Daytime Adaptive Optics for Deep Space Optical Communications

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Outline

- Daytime Optical Communications Challenge
- Phase I Analysis and modeling
- Laboratory Demonstration
  - Schematic Design
  - Key components
- Planned field Demonstration
- Summary

Daytime Optical Communications Challenge

The Problem

- ***Sun scattering from optical surfaces and sky background radiance are noise sources in the in to the optical channel***
  - ***Problem is worse as mission requires communications support at decreasing Sun-Earth-Probe angles***

The Challenge

- ***How to maintain low-power-consumption, low-mass advantage of optical comm in daytime***
  - ***Analysis shows daytime sky radiance can degrade link performance significantly***

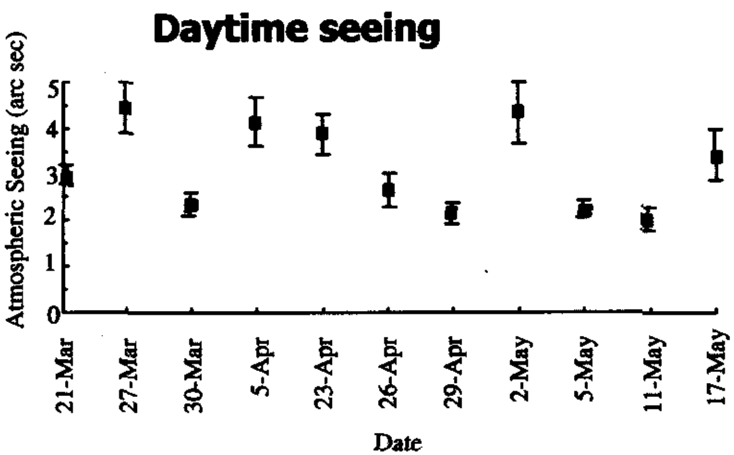
The Approach

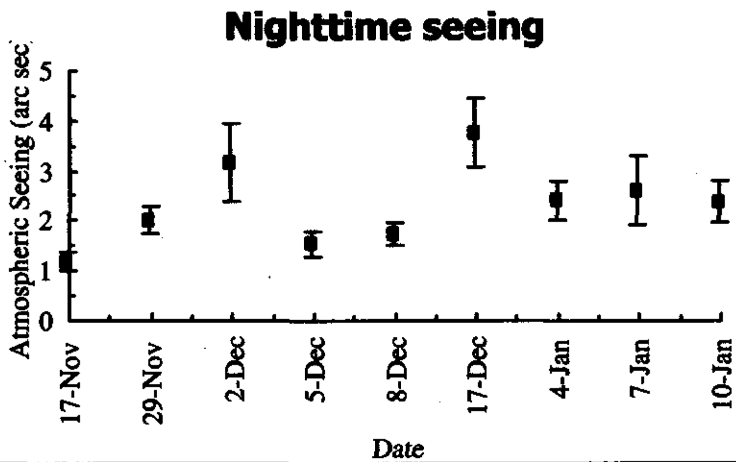
- ***Use a combination of higher order PPM signaling formats and spectral and spatial filters to mitigate effects***
  - ***Advanced signaling formats can increase the complexity of the spacecraft modulator and ground demodulator***
  - ***Narrow line width spectral filters will need to be tuned to accommodate Doppler frequency shifts***
  - ***Spatial filtering will require correcting atmospheric turbulence-induced wave front aberration***

Analysis and modeling

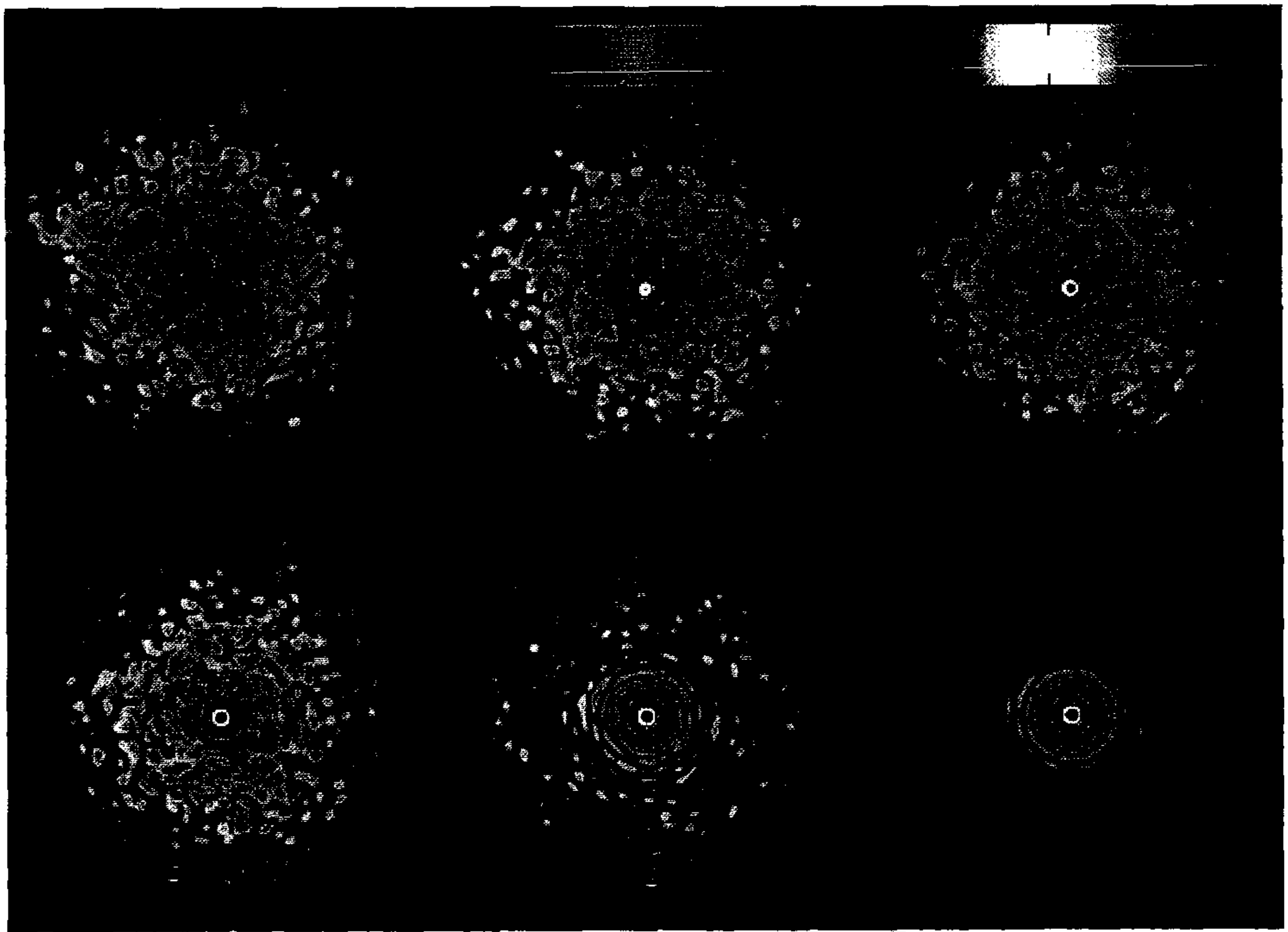
- **Determine wave front aberration for nominal daytime atmosphere conditions at ground receiver site**
  - **Use measured atmospheric seeing values at proposed site**
- **Model wave front correction as a function of actuator density for expected atmospheric conditions**
- **Assess telecommunications system performance as a function of wave front correction for given background levels**

