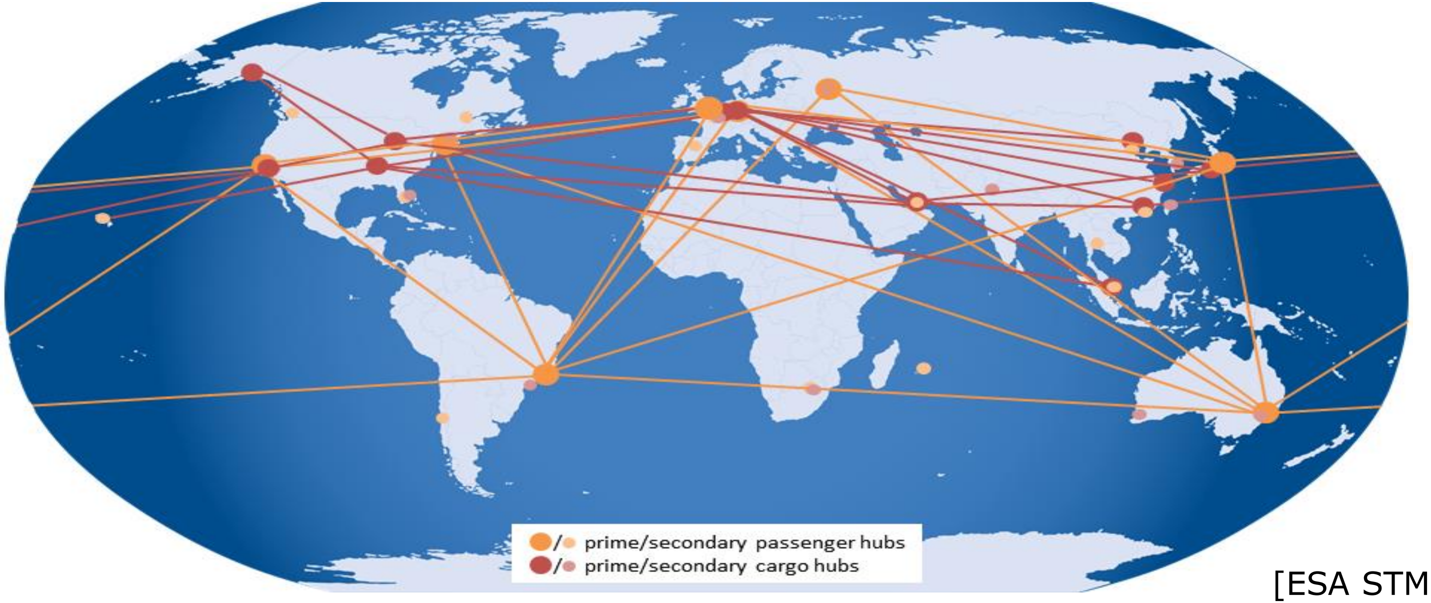
AREAS OF INTERACTION BETWEEN AIR- AND SPACE-TRAFFIC AND THE ROLE OF SPACE SURVEILLANCE

Holger Krag

29/08/2017

Suborbital Flight Routes



[ESA STM Study]

- Route layout based on predicted air traffic evolution
- Routes are likely to develop mostly in the nothern hemisphere
- Usage of existing ground infrastructure (cost efficiency, vicinity to major cities)

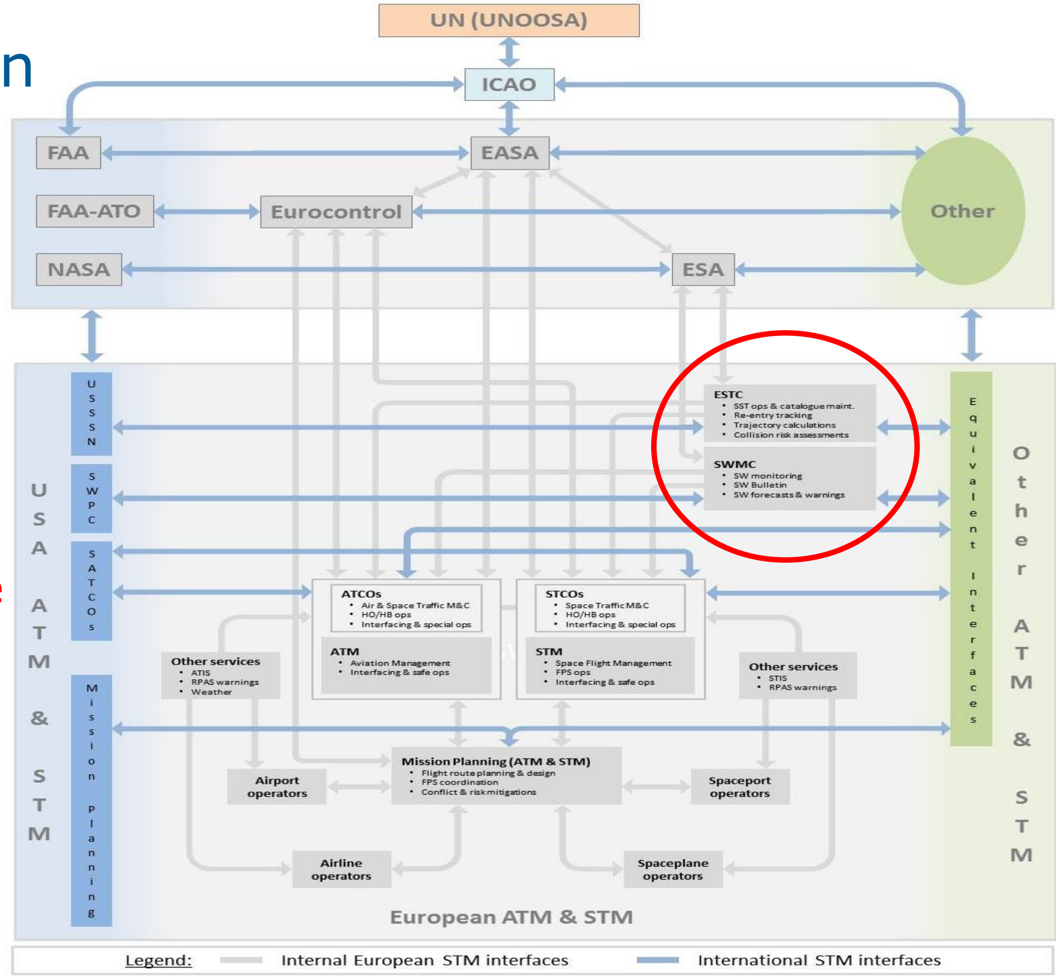

Space Situational Awareness

Global STM/ATM Integration

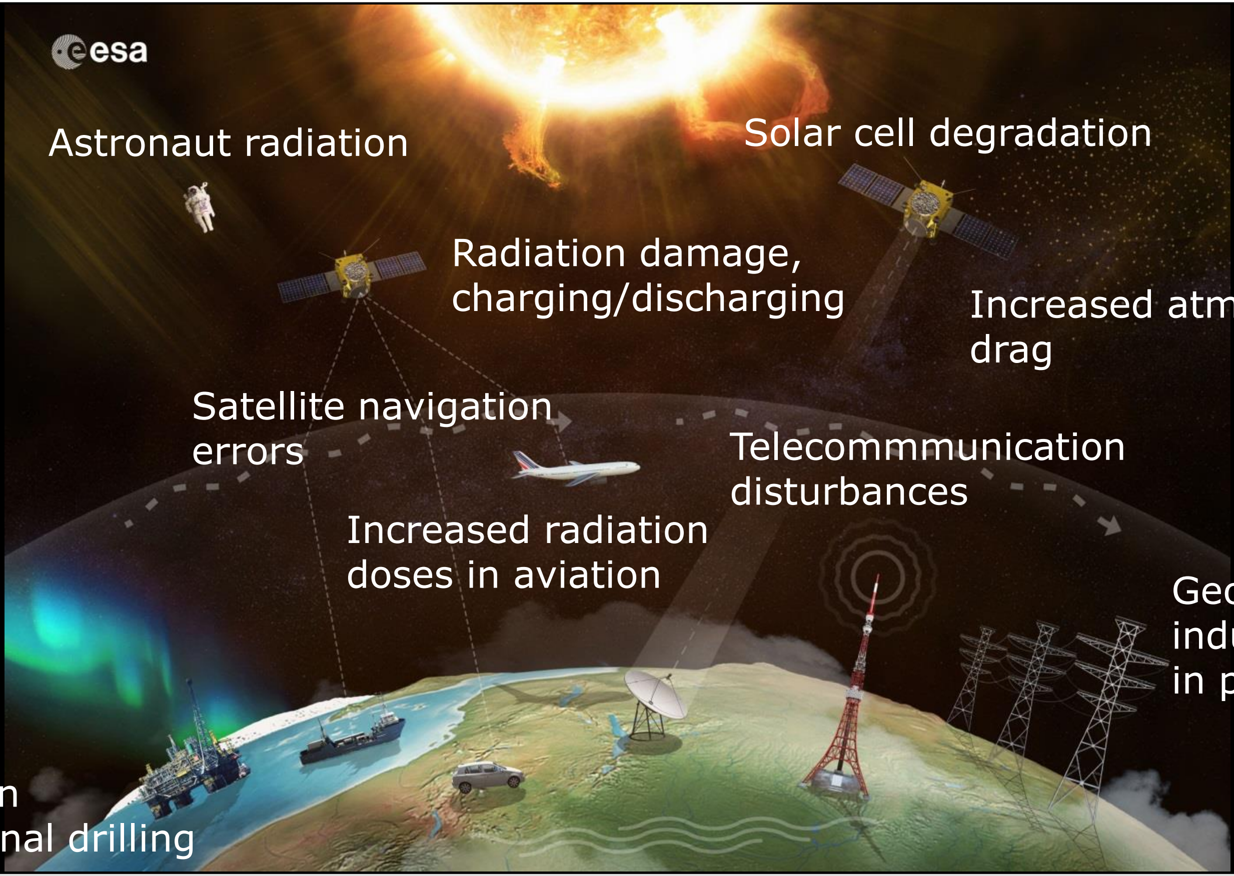
- Identification of key players and stakeholders

  [ESA STM Study]

