August - September 2025

Sustainability in Orbit: Traffic and Risk Report

Women In Data™ Datathon

Enhancing Space Situational Awareness

Presented By: Cosmic Insights

Meet the **Cosmic Insights** team

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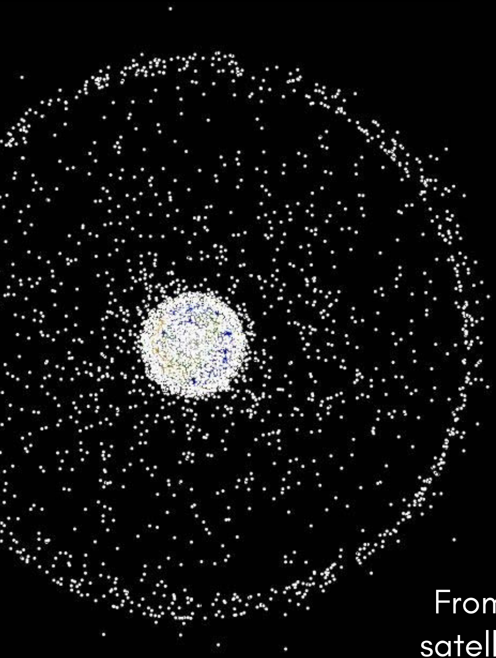
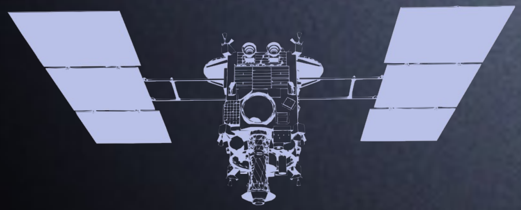
IT'S GETTING CROWDED



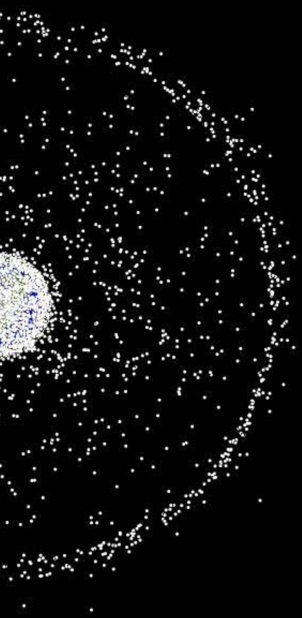


This year, more than **1,200** satellites were launched from January to April. During this period, SpaceX led with **573** Starlink satellites.

In addition to new launches, inactive satellites in low Earth orbit can remain in orbit for **years to centuries**.

From **2020** to **2025**, satellites operating in Earth orbit grew from **3,371** to **15,330**.

How crowded, exactly?



While the global space object catalog tracks thousands of satellites, rocket bodies, and debris fragments, **open data on orbital traffic** remains too fragmented and complex for decision-making.

Stakeholders need **accessible, evidence-based insights** on:

- Where orbital congestion is most severe
- How debris from past launches and collisions continues to shape current risks
- What the conjunction risk landscape looks like today, and how it may evolve as new payloads and constellations are deployed

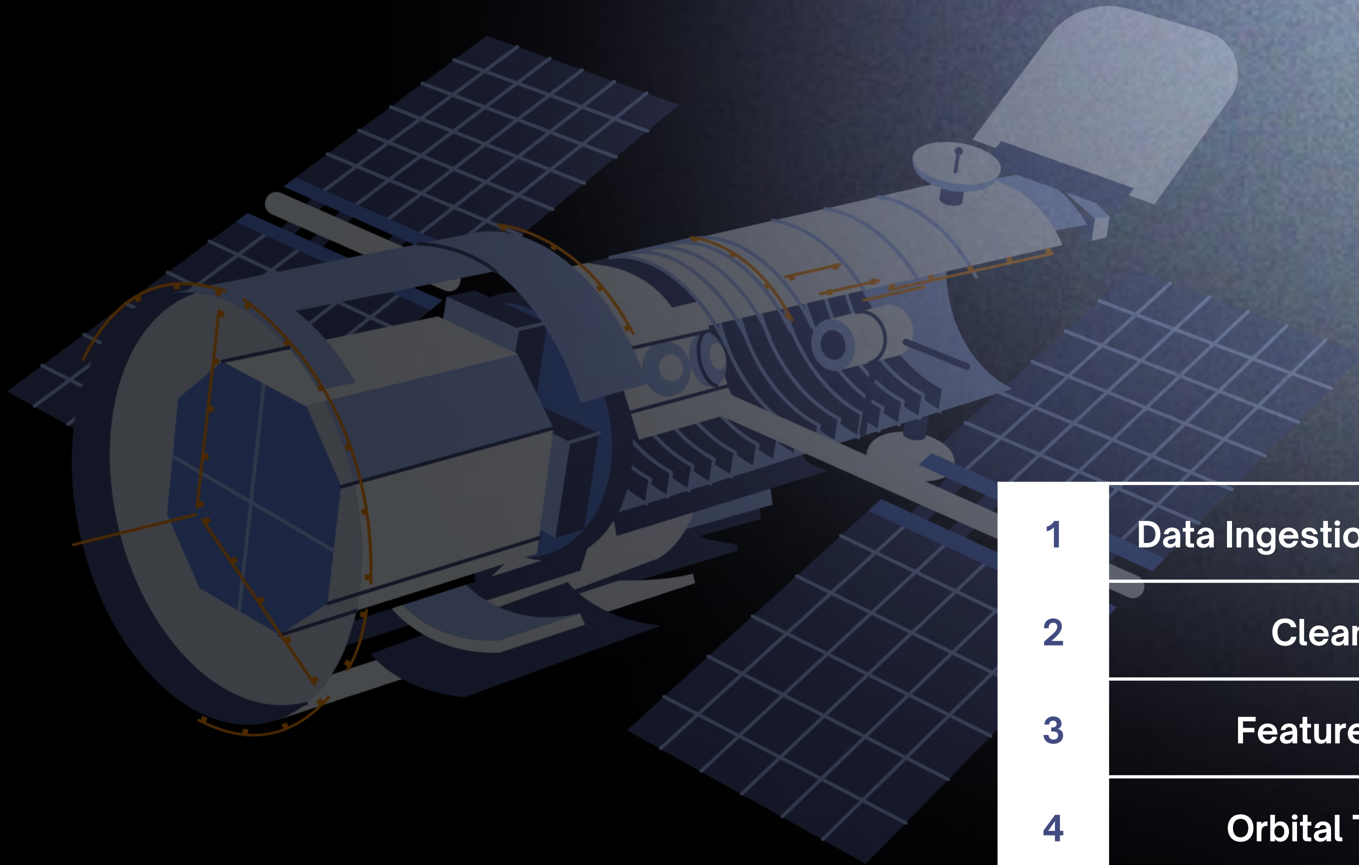
OBJECTIVE

Our **orbital traffic and risk report** aims to support policymakers in making well-informed decisions regarding space safety and environmental regulations.

