DOI: ADD DOINUMBER HERE

SWISS SPACE SUSTAINABILITY RESEARCH DAYS 2025: OUTCOMES AND STRATEGIC ROADMAP

Emmanuelle David, [1†] *Merve Erdem Burger* [2], *Chris Finnlay* [3], *Benjamin Guyot*[4], *Stephan Hellmich* [1]

, *Lucia Kleint*[5], *Andreas Losch* [6], *Deborah Mueller* [7], *Clemence Poirier* [7], *Karin Treyer* [8]

, *Mathieu Udriot* [1] *Marnix Verkammen* [1]

* [1]EPFL, Lausanne, Switzerland, [2]SwissSpace Law Forum, Neuchatel, Switzerland, [3]UniGeneve, Geneva, Switzerland, [4]Spacetalk, Lausanne, Switzerland, [5]UniBern, Bern, Switzerland, [6] University of Zurich, Zurich, Switzerland, [7]ETHZ, Zurich, Switzerland, [8]PSI, Villigen, Switzerland

Emmanuelle.david@epfl.ch, merverdemburger@gmail.com, christopher.finlay@epfl.ch, benjamin.guyot@spacetalk.ch, stephan.hellmich@epfl.ch, lucia.kleint@unibe.ch, andreas.losch@uzh.ch, deborah.mueller@sl.ethz.ch, karin.treyer@psi.ch, clemence.poirier@sipo.gess.ethz.ch, mathieu.udriot@epfl.ch, marnix.verkammen@epfl.ch

[†] *Corresponding Author*

Abstract

The inaugural Swiss Space Sustainability Research Days (January 6-8, 2025, Les Diablerets) united 55 experts from academia, industry, and government to address space sustainability challenges. Through presentations, workshops, and collaborative sessions, participants explored sustainability on Earth from space and sustainability in space, advancing Switzerland's role in sustainable space activities. The event mapped Swiss competences including space weather monitoring, situational awareness, life cycle assessment, and legal aspects. The outcomes strengthened the Swiss space sustainability community's collaborative framework and reinforced Switzerland's position in coordinating research, facilitating knowledge transfer, and leading sustainable space practices within the European space sector

1. Introduction

The Swiss Space Sustainability Research Days [1], held from January 6-8, 2024, in Les Diablerets, Switzerland, marked a pivotal moment for the Swiss space community's commitment to sustainable space activities. This three-day gathering brought together more than 50 experts, including PhD candidates, postdocs, senior researchers, professors, R&D specialists, and industry professionals from all key Swiss research institutions and organizations with significant interests in space sustainability research and development.

The event was strategically designed to address the growing urgency of incorporating sustainability principles into all aspects of space activities. Day one featured compelling keynote presentations and engaging panel discussions that set the foundation for deeper technical exchanges. Days two and three expanded into comprehensive scientific presentations, hands-on workshops, and collaborative poster sessions, creating multiple opportunities for knowledge sharing and networking among participants.

The research discussions encompassed six critical areas that define the current landscape of space sustainability: the environmental impact of space activities on Earth and in space, advances in Space Situational Awareness (SSA) and Space Domain Awareness (SDA), cutting-edge technologies enabling sustainable space operations, space weather

phenomena and their far-reaching implications, initiatives to preserve dark and quiet skies, and the evolving framework of space law and policy.

Beyond academic discourse, this gathering served multiple strategic purposes for Switzerland's space sector. Participants contributed valuable insights for developing Swiss space law, provided essential input for the upcoming ESA Ministerial Conference, explored new Swiss space capacity-building initiatives, and began shaping ideas for establishing a large-scale Swiss consortium dedicated to space sustainability.

The overarching vision that guided these discussions was clear: sustainability must transition from being a peripheral consideration to becoming a central priority within Swiss research activities. This report captures the key insights, innovative solutions, and collaborative frameworks that emerged from this landmark event, documenting the collective expertise and forward-thinking approaches that will help define Switzerland's role in promoting sustainable space exploration and utilization for years to come.

This comprehensive report is structured to provide detailed coverage of the event's core components: following this introduction, Section 2 presents summaries of the keynote addresses that opened the event. Section 3 examines the critical issue of space activities' environmental impact, including detailed workshop descriptions, mapping of expertise and collaboration opportunities, and key outcomes. The paper addresses dark and quiet skies initiatives in Section 4, followed by an exploration of emerging technologies for space sustainability in Section 5. Section 6 analyses the complex landscape of law, policy, ethics, and economics surrounding space sustainability. Finally, Section 7 synthesizes the event's results and presents overarching conclusions that will guide future Swiss space sustainability efforts.

Each section will present a short overview of the presentations, for more information on theses you can see the book of abstract from the conference. [2]

2. Framing Space Sustainability

The Swiss Space Sustainability Research Days brought together leading experts from academia, government, military, and industry to address the pressing challenges of maintaining a sustainable space environment. Five keynote presentations established a comprehensive framework for understanding and addressing space sustainability from multiple perspectives, demonstrating Switzerland's emerging leadership in this critical domain, and anchoring in a global landscape.

Summary of Keynotes

- Setting the Framework: Space Sustainability Framing

Emmanuelle David opened the conference by challenging traditional approaches to space sustainability. Rather than focusing solely on Active Debris Removal (ADR), she introduced the broader concept of space sustainability - a holistic approach that encompasses assessment of environmental impact and protection measures. This concept recognizes that space sustainability extends beyond debris mitigation to include planetary protection, asteroid defence, and comprehensive environmental stewardship. Her framework set up the basis that effective solutions require coordinated approaches addressing multiple environmental threats simultaneously, setting up the conceptual foundation for the interdisciplinary discussions that followed.

- Switzerland's Scientific Capabilities: Space Sustainability and Space Weather at the University of Bern

Prof. Lucia Kleint from the University of Bern showcased Switzerland's advanced capabilities in space monitoring through the Zimmerwald Observatory. The facility operates multiple telescopes ranging from 0.2m to 1m in diameter, with students conducting nightly observations as part of integrated research and training programs. The observatory's precision laser-ranging system, currently accurate to 12mm and soon upgrading to 2mm precision, exemplifies Switzerland's commitment to cutting-edge space surveillance technology.

Of particular significance is the observatory's work on space weather prediction. Prof. Kleint highlighted how solar storms can force electricity grid shutdowns, disrupt satellite operations, and block radar systems through ionospheric

disturbances. The potential threat of super flares, which could destroy modern technologies, underscores the urgency of this research. To address these challenges, the University is developing machine learning approaches for predicting solar eruptions and has applied for National Center of Competence in Research funding of approximately 80 million CHF over 12 years to establish a Swiss Space Weather Hub.

- International Governance: Space Sustainability at the United Nations

Natalia Archinard from the Swiss Foreign Affairs provided insights into Switzerland's diplomatic efforts in space governance. Since joining UNCOPUOS in 2008, Switzerland has actively contributed to international space policy development, including the Long-Term Sustainability guidelines adopted by consensus in 2019. A distinctive aspect of UNCOPUOS discussions is the emphasis on "equitable access to the benefits of space," reflecting the priorities of non-space-faring nations.

