The Deep Space Network
The Most Important Science Tool of the Last 50 Years?

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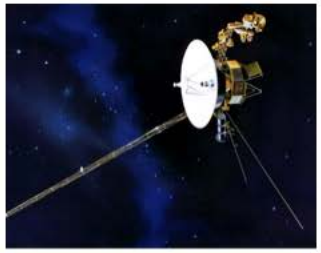
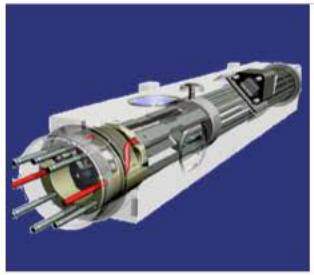
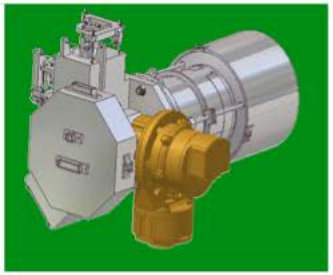
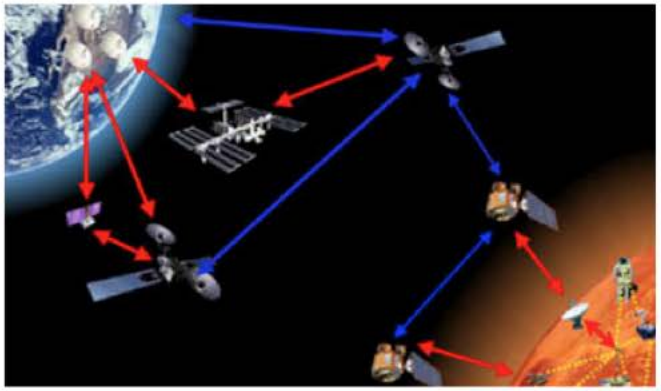
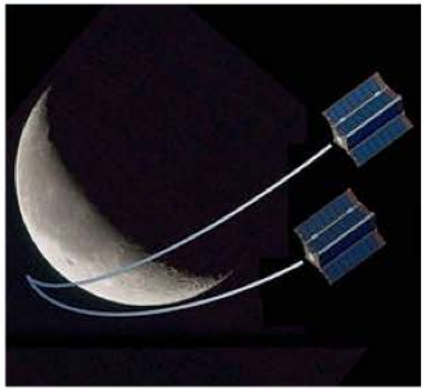




50 Years of Science

The 20th century saw enormous strides in science & engineering

Took only 66 years to progress from first human powered flight to landing humans on the Moon

How can we begin to grasp scientific progress during lifetime of the DSN?

Council for the Advancement of Science Writing represents science journalists who serve as bridge between scientists and public

- Published a "Top 50 List" – starting from 1957
- Pretty close to first 50 years of the DSN!

50 Years of Science

Of top 50 science advances, the Deep Space Network was intimately involved with 22!

Not a bad record

Probably as good as any other scientific instrument

Let's examine the list and the role the DSN has played in advancing science in its first 50 years …

1. Satellites

Sputnik 1 launched in 1957, shocking the world

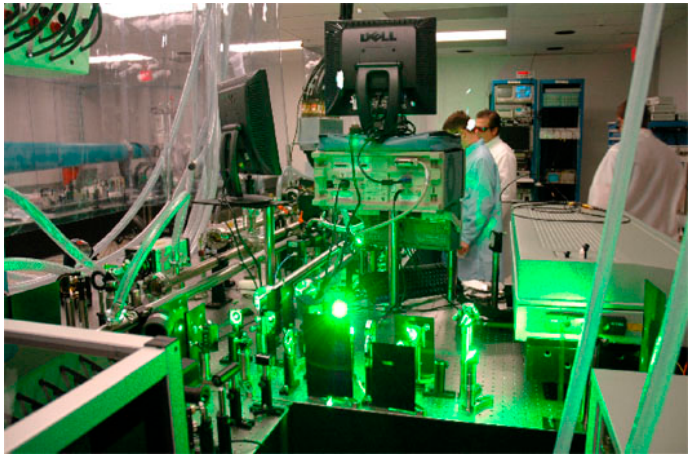
The DSN was built soon after, to enable much more capable satellites

Communicating with satellites was critical – as was navigating them on their journeys, particularly as they left the "safe" low Earth orbit pioneered by the Sputniks

Without the DSN, we would not have had spacecraft to the Moon and, later, to other planets

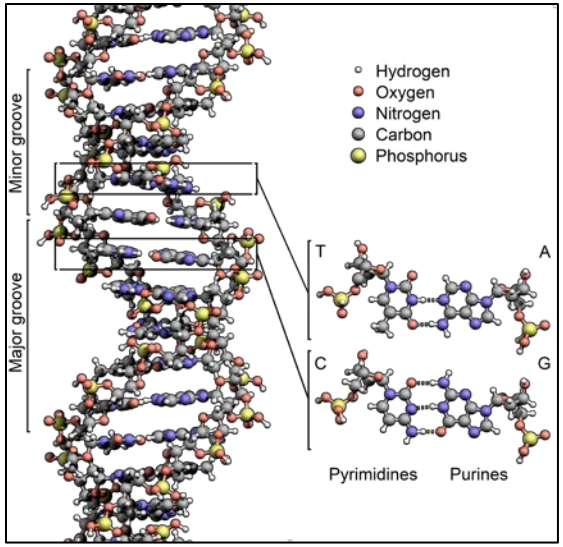
Some non-DSN Science

2. 1960 – The Pill



3. 1960 – Lasers

(remember these …)



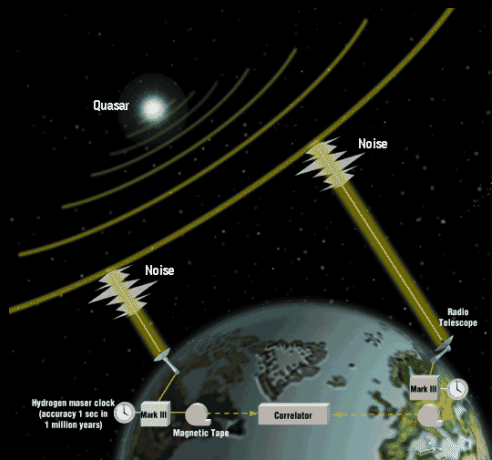
4. 1961 – DNA Code

5. Plate Tectonics

In 1961, model of plate tectonics came into prominence, explaining the observed spreading of the sea floor and uplifting of mountain ranges

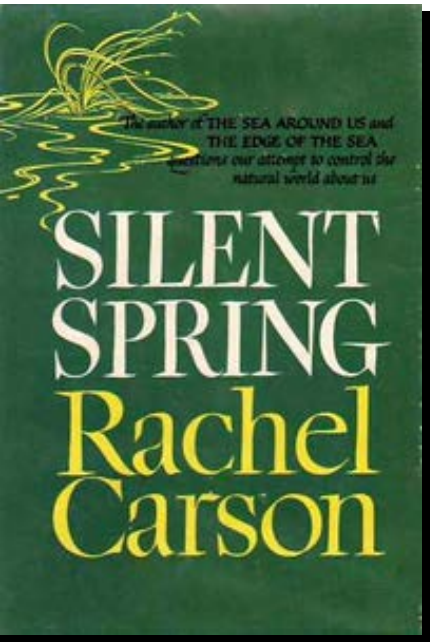
Precise measurement was critical to providing the evidence --- accomplished by observing space radio sources with pairs of antennas on different plates.

The DSN was ideally suited to this task and provided much of the data required to hone this new model



6. Environmental Movement

Jet Propulsion Laboratory
California Institute of Technology



The 1962 book Silent Spring *is credited with starting American environmental movement, leading in turn to global awareness.*

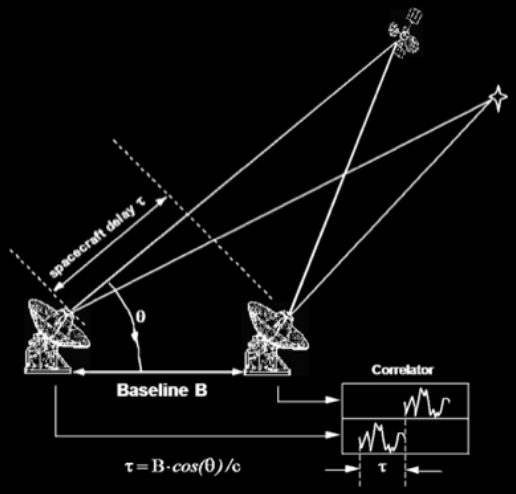
Most scientists also recognize the contributions of "Earthrise" photo, snapped by Apollo 8 astronauts and returned by the DSN.

7. Quasars

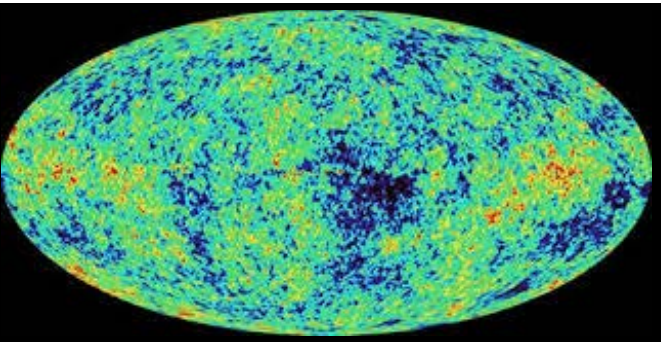
Quasars, energetic galactic nuclei, were discovered in 1963. Unlike other radio emissions from deep space, quasars behave like point sources

Quasars make ideal signposts in deep space because of their stability and the fact that they emit radio waves that can be observed by the DSN.

The DSN has cataloged these sources and uses them for navigating spacecraft in deep space



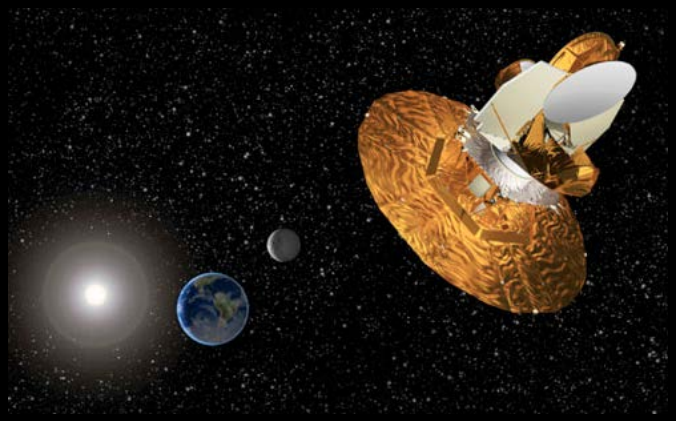
9. Cosmic Background
25. Cosmic Inflation
39. Dark Energy
43. Age of the Universe



Cosmic Microwave Background, a remnant of the Big Bang, discovered in 1964

Much of what we know today about the early Universe, and its subsequent evolution, is from deep-space spacecraft studying the CMB.

The DSN is so sensitive that spacecraft engineers have to account for the power contributed by the Cosmic Microwave Background



11. Moon Landing

In 1969 Neil Armstrong became first human to step onto the Moon. The Apollo Program spurred a host of new technologies to benefit all of us.

The DSN supported all the Apollo missions, providing communications and tracking.

