OCTL Planning, Tests and Operations for the bi-directional link to the OICETS

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Outline

- Experiment overview
- Objectives
- Precursor experiments
- Transmitter and receiver designs
- Data acquisition system
- Data analysis
- Team
- Summary

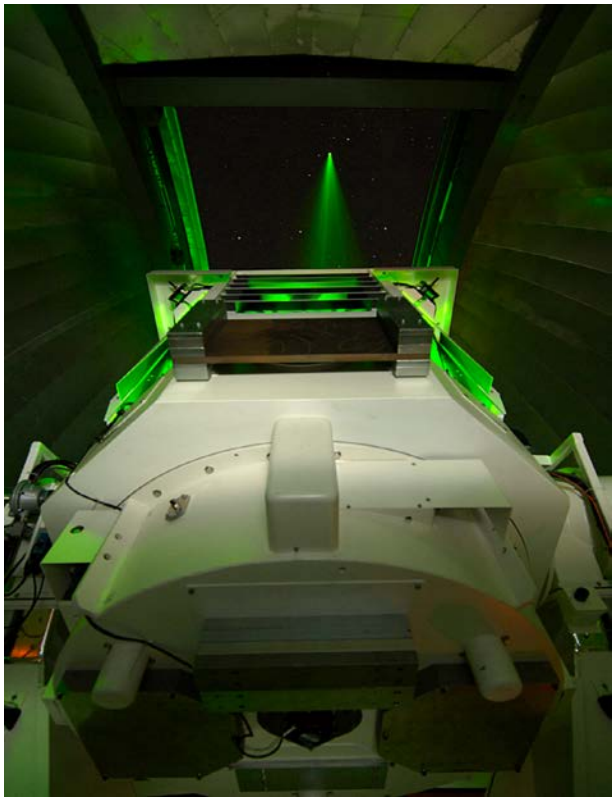
OCTL To OICETS Optical Link Experiment Overview

- JAXA reactivated OICETS satellite in October 2008
  - Supported bi-directional high bandwidth optical link
    - 2Mb/s uplink 50Mb/s downlink
  - Afforded OTOOLE demonstration opportunity
- Challenges
  - Knowledge of satellite position ~ 1mrad required wide uplink beams
    - Required procurement of high power semiconductor lasers at 800-nm and 819-nm frequencies
  - Identified four of eight experiment opportunities allocated over five week period
    - Impacted by weather and low elevation passes near OCTL tree line
- Results
  - Links successfully demonstrated on all four scheduled opportunities May 21, June 2, 4, 11, 2009 under a variety of weather conditions
  - Measured downlink BERs as low as 10^{-8}
  - Received power levels consistent with theoretical models

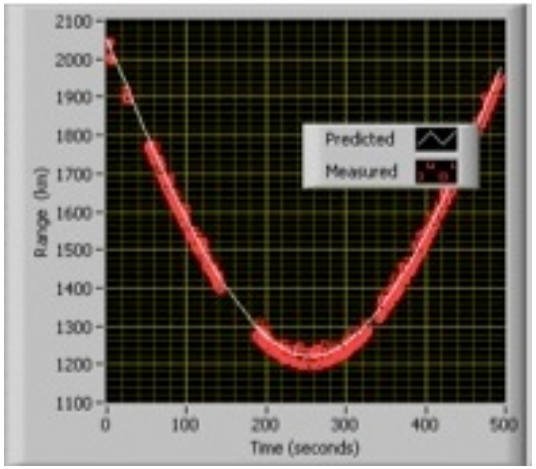
Objectives

- Demonstrate acquisition and tracking and communications with LEO satellite (600km 98 degree inclination) from OCTL
  - Bi-directional optical communications with OICETS LEO satellite from the OCTL
    - 2Mbps uplink, 50 Mbps downlink
- Test operational issues involved with high-bandwidth LEO satellite optical communications support
  - Validate optical communications link models including fade statistics
  - Validate aperture averaging effect on downlink
- Characterize link performance under a variety of atmospheric and background conditions e.g.
  - Partial cloud cover & moonlit sky

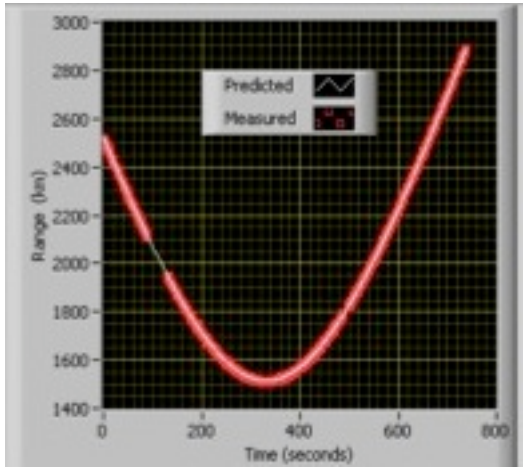
Precursor Experiments



Starlette March 29, 2009
2058 PDT



Ajisai March 30, 2009
0209 PDT



- **Precursor experiments with EGP 1, Lageos, Stella Starlette validated telescope pointing accuracy**
- **Q-switched doubled Nd:YAG 532-nm laser 30-urad uplink beams to validate consolidated predict format file ephemeris generation process and telescope pointing precision for 2-mrad OTOOLE uplink**

