Enabling Rich and Robust Science Data Sets Across the Solar System via Deep Space Communications

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Jet Propulsion Laboratory
California Institute of Technology

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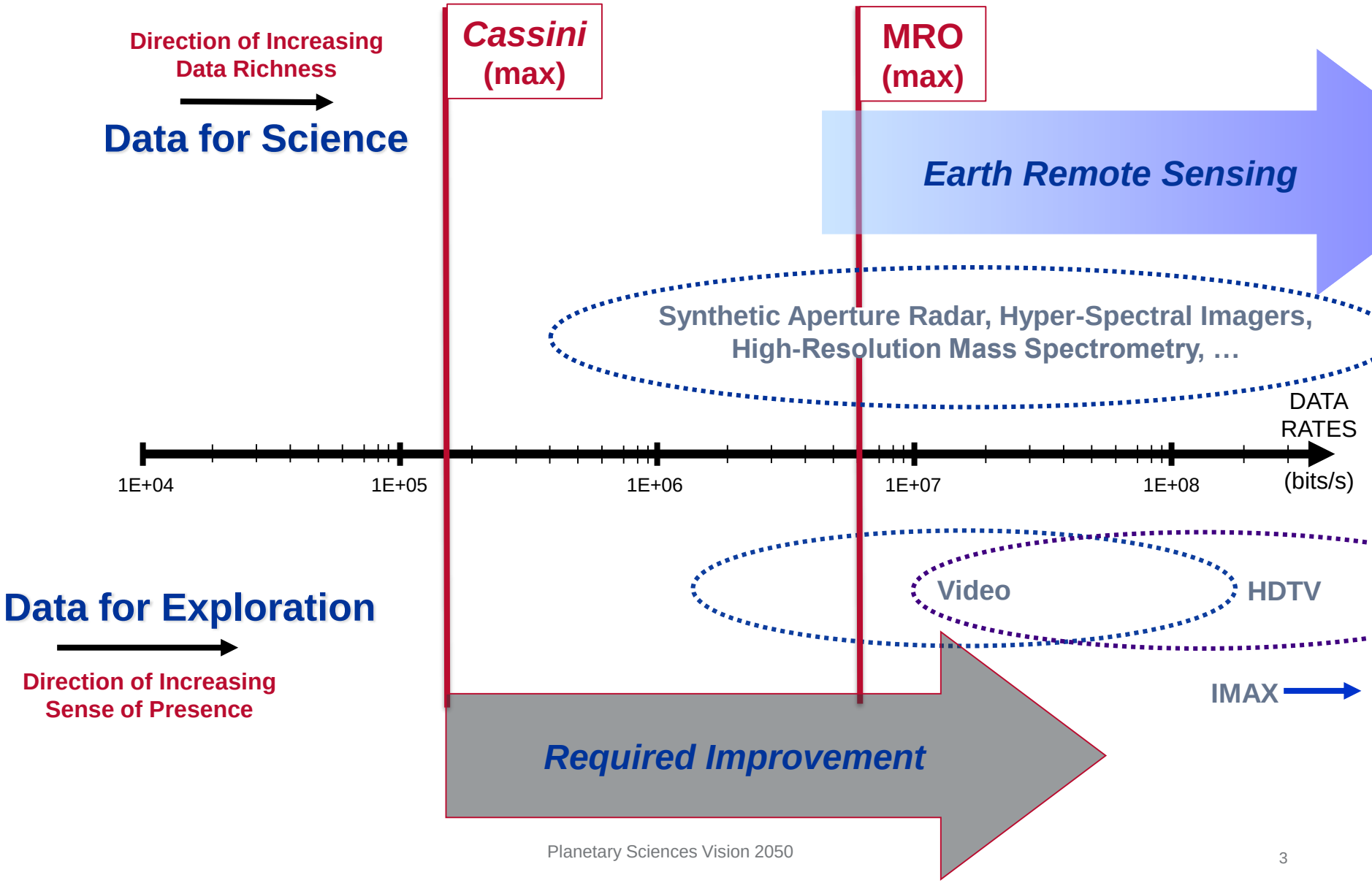
Government sponsorship acknowledged.

Exciting and Ambitious!

We Have a Problem …

Remote Sensing at Other Planets as at Earth



National Aeronautics and Space Administration

Juno

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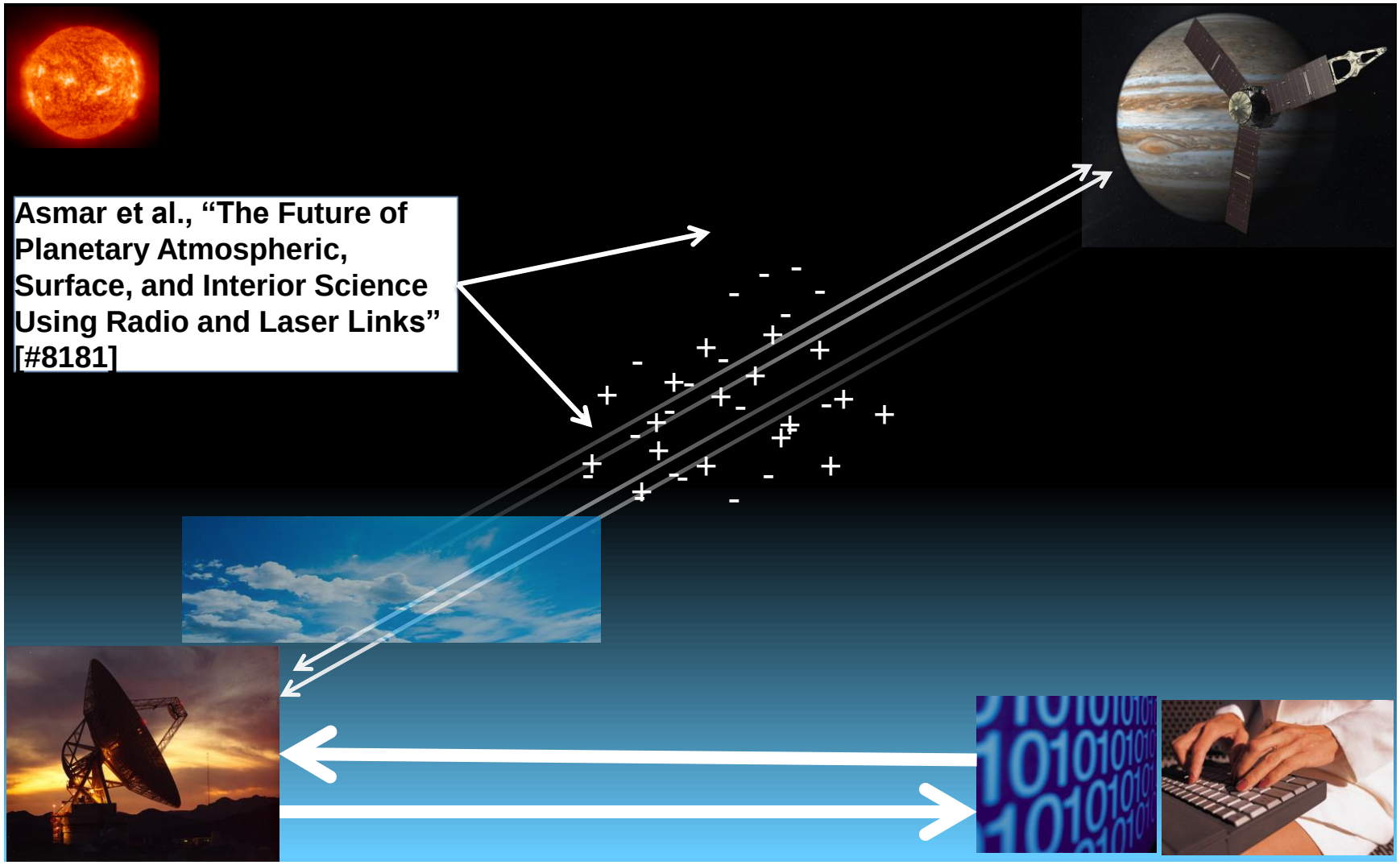
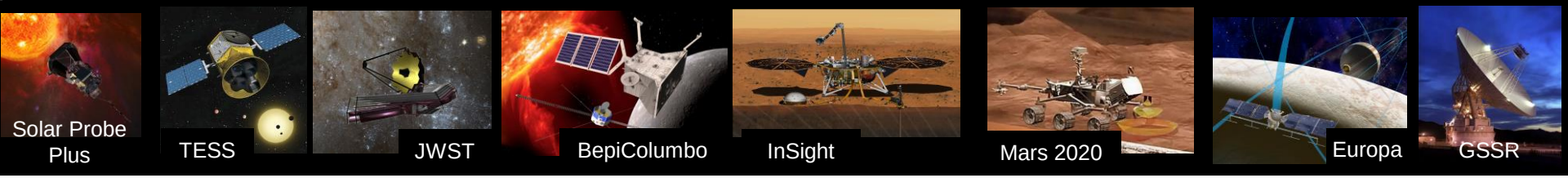
The Deep Space Network View



