Satellite Constellation Data to Drive Thermospheric Density Forecasting Capabilities

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Synopsis:

Interactions between resident space objects in low-Earth orbit (LEO, i.e., orbits below ~1,000 km altitude) and the ambient atmospheric environment cause significant orbital perturbations. While LEO is a most desirable orbital regime from the standpoint of debris disposal, the uncertainty of an object's orbital trajectory is often a limiting factor in the accuracy of conjunction assessments used to determine when and if a collision-avoidance maneuver is needed. At the same time, the increasing population of LEO over the last 5 years has compounded the overall risk of collisions. By combining tracking data from recently launched small satellites, often in the form of high-rate GNSS observables or quantities derived thereof, with attitude and satellite geometry information, the thermosphere can be observed with unprecedented coverage. The necessary information is available, in various forms, from several mega constellations, including Starlink, Spire, and others. This talk will outline the progress, challenges, and limitations of working with commercial datasets as well as the promise of scientifically instrumented, targeted missions.

The Starlink Constellation

Owner/Operator:	SpaceX
Country of Origin:	United States
Application:	Internet service
Website:	www.starlink.com
Spacecraft type:	Small satellite
Launch Mass:	v0.9: 227 kg v1.0: 260 kg v1.5: ~306 kg v2m: 800 kg v2.0: 1,250 kg
Equipment:	Ku-, Ka, & E-band phased array antennas Laser transponders Hall-effect thrusters
Regime:	LEO mid- & high-inclination
Status	Active since 2019 ~6,500 satellites on-orbit (current as of 10/4/2024)

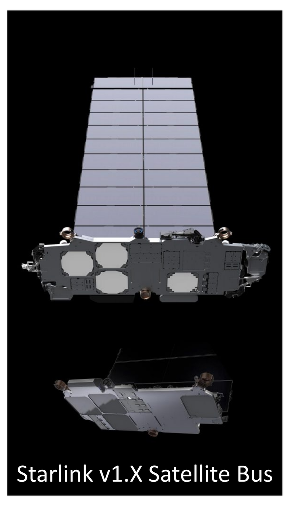
All information above is publicly available from wikipedia.org or space-track.org

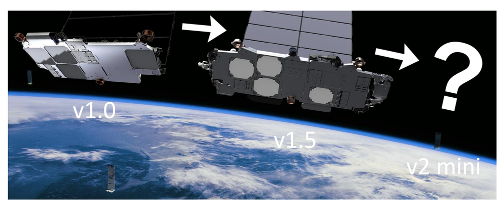
We are using the following data from SpaceX:

- Position & velocity ephemeris
- Attitude & panel articulation
- Estimated non-conservative accelerations (on-board OD filter)
- Satellite geometry files

Periods of interest:

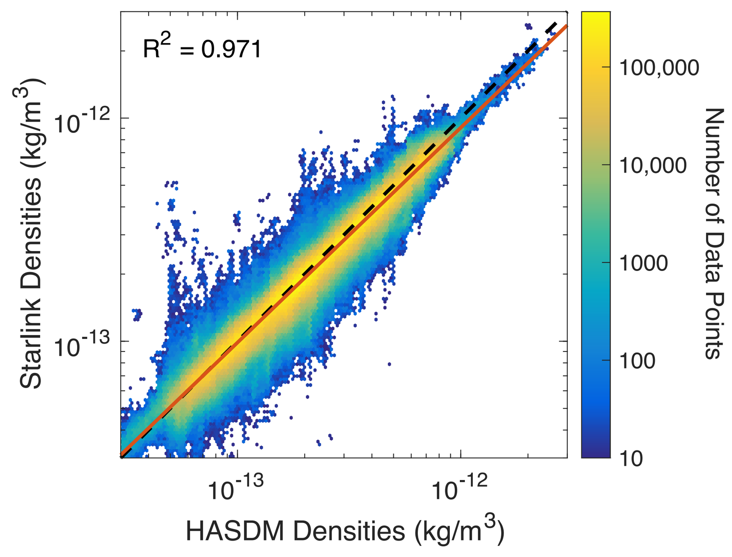
- June 2022—April 2023:
  - ~1,500 v1.0 satellites
- February 2024:
  - ~1,400 v1.0 satellites
  - ~2,900 v1.5 satellites
  - ~700 v2m satellites

