Enhancing Mission Support with New Communications Capabilities in the NASA Deep Space Network

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Jet Propulsion Laboratory

California Institute of Technology

Agenda

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- NASA DSN
- Challenges and enhancements
  - Increased mission support
  - Human space flights
  - Science missions

Where in the world is the DSN?

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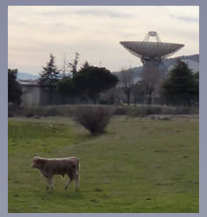
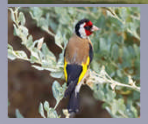
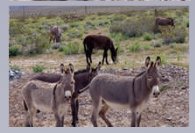
Madrid Deep Space Communications Complex

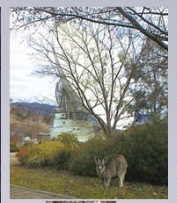
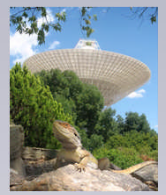
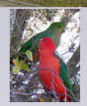




Goldstone Deep Space Communications Complex





Canberra Deep Space Communications Complex

https://youtu.be/PIkmm8f_4DE

Space Flight Operations Facility, Jet Propulsion Laboratory

Current state

- 13 antennas (4 at Goldstone, 4 at Canberra, 6 at Madrid)
  - One 70-m, others 34-m at each site
- Operating at S, X, K (26 GHz return), Ka (32 GHz return, 34 GHz forward)
  - K-band downlink (26 GHz) currently available at 2 antennas per Complex
  - Ka-band uplink (34 GHz) limited to 1 antenna at Goldstone, mainly for radio science application

Supported Missions

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Current missions being tracked by DSN

- Human and robotic space flights
- Flagship missions and cubesats
- Planetary orbiters, landers/rovers, in-situ samplers, astrophysics observatories, interstellar missions
- Multi-spacecraft missions
- Multi-frequency spacecrafts

Current and near future missions associated with JPL

DSN Telemetry Link Margin Performance Analysis Dashboard Mar 2023 help

DOY	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	Average	YTD
SCID-BAND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	linkmargin	
ACE-S 92																															19.10	ACE-S
BIOS-X 7																															23.19	BIOS-X
CAPS-X 176																															13.60	CAPS-X
CHDR-S 151																															12.72	CHDR-S
DSCO-S 78																															18.35	DSCO-S
EMM-X 62																															10.11	EMM-X
HMAP-X 39																															09.17	HMAP-X
INTG-S 199																															13.17	INTG-S
JNO-X 61																															05.33	JNO-X
JWST-K 170																															12.87	JWST-K
JWST-S 170																															13.38	JWST-S
KPLO-S 155																															19.97	KPLO-S
KPLO-X 155																															17.84	KPLO-X
LFL-X 164																															09.28	LFL-X
LRO-S 85																															19.35	LRO-S
LUCY-X 49																															12.22	LUCY-X
M010-X 53																															02.99	M010-X
MEX-X 41																															11.03	MEX-X
M20-X 168																															09.96	M20-X
MMS1-S 108																															12.71	MMS1-S
MMS2-S 109																															12.10	MMS2-S
MMS3-S 110																															12.28	MMS3-S
MMS4-S 113																															12.32	MMS4-S
MRO-X 74																															04.83	MRO-X
MSL-X 76																															14.18	MSL-X
MVN-X 202																															15.15	MVN-X
NHPC-X 98																															06.12	NHPC-X
ORX-X 64																															07.80	ORX-X
PLC-X 5																															06.60	PLC-X
SOHO-S 21																															09.58	SOHO-S
SPP-X 96																															03.49	SPP-X
SPP-X 96																															05.22	SPP-X
STEREOA-X 234																															16.78	STEREOA-X
TESS-K 95																															09.44	TESS-K
TESS-S 95																															17.30	TESS-S
THB-S 192																															10.81	THB-S
THC-S 193																															10.22	THC-S
TRACE-X 143																															05.79	TRACE-X
VGR1-X 31																															03.70	VGR1-X
VGR2-X 32																															01.36	VGR2-X
WIND-S 8																															06.79	WIND-S
DOM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		

