National Academies of Sciences, Engineering, and Medicine
NASA Extended Mission Study

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NASA's Deep Space Network (DSN)

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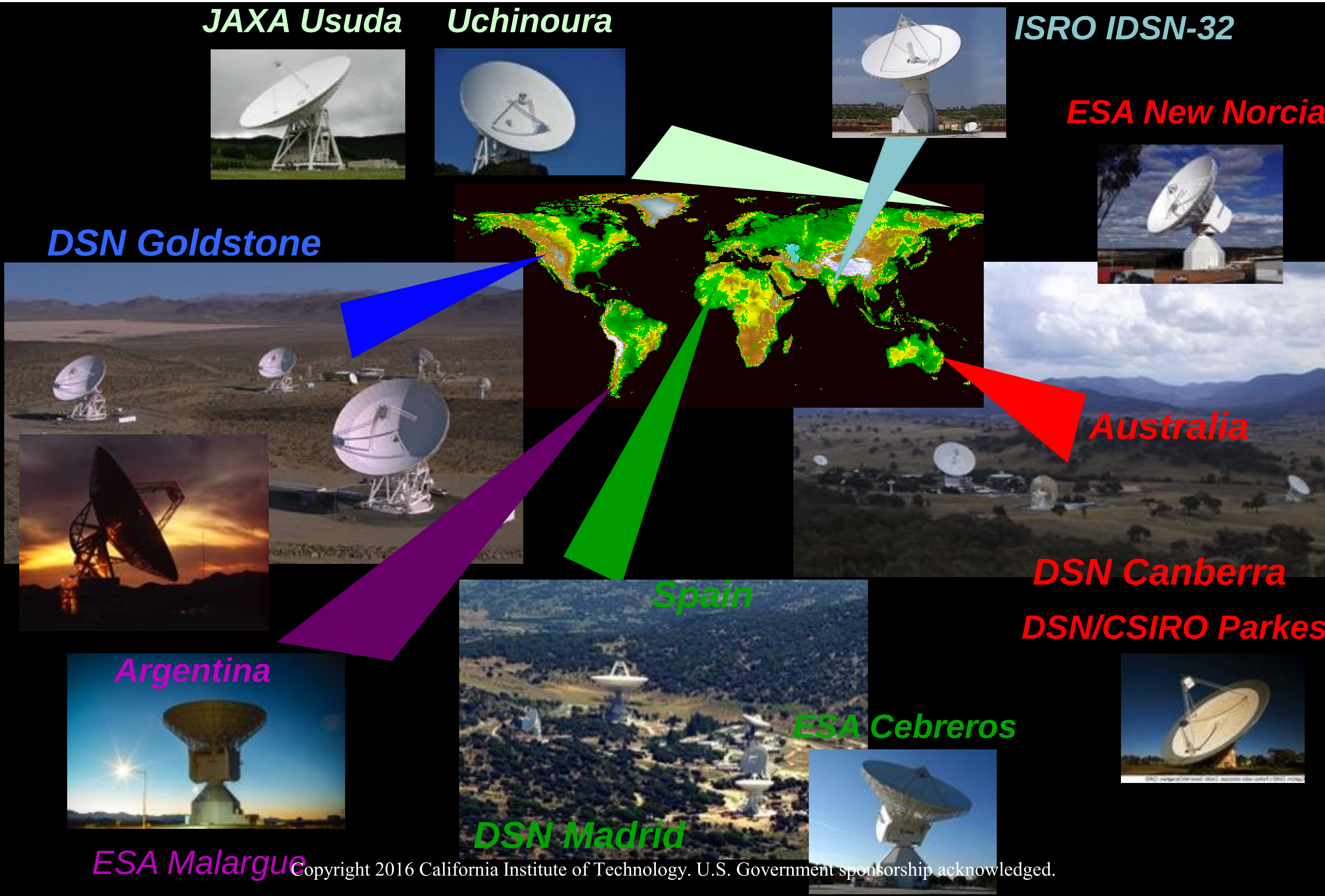
Current Status of DSN

