Deep Space Communications: Past and Future

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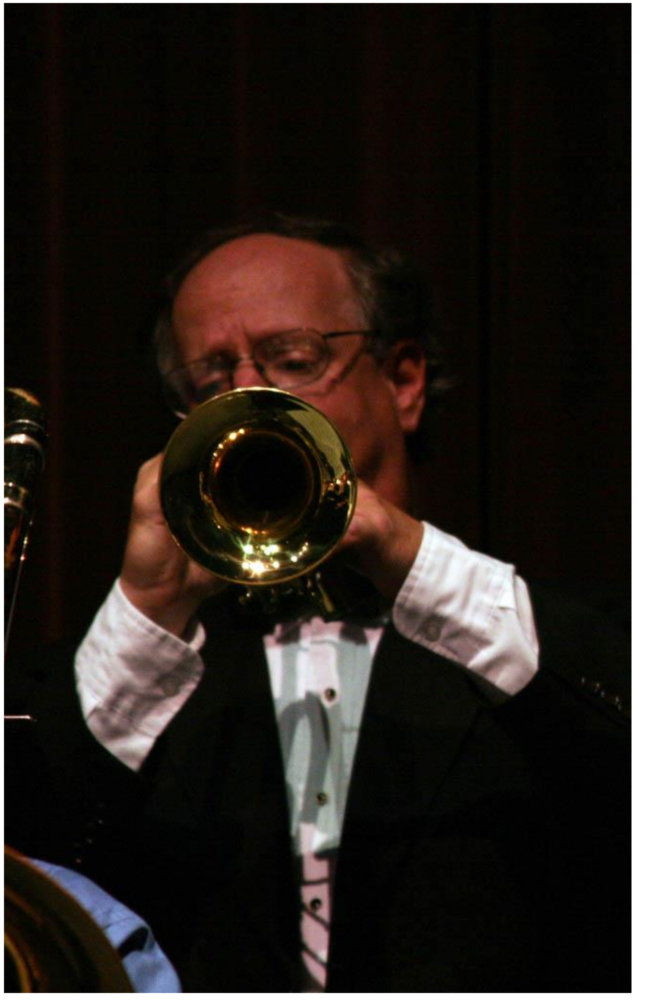
I am Les Deutsch

- Education
  - BS Mathematics, Caltech 1976
  - MS Mathematics, Caltech 1977
  - PhD Mathematics, Caltech 1980
- Career
  - Inventor, Deutsch Research Laboratories
  - Researcher, JPL, NASA
  - Technology Manager, JPL, NASA
- Currently
  - Leads communications and navigation for NASA’s deep space missions
  - Steering committee, Keck Institute for Space Science
  - Caltech organist



- Message: School is important – especially math!

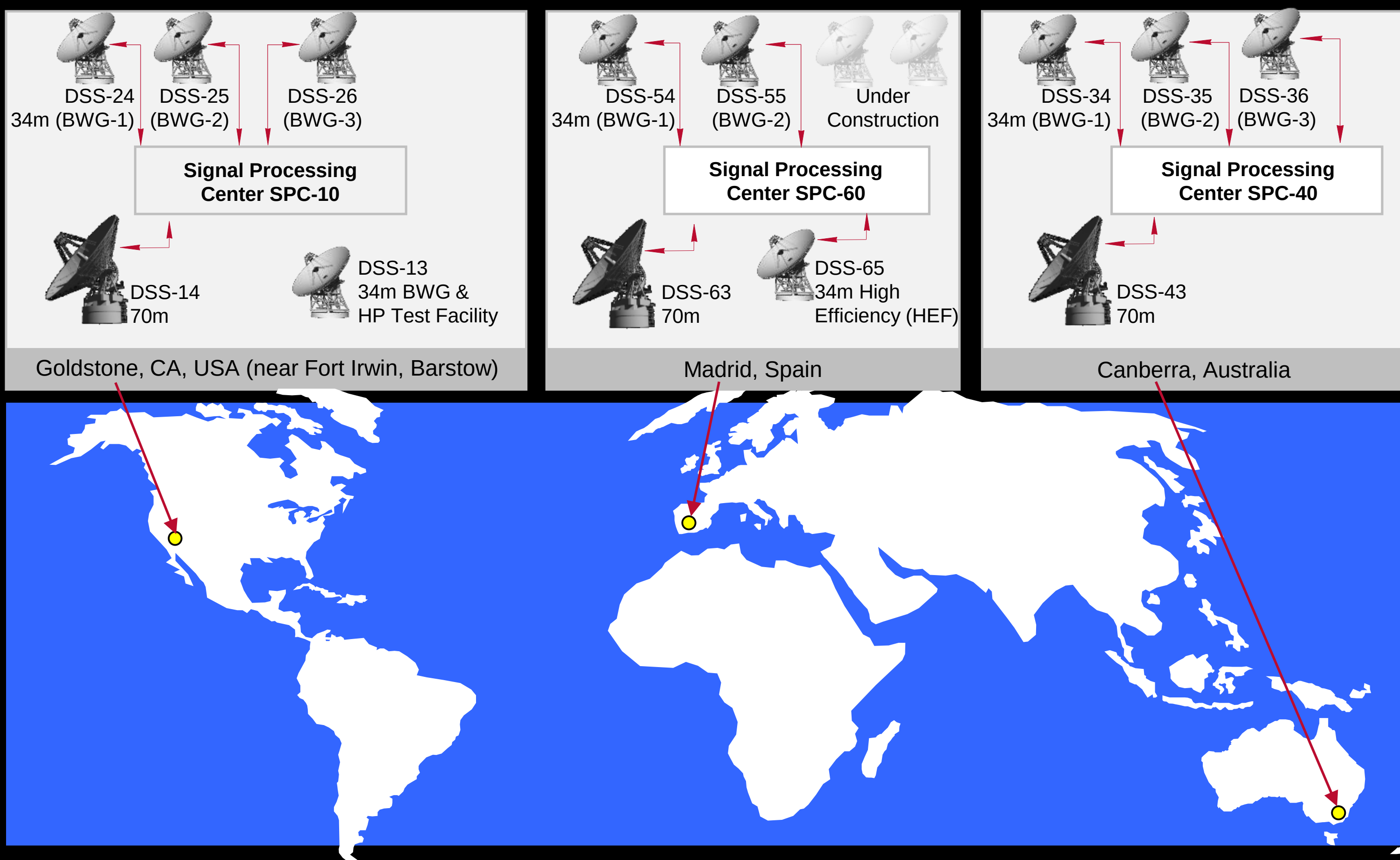
The Deep Space Network
NASA's Connection to the Moon, Planets, & Beyond

