Sustainable Coexistence In Space: How CubeSats and Small Satellites Fit in our Current Space Governance Framework

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August 8, 2023 ∘ 37th Annual Small Satellite Conference ∘ Logan, Utah

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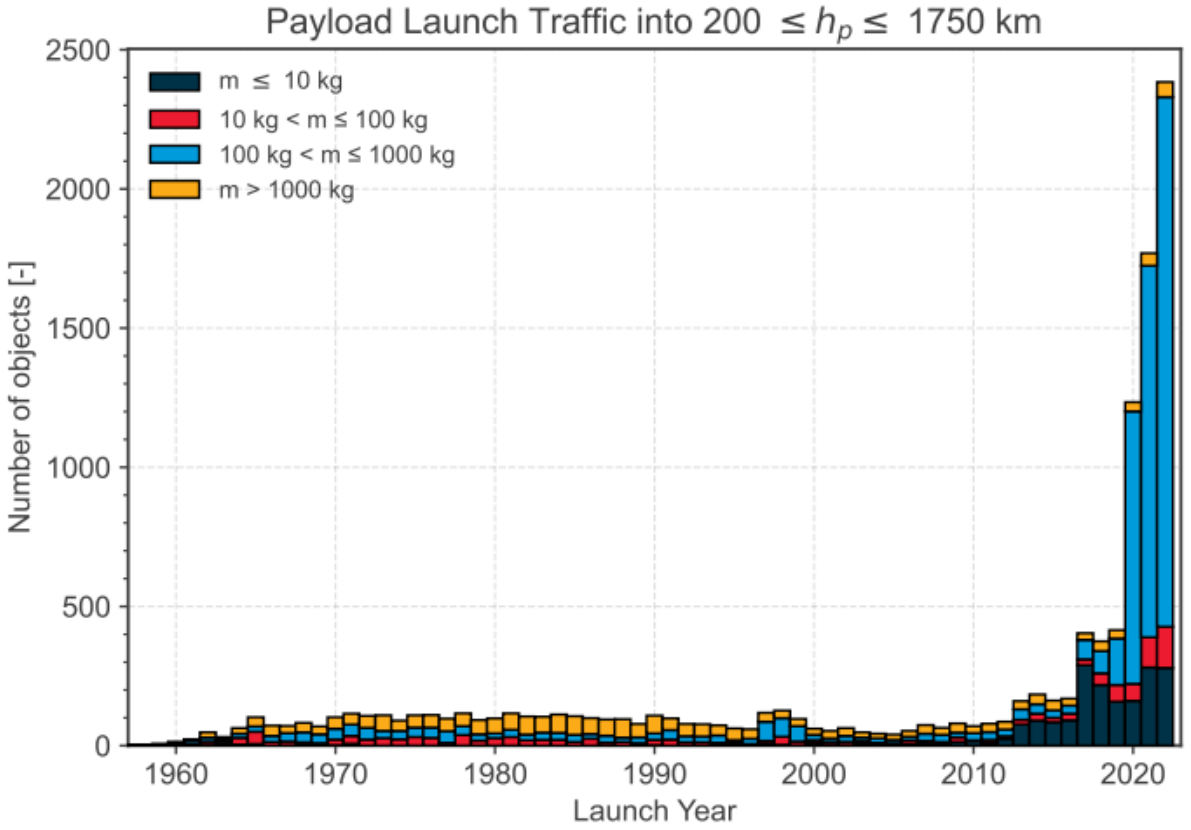
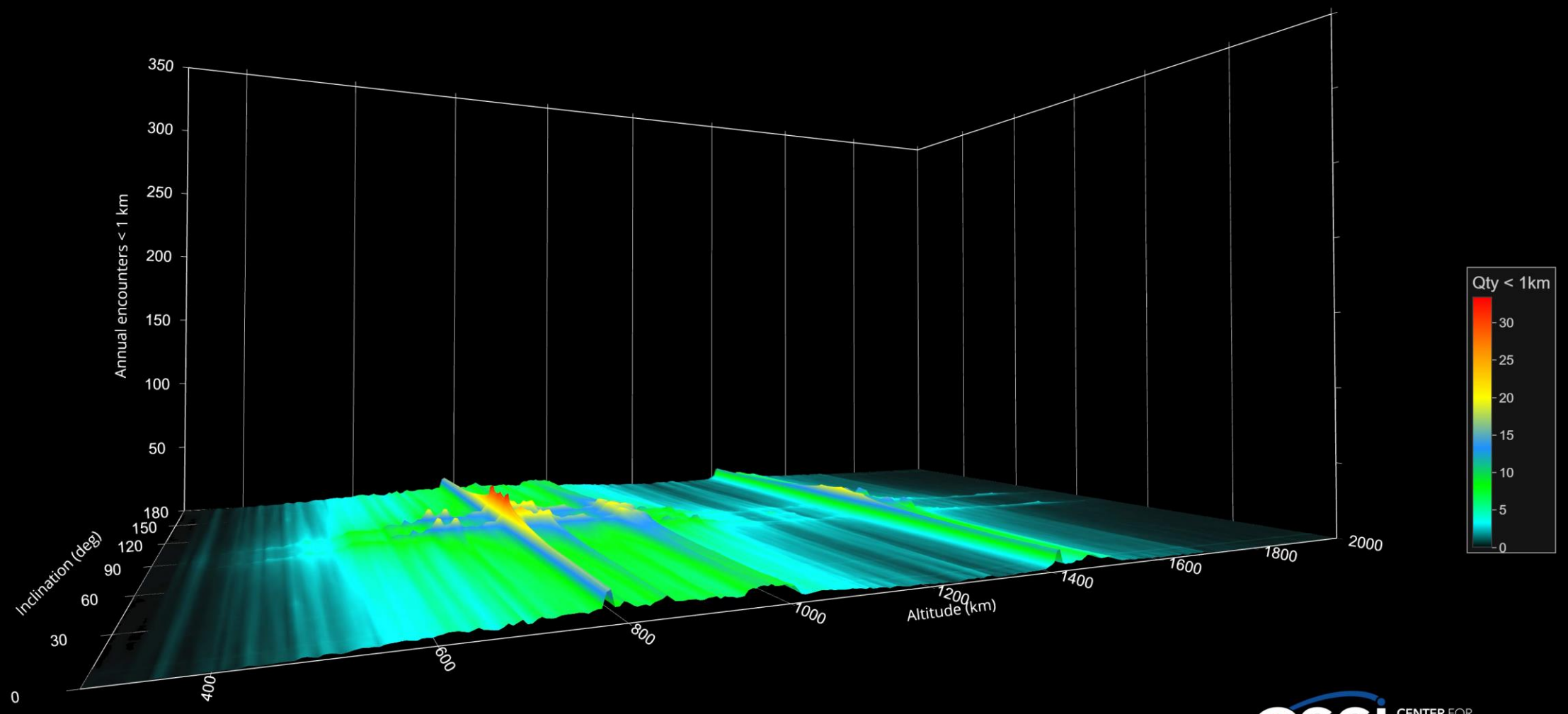
Purpose

