Planetary Radar and Radio Astronomy

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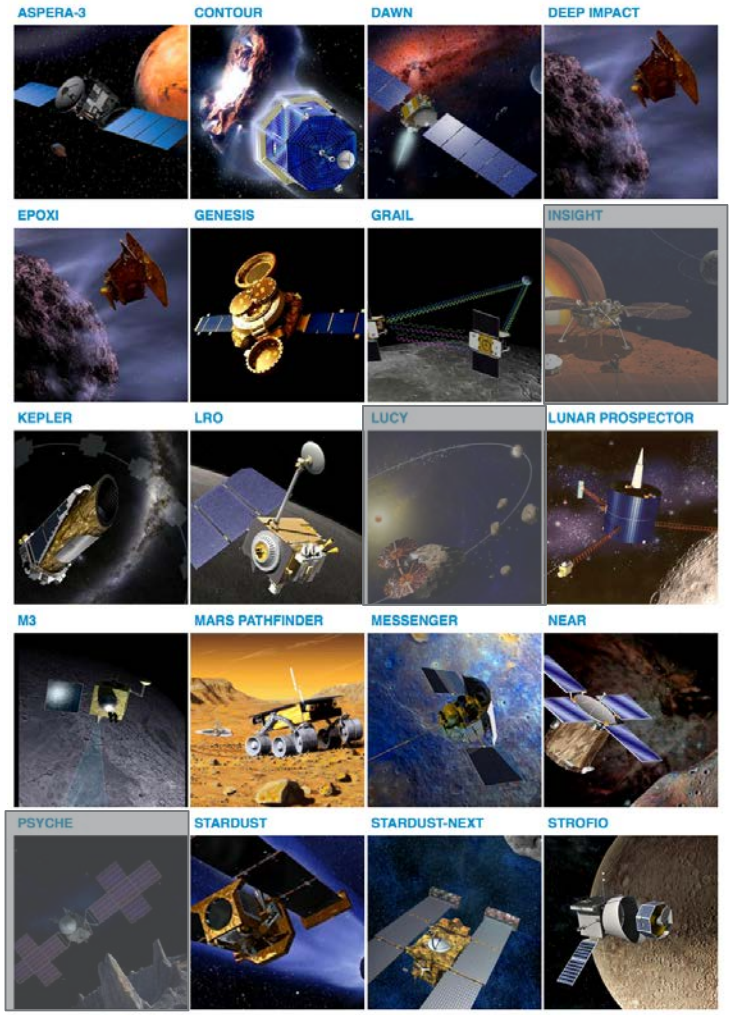
NASA Discovery Missions

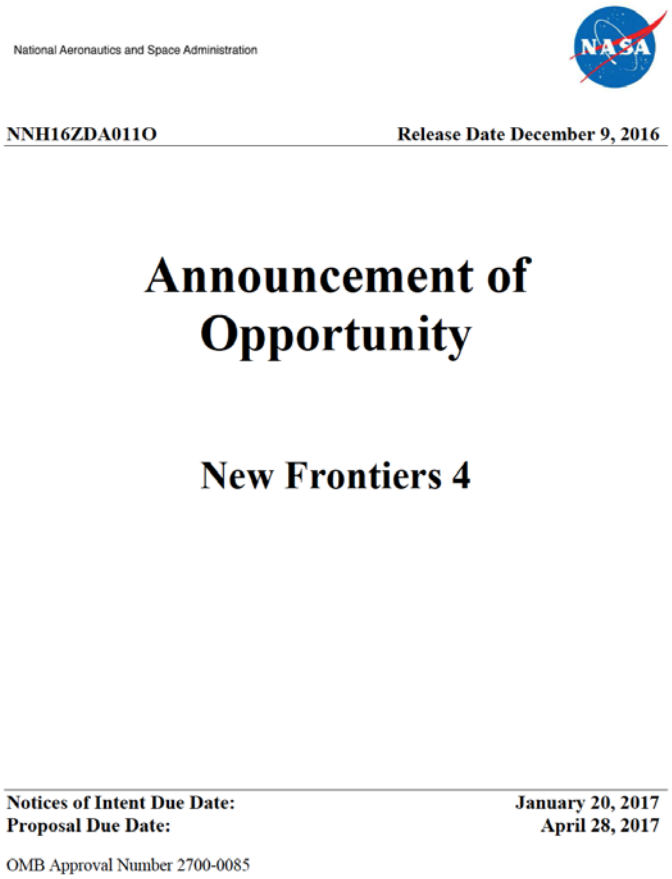
PI-led medium scale



- **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

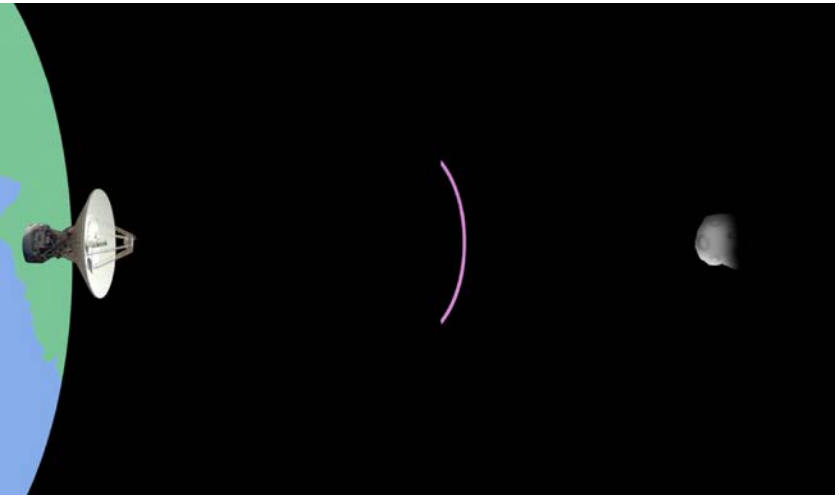
Goldstone DSS-14 (DSN)
70 m antenna, 500 kW transmitter, 4 cm wavelength (X band)

