Planetary Radar and Radio Astronomy

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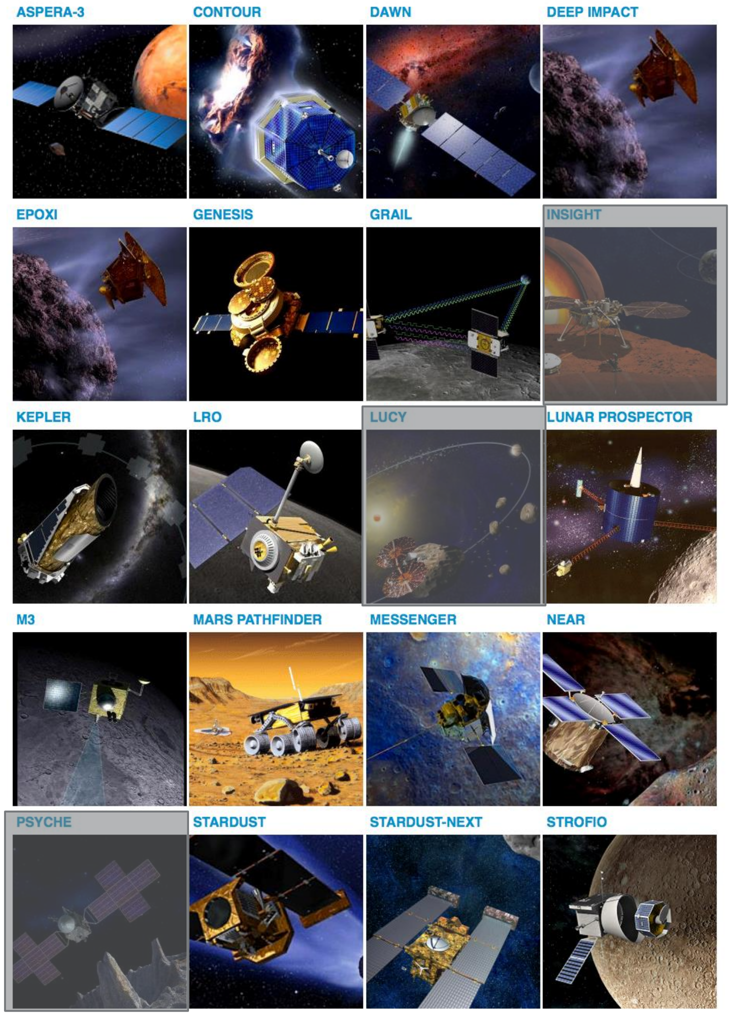
California Institute of Technology

NASA Discovery Missions

PI-led medium scale



- ➢ **Small Bodies**
  - – **75% of current and planned missions (8/12)**

    Includes Lucy and Psyche
  - – **Reflects S/$ ratio**
- ➢ **Extrasolar Planets(!)**

  Kepler

- **Future**

  InSIGHT (2018), Lucy (2021, *planned*), Psyche (2022, *planned*)
- **Instruments**

  ASPERA-3, M3, STROFIO,

New Frontiers

Planetary Science

National Aeronautics and Space Administration

NNH16ZDA011O **Release Date December 9, 2016**

Announcement of Opportunity

New Frontiers 4

Notices of Intent Due Date: **January 20, 2017**
Proposal Due Date: **April 28, 2017**

OMB Approval Number 2700-0085

2.4 Science Objectives for New Frontiers Mission Themes

Proposals […] must describe an investigation that addresses at least one [of] the six mission themes described below. These themes, listed without priority, are:

- **Comet Surface Sample Return,**
- **Lunar South Pole-Aitken Basin Sample Return,**
- **Ocean Worlds (Titan and/or Enceladus),**
- **Saturn Probe,**
- **Trojan Tour and Rendezvous, and**
- **Venus In Situ Explorer.**

Part I: Planetary Radar

National Radar Assets

Also Global Radar Assets

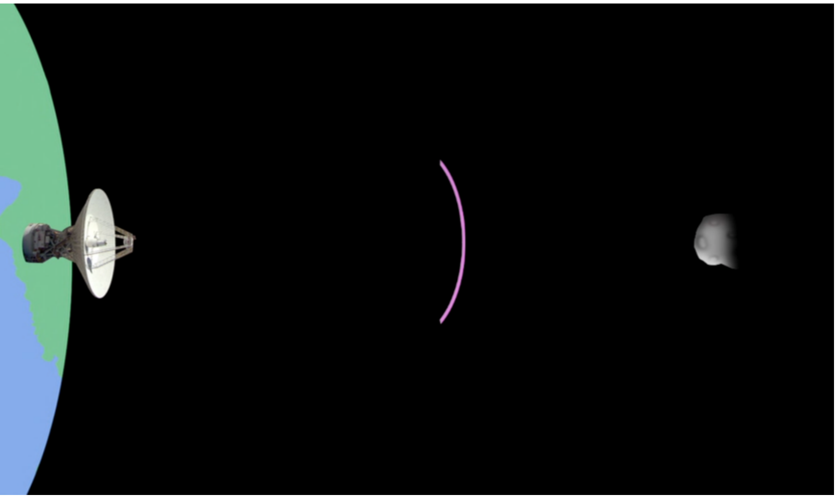
Goldstone DSS-14 (DSN)
70 m antenna, 500 kW transmitter, 4 cm wavelength (X band)

Arecibo (NAIC)
300 m antenna, 1 MW transmitter, λ13 cm (S band)

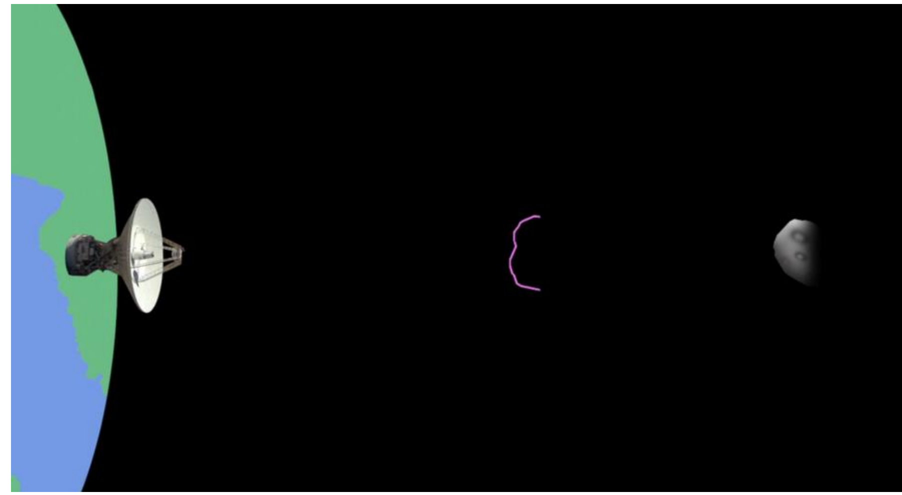
Green Bank Telescope (GBO)
100 m antenna, no transmitter

