Deep Space Optical Communications at NASA

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International Space Development Conference

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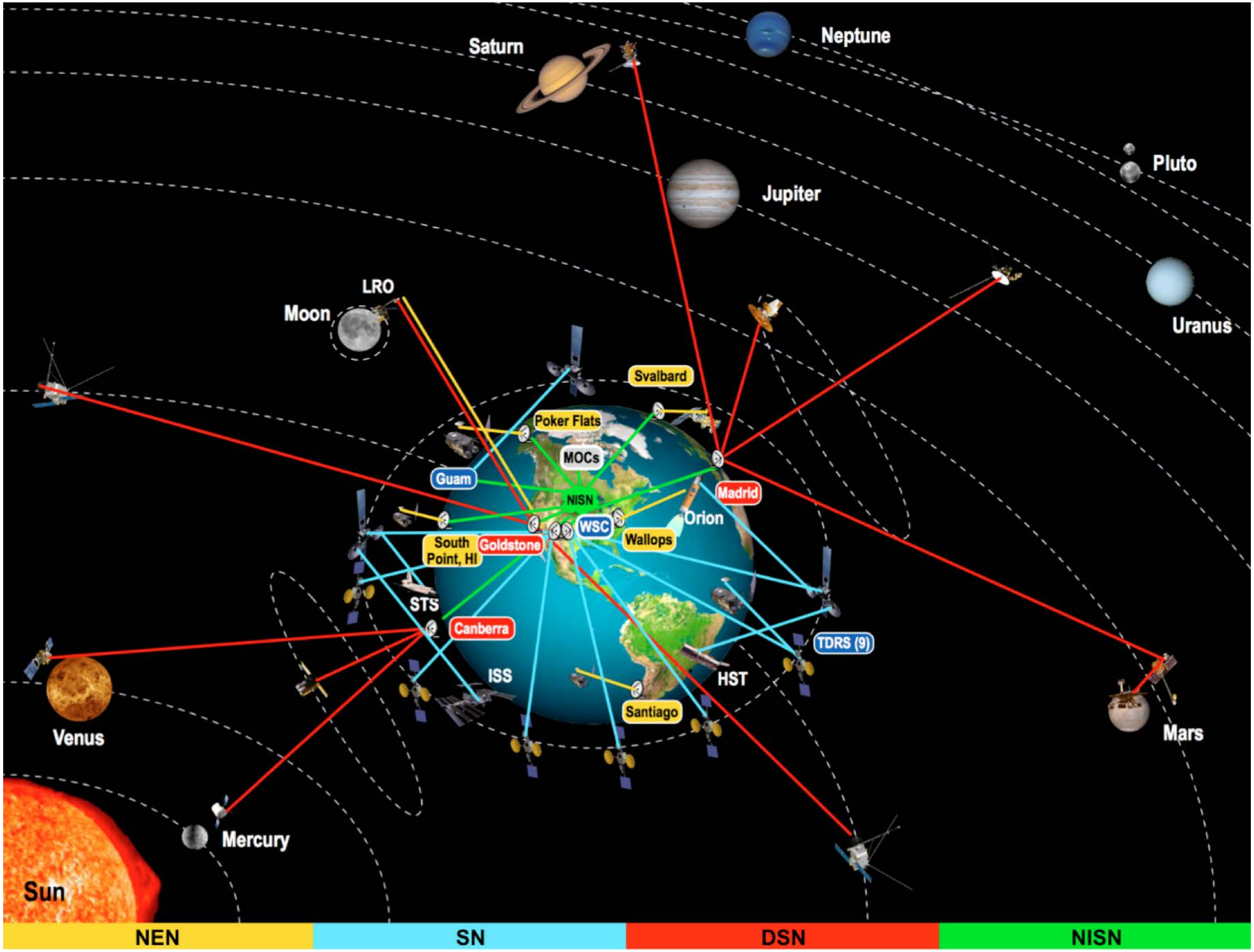
Space Communications Networks



From: Space Communications and Navigation Program Architecture Definition Document

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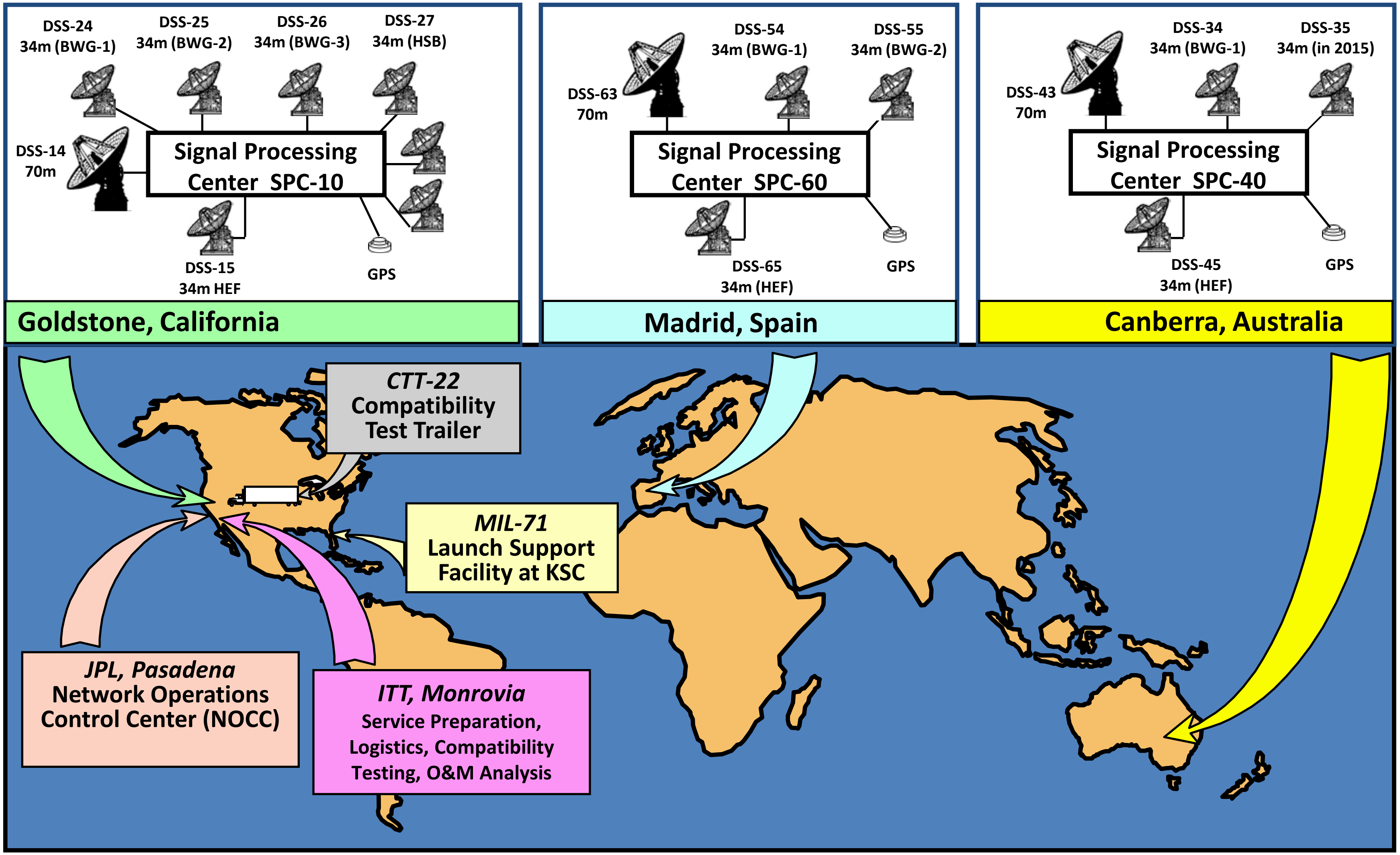
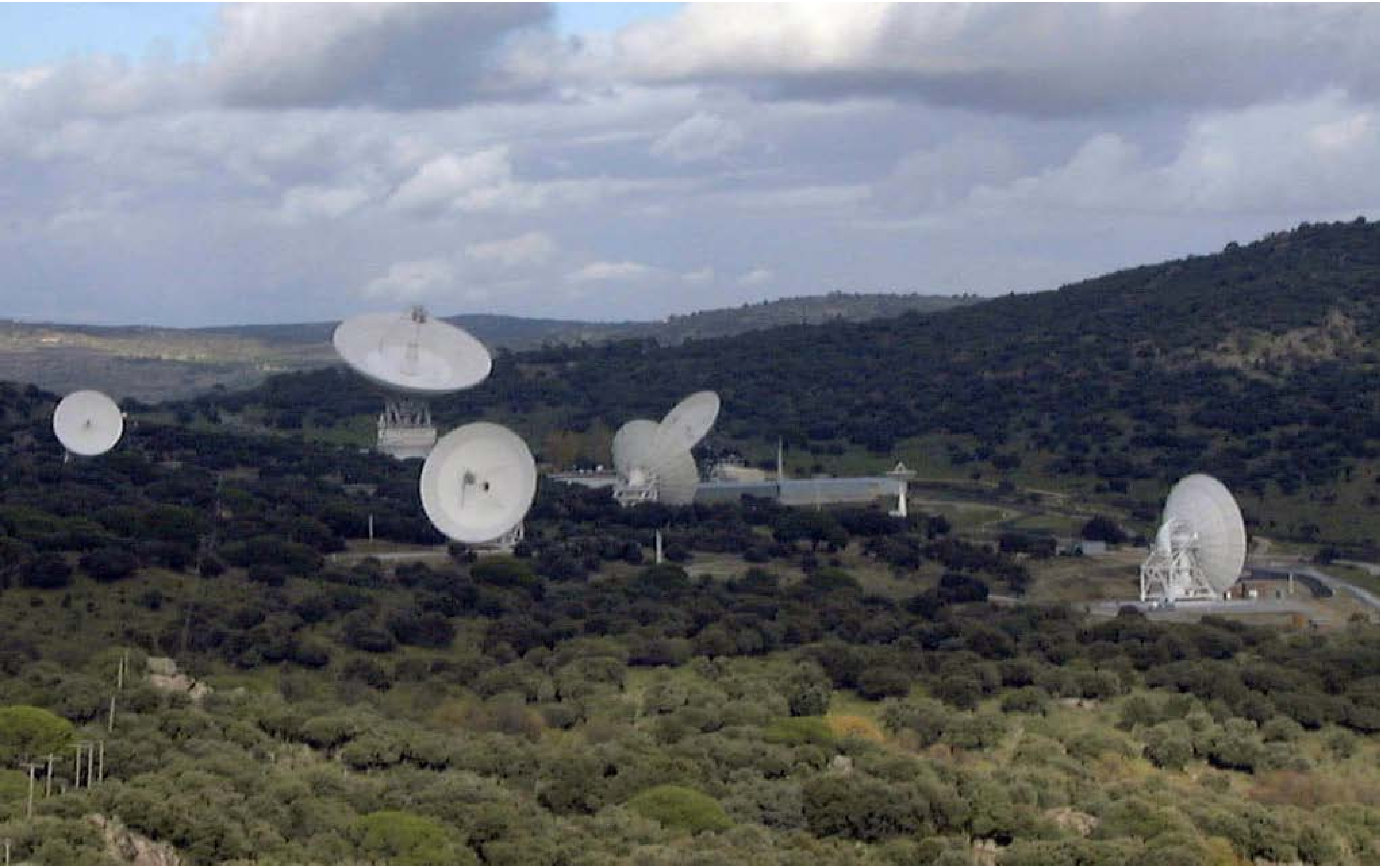
The NASA Deep-Space Network (DSN)