DSN Current and Near-term Capabilities

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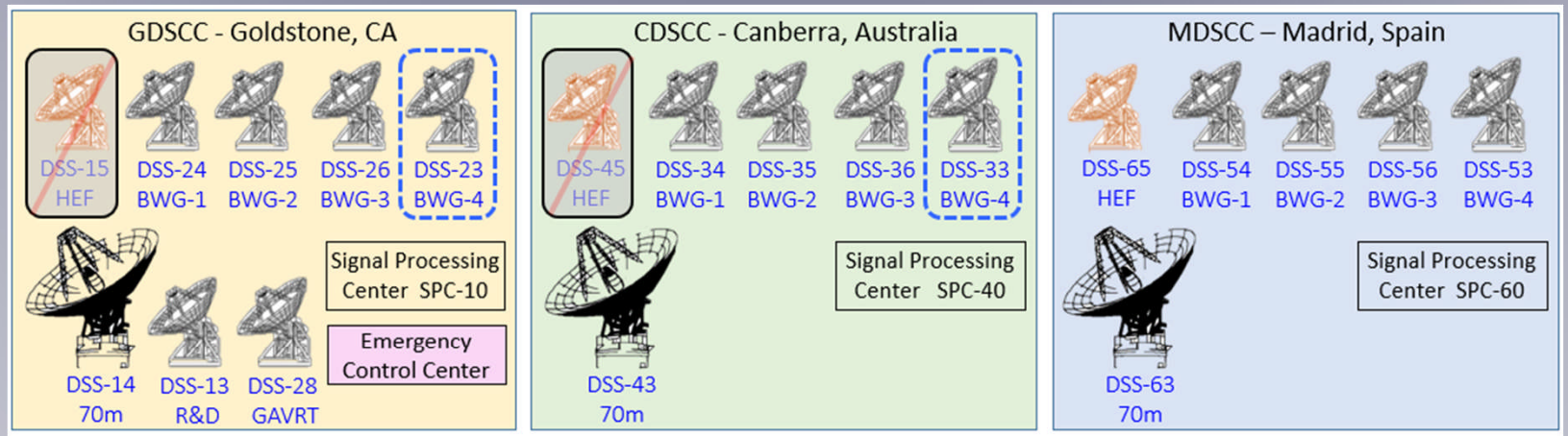

Pasadena & Monrovia, CA

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

Increased Mission Support

Future Mission Loading Forecast

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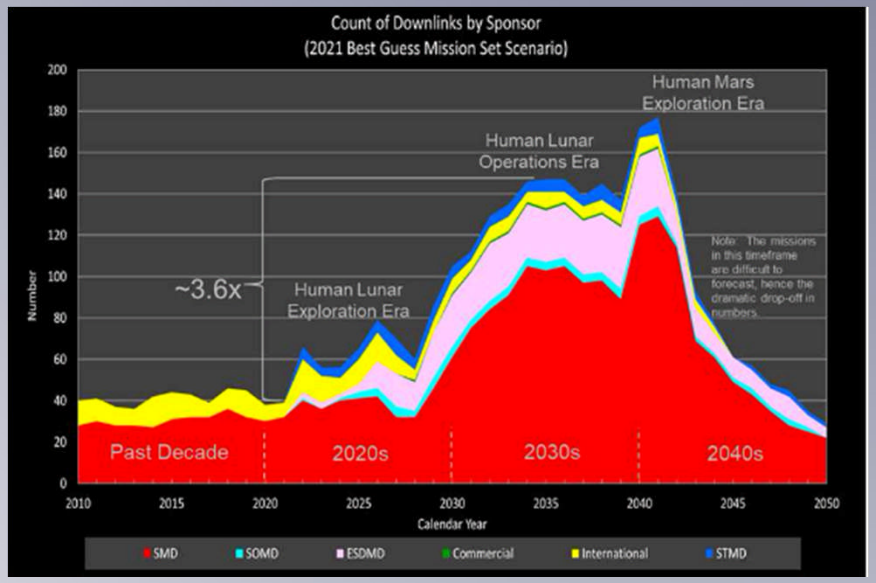

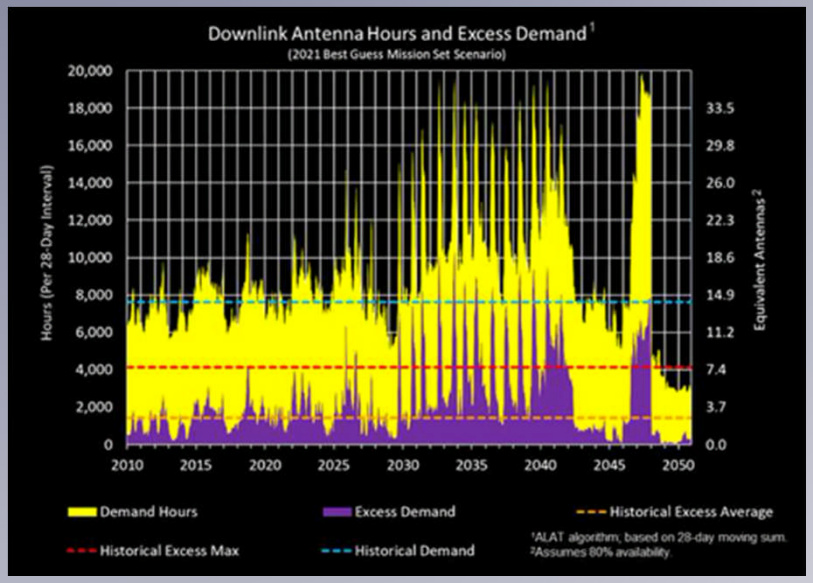

- Missions increase up to x2 at the end of 2020's
  - x3.6 increase in 2030's
- Demand on antenna tracking hours significantly higher than currently available

