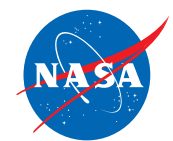


Current and Future Ground-Based Planetary Radar

Planetary Defense Conference 2023



Jet Propulsion Laboratory
California Institute of Technology

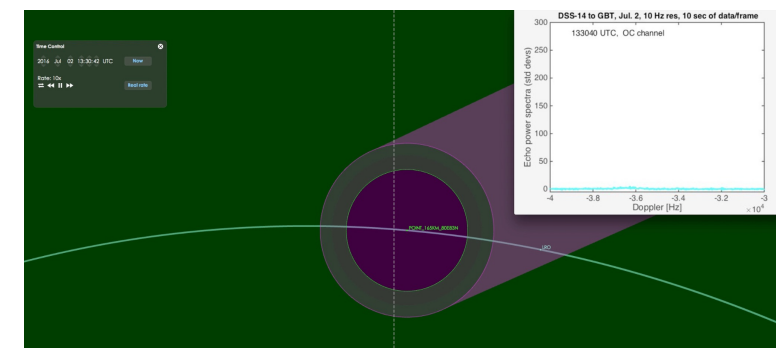
Joseph Lazio

**L. Benner, M. Brozovic, S. Horiuchi, E. Kruzins, R. Liou,
J. Spring, M. Sánchez Net, M. Taylor, V. Vilnrotter,
M. Judd, KISS Study Participants**

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



+



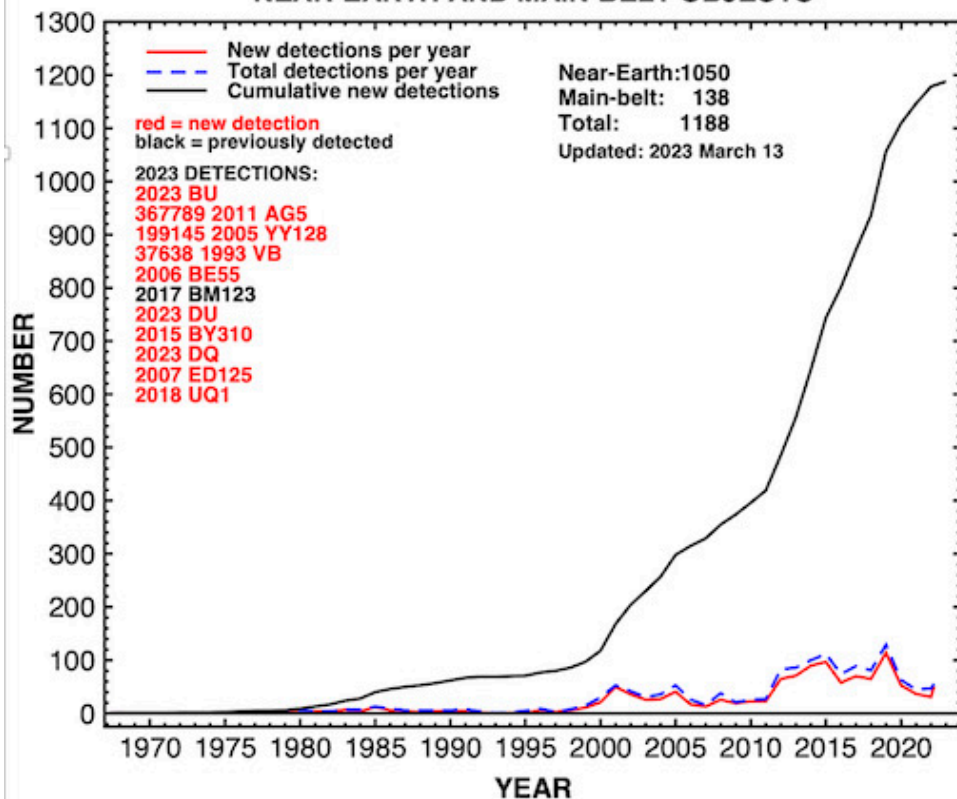
European Demonstrations
Madrid DSS-63 (DSN) 70 m antenna, 20 kW transmitter, 4 cm wavelength (C band)
+ Medicina Antenna

