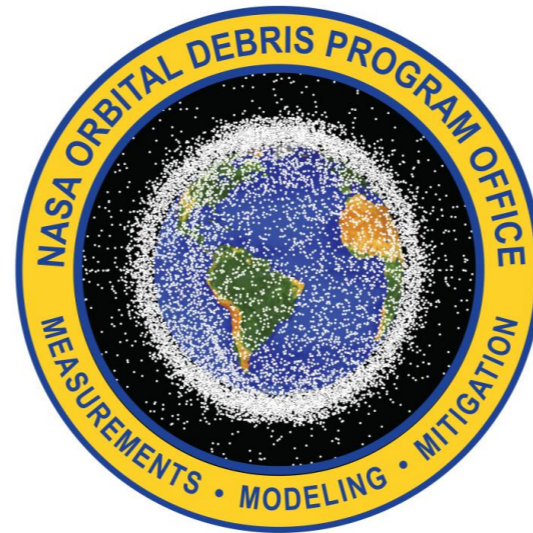


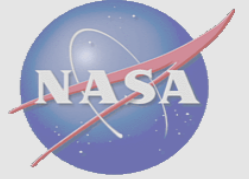


An Overview of Ground-based Radar and Optical Measurements Utilized by the NASA Orbital Debris Program Office



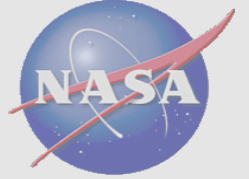
Dr. Alyssa Manis
Radar and Optical Measurements Lead
NASA Orbital Debris Program Office

4th Applied Space Environments Conference (ASEC2023)
11 October 2023



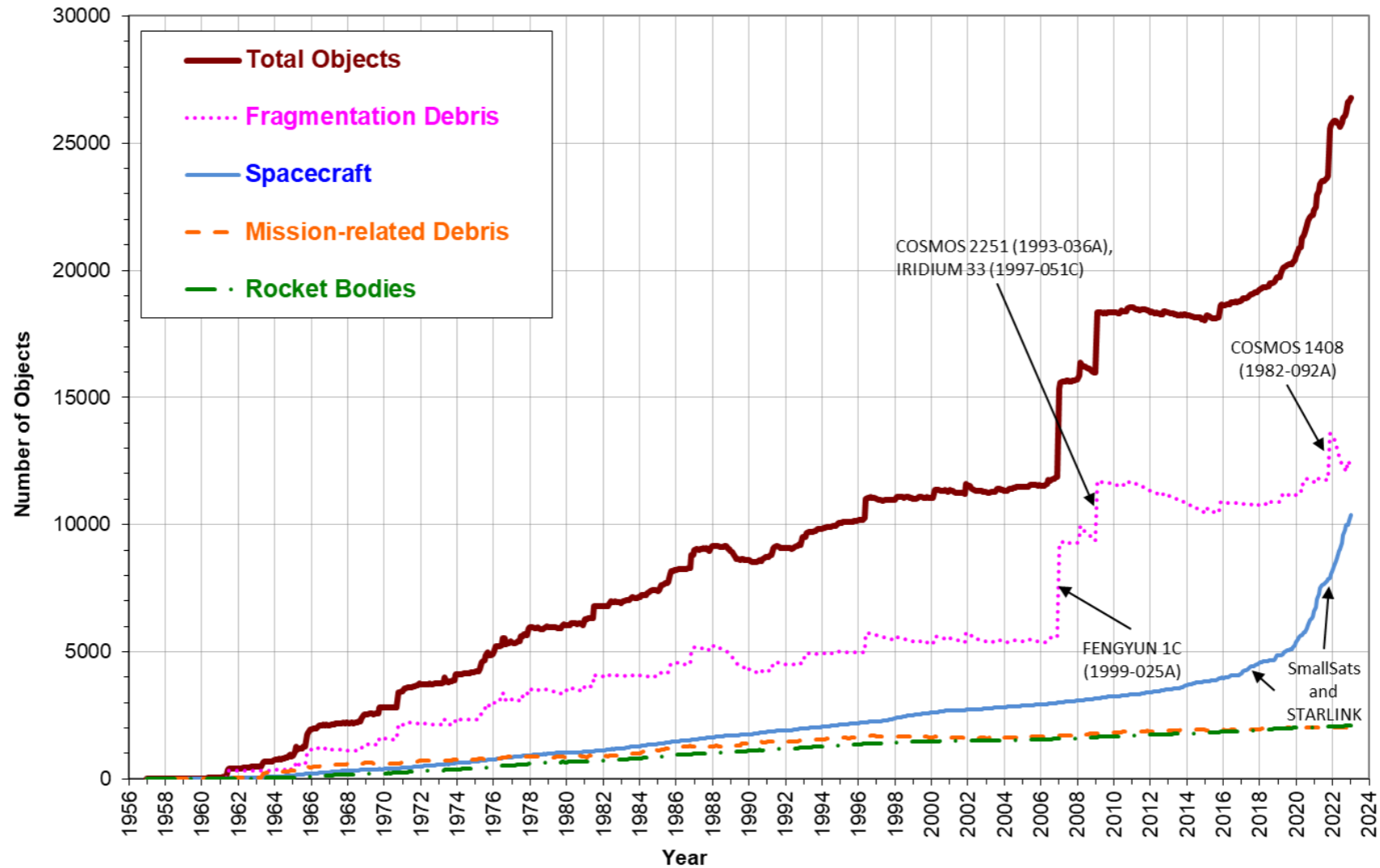
What is Orbital Debris?

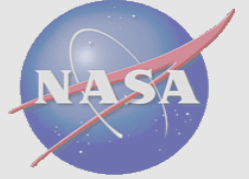
- **Any man-made object in Earth orbit that no longer serves a useful purpose**
 - All man-made objects in orbit are destined to become debris, in one way or another
 - Non-operational spacecraft
 - Derelict launch vehicle stages
 - Fragmentation and mission-related debris
 - Meteoroids are natural objects in orbit about the Sun (handled primarily by our colleagues at the Meteoroid Environment Office at Marshall Space Flight Center in Huntsville, Alabama)



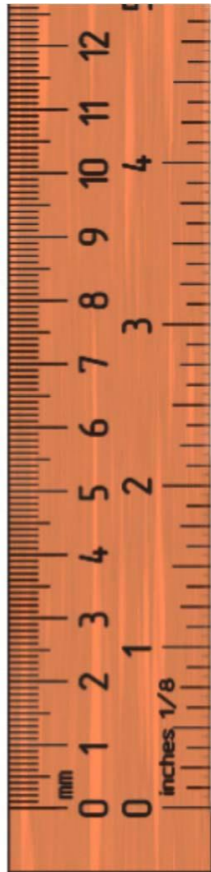
Growth of Cataloged Space Object Population

Monthly Effective Number of Objects in Earth Orbit by Object Type





How Much Junk Is Currently Up There?



