Best practices for sustainability of space operations

Dan Oltrogge

Space Safety Coalition

23 May 2023

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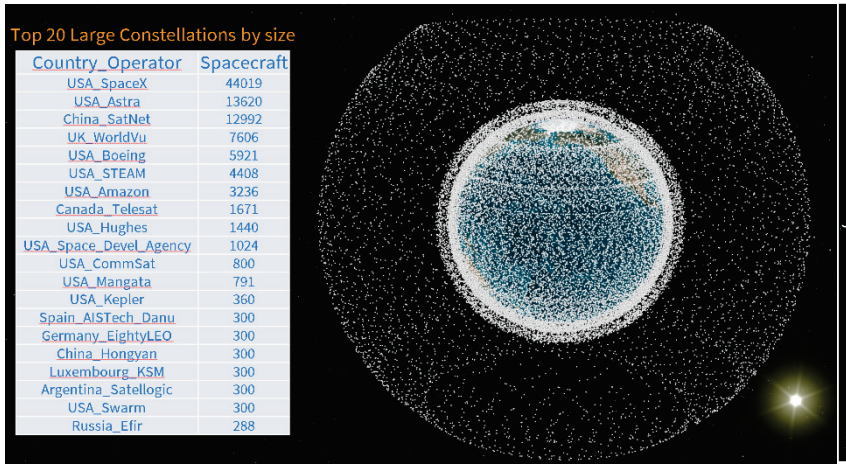
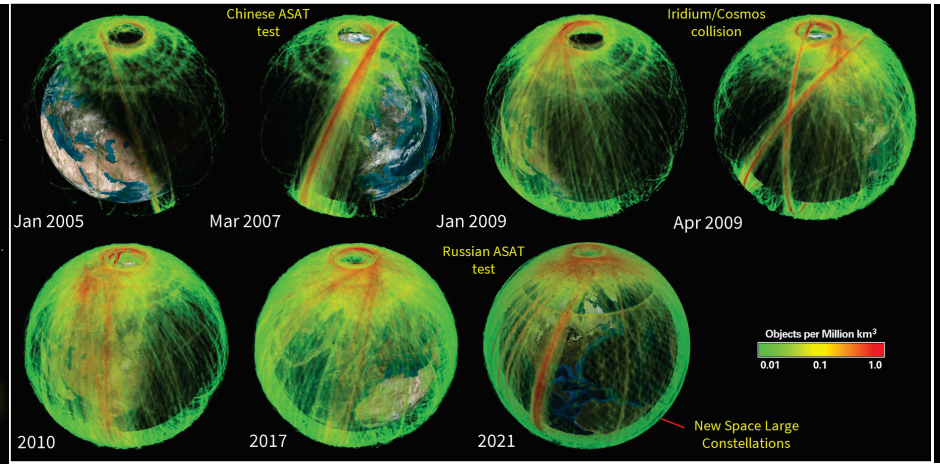
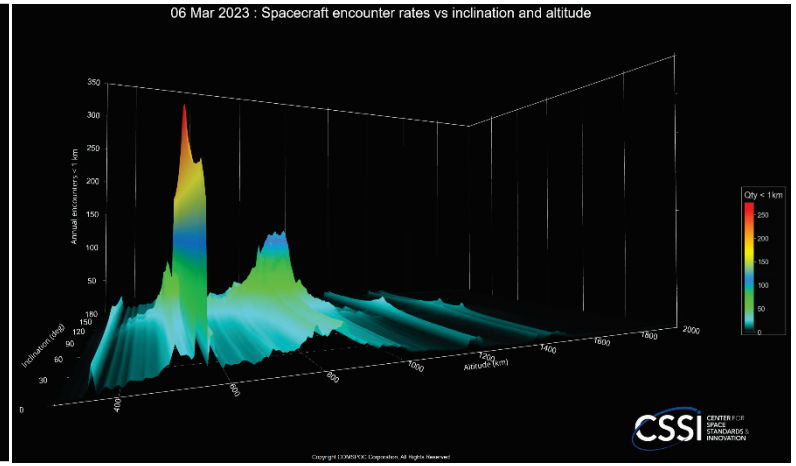
Commercial industry addresses space safety: research, tools, services

