BRINGING POLICY COHERENCE TO SATELLITE CONSTELLATION MITIGATIONS FOR SPACE DEBRIS AND ASTRONOMY

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ABSTRACT

Despite their potential societal and technological benefits, the emergence of satellite constellations brings major challenges for the long term sustainability of low earth orbit and in particular, the growing threat of space debris. Satellite constellations also threaten the conduct of astronomy from both ground and space-based observatories. Since the launch of SpaceX's first batch of Starlink satellites, astronomers quickly organized, established contact with SpaceX and other companies, and formed several working groups to look at the impacts on science and possible mitigations. A number of policy recommendations are emerging, which address mitigation actions for the astronomy community, observatories, industry and government regulators.

As astronomers begin to make recommendations to industry and government on satellite designs, mission profiles and operator practices, the extent to which these recommendations interact with policies and guidelines on space debris mitigation should be considered. With the ultimate goal of space debris mitigation to ensure long term sustainability of low earth orbit, a sustainability perspective can inform policymaking by applying the concept of policy coherence. In this approach, policy coherence stresses integrated policy decision making across multiple dimensions, exploiting mutual synergies, and consideration of unintended side effects, and is incorporated in one of the UN Sustainable Development Goals. In the context of space debris mitigation, policy coherence should result in interoperability in practices, standards, and data across different space actors and policy domains, to achieve the goal of debris mitigation and sustainability.

This paper first presents an analytical framework, which allows astronomy and space debris policymakers to consider their mutual policy coherence. Secondly, recent recommendations proposed by the astronomy community are reviewed, and their coherence against space debris mitigation guidelines are tested. Finally, the framework is expanded to show how policy coherence considerations can help space policymakers within the broader landscape of space governance.

1 INTRODUCTION

The launch of the first batch of SpaceX's *Starlink* satellite constellation on 19 May, 2019 shocked the astronomy community. The train of satellites was visible as a bright 'string of pearls' in the night sky. Even more concerning was the realisation that up to 100,000 satellites could be present in LEO, given the filings with national communications regulators and the ITU [1]. If all these planned constellations come to fruition, several thousand satellites could be overhead at any given place on Earth, with many brightly illuminated by the sun. The astronomy community quickly mobilised to study the problem, reach out to government agencies, and establish cooperation with the main satellite operators.

Astronomers have long been accustomed to dealing with sources of interference from ground-based light pollution to crowded radio spectrum. Yet these ground-based sources of interference are mainly a localised problem, requiring bespoke agreements with local governments to establish dark sky areas or radio quiet zones. The advent of satellite constellations makes the issue global and pervasive, requiring a new approach by the community. These new challenges for astronomy offer a new lens through which to examine space policymaking and the national and international regulatory frameworks that govern space activities. On the one hand, governments around the world invest billions in state of the art astronomical facilities, yet on the other regulate and in some cases fund projects that severely jeopardize these facilities. How could this situation happen? Turning to the subject of this conference, a similar and more economically impactful issue exists concerning space debris and its potential to cause damage to spacecraft and even render parts of Earth's orbital environment inaccessible.

The problem is one of both governance and of public policy. Governance broadly concerns "creating the conditions for ordered rule and collective action" [2] or more specifically, the set of "regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes." [3]. The space governance landscape has changed rapidly in recent years with the burgeoning of private actors and new space-faring nations [4]. The governance landscape is now characterised by a loosely coherent but

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strongly connected set of international organisations, international policy coalitions, national regulators and agencies, and private industry groups, often organising around single policy domains such as space debris or space traffic management [5]. In terms of public policy, governments' approaches to incentivise and regulate the sector fall along largely traditional lines: launch regulation, spectrum management, and national policies emphasizing strategic security and economic industrial development. Most national space regulations and policies also echo the international legal frameworks developed in 1960-80's [6]. While national policies recognise the global nature of the orbital environment and the unintended externalities created by new space activities, they have yet to successfully deal with the requirement for international governance and coordination in a way that maintains nationally-advantageous incentive structures for industry.

