Atmospheric Turbulence Statistics From GOLD Experiments

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Outline

- **What is** GOLD?
- **Experimental** details
- **Up[ink**
  - Scintillation
  - Multi-beam effects
  - Comparison to experimental data
- **Down[ink**
- Summary

What is GOLD?

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GOLD: Ground-Orbiter Lasercomm Demonstration

- ✶ Optical communication experiments between Table Mountain Observatory (TMF) and Japanese Engineering Test Satellite (ETS-VI) '
- ✶ International co-operative effort between NASA, NASDA, CRL and JPL

*Phase I transmissions from October 95 to January 96
Phase II transmissions from March 96 to May 96

GOLD: History

- **ETS-VI** launched **in August 1994**
- **Passes over TMF every three days**
- **Experiment duration** 3-5 hours
- Accomplishments
  - ✦ Two-way space-to-ground laser communication from geostationary ranges
  - ✦ Multiple beam uplink
  - ✦ Daytime acquisition/tracking/comm.

Demonstration Overview

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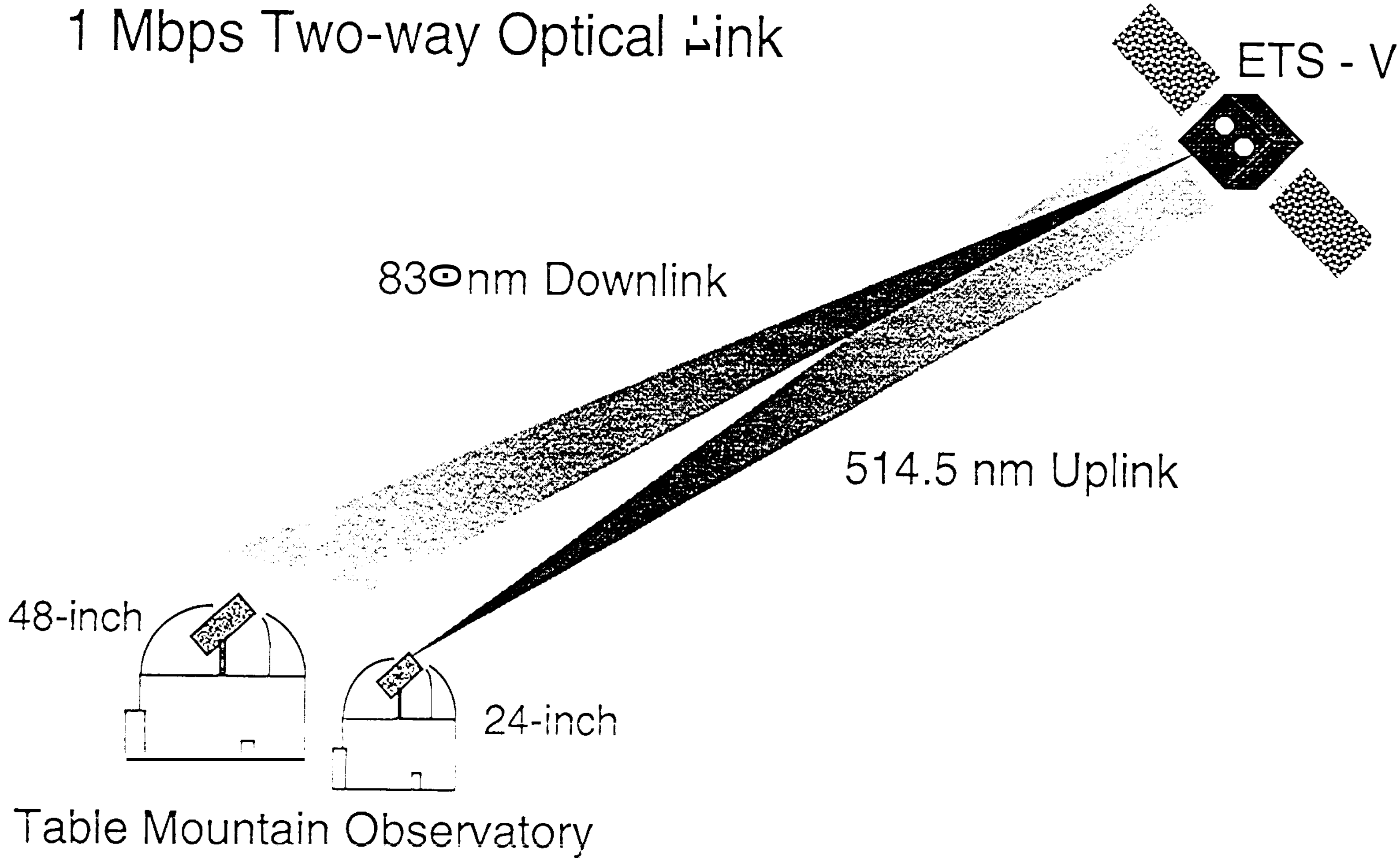
1 Mbps Two-way Optical Link



