Meeting the Communications Challenges of NASA's Future Deep Space Missions

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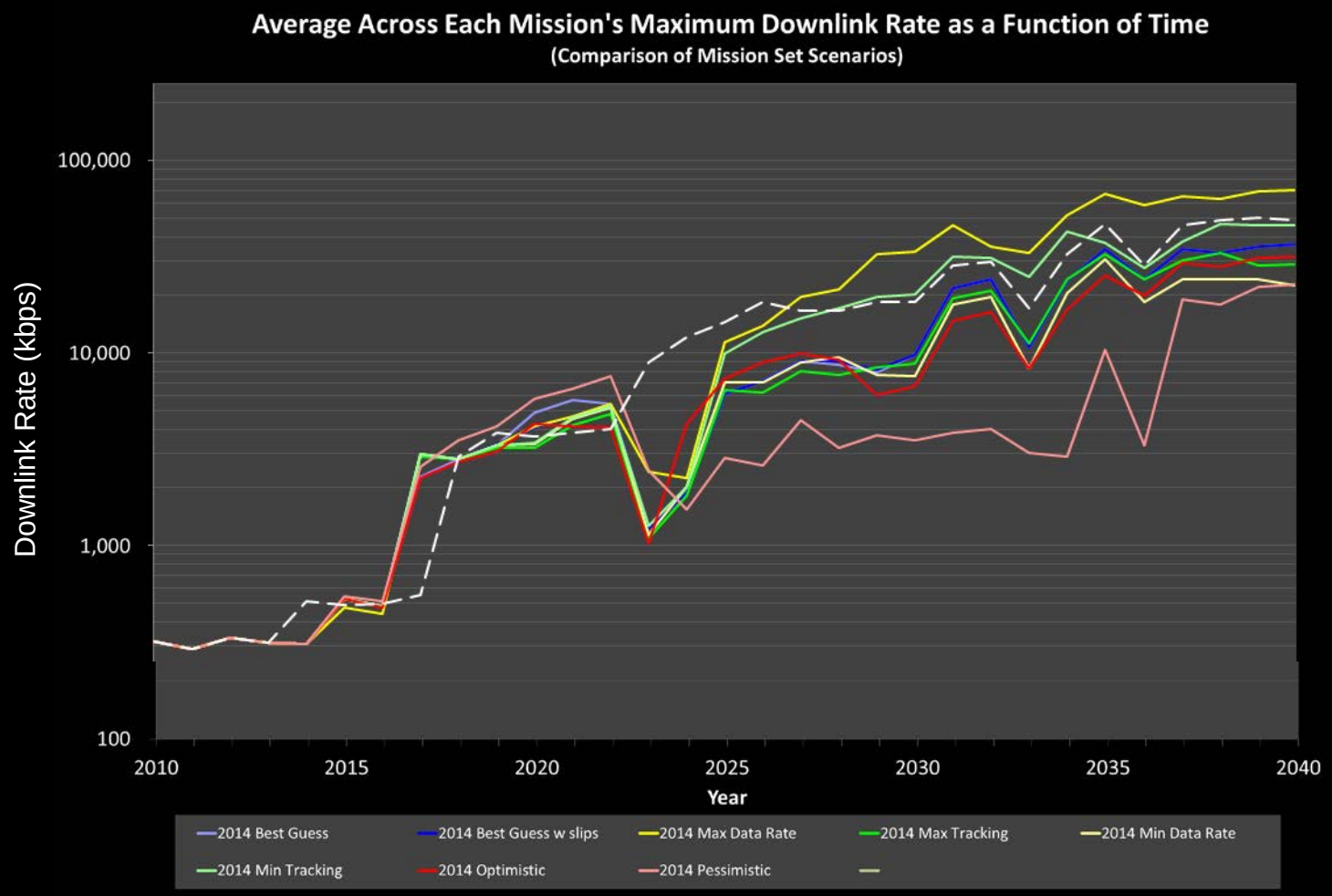
Deep Space exploration is Unique

- Spacecraft mass and power are precious
- Spacecraft go huge distances from Earth
- Navigation is highly dependent on Earth
- Comm system is also a science instrument
- Every mission is unique

Future Mission Data Rate Trends



Visited all major objects in Solar System, Global continuous presence on Mars since 2004

Revisit for more intense study, Smaller spacecraft and constellations, Humans beyond LEO

Mission modeling indicates desire for ~10X data improvement per decade through 2040

