“Space Debris – Why worry? What do we know? And how can we continue?”

100 Jahre Astronomisches Institut - 200 Jahre Uraniae Sternwarte Bern

25/11/2022

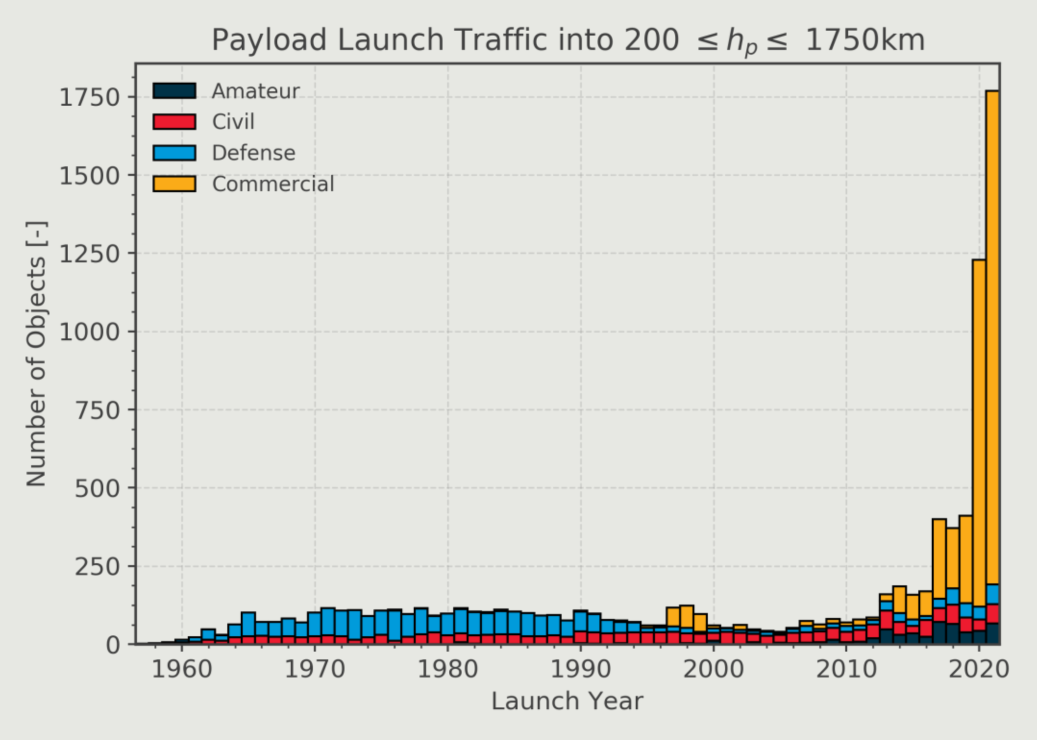
Tim Flohrer

Space Debris

„Space debris are all human-made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional“

Key trends for the orbital environment

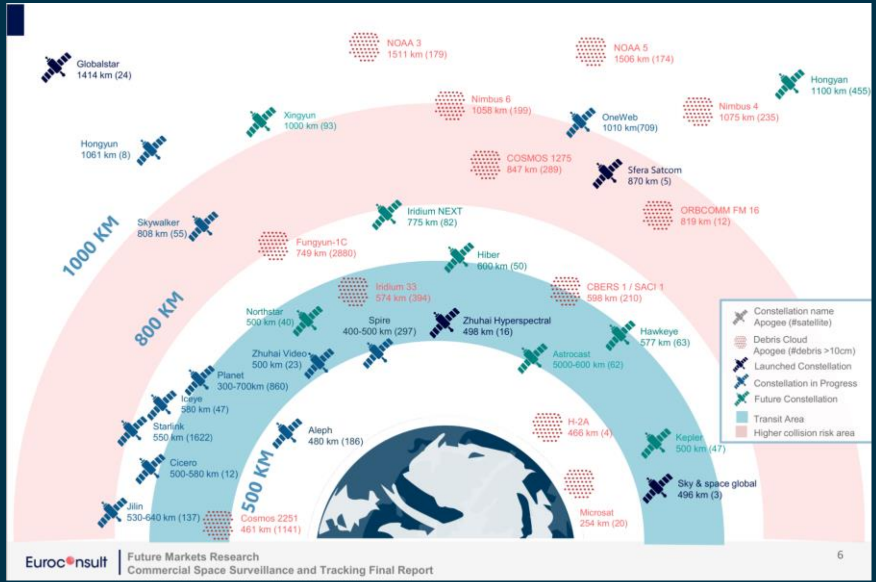
Drastic **increase of launch rate** and thus increase of close approaches between active spacecraft



ESA Space Debris User Portal, **Space Environment Statistics**,
https://sdup.esoc.esa.int/discosweb/statistics

Increase active sats
2010s vs. 2020s
- 370% overall
- 460% for LEO/SSO

Euroconsult, **Satellites to be built and launched by 2029**, 2020



Euroconsult for UKSA, **Commercial Space Surveillance and Tracking**, 2020
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/917912/Euroconsult_-_Commercial_SST_Market_-_for_publication.pdf

"Space is no longer just a destination. Space is a domain, an ecosystem, an enabler."

ESA Director General, Josef Aschbacher, Nov 2022


Time to Act
TIME TO ACT

Zero Debris Approach

Invert ESA contribution to debris population

Net zero pollution strategy

Leave no trace

Debris neutrality

Zero Debris

This approach is inline with the Net Zero Space charter, which was launched Nov 2021 during the Paris Peace Forum in France

Current focus

By 2030

- Design and operate for **probability of successful disposal well above 90%**
- **Removal services for** remaining in-orbit failures

By 2050

- **Circular economy** in space: reuse or recycle 50% of the launched mass.

ESA CDF study “Zero Debris” (Nov 2022)

EOP TIA NAV

ESA Directorates Representatives

SCI STS TEC

CDF Technical Experts

International Law Division Team

Zero Debris CDF

Observers

European Industry (primes, suppliers, service providers)

National Agencies

ESA colleagues

Zero Debris Approach

Zero Debris Approach requires **transversal action** - the 4 pillars:

