Enabling a Larger Deep Space Mission Suite:

A Deep Space Network Queuing Antenna for Demand Access

Marc Sanchez Net (JPL)
Jay Wyatt (JPL)
Mark Johnston (JPL)
Rebecca Castano (JPL)
Stephen A. Townes (JPL)
T. Joseph W. Lazio (JPL)
Benjamin K. Malphrus (MSU)
Jeffrey A. Kruth (MSU)
Chloe Hart (MSU)
Emily Mattle (MSU)

2022 SpaceOps Workshop
June 3rd, 2022

Jet Propulsion Laboratory
California Institute of Technology

Outline

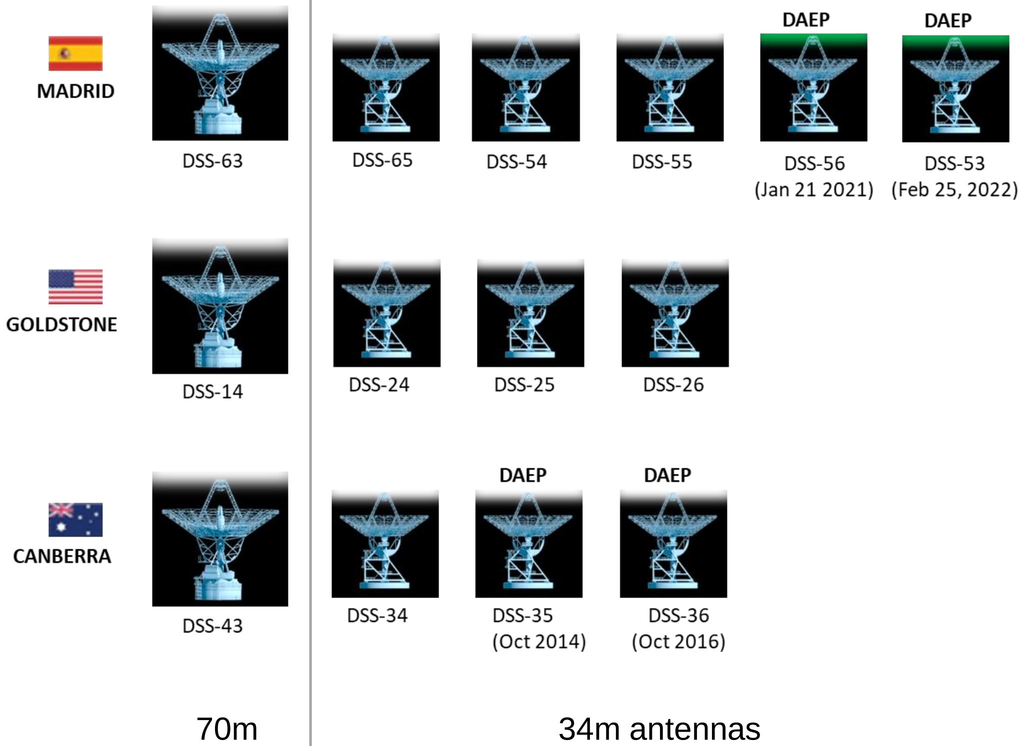
- **Demand Access Operations**
  - Current DSN Operations
  - Demand Access Operations and Capabilities
- **Queuing Antenna**
  - Queuing Antenna Operations
  - Request Signaling Format and Required Queuing Antenna Size
- **DSS-17 as Queuing Antenna Demonstrator**
  - Test 1: Time to configure and slew DSS-17
  - Test 2: Demonstrate correct reception of a spacecraft request

The Deep Space Network

Slide Credit: Stephen Lichten (JPL)

