Durham University

Sandpit on Novel/Non-traditional Observation Techniques

Optical Tracking Capabilities

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GNOSIS

Outline

1. Introduction and state-of-the-field in optical tracking

2. Astronomy-inspired active optical illumination (NAB, Durham Univ.)

3. Wide-field observations for mitigating satellite interference in astronomy (JO, Durham Univ.)

4. Hyperspectral imaging of space objects (MV, Univ. Strathclyde)

5. **Discussion**

Introduction and state-of-the-field in optical tracking

Outcomes of this sandpit

- To initiate discussion around networking, collaboration, accessing funding for projects and research students
- Three presentations but we encourage discussions beyond this
- If we know our current capabilities, then what are our gaps?
  - Passive (imaging)
  - Active (lasers)
- Start planning for future workshops & networking events (post-Omicron?)
- Reach out to industrial and academic partners, potential and existing to build significant collaborations

Optical capabilities for SST (from a non-expert!)

- A few established techniques with many commercial operators
- GEO observations are relatively common from e.g. ExoAnalytics
- LEO observations are becoming more common
- Satellite Laser Ranging is relatively common moving towards daytime operation
- Usually for established objects and with a limited ability to characterise

- **Where can UK research go?**

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Goals
(from a non-expert!)

- High-precision orbital parameters of known objects
    - Particularly for larger objects with the highest potential for damage to environment
- Push to smaller objects
    - Understand number of objects / orbital dynamics
    - Understand space sustainability
- Cooperative and non-cooperative objects
- Discover new objects (debris)
- Characterisation of dynamics and state of objects
- In all orbital planes: LEO through GEO and cis-lunar
- 24x7 operation
- Database that conserves precision with error estimates

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Potential novel / non-traditional techniques (non-exhaustive)

Technologies

- *Laser illumination for characterisation and imaging*
- AO for laser ranging incl. daytime
- *Passive targeted imaging (visible and IR) incl. daytime*
- Wide-field (full-sky?) imaging
- Hyperspectral imaging
- *MKID arrays for simultaneous angle/colour measurement*

Data / algorithm

- Artificial Intelligence (Deep Learning)
- Data fusion including non-optical sensors
- *Light curve characterisation*
- Modern data formats / accessible databases

Applications

- LEO to cislunar custody
- *Space-based sensors*
- *Daytime operation → 24×7*
- Pose estimation
- *Enhanced tasking and cooperation*

Astronomy-inspired active optical illumination

Nazim Ali Bharmal

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Active optical illumination

- Lasers are the alternative illumination source to the sun for optical and infra-red observations.
- High brightness temperature, relatively low radiance → high spectral radiance
- Control over the illumination and polarisation state
- For SSA and SST, together this suggests two areas,
  - Precision in characterisation
  - 24×7 operation