DSN Antennas in Madrid, Spain



SCaN Projected Requirements

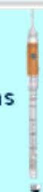
	Today	2015	2018	2025+

Level 0 Requirements

- Provide space communications and navigation services to existing and planned missions. (Today – 2025+)
- Develop a unified space communications and navigation network infrastructure
- Implement internationally interoperable communication protocols
- Provide the highest data rates technically and financially feasible
- Implement a networked communication and navigation infrastructure across space
- Provide anytime/anywhere communication and navigation services for Lunar and Mars human missions

	Today	2015	2018	2025+
Mission Drivers	• Shuttle/ISS • Mars Landers • Great Observatories • Coordinated Earth Observation • LRO	• Orion/ISS • Mars – Coordinated and Complex Science Missions • Lunar Robotic Missions • High Data Volume Hyper Spectral Missions • SAR Earth Observation	• Multiple Cooperating Robotic Missions • Outer Planet – 1	• Hyper spectral imaging at Mars and beyond • Human Lunar Missions • Earth Sensor Web • Mars Exploration • Mars Sample Return
Capabilities	• Up to 300 Mbps (SN) • Up to 150 Mbps (NEN) • Up to 6 Mbps at 1 AU • Radiometric Services	• Up to 1.2 Gbps (SN/NEN) • Standard TT&C Services • Up to 150 Mbps (DSN) – 1 AU • Radiometric Enhancements	• Integrated Network Management • Integrated Service Execution • Space Internetworking	• Up to 1.2 Gbps from the moon (optical) • Optical Communications to 100 Mbps (planetary) • Lunar far side coverage • High capacity multi-node • Inter-networking interoperability





Pre-decisional – for Planning and Discussion Purposes Only

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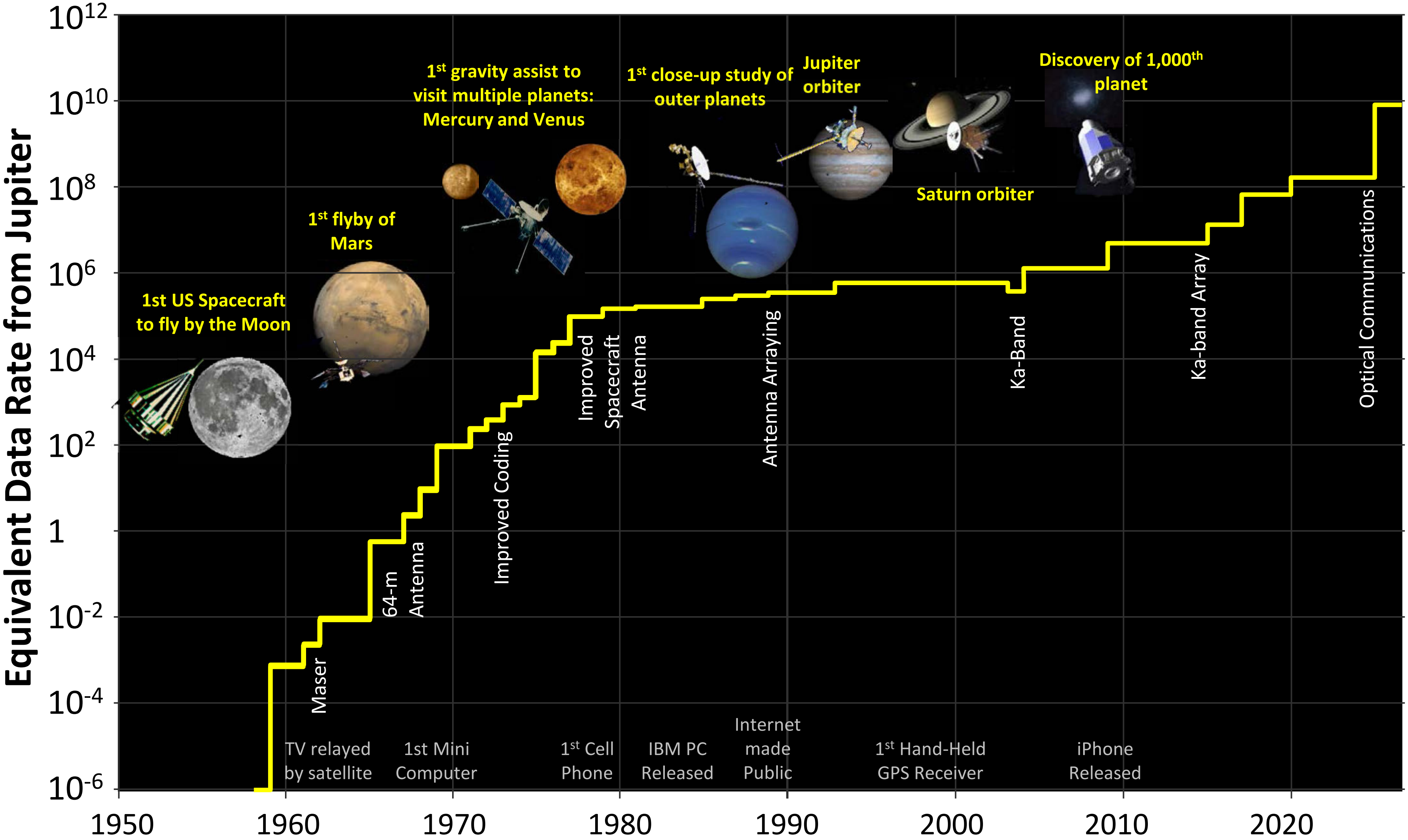
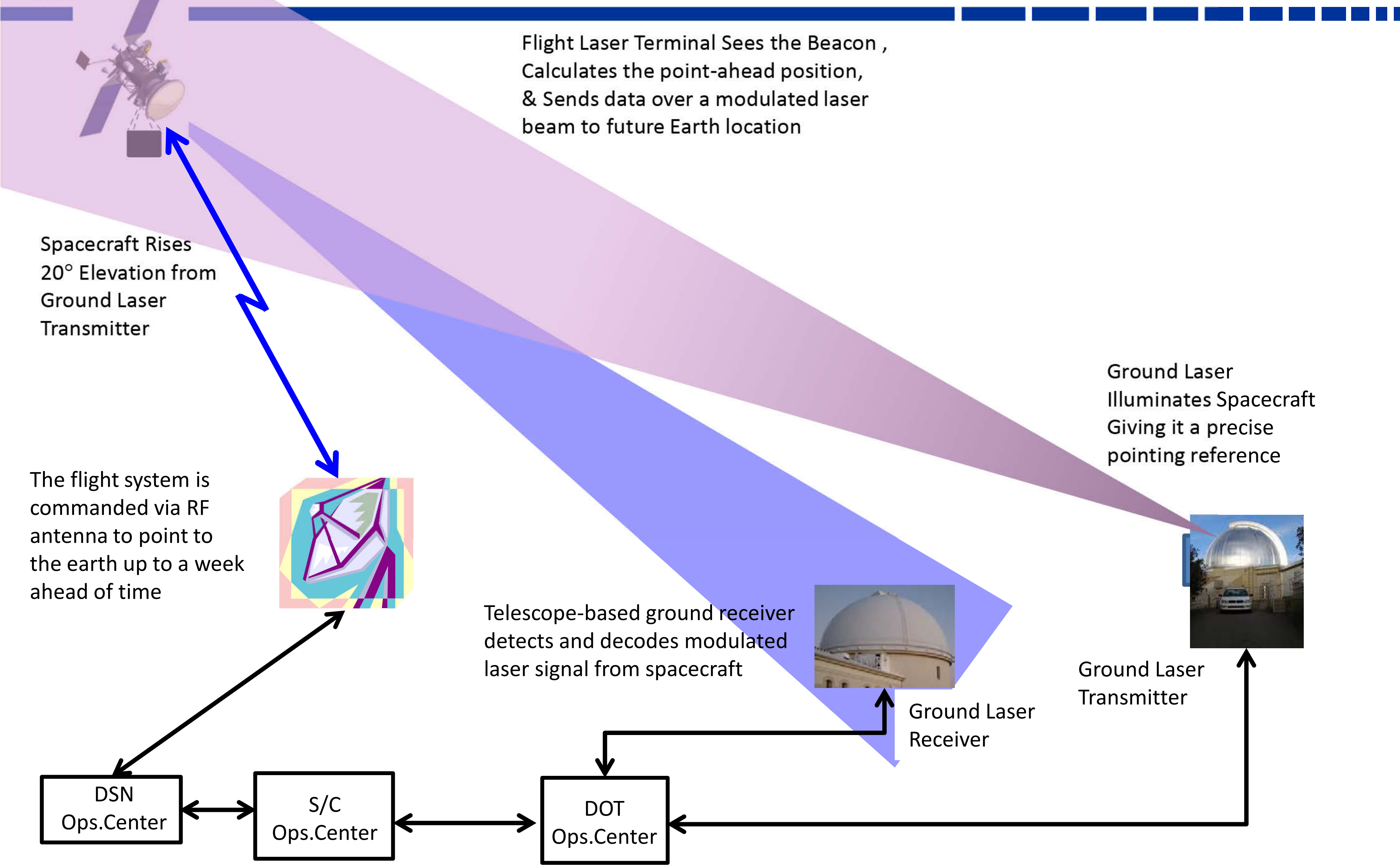
Deep Space Telemetry



