Space Traffic in Low Earth Orbit

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Space Portal Commercial Space Telecon Lecture Series (CST)

Agenda

- Problem statement
- About LeoLabs
- Collision Avoidance
- Analytics tools
- Future of space traffic management

The Traffic Problem in Low Earth Orbit

500->1500->45,000 satellites

hundreds of thousands of pieces of space debris

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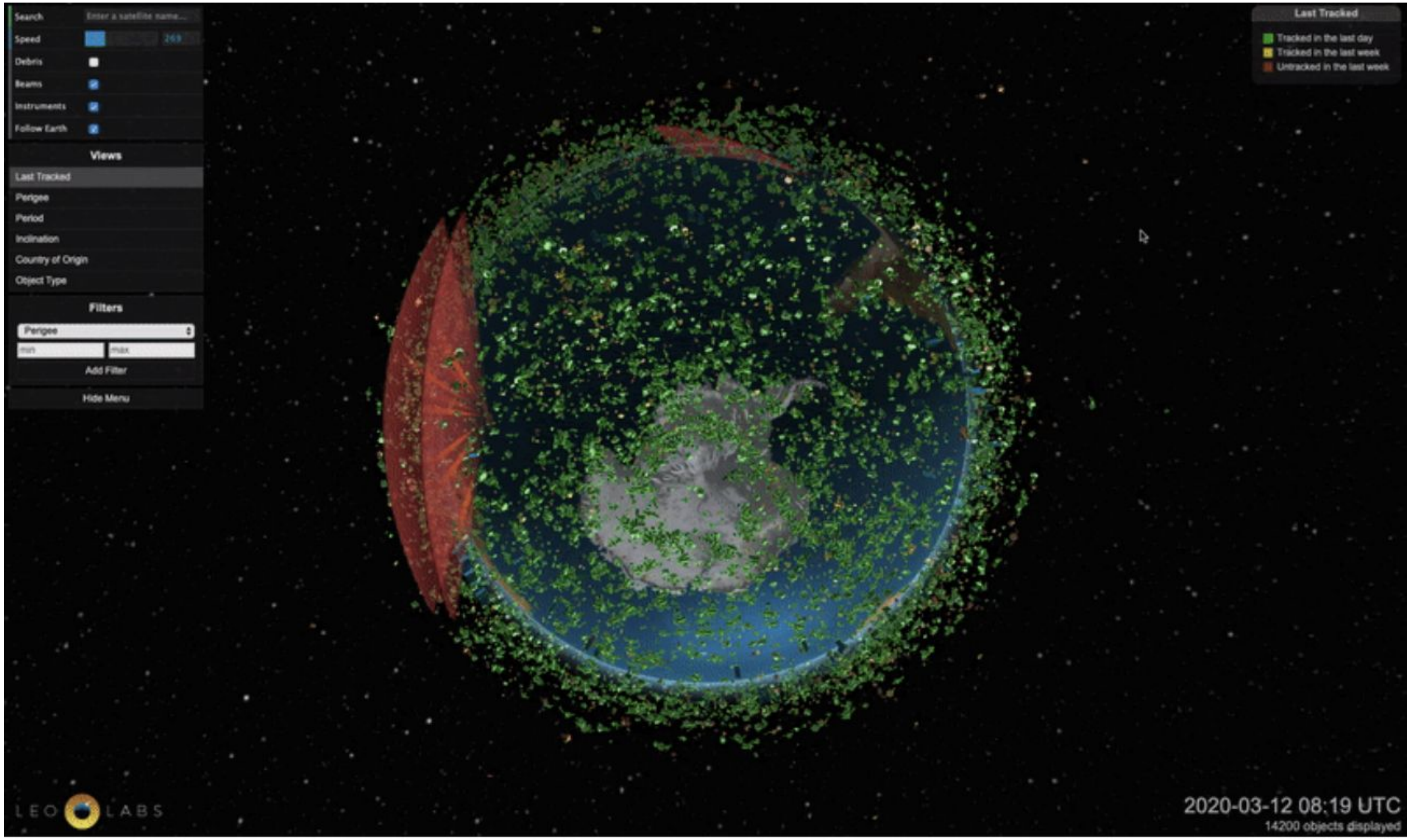
commercial satellite operators

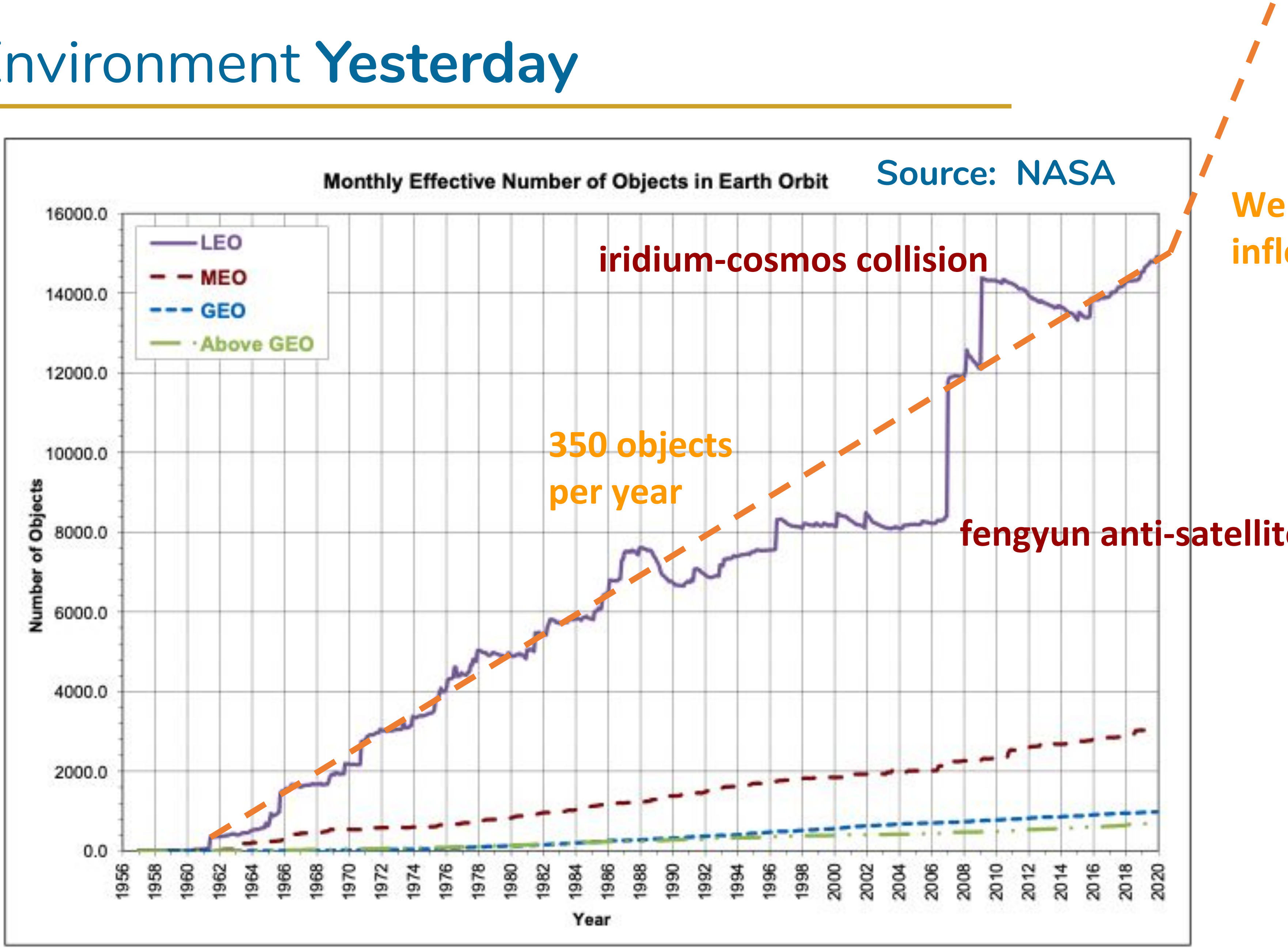
defense and government organizations

academic and research missions



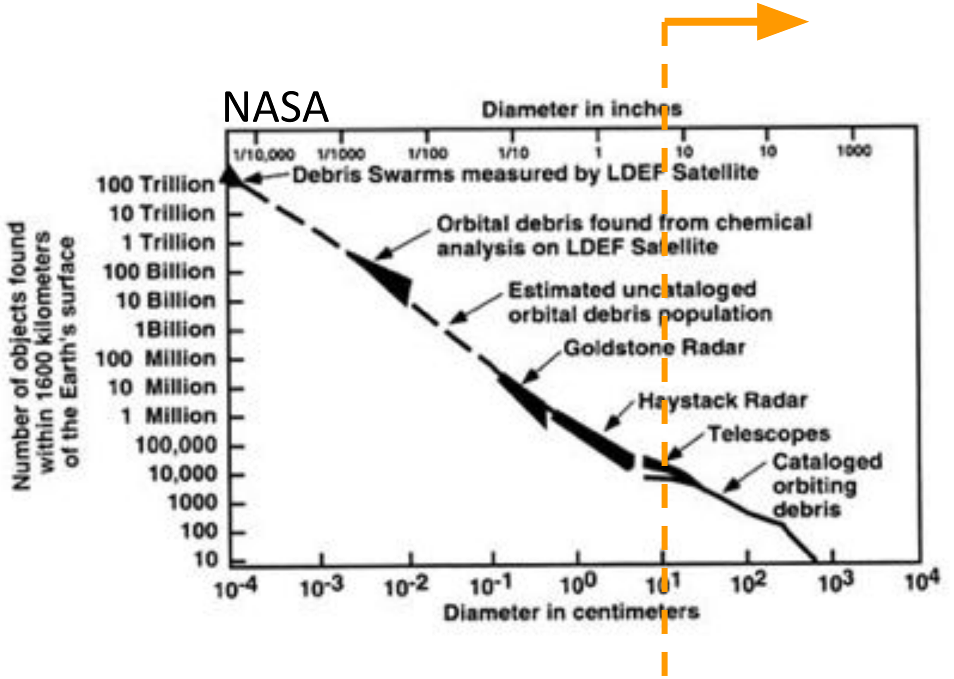
https://platform.leolabs.space/visualizations/leo

