

"Mapping Collision Risk in Low Earth Orbit (LEO)

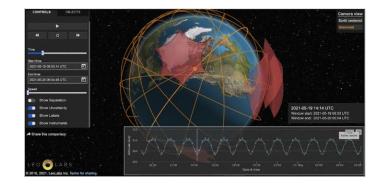
LeoLabs Darren McKnight, Senior Technical Fellow

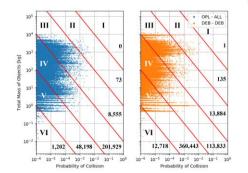
June 2022

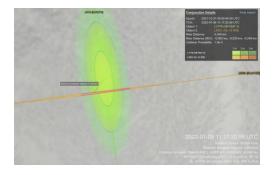
This presentation represents the position of the speaker and does not necessarily reflect a USG position.

LeoLabs: Mapping Low Earth Orbit

- Operational services, scaling with the satellite industry
- More frequent, high-quality, and globallyderived radar observations provide foundation for enhanced...
 - ✓ Launch and early operations awareness and support
 - ✓ Responsive space traffic management
 - Timely, accurate collision risk assessments
 - ✓ Statistical risk and hazard evolution
 - Space incident investigations
 - ✓ Start to catalog sub-10 cm debris in 2022







LeoLabs: Capabilities Trajectory





Costa Rica Space Radars (S-Band), Costa Rica - Active



Kiwi Space Radars (S-Band), Central Otago, New Zealand - Active

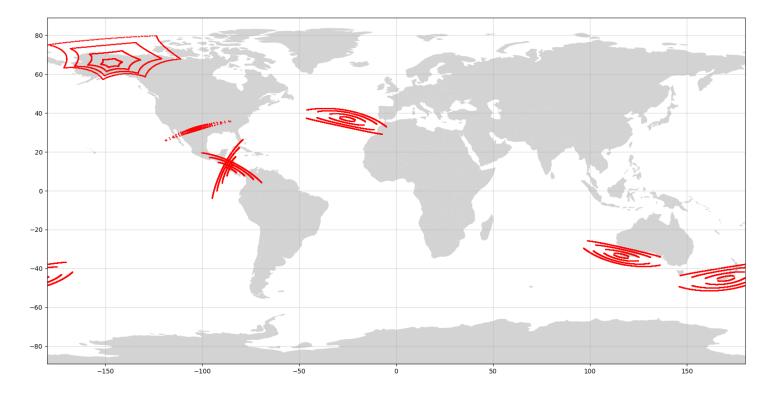


Midland Space Radar (UHF), Midland Texas - Active



Poker Flat Incoherent Scatter Radar (UHF), Fairbanks Alaska - Active

- LEO lacked data solution starts by building the data sources
- Operating 6 radars in 4 locations incl. *Southern Hemisphere*
 - ✓ Will add 6-8 more radars by early 2023
 - \circ $\;$ Drastically improve accuracy and timeliness
 - Goal to develop ability to update every object every orbit
 - ✓ Start cataloging sub-10 cm debris
- Used operationally by SpaceX, OneWeb, NOAA, Maxar, and others
 - Over 60% of operational satellites in LEO



LeoLabs System Metrics

Full transparency on LeoLabs system speed, accuracy, and quantity of data



Key Performance Indicators 4/20/2022 - 5/20/2022			Livestream Counter All time
LATENCY TIME - RADAR PASS TO STATE VECTOR 14 MIN	ACCURACY VS TRUTH DATA DIFFERENCE BETWEEN LEOLABS & TRUTH DATA 30 METERS	PRECISION OF STATE VECTORS RMS UNCERTAINTY 31 METERS	measurements 685,202,872
radar passes 1,015,097	MEASUREMENTS 14,053,547	objects 20,876	state vectors 19,694,208
state vectors 877,212	conjunction data messages 448,721,192	OPERATIONAL EPHEMERIS SCREENINGS 277,300	conjunction data messages 7,805,780,120

