

# Remote Manoeuvre of Space Debris Using Photon Pressure for Active Collision Avoidance

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- EOS Space Systems
- CRC for Space  
Environment Management

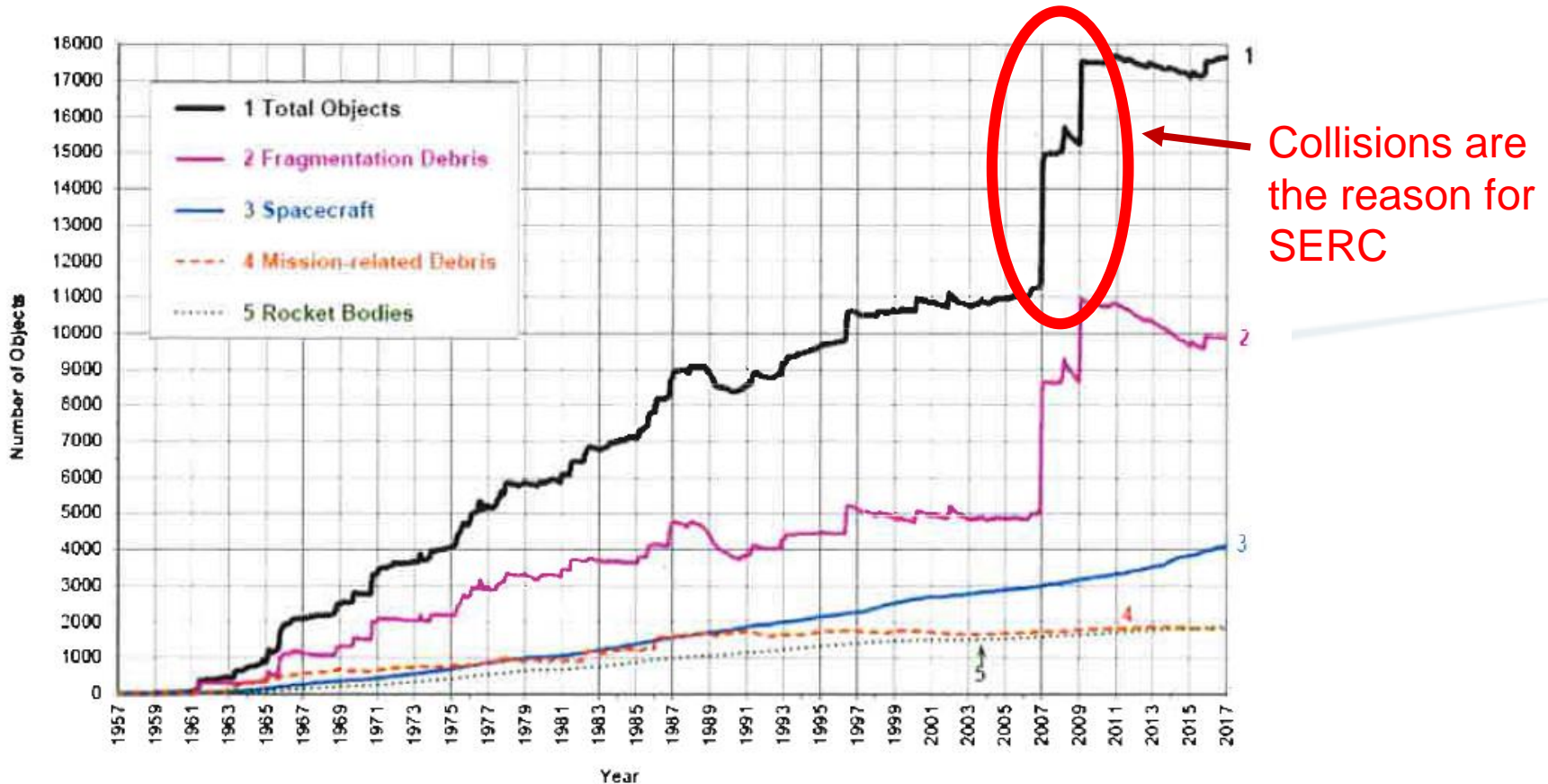
*International Workshop of  
Space Debris Management  
9 Nov 2018*



- CRC for Space Environment Management operated by the Space Environment Research Centre (SERC)
- Five year program 2014 - 2019
- SERC Partners
  - EOS Space Systems
  - Lockheed Martin Australia
  - Optus Satellite Systems
  - The Australian National University
  - RMIT University
  - National Institute of Information and Telecommunications Technology (NICT) Japan
  - Commonwealth of Australia

