Enhancing Near Earth object detection and characterisation by optimising ground-based technology and small satellite constellations

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SGAC

Near Earth Objects
Project Group

Introduction

Near-Earth objects pose a considerable risk to mankind. To comprehend the issue and safeguard our planet, it is essential to monitor and advance technologies to alleviate the risk. NEOs are mineral-rich and potentially provide fresh resources for future space research missions. Monitoring Near-Earth Objects (NEOs) may enhance our understanding of the solar system's origin as well.

By analysing and characterising NEO, we may anticipate its effect and mitigate its repercussions. Larger NEOS provide a higher hazard, but smaller NEOS are more prevalent and have considerable influence. It was believed that small NEOs disintegrate while entering the atmosphere. The Chelyabinsk meteor of size around 18m proves we need to work more on detecting small NEOs. We have around 34,000 known near-Earth asteroids and over 120 comets; still, the work is far from done.

While our ground-based telescopes and radars have proven success in the past, their restricted sensitivity due to climate and weather conditions and other technological restrictions makes space-based technology a crucial need. With the introduction of the Infrared Astronomical Satellite (IRAS), a joint project by NASA, the UK Science and Research Council and the Netherlands Space Agency in 1986, we were able to scan 96% of our sky and also understood the importance of space-based telescopes for NEOs detections. Though the telescope provides necessary support, we have to consider factors like cost, scalability, potential risk of space debris, and the instrument's sensitivity.

The technology of small satellites provides a beneficial alternative to these giant space-based telescopes. The project focuses on the design and optimisation of small sat constellations specifically dedicated to the detection and characterisation of near-Earth objects, aiming to tackle technical challenges and potential future developments. The project also stresses the limitations of current ground-based telescopes and radars and focuses on optimising and integrating their effects with small satellites. Where our major focus is designing and optimising the technology, we have also considered the constraints of cost, scalability, and issues related to quick deployment while mitigating the risks associated with rising space debris and collision avoidance. The project also focusses on analysing prior flyby missions and proposing appropriate modifications to improve the research's effects and enhance NEO's understanding.

The initiative entails a planetary defence strategy to govern operations and enhance global corporations' responsibilities, including those of private stakeholders.

1. Major Challenges in the Detection of NEO

NEOs include both asteroids and comets, which are orbiting the sun within 1.3 astronomical units of Earth. They are present in many sizes and shapes, with the larger ones going from a few metres to a few kilometres. Where bigger ones could become catastrophic risks, smaller ones are still no less dangerous, and it's proven with the Chelyabinsk meteor in 2013. Over 34,000 NEOs have been catalogued until now; still, many remain undetected because of observation gaps.

1.1 Challenges

1. Ground-based limitations: our limited sky coverage, weather dependencies, and instrument sensitivity constraints.
2. Space-based limitations: high cost and scalability issues. This also heightens the risk of space debris.
3. Until now only 40% of NEOs below 140 m are catalogued.
4. Small NEOs are always missed due to the limitation of telescope sensitivity.

1.2 The risk and opportunity with NEO

1. NEOs >140m are also a potential cause of devastation. The Tunguska Event back in 1908 could explain the reason why. On the other hand, the Chelyabinsk meteor of 2013 is also one of the incidents which proves the threat of NEOs below the size of 140m[1].
2. NEOs contain primordial solar system elements and also resources of potential water and metal for future space missions.
3. **Water resources:** C-type asteroids contain up to 20% water by mass (NASA OSIRIS-REx data)[2] and some C-type asteroids, which are dark, carbonaceous bodies, do exhibit water-rich features and are thought to be potential sources of Earth's water[3].

1.3 The NEO Threat Matrix

NEO Size	Impact Energy	Impact Frequency	Example Event
<20m	<1 Mt TNT	~10/year	Chelyabinsk (2013)
20-140m	1-100 Mt TNT	~1/century	Tunguska (1908)
>140m	>100 Mt TNT	~1/100,000 yrs	Chicxulub dinosaur killer

1.4 Key Statistics:

- Current NEO catalog: 34,000+ objects (NASA CNEOS, 2024)
- Detection gap: Only 53% of >140m NEOs found (ESA 2023 report)
- Undetected threats: Estimated 15,000 NEOs >140m remain undiscovered

1.5 Need for Space-Based Solutions

- Infrared detection from space avoids atmospheric interference.
- Small satellites offer cost-effective, scalable coverage.

1. Ground-Based Optical Telescopes

System	Aperture	FOV	Detection Rate	Strengths	Limitations
Pan-STARRS (Hawaii)	1.8m	7 deg²	~100 NEOs/month	Wide-field, high discovery rate	47% downtime (weather/daylight)
Catalina Sky Survey (Arizona)	0.7m (x3 telescopes)	8 deg²	~80 NEOs/month	Rapid follow-up	Limited to V < 22 mag (faint objects)
LSST (Vera Rubin, 2025)	8.4m	9.6 deg²	~1,000 NEOs/month (est.)	Deepest NEO survey ever	Southern Hemisphere focus only

Key Optical Challenges:

1. Daylight Blind Spot: Misses ~40% of NEOs approaching near the sun [4]
2. Atmospheric Seeing: ~1 arcsec resolution limits small-NEO detection [5]

