Jet Propulsion Laboratory
California Institute of Technology

STATUS OF LASERCOM TECHNOLOGY DEVELOPMENT AT JPL

H. Hemmati

AGENDA

1. NASA Sponsored Projects

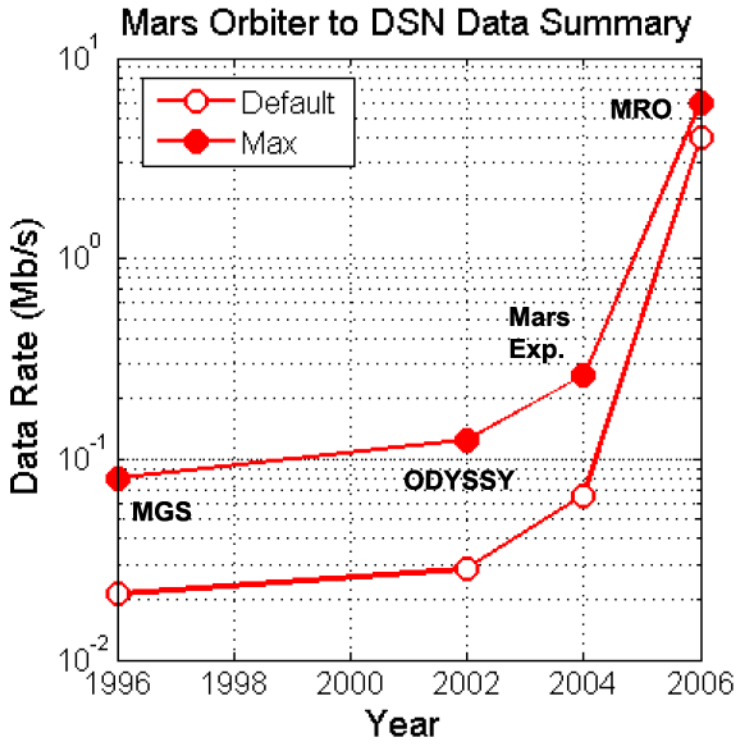
- Planetary Communications Technology
- Mars Laser Communications
- Lunar Surface Communications
- Integrated RF/Optical Ground Receiver

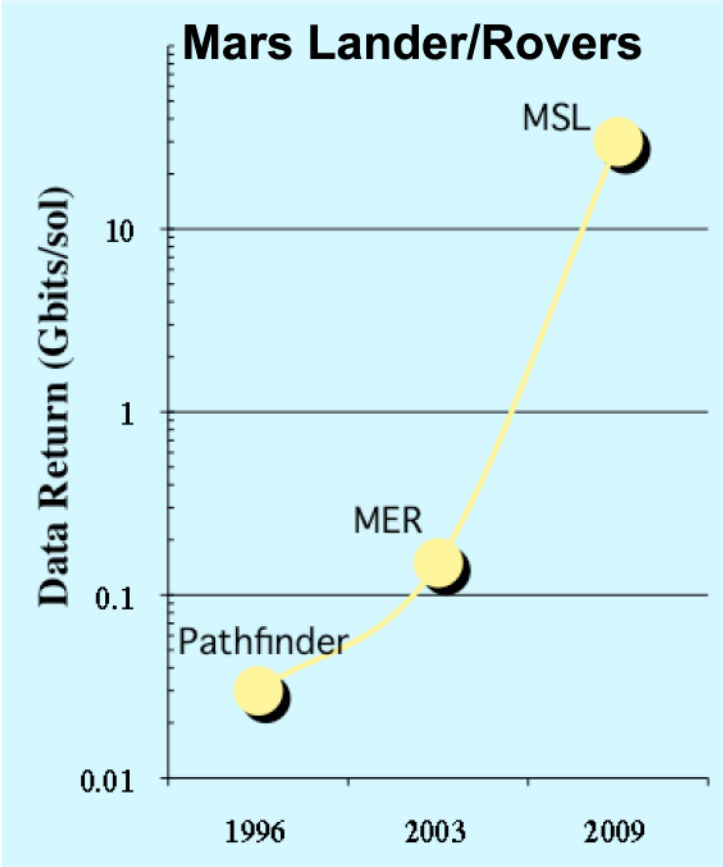
2. Non-NASA Sponsored Projects

- Mars/Moon access/proximity links
- Compact 10 Gb/s LEO terminal
- 1-mm range resolution to planets
- cm-level ranging to airplanes
- 10 Gb/s fiberoptic bus for spacecraft

MOTIVATION & OBJECTIVES

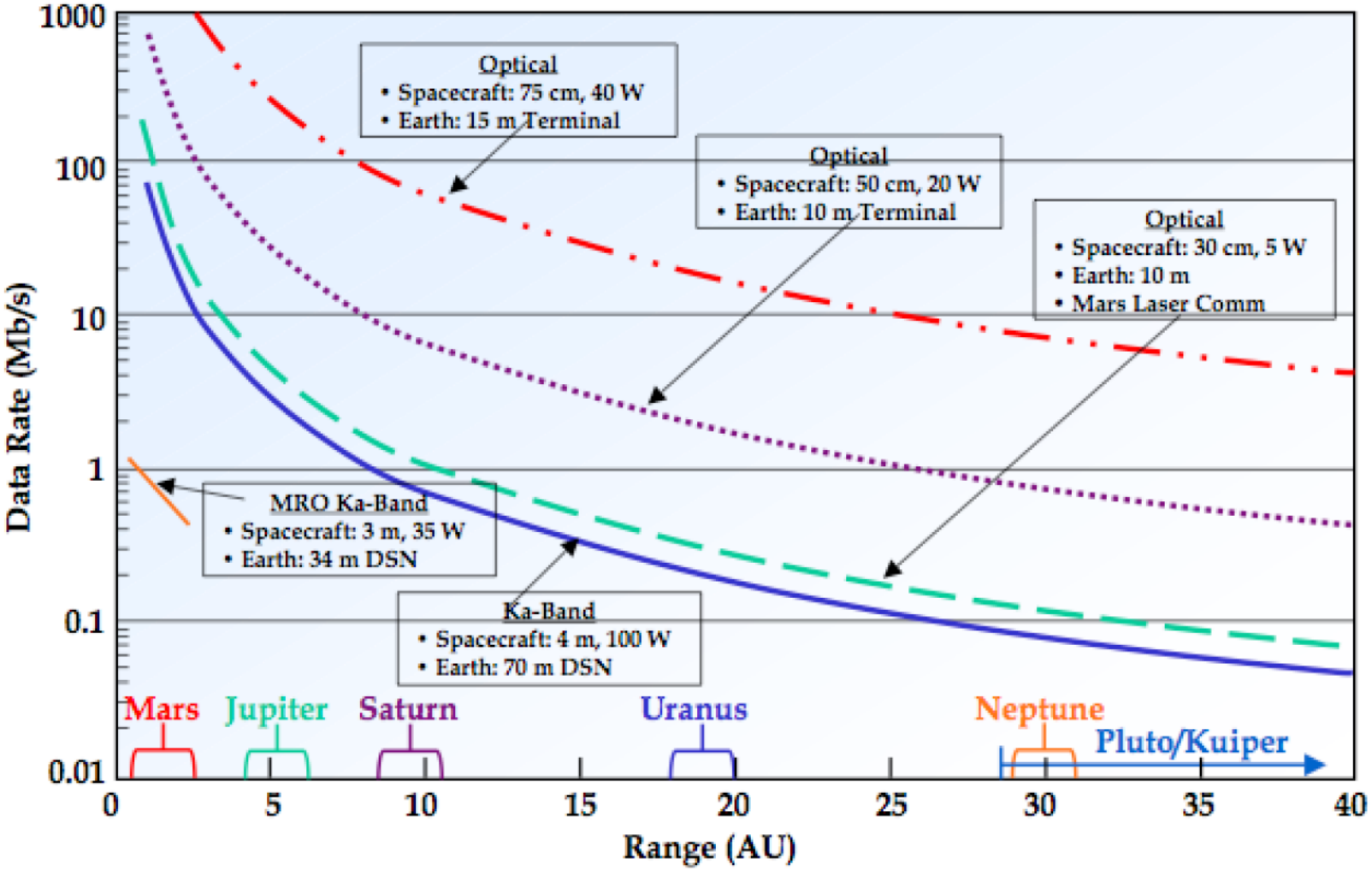
Data Rate Trends:





Data-rate demand continuously on the rise

POTENTIAL OF PLANETARY LASERCOM



JPL'S UNIQUE LASERCOM TECHS

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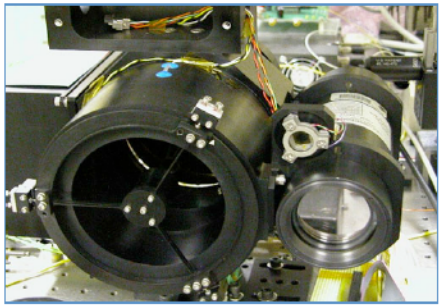
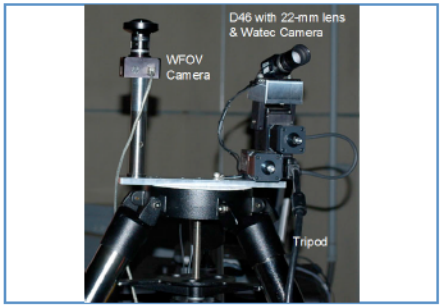
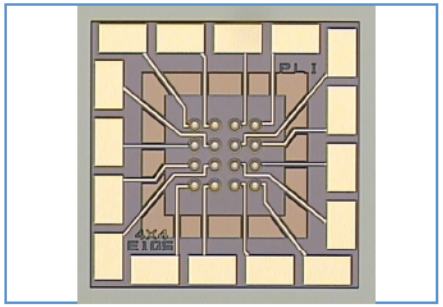


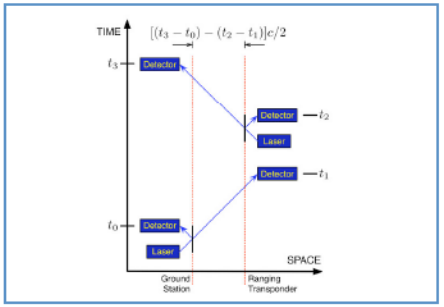
Trunk-Line Comm
Low-Complexity Systems for Comm with Airplanes or Planetary Spacecraft



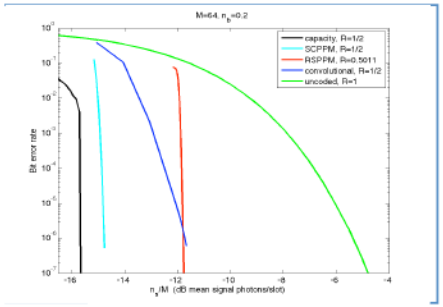
Proximity Link Comm
Simple Autonomous Beam Acquisition for Link to Planes & Orbiters



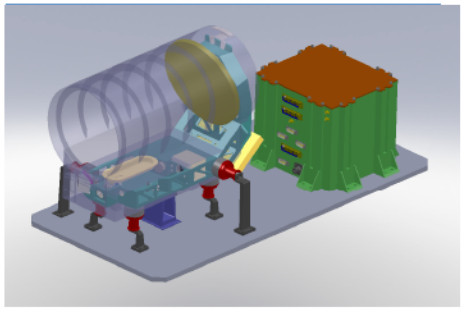
Photon-Starved Comm
State-of-the-Art Single-Photon-Sensitive Detectors (290°K to 2°K)



Precision Ranging
mm-Resolution Active Ranging to Planes/Spacecraft/Moon/Mars

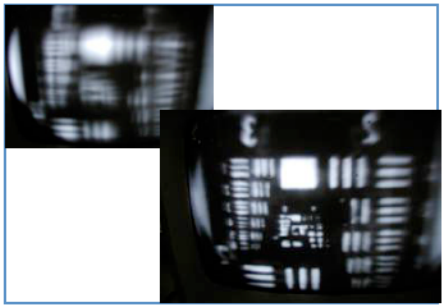


State-of-the-Art Tailored Codes
Efficient Codes (for Optical) Approaching a Fraction of 1 dB of Channel Capacity



State-of-the-Art Vibration Isolation
0.1 Hz Isolated-Platform Supporting Small & Large Optical Systems

High Rate PPM Modulation
High Order Pulse Position Modulation (PPM) Demodulators/Decoders



Low-Cost Large Apertures
Dynamic Compensation of Telescope Aberrations w/ Spatial Light Modulators

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PHOTON COUNTING DETECTORS FOR FLIGHT & GROUND

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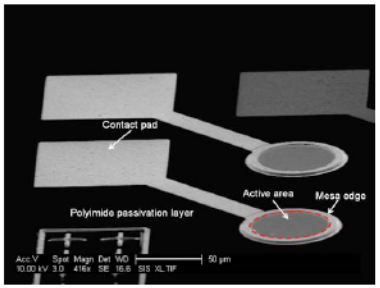
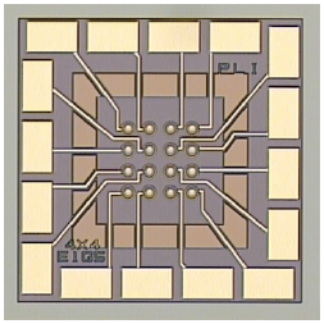
Demonstrated improved performance for 1550 nm single photon detectors incorporating near-room temperature Negative Avalanche Feedback (NAF) to reduce noise and increase photon counting rates

- **Collaborated with three partners to develop these novel InGaAs APD devices**

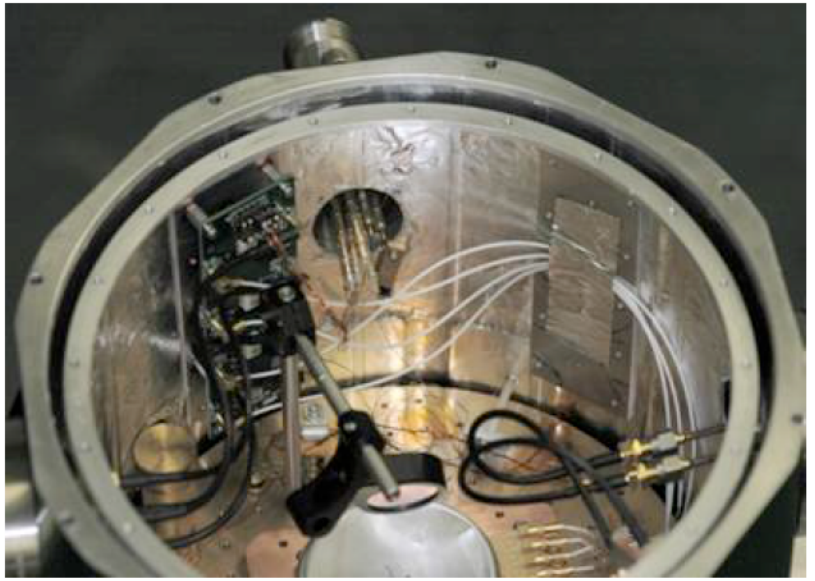


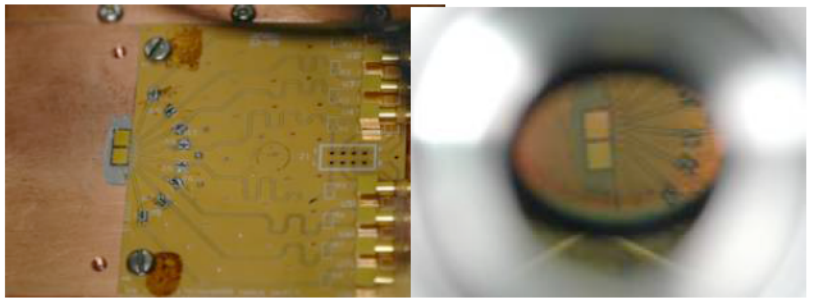
UCSD Transient Carrier Buffer (TCB) Single Photon Detector

