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Orbital Debris Activities at CNES with a Focus on Space Debris Environment Impact Evaluation

Juan-Carlos Dolado-Perez and V. Ruch (CNES)

On this presentation an overview of orbital debris activities at CNES will be given. These activities cover Optical observation, Space surveillance and tracking activities, space environment modelling, re-entry predictions and collision prediction in orbit and at launch.
A focus will be given on studies done concerning the evaluation of the long term evolution of the orbital environment. The focus on this subject has been chosen as many exogenous and endogenous uncertainties sources may be still understood in order to define the mitigation and remediation measures to put in place to guarantee the long term sustainability of space activities.

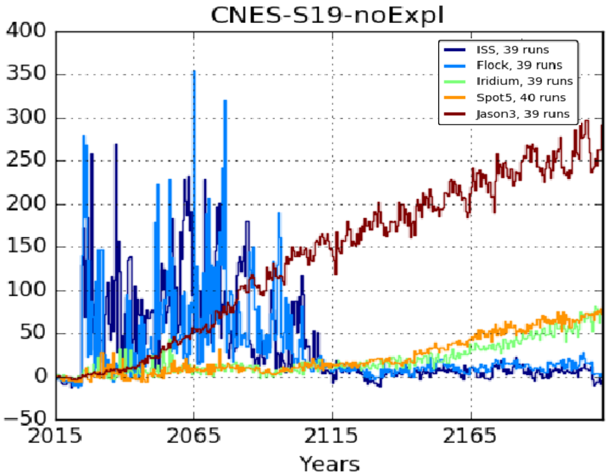

Fig. 1.- Collision risk increase for different missions depending an scenario with two mega-constellations at 1100 and 1200 km.

Biography

Juan-Carlos Dolado-Perez

Juan-Carlos Dolado-Perez is the head of the space debris modelling and risk assessment office at the "Centre National d'Etudes Spatiales" (French Space Agency). Since 2008 he has worked at the system engineering and orbital dynamics sub directorate, where his main research topics concerns the long and middle term re-entry prediction, the long term evolution of the space debris population, the on orbit collision risk assessment, the orbit determination from radar and optical measurements and the uncertainty characterization and propagation.
He is a member of the Inter Agencies Space Debris Committee (IADC)'s French Delegation and of the International Academic of Astronautics (IAA)'s Space Debris Committee

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J.C. DOLADO – V. RUCH

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Chofu, Japan, December 3rd – 5th 2018

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Outline

- Collision Avoidance at Launch
- Optical Space Surveillance
- Data Processing for Cataloguing – Space Surveillance
- Collision Avoidance in – orbit
- Orbital propagation
- Re-Entry Predictions
- Re-Entry Modelling
- Space Debris Environment Modelling – Env. Index

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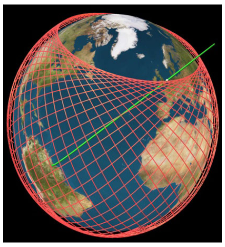
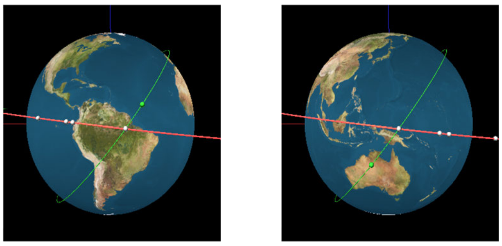
Collision Avoidance at Launch

- Operational Collision Avoidance at Launch since 2010
  - Requirement from FSOA (French Law)
  - Collision Risk analysis with ISS, Soyuz, …
  - Every launch from Guyana Space Center
- Preliminary joint work in the past between JAXA and CNES



Example Soyuz flight: no risk



Example Ariane 5: risks at 5th and 6th orbit

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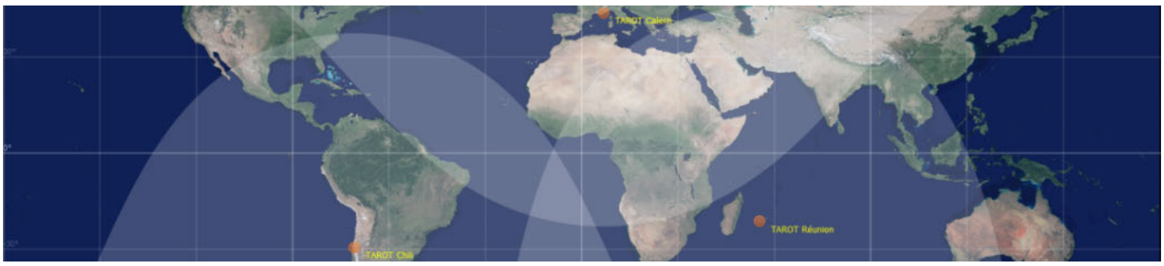
Optical Space Surveillance