Data taken at TMF during 1995-1996 GOLD Experiment at 0.8 μm





Actuator Density Model Results

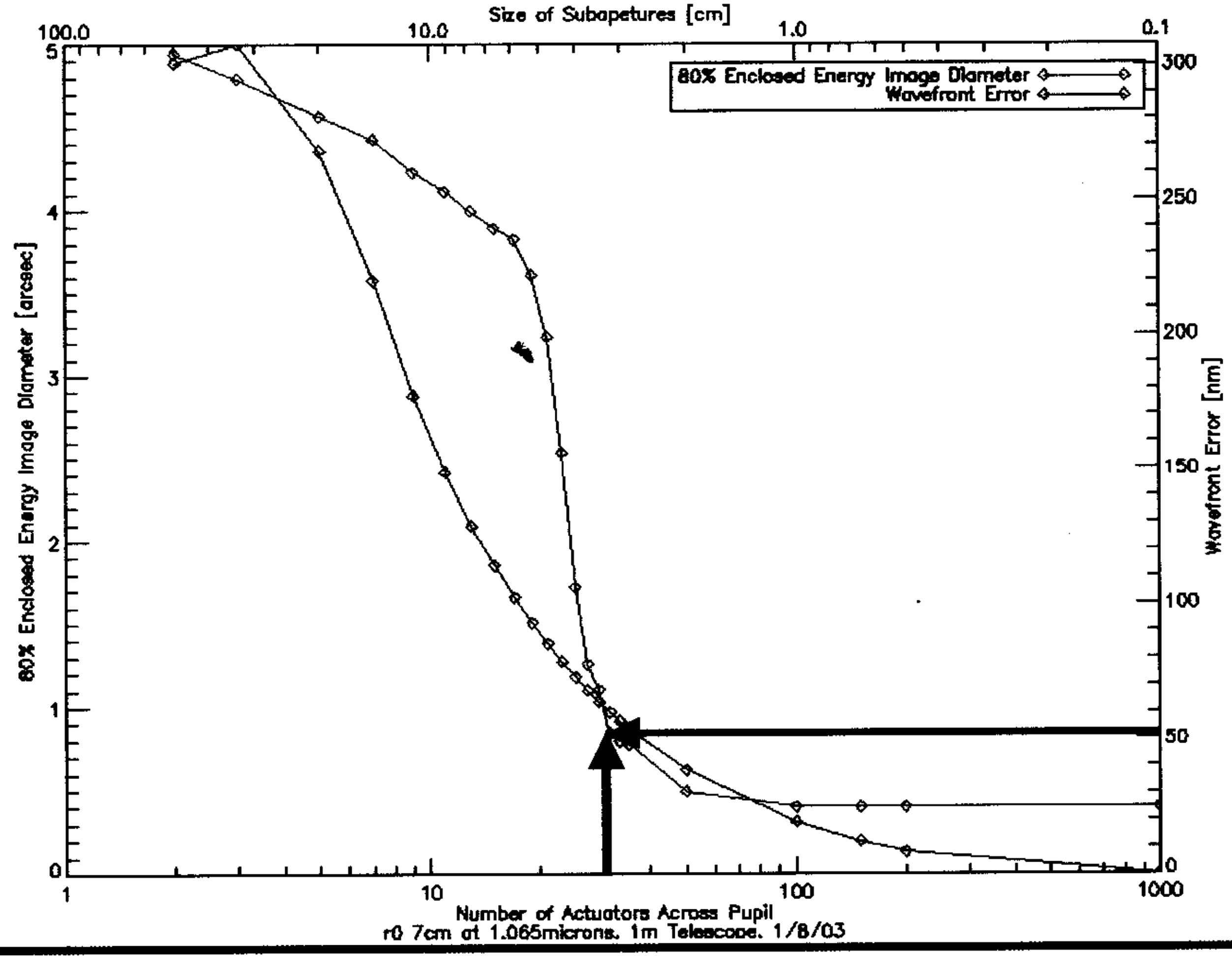


Actuator spacing =d, r_0 =7cm

Modeling Turbulence & Wave Front Correction

- ***Model Parameters***
  - **1 meter telescope**
  - **Wavelength: 1.064 μm**
  - **R0: 7cm at 1.064 μm (3.1 arcsec)**
  - **Number of actuators across pupil range from $(5)^2$ to $(200)^2$**
- ***Method***
  - **Create Kolmogorov phase screen**
  - **Extract a portion corresponding to 1-m**
  - **Create filter function based on DM actuator spacing**
  - **Filter the phase screen with DM filter function**
  - **Propagate phase screen to the image plane**
  - **Sample image at desired pixel scale**

FOV of 80% encircled energy vs. # actuators



Conclusion: *Diminishing returns in performance for greater than (30)^2 actuators on 1-m aperture*

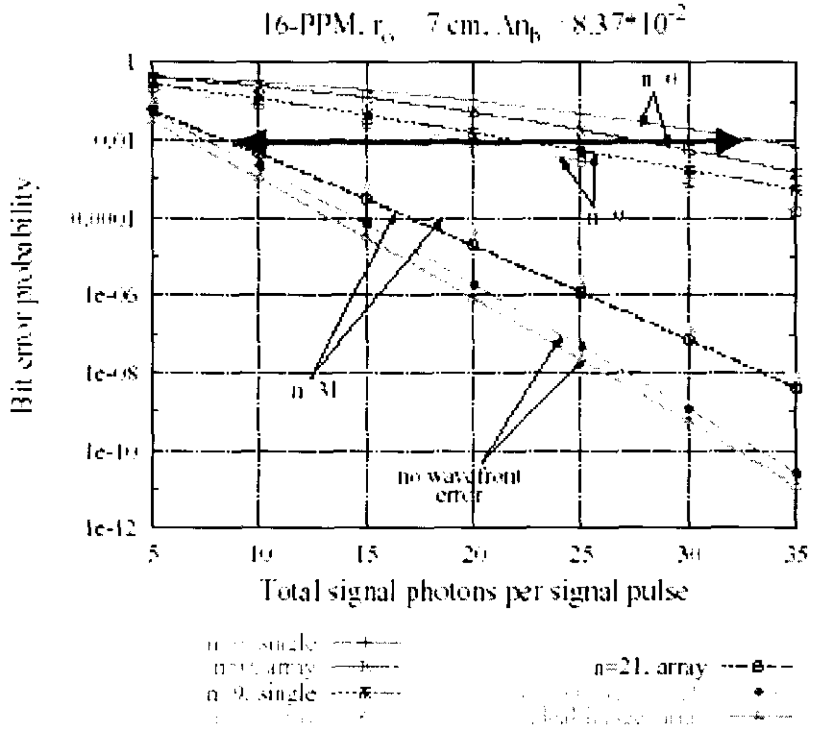
Modeling Performance of Comm Channel

- Use number of actuators as parameter to determine noise in receiver fov with 80% encircled energy
- Background light levels (μW/(cm2-nm-sr)
  - 0.5 => Background from clear sky 3-km altitude receiver station
  - 10 => Nominal sea level sky radiance
  - 100 => sunlight scattered from optics
- Other model parameters
  - Fried parameter r_o => 7 cm
  - Telescope aperture 1-m
  - Filter => 1Å
  - Wavelength 1.064μm
  - Data rate 10 Mbps
    - Modulation 16-PPM, 64-PPM, 256-PPM
  - BER => 0.01 uncoded

