Adaptive Nulling for the Terrestrial Planet Finder Interferometer

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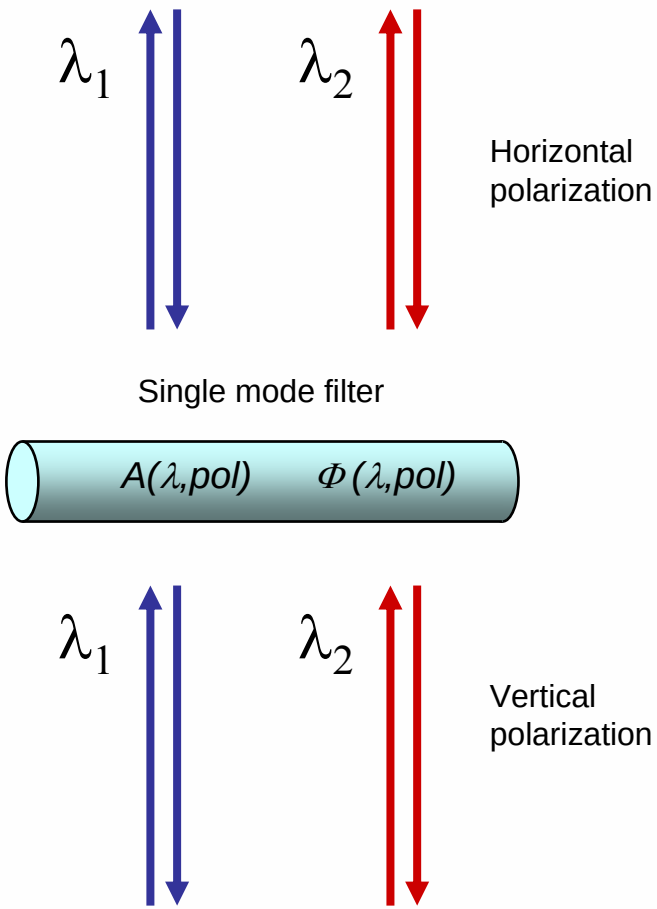
Outline

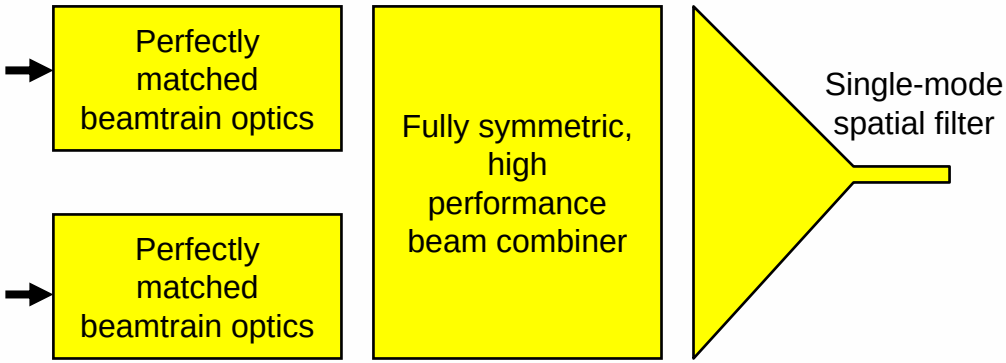
- Background
- How it works
- Development activities
- Summary

Nulling in TPF-I

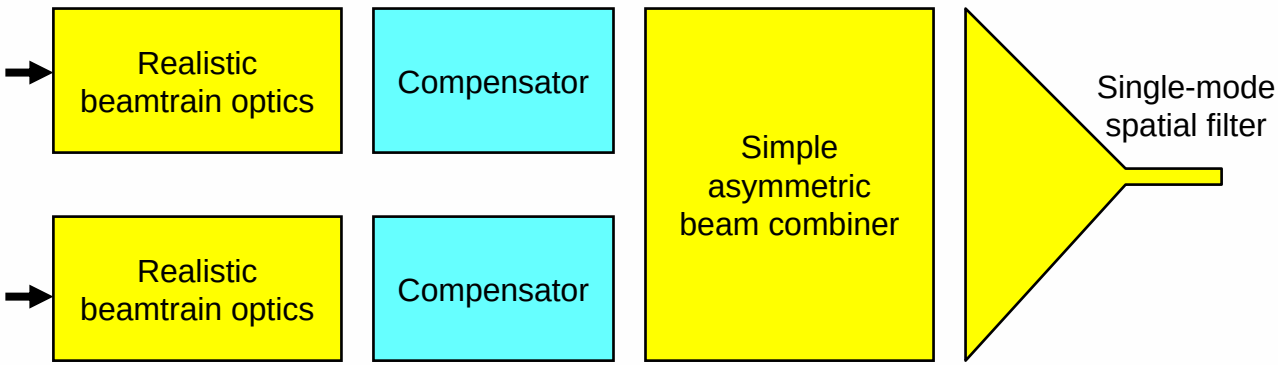


- For deep null require electric fields with
  - equal amplitudes
  - opposite phases
- simultaneously at each wavelength and polarization
- Single-mode filter makes it easier
  - Removes all spatial effects

