Deep Space Network: The Next 50 Years

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What is NASA?

National **A**eronautics and **S**pace **A**dministration

What is JPL?

Jet **P**ropulsion **L**aboratory

One of 10 NASA centers – Robotic exploration of the Universe

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

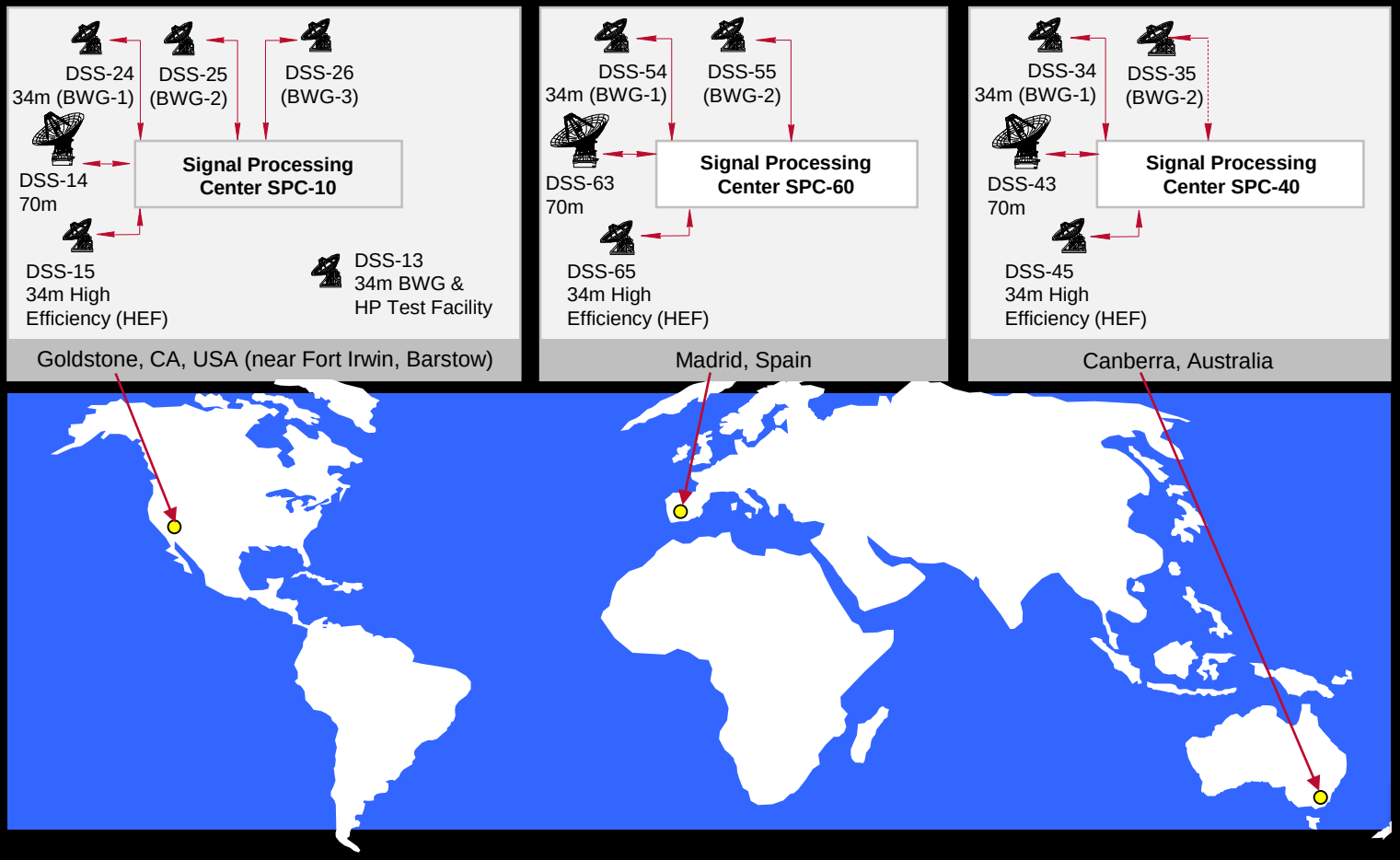
- Message: School is important – especially math!

