Contributions of NASA Deep Space Network to Science and Exploration

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Speaker Background

Tim Pham is the Chief System Engineer of the NASA Deep Space Network. His interest is in system engineering and system development. Besides DSN system engineering work, he also supports the CCSDS activities in Cross Support Transfer Services and the ground system development at the Morehead State University.

Tim has published several papers on antenna arraying, spacecraft tracking, system modeling and performance analysis. He co-authored the book “Antenna Arraying Techniques in the Deep Space Network”. He is recipient of the NASA Exceptional Service Medal, NASA Exceptional Achievement Medal, several NASA New Technology and Space Act Awards, and the IARIA Fellow.

Outline

1. Introduction to DSN
2. Enable space exploration
3. DSN as a science instrument

1. Introduction to DSN

About the DSN

- A U.S. national asset for space communication and research
  - Supporting space exploration by providing communications for NASA and international missions
    - Cross supporting other space agencies (ESA, JAXA, ISRO, etc.)
- Managed by the Jet Propulsion Laboratory in Pasadena, California, under Caltech’s contract to NASA

History of JPL

- Timeline
  - 1930's – a site for rocket propulsion research by Prof. Theodore von Karman of Caltech
  - 1944 – funded by U.S. Army's Ordnance Corp
    - Focused on missile aerodynamics and chemical propulsion
  - 1958 – became part of newly formed NASA
    - Responsible for design and execution of lunar and planetary exploration programs using robotic spacecraft
- Support robotic space exploration
  - Inner and outer planets
  - Orbiters, landers, rovers, planetary flyby missions
- Support human exploration
  - Human landing on Moon and Mars

History of DSN

- First 26-m antenna at Goldstone, California constructed in1958 for Mariner mission support
- Addition of 64-m antenna (later expanded to 70-m) in 1960’s, and 34-m antennas (1980s – present)
- 1958-2000 (highlighted samples)
  - NASA’s first spacecraft flyby to the Moon, Venus, Mars and Jupiter
  - Apollo moon landing
  - Viking landers on Mars
  - Voyager’s grand tour of solar system
  - Long-term planetary orbiters: Galileo (Jupiter), Cassini (Saturn)
- 2000-present (highlighted samples)
  - Reconnaissance orbiters: MRO & Odyssey (Mars), Cassini (Saturn), Juno (Jupiter)
  - Solar physics: Stereo & Parker Solar Probe
  - Interstellar: Voyager, New Horizons
  - Astronomy: James Webb Space Telescope
  - Mars rovers: Spirit/Opportunity, Curiosity, Perseverance
  - Exoplanet search: Kepler, TESS
  - Human Exploration: Artemis, Human Landing System
  - Cubesat missions – MarCO, Artemis

DSN as a tool for Space Exploration and Science

- Robotic missions and emerging crewed missions
  - Explorations of the Moon, Solar system bodies and their moons
    - e.g., LRO, Magellan, Juno, Cassini, New Horizons, Voyager
  - Search for evidences of past life
    - e.g., Mars rovers and orbiters
  - Astrophysics studies of exoplanets, cosmic evolution
    - e.g., Kepler, TESS, SIRTF, JWST
- 35+ missions currently supported by the Deep Space Network (DSN)
  - From high Earth orbit to the edge of Solar System
  - Many upcoming deep space cubesats and NASA's sponsored missions from commercial vendors, e.g., Intuitive Machines lunar landers, SpaceX Human Landing System, Blue Origin's Mark 1