May 26, 1959: First session of the Legal Committee on Peaceful Uses of Outer Space, United Nations Headquarters

STAKEHOLDERS

	Internal Stakeholder	External Stakeholder	Priority Stakeholder
Industry Companies, Satellite Owners/Operators		✓	
Space Policymakers	✓		✓
Government and International Agencies	✓		



APPROACH

1	Data Ingestion, Definitions & Research
2	Cleaning & Processing
3	Feature Engineering & EDA
4	Orbital Traffic Density Maps
5	Conjunction Risk Analysis & Modeling

TOOLS

Sourcing & Defining
Unified Data Library,
Space-Track

Cleaning, Processing & EDA
Python, Jupyter Notebook,
Google Colab

Modeling
Python (spg4)

In-Depth Analysis
Python (matplotlib),
Tableau

Our Datasets

18TH SDS ELEMENT SETS (ELSETS)

18th Space Defense Squadron (SDS):
the primary U.S. Space Force unit for tracking deep space objects

- two-line element sets (TLEs) are the official, high-accuracy orbital parameters for tracked objects

SPACE TRACK SATELLITE CATALOG (SATCAT)

U.S. Space Command, with the **Space Surveillance Network**:
a global set of radar, optical, and space-based sensors

- each entry contains identification data, status, and orbital information such as TLEs

Cleaning + Processing

1

Downloaded **Jan-Aug 2025 Elset** data

Parsed JSON files into **parquet**

Created single dataset for initial cleaning

- 9M rows, 25 columns

2

Reduced dataset to get the **most current epoch** for each unique satellite number

- 29.7K objects

3

Joined processed dataset to SATCAT to gain meaningful categorical information about each satellite

Kept rows for objects listed in the satellite catalog

- 29.1K objects

Ready for EDA!

Feature Engineering + EDA

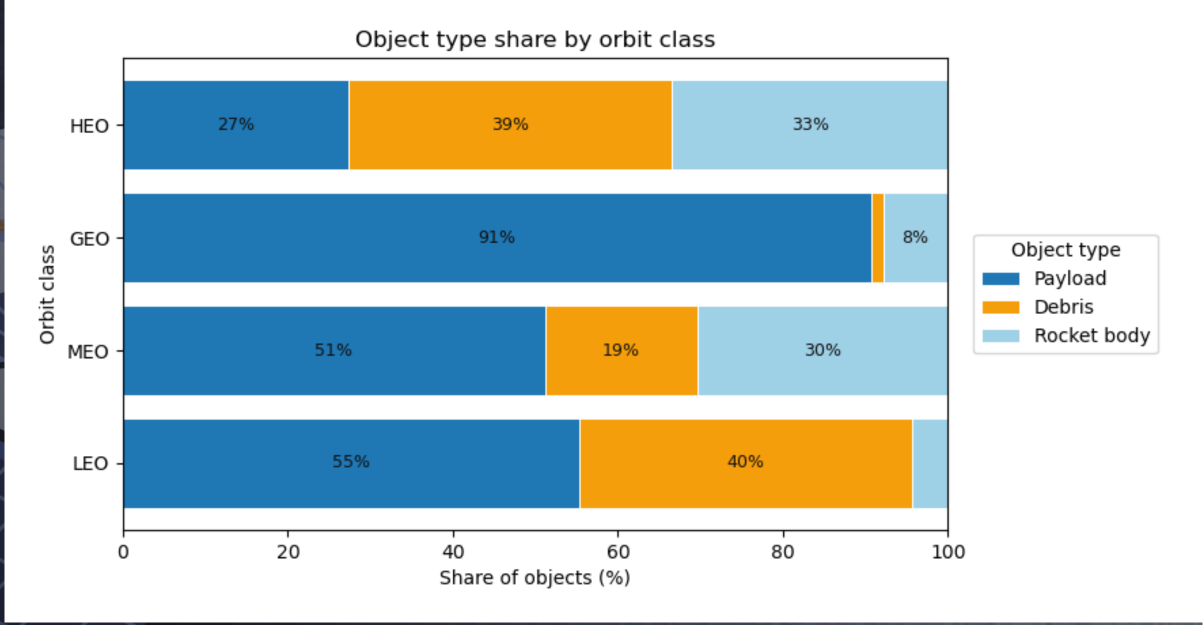
```
39  orbitClass
40  launchDecade
41  inclinationBand
42  eccClass
43  ageInYears
44  shell_idx_100km
45  shell_100km
46  shell_center_km
47  isDecayed
48  isOrbiting
49  isStarlink
50  isOneweb
51  isIridium
52  isConstellation
53  dwelling_alt_km
54  dwelling_alt_km_weighted
55  dwelling_shell_idx
56  dwelling_shell_100km
```