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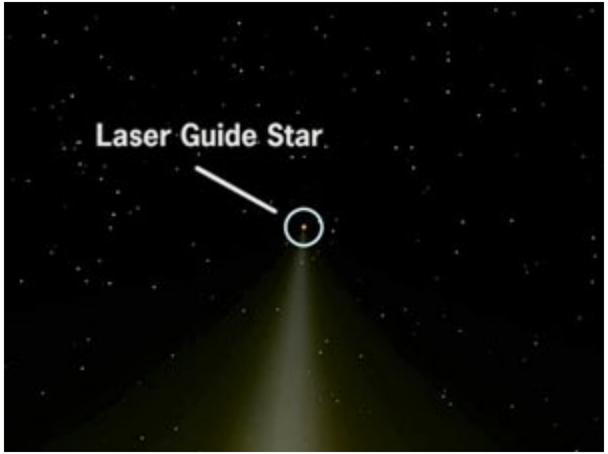
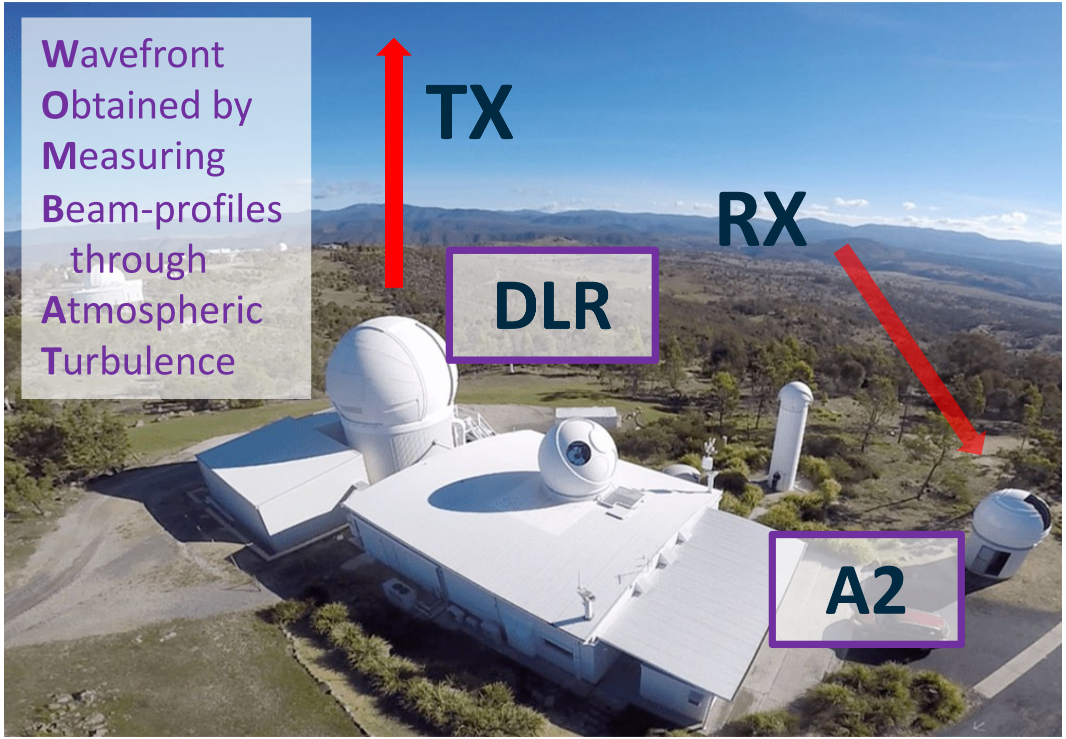
Lasers in astronomy

- Lasers used, now almost turnkey, to generate artificial beacons (stars, hence laser guidestar)
- High spatial coherence hence can be used to probe aberrations above a telescope
- Limited abilities hence active research 10 years ago to solve fundamental issues
- Why not use the back-scatter from the (distorted) plume to estimate aberrations?



Connection with astronomical instrumentation

- EOS Space Systems, (Canberra, Australia)
- Developing technique to measure wavefronts from transmitted laser ranging system beam scattered in atmosphere
- (Application stymied by Covid)



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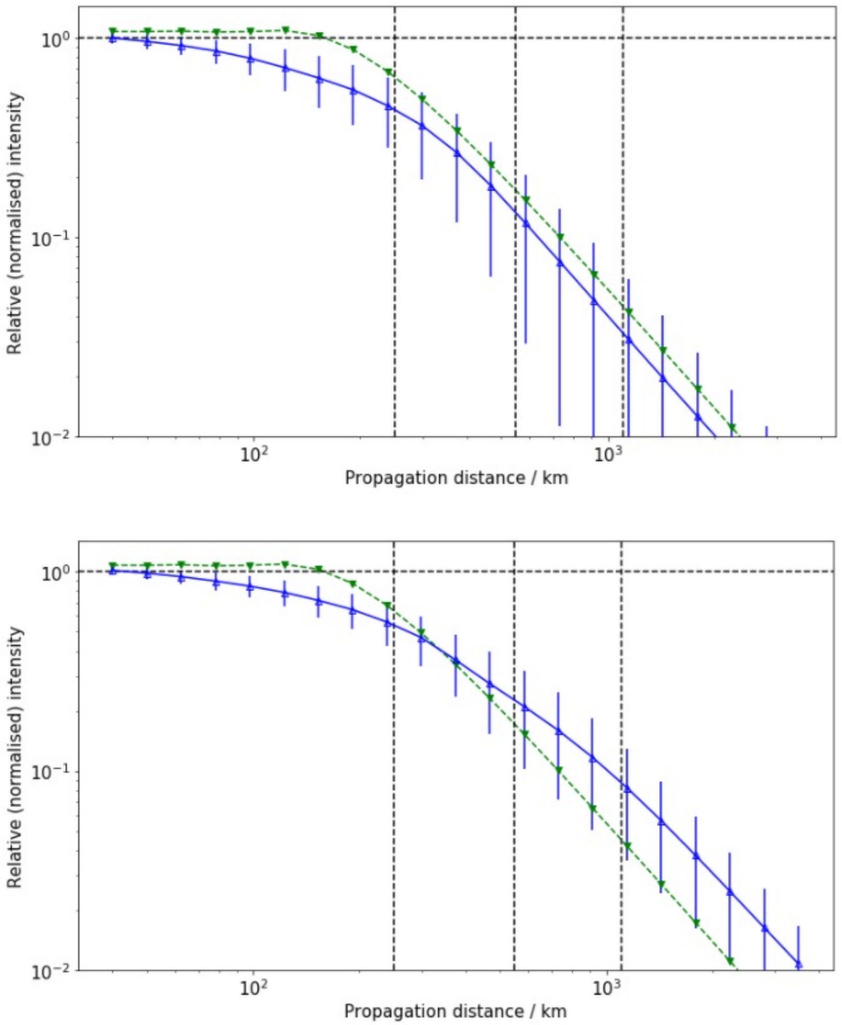
Previous & on-going work