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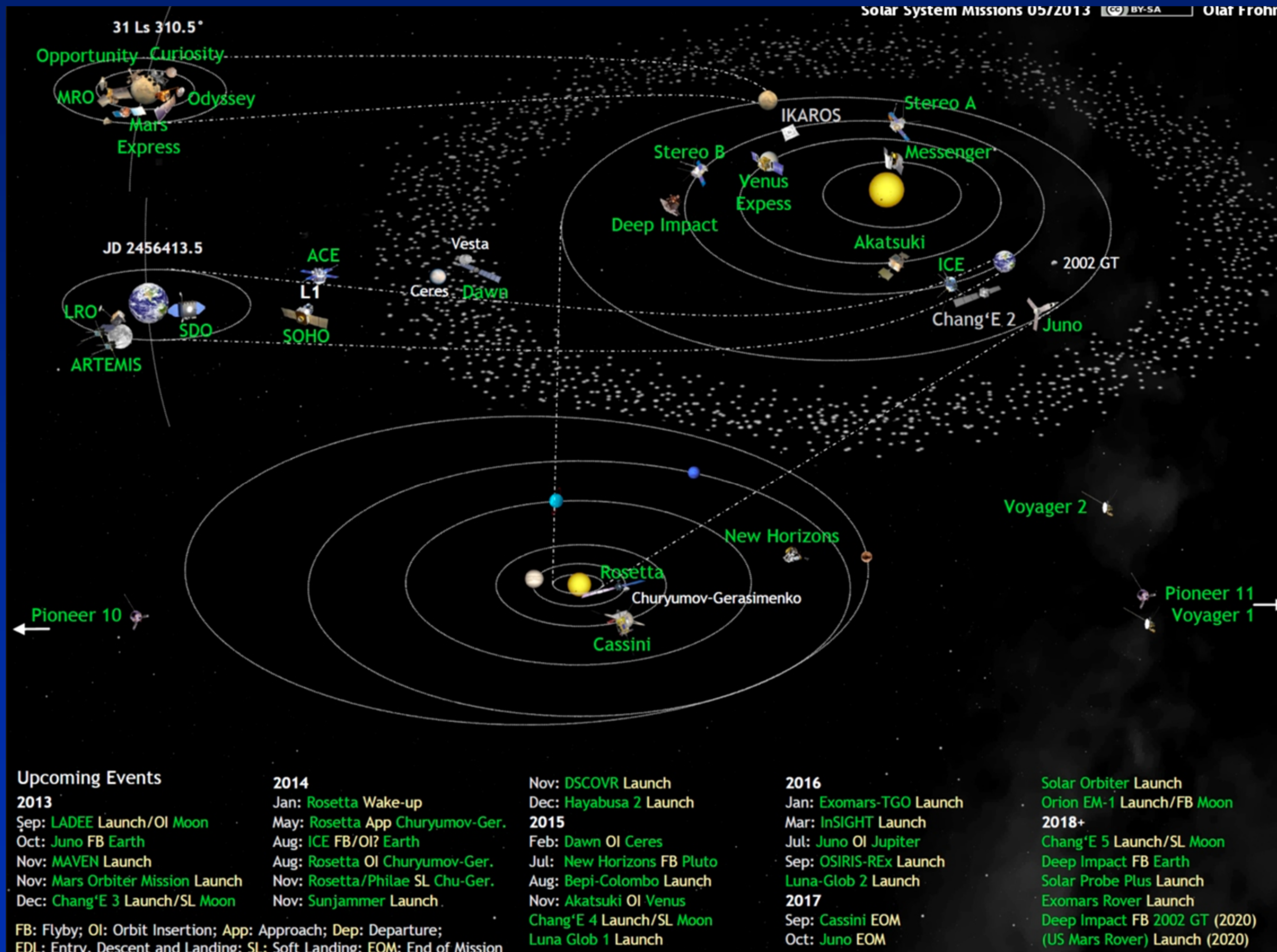
Supported Missions across Solar System



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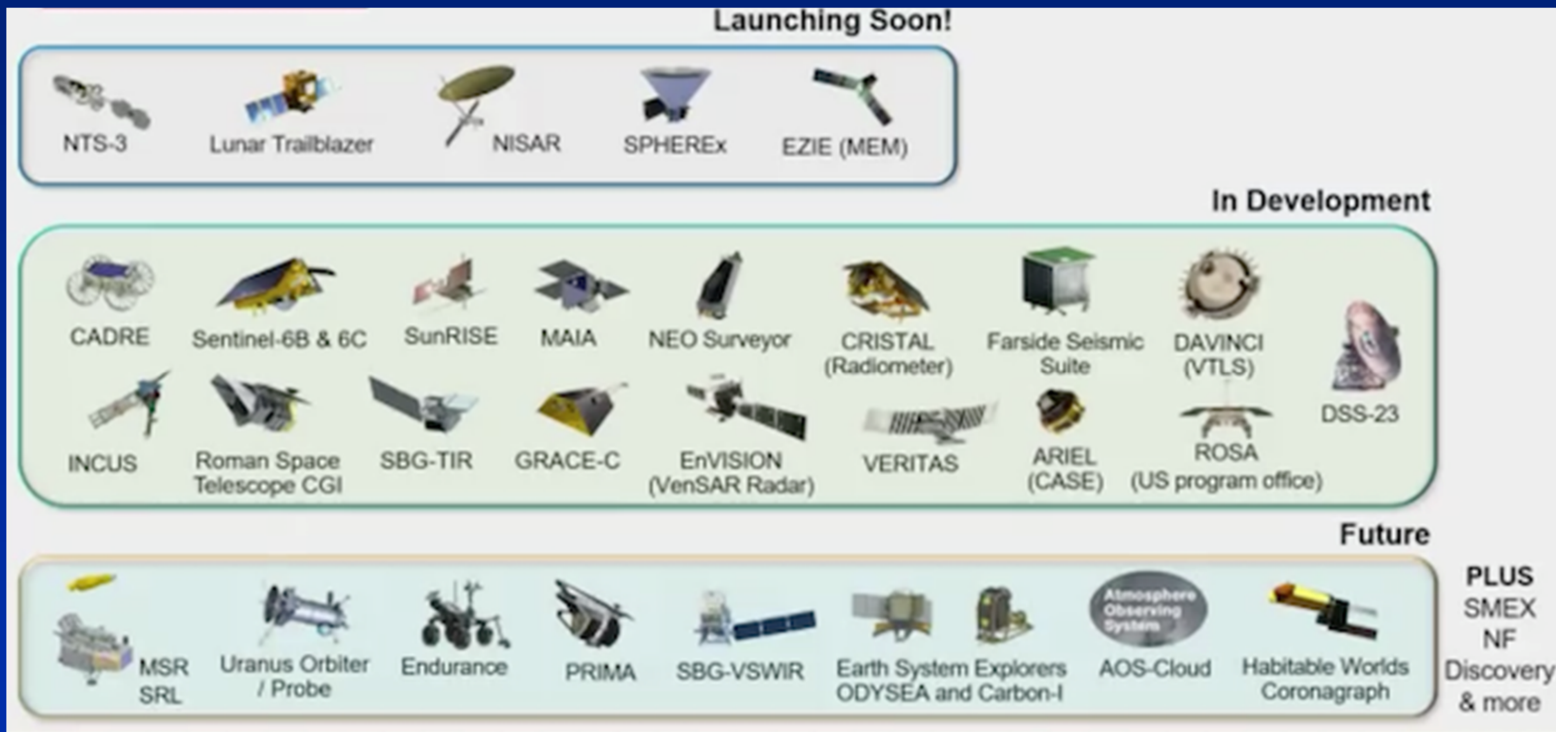
Samples of Upcoming Missions