Space Environment **Yesterday**



We are at an inflection point

Estimates of Debris Size Distributions



https://aerospace.org/article/space-debris-101

Debris Size	Mass (Al.) (grams)	Kinetic Energy	Equivalent TNT (kg)	Equivalent in Size to	Energy of Impact
1 mm	0.0014	71 J	0.0003	Sand grain	Hit by Baseball
3 mm	0.038	1.9 kJ	0.008	Bead	Shot by Bullet
1 cm	1.41	70 kJ	0.3	Blueberry	Falling Anvil
5 cm	176.7	8 MJ	37	Plum	Hit by bus
10 cm	1413.7	70 MJ	300	Softball	Large bomb

- Number of debris objects estimated by statistical models to be in orbit [ESA]:
  - **34,000 objects >10 cm**
  - **900,000 objects from 1 cm to 10 cm**
  - **128 million objects from 1 mm to 1 cm**

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Catastrophic Collisions

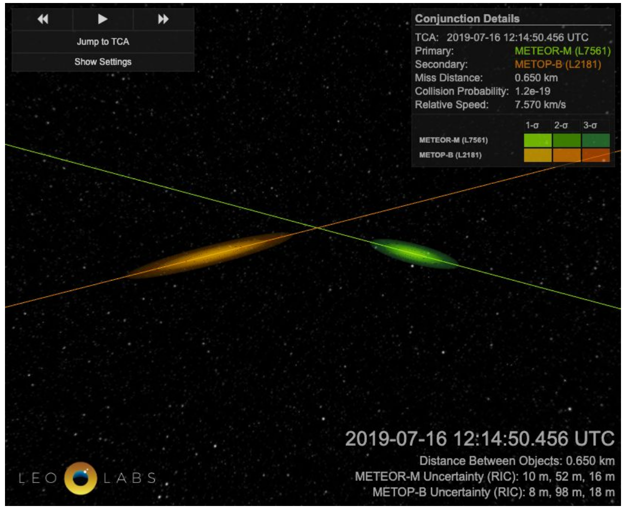
Energy required for catastrophic collision

- Requires ratio of impact energy to target mass to exceed 40 J/g [e.g., J-C Liou, NASA]

Cubesat: 0.35-2 cm

Small sat: 1.6-9 cm

Large sat: 8-44 cm



Need: Track objects in the 1-2 cm range to avoid catastrophic collisions

			Closing Speed (km/s)	1.00	Closing Speed (km/s)	7.00	Closing Speed (km/s)	14.00
Satellite Type	**Mass (kg)**	**Energy for Catastrophic Collision (kJ)**	**Object mass (g)**	**Object Size (cm)**	**Object mass (g)**	**Object Size (cm)**	**Object mass (g)**	**Object Size (cm)**
Giant	10000	400000	400000	43.9	8163.27	12.01	2040.82	7.57
Imaging	3000	120000	120000	29.4	2448.98	8.04	612.24	5.06
Comms	700	28000	28000	18.1	571.43	4.95	142.86	3.12
Small sat	100	4000	4000	9.5	81.63	2.59	20.41	1.63
Cubesat	1	40	40	2.0	0.82	0.56	0.20	0.35

Collision Risk Today

Two uncontrolled objects that are large enough to create new debris if they collide come within 10 meters of each other every day

- Around 5% of these events are observable with existing tracking technologies
- Most of these still go unobserved, because we only look at close approaches with active satellites

Hundreds of derelict rocket bodies and satellites exist in LEO, with a combined mass of over 1000 tons

- These objects have extremely long lifetimes
- A collision between two of them would roughly double the amount of debris in LEO in an instant

We lack data. That also means we lack actionable data, and actionable insights.

- Existing technologies track roughly only 5% of objects with enough mass to be involved in debris generating collisions
- Existing technologies track roughly only 1-2% of objects needed to support sustained human spaceflight
- Objects that we do track might be observed less than 1% of the time.
- We have a serious sparse data problem.

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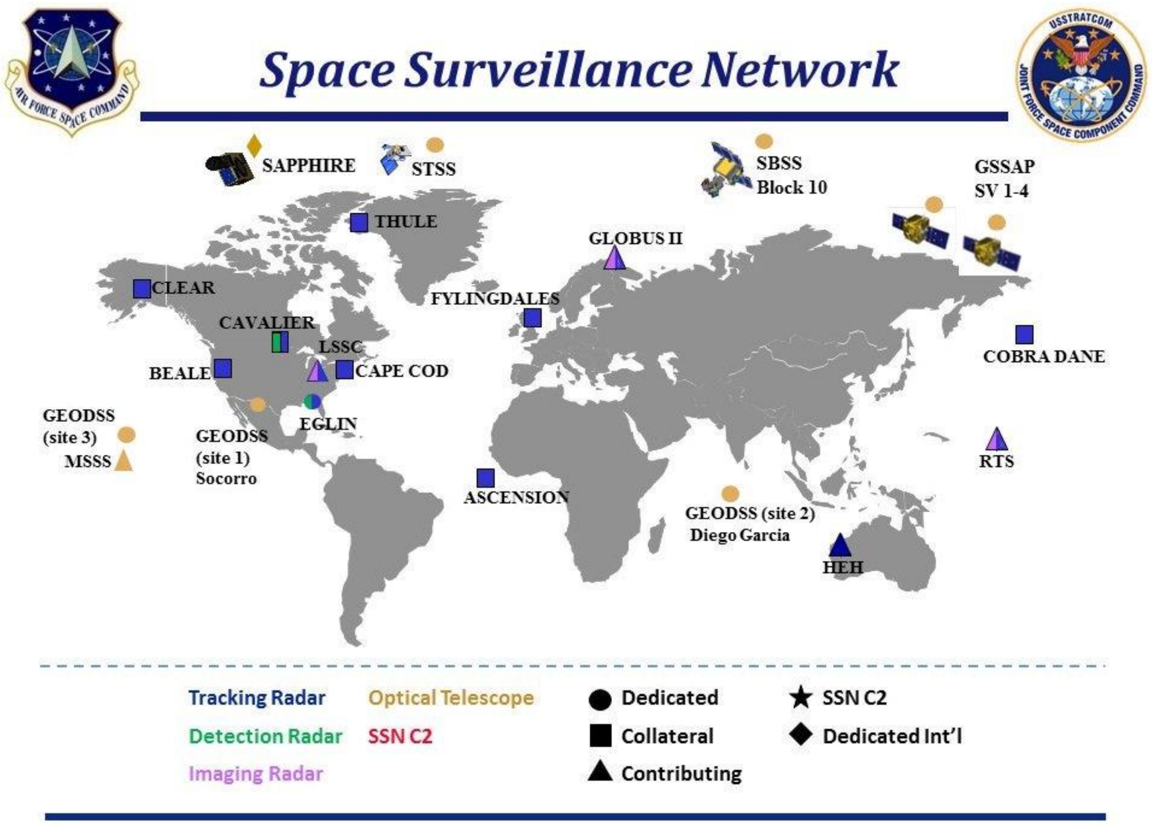
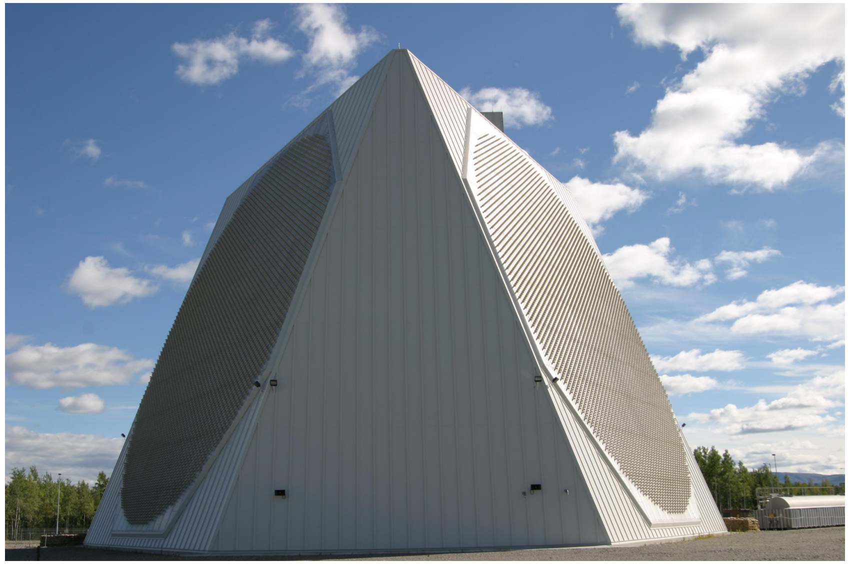
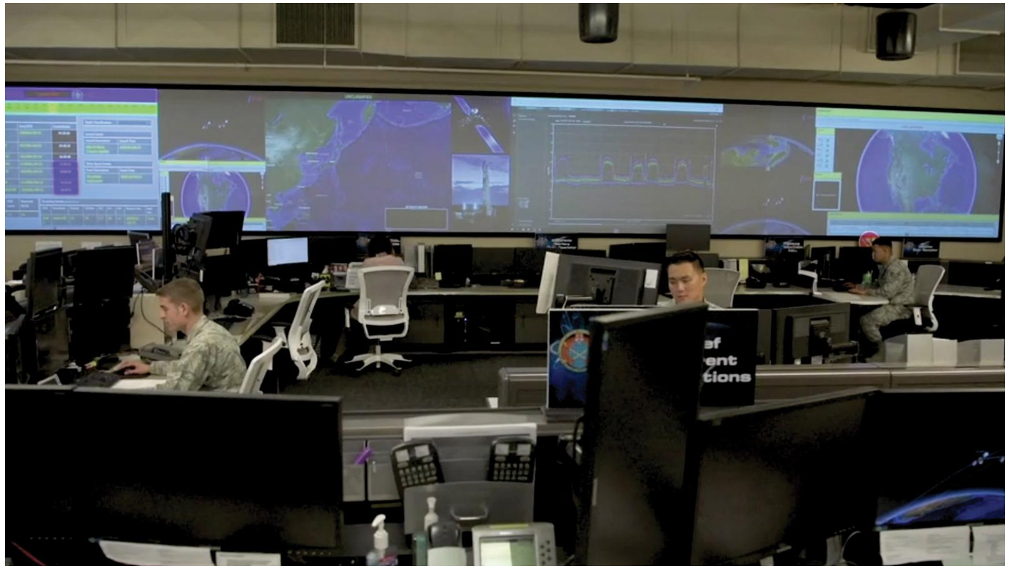
How Space Objects are Tracked (before LeoLabs)

