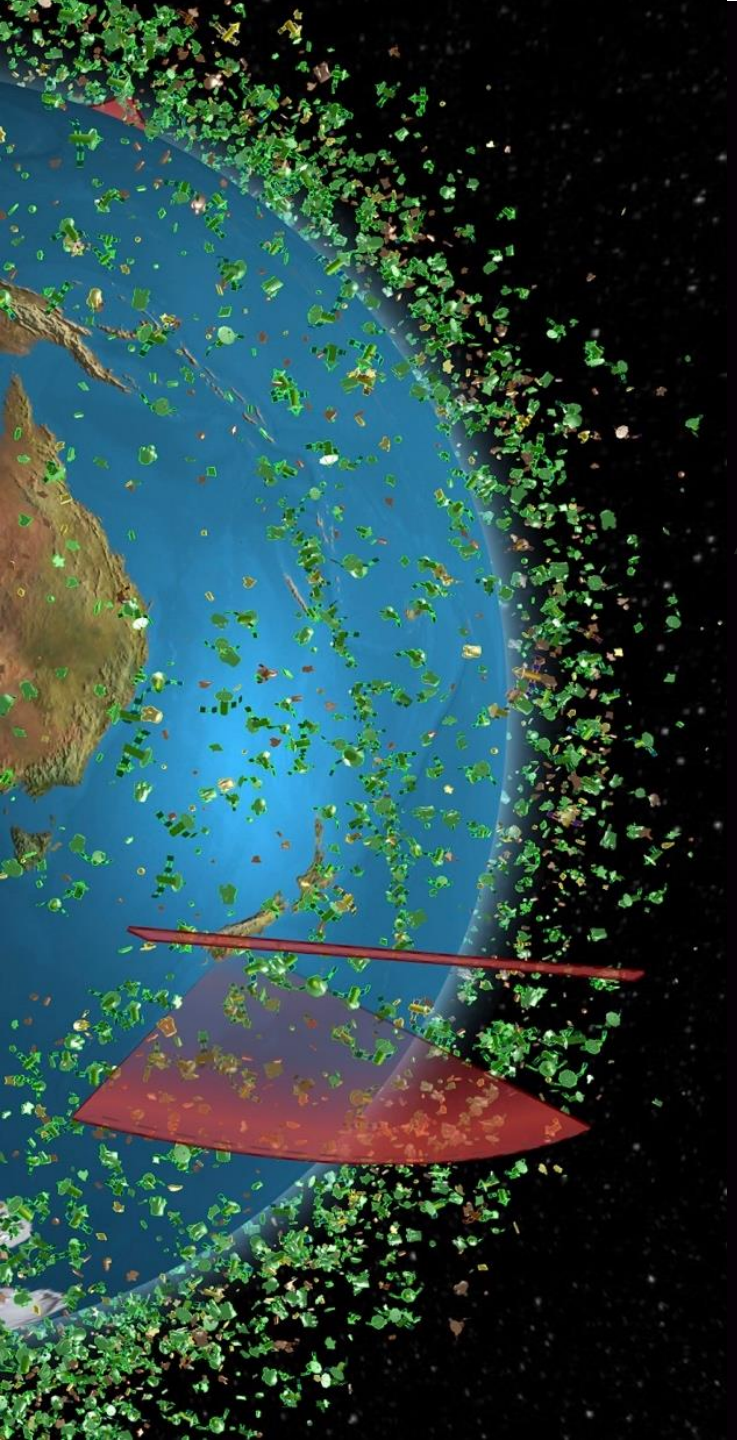


"Mapping Collision Risk in Low Earth Orbit (LEO)

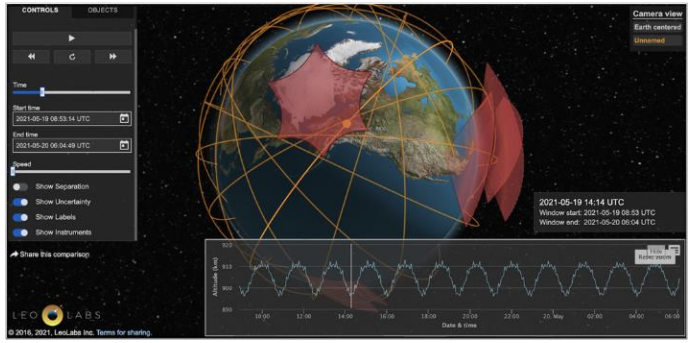
LeoLabs
Darren McKnight, Senior Technical Fellow

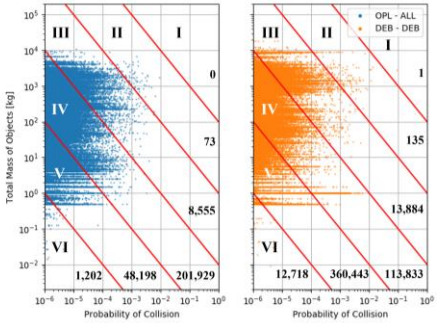
June 2022

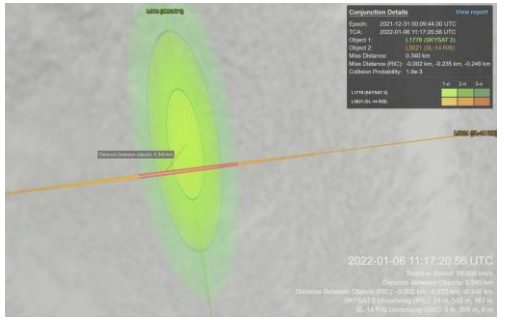
This presentation represents the position of the speaker and does not necessarily reflect a USG position.