Deep Space Network

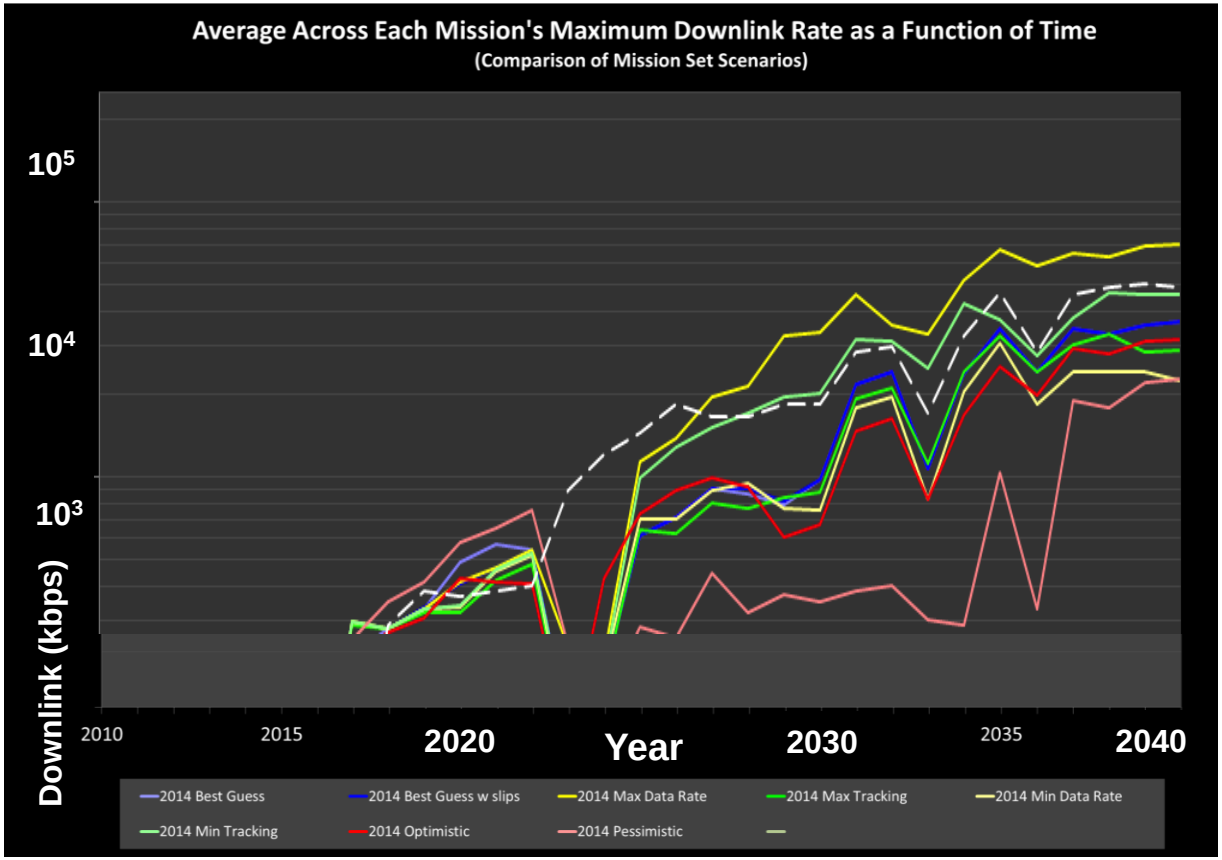
Planetary Sciences-DSN Partnership

Don’t Leave Earth Without Us!



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 ~ 10× data improvement per decade (at least) through 2040**



Decade 0: Improvement over Today

Downlink Maximum

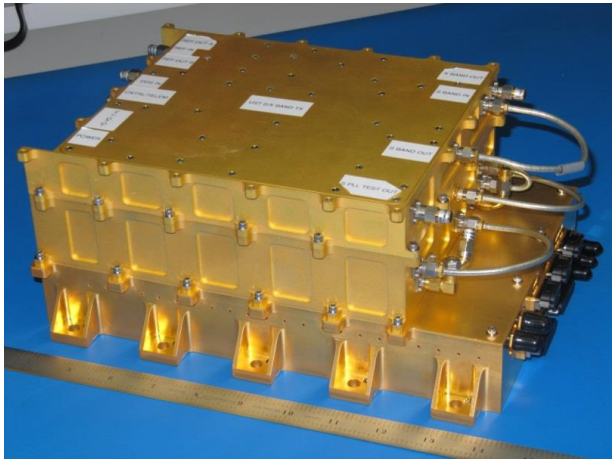
Baseline	Madrid 34 m	Canberra 34 m	Goldstone 34 m
193 Mbps	408 Mbps	540 Mbps	1000 Mbps

- **Assumes**
  - **95% weather conditions (i.e., 95% of the time the atmospheric water vapor is low enough to support the downlink at the required downlink data rate)**
  - **10° elevation**
  - **3 dB margin**
- **Fixed signal-to-noise ratio enables higher downlink data rate**
  - **Download same data volume in less time; or**
  - **Download more data in same time**

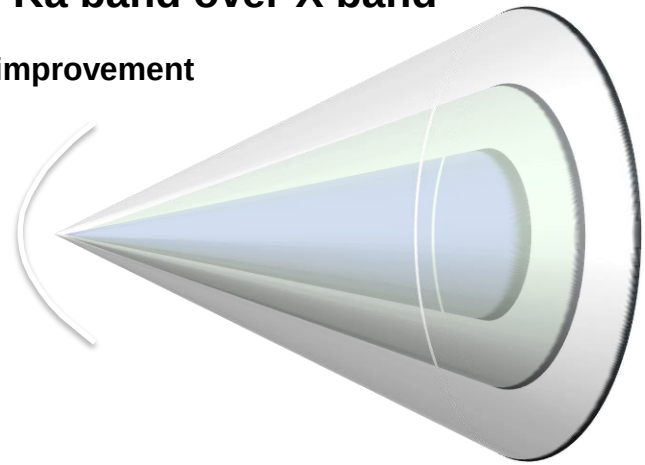
*** 802.11n wi-fi protocol supports 600 Mbps**

