National Aeronautics and Space Administration

Why the DSN Looks Like This

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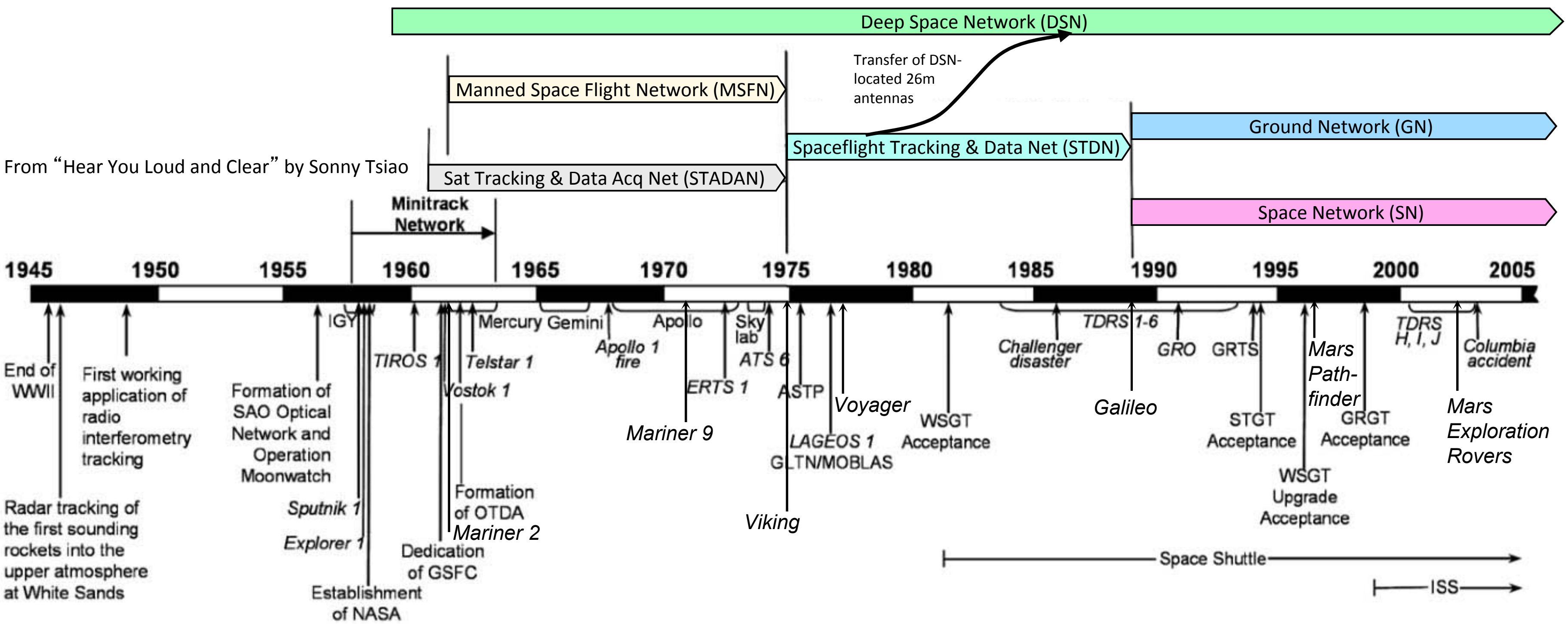
Why the DSN Looks Like This

NASA Network History

From “Hear You Loud and Clear” by Sonny Tsiao



*There was a name change from "Mercury" to "Manned" at the conclusion of Project Mercury

NASA Networks *at a Glance*

- **DSN:** Large, slow-tracking antennas located ~120° apart around the Earth – optimized for tracking spacecraft beyond GEO
- **SN:** Downward-looking Earth-orbiter-based antennas – optimized for highly-capable LEO spacecraft, including human spaceflight
- **NEN:** Small, fast-tracking antennas in many locations – optimized for short-pass tracking of LEO spacecraft

Deep Space is Unique

- Spacecraft mass and power are precious
- Spacecraft go huge distances from Earth
- Navigation is highly dependent on Earth
- DSN is a mission science instrument
- Every mission is unique

Spacecraft mass and power are precious

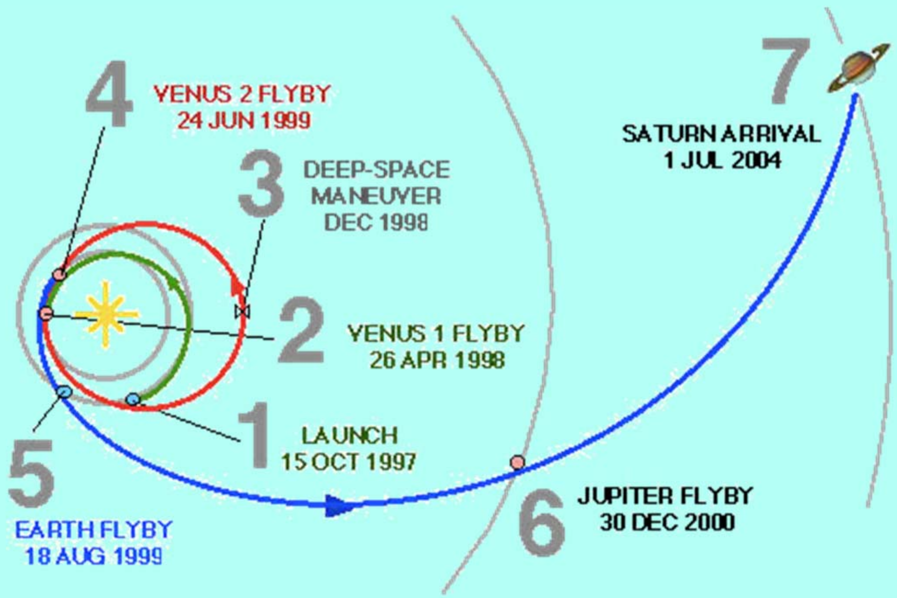
Spacecraft Mass and Power are Precious

- Deep space missions must leave Earth's gravity well – very difficult
  - An Atlas V 551 can lift about 19,000 kg to LEO but only ~500 kg to deep space
- Power generation is very difficult for a spacecraft far from the sun
  - Solar flux goes down by a factor of four each times the distance from the Sun doubles, so a solar panel at Jupiter can only generate a billionth the power as at Earth
  - Nuclear-based generators are both expensive and politically sensitive

