

Towards Using Laser Communications for High Rate Data Return from the Planets

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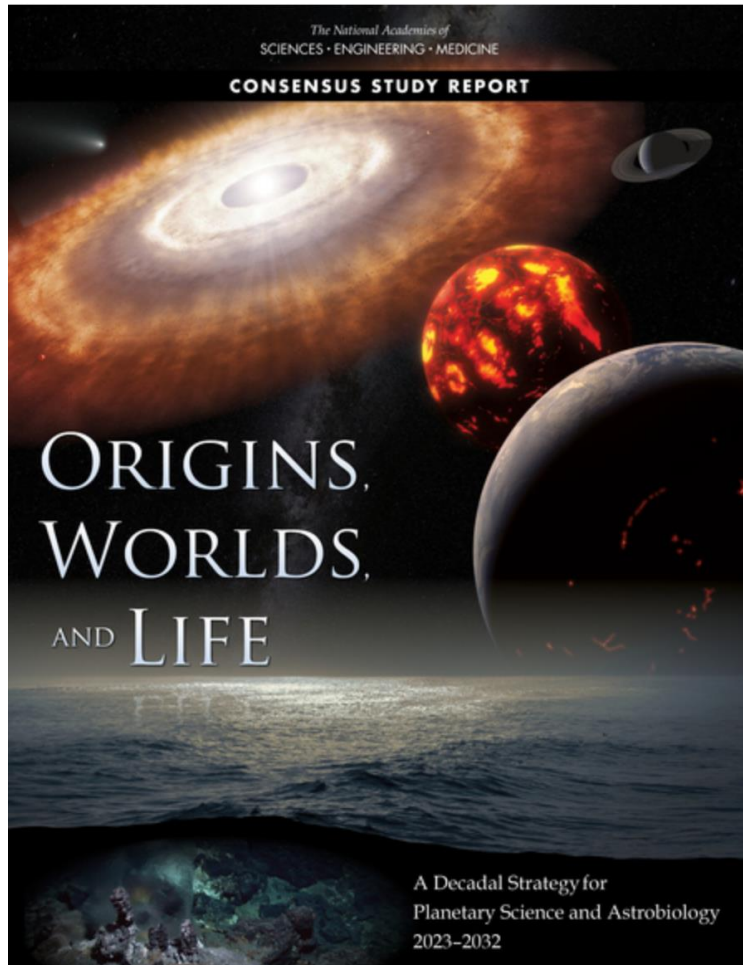
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We Have Visited All the Planets

**But there is still
much to learn,
especially about
the outer-most
planets**



Planetary Science and Astrobiology Decadal Survey



- Published by National Academies, 2023
- Includes recommendations for planetary science mission development in 2023-2032



Decadal Survey Proposals

Large (“Flagship”) missions

Committee prioritized 6 candidate large missions

**Outermost
planets**

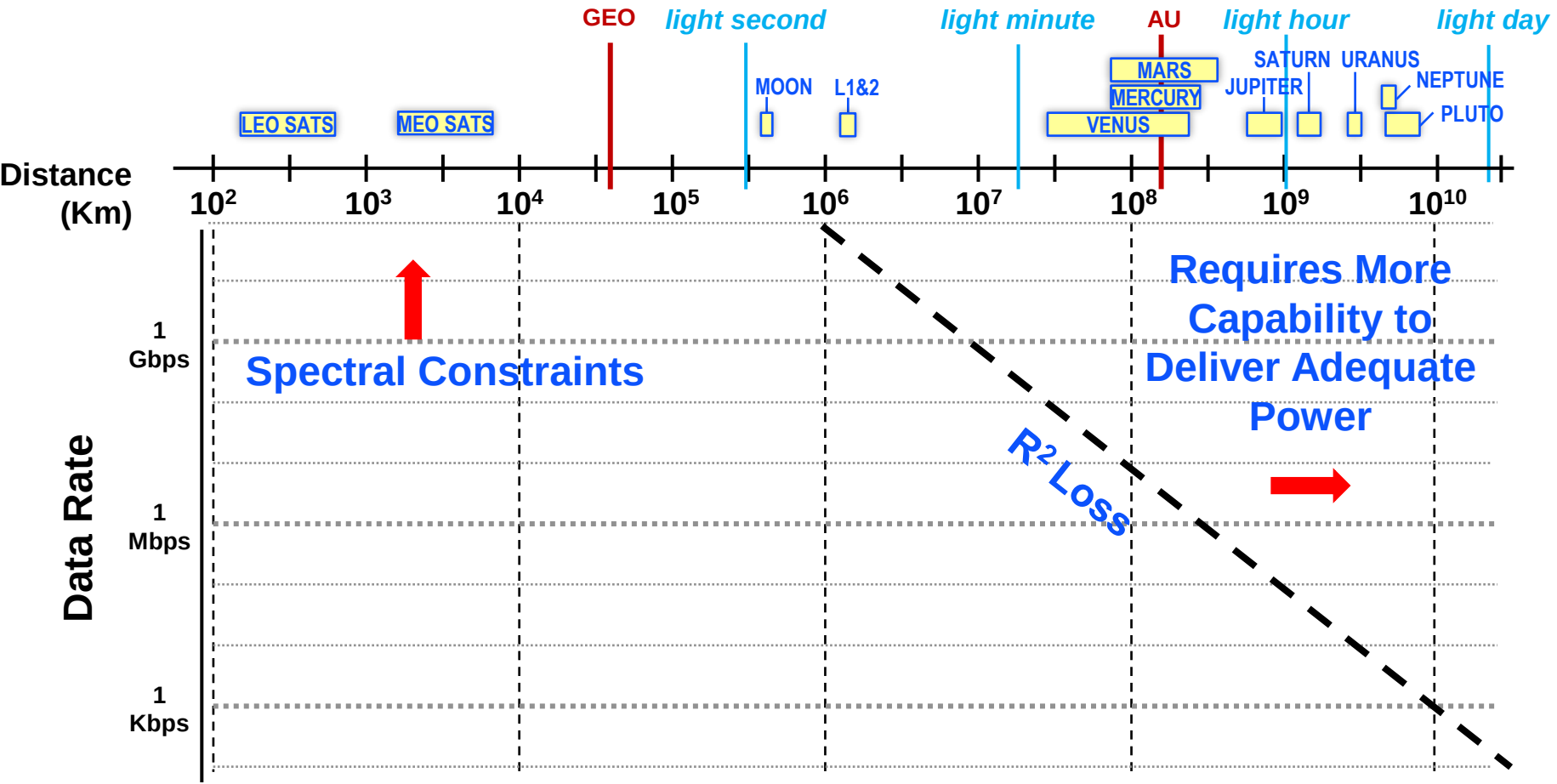


- Enceladus Orbilander
- Europa Lander
- Mercury Lander
- Neptune-Triton Odyssey
- Uranus Orbiter and Probe
- Venus Flagship

Image Credit: NASA



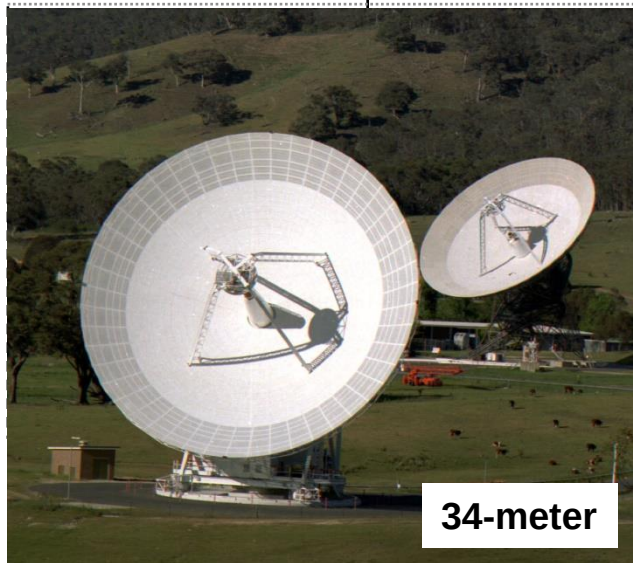
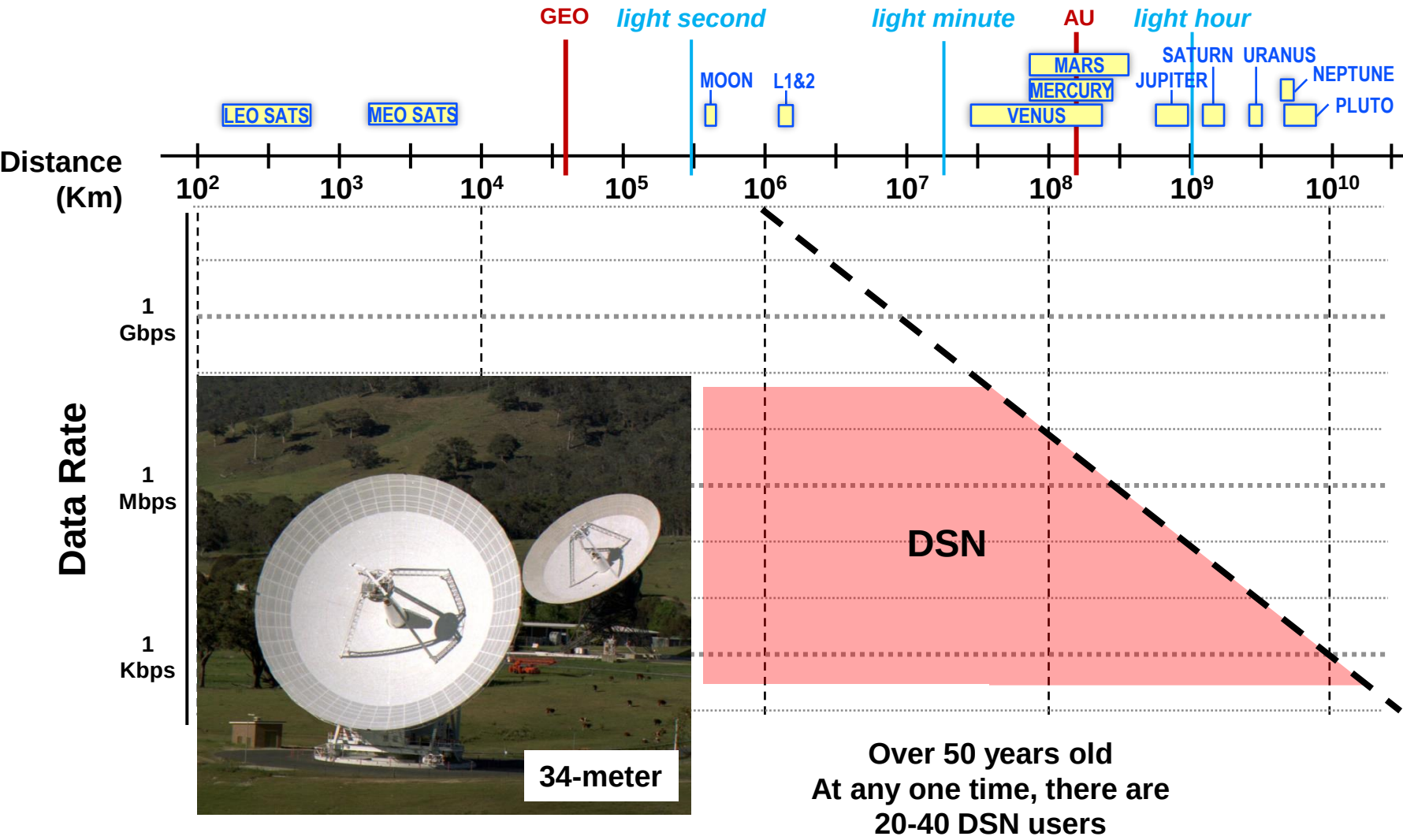
Communication Links to Great Distances





