The ngVLA in the Solar System: Planetary Radar and Spacecraft Telecommunications and Tracking

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Jet Propulsion Laboratory
California Institute of Technology

Part I: Spacecraft Telecommunications, Telemetry, and Command

Voyager at Neptune

1989

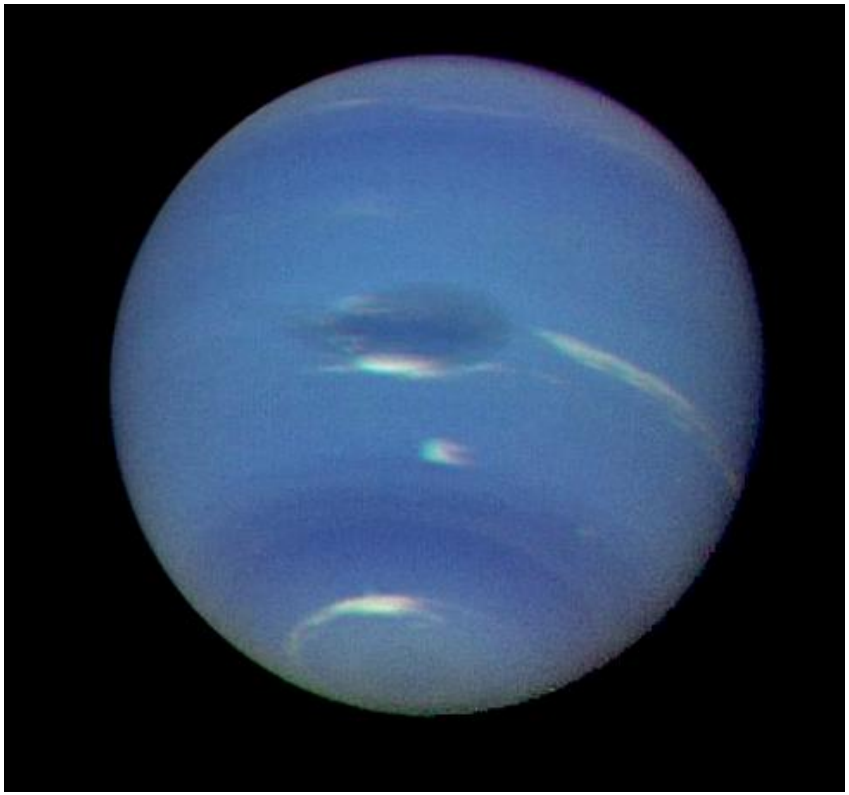
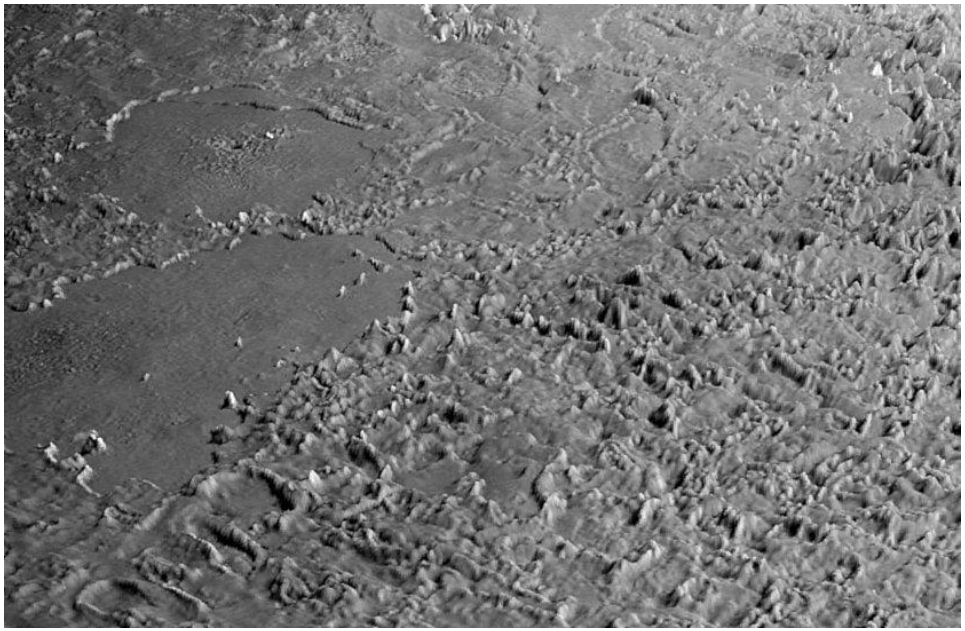


