NASA's Orbital Debris JAO/ES-MCAT Optical Telescope Facility on Ascension Island

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ES-MCAT Project Overview

Dedicated as the Eugene Stansbery Meter Class Autonomous Telescope in 2017

- MCAT Goals: Statistically characterize under-sampled orbital regimes
  - Geosynchronous and near GEO altitudes
  - LILO, i.e. Low inclination Low Earth Orbit (LEO)
    - Evening and morning twilight

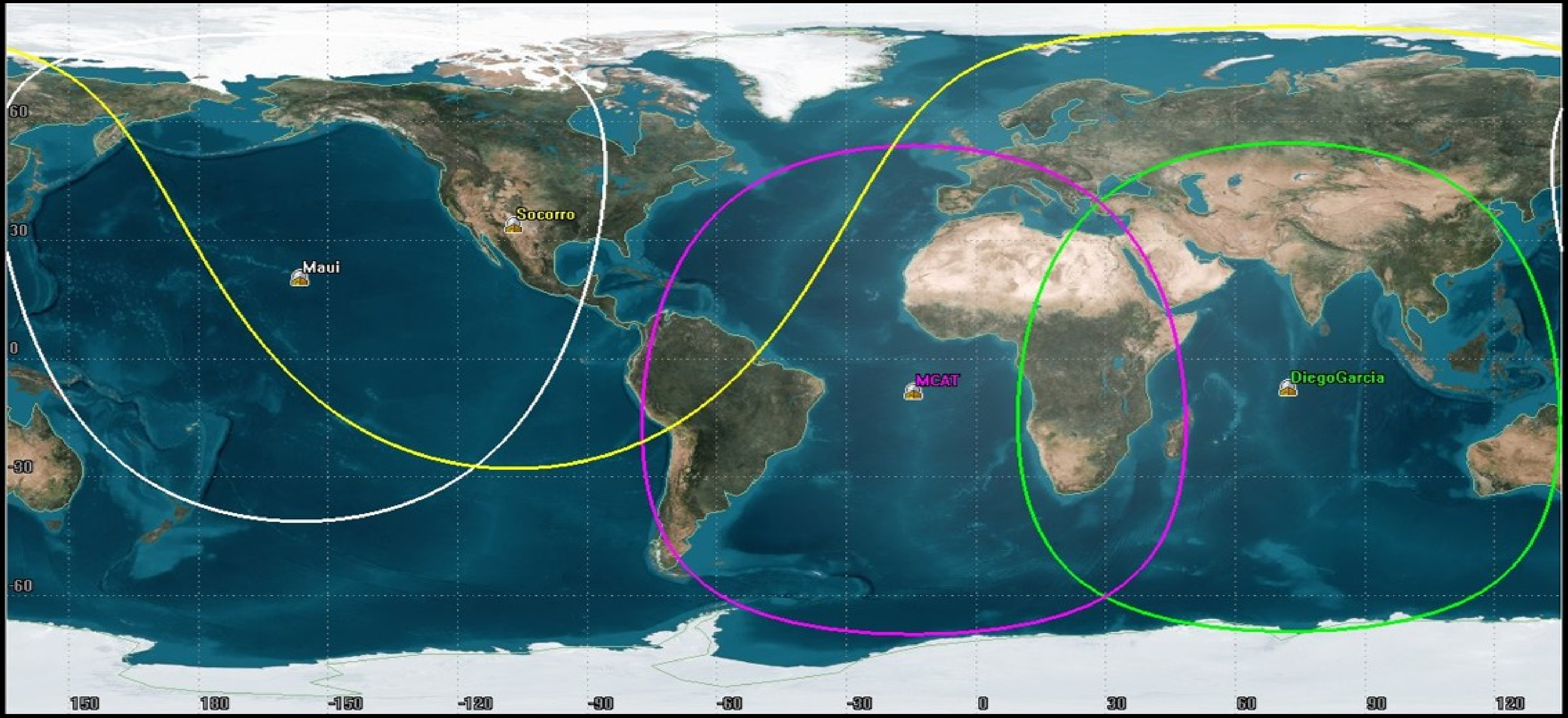
- MCAT Objectives:
  - Monitor and assess orbital debris environment by ***surveying, detecting***, and ***tracking orbiting objects*** at:
    - LEO, MEO, GTO, GEO altitudes
    - GEO debris surveys

- Ascension Island location enables **access to under-sampled low inclination orbits and new GEO longitudes**

(7^o 58′ S, 14^o 24′ W)