Communication Links to Great Distances

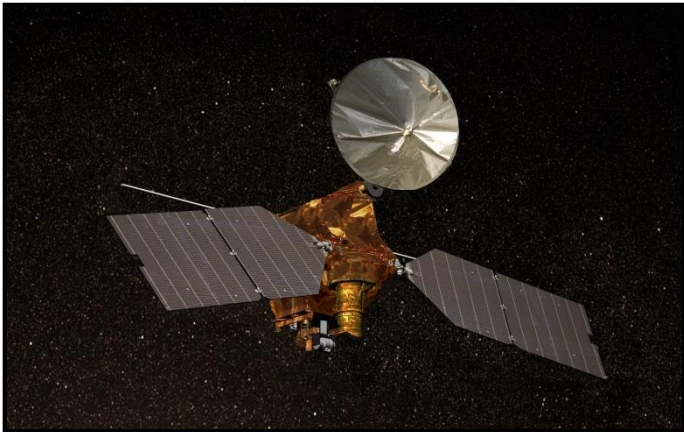
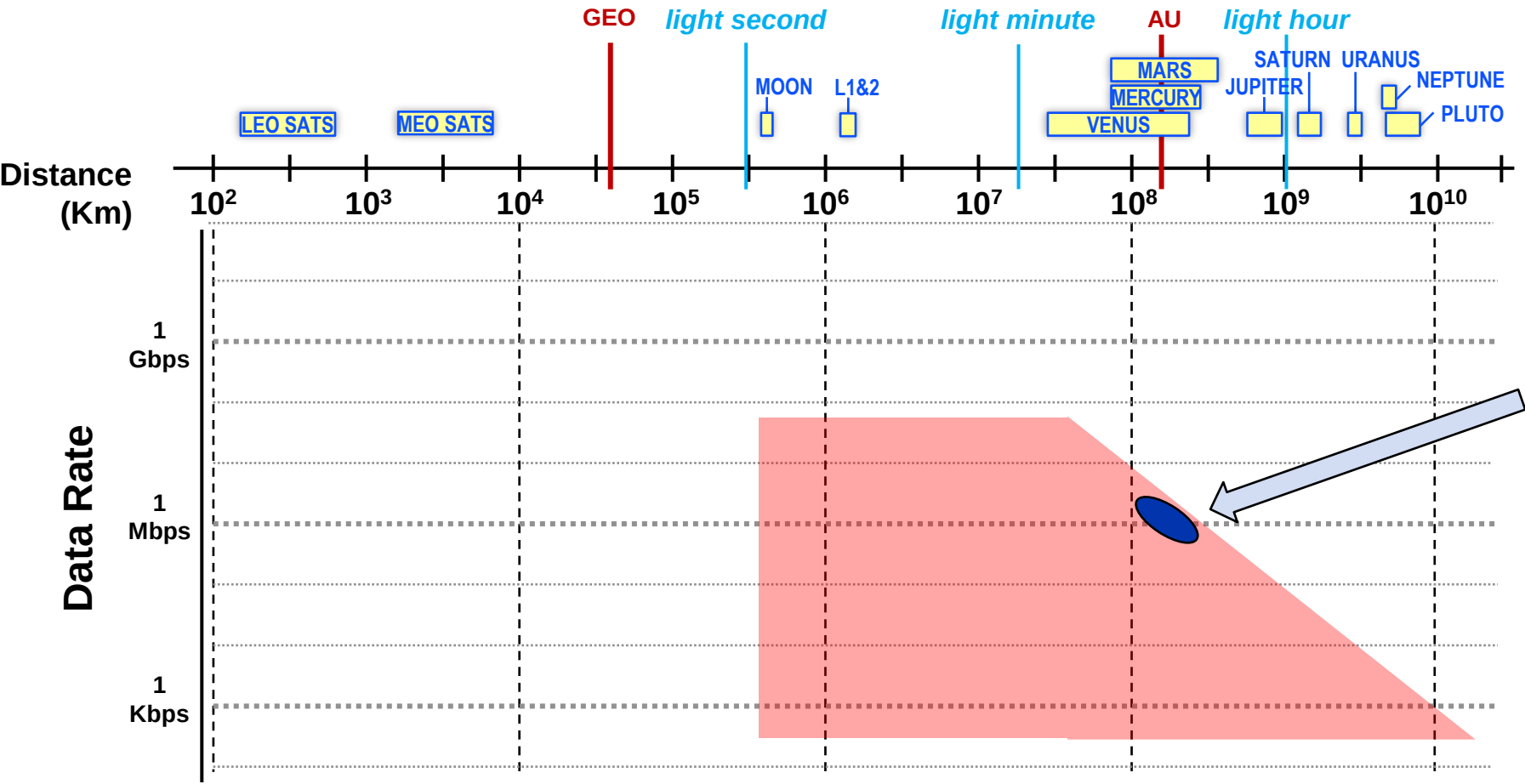
The NASA Deep-Space Network





Communication Links to Great Distances

The NASA Deep-Space Network – Missions

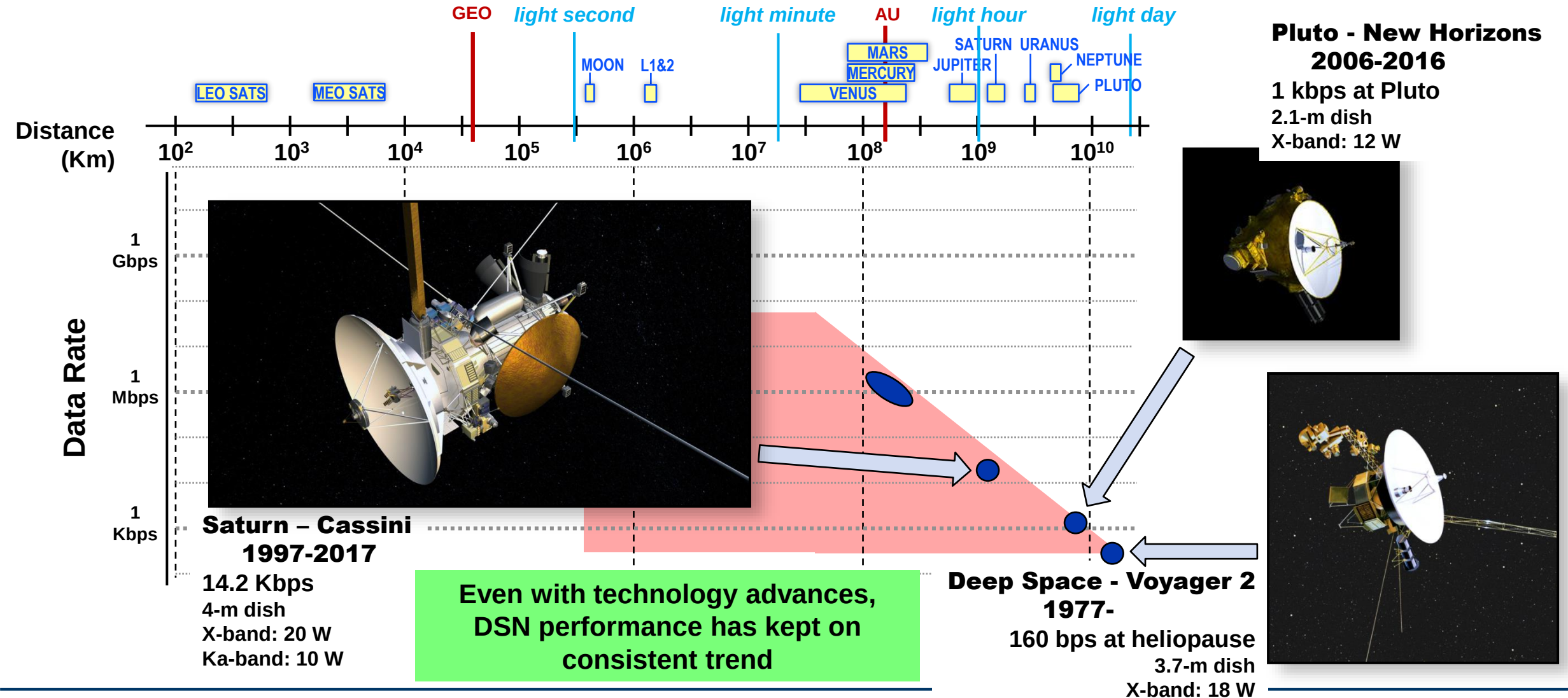


Mars – MRO
2005-
2.6 Mbps (1-6 Mbps)
3-m dish
Ka-band: 35 W
X-band: 100 W



Communication Links to Great Distances

The NASA Deep-Space Network – Missions



Highest priority new flagship: Uranus Orbiter and Probe

- In situ probe & multi-year orbital tour: atmosphere, interiors, magnetosphere, rings, and satellites
- First dedicated study of class of planets that may be most common in the universe
- Technically ready to start now
- Launch on Falcon Heavy Expendable
 - **Optimal launch in 2031-2032 with Jupiter gravity assist to shorten cruise to 12 to 13 yrs**
 - Flexible launch opportunities through 2038 with increased ~ 15 yr cruise and inner solar system gravity assists
- Strong international interest & potential for partnership (e.g., 2021 report of ESA's Voyage 2050 Senior Committee)

