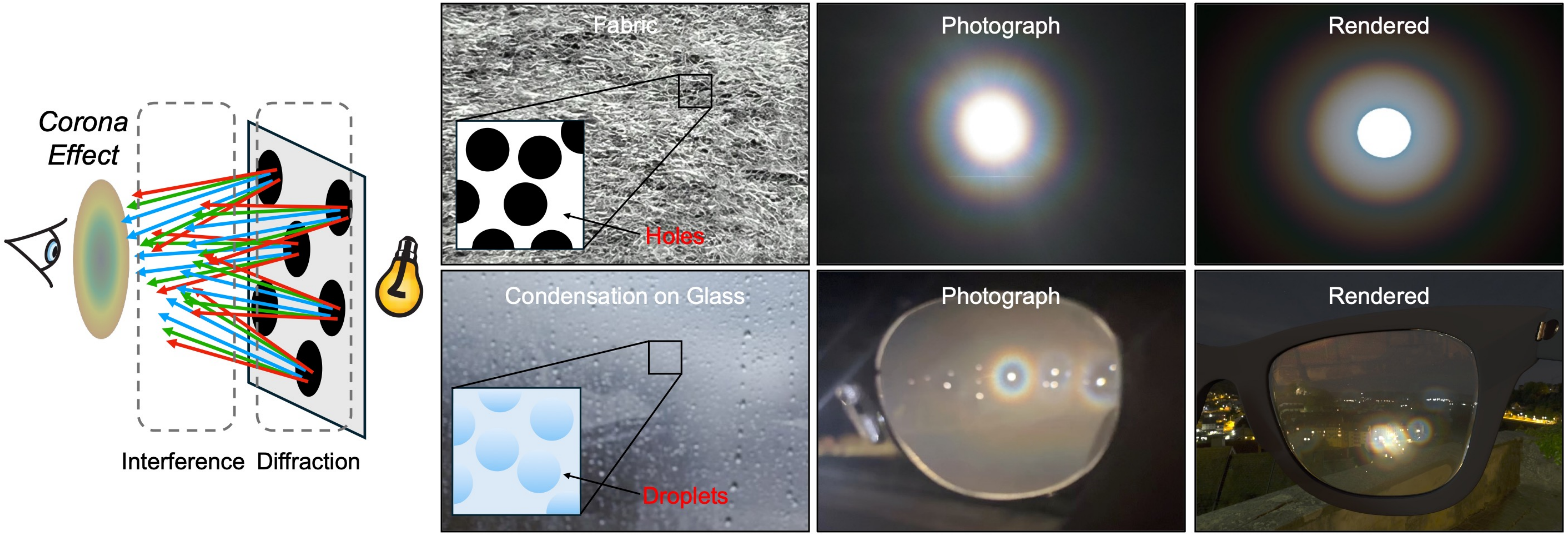
A Wave-optics BSDF for Correlated Scatterers