Spacecraft Mass and Power: Consequences

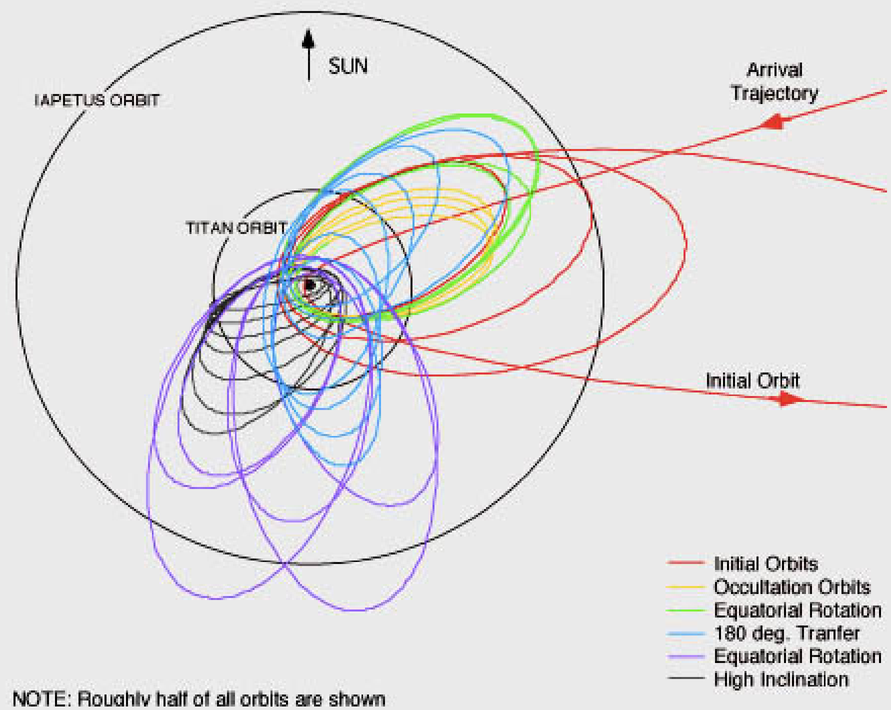
- Spacecraft look like giant antennas with instruments attached
  - Cannot afford high power
  - Transmitters typically tens of Watts
- Trajectories are optimized for lowest propellant consumption
  - Demands on navigation are extreme
  - Lots of critical events
  - Very minor mistakes can mission failure

Example: Cassini Navigation



Cassini "cruise" trajectory:
- Multiple "swing-bys" generated "gravity assists" to save propellant

Cassini "tour" trajectory:
- Multiple moon "encounters" Each sets up the next
- Propellant used only at critical times between encounters

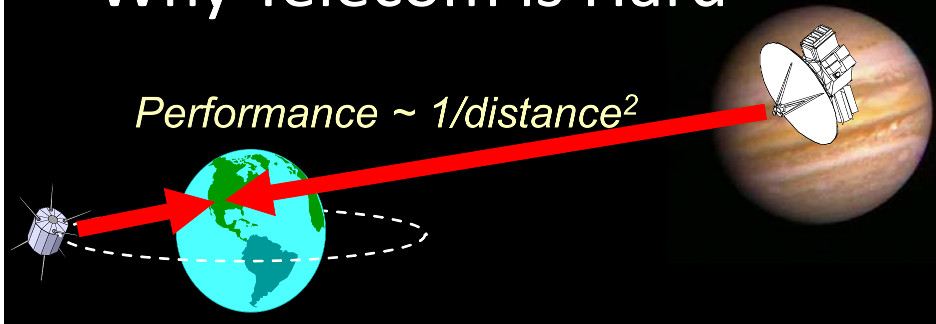


Spacecraft go huge distances from Earth

Spacecraft Go a Huge Distance

- Communications performance is inversely proportional to distance squared
- DSN has huge antennas
- System cannot waste any dBs!
- Spacecraft must be autonomous

Why Telecom is Hard

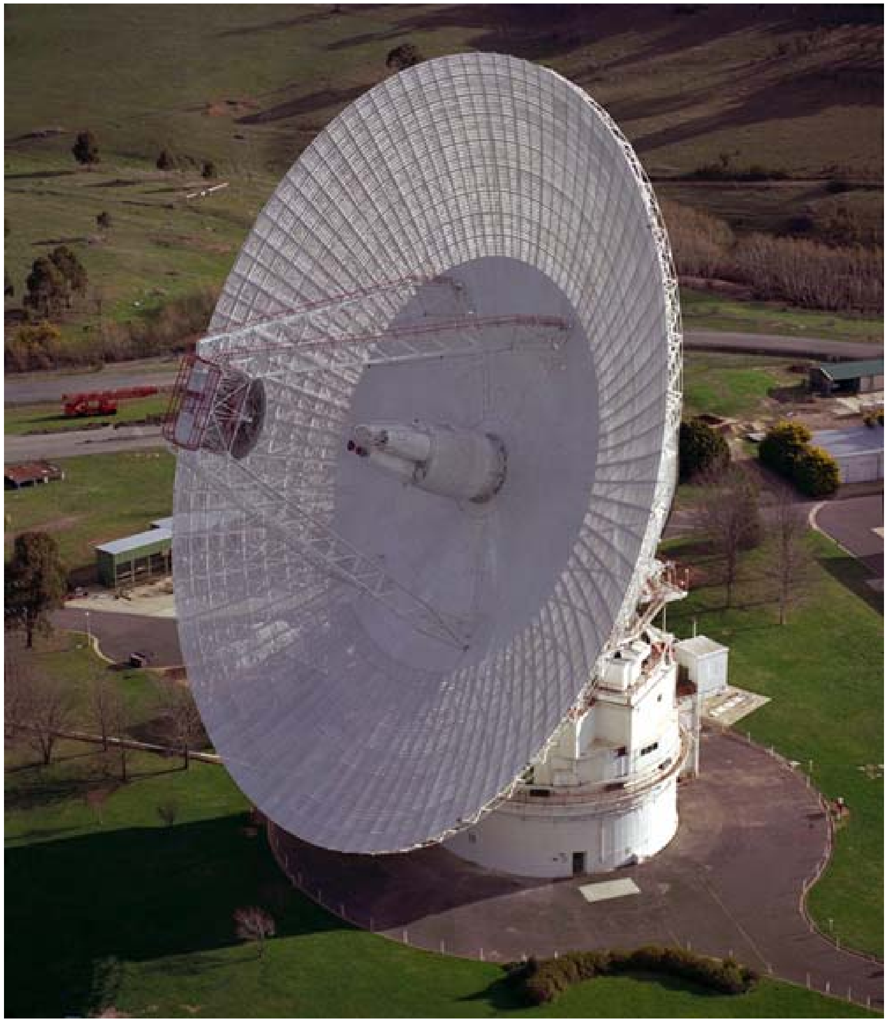


Relative Difficulty

Place	*Distance*	*Difficulty*
Geo	*$4x10^4$ km*	*Baseline*
Moon	*$4x10^5$ km*	*100*
Mars	*$3x10^8$ km*	*$5.6x10^7$*
Jupiter	*$8x10^8$ km*	*$4.0x10^8$*
Pluto	*$5x10^9$ km*	*$1.6x10^{10}$*

DSN has Huge Antennas

- This is what most people recognize most about the DSN
- DSN's 70m antennas are the largest steerable communication antennas in the world
- Each has a 20 KW transmitter



But What Kind of Antennas?