Optical Communications



Deep Space Challenges

- Distances
  - Weak signals result from even minute beam spreading
  - Round-trip light times are so long you can't do cooperative handshake
  - Weak beacons make it difficult to get the beacon signal above detector noise
- Pointing and tracking
  - High-angular resolution tracking is very difficult on a moving spacecraft
  - Point-ahead angles require you to point ahead of where you see the beacon
- Sun angles
  - Scattered light makes it very difficult to see the beacon
  - Thermal effects warp the telescope and optics when the Sun shines down the barrel

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Deep Space Challenges– (1) Weak Signals

Collected by 10 m
Keck Telescope

2.5 AU

5-W light bulb

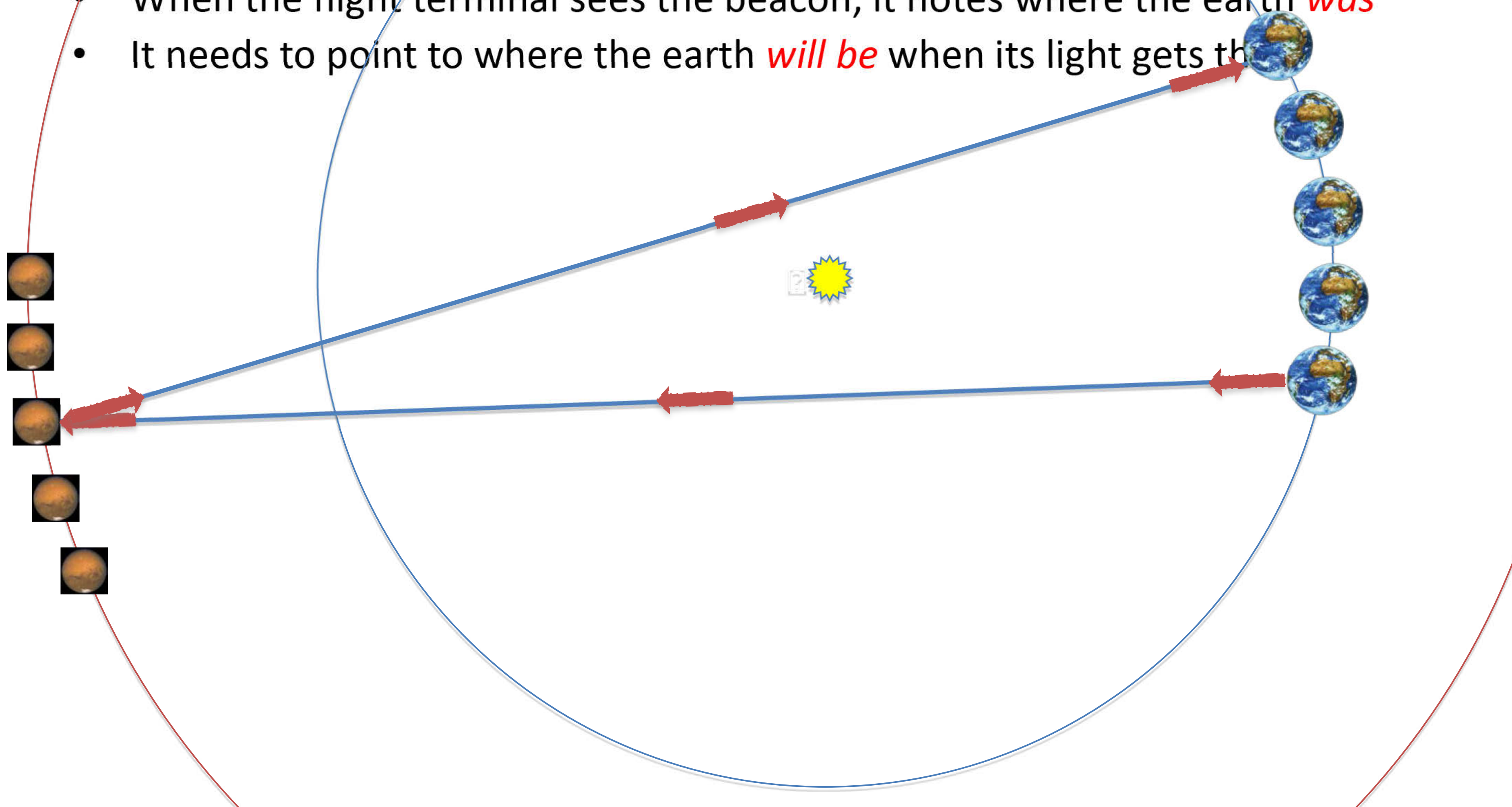
For 1000 years

Use that stored energy
To power a weak light bulb

For 1 nsec!