The Deep Space Network

Antennas currently available at each DSN complex

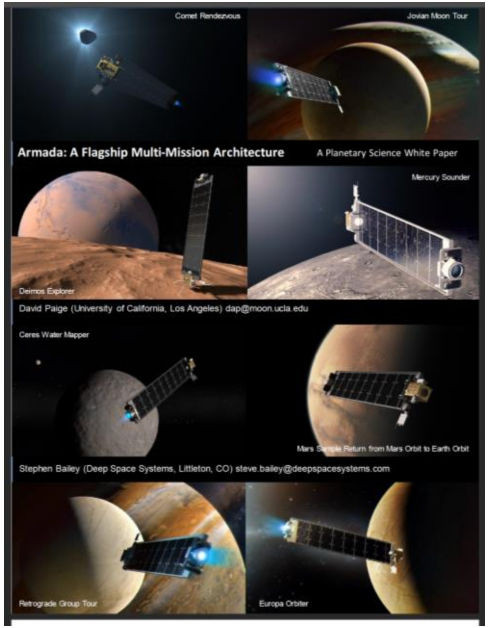


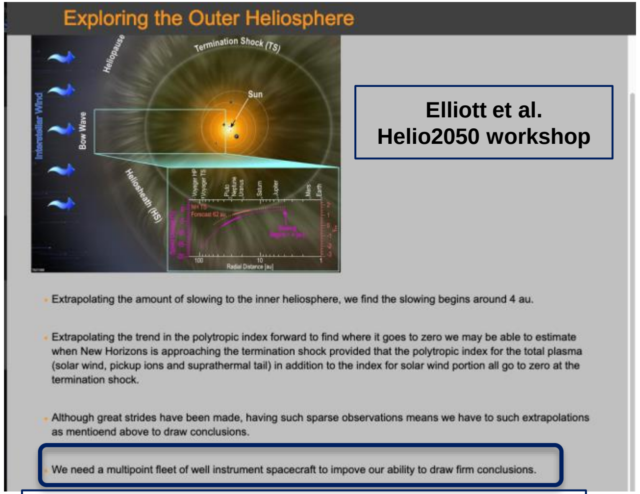
Current operations model

- The DSN supports ~40 users weekly.
- Antennas are heavily subscribed.
- Missions provide the DSN with expected communication and navigation requirements months in advance.
- Often results in “conflicts,” missions requesting more antenna-hours than are available
  - Some missions have hard requirements, e.g., Voyager 2 can use only Canberra antennas because of its location in the sky.
- Then, several weeks are spent negotiating the DSN schedule, ensuring that it is free of conflicts
- Result of this process is set of scheduled contacts that are fixed in time and cannot be changed (except emergency cases).

Future Deep Space Mission Suite

- Market forces leading to large expansion of deep space mission suite over next decades.
- The ARTEMIS-1 launch will add 10 new spacecraft for the DSN to support (~25% increase).
- More agile and efficient operations opportunities for (small) spacecraft across the Solar System.





**Elliott et al.
Helio2050 workshop**

“We need a multipoint fleet of [well-instrumented] spacecraft to improve our ability to draw firm conclusions.”

- Small spacecraft across the Solar System
  - Planetary Science: e.g., Armada concept, BAOBOB concept
  - Heliophysics: Earth-Sun Lagrange points, high ecliptic latitude
- Astrophysics Probes
  - Multiple missions operational at Sun-Earth L2 point
  - Pending Astro2020 recommendations

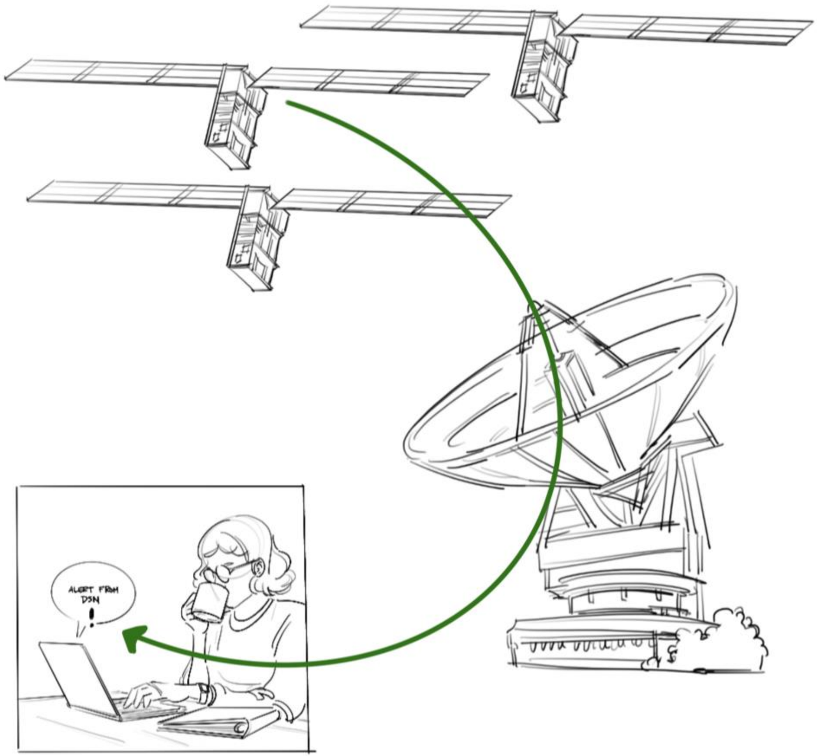
Demand Access Operations

- To support this new deep space mission suite, we are developing the necessary capabilities to enable demand access operations in deep space.

- Demand Access = Ground support is provided to missions in near real-time upon request from the spacecraft.

- Ground support encompasses:
  - Contact time with the DSN 34m and 70m antennas (and associated command, telemetry and navigation services with the DSN).
  - (Optionally) Real-time processing of data received from the spacecraft.

- Demand access operations must be complimentary to and coexist with the current “pre-scheduled” operational paradigm.



Concept of Operations

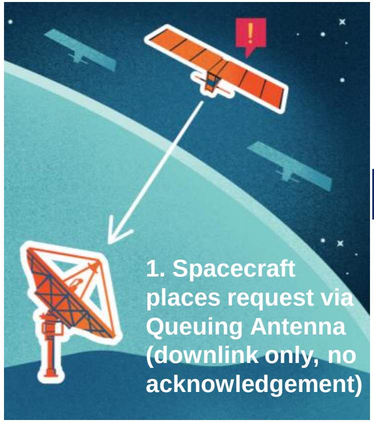
(weeks in advance)

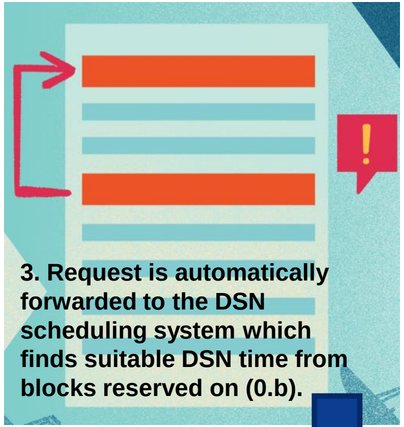
0.a. Mission submits demand access requests for DSN scheduling and ephemeris predicts.