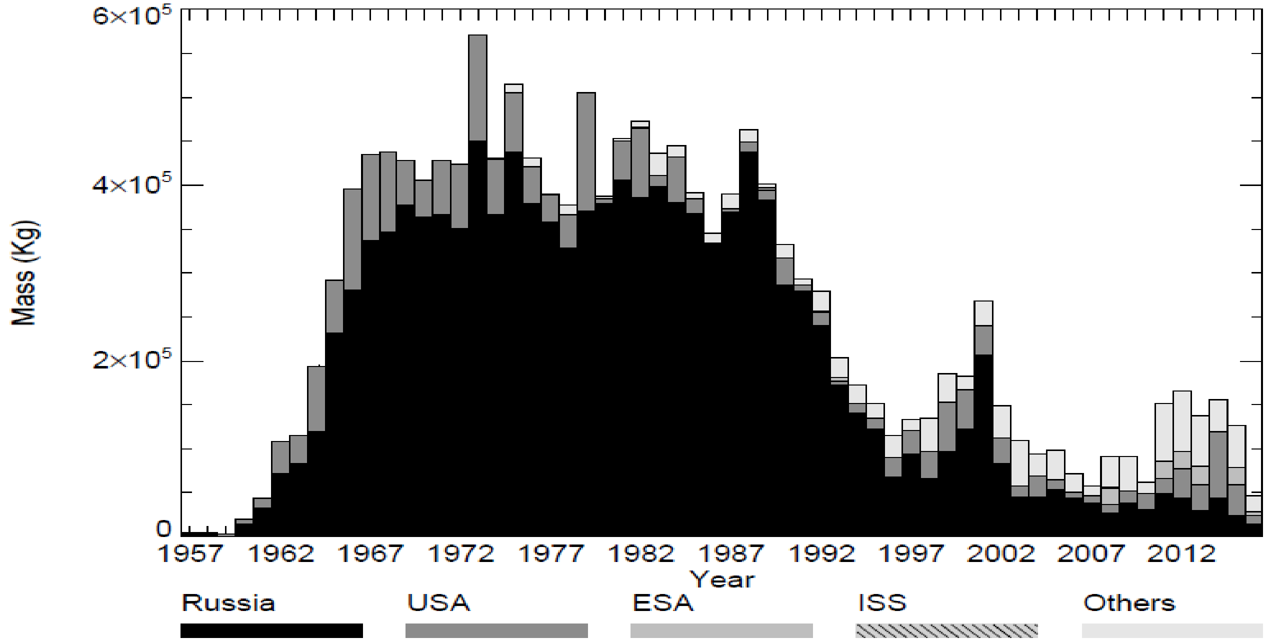
- Contribution of Space Surveillance
  - Space Weather
  - Re-entry Warning
  - Collision Avoidance



Space Weather Hazards to Infrastructure

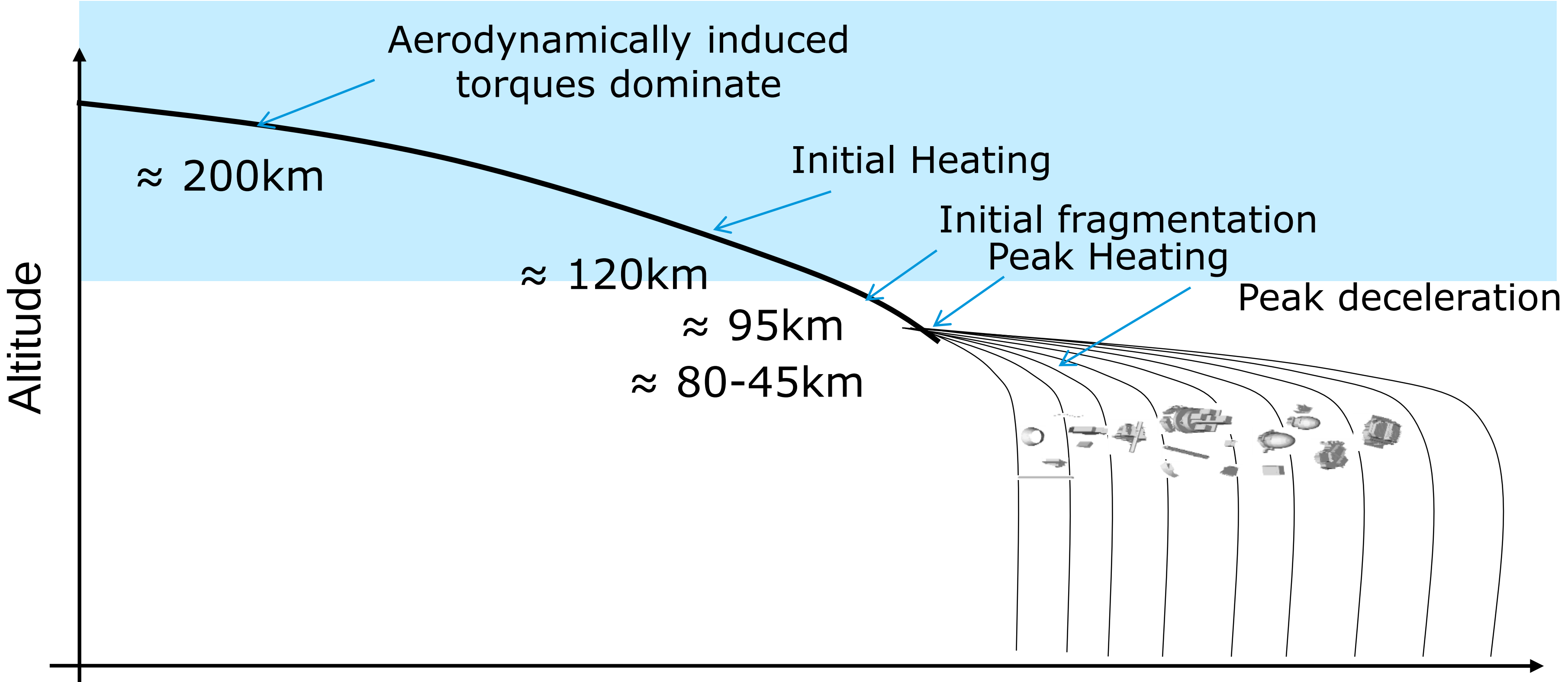


Decayed Mass per Year



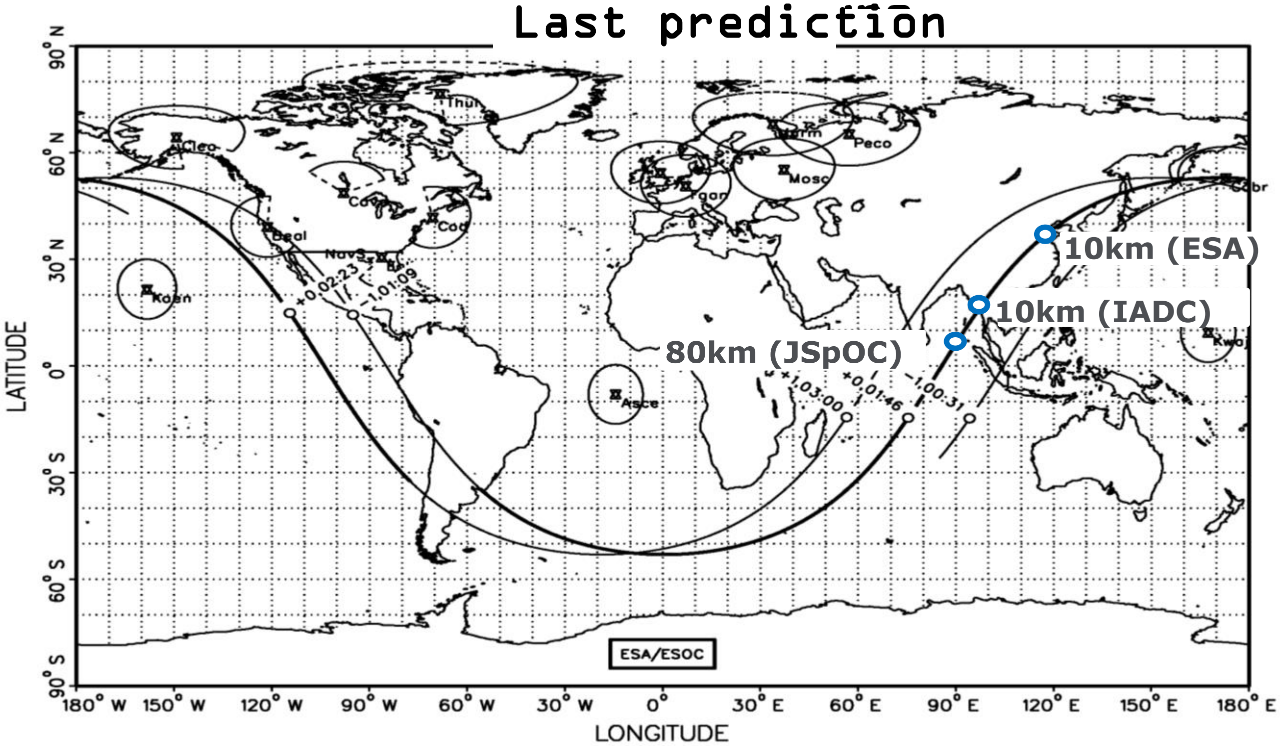
- Excludes Re-entry Vehicles
- Today 400t per year are launched and about 150t decay
- This corresponds to a total cross-section of about 500m² (corresponds to roughly 2 tennis courts)