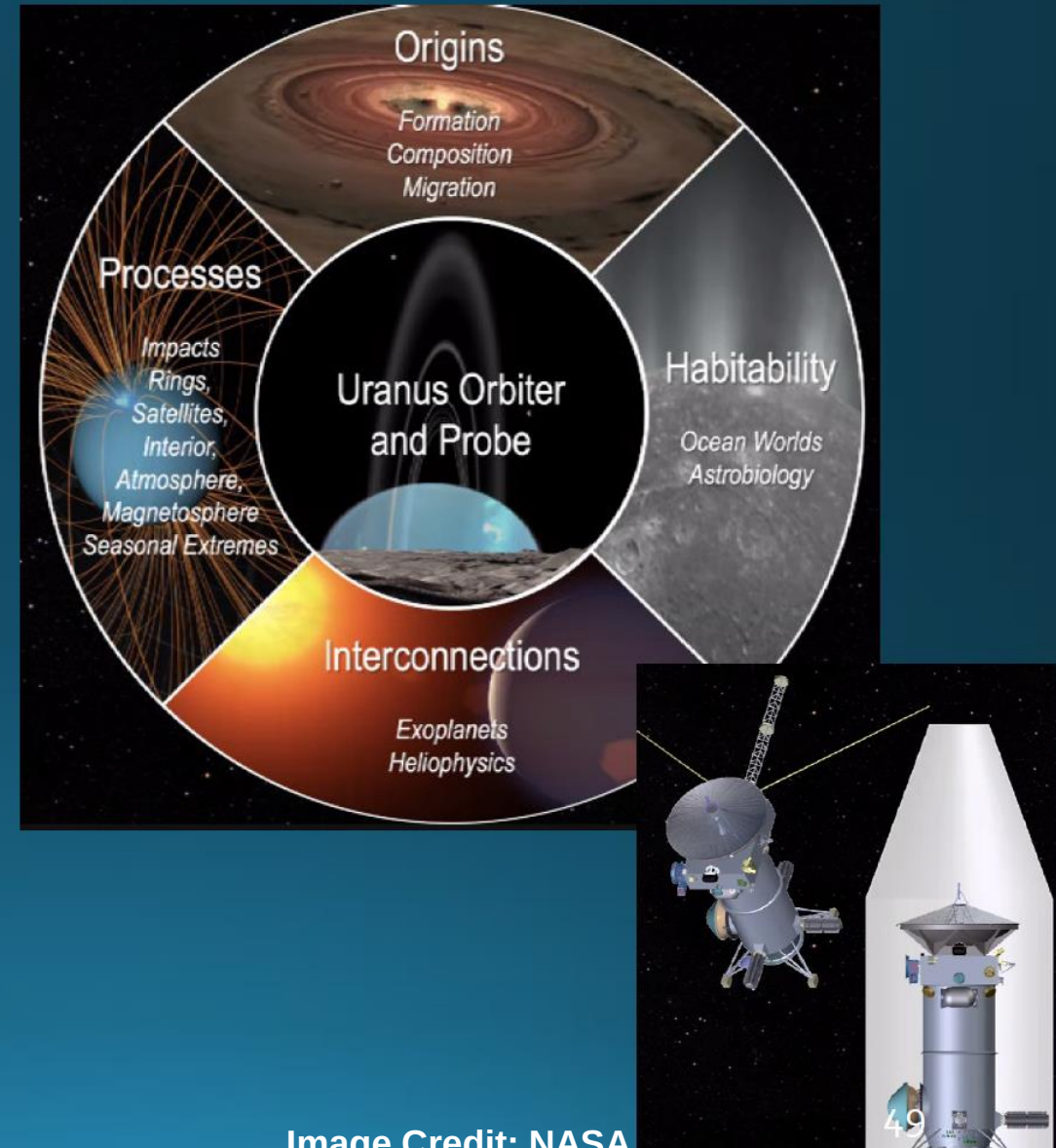
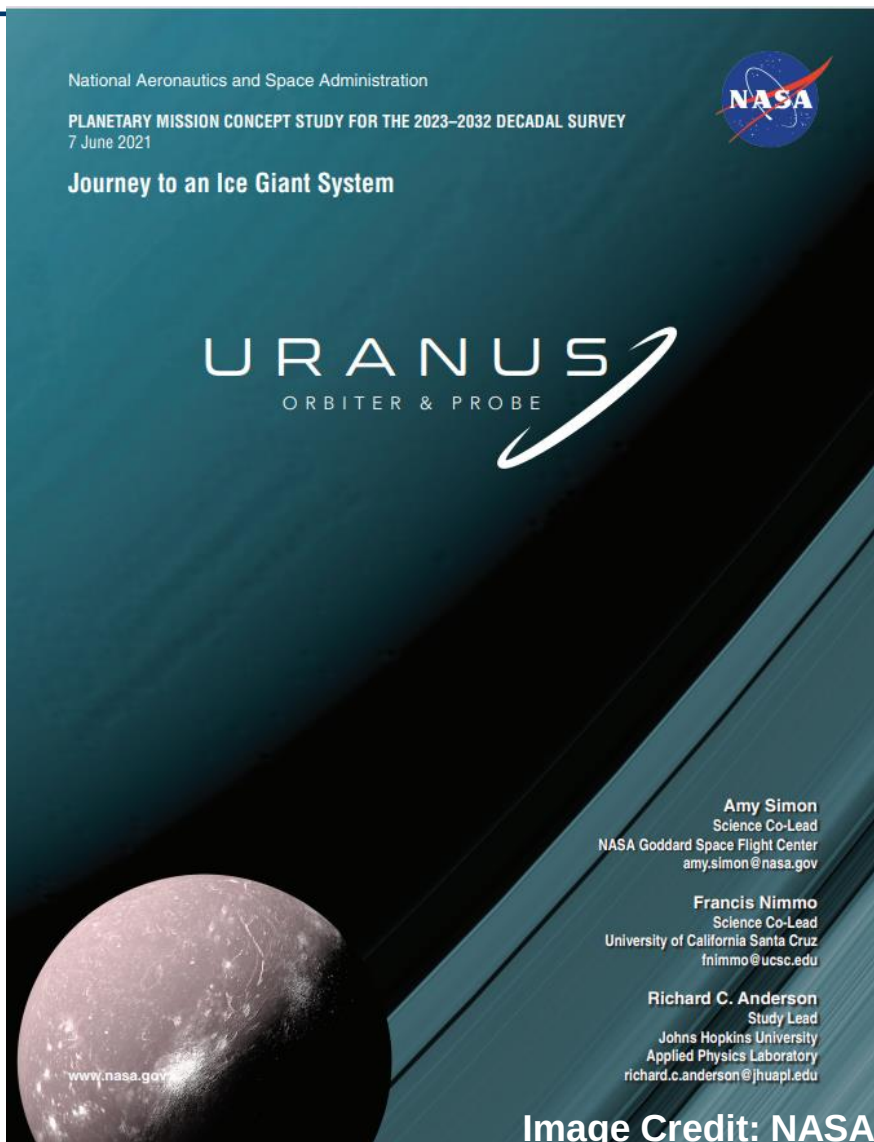


Image Credit: NASA



Uranus Orbiter & Probe Proposal



Uranus Orbiter and Probe

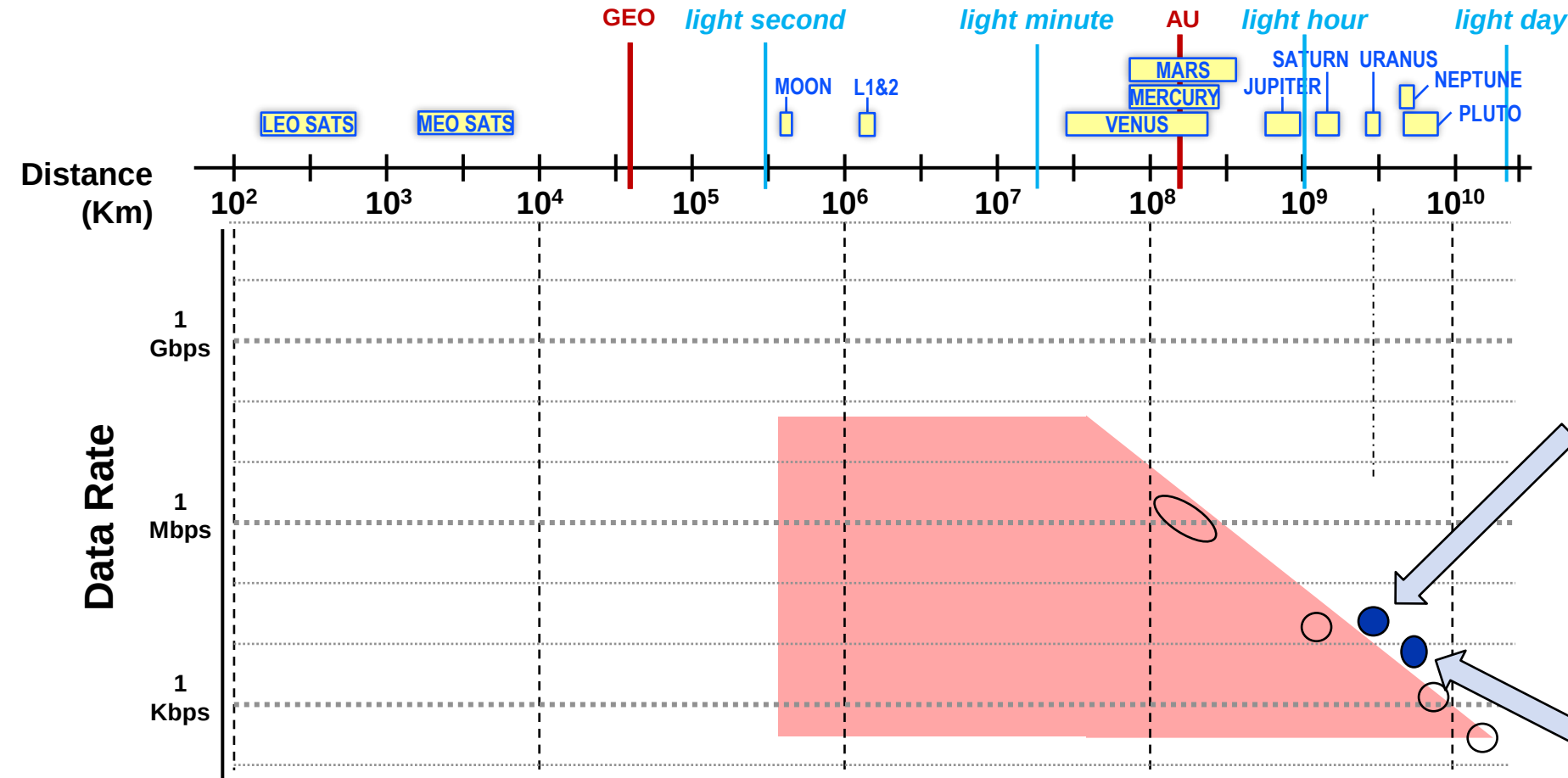
- End-to-end viable mission concept on currently available launch vehicle
- Flexible launch dates starting in 2031 through 2038+
- No new technologies required
- Low-Medium risk (only large mission TRACEd to receive this)

	Phase A–D (FY25\$K)	Phase E–F (FY25\$K)	Total (FY25\$K)
Total w.o Reserves	1,275,940	542,034	1,817,974
Reserves	634,157	135,508	769,665
Launch Vehicle	236,000		236,000
Total	2,146,097	677,542	2,823,640

