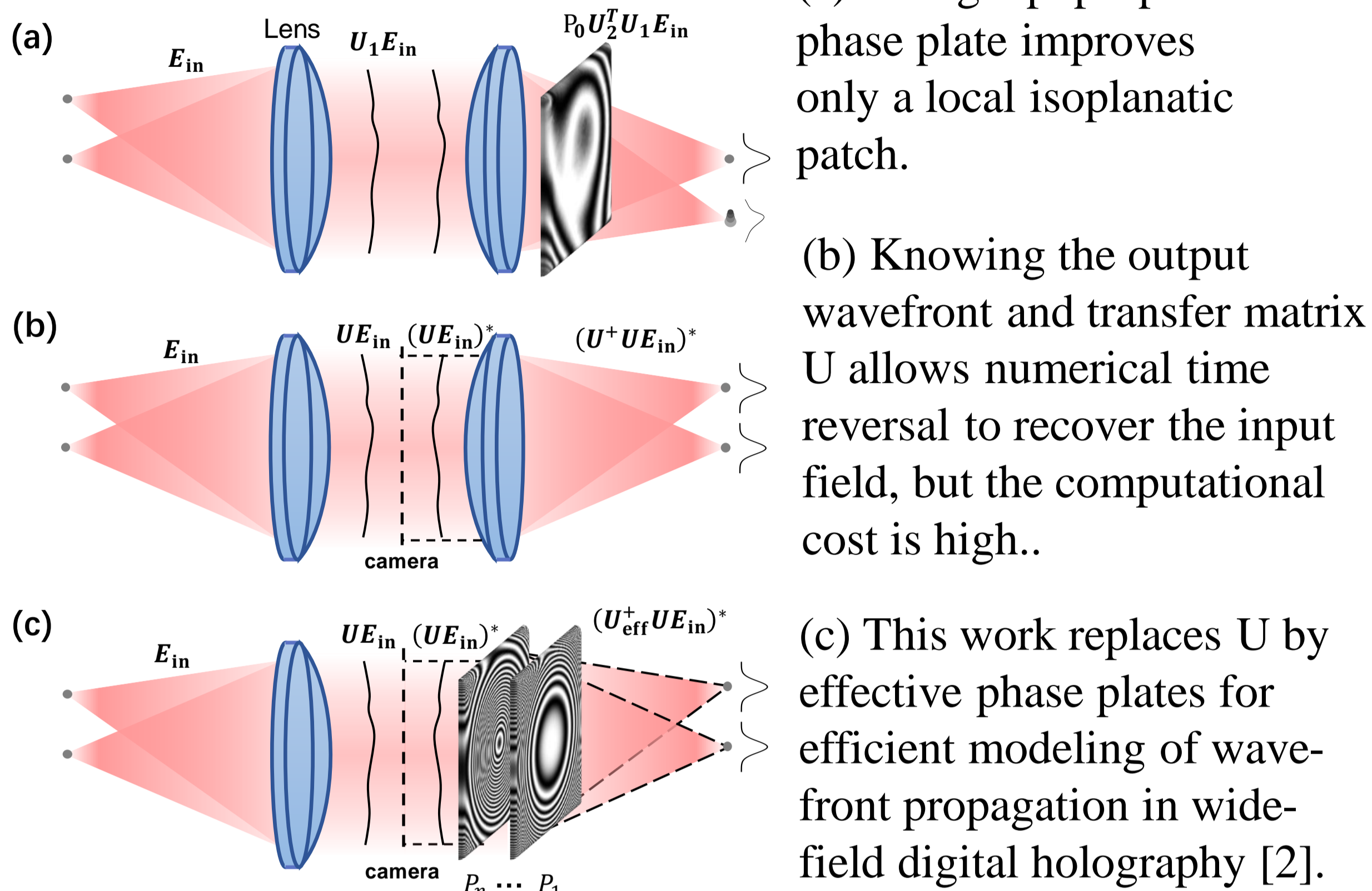