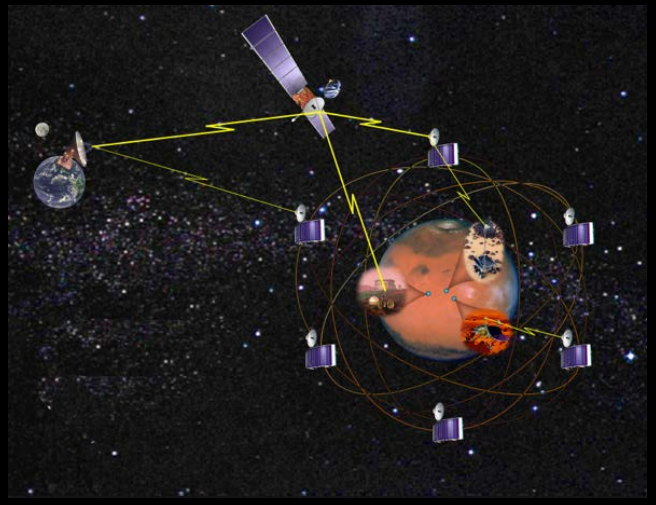
The DSN relayed the video of Armstrong's first steps on the lunar surface

12. Internet

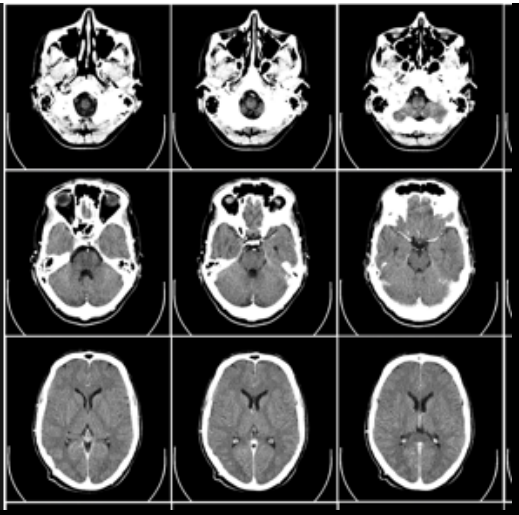
ARPANET was established in 1969 – precursor to today's Internet. Essential to the Internet is a protocol for exchanging information among nodes, accounting for delays and disruptions

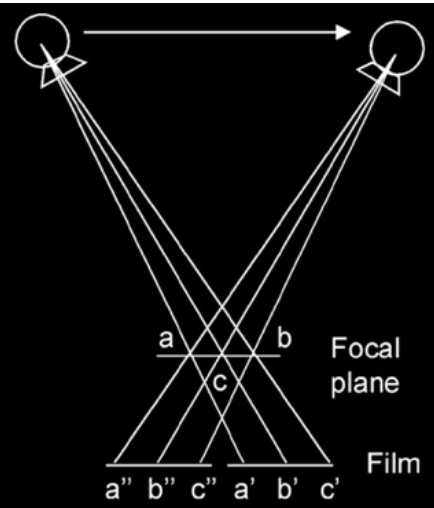
Today, the DSN is working to extend the Internet across the solar system – allowing a virtual presence wherever we are exploring.

DSN scientists are deploying Disruption Tolerant Networking, a new set of protocols that enable robust communications over planetary distances



14. Medical Scanners

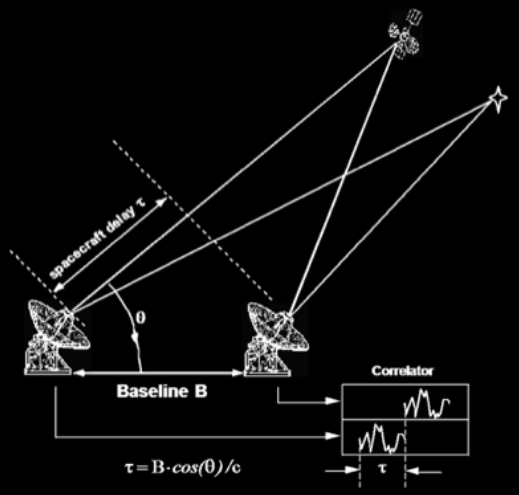




In 1972 Godfrey Hounsfield invented "computer tomography." CT scans revolutionized medical science.

Where have we seen this diagram before?

Mathematics of CT processing derives from the algorithms used for space navigation and radio science. DSN researchers contributed to emerging field of medical scanning in the 1980s.

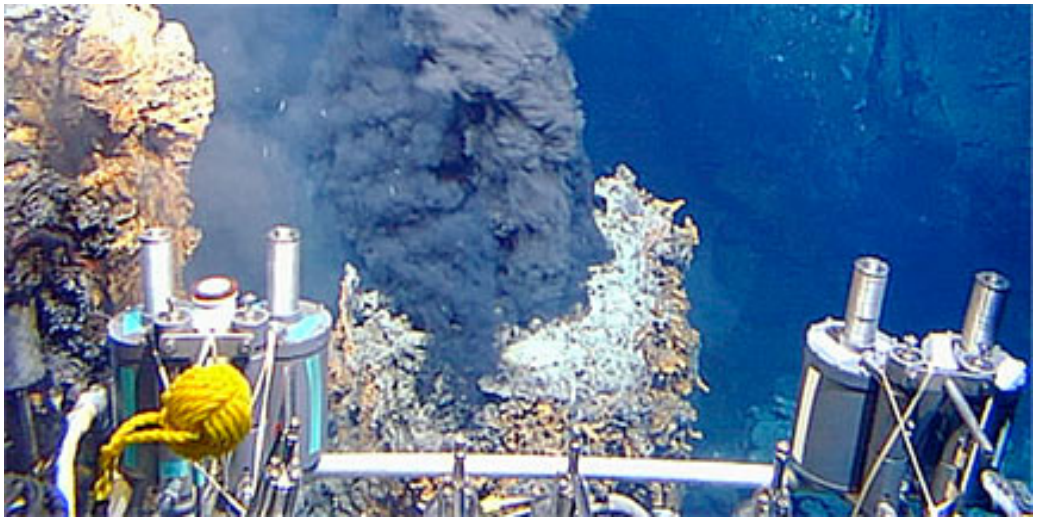


18. Pictures From Other Planets

In 1976, NASA Viking landers sent back first pictures from the surface of another planet: Mars

The DSN has brought back photos, and other information, from all the planets in the solar system. The dwarf planet Pluto will be visited in 2015.

Non-DSN Science?



19. 1977 – Deep-Sea Life

Honorable mention:

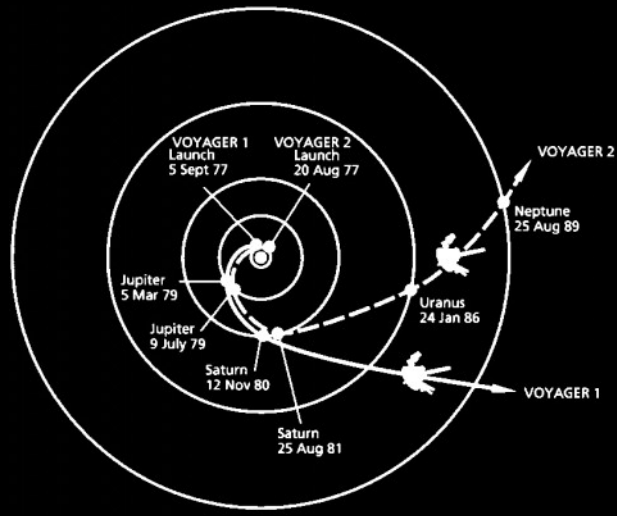
When John Delaney was forming UW's Neptune Project to study life around thermal vents on the ocean floor, he contacted JPL's DSN engineers because their expertise in communicating in hostile environments.

20. Farthest Frontier

In 1977, NASA launched the two Voyager spacecraft to study Jupiter and Saturn

In order to "keep up" with the Voyagers – which went on to visit Uranus and Neptune, the DSN made extensive upgrades and developed substantial new communications technology

Now that Voyager 1 has left the Solar System, every day sets a new distance record with the DSN

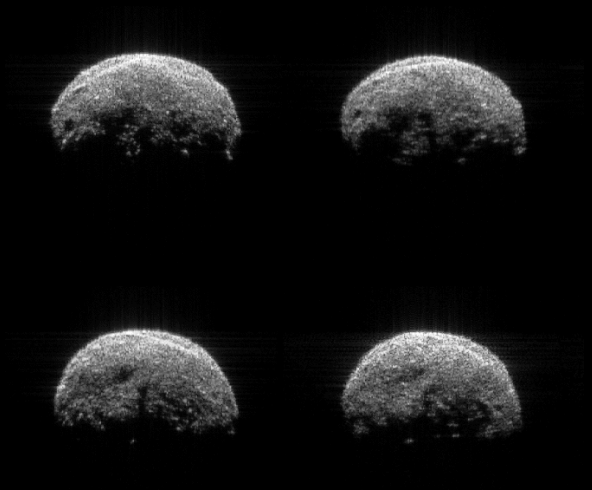


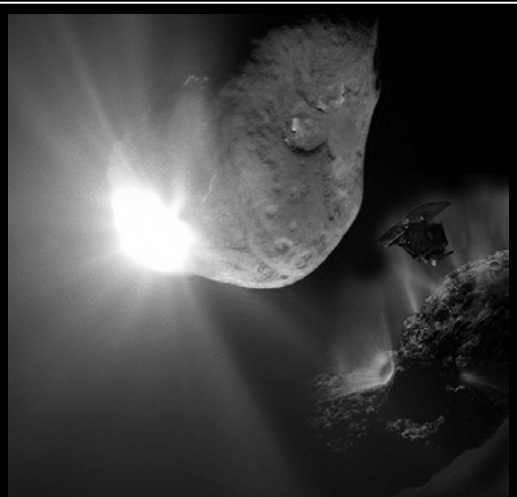
24. Killer Asteroids
31. Catching Up With Comets
33. Witnessing a Cosmic Crash

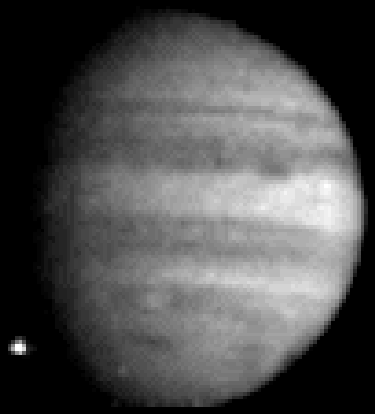
Major collision with an asteroid or comet killed off the dinosaurs proposed in 1980.

Could we be next?

Asteroid and comet chasing, deep space trajectories, radar studies of asteroids and comets --- all have benefited from the DSN and DSN researchers







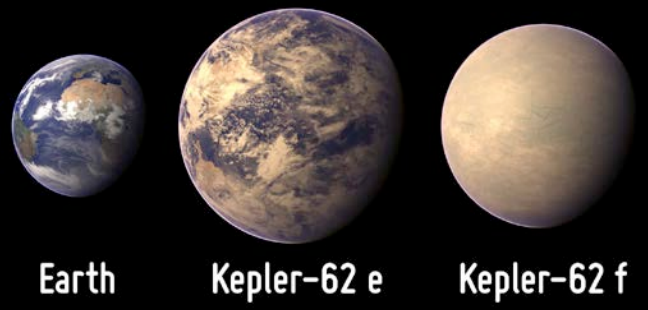
36. Alien Planets
46. Planets Realigned

In 1995, first definitive discovery of a planet orbiting another "normal" star announced

In 2006, "planet" officially defined, and Pluto re-christened as "dwarf planet."

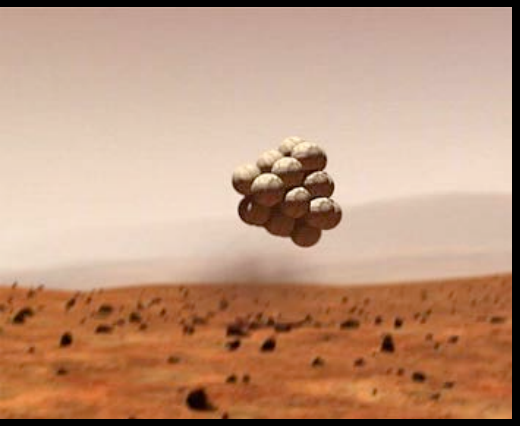
Spacecraft supported by the DSN, primarily Kepler*, have increased the number of known planets from 9 to more than 3500 in the last 50 years.*

Planetary orbits were a consideration in the re-definition of Pluto.



