GNOSIS
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Workshop on Novel/Non-traditional Observation Techniques

Laser illumination for orbital object characterisation

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Background

- Working in AO for twenty years, more recently in laser propagation

- I work in the Centre for Advanced Instrumentation, Durham Uni
  - We (& I) design, fabricate (including metal optics), and deliver + operate optical instrumentation for astronomy
  - Often prototypes but also facility projects
  - Some space work e.g. JWST IFU mirrors and OGSE for ESA EO

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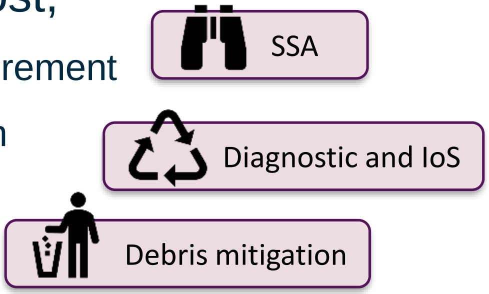
Why am I talking about this, here?

- New to Space Surveillance & Tracking
  - Discussions with Don Pollacco piqued my interest
- This workshop will, I hope, promote discussion on laser illumination of satellites.

- Science questions *I think* need R&D most,
  - Improved snapshot satellite state vector measurement
  - Improved understanding of surface composition
  - Improved surface-to-mass ratio determination

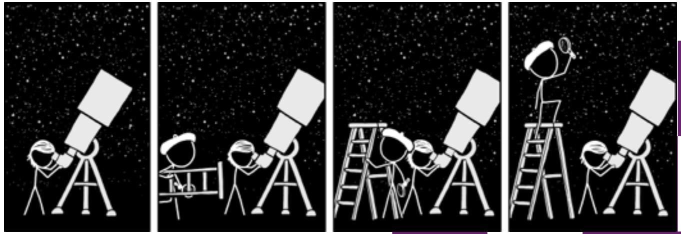


Fundamental issues

- Lasers have incredible brightness temperature
- Sun has incredible irradiance

- Put together, narrow-field and targeted is where laser illumination will aid SST
  - c.f. Laser Ranging

- Illuminating from ground
  - Possibility of space-based is another discussion
- Therefore, seeing (atmospheric corruption) is where to start

