Orbital Debris:
Are We Asking the Right Questions?

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25-year Rule: Good or Bad?

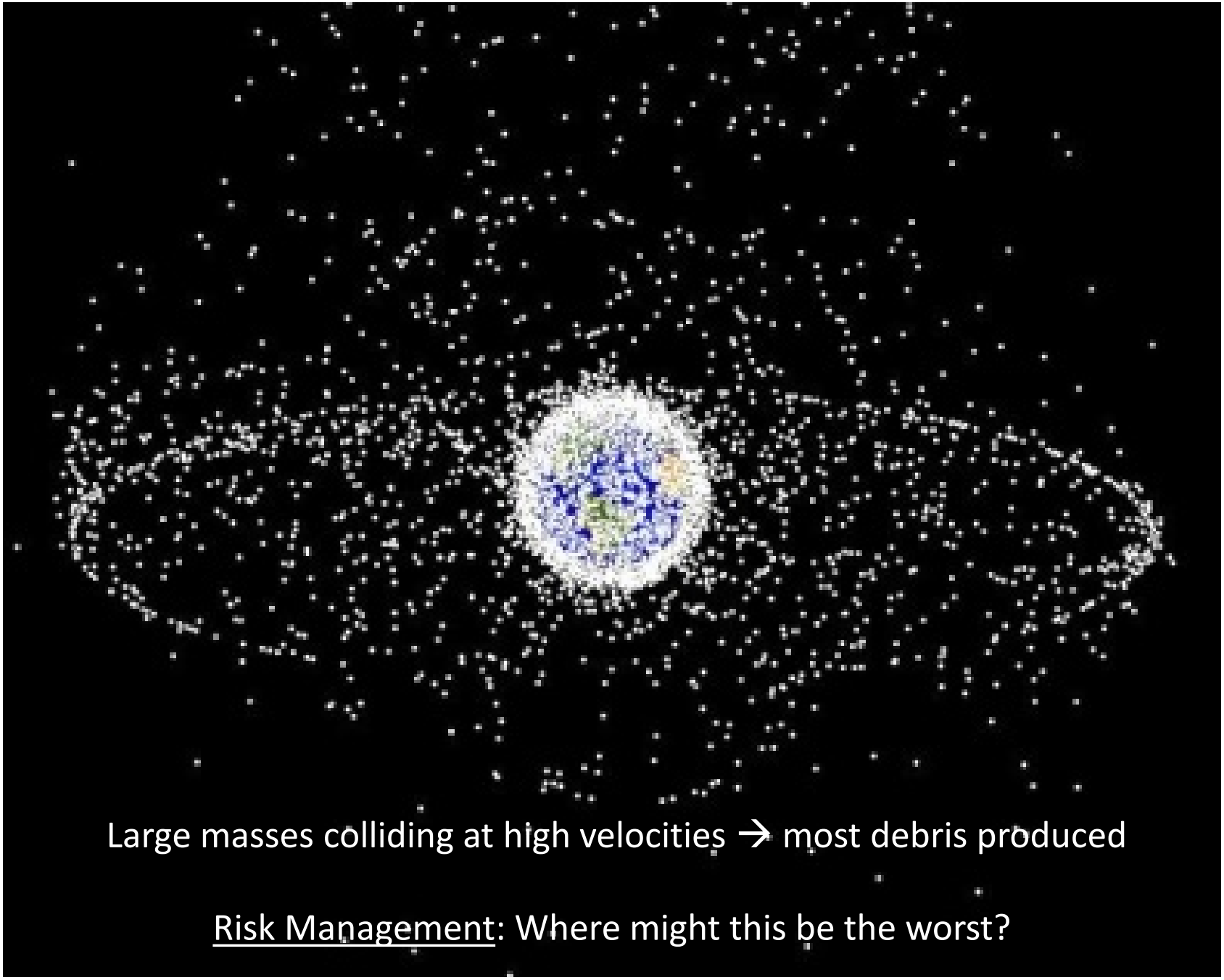
- Established in the mid-1990's when…
  - Much less debris
  - Many fewer operational satellites and spacefaring entities
  - Spacecraft manufacturing was more of an art (one-off and unique) than a science (modular and mass production)

25-year rule should be re-examined:

> Risk-based?

> Function of altitude, mass, and/or mission lifetime?