Radar Equation

… Tyranny of



Radar transmitter transmits toward target …



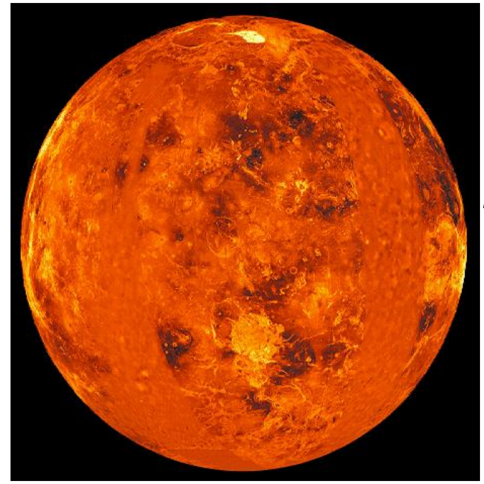
Target reflects, a.k.a. re-transmits, radar signal.

$$P_{\mathrm{RX}} = P_{\mathrm{TX}} \frac{GAs}{(4p)^2 R^4}$$

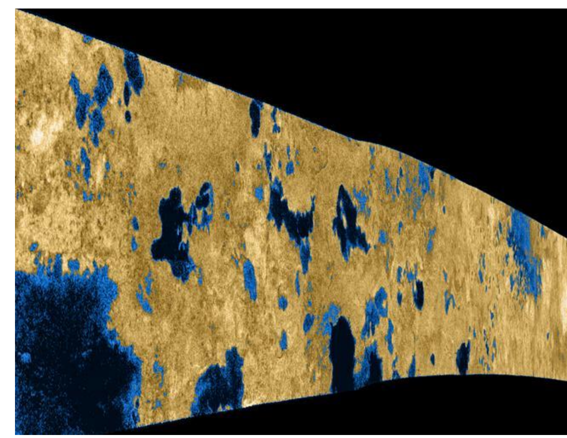
- P_{RX} – received power
- P_{TX} – transmitted power
- *G* – antenna gain
- *A* – antenna area
- σ – radar cross-section
- *R* – range

Planetary Radar Accomplishments

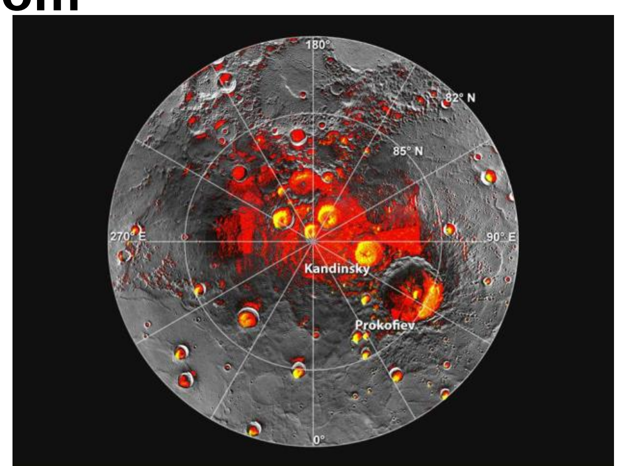
- **First indications of Venus retrograde rotation (1962)**
- **Probing the surfaces of asteroids (1976)**
- **First radar returns from Titan (1989-1993), suggestive of icy surface but with potential liquids**
  - **With VLA! and B. Butler was Co-I**
- **Anomalous reflections from Mercury (1991), indicative of polar ice**



***Magellan* radar image of Venus**
(NASA/Caltech/JPL)

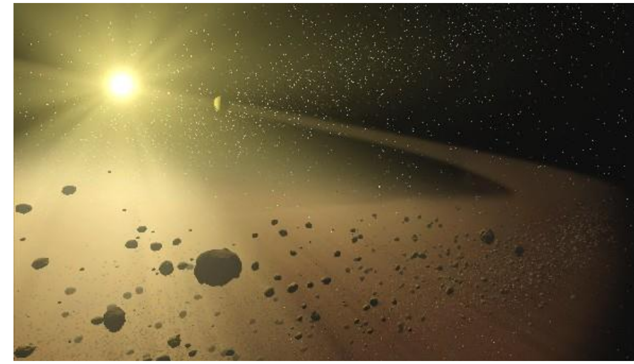


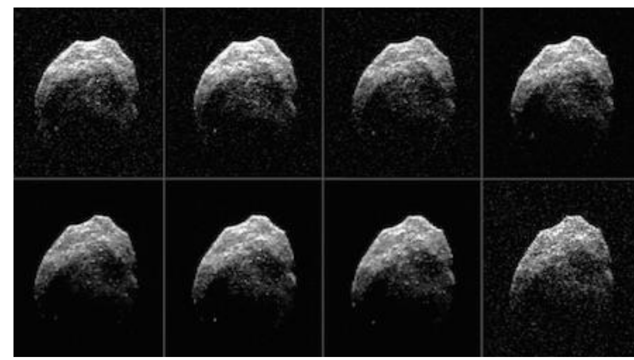
***Cassini* radar image of Titan**
(NASA/JPL/USGS)



MESSENGER+radar image of Mercury
(NASA/HU APL/CIW/NAIC)