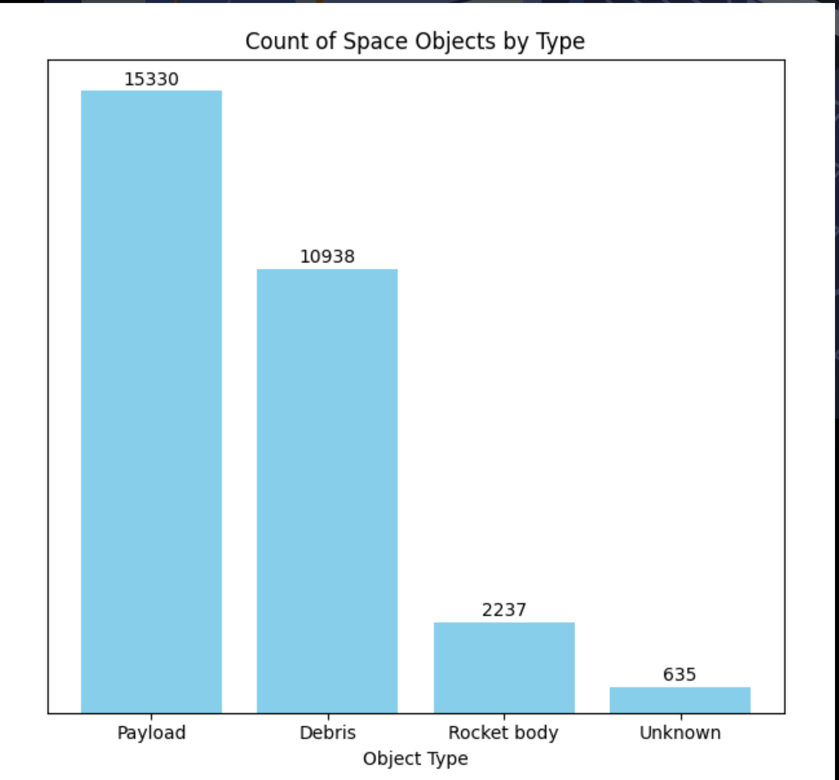
OUR FOCUS

What kinds of objects are in orbit?
Object count, owners

How crowded are the different orbits?
All objects vs. debris only

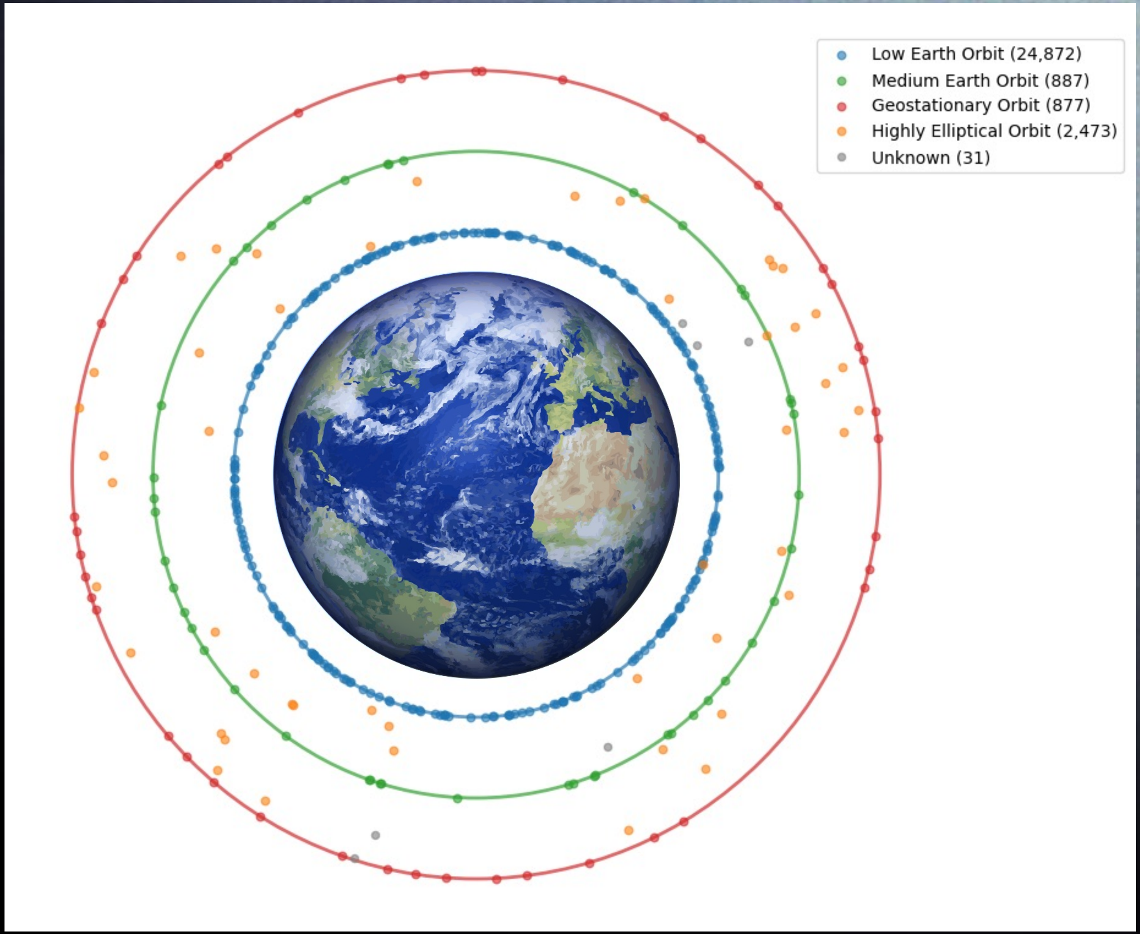
How have payload launches changed over time?
Biggest players in Earth's orbit



