Beam Shaping for Relay Mirrors

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Outline

- Introduction
  - Atmospheric Propagation Modeling
- Beam Shaping Modeling
  - Vacuum and through the Atmosphere
  - Effect on Beam Quality & Solution
- Implementation with AO
- Conclusions

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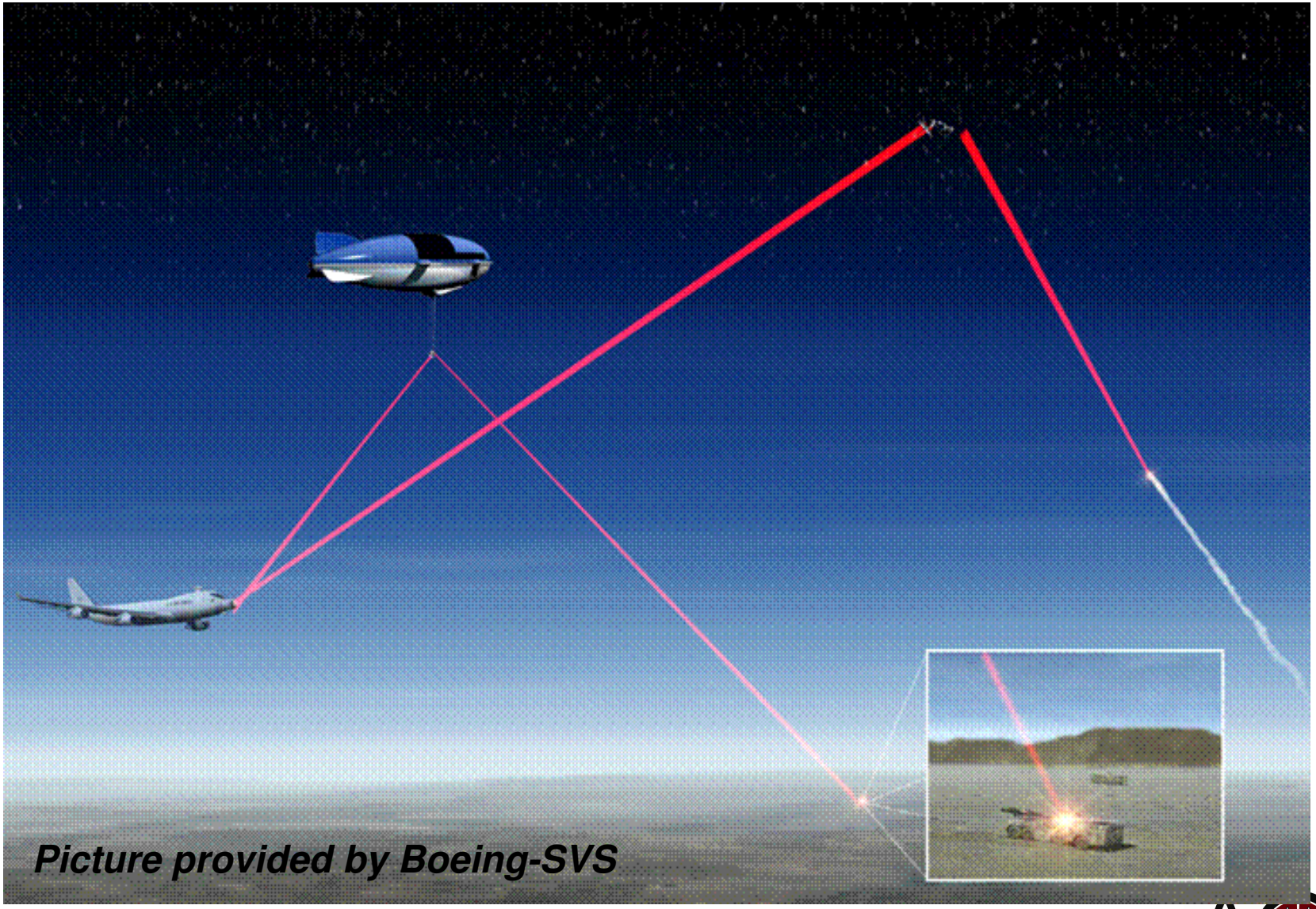
Relay Mirror Application



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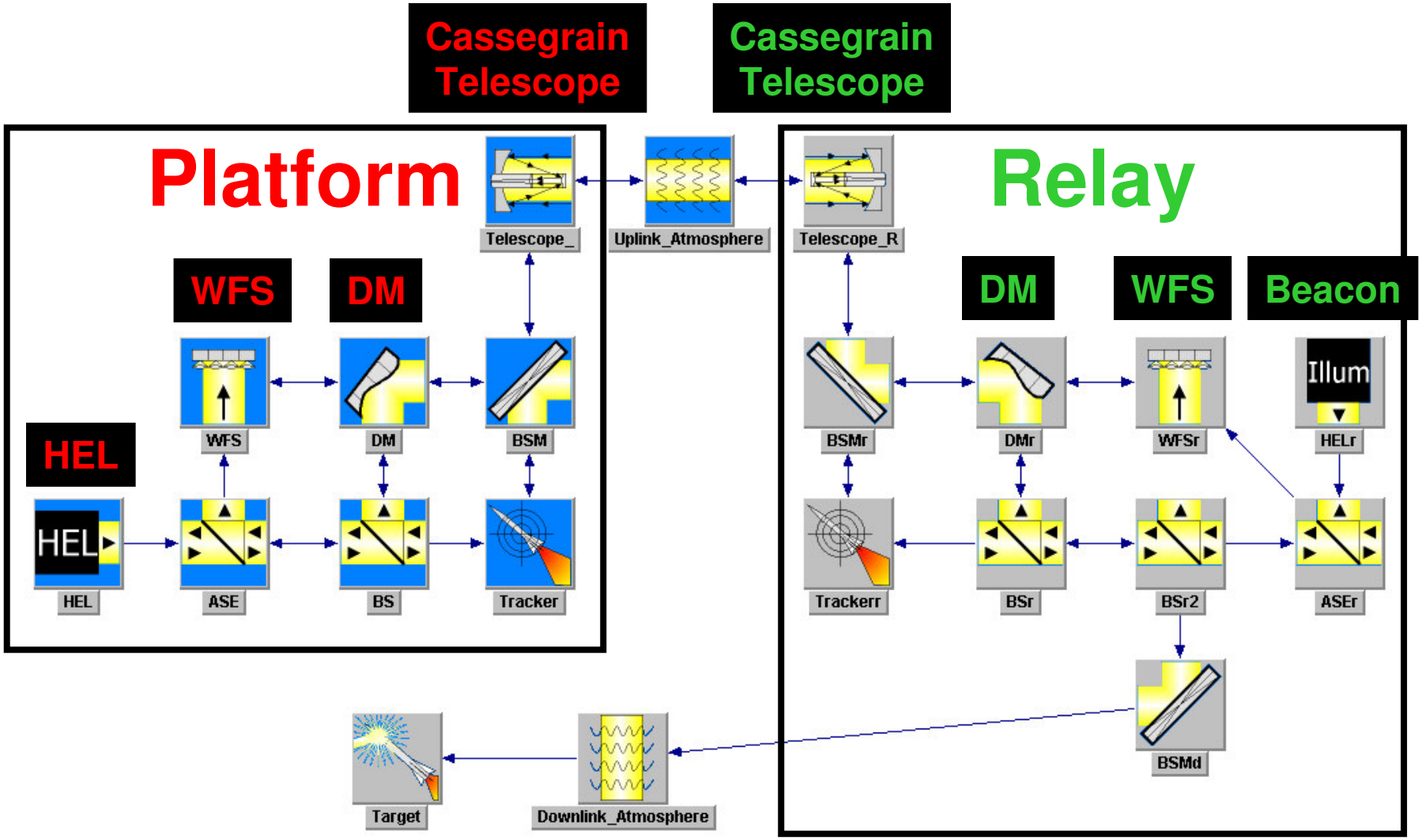
Typical Relay Mirror Optical System



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Model Setup

- Telescope Diameter = 1.5 m
- Central Obscuration Diameter = 0.3 m
- Wavelength (λ) = 1315 nm
- Distance Range = 50km to 400km
  - Fresnel Number ($r^2/\lambda z$) = {8.5 to 1.1}
- Atmospheric Parameters
  - Platform at 12 km altitude (sea level)
  - Relay at 21 km altitude (sea level)
  - Clear1 atmosphere (factor=1)
  - 5 phase screens
  - Low Order Correction turned on
  - 50 random realizations
- Error bars are one standard deviation

Unless otherwise specified, these system parameters were used throughout.

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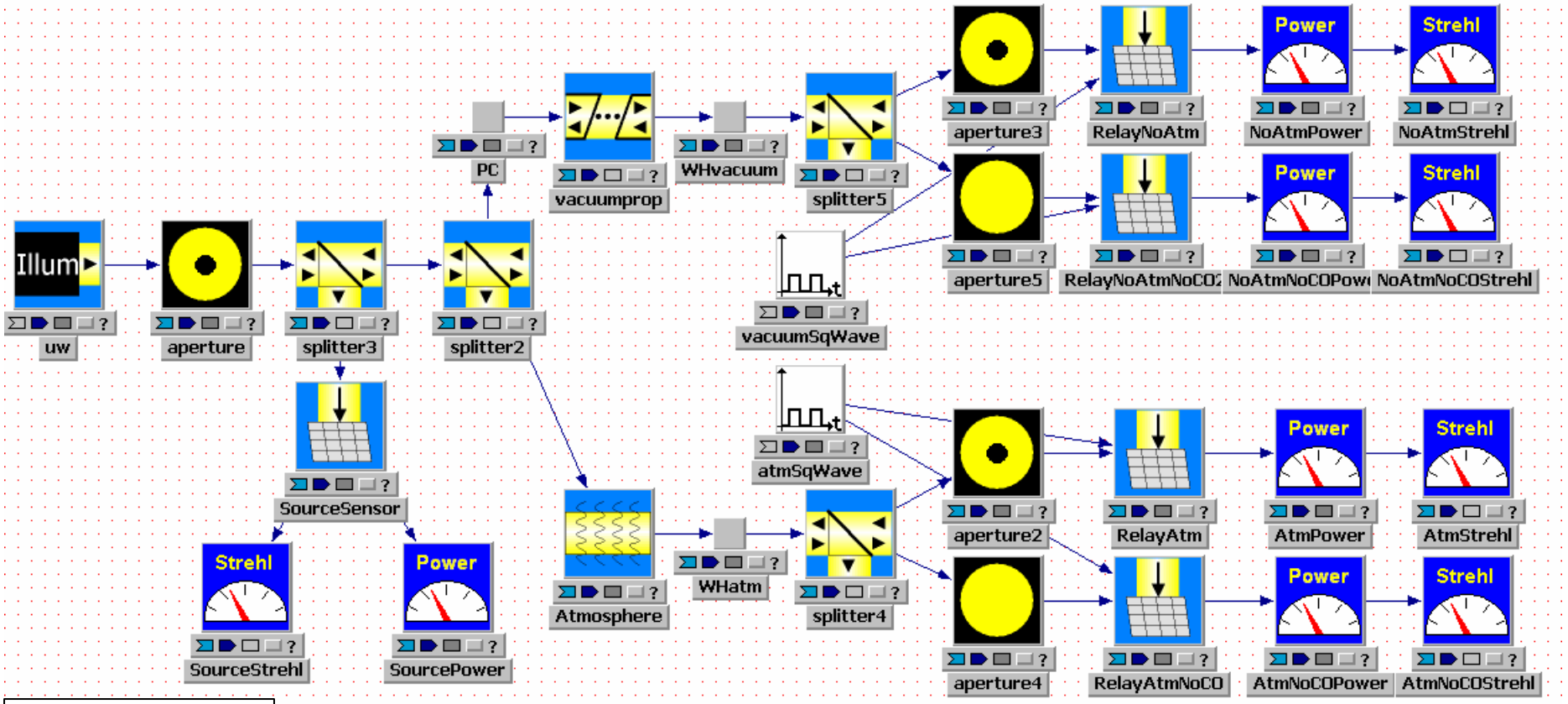
Relay through Vacuum & Atmosphere



