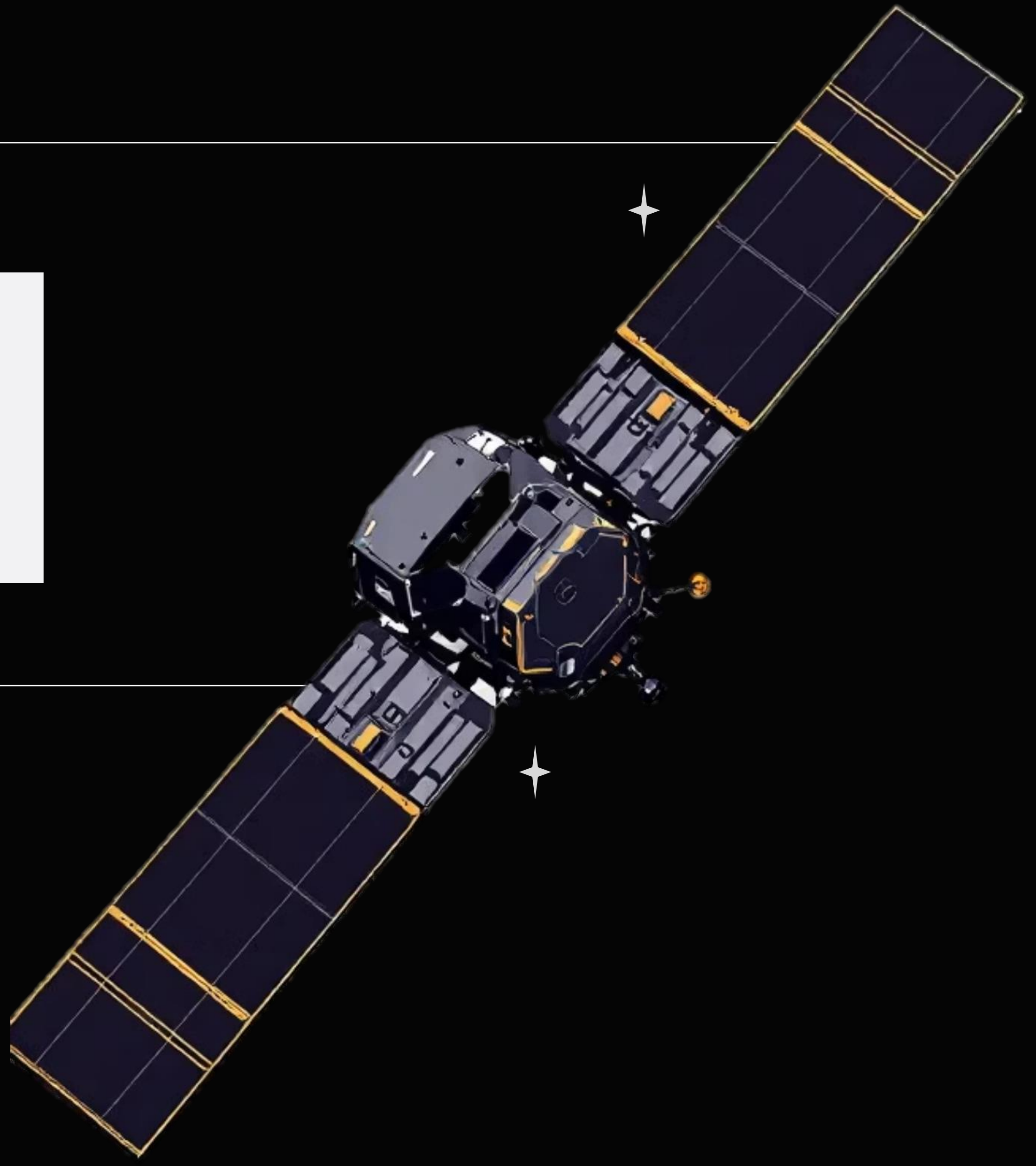

red cones

DAWN

Debris-Aware Autonomy Node

AI-driven collision avoidance
for Sentinel-1A



DAWNlings

The Growing Threat

LEO Congestion Crisis

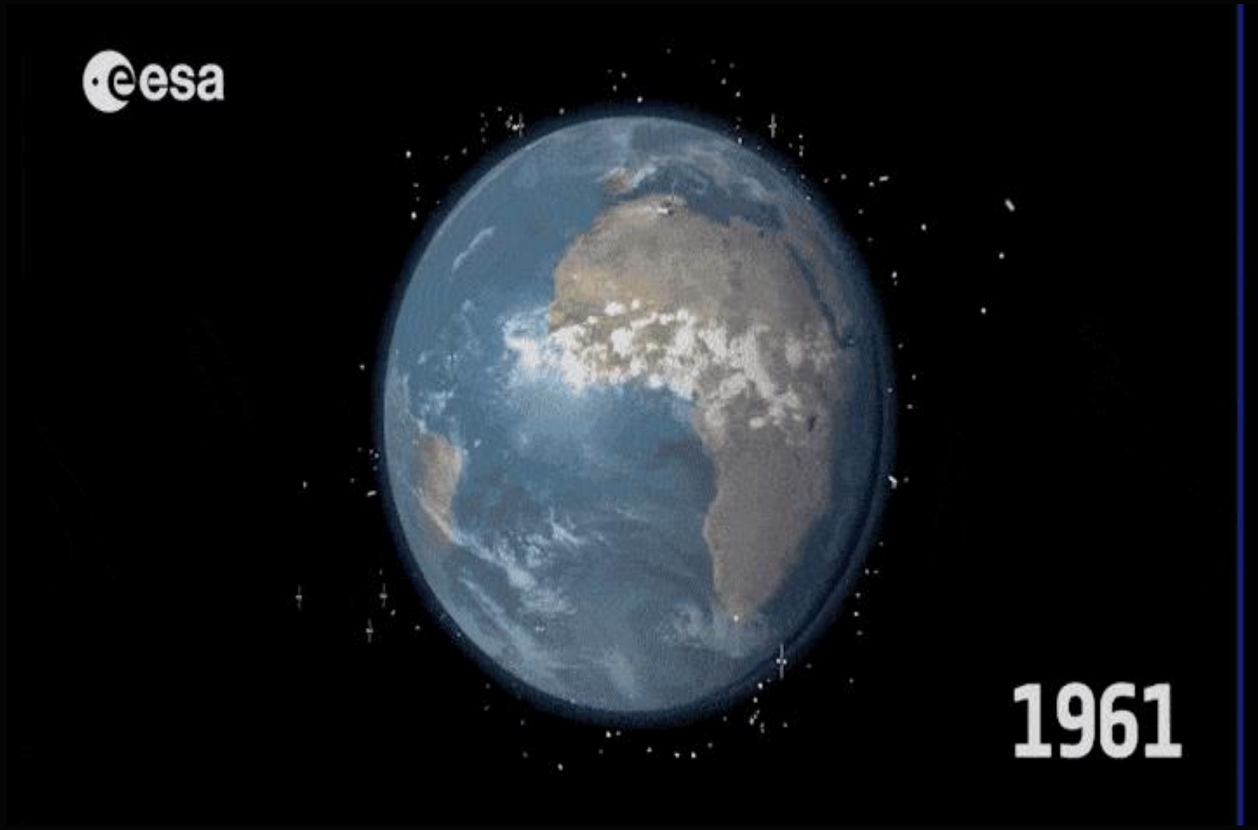
Exponential satellite growth increases collision risk and long-lived debris

- 2009 Iridium-Cosmos collision
- 2007 Chinese ASAT test
- Thousands of persistent fragments

Sentinel-1A Impacts

Real consequences of debris encounters

- 2016: Solar panel strike
- 2025: Permanent data loss
- Multiple CAMs causing downtime



Mission Inspiration

Key Specifications

Launch: April 2014 by

ESA Copernicus Program

Orbit: 693km LEO, sun-synchronous

Provides C-band SAR imaging for land deformation, maritime surveillance, polar ice, and disaster mapping — data feeding into Copernicus Emergency Management Service.

Mass: 2,300kg (130kg fuel)

Period: 98.6 minutes

Critical Systems

AOCS: Star trackers, GPS, reaction wheels, 14 thrusters

Power: 5,900W solar arrays, 324Ah Li-ion battery

Data: X-band downlink, 1,410 Gbit storage

Hit by untracked debris (Aug 2016) and solar array damage & attitude disturbance (+ confirmed data loss event Aug 2025).

