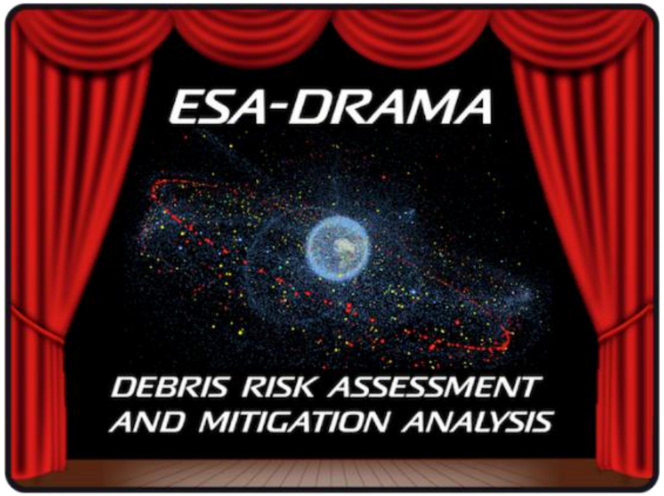
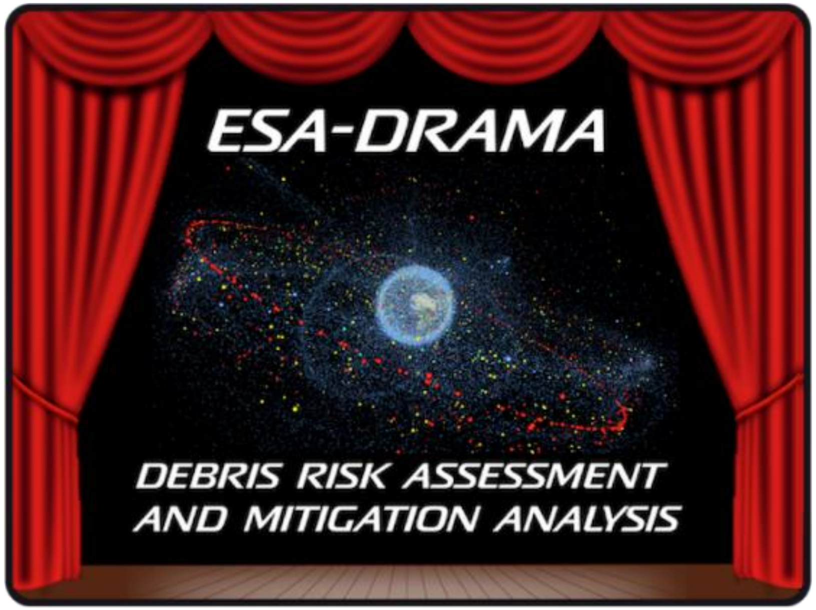
# Re-entry tools:
# DRAMA upgrade and re-entry tumbling state with IOTA

**Ronny Kanzler**

October 25, 2017



# Upgrade of DRAMA's Spacecraft Entry Survival Analysis Codes



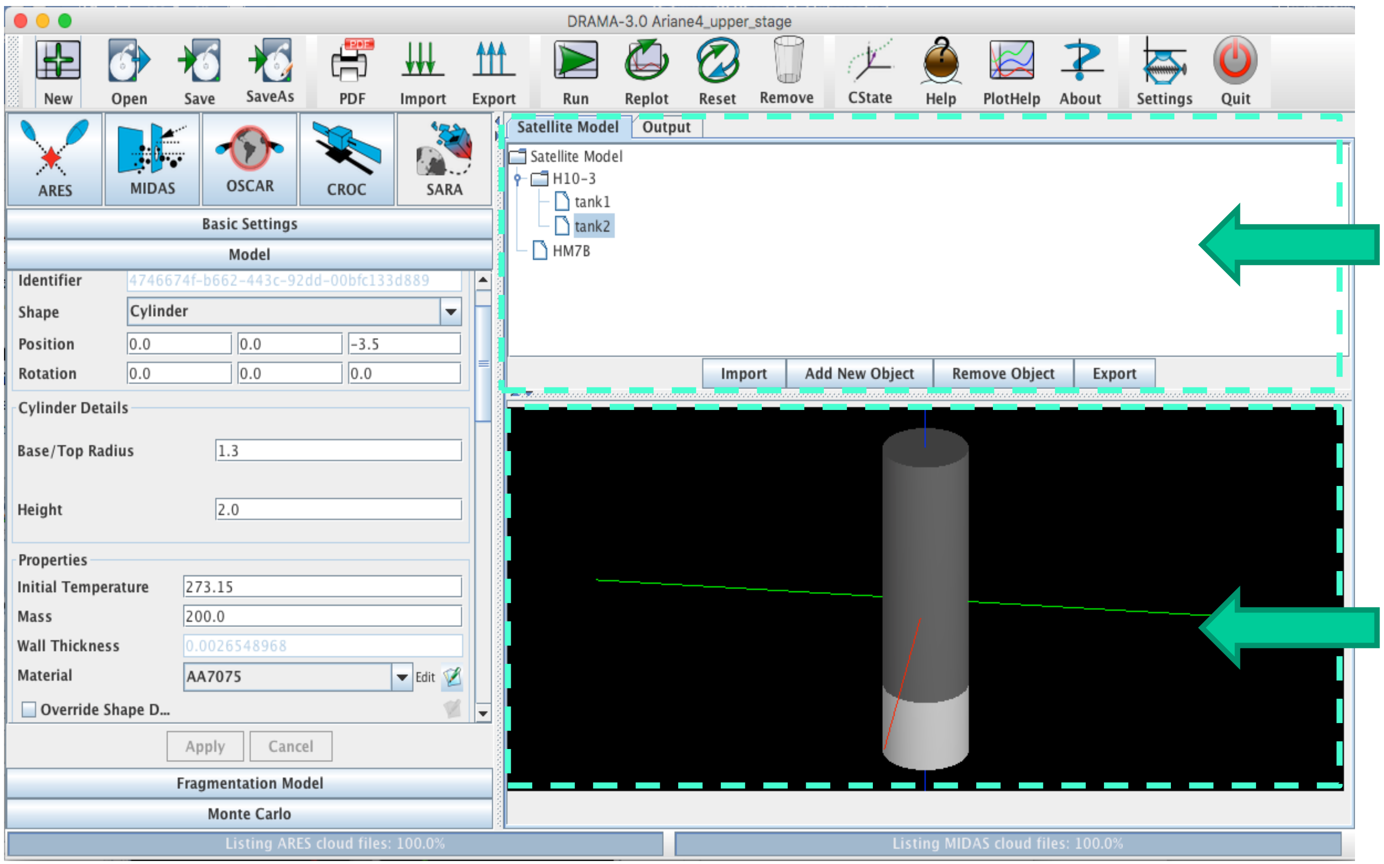

The upgrade of DRAMA is funded by ESA, under Contract No. 40000112447/14/D/SR.