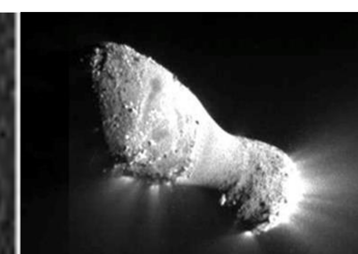
Radar Observations of Asteroids



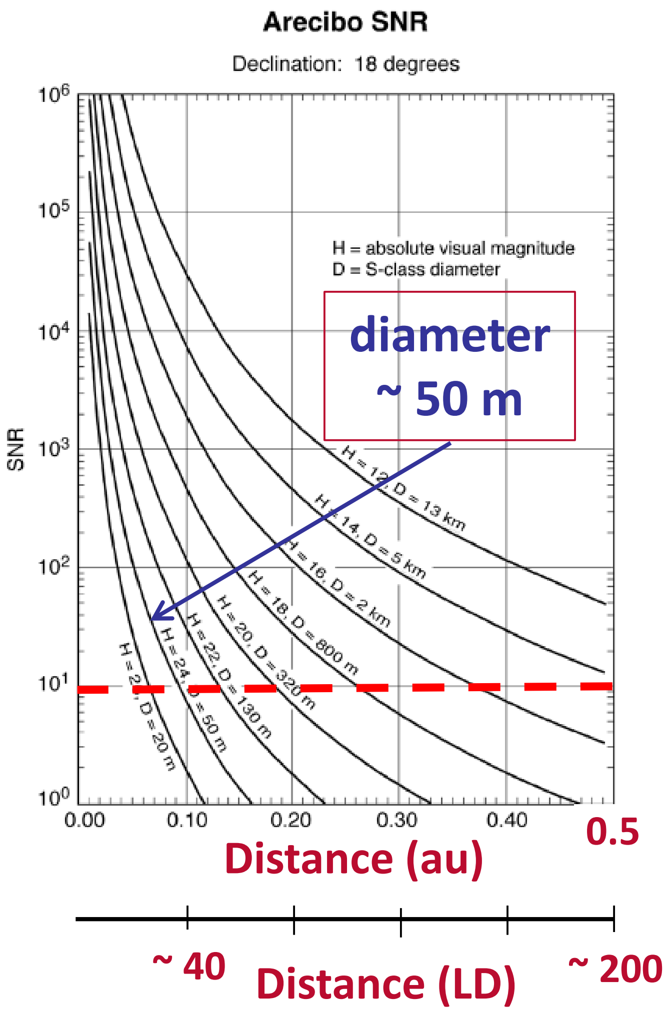


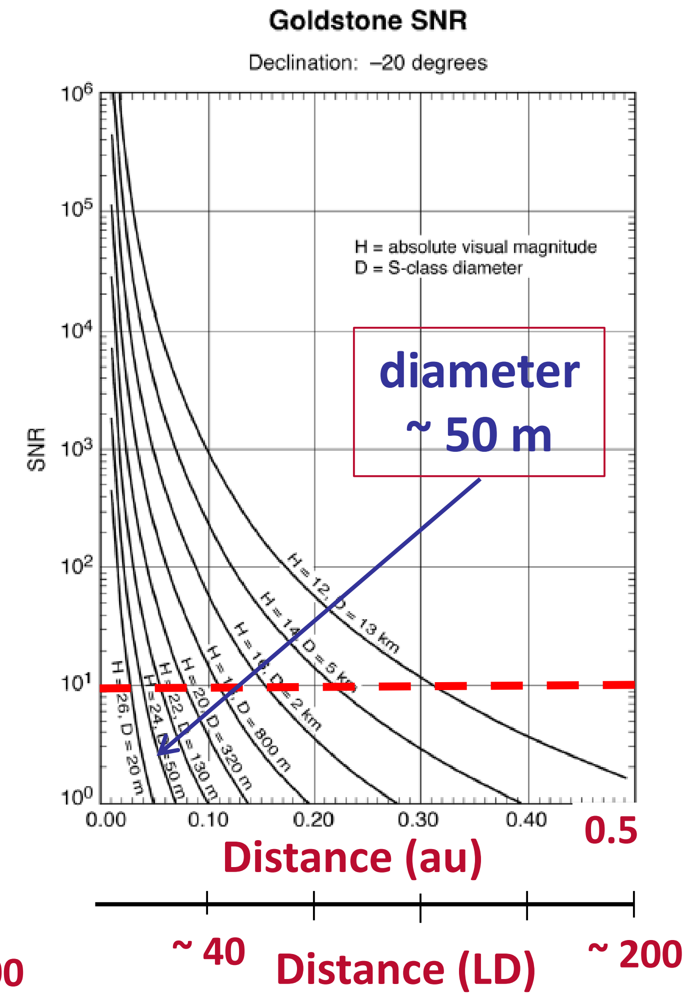
Radar delivers size, rotation, shape, density, surface features, precise orbit, non-gravitational forces, presence of satellites, mass, …

- **Science: Decipher the record in primitive bodies of epochs and processes not obtainable elsewhere**
- **Robotic or crewed missions: Navigation, orbit planning, and observations**
- **Planetary defense: Orbit determination for hazard assessment**



