The Deep Space Network
Status and Future

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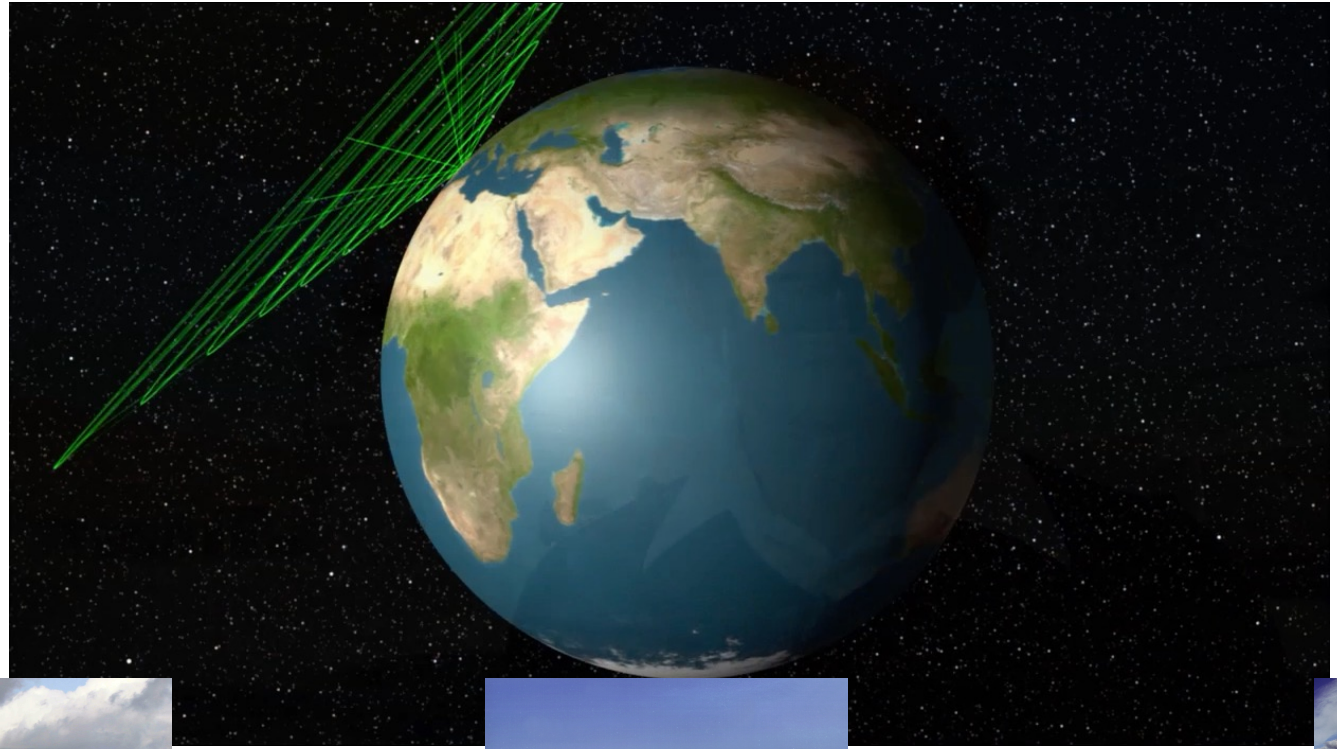
The Deep Space Network



Deep Space Network and Missions

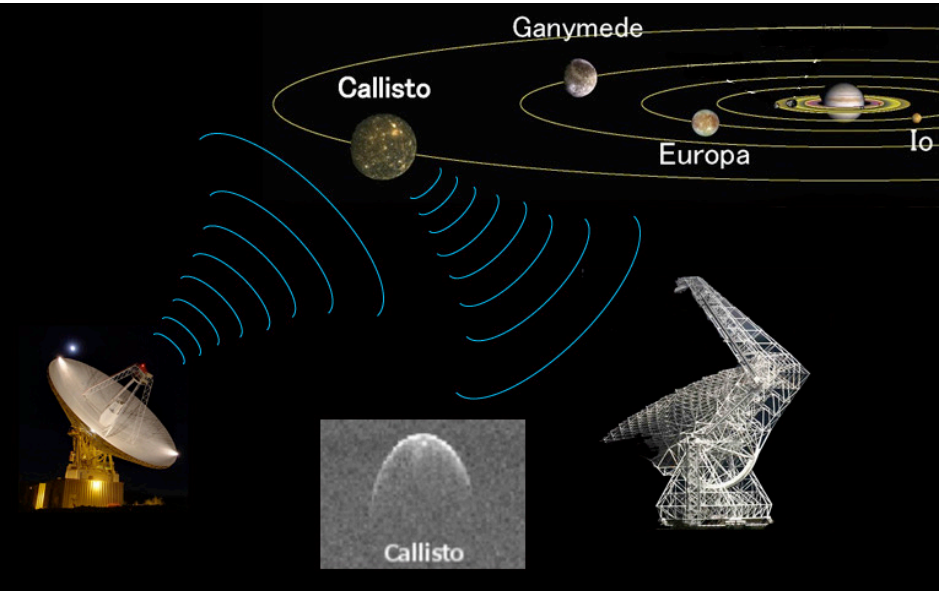
Don’t leave Earth without the DSN!