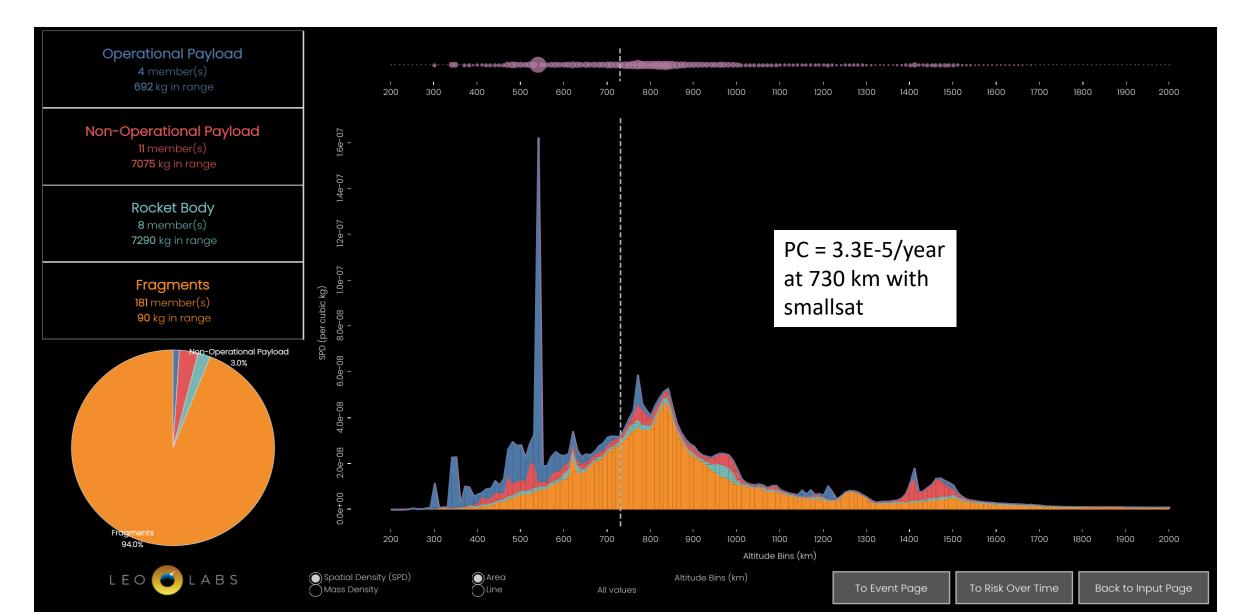
Latency

Time from when an object passes over a LeoLabs radar to when its state vector is available on the platform. Median value taken from the past 30 days.

Total: 14 minutes



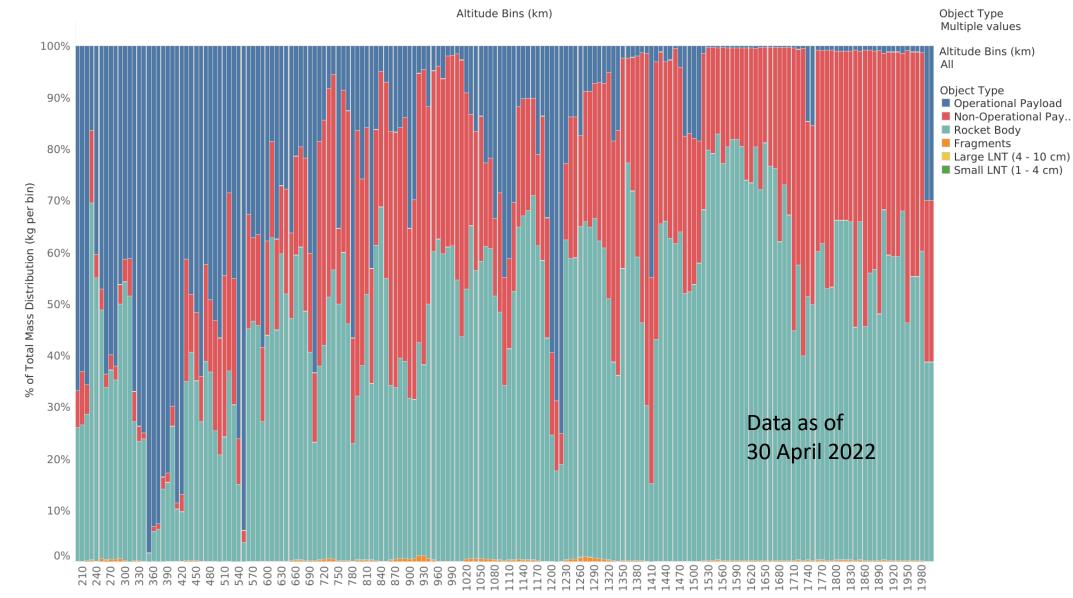
PC (Catalog) = Collision Avoidance Burden Varies Drastically Throughout LEO