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

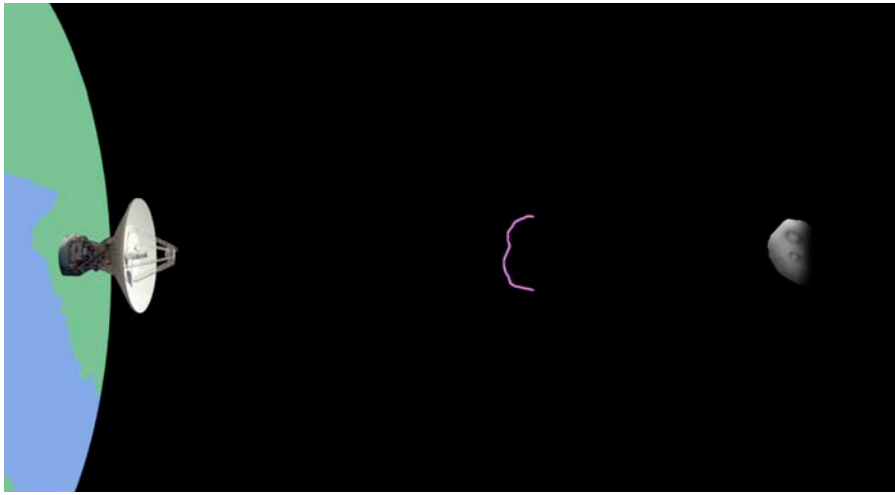
Green Bank Telescope (GBO)
100 m antenna, no transmitter

Radar Equation

… Tyranny of



Radar transmitter transmits toward target …



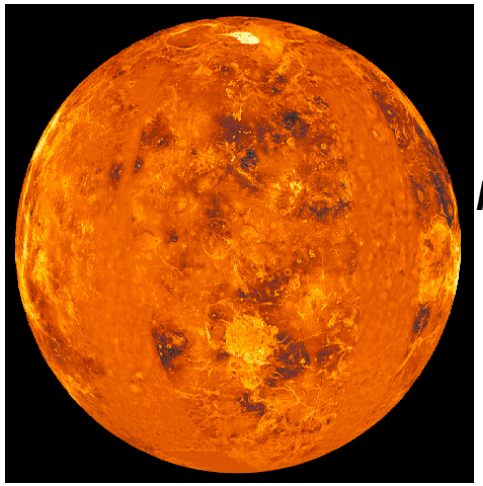
Target reflects, a.k.a. re-transmits, radar signal.

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

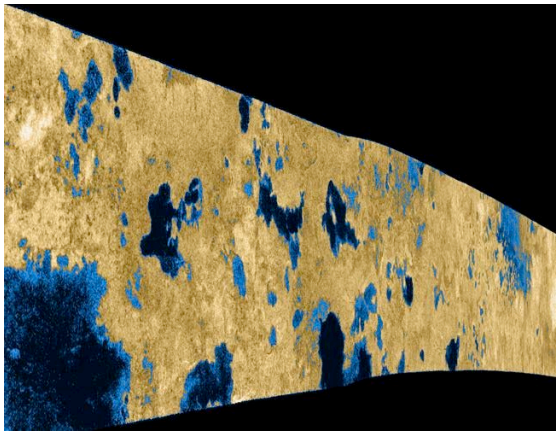
- P_{RX} – received power
- P_{TX} – transmitted power
- G – antenna gain
- A – antenna area
- σ – radar cross-section
- R – range

Planetary Radar Accomplishments

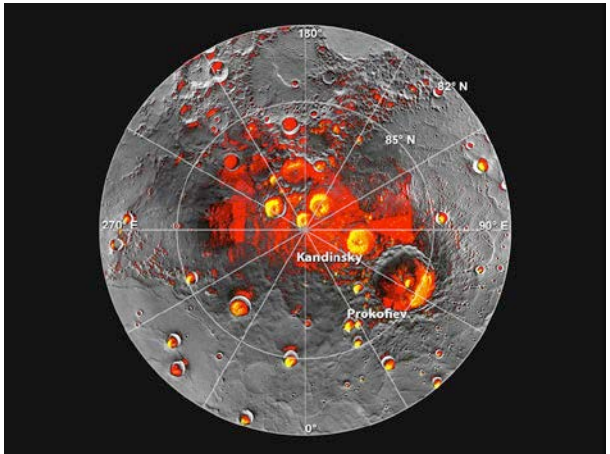
- First indications of Venus retrograde rotation (1962)
- Probing the surfaces of asteroids (1976)
- First radar returns from Titan (1989-1993), suggestive of icy surface but with potential liquids
  - With VLA! and B. Butler was Co-I
- Anomalous reflections from Mercury (1991), indicative of polar ice



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)

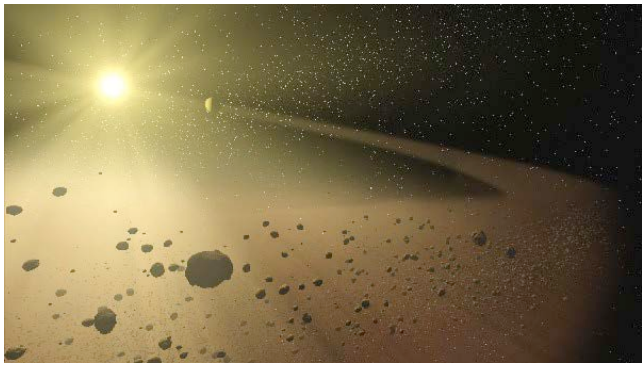
The Moon

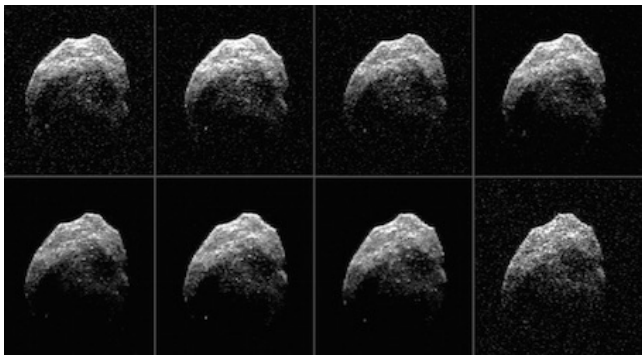
Arecibo-GBT bistatic radar

Southeastern Lunar highlands
Credit: B. A. Campbell, Smithsonian Air & Space Museum, GBT Green Bank Observatory/AUI/NSF, Arecibo Observatory