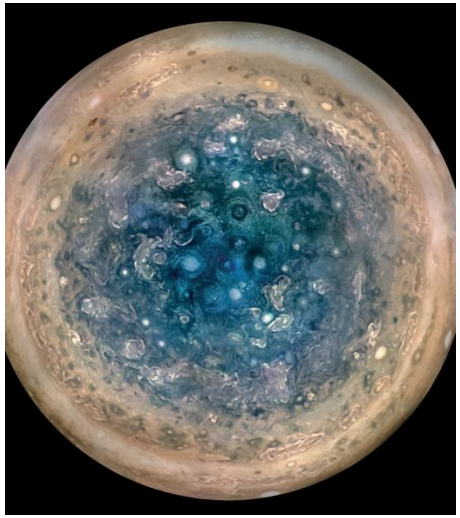
Image credit: NASA/JPL



Triton

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

The Solar System Today



Juno at Jupiter

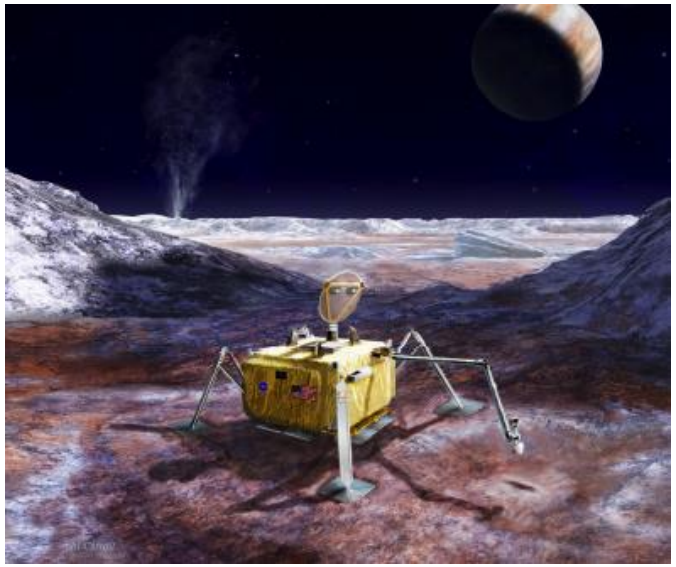
Credit: NASA/SWRI/MSSS/Gerald Eichstädt/Seán Doran; NASA/JPL-Caltech/SwRI/MSSS/Betsy Asher Hall/Gervasio Robles

***Cassini*'s view of Enceladus**

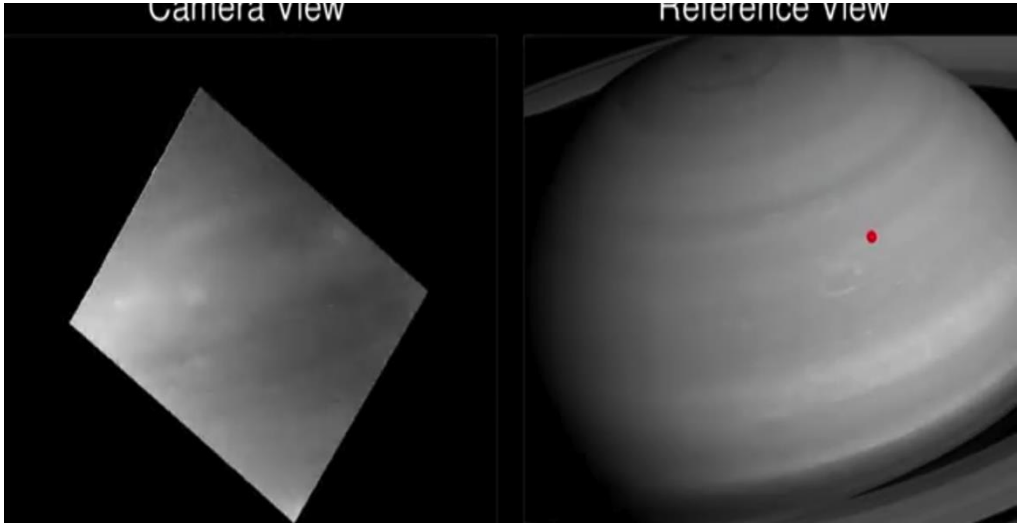
Credit: NASA/JPL-Caltech/Space Science Institute