**Softball size or larger (≥ 10 cm): ~23,000
(tracked by U.S. Combined Space Operations Center, CSpOC)**



Marble size or larger (≥ 1 cm): ~500,000

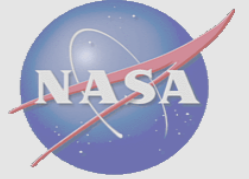


**Dot or larger (≥ 1 mm): >100,000,000
(a grain of salt)**



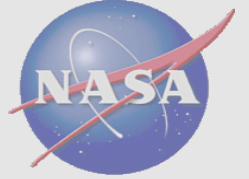
Statistically measured and modeled

- Due to high impact speed in space (~10 km/sec in LEO), even **sub-millimeter** debris pose a realistic threat to human spaceflight and robotic missions
 - 10 km/sec = 22,000 miles per hour (the speed of a bullet ~1,500 miles per hour)
- Total mass: >8000 tons LEO-to-GEO (~2700 tons in LEO)



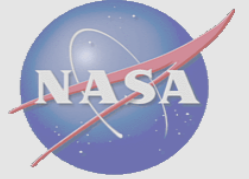
Characterizing Small, Untrackable Debris

- **ODPO uses specialized sensors capable of detecting small objects to develop, verify, and validate statistical models**
- **Sensors operate in “staring” mode to statistically estimate debris distributions in size, altitude, and orbit family**
 - Radar (objects $> \sim 3$ mm in LEO)
 - Optical telescopes (objects $> \sim 10$ cm in GEO)
 - Returned surfaces with damage (in situ, objects $< \sim 1$ mm down to a few μm in size)

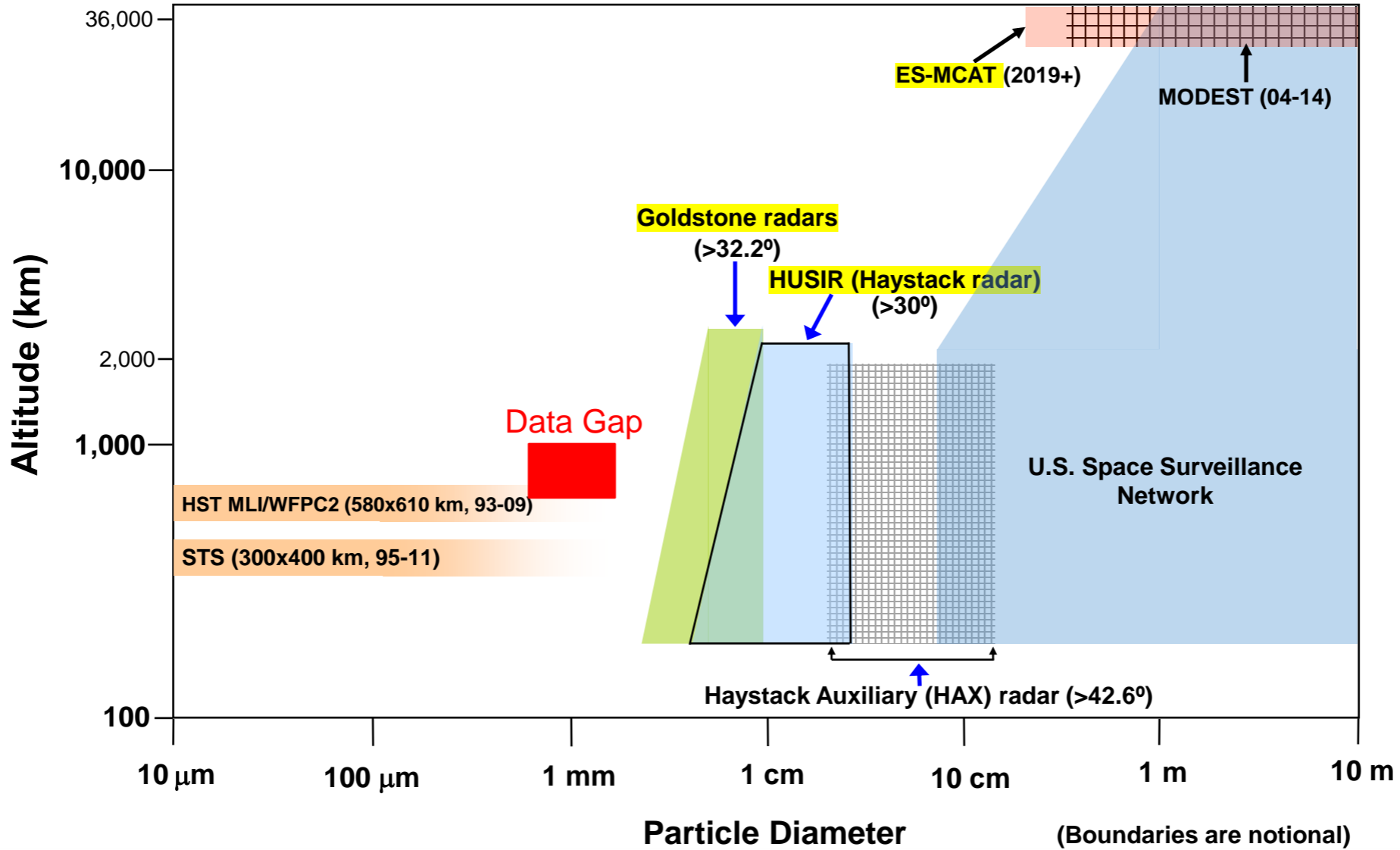


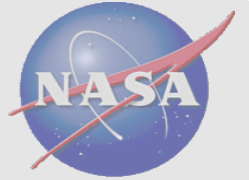
Estimating Debris Parameters

- **We receive surrogate measurements for the orbital debris parameters needed for modeling**
 - Radar
 - Range, range-rate, RCS \rightarrow altitude, inclination, size
 - Optical
 - Right ascension, declination, magnitude \rightarrow RAAN, inclination, mean motion, size
 - Model assumptions/estimations (circular orbits, empirical size estimation models) are used to convert to the parameters we want



Data Coverage





Radar and Optical Measurements in ODPO

Goal: statistically sample OD environment below the threshold of the Space Surveillance Network to build and validate orbital debris models



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



Credit: NASA JPL, <https://deepspace.jpl.nasa.gov/galleries/goldstone/#gallery>



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)

Provide data for building/validating OD models

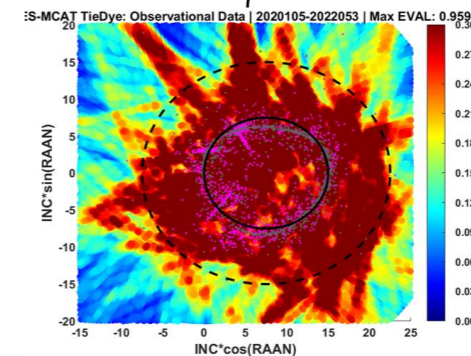
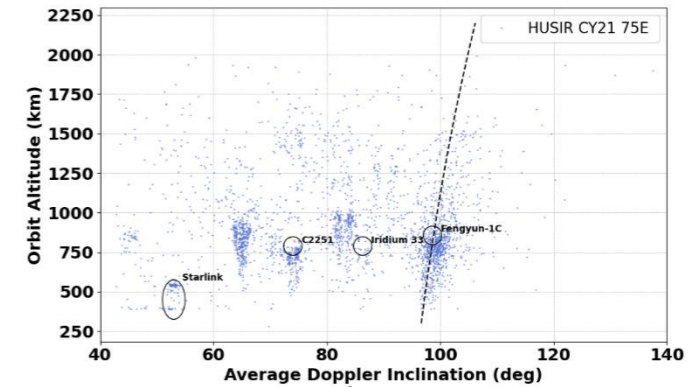


