



ASRC 2026 Adelaide

The Trace, Track and Tackle Sequence

Real-Time Detection, Characterization, Triangulation and Tracking of Leo Debris Through
a Synchronized Network of Observatories and the Use of Machine Learning Algorithms

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SCOOP: From mobile astronomy to operational SSA

A portable observatory platform with applications beyond public outreach astronomy



SCOOP platform

PLATFORM

Australia's first mobile astronomical observatory

Established base

Public outreach astronomy, mobile deployment, remote-field operations and telescope/sensor integration.

New utility

The same mobility and sky-access model becomes a practical sensing layer for LEO debris detection.

TRL 3

prototype proof-of-concept positioning

1–10 cm

core debris focus for pilot scaling

LEO

densest operational orbital region

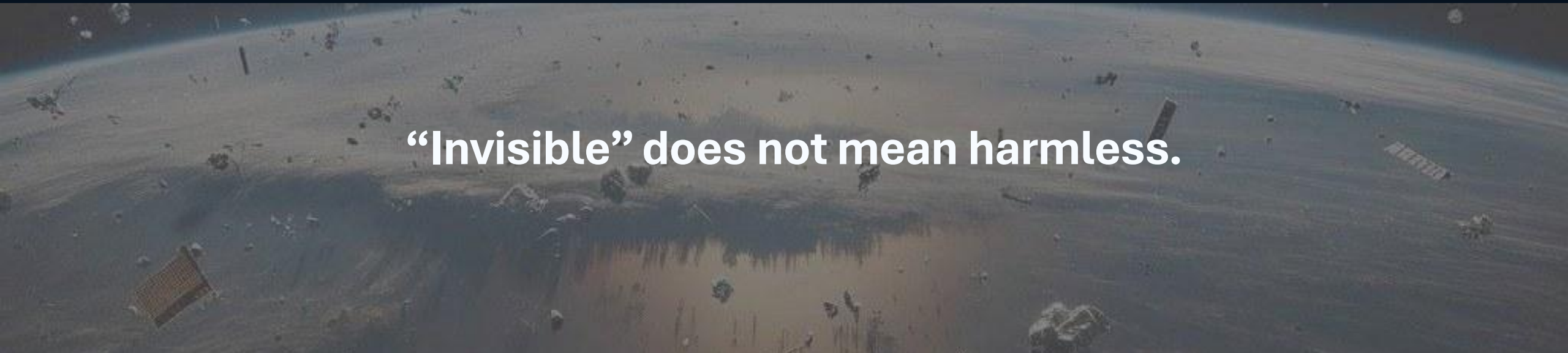
Recognised Australian space innovation



Innovation in Space Debris Detection and Mitigation

The hard problem: Small, uncatalogued LEO debris

The operational blind spot is not only detection; it is precision in real time.

A wide-angle view of Earth's surface from space, showing a dense field of small, dark debris floating in the atmosphere. The debris includes various shapes and sizes, from tiny specks to larger, more complex objects. The Earth's horizon is visible in the background, with a thin layer of blue atmosphere.

“Invisible” does not mean harmless.

1-10 cm

too small for routine catalogues; large enough to damage spacecraft

Most numerous

dominates the risk population by count

LEO

densest part of the near-Earth orbital environment

1–10 cm LEO debris: The asymmetric threat

Population × concentration × kinetic energy makes small debris a precision-critical ADR problem.



■ 1–10 cm debris
 ■ >10 cm debris

30×

**more numerous than
>10 cm debris**

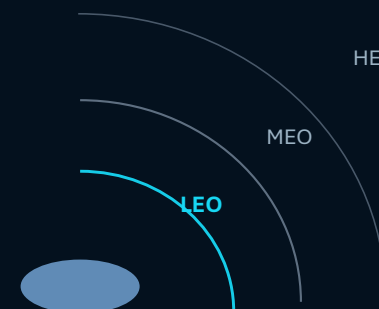
1–10 cm fragments dominate the count, but usually sit below routine catalogue thresholds.



