



ON ORBIT CALIBRATION OF LASER BEAM INTENSITY

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SERC:

- Automated, high-precision laser tracking of space debris has been operationally deployed in Australia for many years
- Leverage accurate debris catalogue to improve safety of navigation in space, and ultimately to **safely** move space debris using ground-based lasers
- Integrate best-available global technologies in an international collaboration
- Initial R&D budget US\$50M plus infrastructure budget US\$60M
- 2018 expansion will double R&D and infrastructure programs

SERC Founding Participants



SERC members represent government, industry and universities across several countries [Japan, USA, Australia].

Expansion to more countries will occur in 2017.

Collisions in Space

- Algorithms propagate all catalogue objects in an *all-on-all* conjunction analysis
- Runs every hour for the entire catalogue to produce 7 days look-ahead for collisions
- Catalogue updated continuously with new tracking data

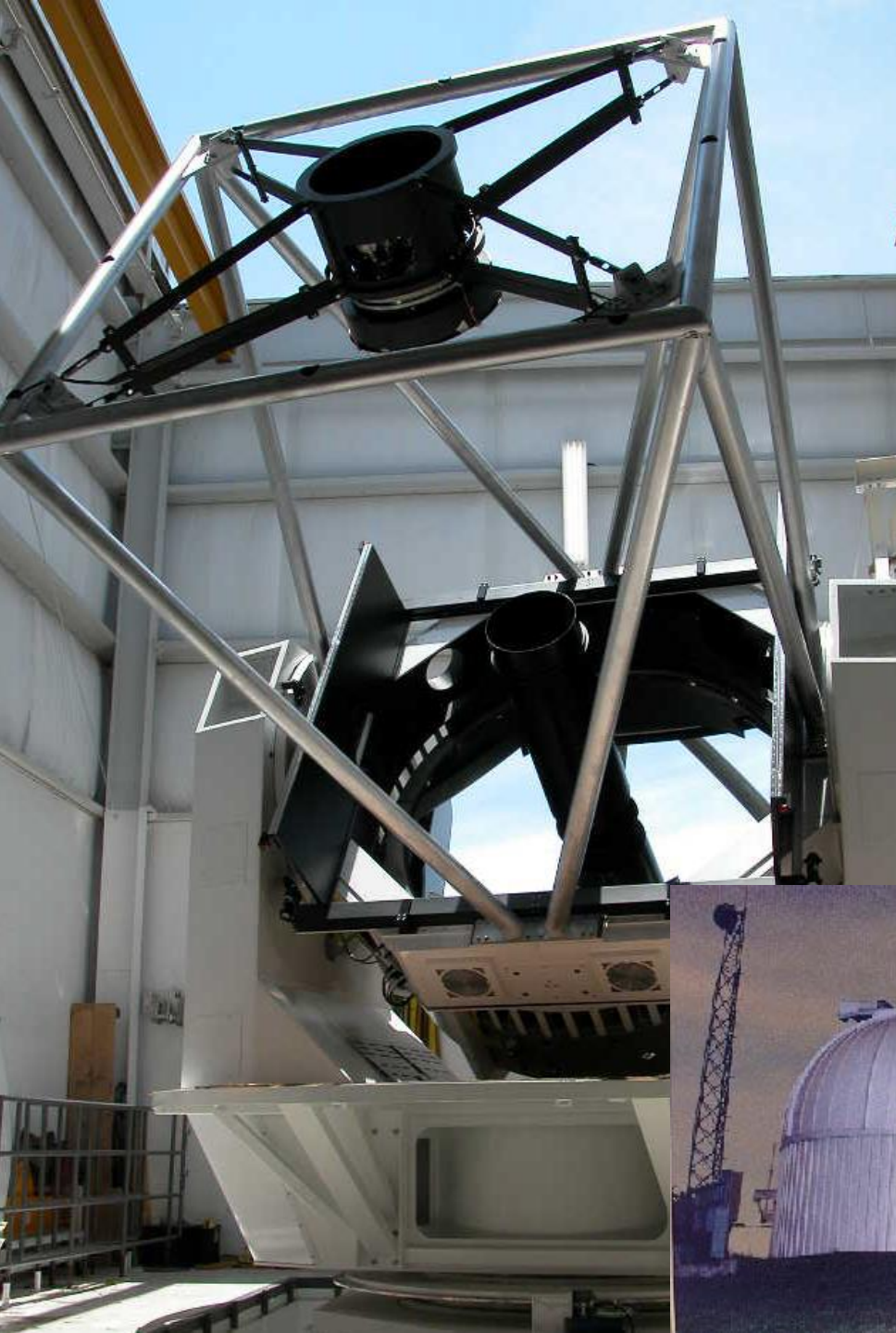
Conjunction Statistics

| Closest Approach | Number of Occurrences |
|------------------|-----------------------|
| <5km | 42,000 per week |
| <1km | 3,000 per week |
| <500m | 700 per week |