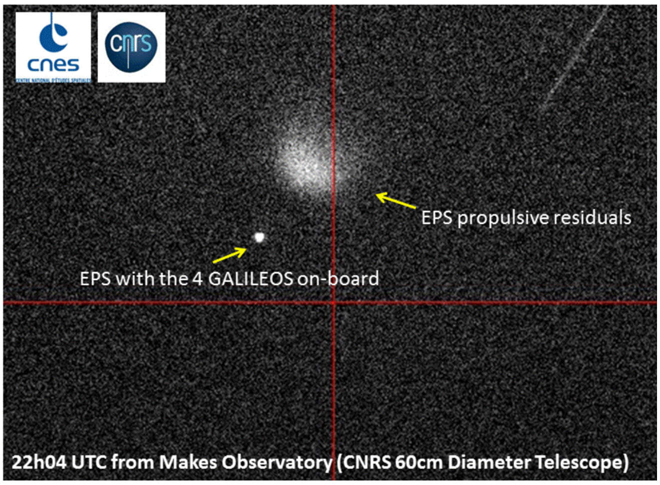
Operations of TAROT network:

- TAROT network covers 70% of GEO belt
  - An additional on-demand site in Australia allows to cover almost 100%
- Catalogue build-up and maintenance of ~500 objects



Optical Space Surveillance

Observation of GALILEO Constellation Launch



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Optical Space Surveillance

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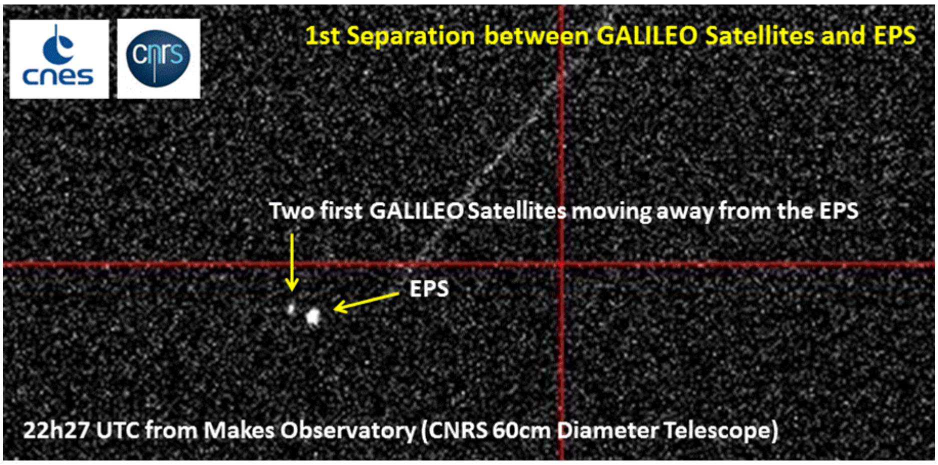

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Optical Space Surveillance

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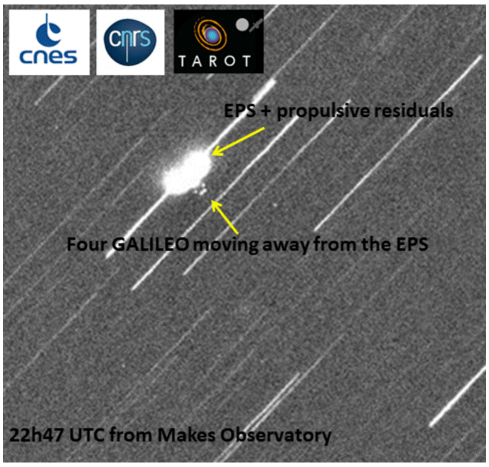