LeoLabs: Mapping Low Earth Orbit

- Operational services, scaling with the satellite industry
- More frequent, high-quality, and globally-derived 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

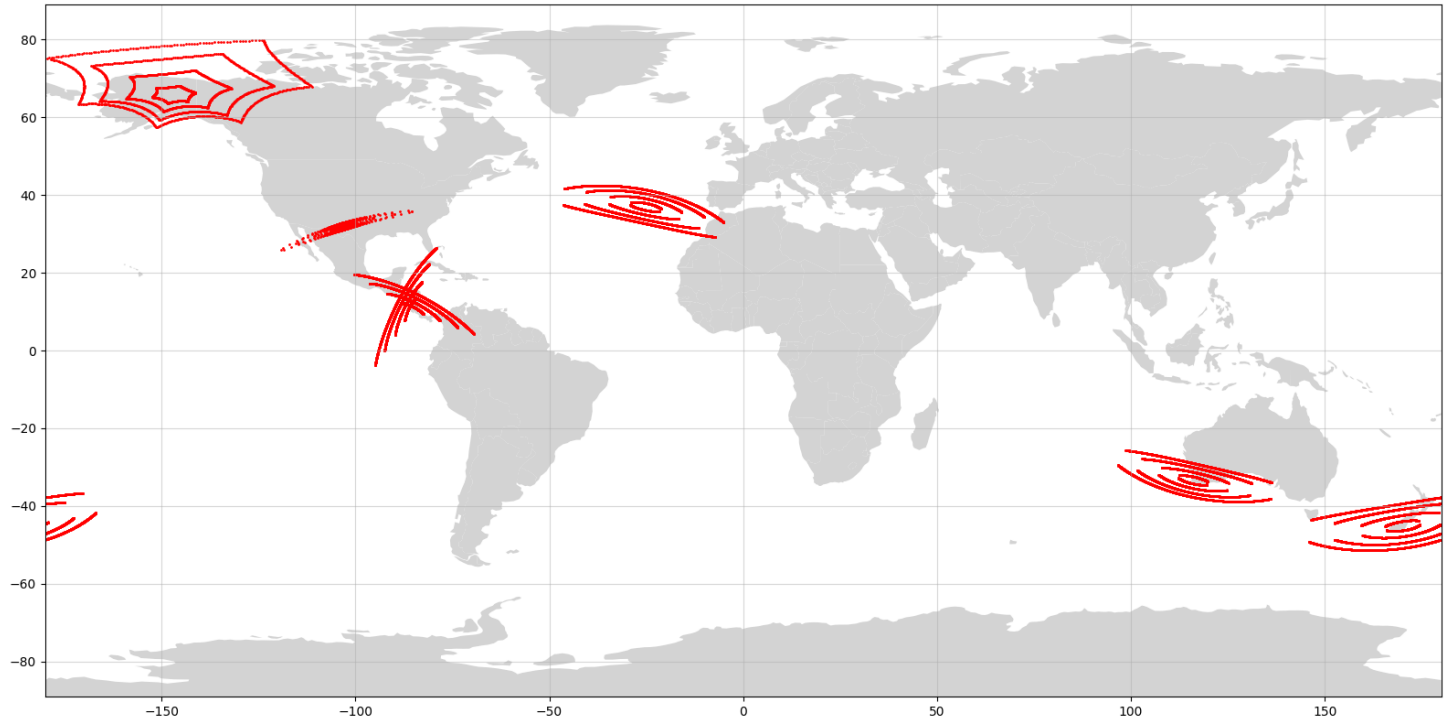
Costa Rica Space Radars (S-Band), Costa Rica – Active

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
    - 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

LEO LABS

Key Performance Indicators

4/20/2022 - 5/20/2022

LATENCY TIME - RADAR PASS TO STATE VECTOR	ACCURACY VS TRUTH DATA DIFFERENCE BETWEEN LEOLABS & TRUTH DATA	PRECISION OF STATE VECTORS RMS UNCERTAINTY
14 MIN	30 METERS	31 METERS
RADAR PASSES	**MEASUREMENTS**	**OBJECTS**
1,015,097	14,053,547	20,876
STATE VECTORS	**CONJUNCTION DATA MESSAGES**	**OPERATIONAL EPHEMERIS SCREENINGS**
877,212	448,721,192	277,300

