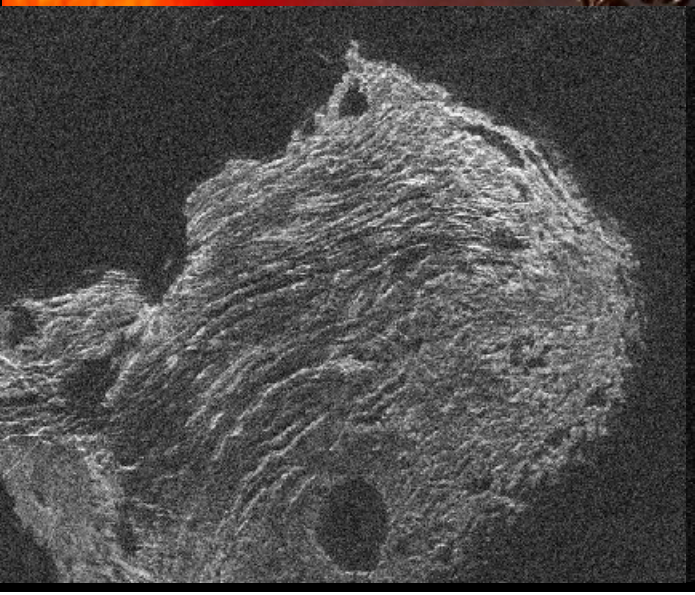
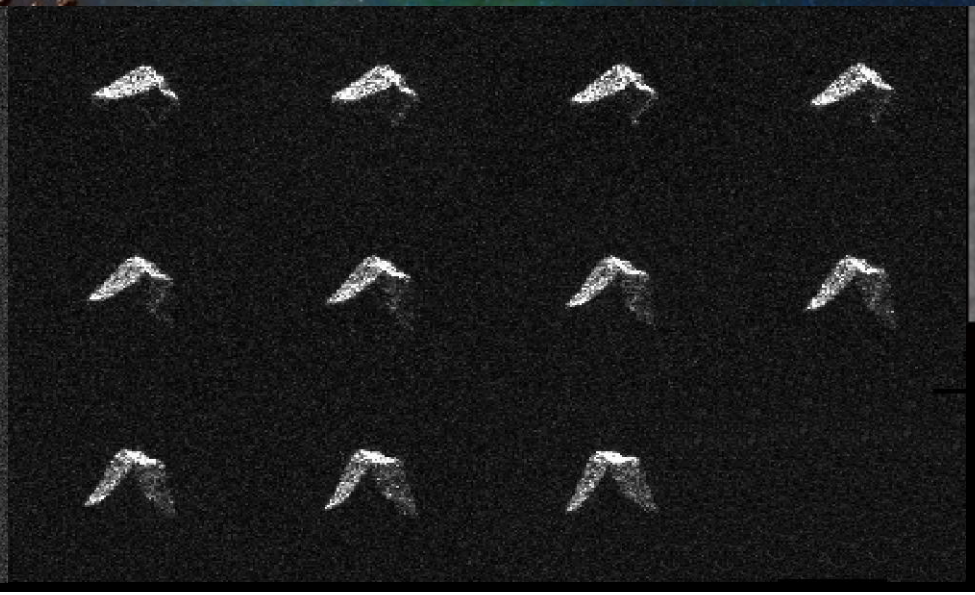




Current and Future Ground-Based Planetary Radar

Planetary Defense Conference 2023

Joseph Lazio

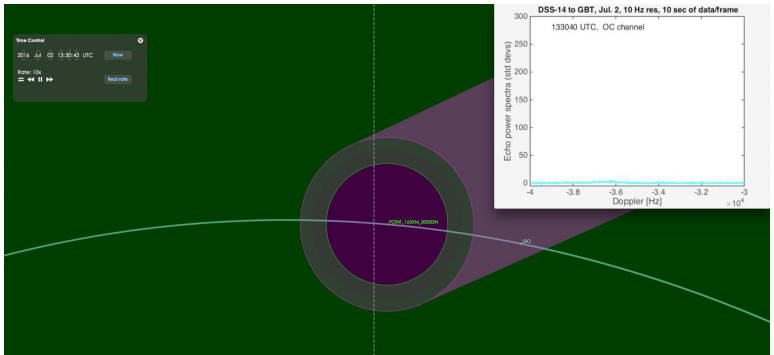
A. Beasley, L. A. M. Benner, M. Brozovic, P. G. Edwards, J. D. Giorgini, S. Horiuchi, E. Kruzins, R. R. Liou, B. Molyneux, S. P. Naidu, R. S. Park, C. J. Phillips, M. Sánchez Net, J. Spring, J. Stevens, M. Taylor, V. Vilnrotter, KISS Study Participants