75%+

**estimated within
the LEO shell**

LEO is a thin, operationally dense altitude band compared with the MEO and high-orbit volumes.



High kinetic energy

$v \approx 7\text{--}8 \text{ km/s}$

$KE \propto v^2$

Centimetre-scale objects can still disable or fragment spacecraft at LEO encounter velocities.

SCOOP focus: detect, trace and track the small debris population that is most numerous, most concentrated and fastest-moving.

ADR methods fail without high-precision orbital parameters

Direct capture and ground-based laser approaches require tight real-time targeting.

Direct capture

Requires a reliable, current trajectory solution before intercept planning and terminal guidance can be attempted.



Laser ADR

Requires the beam to remain on target while the object moves rapidly and may change trajectory under ablation.



Precision target: a few metres in real time

The Trace, Track and Tackle sequence is designed around that control requirement, rather than treating detection as the end point.

The sequence: Detect, refine, then act

A concerted chain to transform a faint streak into a trajectory usable by ADR systems.

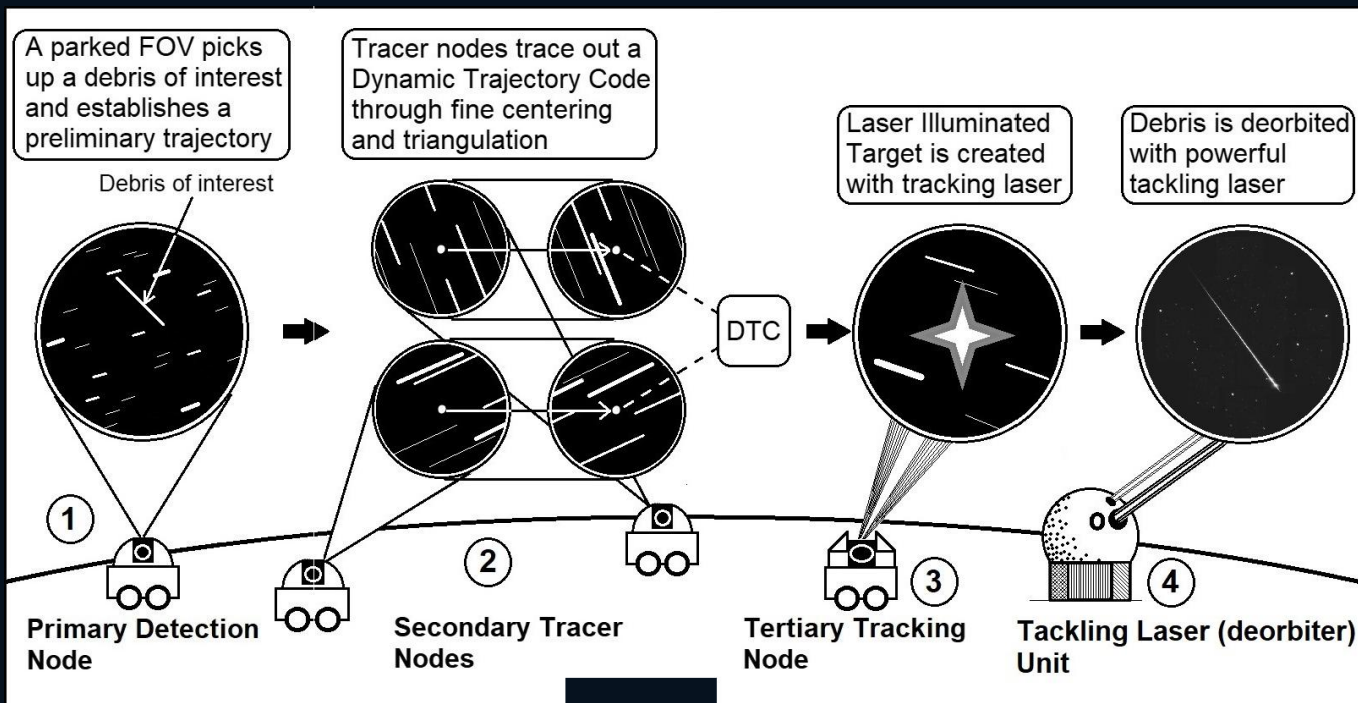


Stare-mode detection
of faint streaks

Dynamic triangulation
and trajectory refinement

Laser illumination / Optical
