National Aeronautics and
Space Administration

Deep Space Planetary Defense Radar Study

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Planetary Science Advisory Committee

Meeting - March 4, 2024

Interagency Deep Space Radar Study
Conducted by Aerospace Corporation

Study Objectives

- Determine common core needs from key government stakeholders for deep space radar capabilities.
- Assess capabilities of current and potential/planned facilities to meet the core set of needs.
- Provide notional reference architectural solutions that satisfy gaps in the core set of needs.

- The full report can be found here:

  https://www.nasa.gov/wp-content/uploads/2023/10/atr-2023-01267.pdf

Disclaimer: The findings and recommendations in this report are not indicative of any Government agency planning or commitments regarding future deep space radar.

Mission Needs & Overlaps

Missions & Needs Identified

Missions	Detection Sensitivity Threshold and Objective	Spatial Resolution	Frequency Constrains	Schedule Considerations	Facility Usage (time)
Planetary Defense	T: Detect 100 m NEA at 50 million km O: Detect 50 m NEA at 50 million km	5 m resolution at 8 million km	Proven success with S-band (2.4 GHz) and X-band (8.5 GHz)	Schedule within a day or two of apparition	<u>10%-20% of facility time needed:</u> • Assume several hours per NEA to be imaged • Assume hundreds of NEAs to be observed per year
Cislunar SSA	T: Detect 1 m metal sphere at Earth-Moon L2 distance O: Detect 0.2 m metal sphere at Earth-Moon L2 distance	N/A	S-band and higher frequencies	Generally easy to schedule well in advance	<u>10%-20% of facility time needed</u>: • Tens of minutes of continuous observations per day • 2-5 days per ~4-week period
Planetary Science	T: Radar echo spectra of Titan at opposition with OC SNR of 600 O: Detect 100 km asteroid at 5 AU	Same as Planetary Defense	< 8 GHz might be preferred	Generally easy to schedule well in advance	10% + of facility time
Atmospheric & Ionospheric Science	• Measure the complete altitude profile of the diurnal plasma line • Measure thermal plasma oscillations in the ionosphere	150 m vertical resolution	Current ISRs operate in the VHF and UHF frequency bands	Generally easy to schedule well in advance	10% + of facility time
Receive-only mission	10% + of facility time				

Full Cislunar SSA need is <u>unknown</u> – more information required on capacity (total and simultaneous # of targets, track and revisit times)

Deep Space Radar Needs Overlaps

Mission Area	Facility Sized for Planetary Defense (X-band)	Facility Sized for Cislunar SSA (X-band)
Planetary Defense	Covered by design	Expect shortfall
Cislunar SSA	Expect overage	Covered by design
Planetary Science	• Satisfy most planetary bodies lacking thick atmospheres • Needs C-band or lower for most planetary bodies with significant atmospheres (Venus, Titan)	• Satisfy some planetary bodies lacking thick atmospheres • Resolution and sensitivity constraints
Atmospheric, Ionospheric, & Geospace Science	No overlap unless additional Tx are considered	• No overlap unless additional Tx are considered • Possible sensitivity limitations for mission

Current and Potential/Planned Facility Performance

Facilities Assessed (Current and Planned)

Transmit Facility	Receive Facility	Planetary Defense		Cislunar SSA	
		Detect 100m NEA at 5e7 km	Detect 50m NEA at 5e7 km	Detect 1m metal sphere at Earth-Moon L2 distance	Detect 0.2m metal sphere at Earth-Moon L2 distance
Goldstone DSS-14		No	No	Yes	No
		(610 m)		(0.25 m)	
Goldstone	GBT	No	No	Yes	Yes
		(430 m)		(0.17 m)	
Goldstone	VLA	No	No	Yes	Yes
		(350 m)		(0.14 m)	
GBT+HPTx *	VLBA	No	No	Yes	Yes
		(340 m)		(0.11 m)	
GBT+HPTx *	VLA	No	No	Yes	Yes
		(210 m)		(0.07 m)	
GBT+HPTx *	ngVLA*	Yes	No	Yes	Yes
		(100 m)		(0.03 m)	

*Potential planned facility

Values in parentheses show the minimum object size that could be detected with the transmit/receive pairings at 50 million km and 450,000 km.

Current facilities do not meet the PD threshold sensitivity

The potential future combination of GBT+HPTx paired with the ngVLA would just meet the PD threshold

Current and Planned Facilities

Identification of capability gaps

- The most capable combination of current facilities is Goldstone to VLA
  - Exceeds the Cislunar objective, but
  - Does not meet the Planetary Defense detection threshold

- The most capable combination of potentially planned future facilities is GBT+High Power Radar to ngVLA
  - Exceeds Cislunar objective, and
  - Meets Planetary Defense threshold, but
  - Does not meet the Planetary Defense detection objective
  - Does not meet all Planetary Science mission needs
  - Does not meet Atmospheric, Ionospheric, and Geospace Science

- Notional facilities were designed to meet the Cislunar and Planetary Defense thresholds & objectives
  - Partially fill the identified capability gaps