# Overview

- Upgraded DRAMA GUI
  - Integration of the new SARA modules into the DRAMA GUI
  - Extended functionality and useability
- SESAM - Spacecraft Entry Survival Analysis Module
  - Aerodynamic and aero-thermodynamic simulation
  - Entirely re-ingeneered from scratch with up-to-date methods
- SERAM - Spacecraft Entry Risk Analysis Module
  - Ground risk analysis based on up-to-date population models
  - Completely revised and newly coded
- Monte-Carlo Wrapper
  - Newly developed for statistical analysis
  - Calculates Declared Re-entry Area (DRA, 99% of ground fragments) and Safety Re-entry Area (SRA, 99.999% of ground fragments)

# Upgraded DRAMA GUI
# Modeling of re-entry objects

- New hierarchical model of the spacecraft & 3D view of the components
- Relations between components
- Event-Trigger system



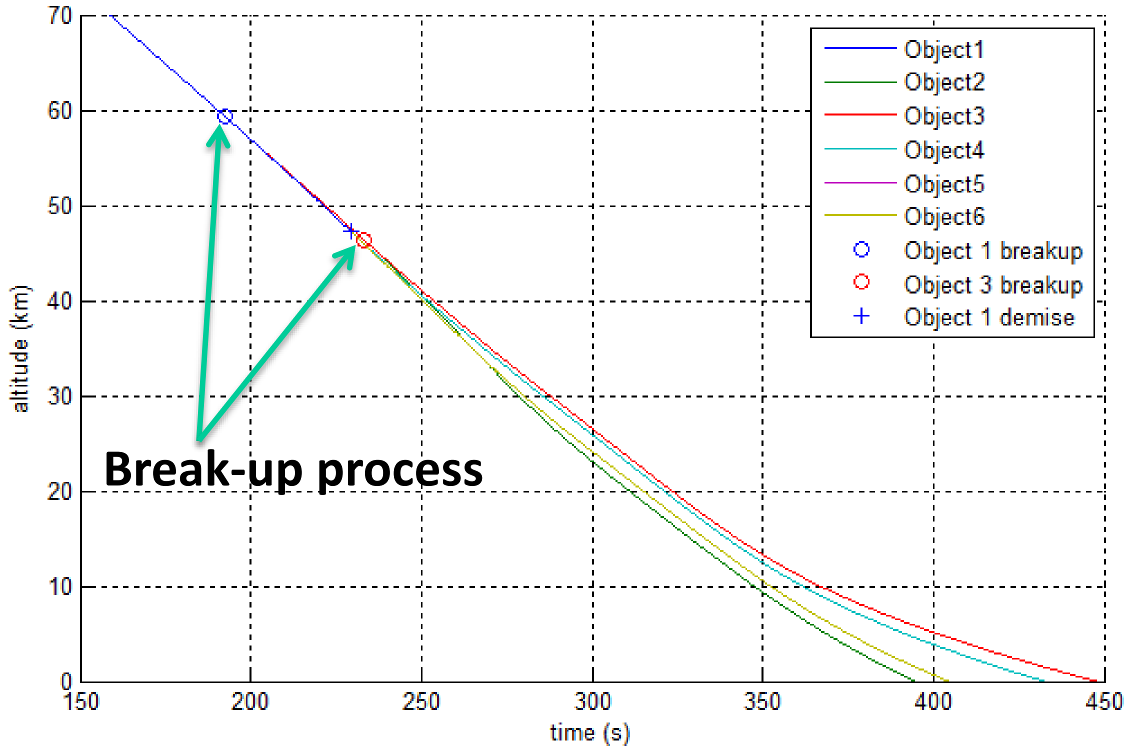

New tree structure instead of table based definition of components

3D view of the components on the same hierarchical level

# SESAM – Re-entry break-up simulation
# Upgraded object oriented simulation approach

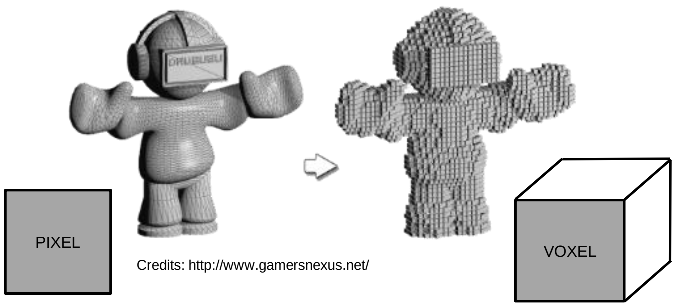
- Model based on multiple geometric shapes (box, cone, cylinder, sphere)
- Pre-computed aerodynamic and aerothermodynamic coefficients
  - ➢ Shape dependent, for drag, lift and sideforce

- Temperature dependent material properties
- Ablation models for metals and CFRP-like materials
- Explosion model based on NASA's Evolve 4.0 break-up model
- Fragment relationships (included-in/connected-to)
- Break-up triggers (altitude, temperature, heat flux, dyn. pressure, mech. Load)