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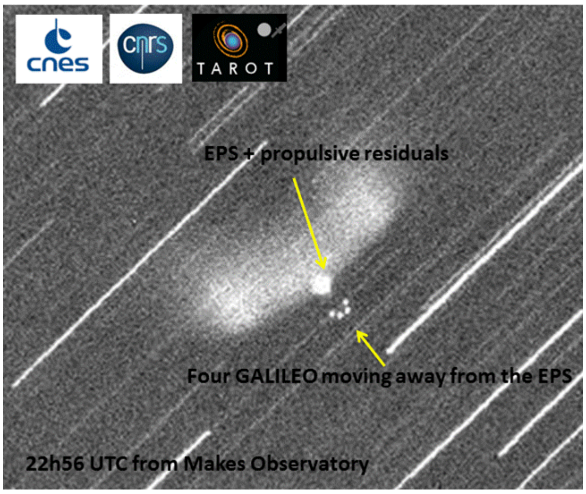
Optical Space Surveillance

Observation of GALILEO Constellation launch



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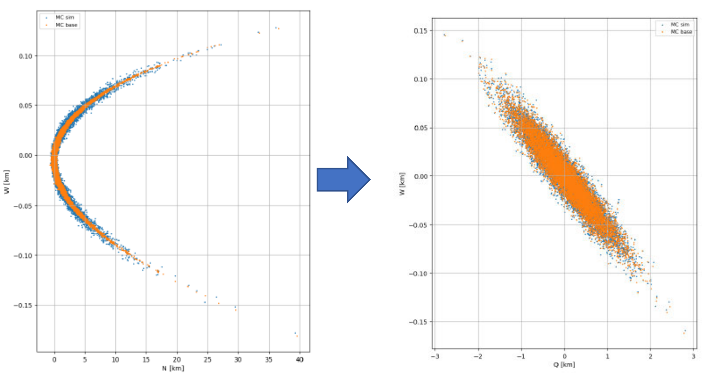
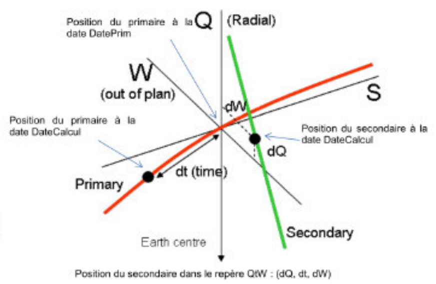
Data Processing for Cataloguing

Progress on the development of techniques for the **enhancement of the covariance realism**:

- **Maintaining the Gaussianity of Covariances matrices**





Use of a reference frame where T [m] is replaced by t [sec]

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Data Processing for Cataloguing

Progress on the development of orbit determination techniques using **Gaussian mixture approaches** as well as “new” **correlation metrics**

- **Log-likelihood vs Mahalanobis**

$$d_L^2 = K\ln(2\pi) + \ln(|\Sigma|) + (x-\mu)^T\Sigma^{-1}(x-\mu)$$

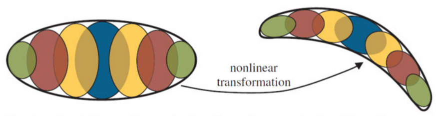
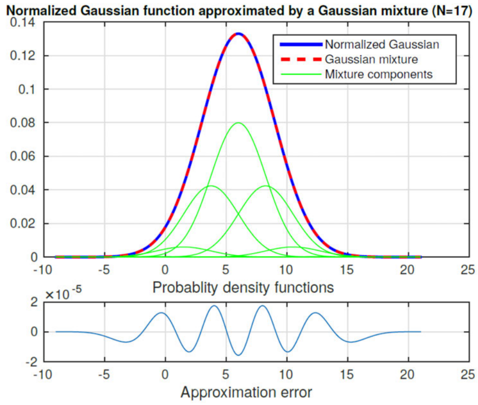


Fig. 2 Depiction of a single Gaussian and its Gaussian sum approximation undergoing a nonlinear transformation.



Horwood, Aragon, Poore. Gaussian Sum Filters for Space Surveillance : Theory and Simulations. Journal of Guidance, Control and Dynamics 34 (2011), 1839-1851

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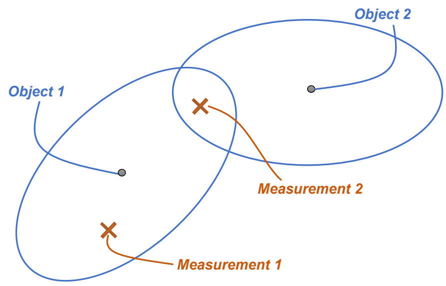
Data Processing for Cataloguing

Progress on the development of advanced techniques for **correlation and cataloguing**:

