

A3

The latest space debris related research and technology activities in the European Space Agency

Holger Krag, ESA

This talk will address ESA's progress in space debris research and technology in 4 domains:

1. ESA operates a conjunction analysis system and currently monitors 10 satellites. The system uses the JSpOC CDM data. A number of novel techniques have been developed including automation in the processing of the data, new algorithms for low delta-v approaches and independent manoeuvre screening. ESA's conjunction assessment system and related statistics and highlights will be presented.
2. Since many years, ESA develops object databases, as well as risk assessment and mitigation analysis software. Methods for the verification of the compliance to on-ground risk and orbital lifetime assessment have been developed. ESA, as an operator of objects in very unusual orbits such as high-eccentric and Lagrange Point orbits has developed novel disposal options which have been validated with these new means. The means and related technology will be presented along with recent examples.
3. Further, ESA runs an ambitious SSA program, for which a system architecture has been designed and a demonstrator phased-array radar has been developed. In addition to this, it operates its own 1m-telescope on Tenerife which has discovered a population of high area/mass objects. Recent radar and optical as well as laser ranging measurements concentrate on the identification of the attitude motion of uncontrolled objects, like Envisat. An overview over the current measurement systems and recent results will be presented.
4. Finally, ESA has been investing in the technology for rendez-vous and capture of uncontrolled objects. Various solutions have been scrutinized in system studies. In parallel, the effect of active removal and the criticality of a given objects in LEO orbit has been studied. This presentation will show ESA's analysis results and the recent plans for the e.Deorbit mission for the controlled removal of an uncontrolled target in LEO.



ESA's e.Deorbit mission



ESA's SSA demonstrator radar

Biography

Dr. Holger Krag

Title: Head of Space Debris Office

Division: Ground Segment Engineering Department

Company: ESA/ESOC

Email: holger.krag@esa.int



Dr. Holger Krag has been a Space Debris Analyst in the Space Debris Office of ESA/ESOC located in Darmstadt, Germany, since 2006. He has worked on the operational conjunction event analysis for various ESA missions, debris risk assessment, mitigation analysis and the Surveillance and Tracking Segment of the European SSA system. Since 2014, he is head of the Space Debris Office. He represents ESA in the IADC (Inter Agency Debris Coordination Committee) and is involved in the development of an ESA mission for the active removal of a non-cooperative space objects from orbit.

From 2002 – 2006 Dr. Holger Krag has served as a System Engineer in the Navigation Business Unit of Thales ATM, responsible for development of a test bed for the ground mission segment of Galileo with permanent collocation in Toulouse, France.

From 1998 – 2002 Dr. Holger Krag was a project scientist at the Technical University of Braunschweig, Germany and conducted more than 4 years of detailed research in the area of space debris environment and observation modeling.



The latest space debris related research and technology activities in the European Space Agency

Holger Krag
ESA/ESOC

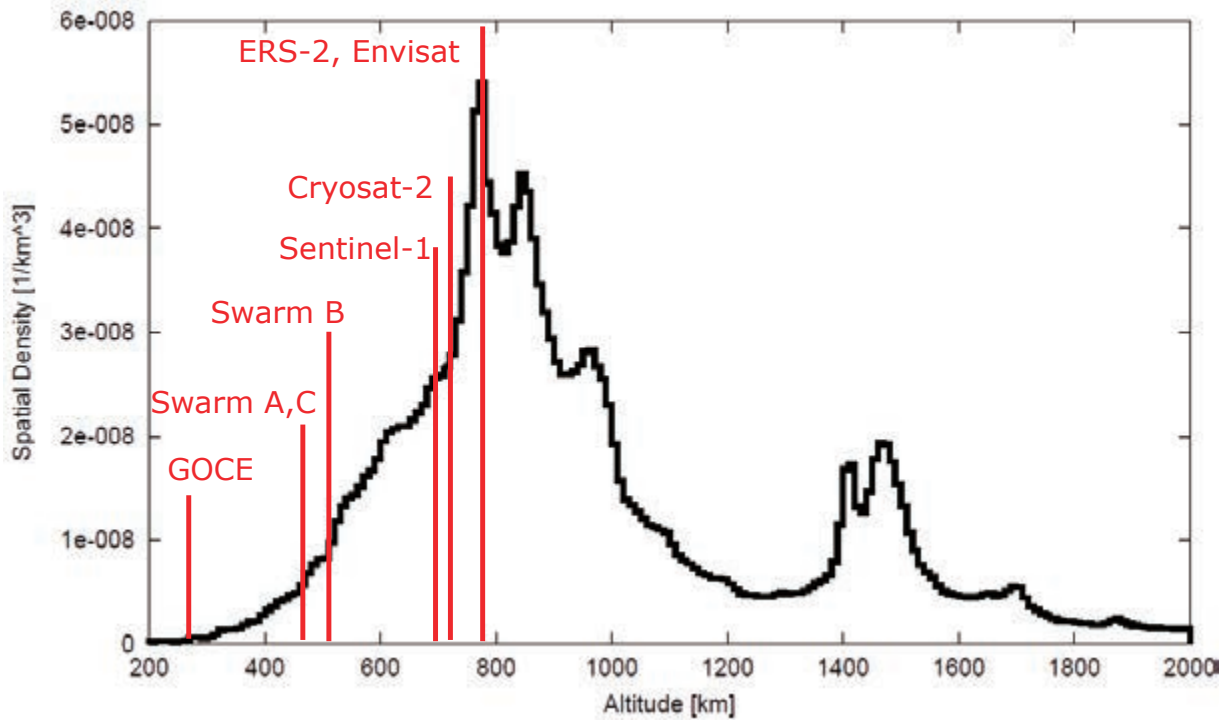
6th Space Debris Workshop
JAXA Chofu Aerospace Center, December 17-19, 2014

Outline

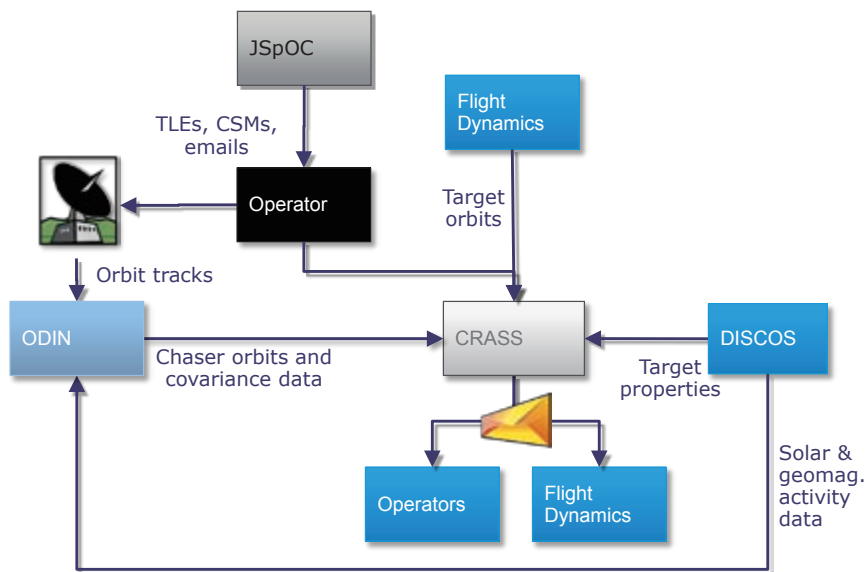


- *Collision Avoidance*
- *DISCOS Database*
- *Compliance Analysis*
- *Mitigation Technology and Re-entry Assessment*
- *Space Situational Awareness and Measurements*
- *Space Debris Modelling*
- *Attitude Measurements of uncontrolled objects*
- *Active Removal (e.Deorbit)*

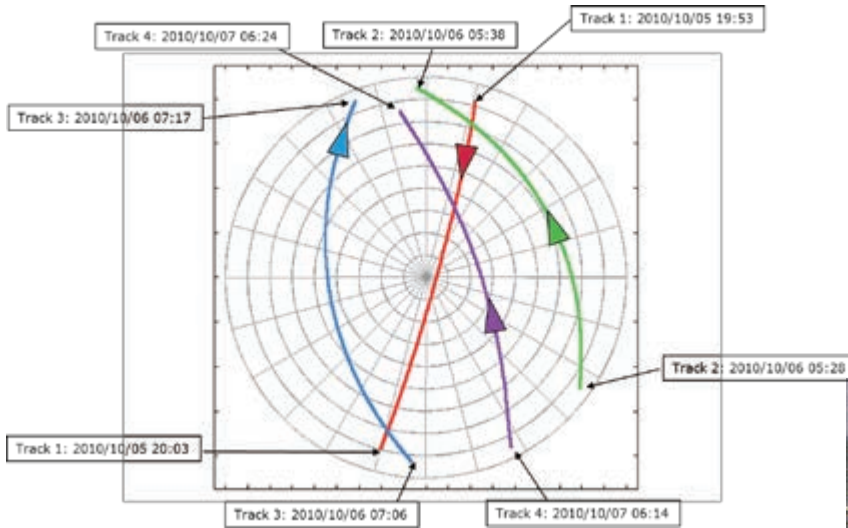
Monitored Missions



Collision Avoidance System (2004-2013)



Orbit Refinement by Tracking



Tracking and Imaging Radar



Monge tracking ship

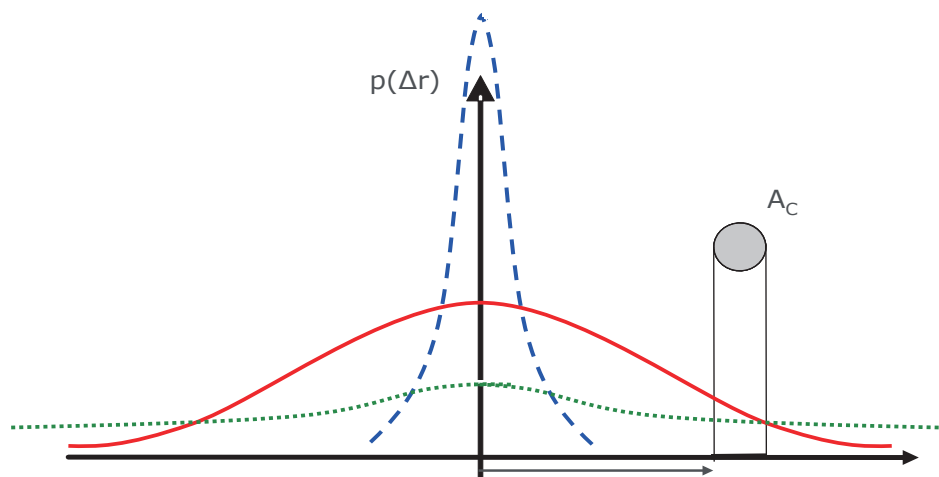
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Impact of Orbit Accuracy on Conjunction Analysis



- Establish new Collision Avoidance Procedures based on the CSM:
 - New threshold collision probability
 - Additional minimum (geometry-dependent?) fly-by distance

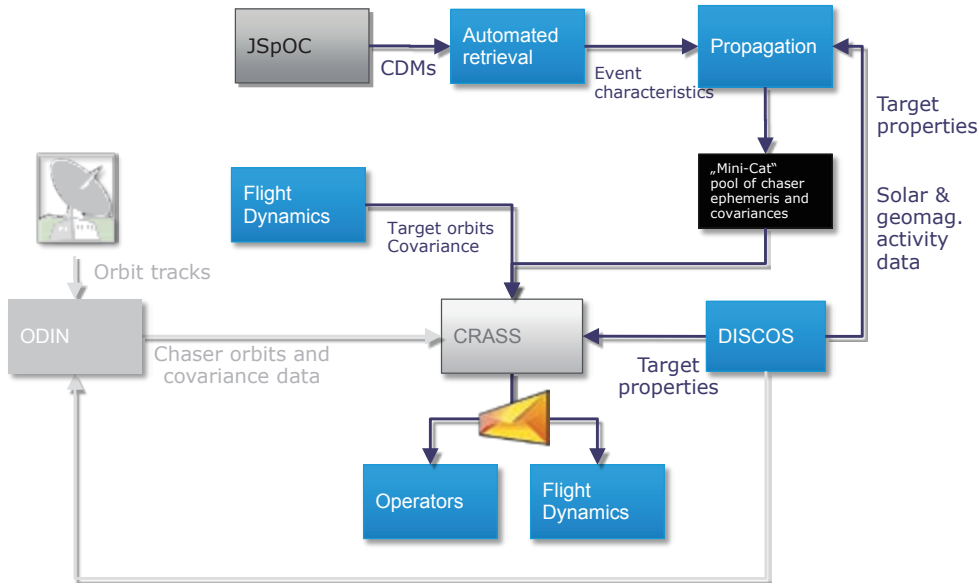


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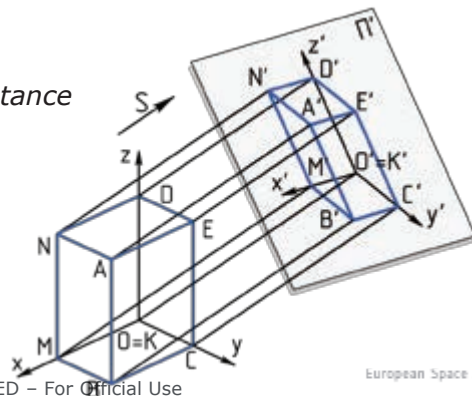
Collision Avoidance System (since 2014)



CORAM

Features:

- *Several Collision Probability Algorithms:*
 - *Alfriend Akella*
 - *Maximum Probability*
 - *Algorithms for low delta-v approaches*
 - *Monte-Carlo*
- *Cross-sectional projections*
- *Manoeuvre planning:*
 - *Sampling of several desired radial fly-by distance*
- *Covariance scaling*



PREEMPT

PREEMPT Manager | Dashboard | Analysis View | Event View | Admin

Event	Mission	Target	Chaser	TCA	Creation Date	Distance [m]	R Distance [m]	R_Pos [m]	H_Pos [m]	T_Pos [m]	P _{min}	P _{max}	T _{min} [s]	T _{max} [s]
25326	2010-013A	2010-013A	1993-01AAE	2014-10-15 20:23:44.036	2014-10-15 10:13:37	11023.00	1755.70	-1755.70	-10588.23	-1167.10	-1.0000e+0	-1.3000e+0	0.03	
25328	2010-013A	2010-013A	1993-03PH9	2014-10-15 12:45:13.267	2014-10-15 10:13:37	11444.00	1031.23	1813.20	11296.43	1302.30	-1.0000e+0	-1.3000e+0	0.03	
25324	2010-013A	2010-013A	1993-03AEG	2014-10-15 20:09:34.26	2014-10-15 10:13:37	18217.00	1177.63	1177.30	17076.23	-2432.00	-1.0000e+0	-1.3000e+0	0.03	
25323	2010-013A	2010-013A	1993-03BCC	2014-10-15 08:45:08.427	2014-10-15 10:13:37	11185.00	1446.89	1446.90	-10327.20	1369.80	-1.0000e+0	-1.3000e+0	0.03	
25322	2010-013A	2010-013A	1997-0317x	2014-10-14 09:30:14.48	2014-10-15 10:13:37	10223.00	1438.70	-1438.70	824.82	-10268.00	-1.0000e+0	-1.3000e+0	0.03	
25321	2010-013A	2010-013A	1997-0319w	2014-10-13 18:21:26.916	2014-10-15 10:13:37	6905.00	907.35	-907.32	1170.95	6720.40	-1.0000e+0	-1.3000e+0	0.03	
25320	2010-013A	2010-013A	1997-0317Y	2014-10-12 04:02:36.187	2014-10-15 10:13:37	8367.00	1291.63	1291.30	-171.43	8344.45	-1.0000e+0	-1.3000e+0	0.03	
25319	2014-016A	2014-016A	9005-01190H	2014-10-17 10:33:34.067	2014-10-15 10:13:34	20867.00	896.40	-896.42	-20086.10	1480.30	-1.0000e+0	-1.3000e+0	0.03	
25318	2014-016A	2014-016A	9005-01190H	2014-10-17 08:51:56.768	2014-10-15 10:13:34	8383.00	762.52	-762.52	-4211.43	-441.00	-1.0000e+0	-1.3000e+0	0.03	
25317	2014-016A	2014-016A	9004-029A	2014-10-17 03:09:55.506	2014-10-15 10:13:34	22327.00	336.13	-336.12	22088.29	23.40	-1.0000e+0	-1.3000e+0	0.03	
25316	2014-016A	2014-016A	1004-025A	2014-10-17 01:33:36.485	2014-10-15 10:13:34	3300.00	1545.00	1545.00	8723.43	0.00	-1.0000e+0	-1.3000e+0	0.03	
25315	2014-016A	2014-016A	9005-01190H	2014-10-17 07:32:15.549	2014-10-15 10:13:34	8365.00	764.00	-764.00	8329.00	592.00	-1.0000e+0	-1.3000e+0	0.03	
25313	2014-016A	2014-016A	9005-01190H	2014-10-17 07:13:19.634	2014-10-15 10:08:29	8485.00	751.52	-751.52	8440.63	602.00	5.3000e+0	5.1000e+0	20.23	300
25314	2014-016A	2014-016A	9005-01190H	2014-10-17 05:34:42.289	2014-10-15 10:13:34	23143.00	638.33	-638.33	23047.69	902.10	-1.0000e+0	-1.3000e+0	0.03	
25314	2014-016A	2014-016A	9005-01190H	2014-10-17 05:34:42.377	2014-10-15 10:08:29	23221.00	595.63	-595.63	23136.13	569.30	1.8000e+0	1.2700e+0	30.62	300
25313	2014-016A	2014-016A	9005-01190H	2014-10-17 05:58:05.088	2014-10-15 10:08:29	8906.00	496.43	-496.47	8707.23	2862.70	5.9000e+0	4.1700e+0	30.62	300
25312	2014-016A	2014-016A	1993-0329K	2014-10-17 05:02:12.086	2014-10-15 10:13:34	16381.00	597.00	597.00	-10279.00	1381.40	-1.0000e+0	-1.3000e+0	0.03	
25312	2014-016A	2014-016A	1993-0329K	2014-10-17 05:02:12.957	2014-10-15 10:08:29	17468.00	596.10	596.30	-10760.90	13734.40	1.0000e+0	2.0100e+0	10.33	295
25311	2014-016A	2014-016A	1994-0317M	2014-10-16 08:54:56.026	2014-10-15 10:08:29	21900.00	811.60	-811.60	-7930.43	20472.20	1.0000e+0	4.3600e+0	20.23	202
25311	2014-016A	2014-016A	1996-0317M	2014-10-16 08:54:45.968	2014-10-15 10:13:35	22912.00	446.59	-446.59	-8274.68	-2161.10	-1.0000e+0	-1.3000e+0	0.03	
25310	2014-016A	2014-016A	2011-021A	2014-10-13 21:32:35.609	2014-10-15 10:08:29	40377.00	8182.35	-11982.30	-29786.10	-3573.90	1.0000e+0	5.1970e+0	5.28	164
25309	2013-067C	2013-067C	9005-07196H	2014-10-13 22:53:01.37	2014-10-15 10:08:34	8446.00	2727.65	-2727.65	1636.70	447.30	8.2100e+1	2.3500e+0	11.61	234
25308	2013-067C	2013-067C	9005-07196H	2014-10-13 01:19:17.009	2014-10-15 10:08:34	10440.00	8047.20	-8047.20	8676.18	7264.00	1.2870e+1	2.4210e+0	11.36	234
25307	2013-067C	2013-067C	2013-067B	2014-10-17 08:59:15	2014-10-15 10:08:34	17288.00	2360.43	-2360.43	-16242.29	-1157.60	1.3000e+0	5.2000e+0	12.27	1277
25306	2013-067C	2013-067C	2013-067B	2014-10-17 07:01:08.521	2014-10-15 10:08:34	17622.00	331.03	-331.03	886.70	-7640.00	1.0000e+0	1.4400e+0	22.68	1272