- "Antennas" are simply telescopes for radio
- Most early powerful telescopes used "equatorial" or "hour-angle/declination" (ha/dec) design
  - "Tilt" is set to compensate for latitude
  - Simple drive then tracks objects in celestial sphere
- Design is elegant
  - Good for high-speed tracking
  - Minimizes "zone of exclusion" (ZOE) around zenith

Early DSN Antennas

- The first DSN antennas used equatorial mounts
- When the STDN closed, its three DSN-colocated 26m equatorial antennas became DSN antennas

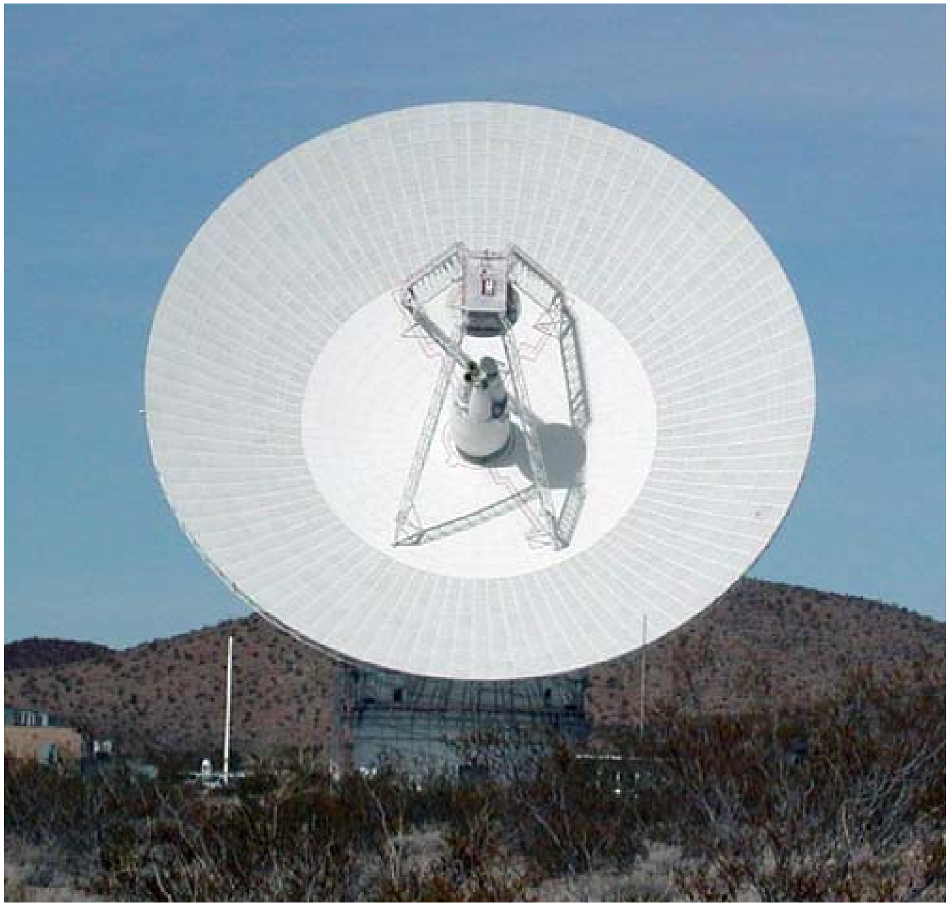
DSS-12 at Goldstone, a 34m Equatorial Mount Antenna

Azimuth/Elevation Antennas

- Many modern telescopes use an "Azimuth/ Elevation" or "Az/El" mount
  - Bottom of telescope rotates parallel to the ground
- This is a simpler, less expensive design
- Modern computer control systems have made this pervasive in recent years
- However, these suffer from ZOE problems
  - Not important for deep space tracking, but critical for LEO tracking

DSN Antennas Are Mostly Az/El

- All DSN antennas built since the 70s are Az/El

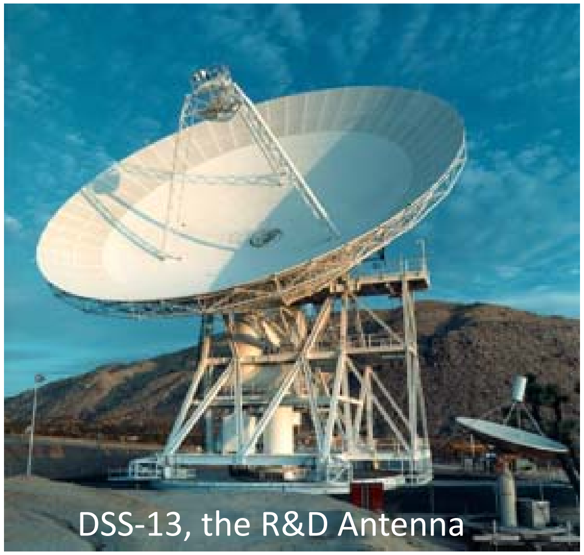


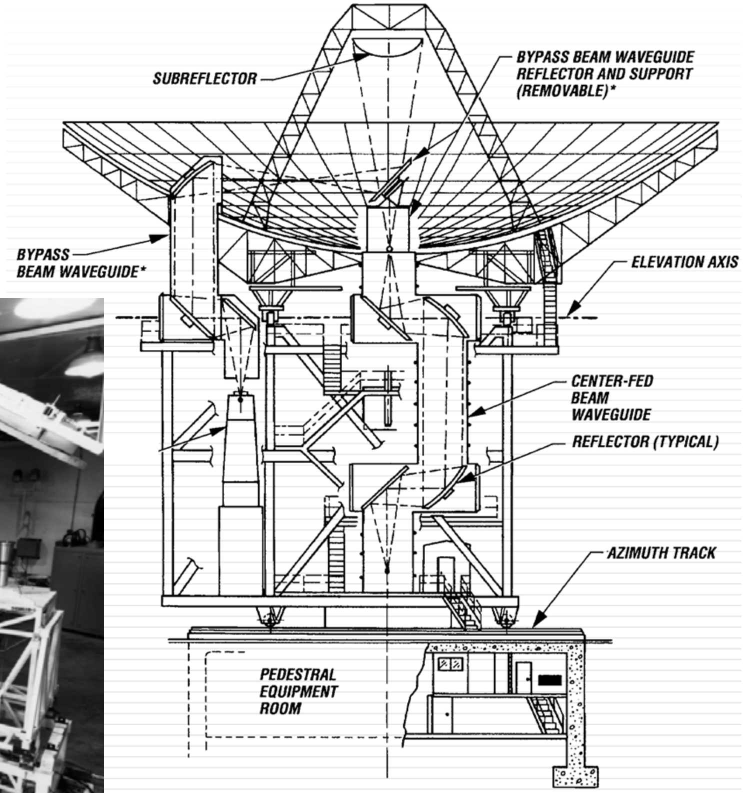
DSS-14 at Goldstone, a 70m Az/El Mount Antenna

DSS-15 at Goldstone, a 34m Az/El Mount Antenna

Az/El++: the Beam Waveguide Antennas

- 34m BWG Antenna is today's standard DSN design – and its an az/el
  - Electronics in basement lab environment
    - Its all done with mirrors!
  - Easy to update
  - Easy to service
  - Safer to operate