- 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

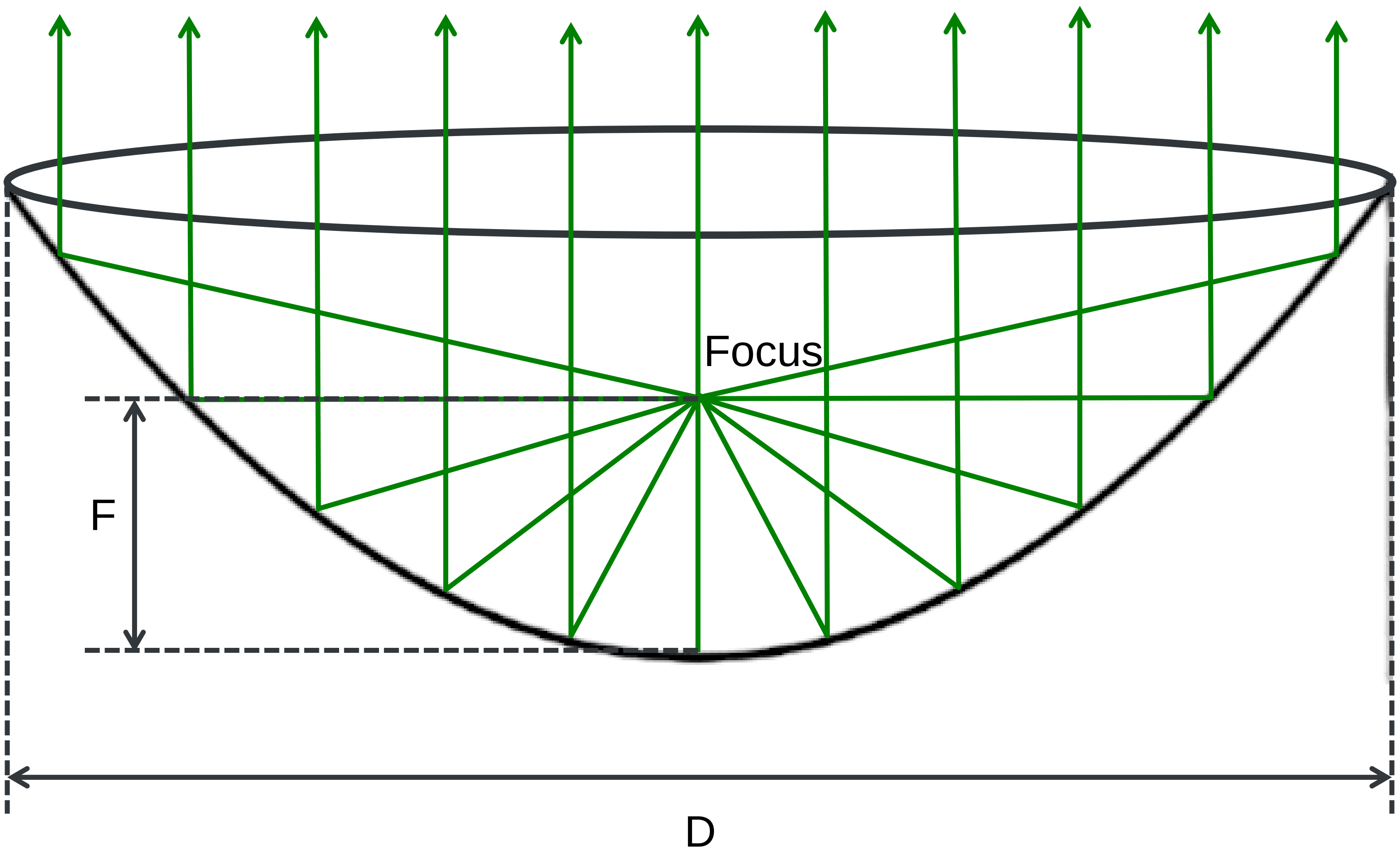
DSN 70m Antenna at Goldstone, California

