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

Craig Smith

- EOS Space Systems
- CRC for Space Environment Management

International Workshop of Space Debris Management

9 Nov 2018

SERC

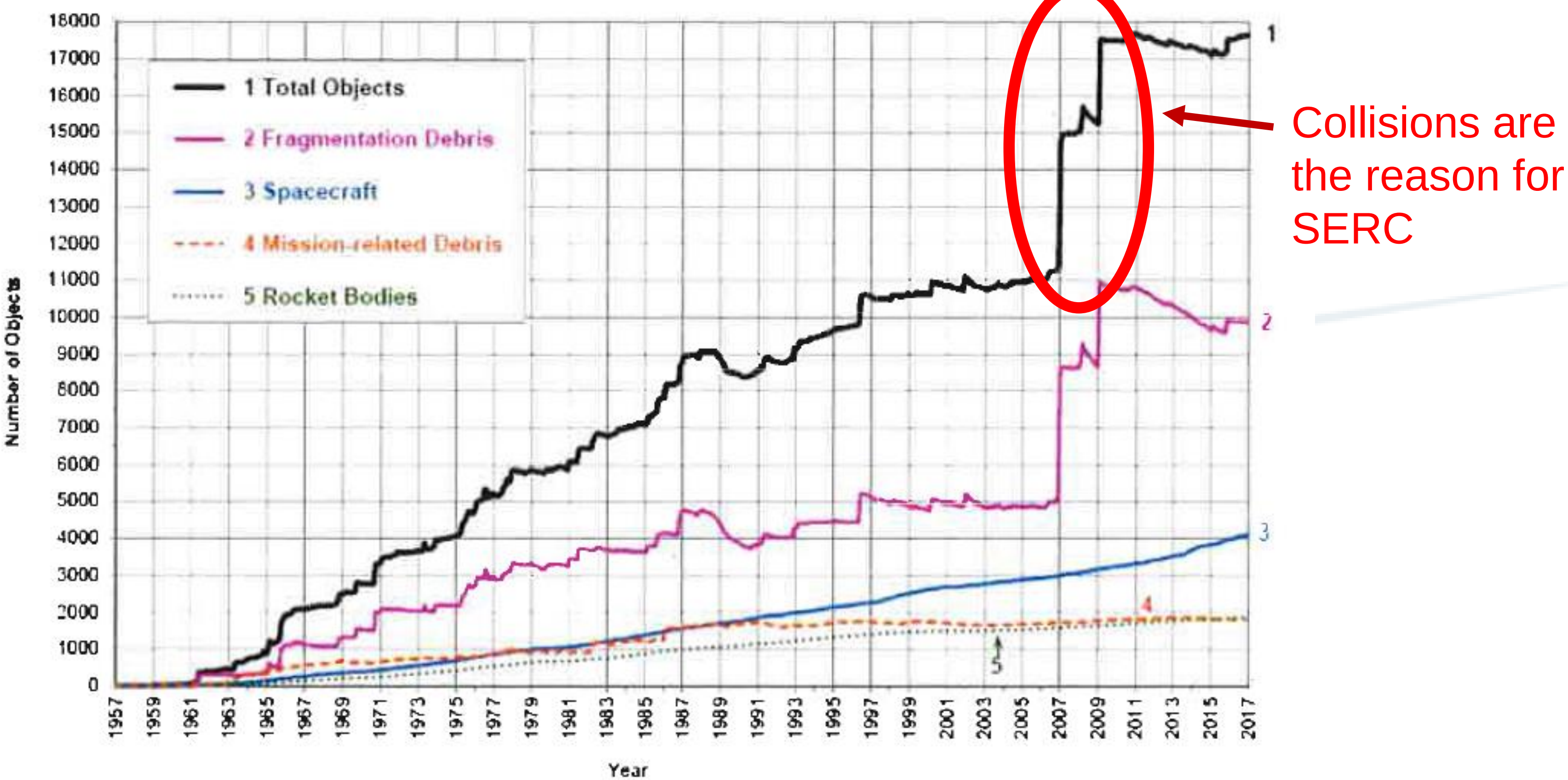
Australian Government
Department of Industry and Science

Business
Cooperative Research
Centres Programme

- 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[4]]

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 µs in the same 3D space.
- If we can shift the point in time that one object reaches an intersection point by 100 µs (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 µs (1m).
- This is avoidance, not removal.