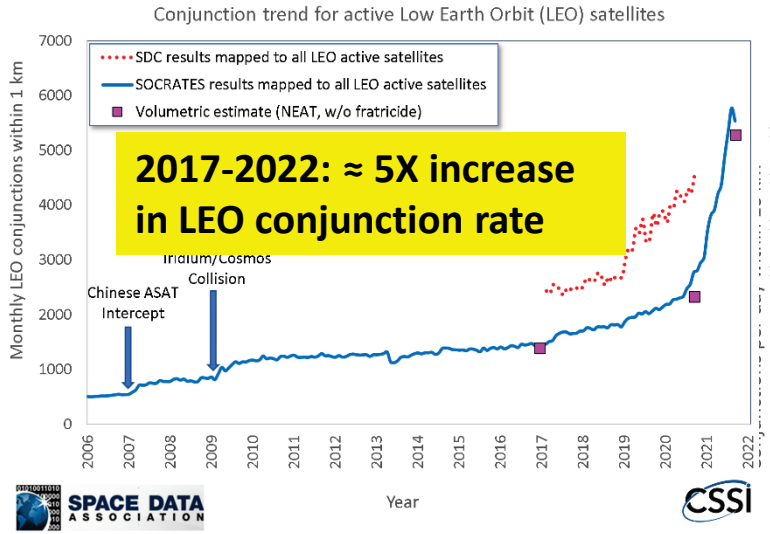




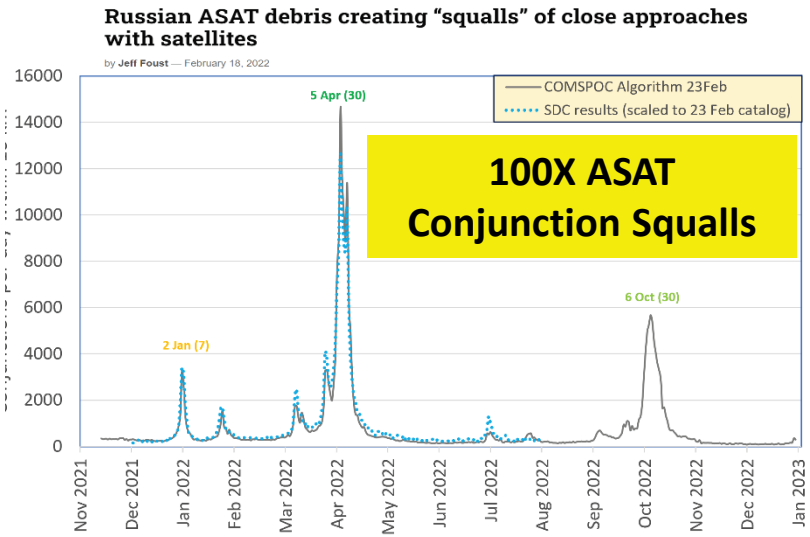


- Large constellations + STM standards
- Conjunction squalls

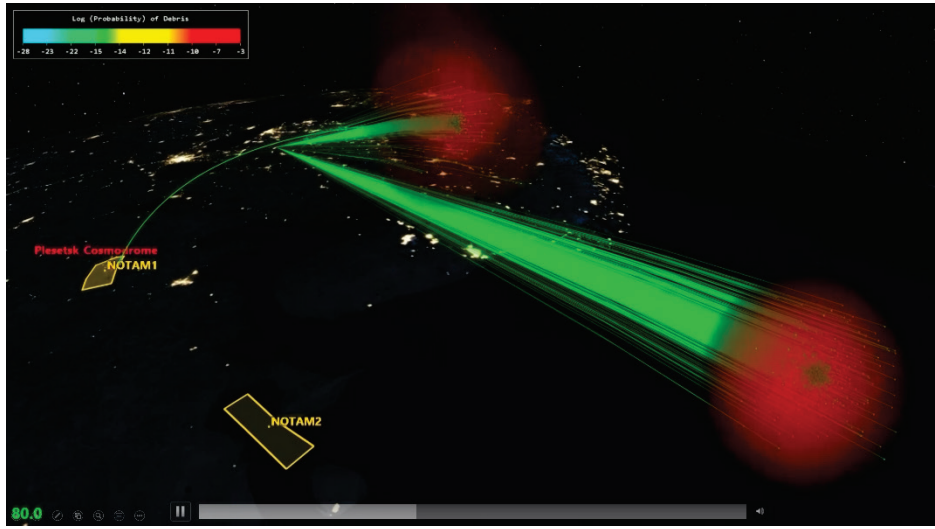
"NEAT" encounter rates (http://www.comspoc.com/neat/)



SPACENEWS



- Spatial density over time
- Implications of ASAT tests



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Current safety of flight insufficient

- **Spacecraft operators can't tell which conjunctions are "too close" using freely-available SSA products.**
- **Spacecraft operators waste staff time and maneuvers due to unnecessary alarms and misleading conjunction assessments***
- **Safety-of-flight services currently suffer inaccuracies, omissions, lack of transparency**
  - **LEO and GEO SSA data incomplete, containing only 4% of estimated population > 1 cm**
  - **Serious collision risks are being missed**
- **As of 2020, 246 non-deliberate fragmentations since 1999 (11.5 per year)****
- **60% S/C + 65% upper stages in LEO successfully disposed****
  - **Environmental stability requires 90-100% successful disposal rate**
- **… and deep into the "New Space" era, having more than doubled the number of active spacecraft in only five years**
- **Commercial space industry best practices help address safety**

* Oltrogge, D.L. and Alfano, S., "The Technical Challenges to Better Space Situational Awareness and Space Traffic Management," Journal of Space Safety Engineering, https://doi.org/10.1016/j.jsse.2019.05.004, May 2019

**ESA Space Debris Office, "Space debris mitigation in practice," Stijn Lemmens, ESA ECSL Workshop – Standards, 20 Mar 2019

***Oltrogge, D.L., Chan, J., Vallado, D.A., Cornelius, J., D'Uva, A.R., Hall, R.A., "Deep Operator and SSA Collaboration For Space Sustainability", 12th IAASS Conference, Osaka, Japan, 23 May 2023

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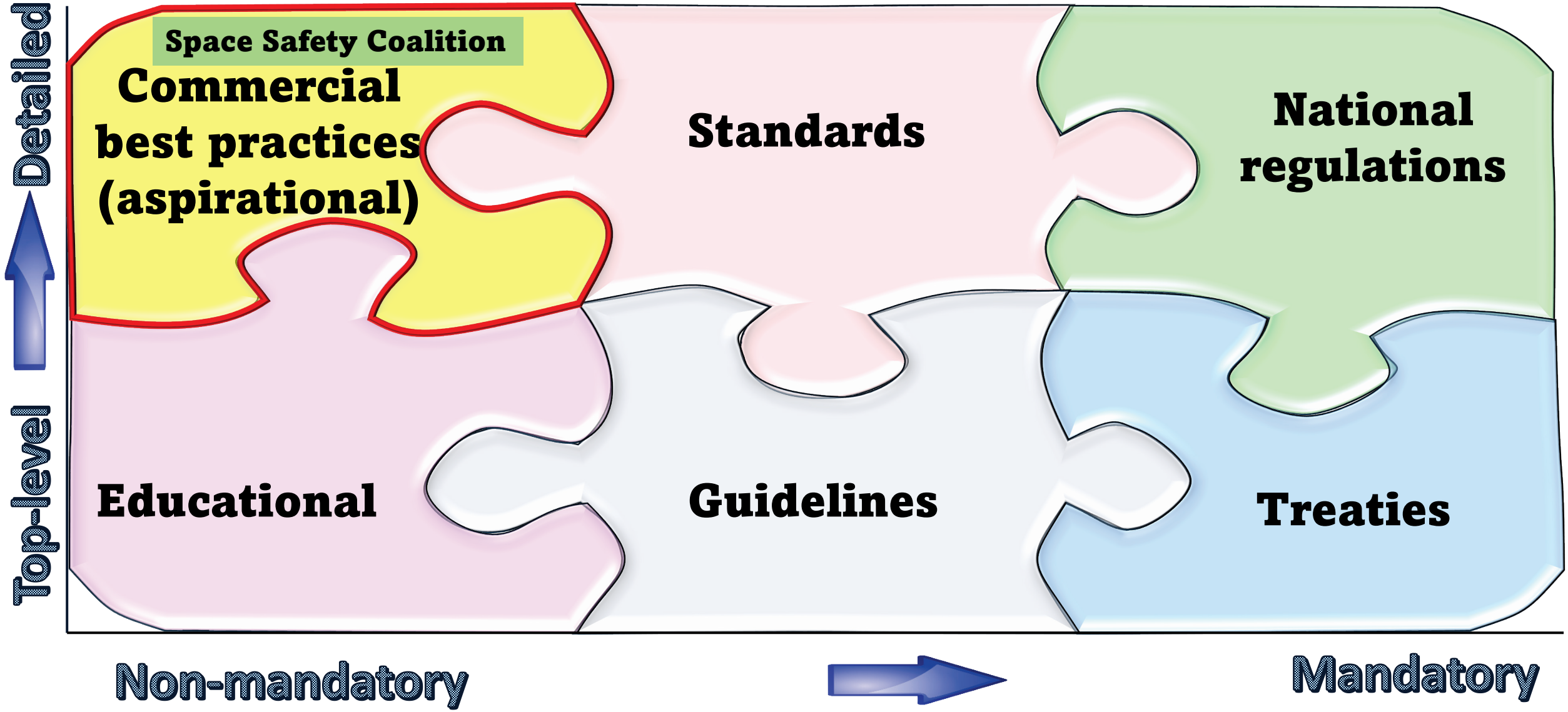
Where can YOU plug in to help promote and enable space sustainability ?



