Astroguard

-Edge AI-Driven Spacecraft Predictive Maintenance.

MUKHTAR GULSIM
2026

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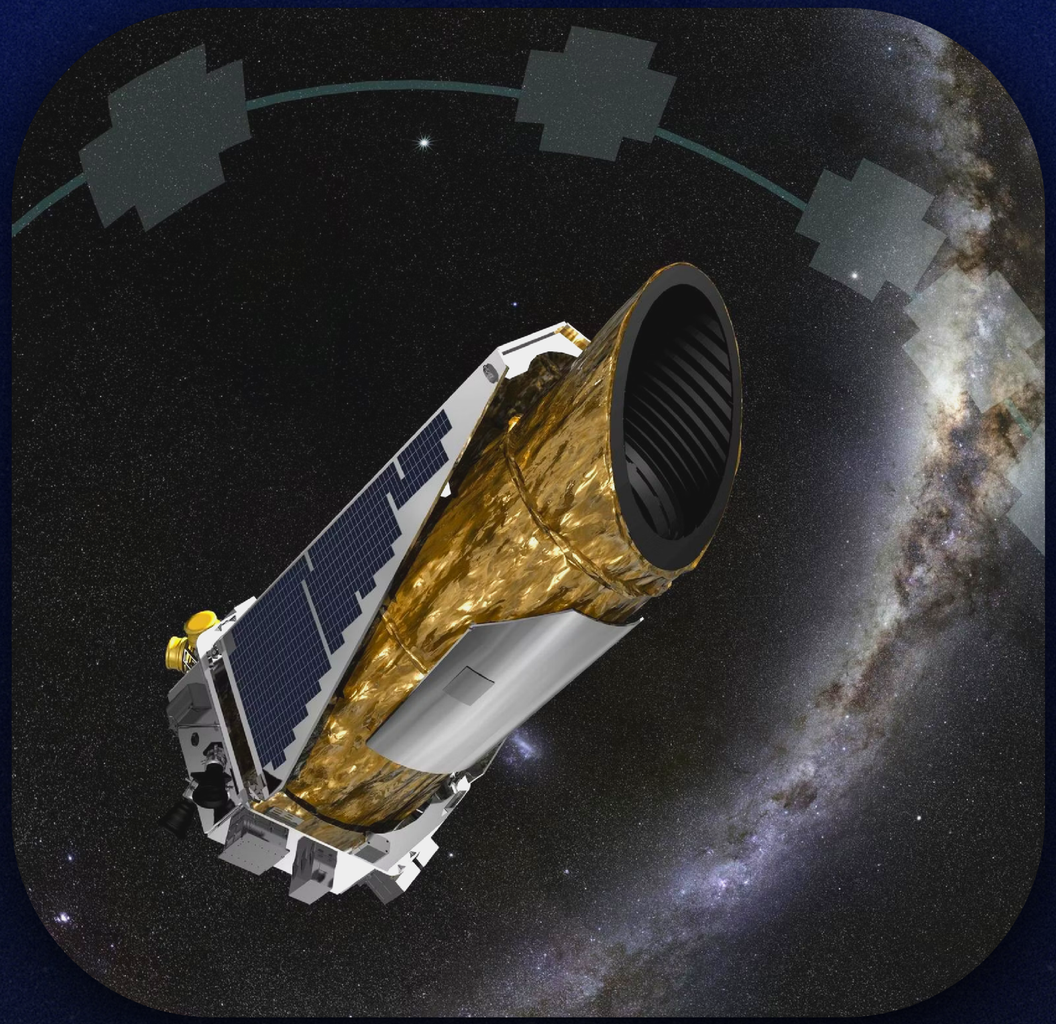
The problem

Core Issue: Reaction wheel failures are a critical threat to space missions. Over 30% of satellite attitude control issues stem from bearing degradation.

- **Root causes:** Microgravity (lubricant imbalance) and Electrostatic Discharge (ESD) from solar storms causing race defects.

The Barrier: Ground-based monitoring is unscalable due to limited telemetry downlink bandwidth (~10 kbps).



Example

In 2013, the Kepler space telescope was forced to abandon its primary exoplanet mission.

- Friction build-up from electrical arcing led to erratic torque fluctuations, resulting in a ~$600M partial loss.
- Similar critical failures crippled FUSE, Dawn, and BIRD satellites.

