

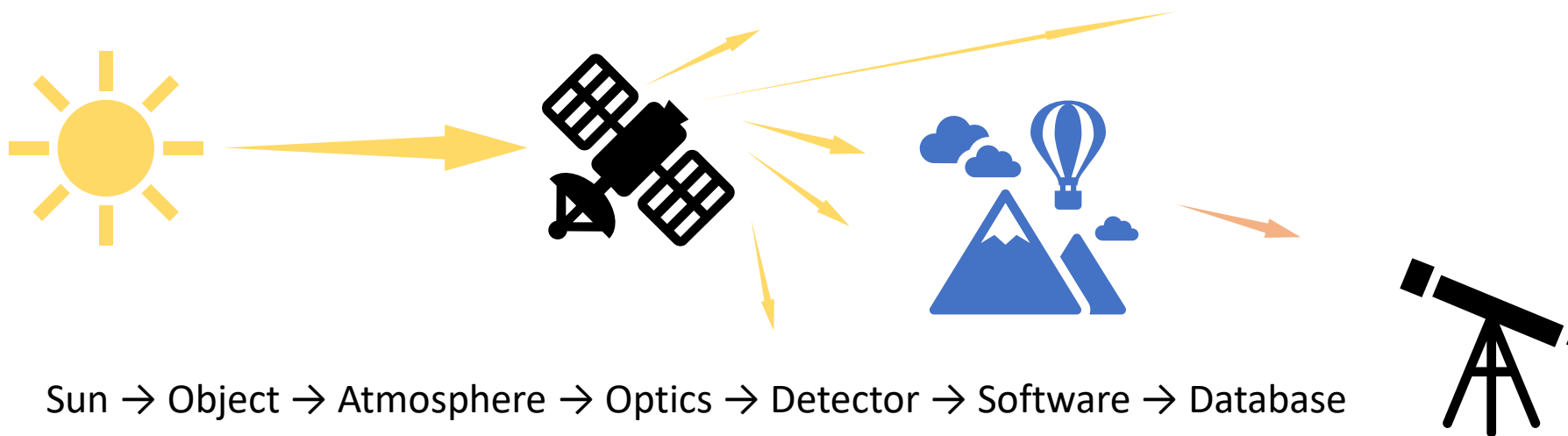
Some Lessons from Ground-based Optical SSA Operations

Dr. Peter Zimmer

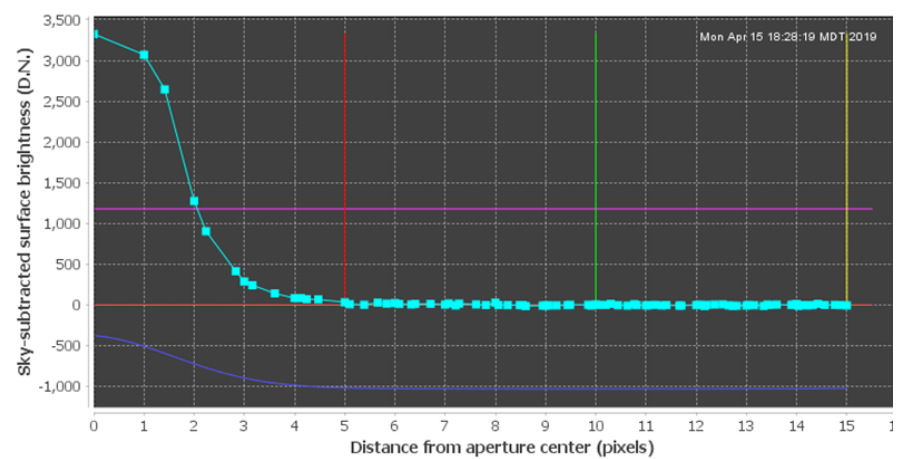
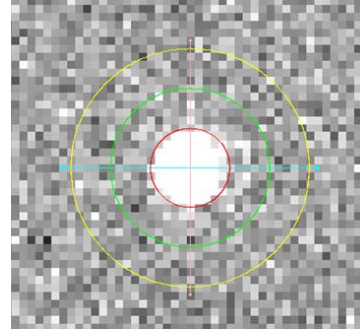
J.T. McGraw and Associates, LLC (JTMA) / COMSPOC