DSN Current Configuration

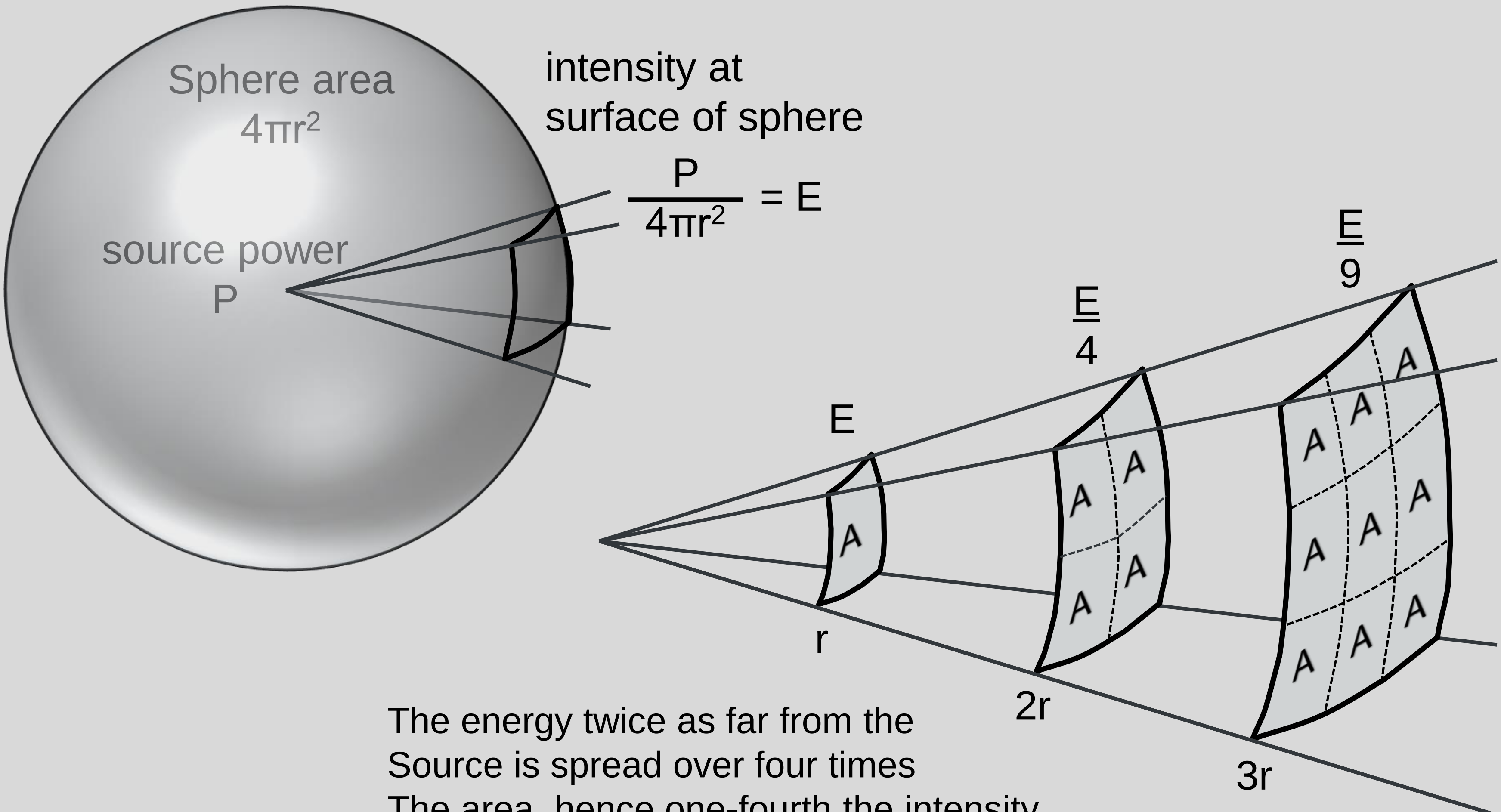


DSN Antennas in Canberra, Australia

Parabolic Antennas



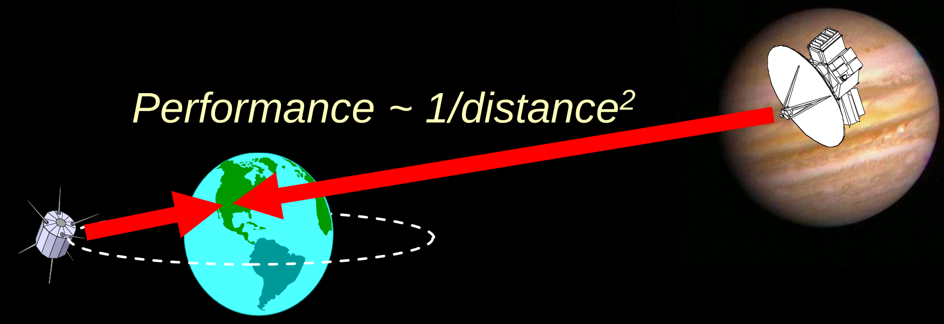
Inverse Square Loss



The energy twice as far from the
Source is spread over four times
The area, hence one-fourth the intensity

Why Telecom is Hard

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



P_R/N_0 = constant / d^2

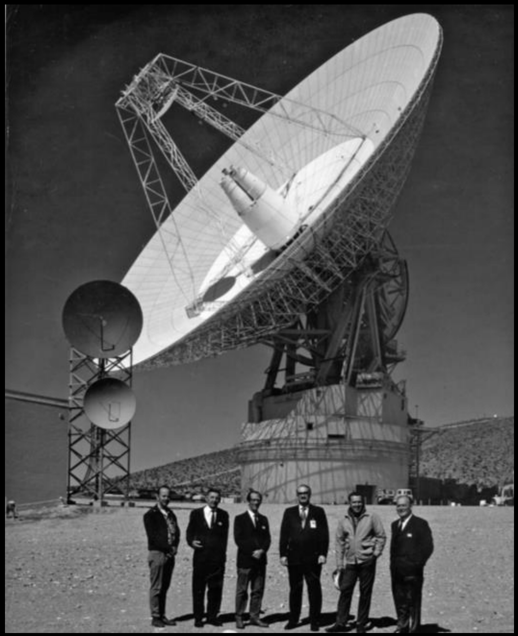
- Need to overcome this problem of physics to be successful in deep space

Relative Difficulty

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

History of Ground Antennas

1958, 26m Station



1966, 64m Station

1979, 34m Station

1988, 70m Station
(converted from prior 64 antennas)

