National Aeronautics and Space Administration

Overview of ODPO Use of Goldstone Data

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JPL / Goldstone Site Visit
21 March 2024

Measurements in the ODPO

Monitor the ever-changing OD environment ⟺ ***Develop and update OD modeling and mission support tools***

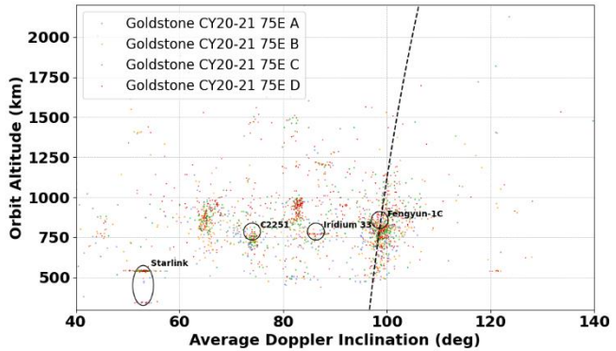
Credit: Reprinted with permission Courtesy of MIT Lincoln Laboratory, Lexington, Massachusetts

Credit: NASA/JPL-Caltech

Provide data for building/validating OD models

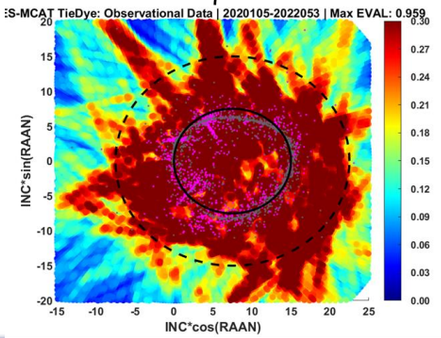
Measurements **Modeling**

Provide feedback on how to improve measurements

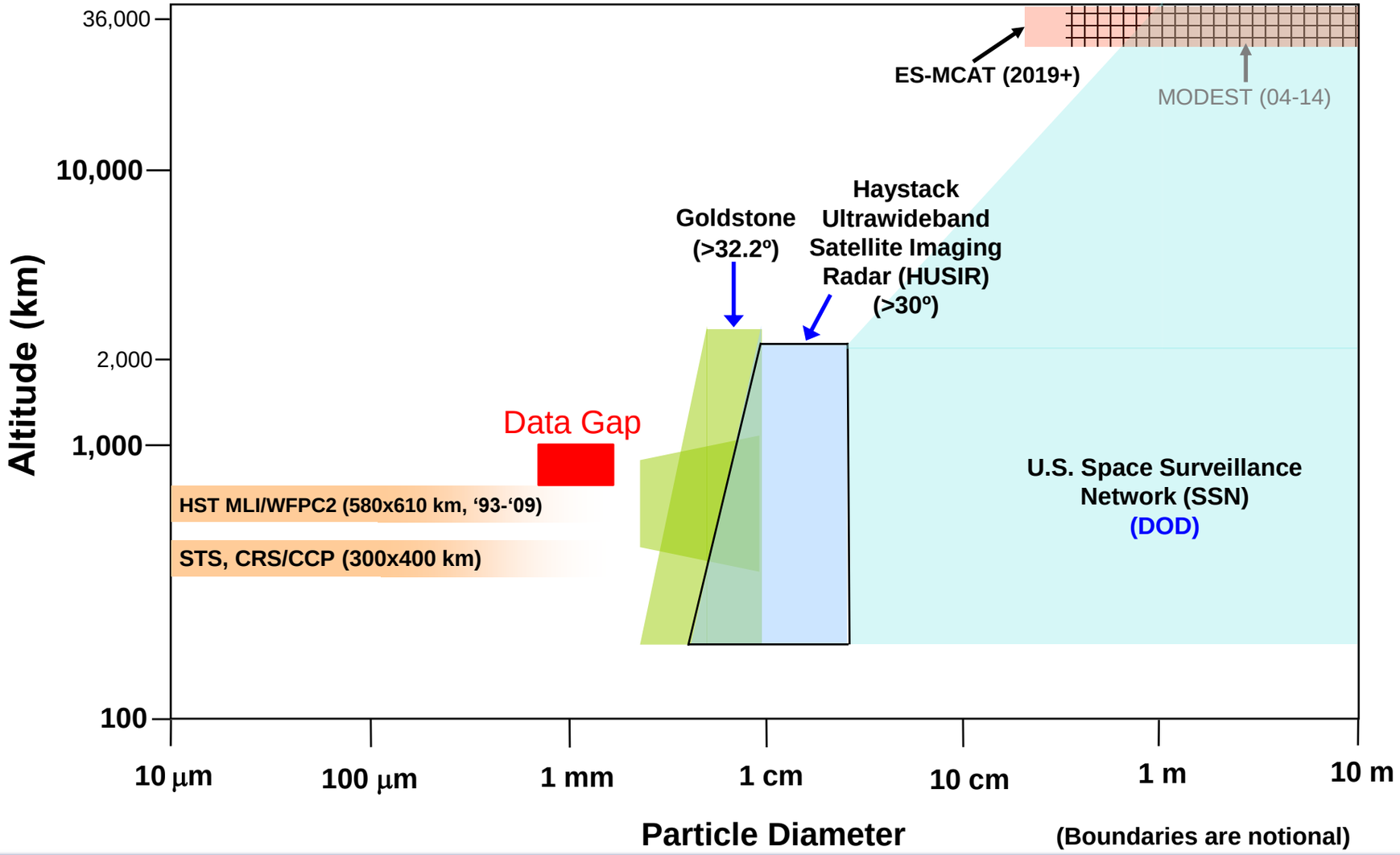


Credit: Ben Hanna

- Haystack Ultrawideband Satellite Imaging Radar (HUSIR)
- Goldstone Orbital Debris Radar
- Eugene Stansbery Meter-Class Autonomous Telescope (ES-MCAT)
- Space Surveillance Network (SSN), Space Fence
- Space Surveillance Telescope (SST)

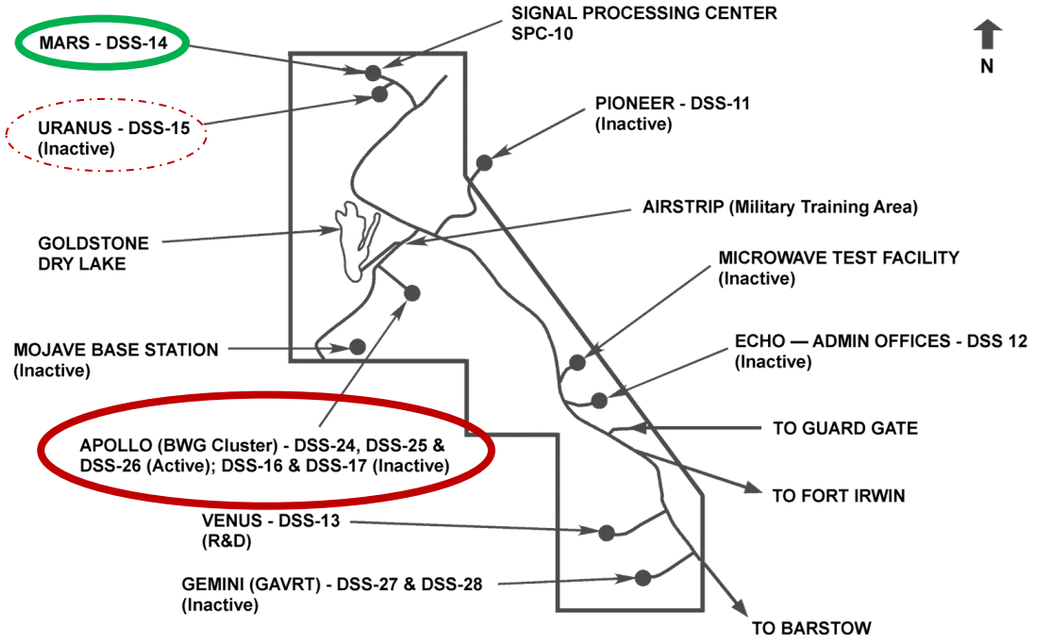


Data Coverage



Goldstone Overview

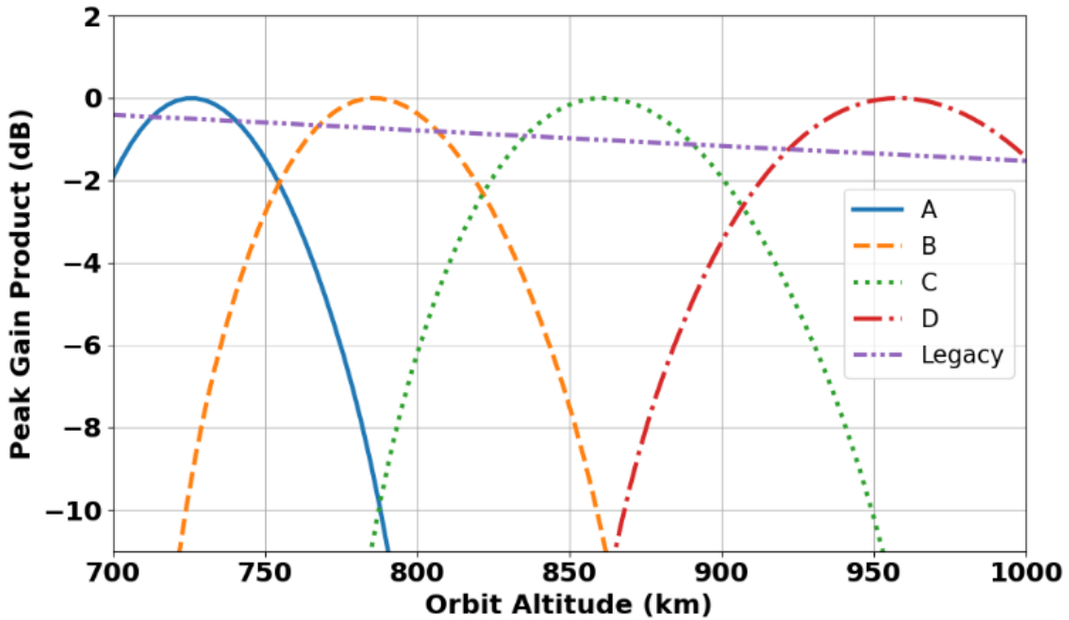
Credit: NASA/JPL-Caltech

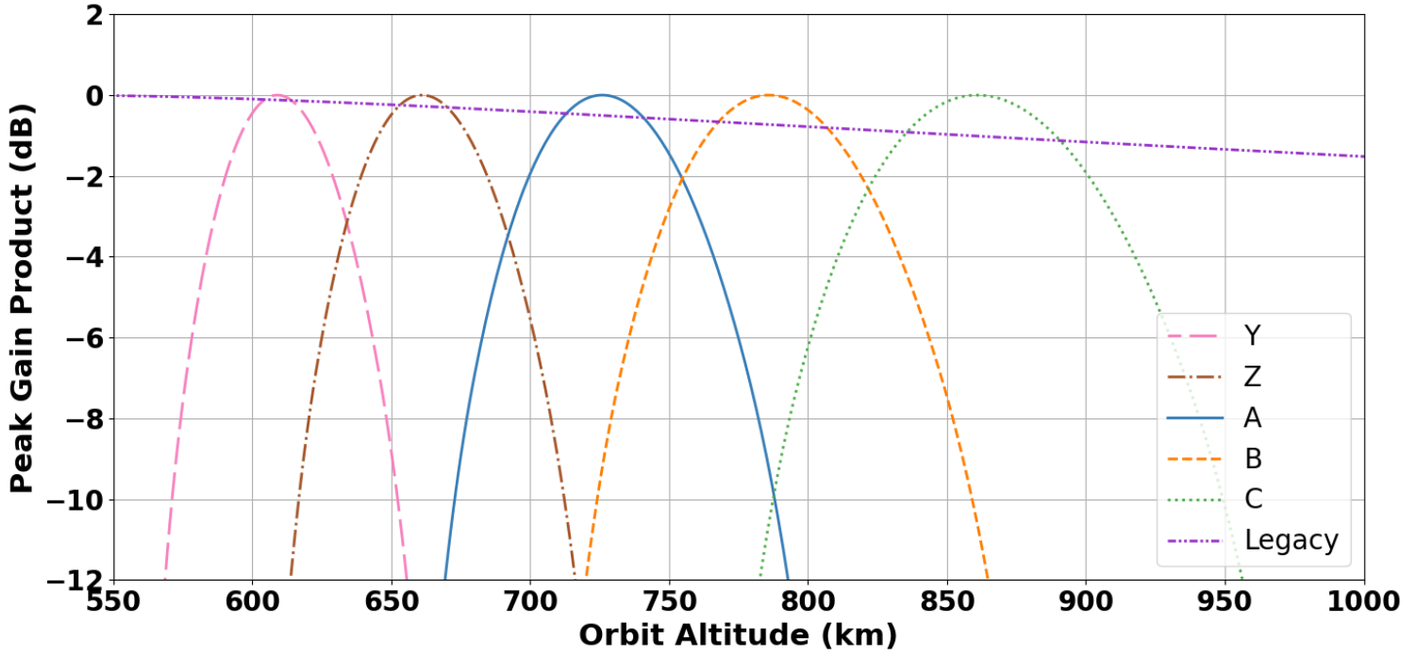


Operating Parameter	Nominal Value
Peak Transmit Power	440 kW
Transmit Frequency	8.56 GHz
Wavelength	3.5 cm
Antenna Diameter	70 m (transmitter) 34 m (receiver)
Beamwidth	0.03° (transmitter) 0.06° (receiver)

- **As of FY 2023, ~290 hours of data each year**
  - Hours split approximately evenly between 4 or 5 pointings focused on LEO altitude range
- **With new pointing plan, sensitivity improved from 3 mm to ~2.2 mm at 1000 km altitude**
- **New sawtooth waveform in development to improve sensitivity**
  - Linear frequency modulated (LFM) or chirp waveform currently in use
- **Investigating capability for MEO observations**