PREEMPT

PREEMPT Manager | Dashboard | Analysis View | Admin

Highest Collision Probability

Level: **7.419e-6**

Next Case: 7.067e-5

Closest Encounter

Level: **676.00 m**

Next Case: 295.00 m

Closest Risky Encounter

Level: **1.70 m**

Next Case: 4.20 m

10 Most Risky Events

Latest	Worst Case
7.419e-6 Event 9117	7.267e-5 Event 9192
7.375e-6 Event 9118	5.220e-6 Event 9119
7.256e-6 Event 9118	6.12e-6 Event 9109
6.825e-6 Event 9109	5.126e-6 Event 9117
6.737e-6 Event 9197	5.034e-6 Event 9197
6.650e-6 Event 9111	7.022e-6 Event 9111
6.214e-6 Event 9118	7.726e-6 Event 9118
6.026e-6 Event 9112	7.155e-6 Event 9106
5.742e-6 Event 9106	7.070e-6 Event 9119
5.686e-6 Event 9119	5.532e-6 Event 9119

Cumulative Risk

Level: **1.160e-4**

Next Case: 2.212e-4

Number of Forecast Events

Level: **142**

Forecast Events above Risk Threshold

Level: **0**

Next Case: 1

Maximum Collision Probability for the last 7 Days

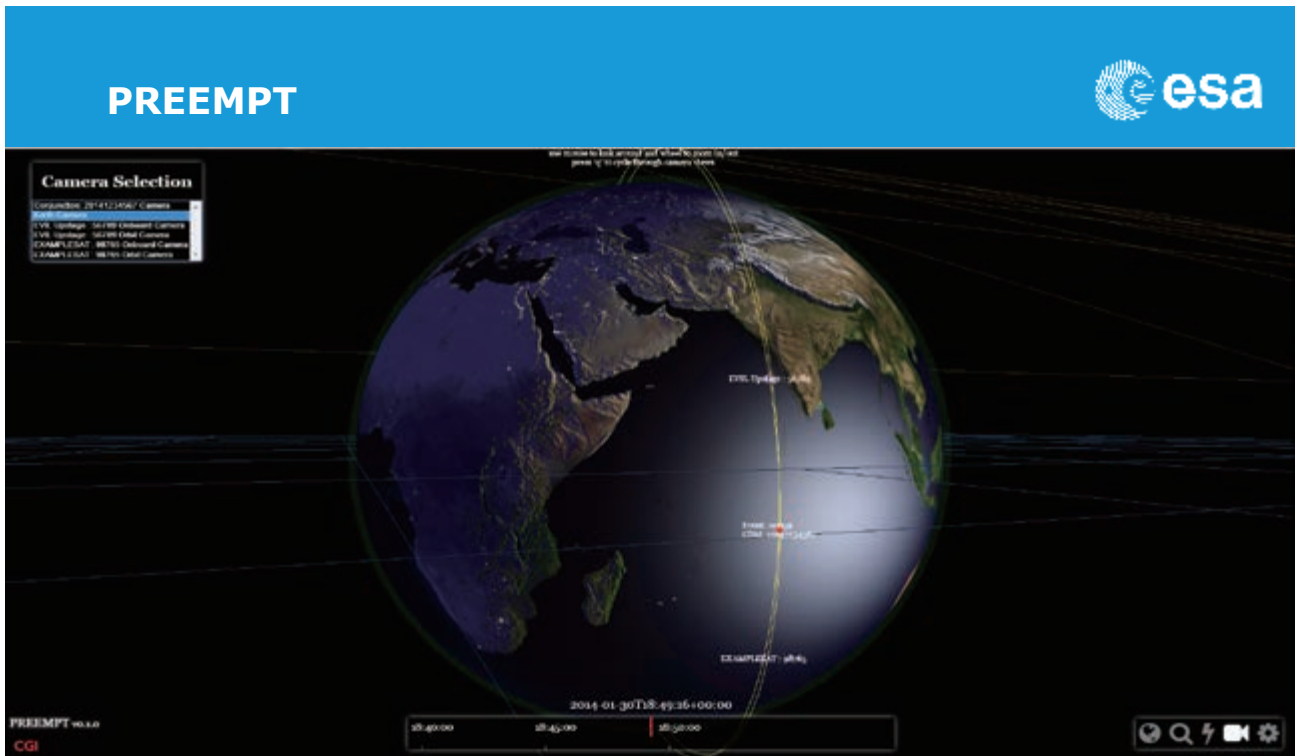
Cumulative Risk for the last 7 Days

Number of Events for the last 7 Days

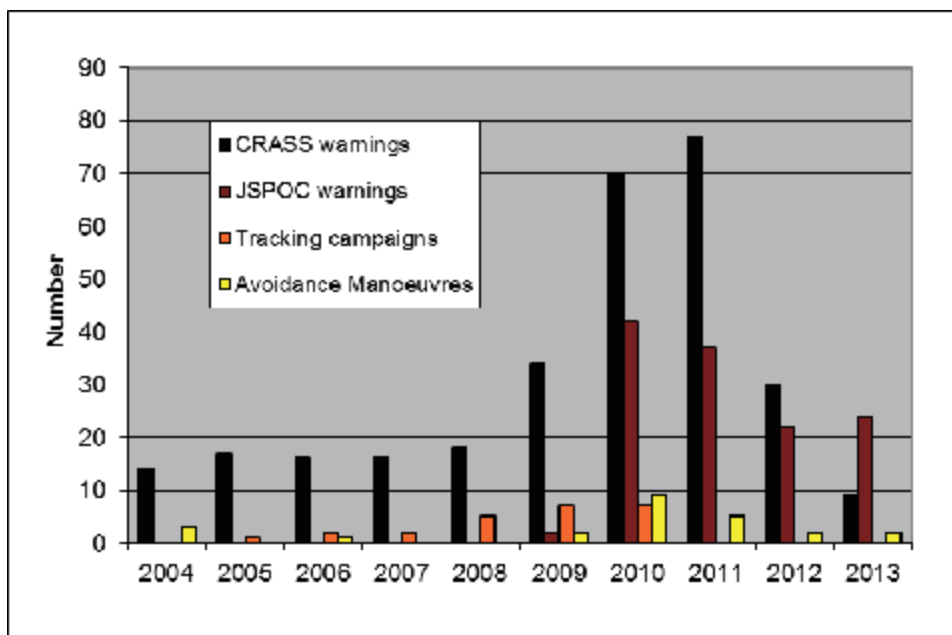
Number of Events above Risk Threshold for the last 7 Days

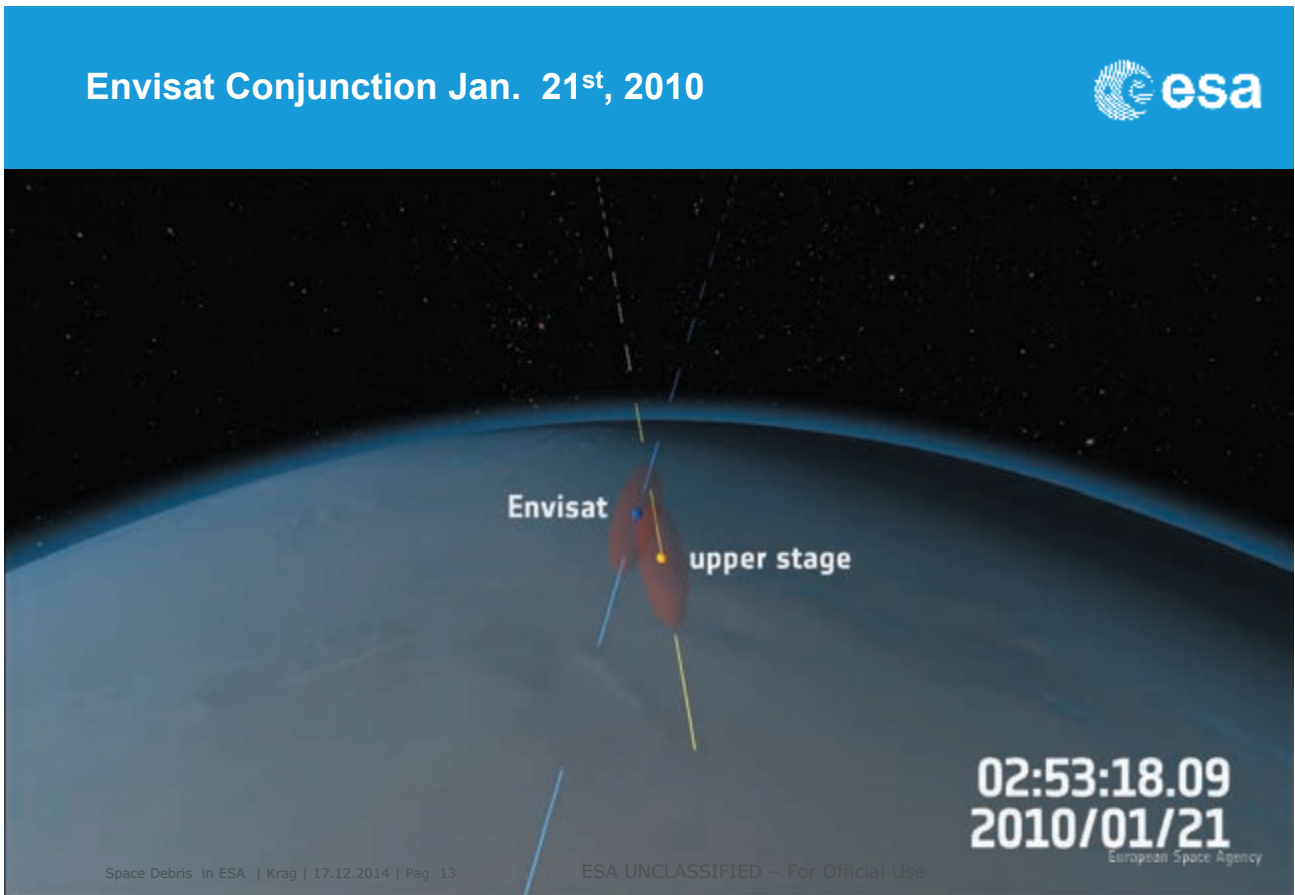
10 Closest Encounters

Latest	Worst Case
676.00 m Event 9004	295.00 m Event 9117
676.00 m Event 9205	676.00 m Event 9204
602.00 m Event 9498	576.00 m Event 9205
602.00 m Event 9108	774.00 m Event 9118
595.00 m Event 9103	930.00 m Event 9246
5245.00 m Event 9206	583.00 m Event 9202
1234.00 m Event 9201	1262.00 m Event 8996



Statistics for ESA Satellites



The new DISCOS Web Frontend

Launch Path

Path Name: Launchpath
Entry Point File: COSPARLaunchNumber
Entry Point value: 2010-006

Launch date	2010-02-13
LauncherName	Vega
Number of payloads	9
Flight number	V001
Related objects	13
Launcher Image	(click for details)

RELATED OBJECTS

COSPAR ID	SATNO	APRN	OBJECT CLASS	Region
2010-006A	0007	LANES	Payload	Low Earth Orbit
2010-006B	0008	ALANEX	Payload	Low Earth Orbit
2010-006C	0009	ALANEX	Payload	Low Earth Orbit

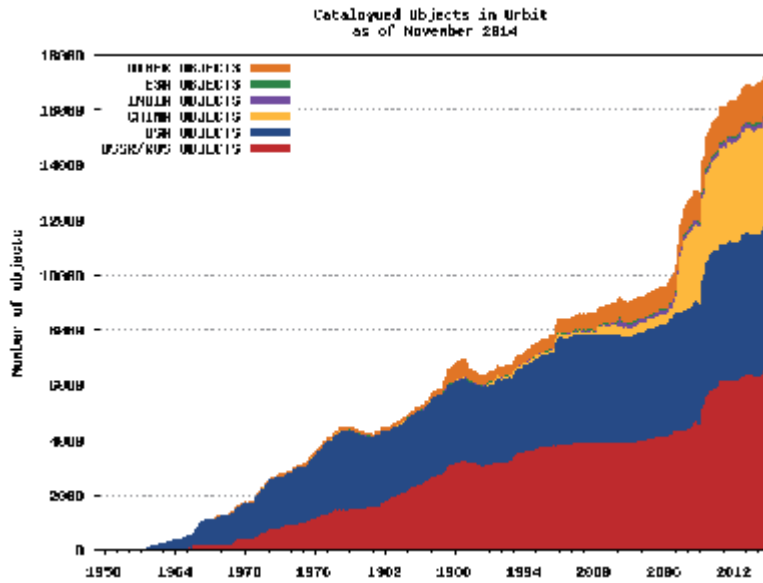
Launches per Launcher with Country

Launcher	Country	Percentage
Ariane 5G	France	19%
Ariane 5	France	15%
Ariane 4	France	11%
Ariane 44LP	France	9%
Delta 2914	USA	9%
Soyuz-FG Proton	Russia	7%
Ariane 5ES	France	7%
Ariane 5ES	France	7%
Proton-K/DM-2	Russia	7%
Delta 2914	USA	5%
Soyuz-U Proton	Russia	5%
Vega	France	5%
Ariane 5G+	France	5%
Dnepr	Ukraine	5%
Proton-K/DM-2	Russia	5%
Atlantis (OV-104)	USA	5%
Other	-	21%

Catalogued objects in orbit



- December 2014: ca. 40000 Objects have been catalogued, of which about 17000 are in orbit

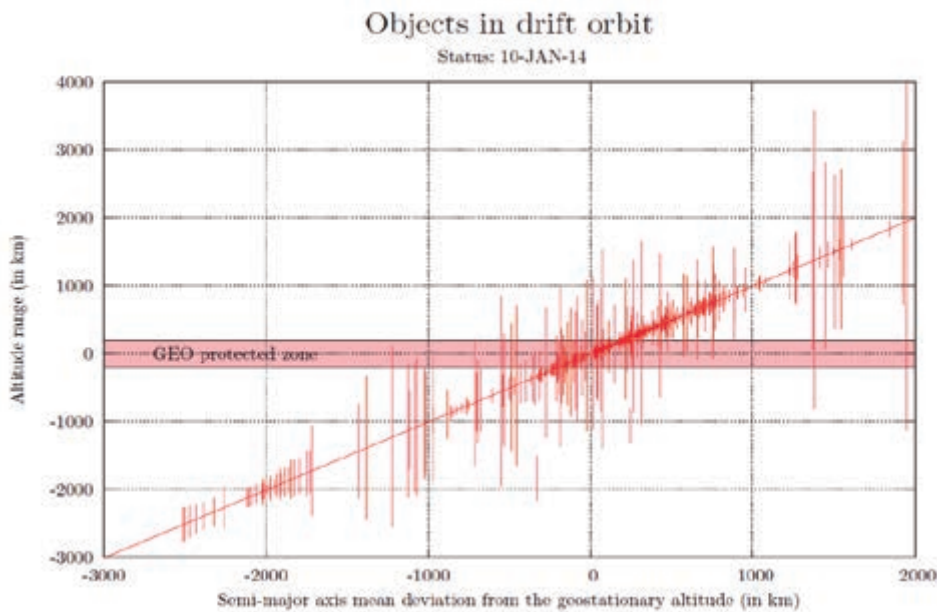


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Distribution of drifters (TLE only)

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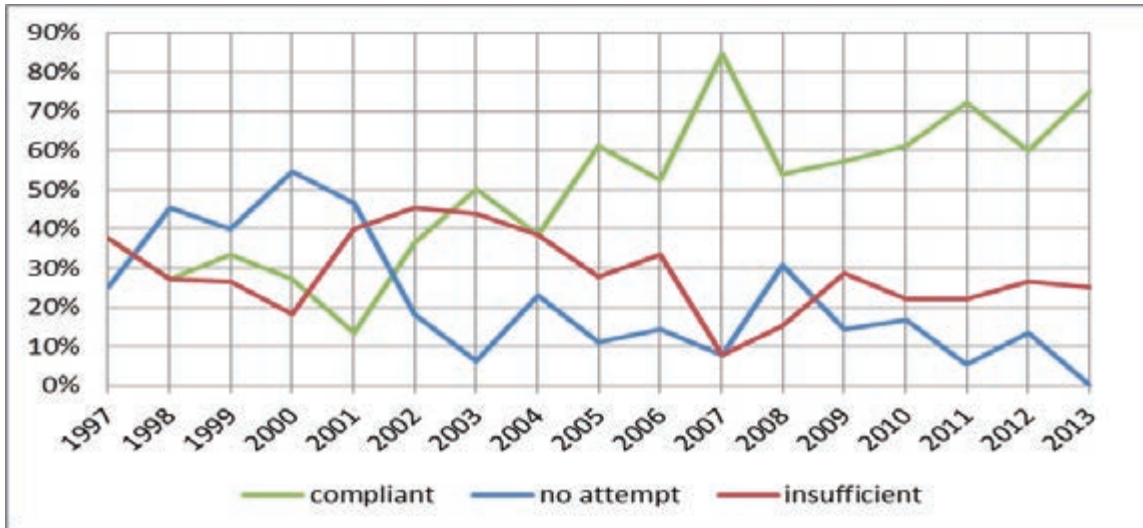
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EoL statistics



