Space Collision Risk System

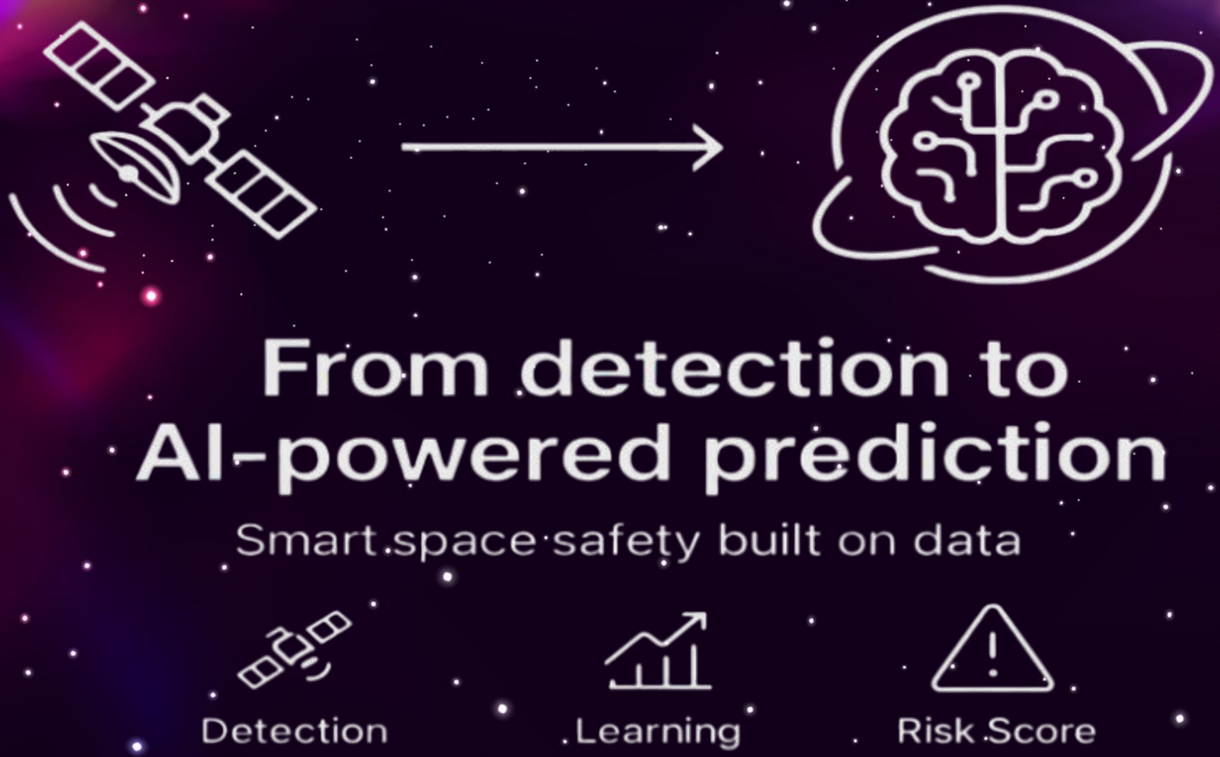
Team Astro Coders, Datathon 2025

Problem Statement

PROBLEM: EARTH'S ORBIT IS CROWDING FAST

- >163 orbital launches in 2025 so far
- 1 Falcon 9 = up to 60 satellites
- 250+ Starlink satellites in May alone
- Space is getting crowded fast

Our Vision


From detection to
AI-powered prediction
Smart space safety built on data
Detection
Learning
Risk Score

Our Approach

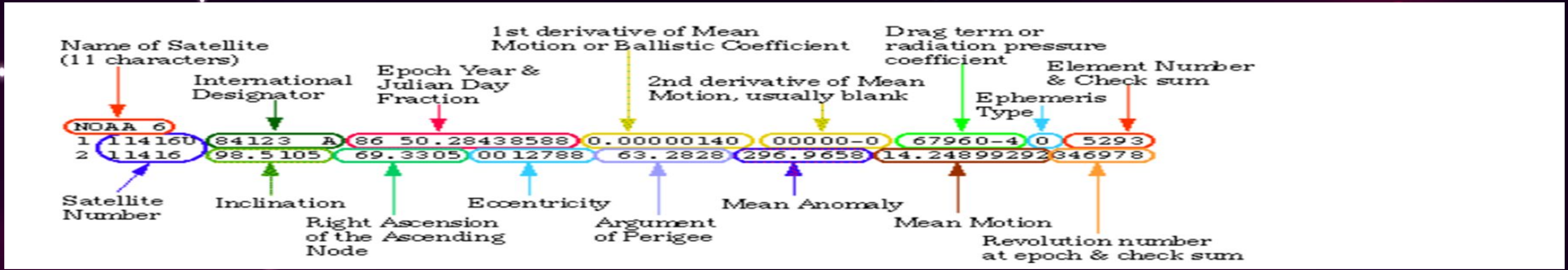
1. Data Exploration/ Problem Statement
2. Exploratory Data Analysis
3. Risk Assessment
4. AI Powered Predictive Platform

DATA OVERVIEW

- ELSET Data was obtained from the Uniformed Space Library for the year 2022, 2023, 2024 and 2025.
- Each year contained orbital object record of about 30,056 satellites.
- A record hold orbital elements classified as a Two-Line Element Set (TLE).
- Spanning first launch between year 1958 – 2024 (limited to data obtain in USL)

TWO LINE ELEMENT SET (TLE): A TLE is a text –based space data that contains a set of orbital parameters of the earth – orbiting object. Typically represented as a Line 1 and Line 2.