The Solar System in 2030

Potential Short Duration Mission Concepts

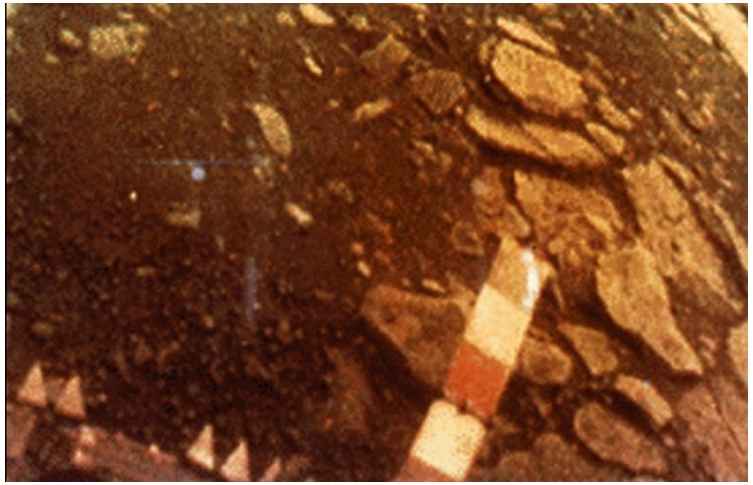


Europa lander



Saturn Probe

Credit: NASA/JPL-Caltech



Venus lander

Credit: NASA History Office

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)**

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

Receiving Antenna Gain

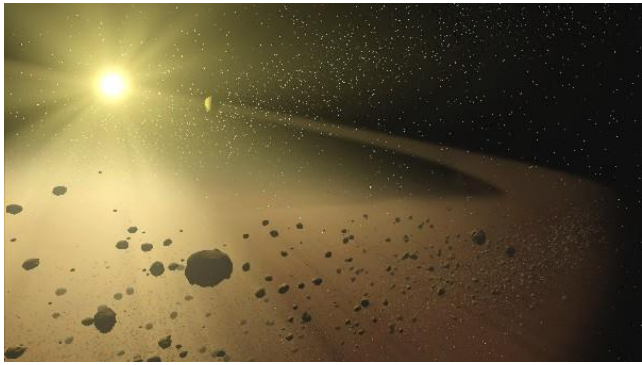
System	X-band	Ka-band
DSN 34 m	68.3 dBi	79 dBi
DSN 70 m (~ 4 × 34 m)	73 dBi (74 dBi)	- (85 dBi)
50 × 20 m	80 dBi	92 dBi

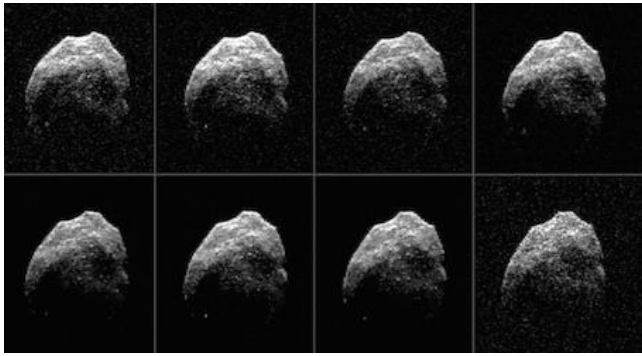
- **If > $10,000/kg to launch something, then huge benefit to having capable ground system for receiving data**
- ➢ **Even modest number of ngVLA antennas could provide powerful augmentation for short duration missions**