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Link Budget: Uplink

Link Distance	37850.0 km	
Elevation Angle	46.2 degrees	
Laser Power	13.2 W	41.21 dBm
Tx Optics Efficiency	0.75	-1.25 dB
Beam Divergence	30.00 micro-rad	
Pointing jitter	0.00 micro-rad	
Pointing offset	4.00 micro-rad	
Pointing loss factor	0.99	-0.04 dB
Propagation loss	9.87E-07 l/m ^2	-60.05 dB
Atm transmission	0.80	-1.34 dB
Receiver Aperture	7.5 cm	
	4.42E-03 m^2	-23.55 dB
Rx Optics Efficiency	0.15	-8.24 dB
Received Power	4.7 nW	-53.27 dBm
Required power	631.0 pW	-62.00 dBm
Link Margin		8.73 dB

Does not include fluctuations due to scintillation or beam motion

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Uplink: Scintillation

- Constructive and destructive interference between waves traveling through different atmospheric cells
- **Due to turbulence and dynamics of the** atmosphere, interference pattern shifts and changes with time
- Point-detector or small area **receiver sees fluctuation in signal strength**

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Scintillation: Theorv

- Scintillat'on var'ance descr'bed by log-normal distribution

$$S \propto |\exp(\chi + i\phi)|^2$$

amplitude and phase of wave

$$f_S(s) = \frac{1}{\sqrt{2\pi\sigma_l^2}}\frac{1}{s}\exp\left[-\frac{1}{2\sigma_l^2}\cdot(\ln s - l_m)^2\right]$$

σ_l: S tillation variance
(variance of 2χ)