- The first line containing object identification data and the first set of orbital parameters.
  - Line 1: **1 26544U 98167A 20300.83067691 .00001534 00000-0 35580-4 0 9896**
- The second line contains additional orbital elements:
  - Line 2: **26544 51.6415 287.4116 0005728 178.6015 181.4241 15.49845347463160**



ORBITAL GROWTH AND EVOLUTION

Earliest 5 years:

Designator_year_launch	satNo
1958	3
1959	4
1960	11
1961	211
1962	25

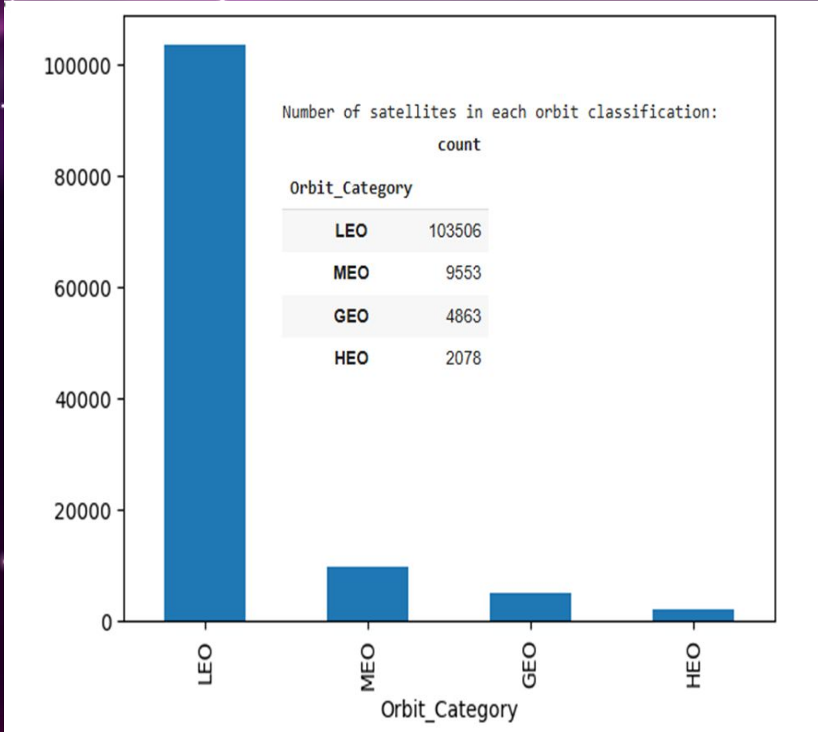
Latest 5 years:

Designator_year_launch	satNo
2020	1161
2021	1787
2022	3128
2023	2846
2024	3073

Earliest 5 years: Imagine the very beginning of the space age, when only a few satellites were being launched each year. These earliest 5 years show us the start of this trend – a small number of satellites going into orbit. It's like looking at the first few cars ever made.

Latest 5 years: Now, fast forward to today. Many more countries and companies are launching satellites for all sorts of reasons. The latest 5 years show us the current picture, with a much larger number of unique satellites being launched each year. It's like looking at all the different types of cars on the road today.

ORBITAL CHARACTERISTICS



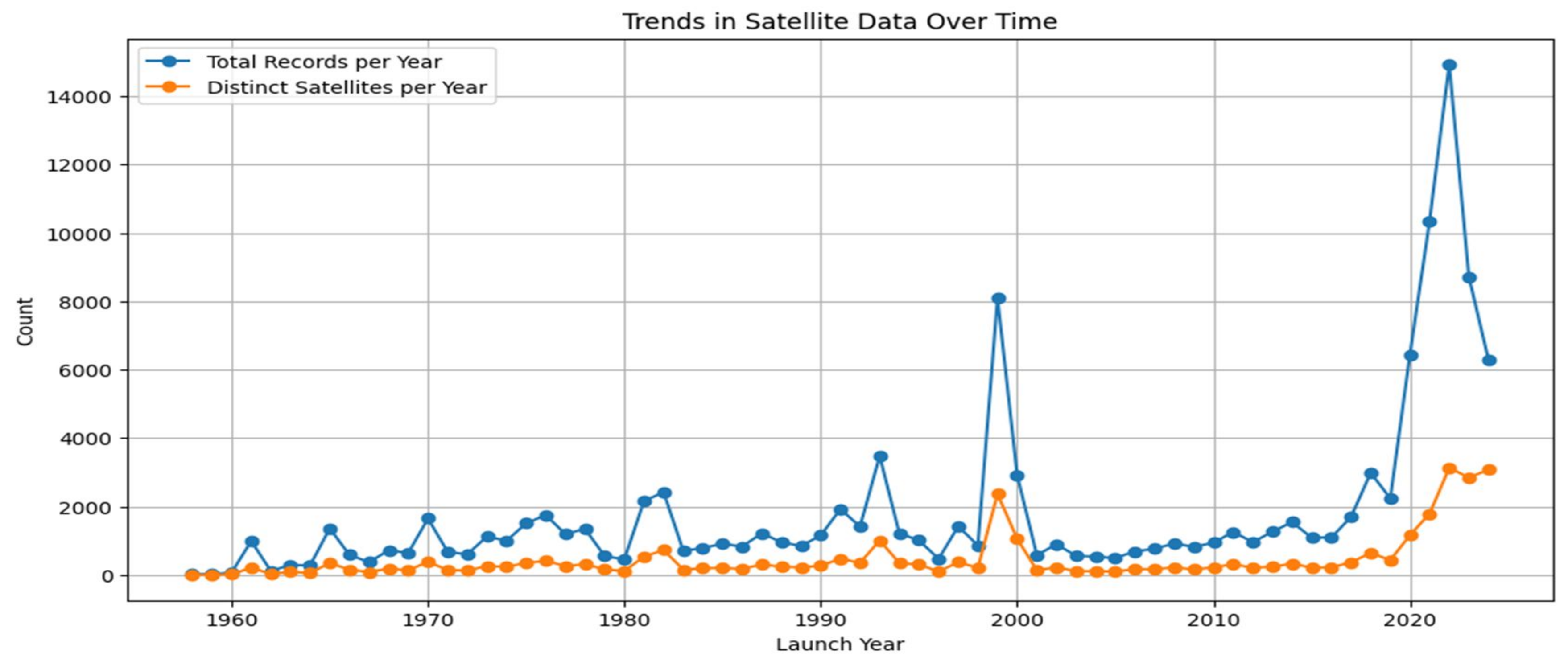
Low Earth Orbit (LEO):
•Altitude between 160 km – 2000km
•Have shorter orbital period and orbit the earth more frequently . Used for earth observation, remote sensing and communication e.g., Starlink.
•As shown in the graph, LEO is the most populated orbit for the dataset.

Medium Earth Orbit (MEO):
•2000km – 35, 786kn above Earth surface.
•Have longer orbital period than LEO satellites.
•Often used for navigation systems e.g., GPS, GLONASS.
•In the data, this is the second most populated orbit.