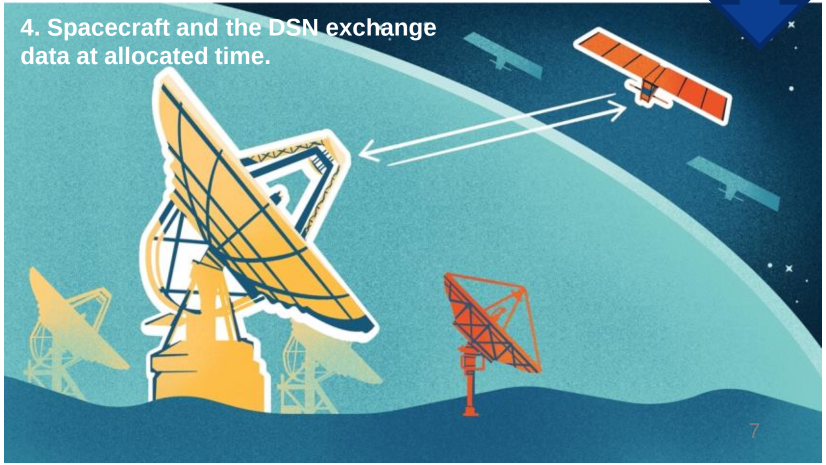
0.b. DSN scheduling team “blocks" periods of time for demand access

0.c. DSN scheduling team builds schedule for the queuing antenna.

0.d. Results from (0.b) and (0.c) are delivered to spacecraft via uplink





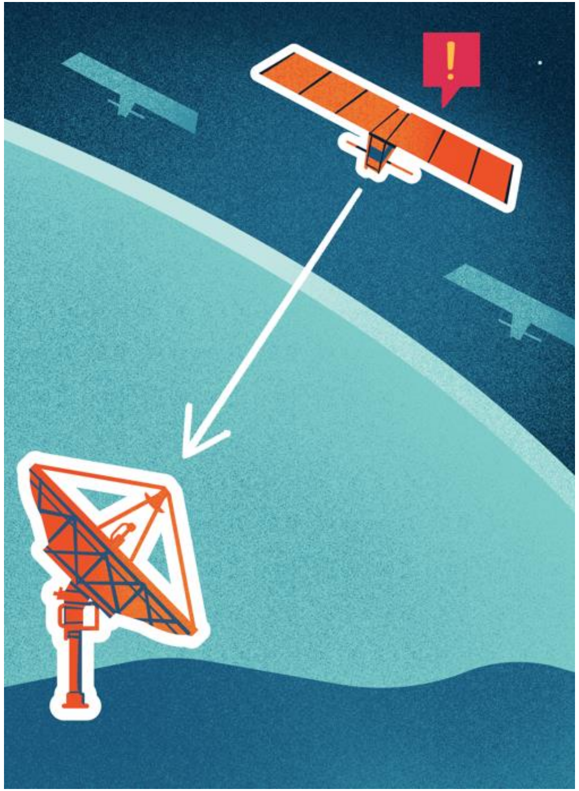


Queuing Antenna Operations (1/2)

- Smaller than the DSN 34m and 70m antennas.

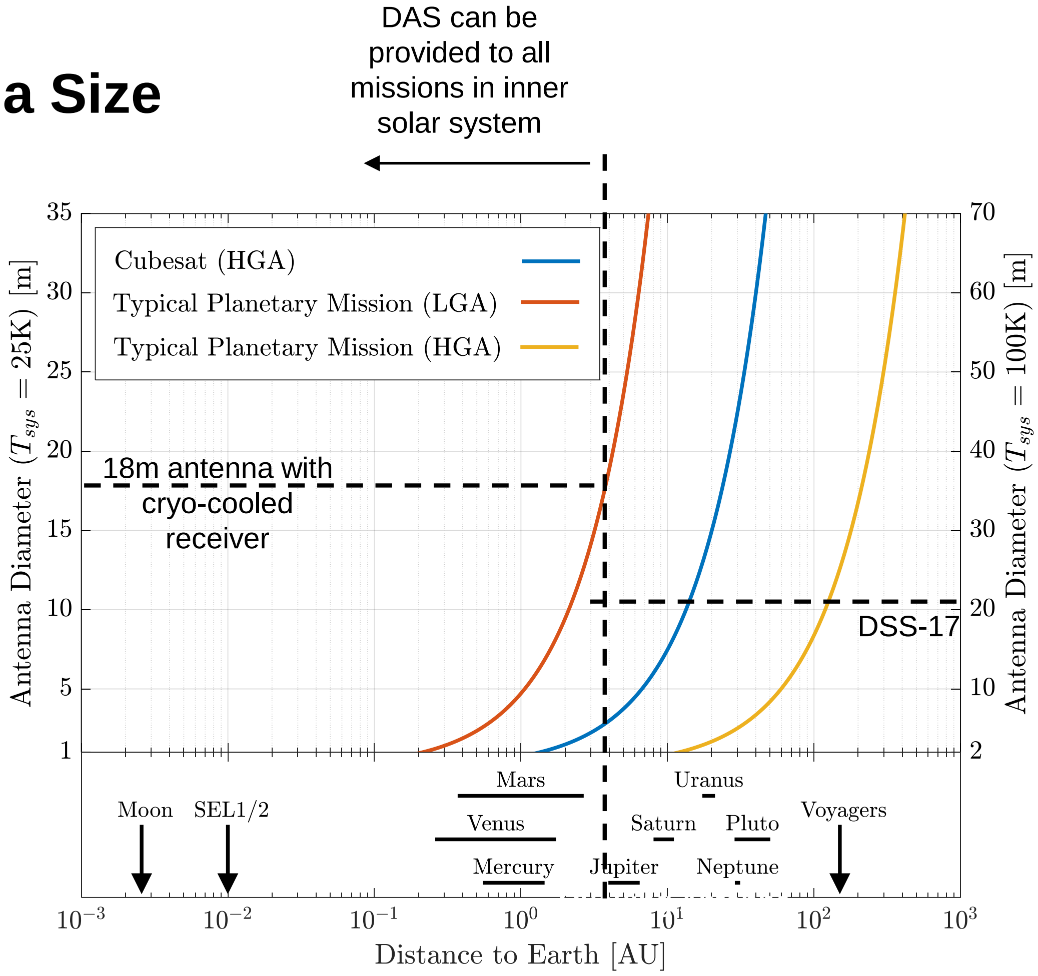
- Antenna is scheduled ahead of time like any other DSN antenna, but taking into account how often the spacecraft needs to be polled.

