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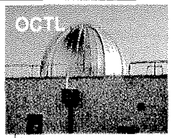


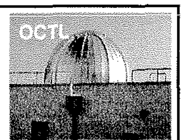
Planned Operations for the JPL Optical Communications Telescope Laboratory (OCTL)

K.E. Wilson

NASA Jet Propulsion Laboratory

CalTech

JPL



Outline

- JPL Optical Communications Program
  - Objective & Roadmap
  - Role of Optical Communications Telescope Laboratory
- Scintillation & Scintillation Mitigation Strategies in Past Demonstrations
- OCTL Telescope Description
  - Optical Train Design & Laser
- Near-Term Experiments
  - Air-to-ground
- Safe Laser Beam Propagation
- Future Demonstrations
- Summary

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JPL's Optical Comm Program

- **Objective**
  - **To Develop advanced communications technology for future NASA deep space and Earth-orbiting missions**

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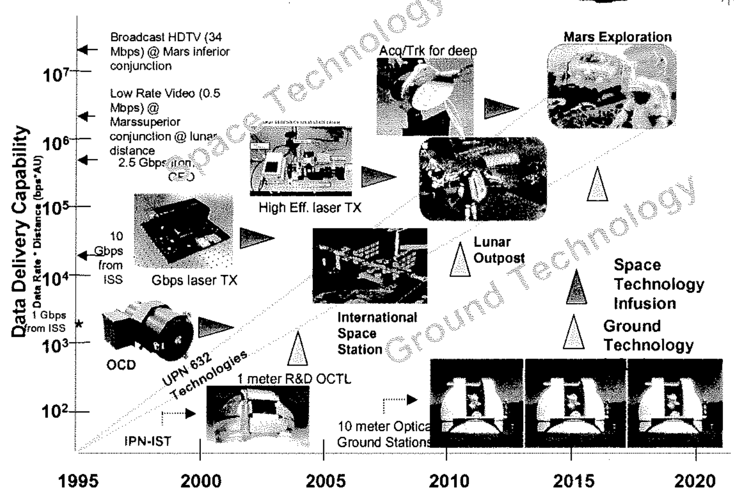
JPL's Optical Comm Roadmap



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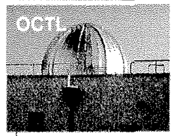

Role Of OCTL

- The Optical Communications Telescope Laboratory is designed to support R & D in optical communications, including
  - Development of strategies to mitigate atmospheric effects on the optical link
  - Development of strategies and procedures for safe laser beam propagation for future optical communications links with Earth-orbiting and deep space probes
  - Evaluating performance of optical communications receivers under different background conditions
  - Serving as a ground station for future optical communications demonstrations
    - Air-to-ground
    - Space to ground

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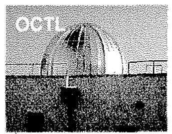
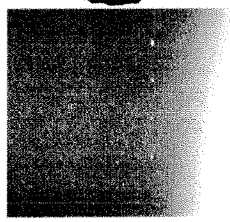


Beacon Tracking For Deep Space Links

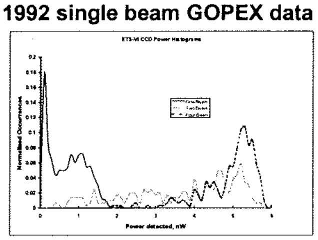
- Analysis shows that a combination of Earth-based laser beacon and onboard inertial sensors can provide required acquisition pointing and tracking for an optical communications link from Mars
- Stable uplink beacon beams with low intensity variance
  - Provide a reliable track beacon signal
  - Support a low BER optical uplink channel
  - Reduce need for large dynamic range tracking detectors
- Challenges to propagating stable uplink beacons to deep space include
  - Uplink beam jitter
  - Beam wander
  - Atmospheric scintillation

Uplink Scintillation

- Scintillation is caused by interference between parts of the laser beam propagating through different atmospheric coherence cells
- Results from 1992 GOPEX demonstration showed significant pulse-to-pulse variation in received signal over 800 msec CCD frame
- Preliminary results from 1996 GOLD demonstration with ETS-VI show that multi-beam strategies can successfully mitigate scintillation



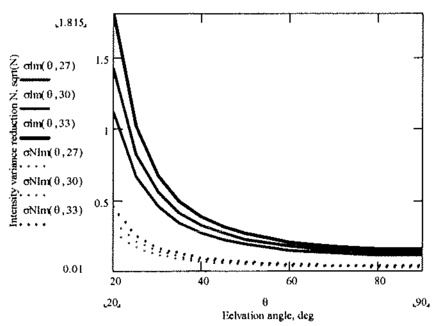
1992 single beam GOPEX data



1996 multi-beam GOLD data

Scintillation Mitigation

- Mitigation strategies include adaptive optics and multi-beam propagation
  - Multi-beam approaches are less costly and are not subject to limits of isoplanatism
- Far-field pattern of multi-beam uplink is a superposition of independent speckle patterns
- Results show that intensity variance is reduced by number of beams



