# Adaptive Optics without Wavefront Sensing: Laser Communication and Directed Energy Applications

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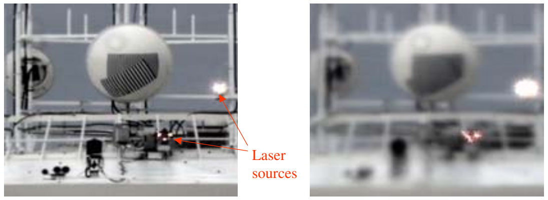
## Wavefront Distortions from Atmospheric Turbulence

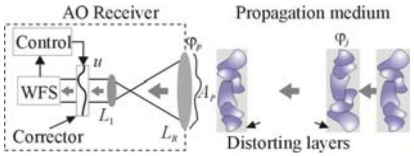
A light beam propagating through the atmosphere is subject to wavefront distortions by atmospheric turbulence due to air-density fluctuations; degradation of image quality or spreading of laser beams occurs.



*Imaging through 2.3km atmosphere under weak and strong turbulence conditions*

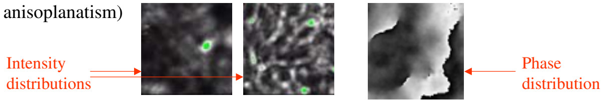
## Conventional Adaptive Optics

Compensation of atmospheric effects by
- measurement of wavefront slopes with a wavefront sensor (WFS)
- wavefront reconstruction
- phase conjugation with a wavefront corrector (e.g. a deformable mirror)



Problem: Doesn't work for many applications, esp. in case of an extended horizontal propagation path (e.g. free-space laser communication, horizontal imaging, or directed energy applications)

- Diffraction transform phase distortions into intensity fluctuations (scintillations) ⇒wavefront slope measurements difficult
- Branch points and phase cuts in the wavefront are challenging for phase conjugation with a deformable mirror
- Wavefront measurements are difficult for extended beacons (partial coherence, anisoplanatism)



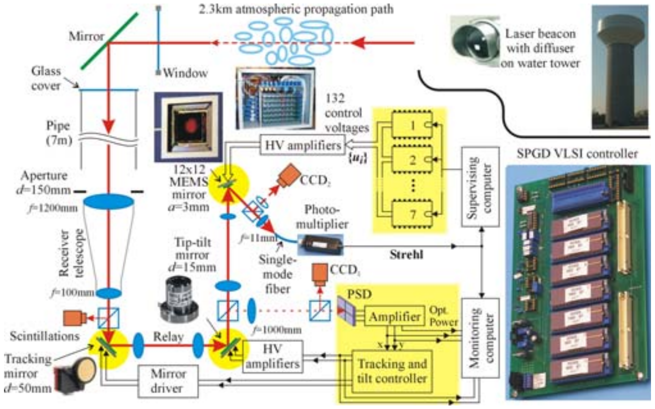
## Stochastic Parallel Gradient Descent (SPGD) Adaptive Optics

- Wavefront correction without measuring the wavefront by blind optimization of a system performance metric $J$
- Definition of $J$ depends on application (e.g. image quality, laser communication signal strength, irradiance at a target, etc.
- Can work under strong scintillation conditions
- SPGD controller applies small perturbation signals $\{\delta u_j\}$ (stochastic with Bernouillie probability distribution) in parallel to all control channels and measures the resulting metric change $\delta J$.
- Update rule for the control voltages $u_j$ at iteration ($n$+1):

$$u_j^{(n+1)} = u_j^{(n)} - \gamma\, \delta J^{(n)}\, \delta u_j$$

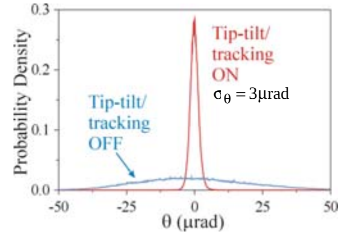
## SPGD Adaptive Optics System Set-up

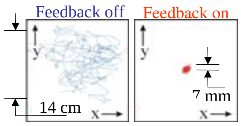
- High-resolution wavefront control with 132-control-channels MEMS mirror (piston type actuation) in combination with independently controlled tracking and fast tip/tilt correction system using piezoelectric actuated mirrors [1,2]
- VLSI SPGD controller: scalable analog VLSI system allows high iteration rates (>10,000/s) avoiding time-consuming D/A conversions [3]
- System installed at ARL's atmospheric laser optics testbed with 2.3km atmospheric propagation path [2,4]
- Uses laser sources with diffuser or multi-mode fiber coupled source as beacon (model for partial coherent beacon)