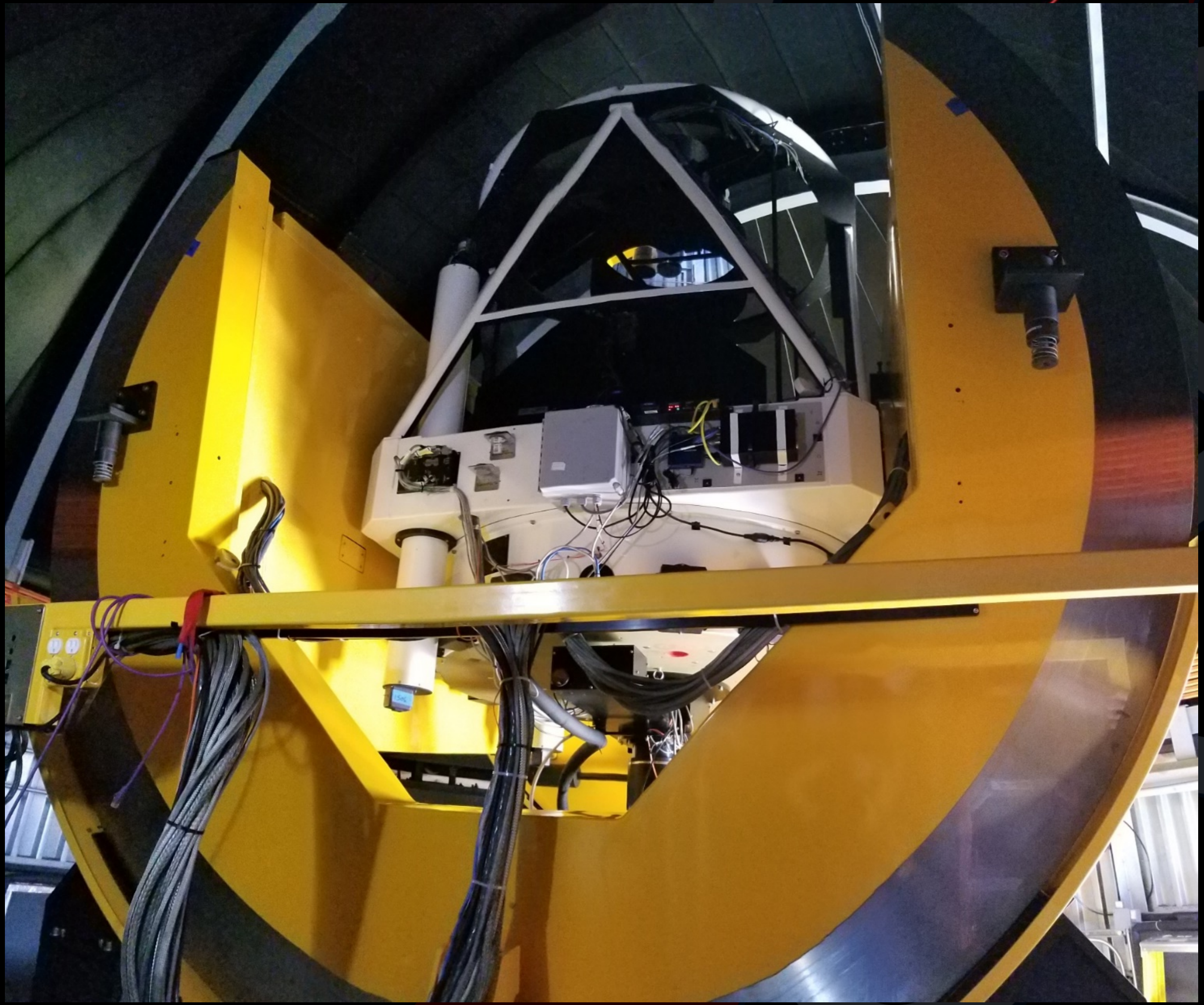
ES-MCAT Location

- Ascension Island: **(7º 58' S, 14º 24' W)**
  - Fills a gap in longitudinal coverage (vs. US GEODSS sensors)

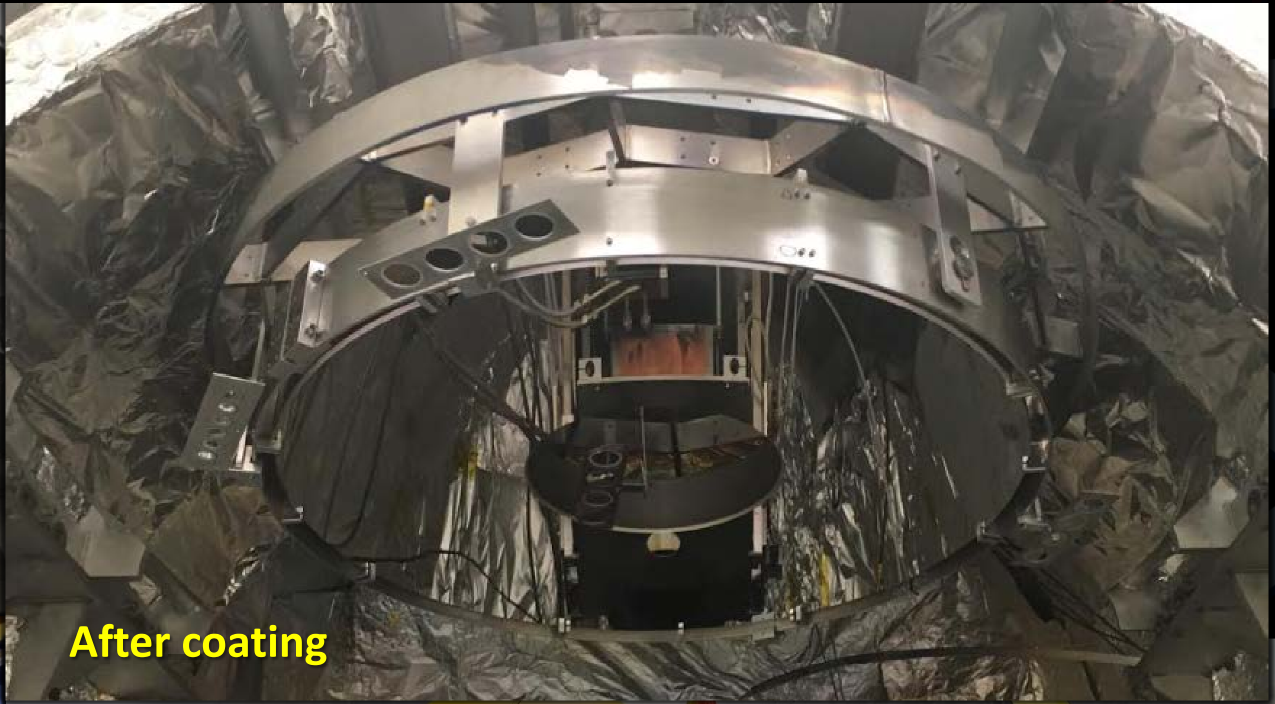


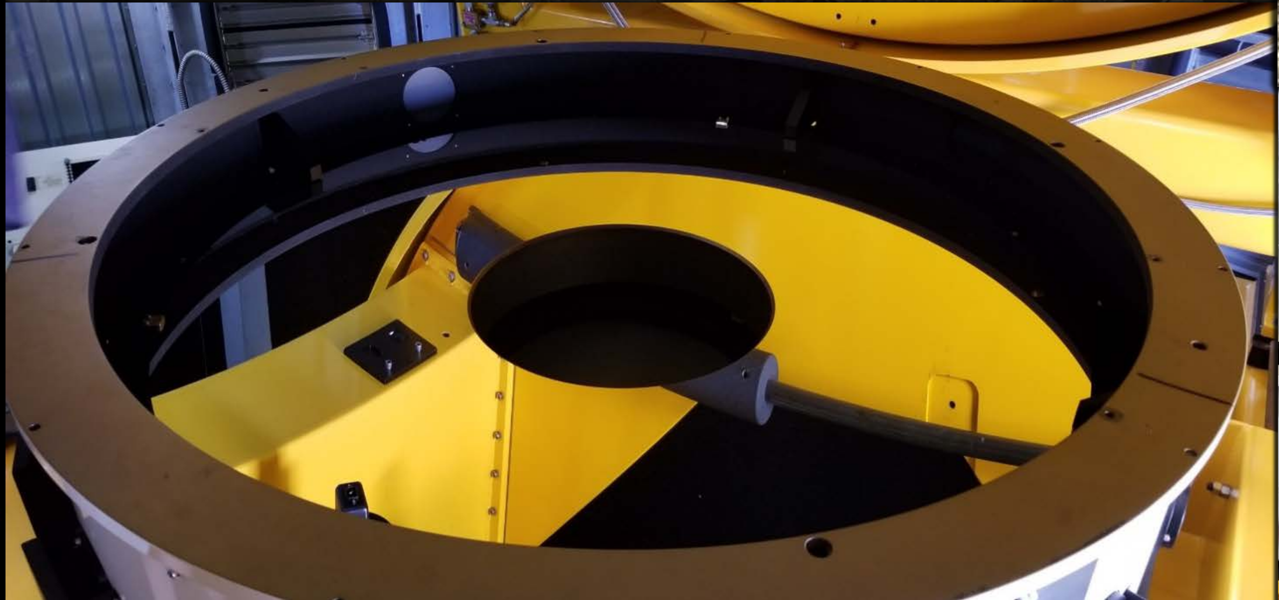
ES-MCAT (AKA MCAT)