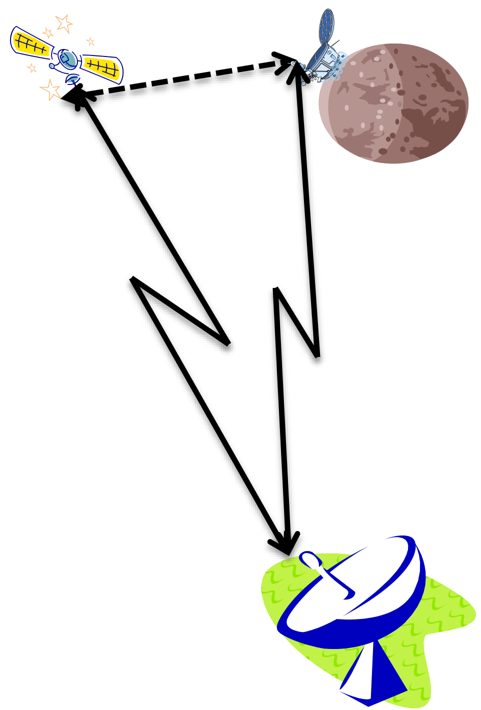
- NASA's Deep Space Network (DSN) was established in December 1963 to provide a communications infrastructure for deep space missions (missions above GEO-1)
- NASA Headquarters Human Exploration and Operations Mission Directorate oversees the DSN through the Space Communications and Navigation Program
- Responsibility for development, operations, research, and management of the DSN is assigned to the Jet Propulsion Laboratory (JPL) Interplanetary Network Directorate (IND)
- NASA directly contracts with the Australian and Spanish governments for operating the two foreign complexes
- DSN is responsible for Tracking, Telemetry, and Command of NASA spacecraft using the DSN antennas and partner tracking sites located around the world.
- The DSN also supports many international spacecraft as well as scientific investigations through radio astronomy, radio science, and radar activities

NASA DSN and Partner Agencies around the globe provide continuous communication and navigation support for deep space missions



Functions of the Deep Space Network

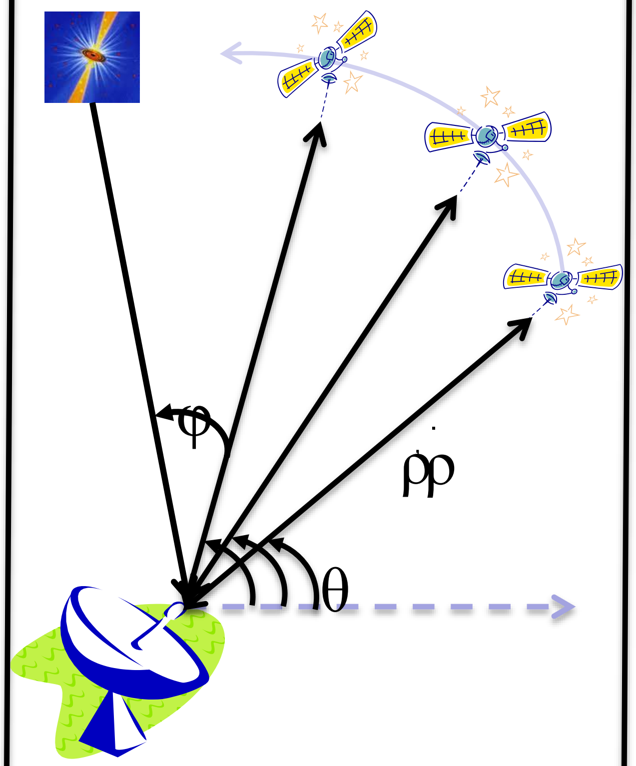
Telecommunication



Uplink (Command): 20KW Transmitters; S-band (2 GHz) and X-band (8 GHz); Data Rates from 10 bps to 10 Kbps

Downlink (Telemetry): S-band (2 GHz), X-band (8 GHz), Ka-band (26 or 32 GHz); Data Rates from 10 bps to 6.6 Mbps

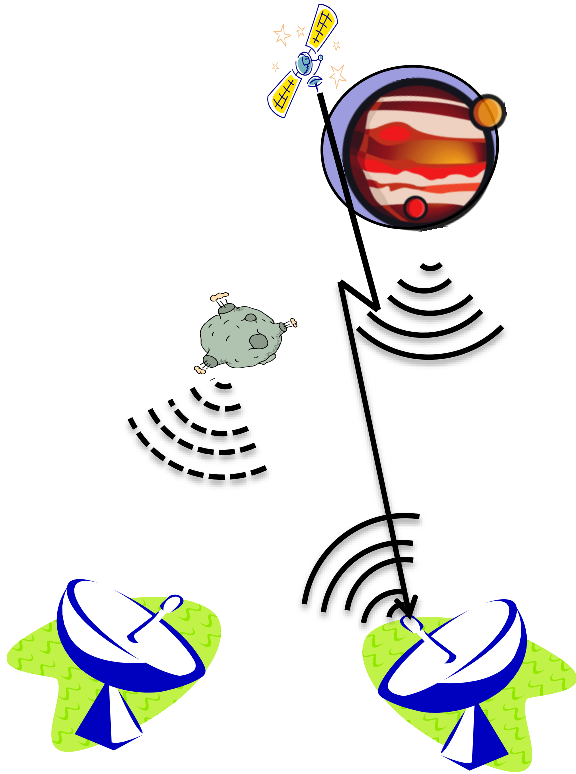
Tracking



Collect multiple data types used for orbit determination:

- Range
- Doppler
- Angles
- Delta-DOR
- Very Long Baseline Interferometry (VLBI)