- Discuss state of our space operations environment today
- Provide broad overview of space governance in the context of small satellite operations
  - Why? Because space governance is the mechanism/enabler for expanding space activities



SOURCE: European Space Agency, *Annual Space Environment Report,* June 12, 2023, *https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf*

10 Feb 2005 : Spacecraft encounter rates vs inclination and altitude



CSSI CENTER FOR SPACE STANDARDS & INNOVATION

Debris Creating ASAT Tests

Date	Country	ASAT System	Target	Intercept Altitude	Tracked Debris	Debris Still on Orbit	Total Debris Lifespan
Sept. 13, 1985	U.S.	ASM-135	Solwind	530 km	285	0	18+ years
Jan. 11, 2007	China	SC-19	FengYun 1C	880 km	3536	2786[A]	16+ years
Feb. 20, 2008	U.S.	SM-3	USA 193	220 km	174	0	1+ year
Mar. 27, 2019	India	PDV-MK II	Microsat-R	300 km	130	0	3.2 years
Nov. 15, 2021	Russia	Nudol	Cosmos 1408	470 km	1790	300[B]	Unknown
				Total	**6349**	**4379**	

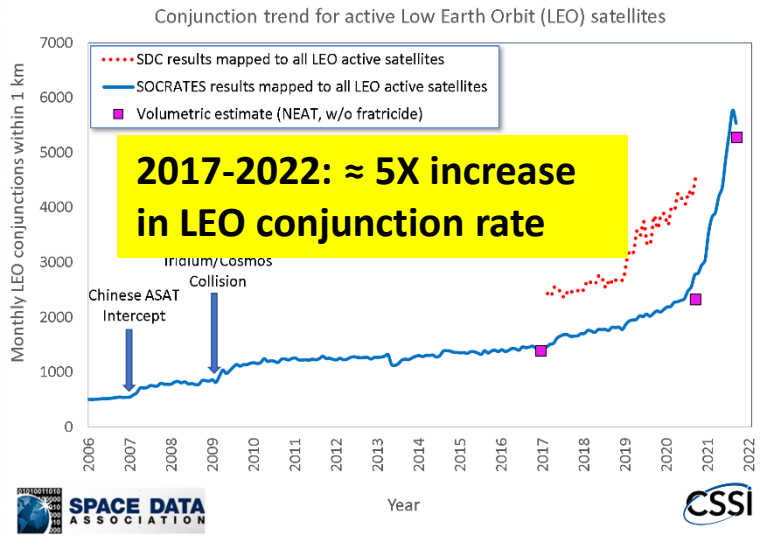
A: as of February 15, 2023
B: as of February 14, 2023

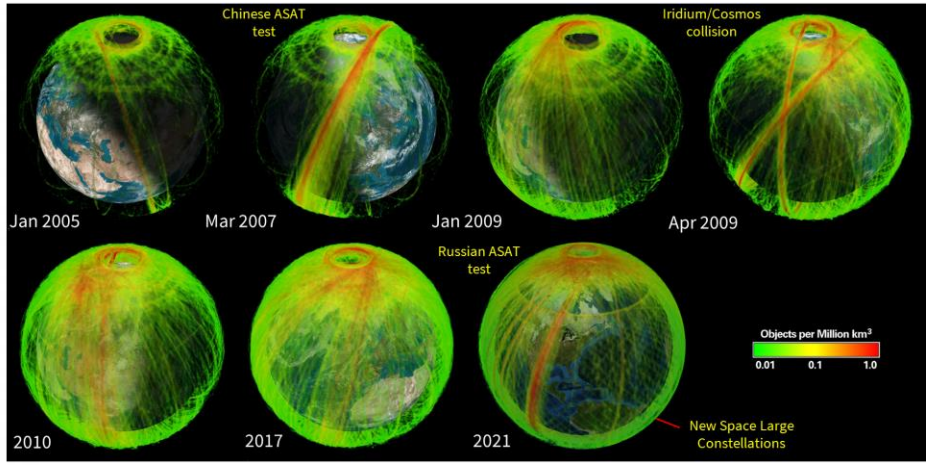
For more complete characterizations, see:

[1] Oltrogge, D.L., Alfano, S., Vallado, D.A., Zimmer, P., Hall, R.H., Wilson, J., Siegers, M., and Aurich, J., "Russian ASAT Debris Cloud Evolution and Risk," 3rd IAA Conference on Space Situational Awareness, Madrid Spain, 4-6 Apr 2022, accessible at https://comspoc.com/Resources/Content/Private/C-20220423T080219/Paper/20220403_Russian_ASAT_Impact_to_Operators_FINAL.pdf

[2] Oltrogge, D.L., Alfano, S., and Hall, R., "Comparison of predicted and observed spacecraft encounters from Russian ASAT test," AMOS 2022 Conference, Maui HI USA, 28 Sep 2022

Space Safety is of Increasing Concern



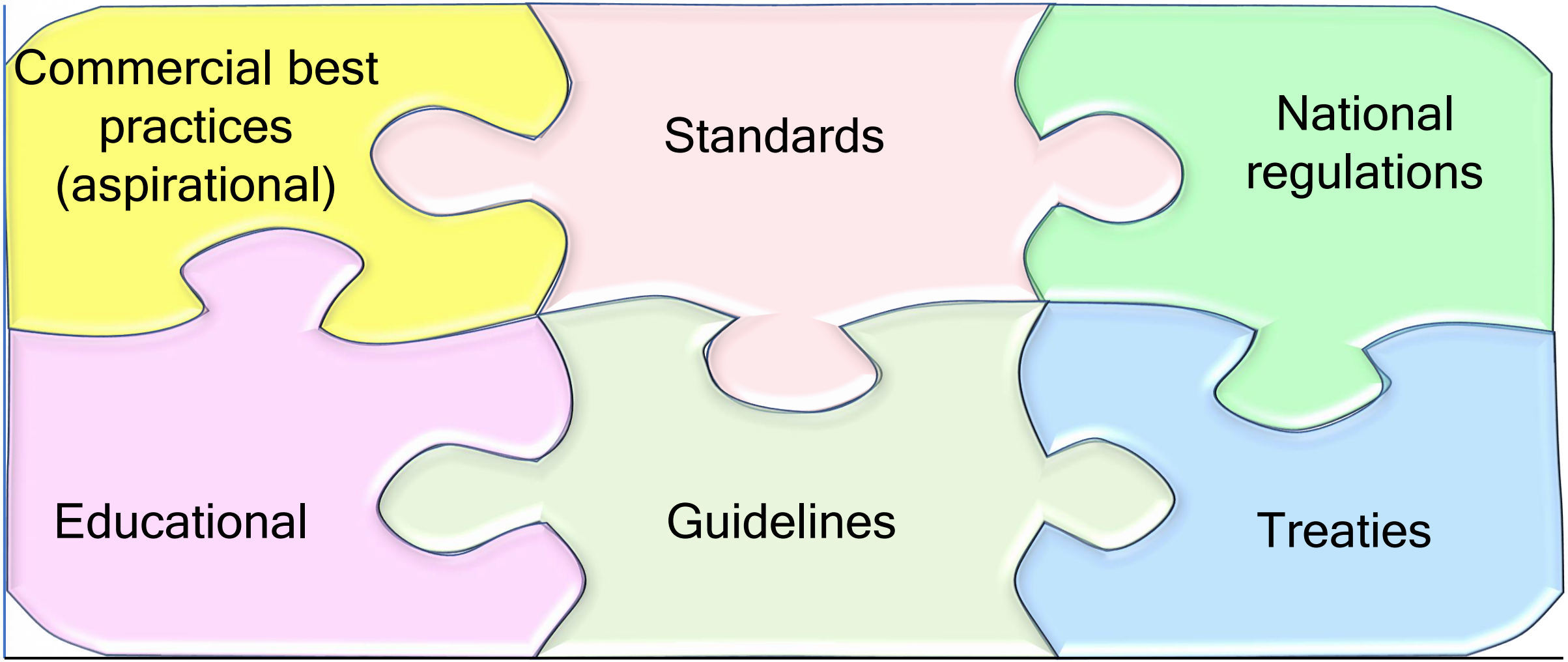


"NEAT" encounter rates (http://www.comspoc.com/neat/)

Much of the regulatory frameworks related to space debris were developed in the context of a less complex operational domain – agencies and industry groups are in the process of updating/refining

- 25-year "rule" for post mission disposal: adequacy and compliance → 5 year
- Population of legacy government debris objects (e.g., spent rocket bodies)
- Large constellations & STM standards
- Conjunction squalls
- Propulsion, maneuverability, and identification?
- Mitigation & remediation

Our Space Governance “Fabric”



Defining Small Satellites

- International community struggled to define a "small satellite," so strove to be size-agnostic
  - No commonly held or standard regulatory definition of small satellite
- Industry and trade group market analyses typically define small satellites as below a threshold of 500kg or 600kg
- Definitions used for regulatory/legal considerations and for industry analysis and tracking may be different
- **CubeSat**: a well-established technical standard for modular small satellites in units of 10 cm × 10 cm × 10 cm size; widely used in academic and commercial missions, but no regulatory or legal meaning

Selected Mass Thresholds used in Regulatory & Policy Definitions for SmallSats

- U.S. Federal Communications Commission: ≤ 180kg
- NASA: ≤ 180kg
- U.S. Federal Aviation Administration Office of Commercial Space Transportation, spacecraft mass classes:

Class Name	Kilograms (kg)	Pounds (lb)
Femto	0.01 - 0.1	0.02 - 0.2
Pico	0.09 - 1	0.19 - 2
Nano	1.1 - 10	3 - 22
Micro	11 - 200	23 - 441
Mini	201 - 600	442 - 1,323
Small	601 - 1,200	1,324 - 2,646
Medium	1,201 - 2,500	2,647 - 5,512
Intermediate	2,501 - 4,200	5,513 - 9,259
Large	4,201 - 5,400	9,260 - 11,905
Heavy	5,401 - 7,000	11,906 - 15,432
Extra Heavy	>7,001	>15,433

https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2018_AST_Compendium.pdf

Standards & Best Practices Relevant to SmallSats

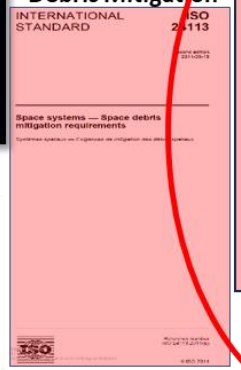
Norms of behavior

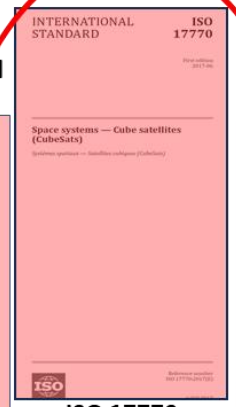
Normative

UNITED NATIONS
Committee on the Peaceful Uses of Outer Space

ISO

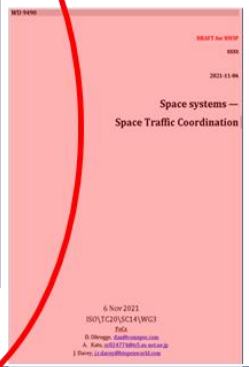
ISO 24113: Orbital Debris Mitigation





ISO 17770: CubeSat Standard

Space Traffic Coord.



Aspirational

Inter–Agency Space Debris Coordination Committee

SSC SPACE SAFETY COALITION

CONFERS

SIA SATELLITE INDUSTRY ASSOCIATION
The Voice of the Satellite Industry

COMMERCIAL SPACEFLIGHT FEDERATION

AIA AEROSPACE INDUSTRIES ASSOCIATION

SECURE WORLD FOUNDATION

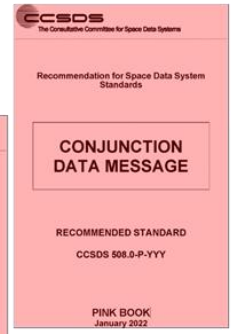
AIAA SHAPING THE FUTURE OF AEROSPACE

Space data exchange

Normative

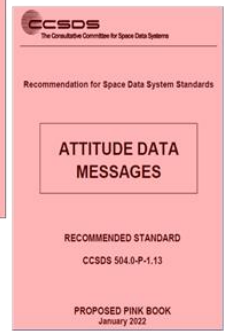
Consultative Committee CCSDS for Space Data Systems

ODM: standardized way to share orbits



CDM: standardized way to share transits

ADM: standardized way to share attitude



Aspirational

SPACE DATA ASSOCIATION

CSSI

CELESTRAK SINCE 1985

CCSDS Data Exchange/Communications Standards

	Existing CCSDS messages and standards											Proposed		Potentially useful new CCSDS messages									Other open access legacy messages
	Attitude Data Message	Conjunction Data Message	Digital Motion Imagery	Events Message*	Orbit Data Message	Pointing Request Message	Radio Freq & Mod. Systems	Re-entry Data Message	Space Data Link Security Stds	Time Code Formats	Tracking Data Message	Fragmentation Data Message	Launch Data Message	Anomaly Data Message	Earth Orientation Parameters Msg	Geolocation Data Message	RF Interference Data Message	RF Characteristics Message	RPO/OOS Data Message	Situation Report Message	Space Catalog Mapping Msg	Space Weather Data Message	Spacecraft CAD Message	ILRS USG *** if shared ***
Attitude	•				•	•				•					•									
Conjunctions	•	•			•					•					•							•		
Maneuvers					•					•			•		•					•				
Orbit & errors					•					•					•						•	•		SP3-d, RINEXv4, IEEE 4003, ILRS, SPEph, VCM, Caliper, .ECI
"Phonebook"					•																			
Reentry								•														•		
RF, RFI, Geoloc							•								•	•								
RPO/OOS			•		•		•		•		•				•			•	•	•	•	•	•	FITS, EOSSA
Space catalog					•	•				•	•				•						•	•		
Space events	•	•		•	•			•		•	•	•	•	•	•		•			•		•		
S/C chars, SoH					•					•		•		•			•	•		•			•	
Sensor track/obs						•				•	•		•		•									B3
STC system	•	•		•	•			•	•	•	•	•	•	•	•		•	•	•	•	•	•		

Characteristics Considered in Regulatory & Licensing Process

Who is operating the satellite/system?

- Is it a commercial operator or purpose?
- Is it an amateur or experimental operator?

May have implications for frequency bands allowed, liability and indemnification requirements, and licensing fees charged

What purpose(s) is the satellite system intended to serve?

- Telecommunications
- Remote Sensing / Earth Observation
- Other Applications

Use of radiofrequency spectrum is regulated under the provisions of the International Telecommunications Union; national administrations may choose to impart specific licensing practices for specific applications; licensing may be at a single agency or in multiple

What are the technical characteristics of the system?