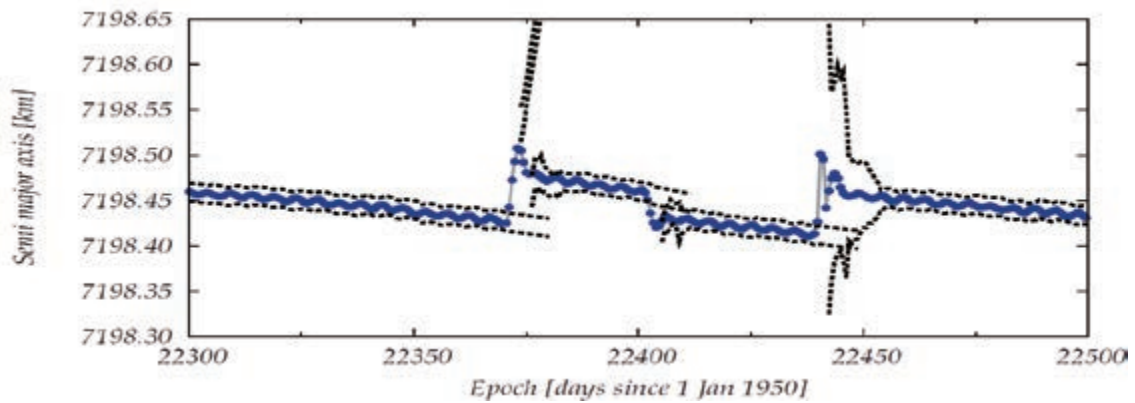
- Average of 16 annual disposals



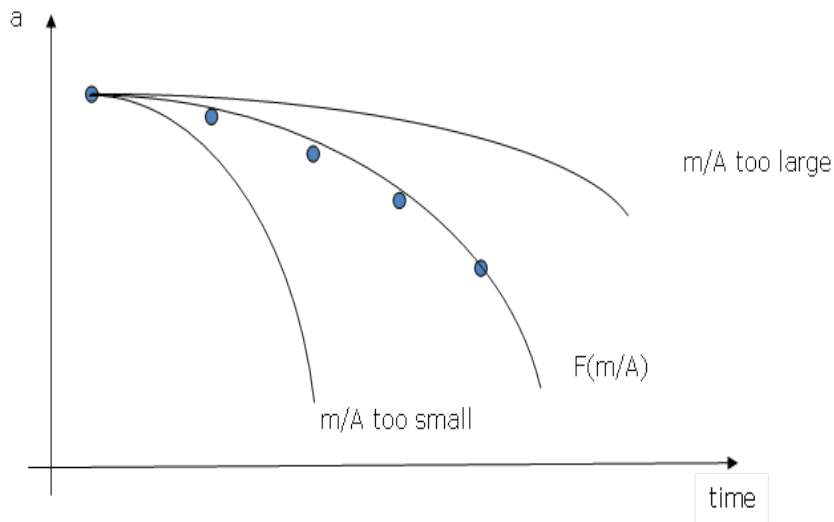
Manoeuvre Detection from TLEs



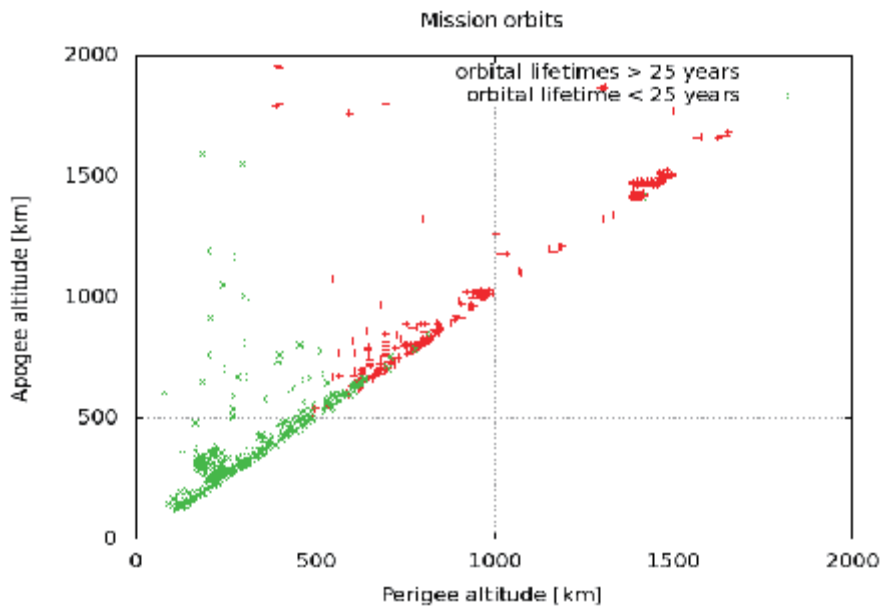
METOP-A between 21/1/2011 and 9/8/2011



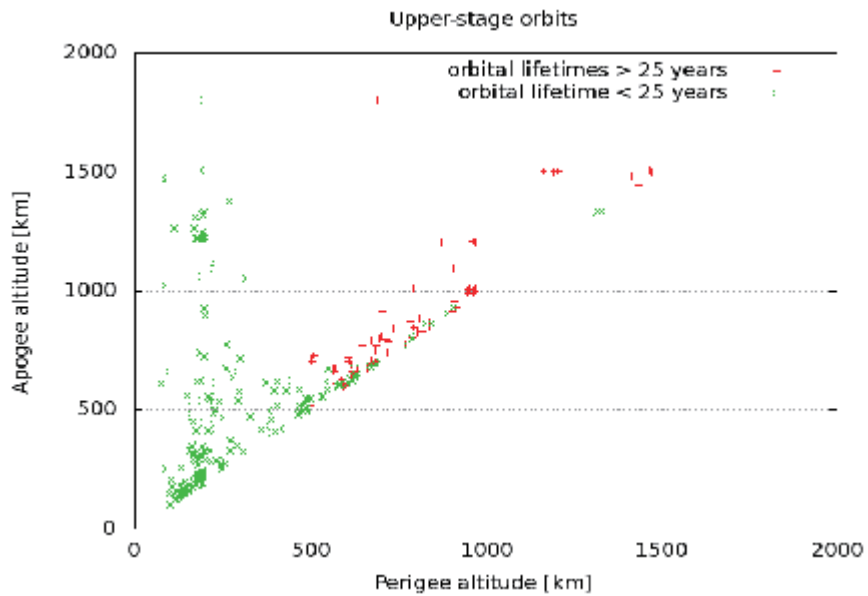
Orbital Lifetime Prediction from TLEs



Destination orbits of spacecraft



Destination orbits of upper-stages

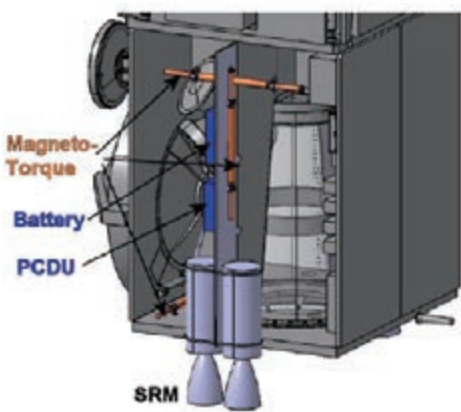


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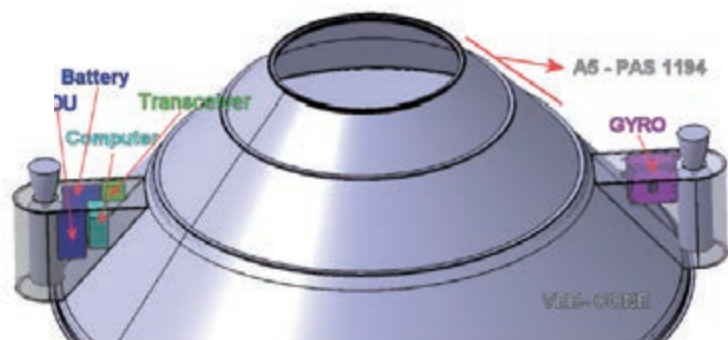
SPADES



Solid **P**ropellant **A**utonomous **D**e-orbit **S**ystem

← Accomodation on LEO Satellite

Accomodation on Ariane 5 GTO state →



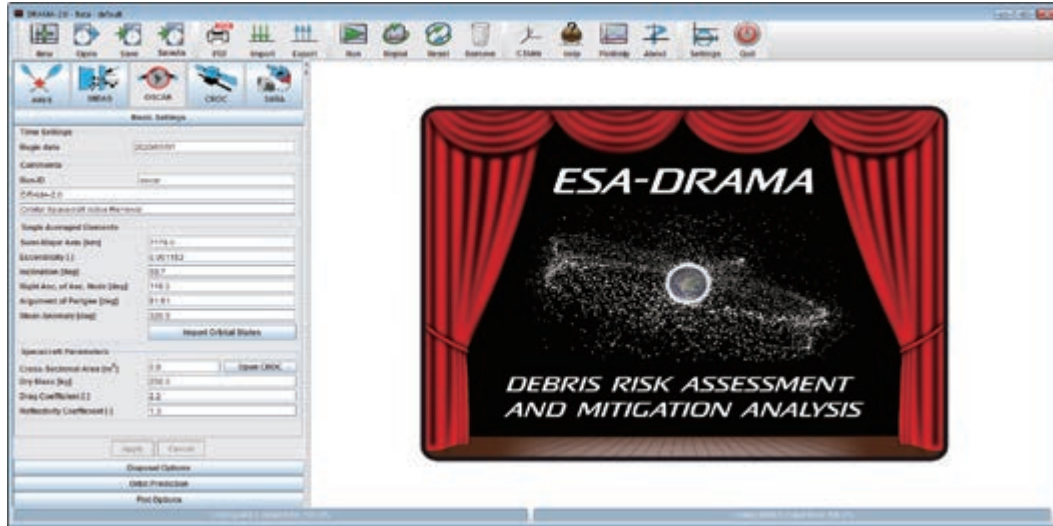
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V2.0 Graphical User Interface

- Windows, Linux, **Solaris**, **Mac-OS**



The DRAMA 2.0 software suite



ARES: Assessment of Risk Event Statistics:
To consider the possible requirements for collision avoidance manoeuvres during a mission.



MIDAS: MASTER (-based) Impact Flux and Damage Assessment Software: To model the collision flux and damage statistics for a mission.



OSCAR: Orbital Spacecraft Active Removal: To analyse the disposal manoeuvre performed by a space system at the end of its useful lifetime.



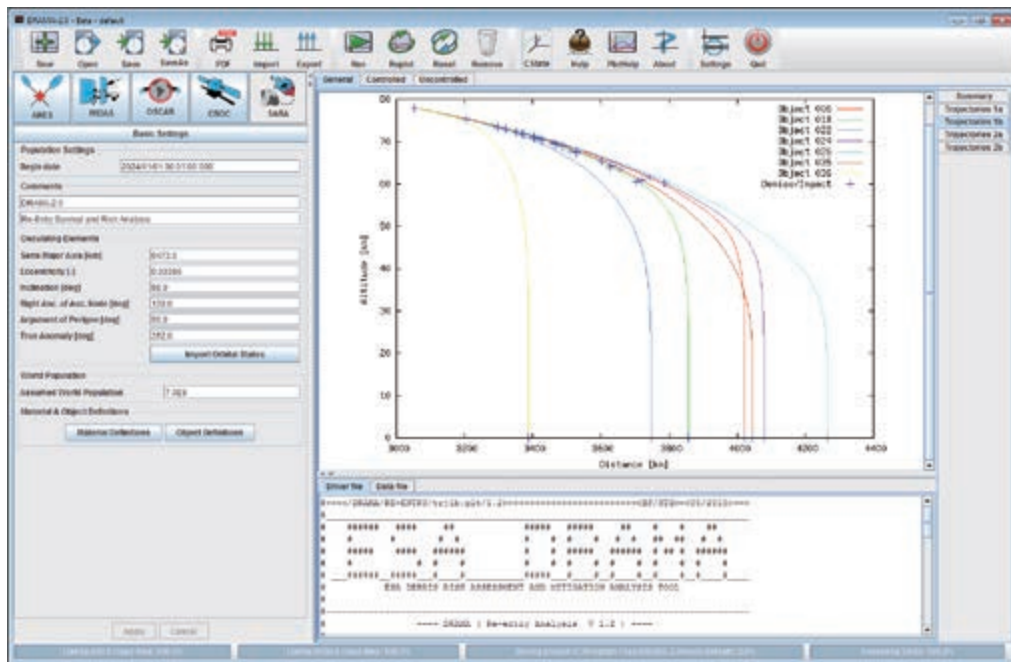
CROC: Compute projected cross-sectional areas of complex bodies



SARA: Spacecraft Entry Survival Analysis Module (SESAM):
To model the re-entry of a space system into the Earth's atmosphere.
SERAM: Spacecraft Entry Risk Analysis Module:

To assess the risk on the ground of objects surviving re-entry.

New Presentation of Results



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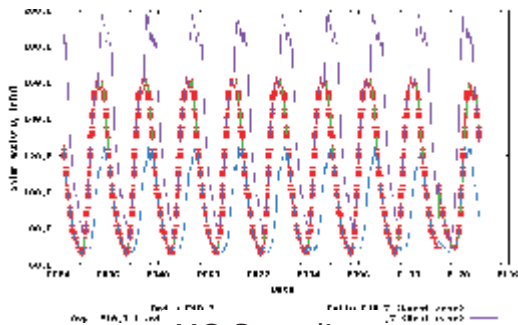
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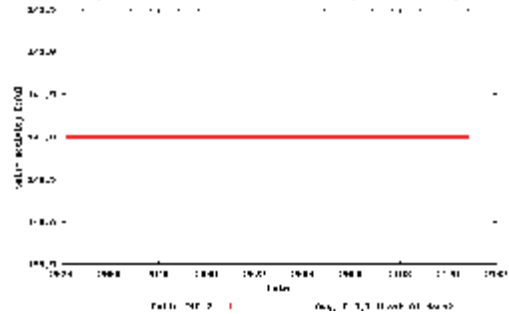
Task #2: Solar Flux Prediction Methods



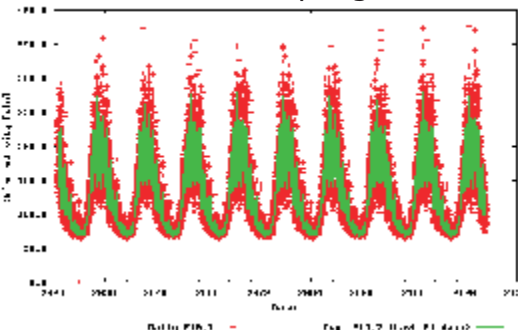
Nominal and Confidence interval



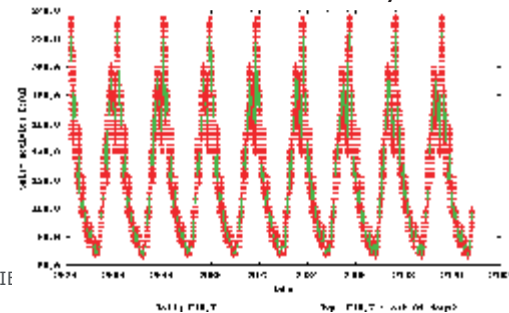
Specific Constant (STELA)



MC Sampling

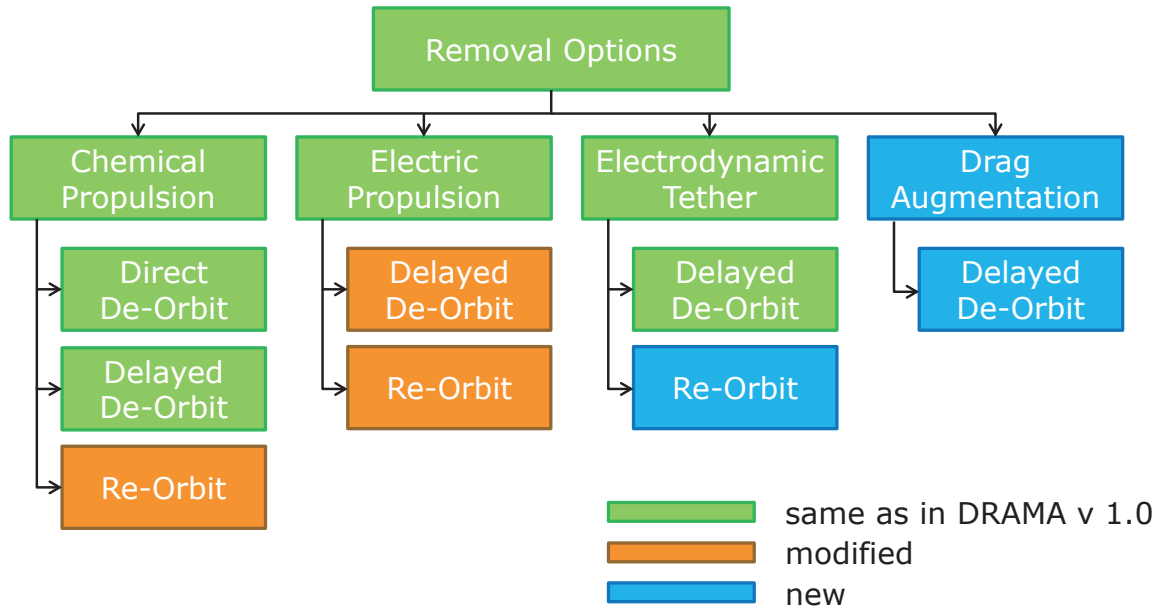


ECSS Reference Cycle

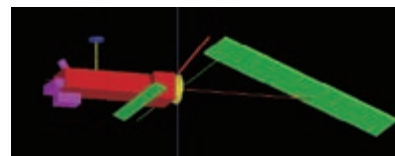
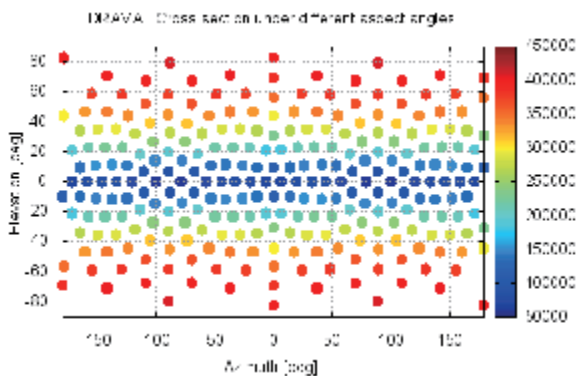
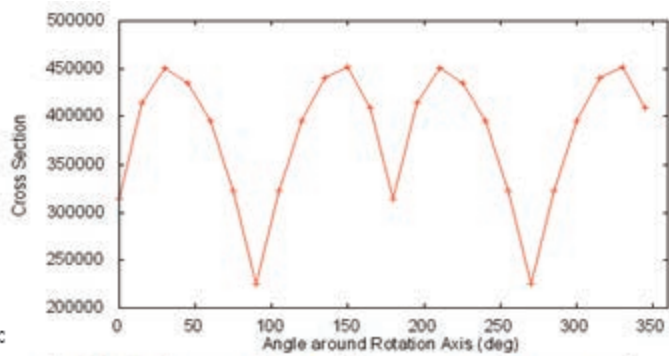
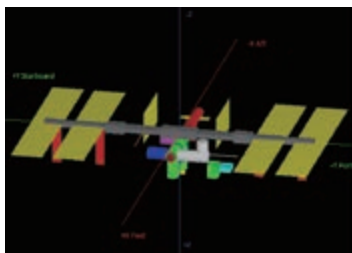