D. Abraham et al., NASA deep space communications: future mission trends and their implications, Spaceops 2023, Dubai, UAE, Mar. 2023

Enhancements

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- Build more antennas
  - Two additional antennas expected to be operational by end of 2020s
  - Additional antennas would require extra funding
- Leverage on assets from other space agencies and university
  - Temporary solution during high demand periods
    - Need to return favor of cross-support tracking at some point
  - Limited availability of ground assets at partner space agencies
  - Morehead state university 21-m as a DSN affiliated node
- Increase antenna utilization via
  - Multiple spacecraft per antenna (MSPA)
  - Opportunistic MSPA (OMSPA)
  - Multiple uplink per antenna (MUPA)

DSN-Affiliated Morehead State University Ground Station

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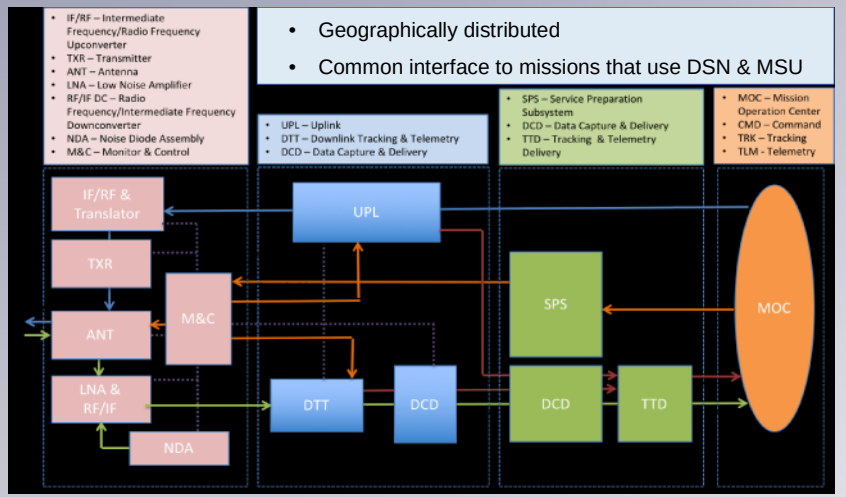
New capability

- Use of 21-m ground station to help offset loading
  - Standard schedule interface as with other DSN antennas
  - Difference in G/T and EIRP accounted in mission planning
- X-band TTC capability
  - Frequency
    - Reception - Both X-band near Earth and deep space bands
    - Transmission - X-band near Earth band, due to spectrum license constraint
  - Equipment
    - Mixture of DSN-developed signal processing equipment and Morehead-developed RF signals
      - Same modulation & coding for telemetry and tracking data
  - Data delivery to/from MOC
    - Command - via SLE at Morehead
    - Telemetry & Tracking – via SLE at JPL