The Optical/Infrared SSA Problem

- Find, monitor, identify and analyze objects in orbit
 - Active illumination: Radar, lidar
 - Passive: RF, thermal, reflected solar, occulted starlight



Optical Observations



- Knowledge of the target object is limited by:
 - Atmosphere: transmission, emission, scintillation, and “seeing”
 - Diffraction from the aperture
 - Imperfections in the optics, both in design and manufacturing
 - Detector: quantum efficiency, read noise, dark, sampling, timing, location
 - Measurement: background estimation, centroid technique, star registration

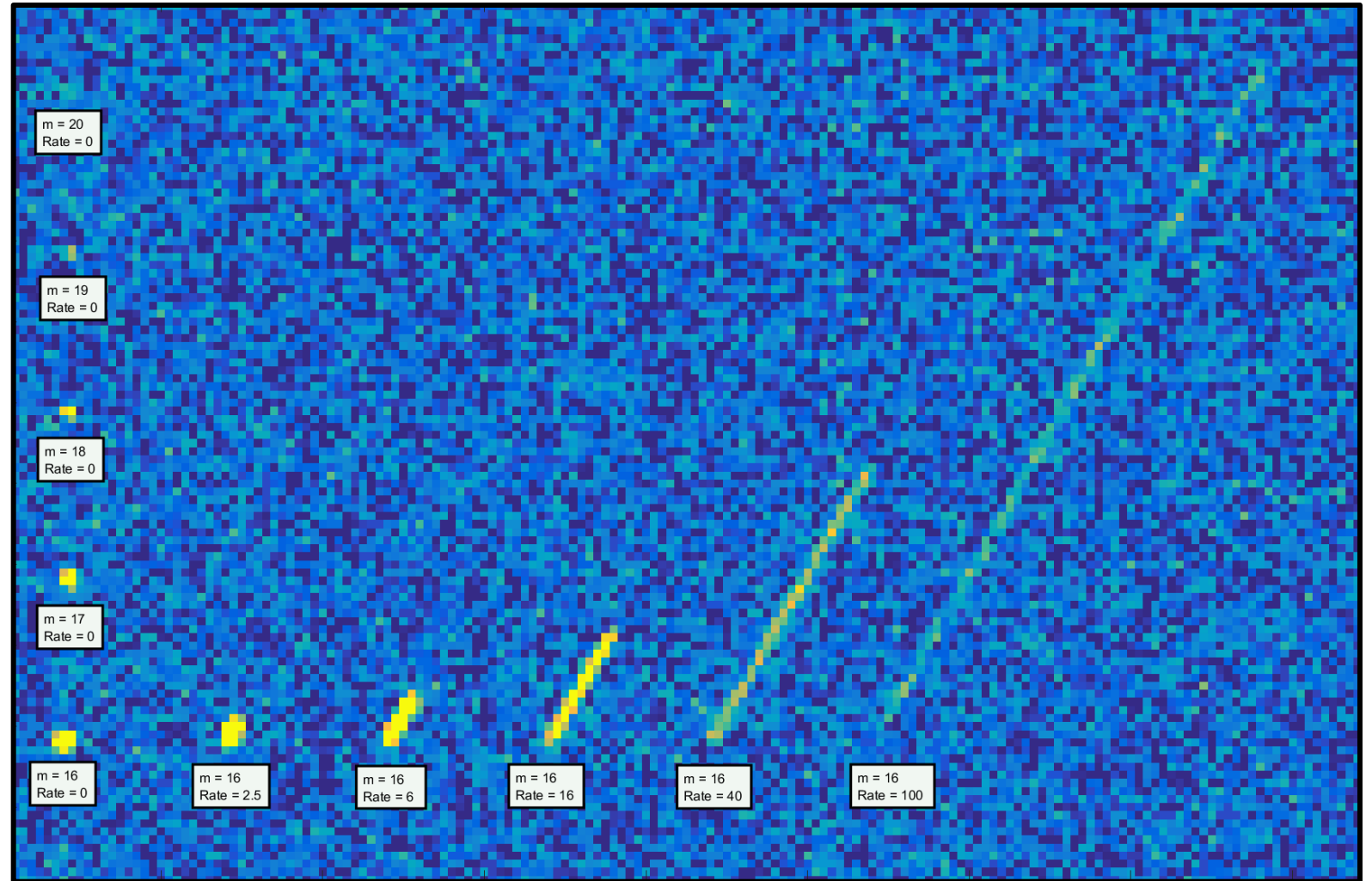
- Signal-to-noise ratio:
 - Measure of intensity precision
 - Positional centroid precision