- **Bayesian data association techniques**
  - Joint Probabilistic Data Association
  - Multi Hypothesis Tracking
  - Multi-Bernouilli – Finite Sets Statistics



#	Joint Event
1	Meas. 1 and 2 from clutter
2	Meas. 1 from Obj. 1, Meas. 2 from clutter
3	Meas. 1 from clutter, Meas. 2 from Obj. 1
4	Meas. 1 from clutter, Meas. 2 from Obj. 2
5	Meas. 1 from Obj. 1, Meas. 2 from Obj. 2

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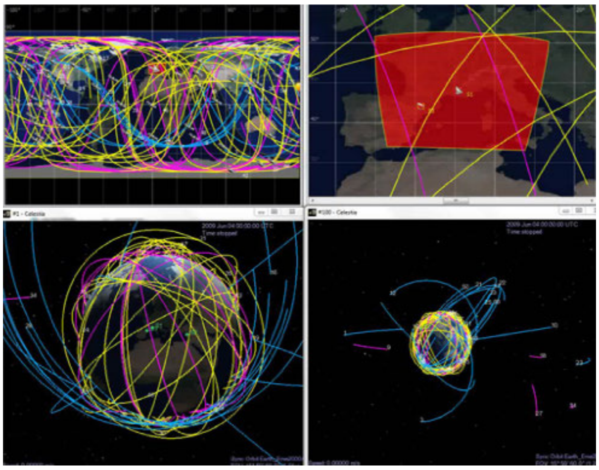
Space Surveillance System Analysis

Supporting the **European Space Surveillance and Tracking Program** through the analysis of the **performance** of the **actual and future architectures**



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Space Surveillance System Analysis

Additional studies to improve our capability to

- Task and Schedule sensors
- Evaluate information gain coming from observations and optimize observation strategies
- Analysis of ionosphere correction models
- Development of IOD methods
- …

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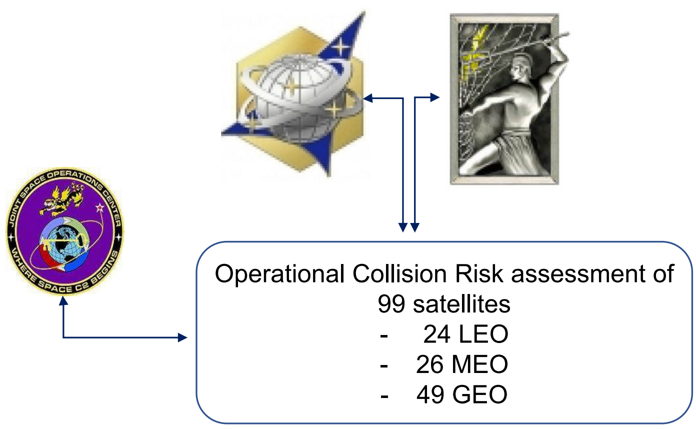
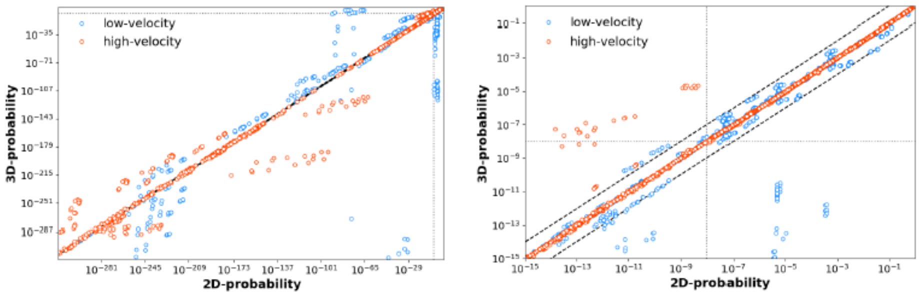
On-Orbit Collision Avoidance



On-Orbit Collision Avoidance

Collision Risk 3-D Probability Computation



(a) All cases   (b) Both 2D and 3D probabilities above 10^{-15}

Fig. 2 Comparison of the 2D and 3D-probability of collision for the generated cases. High-velocity encounters ($> 50\,\mathrm{m\,s^{-1}}$) are plotted in orange and low-velocity encounters ($\leq 50\,\mathrm{m\,s^{-1}}$) in blue.