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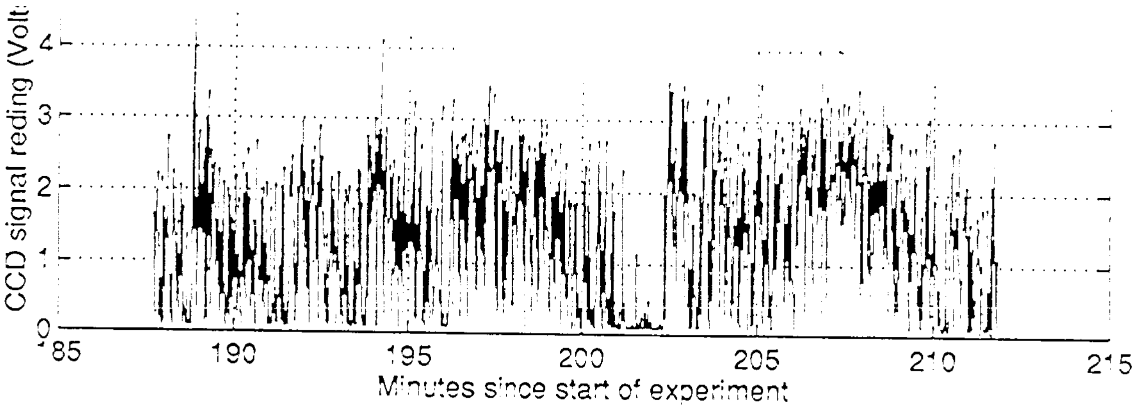
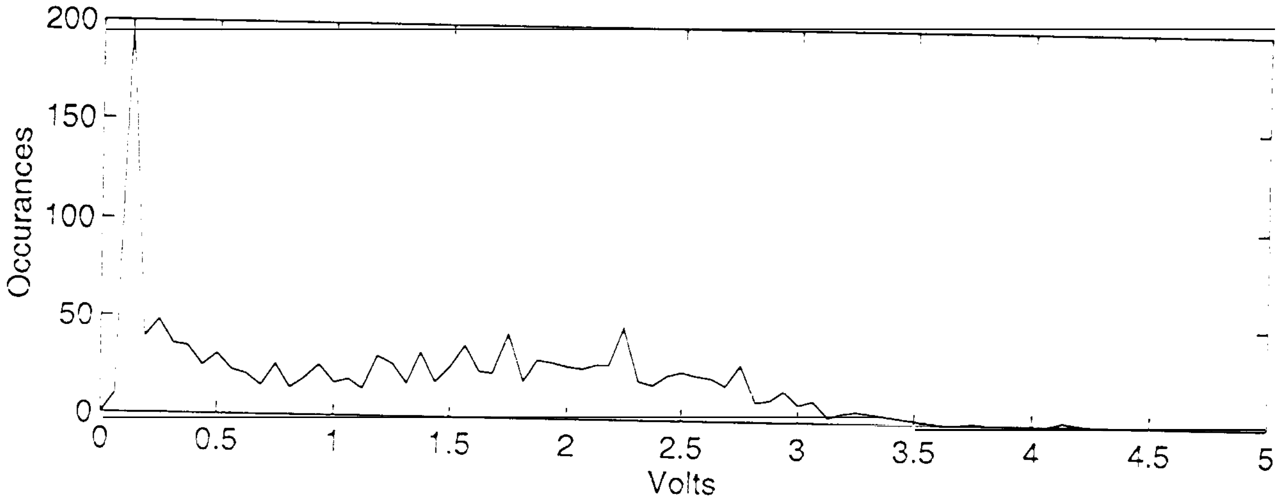
One Beam Uplink Data