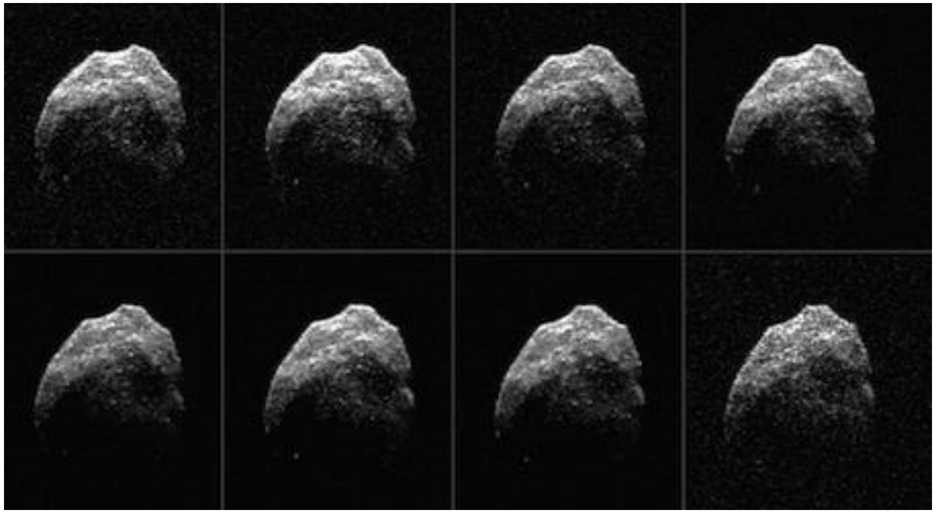
Radar and NEO Detectability





Ostro & Giorgini

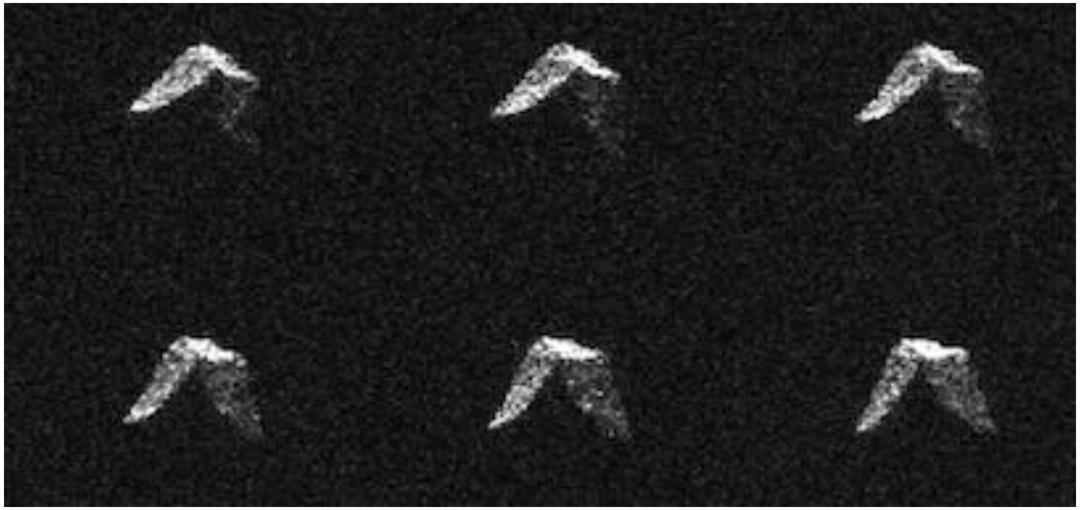
Planetary Radar Recent Results



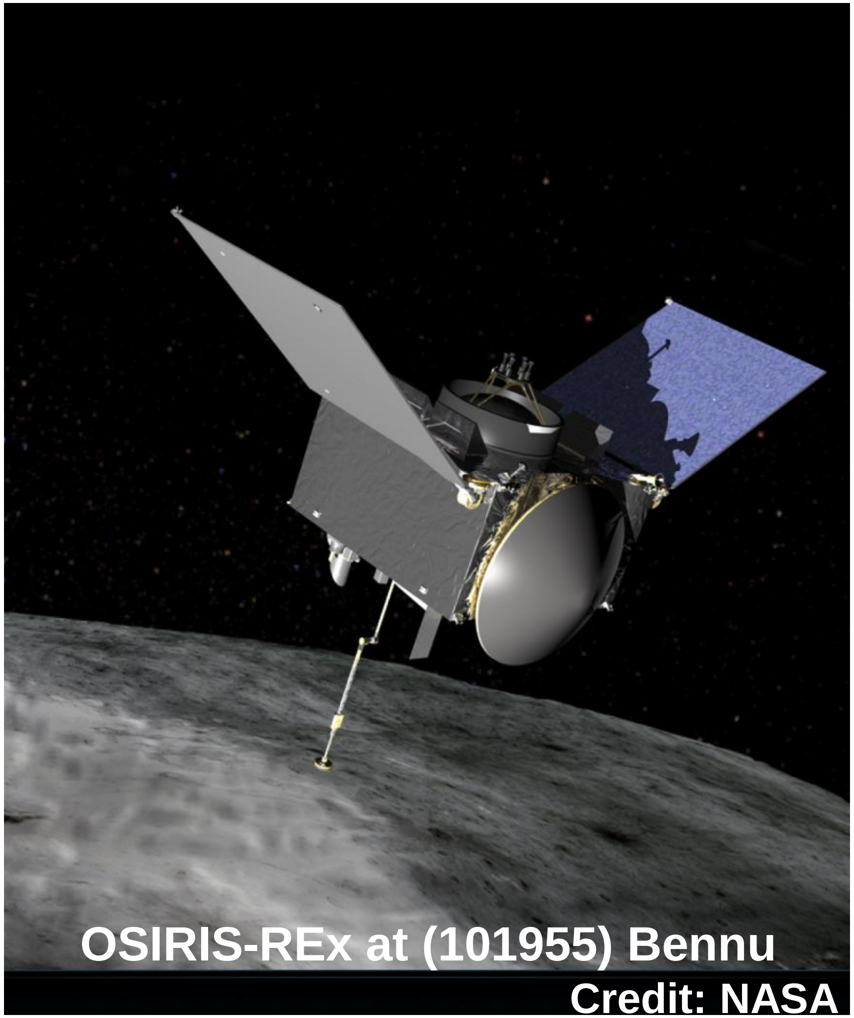
2015 TB145

GSSR-GBT

2017 BQ6



Radar Contributions to Space Missions



Contents lists available at SciVerse ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Shape model and surface properties of the OSIRIS-REx target Asteroid (101955) Bennu from radar and lightcurve observations

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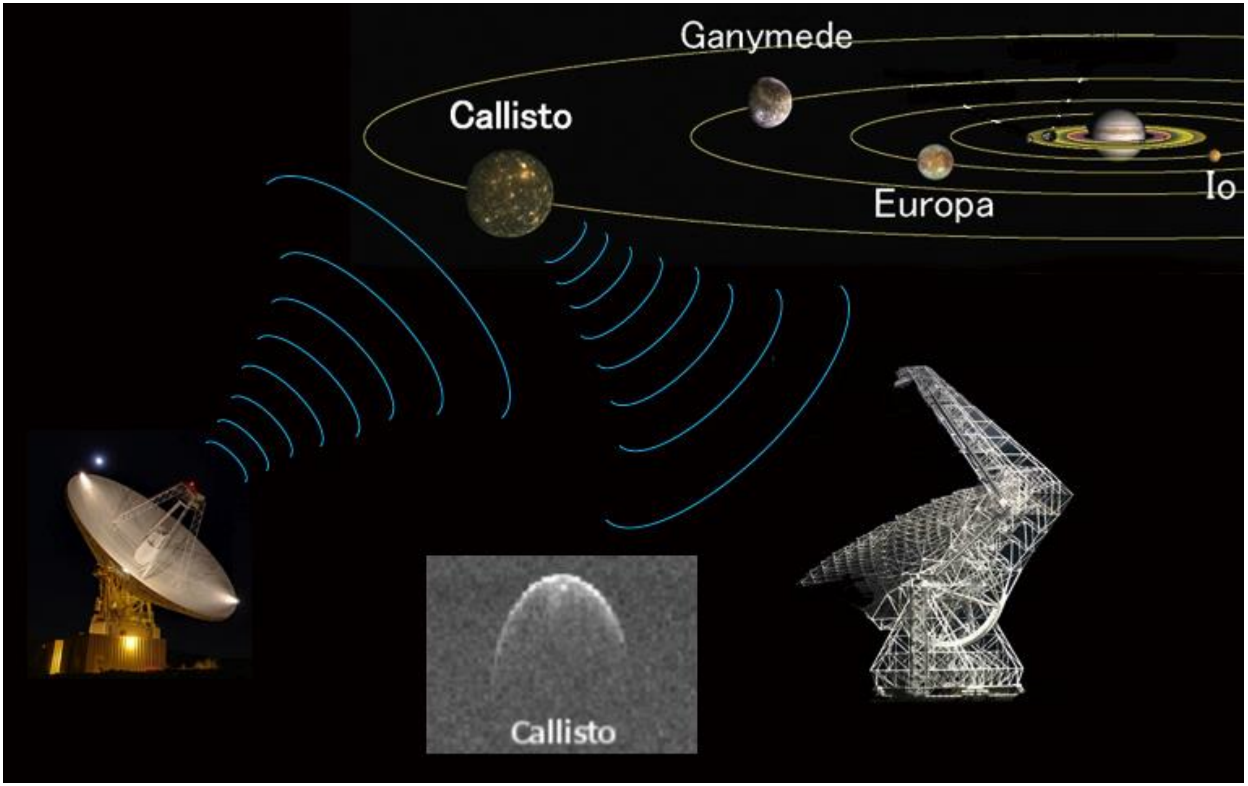
Ranging to the Galilean Satellites