CREDIT: PHL @ UPR Arecibo (phl.upr.edu) April, 2013

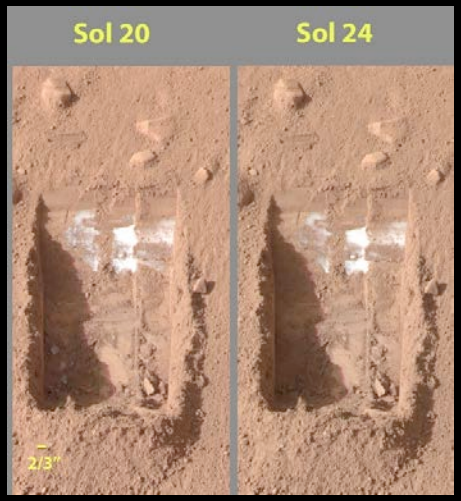
38. Big Bounce on Mars
49. Tasting Martian Water



1997 saw new start for Mars exploration with landing of Mars Pathfinder *and its rover,* Sojourner

Rovers offered potential for more detailed exploration

Succession of ever more capable rovers and landers, following the water, and setting up a Mars relay network with the orbiters

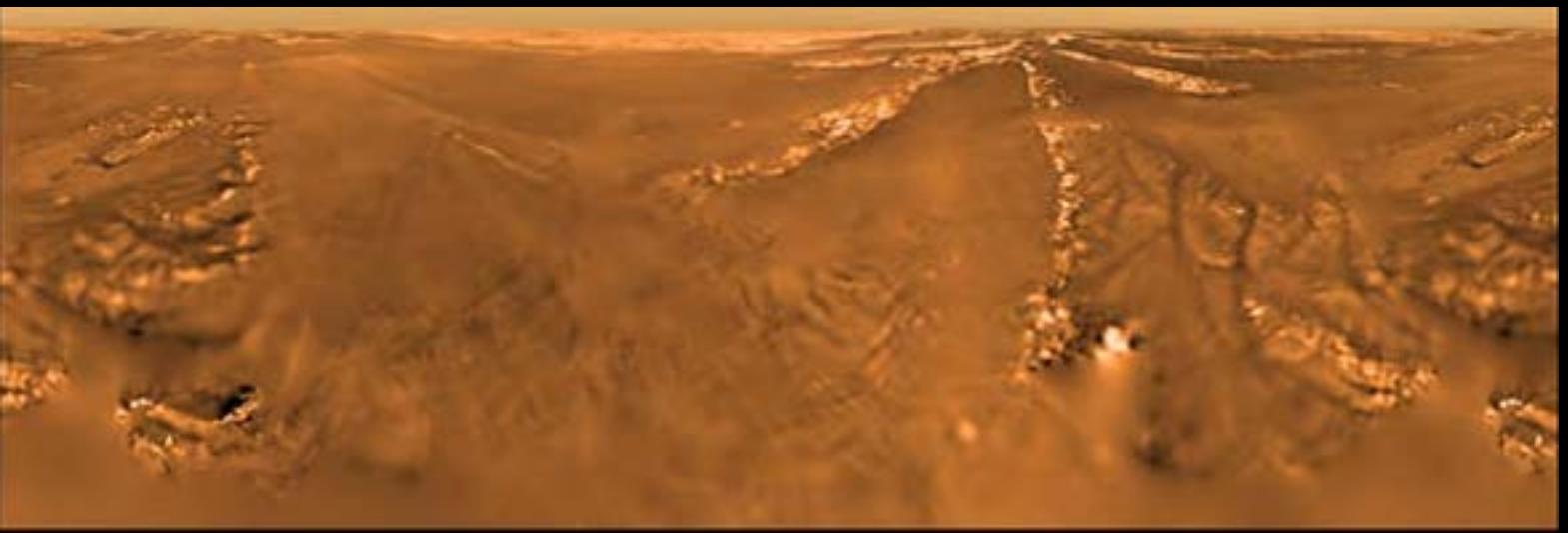


45. Titan Revealed

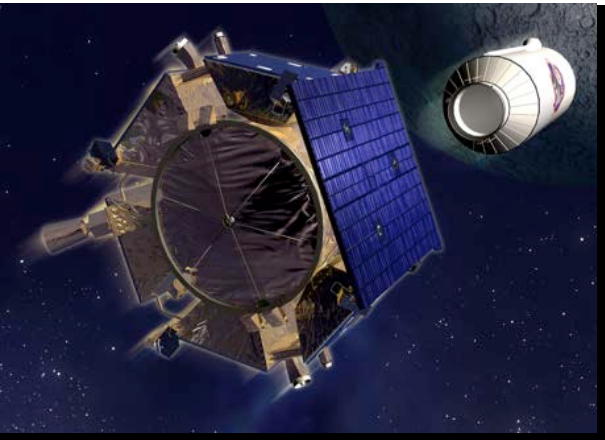
In 2005, Huygens *probe released from* Cassini *and parachuted to surface of Saturn's moon, Titan*

Hidden under perpetual clouds, the only previous images of Titan's surface came from the DSN radar.

A little-known fact is that the Huygens mission was saved through a joint effort of DSN and ESA engineers to work around anomaly discovered after launch



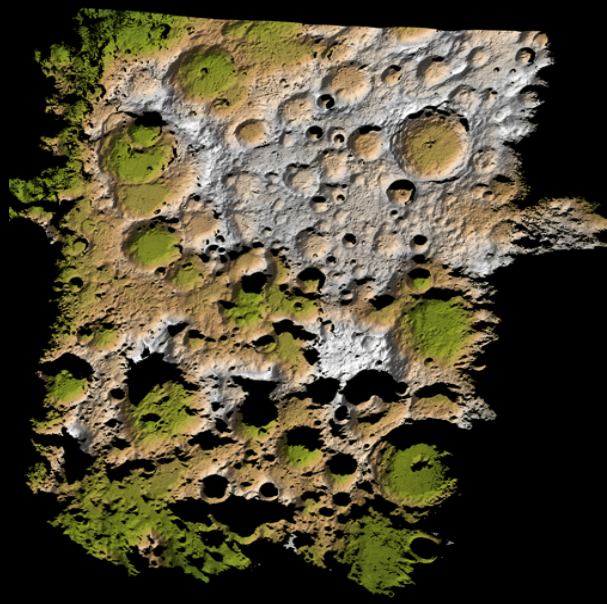
50. Water on the Moon



In 2009, NASA's LCROSS spacecraft was intentionally crashed into the Moon. Water was observed in its plume.

Long suspected that water can exist on the Moon (and Mercury) in areas that are in permanent shadow

First evidence of water on the Moon provided by radar observations – from Arecibo and the DSN. The DSN continues to study these regions on the Moon in support of future human exploration.



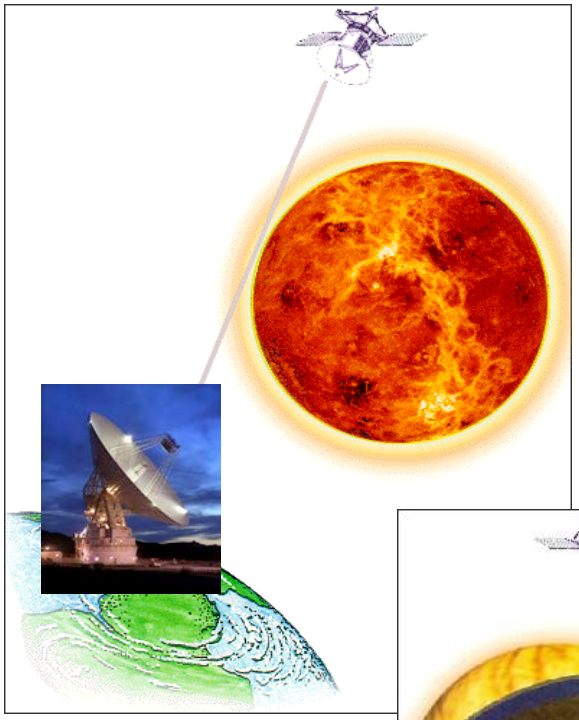
Next 50 Years?

Radio Link Science

Apparent even with early missions that occultations by planetary atmospheres affects quality of radio communications

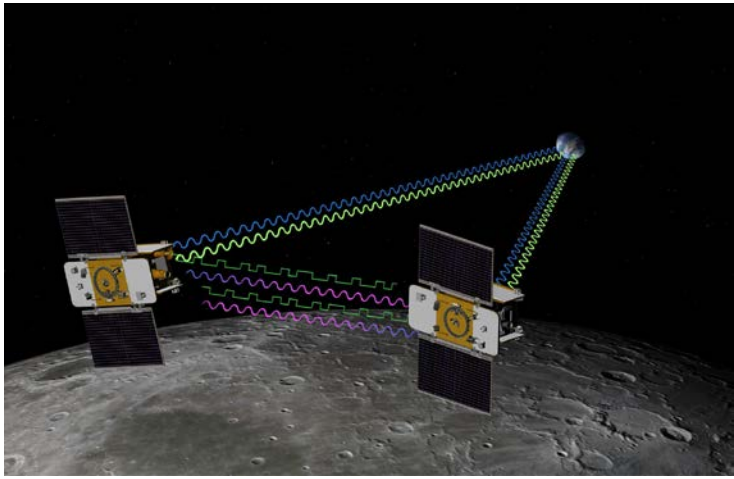
- **Mon dieu! Tragedy!**
- **Or … one person's annoyance is another's data --- Study the atmospheric properties!**
- **Can also study planetary interior!**

➢ **Turn the DSN+spacecraft into one giant science instrument**

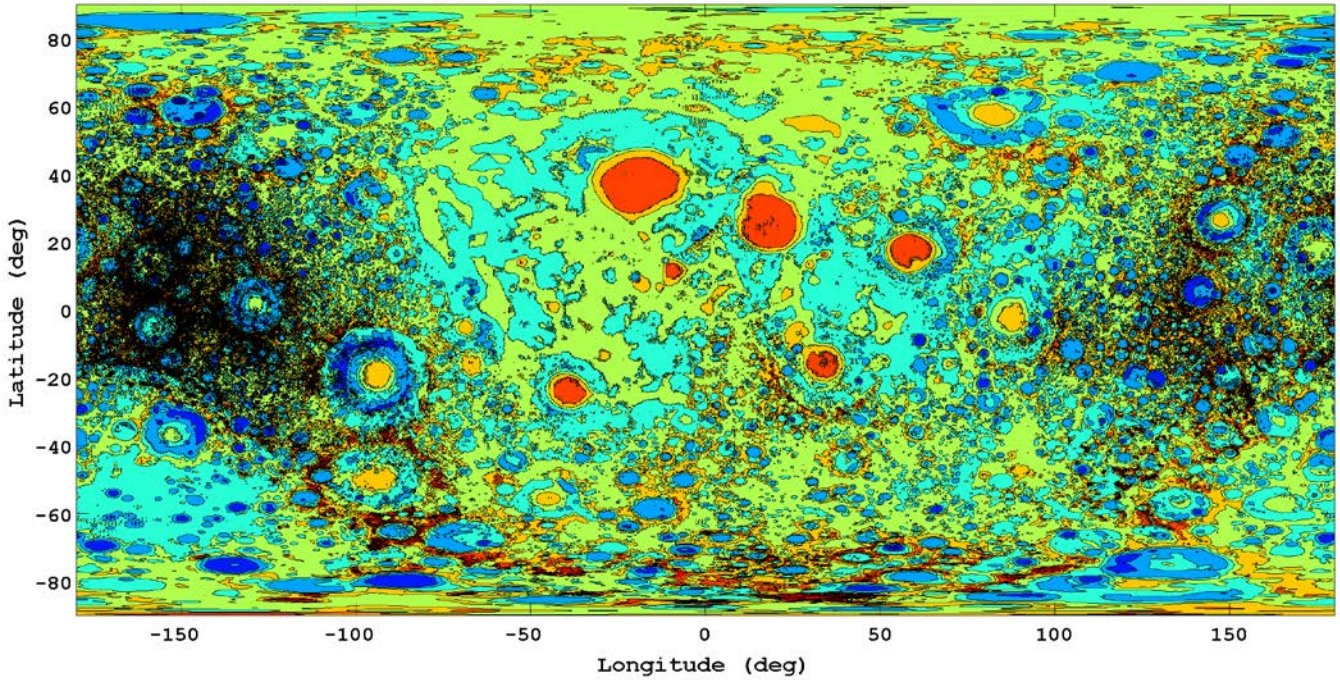


GRAIL Revealing Lunar Interior

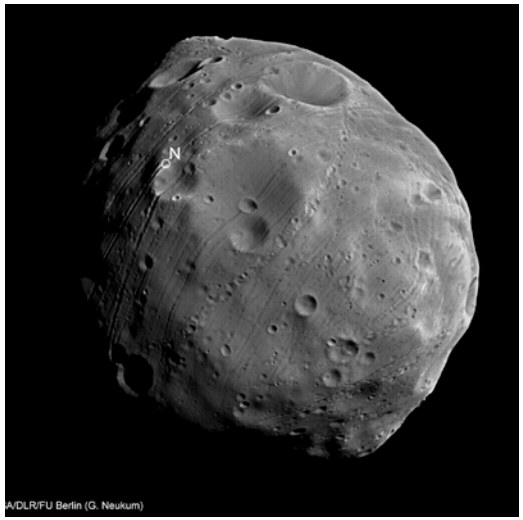
- GRAIL mission made precise measurements of separation between two spacecraft orbiting the Moon
- Changes in separation due to acceleration of one of the spacecraft
- Changes in acceleration result from changes in mass along spacecraft trajectory …