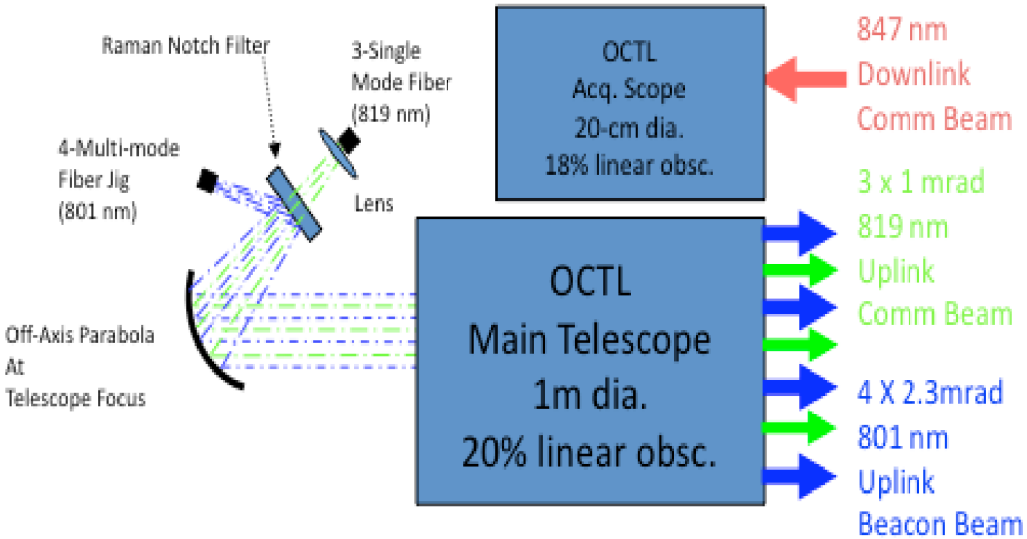
Ajisai Precursor Experiment

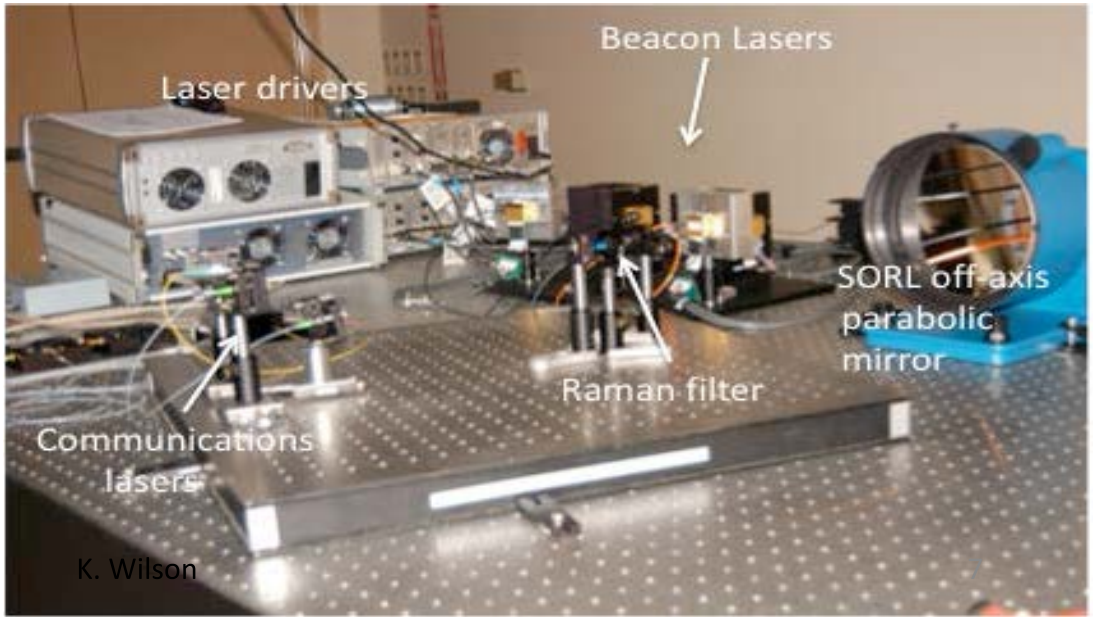
OCTL

EGP 1

OTOOLE Uplink Transmitter

- **Multi-beam OTOOLE uplink design mitigated effects of atmospheric scintillation**
  - **Four beam coarse tracking beacon uplink bandwidth**
    - **2.3 mrad beam divergence**
  - **Three beam fine tracking communications link**
    - **1-mrad beam divergence**
- **Uplink beams were mode matched and coupled to 1-m telescope via 20-cm aperture, 46-cm focus off axis parabolic mirror**