Deep Space Network and Ocean Worlds & Dwarf Planets Missions

Deep Space Network

- **Ocean Worlds and Dwarf Planet science with the DSN**
- **Status and near-term**
- **Longer term**

Ranging to the Galilean Satellites



Goldstone Solar System Radar-*Arecibo*-Green Bank Telescope ranging to Galilean satellites

- **Aiming for 2 km uncertainties in orbits (5× improvement)**
- **Motivation includes improved navigation for Jovian tours**

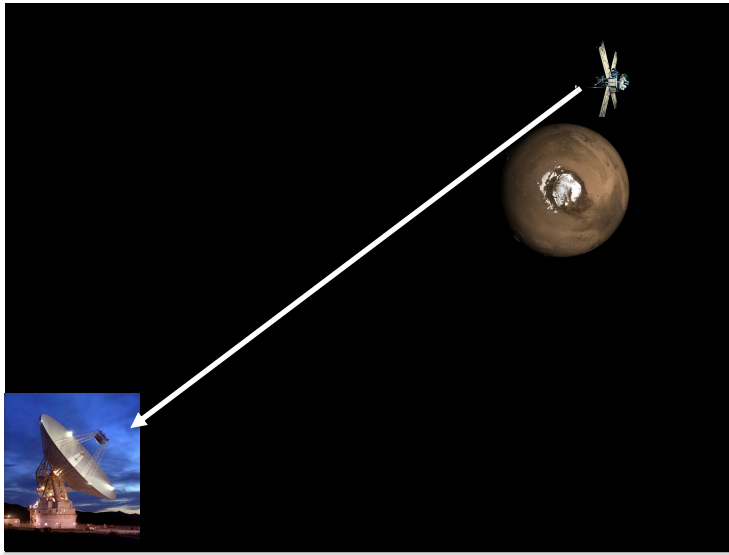
Radio Science

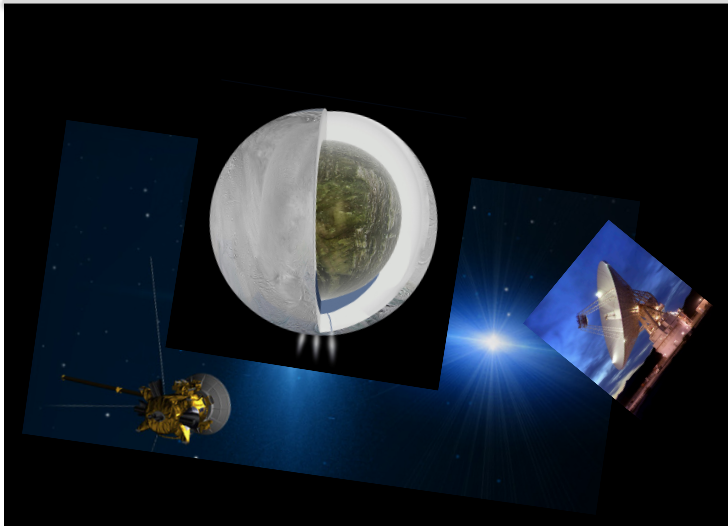
a.k.a. Gravity Science

Apparent even with early missions that occultations by planetary atmospheres would affect radio communications

- **Or one person's annoyance is another's data**
  - **"Occultation Experiment: Results of the First Direct Measurement of Mars's Atmosphere and Ionosphere" (Kliore et al. 1965, *Science*)**
    - **"Preliminary Results on the Atmospheres of Io and Jupiter from the Pioneer 10 S-Band Occultation Experiment" (Kliore et al. 1974, *Science*)**
- **Can also study planetary interior!**
  - **"The Gravity Field and Interior Structure of Enceladus" (Iess et al. 2014, *Science*)**

Turn the DSN+spacecraft into one giant science instrument!