- The request from the spacecraft is unidirectional (downlink):
    - Spacecraft does not know if request has been received.
    - Spacecraft assumes that the request was received. If that is not the case, spacecraft will try again.
    - Queueing antenna does not require a transmit subsystem.



Required Queuing Antenna Size

- Signaling format for request:
  - **Option 1**: Very low rate telemetry
    - Inherited from critical telemetry modes used in JPL deep space missions.
    - 10-20 bps sent using BPSK + Turbo (1/6)
  - **Option 2: DSN Tones**
    - Inherited from the DSN Beacon Tone Service
    - Spacecraft sends a subcarrier
    - Subcarrier frequency indicates the type of request.
    - Nominally 4 requests are supported



How Can the Queuing Antenna Be Implemented?

- Allocate time on DSN 34m antennas to perform queuing operations:
    - Challenge: DSN 34m are already heavily subscribed.
- Build a dedicated ~18m antenna at DSN complexes with cryo-cooled receiver.
    - Challenge: Cost associated with building and commissioning new antennas.
- **DSN partners with external institution and uses antenna time for queuing purposes**
    - Example: 21m antenna at MSU covers similar sky to ~1/2 Goldstone and ~1/2 Madrid
- Queuing antenna is implemented by reserving time on a radio science observatory
    - Example: The ngVLA current design calls for 244 18 meter antennas.

DSS-17 at Morehead State University

Morehead State University Space Science Center
21 Meter Space Tracking Antenna
(Latitude: 38° 11 30.773 N,
Longitude: 83° 26 19.948 W) U.S.A

MSU Operations Center

Room containing DSN receiver and servers

DSS-17 as Queuing Antenna Demonstrator: Test 1

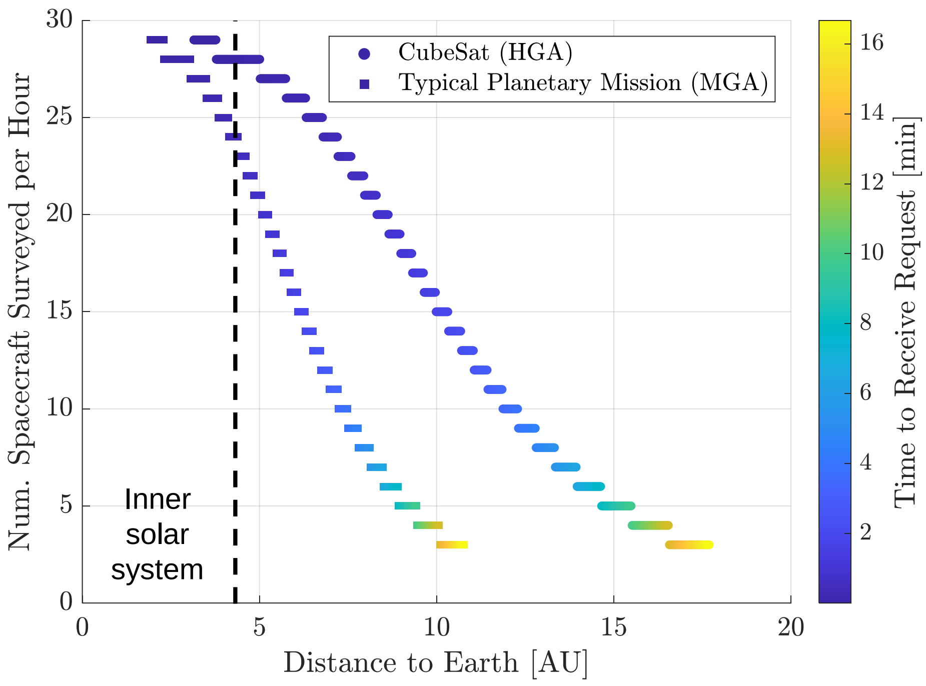
- **Goal**: Measure how many spacecraft could be "polled" by DSS-17 in an hour (assuming visibility).

