

# ESA Space Situational Awareness Programme: Re-Entry Prediction System (RPS) of the Space Surveillance and Tracking Segment

IAASS Conference 2013

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# Outline

- Overview ESA Space Situational Awareness Programme
- Re-entry Prediction System Overview
  - Life-time Prediction System
  - Atmospheric Re-entry Analysis
  - Risk Analysis
- Summary



# ESA's Space Situational Awareness Programme

- Objective of the programme:  
*“The objective of the SSA programme is to support Europe's independent utilisation of, and access to, space through the provision of timely and accurate information and data regarding the space environment, and particularly regarding hazards to infrastructure in orbit and on the ground.”*
- Formally launched on 1 January 2009
- The mandate was extended at the 2012 Ministerial Council until 2019
- The SSA programme is active in three main areas:
  - Survey and tracking of objects in Earth orbit (SST)
  - Monitoring space weather (SW)
  - Watching for NEOs (NEO)

# SSA Space Surveillance & Tracking Segment

The SST segment provides the following services:

- The creation of a catalogue of orbiting objects
- Critical collision avoidance services for satellite operators
- Tracking campaigns, both routine and on-demand in case of an identified collision risk
- The prediction and warning of uncontrolled re-entry events

CO-VIII contract

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Solutions**

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**Atos**

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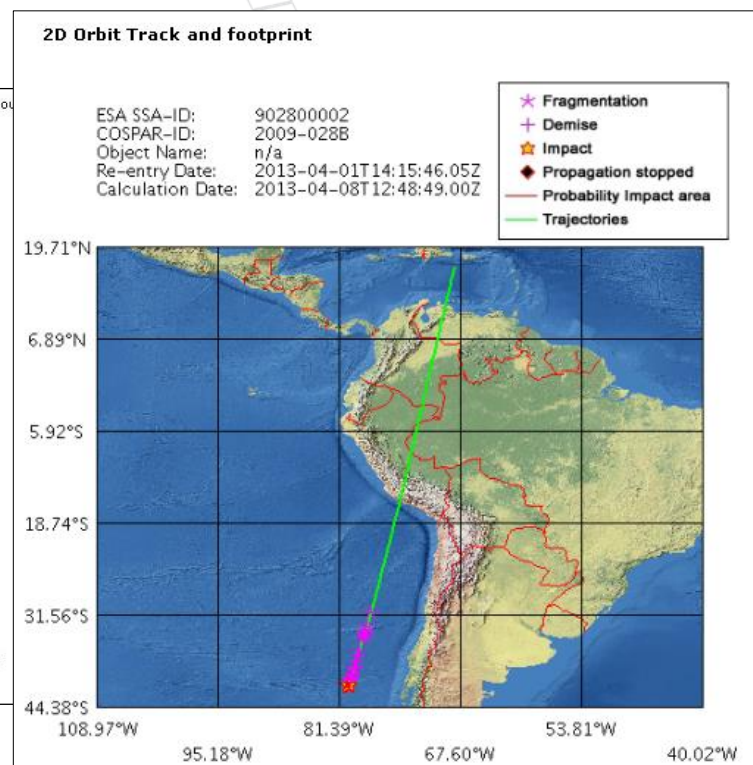
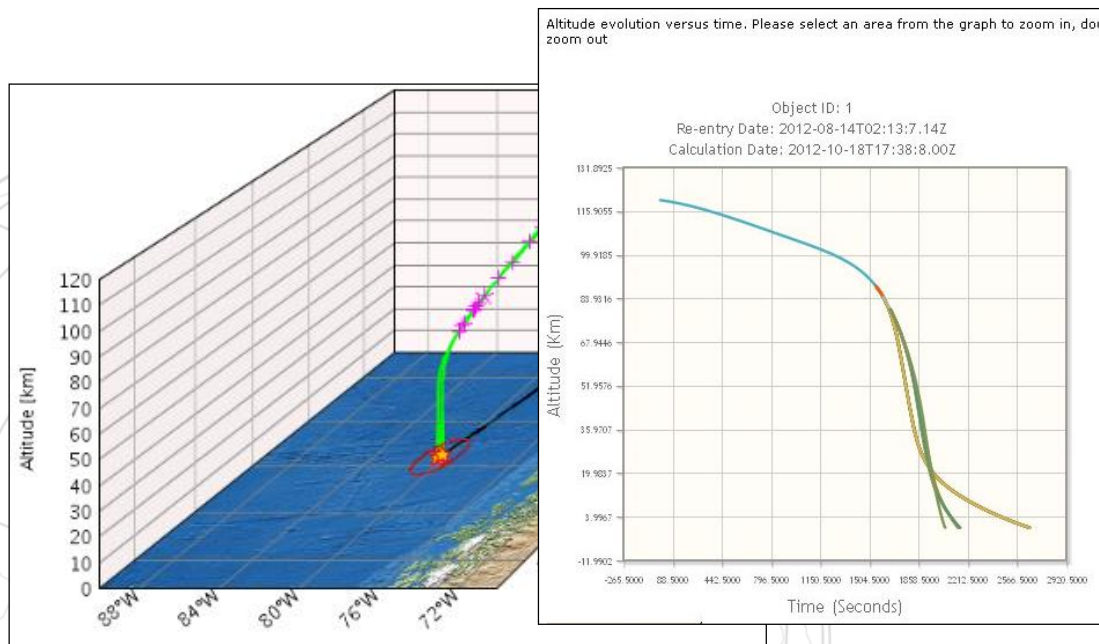