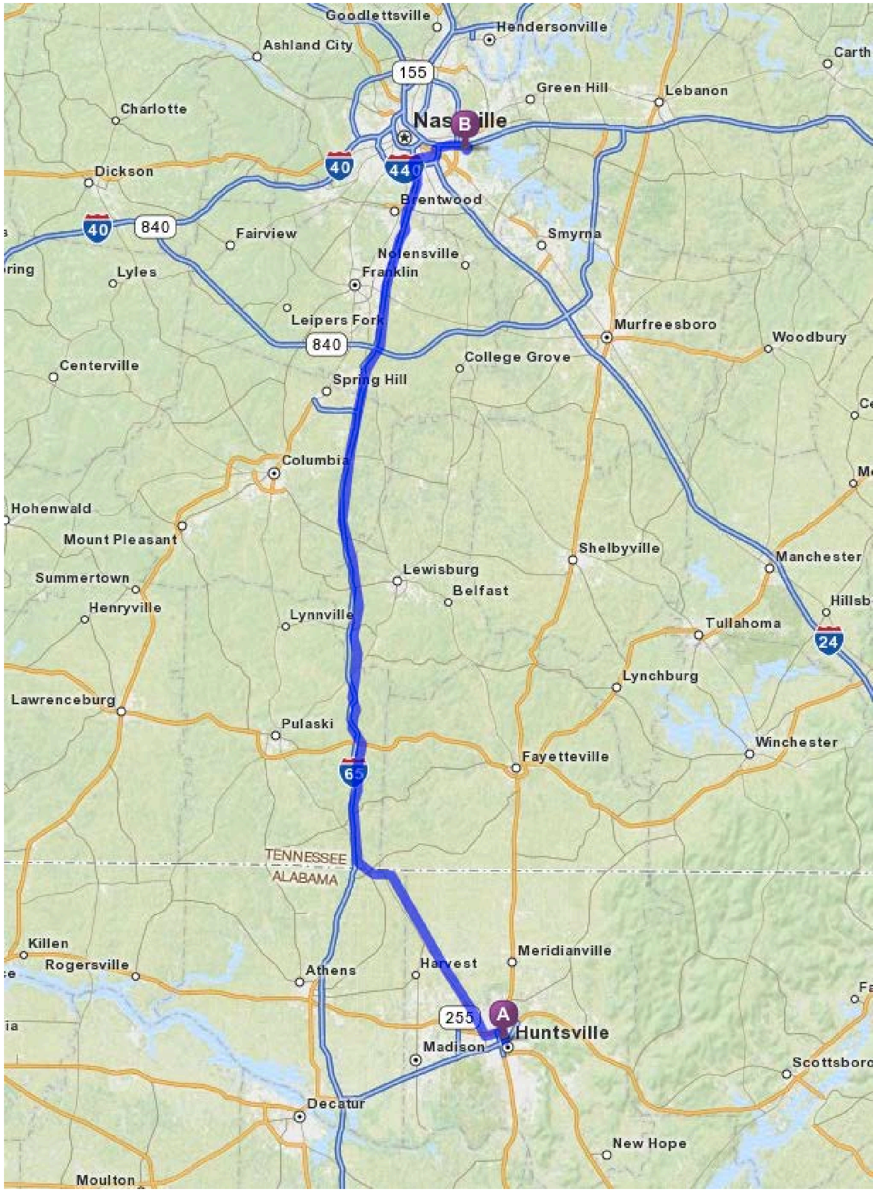
Deep Space Challenges – (2) Point-Ahead Angles

- Mars and Earth are moving in their orbits (24 and 30 km/sec, respectively)
- While light travels pretty fast, it does have a finite speed
- When the flight terminal sees the beacon, it notes where the earth *was*
- It needs to point to where the earth *will be* when its light gets th

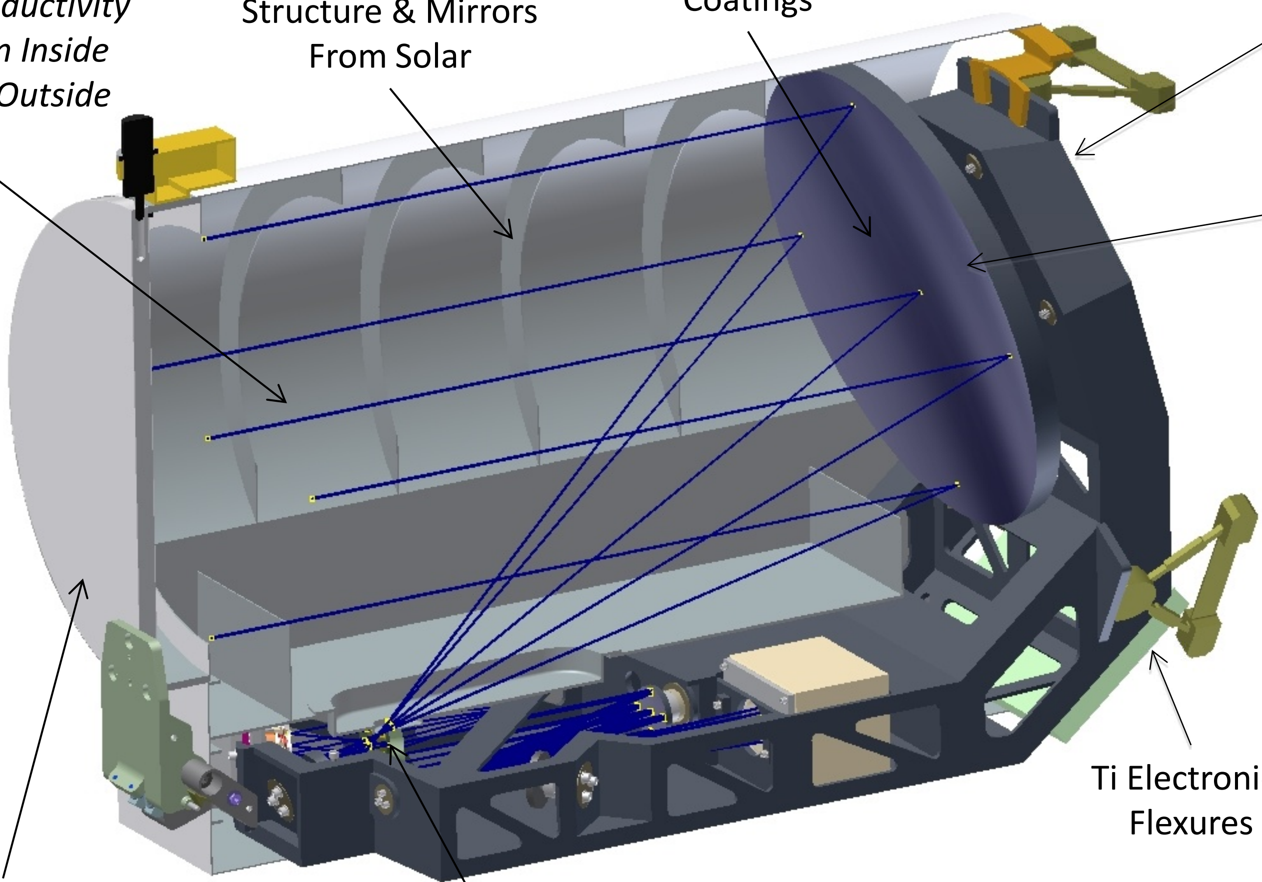


Deep Space Challenges– (3) High Resolution Pointing

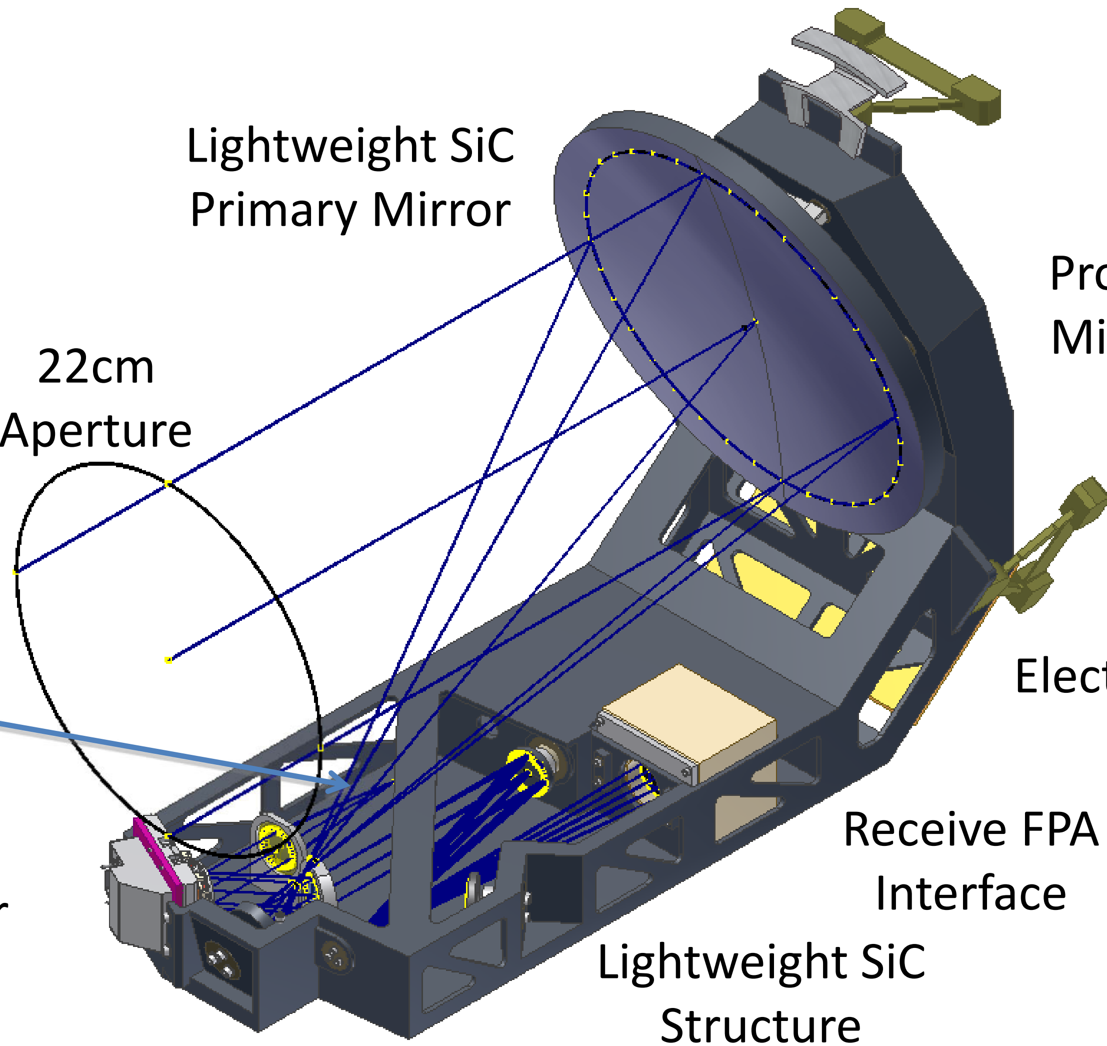
- Our beams are so narrow (8 microradians) we have to be very precise in our pointing
  - Must point to about 1/10 of the width of the beam to stay in the 'sweet spot'
  - In both dimensions
- This is equivalent to placing a golf ball on the lawn outside this civic center, and hitting a hole-in-one
  - At the golf course near the airport
  - That is… near the Nashville Airport (~100 miles)