Jet Propulsion Laboratory
California Institute of Technology

NASA Use Cases

Radar delivers size, rotation, shape, density, surface features, precise orbit, non-gravitational forces, presence of satellites, mass, …

- **Science**: Decipher the record in primitive bodies of epochs and processes not obtainable elsewhere
- **Robotic missions**: Navigation, orbit planning, observations
- **Planetary defense**: Precise orbit determination, size, shape for hazard assessment
- **Space Situational Awareness**: Assessing collision hazard risks between spacecraft, particularly relevant for crewed vehicles



NASA Radar Assets

Goldstone Solar System Radar (GSSR)
70 m antenna, 450 kW transmitter, 3.5 cm wavelength (X band)

+

Southern Hemisphere Asteroid Radar Project
Canberra DSS-43 (DSN) 70 m antenna, 80 kW transmitter, 4 cm wavelength (C band)
+ Australia Telescope Compact Array

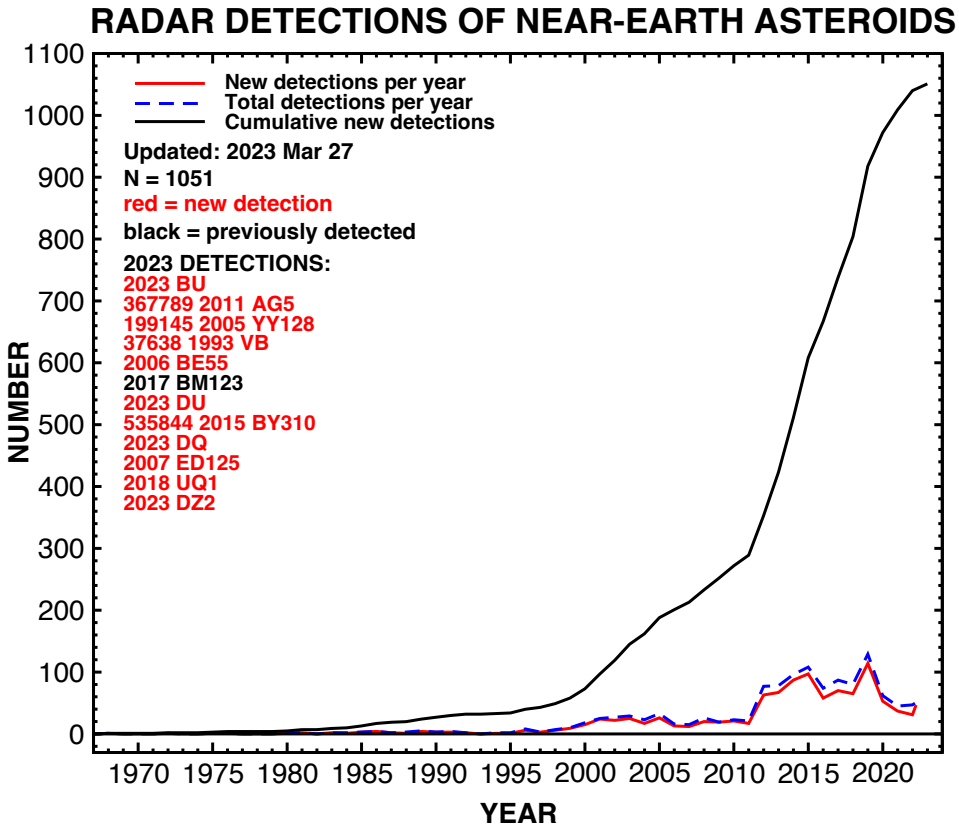
+

European Demonstrations
Madrid DSS-63 (DSN) 70 m antenna, 20 kW transmitter, 4 cm wavelength (C band)
+ Medicina Antenna

Current and Future Ground-Based Planetary Radar

- **Current DSN Asteroid Radar work**
- **Near-term: GSSR Modernization a.k.a. GSSR-2.0**
- **Future: Science Motivation and Implementation**