Radiation Pressure

- Photon Energy
- Photon Momentum

$$E_{ph} := h \cdot \frac{c}{\lambda} \qquad p_{ph} := \frac{h}{\lambda}$$

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME XVII JUNE 1903 NUMBER 5

THE PRESSURE DUE TO RADIATION.[1]

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

AS EARLY as 1619 Kepler[2] 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

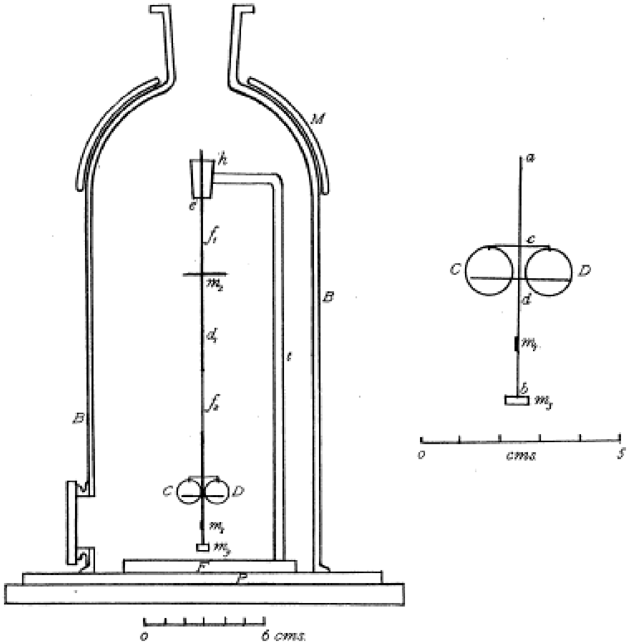
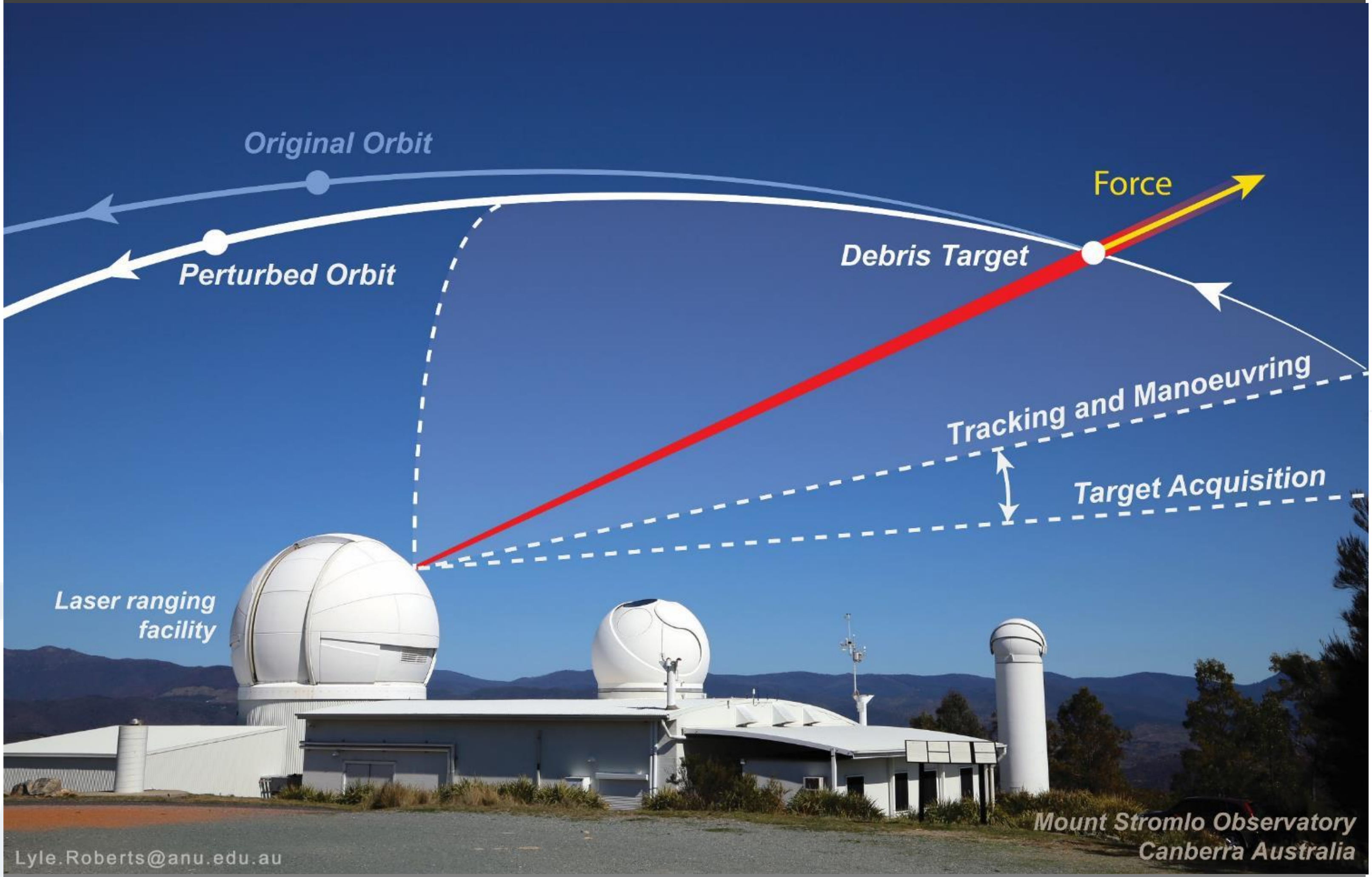


