Adaptive nulling with a deformable mirror in the near-IR

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Outline

- Nulling background and adaptive nuller design
- Near-IR proof of concept experiment
- Results
- Future work and summary

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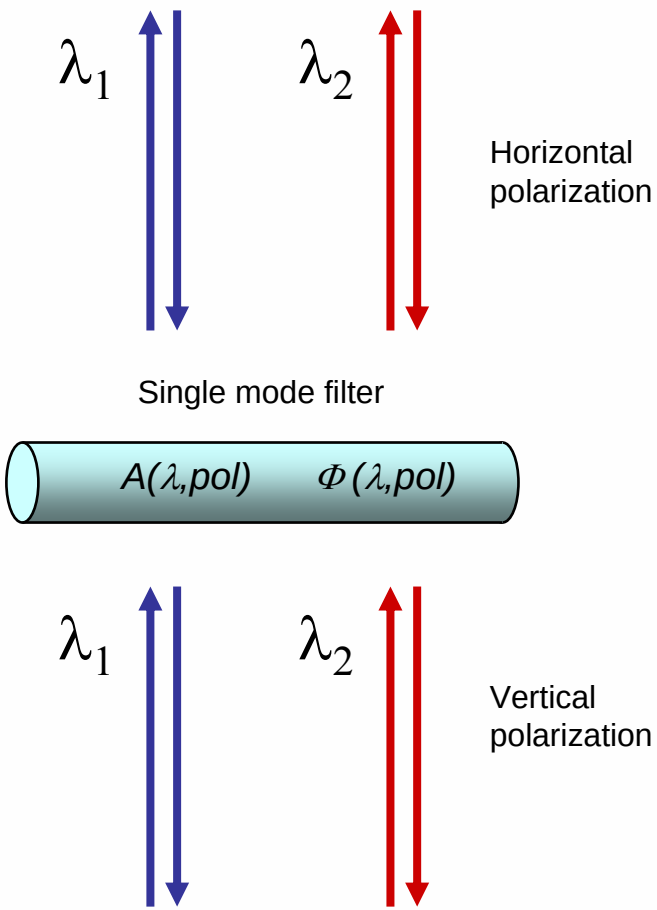
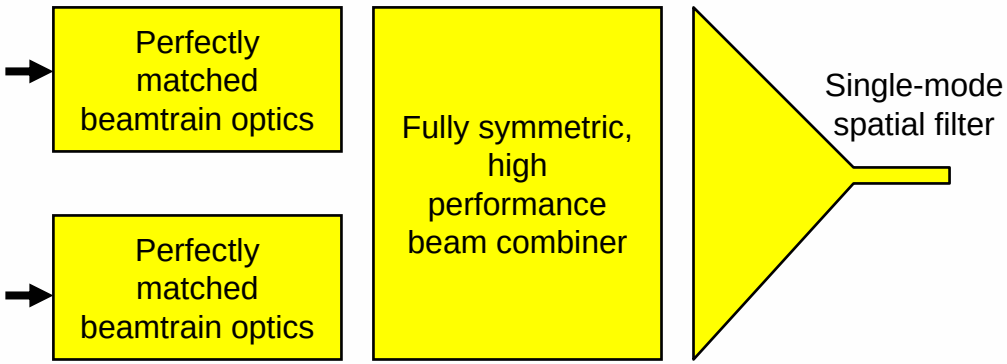
Nulling in TPF-I

