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Applied Physics 157
THY-TX-1

INSTRUCTORS

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Multiple Plane Phase Retrieval methods: a Comparison

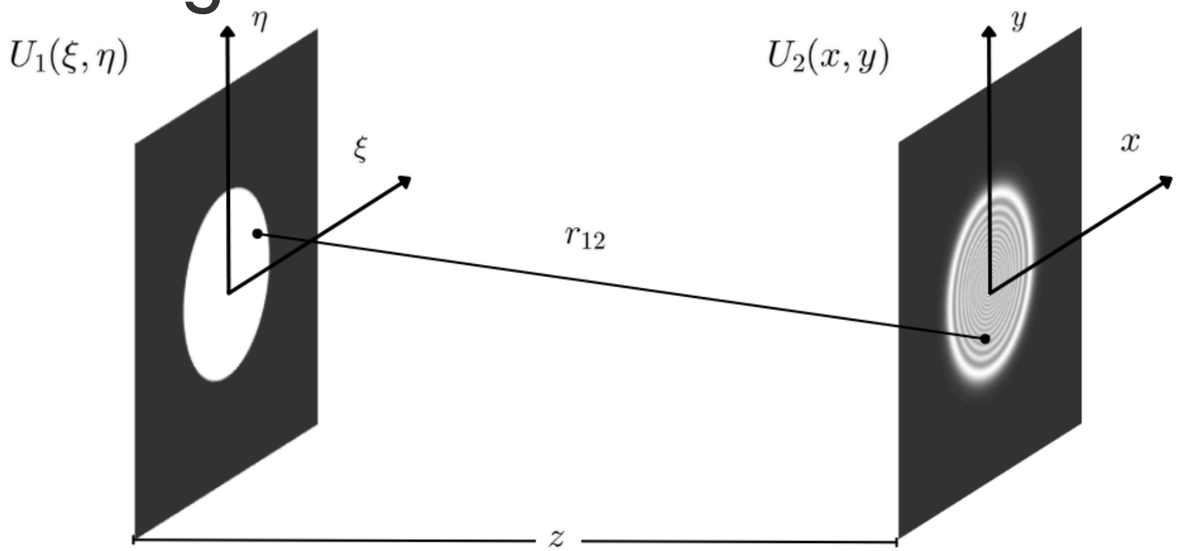
Table of Contents

I Background
Phase

- Non-Interferometric wavefront reconstruction methods
  - not sensitive to vibrations
  - uses intensity measurements from light scattered by the target
- Uses wave propagation equations
  - Transport of intensity equation
  - Fourier transform
  - Rayleigh Sommerfeld diffraction equation

I Background:
Rayleigh-Sommerfeld Diffraction Integral

- Computes the diffracted wave field from a known source plane



$$U_2(x,y) = \frac{z}{i\lambda}\iint U_1(\xi,\eta)\,\frac{\exp(\mathrm{ikr}_{12})}{r_{12}^2}\,d\xi d\eta$$

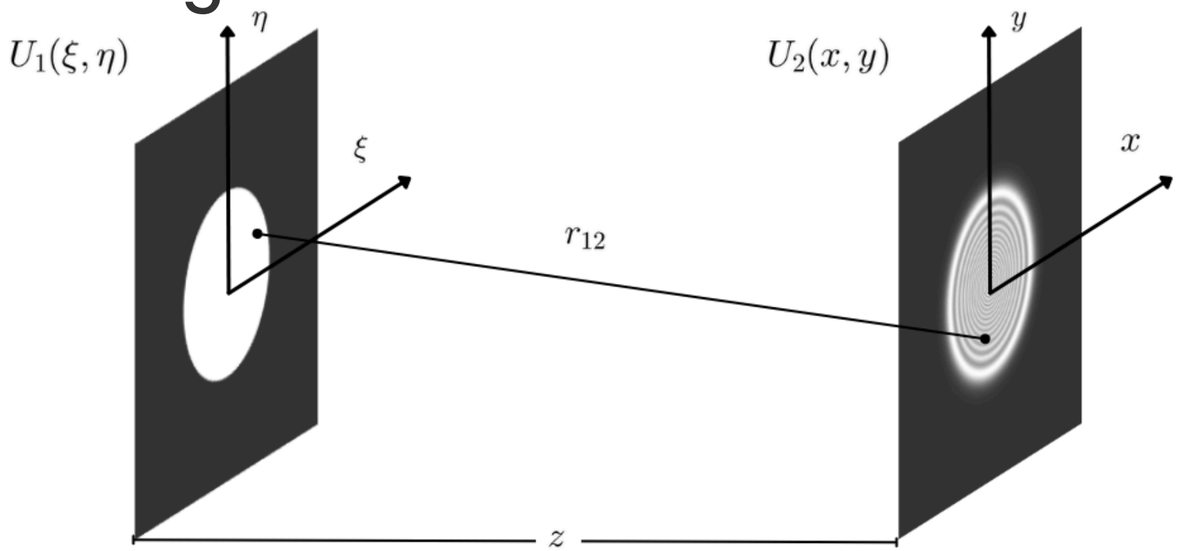
$$r_{12} = \sqrt{z^2 + (x-\xi)^2 + (y-\eta)^2}$$

I Background:
Rayleigh-Sommerfeld Diffraction Integral

- Computes the diffracted wave field from a known source plane

$$U_2(x,y) = \iint U_1(\xi,\eta) h(x-\xi, y-\eta) d\xi d\eta$$

$$U_2(x,y) = U_1(x,y) \star h(x,y)$$

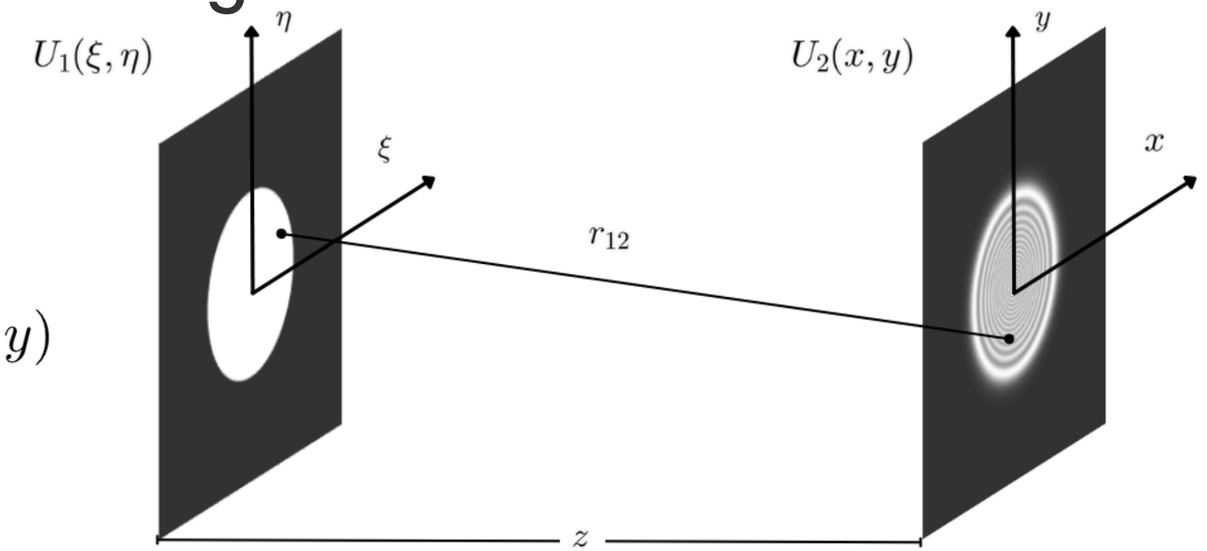


$$U_2(x,y) = \frac{z}{i\lambda} \iint U_1(\xi,\eta) \frac{\exp(\mathrm{ikr}_{12})}{r_{12}^2} d\xi d\eta$$

$$r_{12} = \sqrt{z^2 + (x-\xi)^2 + (y-\eta)^2}$$

I Background:
Rayleigh-Sommerfeld Diffraction Integral

- Computes the diffracted wave field from a known source plane
- Implemented as a convolution integral with impulse response $h(x, y)$