Many nations are now addressing these tensions with developments in national legislation or by creating national space policies which aim to place national development within the "New Space" era. Developments also progress in supporting policies that manage and regulate the space environment. A relatively recent change in the space policy and governance field—and one that mirrors in some way the evolution of environmental [7] and other policy domains [8]—is the emergence of sustainability as an organising principle for policy and governance questions [9] [10]. The recognition that the finite resource of Earth's orbital environment is increasingly under threat from space debris, and that access to this environment is inequitable and poorly governed, is creating the conditions for policy action. At the international level, UN COPOUS succeeded in adopting the Long-Term Sustainability (LTS) Guidelines in 2019 [11][12], which provide a set of nonbinding principles and practices to ensure that the space environment is safe and sustainably governed. At an even broader level, the United Nations Sustainable Development Goals (UN SDG) represent the highest level of political commitment to ensure that technological and societal development progress with proper stewardship of Earth's resources. While these high-level policy frameworks are promising and define concrete political goals, the challenge lies in implementation. In this respect, a sustainability perspective can inform policymaking by applying the concept of policy coherence. In this approach, policy coherence stresses integrated policy decision making across multiple dimensions, exploiting mutual synergies, and consideration of unintended side effects, and is incorporated in one of the UN SDGs [13].

The example of satellite constellations' impacts on astronomy offers an albeit limited but tangible case study to demonstrate the implementation gap and how policy coherence can be applied to improve governance and policymaking. From the launch of SpaceX's first Starlink satellites in 2019, the astronomy community has made substantial efforts to study the problem. Several national working groups have formed with the involvement of the space industry and government and have made recommendations to reduce the impacts on astronomy [14][15]. As of early 2021, the latest of these efforts was led by the International Astronomical Union (IAU), which made a series of policy and technical recommendations to be presented to the UN COPUOS [1]. The various recommendations to industry and government on satellite designs, mission profiles and operator practices, the extent to which these recommendations interact with policies and guidelines on space debris mitigation should be considered. Policy coherence should support interoperability in practices, standards, and data across different space actors and policy domains, to achieve the goal of debris mitigation and sustainability.

This paper first presents an analytical framework, which allows astronomy and space debris policymakers to consider their mutual policy coherence. Secondly, recent recommendations proposed by the astronomy community are reviewed, and their coherence against space debris mitigation guidelines are tested. Finally, the framework is expanded to show how policy coherence considerations can help space policymakers within the broader landscape of space governance.

2 POLICY COHERENCE

Policy coherence can be defined as "an attribute of policy that systematically reduces conflicts and promotes synergies between and within different policy areas to achieve the outcomes associated with jointly agreed policy objectives" [16]. In other words, policy coherence ensures that policies across different sectors and different levels of government are mutually supportive. Policy coherence can refer to "vertical" coherence, meaning synergy between, for example, European level policies from the EU and ESA and policies of the member states. Policy coherence can also be "horizontal" between the different sectors at the same level, for example, between national launch regulations and national environmental protection standards.

While policy scholars have long since recognised the interactions of different policy systems as a worthy subject of study [17], the concept of policy coherence gained traction in the international development sector. The Organisation for Economic Development and Cooperation (OECD) developed a series of recommendations, which aimed to ensure integration of national and international approaches in development initiatives [18]. In the environmental sector particularly in the policy areas of the European Union, policy coherence is recognised as a goal. Building on the work of the OECD, the Goal 17 of the UN SDGs to

"Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development" sets a target to "Enhance policy coherence for sustainable development", again recognising the need to integrate economic, environmental, governance and social dimensions of sustainable development at all levels of national and international policy processes.

The policy schemes developed by the OECD, UN and EU define checklists mainly focusing on the process of policymaking and general governance, however, they lack specific instructions on how to assess coherence between policies. Nilsson et. al. [16] describe one of the first schemes to measure and assess coherence, developing a simple policy framework and cross comparison matrix described in section 4. The framework is used to assess the coherence of the astronomy recommendations developed in [1] against the recommendations on space debris. While the approach in this paper is relatively crude, the process could be expanded with involvement of technical and policy experts, and the consideration of more policy areas.