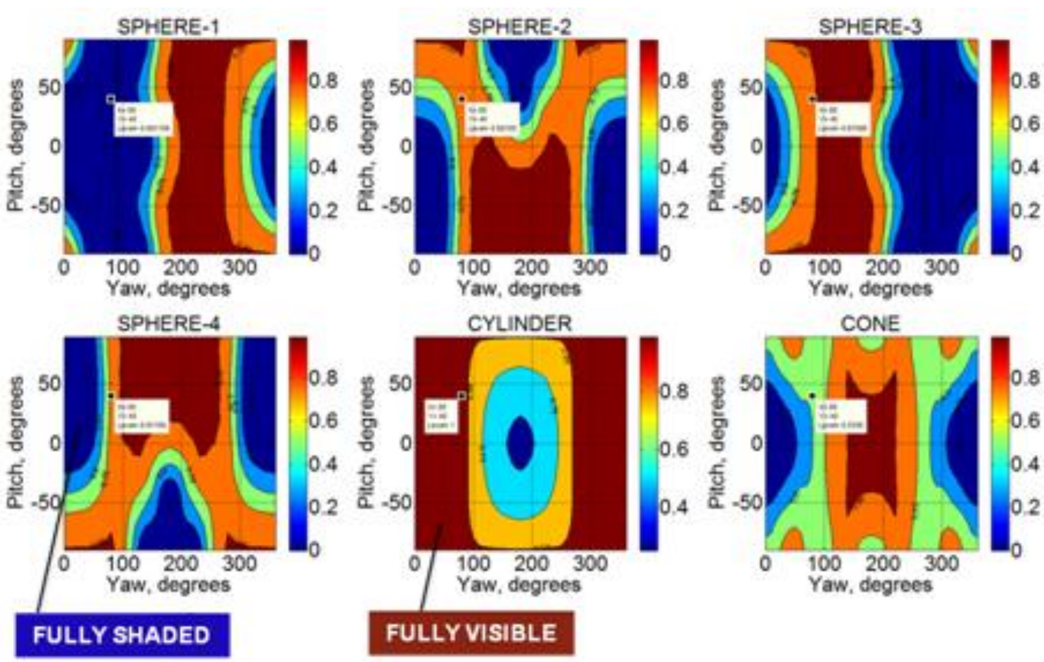


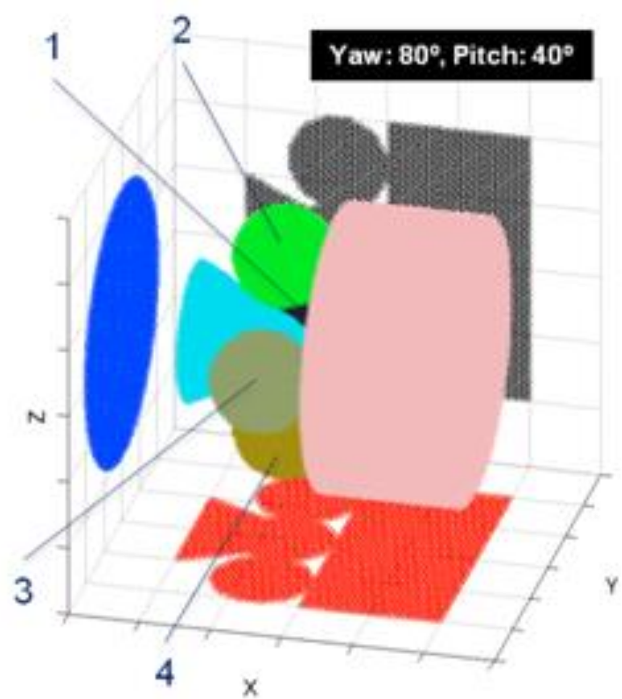
# SESAM – Re-entry break-up simulation
# Voxelator module

- Shadowing of „connected“ objects
  - Partial exposure → reduced heat income
- Visability factor calculated for pitch & yaw angles
  - Object’s contribution to the fragment’s aerothermodynamics



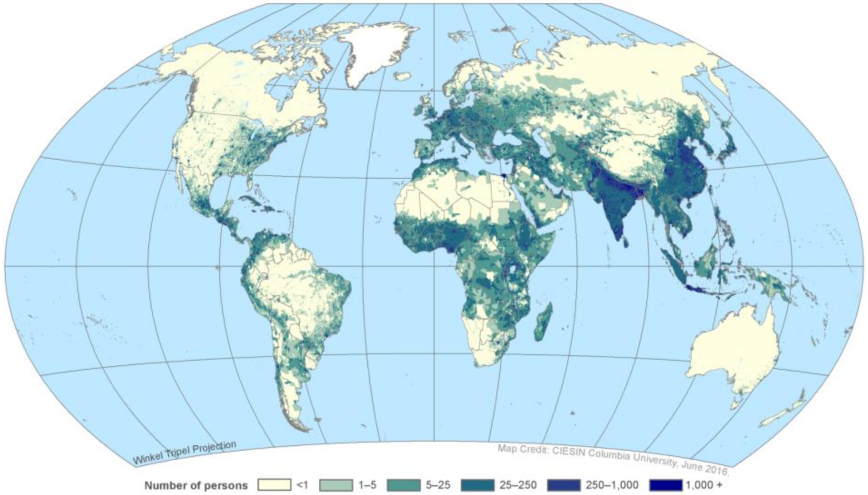

Example: Simplified upper stage model

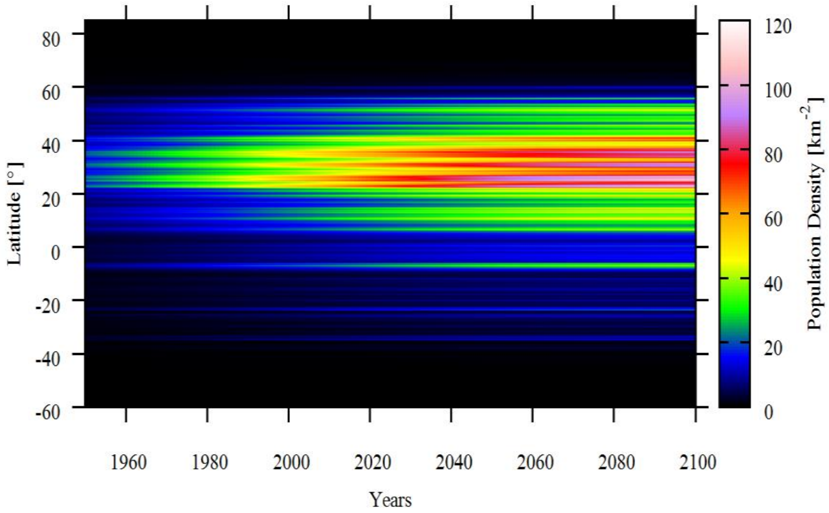


# SERAM – Ground risk assessment Overview

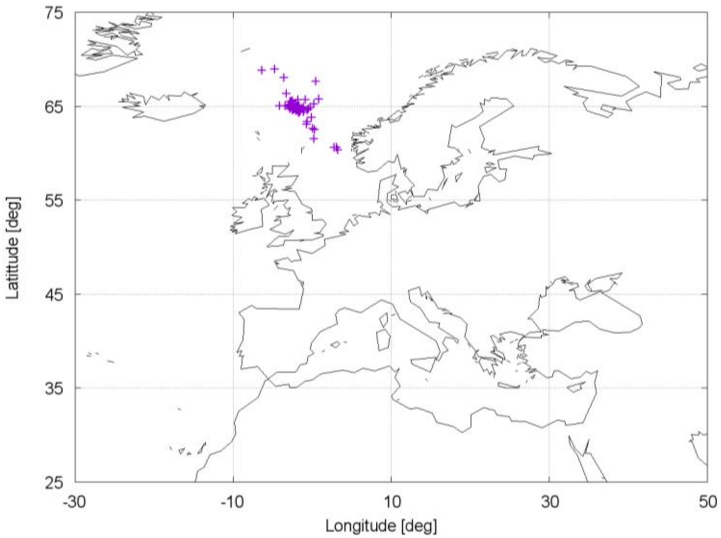
- Definition of scenario and impacting fragments
  - Scenario (controlled, uncontrolled, latitude-band-limited) defined by user
  - List of impacting fragments: SESAM output or user definition
- Gridded Population of the World (GPW)
  - Raster data in 30’’ resolution (1x1 km), 1D by averaging over all longitudes
- United Nations World Population Prospects (UNWPP)
  - Annual population counts for the years 1950 – 2100
  - SERAM derives country dependent population growth (8 growth scenarios)