- 1.3-meter primary mirror
- Fast tracking telescope
  - ~9° angular movement within 2.2/sec
  - >4°/sec slewing
  - 10°/sec^2 acceleration
- Fast tracking ObservaDome
  – 15 deg/sec max angular velocity
  – 24 sec to turn 360 deg
- Wide Field of View
  – 0.9° diagonally

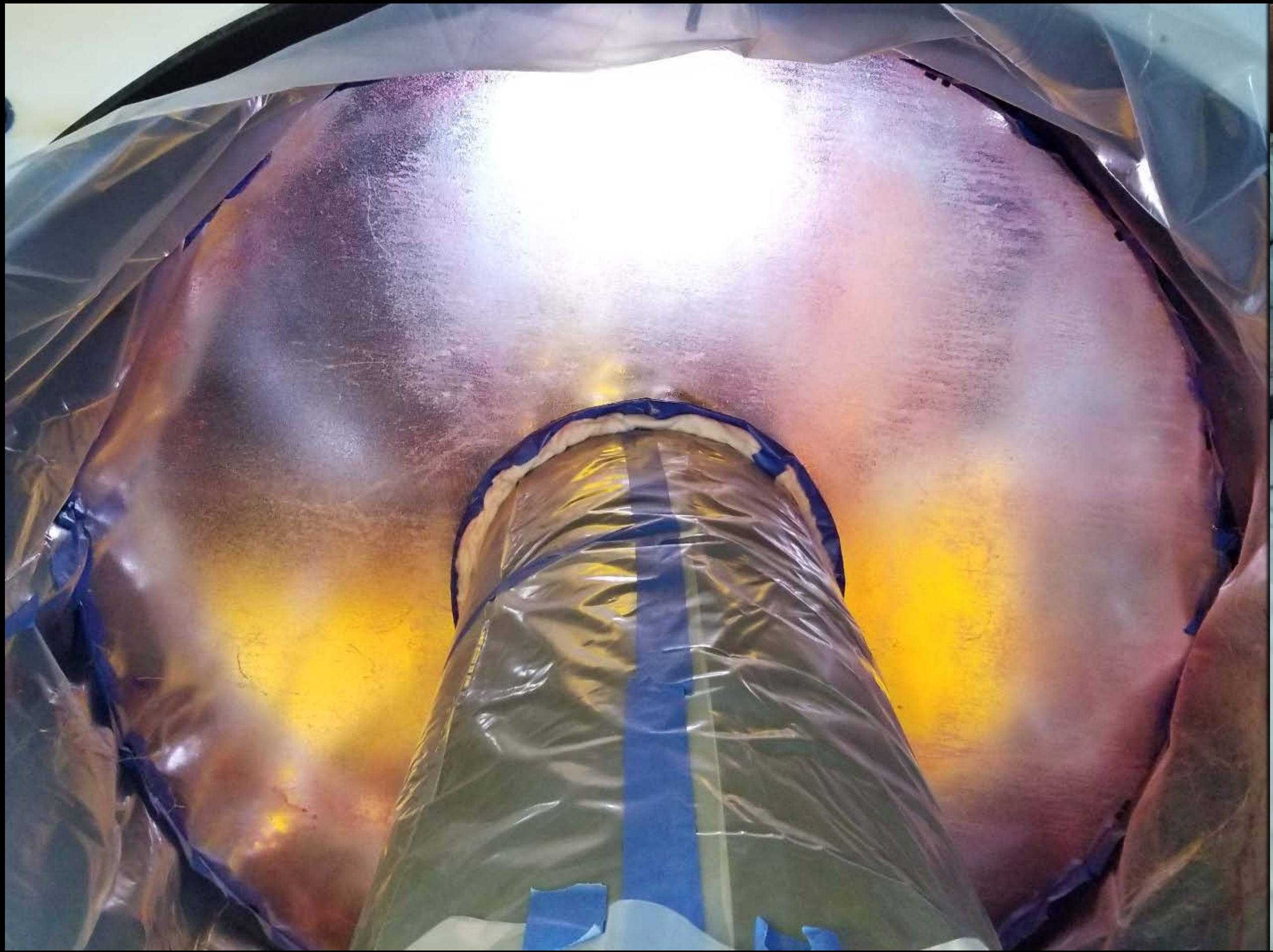


PRIMARY MIRROR RECOAT/REINSTALL: *ZECOAT ENHANCED, PROTECTED SILVER*

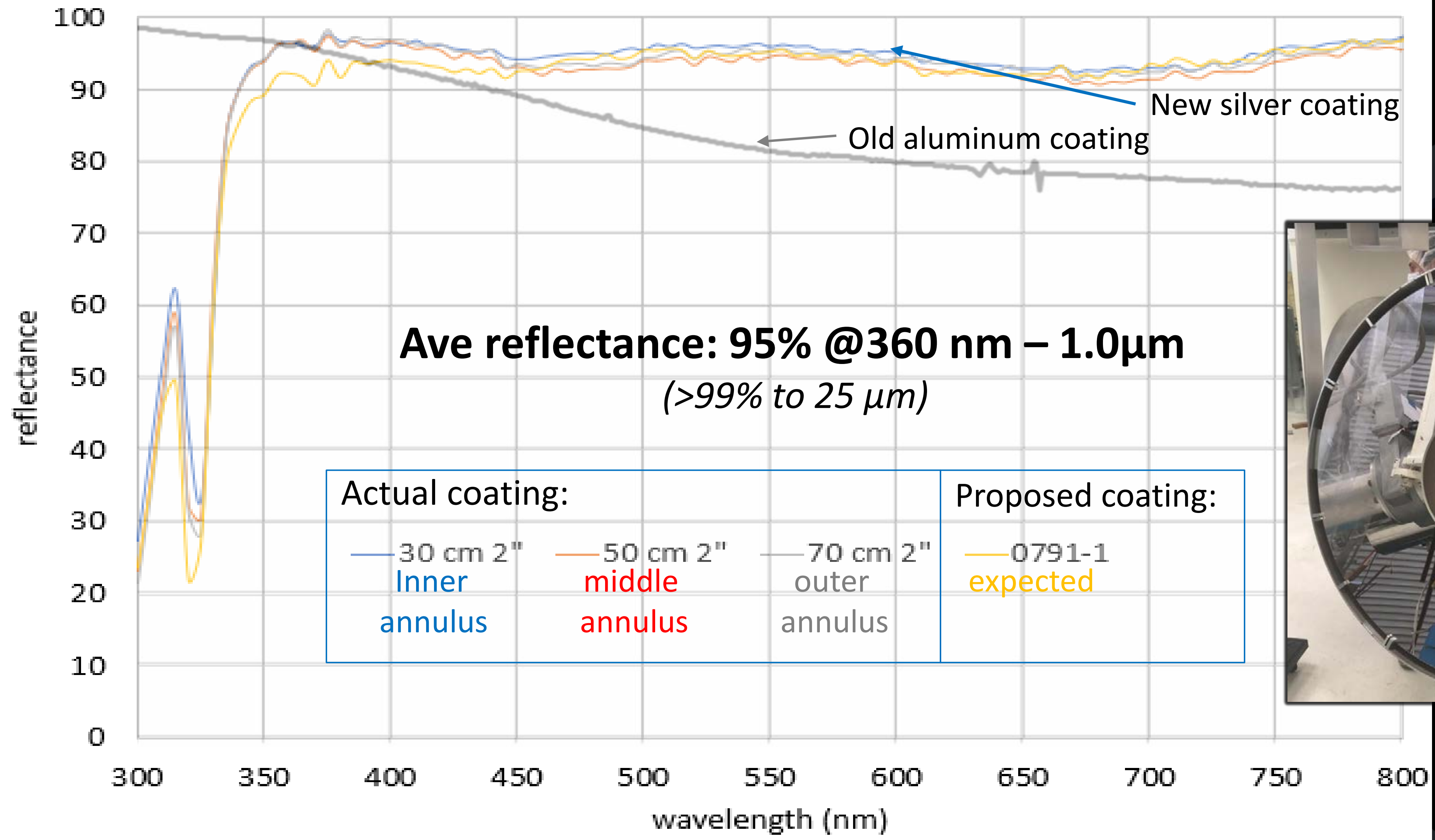




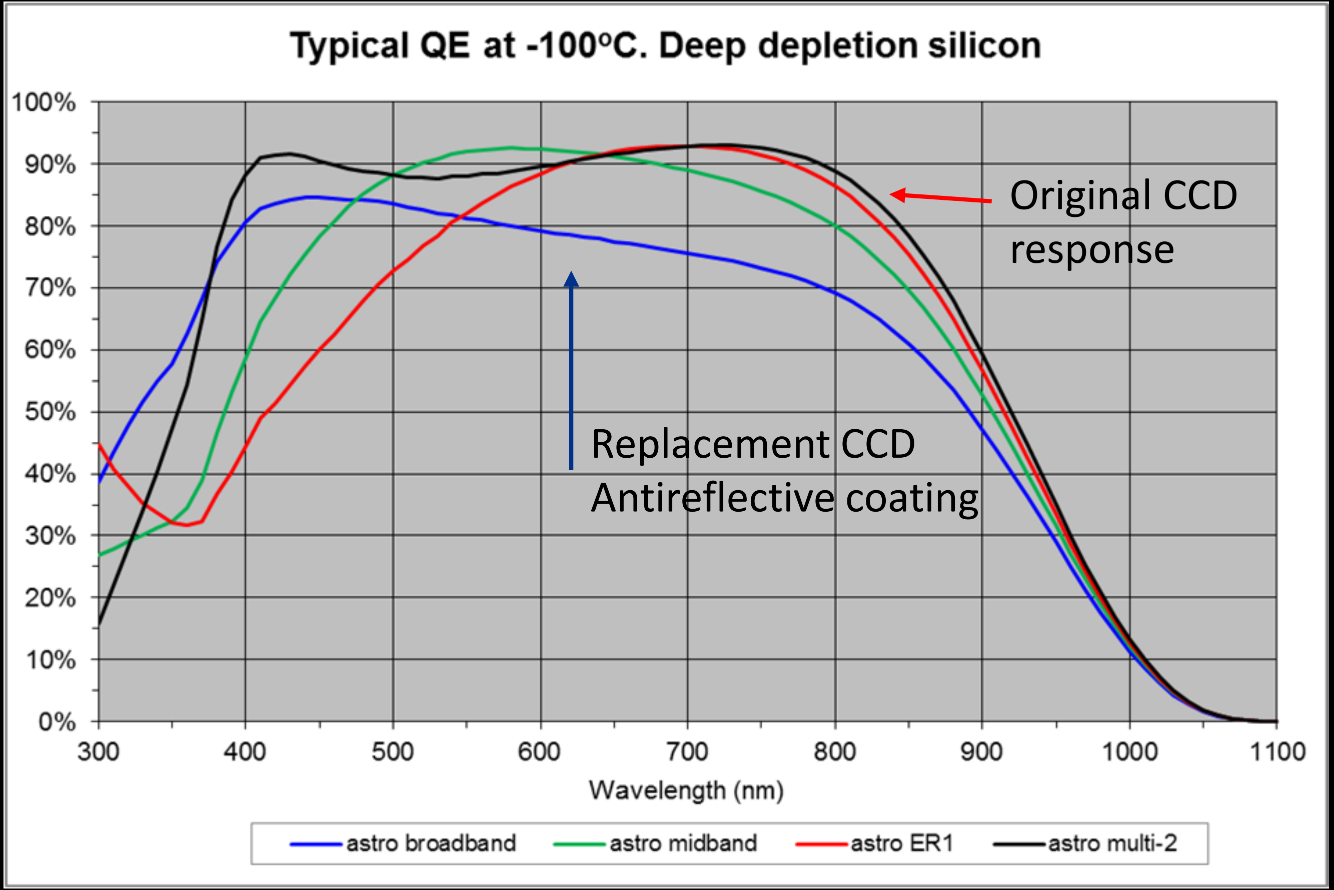
Cleaning the mirror: *First Contact Polymer*



