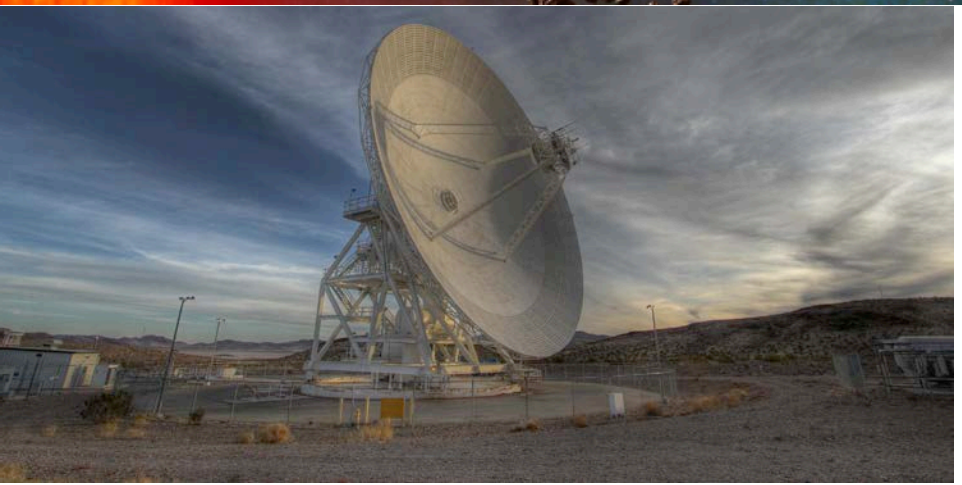

The Deep Space Network

Status and Future

Joseph Lazio, Bradford Arnold, Brian Giovanelli, Michael Levesque, Jeff Berner, Amy Smith

Jet Propulsion Laboratory
California Institute of Technology

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Government sponsorship acknowledged.

The Deep Space Network

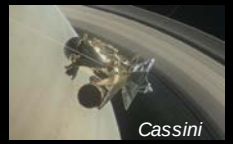
Deep Space Network and Missions

Don’t leave Earth without the DSN!

Deep Space Network and Giant Planet Systems Missions

Pioneer 10

Pioneer 11


Cassini

Voyager 1

Voyager 2

New Horizons

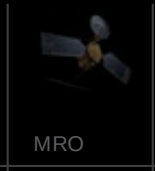
Geotail

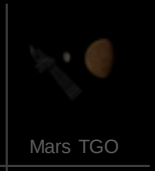
Mars Odyssey

Curiosity

MAVEN

MOM


MRO


Mars TGO

ARTEMIS

OSIRIS REx

XMM

Cluster

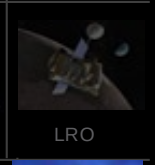
JUNO

Akatsuki

Hayabusa-2

Mars Express

ACE


LRO

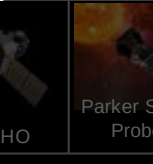
Chandra

MMS

STEREO A

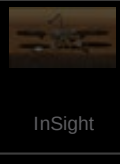
Wind

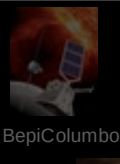
DSCOVR

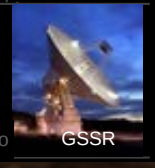

SOHO

Parker Solar Probe

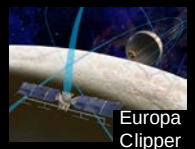
TESS


InSight


BepiColumbo


GSSR

Lucy


Europa Clipper

JUICE

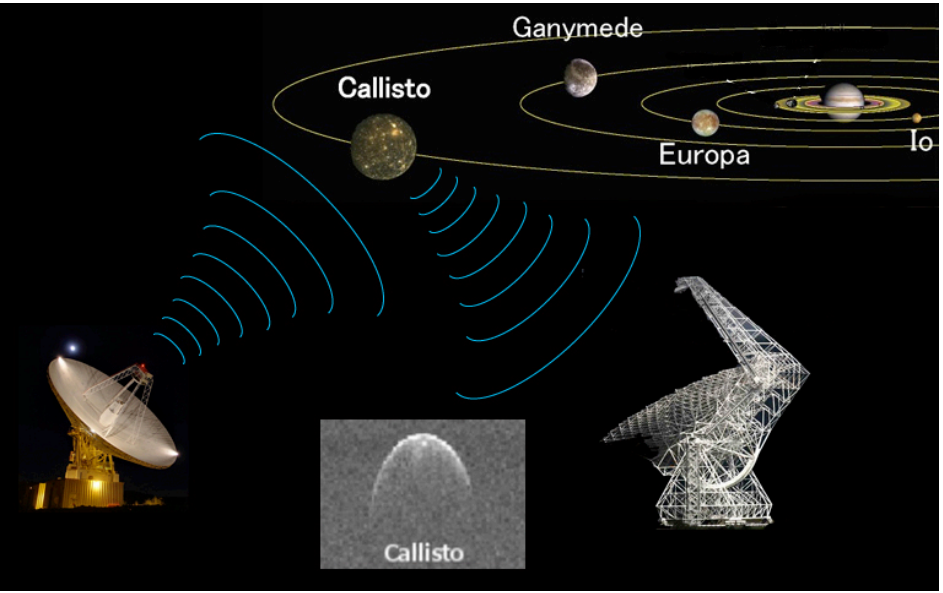
Mars 2020

Don’t leave Earth without the DSN!