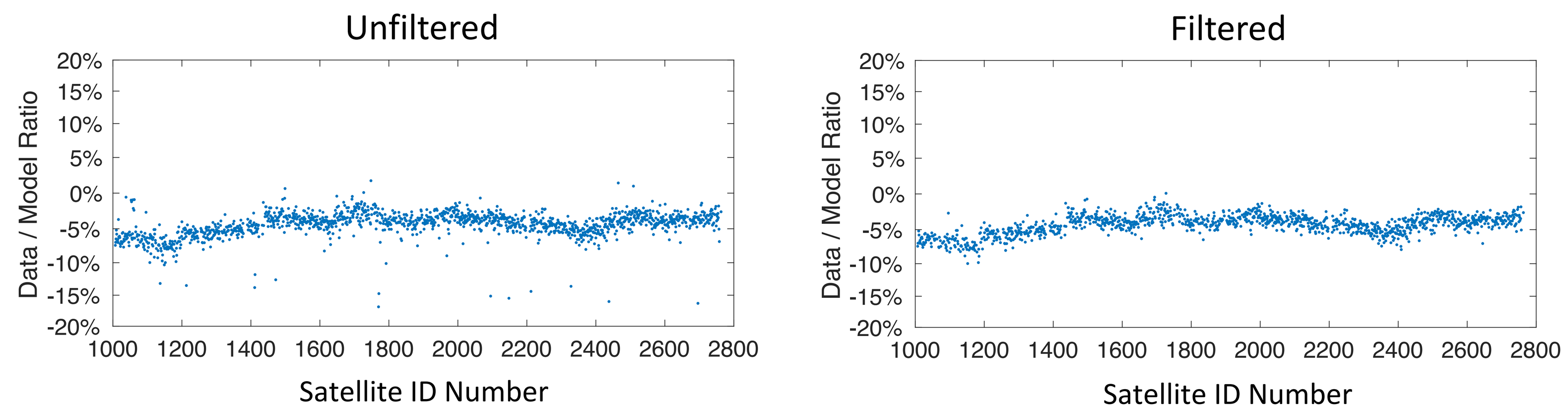




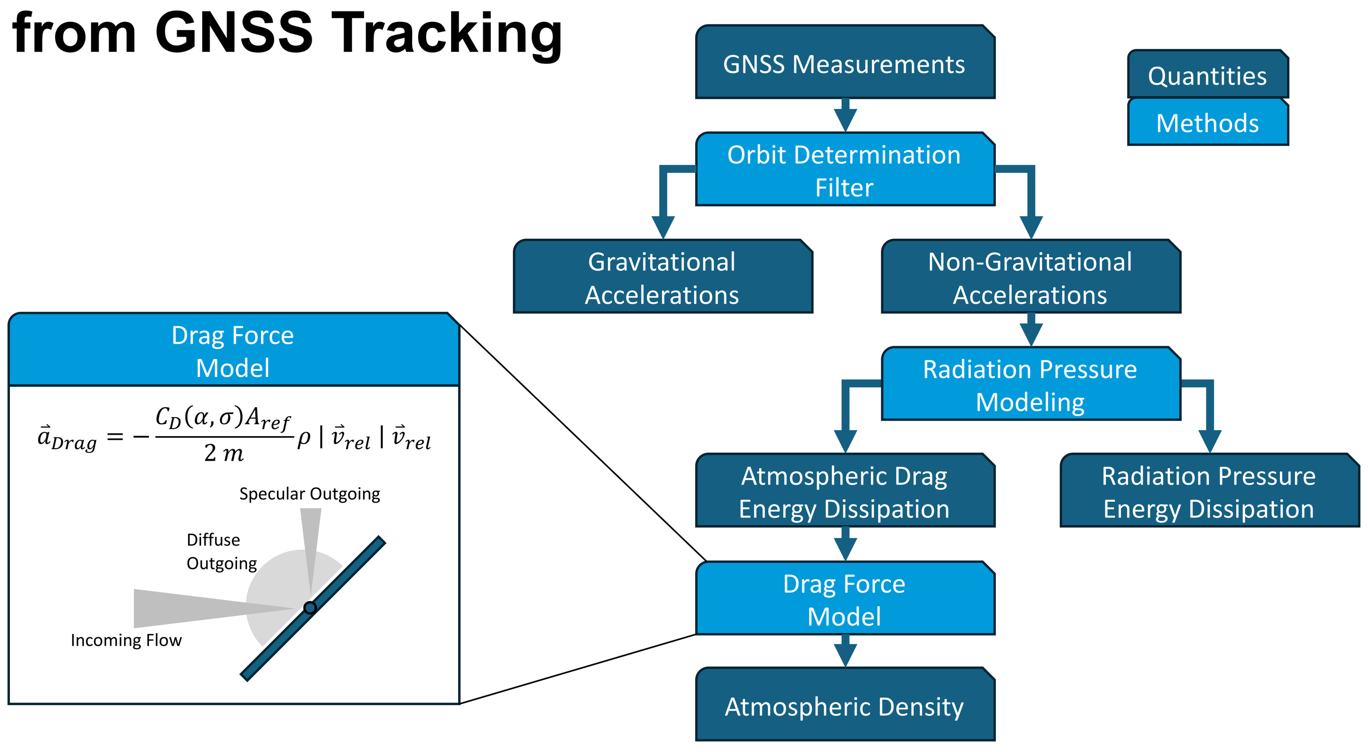
Densities from ~1,500 v1.0 Starlink Satellites (June '22 – April '23)