2. Ground-Based Radar Systems

Facility	Frequency	Range	Accuracy	Strengths	Limitations
Goldstone (CA)	8.56 GHz	0.1–0.3 AU	±10m @ 0.1 AU	Best orbital precision	Only ~200 hrs/year for NEOs
Green Bank (WV)	2.38 GHz	0.05–0.5 AU	±50m @ 0.3 AU	Complements Goldstone	Lower resolution
Arecibo (Lost 2020)	2.38 GHz	0.05–0.5 AU	±7m @ 0.1 AU	Formerly highest resolution	No longer operational

Radar Constraints:

1. Requires Prior Detection: Cannot find new NEOs [6]
2. Power Limits: Only detects NEOs >100m within 0.1 AU [7]

3. Space-Based Infrared Telescopes

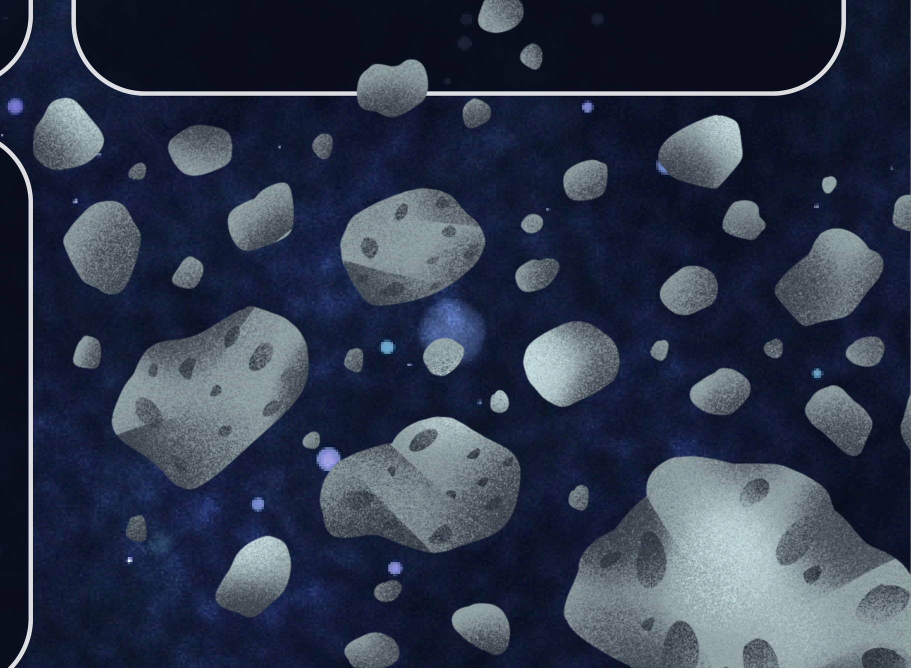
Mission	Years Active	Wavelength	NEOs Found	Strengths	Limitations
IRAS	1983 (10 months)	12–100 μm	~1,800	First all-sky IR map	Short lifetime
NEOWISE	2009–present	3–25 μm	>34,000	Operates day/night	Aging detectors (reduced sensitivity)
NEO Surveyor	Launch: 2028	4–10 μm	~65,000 (goal)	Optimized for NEOs >140m	High cost ($1.2B)

IR Advantages/Challenges:

1. Detects Dark NEOs: Albedo <0.05[8]
2. Single-Point Risk: No redundancy (unlike ground systems)[9].

Final Summary

Method	Discovery	Tracking	Best For	Critical Gap
Ground Optical	High	Moderate	Wide-field surveys	Daylight/weather blind spots
Ground Radar	None	Extreme	Orbit refinement	Requires pre-detection, short range
Space IR	High	Moderate	Dark NEOs, 24/7 ops	Cost, single-mission risk



Why small Sat

Small satellite constellations provide major benefits over conventional systems and provide a disruptive answer for NEO detection. Just 20% the cost of single-spacecraft systems like NEO Surveyor, a network of 24 500kg satellites in Sun-synchronous orbits (600km height) can offer full-sky coverage with 1-hour revisit intervals. While 0.5m telescopes with wide-field CMOS arrays (10deg² FOV) follow objects to V 21 magnitude, each satellite carries optimal payloads: dual-band infrared sensors (5-10μm HgCdTe detectors) identify 20m NEOs at 0.5 AU (SNR>5). The constellation consists of autonomous operation with inbuilt FPGA processors (100 TOPS/W) that do real-time threat assessments, therefore lowering data transmission requirements by 90%.

Constellation Design:

For ninety per cent of the sky, a 12–24 satellite network achieves 1-hour revisit times.

Important qualities consist of:

Artificial intelligence onboard: real-time threat categorisation ranks high-risk items first and filters false positives, such as cosmic rays.

Links Between Satellites: Data at 10 Gbps shared by optical lasers allows quick consensus on orbital routes free from ground-station impediments.

Satellites independently change their observation plans depending on peer-derived risk evaluations.

Trash Reducing Techniques

To solve issues of space sustainability:

Solo Collision Avoidance: With 1-meter manoeuvre accuracy, StarLink-inspired artificial intelligence forecasts and avoids garbage.

Deployable sails—such as Spinnaker-3—ensure degradation from LEO within five years following the mission, following COPUOS recommendations.

Protocols for End-of-Life: Redundant deorbiting systems (thrusters + sails) assure disposal even when main systems fail.

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