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Space Safety Coalition (SSC)

- https://spacesafety.org
- Most operators support space sustainability
  - “It’s just good business sense”
  - Especially important for new large constellations
- SSC is an ad hoc coalition of willing space operators and relevant industry stakeholders
  - Formed to assemble aspirational best space operations practices
  - Not a legal entity
- SSC can make a difference, in *advance* of:
  - Space governance treaties and consensus guidelines
  - Standards
  - National regulations
- Signatories endorse and strive to implement best practices
  - To ensure safety and commercial viability of space activities

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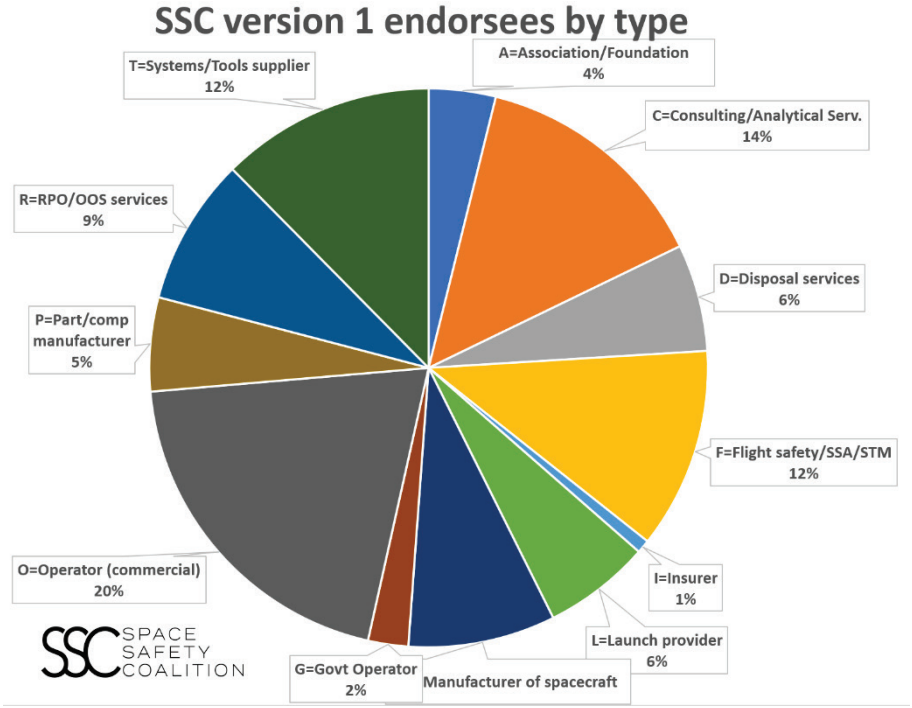
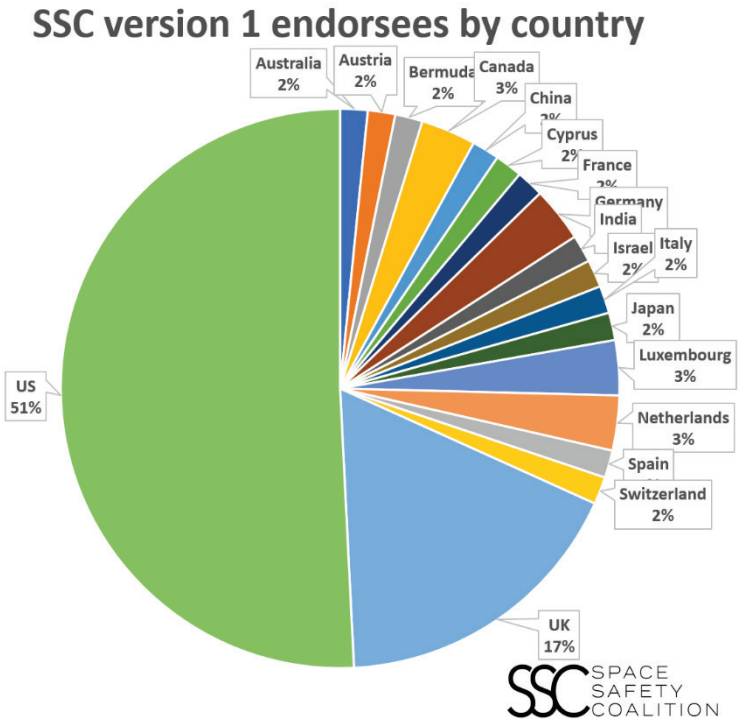
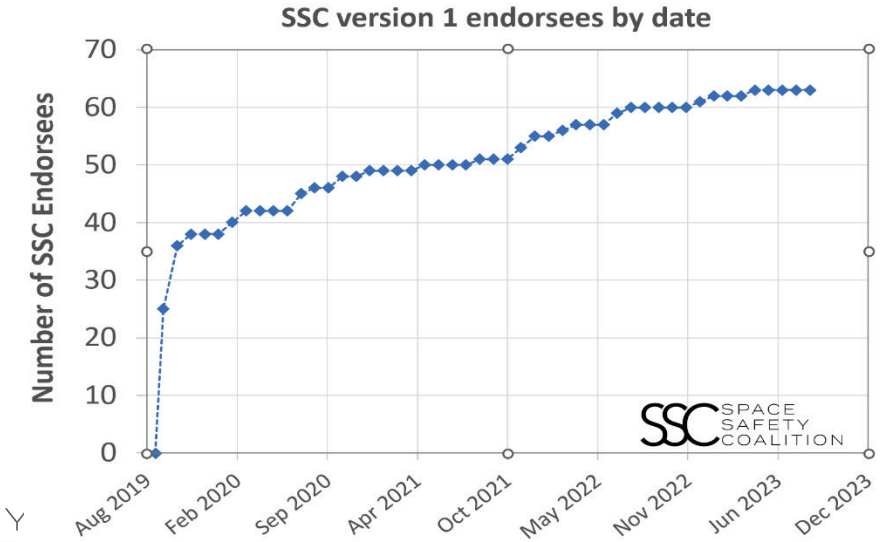
Diverse set of 63 global space organizations endorsed SSC version 1.0