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Orbital Debris Propagation

	CNES	IMCCE	GRUCACI	OCA	UPM	GME	KIAM
NUMERICAL	COWELL						
	DOPRI						
	GBS						
					DROMO		
			7DEPRIF				
SEMI-ANALYTICAL	CODIOR			CODIOR			
	SATLIGHT IV	SATLIGHT IV					
	STELA	STELA					
	THEONA						THEONA
			DSST				
	HEOSAT		HEOSAT				
	NADIA						
ANALYTICAL	SGP4						
	FAST	FAST					
	ATESAT					ATESAT	
	DRI		DRI				

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Orbital Debris Propagation

Improvement of **STELA** semi-analytic propagator

- Use of recurrence formulation for zonal perturbation: maximum degree of development is no more limited to 15
- Development of third body perturbation up to order 8
  - Ability to propagate INTEGRAL orbits (sma = 87941 km, ecc=0.856)
  - Ability to propagate for a decade SIMBOL-X orbit (sma = 106247 km, ecc = 0.75)
- Work ongoing on the inclusion of **short periods** of **non-conservative forces**
  - PRS
  - Drag

Work initiated on the propagation of space debris using density model approaches

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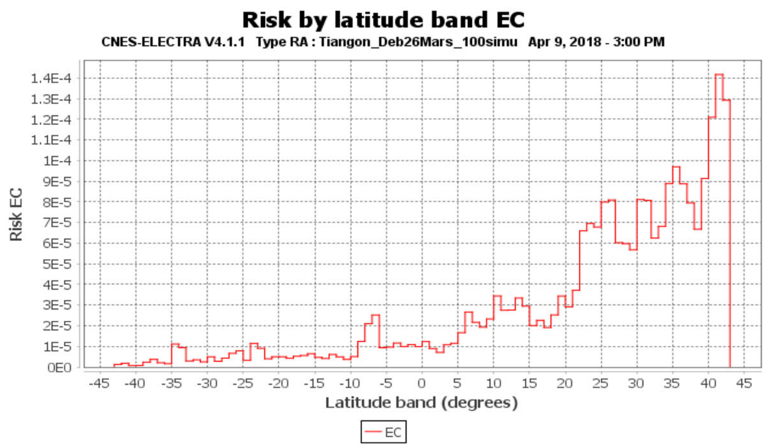
Reentry Predictions

Tiangong-1 Reentry

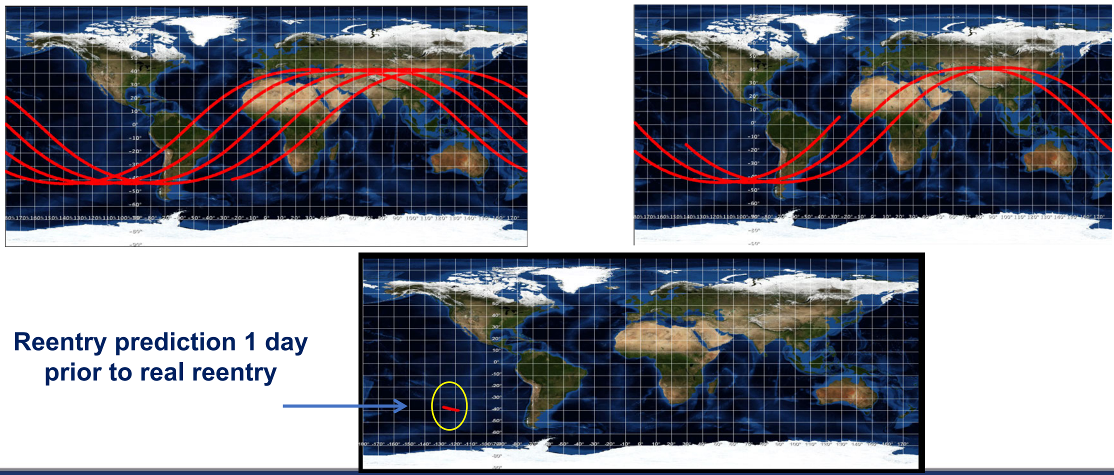
- On-ground risk evaluation > a week prior to reentry



Reentry Predictions

Tiangong-1 Reentry

- **Refinement of the reentry epoch and location with radar observations**



Reentry prediction 1 day prior to real reentry

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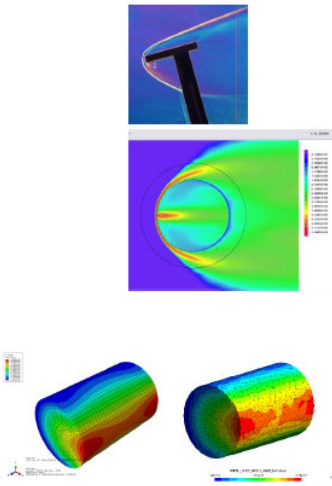
Reentry Modeling