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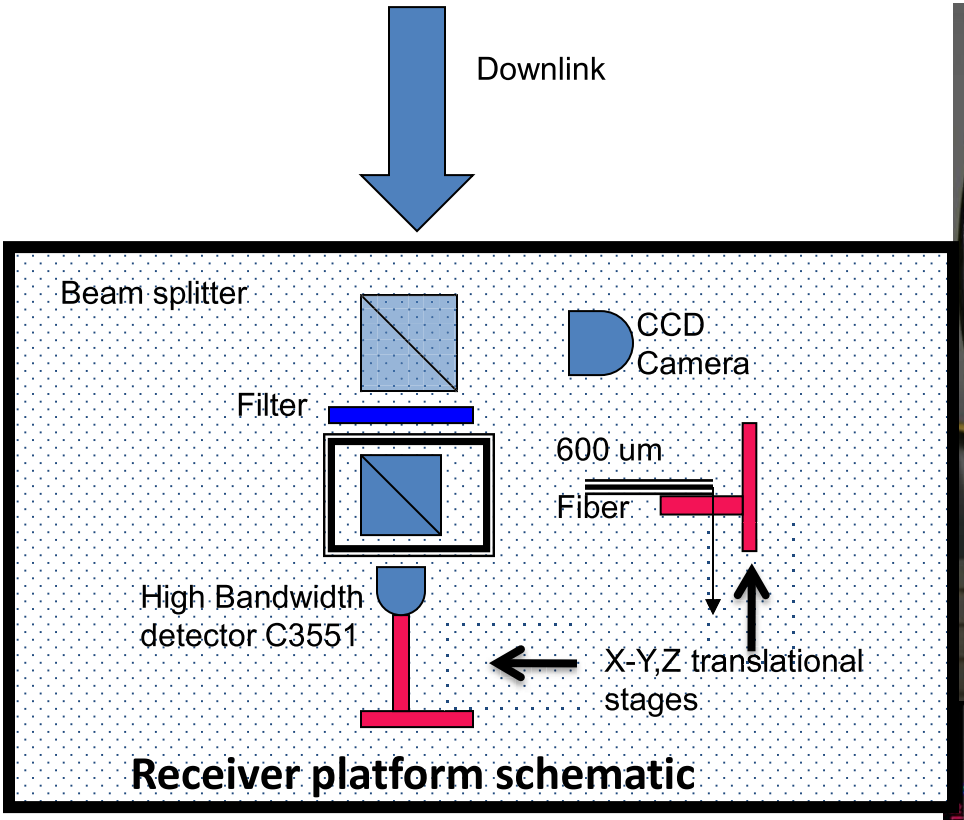
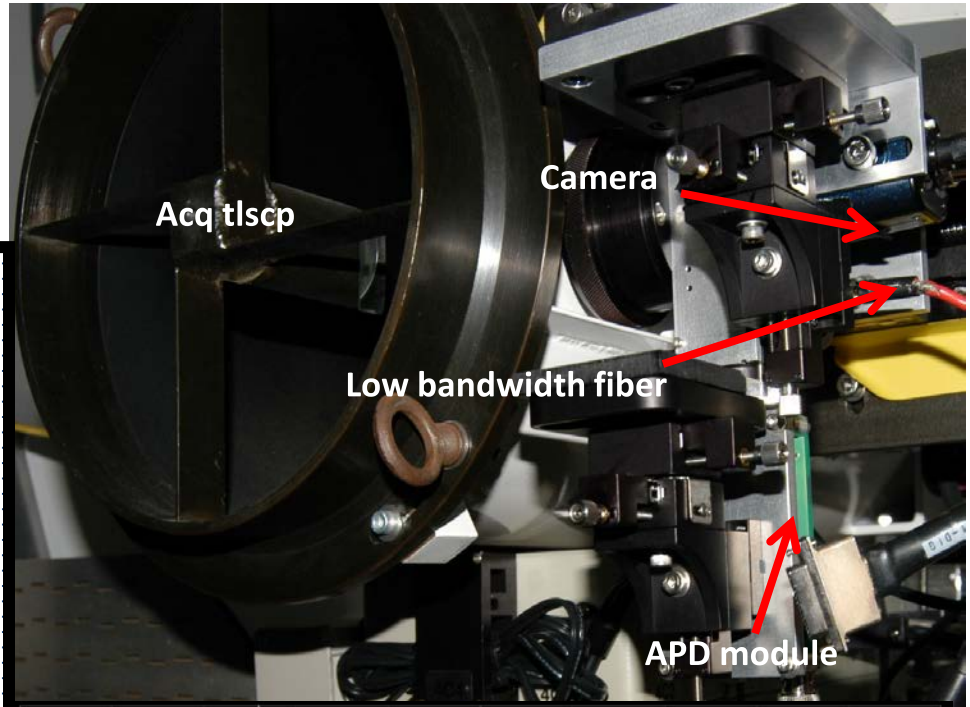
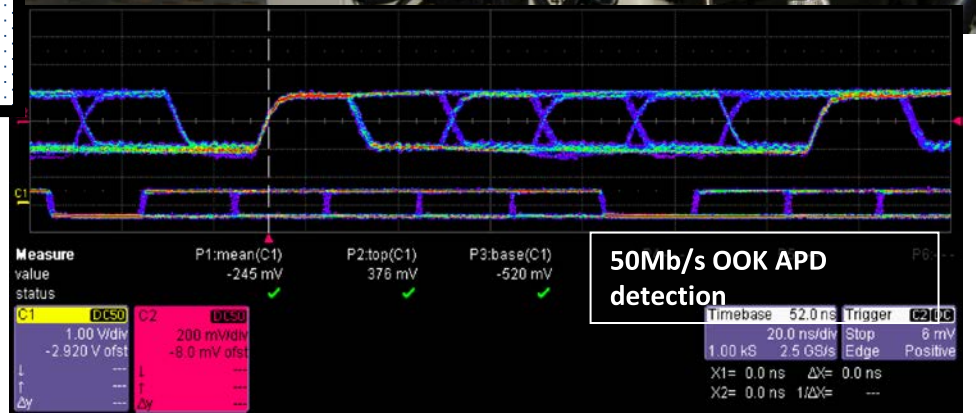
OTOOLE Receiver