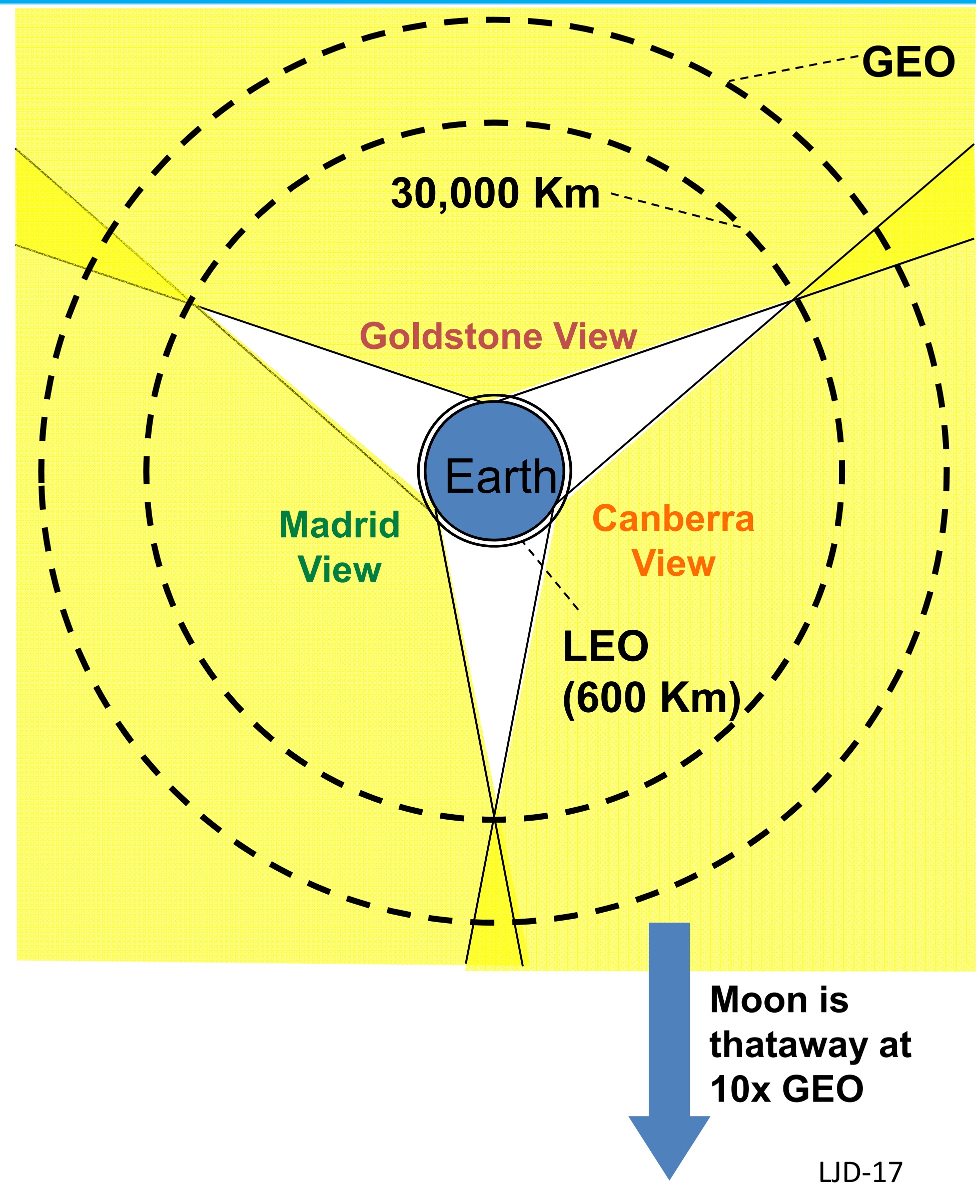




DSS-13, the R&D Antenna

DSN Sites

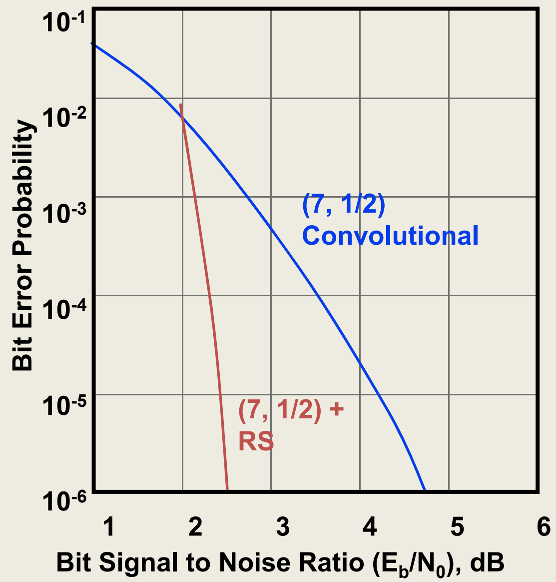
- Three "complexes", ~120º around the Earth
- Can "see" spacecraft in deep space almost all the time
- Not great for low spacecraft – such as deep space mission *launches*!



Cannot Waste a dB

- Deep space missions operate close to theoretical communications efficiency limit (within 1 dB, typically)
- Example: If a spacecraft, designed to work with a 70m antenna, lost a dB of performance, it would take an additional 32m antenna to make up the difference!
  - Cost for three 32m antennas = ~$100M!

Not Wasting dBs: Examples



Coding: Add Reed-Solomon coding to spacecraft and DSN 70m – very low cost

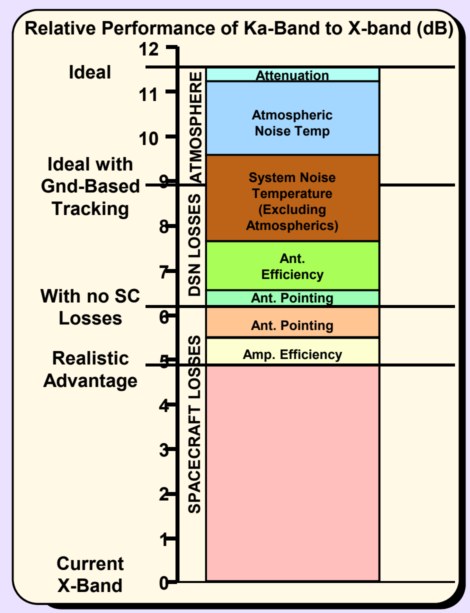
Performance improved by 2.5 dB (78%)

Avoid building ~9 34m antennas at a cost of ~$360M in today's $

Ka-Band: Add 32 GHz radios to spacecraft and DSN 34m for a moderate cost

Performance improved by 6 dB (x4)