Rule of thumb: $\sim \text{FWHM} / (2 * \text{SNR})$

- $$\text{SNR} = \frac{S}{\sqrt{S + n_{pix} * (\langle B \rangle + \sigma_{RN}^2)}}$$
 - S is the signal, in photons
 - B is the background, in photons
 - σ_{RN} is the RMS detector read noise

Trailing Loss

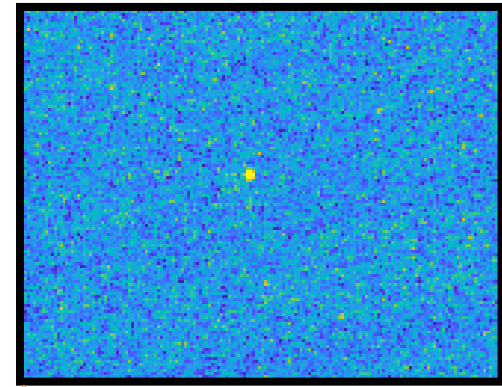
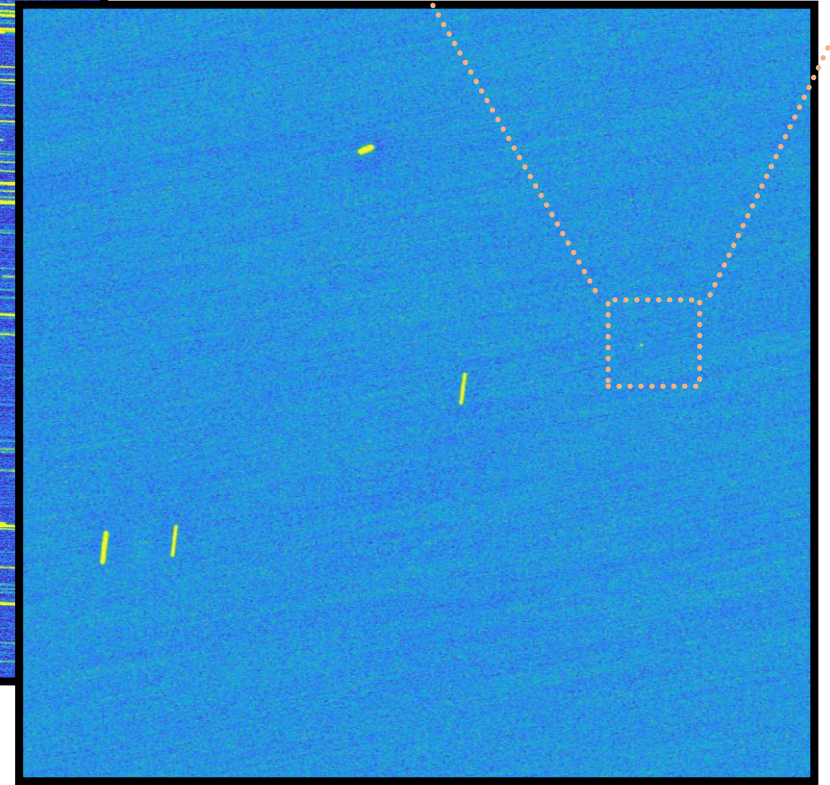
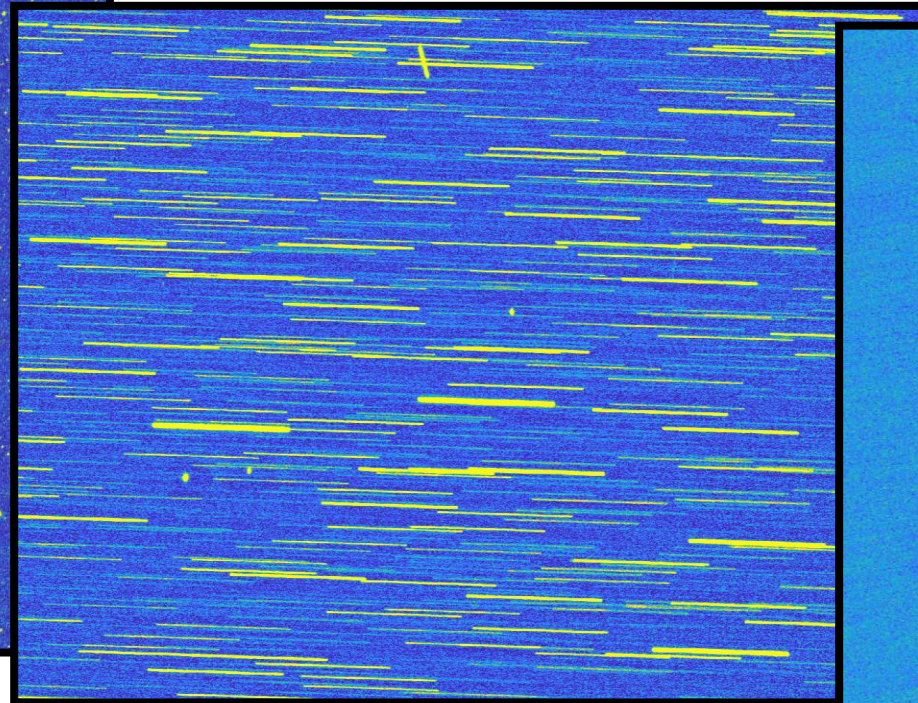
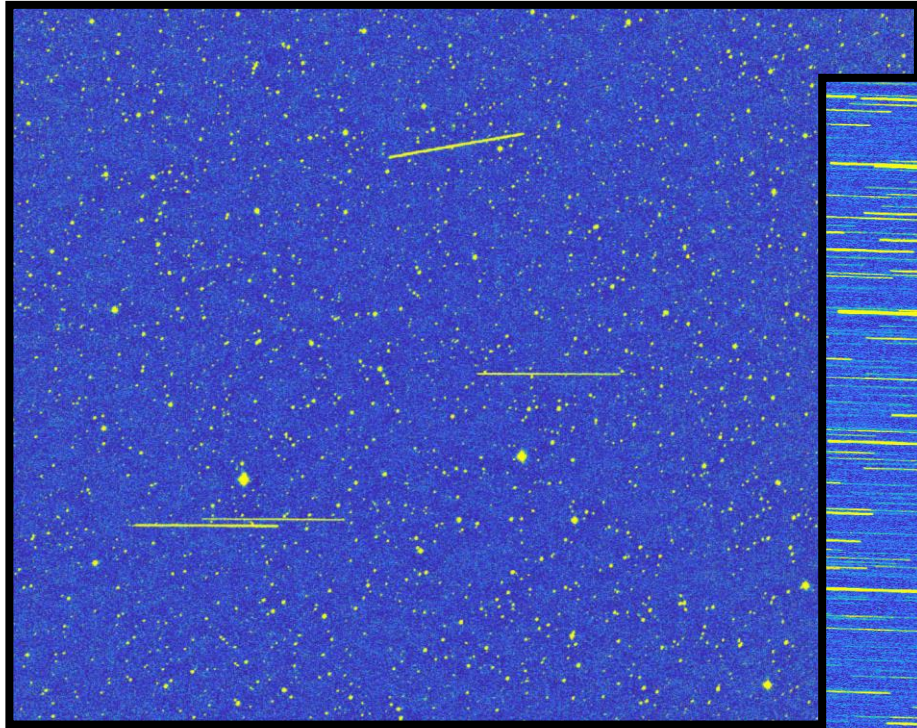
- Telescope tracking
 - Stars
 - Object rate
 - None (GEO)
- Rate mismatch
 - Streaks/Trails
 - Dilutes SNR
 - Increases position uncertainty in along-track direction
- Pick operation mode to suit mission