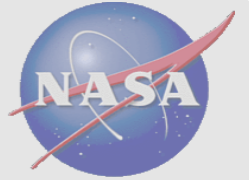
Measurements

Modeling



Provide feedback on how to improve measurements





Radar Measurements Overview



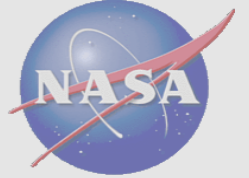
Credit: Reprinted with permission Courtesy of MIT Lincoln Laboratory, Lexington, Massachusetts

Haystack Ultrawideband
Satellite Imaging Radar
(HUSIR) – MIT/LL



Credit: NASA JPL,
<https://deepspace.jpl.nasa.gov/galleries/goldstone/#gallery>

Goldstone Orbital
Debris Radar – JPL



HUSIR Overview

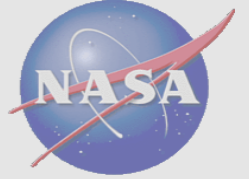
- **Monostatic radar**
- **OD data collection uses pulsed continuous wave (CW) signal at X-band**
- **Historical sensitivity ~5.5 mm**
- **Provides majority of data for scaling background OD populations for ORDEM**
 - Collect ~2/3 of data at 75° elevation, 90° azimuth, ~1/3 of data split between 20° and 10° elevation, 180° azimuth



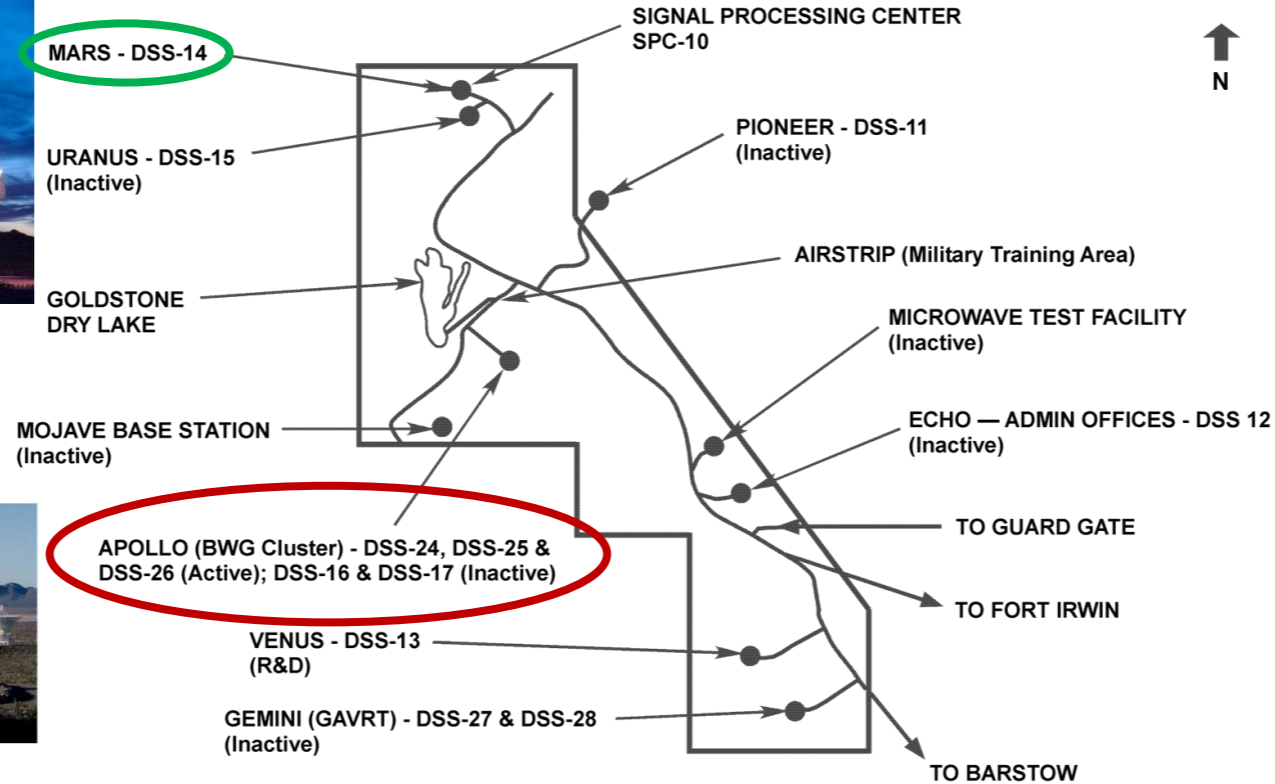
Reprinted with permission Courtesy of MIT Lincoln Laboratory, Lexington, Massachusetts

Operating Parameter	Nominal Value
Peak Transmit Power	250 kW
Transmit Frequency	10.1 GHz
Wavelength	3.0 cm
Antenna Diameter	36.6 m
Beamwidth	0.058°
Sensitivity*	59.2 dB