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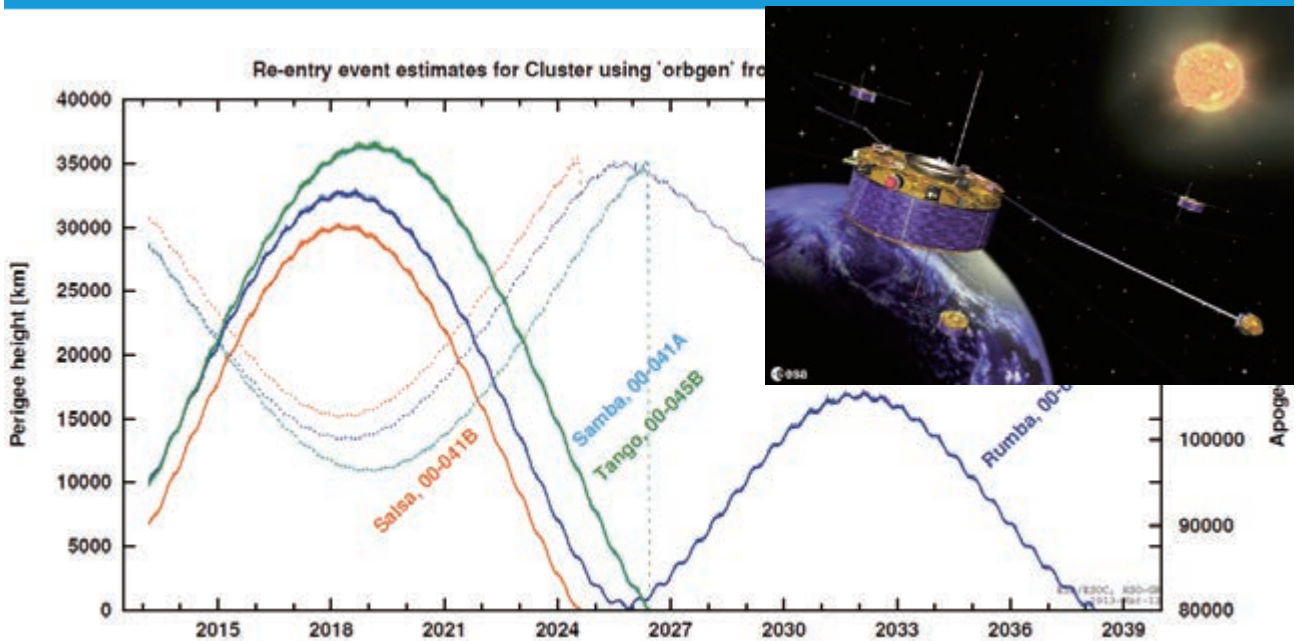
Removal Options Analysed by OSCAR

Cross-Section Computation

Cluster-II Re-entry

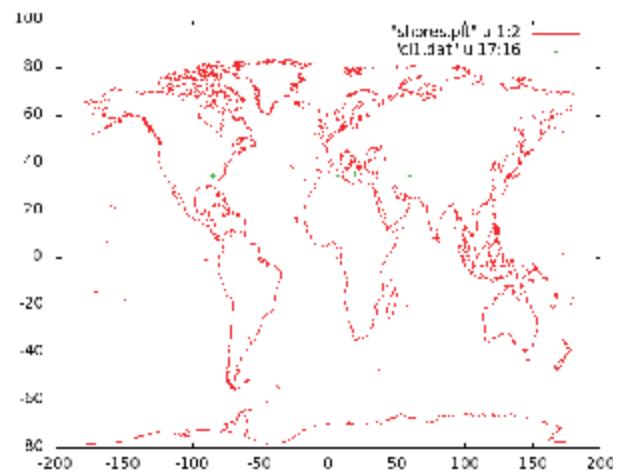
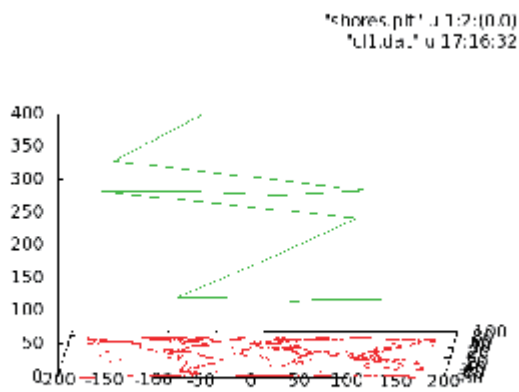


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Cluster-II S/C 1

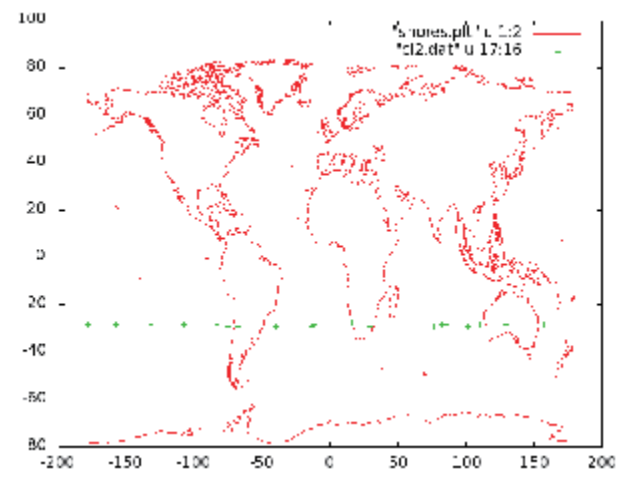
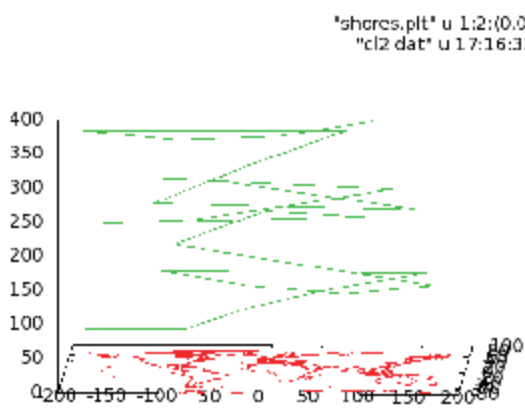


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Cluster-II S/C 2



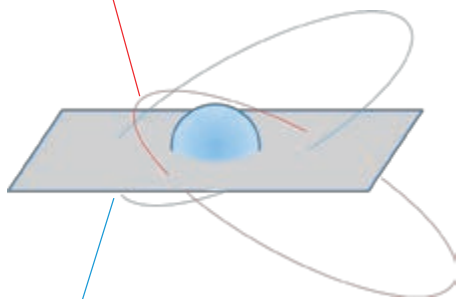
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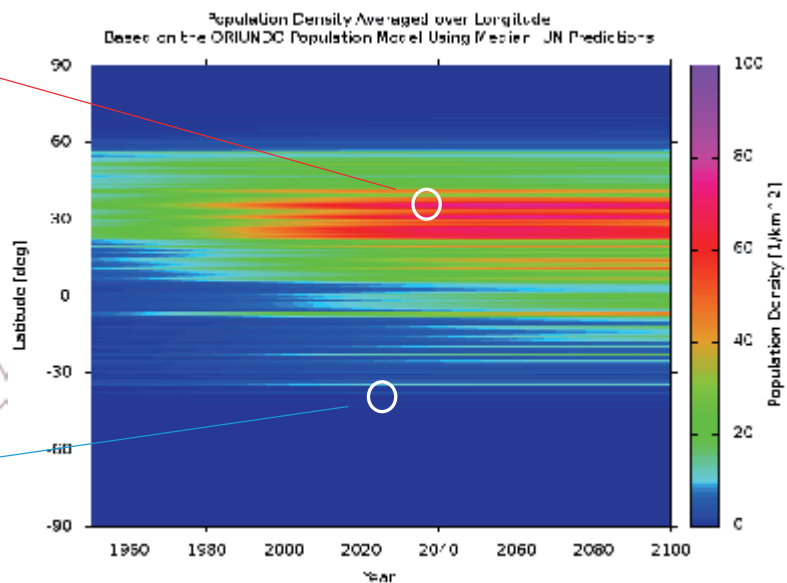
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Cluster-II Line of Apesides and On-ground Risk

Cluster-1 in 2038



Cluster-2/3/4 in 2024-2026



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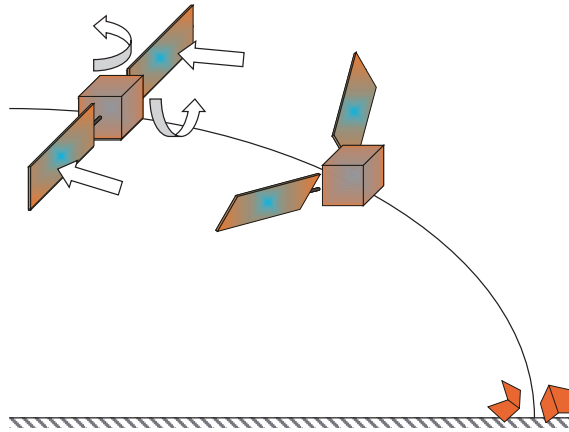
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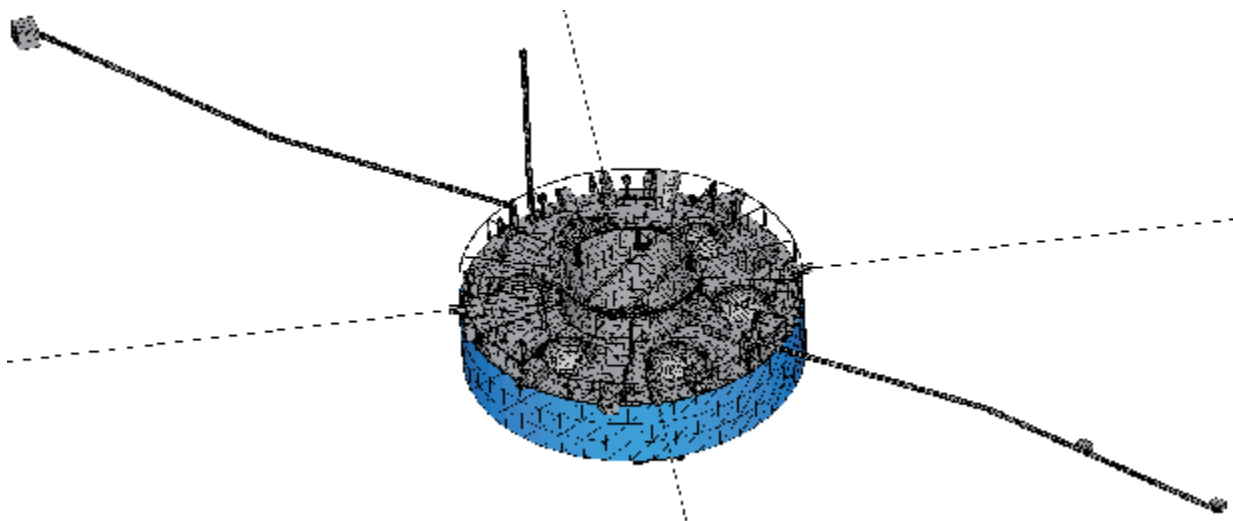
Determining Break-Up process and Survivability



- S/C modeling
→ simplified model
- Aerodynamic analysis
→ forces and torques
- Dynamic analysis
→ trajectory and attitude motion
- Aerothermal analysis
→ heating and melting
- Fragmentation analysis
→ structural fracture and separation due to melting



Modelling Cluster-II – SCARAB Model

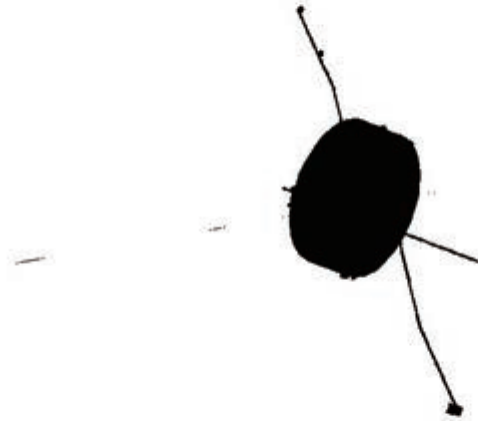
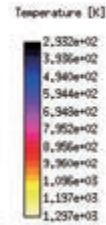


Simulation for Cluster-II Spacecraft 1



T = 0.08008 s
H = 144,705 km
V = 11,082 km/s

Time Lapse Animation (2x real-time)
[flight direction towards the observer; zenith at top]



Space CLUINT - Cluster-II - Spin axis pointing analysis - S/C #1, case 8, perigee pass 2

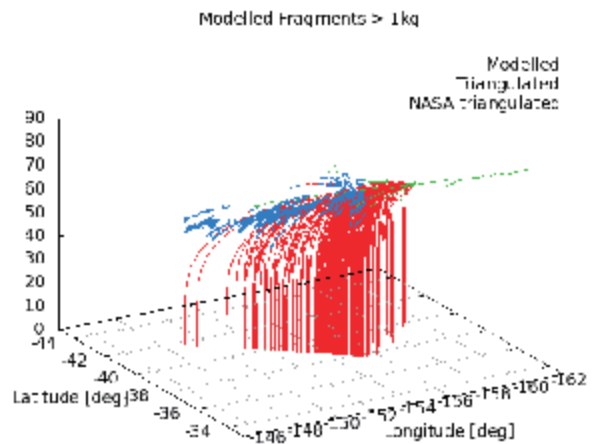


Observations of the ATV-5 Shallow Re-entry



- Re-entry Trajectory: 190km x 75km (normal trajectory: 400km x 0km)

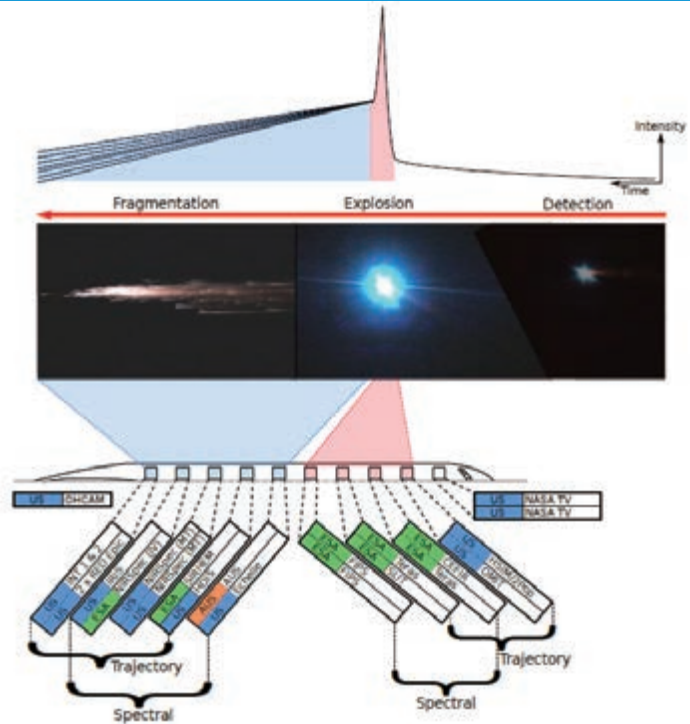
Observation results of ATV-1



ATV: Re-entry observations (1/3)