- Networked array of US DoD and partner sensors
- Centralized operations and processing locations







LEO LABS

A modern space traffic management enterprise

Independent operationally verified data source

- data driven analytics
- certified processes
- transparent

Responsive service model (SaaS)

- real-time & automated
- continuous & on-demand
- information exchange

Scaled for big data

- large numbers of objects
- large amounts of data and insights
- knowledge that grows with data

Coverage

- Every object every orbit
- Global coverage
- Persistent monitoring

LeoLabs, Inc.

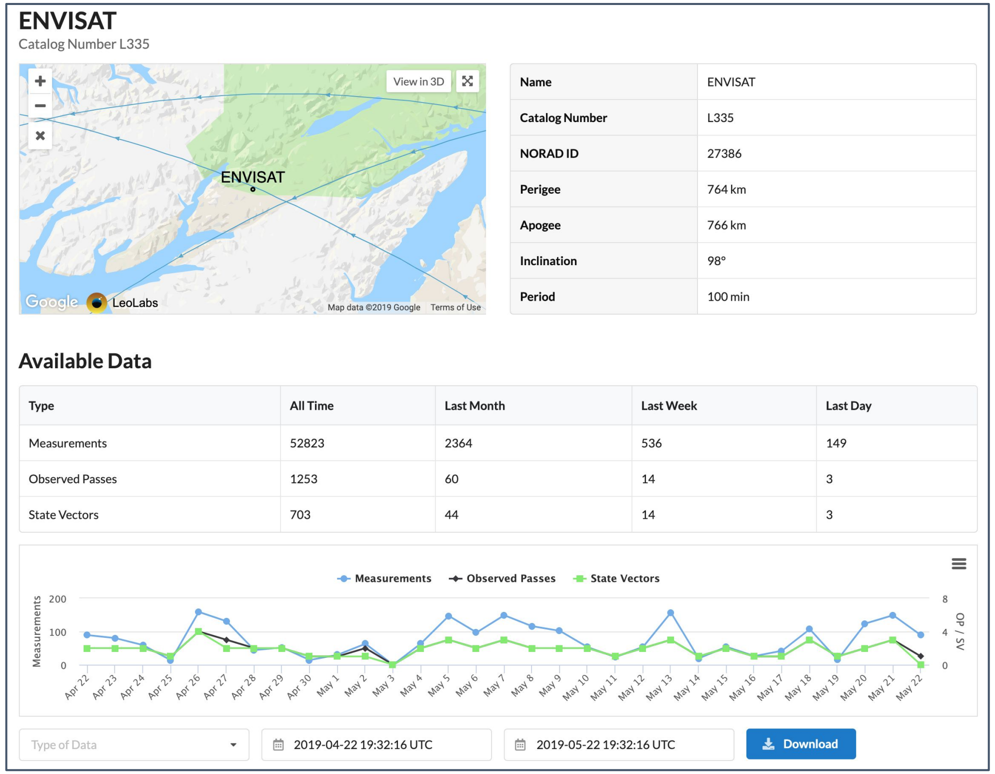
- The information platform for activities in low Earth orbit (LEO)
- Architecture:
    - SaaS platform
    - Unique data source - radars
- Founded on 20 years of R&D
- Horizontal service provider serving:
    - Satellite operators
    - Regulators
    - DOD/IC
    - Insurance

- Award winning Silicon Valley startup
    - 2017 Finspace Award
    - 2018 Satellite Conference Startup Space Grand Prize Winner
    - 2019 Aviation Weekly Annual Laureate Award
    - 2019 SpaceNews Inaugural Space Stewardship Award

LeoLabs Capabilities

Build and operate global network of ground-based, phased-array radars

Cloud-based platform to process and service orbit data products and analytics to customers



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LeoLabs' data source: ground-based radars

- **Rapid construction - each radar is built in less than 1 year**
- Fully automated, remotely accessible, and no on-site staff
- Operate around the clock (through sunlight and clouds)
- Track thousands of objects per hour (phased-array technology)
- Track satellites and debris as small as 2 centimeters (20x more than the Public Catalog)

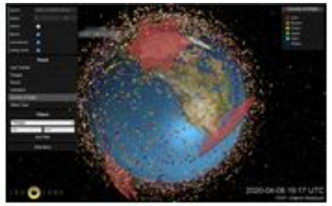

Midland Space Radar (MSR)

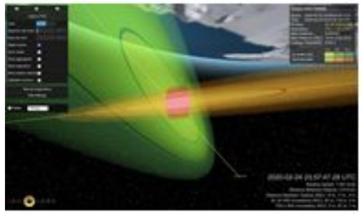

Kiwi Space Radar (KSR)

LEO LABS

Kiwi Space Radar
Commissioned in January 2020

LeoLabs' Unique Service and Delivery Model





Services Delivery
- Data Feeds
- Dashboards

Software Platform
- Orbit-Determination
- Collision Avoidance
- Maneuver Detection
- … and more

Radar **Hardware**
- RF systems
- Electronics systems
- System Integration
- … and more

Site **Infrastructure**
- Operations Center
- Power
- Communications
- Security

✔ SaaS – customer subscribe to services instead of purchasing software or radars. LeoLabs regularly enhances its software platform and radars to stay competitive.

