Daytime Adaptive Optics for Optical Communication to Deep Space

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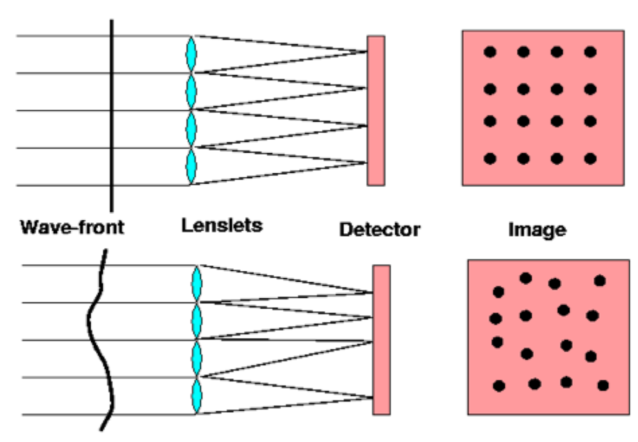
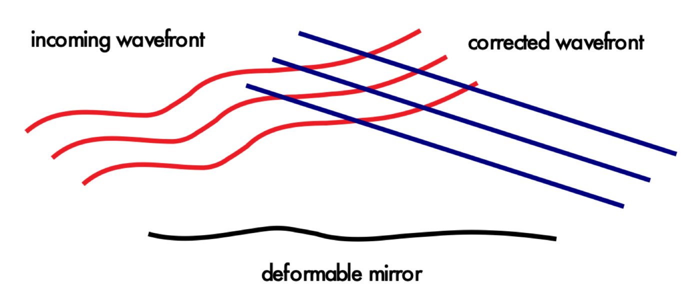
Topical R&TD

Project Objective

Can we use adaptive optics to enable higher data rates for future optical communication with missions in deep space?

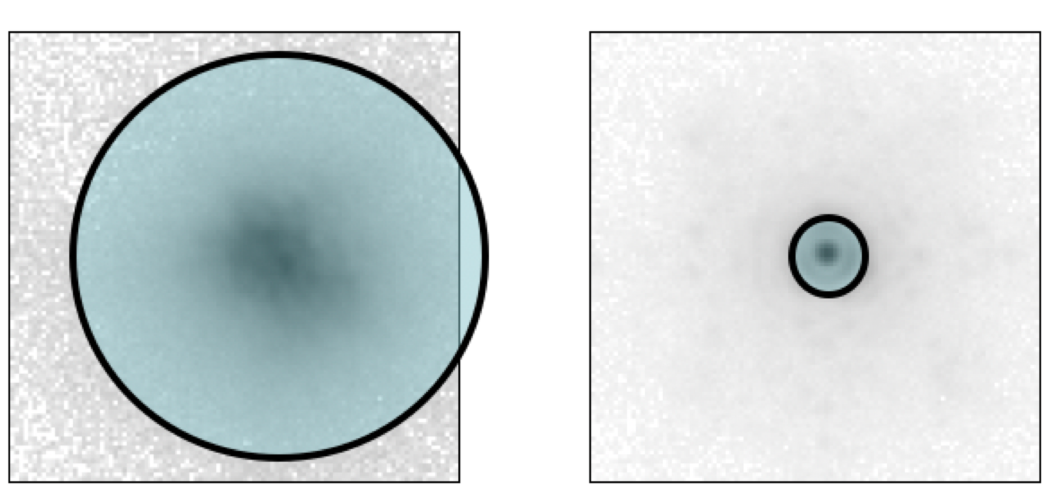
How does Adaptive Optics work?





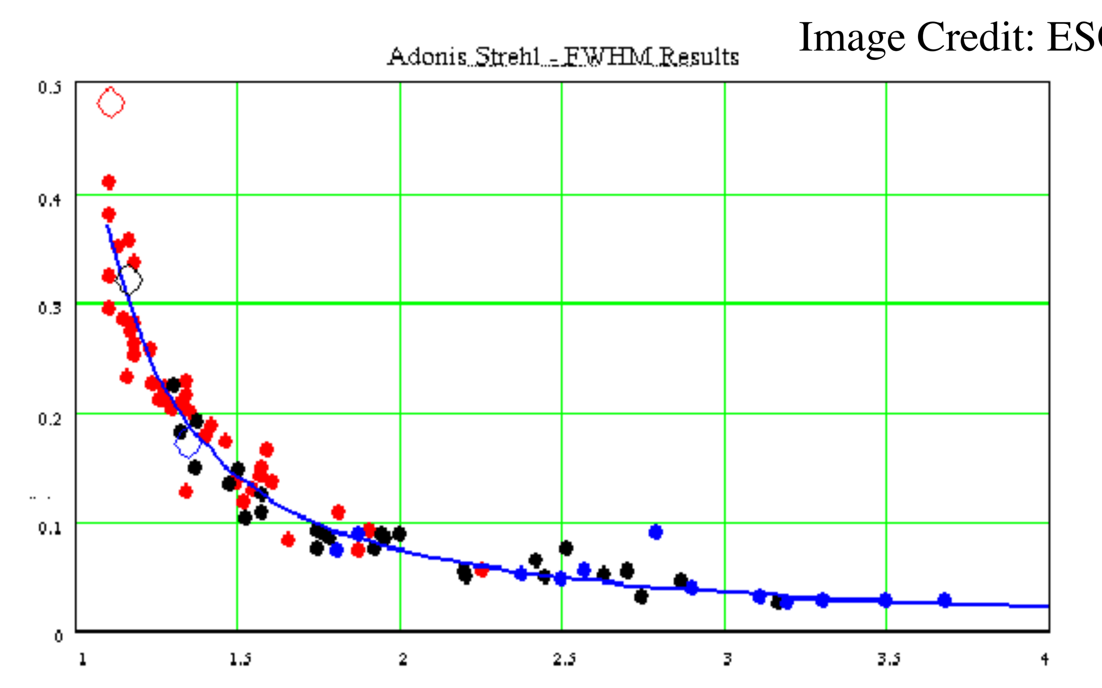
- Atmospheric Turbulence corrupts the wavefront of the incoming light
- A wavefront sensor measures the aberrations
- A deformable mirror is used to correct those aberrations