Deep Space Network

- **Giant planet science with the DSN**
- **Status and near-term**
- **Longer term**

Ranging to the Galilean Satellites



Jupiter's tidal dissipation constrains interior structure

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

- **Aiming for 2 km uncertainties in orbits (5× improvement)**
- **Detect secular acceleration of Galilean satellites from Jovian tides**
- **Determine tidal dissipation parameter k_2/Q**
- **Juno measures k_2**

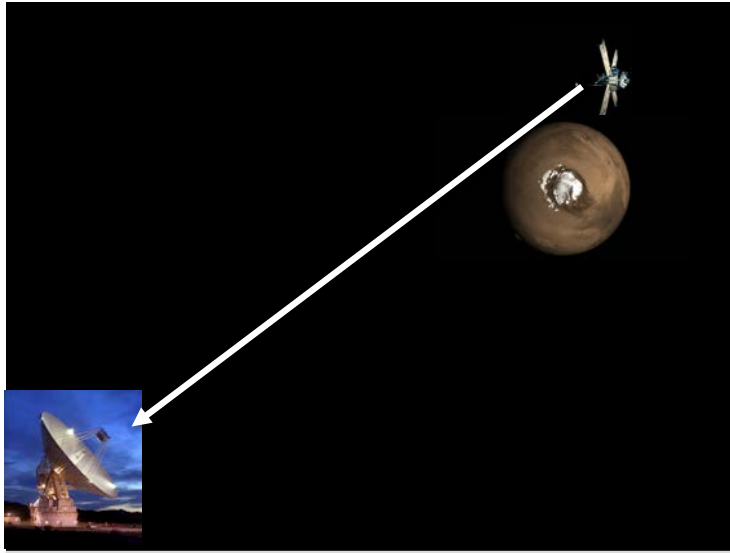
Radio Science

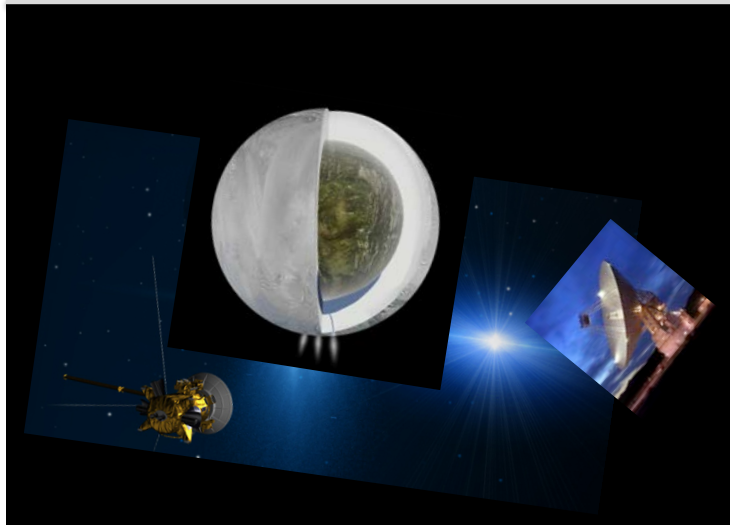
a.k.a. Gravity Science

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

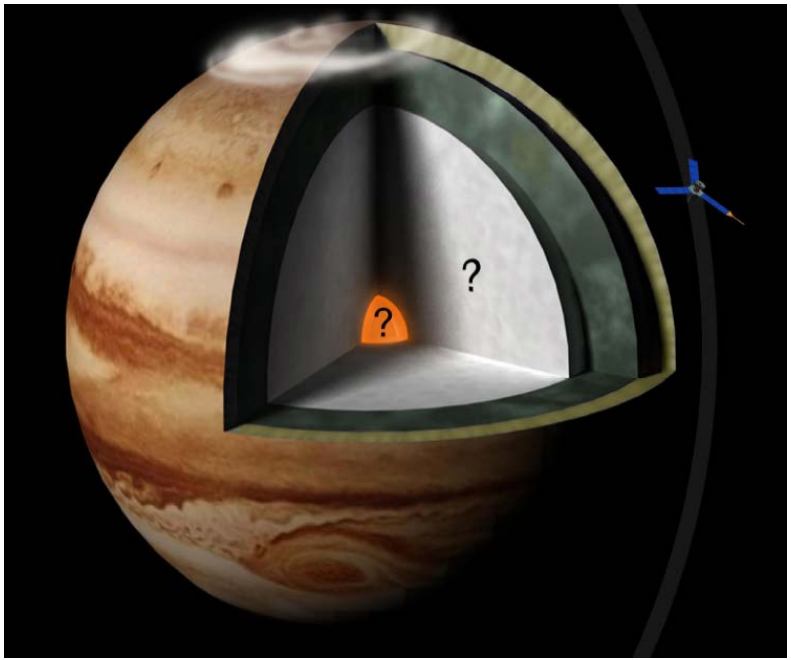
- **Or one person's annoyance is another's data --- Study atmospheric properties!**
  - **"Occultation Experiment: Results of the First Direct Measurement of Mars's Atmosphere and Ionosphere" (Kliore et al. 1965, *Science*)**
    - **"Preliminary Results on the Atmospheres of Io and Jupiter from the Pioneer 10 S-Band Occultation Experiment" (Kliore et al. 1974, *Science*)**
- **Can also study planetary interior!**
  - **"Gravitational Parameters of the Jupiter System from the Doppler Tracking of Pioneer 10" (Anderson et al. 1974, *Science*)**

Turn the DSN+spacecraft into one giant science instrument!