# Re-entry Prediction Services

- Prediction of re-entry events with orbit data stored in a catalogue or orbit data provided by a client user.
- Automatic on-demand updates or manual execution
- Automatic alerting of (affected) clients via email in case of predicted re-entry events
- NOTAM (Notice to Airmen) can be generated automatically
- Access to the analyses results by registered clients via a web-based front-end, e.g.
  - 7-day history of all performed analyses, whereas impact events are highlighted
  - Plots showing re-entry analyses results
  - Reports (e.g. re-entry prediction messages)
- Additional standalone HMI for the service manager

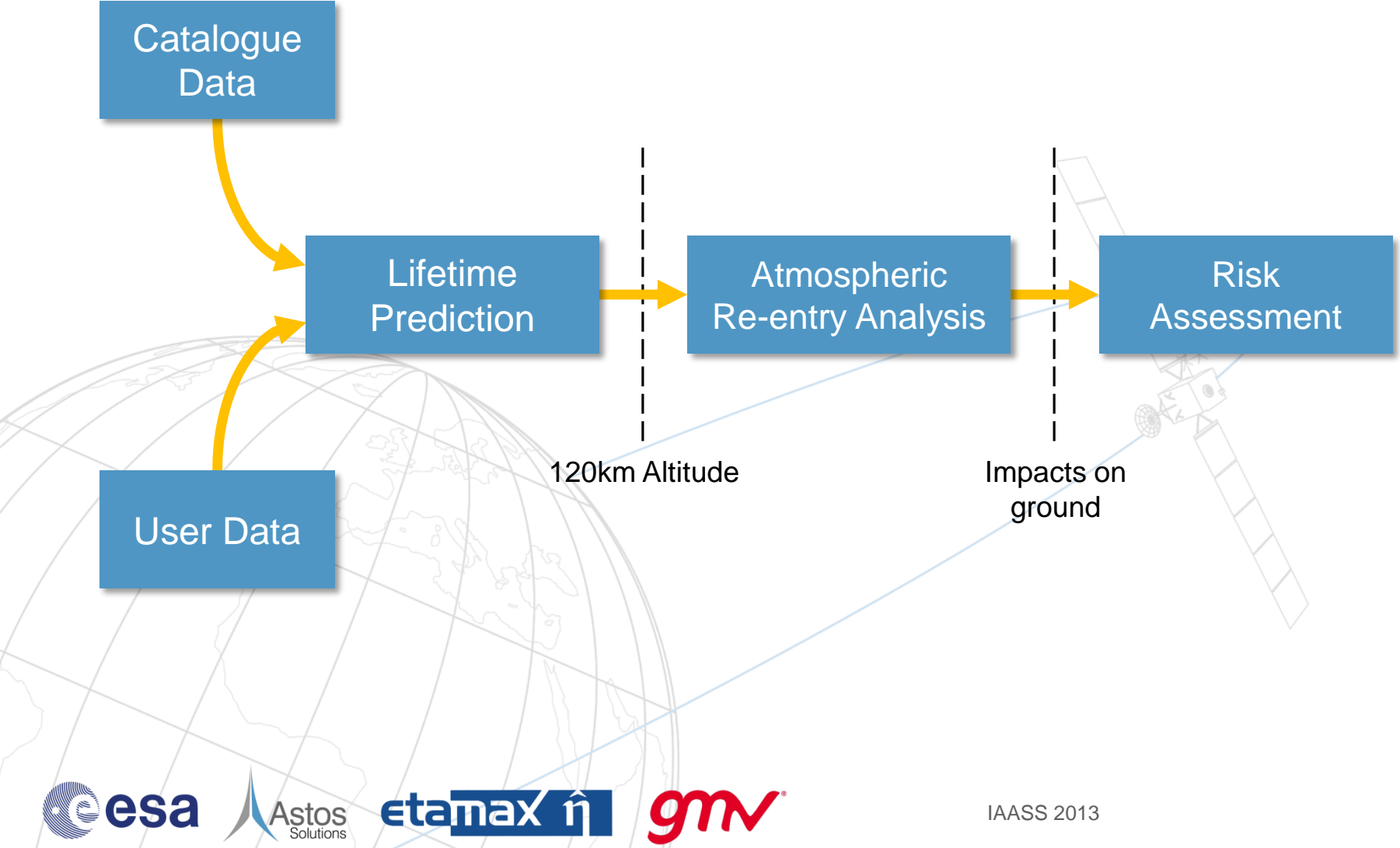
# Web-based Front End Plotting Capabilities