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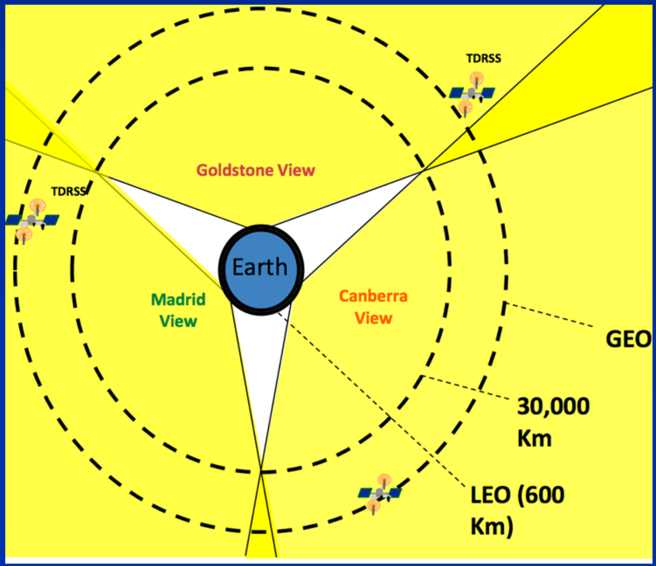
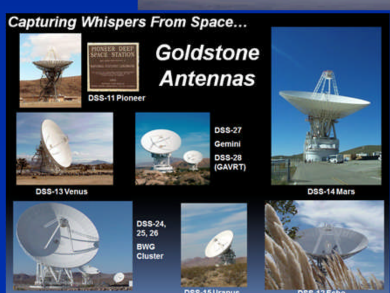
DSN Focus

- Interplanetary spacecraft communications
  - Telemetry, Tracking and Command (TTC)
  - Science (Radio Science, Radar, Very Long Baseline Interferometry & Radio Astronomy)
- Supported Missions
  - Most are NASA missions
  - Few missions from other international space agencies
    - ESA - Integral, Rosetta, Venus Express, Mars Express, etc.
    - JAXA - Hayabusa 1 & 2, etc.
    - ISRO – Chandrayaan 1 & 2, Mars Orbiter



DSN Operations Facilities



Goldstone Complex

JPL Operation Center

Madrid Complex

Canberra Complex

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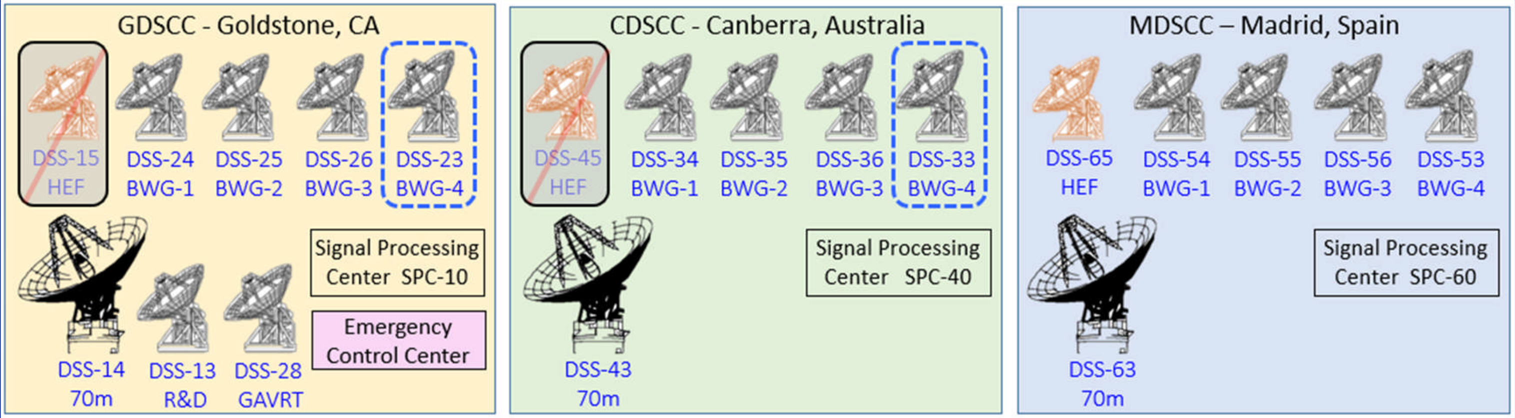
DSN Antennas and Capabilities



