"If it's worth doing, it's worth overdoing" – Ayn Rand

CENTER FOR SPACE STANDARDS & INNOVATION

The Myths and Realities of CubeSat Collision Risk

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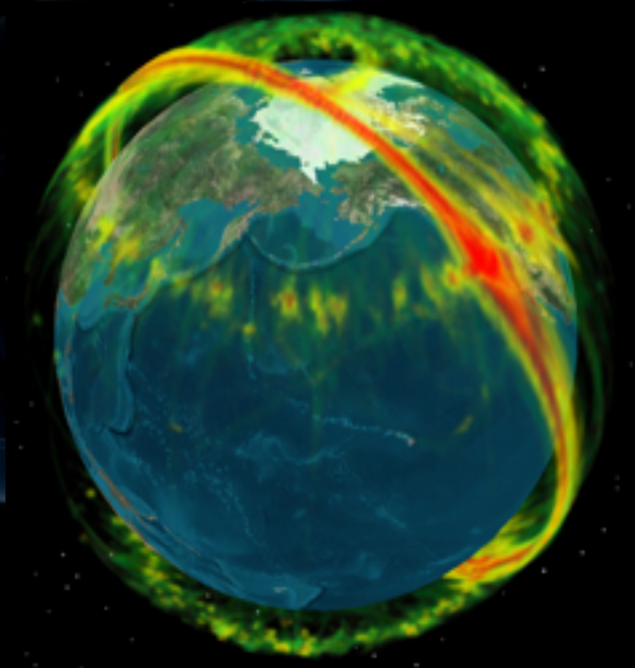
20 April 2016



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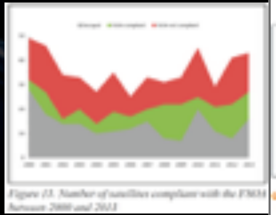
CubeSat Collision Risk: Myths & Realities

Perception	Myth	Reality	Why?
CubeSats = high % of catalog	✓		Only 0.7% of current RSO catalog, and only 0.07% of 2 cm catalog.
	✓	✓	  Oltrogge and Leveque, "An Evaluation of CubeSat Orbital Decay," SmallSat Conference, SSC11-VII-2, Logan UT Morand, V., et al, "Mitigation Rules Compliance in Low Earth Orbit," Intl. Assoc. for the Adv. of Space Safety, JSSC Vol. 1 No. 2, Dec. 2014
CubeSats have small collision risk due to their small size	✓		Collision probability a function of <u>combined</u> hardbody radius; infinitesimally-small S/C still have collision risk
	✓		

CubeSat Collision Risk: Myth vs Reality (cont.)

Perception	Myth	Reality	Why?
CubeSats like a "bullet" w/ orbit lifetimes much longer than big S/C	✓		For equivalent-density shapes, drag is inversely proportional to lineal dimension
[redacted]	✓	✓	[redacted]
Collisions with very small S/C can yield as much debris as large S/C	✓		Large S/C have much more mass & are likely to generate much more debris if hit. This is genesis for "Active Debris Removal" (ADR) concept
[redacted]	✓	✓	[redacted]

CubeSat Collision Risk: Myth vs Reality (cont.)

Perception	Myth	Reality	Why?
We would know if/when collisions occur, because operators routinely and transparently share such collision/anomaly info	✓		Insurance rates, stock holders, cultural inhibitions, customer confidence, competition can all contribute to a lack of transparency
[illegible] CubeSat [illegible]	✓ ✓		[illegible] Labs) is [illegible] CubeSat community have [illegible] JSpOC). Good if the CubeSat [illegible]
Adhering to 25-year lifetime is sufficient.			Best practice: Reenter as soon as is practical upon mission completion. Our international orbital debris mitigation efforts depend upon this.

Reality: CubeSats inhabit LEO with its legacy of debris

Table 1. Top 10 Breakups, January 2016

Rank	International Designator		Common Name	Year of Breakup	Altitude of Breakup	Cataloged Debris	Debris in Orbit	Assessed Cause of Breakup
1	1999	25	Fengyun-1C	2007	850	3428	2880	intentional collision
2	1993	36	Cosmos 2251	2009	790	1668	1141	accidental collision
3	1994	29	STEP-2 Rocket Body	1996	625	754	84	accidental explosion
4	1997	51	Iridium 33	2009	790	628	364	accidental collision
5	2006	26	Cosmos 2421	2008	410	509	0	unknown
6	1986	19	SPOT-1 Rocket Body	1986	805	498	32	accidental explosion
7	1965	82	OV2-1 / LCS 2 Rocket Body	1965	740	473	33	accidental explosion
8	1999	57	CBERS 1 / SACI 1 Rocket Body	2000	740	431	210	accidental explosion
9	1970	25	Nimbus 4 Rocket Body	1970	1075	376	235	accidental explosion
10	2001	49	TES Rocket Body	2001	670	372	80	accidental explosion
						9137	5059	

