National Aeronautics and Space Administration

# NASA Orbital Debris Radar Measurements by the Haystack Ultra-wideband Satellite Imaging Radar (HUSIR)

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# The Debris Environment

- **The DOD is tasked with tracking and cataloging satellites in Earth orbit using the Space Surveillance Network (SSN)**
  - Intact spacecraft, rocket bodies, satellite breakup debris
- **Tracking = determining an orbit of sufficient accuracy to recover the object later and to positively identify it as the same object**
  - Tracking also allows position predictions for collision avoidance
- **Due to limitations of geographic coverage and sensor sensitivity, the tracked catalog is only complete down to some limiting size**
  - Historically, this limit is >10 cm, but the Space Fence has reduced that limit somewhat

# NASA's Approach to the Debris Environment

- **Just because we cannot easily track objects smaller than 10 cm, doesn't mean that we cannot extract useful information on their properties**
  - Number
  - Size distribution
  - Inclination distribution
  - Altitude distribution
  - Sources
- **NASA uses statistical sampling to estimate these numbers**
  - This consists of staring at a region of sky and counting objects that pass through
  - Using knowledge of how orbiting objects behave, a surprising amount of information can be extracted
- **The statistical data is used to build NASA's Orbital Debris Engineering Model (ORDEM)**
  - ORDEM provides estimates of the orbital debris flux environment for spacecraft operators and designers to plan missions and spacecraft shielding

# Radar and Optical Measurements in ODPO

***Goal: To statistically sample the orbital debris (OD) environment below the threshold of the SSN to build and validate orbital debris models***

Credit: Reprinted with permission Courtesy of MIT Lincoln Laboratory (MIT/LL), Lexington, Massachusetts

Credit: Courtesy NASA/JPL-Caltech, https://deepspace.jpl.nasa.gov/galleries/goldstone/#gallery

| |
|---|
| 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) |

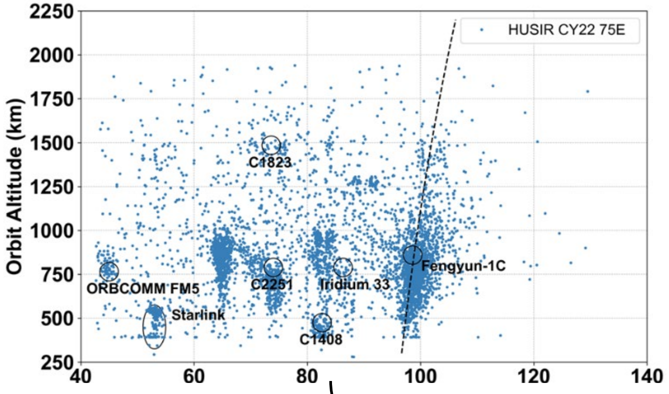
Credit: Ben Hanna

Provide data for building/validating OD models

**Measurements**

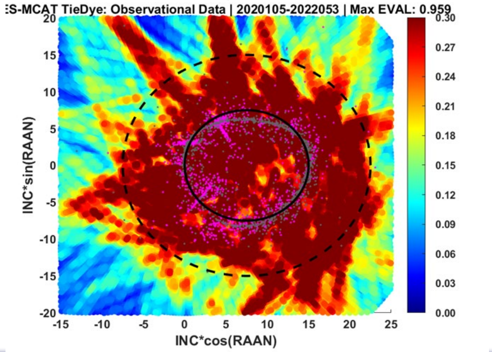
**Modeling**

Provide feedback on how to improve measurements

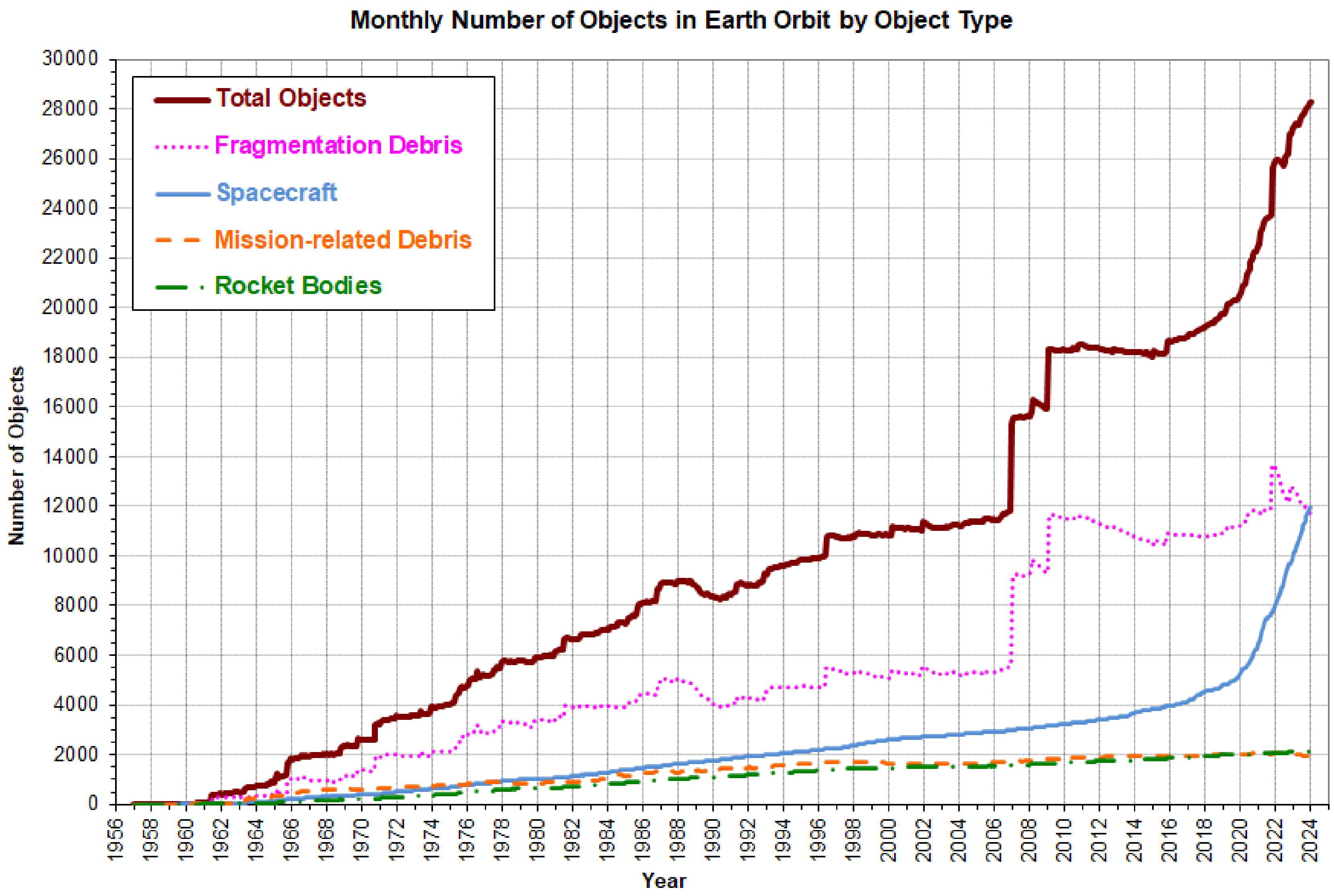




ORDEM
ORBITAL DEBRIS ENGINEERING MODEL

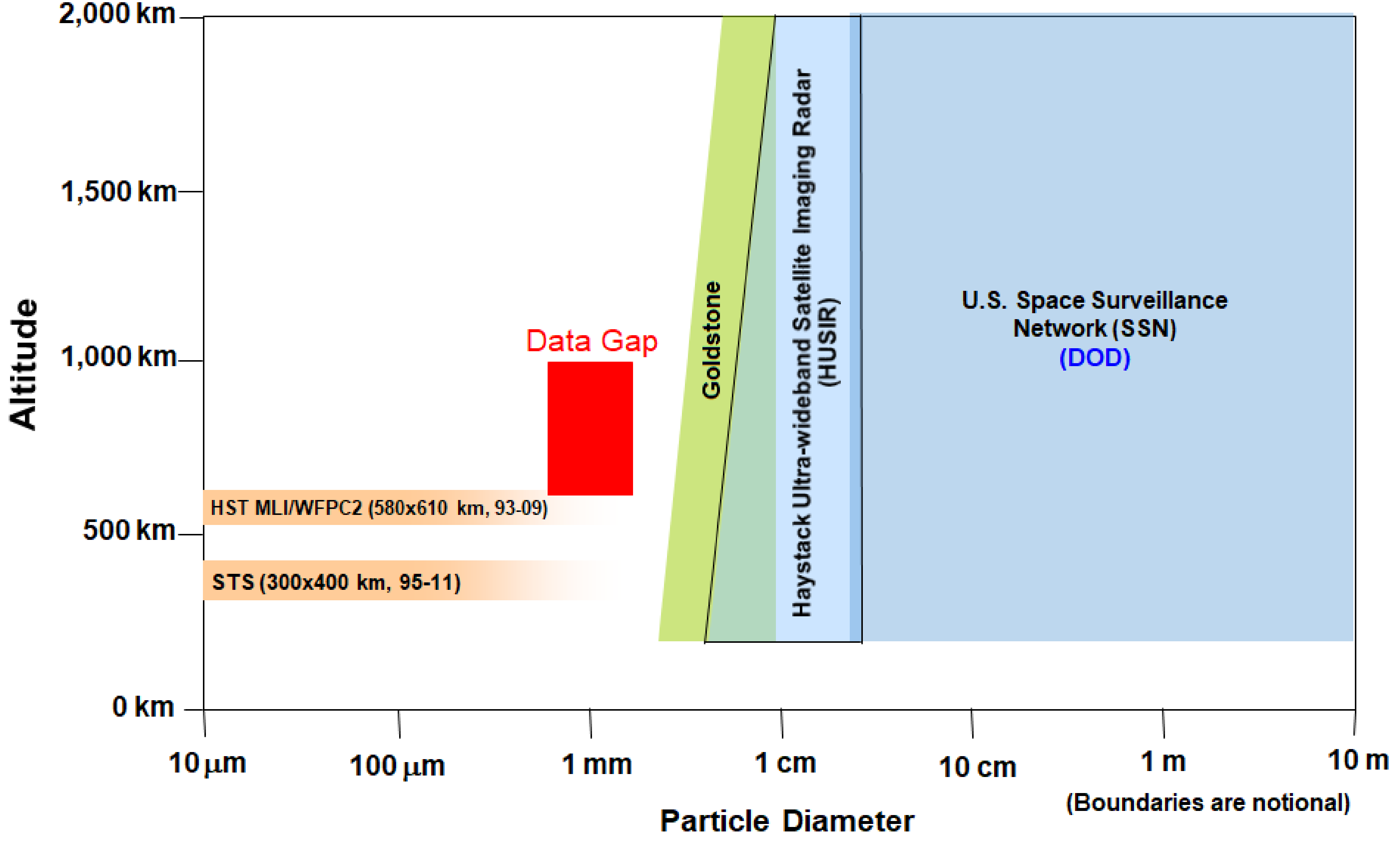


# Growth of Cataloged Space Object Population




**Environment is dynamic, so constant monitoring is necessary**

# Data Coverage



# HUSIR Radar

- **Located in Massachusetts – 42.6° latitude, operated by Massachusetts Institute of Technology, Lincoln Laboratory (MIT/LL)**
- **Haystack Ultrawide Satellite Imaging Radar (HUSIR – previously known as Haystack)**
  - 36 m diameter dish
  - 3 cm wavelength (X-band – 10/10.1 GHz)
  - Can detect debris >5 mm in LEO
  - Narrow beam – 0.058°
- **The radar accurately measures RCS, polarization, range, and Doppler velocity along line of sight, but has trouble measuring other velocity components, so precision orbit not possible**

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

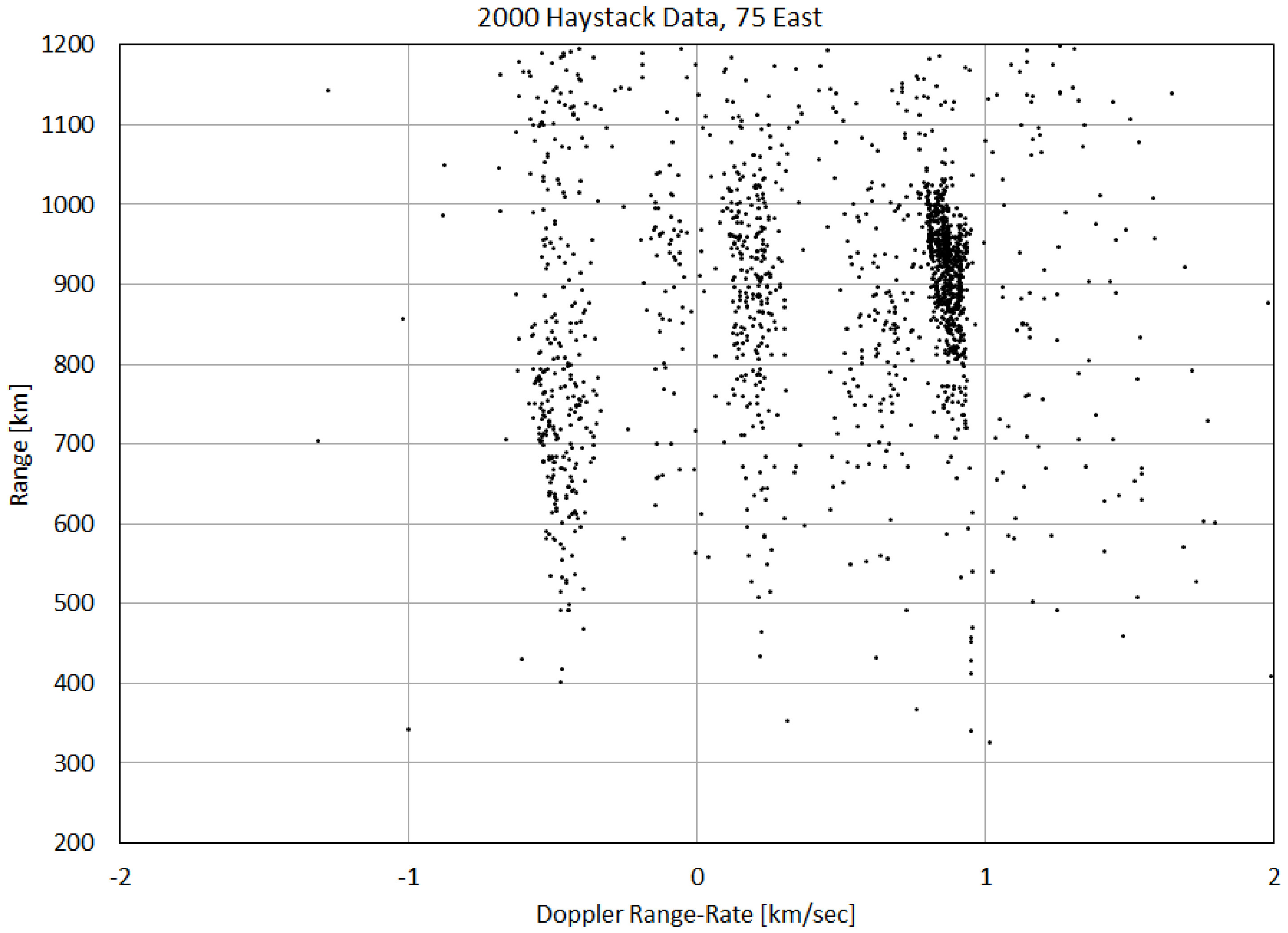
# Estimating Debris Parameters

- **We receive surrogate measurements for the OD parameters we really want for modeling**

Range / Range-Rate (Doppler Velocity)