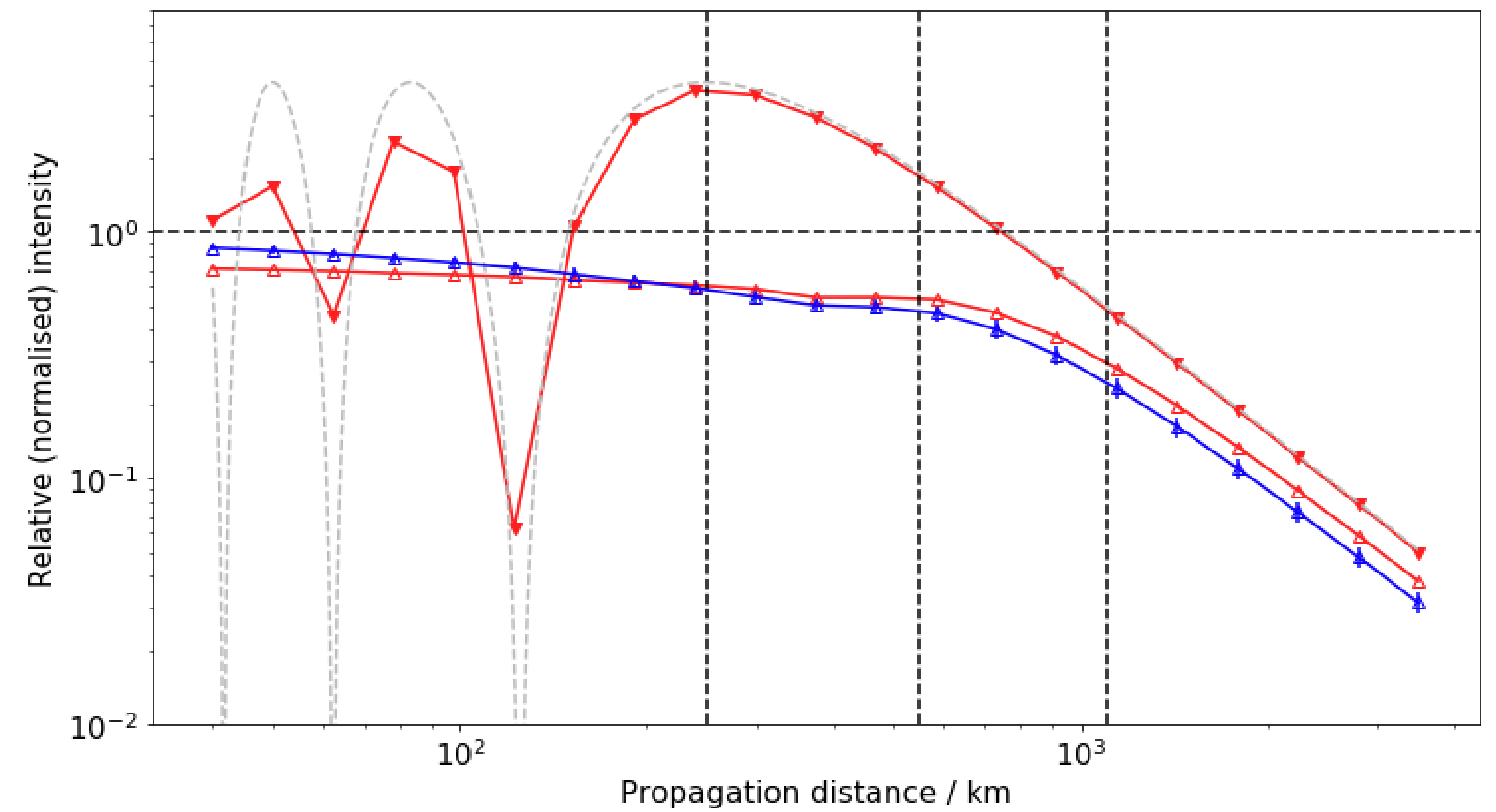


https://xkcd.com/1522/

Quick overview

- Laser/debris ranging takes advantage of LAGEOS *et al*
  - LIDAR—measures radial component of state vector
  - Infer angular components (in/cross-track)

- To <u>measure</u> angular components,
  - Need to know where laser is pointing
  - Need a scale
- To <u>estimate</u> composition,
  - Need to know illumination on target
  - How target responds to illumination: BDRF
- To <u>aid</u> surface-to-mass ratio determination
  - Probably the above



Relative (normalised) intensity
10^0
10^{-1}
10^{-2}
10^2
10^3
Propagation distance / km

Illumination

- Can be confident we know what the illumination profile is
- Need to measure where the beam is going: fortunately this is well explored in astronomy
  - Tomographic tip/tilt estimation (poster at AMOS) has $P > 0.25$ for $\sigma_{\alpha} \leq 0.15''$ which is 0.42m i.e. less than the imparted tip/tilt which has a 1-sigma of 0.82m.
  - Requires on 1m telescope a wide-field imager with ca.480×480 pixels at ca.500Hz and low read-noise: feasible.
- Conclude that, with active correction, can be confident of precisely targeting 1m-size objects

Illumination

- Assumption 1, 1 sq.m object is illuminated
- Assumption 2, can effectively reduce solar flux
  - Narrow field + filter or single-mode fibre (trade-off between background and coupling losses)
- Assumption 3, assuming EBS (x2)
  - Giant EBS (upto x10) has been reported (Zhu ‘96) but then ... ?

- *m*=7.5 (solar V+R equivalent, *m*=3.7)
  - 2×10^4 photons per ms
- Visible 24x7 at a clear site

Illumination

- If limit is 100 photons per exposure, how small can we go?
  - Note that field is about 4m x 4m or 1.5’’ x 1.5’’ ... pretty tiny! but deep, about 1200km.
- Know that reflectivity is high at 1064nm so assuming albedo=0.175 conservatively
- About 10cm is answer at 550km distance
  About 1m at 1500km distance
- For small debris, need a more powerful laser or bigger receiver: with 5m aperture, 1cm at 550km
  - Needn’t be diffraction limited...know where the target is

Recap

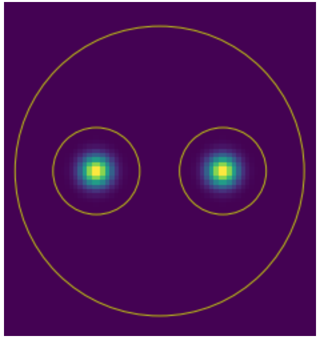
- Have we answered sufficient questions to achieve our goals?