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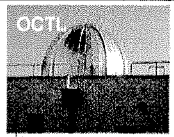
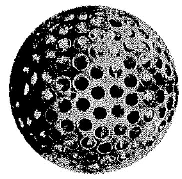
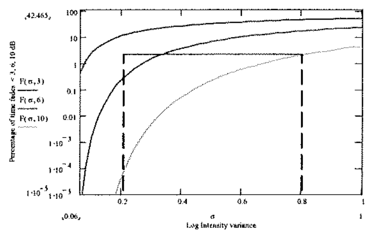
Early Experiments



- **Near-term experiments focus on multi-beam uplink to retro-reflector bearing satellites such as Lageos will allow assessment and validation of**
  - Laser beam propagation models
  - Multi-beam scintillation mitigation strategy
  - Telescope pointing and tracking accuracy
  - Wavelength dependence of scintillation mitigation strategy
- **Mitigation of uplink scintillation increases the probability of retro-reflected signal return**
  - Approach reduces fade depth by several dB



0.6-m Lageos satellite 6000 km altitude



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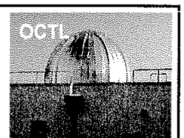
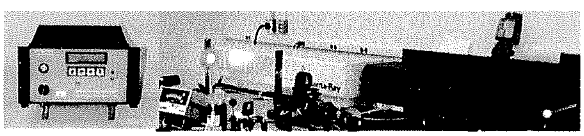
Early Experiments Cont'd





- **Nd:YAG laser output is separated into four beams and propagated through telescope coude path**
  - Optical train is designed to ensure beams are temporally and spatially incoherent when overlapped in far-field
- **Laser repetition rate is varied to facilitate time division multiplexing of transmit/receive signals in the optical train**
  - Facilitates transmit/receive isolation for various ranges of target satellite

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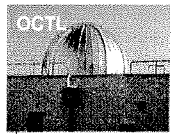
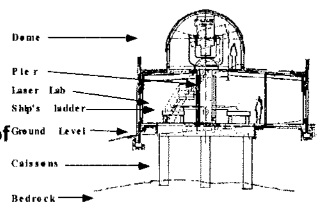
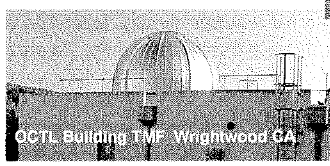


OCTL Description

- Telescope
  - Is 1-m telescope in a Elevation /Azimuth mount
  - Has coude optical path to allow transmission of high power lasers to deep space probes
  - Is high precision tracker capable of tracking satellites from LEO (250-km) to deep space
    - <10 μrad jitter (0.1-10 Hz) at 1°/sec rate
  - Has louver baffles to reject stray light and allow operation to within 30 degrees of sun
- Telescope and pier are bolted to concrete platform anchored into bedrock





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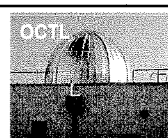
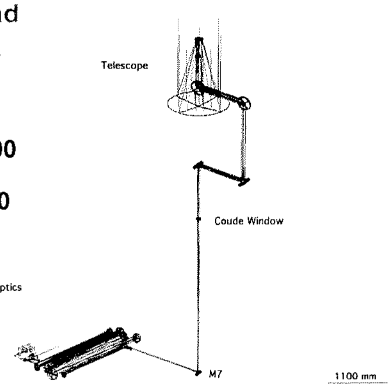


OCTL Telescope Description Cont'd

- **Main Telescope**
  - Focal length => 75.8-m
  - FOV => 500-μrad
  - Total WFE => 0.054-λ
  - M1 – M7 mirrors
    - Protected Denton FSS-99
    - Power handling of up to 100 W average power, and 1J/cm² energy density in 10 ns pulse
- **Obscurations**
  - 5.6% area of primary aperture



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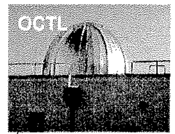
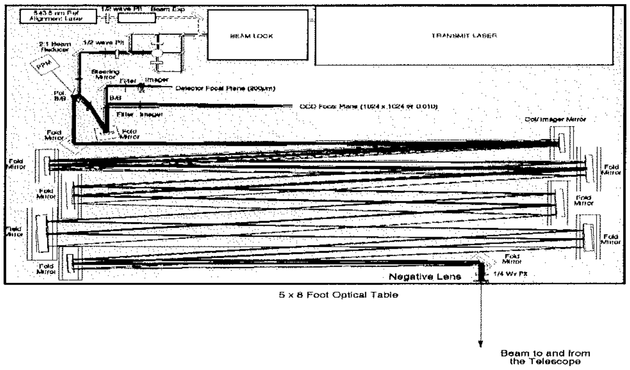
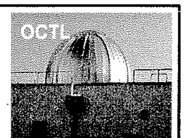
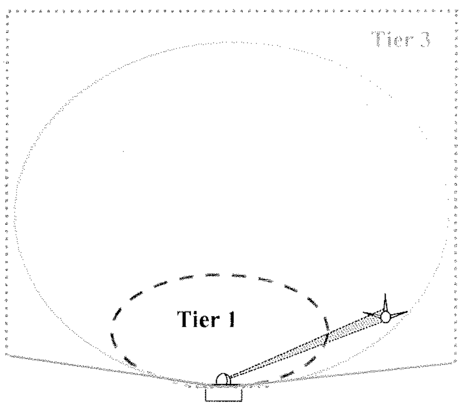
OCTL Multi-beam Optical Train Design