- Very low bias/std with respect to HASDM
- Some satellites are anomalous, and can be easily filtered out using individual satellite health status (see unfiltered / filtered comparison below)
- ~1,500 v1.0 Starlink densities:
  - Mean Bias (data/model): **–4.5%**
  - StD (data/model): **9.98%**



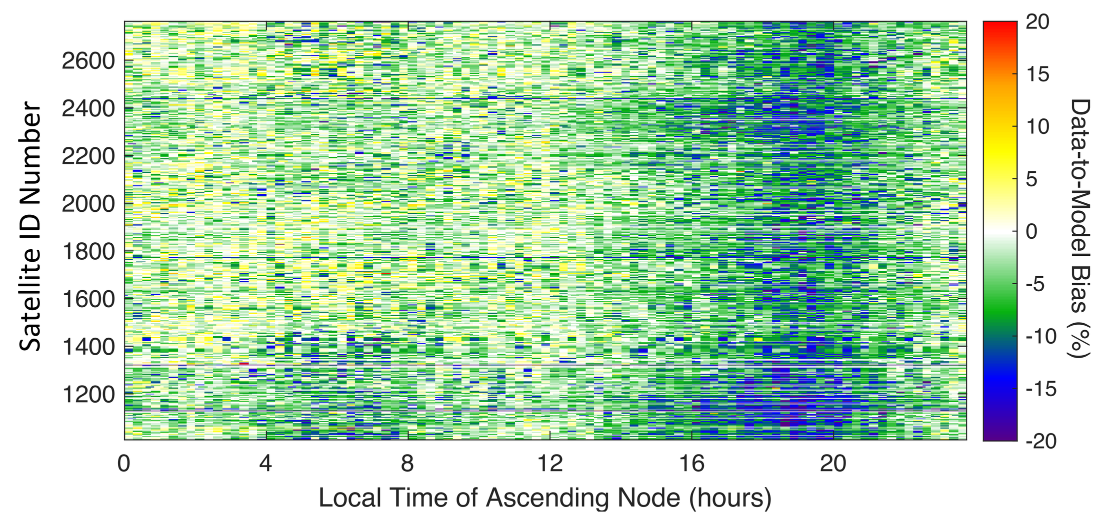


Inferring Atmospheric Densities from GNSS Tracking

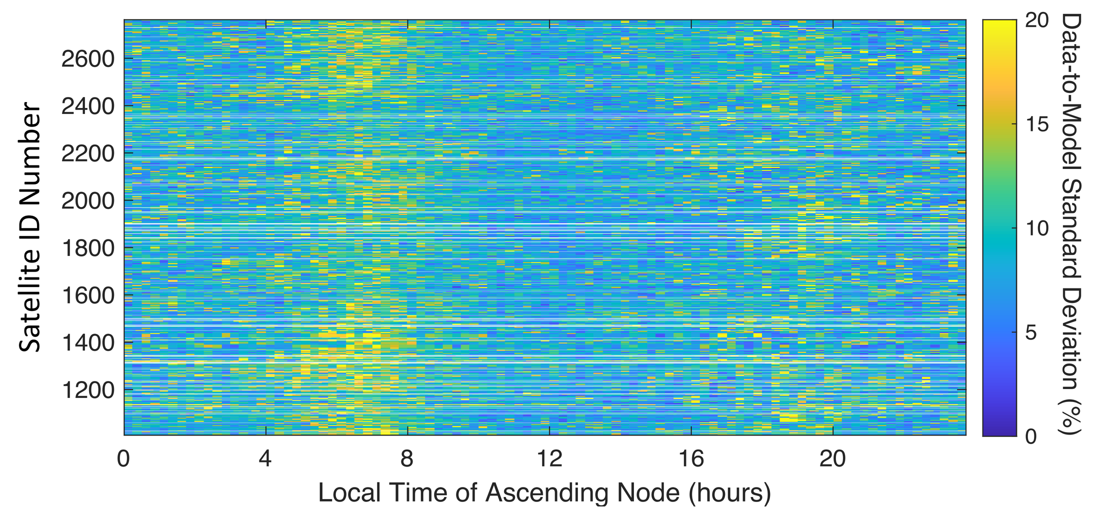


Statistical Performance vs. HASDM (June '22 – April 23')