Adaptive optics for Deep-space Optical Communications

AO Gain vs. Background Noise

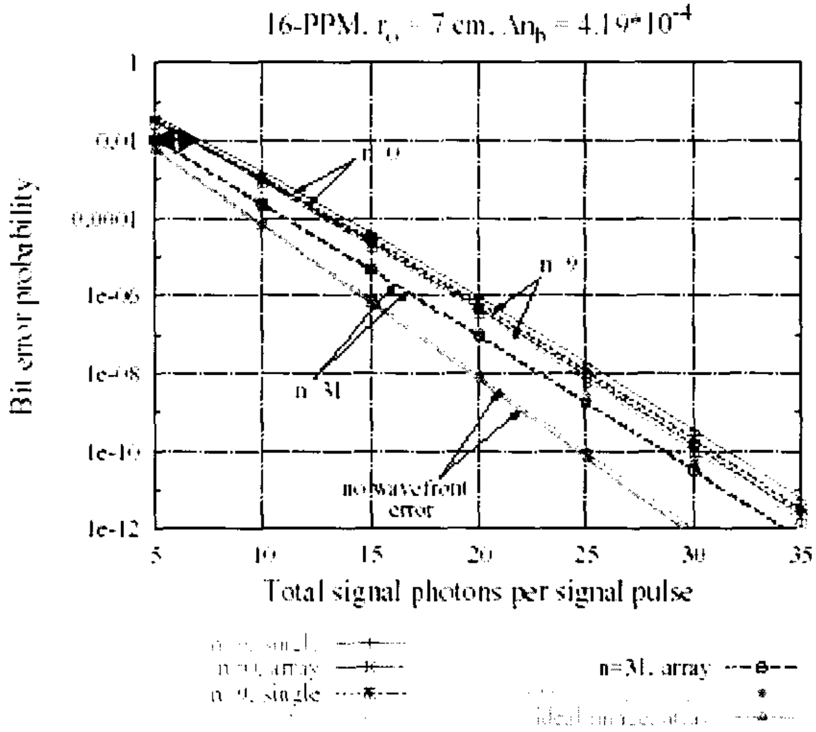
100 μW/(cm2-nm-sr



5.7 dB Gain for 900 actuator DM

2.4 dB Gain for 97 actuator DM

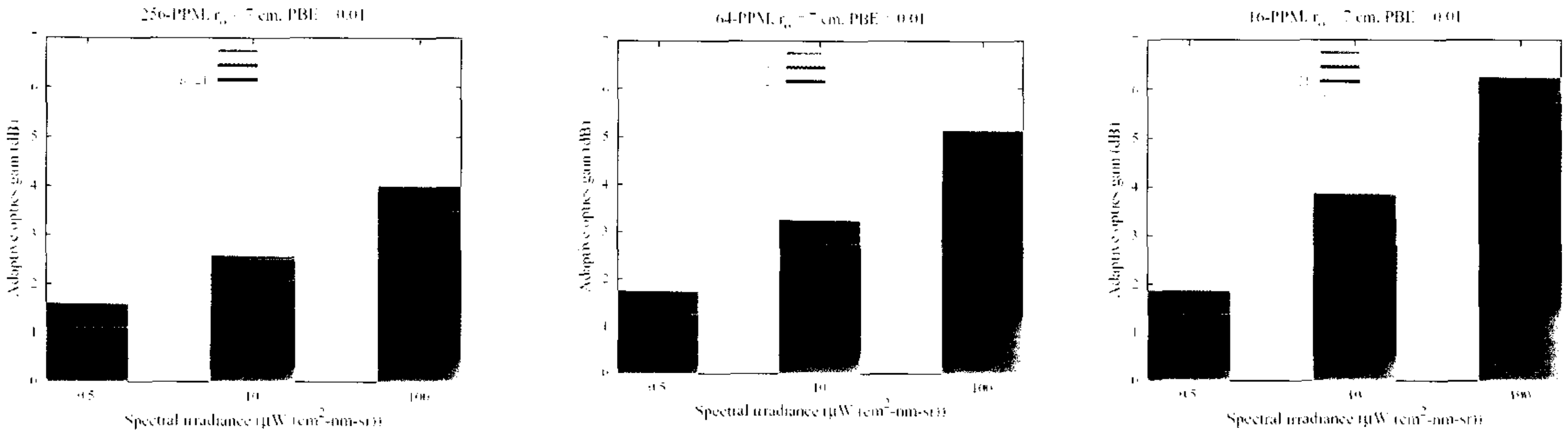
0.5 μW/(cm2-nm-sr



1.3 dB Gain for 97 actuator DM

0.2 dB Gain for 97 actuator DM