Characterization for ADR
engagement guidance

Ground based laser ADR or
Orbital Capture



Outcome: Dynamic Trajectory Code + operational target solution

Single-pass detection
& mitigation

Orbital database with
higher precision

Direct capture or laser
ADR enablement

DETECT: Wide-field primary detection

The first node watches a fixed sky region and turns faint streaks into initial trajectory estimates.

ONEWEB-0352
Altitude 1223km, mag 7.1
FOV 1.3 deg, exposure 200ms, BIN 4, Gain 400
Skywatcher Newtonian 250mm, f/4 in stare mode
Sensor: ZWO ASI294 23mm
25 Mar 2024, 2104
Southern Cross Outback Observatories Project
Adelaide, Australia



1 Primary detection node

- Medium-aperture, ultra-short focal-ratio telescope
- Large field-of-view, zenith stare mode
- Faint streaks detected over short exposures
- Sensor binning / detection enhancement improves sensitivity
- Low-latency upload to central server

Streak → angular velocity → initial path

ML estimate: speed • altitude • direction • size

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1 Primary detection node

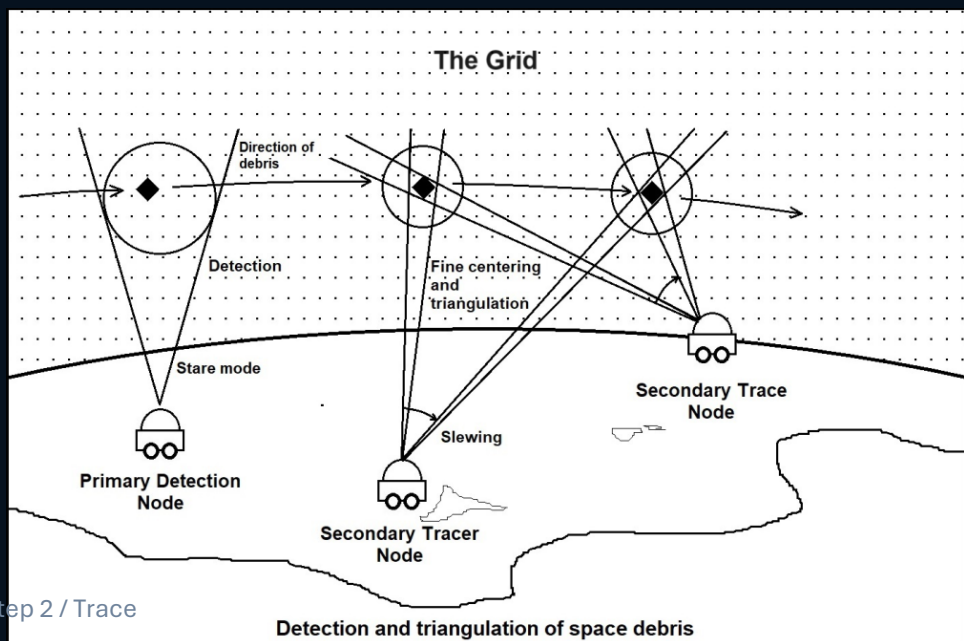
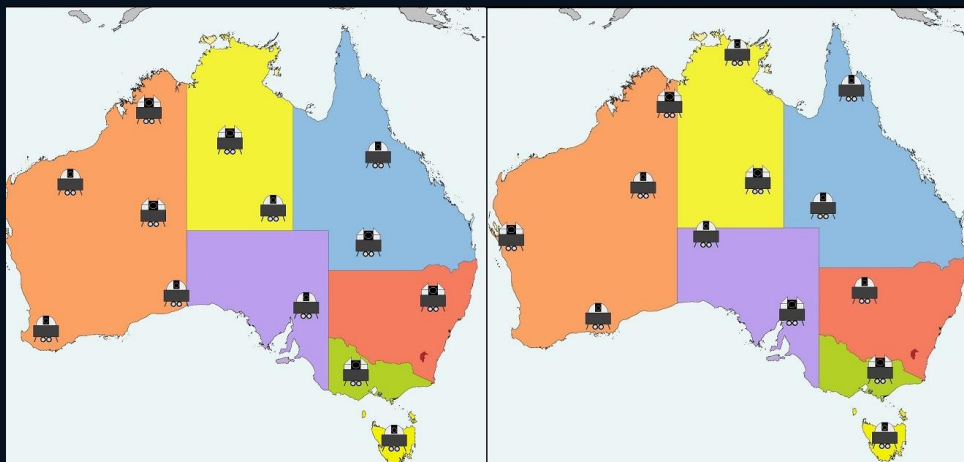
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TRACE: Synchronized tracer nodes trajectory determination and refinement