ABS

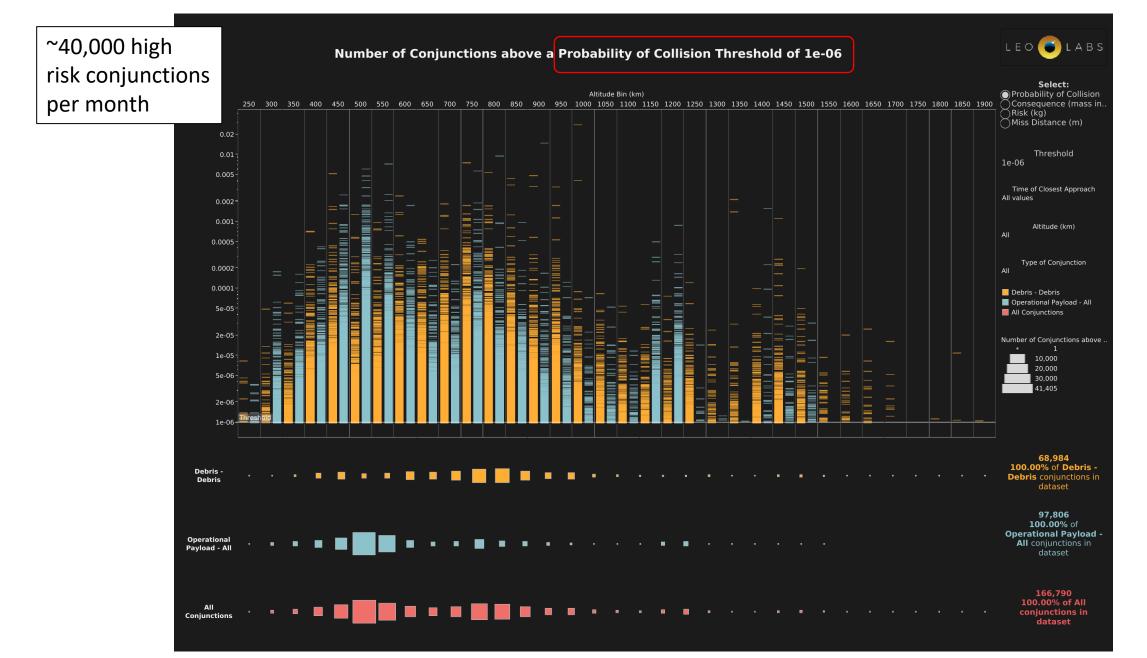
Mass is Distributed Non-Uniformly in LEO Massive Derelicts Drive Future Debris Growth





6

Taking the Heartbeat of LEO... Probability of Collision (PC)