Space Loss

All else being equal, communications performance is inversely proportional to distance squared

P_R/N_0 = constant / d^2

Need to overcome this problem of physics to be successful in deep space

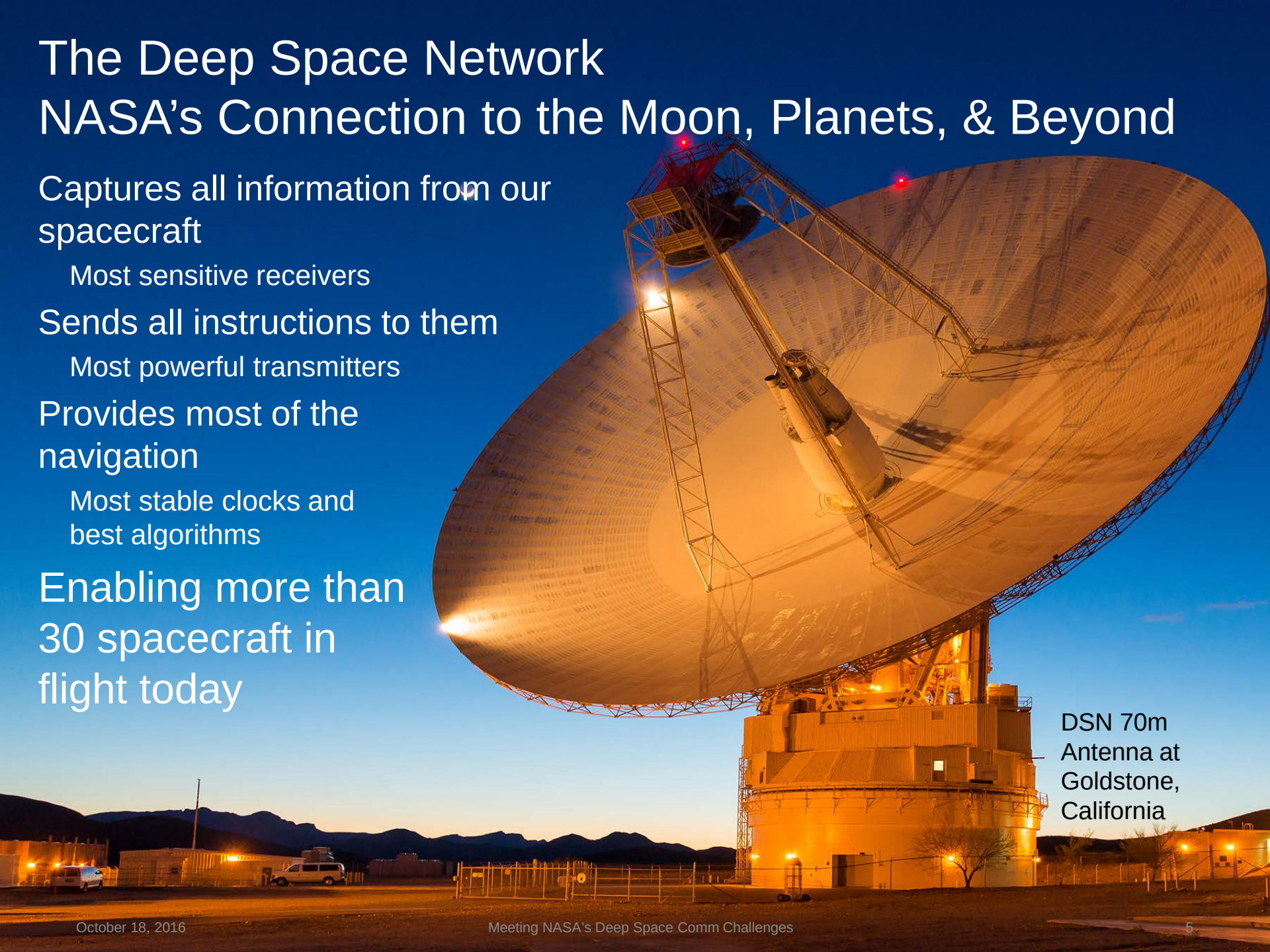
Why Telecom is Hard

Relative Difficulty

Place	*Distance*	*Difficulty*
Geo	*$4x10^4$ km*	*Baseline*
Moon	*$4x10^5$ km*	*100*
Mars	*$3x10^8$ km*	*$5.6x10^7$*
Jupiter	*$8x10^8$ km*	*$4.0x10^8$*
Pluto	*$5x10^9$ km*	*$1.6x10^{10}$*