Deep-space Optical Terminals (DOT) Flight Transceiver



DOT Flight Laser Transceiver Structure



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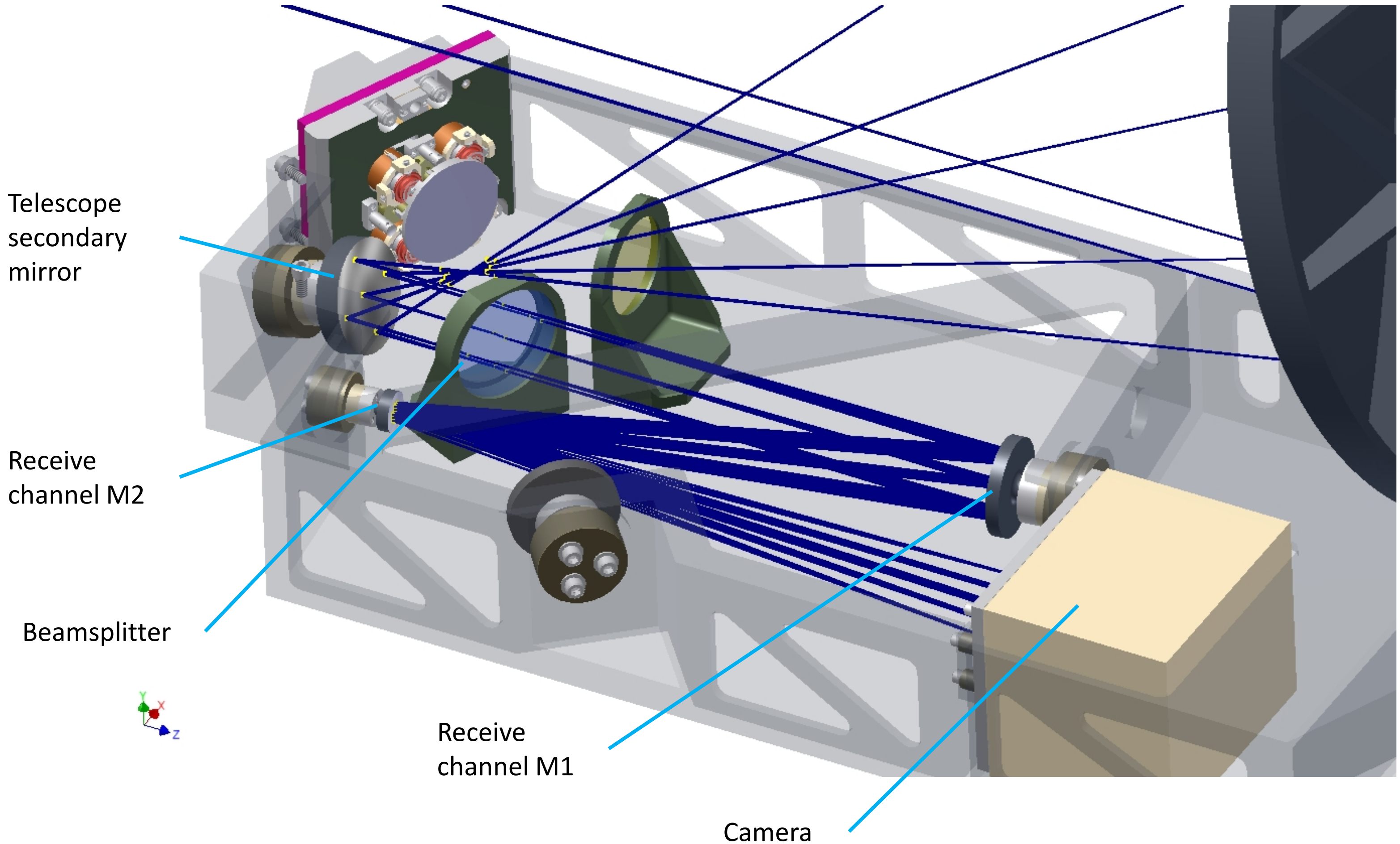
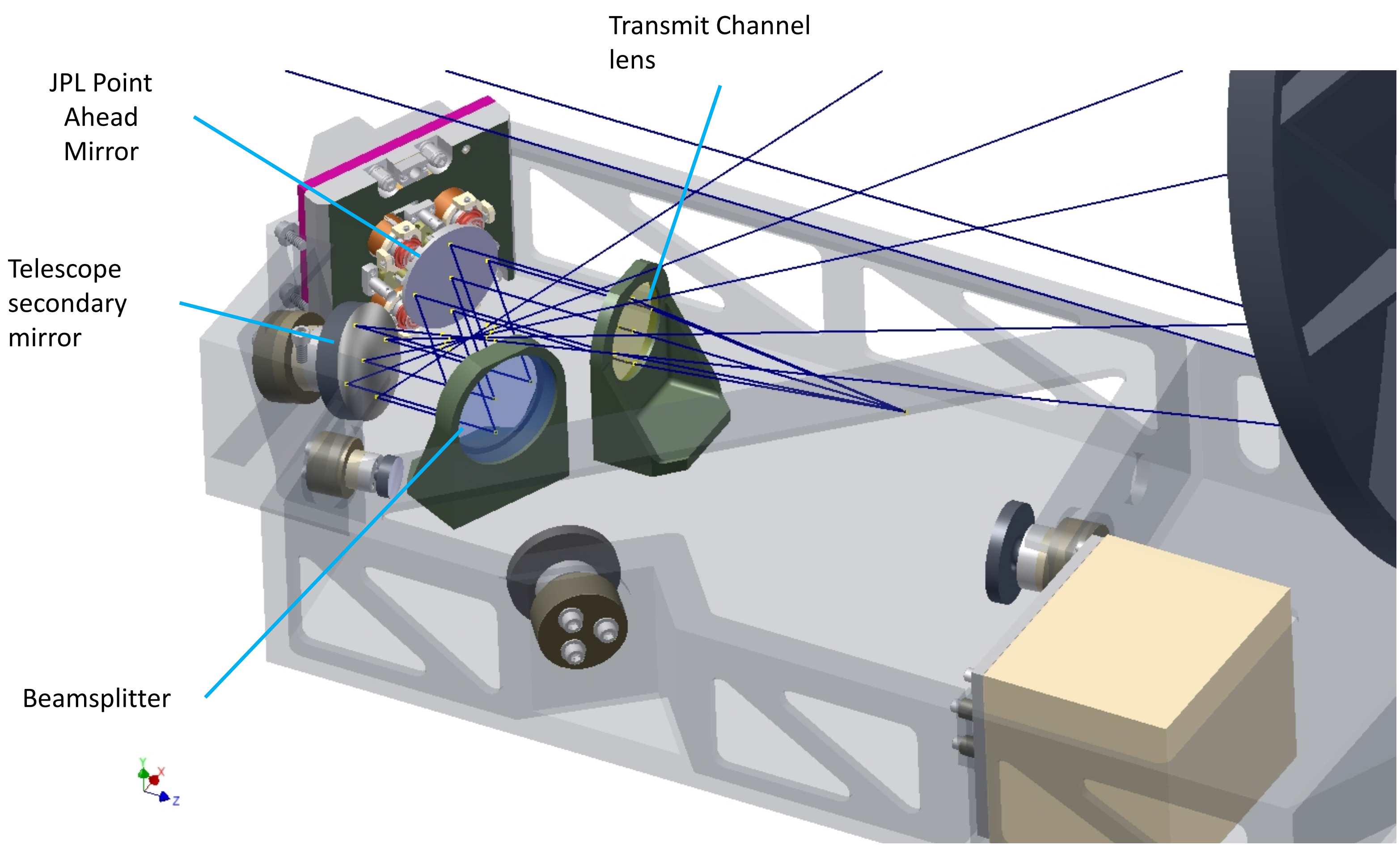
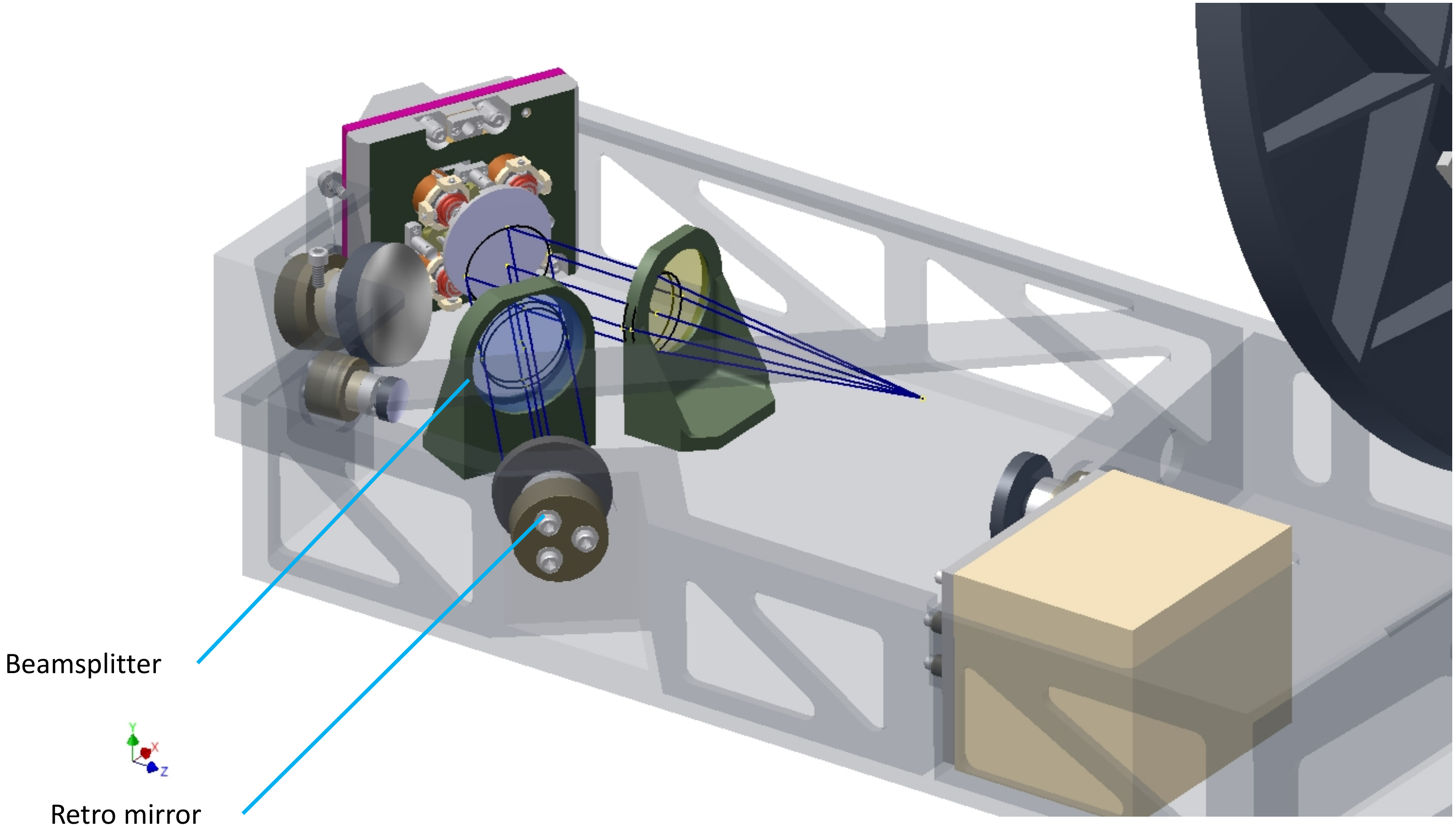
Earth-Imaging Channel