Altitude / Inclination

  - Doppler inclination calculation assumes circular orbits
  - Requires a special pointing mode – 75° elevation, 90° azimuth (East)



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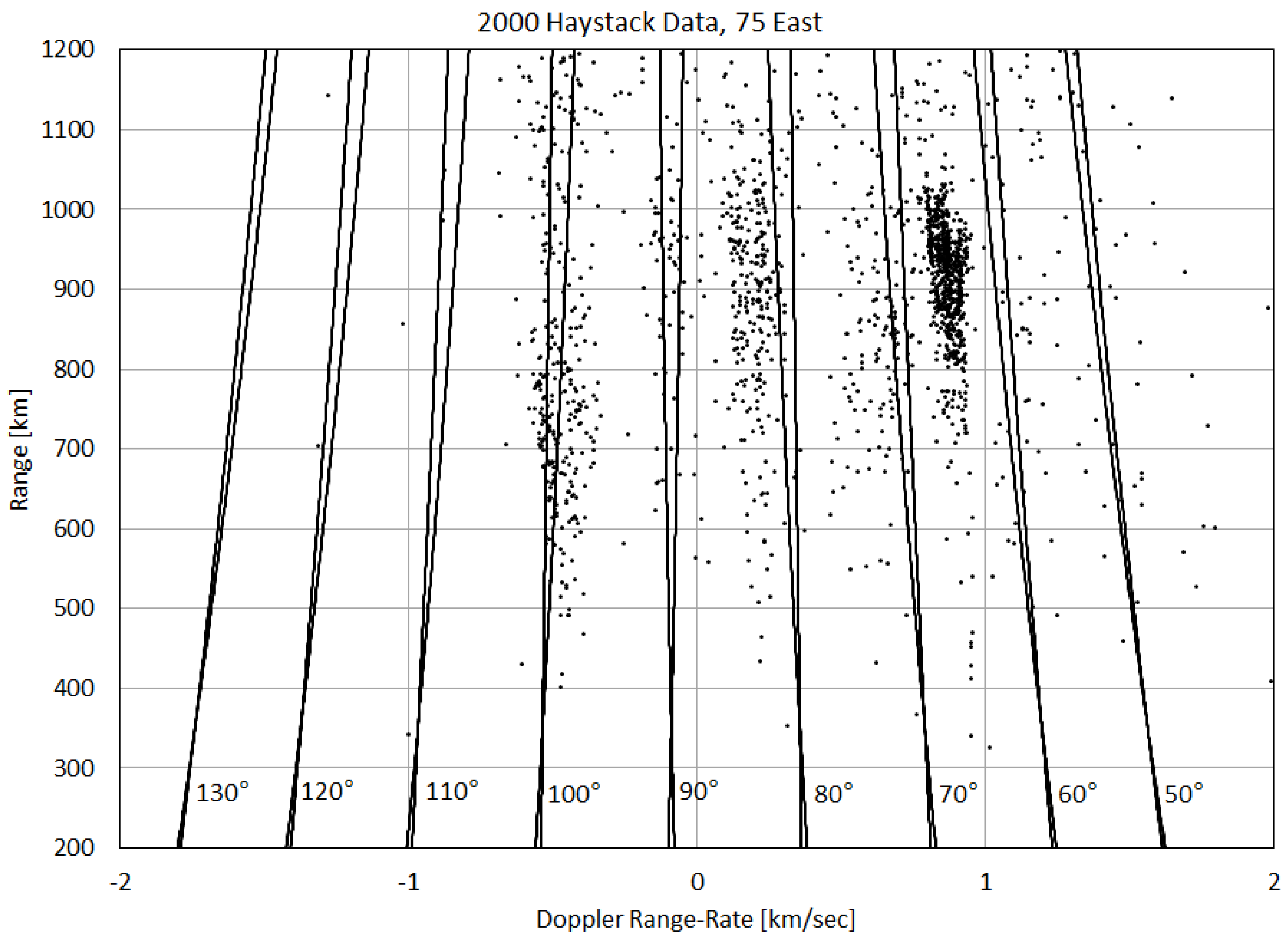
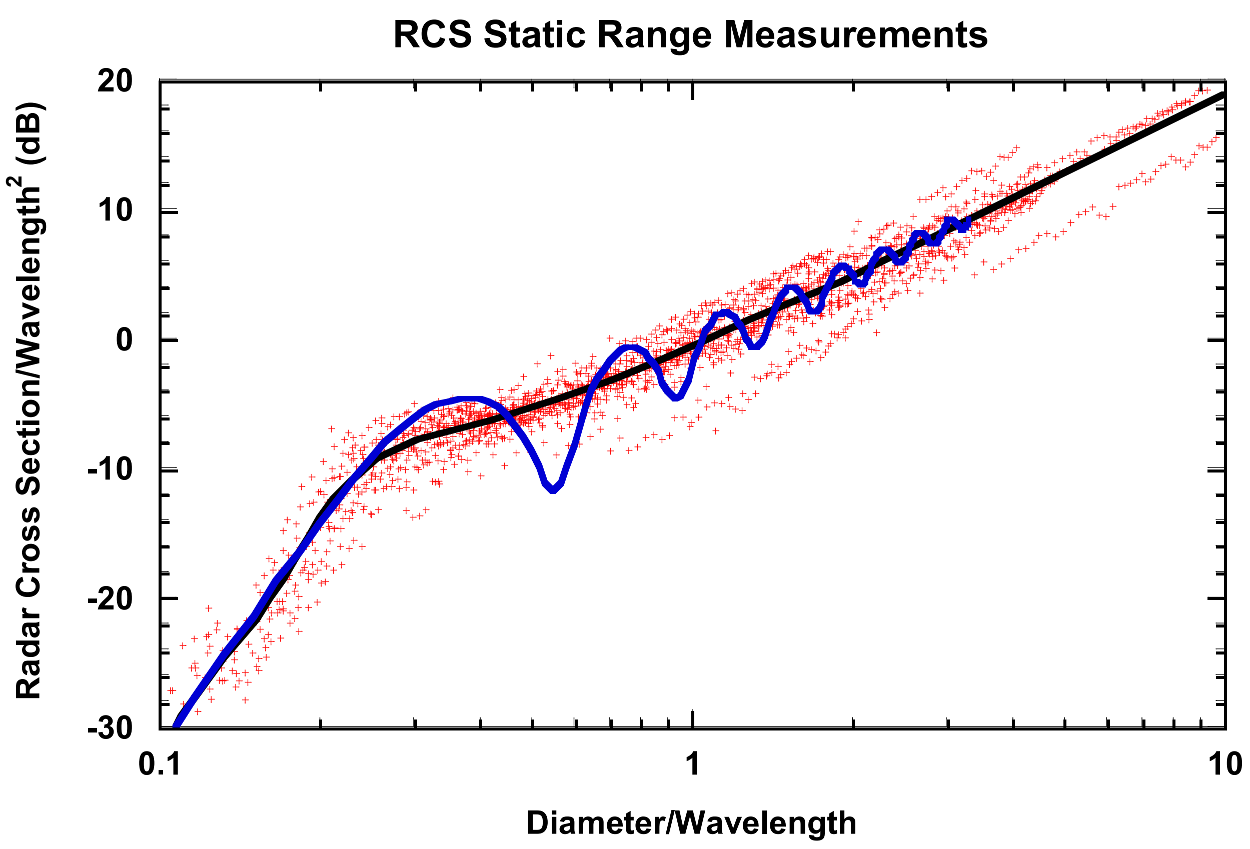


# Estimating Debris Parameters

- **We receive surrogate measurements for the OD parameters we really want for modeling**

RCS → size

- NASA size estimation model
  - Empirical model based on measurements of 39 representative debris objects averaged over many orientations at specific frequencies



# HUSIR Data Collection and Processing

## MIT/LL

**Real Time Target Detection**
Excised continuous record file of detections the meet SNR threshold (CLDT/RTDR files)

**PP Sum, OP Sum, AZ Delta, EL Delta, System Parameters**

**RCS Calibration Scans**
Sphere tracks (.S files)

**Beam Shape Calibration Scans**
Spiral scans (.R files)

## NASA ODPO

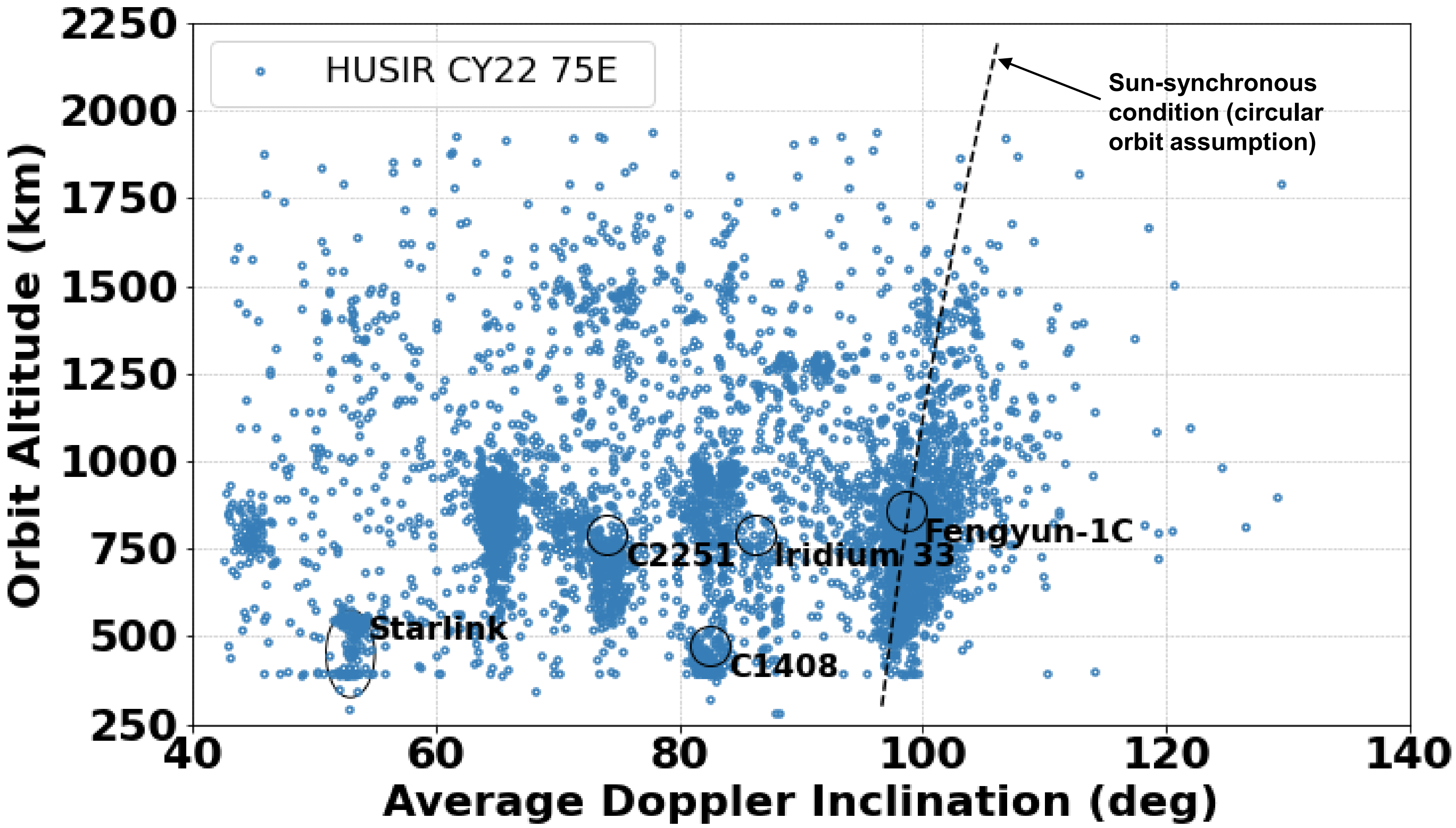
**Processing (DRADIS)**
- Extract calibration constants and I & Q
- Generate RDI and apply SNR threshold
- Apply matched filter to estimate range
- Estimate path through the beam
- RCS Calibration

**Doppler frequency, RCS, range, single pulse SNR, Orbital element estimates**

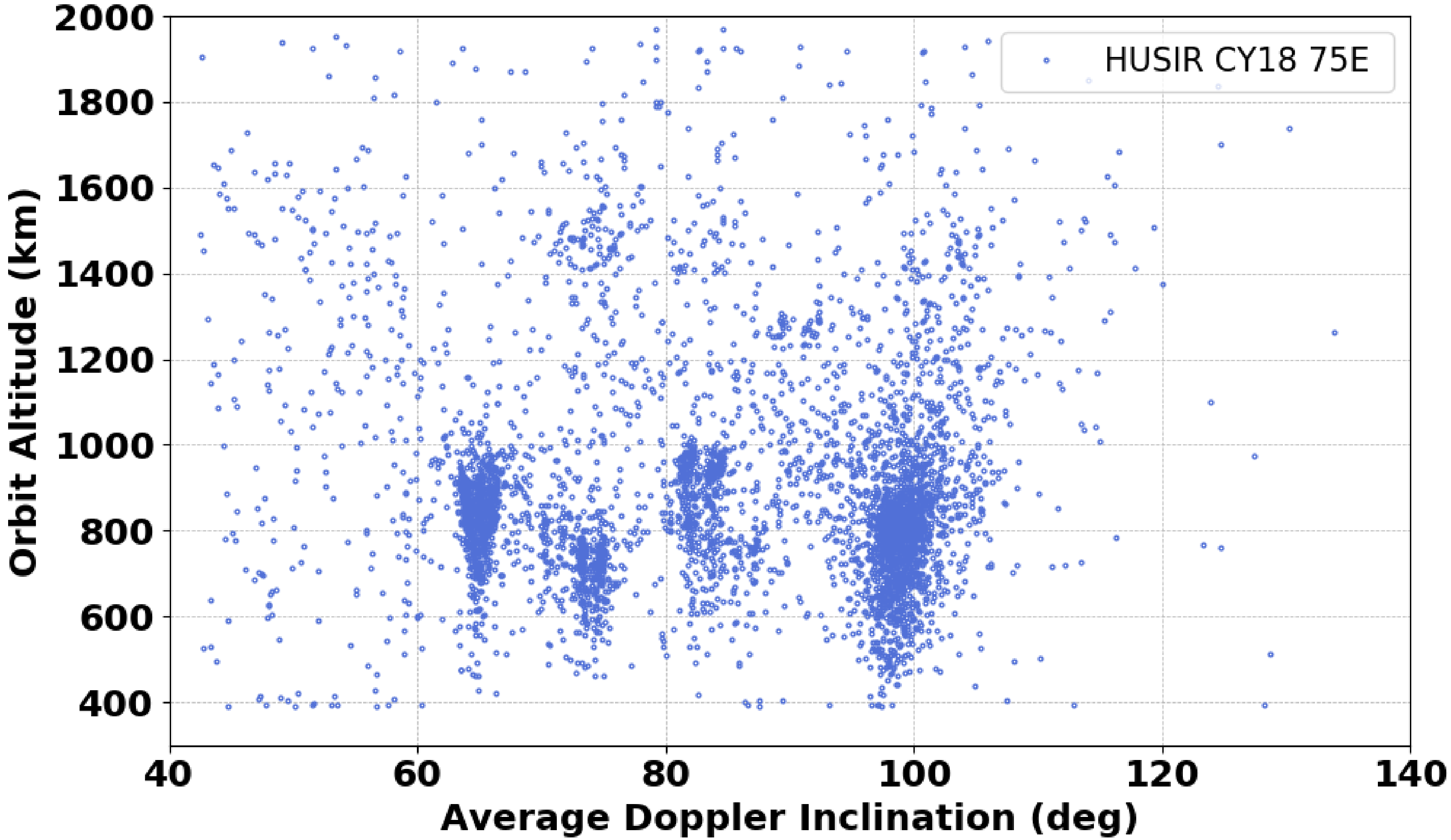
**Data Review**
- Identify presence of RF
- Outlier detection