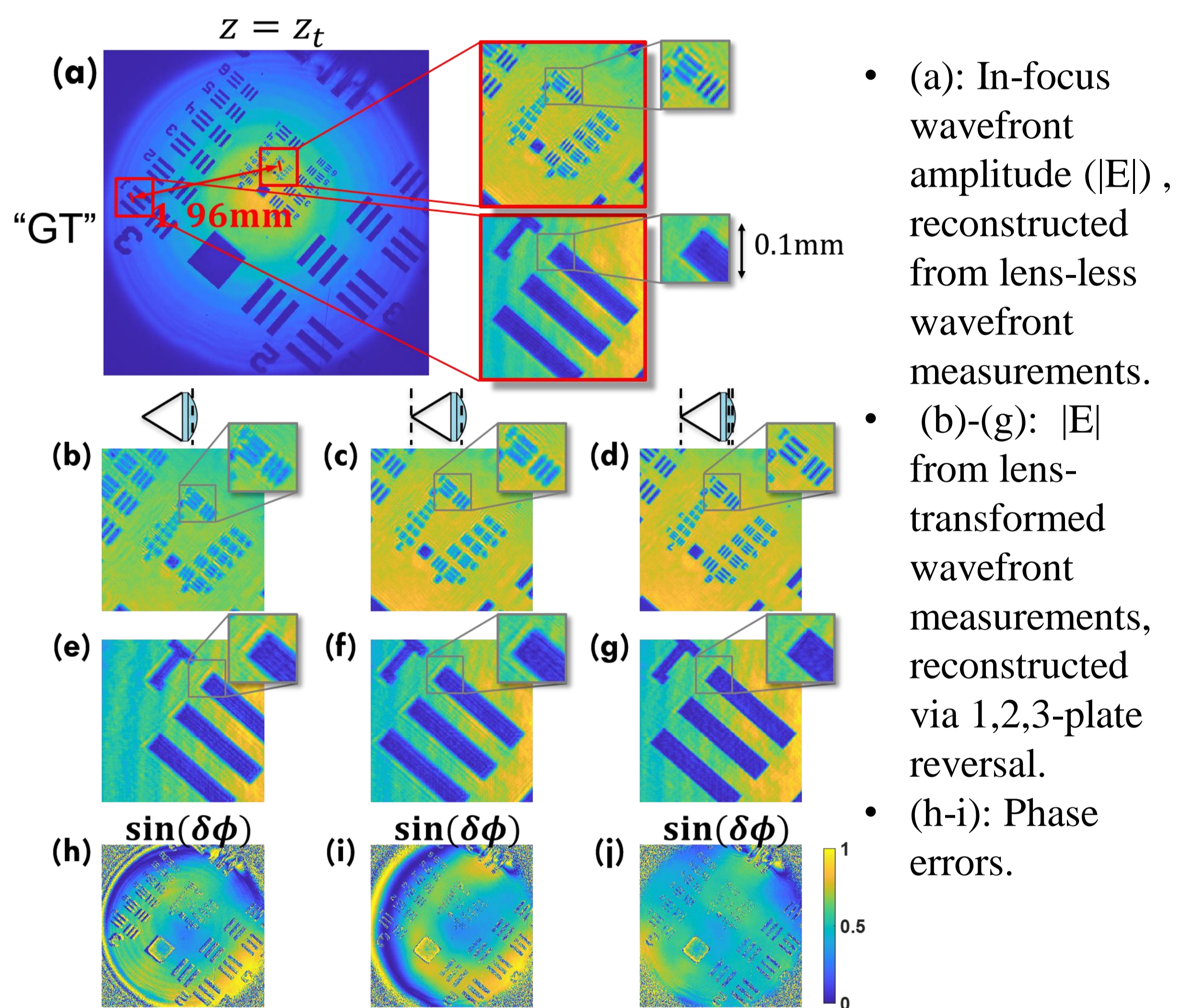