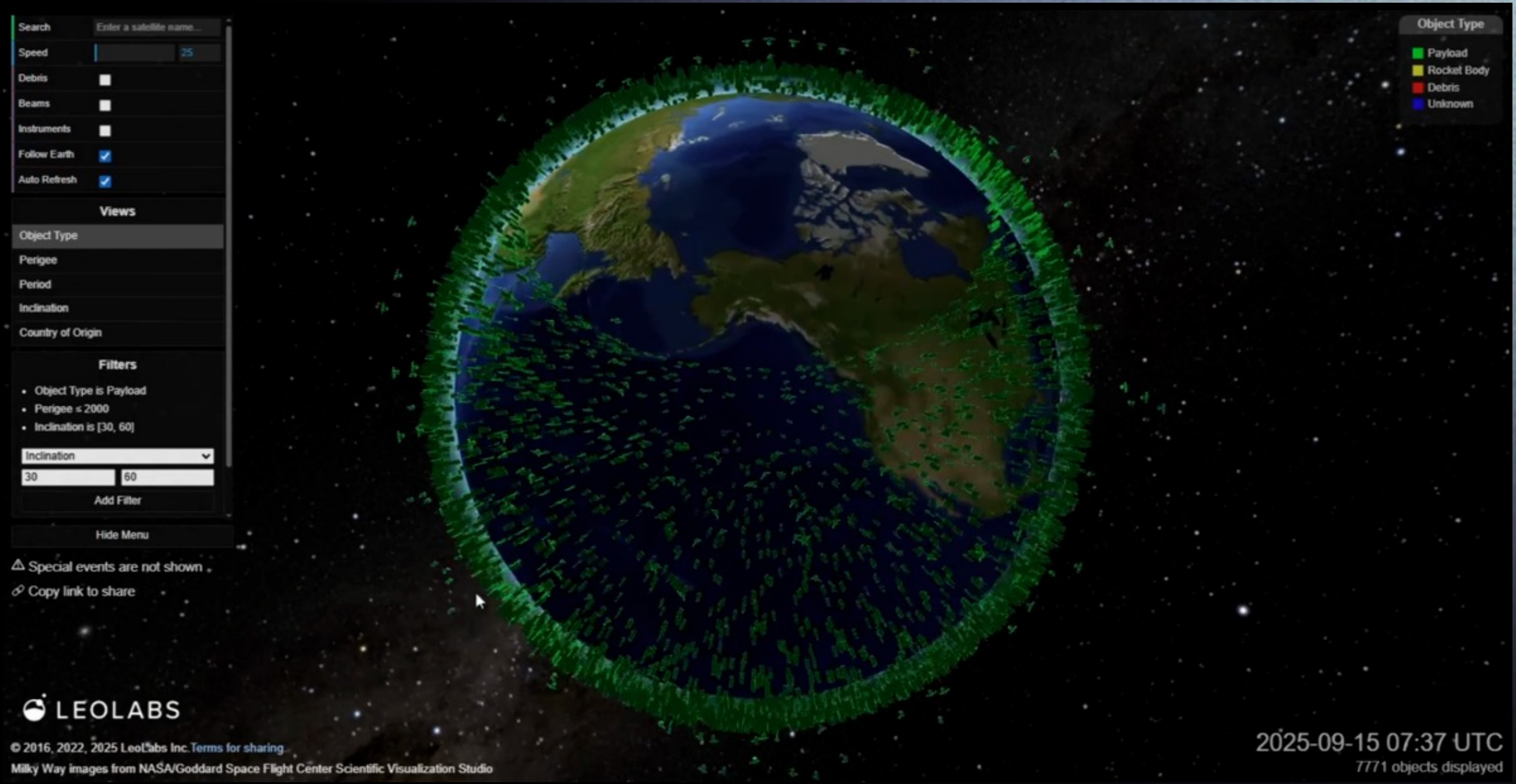


Exploratory Data Analysis

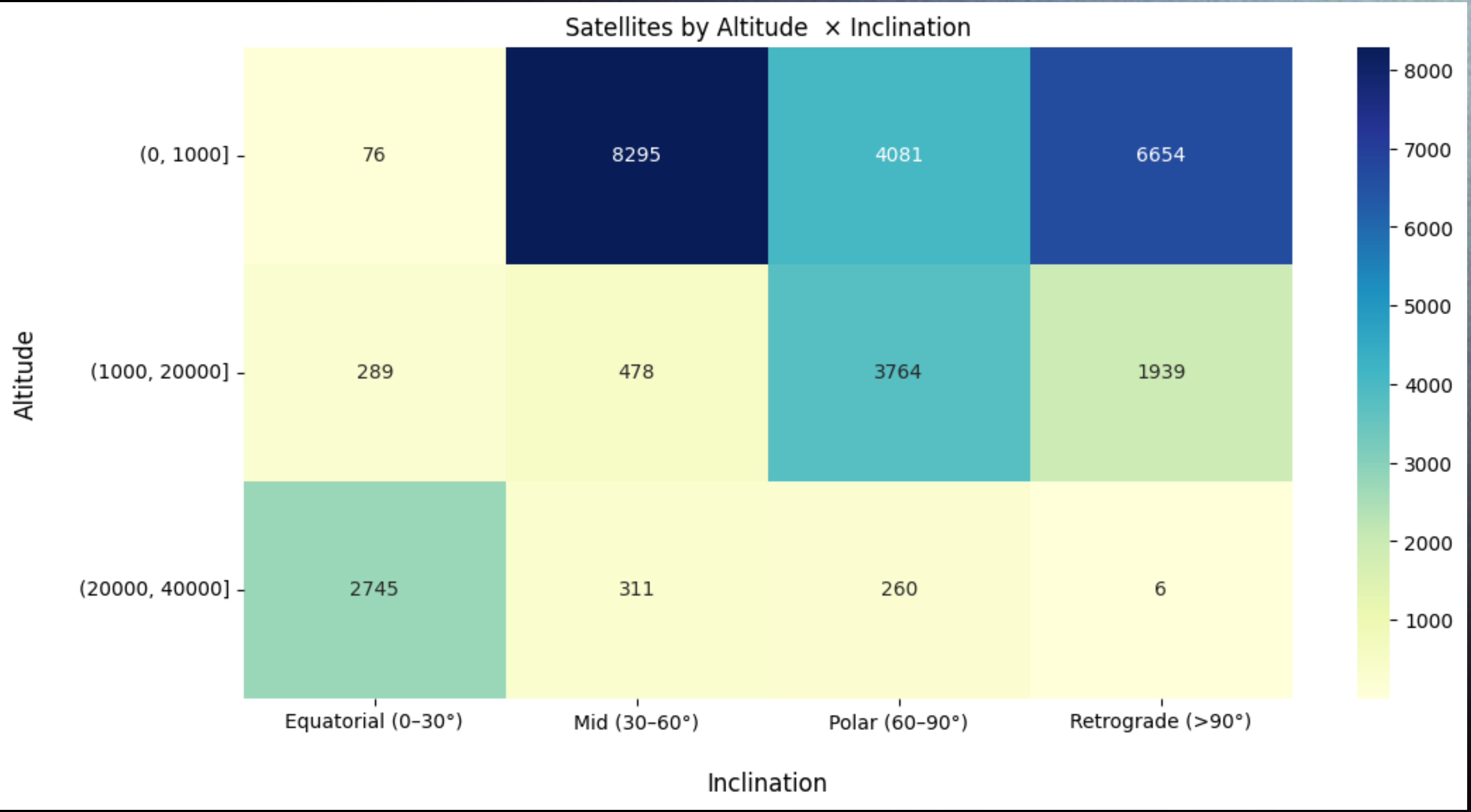
Satellite Orbit Distribution **Around Earth**