WaveTrain
wave optics made easyier

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WaveTrain and tempus

- tempus
  - General Purpose Time-Domain Component-Based Modeling Tool
- WaveTrain
  - Wave-Optics Modeling Tool Based on tempus
- Both are FREE for government work
- WaveTrain is becoming the industry standard for wave-optics modeling
  - It is being used by almost every major government contractor
  - Many of these contractors have contributed to the development of WaveTrain
- An investment in WaveTrain or tempus is not lost because for government use they are:
  - open-source & non-proprietary
- tempus can work with existing modeling software.
  - no duplication of effort or need to learn too much new software

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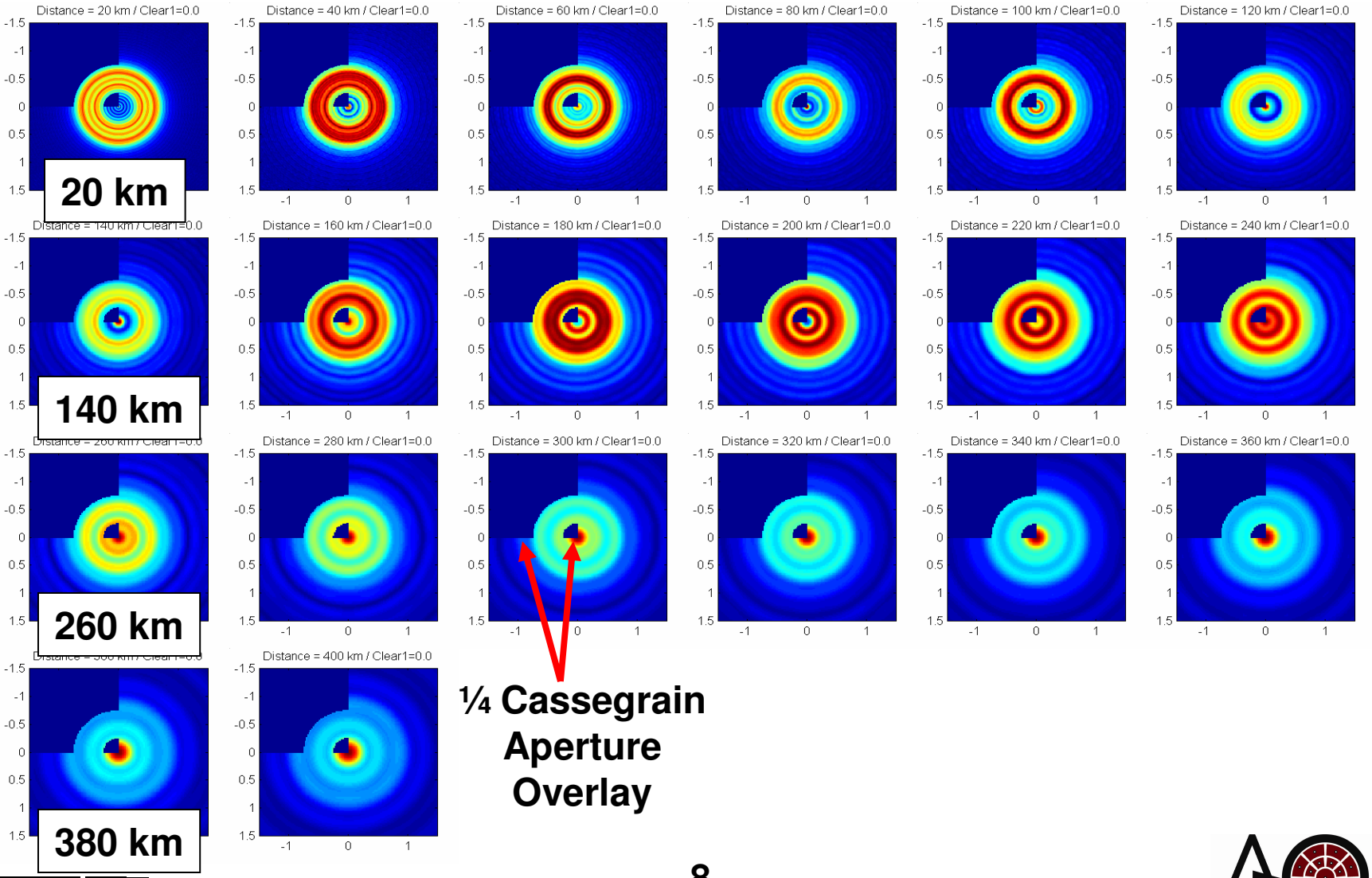
Propagation without Turbulence



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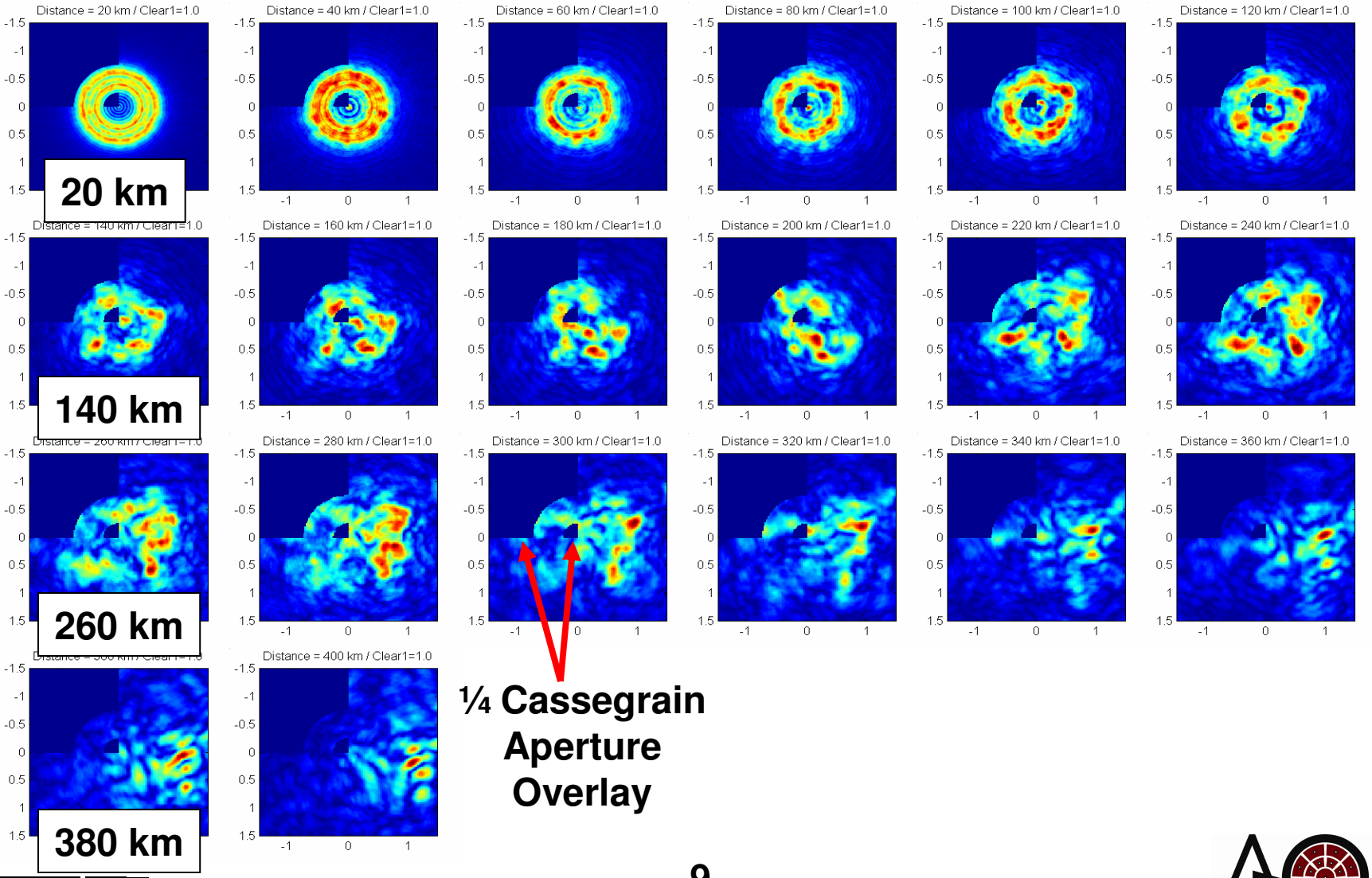
Propagation with Turbulence



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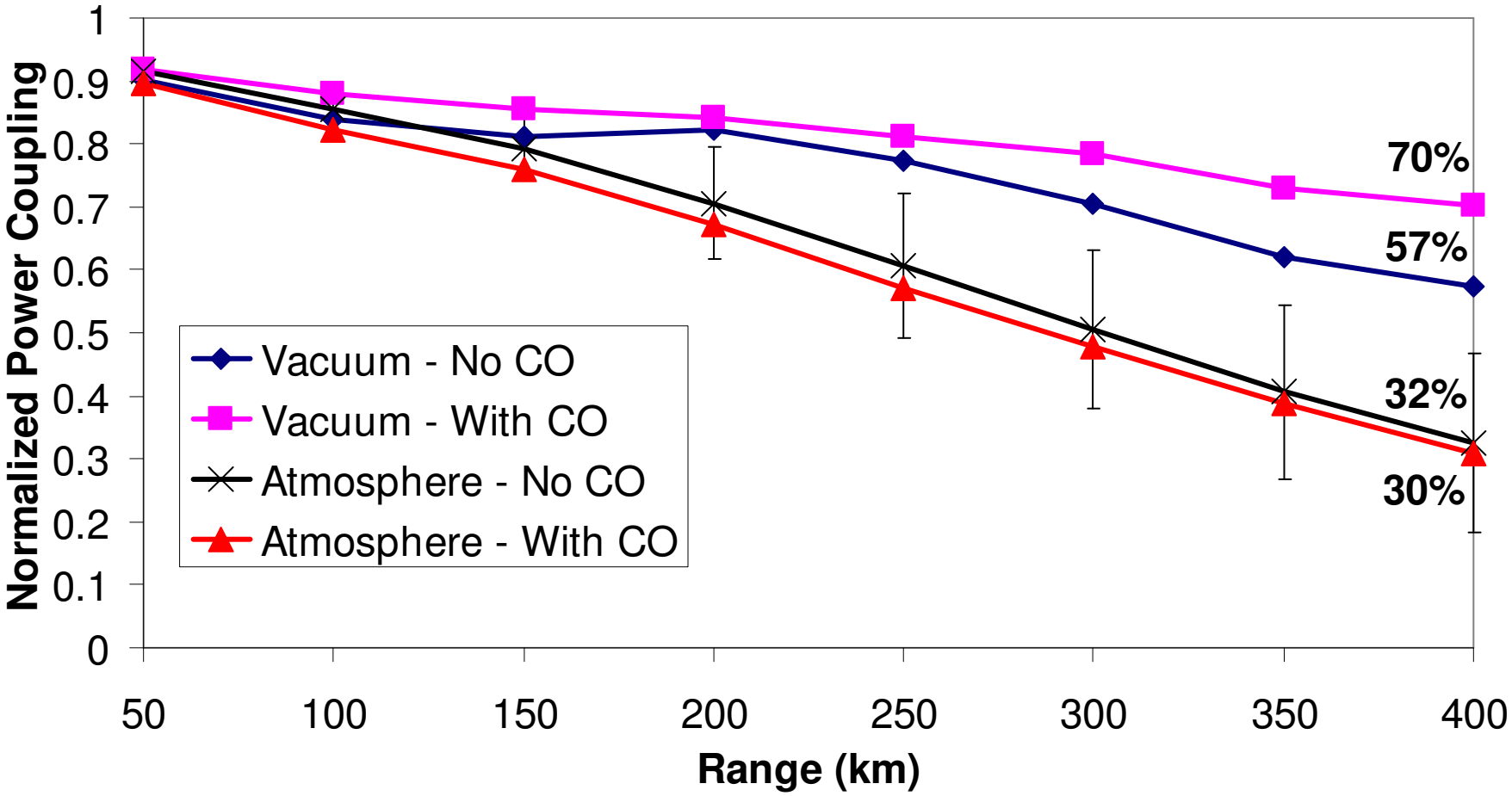
Relay Modeling Results