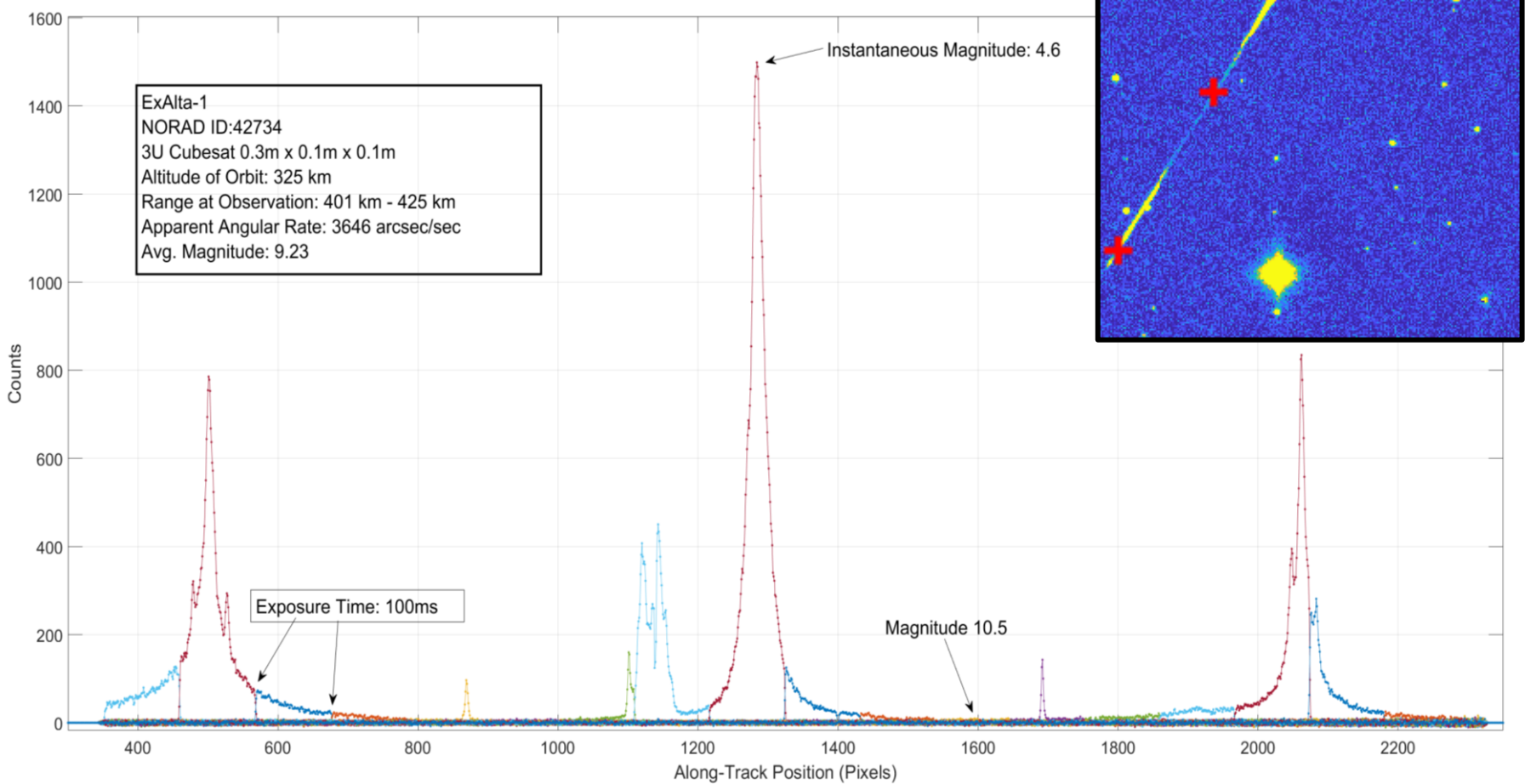