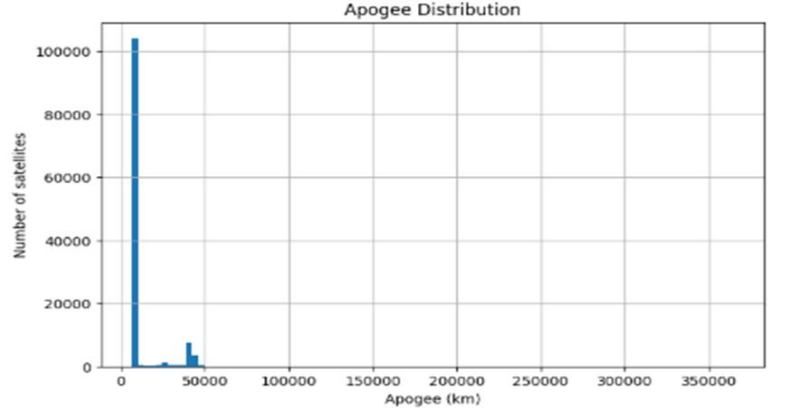
Geostationary Orbit(GEO):
•35, 786km above earth equator.
•Orbits the earth at the same rate as Earth rotates.
•Often used for communication satellites e.g., broadcasting
•Third most populated in the data.

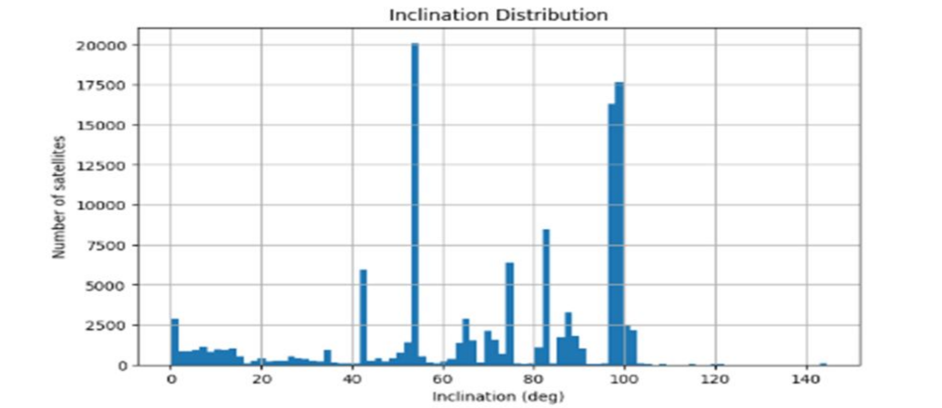
Highly Elliptical Orbit (HEO) – Varies significantly throughout orbit , with a high apogee(farthest point) and a long low perigee (closest point)

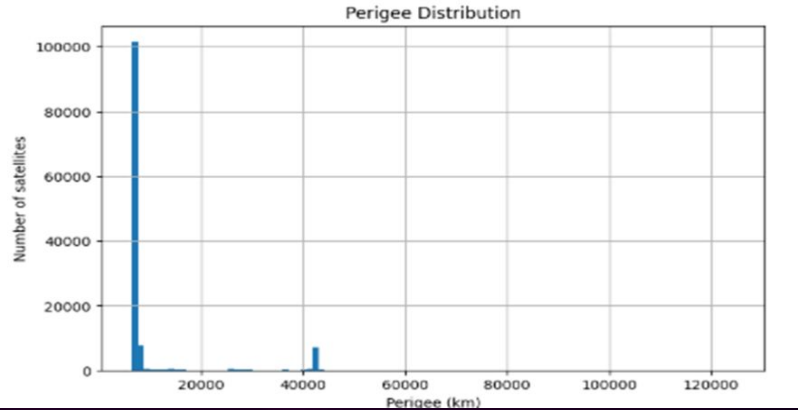
LAUNCH YEAR TRENDS

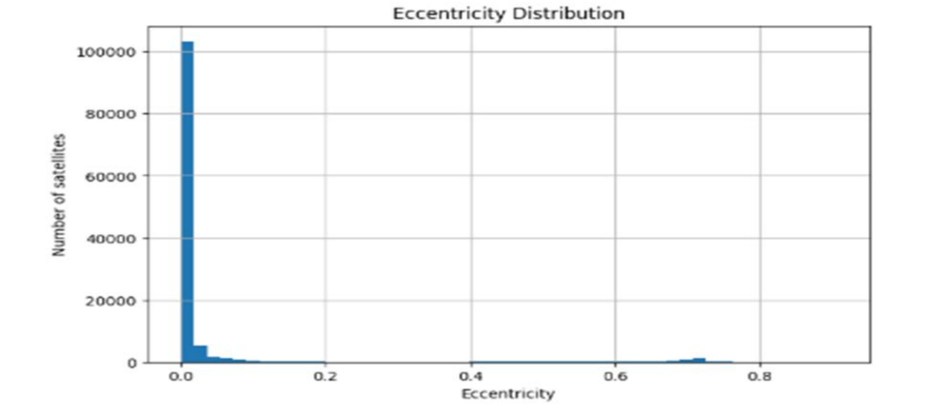


DISTRIBUTION OF ALTITUDE, INCLINATION & ECCENTRICITY









ORBITAL CHARACTERISTICS

Apogee and Perigee:

•Apogee: The farthest point in a satellite's orbit from the Earth.

•Perigee: The closest point in a satellite's orbit to the Earth.

•These values help define the shape and altitude range of a satellite's orbit.

•The distribution of apogee and perigee above show common orbital altitudes used by satellites, like the concentration of satellites in Low Earth Orbit (LEO) which you can see in the histograms.

Inclination:

•Inclination: The angle between a satellite's orbital plane and the Earth's equatorial plane.

•It determines how far north and south a satellite will travel over the Earth's surface.

•Different inclinations are used for various purposes, such as polar orbits (near 90 degrees) for Earth observation, or lower inclinations for communication satellites.

