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Optical Communications from Planetary Distances

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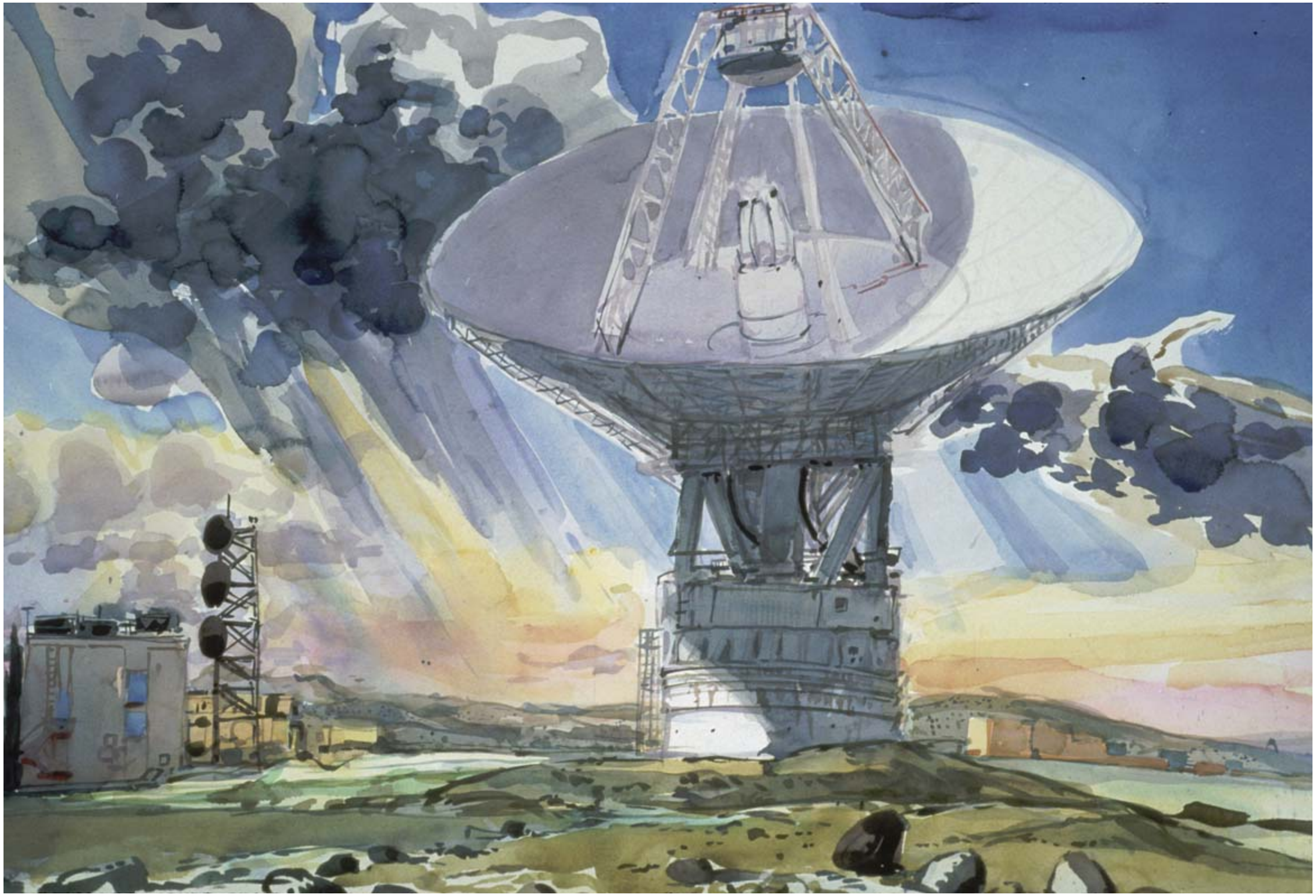
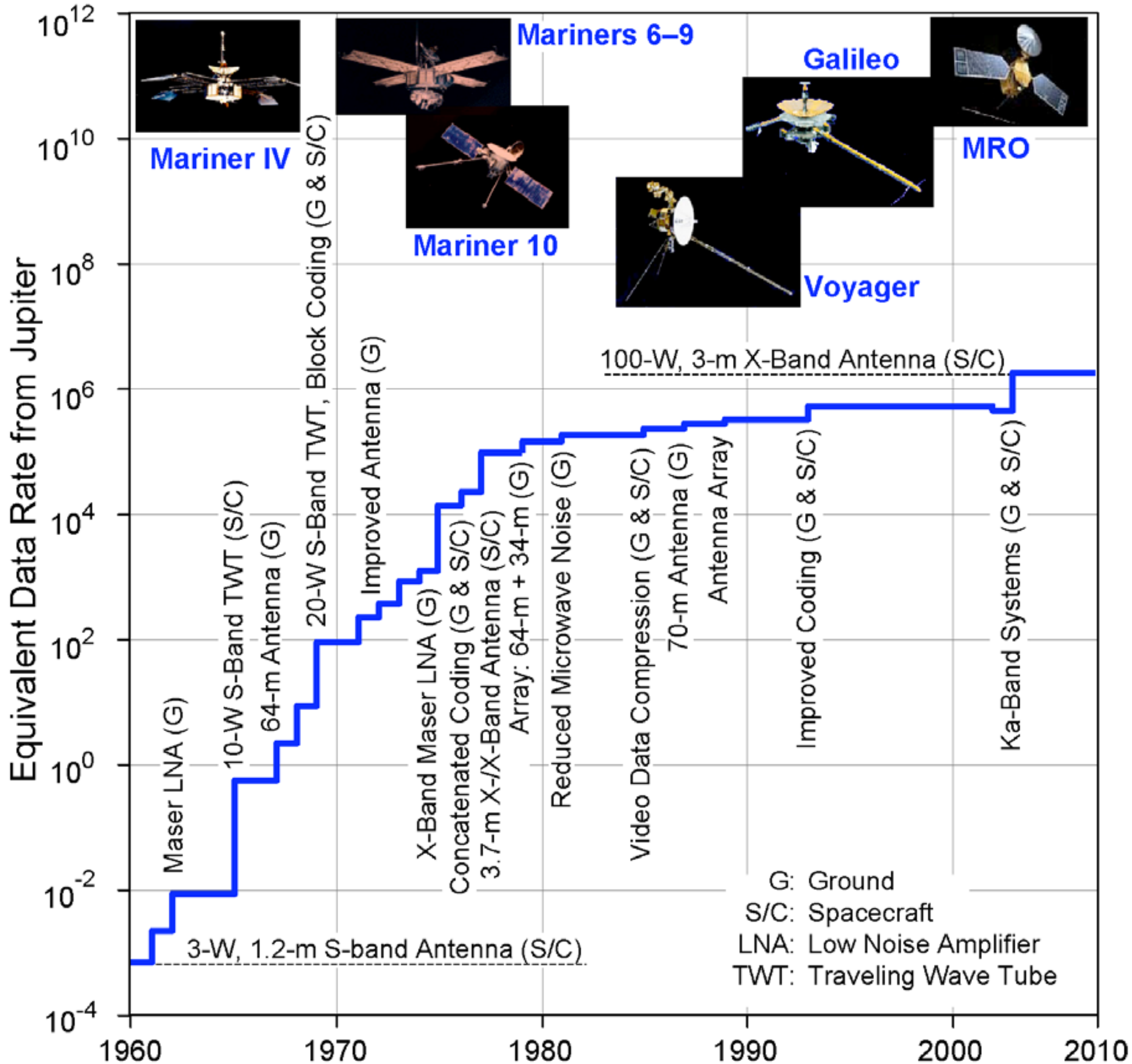
Deep Space Network 70-m Antenna at Goldstone, California