- EXPERIMENTAL DATA
  - From ground tests
  - From flight experiments
- VALIDATION OF THE REENTRY MODELING TOOLS
  - CNES tools: DEBRISK, PAMPERO
  - Existing JAXA – CNES cooperation



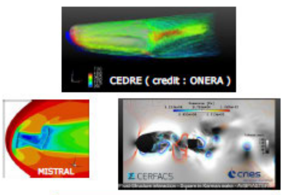
Reentry Modeling

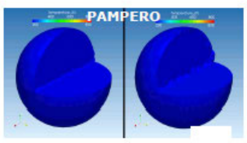
Simulation chain: Physical analysis, validation, model reduction, prediction and certification

Simulation Chain

High fidelity code	Spacecraft oriented code	Object oriented code

Accuracy ←→
Cost ←→
Validation →





DEBRISK
Official certification tool

High fidelity code	Spacecraft oriented code	Object oriented code
▪ Validation ▪ Physical analysis	▪ Sensivity analysis ▪ Research of Meta models ▪ Fragmentation assessment	▪ Sensivity analysis ▪ UQ associated with the results

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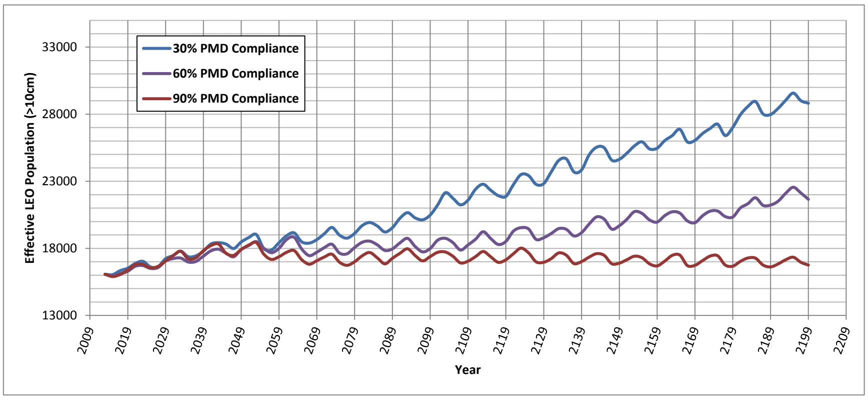
Space Debris Environment Modelling

- Long term evolution of space debris environment, shows a unstable behavior in the LEO regime, if efforts are not made to reduce the number of objects on the environment.



N.B.: PMD Compliance refers to objects non compliant with the 25-Years rule that we have voluntarily de-orbited

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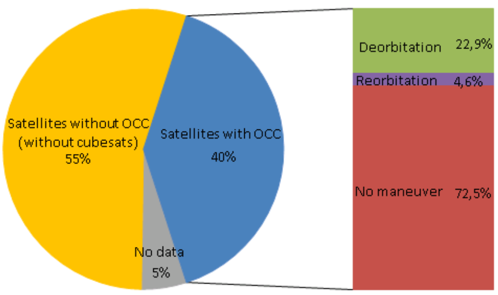
Space Debris Environment Modelling

➤ **SATELLITES Compliance to LEO EOL guidelines**

Satellites (without cubesats) reaching end of life between 2000 and 2017



➤ **Global S/C compliance lying on natural effects**

- ➤ **~17% of OCC satellites compliant thanks to a manoeuver→ 6% of all non cubesats S/C**

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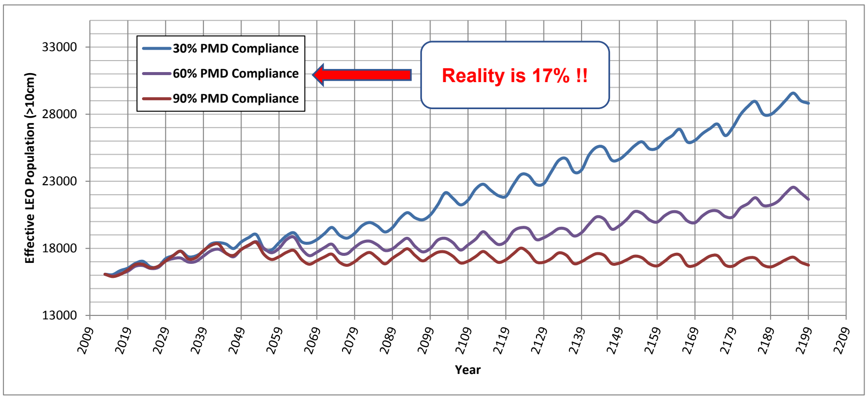
Space Debris Environment Modelling

➤ Long term evolution of space debris environment, shows a unstable behavior in the LEO regime, if efforts are not made to reduce the number of objects on the environment.