1. Evolution of ESA Policy

Introduce a requirement for removal in case a spacecraft fails

2. Upgrade platforms

System level development and integration of innovative technology

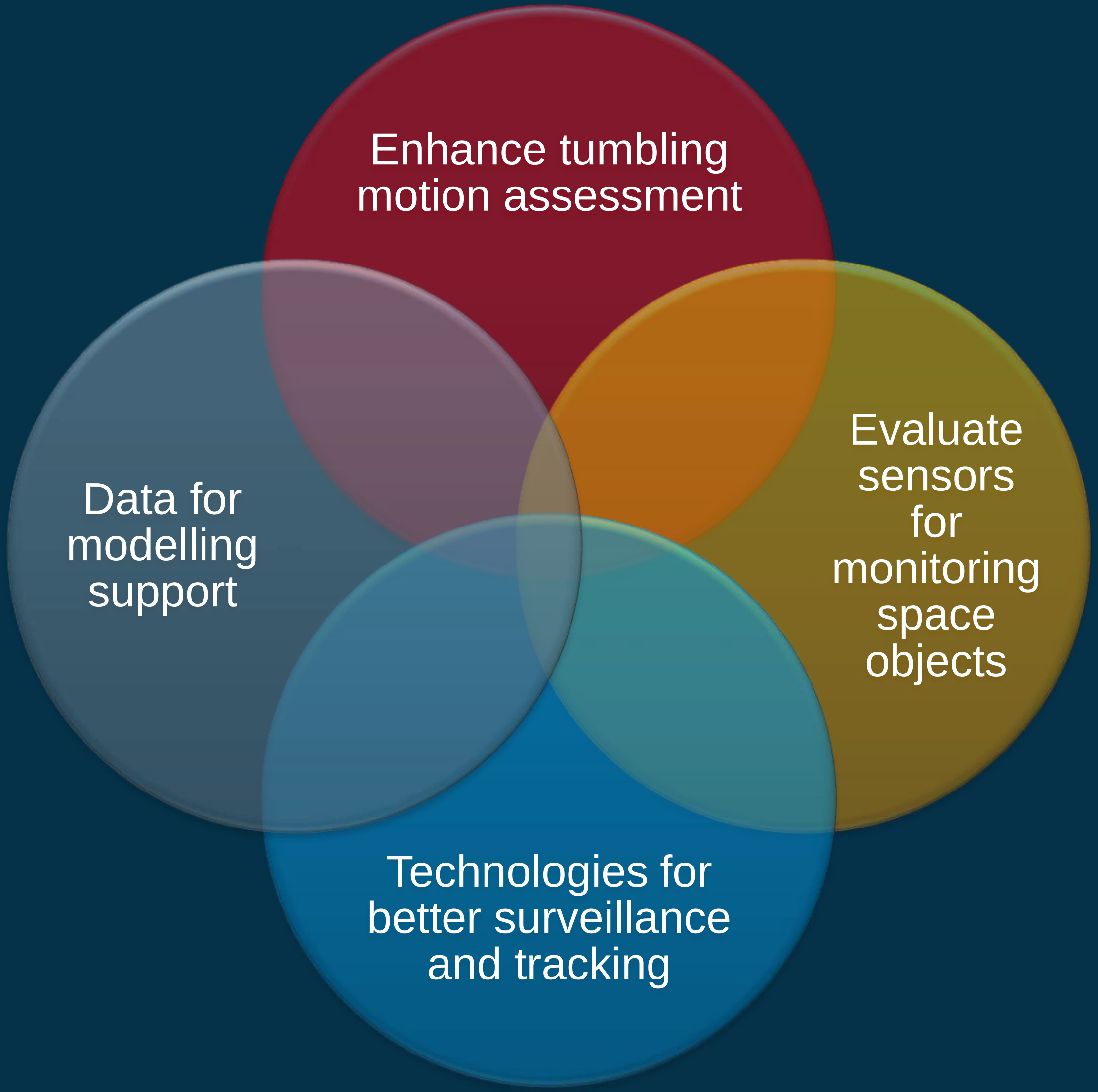
3. Removal services

Demonstrate reliable services, establish standard interfaces

4. Improving operations

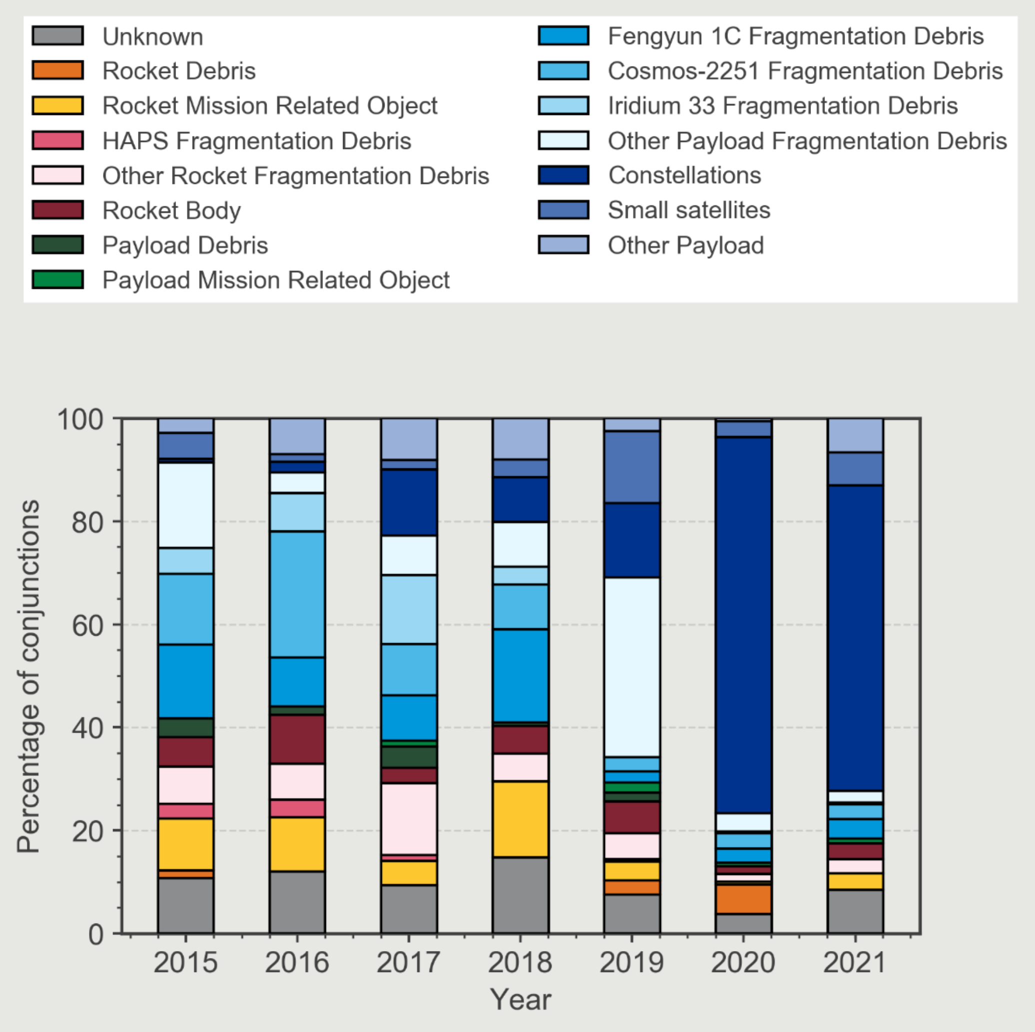
Expanding monitoring and operational capabilities