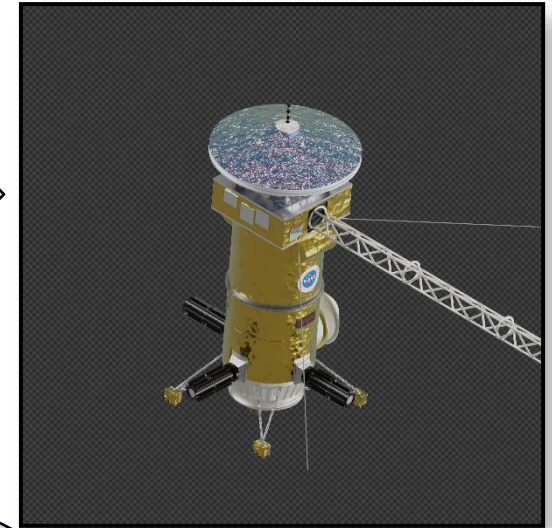


Communication Links to Great Distances

The NASA Deep-Space Network – Missions



**UO&P as proposed
2032-2044**
19.5 kbps at Uranus
3.1-m dish
Ka-band: 58 W



Similar: Triton mission 12 kbps

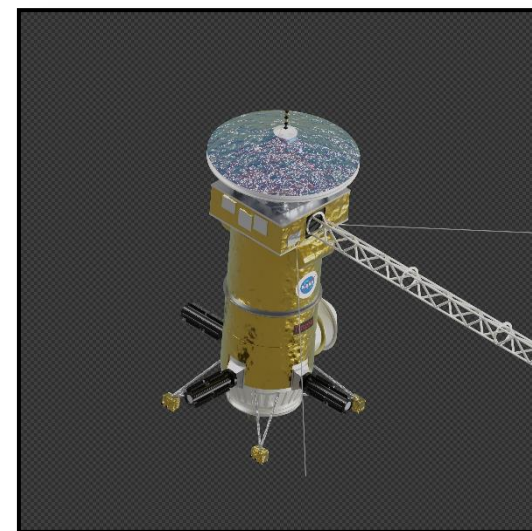
Capability in 2044 would be only slightly better than 1977-2006 trend



Editorial Observation

- Huge missions like this happen only once every few decades
- Cost is billions of dollars
- Return of measurement data is the product
- Predicted – 51.9 GB total UO&P return over entire multi-year mission
 - Equivalent to only 3 DVD-18s
- It seems like any way to increase this metric would be a huge lever-arm on the mission's utility
- ***Why must we impose “old” technology constraints on the data pipe when this mission will not reach its destination for nearly 20 years?***

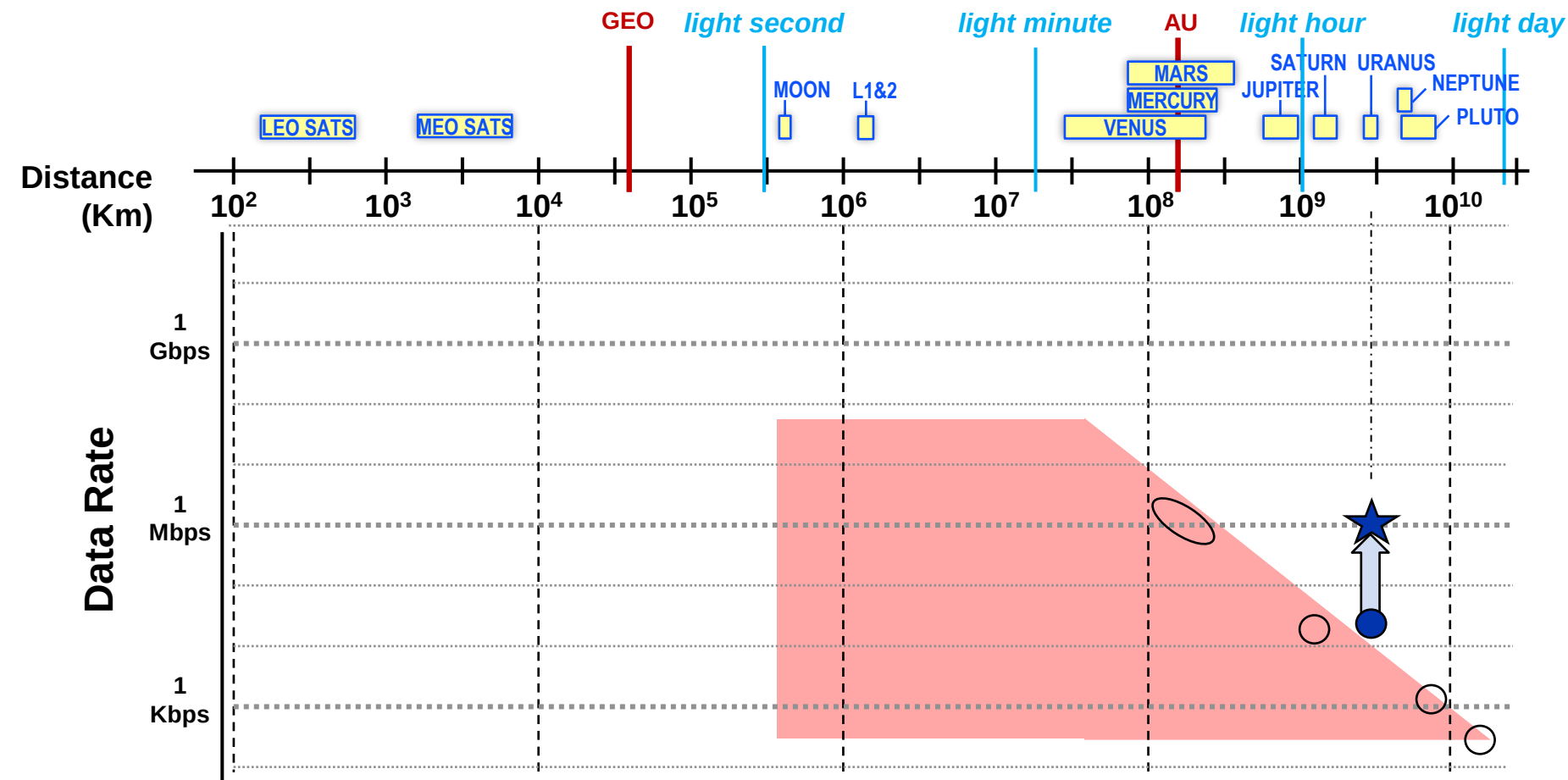
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Communication Links to Great Distances

The NASA Deep-Space Network – Missions



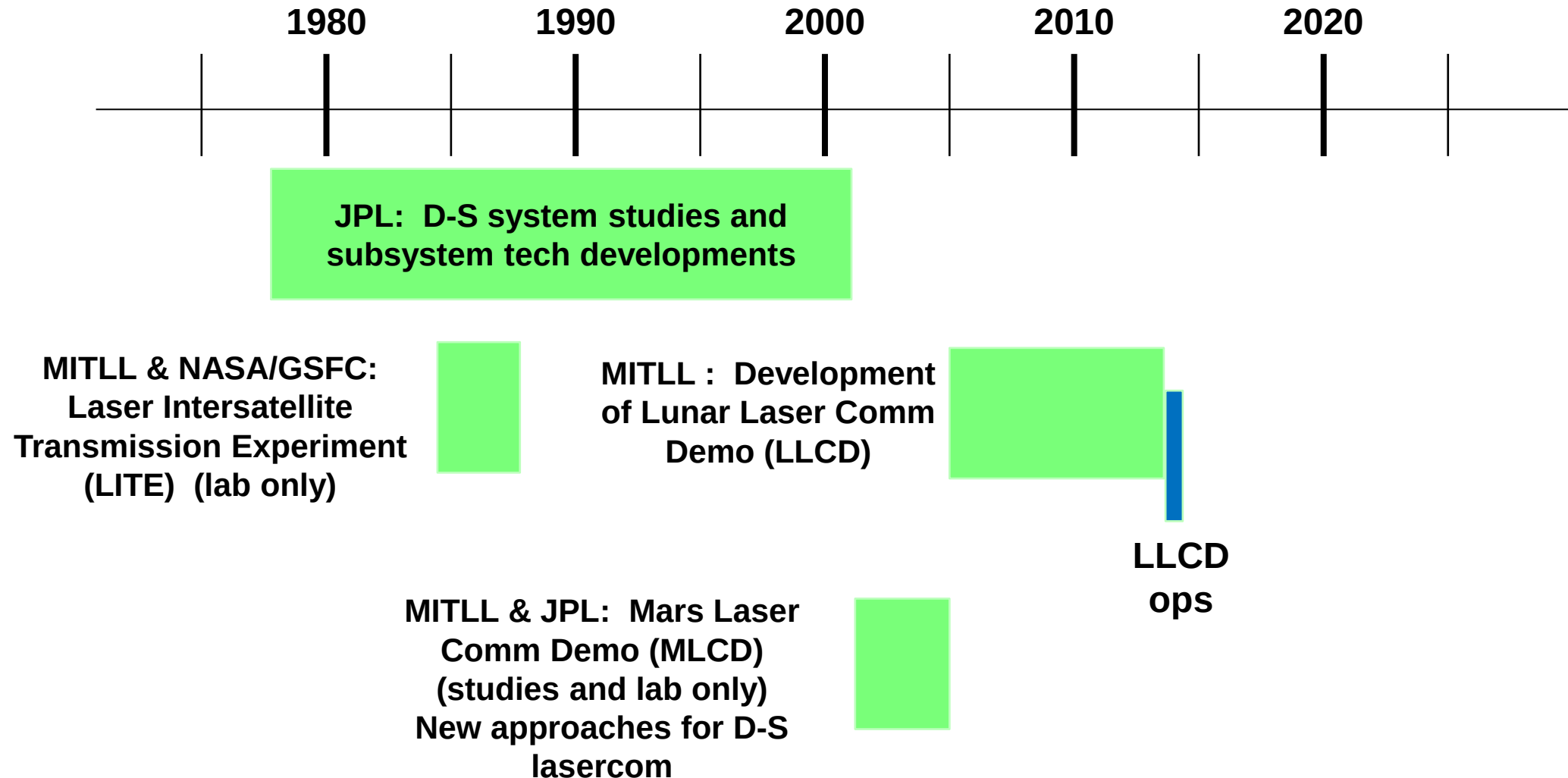
Why not aim at MRO-class data return from \$3B Uranus mission?

Optical ?