- 5km is typical for NORAD position uncertainties
- 500m was the predicted miss distance for Iridium/Cosmos crash

Accurate orbits [$<100\text{m}$ error] resolve almost all potential collisions, and manoeuvre can then protect all satellites

However, debris manoeuvre and debris removal remain key objectives



**Typical EO
Sensors**



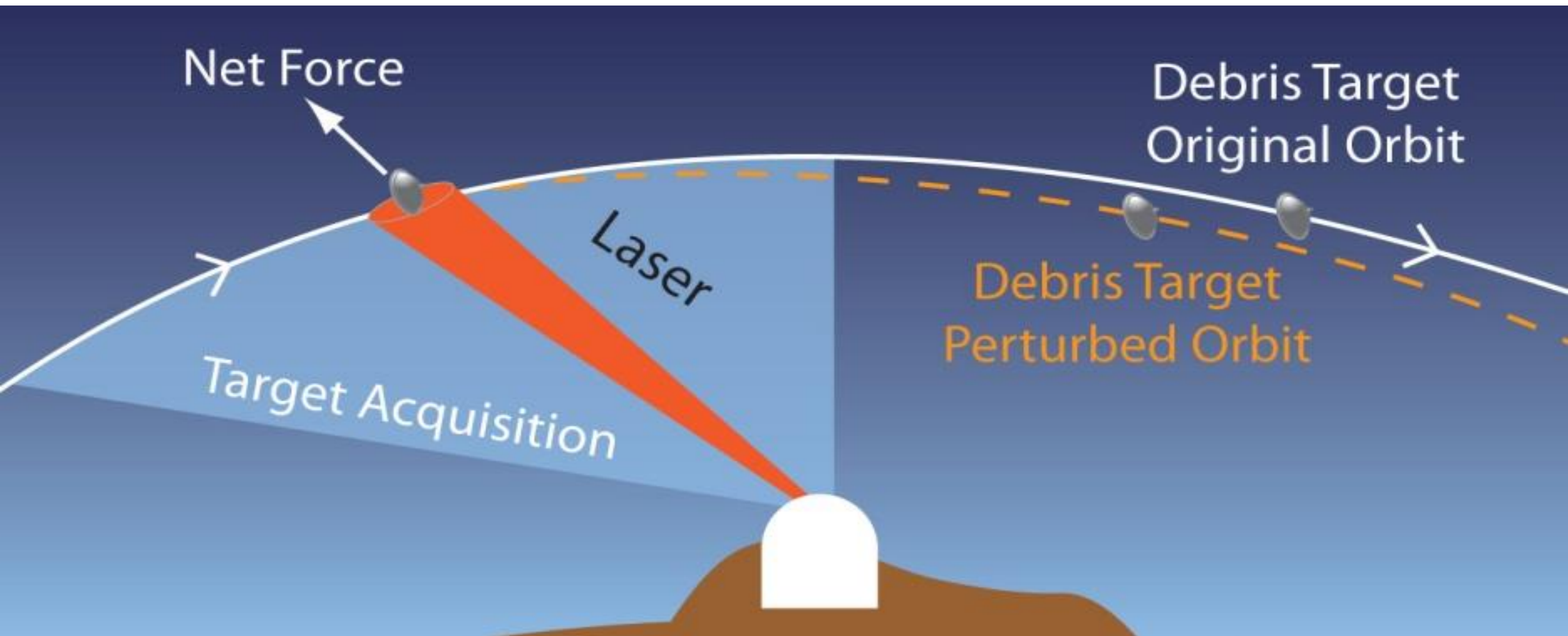


EOS Space Research Centre at Mount Stromlo, Canberra, Australia

EOS Space Debris Site in WA



Manoeuvre by CW Laser Radiation



This is an inherently gentle and slow process



Avoidance vs Removal

- SERC is fully funded to demonstrate the feasibility of reducing the rate at which collisions occur by temporarily relocating debris using *non-threatening* CW lasers
- CW lasers of 20-100 kW produce radiation on orbit similar to solar radiation, and apply radiation pressure
- Laser engagement may need to be repeated a number of times for each object
- It's a temporary solution, but it **buys time** while more permanent solutions are developed and implemented.