Zero Debris – selected opportunities

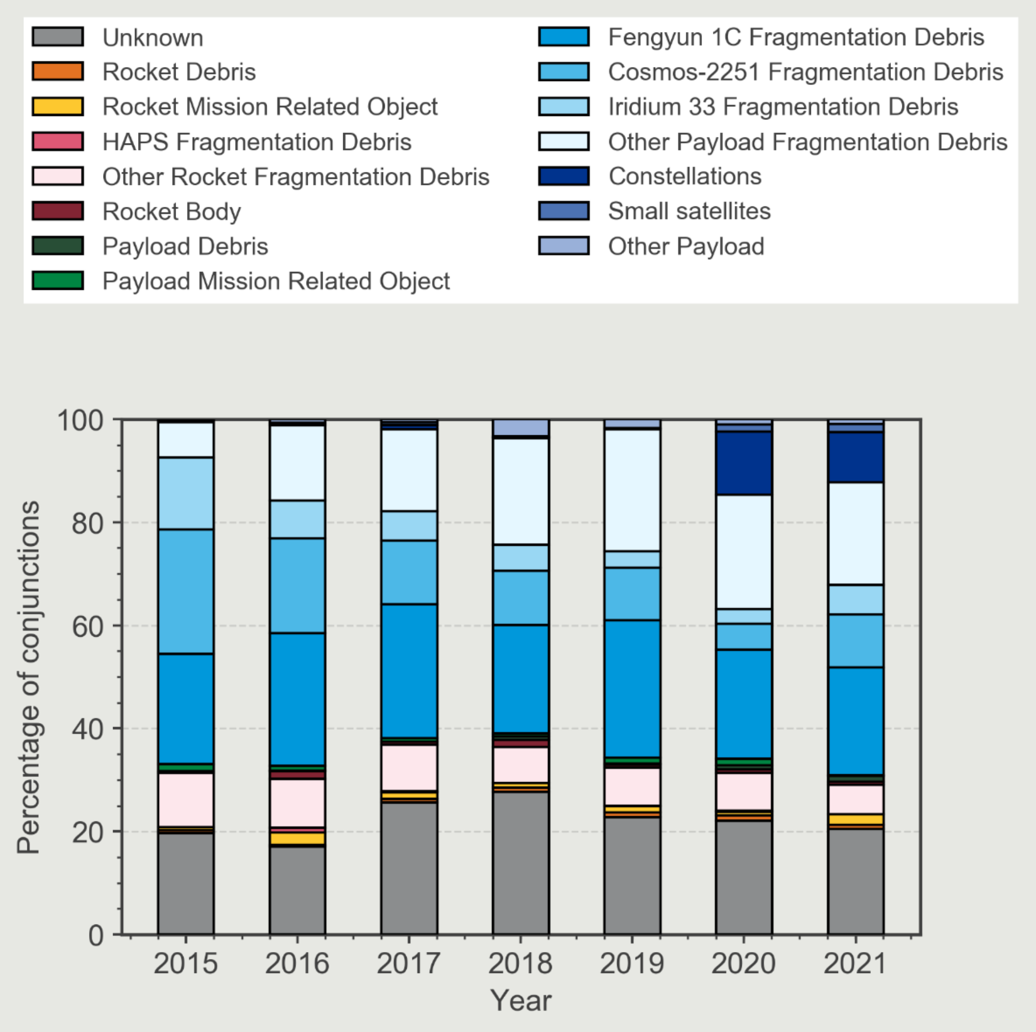


Conjunction statistics

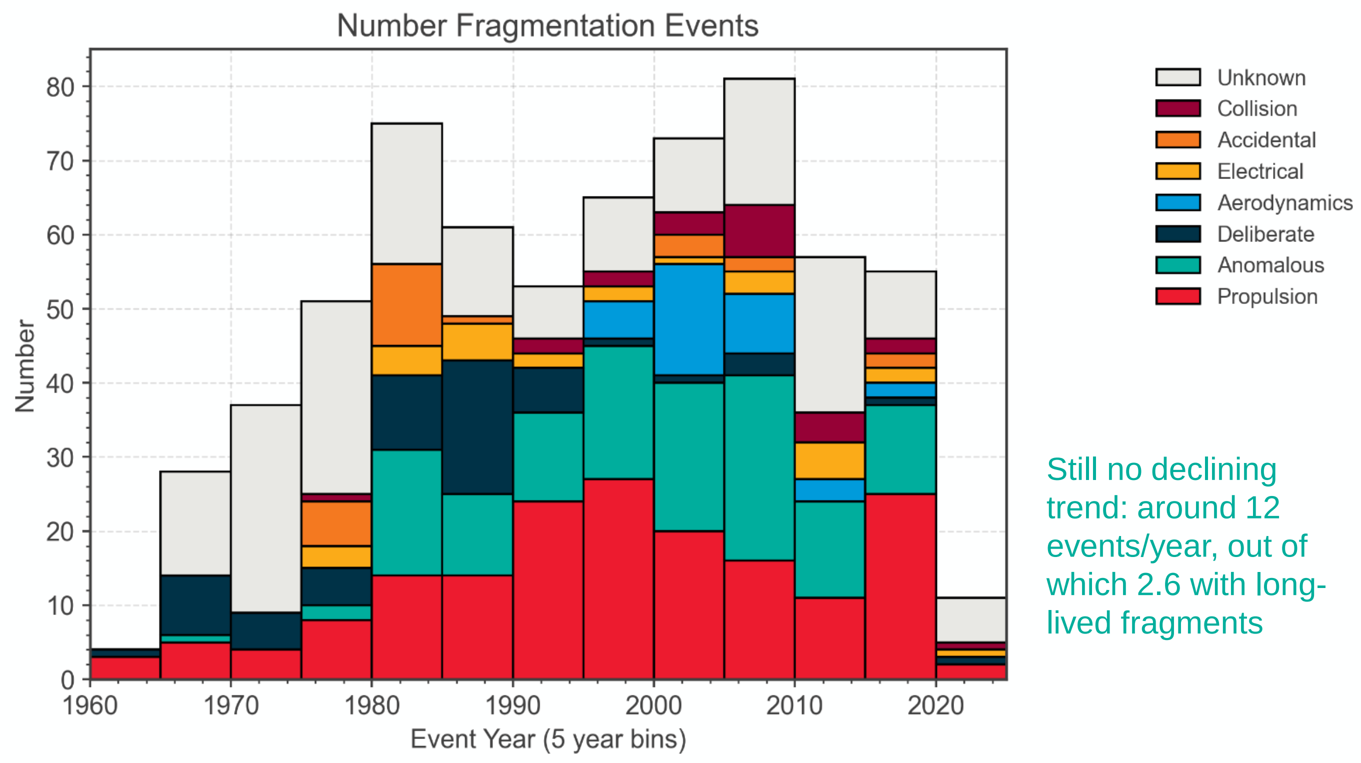
ESA and Copernicus missions in lower LEO (Aeolus and Swarm)



ESA and Copernicus missions in higher LEO (Cryosat-2 and Sentinels)



In-orbit fragmentations



Still no declining trend: around 12 events/year, out of which 2.6 with long-lived fragments

ESA Environment Report
https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

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THE HISTORY OF SPACE DEBRIS CREATION

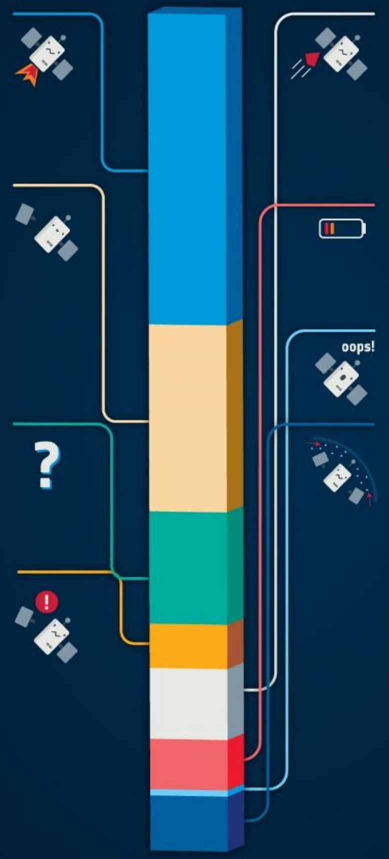
Since the beginning of the space age, there have been **more than 550 confirmed "fragmentation events"** in Earth orbit. Such events have various causes, and some are responsible for creating far greater **quantities of debris** than others.

PROPULSION – 39.52%
Energy left undisposed of on-board a satellite or rocket body can lead to **accidental explosions**, for example due to heat stress.

DELIBERATE – 23.77%
All **intentional breakup events**, e.g. satellites designed to explode if atmospheric re-entry went wrong or detonated as standard procedure once the mission ended, as well as military tests.

UNKNOWN - 14.29%
Assigned whenever there is **insufficient evidence** to support a more specific classification.

ANOMALOUS – 5.64%
Unplanned separation of one or more detectable objects from a satellite that remains essentially intact, e.g. objects shedding due to material degradation such as insulation material or solar panels.



COLLISION – 9.01%
There have been **several collisions observed** between known objects. In some cases, the impactor is too small to be observed, but changes in the orientation and functioning of the satellite indicate an impact has occurred.

ELECTRICAL – 6.4%
Events related to **failures in electrical subsystems**, most due to overcharged batteries exploding.

ACCIDENTAL – 0.8%
Design flaws ultimately leading to breakups.

AERODYNAMICS – 0.56%
A breakup most often caused when **atmospheric drag leads to "overpressure"**.

Thanks to current knowledge and technological development, there will likely be far **fewer propellant-fuelled explosions in the future.** However, with space traffic increasing, the number of **in-space collisions are bound to rise.**

Debris mitigation rules require satellites to be 'passivated' at the end of their life. **ESA is developing technologies to passivate** electrical and propulsion systems, reducing debris creation.