Slew Rate

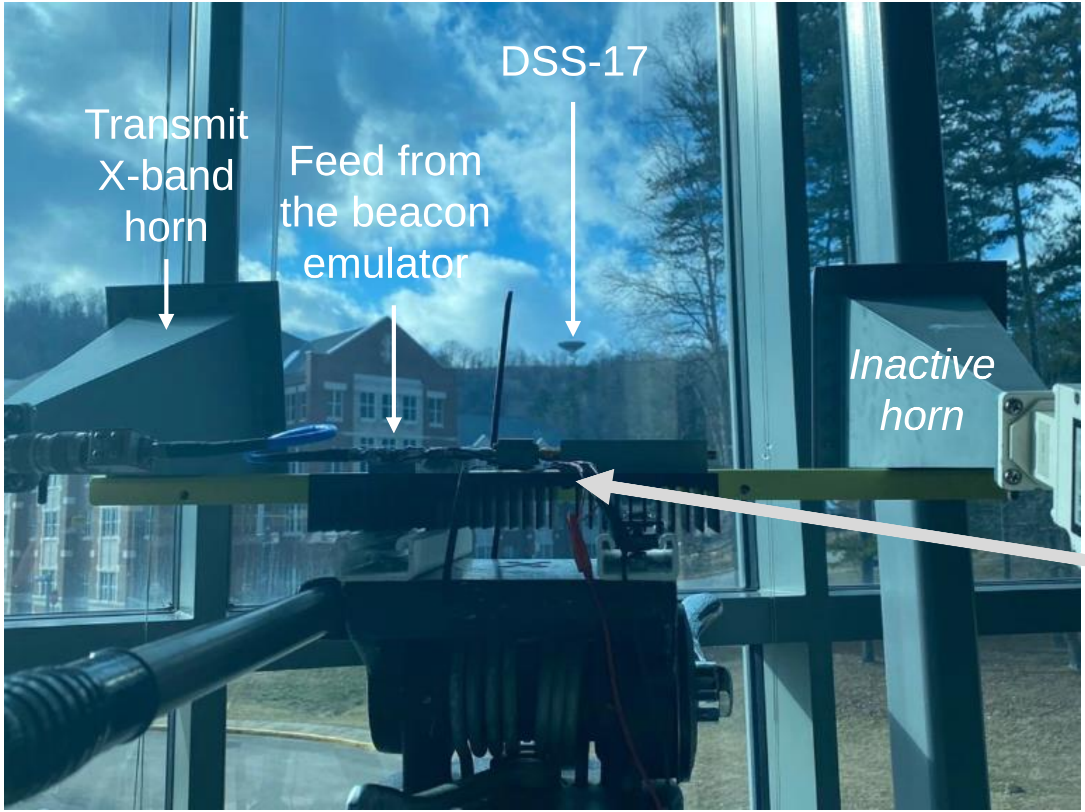
Elevation θ [deg]		Azimuth ϕ [deg]		$\Delta\sigma$	Time Elapsed	Pointing Speed
Initial	Final	Initial	Final	[deg]	[sec]	[deg/sec]
90	30	140	100	60.00	69	0.87
30	60	100	280	90.00	63	1.43
60	20	280	170	82.21	87	0.94
20	70	170	100	64.45	38	1.70
70	30	100	359	65.59	37	1.77
30	80	359	120	65.48	44	1.49
80	20	120	270	78.73	55	1.43
20	40	270	20	91.51	42	2.18
40	75	20	240	62.03	50	1.24
75	90	240	140	15.00	43	0.35

Time to Configure Receiver

Initial Spacecraft ID	New Spacecraft ID	Time Elapsed
Unassigned	57	1:05
57	234	0:33
234	57	0:33
57	234	0:34