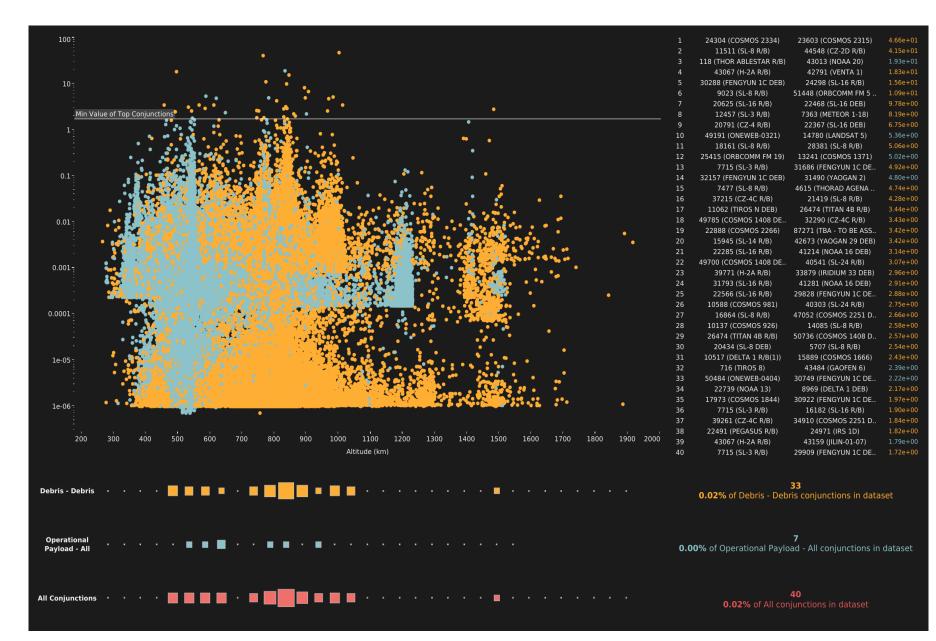


Top 40 Riskiest Events in 2022



• Risk = PC x consequence

- ✓ Total mass involved used as surrogate for consequence
- Higher risk highlights concerns for future debris generation
 - ✓ Clusters of dead objects more of a concern than constellations of smallsats



Risk Map – Derelicts are a Concern!!!