Pasadena & Monrovia, CA

DSN Project Office Pasadena, CA

Deep Space Operations Center (DSOC) Pasadena, CA

Remote Operations Center (ROC) Monrovia, CA

DTF-21 Monrovia, CA
CTT-22 *Mobile*
MIL-71 KSC, FL

Freq. Band	S Up	S Down	X Up	X Down	Ka Up	Ka Down
Deep Space	2.11-2.12	2.29-2.3	7.145-7.19	8.4-8.45	34.2 – 34.7	31.8-32.3
Near Earth	2.025-2.11	2.2-2.29	7.19-7.235	8.45-8.5	25.5-27.0	22.55-23.15

Legend

Decommissioned

Future DAEP

~~Grey – Decommissioned~~

20kW now - Will be upgraded to 80kW

400W now - Will be upgraded to 1kW array feed

• - Deep space band only, * - near earth only

♦, 250W, 1kW - Future DAEP/DLEU/DSN deliveries

◻ - 8m Optical delivered early 2030's

Antenna	Sub-Net	S-Band		X-Band			K-Band		Ka-Band		Optical 1550nm	*Est. Deliv. Dates*
		Up	Down	Up	Down	Radar	Up	Down	Up	Down	Down	
DSS-14	70m	20kW•	√	20kW	√	500kW						*8/2026*
~~DSS-15~~	~~34m HEF~~	~~250W~~	~~√~~	~~20kW~~	~~√~~							
DSS-23	34m BWG			20kW	♦					♦	◻	*10/2025*
DSS-24	34m BWG	20kW	√	20kW	√		250W	√		♦		*8/2023*
DSS-25	34m BWG			20kW	√				400W	√		*5/2028*
DSS-26	34m BWG	250W*	√	80kW	√		250W	√		√		
DSS-33	34m BWG			80kW	♦					♦		*10/2029*
DSS-34	34m BWG	20kW	√	20kW	√		250W	√		√		*2/2024*
DSS-35	34m BWG			20kW	√				1kW	√		*8/2026*
DSS-36	34m BWG	250W*	√	20kW	√		250W	♦		√		*11/2022*
DSS-43	70m	100kW•	√	80kW	√							
~~DSS-45~~	~~34m HEF~~	~~250W~~	~~√~~	~~20kW~~	~~√~~							
DSS-53	34m BWG			20kW	√					√		*10/2029*
DSS-54	34m BWG	20kW	√	20kW	√		250W	√		√		*8/2026*
DSS-55	34m BWG			20kW	√				1kW	√		*5/2027*
DSS-56	34m BWG	250W*	√	20kW	√		250W	√		√		*8/2024*
DSS-63	70m	20kW•	√	20kW	√							*12/2028*
DSS-65	34m HEF	250W*	√	20kW	√							

https://deepspace.jpl.nasa.gov/files/820-100-H.pdf

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2. Supporting Missions

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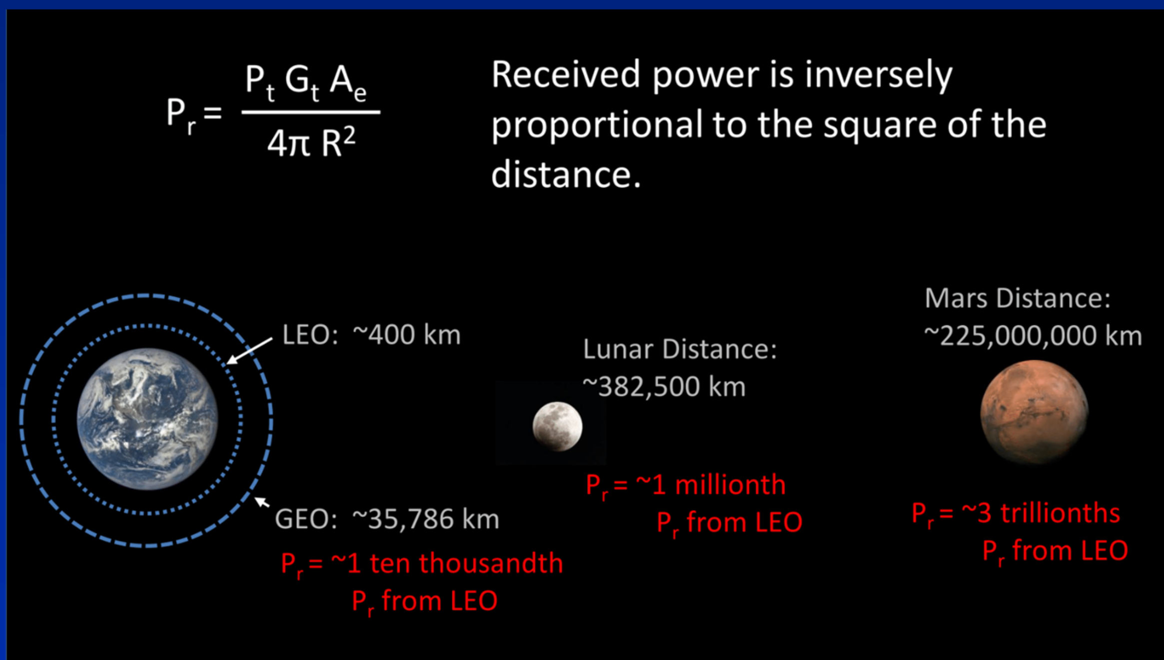
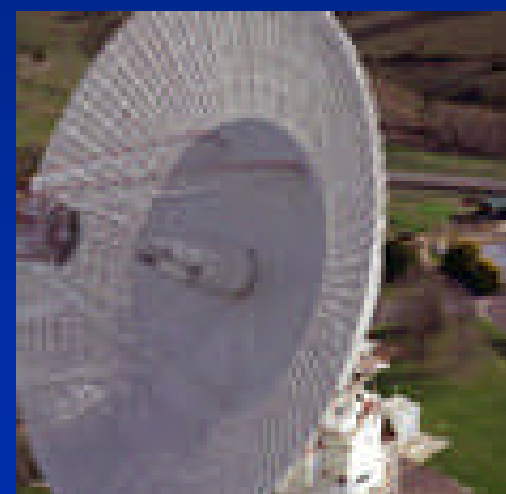
Long Distance, Low Power Communications