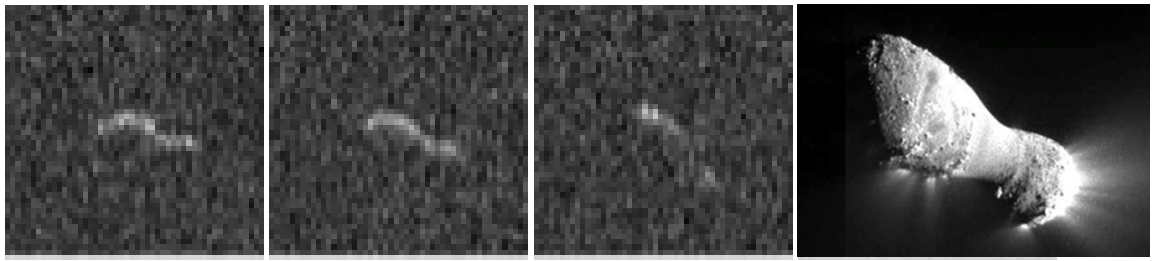
Radar Observations of Asteroids

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

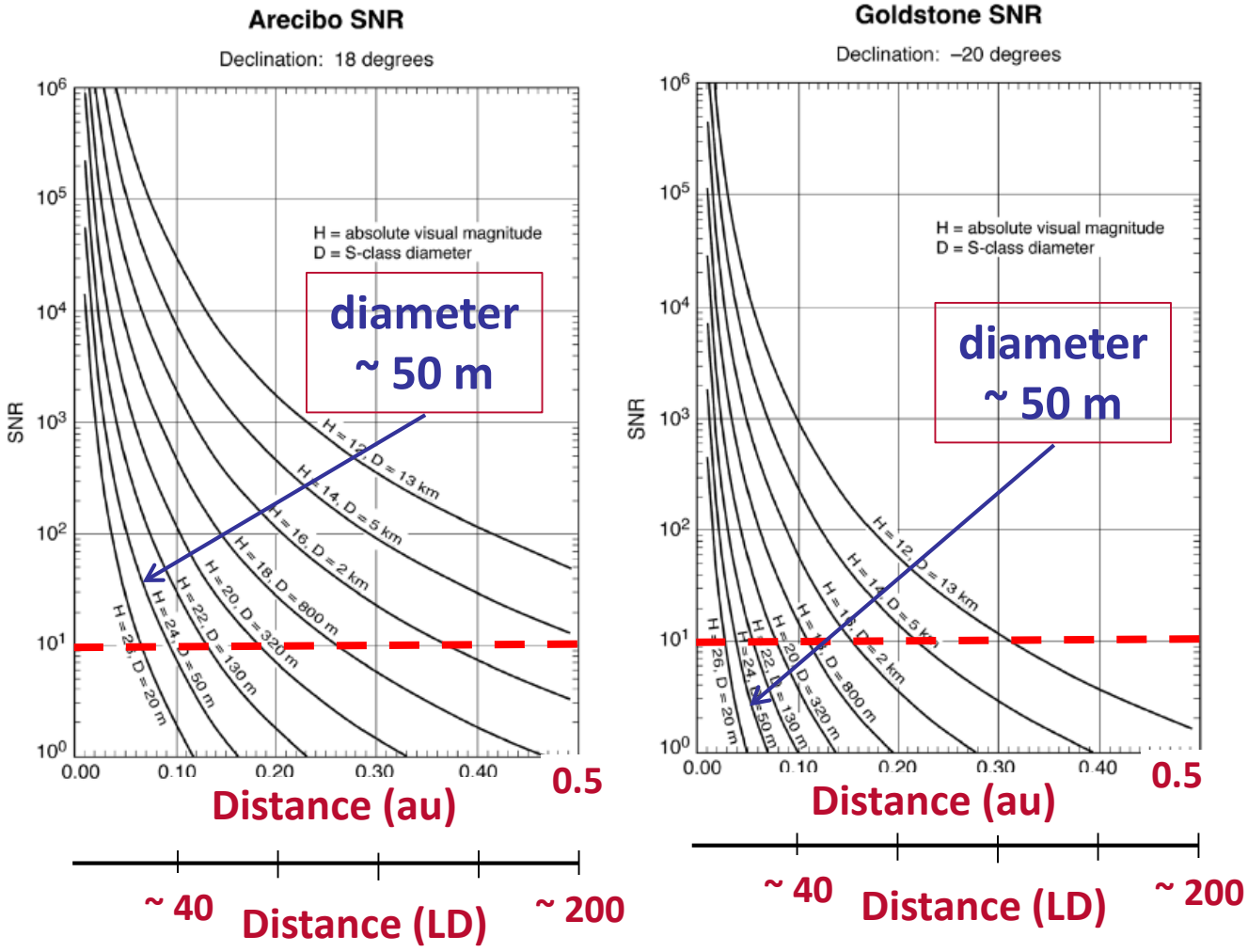




- **Science: Decipher the record in primitive bodies of epochs and processes not obtainable elsewhere**
- **Robotic or crewed missions: Navigation, orbit planning, and observations**
- **Planetary defense: Orbit determination for hazard assessment**