Transmit Channel Components



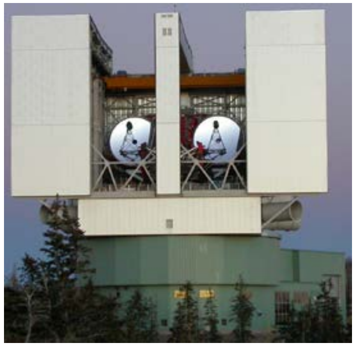
Retro Channel

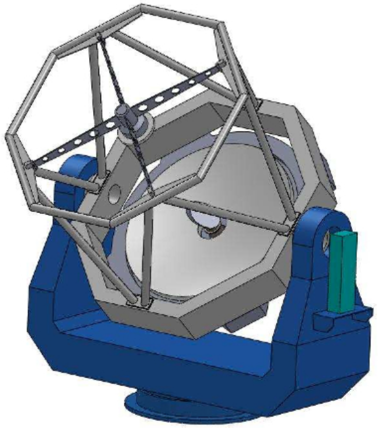


- Residual downlink laser light used
- Re-directs light back into receive channel path
- Acts as pointing reference for downlink beam
- Introduce angular beam offset for dis-ambiguation with reference beacon

DOT Ground Receiver

- **Rent a facility for high data rate links.**
  - LBT is first choice, with twin Keck array as backup at higher cost.
- **Build a telescope to use for all other links, including near-Sun pointing.**
  - Minimum aperture for acquisition is 2.2m.
  - Can also be used for GEO to Lagrange-point ranges.
  - Same design can be used for uplink.
  - Feeds forward to Operational Capability.





This approach is feasible for meeting DOT requirements, with some feed-forward to IOC.

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Ground Beacon Transmitter

- Optical Communications Telescope Laboratory (OCTL)
  - Best meets selection criteria
  - Dedicated NASA telescope for deep space optical communications
- Designed for space-object tracking
  - Demonstrated high-precision pointing with routine satellite ranging demonstrations
  - Demonstrated with bi-directional communications to OICETS
  - Demonstrated near-Sun operation
- Existing necessary infrastructure
  - Secure-access facility
  - Aircraft monitoring and avoidance system
  - Communications infrastructure
  - Dormitory to support long-term operations
  - Proximity to JPL for rapid access and response

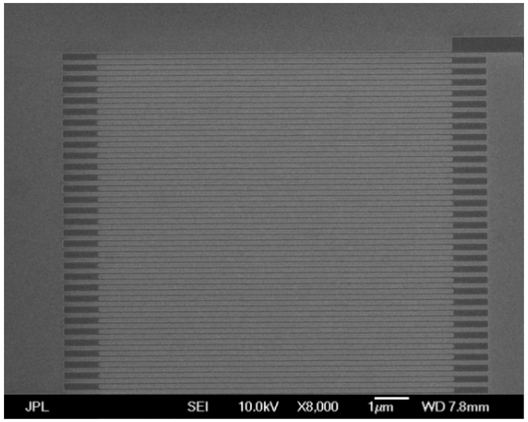
Areas of Technology Development

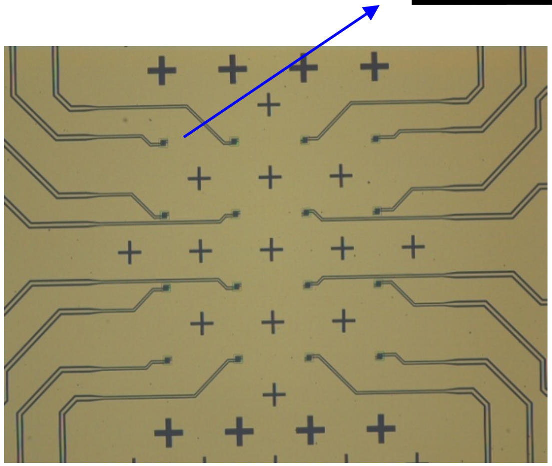
- Low-noise, high-bandwidth detectors – These allow us to see faint signals with less interference from the background
- Ultra-stable vibration isolation technology – This is required to allow us to maintain pointing of the narrow beam
- High-power beacon lasers – Reduces the cost and complexity of acquiring the Earth receiver location
- Low-cost large-aperture telescopes – Allows us to reduce the cost of the space system and enhance total system capabilities

Superconducting Nanowire Arrays

- A SNSPD consists of a very thin (~5 nm) and narrow (~80 nm) superconducting wire which is current biased to just below the transition to the normal state. An incident photon deposits enough energy in the wire to quickly drive it into the normal state thus detecting the photon.
  - Excellent detection efficiencies: > 80% at ~2K
  - High timing resolution: 50 ps 1-σ typical

- GLR requires arrays of several hundred pixels to collect the atmospheric blurred downlink
  - Device arrays are also required at high flux rates as kinetic inductance limits recovery time
  - A 16 pixel system is currently being tested at JPL with a 48 pixel system planned for FY2011.