From November 17, 1995 Experiment

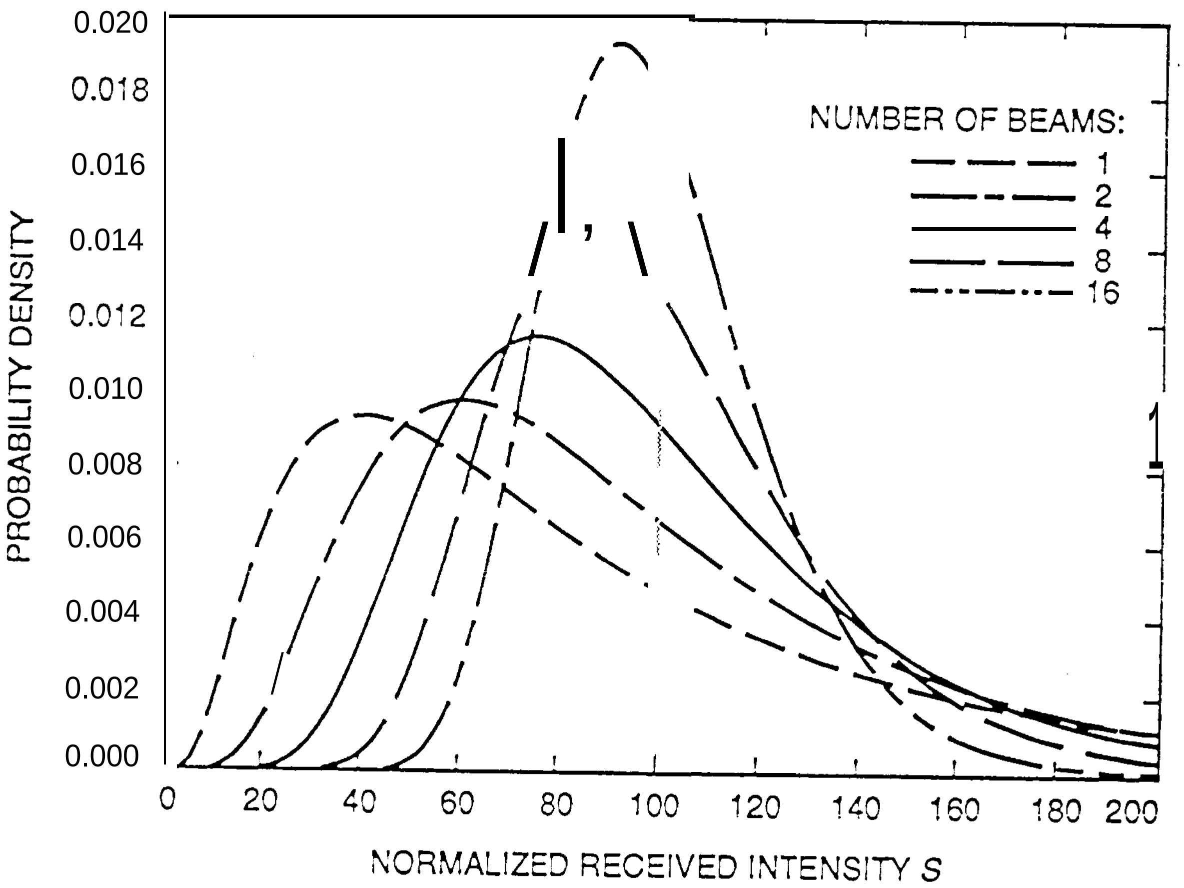




Multi-beam effects

- Multiple beams can be used to reduce scintillation-induced **fades/surges**
  - beams must have independent phase (incoherent between each other)
  - beams must be separated by distances larger than the atmospheric coherence length (a measure of turbulence). Typically 1 to 10 cm.
- PDF is the convolution of log-normal distributions