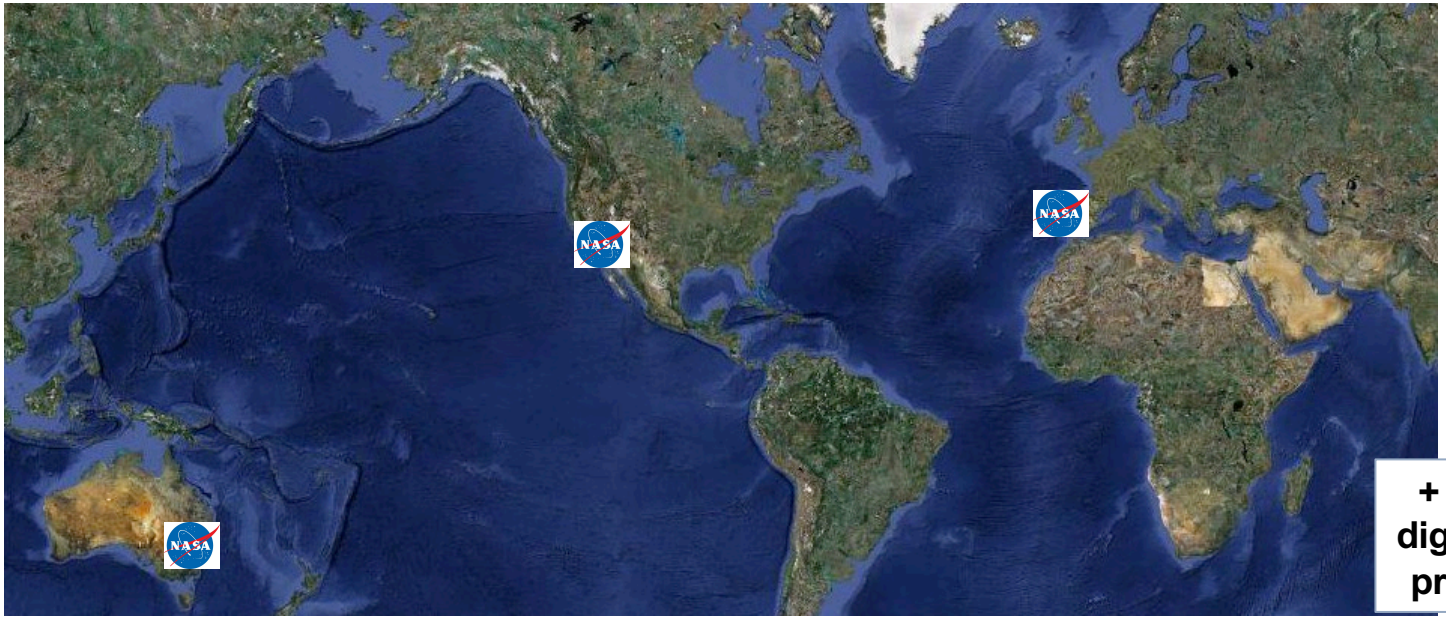


Deep Space Network

- Ocean Worlds and Dwarf Planets science with the DSN
- **Status and near-term (ca. 2025)**
  Notionally funded plans
- **Longer term**

Deep Space Network

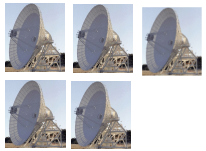
DSN Aperture Enhancement Project (ca. 2023)



+ backend digital signal processing

Canberra

Goldstone



Madrid

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Deep Space Network

Near Term	 Canberra		 Goldstone		 Madrid		✓ = uplink+downlink; ✓= downlink
	 34 m		 34 m		 34 m		
S band	✓✓	✓	✓✓	✓	✓✓✓	✓	
X band	✓✓✓	✓	✓✓✓	✓	✓✓✓✓✓	✓	telemetry, Radio Science, “for communication through the atmosphere of Titan” (*V&V*)
K band	✓✓		✓✓		✓✓		*lunar, E-S L2*
Ka band	✓✓✓		✓✓		✓✓✓		telemetry, Radio Science

Additional Near-Term Improvements

- **70 m transmitters and facilities**
  - **DSS-43 (Canberra) finished in 2021 March**
- **Additional antenna arraying**
- **Delay/Disruption Tolerant Networking (DTN) throughout DSN**
- **Low latency delivery of high data**
  - **For lunar missions**
- **Multiple Spacecraft Per Aperture (MSPA) capabilities**
- **Three Links per Operator**

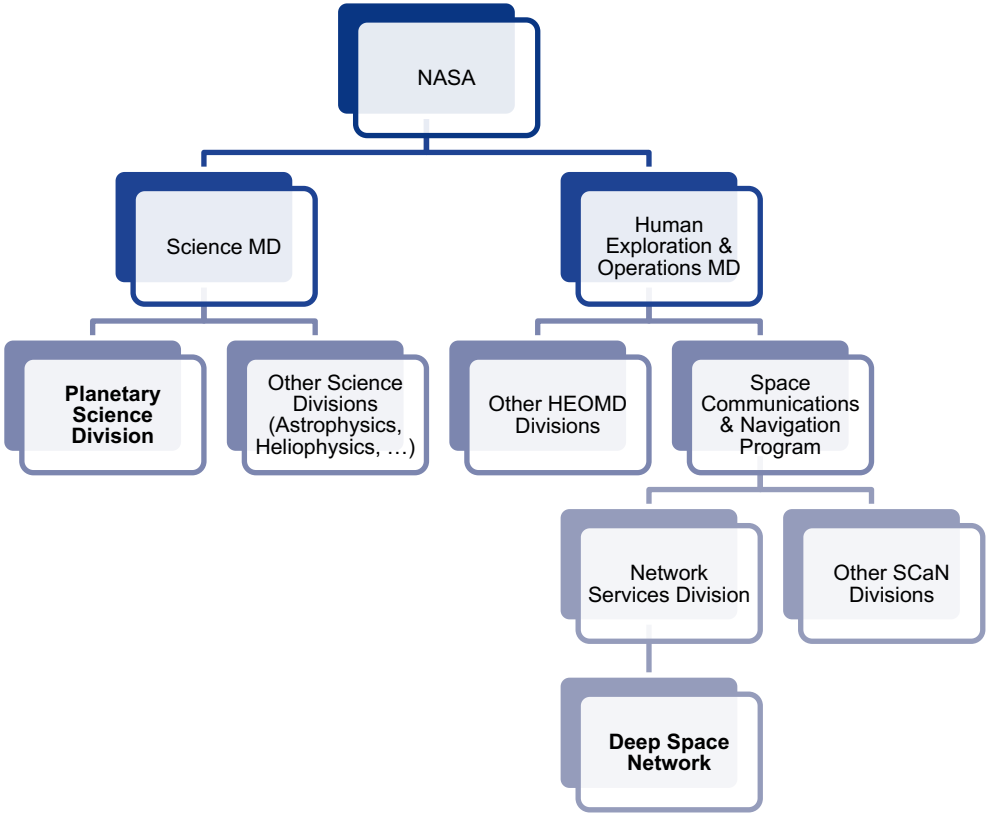
Maintenance

NASA Inspector General report "NASA's Planetary Science Portfolio" (Report No. IG-20-023, 2020 September 16)