Radio Science and Gravity Science



Juno Science Objectives via Gravity Science

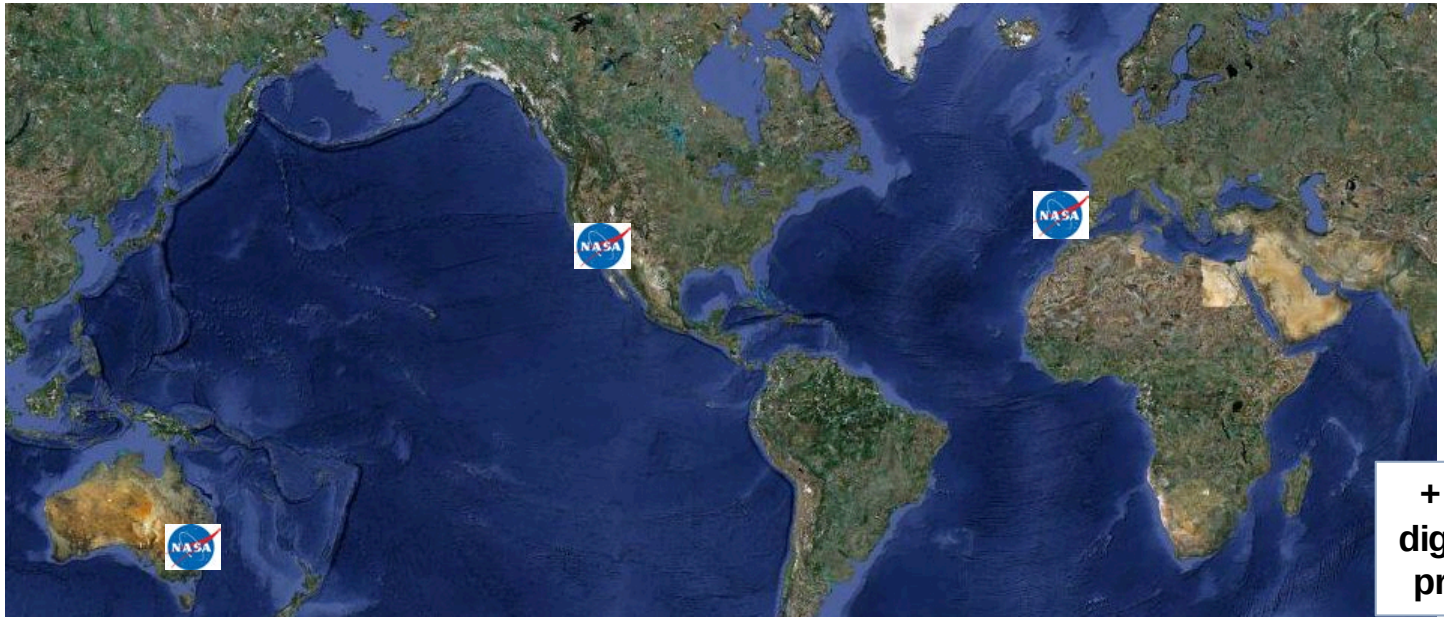
- **Origin**
  - Determine the abundance of water and place an upper limit on the mass of Jupiter's dense core to decide which theory of the planet's origin is correct
- **Interior**
  - Understand Jupiter's interior structure and how material moves deep within the planet by mapping its gravitational and magnetic fields

Deep Space Network

- Giant planet 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

10

Deep Space Network

Near Term	Canberra		Goldstone		Madrid		
	34 m		34 m		34 m		
S band	✓✓	✓	✓✓	✓	✓✓✓	✓	"outer planet atmos-pheric occultations" *(V+V)*
X band	✓✓✓✓	✓	✓✓✓✓	✓	✓✓✓✓✓	✓	telemetry, Radio Science
K band	✓✓		✓✓		✓✓		*lunar, E-S L2*
Ka band	✓✓		✓✓✓		✓✓✓✓		telemetry, Radio Science