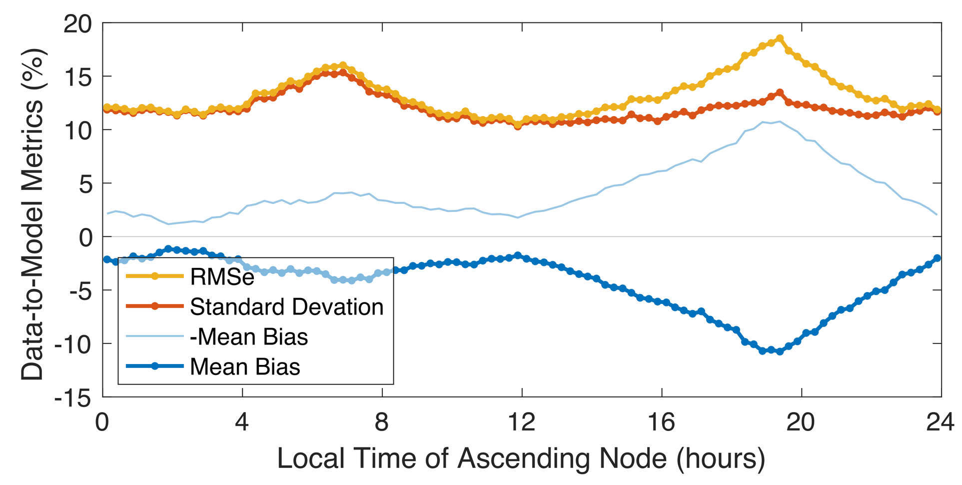
Mean Bias →



St. Dev. →

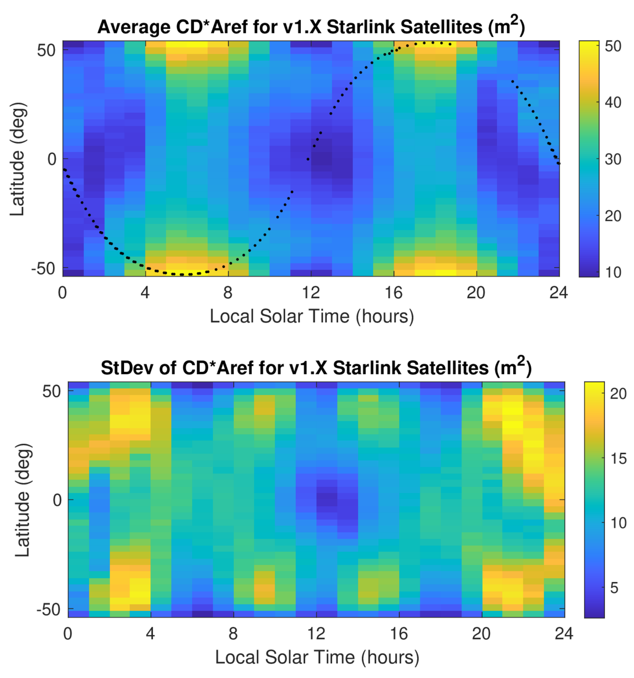


All Metrics →

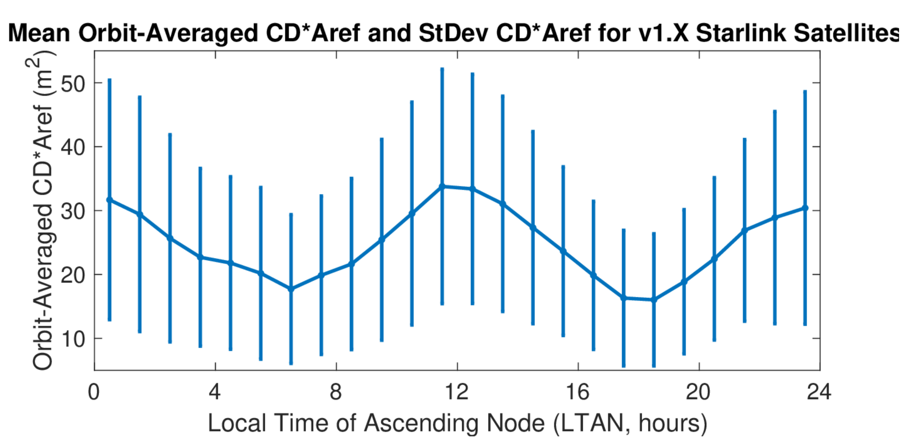