- **"NASA has not adequately funded Deep Space Network (DSN) repair, maintenance, and modernization efforts. … Although DSN is meeting its current operational commitments, in our opinion, budget reductions have impacted the Network's performance and threaten its future reliability."**
- **DSN concurs with recommendations in this report**
- **DSN working with Space Communications and Navigation (SCaN) program in "DSN Road to Green" study**

  Green = low risk, *not* additional funding

DSN within NASA



Deep Space Network

- Ocean World and Dwarf Planet science with the DSN
- Status and near-term
- **Longer term**
  - **Feasibility of higher data rates/larger data volumes from the outer Solar System**
  - **DSS-54 repair**
  - **Ka-band uplink**
  - **Goldstone Solar System Radar modernization**
  - **34 m (beam wave guide) transmitter and control systems**

Deep Space Network

Longer Term

Feasibility of higher data rates/larger data volumes from outer Solar System

- **Challenge: Large distances *R***
- **"Knobs to turn," a.k.a. what we can do**
  - **Wavelength (X vs. Ka vs. laser) [increase G_R]**
  - **Ground antenna (antennas) aperture [increase G_R]**
    - **Spacecraft antenna aperture G_T**
      - ***Cassini* = 4 m diameter**
        - **Yes! but mass**
    - **Spacecraft transmitter power P_T**
    - **Better coding**
      viz. *Galileo*

Link budget

$$P_R = \frac{G_R G_T P_T \lambda^2}{4\pi R^2}$$

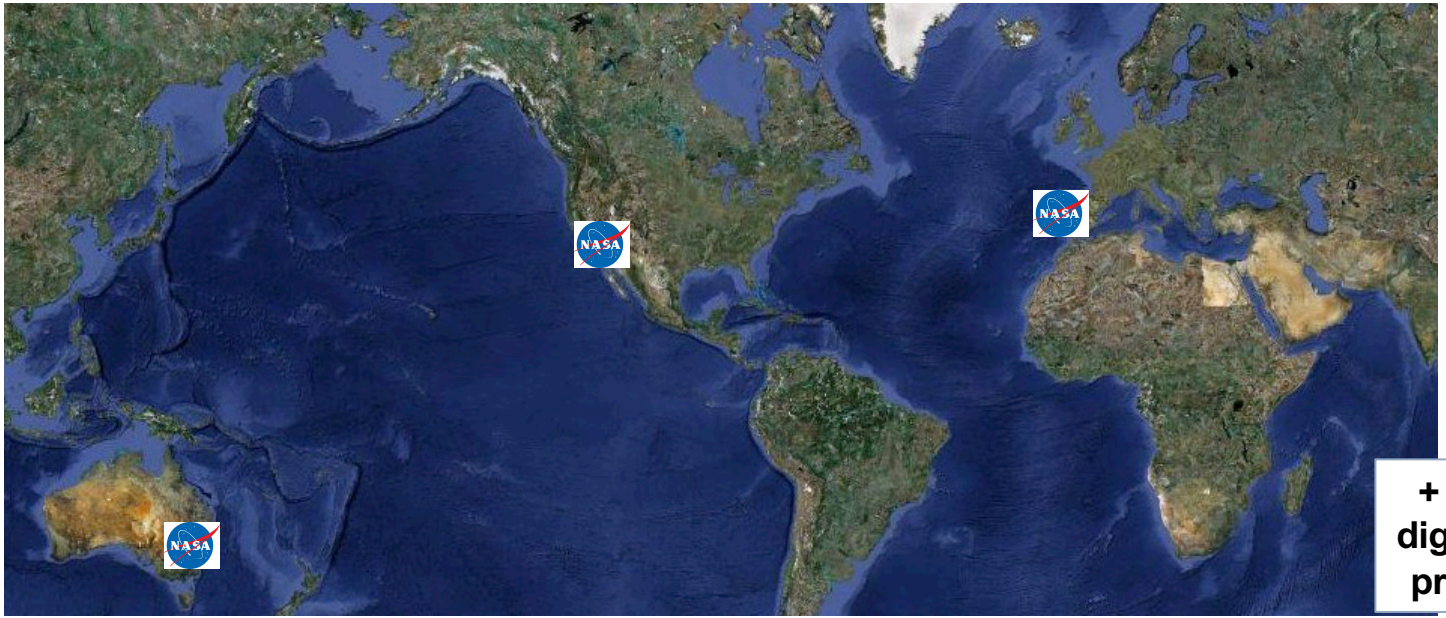
Laser (Optical) Communications

Hybrid RF-Optical Antenna

- **Larger bandwidths = higher data rates**
  - **Ka band better than X band**
- **DSS-23 (Goldstone) intended to be Hybrid RF-Optical Antenna**
  - **Inner panels replaced by mirrors**
  - **Available ca. 2032**
- **Laser communications often designed around high data rates from Mars**
  - ➢ **Significant outer Solar System challenges**
    - ? **Acquisition (beacon)**
    - ? **Pointing**
    - ? **Aperture diameter (ground and flight)**

Deep Space Network

DSN Aperture Enhancement Project (ca. 2027)