- WOMBAT does not solve the beam wander problem
    - Originally designed to compensate high-order aberrations
- Developed analysis of beam wander
- Compensation leads to significant improvement in standard deviation of on-target flux



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Answering characterisation and tracking capabilities

- By correcting for beam wander will increase illumination precision (accuracy)
- Previous work showed: 200W (CW) 1064nm laser can receive at least 100 photons per millisecond exposure from 10cm object at 550km distance with a 1m aperture
- Research directions to discuss,
  - Polarisation retention
  - BRDF estimation
  - Beyond "point source" illumination

Reminder of workshop presentations

- "Resident Object Observation System"
  (Anirudh Sharma, Digantara, India)

- "Laser illumination for orbital object characterisation" and
- "Characterisation of GEO objects from the ground using interferometry"
  (Nazim Bharmal, Durham University)

Wide-field observations for mitigating satellite interference in astronomy

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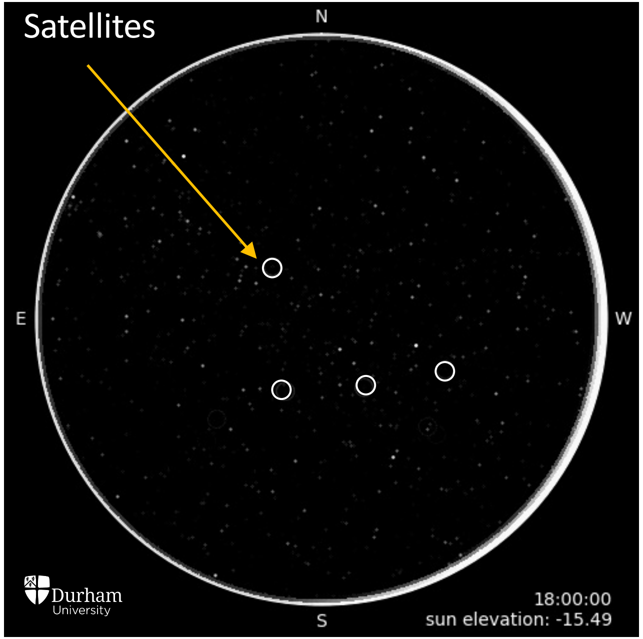
Wide-field passive detection

- Applications
  - Daytime?
  - Data fusion
  - SST at scale
  - Early-warning for other targeted methods
  - Early-warning for astronomical mitigation
- Hardware
  - Field of view vs angular resolution
    - Large area but limited by angular precision of pixel scale
    - Don't need precision to find sat trails (vectors)
  - Wavelength(s)?
- Image Processing (Software)
  - Plate solving
  - Identify satellites (or vectors?)
  - Light curve analysis (temporal resolution)
- Data Management
  - TLE+ database (store precision and errors)
- Cf NORSS Loci