Receiver platform schematic



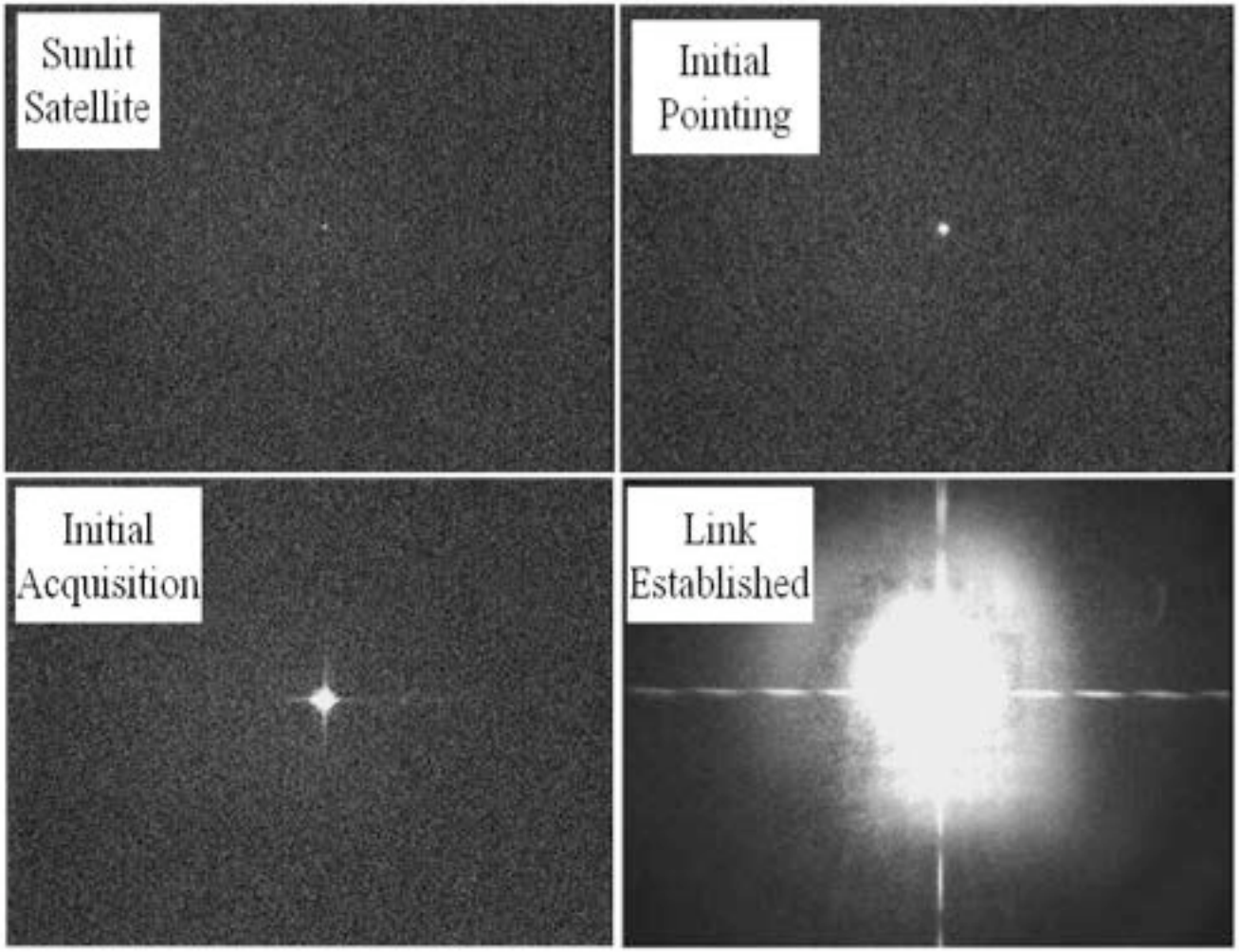


- **Downlink retrieved at 20-cm aperture**
- **Signal split between camera , high bandwidth APD, multi-mode fiber**
- **APD sensitive at 34-nW signal 50 Mb/s OOK modulation clock and data recovery BER 10^{-6}**
- **Analysis predicts 100's nW=>1µW downlink**