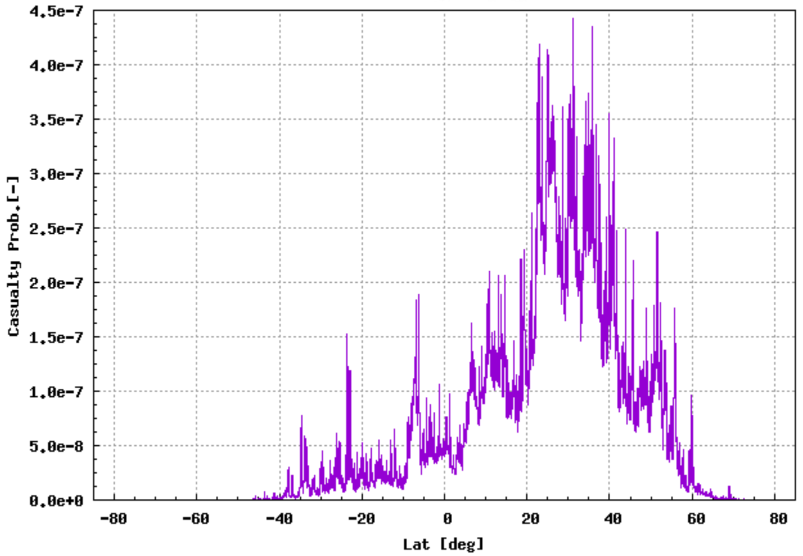


# SERAM – Ground risk assessment
# Output

- Risk results
  - Casualty and fatality probability
  - Results given for each fragment and entire re-entry event
  - Summary in Risk-Results XML file
- Graphical output
  - Impact locations (controlled re-entry)
  - Impact probability vs. latitude
  - Casualty probability vs. latitude
  - Fatality probability vs. latitude




Images: (example plots for visualization)

- Impact locations for a controlled re-entry from a sun-synchronous orbit (top right)
- Casualty probability for an uncontrolled re-entry from a nearly circular orbit (bottom right)

# Monte-Carlo Wrapper
# Input and Simulation

- Multiple runs of SESAM and/or SERAM with varied input parameters
- Different variation methods for input parameters
  - Parametric variation (parameter range and fixed step size)
  - Stochastic variation (normal distribution)
  - Probability distribution (arbitrary, user defined probability density function)
  - Selection
- Possible variation of
  - Initial state
  - Object related parameters (e.g. dimensions, mass, explosion trigger conditions)
  - Material properties (e.g. density, melting temperature)

# Monte-Carlo Wrapper
# Evaluation and Output

- Event-related results
  - Total 1D/2D casualty risk and 1D/2D fatality risk
  - Mass of ground fragments and casualty area
- Fragment-related results
  - Impact location (latitude, longitude)
  - 1D/2D casualty risk and 1D/2D fatality risk
  - Fragment mass and casualty area
- Statistics on
  - Ground impact points
    - Ranges (longitude, along-track, cross-track)
    - Areas (Bounding box, DRA, SRA)
  - Total 1D/2D casualty, 1D/2D fatality risk, mass and casualty area

# Summary

- DRAMA‘s SESAM and SERAM modules have been upgraded
  - Improved object oriented method considering object relations and shadowing
  - Large variety of triggers, for break-ups and explosions at different conditions
  - Support for controlled and uncontrolled re-entries from LEO up to HEO
  - Up-to-date population models (GPW/UNWPP)
  - Input and output in XML format, to improve tool comparability
- Newly developed Monte-Carlo module
  - Different methods to vary SESAM and/or SERAM input parameters
  - Statistical analysis, including determination of DRA and SRA
- Implementation of new functionality into the existing DRAMA GUI
  - Import/export functionality for components and materials
  - Databases for components and materials

# Re-entry tumbling state estimation with ιOTA

ιOTA was developed within ESA's "Debris Attitude Motion Measurements and Modelling" study (ESA/ESOC 4000112447/14/D/SR).

HYPERSCHALL TECHNOLOGIE GÖTTINGEN GMBH

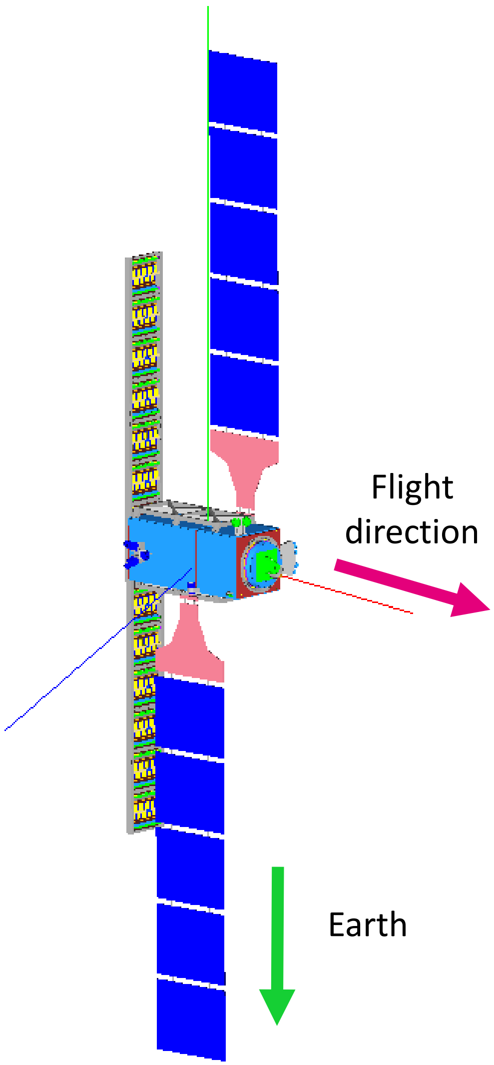
# Initial attitude and tumbling state for re-entry break-up simulations

- Low fidelity (object oriented) re-entry tools
  - 3 Degrees-of-Freedom (DoF)
  - For aerodynamics and aerothermodynamics, random tumbling or other (user) pre-defined attitude/tumbling state
- High fidelity (spacecraft oriented) or mixed approach re-entry tools
  - 6 DoF (either full 6DoF, or on spacecraft level)
  - Simulation of tumbling motion, but still (user) pre-defined initial attitude/tumbling state needed
  - Initial attitude/tumbling variations used to trigger simulation uncertainties
- Real or realistic attitude/tumbling state at re-entry interface
  - **Unknown** - currently, educated guess only
  - Essential for Design-for-Demise (D4D) techniques aimed at early exposure/separation due to potential shadowing/shielding in case of (semi-)stable attitude motion