Negative Feedback Avalanche Detector (NAFD) 16 Element Array



Fabricated 4x4 NbTiN nano-wire superconducting detector arrays designed for microlens coupling to a free space receiver

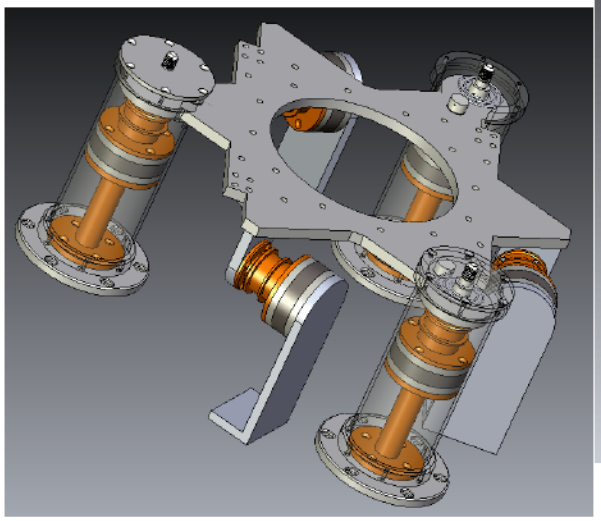


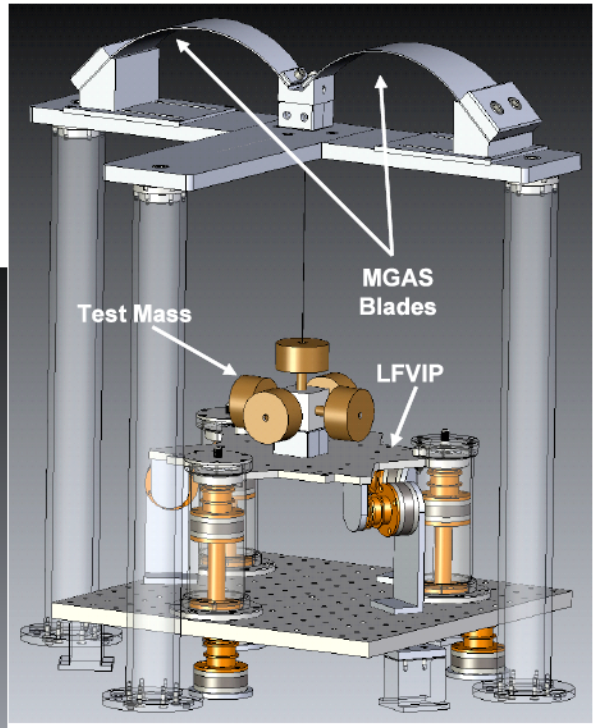


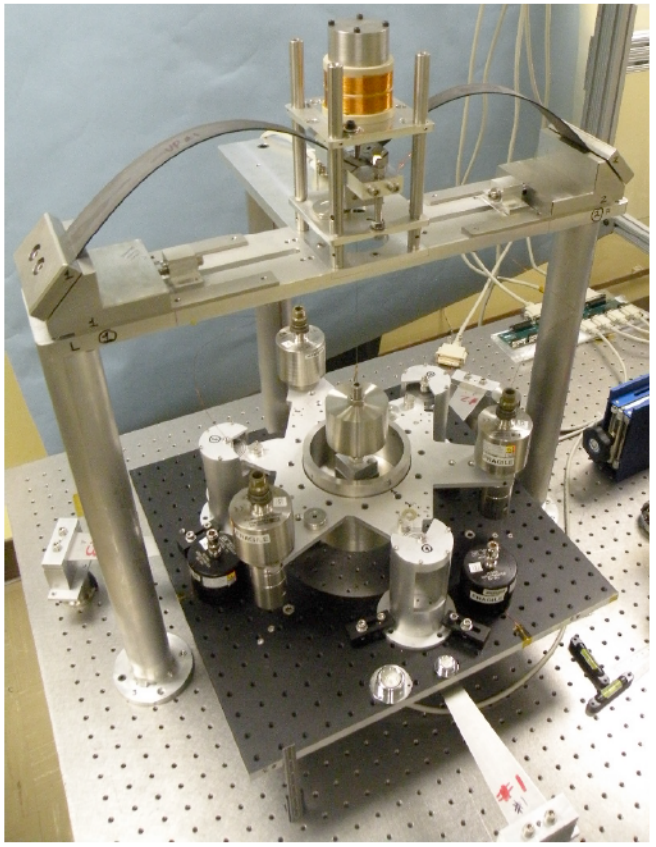
ACTIVE/PASSIVE ISOLATION PLATFORM

Developed a low frequency vibration isolation platform

- Hybrid of both passive and active actuators
- Provides an inertial reference frame above 100 mHz vibration quantification (pitch, roll and vertical)







Vibration Isolation Platform in a Gravity Free Simulation test Setup

FLIGHT LASER TRANSMITTERS

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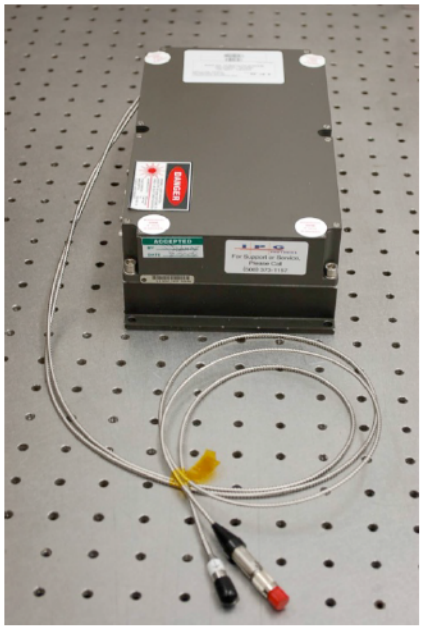
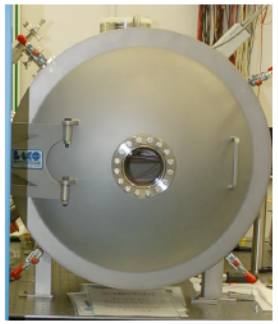
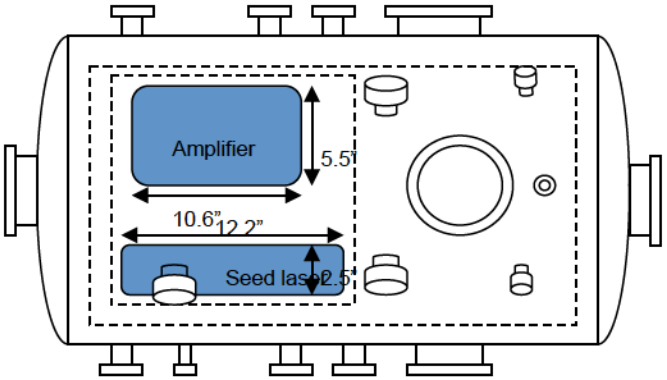
Developed and tested high peak to average power fiber amplifiers at 1550-nm

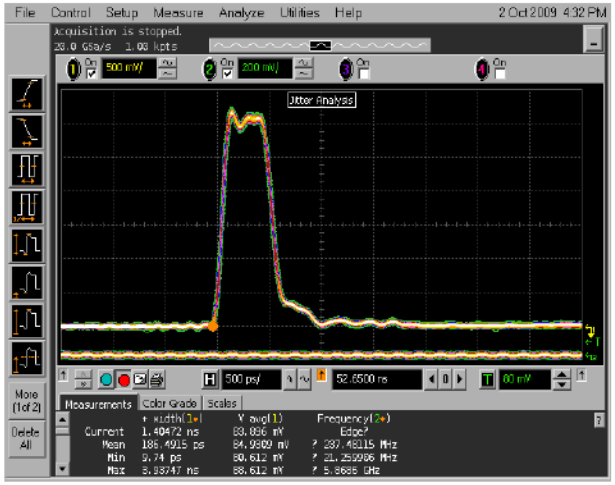
- Used flight grade parts
- Developed a redundant oscillator
- Performed initial thermal-vacuum tests in a dedicated chamber