Science



Radar: Bouncing a radio signal off a celestial body and processing the received reflected signal
Radio Science: Observations of changes in a spacecraft radio signal as it passes through a planetary atmosphere
Radio Astronomy: Observations of naturally occurring radio emissions

DSN Antennas

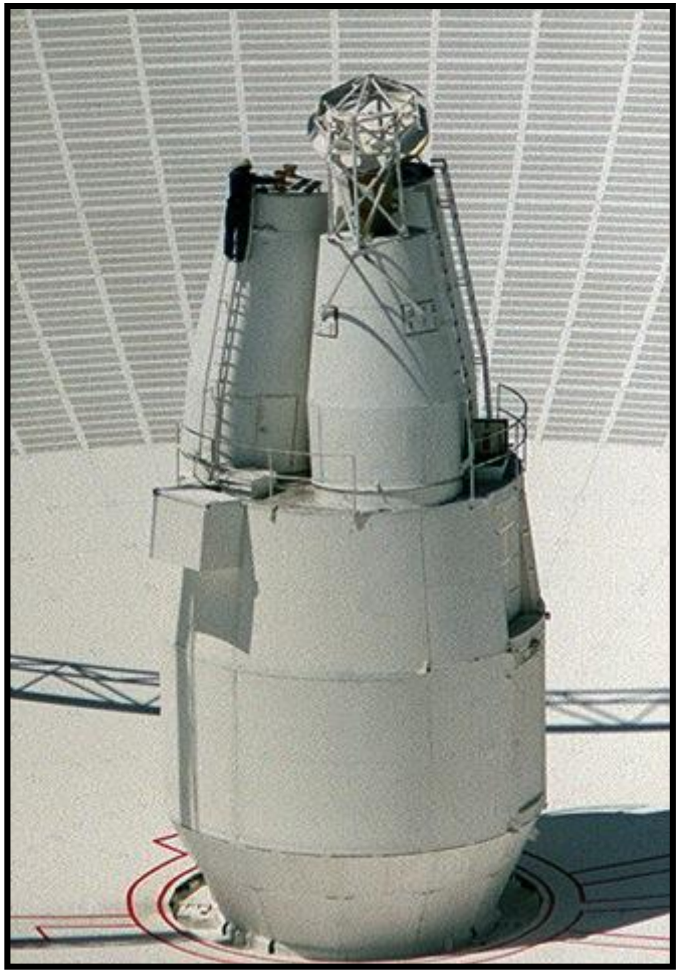
- **70-meter**
  - **Built in the mid-1960s as 64-meter antennas**
  - **Expanded to 70-meters in 1980s**

- **34-meter High Efficiency (HEF)**
  - **Built in mid 1980s**

- **34-meter Beam Waveguide (BWG)**
  - **Built in the mid 1990s**
  - **Utilizes beam waveguide to remove sensitive electronics from the tipping structure to a below-ground pedestal equipment room**