# SERC Objectives

- Collision avoidance and mitigate Kessler Syndrome



Evolution of the number of objects in orbit [NASA<sup>4</sup>]

## Collision Avoidance: Active Satellites

- When a conjunction (potential collision) is predicted most active satellites can manoeuvre to avoid the collision.
  - Micro sats and mega constellations challenge that assumption
- But:
  - Manoeuvres use fuel and shorten satellite lifetime
  - Not on station while manoeuvring
  - Many satellite operators choose to ignore collision warnings
- Satellite operators need/want actionable collision warning information

# Collision Avoidance: Passive Satellites and Space Debris



- Passive Satellites and Space Debris have no maneuver capability
- When debris collides with debris **everyone** loses
- So what can we do about debris collisions and pending Kessler Syndrome cascade?



# SERC Activities



- SERC is looking at techniques and technologies that can help avoid all types of collisions and preserve the orbital environment for future use.
  - From LEO to GEO and Deep Space
  - For passive and active satellites and debris
- In Deep Space this means actionable threat warning
- In LEO this is threat warning and physically stopping the collisions by remote manoeuvre.

# Four Research Programs



- **RP1**: Remote Manoeuvre of Space Debris Using Photon Pressure with Demonstration on Orbit
- **RP2**: New and Improved Orbit Determination and Propagation Techniques
- **RP3**: Conjunction Assessments and Threat Warning Services
- **RP4**: Satellite Based Test Bed



# Research Program 1:

## Remote Manoeuvre of Space Debris Using Photon Pressure

Primary Contributors to RP1:

- EOS Space Systems
- ANU RSAA
- Lockheed Martin Australia
- SERC



# Collision Avoidance

- Two objects at orbital velocities (7.5 km/s) spend  $<100 \mu\text{s}$  in the same 3D space.
- If we can shift the point in time that one object reaches an intersection point by  $100 \mu\text{s}$  (1m in along-track) a collision could be avoided.
- In reality it's a bit more complex than that because our predictions aren't as good as  $100 \mu\text{s}$  (1m).
- This is avoidance, not removal.

# Radiation Pressure



- Photon Energy
- Photon Momentum

$$E_{\text{ph}} := h \cdot \frac{c}{\lambda} \quad P_{\text{ph}} := \frac{h}{\lambda}$$

## THE ASTROPHYSICAL JOURNAL

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### THE PRESSURE DUE TO RADIATION.<sup>1</sup>

By E. F. NICHOLS and G. F. HULL.

AS EARLY as 1619 Kepler<sup>2</sup> announced his belief that the solar repulsion of the finely divided matter of comets' tails was due to the outward pressure of light. On the corpuscular theory