The Deep Space Network
NASA's Connection to the Moon, Planets, & Beyond

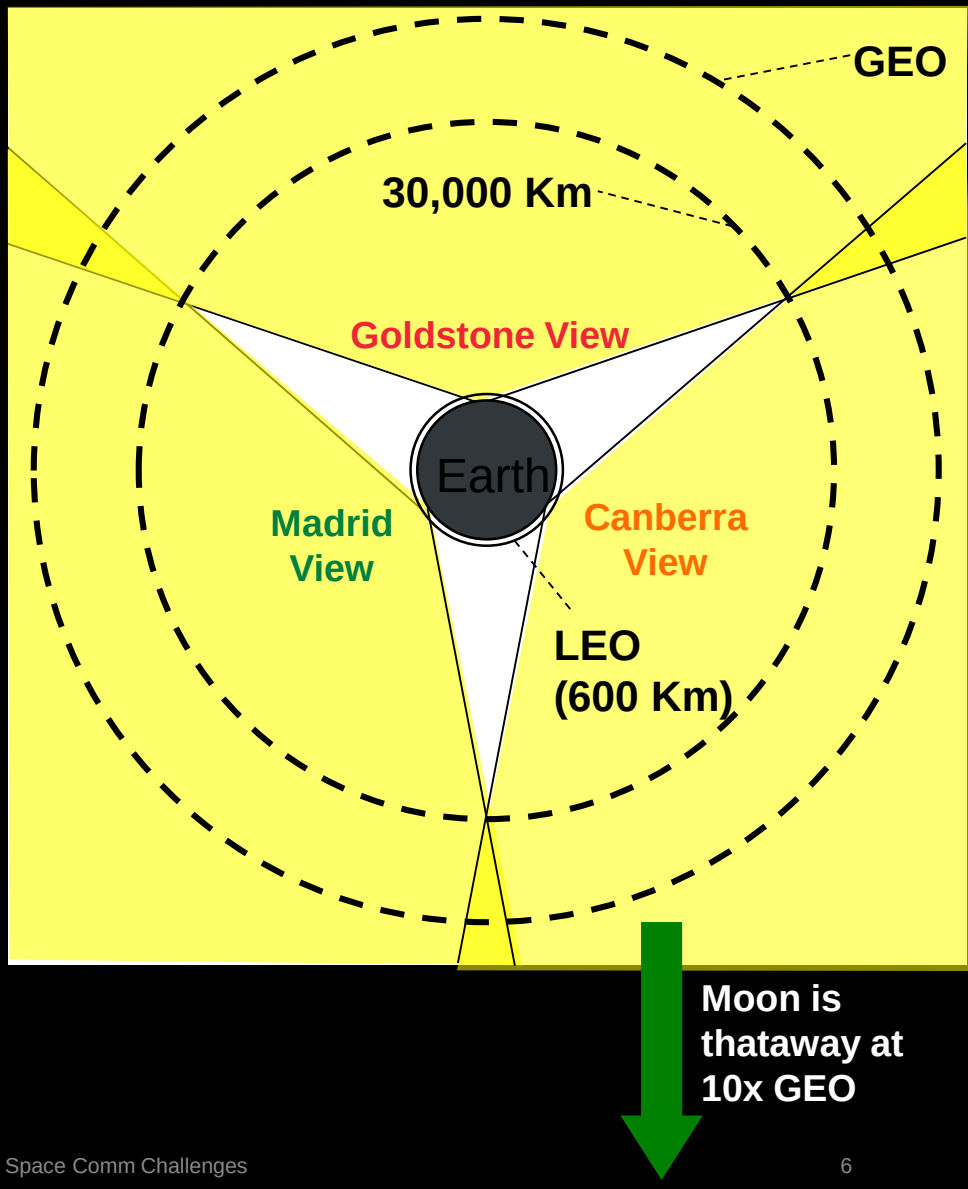
- Captures all information from our spacecraft
  - Most sensitive receivers
- Sends all instructions to them
  - Most powerful transmitters
- Provides most of the navigation
  - Most stable clocks and best algorithms
- Enabling more than 30 spacecraft in flight today



DSN 70m Antenna at Goldstone, California

DSN Sites

- Three "complexes", ~120º around the Earth
- Can "see" spacecraft in deep space almost all the time
- Not great for low spacecraft – such as deep space mission *launches*!