Decade 1: 10× Improvement over Today

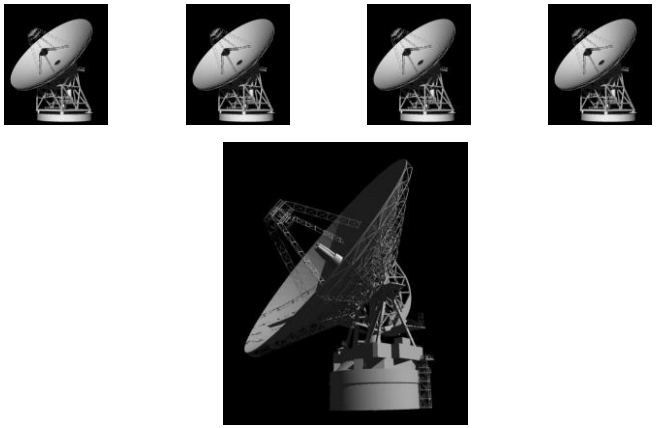
- **Remove bottlenecks on spacecraft and DSN**
  - **Universal Space Transponder (UST)**
  - **Common Platform DSN signal processor**



- **Increase use of Ka band over X band**
  - **Factor of ~ 4× improvement**

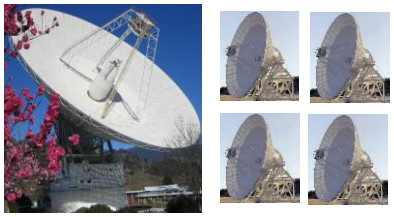


- **Antenna arraying**
  - **DSN Aperture Enhancement Project emplacing additional 34m antennas**
  - **Provides backup for 70m capability as well as arraying beyond 70m**



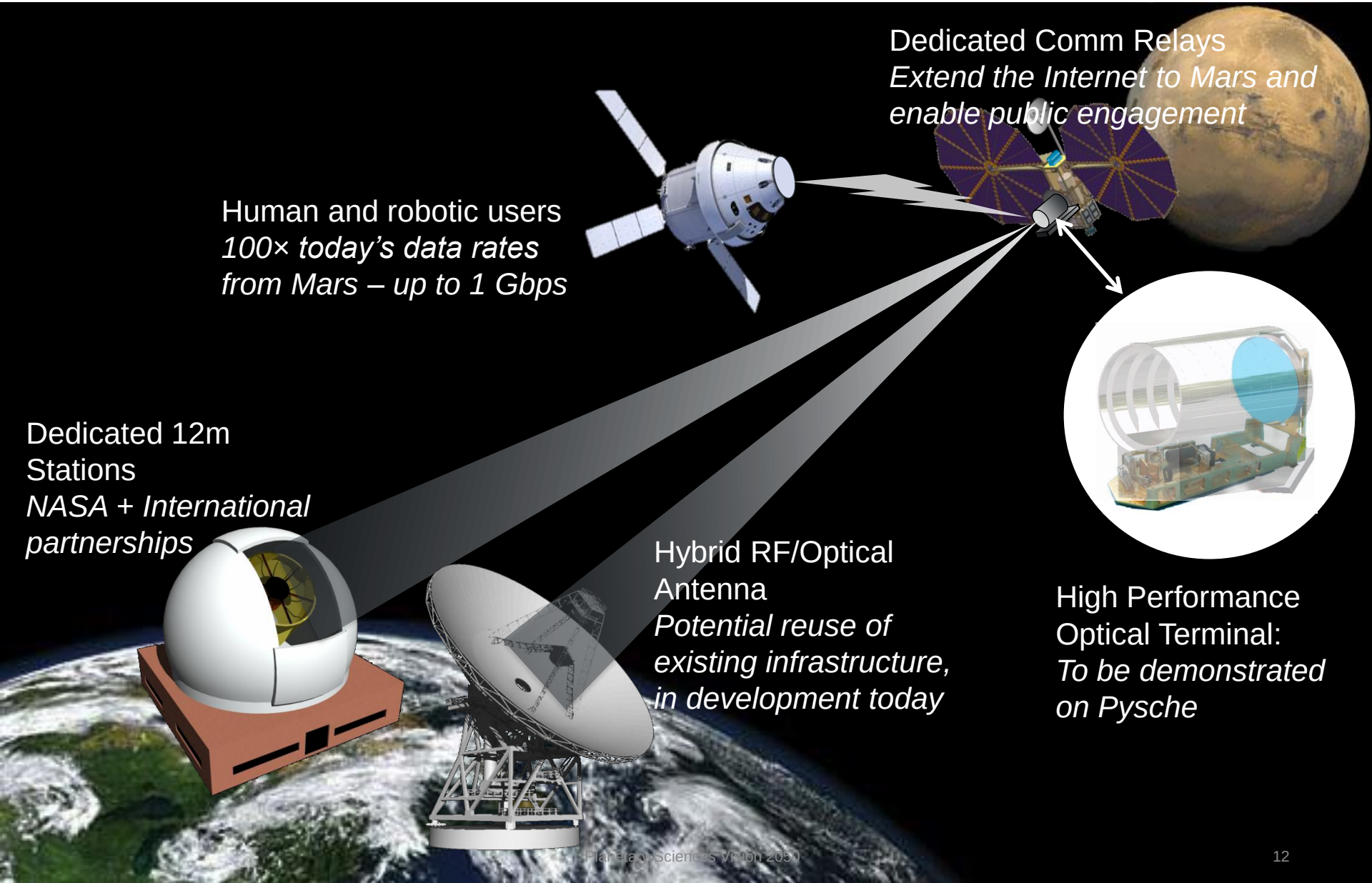
Deep Space Network

DSN Aperture Enhancement Project (through 2025)