**Analysis**
- Size Estimation Model
- Count-rates vs Time/Alt./Inc/Polarization
- Range/Alt. vs Range-rate and Inclination
- Flux vs Altitude
- Range/Altitude vs Total RCS/Size

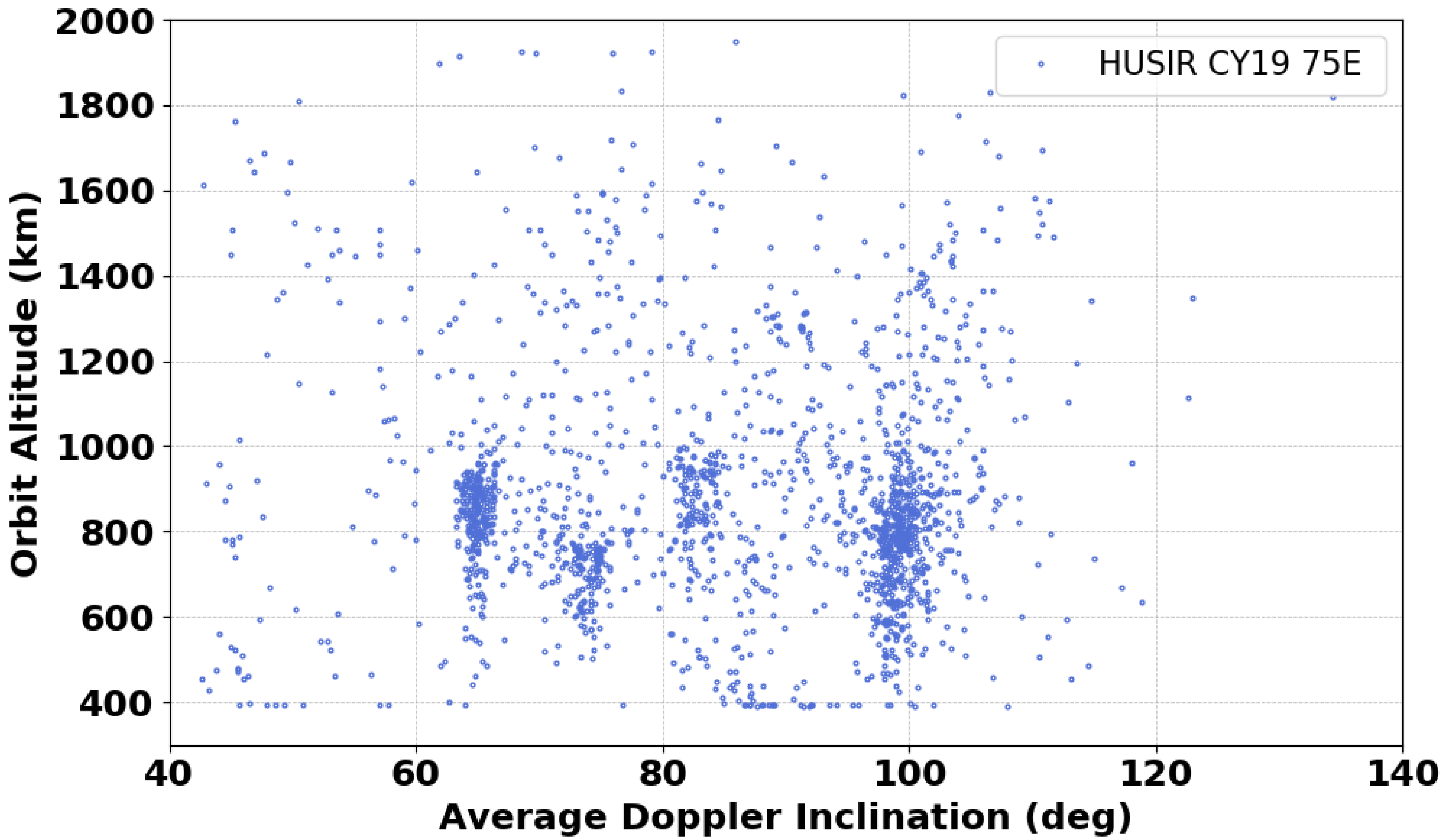
# Altitude vs. Inclination, HUSIR 75E



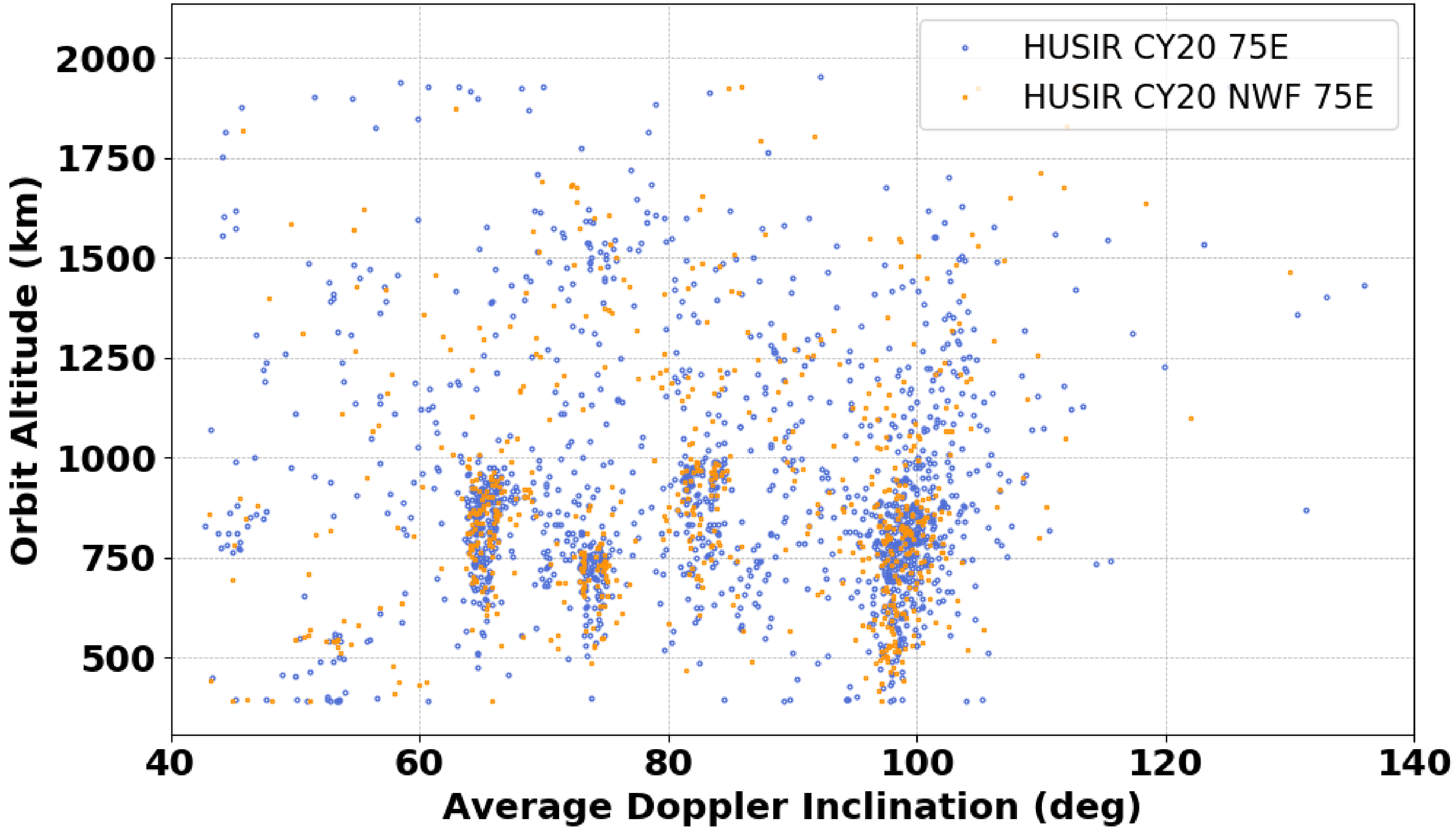
# Altitude vs. Inclination, 2018



# Altitude vs. Inclination, 2019

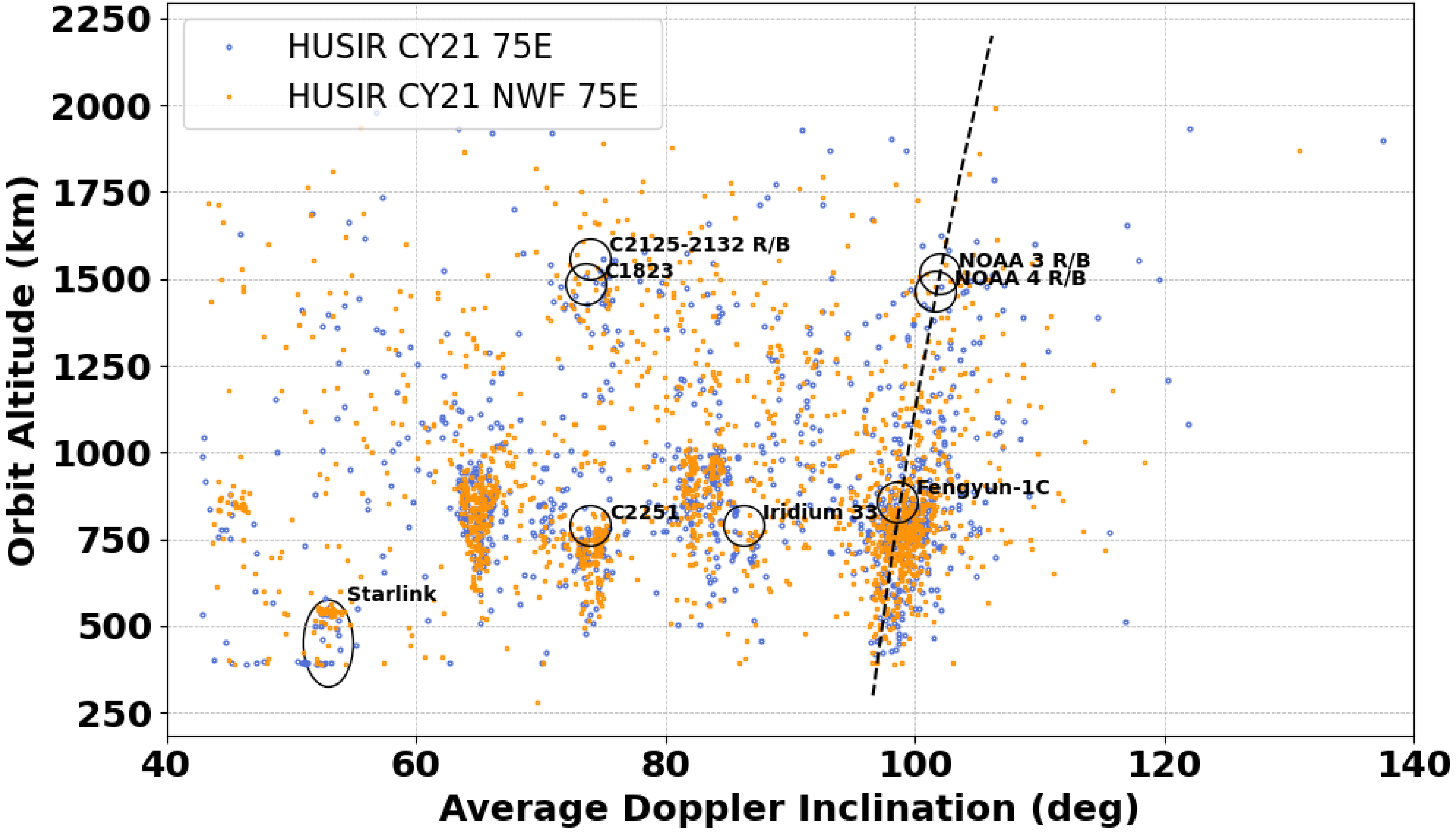


# Altitude vs. Inclination, 2020

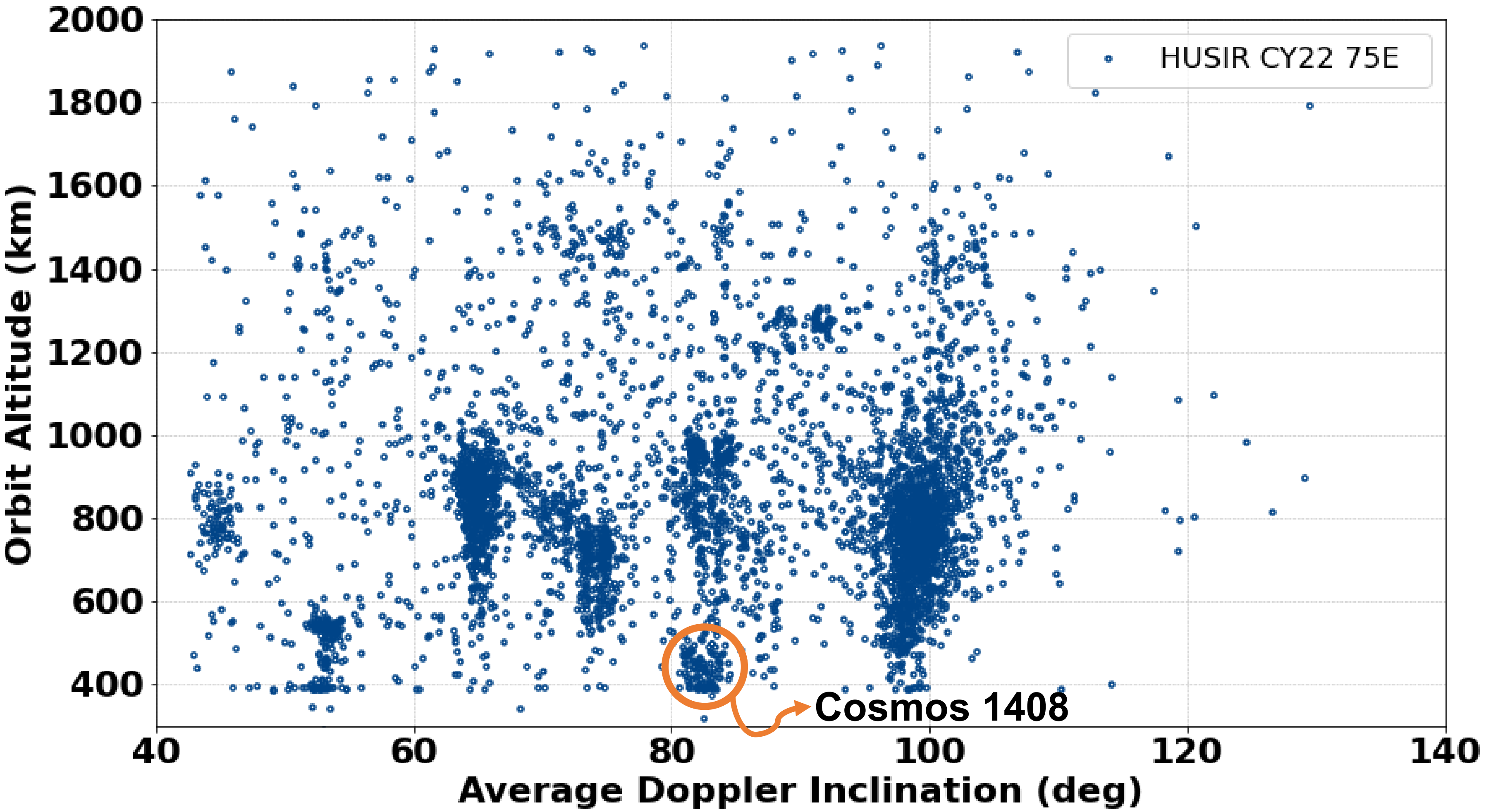



In 2020, we began experimenting with using 10.1 GHz instead of 10 GHz to minimize RFI