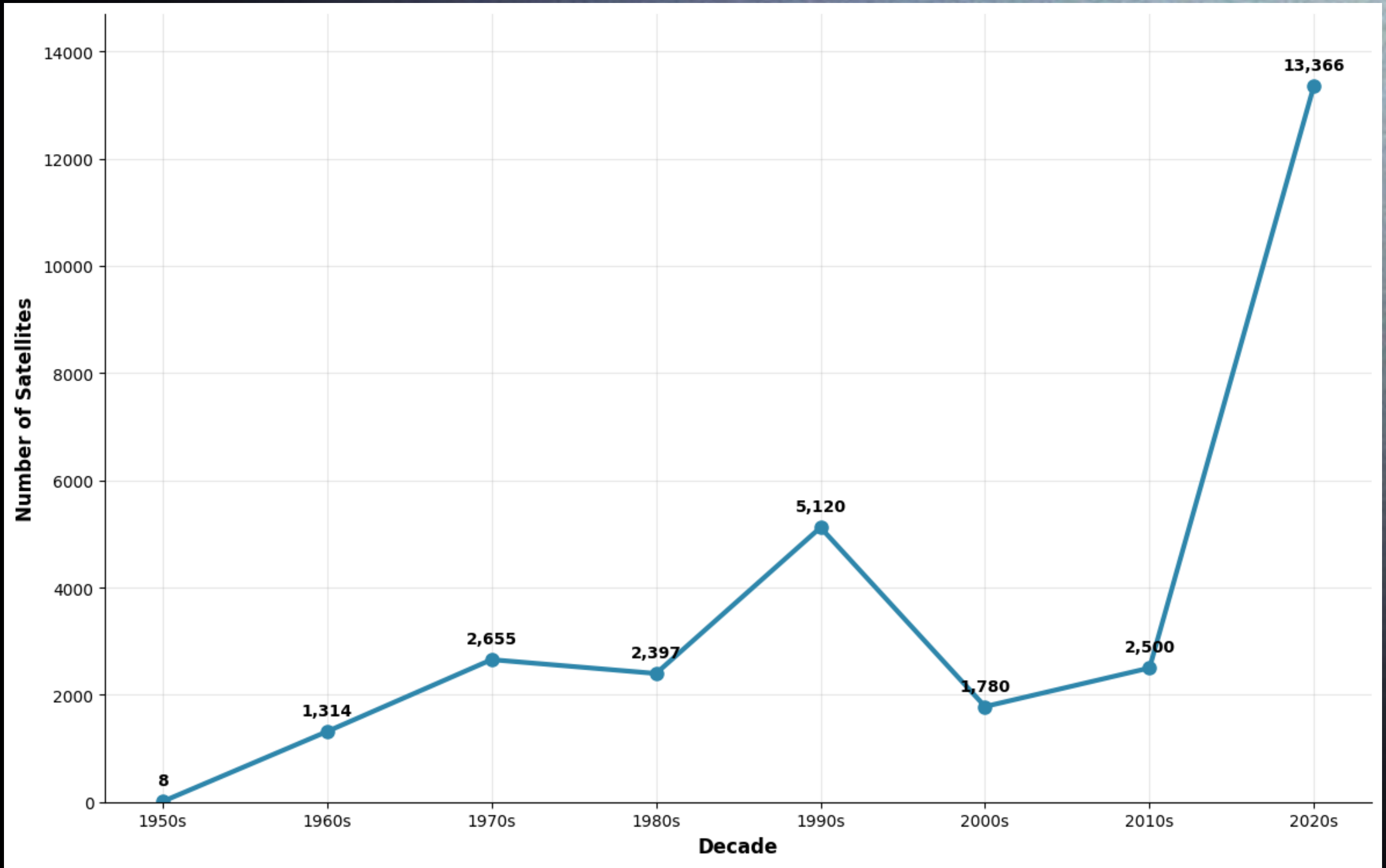
Exploratory Data Analysis

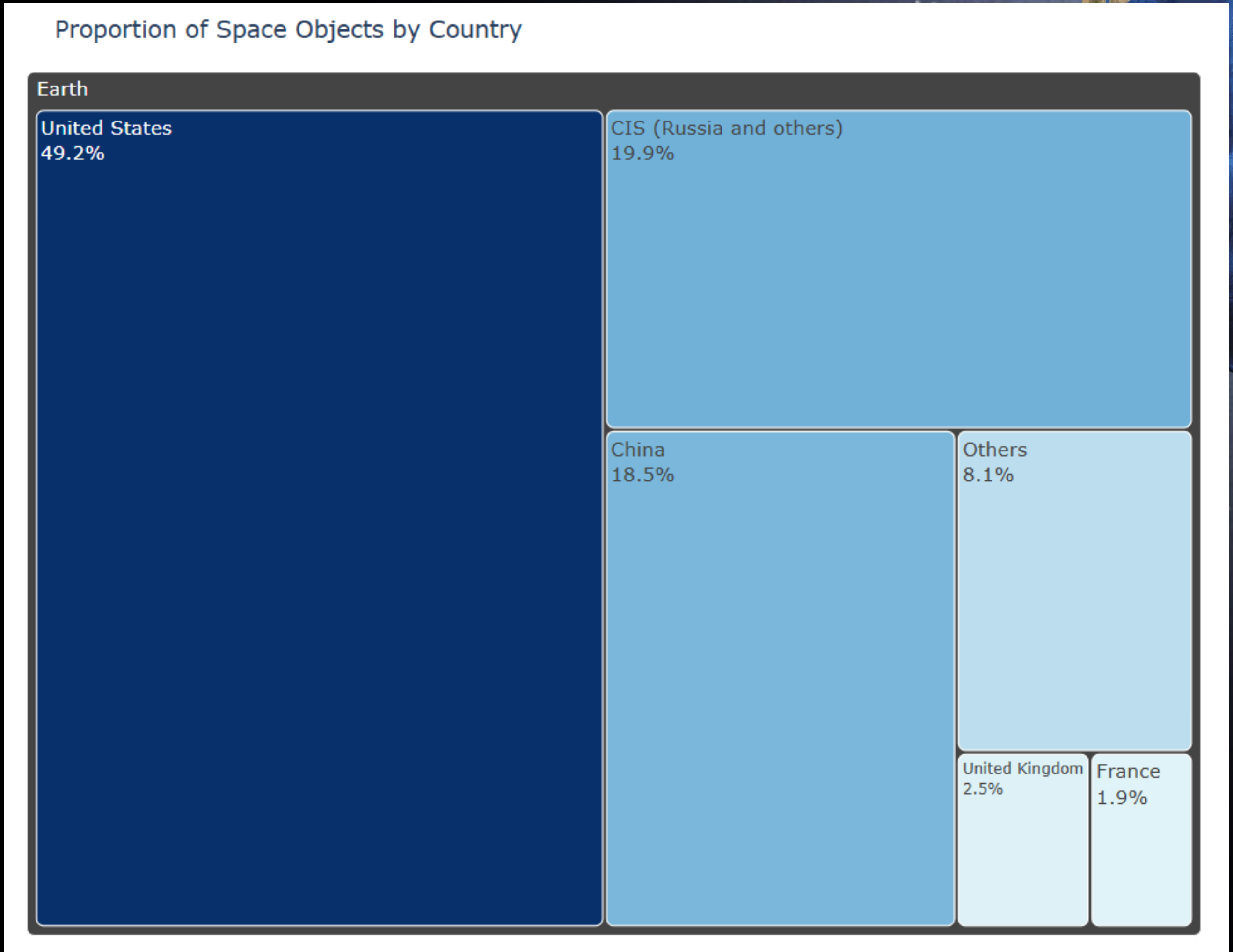


https://platform.leolabs.space/visualizations/leo#view=objectType;type=payload


Satellites by Altitude × Inclination
Altitude
(0, 1000]
(1000, 20000]
(20000, 40000]
76
8295
4081
6654
289
478
3764
1939
2745
311
260
6
Equatorial (0–30°)
Mid (30–60°)
Polar (60–90°)
Retrograde (>90°)
Inclination
8000
7000
6000
5000
4000
3000
2000
1000