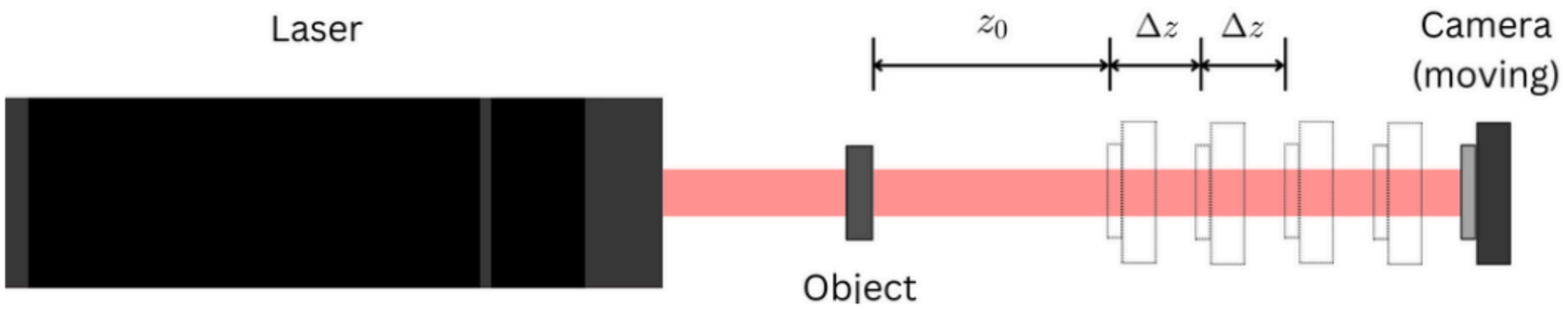
$$U_2(x, y) = \mathfrak{F}^{-1}\{\mathfrak{F}\{U_1(x, y)\}\mathfrak{F}\{h(x, y)\}\}$$

$$h(x, y) = \frac{z}{i\lambda} \frac{\exp\left[ik\left(z^2 + x^2 + y^2\right)\right]}{z^2 + x^2 + y^2}$$

I Background:

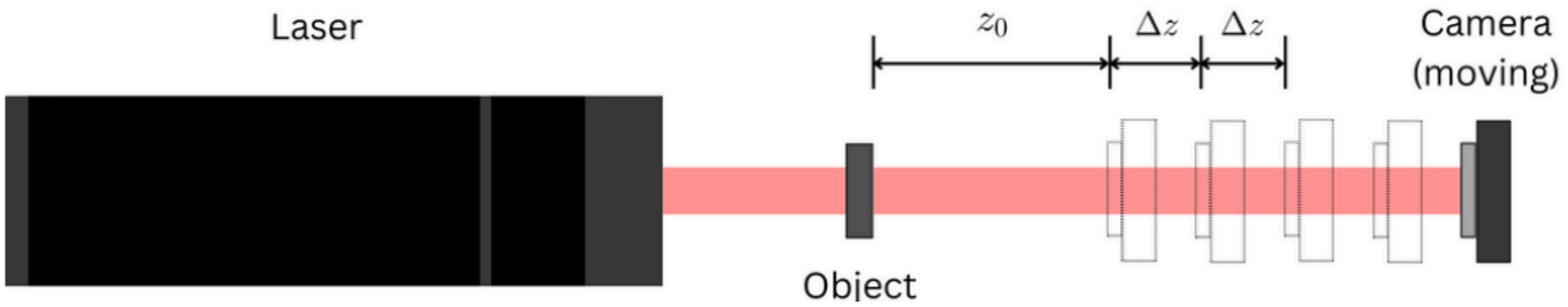
Multiple plane phase retrieval

- Iterative phase retrieval method
- Reconstructs the amplitude and phase information
- Uses multiple intensity recordings from parallel planes
  - Single-beam multiple-intensity reconstruction(SBMIR)
  - Iterative wave function reconstruction(IWFR)



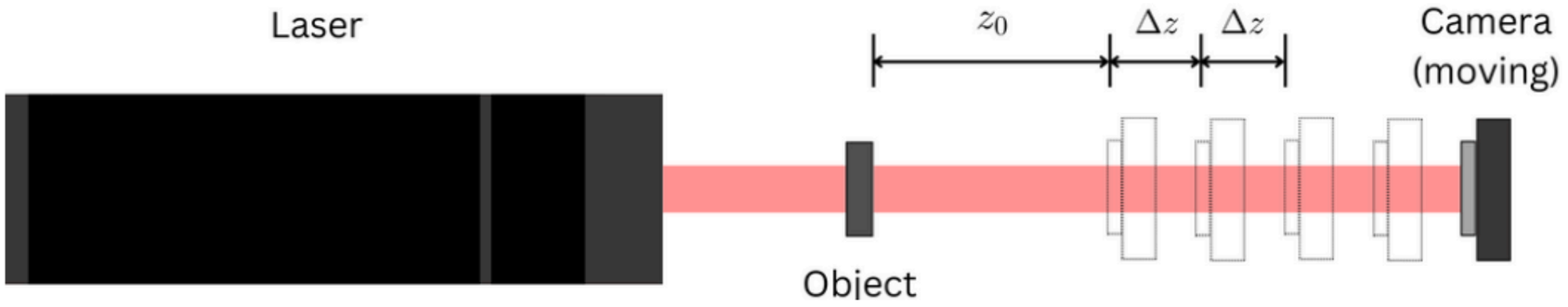
II Objectives

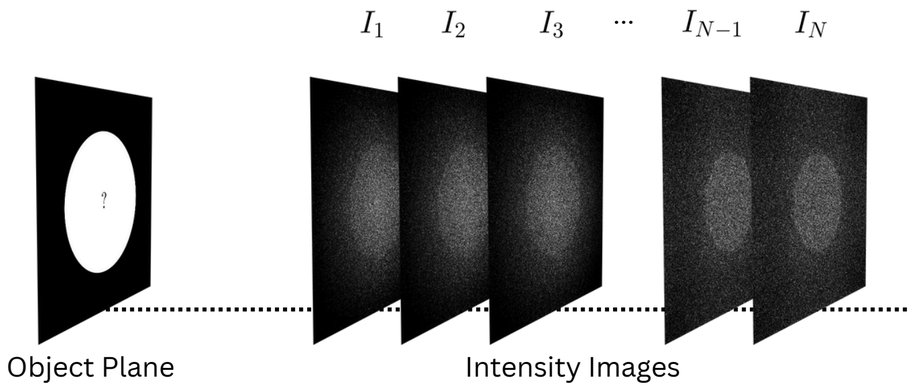
To implement two multiple plane phase retrieval methods and to compare them in terms of run time, rate of reconstruction, and quality of reconstruction.