Two or more mobile observatories keep the object centred and triangulate in real time.



2 Secondary tracer nodes

- Located a few hundred kilometres apart
- Slew along the calculated path from the primary node
- Fine-centre the object in the field of view
- Triangulate telescope pointing and timing data
- Generate a continuously refined trajectory solution

Dynamic Trajectory Code

A real-time coordinate stream designed to guide terminal optical tracking, laser illumination or other ADR assets.

TRACK: Illuminate the object and guide ADR engagement

The system makes the target optically actionable and supports laser ablation.



3

Tertiary tracking node

Laser Illuminated Target (LIT)

A medium-power tracking laser with a broad cross-section at target altitude makes the debris optically visible.

Narrow-field tracking

A high-magnification telescope keeps the LIT in view using rapid course correction.

Self-integrated course correction

Further refinement of the trajectory parameters at high magnification through independent feedback loop

Spectral characterization

Analyze debris material through spectral analysis from laser irradiance

TACKLE: ADR with ground-based laser or direct orbital capture

The system makes the target optically actionable and supports laser ablation.



4

Laser deorbiter units or orbital capture satellites

Tackling laser / ADR

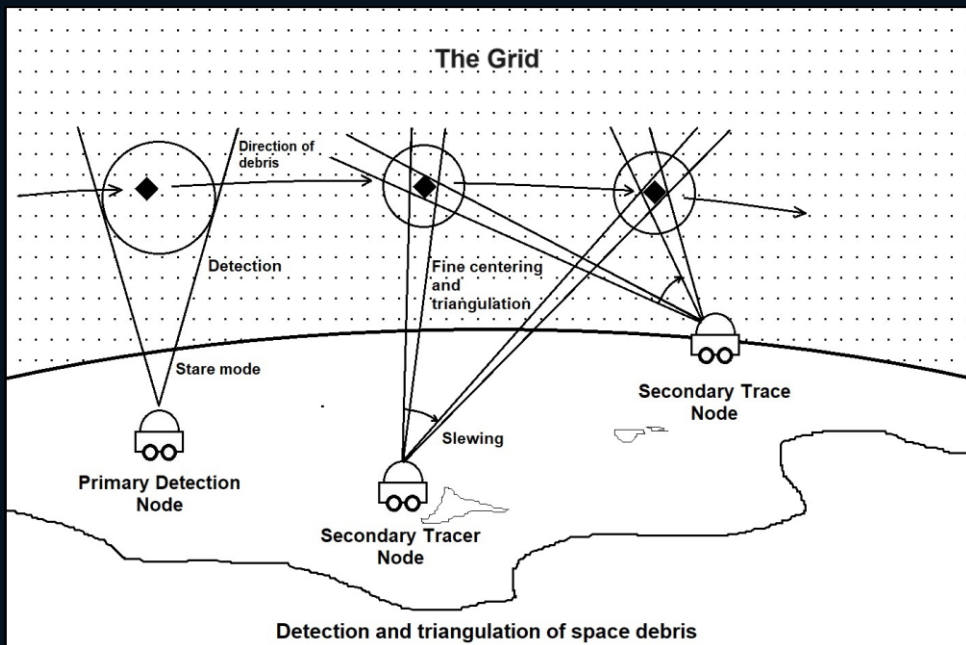
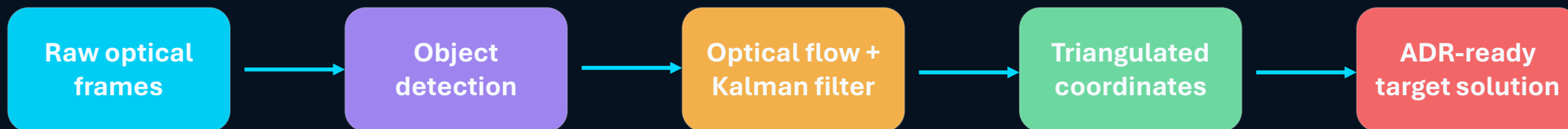
A higher-power focused system uses DTC + LIT feedback to maintain aim during engagement.