Ruomai Yang   Juhyeon Kim   Adithya Pediredla   Wojciech Jarosz

DARTMOUTH
VISUAL COMPUTING LAB

Corona Effect

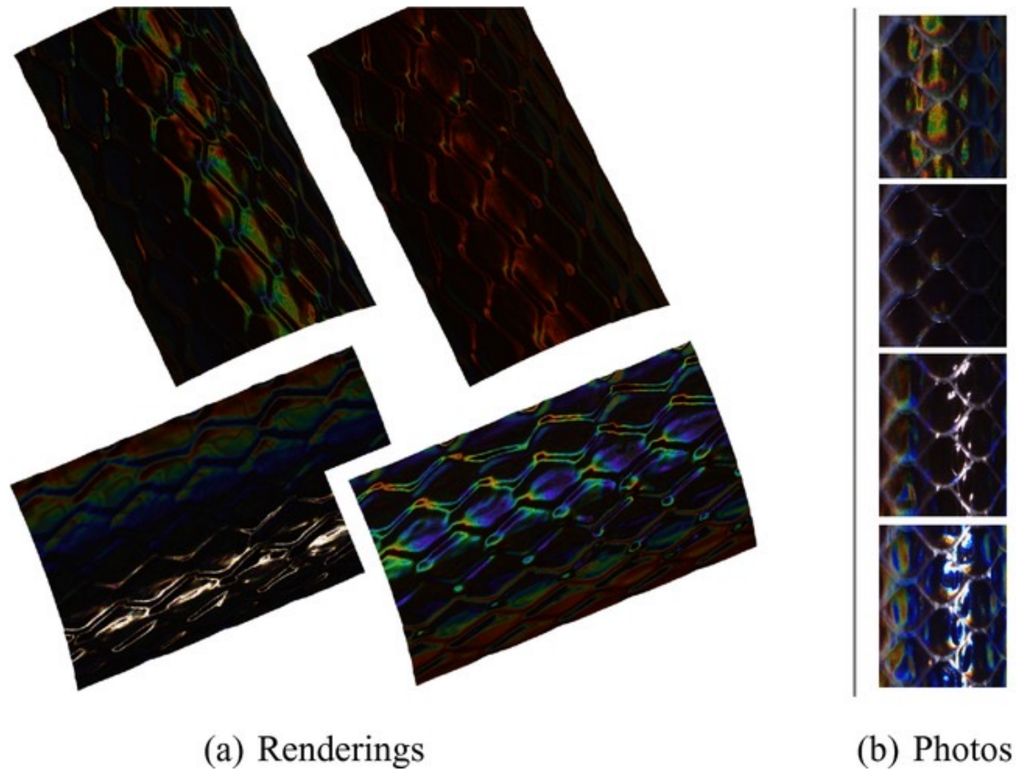
Previous work

Diffraction on surfaces

- Surface roughness generated by Gaussian random process
- Scratches on metal
- Regular pattern (compact discs, biological nanostructures)