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Goals

- Show that beam shaping causes better power coupling and
  - does not significantly deteriorate beam quality
  - can be done in the atmospheric path
  - does not require any additional parts

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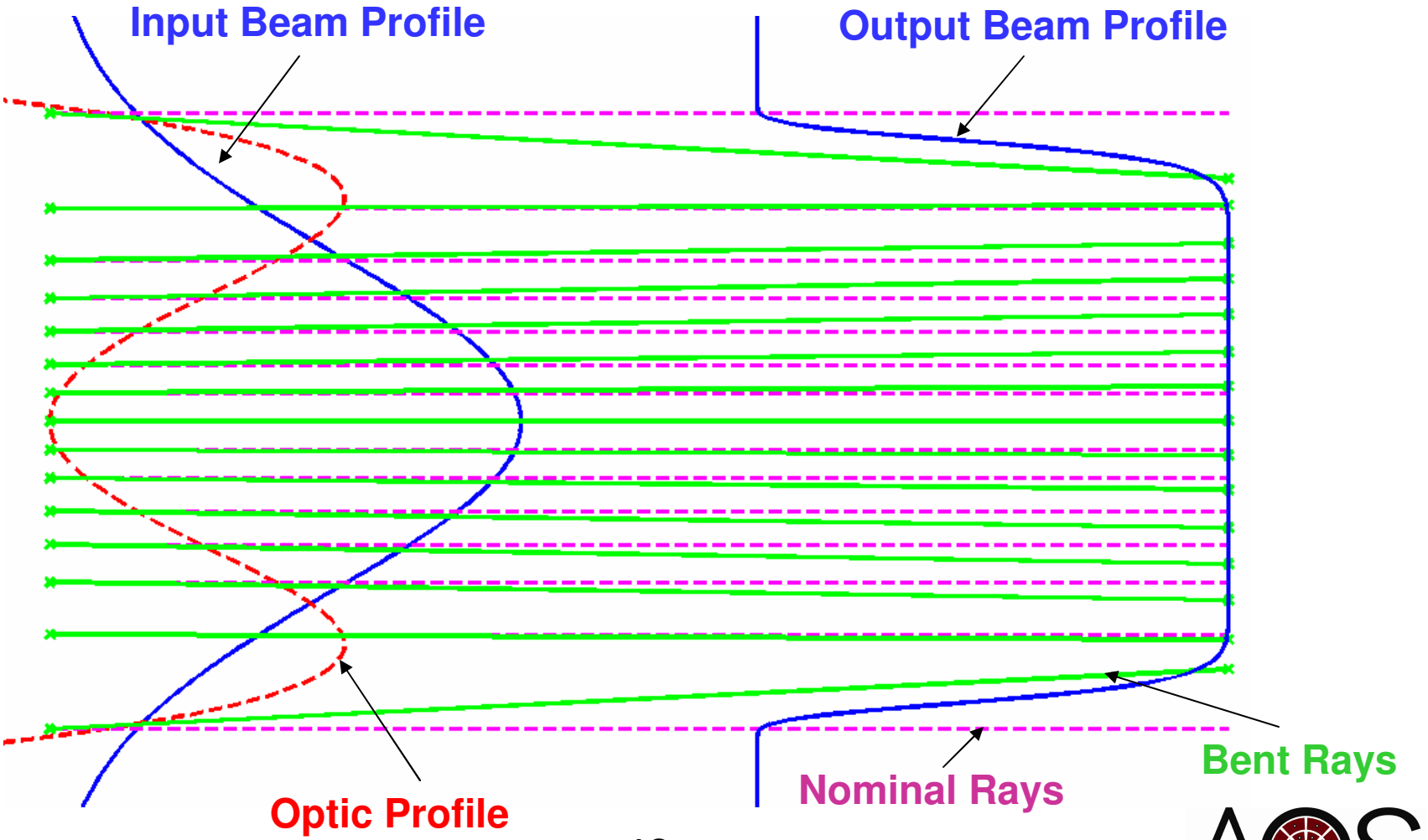
Beam Shaping Concept



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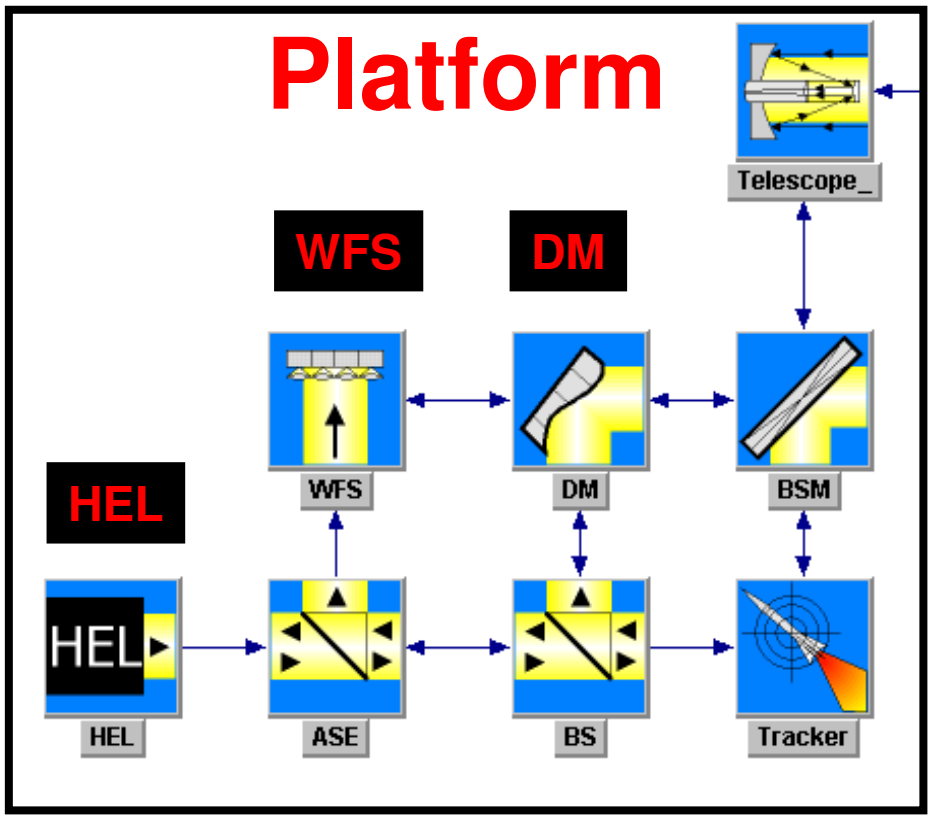
Potential Solution

- Virtually all HEL platforms contain an AO system
- The deformable mirror (DM) in the AO system could be used to apply a phase profile to shape the beam if
  - The amplitude is small
  - The aberration is low spatial frequency
  - The aberration does not significantly reduce beam quality



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Wave-Optics Modeling

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Beam Shaping Implementations

- Iterative Fourier Transform
  - Gerchberg-Saxon
- Searching with a DM
  - GESA and SPGD
- Searching about a basis set
  - Zernikes
  - Radial Polynomials

$$\sum_{i=1}^{n} a_i \left| r \right|^i$$

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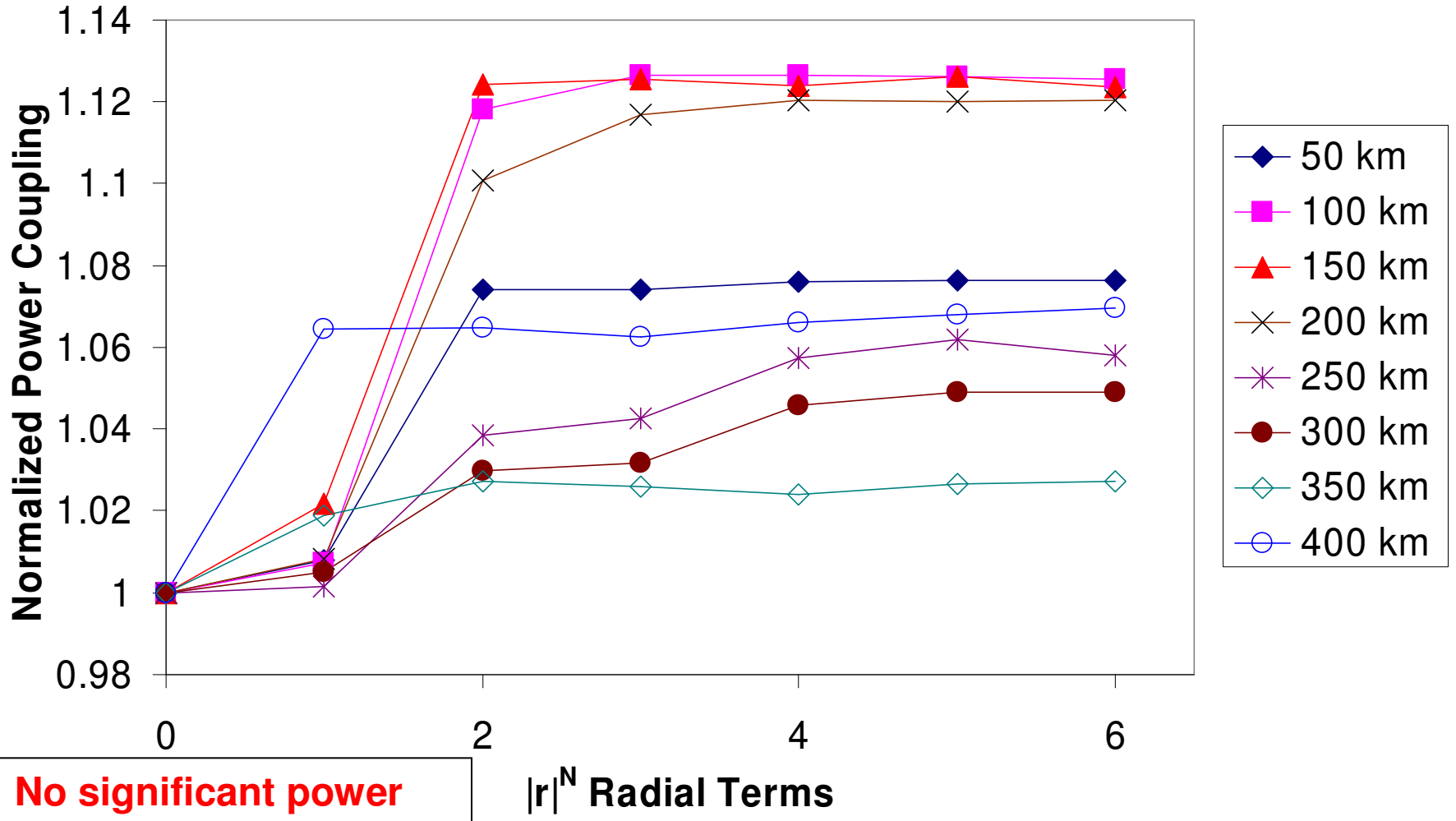
Adding Radial Terms