FIG. 1.

Solar Sail driven by Radiation Pressure

Photon Pressure for Remote Maneuver

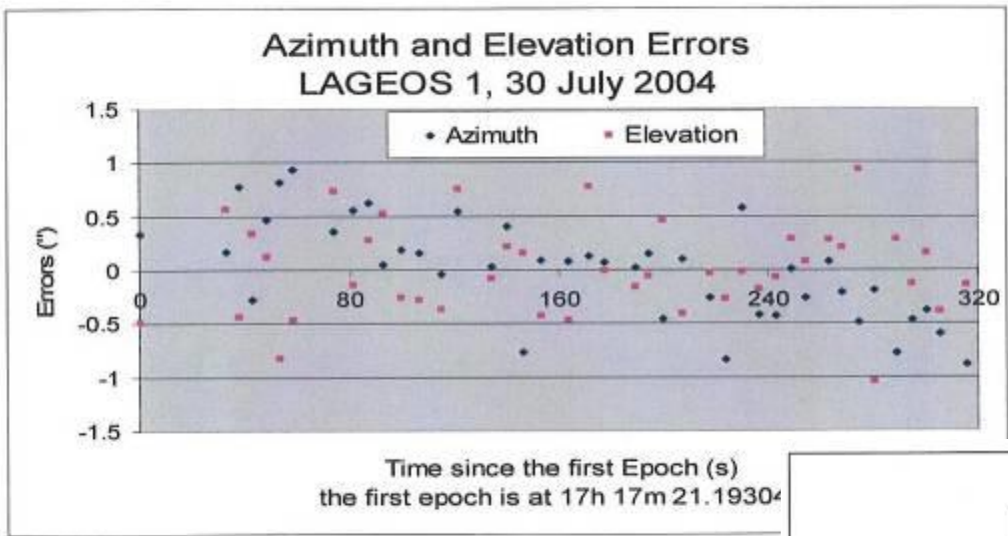


How much is enough?

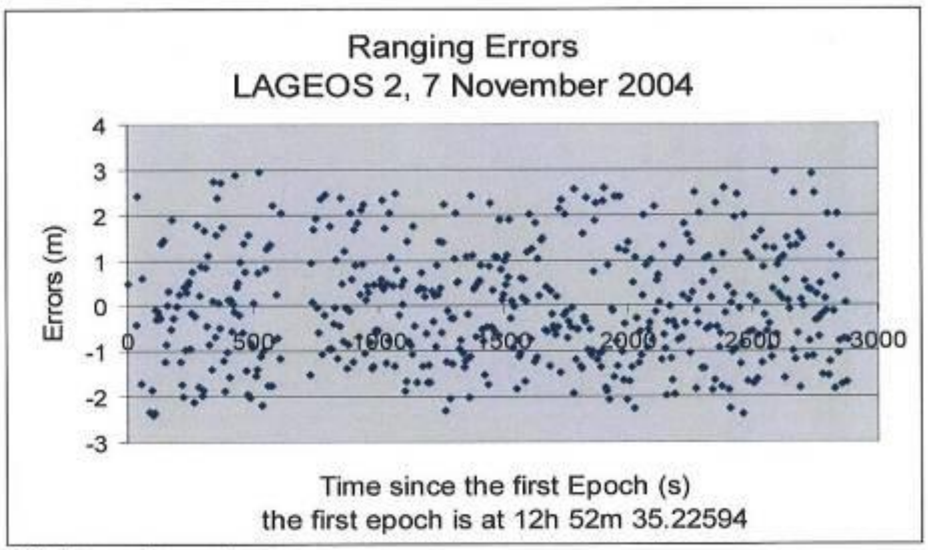
- We are talking about using light pressure to manouver a space debris object. Photon pressure is weak, so we only want to make the smallest change necessary to have an effect

