²
	Ixy:	397.1 kg m²
	Iyz:	344.2 kg m²
	Izx:	-2171.4 kg m²
CoM:		
	x:	-3.905 m
	y:	-0.009 m
	z:	0.003 m





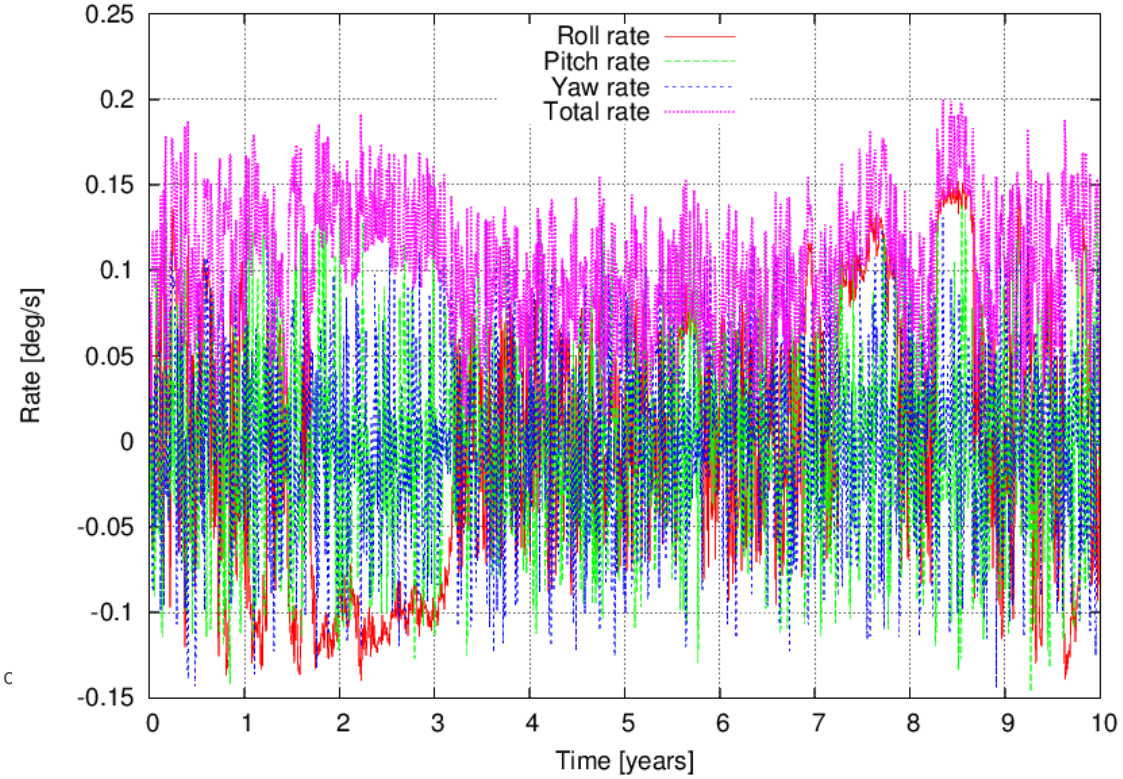
Attitude simulation: Very short term

- With gravity gradient as the major torque, the initial attitude is unstable:
  - Gravity gradient is 2 orders of magnitude stronger then the other torques.
  - Damping of the rotation (e.g. sloshing or Eddy currents), is not considered.