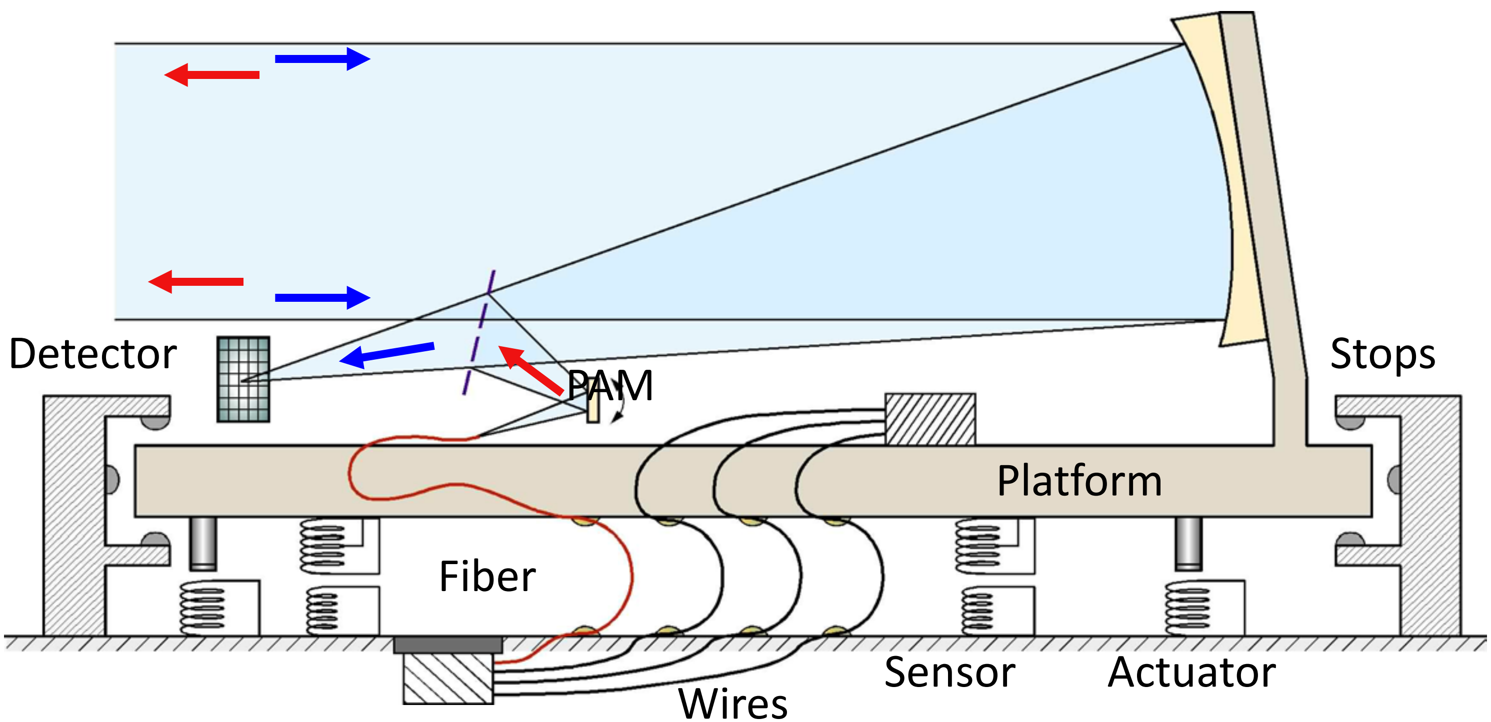


Optical micrograph of a 16 pixel lens-coupled SNSPD array and a SEM micrograph of a single 10 µm SNSPD detector.

Sketch of Vibration Isolation System

Isolated platform with active control of the platform

- Isolation struts with
  - Voice coil actuators
  - Inductive sensors (“LVDTs”) for sensing position of platform relative to spacecraft
- Beacon for sensing pointing
- Sample of transmit beam detected for tracking of downlink pointing (not shown)
- Fine pointing actuation of downlink beam using the point-ahead mirror (PAM)



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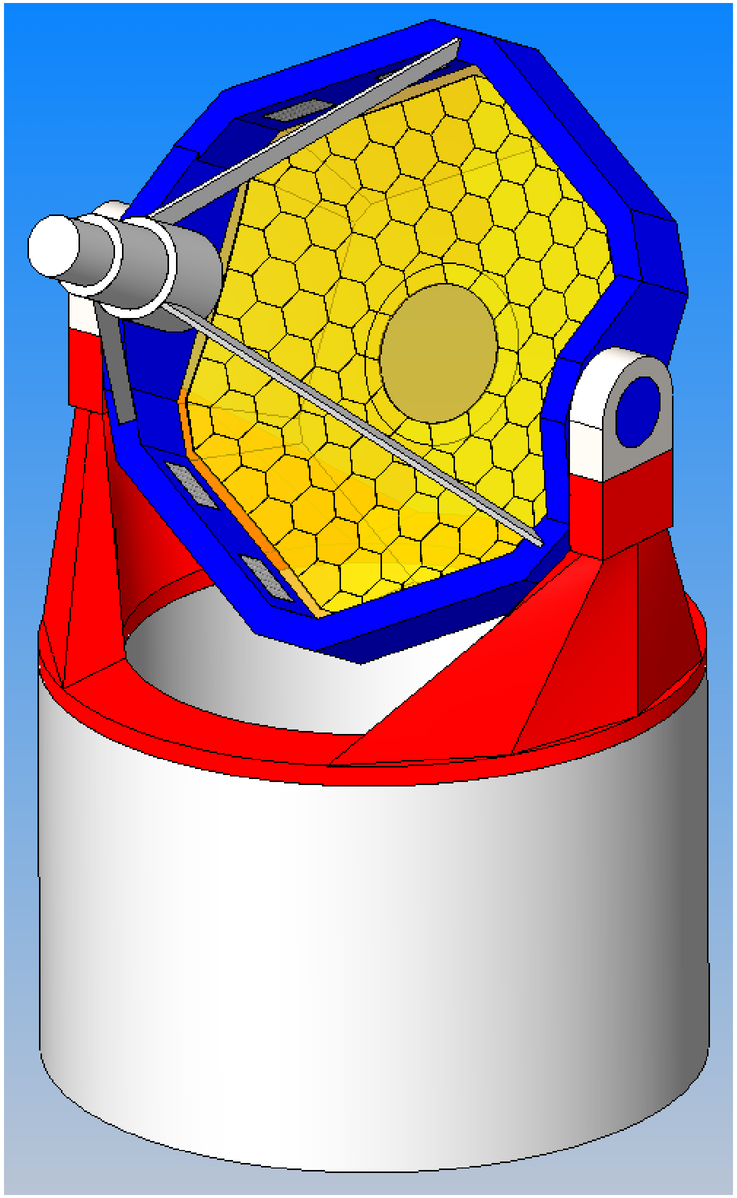
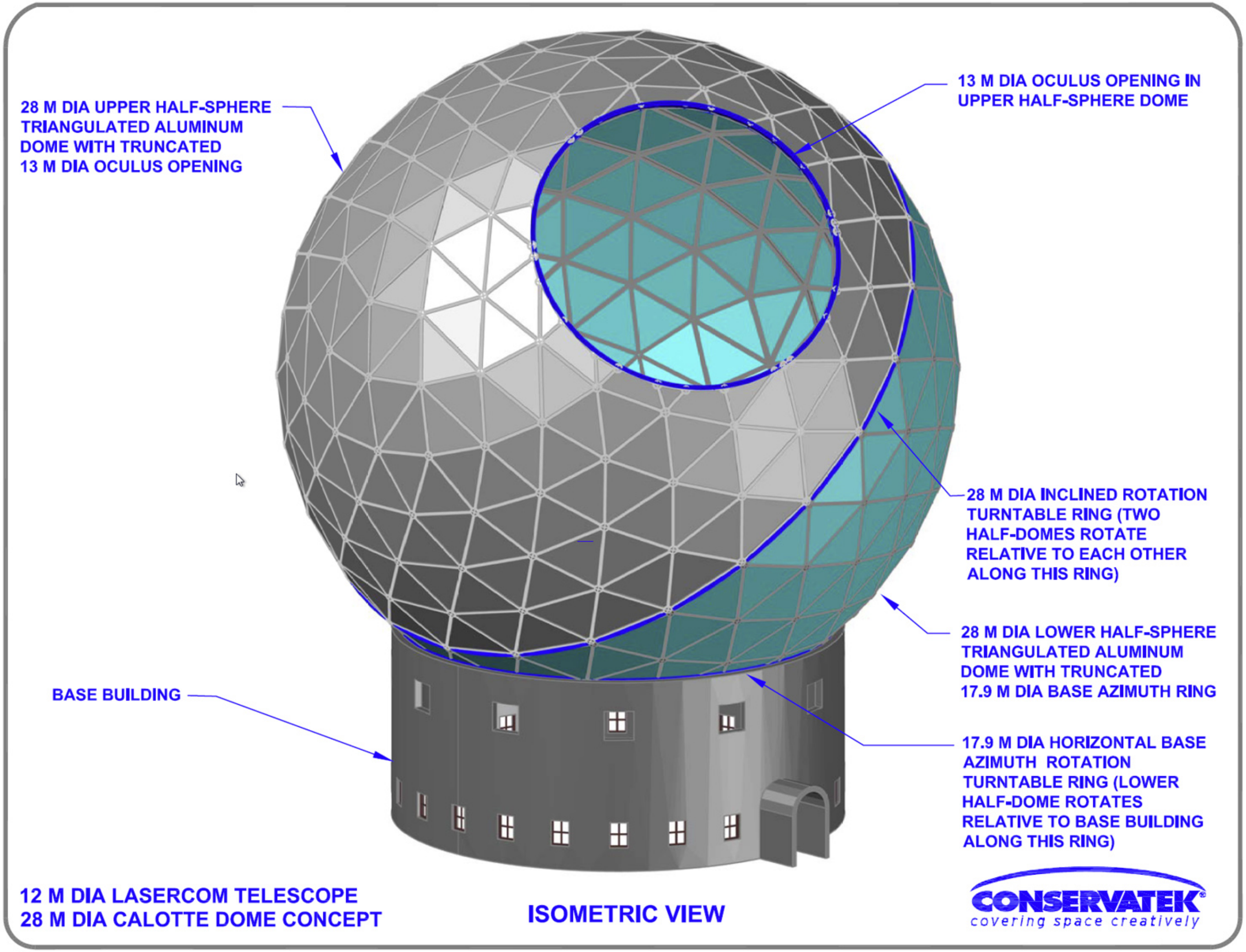
Concept for Inexpensive 12-m Ground Terminal