Design of Notional Reference Architectures

Notional Facilities Designed to Meet Mission Needs

Transmit Facility*	Receive Facility*	Planetary Defense		Cislunar SSA	
		Detect 100m NEA at 5e7 km	Detect 50m NEA at 5e7 km	Detect 1m metal sphere at Earth-Moon L2 distance	Detect 0.2m metal sphere at Earth-Moon L2 distance
11 notional transmitters	9 notional receivers	No	No	Yes	No
		(1100 m)		(0.45 m)	
36 notional transmitters	21 notional receivers	No	No	Yes	Yes
		(220 m)		(0.09 m)	
25 notional transmitters	ngVLA	Yes	No	Yes	Yes
		(100 m)		(0.04 m)	
60 notional transmitters	37 notional receivers	Yes	No	Yes	Yes
		(100 m)		(0.04 m)	
51 notional transmitters	ngVLA	Yes	Yes	Yes	Yes
		(50 m)		(0.02 m)	
95 notional transmitters	59 notional receivers	Yes	Yes	Yes	Yes
		(50 m)		(0.02 m)	

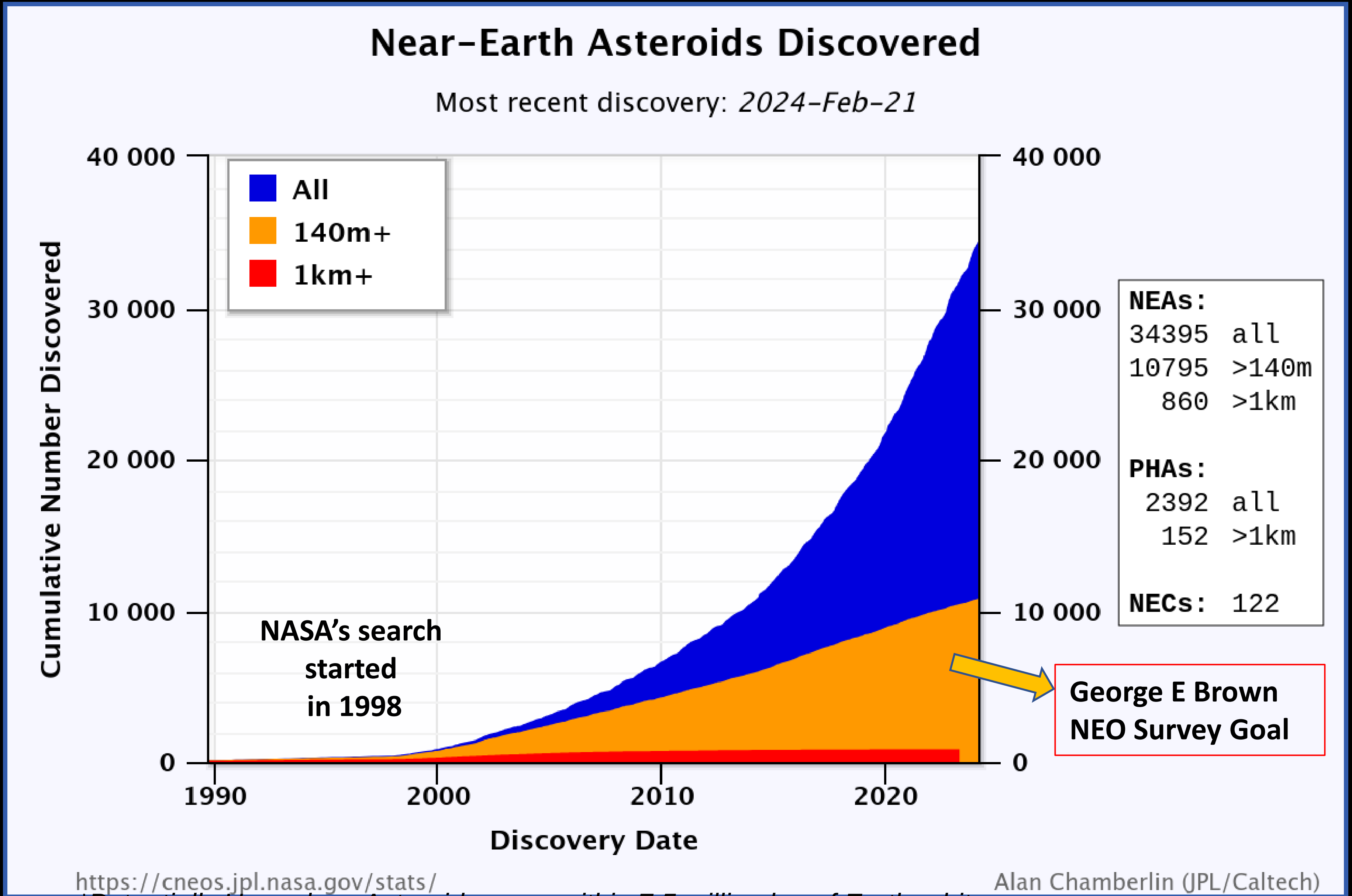
** Bistatic arrays of 18 m transmit and receive antennas, 50 kW transmitted power at X-band per antenna. Values in parentheses show the minimum object size that could be detected with the transmit/receive pairings at 5e7 km and 450,000 km.*

