# Satellite Constellation Data for Thermospheric Density Forecasting


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U.S. DEPARTMENT OF COMMERCE

GDC
GEOSPACE DYNAMICS CONSTELLATION
Exploring Our Connected Atmosphere

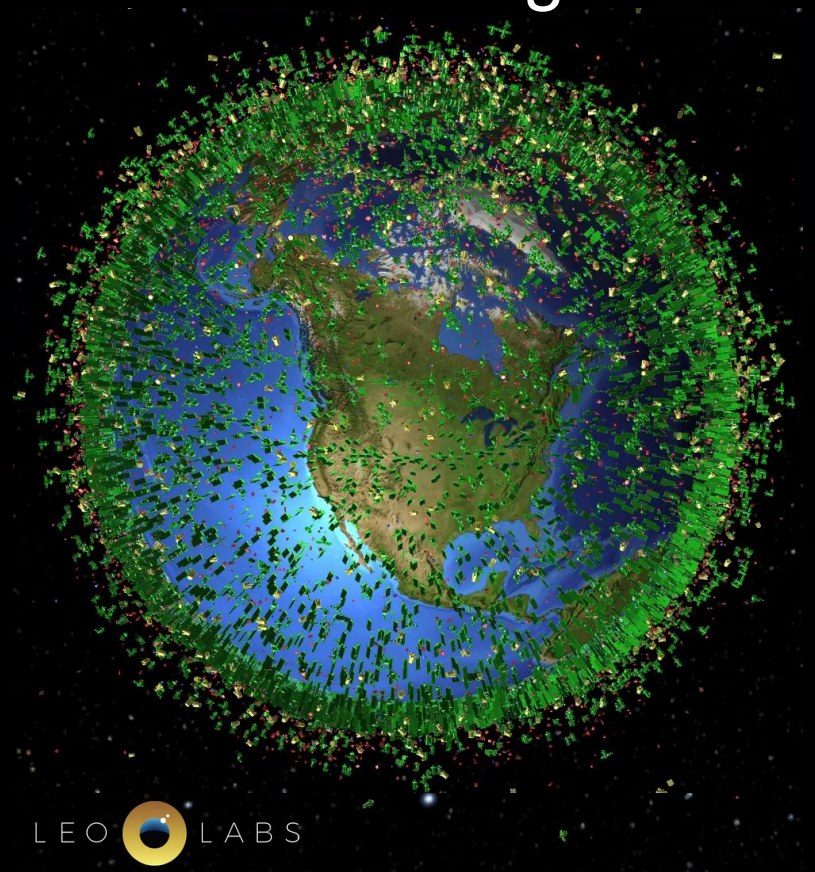
SWORD

SPACEX

SWx TREC

# STM Concerns in LEO:

## Crowding

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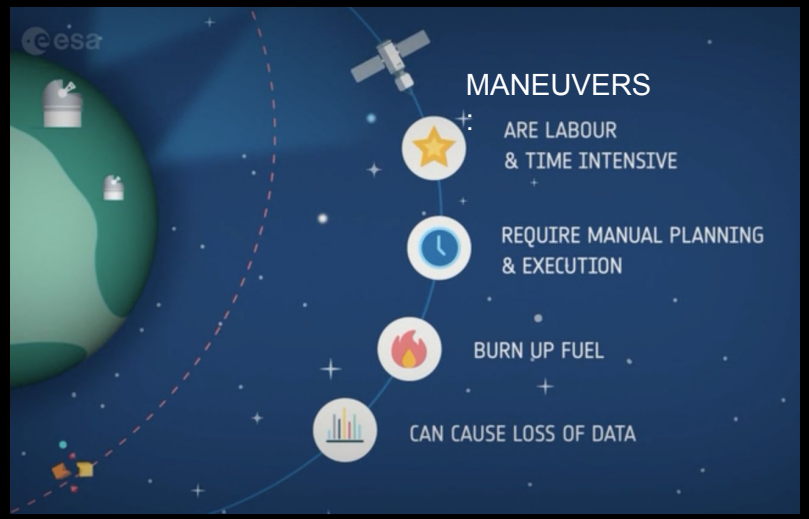
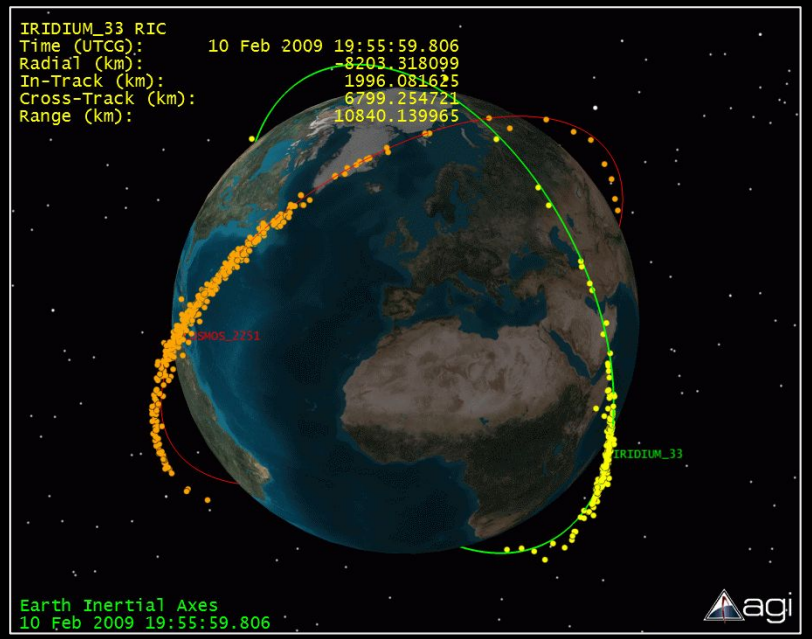
Milky Way images from NASA/Goddard Space Flight Center Scientific Visualization Studio

## Day-to-Day CA




## Collisions



# Sustainability in LEO

The Atmosphere naturally clears out the orbiting population:

- A collision at 500 km is much more manageable than one at 1,200 km

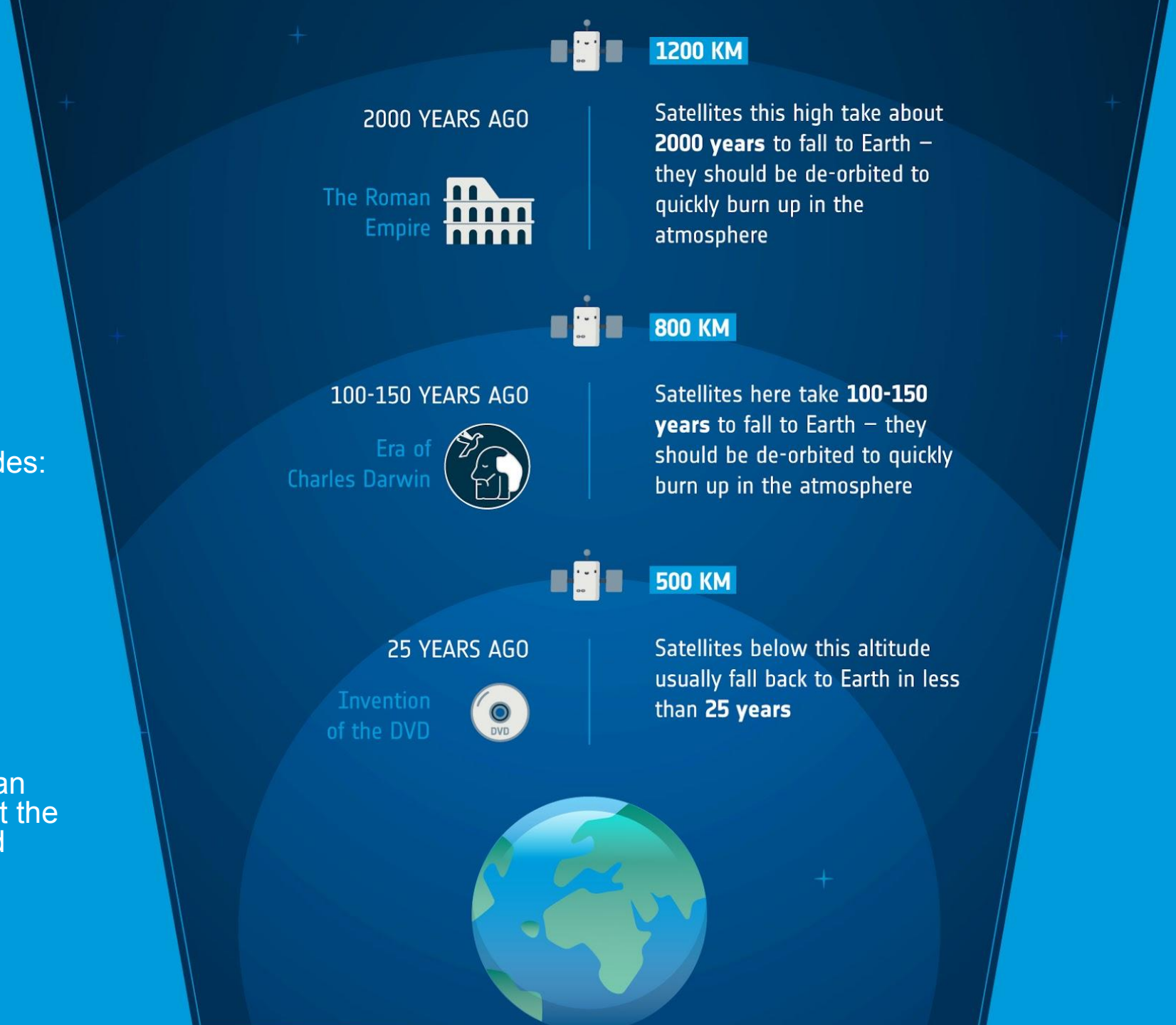
Incentives to operate at lower altitudes:

- Low-latency communications
- Lower launch fuel consumption
- Atmosphere provides a natural fail-safe to clean up debris

Disincentives to operate at lower altitudes:

- Limited ability to forecast neutral environment and predict orbits

**The Space Weather community can provide solutions to help ensure that the lowest orbits can be effectively used



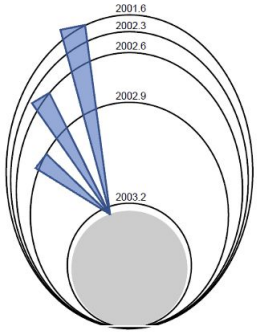

esa

UNITED NATIONS
Office for Outer Space Affairs

# Landscape of Sat Drag Operational Observation

**~25 Years ago:**

**Traditional:**
e.g., Ground-Based
Satellite/Object Tracking




**Realtime Availability / Reliability**

Med/High

**Redundancy**

Medium

**Coverage**

Medium

**Resolution**

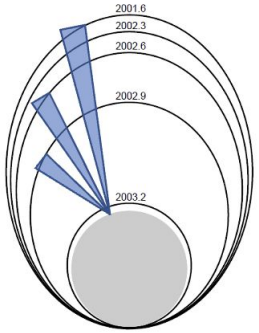
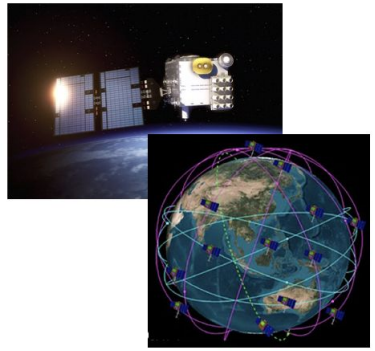
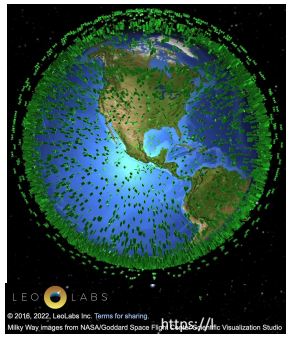
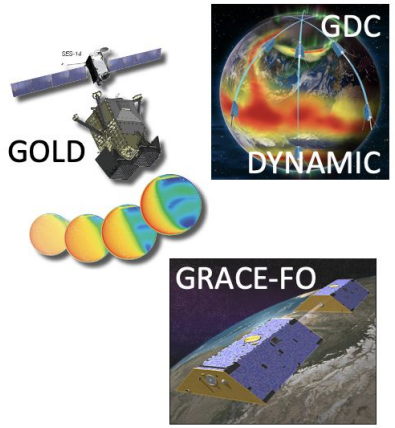
Low

**Information Content**

Low

# Landscape of Sat Drag Operational Observation

**Today:**

| | Traditional: e.g., Ground-Based Satellite/Object Tracking | GNSS-Equipped Constellations: Government: e.g., COSMIC / COSMIC-2 | GNSS-Equipped Constellations: Commercial: e.g., Starlink, Kuiper, Spire, Planet Labs | Dedicated Science Missions: GOLD, GDC, DYNAMIC, GRACE-FO |
|---|---|---|---|---|
| |   |  |   |   |
| **Realtime Availability / Reliability** | Med/High | Low | Low | Low |
| **Redundancy** | Medium | Med/High | High | Low |
| **Coverage** | Medium | Med/High | High | Low |
| **Resolution** | Low | Medium | Medium | High |
| **Information Content** | Low | Medium | Medium | High |

# Landscape of Sat Drag Operational Observation

**Future:**
**(2-5 years if the right steps are taken today)**

| | Traditional: e.g., Ground-Based Satellite/Object Tracking | GNSS-Equipped Constellations: Government: e.g., COSMIC / COSMIC-2 | GNSS-Equipped Constellations: Commercial: e.g., Starlink, Kuiper, Spire, Planet Labs | Dedicated Science Missions: GOLD, GDC, DYNAMIC, GRACE-FO, +GRATTIS, +GRACE-C |
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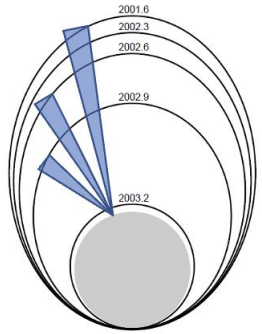
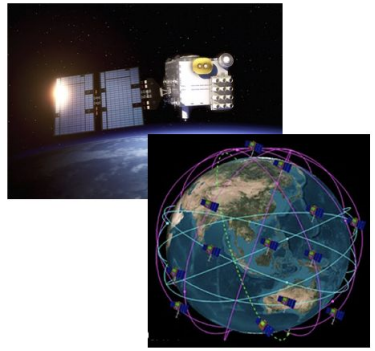
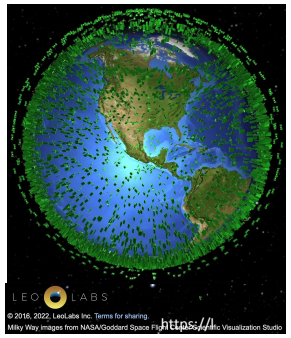
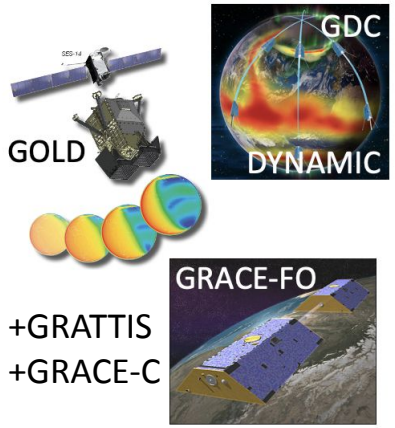
| |   |  |   |   |
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| **Resolution** | Low | Medium | Medium | High |
| **Information Content** | Low | Medium | Medium | High |