- 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

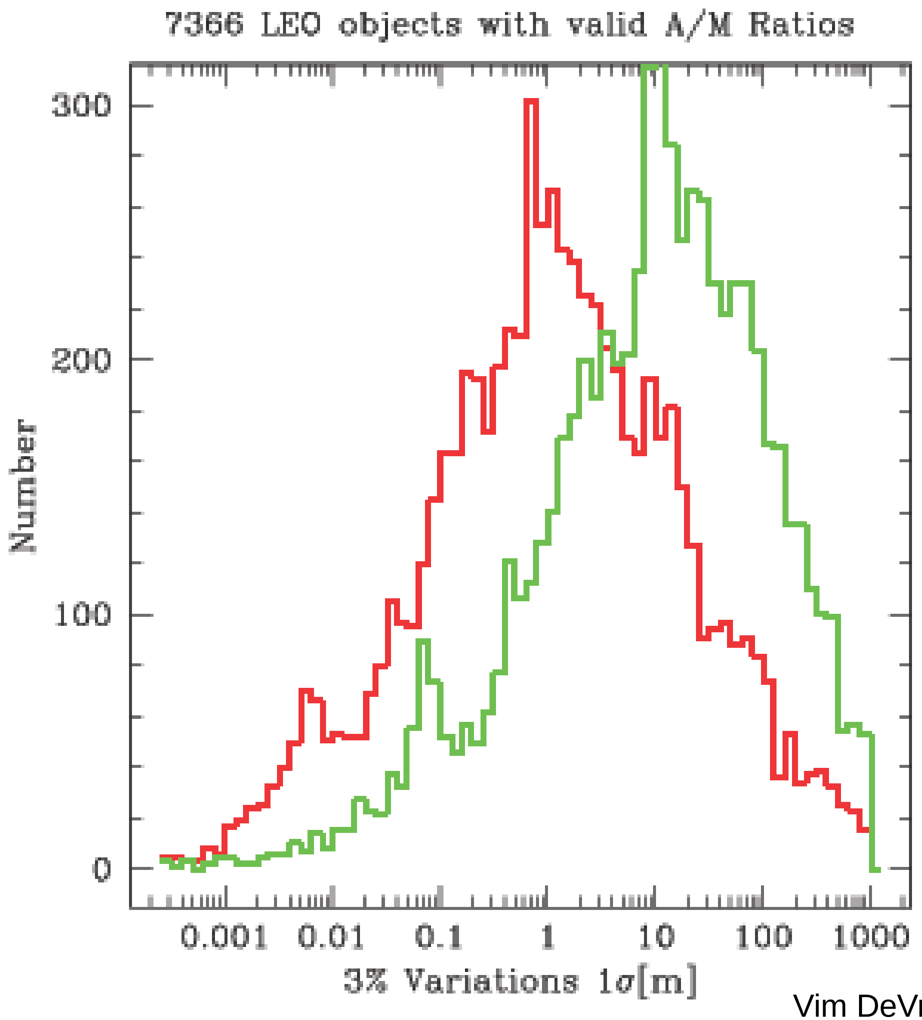


RMS Angular Error ~1.5 arcsec =7m @ 1000km



RMS Range Error ~1m

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?

