SENTINEL - PREDICTIVE ORBIT COLLISION WARNING SYSTEM

TEAM - TENSORS

OM JADHAV

ANUJ JHA

ATHARVA DEO

KAWALJEET SINGH

AKSHAT BHALANI

THE PROBLEM

Space is Getting Crowded and Dangerous

34,000+ debris objects larger than 10cm

Even a small collision may trigger Kessler Syndrome

Avg Collision Velocity = 10km/s

130M debris smaller than 1mm

$1–2 billion lost annually

Existing warning systems provide limited prediction windows and lack ML-powered risk assessment, making collision avoidance reactive rather than proactive.

Collision warnings are often late, uncertain or inaccurate.

Current systems rely on manual monitoring / basic propagation methods.

PROPOSED SOLUTION

An AI-powered early-warning platform that forecasts satellite–debris close approaches 24–72 hours in advance with high reliability.

02. Advanced Risk Assessment & Alerts

- Collision probability scoring using ensemble ML models
- Color-coded visual warnings (Low/Medium/High risk)
- Automated notifications for high-risk conjunctions

01. Intelligent Orbit Prediction Engine

- Real-time ingestion of TLE, orbital data ,optical data
- ML-enhanced trajectory forecasting to correct SGP4 propagation errors
- Continuous re-evaluation as new TLE updates arrive

03. Insightful Monitoring & Analytics Dashboard

- 3D orbit visualization and path projections
- Historical collision pattern analysis for long-term learning
- Trend insights to help optimize avoidance strategies

CHALLENGES & SOLUTIONS

Challenge	Explanation	Solution
Sensor Range vs Response Time	LIDAR range ~100 km gives only ~13 sec response at orbital speeds	Wide-angle detection (500+ km) • Pre-computed maneuvers • Predictive tracking • Emergency fixed ΔV
False Positives → Fuel Waste	Sensor noise or benign objects trigger unnecessary avoidance	Multi-stage filtering • Adaptive fuel-based thresholds • False-positive learning • Fuel-aware cost function
Unknown / Untracked Debris	Majority of debris <10 cm untracked by ground sensors	• Detect all sensor-field objects • Equal risk for unknowns • Debris-density maps for vigilance
TLE/Tracking Data Noise (Ground System)	Public orbital data has drift errors; updates often infrequent	• ML-enhanced SGP4 • AstriaGraph high-frequency data • Ensemble models reduce noise
Real-Time Computation Load	Collision probability must update every orbit cycle	• Vectorized compute • Cloud microservices • Redis caching + real-time WebSockets
Limited Historical Collision Data	Few actual collision events for ML training	• Synthetic data generation • Anomaly detection models • Augment with historical CDM conjunction reports

INNOVATIVE SOLUTIONS/ UNIQUENESS

PREDICTIVE ML ARCHITECTRE

- LSTM NNs for trajectory forecasting
- Random Forest for collision probability classification
- Continuous learning from close approach data

EDGE AI FOR SPACE

- Our decision engine is designed to be computationally lightweight
- Perfect for deployment on resource-constrained satellite hardware
- Real-world "Edge AI" application for space environments
- Minimal power consumption with maximum safety impact

OPEN DATA INTEGRATION

- Hybrid Data Fusion Approach
- Satellites: TLE data (precise, frequent updates)
- Debris: Radar/optical tracking from SSN + ESA databases
- Sensor fusion algorithms to correlate and validate observations
- Kalman filtering for debris trajectory estimation from sparse observations

RISK PRIORITIZATION ENGINE

- Multi-factor risk scoring (velocity, mass, probability, asset value, data confidence)
- Smart filtering to reduce alert fatigue
- Adaptive thresholds based on tracking data quality