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

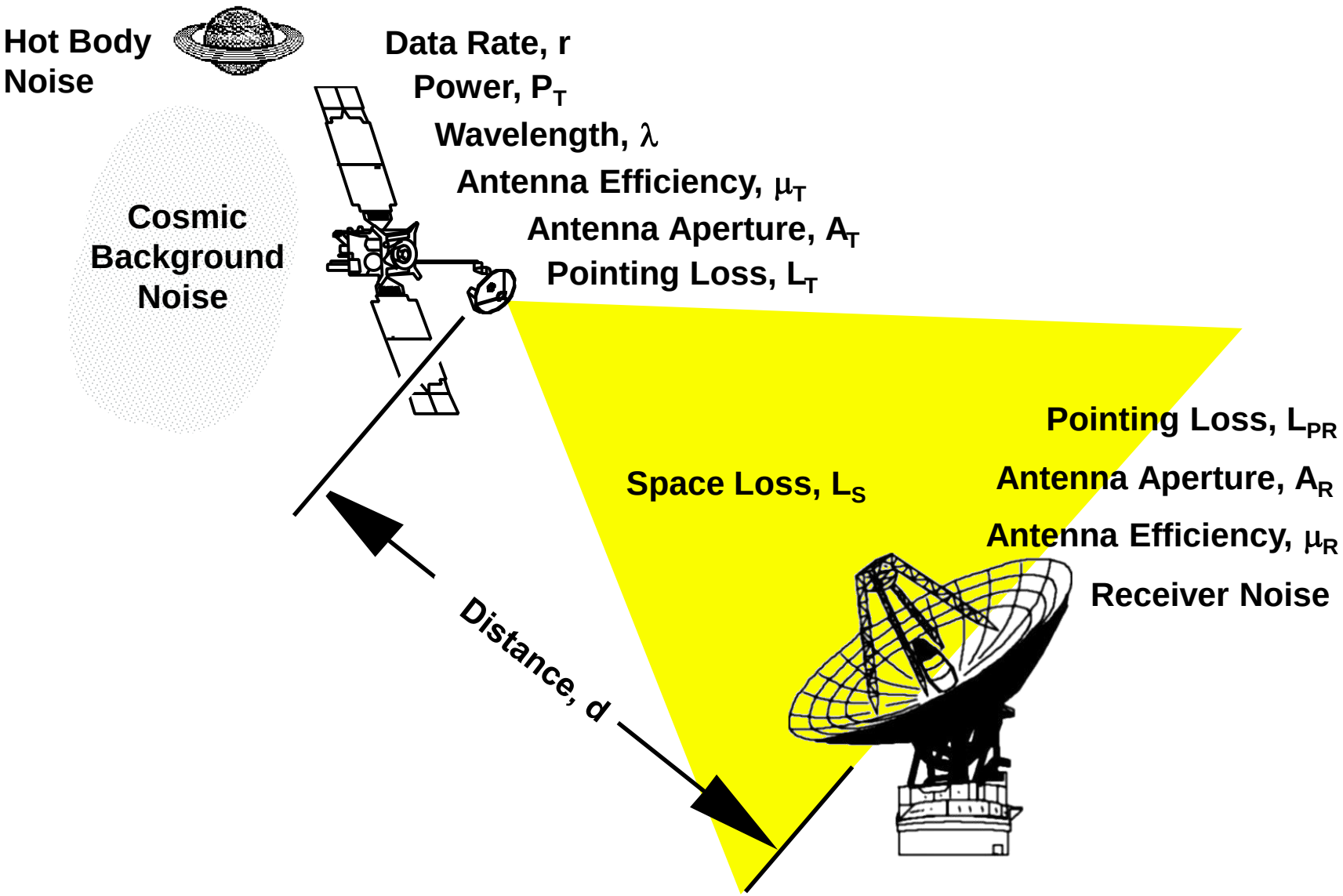
DSN 70m Antenna at Goldstone, California