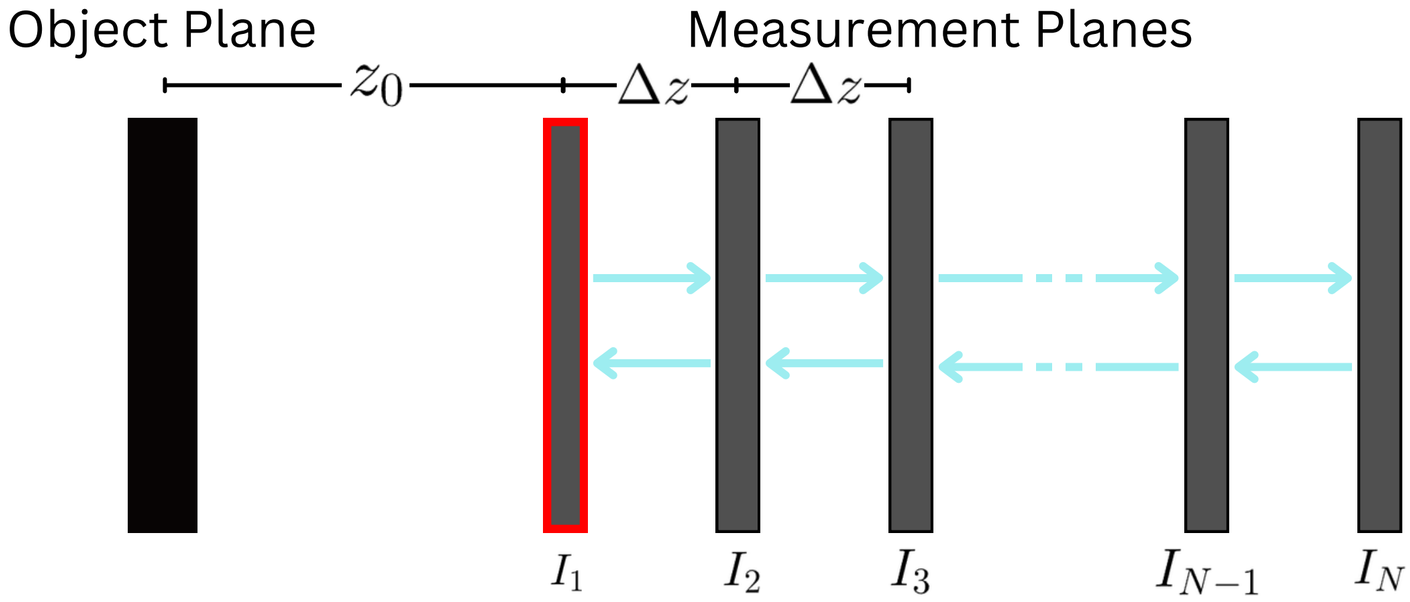
III Methodology:

Multiple plane phase retrieval: recording setup





III Methodology:
Reconstruction method - SBMIR



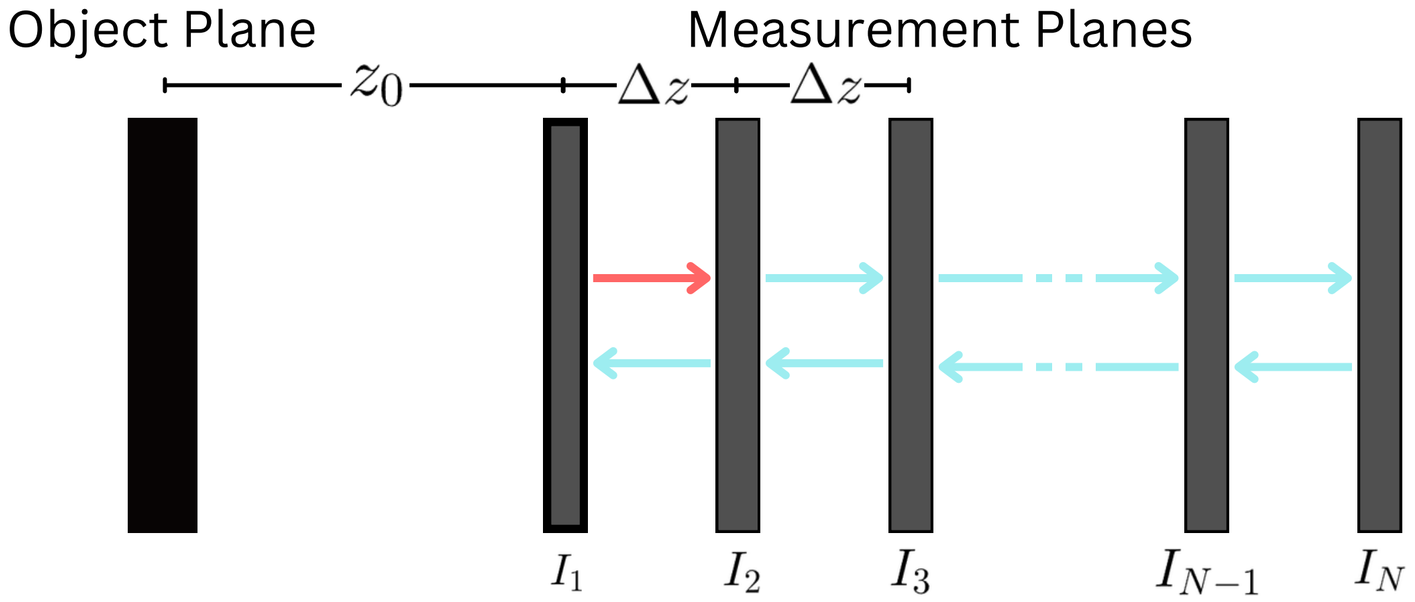
Initializations

Create the guess wave field in the first plane

$$U_1(x,y) = \sqrt{I_1(x,y)}\exp\left[i\phi_{\text{guess}}(x,y)\right]$$

$$\phi_{\text{guess}}(x,y) \in [-\pi,\pi]$$

III Methodology:
Reconstruction method - SBMIR



Initializations

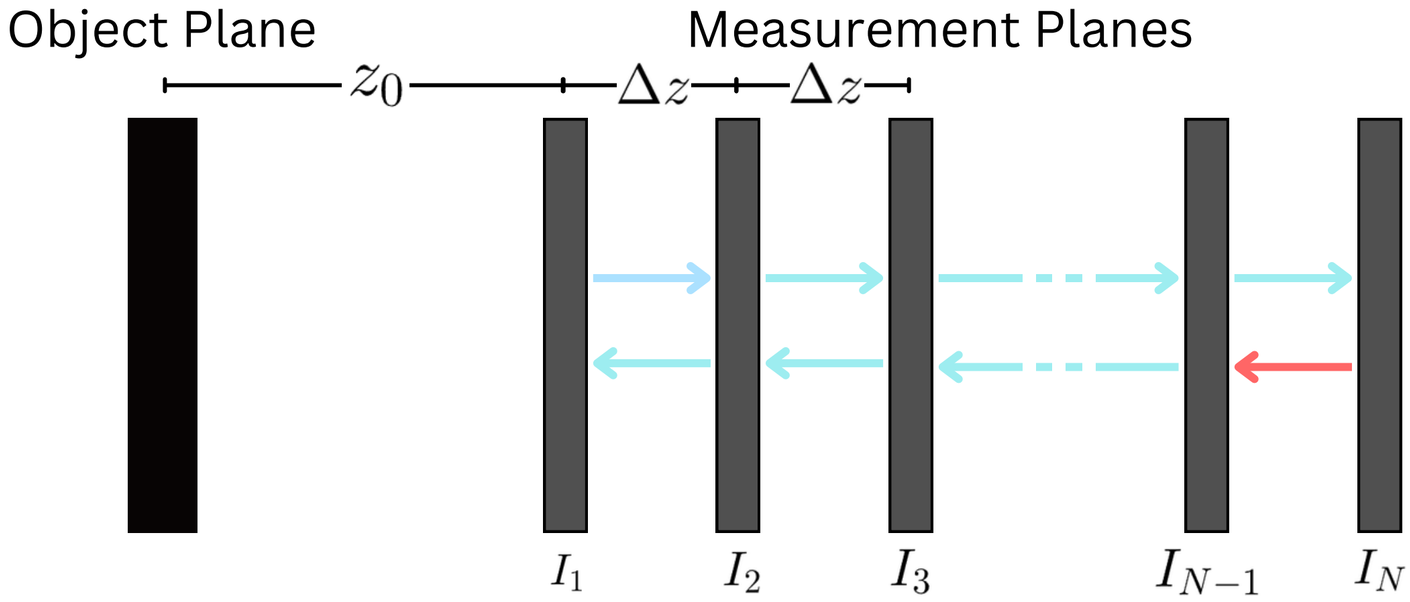
Create the guess wave field in the first plane

Iterative process

Series of propagations and amplitude replacements

$$U_2(x,y) = \mathrm{ASM}_{\Delta z}[U_1(x,y)]$$
$$U_2(x,y) = A_2(x,y)\exp[i\phi_2(x,y)]$$
$$U_2(x,y) = \sqrt{I_2(x,y)}\exp[i\phi_2(x,y)]$$

III Methodology:
Reconstruction method - SBMIR



Initializations

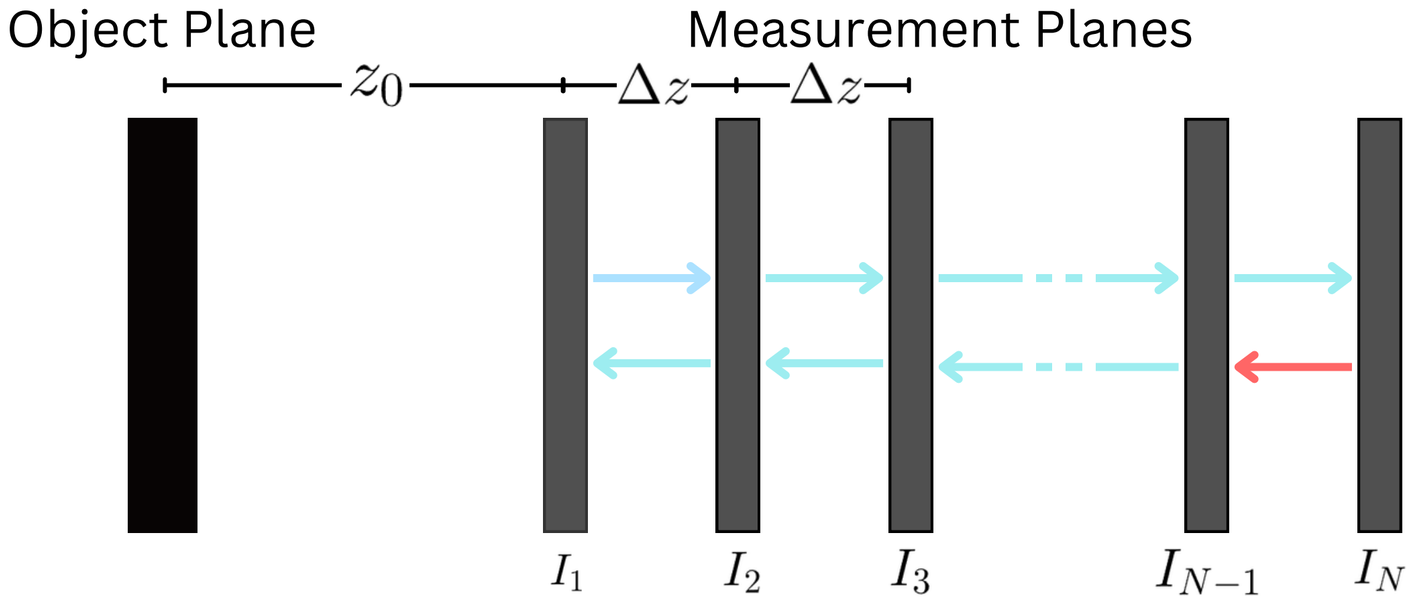
Create the guess wave field in the first plane

Iterative process

Series of propagations and amplitude replacements

$$U_{N-1}(x,y) = \mathrm{ASM}_{-\Delta z}[U_N(x,y)]$$
$$U_{N-1}(x,y) = A_{N-1}(x,y)\exp[i\phi_{N-1}(x,y)]$$
$$U_{N-1}(x,y) = \sqrt{I_{N-1}(x,y)}\exp[i\phi_{N-1}(x,y)]$$