Eccentricity:

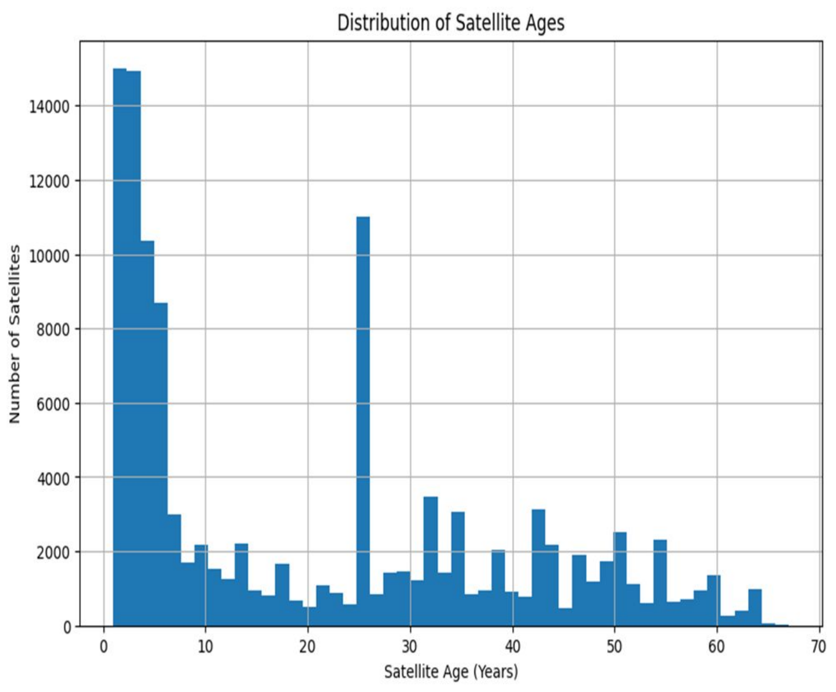
•Eccentricity: A measure of how elliptical a satellite's orbit is.

•A value of 0 indicates a perfect circle, while values closer to 1 indicate more elongated, elliptical orbits.

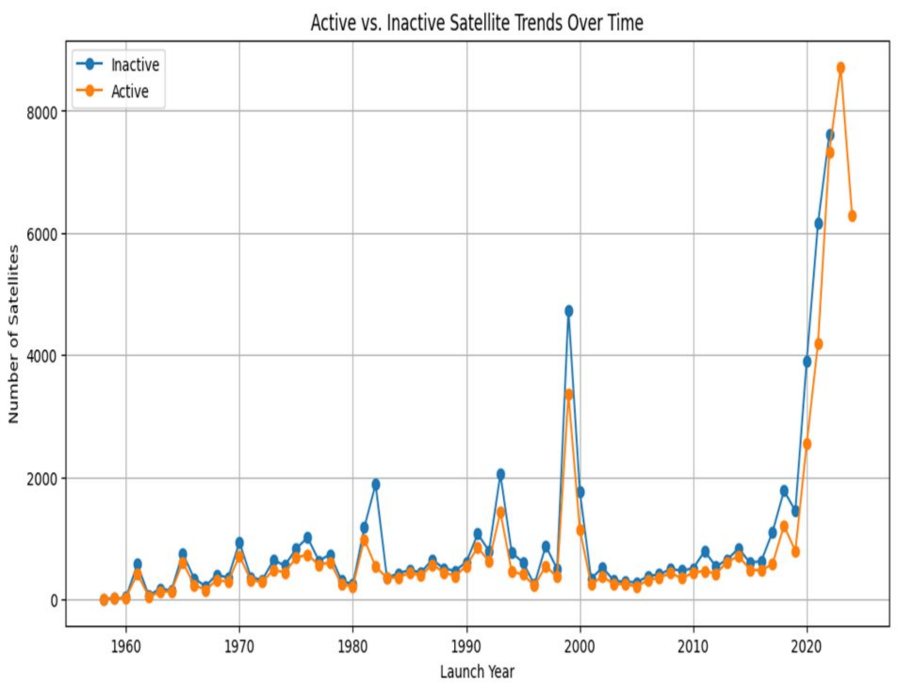
•Many satellites are in near-circular orbits (eccentricity close to 0), as seen in the histogram, which is often desirable for consistent coverage or communication.