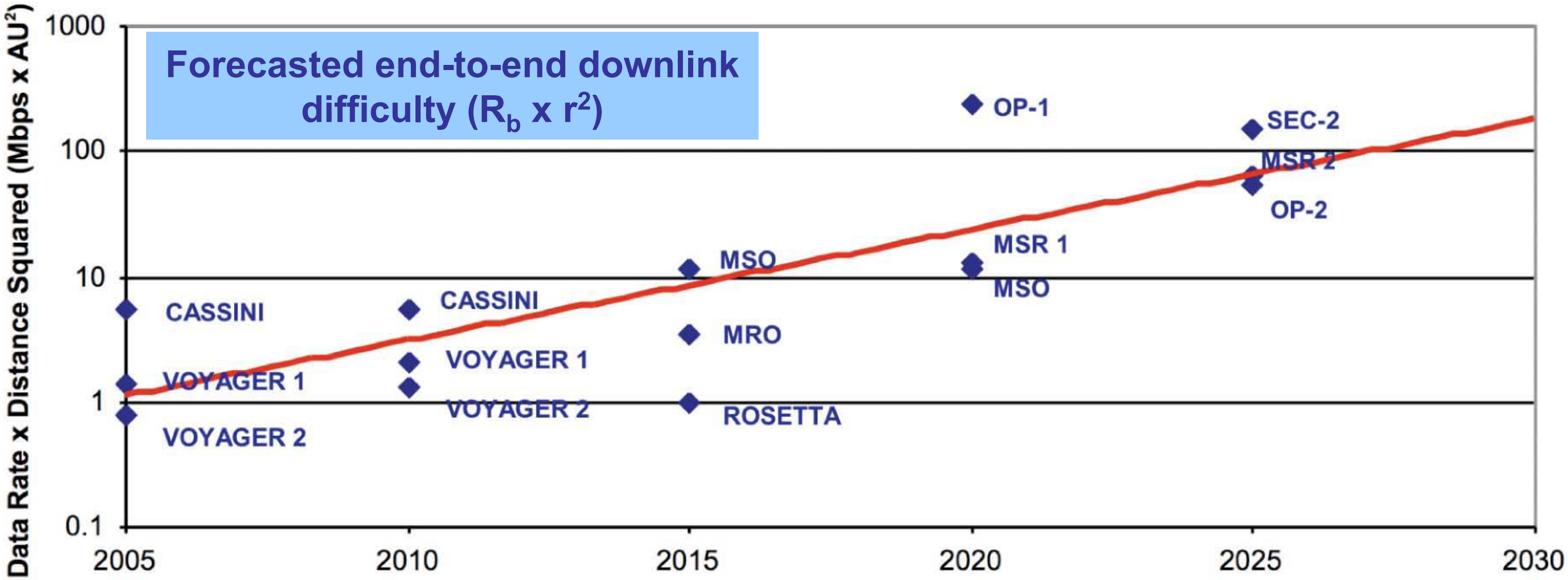
Artwork by Henk Pander



History of Deep Space Telemetry



Future of Deep Space Telemetry



- Maximum end-to-end downlink difficulty is expected to increase roughly two orders of magnitude by 2025
- Although radio frequency (RF) waves may be able to meet future demands, in practice, optical links may provide a better option for meeting such ominous goals.
- It will be difficult, if not impossible, to communicate at near gigabits per second from the deep space using RF means.

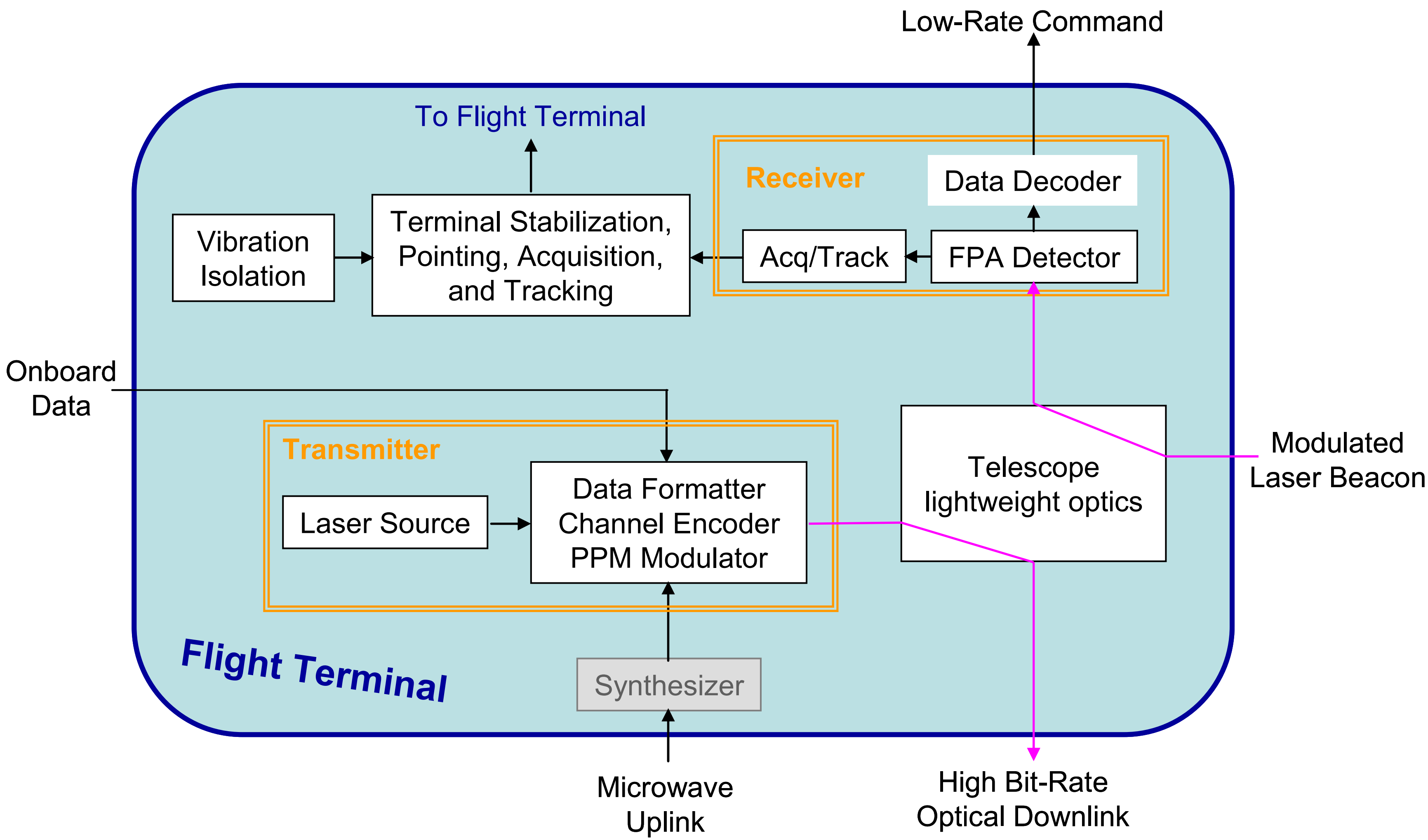
Background

- An important challenge in developing technology for space applications is the identification and utilization of a flight opportunity to test the technology
  - no specific mission has been identified as the first user
- It is important to demonstrate the feasibility of deep space communications, albeit, at a low data rate.
- Feasibility can be proven by closing the link with adequate margin and good pointing and tracking performance
- The first generation of operational systems will use ground-based Earth terminals