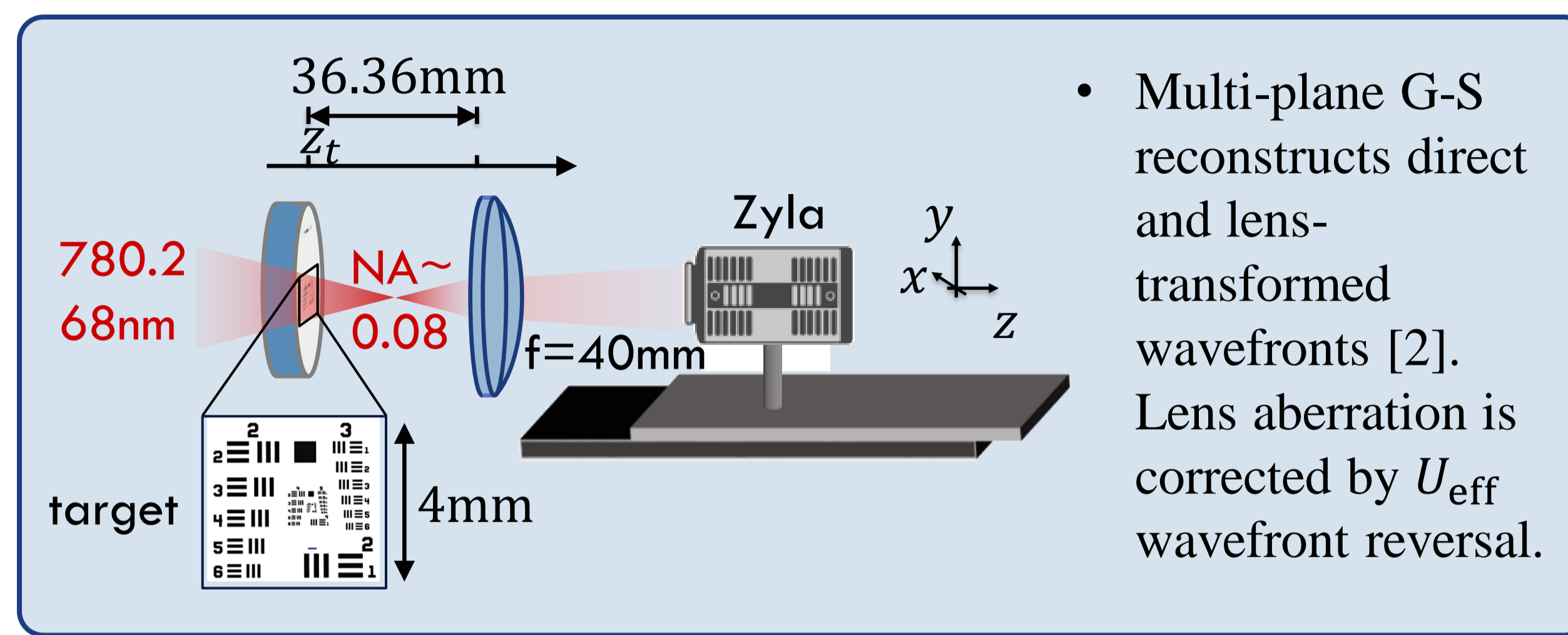
Motivation