* as of 04 January 2016

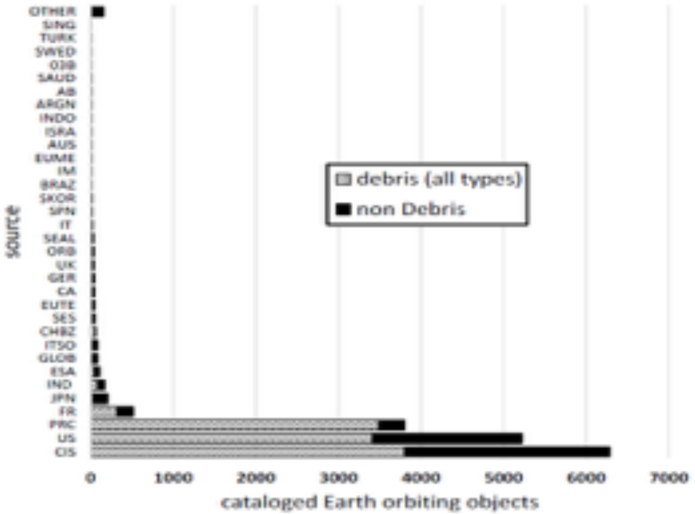
Table 2. Number of Debris in Orbit, January 2016

Rank	International Designator		Common Name	Year of Breakup	Altitude of Breakup	In Orbit*	Total	Assessed Cause of Breakup
1	1999	25	Fengyun-1C	2007	850	2880	3428	intentional collision
2	1993	36	Cosmos 2251	2009	790	1141	1668	accidental collision
3	1997	51	Iridium 33	2009	790	364	628	accidental collision
4	1981	53	Cosmos 1275	1981	980	289	346	battery explosion
5	1970	25	Nimbus 4 Rocket Body	1970	1075	235	376	accidental explosion
6	1999	57	CBERS 1 / SACI 1 Rocket Body	2000	740	210	431	accidental explosion
7	1992	93	Cosmos 2227 Rocket Body #	1992	830	199	279	accidental explosion
8	1975	52	Nimbus 6 Rocket Body	1991	1090	199	274	accidental explosion
9	1973	86	NOAA 3 Rocket Body	1973	1515	179	201	accidental explosion
10	1976	77	NOAA 5 Rocket Body	1977	1510	174	184	accidental explosion
						5870	7815	

* as of 04 January 2016
# multiple events associated with this SL-16 Zenit second stage