Why Do Adaptive Nulling

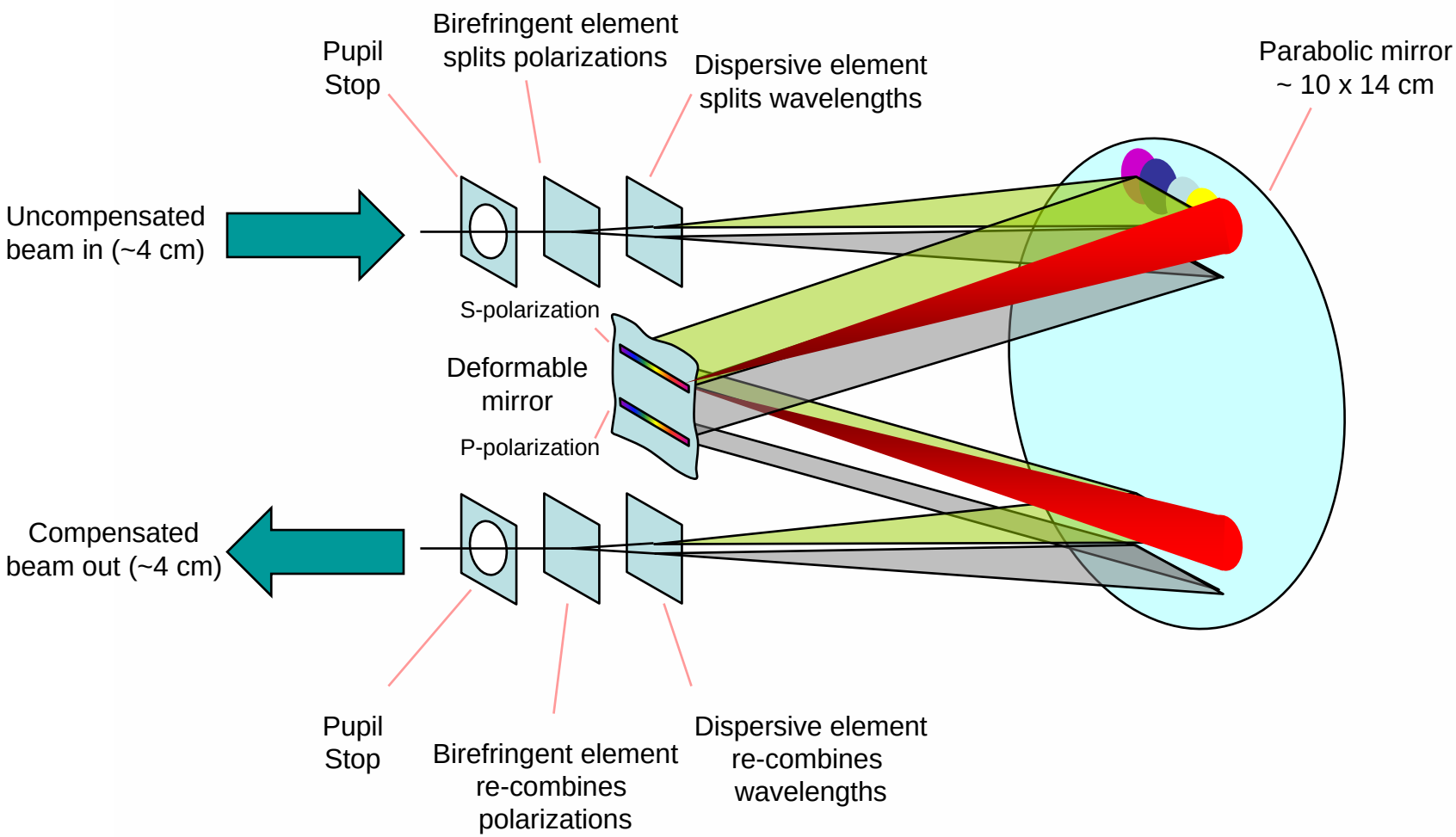


Include a compensator to actively control amplitude and phase for each polarization and wavelength at low bandwidth



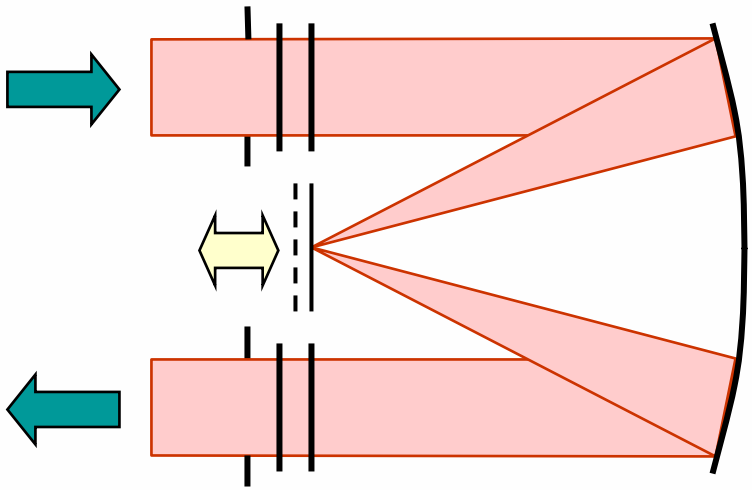
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Parallel high-order compensator design