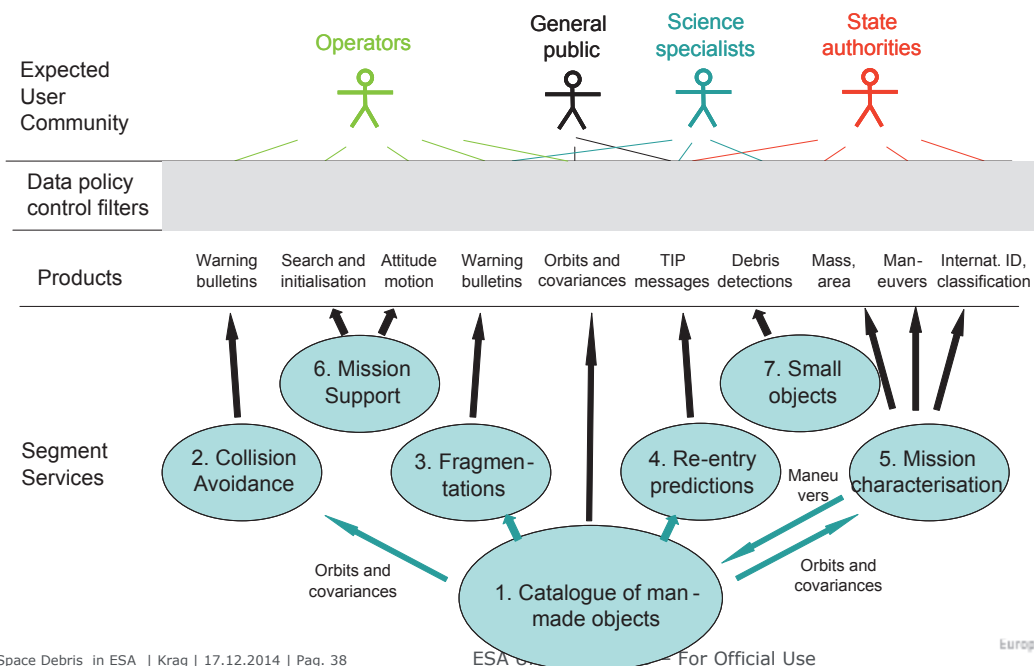


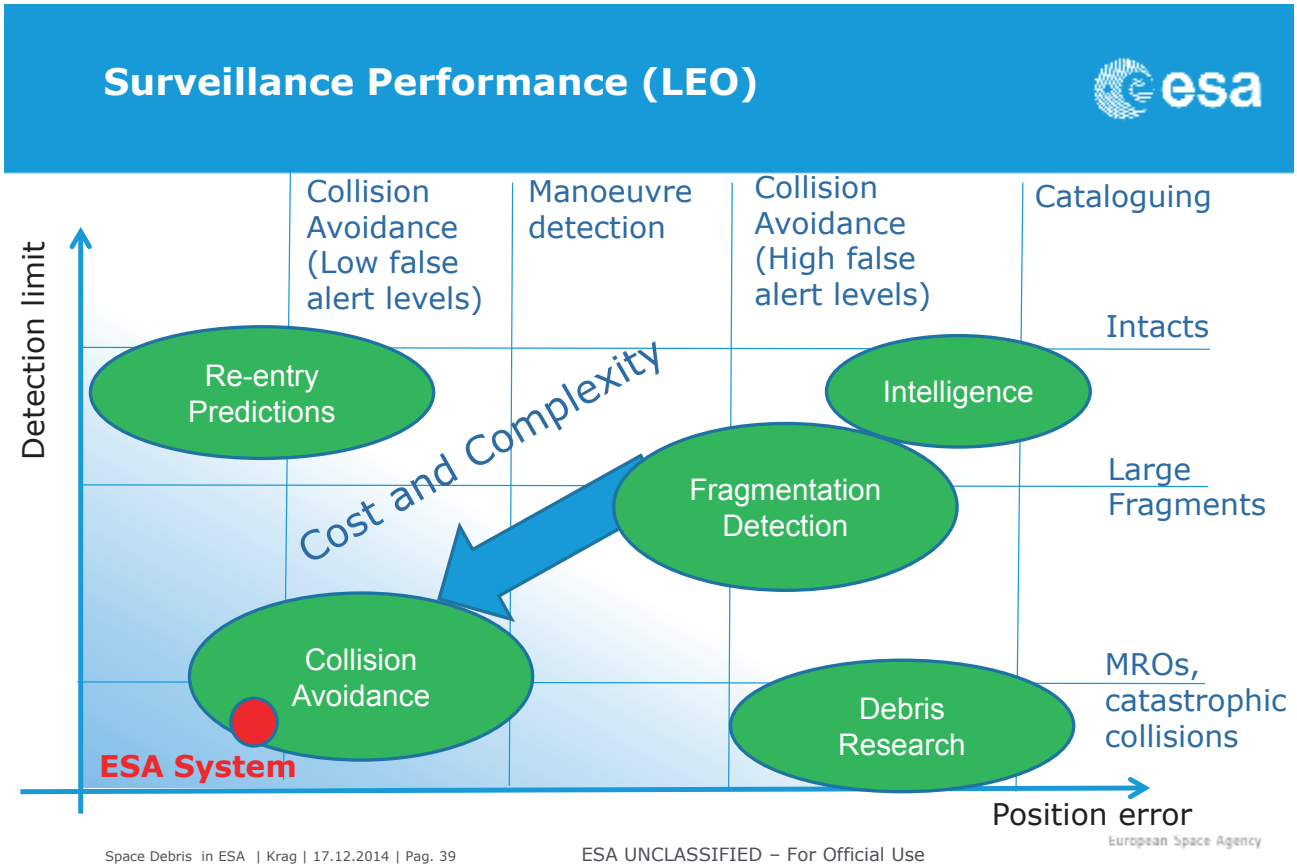
NASA DC-8 Research Aircraft



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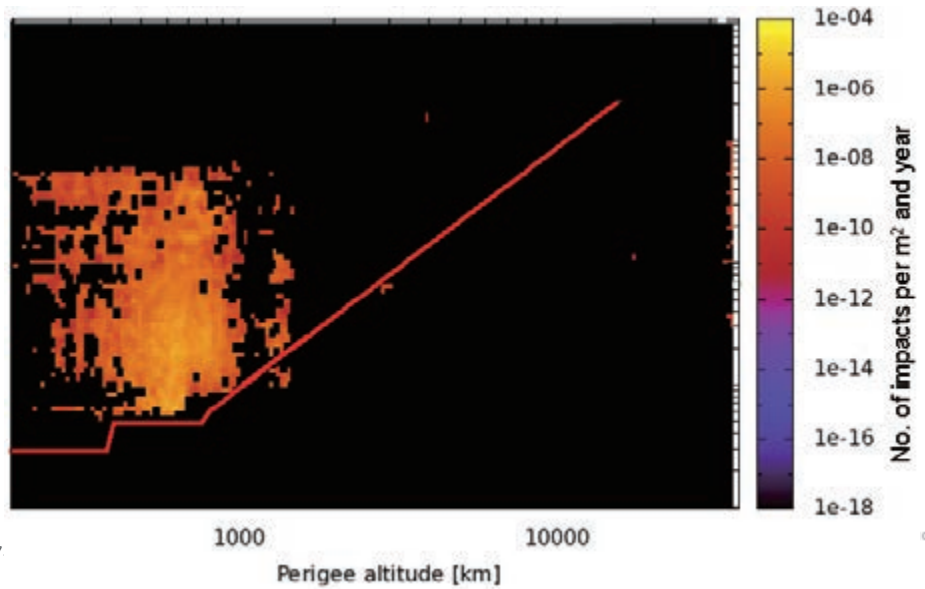
Surveillance and Tracking Services (as per ESA program)





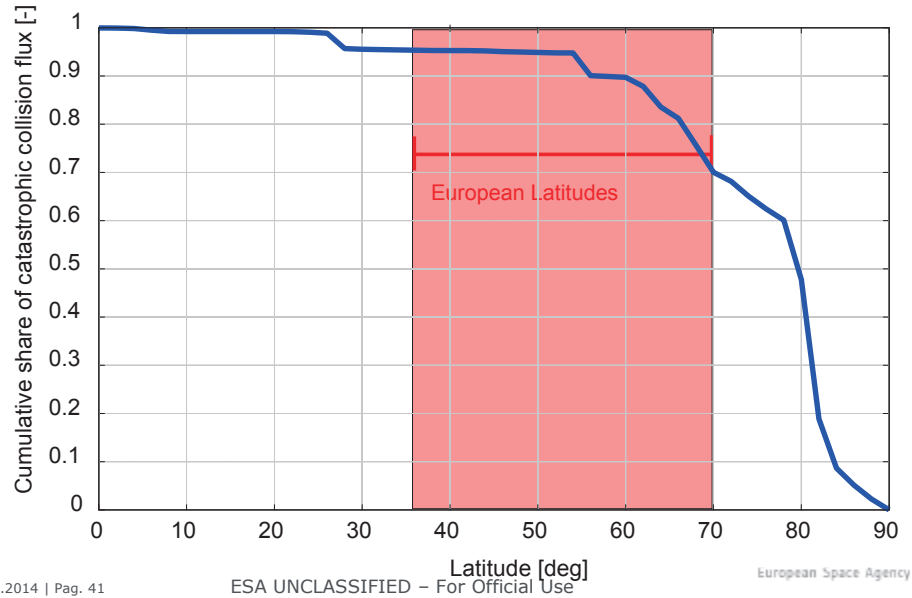
Required System Sensitivity (2/2)

- 98% coverage correspond to the follow radar performance envelope:
 - 32cm @2000km altitude, 8cm @1000km altitude



Loss due to Selected Sensor Latitude

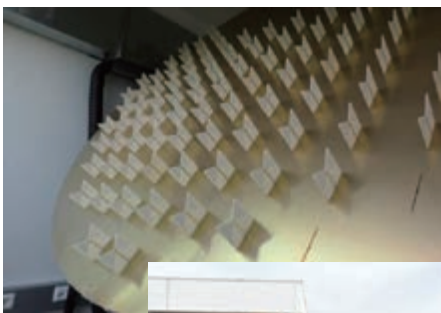
- Loss of another at least 5% due to selection of a site on European mainland



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Demonstrator radar in Santorcaz (Spain)



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ESA Space Debris Telescope Tenerife/Spain (EU)

- Zeiss telescope of 1m aperture and 0.7° field-of-view, Tenerife (lat = 28.17° N, long = 16.30° W)
- Detection threshold: mag 19 - 21 (~ 15 cm objects in GEO), 120° of GEO ring visible



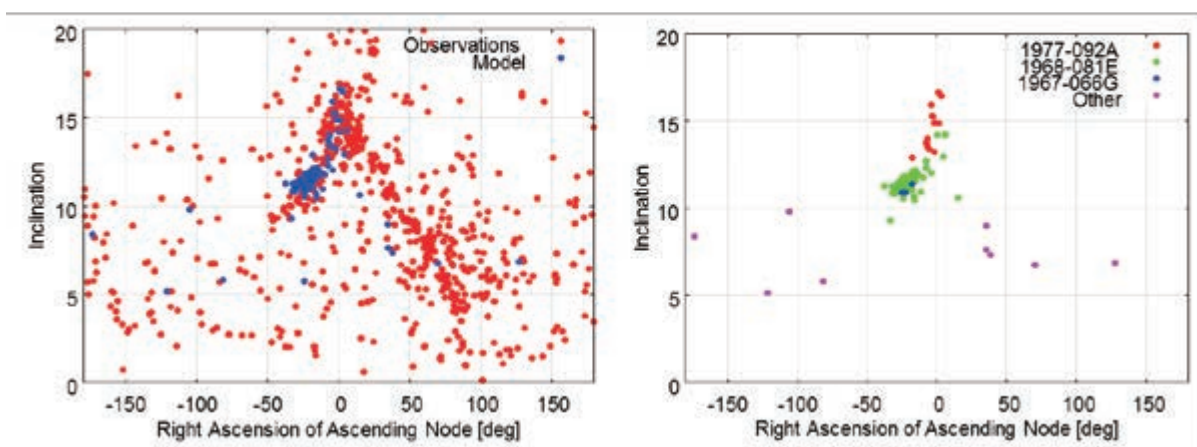
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ESA Space Debris Telescope Tenerife/Spain (EU)

Uncorrelated Detections in 2005 (ESASDT: 928, Model: 115)



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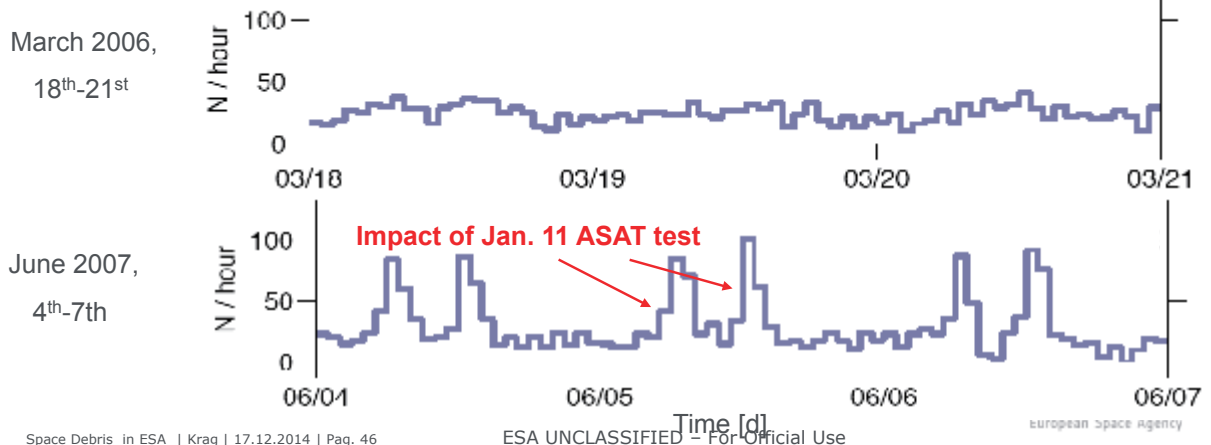
Beampark experiments



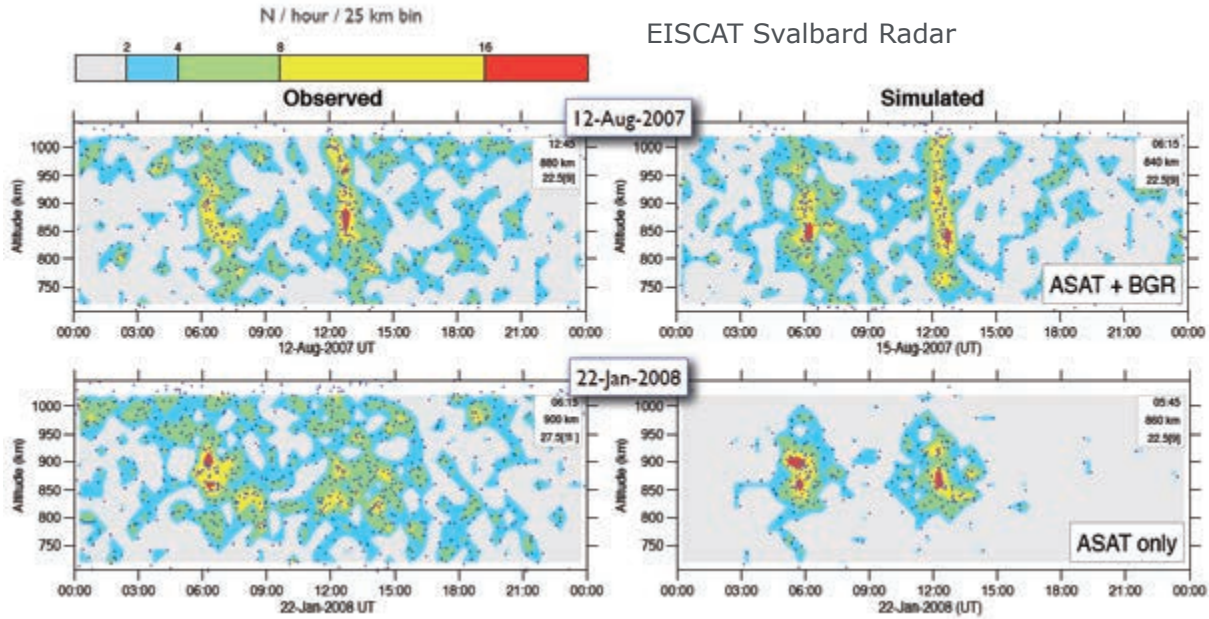
FY-1C ASAT (2/2)



EISCAT Svalbard radar (lon: 16.029° , lat: 78.153°)
(42m and 32m UHF antennas)



Comparison to measurements (2/2)

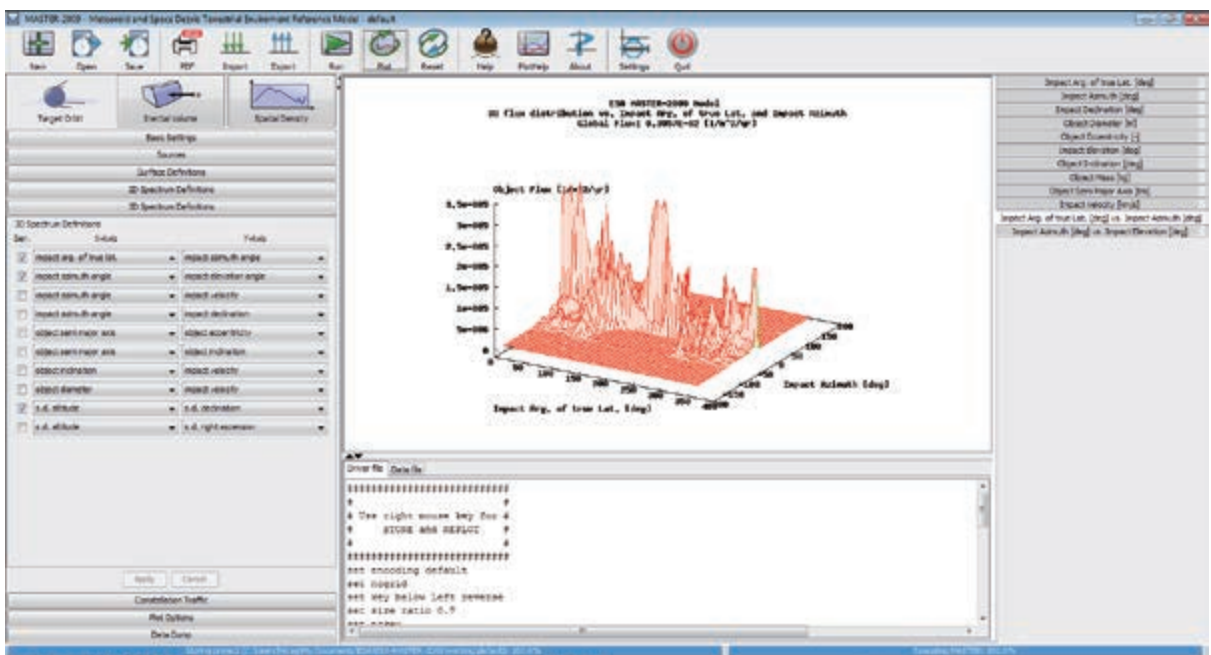


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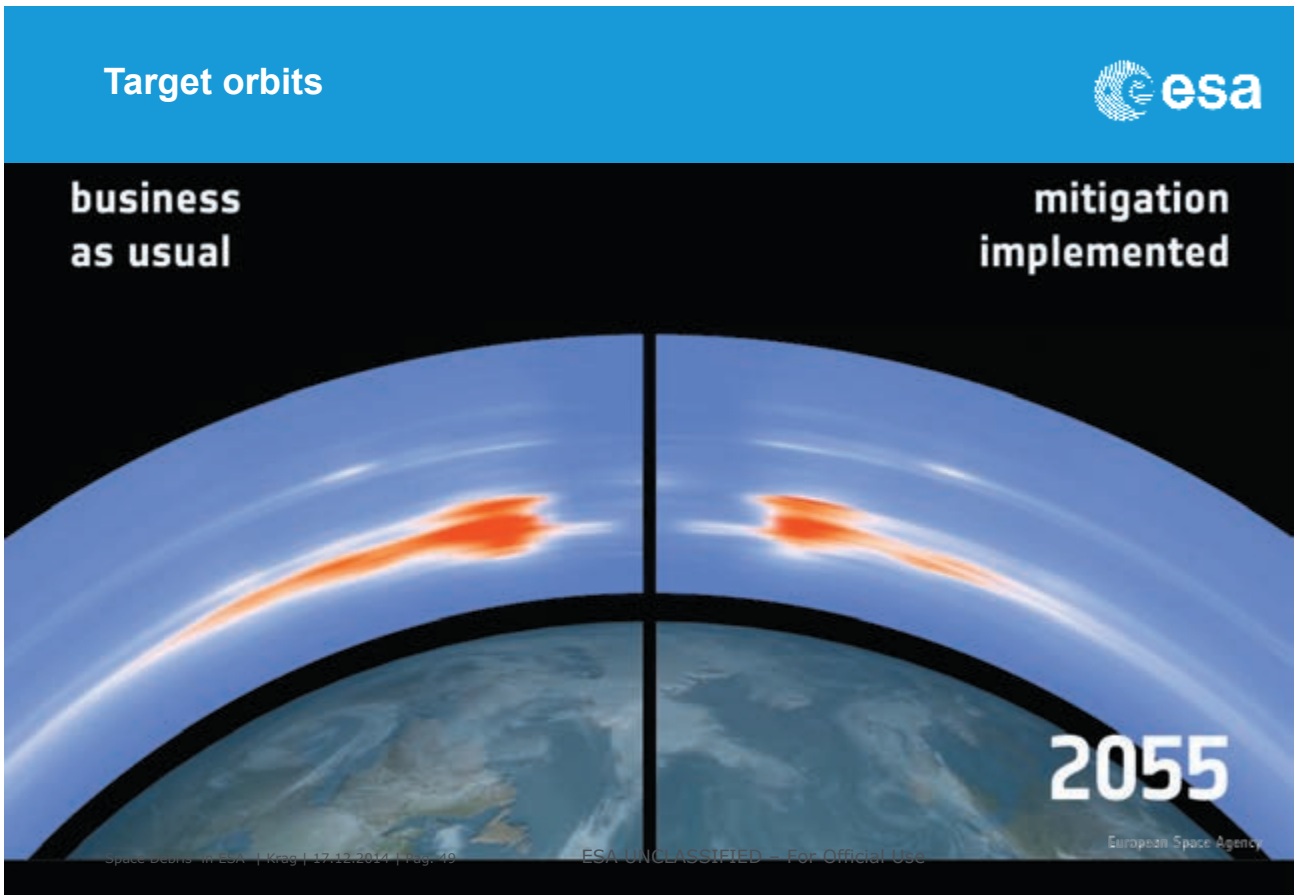
European Space Agency