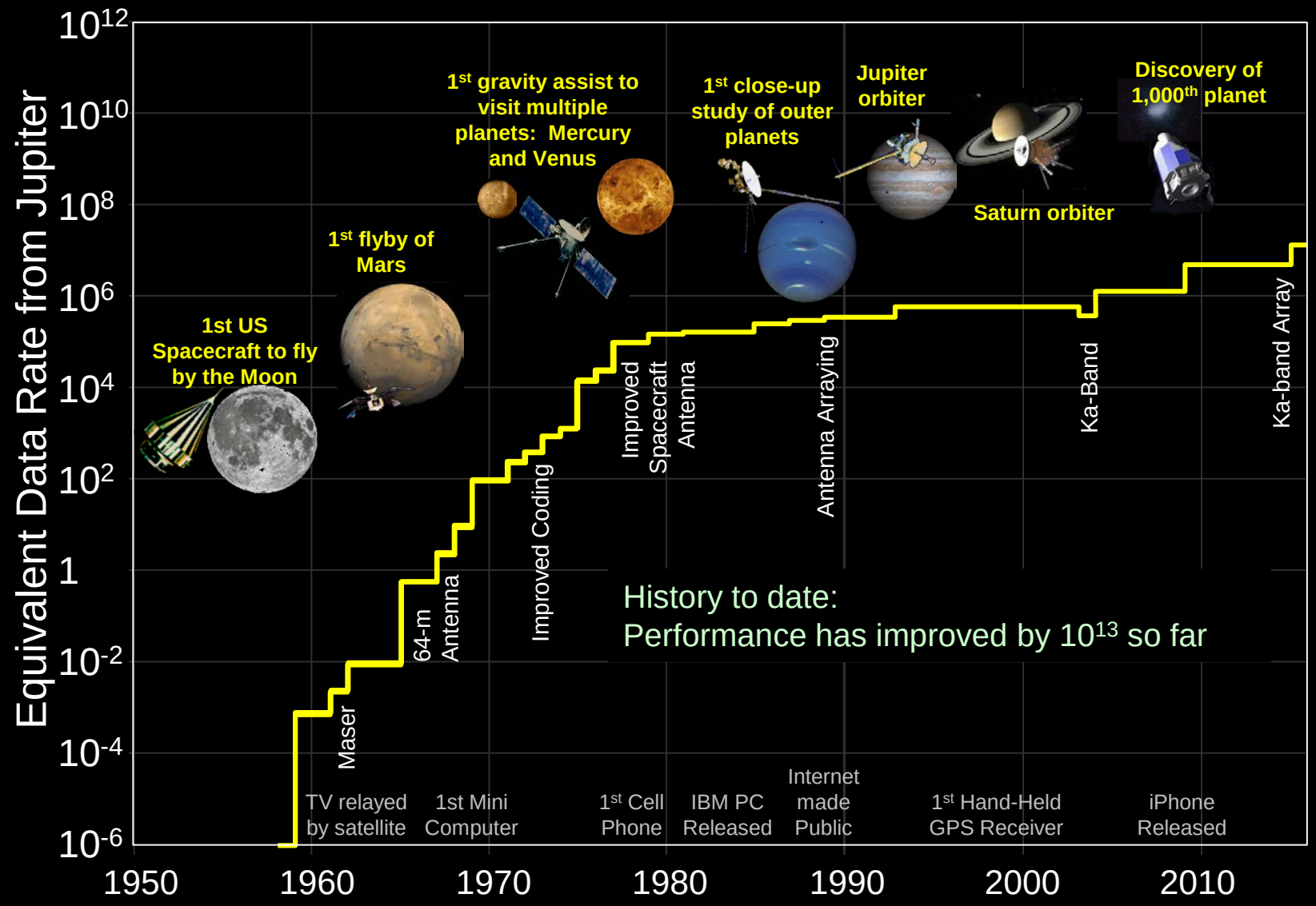


DSN Antennas in Madrid, Spain

Radio Science

- Tracking spacecraft near or behind targets yields important science
- Atmospheric dynamics
  - Circulation
  - Vertical structure
  - Turbulence
- Atmospheric density
- Gravity field mapping
- Special high dynamics receivers are used for this in the DSN

History of Downlink Difficulty



Spinoffs & Benefits to Society

Audio CDs, GPS & Cell Phones

Pseudo-noise & Error-Correcting codes had first practical use in the DSN. They are fundamental enabli technology for these consumer devices