Atmospheric Break-Up



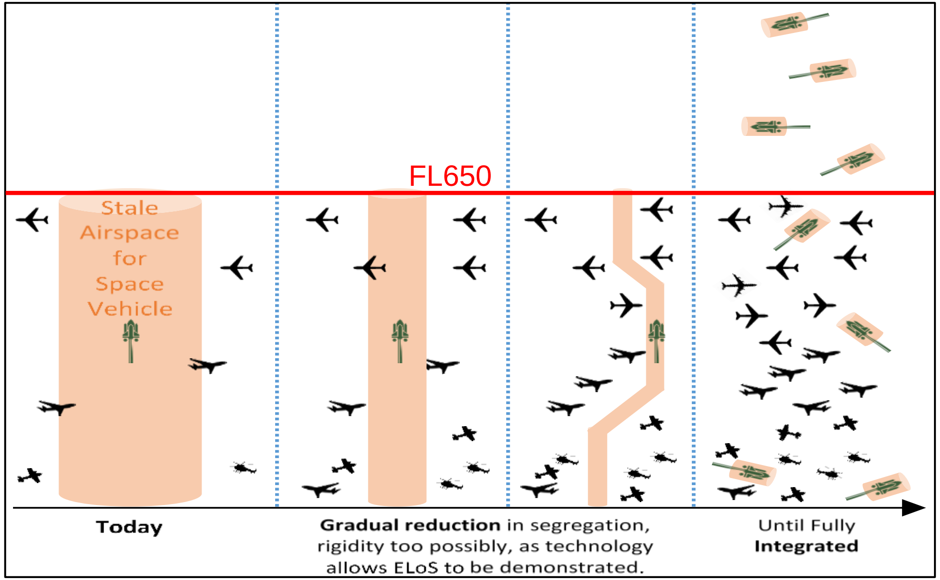
Special Analysis: ROSAT – Ground Tracks

https://reentry.esoc.esa.int

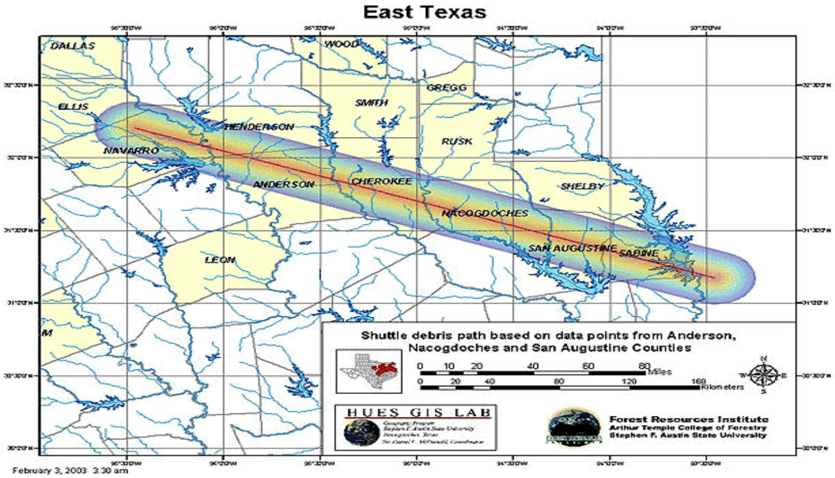


Ascend and Landing Phases

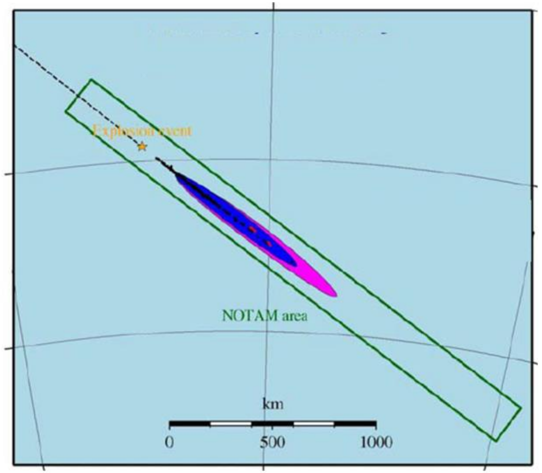
Flight Corridor Handling



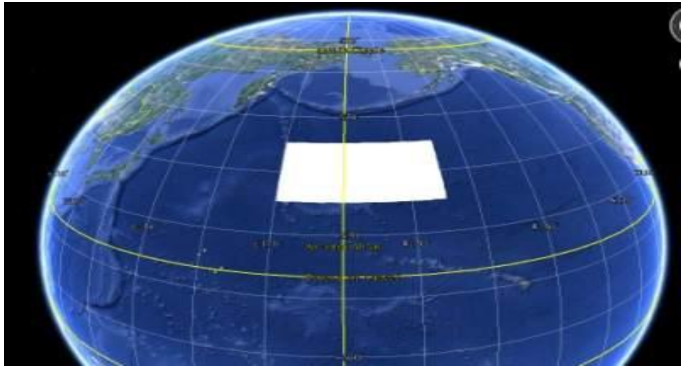
Columbia Accident

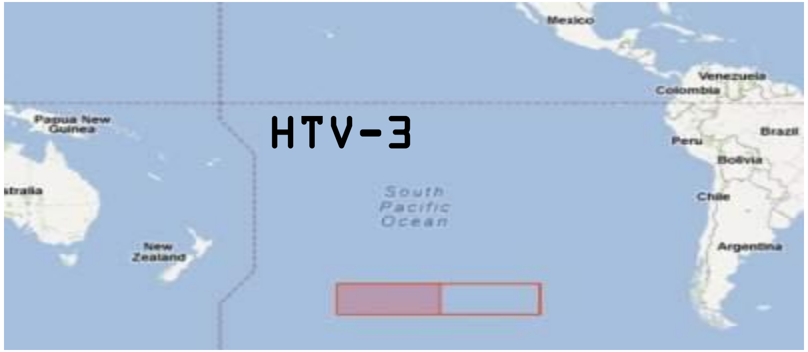


Required NOTAM Areas



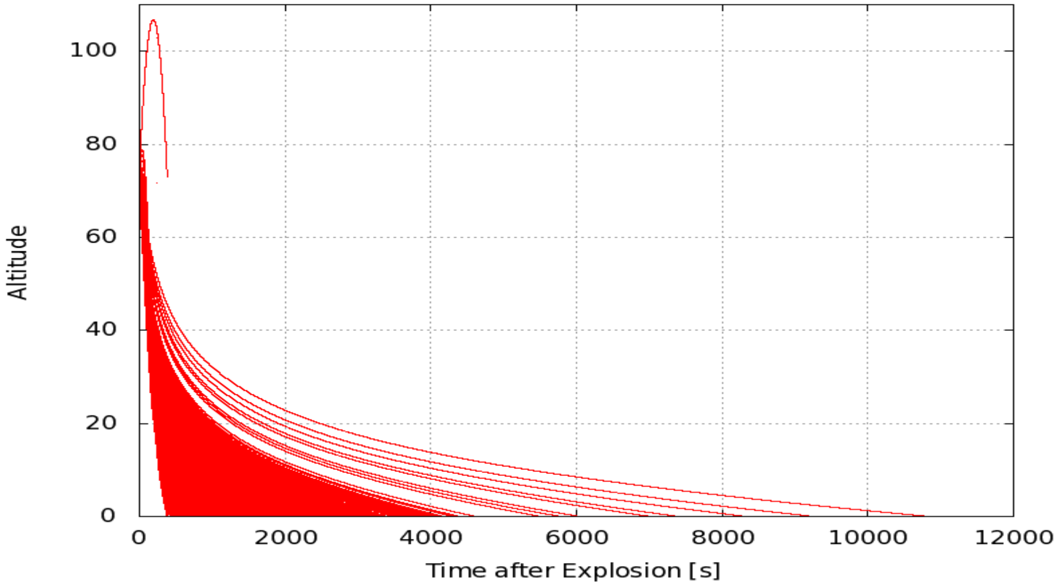
Russian Federal Space Ag





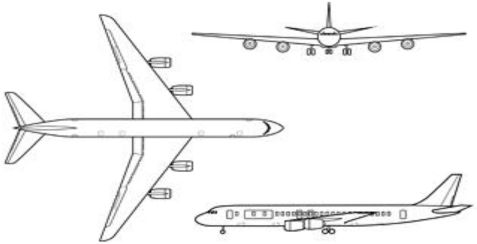
Fragment Fall Durations

Which fragments are relevant?



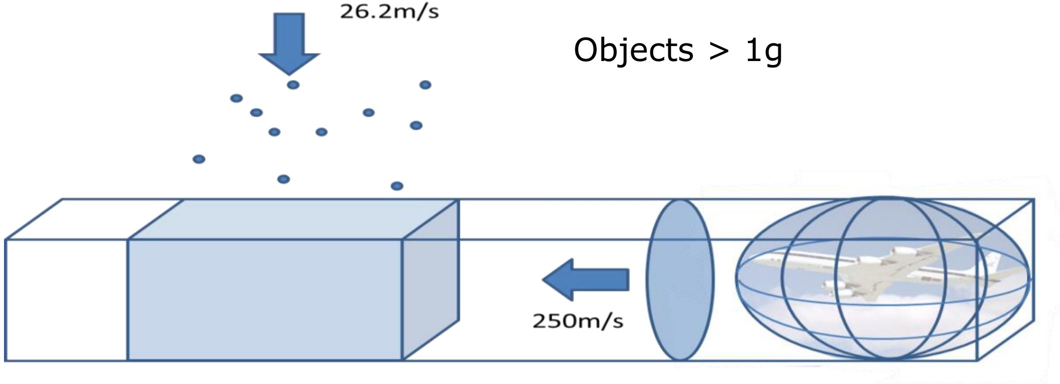
- FAA-JTCG: > 0.05 g (penetrate of aircraft skin)
- FAA-JTCG: > 300 g (catastrophic event)
- RCC 321: > 1g (windshields and turboshaft piston engines protection)

Spatial Density Computation



DC-8 aircraft

Cross-track distance [km]	Spatial density [1/m³]
11.8	$1.12*10^{-3}$
23.6	$1.6*10^{-4}$
35.4	$9.48*10^{-6}$
47.2	$2.26*10^{-7}$
59.0	$2.02*10^{-9}$
70.8	$6.93*10^{-12}$
82.6	$8.99*10^{-15}$