Results of Communications Analysis



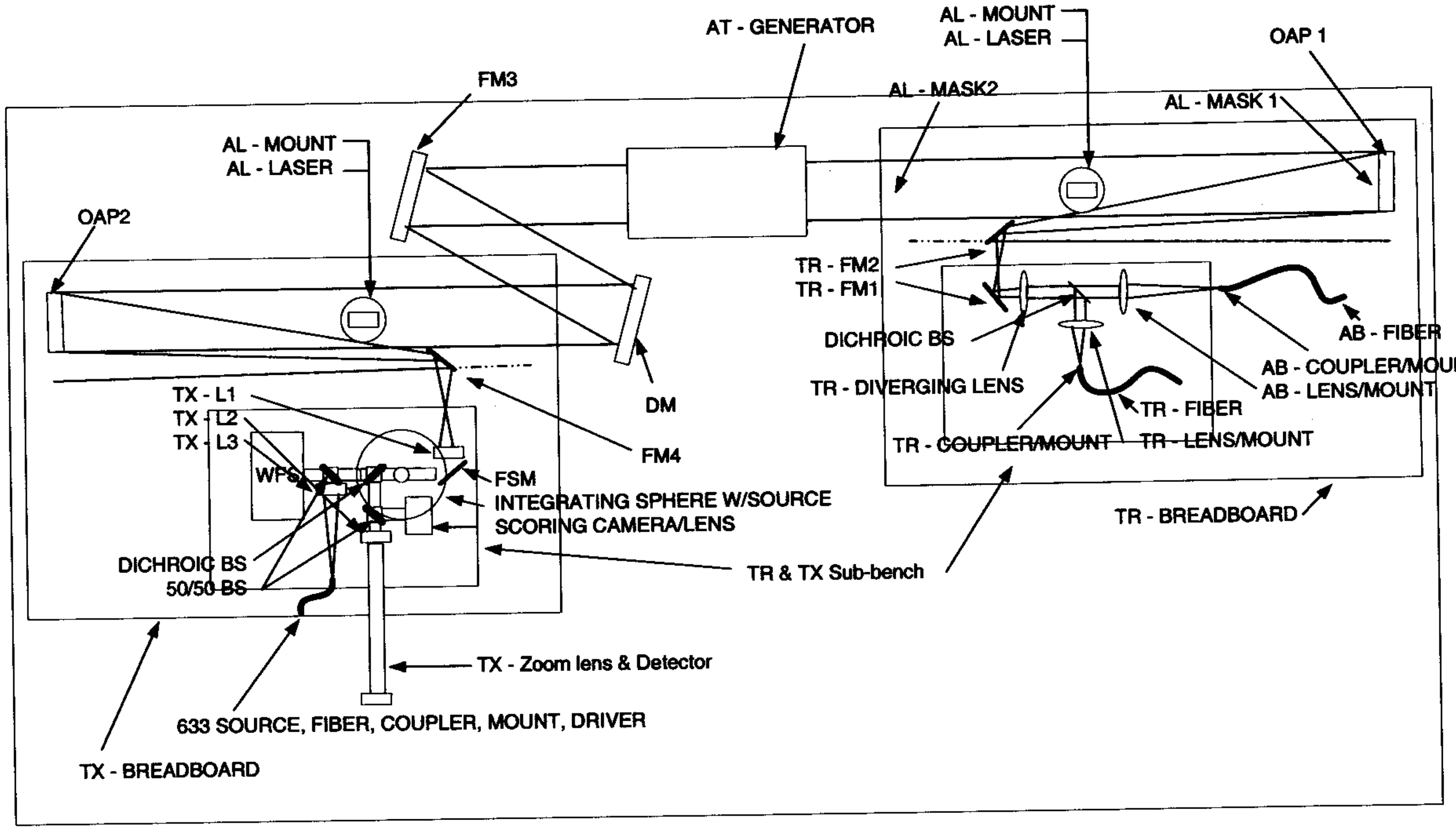
- 1-m aperture with $(30)^2$ actuator AO system can realize significant improvement in system performance at background levels and low signaling formats
  - 1.1- 3.5 dB for 256 PPM
  - 1.2- 4.6 dB for 64 PPM
  - 1.3- 5.7 dB for 16 PPM