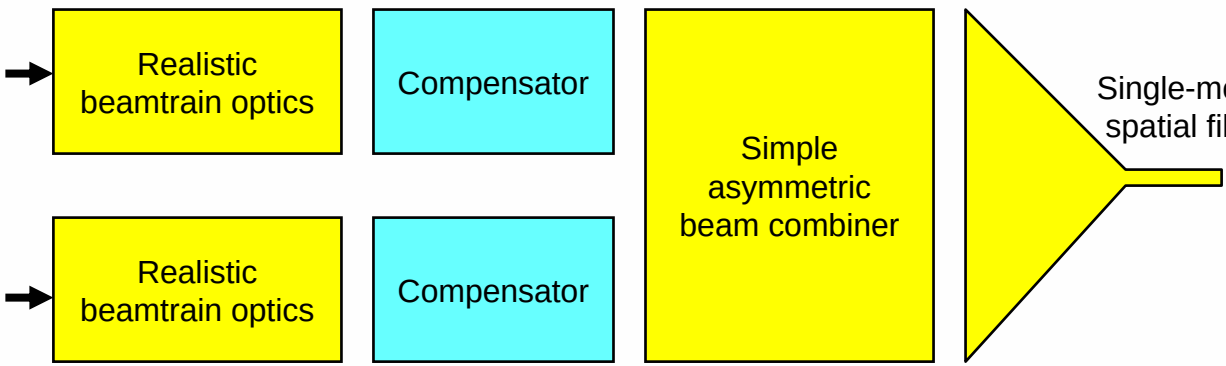


- For deep null require electric fields with
  - equal amplitudes
  - opposite phases
- simultaneously at each wavelength and polarization
- Single-mode filter makes it this simple (removes all spatial effects)