Deorbit effect

Laser ablation slows the object so it re-enters and burns up in the upper atmosphere.

DTC + GRID: A control layer for moving targets

The key output is not a static observation. It is a real-time guidance stream.



GRID options

The LEO environment can be represented in a three-dimensional pixelation matrix using Height Above Terrain, ITRS, AGRS or spherical coordinates.

Designed for real-time precision, not retrospective cataloguing

Why the observatories are mobile

Weather, seeing and geometry are operational variables; mobility creates resilience.

A network of several sub-networks

Static sensors can lose days or weeks to cloud, smoke or poor seeing. A mobile architecture can redeploy to preserve geometry and keep the sequence operational.

Vast reach

field-deployable
nodes

Rapid transit

to suitable sky and
geometry

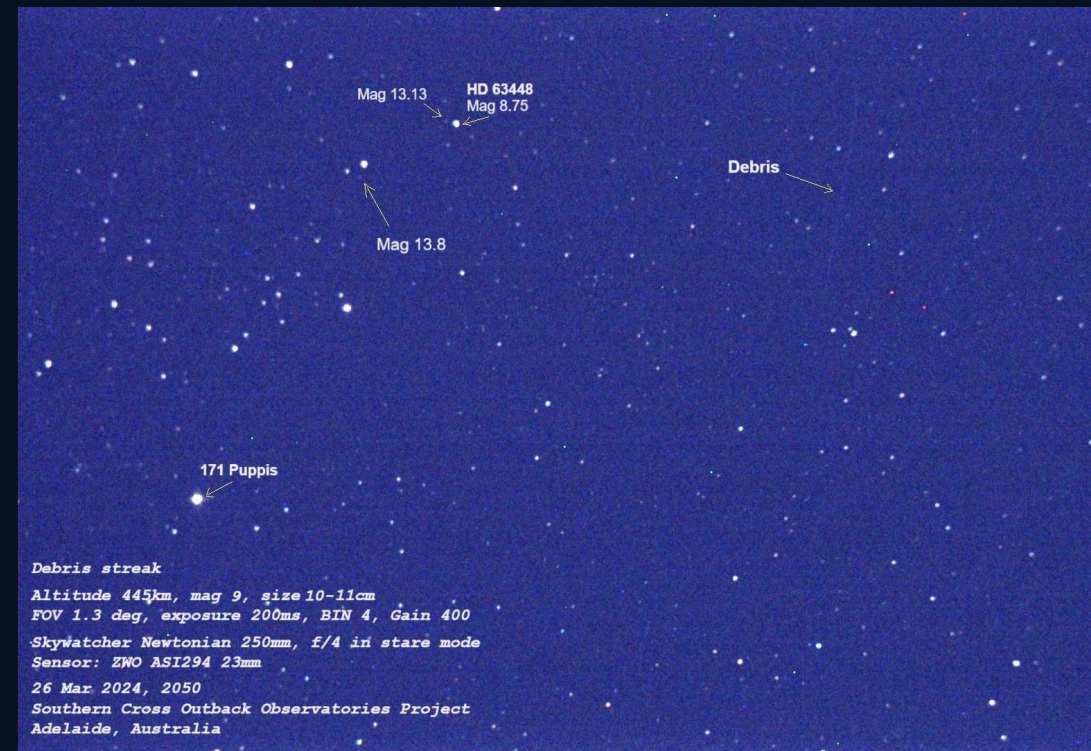
Lower mass

than large fixed arrays



Prototype test run: Primary detection of RSOs

Early experiments used accessible optical hardware to test the detection premise.