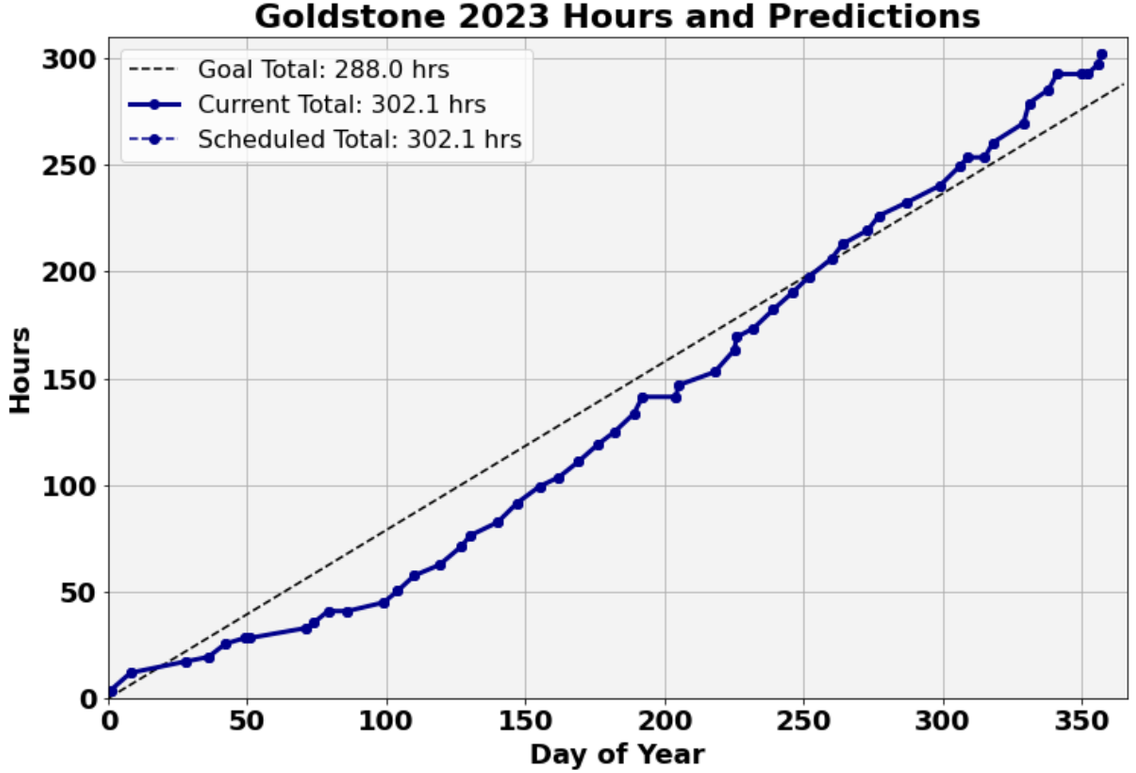
Pointing Geometry

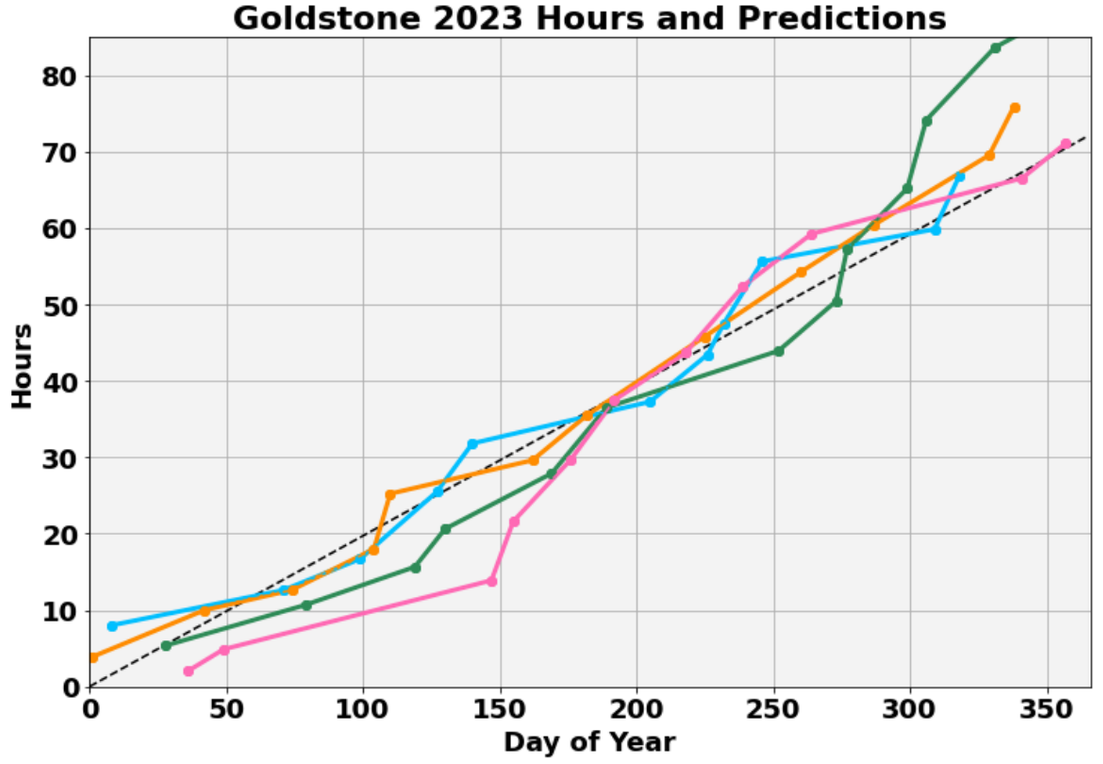




- **New pointing plan developed after DSS-15 was decommissioned to efficiently sample at targeted LEO altitudes**
  - Transmit: DSS-14, Receive: DSS-25/26
- **4 pointings used CY2020-2023: A, B, C, D**
- **5 pointings assigned for 2024: Y, Z, A, B, C**

Goldstone CY2023 Collected and Scheduled Hours

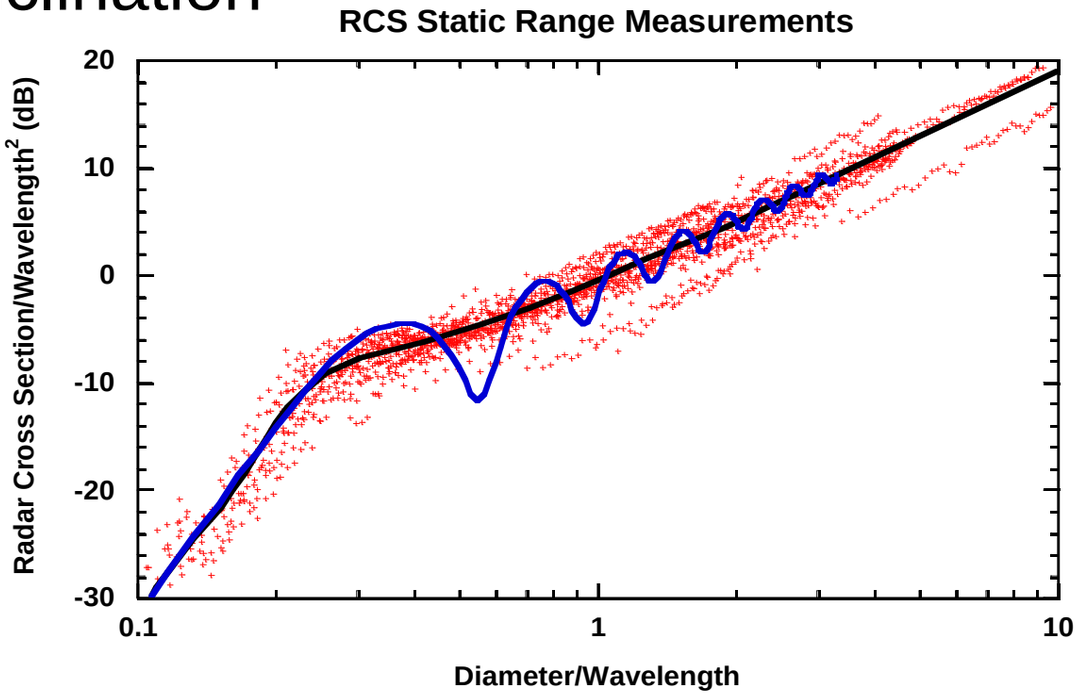




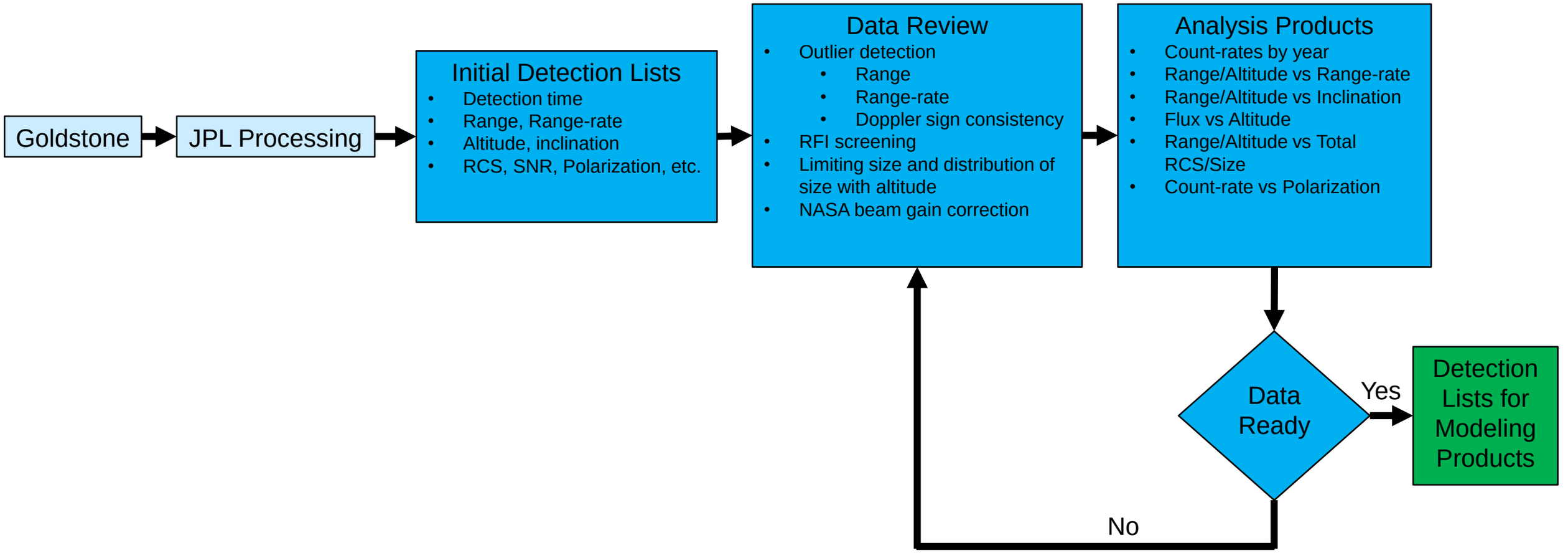
*MEO and failed track hours have been removed from these charts.

Estimating Debris Parameters

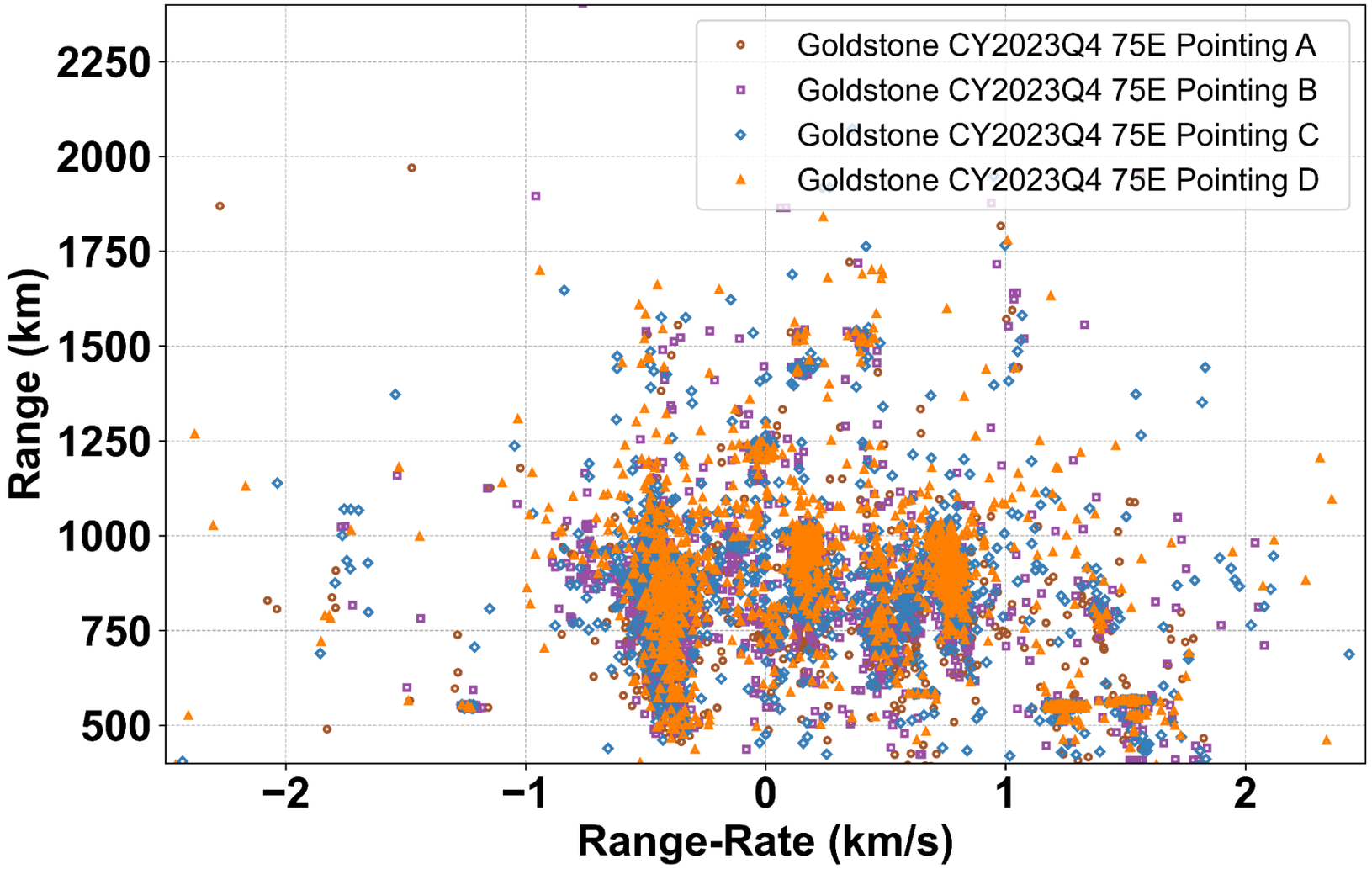
- **We receive surrogate measurements for the orbital debris parameters we really want for modeling (orbital elements, size)**
  - Range, range-rate → altitude, inclination
    - Assuming circular orbits
  - RCS → size
    - NASA size estimation model
      - Empirical model based on measurements of 39 representative debris objects averaged over many orientations at a single frequency