OTOOLE Record

Experiment date	5/21/09	6/2/09	6/4/09	6/11/09
Latest CPF files received, day, PST	5/20, 04:53	6/1, 04:52	6/3/2009, 04:52	6/10/09, 04:52
Start pass (0deg elev.)	2:53:00	3:04:00	03:22:30	3:46:50
End Pass (0 deg elev.)	3:05:00	3:16:30	3:43:10	3:59:20
Max elevation, deg	61	81	58	51
LUCE start (el, PST)	19.8 deg, 2:56:25	20 deg, 03.:07:27	53 deg, 03:28:25	20 deg, 02:52:04
LUCE end (el, PST)	54.2 deg, 3:01:49	60 deg, 03:09:31	20 deg, 03:30:43	48.7 deg, 02:54:19
Pass duration above OCTL tree line, sec	324	350	330	320
LUCE track duration, sec	324	124	138	135
OCTL Link duration, sec	140	100	138	130
Link percentage of track	43.21%	80.65%	100.00%	96.30%
Weather	Clear	Clear	Overcast	Clear
Wind speed, km/hr	10.85 gusts to 29	10 gusts to 18	23 gusts to 40	6 gusts to 10
Data products				
Uplink beacon power, W	1.8	1.8	1.8	1.8
Average uplink comm. power, mW	7	10	22	22
Downlink power received, nW	213-1075	170-300	150-300	100-750
Downlink comm. BER	10E-1 => <10E-6	10e-2 => 10E-5	10e-4 => <10E-6	10e-1 => 10E-5