III Methodology:
Reconstruction method - SBMIR



Initializations

Create the guess wave field in the first plane

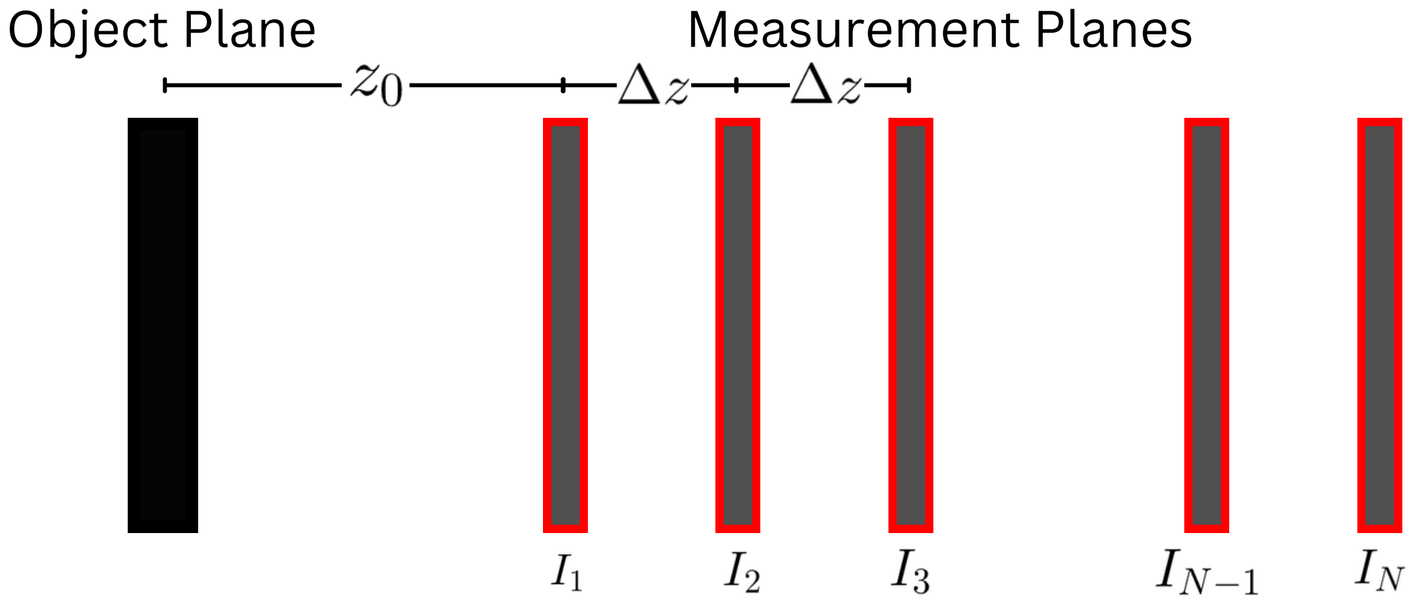
Iterative process

Series of propagations and amplitude replacements

Finalize

propagate the updated wavefront to the object plane

III Methodology:
Reconstruction method - IWFR



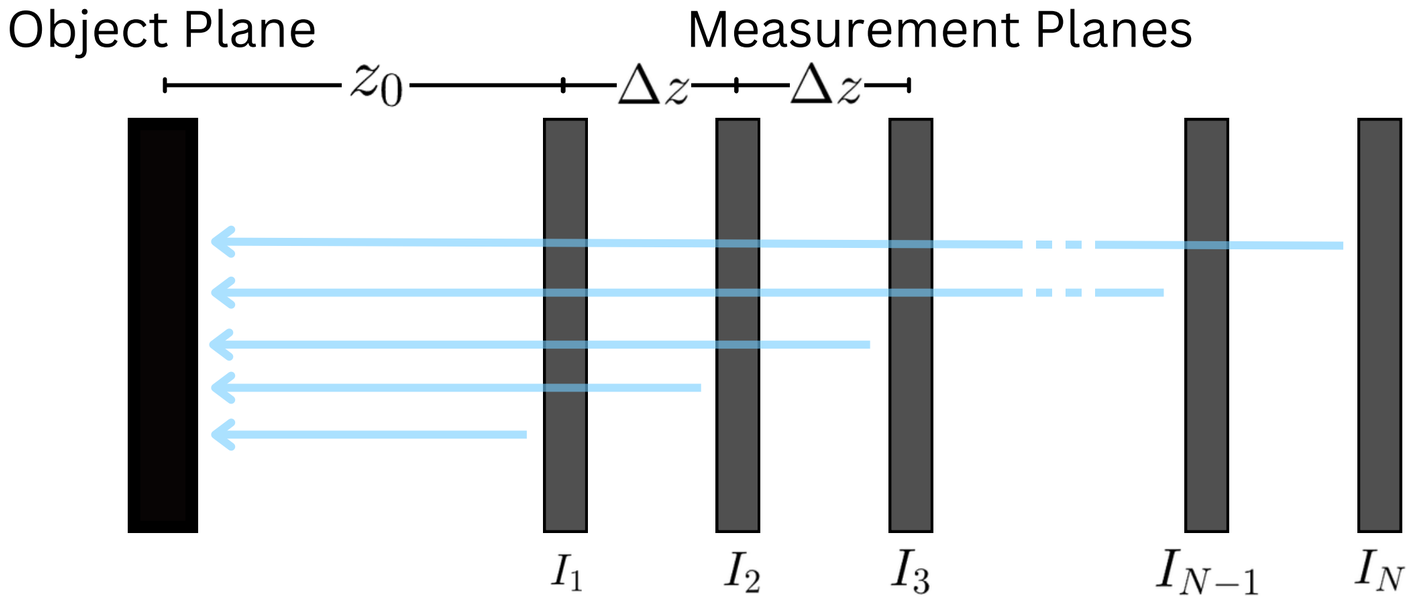
Initializations

Create the guess wave field for all planes

$$U_1(x,y) = \sqrt{I_1(x,y)}\,\exp\left[i\phi_{\text{guess}}(x,y)\right]$$

$$\phi_{\text{guess}}(x,y) \in [-\pi,\pi]$$

III Methodology:
Reconstruction method - IWFR



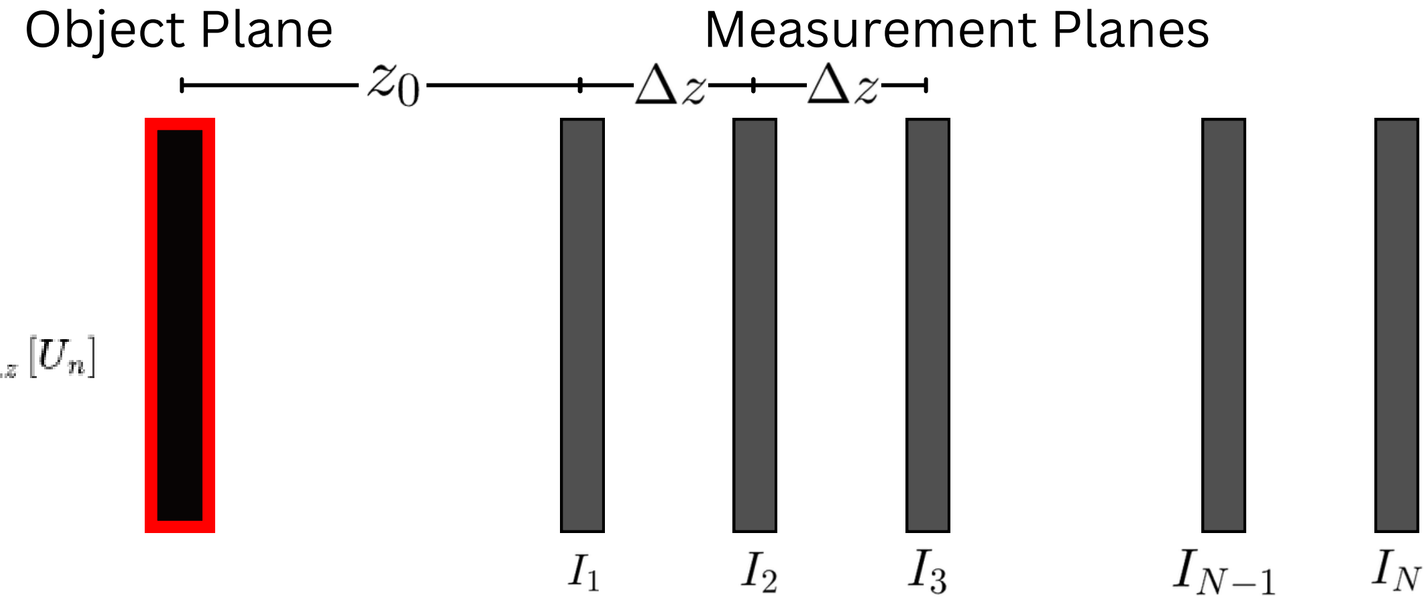
Initializations

Create the guess wave field for all planes

Iterative process

Series of propagations and amplitude replacements

III Methodology:
Reconstruction method - IWFR



$$U_0(x,y) = \frac{1}{N}\sum_{n=1}^{N} \mathrm{prop}_{-\Delta z}\left[U_n\right]$$