Why Do Adaptive Nulling



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



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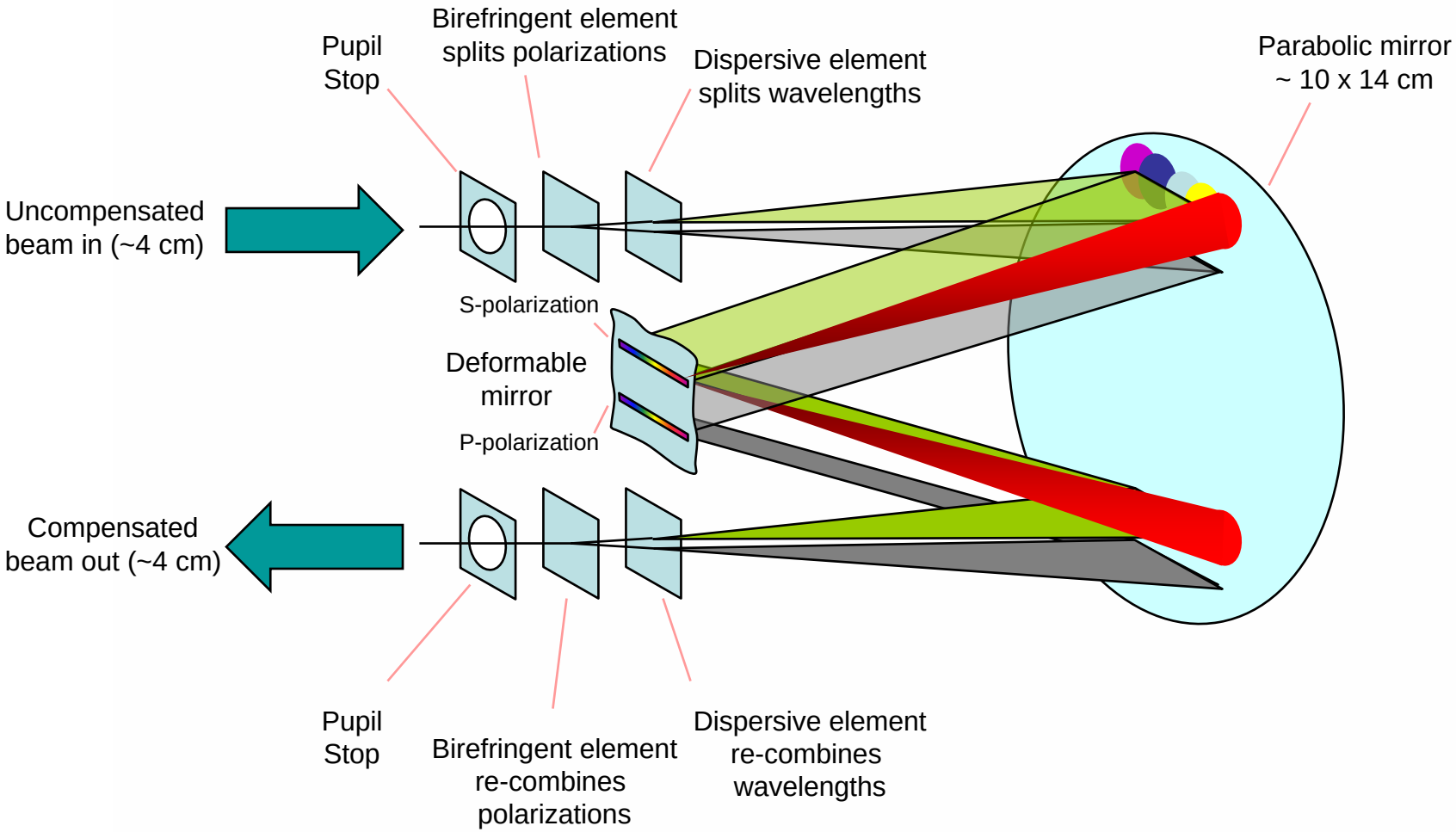
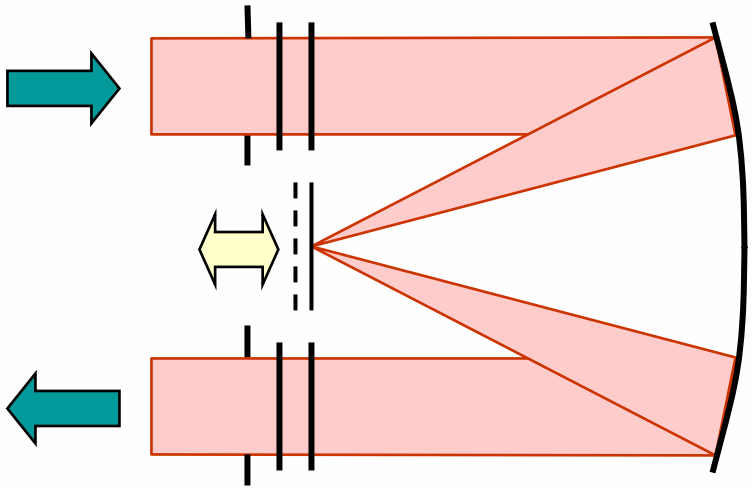
Parallel high-order compensator design