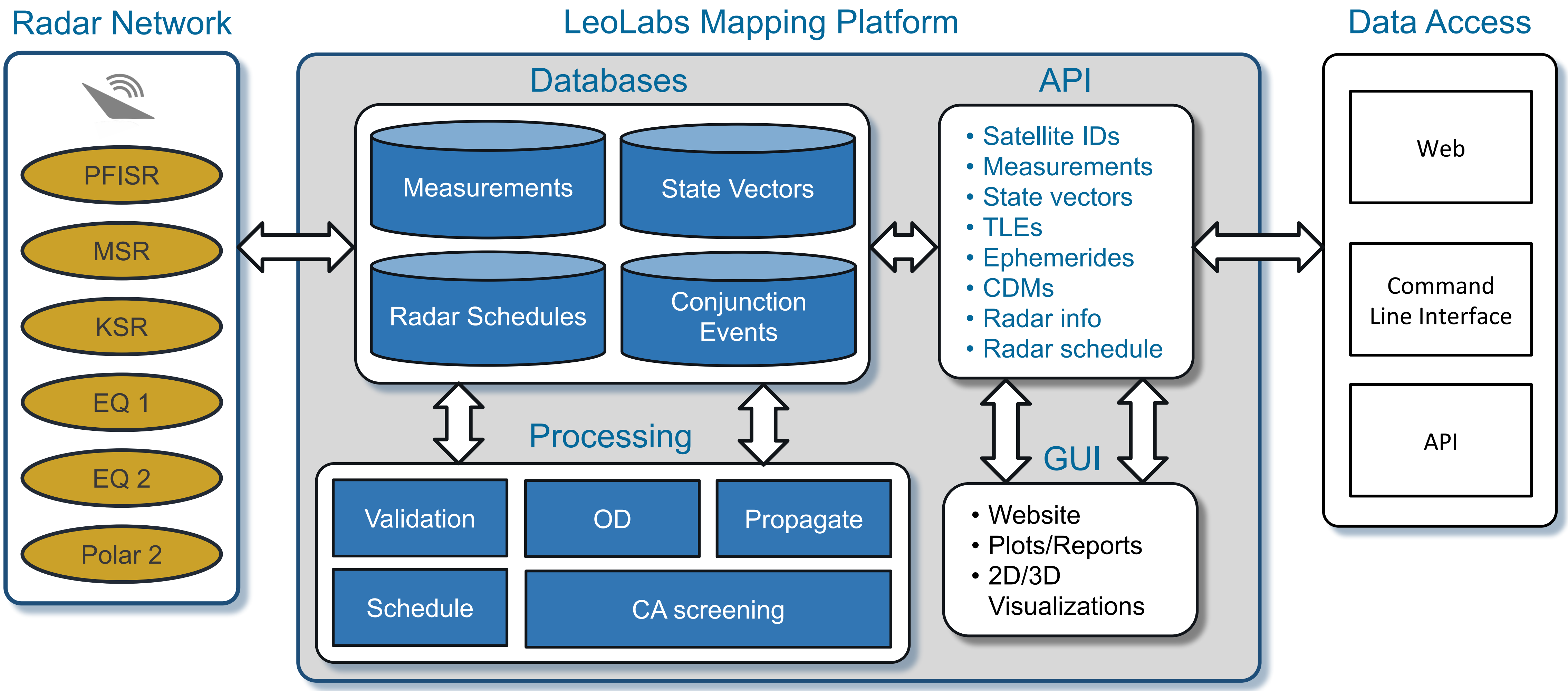
✔ With predictable subscriptions, LeoLabs continues to build radars. Each new radar multiplies the value of subscription services.

✔ Subscriptions feed workforces at LeoLabs and supply chain

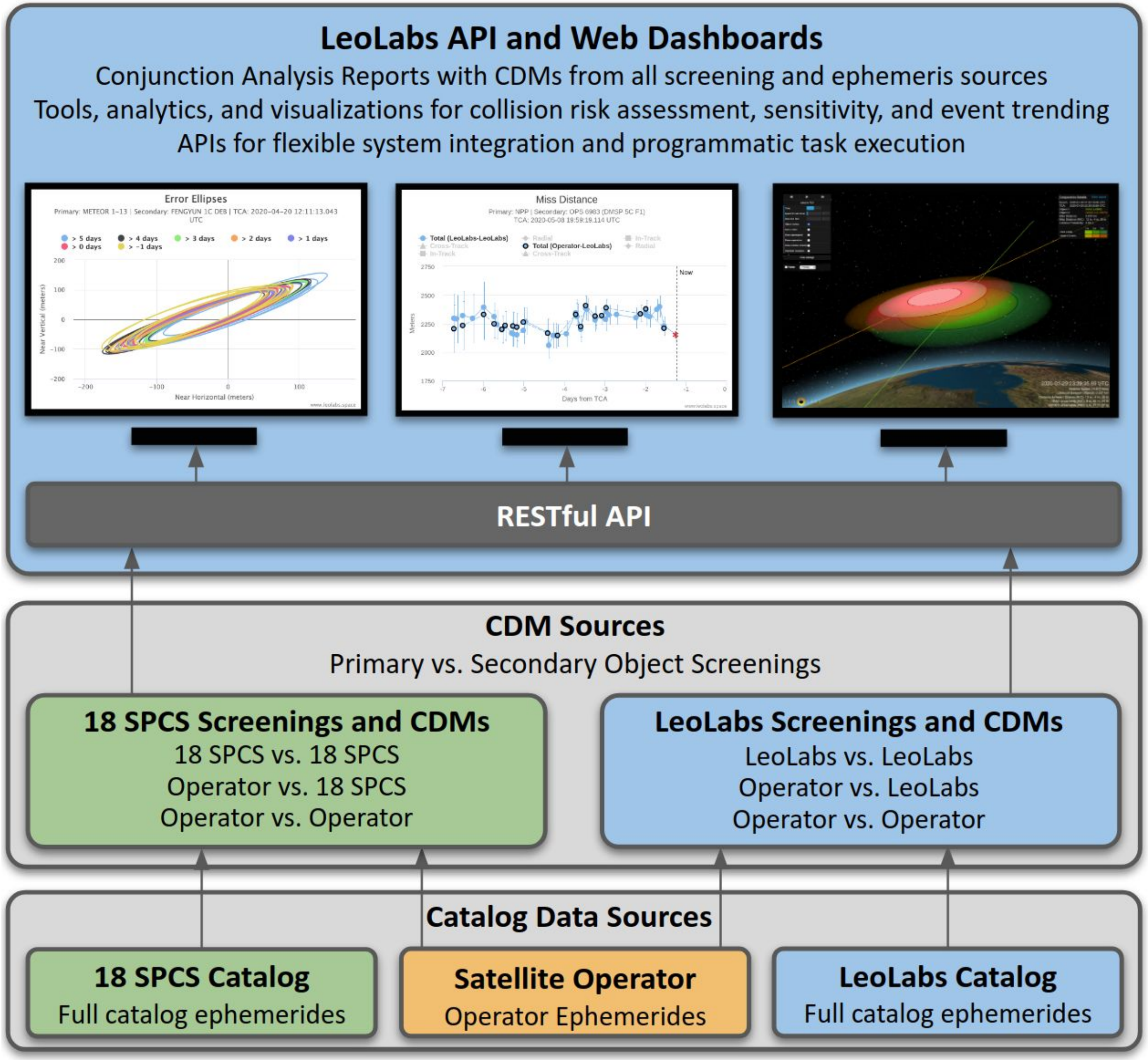
✔ LeoLabs takes calculated risks to build new radars. *The risks are not placed on customers.*

- US Defense Space Sector
- US Civil Space Sector
- US Regulatory Sector
- US Commercial Sector
- Allied Space Sectors
- Insurance Sector

LeoLabs System Architecture



LeoLabs Collision Avoidance



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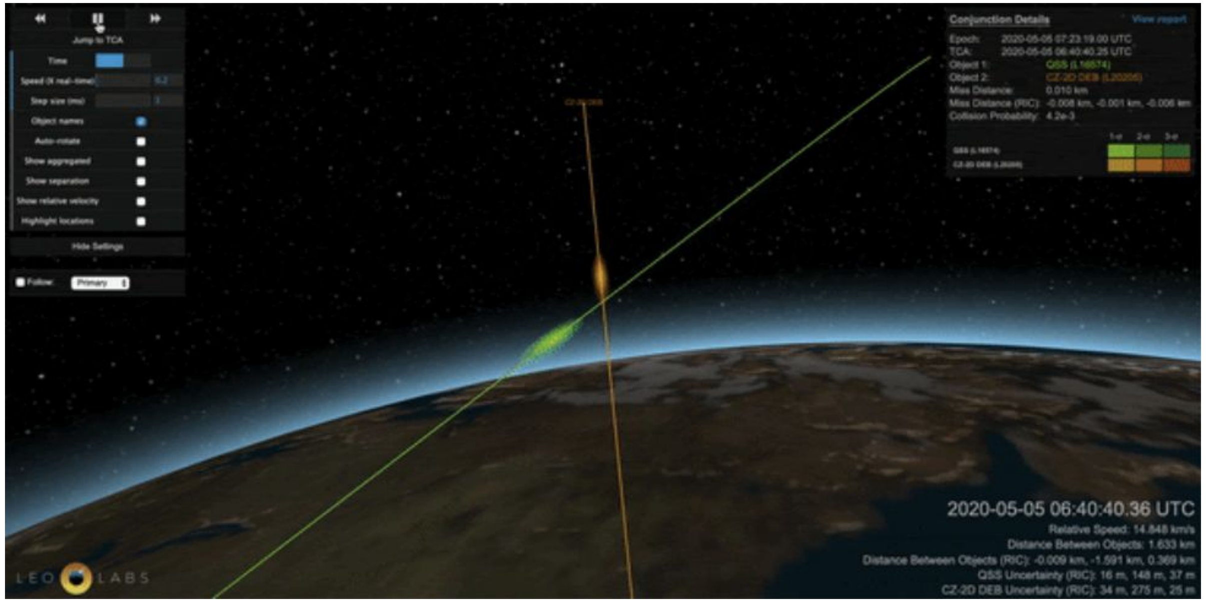
Collision Avoidance

- How close will two objects come?
  - Miss Distance
  - Time of Closest Approach
- What is the likelihood that the objects will collide?
  - Object Sizes
  - Uncertainties
  - Probability of Collision
- What is the potential consequence if the objects do collide?
  - Mass, Velocity, Orbit location, Active Satellites around, …
- Should I maneuver? If so, where?
  - Would like the probability of relative position being outside of some fixed region to be as high as possible $\Pr\{\|\mathbf{r}\| \geq a\} \geq 1 - \epsilon,$