SATELLITES AGES, ACTIVE VS INACTIVE SATELLITE TREND

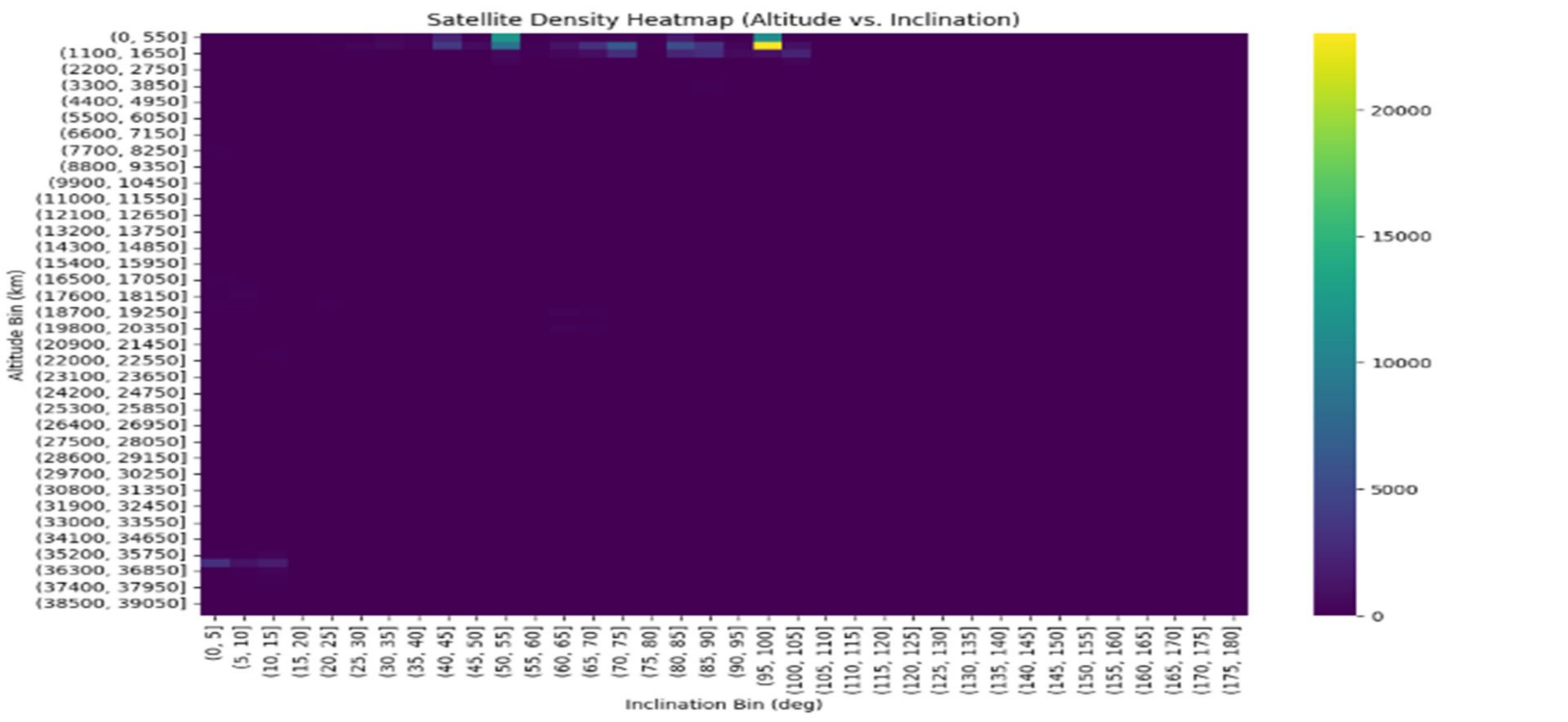
Satellites Ages



Active vs. Inactive Satellite Trend Over Time



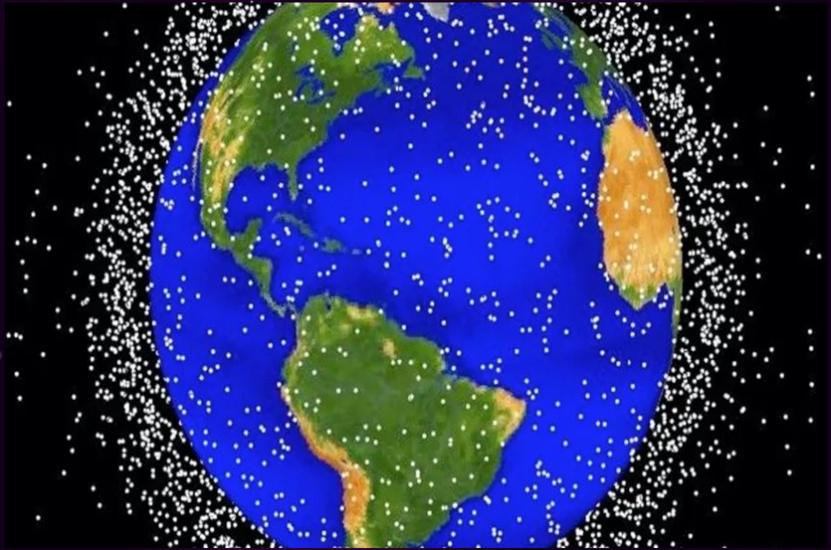
SATELLITES DENSITY



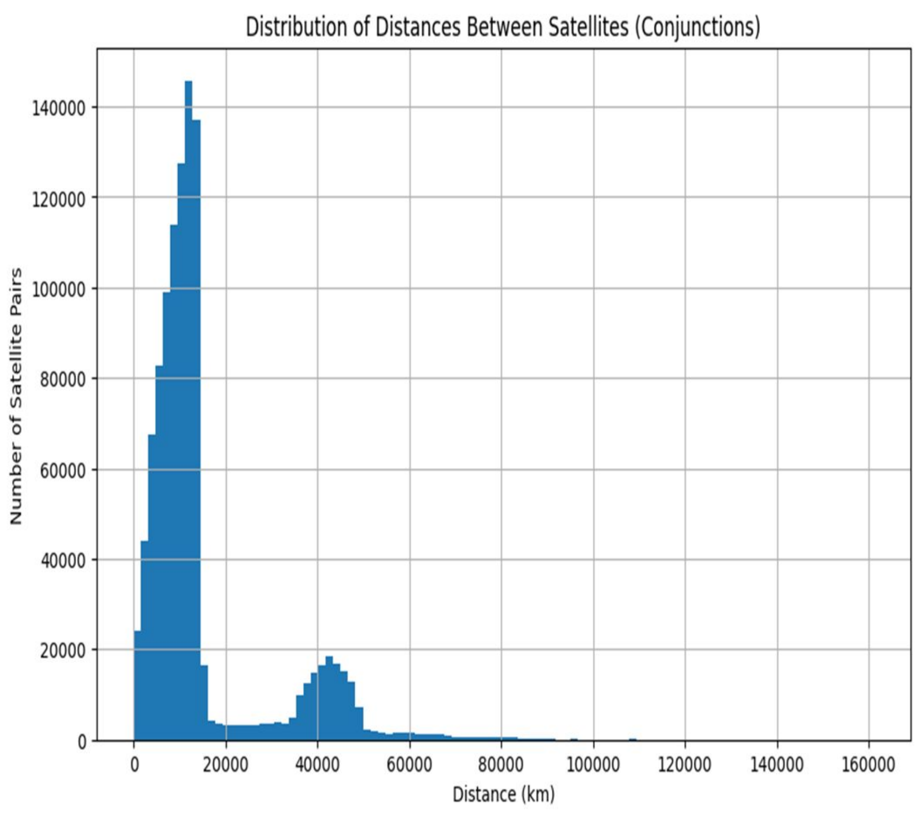
CONGESTED ORBITAL SHELLS

Top 10 Most Congested Orbital Shells:

	altitude_bin	inclination_bin	satellite_count
55	(550, 1100]	(95, 100]	23020
10	(0, 550]	(50, 55]	12056
19	(0, 550]	(95, 100]	11226
46	(550, 1100]	(50, 55]	8707
50	(550, 1100]	(70, 75]	6404
52	(550, 1100]	(80, 85]	5462
44	(550, 1100]	(40, 45]	3941
53	(550, 1100]	(85, 90]	3442
2340	(35750, 36300]	(0, 5]	3209
49	(550, 1100]	(65, 70]	3190