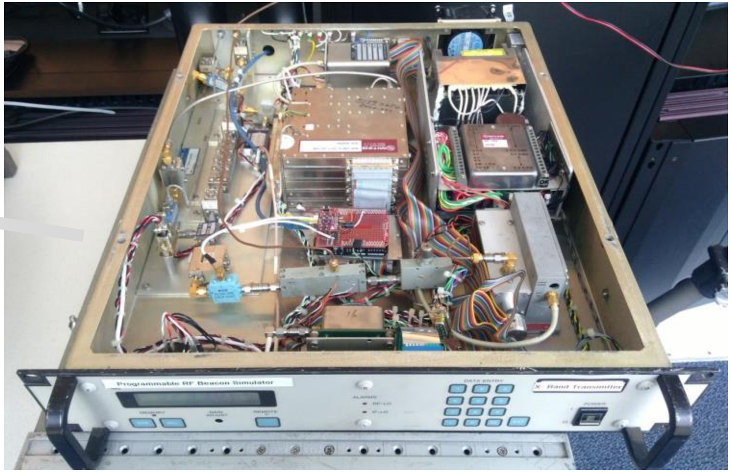


DSS-17 as Queuing Antenna Demonstrator: Test 2



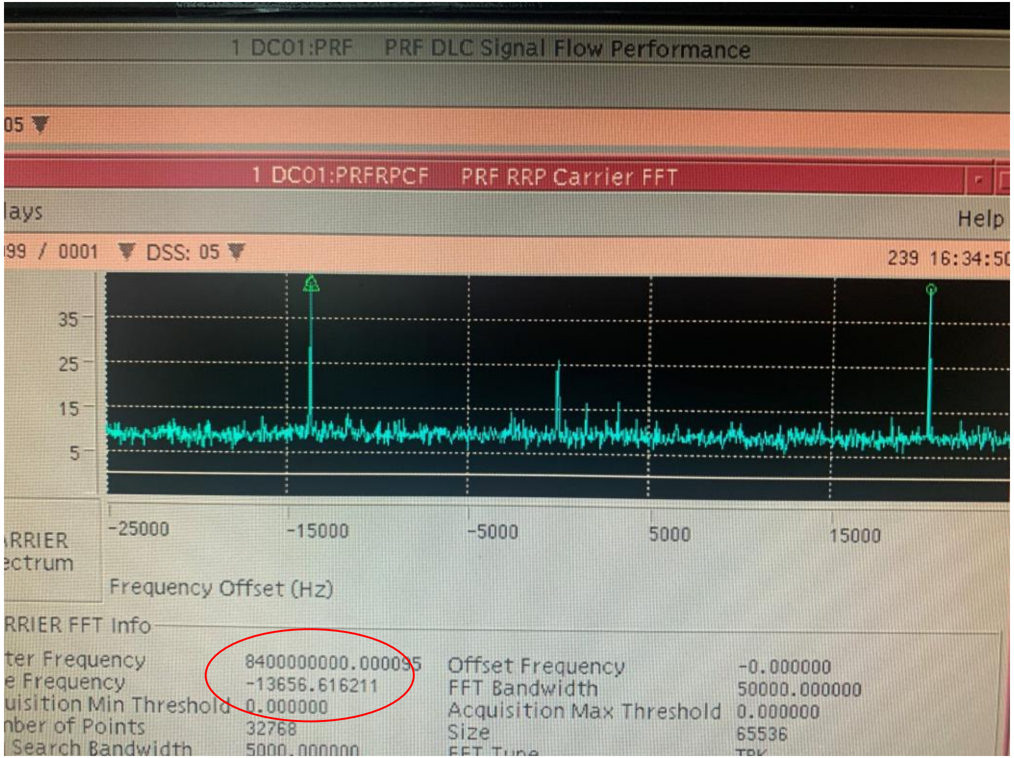
- **Goal**: Demonstrate that DSN tones (spacecraft request) can be detected using DSS-17.

DSN Tone Emulator
Transmits X-band subcarrier. The subcarrier frequency is tunable.



DSS-17 as Queuing Antenna Demonstrator : Test 2

- Tone emulator configured to transmit at X-band (8.4 GHz).
- Tone emulator configured to transmit a subcarrier frequency of 13,500 Hz.
- No Doppler dynamics were provided in the test.
- Successful detection event. Additional tests have also demonstrated forwarding of detection packets to JPL.



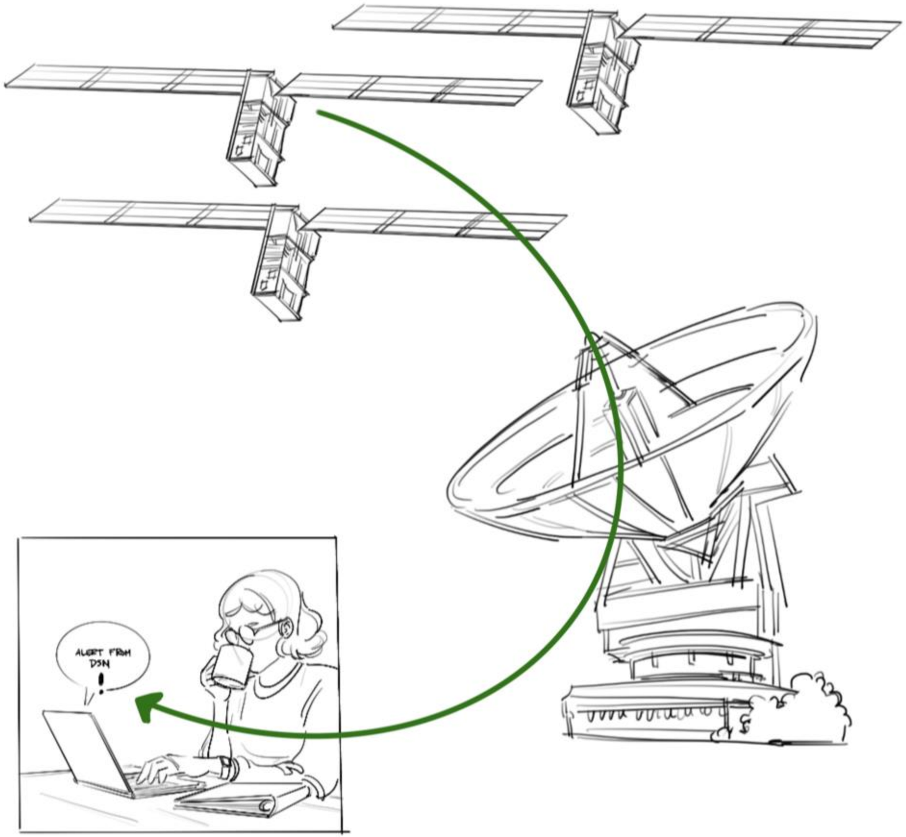
Demand Access for Deep Space Operations

Allows spacecraft to request ground support (DSN and GDS) in near real-time.