3 SPACE DEBRIS AND ASTRONOMY GUIDELINES

COPUOS regularly monitors the regulatory aspects relating to space debris through agenda item IX of the Legal Subcommittee on "General exchange of information and views on legal mechanisms relating to space debris mitigation measures, taking into account the work of the Scientific and Technical Subcommittee." The committee keeps track of the national and international mechanisms responsible for maintaining the safety and sustainability of the outer space environment, particularly mitigating the effects deriving from the proliferation of space debris. The delegations of Canada, the Czech Republic and German in 2019 presented under this agenda item a compilation of all the national and international legal instruments to regulate the matter of space debris [19].

Chief among these tools are the guidelines developed within the Inter-Agency Space Debris Coordination Committee (IADC) [20]. The IADC is an international government forum, which has 13 space agencies among its members and is made up of four Working Groups on measurements (WG1), environment and database (WG2), protection (WG3) and mitigation (WG4) [21]. The latest group, created during the IADC's 17th annual meeting in Darmstadt in 1999, was tasked with outlining the first international guidelines on space debris mitigation. These guidelines were adopted by consensus in 2002, revised in 2007 and formed the basis for the adoption of the subsequent UN Guidelines and ISO standard 24113 on space debris mitigation [19].

These guidelines are not binding, but space operators and organizations are encouraged to apply them to the greatest extent possible. They comprise four focus areas: (1) Limitation of debris released during normal operations, (2) Minimization of the potential for on-orbit break-ups, (3) Post-mission disposal, (4) Prevention of on-orbit collisions [20]. As noted above, based on this document and the discussions within the COPUOS Scientific and Technical Subcommittee (STSC) since 1994, the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space were adopted in the 44th STSC session in 2007 and endorsed by the COPUOS plenary in the 50th session of the same year [22][23].

These sets of guidelines consider the different phases of space missions, including mission planning, design, manufacture and operational (launch, mission, and disposal) phases. The aforementioned documents deal with limiting the debris released during normal operations, minimizing the potentially harmful effects created by operational phases, encouraging reducing the potential for break-ups and accidental collisions, minimizing the amount of new debris, and finally outline the limits for the lifetime of objects in orbit, to reduce the long-term presence after the end of their mission [20][23].

COPUOS work on the sustainability of the outer space environment and the safety of outer space activities after 2007 continued through the creation in 2010 of an agenda item on the long-term sustainability of outer space and the related Working Group under the Scientific and Technical Subcommittee [12]. The Working Group's outcome led in 2019 to the adoption of the LTS Guidelines, including a compendium of measures for ensuring the sustainability of outer space activities and enhancing the safety of space operations [11]. This document is also not legally binding, but States and intergovernmental international organizations are invited to voluntarily implement the guidelines through national legislation or other appropriate instruments. The guidelines are divided into four sections: A) Policy and regulatory framework for space activities, B) Safety of space operations, C) International cooperation, capacity-building and awareness, and D) Scientific and technical research and development [11]. This analysis will take a particular account of sections B and D, which refers more extensively to the measures that can be implemented to manage and mitigate space debris.

None of the aforementioned tools explicitly refer to the concept of satellite constellations. However, some of the recommendations considered in the following analysis are partially comparable with the recommendations developed by the astronomical community and the other operators during the UNOOSA and IAU 2020 Dark and Quiet Skies Conference [1]. In addition, the IADC in 2017 published a Statement on Large Constellations of

Satellites in Low Earth Orbit to provide additional and specific considerations on this issue to ensure adherence of large constellations projects in LEO to the IADC mitigation guideline, which the following analysis will also consider [24].

4 COHERENCE OF ASTRONOMY RECOMMENDATIONS AGAINSTS SPACE DEBRIS GUIDELINES

Nilsson et al. identify three steps to conduct a policy coherence analysis: 1) inventory of policy objectives, 2) creation of a screening matrix, and 3) analysis of the interactions [16].