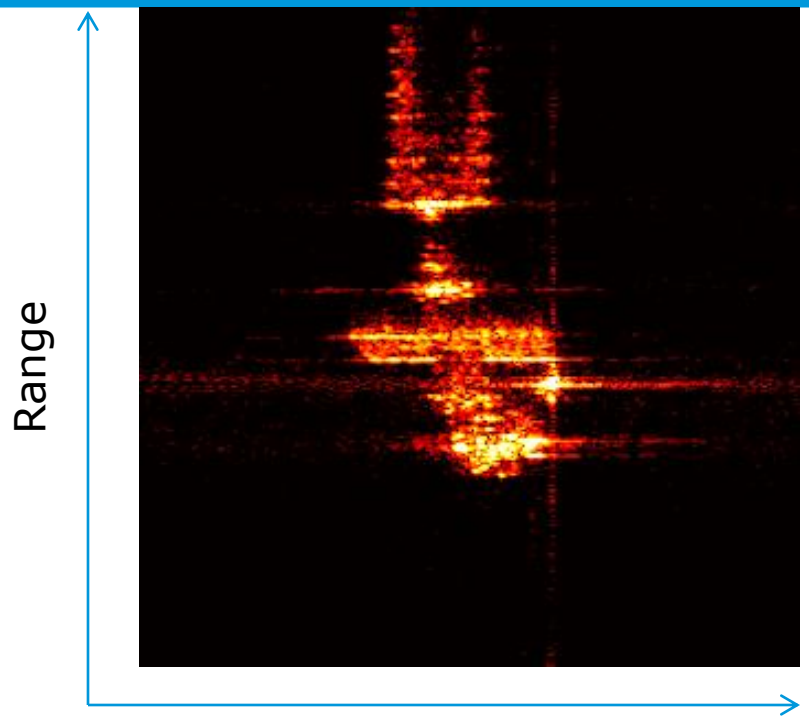


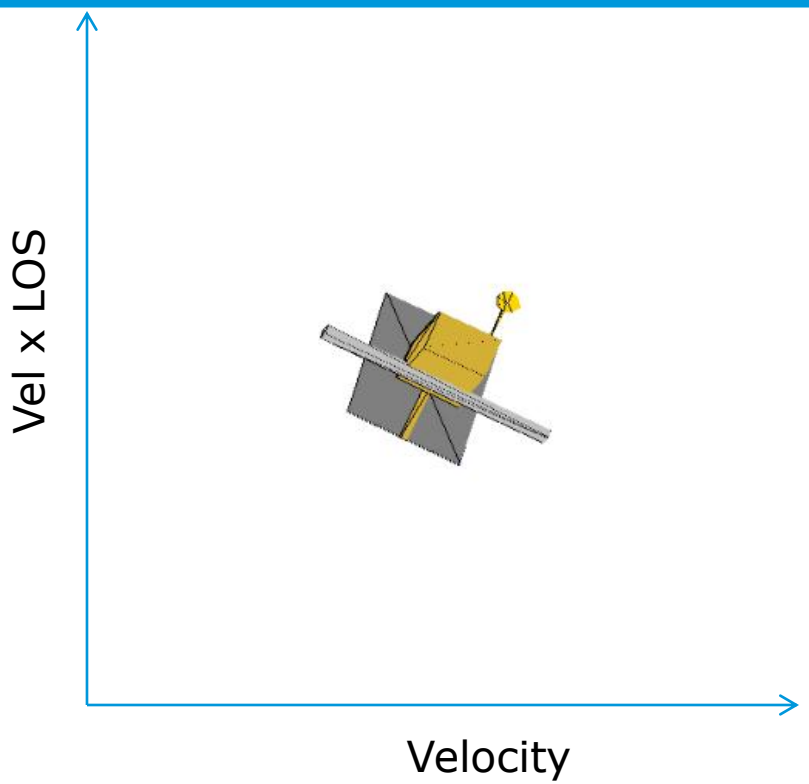
Attitude simulation: Mid term

- With gravity gradient as the major torque, the initial attitude is unstable:
  - Given a release condition close to gravity-gradient stabilisation, the attitude is expected to remain stable.
- On mid-term range (10 years) no sign of gravity-gradient stabilisation (various simulation with different initial attitudes)
  - The overall attitude rates remain stable over all simulation cases.