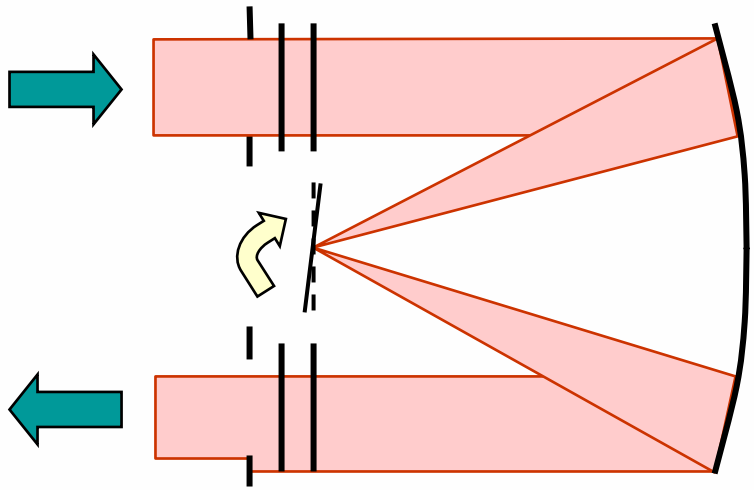


Phase and Amplitude Control

Phase control with piston*:



Amplitude control with tilt*:



- Deformable mirror allows independent control of piston and tilt at each wavelength and polarization

* Side view, shown for single wavelength & polarization

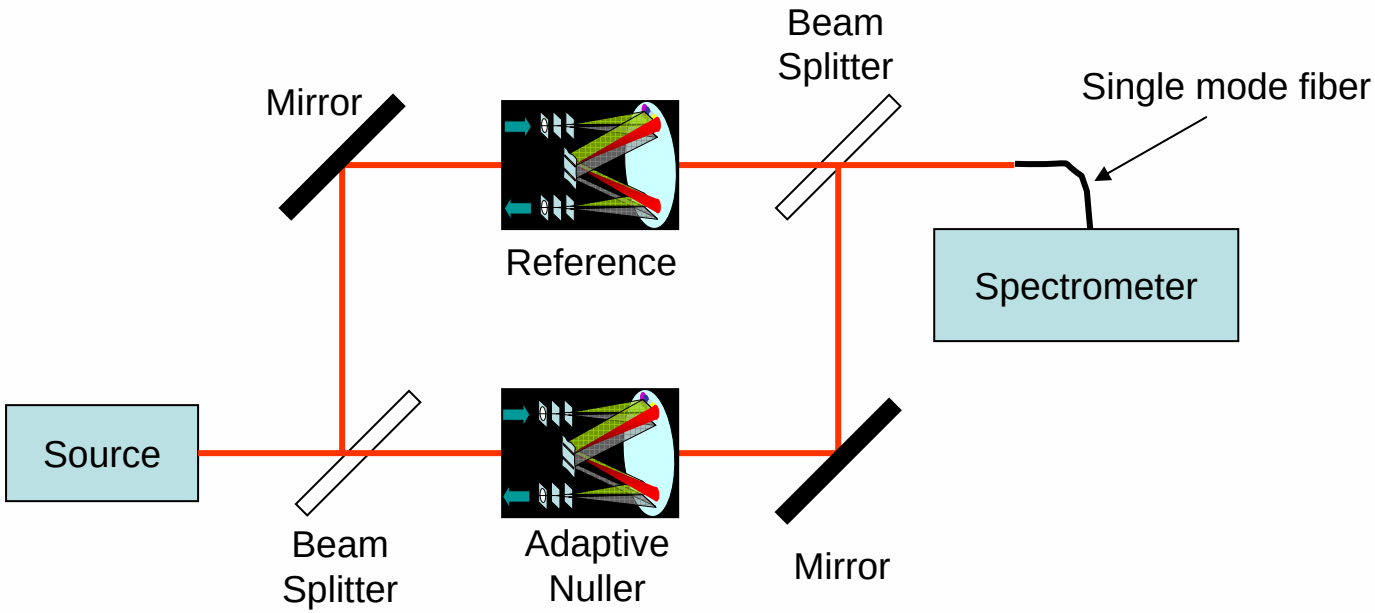
Development activates

- Proof-of-concept experiment (λ = 0.8 to 0.9 μm)
  - Less expensive optics and detectors
  - Relaxed/scaled requirements
  - Demonstrate feasibility of the design
  - Gain experience with the control system
  - Status: Complete – all requirements met/exceeded.
    - Results presented at SPIE 05 Annual Meeting, San Diego.
- Mid-IR experiment (λ = 8 to 12 μm)
  - Requirements traceable to flight needs for phase and intensity control
  - Demonstrate to functionality of the design