Switzerland participates actively in multiple working groups addressing space weather, Dark and Quiet Skies initiatives, and Space Traffic Management. The country's signing of the Artemis Accords demonstrates its commitment to sustainable lunar exploration frameworks. Archinard noted that while guidelines remain voluntary and non-legally binding, there exists a strong mutual understanding among signatories that space exploration must be conducted sustainably. The increasing politicization of issues like constellation deployment in conflicts presents new challenges for international consensus-building.

- Military Perspectives: Sustainability of Space Operations

Col. Ludovic Monnerat presented a sobering analysis of the evolving space security landscape. With over 14,000 satellites currently in orbit and more than 10,000 operational, the space environment has transformed dramatically since 2013. The progression from individual CubeSats to mega-constellations like Starlink represents not just technological advancement but strategic competition, particularly between the United States and China.

The colonel characterized space as becoming a "place of confrontation" where both offensive and defensive capabilities are being developed. He cited concerning developments such as France's laser weapons program and the emergence of de facto territorial claims in certain orbits. From a military perspective, space sustainability links to peace preservation, requiring transparency in operations, automatic identification systems like maritime and aviation sectors, and robust enforcement mechanisms. The military advocates for mandatory sharing of position data, operational status, and planned manoeuvrers to ensure safe operations for all space users.

- Industry Implementation: Amazon Kuiper Space Sustainability Framework

Yash Chandramouli presented Amazon's approach to deploying one of the world's largest satellite constellations sustainably. The Kuiper project, involving 3,232 satellites across multiple orbital planes, aims to address the connectivity needs of one billion unserved households globally. With over 2,000 employees and more than 80 secured launches, the project represents the largest commercial procurement of launch vehicles in history.

Amazon's sustainability framework encompasses four pillars: in-space operations with advanced collision avoidance and data sharing; re-entry and demise protocols including complete spacecraft demise design; atmospheric effects research investigating metal deposition during re-entry; and Dark and Quiet Skies initiatives in collaboration with the astronomy community. Notably, Amazon implements active deorbiting within one year - driven by business considerations rather than regulatory requirements - demonstrating how commercial incentives can align with sustainable practices.

The speaker addressed three common misconceptions about constellation sustainability. First, that space sustainability is "solved" when significant challenges remain. Second, that LEO is too crowded for additional satellites, when MIT studies suggest proper technology investments could support over 2 million satellites safely. Third, that constellations

lack intrinsic motivation for sustainable behaviour, when business interests create strong incentives for responsible operations.

- Academic Innovation: Space Sustainability Research at Politecnico di Milano

Prof. Camilla Colombo from Politecnico di Milano presented ground-breaking research on space debris assessment and mitigation. The THEMIS (Tracking the Health of the Environment and Missions in Space) software tool represents a revolutionary approach to sustainability assessment, combining collision and explosion probabilities with their respective effects to create comprehensive risk profiles. The tool operates in both Space Debris Mode for individual mission assessment and Space Capacity Mode for overall utilization evaluation.

The COMPASS group's research extends beyond traditional trackable objects to include lethal non-trackable fragments larger than 1cm, using advanced modelling techniques like the STARLING method for probabilistic debris cloud propagation. The group's Green Species Project, funded by the European Research Council, aims to develop robust space debris population control through an interdisciplinary framework combining modelling, control theory, and policy development.

Synthesis: Switzerland's Comprehensive Approach

These keynote presentations collectively demonstrated Switzerland's multi-faceted approach to space sustainability. The country combines world-class research facilities, active diplomatic engagement, military preparedness, and industrial collaboration to address sustainability challenges comprehensively. Several key themes emerged across all presentations:

Systemic thinking is essential - space sustainability cannot be addressed through isolated interventions but requires integrated approaches addressing multiple challenges simultaneously. **Technology innovation** provides the foundation for solutions, from advanced monitoring capabilities to autonomous collision avoidance systems. **International cooperation** remains crucial, as effective governance requires consensus-building and equitable frameworks that balance the needs of all stakeholders.

The presentations emphasized that **practical implementation** matters as much as theoretical frameworks. Solutions must be technically feasible, economically viable, and implementable in the near term as constellation deployment accelerates. Finally, **shared responsibility** emerged as a central principle - all space actors, whether governmental, military, or commercial, must contribute to maintaining the space environment for future generations.

Switzerland's leadership in space sustainability rests on its ability to bridge different communities and perspectives. The academic excellence demonstrated by institutions like the University of Bern and international collaborations provides the scientific foundation for evidence-based decision-making. Swiss diplomacy at the UN level helps translate technical solutions into policy frameworks. Military perspectives ensure security considerations are integrated with sustainability objectives. Industrial partnerships demonstrate that commercial success and environmental responsibility can be mutually reinforcing.

As space activities continue to expand exponentially, the frameworks and collaborations established during these keynote sessions provide a roadmap for sustainable development. The challenge now lies in implementing these concepts rapidly enough to preserve the space environment while enabling the benefits of space technology to reach all of humanity. Switzerland's comprehensive approach, combining innovation, diplomacy, security, and commercial engagement, offers a model for how nations can contribute meaningfully to global space sustainability efforts.

3. Impact of Space activities

This session delved into the growing environmental challenges posed by space activities, focusing on the urgent need for innovative frameworks, tools, and policies that foster sustainability in orbit and beyond. The presentations examined cutting-edge approaches to debris management, from the conceptual evolution of zero debris and net zero debris strategies to advanced numerical models for fragmentation and the integration of Life Cycle Assessment (LCA) methodologies into mission design and planning. By bringing together perspectives from industry, academia, and

policy, this session aimed to highlight both the risks of inaction and the opportunities for building a more responsible and resilient space environment.

Summary of the presentations

- *Zero debris vs. net zero debris: Why the difference matters for the future of space activities by Romain Buchs (Clear Space Switzerland):*

The presentation introduced and compared the emerging concepts of zero debris and net zero debris in the context of space sustainability. While *zero debris* focuses on preventing any debris from individual missions, an idealistic principle promoted notably by ESA, *net zero debris* offers a more pragmatic and holistic approach, allowing for balancing debris creation with remediation efforts across missions. Inspired by climate change frameworks like net zero emissions, this approach recognizes the existing debris-filled environment and aims to develop metrics and policies that incentivize responsible behaviour, particularly for satellite constellations and commercial operations. The current regulatory system lacks clear environmental goals, and net zero debris could fill that gap by encouraging international alignment, shared commitments, and measurable sustainability outcomes in space activities.

- *A numerical approach for dynamic fragmentation: Challenges in achieving reliable statistics for space debris by Thibault Ghesquière-Diérickx (EPFL, LSMS):*

The presentation outlined a research project focused on developing a scalable, physics-based, open-source simulation tool to better understand and model space debris fragmentation. With approximately 34,000 objects larger than 10 cm and an estimated 129 million smaller fragments in orbit, many too small to be tracked, collision risks are increasing, particularly following the rapid growth of commercial space activity since 2015. The project examines three approaches to studying debris dynamics: experimental tests using high-speed cameras, theoretical modelling with simplifying assumptions, and numerical simulations.