MOWA: ISAR images for attitude monitoring



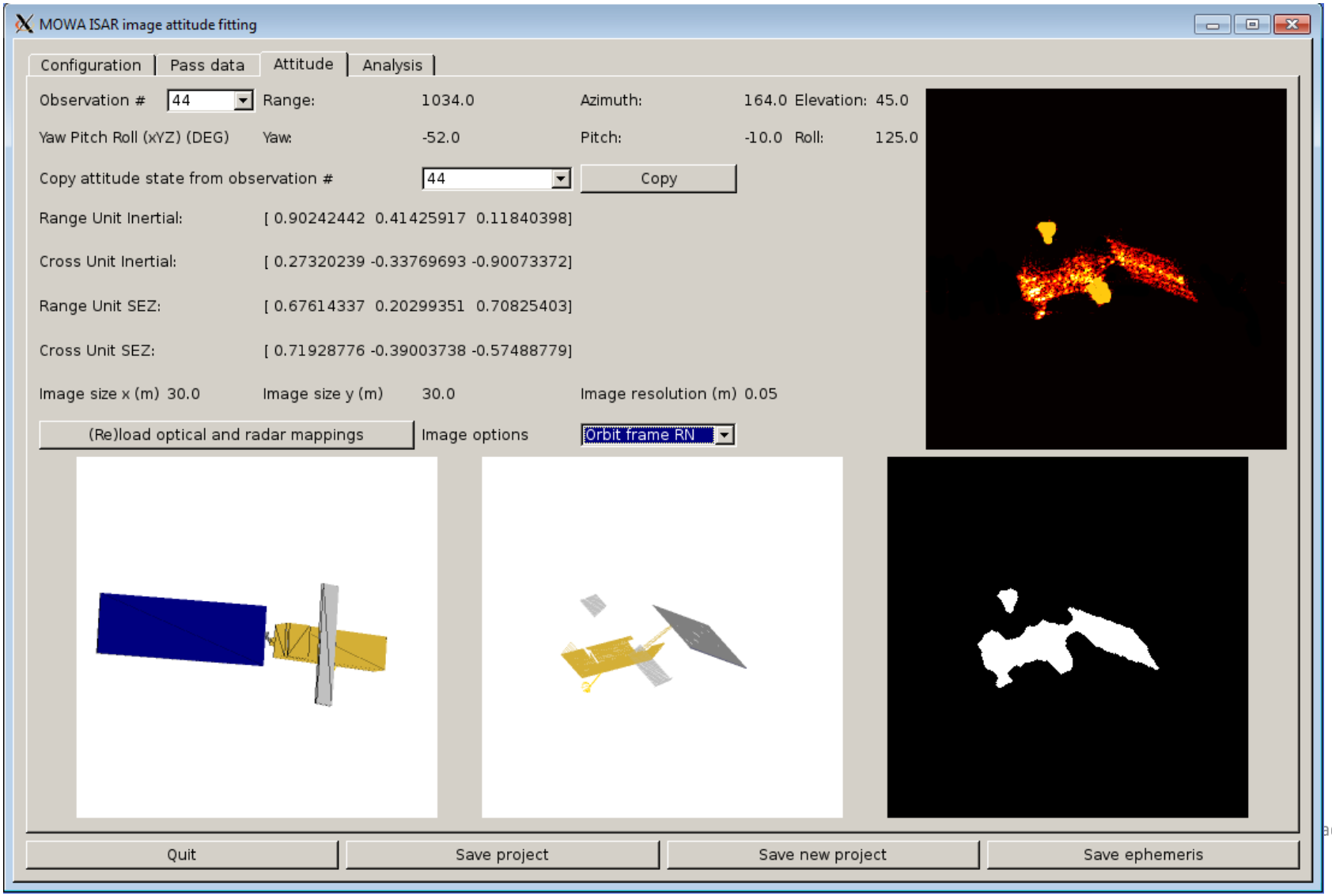


- TIRA offers the possibility to periodically check the state of Envisat with constant and well defined observational means, for each observation requested.
- Range-Doppler space is a counter-intuitive space for analysis.