Construct map of local mass enhancements and deficits



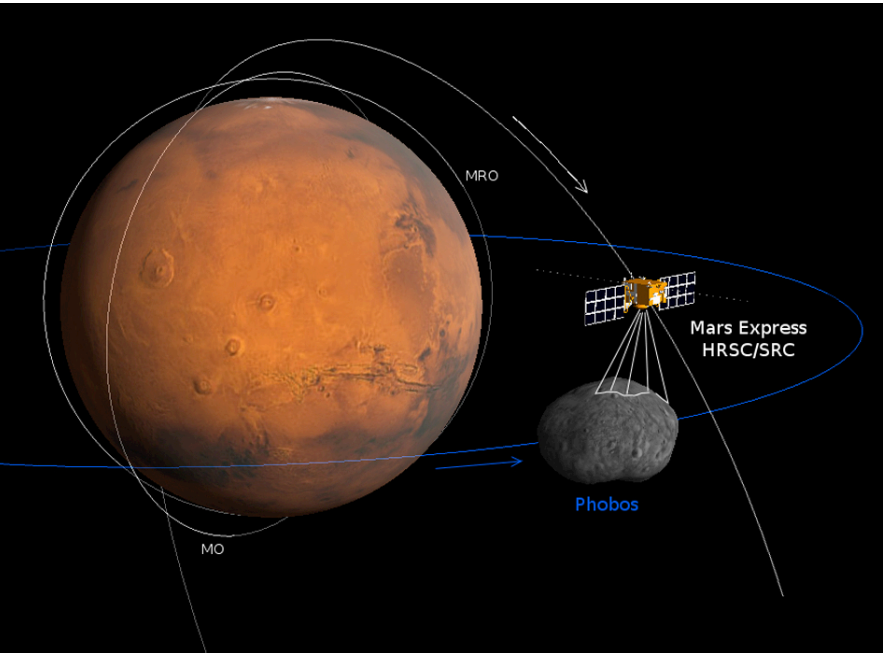
Link Science
Phobos



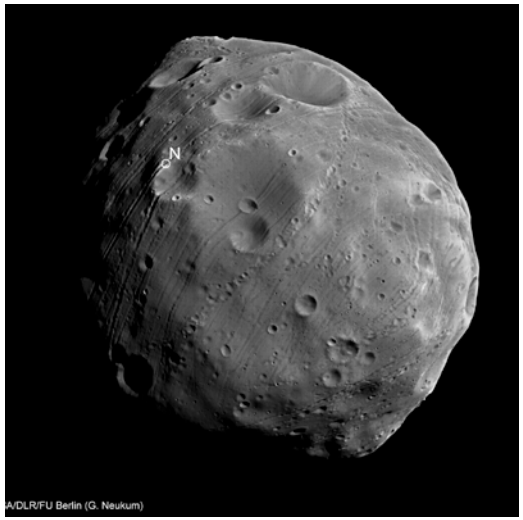
DSN radio science measurements with ESA Mars Express fly-by

- **Determine mass and bulk density**

  $\rho_{bulk} = 1862 \pm 20\ kg/m^3$



Link Science
Origin of Phobos

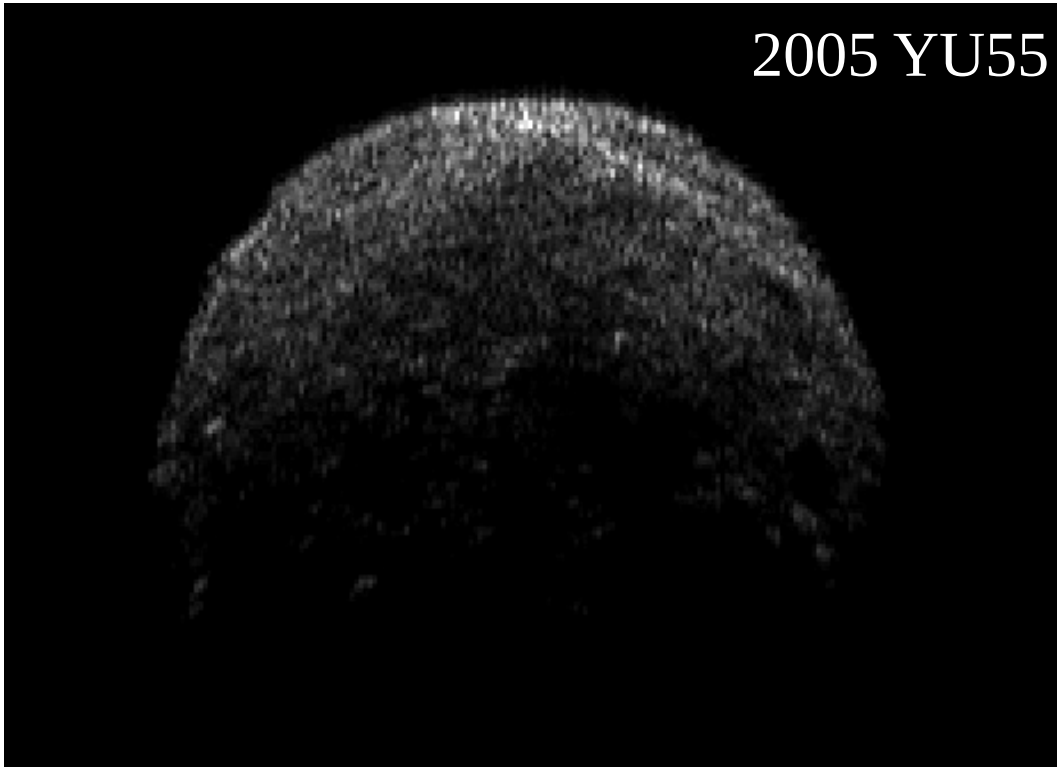


DSN radio science measurements with ESA Mars Express fly-by

- **Bulk density (considerably) lower than "solid" bodies**
- **Has lots of "gaps" inside (a.k.a. "high porosity")**

Phobos re-accreted in place! (?)

Solar System Radar



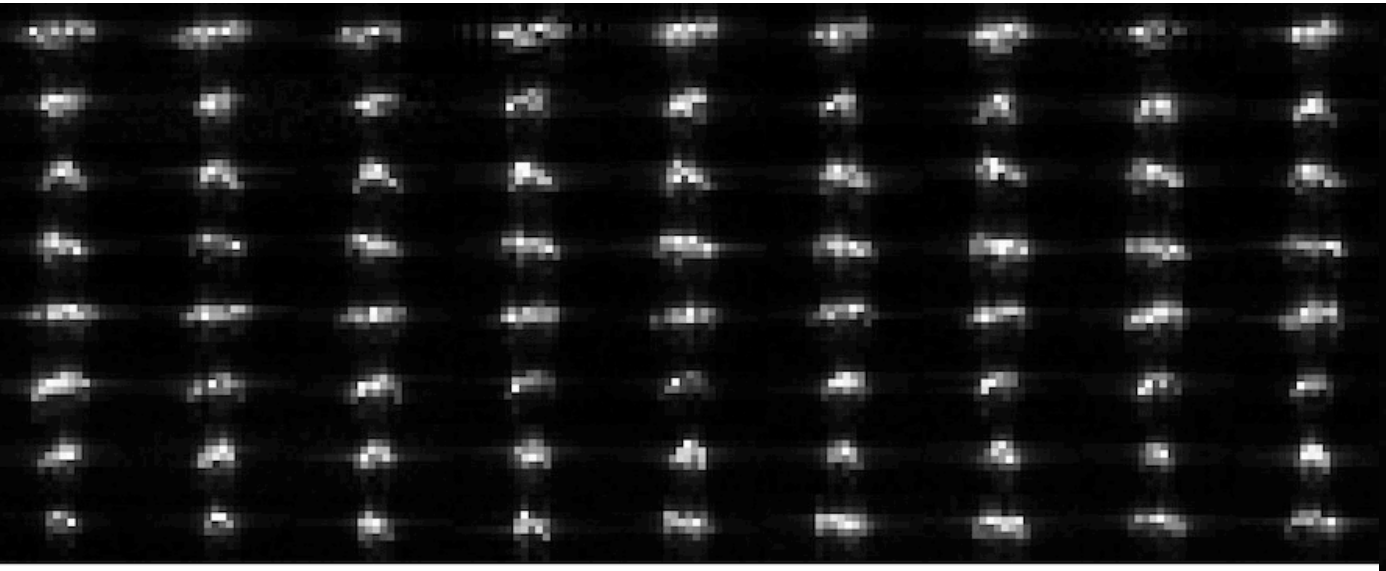
Goldstone Solar System Radar is world-leading facility

- Precise orbital determination
- Rotation periods
- Surface features, with encounter-quality 3.7 m resolution imaging
- Mass, shape, and density

Solar System Radar

Goldstone Radar Images of 2012 DA14

2013 Feb 16

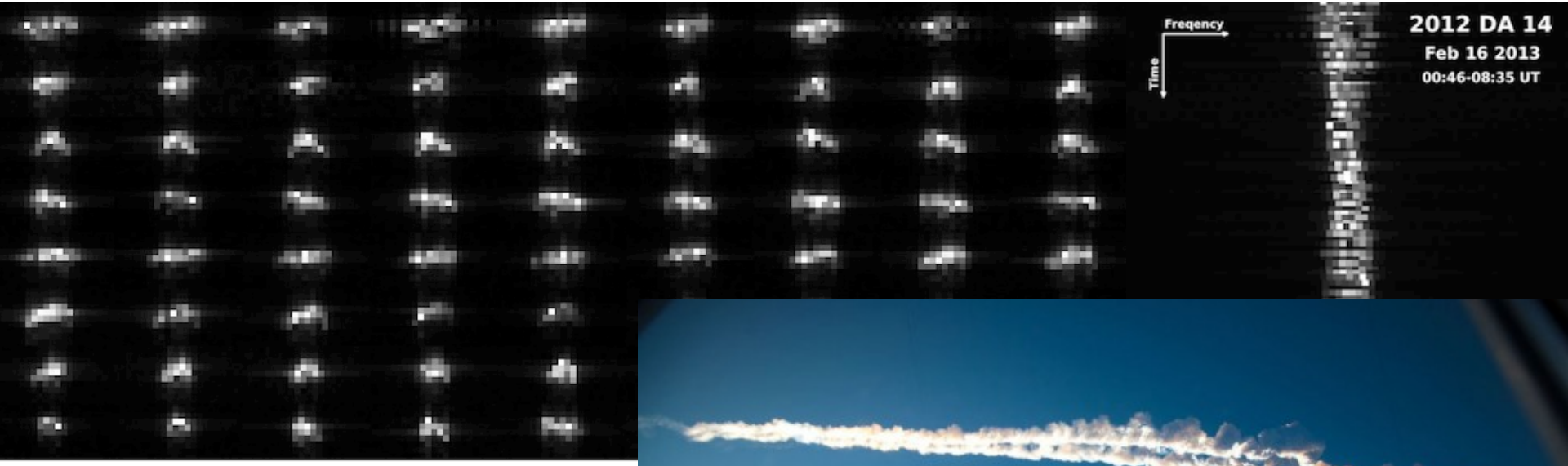


- Elongated object: ~ 40 m x 20 m
- P > 8 h
- Earth torques may have changed the spin state.