Over 10 Collision Avoidance Manoeuvres (CAMs) performed since launch → fuel loss + SAR imaging interruption

Why perfect for DAWN

- Mature bus (PRIMA) with known telemetry interfaces = ideal for retrofit.
- Continuous data link via EDRS = supports on-board/ground AI integration.
- Represents a "legacy yet living" mission to prove AI autonomy without risking new hardware.

Current Limitations

Ground Control Delays

Earth-based decision loops cause minute-level latency, too slow for high-velocity debris encounters.

CAMs (Collision Avoidance Manoeuvres) depend on uplink commands — reactive, not predictive.

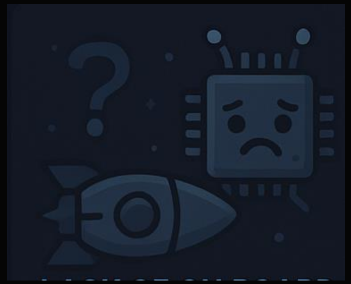
Fuel Inefficiency

Conservative manoeuvre margins consume 30–40% more propellant than optimal.
Every unnecessary burn shortens mission lifespan and interrupts SAR imaging windows.

Tracking Uncertainty

TLE-based debris catalogues fail to resolve small fragments
Limited radar coverage , positional drift errors > 1 km in 24 h during geomagnetic storms.
Result: false alarms, unnecessary manoeuvres, and untracked threats.

