Current and Future Ground-Based Planetary Radar

Planetary Defense Conference 2023

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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

<table>
<thead>
<tr>
<th>Year</th>
<th>GSSR</th>
<th>SHARP</th>
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<tbody>
<tr>
<td>2021</td>
<td>40</td>
<td>6*</td>
</tr>
<tr>
<td>2022</td>
<td>45</td>
<td>7</td>
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<tr>
<td>2023 (to date)</td>
<td>12</td>
<td>3</td>
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</tbody>
</table>

*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

Radar images detect Didymos and Dimorphos

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 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

Trench Excavation for Substation

Original Equipment

New Substation

Hybrid Coolers Installation
Top Level Task Planning

When does it end? 2027 March return to service review

FY23
- Requirements definition & refinement
- Design and non-recurring engineering – GSSR cone, facilities, layouts, transmitter, etc.

FY24
- Manufacturing / procurement – GSSR cone, microwave, transmitter, etc.
- Antenna layout (cont.)

FY25
- Facilities general contractor
- Assemble and Testing – various hardware & subsystems
- Delivery process
- Installation, integration, and test (II&T)
- Test Readiness Review

FY26
- Downtime Start 2025
- Downtime Readiness Review

Dates may be adjusted as design process continues
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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
• …
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
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)

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

Maximize \( P_{RX} \) subject to cost cap including operations!
Planetary Radar Array Performance Evaluation

Sanchez Net et al.
• 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