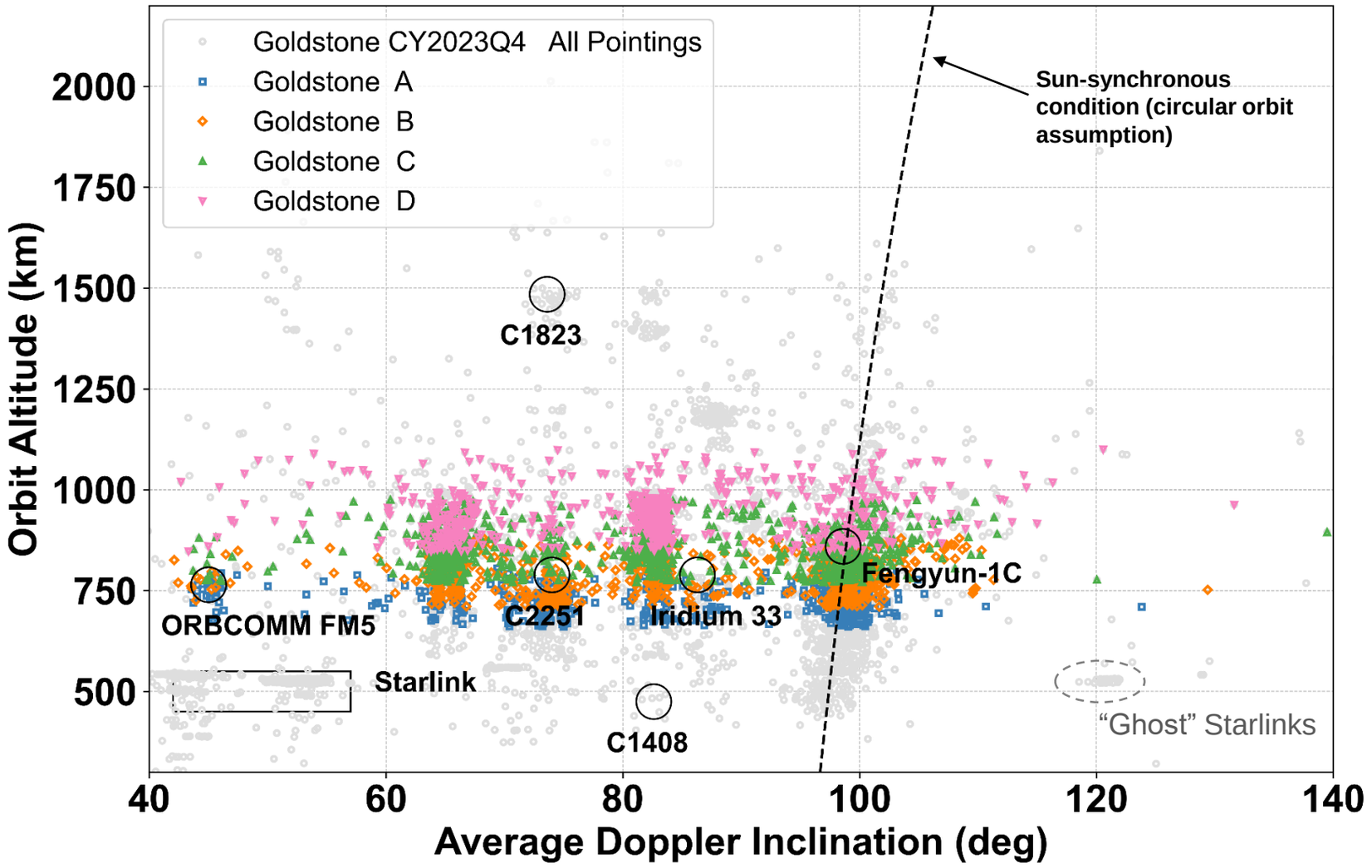
Goldstone Data Processing Pipeline



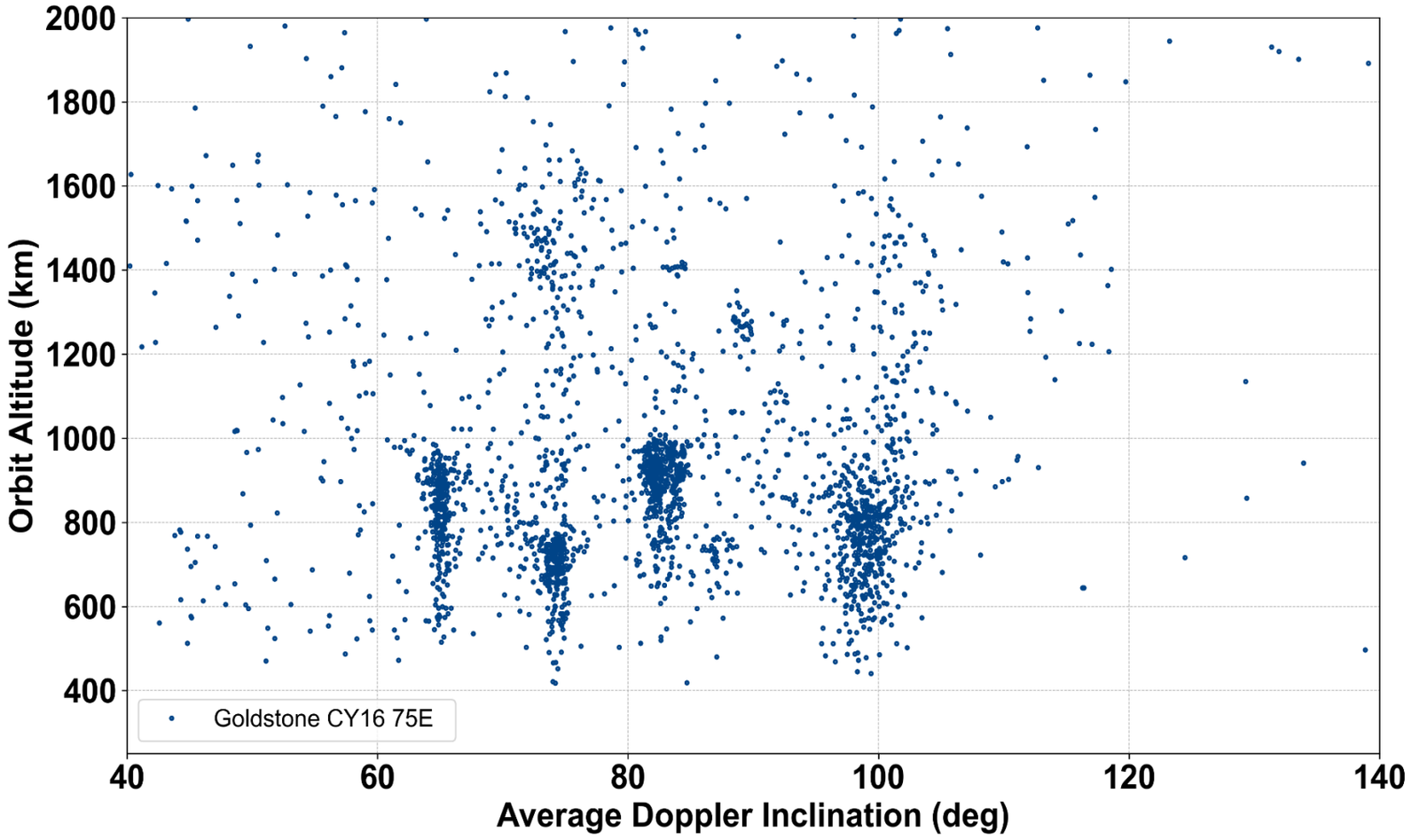
Range vs. Range-Rate, CY2023



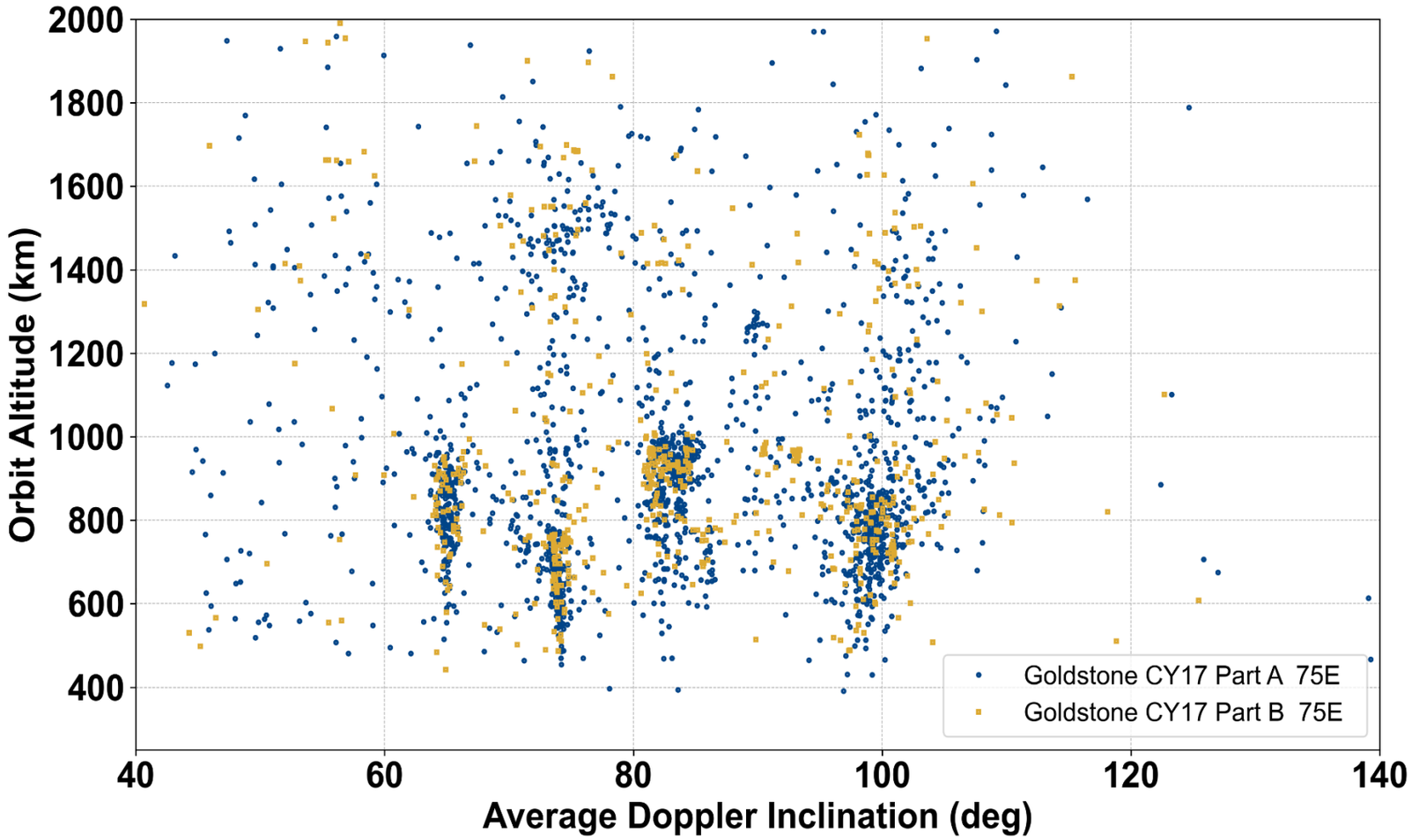
Altitude vs. Inclination, CY2023



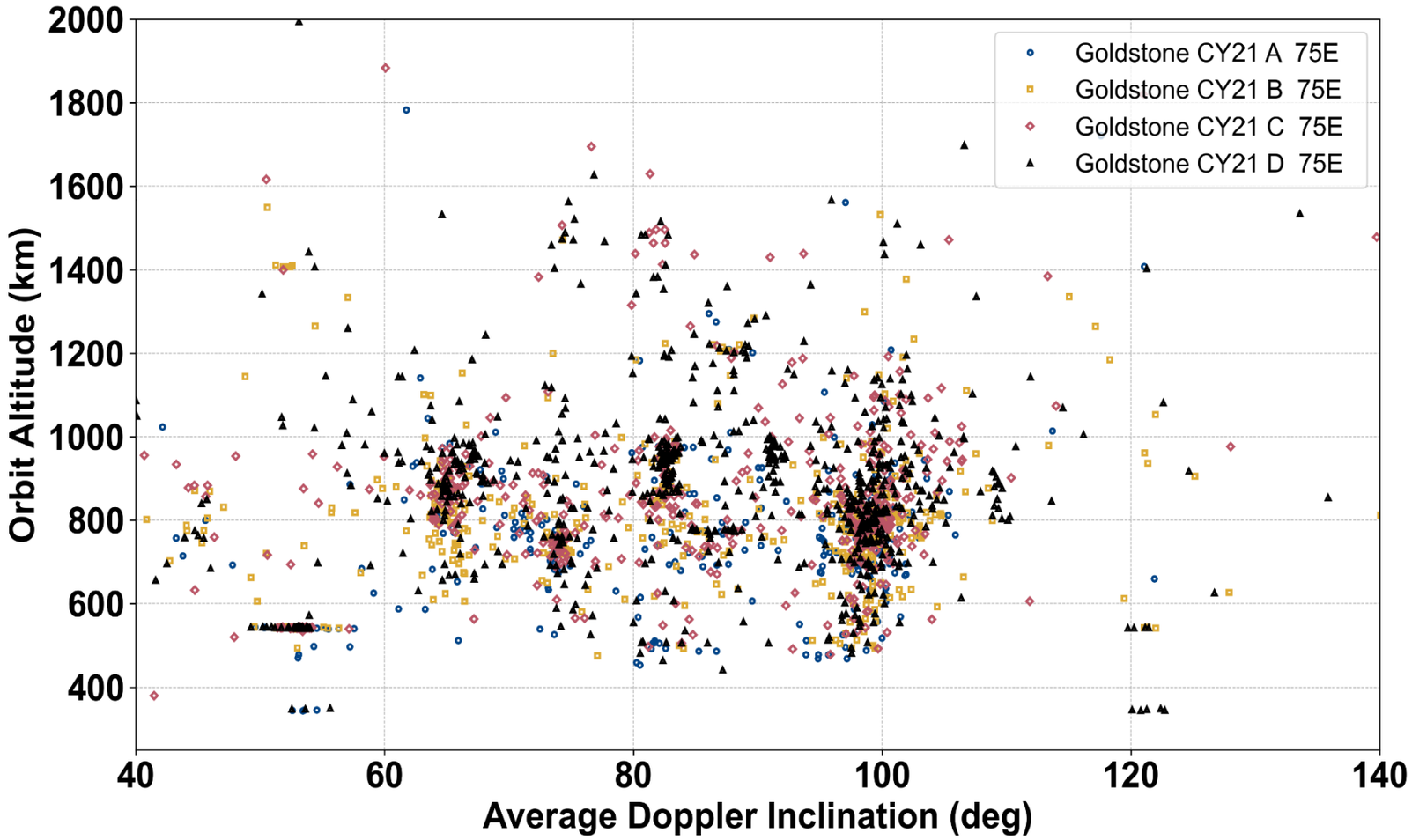
Altitude vs. Inclination, 2016



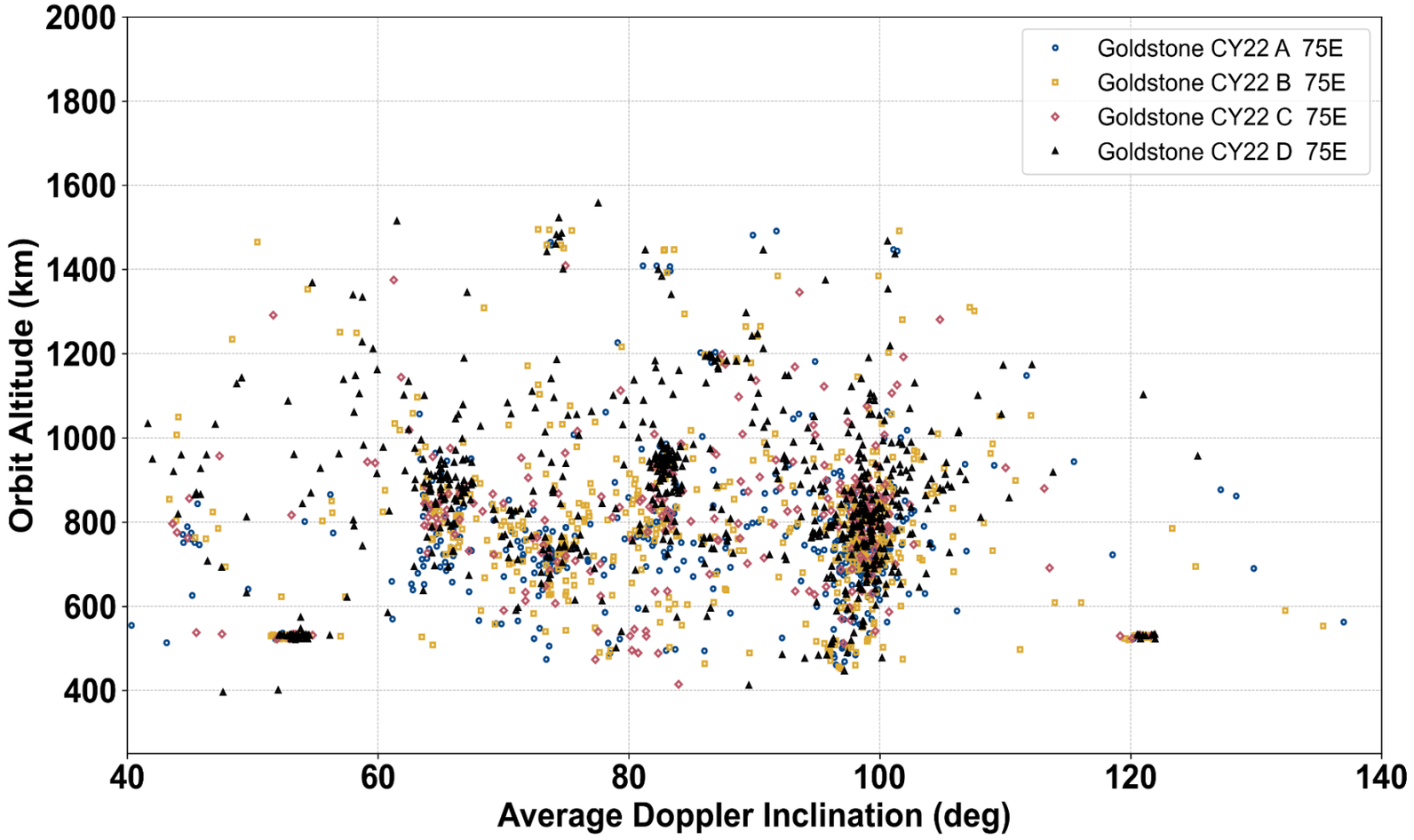
Altitude vs. Inclination, 2017



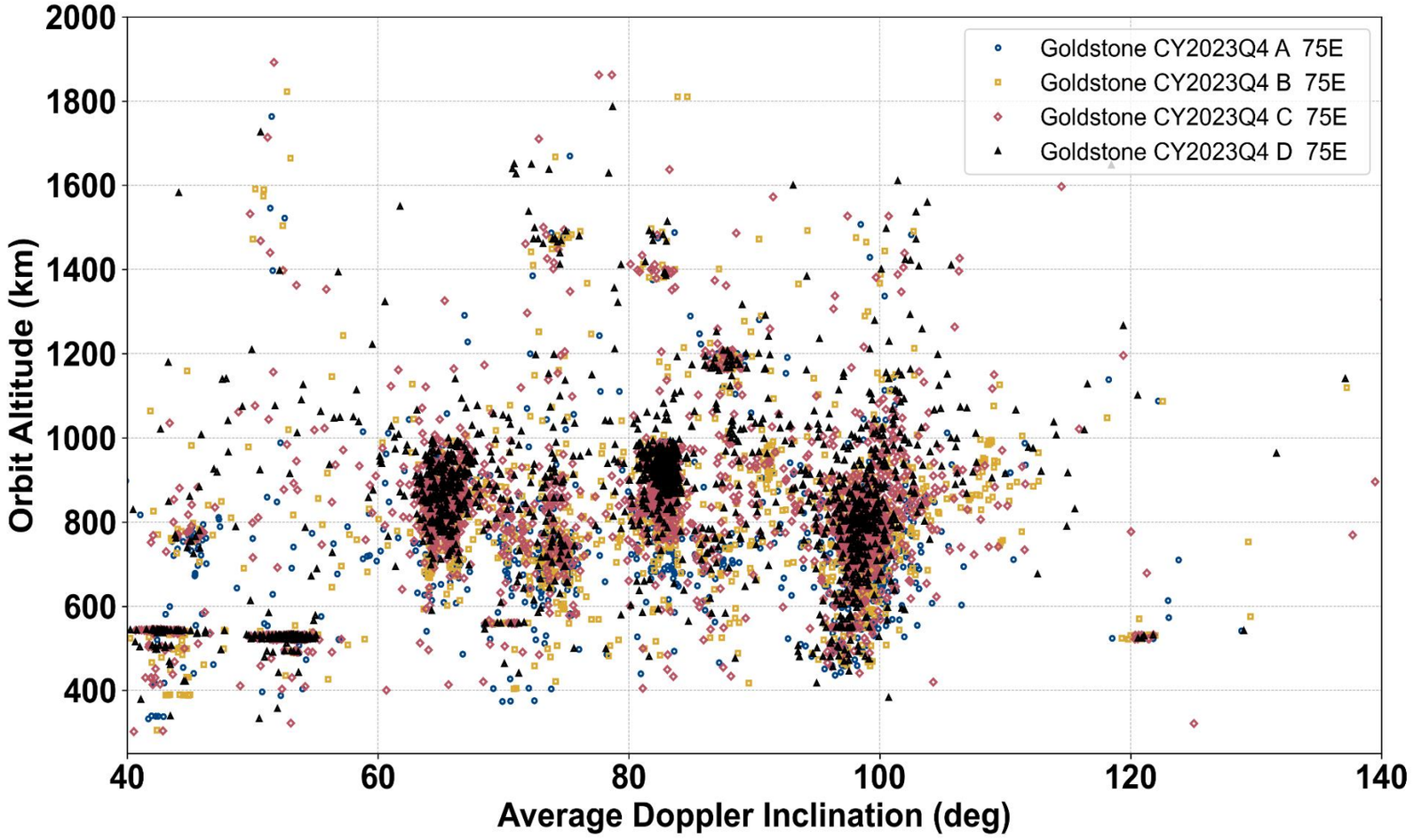
Altitude vs. Inclination, 2021