Multi-beam Uplink PDF



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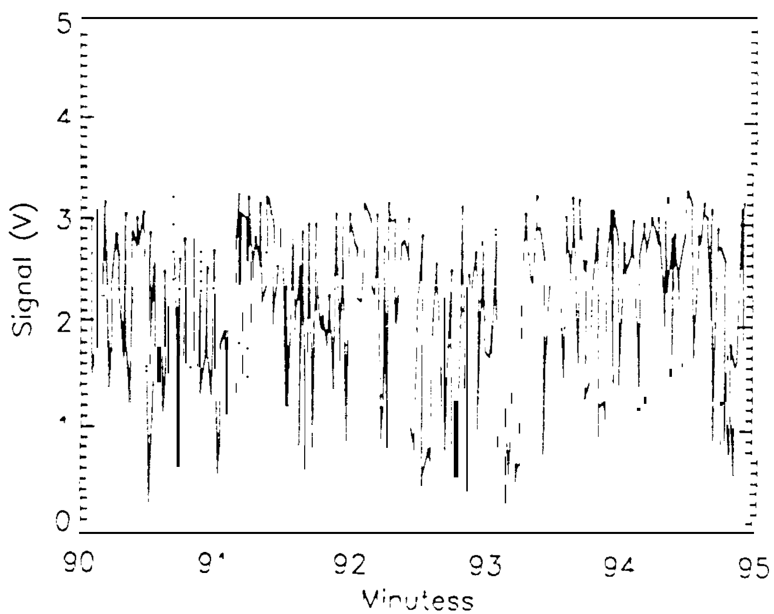
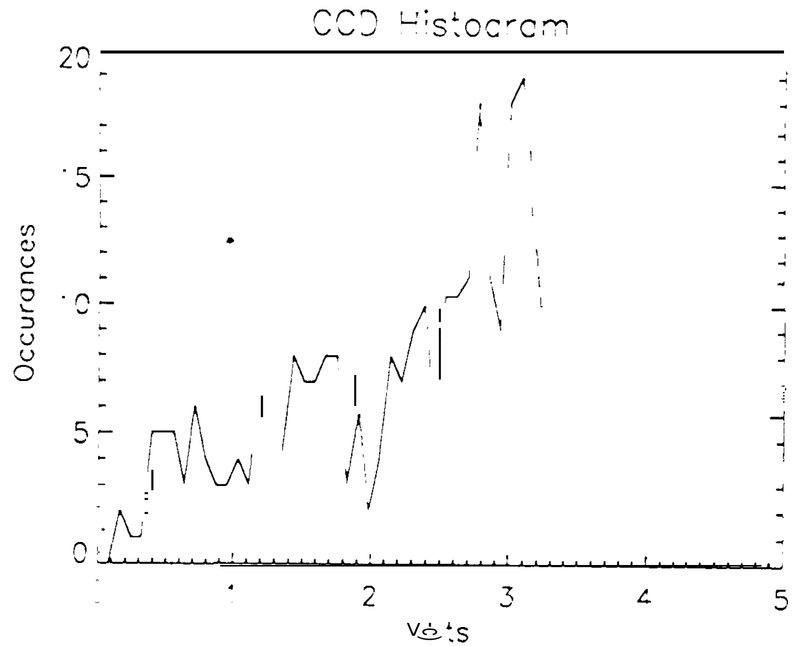
Two Beams

From May 26, 1996 Experiment





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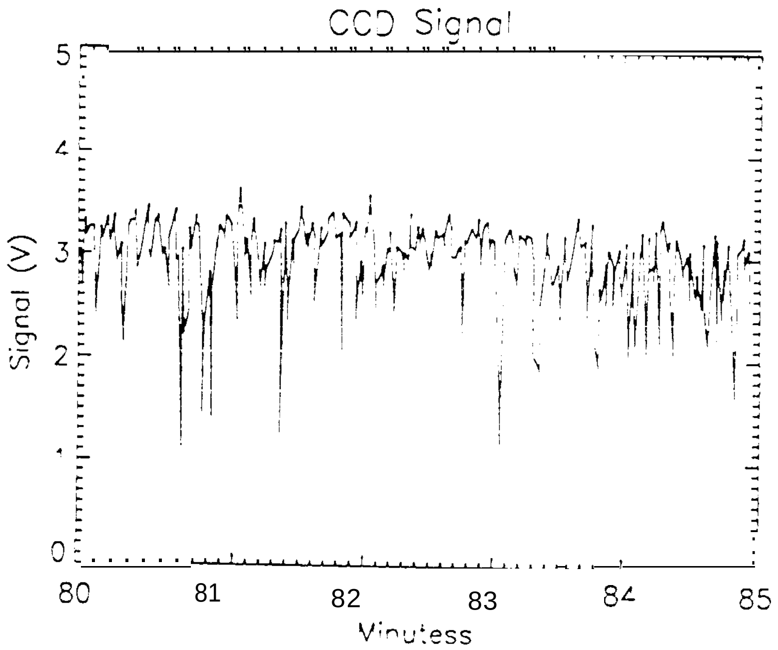
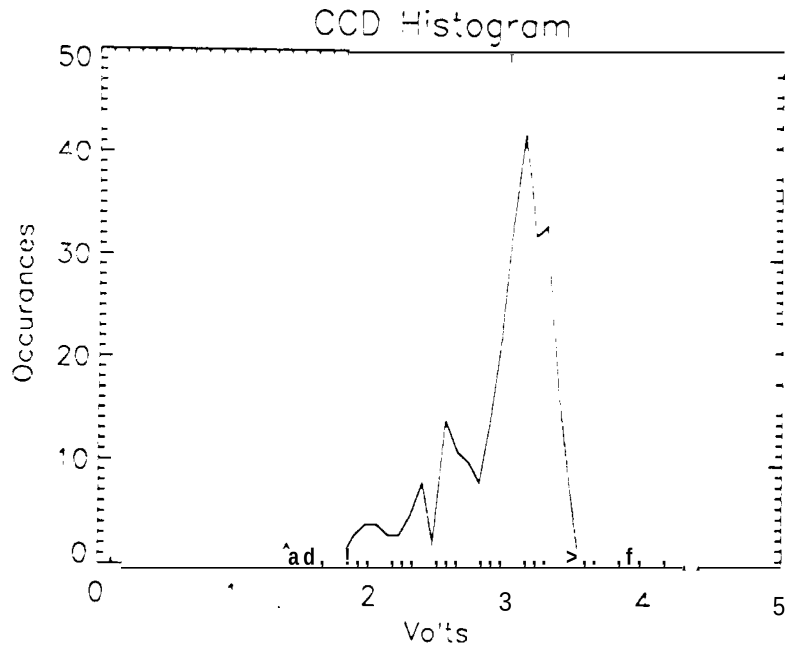
Four Beams