History of Spacecraft Antennas

1964, 0.12m Mariner 4

1966, 1m Mariner 6

1980, 1.5m Viking

2005, 3m Mars Reconnaissance Orbiter

History of Spacecraft Transmitter Power

1964, 10W Mariner 4

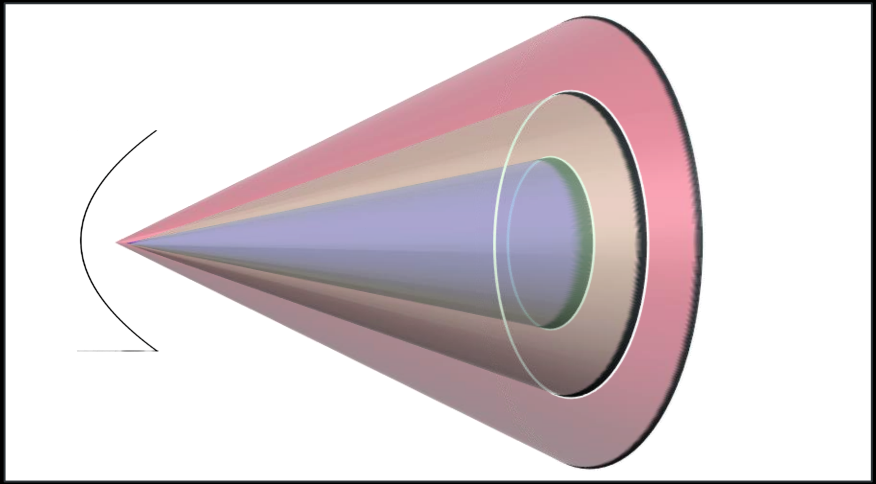
1980, 20W Viking

2005, 100W Mars Reconnaissance Orbiter

Higher Frequency is Good

Signal to Noise = constant/λ^2

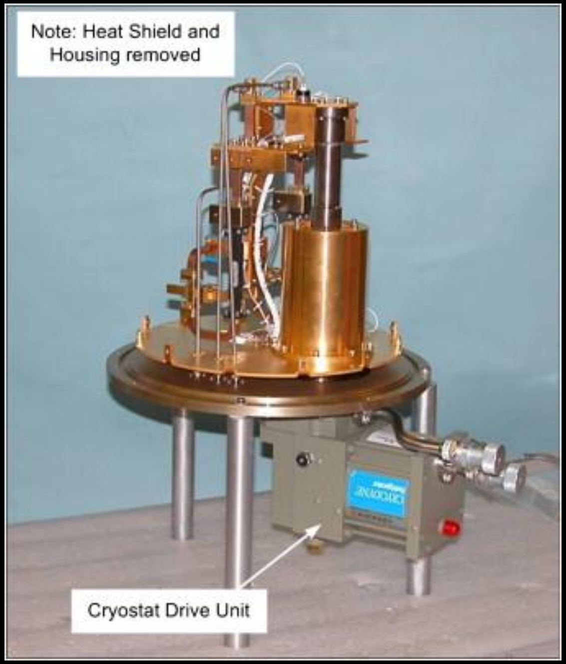
- The first deep space missions transmitted at 960 MHz
- 2.2 GHz (S-band) became standard in 1969
- 8.4 GHz (X-band) became prevalent in the early 1970s
- 32 GHz (Ka-band) is now becoming the standard
- Optical communications is currently in demonstration phase and will become operational in the next decade



Lowering the System Noise

Signal to Noise = constant/T

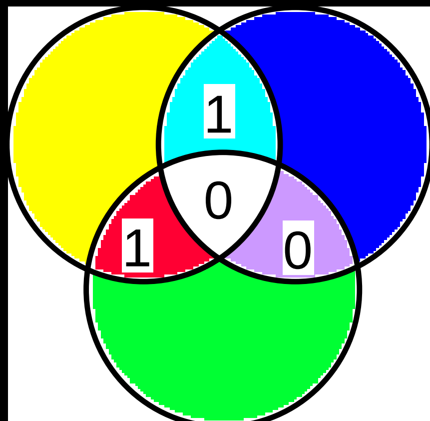
- Some elements to T cannot be controlled
- We concentrate on the contributions of spacecraft and DSN electronics to T
- We carefully avoid RFI
  - Deep space research has its own spectrum assignments from the ITU
- DSN detectors use the best low noise amplifiers we can build or buy
  - Hydrogen masers or HEMTs
  - Physical temperature is ~12 K



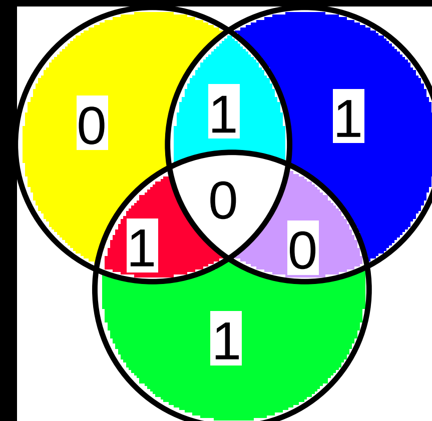
Ka-band (32 GHz) low noise amplifier

Eror Korecting Cods

An example of coding: the (7, 4) Hamming code

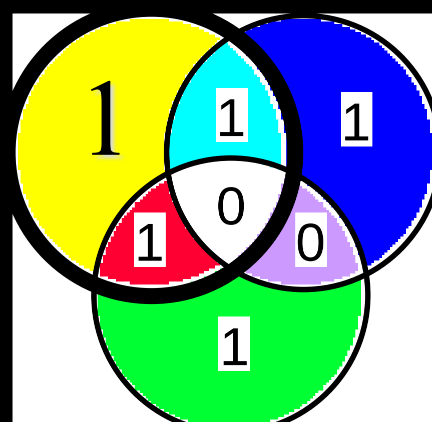


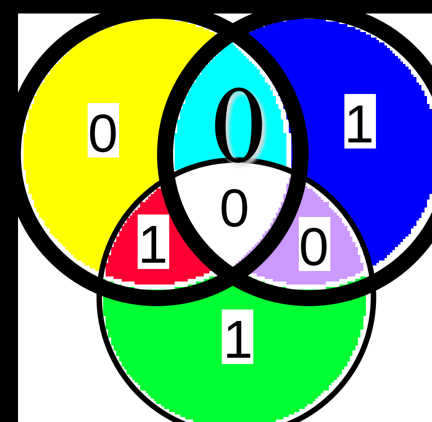
Place 4 information bits in the intersections of the Venn diagram