DSN Current Configuration

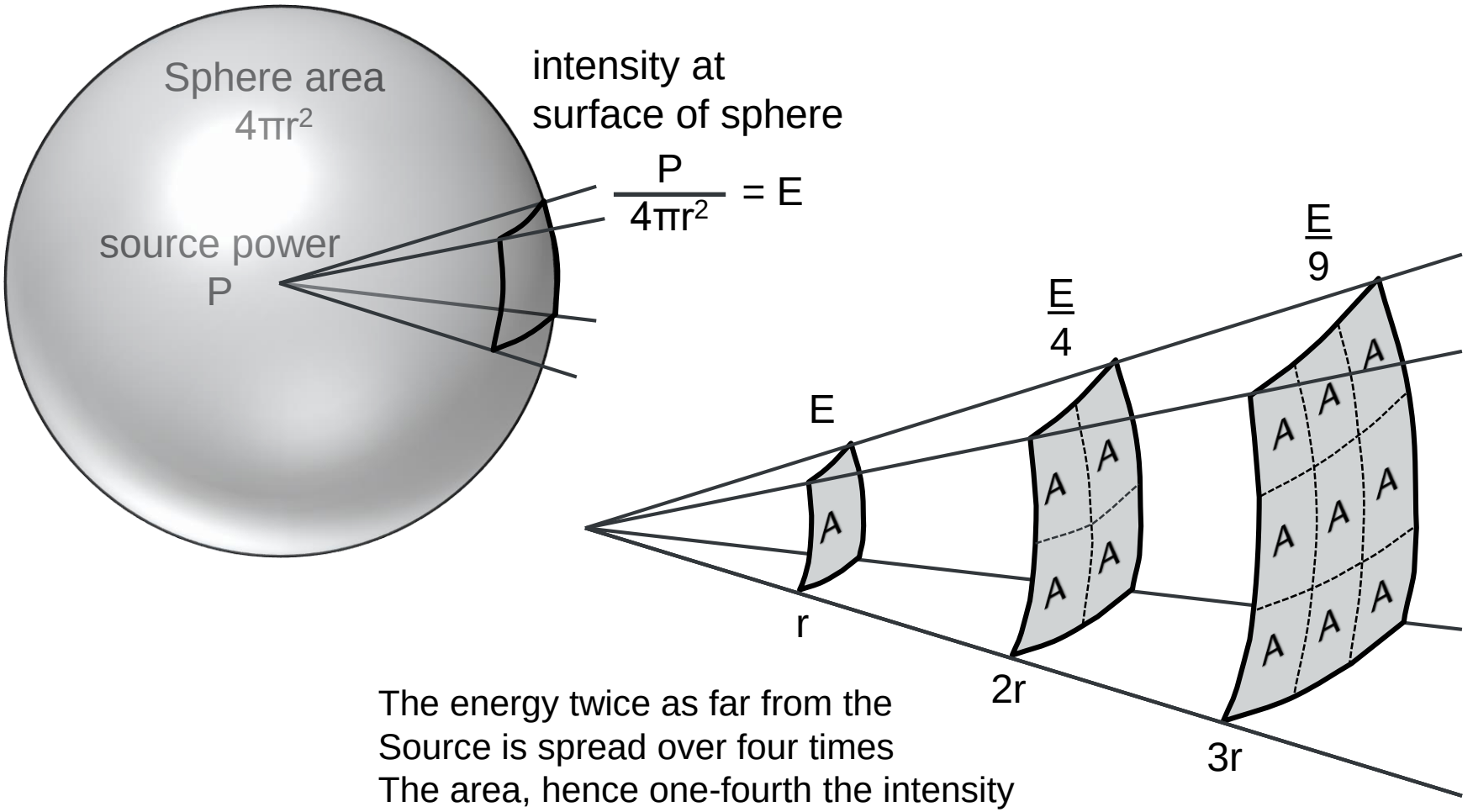


DSN Antennas in Canberra, Spain

Deep Space Link Parameters



Inverse Square Loss



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

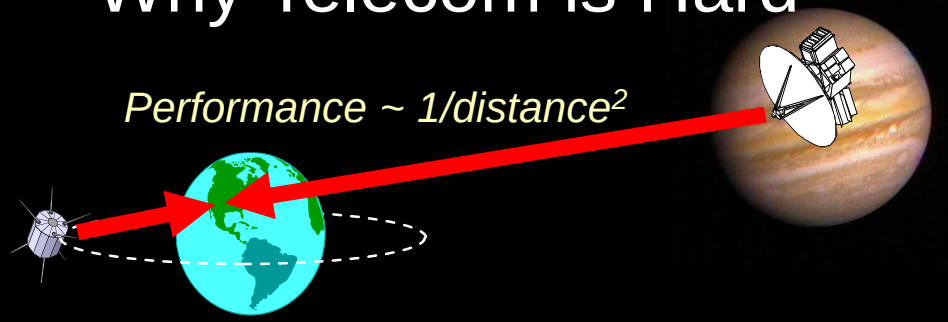
Space Loss

- 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

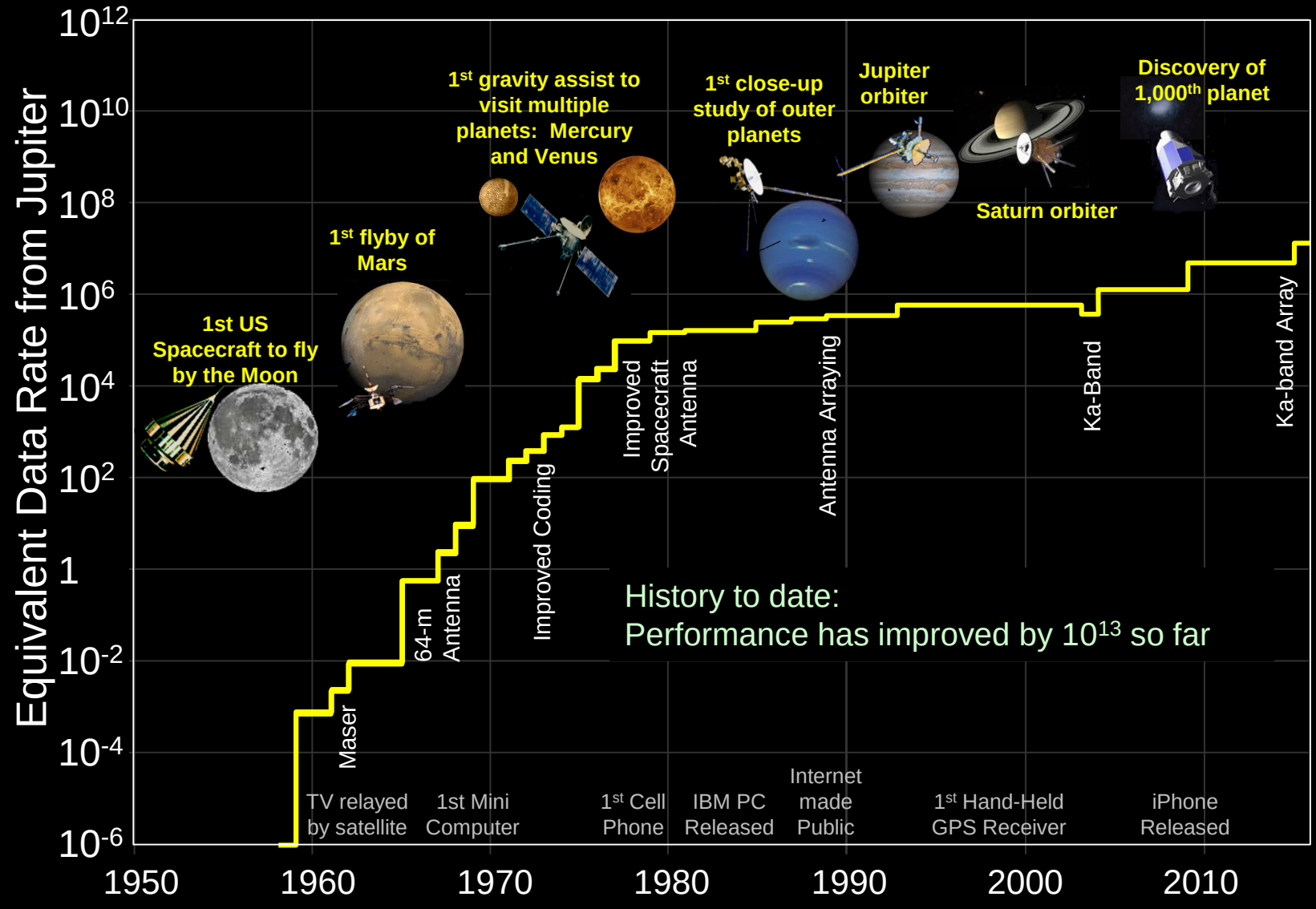
Why Telecom is Hard



Relative Difficulty