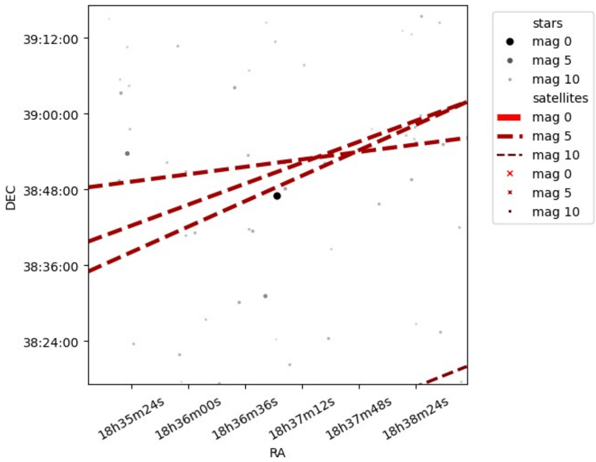
Simulation using Astrosat:
Osborn et al., MNRAS, 509(2), 2022
Durham Uni + NORSS

Satellite mitigation for astronomy:

- Astrosat intercept prediction from TLEs
- Real-time all-sky monitoring
- Validation of prediction
- Early-warning
- Database of sat brightness to improve model

- Avoid, shutter or post-process

- **Can this also be useful for SST?**



Name	Time (UTC)	Duration (s)	Mag (V)
BEIDOU-3 M9	00:13:46	291.7	13.83
ORBCOMM FM118	00:21:44	5.9	6.56
COSMOS 2518	00:49:11	86.4	13.86
STARLINK-1561	00:58:49	2.4	6.10
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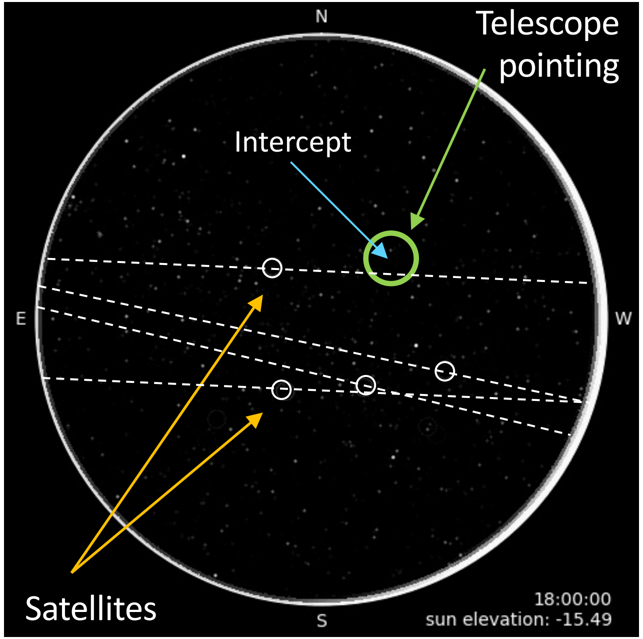