Fill in the diagram so that the circles have an even number of 1's

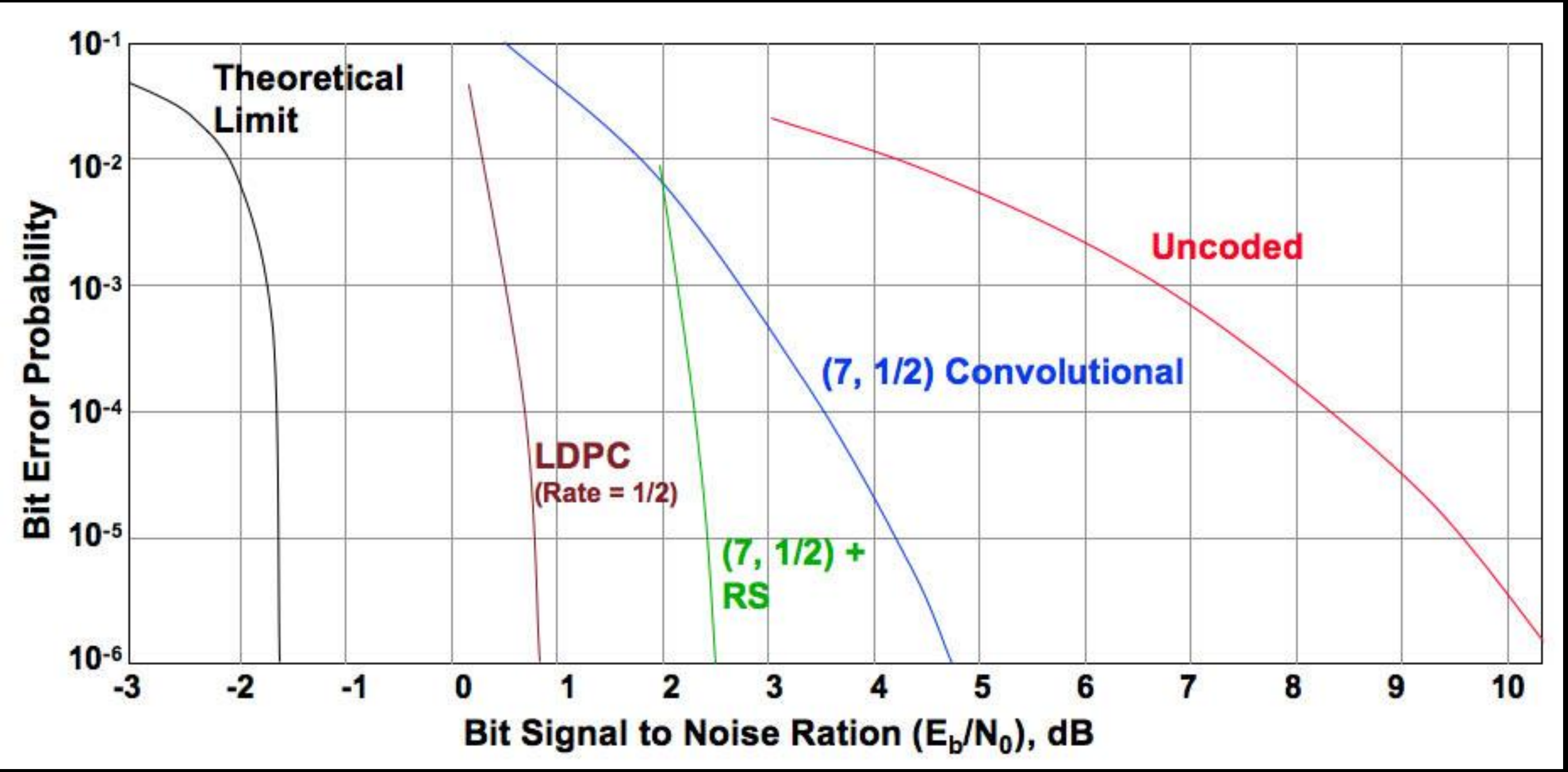
If a single error occurs, it can be corrected by locating the circles with an odd number of 1's and changing the bit in their intersection





Better and better codes

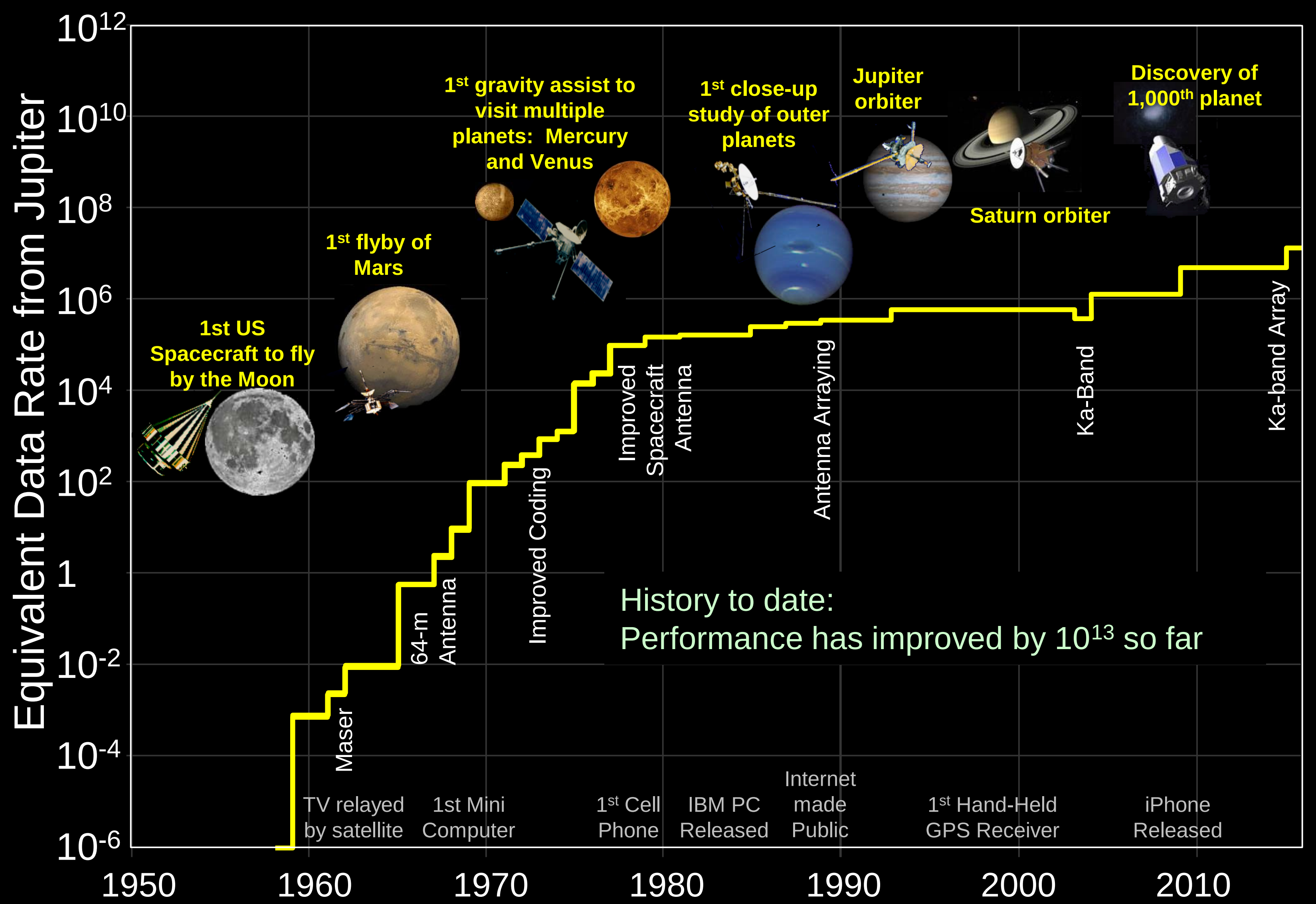
- Codes allow same data to be transmitted with less power



Compression – Being stingy with bits

- Data compression is like texting
  - FYI JOE’L BRB 2 HELP L8R
  - Four your information, Joe will be right back to help later
  - Compression ration = 39:24, or almost 2:1
- Images can be compressed 10:1
- Videos and hyperspectral images even more
- Even better: Use data onboard to answer questions and only send the answers!
  - Navigation – where am I now?
  - Locating interesting areas in a scene
  - Onboard science