No significant power increase beyond 4th order

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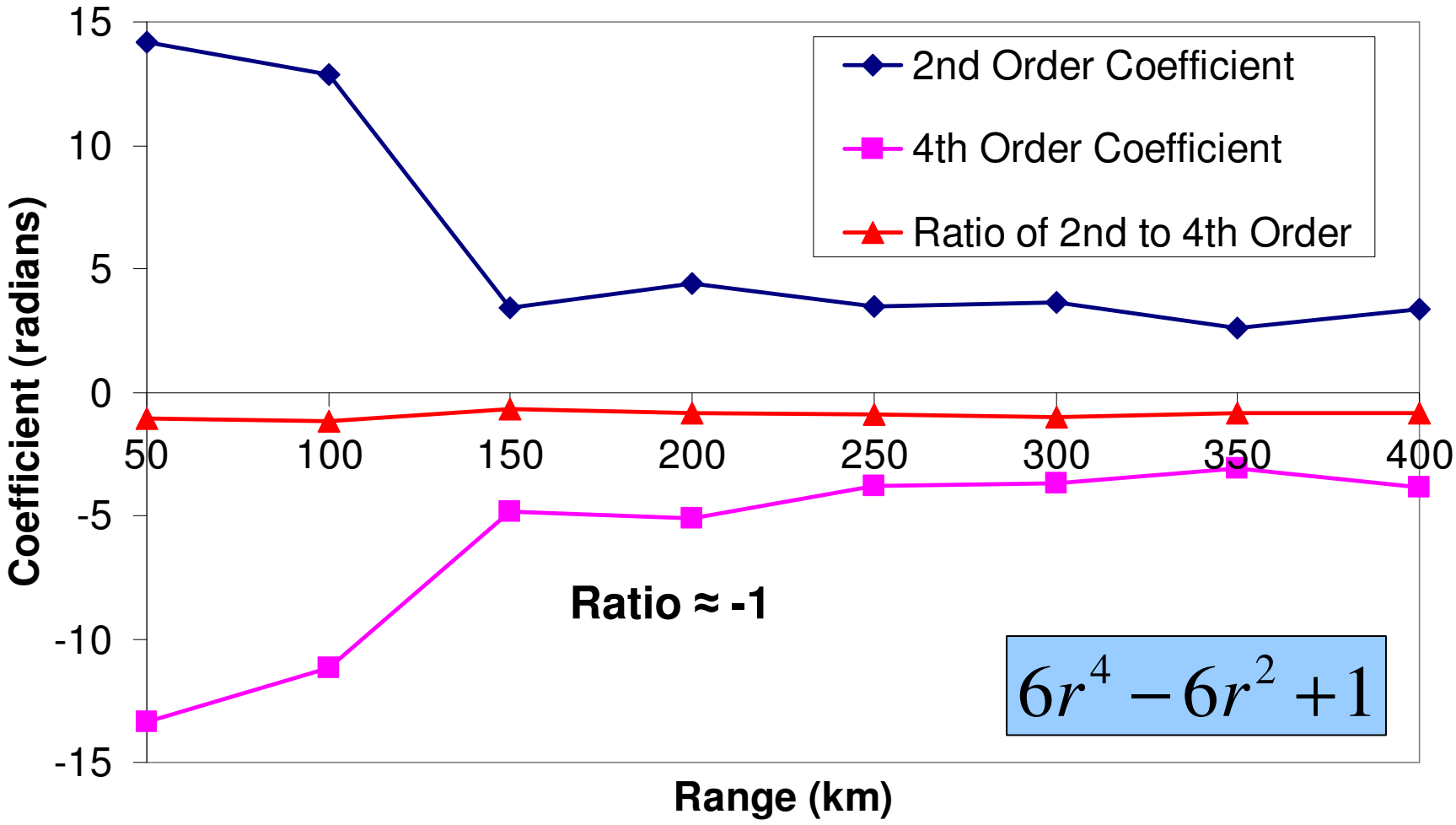
2nd and 4th Order Terms Only



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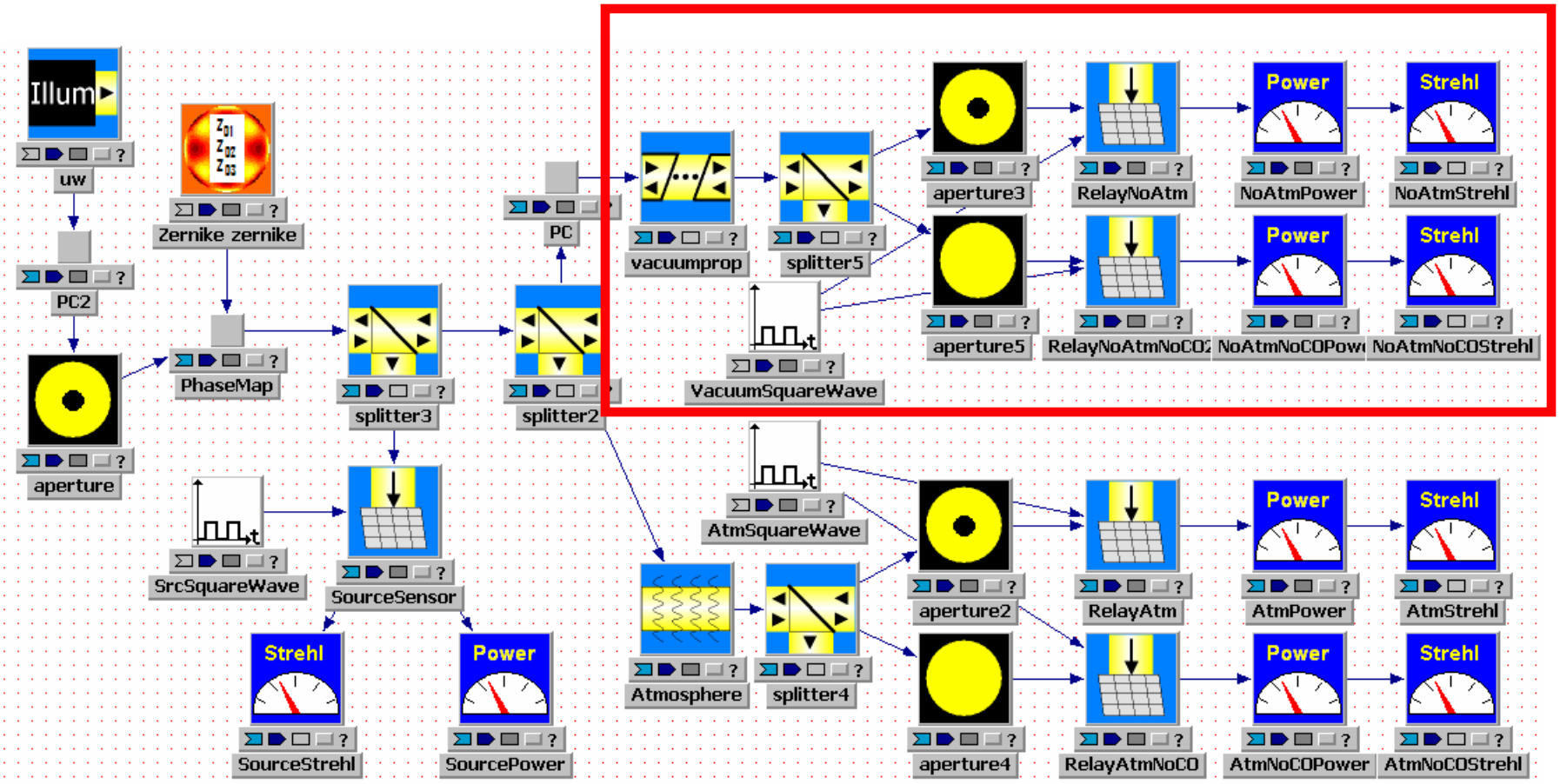
Optimizing Spherical Aberration in Vacuum



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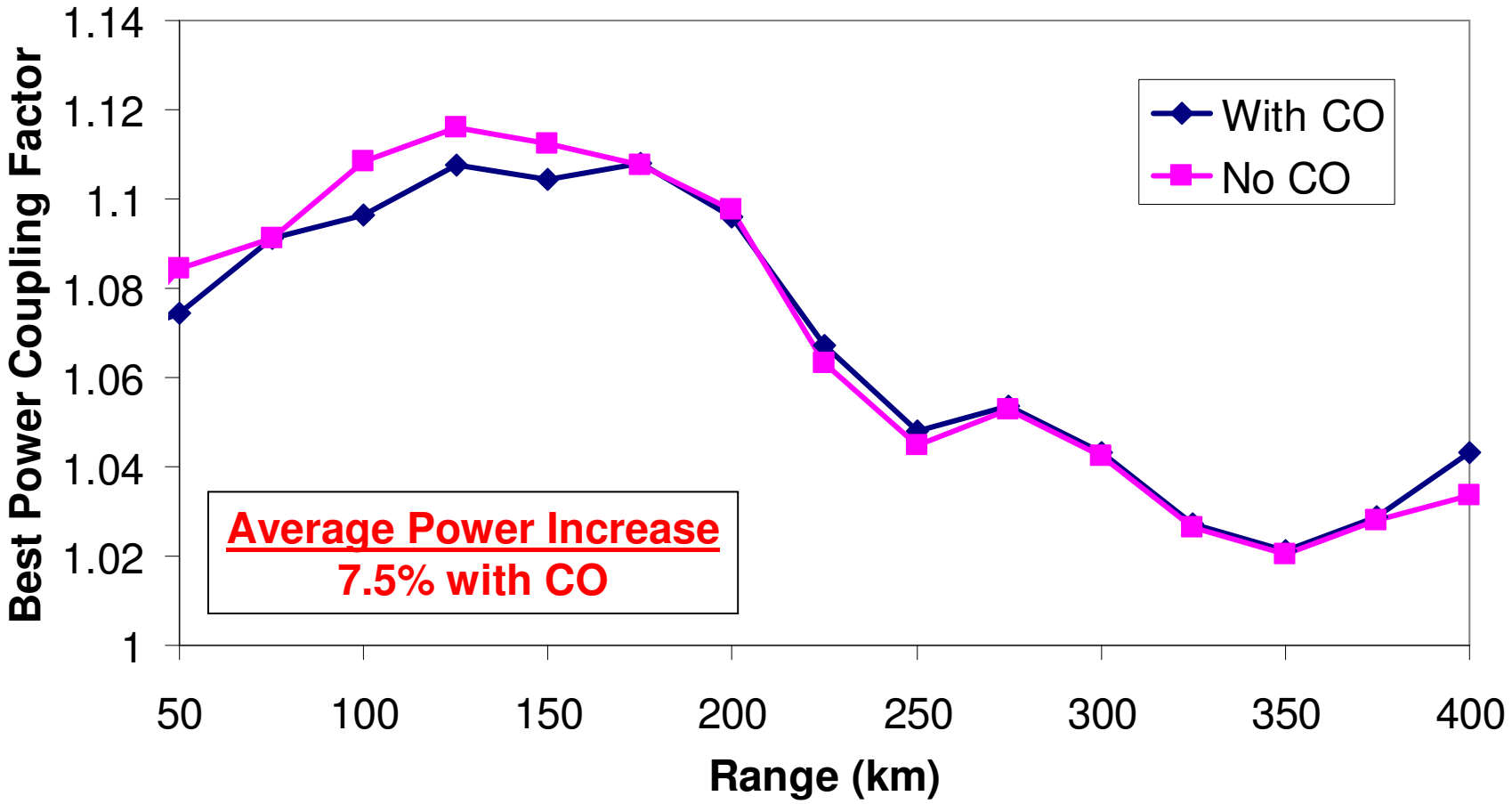
Spherical Aberration Power Coupling Increase