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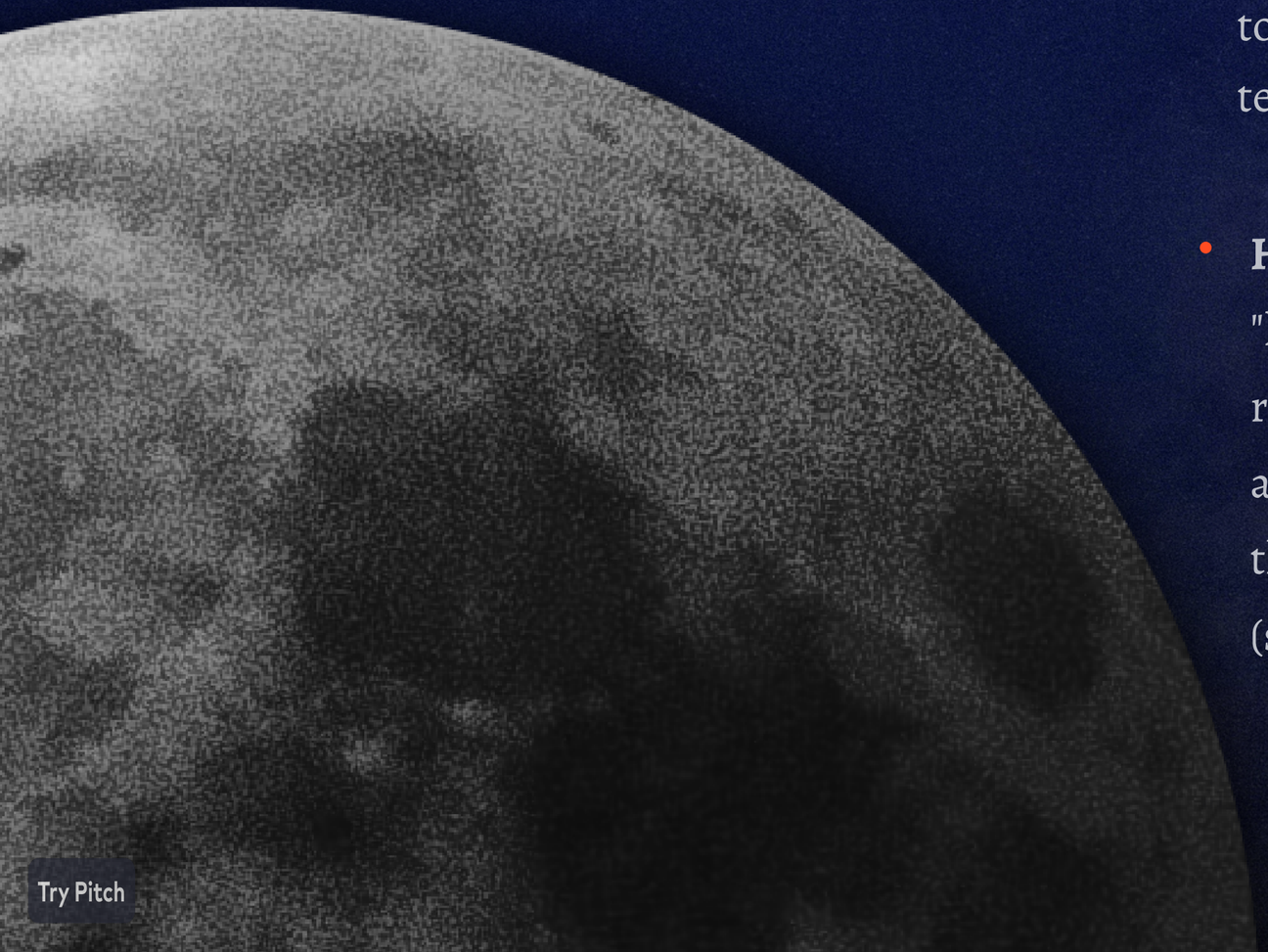
The Solution

AstroGuard: The Spacecraft 'Digital Immune System'



- **Edge-Native AI:** Vibration analysis runs autonomously onboard the satellite. No need to download gigabytes of raw telemetry to Earth.
- **How it works**: The AI learns the "healthy heartbeat" of the reaction wheel. If it detects anomalies, it instantly verifies them using physical laws (spectral analysis).
- **The Result:** Predicts critical failures **7 days** in advance (7-day RUL).
  - Reduces telemetry data transmission by **99.9%** (sending only status alerts, solving the 10 kbps bottleneck).