Deep Space laser Communications
Challenges & Technical Solutions

- Optical Channel
  - Photon starved link due to vast planetary distances
  - High levels of background light during day time operation,
  - Reception in the presence of the atmosphere (attenuation, scintillation, signal loss, etc.)
- Technology solutions
  - Narrow laser beams focus energy for long distance applications
    - Space terminal vibration isolation and precise pointing
  - Pulse position modulation (PPM) at the transmit end
  - Photon counting at the receive end
  - Ground terminal static and dynamic corrections to combat telescope deformations and channel induced anomalies
  - Channel error correction via encoding

Optical Flight Terminal Conceptual block Diagram

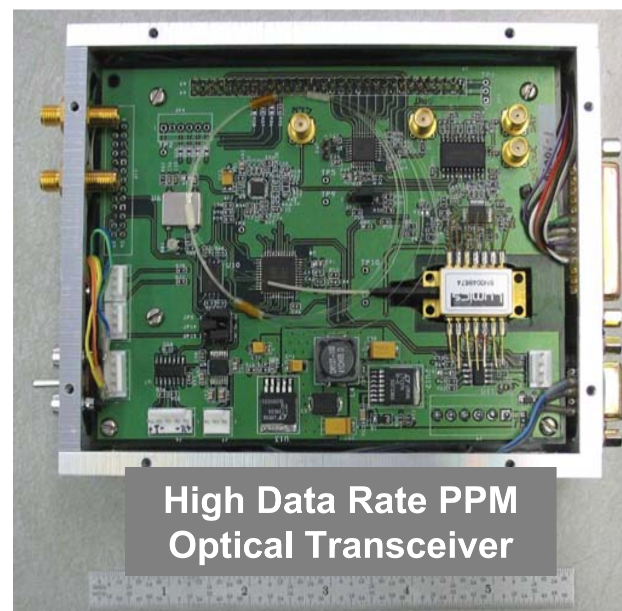


Optical Flight Terminal

High Data Rate PPM Transmitter

- High order PPM requires an efficient laser amplifier with a high peak to average power ratio
  - Yb fiber lasers operating near 1060 nm or Er/Yb fiber lasers operating near 1550 nm
- JPL is now implementing data rates in the 50 to 1200 Megabits per second range using sub-nanosecond PPM slot widths
- JPL has developed a series of FPGA encoders and modulators that operate a slot rates down to 100 picoseconds with real time data inputs to 1.2 gigabits per second.