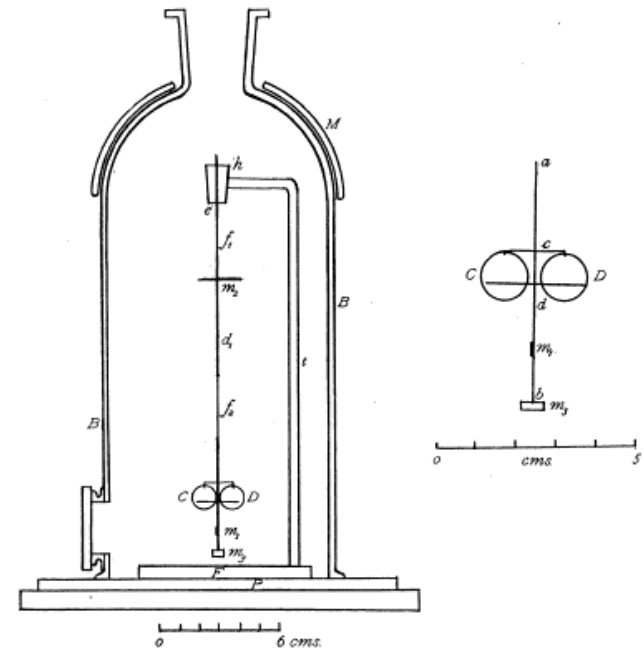
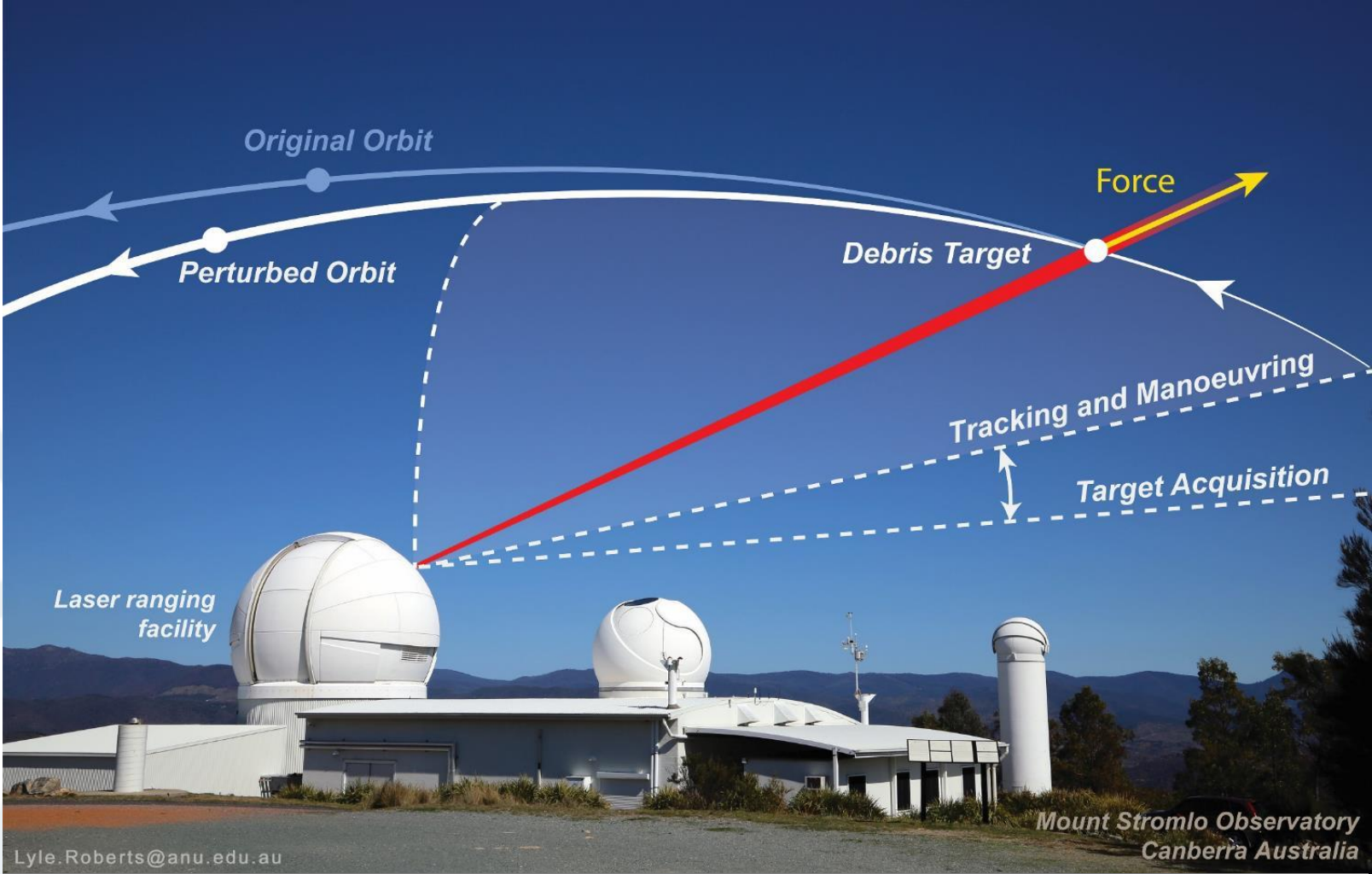


FIG. 1.