Enables a larger, more diverse deep space mission suite for future exploration of the solar system.

Core capabilities of the concept have been prototyped during FY21 and we are continuing to mature them during FY22.

We are using DSS-17 and Lunar IceCube (hopefully) as a way to demonstrate the key technologies for the queuing antenna.



Additional References

- Queuing Antenna:
    - Marc Sanchez Net et al. "Enabling a Larger Deep Space Mission Suite: A Deep Space Network Queuing Antenna for Demand Access." *2022 IEEE Aerospace Conference*. IEEE, 2022.
- DSN Scheduling and Demand Access:
    - T. M. Hackett, M. Johnston, and S. G. Bilen, “Spacecraft block scheduling for NASA’s deep space network,” in 2018 SpaceOps Conference, 2018, p. 2578.
    - J. M. Dhamani, Nihal and G. Lucena, “A demand access paradigm for NASA’s deep space network,” in 2021 InternationalWorkshop on Planning and Scheduling for Space, 2021.
- On-demand GDS:
    - Costin Radulescu, “On-demand Ground Data System (GDS) using a Cloud Architecture”. GSAW 2022
    - https://aws.amazon.com/quickstart/architecture/ammos-smallsat-toolkit/

Jet Propulsion Laboratory
California Institute of Technology

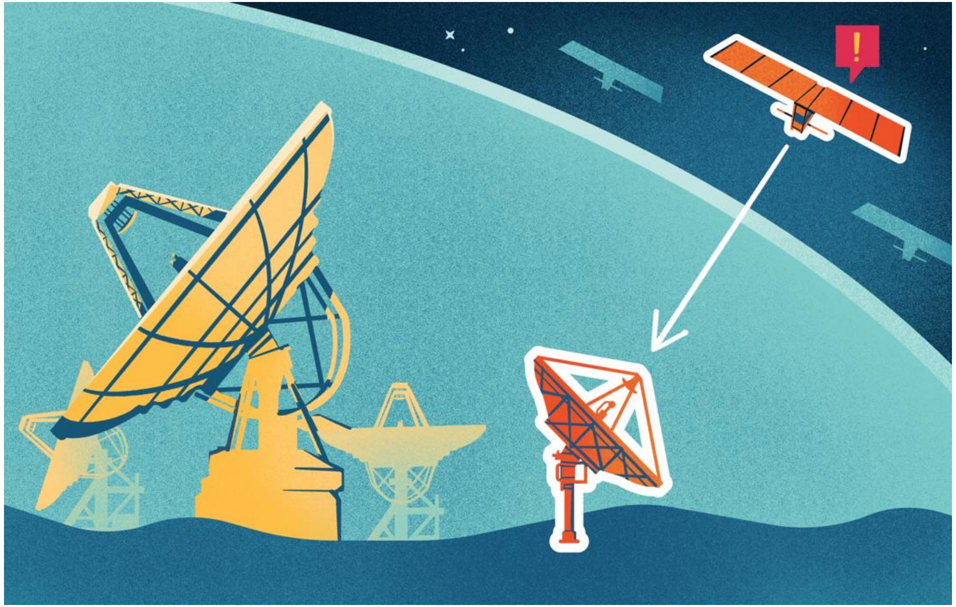
jpl.nasa.gov

Demand Access Operations: DSN

- Architected to **avoid acknowledgements** from the DSN to the spacecraft (due to long round-trip light-time delay).

- Leverages a **new DSN Queueing Antenna** to receive requests from the spacecraft:
  - Smaller than current DSN 34m antennas.
  - Only downlink capability is needed.
  - Queueing antenna is scheduled using predicts of the spacecraft using demand access.
  - Requests are placed using a DSN Beacon Tone.

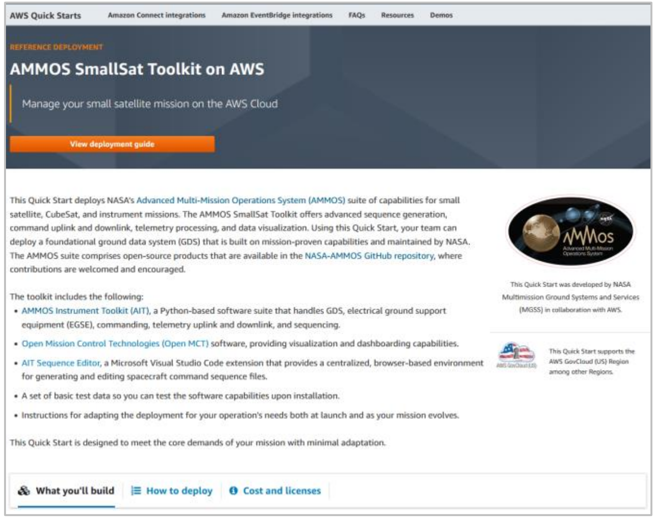
- **DSN scheduling system (SSS) is upgraded** to provide the necessary capabilities for demand access.
  - Track reservation optimizer.
  - Just-in-Time (JIT) track allocator.
  - Gap fill scheduler.