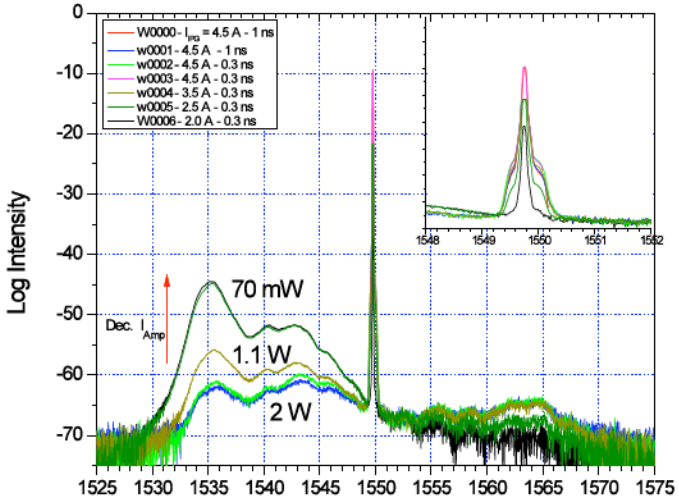
1550 nm 2W Er/Yb co-doped Optical Amplifier







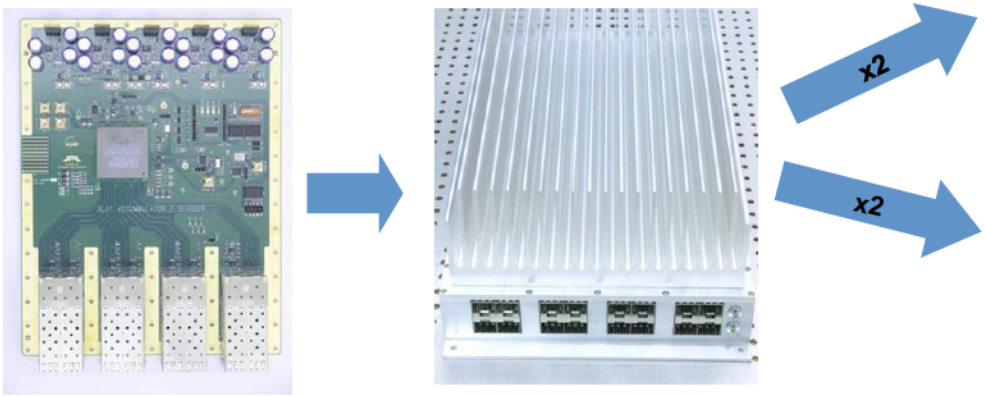
Infinite Persistence Time Trace (5 min.)
300 ps at 10/100 MHz, 2 W output



Output Pulse Spectrum

HIGH ORDER PPM ELECTRONICS

Ground RCVR hardware provides the capability to receive and decode photon counting optical links at data rates to greater than 1 Gb/s



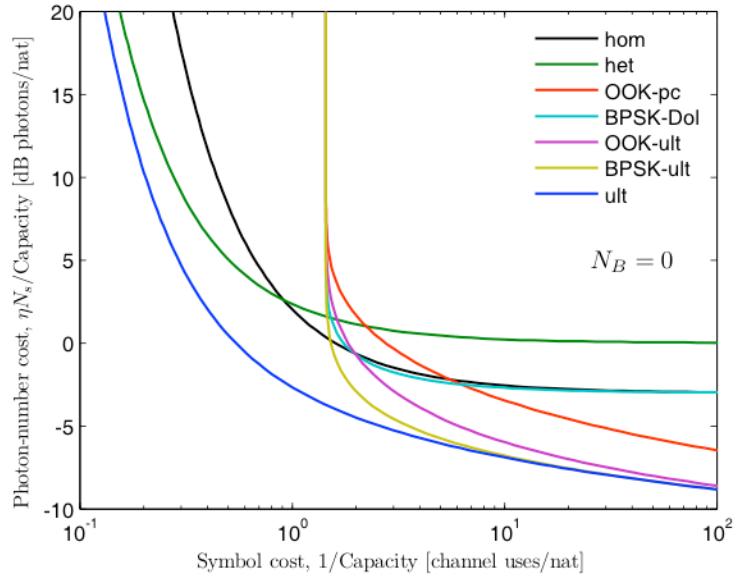
SaND scalable SCPPM Decoder

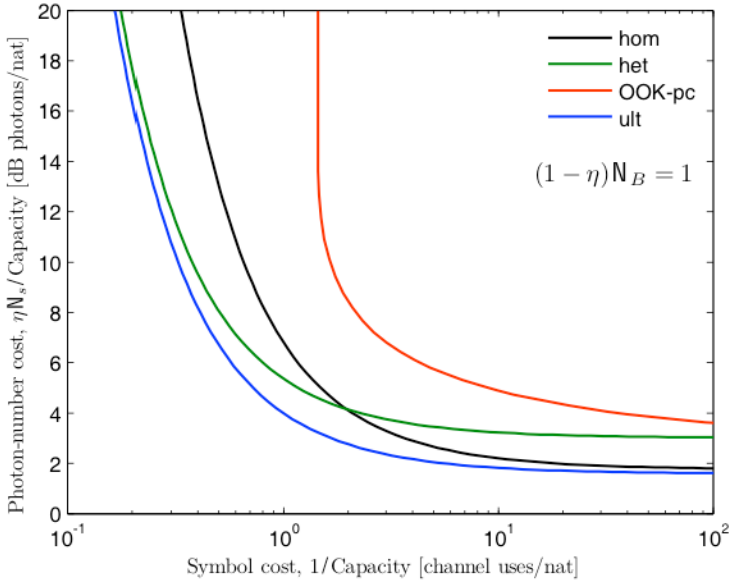
CRX scalable PPM Optical Receiver

NEAR-CAPACITY CODES

Developed modulation/codes that approach a fraction of 1-dB of channel capacity

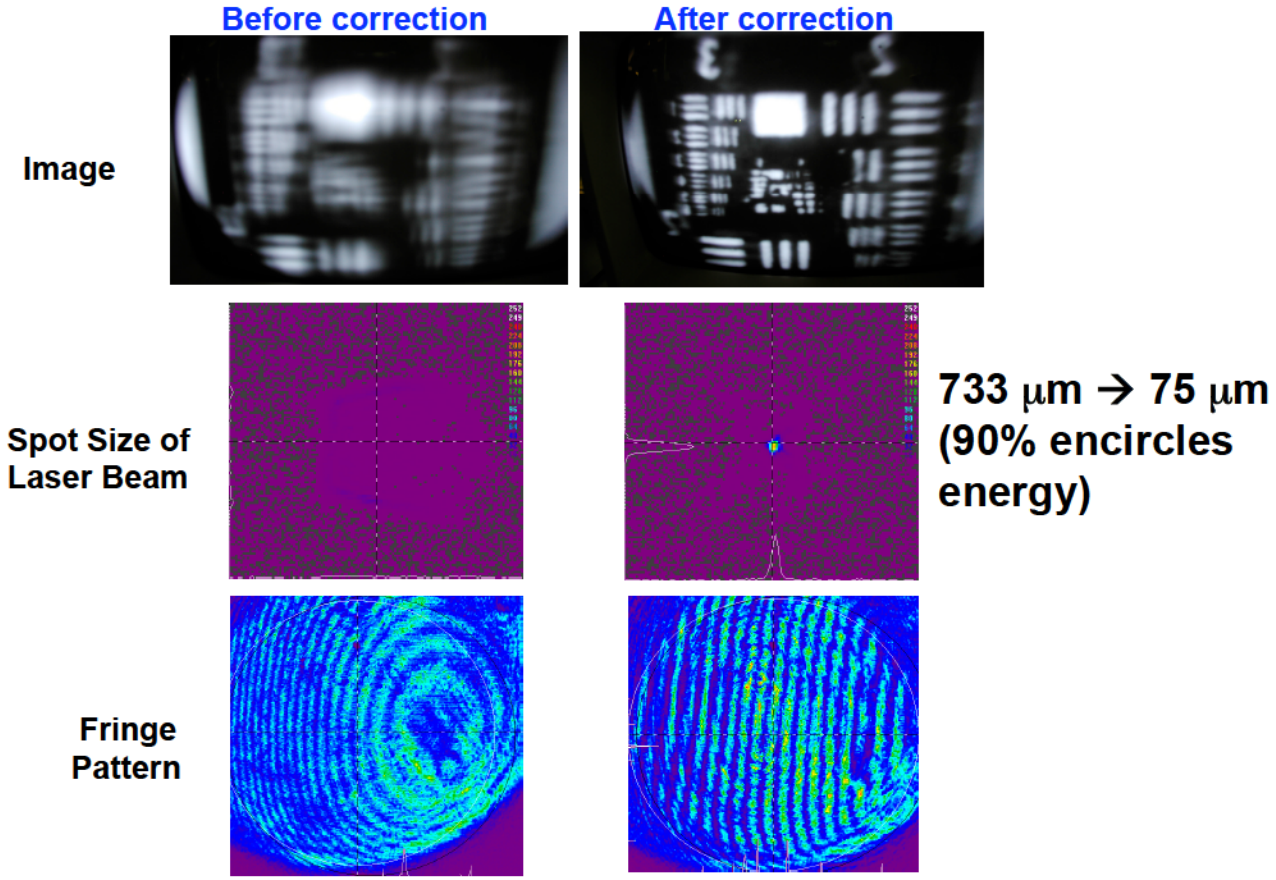
- OOK/PPM with photon-counting has best performance for few photons per channel use.
  - Requires high peak to average power ratios from the lasers
  - BPSK links eliminate the difficult challenge of high peak to average power laser transmitters