*Defined as the single pulse SNR for a 1 m² object (RCS) at 1000 km

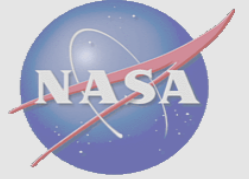


Goldstone Overview



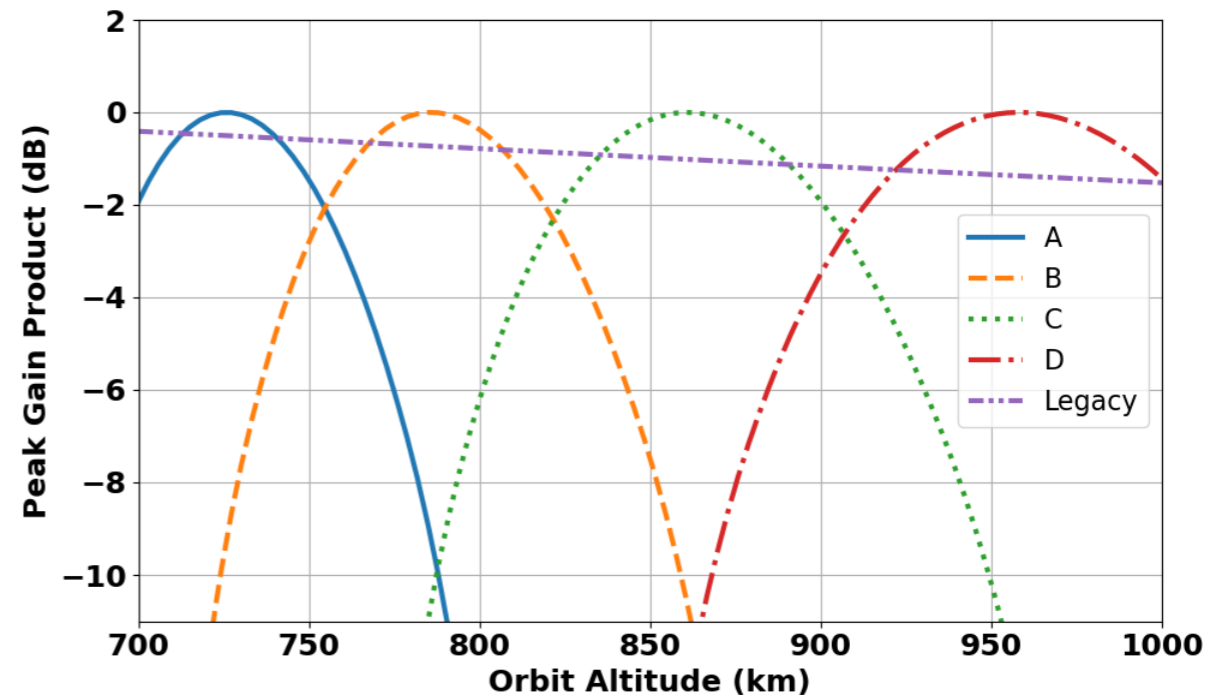
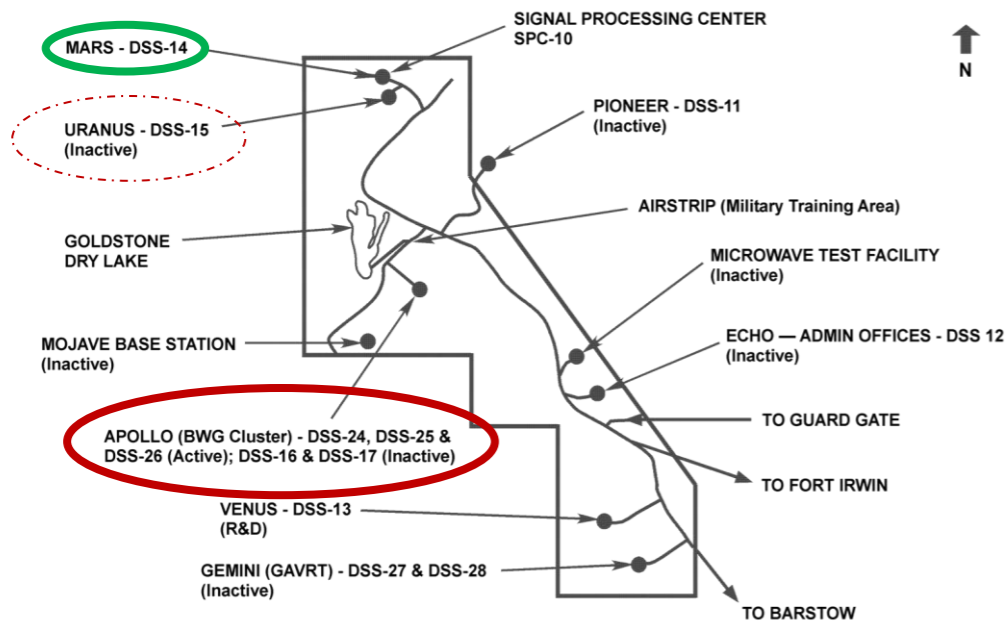
Operating Parameter	Nominal Value
Peak Transmit Power	440 kW
Transmit Frequency	8.56 GHz
Wavelength	3.5 cm
Antenna Diameter	70 m (transmitter) 34 m (receiver)
Beamwidth	0.03° (transmitter) 0.06° (receiver)

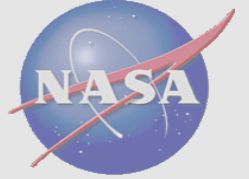
- **Bistatic radar**
- **Linear frequency modulated (LFM) waveform or chirp**
 - New sawtooth waveform in development
- **Extends the OD data coverage from HUSIR to slightly smaller sizes**