IRAS - GGSE-4 Conjunction Example

https://medium.com/@leolabs_space/the-iras-ggse-4-close-approach-a99de19c1ed9

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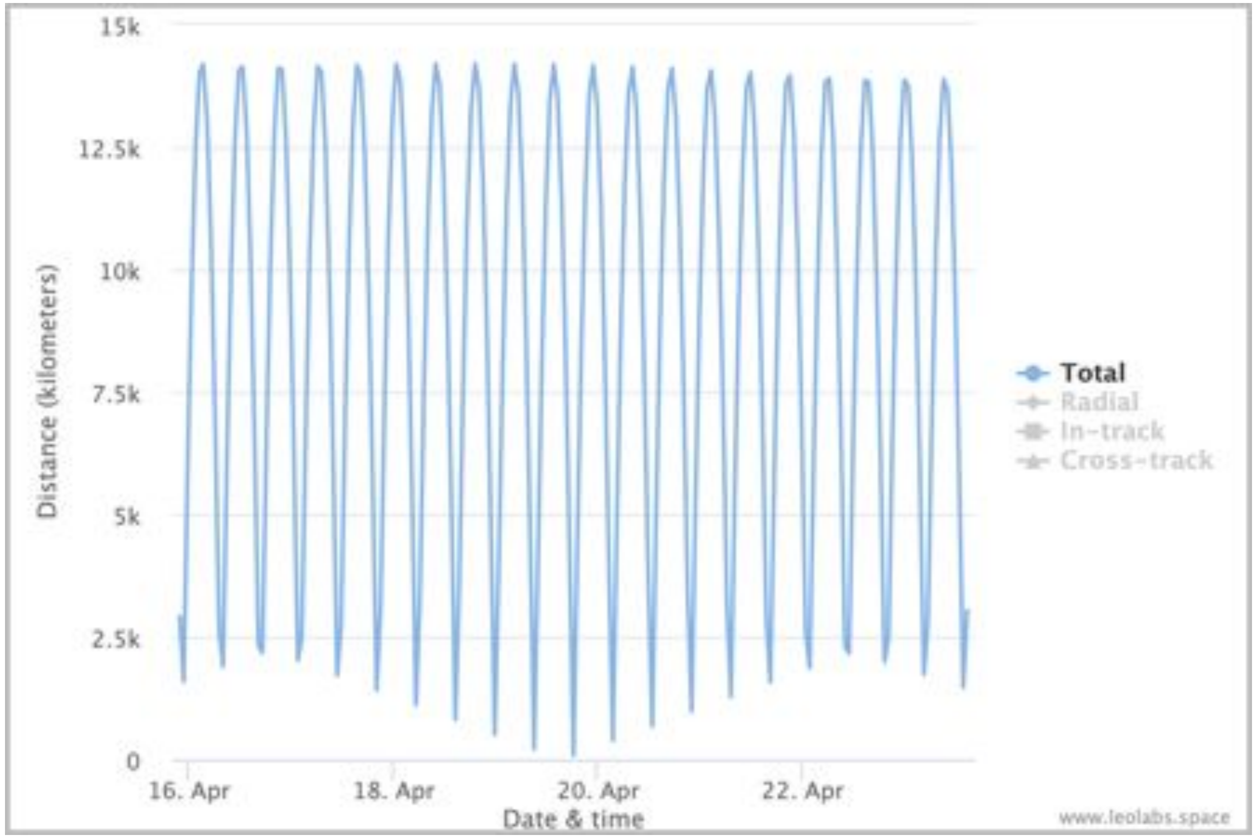
Collision Consequence

- Conjunctions should be measured by their potential impacts
  - To the environment, the lifetime of any debris created
  - To active satellites, human spaceflight
  - Space sustainability ratings

Center of Cluster (Span)	# of Objects and Mass (kg)	PC/yr and Probability of First Collision by 2019	Mass Involved in Typical Collision	Debris Generated from Collision Trackable (LNT)	Comments
775 km (60)	101 ~100,000	~1/400 4%	~1,600 – 2,800 kg	~4,500 (~60,000)	**Most operational satellites affected**
850 km (45)	75 ~208,000	~1/800 1%	~6,000 – 18,000 kg	~16,000 (~200,000)	**Most consequential events**
975 km (115)	314 ~335,000	~1/90 11%	~1,600 – 2,800 kg	~4,500 (~60,000)	**Most likely events**

Mcknight, 2019

Walk-in between Adeos and Cosmos 1354 – large defunct objects



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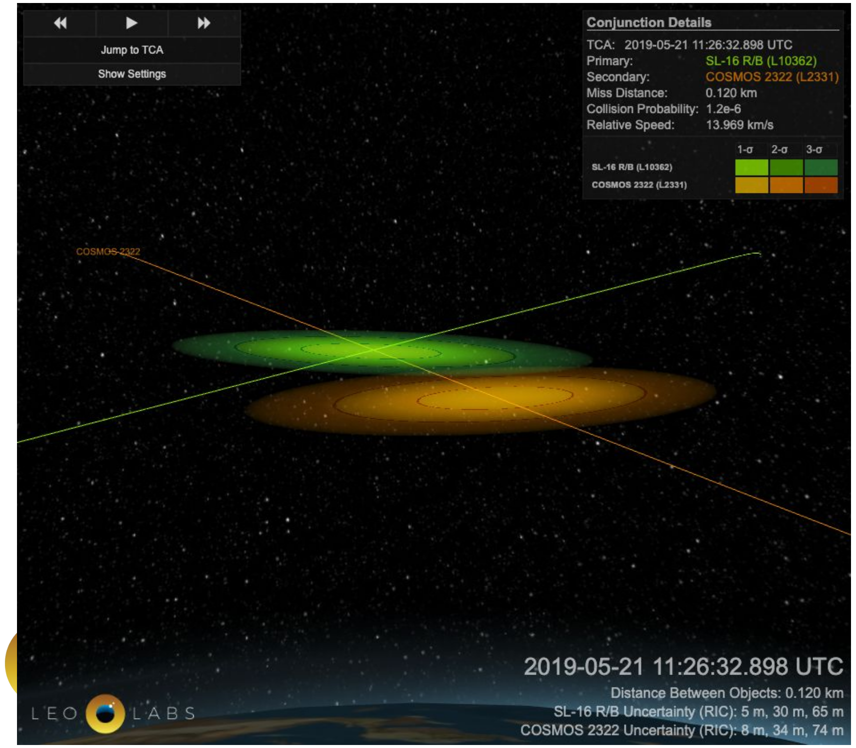
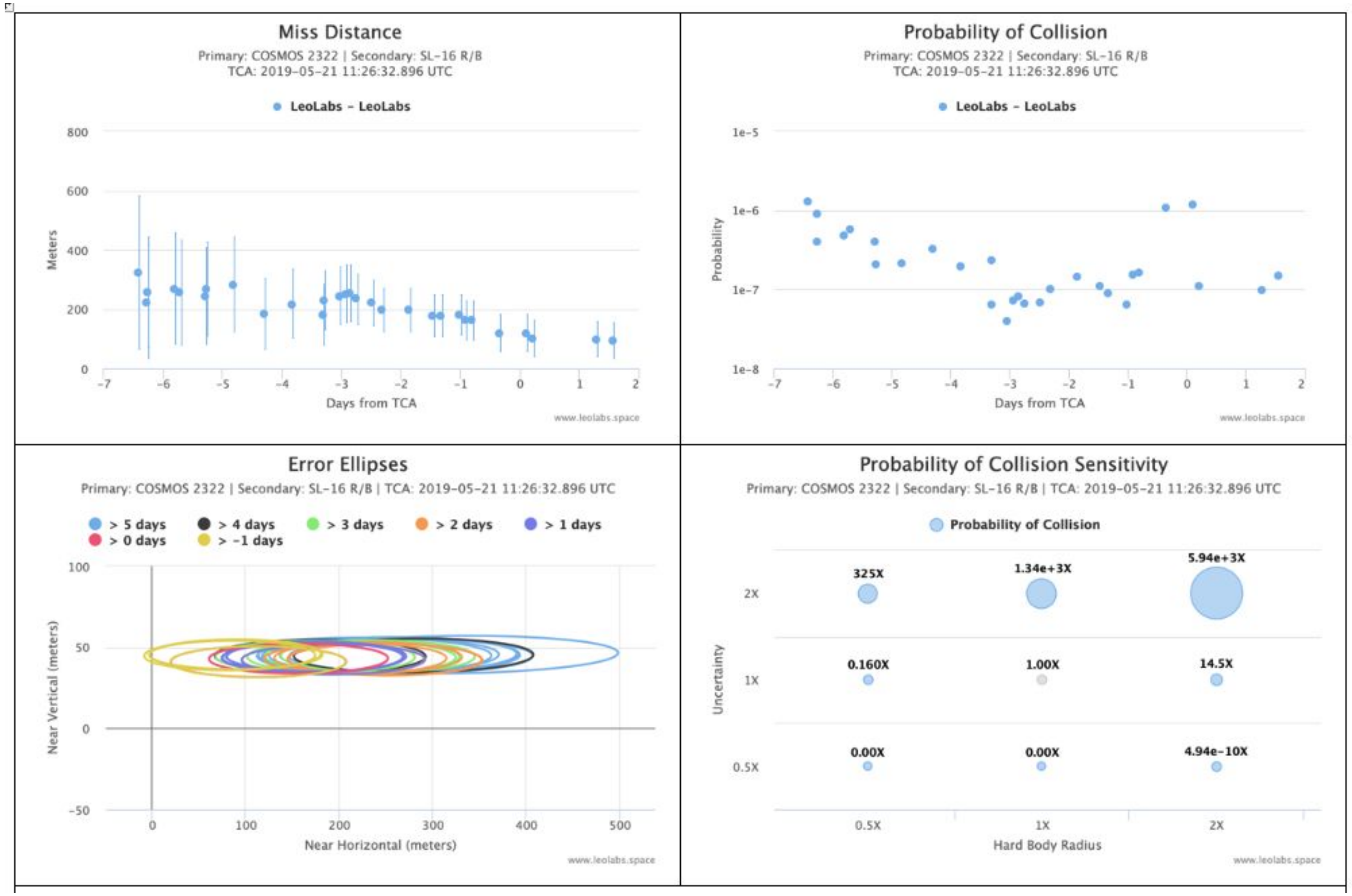
Example: Two Large Defunct Objects (S/L-16 R/B)