From May 26, 1996 Experiment





Fit to Experimental Data

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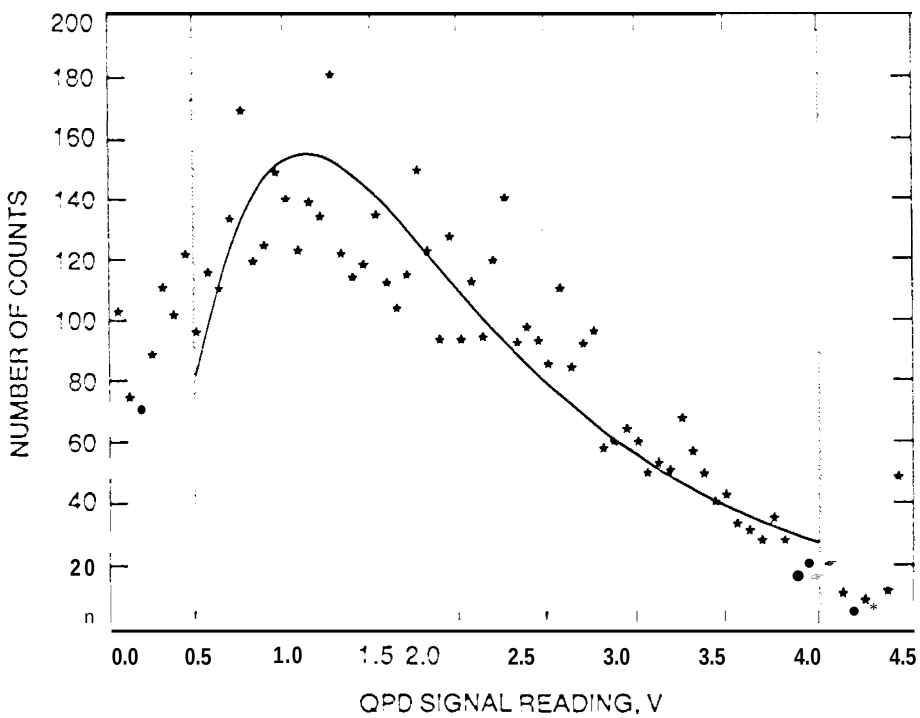
Two-beam data from November 17, 1995 Experiment