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

ASTEROID RADAR HISTORY NEAR-EARTH AND MAIN-BELT OBJECTS



Recent DSN Asteroid Radar Detections

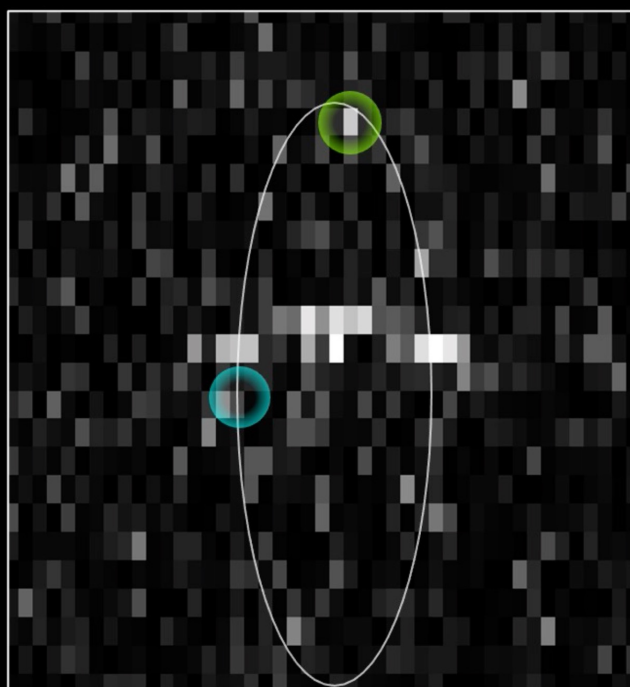
	GSSR	SHARP
2021	40	6*
2022	45	7
2023 (to date)	12	3

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

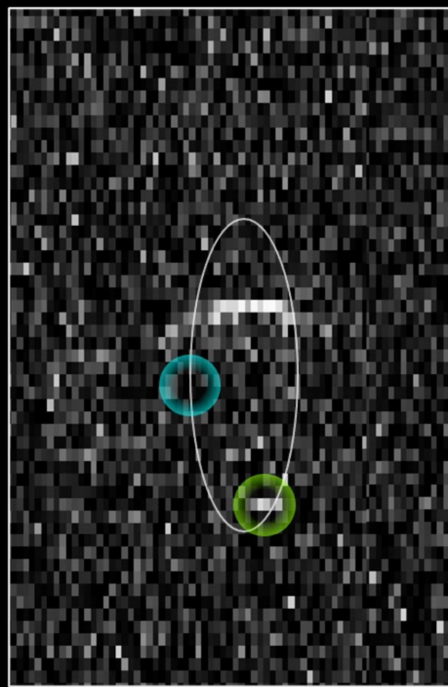
Double Asteroid Redirect Test (DART) Mission

GSSR-GBT Provided First Evidence for DART Mission Success

Radar images detect Didymos and Dimorphos



2022 Oct 04 11:55:39 UTC



2022 Oct 09 10:56:47 UTC

- Dimorphos
- Expected Dimorphos from previous 11 hr. 55 min. orbit
- Dimorphos orbit

Credit: NASA/Johns Hopkins APL/JPL/NASA JPL Goldstone Planetary Radar/National Science Foundation's Green Bank Observatory

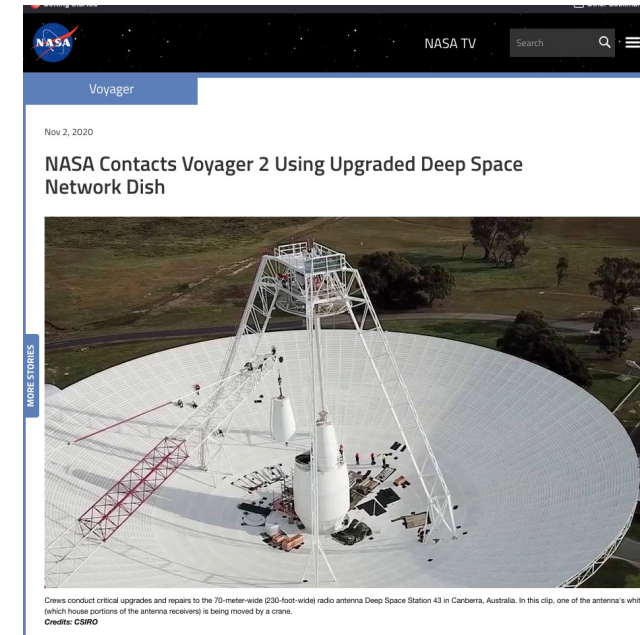
Current and Future Ground-Based Planetary Radar