# Altitude vs. Inclination, 2021

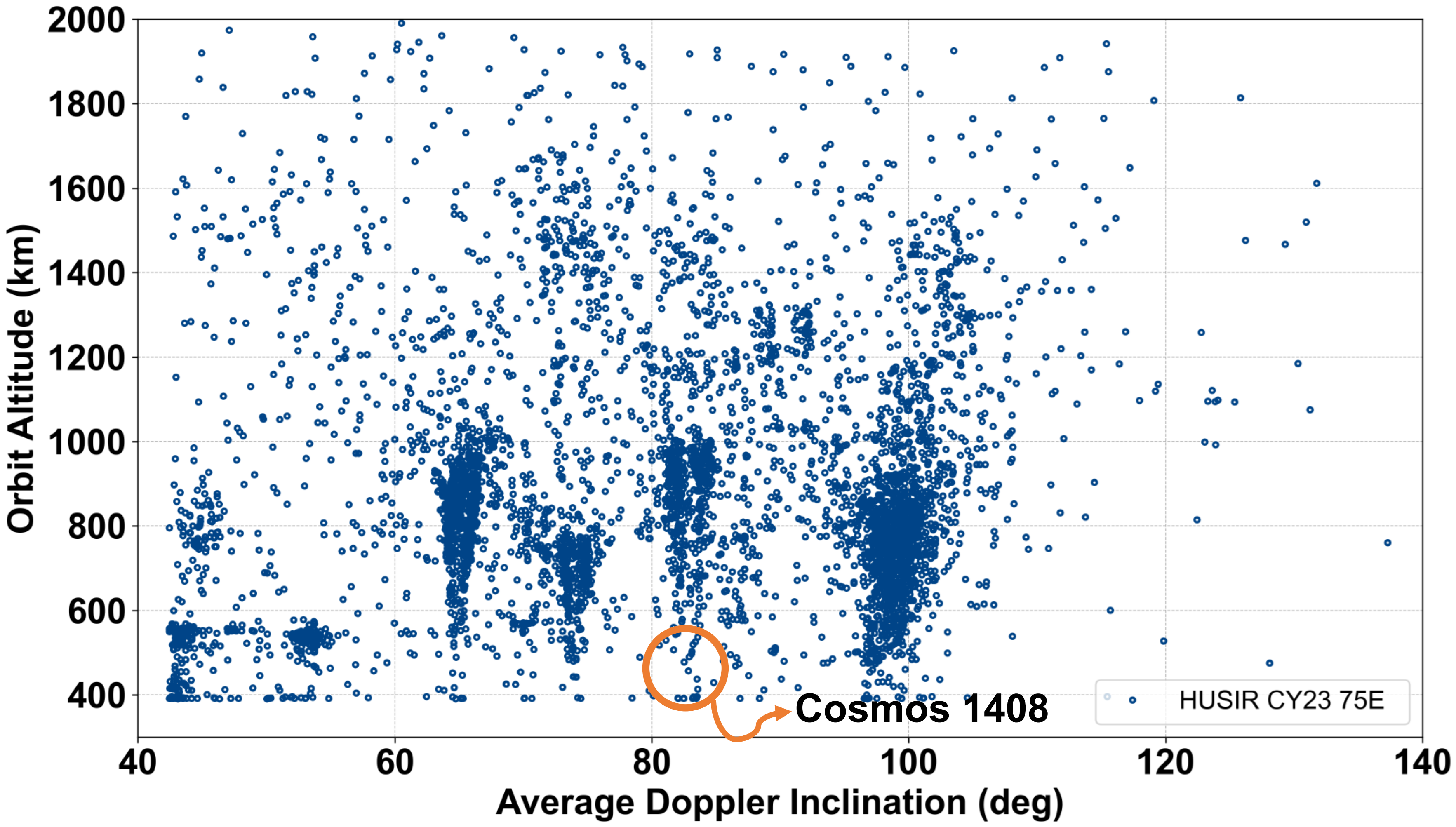


# Altitude vs. Inclination, 2022

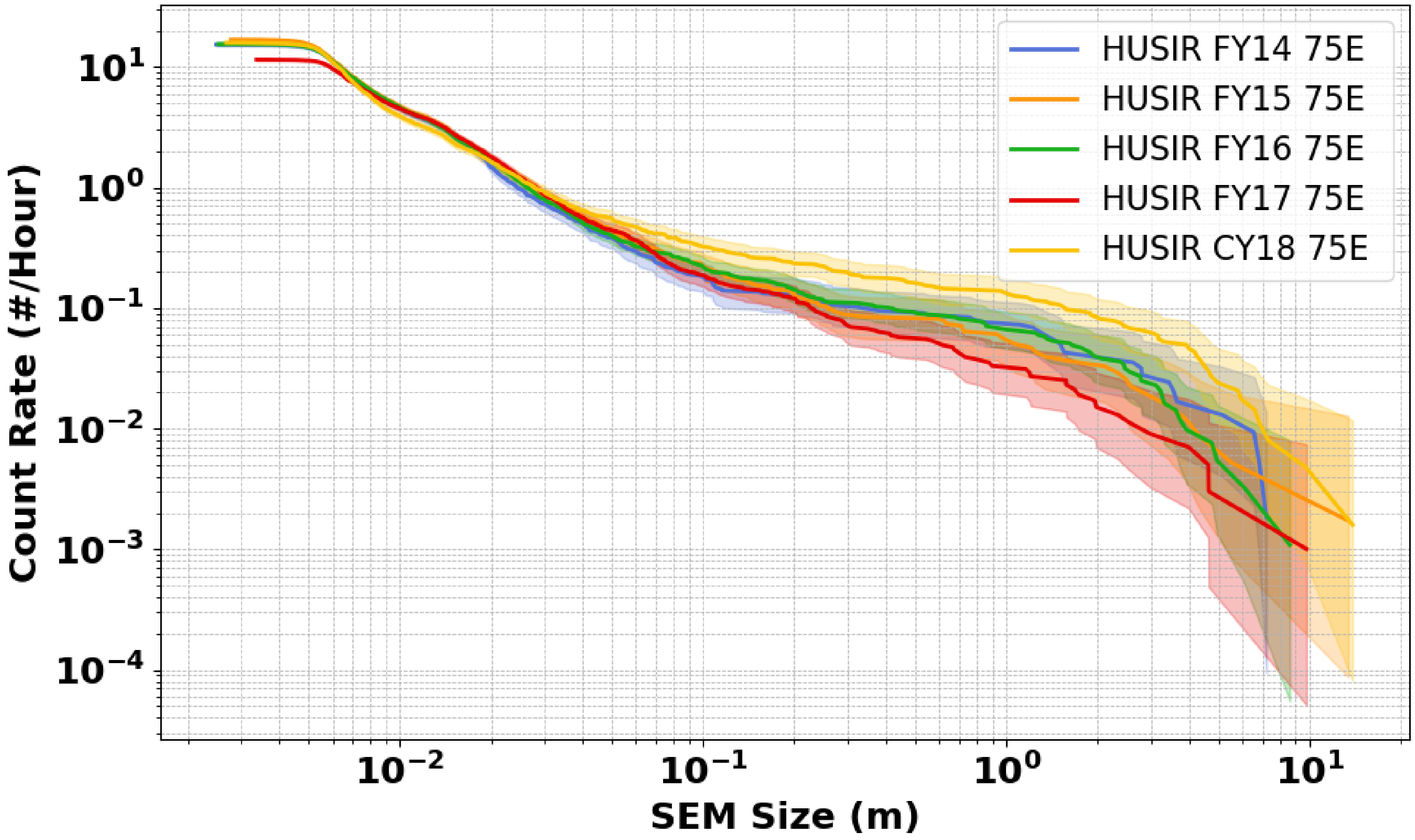



Cosmos 1408 was the target of the Russian ASAT test in November 2021

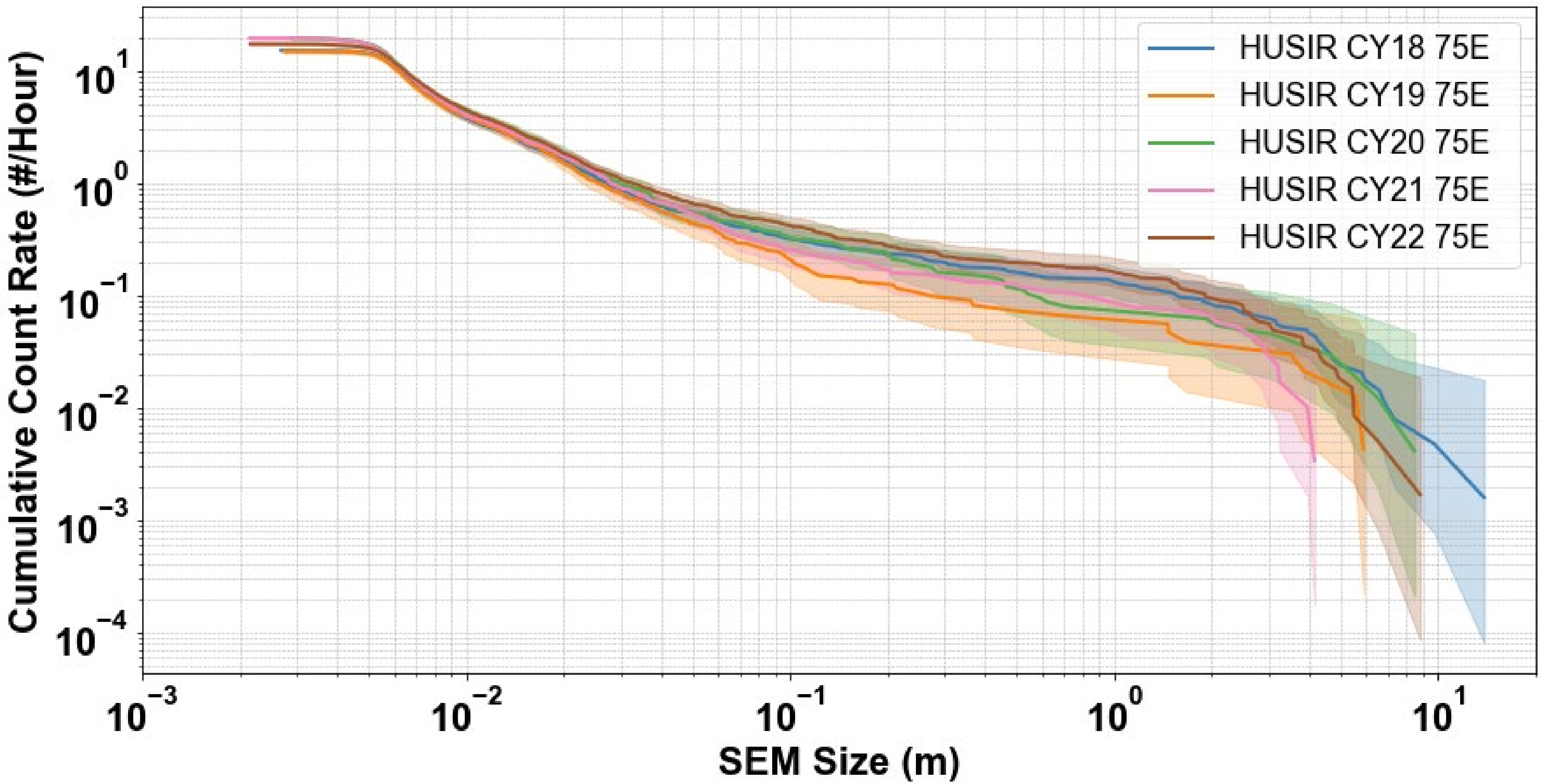
# Altitude vs. Inclination, 2023



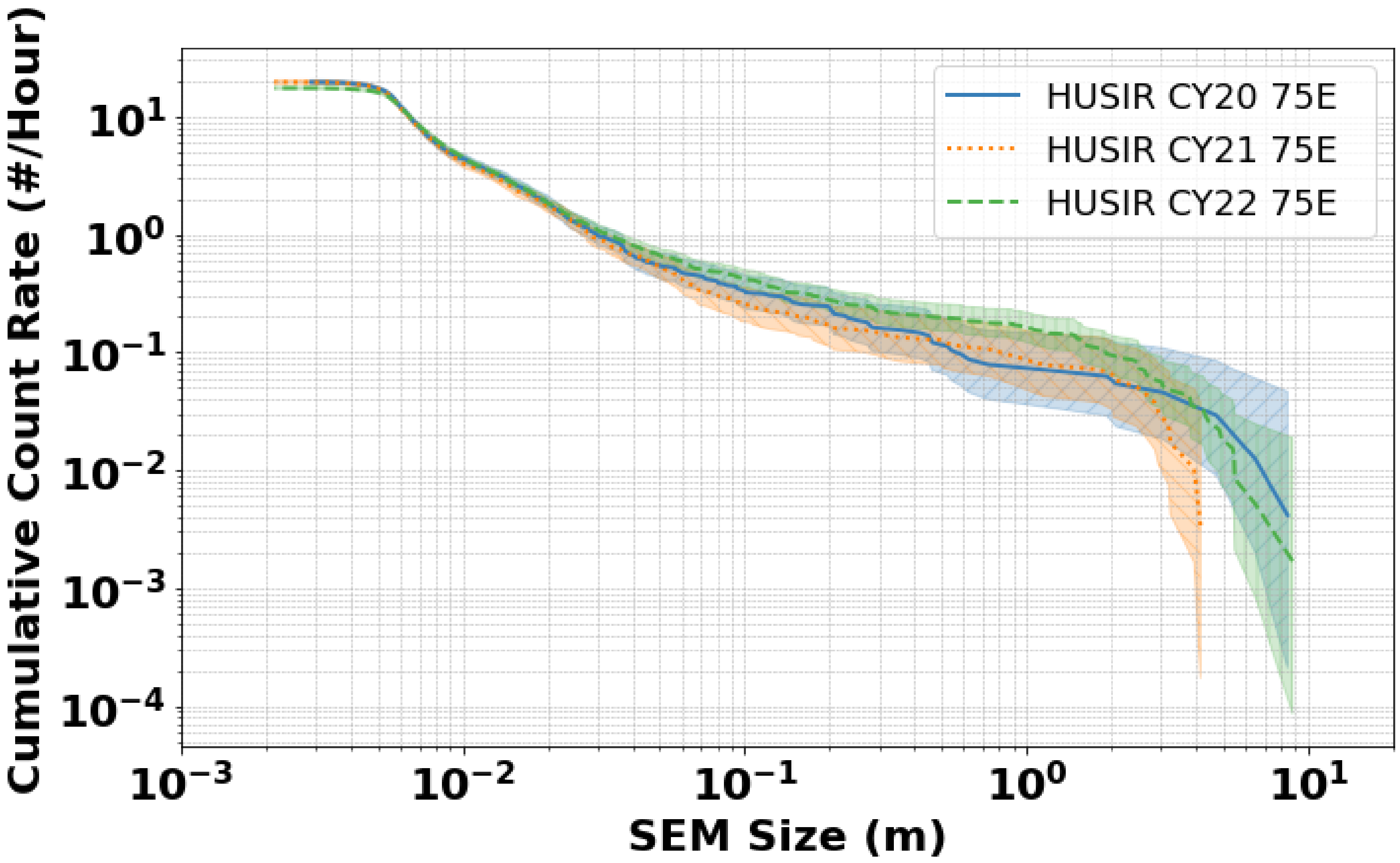
# Count Rates over Time, HUSIR 75E



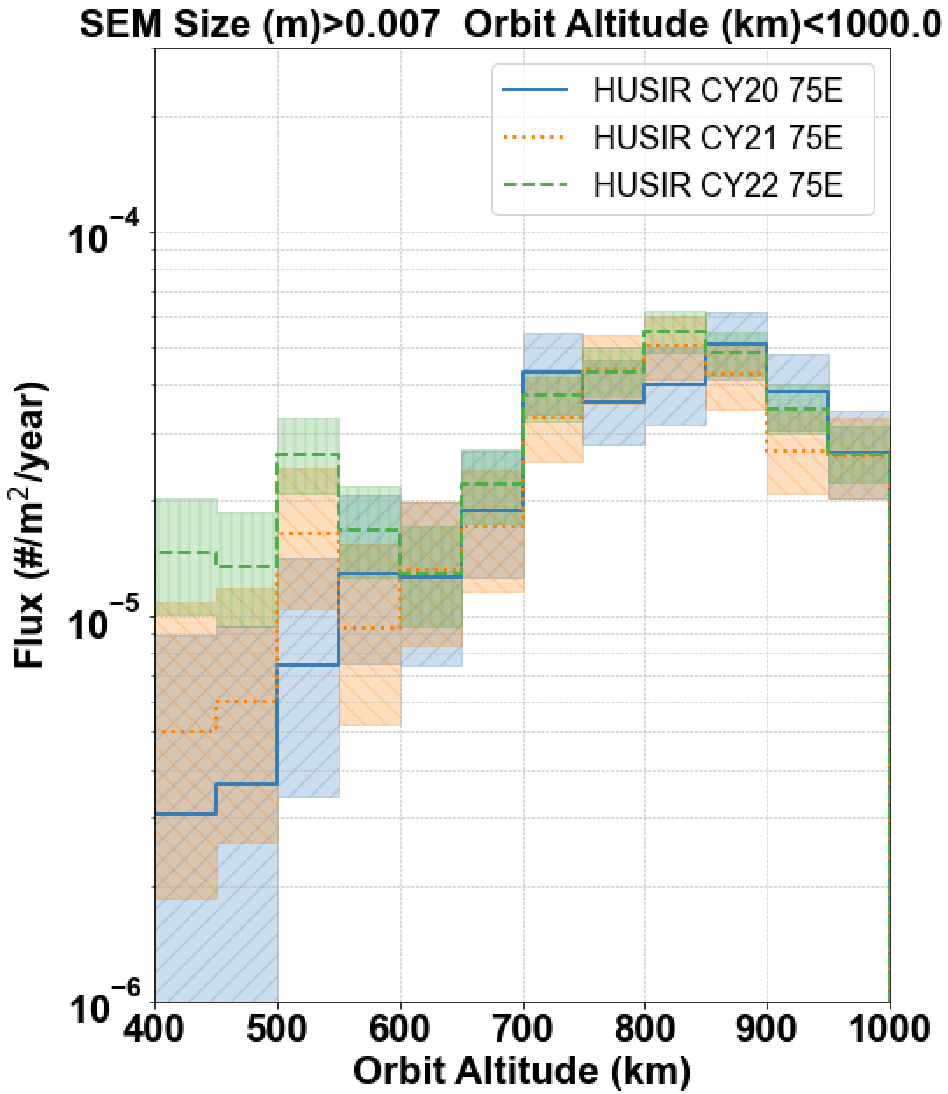
# Count Rates over Time, HUSIR 75E (continued)