# Solar Sail driven by Radiation Pressure



# Photon Pressure for Remote Maneuver



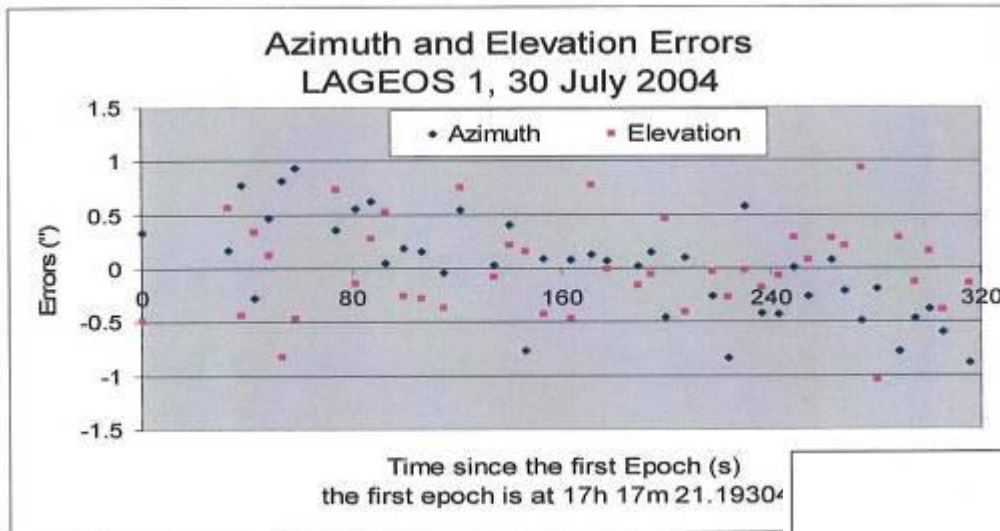
Lyle.Roberts@anu.edu.au

# How much is enough?

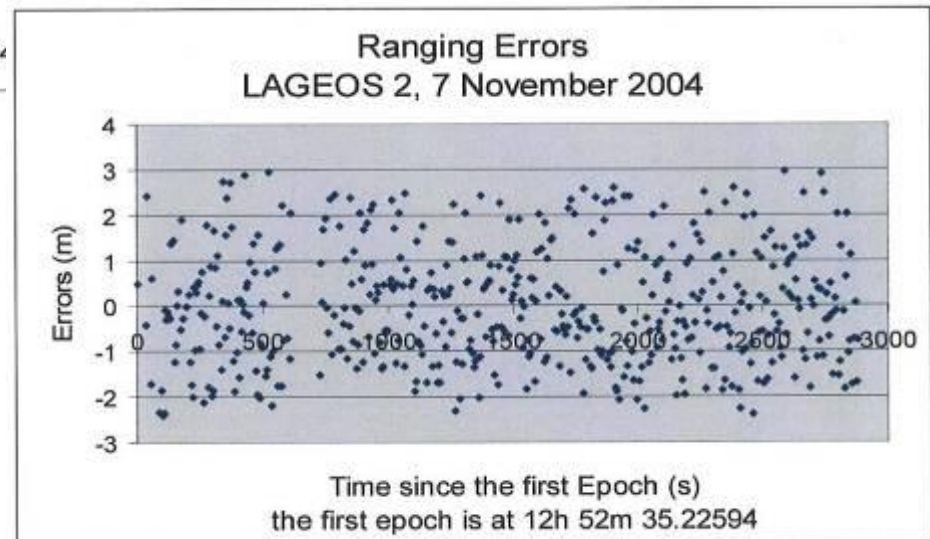


- We are talking about using light pressure to manouver a space debris object. Photon pressure is weak, so we only want to make the smallest change necessary to have an effect
- So it comes to a balance between
  - how accurately we can measure the position
  - how accurately we can propagate the orbit
  - how far is it practical to move an object using lasers from the ground

# Measurement Accuracy



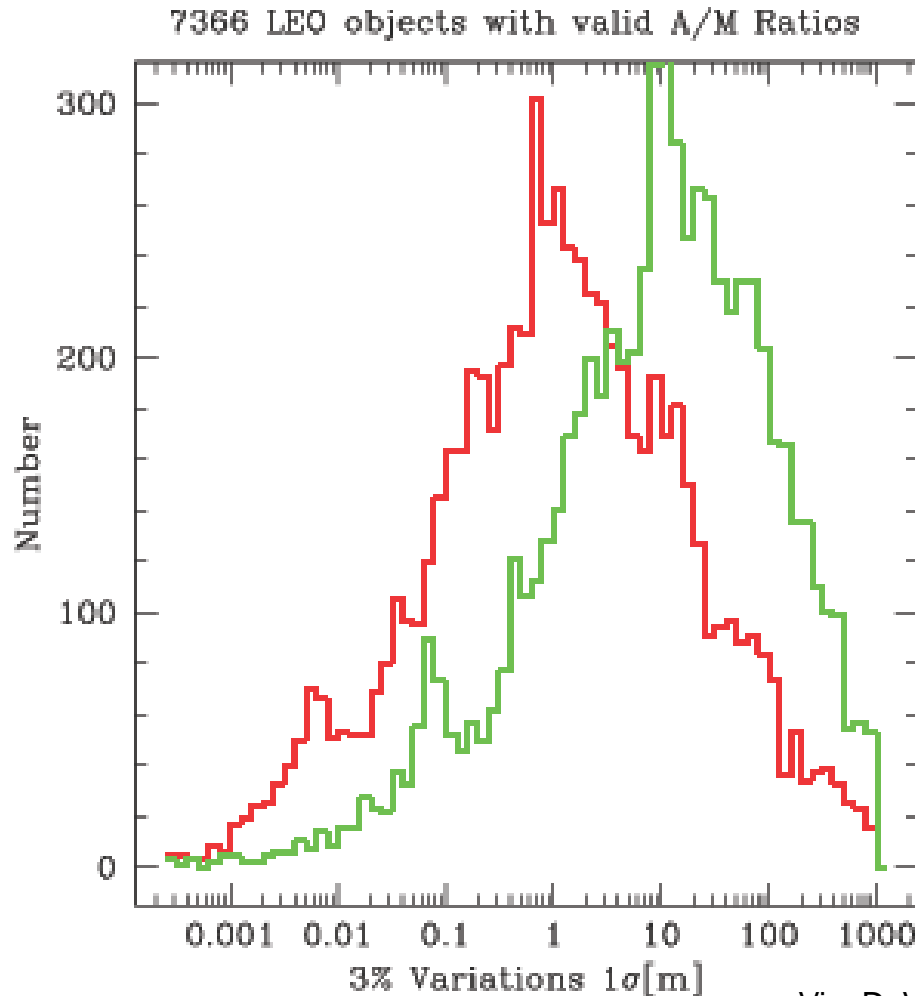
RMS Angular Error  $\sim 1.5$  arcsec  $\approx 7\text{m}$  @ 1000km