Part II: Planetary Radar

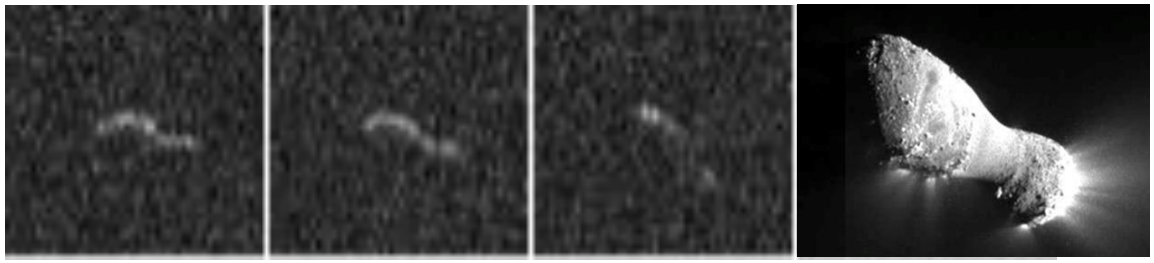
Radar Observations of Asteroids

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**



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

Diversion

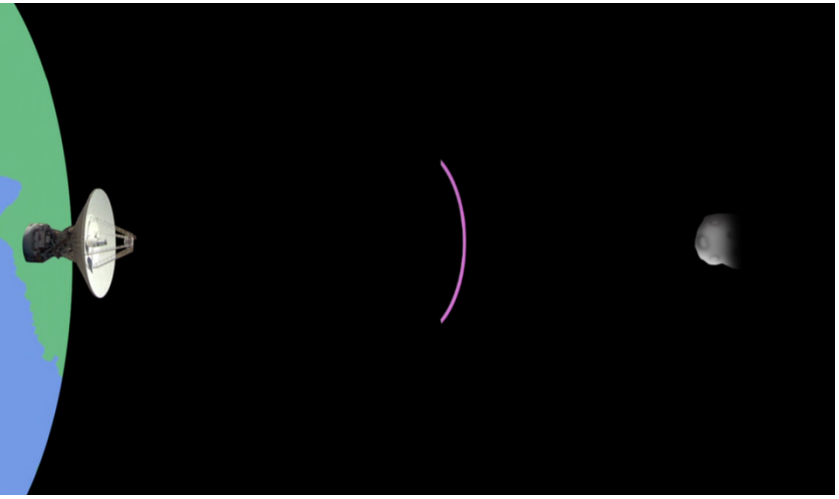
a.k.a. Exercise for the Reader

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

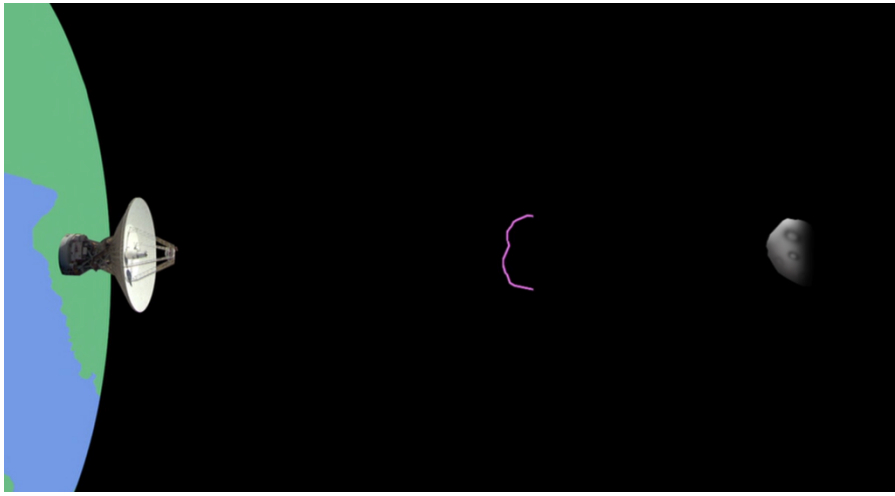
- ¿ **In the 40 year history of the VLA, the total amount of energy collected by its antennas is …?**
  - **Compare to snowflake falling on one of the antennas …**
- ¿ **How long could you run your household on 500 kW?**
  - **Wuggazer-Lazio household ~ 4 yr**

Radar Equation

… Tyranny of



Radar transmitter transmits toward target …

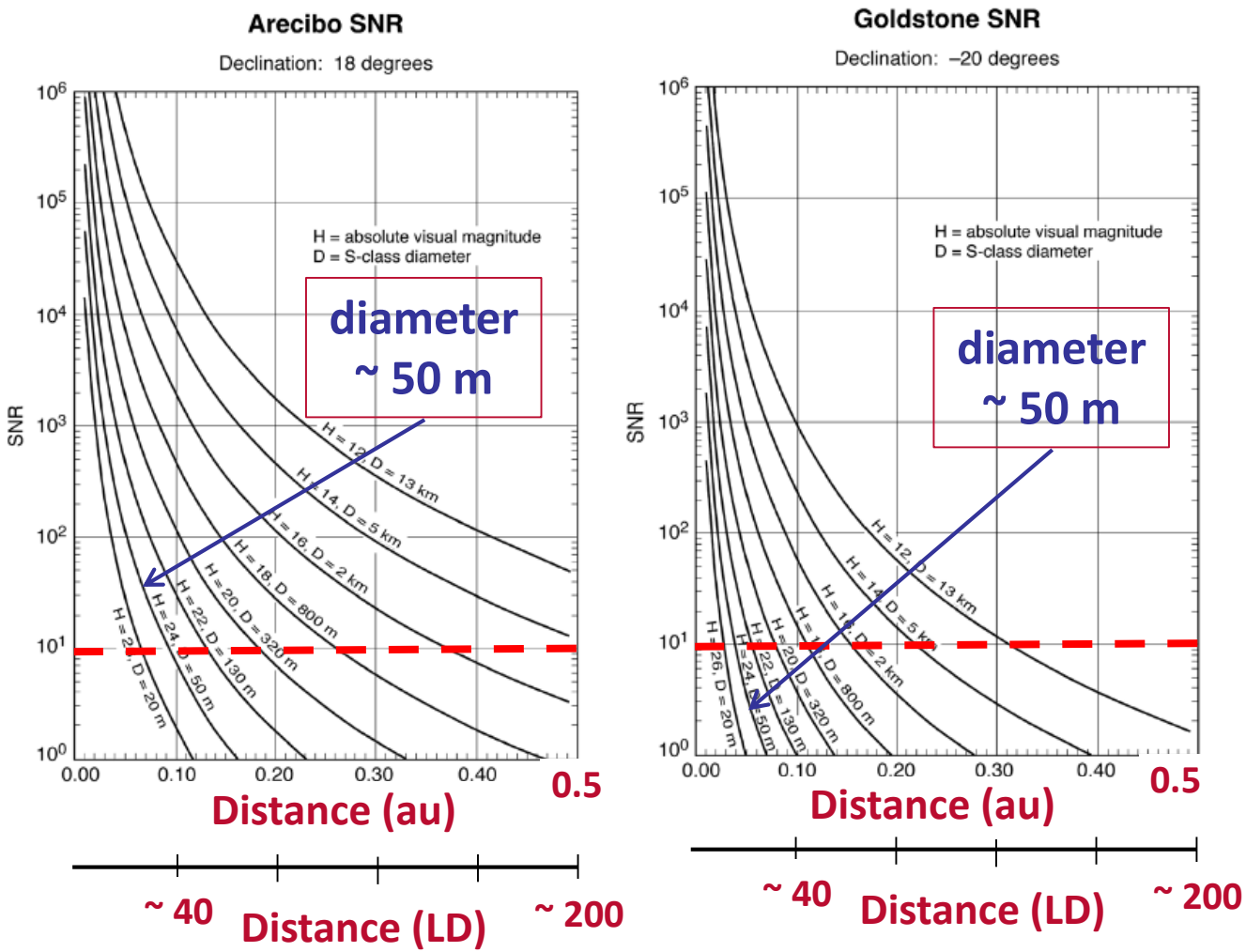


Target reflects, a.k.a. re-transmits, radar signal.