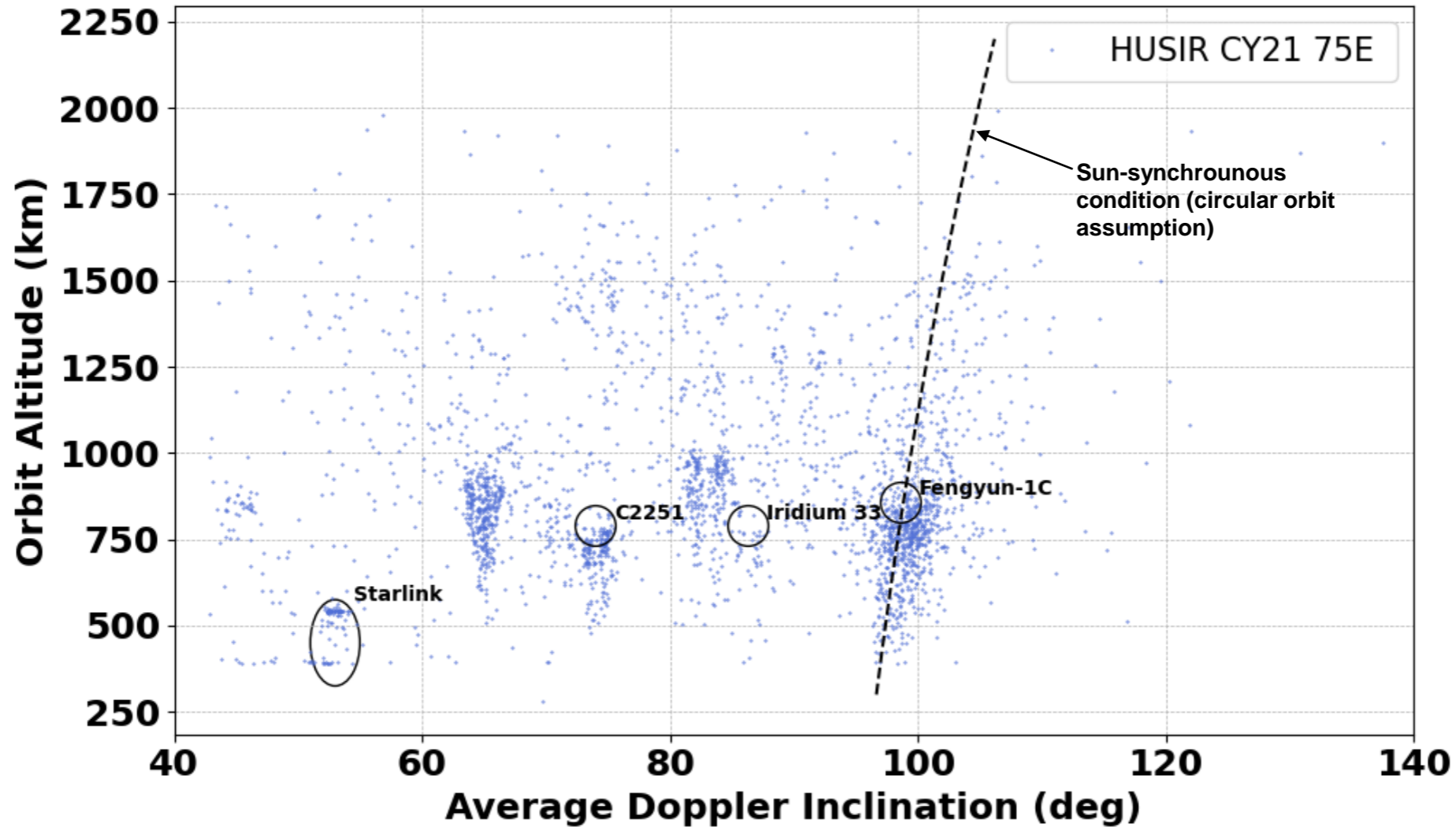
Goldstone Beam Overlap Pointing Plan

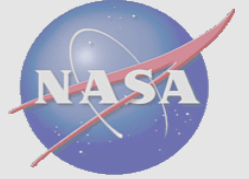
- **Increased baseline with new configuration reduced instantaneous altitude coverage**
 - 500 m with DSS-14/15
 - 10 km with DSS-25/26
- **Pointing plan developed to efficiently sample 700 – 1000 km in altitude**
 - Pointings chosen to be no more than 1.5 dB less sensitive than the legacy system at any given altitude