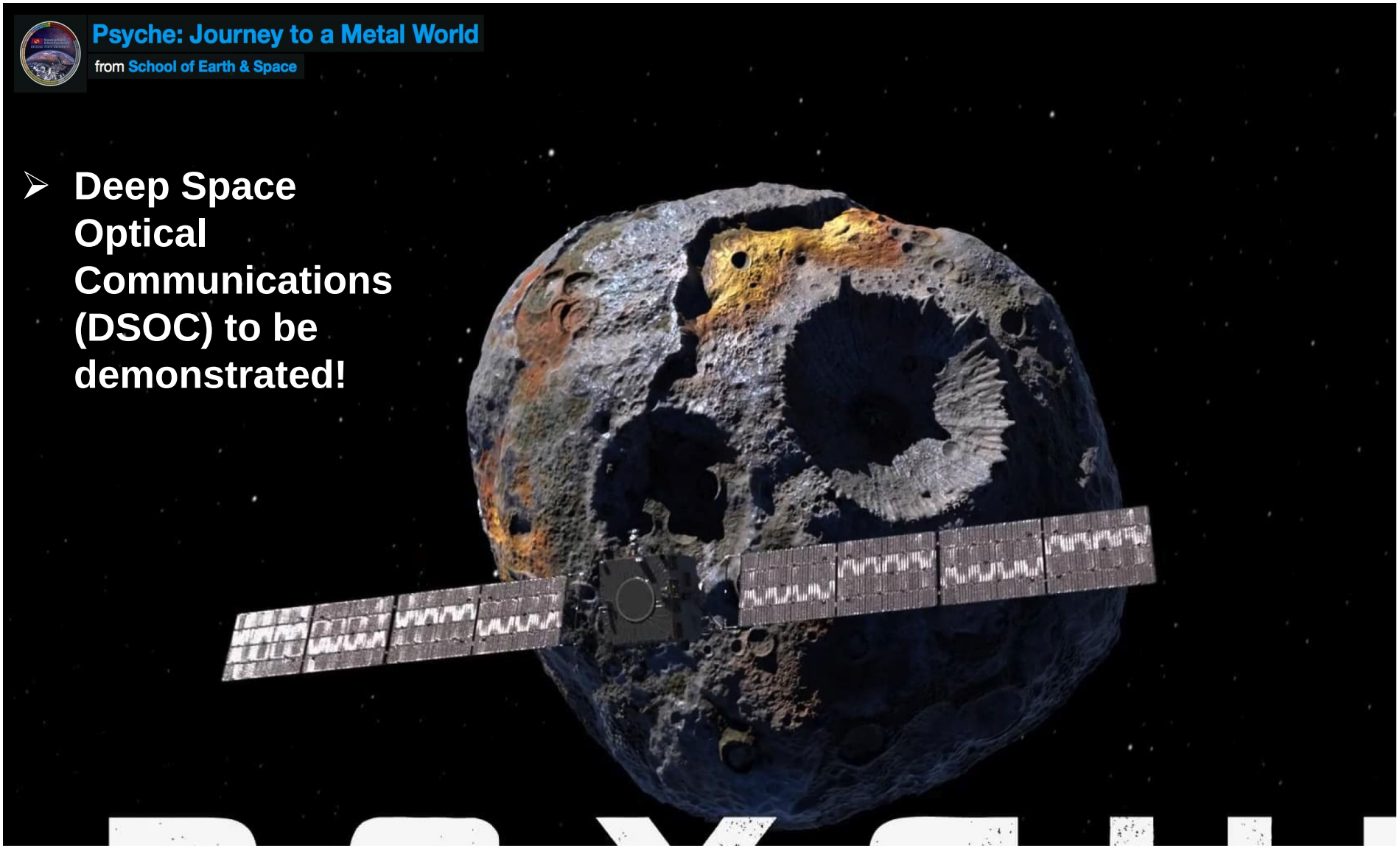


Canberra **Goldstone** **Madrid**

Decade 2+: 100× Improvement over Today



Laser Communication

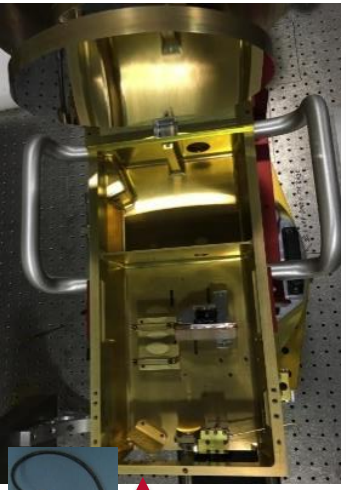


- Deep Space Optical Communications (DSOC) to be demonstrated!

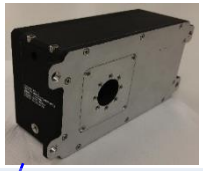
DSOC Technologies & Advances

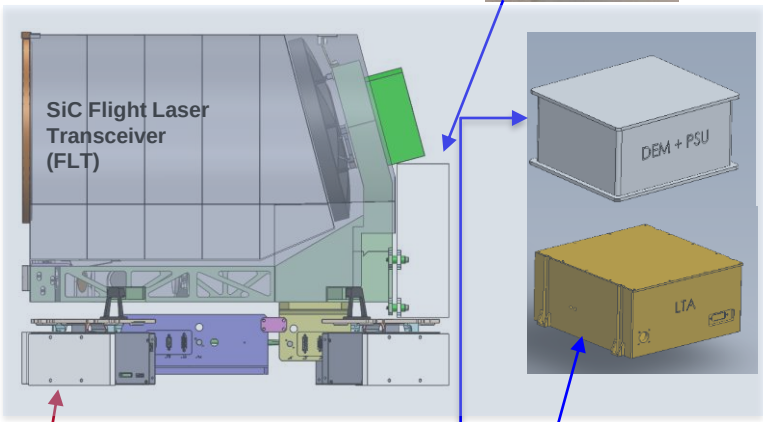
FLIGHT LASER TRANSCEIVER (FLT)

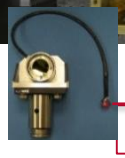
Aluminum Optical Transceiver Assembly



Photon-Counting Camera

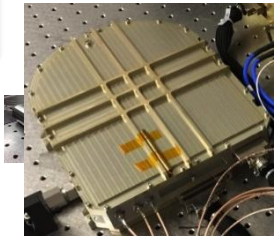




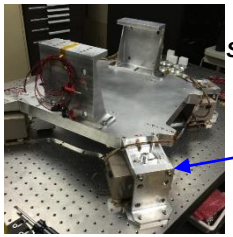


Point-Ahead Mirror

flight-like electronics



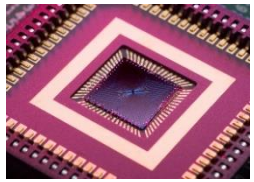
Laser Transmitter
Average Power 4 W



Single strut photo

Isolation Pointing Assembly

GROUND TECHNOLOGY

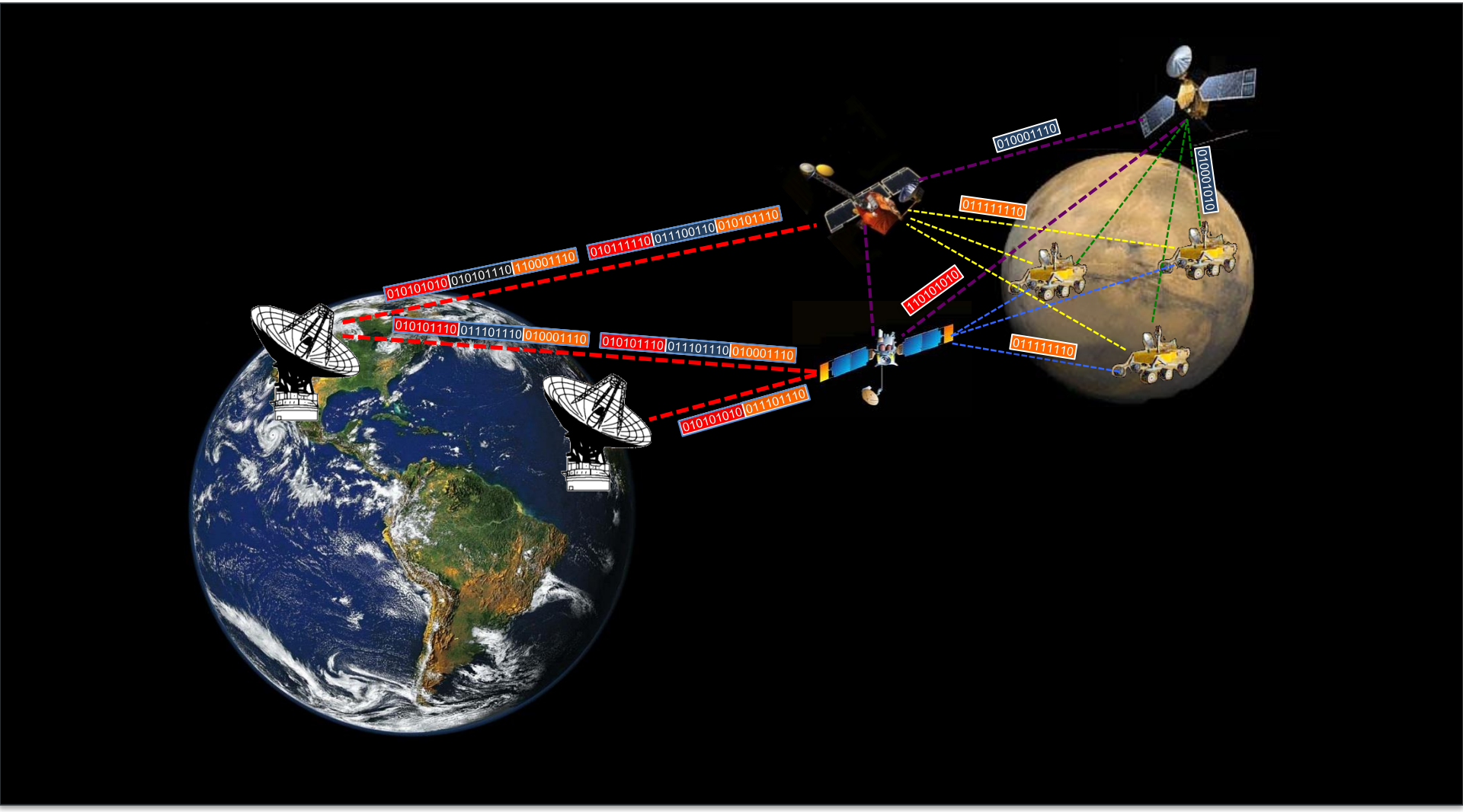


Packaged Nanowire Array

Electron microscope detail of 320 µm active area tungsten silicide (WSi) superconducting nanowire single photon detector (SNSPD) array