HYPERSCHALL TECHNOLOGIE GÖTTINGEN GMBH

# Relevance of tumbling for Design for Demise

- Certain D4D techniques rely on early heating of joints (e.g. an early separation mechanism)
- For stable or quasi-stable attitudes, heat flux to such joints may be limited
  - ➢ Early separation may not be reached due to attitude stabilities during re-entry
- Example: Sentinel-1, analysed within ESA's "Multi-Disciplinary Assessment of Design for Demise Techniques" study
  - ➢ Relatively stable attitude with CSAR antenna trailing in upright position (initial state assumption)
  - ➢ Pendulum motion around roll axis, but no further tumbling (down to 80 km altitude possible)
  - ➢ Full shielding of CSAR antenna joints for this attitude
  - ➢ Result: no early separation of CSAR antenna possible



# In-Orbit Tumbling Analysis – ιOTA

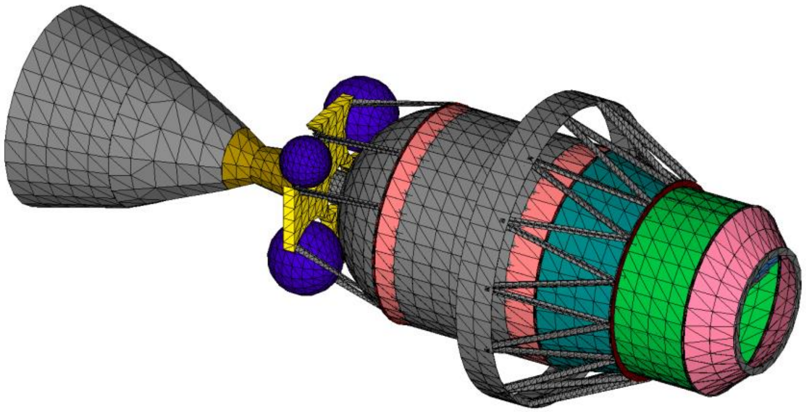
- ιOTA is a prototype software tool to simulate the attitude and orbit motion of intact decommissioned objects in Earth orbit
  - ➢ Considering all relevant internal and external forces and torques
  - ➢ Short-term high accuracy attitude simulation
  - ➢ Long-term trend prediction
  - ➢ Generation of simulated measurements to support observers and for observation based validation of the software, i.e. light curves, satellite laser ranging (SLR) data, simplified radar images and approximate radar cross-section
- ιOTA is aimed to provide vital information for Active Debris Removal (ADR) missions on the attitude motion evolution of ADR targets
- ιOTA could also be used to predict the tumbling state of decommissioned spacecraft during natural decay, down to the re-entry interface

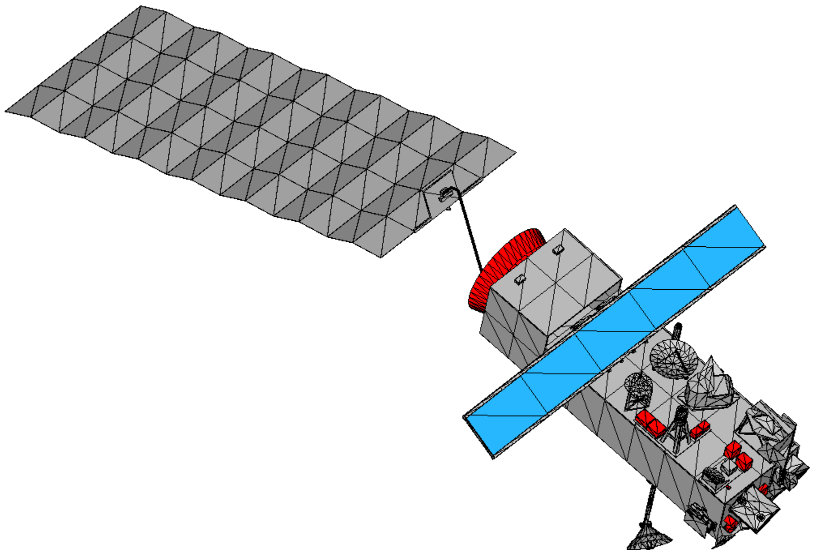
# ιOTA
# Simulation of external and internal effects

- Simulation of all relevant internal and external forces and torques
  - Aerodynamic drag (force and torque) - **NRLMSISE-00**
  - Magnetospheric (eddy current) damping (torque) - **WMM2015**
  - Internal damping (tank sloshing) (torque and CoG displacement)
  - Solar radiation pressure (force and torque)
  - Gravitational influence of Earth (force and torque) - **EGM96/EGM2008**
  - Gravitational influence of Moon and Sun (force)
- Optional user defined events
  - AOCS events
    - Magnetic torquers (torque)
    - Reaction wheels (torque)
    - Thruster firing (force and torque)
  - Outgassing or impact events