- Long distance communications
  - Lunar missions (0.002 AU) to Voyager at 140 AU





D. Abraham, Working Toward More Affordable Deep Space Cubesat Communications: MSPA and OMSPA, *https://www.dropbox.com/sh/fx8auva239g0wx9/AADMzWa7wgXpl0KmmoFk2rgaa/D2-Abraham?dl=0&preview=ISSC2016_WorkingTowardAffordableCommunications_URS257550.pptx#*

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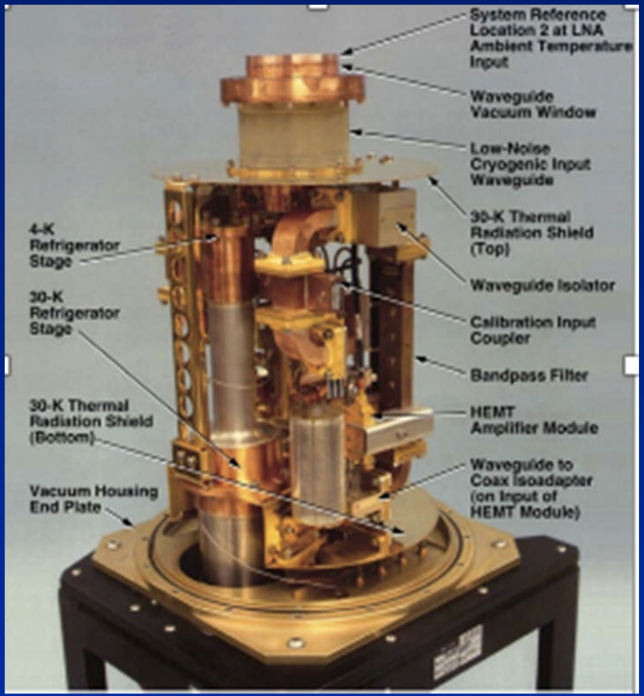
70-m Antennas

- Largest and most sensitive antenna in the DSN
  - First 64-m antenna constructed at Goldstone in 1966 to extend communications to missions beyond Mars
  - Later expanded to 70-m in 1988 for Voyager 2's Neptune encounter
- Weigh 2.7 million kg
- Antenna structure floats on a thin film of oil of thickness of a sheet of paper
- Surface accuracy within 1 cm across its 3850 square meters parabolic reflector

Ref. https://www.nasa.gov/directorates/heo/scan/services/networks/deep_space_network/complexes

Design Focus in Deep Space Communications

- Low-power communications require
  - Antenna with maximum G/T
    - Large aperture (34-m/70-m)
    - Cryo-cooled LNA with very low system noise temperature (< 10 K)
  - Modulation & coding optimized for low power regime
    - Typical modulation: BPSK, QPSK
    - Typical coding: Convolutional, Reed Solomon, Concatenated, Turbo, Low-density parity check
  - Maximum EIRP for emergency search