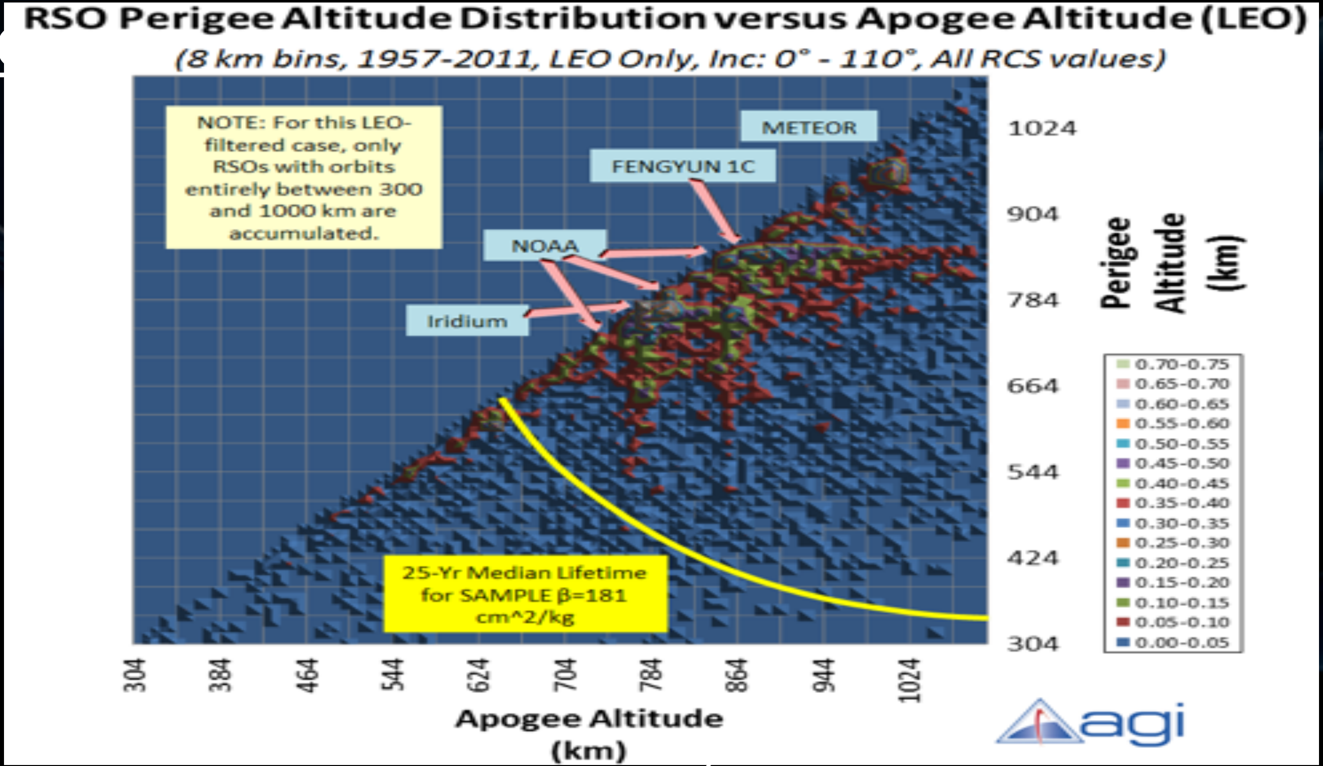
Source: NASA

Orbital Debris Quarterly News



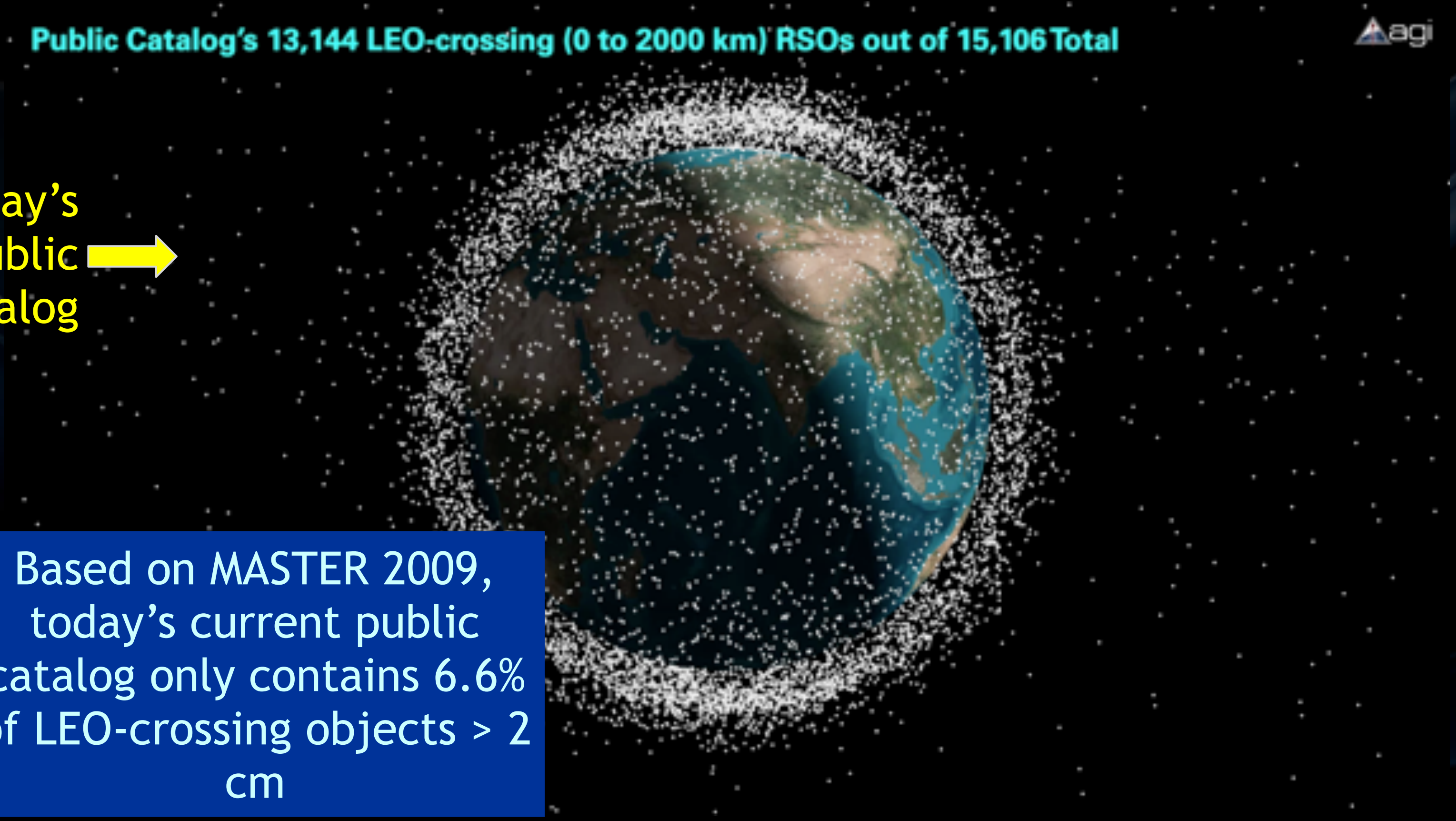
Reality: Shortening orbit lifetime is a key ODM tenet