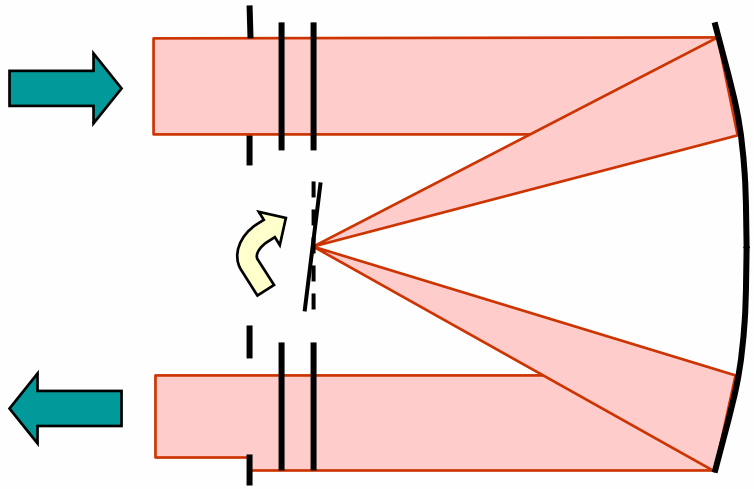


Phase and Amplitude Control

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 to be done in the near-IR ($\lambda < 1\mu m$, 100 nm bandwidth)
  - Less expensive optics and detectors
  - Relaxed/scaled requirements
  - Demonstrate feasibility of the design
  - Gain experience with the control system
- Transition to the mid-IR ($\lambda = 8$ to 12 µm)
  - Requirements traceable to flight needs for phase and intensity control
  - Demonstrate to functionality of the design

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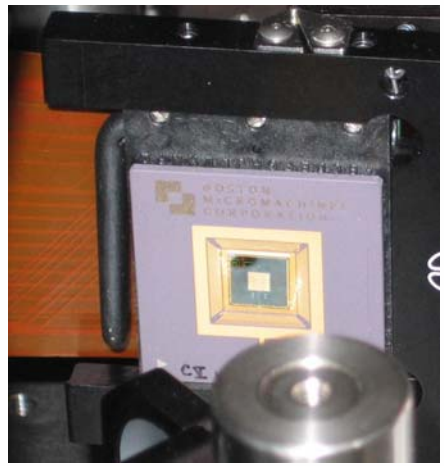
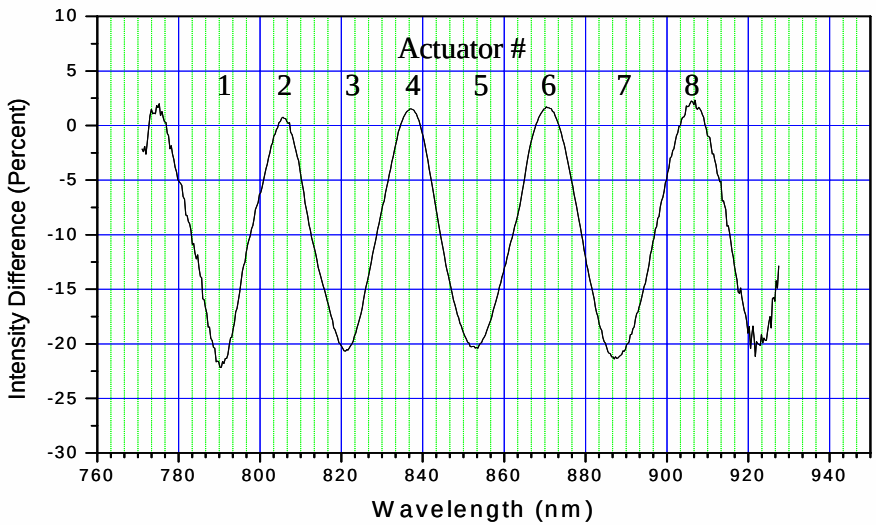
Experimental Setup