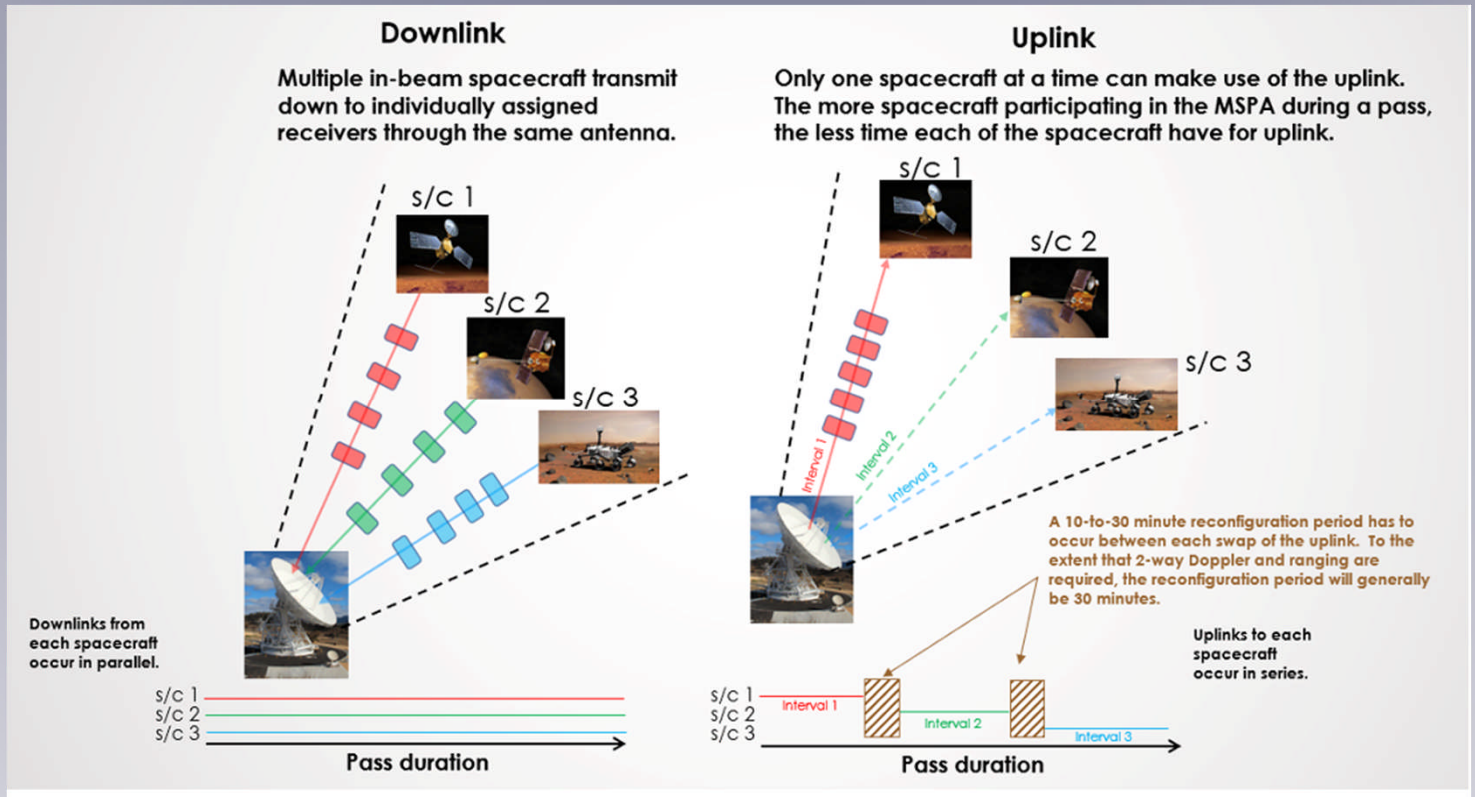


Current progress

- Operational and providing support to CAPSTONE, Lunar IceCube, HMAP, etc.

Reference: B. Malphrus, Deep Space Station 17: A University-Operated Affiliated Node On the NASA Deep Space Network for Interplanetary Small Satellite Missions, 73rd International Astronautical Congress, Paris, France, September 18-22, 2022

Multiple Spacecraft per Antenna (MSPA)



- Simultaneous downlinks, currently 4-MSPA, extendable to 8-MSPA
- Time-multiplexing uplink, one spacecraft at a time
  - Command, 2-way Doppler and 2-way ranging data is limited to each spacecraft's portion of uplink

D. Abraham et al., Antenna beam sharing: Progress toward multiple uplinks per antenna, Spaceops 2023, Dubai, UAE, Mar. 2023

Opportunistic Multiple Spacecraft Per Antenna

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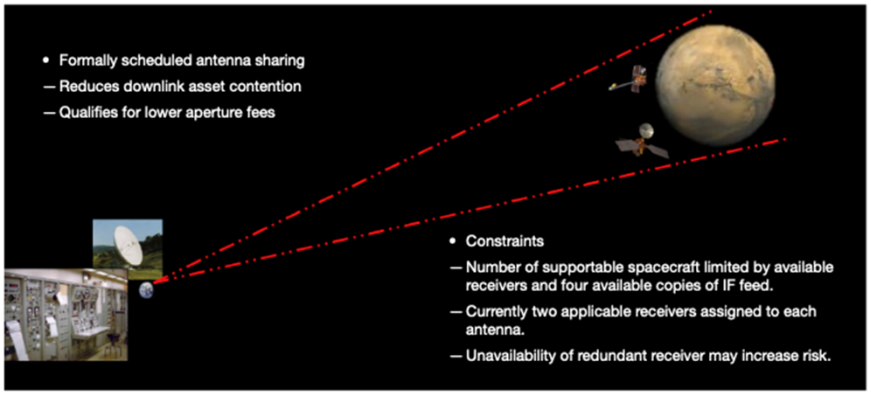

Figure 1. Traditional MSPA.

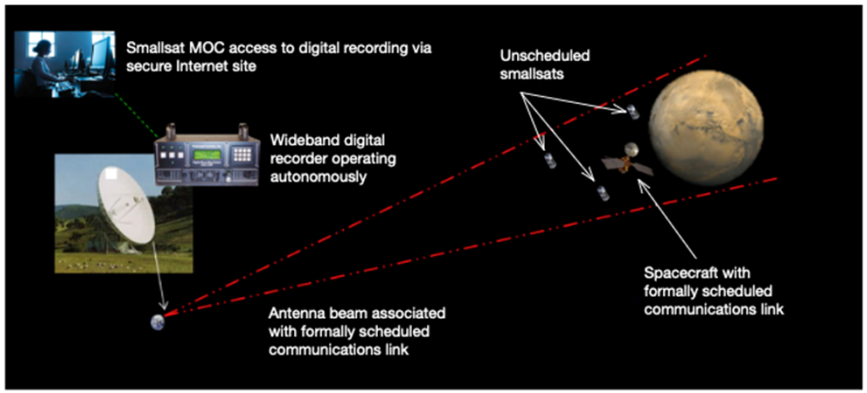

Figure 2. Opportunistic MSPA. Everything received through the antenna beam is digitally recorded. Smallsats transmit open loop when in a host spacecraft's beam. Smallsat MOCs retrieve the relevant portion of the digital recording for subsequent demodulation and decoding.