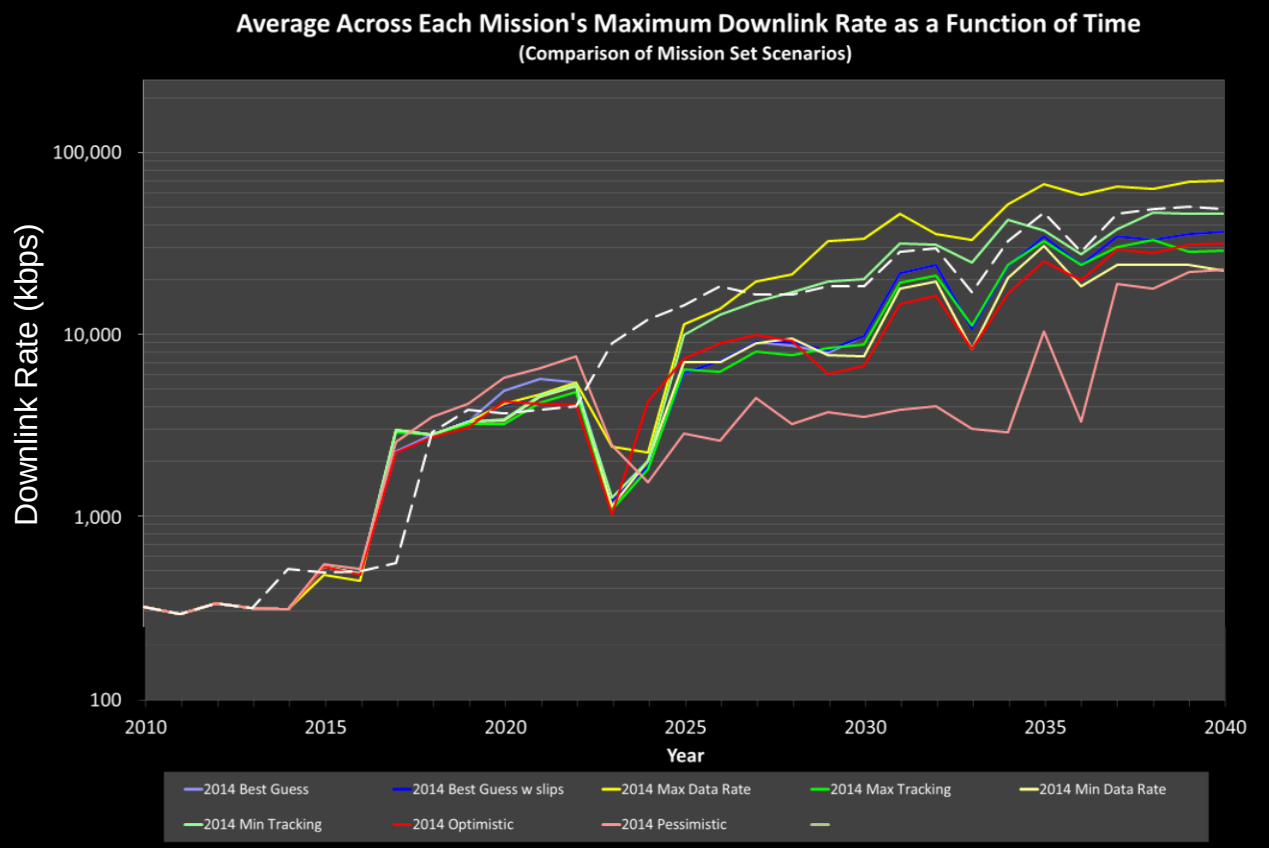
Place	*Distance*	*Difficulty*
Geo	*$4x10^4$ km*	*Baseline*
Moon	*$4x10^5$ km*	*100*
Mars	*$3x10^8$ km*	*$5.6x10^7$*
Jupiter	*$8x10^8$ km*	*$4.0x10^8$*
Pluto	*$5x10^9$ km*	*$1.6x10^{10}$*

History of Downlink Difficulty



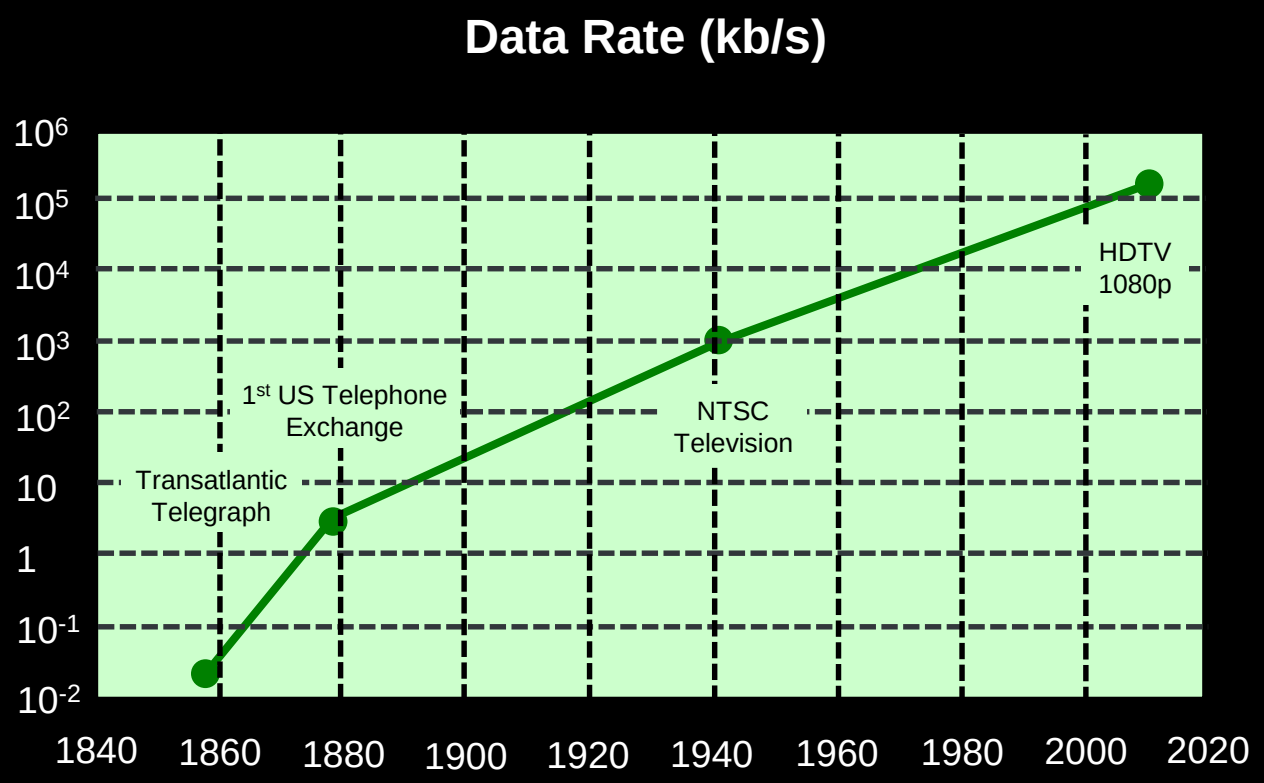
Future Mission Data Rate Trends

- 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
- After 2040?