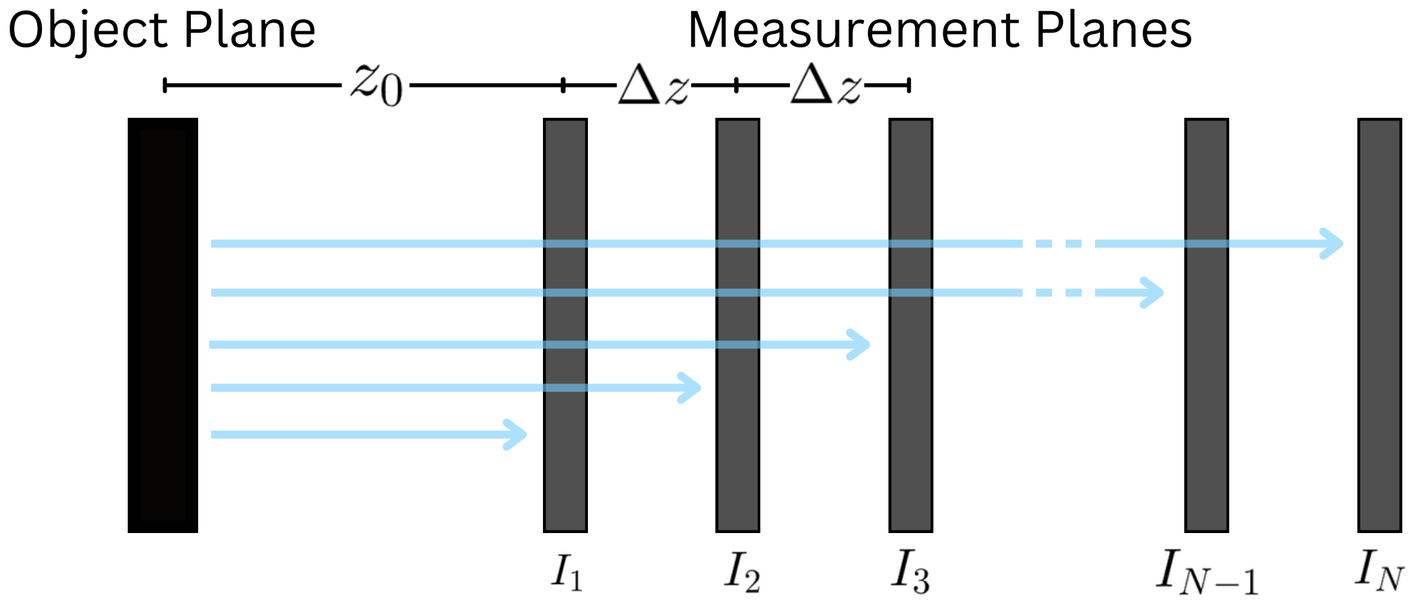
Initializations

Create the guess wave field for all planes

Iterative process

Series of propagations and amplitude replacements

III Methodology:
Reconstruction method - IWFR



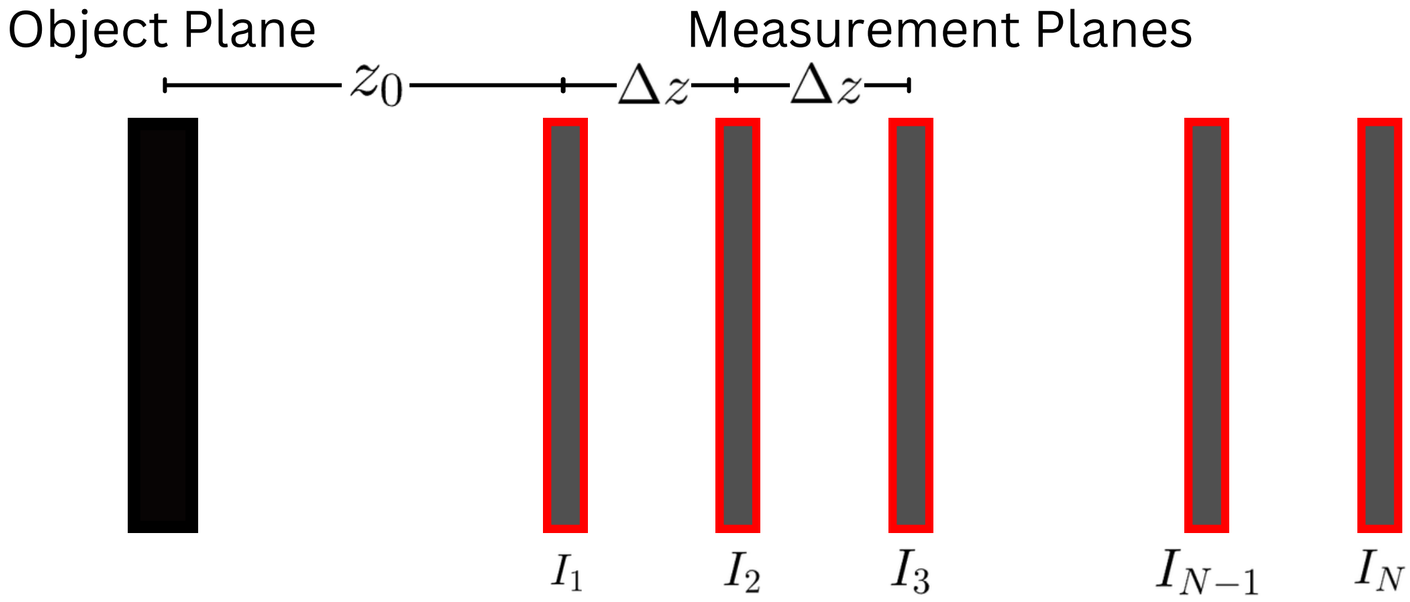
Initializations

Create the guess wave field for all planes

Iterative process

Series of propagations and amplitude replacements

III Methodology:
Reconstruction method - IWFR



Initializations

Create the guess wave field for all planes

Iterative process