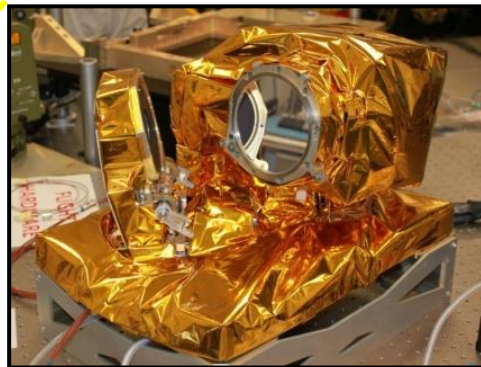
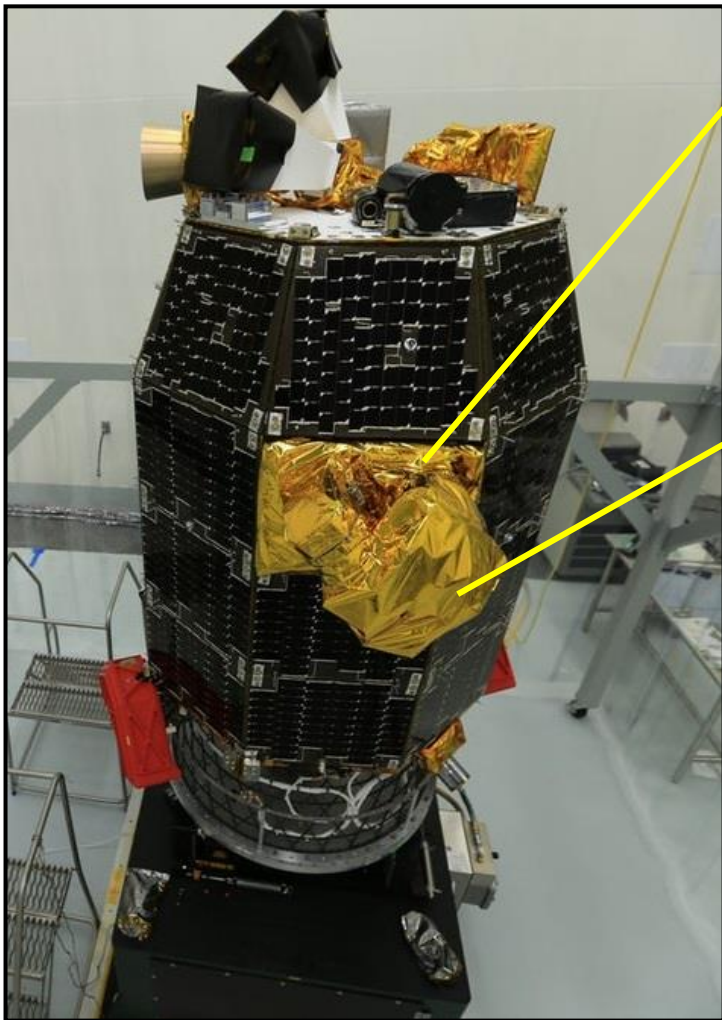
NASA Development of Deep Space Optical Comm

Main Steps





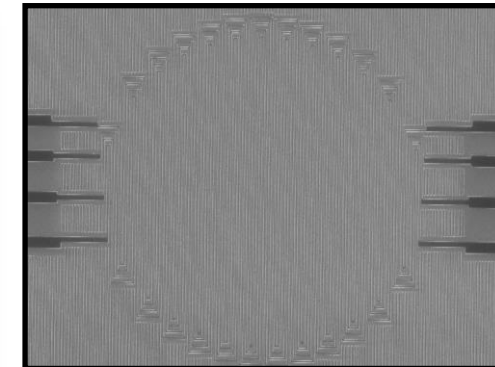
Lunar Laser Communication Demonstration 2013-2014



**LLCD Space Terminal
on LADEE***



**LLCD Ground
Terminal at WSC**



**Superconducting nanowire
single photon detecting
(SNSPD) array**

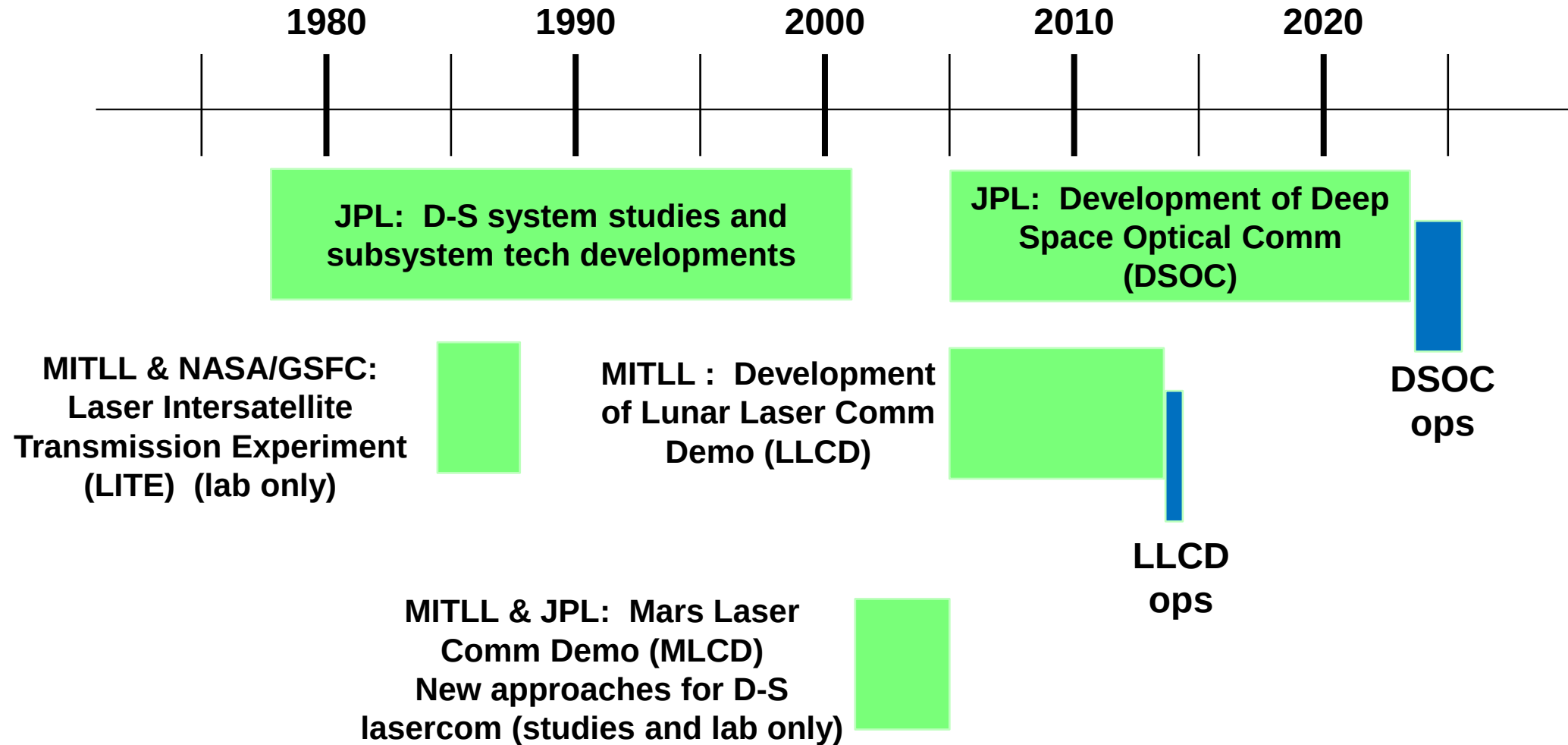
- MITLL/NASA - SCan, GSFC, ARC (plus JPL, ESA)
- NASA's first space lasercom
- 622/20 Mbps from/to Moon – error-free
- Longest lasercom link at time
- Highly valuable (unplanned) usage by LADEE team
- 1-cm real-time ranging of lunar-orbiting spacecraft
- *Changed many minds at NASA*

NASA



NASA Development of Deep Space Optical Comm

Main Steps

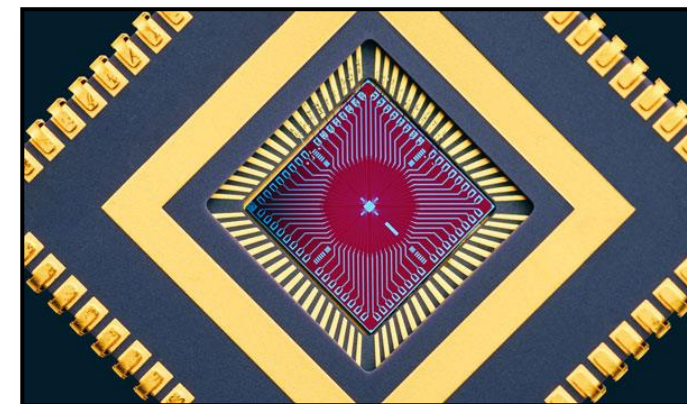
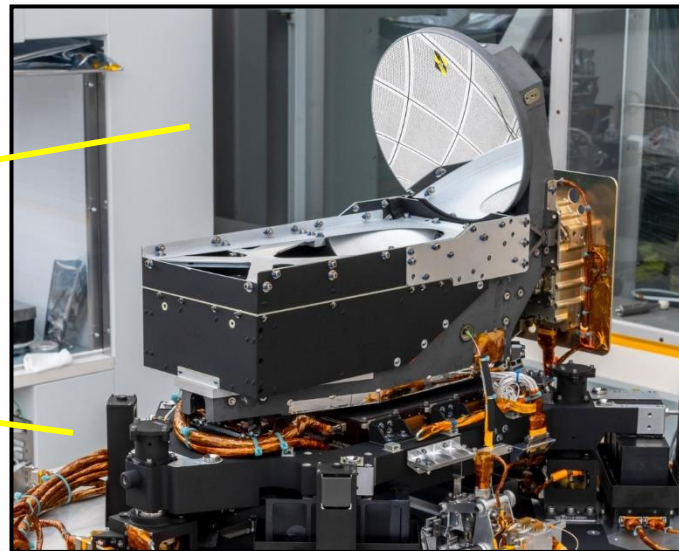