- Post-mission orbit lifetime < 25 yr, preferably sh



Oltrogge and Kelso, "Getting To Know Our Space Population From The Public Catalog, AAS 11-413

Myth: “Low Earth Orbit (LEO) population is known”



Today's public catalog

Based on MASTER 2009, today's current public catalog only contains 6.6% of LEO-crossing objects > 2 cm

Myth: “Small debris isn’t a threat”

Space Debris – Why be Concerned ?

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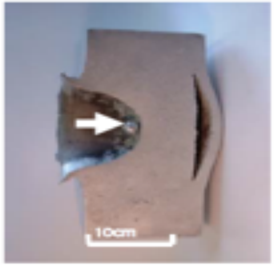

1 cm Al-sphere
at 10 km/s

=

mid-size car of
1.5 tonnes at 50 km/h

=

explosion of a
hand grenade

- 1 gram impactor at 2 km/s ➜ 1 gram TNT (at 16 km/s ➜ 64 grams TNT)
- 1 mm objects (≈ 170,000,000) ➜ can damage satellite sub-systems
- 1 cm objects (≈ 740,000) ➜ likely to disable satellites; limit of ISS shielding capabilities for its manned modules
- 10 cm objects (≈ 29,000) ➜ likely to cause catastrophic satellite break-ups; limit of operational tracking capabilities of surveillance networks

H. Klinkrad (ESA) | 6th IAASS Conference | 21-May-2013 | page 6
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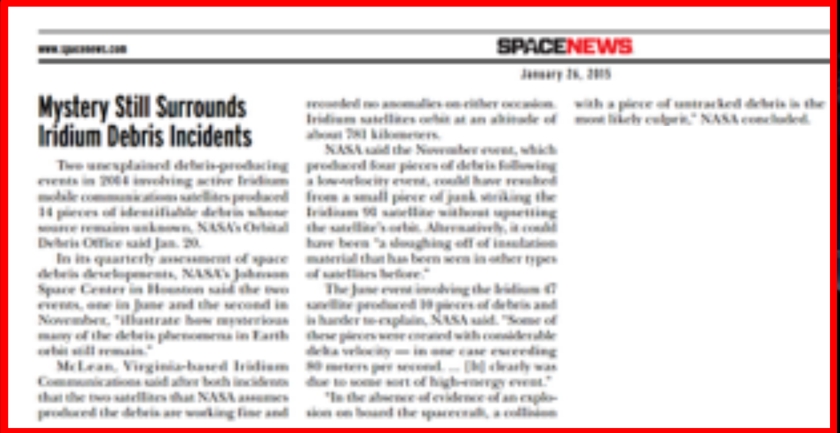
Is “Kessler Syndrome” real ? Answer: TBD.