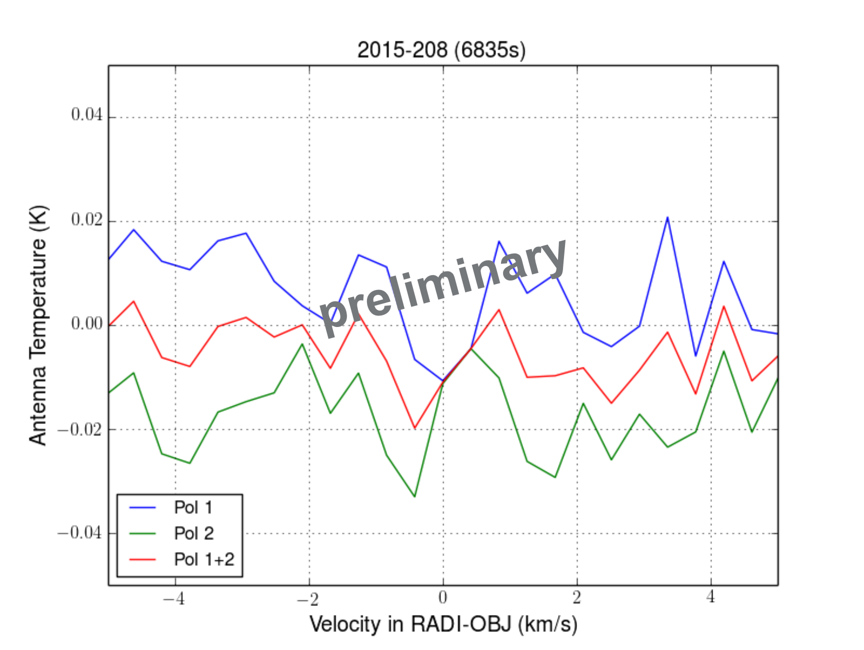


Jupiter's tidal dissipation constrains interior structure

- **GSSR, Arecibo, GBT 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**

Part III: Planetary Radio Astronomy

Radio Astronomy of Solar System Objects



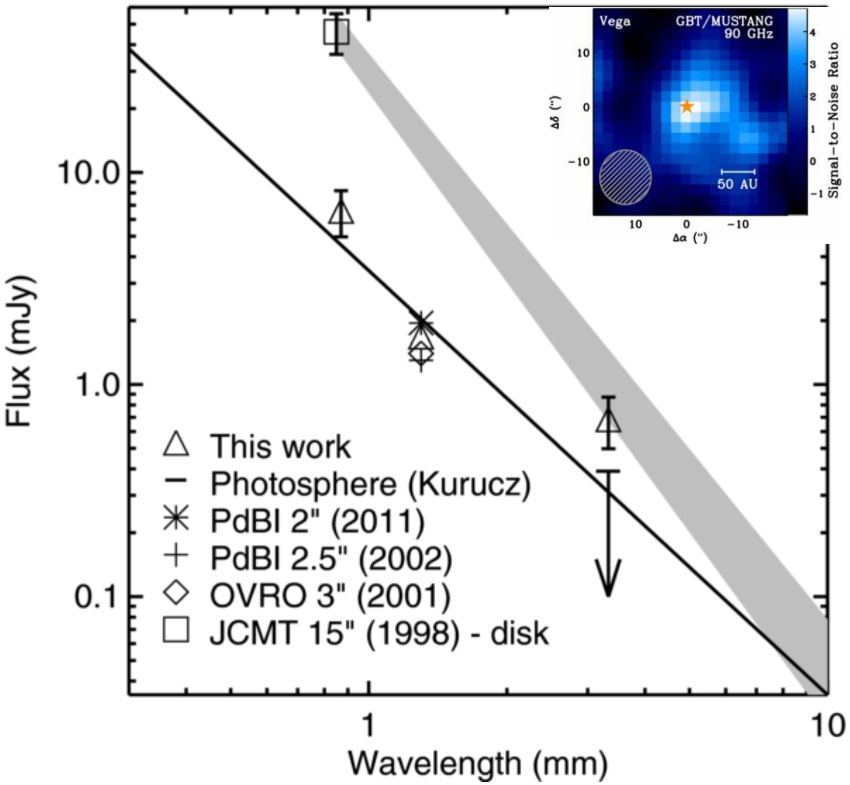
DSS-43 (a.k.a. Tid) H_2O observations of 67P

- **In conjunction with Rosetta/MIRO observations**
- **Spectra acquired, and in processing**

[A] community workshop […] meant to provide [NASA's Planetary Science Division] with a very long-range vision of what planetary science may look like in the future. The workshop is to gather the leading experts in Solar System planetary science and related disciplines, together with experts in space technologies, to identify potential science goals and enabling technologies that can be implemented by the end of the 2040s and would support the next phase of Solar System exploration.

From Protoplanetary Disks to Debris Disks

Solar and Extrasolar



Millimeter-wavelength spectral energy distribution of Vega
(Hughes et al.)

Boundary between solar and extrasolar planetary science is frontier

- **Expand studies of nearby extrasolar debris disks**
- **Include molecular observations**
- **…?**

Likely joint with ALMA and/or VLA …

Part III: Spacecraft Telecommunications, Telemetry, and Command

Voyager at Neptune

1989

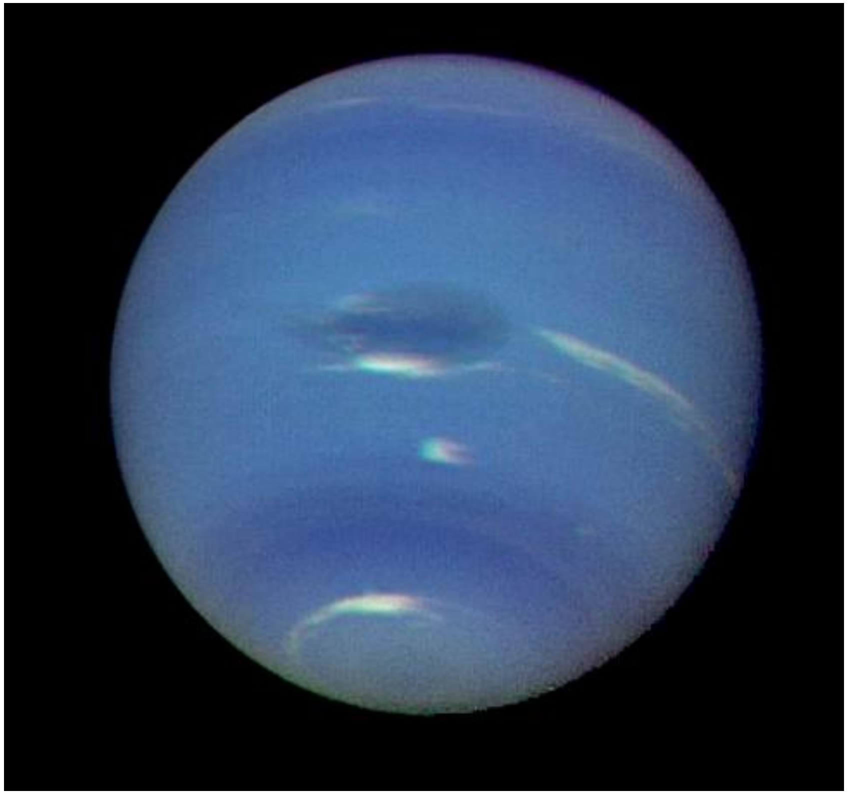
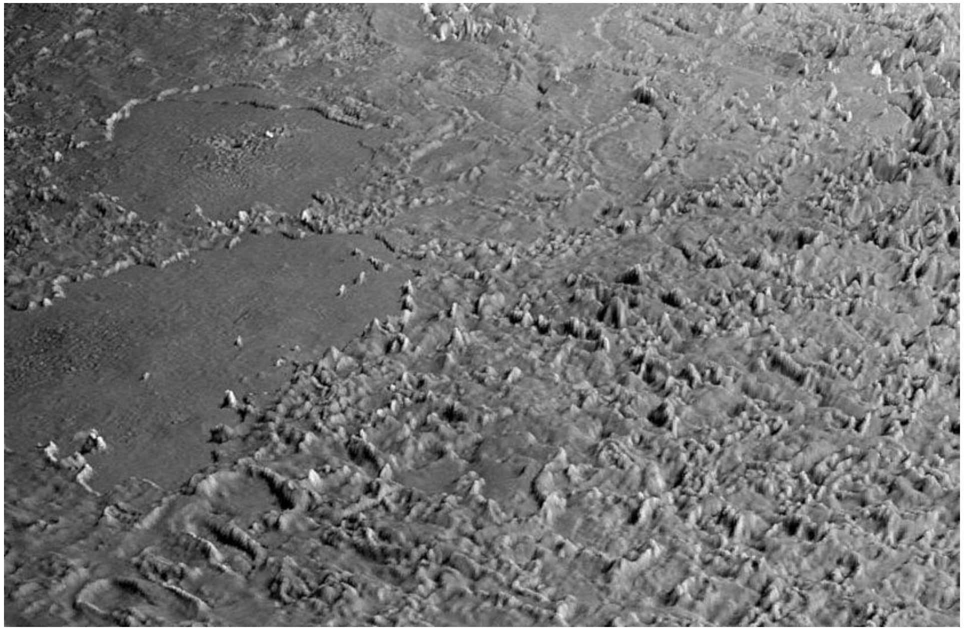