Laboratory experiment

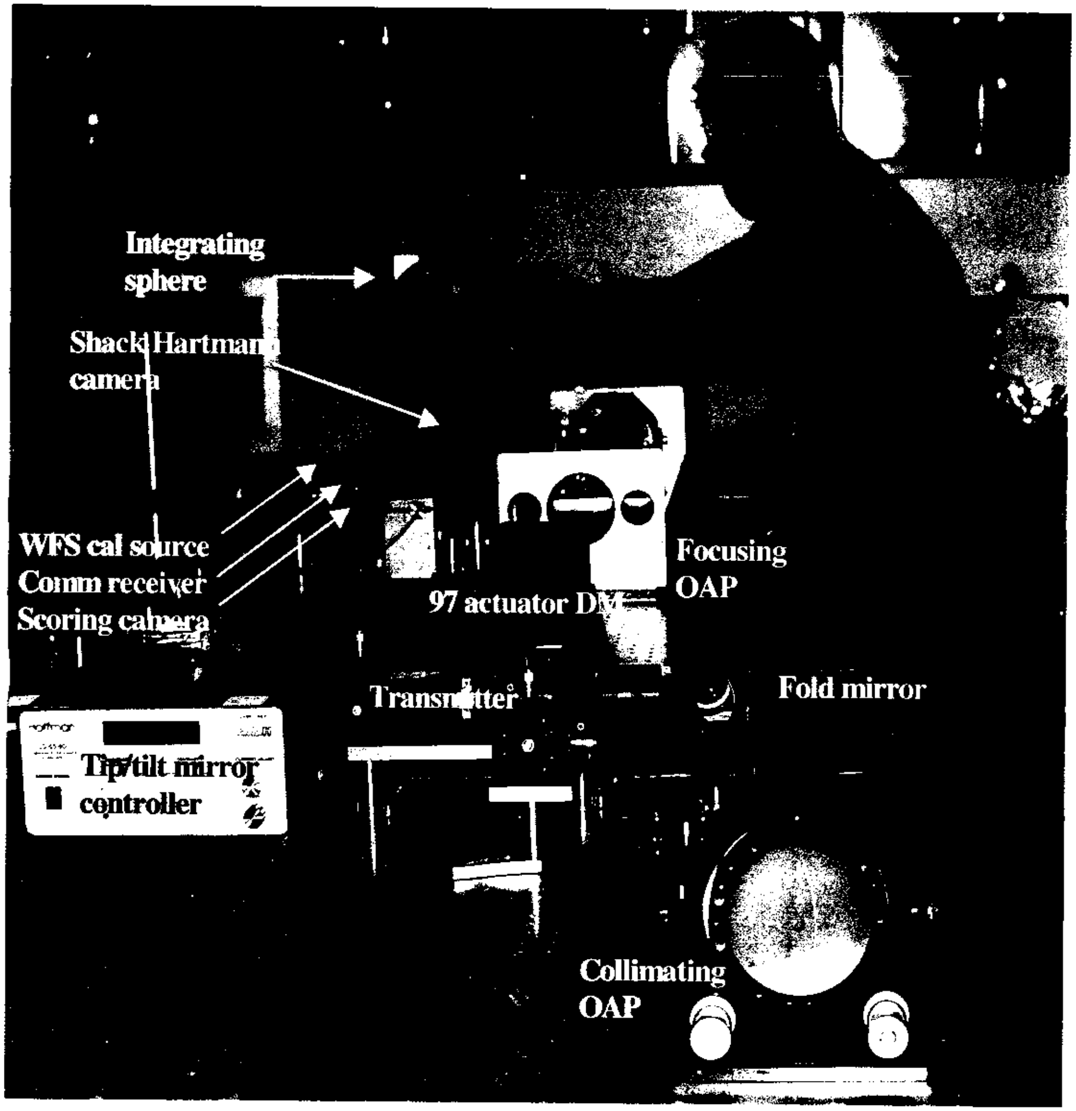
- Objective
  - To develop adaptive optics test bed to validate system performance models
- Approach
  - Simulate atmospheric turbulence and sky background level in optical train
  - Evaluate effect of signaling format, and adaptive optics wave front correction on BER of optical link
  - Demonstrate enhancement in link performance with adaptive optics
    - Assess performance as function of background level
  - Revise models as appropriate