MASTER-2009 Application



SDM Training | Krag | 2013 | Pag. 48

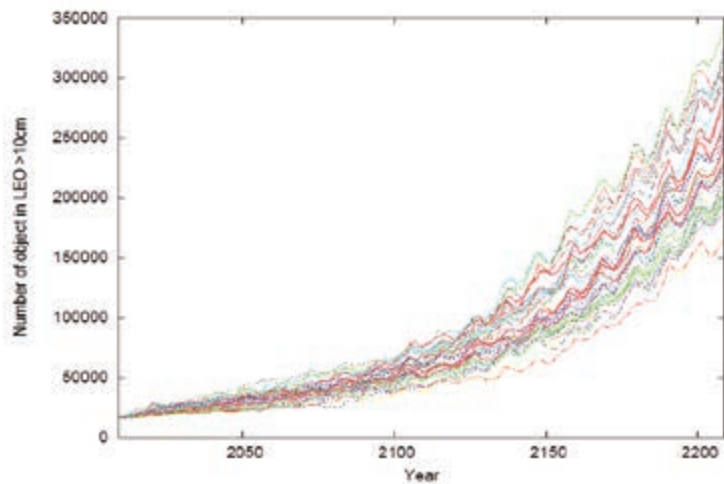
European Space Agency



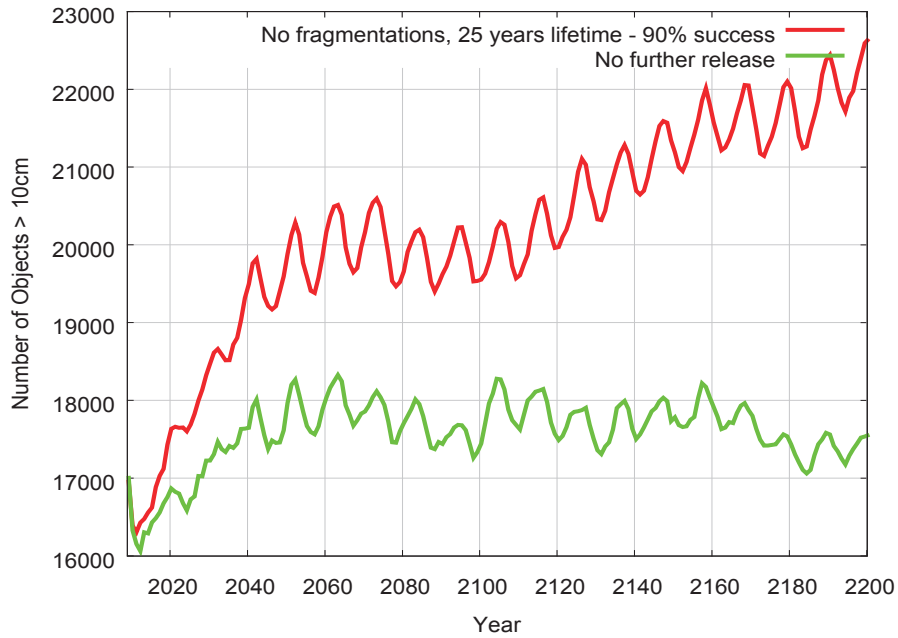
Environment Projections



- DELTA
 - Debris Environment Long-Term Analysis
 - 3-D time dependant semi-deterministic model
 - Traffic models (launch cycle of the past 8 years)
 - Debris mitigation measures
 - Simulation of environment response to active debris removal



DELTA results: Future evolution of the environment



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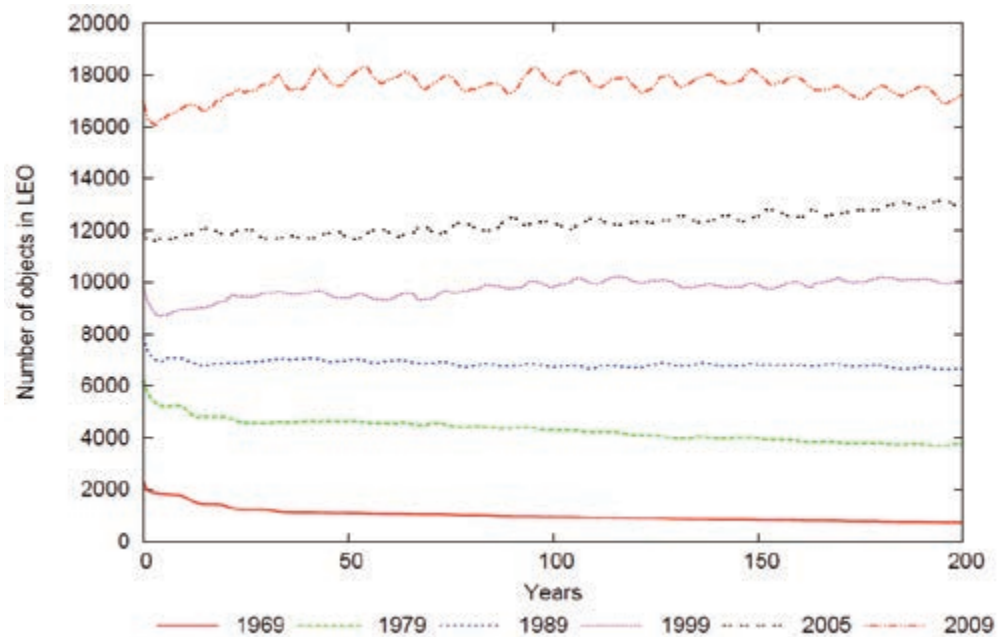
European Space Agency

Analysis of different historical populations



No further release:

- No launches
- No explosions

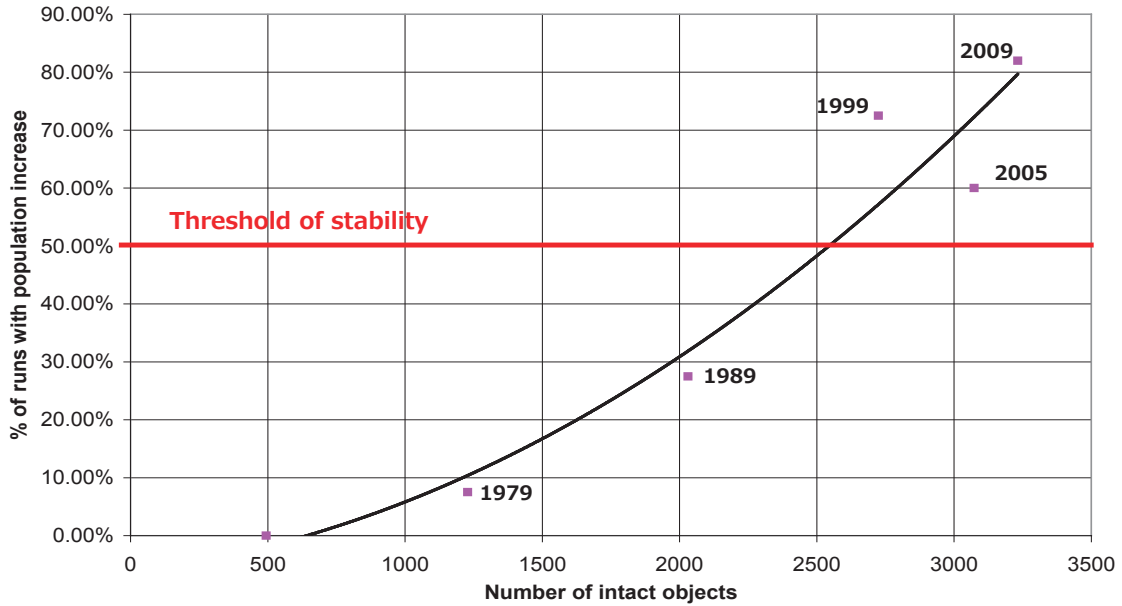


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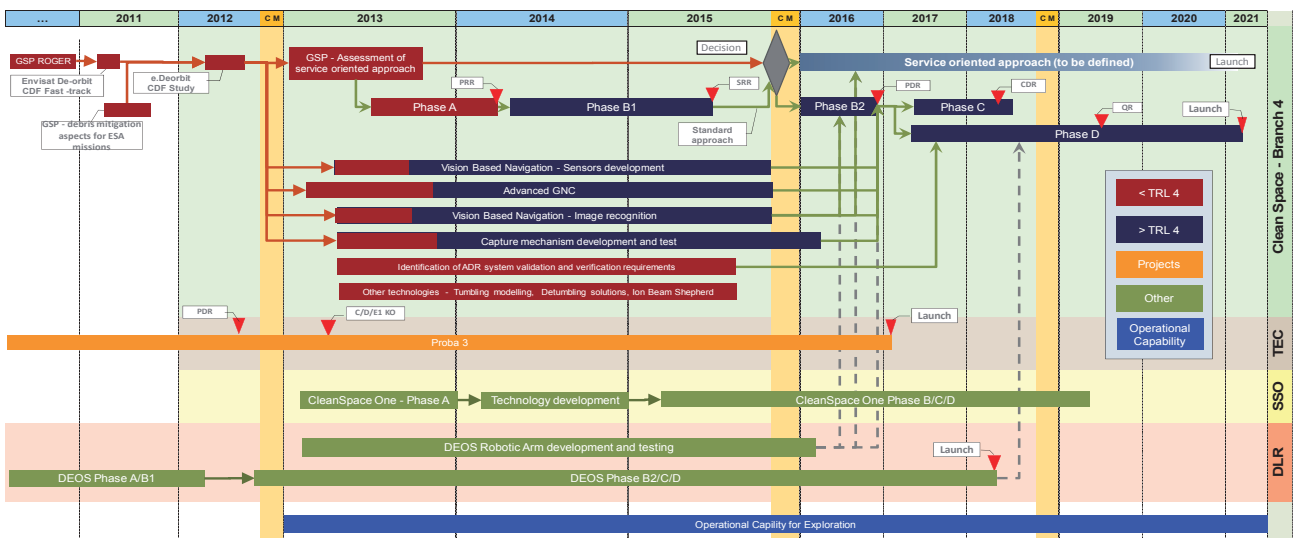
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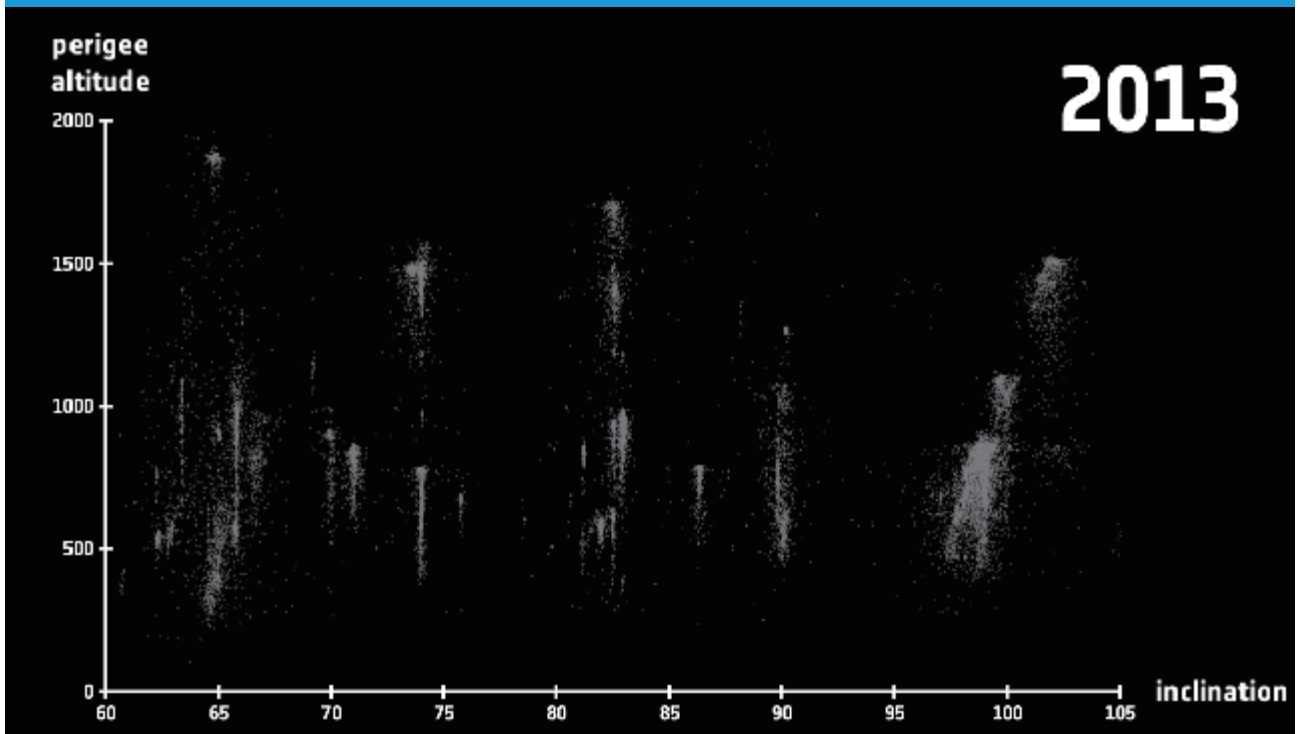
Stability of historical populations



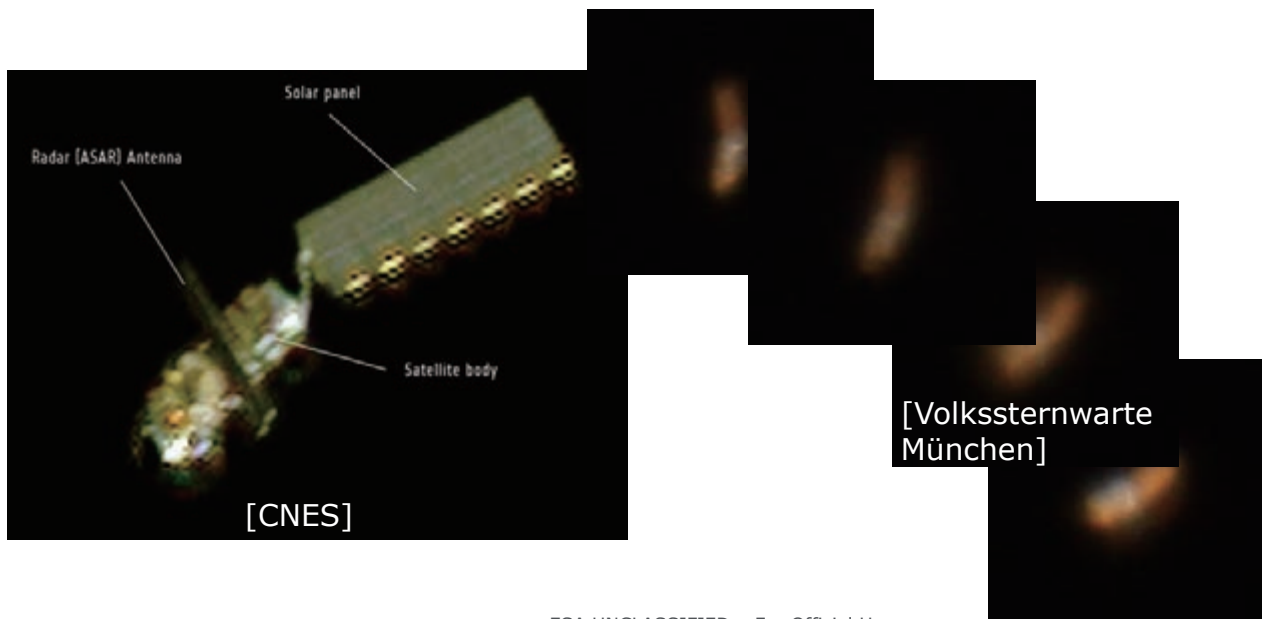
Branch 4 Space Debris Remediation Roadmap



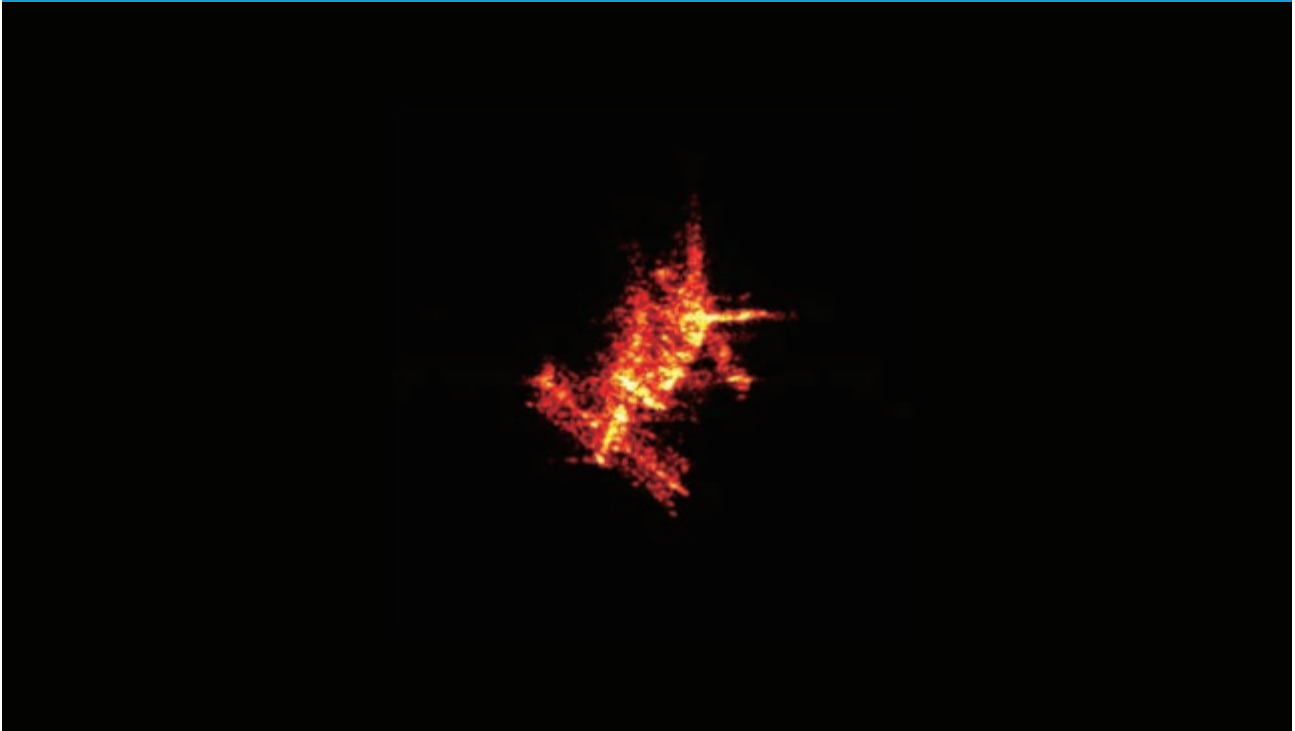
Orbital regions of interest (1/2)