The research team focuses on the numerical approach, employing the finite element method combined with cohesive zone models to simulate crack initiation, propagation, and fragment formation during high-velocity impacts. These simulations emphasize energy conservation and accurate spatial discretization to ensure physical reliability. Initial results show realistic energy transfer and fragmentation patterns, supporting the development of statistical data on fragment size, velocity, and mass. This data will feed into long-term models for orbital debris evolution. The project is a collaboration between two research labs, EPFL LSMS focusing on computational modelling, and Centrale Nantes contributing additional research, supported by the Swiss National Science Foundation. The aim is to create an accessible tool that can aid companies, agencies, and researchers in better understanding and managing space debris.

- *Estimating the environmental impacts of human activities related to space with life cycle assessment: Status quo and outlook by Karin Treyer (Paul Scherrer Institute):*

The presentation highlighted the expanding role of Life Cycle Assessment (LCA) in promoting sustainability within the space sector, extending beyond the traditional economic concerns—such as space debris threatening business interests to include environmental and social dimensions. While LCA is a well-established tool in other industries for evaluating environmental impacts across a product or service's life cycle (from raw material extraction to disposal), its application in space is still emerging. ESA and EU task forces are actively developing standardized guidelines and databases, aiming to make LCA a mandatory part of mission planning and sustainability reporting. Unlike narrow tools like carbon foot printing, LCA captures a wide array of environmental impacts, such as ozone depletion, acidification, resource use, and toxicity.

However, implementing LCA in the space sector presents unique challenges: (a) data gaps exist for space-specific materials, propellants and processes; (b) emissions from launch and atmospheric re-entry in high-altitude are not known in detail, and resulting environmental impacts are still not fully understood; (c) to guide eco-conscious decisions, engineers should integrate LCA early in the design process – which is when the data basis is still incomplete. (d) assessments should be carried out by trained experts using a shared framework to ensure consistency and reliability, which is not yet streamlined in the space sector. Furthermore, sustainability efforts must go beyond individual missions to assess the sector as a whole, accounting for potential accumulation effects and long-term environmental consequences due to the fast-growing space sector. ESA has already applied LCA in major programs like Copernicus

and Galileo, and is targeting a 46% reduction in greenhouse gas emissions by 2030[1]. Ultimately, enhancing LCA methodologies will support more responsible, transparent, and informed decision-making in space activities, contributing to long-term sustainability and aligning with broader environmental policies on raw materials consumption and sustainable production.

- *Sustainability for space: Identified knowledge and data gaps, and research opportunities by Mathieu Udriot (École Polytechnique Fédérale de Lausanne):*

The presentation highlighted the development of a specialized Life Cycle Assessment and Comparison Tool (ACT) for the space sector, initiated through an ESA-funded project to address the growing need for addressing environmental sustainability in space missions. Traditional LCA methods are not fully equipped to handle the unique characteristics of space systems, such as long development timelines, low production volumes, specialized and often confidential materials, and limited environmental data—particularly for launch and re-entry phases. The initial one-year project successfully produced a proof of concept, leading to a second phase focused on refining ACT for broader industrial use. The tool enables engineers to integrate environmental criteria early in the design phase, supports prospective assessments for systems launching in the future, and uses databases tailored to space-specific materials and propellants. It allows users to model missions, define technical parameters (e.g., trajectories, REACH-regulated materials), and calculate environmental indicators, helping to identify design hotspots for eco-optimization[3]. However, the project also revealed major gaps, including a lack of both foreground (mission-specific) and background (industry-wide) data, especially during design, manufacturing, testing, and refurbishment stages. Methodological challenges persist, such as the need for simplified LCA approaches suitable for early-stage design and the integration of new impact categories like space debris, high-altitude emissions impacts, and re-entry-related ocean impacts—none of which are currently addressed by ISO LCA standards [4].

Summary of workshop: Common language and definition of space sustainability

The goals of this workshop were that participants: (1) develop a mutual understanding of space sustainability, (2) Identify and prioritize topics / actions relevant for space sustainability and (3) get an insight in the expertise which exists in Switzerland with regards to space sustainability. The workshop was attended by 35 conference participants and ran for 1.5 hours. It was a success in the way that it fostered discussions on what space sustainability should be, which aspects are most needed to increase space sustainability, and which expertise exists in Switzerland to tackle them.

A dedicated introduction into “space sustainability” was not part of the workshop, as keynotes and session presentations which had taken place before the workshop have already prepared the floor for directly diving into discussions. Main sustainability definitions mentioned in the presentations before the workshop Are the definition provided in 2018 by the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) for the Long-term Sustainability of Outer Space Activities and its extended version by Wilson et al. [5] introducing the three pillars of space sustainability. Discussions during the first part of the workshop further based themselves on theses pillars:

- **Sustainability from space** for activities which use space to tackle global problems, i.e., for enhanced sustainability on Earth with the help of the use of space in the narrative “Because we use space, we are better down here on Earth.”
- **Sustainability in space** when space is viewed as a “natural resource for preservation, exploitation and exploration “. (Nowadays the aspect most meant with space sustainability as it affects economic interests)
- **Sustainability for space:** “Protecting the terrestrial environment from the impacts of space activities”.

The workshop was started by a short icebreaker, from which three questions were derived to be discussed in groups (*Figure 1*). After a summary of those group discussions, the plenum moved forward to list current and future projects and map complementary expertise.

[1] https://www.esa.int/About_Us/Climate_and_Sustainability/The_ESA_Green_Agenda

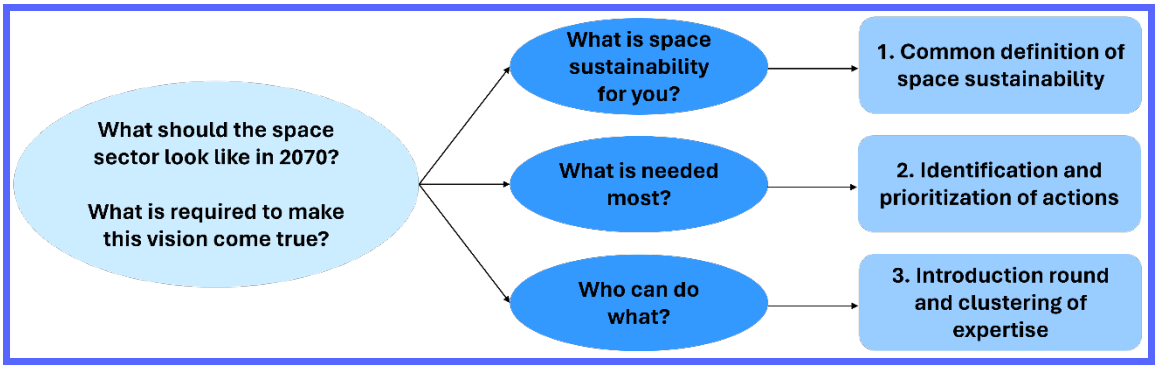

Figure 1- Icebreaker used as introduction to the workshop (left) and derivation of workshop goals (middle/right).