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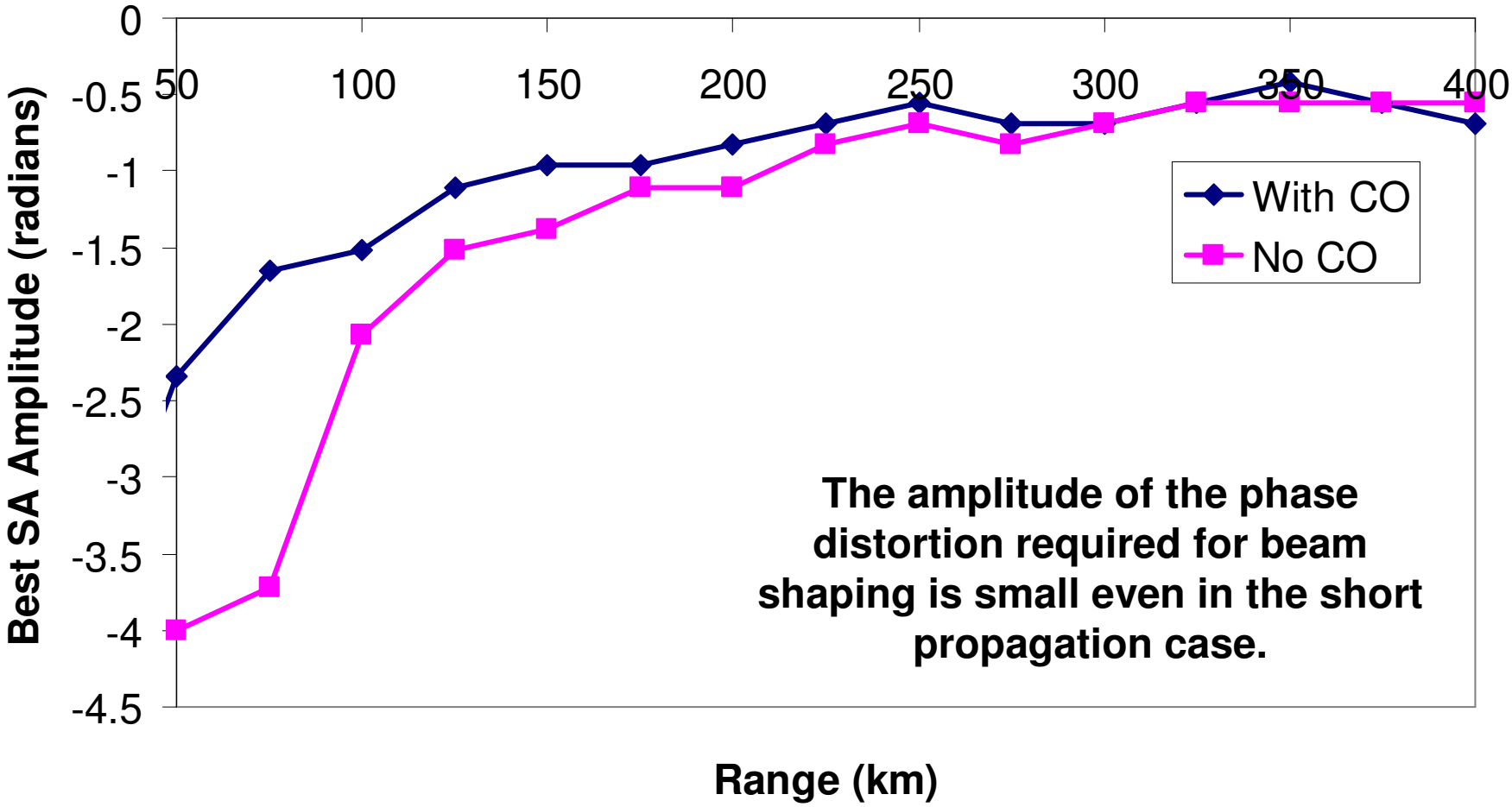
Best Spherical Aberration Amplitude



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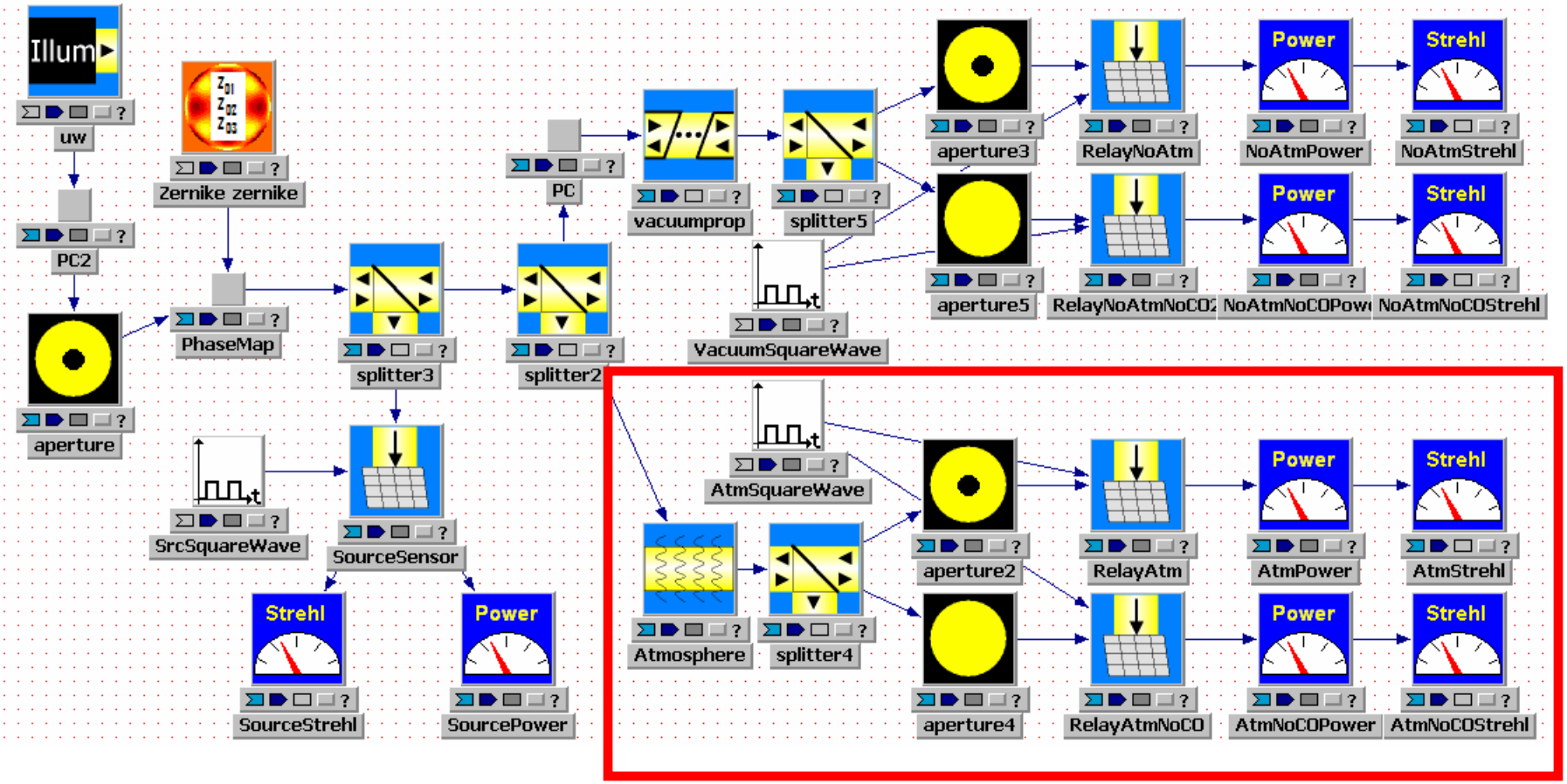
Optimizing Spherical Aberration