ZeCoat Enhanced Protected Silver

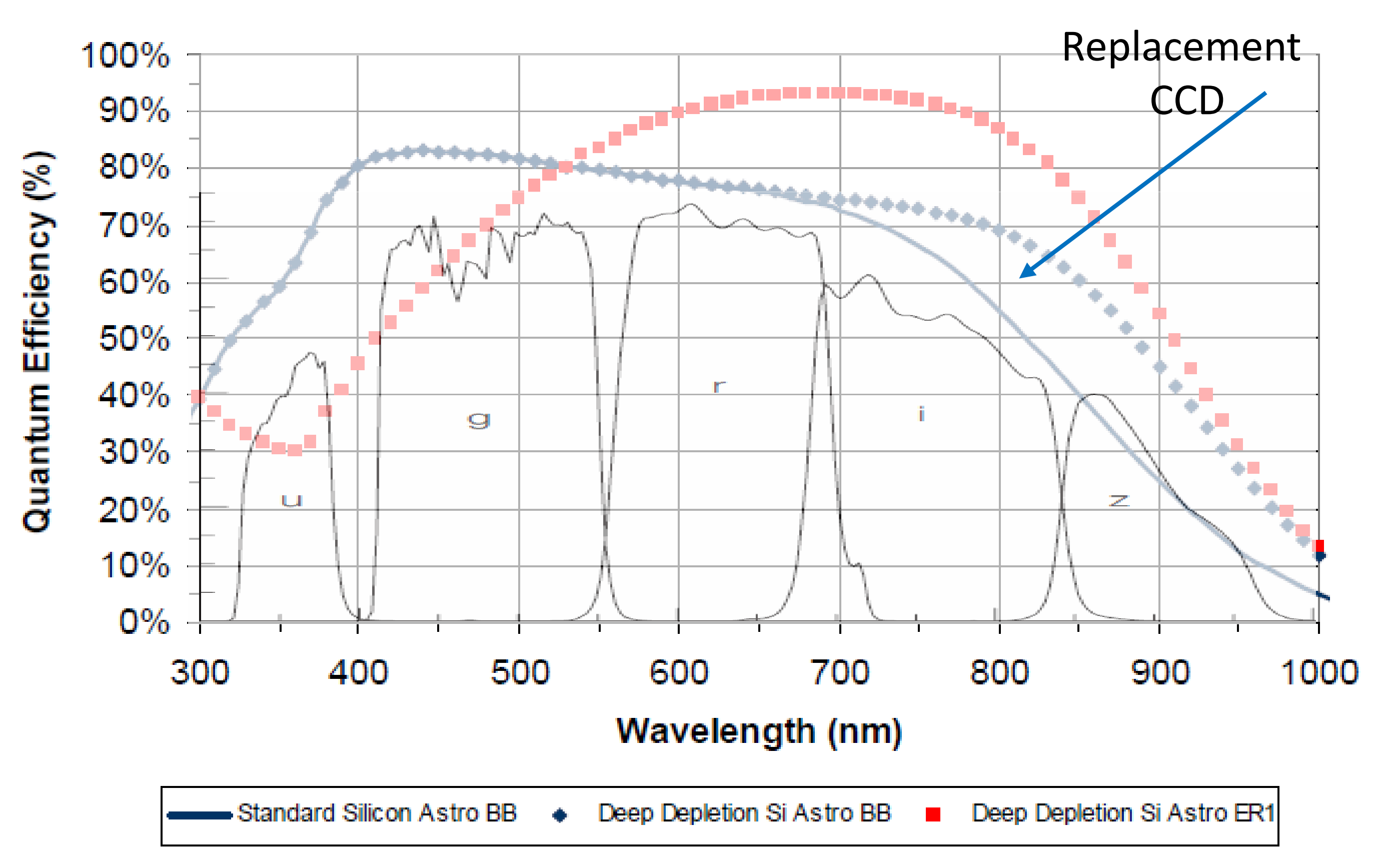


REPLACEMENT CCD CHIP: WAS ER1 COATING, NOW BROADBAND



Performance

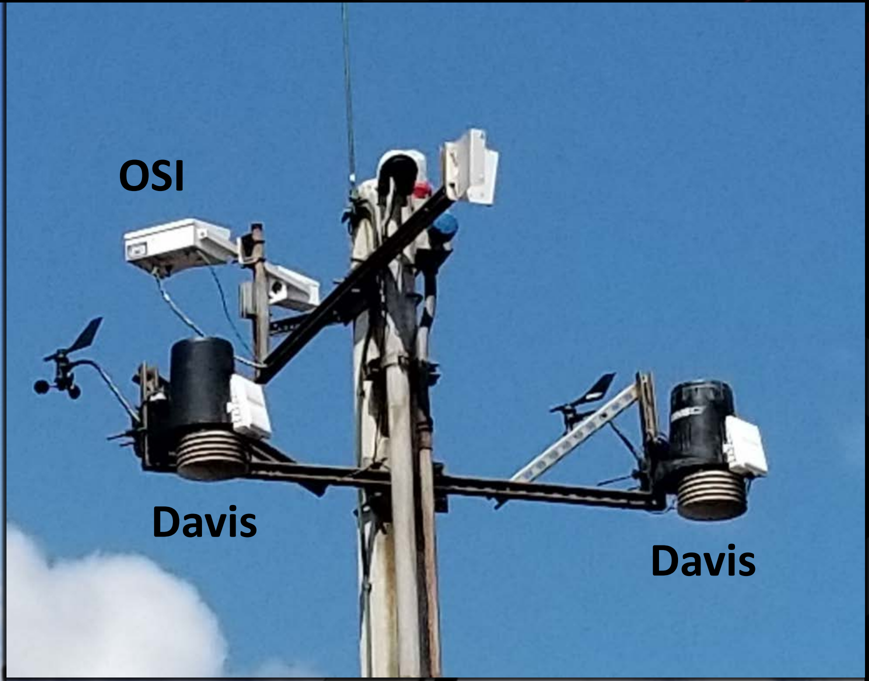
- Reflectance and Transmittance Considerations
  - 1.3m Primary mirror: >95.5% reflective
  - Secondary mirror: ~90%
  - Filters + atmosphere: g' r' i' z'
    - 70 - 20%
  - CCD chip: ~78% best, ~40% worst
- Detect capability at r'
  - 20.6 for 5 sec, SNR=3
  - 19.6, 5 sec, SNR=8
- Tracking capability
  - Anything 200 km LEO & beyond