EOS

Orbital Velocity

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

Allocated time to effect change

$$\Delta Time := 24 \cdot 3600 \cdot s$$

Required Along Track Distance after delta T

$$\Delta D := 100m$$

Required Velocity Change

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

System Parameters

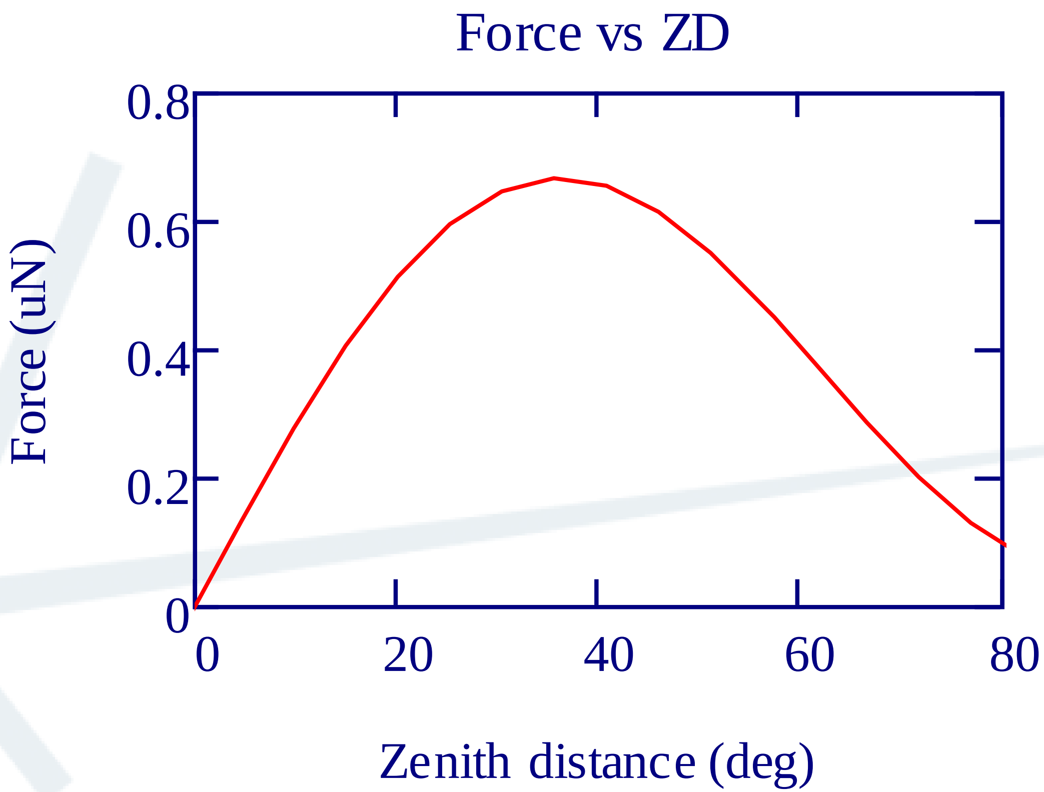
Parameter	Value
Orbit Altitude	500 km
Target Diameter	20 cm
Target Mass	0.2 kg
Beam Director Diameter	1.8 m
Laser Power	18 kW
Laser Beam Quality (M^2)	1.2
Delivered Strehl	0.3