Key Subsystems of the DSN

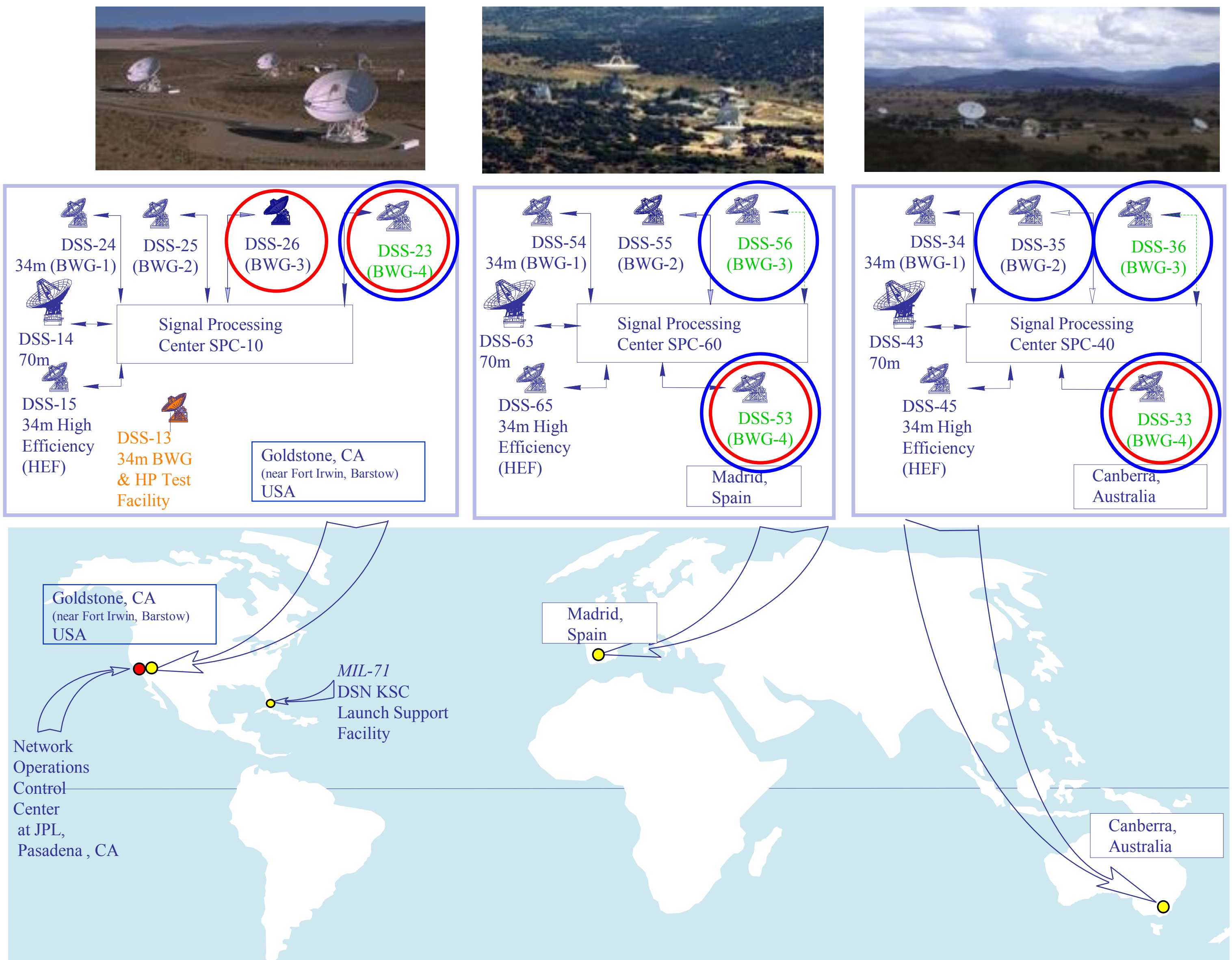
- Front-end Electronics
  - Microwave systems
    - Specially design feed horns and wave guides
    - Support multiple frequencies
      - S-band (~2GHz)
      - X-Band (~8GHz)
      - Ka-band (~26 GHz and ~ 32GHz)
  - Low Noise Amplifiers
    - Cryogenically cooled devices operating around 6-12 K
  - Transmitters
    - High Power Transmitters for both S- and X-bands
    - Radar Transmitters for radar astronomy



Looking to the Future

Interplanetary Network Directorate

DSN Facilities by 2025



Antennas
Operational Dates

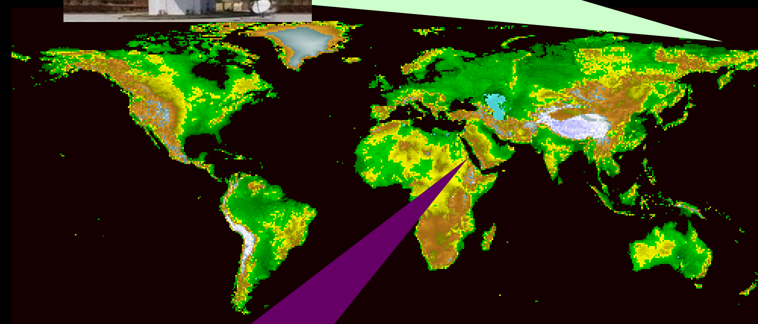
DSS-35	**10/2014**
DSS-36	**10/2016**
DSS-56	**10/2019**
DSS-53	**10/2020**
DSS-33	**10/2022**
DSS-23	**10/2024**

80 kW XTR
Operational Dates

DSS-26	**9/2015**
DSS-53	**10/2020**
DSS-33	**10/2022**
DSS-23	**10/2024**

Potential New Partnering Agencies for DSN Cross Support

KARI (South Korea)



United Arab Emirates (UAE)

Drivers, Opportunities, and Enhancements

- **Drivers**
  - Continue to meet current and future commitments and fund new antennas
  - Position DSN for new mission types
    - Human Spaceflight
    - Deep Space Cubesats
- **Opportunities**
  - Provide enabling capabilities for missions through new technologies and advanced engineering
  - Engage other space agencies, other US agencies, and Universities to accommodate the increase in required support
  - Increase level of automation for real-time station operations
- Multiple Spacecraft Per Antenna (4-MSPA)
  - Support Mars missions, formation flying missions, Cubesats
  - Expand current downlink availability from 2 to 4 spacecraft simultaneously
  - Add multiple uplink switching
- Data Services Capabilities
  - Add LDPC Coding and Enhanced SLE Forward CLTU Service
  - Enhance service management capabilities
  - Provide higher uplink/downlink data rates
  - Add web interface for command and telemetry data delivery