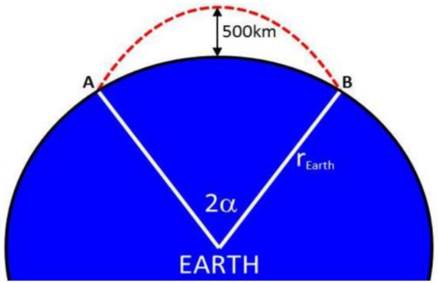


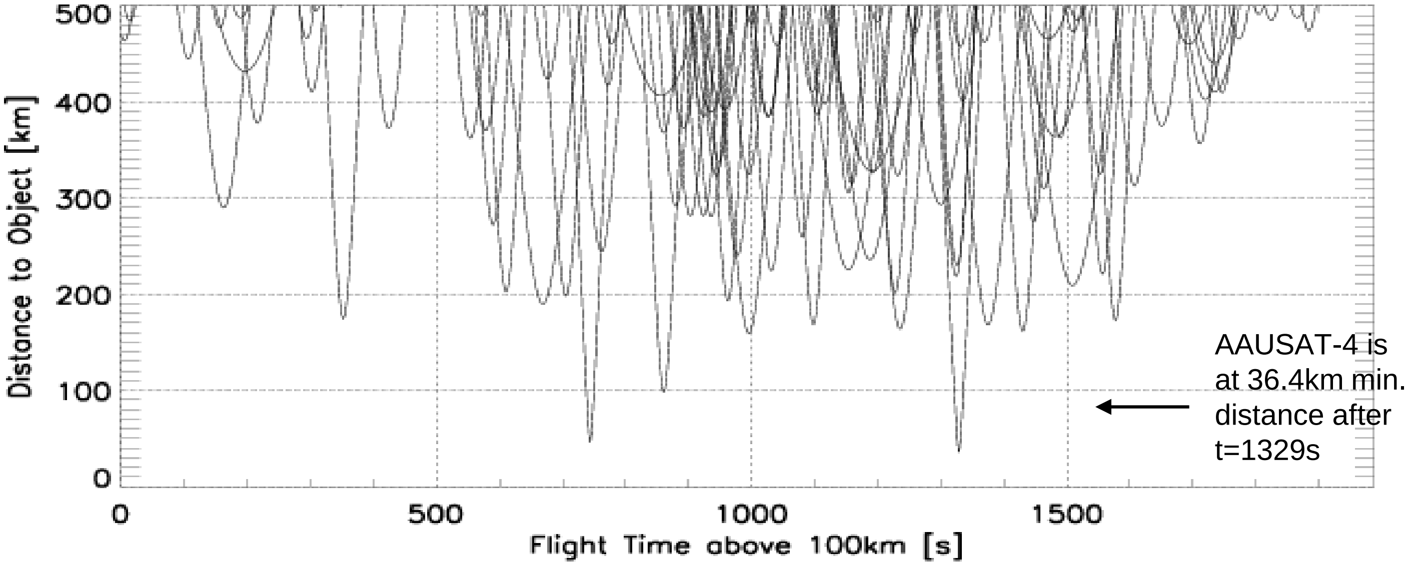
Objects > 1g

Complies with a risk threshold of 10^{-8}

Collision Risk in Space – Tracked Objects

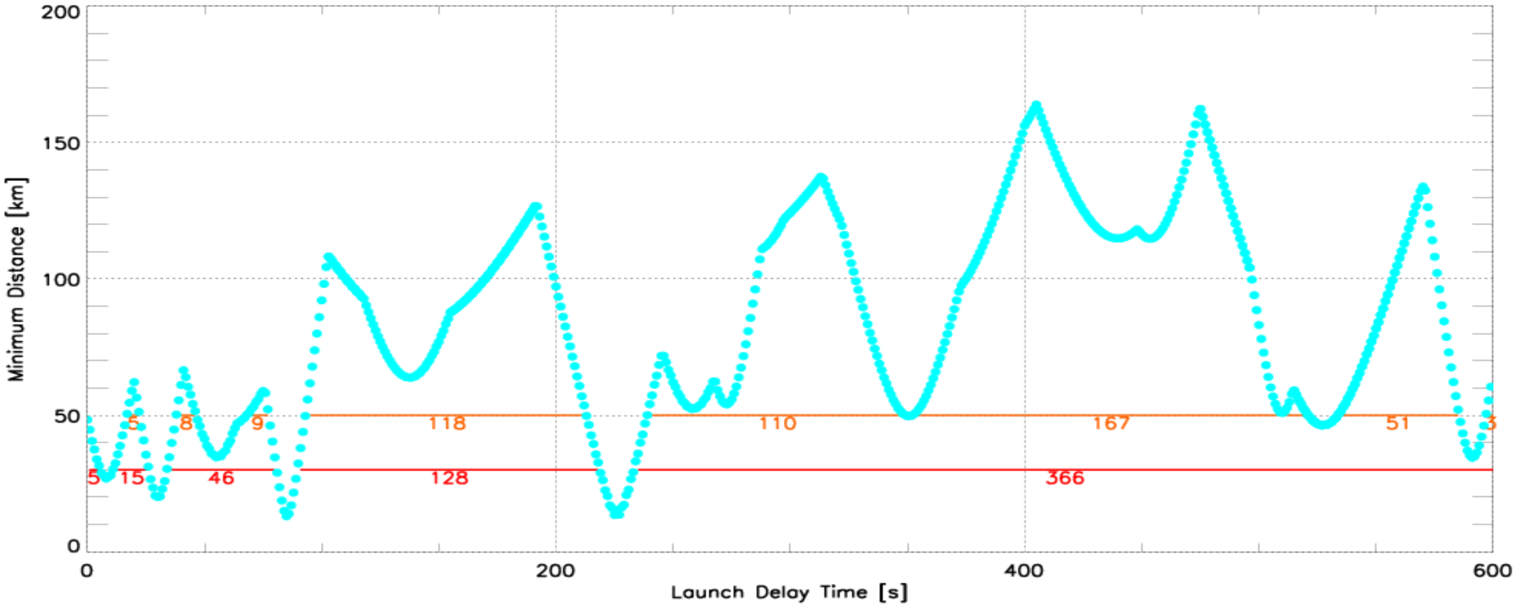
- Sample p2p suborbital flight, with a distance of 15,000km and 500km peak height



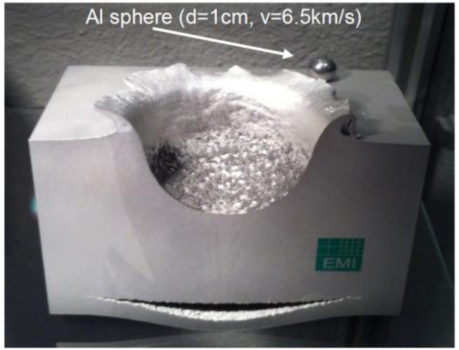


Control of collision risk by flight delays

- Sample p2p suborbital flight, with a distance of 15,000km and 500km peak height



Collision Risk in Space – Small Objects



	Particles > 1mm	Particles > 5mm	Particles > 1cm
Impacts/15000km [1/m²/15000km]	$1.2\cdot10^{-7}$	$7.2\cdot10^{-9}$	$1.5\cdot10^{-9}$

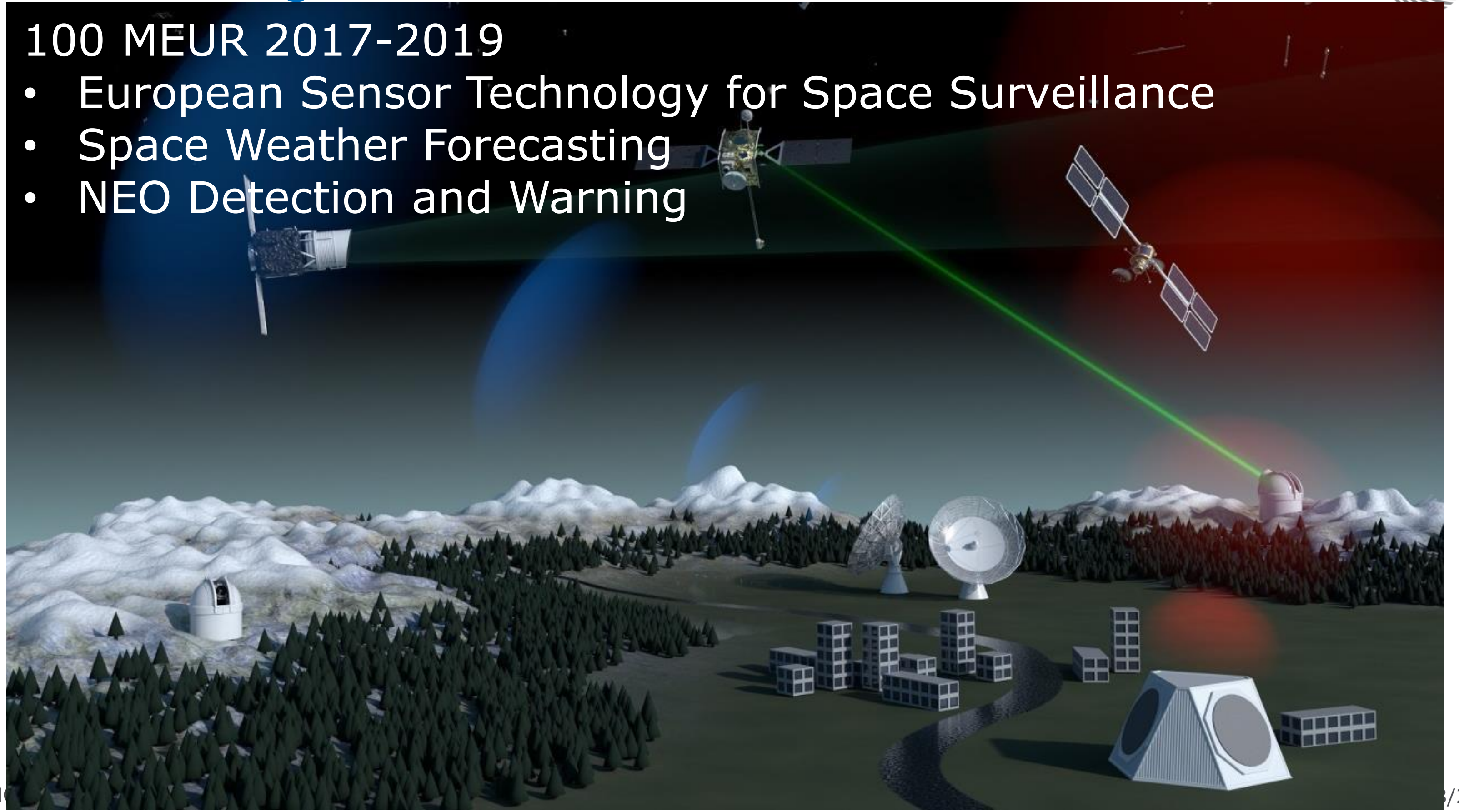
- Assumption: The probability of all catastrophic failure conditions (loss of life &/or vehicle) to SSV and its occupants shall be better than 1x10-4 per flight
- There are a total of 100 potentially catastrophic failure conditions which have an equal share of this budgeted requirement

SSV shielding capacity (debris size, mm)	Maximum cross-sectional area (m²)
1	10
5	100
10	1000

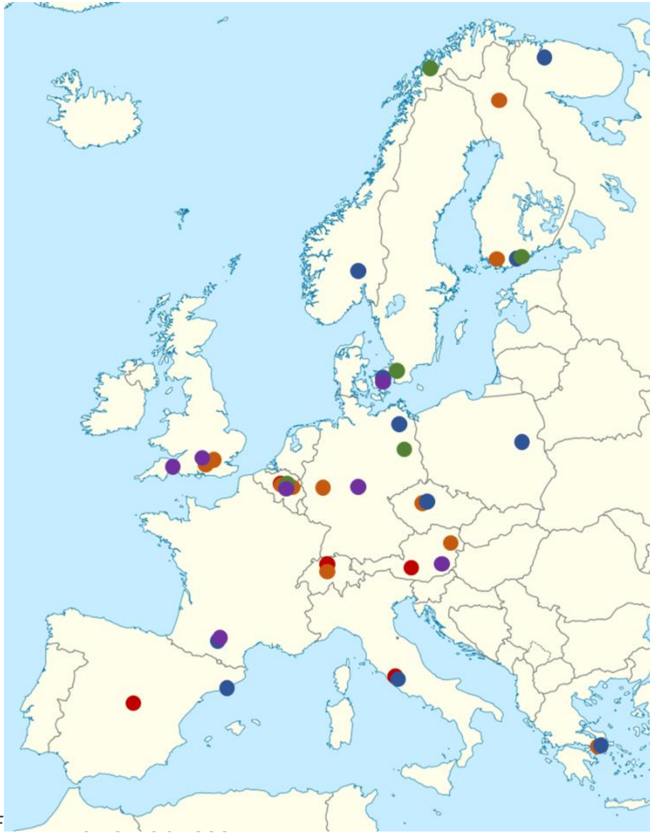
ESA SSA Program

100 MEUR 2017-2019

- European Sensor Technology for Space Surveillance
- Space Weather Forecasting
- NEO Detection and Warning