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AI Architecture: The core engine

- **Unsupervised Learning:** A Deep MLP Autoencoder trained exclusively on healthy baseline data.
- **Latent Compression:** The encoder compresses vibration telemetry (128 → 64 → 32 dimensions) to capture the exact nominal state of the wheel.
- **Anomaly Detection:** Any structural degradation alters the vibration pattern, triggering an immediate spike in the Mean Squared Error (MSE) reconstruction loss.

$$L = \frac{1}{N}\sum_{i=1}^{N}(x_i - \hat{x}_i)^2$$

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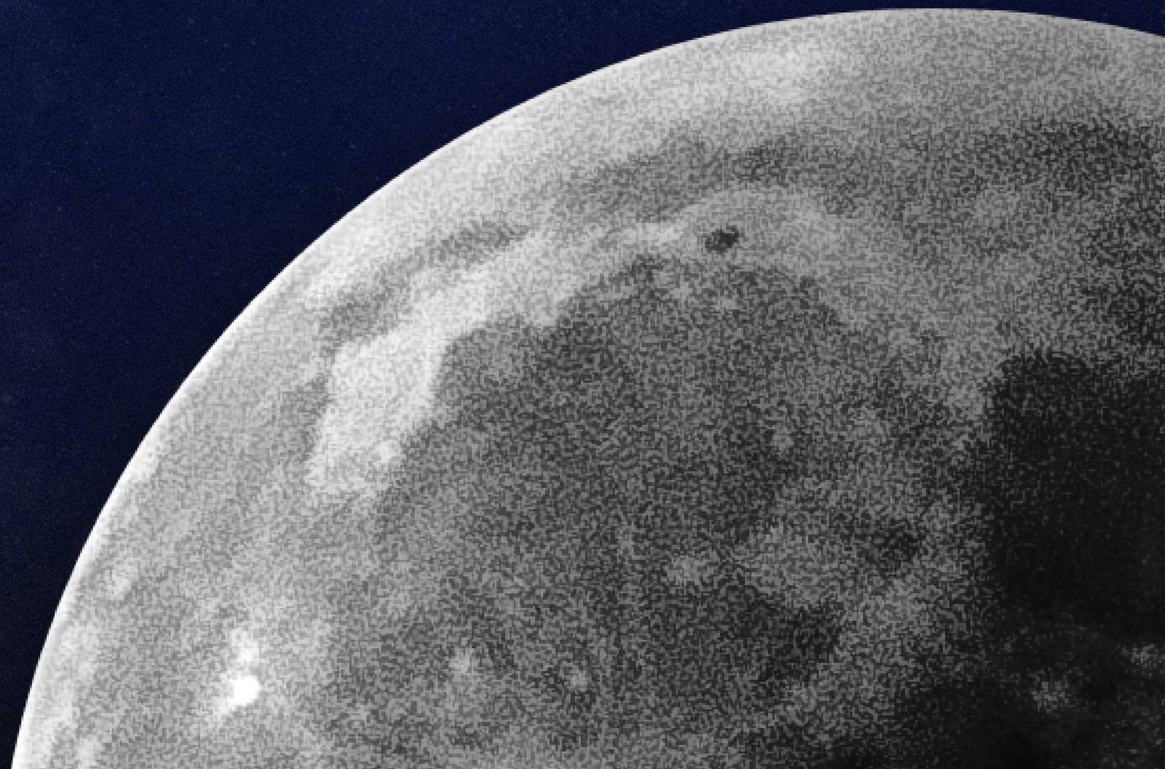
AI Meets Physics: Spectral Verification

- **The Double-Check:** High anomaly scores (MSE spikes) trigger a secondary, physics-based verification.
- **FFT Analysis:** The system applies a Fast Fourier Transform (FFT) to analyze the high-loss vibration samples.
- **Targeting the Root Cause:** It searches for exact mechanical fault patterns—specifically the Ball Pass Frequency Outer (BPFO) signature at ~166 Hz.
- **The Result:** Eliminates false positives. The AI doesn't just guess; it proves the mechanical failure.