Requirements

#	Requirement	mid IR	Flight
1	Wavelength range of operation	8 – 12 µm	7-17µm
2	Metrology wavelength	1.319 µm	0.5 - 2 µm
3	# independent spectral degrees of freedom	> 5	> 5
4	# independent polarization states	1	2
5	Null depth across the band	$< 10^{-5}$	$< 10^{-5}$
6	Amplitude correction range	> 5%	> 5%
7	Amplitude precision / stability (1 σ)	< 0.12%	< 0.1%
8	Phase correction range	> 1 µm	> 2 µm
9	Phase precision / stability (1 σ)	< 5 nm	< 1 nm
10	Throughput reduction	< 50 %	< 50 %
11	Polarization isolation	NA	> 50 dB

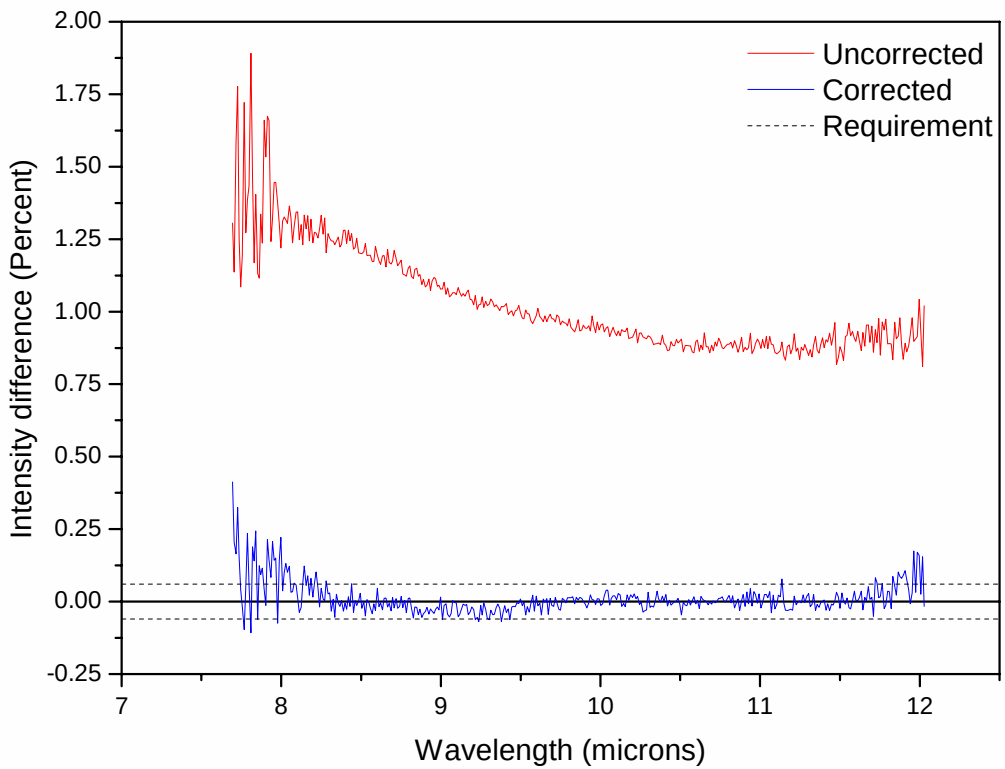
Simplified Experimental Setup



- Mach-Zehnder type interferometer
- Reference is a “fixed” version of the adaptive nuller.
- Laser metrology to maintain a stable difference between the two arms.