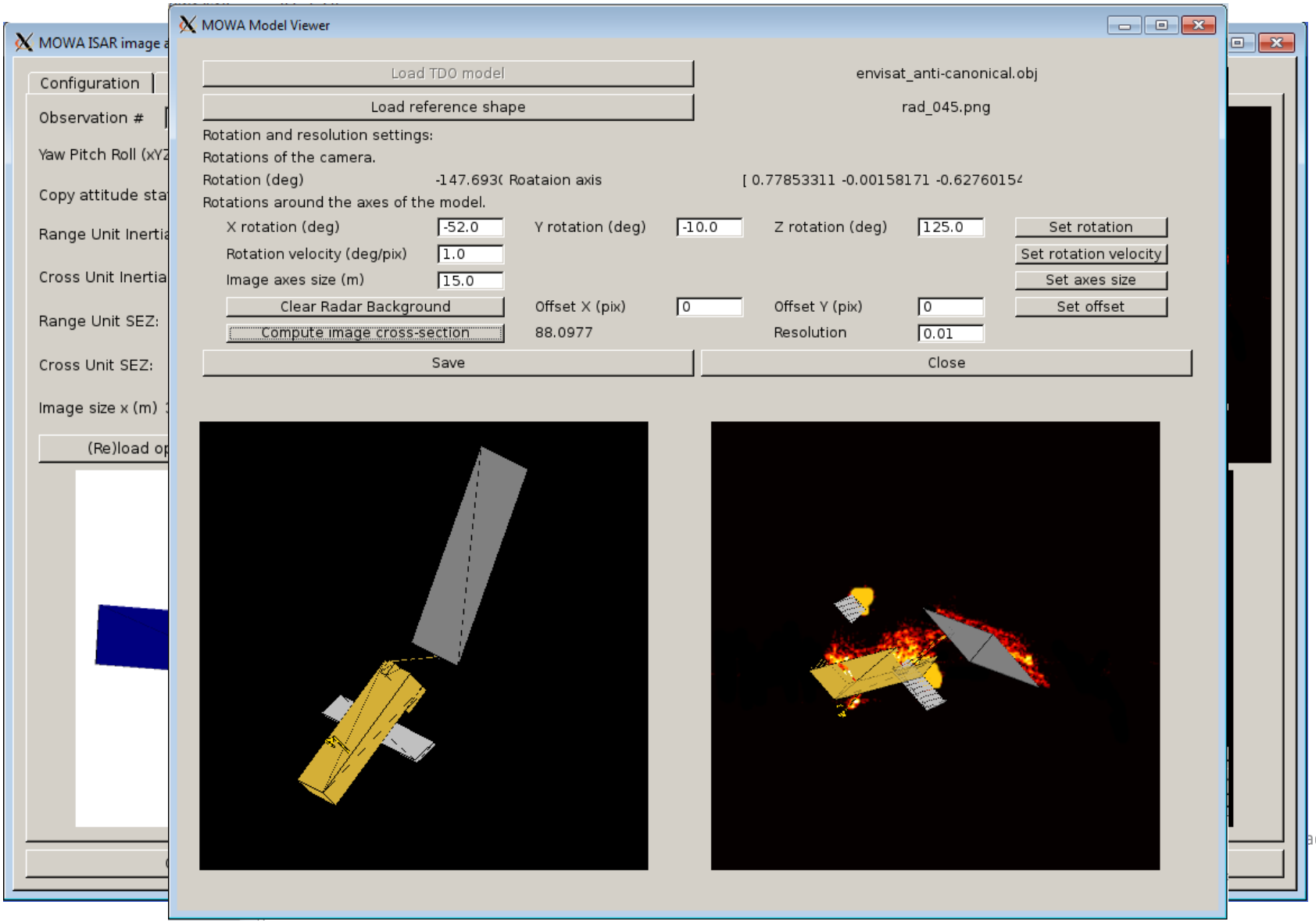
MOWA Sensor model

- A sensor model was developed to facilitate the interpretation of ISAR images by an operator and to derive attitude information from them.
    1. 3D-model based.
    2. Detection of off-nominal behaviour: Predefined attitude behaviour, e.g. Sun or Earth pointing modes, can be loaded for a given model and a simulated the ISAR image can be generated at a desired epoch.
    3. Verification of hardware deployment (ATV): Signals coming from given components can be tracked to assist in operations.
    4. A graphical user interface is available to assist an operator in estimating unknown attitudes from an observation sequence.
    5. Data can be extracted from the estimation process.