- **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 GSSR Transmitter System**
- **Replace GSSR feed cone with new feed cone**
 - Feed cone has been through many upgrades and is in need of replacement to aid in better organization of hardware and larger door to aid in replacement of Klystrons
- **Replace cooling system**
 - Retain system topology
- **Update GSSR 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



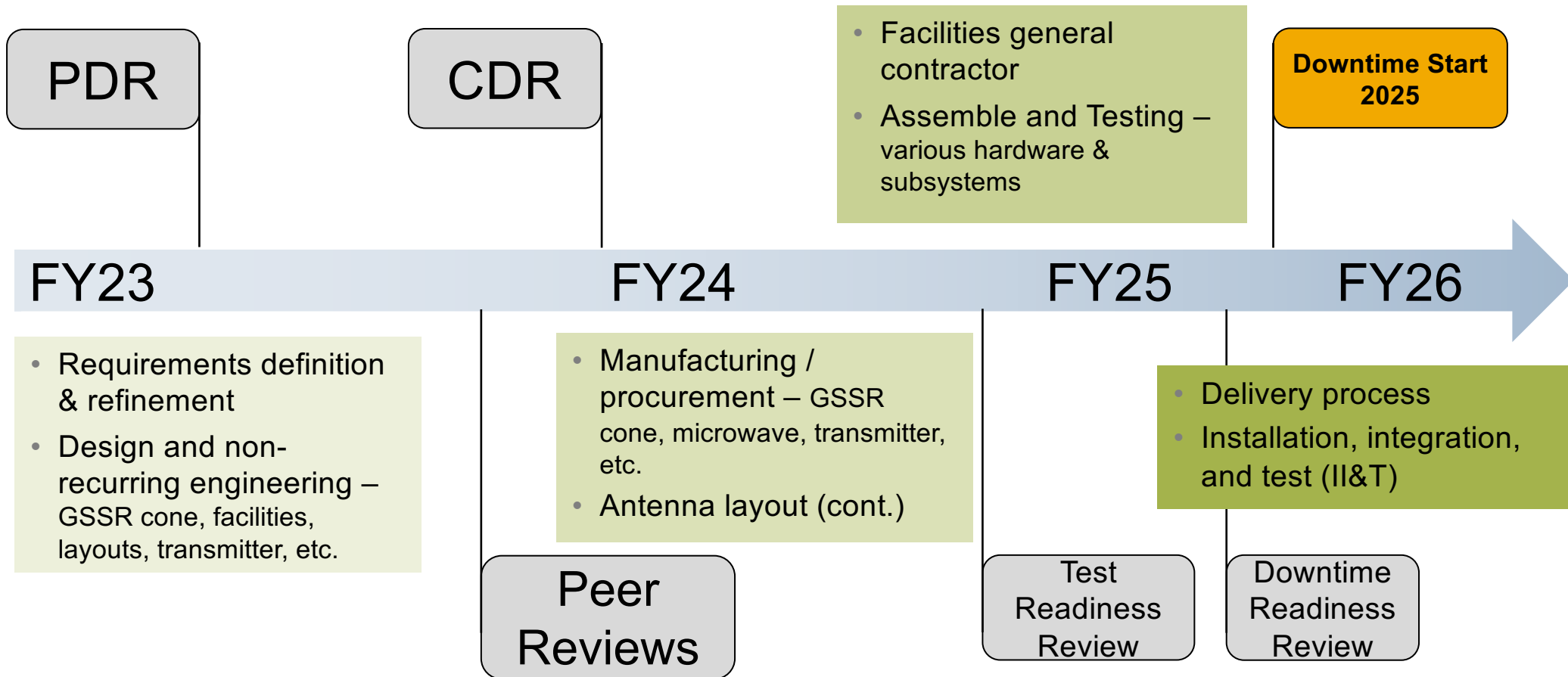
Original Equipment



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

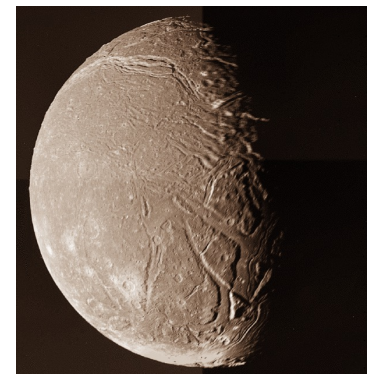
- **Near-Earth Asteroids and Planetary Defense**
- **Venus**
- **Outer Solar System**

