# Guidestar-Free Adaptive Optics With Asymmetric Apertures

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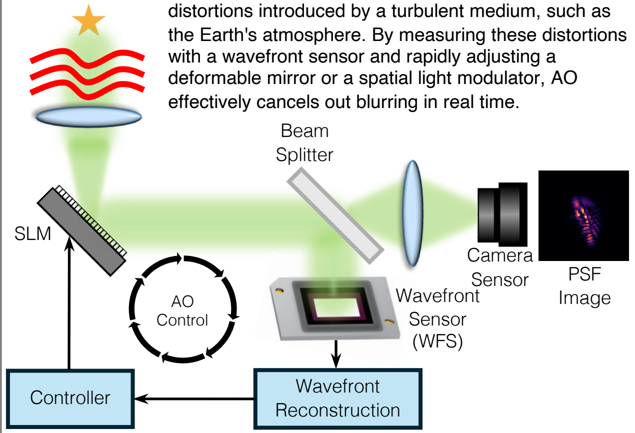
## Conventional Adaptive Optics

Adaptive Optics (AO) improves the performance of optical systems by dynamically correcting wavefront distortions introduced by a turbulent medium, such as the Earth's atmosphere. By measuring these distortions with a wavefront sensor and rapidly adjusting a deformable mirror or a spatial light modulator, AO effectively cancels out blurring in real time.




## What's Wrong with AO Today?

Conventional AO relies on a bright point source, or a **guidestar** alongside a wavefront sensor (WFS), to sample the distorted wavefront. Beyond the guidestar requirement, relying on a physical Shack-Hartmann **wavefront sensor** imposes severe practical limits. Subaperture sampling fundamentally restricts spatial resolution, while the extra optics drastically increase hardware complexity and inflate the system's size, weight, power, and cost (SWaP-C).

## AO Forward Model

$$Y = X \circledast H + \epsilon, \quad H = \left|\mathcal{F}\{A \circ e^{j\phi_o}\}\right|^2$$

We assume a spatially invariant forward model, i.e., isoplanatic turbulence or scattering restricted to the memory effect region. Under this model, the measurement process can be described as above, where $\circledast$ denotes two-dimensional convolution, $H$ denotes the system's aberrated PSF, and $\epsilon$ accounts for additive noise. The system's PSF is the Fourier transform intensity of the pupil function, where $\phi_o$ denotes the unknown phase aberration/wavefront error.

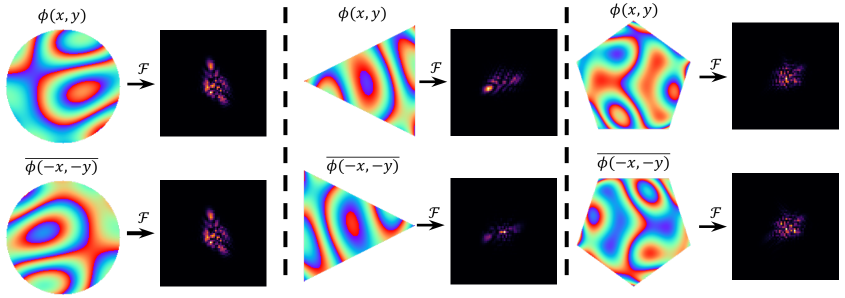
## Can We Replace Wavefront Sensor with Computation?

We can, **IF** we can recover wavefront errors from PSF measurements.

**BUT** conventional symmetric apertures, such as circular apertures, introduces ambiguities in this phase retrieval process.

## Asymmetry Enables Phase Retrieval Based Wavefront Sensing

For a circular aperture, the original phase $\phi\ (x,y)$ and its conjugate-flipped counterpart $\phi\ (-x,-y)$ produce identical PSFs after the Fourier transform, leading to phase ambiguity in intensity-only measurements [1]. In contrast, for triangular and pentagonal apertures—representatives of a broader class of asymmetric apertures such as polygons with an odd number of sides—the wavefront phases $\phi\ (x,y)$ and $\phi\ (-x,-y)$ yield distinct PSFs. This asymmetry enables unique phase retrieval from intensity measurements, resolving the ambiguity present in symmetric apertures [1].

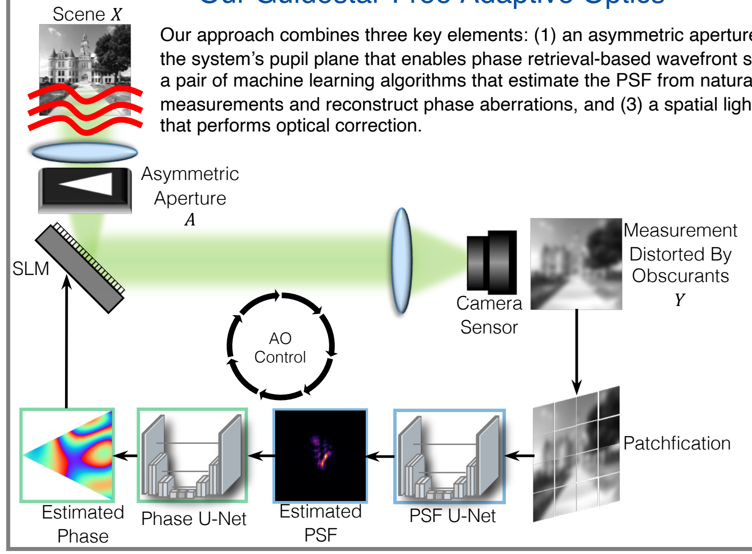



## Eliminating the Need for Guidestars

While asymmetric apertures eliminate the physical wavefront sensor, existing wavefront-sensorless AO methods still require a bright guidestar to measure an isolated PSF [1]. We eliminate guidestar requirement with deep learning. Our framework uses a "PSF U-Net" to directly extract the blur kernel from a natural scene measurement.