- Three groups of ca. 10 people rotated every 10 minutes between three flipcharts representing one topic each. What is (space) sustainability for you (Sustainability for/in/from space)? The goal was to create a common definition in the room of what space sustainability should be, and interact on different understanding of this term. Identification & Prioritization: What is needed most to reach sustainability in the space sector from the viewpoint of your background and experience? The goal was to identify aspects and prioritize them into urgent, important, or nice-to-have. The result of this discussion is summarised in ***Table 1***.
- Who is doing what? Which expertise do we have in the room? The goal was to get to know and understand each other. The majority of the attendees came from research and policy. Minorities were present from law, communication, technology engineering, and security.
- After the group work, the plenum reconvened on an online whiteboard to note down and cluster existing projects, collaboration ideas, needed expertise, potential co-supervision of students, and existing funding opportunities on an online whiteboard. As many projects and ideas were reported within a short time frame, the conclusion was that an online sharing platform set up after the conference would be helpful to continue with this collection to support materialization of projects and collaborations.

Table 1 : Clustering the main keywords given and prioritized by the workshop attendees into topics. Topic clustering was made by workshop moderators after the workshop, which might imply the risk of misunderstanding certain keywords.

Topic cluster	Urgent	Pressing	Less pressing
Coordination / cooperation and responsibilities	SSA capabilities (in orbit) Define maximum space capacity Phone book for coordination Global traffic management / coordination increase (public) awareness	Inter-operability (standard) Incentives for good behaviour "Public-eye" for space (NGO) Beyond Earth orbits	De-militarisation of space
Regulations / governance	Enforcing existing laws	Regulate unintended emissions Rules for human exploration Protect dark and quiet skies	Regulate space-based light pollution
Technologies / Science	ADR for large debris Measurements campaigns Quantify launch and re-entry emissions Standard simulation models and metrics Eco-design	Test and scale space robotics Understand space weather Increase satellite cybersecurity Improve radiation-hard hardware	
Concept by one of the groups	ENFORCE existing laws	AGREE on next steps based on our current knowledge	DISCUSS

Conclusions and main outcomes

The presentations in this session underscore the critical role of comprehensive, data-driven, and interdisciplinary approaches to ensuring the long-term sustainability of space activities. From refining models of debris generation to applying holistic LCA frameworks, the presenters have identified key knowledge gaps and outlined innovative solutions to manage environmental impacts throughout the entire lifecycle of space missions. During the workshop, insights from the participants highlighted the need for international collaboration, standardized practices, and forward-looking policies that address not just immediate technical concerns but also the broader ecological and societal implications of space exploration and commercial activities. By embracing these challenges, the space sector can contribute to a safer, cleaner, and more sustainable future in space and on Earth.

4. Dark and Quiet Skies

This session brings together experts and initiatives dedicated to safeguarding the natural night sky from the increasing disruptions posed by satellite constellations, space debris, and commercial ventures. The presentations explore the growing challenges to both optical and radio astronomy, as well as the broader environmental and cultural impacts of bright skies. Key topics include the IAU Centre's global efforts to mitigate satellite interference, Swiss contributions to balancing technological progress with astronomical research, advocacy for protected radio frequencies, innovative monitoring of space debris, and the threat of space-based advertising to ecosystems. Together, these presentations highlight the urgency of implementing technical, regulatory, and policy solutions to preserve the celestial sphere for

science, ecosystems, and humanity's shared heritage. This session also led to the publication of a paper at the European Space Debris Conference in Darmstadt. [6]

Summary of presentations

- *Three years of the IAU Centre for the Protection of the Dark and Quiet Skies: accomplishments and looking ahead by Federico Di Vruno (SKA Observatory*):

This presentation addressed the growing impact of large private satellite constellations on astronomy and space sustainability. Unlike national space agencies, private companies are primarily driven by ownership and profit, leading to a rapid expansion of satellites that interfere with both optical and radio astronomy. Visible satellites contaminate telescope images, while microwave emissions and onboard electronics disrupt radio observations, especially concerning given the increasing satellite density. These constellations also pose risks through long-term space debris accumulation and upper atmosphere pollution.

Mitigation strategies include real-time satellite tracking software, reducing satellite reflectivity, and creating radio quiet zones near major observatories. Efforts are coordinated through the IAU which organize observing campaigns, build databases, and engage with companies early in the design phase to propose mitigations. While successful collaborations have occurred with some companies and the European Commission, outreach to other like Chinese operators has been difficult. Public education efforts are also underway through YouTube content.

Lastly, the IAU is an observatory member at the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS), with support from delegations like Switzerland, Chile, and Spain (group of friends), to advocate for regulation. Although progress is slow, the issue has finally been added to the official UN agenda, providing a critical opportunity to address long-term threats to the night sky.

- *The Importance of Dark and Quiet Skies in Swiss Astronomy by Carolyn Crichton (SKA Switzerland Consortium):*

This presentation outlined the growing concern among Swiss scientists, particularly at EPFL, regarding the impact of large satellite constellations on ground-based astronomy. Switzerland, as part of international efforts like the SKA Observatory and UNCOPUOS's "Group of Friends," is actively involved in protecting dark and quiet skies. Satellite trails are disrupting optical observations, causing significant data loss, while unintended radio emissions, currently unregulated, are interfering with sensitive instruments used to detect faint cosmic signals. Swiss efforts focus on a balanced approach, acknowledging the country's role in the satellite industry while promoting mitigation measures such as emission reduction, brightness control, and improved backend data filtering. EPFL also leads national coordination through roundtables and policy engagement, aiming to develop sustainable solutions in partnership with industry, government, and the scientific community.

- *The Committee on Radio Astronomy Frequencies - advocating for spectral resources for radio astronomy by Susanne Wampfler (Center for Space and Habitability, University of Bern):*

The presentation discussed the complexities of managing the radio frequency spectrum, which is considered a national resource similar to forests and water. In Switzerland, this is regulated by OFCOM (BAKOM), but since radio waves don't stop at national borders, international coordination is necessary, primarily led by the ITU at the global level and CEPT in Europe. Every four years, the ITU revises frequency allocations at the World Radiocommunication Conferences (WRC), with the next conference in 2027. Radio astronomy, recognized since 1959 as a passive radiocommunication service, is allocated only a small, often-shared portion of the spectrum. As new technologies, particularly high-frequency, high-data-rate satellite constellations, emerge, interference issues become more complex, challenging traditional methods like establishing radio-quiet zones.

In Switzerland, the Swiss Academy of Sciences and the Swiss Commission for Astronomy represent national interests, working alongside international observatories and organizations like the SKA Observatory. Efforts include monitoring spectrum usage, conducting compatibility studies using specialized software, representing interests at meetings with OFCOM, publishing research, and engaging in public outreach. However, funding is limited, with most contributors working voluntarily. The presentation emphasizes that radio astronomy's contributions to technological advancement, such as Wi-Fi and satellite communications, highlight its broader societal value. To sustain this, a balanced approach

is needed, combining technical solutions and policy advocacy to ensure the continued protection of the radio spectrum for astronomical research amidst growing commercial pressures.