RMS Range Error  $\sim 1\text{m}$



# Natural Variability



- Plot of in-track variability after 24 hours
- Red and green curves use different A/M estimators
- The majority of objects have in-track uncertainty <100m after 24 hours.

Vim DeVries: LLNL



# How much velocity change do we need to get 100m separation?



Orbital Velocity

$$v := \sqrt{\frac{G \cdot M_E}{R_E + \text{Alt}}} \quad v = 7454 \text{ m} \cdot \text{s}^{-1}$$

Allocated time to effect change

$$\Delta \text{Time} := 24 \cdot 3600 \cdot \text{s}$$

Required Along Track Distance after delta T

$$\Delta D := 100 \text{ m}$$

Required Velocity Change

$$\Delta v_{\text{desired}} := \frac{\Delta D}{\Delta \text{Time}} \quad \Delta v_{\text{desired}} = 1.157 \cdot \frac{\text{mm}}{\text{s}}$$

# System Parameters

Parameter	Value
Orbit Altitude	500 km
Target Diameter	20 cm
Target Mass	0.2 kg
Beam Director Diameter	1.8 m
Laser Power	18 kW
Laser Beam Quality ( $M^2$ )	1.2
Delivered Strehl	0.3

A/M=0.2

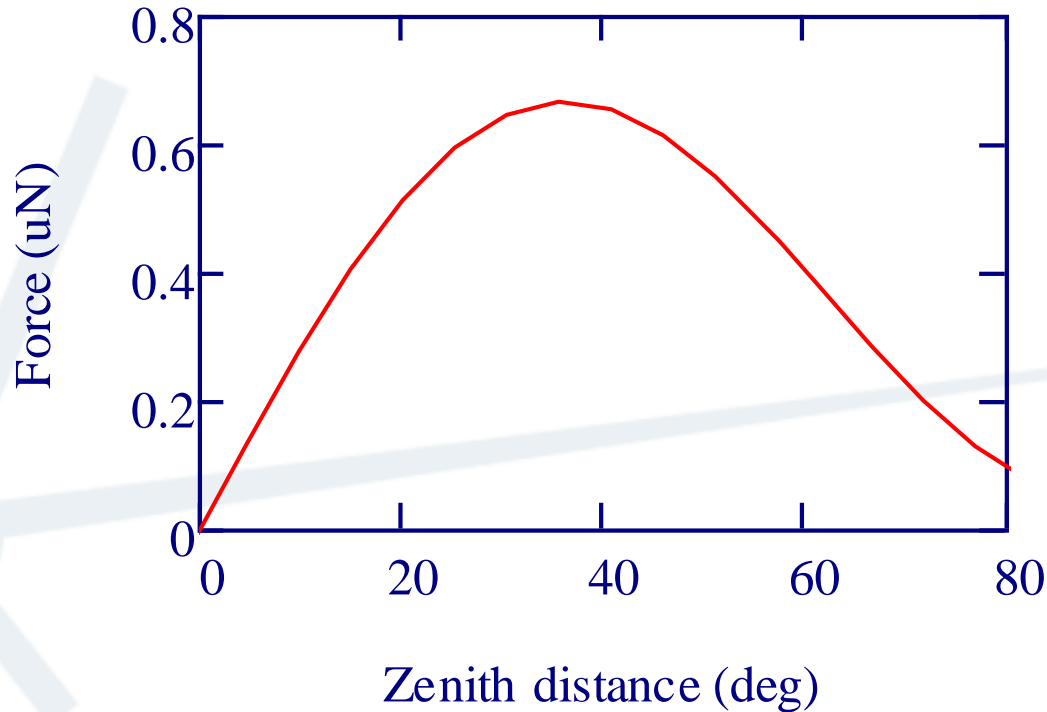
Effect depends on range, atmosphere, dwell time, orbit geometry...