Adaptive optics for Deep-space Optical Communications

Laboratory Demo Schematic



Test bed

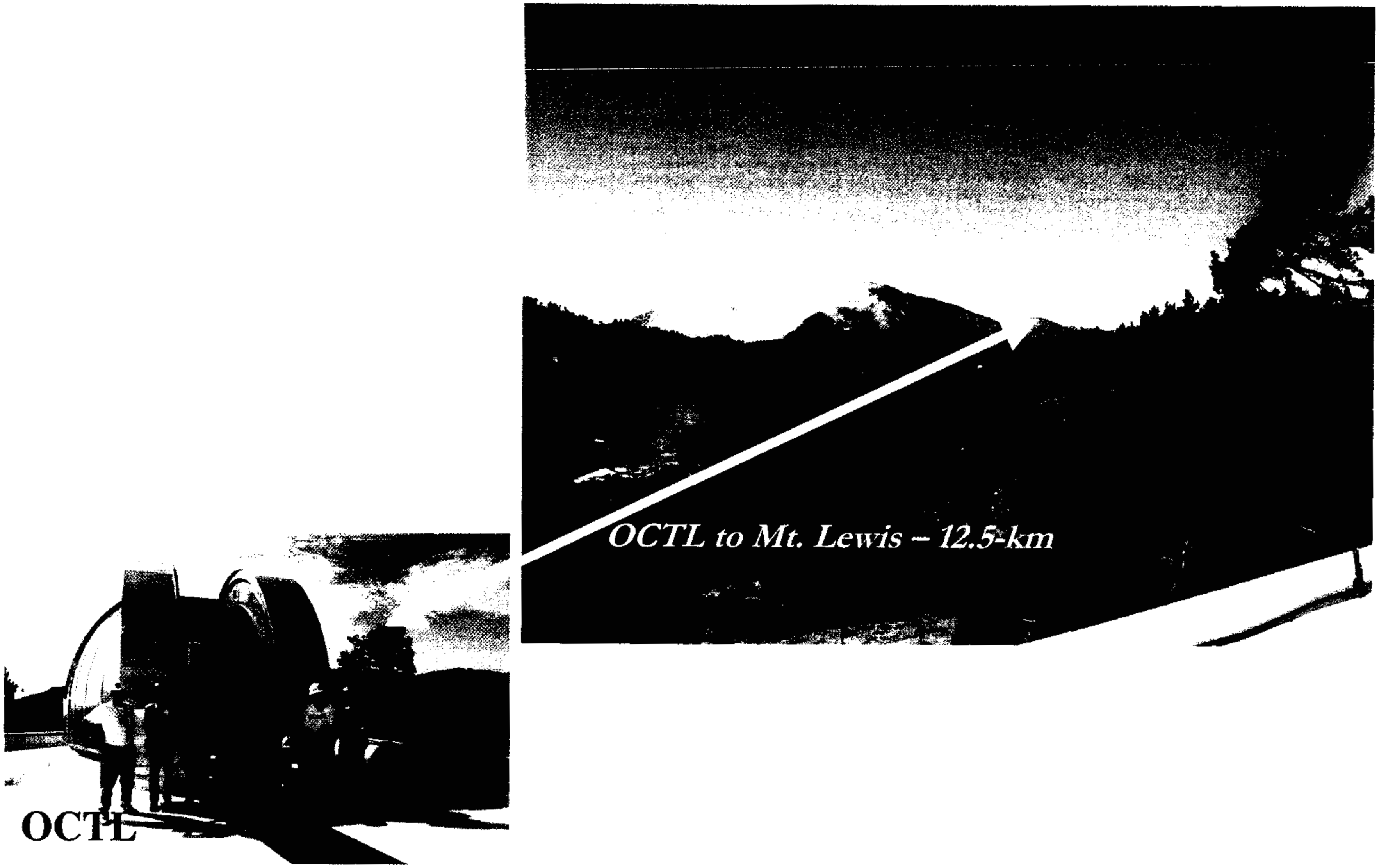

Integrating sphere
Shack Hartmann camera
WFS cal source
Comm receiver
Scoring camera
97 actuator DM
Focusing OAP
Transmitter
Fold mirror
Tip/tilt mirror controller
Collimating OAP