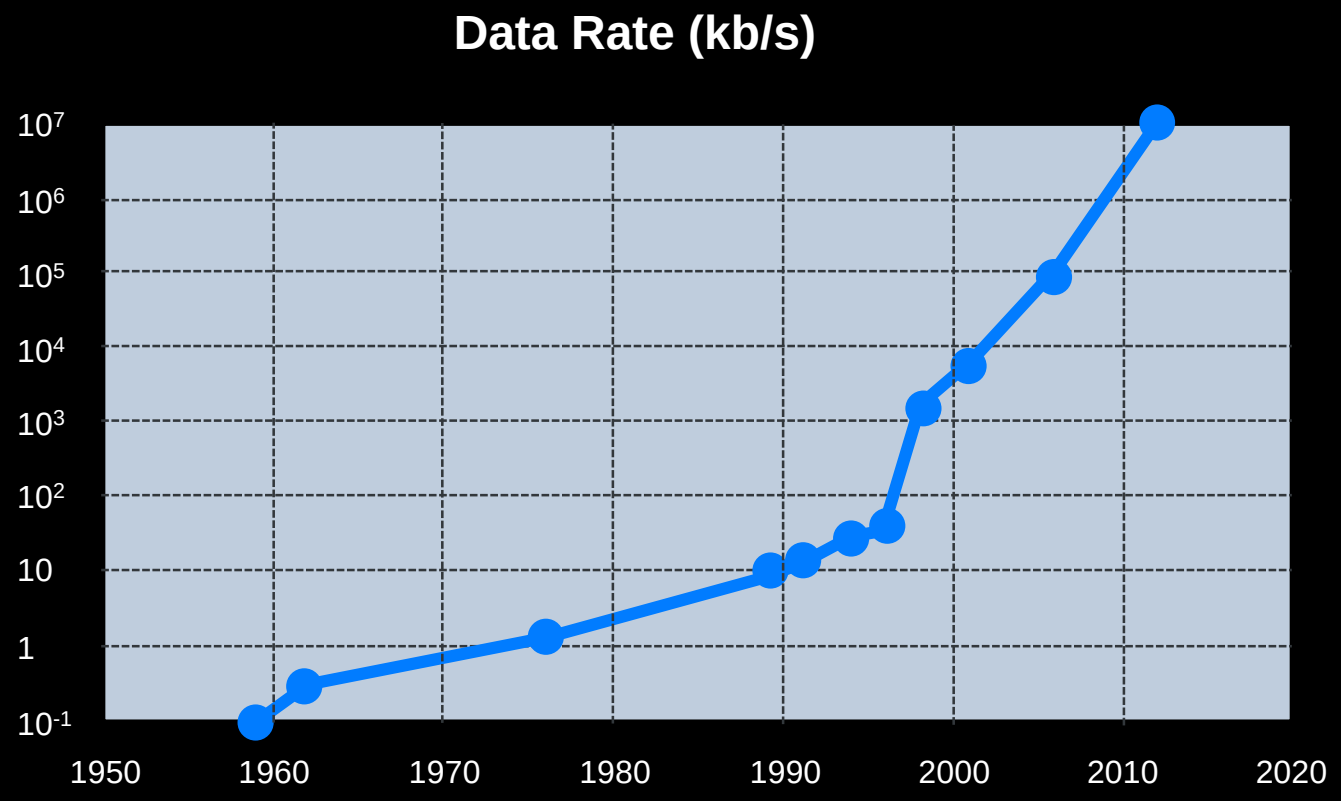
Long Term Communications Trend

- We can look at long term trends for communications in general
- Data gleaned from the Internet leads to ~0.34 orders of magnitude per decade
- But we all know (feel?) the information age has changed this



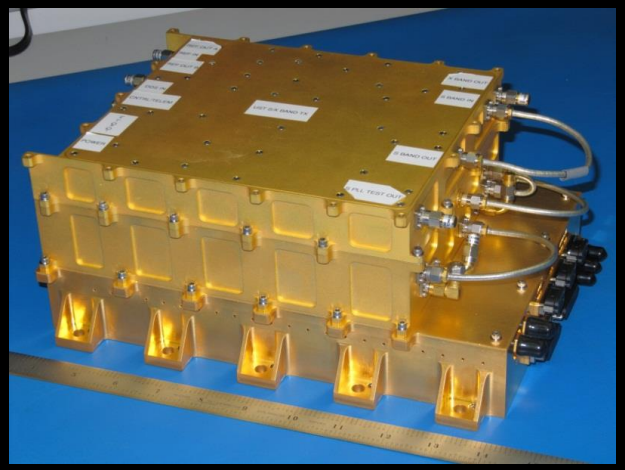
Internet Communications Trend

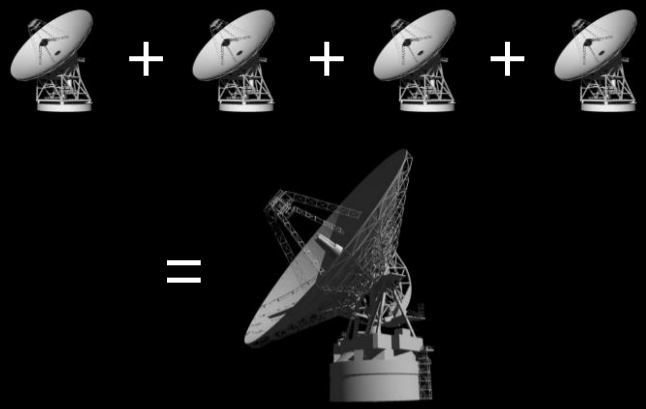
- Consider the trend in digital communications since the Internet was invented
- This trend is ~1.3 orders of magnitude per decade
- We believe spacecraft data needs will grow similarly – so we will use 1.0 orders of magnitude per decade