✓ = uplink+downlink; ✓= downlink

Additional Near-Term Improvements

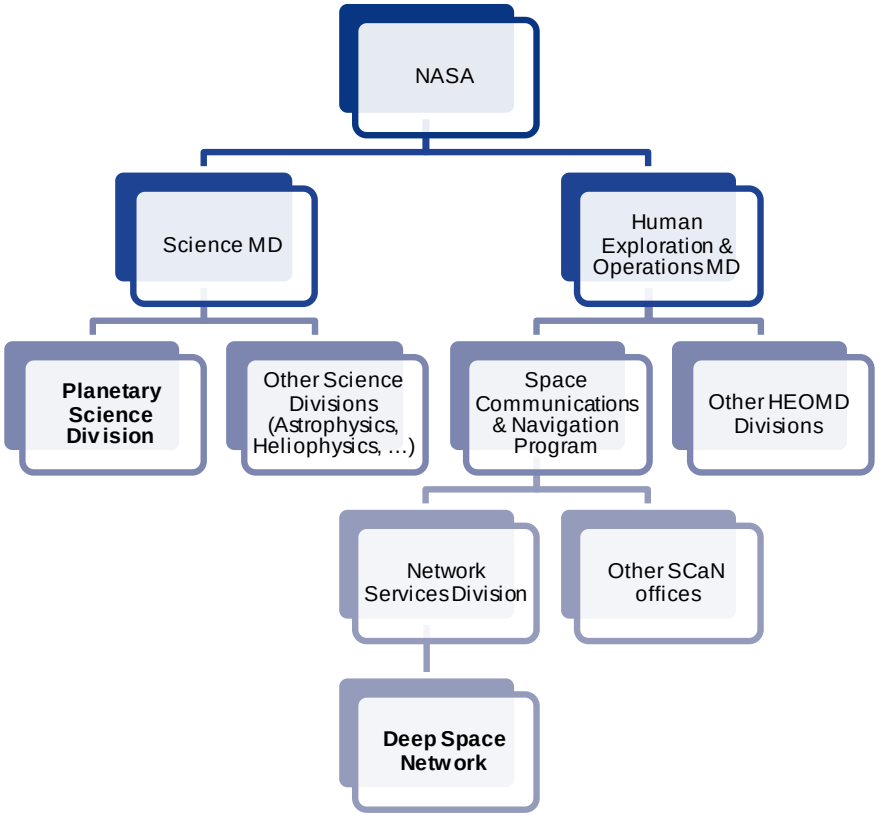
- **70 m transmitters and facilities**
  - **DSS-43 (Canberra) finishing in 2021 February**
- **Additional antenna arraying**
- **Delay/Disruption Tolerant Networking (DTN) throughout DSN**
- **Low latency delivery of high data**
  - **For lunar missions**
- **Multiple Spacecraft Per Aperture (MSPA)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

- Giant 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 the outer Solar System

- **Challenge: Large distances**
- **"Knobs to turn"**
  - **Wavelength (X vs. Ka vs. laser)**
  - **Ground antenna (or antennas) aperture 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

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

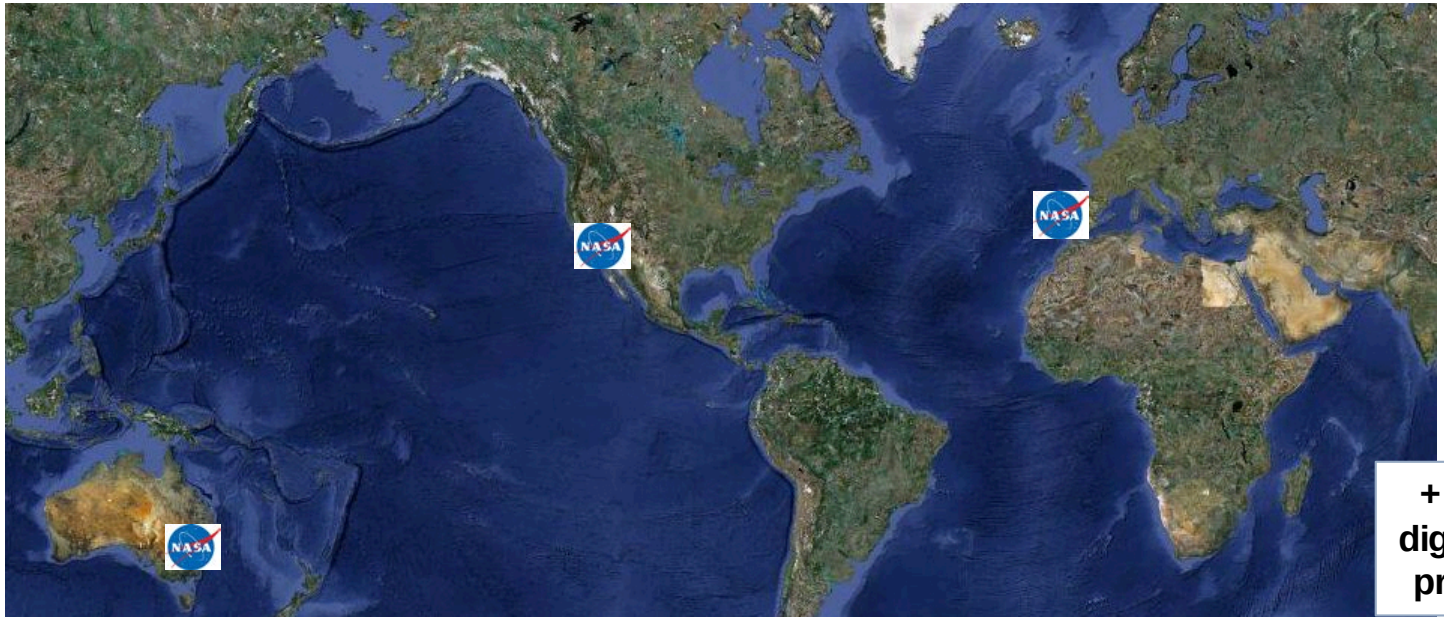
Laser (Optical) Communications

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. 2027
- Laser communications often designed around high data rates from Mars
  - ➢ Significant outer Solar System challenges
    - ? Acquisition (beacon)
    - ? Pointing

Deep Space Network

DSN Aperture Enhancement Project (ca. 2027)