1W Fiber Amplifier Module

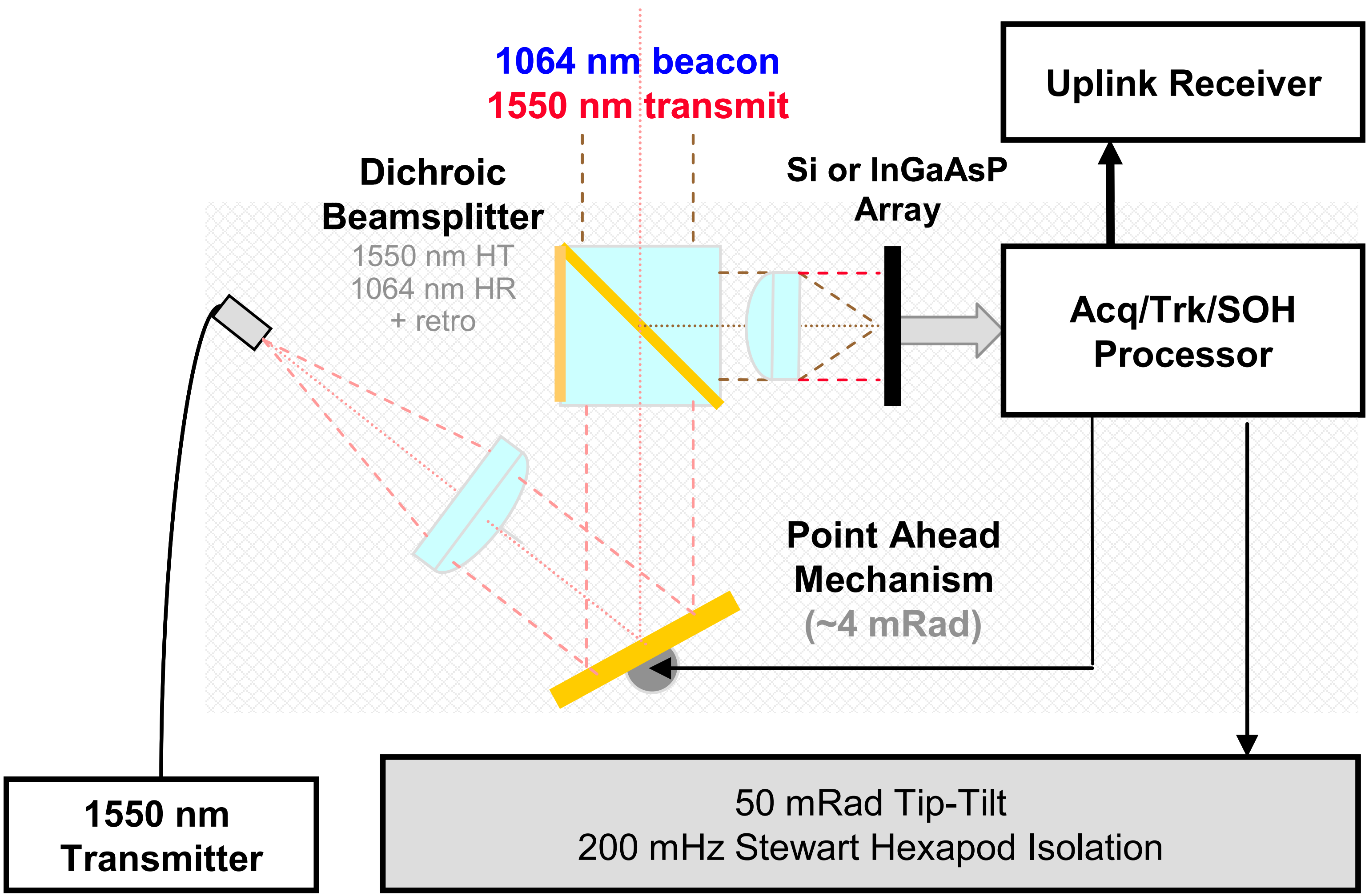


High Data Rate PPM Optical Transceiver

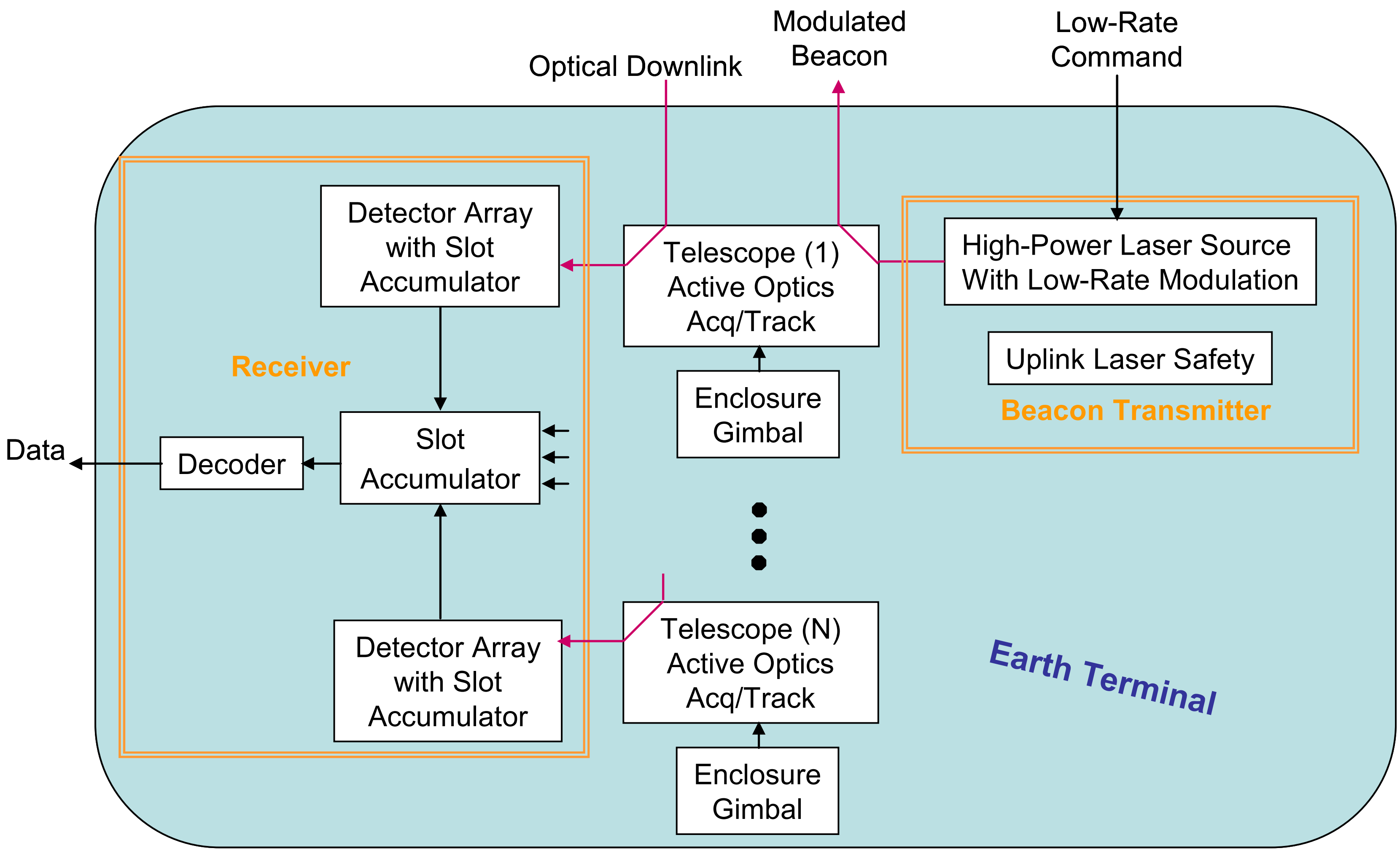
Optical Flight Terminal
Flight Receiver

- Flight photon counting detector qualification
  - InGaAs(P) single photon sensitive Negative Avalanche