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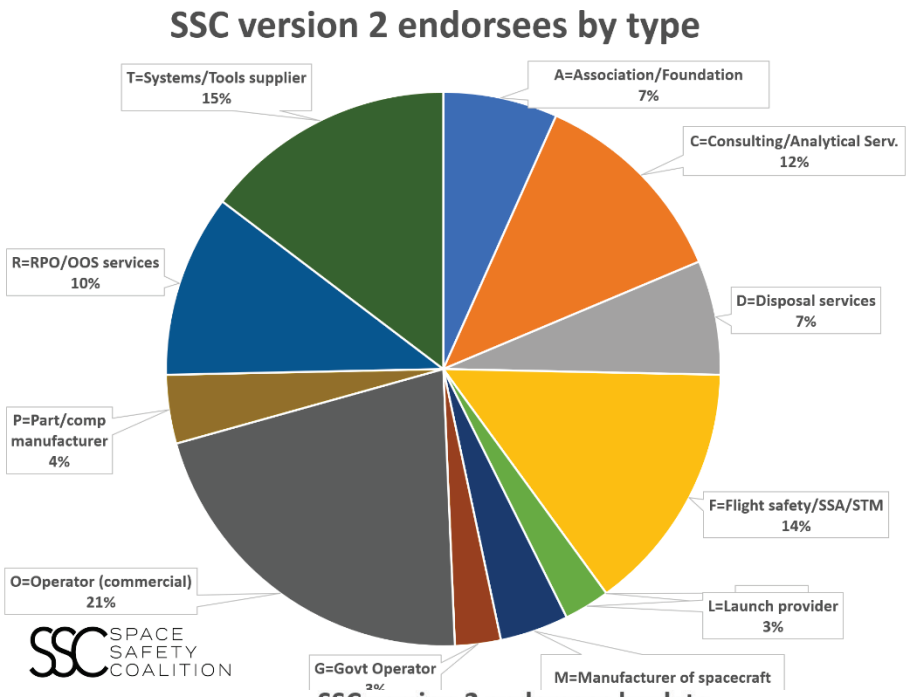
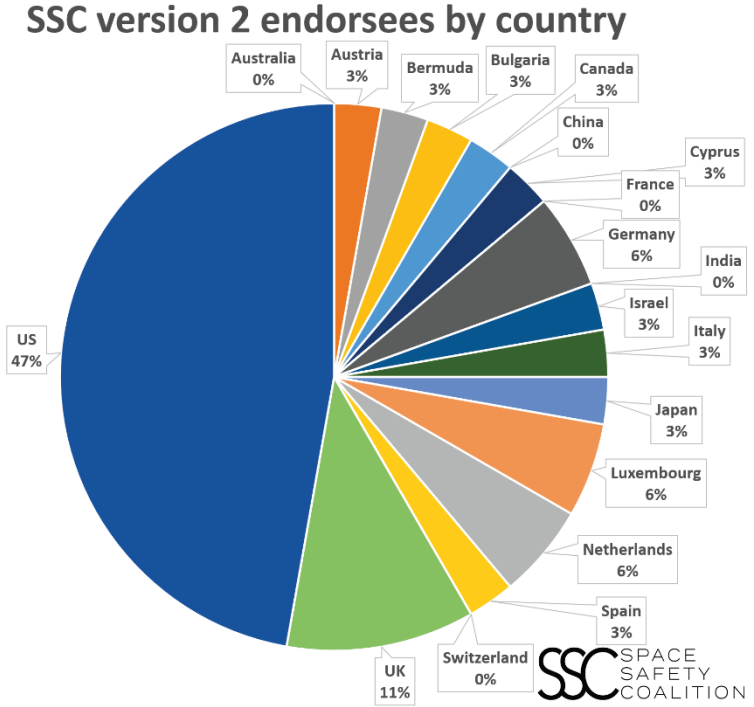
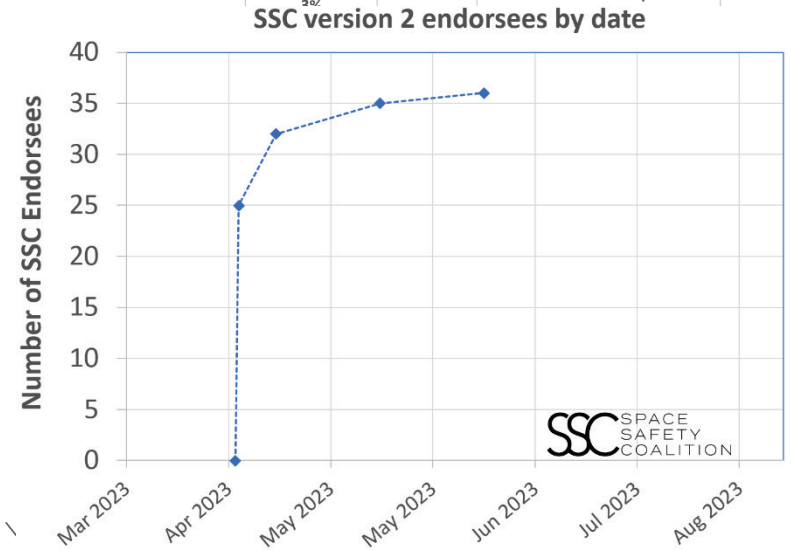
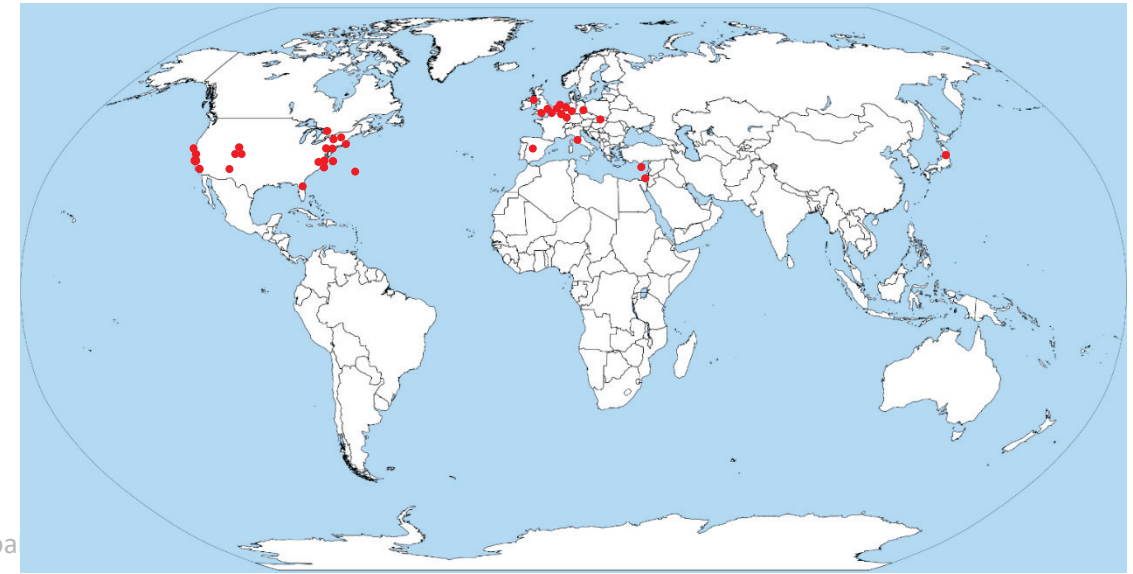
Diverse set of 36 global space organizations already endorse SSC version 2