- What orbit will it operate in? LEO? GEO?
- Will it operate as a constellation or a single satellite?
- How will it be launched?

Differing licensing types may be advisable based on the type of expected operations; ITU requirements differ for GSO and NGSO; launch may occur outside of your national jurisdiction

U.S. FCC Licensing Categories for Satellite Systems (“space stations”)

- In the United States the Federal Communications Commission (FCC) is the regulatory authority responsible for overseeing access to non-Federal spectrum
- All non-governmental satellite operators must obtain a license from the FCC
- The FCC also plays a significant role in regulation of space debris mitigation

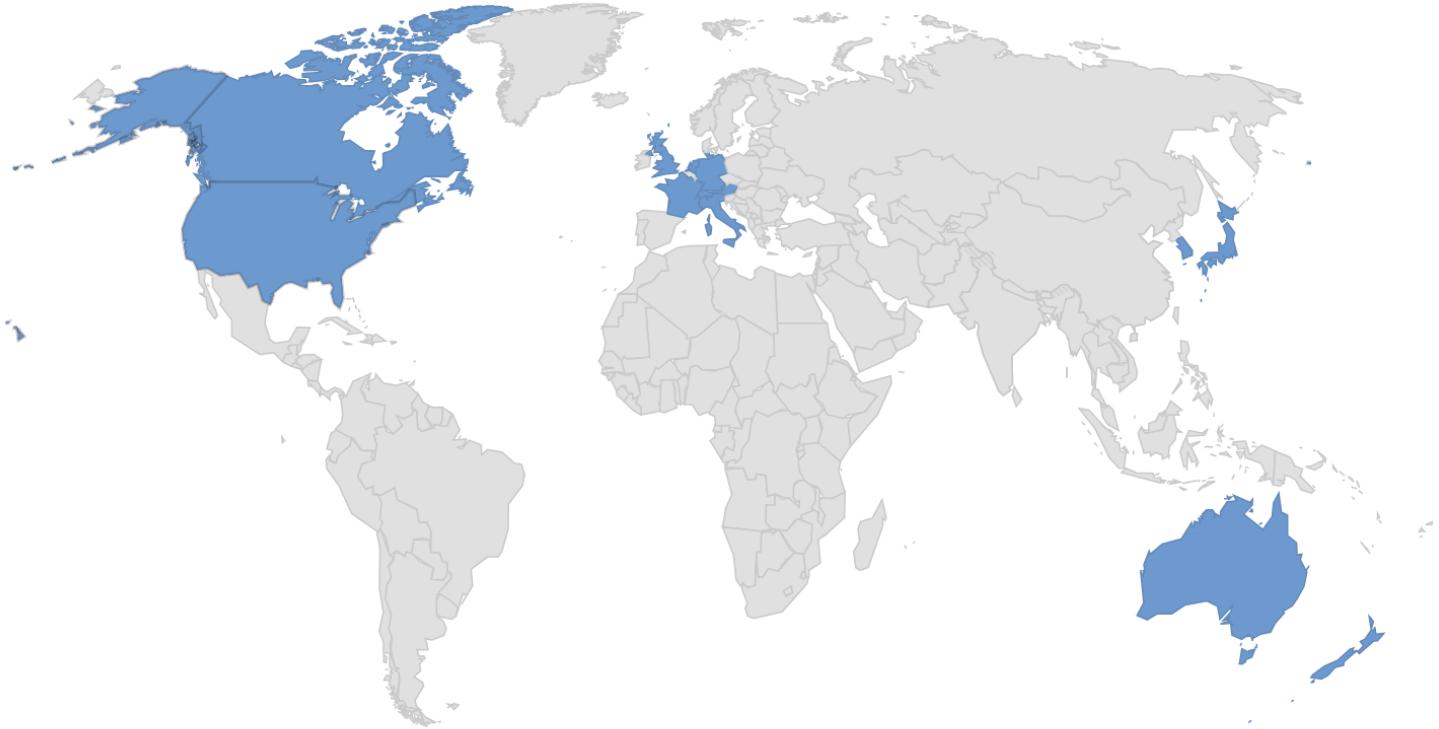
FCC License Categories for “Space Stations”	
License Part	**Intended Operators/Applicants**
Part 25 (Commercial GSO)	• Commercial operations at the geosynchronous orbit (GSO), primarily communications applications and primarily large satellites
Part 25 (Commercial NGSO) ➢ Regular Subcategory ➢ Streamlined Small Satellite Subcategory	• A range of commercial applications in non-geostationary-satellite orbit (NGSO) – e.g. Low Earth Orbit – including commercial constellations • New subcategory implemented in 2020 to address small satellites.
Part 5 (Experimental)	• Experimental radio operations, including satellites. In the satellite context, Part 5 licenses are used the most by university small satellite community
Part 97 (Amateur)	• Amateur radio service satellite operations. Also used among the university and amateur small satellite community; serves as less of a license and more of a notification to the FCC about the satellite’s planned use of the reserved amateur radio spectrum.