4.1 Inventory of Policy Objectives

We examined some selected objectives of the instruments established for the regulation of the space debris mentioned above. In particular, we looked at the IADC Space Debris Mitigation Guidelines [20], at the IADC Statement on Large Constellations [24], elaborated to provide specific indications on the implementation of the former regarding this particular constellation issue. Finally, we picked some of the UN COPUOS LTS Guidelines [11] concerning the mitigation of space debris and data sharing relating to space objects in orbit.

Then we compared these recommendations with those elaborated during the Dark and Quiet Skies Conference addressing industry and satellite operators. We selected the recommendations concerning licensing or design requirements and those relating to data sharing on satellite orbits and positional and timing information.

4.2 Creation of a Screening Matrix

Accordingly, we created a matrix to assess the interaction between the various recommendations. In the first vertical column of Table 5, we included the recommendations selected from the Dark and Quiet Skies Conference's final report. We selected recommendations relating to two categories. Firstly, the recommendations for Industry and Satellite Operators relating to "Design missions to minimise negative impacts on astronomical observations" (R13, R14), "Design satellites to minimise negative impacts on astronomical observations" (R15, R17), "Conduct satellite operations in a manner that minimise negative impact on astronomical observations "(R18, R19, R21, R22). And secondly, the recommendations for National Policymakers and Regulatory Agencies, and in particular referring to "Licensing Requirements" (R34), "National Standards Agencies" (R37), and "National Economic and Space Policymakers" (R38, R39) [1].

On the horizontal row of Table 5, we entered recommendations from the debris policy tools mentioned before: IADC Guidelines, Statement on constellations and the LTS Guidelines. For the IADC Guidelines, we selected the Recommendations of Section 5 - Mitigation Measures, relating to the creation of space debris and its mitigation [20].

For the IADC Statement on Large Constellations, we considered the recommendations of Chapter 4. IADC Considerations in View of Large Constellation Deployment in Low Earth Orbit, and in particular Section 4.2 on Constellation Design, Section 4.3 on Spacecraft Design, and Section 4.4. on Operations [24].

Table 1. Dark and Quiet Skies Conference Recommendations [1]

Stakeholder	Section	Number	Full Text
Industry and Satellite Operators	Design missions to minimise negative impacts on astronomical observations	R13	Minimize the number of satellites required to fulfil their missions. In general, minimizing altitude should take priority over minimizing the number of satellites.
		R14	Minimize the time satellites spend in orbit when not in service.
	Design satellites to minimise negative impacts on astronomical observations	R15	Design satellites to minimize overall brightness at all orbital phases, dynamic variations, and specular flares when observed from the ground. Investigate and implement all commercially reasonable design and operational measures to reduce average brightness from diffuse reflection as much below 7 visual magnitude as possible. Reflected sunlight ideally should be slowly varying with orbital phase to be fainter than 7.0 Vmag +2.5 × log(SatAltitude / 550 km), or equivalently, 44 × (550 km / SatAltitude) watts/steradian, as recorded by high etendue (effective area × field of view), large-aperture ground-based telescopes.

Stakeholder	Section	Number	Full Text
		R17	Provide greater detail on antenna power density fluxes, beam patterns and out of band sidelobes across the range of operating frequencies, than provided for ITU and regulator filings. Design satellites to have sidelobe levels that are low enough that their indirect illuminations of radio telescopes and radio-quiet zones do not interfere, individually or in the aggregate.
	Conduct satellite operations in a manner that minimise negative impact on astronomical observations	R18	Provide astronomers with pre-launch predictions and timely post-launch confirmations of the initial deployment orbits for satellites
		R19	Maintain and make available to astronomers, satellite ephemeris predictions with a sky location precision of arcseconds and a time precision of a tenth of a second, up to 12 hours in advance. Ephemeris predictions should be accompanied by covariance information and other (to be determined) metadata necessary to support mitigation efforts by observatories. (Note: these positional and timing requirements need further analysis)
		R21	Minimize the possibility of specular reflections and flares interfering with observatory activities through operational means (i.e., articulating components, controlling orientation, etc.). If flares cannot be avoided, operators could work with affected observatories to predict such occurrences.
		R22	Provide predictive models for satellite brightness versus orbit, relative to geographic locations.
National Policymakers and Regulatory Agencies	Licensing Requirements	R34	Formulate satellite licensing requirements and guidelines that take into account the impact on stakeholders, including astronomical activities, and that coordinate with existing efforts in relation to radio astronomy and space debris mitigation.
	National Standards Agencies	R37	Develop spacecraft systems and operational standards that take into account the impacts on astronomical science. Areas include reflectivity of surface materials, brightness of space objects, telemetry data, and spurious antenna emissions.
	National Economic and Space Policymakers	R38	Support the development of space domain decision intelligence collecting data of proposed satellite constellations and existing orbiting space objects, model-ling satellites, their operations in the space environment, and estimate uncertainties to assess the impact of satellite constellations on ground-based astronomical observations.
		R39	Investigate policy instruments that account for negative externalities of space industrial activities, including on astronomical activities, and develop incentives and inducements for industry and investors.