Why does even mediocre AO help?



The PSF for an uncorrected image on the left and an AO corrected image on the right. The black circles show the size of an aperture that would encompass most of the light of the PSF. AO enables the user to use a smaller aperture to capture the same amount of light with a dramatically reduced amount of background signal.

Image Credit: ESO



The diffraction limit spatial resolution is achieved very closely already at Strehl ratios of 0.15 - 0.2. Higher Strehl ratios do not add significantly to the spatial resolution, but only add to the photon concentration and SNR of the observed features.

Computed the benefit of Adaptive Optics on Downlink Data Rates:

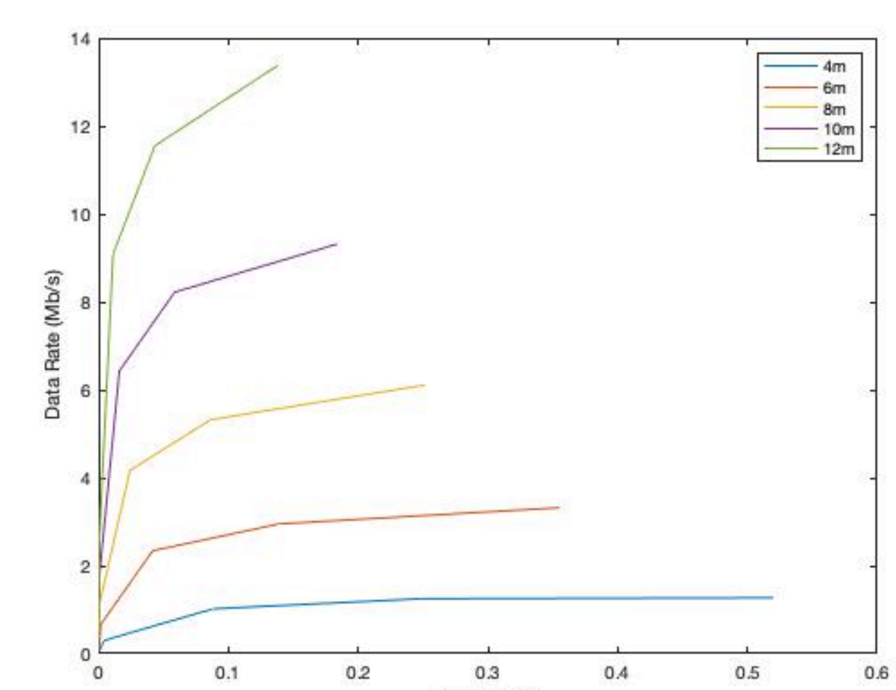
Used following assumptions

- 4W downlink laser
- At Mars during opposition (2.62 AU range)
- 30° elevation
- r_0 of 3cm
- SNSPD Detector

Used r_0 as a surrogate for AO performance. Better AO produces a larger effective r_0

Data rate in Mb/s

	D=4m	D=6m	D=8m	D=10m	D=12m
r_0=3cm	0.045	0.095	0.15	0.21	0.28
r_0=10cm	0.3	0.67	1.17	1.78	2.5
r_0=50cm	1.02	2.34	4.17	6.43	9.08
r_0=100cm	1.25	2.95	5.32	8.22	11.55
r_0=200cm	1.27	3.32	6.11	9.32	13.38



The achievable data rate for different Strehl ratios. The lines correspond to a variety of telescope diameters. The data rates quickly plateau after modest Strehl ratios.