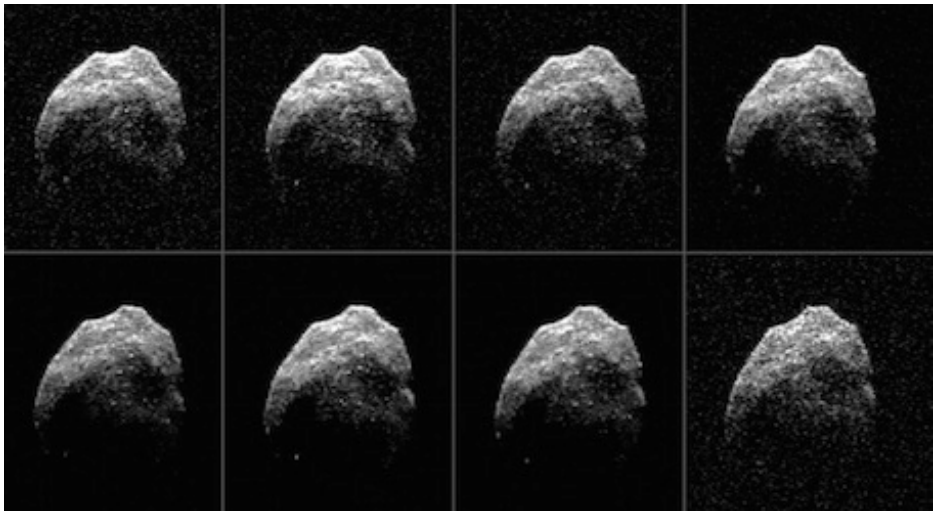


Radar and NEO Detectability

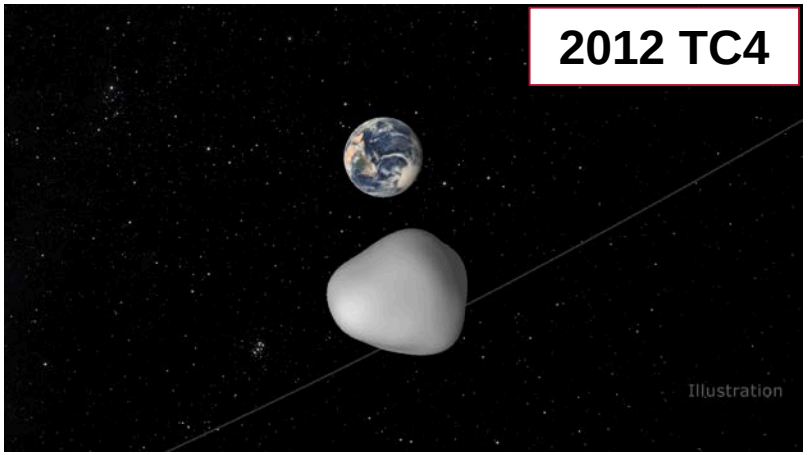


Ostro & Giorgini

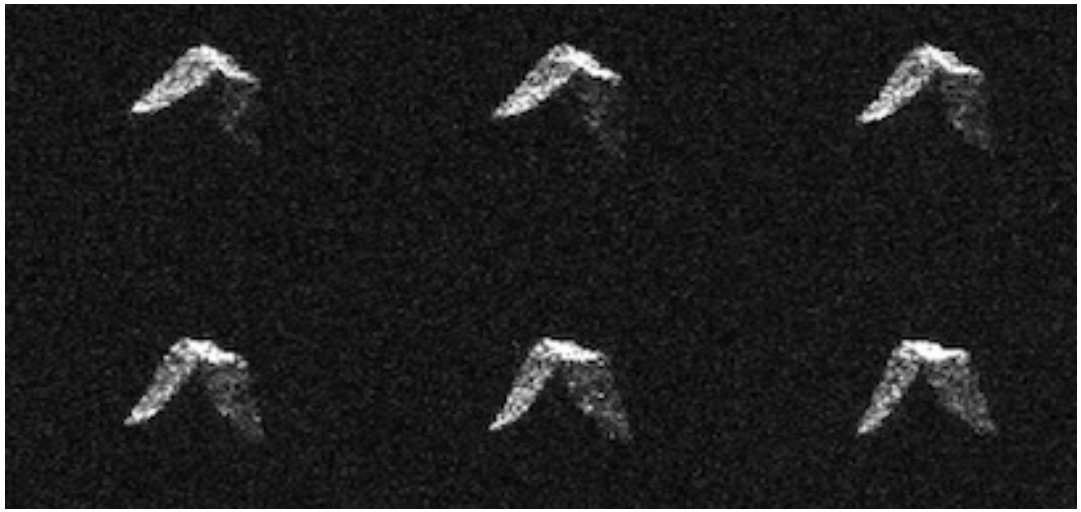
Planetary Radar Recent Results



2015 TB145
GSSR-GBT

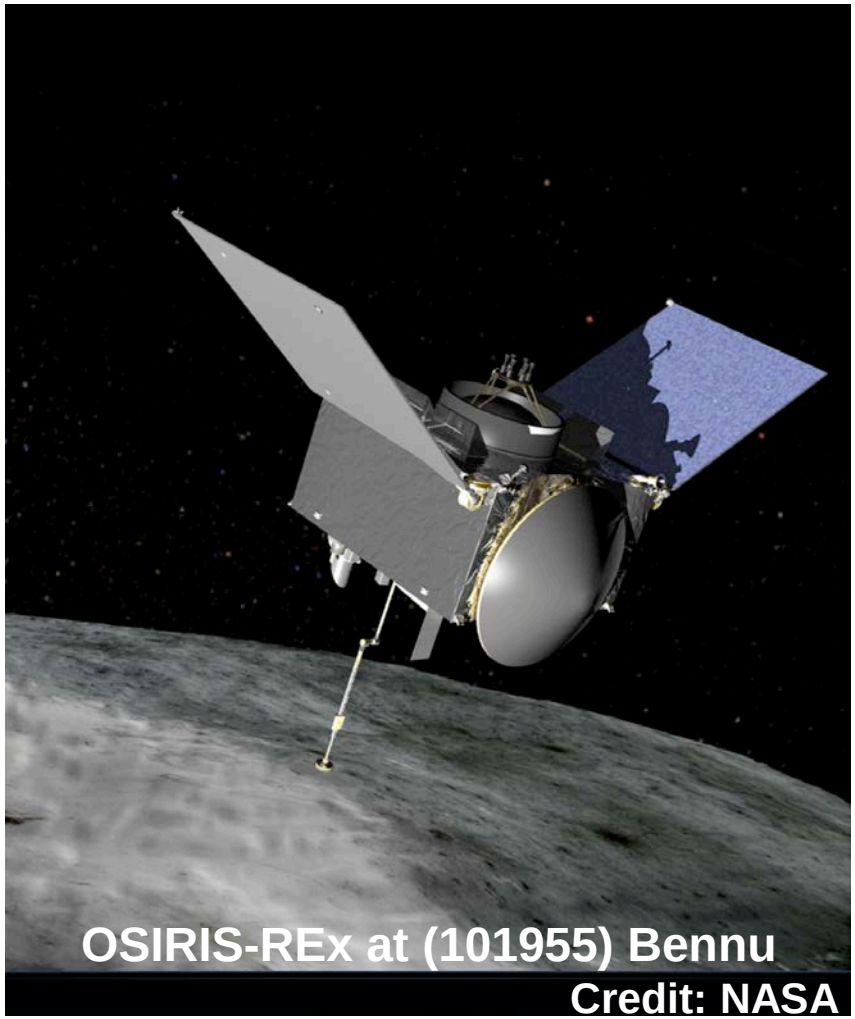


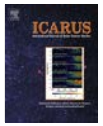
Credit: NASA/JPL-Caltech



2017 BQ6