Precise imaging requires high resolution, large FOV, and high photon-detection efficiency, especially in ultracold physics and quantum platforms. Conventional wide-field aberration correction often uses complex multi-element optics, causing scattering and photon loss [1]. This work proposes and demonstrates that a single imaging lens can be represented numerically by an array of phase plates, enabling efficient, wide-field aberration correction via wavefront reversal.

Principle

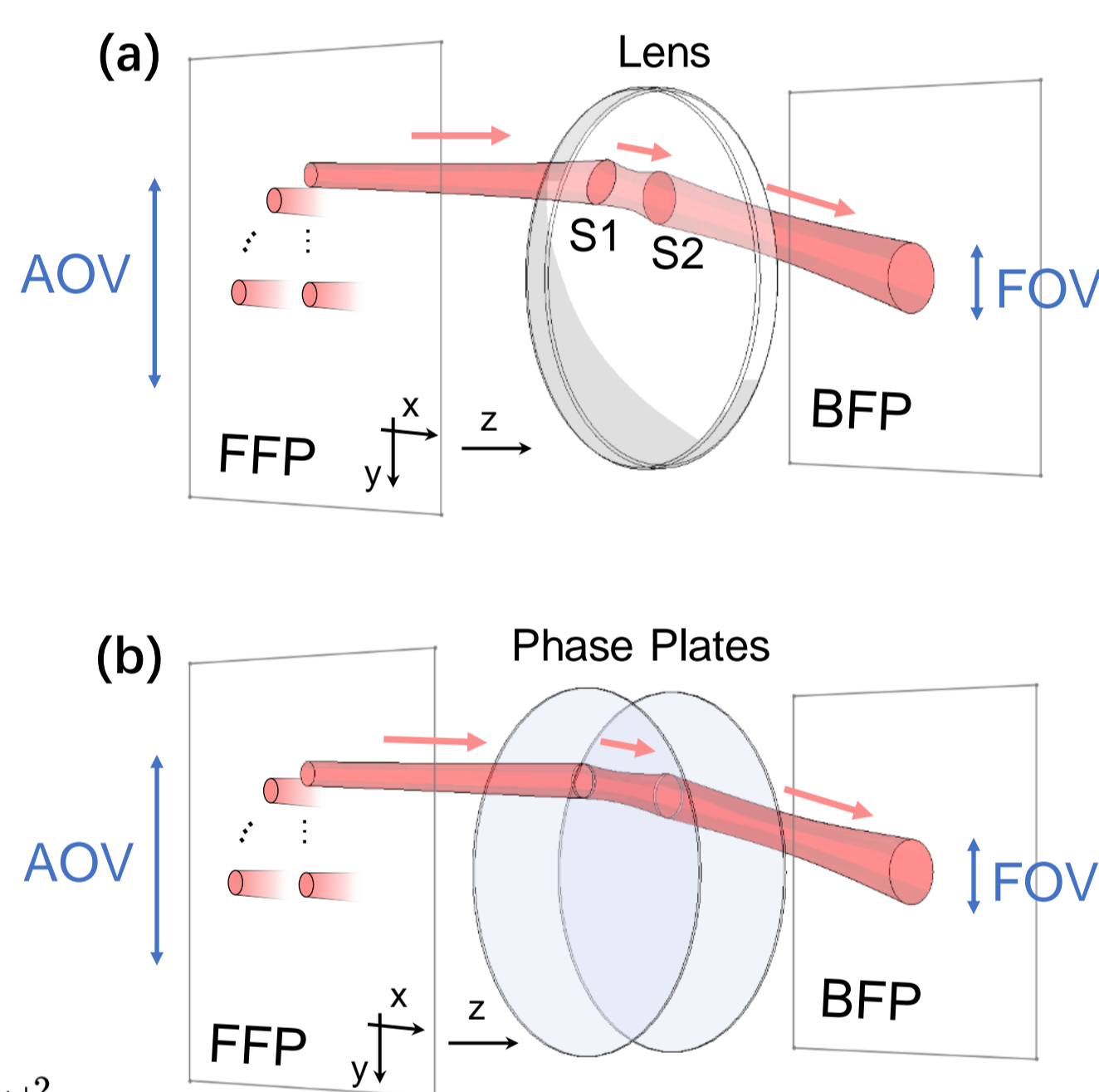


Experimental demonstration

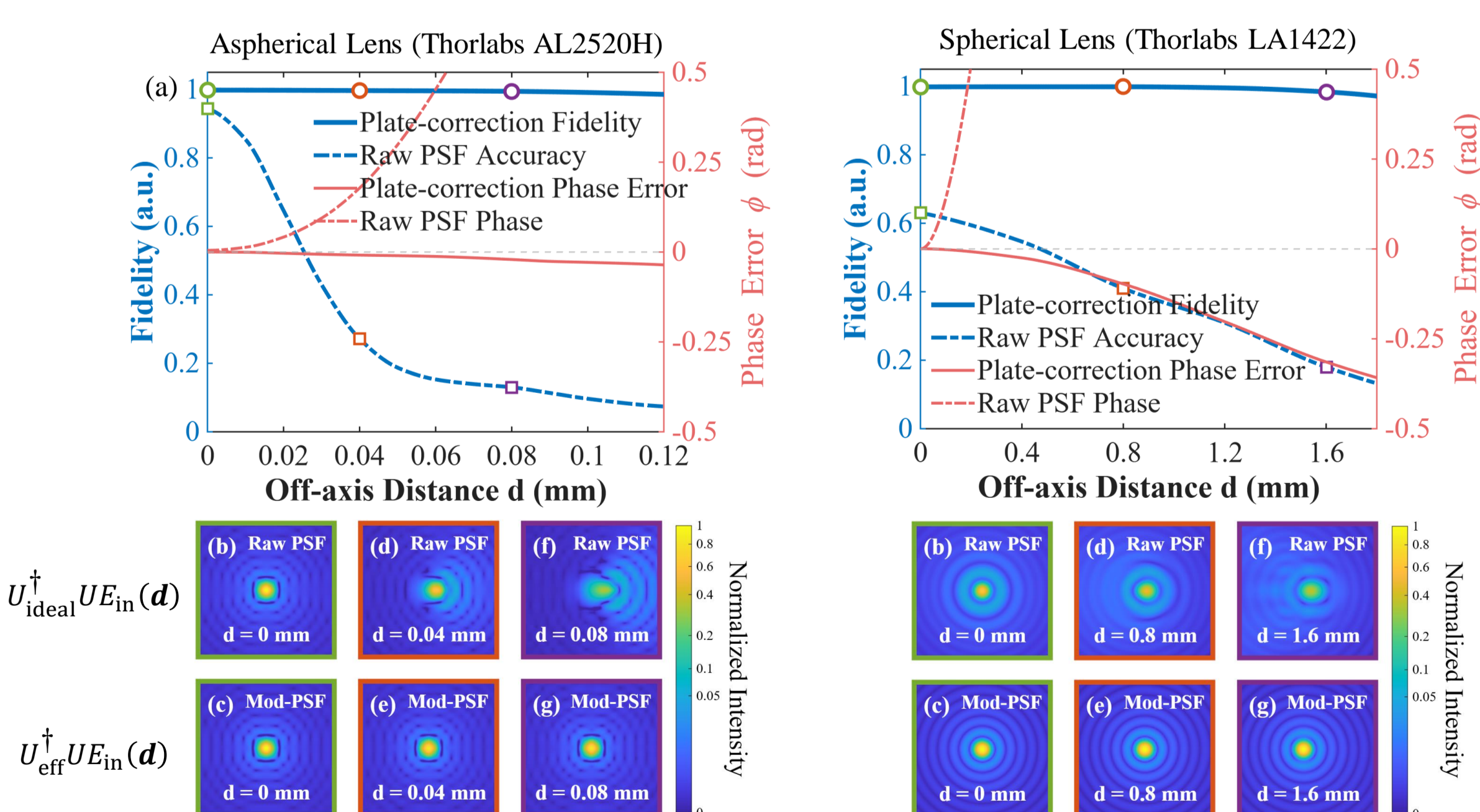


Representing a lens with an array of plates

- Lens geometry defines U between the front and back focal planes, evaluated as $U = U_{S2, \text{BFP}} U_{S1, S2} U_{\text{FFP}, S1}$ (a), which can be efficiently represented by an array of plates (b) to facilitate 2D wavefront propagation.
- Free-space propagation U_f plus phase plates $P_j = e^{i\phi_j}$ forms U_{eff} .
- By adjusting ϕ_j and positions z_j , the loss function is minimized within FOV and AOV of interest: $\mathcal{L} = \sum_s |\langle E_s^F | U_{\text{eff}}^\dagger U | E_s^F \rangle - 1|^2$.