# User input

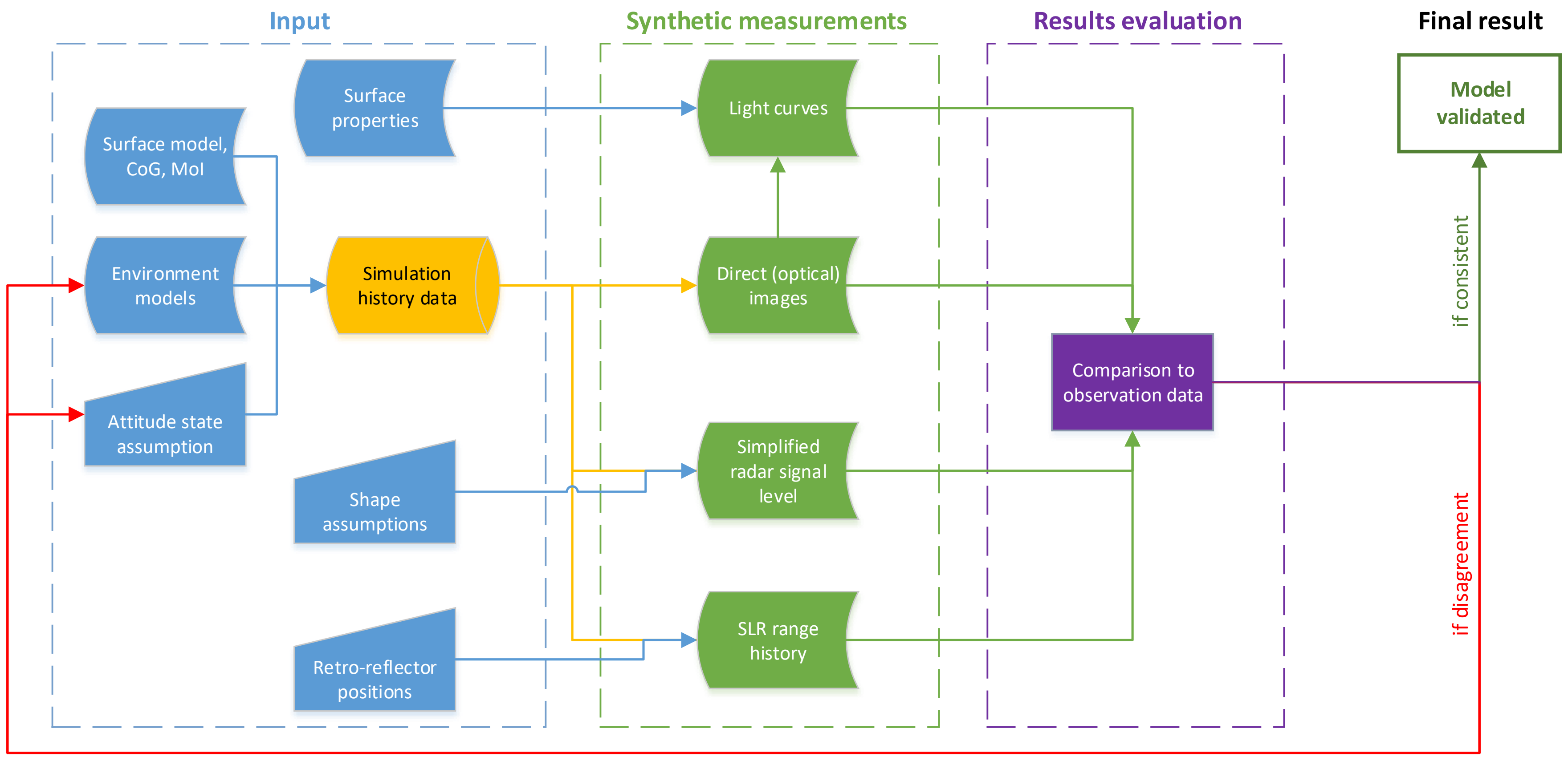
- User input needed:
  - Spacecraft surface geometry model (panel based) in .obj format
  - Spacecraft mass, (initial) center of gravity position and moments of inertia
  - Initial spacecraft attitude state, orbit and corresponding epoch, based on measurements and observations or known state at EOL
  - Initial assumption on damping coefficient for eddy current damping





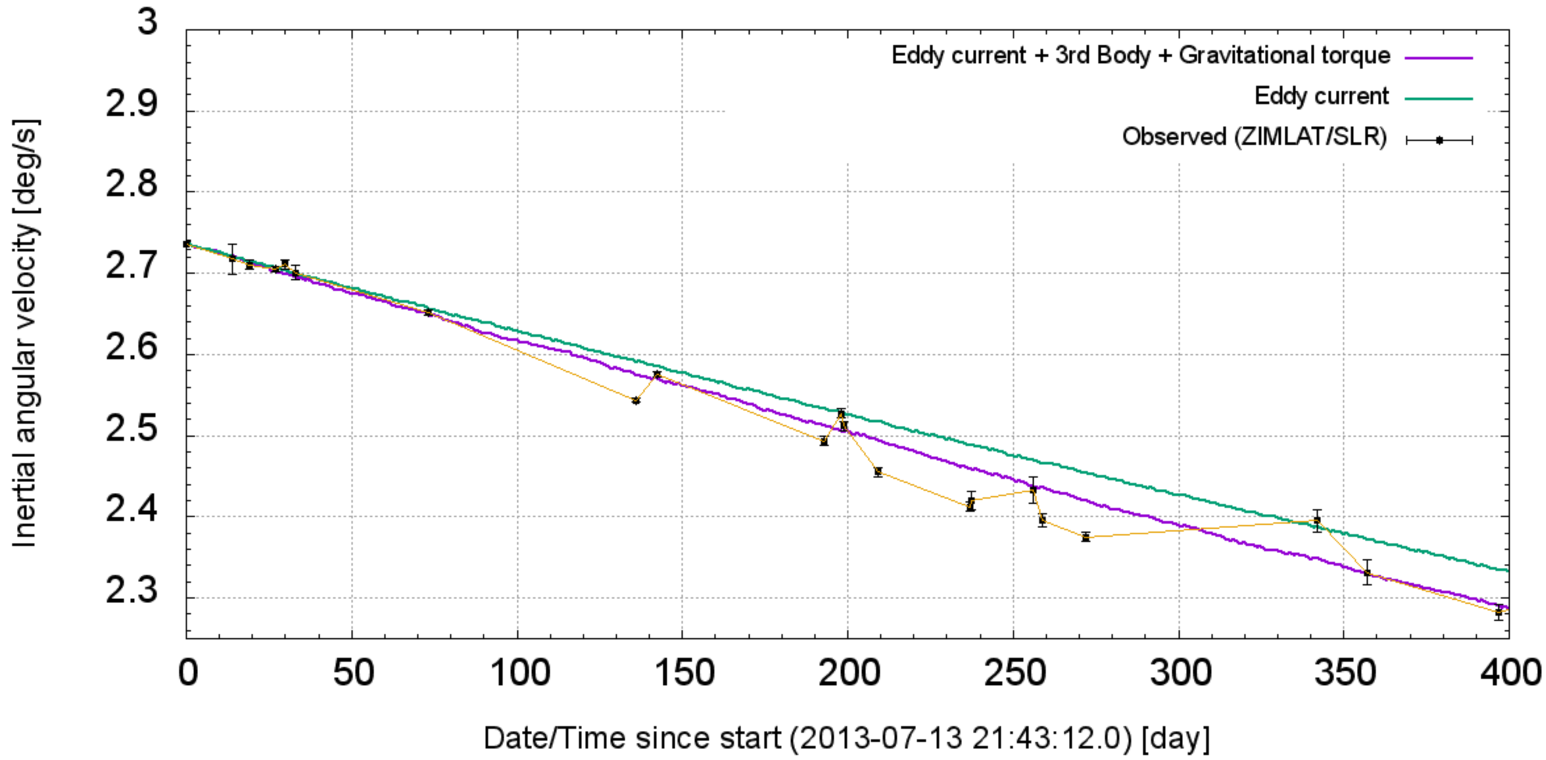
# Synthetic measurements and Validation by observations

- Comparison of simulation results and observation data lead to improvement of initial attitude state assumption and simulation models
  - ➢ eddy current damping coefficient determination