Filter response with atmospheric extinction overlaid on CCD QE

Weather – Autonomous Monitoring

- Davis weather station (x2)
  - Wind gusts & ave
  - Temperature
  - Humidity
  - Dew point
- ASE rain sensors (x2)
- OSI rain sensors (x2 → 1)
- Condensation monitor
  - Thermocouples attached to primary
  - Monitors dewpoint vs. mirror temp

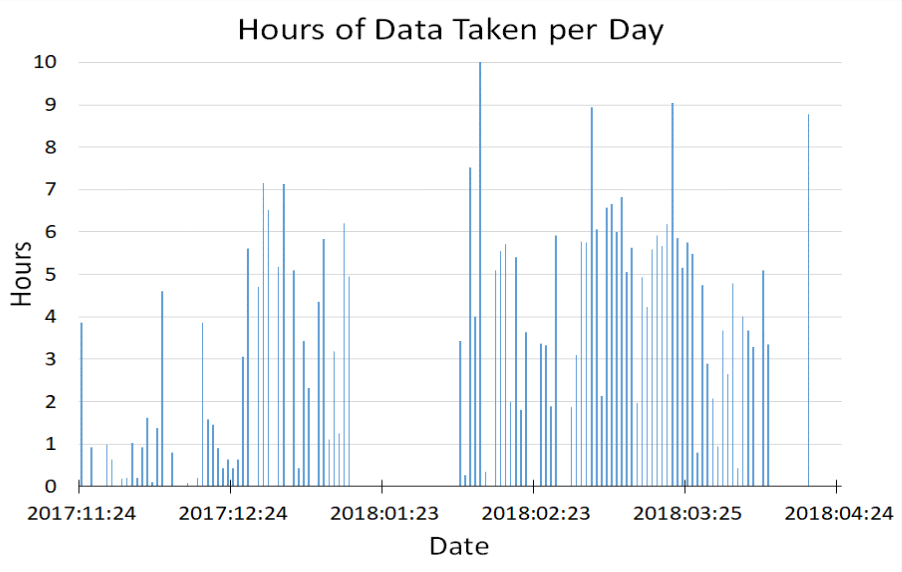


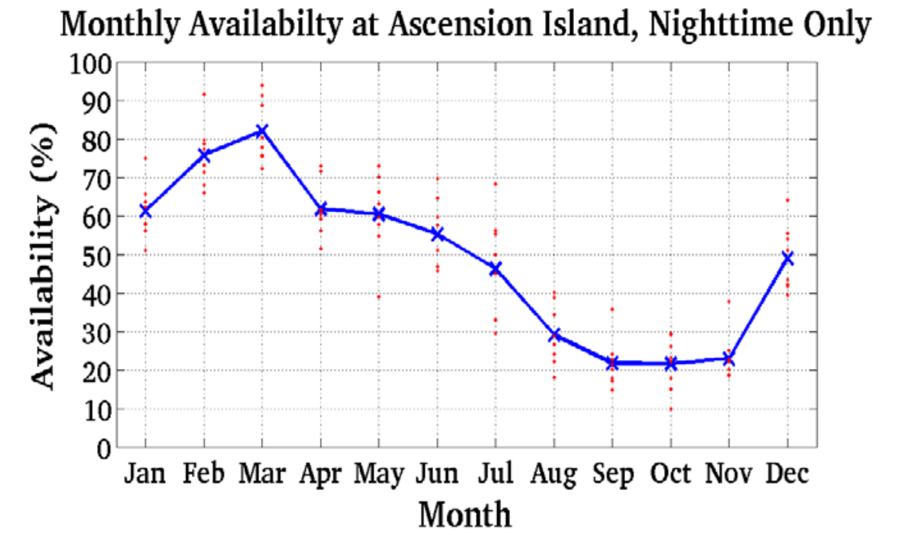
Weather and Up-time

- Weather: 40% up time

  CLOSE/reopen

  - Humidity: 90%/85%
  - Wind gust: 45/33 mph
  - Wind average: 35/30 mph
  - Dew point: 1.67/2.78°C
  - Rain
  - 20 min above reopen limits required to reopen
- Clouds folded in: Up-time ~34%





DATA COLLECTED, PROCESSED, ANALYZED, ALL AUTONOMOUSLY

- Autonomously:
  1. Collected with SDSS or Johnson/Bessel filters
  2. Pre-processed: bias subtract and flat field images
  3. Photometrically and astrometrically calibrated
  4. Debris objects identified (detected)
  5. Objects matched from one image to the next
  6. Orbit determination of matched debris objects
  7. Correlate objects
     - Correlated targets (CT) identified in (SSN catalogue) & logged
     - Uncorrelated Targets (UCT) logged

DATA COLLECTION (STEP 1)

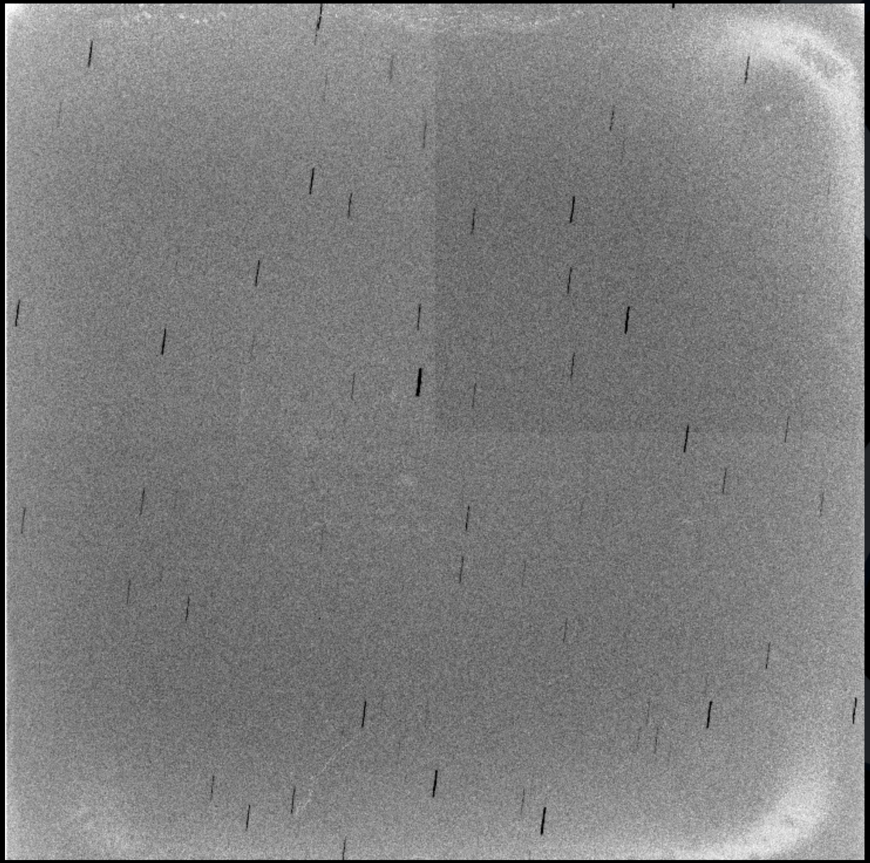
- GEO Survey/GEO Follow-up: *Distribution of debris in GEO belt (#, brightness, type)*
  – Achieved via sweep of inertial volume near GEO altitudes spanning 0-15° inclinations
  – Patterned sweep is performed either by counter-sidereal drift scan (TDI) or rate-tracked at expected GEO rates