Solar System Radar

Goldstone Radar Images of 2012 DA14

2013 Feb 16



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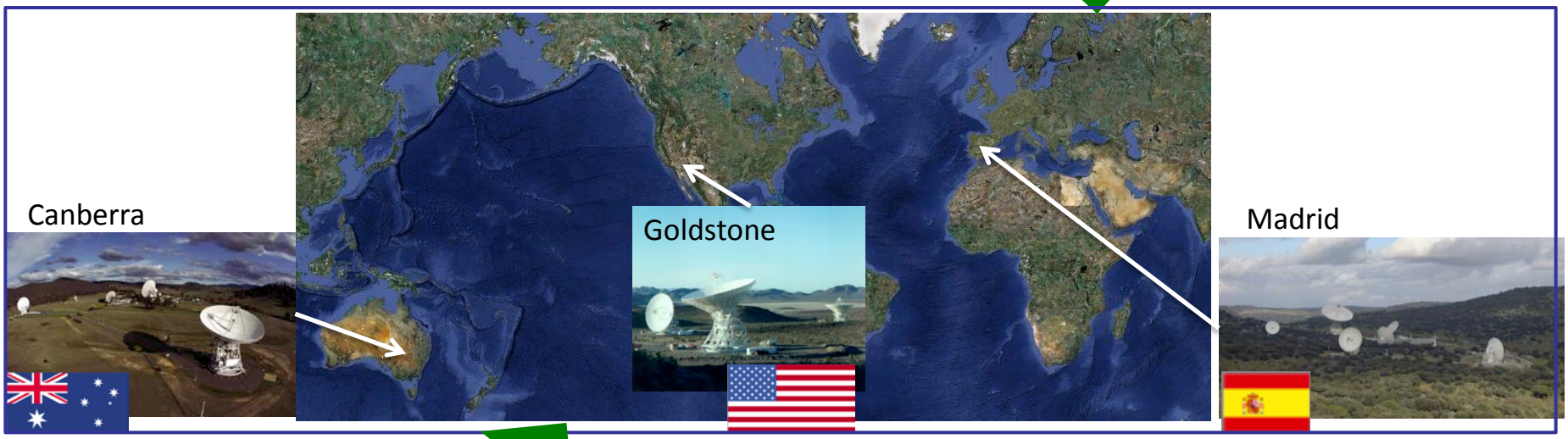
Deep Space Network



50 years of enabling solar system-class (and beyond!) science

Benefits to science and society beyond simply transmitting data

Let's keep opening frontiers

Deep Space Network

- Three major tracking sites around the globe, with 16 large antennas, provide continuous communication and navigation support for the world's deep space missions
- Currently services ~ 35 spacecraft both for NASA and foreign agencies
- Spigot for science data from most spacecraft instruments exploring the solar system
- $2B infrastructure that has been critical to the support of 10's of $B of NASA spacecraft engaged in scientific exploration over the last few decades

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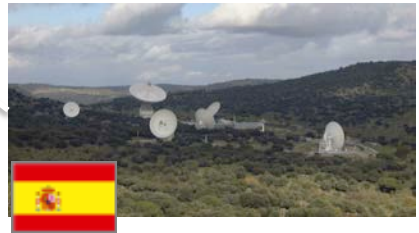
Canberra

Madrid



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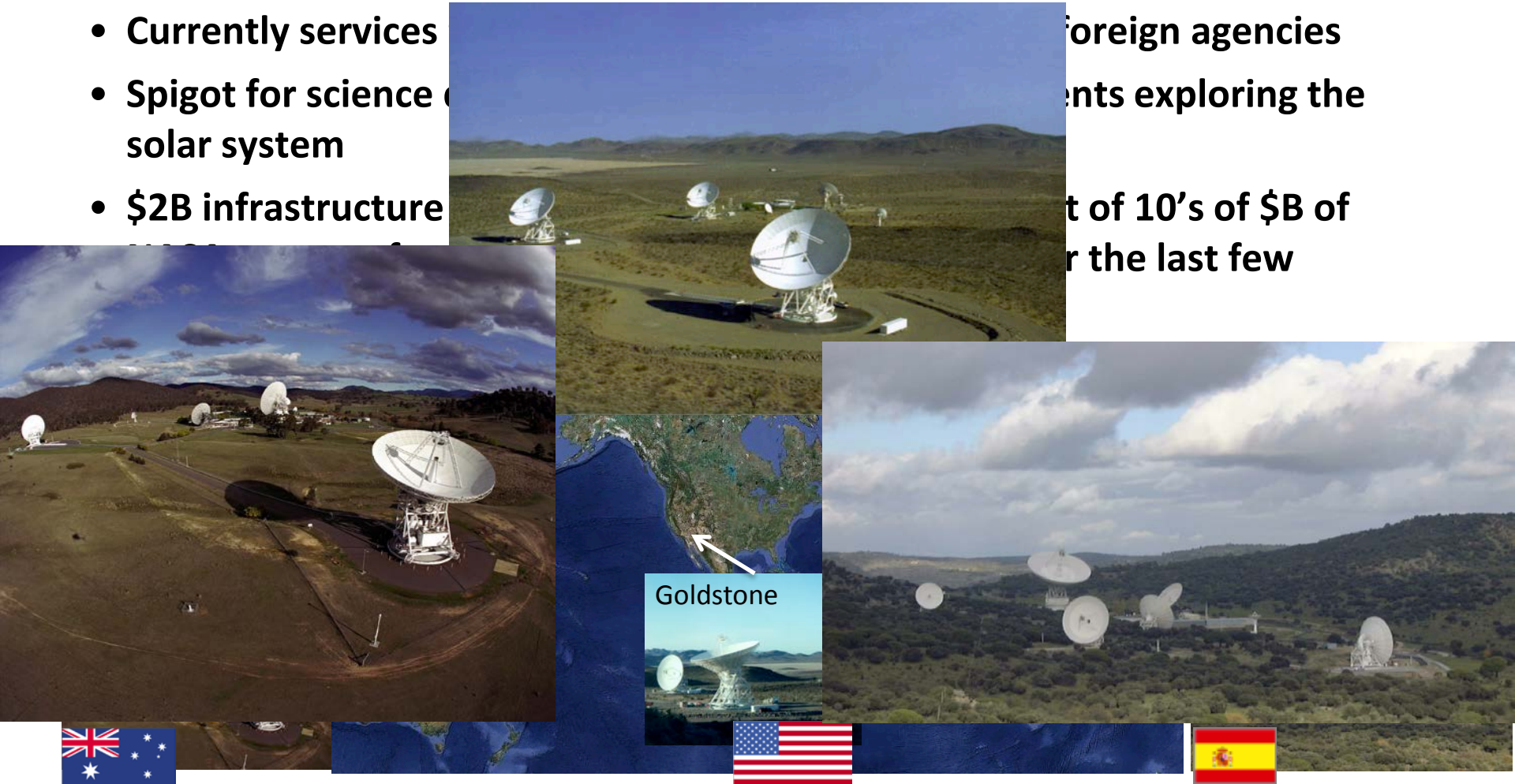


Next 50 Years?

Laser communications

Interplanetary Internet

Complete catalog of NEOs

Detection of gravitational waves

[Deep space industry]

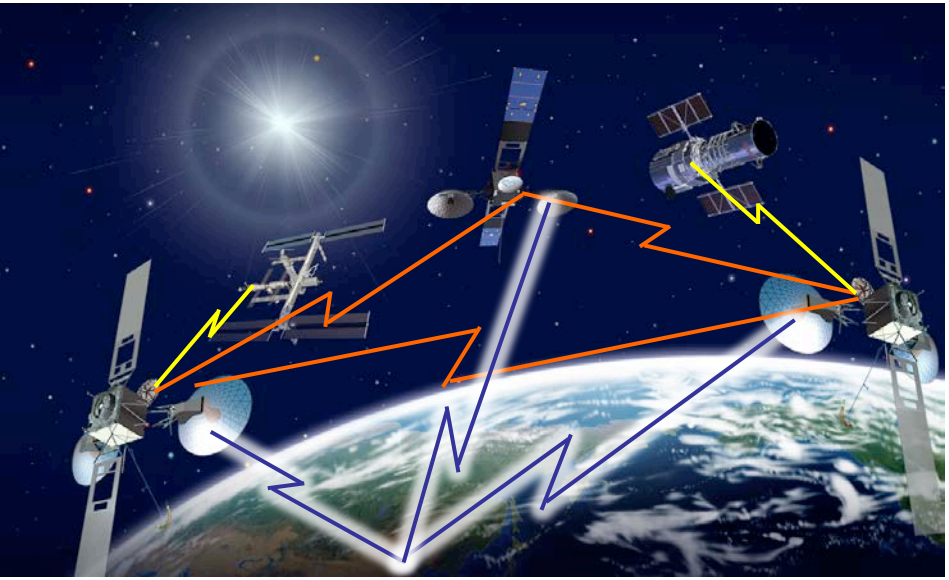
[Humans on Mars]

Extraterrestrial life

Planetary Communications Networks

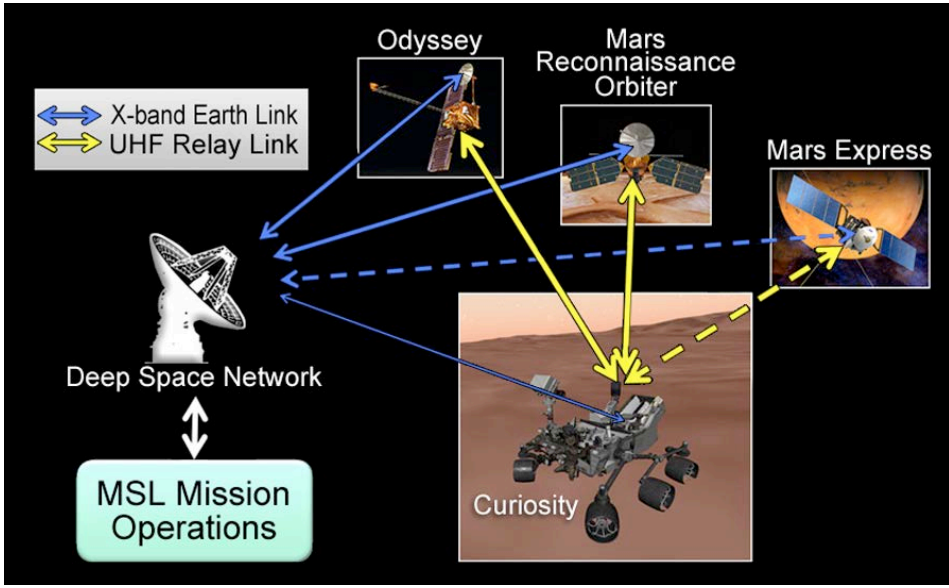
Jet Propulsion Laboratory
California Institute of Technology