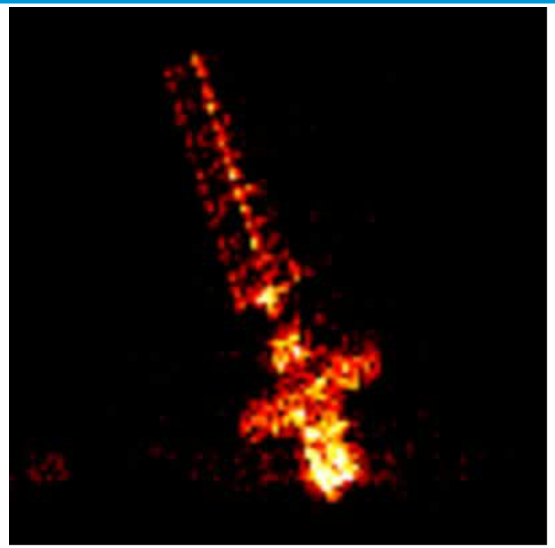
MOWA Sensor model

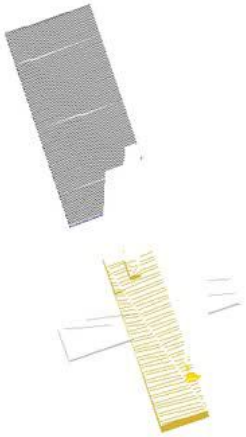


MOWA Sensor model



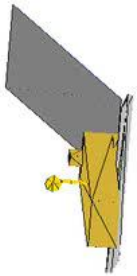
MOWA

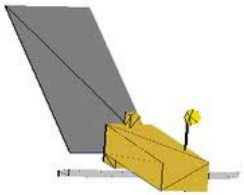




Radar mapping

Zenith





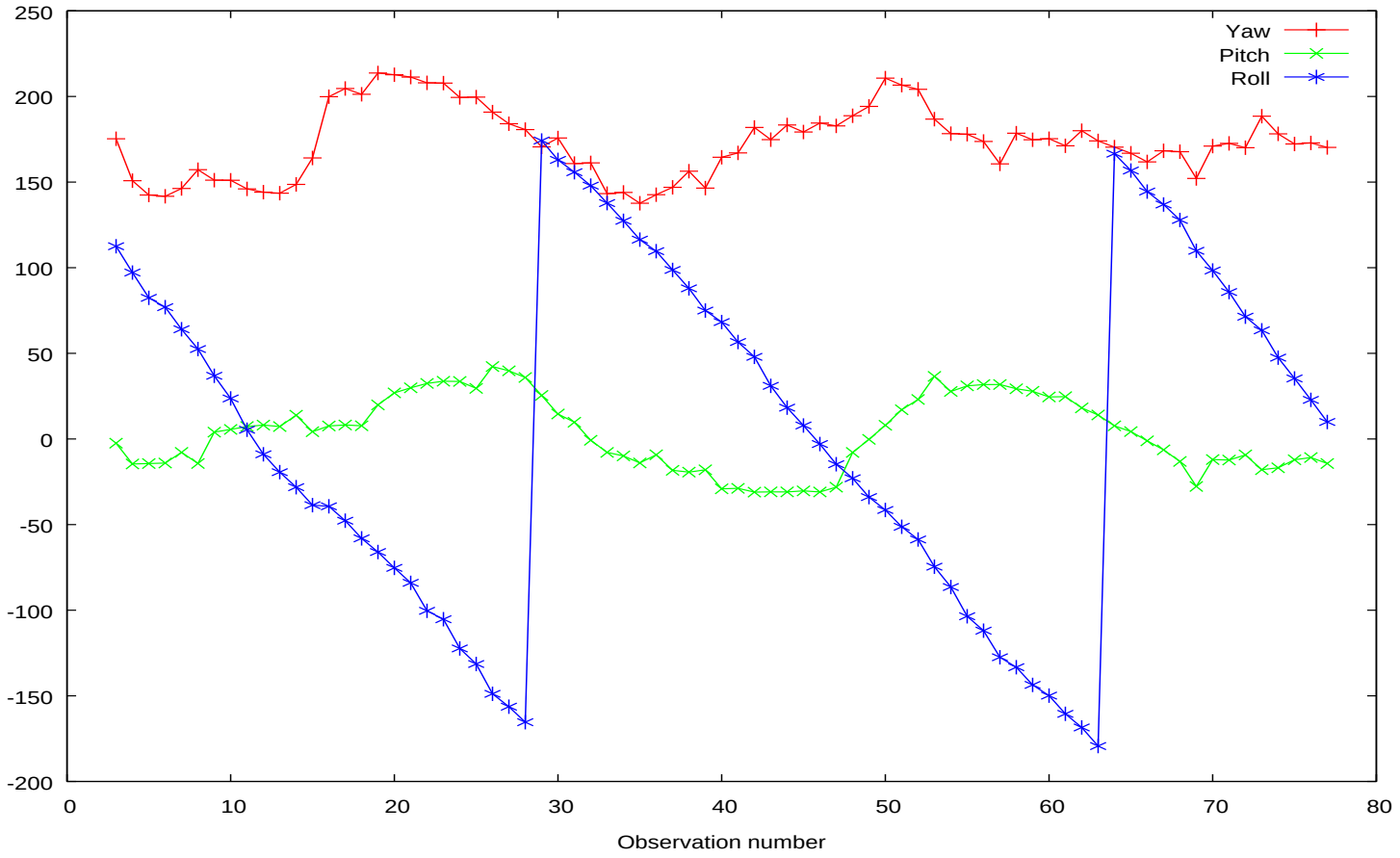
LOS x AA

Out-of-plane

Aspect Angle

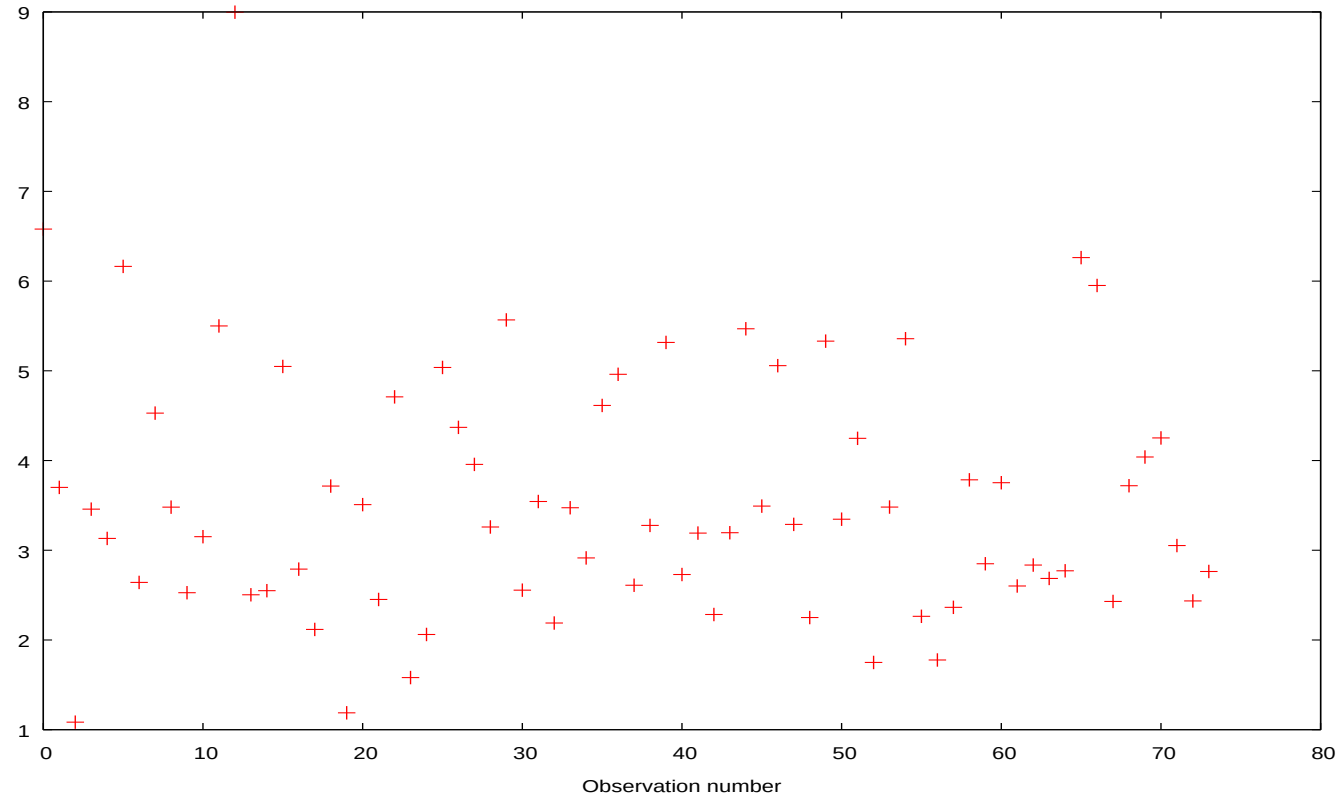
New Envisat ISAR observation

- New ISAR observations for Envisat were acquired on 13/11/2013 and 21/11/2013.



New Envisat ISAR observation

- Average rotation rate 3.5 deg/s, median 3.2 deg/s.
- Attitude rates 20 faster than what was expected from simulations.



Envisat SLR observations

- Independent SLR observations by various stations around the world continued for the past two years, yielding a continuous dataset to derive attitude information from.