Goldstone Solar System Radar

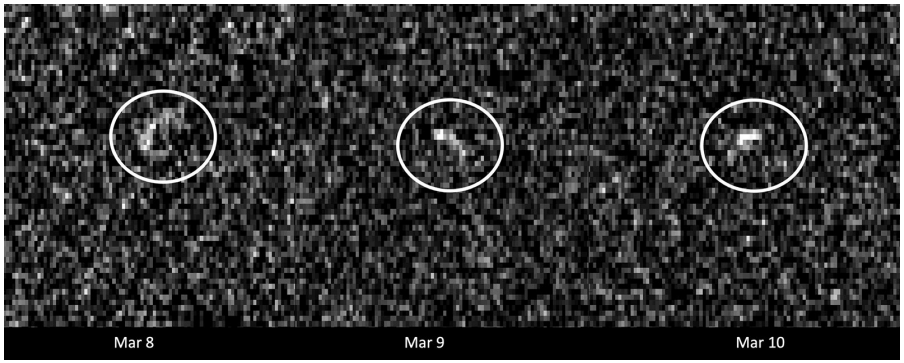


Recent DSN Asteroid Radar Detections

	GSSR	SHARP
2021	40	6*
2022	45	7
2023 (to date)	12	3

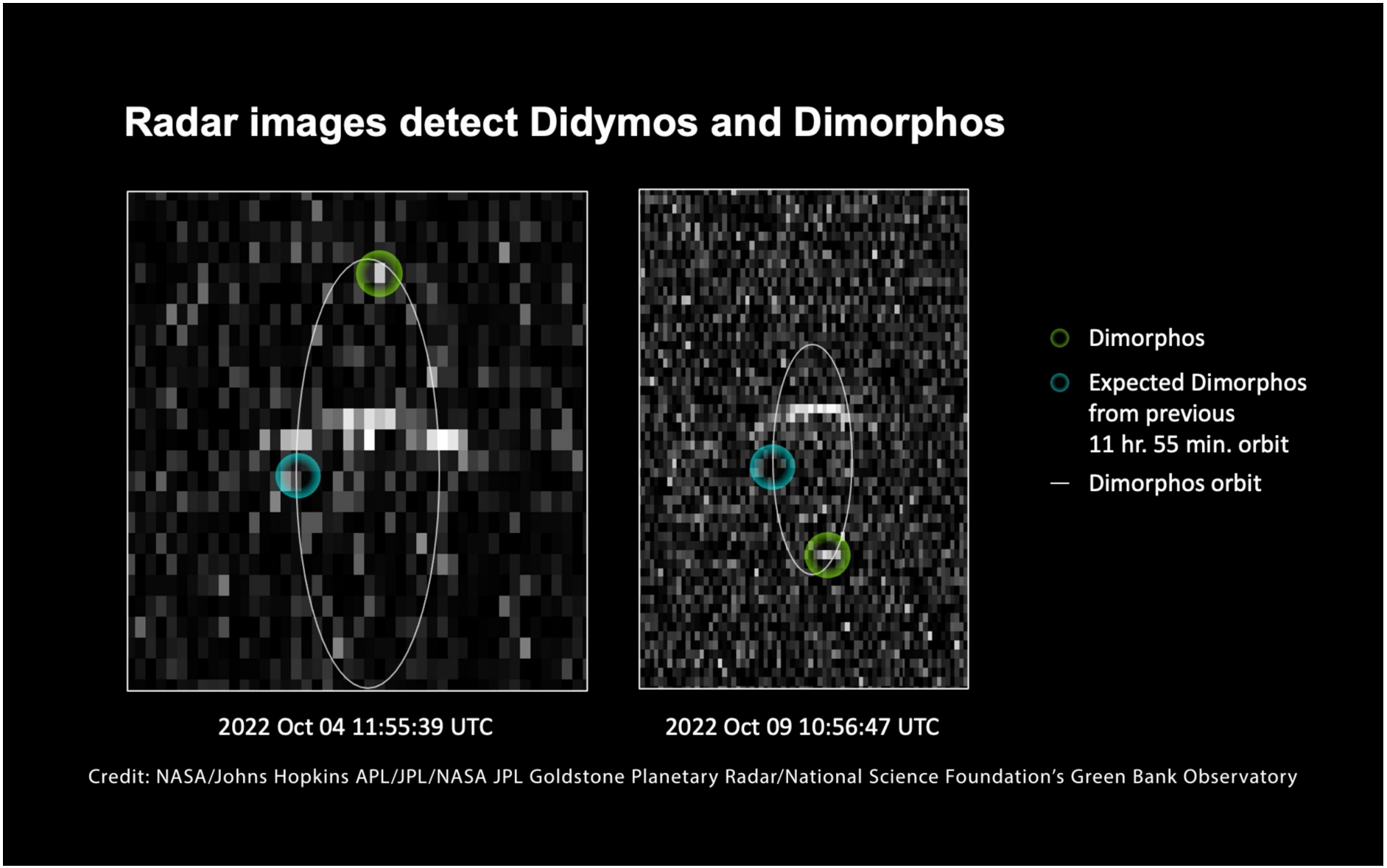
*Canberra 70 m antenna undergoing scheduled maintenance for portion of 2021