New capability

- Wideband record downlink signal that captures multiple spacecraft in the beam
- Extract telemetry data for 16 spacecraft, up to 256 kbps, within 24 hrs from tracking schedule
- Deliver data via same interface as with normal tracking passes
- Fully automated process for subscribed mission users
  - DSN determines which spacecraft is in the antenna beam per ephemeris and process data automatically

Current progress

- Under Acceptance testing. Operational in 2023

D. Abraham et al., Opportunistic MSPA Demonstration #1: Final Report, Interplanetary Network Progress Report, Feb. 2015
https://ipnpr.jpl.nasa.gov/progress_report/42-200/200B.pdf

Multiple Uplink per Antenna (MSPA)

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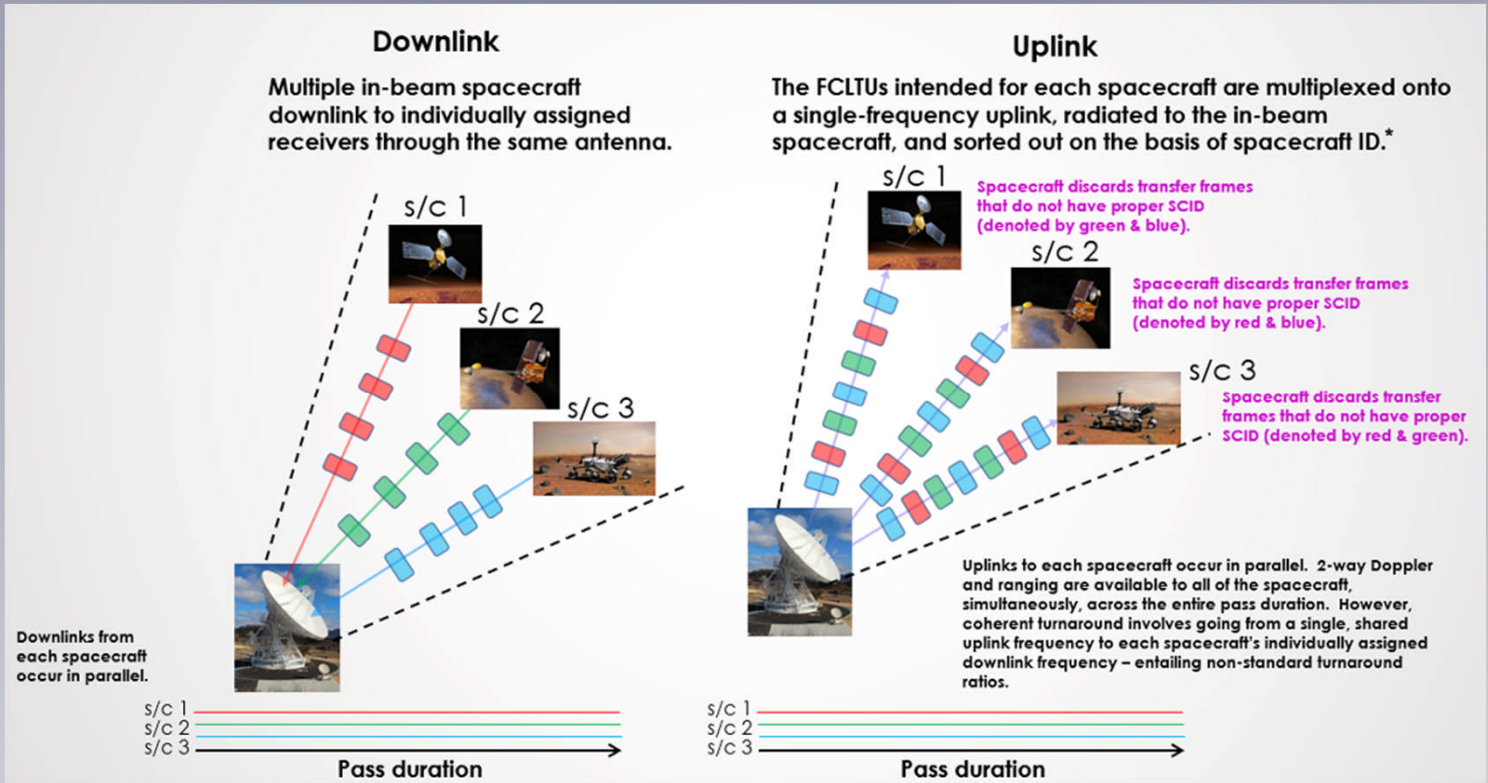