- May already be seeing secondary collisions…
  - Iridium/Cosmos collision (10 Feb 2009)
  - In 2014 alone, there were 2 more Iridium fragmentation events



www.spacenews.com

SPACENEWS

January 26, 2015

Mystery Still Surrounds Iridium Debris Incidents

Two unexplained debris-producing events in 2014 involving active Iridium mobile communications satellites produced 14 pieces of identifiable debris whose source remains unknown, NASA's Orbital Debris Office said Jan. 20.

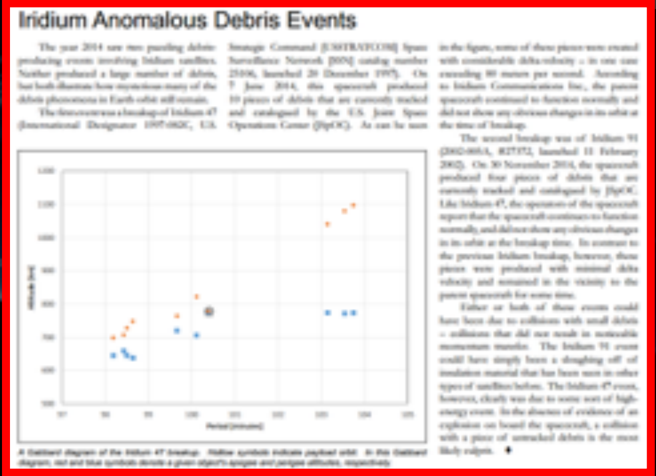
In its quarterly assessment of space debris developments, NASA's Johnson Space Center in Houston said the two events, one in June and the second in November, “illustrate how mysterious many of the debris phenomena in Earth orbit still remain.”

McLean, Virginia-based Iridium Communications said after both incidents that the two satellites that NASA assumes produced the debris are working fine and recorded no anomalies on either occasion. Iridium satellites orbit at an altitude of about 781 kilometers.

NASA said the November event, which produced four pieces of debris following a low-velocity event, could have resulted from a small piece of junk striking the Iridium 91 satellite without upsetting the satellite's orbit. Alternatively, it could have been “a sloughing off of insulation material that has been seen in other types of satellites before.”

The June event involving the Iridium 47 satellite produced 10 pieces of debris and is harder to explain, NASA said. “Some of these pieces were created with considerable delta velocity — in one case exceeding 80 meters per second. … [It] clearly was due to some sort of high-energy event.”

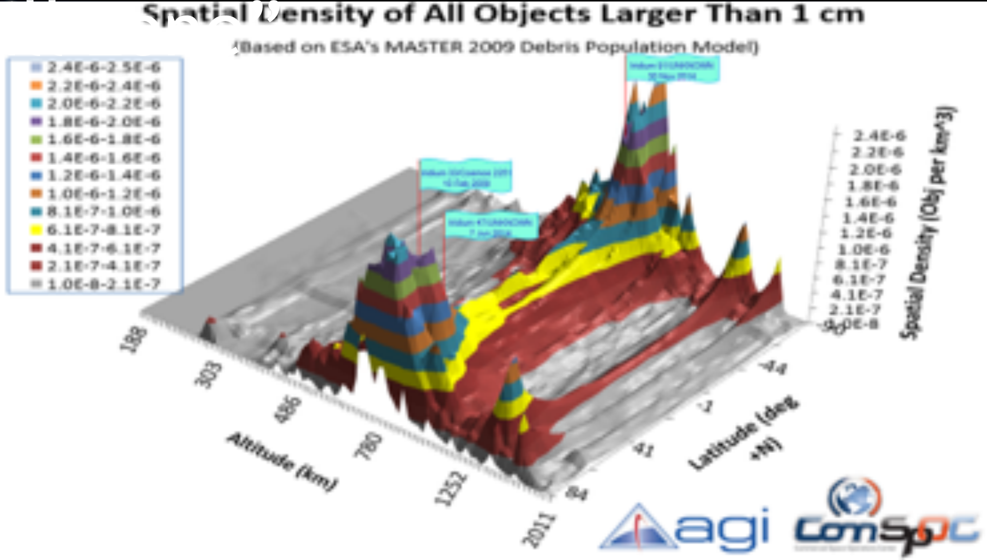
“In the absence of evidence of an explosion on board the spacecraft, a collision with a piece of untracked debris is the most likely culprit,” NASA concluded.