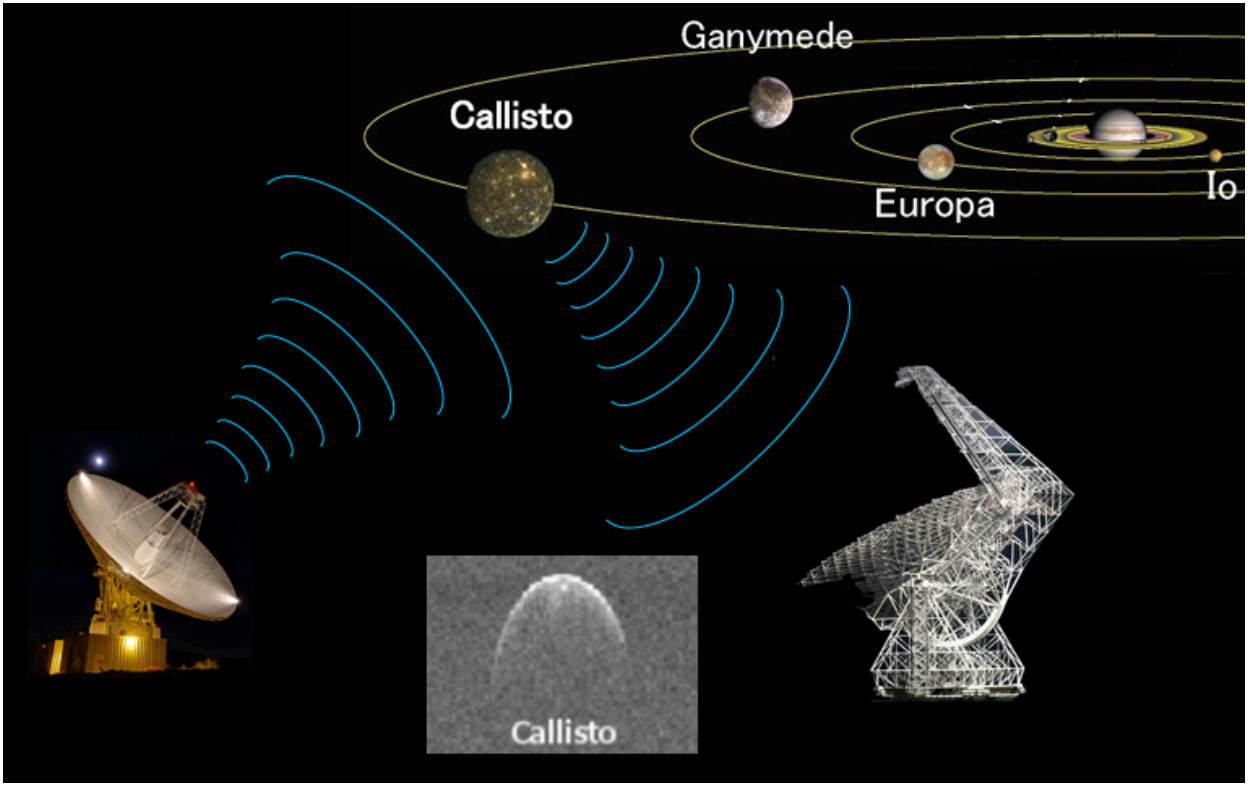
Radar Contributions to Space Missions





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

Ranging to the Galilean Satellites

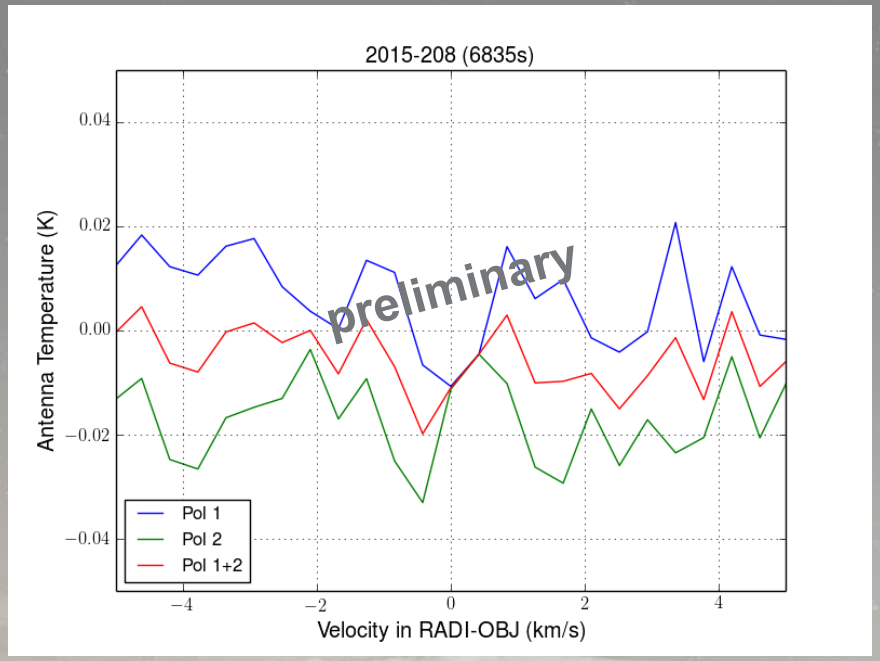


Jupiter's tidal dissipation constrains interior structure

- **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 II: Planetary Radio Astronomy