Stam 1999

Werner 2017



Dhillon et al. 2014

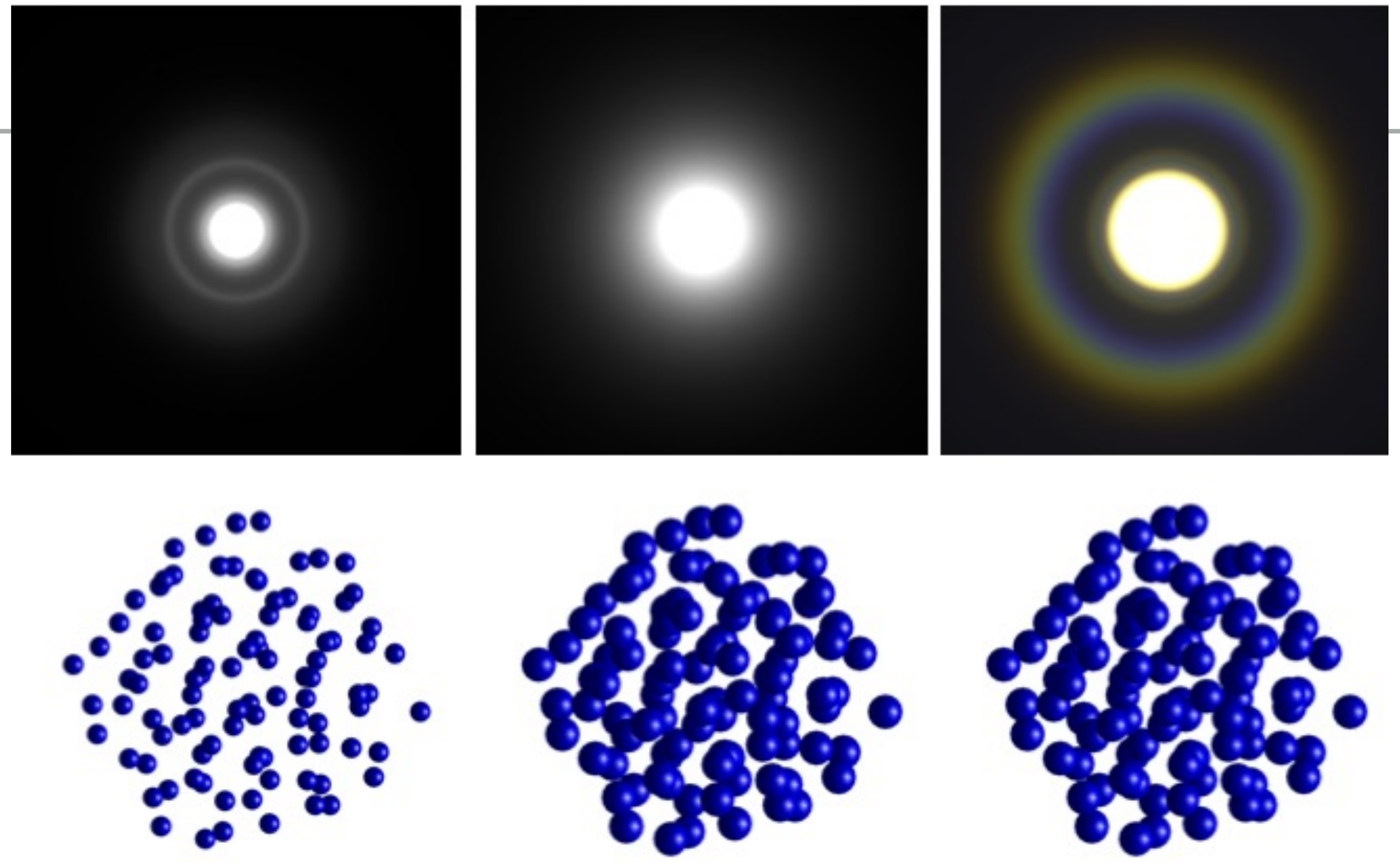
Previous work

Diffraction on surfaces

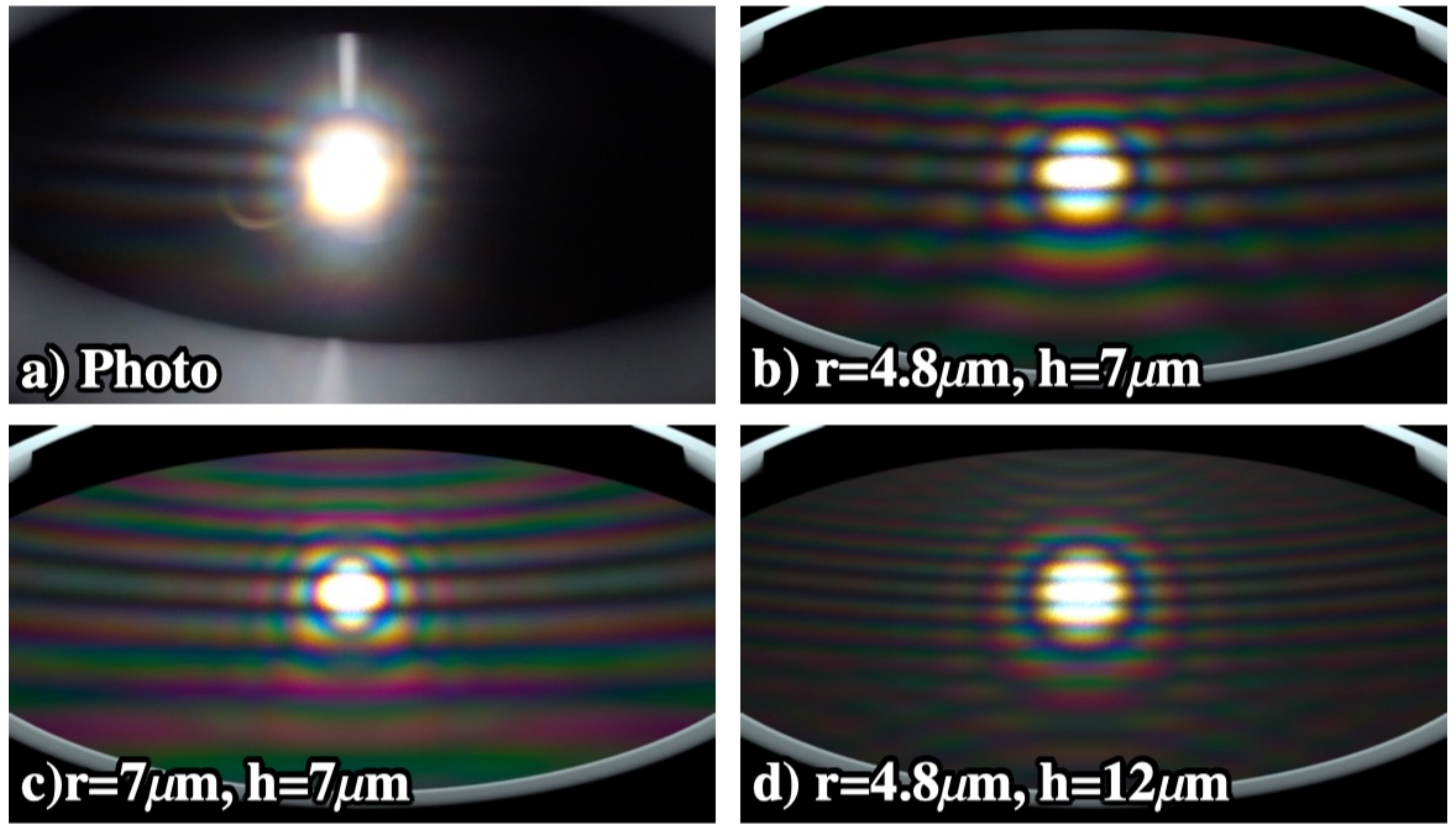
- Surface roughness generated by Gaussian random process
- Scratches on metal
- Regular pattern (compact discs, biological nanostructures)