Up-to-date as of December 2020

→ THE EUROPEAN SPACE AGENCY

Space for our modern societies

ESA's activities supporting about 230 000 jobs in Europe ➔ only 5-6% of global

Global space economy: US$447B in 2020 (source: statista)

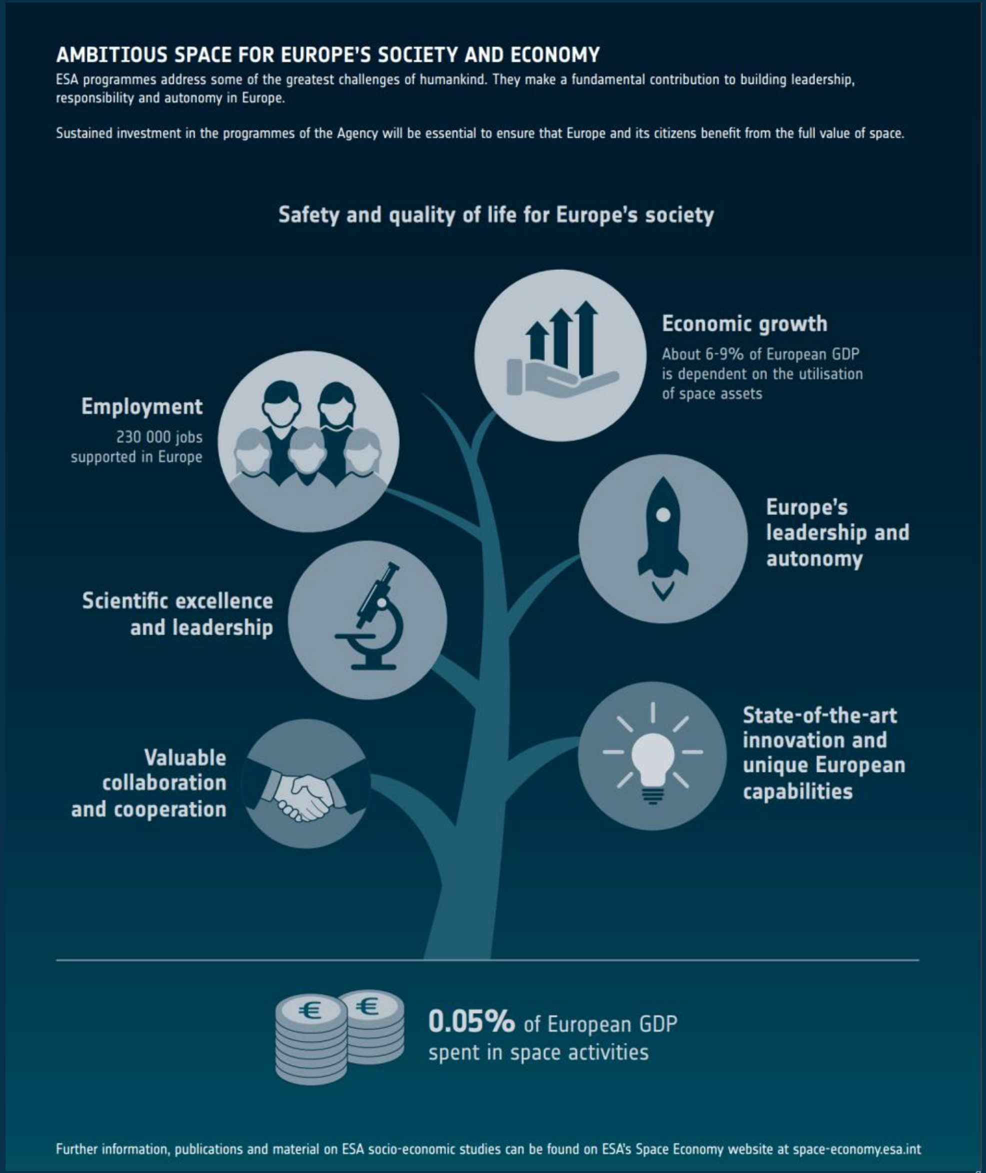
2021: European space industry

- 29% of the global upstream market (=9B€)
- 24% of the global downstream market (=60B€)

ESA responsible for almost 60% of all space budgets spent in Europe

Outlook:

- **Cheaper commercial satellites (6 to 7 times below institutional/science)**
- Launch prices aiming at <10-20k$/kg
- Global revenue raising from US$350B to US$1T in 2040 (Morgan Stanley)
- Investment of US$150B into large constellations (Eurospace)
  - → **massive cost reductions in satellite design and operations**
  - → new service industry
  - → challenge for mitigating and managing space debris



Disposal statistics in LEO

Performance still far from target for satellites in LEO in non-natural compliant orbits

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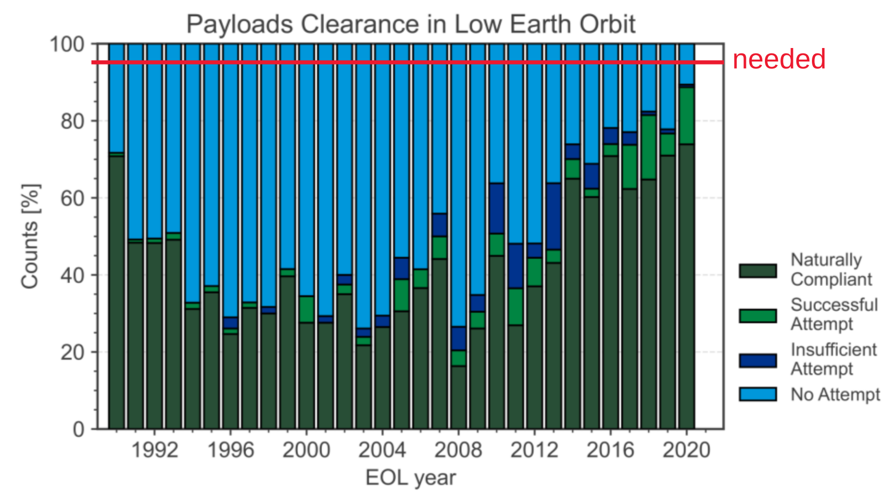
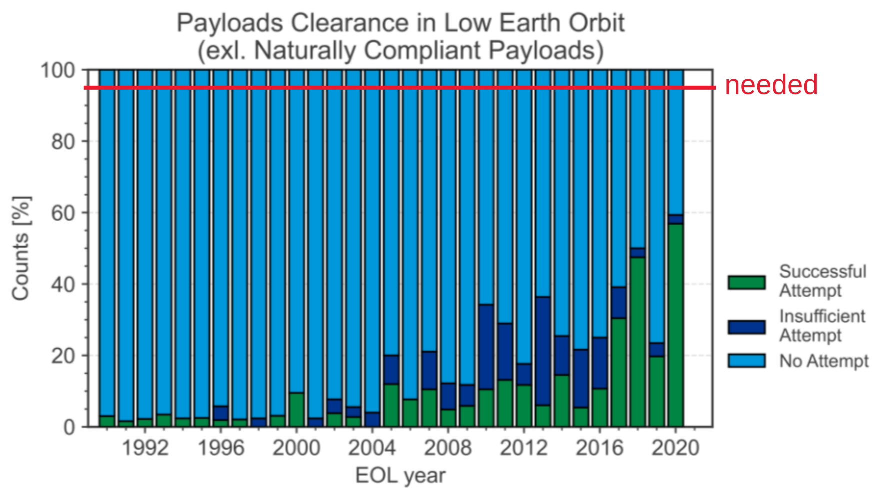
Shift towards operations in naturally compliant orbits





Improving performance over time for rocket bodies in LEO: less than 20% of stages left in non-compliant orbits

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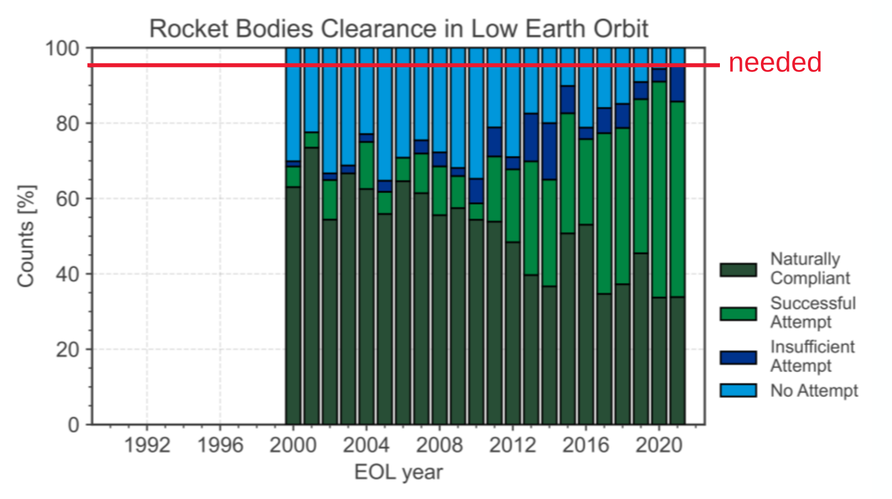
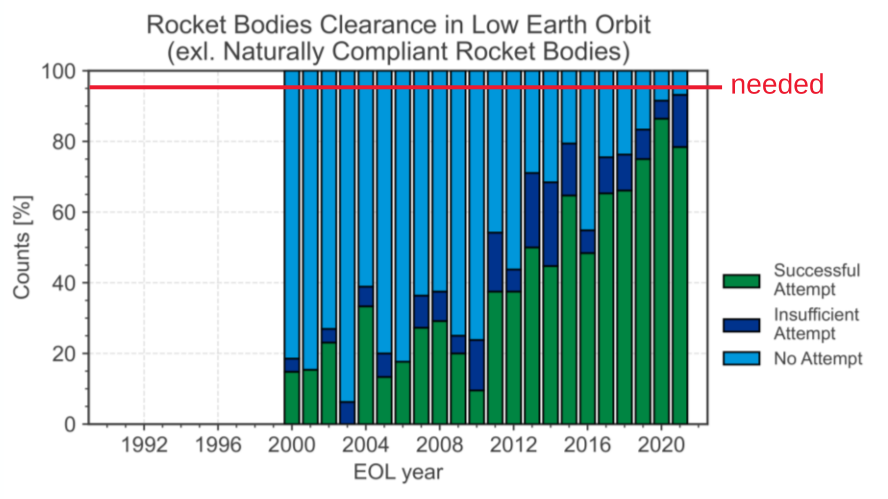
Increase of controlled re-entries