Apophis 2021 March



Double Asteroid Redirect Test (DART) Mission

GSSR-GBT Provided First Evidence for DART Mission Success

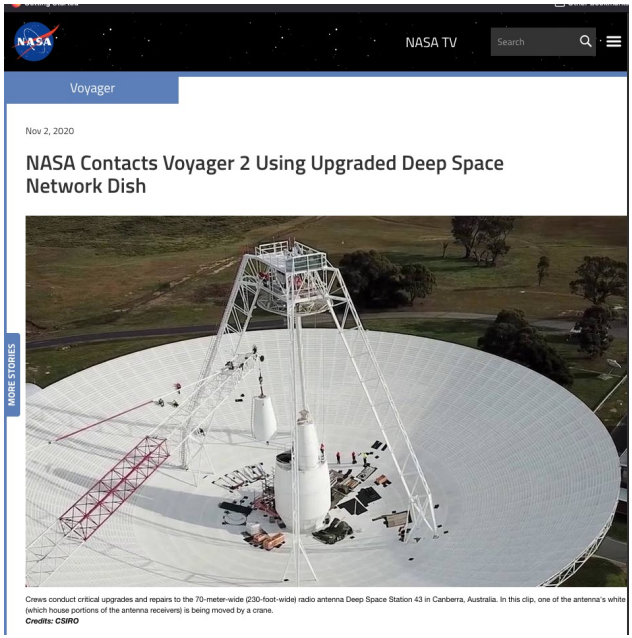


Current and Future Ground-Based Planetary Radar

- Current GSSR work
- **Near-term: GSSR Modernization a.k.a. GSSR-2.0**
- Future: Science Motivation and Implementation

Introduction

Overview



- **The DSN has on-going task to replace operational transmitters and modernize facility infrastructure of 70 m antennas**
  - ✓ **Canberra (DSS-43) completed in 2021**
  - **Goldstone (DSS-14) scheduled for 2025-2027**
  - **Madrid (DSS-63) scheduled for (no earlier than) 2028**
- **The DSN adding replacement of GSSR Transmitter to 70 m Transmitter Replacement and Facility Modernization Task at Goldstone**
  - **GSSR transmitter replacement concurrent with 70 m Transmitter Replacement and Facility Modernization Task at Goldstone will lead to reduction in costs and downtime due to downtime efficiencies**
  - ➢ **Scope of full 70 m Transmitter Replacement and Facility Modernization Task is much broader**

GSSR Transmitter Replacement Implementation Overview

Task Scope

- **Replace Transmitter System**
- **Replace GSSR feed cone with new feed cone**
- **Replace cooling system**
- **Update control architecture and operations concept**
- **Update microwave control system to support new transmitter and improve system response time**

Canberra TT&C Cone Replacement

Antenna Facilities

Experience from DSS-43 (Canberra)