+ backend digital signal processing

Canberra

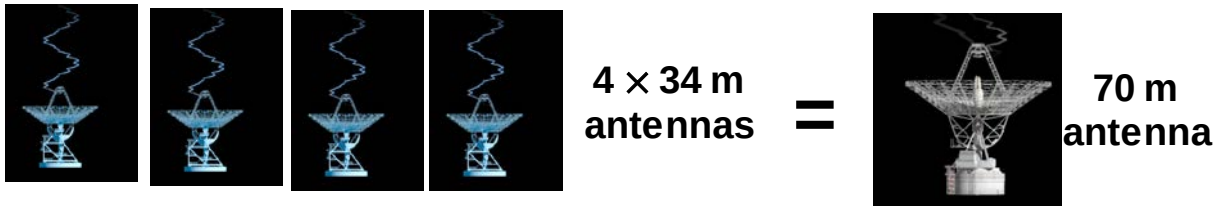
Goldstone

Madrid

18

Higher Data Rates from the Outer Solar System

Part I – Additional Antenna Arraying

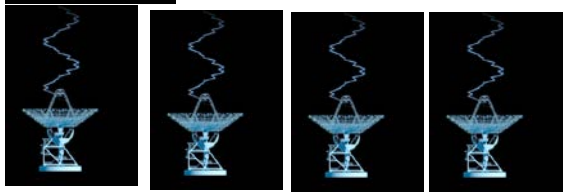


- **Voyager and New Horizons already use antenna arraying**
- **On-going developments aimed at additional capabilities**
  E.g., simultaneous arrays of 70+34 and 3×34
- **Limited number of antennas in DSN result in scheduling challenges**

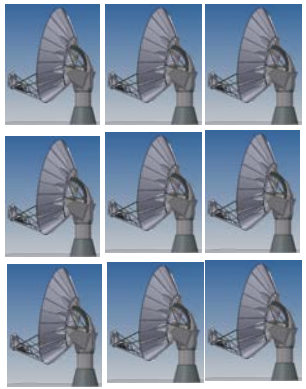
Higher Data Rates from the Outer Solar System

Part II – Additional DSN Antennas

70 m antenna



34 m antennas



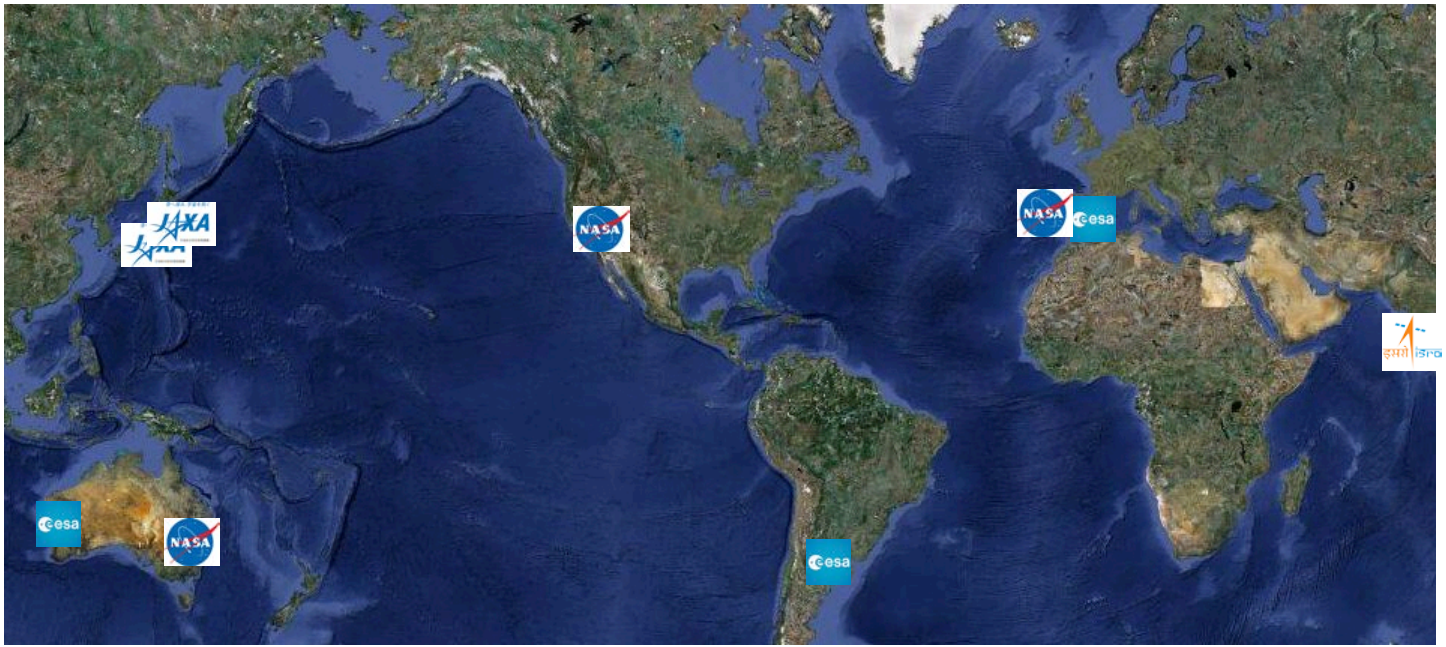
smaller diameter antennas

Continue DSN Aperture Enhancement Project, adding additional antennas

- Consistent with recommendation from *V&V*
- 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