Livestream Counter

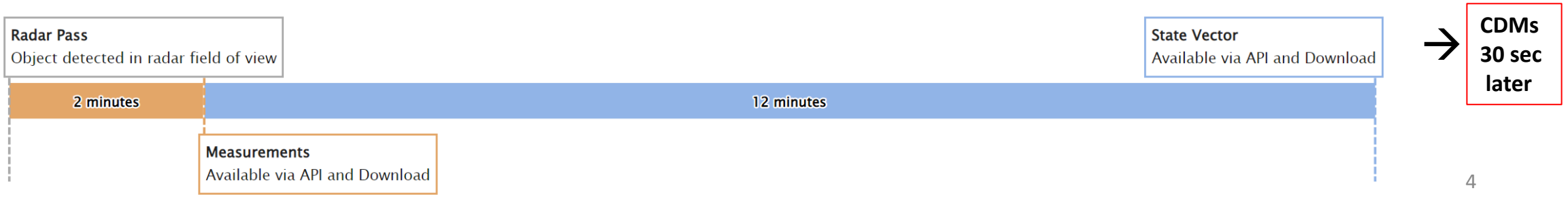
All time

MEASUREMENTS	STATE VECTORS	CONJUNCTION DATA MESSAGES
685,202,872	19,694,208	7,805,780,120

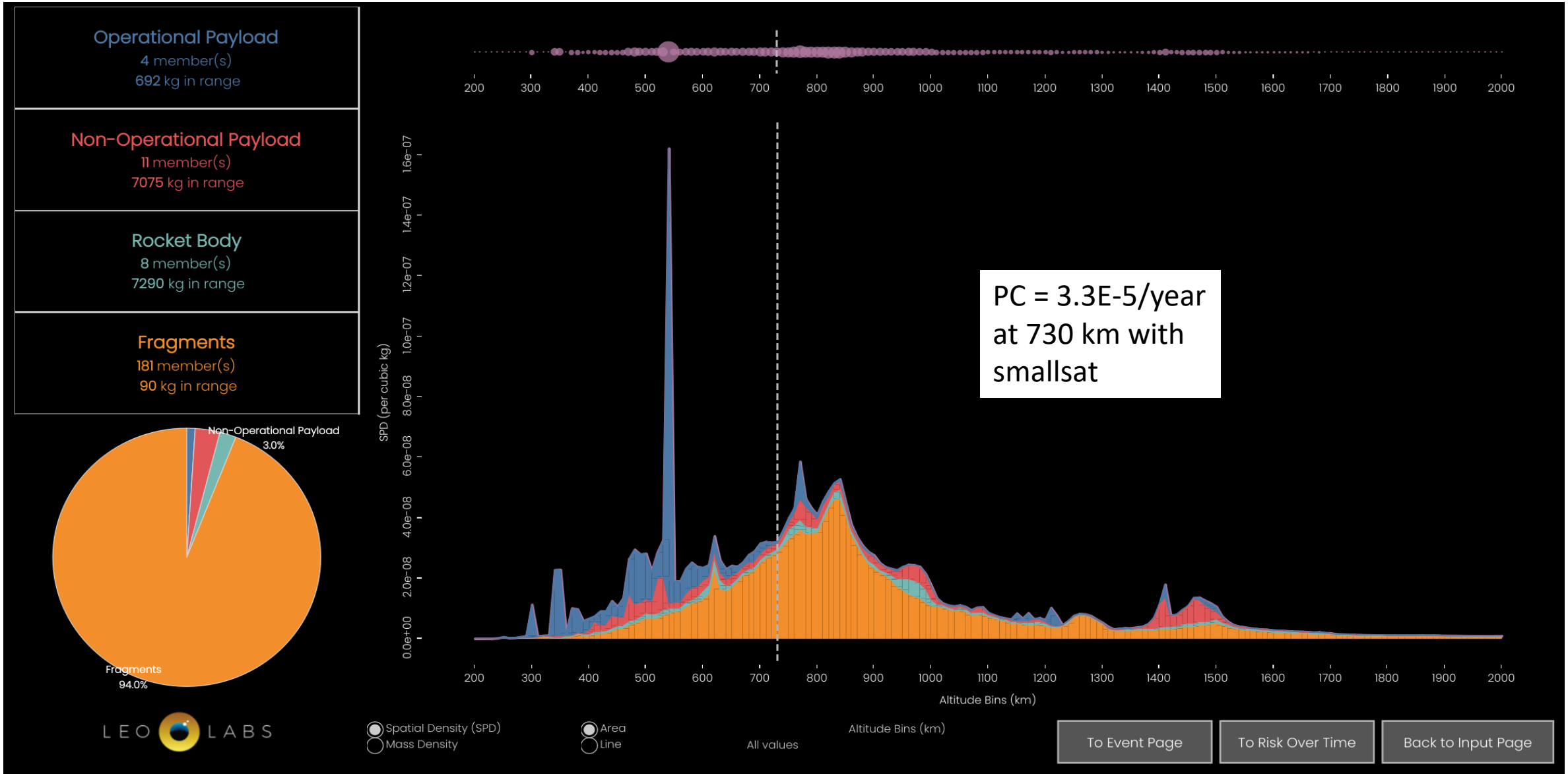
Latency