Sensitivity to Drag & Area Modeling:

Instantaneous (C_D*A_{ref})

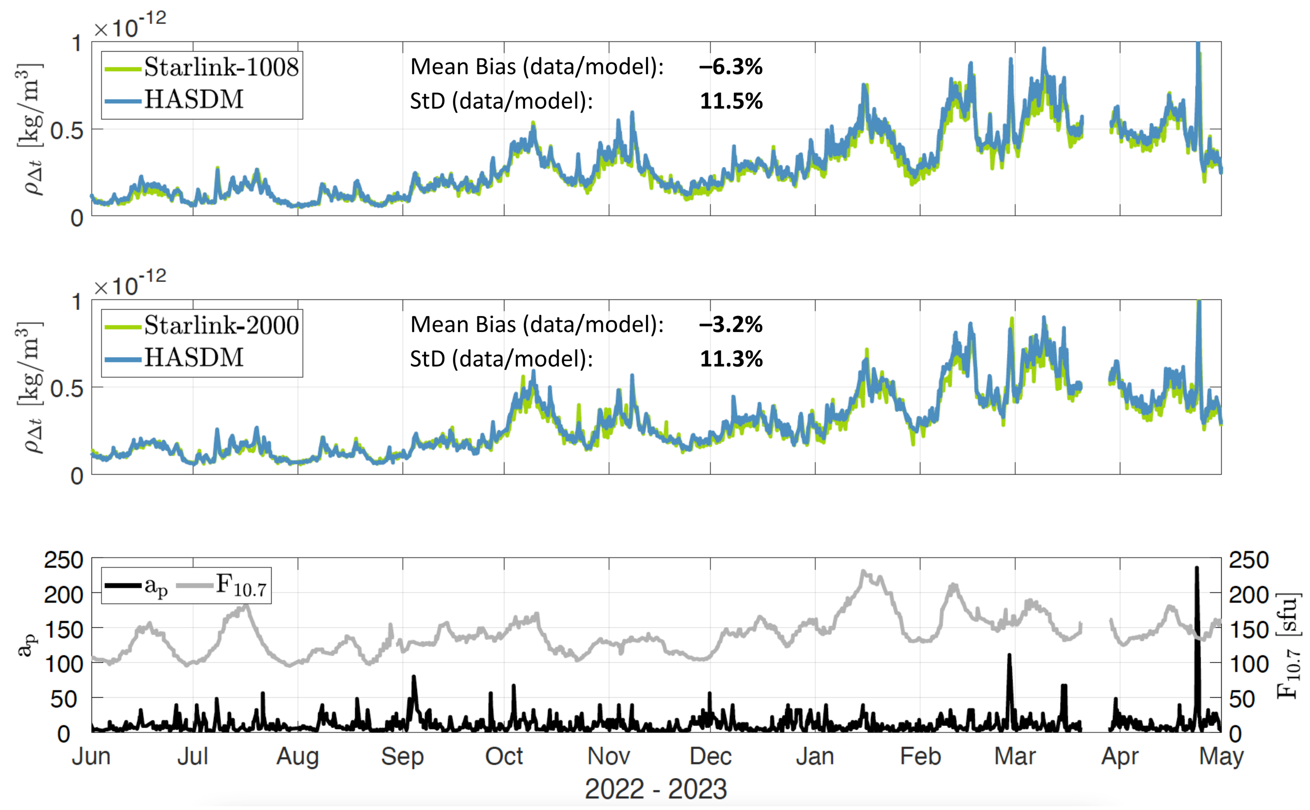


Orbit-Averaged (C_D*A_{ref})