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

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

Radar and NEO Detectability

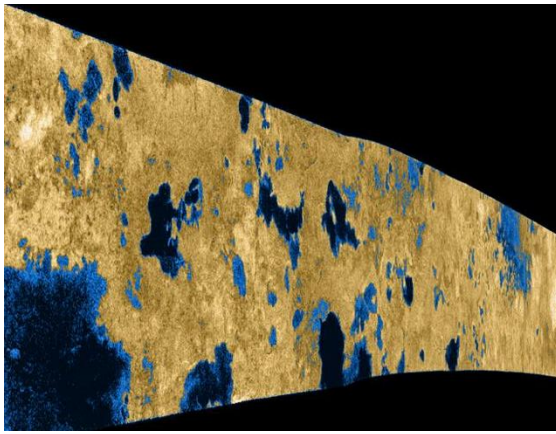


Ostro & Giorgini

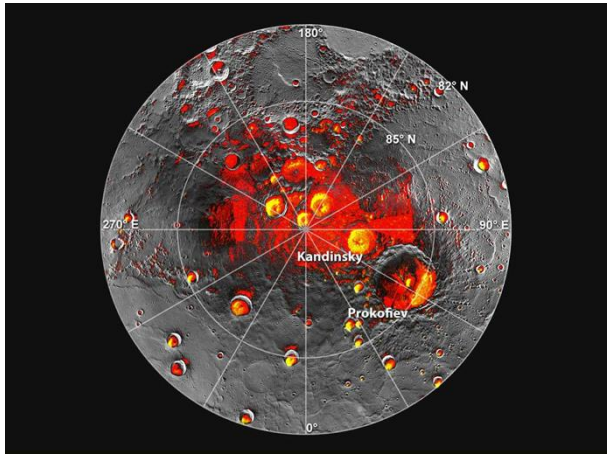
Planetary Radar Accomplishments

- **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)**

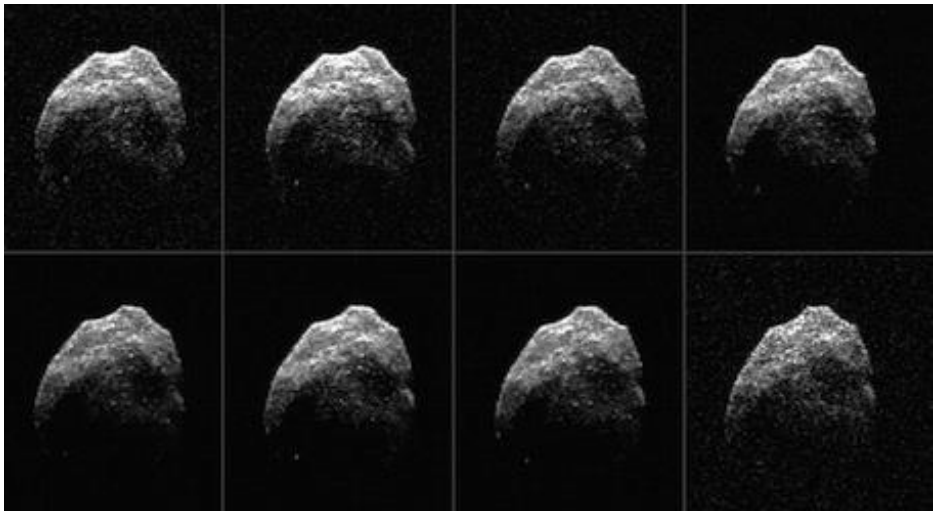


***Cassini* radar image of Titan (NASA/JPL/USGS)**



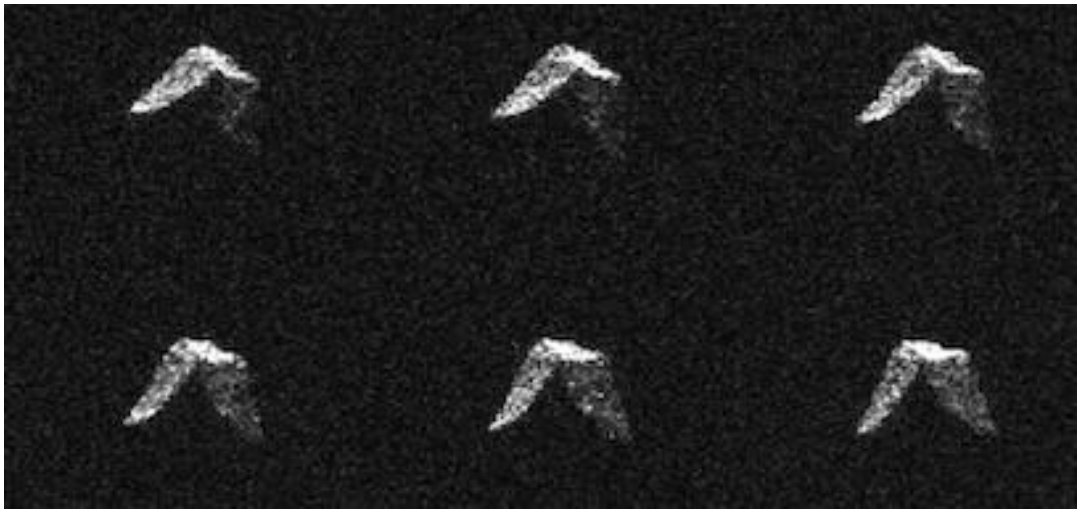
MESSENGER+radar image of Mercury (NASA/HU APL/CIW/NAIC)