It takes several times more antennas to meet the PD sensitivity needs than the cislunar SSA sensitivity needs

Conclusions

- There are areas of significant overlap in needs between the many missions and stakeholders.
- A radar facility designed for the planetary defense mission could
  - Fully satisfy cislunar SSA mission needs
  - Contribute significantly to planetary science needs
- A radar facility designed for the planetary defense mission would not satisfy, without modifications
  - Atmospheric, ionospheric, and geospace mission needs
  - Earth Orbit SSA mission needs
- In terms of capacity, it would be reasonable for the planetary defense, planetary science, and cislunar SSA missions to share time on a multi-use facility
  - Some uncertainty in the fractional facility time that would be desired by the cislunar SSA community.
- $500M facility with tens of transmit and receive antennas will meet the cislunar SSA threshold sensitivity
  - Assumed 18 m apertures and 50 kW X-band transmitters
- ~$2.2B facility with ~100 transmit and receive antennas will meet the planetary defense threshold sensitivity
  - Assumed 18 m apertures and 50 kW X-band transmitters
  - More than meets the cislunar SSA needs
- Pairing the GBT high-power radar facility (GBT+HPTx) with the ngVLA could satisfy the threshold planetary defense mission sensitivity needs

Significant investment would be needed to meet the mission needs with a dedicated, multi-use deep space radar



*Potentially Hazardous Asteroids come within 7.5 million km of Earth orbit

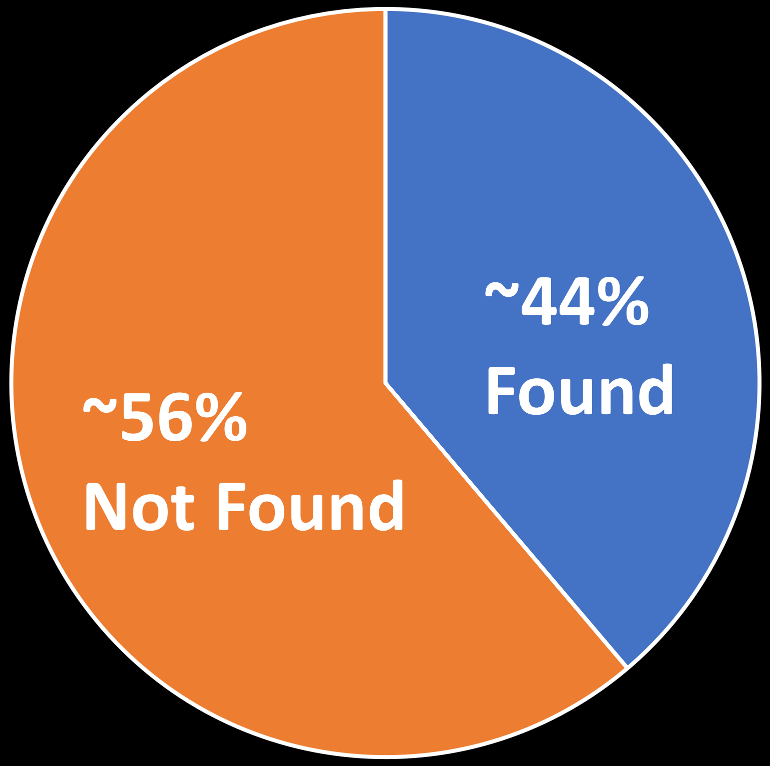
Progress Toward Finding 90% of NEOs 140 Meters and Larger

Total Population estimated to be ~25,000

NEO Survey Status as of 31 Dec 2023

George E Brown NEO Survey Goal: **(tasked in 2005)**

Find at least 90% of NEOs 140 meter and larger within 15 years



At the current assets' discovery rate, it will take more than 30 years to complete the survey.

New capabilities in development will cut that time in half.

PLANETARY DEFENSE
COORDINATION OFFICE

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Study Flow

Stakeholder Inputs
- NSF
- NASA
- DoD

Potential Mission Areas
- Planetary Defense
- Cislunar SSA
- Atmospheric Science
- Planetary Science
- Radio Astronomy
- Earth Orbit SSA

Needs Analysis
Driving vs. Informing:
- Planetary Defense and Cislunar SSA **drive** design
- Planetary Science and Atmospheric Science **inform** design

Define Trade Space, e.g.,
- Frequency band(s)
- Single dish vs. array

FFRDC and UARC
SME Inputs:
- JHU/APL
- JPL
- NRAO
- MITLL

Trade Decisions
- Freq. Bands
- Tx Power
- Tech Assumptions

Reference Architectures

Threshold Cislunar
- Mid-Term: 10-15 years
- Low technical risk

Threshold PD
- Mid-Term: 10-15 years
- Low technical risk

Objective Cislunar
- Mid-Term: 10-15 years
- Scaled up Threshold

Objective PD
- Far-Term: 20-25 years
- Scaled up Threshold