# Force vs Zenith Distance



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

Force vs ZD



Integrate under the curve and divide by mass gives  
 $\Delta v = 0.3 \text{ mm/s}$  or 3 passes for 1mm/s change  
(acceptable for a demo)

# Key Technologies



- Accurate laser tracking
- Adaptive optics to concentrate the energy
- High power laser and beam delivery system
- Demo system being developed at Mt Stromlo

# A Remote Manoeuvre Experiment



The screenshot displays the NEOT Application - RT 0.0 interface. It features three main camera viewports at the top: 'WFOV Image' (Wide Field of View) showing a bright comet-like object, 'MFOV Image' (Medium Field of View) showing a similar object with a green crosshair, and 'NEOV Image' (Narrow Field of View) showing a close-up of the object with a green box and coordinate axes (Az, Alt, X, Y). Below these are several control and monitoring panels:

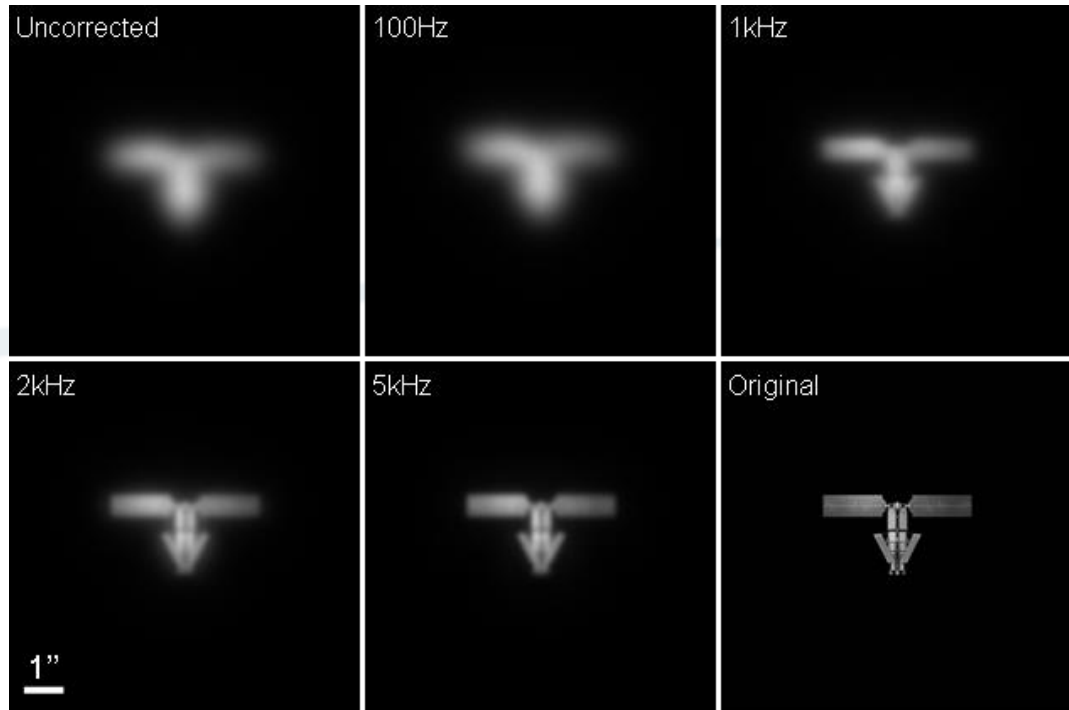
- WFOV Accumulator:** A dark panel showing a faint streak.
- Streak Detection (Object):** A control panel with fields for Target Id (indium12), Target Rise Time (18/10/2005 10:26:00), Target Set Time (18/10/2005 10:41:00), Detection Streak Detection Time (18/10/2005 10:20:30), and Target Elevation (degrees). It includes buttons for Reset, Panic, Clear, and Set Cloudy, and checkboxes for Detect Streaks, On (Off), Detect, and Off (On).
- Events:** A log window showing a series of timestamped events such as 'Generated splines for object', 'Got 3000 best points for object', and 'TVT no input - inhibit laser'. The status is set to 'Run'.
- Telescope:** A panel with 'Connect' and 'Disconnect' buttons, Azimuth (Az) [46.675], Altitude (Alt) [44.720], and Time [18/10/2005 10:33:13].