Feedback and Geiger mode detectors for space operation
- Development and demonstration of Doppler rate estimation algorithm in hardware based upon using GHz rate PPM slot clock

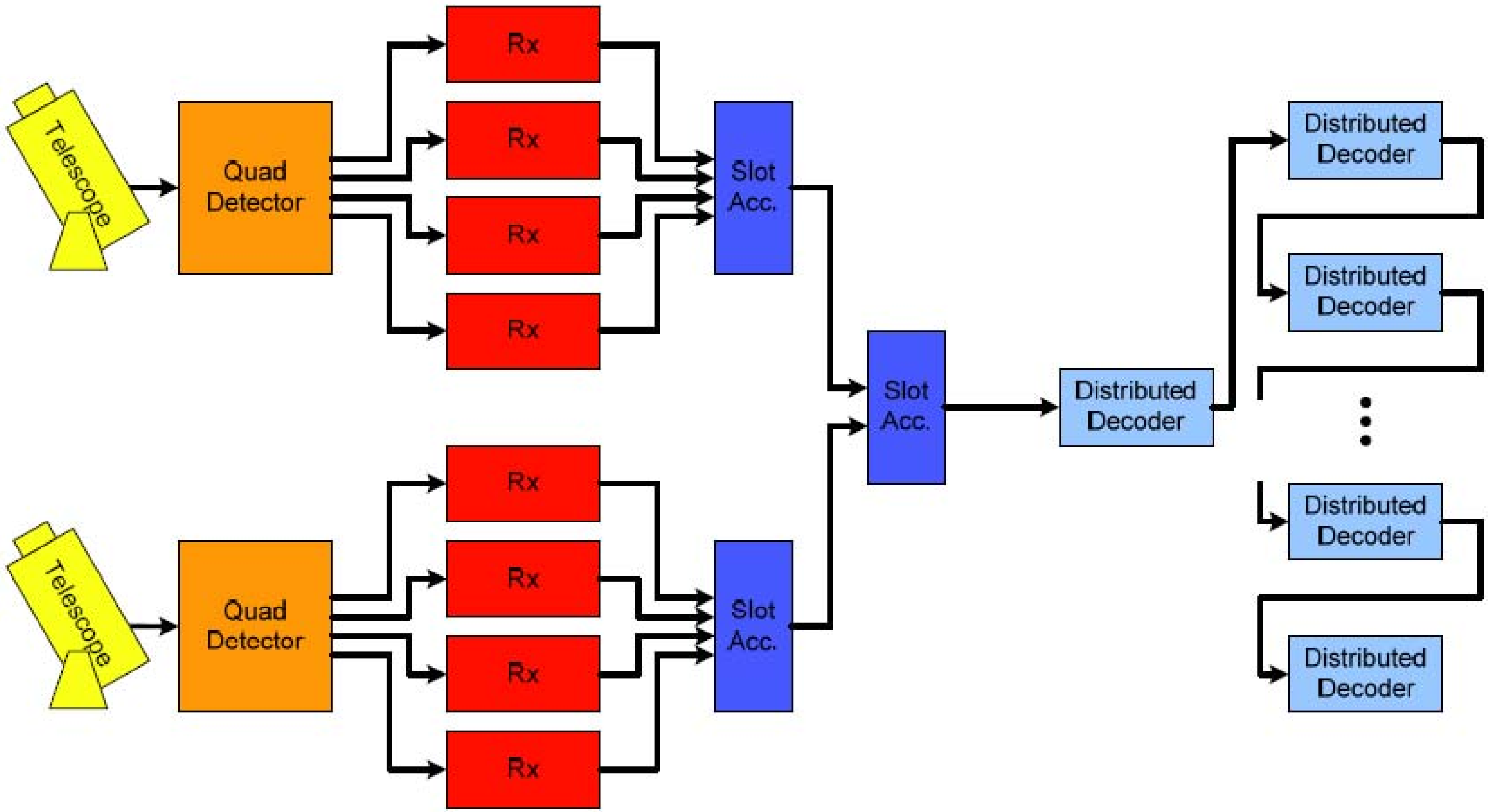
Acquisition/Tracking/Pointing system based on Disturbance Free Platform concept