Demand Access Ops: GDS and SDS (outside of scope)

- Projects have **the option to use a cloud-based GDS and SDS** to automatically process data received from a demand access DSN contact.

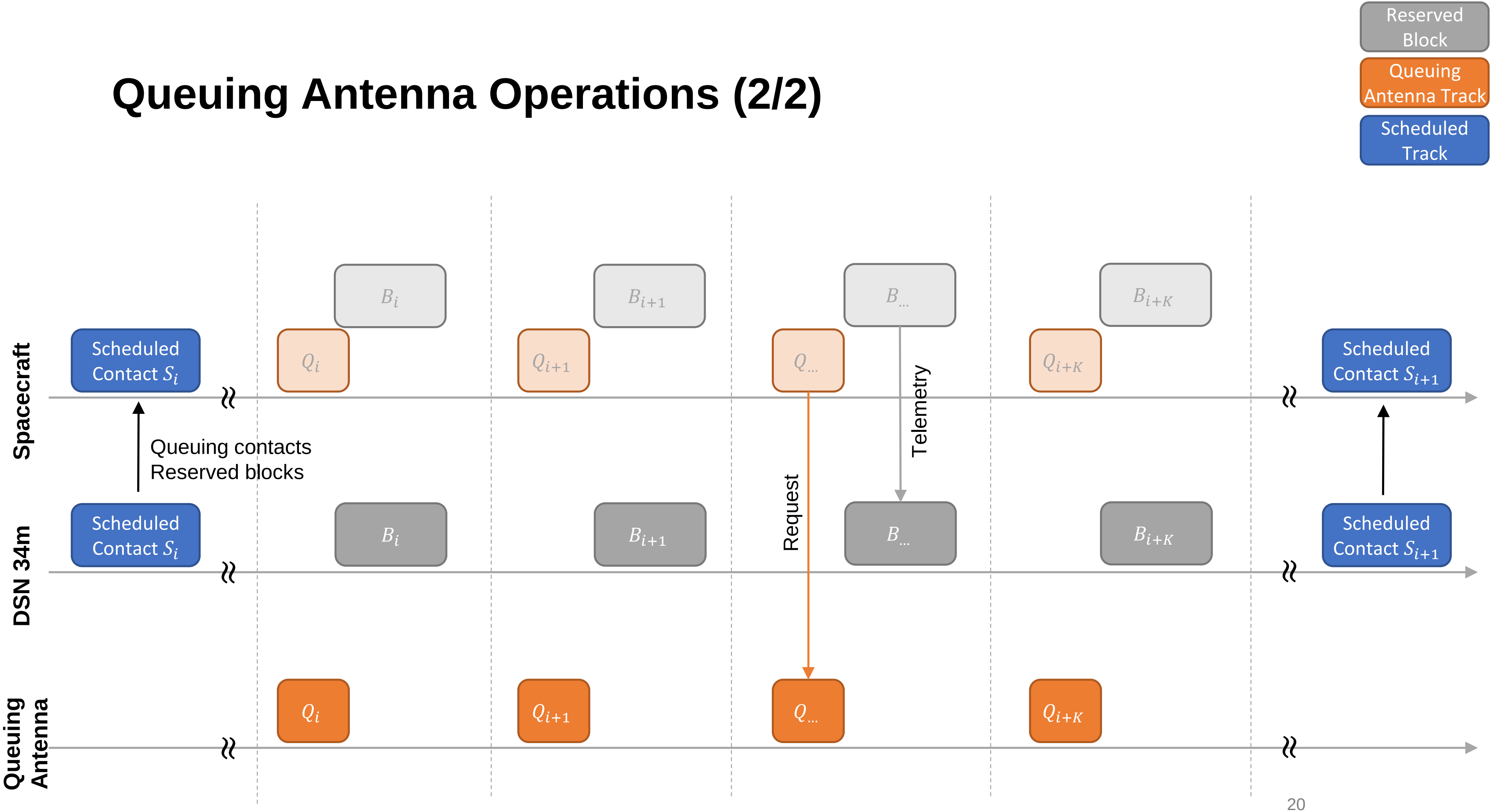
- On-demand GDS/SDS builds upon AMMOS' new cloud-native architecture to:
  - Provide interfaces between GDS/SDS and SSS so that GDS/SDS is spun up and down for demand access passes.
  - Automate adaptation, configuration and deployment of the GDS and SDS.



- Projects have **the option to use DTN** to automate end-to-end reliable data transfer with demand access operations.

DELAY/DISRUPTION TOLERANT NETWORKING

Queuing Antenna Operations (2/2)



Spacecraft Request Format (DSN Beacon Tone)

- The spacecraft transmits a squarewave subcarrier with suppressed carrier (inherited from DSN Beacon Service).
- The frequency of the subcarrier directly encodes the information being conveyed by the spacecraft.
- Subcarrier frequency can be tailored to each spacecraft (15 kHz assumed in the example).
- On the ground, the receiver detects the tone using incoherent summation of FFTs:
    - Computationally efficient.
    - High power efficiency if long integration times are used.