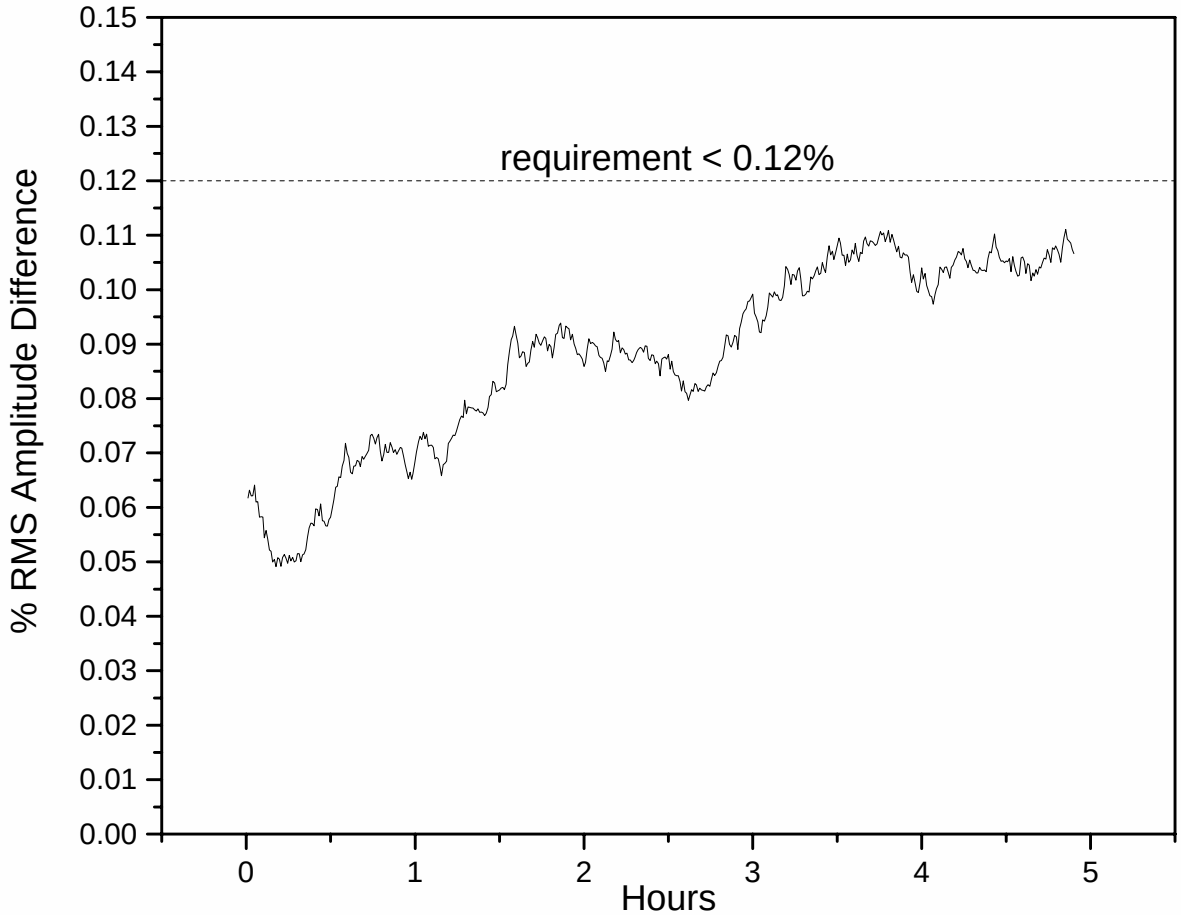
Intensity Correction

- Block each arm and measure the spectrum
- Calculate the difference/sum = % difference
- Positive = more light in the adaptive nuller arm



Intensity Dispersion Stability

- TPF plans to use the adaptive nuller in a “quasi-static” mode.
- Once adjusted, it will need to hold through the measurement without drifting.
- Correction is made once at T=0, RMS of intensity dispersion is measured over time.



Things left to do

- Phase dispersion adjustment.
  - Phase dispersion is measured with spectral fringes
  - Optical path difference needs to be stabilized during spectral measurement.
  - Fine-tuning optical metrology, we expect results soon.
- Cross-coupling effects
  - Intensity causes phase error, and vise versa.
  - Would converge after 4-5 iterations in the near-IR.
- Measure null improvement.
  - Also requires the optical path difference be stabilized during measurement
- Improvements to spectrometer
  - Linear mercury-cadmium-telluride array.
    - Much faster than single pixel scanning spectrometer
  - All reflective optics (Remove germanium lens)
    - More throughput
  - New single mode fiber
    - Even more throughput.

Summary

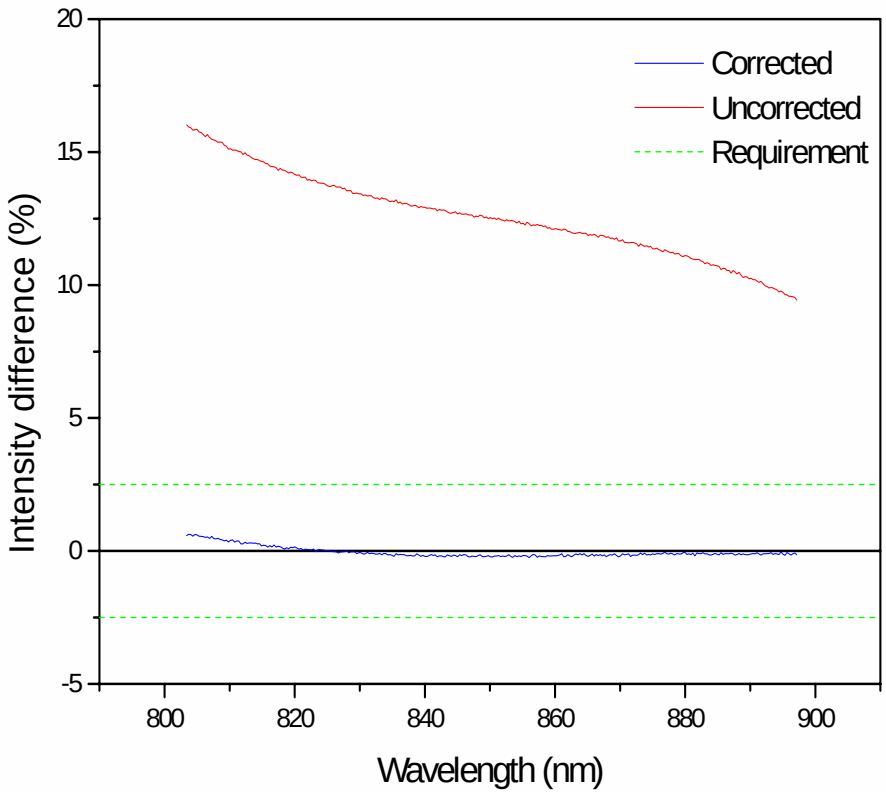
- Adaptive nulling eases requirements on optics and beam combiner
  - Realistic manufacturing tolerances
  - Does not require a highly symmetric beam combiner
- Design for a parallel high-order compensator
  - Based on a deformable mirror actuator
- Mid-IR experiments in progress
  - Intensity correction working well.
  - Metrology to stabilize path for phase correction.
  - Examine the cross-coupling effects, make null measurements.