CONJUNCTION ANALYSIS

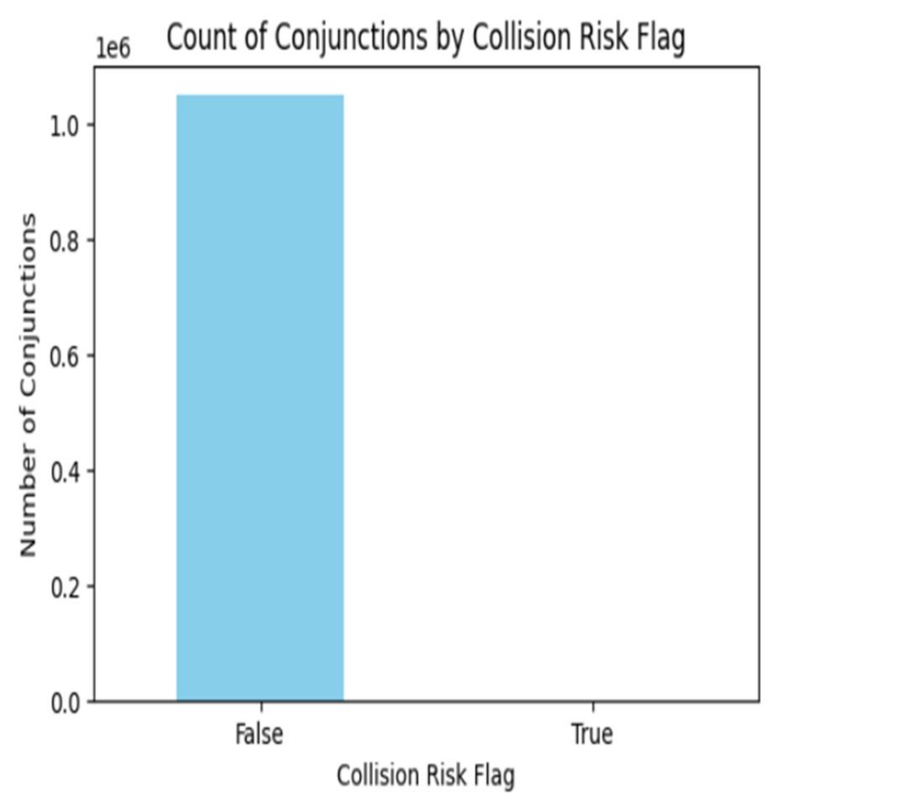


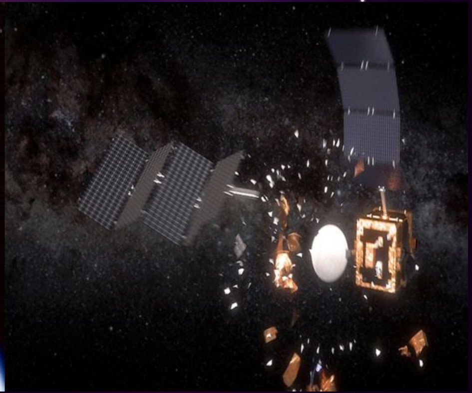
- **The large peak at lower distances: A** significant peak can be observed in the histogram at the lower end of the distance range (closer to 0 km). This indicates that there are many potential conjunctions where the satellites are predicted to come relatively close to each other. These are the events that would require closer monitoring for potential collision risk.

- **The second peak at higher distances:** There seems to be another, smaller peak at a greater distance. This suggests there's another group of potential conjunctions where the satellites are further apart, but still within a range that was included in the conjunction analysis data.

- **The overall shape:** The shape of the histogram gives an idea of the typical distances between satellites when a potential conjunction is identified. It highlights that while many conjunctions involve relatively large distances, there is a notable concentration of events at closer ranges, which are of higher concern for space traffic management.

COLLISION RISK FLAG





Count of conjunctions by Collision Risk Flag:

	count
Collision_Risk_Flag	
False	1048050
True	525

KEY FINDINGS:

- The top 10 congested shells are concentrated in the lower altitude bins (primarily 0-550 km and 550-1100 km) across various inclination ranges, with a notable cluster around 95-100 degrees inclination.

- Top 10 satellite counts ranging from 1,376 to 3,136 in these specific altitude and inclination bins.

- There is also one highly congested shell in the geostationary orbit altitude range (35750, 36300] km with a very low inclination (0, 5] degrees.
-
- Majority of potential conjunctions in this dataset are flagged as having no collision risk (False). The number of conjunctions flagged with a collision risk (True) is very low in comparison.

KEY FINDINGS:

- However, even the small number of flagged collision risks means that these specific events require monitoring and potentially further action to prevent an actual collision. So, while the overall risk might appear low based on the count of flagged events, the presence of *525* flagged risks highlights the need for continued monitoring and space traffic management

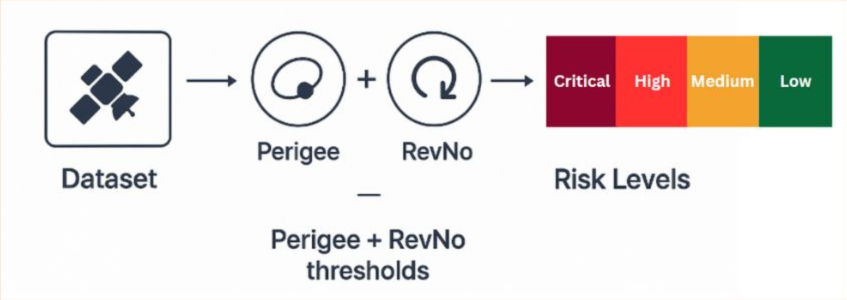
Satellite Orbit Visualization

Turning Orbital Data into Risk Intelligence

1.Developed a **Basic Risk Assessment System** to translate orbital data into actionable risk levels

- Focused on two key orbital parameters:
  - **Perigee** → lowest orbital point → higher drag & congestion risk
  - **RevNo** → total orbits completed → indicator of satellite age/control

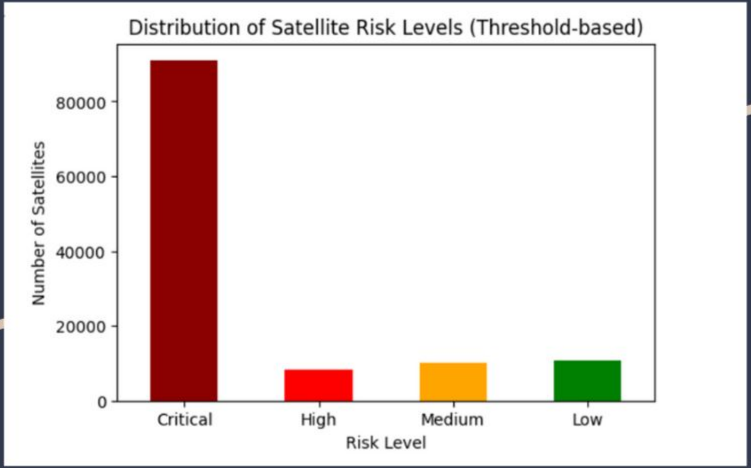
- Applied threshold rules → grouped satellites into Critical, High, Medium, Low
- Added **reason codes** → every risk label is transparent & interpretable.