+ backend digital signal processing

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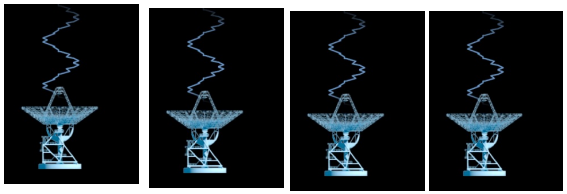
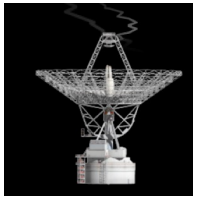
Higher Data Rates from the Outer Solar System

Part I – Additional Antenna Arraying



4 × 34 m antennas **=**

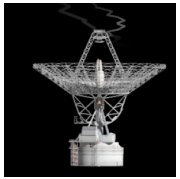


70 m antenna

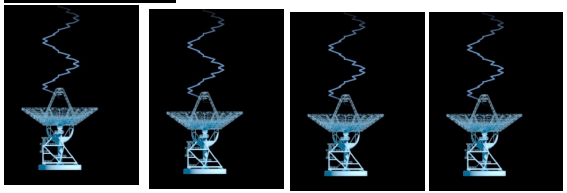
- **Voyager and New Horizons already use antenna arraying**
- **On-going developments aimed at additional capabilities**
  - **E.g., simultaneous arrays of 70+34 and 3×34**
- **Limited number of antennas in DSN result in scheduling challenges**
  - **vis. *Visions & Voyages***

Higher Data Rates from the Outer Solar System

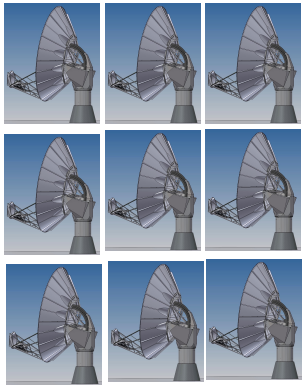
Part II – Additional DSN Antennas



70 m antenna



34 m antennas



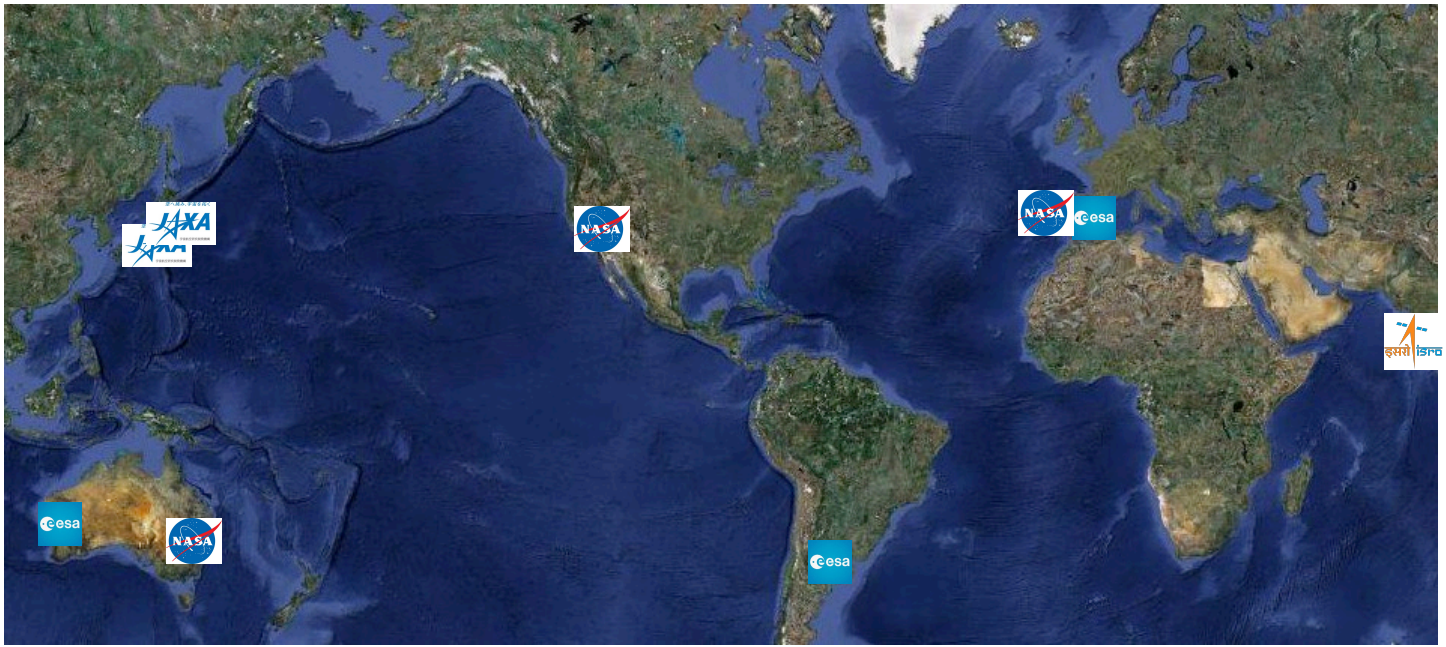
smaller diameter antennas

Continue DSN Aperture Enhancement Project, adding additional antennas

- Consistent with recommendation from *Visions & Voyages*
- Additional robustness
- Additional flexibility
  - Array antennas when needed for high gain (outer Solar System)
  - Voyager and New Horizons already use antenna arraying, but limited number of antennas in DSN result in scheduling challenges