LOW-COST LARGE DIAMETER MIRRORS

- **Active compensation of low-cost multi-meter diameter mirrors using Spatial Light Modulators (SLMs) and deformable mirrors**
  - Applied to mirrors 1-m diameter (so far)



ATMOSPHERIC VISIBILITY MONITORING

Monitoring the atmospheric optical channel at JPL's Table Mountain Facility with a suite of instruments

Daytime All-Sky Camera

Mid-IR Day/Night Cloud Camera

Sun Photometer

Nighttime DIMM/MASS

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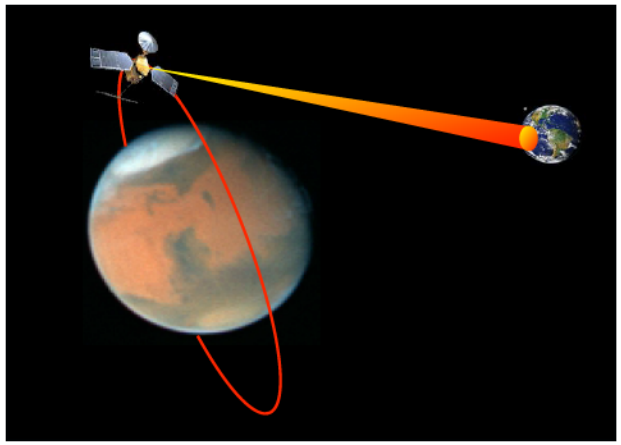
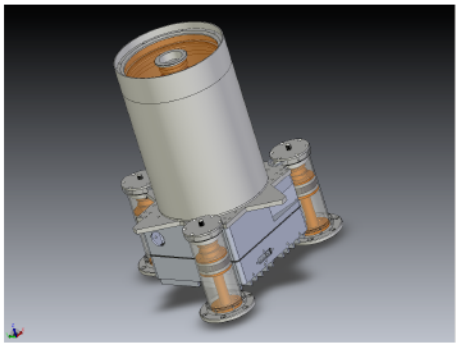
Gb/s SCALE MARS LASERCOM

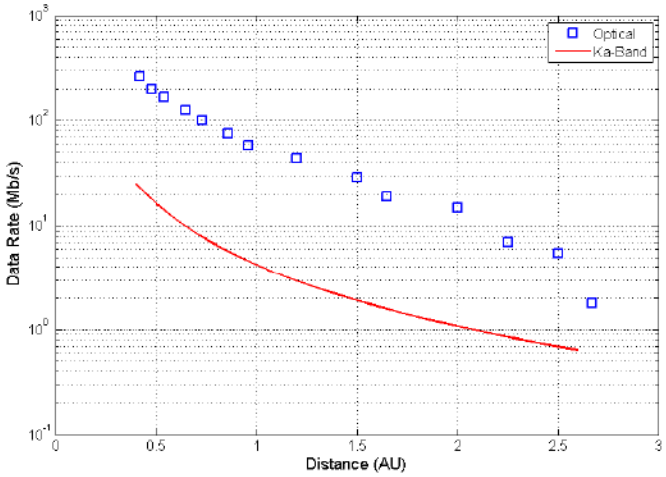
Mars Orbiter to Earth Trunk Line

- Small diameter optical transceiver
- Modest average laser power
- 0.25 Gb/s downlink from 0.4 AU
  - Scalable to 1 Gb/s from 1-AU
- 10 Mb/s downlink from 2.5 AU
- 0.2 Mb/s data uplink
- Received by 12-m ground telescope
- Mass/power estimate: < 30-kg & <110 w



Flight Optical Transceiver Concept





Factor of 10-100 increase over the state-of-the-art!!!