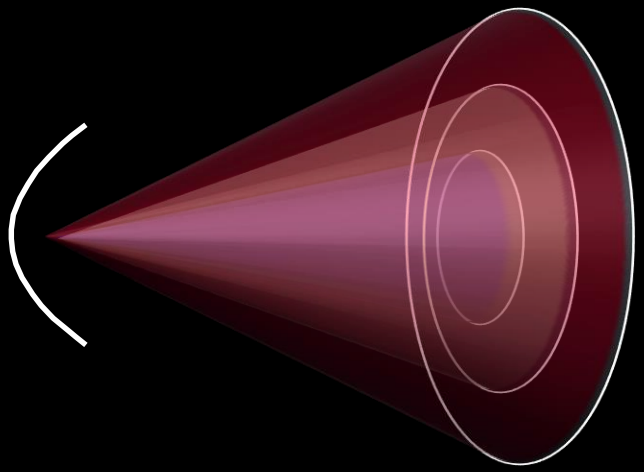


Decade 1: 10X Improvement over Today

- 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

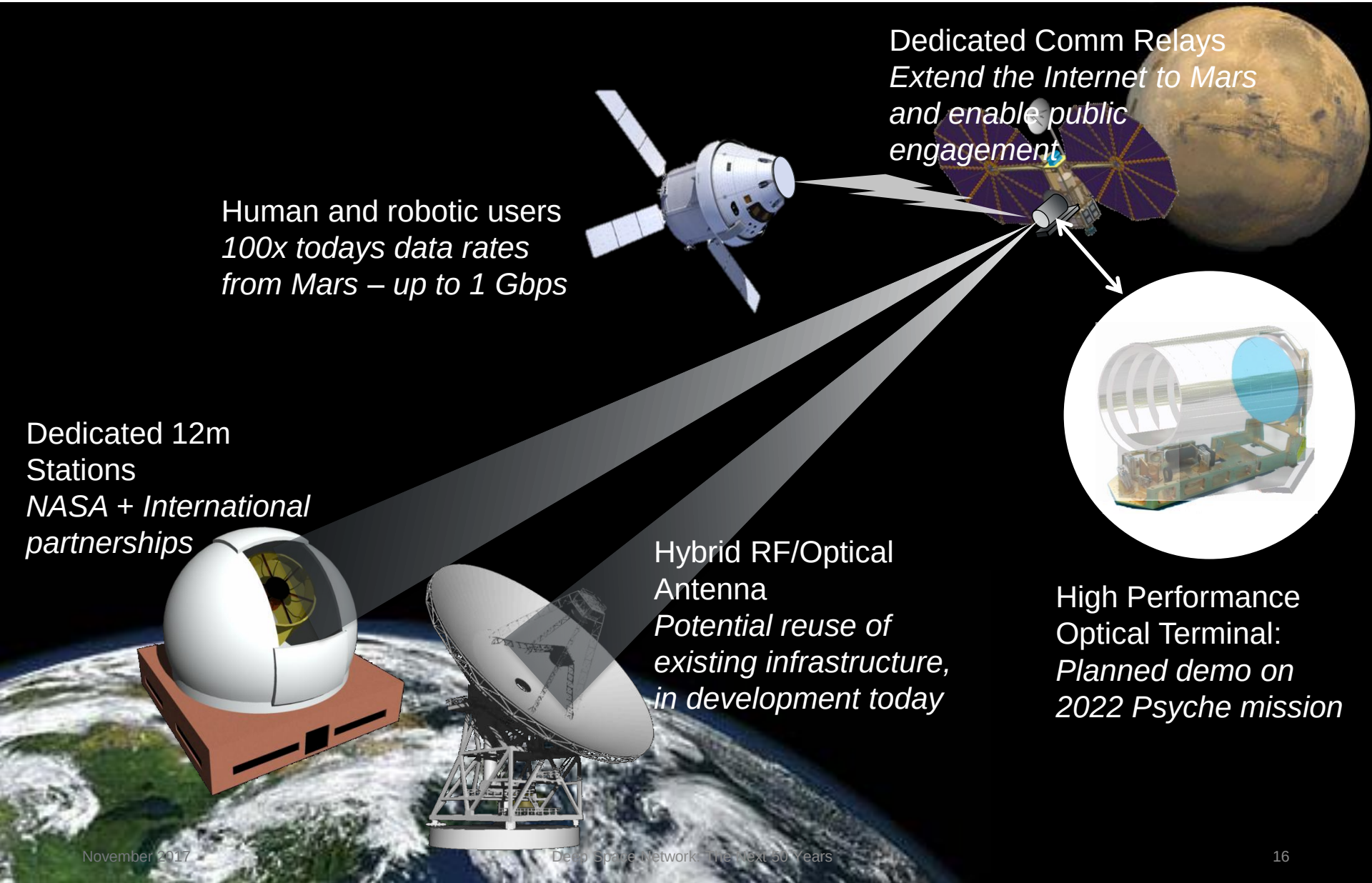







The Deep Space Network
Presents...