DSN Future

- Operational Efficiencies
  - "Two Links per Operator" (each operator assigned to two supports in parallel)
    - Increased from previous "One Link per Operator" (installed in 2012)
  - Automated Link Building (installed in 2014)
    - Automatically builds a link from a pool of shared uplink/downlink equipment, based on accurate tracking plan
  - "Follow the Sun Operations" (transition in 2018)
    - Move from 24x7 operations at all 3 DSN complexes to 8-hour operations conducted at one complex at a time (Operations conducted from site with daytime hours)
  - "Three Links per Operator" procedure to be transitioned in 2020
- Future Capabilities
  - RF/Optical Antennas
    - Provide easy transition to optical links
    - Optical missions will continue to have RF needs
    - Make use of lower cost antenna design
  - Ka-band uplink at each complex
    - Ka-Band uplink currently only at Goldstone
    - Command capability to provide higher uplink data rates
    - Depends on development of Ka-band solid state amplifier

Common Platform
Next Generation Receiver

Background
- There are multiple receivers (closed loop, open loop, VLBI) on multiple H/W platforms, some of which are 15 years old
- Obsolete hardware and software

Goal
- Common commercial FPGA based hardware platform (same hardware as SCaN's Space Network's SGSS)
- Shared development and code bases
- Simplified maintenance and reduced sparing costs

Key Features
- One digitization (versus each receiver digitizing)
- Digital signal distribution (versus current analog distribution)
- Common hardware for all receiver types

Plan
- Phase 1 (2014-16) – New ADC and open loop receiver
- Phase 2 (2017-19) – Digital distribution/closed loop receiver
- Phase 3 (2019-21) – Arraying and VLBI

SGSS DSP Hardware / JPL Prototype Hardware

Annapolis ADC FMC card

Annapolis uTCA FPGA card

uTCA Chassis

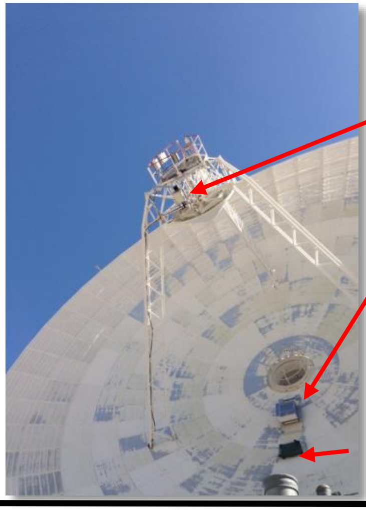
Brocade 10GbE Switch

DSN developing next generation receiver using commercial hardware, reducing development, operation and maintenance costs and improving reliability.

Advanced Engineering Update

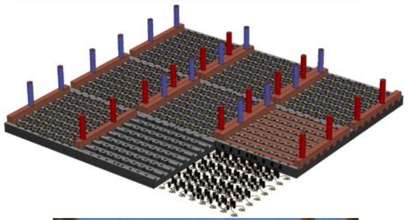
RF/Optical Demonstration

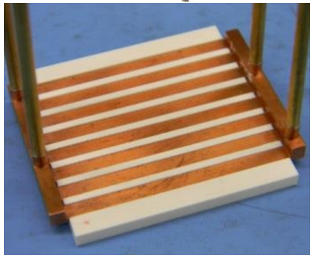
- Two Actuated Segments and a Secondary-Mounted Camera are Operational at DSS-13. Goals:
  - Demonstrate acquisition and alignment of the two segments relative to each other and the RF beam center
  - Determine the achievable spot sizes on the detector for a wide range of tracking conditions
  - Determine the effects of the open air (no dome) approach including atmospheric seeing and contamination of the mirror surface
  - Quantify the effects of temperature gradients and wind on the system and determine the viability of fast steering mirrors and active loops to control these effects



Ka-Band Uplink Array Development

- Developing a 1 kW Solid State Array Will Replace Existing Klystron-Based Ka-Band (34.5 GHz) Uplink Transmitter
  - Based on a 9-tile design with each tile containing 64 2.5 W commercial MMIC amplifiers
  - Efficiency comparable to klystron with greatly reduced power density and power supply voltage requirements
  - Takes advantage of the rapidly developing MMIC market and eliminates a single point of failure (klystron)
  - Unique features of the design include integrated water cooling, low temperature co-fired ceramic materials, and unique packaging





Array CAD Model and Tile Cooling Manifold

Even in a very tight budget environment we continue to invest in the future DSN

Conclusion

- **The DSN continues to provide excellent support to over 30 deep space missions, worth Over $32b using the DSN's diverse capabilities; DSN support of missions manned (beyond GEO) and Deep Space unmanned is key to NASA's success for the next 50 years.**
- **Advances made by the DSN JPL workforce have been directly influential upon commercial development. They wrote the book on deep space communications but this unique and creative JPL workforce is disappearing due to declining budget.**
  - **Council for the Advancement of Science Writing identified "50 Science Sagas for 50 Years," the 50 top advances in science & technology since 1957. Of those 50 advances, the DSN has been involved with 22 of them.**
- **Budget realities over has driven the DSN into a culture of "finding efficiencies while maintaining performance".**

The DSN stands ready to support NASA and non-NASA customers to help advance the goals and priorities of our nation.