BACKUP

SLIDES

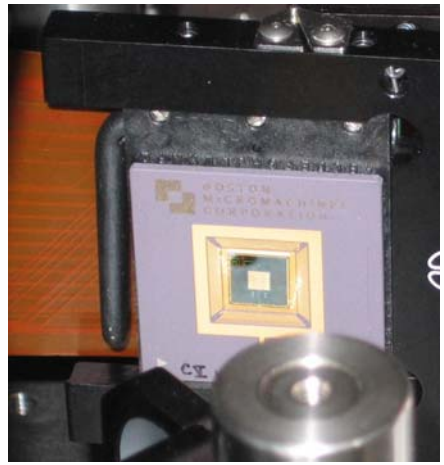
Near-IR Intensity dispersion

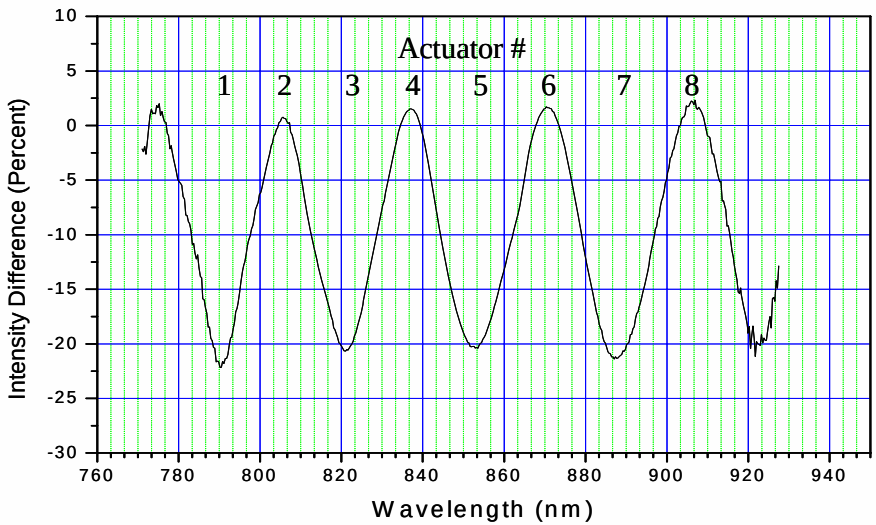
- Due to difference in coated optics.
- Still need to generate intensity dispersion in mid-IR



Deformable Mirror

- MEMS deformable mirror from Boston Micromachines.
- 140 actuators (12x12 – 4 corners)
- 3mm square continuous membrane
- ~1.8µm travel per actuator