- TLE Tracking: *Object of Interest*
  – Track at object's known (TLE/Two-line Elements from Space-track.org) or estimated TLE rate
  – Collect astrometric or photometric data of specific targets

- Orbit Scan: *Break-ups*
  – Calculate the expected orbital motion of a 'virtual object' and track at that rate
  – For discovering and characterizing fragments from a break-up event

DATA CALIBRATION (STEP 2)

- Pre-process
  - Bias or dark subtracted
    - Remove baseline counts from electronics noise
  - Flat fielded (divided)
    - Remove non-uniformities
    - Flatten out pixel sensitivity differences



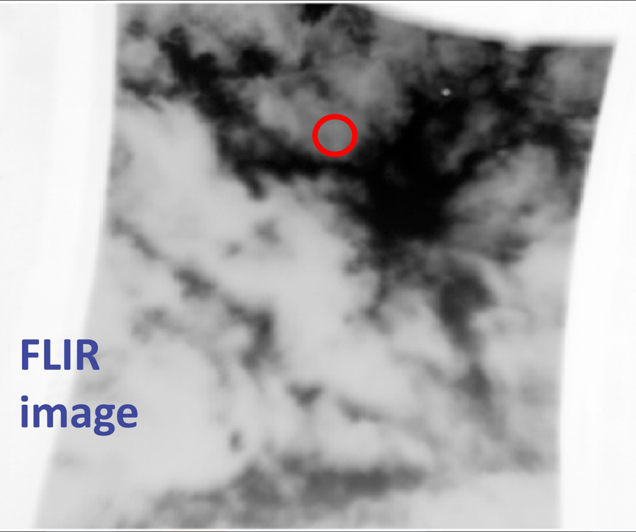
Before flat fielding

After flat fielding

Data Calibration (Step 3)

- Photometric (*brightness*) calibration
  - – Can handle streaks or point-sources
  - – Gaia catalogued stars translates 'counts' to real flux (erg/cm^2/s/Å)
    - 1.7 billion sources
  - – Extinction from the atmosphere solved for using stars *on that image*
    - *On-chip calibration handles image to image variations*
    - **Atmospheric scattering**: Airmass accounted for
      - – more extinction as you look lower in the sky through more air
    - **Transparency**: clouds accounted for

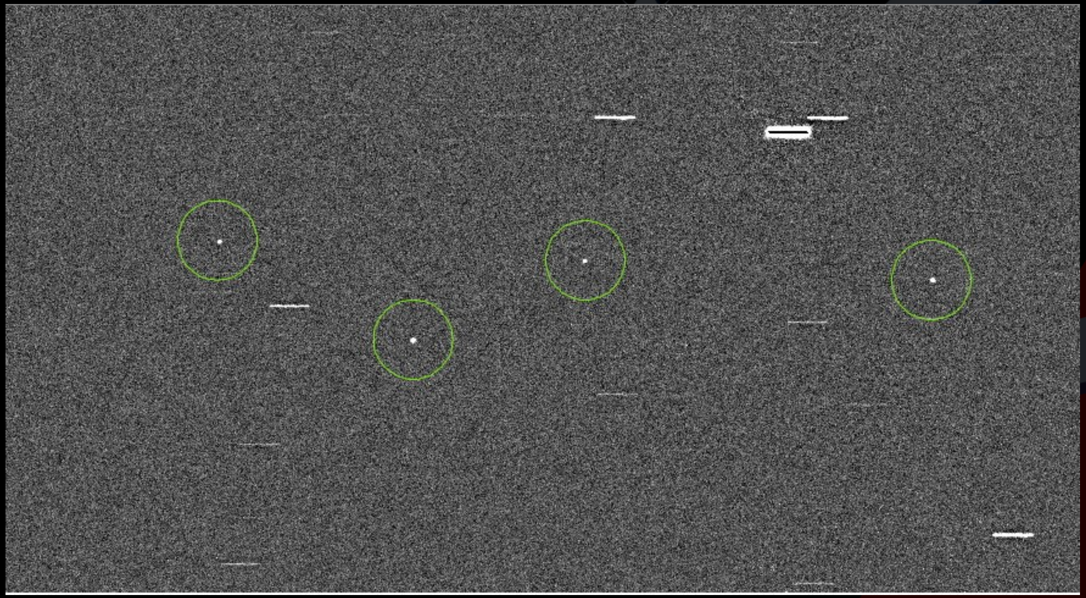
  - – *Image not taken if the FLIR infrared camera indicates it's too cloudy*



Infrared image looking through the slit of the dome

DATA CALIBRATION (STEP 3)

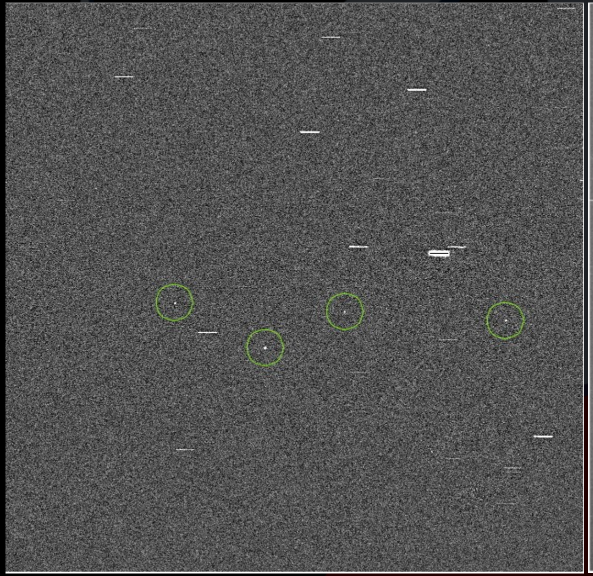
- Astrometric (position) calibration
  - Pointing (RA, Dec) of the telescope → which stars from Gaia are expected in the field of view
    - Solves for offsets compared with expectations from the telescope pointing model
  - Solves for additional parameters (rotation, anamorphic distortion, sheer)
    - MCAT: 0.2″ typical errors from these (not including pointing errors)