	Objects by C	Conjunction Count and Aggregate	ed Risk		Rank by Conj	unctio	n Count	Rank by Aggre	gated R	Risk	LEO 🕞 LABS
50,000-					COSMOS 1408 DEB		32,008	SL-16 R/B		143.4	
-					FENGYUN 1C DEB		31,798	FENGYUN 1C DEB		121.7	Rank by Object Name or NORAD ID
		0	0		COSMOS 2251 DEB		14,284	SL-8 R/B		115.3	Name
	cc	DSMOS 1408 DEB	FENGYUN 1C DEB		NOAA 16 DEB		11,483	NOAA 16 DEB		58.4	ONORAD ID
20,000-					IRIDIUM 33 DEB		6,121	CZ-2D R/B		51.5	
20,000					TBA - TO BE ASSI		5,930 5,530	COSMOS 2315		46.6 46.6	
	O COSMOS 2251 DE				DMSP 5D-2 F13 D DELTA 1 DEB		4,674	COSMOS 2334 COSMOS 1408 DEB		46.3	Filter by Object Name/ID All
	COSMOS 2251 DE	0			SL-8 R/B		4,639	H-2A R/B		33.9	All
10,000-		NOAA 16 DEB			RESURS O1 DEB		4,493	SL-3 R/B		32.6	
-					NOAA 17 DEB	11	3,771	COSMOS 2251 DEB	11	28.3	Highlight Object Name/ID
-	TBA - TO BE ASSIGNE				COSMOS 1275 DEB	12	3,564	SL-16 DEB	12	22.9	
5,000-	ODMSP 5D-2 F13 D	EB			CZ-4 DEB		2,925	CZ-2C R/B		19.9	
-	ODELTA 1 DEB		O SL-8 R/B		SL-16 DEB		2,598	THOR ABLESTAR R/B		19.5	
	RESURS O1 DEB				SL-16 R/B		2,437	CZ-4C R/B		19.0	Origin Country Group
-	OCZ-4 DEB				CZ-2D DEB		2,406	VENTA 1		18.3	All
	O SL-16 DEB O				THORAD AGENA D		2,306	DMSP 5D-2 F13 DEB		15.6	
2,000-	OMETEOR 2-5 DEB SL-3 R/B			SL-16 R/B	METEOR 2-5 DEB		2,180	SL-14 R/B		14.9	Туре
	ОО SL-14 R/B				SL-3 R/B		2,161	CZ-4B R/B		13.8	Multiple values
	SO OCZ-2C R/B				PLANET		1,971	TBA - TO BE ASSIGNE		13.1	· · · · · · · · · · · · · · · · · · ·
1.000-					SL-14 DEB		1,869	TITAN 4B R/B		12.3	Aggregate Selection
-,	Q CZ-4C R/B O				DMSP 5D-2 F11 D PEGASUS DEB		1,634 1,608	IRIDIUM 33 DEB		12.1 11.9	🔘 Risk (kg)
-	O O PSLV R/B	В			IRIDIUM	23 24	1,608	ORBCOMM FM 5 DEB	<u>23</u>	11.9	Prob of Collision
		O CZ-2D R/B			PSLV DEB	24	1,295	THORAD AGENA D D	24	10.1	
_ک و 500-	STITAN 3C TRANSTAGE DEB	CZ-2D R/B			SL-14 R/B	26	1,278	RESURS O1 DEB	26	9.1	Threshold
. ctio	S.					27	1,223	METEOR 1-18	27	8.2	1e-06
in .	ariane 40 r/b				YUNHAI 1-02 DEB		1,220	SL-24 R/B		7.9	
Con	🦉 🚬 🔿 TITAN 4B R/B				CZ-2C R/B	29	1,214	CZ-4 R/B		7.6	
້ອ 200-	O TITAN 4B R/B				CZ-4B DEB	30	1,151	IRIDIUM	30	7.6	Altitude (km) All values
Number of Conjunctions - 000					CZ-4B R/B		1,044	COSMOS 1275 DEB		7.4	
tur,	SL-24 R/B				CBERS 1 DEB		1,022	CZ-4 DEB		6.5	
	5				THOR ABLESTAR		1,021	NOAA 17 DEB		6.2	Time of Closest Approach
100-	· 🖗 🛛 🖉				CZ-4C R/B		942	PSLV R/B		5.8	All values
-	🕌o THOR ABLESTAR R/B				CZ-4C DEB		835	LANDSAT 5		5.4	
	OCZ-4 R/B				H-2A R/B STARLINK		828	COSMOS 1371		5.1 4.8	
50-					STARLINK SL-18 DEB	37	747	SL-8 DEB METEOR 2-5 DEB	37	4.6	Fragment
					METEOR 2-8 DEB	39	717	BREEZE-KM R/B	39	4.5	Non-Operational Payload
	_ <u>_</u>				PSLV R/B	40	631	ARIANE 40 R/B		4.1	Rocket Body
	🔒 осоѕмоѕ 1371				COSMOS 1867 CO	41	601	DMSP 5D-2 F11 DEB	41	3.8	
20-					SL-3 DEB		590	SL-14 DEB		3.8	
20-	YAOGAN 29 DEB				CZ-2D R/B	43	561	TIROS N DEB		3.5	
	CLANDSAT 5				TITAN 3C TRANST	44	486	COSMOS 2266	44	3.5	* indicates multiple object types
					METEOR 2-7 DEB		457	YAOGAN 29 DEB		3.4	within the object name
10-	VENTA 1				METEOR 2-17 DEB		428	DELTA 1 R/B(1)		3.3	
-	O METEOR 1-18				FREGAT DEB		423	COSMOS 1867 COOL		2.9	
	• • O COSMOS 2266	OCOSMOS 2315			MINOTAUR 4 DEB		401	THOR ABLESTAR DEB		2.8	
5-	00 COSMOS 981	0			WORLDVIEW 2 DEB COSMOS 252 DEB		379 371	COSMOS 981 COSMOS 926		2.8 2.6	
	0	COSMOS 2334			PEGASUS R/B		348	PSLV DEB		2.6	
					ARIANE 1 DEB	52	336	COSMOS 1666	52	2.6	
•	•				THORAD DELTA 1		327	TIROS 8		2.4	
					ARIANE 40 R/B		320	PEGASUS R/B		2.3	
2-	Φ				SL-24 DEB		298	CZ-2D DEB		2.2	
					SCOUT G-1 DEB	56	295	NOAA 13	56	2.2	
					DELTA 1 R/B		292	COSMOS 1844		2.2	
1_	0 10 20 30				SL-8 DEB *		285	PEGASUS DEB		2.1	
	0 10 20 30	40 50 60 70 80 90 100	110 120 130	140 150			279	YUNHAI 1-02 DEB		2.1	
		Risk (kg)			COSMOS 375 DEB		271	IRS 1D		1.9	
		NISK (Kg)			OPS 4682 DEB		270	ENVISAT		1.8	