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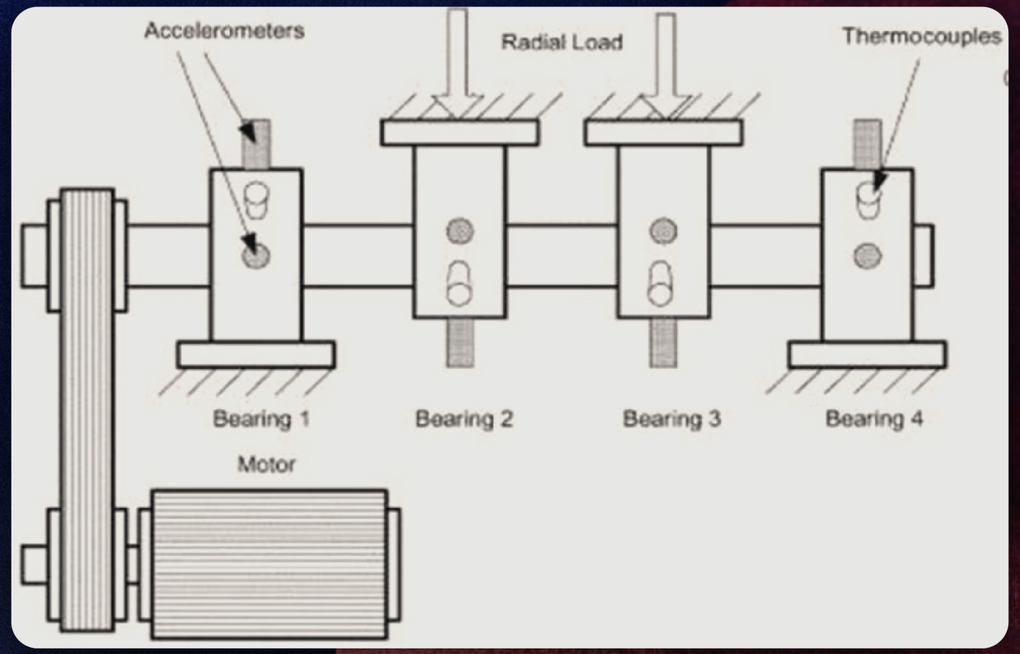
Technical Validation

The Testing Environment:

- **Data Source:** Validated using the NASA IMS Bearing Dataset.
- **Conditions:** Rexnord ZA-2115 bearings subjected to a 6,000 lbs radial load at 2,000 RPM.
- **Sensor Setup:** Data captured via high-precision accelerometers and thermocouples.



Prognostic Breakthrough

- **Target:** Early detection of outer race degradation (BPFO).
- **Lead Time:** AstroGuard successfully predicts failure **7.0 ± 0.4 days** in advance.
- **Accuracy:** Achieved a **0.97 AUROC** (Area Under the Receiver Operating Characteristic curve).

$$BPFO = \frac{N_b}{2} \cdot f_r \cdot \left(1 - \frac{B_d}{P_d} \cos \beta\right)$$