    1. From the signal produced by the laser reflections from the retro-reflector panel, the spin-axis can be determined.

    2. With the kHz SLR available from the Graz station, the spin period given a spin axis can be estimated.

    3. The attitude data is derived from the observation data under the assumption that the spin-axis remained stable from May 2013 onwards.

Envisat SLR observations

[D. Kucharski, G. Kirchner, et all; *Attitude and spin period of space debris Envisat measured by Satellite Laser Ranging*][personal communications]

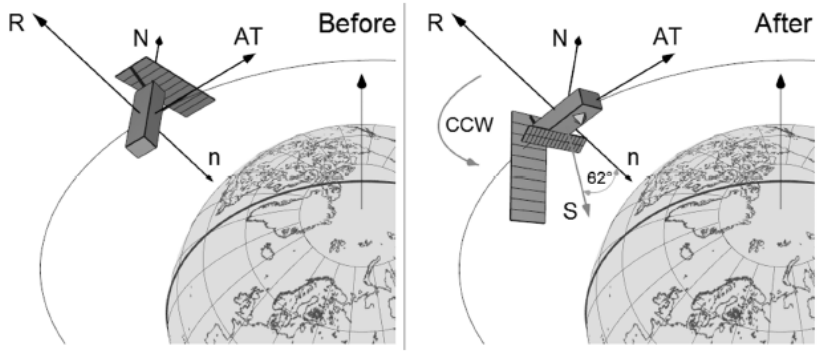
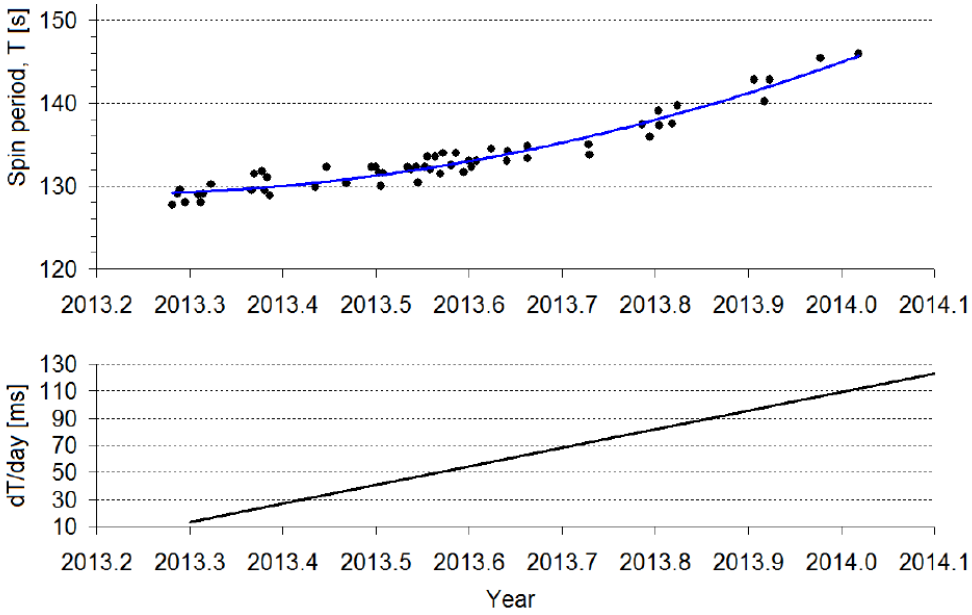


Fig.7. Orientation of Envisat. Left: during the mission - nadir stabilized; Right: after May, 2013, the satellite spins in the counter clockwise direction about the spin axis S. Vectors: radial (R), normal to the orbital plane (N), along track (AT), nadir (n); a ground track of the polar orbit is marked.



- The recent attitude states derived independently from ISAR and SLR data are in good agreement qualitatively with each other (but quantitative different, probably due to different assumptions). Both methods are complementary.

Conclusions

- ESA is going to launch a GSTP study into attitude determination techniques using different sensors.
- Tool developed to be able to determine attitude based on ISAR images.
- The recent attitude states do not match the predicted behaviour:
  - Rotation rate 3.5deg/s when maximum 0.2deg/s was predicted
  - In plane rotation dominates instead of gravity gradient stabilised rotation anticipated by few studies.
  - Due to uncertainties on state and stability of rotation, also on physical properties of Envisat.
- Continuous monitoring will help to improve the predictions.
- Simulations after each measurement campaign could help to limit uncertainties.
- It is necessary to know expected and real rotation for any ADR attempt.