Ka-Band: *MRO Ka-band transmitter (link limited), 34 m antenna.*

MARS TRANSCEIVER

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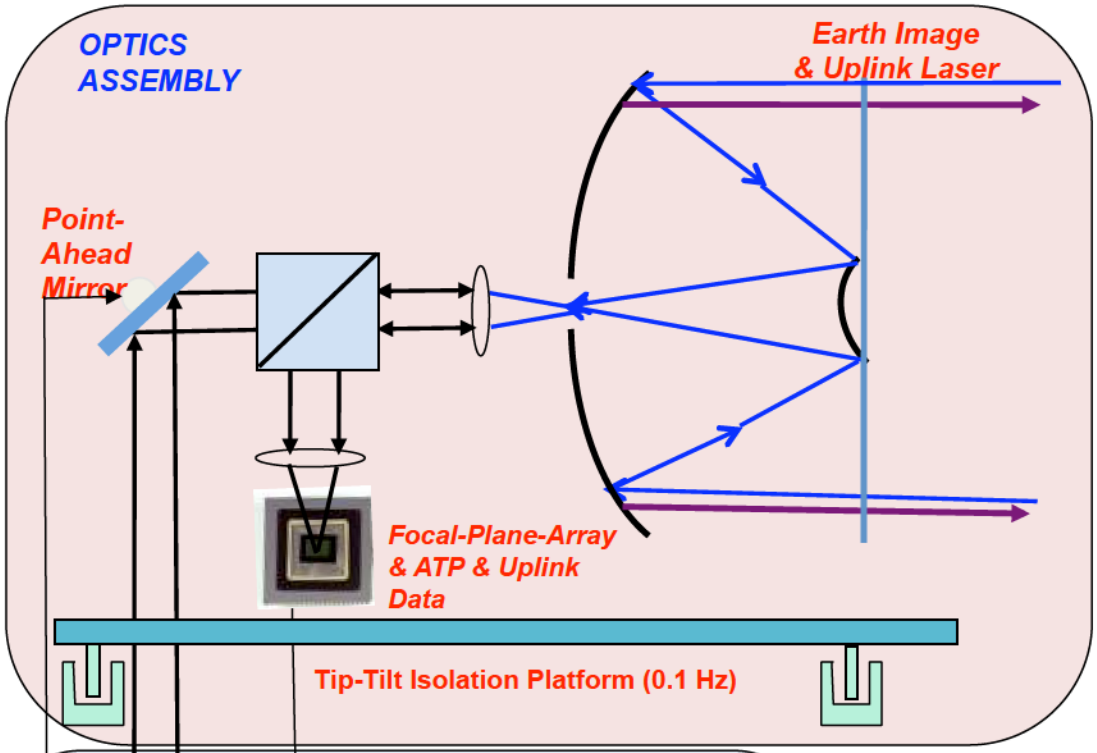
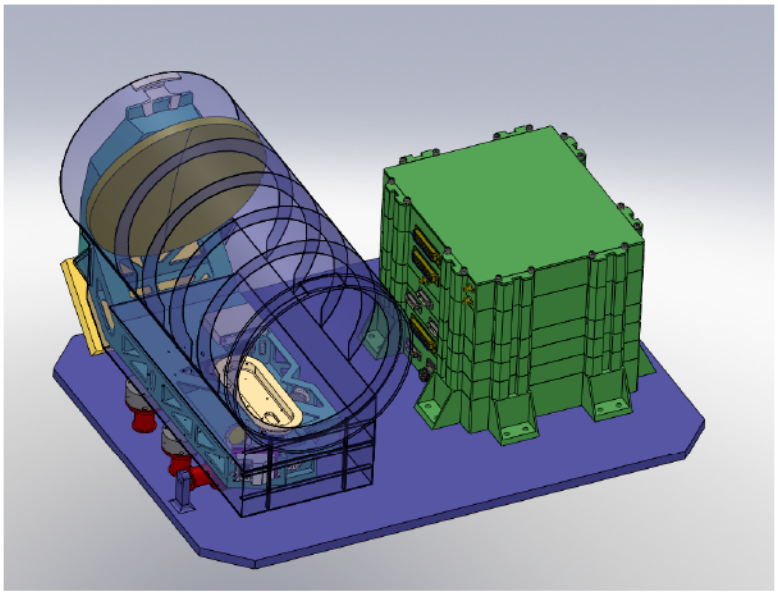
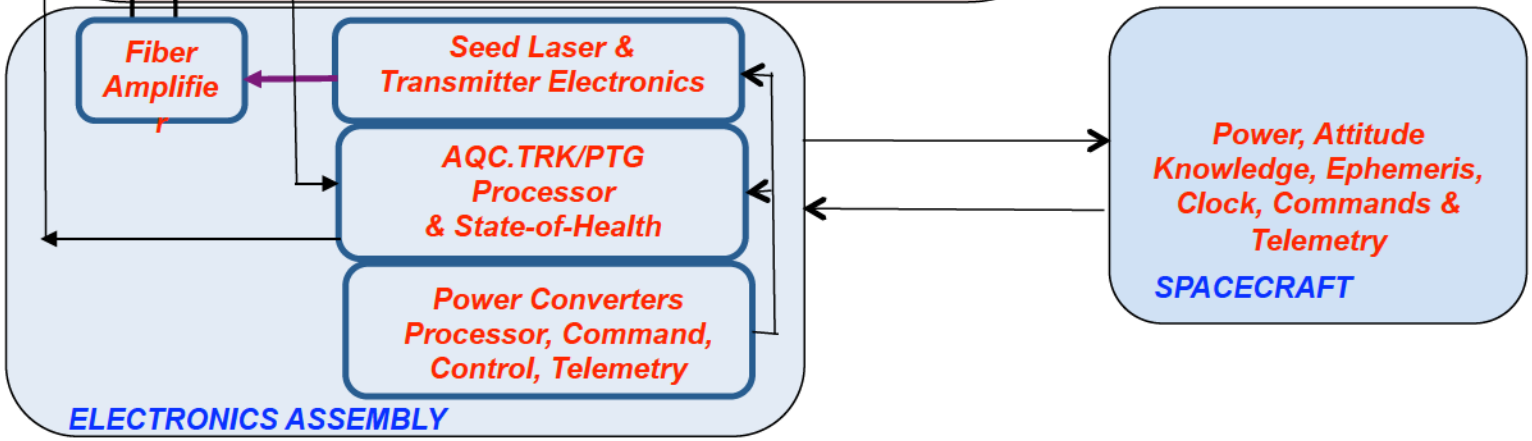






1. NASA Sponsored Projects

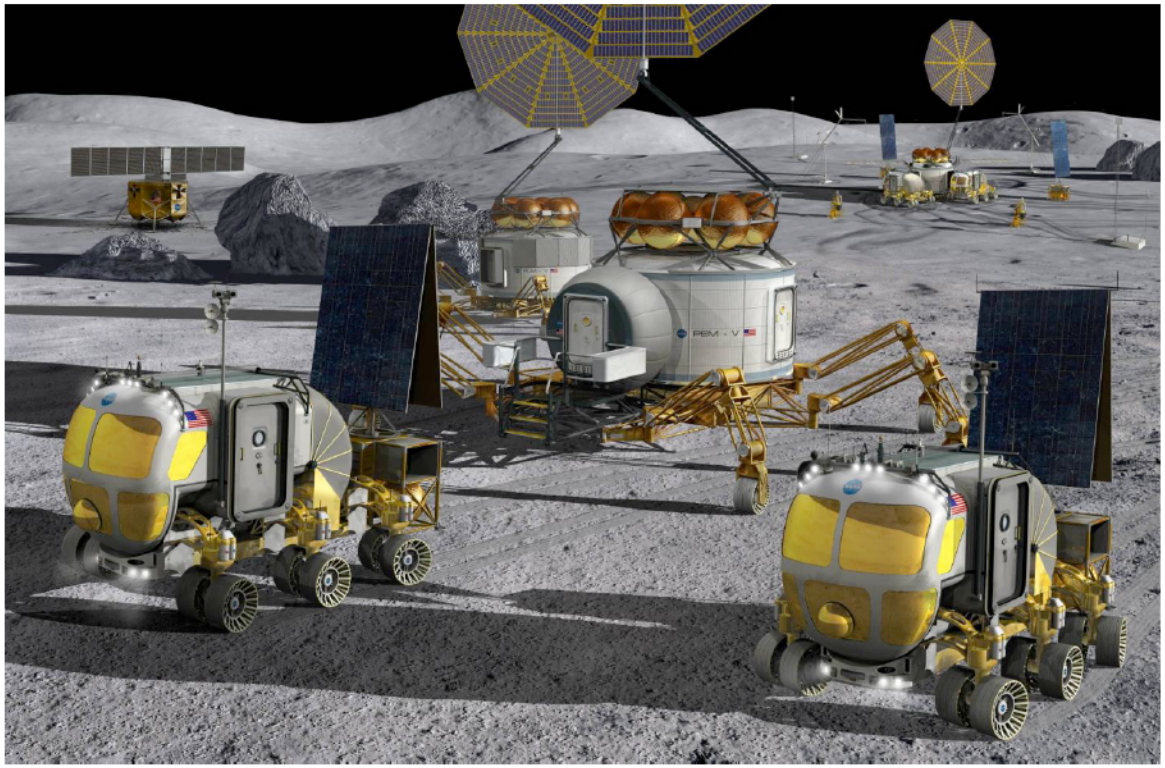
- Planetary Communications Technology
- Mars Laser Communications
- **Lunar Surface Communications**
- **Integrated RF/Optical Ground Receiver**

2. Non-NASA Sponsored Projects

- Mars/Moon access/proximity links
- Compact 10 Gb/s LEO terminal
- 1-mm range resolution to planets
- cm-level ranging to airplanes
- 10 Gb/s fiberoptic bus for spacecraft

LUNAR SURFACE LASERCOM

- **Study to evaluate lunar surface optical communications supporting:**
  - **High bandwidth direct-to-Earth (DTE) from Lander rovers and with early outposts**
  - **Later deployment of lunar relay satellite with links between surface assets and surface-to-Earth**
  - **Surface-to-surface and over the horizon relay links**
  - **Precision navigation**



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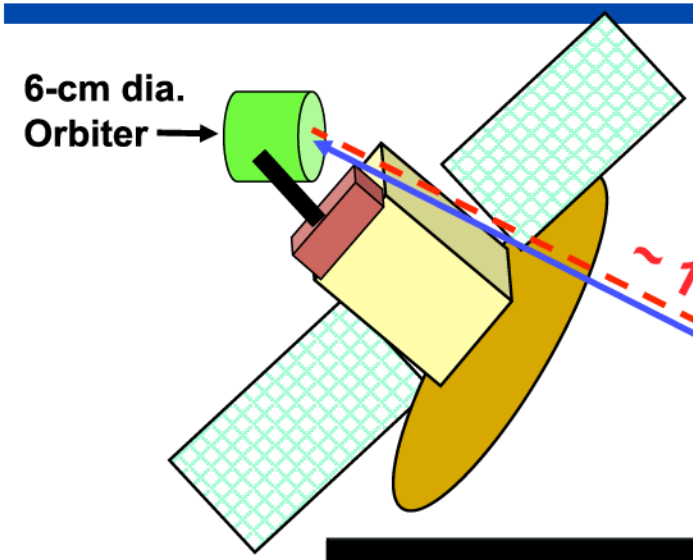
MOON & MARS ACCESS LINK