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What is SSC's "Best Practices for the Sustainability of Space Operations" ?

- **A ground-breaking "living" best practices document that:**
  - **Part 1:** Endorses existing international guidelines, standards (**IADC, UN, ISO, CCSDS**)
  - **Part 2:** Contains **over forty additional specific best practices** to further enhance and secure the long-term sustainability of space operations
  - Initially motivated by perceived unpreparedness for LEO large constellations
  - Originally developed by 36 space operators and relevant industry stakeholders
- **Spans all phases of design and spaceflight, orbit regimes, spacecraft form factors, life cycle phases, and mission types**
- **Although non-normative, signatories "endorse and agree to promote and strive to implement" these best practices to preserve the space operations environment for current and future generations.**
  - Commercial willingness to follow these best practices alleviates need for heavy-handed regulations

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Relevance to UN COPUOS Long-Term Sustainability (LTS) guidelines

- **SSC's best practices address majority of United Nations 2019 LTS guidelines**
  - A/AC.105/C.1/L.366 "Guidelines for the Long-term Sustainability of Outer Space Activities"

Guideline	Guideline Title	SSC Endorsement Doc
Policy and regulatory framework for space activities		
A.1	Adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities	
A.2	Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities	
A.3	Supervise national space activities	
A.4	Ensure the equitable, rational and efficient use of the radio frequency spectrum and the various orbital regions used by satellites	
A.5	Enhance the practice of registering space objects	Endorses spacecraft owner, operator and stakeholder exchange of information relevant to safety-of-flight and collision avoidance with other space operators and stakeholders

Guideline	Guideline Title	SSC Endorsement Doc
International cooperation, capacity-building and awareness		
C.1	Promote and facilitate international cooperation in support of the long-term sustainability of outer space activities	Incorporates by reference IADC, UN COPUOS and ISO/CCSDS guidelines and standards which promote international cooperation
C.2	Share experience related to the long-term sustainability of outer space activities and develop new procedures, as appropriate, for information exchange	Spacecraft owners, operators and stakeholders should exchange information relevant to safety-of-flight and collision avoidance via intra-operator coordination and SSA and STM service entities
C.3	Promote and support capacity-building	Incorporates by reference IADC, UN COPUOS and ISO/CCSDS guidelines and standards which promote capacity building
C.4	Raise awareness of space activities	Incorporates by reference IADC, UN COPUOS and ISO/CCSDS guidelines and standards which promote space activities

Guideline	Guideline Title	SSC Endorsement Doc
Safety of space operations		
B.1	Provide updated contact information and share information on space objects and orbital events	Endorses data sharing relevant to orbital debris mitigation and collision avoidance
B.2	Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects	Endorses accurate orbit solutions and data sharing
B.3	Promote the collection, sharing and dissemination of space debris monitoring information	Encourages use of SSA and STM entities to share safety of flight data
B.4	Perform conjunction assessment during all orbital phases of controlled flight	Endorses Active Collision Avoidance when feasible
B.5	Develop practical approaches for pre-launch conjunction assessment	Endorses use of launch providers who take steps to preclude collisions between spacecraft, stages of the launch vehicle, active space and debris throughout deployment phase
B.6	Share operational space weather data and forecasts	
B.7	Develop space weather models and tools and collect established practices on the mitigation of space weather effects	
B.8	Design and operation of space objects regardless of their physical and operational characteristics	Endorsed practices are agnostic of size/form factor/function.
B.9	Take measures to address risks associated with the uncontrolled re-entry of space objects	Advocates for design for demise and 1.e-4 casualty risk per spacecraft
B.10	Observe measures of precaution when using sources of laser beams passing through outer space	

Guideline	Guideline Title	SSC Endorsement Doc
Scientific and technical research and development		
D.1	Promote and support research into and the development of ways to support sustainable exploration and use of outer space	Incorporates by reference and promotes IADC guidelines which are based upon such research
D.2	Investigate and consider new measures to manage the space debris population in the long term	Incorporates by reference and promotes IADC guidelines which are based upon such investigations

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Space Safety Version 2: Highlights of Part II