Corona effects

- Bulk scattering
- Quetelet ring



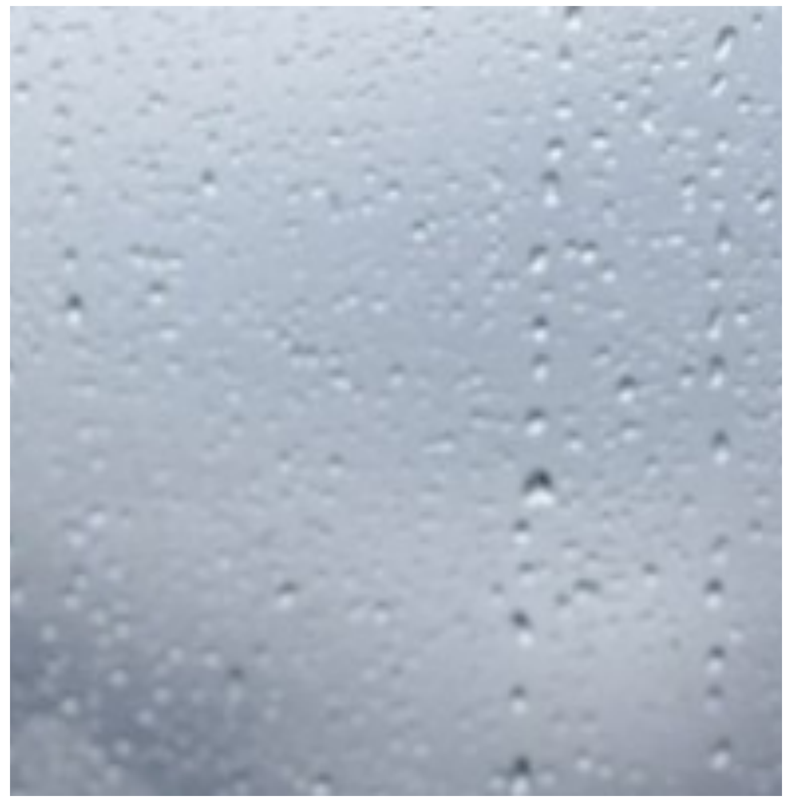
Guo et al. 2021



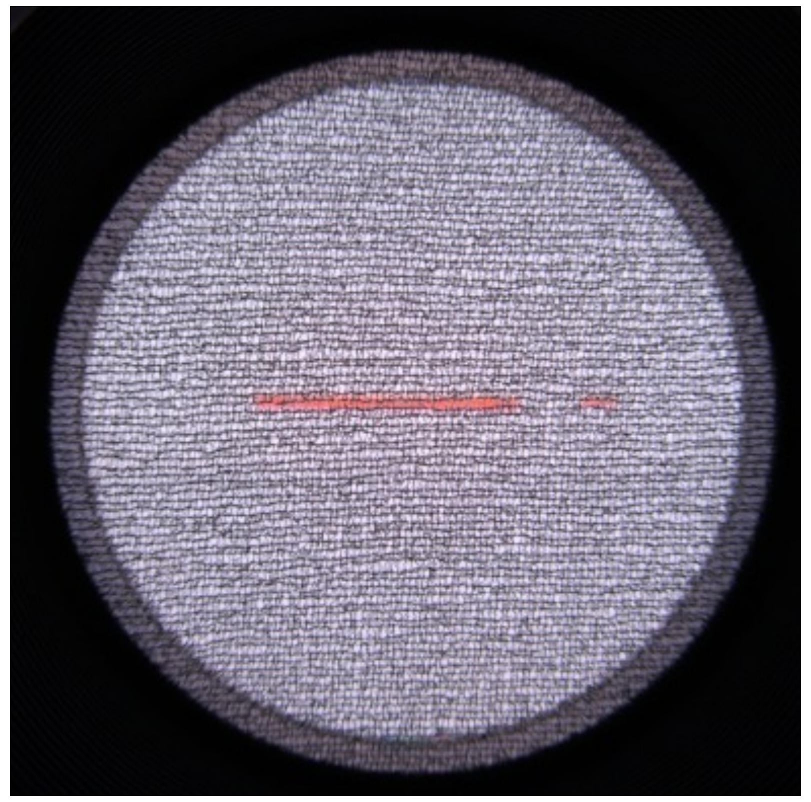