PC Map: Debris Clouds Drive Concerns

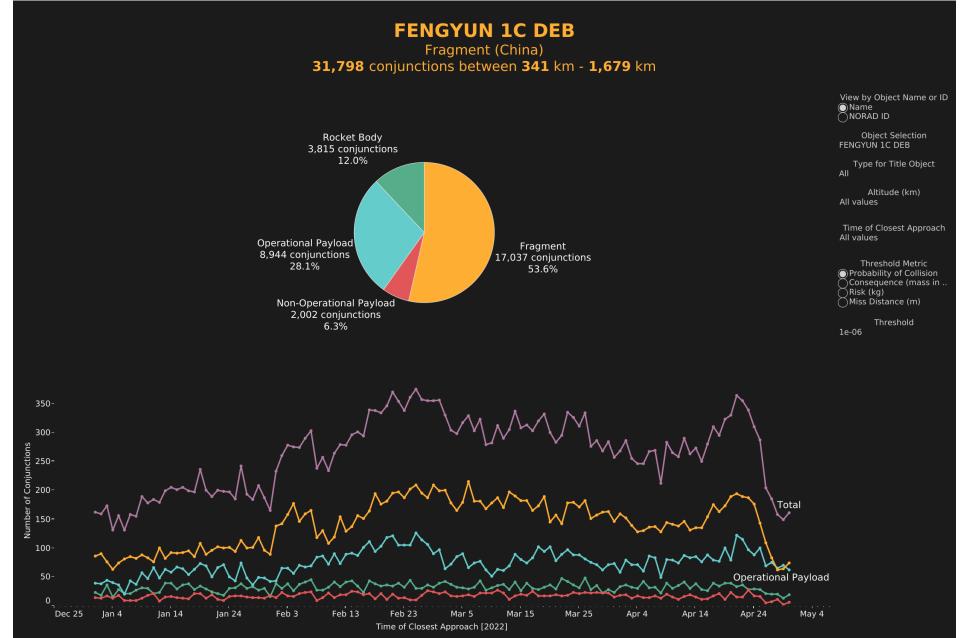
- Feng-yun 1C
 √~#2,800
- Cosmos 1408 ✓~#900
 - ✓ Nearly half of debris has reentered
- Cosmos 2251 ✓~#1,100
- Altitude and mechanism of breakup both matter...