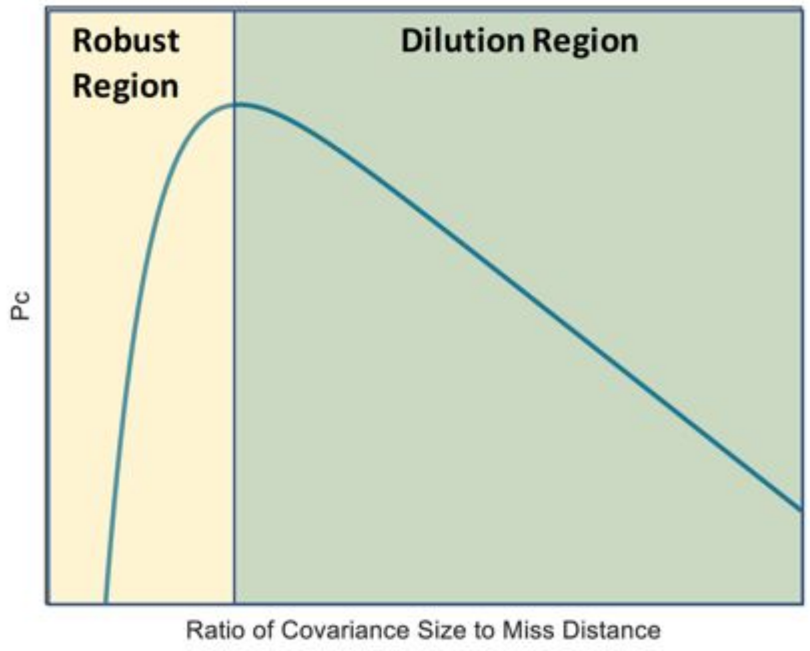
- Combined mass of over 11,000 kg
- Repeated close encounters every ~2 months
    - Will repeat over lifetime of objects
- 14 km/s closing speed
- 95 meter miss distance
- Extreme sensitivity to HBR and uncertainty used in calculations





Importance of data: Information Dilution

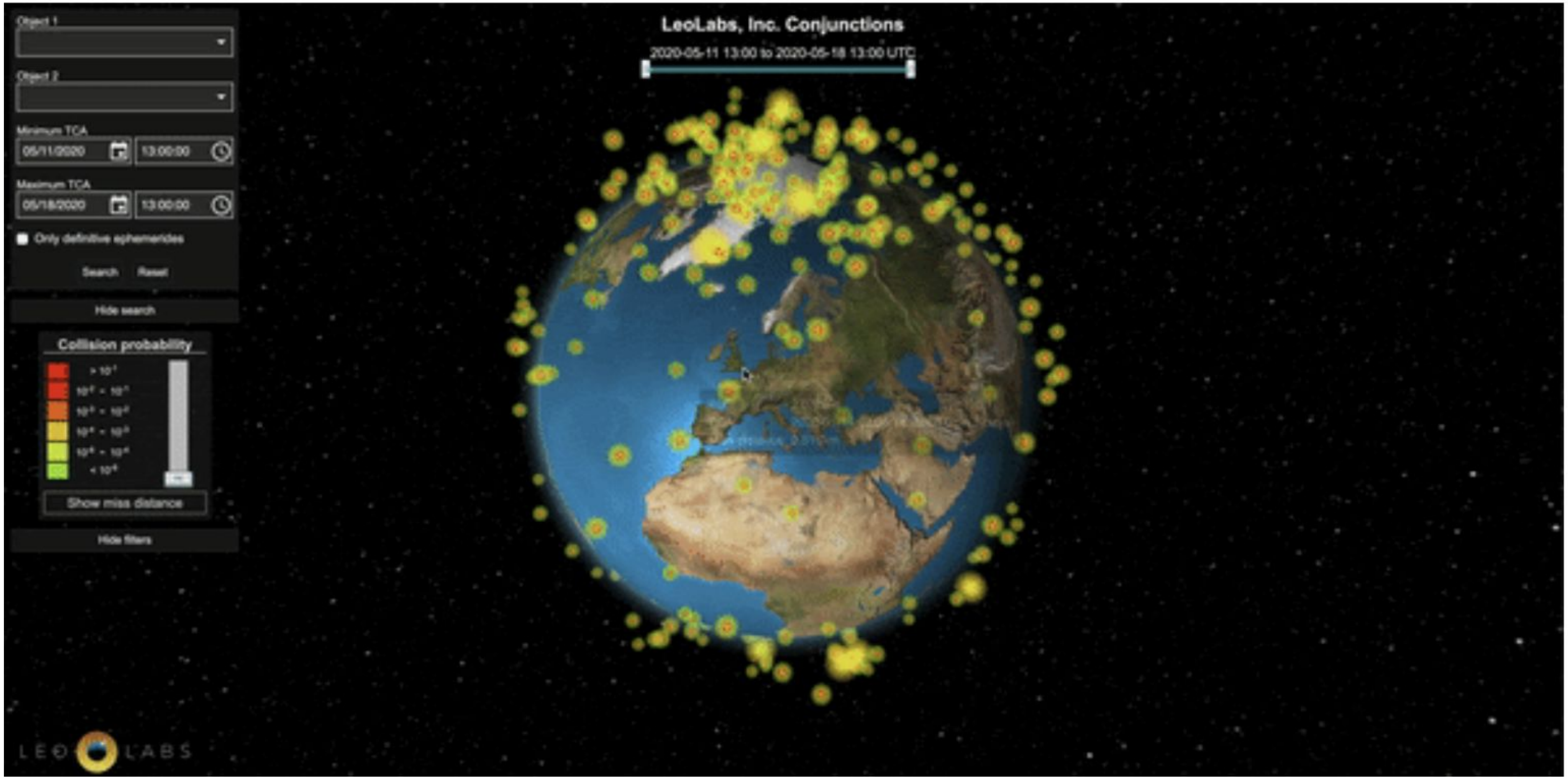
- **Probability of collision** varies with size of uncertainty on position of object
  - If uncertainties are large, probability of collision goes to zero
- Aleatory vs. epistemic knowledge:
  - Uncertainty represents imperfect knowledge rather than randomness
- Bottom line
  - Need good data to ensure that Pc is accurately estimated