What The DSN Enables!!!

The DSN is an internationally recognized NASA resource enabling missions worth over $32 billion dollars

Our partners cannot succeed without the DSN

"The DSN, Don't leave Earth without us!"

Committee Questions

Mission Prioritization

How are different missions treated differently? Are there any differences when missions are in their prime or extended phase? For example, would an extended phase mission be lower priority for DSN time than one in primary mission?

- Normally all missions are treated equal and scheduling is handled via negotiations.
- When there are conflicts then Prime Mission and/or Science value are deciding factors in resolving the conflict. This can be handled between project schedulers, but there is an escalation process to resolve conflicts (i.e. Scheduler to Mission Managers to Project Managers to Program Offices to Mission Directorates). Almost all are handled between Schedulers or Mission Managers.

- Looking into having SMD provide a prioritization to DSN missions, as is currently done by NEN and SN.

Prime vs Extended Mission Requirements

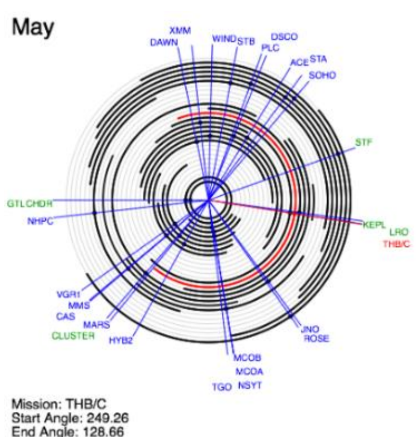
If the number of missions in extended phase is increasing, for example, could that create undue demands on the DSN? (Another way to look at this is: are prime missions driving DSN requirements entirely? Or are extended missions also driving requirements for DSN? This could include not only demands for time, but technology upgrades.)

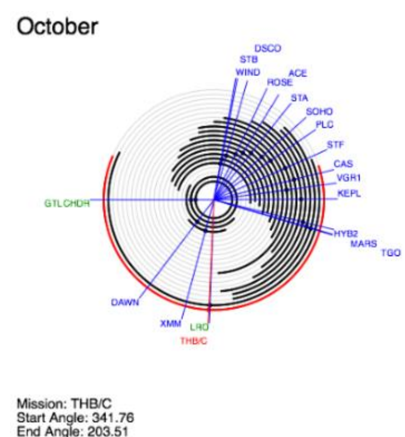
- **Both prime and extended missions drive changes to the DSN. These are both in time and technology.**
- **Demand for time can be resolved in varying ways including reducing extended mission track times, minimizing extended missions view period overlap, etc**
- **Demand to stay on technology DSN is looking to deprecate can effect support. E.g. Continued S band use for Human Space Flight (HSF), or not moving to SW based radios, or not utilizing bands that would support higher data rate/return**