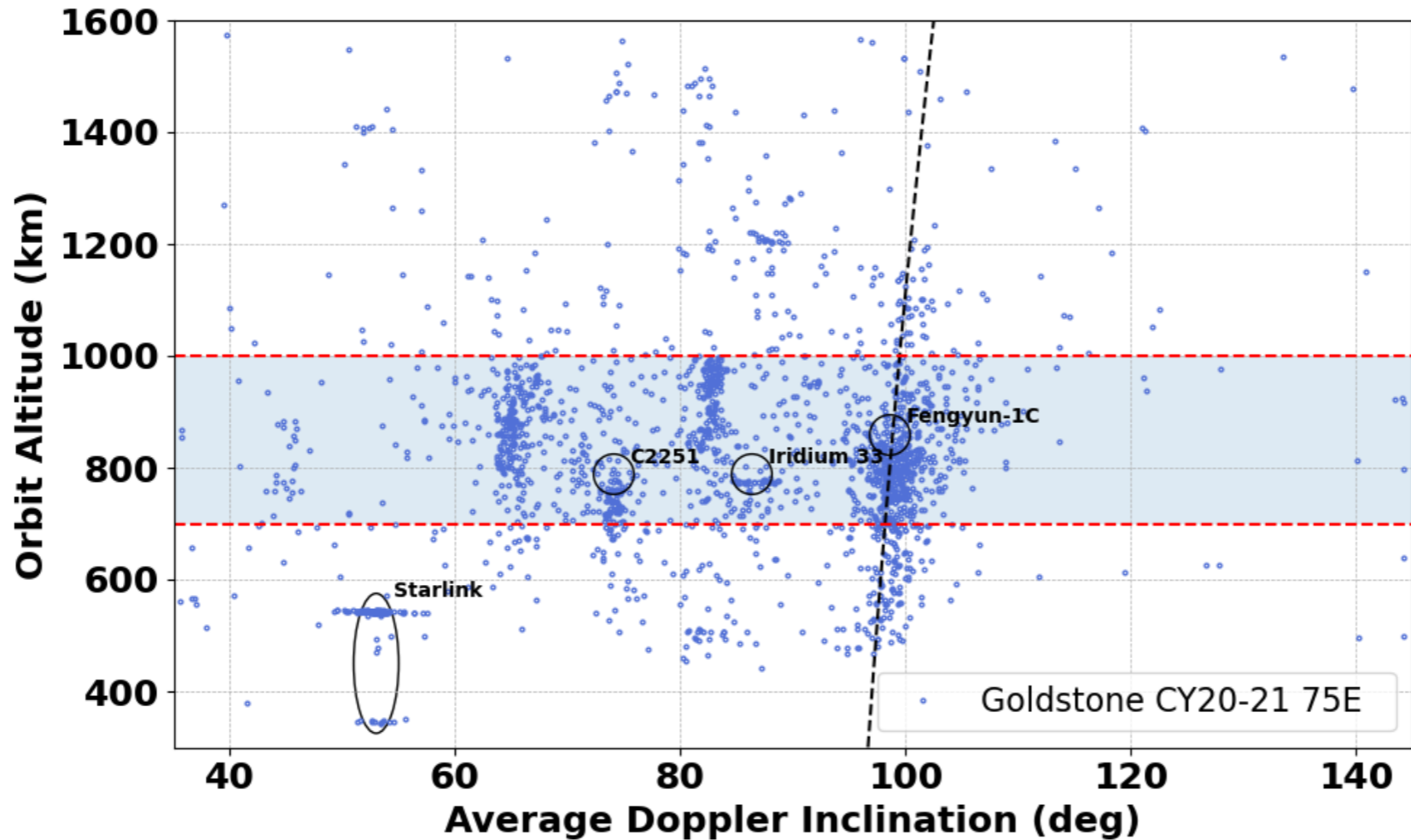


Altitude vs. Inclination: HUSIR

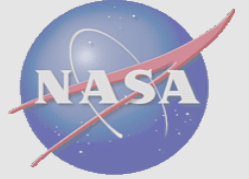




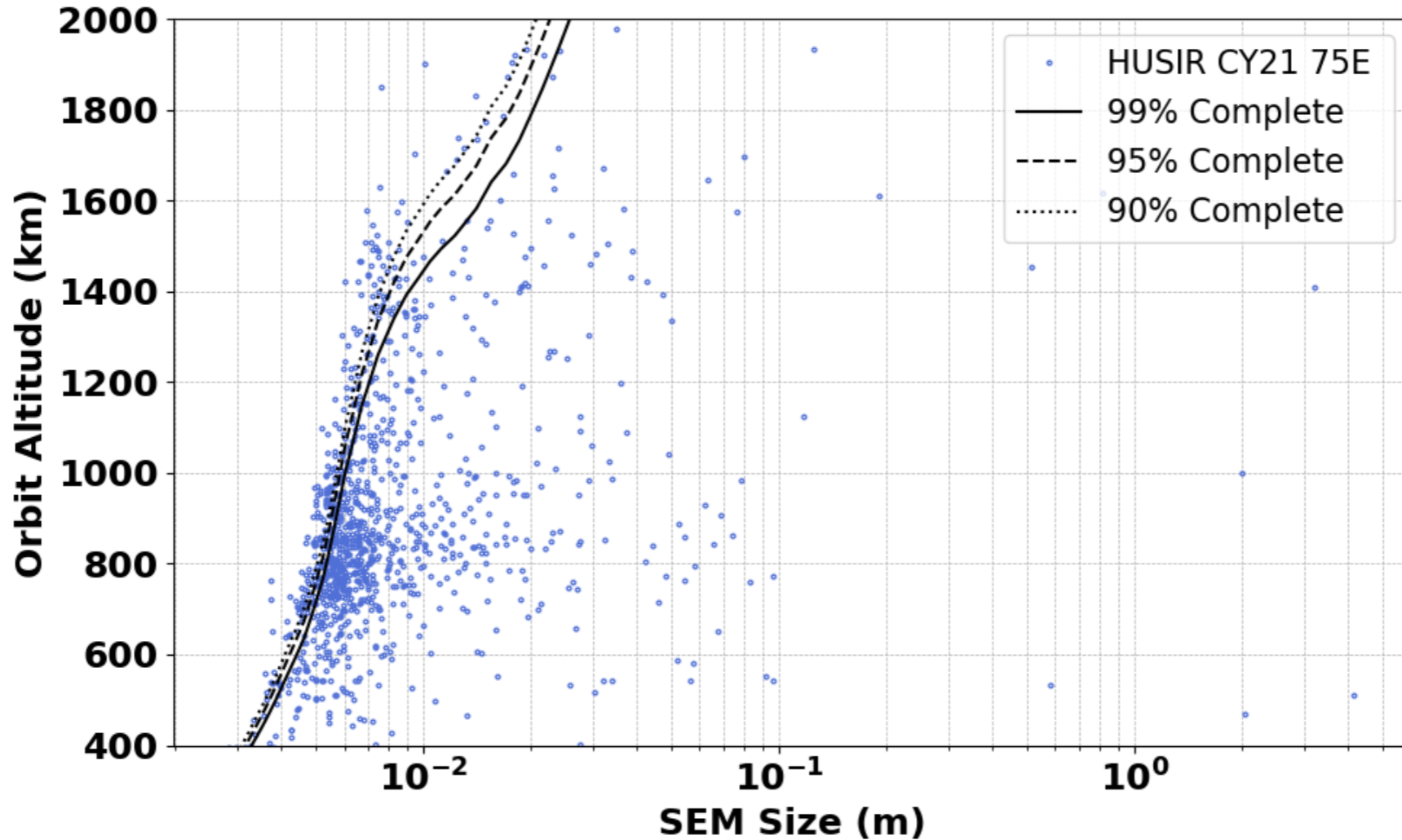
Altitude vs. Inclination: Goldstone



Same debris families seen in HUSIR data

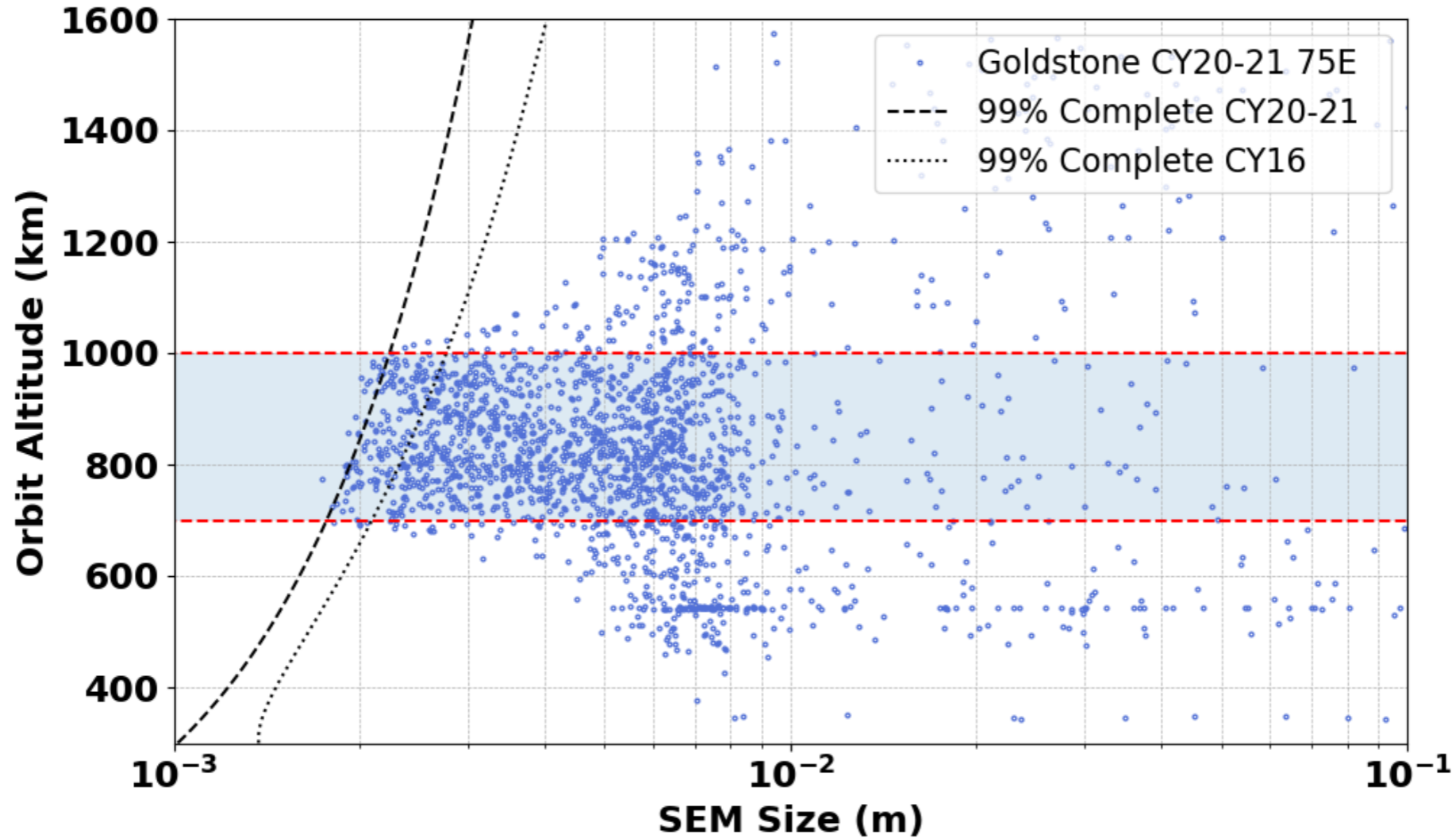


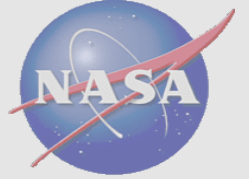
Altitude vs. Size: HUSIR





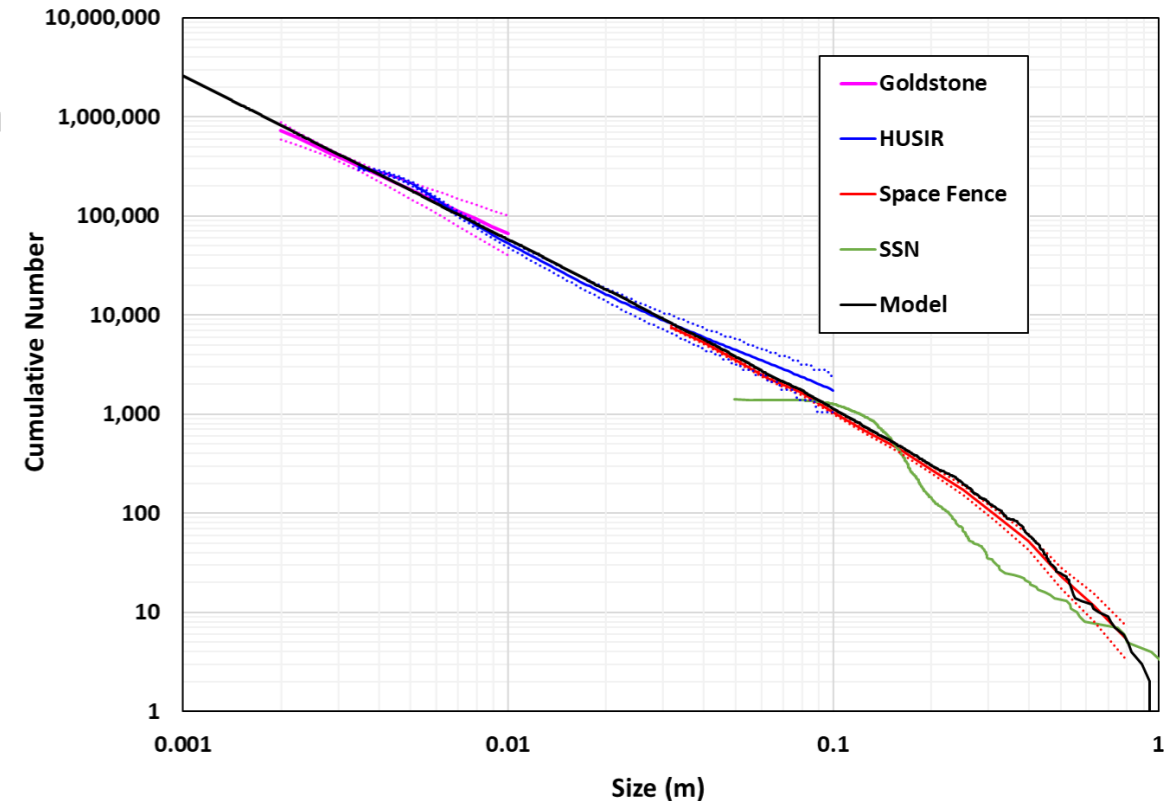
Altitude vs. Size: Goldstone



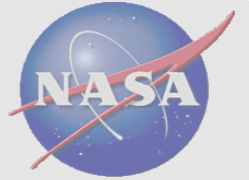


Special Observations

- 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

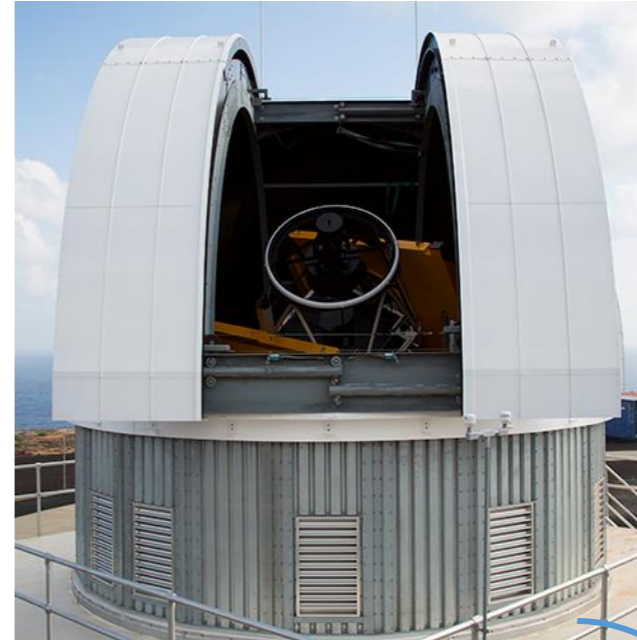


Cumulative size distribution of the Cosmos 1408 fragments based on special radar measurement data. The black line is the NASA SSBM prediction



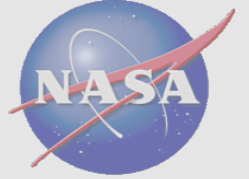
Optical Measurements Overview

- **Eugene Stansbery Meter Class Autonomous Telescope (ES-MCAT)**
 - Joint NASA-Air Force Research Labs (AFRL) project, located on the U.S. Space Force base on Ascension Island (Space Launch Delta 45, Detachment 2 near the Ascension Auxiliary Air Field)
 - $7^{\circ} 58' S$, $14^{\circ} 4' W$, 350' EI
 - 1.3-m, f/4, DFM Engineering fast-tracking optical telescope paired with an ObservaDome fast-tracking dome
 - Accommodates tracking debris at all orbital altitudes
 - Field of View: $0.68^{\circ} \times 0.68^{\circ}$, 0.96° diagonal
 - Limiting Magnitude ~ 19.5 (estimated from data for primary mirror in good condition in r')
 - Near equatorial latitude ensures that low-inclination LEO, GEO, and GEO transfer orbit (GTO) target orbits pass overhead