Table 2. IADC Guidelines [20]

Section	Title	Full Text
5. Mitigation Measures	5.1 Limit Debris Released during Normal Operations	In all operational orbit regimes, spacecraft and orbital stages should be designed not to release debris during normal operations. Where this is not feasible any release of debris should be minimised in number, area and orbital lifetime. Any program, project or experiment that will release objects in orbit should not be planned unless an adequate assessment can verify that the effect on the orbital environment, and the hazard to other operating spacecraft and orbital

Section	Title	Full Text
		stages, is acceptably low in the long-term. The potential hazard of tethered systems should be analysed by considering both an intact and severed system.
	5.2 Minimise the Potential for On-Orbit Break-ups	On-orbit break-ups caused by the following factors should be prevented using the measures described in 5.2.1 − 5.2.3: (1) The potential for break-ups during mission should be minimised (2) All space systems should be designed and operated so as to prevent accidental explosions and ruptures at end-of- mission (3) Intentional destructions, which will generate long-lived orbital debris, should not be planned or conducted.
	5.3 Post Mission Disposal 5.3.2 Objects Passing Through the LEO Region	Whenever possible spacecraft or orbital stages that are terminating their operational phases in orbits that pass through the LEO region, or have the potential to interfere with the LEO region, should be deorbited (direct re-entry is preferred) or where appropriate manoeuvred into an orbit with a reduced lifetime. Retrieval is also a disposal option. A spacecraft or orbital stage should be left in an orbit in which, using an accepted nominal projection for solar activity, atmospheric drag will limit the orbital lifetime after completion of operations. A study on the effect of post-mission orbital lifetime limitation on collision rate and debris population growth has been performed by the IADC. This IADC and some other studies and a number of existing national guidelines have found 25 years to be a reasonable and appropriate lifetime limit. If a spacecraft or orbital stage is to be disposed of by re-entry into the atmosphere, debris that survives to reach the surface of the Earth should not pose an undue risk to people or property. This may be accomplished by limiting the amount of surviving debris or confining the debris to uninhabited regions, such as broad ocean areas. Also, ground environmental pollution, caused by radioactive substances, toxic substances or any other environmental pollutants resulting from on-board articles, should be prevented or minimised in order to be accepted as permissible. In the case of a controlled re-entry of a spacecraft or orbital stage, the operator of the system should inform the relevant air traffic and maritime traffic authorities of the re-entry time and trajectory and the associated ground area.
	5.4 Prevention of On-Orbit Collisions	In developing the design and mission profile of a spacecraft or orbital stage, a program or project should estimate and limit the probability of accidental collision with known objects during the spacecraft or orbital stage's orbital lifetime. If reliable orbital data is available, avoidance manoeuvres for spacecraft and co-ordination of launch windows may be considered if the collision risk is not considered negligible. Spacecraft design should limit the consequences of collision with small debris which could cause a loss of control, thus preventing post-mission disposal.