https://platform.leolabs.space/visualizations/conjunctions/stream

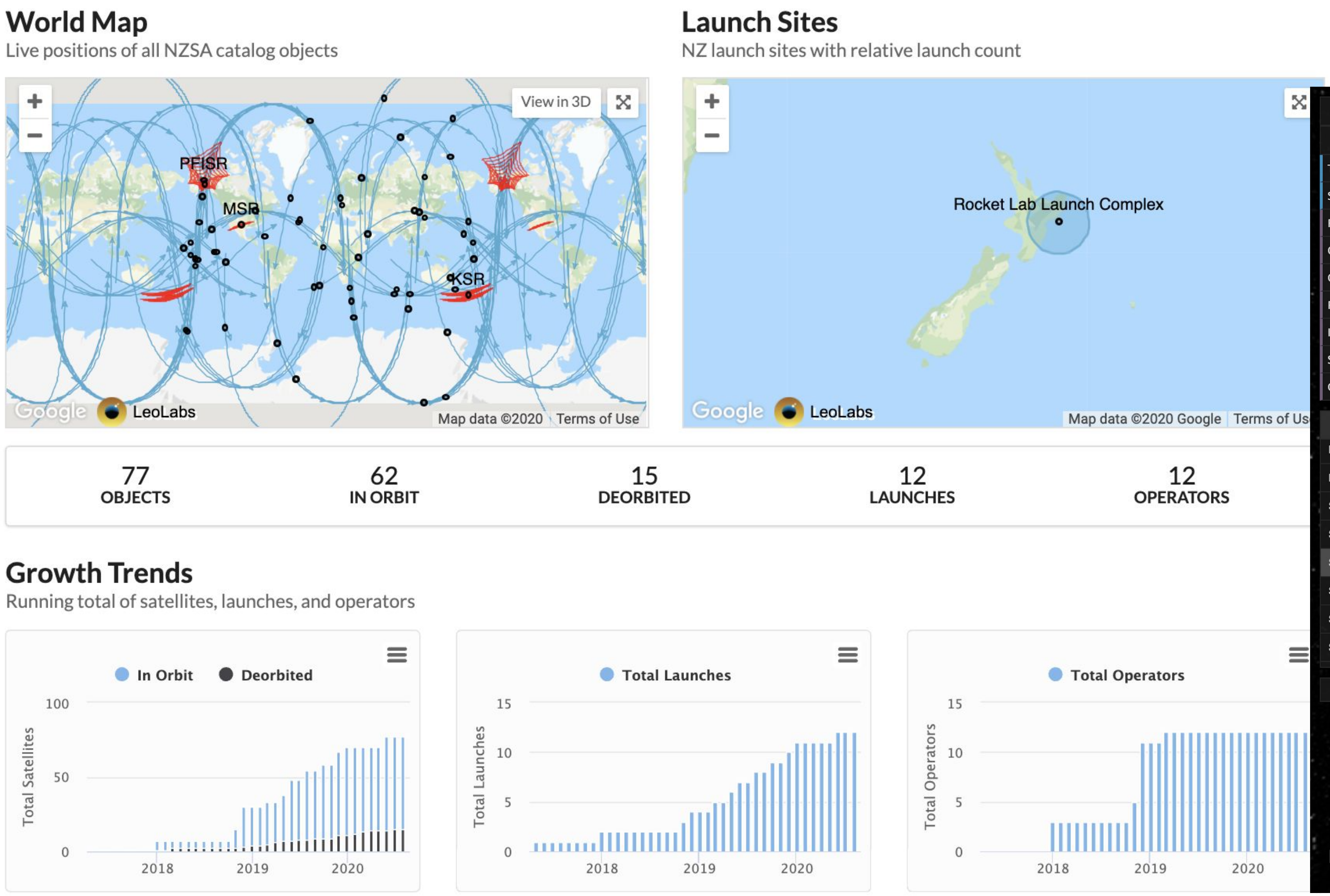
Continuous Assessment of Risk in Orbit

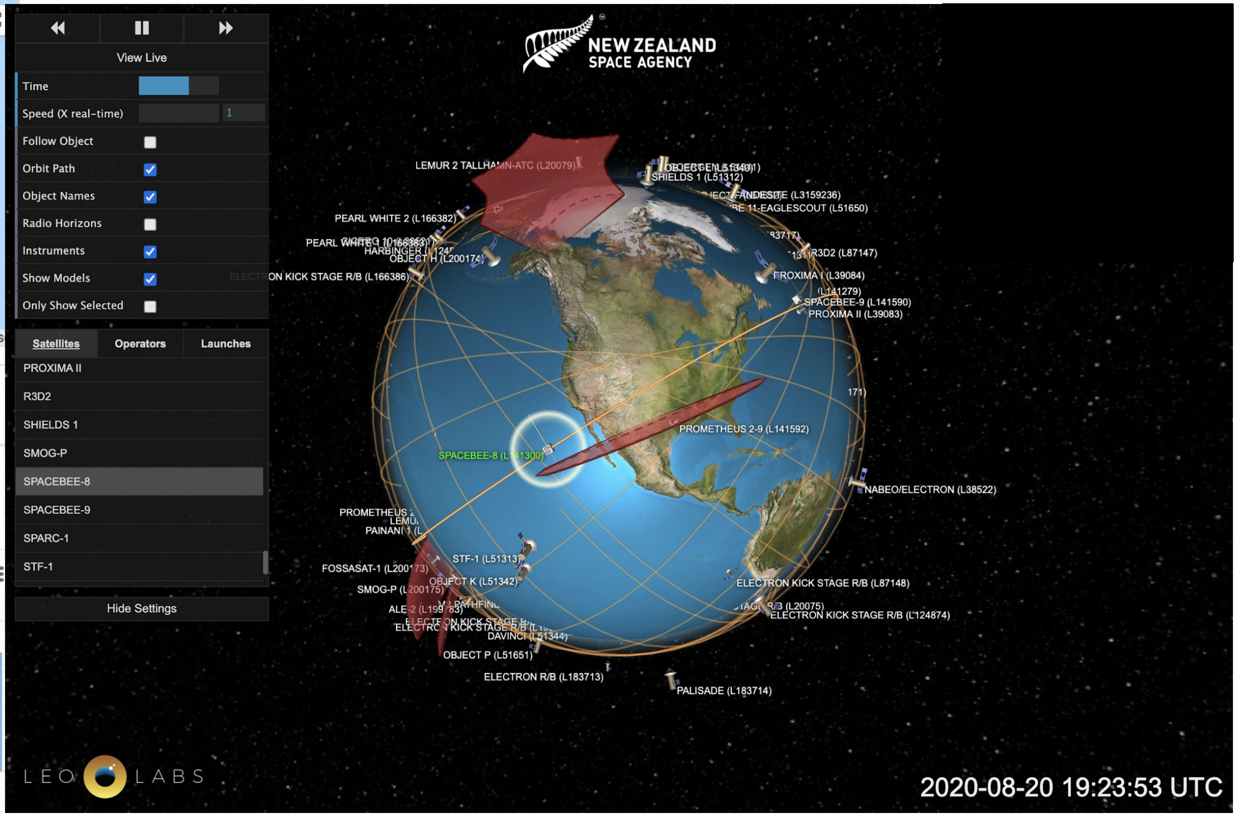
Real-Time On-Demand Streaming Actionable