Active satellites

Defunct satellites

Rocket bodies

Unknown RSOs

Large-to-small debris
signatures

Prototype results: Faint streaks are detectable

A captured RSOs demonstrates the detection mode and image-processing premise.



Detection is the first proof point

The next proof point is synchronized multi-node tracing: maintaining target lock across sites and producing the Dynamic Trajectory Code in real time.

10–11 cm

objects characterised
in March 2024 analysis

12–20 cm

routine detections
since prototype runs

Case result 1: Estimated ~11 cm object at ~1000 km

Streak geometry + apparent magnitude provides a first-order debris size estimate.



OBSERVED FRAME ANALYSIS

323 px

streak length in 200 ms

0.0838°

angular span over
exposure

Mag ~10

motion-corrected
equivalent

Workflow: compare the streak with the faintest known star in the frame, correct for motion-induced spreading, derive angular velocity, estimate altitude, then plot magnitude against size.

Result: approximately 11 cm at 1000 km altitude

Case result 2: Estimated ~10–11 cm object at ~445 km

A second March 2024 streak supports the same detection envelope at lower altitude.



OBSERVED FRAME ANALYSIS

760 px

streak length in 200
ms

0.197°

angular span over
exposure

Mag ~9

motion-corrected
equivalent

The shorter range and faster angular motion create a longer streak, allowing a similar magnitude correction and size estimate.

Result: approximately 10–11 cm at 445 km altitude

Prototype detection envelope

The prototype already reached a meaningful small-debris threshold with modest hardware.

Parameter	Prototype		Pilot		Magnitude gain	Magnitude limit
Current						9.0
Sensor size	23mm		70mm		+1.1	10.1
Aperture	25cm		100cm		+3.0	13.1
SNR	Low		High		+1.5	14.6
Focal Ratio	f/4 (1m)		f/1.4 (1.4m)		-0.4	14.2
Sensor quality	Multicolor		Monochrome		+1.1	15.3
Sky	Bortle 5		Bortle 1		+2.3	17.6

250 mm f/4

Skywatcher 250 Quattro

ASI294

23 mm CMOS sensor

1.3°

field of view

Exposure regime

200 ms exposures, 4×4 binning and high gain to increase faint-streak detectability.