> OneWeb: shortest of 1x op life or 5years

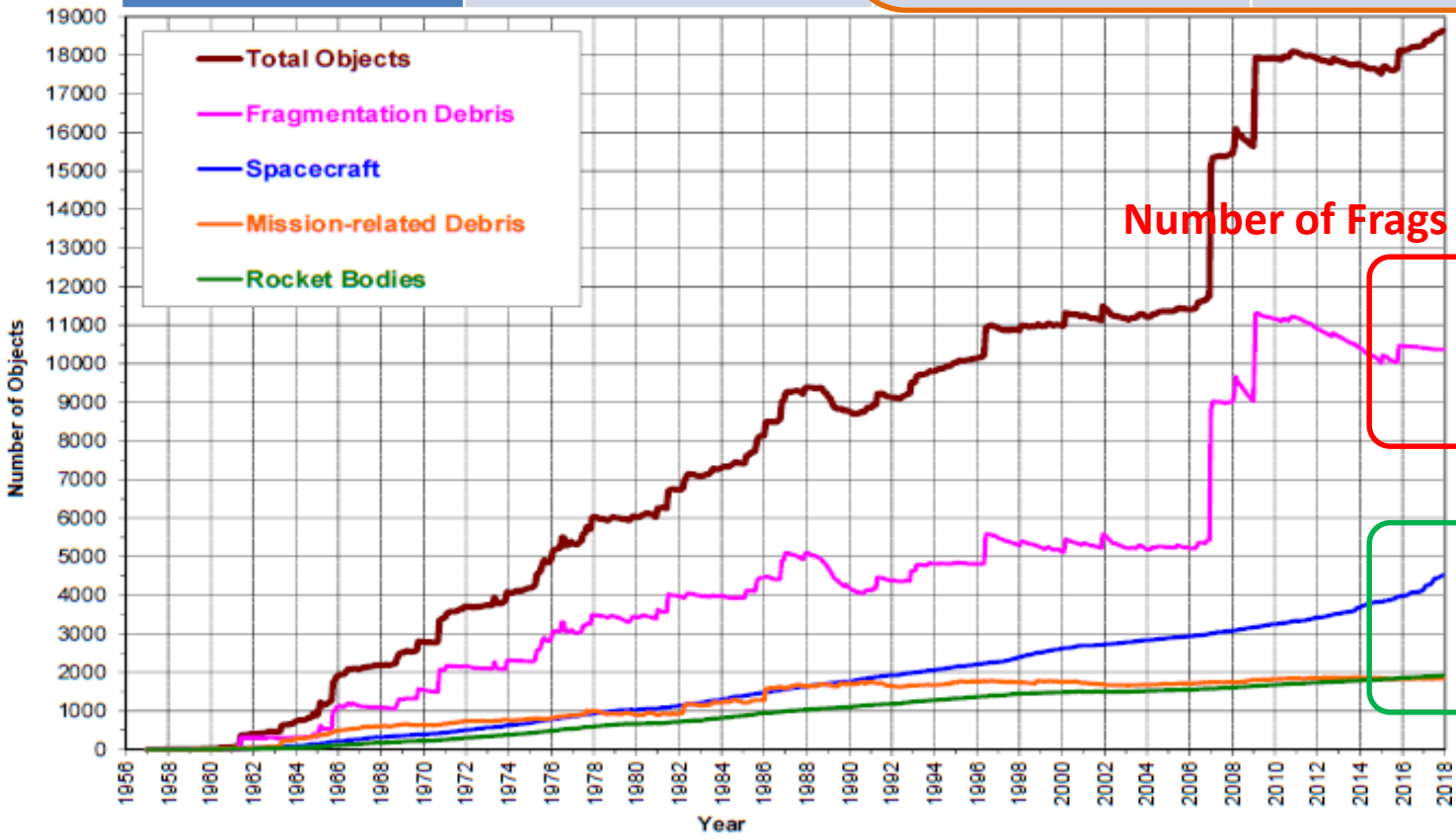


Large masses colliding at high velocities → most debris produced

Risk Management: Where might this be the worst?