A History of Improving Communications



Spinoffs & Benefits to Society

Audio CDs, GPS & Cell Phones

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

Plate Tectonics

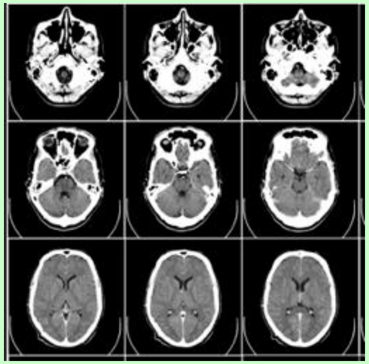
Before GPS, Simultaneous observations of radio sources from DSN antennas on different continents provided the best evidence for plate movement

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

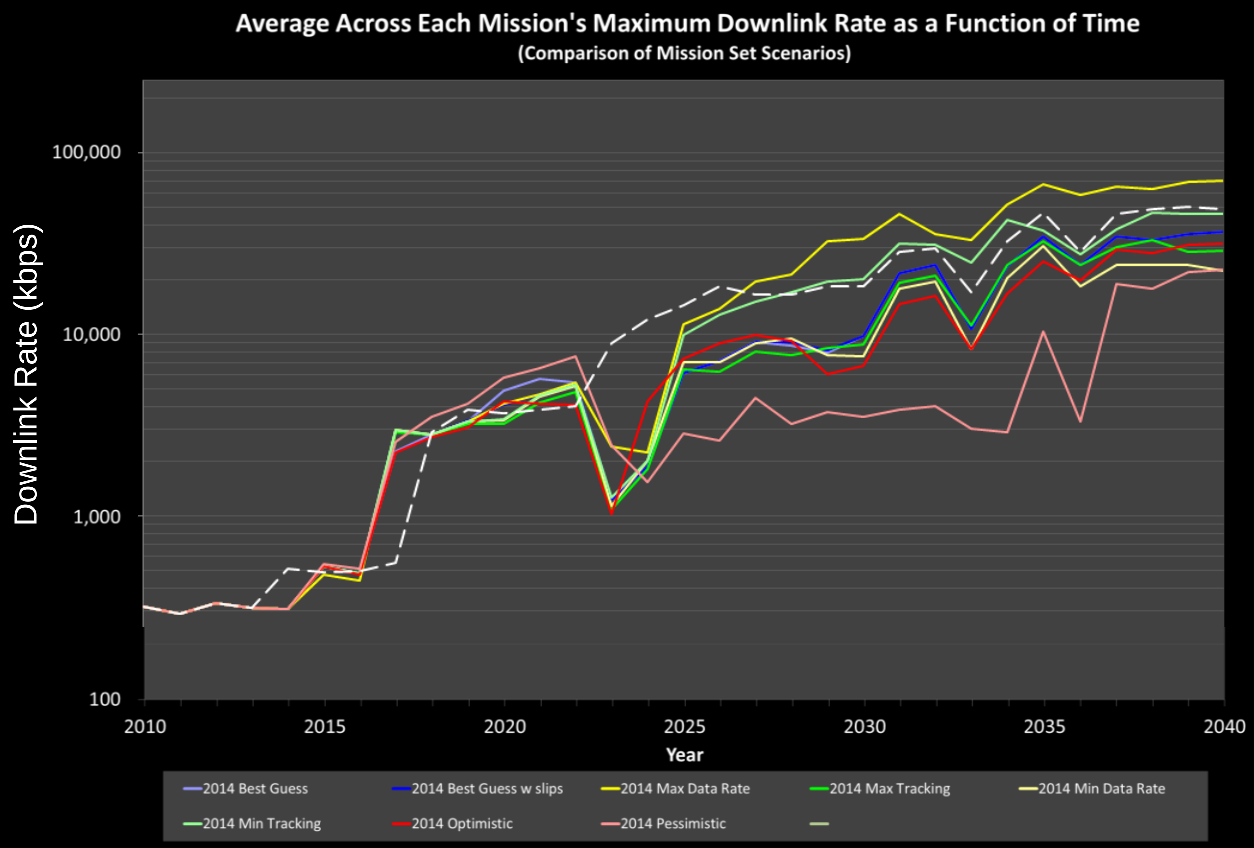


Phase-coherent Doppler

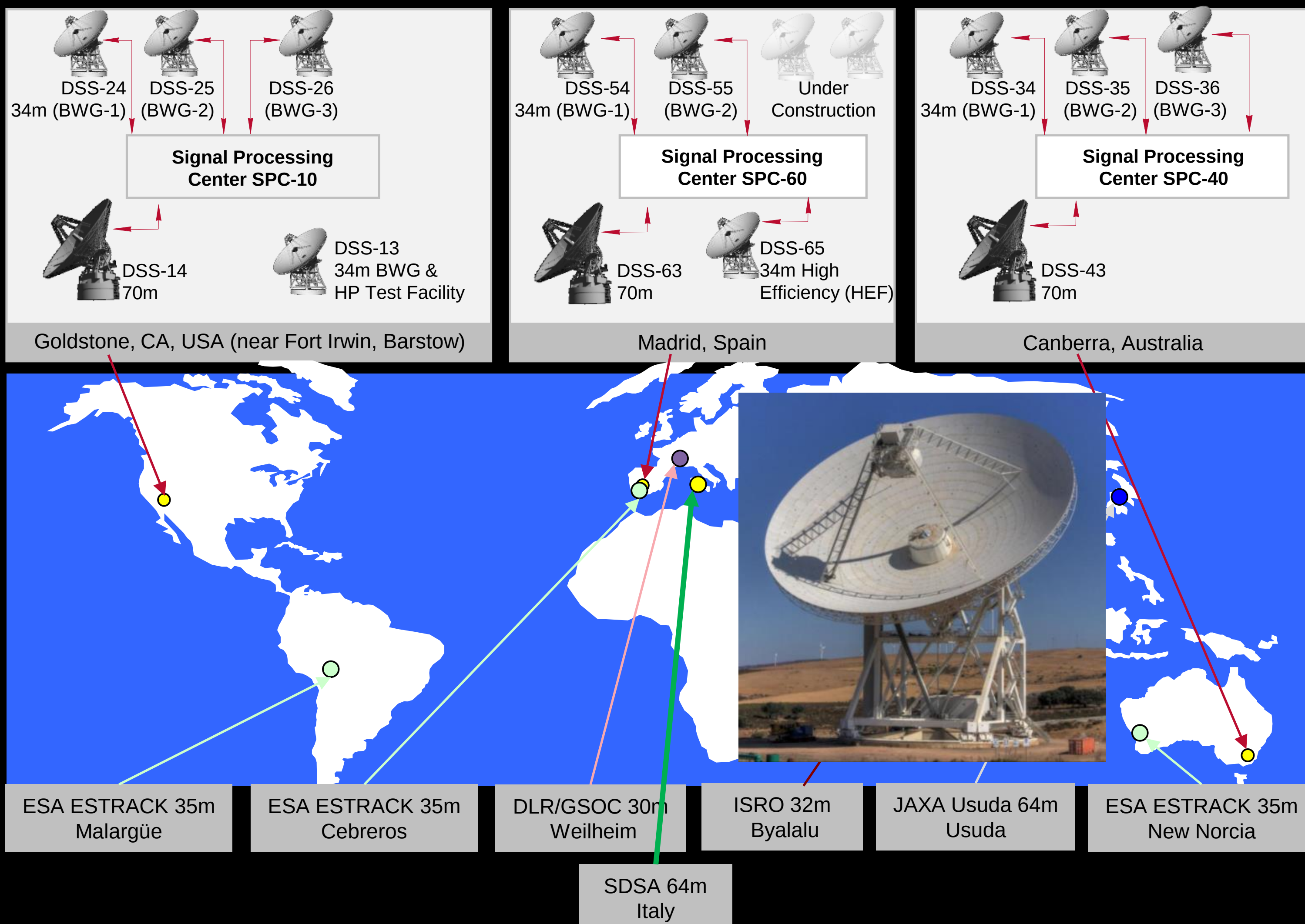
DSN navigation and radar techniques contributed to development of additional sensor systems