Higher Data Rates from the Outer Solar System

Part IIIa – Partnerships with Other Space Agencies



New Norcia
Cebreros
Malargüe

Canberra
Goldstone
Madrid

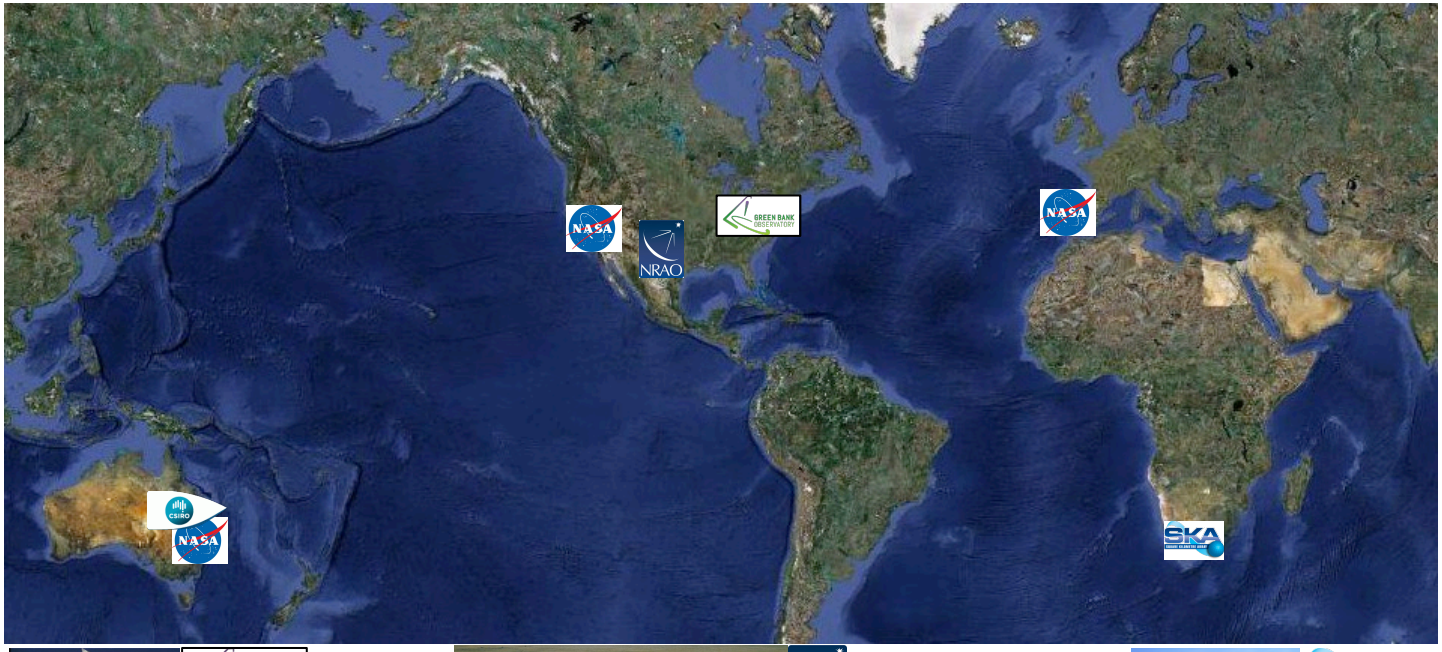
Usuda
Uchinoura

Byalalu

Higher Data Rates from the Outer Solar System

Part IIIb – Partnerships with Radio Telescopes

Radio telescopes with current or planned X- and/or Ka-band capabilities



Parkes Radio Telescope
✓ **Voyagers**

Green Bank Telescope
✓ **Mars missions**

Very Large Array
✓ **Voyager 2**
next-generation VLA?

Square Kilometre Array?

Deep Space Network

- DSN is and has been integral to Ocean Worlds and Dwarf Planet science
  - Spacecraft telemetry
  - Radar and Radio Science
- DSN adding new antennas, and additional improvements, planned in near term
- Significant issues with deferred maintenance
- Multiple opportunities and challenges for higher data rates/larger data volumes from outer Solar System in longer term

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backup

(Inter-)National Radar Assets

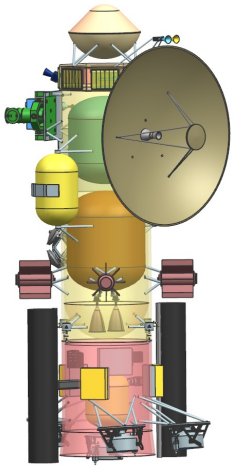
Goldstone DSS-14 (DSN)
70 m antenna, 500 kW transmitter, 4 cm wavelength (X band)

Arecibo (NAIC)
300 m antenna, 1 MW transmitter, 13 cm wavelength (S band)

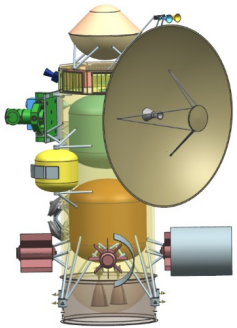
Green Bank Telescope (GBO)
100 m antenna, receive-only

Canberra DSS-43 (DSN) + Australia Telescope Compact Array
70 m antenna transmit + 5 × 22 m receive