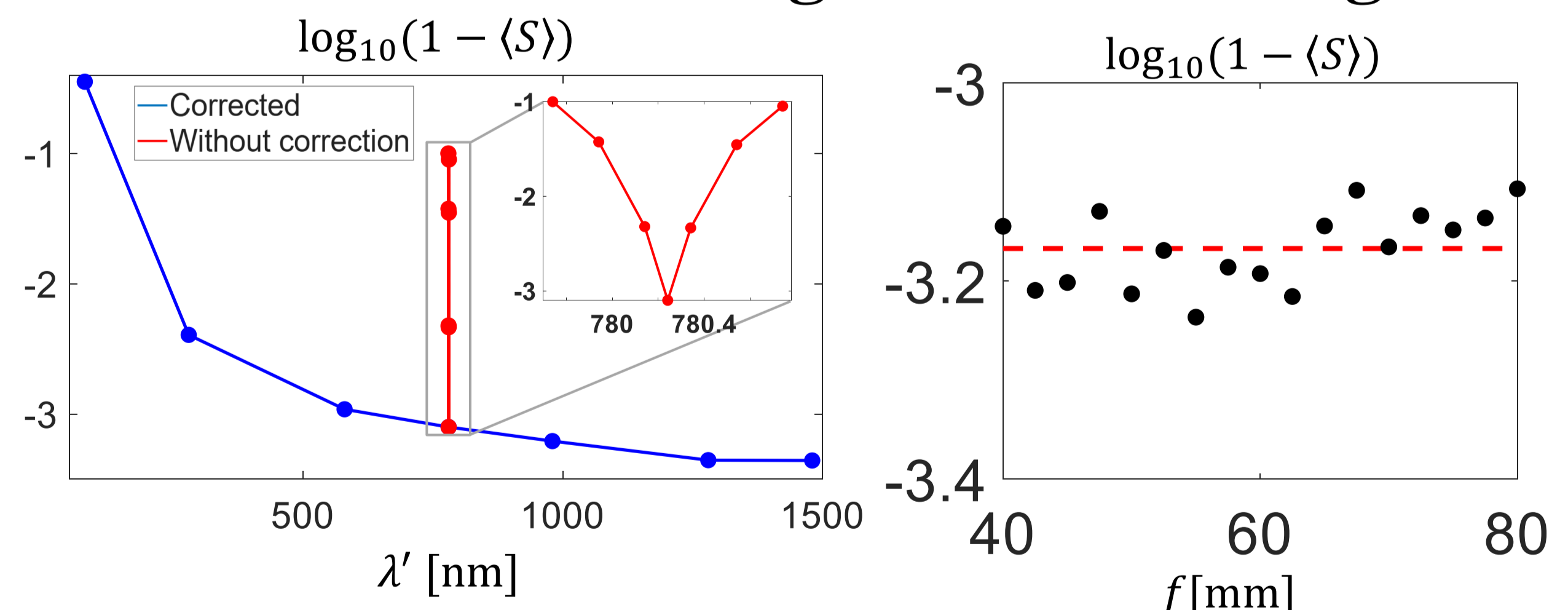


Examples: Aspherical lens and spherical lens



- Using Rayleigh-Sommerfeld propagation, the reversed counterparts $U_{\text{eff}}^\dagger U E_{\text{in}}(\mathbf{d})$, $U_{\text{ideal}}^\dagger U E_{\text{in}}(\mathbf{d})$ are computed using phase plates and an ideal Fourier lens respectively.
- The similarity between $U_{\text{eff}}^\dagger U E_{\text{in}}(\mathbf{d})$ and $E_{\text{in}}(\mathbf{d})$ measures the aberration-correction performance of phase plate.
- Lens aberration can be precisely corrected via wavefront reversal through a 3-plate combination, leading to diffraction limited FOV with $(\text{FOV}/\text{res})^2 > 10^5$ for single lens.

Correction of wavelength and focal length



- By rescaling plate parameters, multi-plate designed at one wavelength can be applied to another within a wide range of wavelengths.
- Plate array design can be reoptimized for lenses with different focal lengths toward 99.9% accuracy.

Summary and outlook

- A lens can be efficiently represented by a small number of equivalent phase plates.
- The proposed wavefront-reversal method enables wide-field aberration correction with reduced computational complexity.
- Toward single-lens digital holographic imaging [2] combining precision, volume-of-view and photon detection efficiency.

[1] E. Altuntas and I. B. Spielman, Phys. Rev. Res. 3, 043087 (2021).

[2] X. Huang et al., Phys. Rev. Res. 7, 013054 (2025).