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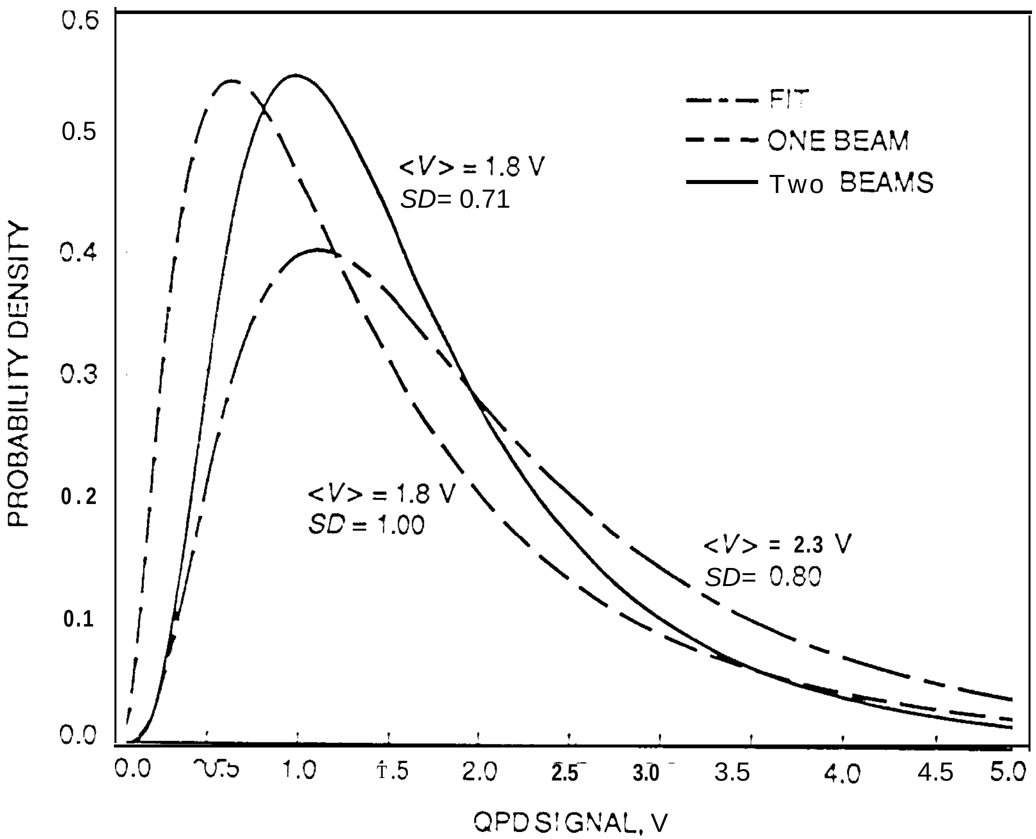
Theory and Experiment

From November 17, 1995 Experiment



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Downlink

- Scintillation significantly reduced by large (greater than 1 m) aperture
  - Intensitv averaged over constructive plus destructive interference
- Beam wander is the dominant effect

Link Budget: Downlink

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Link Distance	37850 km	
Elevation Angle	46.2 degrees	
Laser Power	28 mW	14.47 dBm
Tx Optical Efficiency	0.3	-5.23 dB
Beam Divergence	30 micro-rad	
Pointing jitter	6 micro-rad	
Pointing offset	6 micro-rad	
Pointing loss	0.98	-0.09 dB
Propagation loss	9.87E-07 1/m^2	-60.05 dB
Atm transmission	0.9	-0.46 dB
Receiver Aperture	120 cm	
Area (w 20% obsc.)	1.09 m^2	0.36 dB
Rx Optical Efficiency	0.75	-1.73 dB
RECEIVED POWER	5.33 nW	-52.73 dBm
THRESHOLD POWER	700 p w	-61.55 dBm
Link Margin		8.82 dB