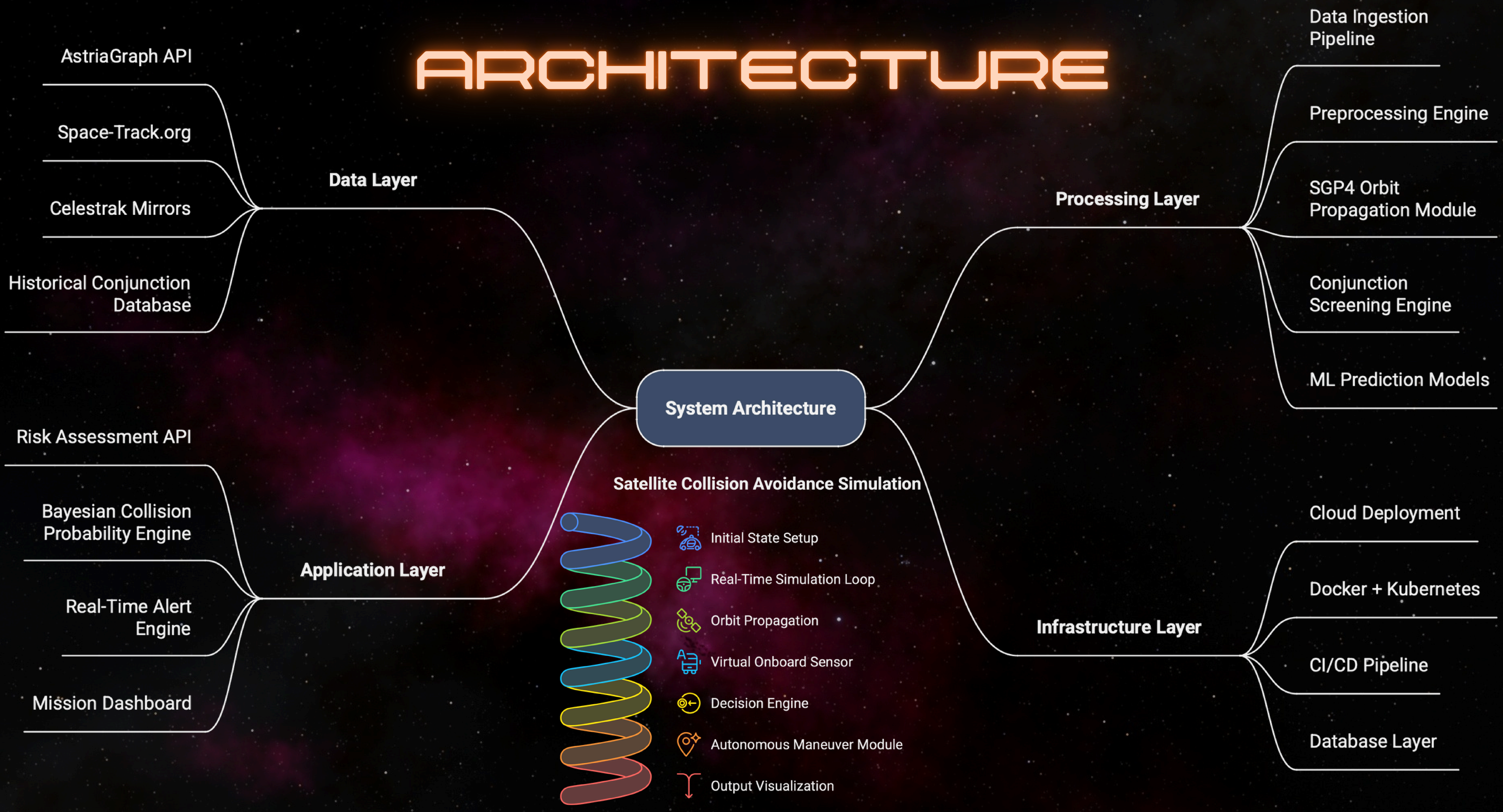
EXTENDED PREDICTION WINDOW

- 24-72 hour forecasts vs. industry standard 6-24 hours
- Uncertainty quantification for debris with limited tracking data
- Gives operators time for multi-stakeholder coordination

TECH STACK

Layer	Technologies / Tools	Purpose
Data Sources	*AstriaGraph API, Space-Track.org, Celestrak*	Live / historical satellite & debris tracking data
Programming Languages	*Python, JavaScript (React)*	Backend computation, frontend dashboard
Orbit & Physics Engine	*SGP4, Skyfield*	Accurate orbital propagation & simulation
Machine Learning	*PyTorch, Scikit-learn, XGBoost*	Trajectory prediction, drift correction, risk scoring
Streaming & Pipelines	*Apache Kafka*	Real-time data ingestion & event pipelines
Backend Services	*FastAPI, Redis Pub/Sub*	APIs, real-time alerts, risk computation
Frontend / Visualization	*React, D3.js, Three.js*	Dashboard, 3D orbit visualization, heatmaps
Simulation Framework	*Python + Skyfield + Custom ΔV Engine*	Real-time maneuver simulation environment
Databases	*PostgreSQL, TimescaleDB, Redis Cache*	Time-series storage, fast reads, caching
Infrastructure / DevOps	*AWS/Azure, Docker, Kubernetes, GitHub Actions*	Deployment, scalability, CI/CD automation
Monitoring	*AWS CloudWatch, Grafana (optional)*	System health, performance metrics

ARCHITECTURE



FUNCTIONALITY DEMO

PHASE 1: CONTINUOUS MONITORING (ALWAYS ON)

- Continuously scan 360° with LIDAR & cameras.
- Onboard ML detects and identifies potential debris.
- Maintain a live track file for all targets.