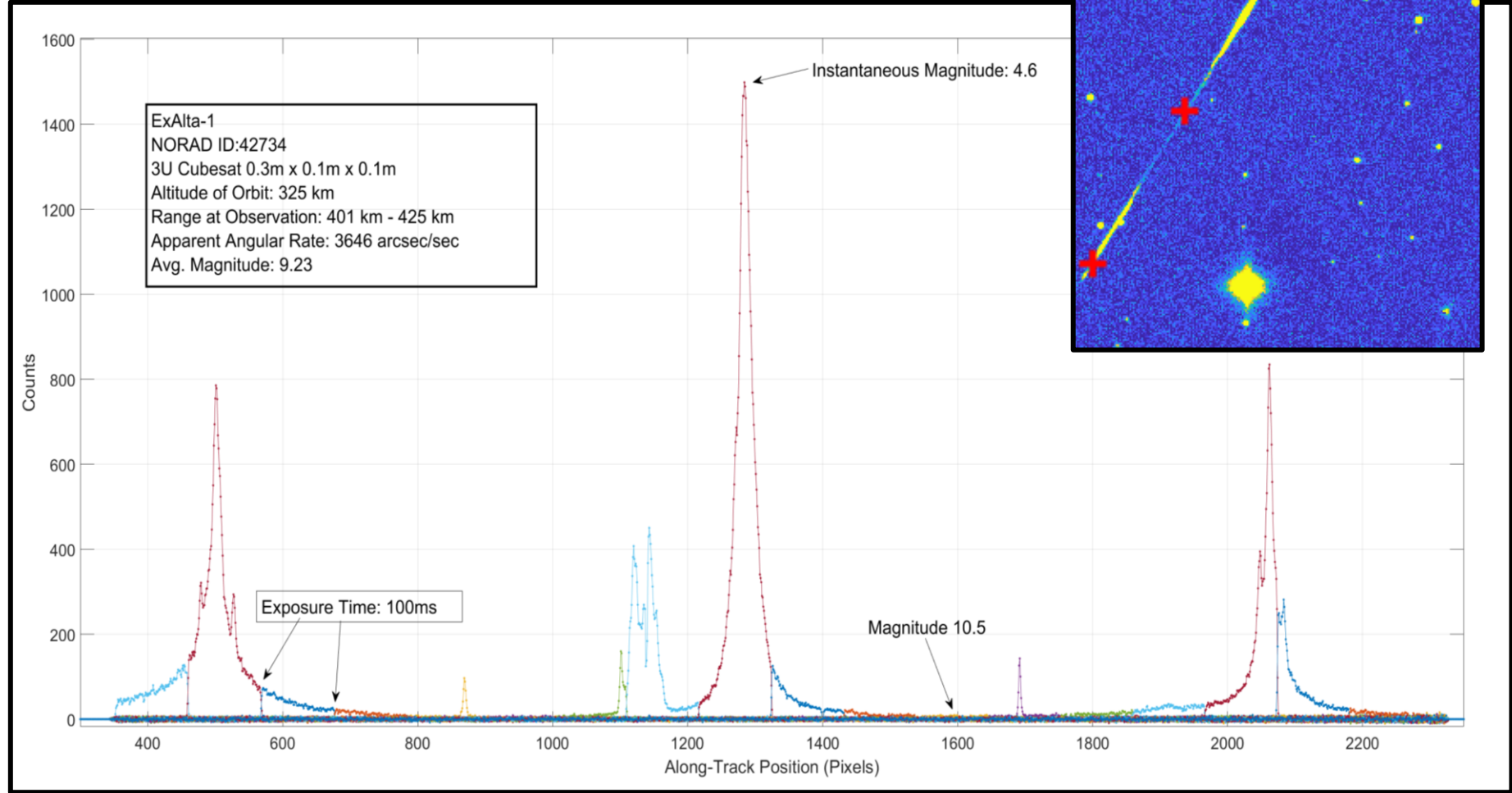
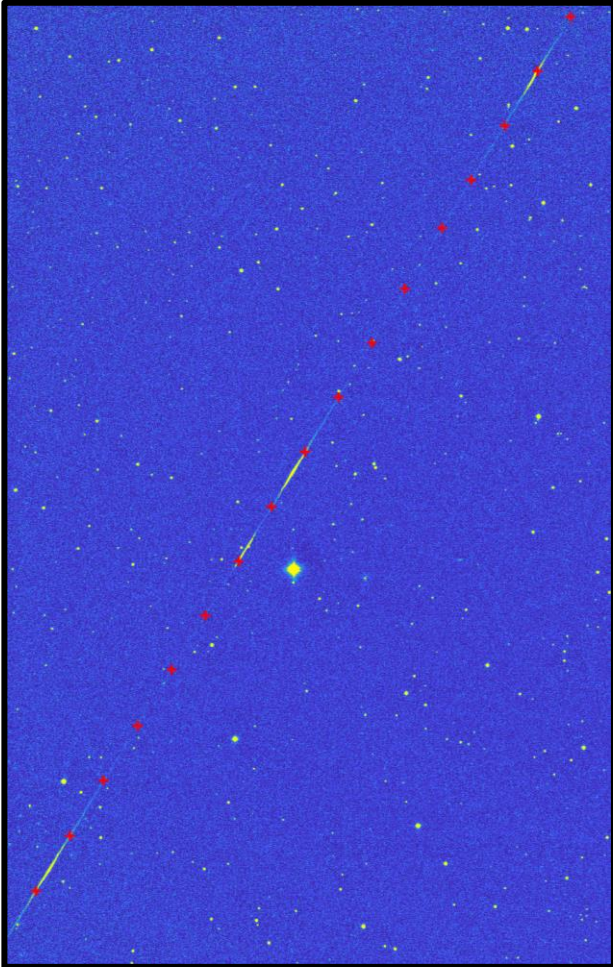
SSA Observation Modes and Choices