Data as of 1	.5 May 2022
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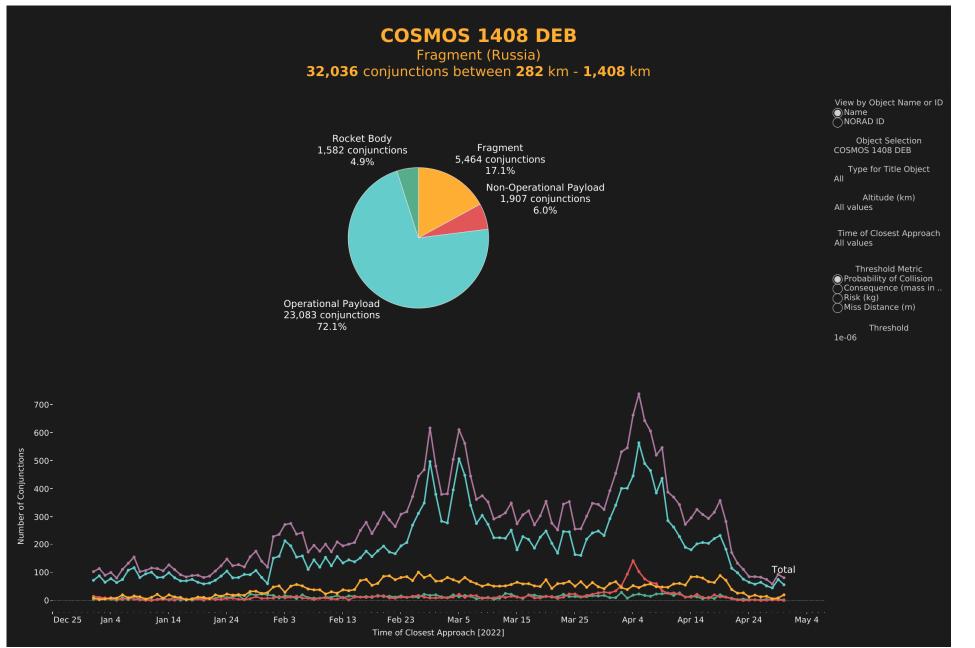
Ob 50,000-	jects by Conjunction Count and Aggregated Probability of Collision	Rank by Conjunction Count			Rank by Ag Probability o	gregated f Collision	L E O 😴 L A B S
	FENGYUN 1C DEB	COSMOS 1408 DEB		32,036	FENGYUN 1C DEB	1 0.19	²⁵ Rank by Object Name or NORAD II
		FENGYUN 1C DEB		31,798	COSMOS 1408 DEB	2 0.16	
	COSMOS 1408 DEB	COSMOS 2251 DEB		14,285	COSMOS 2251 DEB	3 0.08	
20,000-		NOAA 16 DEB		11,484	SL-8 R/B		
20,000		IRIDIUM 33 DEB		6,122	NOAA 16 DEB	5 0.04	
	COSMOS 2251 DEB	TBA - TO BE ASSI		5,931	TBA - TO BE ASSIGNE	6 0.03	
		DMSP 5D-2 F13 D		5,530 4,674	COSMOS 2315	7 0.02 8 0.02	
0,000 -	NOAA 16 DEB	DELTA 1 DEB SL-8 R/B		4,639	COSMOS 2334 DELTA 1 DEB	9 0.02	
	IRIDIUM 33 DEB	RESURS O1 DEB		4,493	IRIDIUM 33 DEB	10 0.02	
·	5D-2 F13 DEB OTBA - TO BE ASSIGNED	NOAA 17 DEB	11	3,771	DMSP 5D-2 F13 DEB	11 0.02	
5,000 - DMSH	SURS 01 DEB 0 0 0	COSMOS 1275 DEB		3,564	SL-3 R/B	12 0.02	29
- KES	© NOAA 17 DEB SL-8 R/B	CZ-4 DEB	13	2,925	RESURS O1 DEB	13 0.02	Origin Country Group
		SL-16 DEB		2,598	CZ-4 DEB	14 0.01	99 All
	SL-16 DEB O CZ-4 DEB	SL-16 R/B		2,437	SL-16 DEB		
.000 -	ു ^{ള്} ം	CZ-2D DEB		2,407	NOAA 17 DEB	16 0.01	
	SL-3 R/B	THORAD AGENA D		2,306	COSMOS 1275 DEB	17 0.01	Iype
		METEOR 2-5 DEB SL-3 R/B		2,180	SL-16 R/B THORAD AGENA D D	18 0.01 19 0.01	⁵⁹ Multiple values
	90 SL-14 R/B	PLANET	20	1,971	CZ-2D DEB	20 0.01	39
.,000 -		SL-14 DEB	20	1,869	IRIDIUM	20 0.01	
		DMSP 5D-2 F11 D	22	1,634	PLANET	22 0.01	
	ଞ୍ଚି COSMOS 1867 COOLANT ୧୦୦୦	PEGASUS DEB		1,608	H-2A R/B	23 0.01	
500-	Q TITAN 3C TRANSTAGE DEB	IRIDIUM	24	1,472	CZ-2D R/B	24 0.01	
	g	PSLV DEB		1,295	THOR ABLESTAR R/B	25 0.01	10.06
	X	SL-14 R/B		1,278	SL-14 R/B	26 0.00	99
	👼	SL-8 DEB		1,223	METEOR 2-5 DEB	27 0.00	
200-		YUNHAI 1-02 DEB		1,220	SL-8 DEB	28 0.00	Aititude (KIII)
00-	O ORBCOMM FM 5 DEB	CZ-2C R/B CZ-4B DEB	29 30	1,214	CZ-4C R/B SL-14 DEB	29 0.00 30 0.00	
		CZ-48 DEB		1,151	COSMOS 1867 COOL	30 0.00	
		CBERS 1 DEB	32	1,022	ORBCOMM FM 5 DEB	32 0.00	
-00		THOR ABLESTAR		1,021	PEGASUS DEB	33 0.00	
· ·	O THOR ABLESTAR R/B	CZ-4C R/B		942	DMSP 5D-2 F11 DEB	34 0.00	
	O CZ-4 R/B	CZ-4C DEB	35	835	PSLV DEB	35 0.00	73