The DSN and the Interplanetary Internet

Extends today's Internet across the Solar System

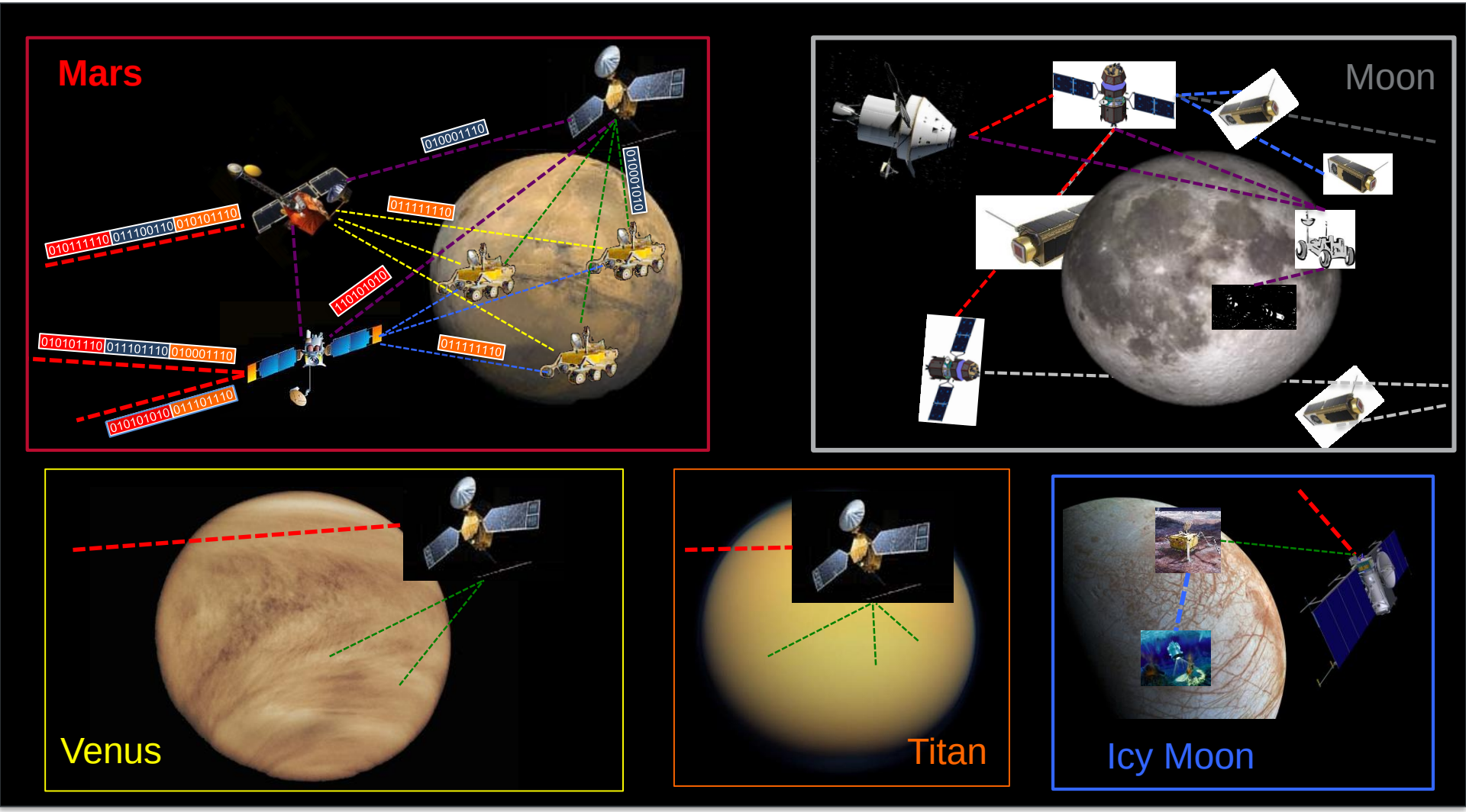


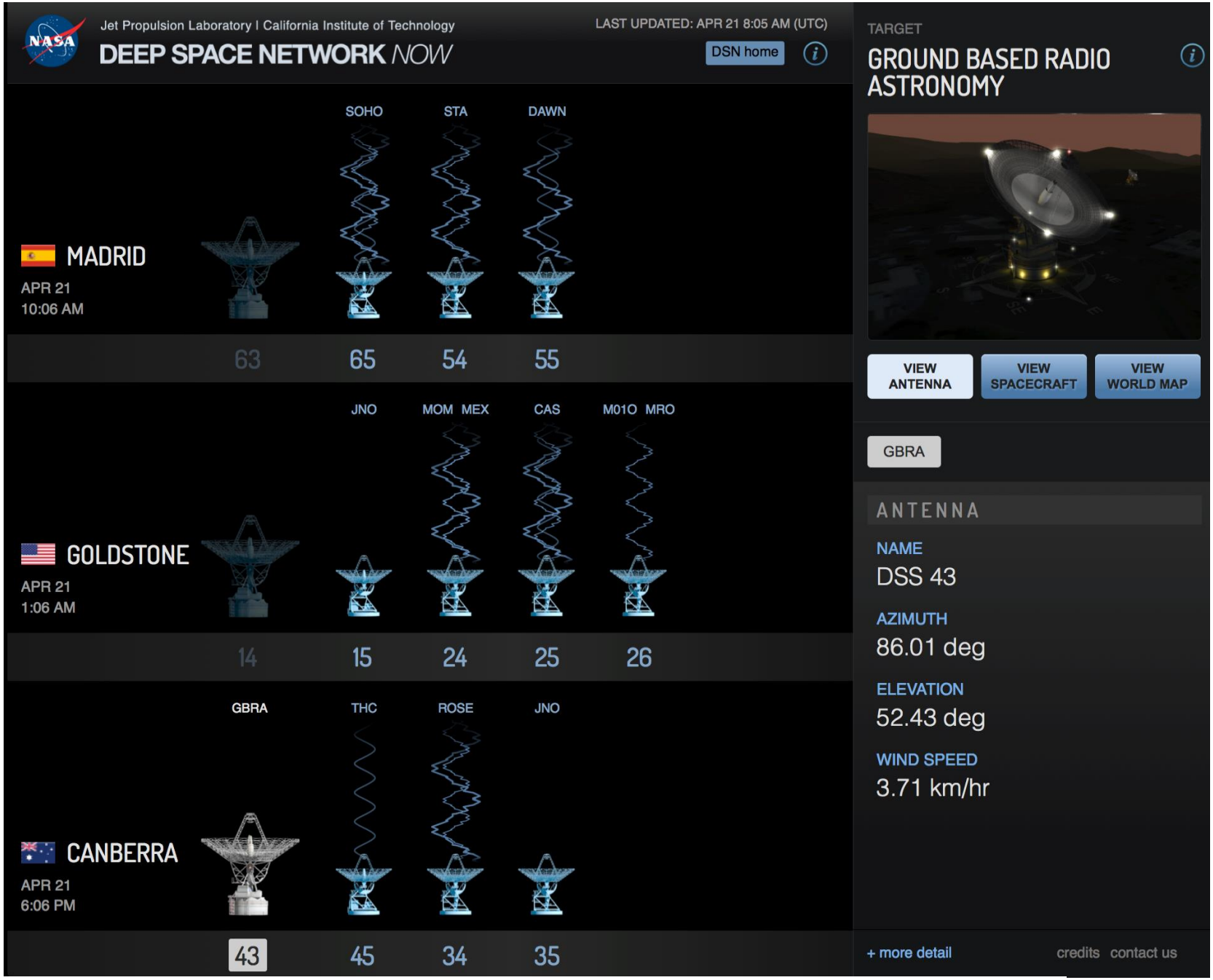
Strata at Base of Mt Sharp

Indicates flow of water before the mountain formed

The DSN and the Interplanetary Internet

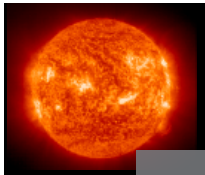
Extends today's Internet across the Solar System