Xia et al 2023

Materials that cause Corona Effect

Random, but **Non-overlapping** : **correlated**



Condensation

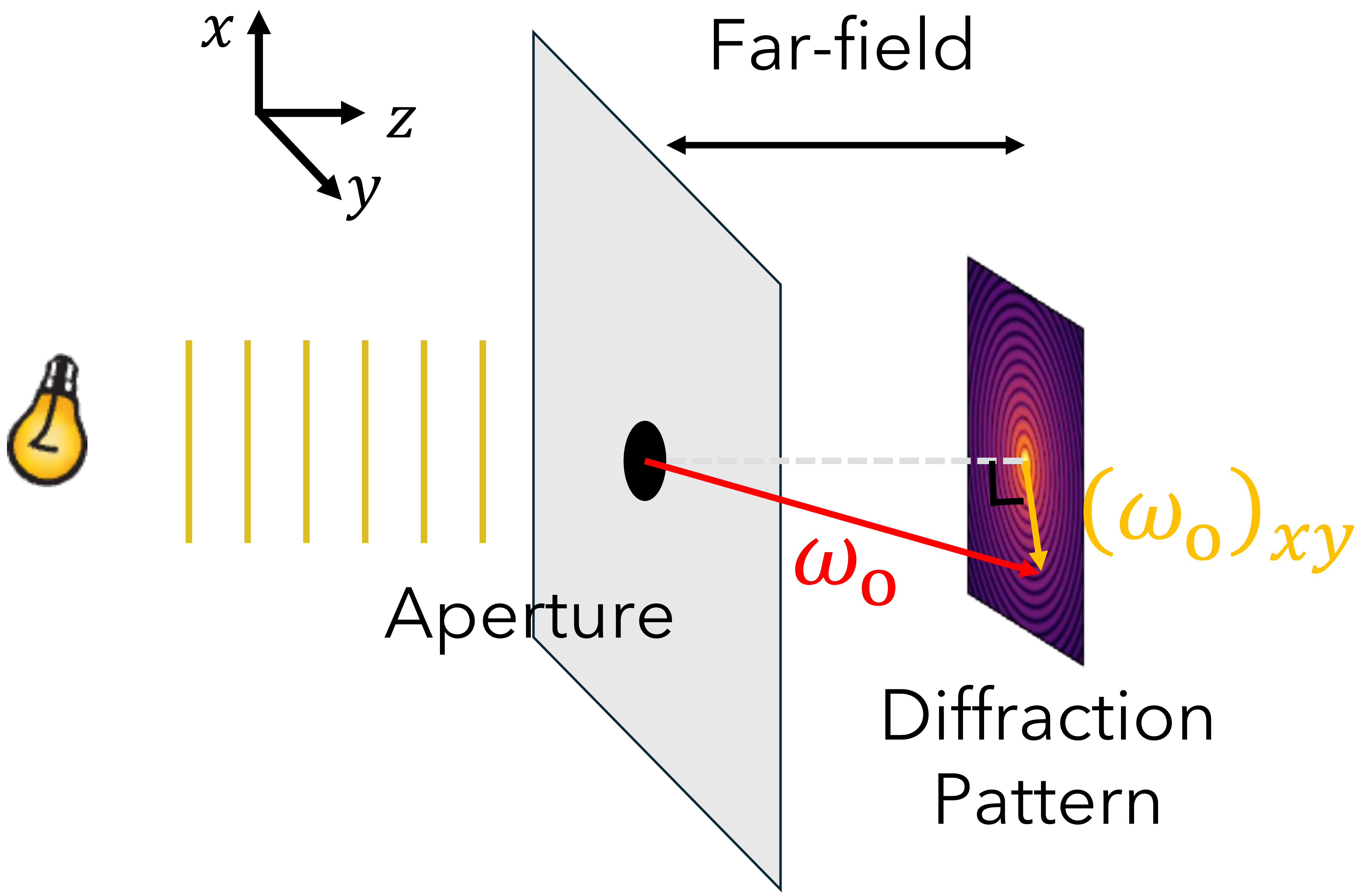