PHASE 2: THREAT DETECTION (TRIGGERED)

- Estimate trajectory of close-approach objects.
- Run simulations to calculate precise collision probability.
- High-risk threats trigger an emergency response.

PHASE 3: AUTONOMOUS AVOIDANCE (RESPONSE)

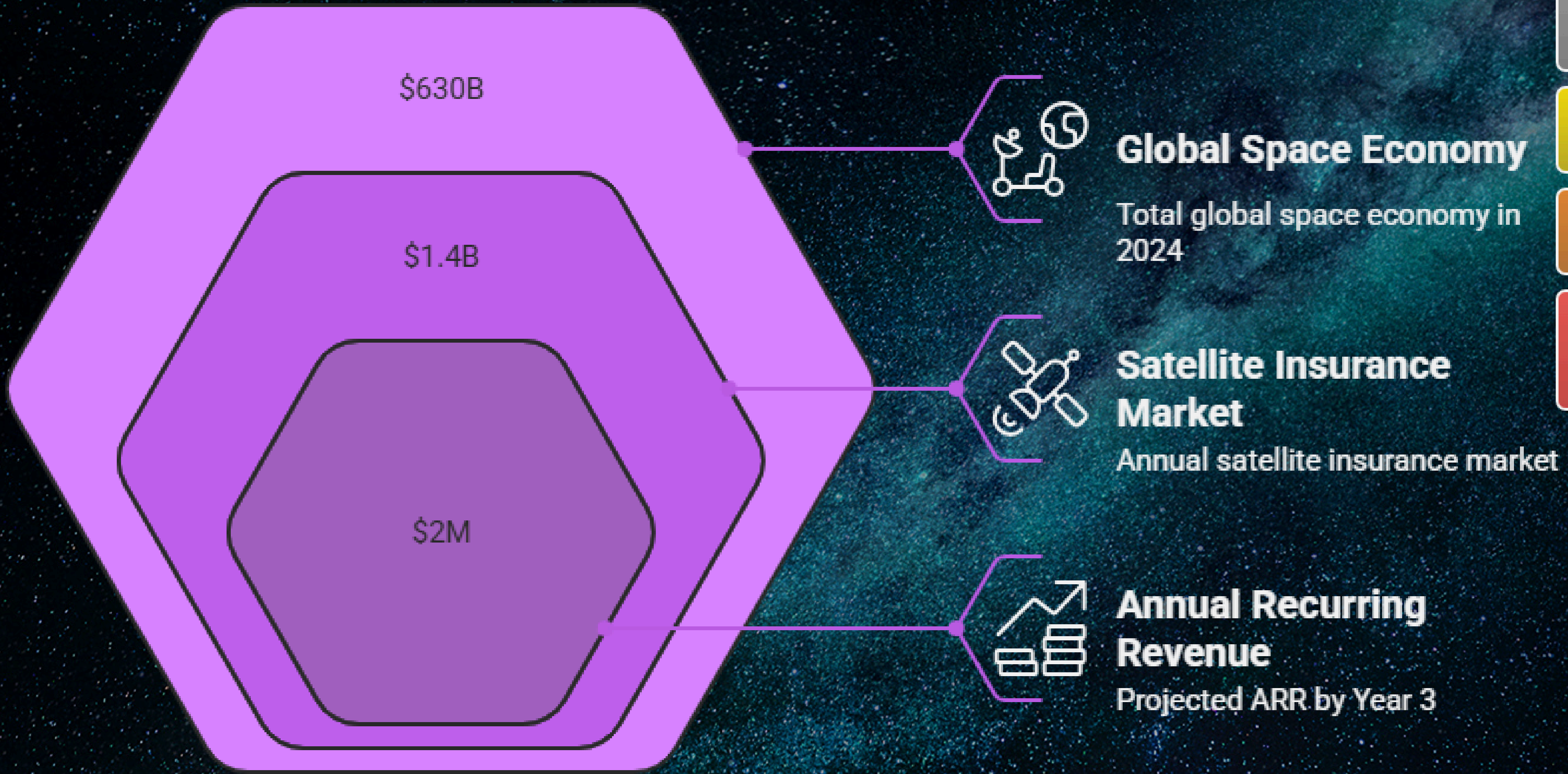
- AI agent computes optimal, fuel-efficient maneuver.
- Run final safety checks (fuel, mission constraints).
- Execute maneuver within 60 seconds of threat confirmation.
- Log all sensor data and decisions to the black box.