Radio Astronomy of Solar System Objects



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

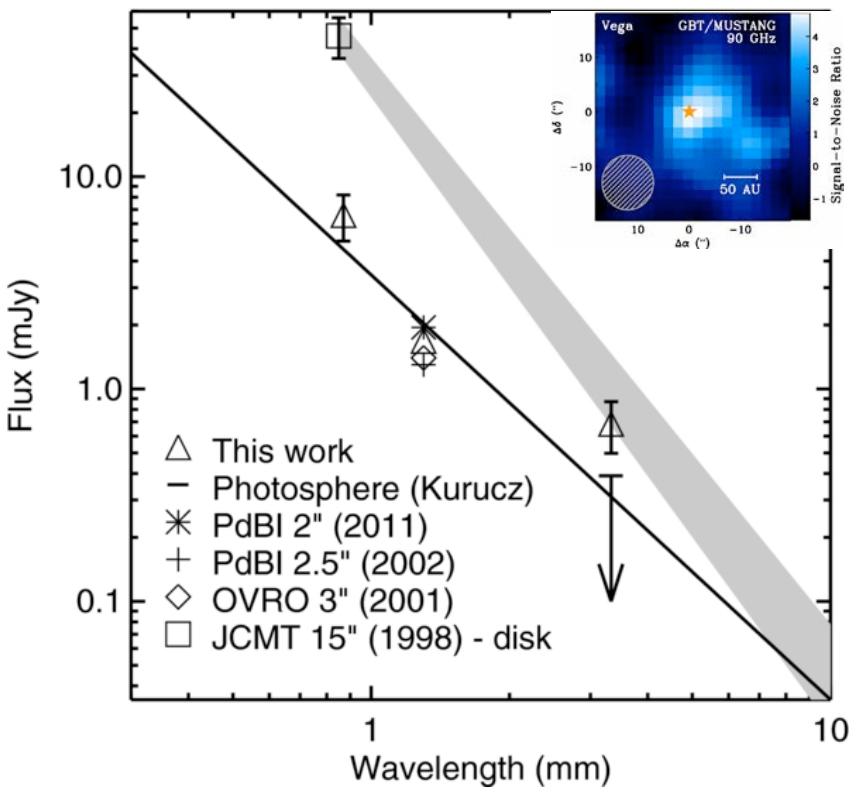
- In conjunction with Rosetta/MIRO observations
- Spectra acquired, and in processing

[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.

TJWL: Extrasolar planets!