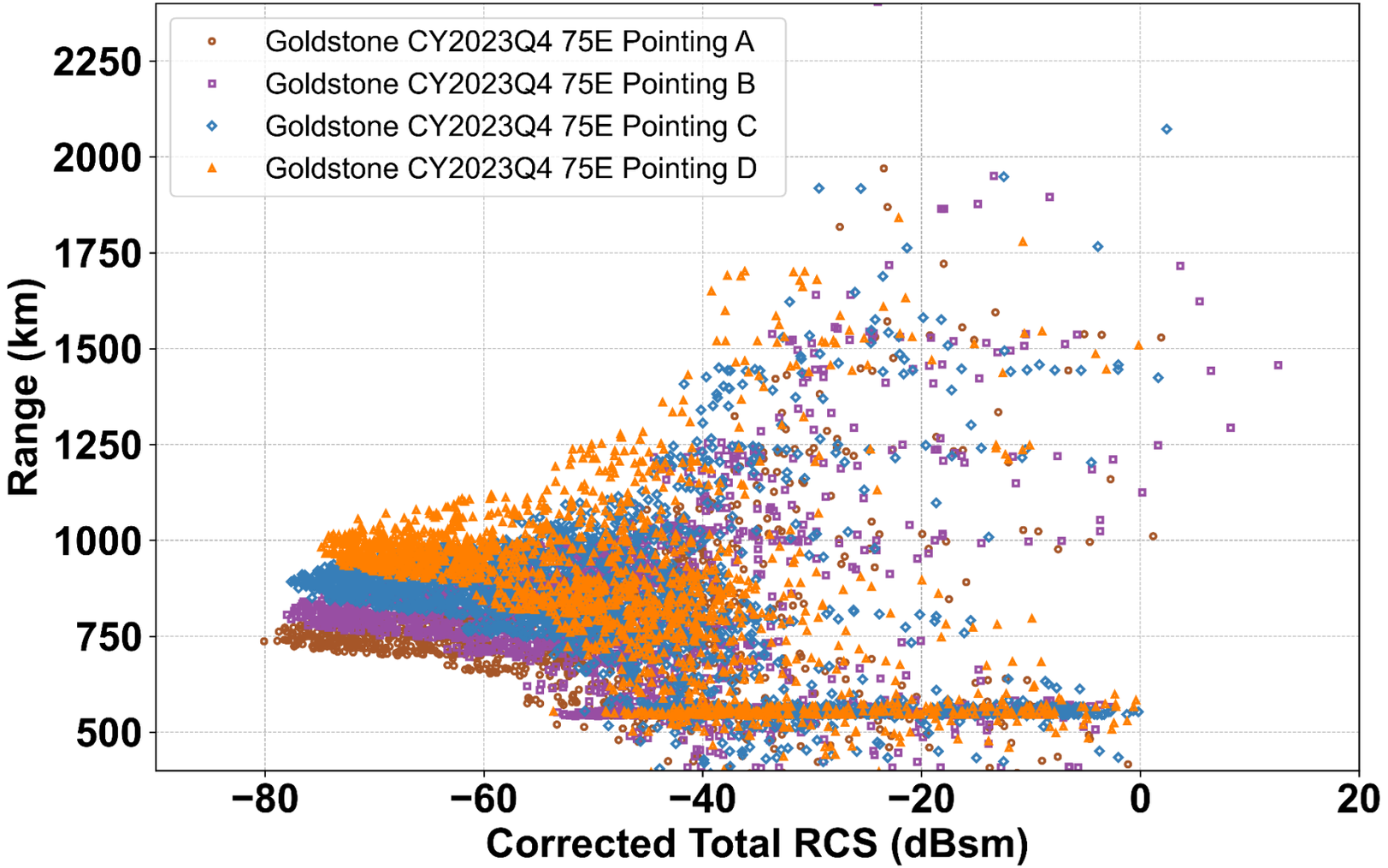
Altitude vs. Inclination, 2022



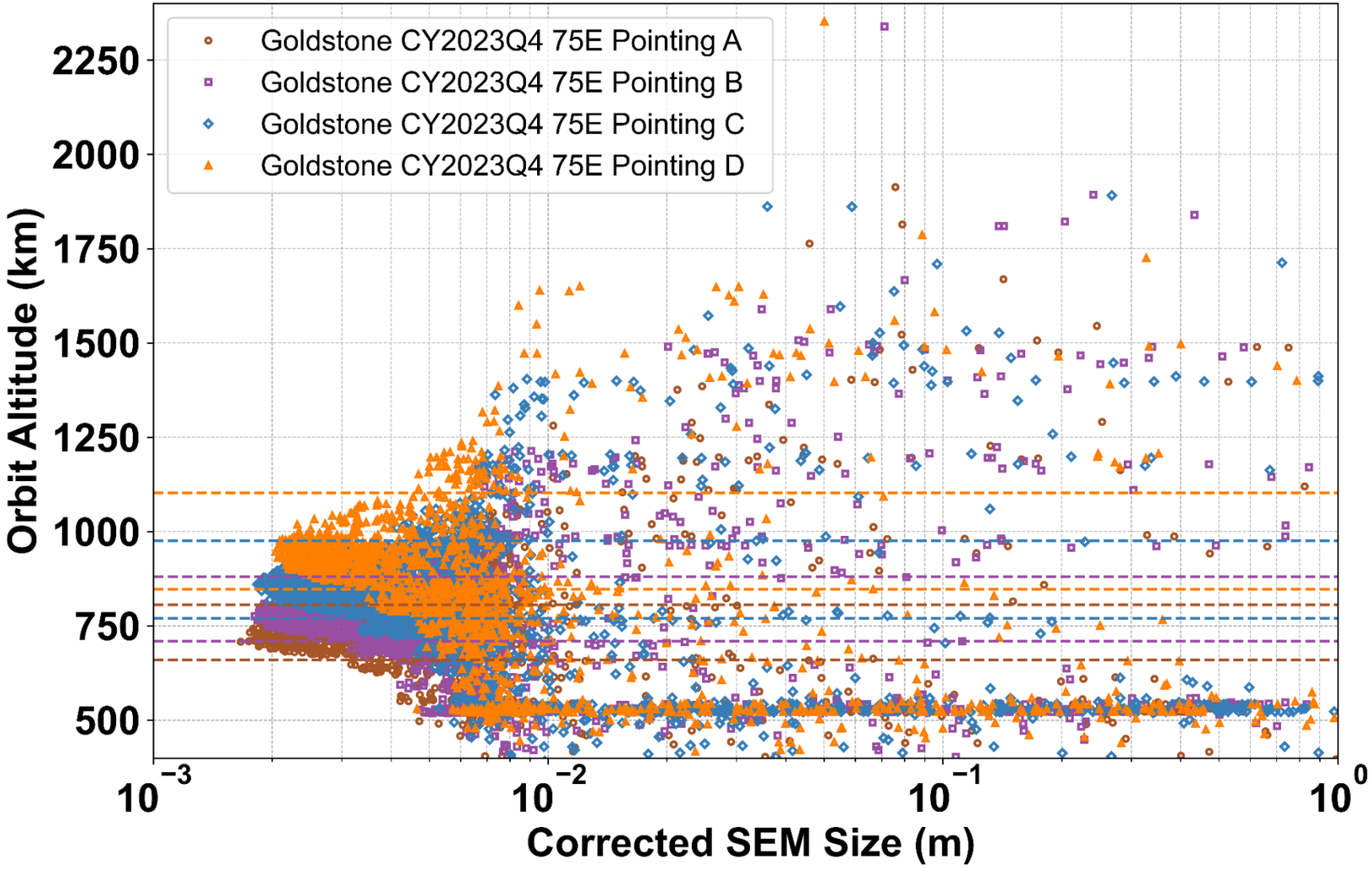
Altitude vs. Inclination, 2023



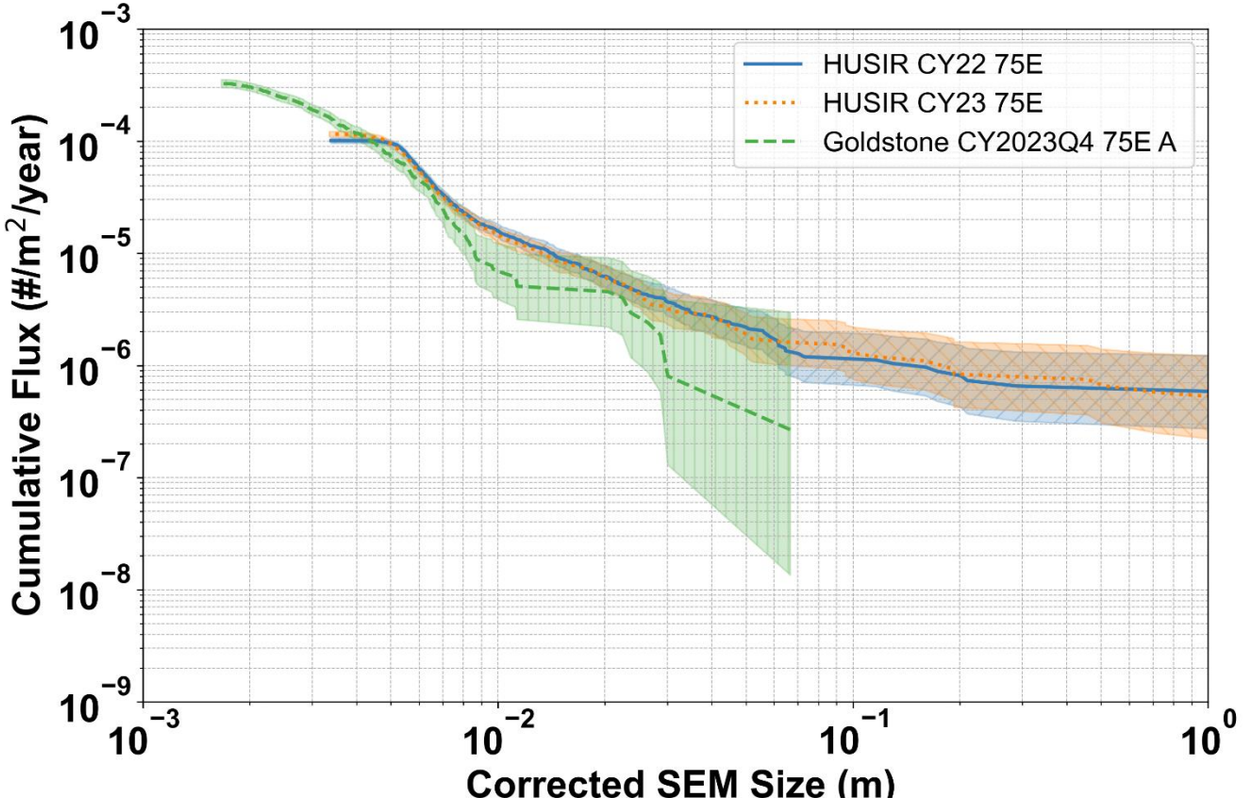
Range vs. RCS, CY2023

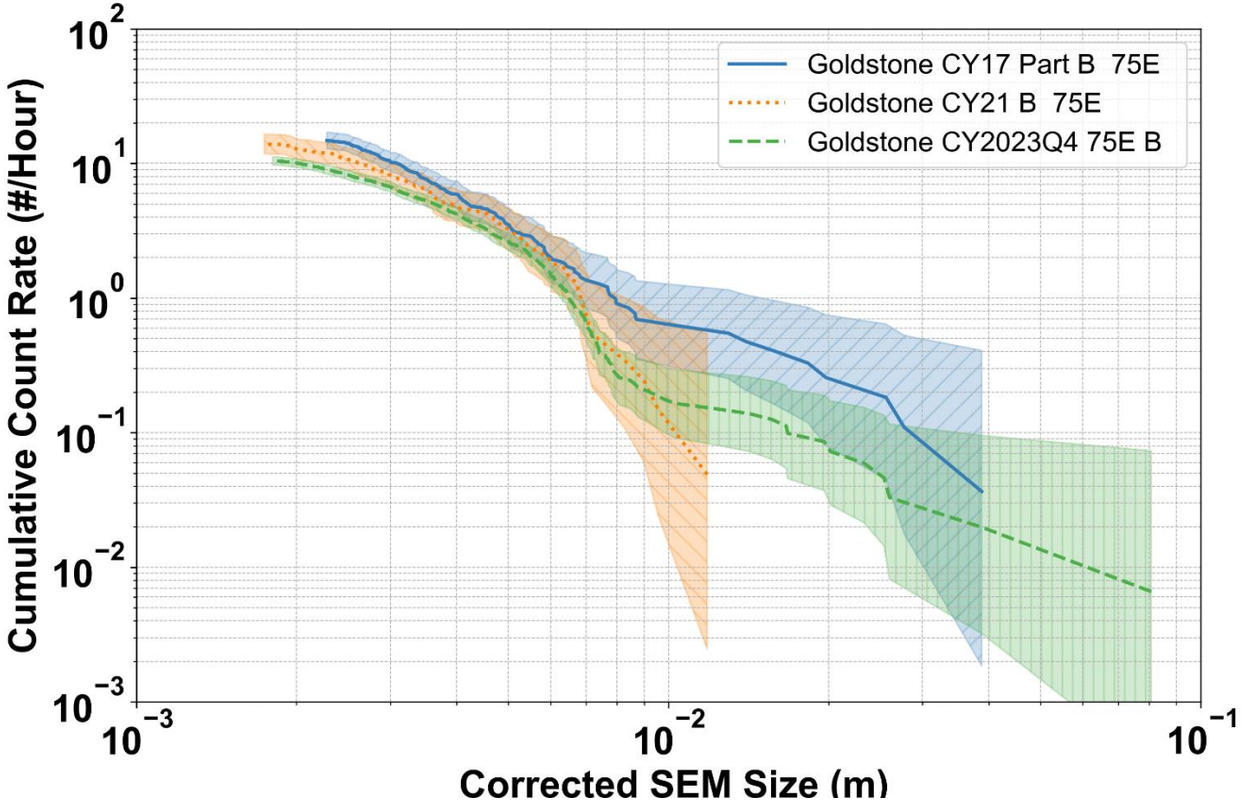


Altitude vs. Size, CY2023



Cumulative Count Rate vs. RCS, 2017-2023

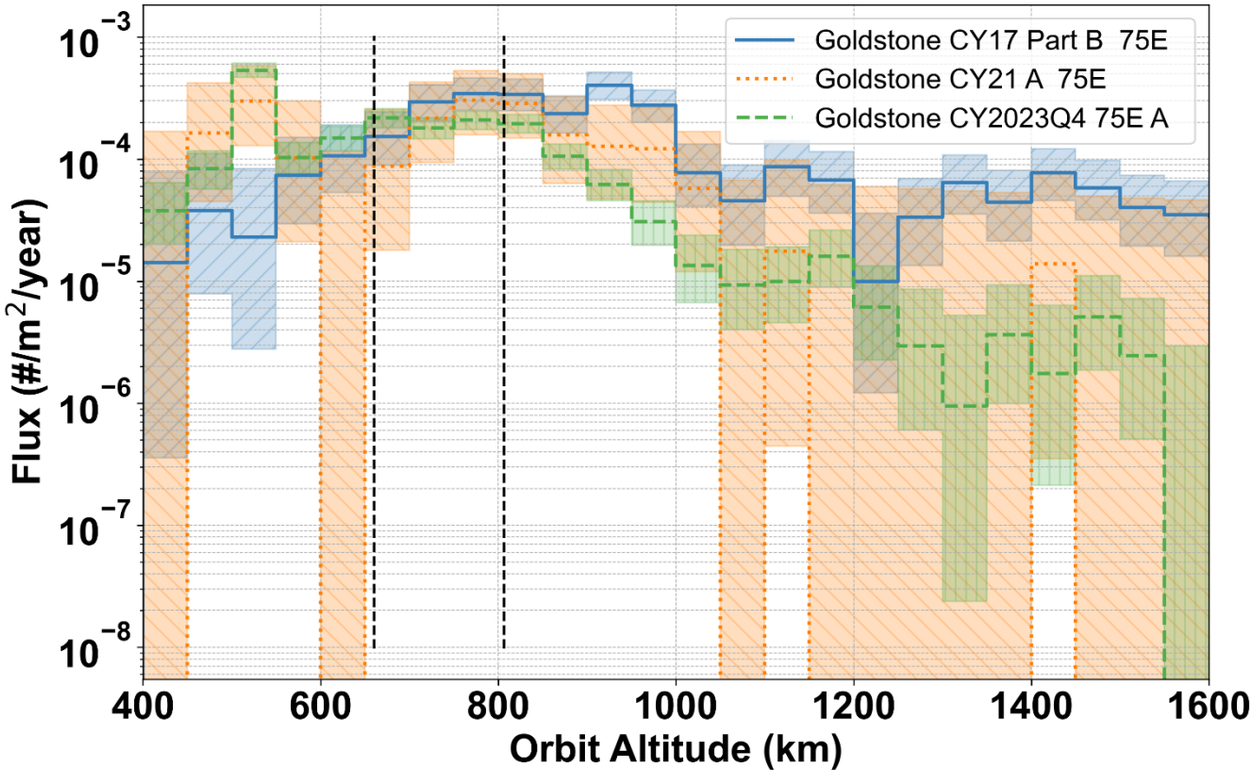


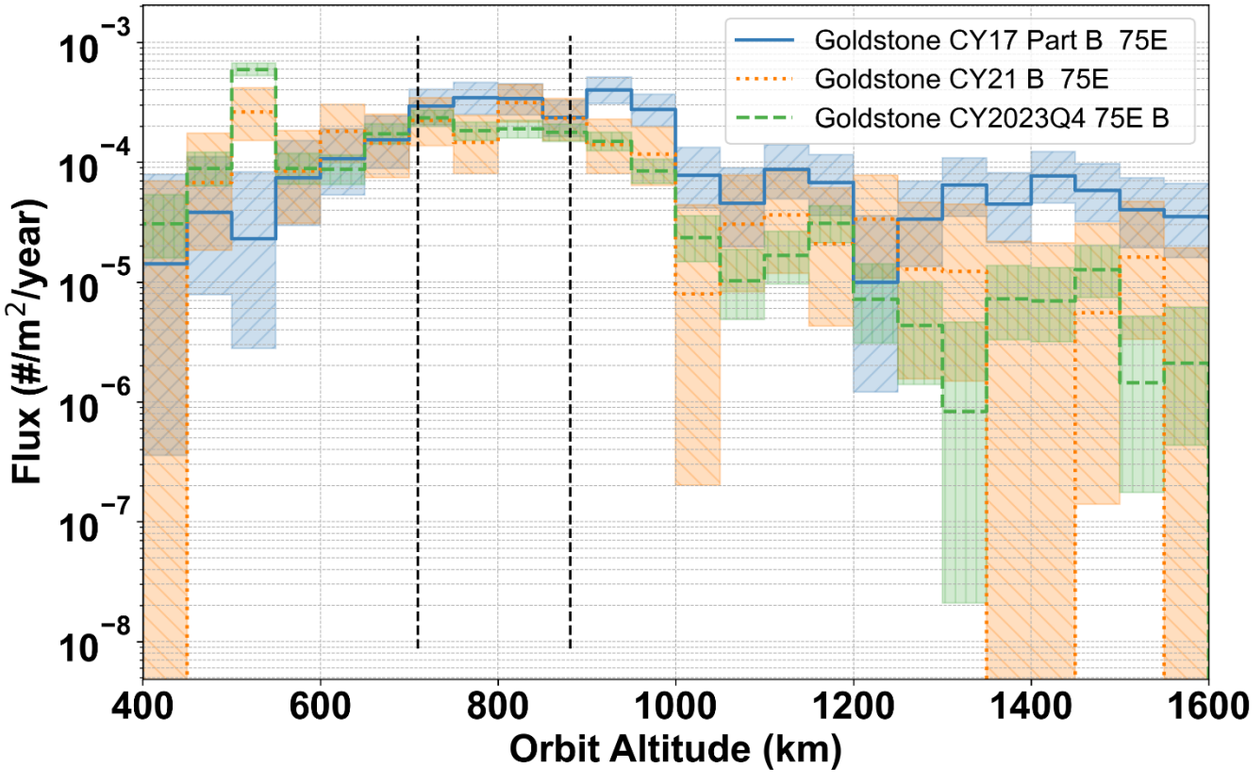


*2022 data excluded due to single polarization