1.System Outputs: CSV

perigee	revNo	dataMode	satNo	data_year	risk_level	risk_reason
6683.636	585	REAL	45066	2025	Low	Safe orbit
6817.471	25237	REAL	45748	2025	Critical	RevNo above 6000
6801.88	24203	REAL	46138	2025	Critical	RevNo above 6000
6795.587	585	REAL	46707	2025	Low	Safe orbit
6850.156	12809	REAL	53796	2025	Critical	RevNo above 6000
6767.693	5534	REAL	58782	2025	High	RevNo between 4000–6000
6806.64	5119	REAL	58945	2025	High	RevNo between 4000–6000
6765.451	3661	REAL	59793	2025	Medium	RevNo between 2000–4000

Bar chart:

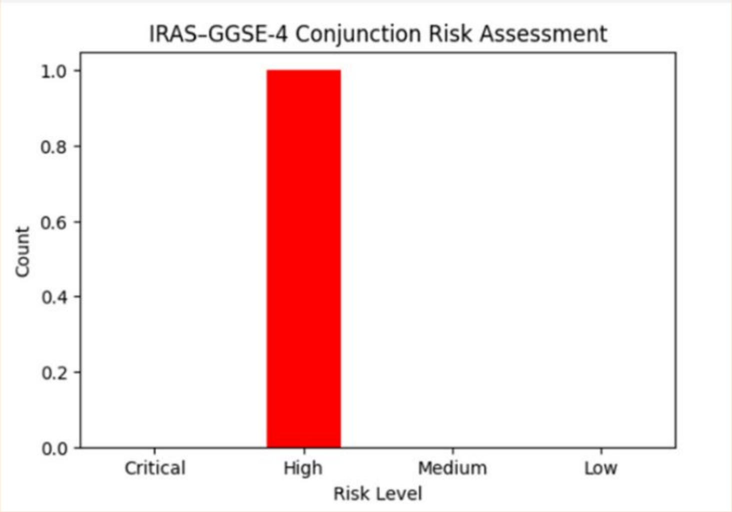


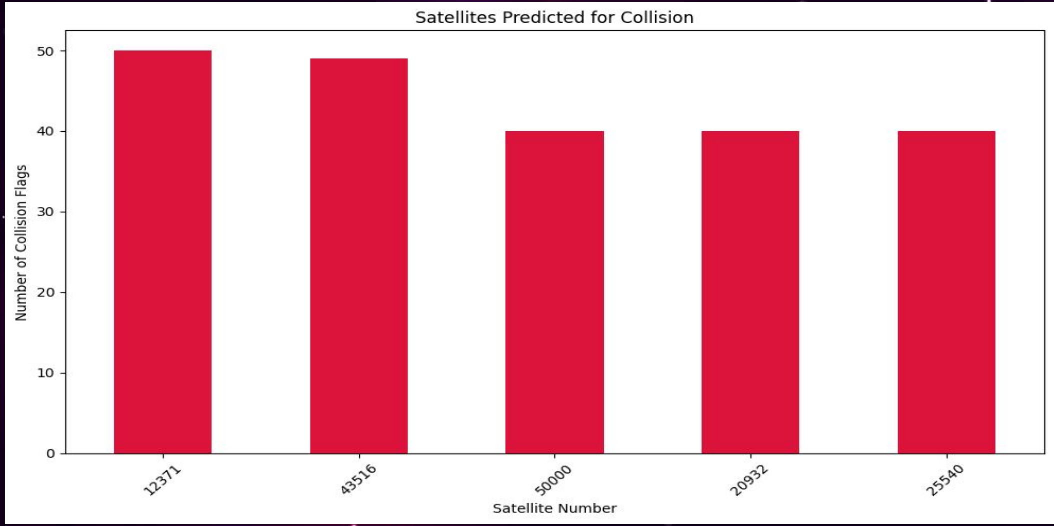
From Data to Decisions

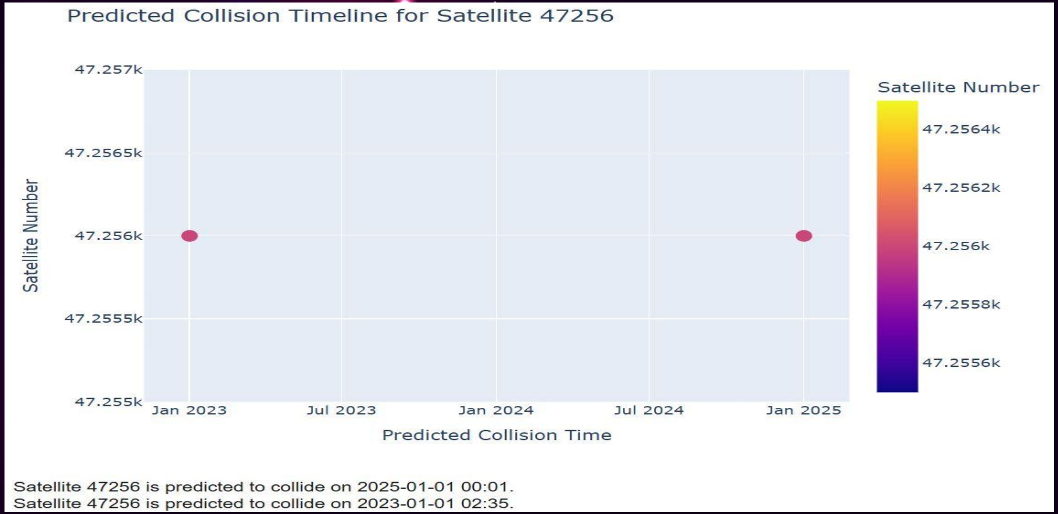
Real-World Validation:

- Detected the **IRAS–GGSE-4** conjunction (Jan 2020) as **Critical.**
- Matches independent assessments of this event as an extreme risk

- **Key Takeaway**: Raw orbital data is now actionable, interpretable, and decision-ready.