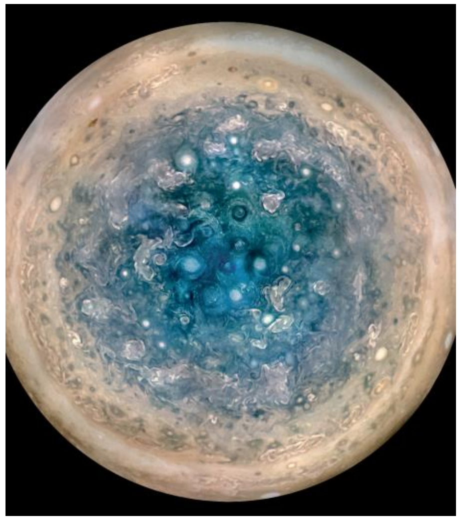
Image credit: NASA/JPL



Triton

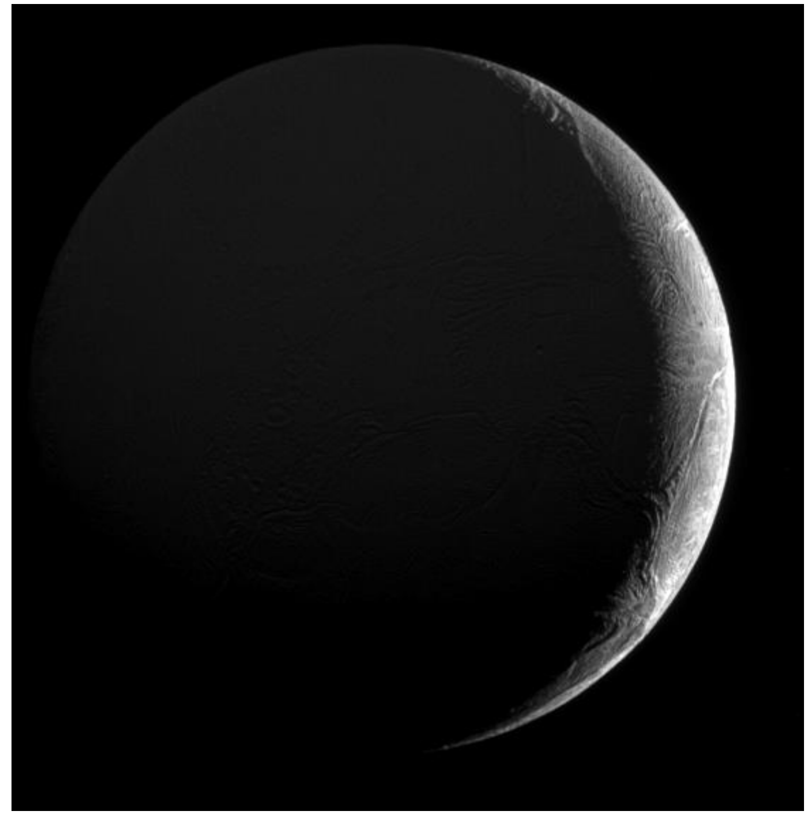
Credit: NASA/JPL/Universities Space Research Association/Lunar & Planetary Institute

The Solar System Today



Juno at Jupiter

Credit: NASA/SWRI/MSSS/Gerald Eichstädt/Seán Doran; NASA/JPL-Caltech/SwRI/MSSS/Betsy Asher Hall/Gervasio Robles

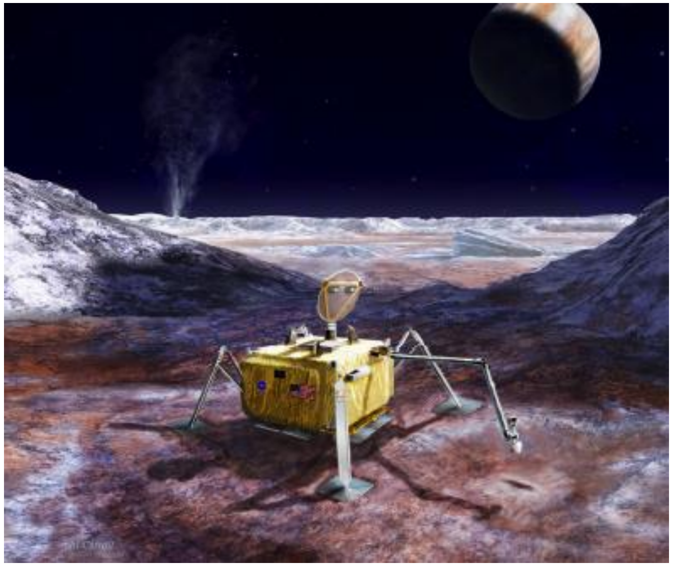


***Cassini*’s view of Enceladus**

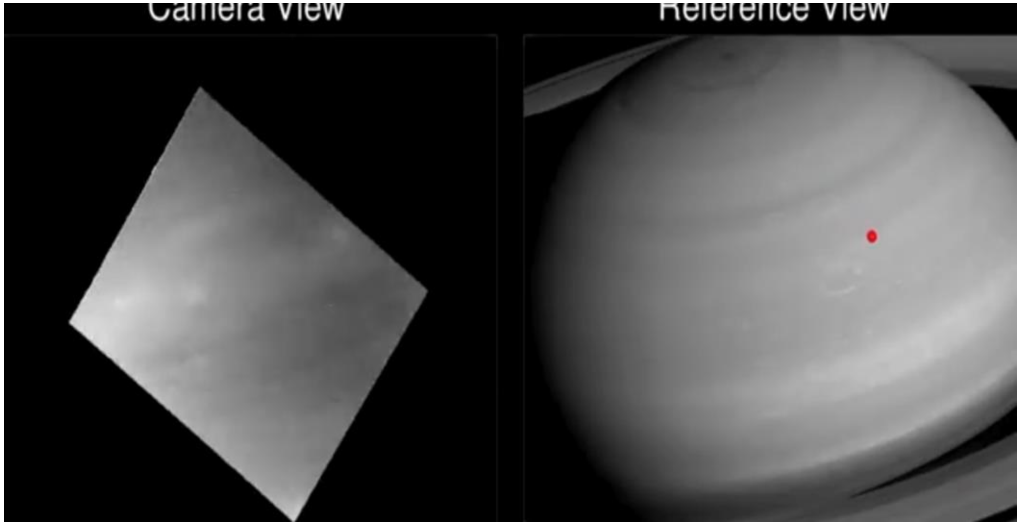
Credit: NASA/JPL-Caltech/Space Science Institute

The Solar System in 2030

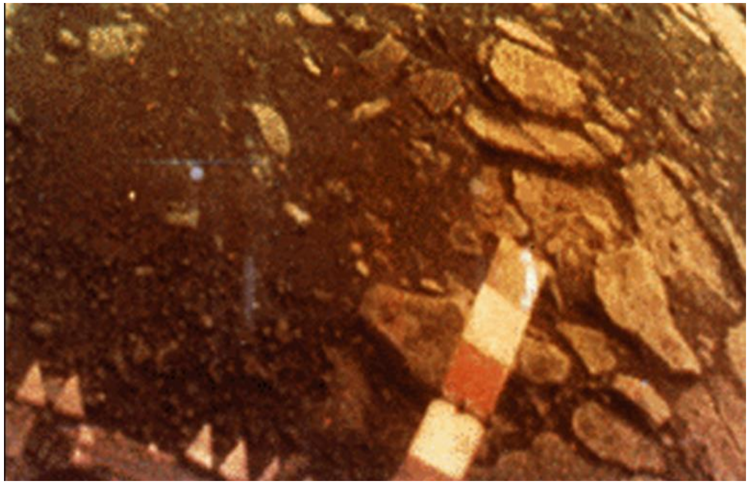
Potential Short Duration Mission Concepts