How much manoeuvre is enough?

If we assume we act in the final 48 hours before a predicted collision

- SERC special catalogue has the positions of each object for 48 hours to 80 m uncertainty.
- We need to move one object >160 m to be sure of avoiding a collision
- This means we need an average velocity change of 1 mm/sec over 48 hours

Debris velocity change: worked example

| Parameter | Value |
|------------------------------|--------|
| Orbit Altitude | 500 km |
| Debris Dimension | 20 cm |
| Debris Mass | 0.2 kg |
| Beam Director Diameter | 1.8 m |
| Laser Power | 20 kW |
| Laser Beam Quality (M^2) | 1.2 |
| Delivered Strehl | 0.3 |

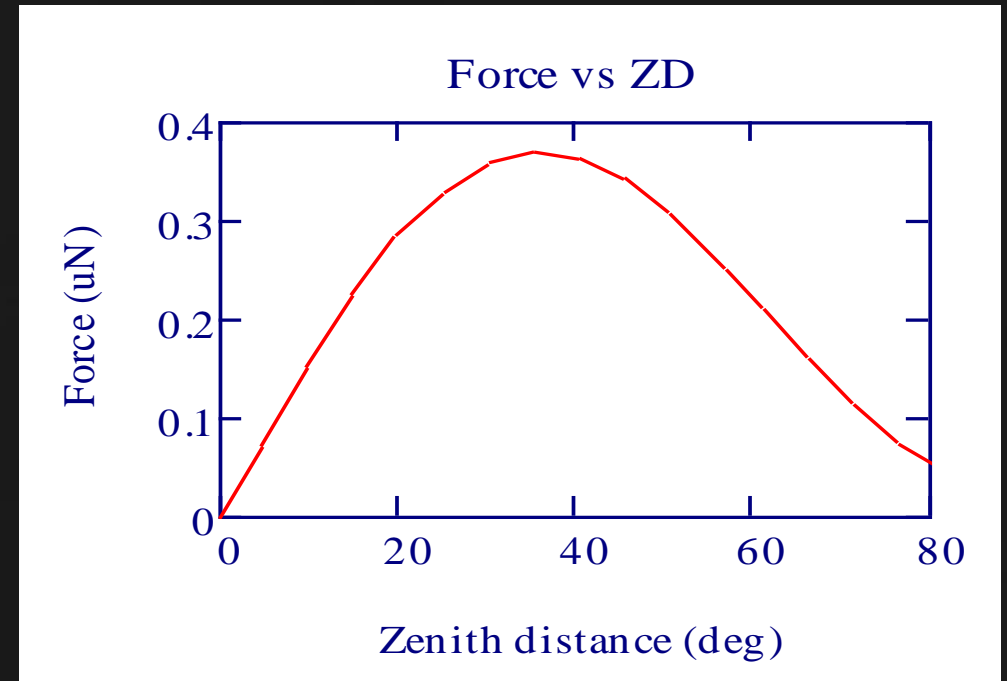
A/M=0.2

Velocity Change

Allowing for photon flux, range, along track vector and dwell time vs ZD

Integrate under the curve and divide by mass gives $\Delta v = 0.16$ mm/s or 6 passes for 1mm/s change

SERC baseline configuration provides marginal performance but affordable phenomenology verification is needed



“Artificial” debris is required to achieve proper characterization of the phenomenology and fully assess the operational utility [affordability]

A black pyramid-shaped satellite is shown in space, with the Earth's blue and white surface visible in the background. The satellite has a central gold-colored component and is oriented towards the viewer.

Test Satellites

SERC will build and launch TWO test satellites by 2020 to calibrate laser beam properties in space.

Satellites will have corner cubes, laser power measurement, precision navigation, and radiation sails.

Use by collaborating agencies will be permitted.

SERC will release AO in 2017 for use of these satellites by collaborators



Project Timeline

1. 2016: Precision debris tracking and orbit propagation
2. 2017: AO system and 20 kW laser operational
3. 2018: Launch test satellite #1 for beam monitoring on orbit
4. 2019: Launch test satellite #2 for thrust measurement
5. 2020: Debris manoeuvre experiments



Summary

1. Demonstrate by 2020 that photon pressure can be used to modify the orbit of smaller debris objects
2. Requires:
 - Precision tracking
 - Accurate orbit propagation
 - Energy Concentration (beam director & AO).
3. Ca. 50% of small [$<10\text{kg}$] objects can be moved
4. Reduces collision risk and buys time for debris removal



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