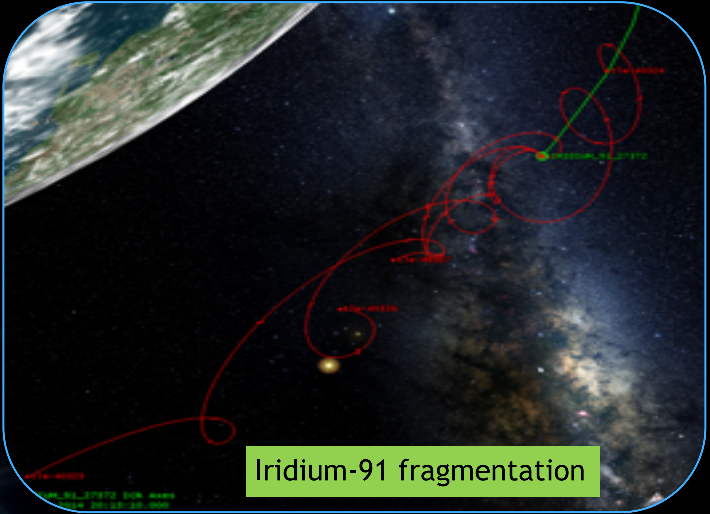


Iridium Anomalous Debris Events

Reality: “One collision event can lead to others”

- Strong possibility; Iridium-47 & -91 collisions occurred in high spatial density post-Iridium-33 “k



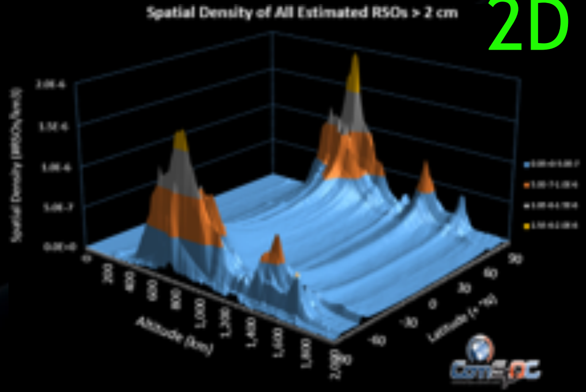


Once created, such high-density zones are ≈ permanent

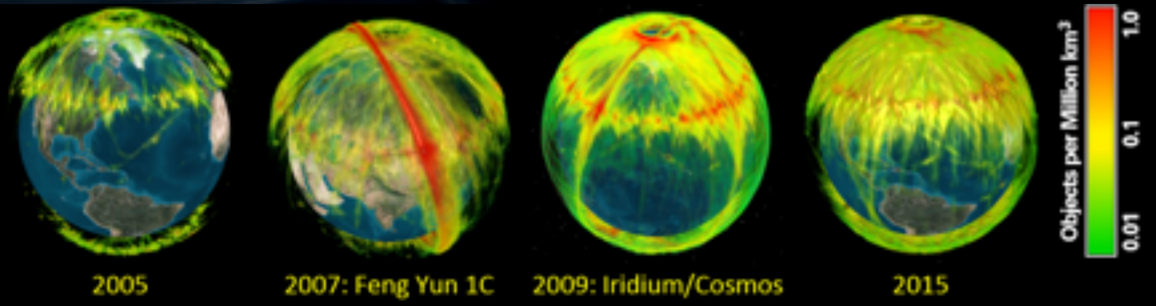
Depicting Spatial Density in 1D, 2D and 3D

st-collision debris
mewhat visible in
) portrayal;
amatic congestion
2D & even more in
)

2D



3D



100 X per decade !

Assessing collision risk

$$Risk = Probability_{Event} \times Consequence_{Event}$$

- Debris mitigation: want to avoid high Pc events that ruin space
- Generally well-advised to avoid high-probability, high-consequence events in life

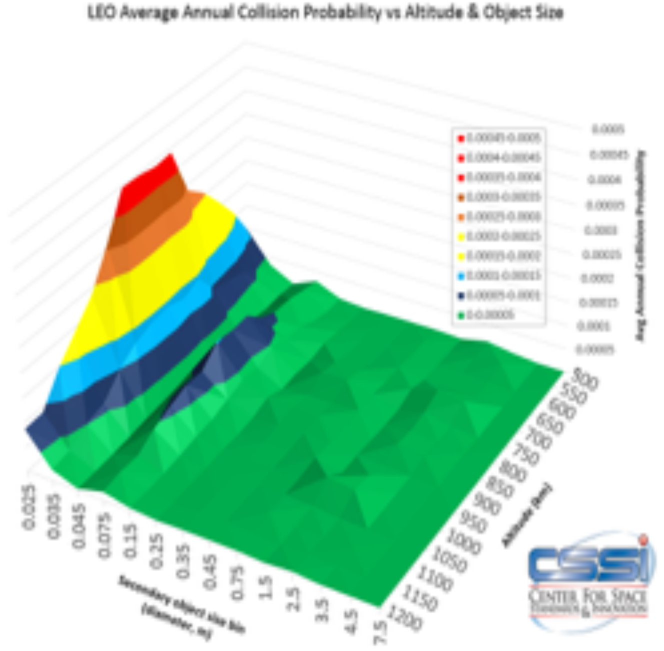
Reality: High Pc over 10 yrs for large constellations!