SSA Networking European SWE Assets



Data archives

- SSA SWE Data Centre (Redu)
- Federated data repositories

SSA SWE Coordination Centre

- User Helpdesk
- Space Pole, Belgium

SWE Expert Service Centres (ESCs)

Solar Weather | Ionospheric Weather | Space Radiation | Geomagnetic Conditions | Heliospheric Weather

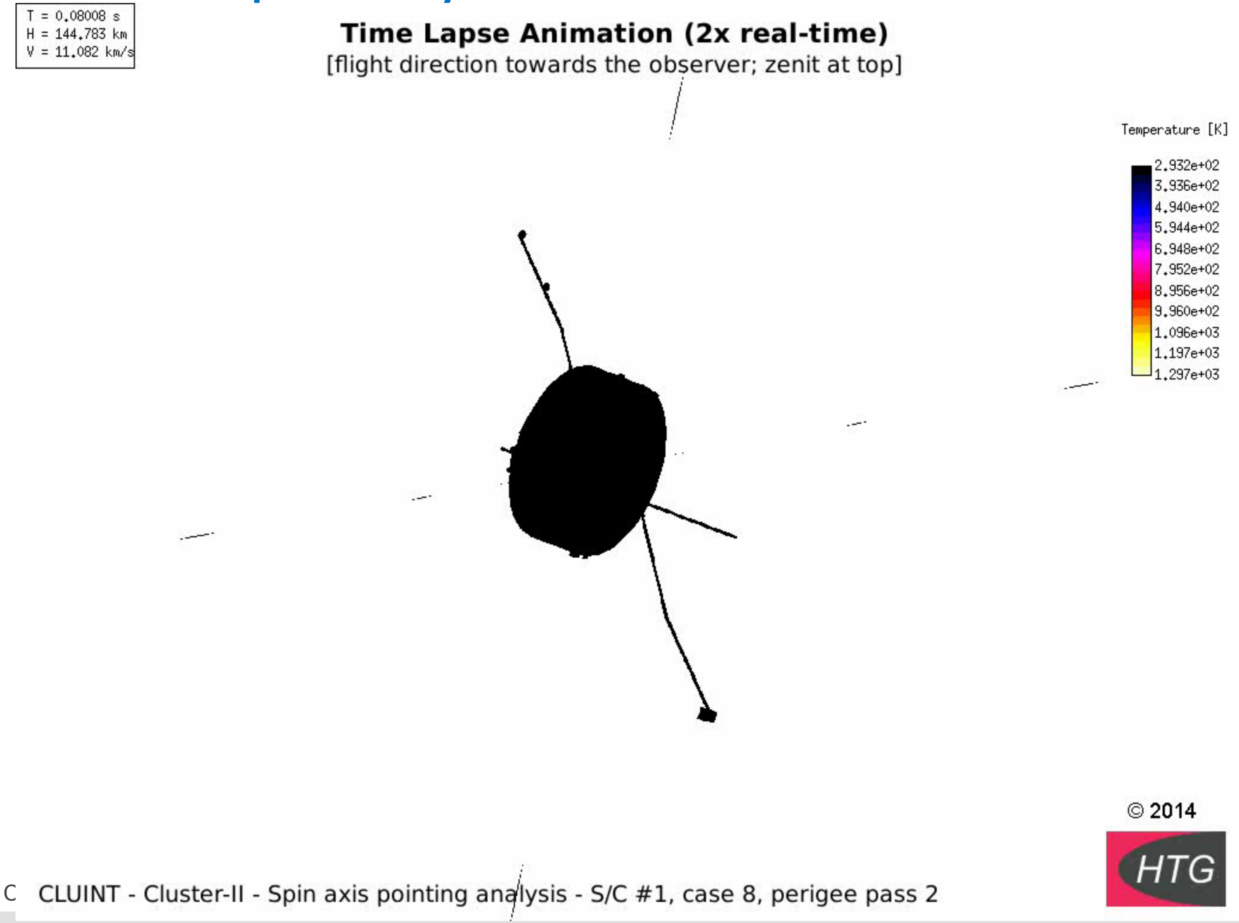
European expert groups and centres of excellence

Sensor systems

ESA SST Developments

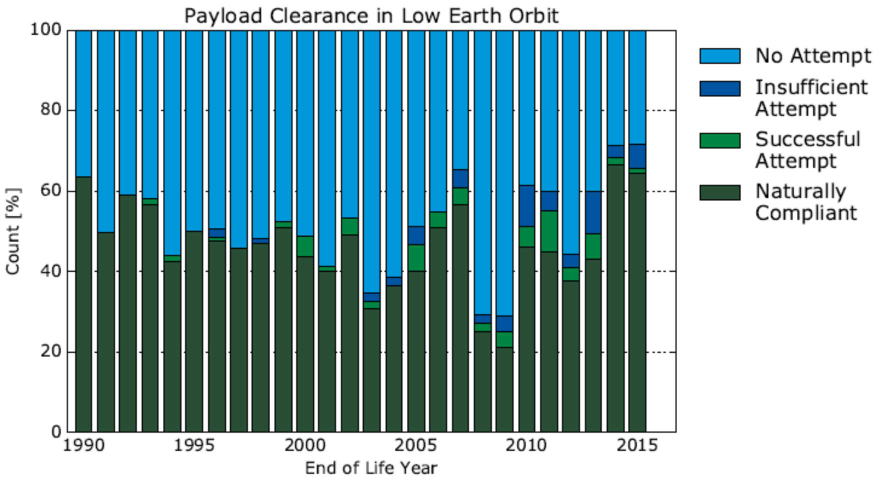
Back-Up

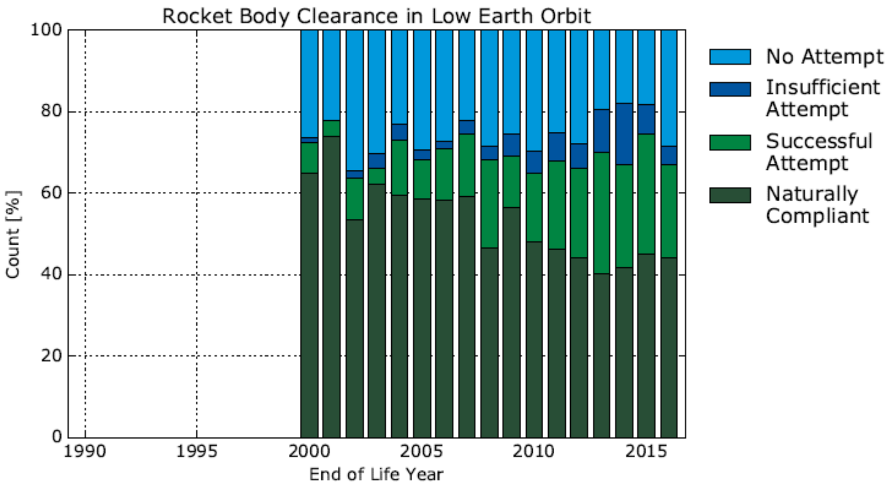
Re-entry Break-up Analysis: SCARAB for Cluster-II



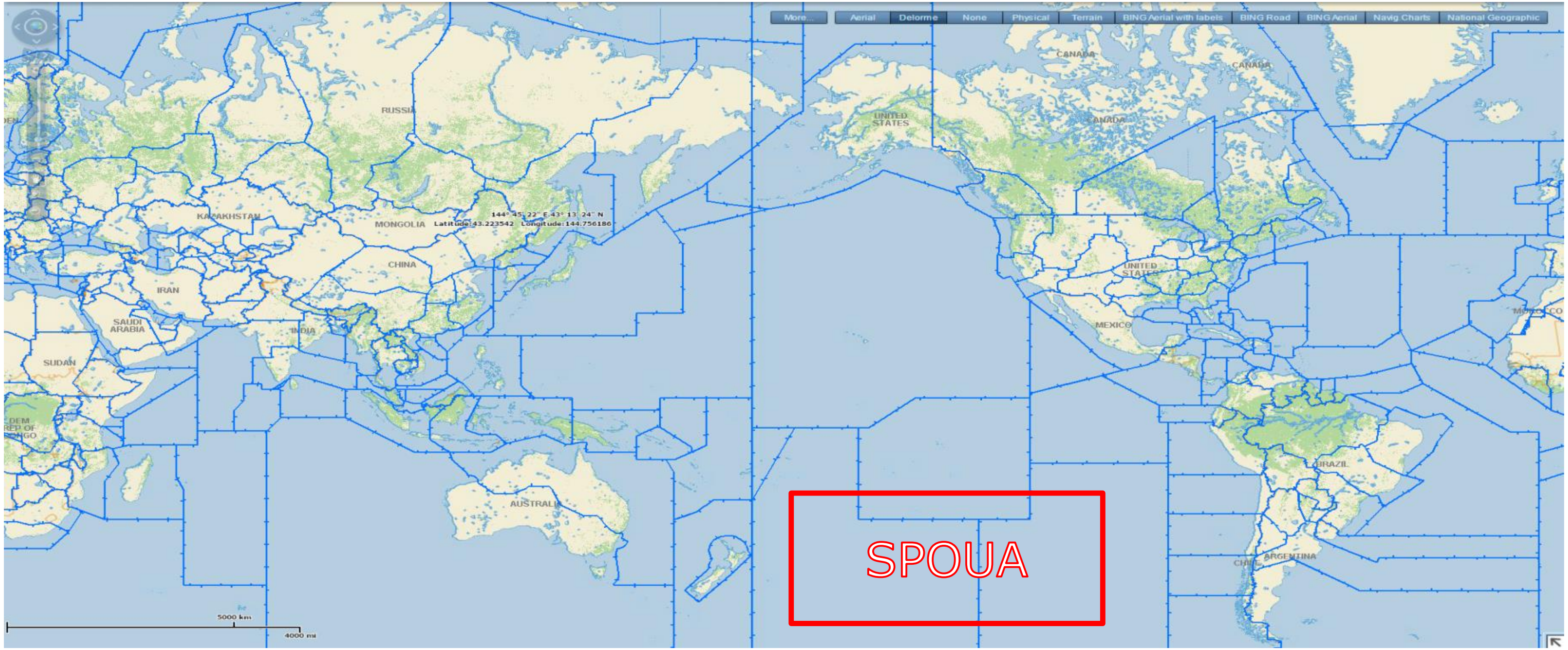
Annual Mitigation Compliance Review – Clearing Protected Zones

https://www.sdo.esoc.esa.int/environment_report/Environment_Report_I1R2_20170427.pdf



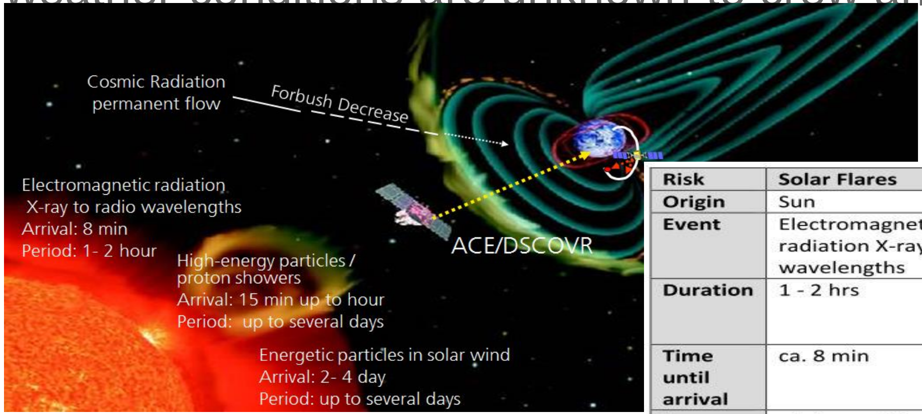


Flight Information Regions (FIR)



Space Weather

Risk register listing the most critical risks and impacts that could occur if space weather conditions are unknown to crew and passengers.