Flux vs. Altitude, 2017-2023

SEM Size (m) > 0.03

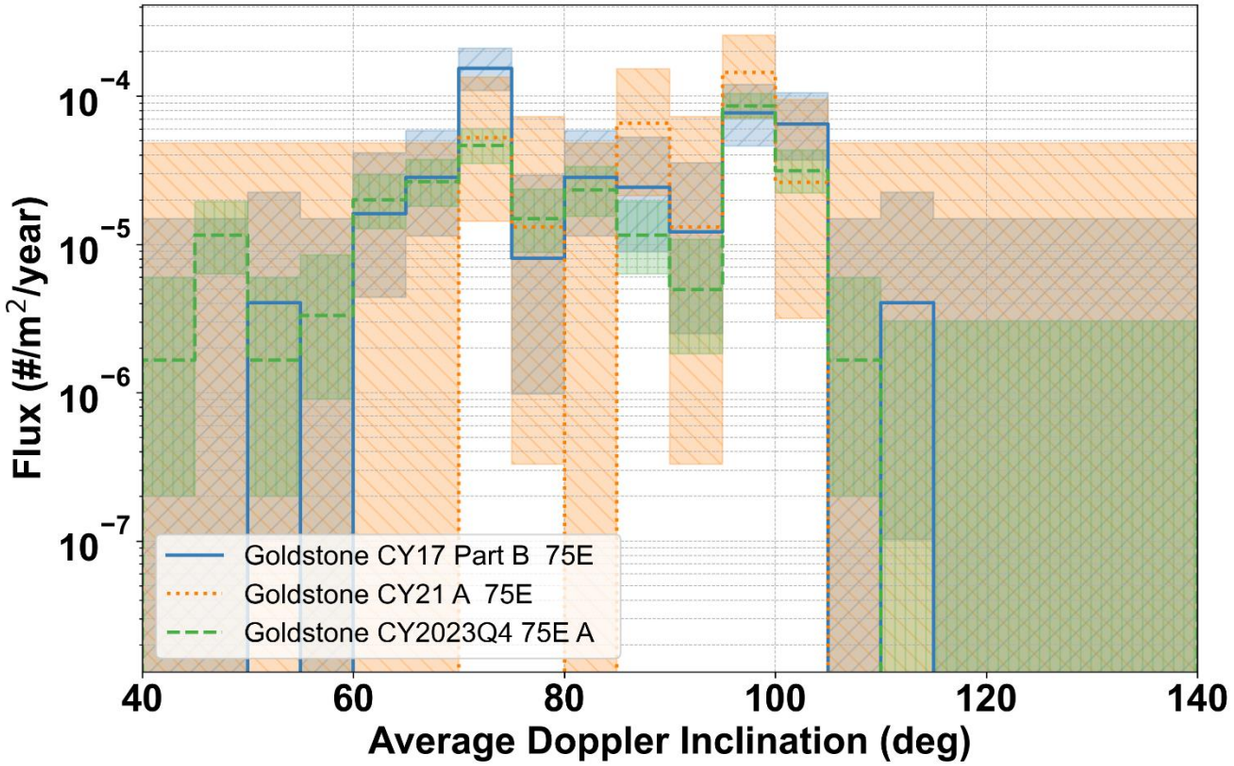




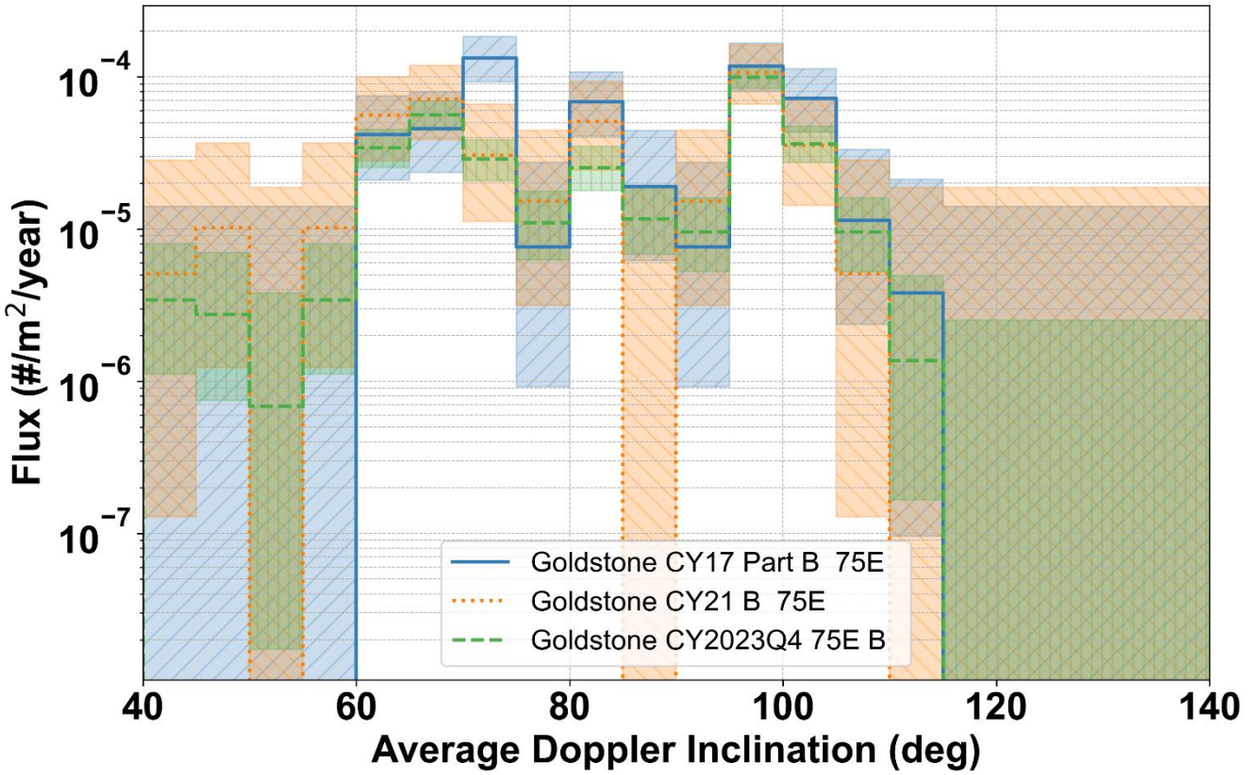
*2022 data excluded due to single polarization

Flux vs. Inclination, 2017-2023

SEM Size (m) > 0.03; 660.3 < Orbit Altitude (km) < 806.4

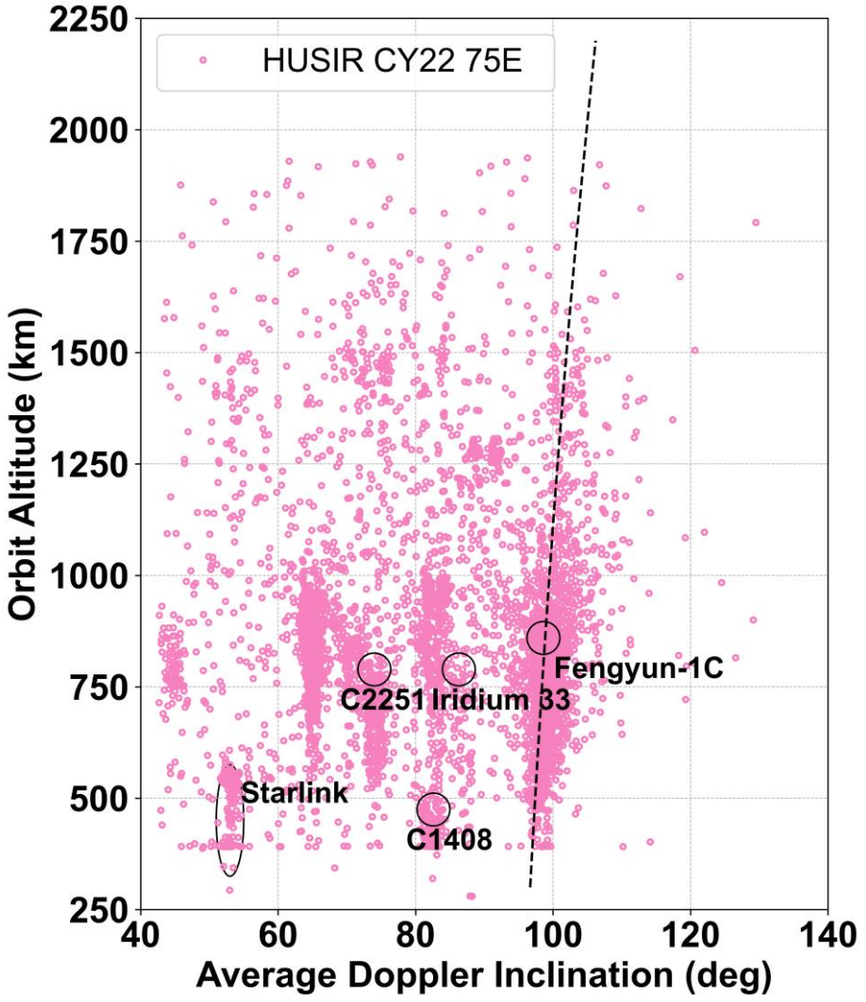


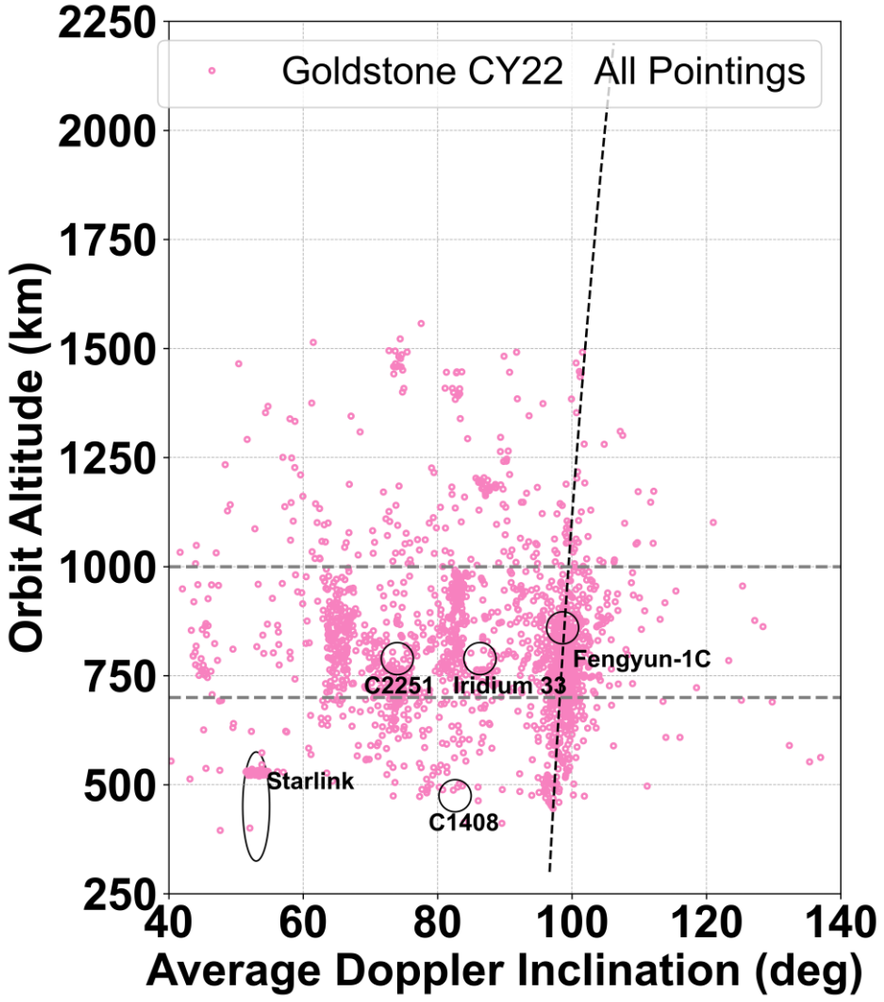
SEM Size (m) > 0.03; 709.7 < Orbit Altitude (km) < 881.0



*2022 data excluded due to single polarization