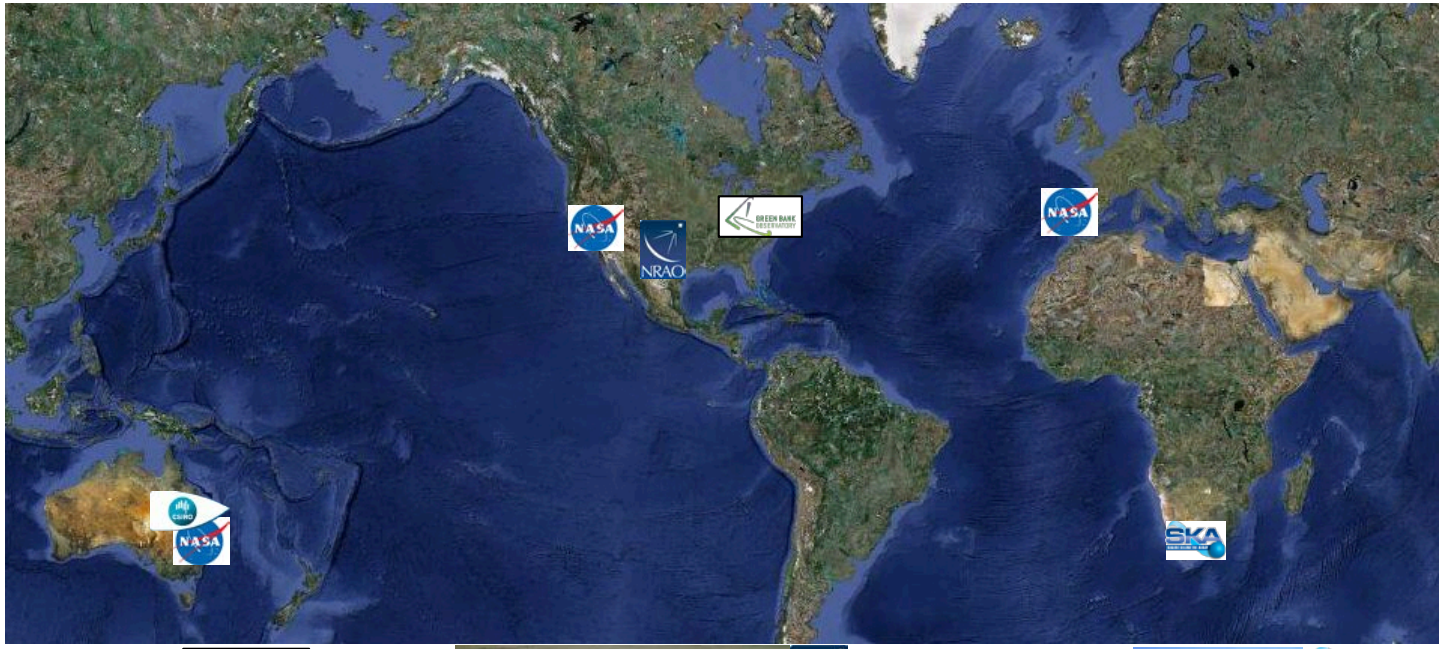
Usuda
Uchinoura

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?

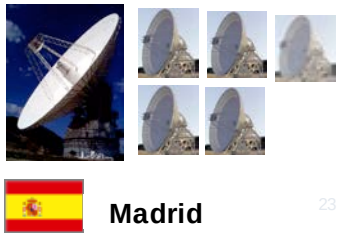
Summary

Deep Space Network

- **DSN is and has been integral to Giant 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 Giant Planets in longer term**

Canberra

Goldstone



Madrid

23

backup

(Inter-)National Radar Assets

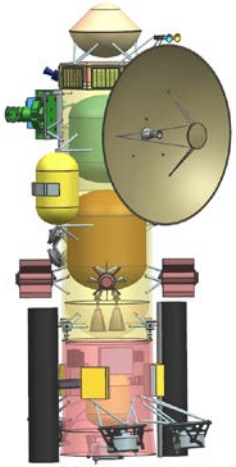
Goldstone DSS-14 (DSN)
70 m antenna, 500 kW transmitter, 4 cm wavelength (X band)

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

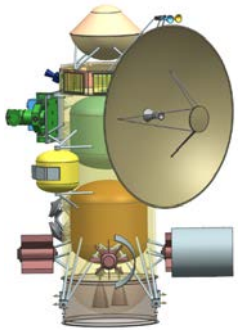
Green Bank Telescope (GBO)
100 m antenna, receive-only