- Prime Focus Design w 110 m^2 Collecting Area
- Spherical Segmented Primary Mirror
- Compact Size
- Novel and Cost Effective Dome Approach
- Most Concepts Already Demonstrated with Recent Astronomical Telescopes
- Some "New" Designs
- Meets All Requirements Except Detector Package "Vertical Orientation"



Dome Concept by Conservatek (TX)



Summary

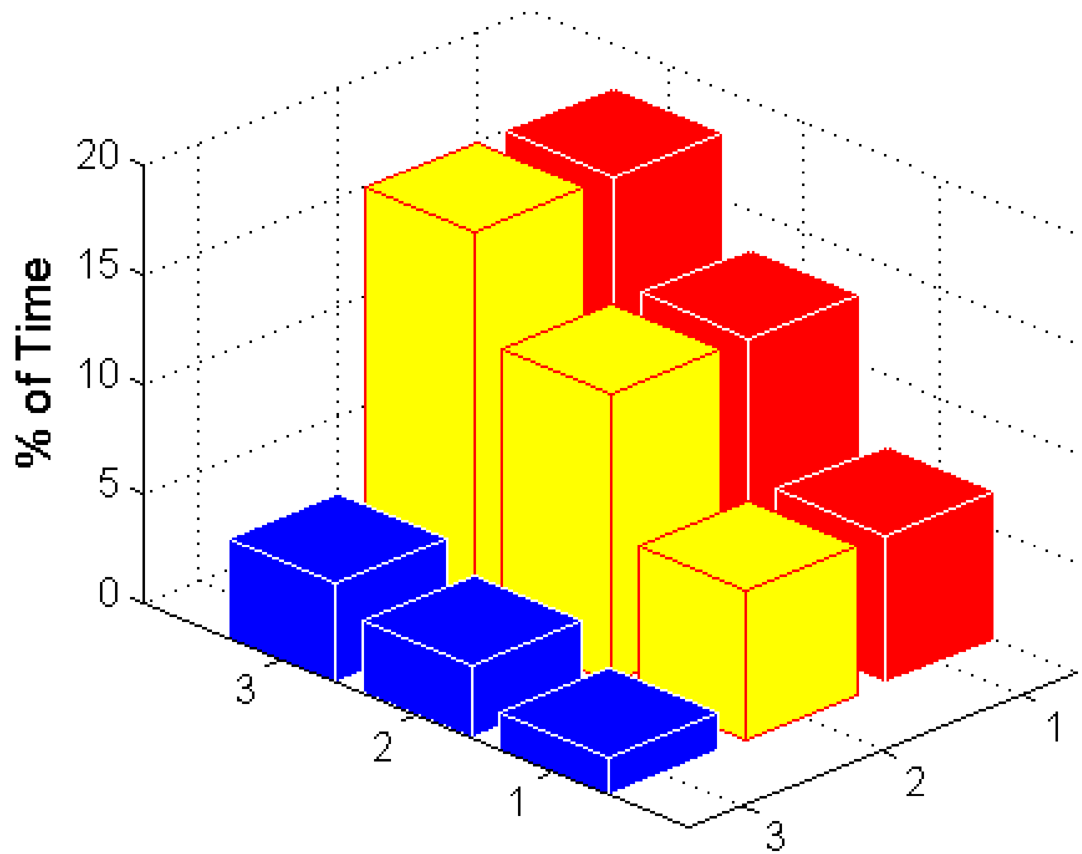
- NASA is pushing the development of high-bandwidth optical communications for interplanetary support of
  - High-bandwidth instrumentation
  - Human presence
- The Deep-space Optical Terminals (DOT) project incorporates the latest designs and technology for supporting this
  - Flight Laser Terminal with 22-cm aperture
  - Existing astronomical telescope receiver
  - Newly-designed 2.2-meter telescope for near-Sun operations
- NASA is investing in the development of advanced technologies for low-cost systems and operations
  - Extremely sensitive silicon nanowire detectors
  - Low-frequency space-qualified stabilization systems
  - Low-cost large-aperture receive telescopes

BACKUP

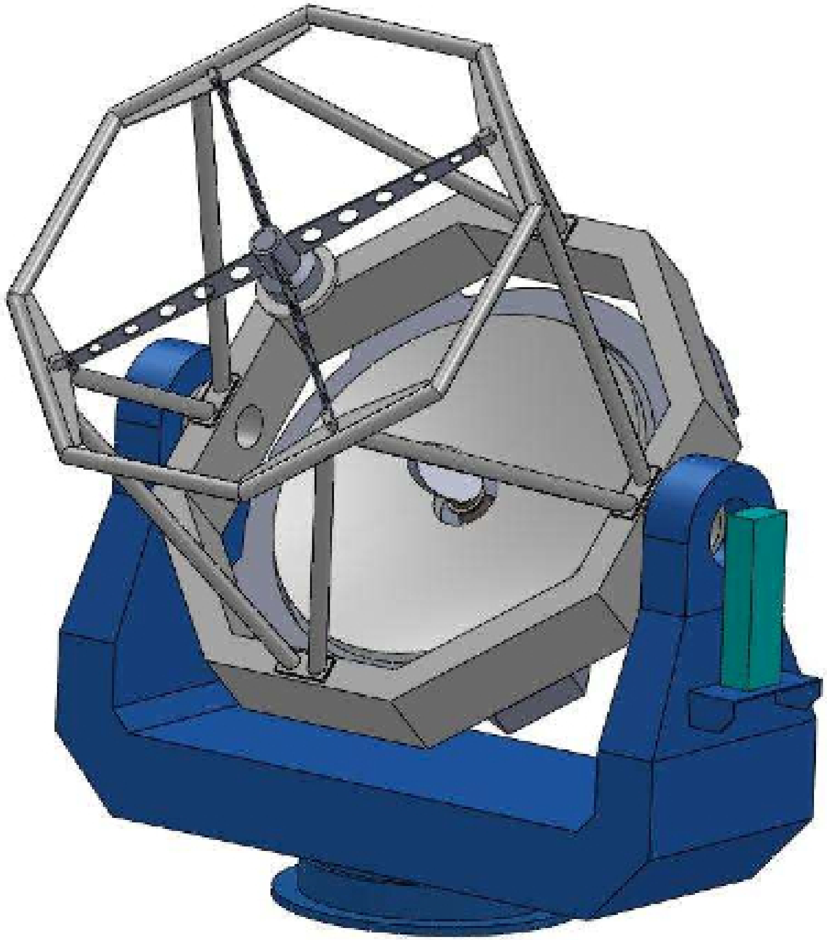
Link Characteristics

- **Demonstration Opportunities**
  - 95% of link conditions
    - 5% outage solar conjunction
  - 90% of atmospheric conditions
    - 10% outage due to extreme attenuation, winds, humidity
  - Overall 85% of CFLOS duration
- **Design targets nominal and worst conditions**
  - In general dominated by nominal to worst
  - Actually seasonal perturbations will affect performance

Over 60% Cloud-Free Line-of-Sight duration at Nominal-to-Worst Conditions



2.2 Meter Ground Terminal



- Telescope must be designed for near-Sun pointing (5° Sun-Earth-Probe or SEP angle).
  - Preliminary analysis indicates this can be met with proper choice of materials, coatings, and baffling.
- Standard telescope designs meet all other requirements.

NASA Experience with Optical Communications

- GOPEX – Deep space optical transmission from Earth to Galileo spacecraft at ~ 6 million km – succeeded in 1992
- GOLD – Bi-directional optical communications between Earth and geosynchronous Japanese ETS VI spacecraft – succeeded in 1995
- MLCD – Deep space optical communications demonstration project between Earth and Mars orbit – project cancelled
- Messenger – Bi-directional deep space optical transmission between Earth and Messenger spacecraft at 24 million km – succeeded in 2006
- OTOOLE – Bi-directional optical communications between Earth and Japanese OICETS optical communications satellite – succeeded in 2010
- LLCD – Bi-directional optical communications link between Earth and LADEE lunar spacecraft – expected in 2013
- OPALS – Optical downlink demonstration from the ISS to earth – baselined to launch in 2012
- ISS-link – Bi-directional optical link from ISS to ground – baselined for 2015