COLLISION PREDICTION USING AI

The flow of prediction of collision between the satellites.

1. **Data Preparation**
2. **Feature Engineering**
3. **Anomaly Detection**

This bar chart highlights the five satellites most frequently flagged for potential collisions, with each satellite represented by its unique identification number. The y-axis shows the number of times each satellite was detected as anomalous, indicating repeated proximity risks.

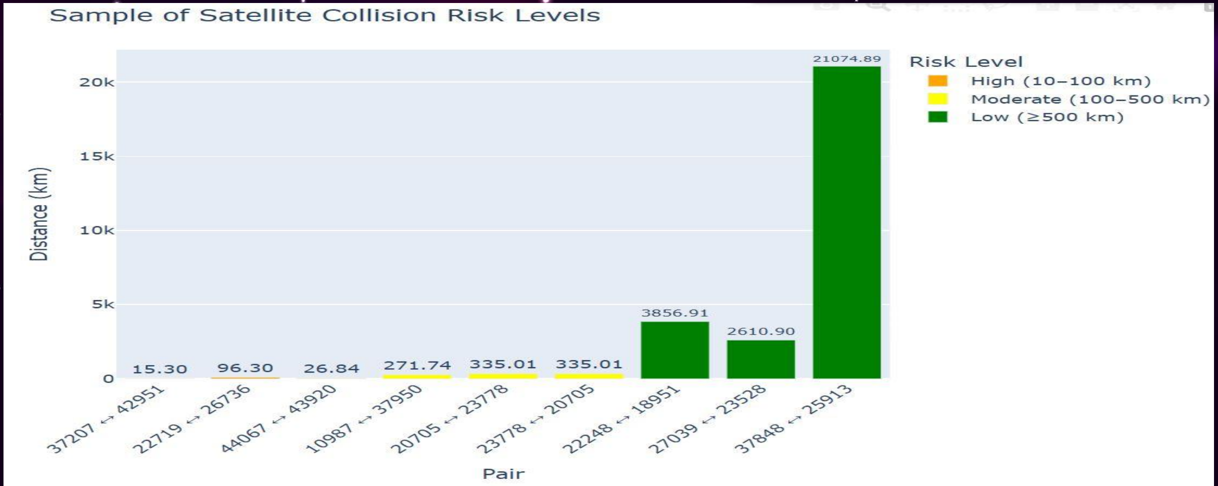
Whereas the scatter plot shows that the predicted collision times for two satellites over a span from mid-2022 to early 2025. Each point represents a collision event, color-coded by satellite number, with distinct clusters around satellites. The timeline helps visualize when and how frequently each satellite is at risk.

RISK ASSESSMENT BASED ON COLLISION PREDICTIONS AND SUGGESTED ACTION

By classifying satellite pairs into **Critical**, **High**, **Moderate**, and **Low** risk levels based on their proximity, we can:

a. Prioritize urgent collision alerts.
b. Inform satellite operators for evasive maneuvers.
c. Visualize and monitor orbital safety trends over time.

In the above graph the x-axis represents satellite pairs approaching a potential collision. The y-axis displays the calculated distance between them, with each bar indicating the corresponding risk level based on their proximity. The below graph gives suggested actions for the predicted collisions risks.



Satellite A	Satellite B	Distance (km)	Risk Level	Timestamp	Recommended Action
45246	43823	15.29	High (10–100 km)	N/A	Initiate orbital adjustment for Satellite 45246 to avoid collision with Satellite 43823.
10987	37950	271.74	Moderate (100–500 km)	N/A	Monitor Satellite 10987 and 37950; current distance is safe but should be observed.
13782	15453	288.44	Moderate (100–500 km)	N/A	Monitor Satellite 13782 and 15453; current distance is safe but should be observed.
47256	36106	1532.80	Low (≥500 km)	N/A	No immediate action required; Satellite 47256 and 36106 are at a safe distance.
25465	36592	5601.29	Low (≥500 km)	N/A	No immediate action required; Satellite 25465 and 36592 are at a safe distance.

Risk Collision & Debris Management

Total Pairs by Risk Level

Risk Level

All

High Risk

6

Moderate Risk

48

Top 6 Closest Satellite Approaches

Satellite A	Satellite B	Pair	Distance (km)	Risk Level
11397	8697	11397 ↔ 8697	0.1K	High (10–100 km)
22719	26736	22719 ↔ 26736	0.1K	High (10–100 km)
26736	22719	26736 ↔ 22719	0.1K	High (10–100 km)
37207	32019	37207 ↔ 32019	0.0K	High (10–100 km)
38978	33749	38978 ↔ 33749	0.1K	High (10–100 km)
40364	38778	40364 ↔ 38778	0.0K	High (10–100 km)
2654	33055	2654 ↔ 33055	2.2K	Low (≥500 km)
2868	42749	2868 ↔ 42749	2.6K	Low (≥500 km)
3431	42432	3431 ↔ 42432	0.6K	Low (≥500 km)
3623	38352	3623 ↔ 38352	3.6K	Low (≥500 km)
3674	11561	3674 ↔ 11561	4.5K	Low (≥500 km)
3692	36033	3692 ↔ 36033	1.8K	Low (≥500 km)
3947	21639	3947 ↔ 21639	3.8K	Low (≥500 km)
4297	25611	4297 ↔ 25611	1.8K	Low (≥500 km)

Conclusion

- Our model detected anomalous satellites using orbital and motion data with Isolation Forest.
- The satellites identified were classified into Critical, High, Moderate, and Low based on proximity analysis.
- Results match known events, confirming the model’s validity.
- Our dashboard translates raw orbital data into actionable insights for risk mitigation.

Recommendations: Managing the New Space Era

1. Use AI for Real-Time LEO Traffic Monitoring
2. Develop a Predictive Collision Risk Index
3. Enforce End-of-Life Protocols & Deorbiting
4. Monitor Congestion in Critical GEO Shells
5. Build a Public Orbital Safety Dashboard

Final Thought

Space is no longer an infinite void, it is a finite, shared resource. As orbital traffic increases, the stakes rise. Proactive governance, predictive analytics, and international cooperation are essential for long-term space sustainability.