# Starlink Constellation

Owner/Operator: SpaceX

Country of Origin: United States

Application: Internet service

Website: www.starlink.com

Spacecraft type: Small satellite

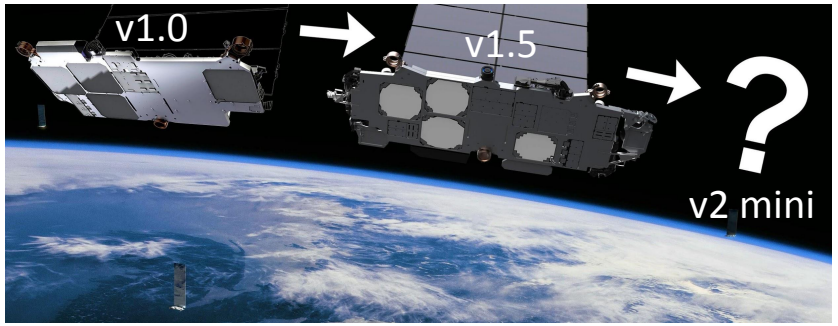
Launch Mass: v0.9: 227 kg
v1.0: 260 kg
v1.5: ~306 kg
v2m: 800 kg

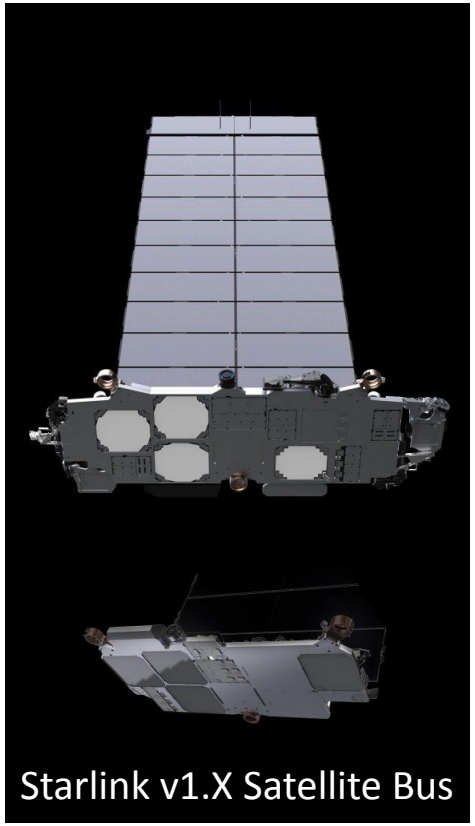
Equipment: Ku-, Ka, & E-band phased array antennas
Laser transponders
Hall-effect thrusters

Regime: LEO
mid- & high-inclination

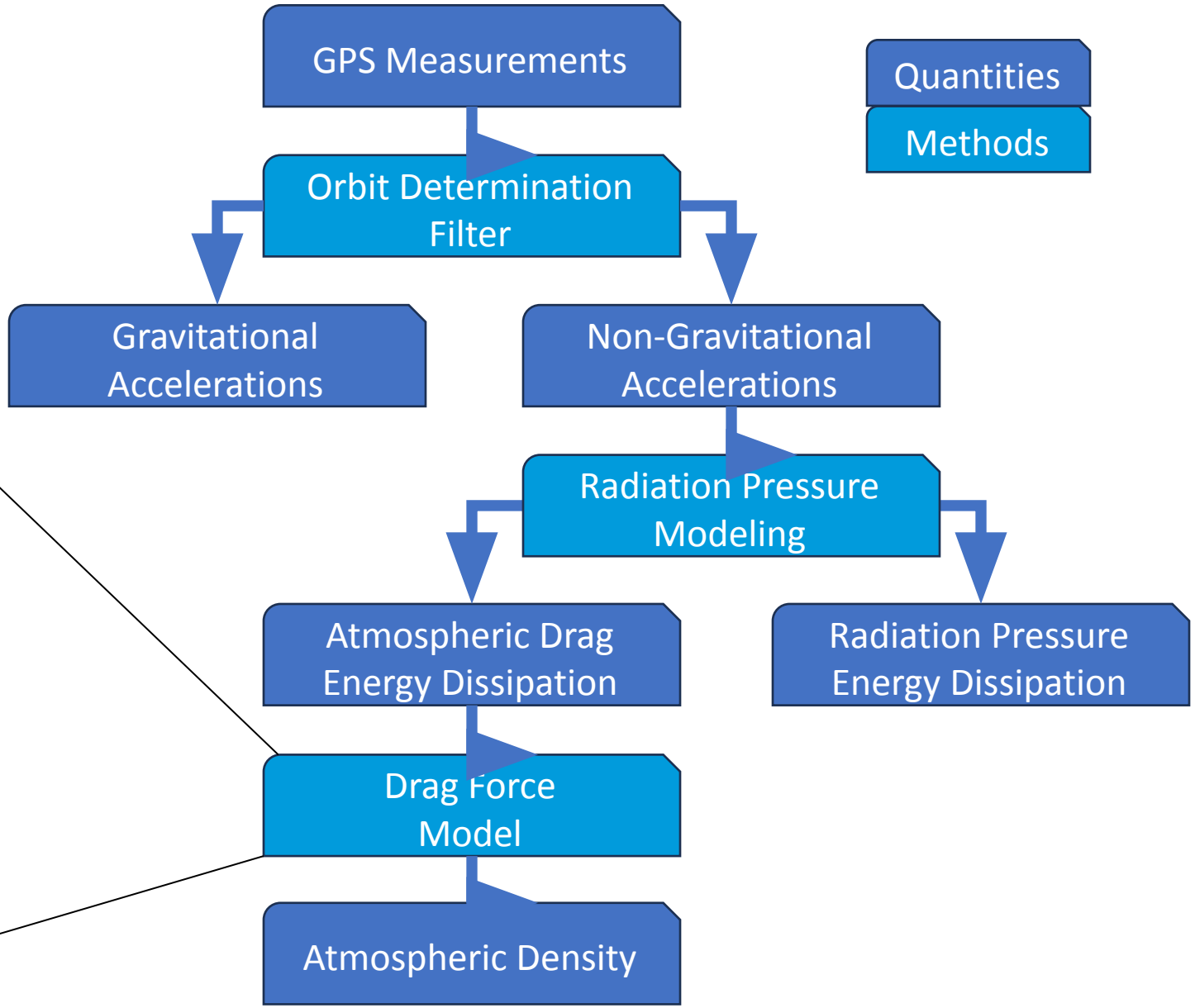
Status 8,165 satellites on-orbit (as of 8/25/2025)
Active since 2019