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



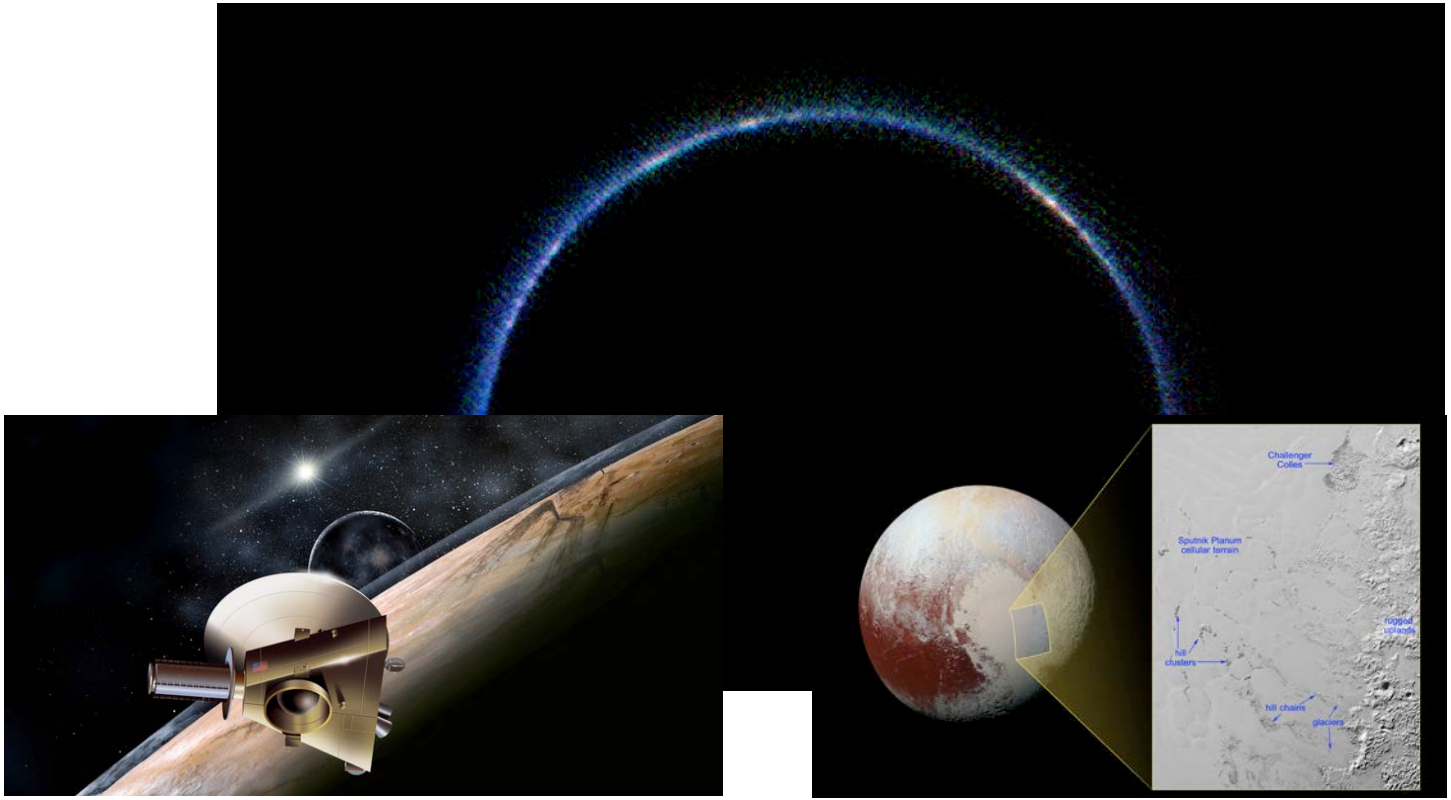
Uranus Orbiter with Probe and 50 kg payload