Credit: Ben Hanna





ES-MCAT GEO Survey

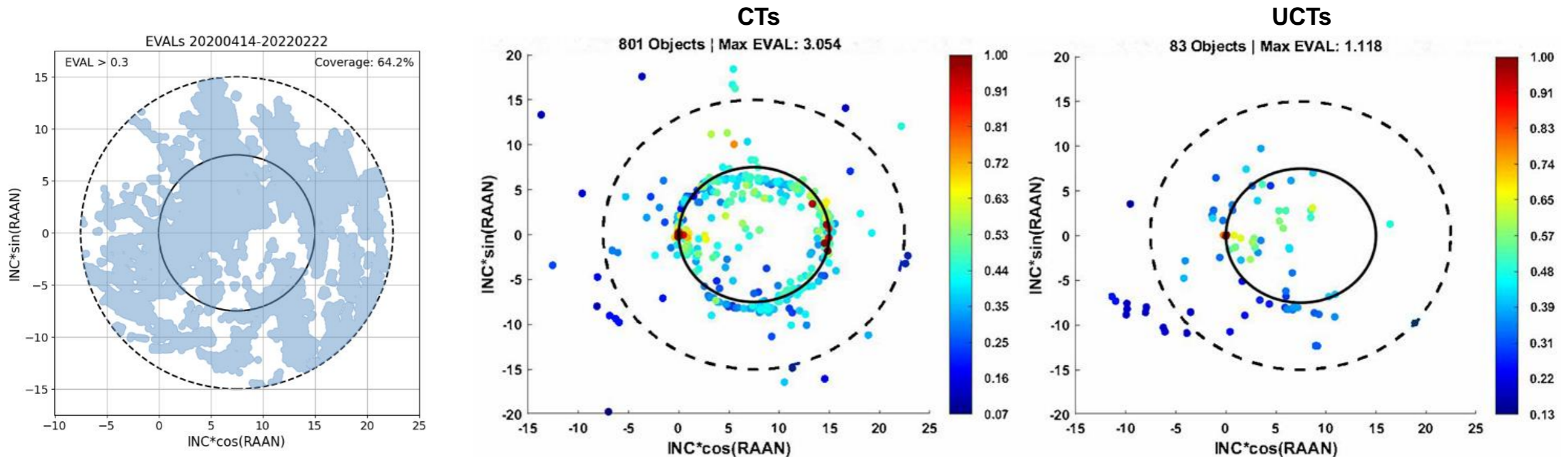
- **First GEO survey completed**

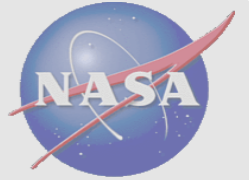
- Covers 14 April 2020 – 22 Feb 2022

- Focused on maximizing coverage over region of interest

- Area in Cartesian coordinates ($INC \cdot \cos(RAAN)$, $INC \cdot \sin(RAAN)$), centered at $(7.5^\circ, 0^\circ)$ with a radius of 15°

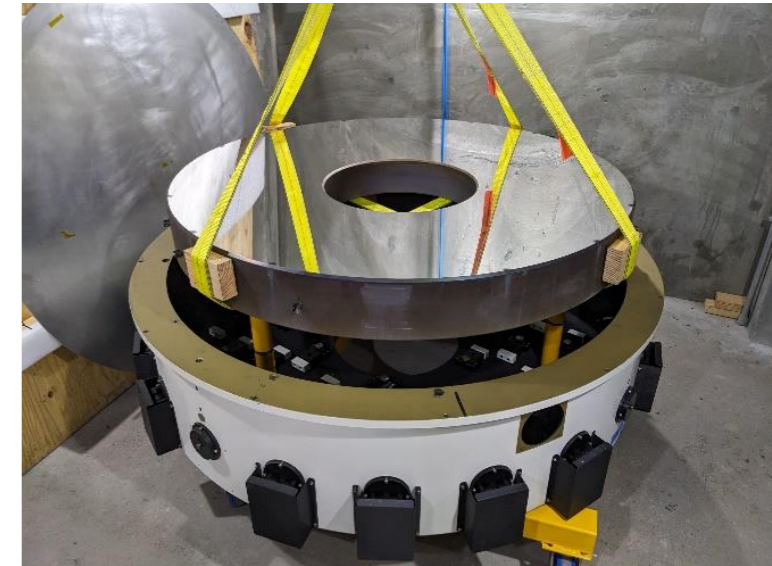
- Goal is to cover this region with an expectation value (probability of detection) ≥ 0.3



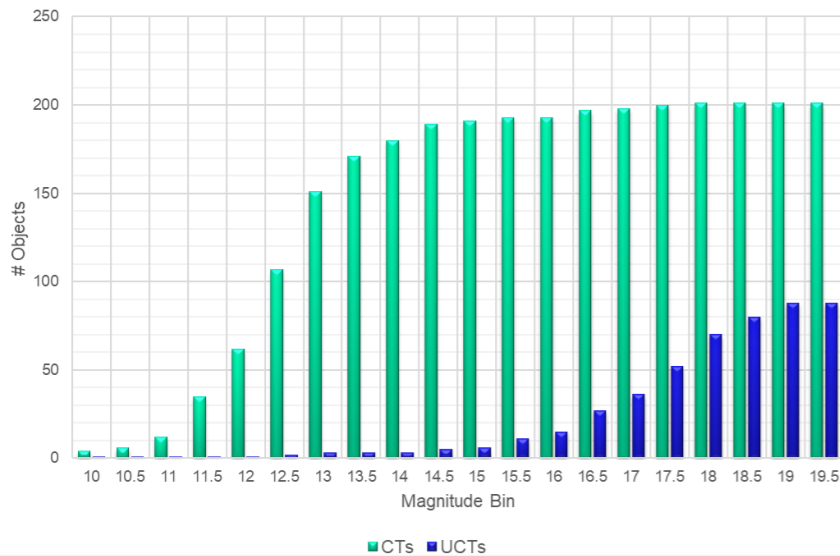


ES-MCAT Second GEO Survey

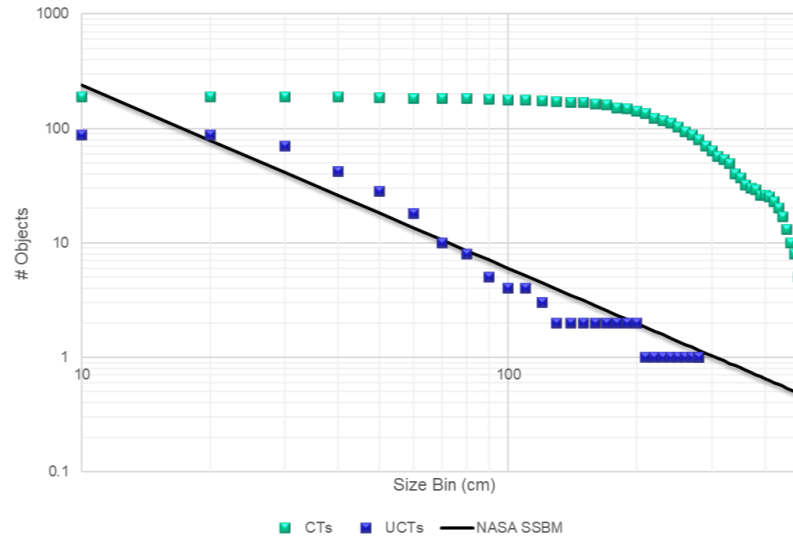
- **Primary mirror recoated and replaced**
 - Degradation of mirror coating was seen due to COVID-induced travel restrictions and limited cleaning from 2020-2021
 - New coating developed to achieve a minimum 90% reflectivity
 - Mirror removed in May 2022, replaced in January 2023
- **Second GEO survey began in January 2023**

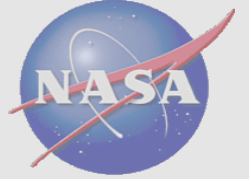


2023-2025 GEO Survey: CTs and UCTs Cumulative Magnitudes
01/18/2023 - 03/30/2023



2023-2025 GEO Survey: CTs and UCTs Cumulative Sizes
01/18/2023 - 03/30/2023





Thank you!

- **Any questions?**