JPL: Deep Space Optical Comm 2023-



**DSOC Space Terminal
on PSYCHE**



**Superconducting nanowire
single photon detecting
(SNSPD) array**



**Hale Telescope receiver
OCTL transmitter**

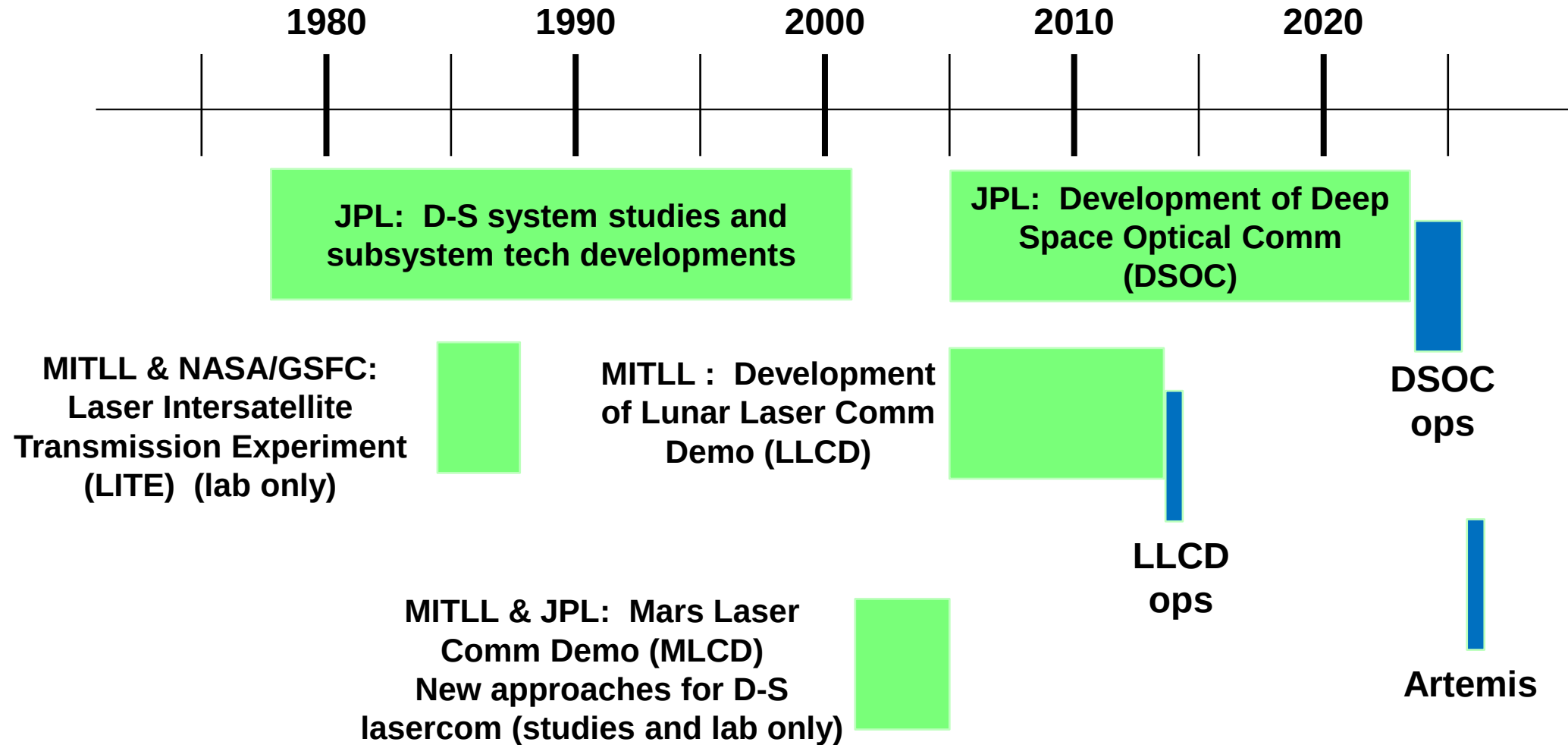
- JPL/NASA - SCan, MITLL
- NASA's first truly Deep Space lasercom
- 8.3-267 Mbps return (depending on range)
- Longest lasercom link ever (400 M km so far)
- Validates D-S system design

Photos courtesy of NASA



NASA Development of Deep Space Optical Comm

Also of interest





Artemis II (Sept 2025)



Artemis II – Orion space capsule to take 4 astronauts around the Moon

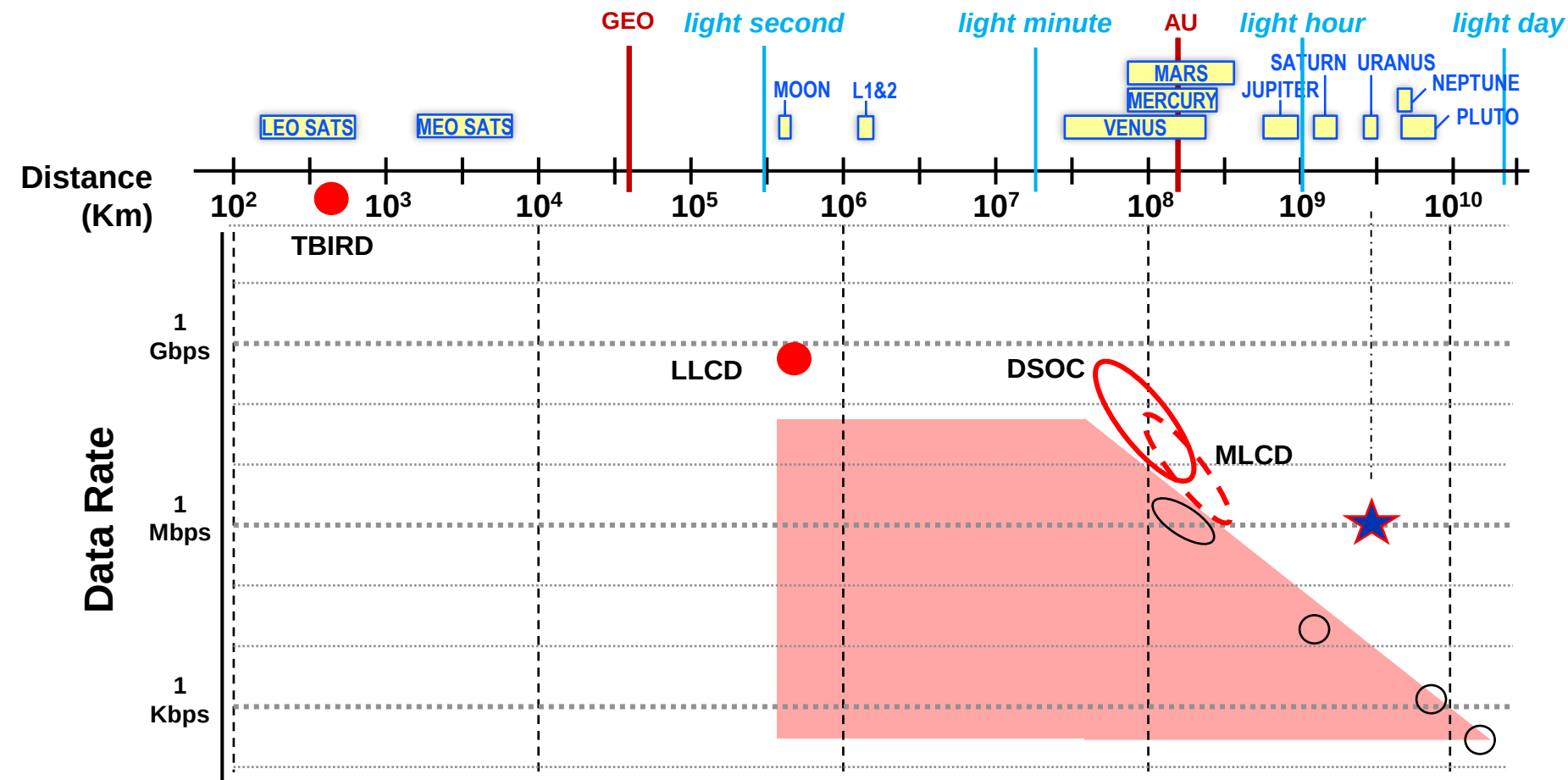
Lasercom, similar to LLCD, will provide HD TV

Image Credit: NASA



Communication Links to Great Distances

Optical Communications



Constraints of these demos:

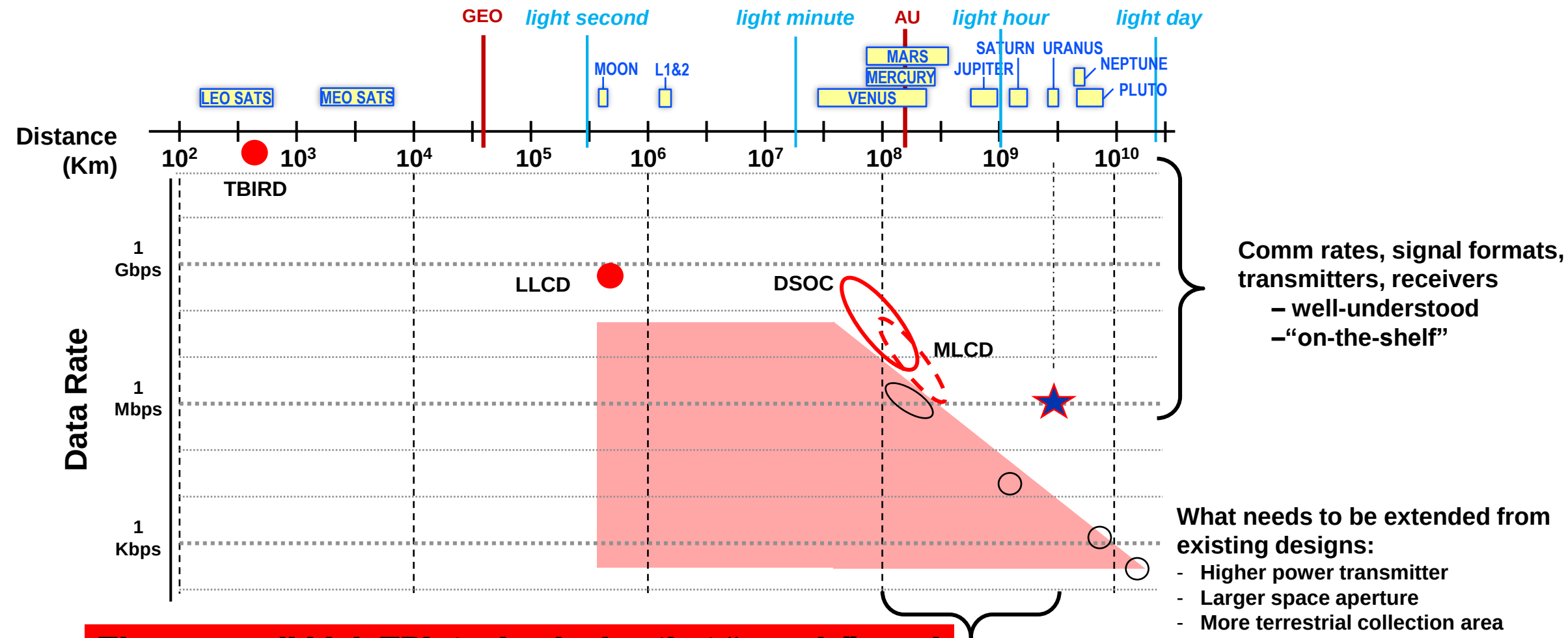
- **MLCD (2003-5)**
 - New detector technology
 - D-S system understanding
- **LLCD (2008-13)**
 - Meet only lunar needs
 - Space terminal size
 - Transmit power
 - Novel detectors
- **DSOC (2015-2025)**
 - Space aperture size
 - Transmit power
 - Goal: just beat DSN