Space Safety Coalition

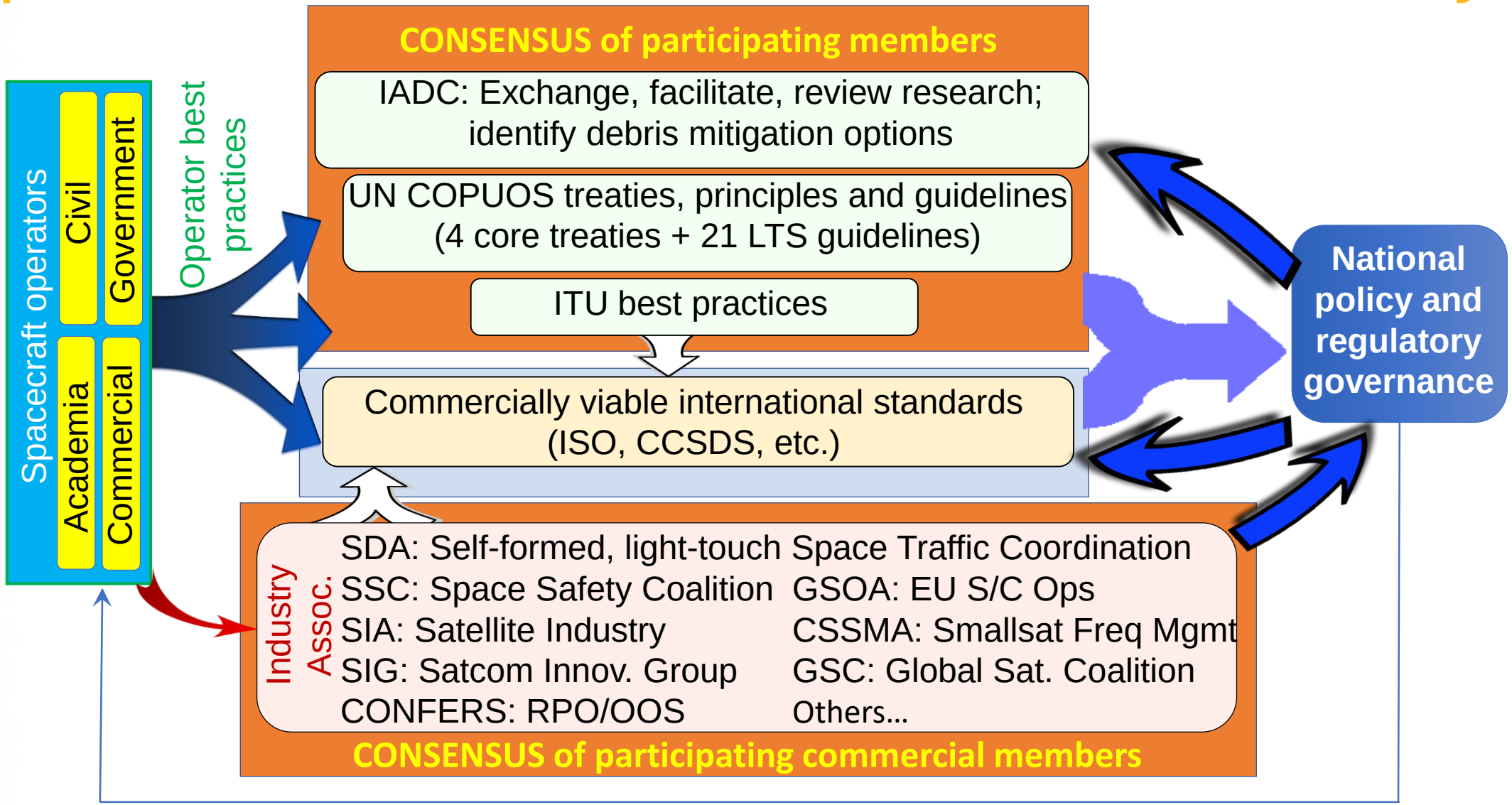
- Most operators support space sustainability
  - “It’s just good business sense”
  - Especially important for new large constellations
- The SSC is a ad hoc “light touch” coalition of willing space operators and relevant industry stakeholders, formed to assemble aspirational best practices for the long-term sustainability of space operations.
  - Not a legal entity
  - https://spacesafety.org
- In advance of space governance treaties, consensus guidelines, standards and national regulations, the SSC can make a difference!
  - Concept is one of self-regulation
- While non-normative, signatories *endorse and agree to strive to implement* best practices to ensure safety and commercial viability of space activities.

Direct Ascent-ASAT Moratorium

- In April 2022, the United States became the first country to declare a commitment to no longer conduct destructive DA-SAT missile tests
- 13 countries have made the commitment not to conduct destructive DA ASAT missile tests
- UNGA Resolution supporting ASAT test moratorium: passed Dec. 7 2022. A total of 155 nations voted in favor of the resolution



Space Governance Framework: A Virtuous Cycle



"Space Governance in the New Space Era," Daniel L. Oltrogge and Ian A. Christensen, The Journal of Space Safety Engineering, Volume 7, Issue 3, September 2020, Pages 432-438

Thank You

Ian Christensen - ichristensen@swfound.org
Dan Oltrogge - dan@comspoc.com

Side event for continued discussion:

Space Debris and ASAT Testing: Protecting the Operational Environment for SmallSats

When: Wednesday, August 9, 2023
Time: 9:45 AM - 10:45 AM Mountain Daylight Time
Where: Eccles Science Learning Center (ESLC) Room 46

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Additional Resources (1 of 7)

- https://www.space-track.org/ - has a range of information on SSA services and registration best practices
- NASA Cubesat 101 Guide – discussion of "Basic Concepts and Processes for First-Time CubeSat Developers" - includes overview of regulatory requirements/agencies
- Small satellite handbook – Currently under development at ITU-R Working Party 4A (WP 4A)
- "Small Satellite Regulation in 2021" – Conference paper from 2021 Small Satellite Conference, Logan, UT by Lynne M. Montgomery & Christopher D. Bairan providing an overview of U.S. Federal Communications Commission regulatory practices for small satellites as of 2021
- "A Handbook for Post-Mission Disposal of Satellites Less Than 100 kg" - International Academy of Astronautics study group report, provides guidance to the designers, developers, and operators of small satellites on ways to select and implement post-mission disposal (PMD) solutions