- History of fragment parameters like mass, kin. energy, position velocity or covariance matrix elements
- 2D and 3D map plots providing GIS data layers (predefined or uploaded by the user; GeoTIFF and ESRI® Shapefile are supported)





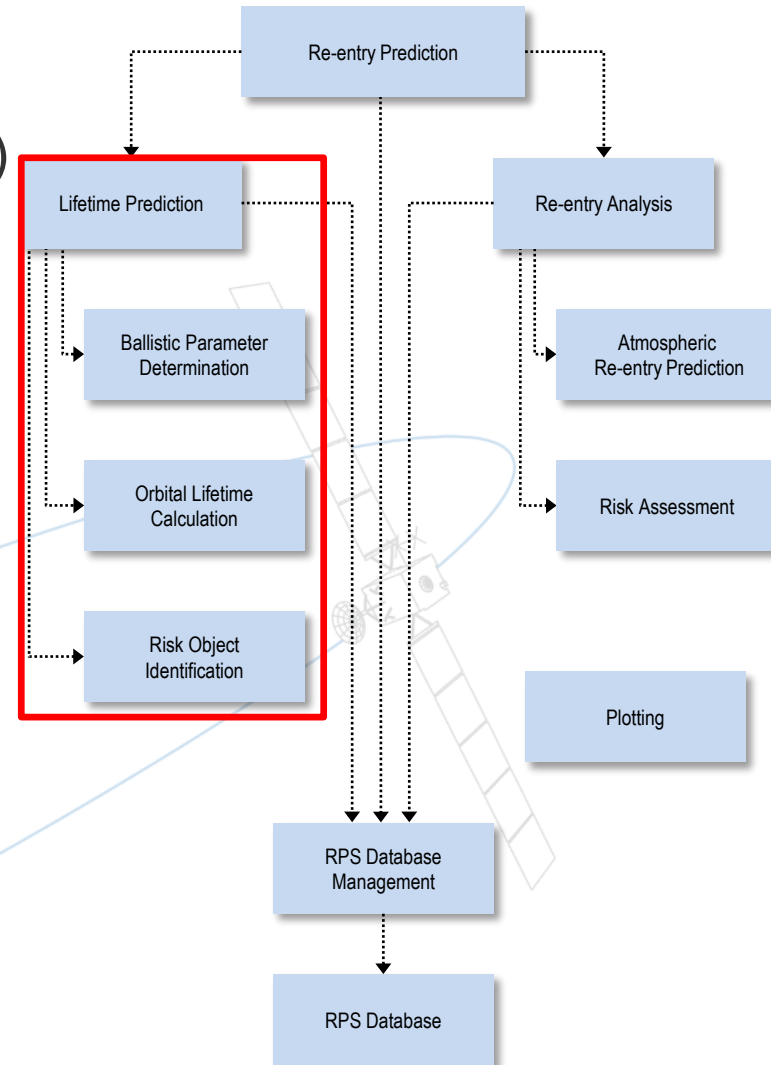
# Re-entry Prediction System



# Lifetime Prediction System (LPS)

Composed of:

- Ballistic Parameter Determination (BPD) calculation or determination of the ballistic parameter
- Orbital Lifetime Calculation (OLC) estimation of the orbital lifetimes by means of different propagation methods
- Risk Object Identification (ROI) definition of the monitoring level and propagation of objects to the starting point of the atmospheric re-entry

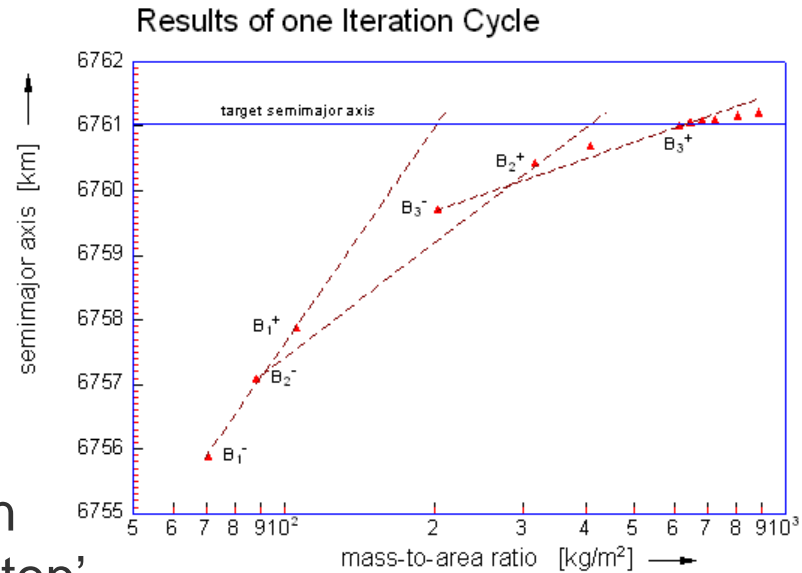


# LPS – Ballistic Parameter Determination

- Check the availability of mass ( $m$ ), cross section ( $A$ ) and drag coefficient ( $c_D$ ),
  - If drag coefficient is not available, 2.2 is used as default value
  - If mass and cross section are available, the ballistic parameter ( $B$ ) is calculated:  $B = c_D \cdot A/m$
- Determination of  $B$  using a ‘shooting method’ for objects
  - with missing information ( $m$ ,  $A$ ) and
  - with perigee altitude less than 2000 km (drag force is the major driver)

# LPS – BPD – Shooting Method

- $n$  data pairs from the orbital history
  - Decreasing semi-major axis
  - User defined minimum time interval between the element sets
- $B$  is determined for each data pair
  - Initial  $B_{i+1}$  from logarithmic interpolation with results from preceding 'shooting step'
  - Two propagations with different  $B$ 's (yielded from the difference between  $B_{i+1}$  and  $B_i$ )
  - Iteration until the difference between  $B_{i+1}$  and  $B_i$  is less than a user defined threshold
- The resulting ballistic parameter is the mean value of all  $B$ 's of the data pairs