Power and Cooling Systems

Hybrid Coolers Installation

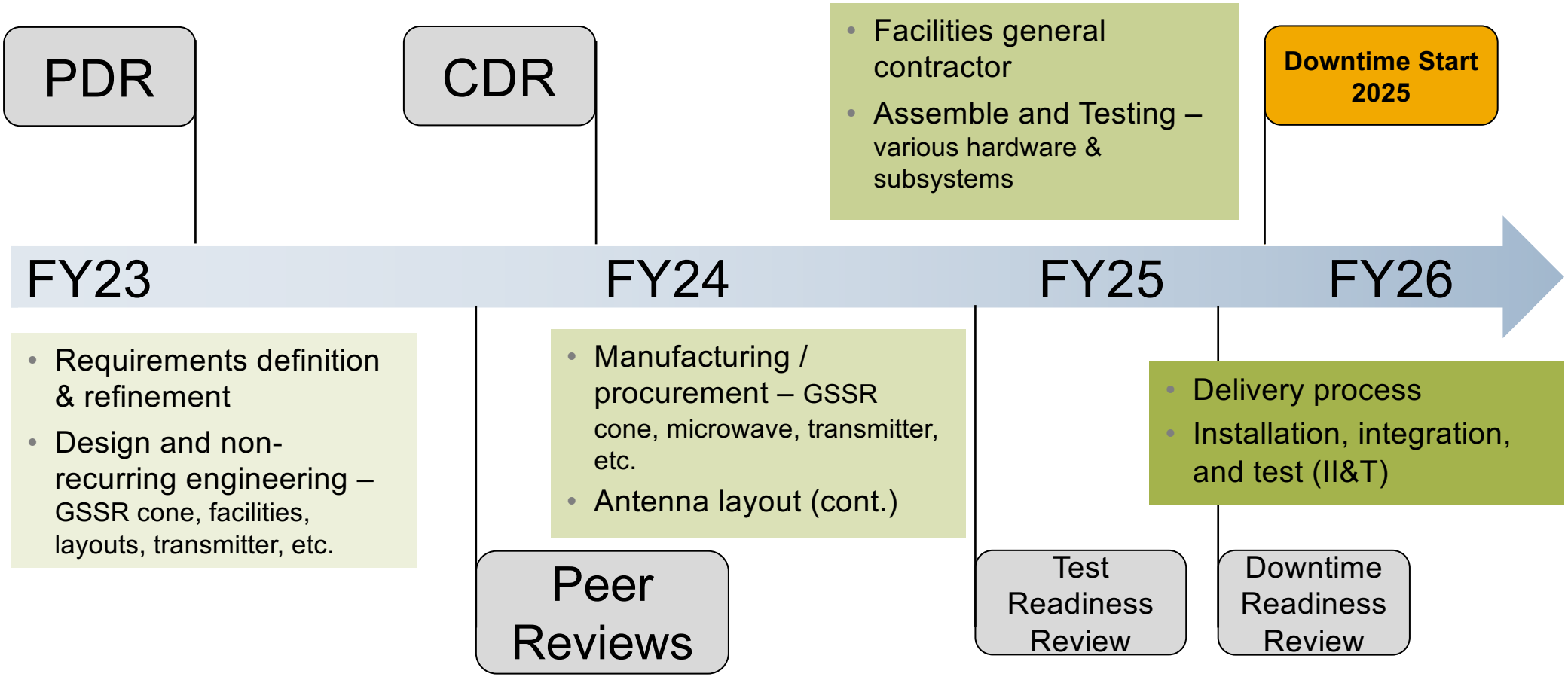
Trench Excavation for Substation

Original Equipment

New Substation

Top Level Task Planning

When does it end???? **2027 March** return to service review

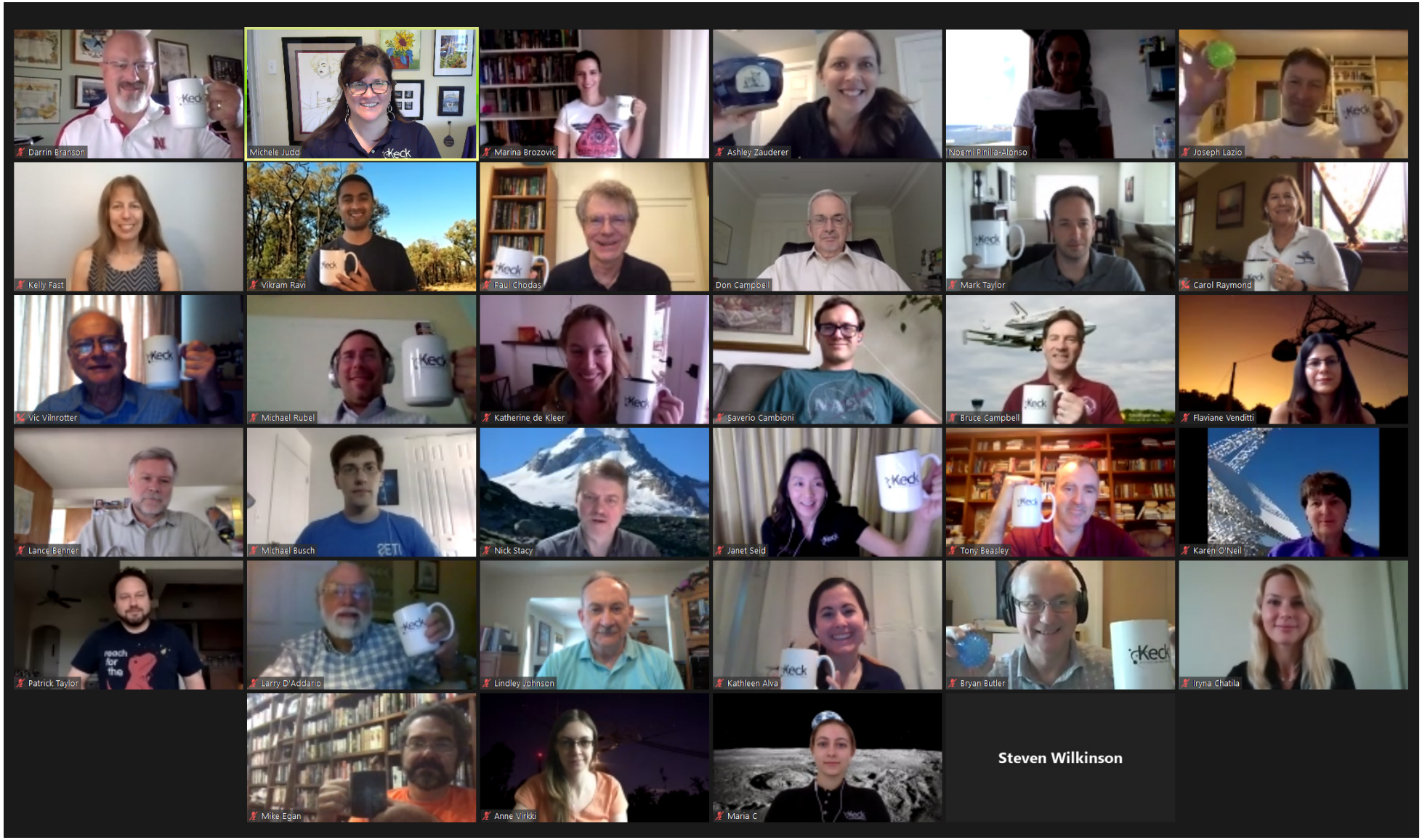


Dates may be adjusted as design process continues

Current and Future Ground-Based Planetary Radar

- Current GSSR work
- Near-term: GSSR Modernization a.k.a. GSSR-2.0
- **Future: Science Motivations and Implementation**

W. M. Keck Institute for Space Studies Next-Generation Planetary Radar Study



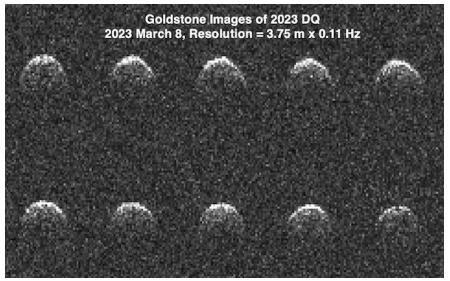
Future: Driving Science Cases

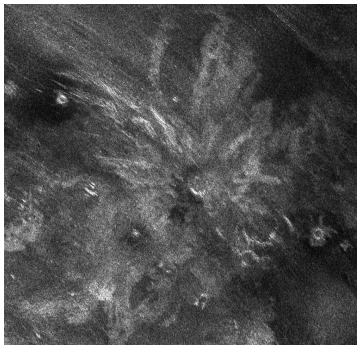
Driving use cases identified at KISS Workshop

- **Near-Earth Asteroids and Planetary Defense**
- **Venus**
- **Outer Solar System**