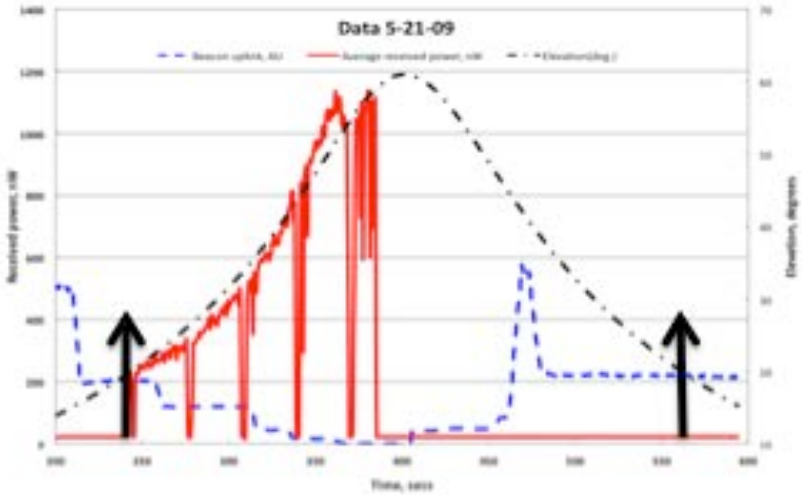
OTOOLE June 4, 2009

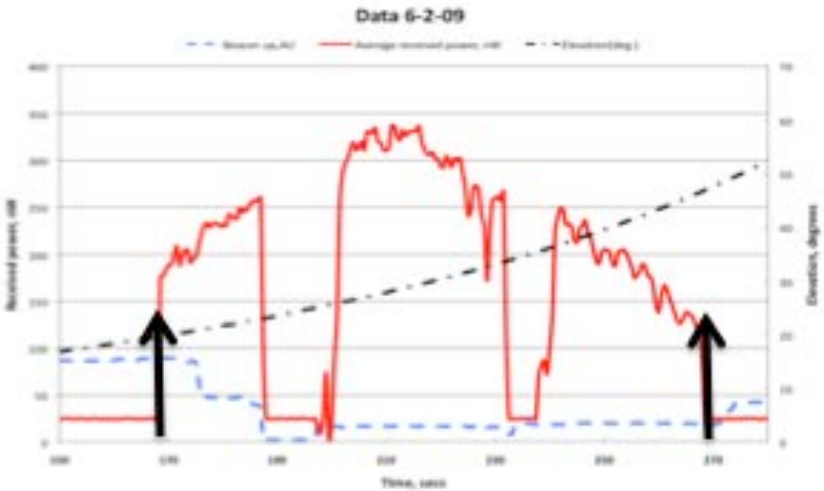


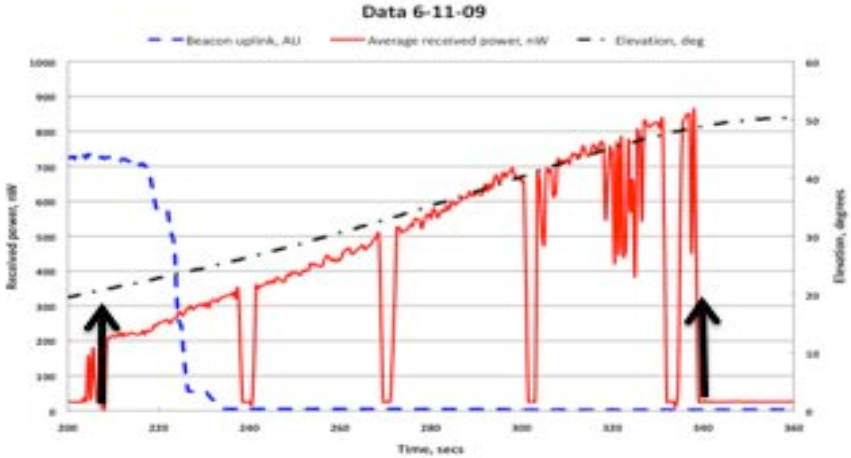
O'TOOLE
JUNE 4, 2009

(SHORT SEQUENCE)