- **Endorsement of over forty additional best practices not captured in current IADC, UN or ISO documents that are seen as critical to maintaining safe space operations in all orbital regimes (both NGSO and GSO), including:**
  - Operator exchange of information relevant to safety-of-flight and collision avoidance with other space operators and stakeholders in accordance with each operator's country export regulations;
  - Satellite operator selection of launch vehicles with due consideration of sustainability of the space operating environment;
  - Responsible mission and constellation design to prioritize space safety for spacecraft & constellations;
  - Commitment to spacecraft designs that facilitate successful disposal (striving for a probability of successful disposal of 95%), actively avoid collisions, minimize casualty risk, mitigate risk of post-mission fragmentation, ensure sensor trackability and facilitate spacecraft servicing and removal;
  - Commitment to space operations that actively avoid collisions, properly passivate satellites either upon end-of-mission or after a suitable active collision avoidance phase has been completed, dispose the satellites within 5 years of end-of-mission for manoeuvring spacecraft and maintain accurate spacecraft positional knowledge.

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Additional endorsed best practices beyond IADC, UN, ISO & CCSDS)

- **Clause 1: Avoid intentional space object fragmentation or collision**
- **Clause 2: Exchange operator data in a manner that:**
  - Includes PoCs, ephemerides w/maneuvers ability to maneuver and maneuver plans
  - Respects owner/operator IP, proprietary info and country export regulations
  - Protects data providers from legal liability associated with good faith data sharing
- **Clause 2: Strive to use launch vehicle systems that:**
  - Deorbit upper stages for LEO launches
  - Keep upper stages out of GEO protected region for > 100 years
  - Have passivation reliability > 90%
  - Have post-mission disposal reliability > 90%

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Additional endorsed best practices (cont'd)

- **Clause 4: Strive to design constellations that:**
  - Are separated in altitude (large-on-large)
  - Limit need for active control to mitigate collision risk within, between constellations
  - Minimize long-lasting impact of Dead-on-Arrival spacecraft
- **Clause 5: Strive to design spacecraft that:**
  - Achieve a post-mission disposal probability of 0.95
  - Have a disposal plan
  - Perform effective collision avoidance maneuvers if Ha> 400 km
  - Residual casualty risk of < 1:10000 for reentering S/C, and consider aggregate risk
  - Facilitate servicing, capture and deorbit
  - Facilitate passive sensor observability from the ground
  - Consider methods to ensure secure, protected communications

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Additional endorsed best practices (cont'd)

- **Clause 6: Consider mission- and component-level design and operations that can facilitate inspection, refueling, and timely post-mission disposal:**
  - features for grappling, docking, and/or berthing, closeouts, serviceable interfaces
  - Enhanced trackability
  - Modular design
  - Detailed, up-to-date spacecraft documentation
- **Clause 7: Strive to operate spacecraft in a manner that:**
  - Implements collision avoidance when Ha>400 km & Pc>0.0001
  - Detects and mitigates anomalies that lead to loss of control, fragmentation
  - Reassesses spacecraft disposal capability when considering mission extension
  - Disposes spacecraft with periodic GEO presence outside of GEO for > 100 years
  - Promotes post-mission passivation, but balanced with collision avoidance
  - Disposes LEO satellites via reentry (w/in 5 years if maneuverable, or ASAP when not)
  - Maintains current and 48h spacecraft positional knowledge to within 500m 2σ

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Additional endorsed best practices (cont'd)

- **Clause 8: Rules of the Road (RotR) and Maneuver Prioritization:**
  - Defines 5 categories of maneuverability and expected avoidance action

	Nonmaneuverable	Minimally Maneuverable	Maneuverable	Automated collision avoidance	Crewed
Nonmaneuverable	N/A	Minimally maneuverable S/C moves	Maneuverable S/C moves	Automated COLA S/C moves	Crewed vehicle moves
Minimally Maneuverable		Satellites moving into or out of their designated mission orbit should yield to satellites in their mission orbit. Otherwise, decided in bilateral discussion.	Maneuverable S/C Moves	Automated COLA S/C moves	Crewed vehicle moves, unless other arrangements are in place
Maneuverable			Satellites moving into or out of their designated mission orbit should yield to satellites in their mission orbit. Otherwise, (or in cases where both satellites are moving into or out of their mission orbits), decided in bilateral discussion.	Automated COLA S/C moves	Crewed vehicle moves, unless other arrangements are in place
Automated collision avoidance				Established via pre-coordinated agreement	Crewed vehicle moves, unless other arrangements are in place
Crewed					Bilateral discussion to determine who maneuvers.

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Additional endorsed best practices (cont'd)

- **Clause 9: Security to Prevent Unauthorized Access:**
  - ISO 27001: Information technology - Security techniques
  - CCSDS 352.0-B-2: Cryptographic Algorithms, and CCSDS 355.0-B-1: Space Data Link Security Protocol and associated NIST cybersecurity requirements for space systems and U.S. Space Policy Directive-5)
  - Ensure ground infrastructure protected from cyber-attack and Command-and-Control link is protected from spoofing, jamming, command replay, hardware backdoor commands
  - Intrusion Detection System w/continuous monitoring

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What's new in SSC's "living" Best Practices document version 2 ?

- **Substantial update to SSC's best practices document published 4 Apr 2023**
  - 36 space companies have already endorsed
- **Version 2 of SSC's best practices contains eleven major updates:**

1. Updated to latest versions of ISO, CCSDS, IADC, and UN documents.
2. Incorporated Rules of the Road.
3. Avoidance of intentional space object fragmentation or collision.
4. Encourages adoption of CCSDS standards for space data sharing.
5. Guidance to spacecraft operators regarding space data sharing of orbital ephemerides, maneuvers, covariances.
6. Encourages use of launch systems that deorbit upon completion.
7. More stringent post-mission disposal goals for GEO and LEO spacecraft.
8. Clarifies disposal passivation best practices, capabilities and functions, and associated knowledge transfer.
9. Encourages collision avoidance during deorbit phase unless post-mission lifetime is longer than 5 years.
10. Spacecraft anomaly or failure root cause assessment, recovery, and sharing.
11. Cybersecurity and prevention of unauthorized access.