TPF Terrestrial Planet Finder Interferometer

Deformable Mirror

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

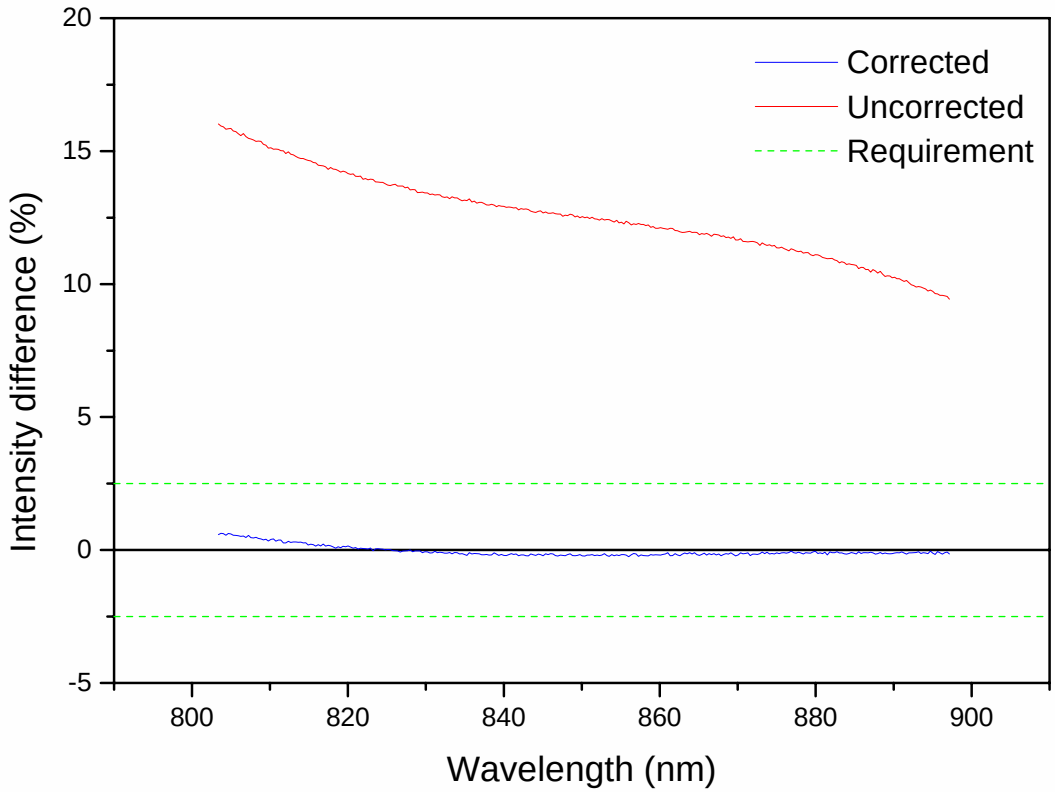




- Tilting every other actuator
- 8 actuators to control the spectrum

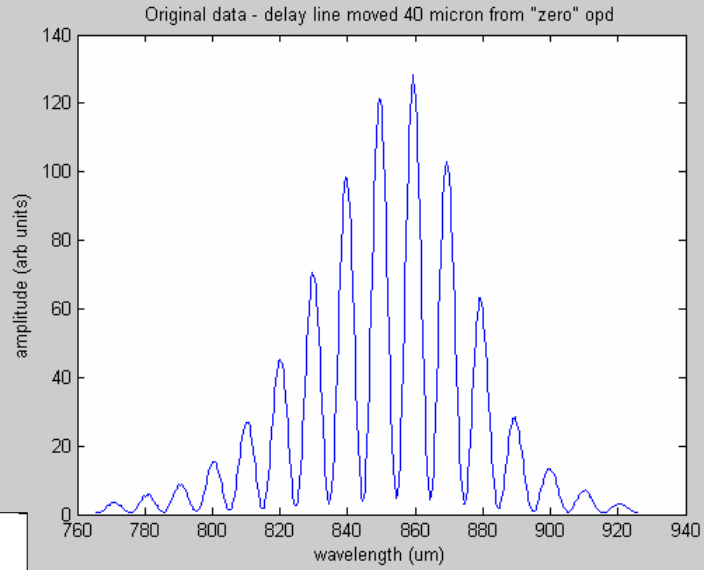
Correction of intensity

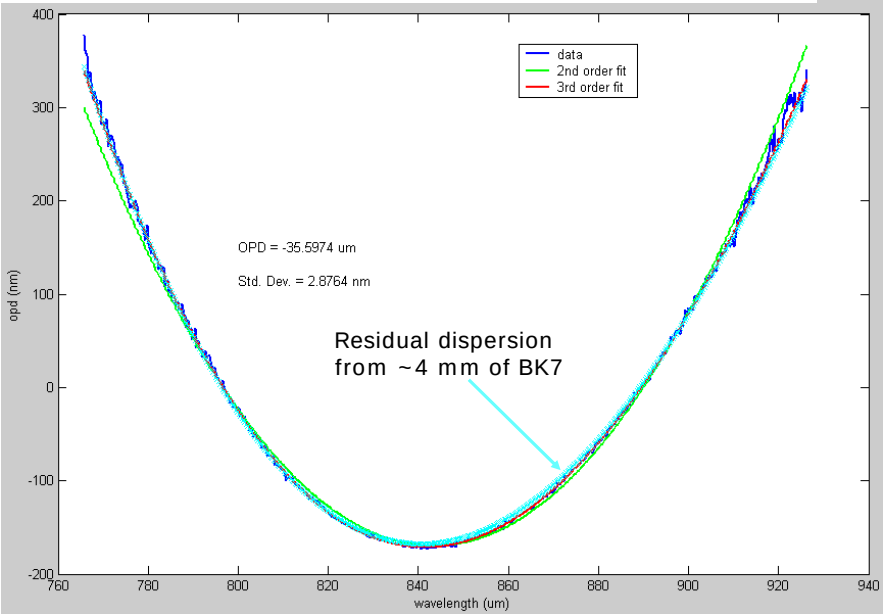
- Shutter off each beam separately, then calculate the difference over the sum.