The bottom of the interface shows a menu bar with options like WFOV, Camera, Object, RaDec, Schedule, BoreSight, OrientScale, Magnitude, Accumulator, MFOV, Camera, BoreSight, OrientScale, Magnitude, TVT, Time, Telescope, Events, and Help. The Windows taskbar at the very bottom shows the Start button, NEOT application, and system tray with the time 5:31 PM.



# Adaptive Optics

- Adding a high-order AO systems (with ANU)
  - For resolved passive imagery
  - Active imagery
  - Increased range
  - Remote Manoeuvre

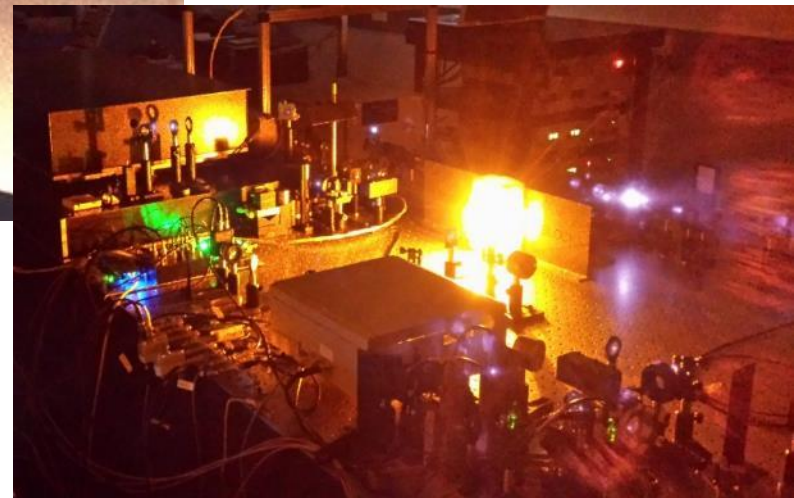


Iridium satellite @ 1000km

# Laser Guide Stars



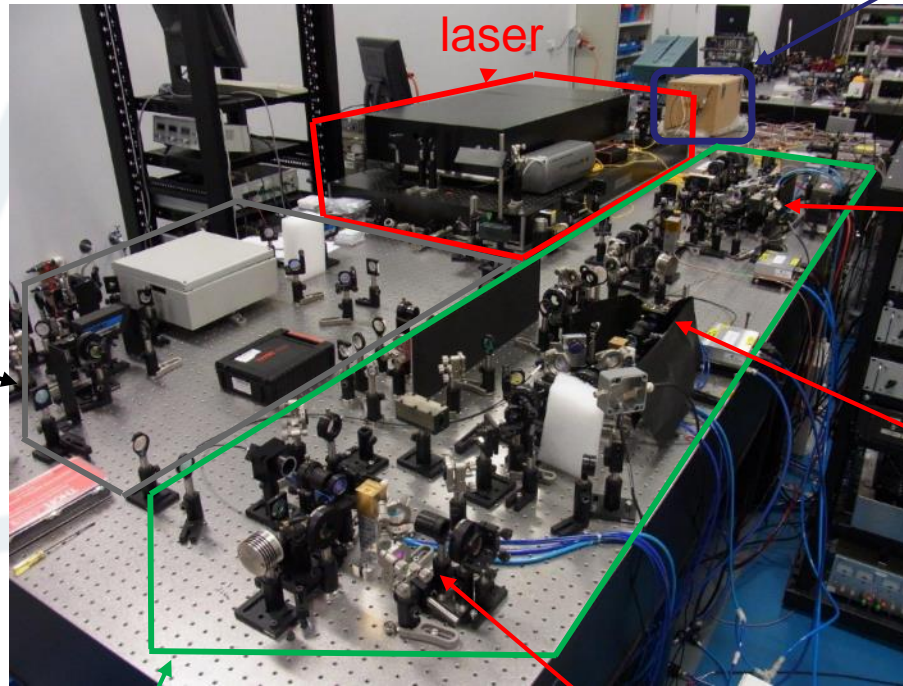
- ❑ Sodium laser for AO guide star for active beam correction.
- ❑ Sum frequency generation currently ~10W
- ❑ Next stage 30W