Europa lander



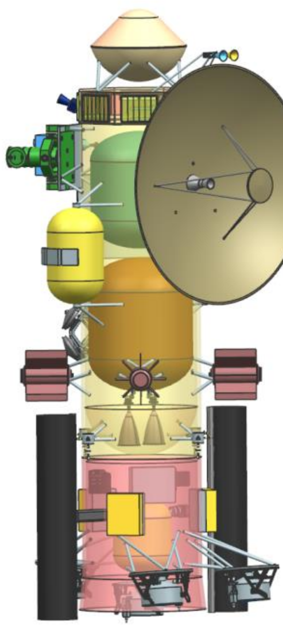
Saturn Probe
Credit: NASA/JPL-Caltech



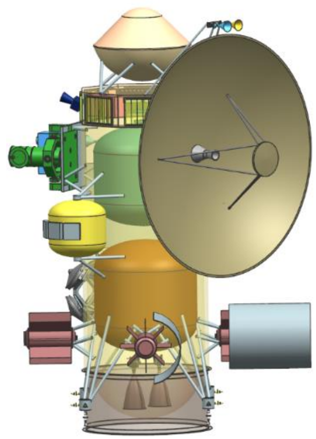
Venus lander
Credit: NASA History Office

The Solar System in 2030+

Ice Giant Mission Concept



Neptune Orbiter with Probe, SEP, and 50 kg payload



Uranus Orbiter with Probe and 50 kg payload

Predecisional - For planning and discussion purposes only.
URS CL#17-0488

"[S]tudies performed for this decadal survey showed, [e.g.,] that the best downlink location for an ice giant mission would be Goldstone; since the VLA is in the same footprint as Goldstone, it could provide a critical back-up."

Vision and Voyages for Planetary Science in the Decade 2013--2022

Spacecraft Signals and the Link Budget

a.k.a. Signal-to-Noise Ratio

MRO Spacecraft Parameters

Antenna	3 m
Transmitter Power	100 W
Frequency (Wavelength)	8.4 GHz (3.55 cm)
Data Rate (max.)	**6 Mbps**

Received Power = Transmitted Power * Gains / Losses

- **Simple version**

$$P_{RX} = G_{RX}[P_{TX}G_{TX}/(4\pi R^2)]$$

- **More exact version (in dB)**

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - L_{TX} - L_{fs} - L_{media} - L_{RX}$$

Data Rate related to bit error rate

$P_{RX} \rightarrow E_b$

$\log(E_b/N_0)$ **a.k.a. signal-to-noise ratio**

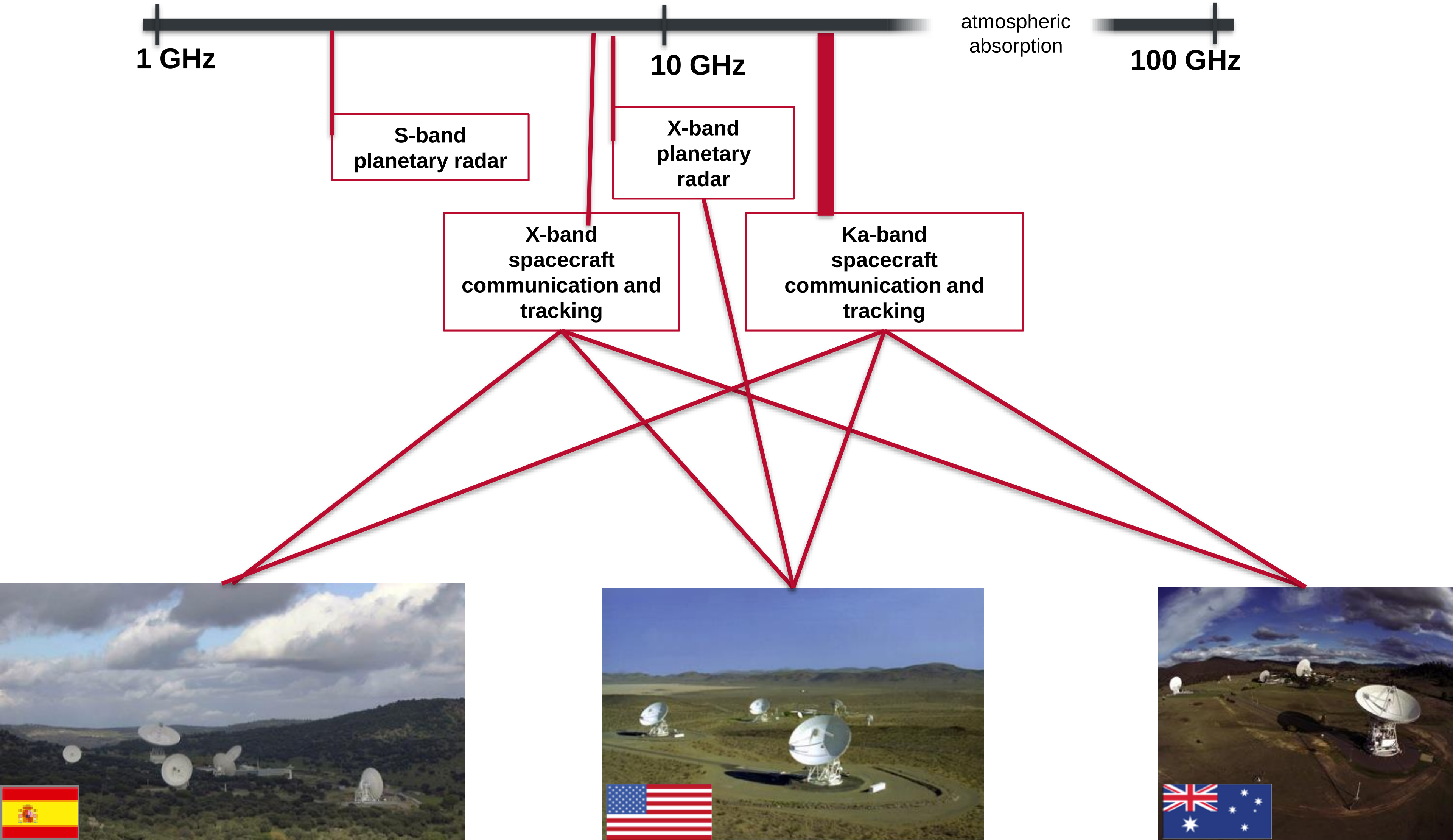
Receiving Antenna Gain

System	X-band	Ka-band
DSN 34 m	68.3 dBi	79 dBi
DSN 70 m (~ 4 × 34 m)	73 dBi (74 dBi)	- (85 dBi)
50 × 20 m	80 dBi	92 dBi

- If > $10,000/kg to launch something, then huge benefit to having capable ground system for receiving data