Additional Resources (2 of 7)

Of the five United Nations treaties on outer space, the *four core treaties* are:

- **The "Outer Space Treaty"**
  - Treaty on Principles Governing Activities of States in Exploration and Use of Outer Space, including Moon and Other Celestial Bodies
  - General Assembly (GA) resolution 2222 (XXI), entered into force 10 Oct 1967
- **The "Rescue Agreement"**
  - Agreement on Rescue of Astronauts, Return of Astronauts and Return of Objects Launched into Outer Space
  - GA resolution 2345 (XXII), entered into force 3 Dec 1968
- **The "Liability Convention"**
  - Convention on International Liability for Damage Caused by Space Objects
  - GA resolution 2777 (XXVI), entered into force 1 Sep 1972
- **The "Registration Convention"**
  - Convention on Registration of Objects Launched into Outer Space
  - Adopted by the General Assembly in its resolution 3235 (XXIX), entered into force 15 Sep 1976

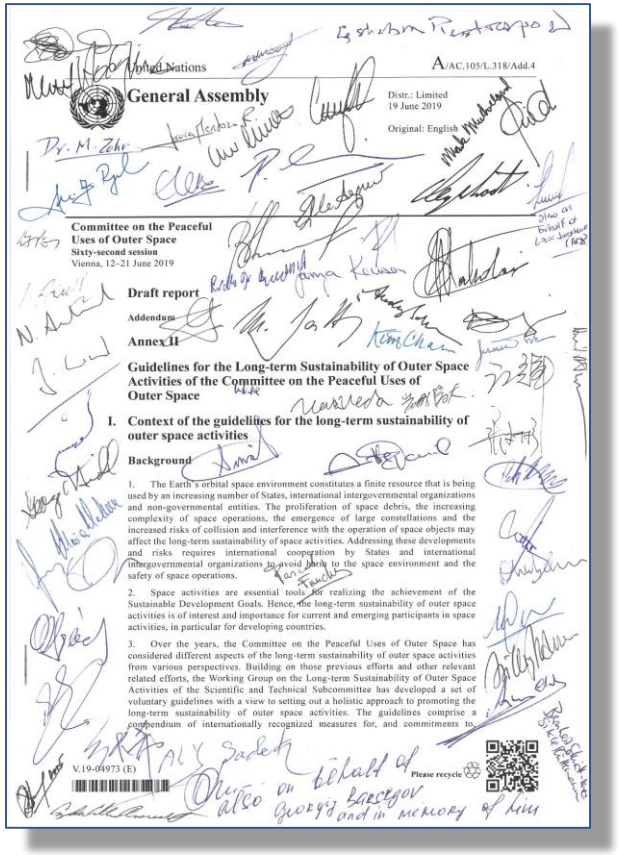
- Fifth treaty, **the "Moon Agreement",** exists but remains largely unratified, unenforced
  - Agreement Governing the Activities of States on the Moon and Other Celestial Bodies
  - GA resolution 34/68, published 11 Jul 1984

Additional Resources (3 of 7)

UN COPUOS Space Sustainability (“LTS”) Guidelines

- Working Group on Long-Term Sustainability of Outer Space Activities worked from 2010 – 2018.
- Adopted 21 Guidelines and a politically significant preamble
- Adopted by consensus of 92 States
- Address all kinds of space activities & all mission phases
- Voluntary & non-binding

- The guidelines address:
  - Policy and regulatory framework for space activities
  - Safety of space operations
  - International cooperation, capacity-building, & awareness
  - Scientific and technical research and development



United Nations A/AC.105/L.318/Add.4

General Assembly

Distr.: Limited
19 June 2019

Original: English

Committee on the Peaceful Uses of Outer Space
Sixty-second session
Vienna, 12–21 June 2019

Draft report

Addendum

Annex II

Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space

I. Context of the guidelines for the long-term sustainability of outer space activities

Background

1. The Earth's orbital space environment constitutes a finite resource that is being used by an increasing number of States, international intergovernmental organizations and non-governmental entities. The proliferation of space debris, the increasing complexity of space operations, the emergence of large constellations and the increased risks of collision and interference with the operation of space objects may affect the long-term sustainability of space activities. Addressing these developments and risks requires international cooperation by States and international intergovernmental organizations to avoid harm to the space environment and the safety of space operations.

2. Space activities are essential tools for realizing the achievement of the Sustainable Development Goals. Hence, the long-term sustainability of outer space activities is of interest and importance for current and emerging participants in space activities, in particular for developing countries.