Downlink: Data

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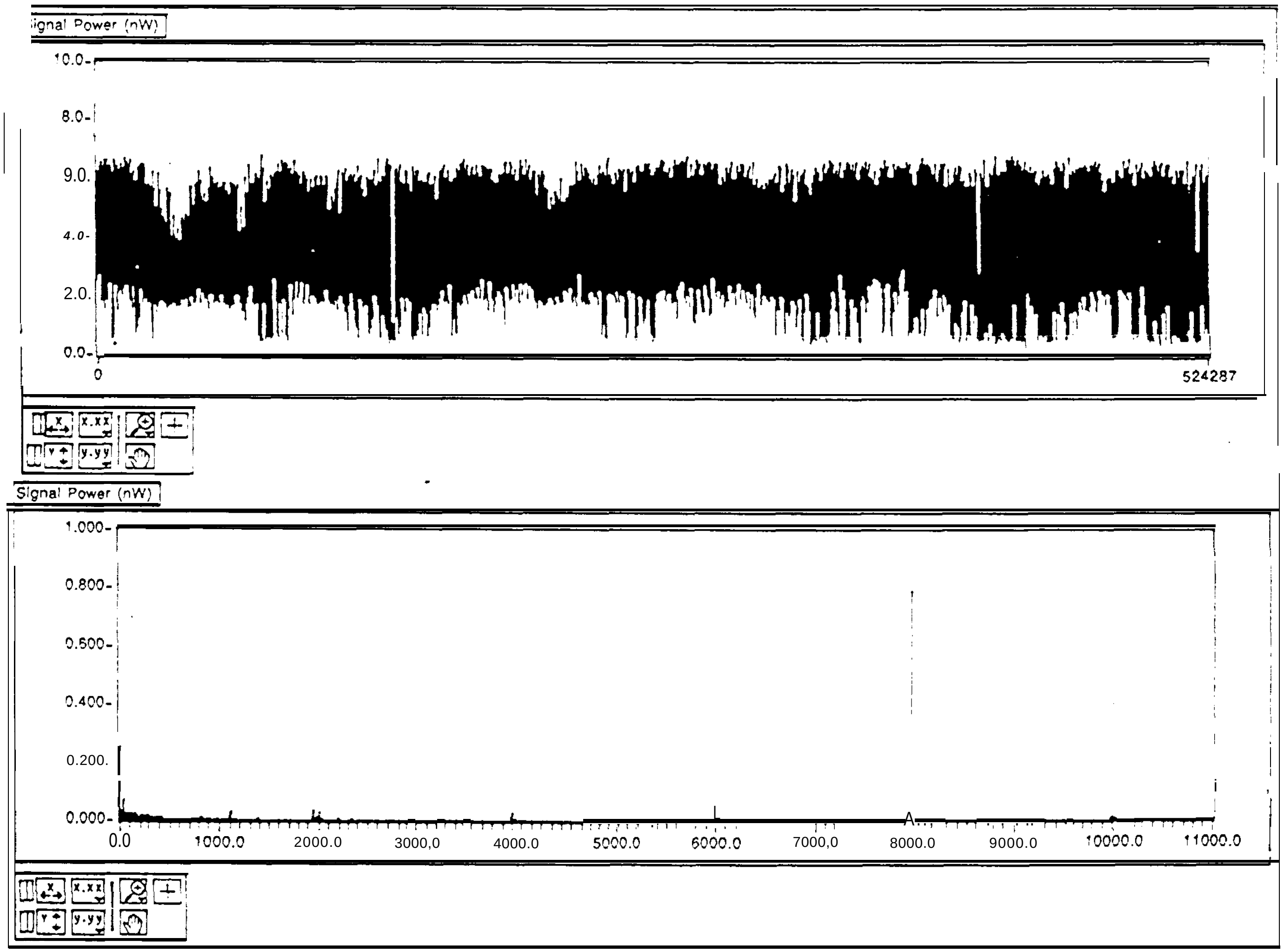
22kHz-sampled downlink signal



Conclusions

- **Experimental data clearly shows significant reduction** in scintillation with multiple beams
- Collected data includes combination of atmospheric effects as well as spacecraft vibrations and pointing errors
- Further analyses required to **deconvolve** these effects