Field Demonstration

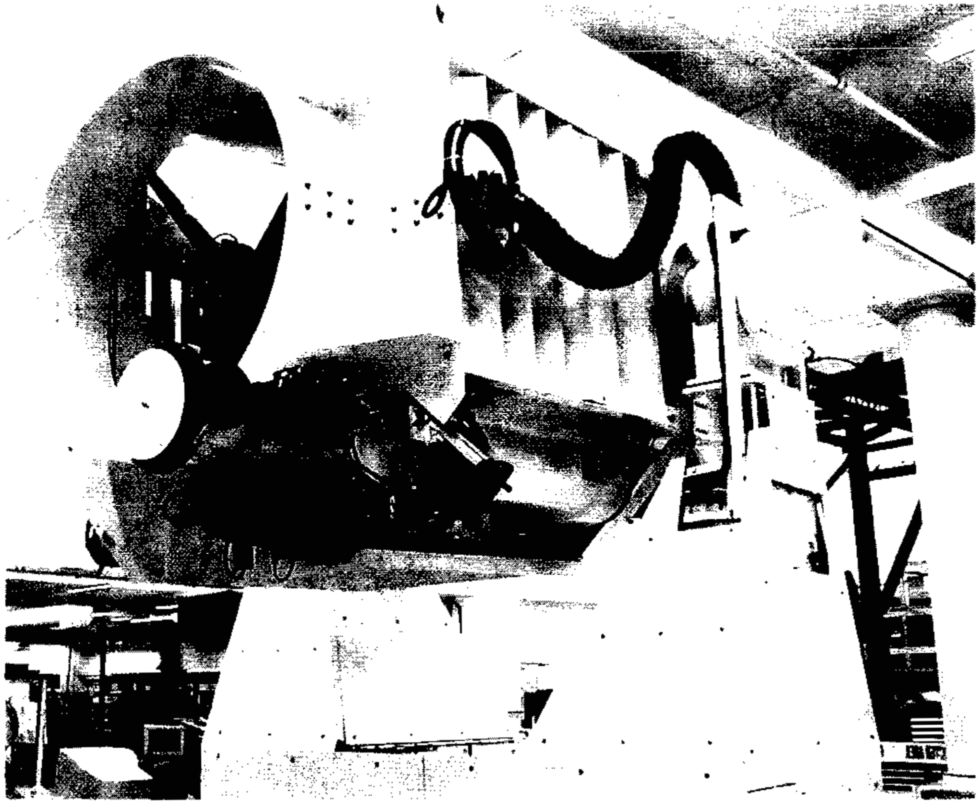
- Horizontal path demo at TMF uses
  - 1-m OCTL telescope
  - Transmitter 12.5 km away
  - Telescope designed to
    - Operate up to 30 degrees of sun without performance degradation
    - Operate down to 10 degrees of sun with 10% degradation
  - Results will enable
    - Models to be improved
    - Techniques to be developed to enable optical comm at small Sun-Earth-Probe angles

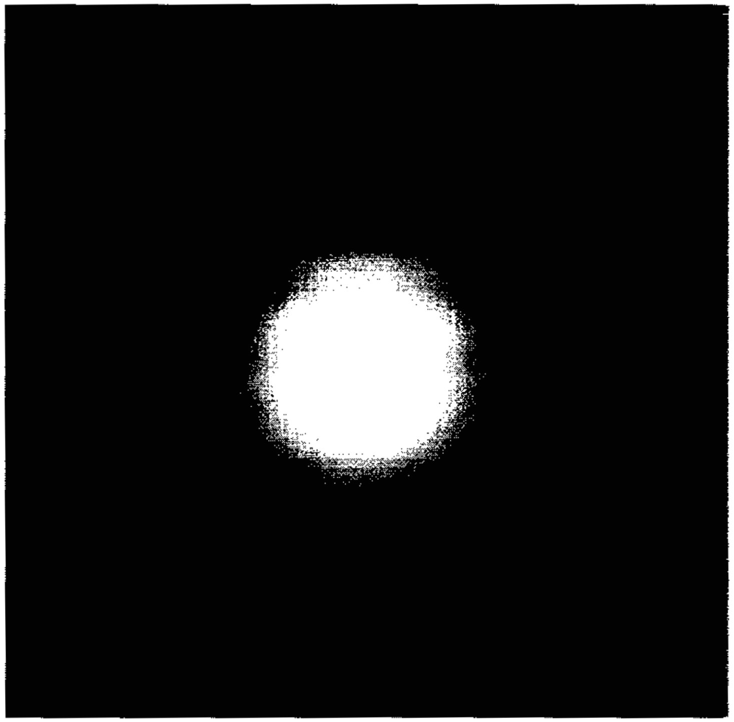
Adaptive optics for Deep-space Optical Communications