Series of propagations and amplitude replacements

$$U_n(x,y) = A_n(x,y)\exp\left[i\phi_n(x,y)\right]$$

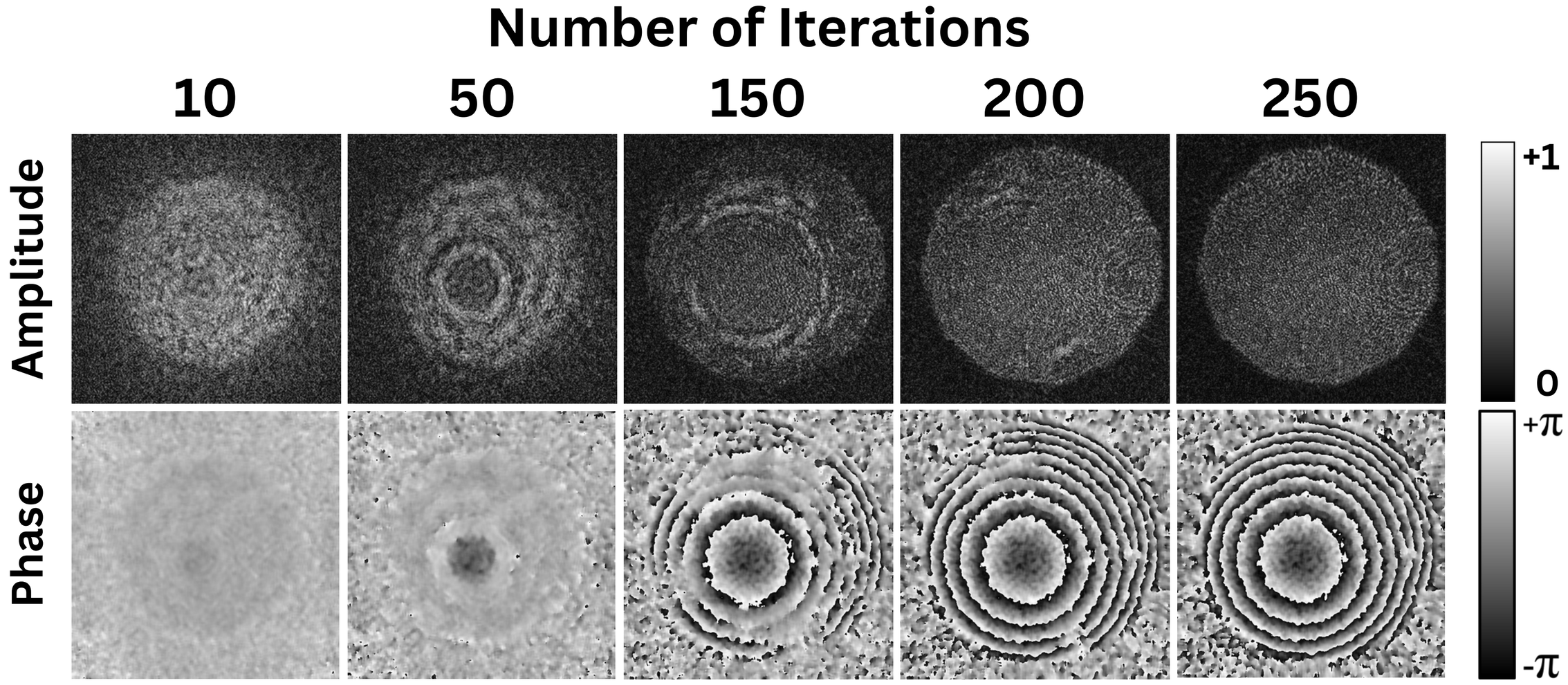
$$U_n(x,y) = \sqrt{I_n(x,y)}\exp\left[i\phi_n(x,y)\right]$$

III Methodology: Reconstruction methods

	IWFR	SBMIR
Propagations per iteration	2N propagations	2(N-1) propagations
Constraints	Applied for each propagation but becomes part of an average	Applied for each propagation

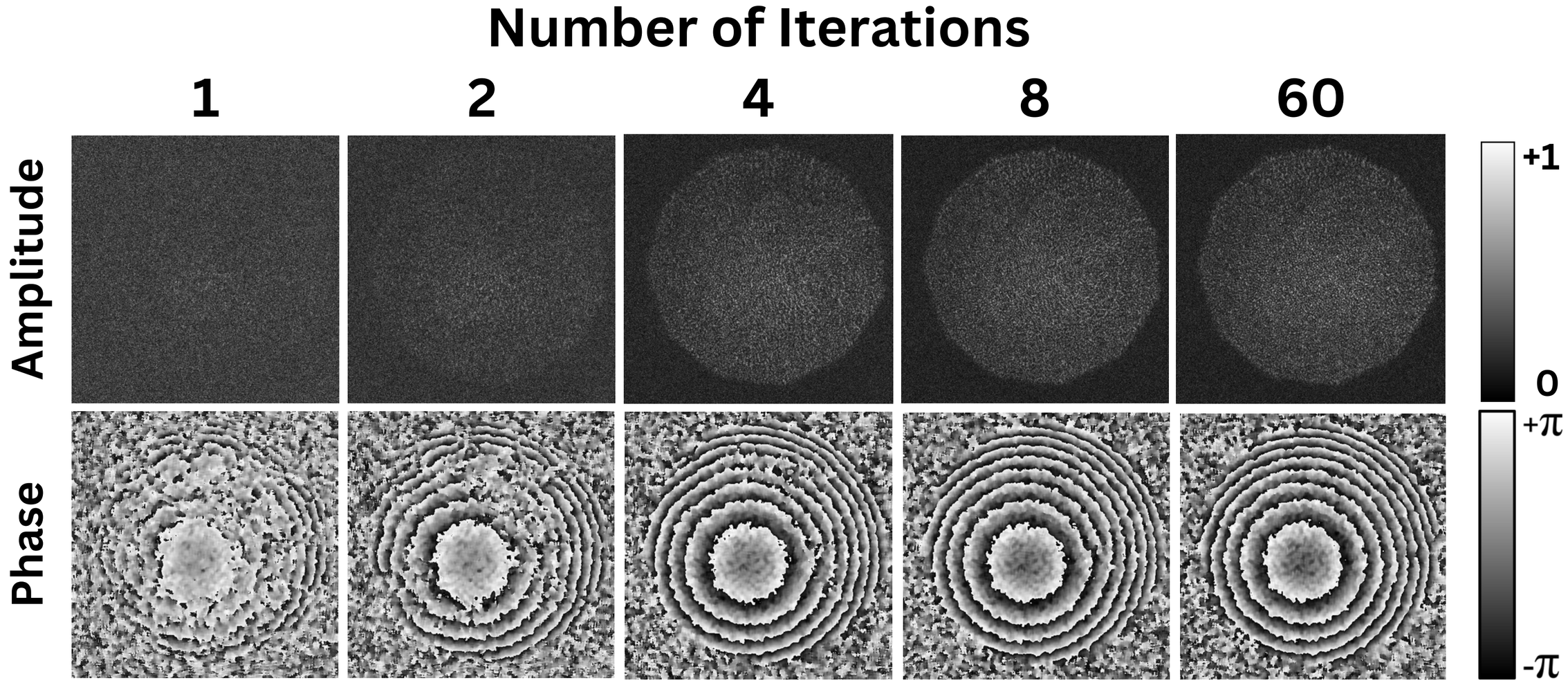
IV Results and discussion:
Reconstructions using IWFR