Challenge: Future Missions Need More Data

- Science Directions
  - Have visited all major objects in Solar System, Global continuous presence on Mars since 2004
  - Trends: Revisit for more intense study, Smaller spacecraft and constellations, Humans beyond LEO
- Mission modeling indicates desire for ~10X data improvement per decade through 2040
- How can we improve even more?

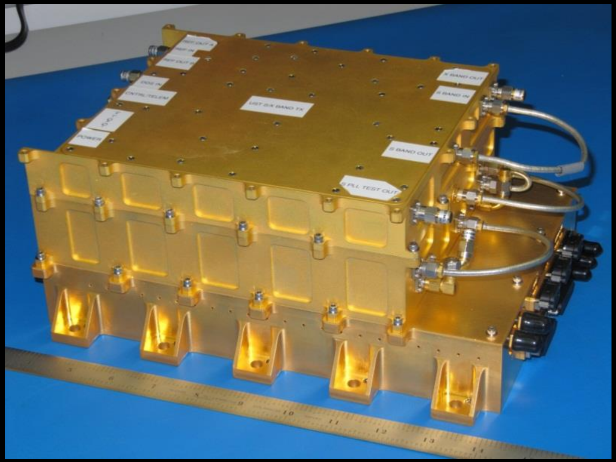


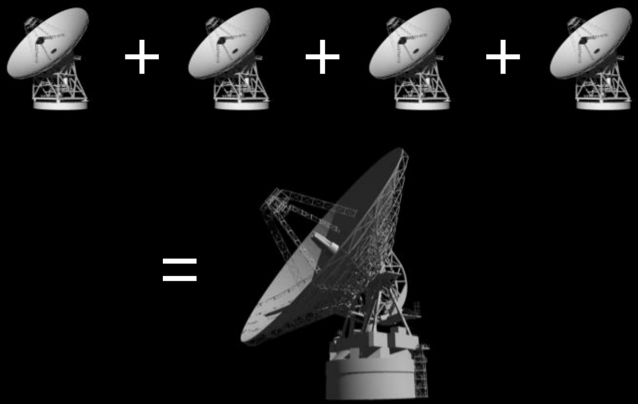
The Global Community of DSN

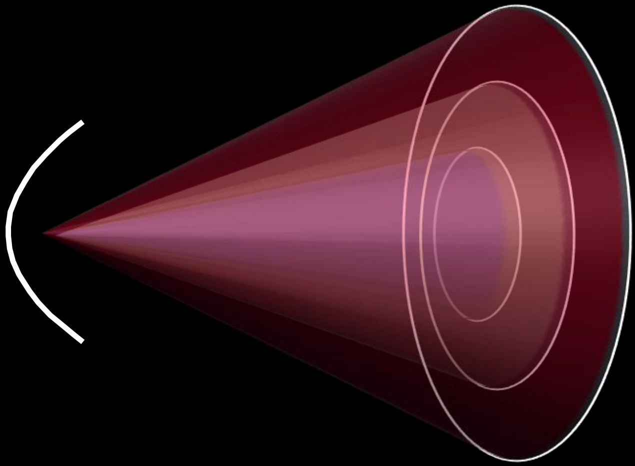


Decade 1: 10X Improvement over Today

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







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

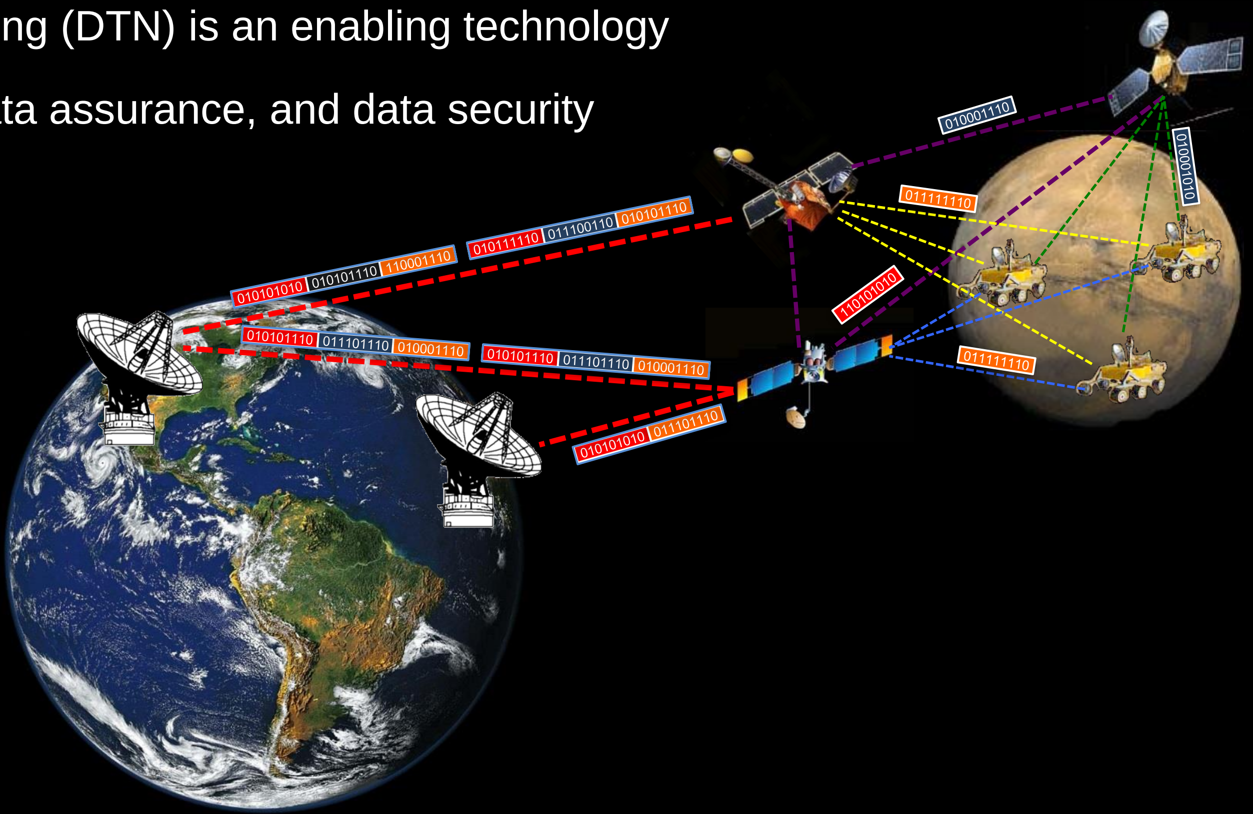
- Viking, Galileo Probe, Huygens, and Philae have taken advantage of this architecture