3. Over the years, the Committee on the Peaceful Uses of Outer Space has considered different aspects of the long-term sustainability of outer space activities from various perspectives. Building on those previous efforts and other relevant related efforts, the Working Group on the Long-term Sustainability of Outer Space Activities of the Scientific and Technical Subcommittee has developed a set of voluntary guidelines with a view to setting out a holistic approach to promoting the long-term sustainability of outer space activities. The guidelines comprise a compendium of internationally recognized measures for, and commitments to,

V.19-04973 (E)

Please recycle

Full texts of agreed guidelines available in UN document **A/74/20, Annex II**

Additional Resources (4 of 7)

International Telecommunications Union (ITU)

- First published in 1993, “Environmental protection of the geostationary-satellite orbit ” S.1003.2 recommends:
  - Minimize release of debris into GSO during deployment
  - Minimize life of elliptical transfer orbits w/apogee near GEO
  - At End-of-Life, raise GSO S/C to GEO+200km+perturbations
  - Avoid RFI during transfer to GEO graveyard orbit
- Due to its character as [an ITU recommendation], it is not legally binding

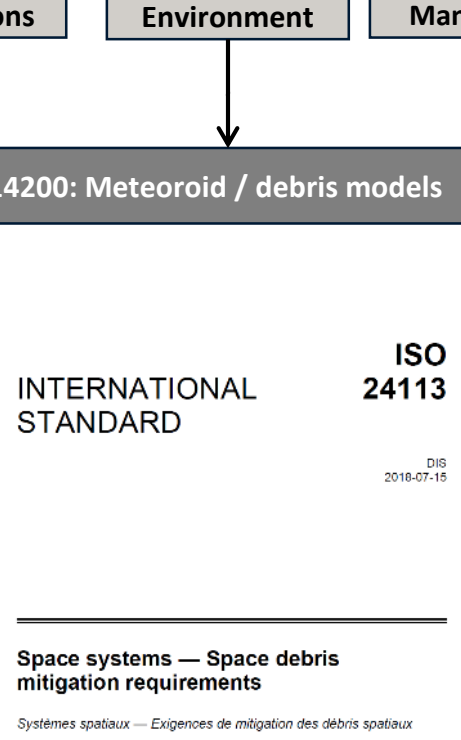
https://www.itu.int/rec/R-REC-S.1003/en

Additional Resources (5 of 7)

ISO Standards

ISO TC20/SC14

- **WG1** Design
- **WG2** Integ. / test
- **WG3** Operations
  - 16158: Avoiding collisions
  - [16164: Disposal of satellites in LEO]
  - [16699: Disposal of orbital stages]
  - [23339: Propellant mass estimation]
  - [26872: Disposal of satellites at GEO]
  - 27852: Determining orbit lifetime
  - 27875: Re-entry risk management
- **WG4** Environment
  - 14200: Meteoroid / debris models
- **WG5** Management
- **WG6** Materials
- **WG7** Debris
  - 11227: Test procedures for ejecta
  - 16126: Survivability against impacts
  - [16127: Prevention of s/c break-ups]
  - 18146: Space debris mitigation design and operations manual for S/C
  - 20590: Space debris mitigation design and operations manual for LV
  - 20893: Detailed debris mitigation requirements for LVOS
  - [21095: Procedure for limiting re-entry risk]
  - 23312: Detailed debris mitigation requirements for S/C
  - 24113: Space debris mitigation requirements



INTERNATIONAL STANDARD

ISO 24113

DIS
2018-07-15

Space systems — Space debris mitigation requirements

Systèmes spatiaux — Exigences de mitigation des débris spatiaux

ISO TC20/SC14 builds space standards for best practices

Additional Resources (6 of 7)

Data exchange message formats

- **Key/Value Notation (KVN):** Original CCSDS message format
  - **Example:** `REF_FRAME = TEME`
- **XML schema:** Added to CCSDS messages ≈ 2001
  - **Example:** `<REF_FRAME>TEME</REF_FRAME>`
  - SANA Registry hosts CCSDS NAV WG XML schema: https://sanaregistry.org/r/ndmxml_unqualified/ndmxml-3.0.0-master-3.0.xsd
- Other more 'modern' & succinct formats could include:
  - **J**ava**S**cript **O**bject **N**otation (JSON)
    - **Example:** `'{"name":"John", "age":30, "car":null}'`
  - **FlatBuffers is an efficient cross platform serialization library for C++, C#, C, Go, Java, Kotlin, JavaScript, Lobster, Lua, TypeScript, PHP, Python, Rust and Swift**
- **Why doesn't CCSDS support these other formats as well?**
  - **CCSDS agencies/volunteers must test ALL formats**
  - **To conserve resources, only KVN and XML used**
  - **But relatively easy to use keywords and values to populate these other formats**

Additional Resources (7 of 7)

CCSDS: New Orbit Comprehensive Message

- Cartesian and mean/osculating element set time histories (“trajectories”)
- Spacecraft physical characteristics
- Covariance time histories
- Detailed maneuver time histories
- Force model/perturbations description
- Orbit Determination method, characteristics and parameters
- User-defined parameters

Table 6-1: OCM File Layout and Ordering Specification

Section			Content	Status M/O
OCM Header			A single header of the message	M
OCM Metadata			A single metadata section (data about data)	M
Data	trajectory data 1	data description	One or more trajectory state time histories (consisting of one or more trajectories)	O
		data lines		
	⋮			
	trajectory data $n_{trajectory}$	data description		
		data lines		
	physical properties		A single space object physical characteristics section	O
	covariance data 1	data description	One or more covariance time histories (each consisting of one or more covariance matrices)	O
		data lines		
	⋮			
	covariance data $n_{covariance}$	data description		
		data lines		
	maneuver data 1	data description	One or more maneuver specifications for either impulsive or finite burns or acceleration profiles	O
		data lines		
	⋮			
	maneuver data $n_{maneuver}$	data description		
		data lines		
	perturbations parameters		A single perturbations parameters section (required if an orbit determination section is provided)	C
	orbit determination		A single orbit determination data section	O
	user-defined parameters		A single user-defined parameters section containing data and supplemental comments (explanatory information)	O