50-		H-2A R/B	36	828	CZ-4B DEB	36 0.00	
	O SCOUT A R/B	STARLINK		747	CZ-4B R/B	37 0.00	
		SL-18 DEB		741	COSMOS 1371	38 0.00	
	COSMOS 1371	METEOR 2-8 DEB	39		THOR ABLESTAR DEB	39 0.00 40 0.00	
		PSLV R/B COSMOS 1867 CO		631 601	SCOUT A R/B VENTA 1	40 0.00	
20-	Ö	SL-3 DEB	41 42	590	PSLV R/B	41 0.00	
		CZ-2D R/B		561	EXPLORER 40 (INJUN	43 0.00	
	O VENTA 1	TITAN 3C TRANST		486	CZ-2C R/B	44 0.00	
10-		METEOR 2-7 DEB		457	CBERS 1 DEB	45 0.00	
	METEOR 1-18	METEOR 2-17 DEB	46	428	YUNHAI 1-02 DEB	46 0.00	
	O COSMOS 2315	FREGAT DEB	47	423	COSMOS 2266	47 0.00	
		MINOTAUR 4 DEB		401	CZ-4C DEB	48 0.00	
	O EXPLORER 40 (INJUN-5)	WORLDVIEW 2 DEB		379	CZ-4 R/B	49 0.00	
		COSMOS 252 DEB		371	METEOR 1-18	50 0.00	
	9	PEGASUS R/B ARIANE 1 DEB	51 52	349 336	SL-3 DEB SL-24 R/B	51 0.00 52 0.00	
		THORAD DELTA 1	52	336	COSMOS 252 DEB	53 0.00	
						54 0.00	
	$\mathbf{\omega}$			320	STARLINK		28
		ARIANE 40 R/B		320 298	STARLINK PEGASUS R/B		
	oo		54 55 56	<u>320</u> 298 295	PEGASUS R/B TITAN 4B R/B	54 0.00 55 0.00 56 0.00	27
2- 0		ARIANE 40 R/B SL-24 DEB		298	PEGASUS R/B	55 0.00	27 27
2- 0	00 .00 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19 0.20	ARIANE 40 R/B SL-24 DEB SCOUT G-1 DEB	55 56	298 295	PEGASUS R/B TITAN 4B R/B	55 0.00 56 0.00	27 27 26 26

Feng-yun 1C Cloud – Largest Debris Cloud

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C1408 PC Hazard – Affects More Operational Payloads EO C LABS



Cosmos 1408 and Feng-yun 1C ASAT Clouds

Together, the two ASAT debris clouds account for 38% of high PC (PC > 1E-6) conjunctions in LEO during first four months of 2022

Cosmos 1408 has lost nearly half of debris (i.e., ~800 of ~1,700 have reentered) so Feng-yun 1C has triple the number of objects on orbit but...

- Cosmos 1408 has same number of high PC conjunctions
- Cosmos 1408 has triple the number of high PC conjunctions with operational satellites



LeoLabs' Position on Activities Needed for Sustained Space Safety

Small covariance Conjunction Data Messages and catalog sub-10cm debris

Complete cessation of on-orbit ASAT events

Cooperative space traffic management practices

Removal of massive derelicts from upper LEO to prevent continual large debris-generating events