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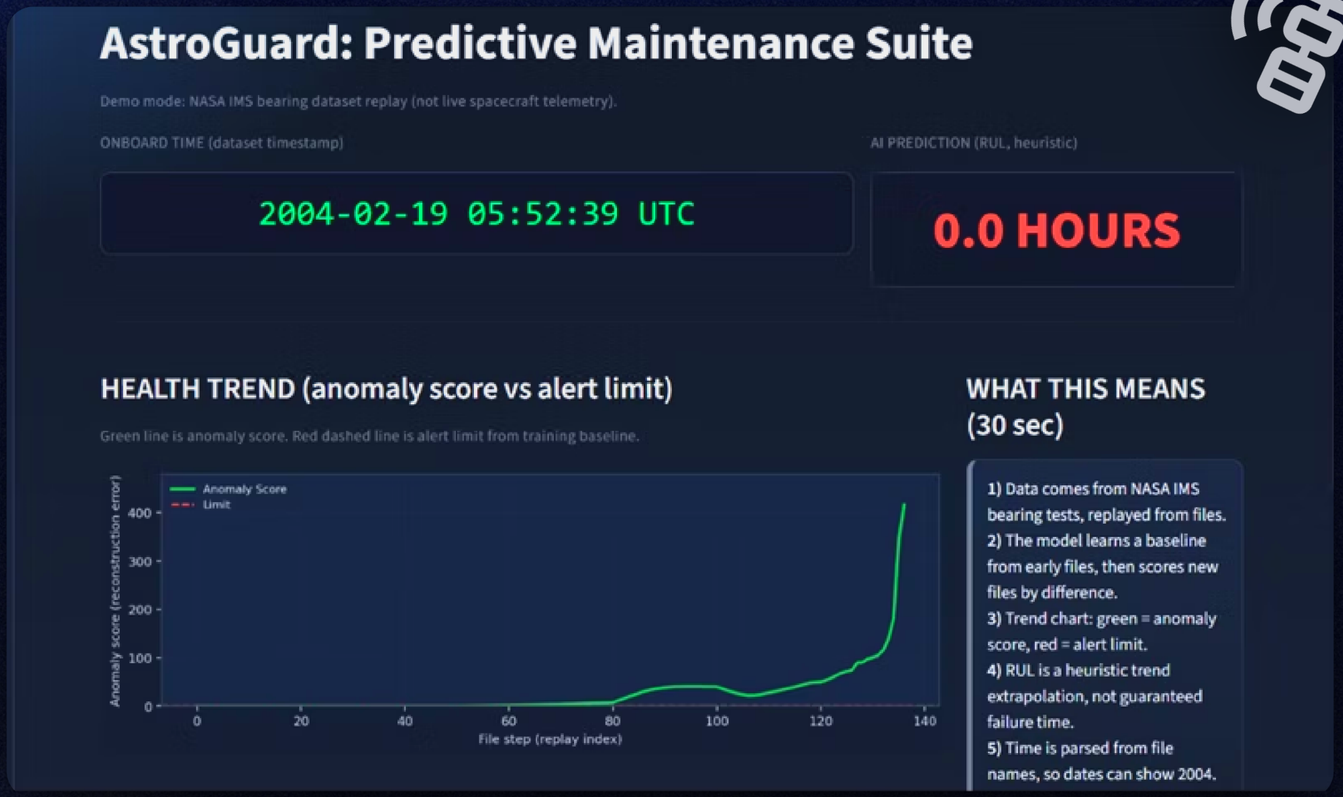
Edge Deployment & MVP

AstroGuard Mission Control

- **Hardware-Agnostic Engine:** Fully containerized via Docker to ensure seamless integration with onboard satellite Linux systems.
- **Ultra-Lightweight Performance:** Optimized to require **<20ms** inference time and **<10MB** RAM, making it compatible with legacy processors like the RAD750.
- **Bandwidth Efficiency:** Compresses telemetry transmission by **99.9%** by processing raw vibration data locally and sending only critical health status updates.



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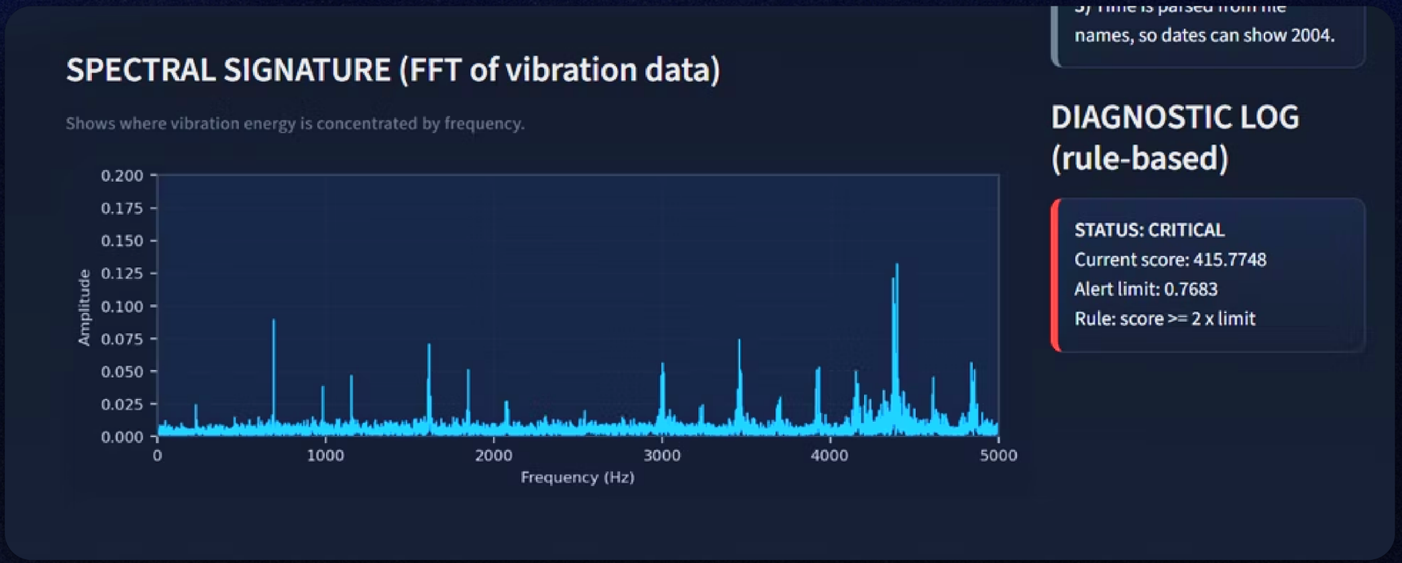
Real-Time Analytics (Prognostics)