*from wikipedia.org and space-track.org



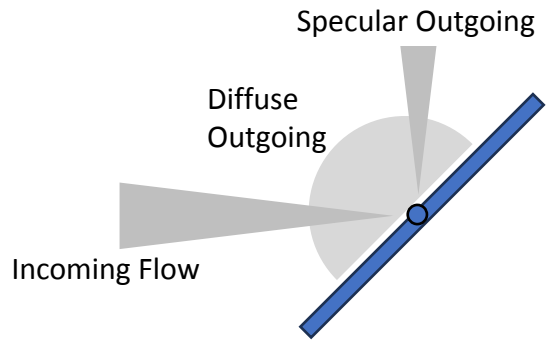


Starlink v1.X Satellite Bus

# Turning GPS Tracking into Atmospheric Densities




## Drag Force Model

$$\vec{a}_{Drag} = -\frac{C_D(\alpha,\sigma)A_{ref}}{2\,m}\rho \mid \vec{v}_{rel} \mid \vec{v}_{rel}$$



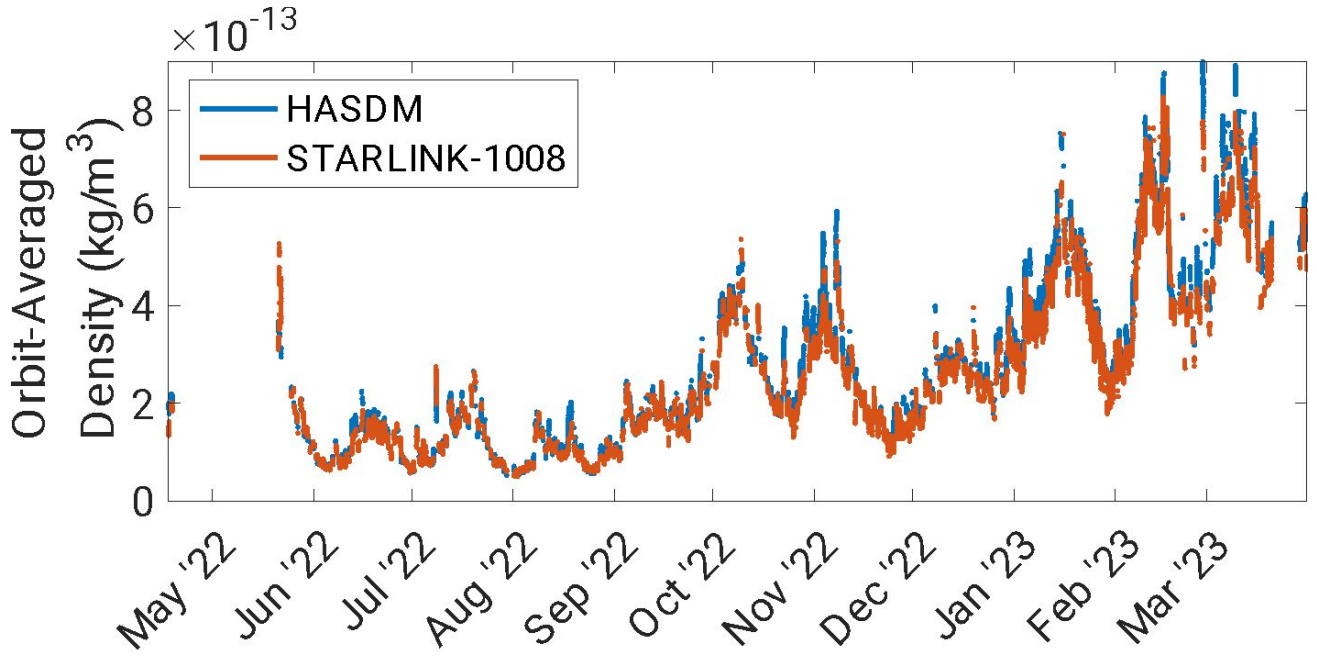
# Densities from 1 Starlink Satellite

April 2022 – April 2023

- Very low bias/std with respect to HASDM
- E.g., STARLINK-1008:

  Mean Bias (data/model): **–6.5%**

  StD (data/model): **11.6%**



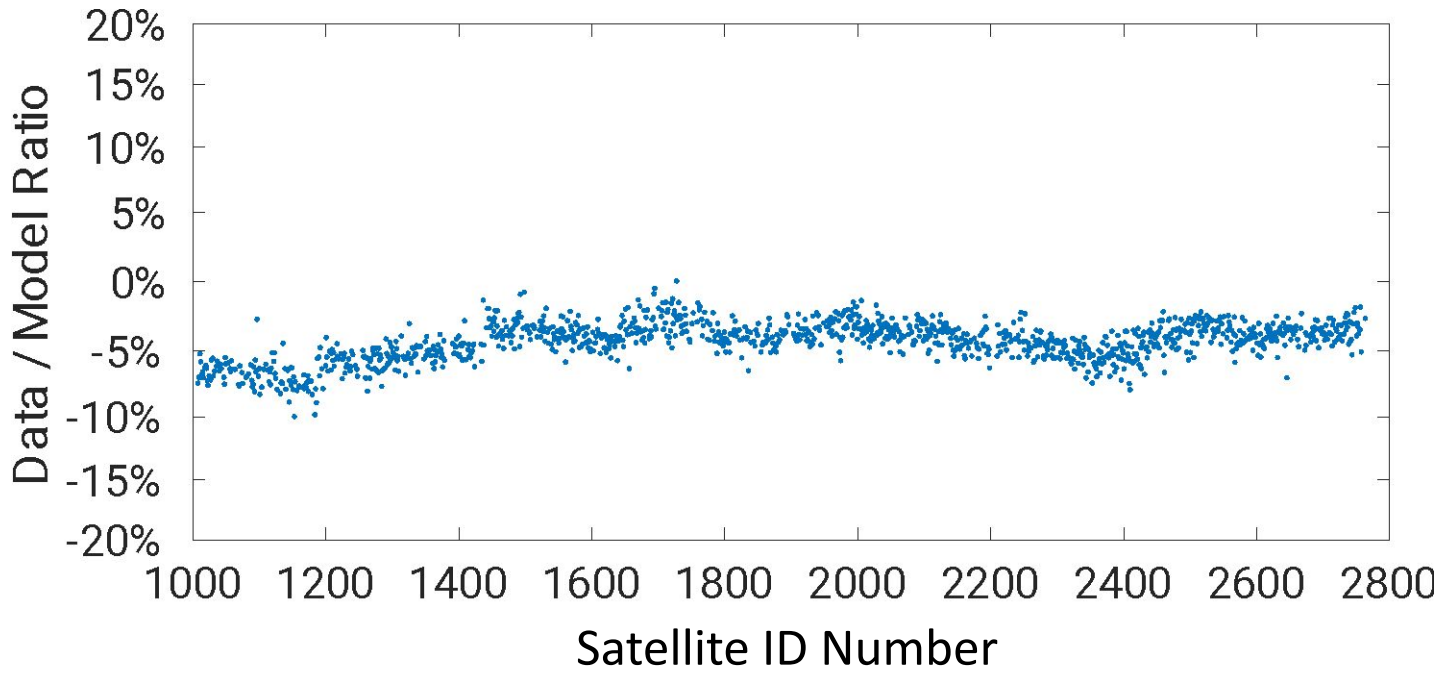
# Densities from ~1,500 Starlink Satellites

April 2022 – April 2023

- Still very low bias/std with respect to HASDM
- Some satellites are anomalous, and can be easily filtered out using individual satellite health status
- ~1,500 v1.0 Starlink densities:

  Mean Bias (data/model): **–4.5%**

  StD (data/model): **9.98%**



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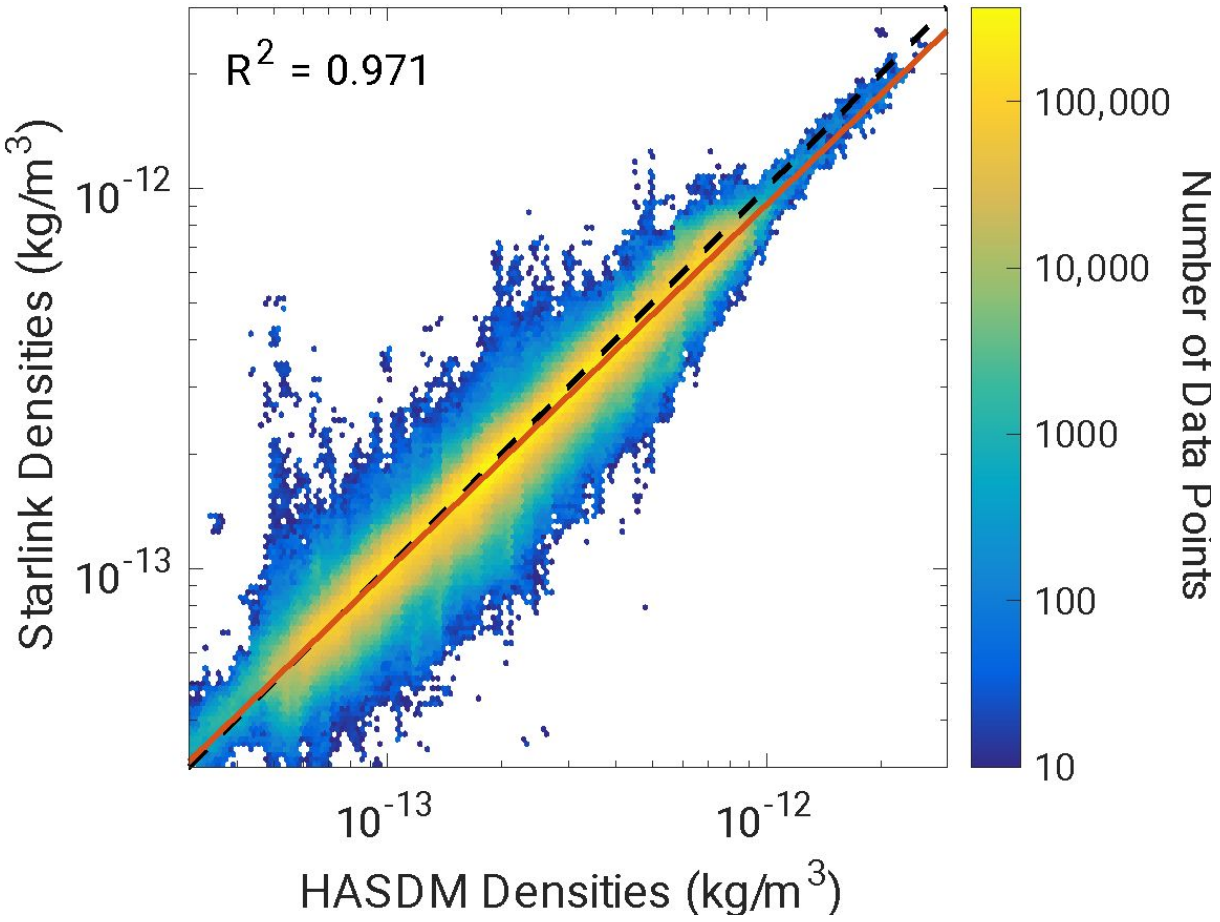
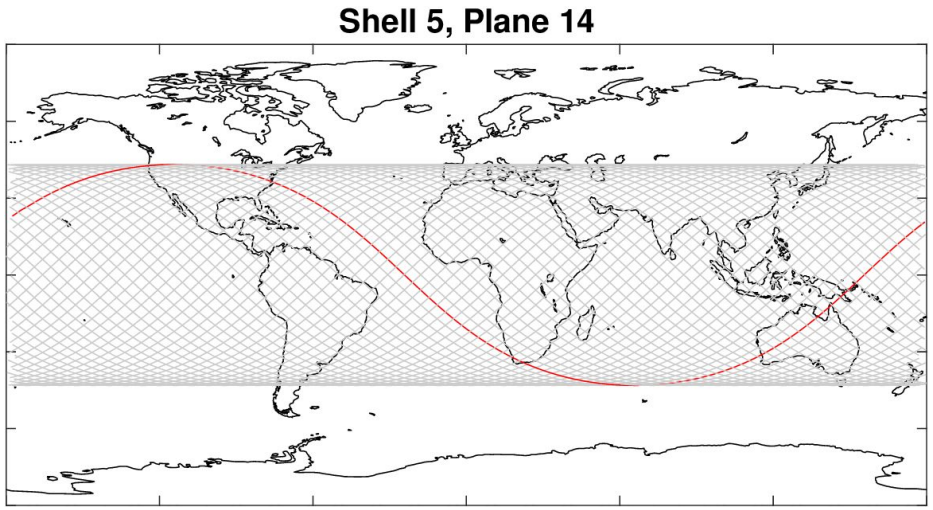
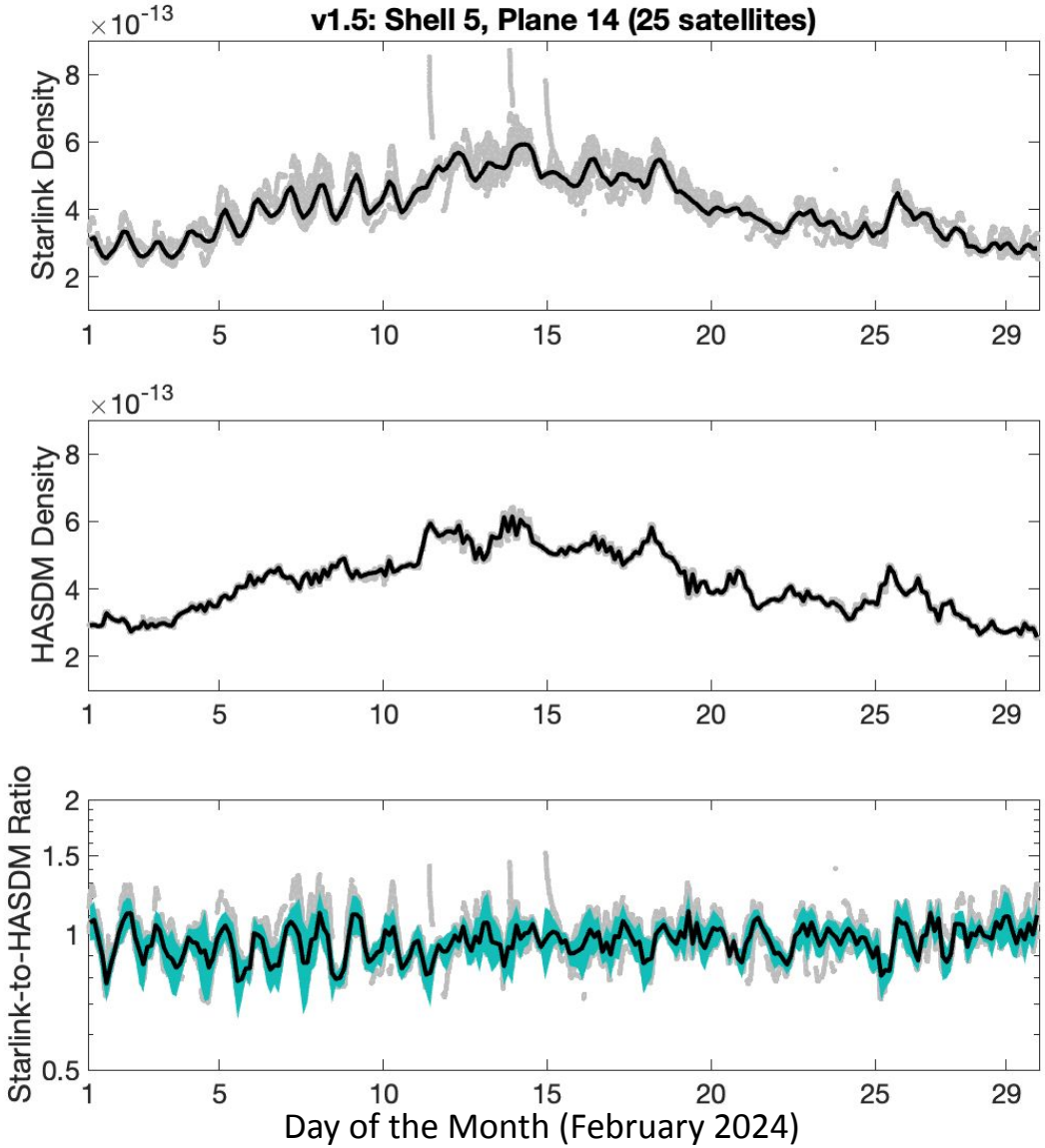