Planetary Radar Recent Results



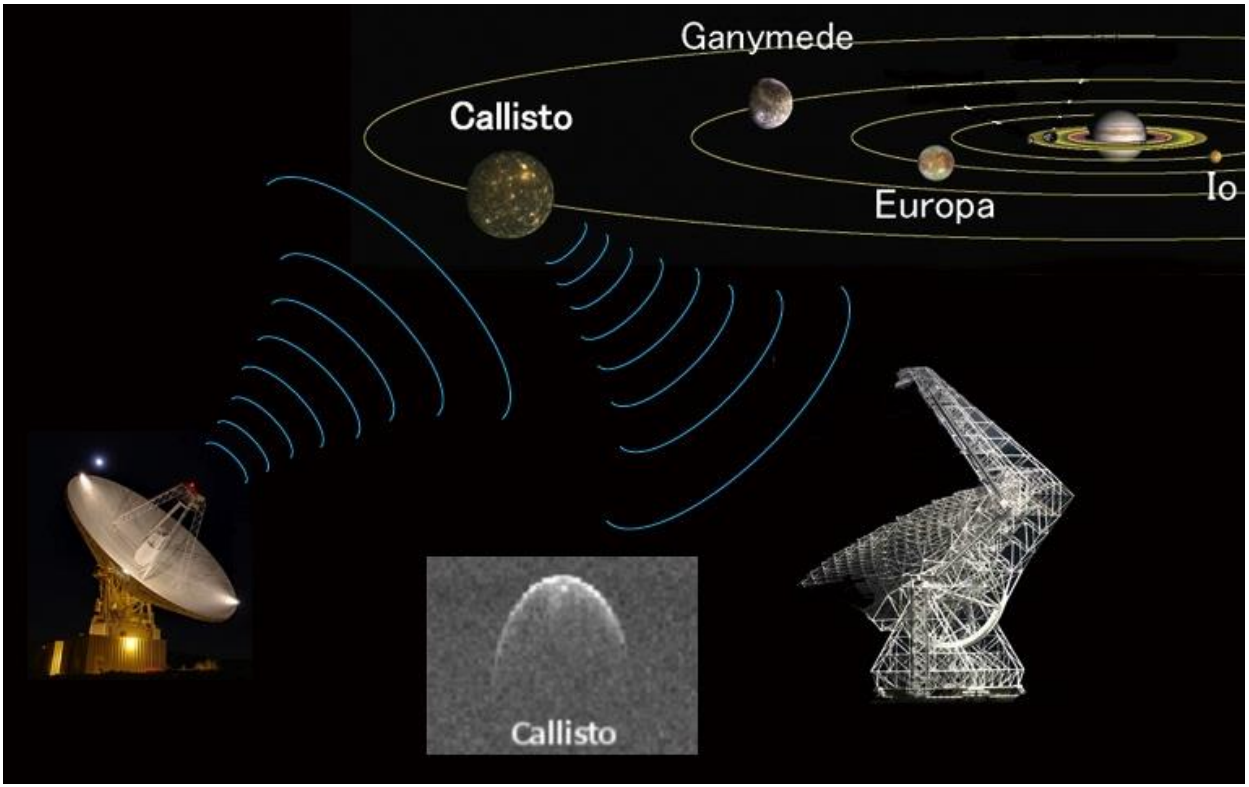
2015 TB145

GSSR-GBT



2017 BQ6

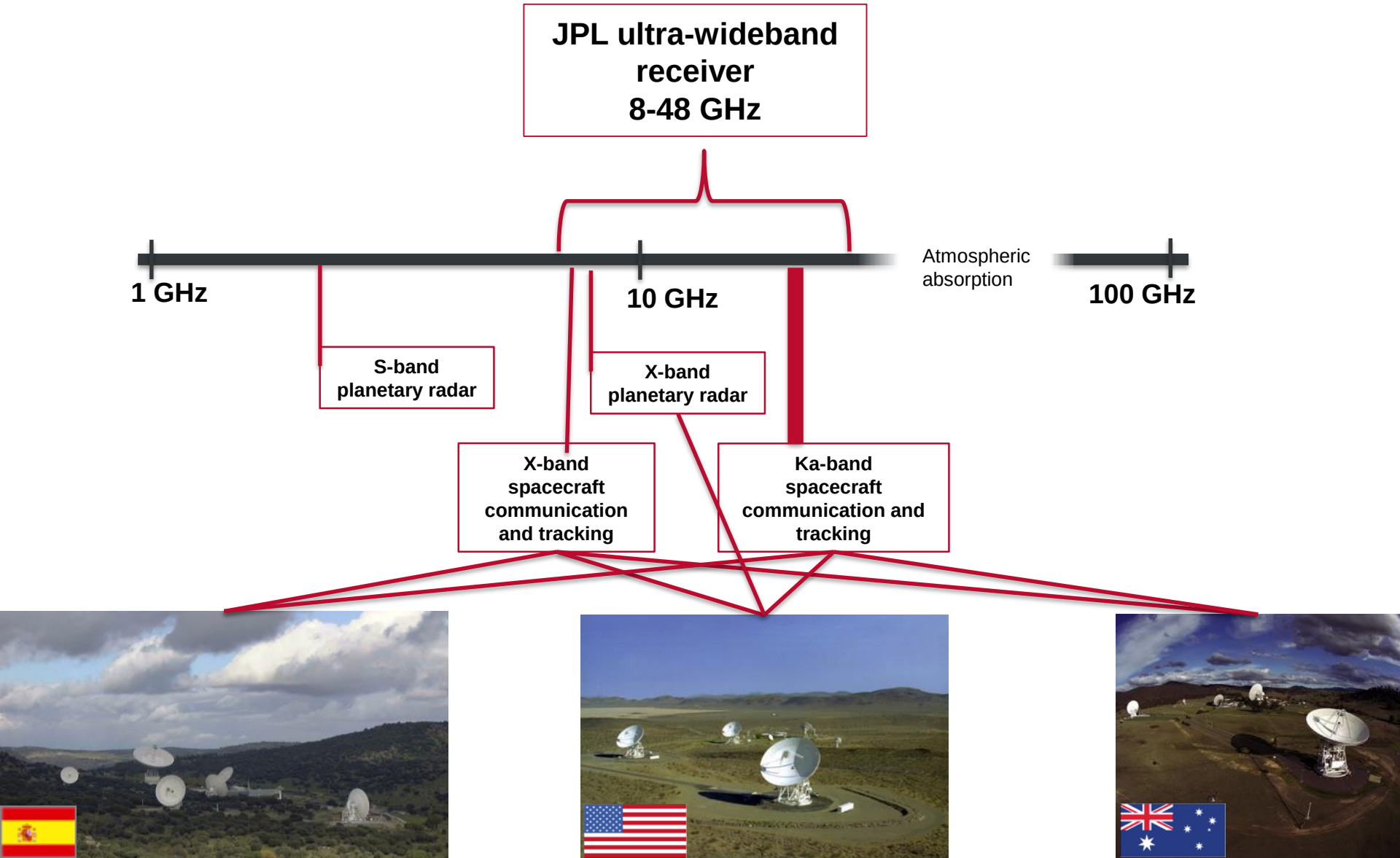
Ranging to the Galilean Satellites



Jupiter's tidal dissipation constrains interior structure

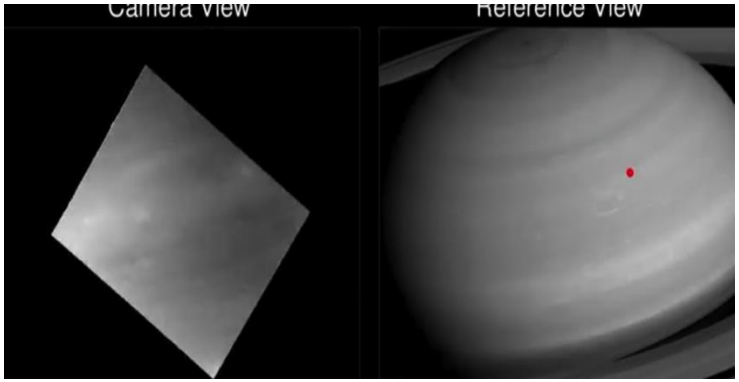
- **GSSR, Arecibo, GBT ranging to Galilean satellites**
  Aiming for 2 km uncertainties in orbits (5× improvement)
- **Detect secular acceleration of Galilean satellites from Jovian tides**
  - **Determine tidal dissipation parameter k_2/Q**
  - **Juno measures k_2**