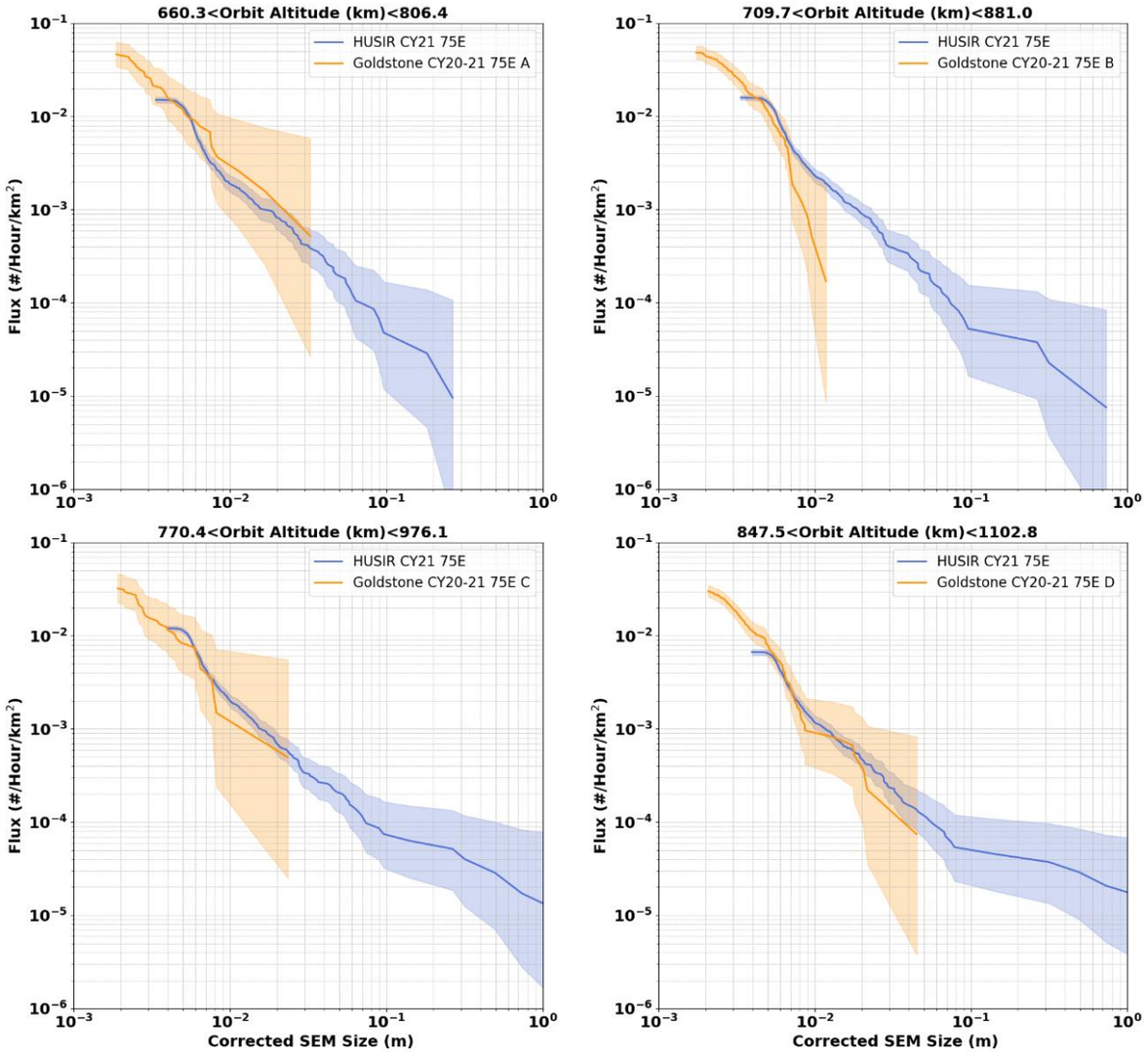
HUSIR Comparison – Altitude vs. Inclination





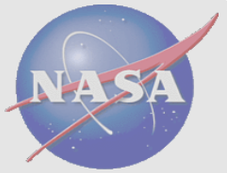
- **Haystack Ultrawideband Satellite Imaging Radar (HUSIR), operated by MIT/LL**
  - Provides most data for LEO debris >5.5 mm
- **Similar orbit families apparent in both datasets**

HUSIR Comparison – Cumulative Flux vs. Size



- **Goldstone data complements HUSIR data and extends coverage to smaller sizes**