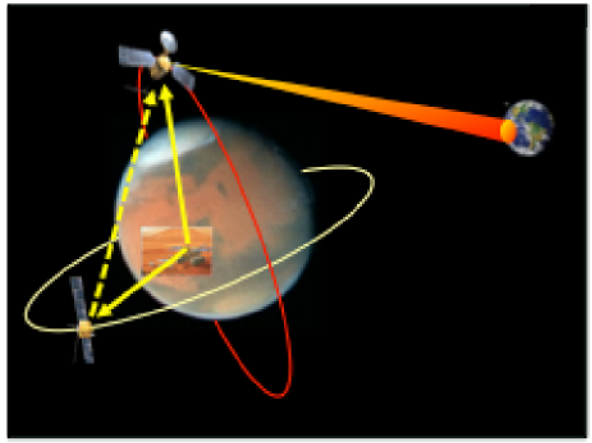


~ 100 kb/s

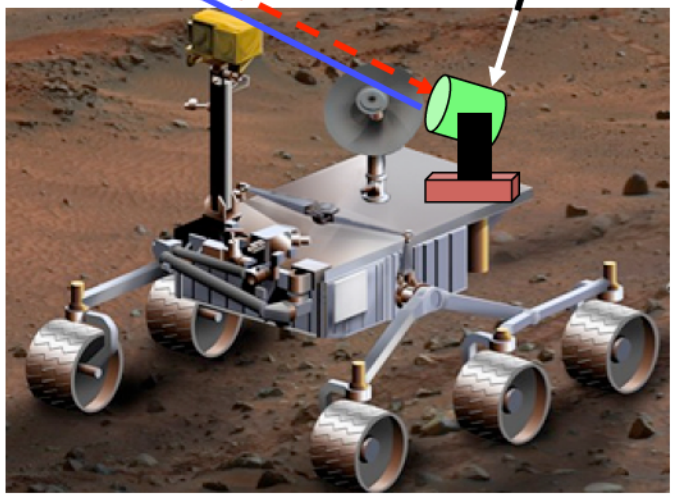
> 250 Mb/s

Developed and validated flight transceiver designs for Mars proximity links:

- Return data volumes of **10-100 Gb/sol**
  - Instantaneous data-rates of **50-250 Mb/s**
- Transmit orbit-to-surface data rates of **10-100 kb/s**
- Addressed Mars optical depth and dust accumulation



2.5-cm diameter Transceiver



Key Characteristics

- Emphasized low mass/power burden on host spacecraft
- Low-complexity acquisition tracking pointing

AIRCRAFT TEST OF THE SYSTEM

- Completed multiple successful air-to-ground nighttime campaigns
  - Established link acquisition and tracking procedures
  - Demonstrate end-to-end data transfer night/day over 20-30 Km range

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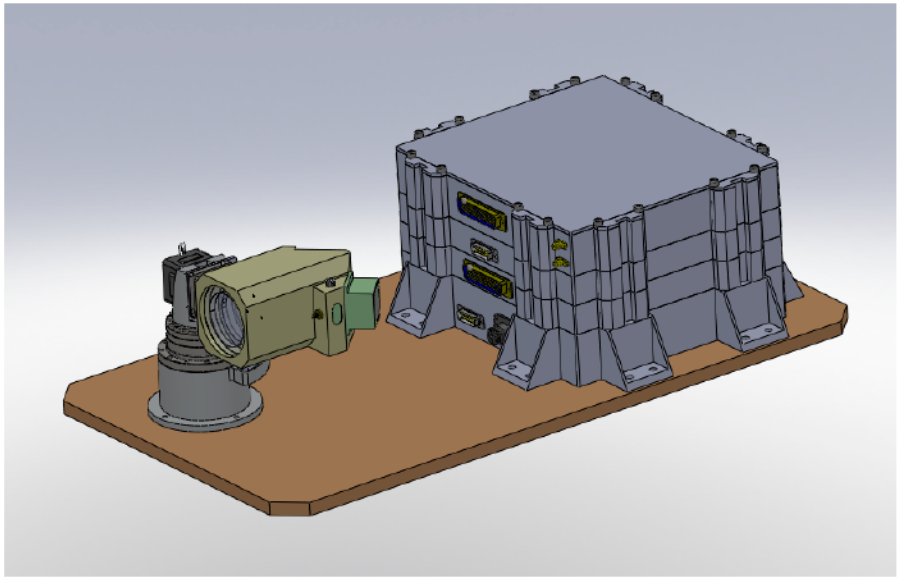
COMPACT 10 Gb/s LEO TERMINAL

Jet Propulsion Laboratory
California Institute of Technology

- Compact (5-cm aperture diameter) flight transceiver
- Launch-lockable compact gimbal with 20 μrad pointing jitter
- Capable of 10 Gb/s downlink data-rate
- Includes a fine-pointing mirror
- All subsystems have traceability to flight qualified parts
- Airplane tests planned within 6-months
- 0.6-m ground aperture assumed



Scaled View of Flight System

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- **1-mm range resolution to planets (active laser ranging)**
- **cm-level ranging to airplanes**
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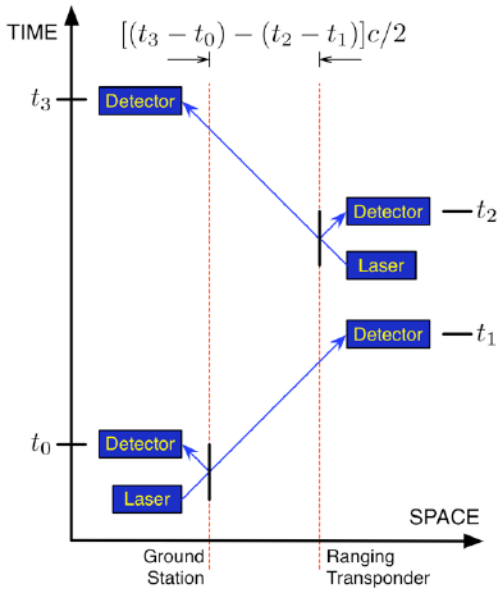
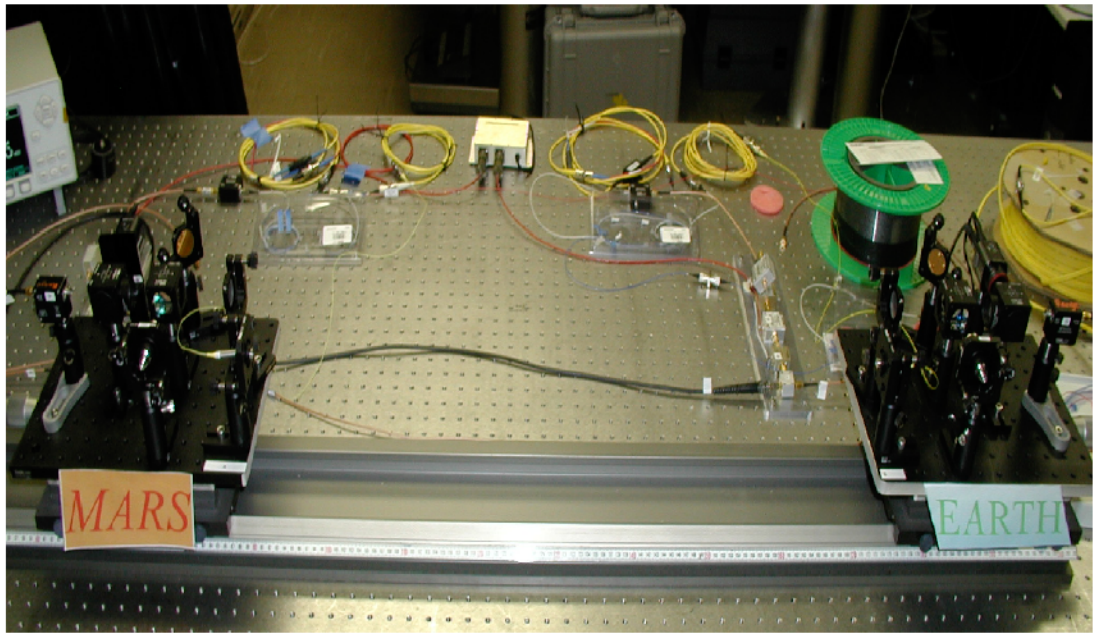
LASER RANGING TO PLANETS