Terrestrial Network



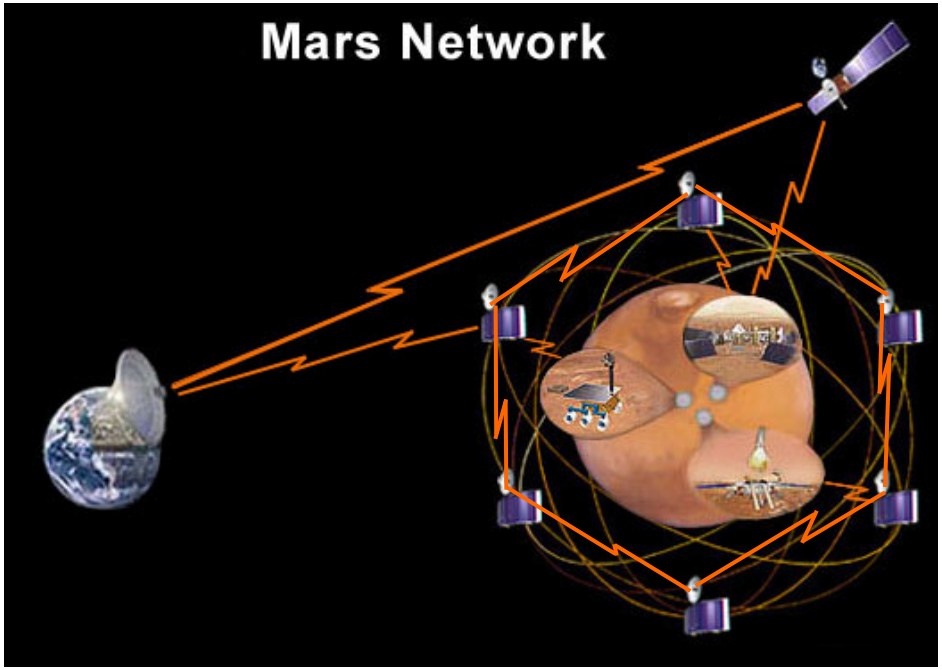
Communication flow between spacecraft, relays, and ground --- "Internet like" and robust against disruptions

Martian "Network"

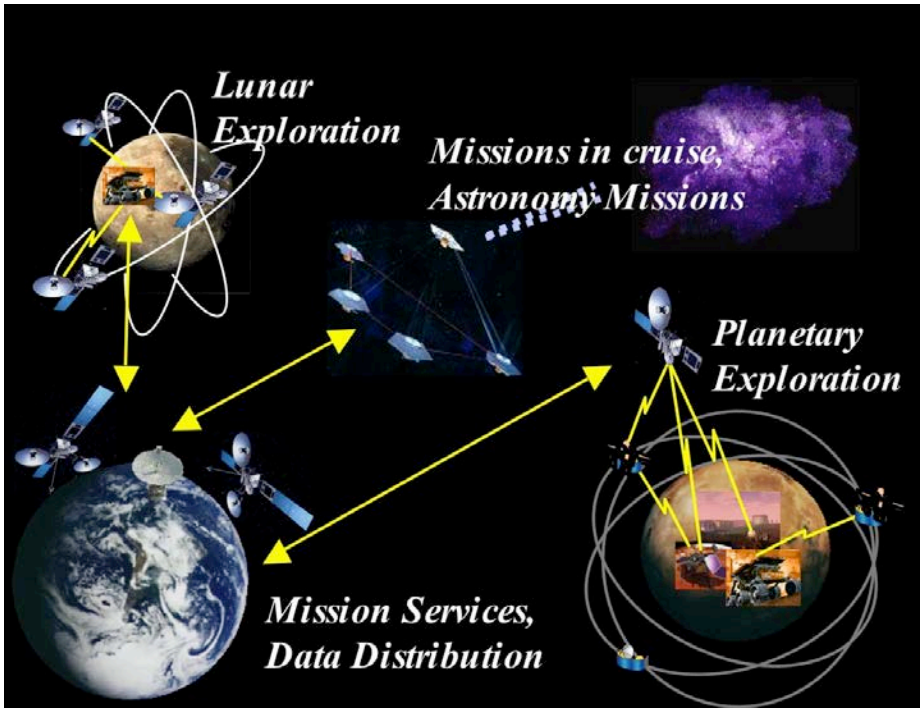


Communications between orbiters and Earth, orbiters relay communications to landers/rovers (and Curiosity can communicate directly to Earth), but …

Interplanetary Internet



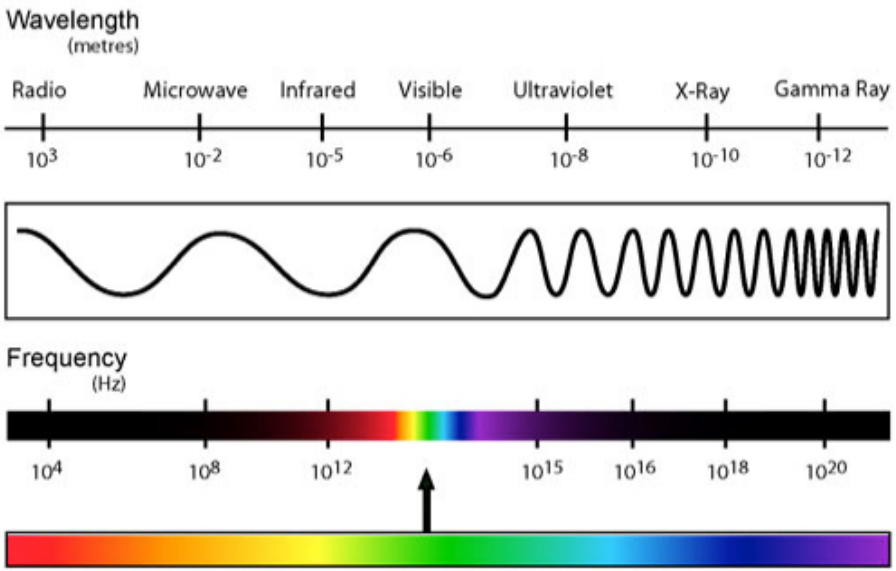
Communication flow between Earth, relays, and Mars --- "Internet like" and robust against disruptions



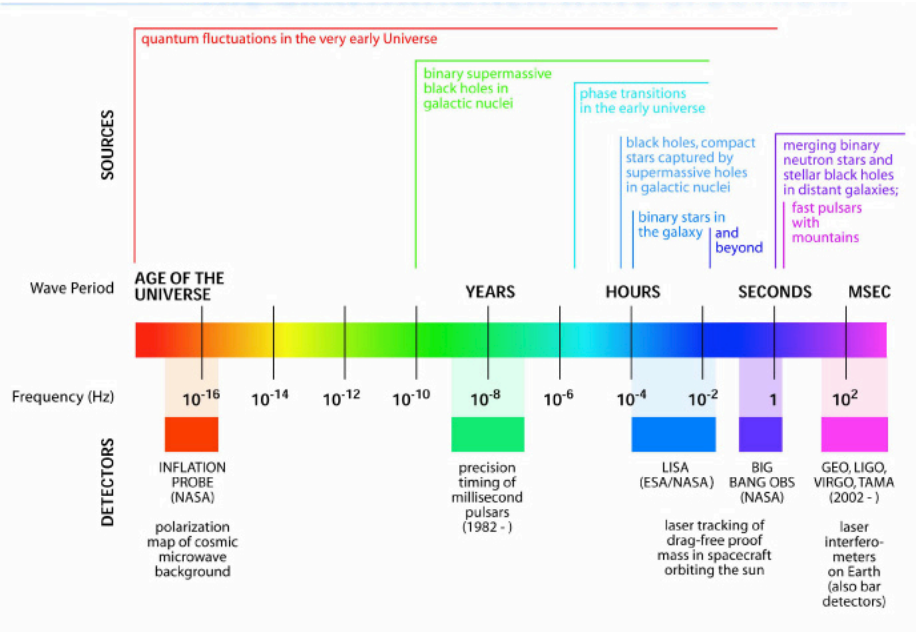
Move into the solar system --- Moon, Mars, asteroid belt, …

Gravitational Waves

Electromagnetic Spectrum



Gravitational Wave Spectrum



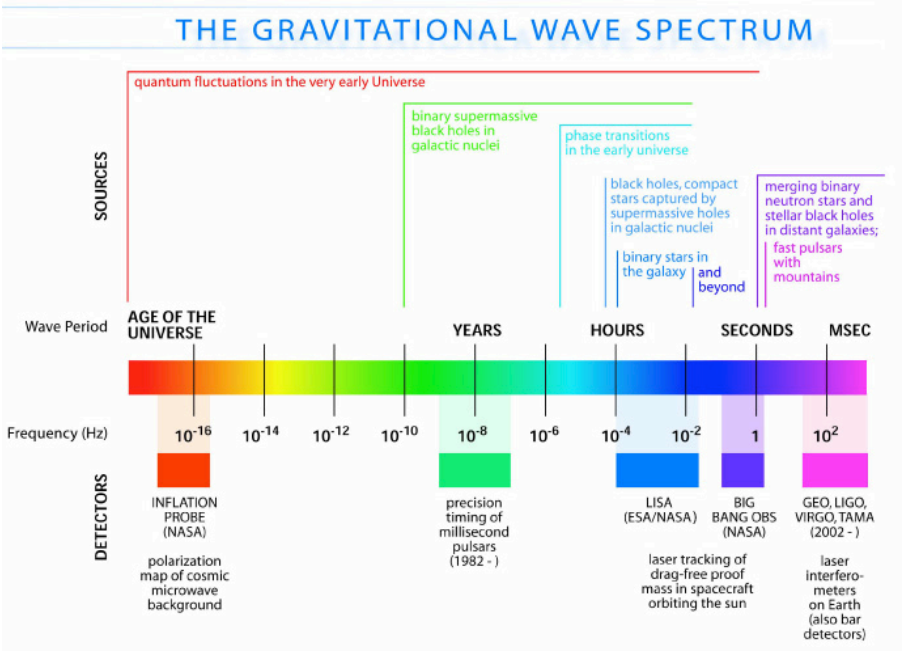
Gravitational Waves
Who Cares?

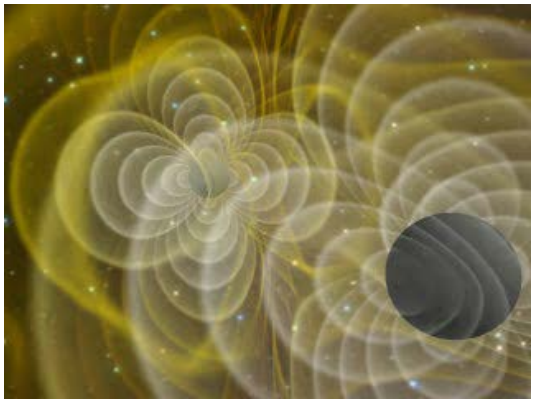
- **One of final untested predictions of Einstein's Theory of General Relativity**

  Initial work already yielded one Nobel Prize in Physics

- **Identified by U.S. astronomy community as "science frontier discovery area" *(U.S. National Academy of Sciences)***