Phase Measurement

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

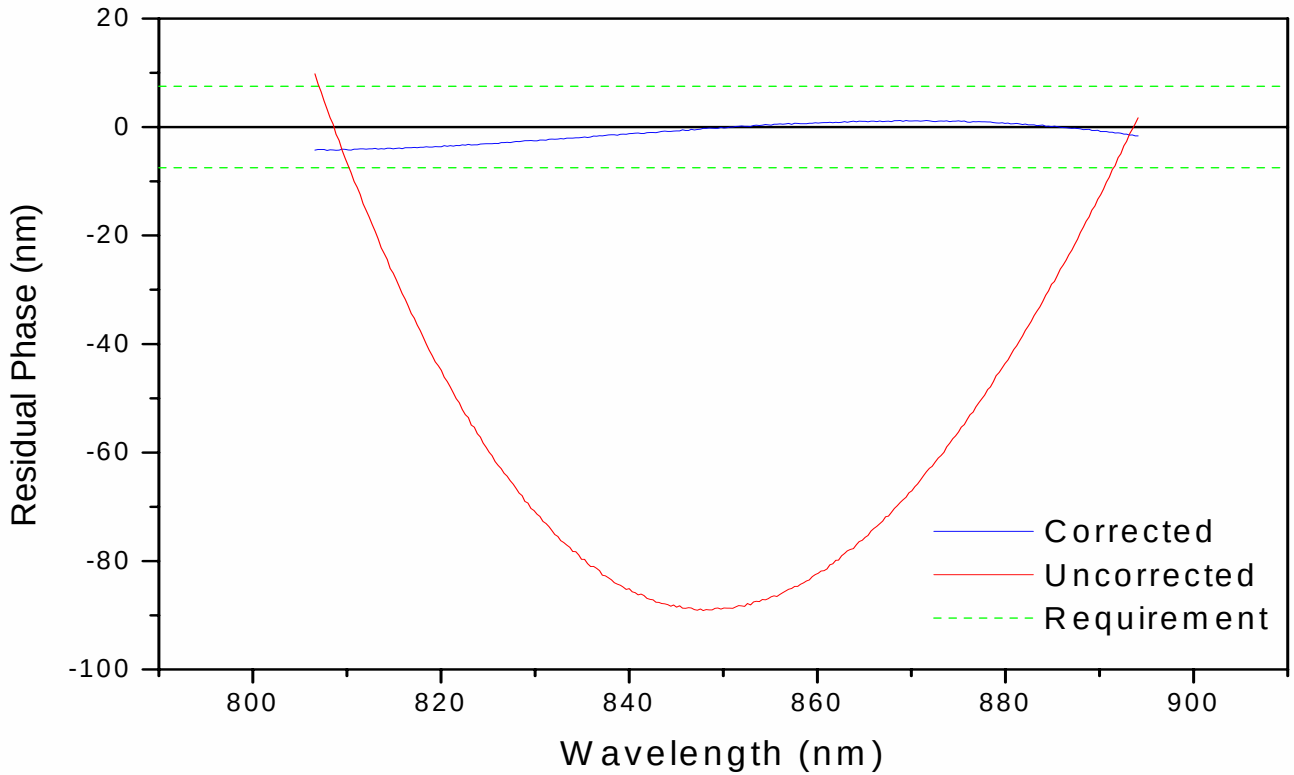




- Final output is residual phase versus wavelength
- Measured residual agreed with calculated residual for a BK7 window in one arm.

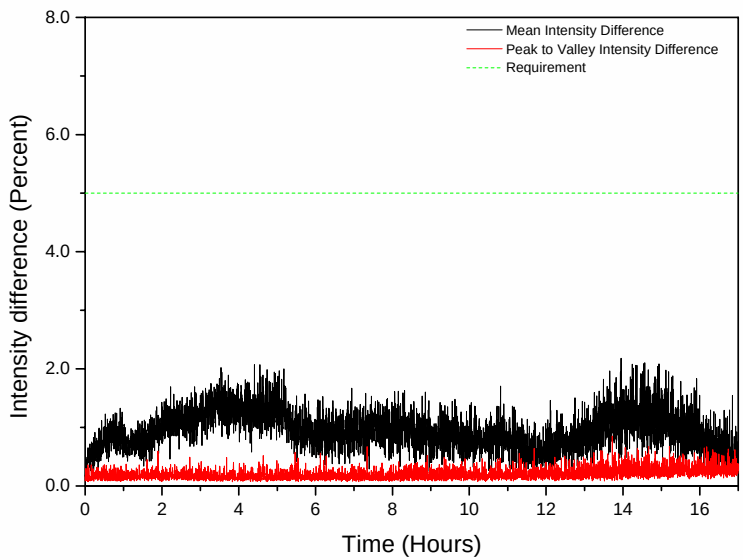
Correction of phase

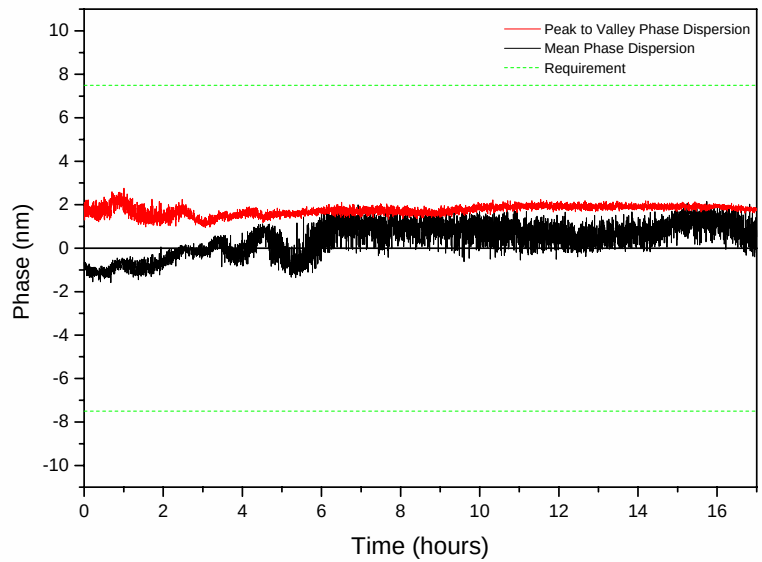
- Appropriate actuators are adjusted with piston to zero the residual phase.
- Cross-coupling between amplitude and phase converged after 3-5 iterations.