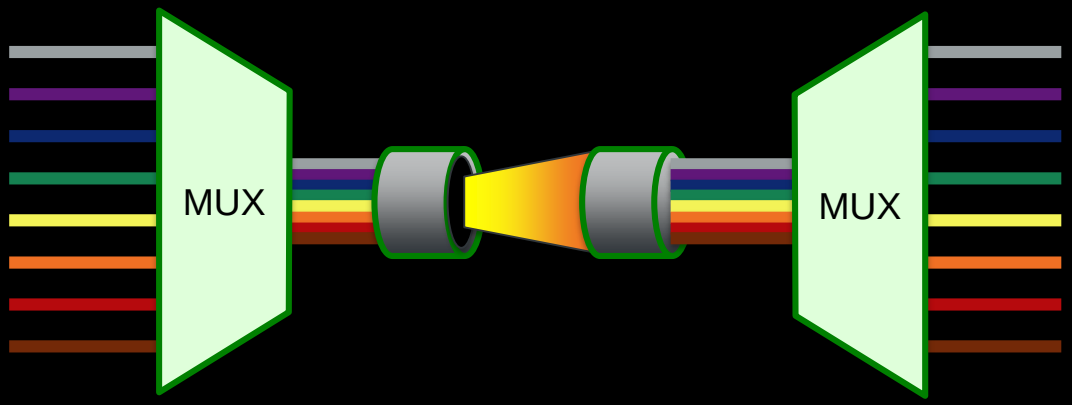
Decade 2: 100X Improvement over Today



Decade 3: 1,000X Improvement over Today

Additional factor of 10 comes from second generation optical communication

- 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



Decade 4 & 5: 1,000,000X Improvement over Today

It is hard to predict exactly what technologies will pay off in this time frame for the remaining factor of 100

However, history shows that the DSN has found radio improvements even after 50 years of maturation

Some possibilities:

- Further increases in transmitter efficiency
- Better power sources for spacecraft, perhaps driven by human exploration far from Earth
- Further improvements in DWDM technology
- Antenna arraying on a massive scale
- Disruptive technologies
  - Quantum communications
  - X-ray communications

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

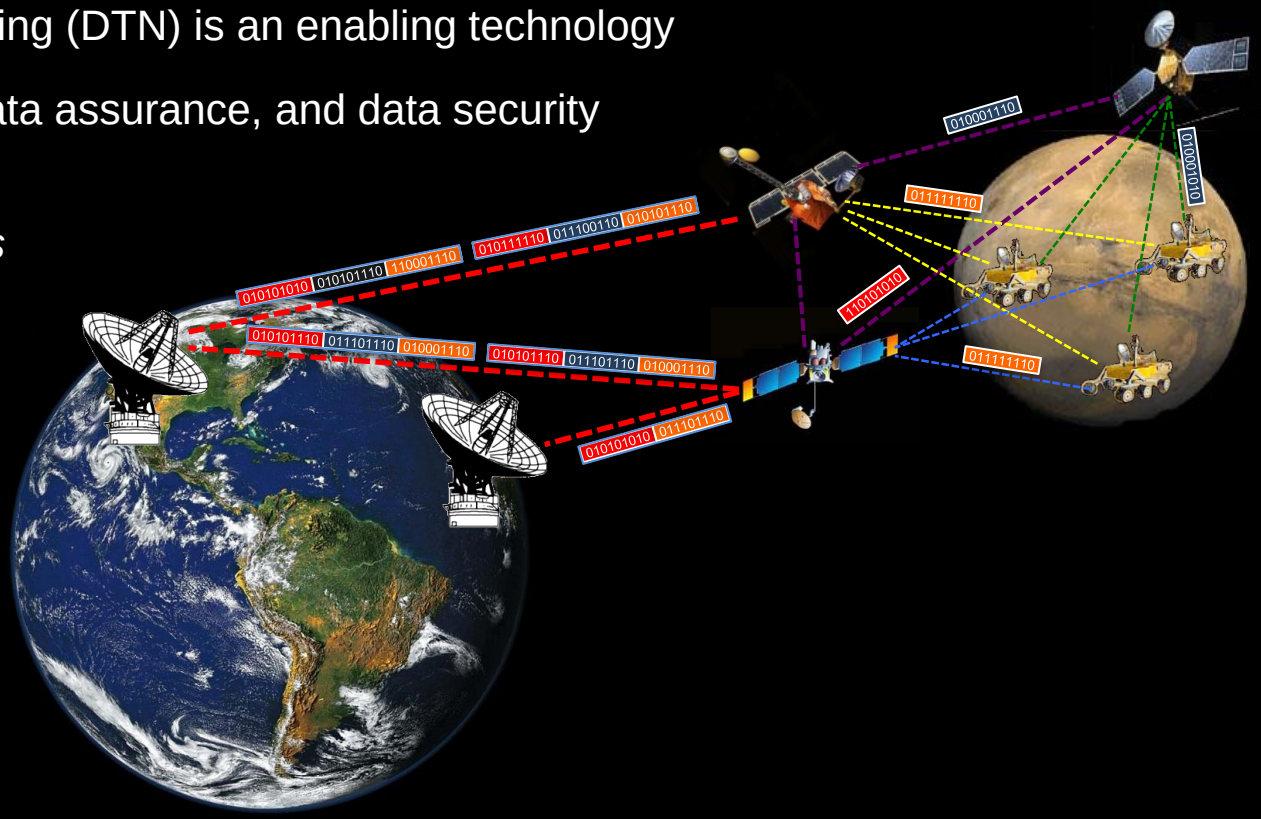
- Viking, Galileo Probe, Huygens, and Philae have taken advantage of this architecture

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



DSN Data Rates: Next 50 Years

Taking all of this into account, here are some likely data rate capabilities for the future DSN