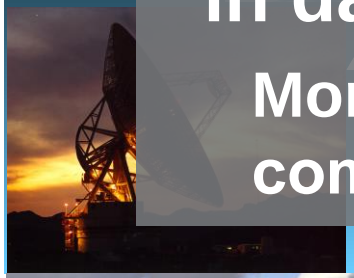


http://eyes.nasa.gov/dsn/dsn.html

Conclusions

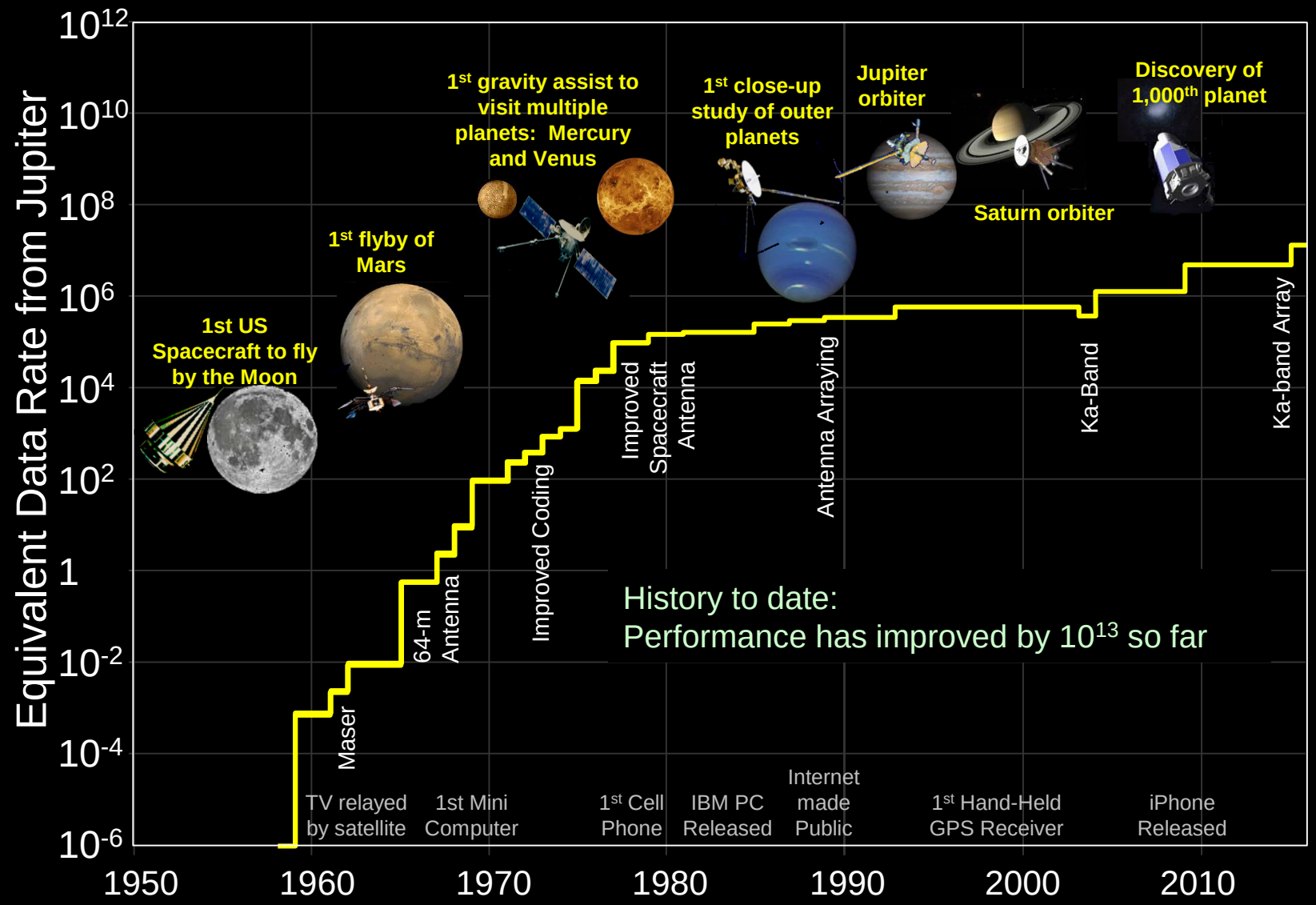


- Ambitious science missions realized iff sufficient data returned
- Deep Space Network technologies in hand or nearly so for significant improvements in data transport
  - More antennas, Ka band, laser communication, …