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

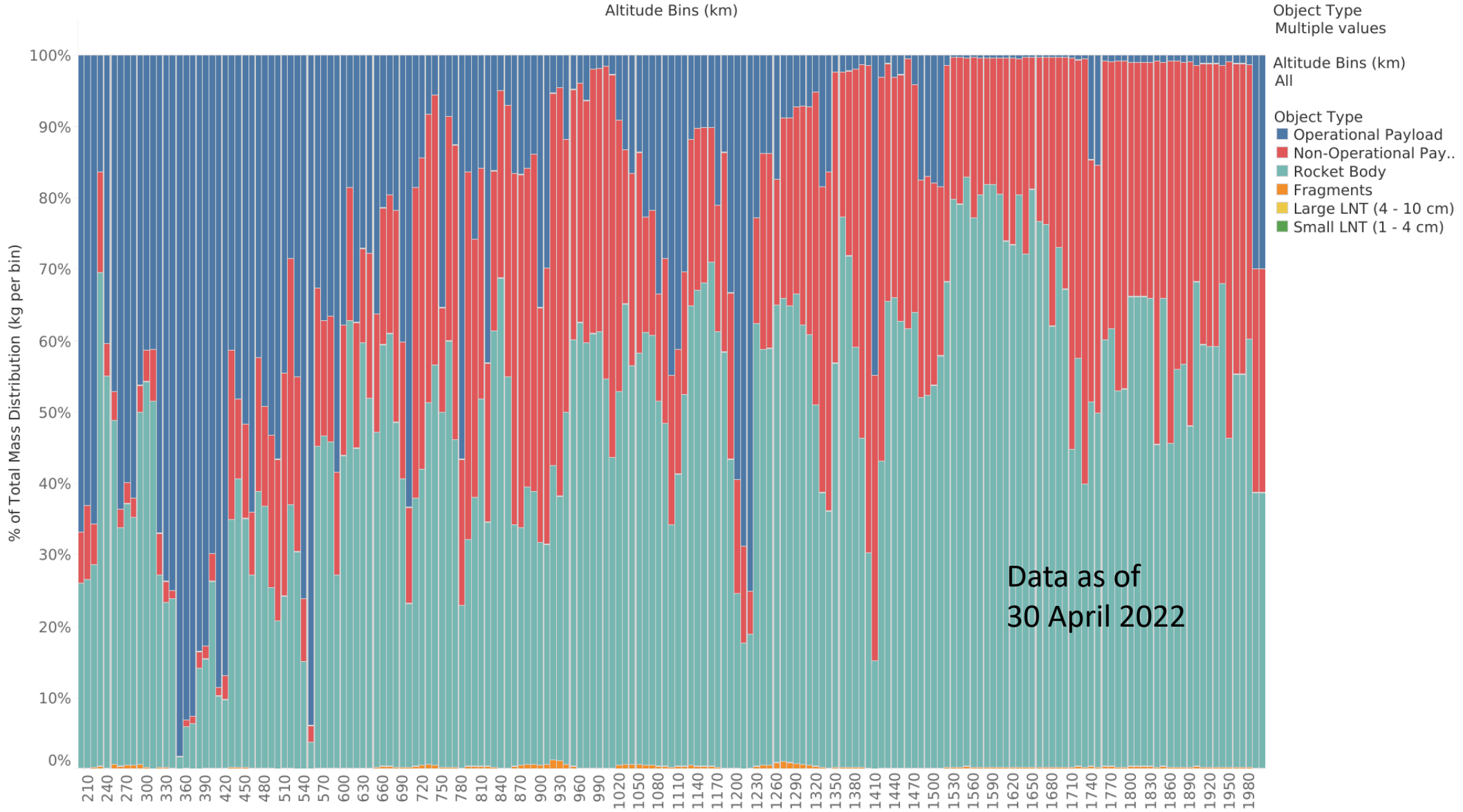


PC (Catalog) = Collision Avoidance Burden *Varies Drastically Throughout LEO*



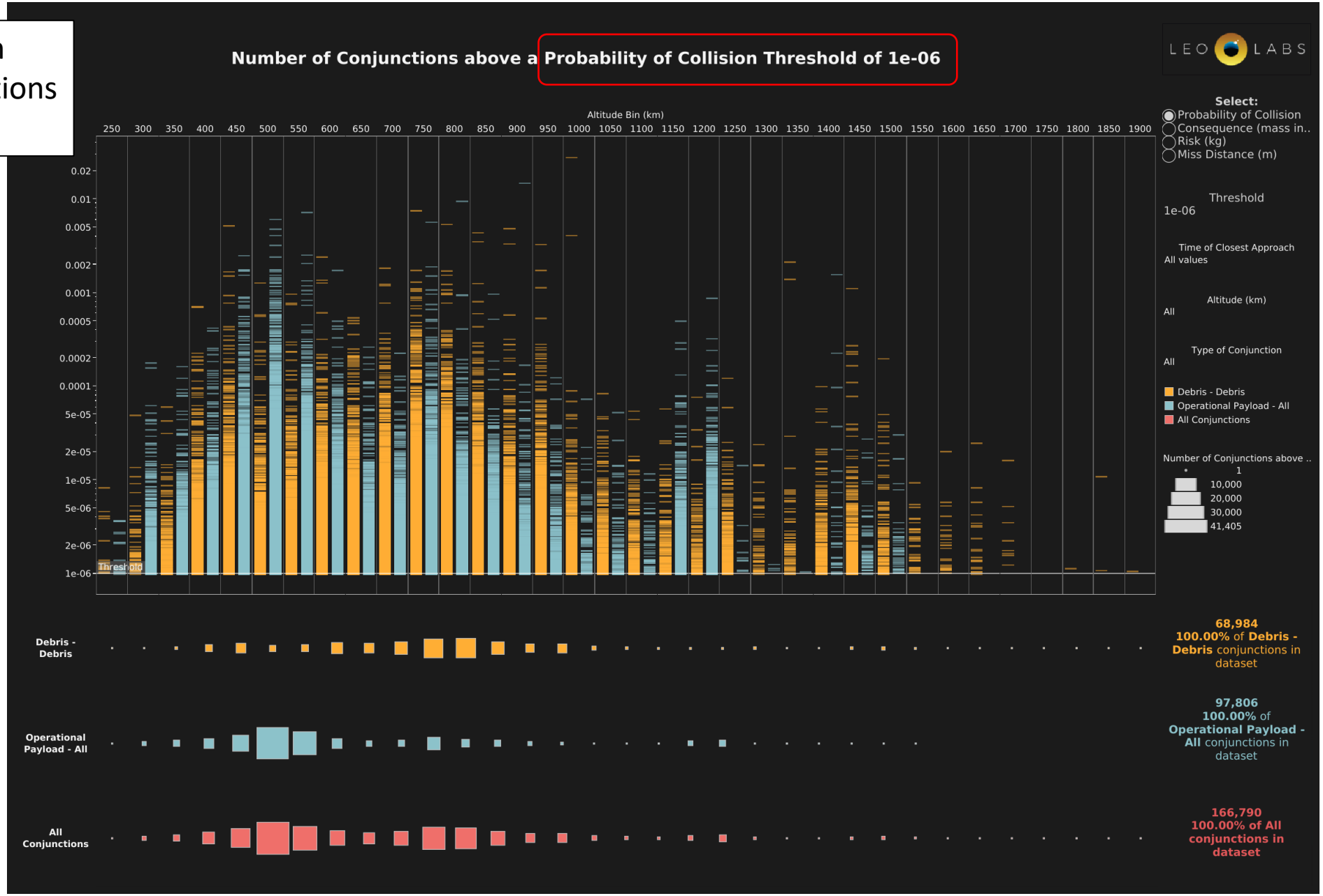
Mass is Distributed Non-Uniformly in LEO