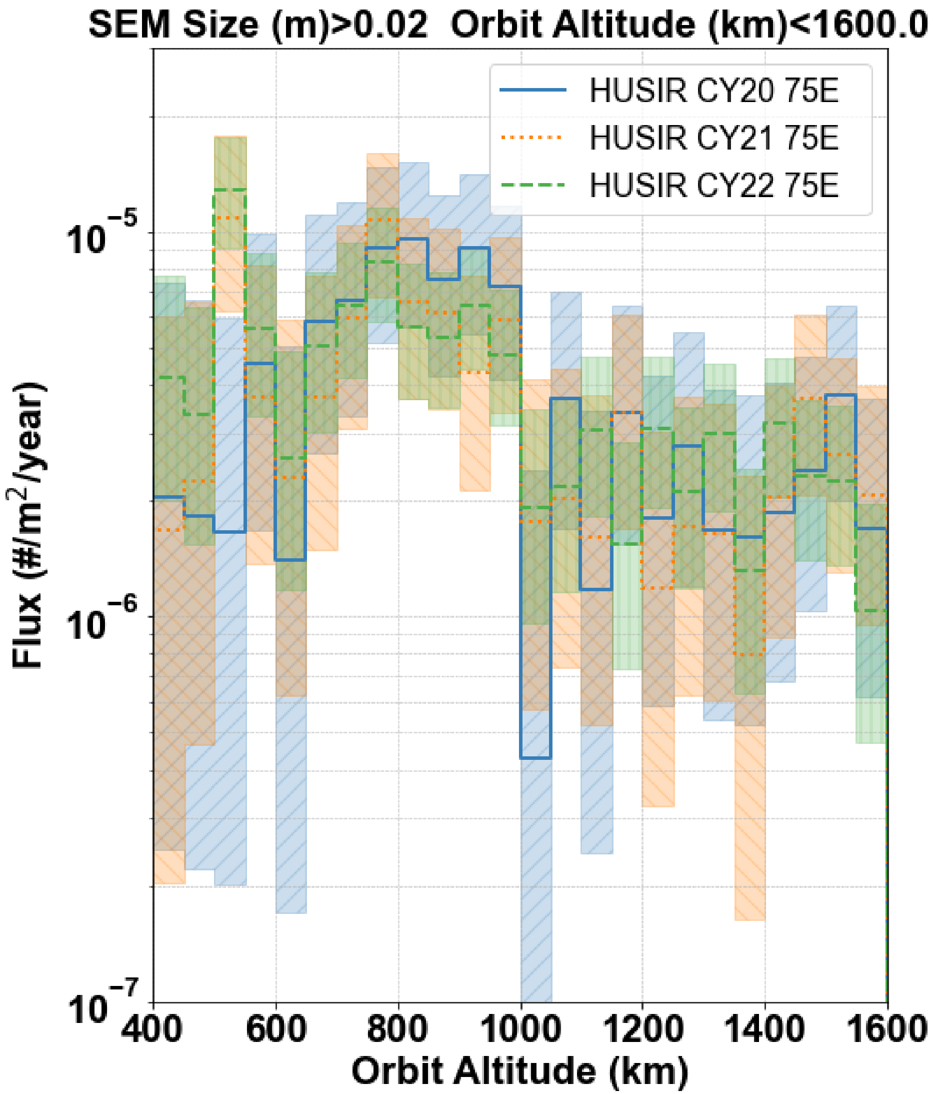


# Count Rate vs. Size, 2020-2022

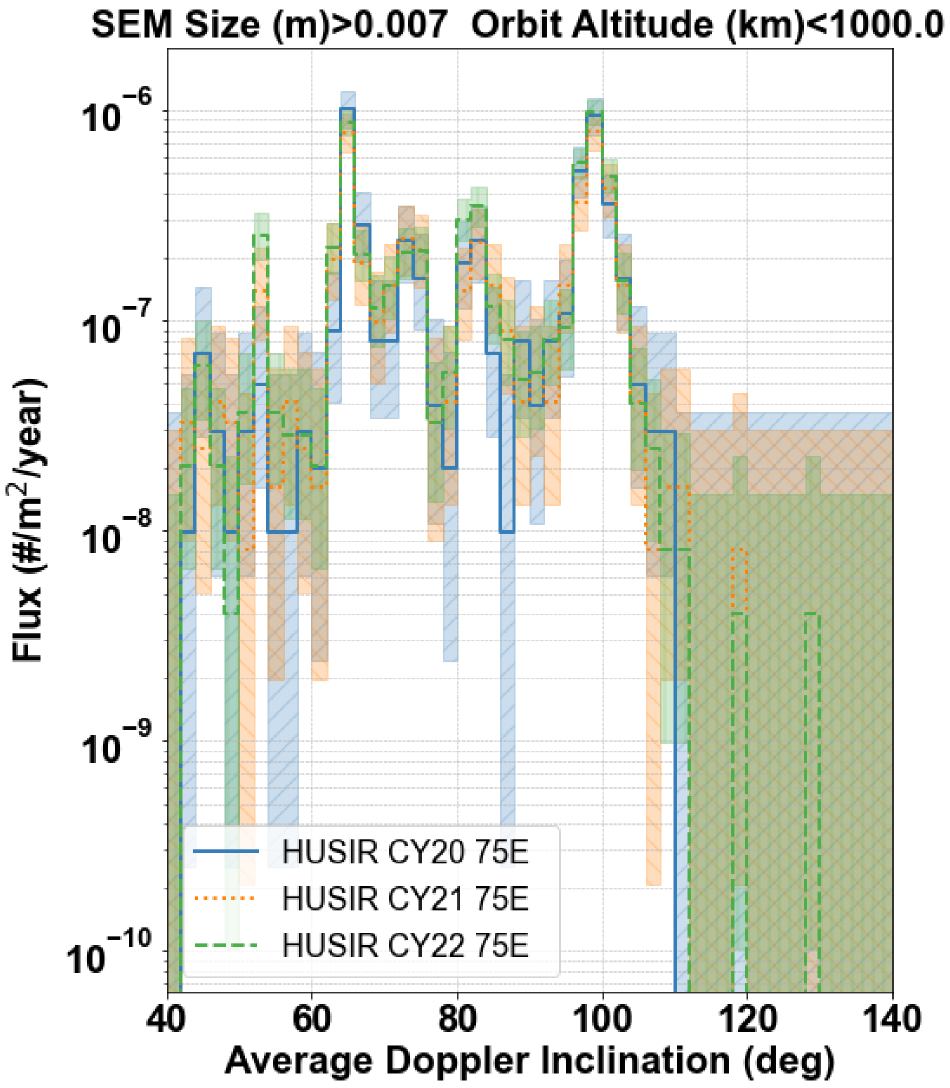


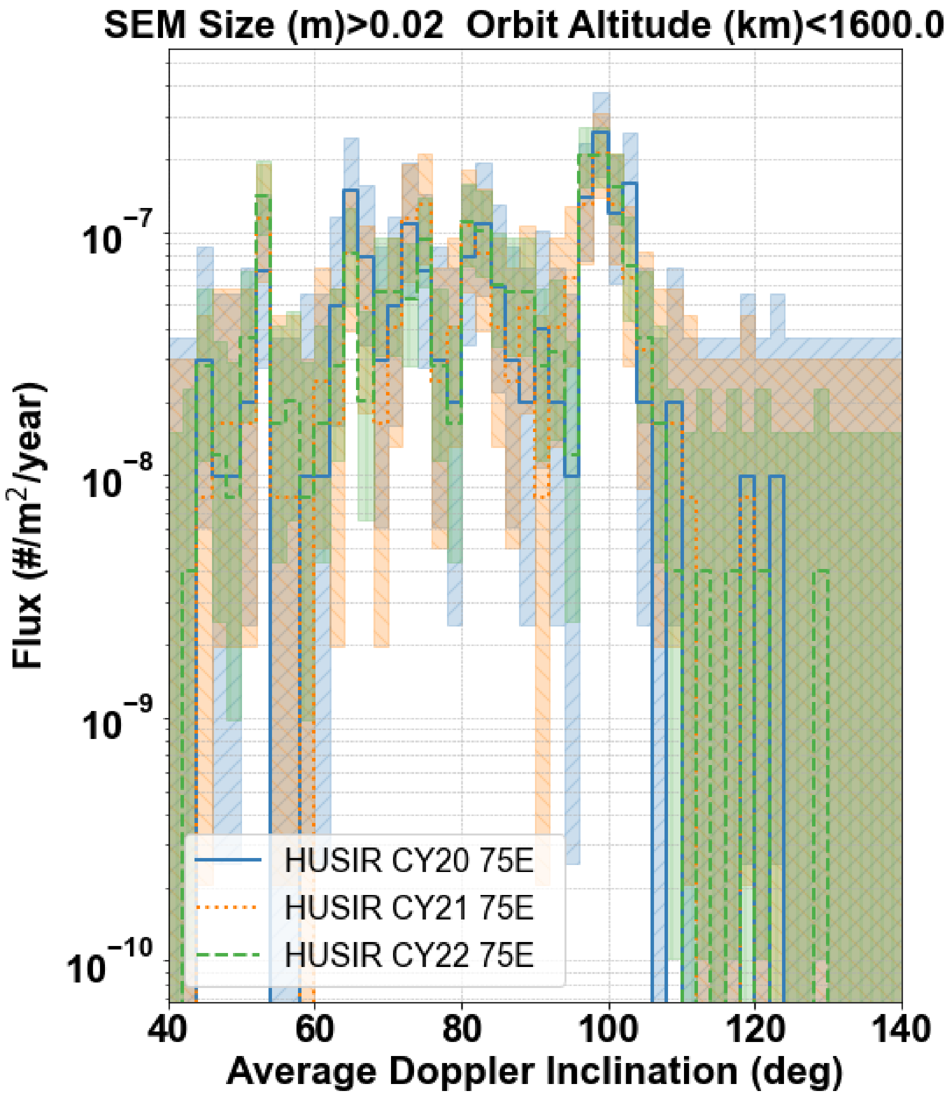
# Flux vs. Altitude



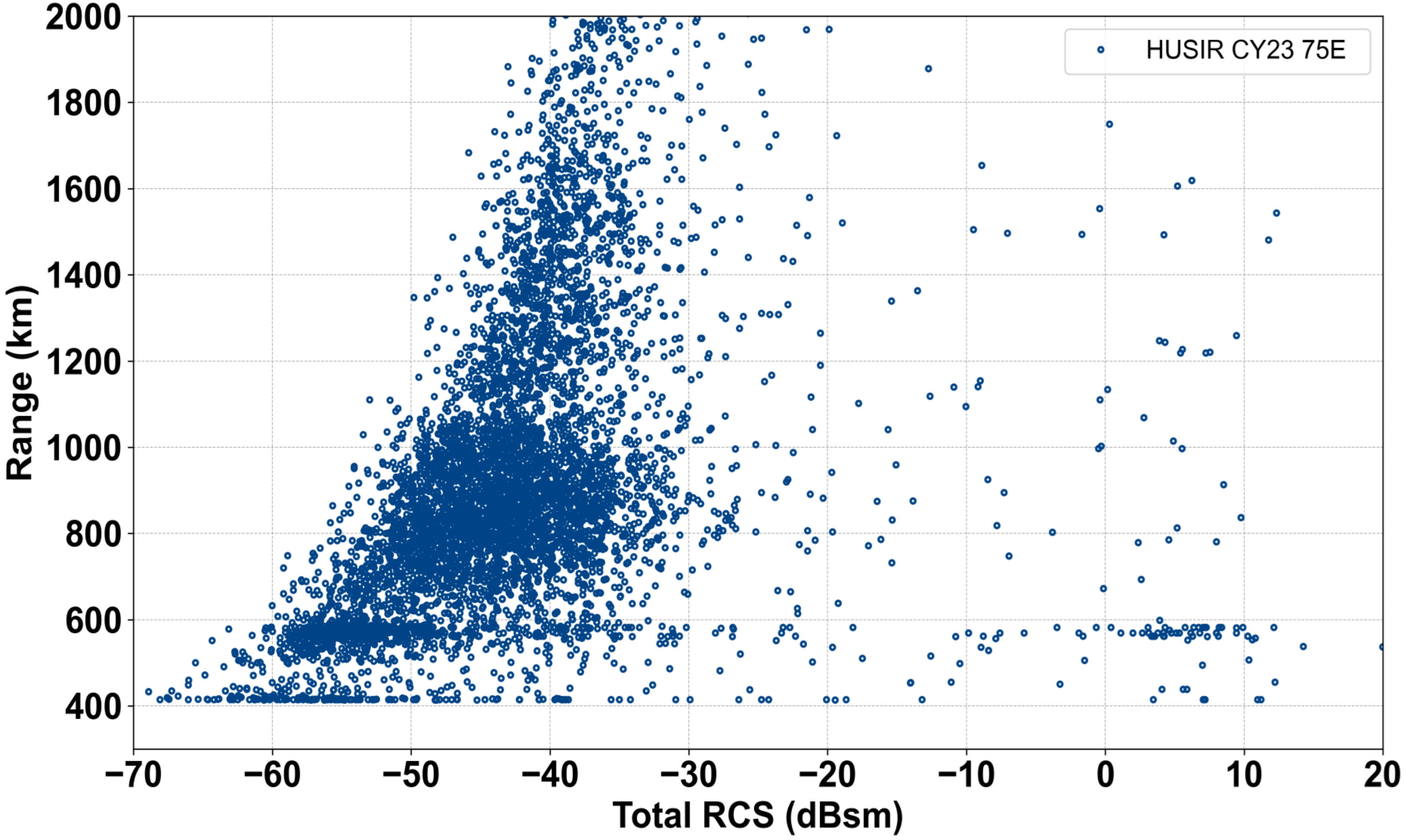



# Flux vs. Inclination

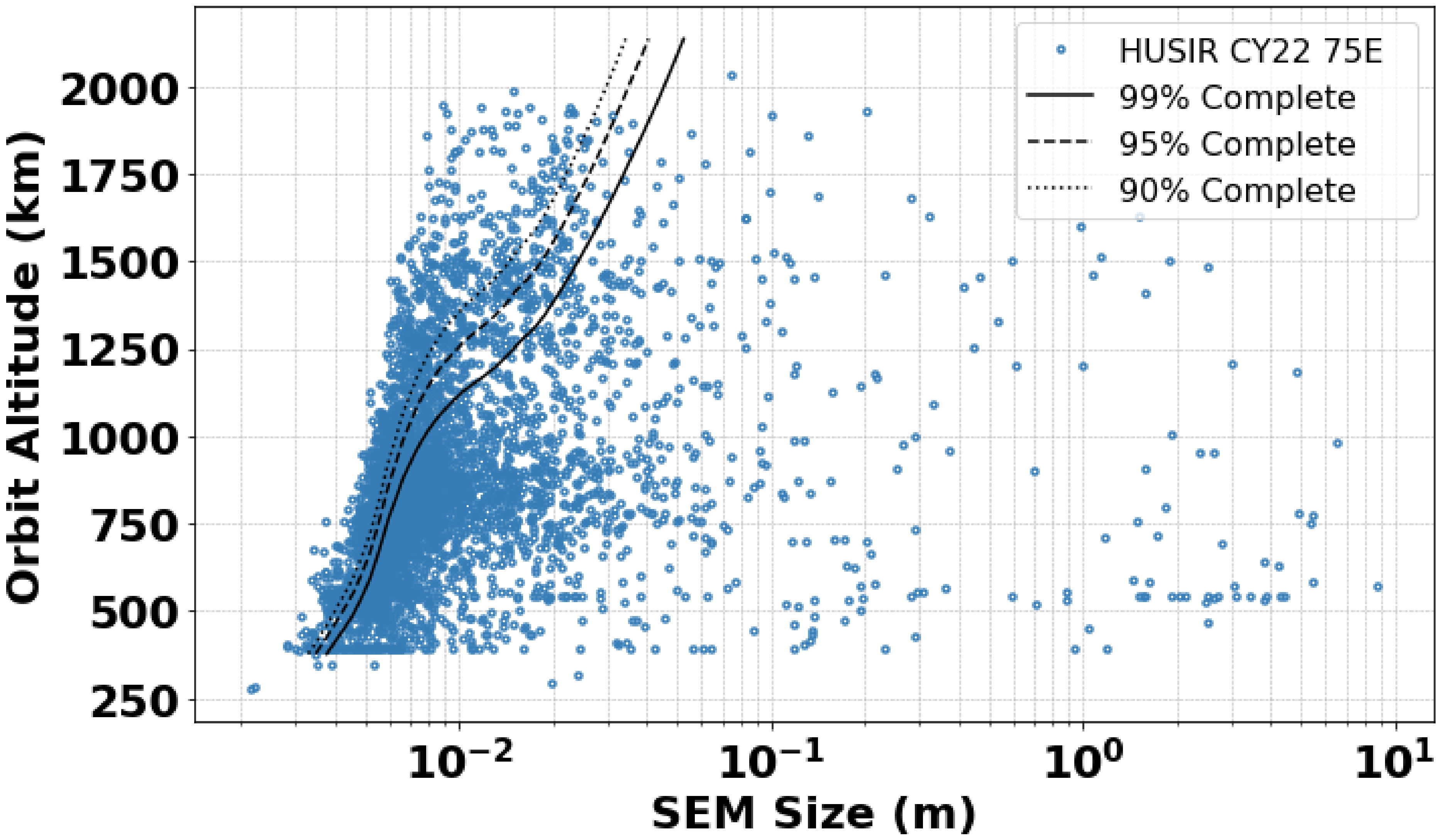


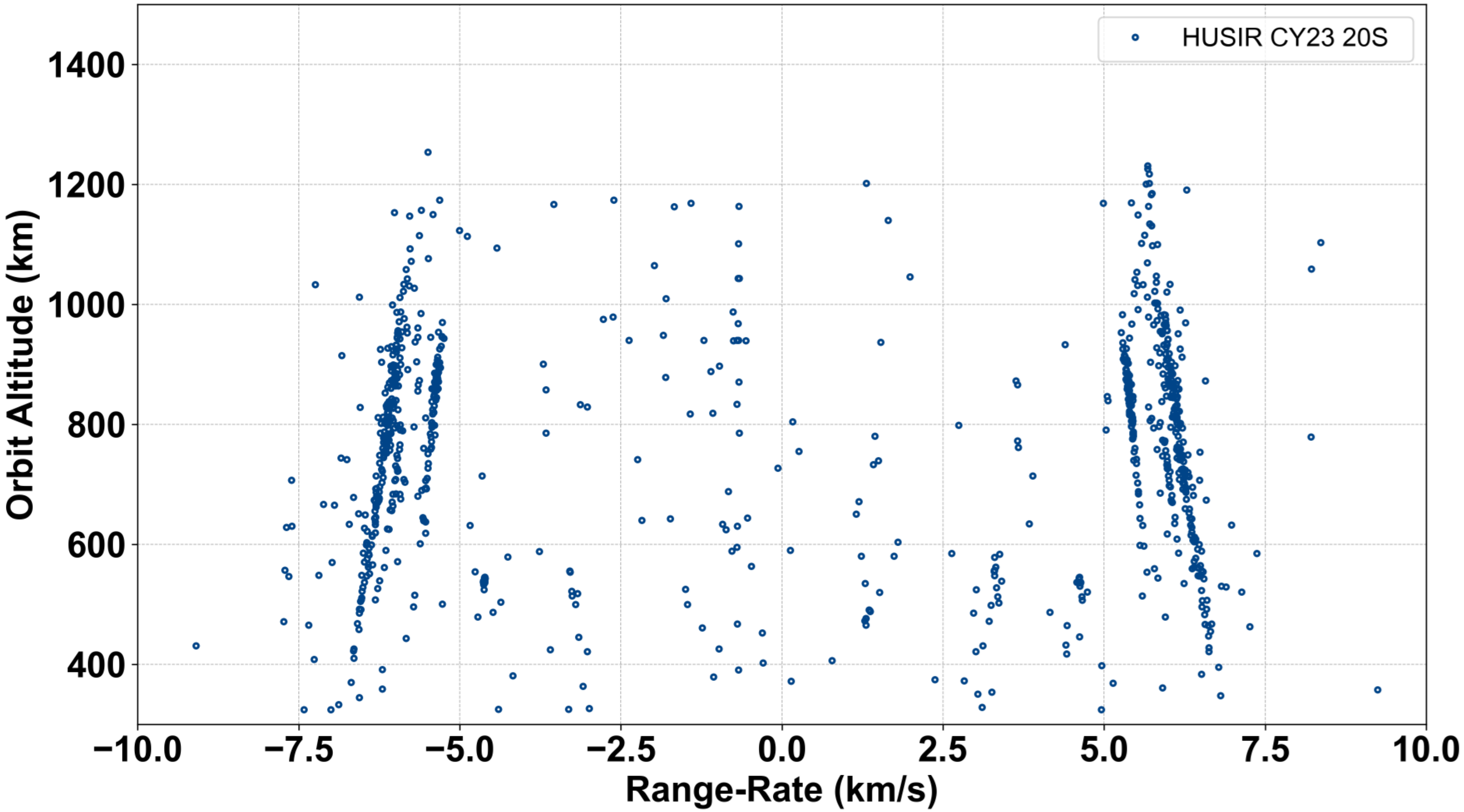
# Range vs. RCS, HUSIR 75E



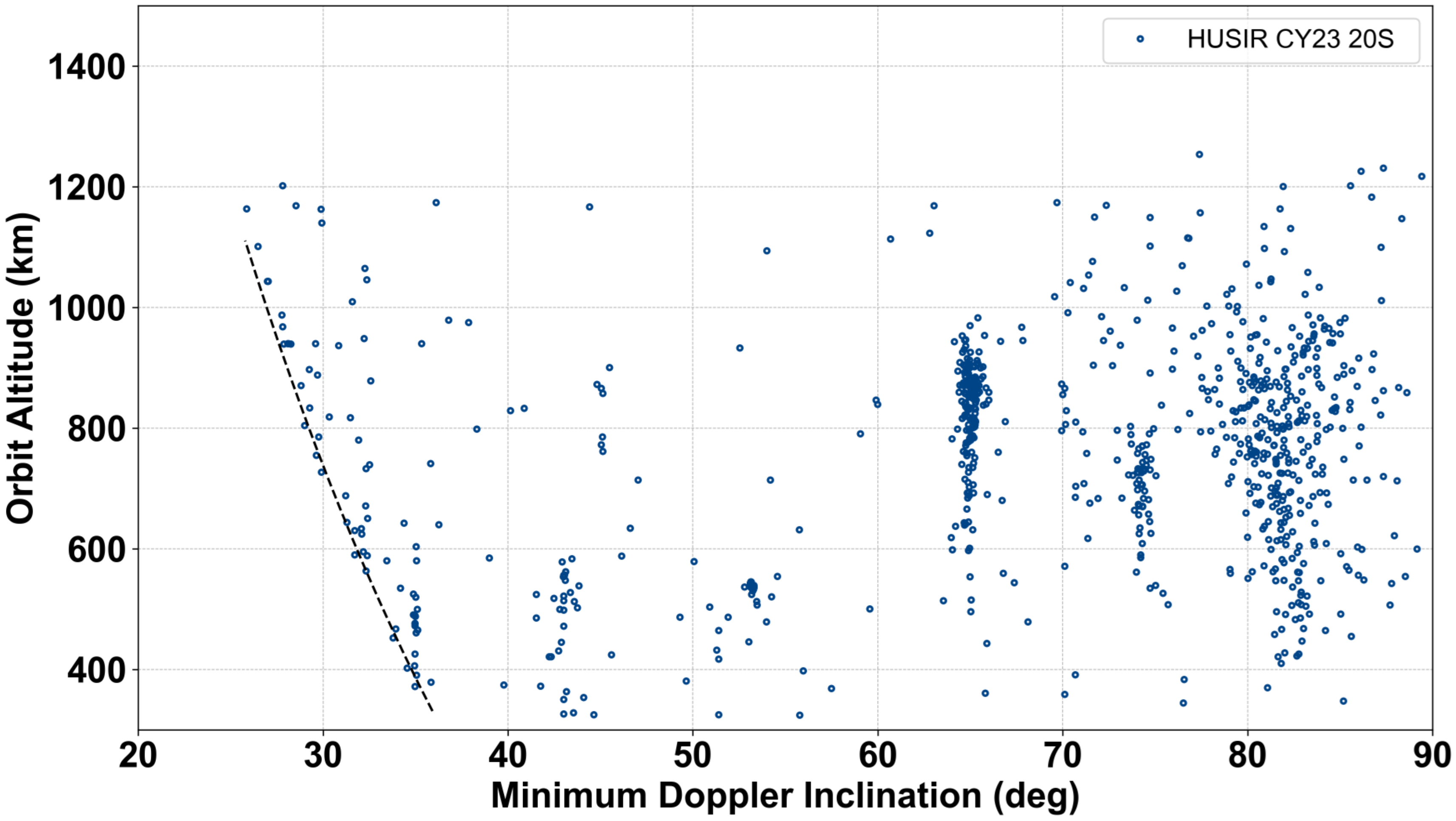
# Altitude vs. Size, HUSIR 75E



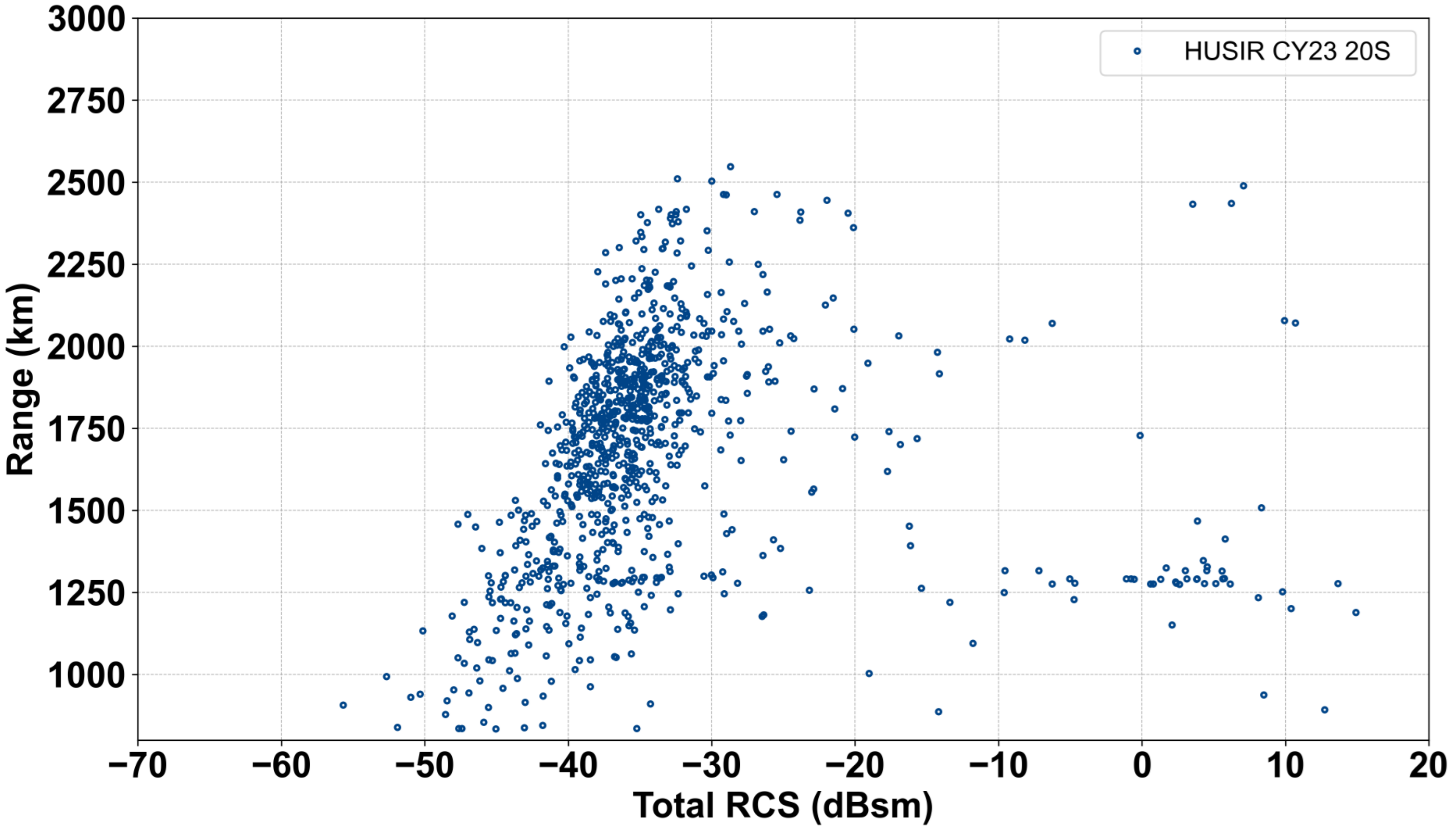