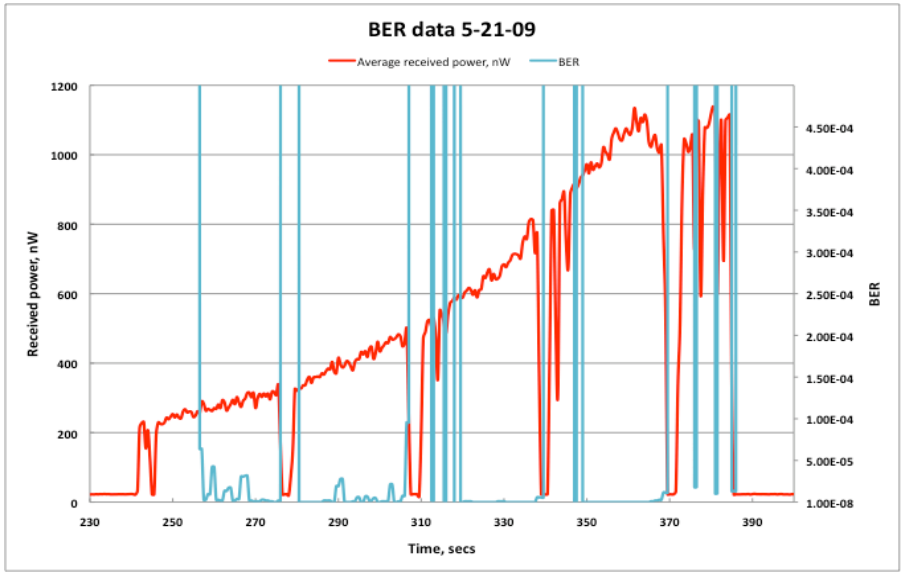
OTOOLE Downlink

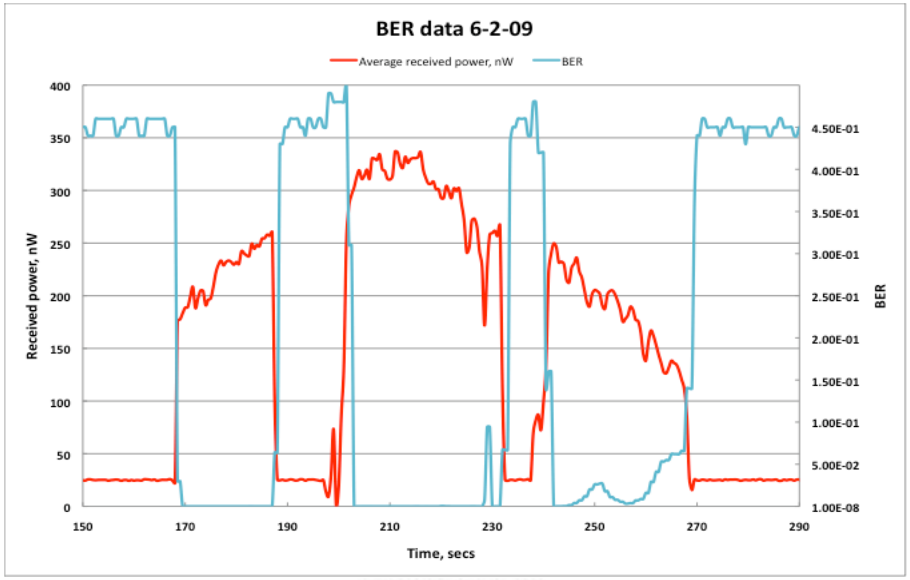




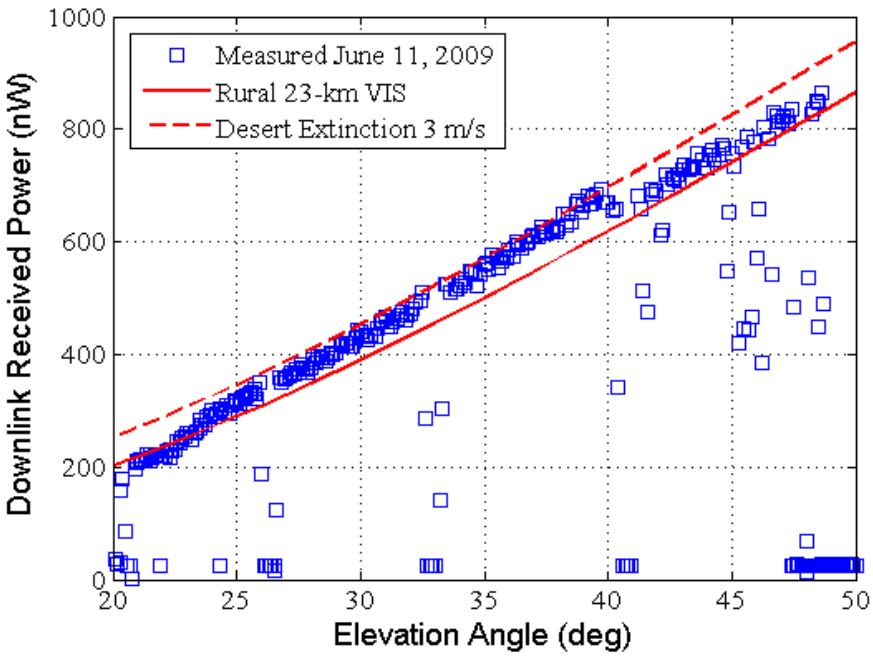


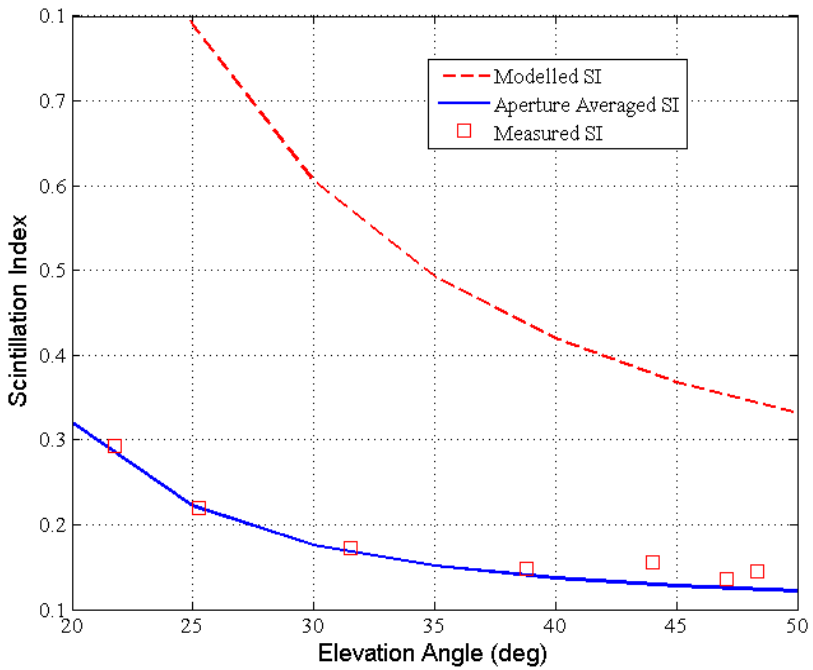
Downlink BER





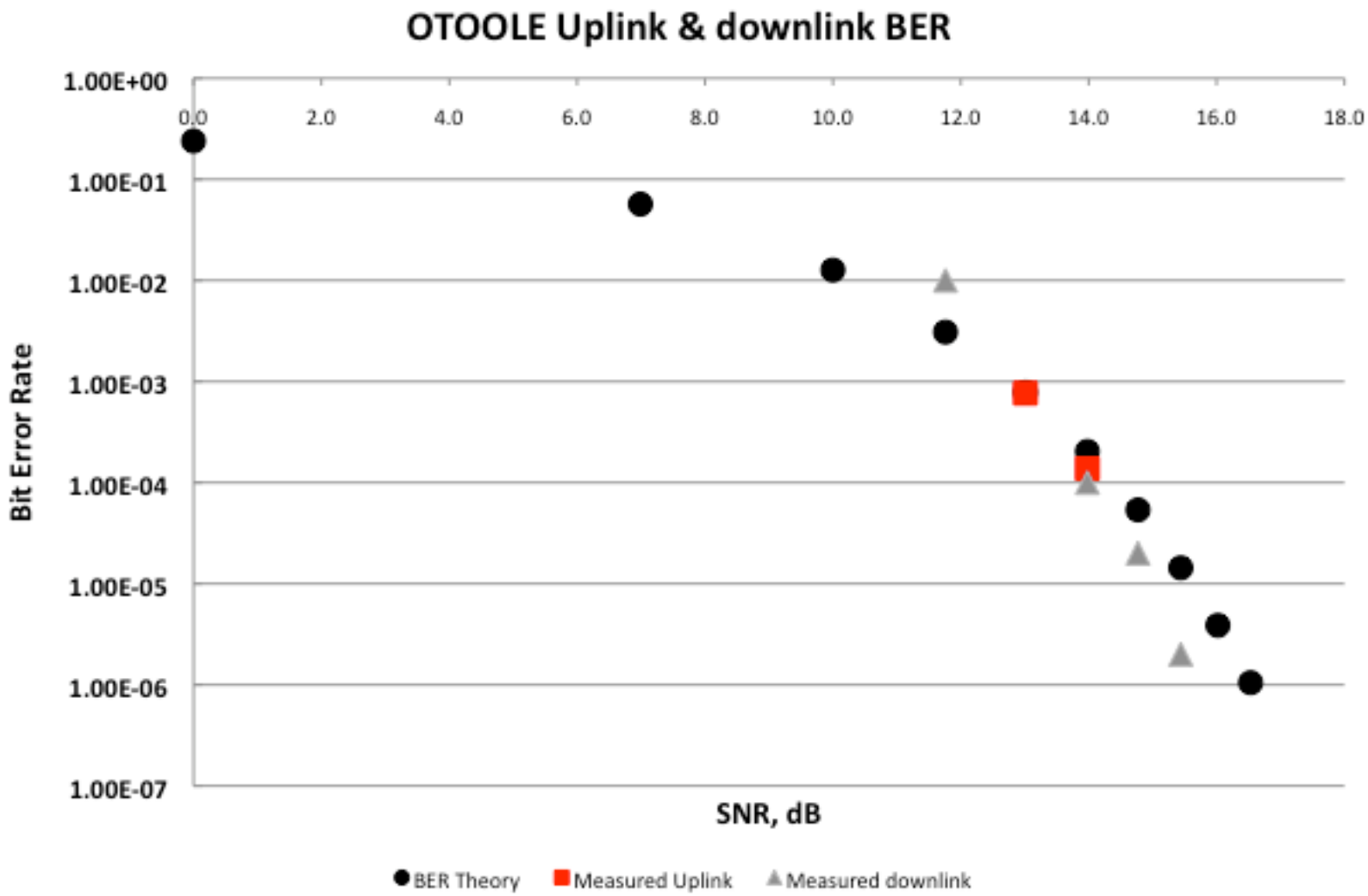
OTOOLE Data Analysis



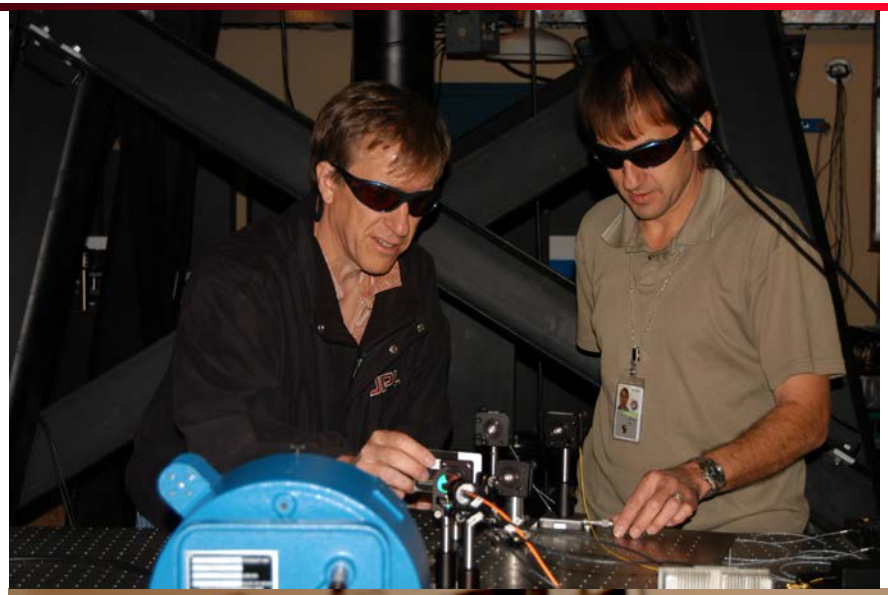


- **Optical communications link analysis models show good agreement with measurements under operating atmospheric conditions**
  - **Variation in downlink power with elevation angle**
  - **Aperture averaging effect on scintillation index**

Bit Error Rate Analysis



OTOOLE Team



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Summary

- OTOOLE was demonstrated successfully on all opportunities
- Experiment met all objectives and validated link analysis models
- Demonstrated high bandwidth bidirectional optical link under variety of atmospheric conditions
- Demonstrated precision acquisition and tracking of LEO satellite from the OCTL