Table 3. IADC Statement on Large Constellations [24]

Section	Sub-section	Full Text
4.2 Constellation Design	4.2.1 Altitude Separation	It is recommended to consider sufficient altitude separation between all parts of the constellation and with respect to other large constellations and crowded orbits in order to minimise the potential collision risk.
	4.2.2 Number of spacecraft	There is a relationship between the number of spacecraft failures on orbit and the associated impact on the space environment. This also has direct consequences for the workload connected with conjunction assessment and potential collision avoidance. It is recommended to consider higher probability of success of the Post Mission Disposal for large constellations.
4.3 Spacecraft Design	4.3.1 Reliability of the Post Mission Disposal (PMD) Function	The reliability of the post mission disposal function will have a major impact on the orbital environment, in particular for constellations that consist of a large number of satellites operating at high altitudes within LEO. The following measures are therefore recommended: Design for sufficient on-board redundancies of all functions involved in the post mission disposal Design of a monitoring function for the post mission disposal capability
	4.3.2 Design	Consider spacecraft design that will minimise the likelihood of explosions

Section	Sub-section	Full Text
	measures to minimize consequences of break-ups	Consider capability for collision avoidance in the design.
	4.3.4 Structural Integrity	Today, accidental explosions are responsible for a significant number of fragments in LEO. Sound implementation of passivation measures according to the IADC guidelines and the associated support documents are, thus, essential. Consider high overall spacecraft reliability design to minimise the probability of accidental explosions during operation and improve the likelihood of successful post mission disposal Often, critical components/designs leading to accidental explosions are only identified years after launch/operation in orbit, if at all. For example, battery designs which have resulted in favouring explosions during or after operations have only become apparent after a few years in space, after a certain number of duty cycles, or as soon as certain temperatures are reached in non-nominal attitude or non-nominal orbits (often years) after operations. For large constellations, systemic problems may be manifested due to the large numbers of the same spacecraft series and the associated short production times involved. It is possible that the first of such unanticipated failures occurs once the whole of the series is launched so that design retrofit is not a viable option. New technology has the potential to allow automatic passivation of spacecraft after loss of contact in a safe manner (e.g. electromagnetic cable cutters / valves that react upon loss of voltage)
	4.3.5 Trackability	The load on surveillance systems will grow dramatically with the deployment of large constellations. Likewise, the number of conjunction events in these altitudes will grow. Enhancing trackability, e.g. by adding onboard active and/or passive components can improve the orbit determination and prediction. This would have positive impact on conjunction analysis. It is recommended to enhance trackability by adding onboard active and/or passive components It is recommended to provide information on planned trajectories prior to performing orbit transfer manoeuvres (e.g. during deployment to the operational orbit and disposal)
4.4 Operations	4.4.2 Collision Avoidance	Active collision avoidance brings benefit, both, to the integrity of the constellation and the remainder of the space environment. The overall number of conjunction alerts raised for the constellation spacecraft may have a strong impact on operations of the constellation and other operators. Efficient processes are required to manage this process. The many avoidance manoeuvers could come on top of routine manoeuvres for constellation management, including during the ascent and descent phase. This means that efficient and open communication with surveillance networks and/or other concerned operators is required for the timely sharing of relevant data. Operational collision avoidance should be performed Manoeuvre plans should be communicated to the relevant actors in a timely manner
	4.4.3 Disposal Strategy	IADC simulations have clearly shown that a post mission disposal towards sufficiently low altitude is preferred over orbit raising to above 2000km. In view of the large constellations, the latter could ultimately lead to the onset of collisional cascading in altitudes above 2000km, with consequent negative effects to lower altitudes. Following the 25-year lifetime limit has fewer negative long-term effects to the environment than some other disposal options. To further limit the potential negative effects to the environment, operators are encouraged to consider additional measures beyond the existing guidelines, such as shortening post mission disposal lifetime and maintaining the collision avoidance capability during the post mission disposal phase. Monitor on a regular basis the availability of the post mission disposal function and initiate disposal actions as soon as post mission disposal reliability drops to a critical level, even if design lifetime is not reached

Finally, concerning the LTS Guidelines, we selected some guidelines of section B on the Safety of Space Operations and of section D on Scientific and Technical Research and Development, picking in both cases those relevant to the mitigation of the space debris [11].