Radio Science and Gravity Science



Neptune Orbiter with Probe, SEP, and 50 kg payload



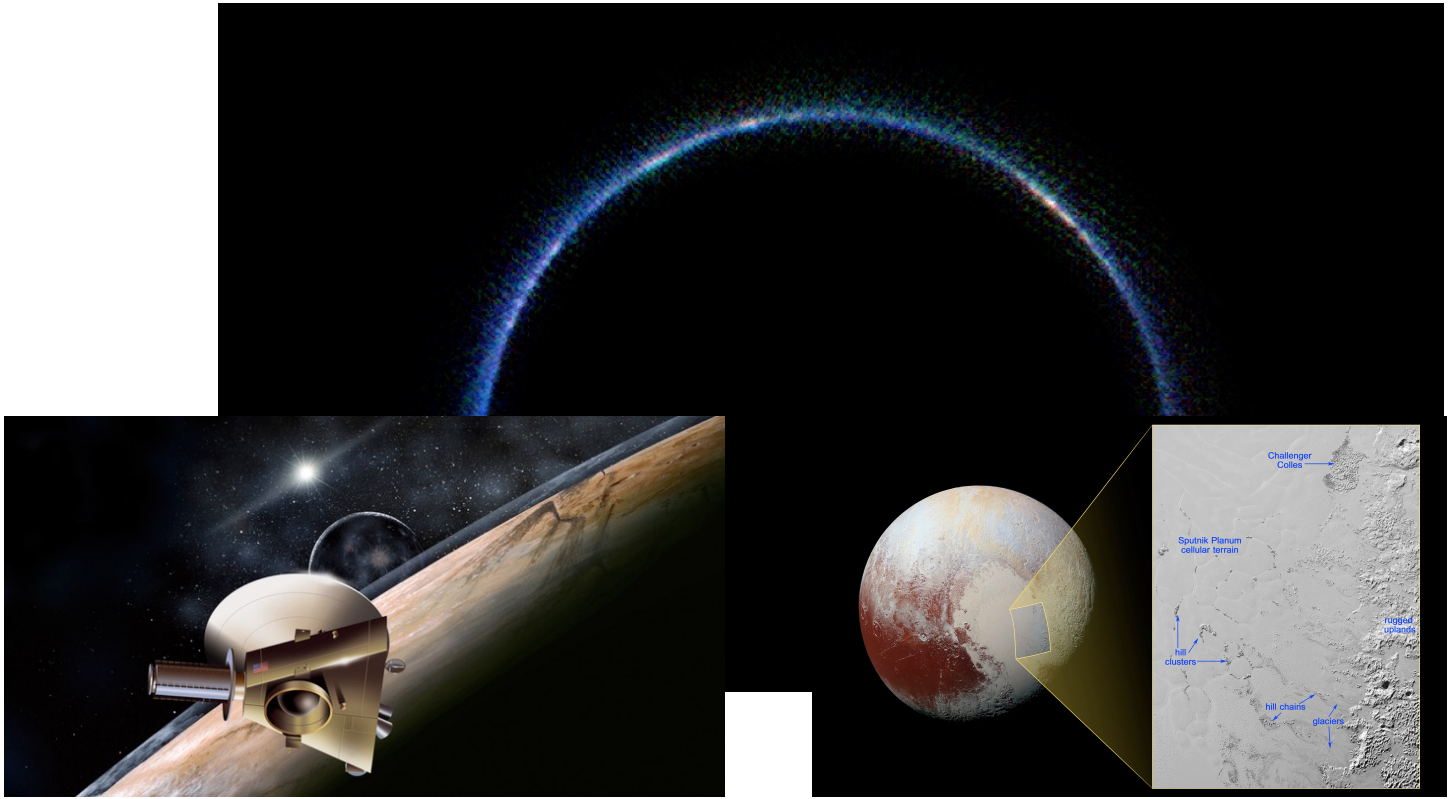
Uranus Orbiter with Probe and 50 kg payload

Ice Giant Mission Concept Science Objective

1. **Constrain the structure and characteristics of the planet's interior, including layering, locations of convective and stable regions, internal dynamics**