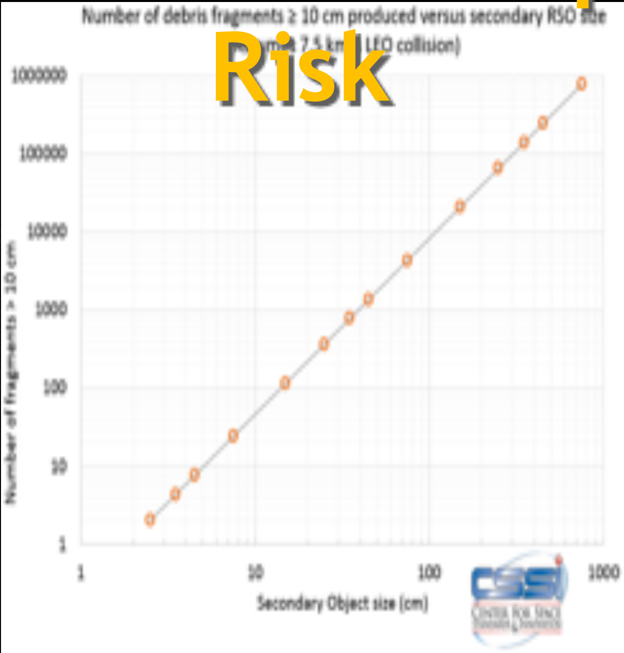
Operator	Orbit				Versus public catalog		Versus estimated objects ≥ 2 cm	
	# S/C	Alt (km)	Incl (deg)	S/C size (m)	Expected collisions if unmitigated	Expected warnings < 3 km	Expected collisions if unmitigated	Expected warnings < 3 km
LeoSat	140	1400	90	2	.008	46,670	.1	600,000
Spire	100	651	97.9	0.3	0.00001	2,780	.0001	35,710
OneWeb	648	1200	87	2	0.09	764,640	1.1	9,831,090
SpaceX	4000	1100	90	2	0.21	1,797,780	2.8	23,114,290
Skybox	28	576	97.8	1.5	.0001	610	.0012	7,780
Globalstar	40	1400	52	9.7	.0261	9,670	.34	124,290
Iridium	71	780	86.4	4.3	.184	335,880	2.4	4,318,460
Orbcomm	31	750	45	10.5	.008	1,880	.1	24,136

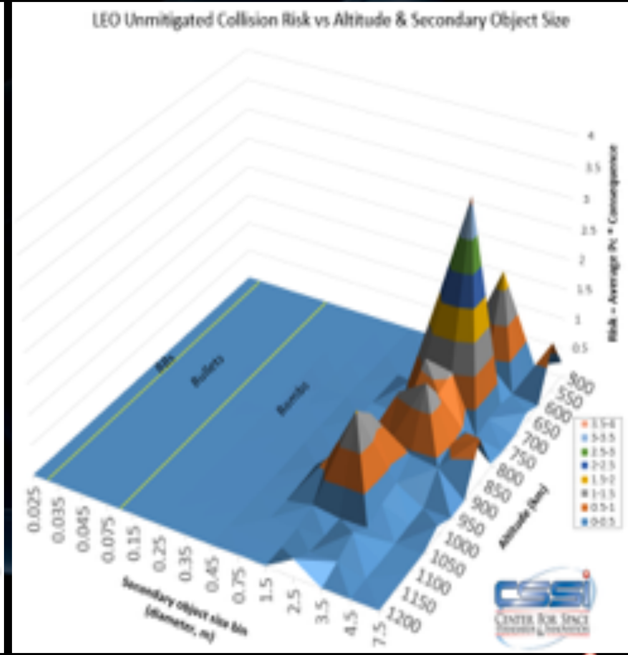
*Alfano, S. & Oltrogge, D., “Volumetric Encounter Analysis Enhancements,” AAS 15-581, 2015 Astro Specialst Conf, Vail, CO