Horizontal Path Field Demo



Field Demonstration cont'd





Strehl 0.912

PSF Size: HiRes

Wavelength-Out: 632.8 nm

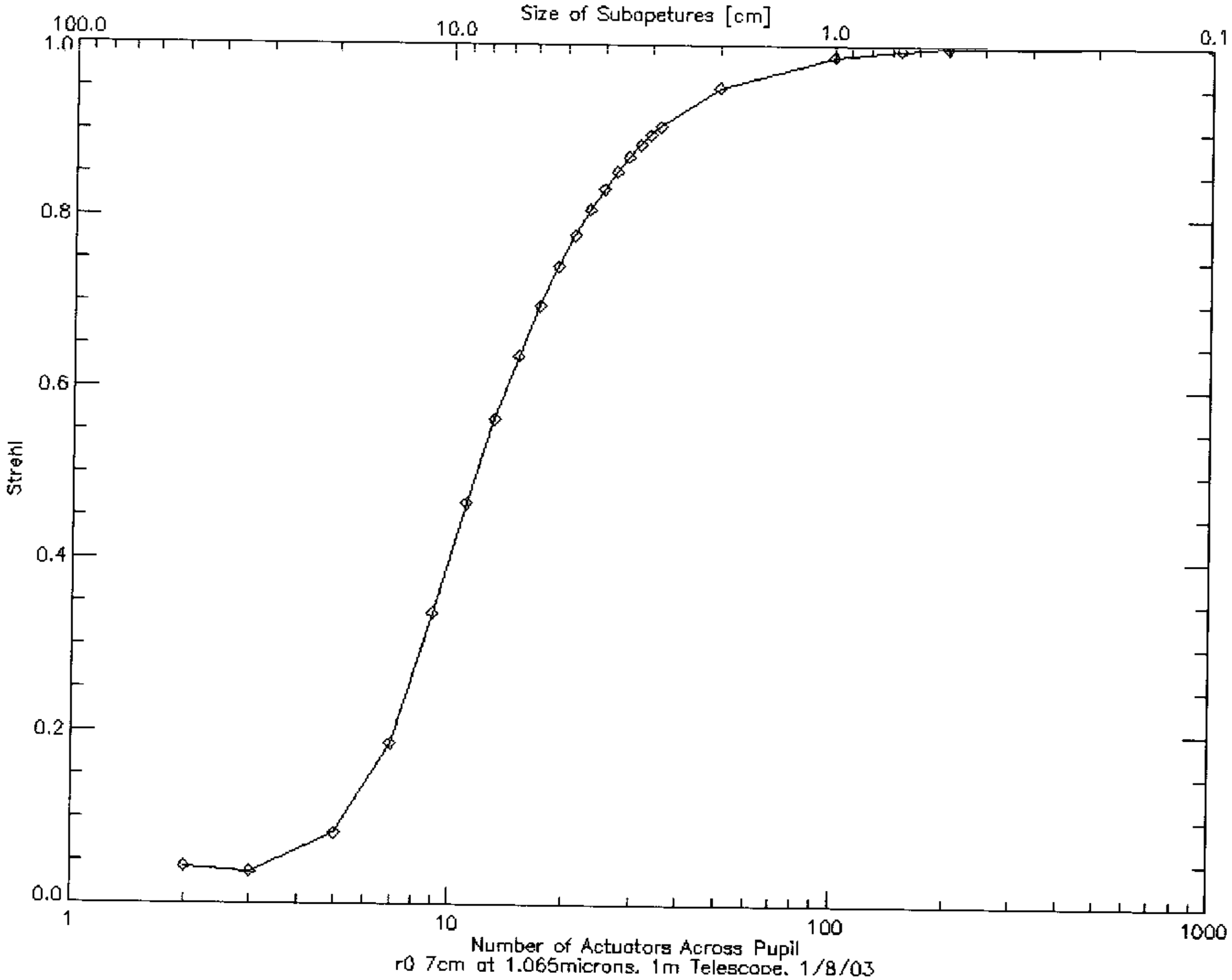
- OCTL telescope to be installed at TMF is
  - Built to $\lambda/13$ RMS performance at 632 nm
  - Designed to operate at 30 degrees to Sun

Summary

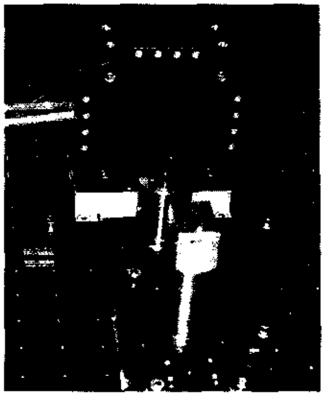
- Analyzed improvement in optical comm link performance obtained by using AO in presence of background
- Analysis based on measured atmospheric seeing at TMF
  - Results show that improvement is dependent on communications modulation format and decreases with increasing M-ary PPM value
    - Gains as high as 6dB can be realized in high background environments at 16 PPM
    - Gains are 3.5 dB at 256 PPM and similar background environment
- Results show that 900 actuators/ sq-m of aperture can achieve high background rejection
- Testbed to characterize AO system performance is currently being developed
  - Expect results in early ‘04
- Described field demonstration using high precision OCTL telescope

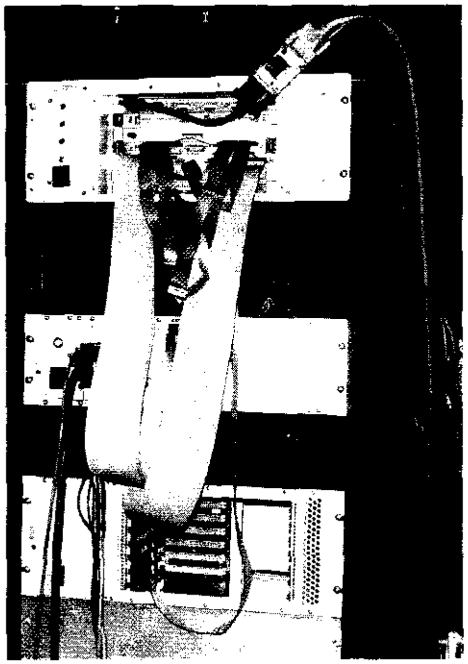
Backup VGs

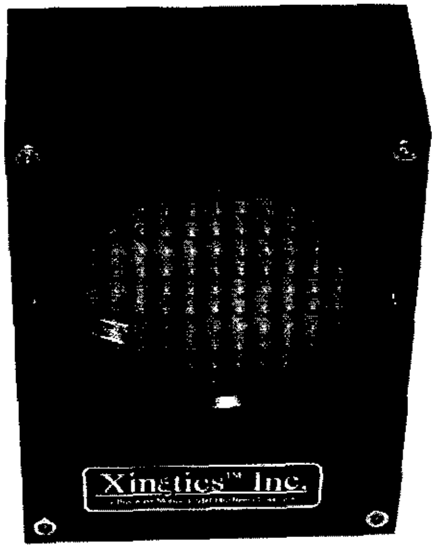
Strehl


Size of Subapetures [cm]
100.0
10.0
1.0
0.1
Strehl
1.0
0.8
0.6
0.4
0.2
0.0
1
10
100
1000
Number of Actuators Across Pupil
r0 7cm at 1.065microns, 1m Telescope, 1/8/03

Major components







- Shack-Hartman WFS & Control Electronics
- 80x80 pixels (EEV39 CCD)
- Frame rate
  - 1100Hz full frame
  - >2KHz at 32x32 pixels
  - 3 to 7 electrons of read noise

- 97 actuators DM
- 7mm actuator spacing
- 4 microns stroke
- >2KHz actuators bandwidth