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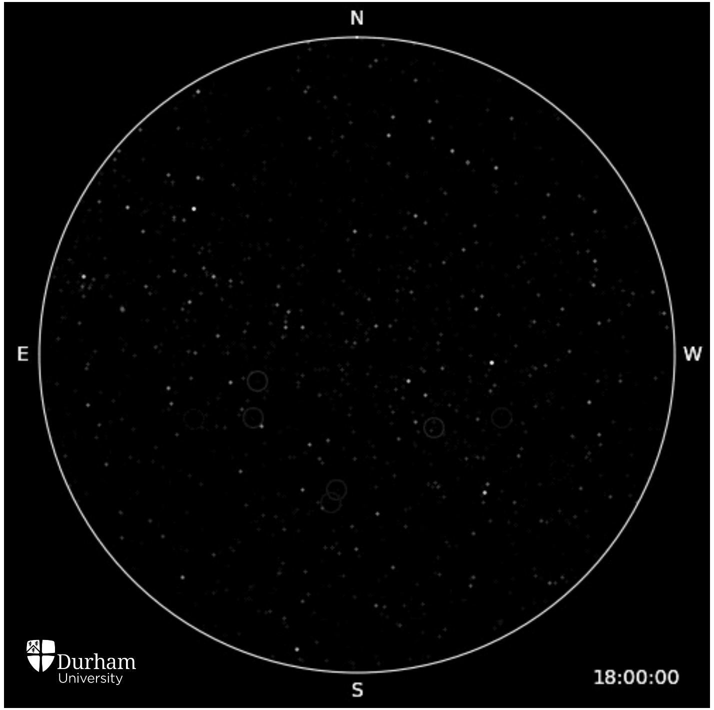
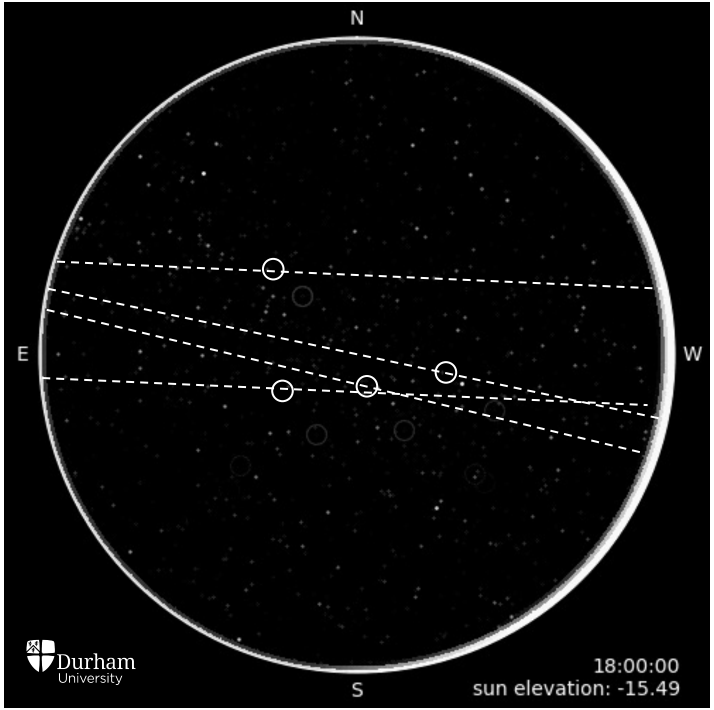
Wide-field passive detection for SST

Simulation of Starlink satellites from Durham using Astrosat





Track satellites across sky

SST at scale

Precisions?

Early-warning for more sophisticated methods?

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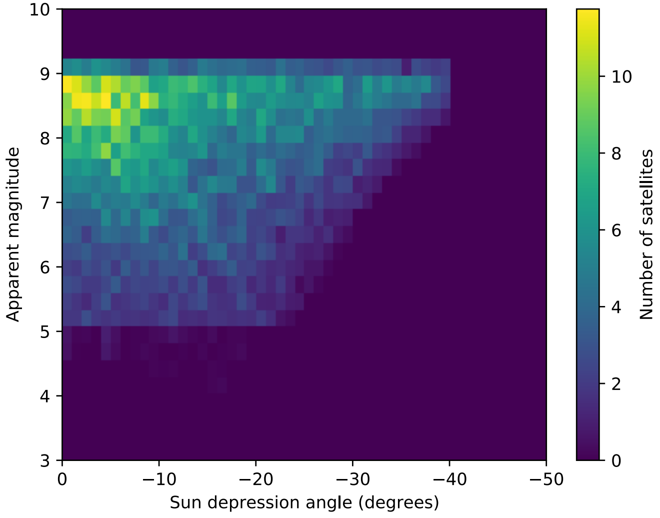
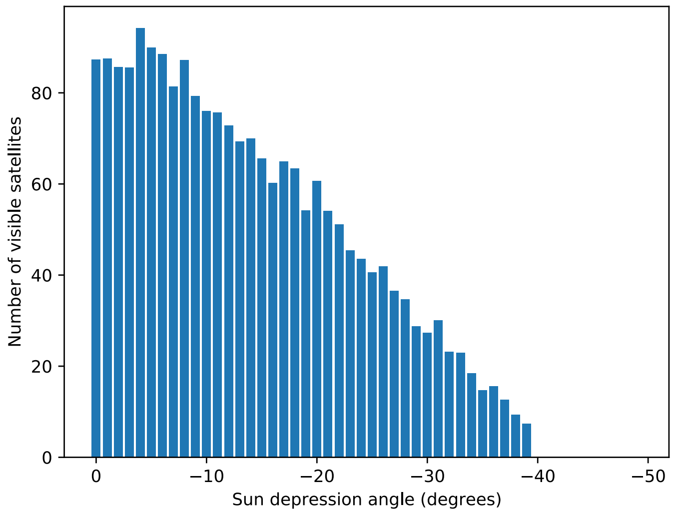
Optical satellite tracking: Problems