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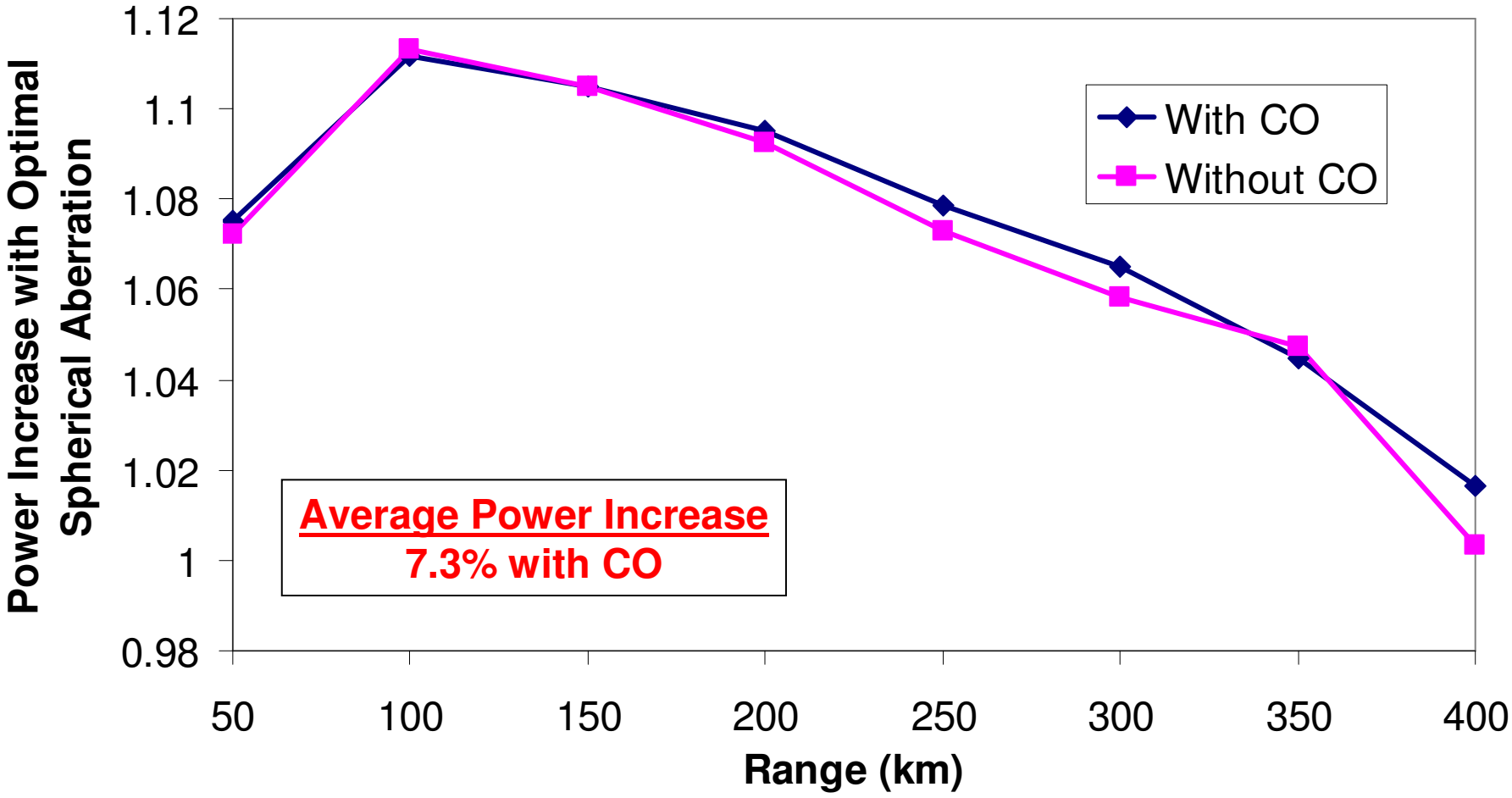
Comparing Atmospheric Received Power with and Without Spherical Aberration



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Effect of Beam Shaping on Beam Quality

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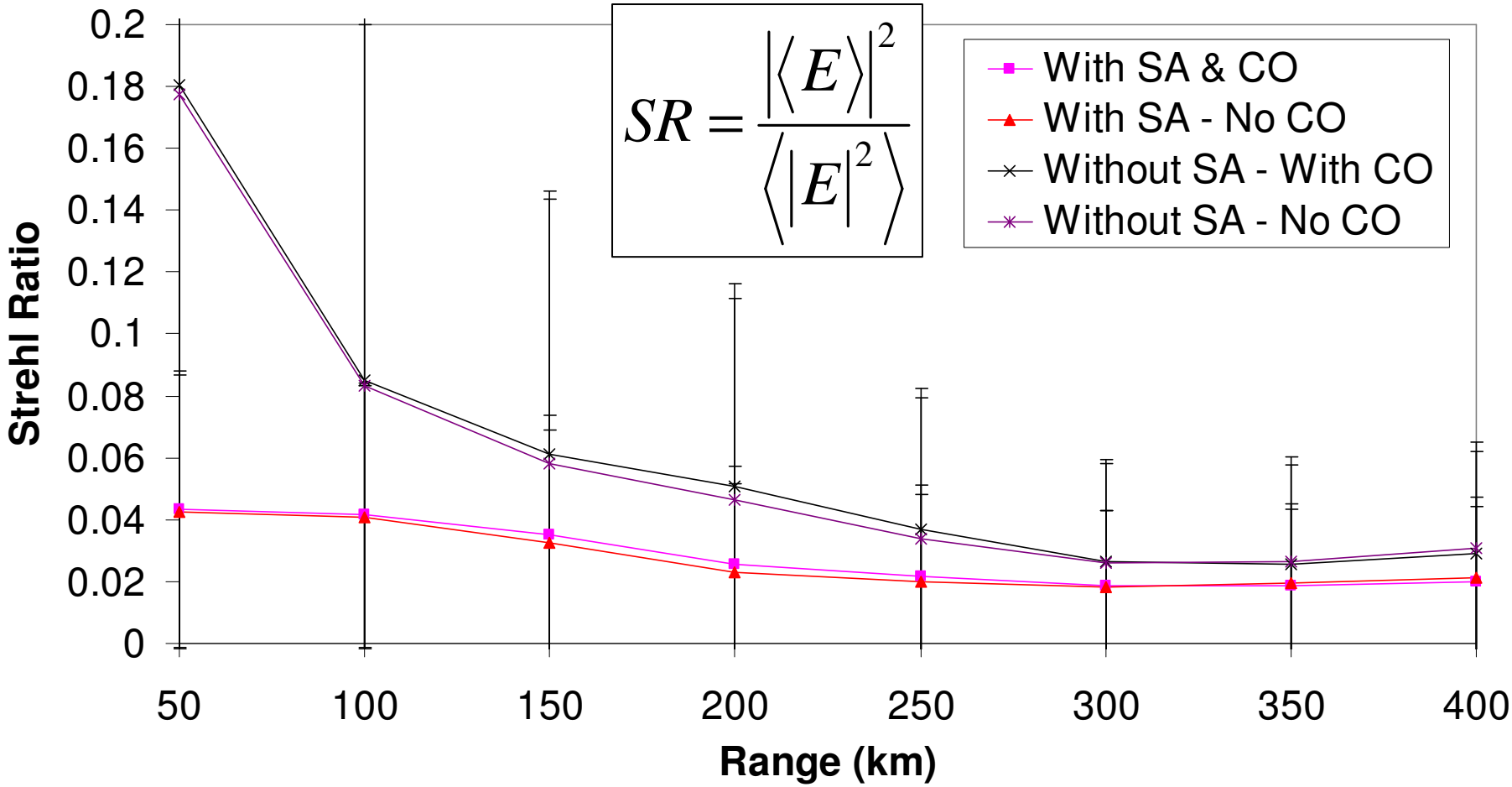
Comparing Atmospheric Strehl Ratio with and Without Spherical Aberration



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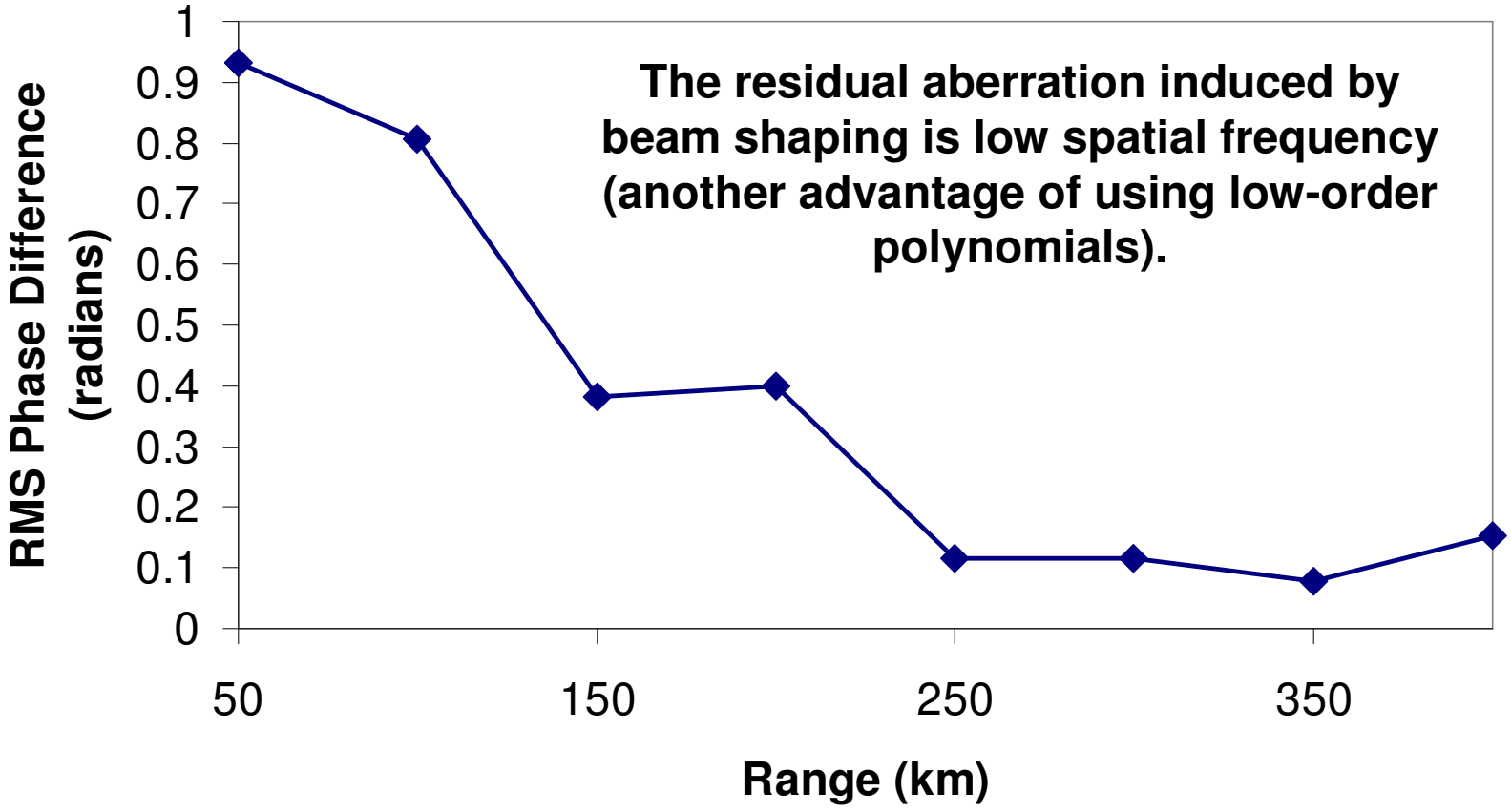
RMS Phase Difference with and without Optimal Spherical Aberration