Avoid building ~9 34m antennas at a cost of ~$360M in today's $

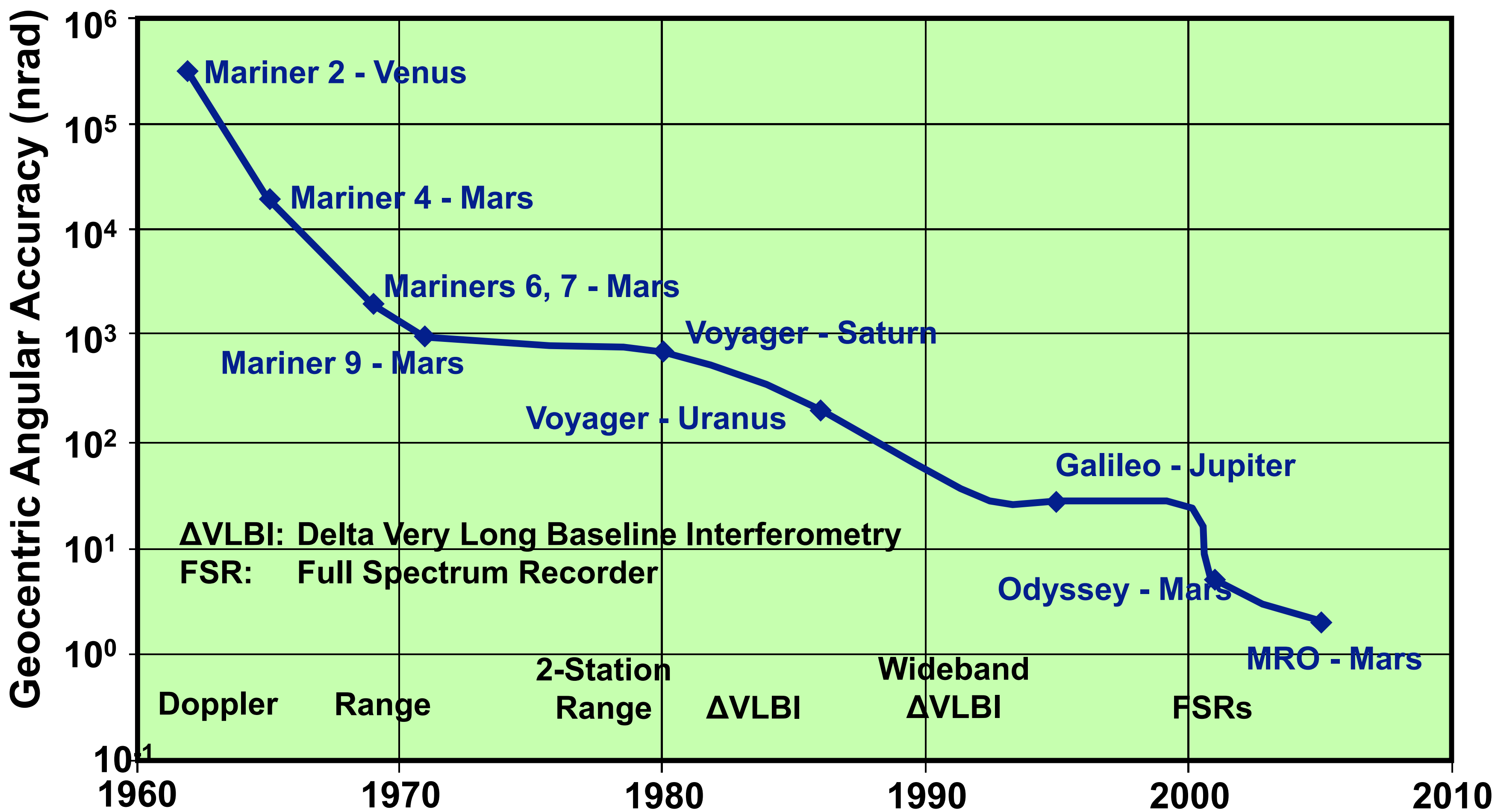


Navigation is highly dependent on Earth

Navigation is Highly Dependent on Earth

- It can take minutes to hours for signals to travel between the spacecraft and Earth
- Decisions must often be made faster than this – requiring spacecraft autonomy
- Spacecraft are usually “sequenced”, meaning they are programmed to operate for long periods without commands from Earth
- Spacecraft manage the data they acquire, storing it until it can be sent back to Earth
- Emergencies require special “safing” algorithms

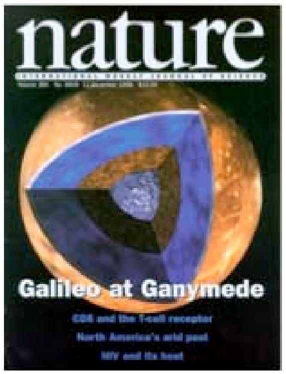
Deep Space Angular Tracking



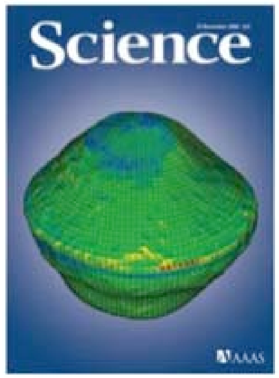
DSN is a mission science instrument

The Impact of DSN Science

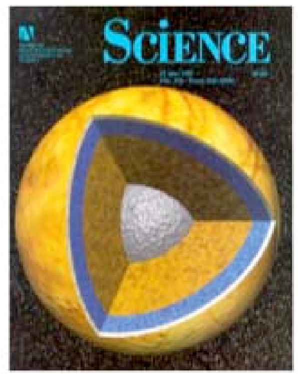
DSN science has provided a continuing torrent of forefront discoveries – many high impact papers and mission investigators



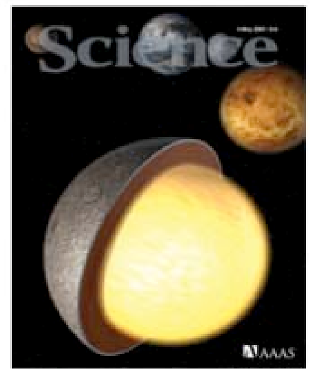
Interior of Ganymede



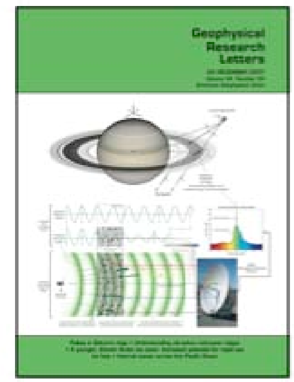
Asteroids in 3-D



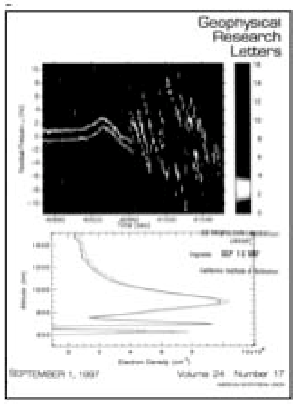
Oceans on Europa?