- Simultaneous downlinks, currently 4-MSPA, extendable to 8-MSPA
- Simultaneous uplink with multiplexed command data sent to multiple spacecraft
  - Each spacecraft sort out its command data
  - Each spacecraft accounts for uplink Doppler shift
  - 2-way Doppler and ranging data available throughout the tracking pass

D. Abraham et al., Antenna beam sharing: Progress toward multiple uplinks per antenna, Spaceops 2023, Dubai, UAE, Mar. 2023

Human Spaceflight Support

Human Lunar Exploration

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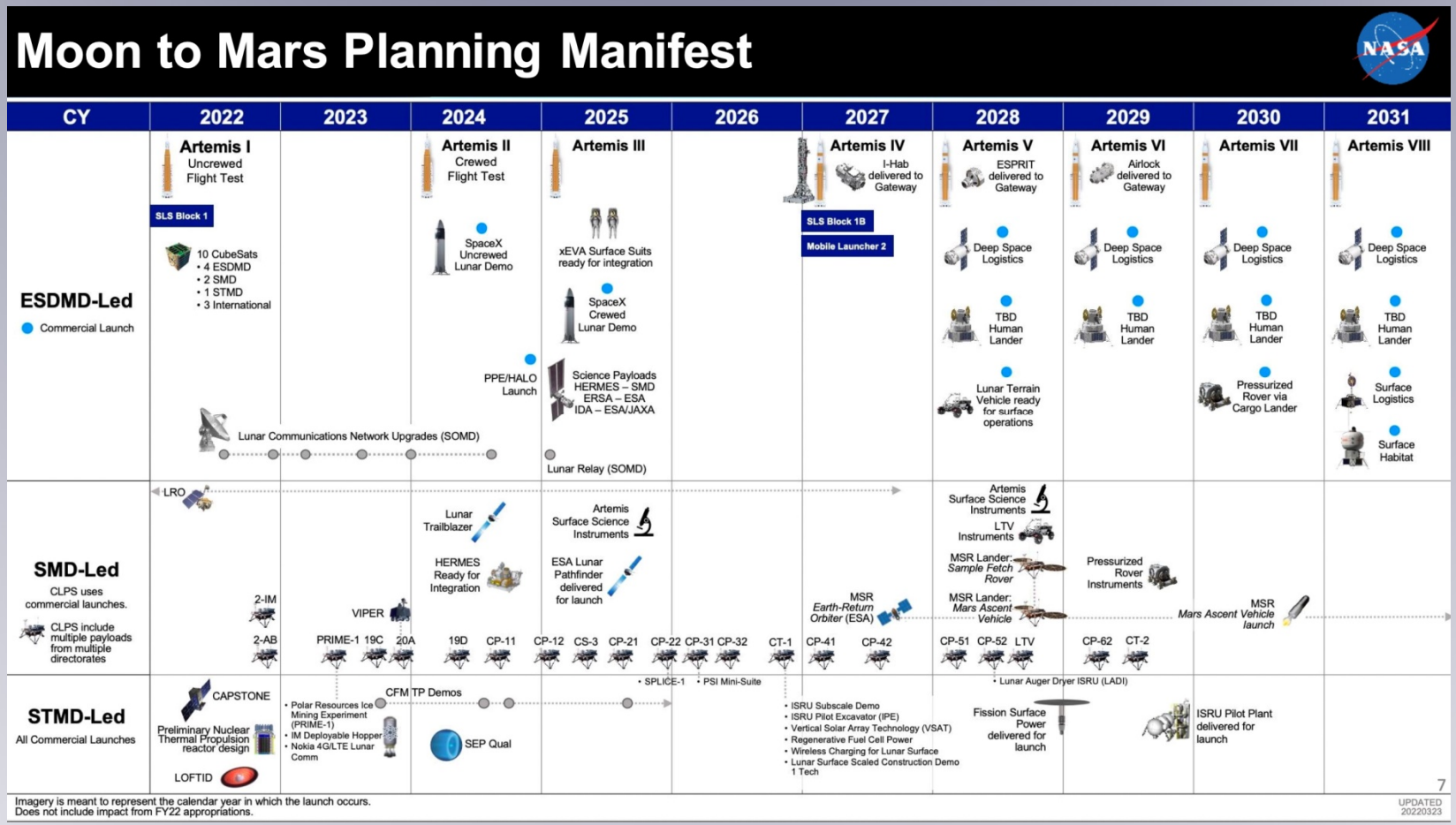

https://www.nasa.gov/sites/default/files/atoms/files/fy23_nasa_budget_request_summary.pdf