Adaptive, Flexible to Mission Needs

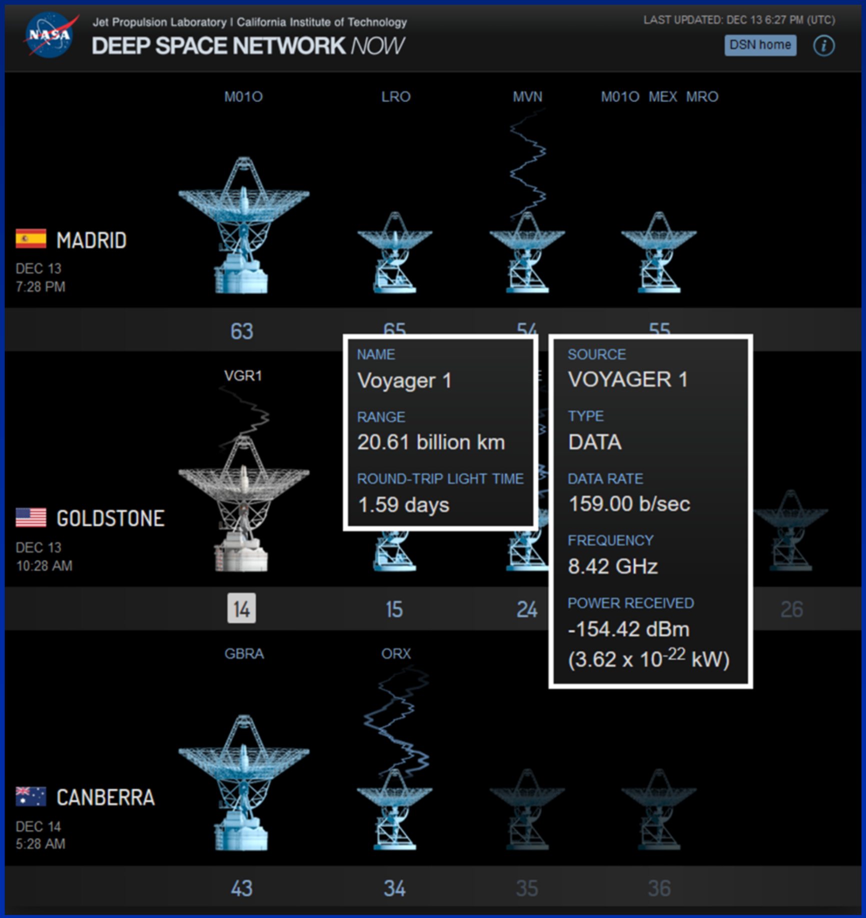
- Wide range of data rates
  - High rate –TESS (125 Mbps),
  - Low rate – Voyager (160 bps)
- Various latencies
  - Low latency (sub-minutes) – JWST, VIPER
  - Minimum latency variation – Astronauts voice communications
- Multiple frequencies - S, X, K, Ka
  - Driven by performance and spectrum allocation
- Various transmitting powers
  - Low power (~100W, after launch)
  - High power (100 kW for Voyager)
- Data path
  - Direct to/from Earth
  - Relayed by orbiter
- Various signal formats optimized for operational need
  - Telemetry frames with forward error correction codes
  - Beacon tones for long cruise
  - MFSK for entry descent landing

Operations Considerations

- Operations cost efficiency
  – Follow the Sun operation
  – Automation
- Antenna utilization efficiency
  – Multiple spacecraft per antenna
  – Arraying
- Special mission operating modes
  – MFSK for Entry Descent Landing
  – Beacon for long duration flight
- Antenna scheduling
  – Competing priorities among users
  – Launch delay
- Cybersecurity
  – System upgrades
  – Network connections to mission users

Follow the Sun Operations

- Moving DSN operations from where each DSN Complex controlling its antennas to a global operations where each Complex takes turn to operate the entire DSN
  - Reduced staffing at each DSN sites from around the clock to 9 hrs/day



https://eyes.nasa.gov/dsn/dsn.html

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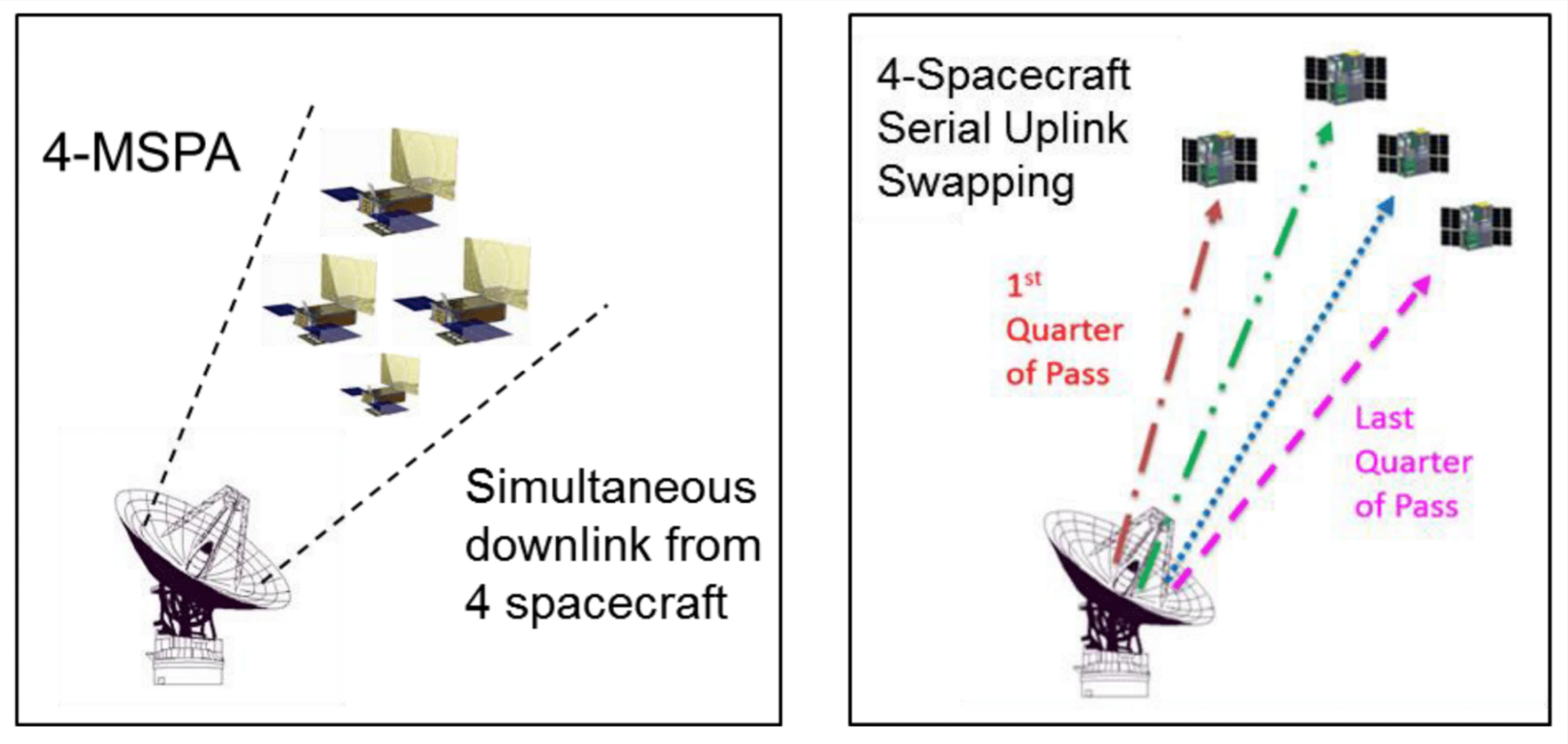
Multiple Spacecraft per Antenna Operations