Tracking at GEO Rates:
Stars are streaks
Objects are point sources

DETECT, *MATCH, MERGE (STEP 4)*

- <u>Detect</u>
  - – Search for objects with a signal-to-noise (SNR) ratio > threshold (currently 6.0)
  - – Stars
    - Streak length/direction of stars calculated using:
      - – telescope track rate, exposure time, known rate of motion of a star
  - – GEO objects during GEO survey
    - point sources
  - – Non-GEO objects
    - Streaks of different length/direction than stars

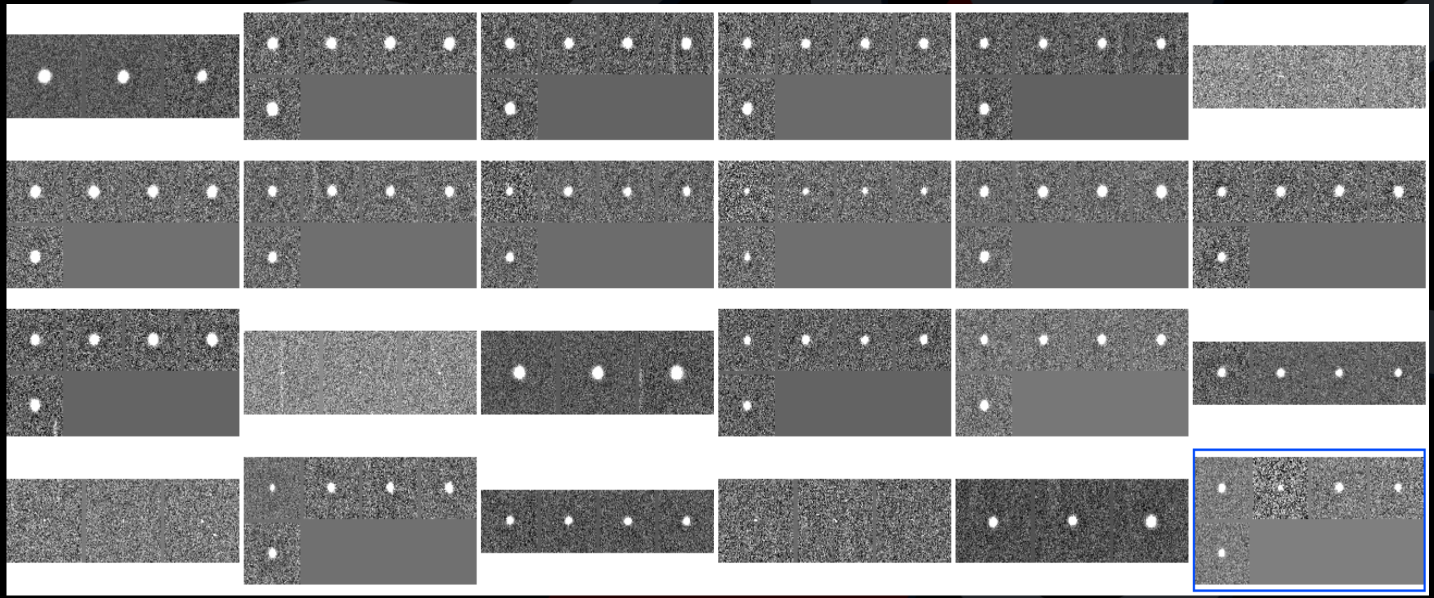


GEO tracking

LEO tracking

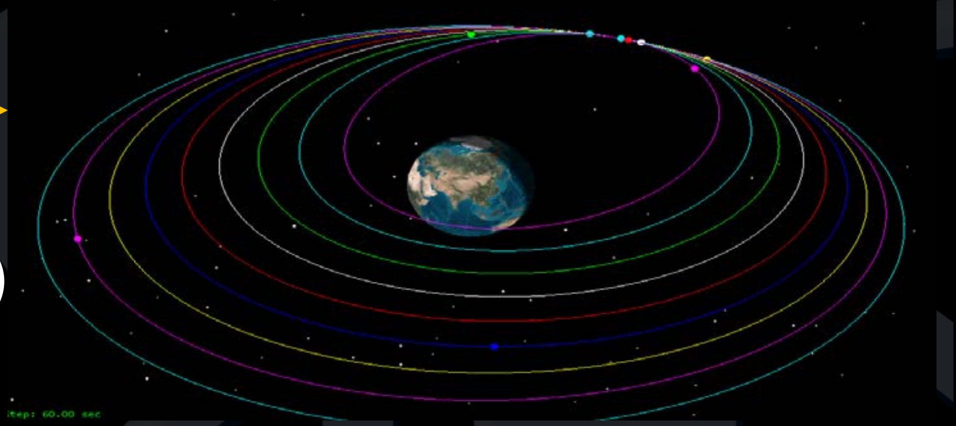
DETECT, MATCH, MERGE *(STEP 5)*

- Match
  - With the each detected 'object' in GEO, calculate where other GEO objects are expected in subsequent images to 'match' them up
- Merge
  - Cross-check back/forward to see which matched objects link up as the same object
  - 8 images of each location taken
    - *Assuming clouds don't interfere*
  - Must have ≥ 4 objects from 4 images merged to confirm it as an 'object'
  - SNR ≥ 7.0 to qualify



ORBIT DETERMINATION & CORRELATING DATA (STEPS 6 & 7)

- <u>Orbit determination</u>
  - – Assume a circular orbit because →
    - Not enough observations to estimate eccentricity
  - – Calculate initial orbital elements → Two Line Element (TLE)
  - – Propagate TLE forward with SGP-SDP* algorithm
    - Refined and optimized with MCMC** algorithm



Frith et al., AMOS 2017

- <u>Correlate</u> TLE of object with known objects in the spacetrack.org cataloguse
  - – SSN correlations completed at NASA Johnson Space Center

→Data delivered to NASA's Engineering Model, ORDEM

**(SGP): Simplified General Perturbations model; (SDP): Simplified Deep-space Perturbations model*
***(MCMC): Metropolis-Hastings Markov-Chain Monte-Carlo*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ASCENSION ISLAND
Greg Cooke Photography