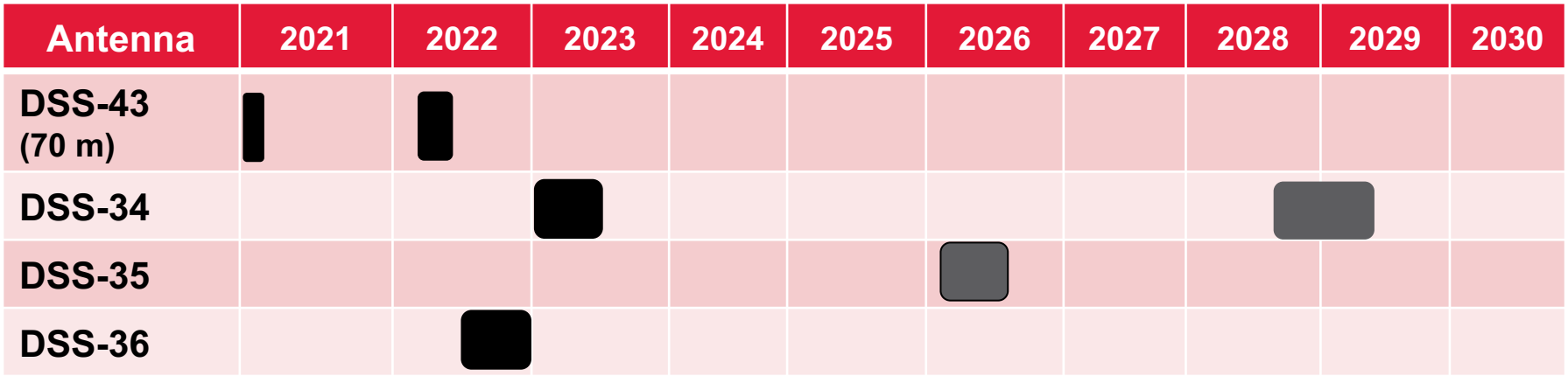
DSN-REX

New Horizons



Future Antenna Downtimes

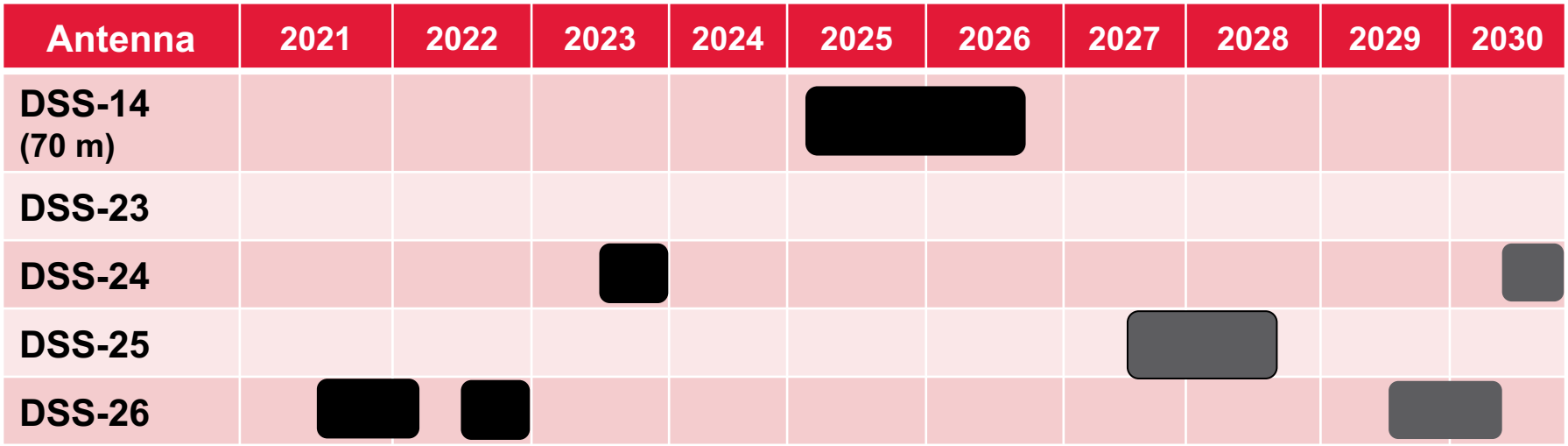
Canberra Complex



Intervals shown are representative and subject to change

Future Antenna Downtimes

Goldstone Complex



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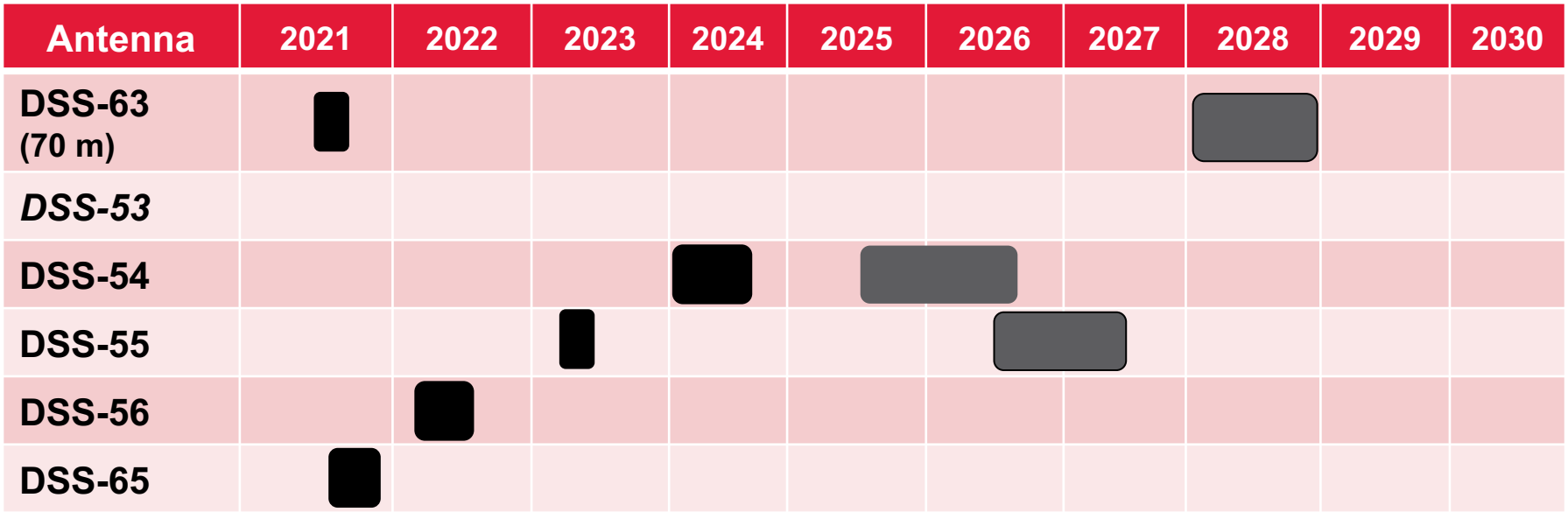
Future Antenna Downtimes

Madrid Complex



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