- **Probes most extreme environments in Universe**

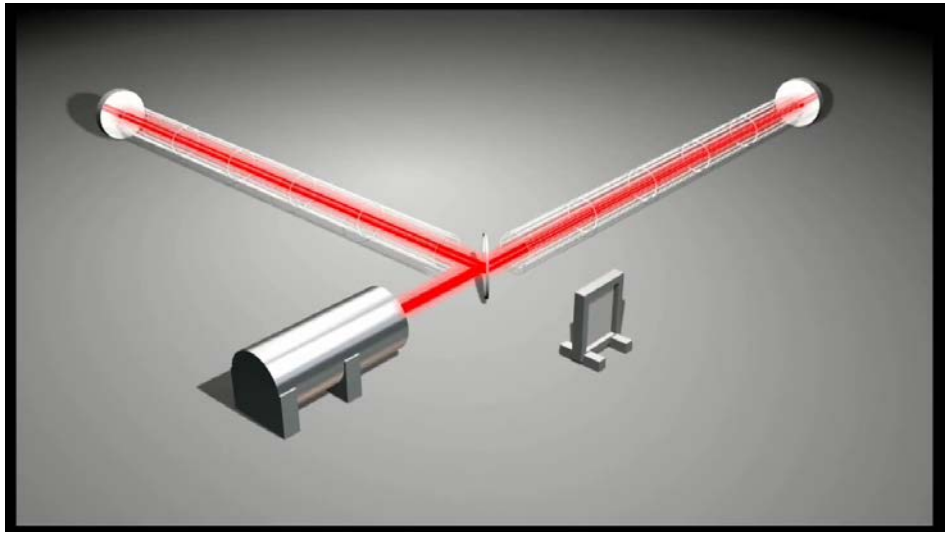


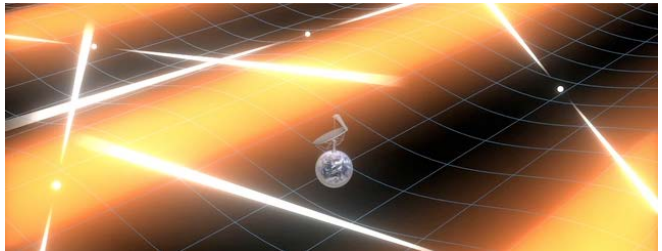


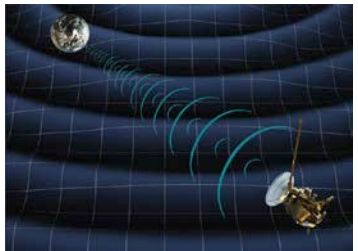
Gravitational Wave Detectors

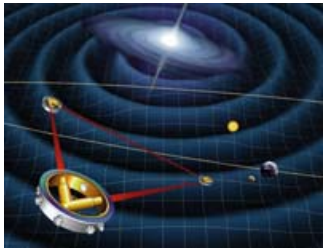
All modern gravitational wave detectors use same principle

- Gravitational wave modifies distance (a.k.a. spacetime metric)
- Measure distances between collection of objects (test masses)
- Changes result from passing gravitational waves





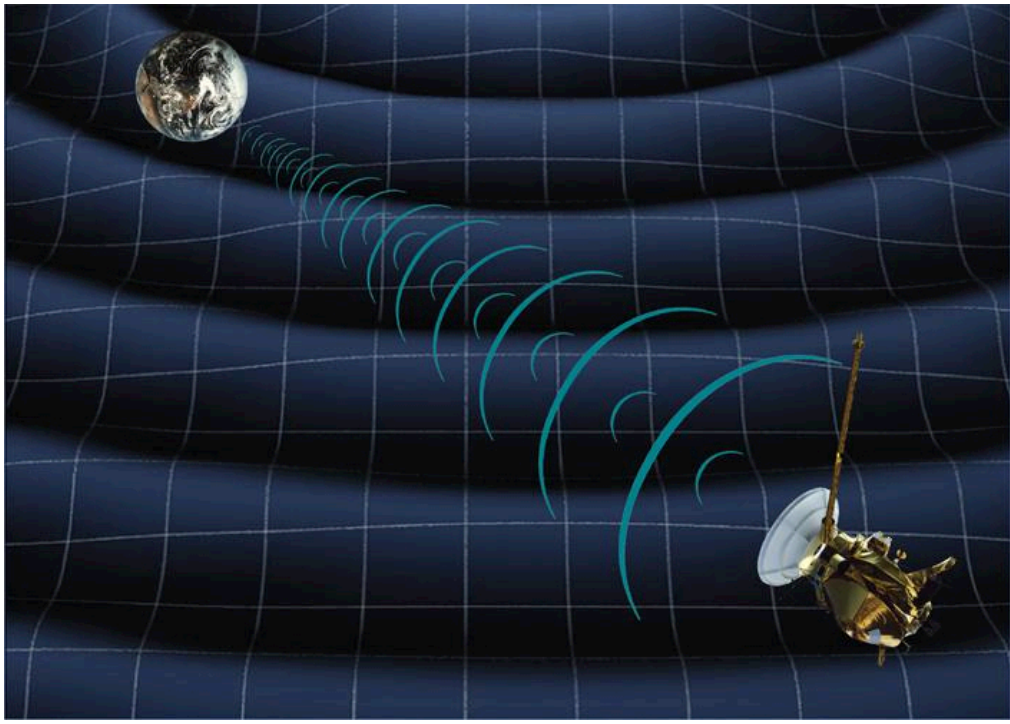




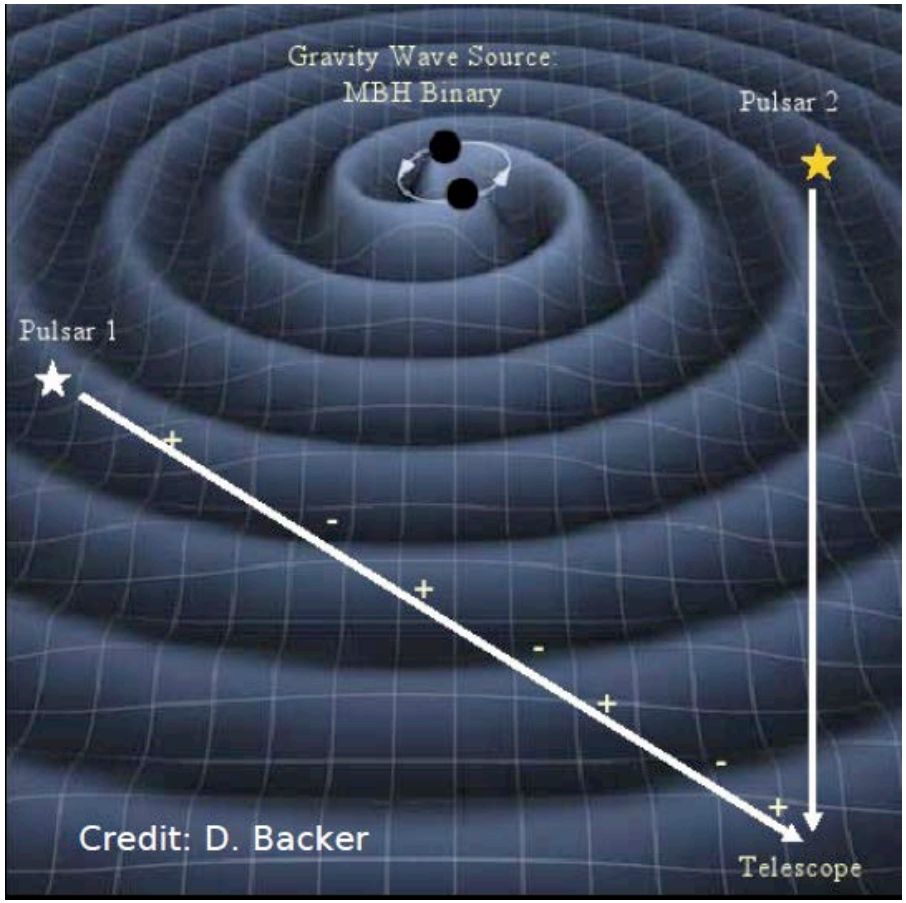
Spacecraft Tracking and Gravitational Waves

Spacecraft-Earth forms gravitational wave detector

- First suggested by Estabrook & Wahlquist (1975), both JPL
- DSN has long history --- Pioneer, Viking, *Cassini*
- DSN-*Cassini* limits ~ 1000 × better than previously obtained



Radio Pulsars, DSN, and GWs



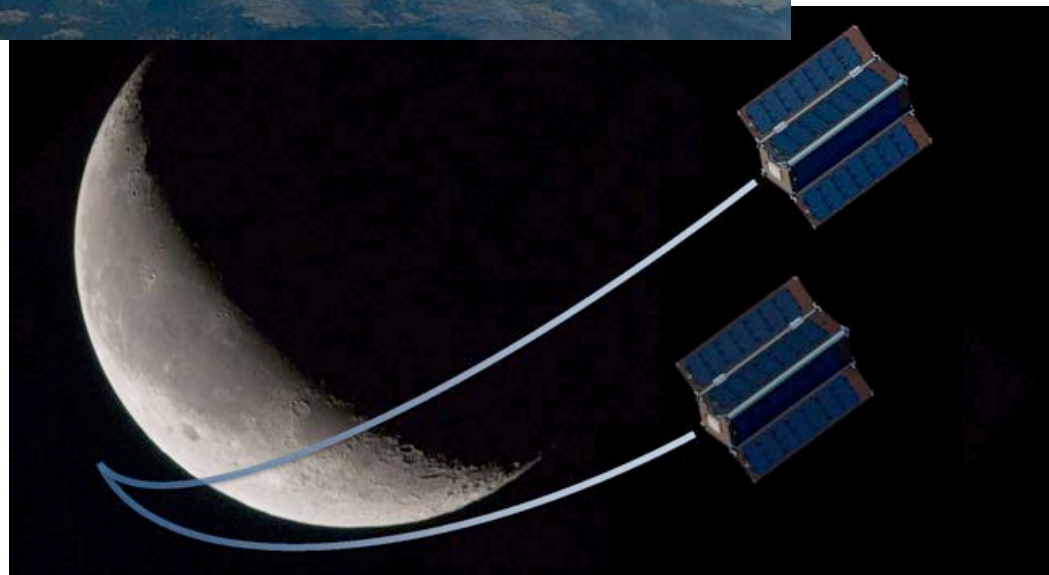
Technique first proposed by Hellings & Downs (JPL)

Searching for gravitational waves emitted by supermassive black holes at centers of galaxies as they in-spiral together ….

Deep Space SmallSat Constellations

Jet Propulsion Laboratory
California Institute of Technology

- Imagine fleets of spacecraft at other planets
- Imagine dropping many probes into a planet's atmosphere …
- May be possible with "smallsats"
- Requires whole new way to operate the DSN …



Beyond the Moon Landing

In 1969 Neil Armstrong became first human to step onto the Moon.

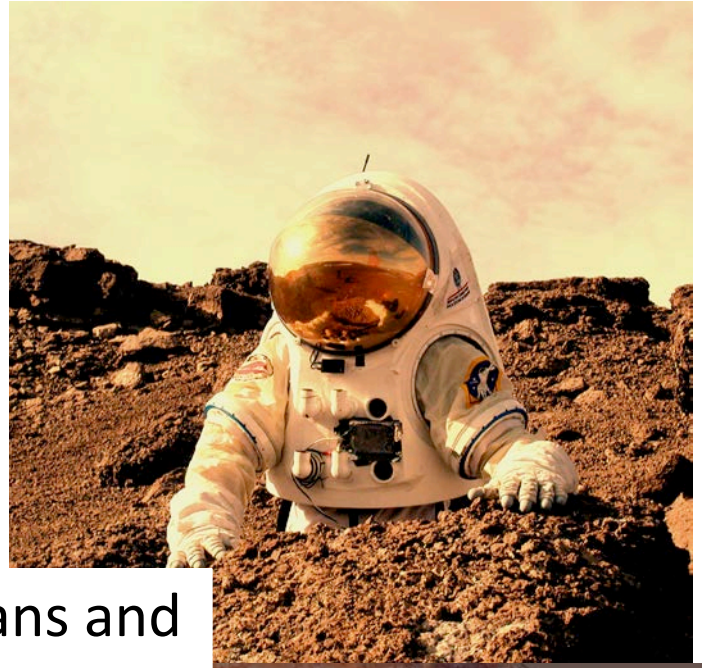
The DSN supported all the Apollo missions, providing communications and tracking.

Where next?

Beyond the Moon Landing

Deep Space Industry?

Humans on Mars?