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



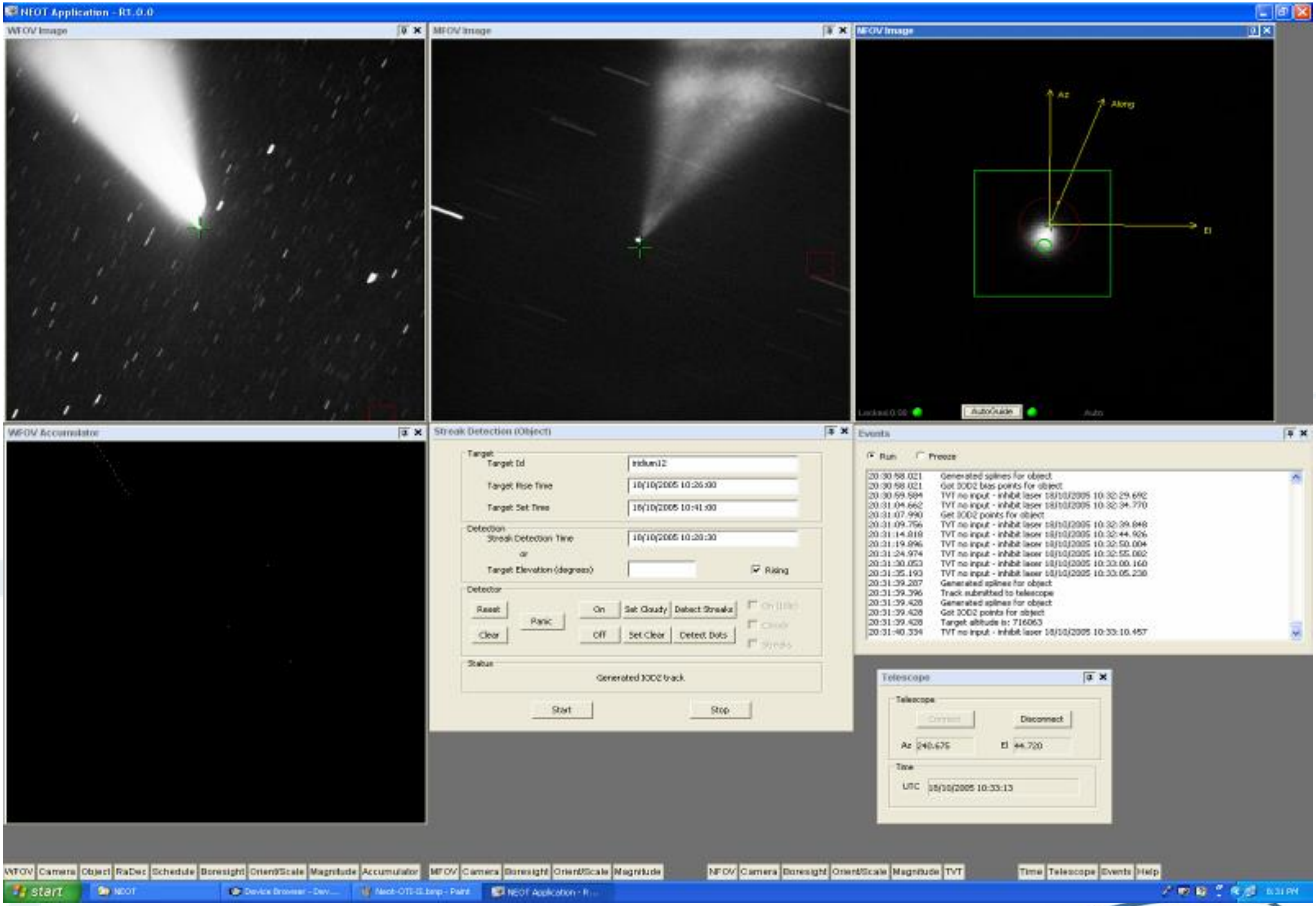
Integrate under the curve and divide by mass gives
Δv =0.3 mm/s or 3 passes for 1mm/s change
(acceptable for a demo)

Key Technologies

- Accurate laser tracking
- Adaptive optics to concentrate the energy
- High power laser and beam delivery system

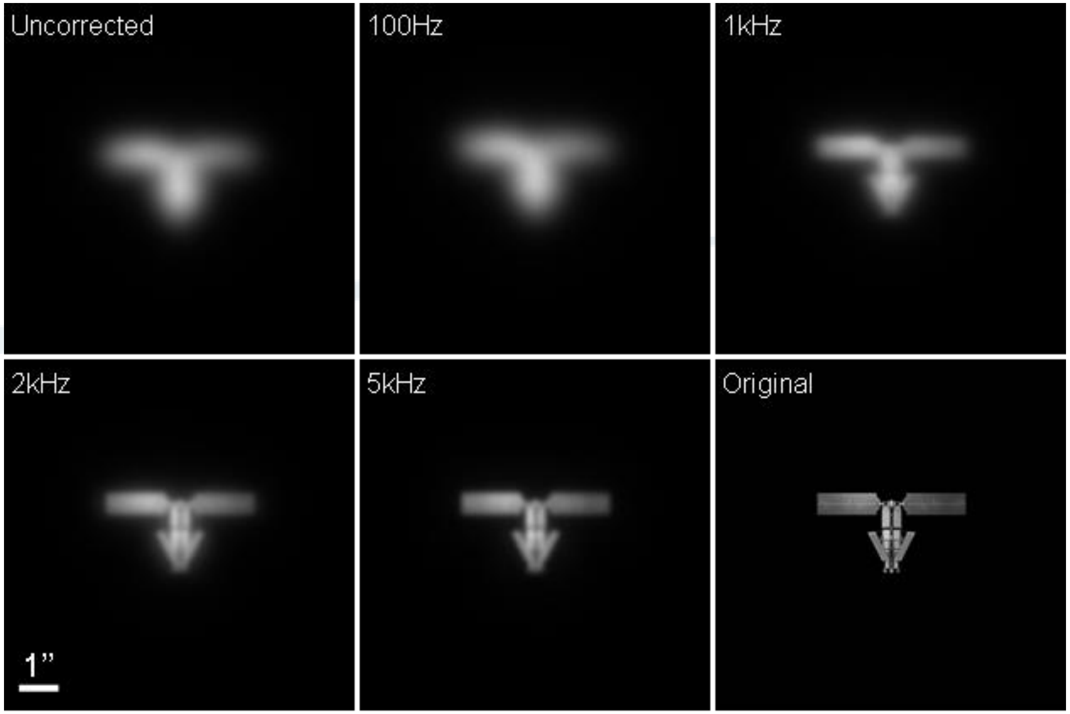
- Demo system being developed at Mt Stromlo