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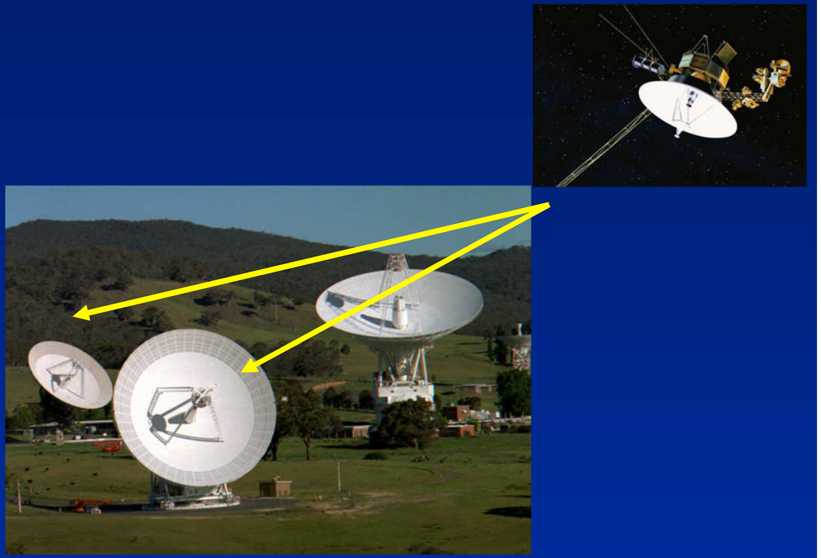
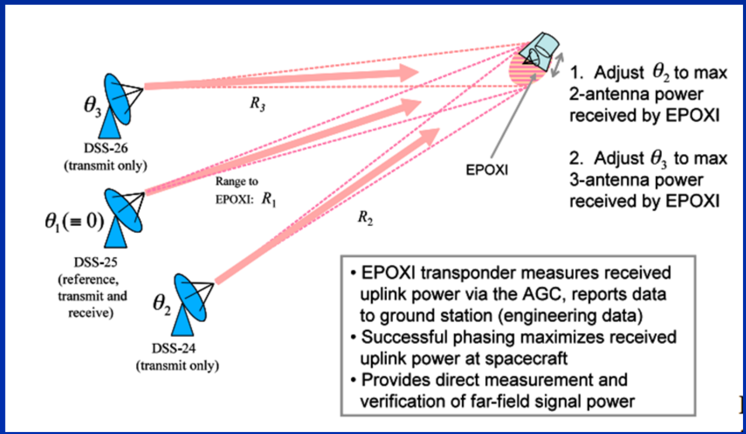
Antenna Array for Low Signal Conditions

- A way to enhance antenna aperture and signal reception
  - Used for support to Voyager, Spitzer, New Horizons missions
- Downlink array
  - Aperture combining - Multiple 34-m or in combination with 70-m antenna
  - Polarization combining on 70-m
- Uplink array (R/D capability)
  - Achieve gain proportional to N^2, instead of N as with downlink, where N=number of antennas





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Ref.: Vilnrotter, Uplink Array Concept Demonstration with the EPOXI Spacecraft, IEEE Aerospace, 2009

DSN as a Science Instrument

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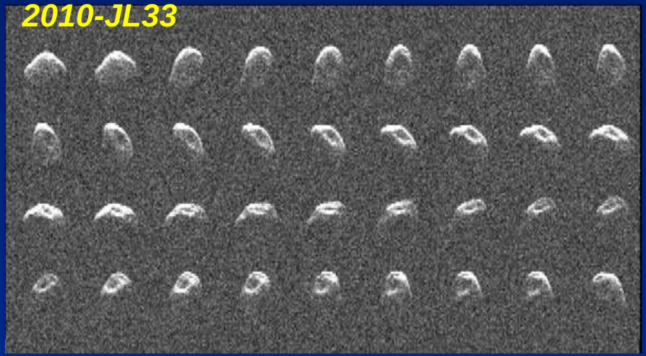
Goldstone Solar System Radar

- Research focus
  - Planetary radar
  - Asteroid detection
- High power transmitter 500 kW, X-band
- Co-observing with Green Bank and Arecibo Observatory(1)