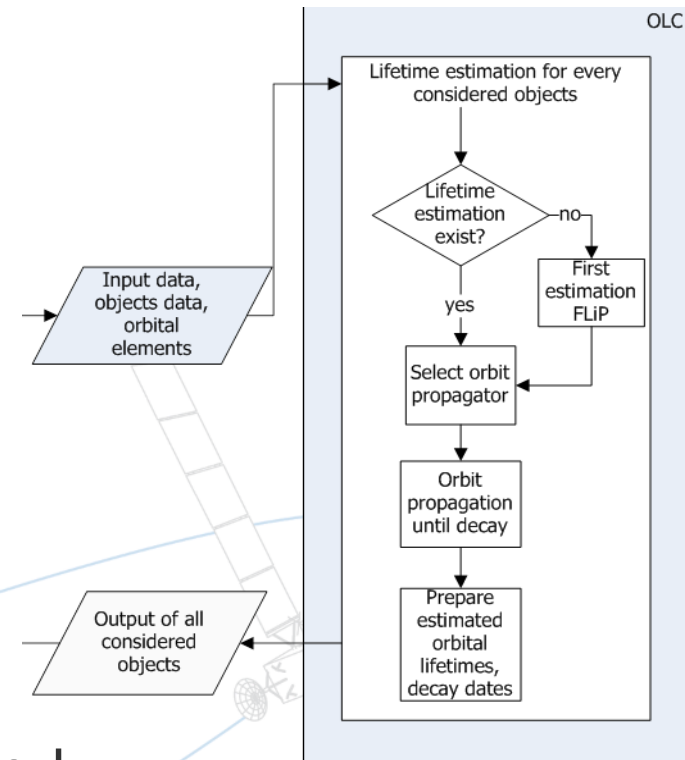


*Scheme of one iteration cycle*

# LPS – Orbital Lifetime Calculation

## Lifetime estimation for objects

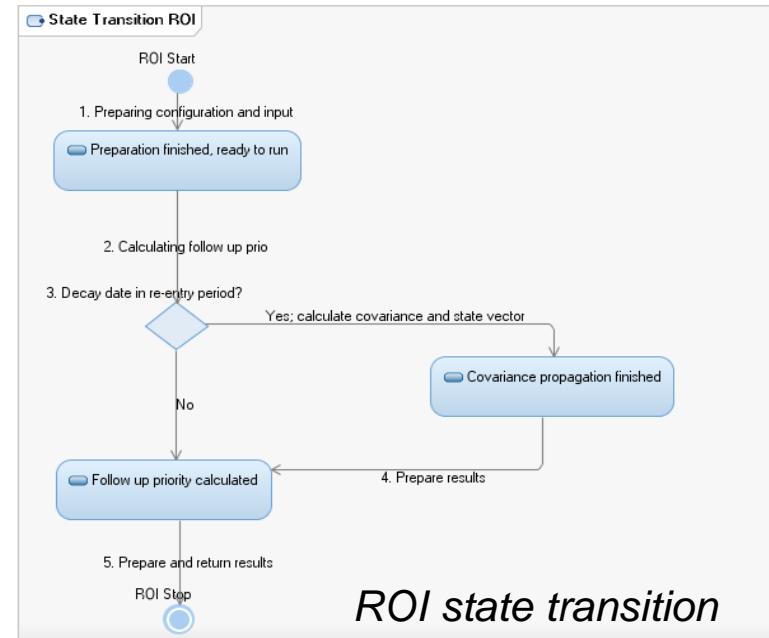
- with perigee altitude less than 5000 km,
- not already identified as re-entering (re-entering objects are handled by ROI)
- Three propagators are used
  - FLiP (King-Hele, straight forward)
  - ORBPRO (King-Hele, incremental)
  - Propag (from NAPEOS, numerical)
- Propagators are mapped to 6 user defined lifetime classes, based on the targeted accuracy
  - Analytical propagators for long lifetimes, due to performance
  - Numerical propagator for objects with short lifetimes or high eccentricity, where higher accuracy is required