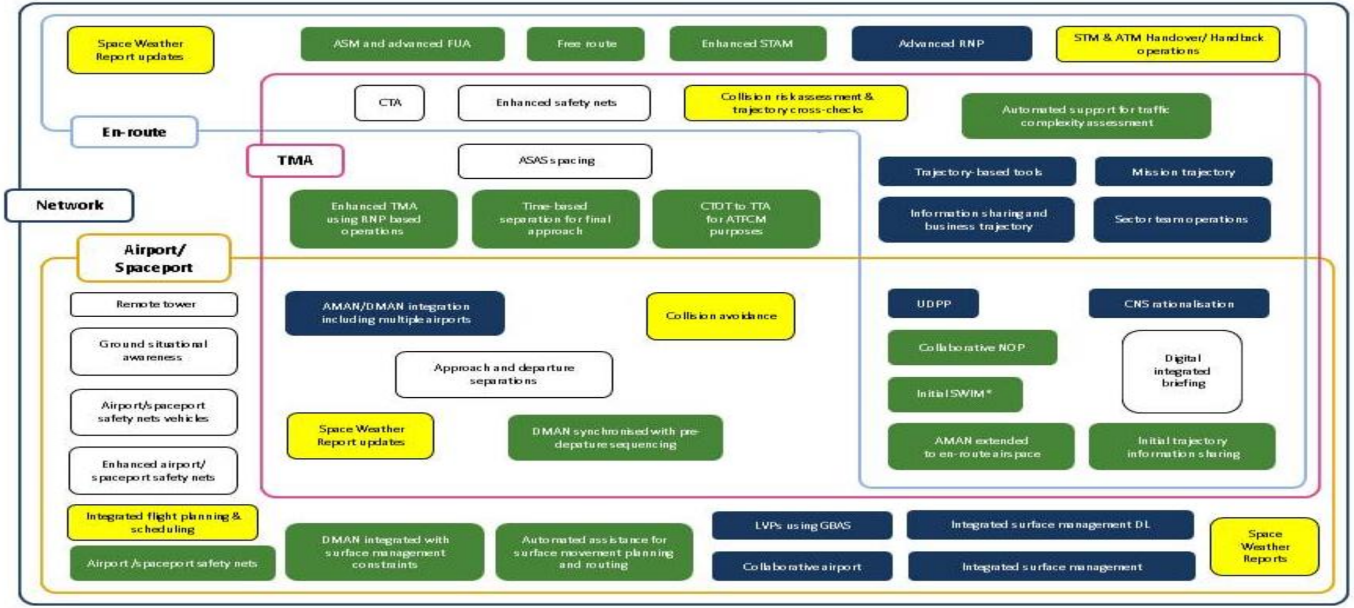


Space Weather Overview - Background image courtesy NASA

Risk	Solar Flares	High Energetic Particles	Coronal Mass Ejection
Origin	Sun	Sun / Cosmic Rays	Sun
Event	Electromagnetic radiation X-ray to radio wavelengths	High-energy particles / proton showers	Energetic particles in solar wind
Duration	1 - 2 hrs	Solar event: Up to several days Cosmic Rays: Continuous	Up to several days
Time until arrival	ca. 8 min	15 min up to one hour	2 - 4 days (depending on solar wind speed)
Causes	• Enhanced ionization at the bottom of the Ionosphere (D-Layer) • Heating of the Thermosphere	Radiation	• Solar storm (extreme solar wind) • Thermosphere heating • Geomagnetic storms, • Particle precipitation, • Ionospheric disturbances
Impact	• Navigation (Positioning, Loss of Lock), • Radio Blackouts (Signal disturbance GNSS) • Drag effects	• Radiation damage (Space /Air Crew and Passengers) • SEU, Latchup • Interference • Degradation (Solar cell damage, etc.)	• Internal/External charging • Drag effects, Navigation (Positioning), Communication (HF), Geomagnetic induced currents
Forecast	No	Yes	Yes
Nowcast	Yes	Yes	Yes

Table 3: Risk register associated with unawareness of space weather events

Integrating STM and the ATM system



InitialSWIM* includes the following PCP Essential Operational Changes:

- common infrastructure components;
- SWIM infrastructure and profiles;
- aeronautical information exchange;
- meteorological information exchange;
- cooperative network information exchange;
- flight information exchange.

Add-on Operational Changes for STM

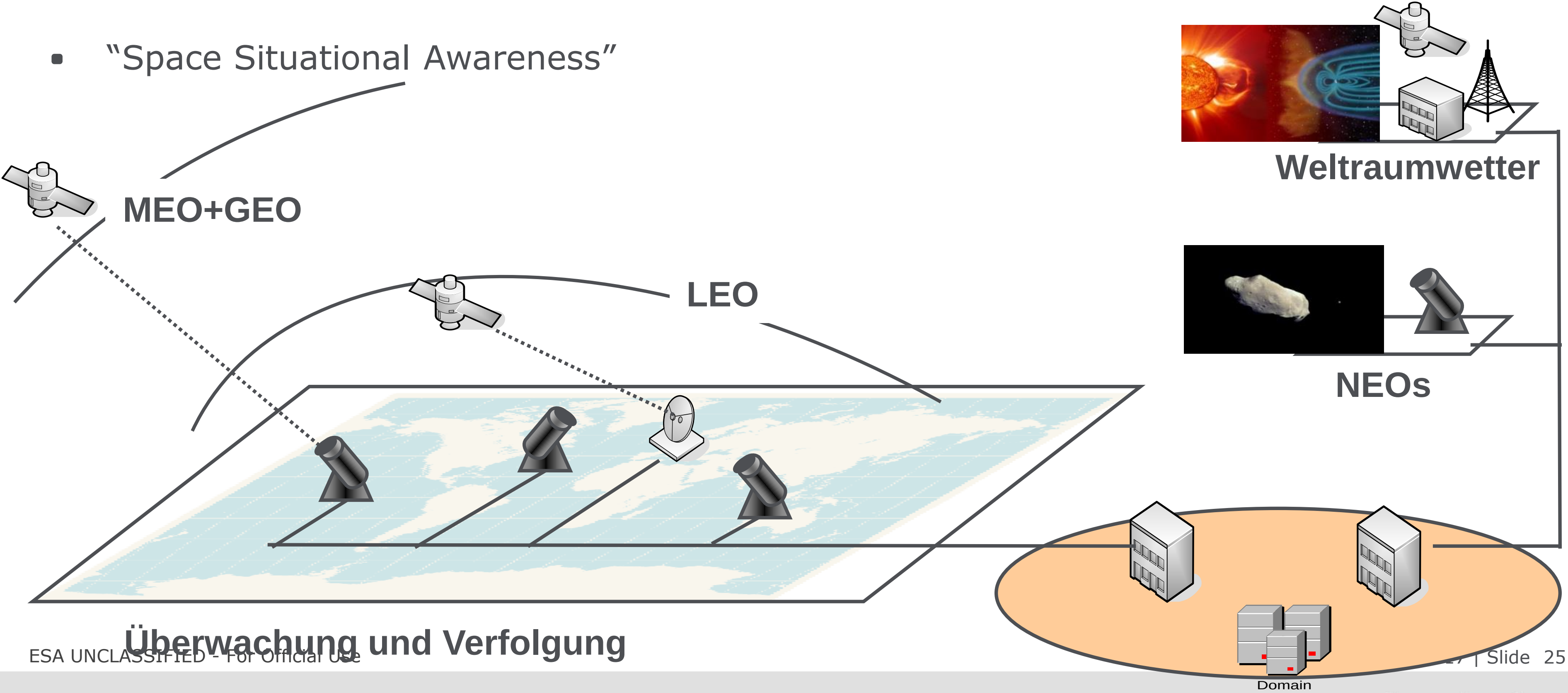
Operational Changes

PCP Essential Operational Changes

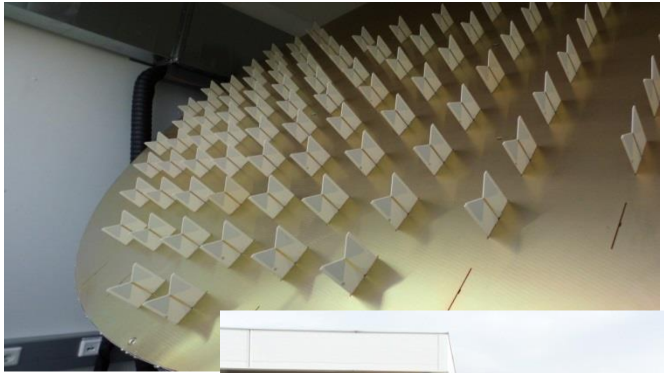
New Essential Operational Changes

Weltraumüberwachung

- “Space Situational Awareness”