A Remote Manoeuvre Experiment



Adaptive Optics

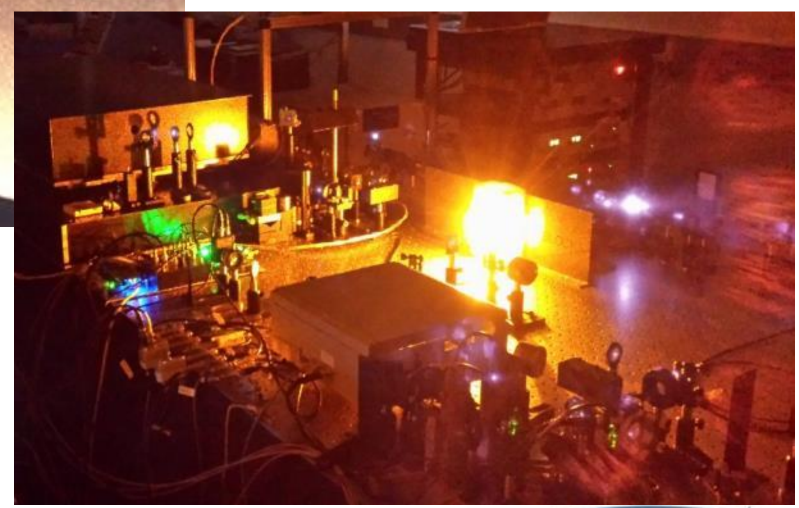
- Adding a high-order AO systems (with ANU)
  - For resolved passive imagery
  - Active imagery
  - Increased range
  - Remote Manoeuvre