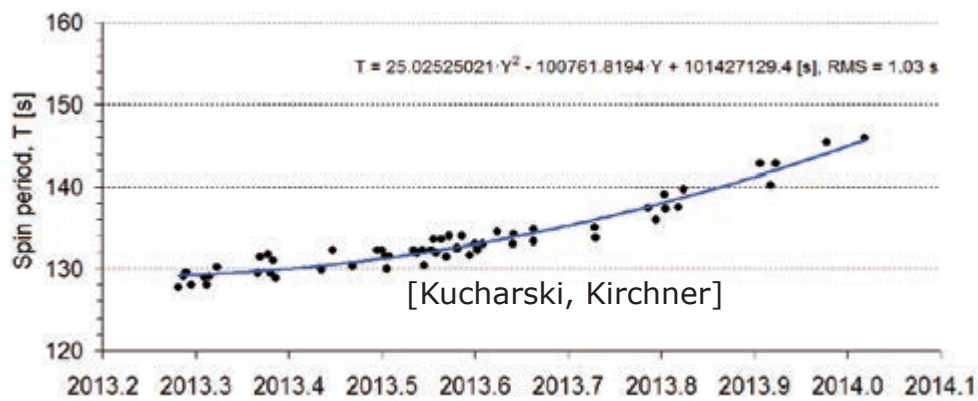
Attitude Measurements



Identification of attitude motion from ground (TIRA imaging radar)



Laser Ranging for Attitude Measurements

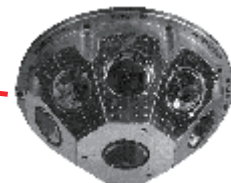


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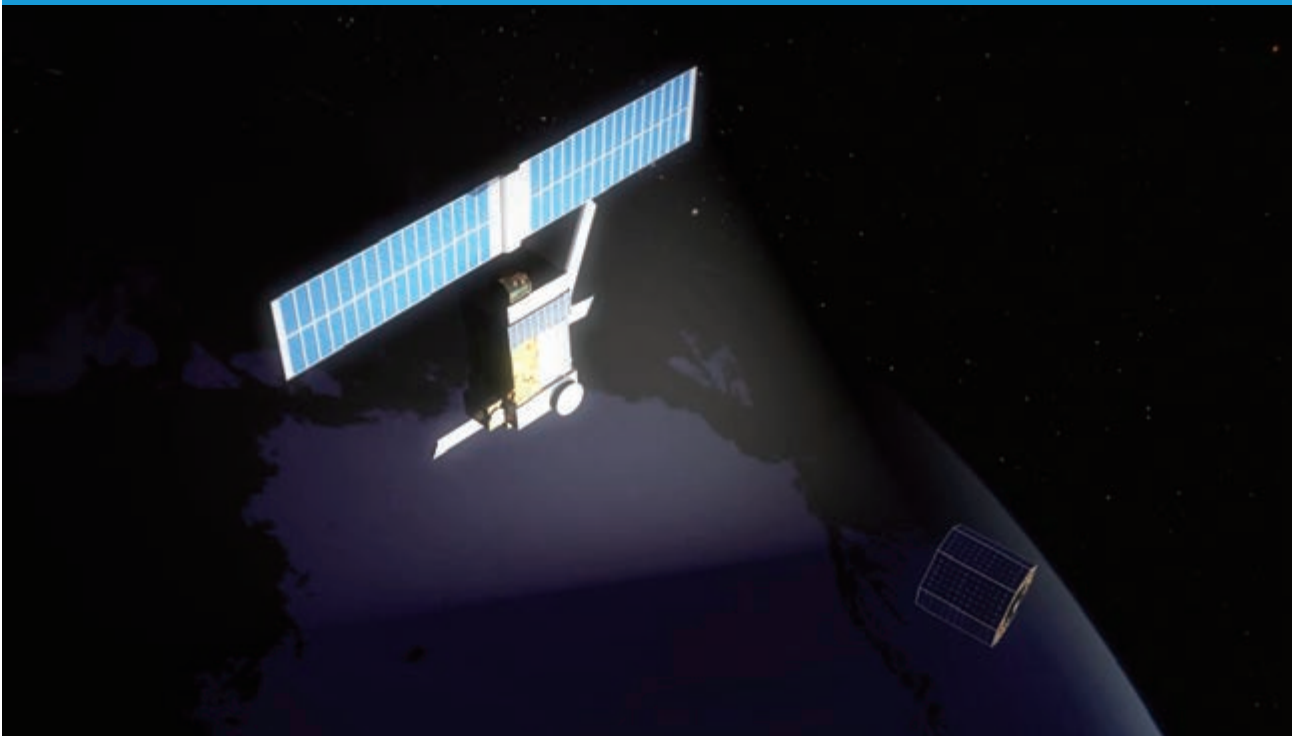
ESA U

Laser Retroreflector



agency

Capture (controlled re-entry): Robotic Arm



Capture (controlled re-entry): Tentacles



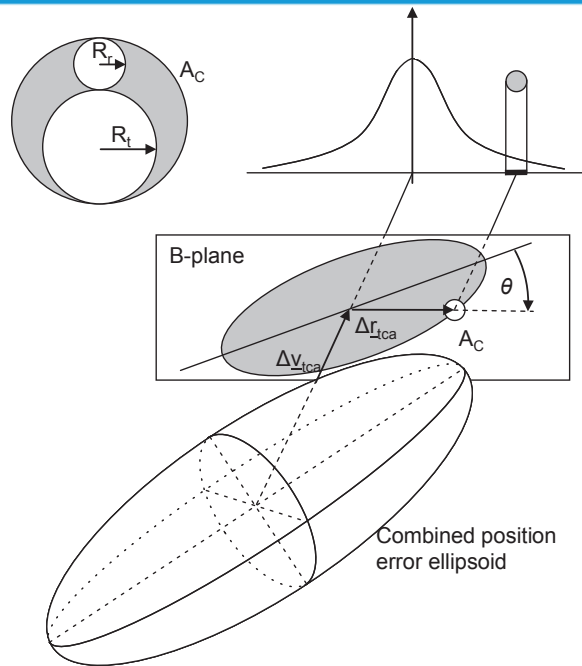
Capture (controlled re-entry): Net



Back-Up Slides

Collision Probability Algorithm esa

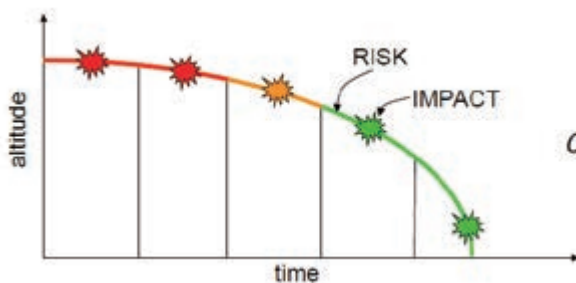
1. Determination of combined target+chaser cross section
2. Combination of the two error covariance matrices into a single one (3D ellipsoid)
3. Projection of ellipsoid onto the B-plane
 - a. \perp distance vector
 - b. \perp relative velocity vector
4. Integration of projected probability over cross-section = collision probability



Approaches to describe criticality esa

ESA approach considers:

- the risk of this object to collide with other objects,
- the impact a fragmentation of this object would have on the overall population



$$C_{crit} = C_{risk} \cdot C_{impact}$$

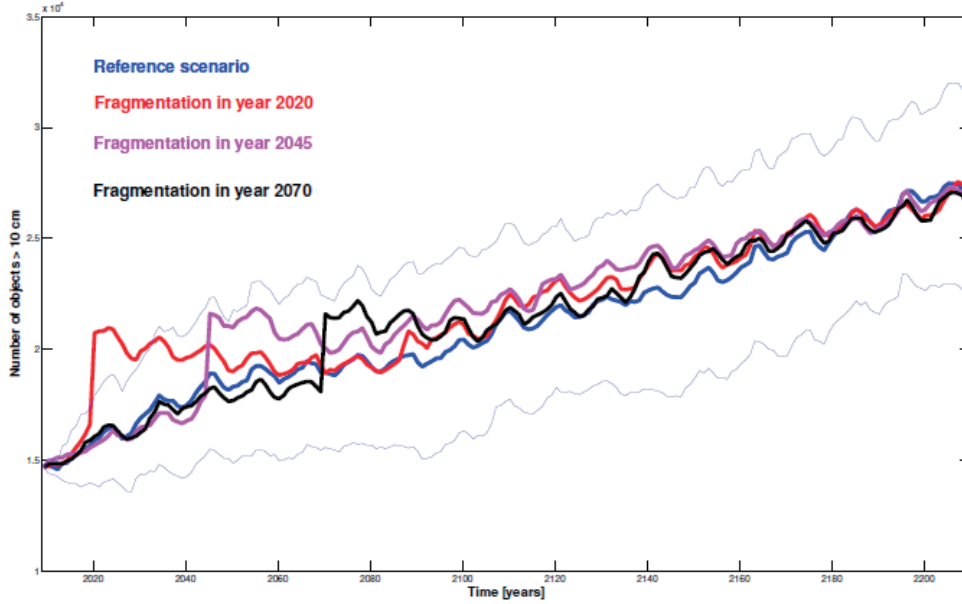
$$C_{crit} = \sum_{t=t_{start}}^{t_{end}} [C_{risk,t} \cdot \int_{\tau_{frag=t}}^{t_{end}=t_{end}} (\Delta p) d\tau]$$

Other approaches:

Figure-Of-Merit: FOM = flux * A * m^{0.75} * ROL

- flux [1/m²/yr]: Debris flux in the target's orbit
- A [m²]: Geometrical cross-section area
- m^{0.75} [kg]: Mass of target raised to the power of 0.75
- ROL [yrs]: Remaining orbital lifetime of the target object

Envisat Break-Up Consequences

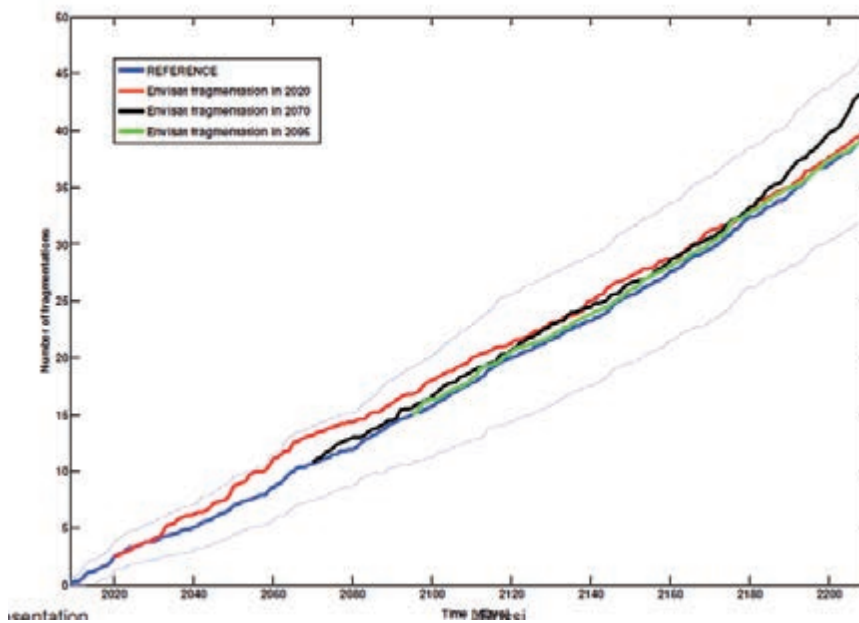


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Envisat Break-Up Consequences

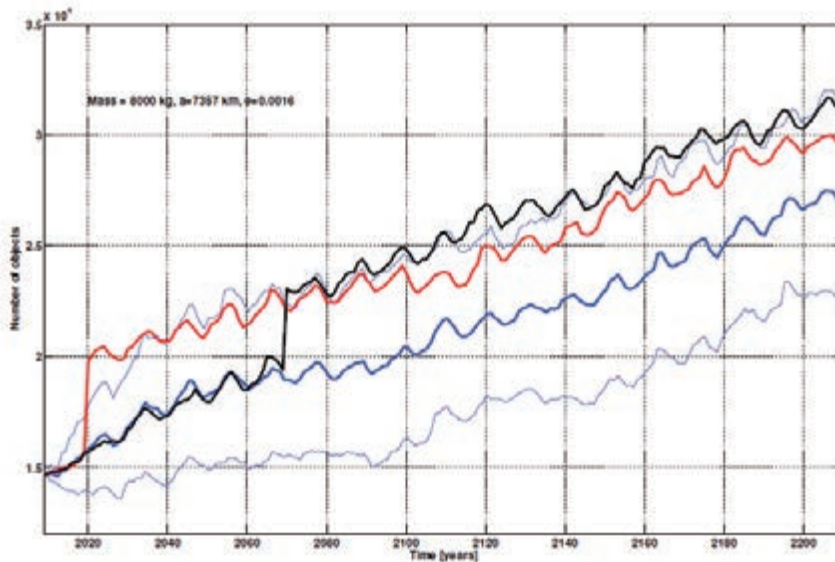


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Zenith Break-Up Consequences

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Technology Required for Remediation



Object	Norad Designator	a [km]	e [-]	Incl [°]	-log(crit)	Changed*	
SL-16 R/B	25400	7190.04	0.001194708	98.32	0.37	↗	2
SL-16 R/B	25407	7223.23	0.000427786	71.01	0.37	↗	3
SL-16 R/B	17590	7219.87	0.001134369	71.00	0.37	↑	9
SL-16 R/B	19120	7211.76	0.001566885	71.02	0.37	↑	15
ENVISAT	27386	7148.48	0.00113031	98.40	0.43	↘	-4
METOP-A	29499	7202.59	0.001121819	98.68	0.92	↑	60
COSMOS 2360	25406	7234.58	0.000468583	70.81	0.98	↑	22
RESURS O1-N4	25394	7192.94	0.001076055	98.39	1.11	↑	17
COBE	20322	7260.29	0.001874581	99.00	1.15	↑	58
ARGOS	25634	7210.65	0.001504719	98.78	1.16	↑	34
SPOT 3	22823	7211.21	0.001397824	98.78	1.30	↑	45
ARIANE 40+ R/B	23561	7150.34	0.001092256	98.66	1.41	↑	21
ARIANE 40 R/B	25261	7164.84	0.001233803	98.39	1.41	↑	22
ARIANE 40 R/B	21610	7140.48	0.001378068	98.75	1.41	↑	46