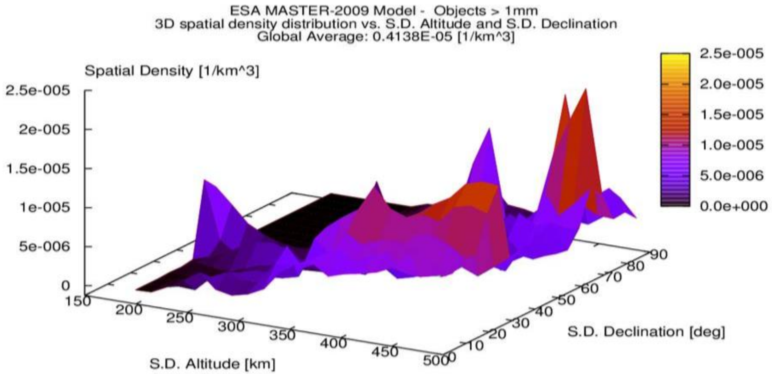
Radar-Prototyp

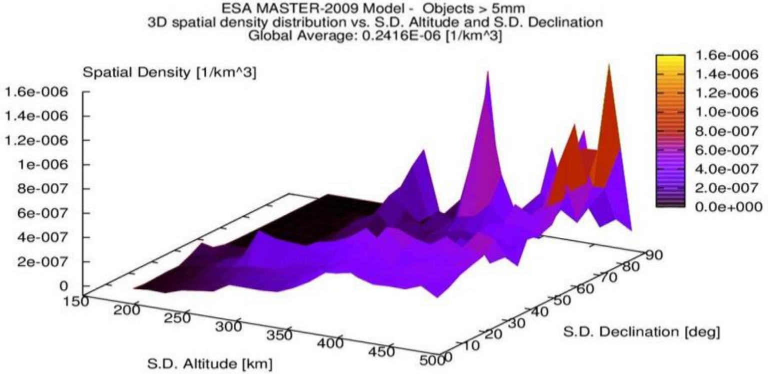


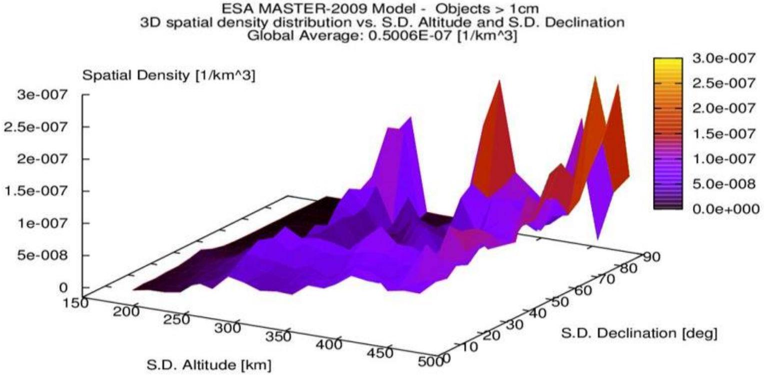
ESA-Teleskop Teneriffa

Space Debris and Space Surveillance and Tracking

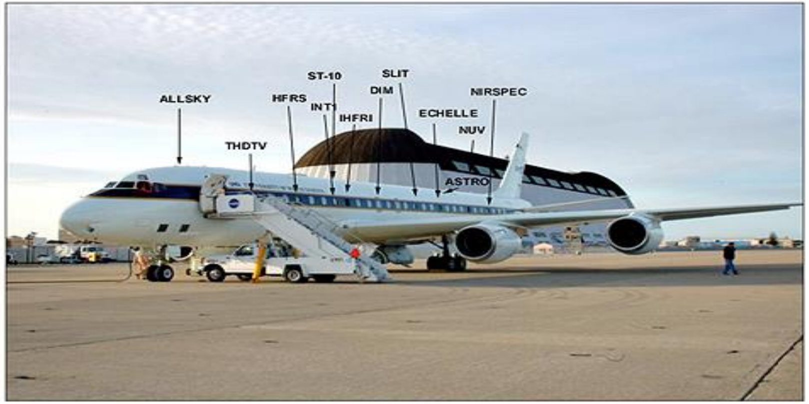
Spatial densities of non-traceable objects as a function of altitude and declination



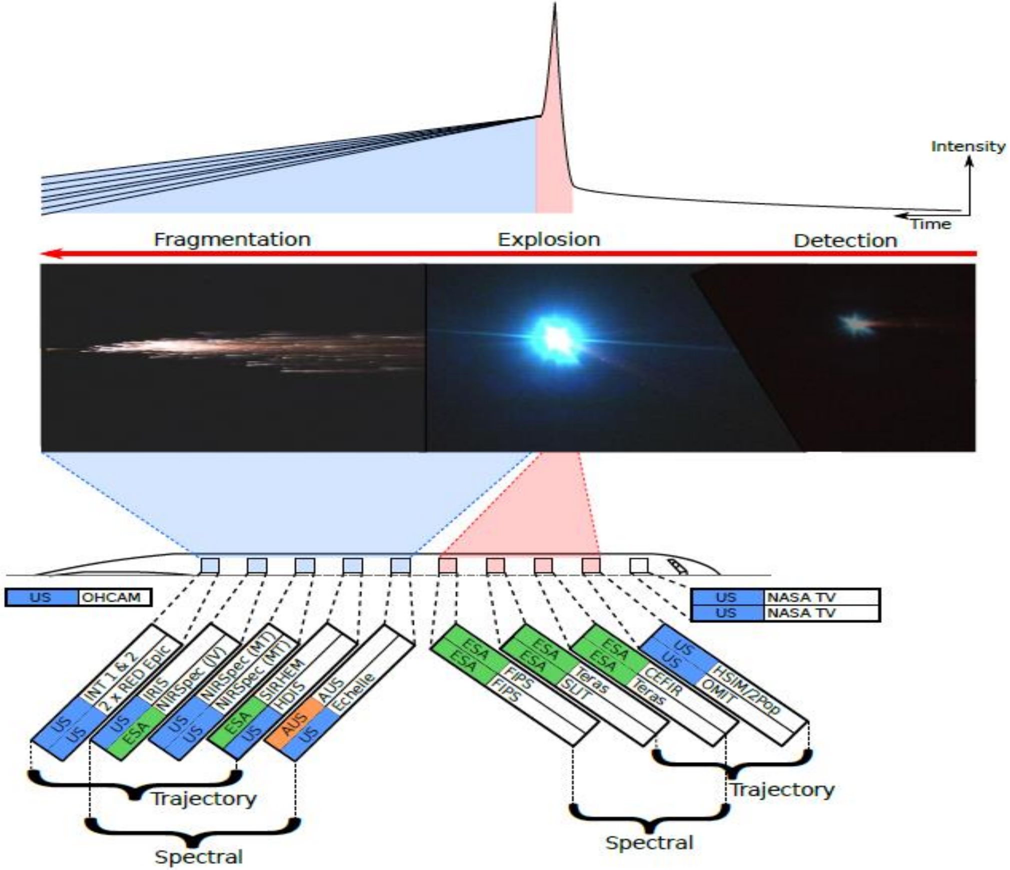




Campaign Setup

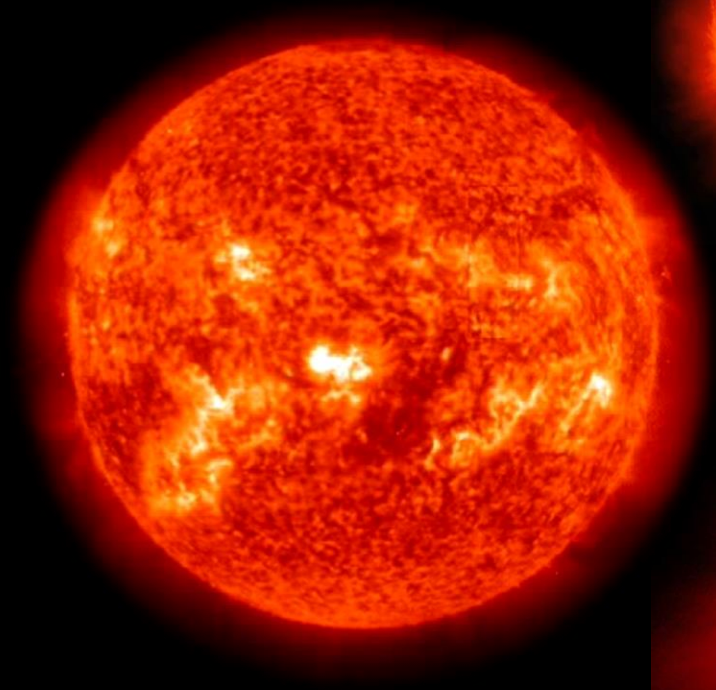


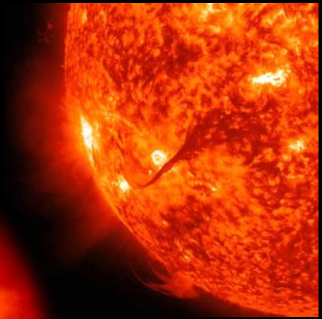
NASA DC-8 Research Aircraft

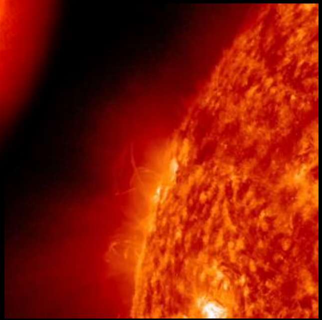


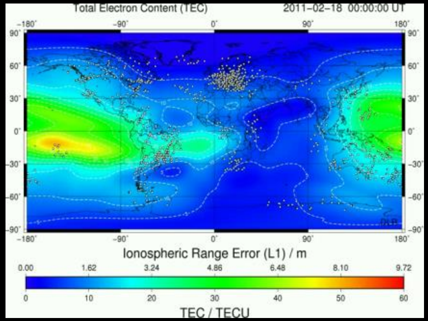
Results

What is ”Space Weather”?