Over/Under Subscription

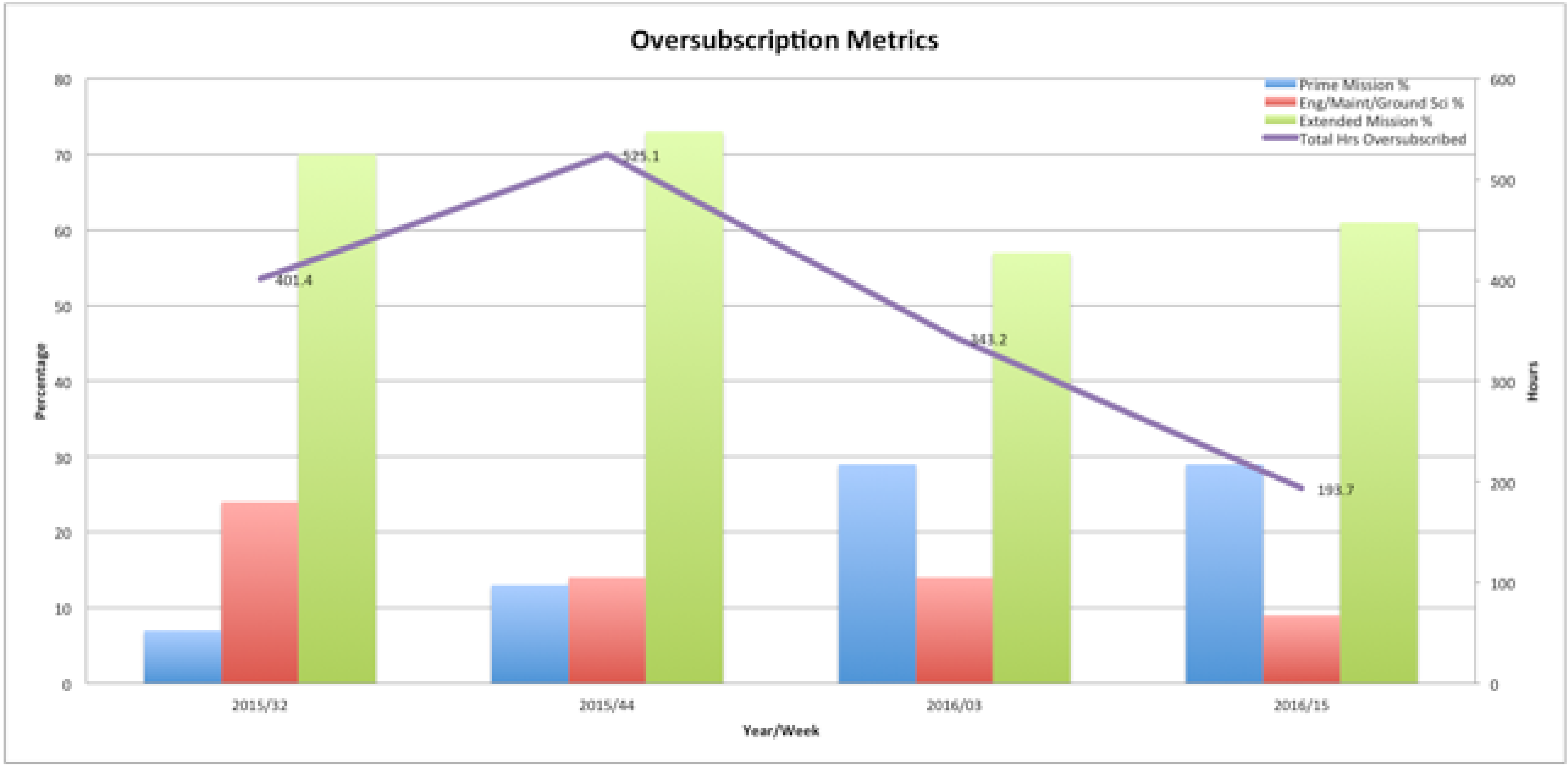
Is the DSN able to accommodate all the mission requests for DSN time? If not, what percentage of requested time are the missions getting? How subscribed/over-subscribed is the DSN?

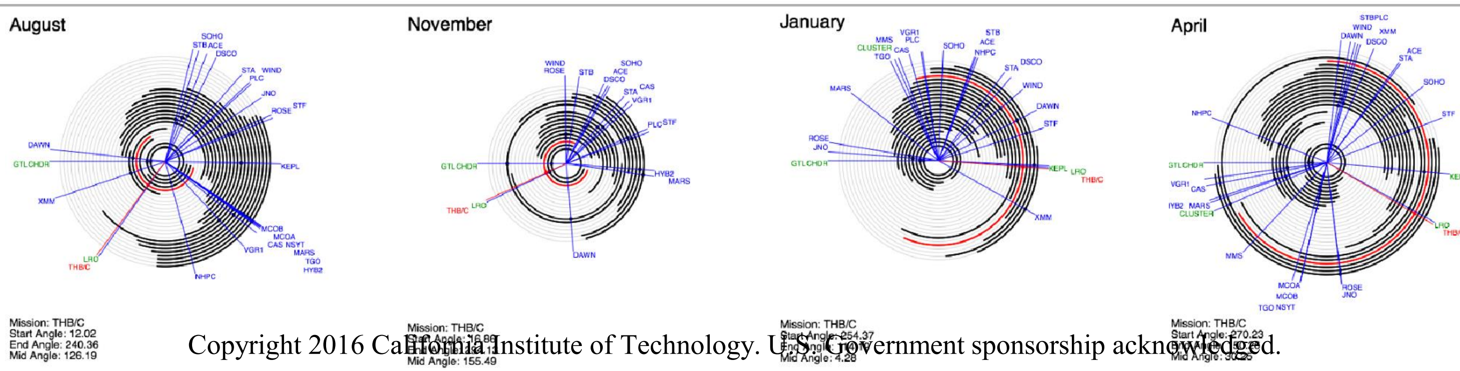
DSN is able to meet all current Mission L1 requirements with the commitment being 95%. Missions generally receive 99+% of their data. When most/all missions are within 90-180 degrees to each other in right ascension there tends to be an over subscription when they are in view, and less over subscription when out of view. The schedule is negotiated to be conflict free, although Missions ask for more time than 95% commitment.





Over/Under Subscription (Cont)





Extended Mission DSN Usage

Are there any standard items that missions up for extension should include in their proposal concerning DSN usage?