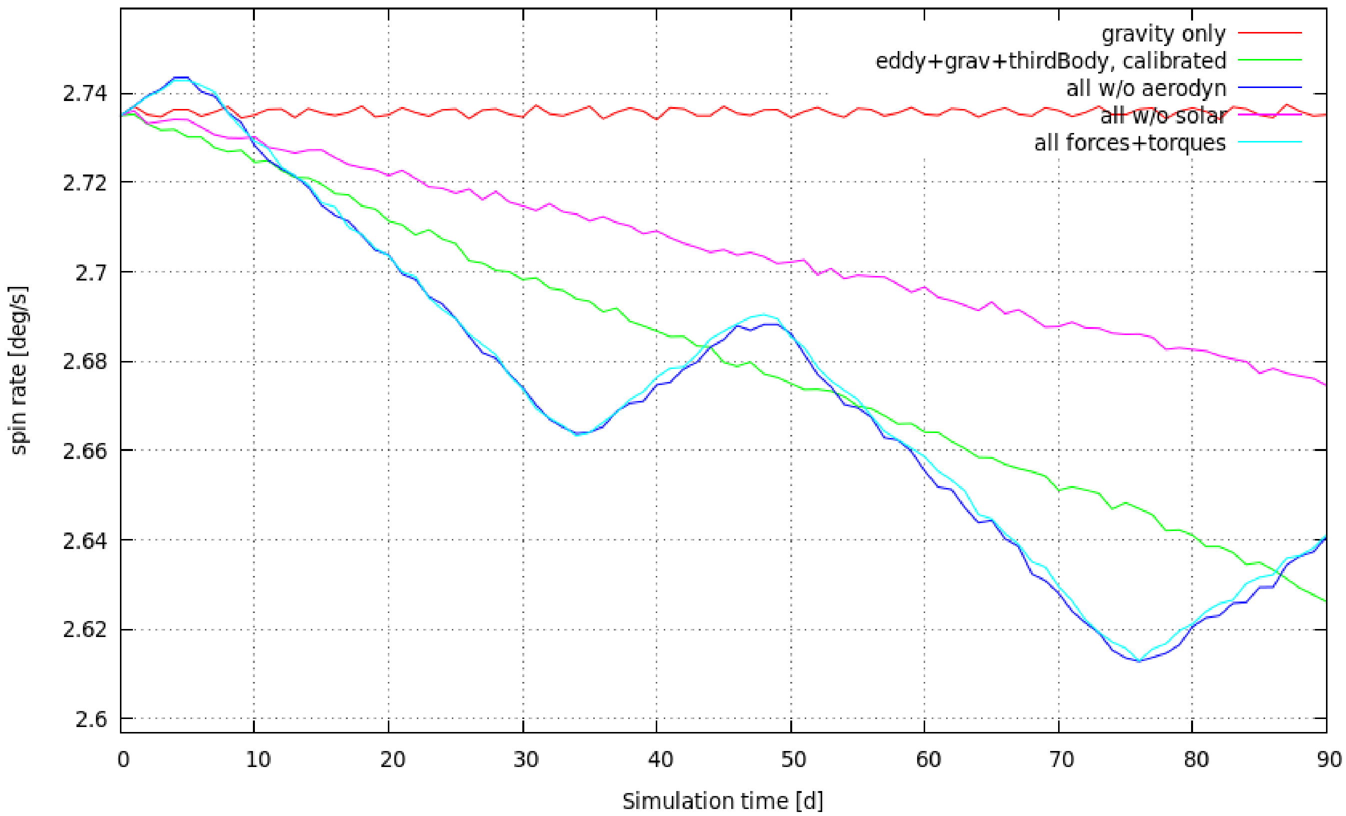
# Validation by observations
# Envisat – long-term trend simulation

- Combined observations from AIUB, IWF, FHR
  - ➢ Light curves, satellite laser ranging, radar images
- Comparison of ιOTA simulations and measurement data on short-term (direct comparison of synthetic data) and long-term de-tumbling (trend prediction)



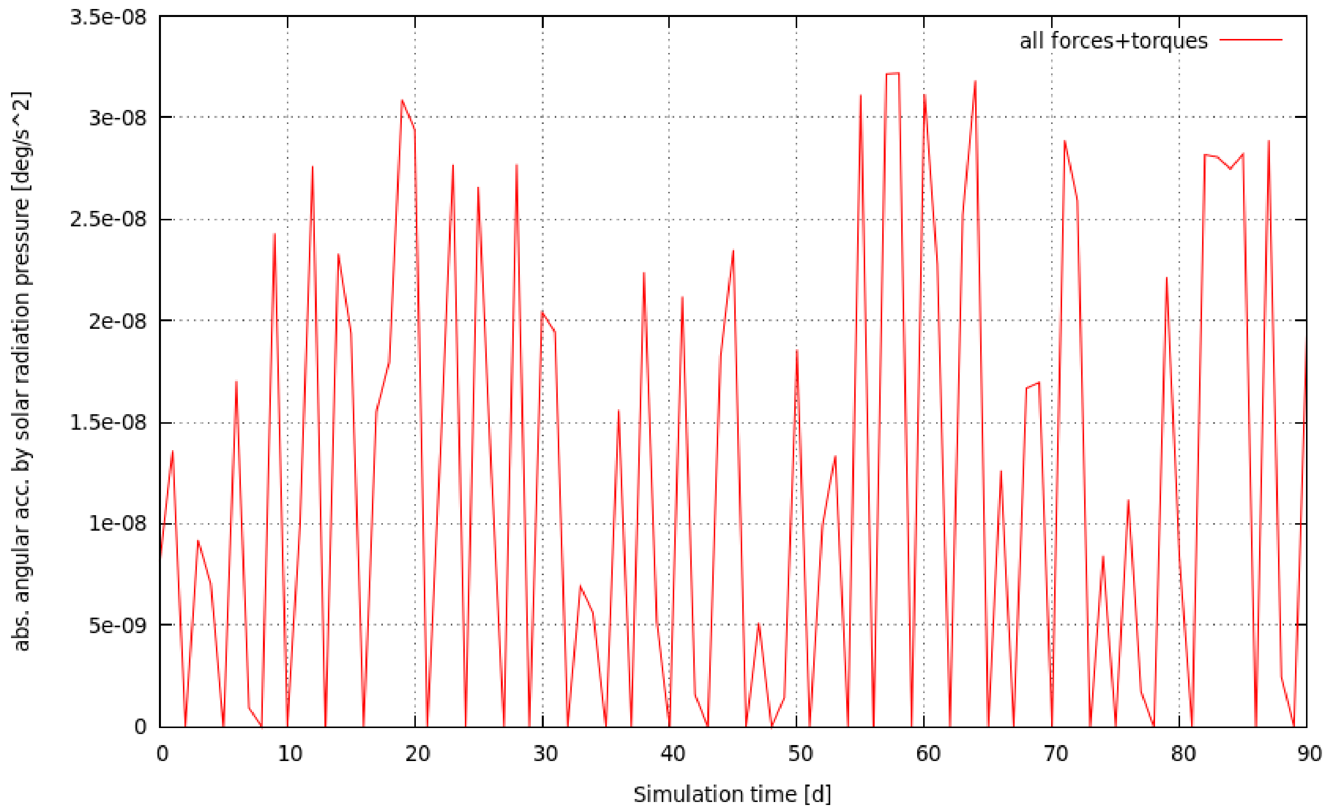
# Validation by observations
# Envisat – long-term trend simulation