Uncontrolled Re-entry - risks

Proposed French airspace closures now active. ***Source:*** *Direction générale de l'aviation civile*

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THE ROLE OF REENTRIES

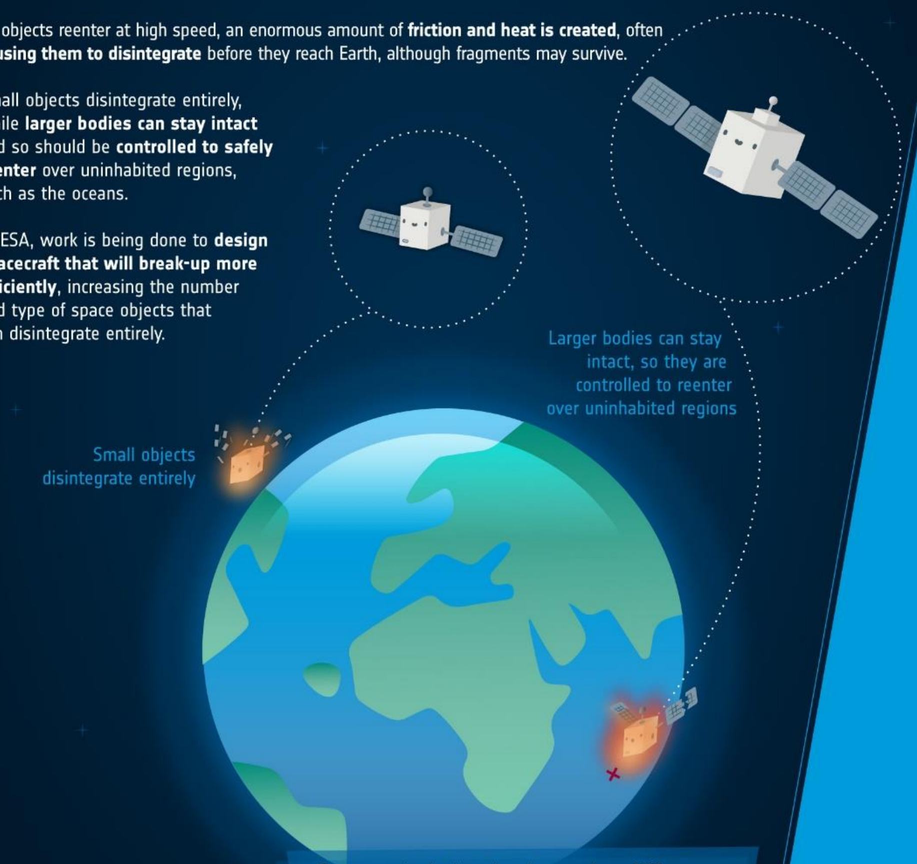
Every mission comes to an end – what then?

Rockets and satellites left in orbit can collide, creating dangerous debris. To comply with international debris mitigation guidelines, those in low-Earth orbits **should be designed to safely reenter Earth's atmosphere.**

As objects reenter at high speed, an enormous amount of **friction and heat is created**, often **causing them to disintegrate** before they reach Earth, although fragments may survive.

Small objects disintegrate entirely, while **larger bodies can stay intact** and so should be **controlled to safely reenter** over uninhabited regions, such as the oceans.

At ESA, work is being done to **design spacecraft that will break-up more efficiently**, increasing the number and type of space objects that can disintegrate entirely.



Every year in the last decade saw about 100 satellites and rocket bodies reenter Earth's atmosphere, with a total annual mass of roughly 150 tonnes (similar in weight to a small house!). Managing reentries is a fundamental aspect of ensuring the sustainable use of space.

Up-to-date as of December 2020

ESA's Space Safety Goals

- Space Weather early warning system tailored to European user needs
- Early warnings for asteroids >40 m about three weeks in advance,
- Capability to deflect asteroids smaller than 0.5 km (2 years before)
- Established European players for a growing market of space-traffic technologies and products
- Prepare European industry for a zero-debris policy and a circular economy in space

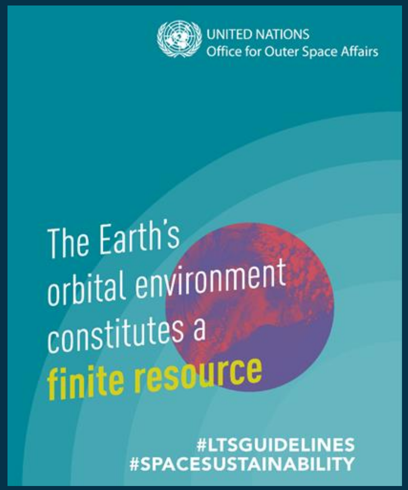
What's next? Space Traffic Management (STM)

New Space reality calls for

- Ensuring safe operations
- Facilitating close proximity operations
- Supporting ground- and space-based infrastructure.

➔ European STM

1. Improvement of sensor capabilities
2. New service developments
3. Technologies from academic and commercial research



UN COPUOS Working Group on Long Term Suitability of Outer Space Activities

- 2005 IADC Space Debris Mitigation Guidelines (revised 2007)
- 2007 UN Space Debris Mitigation Guidelines (7 guidelines)
- 2010 - 2018 UN COPUOS Working Group on the Long-term Sustainability of Outer Space Activities (21+ guidelines)
  - A Policy and regulatory framework for space activities
  - B Safety of space operations
  - C International cooperation, capacity-building and awareness
  - D Scientific and technical research and development (one GL originally proposed by CH)
- 2021 – 2025 New UN COPUOS Working Group on LTS

➔ non-binding (“soft law”)

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Meeting hosted by Switzerland on