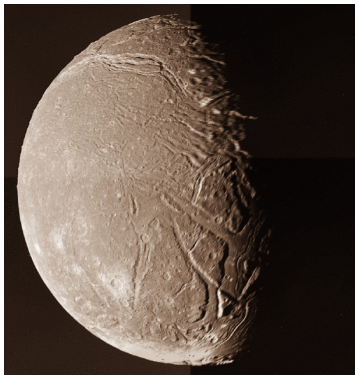
Other potential targets

- **Mini-moons**
- **Interstellar objects**
- **Earth Trojans**
- **…**





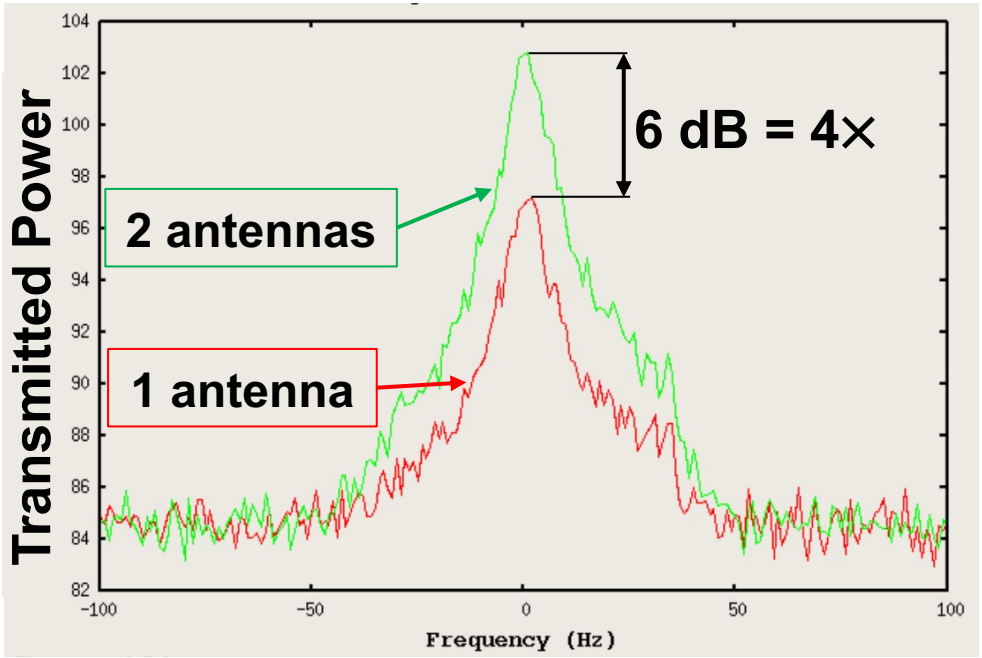
Venus / Sif Mons



Ariel

Future II: Arrays of Transmitting Antennas


DSN antennas @ Goldstone



- ✓ **Arrays of receiving antennas are well-developed**
  Both for radio astronomy (1974 Nobel Prize) and DSN

- **Arrays of transmitting antennas**
  - **Array gain $G_{TX} \propto N^2$ for *N*-antenna array**
  - ✓ **Demonstrated in context of communication for up to 3 antennas**
  - ➢ **Need to show ranging performance expected for planetary radar**
    On-going work at JPL and elsewhere to do so

Vilnrotter et al.;
D'Addario et al.

Planetary Radar Trade Space

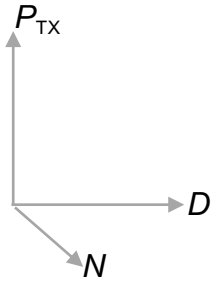
Received Power (a.k.a. Radar Equation)

$$P_{RX} = \frac{1}{(4\pi)^3} G_{RX}(P_{TX}G_{TX})\lambda^2 \frac{\sigma}{R^4}$$

Effective Isotropic Radiated Power (EIRP)