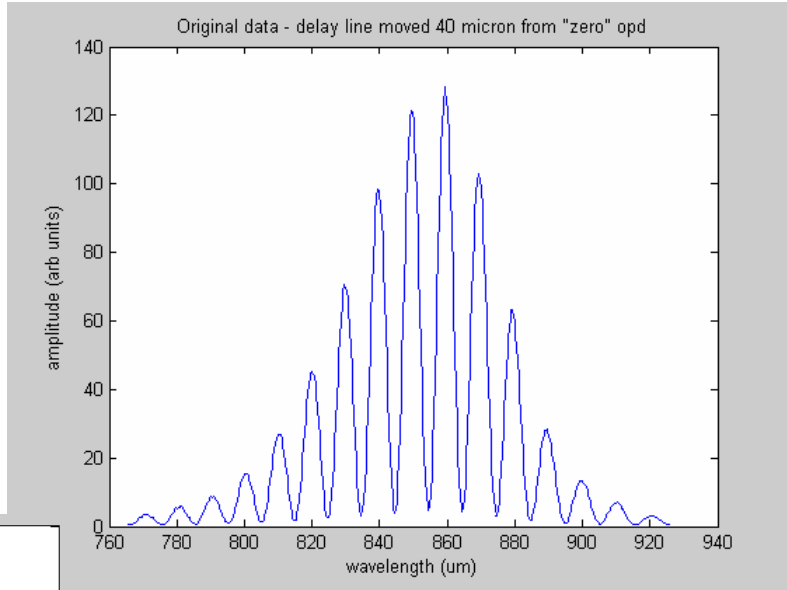


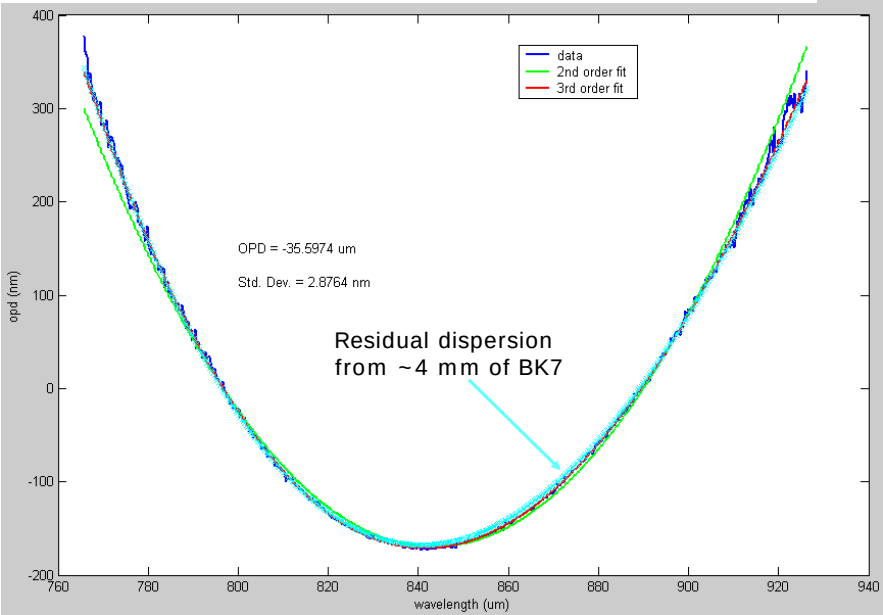


- Tilting every other actuator
- 8 actuators to control the spectrum

Phase Measurement

- Based on a Hilbert transform.
- Measure spectrum with path offset from null
  - Fourier transform
  - Filtering
  - Inverse Fourier transform
  - Remove linear part (OPD)

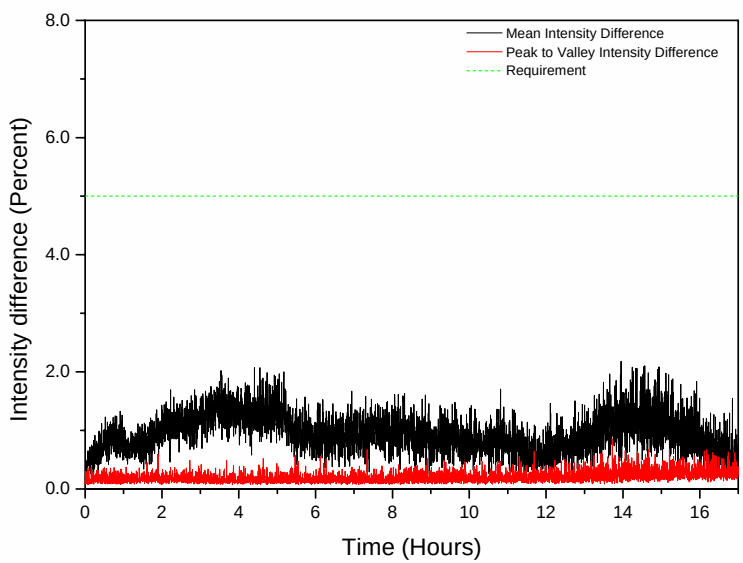


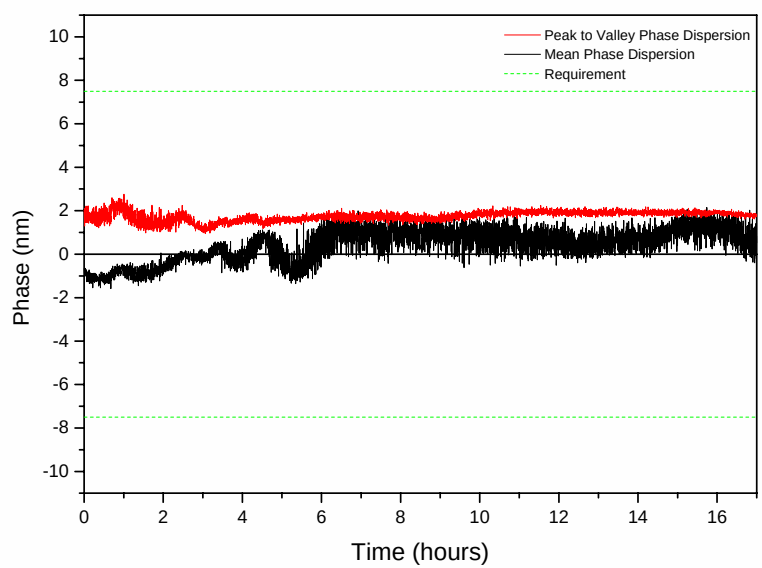


- Final output is residual phase versus wavelength
- Measured residual agreed with calculated residual for a BK7 window in one arm.