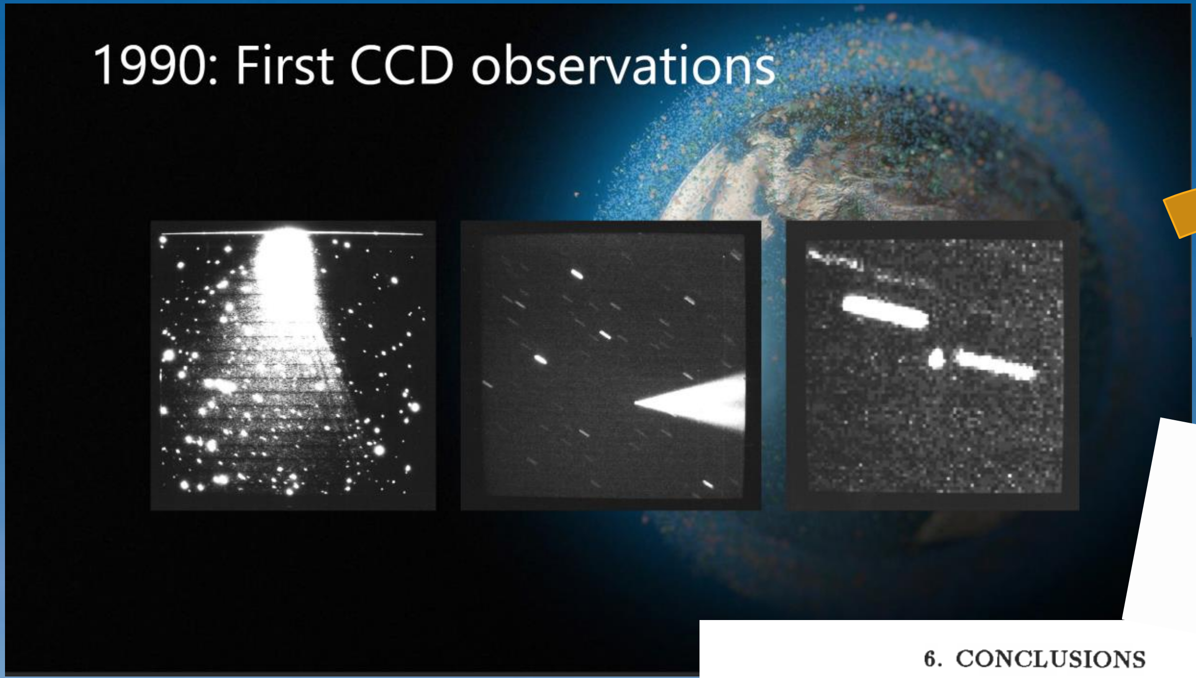
Possible further work on the long-term sustainability of outer space activities

Chaired by Dr Natália Archinard, Head of the Swiss delegation to UNCOPUOS, with the support of Prof. Thomas Schildknecht, Director of Zimmerwald Observatory, University of Berne

Tuesday 11 June 2019, 9:30-18:00

Board Room D, Vienna International Center

Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald



Proceedings of the First European Conference on Space Debris, Darmstadt, Germany, 5-7 April 1993 (ESA SD-01)

GROUND BASED OPTICAL OBSERVATIONS OF SPACE DEBRIS USING CCD TECHNIQUES

T. Schildknecht, U. Hugentobler, A. Verdun, G. Beutler
Astronomical Institute, University of Berne, Switzerland

6. CONCLUSIONS

The simulations show that it is feasible to observe objects down to a size of 5 cm in GEO or GTO and down to 1 cm in LEO (assuming an albedo of 0.3) using a moderate size telescope of 1 m aperture and CCD image procesing techniques. The necessary effort for telescope control, data acquisition and real time processing, specially when observing objects in LEO, is considerable. Measurements stemming from the experimental setup at the Zimmerwald Laser telescope clearly demonstrate the potential of the technique.

From Zimmerwald experience to ESA's space debris surveys

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30 years of history in collaboration between ESA's OGS and AIUB

- CCD Algorithms for Space Debris Detection, 1993 – 1995
- CCD Off-line Data Processing System, 1995 – 1998
- Level-1 Telescope Control and On-line Data Processing System, 1996 – 2008
- Geostationary Orbit Objects Survey, 1996 – 2004
- Geostationary Transfer Orbit Survey, 1997 – 2005
- Space Debris Optical Observations and Analysis with ESA 1m Telescope, 2003 – 2009
- Upgrade #2 of the OGS (Optical Ground Station) Control System and Processing Software, 2004 – 2010
- Spectroscopic Measurements of GEO objects, 2008 – 2010
- Identification and Analysis of MEO Observation Strategies for a future European Space Surveillance System, 2008 – 2011
- Adaptation of the Planning Tool and Processing Software to the new SD Camera (OGS software), 2010 – 2014
- Development and Simulation of Strategies for the Detection and Tracking of MEO Objects, 2011 – 2013
- Framework Research Contracts on Optical Analysis of Space Debris Objects, 2013 - today

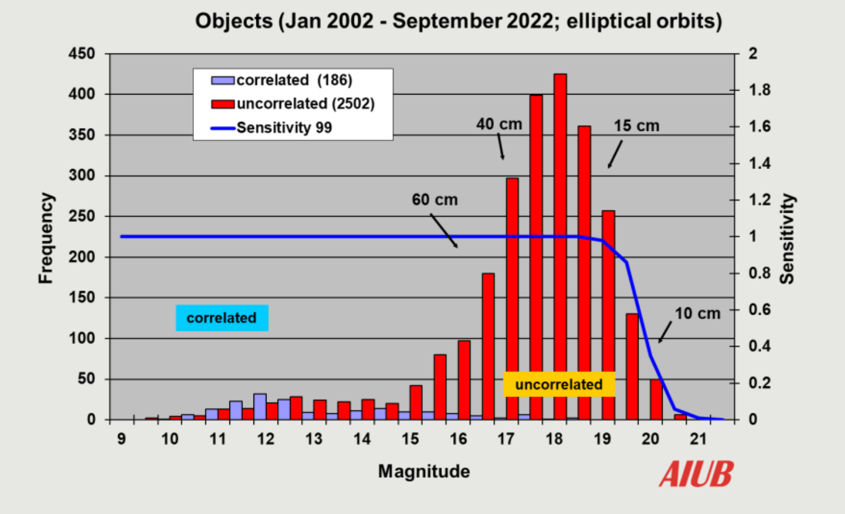
- (Plus numerous further activities in various consortia addressing space debris, SSA, and Space Safety)

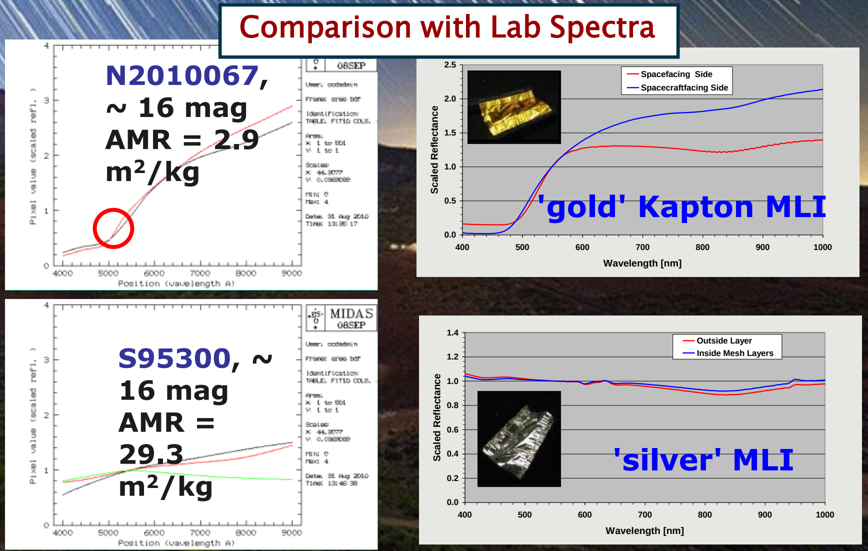
Highlights from 25 years of ESA's space debris surveys

- 1997 Test survey in Zimmerwald with 1-m telescope
- 1999 first light, first IADC GEO campaign (13 nights)
- 2001 discovery of large population of small-size objects in GEO
- 2002 discovery of at least 4 clusters of small debris at high inclination in GEO
- 2004 discovery of HAMR objects ➔ since then maintenance of orbits with Zimmerwald and other international partners
- 2010 first spectra of GEO HAMR debris
- 2011 small-size debris in GPS and GLONASS orbits found
- 2014 discovery of debris (HAMR) in Molniya orbits
- 2019 characterization of debris clouds from breakup events in HEO

➔ AIUB's support to surveys delivering essential input for ESA's MASTER model (~7000 users worldwide, baseline for DRAMA tool)

➔ Evolution into mission support and enabling new space safety activities (risk modelling, space debris consequences, space logistics)





ESA – AIUB collaboration – return in academic theses

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Lizentiat

- 1993 A.Verdun Objekterkennung und Zentroidbestimmung bei CCD-Richtungsbeobachtungen,