Plate Tectonics

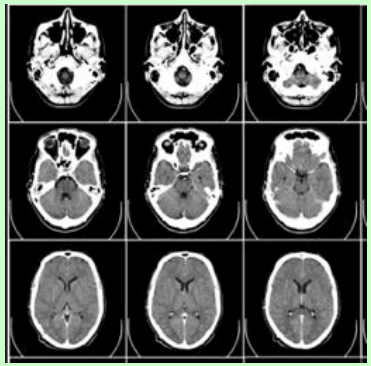
Before GPS, Simultaneous observations of radio sources from DSN antennas on different continents provided the best evidence for plate movement

Fiber-Optic Frequency Distribution

Developed by the DSN to synchronize antennas, this forms the basis for many of today's TV systems

CT scans

The mathematics for navigation using multiple DSN antennas led to medical scanners, revolutionizing the medical industry

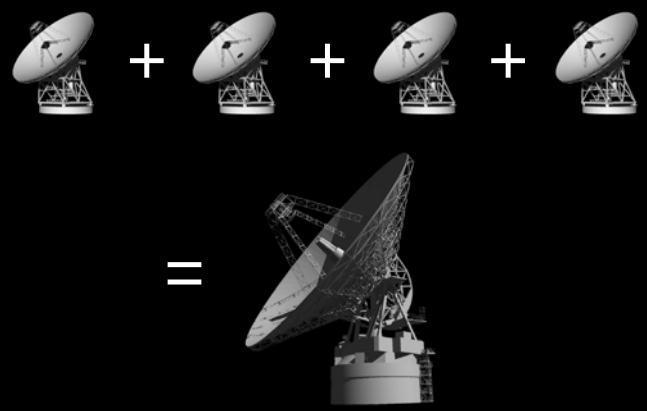


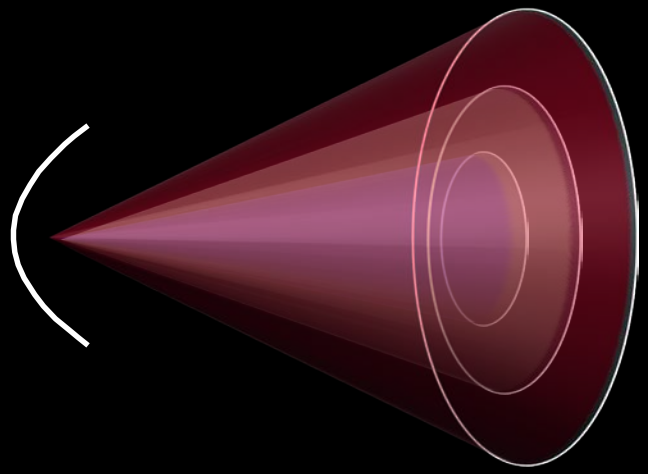
Phase-coherent Doppler

DSN navigation and radar techniques contributed to development of additional sensor systems