Table 4. Long-term Sustainability Guidelines [11]

Section	Guideline
B. Safety of space operation	Guideline B.1 Provide updated contact information and share information on space objects and orbital events
	Guideline B.2 Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects
	Guideline B.3 Promote the collection, sharing and dissemination of space debris monitoring information
	Guideline B.8 Design and operation of space objects regardless of their physical and operational characteristics
D. Scientific &technical research and development	Guideline D.2 Investigate and consider new measures to manage the space debris population in the long term

To evaluate the synergies, we used a scale from 0 to 3 that considered the various interaction levels. Some relations have been indicated with a negative level of -1 to underline the likely negative interaction caused by an incompatibility of the policy objectives. To ensure better visualisation of the matrix, we also represented the interaction graphically with multiple shades of green (and red in the case of negative interactions)., as shown in Table 5.

4.3 Analysis of Interactions

The analysis showed that the interactions between policy goals are minimal, as evident from Table 5. Of the 204 relationships analysed, 58 were found to interact positively, and only 10 negatively. The other remaining relationships (136) do not present any kind of interaction. We have highlighted three types of interplays: some (15) have fully coherent objectives, most (43) are only partially coherent, and the remaining (10) are partially non-coherent.

Regarding the first category of fully coherent objectives, those have as target the permanence of objects in orbit and the reduction of the lifetime orbit and therefore aim to minimise the impacts of the space debris by reducing objects located in space. The objectives concerning the traceability of objects in orbit are also fully coherent, which encourage the sharing of data relating to the satellites' positional and timing information. Subheadings or subsection headings are to be in lower case with initial capitals and bold font. They should be flush with the left-hand margin, on a separate line.

Furthermore, the sharing of data on satellite orbits support also estimates the probability of collisions and space debris management. Therefore, these objectives are partially consistent in the analysis of the interactions between the recommendations relating to astronomy and those focused on the mitigation of space debris.

Finally, some of the astronomical community's recommendations are partially non-coherent with the other policies' objectives, particularly the recommendations to reduce the brightness of space objects. Indeed, by limiting the brightness, these measures could decrease the visibility of objects in orbit and negatively impact the thermal control of satellites, increasing the chances of on-orbit break-ups and imposing new design constraints on systems. Consequently, possible negative interaction exists unless stringent regulation and standards are in place to ensure darkening measures do not impact satellites' thermal control and trackability.