Optical Ground Terminal Conceptual Block diagram



Downlink Array Receiver Architecture

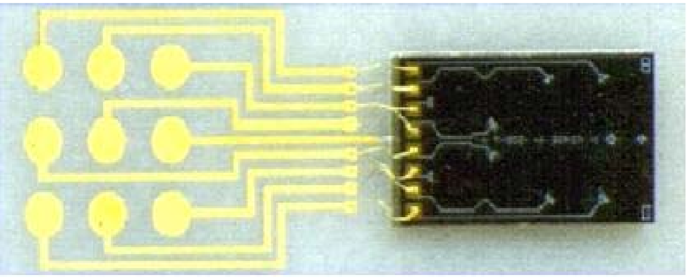


High Efficiency Photon Counting Detector

- High single photon detection efficiency (SPDE) reduces spacecraft burden (less laser transmit power)
- Low output pulse jitter is required for reception of PPM signals at high data rates.
- Dark count rate requirements are less stringent than other photon counting applications due to the high background fluxes encountered during daytime link operations
- Detector count rate limitations (linearity) can be mitigated through the use of array architectures
- JPL has heavily invested in a state-of-the-art characterization facility for photon counting detectors
- The most viable technology presently commercially available is the InGaAs(P) intensified photodiode (IPD)
  - Was validated to photon count in the near-infrared with high efficiency (> 40% SPDE) and operate with minimal cooling (220K)
  - IPD is a vacuum tube device that suffers from photocathode degradation with a lifetime on the order of a few thousand hours.

Detector, cont.

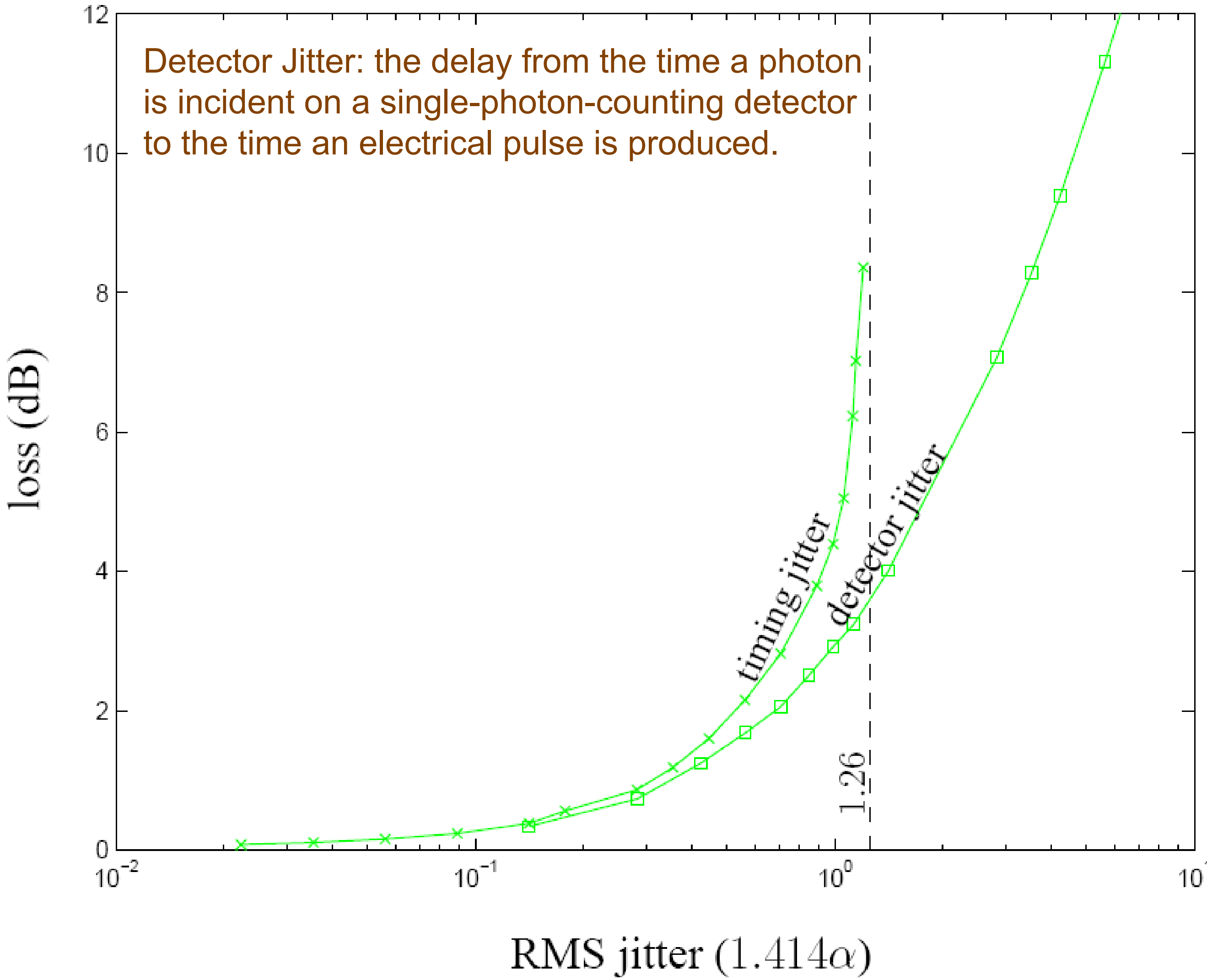
- Most promising has been demonstration Negative Avalanche Feedback (NAF) avalanche photodiodes with InGaAs absorbers for non-Geiger mode photon counting in the near infrared
- This technology has been previously demonstrated in silicon for visible wavelengths
- The NAF operational mode eliminates the requirement for the reset circuitry and read-out electronics that are required for semiconductor photon counters using Geiger mode operation.
- JPL has validated high gains (greater than 105) with excess noise factors near 1.0 in an InGaAs/InP material system and confirmed single photon response in sub-Geiger mode operation.