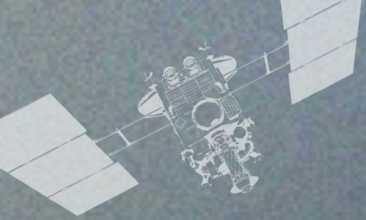
Launches per Decade

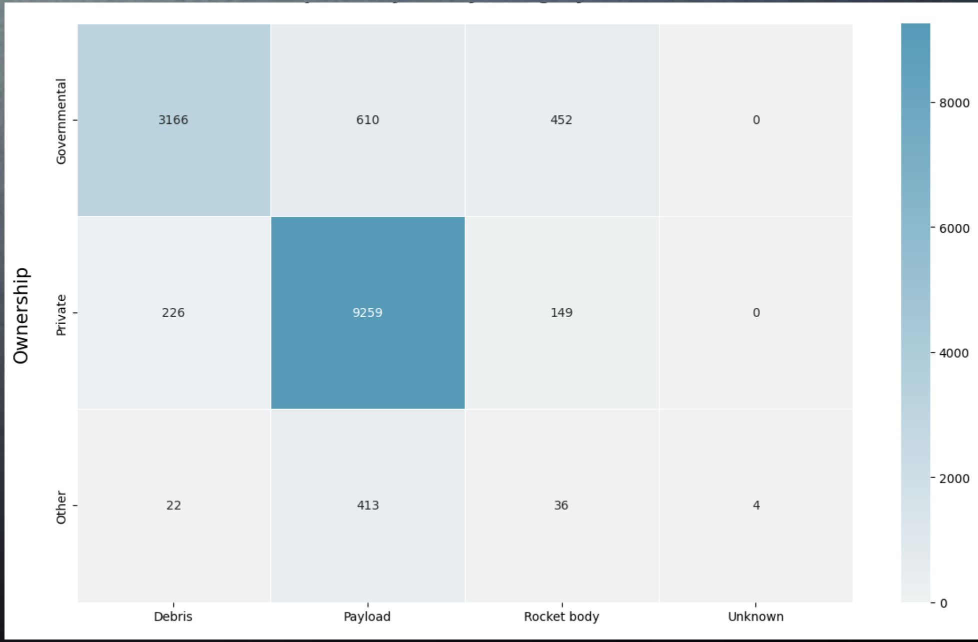




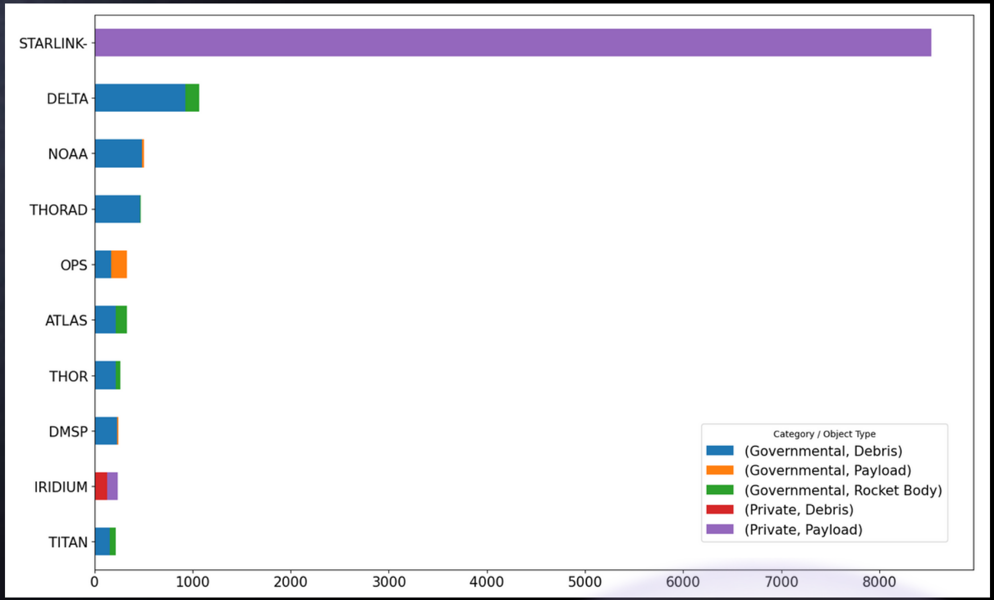
Biggest Players in Earth's Orbit

Exploratory Data Analysis





U.S. Space Objects by Ownership, 2025



Ownership by Program

Top 10 U.S. Programs

Exploratory Data Analysis

1. Payload is the most common space object across all orbits - **15330 items**.
2. The most populated orbit is LEO (Low Earth Orbit) - **85.35%** of all distribution.
3. Most objects are clustered on specific orbital planes at **30° - 60° angle** of that plane, relative to the equator.
4. Starting in the 2010s, the venture capital boom in the space sector has driven the overall trend of increasing satellites around Earth.
5. The U.S. is responsible for a majority (**49%**) of all tracked objects in space.
6. The private space program STARLINK is largely responsible for exponential growth in LEO.
7. Many older programs, like ATLAS, have generated significant debris.
8. The debris population can be traced to specific launch campaigns and programs from the past 60 years. The current debris problem is a legacy of operations that did not prioritize end-of-life disposal.

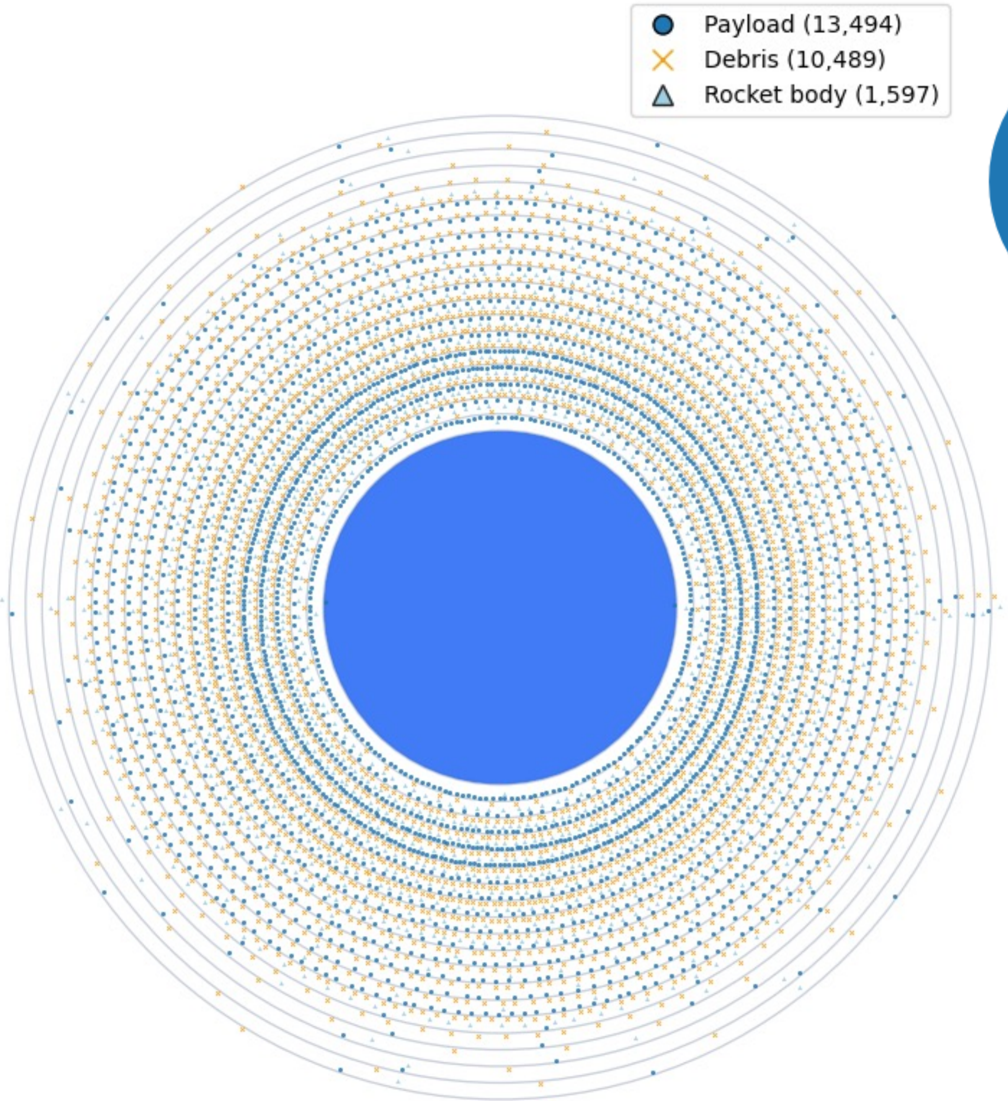
KEY FINDINGS

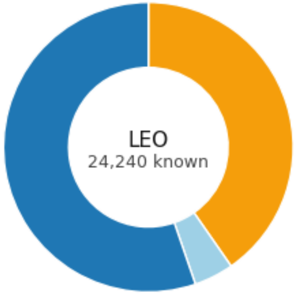
ORBITAL TRAFFIC

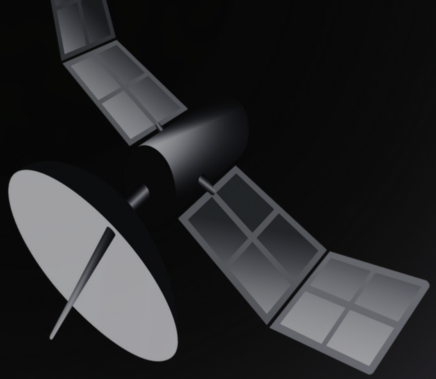
Where does orbital traffic concentrate?