Extended missions should consider making their contacts more efficient. Identify ways to use less resource or use less tracking time. Some DSN capabilities which can help are:

- Multiple S/C Per Aperture (MSPA)
- DSCC Downlink Array (DDA)
- Opportunistic MSPA (MSPA) using open loop recording

Some of these are a limited resource themselves, so how effective they are for a particular mission varies.

Requirements Allowing DSN Flexibility

What types of mission requirements would give DSN more flexibility in allocating DSN resources?

Decreasing requirements compared to prime mission.

- **Not playing back data twice**
- **Utilizing less instruments (or changing instrument use) during extended mission**
- **Selective data over fewer contacts**
- **Shorter sequence cycles to take advantage freed up time.**

DSN Considerations for Extended Missions

Are there DSN issues that missions need to be aware of when proposing extensions? What types of DSN mission requirements give missions the best chance of meeting their requirements?

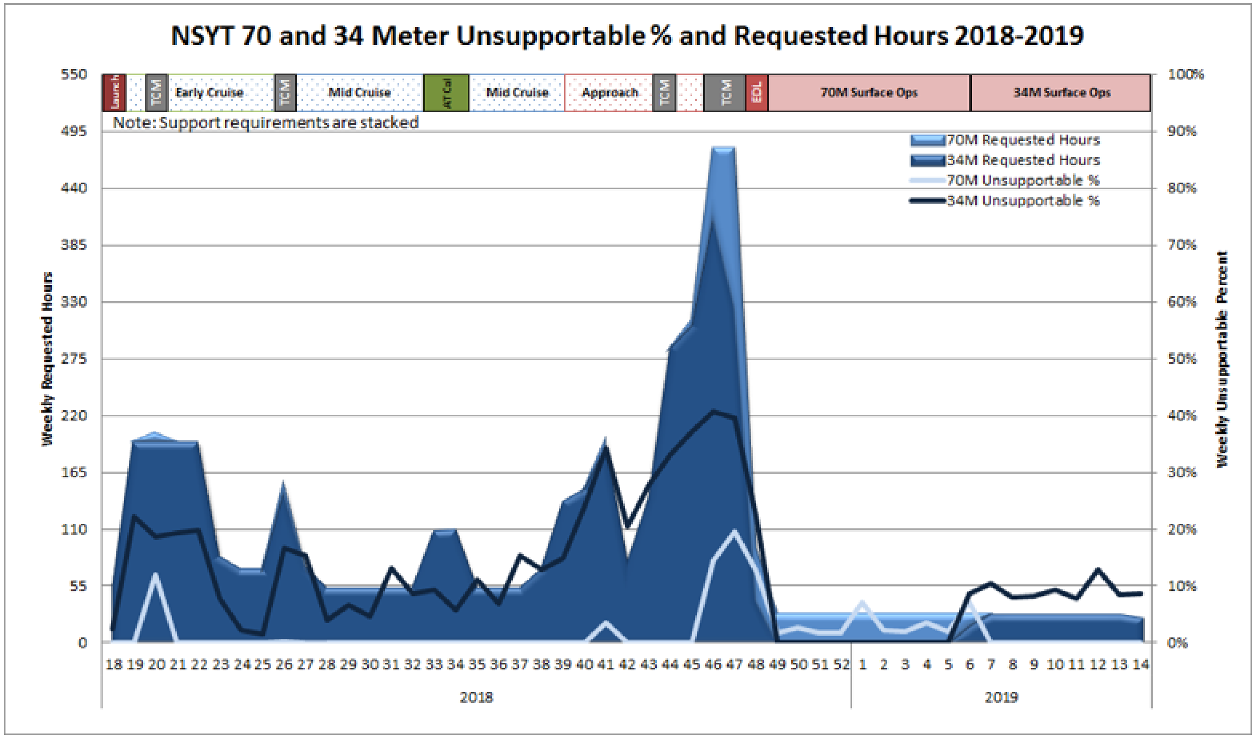
As a mission completes their Prime Mission the loading on the DSN for supporting an extended mission can change. A loading study should be done with Extended Mission Proposals. The longer a mission extends the more likely they are to run into deprecation of services. For example VGR has had to deal with changes in Network Services and Mission Services with little/no funding for the Project to accommodate.

Look at CON OPS changes like: Unattended tracking; Not relying on local dayshift tracking for all command uploads and/or significant events.

Being supportive of (even embrace) DSN changes for the future.

Loading Study Example

Figure 1: NSYT Supportability 2018 - 2019



DSN View Evaluating Mission Extensions

From the DSN point of view, are there any items that committees should consider when evaluating and granting mission extensions?

- **Evaluate how existing/extended missions impose on upcoming/prime missions use of multi-mission services (e.g. DSN, NEN, SN, etc…). Have extended missions look into minimizing use of multi-mission services..**
- **Evaluate the frequency that the S/C uses, e.g. X-band, S-Band etc. and compare that to the availability of assets in the DSN that support the S/C needs (and other missions using that same band).**