- Simulation for different force and torque combinations
  - ➢ Periodic spin up and spin down resulting from solar radiation pressure acceleration



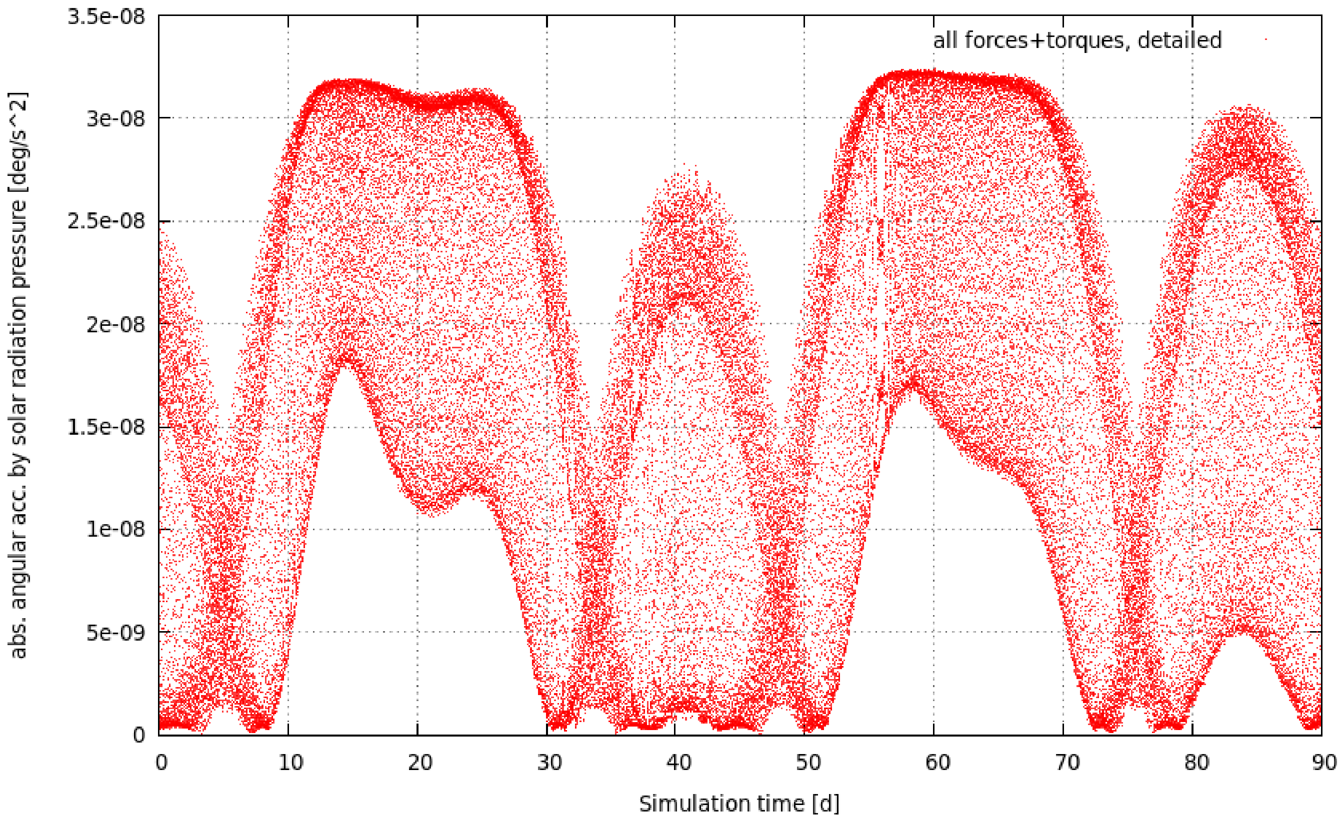
# Validation by observations
# Envisat – long-term trend simulation

- Some periodicity in solar radiation pressure driven angular accelerations
  - ➢ Simulation output step size of 1 day → under sampling !
  - ➢ Better time resolution is needed to identify such effects



# Validation by observations
# Envisat – long-term trend simulation

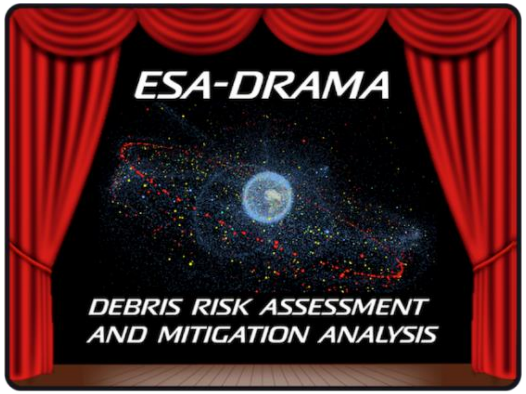
- Max/min angular acceleration: solar array fully/almost not illuminated
  - ➢ Spin up/spin down: angular acceleration in spin direction/opposed to spin
- Similar behaviour observed (!) for TOPEX spacecraft



HYPERSCHALL TECHNOLOGIE GÖTTINGEN GMBH

# Next steps towards re-entry state prediction

- In current (prototype) state of ιOTA, full forces and torque simulation is not feasible to simulate 25 years of natural decay after EOL
  - Estimate: 25 years simulated for Envisat ≈ 1 year computation time
- Improvements planned
  - Optimization and further refinement of simulation methods
  - Performance optimization, e.g. by parallelization (GPU)
- Continued validation
  - Compare ιOTA's long term orbit propagation to real (historical) spacecraft orbits (e.g. based on TLEs)
  - Compare ιOTA's long term attitude propagation to attitude of operational spacecraft, e.g. apply historical AOCS events to integrated attitude to maintain operational attitude
  - Additional validation with observations (more observations and improved initial state solutions needed)




# Thank you!

# Questions?

Contact:

Ronny Kanzler

Project Manager

r.kanzler@htg-hst.de