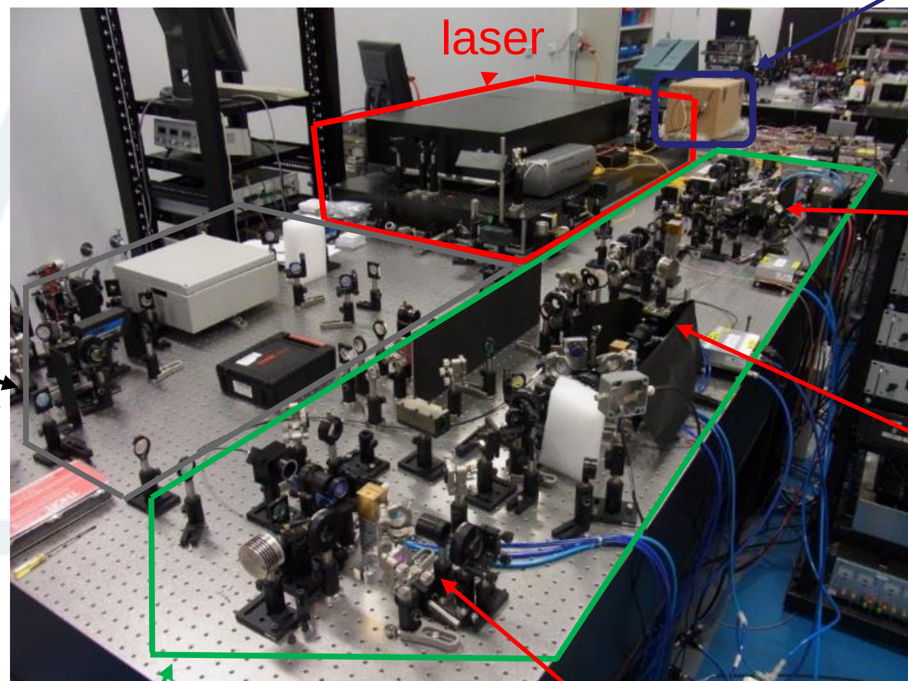
Iridium satellite @ 1000km

Laser Guide Stars

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

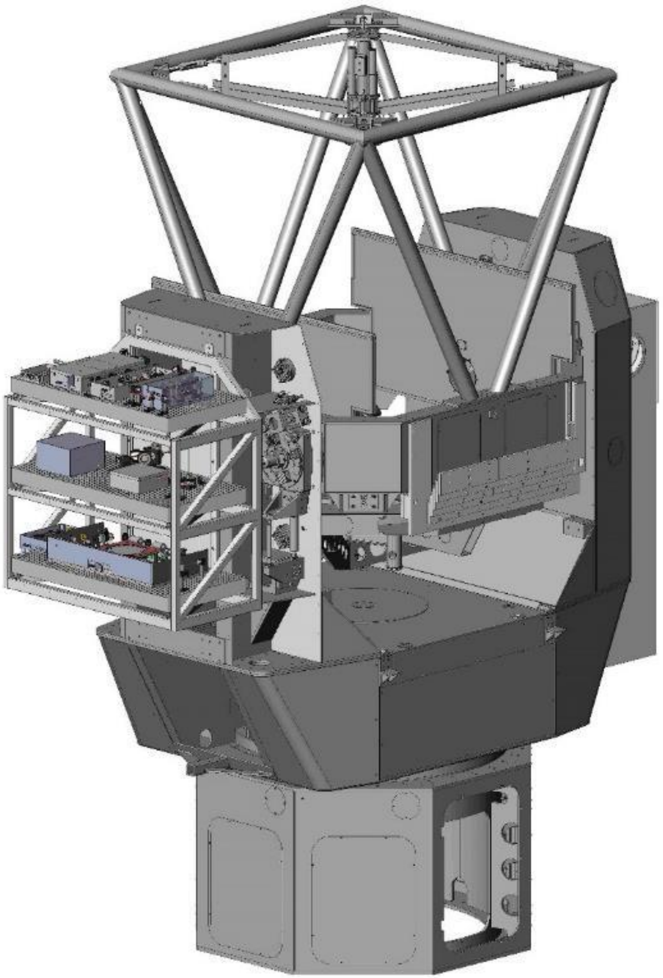


Guide Star Laser prototype



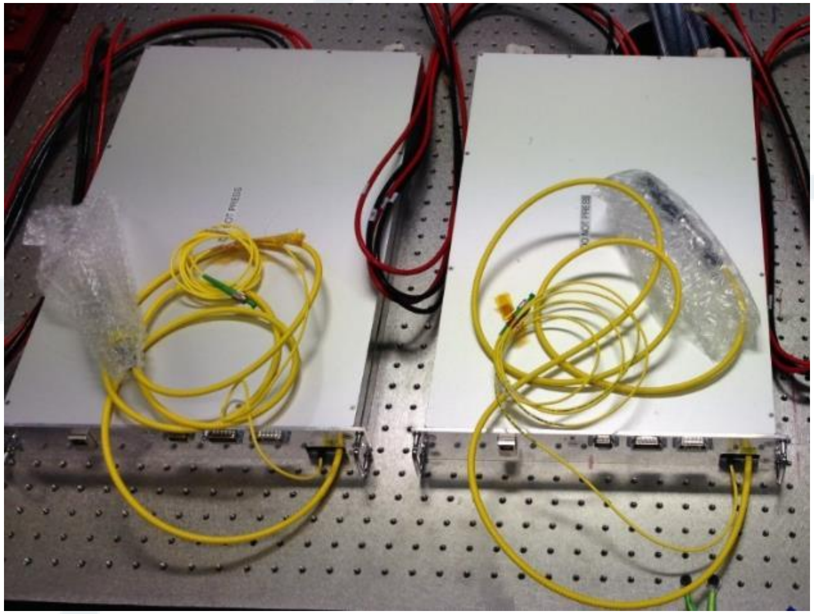
GSL on the telescope

- 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.