Communications characteristics for Human Lunar Exploration

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- Reliance on S-band for TTC
  - Legacy flight equipment
- Higher uplink & downlink data rates at K-band
  - For human interactions
- Higher reliability requirement
  - Dual antenna configuration for hot backup
- Multiple tracking objects for human landing
  - Orbiters/Relayers, landing vehicles, surface rovers

26-GHz K-band Downlink

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Capability

- Two 34-m BWG antennas at each Goldstone, Canberra, Madrid Complex
  - Prior capability of one antenna per Complex
- Data rate: 150 Mbps, max.
- LDPC, convolutional, Reed Solomon decoding
- WAN bandwidth from Complex to JPL
  - Currently ~100 Mbps
  - Expanding to ~200 Mbps by 2024

Current progress

- Goldstone – 2 antennas completed (DSS-24, -26)
- Canberra – 2 antennas completed (DSS-34, -36)
- Madrid – 2 antennas completed (DSS-54, -56)

R. Labelle, Ka-band High Rate Telemetry Upgrade for the NASA Deep Space Network,
60th International Astronautical Congress, Daejeon, South Korea, October 12-16, 2009

22-GHz K-band Uplink

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New capability

- Two antennas at each Goldstone, Canberra, Madrid Complex
- Capable of simultaneous dual uplinks at (S & K) or (X & K)
- 250 W transmitting power, 127.7 dBm EIRP
- 20 Mbps uplink max.*
- Unfiltered/filtered QPSK modulation*
- LDPC & RS encoded*

Current progress

- Goldstone – 1 antennas completed, 1 pending (2023)
- Canberra – 1 antennas completed, 1 pending (2025)
- Madrid – 2 antennas pending (2024, 2026)

* *Modulation, coding and data rates are available on all frequency bands*

Delay/Disruption Tolerant Network (DTN)

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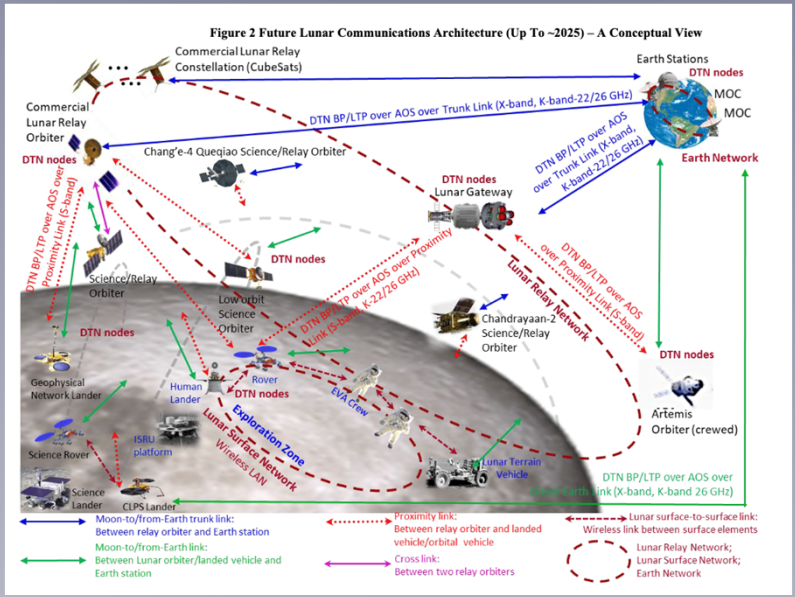

IOAG Lunar Communications Architecture Study Report
https://www.ioag.org/Public%20Documents/Lunar%20communications%20architecture%20study%20report%20FINAL%20v1.3.pdf

Driver

- To simplify a reliable data transfer, especially over multi-hop networks

New capability

- Initial deployment supporting KPLO mission in August 2022
- General multi-mission capability expected in next delivery, by end of 2023

Current progress

- KPLO support – demonstrated with spacecraft
- Multi-mission support – operational pending, end of 2023

Greater Science Data Return with Ka-band and Optical

32-GHz Ka-band Downlink

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- Most of 34-m antennas already equipped with Ka-band downlink
- 70-m antennas can be enhanced with Ka-band to provide additional capacity

34-GHz Ka-band Uplink

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New capability

- One antenna at each Goldstone, Canberra, Madrid Complex
  - Current capability (300 W) limited to 1 antenna at Goldstone, mainly for radio science services
- Full forward service for command and ranging
- Capable of simultaneous dual uplinks at X & Ka
  - Useful to remove atmospheric noise in radio science experiments
- 800 W transmitting power, 133.6 dBm EIRP
- 20 Mbps uplink max.
- LDPC & RS encoded

Current progress

- Goldstone – pending, 2028
- Canberra – pending, 2026
- Madrid – pending, 2027

* *Dates may change per Veritas mission schedule*

Reference: 810-005, Module 104 "34-m BWG Stations Telecommunications Interfaces", https://deepspace.jpl.nasa.gov/dsndocs/810-005/104/104O.pdf