Which orbital shells have the highest debris-to-payload density?

Where are constellation satellites located?



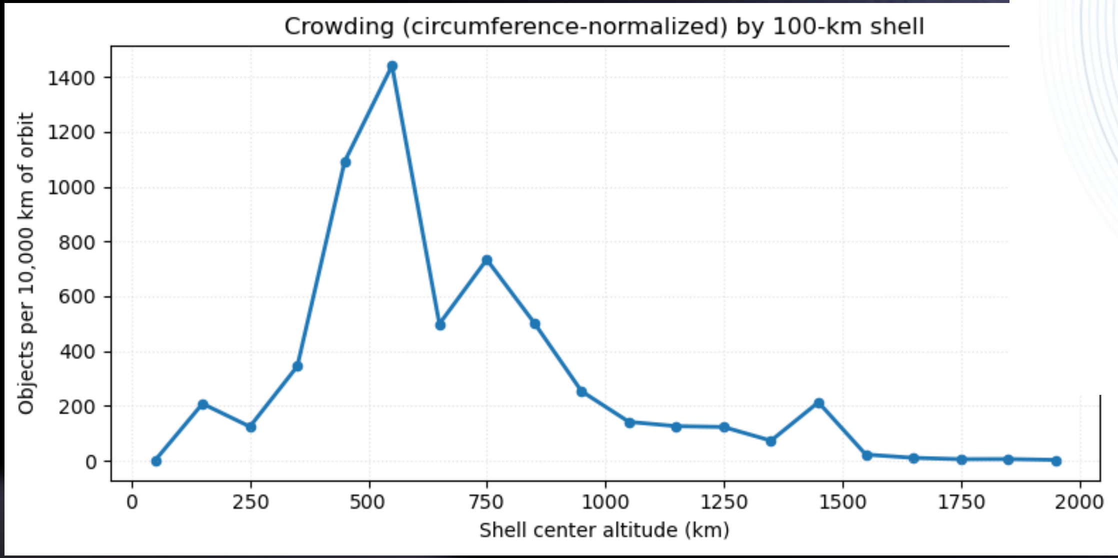


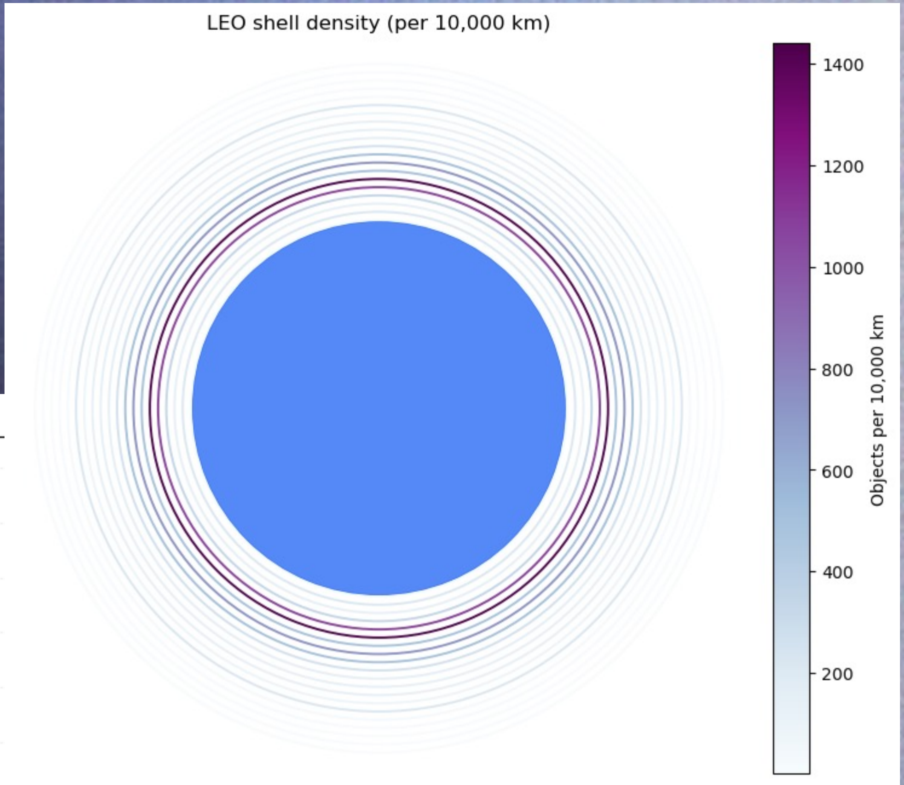


LEO Congestion

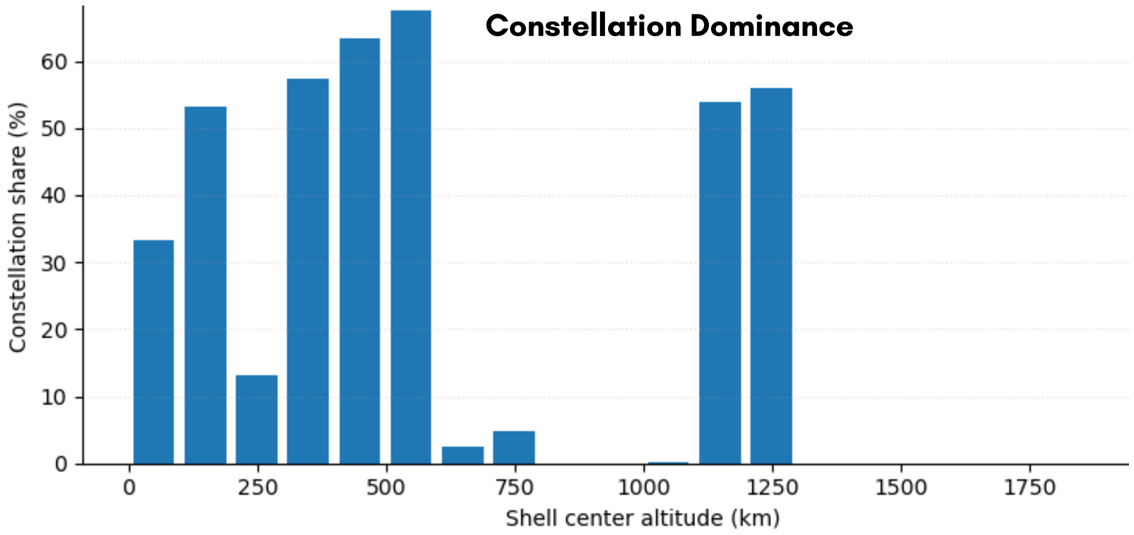
Orbital Density Analysis

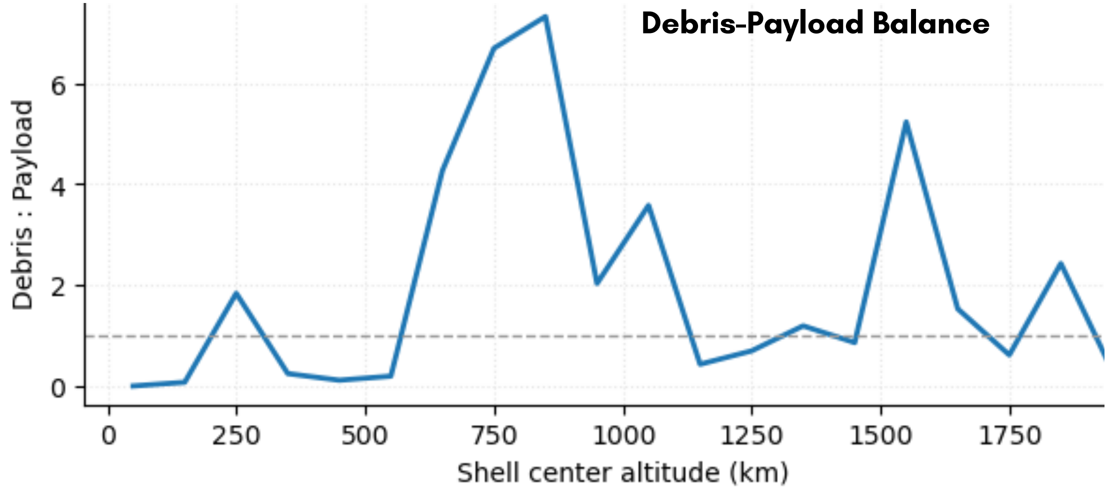
LEO CONGESTION

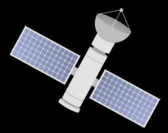




Orbital Density Analysis







Constellation satellites are strategically located in shells with lower debris to payload ratios

Orbital Density Analysis

Conjunction Risk

Workflow

Setup

- Define scope
- Import libraries and dataset
- Data wrangling
- Configure conjunction analysis
- Build propagators

Execute/Propagate

- Run coarse propagation
- Deduplicate coarse candidates
- Refine locally

Analysis & Reporting

- Risk report
- Summary and recommendations

Visualize in Tableau!

```python
import pandas as pd
import numpy as np

from pathlib import Path
from datetime import datetime, timedelta, timezone
from dataclasses import dataclass
from sgp4.api import Satrec, SGP4_ERRORS, jday, WGS72
from scipy.spatial import cKDTree
```

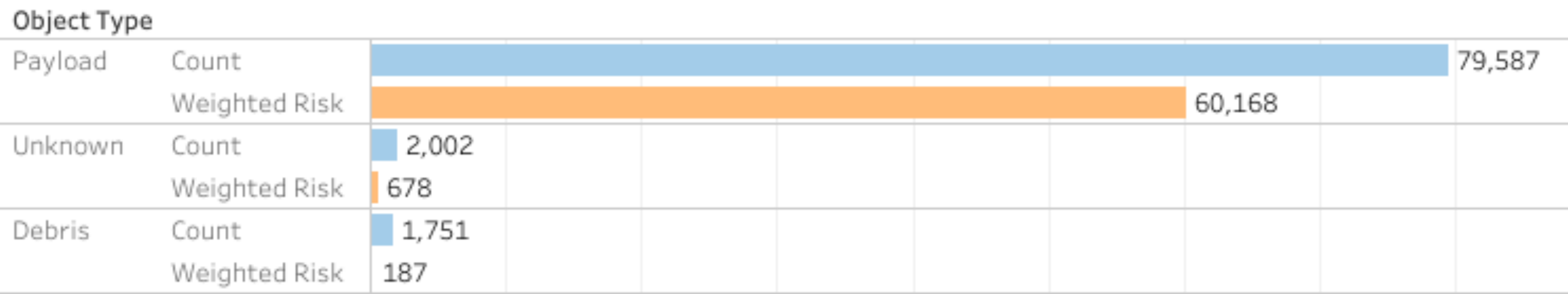
Pair Summary

Pair Type	Count	Distance < 1 km	Minimum (km)	Median (km)
Payload–Payload	38,713	5,249	0.01	10.15
Unknown–Unknown	494	42	0.03	7.41
Payload–Unknown	958	32	0.11	10.45
Payload–Rocket body	293	2	0.27	14.09
Debris–Payload	910	1	0.41	14.50
Debris–Unknown	37	0	1.02	12.81
Debris–Debris	193	0	1.18	12.88
Rocket body–Unknown	19	0	1.98	13.42
Rocket body–Rocket body	10	0	2.60	18.33
Debris–Rocket body	43	0	4.55	14.85

Distance IQR by Object Type (in km)

Object Type	Q1	Median	Q3	Risk Share
Payload	3.07	10.22	14.96	98.6%
Unknown	4.51	8.85	13.58	1.1%
Debris	9.65	14.11	16.98	0.3%

Weighted Risk by Object Type



- Our analysis confirms that close approaches in the thousands can occur daily in low Earth orbit.
- Median miss distances are typically in the **8-14 km range**.
- For Payload-Payload conjunctions, **5249 events (about 14%)** have miss distances below 1 km. Following with 74 events with miss distances below 1 km, conjunctions involving Unknown objects should not be overlooked. Although debris and unknown objects contribute marginally, their presence still complicates risk management.