Single Photon Detectors

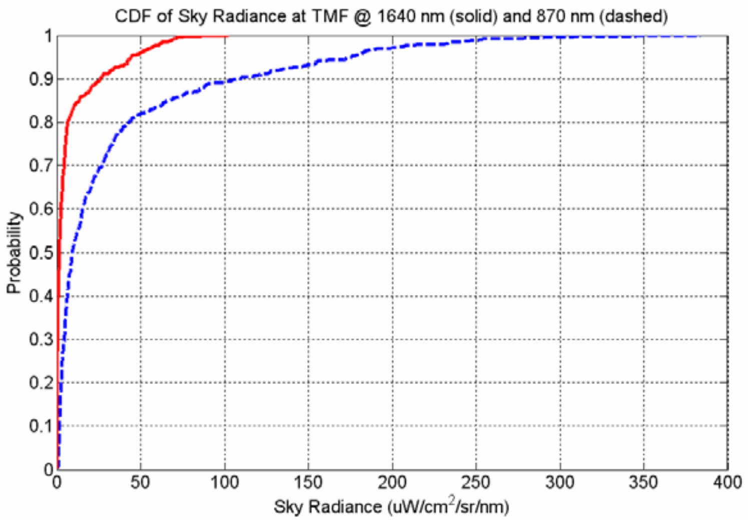
Characterizing Receiver Anomalies

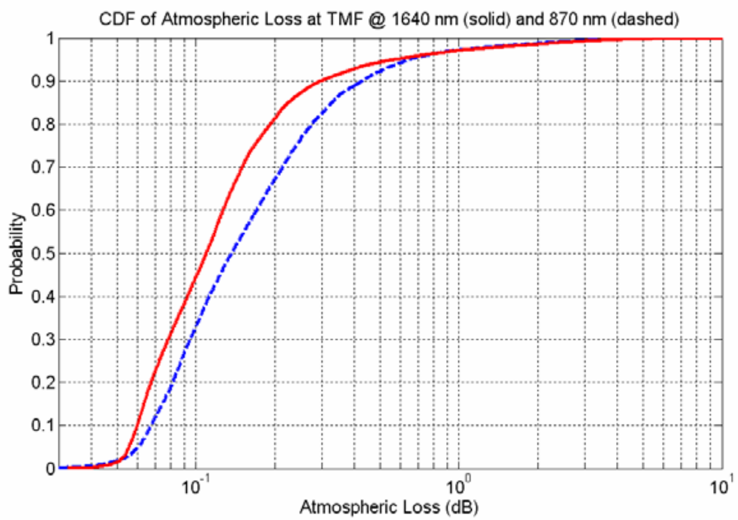
Detector Jitter and Receiver Slot Synchronization Error



Optical Channel

Presence of Sunlight and Atmospheric Effects





- Atmospheric Visibility Monitoring instruments at Table Mountain
  - AERONET sun photometer (870, 1020, 1610 μ) for sky radiance and attenuation monitoring
  - Telescope with MASS/DIMM for atmospheric turbulence monitoring
  - Infrared camera for day/night cloud coverage monitoring

Summary

- Future deep space missions will demand telemetry services that can better served with optical links as opposed to radio links
- JPL is developing the first generation flight optical products for use by missions scheduled for launch in 2012 or later
  - Compact flight terminal
    - Flight terminal pointing and tracking
    - Space qualification
  - Large equivalent aperture ground receiver
    - Arrayed telescopes and arrayed detectors
  - Cryogenic station for detector characterization
  - End-to-end link characterization

Cryogenic Probing Optical Detector Station Test Dewar