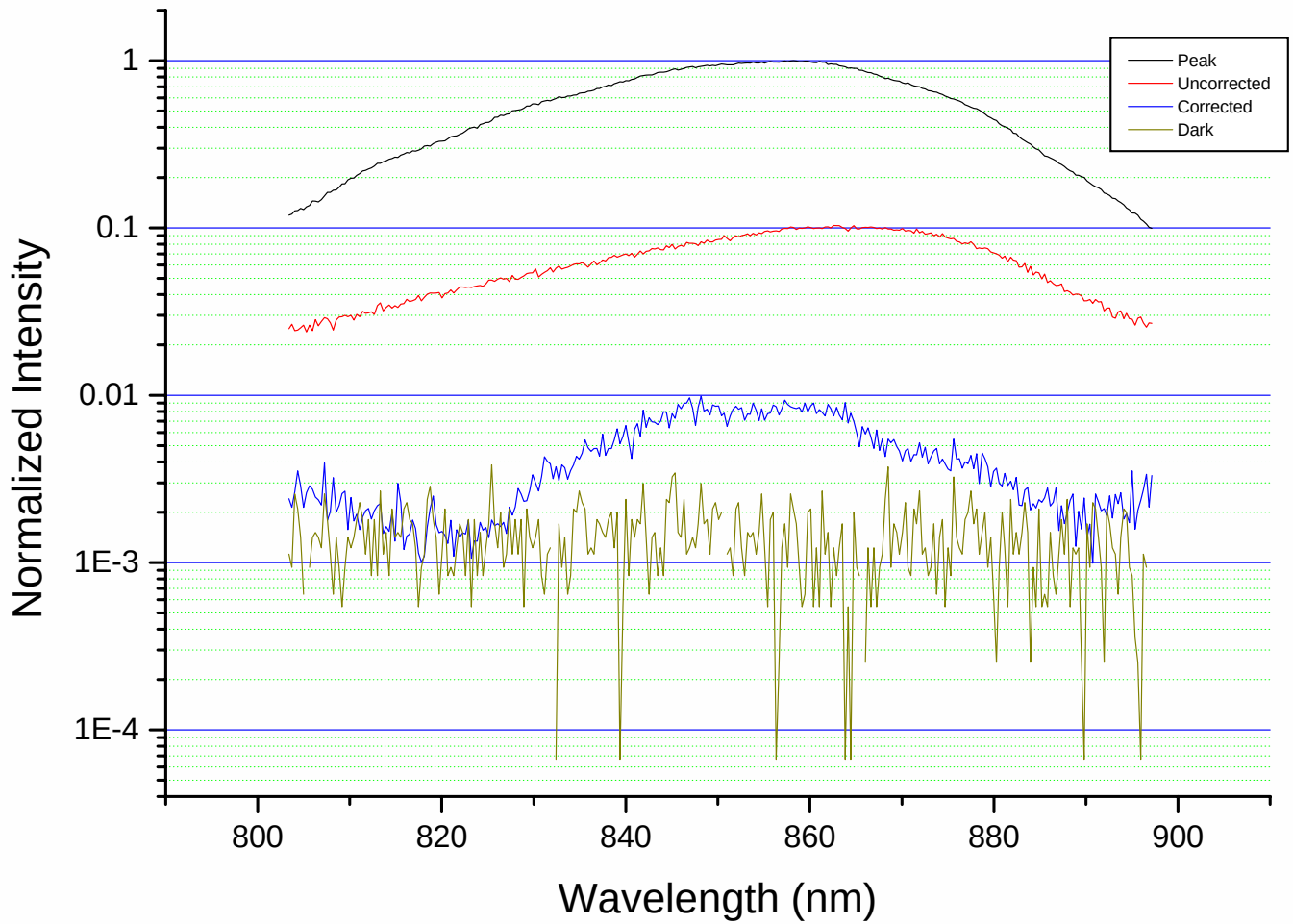
Long term stability

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



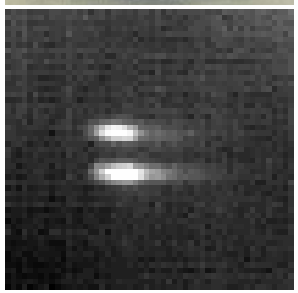


Null Improvement



Transition to mid-IR

- 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.
- Scheduled to be completed May, 06.