- Weighted risk is dominated by payloads at **98.6%**. With Q1 miss distances lower than those of other objects, conjunctions between operational spacecraft are both more frequent and riskier.

KEY FINDINGS

Recommendations

- Estimate the risk of new debris appearing based on decay of current payload
- Explore the 2009 incident to model the effects and spread of debris
- Incentivize debris collection policies and recycling (e.g. garbage collectors)
- Introduce approaches to payload and rocket body retirement (i.e. prevention of new debris generation orbiting the congested planes, back-to-earth collection and recycling)

Recommendations for Space Traffic Management

- Establish binding international standards for conjunction assessment and collision avoidance
- Mandate maneuver protocols and thresholds, e.g. automated avoidance systems
- Classify "Unknown" objects to better assess risk
- Promote international agreements on information sharing, debris mitigation, and maneuver coordination

Obstacles

- Asynchronous work with team members in 3 timezones
  - Fixed weekly meeting time, pairwise meetups
- Managing different environments (Windows vs. Mac, CoLab vs. Jupyter, Tableau vs. coded plots)
  - Used our strengths to work in the environments we were comfortable with
- Lack of industry experience (orbital mechanics), unfamiliarity with new Python packages
  - Compiled research, videos, resources, schema tables
  - Referred to SGP4 documentation

Conclusion

Open orbital data, when cleaned and contextualized, can deliver **actionable insights for Space Situational Awareness**.

Orbital congestion and conjunction risks are **concentrated in predictable shells**, highlighting the need for targeted monitoring.

The **legacy of past debris generation** continues to shape today's orbital environment, underscoring the importance of prevention and policy.

Our workflow demonstrates that **accessible, reproducible analytics** can bridge the gap between raw orbital data and stakeholder decision-making.

Thank you so much, Women In Data!

...for giving us the chance to connect, build community, and improve our space awareness together

Explore our complete work below:

[2025 WiD Project Repository]

Presented by Cosmic Insights

Sources

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