Massive Derelicts Drive Future Debris Growth



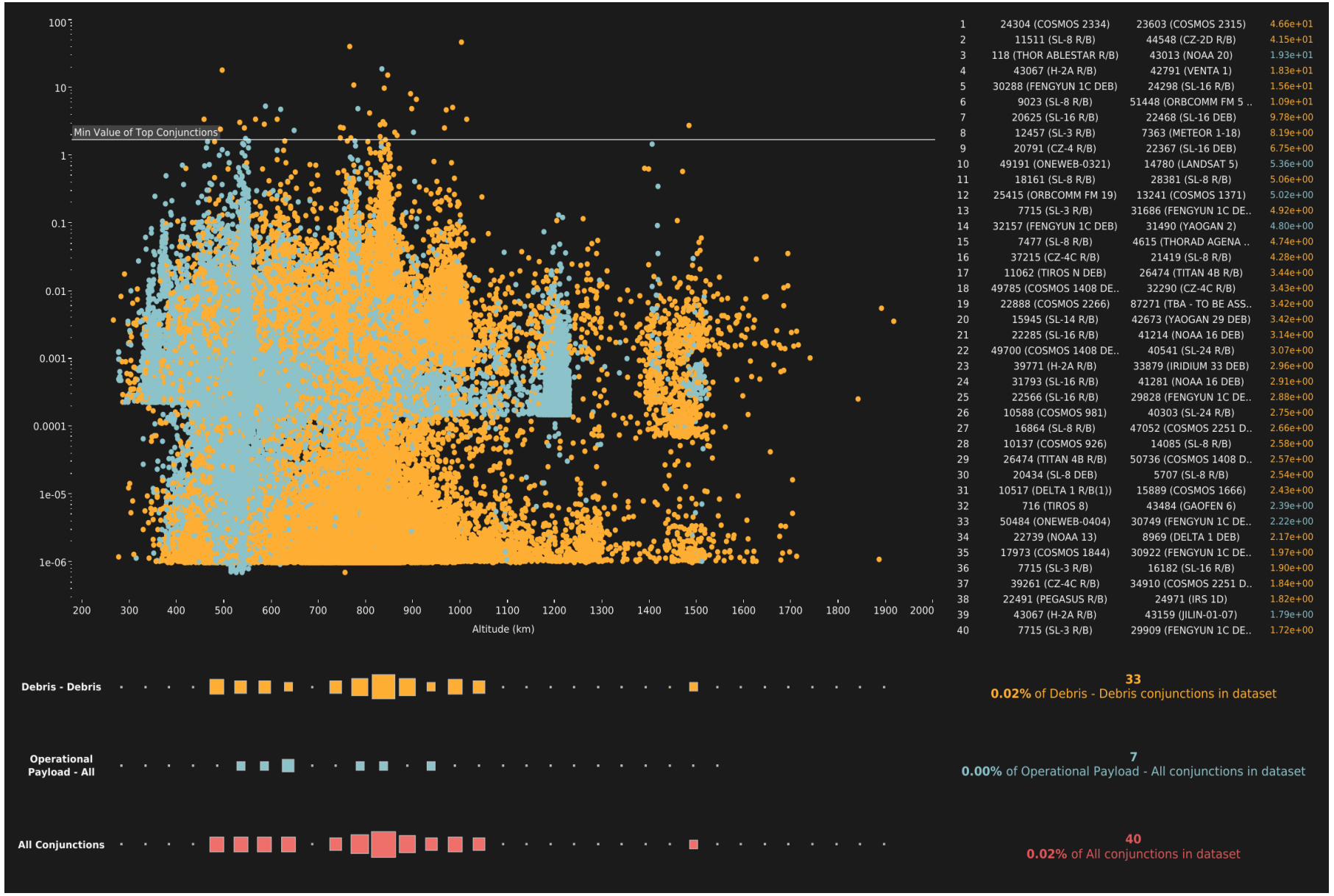
Taking the Heartbeat of LEO… Probability of Collision (PC)