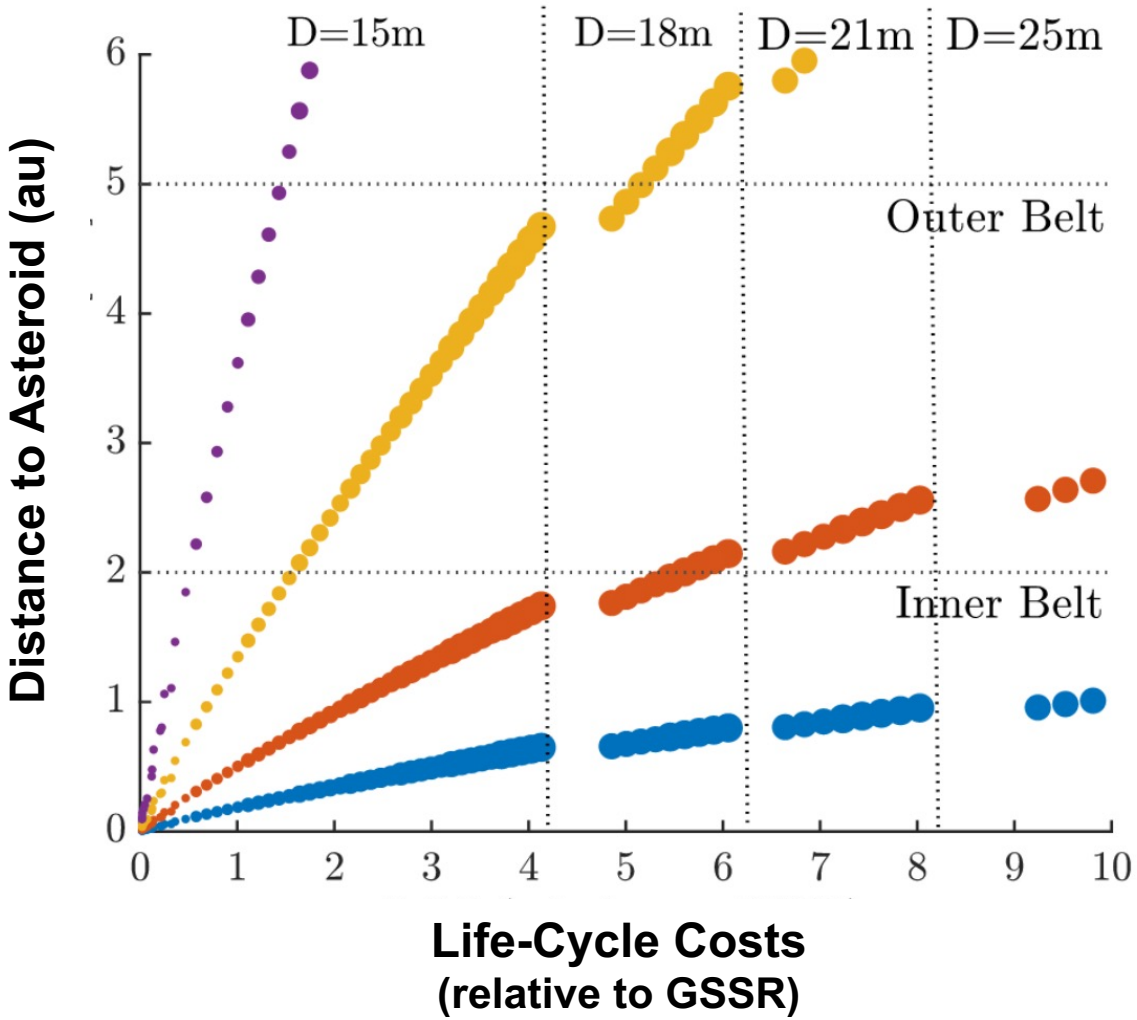
$$\text{EIRP} \propto N^2 D^2 P_{TX}$$

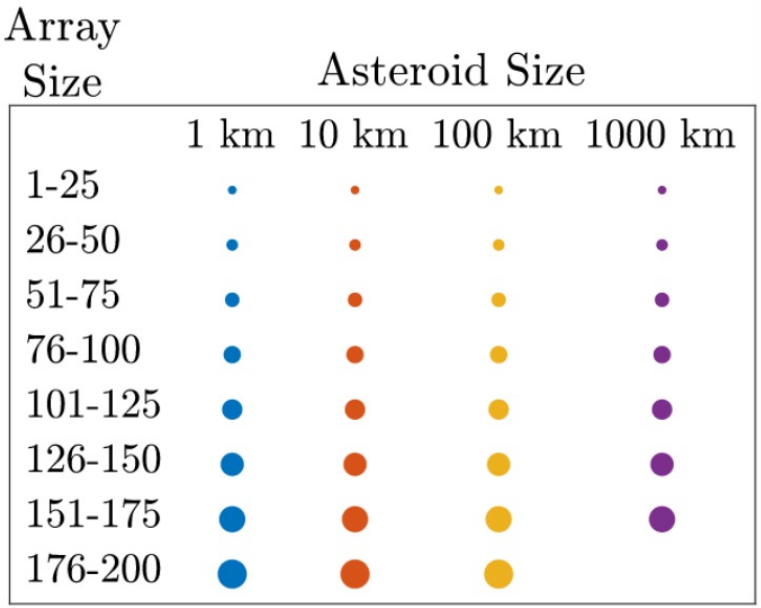
- **Number of Antennas** (N^2)
- **Antenna Diameter** (D^2)
- **Transmitter Power per Antenna** (P_{TX})



- **Maximize P_{RX} subject to cost cap including operations!**

Planetary Radar Array Performance Evaluation





Sanchez Net et al.

Current and Future Ground-Based Planetary Radar

- **Current DSN Asteroid Radar work**

  Planetary Science, Mission Design & Navigation, Planetary Defense, Space Situational Awareness

- **Near-term: GSSR Modernization a.k.a. GSSR-2.0**
  - **Replace nearly everything except the antenna mechanical structure itself**
  - **Starts ~ mid-2025, ends ~ 2027 March**
- **Future: Science Motivation and Implementation**
  - **Solid-state transmitters and power amplifiers**
  - **Planetary radar array**

Jet Propulsion Laboratory
California Institute of Technology