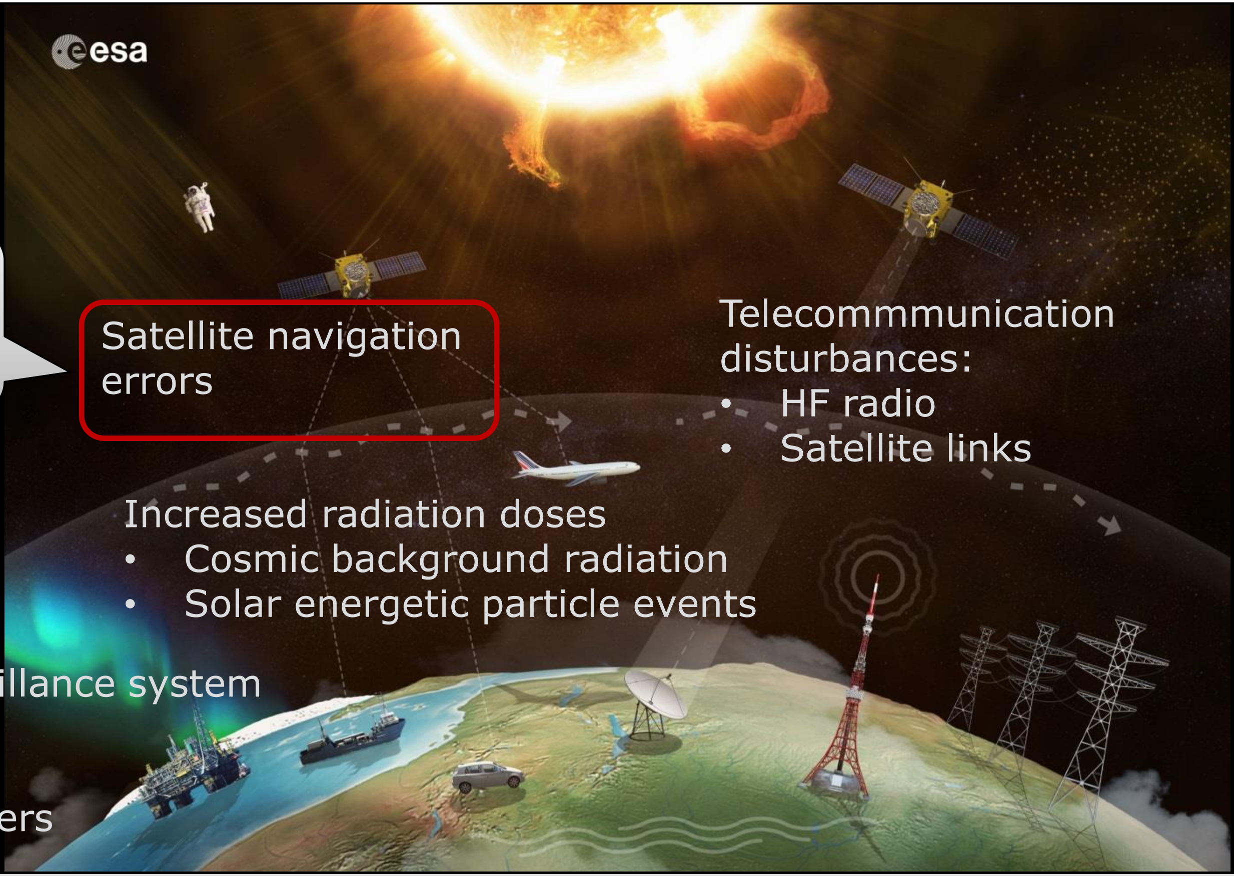








Space Weather Hazards to Aviation



Significance increasing rapidly

Satellite navigation errors

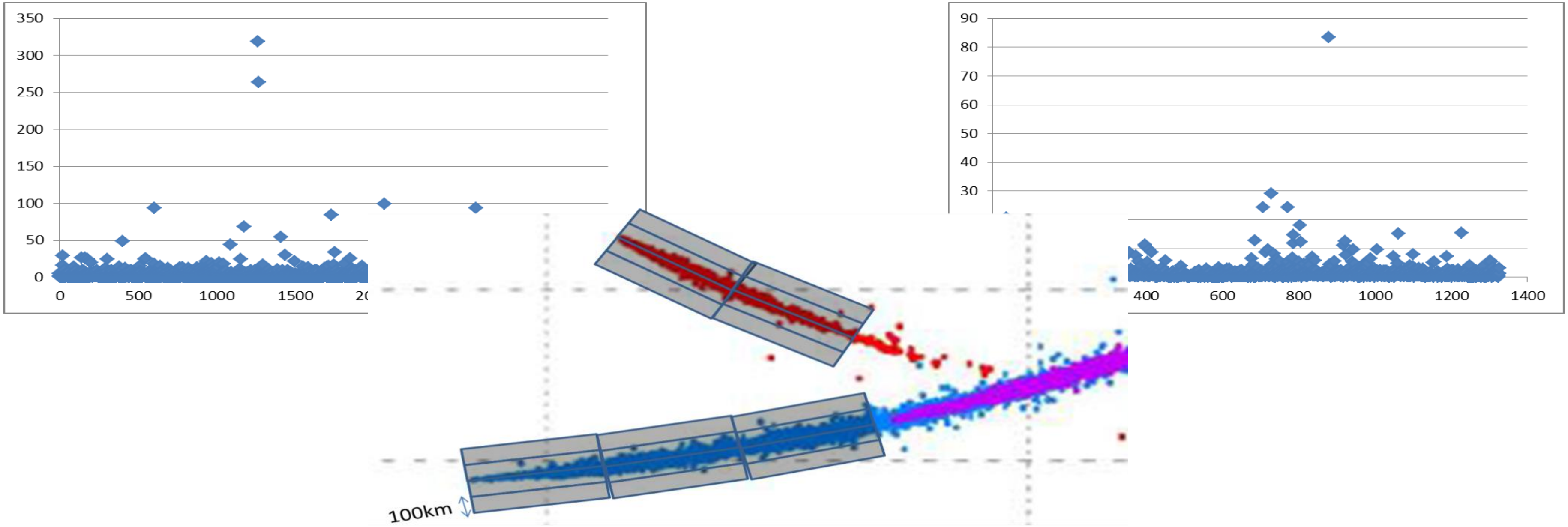
Telecommmunication disturbances:
- HF radio
- Satellite links

Increased radiation doses
- Cosmic background radiation
- Solar energetic particle events

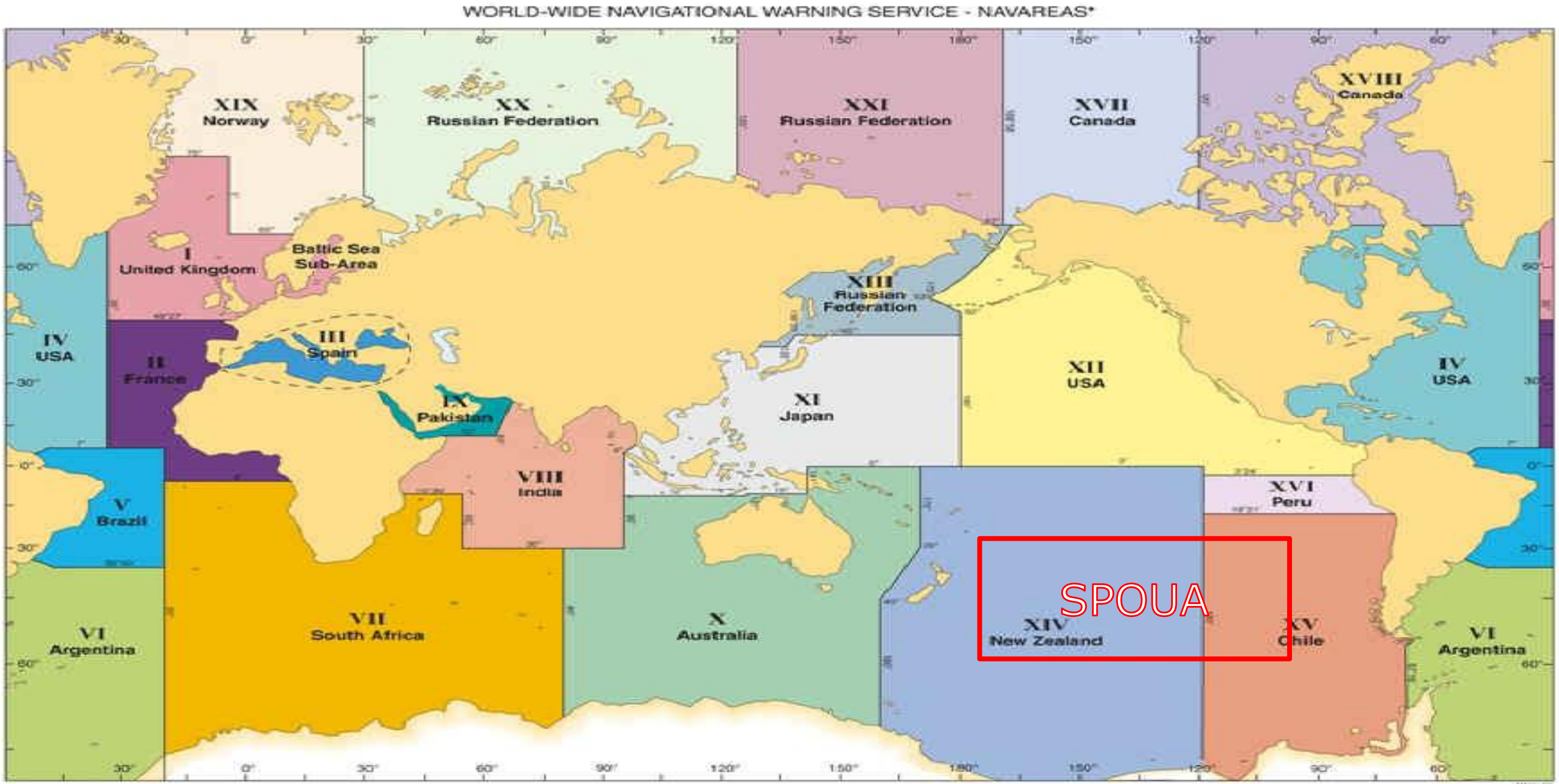
Ground surveillance system disturbances
- Radars
- Transponders

Cross-Track Dispersion of Fragments

- Assumption of Gaussian distribution is limited
- Sometime objects beyond 100km

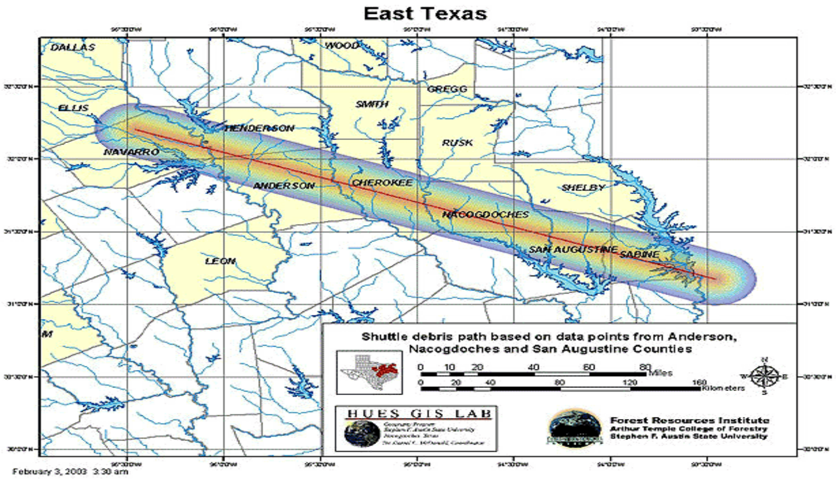


NAVAREAs


WORLD-WIDE NAVIGATIONAL WARNING SERVICE - NAVAREAS*
XIX
Norway
XX
Russian Federation
XXI
Russian Federation
XVII
Canada
XVIII
Canada
I
United Kingdom
Baltic Sea
Sub-Area
XIII
Russian
Federation
IV
USA
II
France
III
Spain
IX
Pakistan
XI
Japan
XII
USA
IV
USA
VIII
India
V
Brazil
XVI
Peru
SPOUA
XIV
New Zealand
XV
Chile
VI
Argentina
VII
South Africa
X
Australia
VI
Argentina

Safety & Reliability

Columbia Accident



Results

- Maximum allowed density for expected number of impacte $E_N < 10^{-8}$

$$\rho < \frac{E_N}{v \cdot A \cdot t}$$

- Result: $3.64 \cdot 10^{-14}/m^3$
- Corresponds to 7σ
- And this corresponds to 82.6km
- Synthesis:

Distance required due to explosion delta-v	82.6km
Mean value offset	2.9km
Wind/lift	15km
Sum	**100.5km**