# Guide Star Laser prototype



Sum-Frequency Generator



1050 nm laser

1342 nm tunable oscillator

Amplifier #1

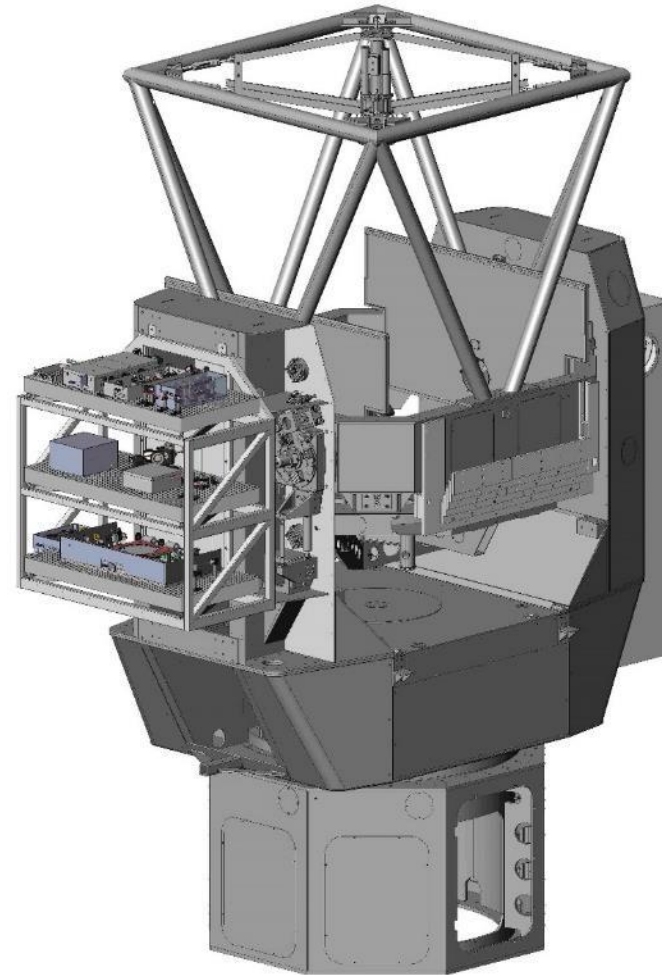
Amplifier #2

1342 nm laser

Amplifier #3

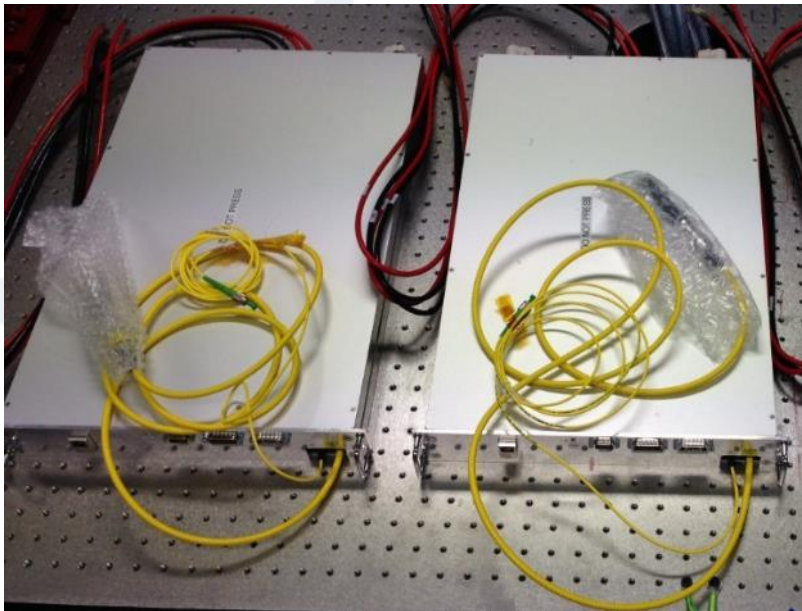
# GSL on the telescope

- 3 planes of CF benches
- 1340, 1050nm on separate planes.
- SFG and frequency locking on third plane
- Environmental box to surround



# Combining beams

- We use spectral beam combination to combine 1 x 10kW and 4 x 2kW lasers for 18 kW
- High efficiency
- Continuous operation



*2kW CW fibre amplifier modules*



*10kW laser module)*



# Summary



- Making excellent progress in all research programs
- Integration remote manoeuvre systems onto telescope this year with on-orbit tests to commence 2019.