Reality: Large debris in select orbits of greatest concern
A. D'Uva coined the phrase :
"BBs" (< 2 cm) vs "Bullets" (2 – 10 cm) vs "Bombs" (> 10 cm)

Pc x Consequence = Risk







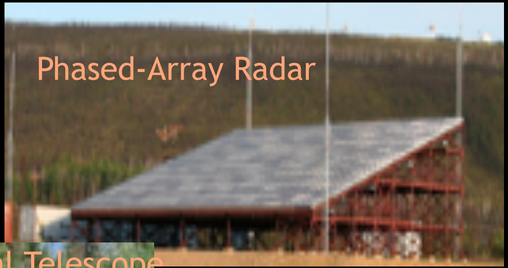
Myth: "Laws prevent collisions and debris creation"

- Article 6 of Outer Space Treaty (1967) requires authorization and continuing oversight of non-traditional services (http://www.state.gov/t/isn/5181.htm)
  - *"States Parties to the Treaty shall bear international responsibility for national activities in outer spa... and other celestial bodies, whether such activities are carried on by governmental agencies or by... and for assuring that national activities are carried out in conformity with the provisions se... activities of non-governmental entities in outer space, including the Moon and other ... authorization and continuing supervision by the appropriate State Party to the T... space, including the Moon and other celestial bodies, by an international ... Treaty shall be borne both by the international organization and by ... organization."*
  - In principle, launching country liable - - b...
  - Some State Parties gain commerci... ...igations
  - Liability assigned to states ... treaty doesn't cover clean-up
- Space Code of C... ...d Confidence-Building Measure
  - *"Subs... ...his Code is not legally binding, and is without prejudice t...*
  - ... of the UN has invited procedural complications that ... ...bo" - http://www.thespacereview.com/article/2851/1
  - ... dead" – opinion of legal colleague
- ... Parties mandate adherence to ISO, CCSDS and ECSS standards
- ... Wild West" in space; regulators have no tools in their regulatory toolbox

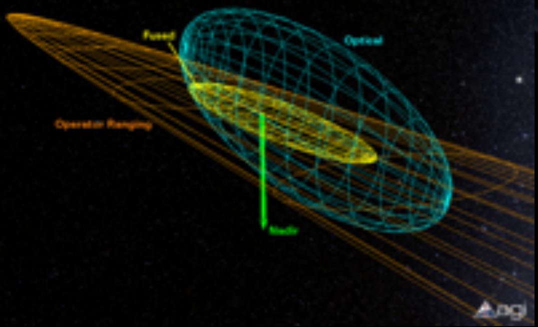
Suggest incorporating expected operational behavior norms and best practices content into CubeSat standards

Reality: USG & private sector can help prevent collisions

- JSpOC SSA Data Sharing Agreement (free service)
- Viable commercial services exist to refine tracking & SoF
  - Space Data Association (data sharing for SoF & RFI mitigation)
    - Small satellite-leaning membership fee structure
  - AGI's Commercial Space Operations Center (ComSpOC) is the first commercial multi-phenomenology SSA service; merges state-of-art processing w/data fusion, good sensors
- Identical CubeSats pose huge track mis-association & cross-tag issues for non-cooperative radar and optical tracking sensors
  - RF techniques & data fusion best-addresses these



Fusion of operator ranging & optical obs



Reality: CubeSats could become more regulated

- Drones originally had very little regulation
  - "Bad actors" (UK Airbus incident) leading to drone constraints
- Cellphones originally not heavily regulated
  - Violation of common-sense norms led to safety regulations
    - No texting or even holding phone while driving in many states
    - No transmissions during critical aircraft phases-of-flight
- Proliferation of CubeSats, sprites, etc. exposing space operations gaps & shortcomings across space industry
  - May lead to new "flight rules"
  - 11 launching states could ban or constrain "bad" CubeSat launch

My 2₵: Don’t stir Momma Bear (State Party) to act

- Dan Oltrogge (oltrogge@agi.com)
- For more information:
  - http://www.centerforspace.com/
  - Phone: 1.610.981.8000

Pop Quiz!

1. What treaty assigned debris liability ?
2. What % of > 2 cm catalog is currently tracked ?
3. What % of large operators violated IADC guidelines 2000-2013 ?
4. What does SDA stand for ?
5. What is classic definition of "risk" ?

Thank you and (time permitting) questions …