# Range vs. Range-Rate, HUSIR 20S



# Altitude vs. Inclination, HUSIR 20S

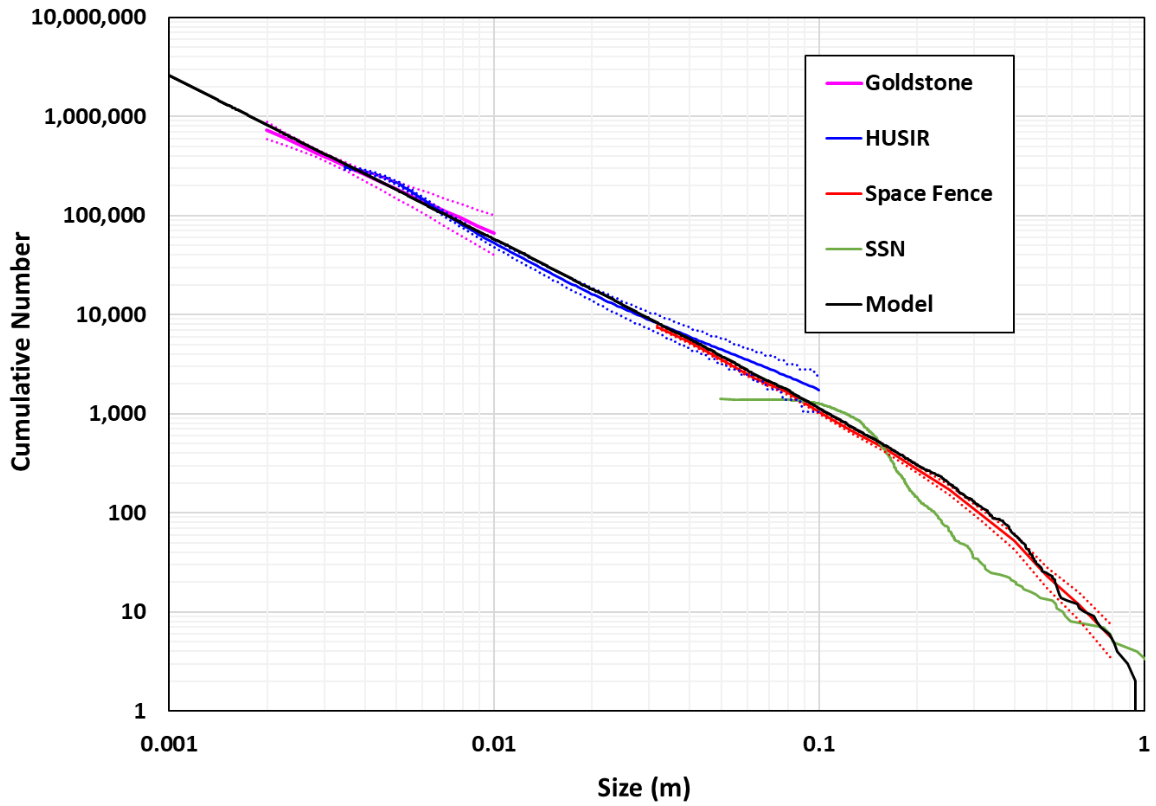


# Range vs. RCS, HUSIR 20S



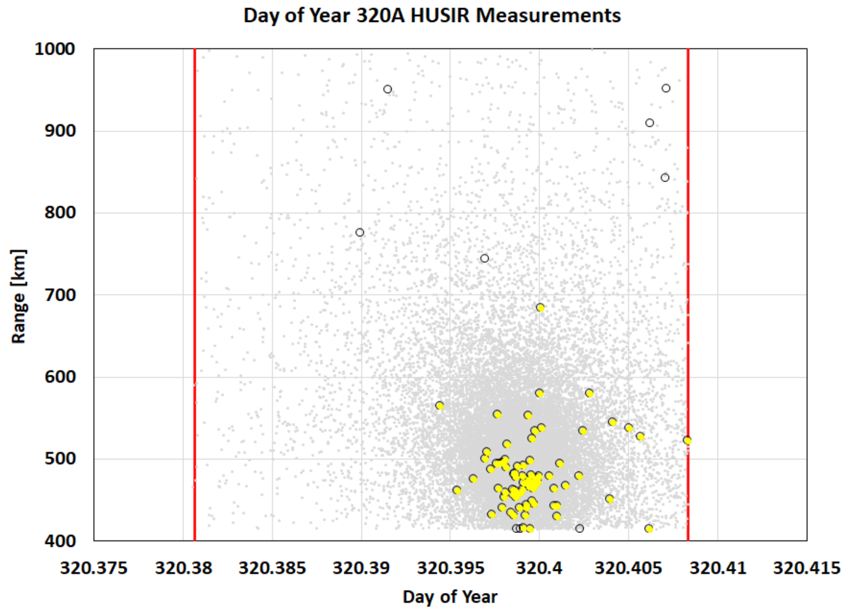
# Special Observations – Cosmos 1408

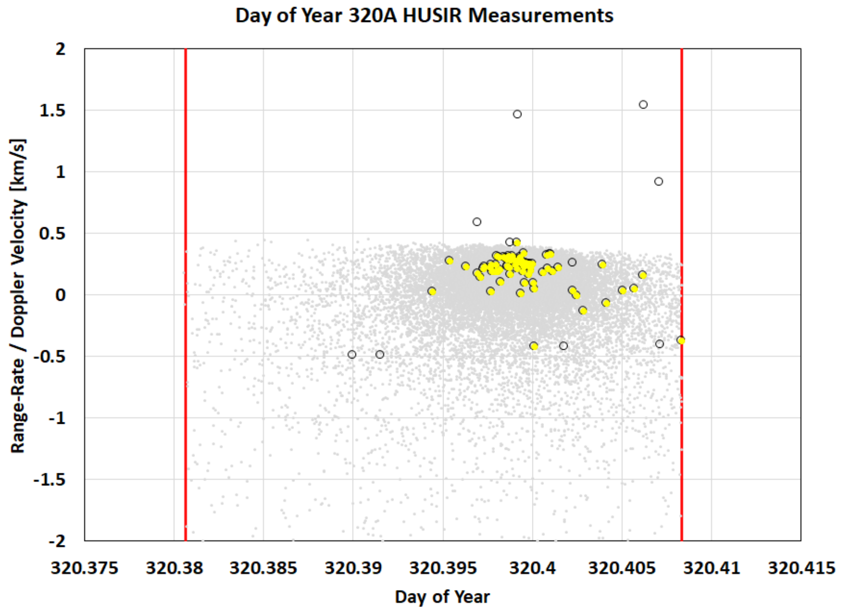
- HUSIR and Goldstone are also used for special breakup observations
- Following the ASAT test conducted by the Russian Federation on Cosmos 1408 