~40,000 high risk conjunctions per month



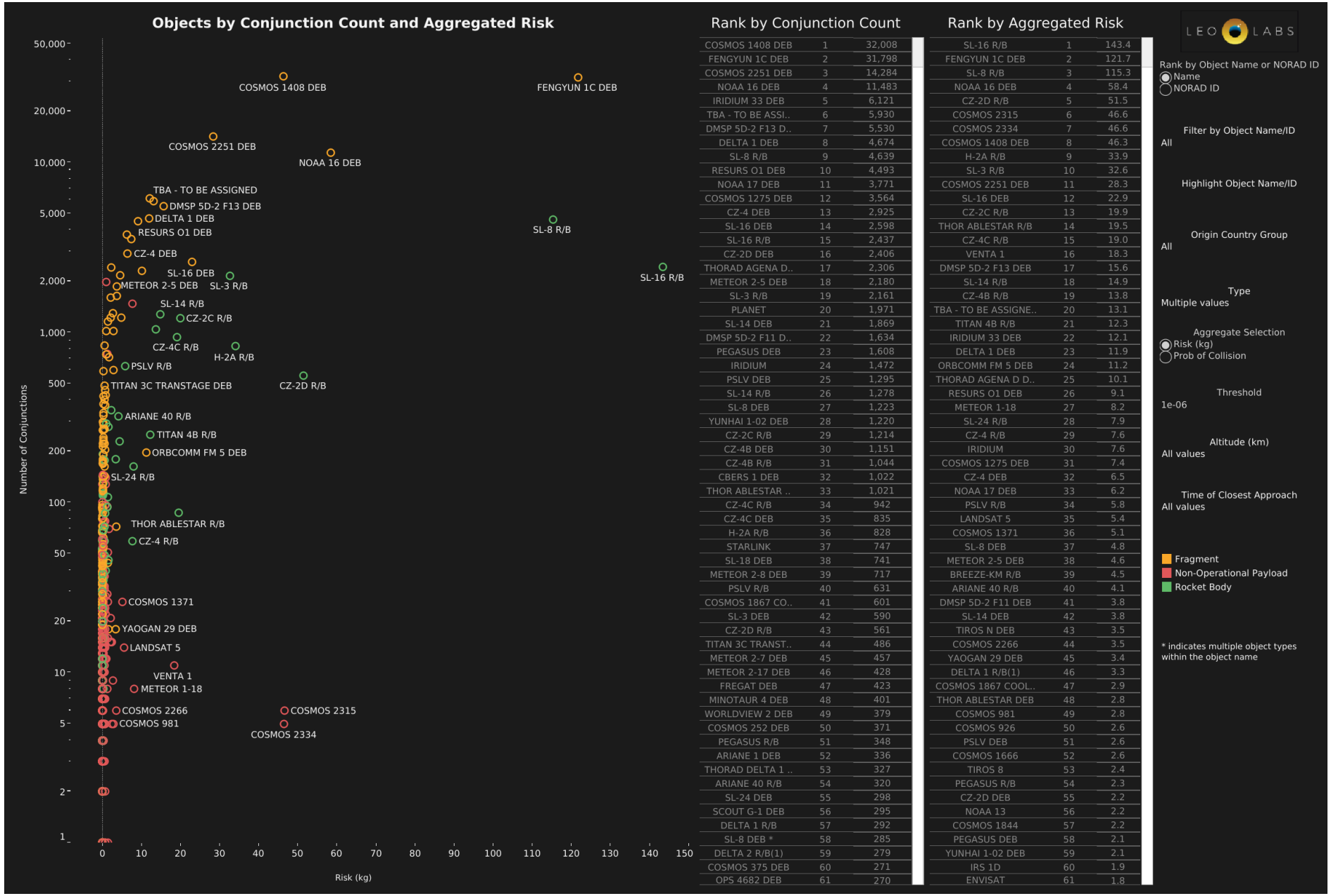
Top 40 Riskiest Events in 2022

- 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



1	24304 (COSMOS 2334)	23603 (COSMOS 2315)	4.66e+01
2	11511 (SL-8 R/B)	44548 (CZ-2D R/B)	4.15e+01
3	118 (THOR ABLESTAR R/B)	43013 (NOAA 20)	1.93e+01
4	43067 (H-2A R/B)	42791 (VENTA 1)	1.83e+01
5	30288 (FENGYUN 1C DEB)	24298 (SL-16 R/B)	1.56e+01
6	9023 (SL-8 R/B)	51448 (ORBCOMM FM 5 ..)	1.09e+01
7	20625 (SL-16 R/B)	22468 (SL-16 DEB)	9.78e+00
8	12457 (SL-3 R/B)	7363 (METEOR 1-18)	8.19e+00
9	20791 (CZ-4 R/B)	22367 (SL-16 DEB)	6.75e+00
10	49191 (ONEWEB-0321)	14780 (LANDSAT 5)	5.36e+00
11	18161 (SL-8 R/B)	28381 (SL-8 R/B)	5.06e+00
12	25415 (ORBCOMM FM 19)	13241 (COSMOS 1371)	5.02e+00
13	7715 (SL-3 R/B)	31686 (FENGYUN 1C DE..)	4.92e+00
14	32157 (FENGYUN 1C DEB)	31490 (YAOGAN 2)	4.80e+00
15	7477 (SL-8 R/B)	4615 (THORAD AGENA ..)	4.74e+00
16	37215 (CZ-4C R/B)	21419 (SL-8 R/B)	4.28e+00
17	11062 (TIROS N DEB)	26474 (TITAN 4B R/B)	3.44e+00
18	49785 (COSMOS 1408 DE..)	32290 (CZ-4C R/B)	3.43e+00
19	22888 (COSMOS 2266)	87271 (TBA - TO BE ASS..)	3.42e+00
20	15945 (SL-14 R/B)	42673 (YAOGAN 29 DEB)	3.42e+00
21	22285 (SL-16 R/B)	41214 (NOAA 16 DEB)	3.14e+00
22	49700 (COSMOS 1408 DE..)	40541 (SL-24 R/B)	3.07e+00
23	39771 (H-2A R/B)	33879 (IRIDIUM 33 DEB)	2.96e+00
24	31793 (SL-16 R/B)	41281 (NOAA 16 DEB)	2.91e+00
25	22566 (SL-16 R/B)	29828 (FENGYUN 1C DE..)	2.88e+00
26	10588 (COSMOS 981)	40303 (SL-24 R/B)	2.75e+00
27	16864 (SL-8 R/B)	47052 (COSMOS 2251 D..)	2.66e+00
28	10137 (COSMOS 926)	14085 (SL-8 R/B)	2.58e+00
29	26474 (TITAN 4B R/B)	50736 (COSMOS 1408 D..)	2.57e+00
30	20434 (SL-8 DEB)	5707 (SL-8 R/B)	2.54e+00
31	10517 (DELTA 1 R/B(1))	15889 (COSMOS 1666)	2.43e+00
32	716 (TIROS 8)	43484 (GAOFEN 6)	2.39e+00
33	50484 (ONEWEB-0404)	30749 (FENGYUN 1C DE..)	2.22e+00
34	22739 (NOAA 13)	8969 (DELTA 1 DEB)	2.17e+00
35	17973 (COSMOS 1844)	30922 (FENGYUN 1C DE..)	1.97e+00
36	7715 (SL-3 R/B)	16182 (SL-16 R/B)	1.90e+00
37	39261 (CZ-4C R/B)	34910 (COSMOS 2251 D..)	1.84e+00
38	22491 (PEGASUS R/B)	24971 (IRS 1D)	1.82e+00
39	43067 (H-2A R/B)	43159 (JILIN-01-07)	1.79e+00
40	7715 (SL-3 R/B)	29909 (FENGYUN 1C DE..)	1.72e+00

Risk Map – Derelicts are a Concern!!!