First NASA demos (highly-constrained) of Deep-Space optical communications



Communication Links to Great Distances

Readiness of Optical Communications for UO&P



These are all high-TRL technologies that "merely" need customized designs and infrastructure investment



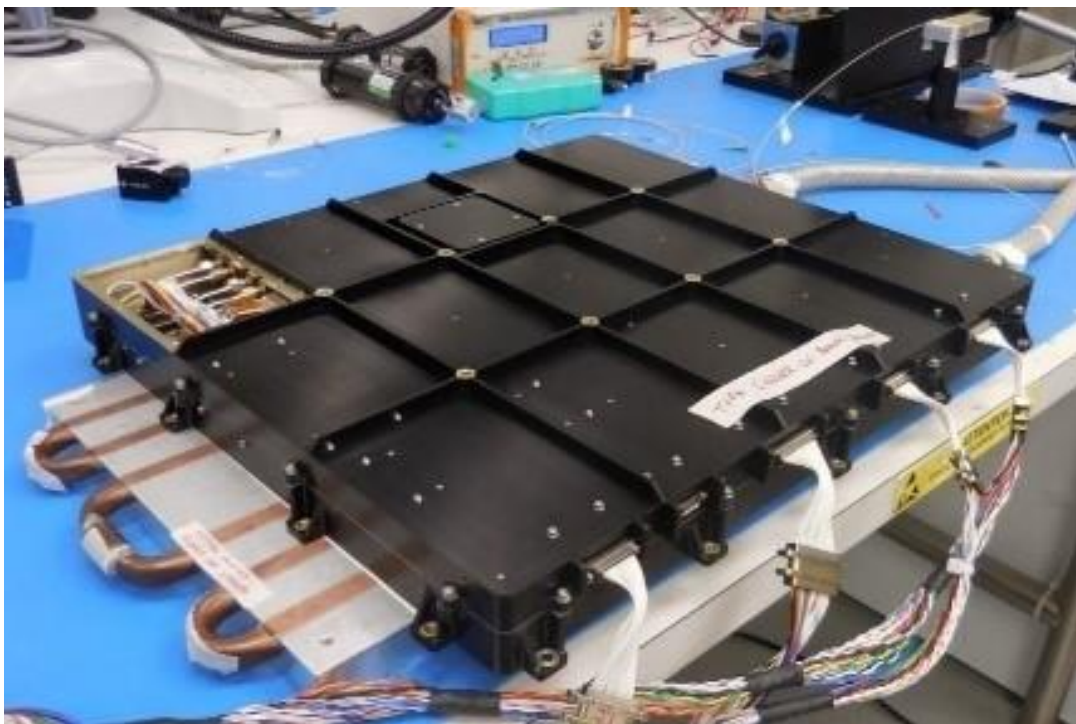
Possible UO&P Optical Link

	MLCD	LLCD	DSOC	UO&P Possibility
Transmit power	5.0 W @ 1.06 μm	0.5 W @ 1.55 μm	4.0 W @ 1.55 μm	15 W @ 1.55 μm
Space aperture	30 cm	10 cm	22 cm	50 cm
Terrestrial collection area	1@ 5-m	4@40-cm	1@5-m	4@ 2.5-m

1-2.5 Mbps



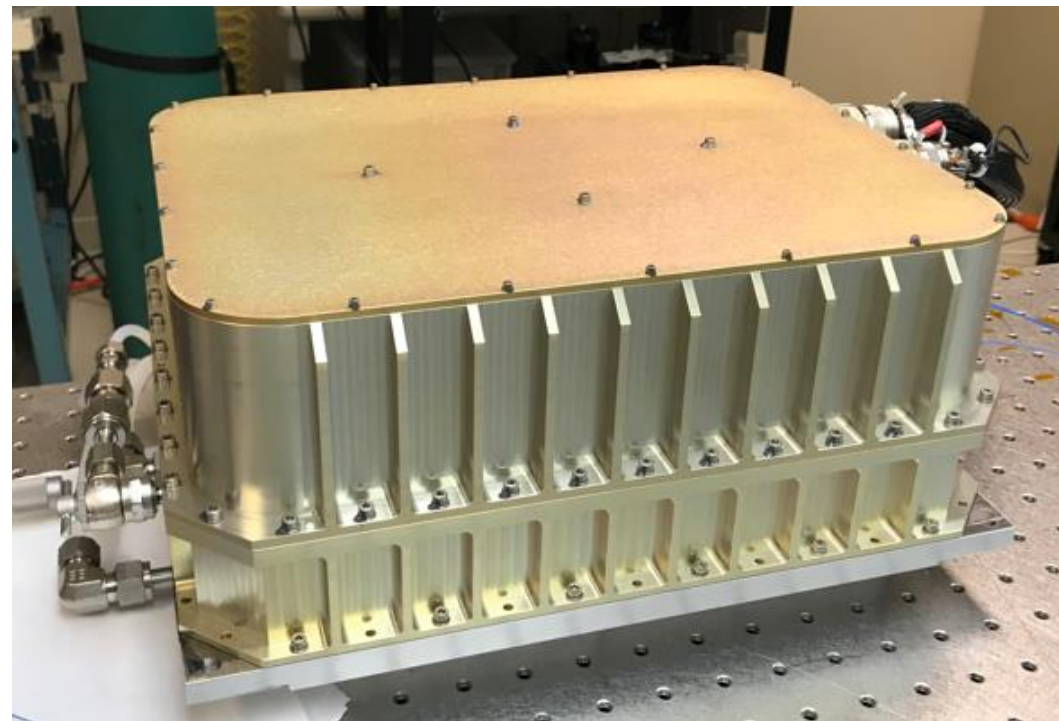
Space Optical Transmitter



© CACI, Used with Permission

DSOC 4-W¹
(JPL-CACI)

A number of companies
developing 5-20-W designs



© Fibertek, Used with Permission

50-W²
(Fibertek)

Design for custom 15-W proposal is already high TRL technology in 2024
Would fit in 100-W wallplug spec of proposed Ka-band design



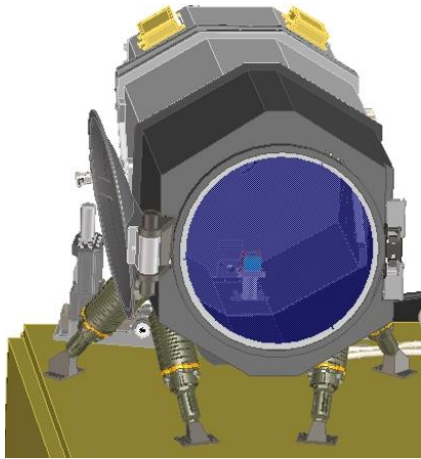
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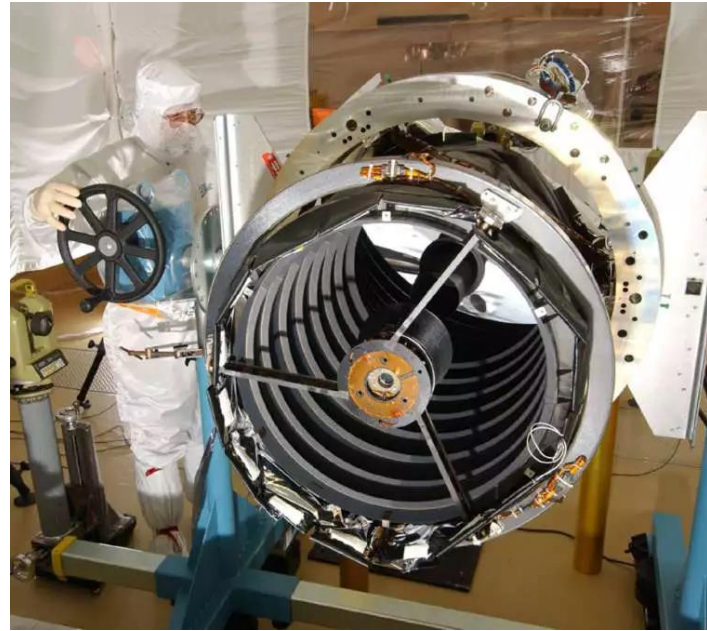
1-2.5 Mbps



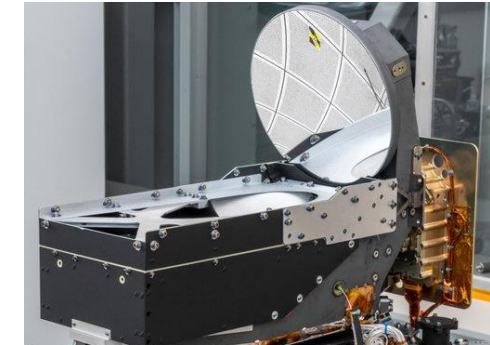
Space Telescope



**MLCD Design
30-cm
(MITLL)**



**HiRISE Telescope
50-cm**



**DSOC 22-cm
(JPL)**

**50-cm proposal (no gimbal required) can be considered high TRL
UO&P can steer to 1 mrad – simplifies mount and Point/Acq/Trk
HiRISE complete instrument weighs 64.2 kg**



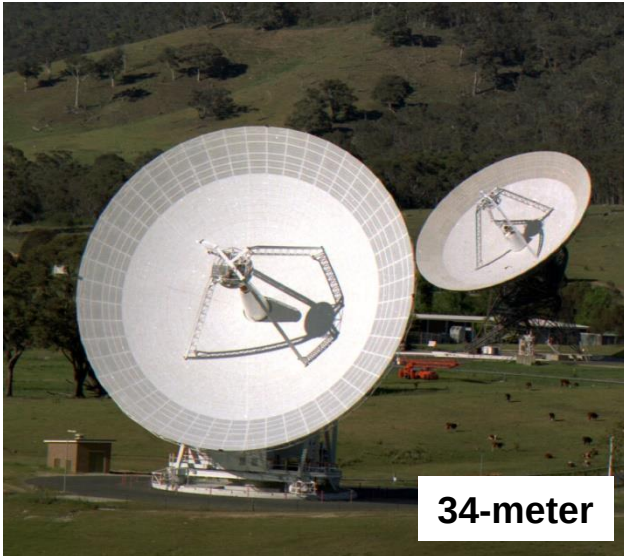
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1-2.5 Mbps



Ground Infrastructure



- **NASA Deep Space Network (RF)**
 - Three sites around world for 24-hour coverage
 - Multiple antennas at each site to support several simultaneous missions/links
 - For reference: new 34-meter antenna costs \$50-\$75M
- **A future Optical Deep Space Network would need**
 - 5-8 sites around world for 24-hour coverage plus some redundancy for cloud outages
 - Telescopes at each site to support several simultaneous links
 - Multiple telescopes of 0.75-2.5-m for links out to Lagrange
 - EITHER
 - Large telescope (3-9 meters) for extremely long links, or
 - Capability of arraying smaller telescopes for extremely long links