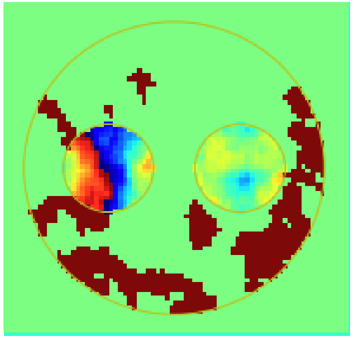
- To measure angular components,
  - Need to know where laser is pointing
  - Need a scale
- To estimate composition,
  - Need to know illumination on target
  - How target responds to illumination: BDRF
- To aid surface-to-mass ratio determination
  - Probably the above

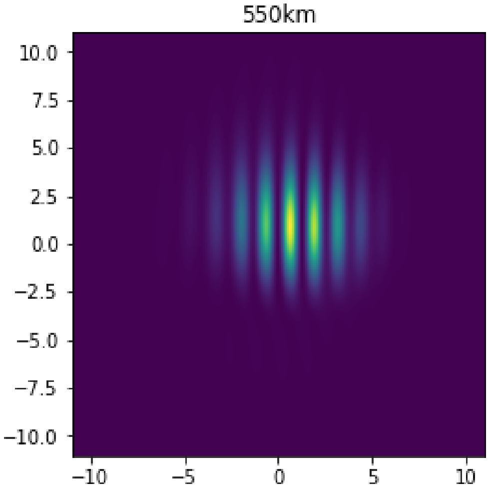
Making a scale

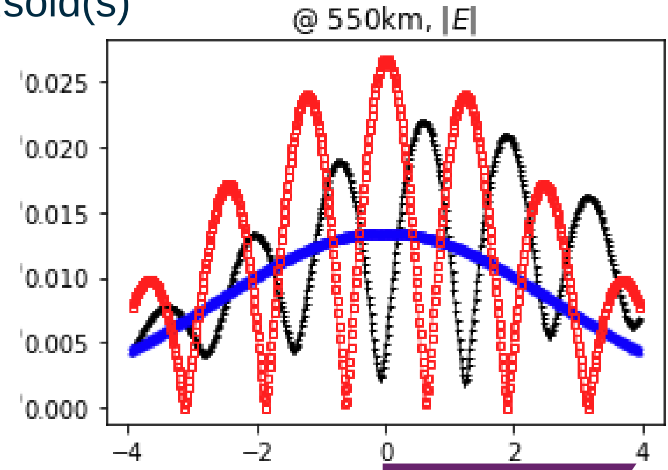
- Radial component by time-of-flight if appropriate
  - Laser ranging measures this already
- Lateral components required

- Scale required is of order 1m
- Natural motivation is to project two-plus beams ➔ sinusoid(s)









Making a scale

- Can make a lateral scale but phase shift between beams will cause scale **phase** and **visibility** to vary
- A solution is high-speed scanning of fringes *over* target
  - Freeze fringes → measure → move fringes and repeat
  - Target motion within isoplanatic patch, ca 1'', for 4ms
- Aim to keep laser power at same levels
  - Could increase laser power but other issues: so far well below solar power densities
  - Thus, equivalent to *m*=10 for 1 ms exposure
- With CW can use AOM or similar to modulate frequency of one beam → fringe phase rotates and temporal signal returns 1D velocity

Where would you do this?

- La Palma is an excellent location
  - Astronomical observatory
  - 28.5°N
- Skies closed to traffic for lasers
- Experience in doing this
- Second observatory 145km distant, Tenerife
  - Allows for BDRF estimate
  - DebrisSat results → composition

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Summary

- Laser illumination from the ground for SST has some promising applications
- Advantages include day-night operation and ability to control illumination on target
- Technologies all exist and are CotS
- Ability to control propagation is key to accurate illumination
  - Limited to night conditions for now
- Ability to project pattern is key to precision location determination
  - **Outstanding:** determine precision of projected fringes state vector estimation

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