- How noise and errors affect ground-based SSA obs depend on how the observations are taken:
 - Cislunar – long exposure times ($>15s$), fully sky background noise limited
 - Atmospheric turbulence effectively averaged out
 - Intrinsic source brightness unlikely to be changing significantly during exposure
 - Mostly standard astronomical observations
 - GEO/MEO – intermediate exposures ($\sim 1s$), background and read noise
 - Positions and intensity various depend significantly on atmospheric turbulence
 - Intrinsic source brightness unlikely to be changing significantly during exposure
 - LEO – short exposures ($< 1s$), read noise dominated
 - Atmosphere drives large intensity variations and dominates position errors
 - Intrinsic brightness can change very rapidly within exposure time

Sample Observations: GEO

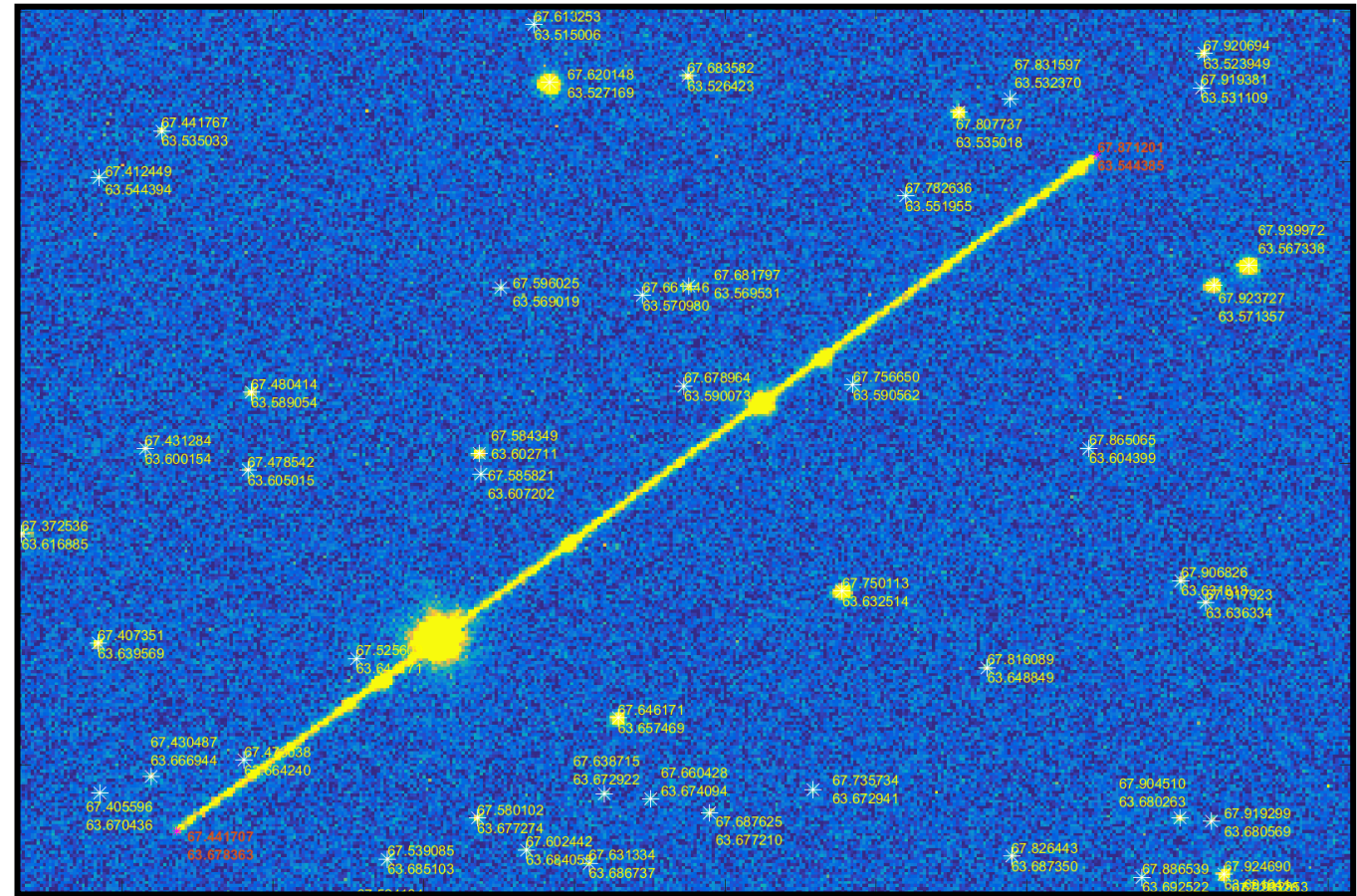


Sample Observations: LEO



Stellar Reference

- Astrometric catalogs provide reference into inertial frame
 - GAIA EDR3 (faint)
 - Hipparcos (bright)
- Measure and match stars
 - Fit observed to catalog positions
 - Typical residuals $< 1''$
 - Use model to determine sky positions for target objects



Critical Metadata

- Where were the observations taken
 - Easy for ground-based systems – telescope lat/lon/alt
 - Errors under 1m are typical
 - More involved for space-based observations
- When were the observations taken
 - Measure when an observation was taken as accurately as possible
 - 1 ms timing error -> 7m along track error in LEO
 - PC clock can be disciplined, but timing jitter in camera operation dominates
 - GPS timing is easy
 - But it needs to operate at the camera signal level
 - Either on board the camera or with trigger lines
 - Must correct for sensor-level timing, such as rolling shutter operation

Observations Against Calibration Objects

- Routine checks by observing objects with high precision ephemeris
 - Satellite laser ranging targets – e.g. AJISAI
- Best measure of uncertainty