Lack of On-Board Intelligence



Satellites are blind passengers, fully dependent on ground stations.
No adaptive learning or real-time autonomy onboard to handle uncertainty.

Introducing DAWN

Retrofittable on-board AI system enhancing Sentinel-1A operational resilience

01

Debris Trajectory Prediction

Graph Neural Networks (GNNs) is used to works with graph-structured data, suitable for predicting debris trajectories paths under uncertainty

02

Maneuver Planning

RL allowing machines to interact with the environment and received feedback, proposes maneuvers. CC-MPC act as a filter, rejecting risky maneuvers.

03

Object Classification

lightweight computer vision (CV) model that classifies nearby debris, monitor space debris of size between 5 mm to 0.5 mm in diameter. Eg. NASA’s Space Debris Sensor (SDS).

04

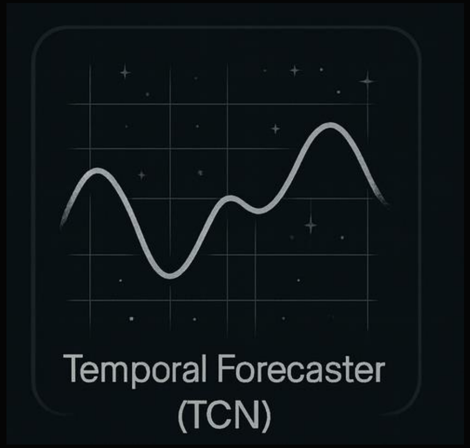
Deorbit Scheduling

Safe orbital exit planning reduces long-term debris risk. DAWN autonomously plans safe orbital exit trajectories by analysing propellant, reserves, drag, and conjunction risk to ensure controlled re-entry or graveyard transfer.

Hybrid Physics-AI Approach

Uses SGP4 and semi-analytic propagators to maintain orbital fidelity and enforce physics-informed constraints on learning, ensuring that AI-generated trajectories remain dynamically feasible.

A Multi-Relational Graph Neural Network that models spatial-temporal dependencies between debris objects, satellites, and perturbations. The Bayesian layer quantifies epistemic and aleatoric uncertainty for risk-calibrated predictions.



A Temporal Convolutional Network that captures sequential patterns in debris movement under dynamic conditions such as solar storms and atmospheric drag spikes.

A Chance-Constrained Model Predictive Controller acting as a probabilistic safety gate. It validates manoeuvre proposals from the RL agent, rejecting any action that exceeds pre-defined collision thresholds.

Integrates prediction, decision, and verification in real time. The system updates every 10–30 minutes, continuously ingesting space-weather, debris catalog, and orbital telemetry feeds to re-optimise actions.

AI Architecture: Trajectory Prediction

Orbital State Input

Keplerian elements, velocity, area-to-mass ratio

Space Weather Data

F10.7, Ap/Kp, Dst indices with SWPC forecasts

Bayesian MR-GCN

Multi-relational graph captures debris interactions

Distributional Forecast

Calibrated uncertainty bounds for risk assessment

Ethical & Regulatory Framework

Meaningful Human Control (MHC)

AI performs analysis, but humans authorize all final manoeuvres — ensuring accountability and preventing automation complacency.

Explainable AI (XAI)

DAWN's decision pathways are transparent and interpretable, allowing operators to justify AI-driven actions.

Legal and Treaty Compliance

Aligns with the Outer Space Treaty (1967), Liability Convention (1972), and principles from International Humanitarian Law (Article 36) — ensuring decisions remain traceable to human oversight.

Cybersecurity and Dual-Use Safeguards

Implements ISO/IEC 27001 standards and human-in-the-loop protocols to prevent misuse, interference, or algorithmic repurposing.

Soft Law and Standards Alignement

Complies with ISO/IEC 42001:2023 and CCSDS standards for responsible AI management and data interoperability, embedding safeguards ahead of formal regulation.

Design Trade-Offs

Autonomy ↔ Control

- **Hybrid model:** AI analyses and recommends manoeuvres using GNNs and RL-based CC-MPC, but human controllers authorize final actions.
- Combines AI precision with human accountability, following **MHC**, **XAI**, and **NASA's 2023 AI Ethics Framework**

Efficiency ↔ Sustainability

- **Multi-objective optimization:** Balances fuel use, collision avoidance, and orbital longevity.
- Incorporates **ESA Zero Debris Charter (2023)** and **UNCOPUOS** guidelines to minimize debris and extend mission lifespan.

Transparency ↔ Security

- **Controlled transparency:** XAI provides explainability while protecting sensitive data.
- Shares information only within **ISO/IEC 27001**-compliant networks, preventing interference or misuse

Imagine:

Satellites that predict, cooperate, and self-correct.

No operator fatigue. No debris blind spots. No Kessler cascade.

THAT'S THE GOAL!