in November 2021, the ODPO partnered with MIT/LL and NASA JPL to collect special radar measurement data on small Cosmos 1408 fragments using HUSIR and Goldstone
- 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

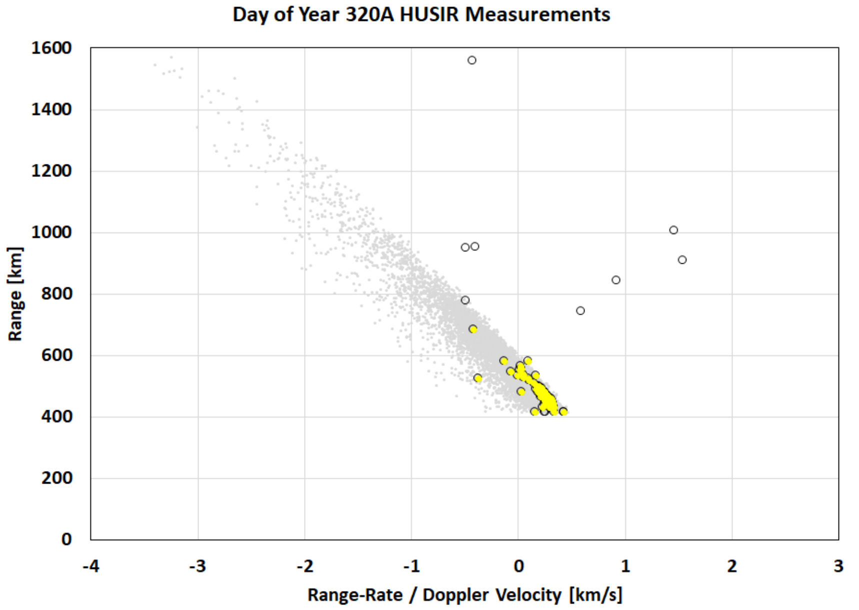


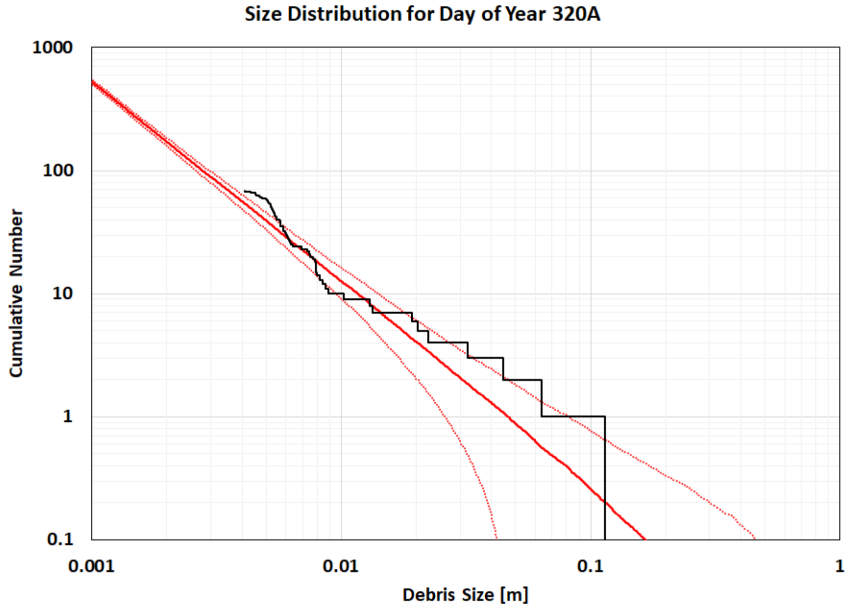

Cumulative size distribution of the Cosmos 1408 fragments based on special radar measurement data - the black line is the NASA SSBM prediction