Optical Capability

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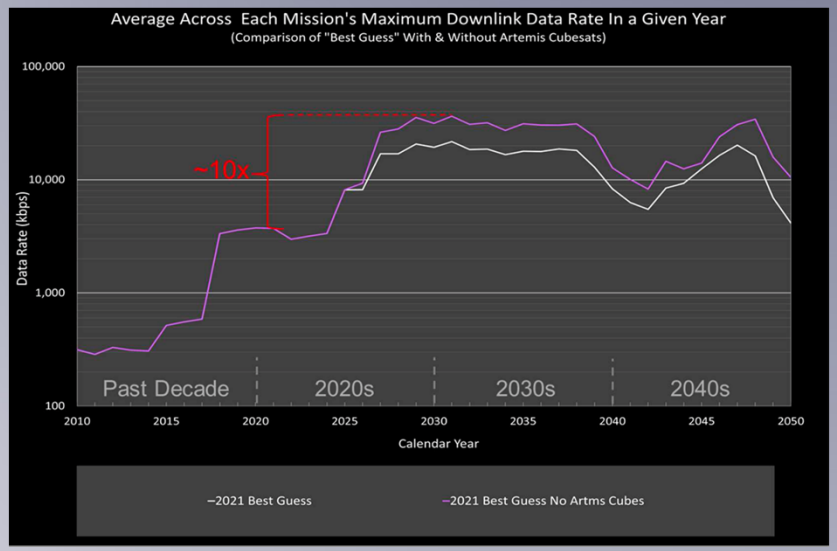
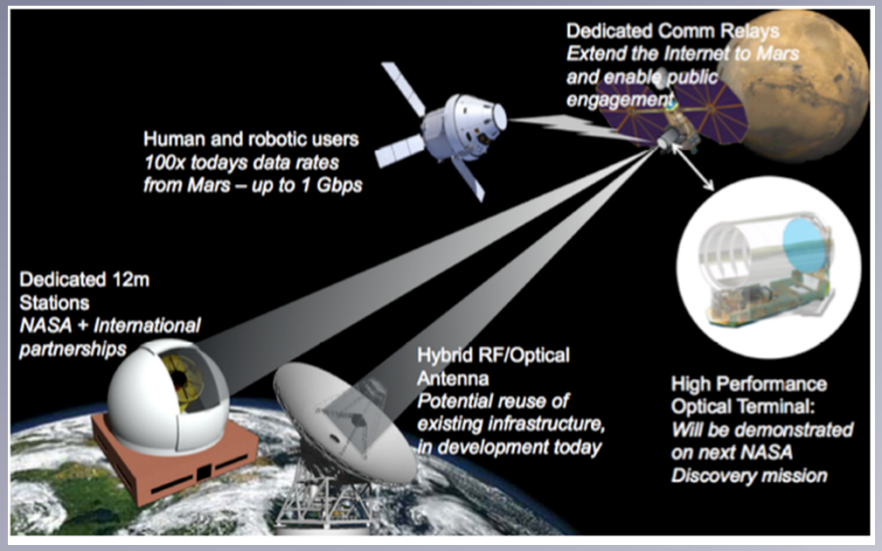
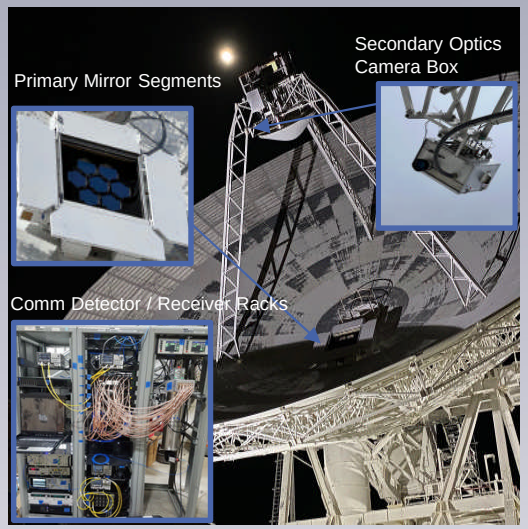




- 7-panel optical system co-located on 34-m RF antenna
  - Demo with Psyche mission, ~2024
- 64-panel optical system co-located on 34-m RF antenna
  - Future deployment, ~ end of 2020s



B. Tehrani, JPL internal report, Jan. 2023

D. Abraham et al., Antenna beam sharing: Progress toward multiple uplinks per antenna, Spaceops 2023, Dubai, Mar. 2023

Summary

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- Many new capabilities being introduced into DSN to better support future missions

- Challenges and enhancements
  - Mission loading increase
    - More antennas
    - More efficient use of antennas with MSPA, OMSPA and MUPA
  - Human spaceflight to Moon & Mars
    - Higher command throughput
    - Use of K-band spectrum
    - Reliable data transfer with DTN for complex multihop communications architecture
  - Science missions with higher data rate
    - Ka-band uplink & downlink
    - RF/Optical antenna