Autonomous Onboard Intelligence

- **Health Trend Monitoring:** The dashboard tracks the **Anomaly Score** (MSE) in real-time, instantly flagging exponential deviations from the healthy baseline.
- **Remaining Useful Life (RUL):** Provides engineers with a precise countdown to potential failure, enabling proactive maintenance scheduling.
- **Physics-Based Verification:** Every AI-detected anomaly is cross-referenced with **FFT spectral analysis** to confirm mechanical defects like outer race degradation



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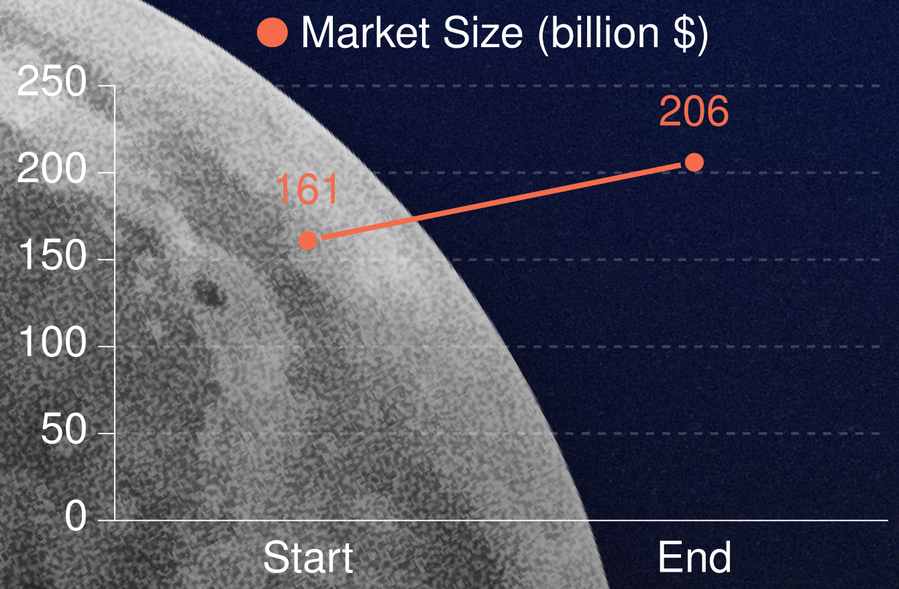
Market Analysis

The Expanding Space Economy

- **Satellite Services Market:** Valued at **$161 Billion** in 2026, projected to reach **$206 Billion** by 2030 (6.3% CAGR).
- **The Mega-Constellation Boom:** The rapid deployment of networks like Starlink (projected to exceed 10,000 satellites by 2026) makes manual, ground-based monitoring unscalable.



The Financial Impact

- **High Failure Rates:** Over 30% of attitude control issues stem from bearing and lubrication degradation.
- **AstroGuard's ROI:** Offers a massive Return on Investment (ROI) by potentially saving **$100M+** through mission extension and proactive anomaly warnings.