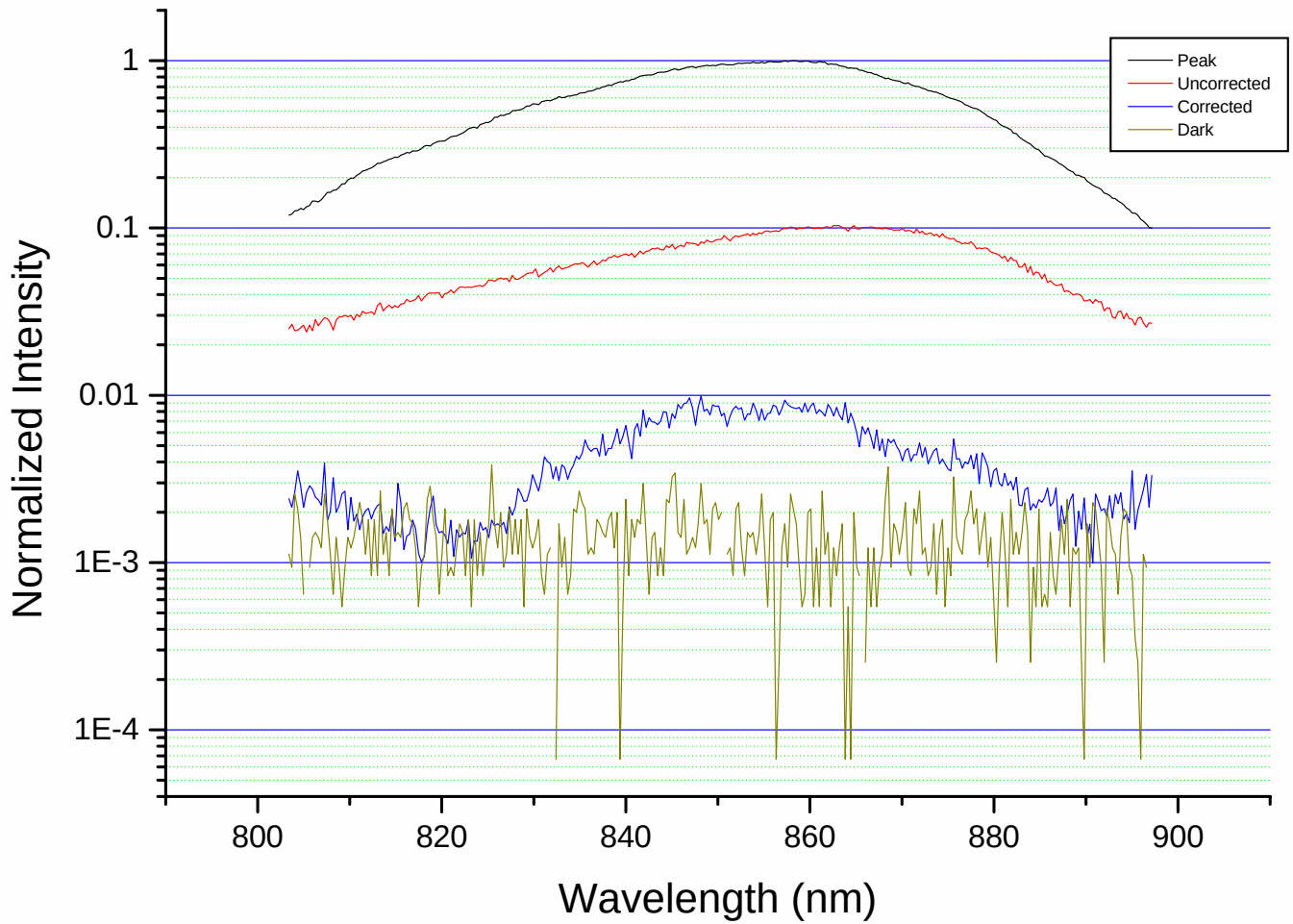
Long term stability – near-IR

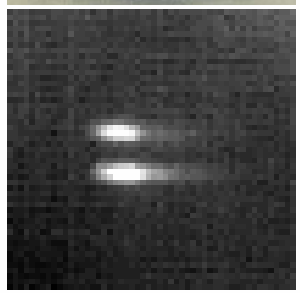
- TPF plans to use the adaptive nuller in a “quasi-static” mode.
- Once adjusted, it will need to hold through the measurement without drifting.
- Mean and peak/valley of each spectral measurement is plotted over time to show stability.





Null Improvement – near-IR



Mid-IR components

- Using ceramic heater as source
- Transmissive optics replaced with appropriate materials (ZnSe)
- Wollaston prism tested separately.
  - CdSe is the only birefringent material
  - Manufactured by Cleveland Crystals
  - Cost ~ $27k each.
  - Test sample had good agreement with our Zemax model.
- Built a mid-IR spectrometer
  - Grating and single pixel mercury cadmium telluride detector on a computer controlled translation stage