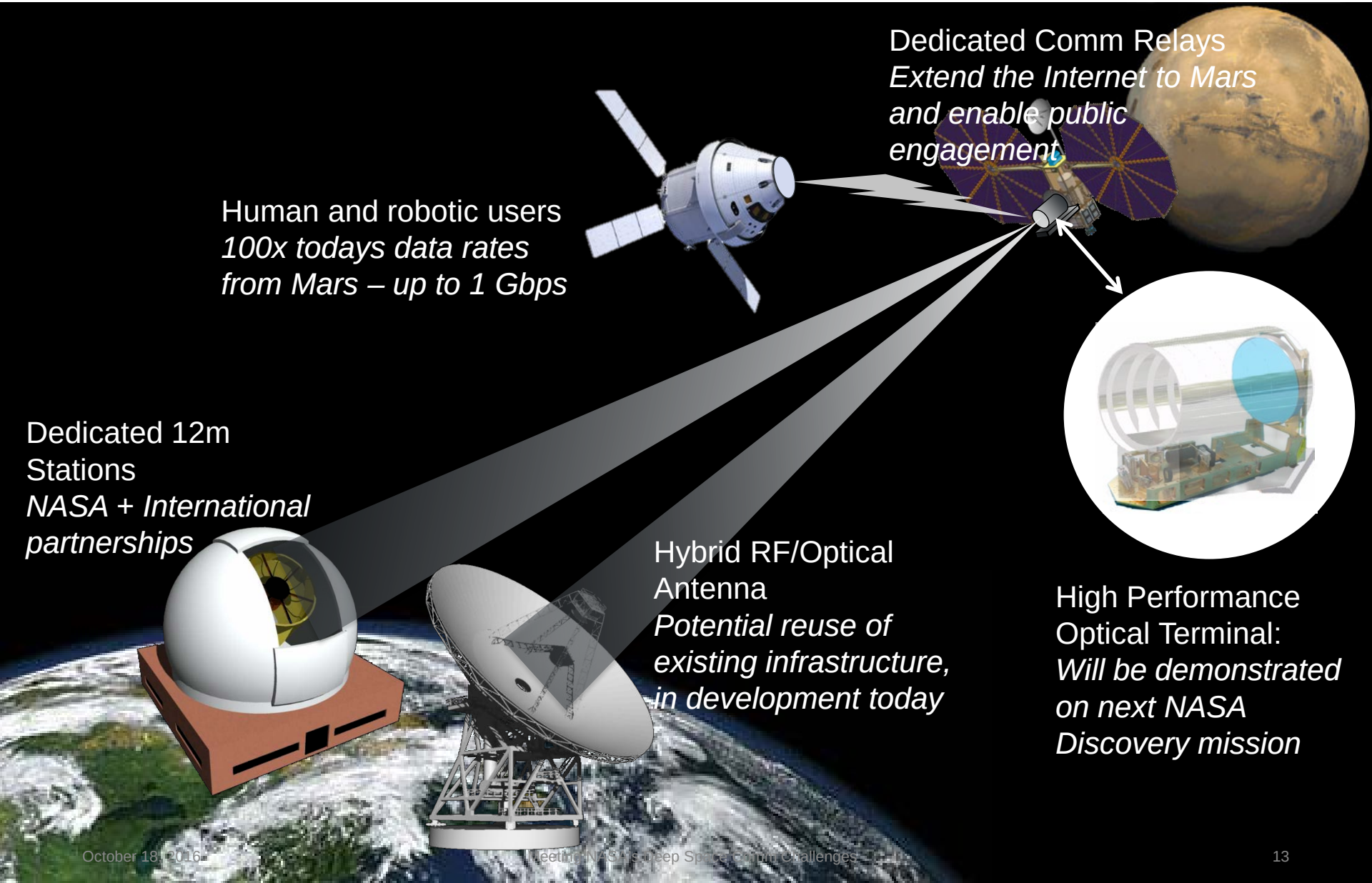
Future RF System Improvements

- Remove bottlenecks on spacecraft and DSN
  - Universal Space Transponder (UST)
  - Common Platform DSN signal processor
- Increase use of Ka-band over X-band
  - Factor of ~4 improvement
- Antenna arraying
  - DSN Aperture Enhancement Project emplacing additional 34m antennas
  - Provides backup for 70m capability as well as arraying beyond 70m





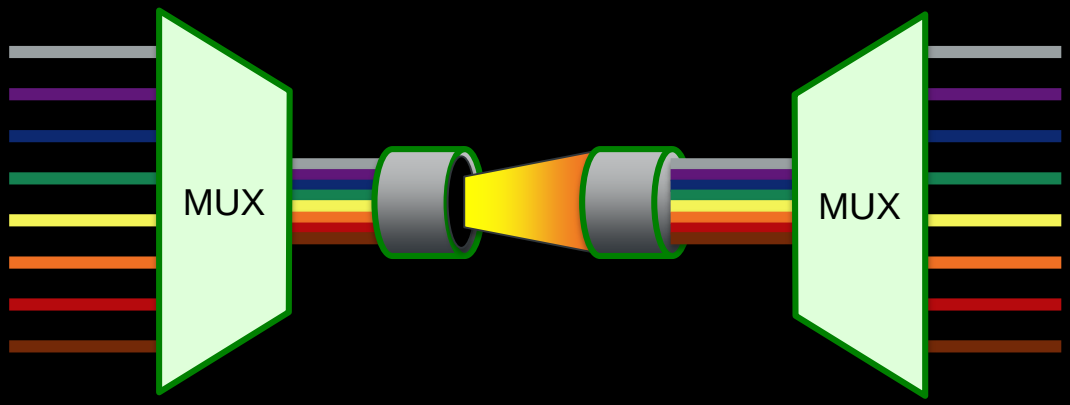
Optical Communications



2nd Generation Deep Space Optical COmm

Additional factor of 10 can come from:

- Increased laser efficiency
  - ~12% today to ~25% in this time frame
- Dense wavelength division multiplexing (DWDM)
  - Provide 10s-100sof downlink channels
  - Take advantage of new ASICs for coding and modulation
- Coherent communications
  - Possible factor of 3 to 5 improvement for outer planet missions
- Natural evolution of components to reduce size, weight, and power



Relays and Networking

Some of these capabilities will not be practical on smaller spacecraft

Communications capability can be provided to these more capable relay spacecraft

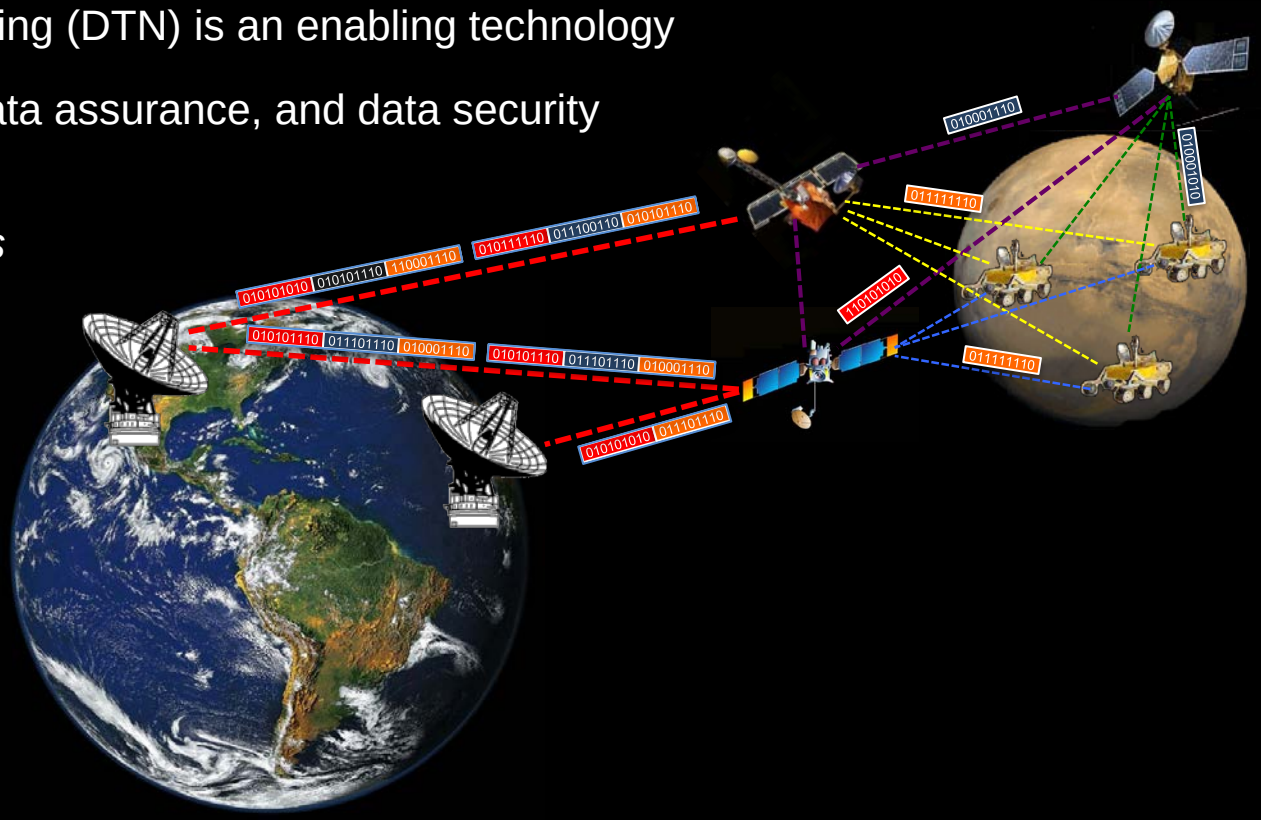
- Viking, Galileo Probe, Huygens, and Philae have taken advantage of this architecture