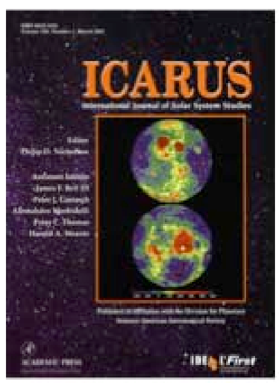
Mercury Liquid Core



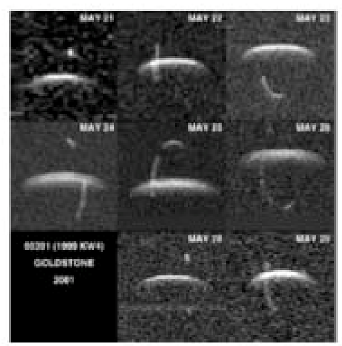
Saturn's Rings



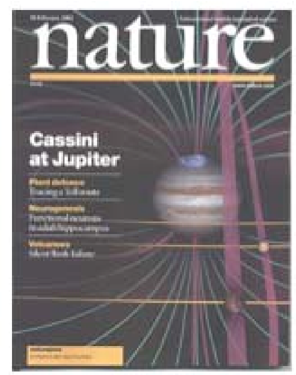
Mars Ionosphere



Moon Gravity Field



Binary Asteroids

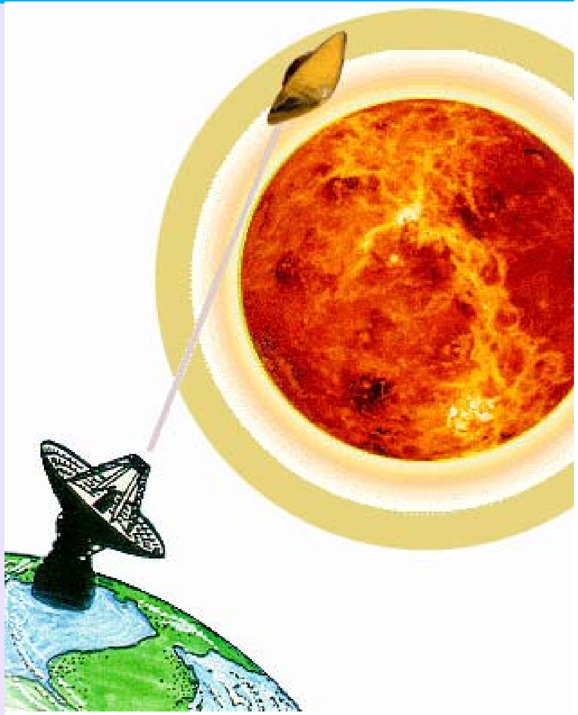


Student Study of Juptier Radio Emission

Saturn's Rings

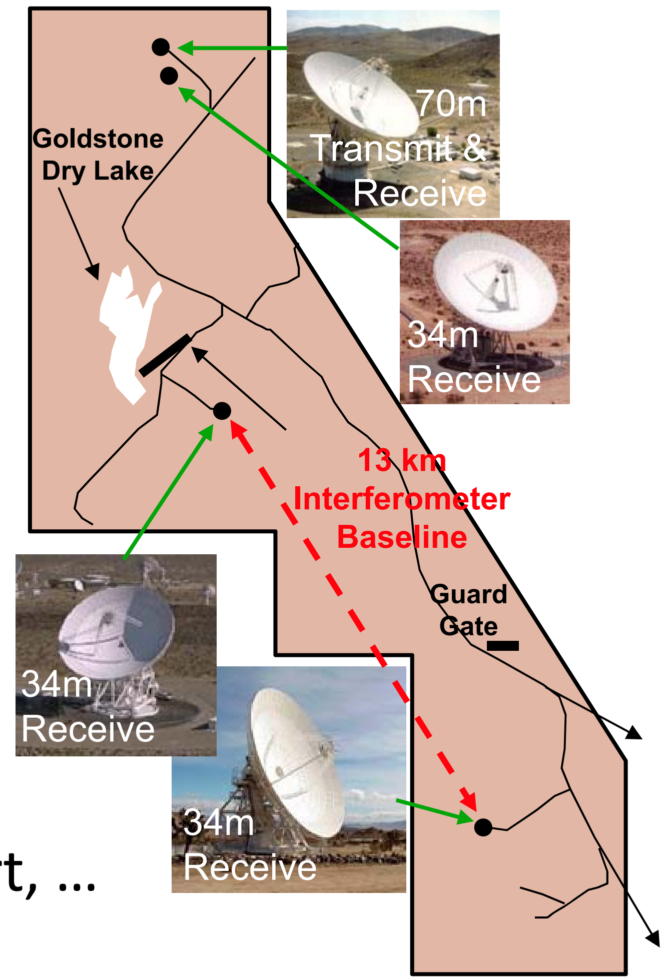
Radio Science

- Tracking spacecraft near or behind targets yields important science
- Atmospheric dynamics
  - Circulation
  - Vertical structure
  - Turbulence
- Atmospheric density
- Gravity field mapping
- Special high dynamics receivers are used for this in the DSN

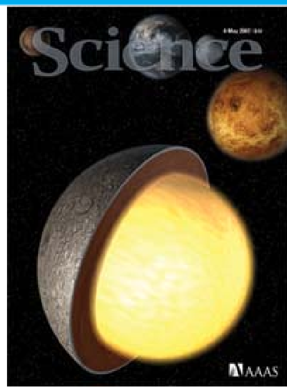


The Goldstone Radar Facility

- Unique for high-res ranging and imaging of planets, small-bodies
  - 500 kW X-band transmitter
  - Can be used with Arecibo
- Wide variety of science
  - Surfaces: images, topography, ice, physical characteristics, chemical composition
  - Dynamics: Orbits, rotations, spin axes
- Mission use
  - Landing site evaluation, emergency support, …
  - Mission science support
- NASA approved science investigators