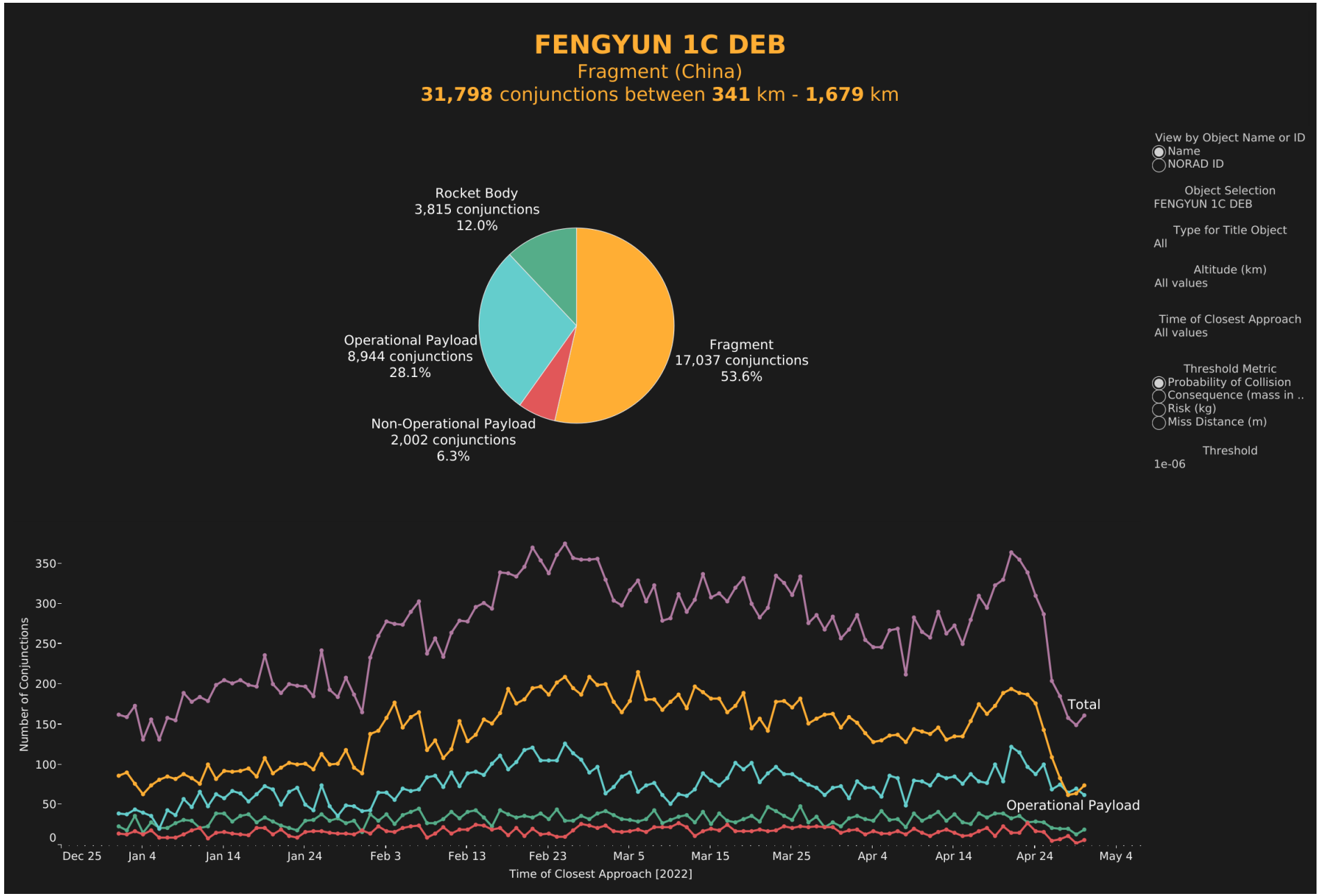


PC Map: Debris Clouds Drive Concerns

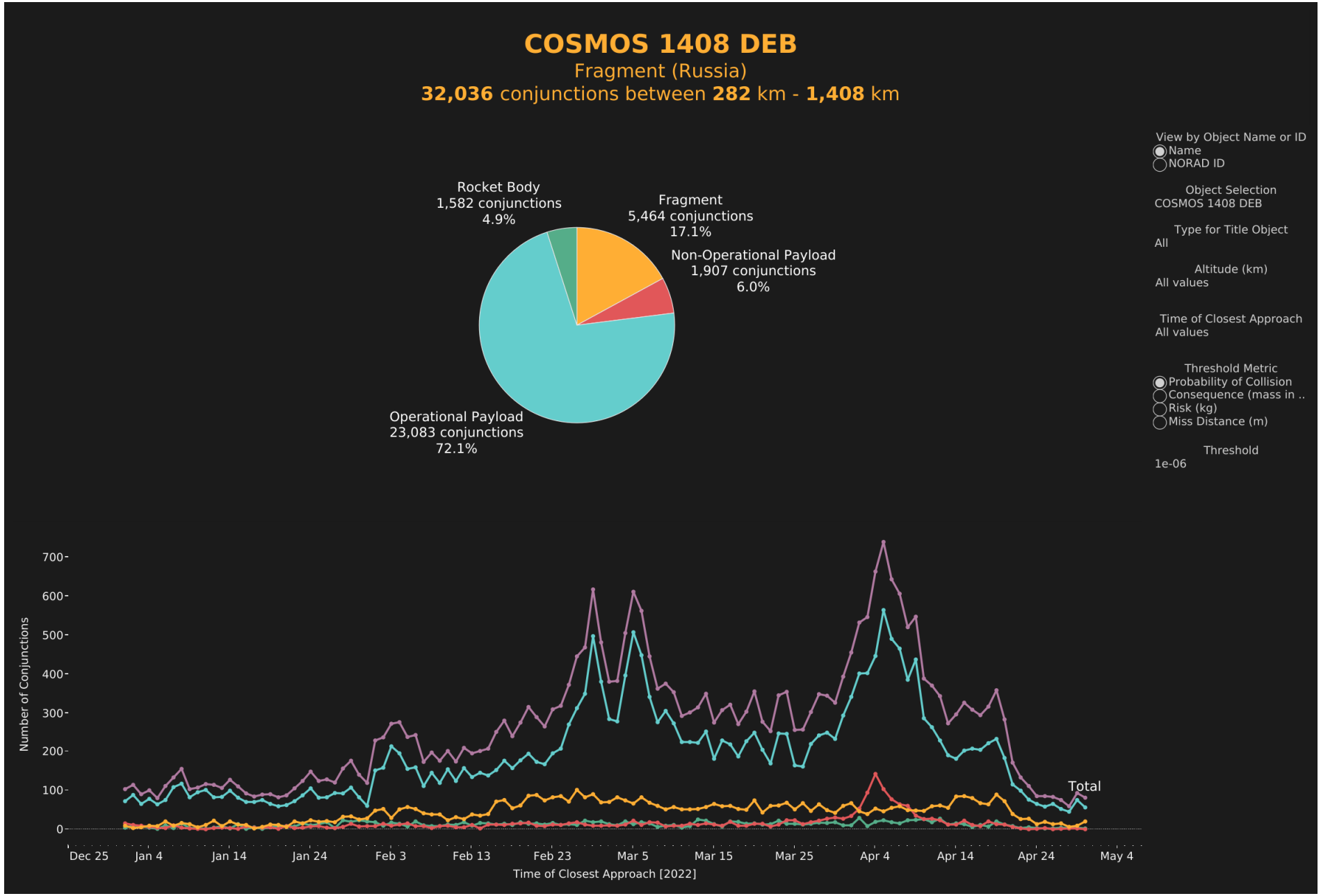
- Feng-yun 1C
  - ✓~#2,800
- Cosmos 1408
  - ✓~#900
  - ✓Nearly half of debris has reentered
- Cosmos 2251
  - ✓~#1,100
- Altitude and mechanism of breakup both matter…

Data as of 15 May 2022

Feng-yun 1C Cloud – Largest Debris Cloud



C1408 PC Hazard – Affects More Operational Payloads



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