Developing OD Models

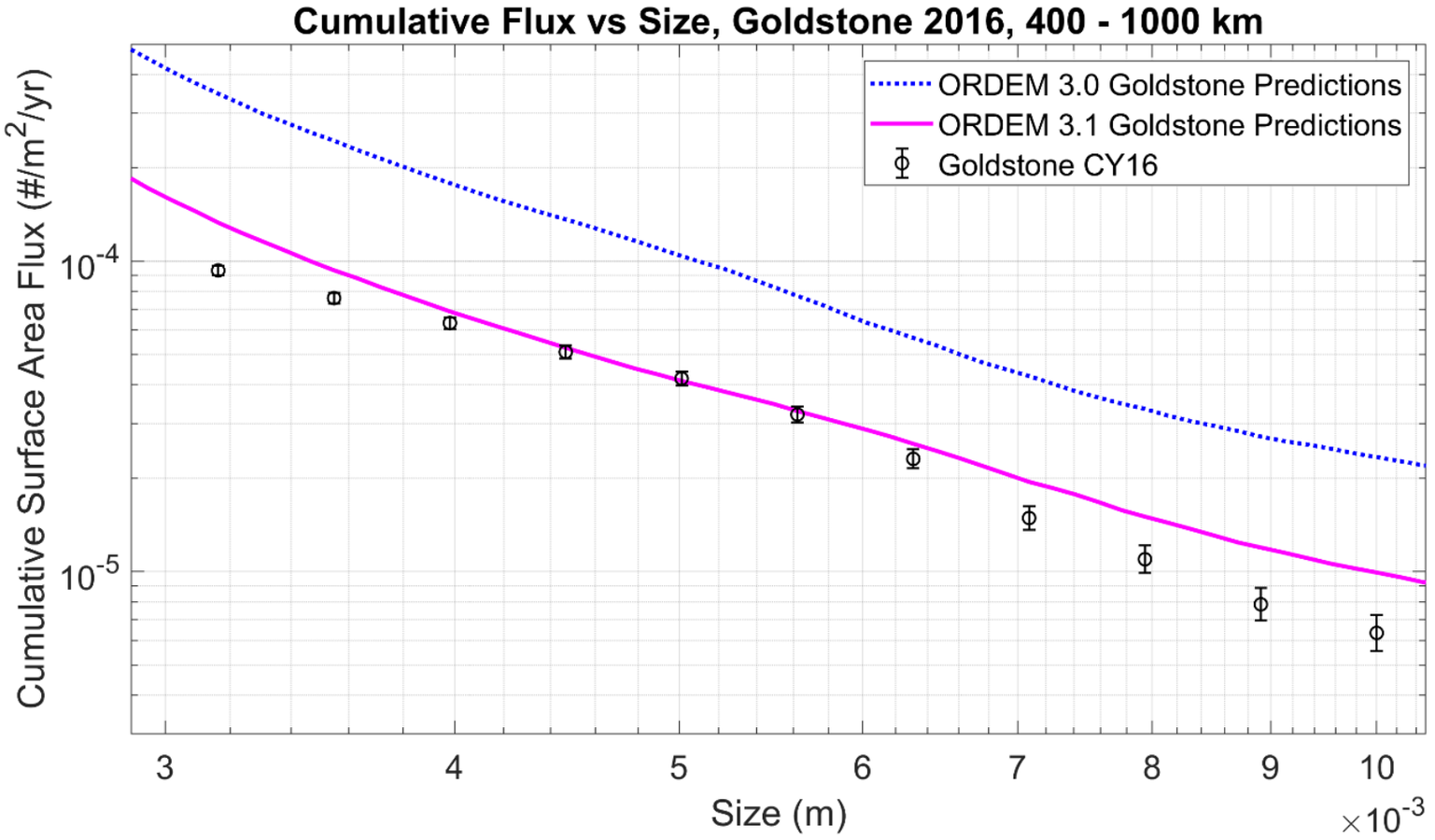


- **Goldstone annual data is ultimately used to build and validate model populations for the Orbital Debris Engineering Model (ORDEM)**

Data Source	Size Limit (approximate)	Years covered ORDEM 3.0 (2014)	Years covered ORDEM 3.1 (2019)	Years covered ORDEM 4.0*
Goldstone	3 – 6 mm	2009	2016-2017	2016-2023+

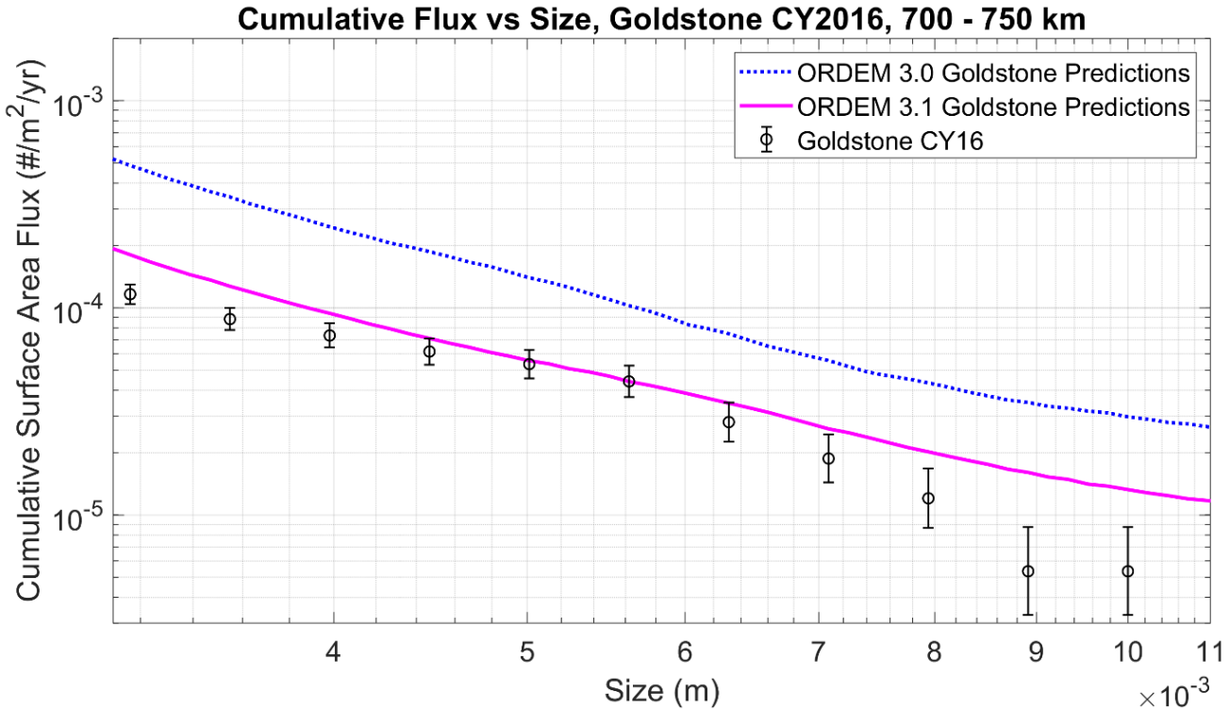
*currently in development

Goldstone Validation Data for ORDEM 3.1 (1)

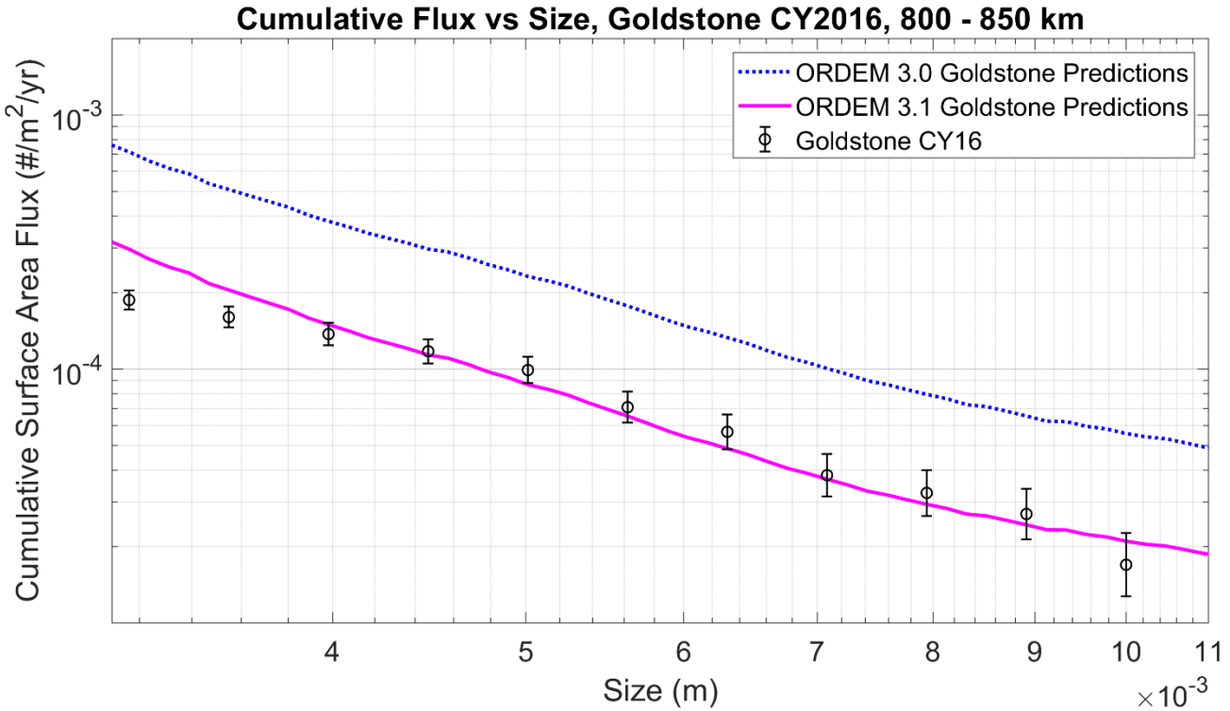


Goldstone Validation Data for ORDEM 3.1 (2)