Stellar limit

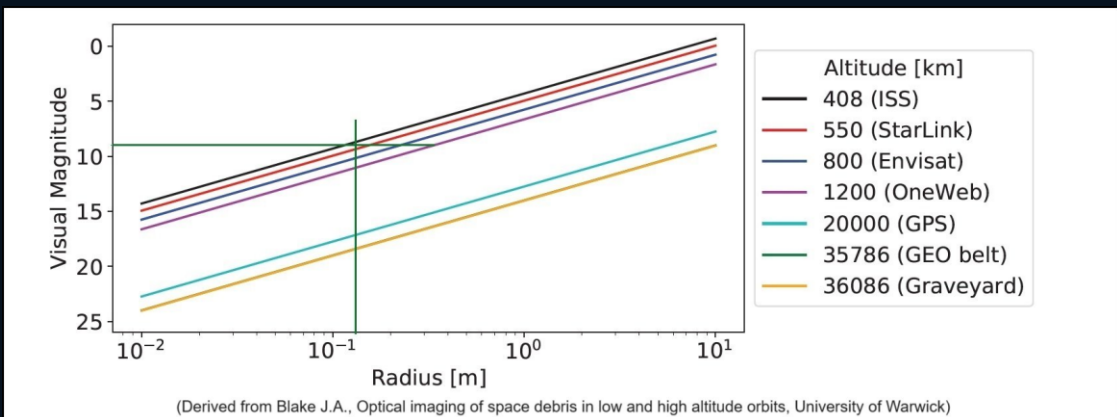
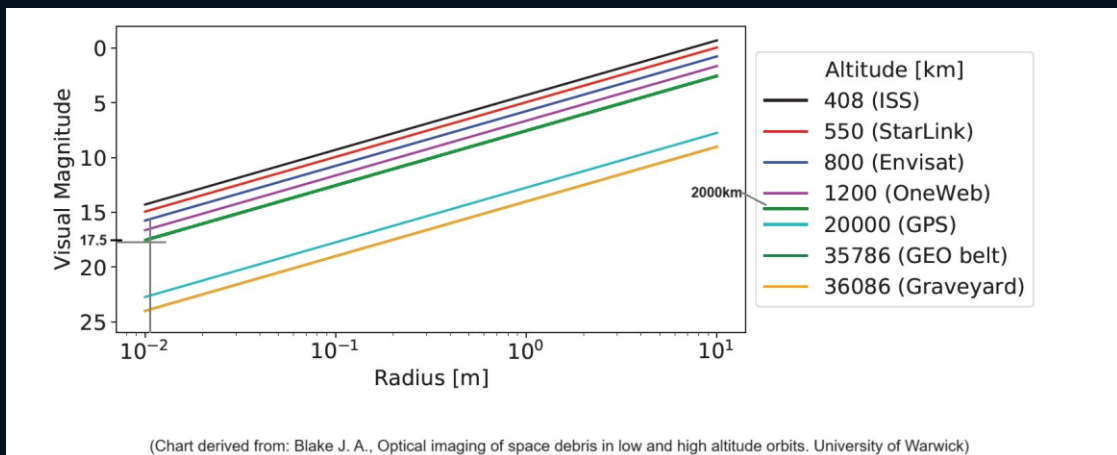
Faintest stars around magnitude 15; operationally stronger around magnitude 14.

Debris equivalent

Debris detection envelope around magnitude 10; stronger around magnitude 9.

Prototype → Pilot: A scaling path, not a leap of faith

The pilot upgrades aperture, focal ratio, sensor area, sky quality and network geometry.



Pilot primary detection node

Expected mobile upper limit: ~1 m aperture, shorter focal ratio, larger sensor and wider field-of-view, deployed under darker outback skies.

Larger aperture

Shorter f-ratio

Larger sensors

Darker skies

Synchronized sites

Real-time ML

Target: 1–10 cm LEO debris

AI closes the loop between seeing and steering

The system uses machine vision to guide telescope slewing and trajectory refinement in real time.

1

Object detection

detect faint streaks against star fields and noise

2

Optical flow

estimate apparent motion and direction across frames

3

Kalman filtering

stabilise the estimate under noisy observations

4

Closed-loop control

send slew updates to the tracer nodes and ADR assets

Output: continuously updated Dynamic Trajectory Code



Positioning: Precision-oriented, deployable optical SSA

The value proposition is a networked method for the debris class that is currently difficult to catalogue.

Dimension	Large radar / fixed SSA	Single-site optical	SCOOP sequence
Target class	Stronger for larger catalogued objects	Limited by geometry and brightness	Optimised for uncatalogued 1–10 cm LEO debris
Architecture	Capital-intensive fixed assets	One line-of-sight	Mobile synchronized network
Core output	Track catalogue / surveillance	Observation record	Real-time DTC for ADR guidance
Resilience	Location constrained	Weather constrained	Can redeploy sub-networks

Designed around ADR precision

Rather than producing only a detection record, the sequence is built to generate a target solution actionable by ground-based or orbital debris-removal systems.



INVESTMENT AND PARTNERSHIP OPPORTUNITIES

Let's build the optical precision layer for small-debris ADR.

Next phase: pilot deployment of synchronized mobile observatories, real-time triangulation, DTC generation and ADR integration pathways.

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