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Comparison of SSC Best Practices Versions 2.0 and 1.47

	2023 SSC Best Practices (v 2.0)	2019 SSC Best Practices (v 1.47)
IADC guidelines	Revision 3 (2021)	Revision 1 (2007)
ISO international standards	ISO 24113 (2019) [et al]	ISO 24113 (2011) [et al]
21 UN COPUOS LTS Guidelines	June 2019	June 2019
Aspirational best practices	42	42
Rules of the road	☑	☒
Avoiding intentional fragmentation	☑	☒
Exchange of ephemerides and planned maneuvers	☑ and additional ephemeris traits, covariance, and widespread adoption of CCSDS NavWG standards	☑
Use of launch systems that seek to minimize environmental impacts	☑	☒
Post-mission disposal goals	95% for 5 yr and 99% for 25 yr life	95% for GEO and LEO
Post-mission passivation guidance	More detailed guidance and goals, depending upon post-mission lifetime	Recommends it be done
Post-mission collision avoidance	Encouraged if post-mission life < 5 yrs	☒
Positional knowledge and errors	Conduct regular ongoing assessments	☒
Spacecraft anomaly assessment	Anomaly/failure root cause investigation	☒
Security	Cybersecurity, prevent unauthorized access	☒

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How you can participate

- Legal entities that have a direct and material interest in space safety and sustainability are encouraged to participate in the Space Safety Coalition by simply emailing the following content to **info@spacesafety.org**:
  - Confirmation of your entity's endorsement of the SSC's current set of best practices, posted at **spacesafety.org**.
  - Provide a narrative statement of approximately 250 words describing how your organization is a space operations stakeholder interested in sustainability.
  - Your entity's full legal name.
  - Your designated point of contact, phone and email.
  - A quality logo, suitable for incorporating into the best practices document as well as for posting on the SSC website.

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Learn how to promote space safety and long-term sustainability of space operations at: https://spacesafety.org or email us at info@spacesafety.org

Dan Oltrogge

Space Safety Coalition Administrator

dan@spacesafety.org

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HOME ENDORSEES IN THE NEWS HOW TO JOIN ABOUT

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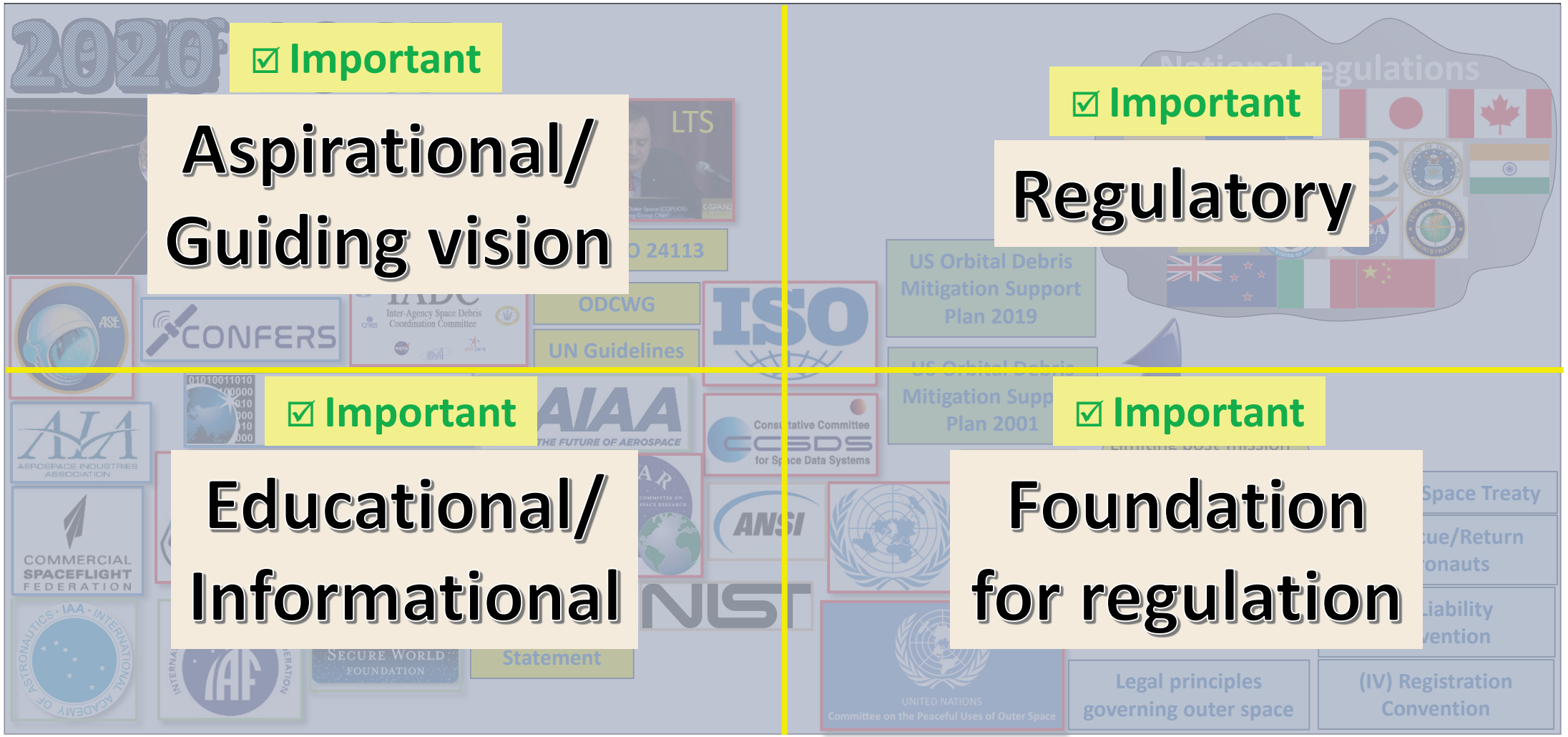
Best Practices for the Sustainability of Space Operations

Space safety policy landscape continuum

Color scheme:
Non-Gov't Organizations | National regulations
Industry Associations | International bodies



SSC best practices: Highlights of Part I

- **Endorsement of and planned adherence to current international best practices and standards, to include:**
  - **IADC guidelines for international space debris mitigation**
  - **UN COPUOS guidelines for international space debris mitigation**
    - Including 2019 UN consensus LTS guidelines
  - **ISO TC 20/SC 14 24113: "Space Systems - Space Debris Mitigation"**
  - **CCSDS international standards (typically co-published with ISO)**

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Space Safety document: Part II