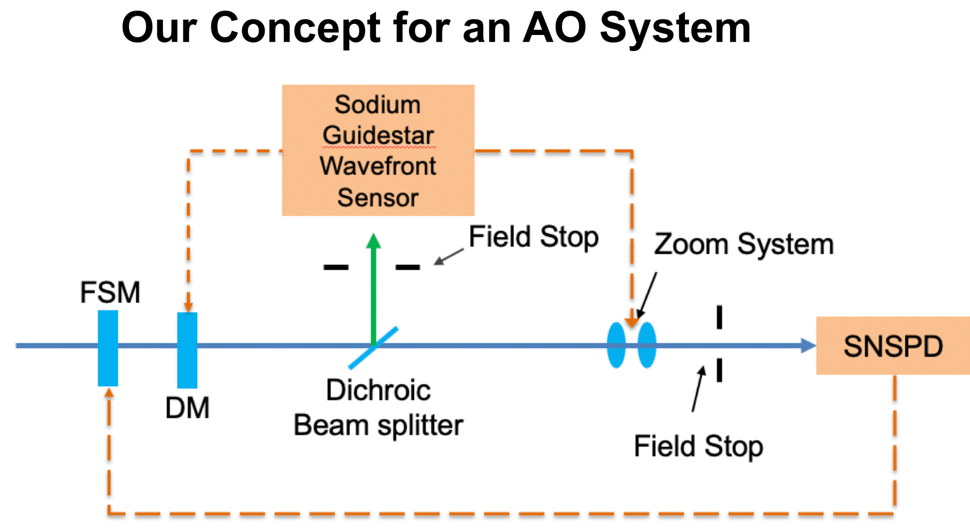
AO can actually make things worse

•AO will concentrate the light into a smaller spot, but this poses a problem with a photon counting detector.

•Need to keep the photon density constant by zooming in as the PSF gets smaller.

•This is the key innovation

Our Concept for an AO System



Block diagram of the proposed AO concept for communicating with spacecraft in Deep Space. The blue arrow is the light path of the system (with all the FSM and DM being depicted as transmissive to simplify the diagram.) The dashed lines are control signals from sensors to active elements.

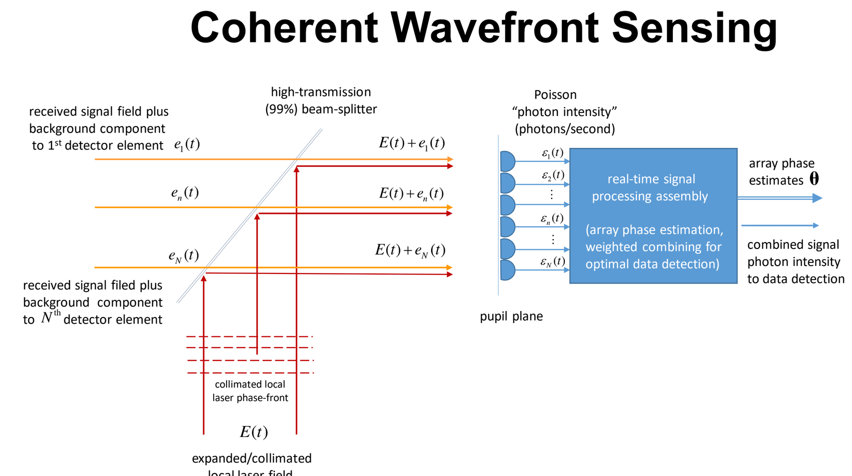
Technology Gap List

Technology	TRL	Notes
SNSPD	TRL 6+	Planned to be used on DSOC
FSM	TRL 9	Not a concern
Sodium Filters	TRL 3	Used in some tests
Laser Line Filters (1550nm)	TRL 5	Planned to be used on DSOC
Deformable Mirrors	TRL 3	Xinetics & BMC DMs don't have the stroke. Will need to use ALPAO or Cilas, which we don't have experience with.
Pyramid Wavefront Sensors	TRL 9	JPL has little experience with these

Benefits to NASA and JPL :

- AO can enable smaller telescopes to have the same data rate as much larger and more expensive telescopes.
- For example a 4m telescope can achieve the same data rate as a 12-m telescope.
- Alternatively we can increase the data rate by 50 times with a modest AO system

Coherent Wavefront Sensing



We also evaluated a Coherent Wavefront Sensor concept that virtually eliminates background interference, and in addition improves detection performance in high background environments, thus enabling efficient daytime optical communications over the photon-starved deep-space optical channel.

Publications:

•*Daytime Adaptive Optics for Deep Space Optical Communication*, L.C. Roberts Jr., S.R. Meeker, S. Piazzolla, J.C. Shelton, 2019, Proc. SPIE., 11133, 1113308

•*Coherent Wavefront Sensor for Optical Communications through Atmospheric Turbulence in Strong Background Environments*, V.A. Vilnrotter, L.C. Roberts Jr., J.C. Shelton 2019 The Interplanetary Network Progress Report, 42-218, 1

•Provisional Patent filed, "*Daytime Adaptive Optics for Deep Space Optical Communication*"

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