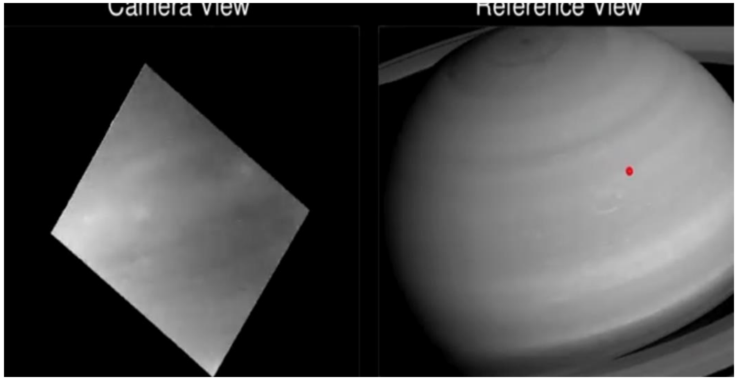
➢ Even modest number of ngVLA antennas could provide powerful augmentation for short duration missions

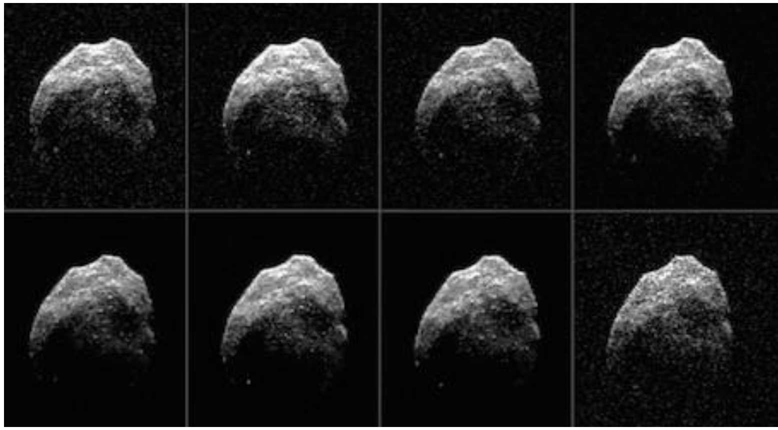
Relevant Telescope Parameters



Spacecraft Tracking and Planetary Radar

- **Frequency coverage**
  - ✓ **secondary spacecraft tracking asset**
  - ✓ **bistatic planetary radar**
- **Substantial aperture**
  - ✓ **enhance short duration missions**
  - ✓ **radar study of smaller and/or more distant objects**





Backup

Jet Propulsion Laboratory
California Institute of Technology

The DSN and Spacecraft Signals

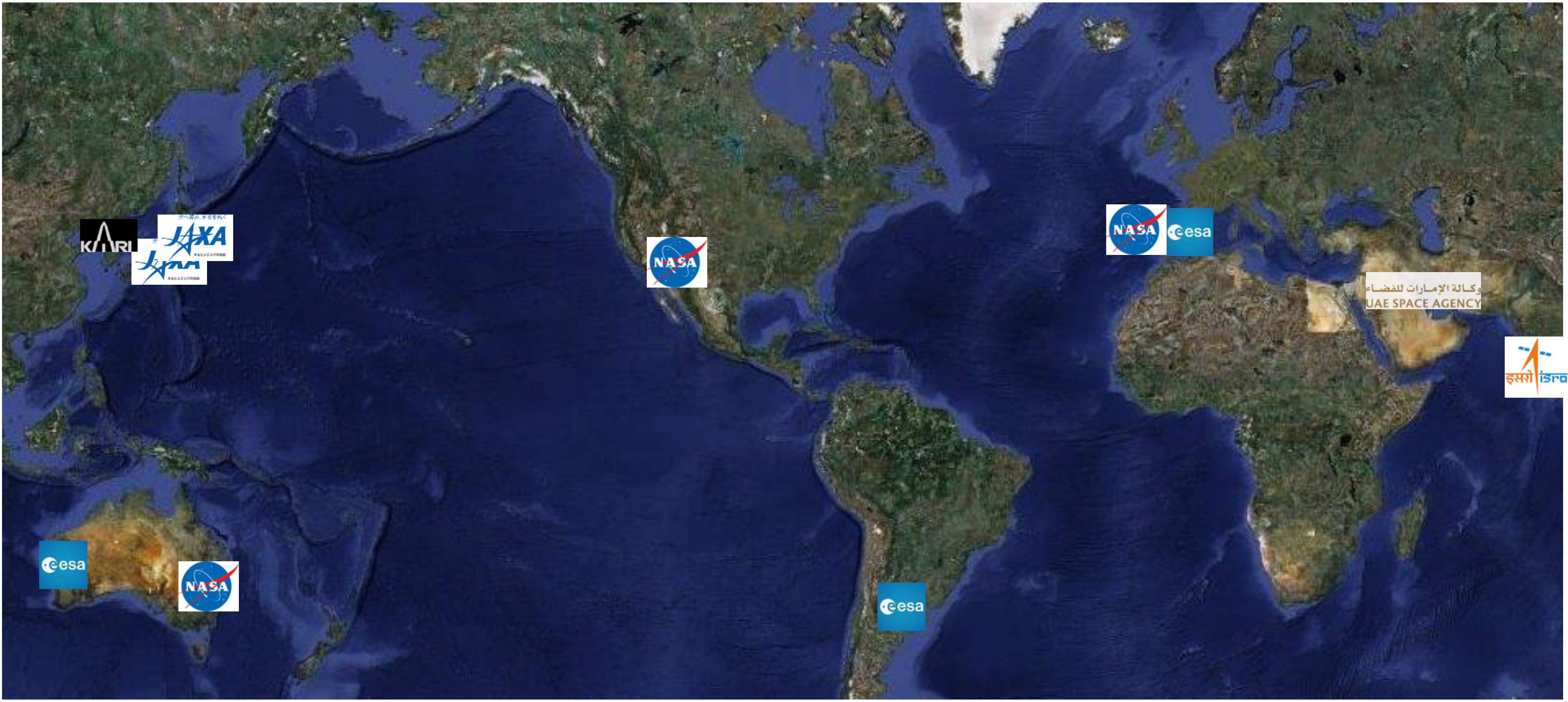
Signals from Distant Spacecraft are Faint

Consider Mars Reconnaissance Orbiter (MRO)

Similar spacecraft parameters for Voyager, *Cassini*, Juno

- **At 1 au (typical Earth-Sun distance)**
  - **$P_{RX} \approx -140$ dBW**
  - **$P_{RX} \approx 10^{-14}$ W**

The International Deep Space Network Village



Diversion

a.k.a. Exercise for the Reader

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

- **In the 40 year history of the VLA, the total amount of energy collected by its antennas is …?**
  - **Compare to snowflake falling on one of the antennas …**
- **How long could you run your household on 500 kW?**
  - **Wuggazer-Lazio household ~ 4 yr**

Planetary Sciences: Toward 2030

Themes	Questions	Destinations
Building New Worlds	1. What were the initial stages, conditions and processes of solar system formation and the nature of the interstellar matter that was incorporated?	Comets, Asteroids, Trojans, Kuiper belt objects
	2. How did the giant planets and their satellite systems accrete, and is there evidence that they migrated to new orbital positions?	Enceladus, Europa, Io, Ganymede, Jupiter, Saturn, Uranus, Neptune, Kuiper belt objects, Titan, Rings
	3. What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by	Mars, Moon, Trojans, Venus, Asteroids, Comets