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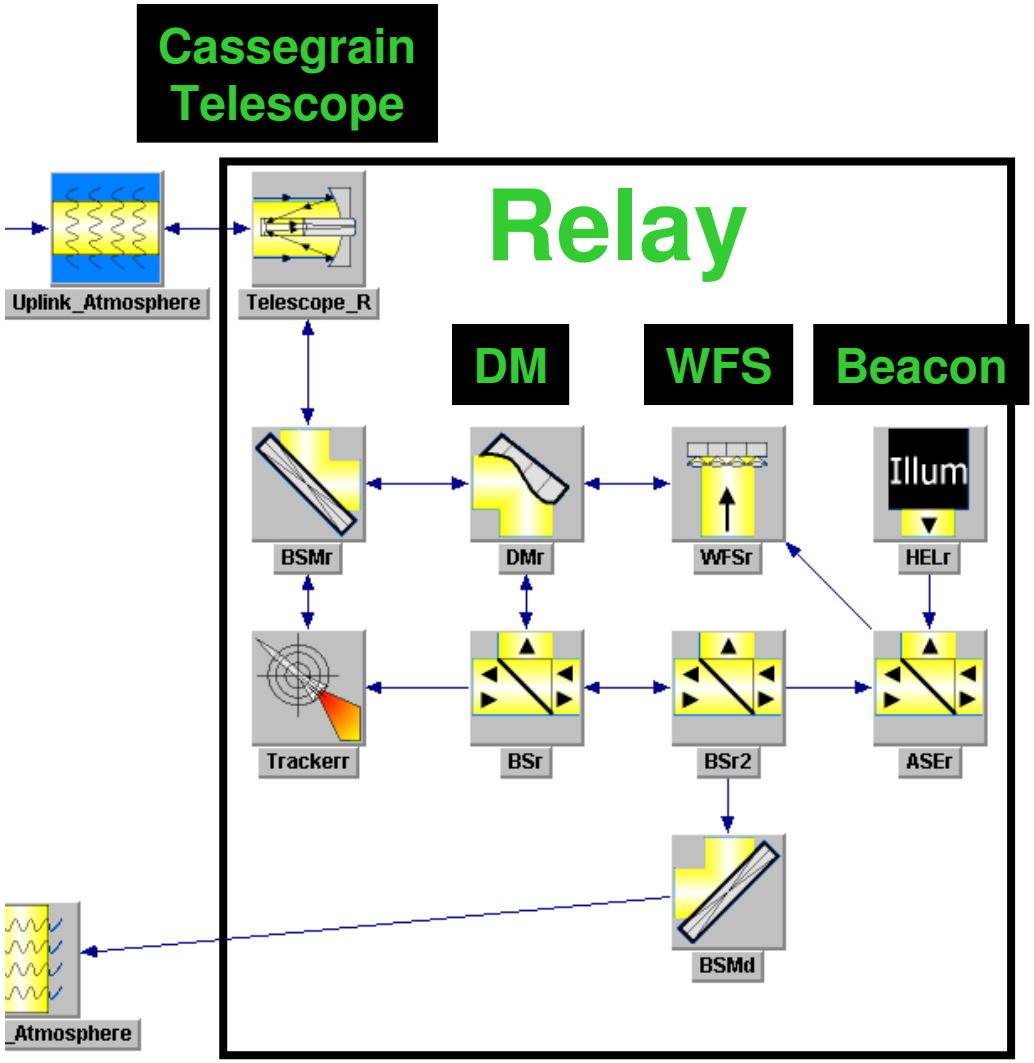
Counteracting Beam Quality Degradation

- Many relay mirror system designs have an AO system on the relay platform that can easily clean-up the beam.



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Beam Shaping Laboratory Evaluation

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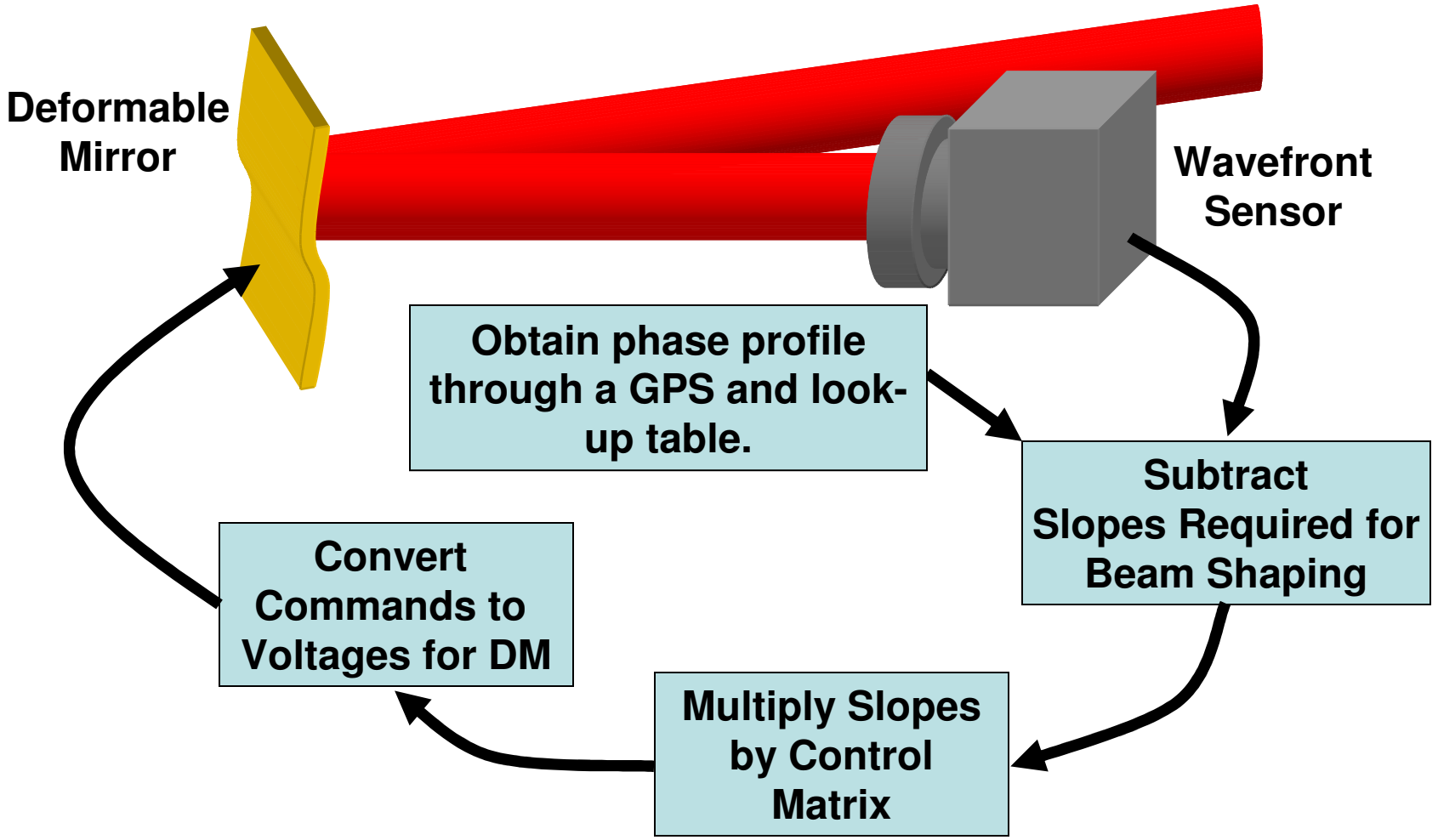
Combining Shaping and AO



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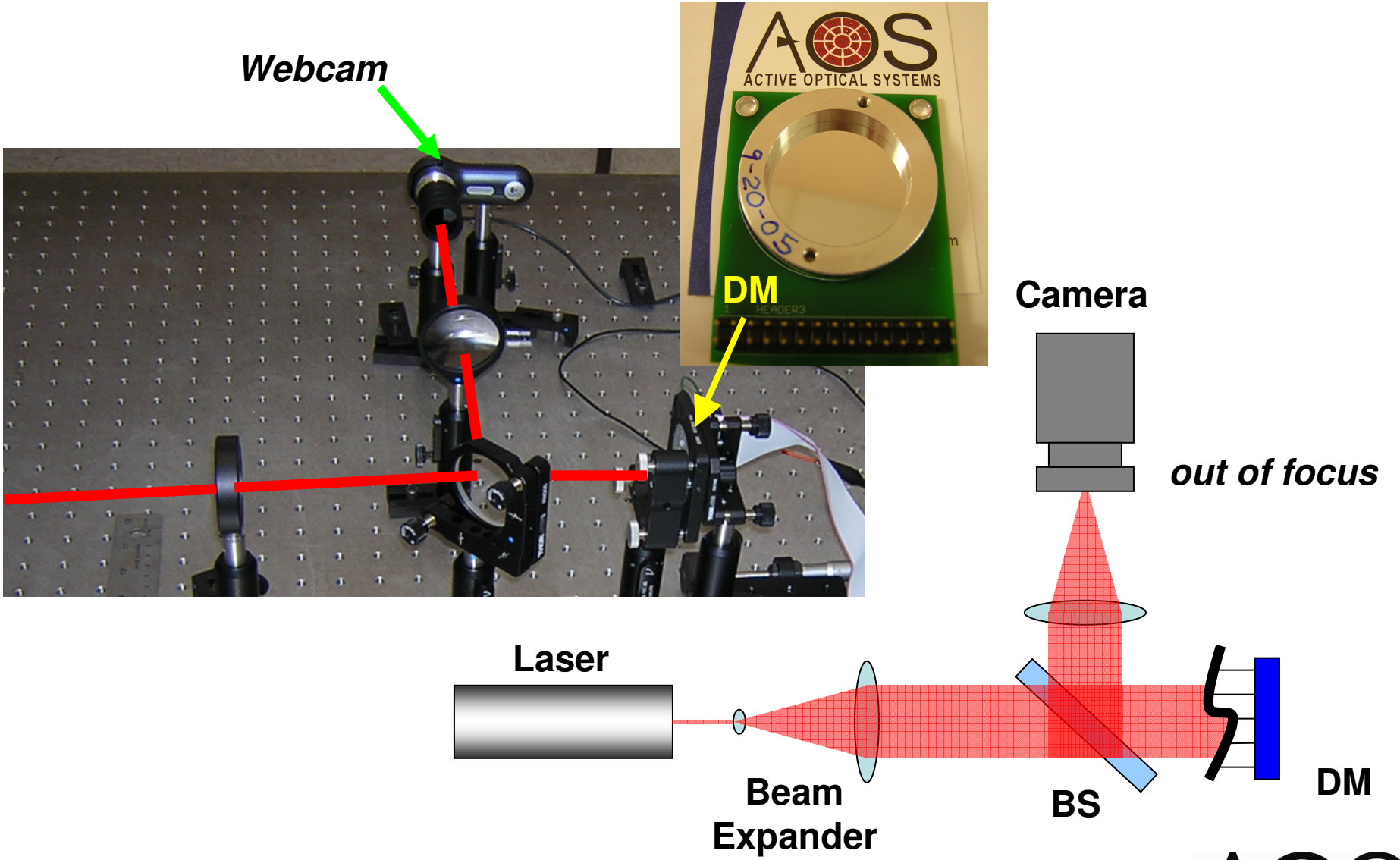
Demonstration System Architecture