# Still Images: Monitoring Statistics and Data Quality In-Plane

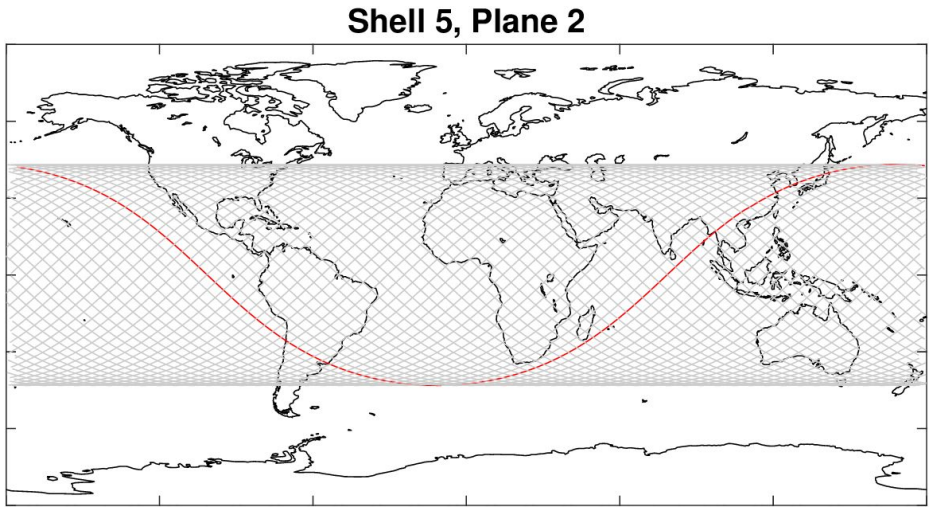
February 2024

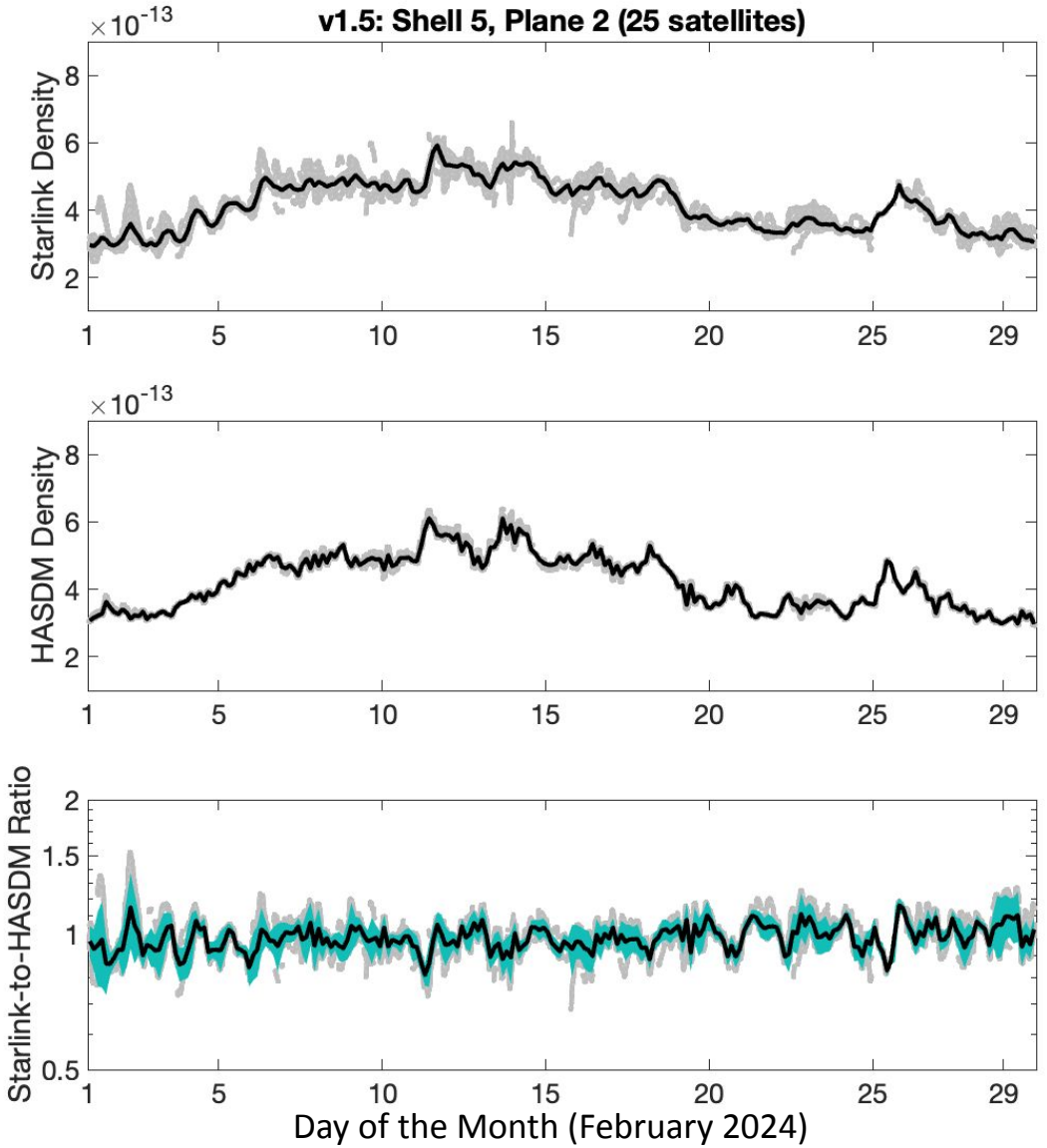


# Monitoring Statistics and Data Quality In-Plane

February 2024



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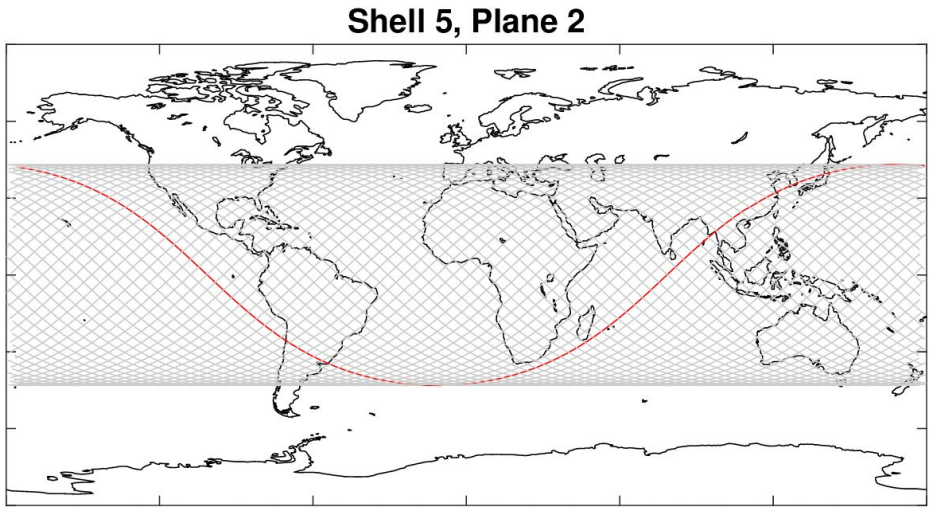


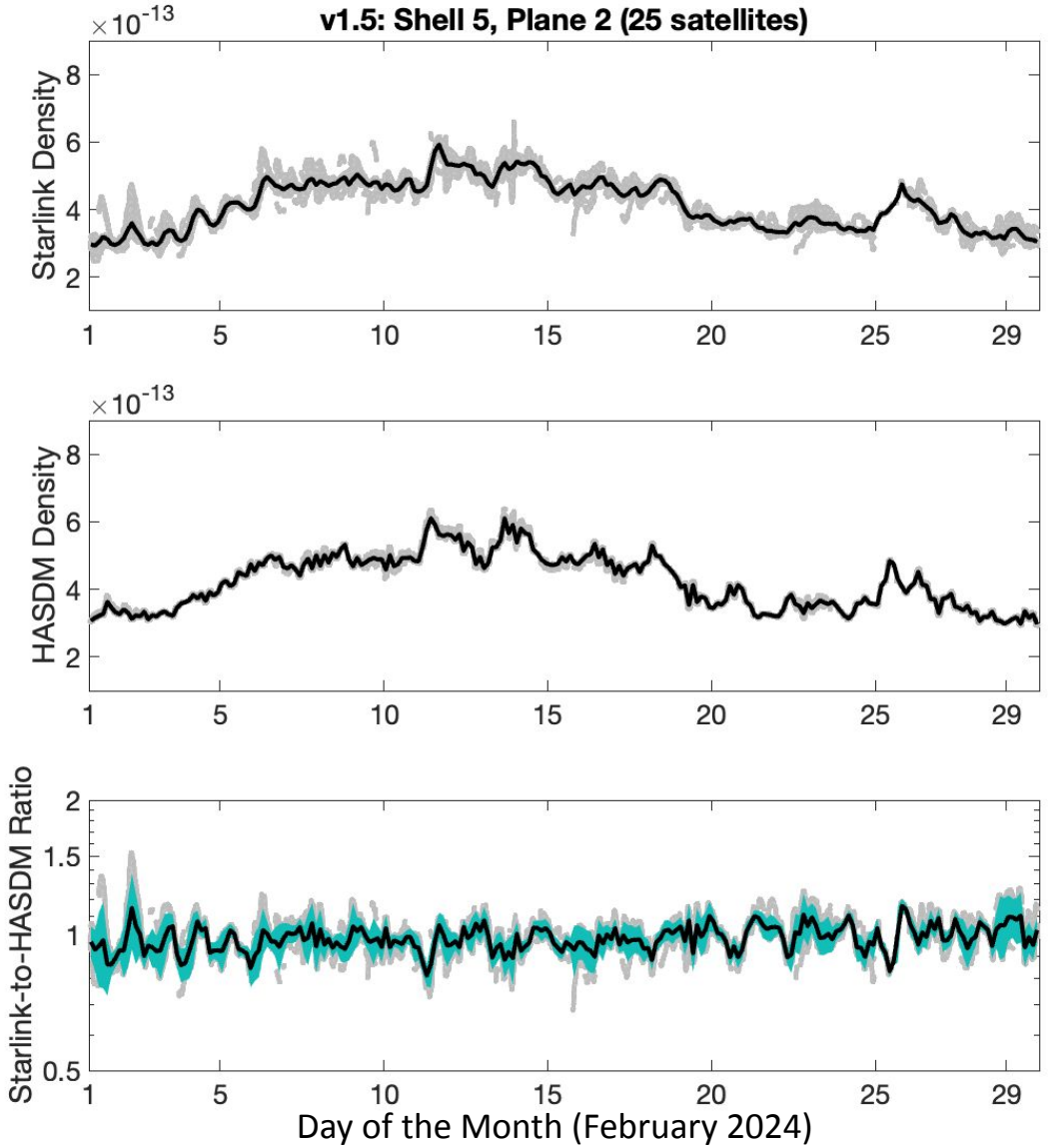