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**
- **…?**

➢ **Potential growth area with TESS**

➢ **Likely joint with ALMA and/or VLA …**

Part III: Spacecraft Telecommunications, Telemetry, and Command

Voyager at Neptune

1989

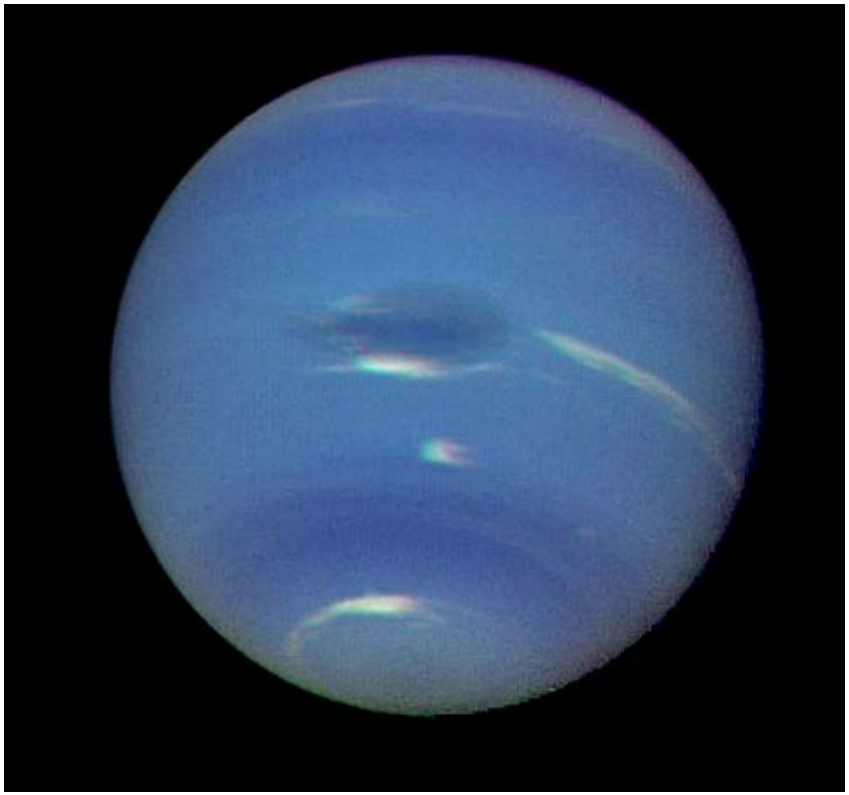
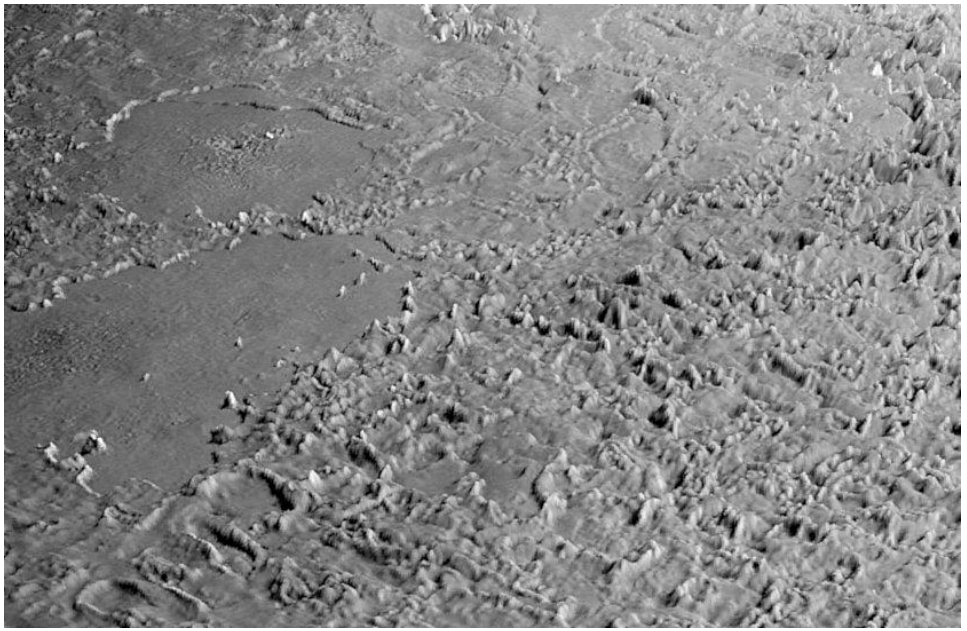
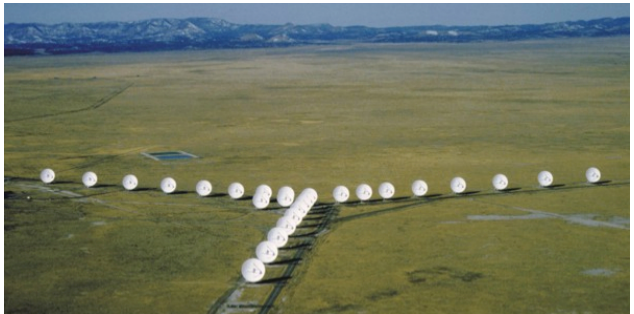