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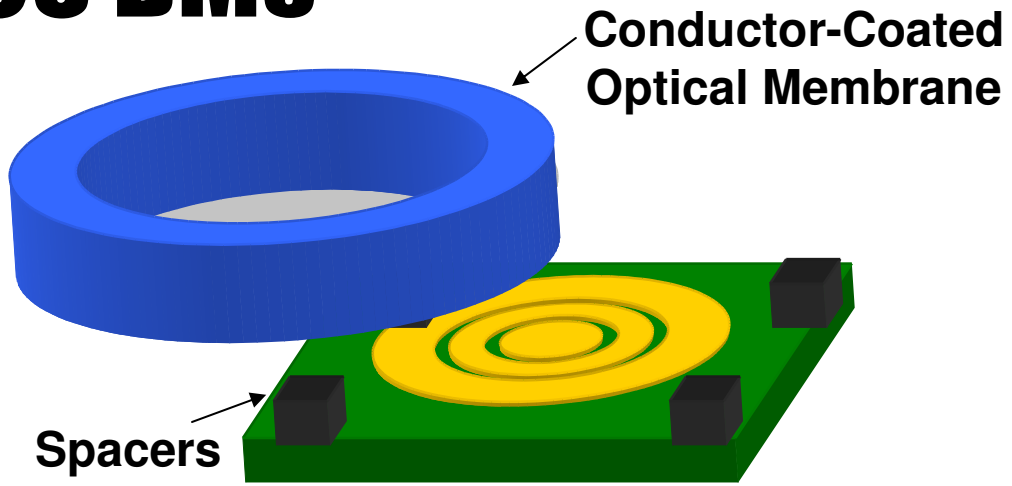
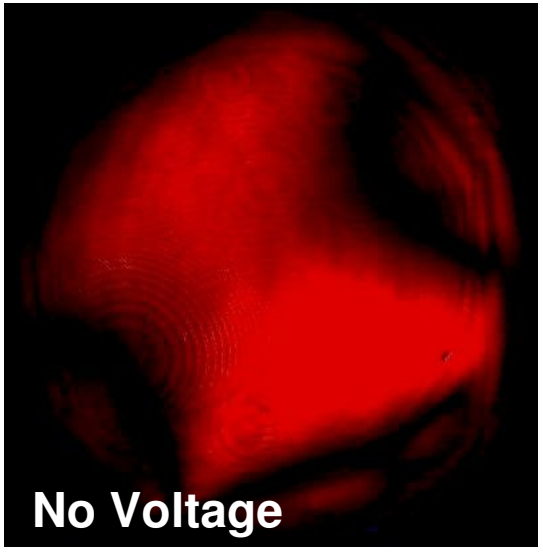
AOS DMs

- Measured ~500 Hz resonance (1” diameter)
- Available up to 6” in diameter COTS
  - ~1 m possible
- Achieved ~1 m focal length
  - 40µm throw with 330V
- Electrostatic snap-down did not rupture membrane





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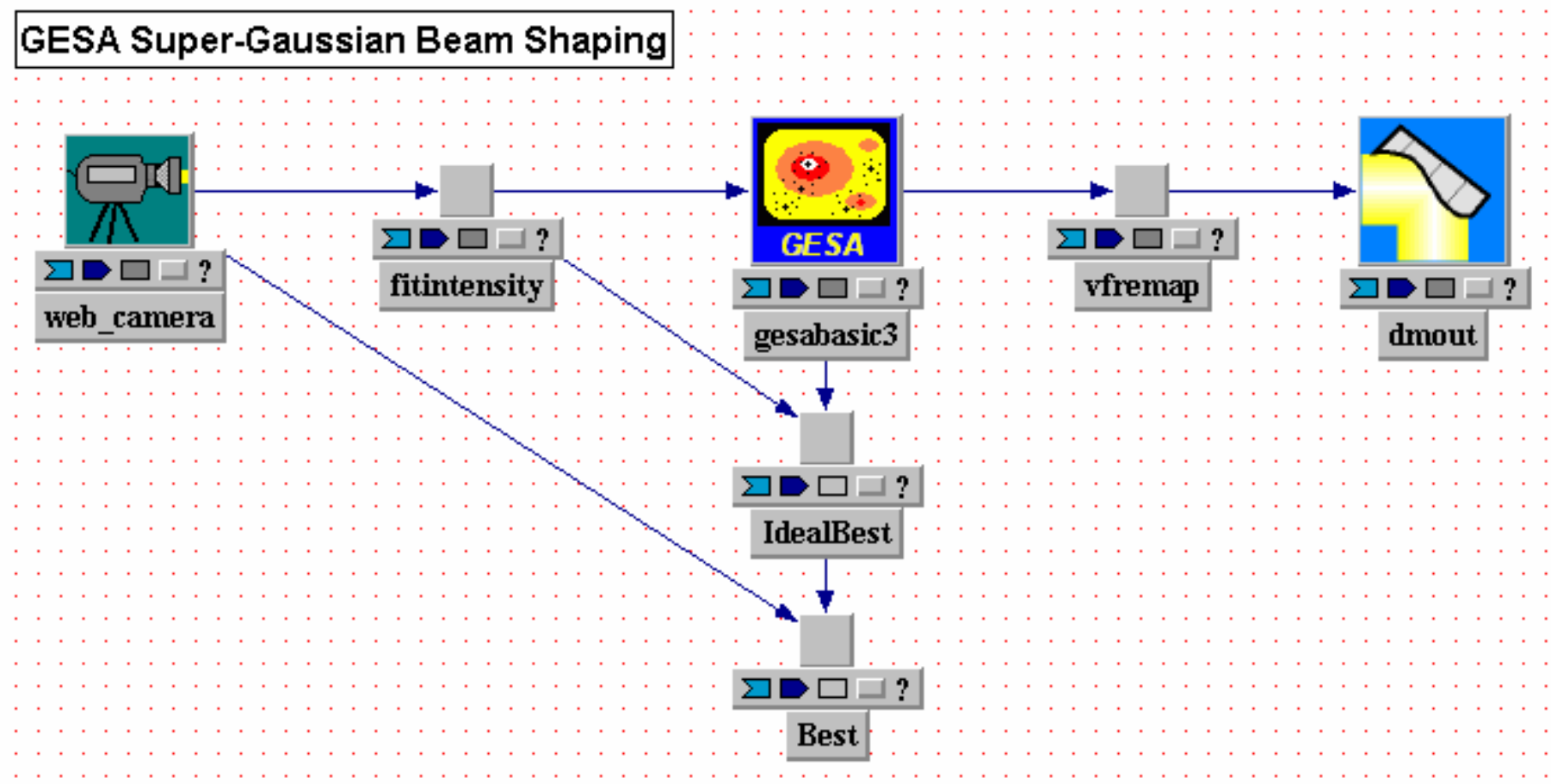
WaveTrain Setup



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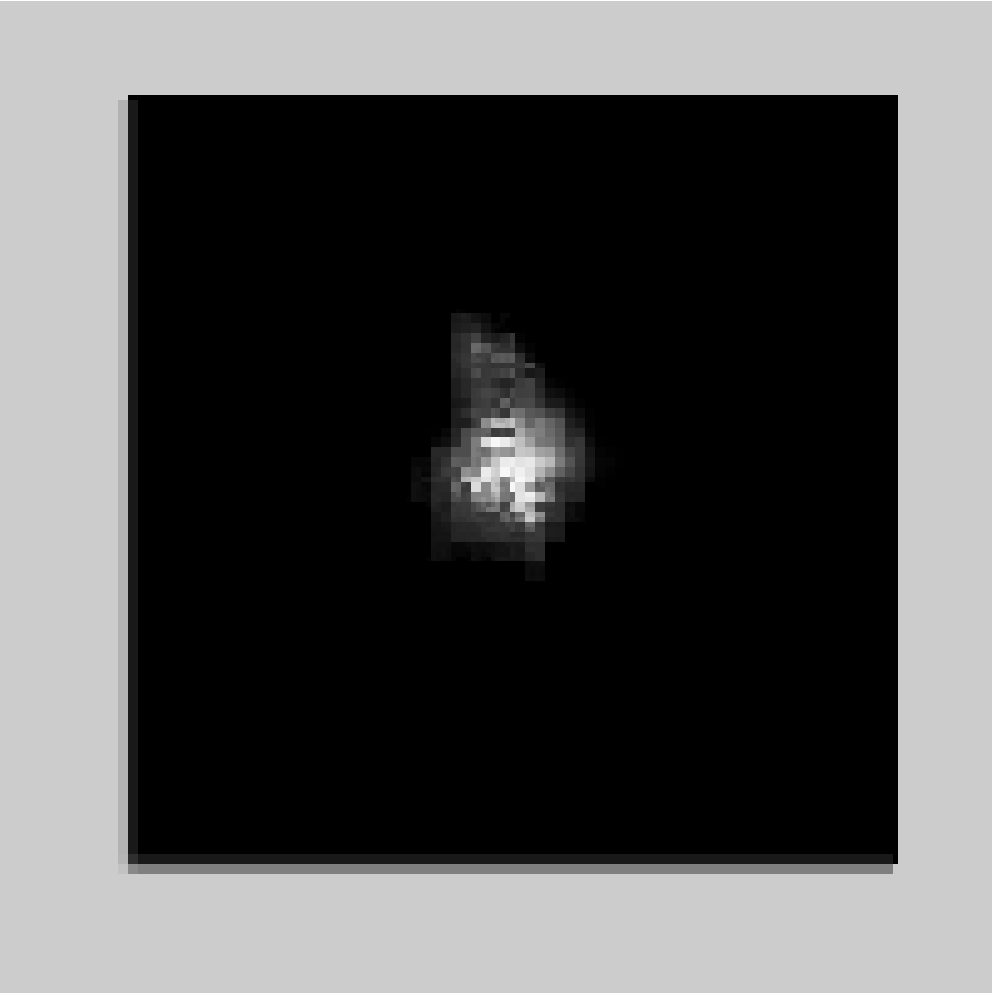
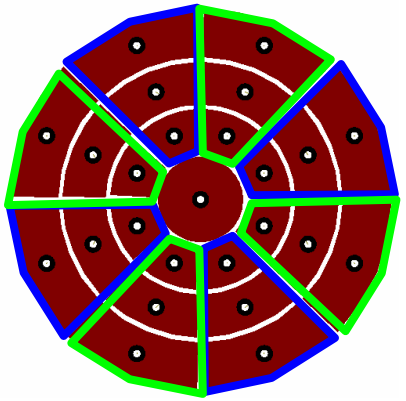
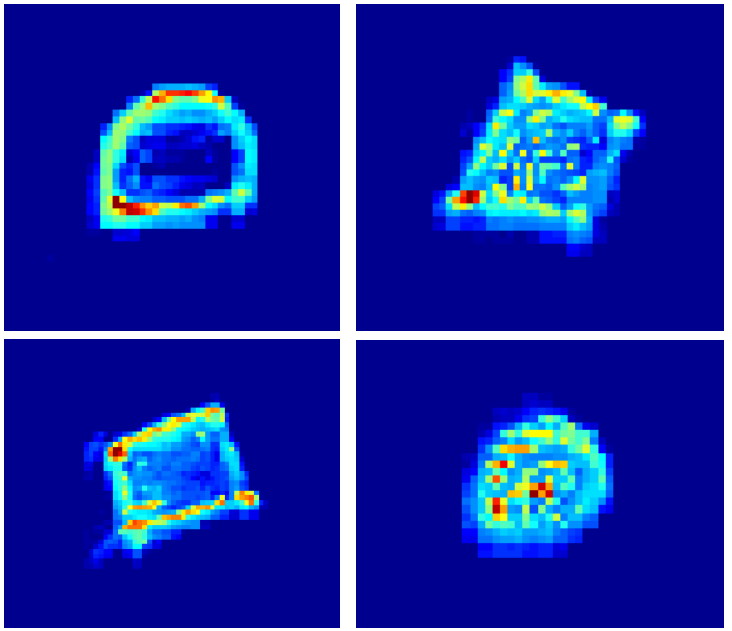
Beam Shaping with a Deformable Mirror







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Conclusions

- Beam shaping can increase the coupling for a typical relay engagement by 7.3% on average
  - Even in the presence of atmospheric turbulence
- Can be implemented for free in a relay system with adaptive optics.

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Questions?

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