- **Demonstrated 1-mm range resolution – along with the lasercom link - on optical links depicting:**
  - **Utilizes 4-way time tagging and asynchronous transponding mode**
  - **Random errors less than 1mm with just a few pulse pairs.**
  - **Measuring Earth-Mars range to 1mm would provide valuable tests of fundamental physics.**
  - **Field tests underway**

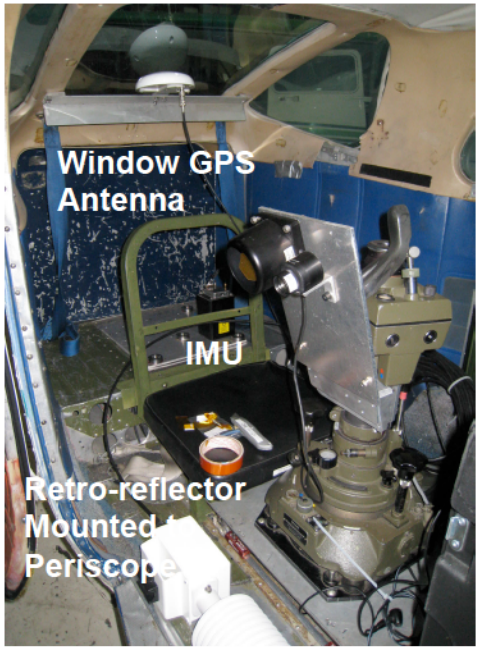


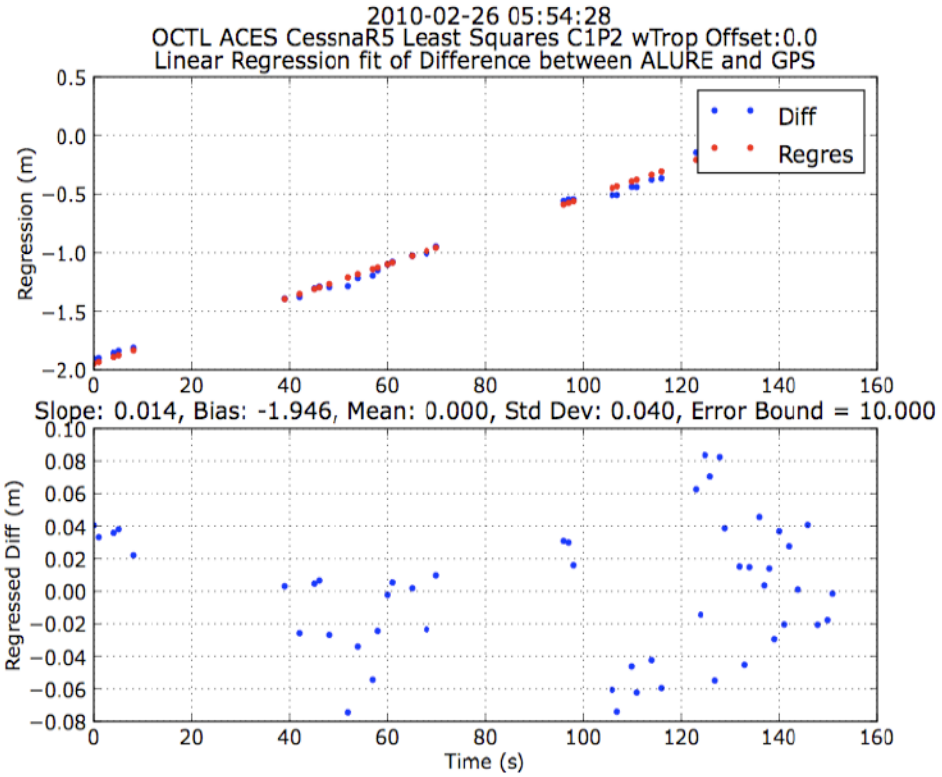


LASER RANGING TO AIRPLANES

Ground to aircraft ranging tests comparing optical and DGPS range measurements

- Aircraft results over 5 km range showed systematic error with agreement to ~1-m
  - Residual error <10cm post systematic error correction





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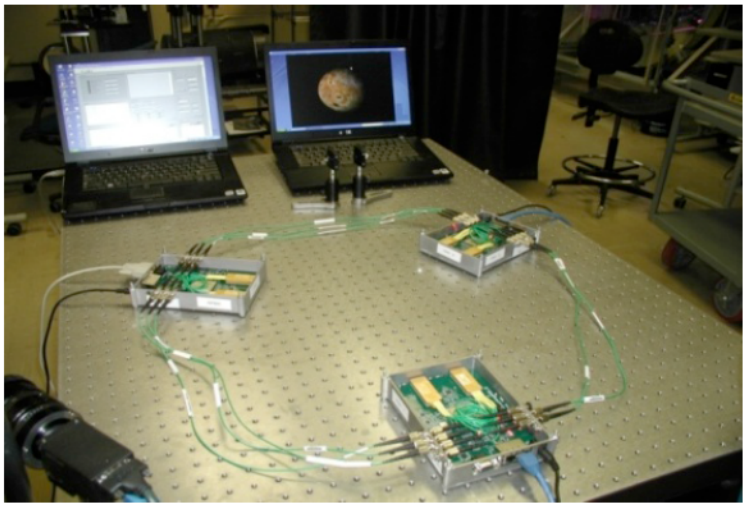
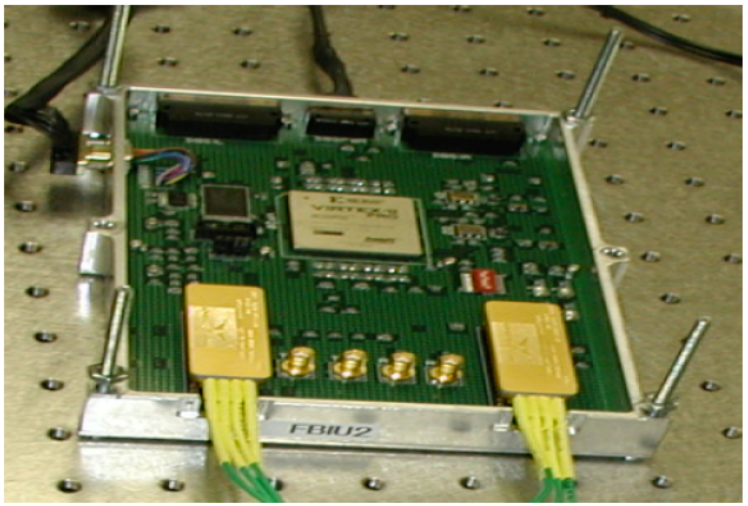
10 GB/S FIBEROPTIC BUS FOR S/C

Objectives:

Demonstrate multi-Gb/s fiberoptic data bus to meet the need of current and future NASA advanced missions with the following features:

- Increased onboard data-flow throughput relative to current state-of-the-art (from less than 100 Mb/s to 10 Gb/s)
- Reduction of system integration cost by simplification of integration and testability
- Elimination of current EMI and crosstalk challenges while improving overall reliability
- Reduction of cabling complexity, mass and power consumption by at last a factor of three, and latency to sub us and jitter to sub-ns (three magnitude reduction)
- Evaluation of the bus under emulated realistic environmental conditions





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