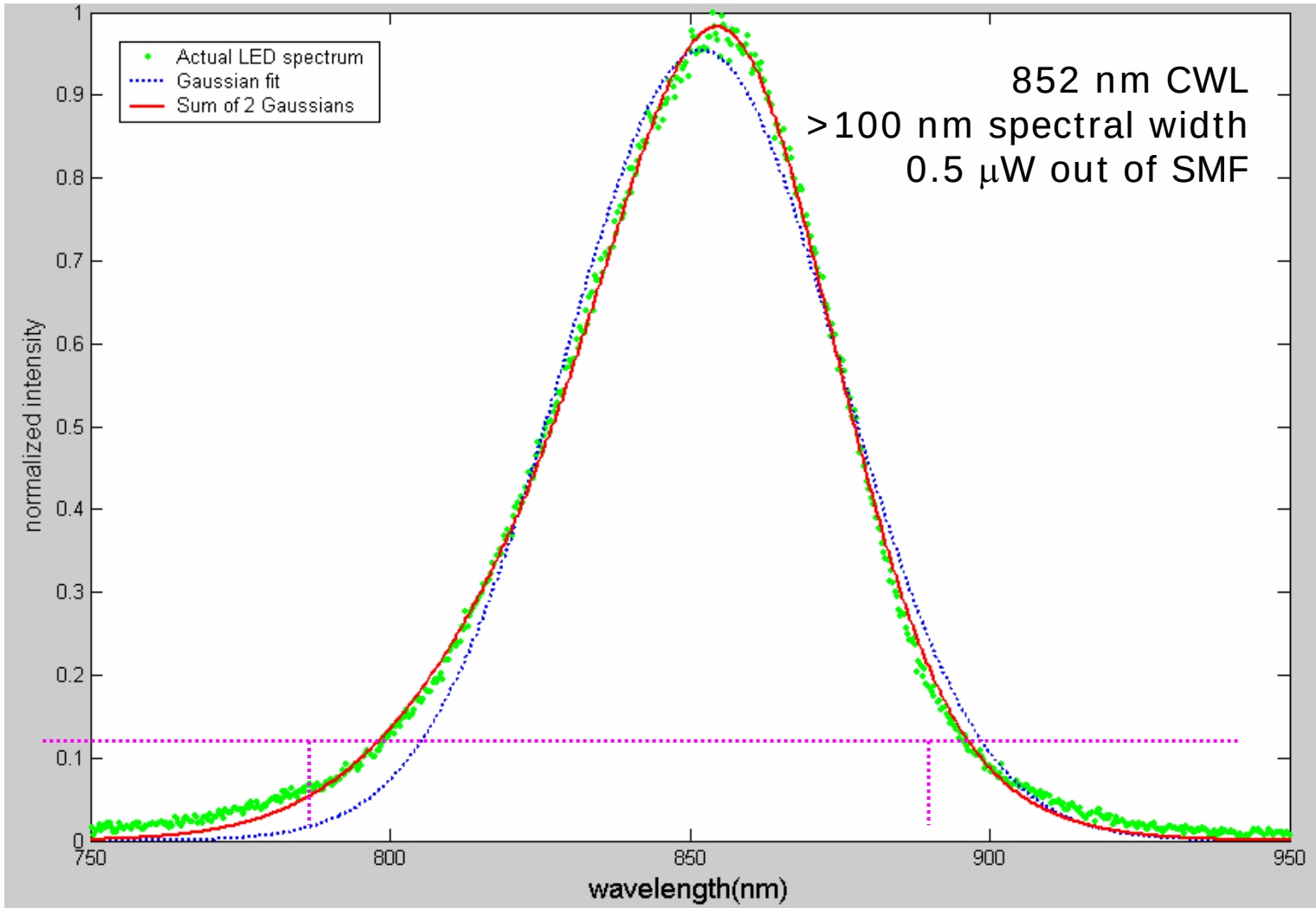
Summary

- 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
  - Tested in the near-IR
  - Met or exceeded all requirements
- Mid-IR transition in progress
  - To be completed in spring of 06

BACKUP

SLIDES

LED as WLS


Actual LED spectrum
Gaussian fit
Sum of 2 Gaussians
852 nm CWL
>100 nm spectral width
0.5 μW out of SMF
normalized intensity
wavelength(nm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
750
800
850
900
950