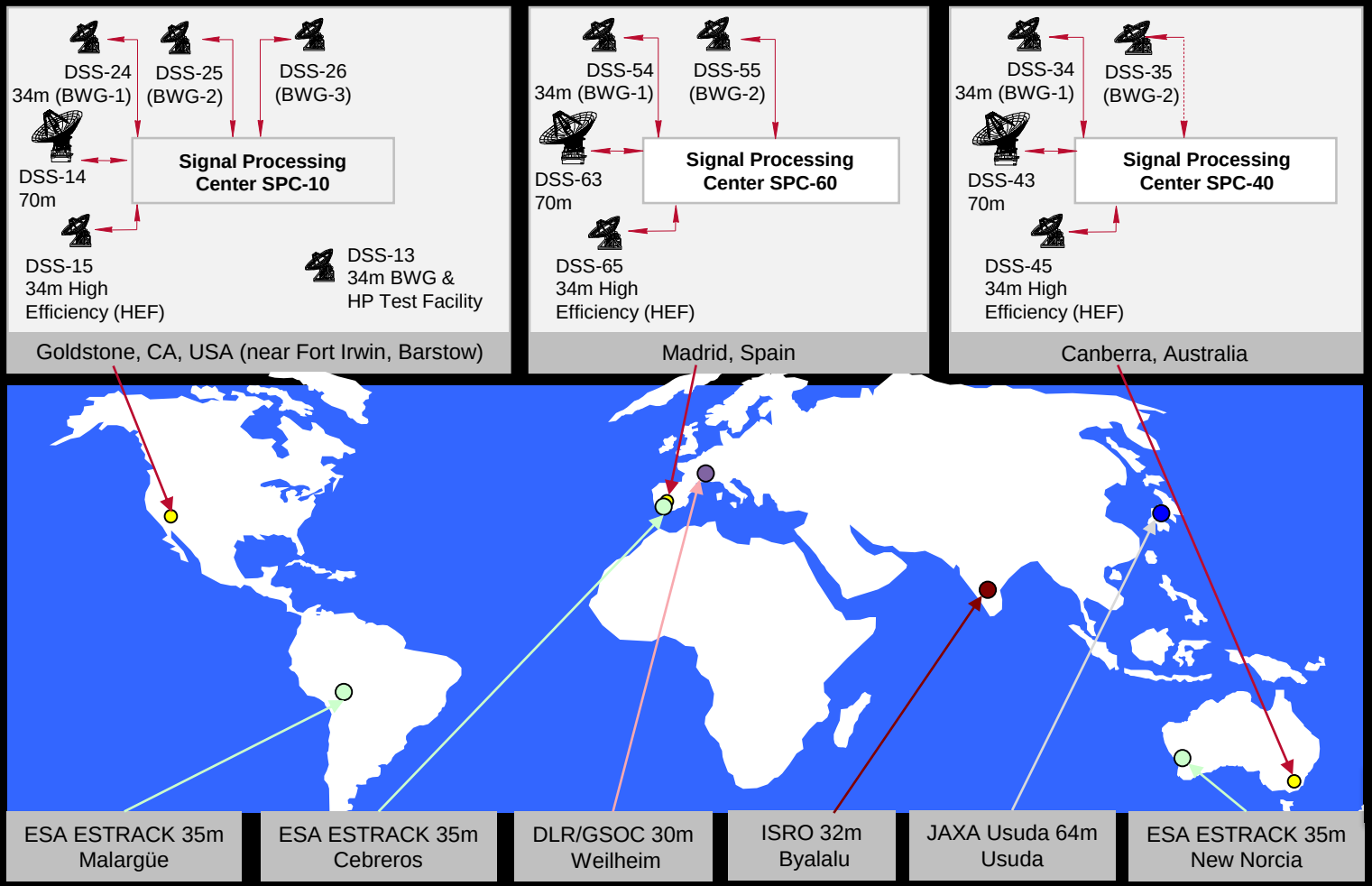
	Distance (AU)	Today (Mbps)			2025 (Mbps)		2035 (Mbps)	2045 (Mbps)	2055 (Mbps)	2065 (Mbps)
DSN Configuration		34m X-band	3 x 34m X-band	34m Ka-band	4 x 34m Ka-band	Optical	Optical	Optical	?	?
Spacecraft Configuration		3m antenna 100 W transmitter 1/6 Turbo code	3m antenna 100 W transmitter 1/6 Turbo code	3m antenna 100 W transmitter 1/6 Turbo code	3m antenna 180 W transmitter 1/2 LDPC code	0.3m optics 10 W transmitter PPM modulation	0.5m optics 50 W transmitter PPM modulation	0.5m optics 200 W transmitter 2nd gen modulation	?	?
Venus (Closest)	0.3	80.0	240	320	2,304	2,800	2.9E+04	2.9E+05	2.9E+06	2.9E+07
Venus (Farthest)	2.4	1.3	3.8	5	36	44	460	4,603	5.E+04	5.E+05
Mars (Closest)	0.6	20	60	80	576	700	7.E+03	7.E+04	7.E+05	7.E+06
Mars (Farthest)	2.6	1.1	3.2	4.26	30.7	37	392	4.E+03	4.E+04	4.E+05
Jupiter	5.4	0.247	0.741	0.99	7.1	8.6	91	909	9,093	9.E+04
Saturn	10.1	0.071	0.212	0.28	2.0	2.5	26	260	2,599	3.E+04
Uranus	19	0.020	0.060	0.08	0.57	0.70	7.3	73.4	734	7,345
Neptune	30.3	0.008	0.024	0.03	0.23	0.27	2.9	28.9	289	2,888

NASA's budget can not accommodate huge increases in DSN investment

We will achieve this through a combination of

- Internal technology and capability development
- Partnering with other parts of NASA, other US agencies, and other space agencies
- Leveraging developments from academia, industry, and other appropriate sources

The Global Community of DSN



Conclusion

- **The DSN has performed well for its 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**
- **As we move into the next 50 years, the DSN and its global brethren will be equally important**
  - **They will benefit from a host of new technologies**
  - **They will give back to society additional knowledge and technologies to benefit society**
- **We look forward to presenting another paper in 50 years about the DSN's first century and what we might expect in the next**