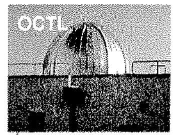
Safe High-power Laser Beam Propagation

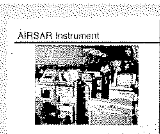




- OCTL researchers are working with US government agencies to implement safe laser beam propagation strategy that will support future unattended laser beam propagation to deep space
- Have defined four tiers of safety to ensure safe operation and propagation of laser beams into space
  - Tier 0
    - Occupational Safety and Health Administration, responsible for safe use of lasers in work environment
  - Tiers 1 & 2
    - Federal Aviation Administration, responsible for propagation of lasers in navigable air space
  - Tier 3
    - Laser Clearinghouse, responsible for safe propagation of lasers into space

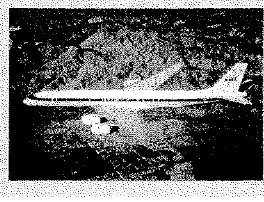
Bi-directional Link NASA Air- to-Ground Stations

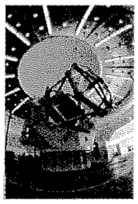




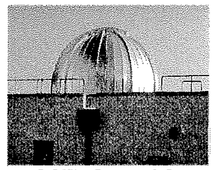
Optical Comm. Terminal

MASTER Instrument





AEOS Ground Stn.
Maui, HI



OCTL Ground Stn.
Wrightwood, CA

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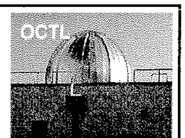
Mission Operations Scenarios



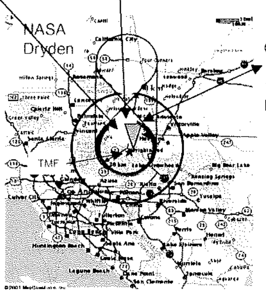
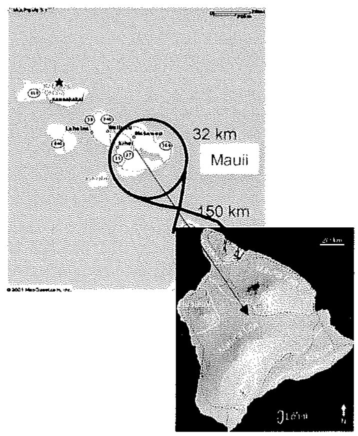


Table Mountain Campaign



Hawaii Campaign

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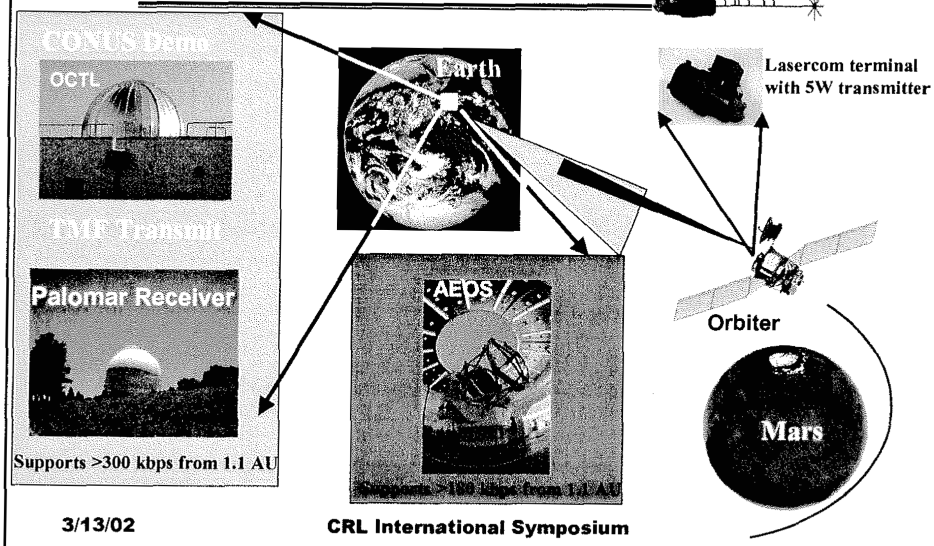
Future concepts



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Summary

- Construction of the OCTL is a critical element in JPL's optical communications program designed to meet NASA's need for high bandwidth near-Earth and deep space links
  - Facility will enable development of beacon-assisted tracking strategies to of ground stations from deep space
    - Near-term experiments with Earth-orbiting satellites and aircraft will use multi-beam uplink scintillation mitigation strategies
  - Concepts for early deep space link demos would use OCTL uplink as track beacon and large 5-m telescope as ground receiver