- **Endorsement of <u>over forty</u> best practices** not captured in current IADC, UN or ISO documents that are seen as critical to maintaining safe space operations in all orbital regimes (both NGSO and GSO), including:
  - Exchange of specific information relevant to safety-of-flight and collision avoidance
  - Selection of launch vehicles with due consideration for space sustainability
  - Responsible mission and constellation design to prioritize space safety
  - Spacecraft designs that facilitate successful disposal reliability of up to 95%
  - Minimization of casualty risk
  - Mitigation of post-mission fragmentation risk
  - Designs that facilitate sensor trackability
  - Designs that facilitate spacecraft servicing and active removal;
  - Active avoidance of collisions
  - Passivation of spacecraft upon end of mission or after collision avoidance phase
  - Disposal within 5 years of end-of-mission for manoeuvring spacecraft
  - Maintaining accurate spacecraft positional knowledge

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Space industry initiatives and best practices in global space governance context

SSC in context of our space governance framework *virtuous cycle*

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Must address space debris holistically…

- **Must be untiring in our pursuit of mitigating debris**
- **The big picture* is that we:**
  - **Must avoid predictable collisions – this is SSA/STM (necessary but not sufficient).**
  - **Must minimize the creation of new debris – this is Debris Mitigation (necessary but not sufficient).**
  - **Must remove massive derelict objects currently in LEO as they are the most likely source of future LNT risk – this is Debris Remediation (necessary but not sufficient).**
- **Commercial space industry best practices help address safety!**

"Repeat after me…" steps to address debris, D. McKnight and T. Maclay, 2019 IAC, Washington D.C., 20 Oct 2019

Ideal mix of international, inter-agency, and industry contributions

- **International**
  - **UN COPUOS:**
    - Treaties
    - Principles
    - Guidelines (Long-Term Sustainability)

- **Inter-agency**
  - **IADC: Debris research and guidelines**
  - **CCSDS: Data message standards**
- **National**
  - **Regulatory**
  - **Applications**
  - **Monitoring**

- **Industry (companies, associations, coalitions):**
  - **Research for operations, environment**
  - **Higher-TRL innovations**
  - **Commercial best practices**
  - **Conducting operations**
  - **Manufacturing**
- **Academia:**
  - **Research for operations, environment**
  - **New, typically lower-TRL, innovative techniques, algorithms**

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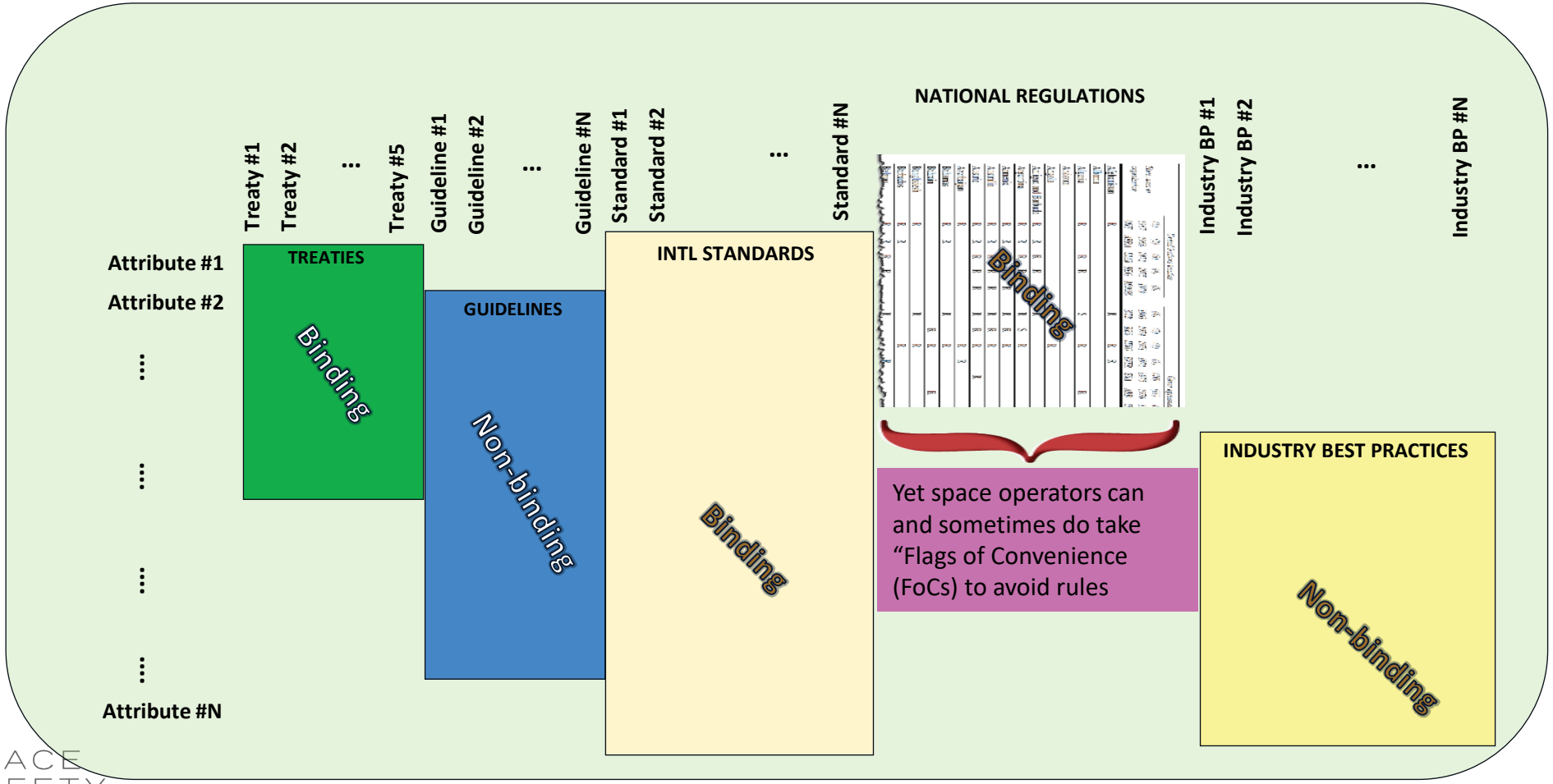
Basic types of international space cooperation

- **Today, our landscape is a mix of treaties, principles, guidelines, standards, and industry best practices**



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