- *Space debris detection and characterization from the ESO VST archive by Elisabeth Rachith (École Polytechnique Fédérale de Lausanne):*

The presentation was about analysing a vast dataset of images captured by ESO VST systems, each with a resolution of 2000 x 4000 pixels. Focusing on a month of data from September 2015, 700 distinct objects and resulting in over 700 streaks by correlating the images with known object catalogues are identified. Many of these objects were located in Low Earth Orbit (LEO) and Geostationary Orbit (GEO), with detection sensitivity down to 3–5 cm in LEO and around 20 cm in GEO. Using a sophisticated detection system combining convolutional neural networks and a transformer model, adapted from edge detection techniques in fields like autonomous driving, we trained the system on over 20,000 images to handle diverse image scenarios, including faint or cluttered backgrounds. After streak detection, we performed image reduction and calibration with Gaia DR2 data, measuring flux and timing to track object passages. Notably, a significant number of detected streaks did not match known catalogues, suggesting the presence of uncatalogued objects. To address this, we established a new light curve repository at EPFL. A test analysis of January 2022 data, consisting of over 1,000 images and one filter, detected nearly 3,000 streaks, of which 1,182 were linked to known objects, comprising about 200 distinct items, including 99 active payloads and 53 rocket bodies, underscoring the scale of space debris and the importance of sustained monitoring efforts.

- *Under a False Moon: Spaceflight's impact on the celestial sphere by Miles Timpe (ARIS):*

The study presents a cautionary outlook on the future of the night sky, highlighting the emerging threat of space-based advertising projects like Russia's Starbucket and Reflect Orbital, which plan to use solar reflectors in orbit to display bright messages visible from Earth. These artificial light sources could disrupt the natural light environment of the celestial sphere, which has guided biological rhythms and navigation for billions of years, affecting ecosystems and species such as migratory birds that depend on star patterns for orientation. Technical feasibility and economic profitability make such projects likely to proceed, with proposed advertising revenue rivalling high-profile terrestrial campaigns like Super Bowl ads. Despite widespread disapproval, regulating or banning these intrusive projects has proven challenging, emphasizing the urgent need for policy intervention to preserve dark and quiet skies.

Summary of roundtable- Challenges ahead: how to deal with interference from satellite mega-constellations?

A roundtable titled "Challenges ahead: how to deal with interference from satellite mega-constellations?" including stakeholder from scientific community (Susanne Wampfler from University of Bern, Piero Benvenuti from International Astronomical Union, Chris Finlet from University of Geneva), military (Jean Noel Pittet from Swiss Arm Forces), and private sector (Yash Chandramouli from Amazon) is organized to discuss how the individual stakeholders can support each other to protect next generation radio telescopes such as the SKAO from RFI caused by satellite constellations.
The discussion highlighted the critical need for improved tracking of satellites and their emissions to support dark and quiet skies initiatives. Chris and Yash emphasized the importance of sharing satellite ephemeris and frequency data, with Yash noting that companies like Starlink publish their ephemeris, though improvements are needed in robustness and measurement quantity. Susanne expressed concern about dedicating valuable telescope time for satellite tracking and suggested the development of dedicated ground stations instead. Jean Noel and Piero discussed the sensitive nature of military data and the need for anonymized databases that could be correlated with astronomical observations, while acknowledging the complexities of data protection and sharing policies. The debate also touched on the potential for anonymized or reduced-accuracy data to be shared, and the challenges of balancing transparency with strategic considerations.

Audience questions probed the role of governments in pushing the military to release more data, with Jean Noel pointing out the strategic decision-making involved and the partial data sharing already seen in the US. Ludovic Monnerat explained that satellites themselves cannot be hidden due to radar detection, though their activities might be obscured. The potential of optical communication to reduce radio interference was explored, with concerns raised about unintended emissions from associated electronics.

In the solutions segment, participants suggested creating anonymized databases to improve precision in tracking and managing interference, while also recognizing the need to better characterize unintended emissions. The discussion also acknowledged the complexity introduced by the large number of satellites in constellations and the challenges of getting cooperation from all operators, especially the major players. Finally, legal and licensing barriers, as well as data ownership concerns, were identified as obstacles to more open data sharing. The session concluded with a

recognition of the need for collaborative efforts between operators, regulators, and the scientific community to ensure sustainable and interference-free access to space.

The discussions in this session underscore the pressing need to balance technological advancement with the protection of dark and quiet skies. From developing collaborative mitigation strategies with satellite operators to refining data-driven debris monitoring systems, the speakers emphasized that preserving the integrity of the night sky requires proactive international cooperation and the integration of sustainable practices into commercial and scientific space activities. Radio astronomy's vital contributions, the risks of emerging light pollution from orbit, and the growing presence of uncatalogued debris illustrate the multifaceted challenges ahead. As the sky becomes increasingly crowded, bold and coordinated action is necessary to ensure that humanity's window to the universe remains clear and undisturbed for future generations.

5. Technologies for space sustainability

This session showcases pioneering technologies and strategies aimed at promoting space sustainability, drawing on a diverse set of expertise and innovations. From CERN's ground-breaking contributions to radiation-hardened electronics, advanced payloads, and onboard data processing to ClearSpace's agile approach to active debris removal, the presentations highlight practical solutions for tackling the mounting challenges of space debris and mission safety. The discussions also underscore the critical role of organizations like COSPAR in fostering international cooperation and policy development, as well as the transformative potential of autonomous pose estimation technologies and sustainable satellite constellations for Earth observation and climate science. Together, these presentations illustrate how technological innovation, global collaboration, and forward-looking policies are essential to ensure the long-term sustainability of human activities in space.

Summary of presentations

- *Accelerating Space and Earth Sustainability through CERN Innovation by Enrico Chesta (CERN) and Thomas Rimbot (CERN):*

This presentation showcased CERN's multifaceted contributions to both space and Earth sustainability through its expertise in accelerators, detectors, and computing. It highlights CERN's innovations across four critical levels: satellite platforms, payloads, data processing, and experiments. Specifically, CERN leverages its deep understanding of radiation effects—gained from particle physics research—to develop radiation-hardened electronics, enhancing the resilience of satellites and reducing space debris risks. In payloads, CERN contributes by advancing small, efficient components, exploring novel thermal management solutions, and developing state-of-the-art detector technologies for improved Earth observation. The organization's robust data management capabilities, honed through processing terabytes of particle collision data, provide valuable insights for managing ground segments, end-of-life scenarios, and onboard AI-driven data processing, such as its partnership with ESA on EUCLID and other AI and quantum computing initiatives. Lastly, CERN applies its fundamental physics expertise to study cosmic radiation and its potential influence on Earth's climate, exemplified by the AMS-02 experiment on the ISS and Earth-bound simulations. The presentation underscores CERN's role as a hub of innovation and knowledge transfer, demonstrating how its technologies and methodologies can enhance safety, interoperability, and sustainability for both space exploration and Earth systems.