Image credit: NASA/JPL



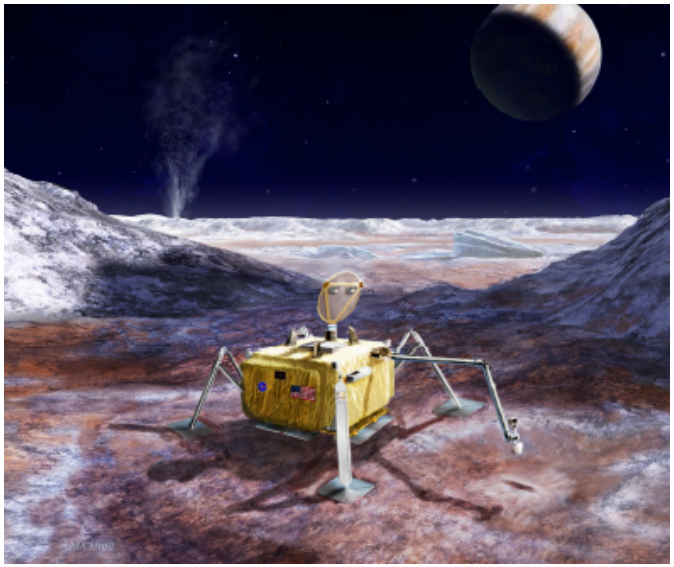
Triton

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

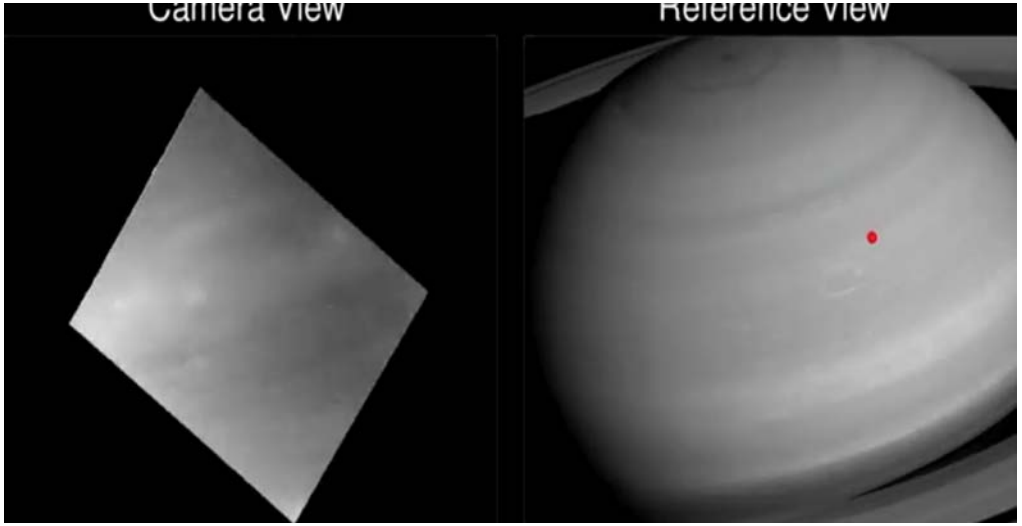


The Solar System in 2030

Potential Short Duration Mission Concepts

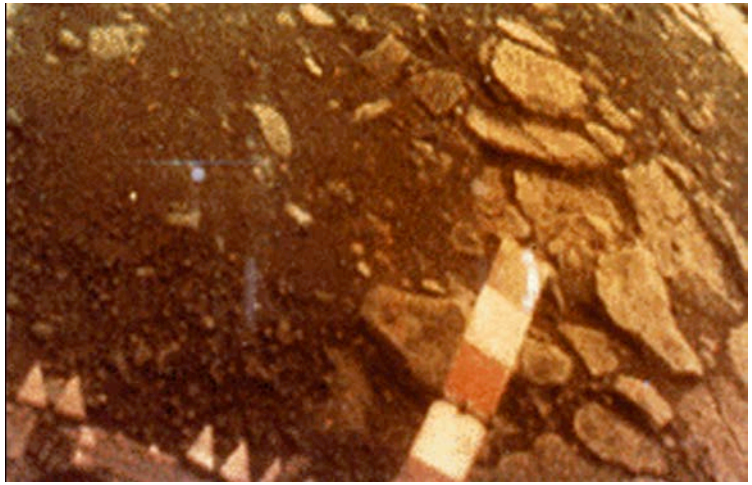


Europa lander



Saturn Probe

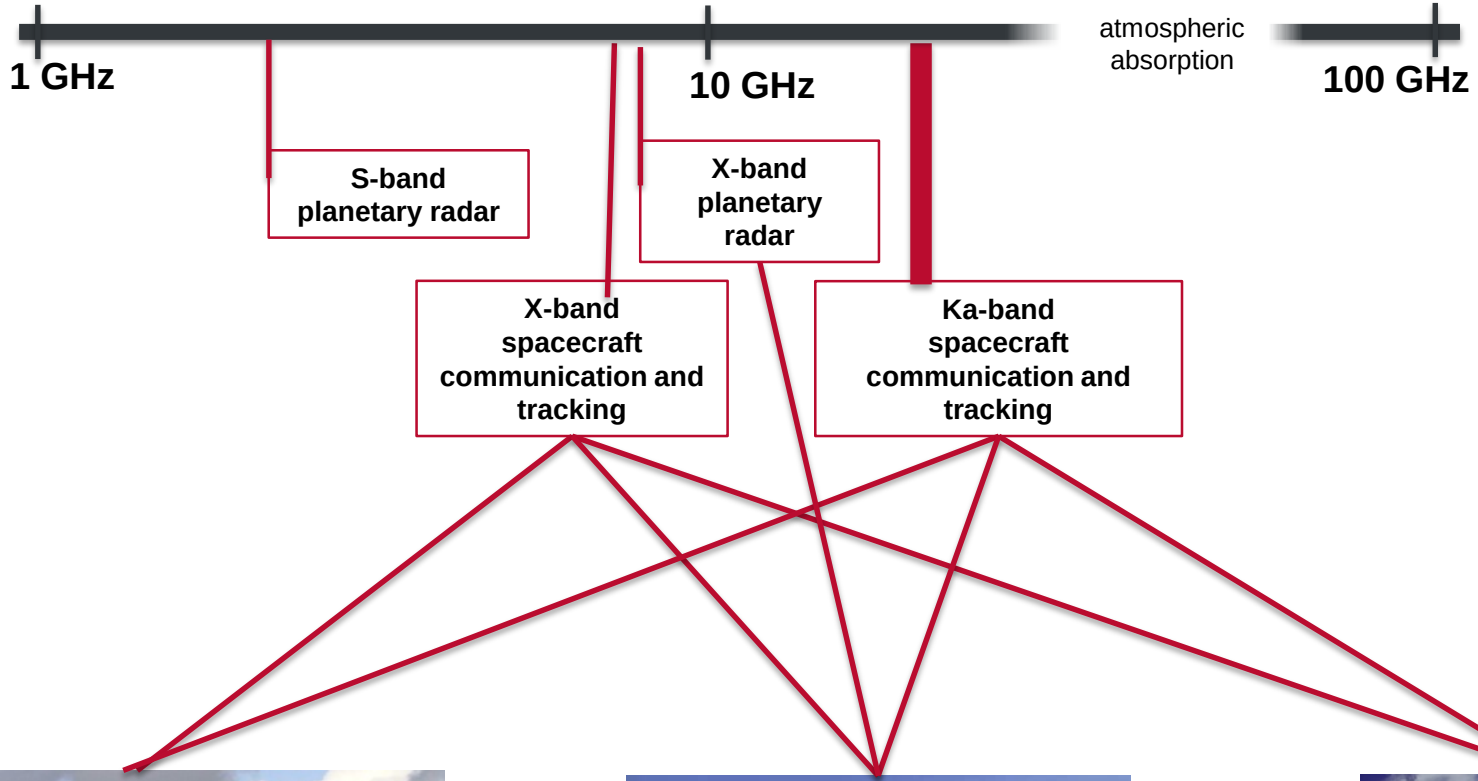
Credit: NASA/JPL-Caltech

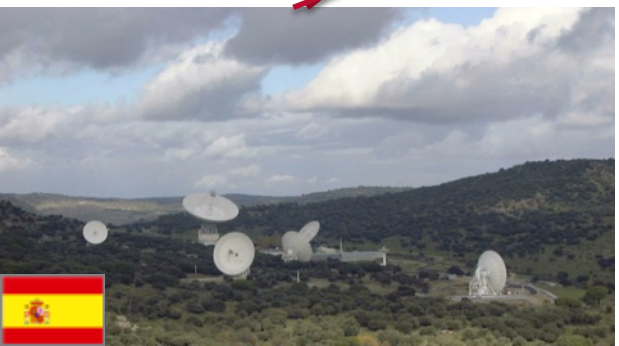


Venus lander

Credit: NASA History Office

Relevant Telescope Parameters





Planetary Radar and Radio Astronomy

- **Radar is multi-purpose**
  - **Science, navigation, planetary defense**
  - **R^{-4} is *huge* difference to standard radio astronomy**
  - ✓ **GBT enables study of smaller and/or more distant objects**
- **Planetary radio astronomy**
  - **Molecular studies of objects in solar system**
  - ¿ **Potential solar-extrasolar frontier?**
- **Spacecraft tracking**
  - ✓ **enhance short duration missions**