(1) Arecibo became non-operational in 2020



http://www.spaceref.com/news/viewpr.html?pid=32483

2012-DA14

http://www.space.com/19804-asteroid-flyby-nasa-radar-2012-da14.html

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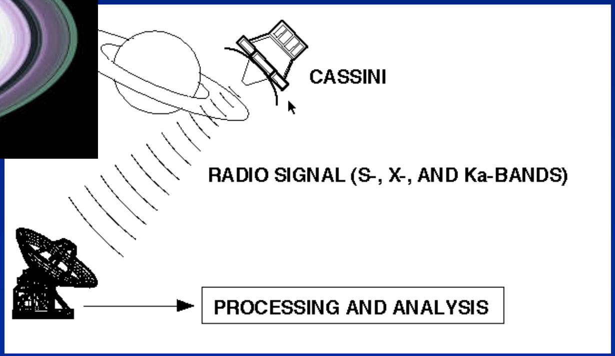
Radio Science

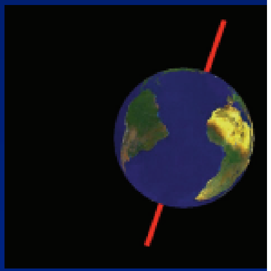
- Properties of planet's atmosphere or planetary ring can be studied from measurements of received signal's phase, frequency and amplitude
  – Change in signal amplitude reveals information on object's density
  – Change in signal frequency, with proper signature, reveals possible passing gravitation wave
- Require very high frequency stability and spectral purity in system performance

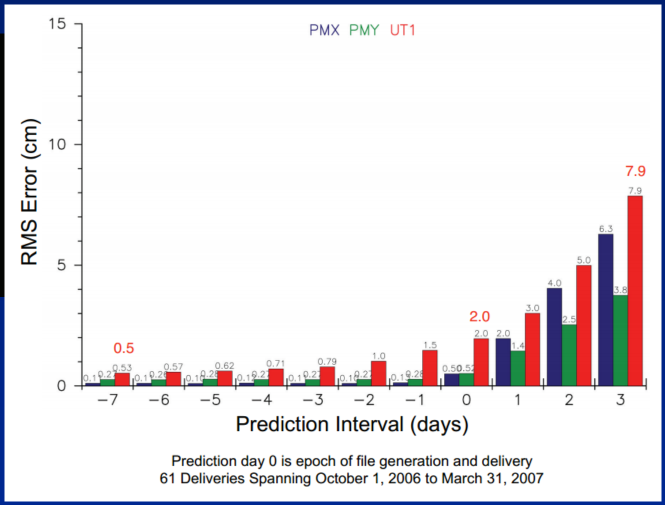


http://saturn.jpl.nasa.gov/spacecraft/cassini orbiterinstruments/instrumentscassinirss/

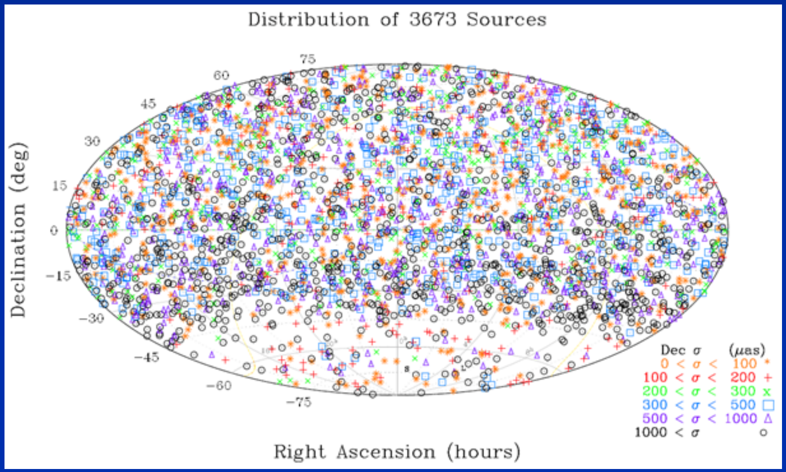
Very Long Baseline Interferometry & Radio Astronomy

- Study Earth deformation and rotational change through Time/Earth Motion Precision Observation (TEMPO) measurements
  - Location of spin axis relative to celestial frame (precession-nutation motion), terrestrial frame (polar motion), angle that Earth rotates about spin axis (spin)
  - Data also used to improve spacecraft navigation
- Characterize signal fluctuation of cataloged quasars at X- and Ka-band





http://www.cbk.waw.pl/~kosek/EOPPW2009/contributions/session1/session1.3/tue04_Gross.pdf



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Performance Considerations

- High frequency/phase stability
  - Co-observing phase calibration required
- High recording bandwidth
  - The signal is in the noise!
- Low latency in data delivery
  - Data transfer over WAN is a challenge
- High power transmitter for radar
  - Reliability considerations

Summary

- DSN is a key contributor to robotic and human space exploration
- Designed for maximal signal reception with extremely low noise and large antennas, and different techniques of modulation, coding, and arraying
  - Variety of configurations to meet mission needs
  - Operations efficiency via automation, multi links per operator, multiple spacecraft per antenna
- Serve as a ground-based science instrument for radio science, planetary radar and radio astronomy research
  - Amplitude & phase stability are key to science observations