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Target Market & Customers

Primary Customers

- **Mega-Constellation Operators:** Companies like SpaceX (operating 9,300+ Starlink satellites) and OneWeb.
- **CubeSat Providers:** Commercial and academic operators managing smaller satellite networks.

Customer Pain & AstroGuard's Value

- **The Pain:** Maintenance and replacement operations for failed satellites in large constellations cost millions of dollars annually.
- **The Value:** AstroGuard extends satellite lifespan and prevents mission loss, offering a massive ROI by potentially saving operators **$100M+**.

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Competitor Analysis

The Current Landscape

- **Traditional Space AI (e.g., Space-Eyes):** Focus primarily on Earth observation and analyzing satellite imagery, ignoring onboard hardware health.
- **Classical Frameworks:** Rely on ground-based systems (NASA/ESA PHM) or resource-heavy supervised models that cannot run in deep space.

Feature	Ground PHM	Space-Eyes	**Astroguard**
Edge-Native	-	-	+
Unsupervised	-	-	+
Low Bandwidth	-	-	+

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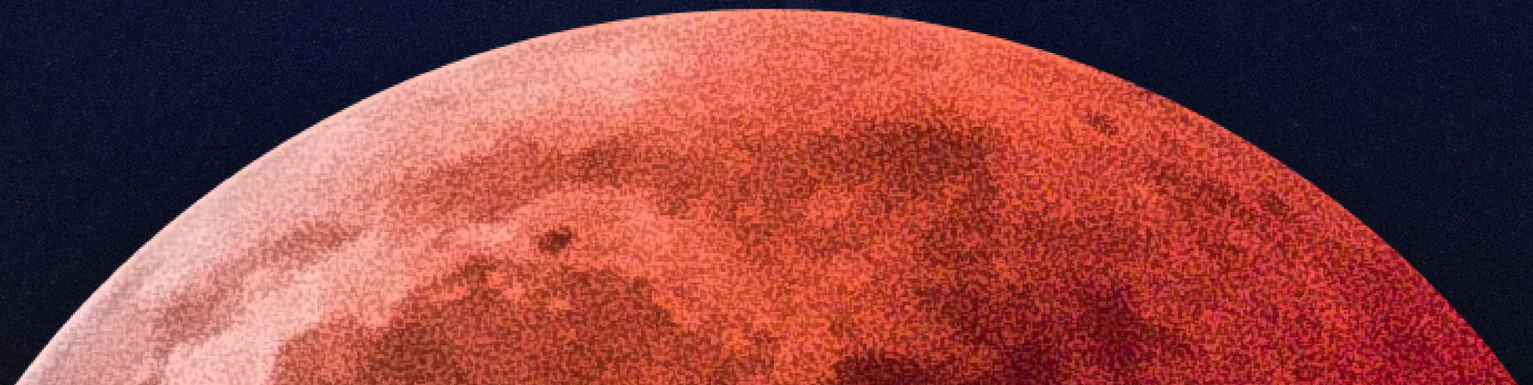
Business Model

B2B Enterprise Strategy

- **Tier 1: Edge Licensing (Onboard):** A one-time integration fee per satellite to deploy the AstroGuard Docker container during the manufacturing phase.
- **Tier 2: SaaS Subscription (Ground):** An annual subscription for access to the AstroGuard Mission Control dashboard, real-time API, and ongoing AI model updates.

Scalability & Pricing Logic

- **Volume Discounts:** Tiered pricing designed for mega-constellations (e.g., scaling from 10 to 1,000+ satellites).
- **The ROI Equation:** The cost of an AstroGuard license is a fraction of a percent compared to the $1M+ cost of replacing a single failed satellite.



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Future Roadmap

1

Phase 1: Hardware-in-the-Loop (HIL) Testing

Deploying the AstroGuard Docker container on flight-equivalent hardware (e.g., Jetson Nano, RAD750 emulators) to stress-test the <20ms inference time in real-world constraints.

2

Phase 2: Subsystem Expansion

Expanding the AI model to monitor other critical spacecraft components, such as Solar Array Drive Assemblies (SADA) and battery thermal management.

3

Phase 3: In-Orbit Demonstration (IOD)

Partnering with a CubeSat operator or university program to launch a functional AstroGuard payload for live space testing by 2027.

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Thank you for attention!

my email: mukhtarovagulsims@gmail.com

The source code and deployment instructions are available at:

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