Other potential targets

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

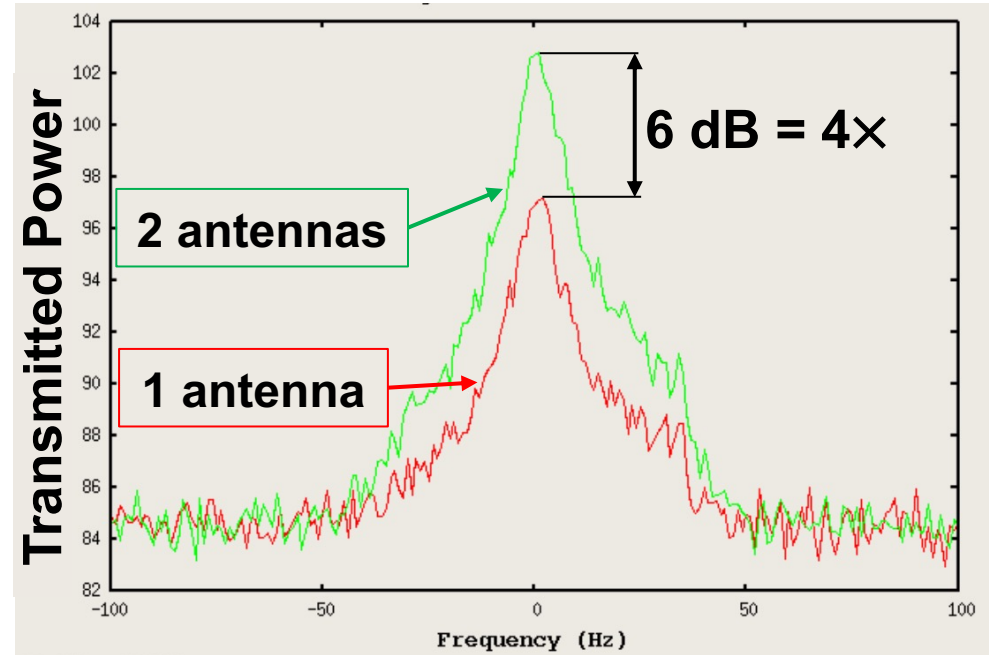


Venus / Sif
Mons



Ariel

Future II: Arrays of Transmitting Antennas



✓ 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.

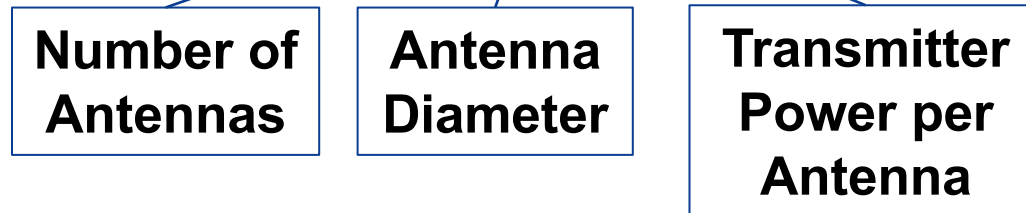
Planetary Radar Trade Space

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

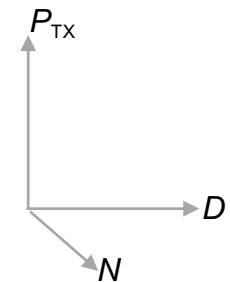
$$P_{RX} = \frac{1}{(4\pi)^3} G_{RX} \underbrace{(P_{TX} G_{TX})}_{\text{Effective Isotropic Radiated Power (EIRP)}} \lambda^2 \frac{\sigma}{R^4}$$

Effective
Isotropic
Radiated Power
(EIRP)