# Special Cosmos-1408 Breakup Cloud Observation Example

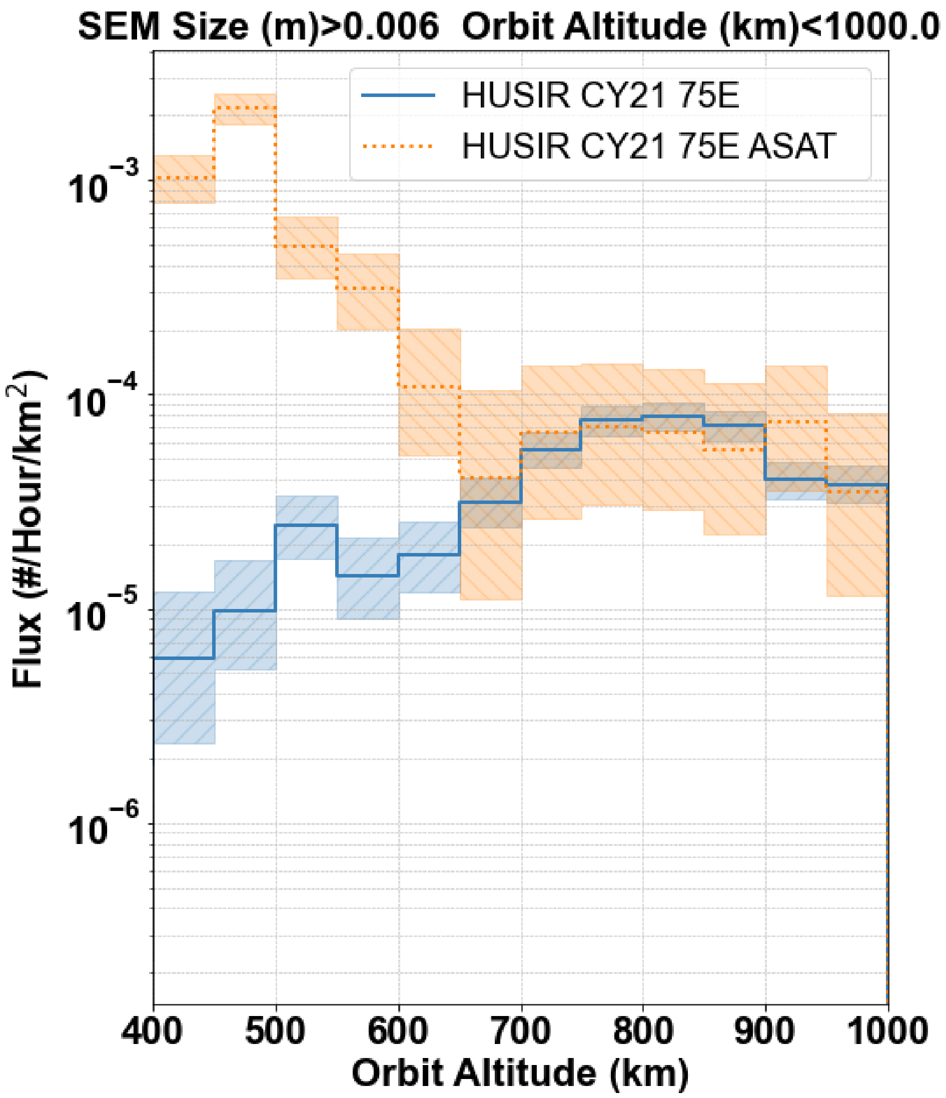


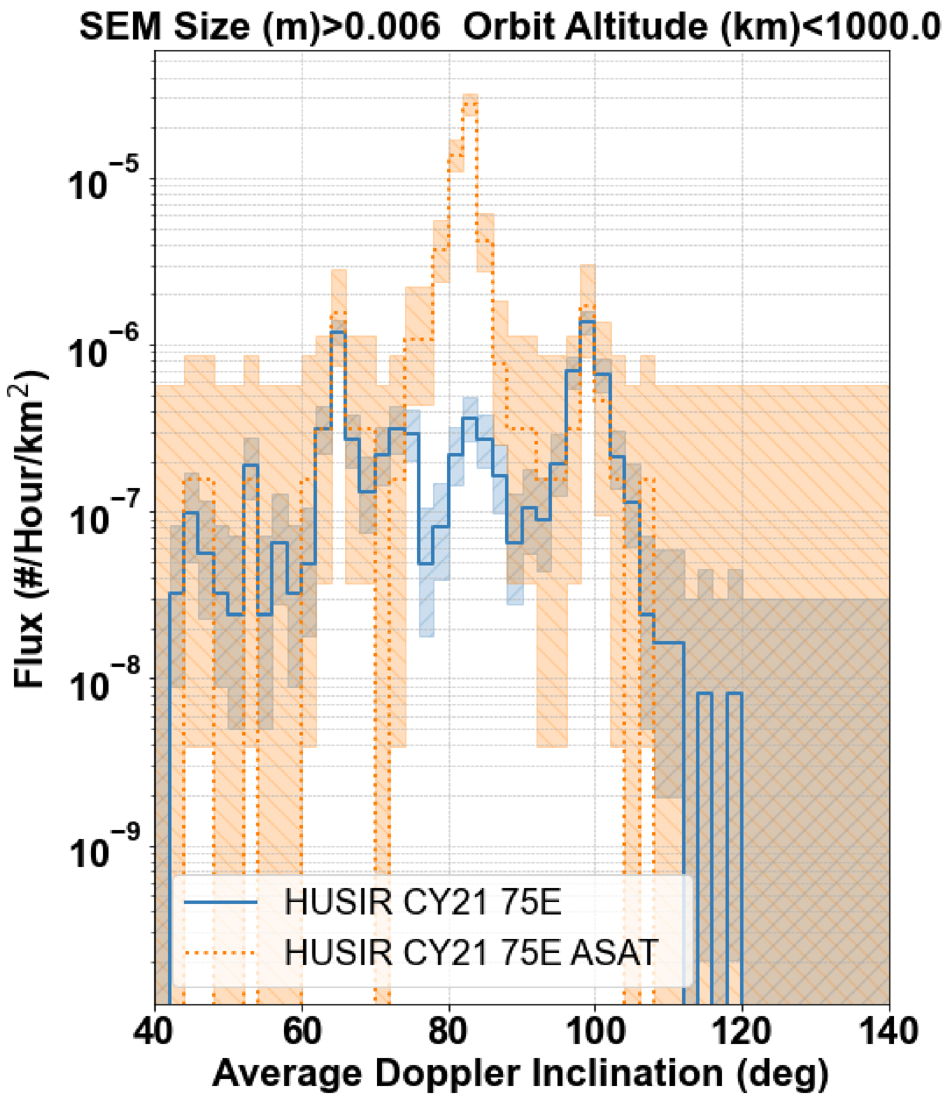



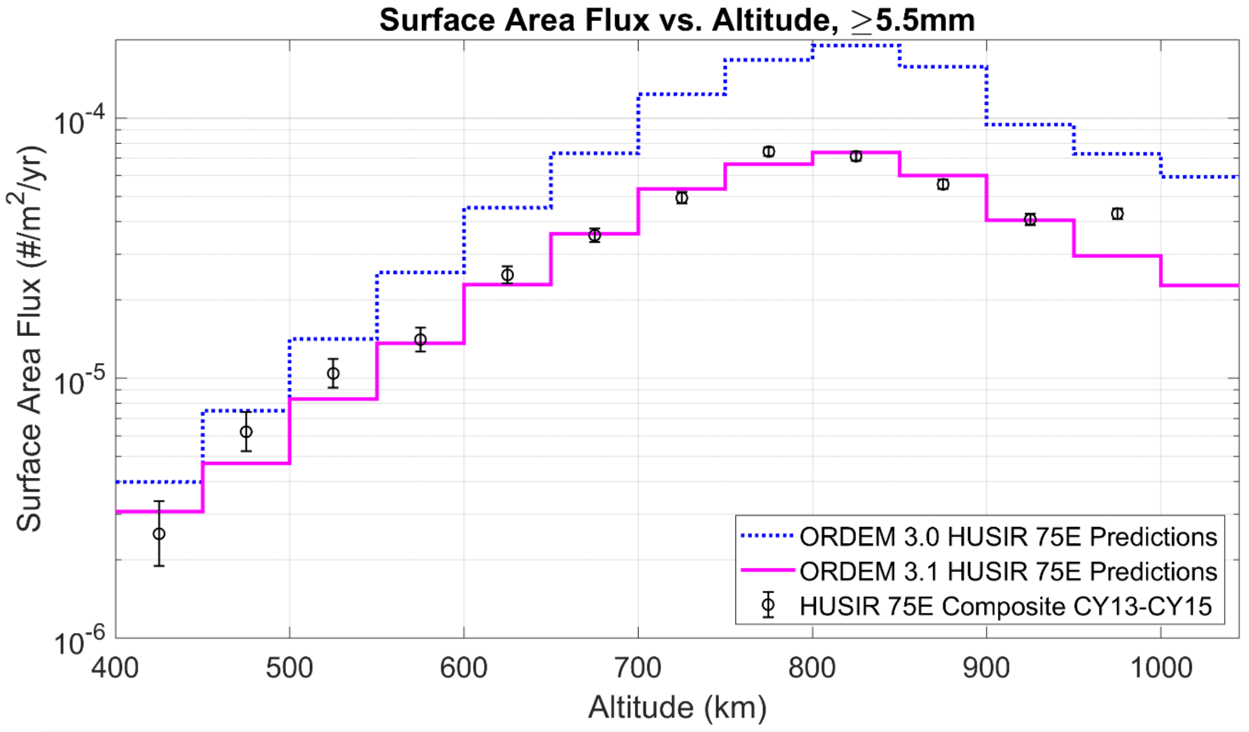
# Flux vs. Altitude, Cosmos 1408

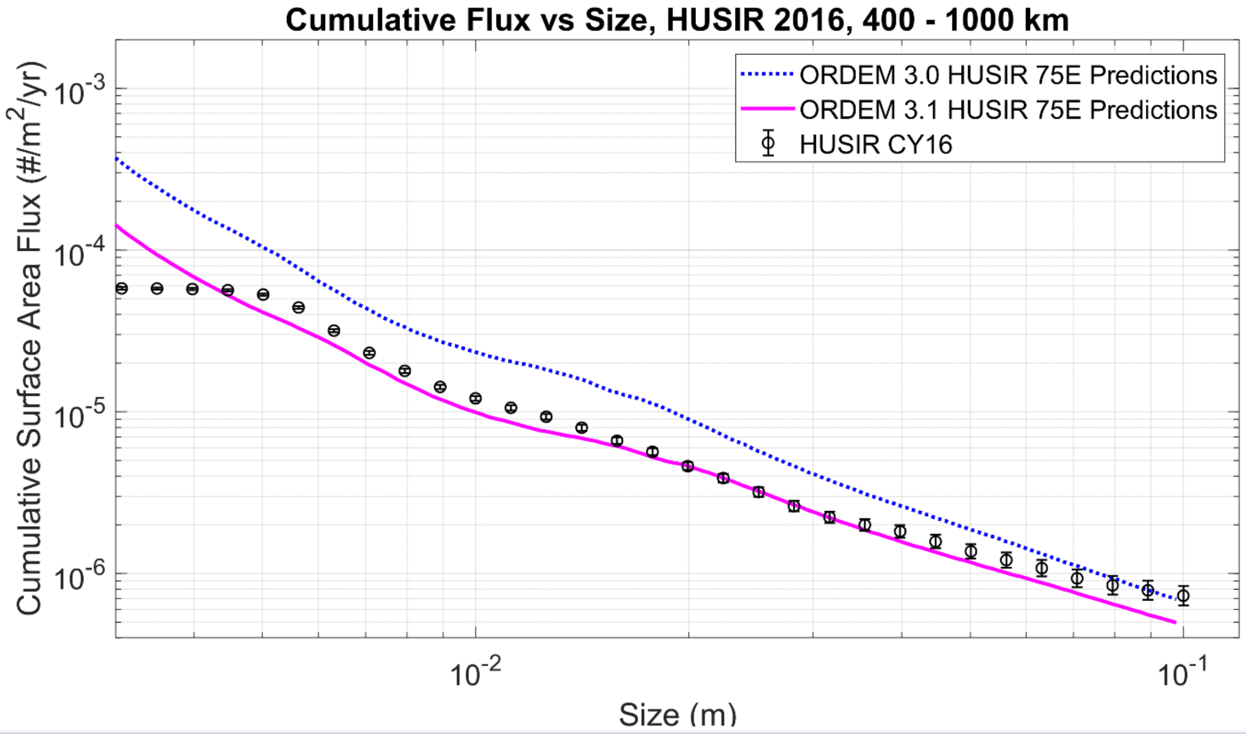


# Developing OD Models

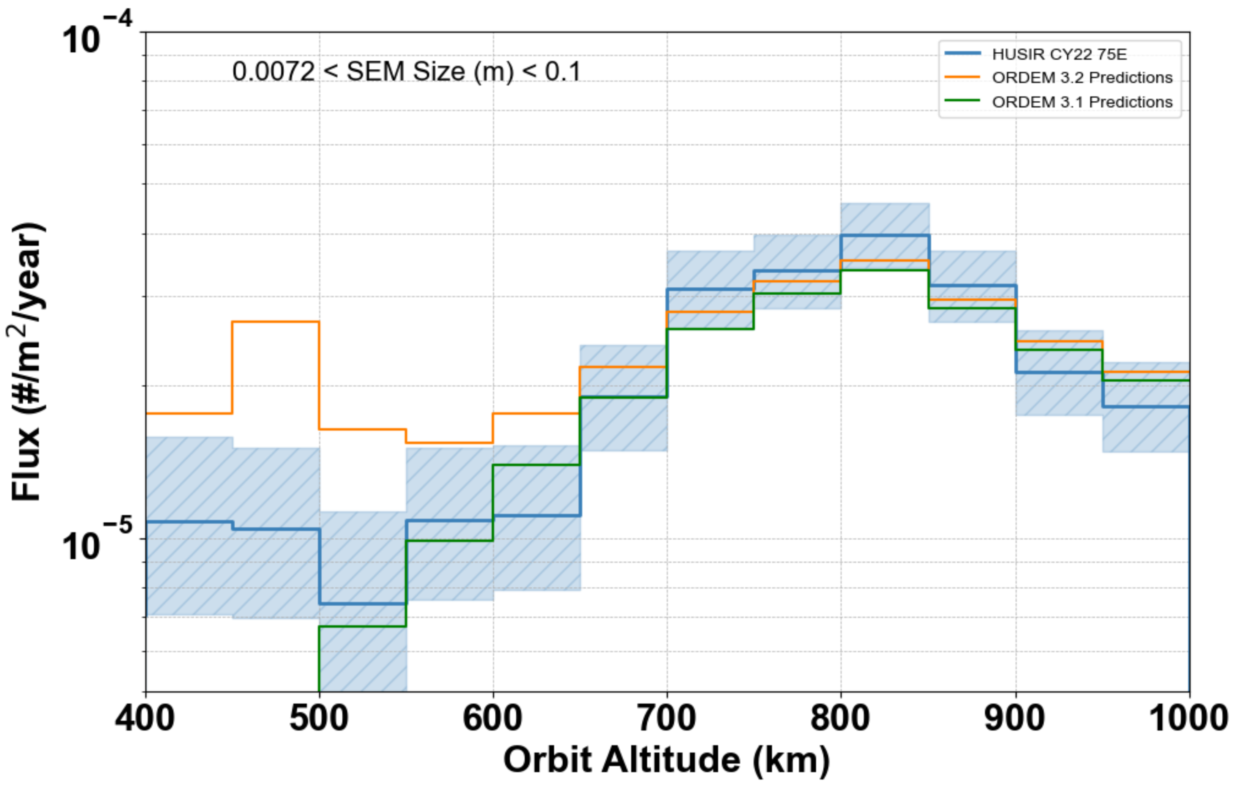
- **HUSIR data is used to scale initial model populations for building and validating the Orbital Debris Engineering Model (ORDEM)**

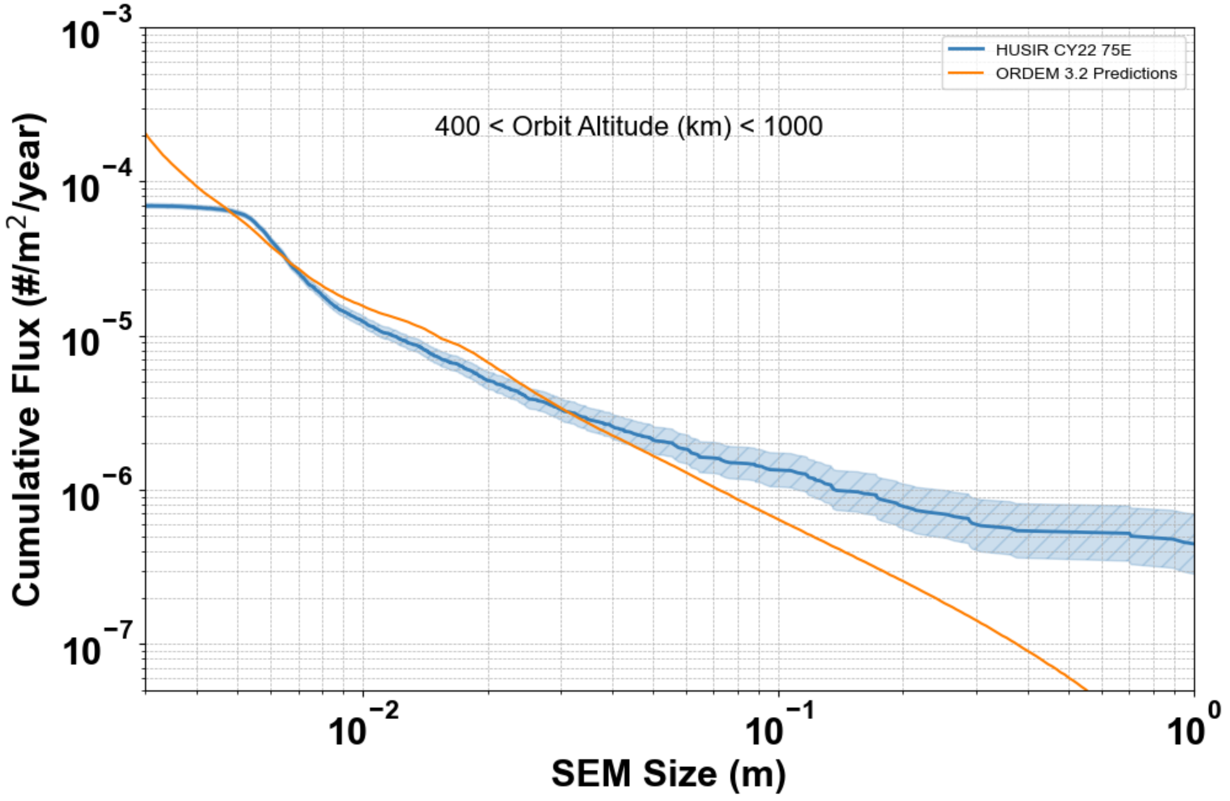


# Developing OD Models

- **HUSIR data is used to empirically scale model populations for building and validating the Orbital Debris Engineering Model (ORDEM)**
- **Work is ongoing on the next generation ORDEM 4.0, and HUSIR data will play a very important part in creating that model debris population**



# Summary

- **The SSN catalog is the tip of the proverbial iceberg when it comes to monitoring OD**
  - HUSIR/Haystack has been used to discover sources of small debris not identified by the SSN
- **The number of debris fragments increases dramatically with decreasing size**
- **Sensors such as HUSIR are vital tools for creating and validating the NASA models used to make accurate risk assessment for crewed/uncrewed missions**
- **Such sensors can be used to measure "fresh" breakups and characterize their risk to operational spacecraft**
  - Data can be used to validate our breakup models
- **The environment is dynamic, and needs to be continually monitored for dramatic changes**