OLC Workflow

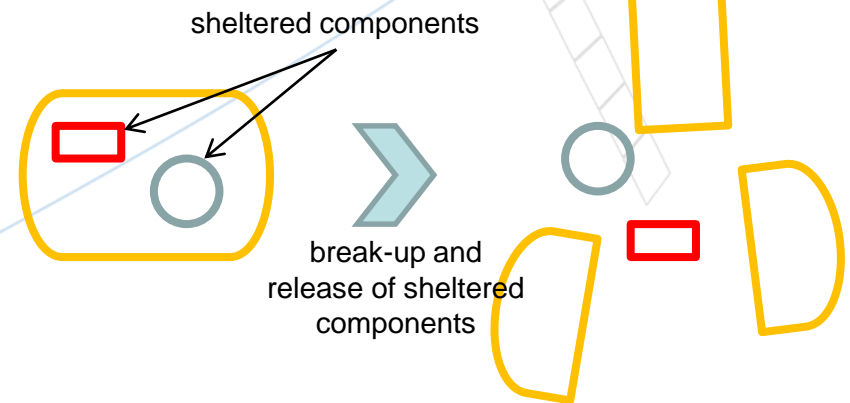
# LPS – Risk Object Identification

- 3 risk criteria
  - Mass ( $m$ )
  - Ballistic Parameter ( $B$ )
  - Cross Section ( $A$ )
- List of objects defined as hazardous
- 3 monitoring levels can be assigned
  - No tracking: perigee altitude  $> 5000$  km
  - Low fidelity: risk criteria thresholds are not passed
  - High fidelity:  $m >$ ,  $B <$  or  $A >$  than the user defined thresholds or the object is marked as hazardous (is on the list)
- Propagation of objects that re-enter in a predefined time interval using Propag (NAPEOS)
- Provision of initial state vector and covariance matrix for ARPS



# Atmospheric Re-entry Analysis (ARPS)

- Object-oriented approach, i.e. the re-entry object definition is based on a set of primitive shapes
  - Materials are associated on primitive level
  - Predefined set of primitives for each object class (debris, rocket body or spacecraft)
  - Dimensions and masses of each predefined primitive are adapted to fit the ballistic coefficient and mass from LPS
  - Tree-like definition of fragments (multiple fragmentations/explosions) supporting also sheltering of objects



# Atmospheric Re-entry Analysis (2)

- Fragmentations and explosions are dynamically triggered whenever a defined threshold is exceeded (e.g. altitude, dynamic pressure, acceleration, temperature)
- Stochastic explosion model derived from NASA Evolve 4 model
- Lumped thermal mass model (we assume fast tumbling objects)
- Heat flux calculation based on formulations by Detra, Kemp & Ridell
- 3 DoF propagation with variable step size (several atmospheric models, EGM96 gravity model)
- Propagation of the initial state covariance by means of the state transition matrix (linearization; based on finite differences)



# Risk Assessment

The risk assessment component provides:

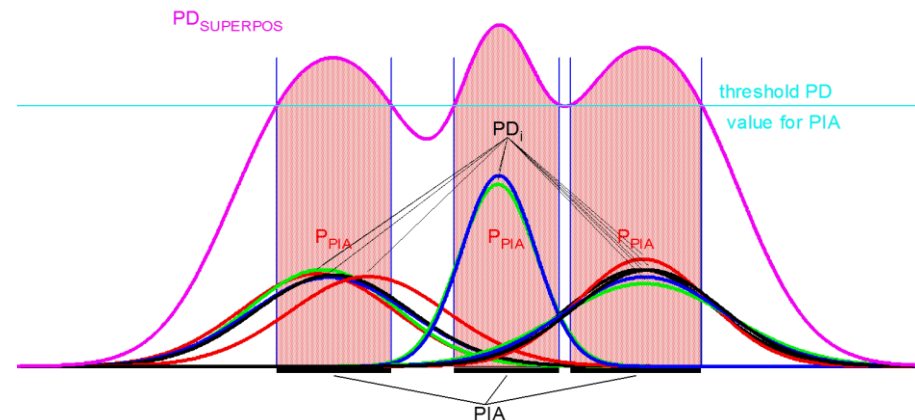
- The impact probability for each country\*
- The probability impact area (area and contour)
- Probability to fall on land
- Casualty probability\*\*
- Fatality probability\*\*

\*) including territorial waters

\*\*\*) based on extrapolated GPW V3 population density data

# Probability Impact Area Determination

- Multivariate normal distribution results in elliptical impact areas for individual fragments
- Impact ellipse “dimensions” derived from the covariance matrix that is transformed into the cross-/downrange frame
- Individual error ellipses are superimposed assuming no correlation between the fragment’s impact locations
- Iterative identification of the correct threshold probability density that defines the border of the probability impact area
- The impact probability defining the probability impact area is specified by the user



# Summary

- The presented capabilities of the SSA-SST re-entry prediction service allow a fast and automatic notification in case that a predicted re-entry might cause a threat.
- Through an easily accessible web-based front end consecutive observations and updated trajectory data can be either calculated on-demand in the system or injected by clients themselves.
- This allows for a rapid response to the changing evolution of a re-entry event and enables for accurate space situational awareness.
- This level of current knowledge is mandatory for the effective deployment of countermeasures such as civil protection emergency protocols or (air)traffic rerouting.

# Thank you!