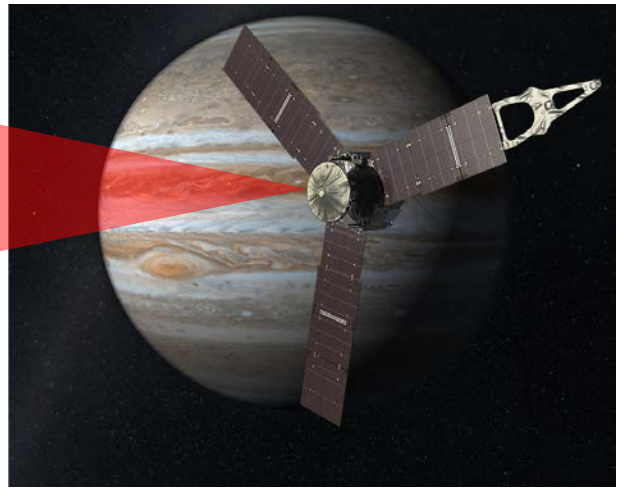
Moving humans and industry into deep space will require deep space communications support.

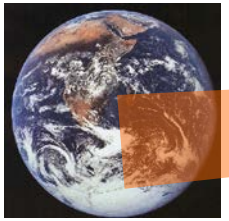
Laser Communication
Why?

Consider Juno mission at Jupiter …
(orbital insertion 2016 July 5)

0.018 Mbps
(at least)

~ 200 Earth diameters



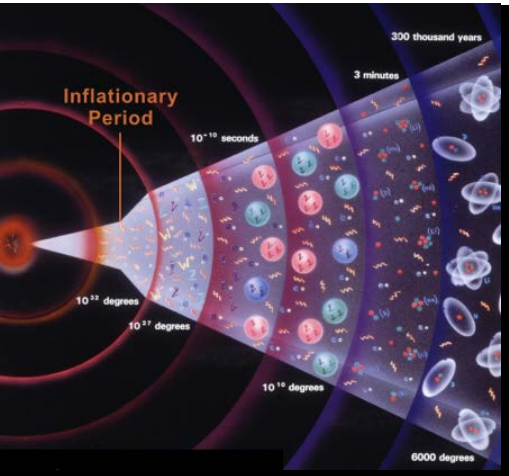


~ 2.5 Mbps (at least)

Optical Communication

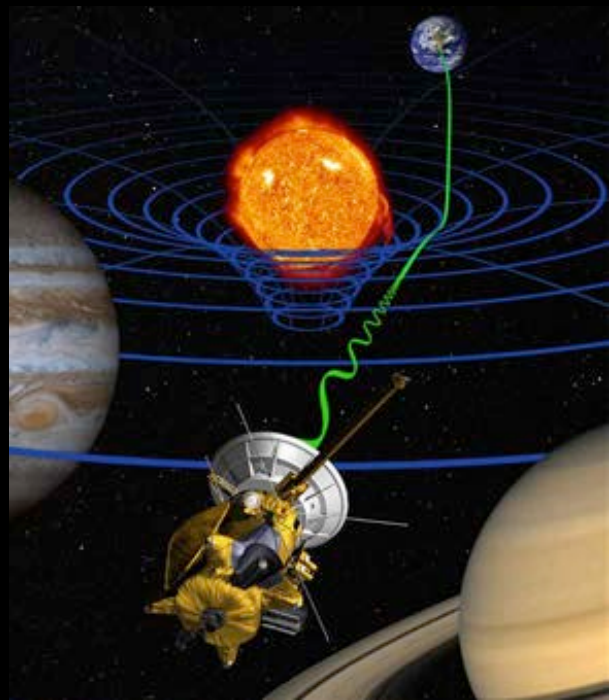
- **Lasers have the potential to offer much higher communication bandwidths, i.e., more science data!**
  - **Like fiber optics, without the fiber**
- **Already demonstrated …**
  - **… though not yet in deep space**

25. Cosmic Inflation



In 1980, inflationary big bang model is put forward, explaining the first moments of the Universe

Evidence for the model is collected by spacecraft tracked by the DSN. In addition, direct science observations by the DSN, using the Cassini *spacecraft as a radio source, provide further proof.*

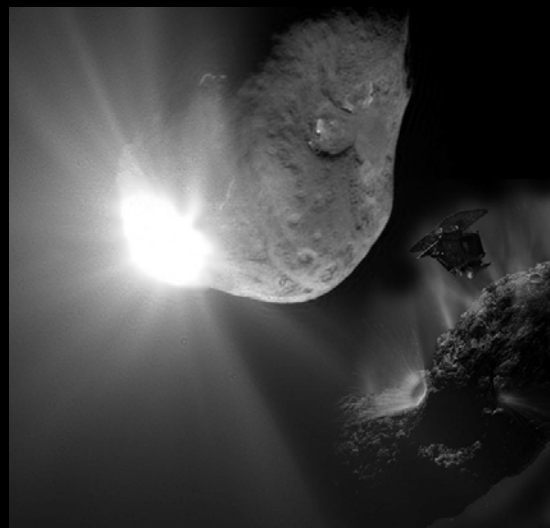


31. Catching Up With Comets

In 1984 ESA's Giotto spacecraft rendezvoused with Halley's Comet. The DSN supported the Giotto mission and returned images of the comet.

The DSN has since supported several spacecraft visiting comets, including Deep Impact and Stardust sample return mission.

A lesser-known fact is that the DSN was used to recover the Giotto spacecraft when it mistakenly turned its antenna away from, Earth. This is an example of "1,000,000 mile screwdriver."



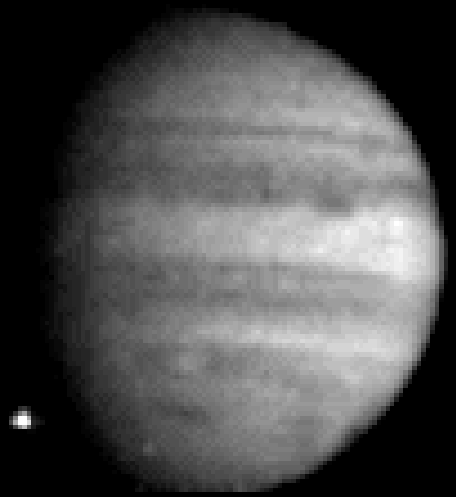
33. Witnessing a Cosmic Crash

Jet Propulsion Laboratory
California Institute of Technology

In 1994, world watched as the remnants of Comet Shoemaker-Levy 9 crashed into Jupiter –first time we saw this phenomenon

Actual impact happened on the far side of Jupiter as viewed from Earth. Only the Galileo spacecraft had a direct view!

DSN tracked the Galileo spacecraft which captured photographs of the actual collisions

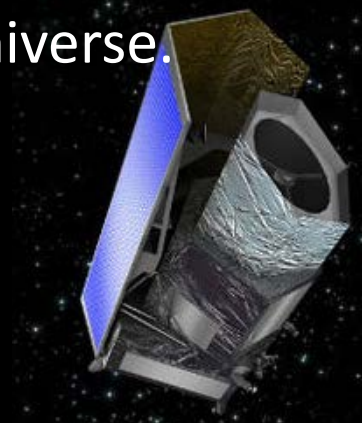


39. Dark Energy

In 1998, observations of distant exploding stars led astronomers to accept the notion of "dark energy," which is causing the expansion of the Universe to accelerate with time.

DSN support of space missions (e.g., *WMAP*, *Planck*, *Chandra*, and *Spitzer*) helped cement concept of dark energy. Their measurements also helped improve estimates of the Hubble constant, which sets the scale of the Universe.

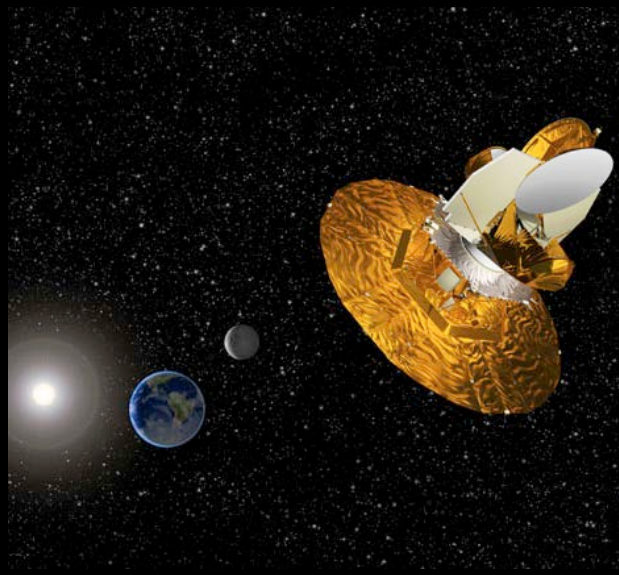
The DSN will support ESA's Euclid mission, which will be dedicated to the search for dark energy



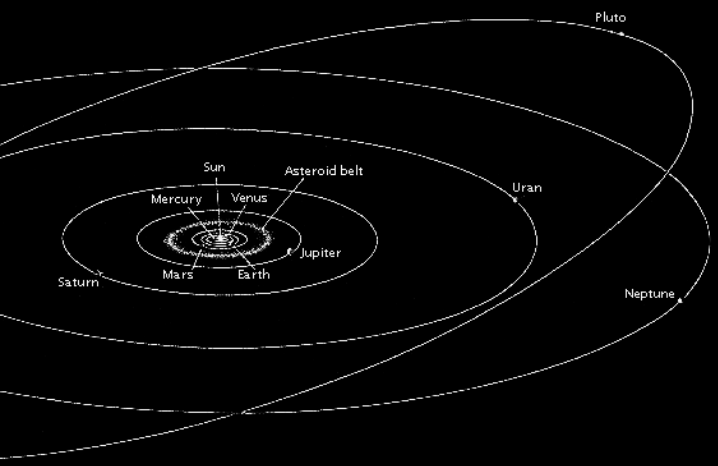
43. Age of the Universe

Estimated age of the Universe was much better determined in 2001 to be 13.7 billion years.

Best estimate uses data from NASA's WMAP and ESA's Planck *spacecrafts, supported by the DSN.*



46. Planets Realigned

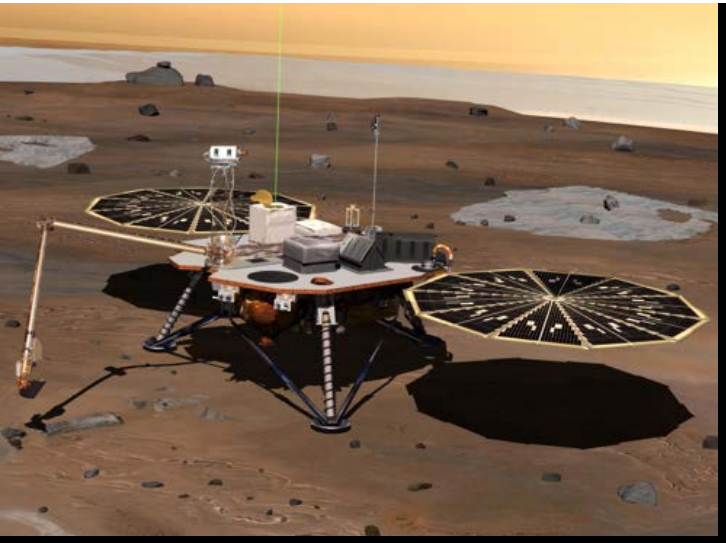


In 2005, discoveries of large Kuiper belt objects led to re-definition of a planet and Pluto as a dwarf planet

Decision to change the official definition of "planet" stems in part from the discovery of exoplanets as well as observations of comets and Kuiper belt objects.

The DSN's role comes from support of spacecraft that discover such objects and from ongoing research into planetary orbits

49. Tasting Martian Water



In 2008, NASA's Phoenix spacecraft lands on Mars and samples water from just under the surface.

DSN supported Phoenix as well as all other spacecraft on Mars' surface.

Much additional evidence for liquid water on Mars has come from studying photos from Mars orbiters showing "rivlets" that come and go with seasons