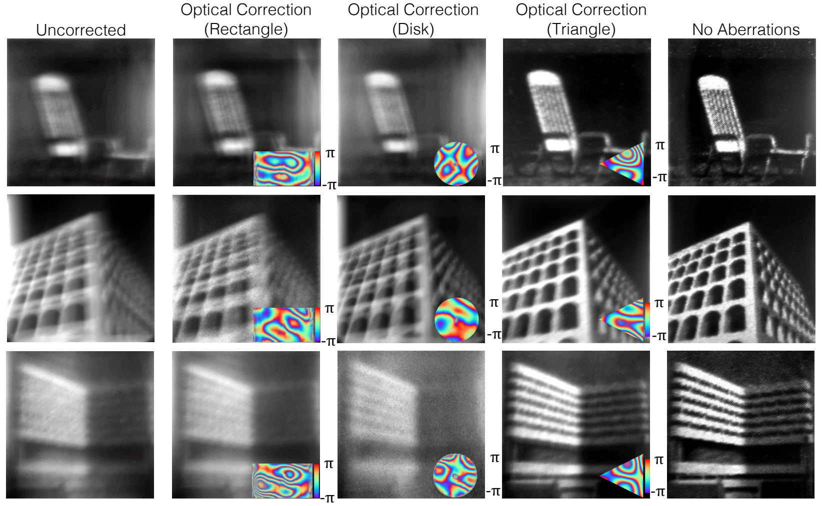
## Our Guidestar-Free Adaptive Optics

Our approach combines three key elements: (1) an asymmetric aperture placed at the system's pupil plane that enables phase retrieval-based wavefront sensing, (2) a pair of machine learning algorithms that estimate the PSF from natural scene measurements and reconstruct phase aberrations, and (3) a spatial light modulator that performs optical correction.



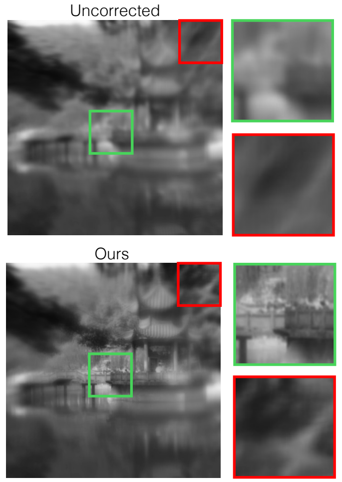

## Experimental Aberration Correction Results

Our triangular aperture enables imaging through various obscurants such as nail polish, onion skin and optical diffusers.



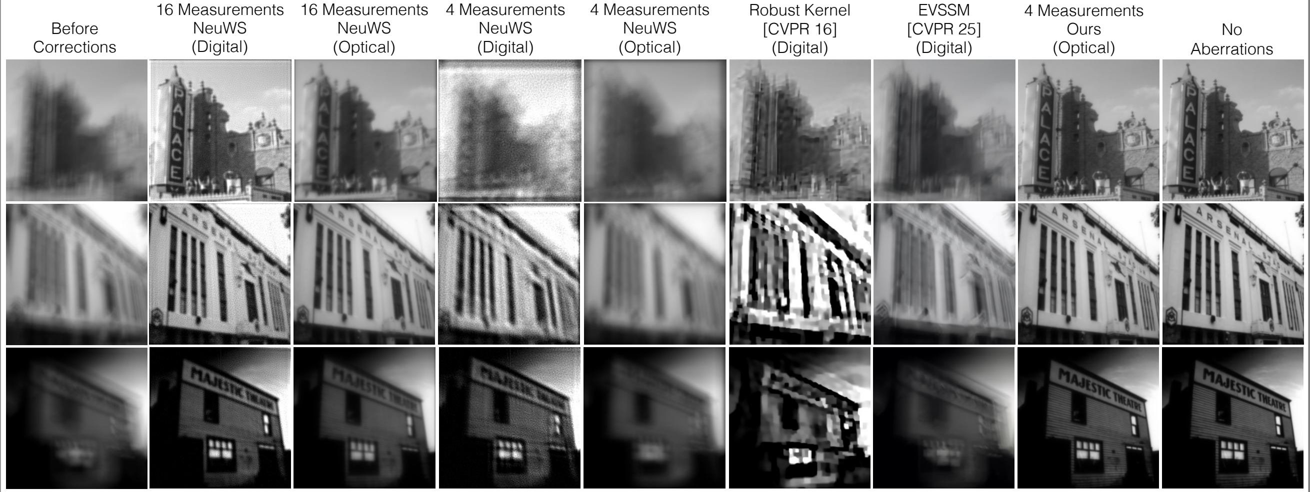

## Anisoplanatic Aberrations

In principle, one can correct anisoplanatic aberrations with our system patch-by-patch and stitching together the results.




## Simulated Results Compared with Wavefront Shaping & Deblurring Methods

Our method outperforms SOTA guidestar-free wavefront shaping and image deblurring methods.




[1] Chimitt et al.," Wavefront Estimation From a Single Measurement: Uniqueness and Algorithms", *IEEE TCI*, 2025.