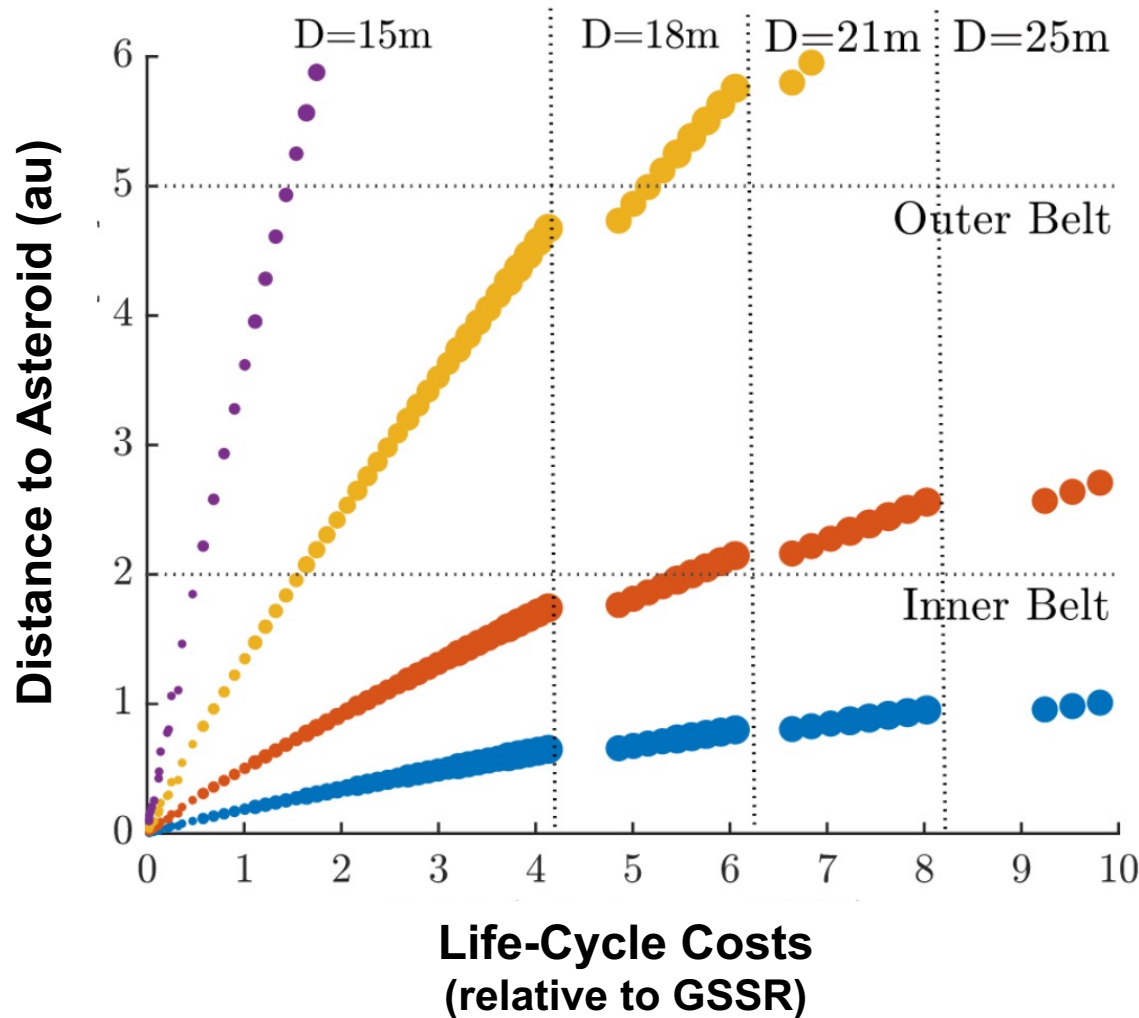
$$\text{EIRP} \propto N^2 D^2 P_{TX}$$



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



Planetary Radar Array Performance Evaluation



Array Size	Asteroid Size			
	1 km	10 km	100 km	1000 km
1-25	•	•	•	•
26-50	•	•	•	•
51-75	•	•	•	•
76-100	•	•	•	•
101-125	•	•	•	•
126-150	•	•	•	•
151-175	•	•	•	•
176-200	•	•	•	•

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