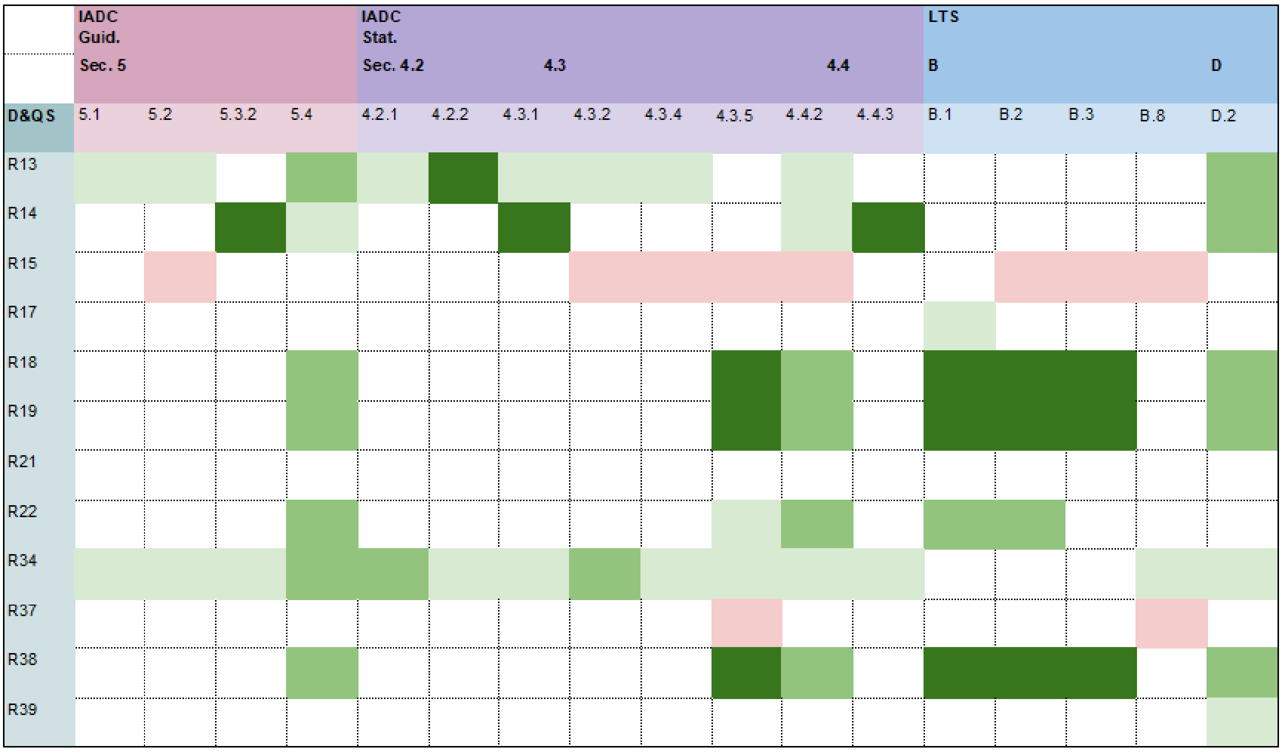
Accordingly, the astronomy community's recommendations to design space objects considering the impacts on astronomical activities are also indicated with negative interaction since this design could negatively impact the space debris' mitigation measures.

5 CONCLUSIONS

The case of satellite constellations has offered us an instructive example of how policy tools regulating similar circumstances from different viewpoints can be assessed for their coherence. In this instance, we have seen how, on the one hand, satellite constellations can limit the observations of the astronomical community and how, at the same time, they can increase the risks stemming from the creation of additional space debris, causing a worsening of the conditions of sustainability of the outer space environment. We observe through the analysis of the various stakeholder groups' recommendations that policy objectives have varying levels of positive coherence and in some cases, prove to be counterproductive. In this example, the few potentially incoherent recommendations relate to engineering challenges and their mitigation would require additional constraints on the design and operation of spacecraft but are not necessarily showstoppers. The importance of this policy coherence analysis is in providing a systematic way to identify these issues from which a roadmap or work plan can be developed for regulatory bodies. Analysis of incoherence also reveals in general areas where policy dialogue and policy learning are necessary across policy domains.

Therefore, from a global perspective of sustainability and the intent of responding to different interests more comprehensively, policies regarding the impact of space debris should in the future succeed in promoting the synergies between the political objectives existing in the various areas of space activity. Policy coherence can reduce conflicts and direct politics towards global and all-encompassing solutions. Still, to this end, continuous dialogue between stakeholders is necessary to allow a holistic approach and policies optimization.

Table 5. Recommendations Interactions



	IADC Guid.				IADC Stat.								LTS				
	Sec. 5				Sec. 4.2		4.3				4.4		B				D
D&QS	5.1	5.2	5.3.2	5.4	4.2.1	4.2.2	4.3.1	4.3.2	4.3.4	4.3.5	4.4.2	4.4.3	B.1	B.2	B.3	B.8	D.2
R13	░	░		▦	░	🟩	░	░	░		░						▦
R14			🟩	░			🟩				░	🟩					▦
R15		🟥						🟥	🟥	🟥	🟥			🟥	🟥	🟥	
R17													░				
R18				▦						🟩	▦		🟩	🟩	🟩		▦
R19				▦						🟩	▦		🟩	🟩	🟩		▦
R21																	
R22				▦						░	▦		▦	▦			
R34	░	░	░	▦	▦	░	░	▦	░	░	░	░				░	░
R37										🟥						🟥	
R38				▦						🟩	▦		🟩	🟩	🟩		▦
R39																	░

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