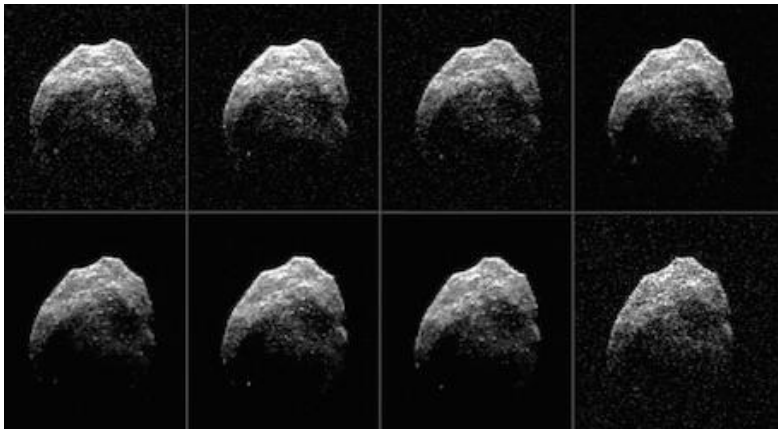
Relevant Telescope Parameters



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

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)**

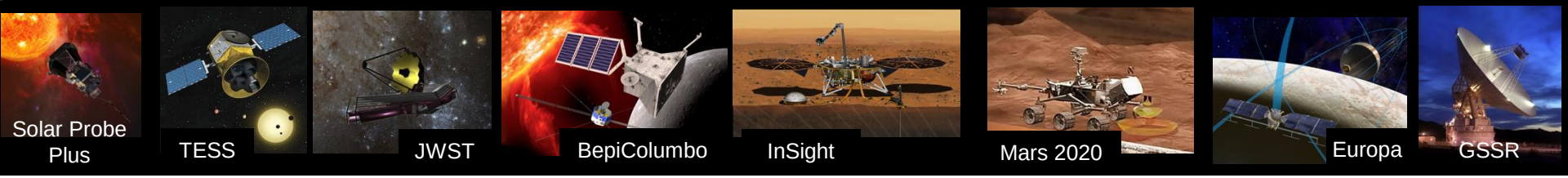
➢ $P_{RX} \approx -140$ **dBW**

➢ $P_{RX} \approx 10^{-14}$ **W**

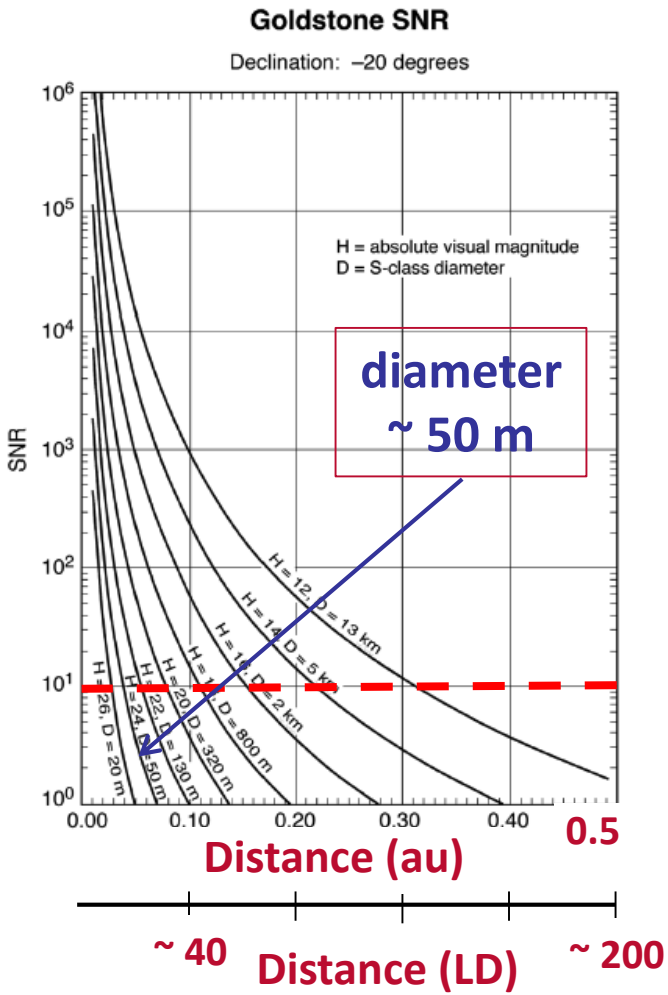
The International Deep Space Network Village

Planetary & Space Sciences-DSN Partnership

Don’t Leave Earth Without Us!



Radar Detectability



Signal-to-noise ratio (S/N) depends on

- System
  - transmitter power
  - receiver collecting area
  - receiver temperature
- Object
  - $(\text{distance})^{-4}$
  - $(\text{diameter})^{3/2}$
  - $(\text{rotation period})^{1/2}$
  - radar albedo
- Integration time : $t^{1/2}$