Master

- 1999 E. Wenger *CCD Positions of Slow Objects*
- 2001 R. Musci *Detection of Space Debris in the Geostationary Belt*
- 2014 K. Schild *Detection of Faint Streaks on CCD Images*
- 2015 E. Linder *Extraction of Space Debris Spin Rates from Optical Light Curves*
- 2015 J-N. Pittet *Attitude determination of passive orbiting objects using SLR data*
- 2021 G. Tornare *A method to derive angular observations of low earth flying objects without astrometric reduction*
- 2022 P. Rösli *Determination of the Rotation Axis Direction of Space Debris from Light Curves*

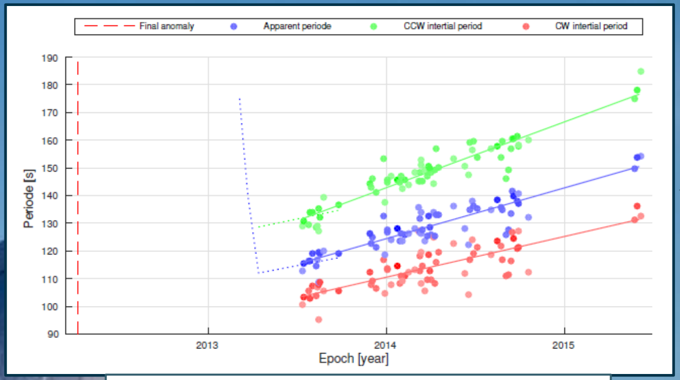
PhD

- 2006 R. Musci *Identification and Recovery of GEO and GTO*
- 2011 C. Früh *Astrometric Image Processing*
- 2011 T. Flohrer *Observation Scenarios for Space Surveillance*
- 2012 J. Herzog *Cataloguing High-Altitude Objects*
- 2017 M. Zittersteijn *Space debris cataloging of GEO objects by using meta-heuristic methods*
- 2017 E. Cordelli *Improvement of Space Debris Orbits*
- 2021 (with ESA) B. Reihs *Processing of Space Surveillance Observations*
- 2022 J. Rodriguez *Efficient Laser Ranging to Space Debris*
- 202x A Rachman *Attitude determination of inactive GLONASS satellites*
- 202x NN *Debris attitude motion and object characterization using high resolution single photon counter light curves*
- 202x NN *Improved orbits of space debris through multi-static laser ranging observations*

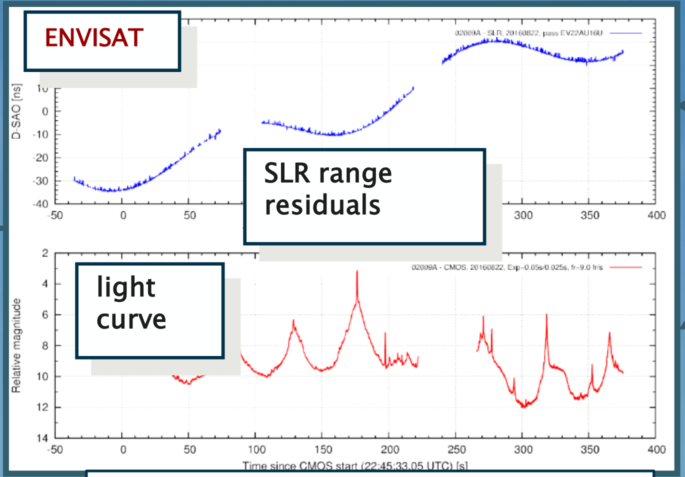
Habilitation

- 2004 T. Schildknecht *The Search for Space Debris in High-Altitude Orbits*

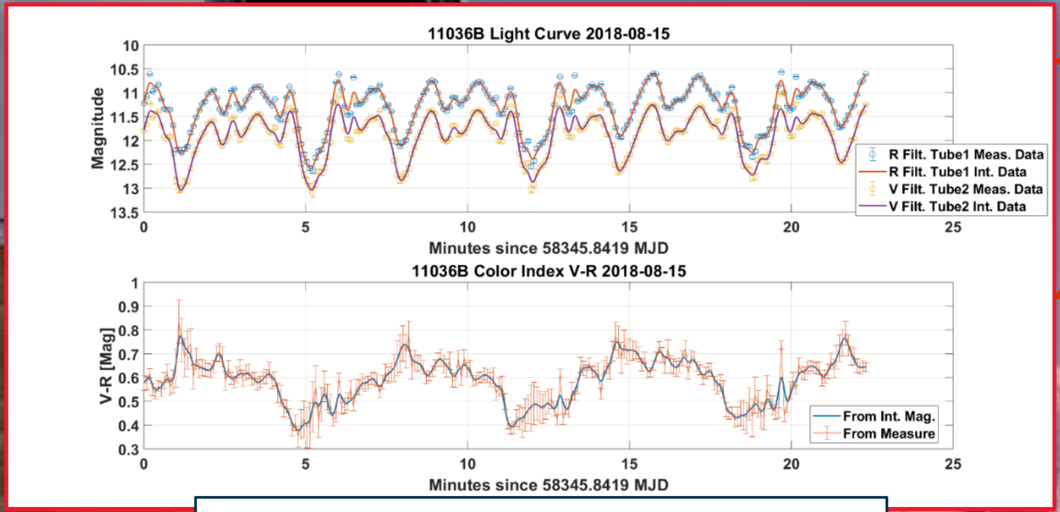
From data acquisition to data analytics -
Downstreaming ESA OGS and SwissOGS Optical Sensors