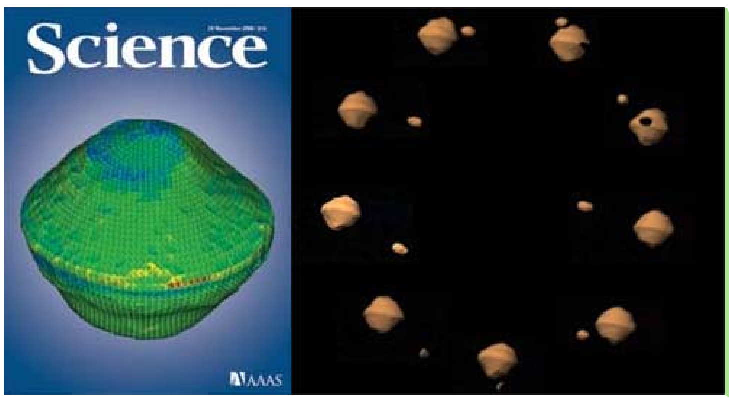


Goldstone Radar: Recent Highlights



Discovery of Mercury liquid core

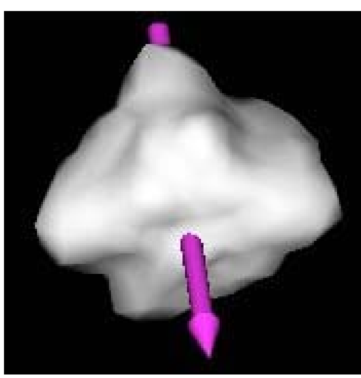
– Supports Messenger mission



Radar Imaging and Topography of Unusual Asteroids

– Support NEO Program

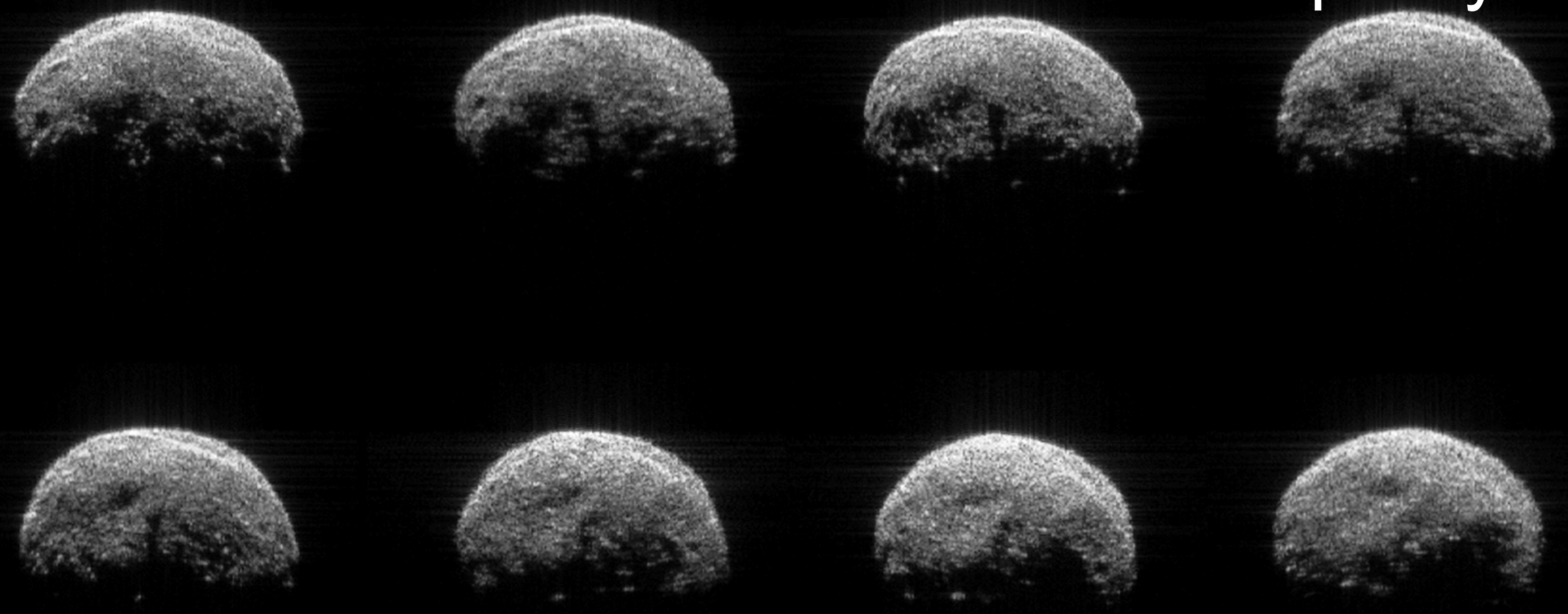
– Asteroid 1999 KW4 – A binary pair of asteroids, with the larger object being extremely oblate because it is close to it's breakup rotation rate



– Asteroid 2000 PH5 – Asteroid found to increase spin rate due to sunlight torque (Science, 13 April 2007)

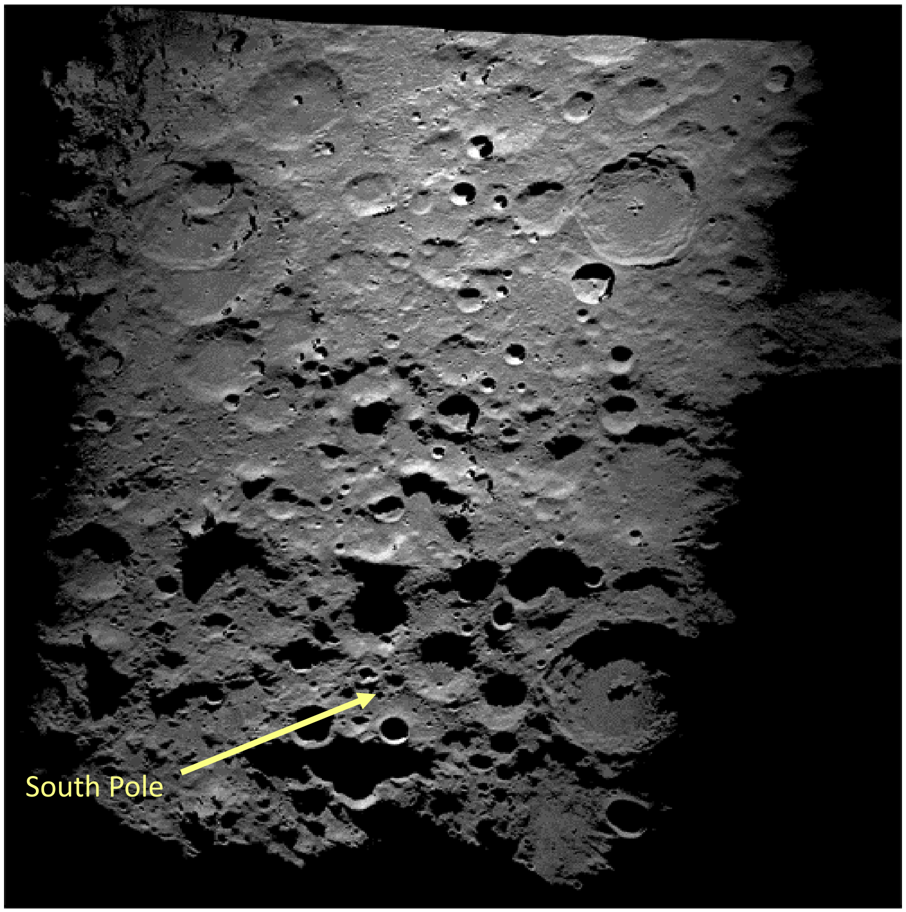
A Very Close Encounter

- In November 2011, Asteroid YU55 came closer to the Earth than our own Moon
- The Goldstone Radar imaged YU55 at 3.75 m resolution – better than encounter quality!