- *The Panel on Exploration of the Committee on Space Research by André Galli (University of Bern):*

This presentation centred on COSPAR, the Committee on Space Research, which is a scientific body under the International Science Council. COSPAR promotes international cooperation in space research and was the first organization to be granted observer status at the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) in 1962. The organization holds assemblies every two years in different countries to ensure inclusive access to discussions and advances in space research. The speaker, a co-chair of COSPAR's Panel on Exploration, discusses the organization's focus areas, including near-Earth astronomy, Earth observation, planetary science, and space sustainability. There are currently 15 active panels, some of which are closely tied to sustainability issues. The speaker highlights three major areas of concern for space researchers: space debris, which threatens the safety of future space missions; the Moon, with increasing human missions requiring thoughtful policy frameworks; and near-Earth objects (NEOs), with discussions around resource utilization, planetary defence, and space mining. Emerging topics such as atmospheric pollution from space activities, planetary protection for Mars missions, and the preservation of dark skies are also raised. The Kessler Syndrome, which predicted a catastrophic cascade of space debris collisions, is cited as a pressing concern, with current satellite launch rates far exceeding safe levels. The speaker references research indicating that without significant mitigation efforts, such as active debris removal, space sustainability may be compromised within this century. There is also a call for considering space as an 18th Sustainable Development Goal

(SDG) to elevate its importance at the UN level, emphasizing that space sustainability is not only essential for Earth but also for preserving the future of space exploration. The speaker concludes by emphasizing the need for a discussion on sustainability matters at COSPAR including all stakeholder in order to reach to a framework to ensure sustainable space exploration.

- *Filling the toolbox while defining the job product management at ClearSpace by Kees van der Pols (ClearSpace Switzerland):*

The presentation outlined ClearSpace's origins, mission, and strategic approach to advancing space sustainability through debris removal and satellite servicing. Founded in 2018 with roots in the SwissCube project of 2009, ClearSpace arose from the need to tackle increasing space debris challenges. The company has secured ESA and UKSA contracts to remove space debris from space. ClearSpace's strategy combines a top-down approach—defining services such as inspection, removal, and life extension—with a bottom-up focus on rapidly prototyping, testing, and iterating technologies. This approach balances strategic focus with adaptability, essential in a market where rapid, affordable, and flexible solutions are needed. Key technologies include relative navigation systems, autonomous rendezvous and proximity operations (RPO), secure ground operations, and scalable ground infrastructure. The company's culture encourages innovation through hands-on testing—even building and breaking non-space-qualified prototypes—to learn and improve. ClearSpace acknowledges the evolving commercial market's demands for faster and cheaper solutions and aims to build a versatile "toolbox" of technologies and services that can adapt to client needs. The ultimate goal is to offer reliable, flexible, and cost-effective satellite servicing solutions, contributing to a more sustainable space environment.

- *Global Navigation Satellite Systems and Constellations of Earth Observation Satellites: Sustainable Satellites for Science and Society by Adrian Jäggi (University of Bern):*

The presentation highlighted the importance of sustainable satellite systems in supporting Earth observation and climate science, emphasizing how such infrastructure underpins essential societal services. Starting with ESA's Copernicus program, it describes how satellites provide critical data for climate monitoring, emergency response, and security. The speaker focuses on the Copernicus Climate Change Service, which combines satellite data with modelling to assess how climate is changing and how it may impact society. The presentation underscores the infrastructure supporting these services, including precise satellite positioning systems (like GNSS and laser ranging) and international collaborations such as the International GNSS Service and the International Association of Geodesy. The presentation showcases how gravity-sensing satellites, such as NASA's GRACE missions, provide precise data on ice mass loss and water storage, enabling critical insights into sea level rise and water management. The speaker notes the challenges of ensuring continuity and operational use of such satellite data and advocates for long-term investments in sustainable Earth observation systems. The presentation concludes with a call to national and international space agencies and decision-makers to prioritize sustained investment in satellite constellations, technological advancements, and operational services to maximize societal benefits from space-based observations.

- *Towards Autonomous Pose Estimation for Unseen Satellites by Andrew Price:*

The presentation focused on advancing autonomy in space systems, particularly for space debris removal, in-orbit construction, and other future missions. It highlights the importance of pose estimation—specifically uncooperative pose estimation where objects provide no navigational cues—using neural networks trained to estimate an object's position and orientation. The speaker discusses how EPFL's CVLab addresses challenges in estimating the pose of previously unseen objects, compressing neural networks for deployment on limited space hardware, generating sufficient training data, and ensuring algorithm robustness in space environments. Examples include demonstrating pose estimation of a rocket body trained on household object images and compressing neural networks by a factor of eight while maintaining high performance. These advances are essential for enabling scalable, autonomous solutions in orbit and beyond.

The presentations in this session underline the vital role of advanced technologies and coordinated frameworks in securing a sustainable future for space exploration and Earth observation. Whether through CERN's innovative applications of particle physics, ClearSpace's scalable servicing solutions, COSPAR's global engagement on policy and sustainability, or new methods in pose estimation and Earth system monitoring, these initiatives collectively demonstrate the importance of combining technological ingenuity with collaborative efforts to tackle space sustainability. In the end, they emphasize the need for continuous investment, innovation, and policy evolution to mitigate risks, safeguard the orbital environment, and enhance the societal benefits derived from space-based systems.

6. Law, Policy, Ethics and Economics of Space Sustainability

The presentation in this session highlights how legal instruments, ranging from UN treaties and national laws to emerging EU regulations, are evolving to address challenges such as space debris mitigation, space traffic management, and environmental protection. Expert contributions explore the essential role of dedicated centers and organizations in supporting operational safety, as well as the cultural and philosophical implications of space expansion under the concept of "planetary sustainability" to be protected by an established 18th SDG. Furthermore, insights into investor perceptions reveal the critical intersection between sustainability narratives, financial viability, and regulatory readiness in shaping the future of space ventures. This chapter also includes a case study on Spacetalk, a platform aiming to promote information sharing among space operators. Through these diverse perspectives, the session aims to foster a deeper understanding of the multi-layered governance and market dynamics essential for a sustainable and inclusive space environment.

Summary of presentations

- *Ensuring sustainability from a legal perspective by Merve Erdem Burger (Swiss Space Law Forum):*

The presentation explored how sustainability in outer space can be safeguarded through legal frameworks at the international, supranational, and national levels. It first identifies key elements for this analysis, including the implementation and evolution of space law, space debris mitigation, environmental protection, space traffic management (STM), space situational awareness (SSA), in-orbit servicing, and the circular economy. At the international level, it shows the obligation for states to implement space law, and how Article IX of the OST, the Space Debris Mitigation Guidelines, and the LTS Guidelines address space debris mitigation and environmental protection. It also demonstrates the promotion, establishment, and use of STM, SSA, and in-orbit servicing through the LTS Guidelines. At the national level, the presentation examines how states implement space law and adopt measures for space debris mitigation, STM, SSA, in-orbit servicing, and the circular economy. At the supranational level, it considers the drafting of the EU Space Act and the Product Environmental Footprint Category Rules (PEFCR) for the space sector as significant steps toward harmonized sustainability measures in Europe. Finally, the presentation raises questions about the future of legal protection for sustainability in space, including whether new international and regional instruments will emerge, and whether national space laws will become more harmonized or fragmented.