Evolution of attitude state

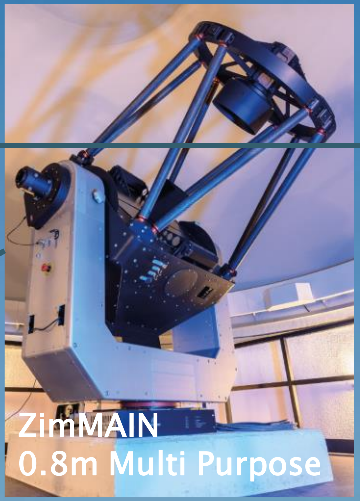


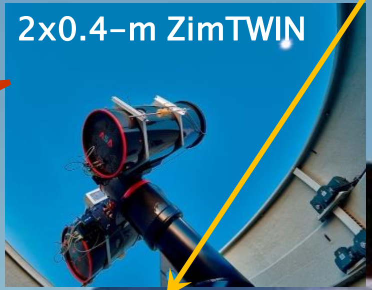
Tumbling motion estimation

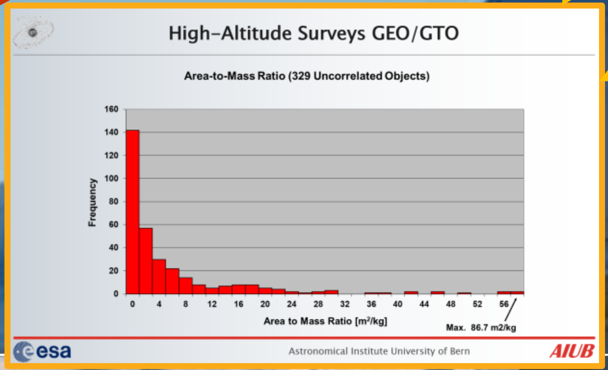


nozzle vs. top side color difference

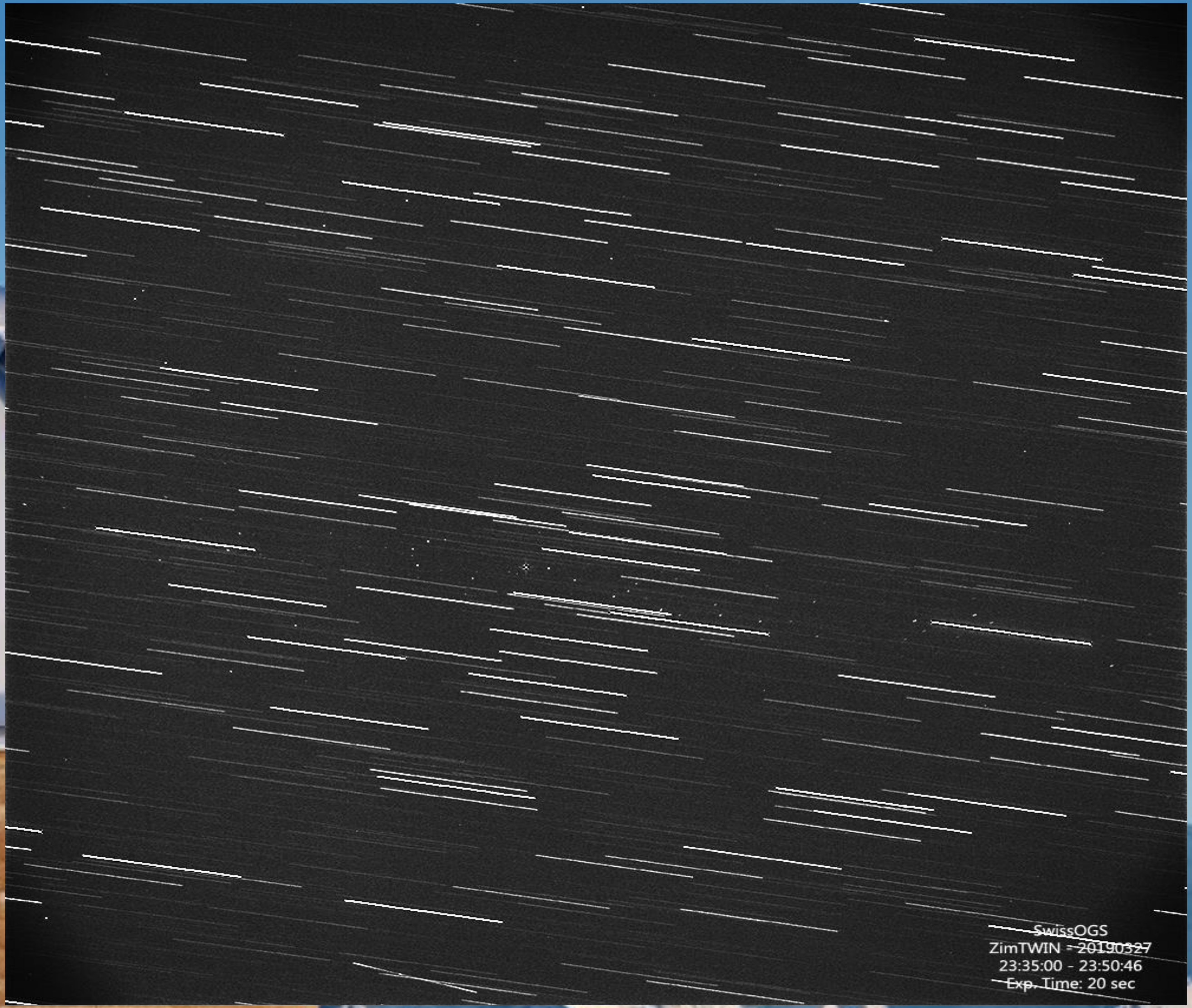
Simultaneous Multicolor Photometry







From data acquisition to data analytics - Outreach from first scientific results



SPACE SAFETY

https://www.esa.int/Space_Safety/Rocket_break-up_provides_rare_chance_to_test_debris_formation

Rocket break-up provides rare chance to test debris formation

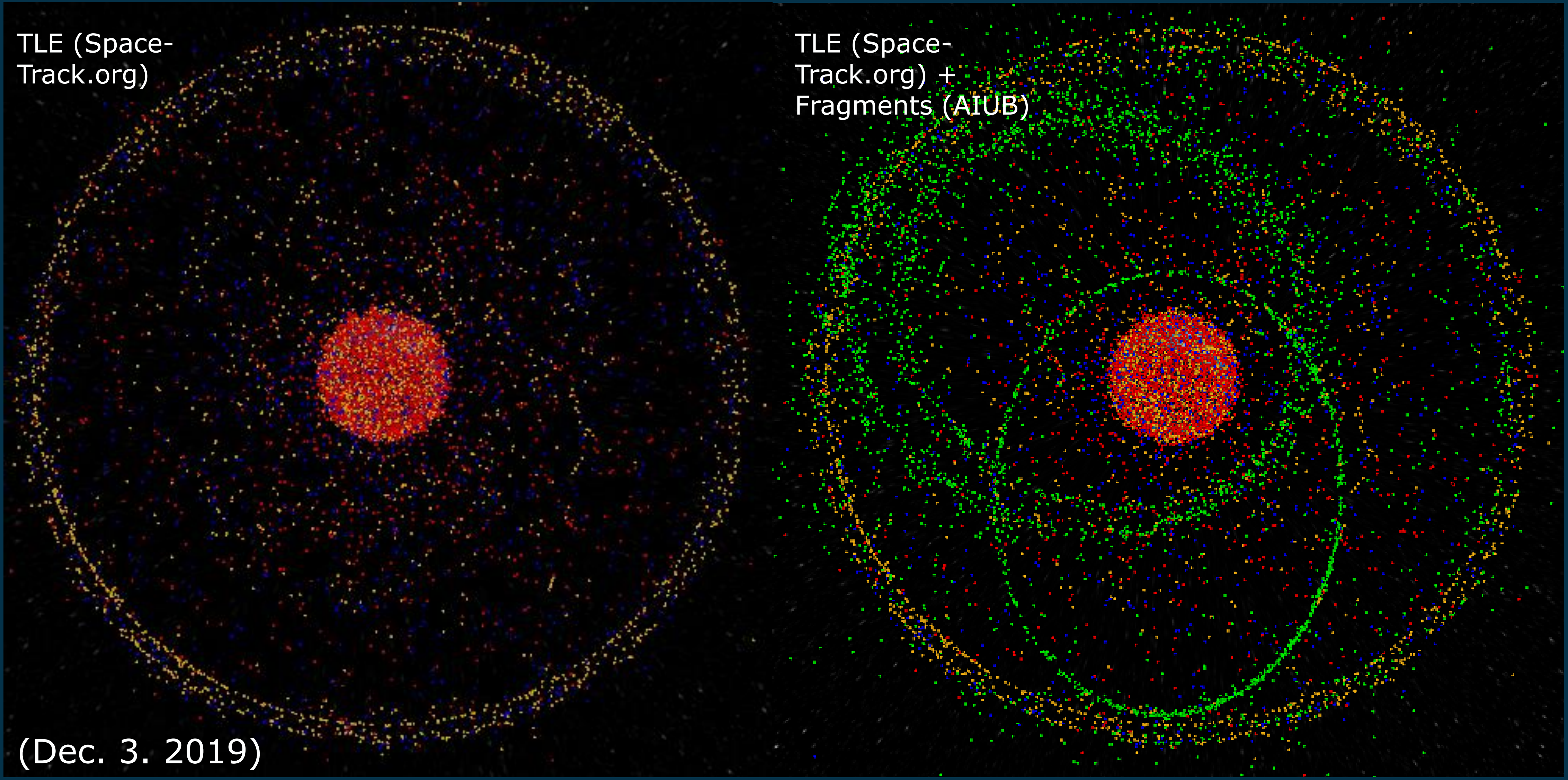
12/04/2019 9435 VIEWS 99 LIKES

ESA / Space Safety

The discarded 'upper stage' from a rocket launched almost ten years ago has recently crumbled to pieces.

"Leaving a trail of debris in its wake, this fragmentation event provides space debris experts with a rare opportunity to test their understanding of such hugely important processes", explains Tim Flohrer, ESA's Senior Space Debris Monitoring Expert.

From data acquisition to data analytics - Modelling input



Take home message

Space is …

- An indispensable resource for growth on Earth
- Supporting sustainability on Earth
- A limited natural resource and long-term sustainability of orbital activities must be ensured!

Space debris is …

- A topic of growing global concern and needs to be addressed through international collaboration
- Must be addressed in design and operation of all spacecraft
- A problem that cannot be understood and solved without scientific expertise
- Exists in Cislunar space (…)

AIUB and its observatory

- Help to manage the critical space debris challenges for space utilisation today
- Provide and develop the infrastructure for data acquisition, modelling, and collaborative observation technology
- Success in supporting the growing space safety and STM domains (commercialisation, downstream use of data, analytics)
- Research opportunities for the next generation of scientists and engineers at all steps
- Contribute central expertise to policy building and implementation at international levels