# Characteristics of the Object Tracking Datasets

**Strengths:**

- Excellent horizontal coverage
- Commercial tracking data will scale along with the crowdedness of LEO
- Noise offset by the large volume of coincident data

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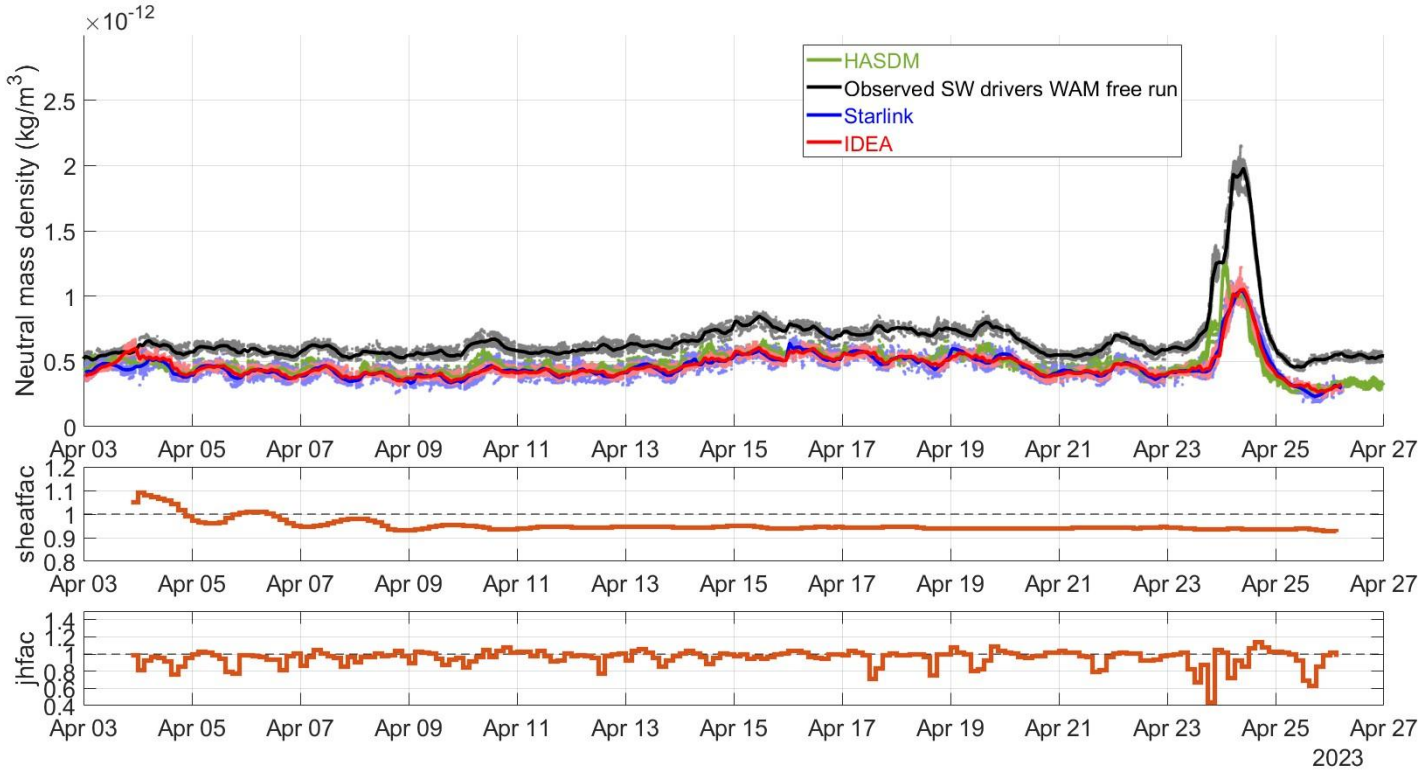
**Limitations:**