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Re-entry Removal List

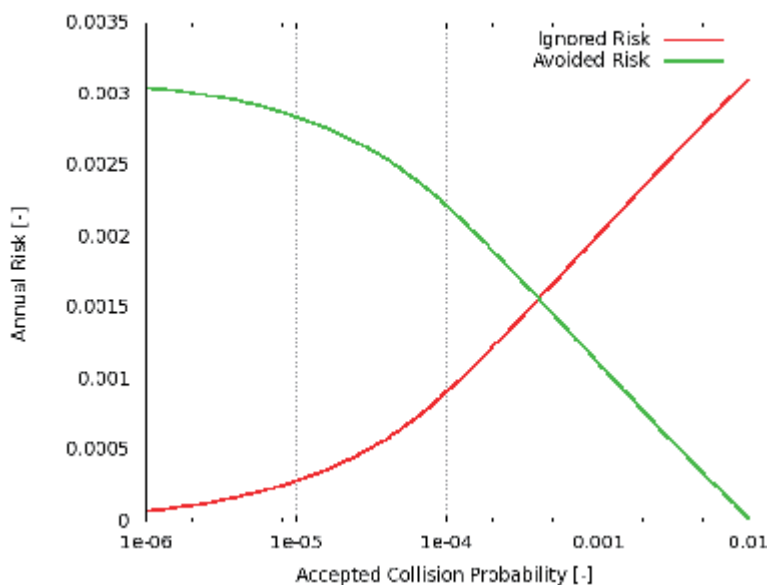


OBJ. TYPE	IDYR	IDN	IDP	OWNER	OBJECT NAME	MASS [tonnes]	R-DECT. [kg]	M_APO [km]	M_PER [km]	#C [NO.]	LIFETIME [years]	10th FLUX [1/m ² /year]	COLL. RATE [1/year]	Z [km]	Z [km]	COLL. SEVERITY [ppm]	# [NO.]	Z [km]	COLL. SEVERITY [ppm]	# [NO.]	Z [km]	
DC	2002	3	A	ESA	Envisat	8111	83.0467	795.039878	793.403991	98.8491	223.2147	2.22E-05	1.42E-03	1.100E+01	1.10E+01	1.10E+01	1.10E+01	1.10E+01	1.10E+01	1.10E+01	20	48%
RB	1996	61	B	RU	Zarya-2 second stage	8226.97	33.4262	843.422084	838.480276	70.8916	747.2425	1.95E-05	6.51E-04	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	2	73%
RB	1996	43	G	RU	Zarya-2 second stage	8226.97	33.4262	816.783229	802.410411	98.32	474.4788	1.91E-05	6.37E-04	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	21	48%
RB	2000	6	B	RU	Zarya-2 second stage	8226.97	33.1642	864.848796	828.424209	70.9966	694.6168	1.79E-05	6.31E-04	7.48E+00	7.48E+00	7.48E+00	7.48E+00	7.48E+00	7.48E+00	8	66%	
RB	1999	48	B	RU	Zarya-2 second stage	8226.97	33.4262	844.817217	836.303409	71.0119	714.8631	1.94E-05	6.19E-04	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	3	66%	
RB	1999	102	B	SU	Zarya-2 second stage	8226.97	33.4262	849.812987	831.452151	70.9989	687.7599	1.93E-05	6.11E-04	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	11	63%	
RB	1994	77	B	RU	Zarya-2 second stage	8226.97	33.4262	844.821655	840.084125	70.9764	770.9291	1.92E-05	6.10E-04	12.40E+00	12.40E+00	12.40E+00	12.40E+00	12.40E+00	12.40E+00	3	70%	
RB	1995	55	B	RU	Zarya-2 second stage	8226.97	33.4262	852.096762	830.413946	71.0211	704.9423	1.90E-05	6.02E-04	11.40E+00	11.40E+00	11.40E+00	11.40E+00	11.40E+00	11.40E+00	9	63%	
RB	1990	48	B	SU	Zarya-2 second stage	8226.97	33.4262	888.30870	833.433179	70.9966	698.8942	1.77E-05	6.02E-04	12.40E+00	12.40E+00	12.40E+00	12.40E+00	12.40E+00	12.40E+00	9	61%	
RB	1989	39	B	SU	Zarya-2 second stage	8226.97	33.4262	843.881203	814.700926	71.0134	671.8422	1.72E-05	6.14E-04	14.40E+00	14.40E+00	14.40E+00	14.40E+00	14.40E+00	14.40E+00	19	49%	
RB	1987	41	B	SU	Zarya-2 second stage	8226.97	33.4262	847.178981	824.379891	71.0072	660.8488	1.71E-05	6.12E-04	18.40E+00	18.40E+00	18.40E+00	18.40E+00	18.40E+00	18.40E+00	11	41%	
RB	1987	27	B	SU	Zarya-2 second stage	8226.97	33.4262	841.448973	833.069817	71.0066	703.8773	1.70E-05	6.08E-04	18.40E+00	18.40E+00	18.40E+00	18.40E+00	18.40E+00	18.40E+00	13	60%	
RB	1985	97	B	SU	Zarya-2 second stage	8226.97	33.4262	845.826487	832.419493	71.0022	694.6586	1.70E-05	6.07E-04	17.40E+00	17.40E+00	17.40E+00	17.40E+00	17.40E+00	17.40E+00	15	59%	
RB	1984	23	B	RU	Zarya-2 second stage	8226.97	33.4262	847.186476	841.033119	70.9988	798.6891	1.68E-05	6.02E-04	18.40E+00	18.40E+00	18.40E+00	18.40E+00	18.40E+00	18.40E+00	7	64%	
RB	1982	93	B	RU	Zarya-2 second stage	8226.97	33.4262	848.489199	836.863473	71.0201	764.1832	1.67E-05	6.08E-04	19.40E+00	19.40E+00	19.40E+00	19.40E+00	19.40E+00	19.40E+00	10	63%	
RB	1982	16	B	RU	Zarya-2 second stage	8226.97	33.4262	850.911878	838.964296	71.0102	708.1642	1.67E-05	6.08E-04	20.40E+00	20.40E+00	20.40E+00	20.40E+00	20.40E+00	20.40E+00	14	59%	
RB	1993	69	B	RU	Zarya-2 second stage	8226.97	33.4262	850.780087	823.336716	70.9912	682.9095	1.66E-05	6.01E-04	21.40E+00	21.40E+00	21.40E+00	21.40E+00	21.40E+00	21.40E+00	16	64%	
RB	1982	76	B	RU	Zarya-2 second stage	8226.97	33.4262	847.383131	829.388608	70.9987	688.8037	1.63E-05	6.08E-04	22.39E+00	22.39E+00	22.39E+00	22.39E+00	22.39E+00	22.39E+00	17	66%	
RB	2007	29	B	SU	Zarya-2 second stage	8226.97	33.1642	847.214901	843.987896	70.9779	826.6499	1.49E-05	6.24E-04	23.37E+00	23.37E+00	23.37E+00	23.37E+00	23.37E+00	23.37E+00	8	68%	
RB	2004	21	B	RU	Zarya-2 second stage	8226.97	33.1642	848.498223	843.346478	71.0229	816.1111	1.48E-05	6.20E-04	24.37E+00	24.37E+00	24.37E+00	24.37E+00	24.37E+00	24.37E+00	8	63%	
DC	2002	56	A	JP	Mitsubishi (Ariane 2)	3690	90	826.47936	803.819087	98.4223	205.1914	1.90E-05	1.14E-03	2.91E+00	2.91E+00	2.91E+00	2.91E+00	2.91E+00	2.91E+00	20	16%	
RB	2001	96	F	RU	Zarya-2 second stage	8226.97	33.1642	1027.81134	995.423199	99.1949	1035.8813	1.94E-05	3.60E-04	25.28E+00	25.28E+00	25.28E+00	25.28E+00	25.28E+00	25.28E+00	1	100%	
DC	2006	44	A	ESA	METOP-A	4086	34.2012	820.983264	819.881237	95.87	274.6385	1.93E-05	6.02E-04	3.47E+00	3.47E+00	3.47E+00	3.47E+00	3.47E+00	3.47E+00	23	13%	
RB	1999	39	B	RU	Zarya-2 second stage	8226.97	33.4262	840.40964	829.384118	67.2447	78.213	0.71E-06	3.29E-04	26.21E+00	26.21E+00	26.21E+00	26.21E+00	26.21E+00	26.21E+00	24	4%	
RB	2002	56	E	JP	H-2A second stage	4000	21.4276	841.48484	736.903416	98.888	121.9932	2.08E-05	6.08E-04	4.47E+00	4.47E+00	4.47E+00	4.47E+00	4.47E+00	4.47E+00	26	9%	
RB	1994	74	B	RU	Zarya-2 second stage	8226.97	33.4262	849.880283	842.204833	98.8807	88.798	0.87E-06	3.20E-04	27.23E+00	27.23E+00	27.23E+00	27.23E+00	27.23E+00	27.23E+00	25	4%	
DC	2006	2	A	JP	Daichi	4600	91.7811	898.489765	893.627354	98.1819	63.8874	1.13E-05	6.07E-04	13.42E+00	13.42E+00	13.42E+00	13.42E+00	13.42E+00	13.42E+00	27	3%	

Situation before CSM



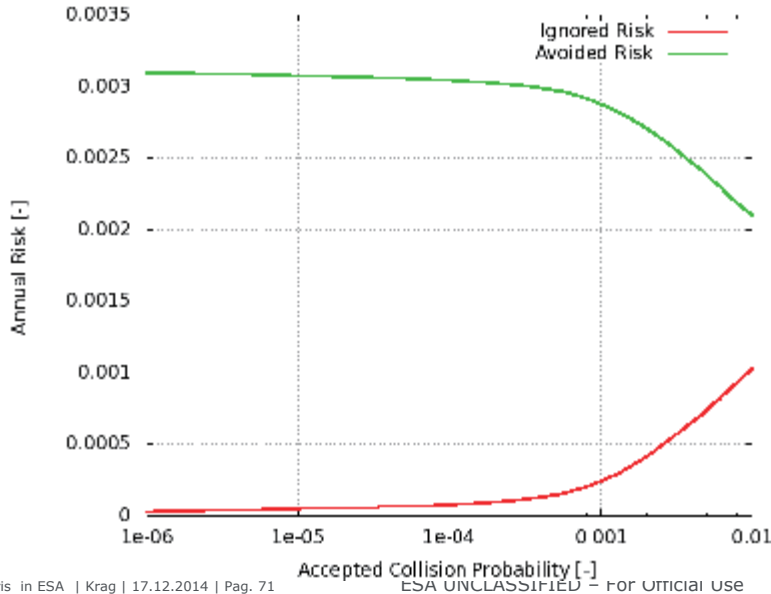
- Example: Envisat: 26m span, 8t mass, initial covariance ca. 10m x 56m x 14m
- TLE screening (initial chaser covariance ca. 225m x 750m x 195m)



Situation with the new CSM



- Example: Envisat: 26m span, 8t mass, initial covariance ca. 10m x 56m x 14m
- JSPOC screening (CSM chaser initial covariance ca. 23m x 75m x 20m)



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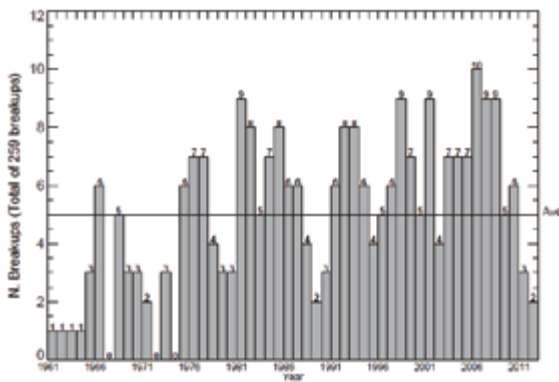
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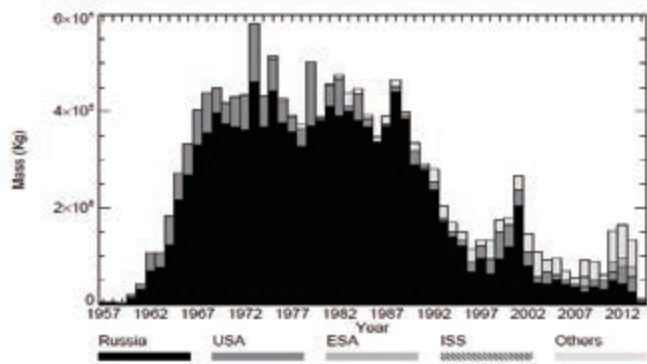
Analyses with DISCOS



Number of events per year



Re-entering mass per year (uncontrolled)



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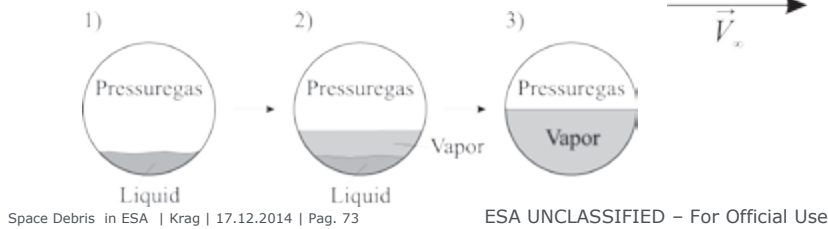
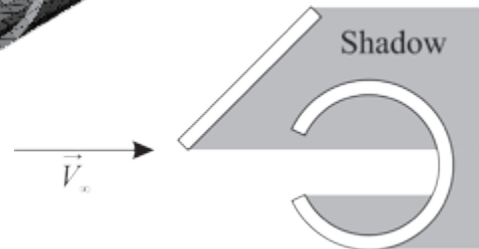
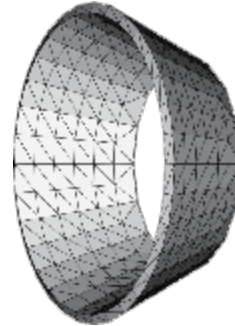
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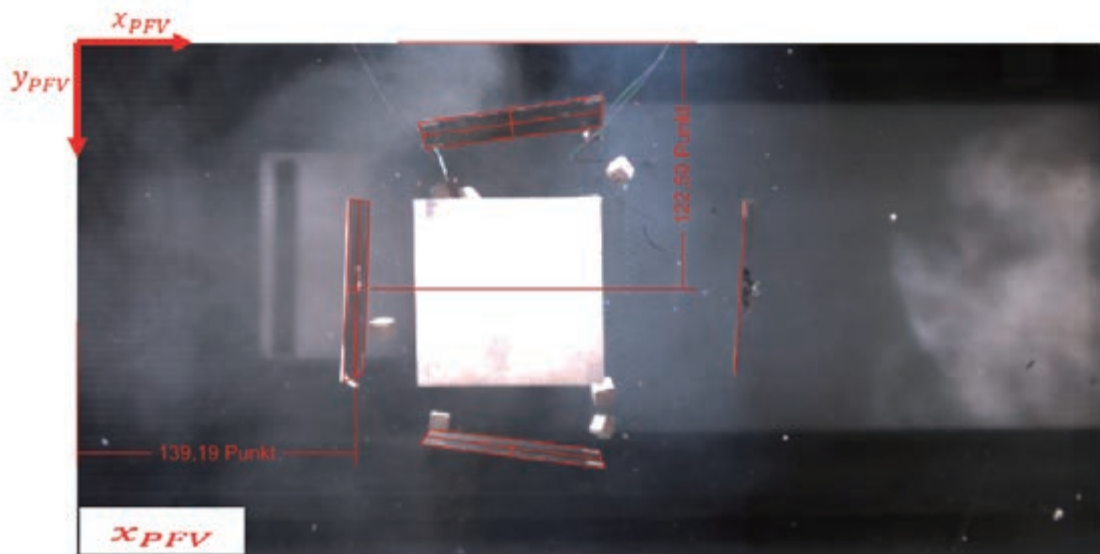
SCARAB modelling principles



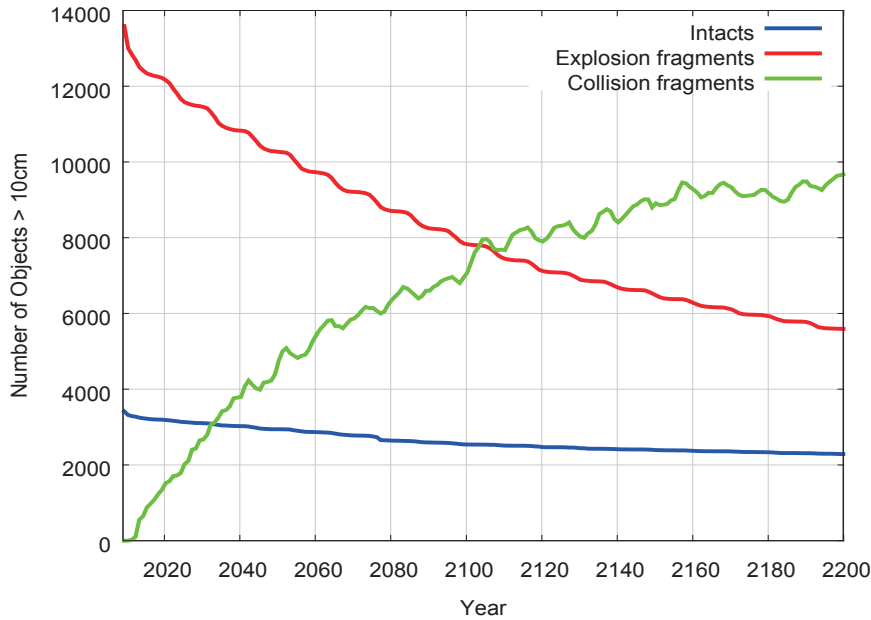
- Model built from "primitive shapes"
- Modelling approach are subject to a shadow analysis based on geometric area projections in flow direction.
- No flow expansion behind shadowing panels ($Ma \rightarrow \infty, S \rightarrow \infty$)
- Tank bursting analysis



Understanding catastrophic break-up



No further release scenario



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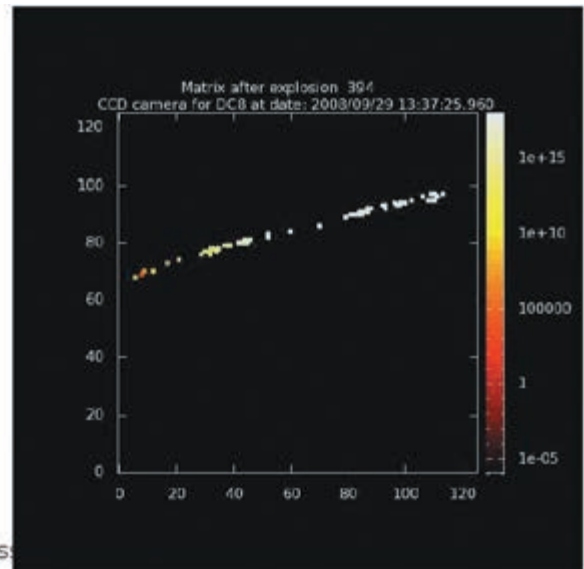
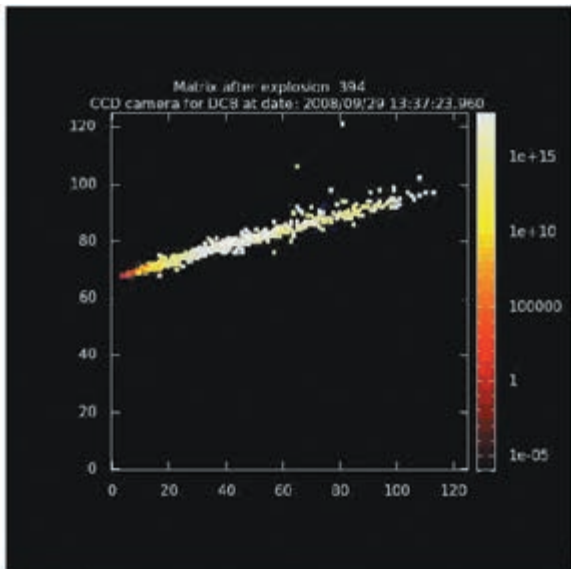
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ATV-1 DC-8: different fragmentation model

DC8 airplane, Camera mounting: AZ=100deg, EI=0deg.
 Camera properties: FOV=40deg, Lpix=0.02mm, D=0.3m, Npix=125
 Solar panel break-off altitude = 95km. Explosion altitude = 78km.

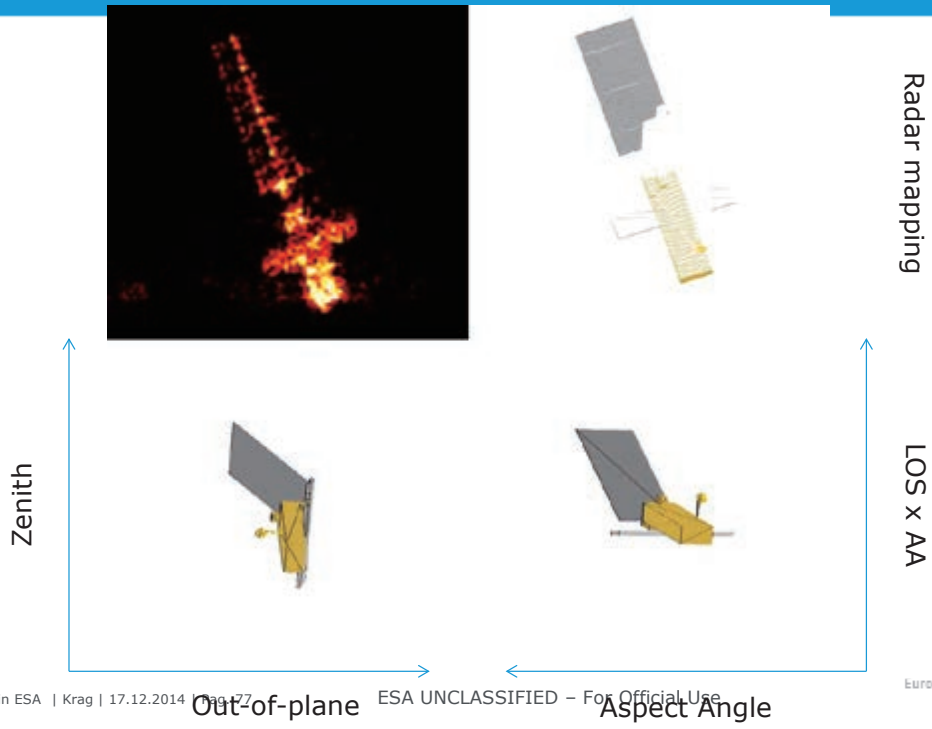
Evolve Model

ACTA Model



UNCLAS

Latest Envisat ISAR observation



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