Disruption Tolerant Networking (DTN) is an enabling technology

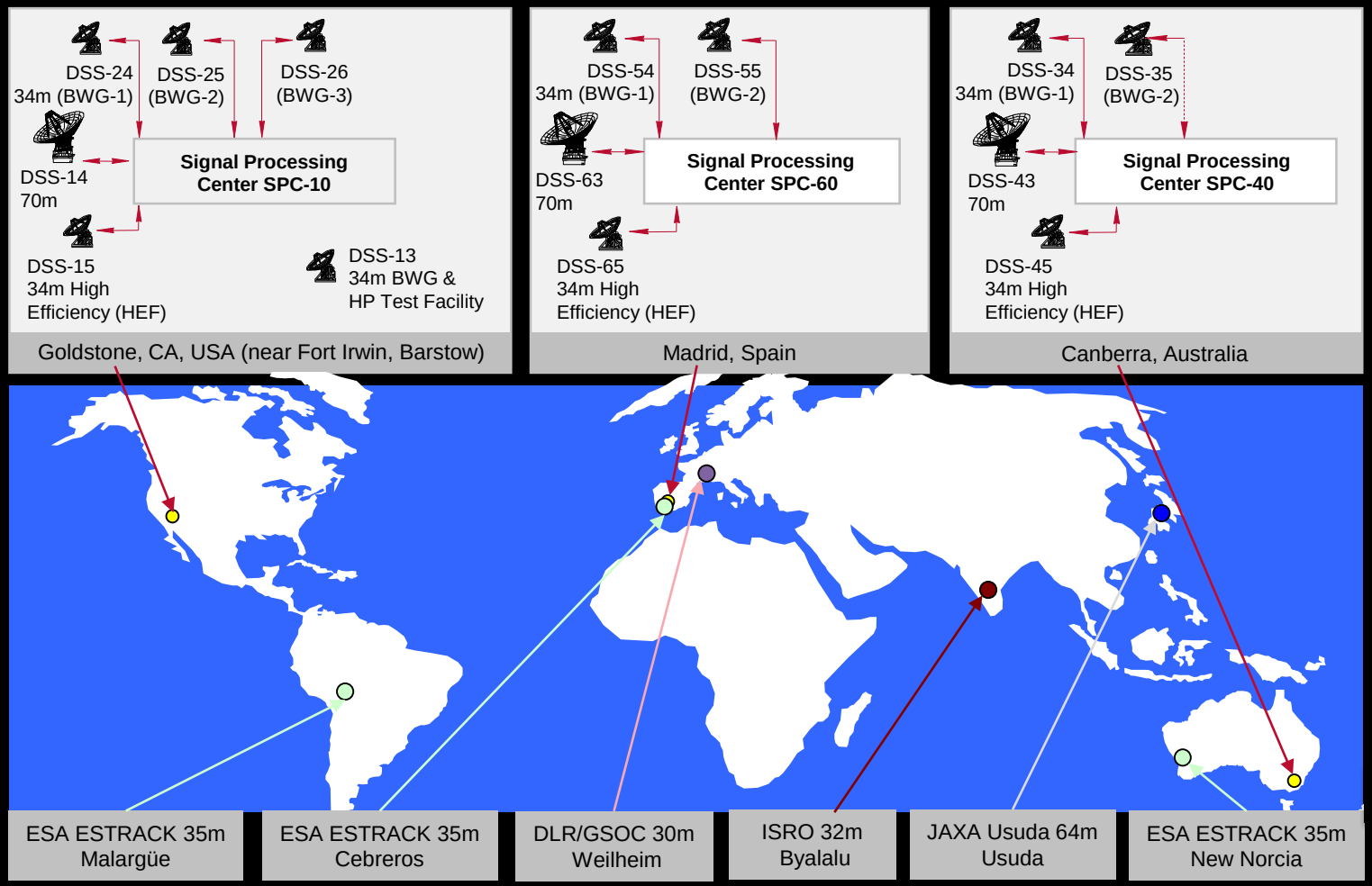
- Provides automation, data assurance, and data security

NASA and our partners will emplace *planetary networks* to support areas of future intense exploration

- Today's *Mars Network* provides these services to landers and rovers



The Global Community of DSN



Deep space optical comm ground stations will likely be international

Conclusion

- We have done well in our first 50 years
  - Enabled much of humankind's exploration beyond geosynchronous orbit
  - Contributed to much of what we know about the our Solar System's planets, comets, asteroids as well as other star systems and galaxies
- Our future deep space missions will demand ever-increasing communications performance
  - They will benefit from a host of new technologies
  - Will return to society the benefits of these technology developments
  - NASA will not do this alone – deep space exploration has become a global effort
- We will continue enable exploration of the Solar System and beyond
  - Understanding the history and evolution of own system
  - Sending humans beyond the Earth/Moon system for the first time
  - Examining exoplanets in ever increasing detail