Large Objects in Space - Number vs Mass

	Number / Mass (million kg)			
Orbital Regime	Operational Payloads	Non-Operational Payloads	Rocket Bodies	Total
LEO	~950 / 0.5	~1,100 / 1.8	~1,250 / 1.2	~3,300 / 3.4
HEO	~250 / 0.3	~50 / 0.1	~300 / 1.5	~600 / 1.9
GEO	~500 / 1.5	~650 / 1.6	~ 250/ 0.5	~1,400 / 3.6
Total	~1,700 / 2.3	~1,800 / 3.4	~1,800 / 3.2	~5,300 / 8.9



Number of Frags → Current Hazard

Mass → Future Hazard

Future Debris Hazard → Mass

FengYun @ 850kg → +3,200 fragments

1	ISS	<400km	417,000
2	TIANGONG 2	<400km	8,500
3	ENVISAT	~765km	8,506
4	ZENIT R/B	~845km	8,300
5	ZENIT R/B	~845km	8,300
6	ZENIT R/B	~845km	8,300
7	ZENIT R/B	~845km	8,300
8	ZENIT R/B	~845km	8,300
9	ZENIT R/B	~845km	8,300
10	ZENIT R/B	~845km	8,300
11	ZENIT R/B	~845km	8,300
12	ZENIT R/B	~845km	8,300
13	ZENIT R/B	~845km	8,300
14	ZENIT R/B	~845km	8,300
15	ZENIT R/B	~845km	8,300
16	ZENIT R/B	~845km	8,300
17	ZENIT R/B	~845km	8,300
18	ZENIT R/B	~845km	8,300
19	ZENIT R/B	~845km	8,300
20	ZENIT R/B	~845km	8,300
21	ZENIT R/B	~845km	8,300
22	ZENIT R/B	~765km	8,300
23	ZENIT R/B	~765km	8,300
24	ZENIT R/B	~765km	8,300
25	COSMOS 2441	Low-e LEO	7,800

200,000kg in one sliver of LEO;
Nearly 10% of all derelict mass:
Collision → double catalog population
The Mean is Meaningless

Constellations vs Clusters

Constellations

Name	#	Total Mass (kg)	Altitude Span (km)	Trackable Collision Makes
Spire	175	875	400-600 (200km)	14
Iridium	72	40,000	~760-770 (10km)	1,600
OneWeb	720	108,000	~1150-1250 (100km)	450
SpaceX IOC	800	308,000	~1100-1300 (200km)	2,300

Clusters

Name	#	Total Mass (kg)	Altitude Span (km)	Trackable Collision Makes
C775	89	100,000	730-800 (70km)	4,500
C850	36	208,000	815-860 (45km)	16,000
C975	286	560,000	900-1025 (125km)	4,500
C1500	106	179,000	1340-1660 (320km)	5,000

Clusters have all been in place since 2007 – "rolling the dice" continues…

> Cum PC: 11% for C975 and 1% for C850

Have no capability and no intent to avoid collisions

Collision result would 10x-100x worse than an inter-constellation collision

Just Getting "Lucky"?

Normalization of Deviance

- Probability of Collision (PC) for Iridium-33/C2251 and Cerise collisions: $2x10^{-4} – 5x10^{-3}$
- Top five most risky encounters over last year shown below
  - Total mass involved ~2,000kg - ~12,000kg

Object 1	Object 2	Date	Miss (m)	Radial Miss (m)	Relative Velocity (km/s)	Altitude (km)	PC
9044 - SL8 RB	9737 - K890	26JUL17	46	45	~14.0	~1008	$~1x10^{-3}$
11425 - K1110	18095 - K1850	14OCT17	61	27	~14.1	**~791**	$~5x10^{-3}$
6149 - SL8 RB	10020 - SL8 RB	14NOV17	67	41	~14.2	~973	$~5x10^{-4}$
22693 - SL14 RB	27055 - K2384	30DEC17	108	8	~9.8	**~1434**	$~8x10^{-4}$
28353 - SL16 RB	23087 - K2278	27FEB18	126	26	~8.8	~858	$~1x10^{-3}$

Note: Positional uncertainty ~100m

Would have doubled the cataloged population and created **~200,000 lethal nontrackable (LNT) debris**

So What is the Real Space Safety Issue?

- mm-sized debris (i.e., LNT) poses ~97-99% of the space safety risk from orbital debris
  - The major source of this population is breakup events of large objects
    - Especially problematic are the massive derelicts
      - As just shown…
  - The LNT population can only be determined by:
    - Inferred from spacecraft anomalies and failures
    - **Directly from dedicated *in situ* sensors**

It is urgent to start <u>remediation</u> now to eliminate LNT sources
> e.g., Active Debris Removal (ADR) missions
> Just in time Collision Avoidance (JCA) or JADR?