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**

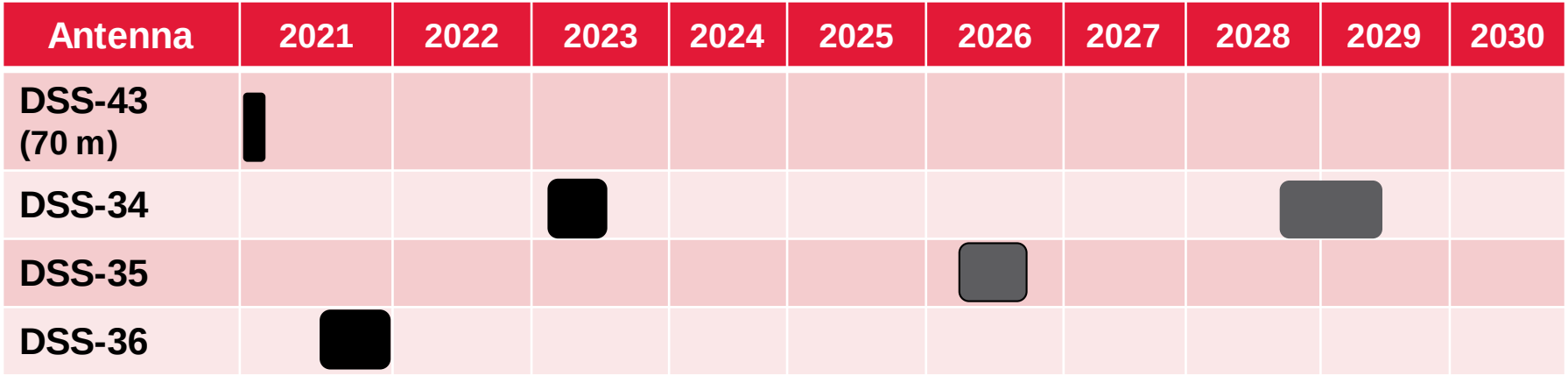
DSN-REX

New Horizons



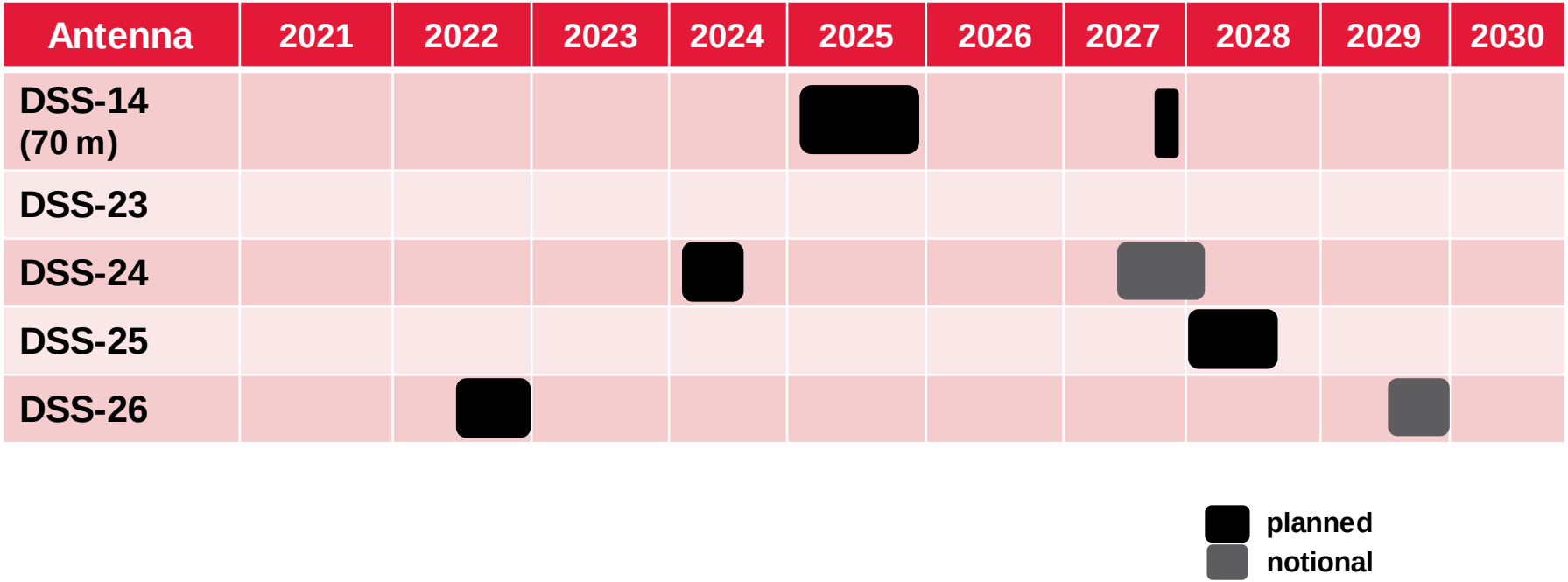
Future Antenna Downtimes

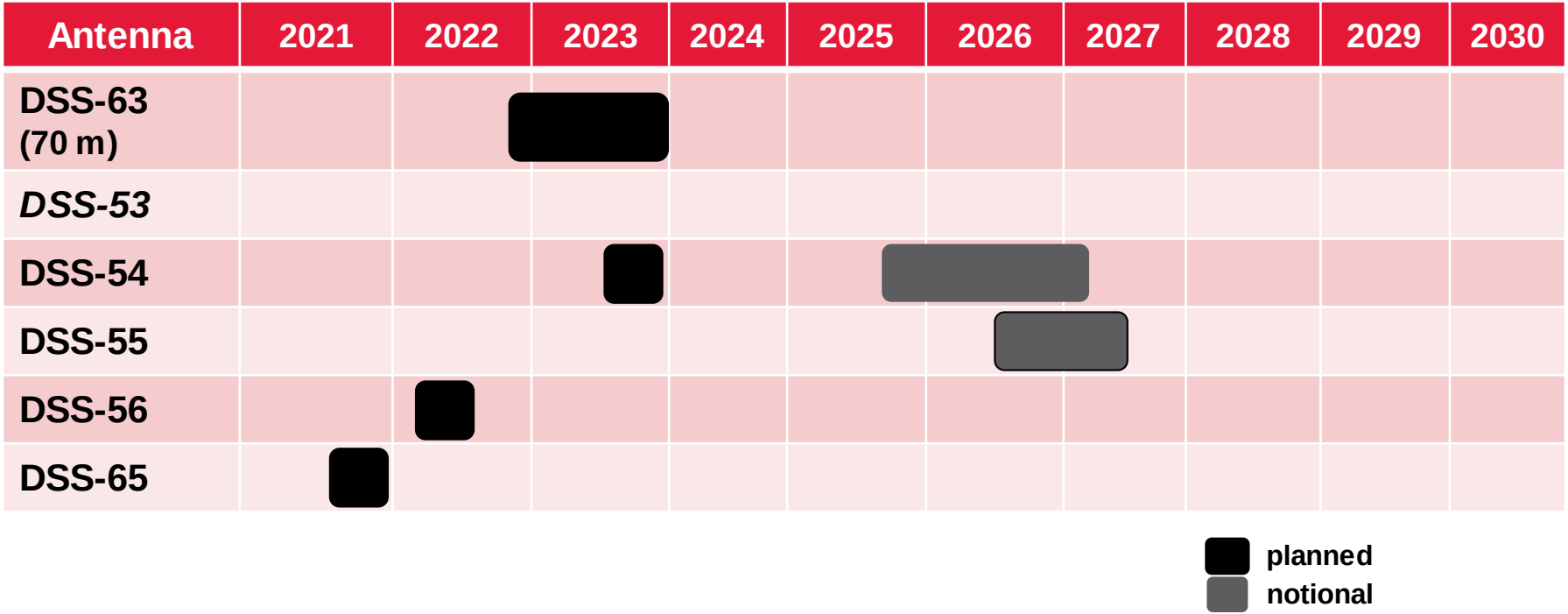
Canberra Complex



Future Antenna Downtimes

Goldstone Complex



Future Antenna Downtimes

Madrid Complex