Regulatory and Compliance Monitoring

Space Sustainability starts with actionable, transparent, and real-time data

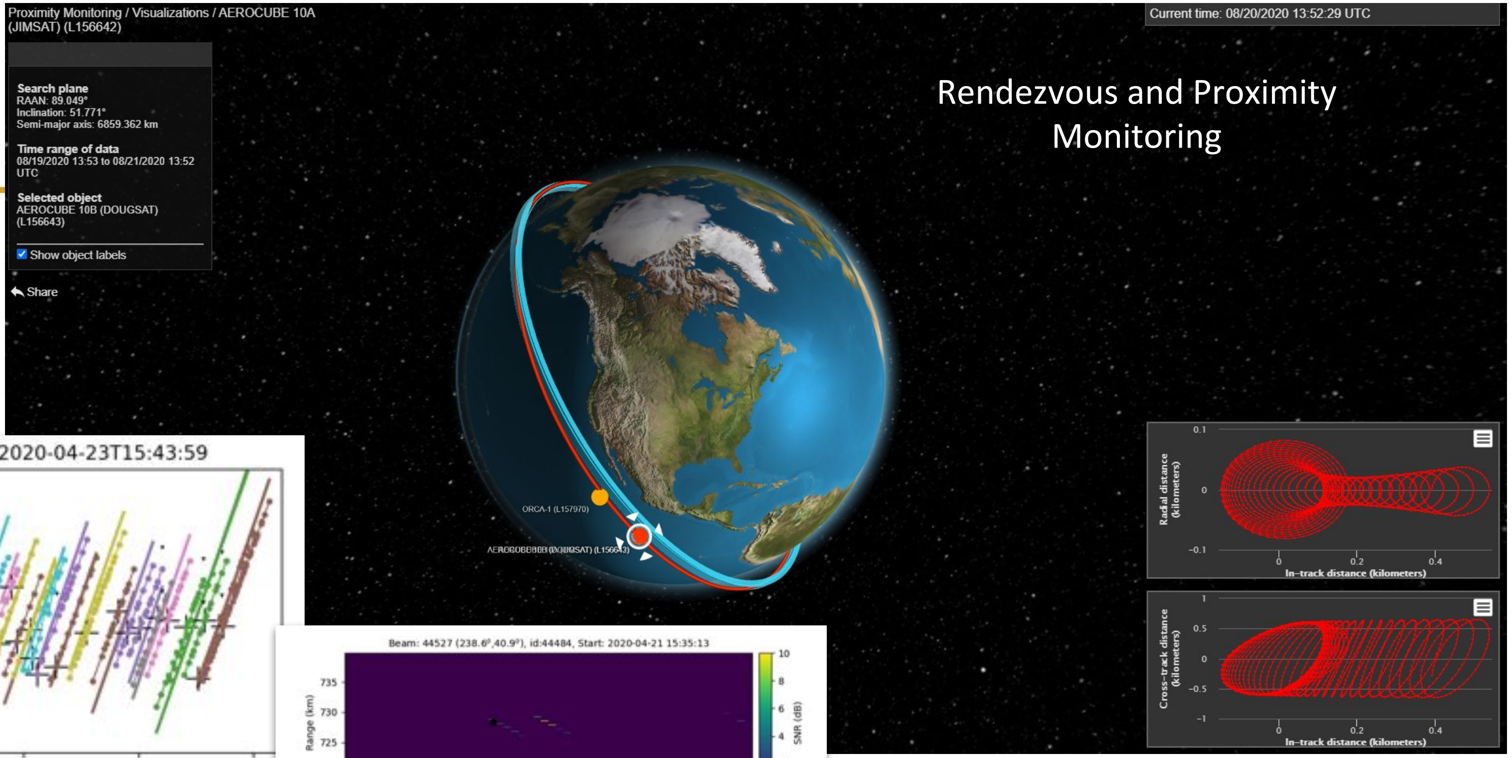


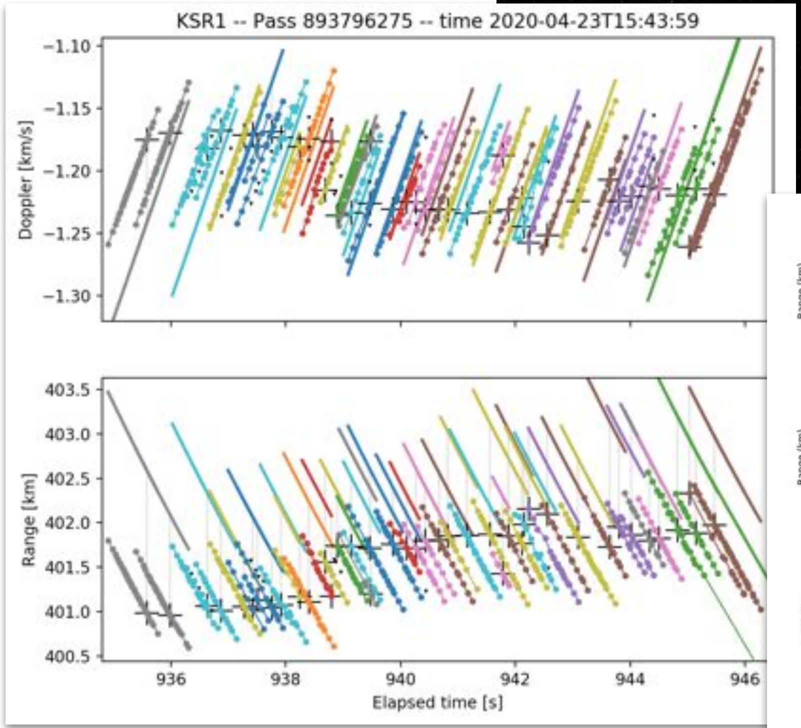


Analytics and Insights

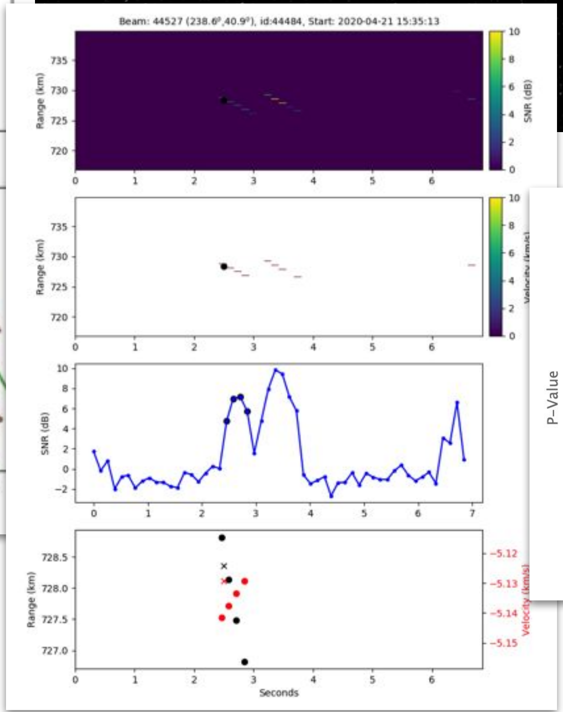
SSA Challenges Today

- Rendezvous and Proximity Operations
- Launches of 50-100 satellites
- Satellites deploying satellites
- Maneuvers and attitude changes
- Breakups, collisions, and weapons tests

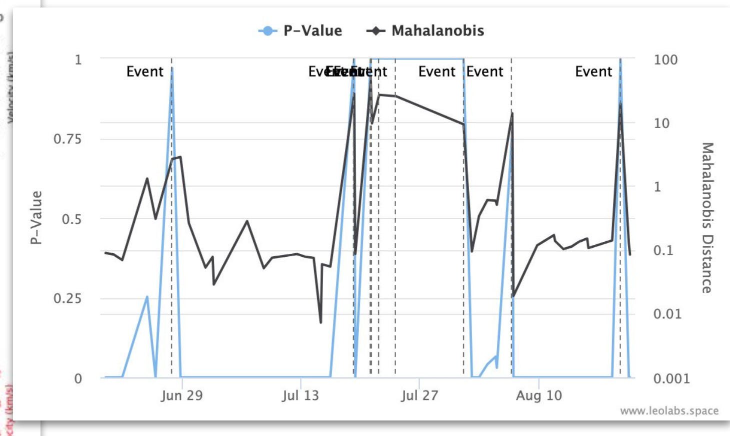




Starlink tracking - 60 satellites



Aerocube sphere deployment



Maneuver Detection

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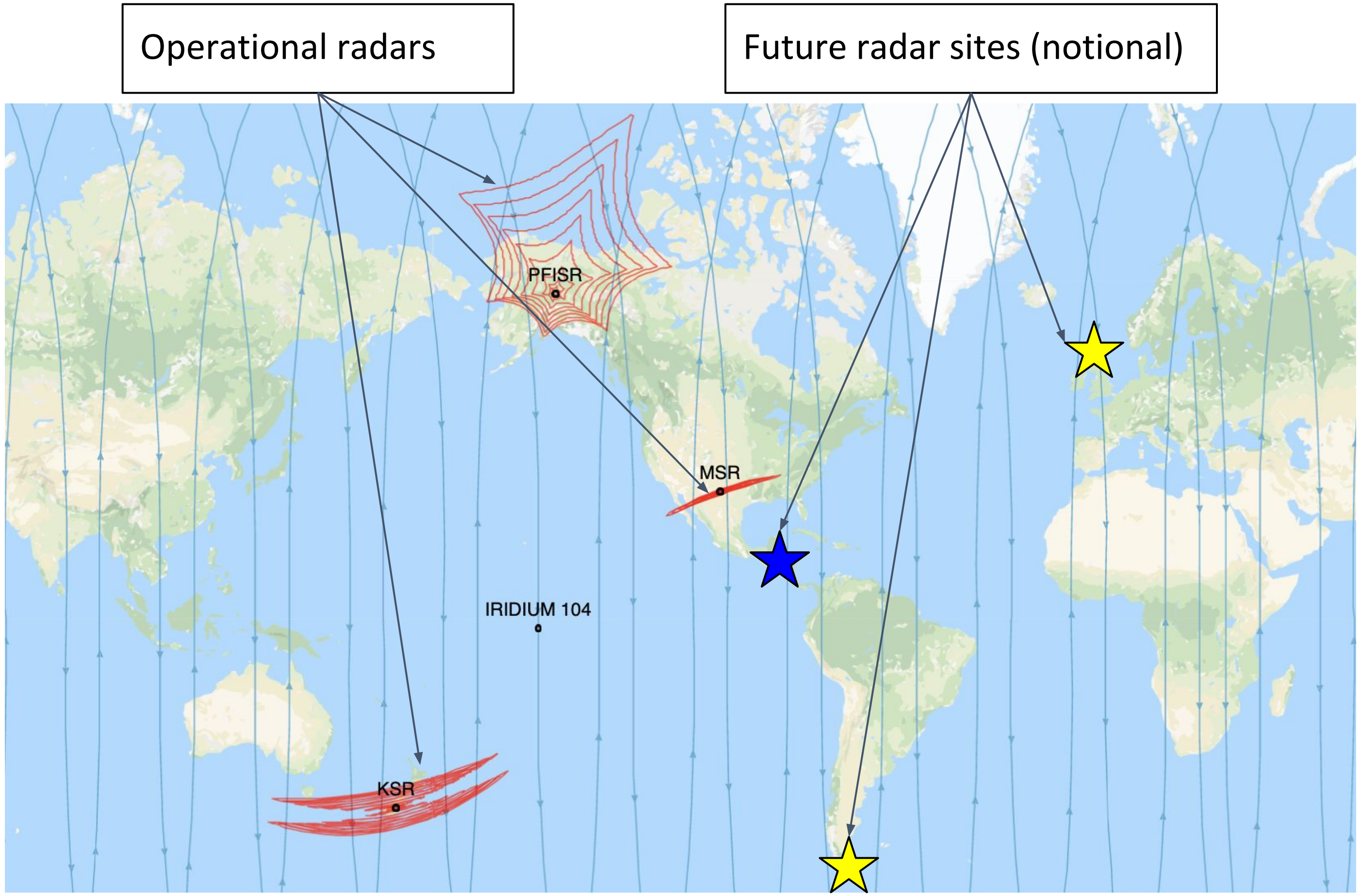
The Near Future: LeoLabs Transformational Radar Network



- Distributed architecture delivers unprecedented capabilities:
  - Insights on new incidents in 4 hours or less
  - Coverage from the Southern Hemisphere and the Equator
  - Small debris and satellites
- 3 radars operating today
- 6 radar network will be complete by 2022
- Service delivered today:
  - >500,000 measurements per day
  - >13,000 state vector updates per day
  - >800,000+ high-risk conjunction data messages per day
  - up to 6 revisits per day on high-interest objects

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Conclusions / Key Take-Aways

LEO will become a trafficked environment

- There is a need for modern infrastructure services to support the growing space industry
- The needs of stakeholders will evolve as constellations of satellites are deployed

Actionable Data

- We need actionable data and insights to support LEO stakeholders
- We need to address the sparse data problem through a distributed network with global coverage

Transparency

- The best way to ensure space sustainability is through active monitoring
- When risks are exposed, quantified, and well-understood, behavior and policy will evolve

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