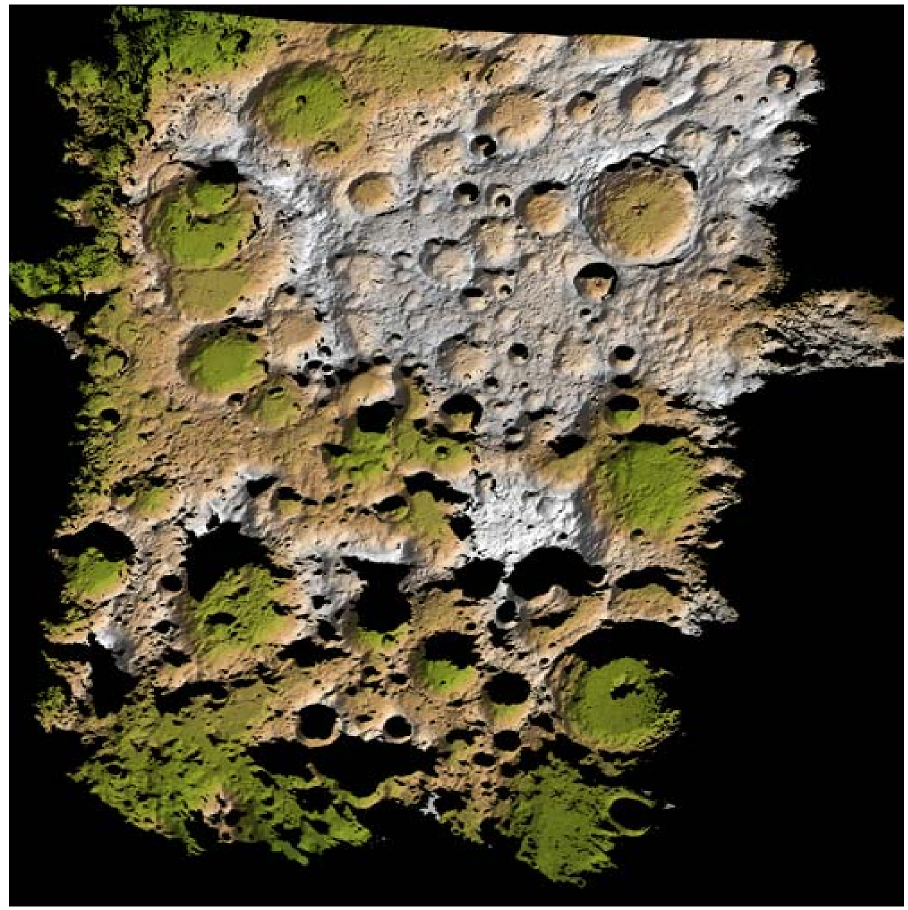


Goldstone Radar: Lunar Science

Unprecedented imaging (20m resolution) and topography resolution of Lunar South Pole where the Sun never shines!



Radar Image



Digital Elevation Map

Every mission is unique

Every Mission is Unique

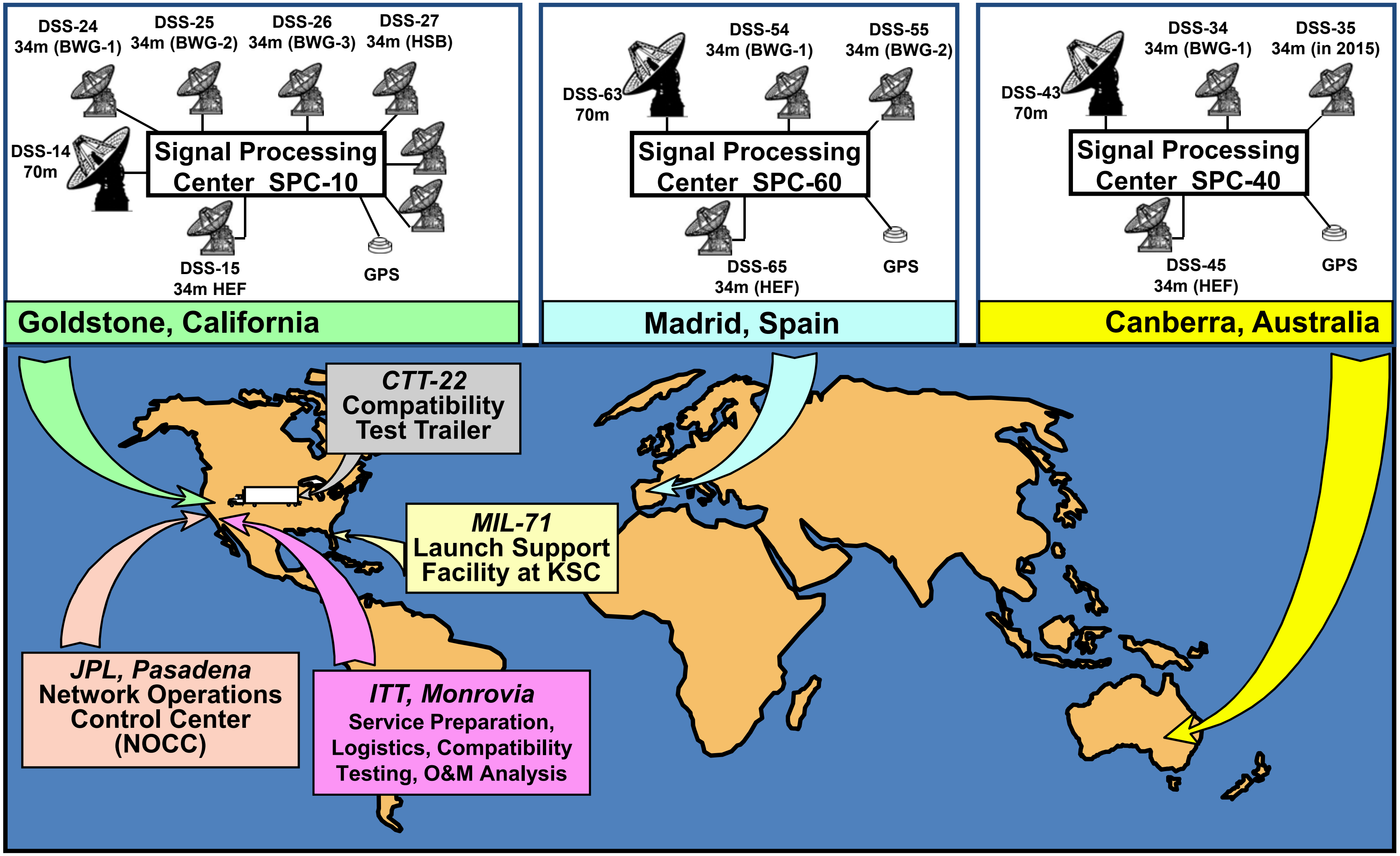
- There are a myriad of deep space targets: planets, moons, asteroids, comets, and parking spaces for astronomical observatories - each with their own
  - Set of scientific questions
  - Unique trajectory challenges
  - Unique spacecraft bus, instruments, and porpulsion
- Even popular targets (e.g. Mars) are visited only every few years, with differing spacecraft

Unique Missions ⇒ Unique Solutions

- Communications and navigation can be different for each mission
  - Often requires special studies to optimize performance and maximize success
  - Missions have their own comm and nav experts
- New technology is often infused in both the spacecraft and the DSN – creating something new for every missions

So, the DSN looks like this …

DSN Facilities



DSN Antennas in Madrid, Spain