- Altitudinal coverage
- Spatiotemporal resolution
- Information content of mass density
- Force model assumptions

# Driver Estimation-Type Assimilation of Starlink Densities into WAM:

## Nowcast Mode



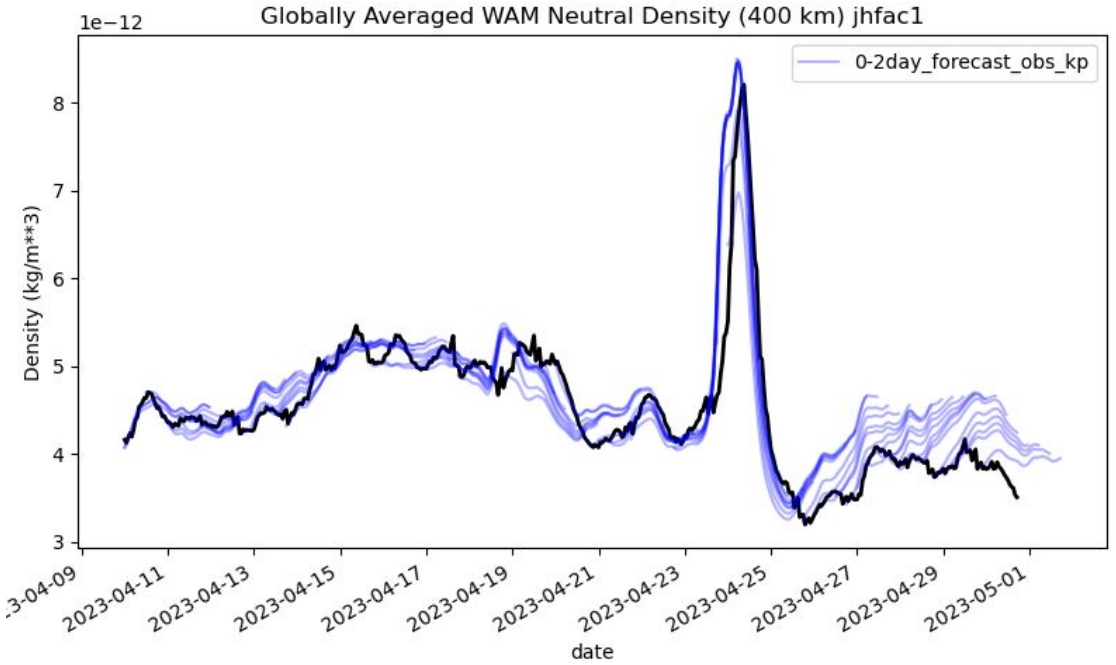

Courtesy of Ching-Chung Cheng and SWPC/CIRES team

- Using only ~30 Starlink satellites from distributed LTAN planes
- Initial assimilation results show that POD-derived thermospheric density clearly improves the fidelity of NOAA's operational thermospheric density model
- Already Underway:
  - Parallelize processing / forward modeling
  - Apply uncertainty quantification to satellites in coincident LTAN planes for the purposes of L.S. weighting and outlier detection
  - Assimilate entire constellation: 1,000's of satellites
  - Demonstrate real-time capabilities

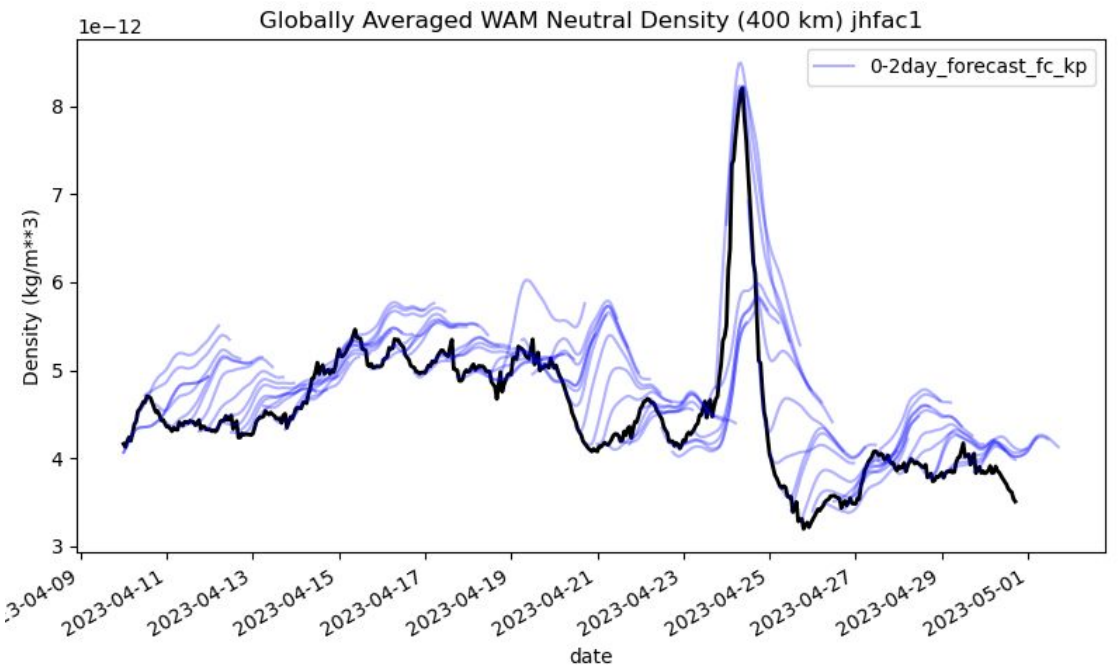
# Driver Estimation-Type Assimilation of Starlink Densities into WAM:

## 2-Day Forecast Mode

### Using Ideal Forecasted Drivers




### Using Issued SWPC Forecasted Drivers




Courtesy of Ching-Chung Cheng
and SWPC/CIRES team

# Thank you