- *Expert centre for space safety providing services in support of a sustainable use of outer space by Thomas Schildknecht* (University of Bern, AIUB):

The presentation provided an overview of the evolution and current activities of an expert center focused on space situational awareness and sustainability, established in 2014. It highlights the center's role in supporting a diverse range of stakeholders—including space debris offices, commercial operators, academia, government agencies, and standardization bodies—by offering services like sensor validation, qualification, data acquisition, and observation support for space object tracking and re-entry events. The center maintains a network of sensors and collaborates with partners under service-level agreements to provide high-quality, validated data. The presentation showcases examples such as the re-entry observation of ESA's Cluster satellites and the use of precise GNSS and laser ranging data to refine predictions and enhance orbital safety. It emphasizes the need for continuous improvement, flexible business models, and sustainable operational frameworks to adapt to evolving demands and technologies. The center is transitioning towards becoming a non-profit organization to ensure ongoing support for space sustainability, including data exchange platforms, collaborative research, and policy support for the broader space community.

- *Setting off sustainably: Planetary sustainability and space 4.0 by Andreas Losch (University of Zurich):*

The presentation explored the complexities and challenges of achieving sustainable space development within the context of increasing commercial space activities, public-private partnerships, and pressing global sustainability issues. It critiques the narratives of unchecked growth and the "joyriding" of billionaires into space while acknowledging their visionary goals of space tourism, resource extraction, and multi-planetary living.

Central to the discussion in the presentation is the concept of sustainability, not just on Earth but extended to planetary and orbital scales, emphasizing environmental, economic, social, and cultural dimensions. Key issues include the management of space debris, planetary protection, potential cultural and legal conflicts over space resources, and the risk of contaminating other celestial bodies. The presentation advocates for a reframing of sustainability, integrating Earth and space considerations under the idea of "planetary sustainability" and proposing the establishment of the 18th sustainable development goals dedicated to space. Moreover, the presentation proposes concepts like orbital boundaries and circular economies in space in order to balance long-term aspirations for space expansion with the

urgent need to preserve Earth's fragile environment and societal well-being, emphasizing responsible stewardship and recognition of space as a shared common.

- *Investors' perception of sustainability aspects in space ventures by Sebastian Bélanger Villanueva, Emmanuelle David, Angelina Frolova, Patrick Smit (École Polytechnique Fédérale de Lausanne):*

This presentation outlined a research project focused on understanding how private investors perceive sustainability in the space sector and how their perceptions influence investment decisions. Recognizing that sustainable development in space requires more than scientific ambition—it also needs financial backing—the research explores why sustainable space ventures often remain overlooked by impact-oriented investors. Using both qualitative interviews and quantitative analysis of over 200 space companies funded by 30+ investment funds, the study examines investor perceptions of risk, value, and regulatory dependency, as well as challenges in measuring ESG performance for space. Early findings show that space sustainability is often seen as secondary to profitability, and that many investors lack a clear understanding of its broader dimensions beyond debris mitigation. The project aims to define space sustainability, evaluate its financial materiality, and develop actionable recommendations for investors, space entrepreneurs, and policymakers. It also seeks to help space ventures better narrate their sustainable value and bridge gaps between the finance and space sectors, while being transparent about limitations in data, theory, and potential researcher and interviewee biases.

- *Space traffic management by Benjamin Guyot (SpaceTalk):*

The presentation, delivered by a legal expert and founder of Space Talk, highlighted the critical need for global coordination of space traffic management (STM) to address the rising congestion and risk in orbit. Currently, space traffic is managed by national or regional entities such as the U.S. Office of Space Commerce, USST in Europe, and similar entities in Russia and China, often in cooperation with private companies. However, this system lacks unified standards, effective communication, and clear accountability, leading to fragmented coordination and potential hazards, including collision risks and liability issues. The speaker emphasizes the absence of a global supervisory body and proposes Spacetalk, a digital platform designed to serve as a “phone book” for space operators to communicate, coordinate manoeuvres, and share critical data like trajectory, object status, and manoeuvre intentions. The platform is envisioned as a neutral, transparent, multilingual system to foster dialogue and mutual understanding between stakeholders, including major space powers and private actors, while addressing legal and operational gaps in current STM practices.

Summary of workshop- Swiss good offices in Space Traffic Management

An exploratory workshop was organized on the topic of “Swiss good offices in Space Traffic Management”.
The workshop started from the basis that space is increasingly being considered as a warfighting domain and that the orbital environment is progressively weaponized, the perspective of an armed conflict in space is becoming more plausible. Space is also more crowded and there is still no global Space Traffic Management system in place. Disagreements among operators are set to increase in the future.
In this context, Switzerland may have a role to play in STM. As Switzerland aims to stay relevant in the diplomatic scene, especially as a mediator in armed conflicts, the tradition of Swiss good offices may be extended to space. In addition, Swiss space company SpaceTalk is developing a collaborative communication platform where operators can share data and coordinate collision alerts and manoeuvres. Therefore, this workshop aimed at assessing whether the tradition of Swiss mediation could be extended to disagreements between operators regarding manoeuvres in space, including regarding collision avoidance manoeuvres.

Clémence Poirier (Center for Security Studies at ETH Zurich) first introduced key notions of what is “good office” in the context of international relations, how it is conducted by Switzerland to address international conflicts.

Participants were divided in three groups and had to work on three different scenarios. These scenarios took place in peacetime, war time; between state actors, commercial operators, etc., in order to give a broader perspective at STM issues and how Swiss mediation could take place in these situations.

- The first scenario involved the company “Xincoms” from the country of Xinlandia and company “Satellite Inc.” from the country of Freedomia, which both had a satellite in LEO. The satellites were about to come very close to each other and there was a risk of collision. Freedomia’s and Xinlandia’s SSA data provided contradictory information about the likelihood of the collision. Both operators disagreed on which one had to manoeuvre to avoid the collision and tensions increased between them.
- The second scenario involved the company “HebraOrbit” from the country of Shalomia and the company “Persat Systems” from the country of Zarathustra, which both had a satellite in GEO. They only had very limited SSA capabilities. Available SSA data showed that the two satellites would come close to one another

with a medium-to-high risk of collision. Neither party trusted the other's data, leading to uncertainty and distrust. Zarathustra's satellite refused to manoeuvre, and the Shalomian satellite did not have manoeuvring capabilities. The situation quickly escalated and was considered as an intentional and deliberate act of war by Shalomia.

- The third scenario focused on the company "Monarch Orbitals" from the state of Monarch Isles, which had a satellite in GEO that broke up and created thousands of debris. The state of Tsarovia, which owned a highly manoeuvrable space plane currently in orbit, took advantage of the creation of multiple debris to deploy a miniature highly manoeuvrable space object. The miniature object was mistakenly labelled as a piece of debris. The object was then slowly moving to conduct hostile and unannounced close-up inspections and eaves dropped around satellites in GEO.

Participants had to brainstorm and respond to questions regarding each scenario covering topics such as the potential role and legitimacy of Switzerland to act as a mediator between operators in case of disagreements, the compatibility with Swiss neutrality, the scope of its potential involvement, the technical challenges for Switzerland to play such a role and the differences with armed conflicts on Earth. Participants also discussed the potential governance and features of Swiss mediation in outer space.