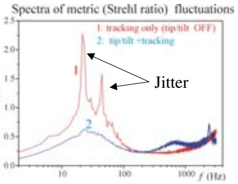


## Mitigation of Atmospheric Distortions: Experimental Results

**Compensation of tip/tilt distortions only:**

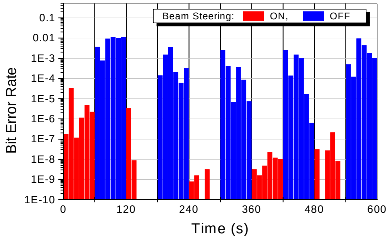




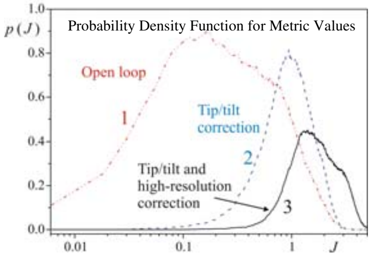


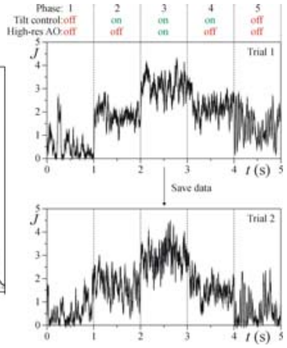
Beam steering applied to free-space optical communication over 2.3km

Optical power $P$ = 60µW from single-mode fiber source provides the same BER as 10mW laser diode with diffuser

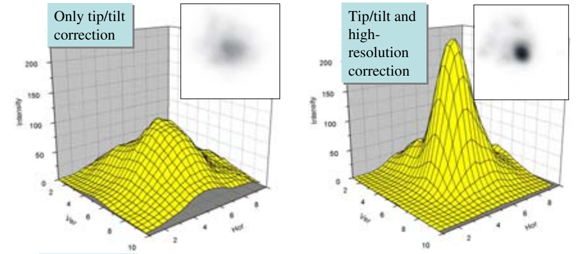


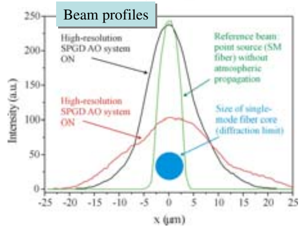
**Wavefront correction with low- and high-resolution systems:**

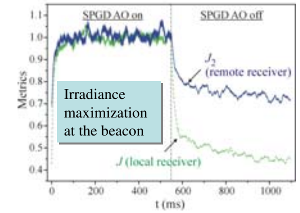




Intensity distributions in the focal plane:







## References

[1] "Dynamic wave-front distortion compensation with a 134-control-channel submillisecond adaptive system," T. Weyrauch and M. A. Vorontsov, *Opt. Lett.* **27**, 751-753 (2002).

[2] "Mitigation of atmospheric-turbulence effects over 2.4-km near-horizontal propagation path with 134 control-channel MEMS/VLSI adaptive transceiver system," T. Weyrauch and M. A. Vorontsov, *Proc. SPIE* **5162**, 1-13 (2003).

[3] "Analog VLSI parallel stochastic optimization for adaptive optics," R. T. Edwards, M. Cohen, G. Cauwenberghs, M. Vorontsov, G. W. Carhart, in *Learning on Silicon*, G. Cauwenberghs and M. A. Bayoumi, eds. (Kluwer, Boston, 1999), pp. 359-382.

[4] "Atmospheric laser optics testbed (A_LOT): atmospheric propagation characterization, beam control, and imaging results," M. A. Vorontsov, G. W. Carhart, M. Banta, T. Weyrauch, J. Gowens II, and J. C. Carrano, *Proc. SPIE* **5162**, 37-48 (2003).

## Acknowledgments

We are grateful to Marc Cohen for the cooperation regarding the VLSI SPGD system. The experiments on atmospheric propagation were performed at the U.S. Army Research Laboratory in Adelphi, MD. We thank our colleagues Gary Carhart and Matthew Banta for their cooperation. The project was funded in part by the Joint Technology Office (JTO).