- No satellites visible in dark sky
- Need to work with sky background
- Field of view (full-sky?)
- Pixel scale (angular precision – but can get sub-pixel accuracy from trail)
- Exposure time (satellite signal doesn't care about this but it does amplify background noise)

Starlink - model





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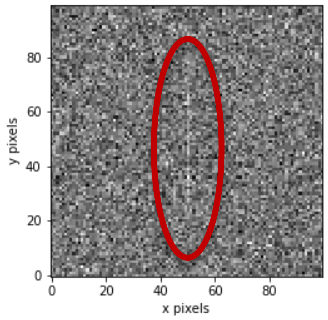
Optical satellite tracking: Problems

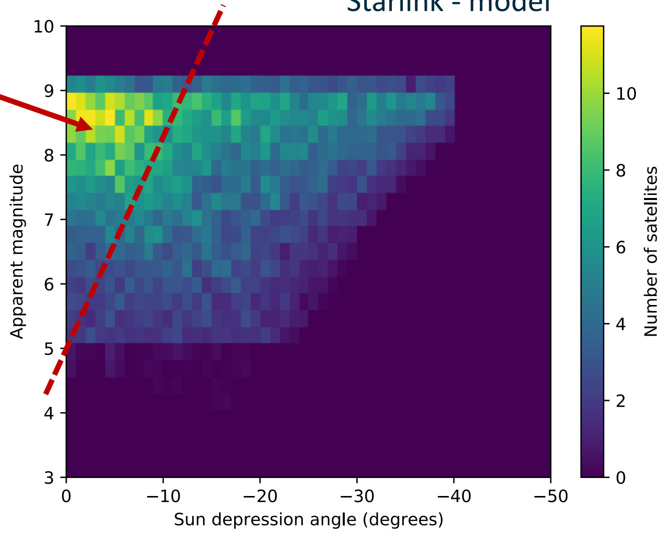
- No satellites visible in dark sky
- Need to work with sky background
- First guess of parameters (probably optimistic)
- For astro need to know where it is going *not* where it is (easier)
- How deep does it need to go?

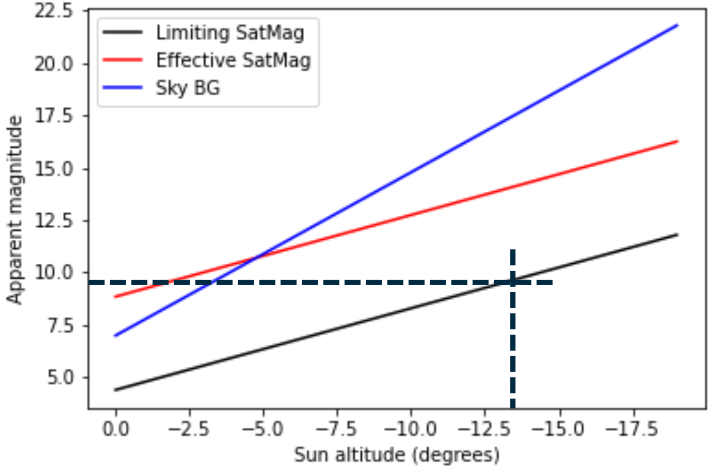
Mock date, SNR =1



Starlink - model

Can't see these ones





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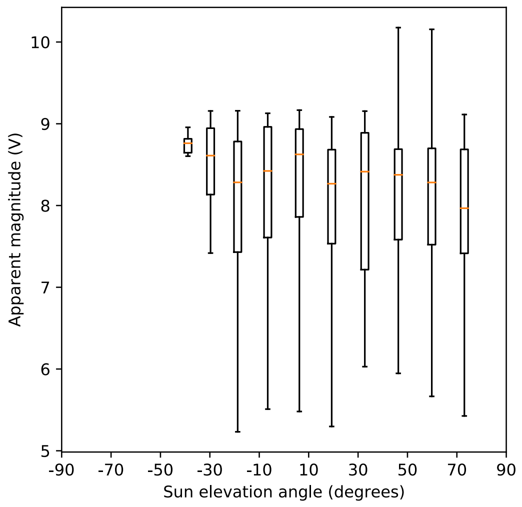
Optical satellite tracking: Daytime?

If we can solve background:

- Model priors
  - Shape
  - Location
- Filtering
- Satellites are as bright during the daytime

Brightness of SL satellites



Night Day

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Hyperspectral imaging of space objects

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