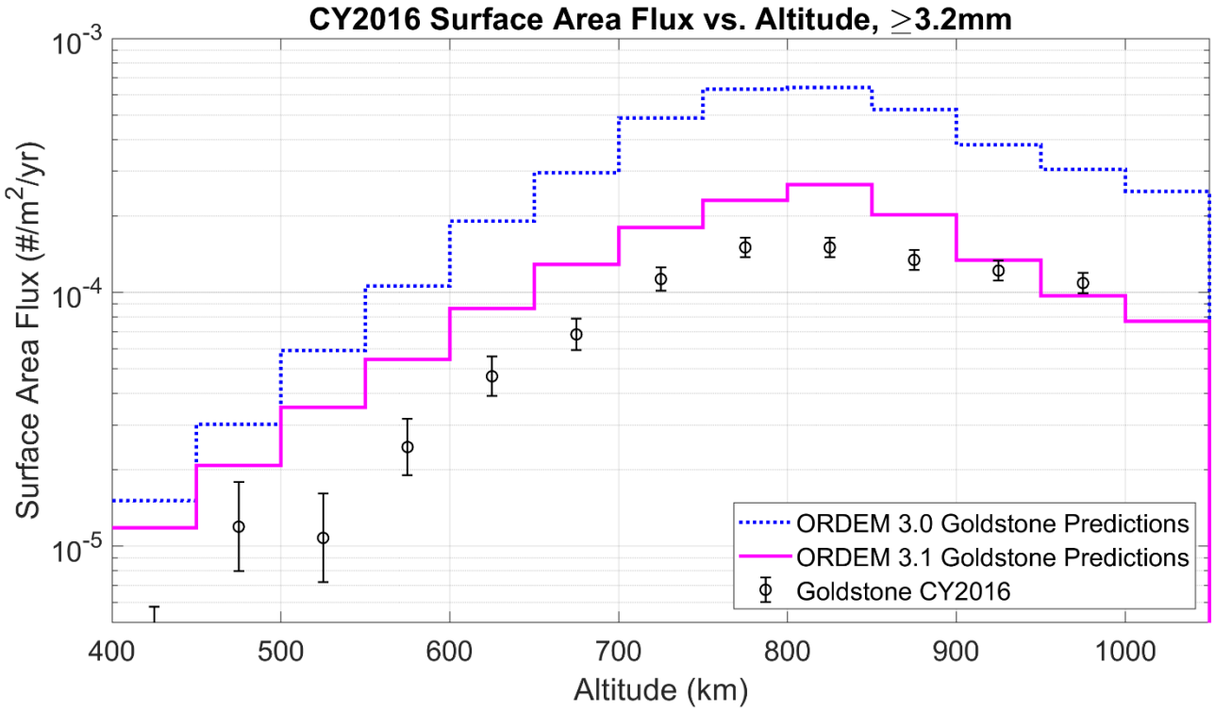
A-Train

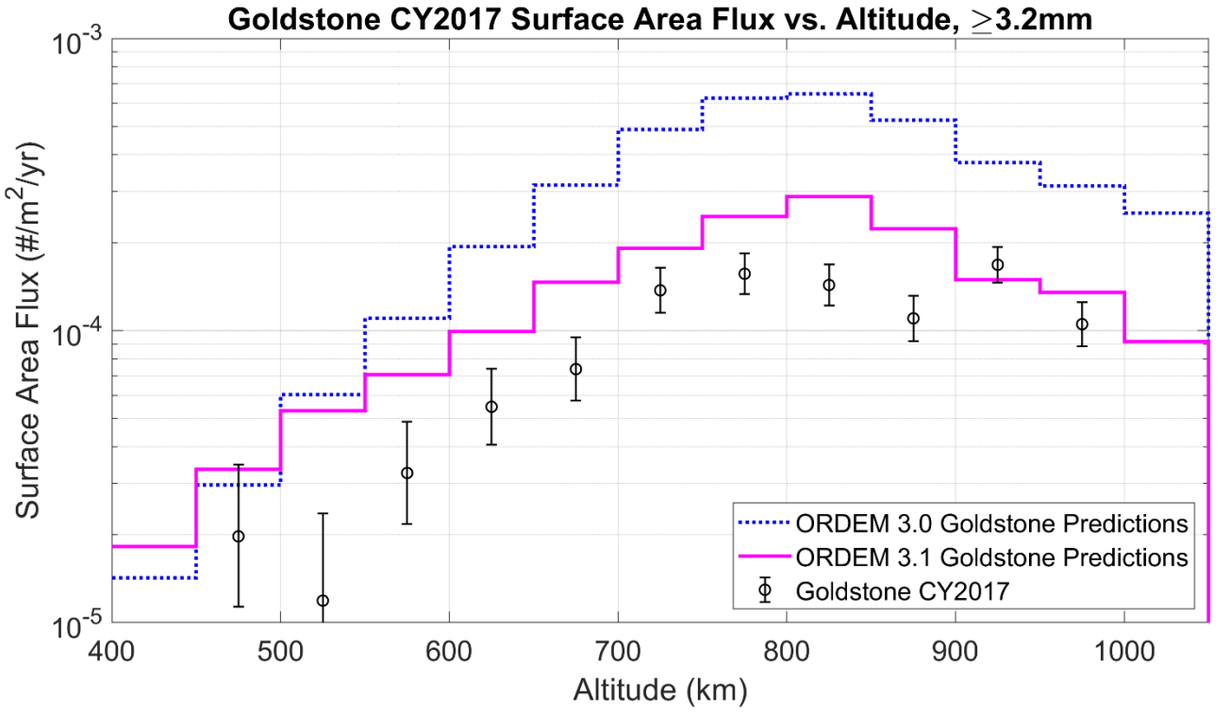


JPSS-1/NOAA 20

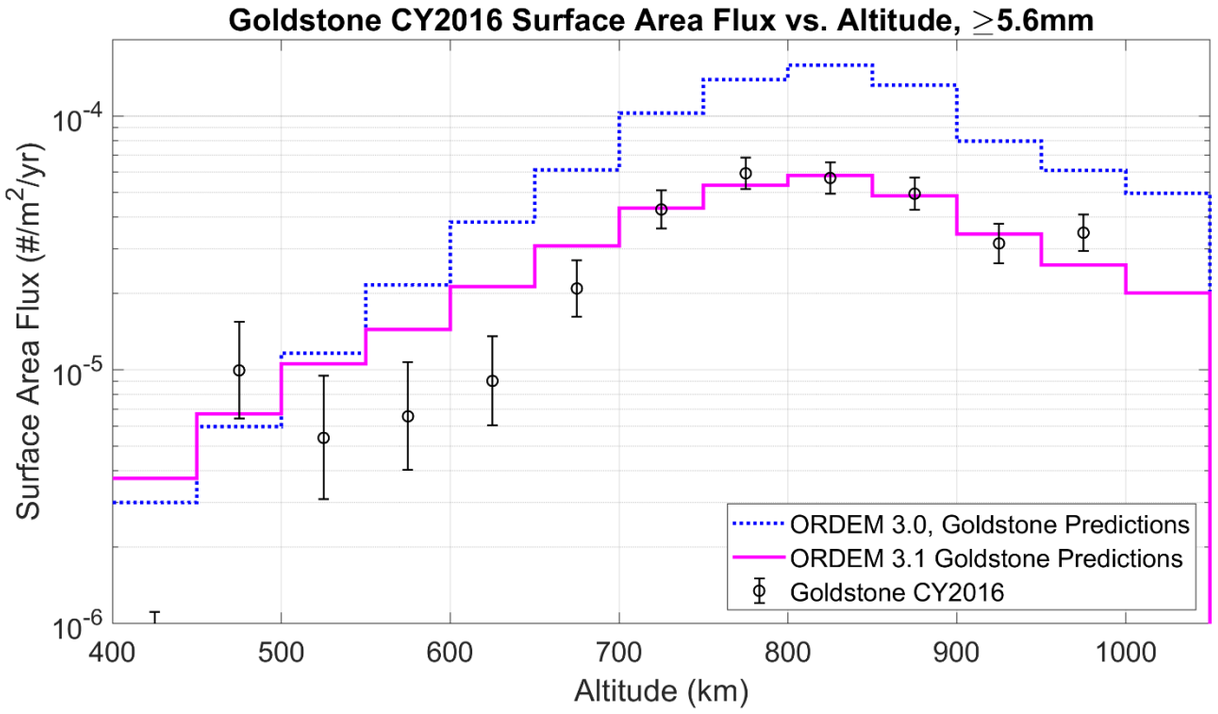


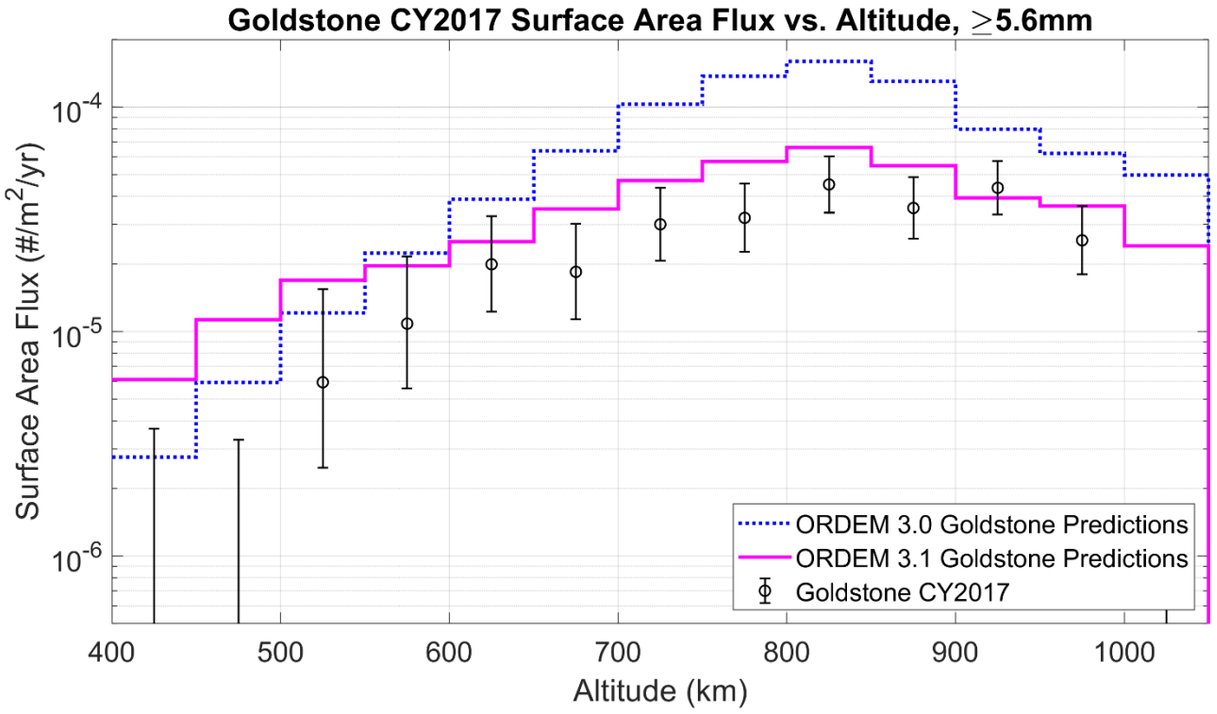
Goldstone Validation Data for ORDEM 3.1 (3)





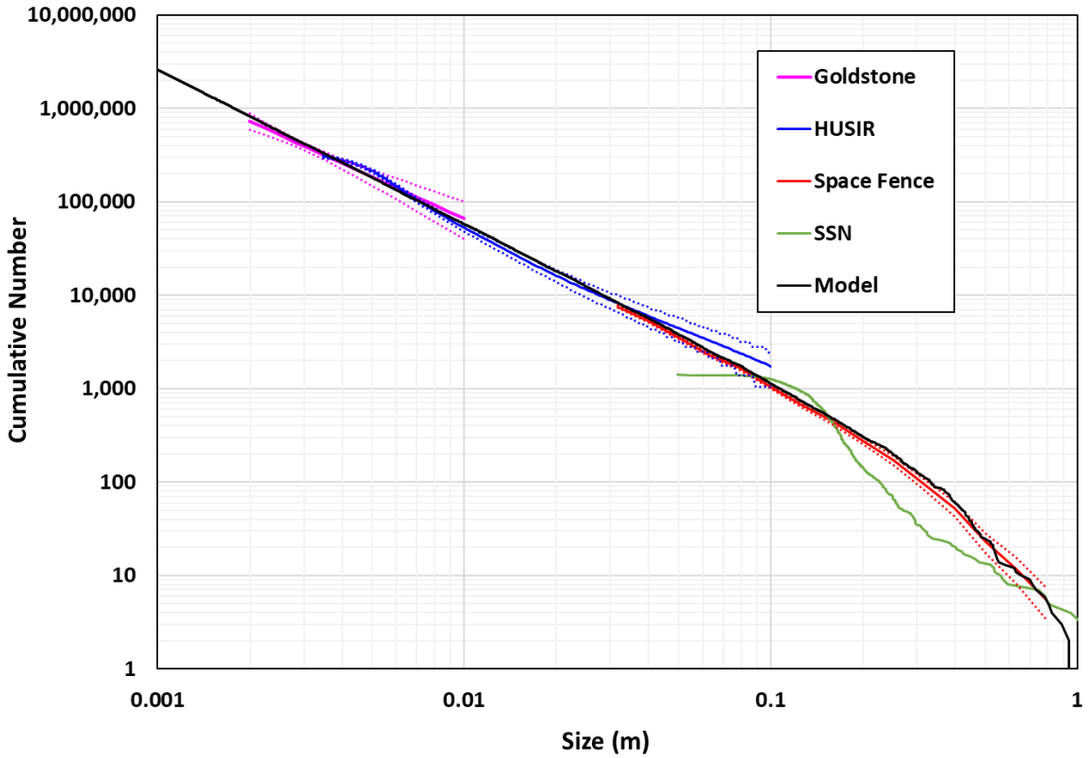
Goldstone Validation Data for ORDEM 3.1 (4)





Special Observations – Cosmos 1408

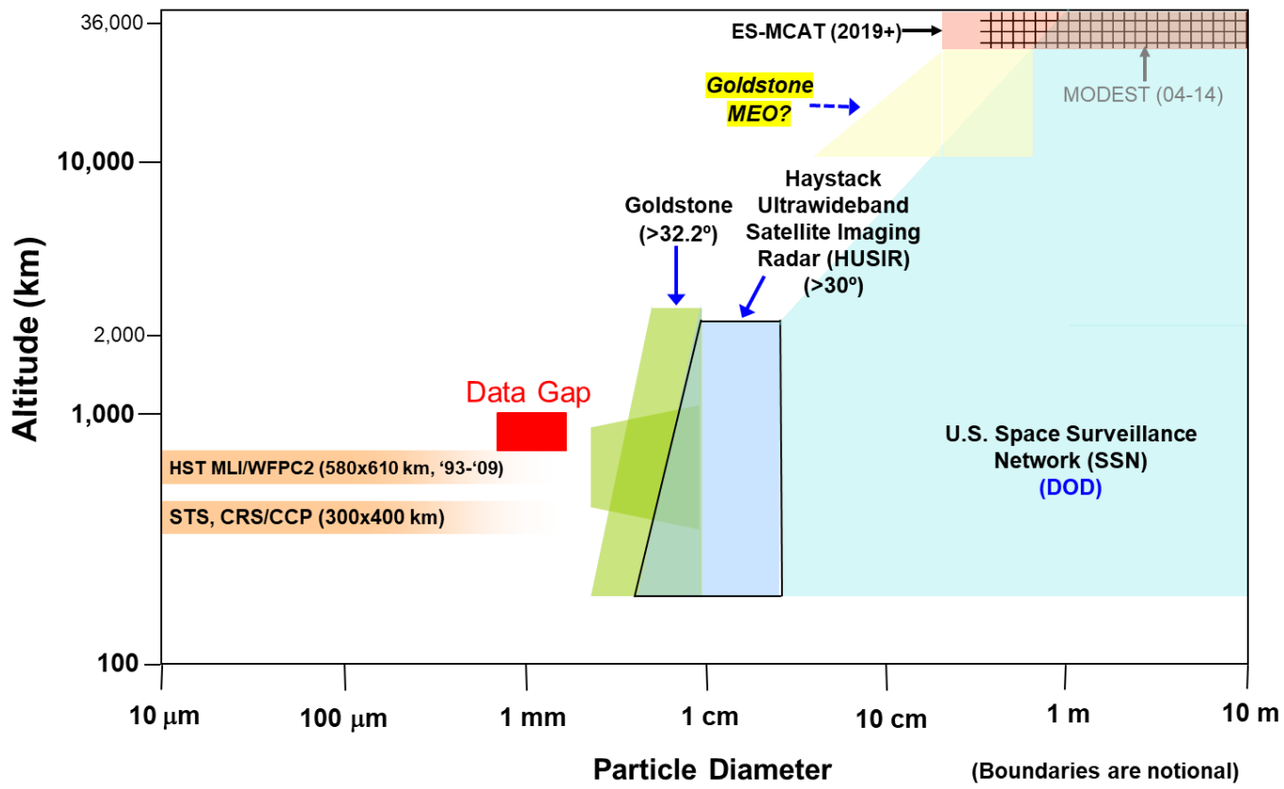
- Goldstone and HUSIR are also used for special breakup observations
- Following the ASAT test conducted by the Russian Federation on Cosmos 1408 in November 2021, the ODPO partnered with MIT/LL and NASA JPL to collect special radar measurement data on small Cosmos 1408 fragments using HUSIR and Goldstone
- MIT/LL, in coordination with the 18 SPCS, also shared a unique Space Fence data set consisting of the initial two passes of the Cosmos 1408 fragment cloud
- Model predictions from the NASA Standard Satellite Breakup Model (SSBM) match special datasets very well
- ORDEM 3.2 was released in March 2022, including the modeled Cosmos 1408 breakup fragments



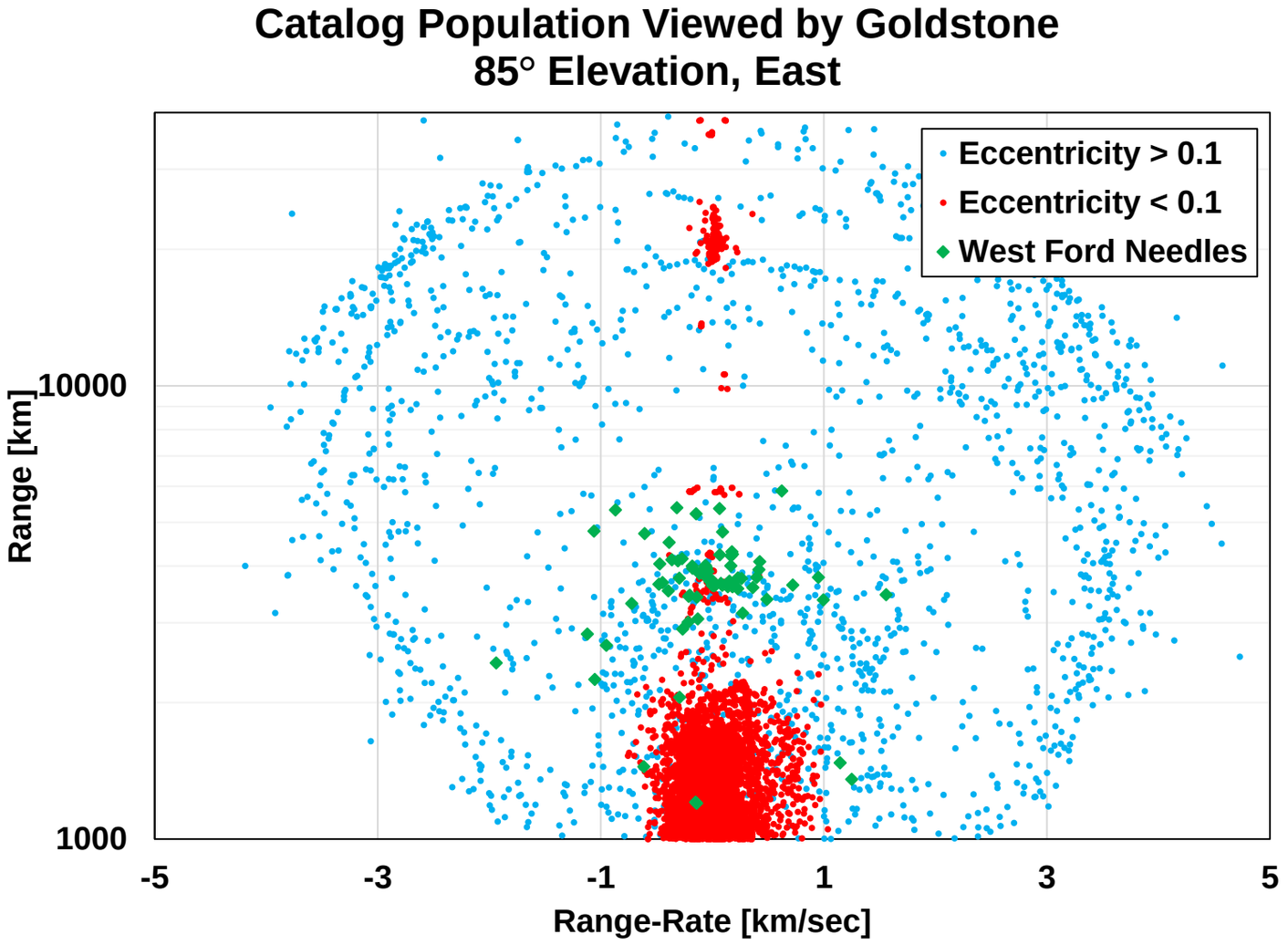
Cumulative size distribution of the Cosmos 1408 fragments based on special radar measurement data. The black line is the NASA SSBM prediction

MEO Observations (1)

- **Currently, we have no data on small debris in MEO for use in developing OD models**
  - MEO observations with Goldstone would help fill this data gap
- **Why MEO?**
  - Navigation spacecraft constellations (GPS, etc.)



MEO Observations (2)



MEO Observations (3)

DSS14 azimuth = 90.00 elevation = 85.00, DSS25