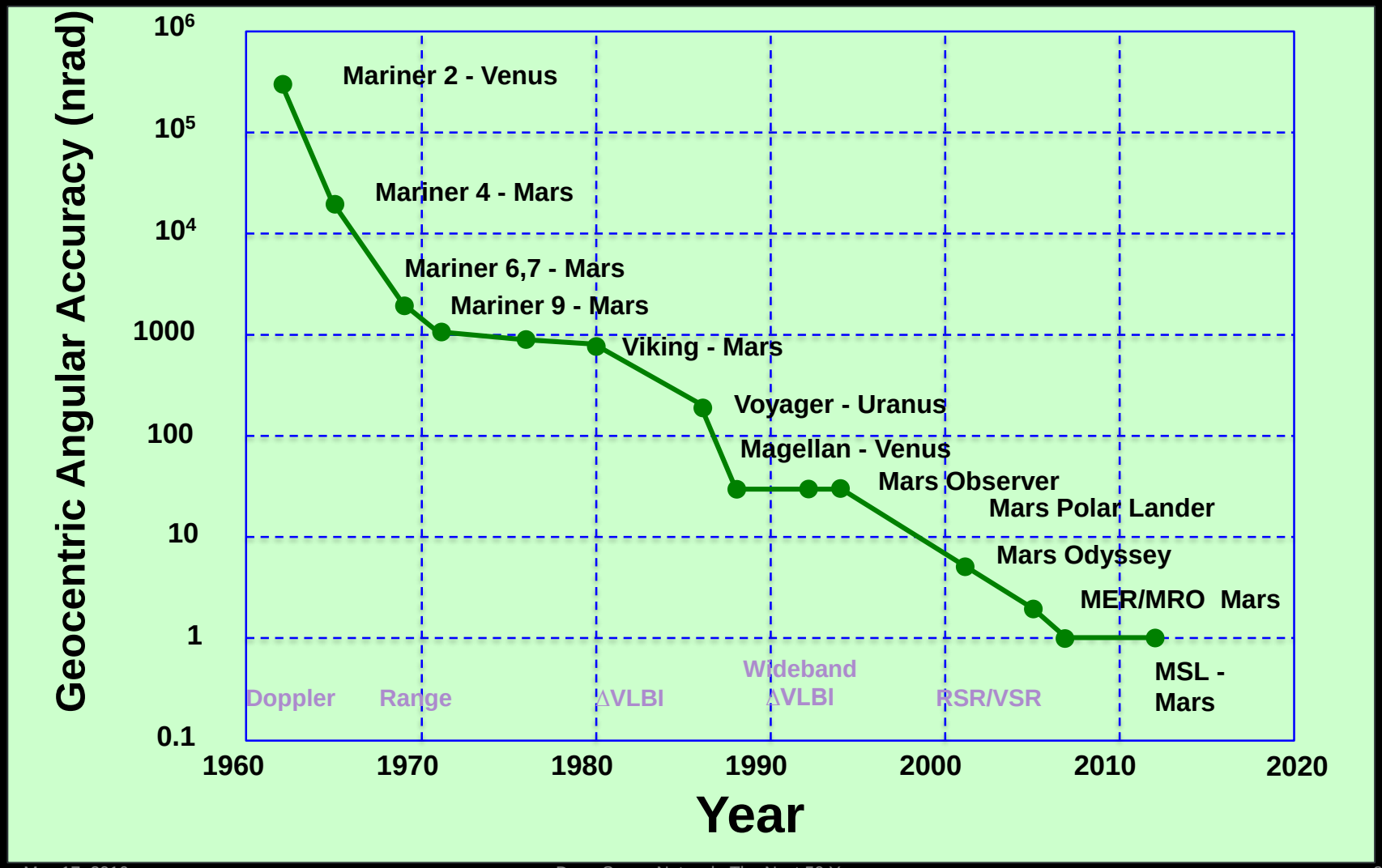


BACKUP

History of Downlink Difficulty

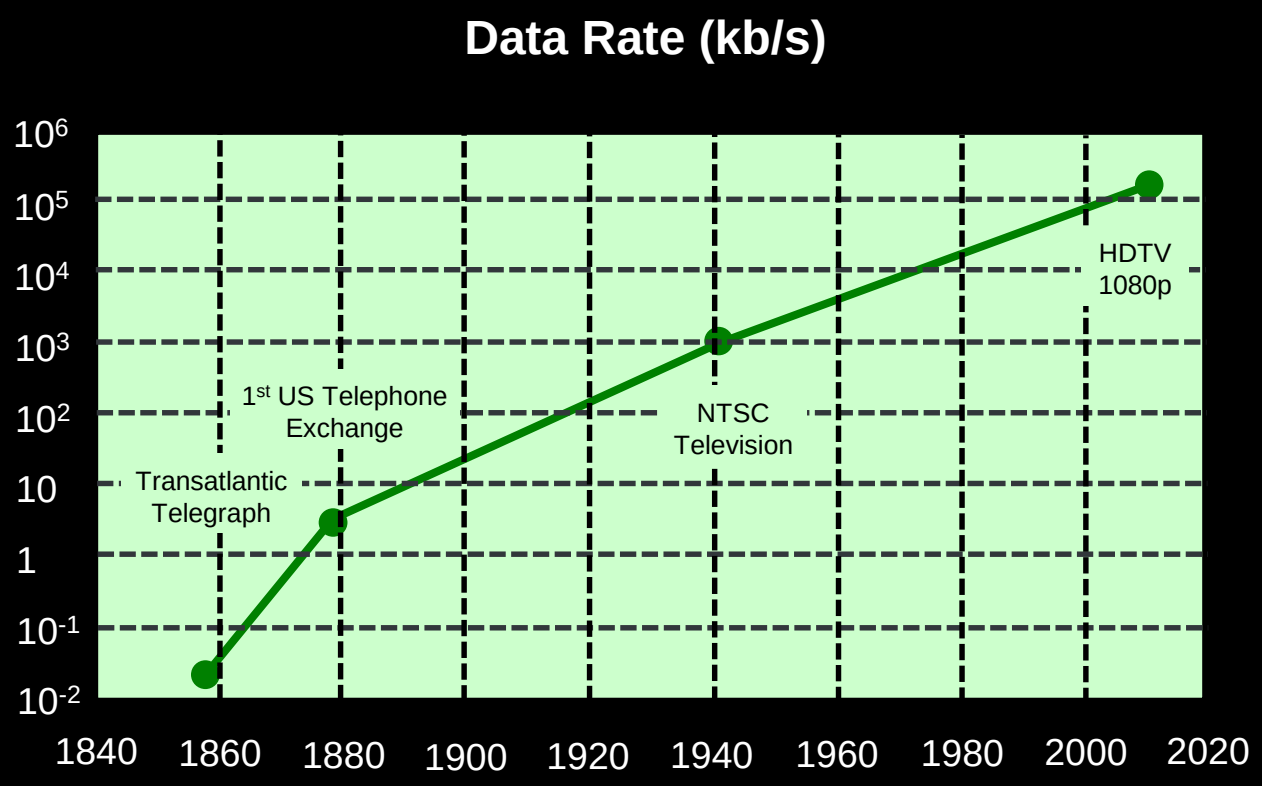


History of Navigational Angular Accuracy



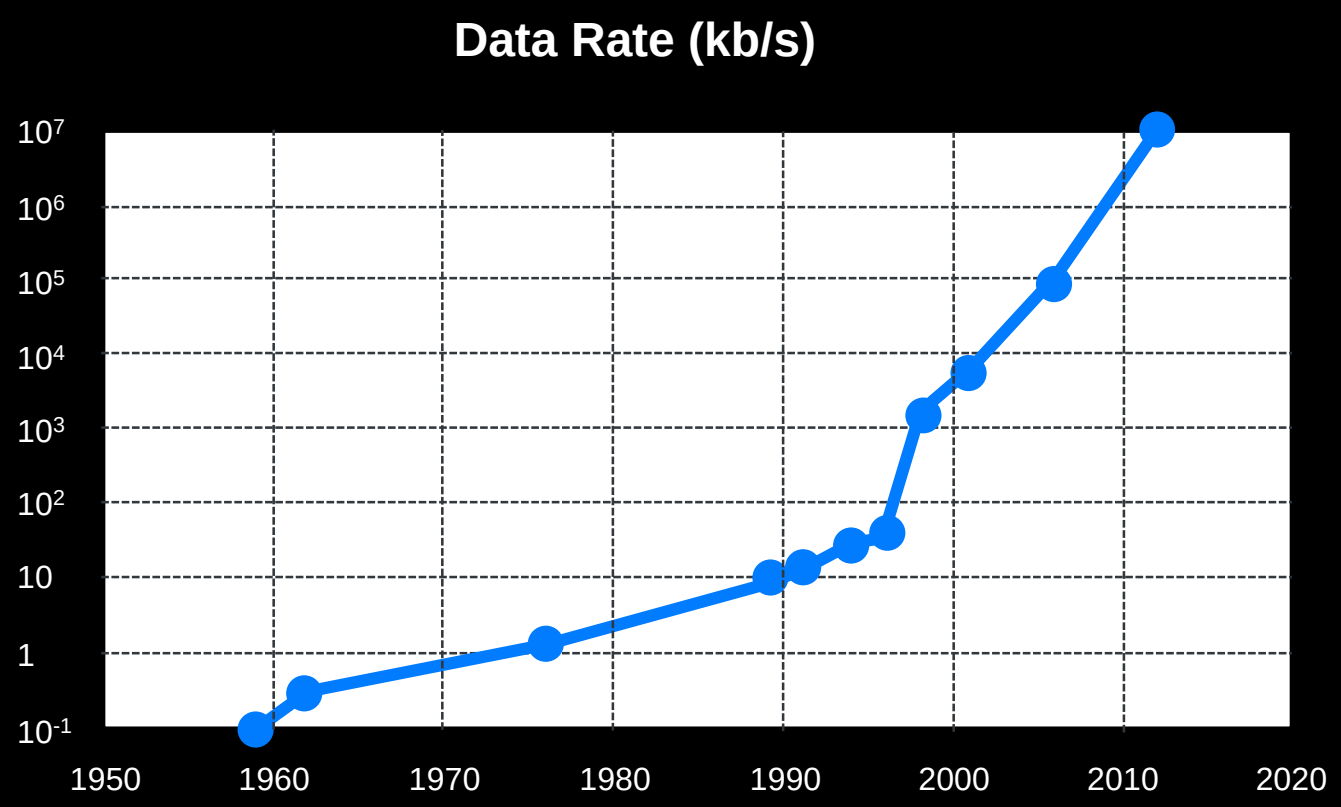
Long Term Communications Trend

- 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

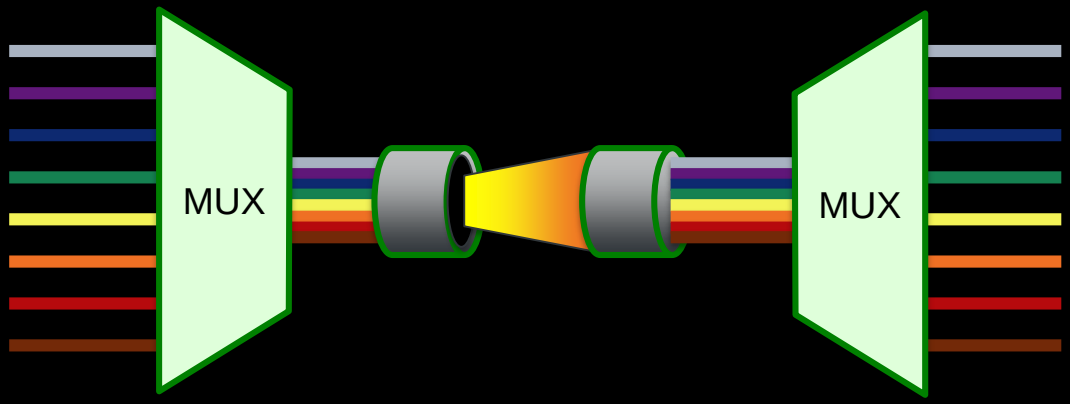
- Consider the trend in digital communications since the Internet was invented
- This trend is ~1.3 orders of magnitude per decade
- We believe spacecraft data needs will grow similarly – so we will use 1.0 orders of magnitude per decade



Decade 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

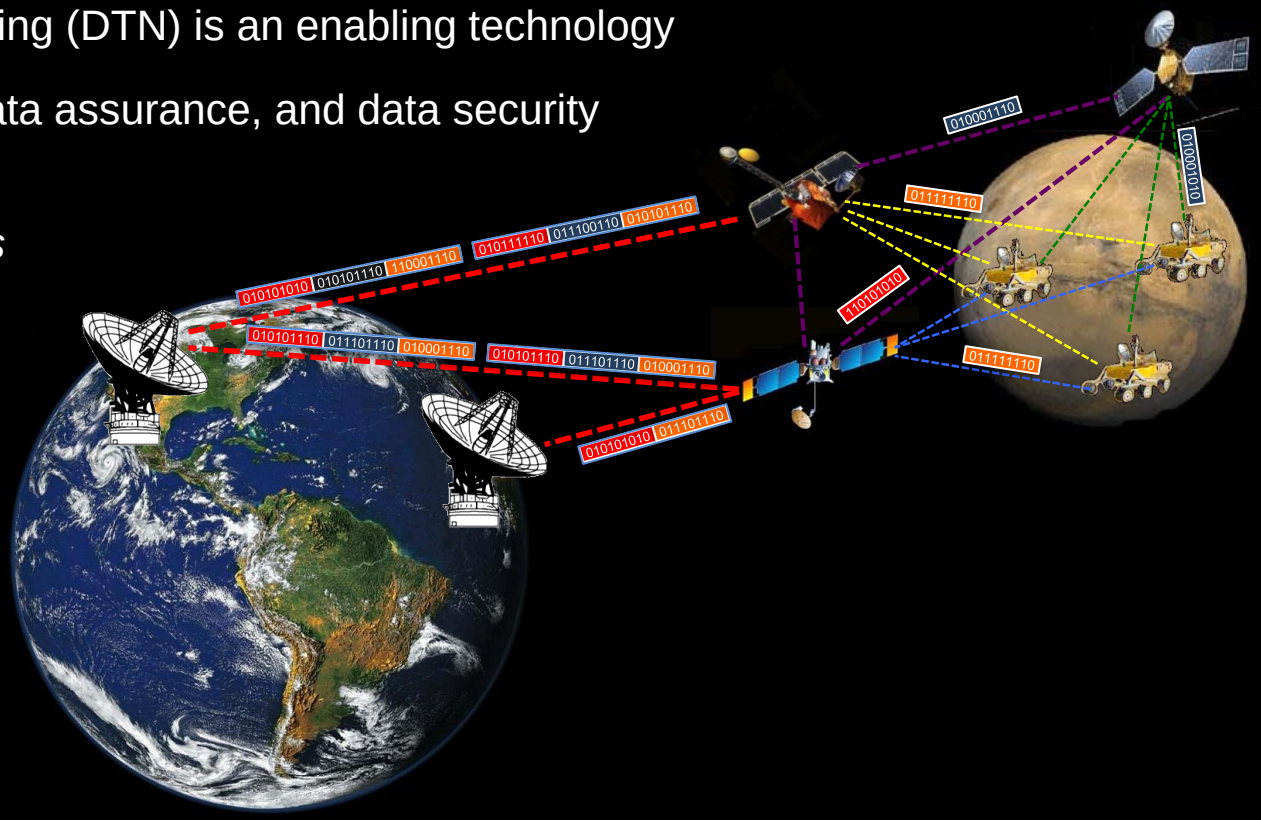