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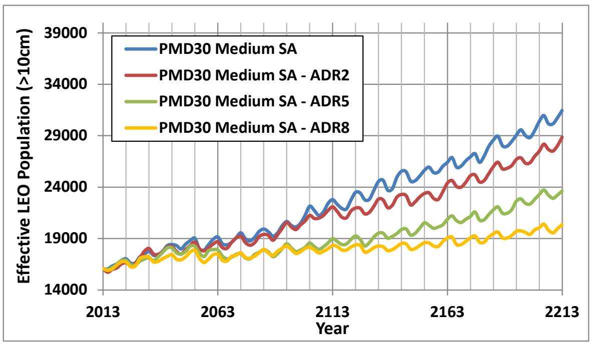
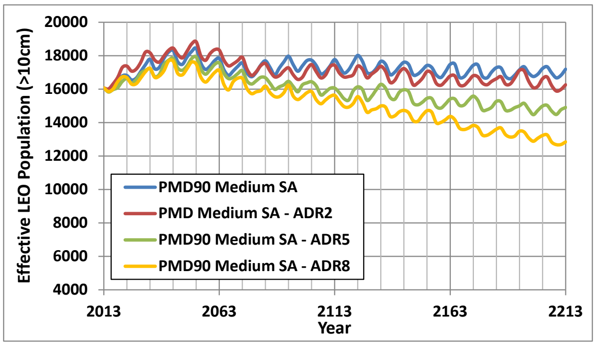
Space Debris Environment Modelling

➢ Mitigation and Remediation Complementarity





Mitigation is needed whichever the Remediation Scenario

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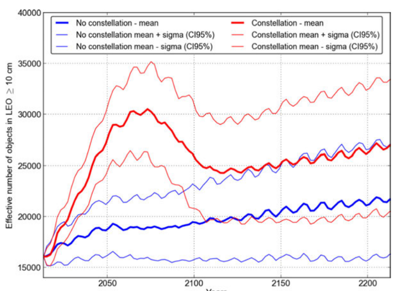
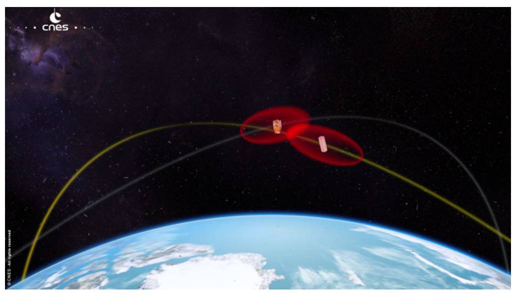
Space Debris Environment Modelling

➢ Large Constellation Effect and Environmental Index





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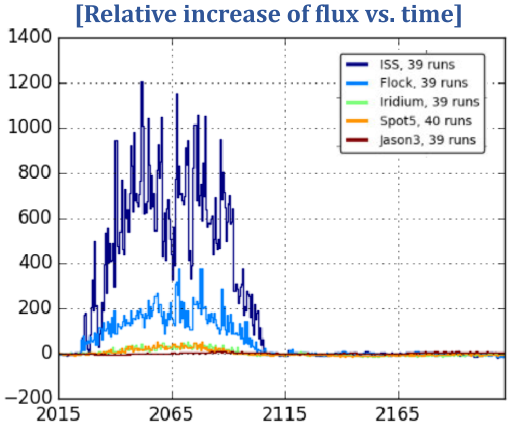
Space Debris Environment Modelling

➢ Large Constellation / small sats Effect and Environmental Index

Scenario 1 vs. Baseline
[Relative increase of flux vs. time]