Disruption Tolerant Networking (DTN) is an enabling technology

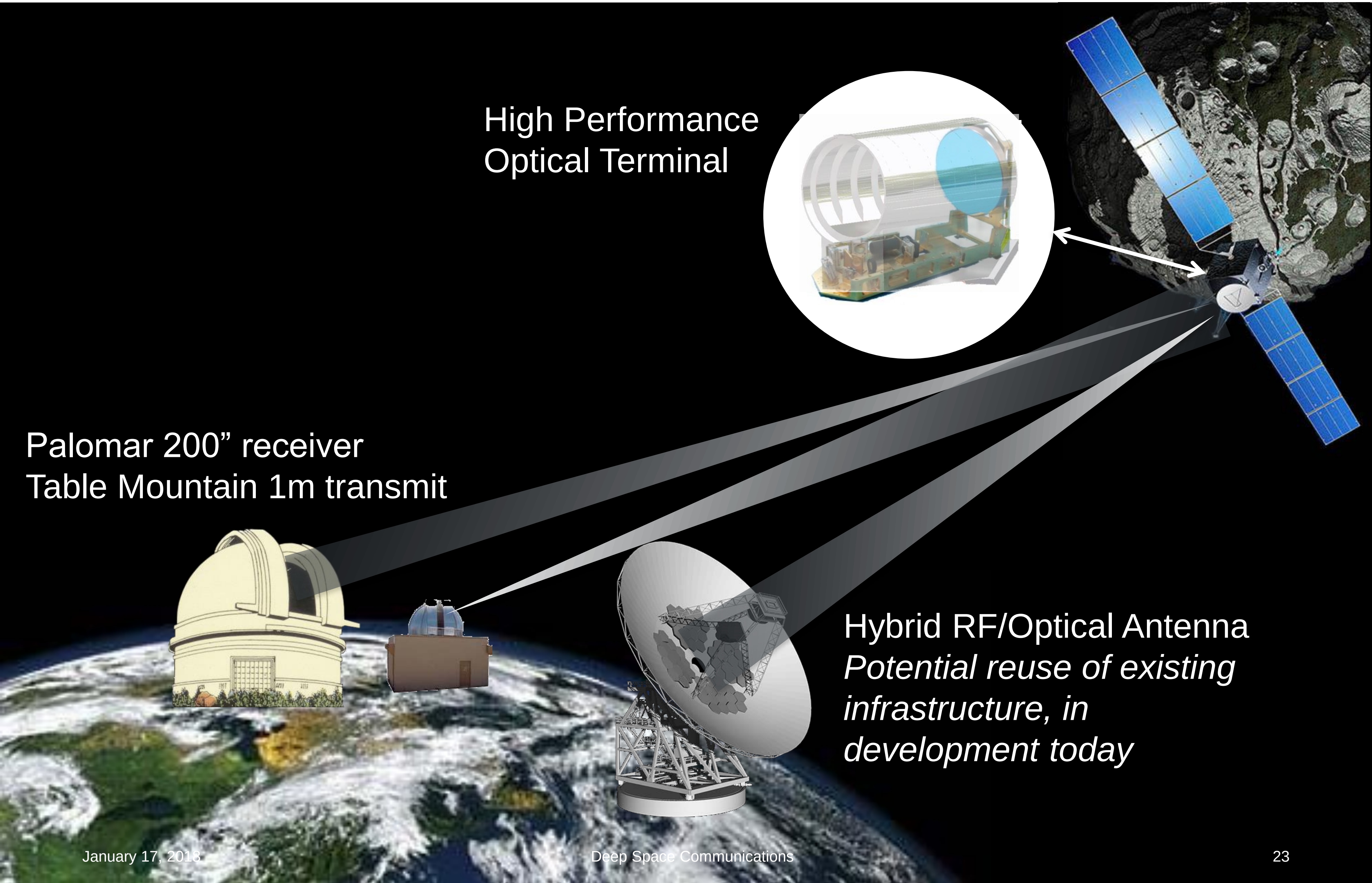
- Provides automation, data assurance, and data security

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



Decade 2: 100X Improvement over today



Conclusion

- The first 50 years of deep space communications has been very productive
  - 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
- As we move into future, the DSN and its global brethren have a continued challenge
  - There is much more to learn and lot more bits to move over great distances
- We face this challenge together, as a global community of explorers
  - We will benefit from a host of new technologies
  - We will give back to society additional knowledge and technologies to benefit society