- Viking, Galileo Probe, Huygens, and Philae have taken advantage of this architecture

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

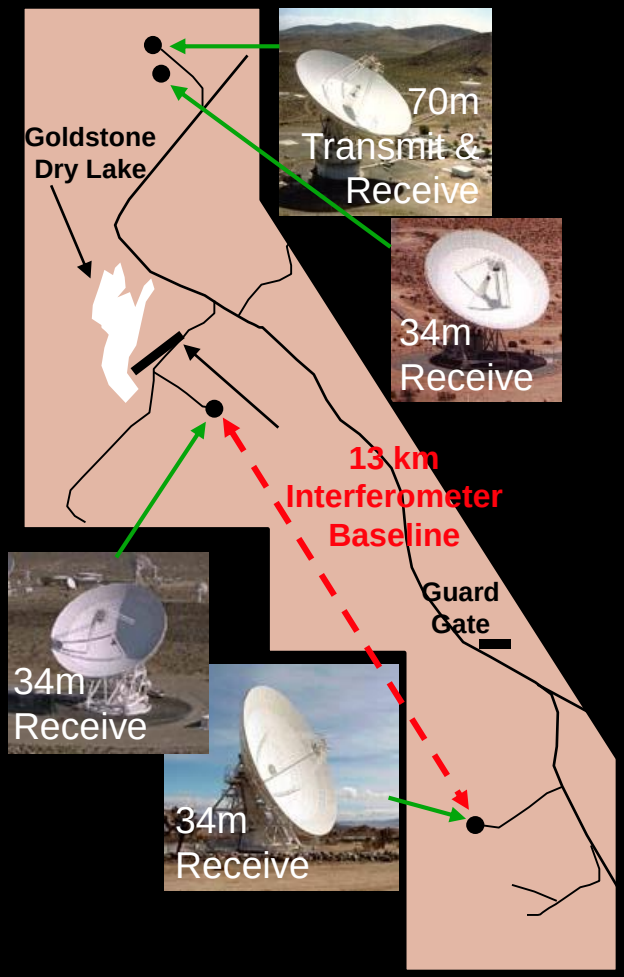
Taking all of this into account, here are some likely data rate capabilities for the future DSN

	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 Goldstone Radar

- Unique for high-res ranging and imaging of planets, small-bodies
  - 500 kW X-band transmitter
  - Can be used with Arecibo
- Wide variety of science
  - Surfaces: images, topography, ice, physical characteristics, chemical composition
  - Dynamics: Orbits, rotations, spin axes
- Mission use
  - Landing site evaluation, emergency support, …
  - Mission science support
- NASA approved science investigators