Test object:
Decagon aperture and a lens
Number of intensity measurements: 10



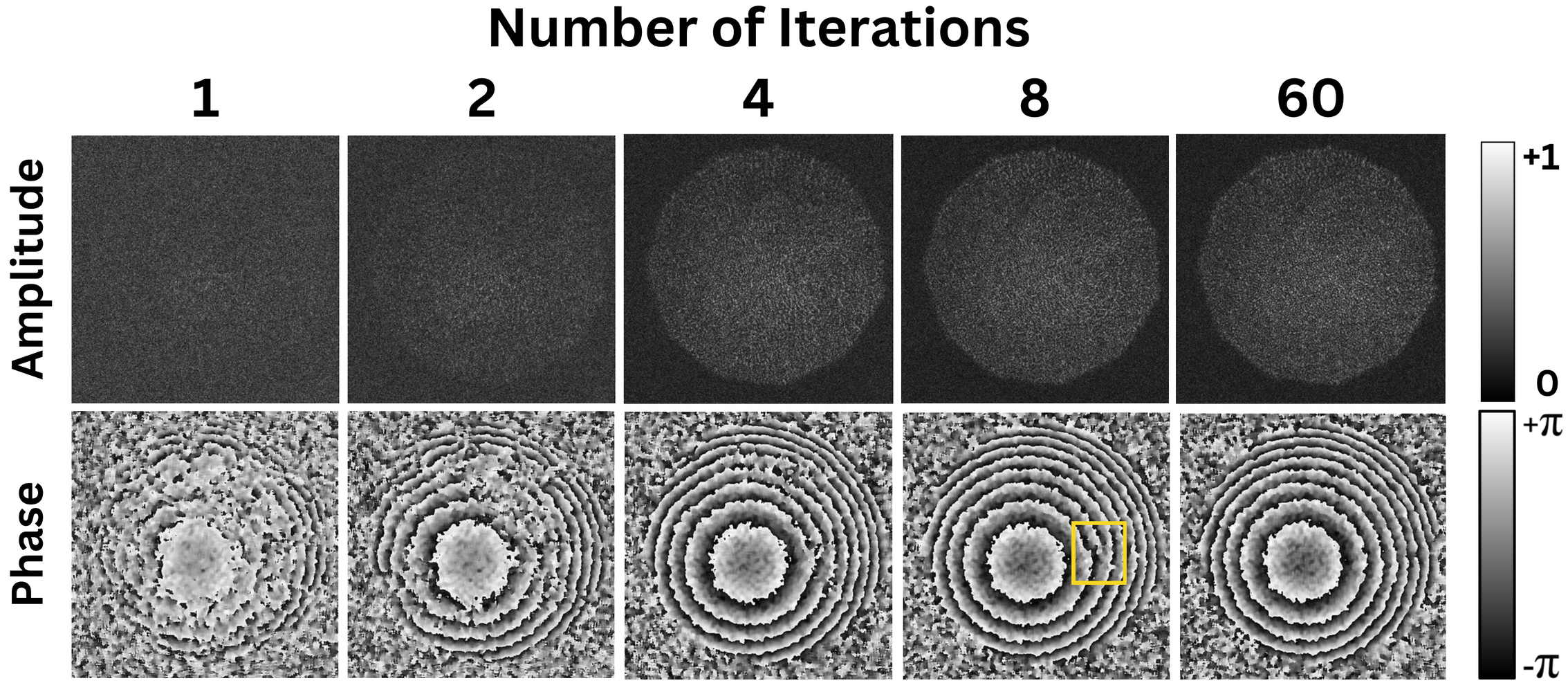
IV Results and discussion:
Reconstructions using SBMIR

Test object:
Decagon aperture and a lens
Number of intensity measurements: 10



IV Results and discussion:
Reconstructions using SBMIR

Test object:
Decagon aperture and a lens
Number of intensity measurements: 10



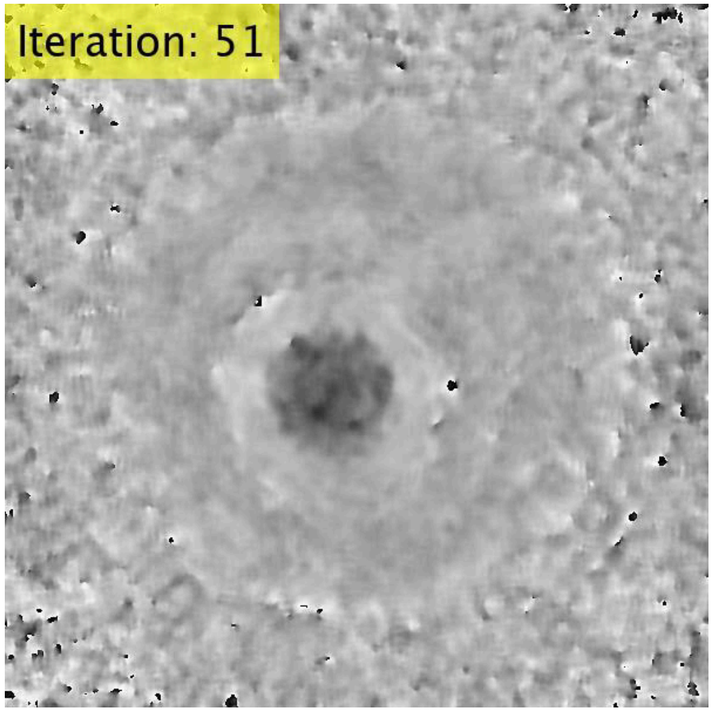
IV Results and discussion:
Reconstructions using SBMIR

Test object:
Decagon aperture and a lens
Number of intensity measurements: 10

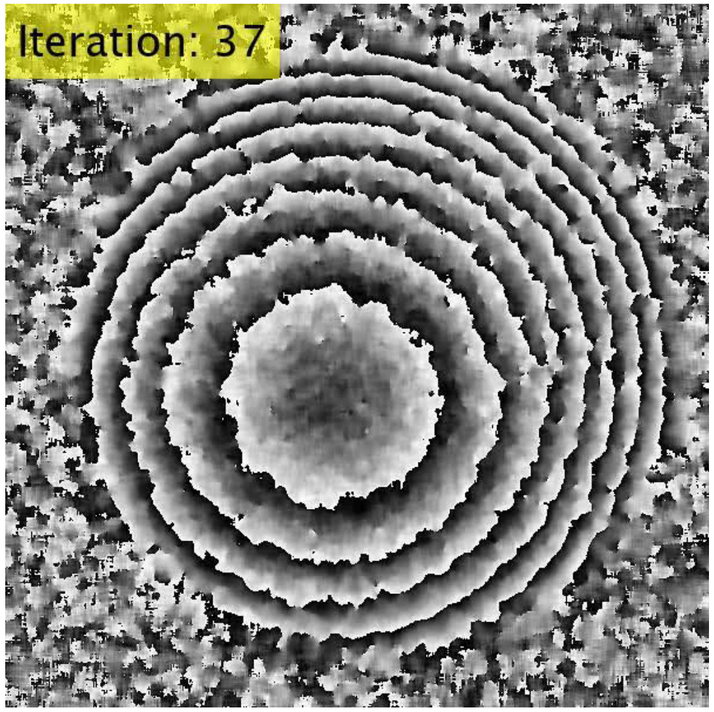
	IWFR	SBMIR
Run time (500 iterations)	204.23 seconds	154.19 seconds
Iterations required to reconstruct		
Visible decagon:	150 iterations	4 iterations
Phase error removal:	480 iterations	60 iterations

V Conclusions:

- Implemented the use of both IWFR and SBMIR method to reconstruct the target object
- Shown that the SBMIR algorithm was able to reconstruct the object faster both in terms of number of iterations and run time



IWFR



SBMIR

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Thank you for listening!