PHASE 4: GROUND REPORTING (POST-EVENT)

- Report the threat and maneuver on the next ground pass.
- Ground control validates the autonomous decision (monitoring only).
- Ground can disable the system, but cannot block an emergency dodge.

MARKET OPPORTUNITY & BUSINESS PLAN

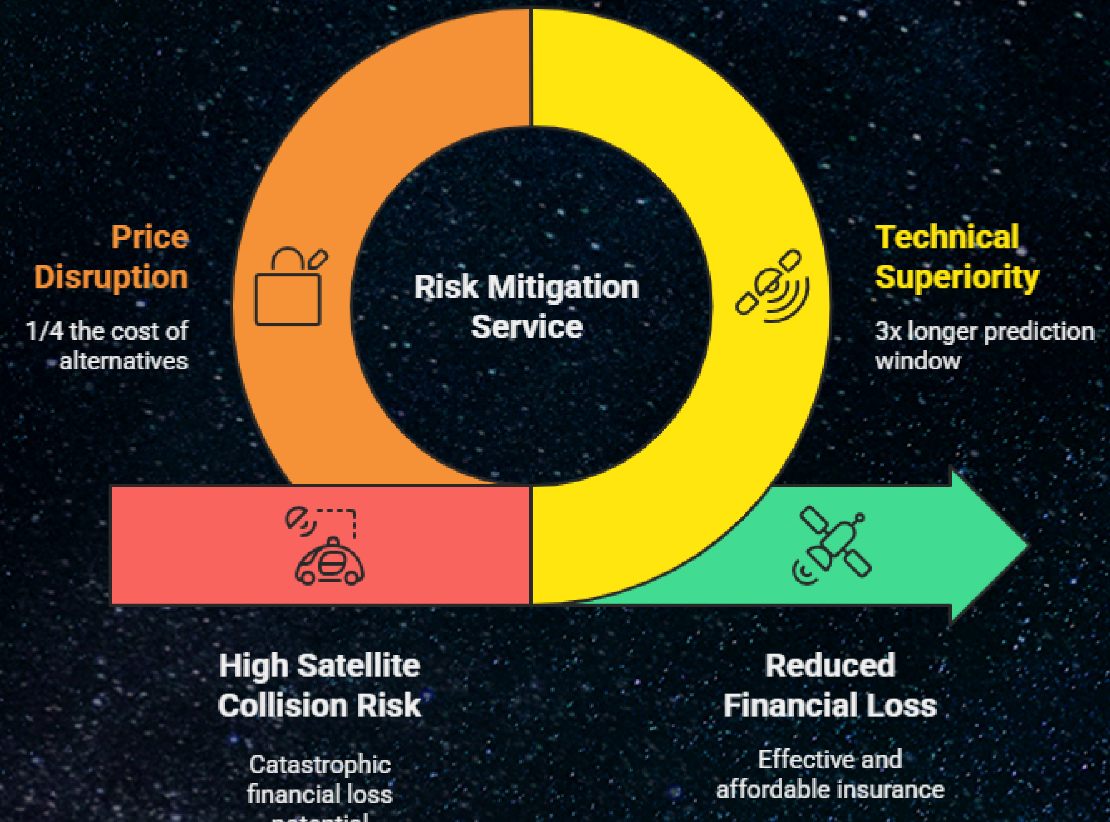
Satellite Insurance Market Size and Revenue Projections



Go-to-Market Strategy

Characteristic	Primary Market	Secondary Market	Emerging Market
Customer Base	1,000+ companies	Government & Defense	Mega-Constellations
Key Focus	Adoption via subscription	Reliability and mission security	Scalability for massive data
Revenue Driver	Tiered subscription model	Enterprise contracts, consultation	Unlimited API access, custom pricing

Cost-Effective Satellite Collision Mitigation



THANK YOU