Conclusion of workshop

Participants mostly agreed that Switzerland could play a mediating role in STM and that it was compatible with Swiss neutrality and outlined that Swiss mediation in STM would increase the relevance of Switzerland's in space affairs, a domain in which it is already legitimate, trusted, and recognized. Participants suggested that such a role would need to be coupled with greater involvement of Switzerland in international discussions regarding responsible space behaviours and the development of standards for STM and space debris mitigation. Participants also highlighted that mediation could occur after collision manoeuvres took place in order to assess what happened, assess the potential damage, and improve future coordination. More practically, participants underlined that a software platform similar to Spacetalk could be used for mediation purposes by incorporating a feature that would enable operators to request mediation.

In terms of governance, participants highlighted that various governance mechanisms were possible, whether the platform is simply hosted in Switzerland and managed by an international organization or association or run by the Swiss government. However, participants disagreed on whether Switzerland should stick to a mediating role by putting operators in contact or be more active by providing data and recommending courses of action.

Overall, this workshop enabled participants to think outside the box and have a strategic foresight-oriented discussion regarding space sustainability issues.

The workshop also led to a publication of the Center for Security Studies at ETH Zurich on the topic of Swiss good offices in space. [7]

In summary, the discussions in this session underscore the pressing need for comprehensive and coordinated approaches from legal, policymaking, ethical, and economic perspectives. Therefore, the session's presentations recommend advancing legal frameworks, standardizing space traffic management, promoting responsible stewardship of celestial resources, and integrating sustainability into investment strategies. Moreover, the presentations highlight the expansion of Earth system boundaries and the adoption of an 18th Sustainable Development Goal (SDG) for space, the establishment of centers of excellence, and the creation of an open platform that enables space operators around the globe to coordinate their space traffic management efforts as practical measures to ensure space sustainability.

7. Poster session

Besides the above workshops and technical sessions, the SSSRD also hosted a poster session, in which students and professionals showed their work. A summary of the topics is given in the table below.

	Poster title	Topic	Presenters / authors
1.	Student SSA Team Efforts in Tracking and Detecting Orbital Debris	Tech for space sustainability (SSA)	SSA team *students
2.	Governing the Global Space Commons How to Think of Space Issues?	Space Sustainability[8]	Sasha Nick, Jean-Paul Kneib
3.	Optimization of GEO Satellites On-Orbit Refuelling for Sustainable Space Logistics	In Orbit Services	Hannah Besser *student
4.	EPFL's Handbook on sustainable practices for spacecraft mission design	Ecodesign	Marnix Verkammen
5.	Space-based surveillance of Resident Space Objects with the CHEOPS space telescope	DQS	Luís Gonçalves (Universidade de Aveiro)
6.	Detailed Brightness Analysis of NASA's Advanced Composite Solar Sail System (ACS3) from ground-based optical Observations	DQS	Stephan Hellmich (EPFL)

8. Conclusion

The first Swiss Space Sustainability Research Days hosted 55 Swiss experts during three days in Les Diablerets, Switzerland. This event was the opportunity to map Swiss expertise, brainstorm on potential project and think how Switzerland could be more active to solve one of our centuries.

The workshop opened with a series of keynotes to set up the concept of space sustainability and what are the main competencies in Switzerland, EPFL expert framed space sustainability, while Uni Bern depicted the capacities from the Zimmerwald observatory and the plans to better anticipate space weather. Swiss official from the foreign affairs and the Swiss armed forces depicted their stance and how their respective offices can influence sustainability. Finally, the session was concluded with two presentations for international experts from PoliMilano and Amazon Kuiper Project to show how the Swiss actors are placed on the global map.

The second day opened with talks on the impact of space activities on the environment and a workshop defining space sustainability to ensure that all players had the same understanding and to connect project ideas and expertise. From this the audience moved on to discuss the dark and quiet skies with also a panel discussion- Challenges ahead: how to deal with interference from satellite mega-constellations? Finally, the second day was concluded with presentations on key technology development enabling space sustainability from radiation technologies to on-orbit servicing. The combination of the different topics showcases the complexity of problem solving.

The third day focused on the presentation on the Law, Politics, Ethics and Economics of Space Sustainability. First an overview of different space law was given, a representant of COSPAR presented how the scientific community addresses sustainability then the ethics of space sustainability has been discussed. The session continued with a presentation on the perception of space sustainability by investors and concluded on consideration on space traffic management. The presentations have set the floor to then see how Swiss good offices could be used for space diplomacy. Participants mostly agreed that Switzerland could play a mediating role in STM and that it was compatible with Swiss neutrality. Participants outlined that Swiss mediation in STM would increase the relevance of the country in space affairs in a domain in which it is already legitimate, trusted, and recognized.

The three days' conference led to the publication of three papers including this one [6], [7], [8] and the opening of the EPFL Sustainable Space Hub to all Swiss actors. While the second edition is not yet planned, the goal is to strengthen to Swiss Community and push the research.

9. References

[1] "Swiss Space Sustainability Research Days." Accessed: Jun. 26, 2025. [Online]. Available: https://espace.epfl.ch/event/swiss-sustainability-research-days/

[2] C. Poirier *et al.*, "Swiss Space Sustainability Research Days 2025 - Book of Abstracts," Jan. 2025. Accessed: Jul. 01, 2025. [Online]. Available: https://infoscience.epfl.ch/handle/20.500.14299/251791

[3] M. , T. K. , F. J.-S. , V. M. , G. V. , W. E. , de O. A. , U. A. , & D. E. Udriot, "Sustainability of End-to-End Space Transportation Missions: Modelling Technical and Environmental Aspects for Early Phases Ecodesign Decision Support," in *75th International Astronautical Congress 2024.*, 2024.

[4] M. , V. M. T. K. & F. J.-S. Udriot, "REACT Announcement of Opportunity," 2024. Accessed: Jun. 26, 2025. [Online]. Available: https://infoscience.epfl.ch/entities/publication/7653ae2f-8147-4b9f-a7b5-c3acbc1c77d1

[5] A. R. Wilson and M. Vasile, "The space sustainability paradox," *J Clean Prod*, vol. 423, p. 138869, Oct. 2023, doi: 10.1016/J.JCLEPRO.2023.138869.

[6] E. David, S. Hellmich, and C. Crichton, "THE IMPORTANCE OF DARK AND QUIET SKIES IN SWISS ASTRONOMY AND THE DIALOG WITH THE SPACE INDUSTRY."

[7] Clemence Poirier, "Swiss Good Offices in Space," *Center for Security Studies (CSS)*, vol. 13/3, Apr. 2025, doi: 10.3929/ethz-b-000731274.

[8] S. Nick and J.-P. Kneib, "Governing the Global Space Commons How to Think of Space Issues?," 2025.

Acknowledgements:

Part of the scientific work presented in this publication is funded by the ESA FLPP in the REACT project.

The workshop was financed by the participants fees and also support from EPFL Space Center.