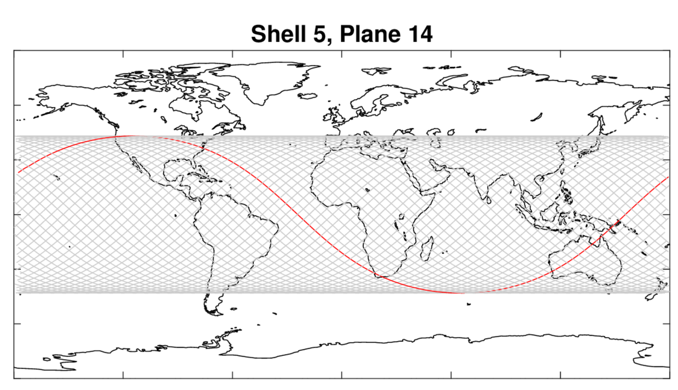


- CD has been calculated assuming Diffuse Re-emission with an Incomplete Accommodation (DRIA) of α = 0.93.
- Error bars above represent the variation of the instantaneously calculated C_D*A_{ref} along a given LTAN orbit.

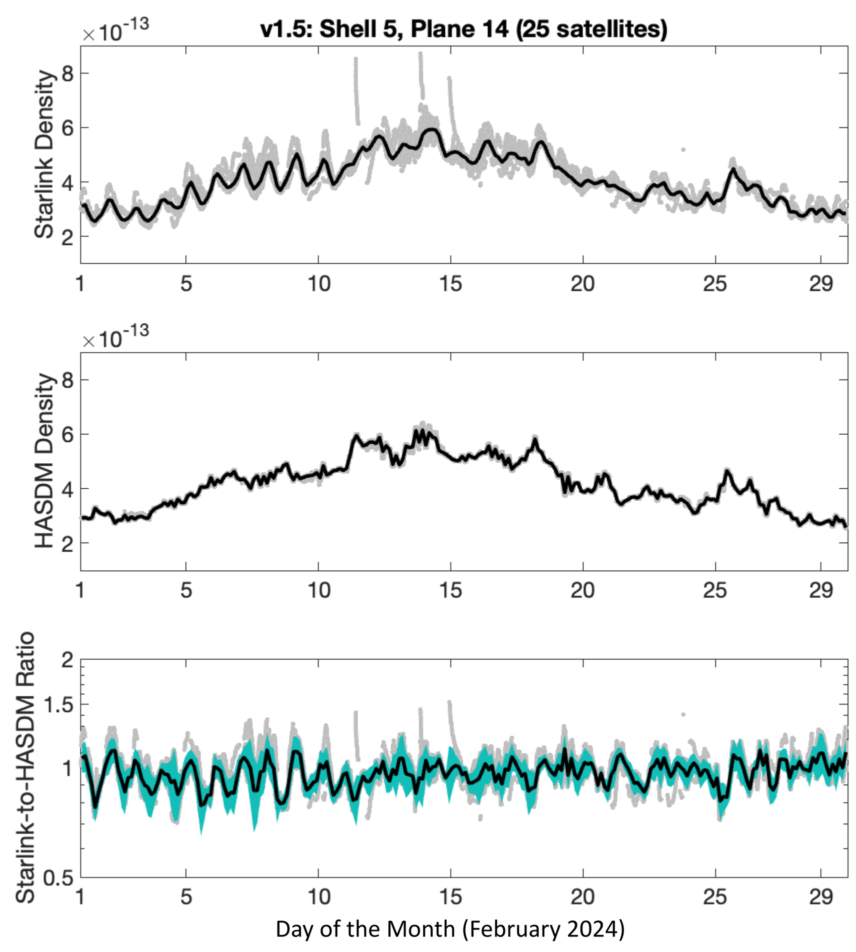
Orbit-Effective Densities from two Starlink Satellites (June '22 – April '23)



Assessing In-Plane Statistics and Data Quality (February '24)



- Grey: Raw Starlink (top), HASDM (middle), or ratio (bottom) orbit-effective densities from all satellite in shell 5/plane 14 orbits
- **Black: 3-hourly binned & averaged densities from current shell 5 / plane 14 orbits**
- **Cyan: 2-σ error bars based on variability within the current shell 5 / plane 14 orbits**



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