GENERAL		
	Objects > 10 cm	X
	1cm < Debris < 10cm, generated by NASA BU	
BACKGROUND		
	PMD 90%	X
	PMD 20%, max lifetime 25 years	
	PMD 20% in 2013, rising linearly and stabilizing at 90% in 2050, max lifetime 25 years	
EXPLOSIONS		
	Explosions: - random number of explosions per year (between 5 and 12) - 5 < nb debris < 250 - Exploding objects were launched before 2020	
CONSTELLATIONS		
	Constellation Altitude (km)	1100
	Injection Altitude (km)	direct
	Electric orbiting duration (days)	
	Collision avoidance effectiveness rate (%)	100
	PMD rate (%)	90
	PMD deorbitation orbit type	eccentric
	PMD target lifetime (years)	**25**
	Electric PMD duration (years)	
	Launch stages : none (direct reentry)	X
	Launch stages : PMD 90%, target lifetime = 25 years	
CUBESATS		
	Cubesats launchs: from 200 in 2013 to 600 in 2050 and later, <600km	
	Cubesats launchs: from 20 in 2013 to 60 in 2050 and later, >600km	

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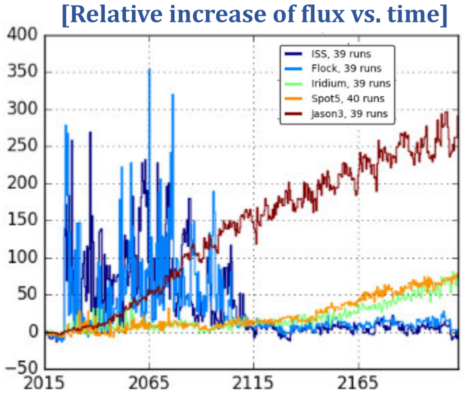
Space Debris Environment Modelling

➢ Large Constellation / small sats Effect and Environmental Index

Scenario 10 vs. Baseline
[Relative increase of flux vs. time]



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EXPLOSIONS				
	Explosions: - random number of explosions per year (between 5 and 12) - 5 < nb debris < 250 - Exploding objects were launched before 2020			
CONSTELLATIONS				
	Constellation Altitude (km)	600	1100	1200
	Injection Altitude (km)	direct	450	450
	Electric orbiting duration (days)		50	50
	Collision avoidance effectiveness rate (%)	90	90	90
	PMD rate (%)	100	90	90
	PMD deorbitation orbit type			
	PMD target lifetime (years)			
	Electric PMD duration (years)		2	2
	Launch stages : none (direct reentry)	X	X	X
	Launch stages : PMD 90%, target lifetime = 25 years			
CUBESATS				
	Cubesats launchs: from 200 in 2013 to 600 in 2050 and later, <600km			
	Cubesats launchs: from 20 in 2013 to 60 in 2050 and later, >600km			

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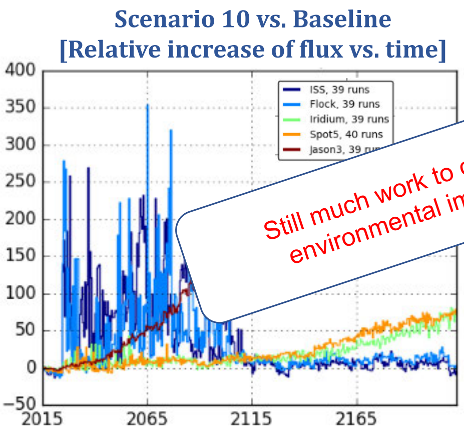
Space Debris Environment Modelling

➢ **Large Constellation / small sats Effect and Environmental Index**



GENERAL			
Objects > 10 cm		X	
1cm < Debris … ated by NASA BU			
BACKGROUND			
… s			
… and stabilizing at 90% in 2050,		X	
… andom number of explosions per year (between 5 and 12) - 5 < nb debris < 250 - Exploding objects were launched before 2020			
CONSTELLATIONS			
Constellation Altitude (km)	600	1100	1200
Injection Altitude (km)	direct	450	450
Electric orbiting duration (days)		50	50
Collision avoidance effectiveness rate (%)	90	90	90
PMD rate (%)	100	90	90
PMD deorbitation orbit type			
PMD target lifetime (years)			
Electric PMD duration (years)		2	2
Launch stages : none (direct reentry)	X	X	X
Launch stages : PMD 90%, target lifetime = 25 years			
CUBESATS			
Cubesats launchs: from 200 in 2013 to 600 in 2050 and later, <600km			
Cubesats launchs: from 20 in 2013 to 60 in 2050 and later, >600km			

Still much work to do to evaluate the global environmental impact of space missions

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Thank You for your Attention