Arrayed Telescopes

LLCD demonstrated scalable receiver array that supports Deep-Space-type efficient signaling



Concept also works with array of separate telescopes



**40-cm array
NOAO Chile**

CTIO/NOAO*

**Combining is particularly simple when use photon-counting receivers (which are comm-optimum)
Once have aligned timing, merely add together digital '1's of photon detections**

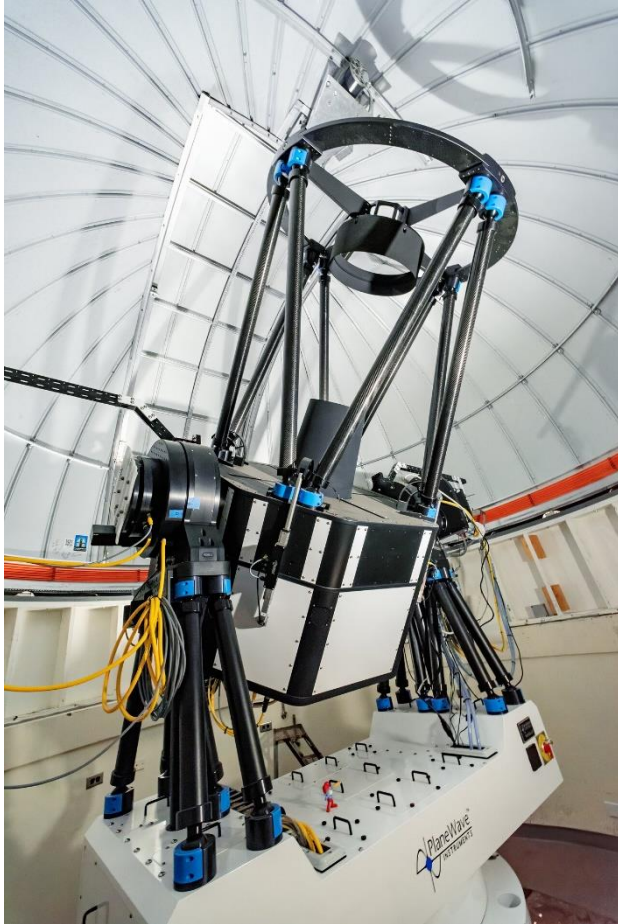


Terrestrial Optical Comm Infrastructure Design Proposal

- **5-8 sites around world**
 - Support all space angles at all hours
 - Provide some weather redundancy
 - Observation: weather redundancy for any one mission also provides many more telescopes to serve larger community of users
- **Multiple 0.7-1.5-m telescopes at each site**
 - Support growing constellation of science and exploration missions
 - GEO, cislunar, Lagrange ranges
- **Several 1.5-3.0-m telescopes at each site**
 - Multiple simultaneous missions at Lagrange to asteroids ranges, or
 - Planetary ranges via telescope arraying
- **Telescope modularity allows for**
 - Maximum flexibility – numerous medium-size missions or few long-range missions
 - Many options for time sequencing of worldwide buildup



Building the Ground Infrastructure



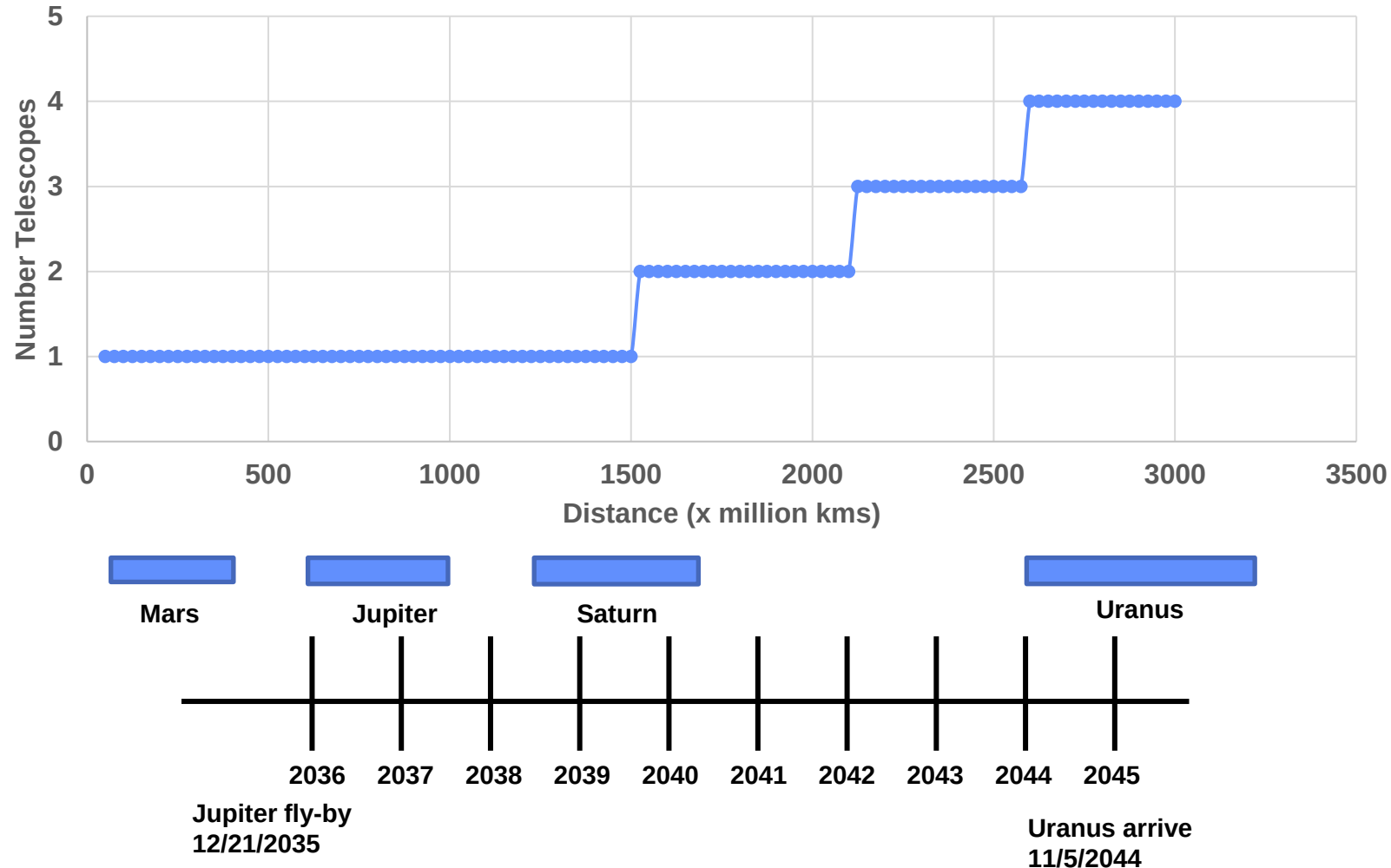
**4 @ 2.5-meter equivalent to 5-meter
Cost of each < \$10M**

Question: how to build up O-DSN?

1-2-meter telescopes available commercially



Example Build Sequence for UO&P



- It will take over a decade to travel from Mars distance to Uranus
- Max data rate would require fewer receive telescopes at shorter distances
- Single 2.5-m telescope would support max rate until 2040
- New telescope could be added every couple years to support max rate at all distances



Other UO&P Optical Comm Considerations

- **Pointing & Tracking**
 - 1 mrad pointing capability of spacecraft *simplifies* acquisition and tracking design
 - Use MLCD-style inertial and Earth-image tracking combined with DSOC uplink beacon
- **Uplink comm**
 - DSOC-style uplink possible, but providing very low rates (uplink through atmosphere is more difficult)
 - Multiple arrayed DSOC uplinks could achieve higher far-field power to achieve desired rate
 - Note – RF uplink transmits 20 kW
 - Ultimately, 0.5-1.0-meter-class orbiting optical uplink terminal would be more capable
- **Daylight operation**
 - Several weeks per Earth year, Uranus will appear near sun in sky
 - Several proposed (but not yet fielded) receiver techniques would keep daytime performance near 1 Mbps year-round



False Rumors You May Have Heard*

- “Lasercom pointing is too difficult”
 - NO! The problem and the technology are both well understood. There are many hundreds of space lasercom terminals working today.
- “Lasercom pointing needs put too many requirements on the spacecraft”
 - NO! The spacecraft just needs to aim the terminal in the general direction. The terminal then finds and corrects its own fine pointing with onboard sensors and mechanisms. In most designs, there is an optical beacon (or incoming comm beam) for it to aim at.
- “Lasercom only works if there is also a radio uplink to correct the pointing”
 - NO! The optical system is completely self-operating. In fact, on LLCD, we even sent optical commands up to modify terminal settings during a session, as well as monitored performance via optically-sent telemetry.
- Lasercom hasn’t really been done”
 - FALSE! Every connection and distance has been demonstrated multiple times. Some mission types already have hundreds of terminals in operation.

* We have heard these and more from *decision-makers* as reasons not to even consider lasercom!



What Will It Take to Implement Lasercom?

- **Communications “requirements” are almost certainly the maximum rates scientists THINK they can ask for**
 - **Scientists should consider the measurements they would LIKE to have, and ask for communications as if that weren’t a constraint**
- **Note: the RF Deep Space Network is already over-subscribed – low-cost ground terminals could fill the needs**
- **As we showed, we could build up a global collection of telescopes to:**
 - **First satisfy nearer-to-Earth missions such as lunar, Lagrange**
 - **Build up enough to make weather be a geographical non-issue**
 - **Put in place the software to combine telescope outputs to satisfy more distant missions**



How Can You Help to Get Lasercom To Be a Player?

- **Come talk to the space science and exploration lasercom community to find**
 - What is possible for your mission
 - What is a possible match to your technical solutions
- **Bring up higher-rate solutions when scoping out new missions; squash the technology falsehoods**
- **Think of new data-unconstrained science/exploration measurements that could revolutionize your field**
- **Be an advocate for higher data rates – talk to decision makers**
- **Don't settle for only incremental improvements since 50 years ago**



Summary

- **UO&P has been proposed using familiar-to-scientists technologies**
 - Huge distance constrains DSN-based comm to 20 kbps (Ka-band; 7 kbps at X-band)
- **Optical comm could achieve 50-100 times the science data return (even more for more money)**
- **Optical comm, although it does not have 50 years of experience, has been developed and successfully demonstrated multiple times in past 25 years**
 - Space technologies are all high TRL
 - Only ground infrastructure is missing – these are also high TRL
- **Even if UO&P had to develop the ground infrastructure by itself, the cost would be a small fraction of the \$2.8B present cost, resulting in a 50-100 times higher payoff**
- **If space scientists all recognized the potential great increase in science data return via optical, a new ground infrastructure could be paid for, built, and shared by the whole community**



MIT Lincoln Laboratory

DoD Federally Funded Research and Development Center



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