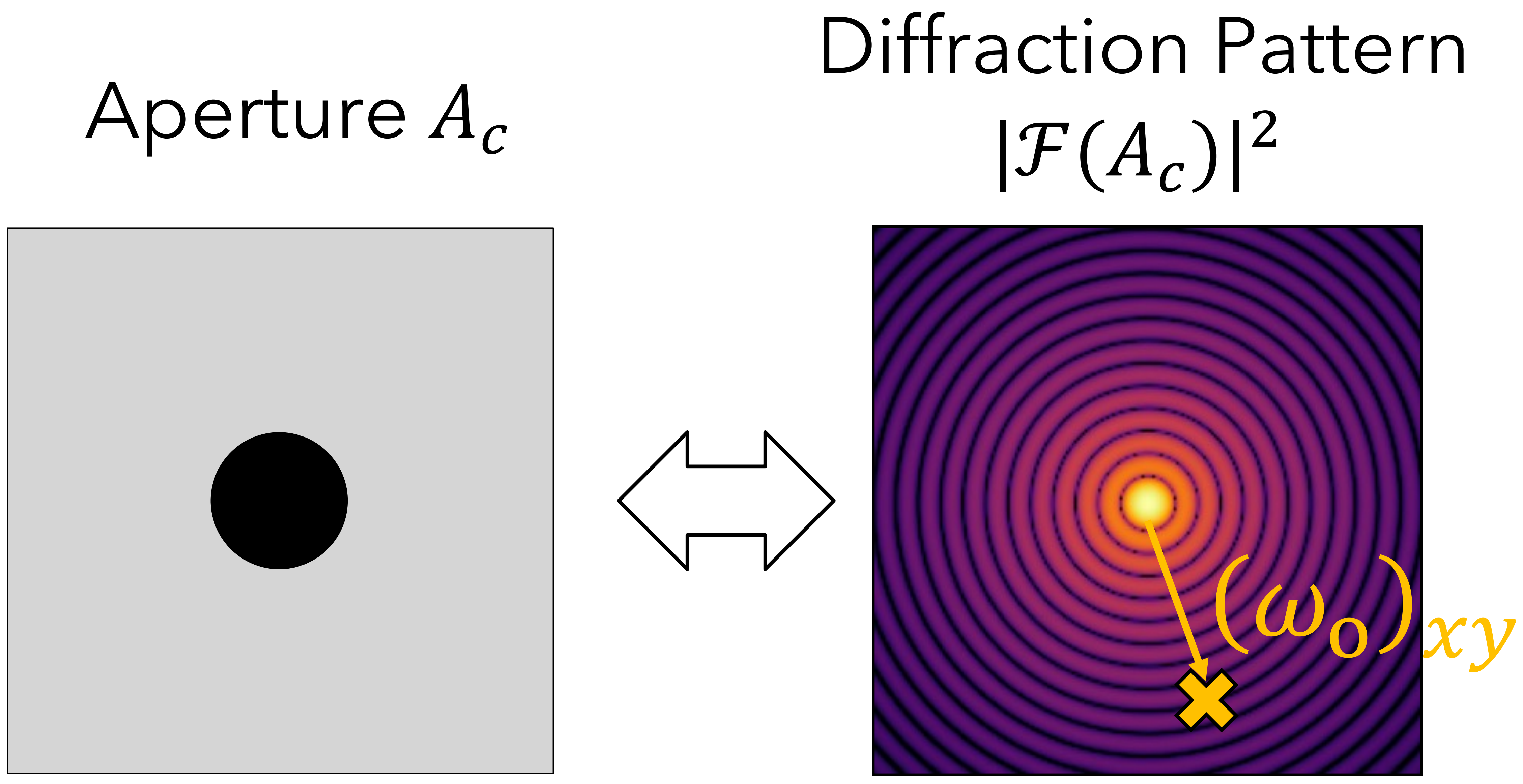
Fabric

Fabric

Proposed Method

Preliminary: Fraunhofer Diffraction

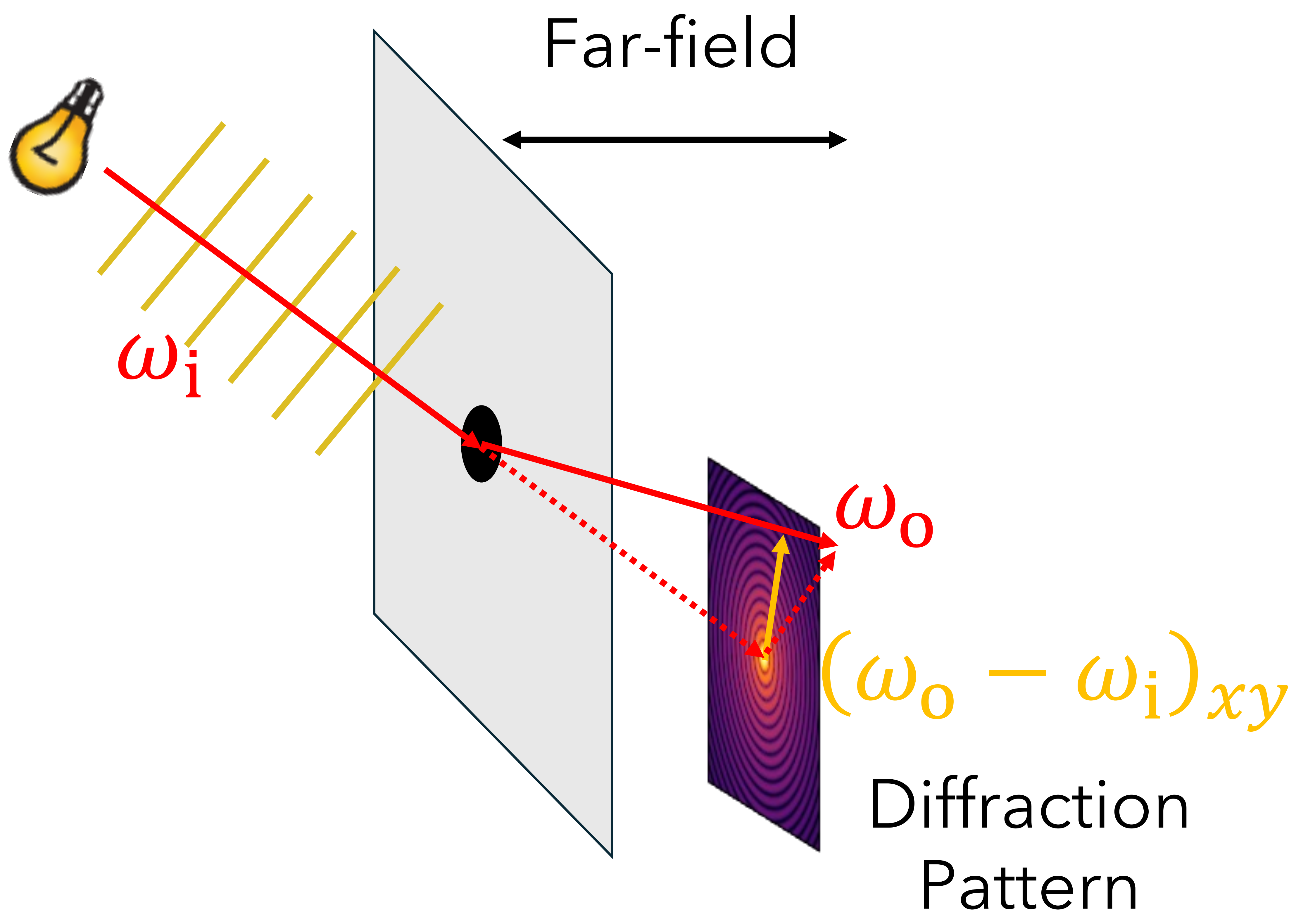


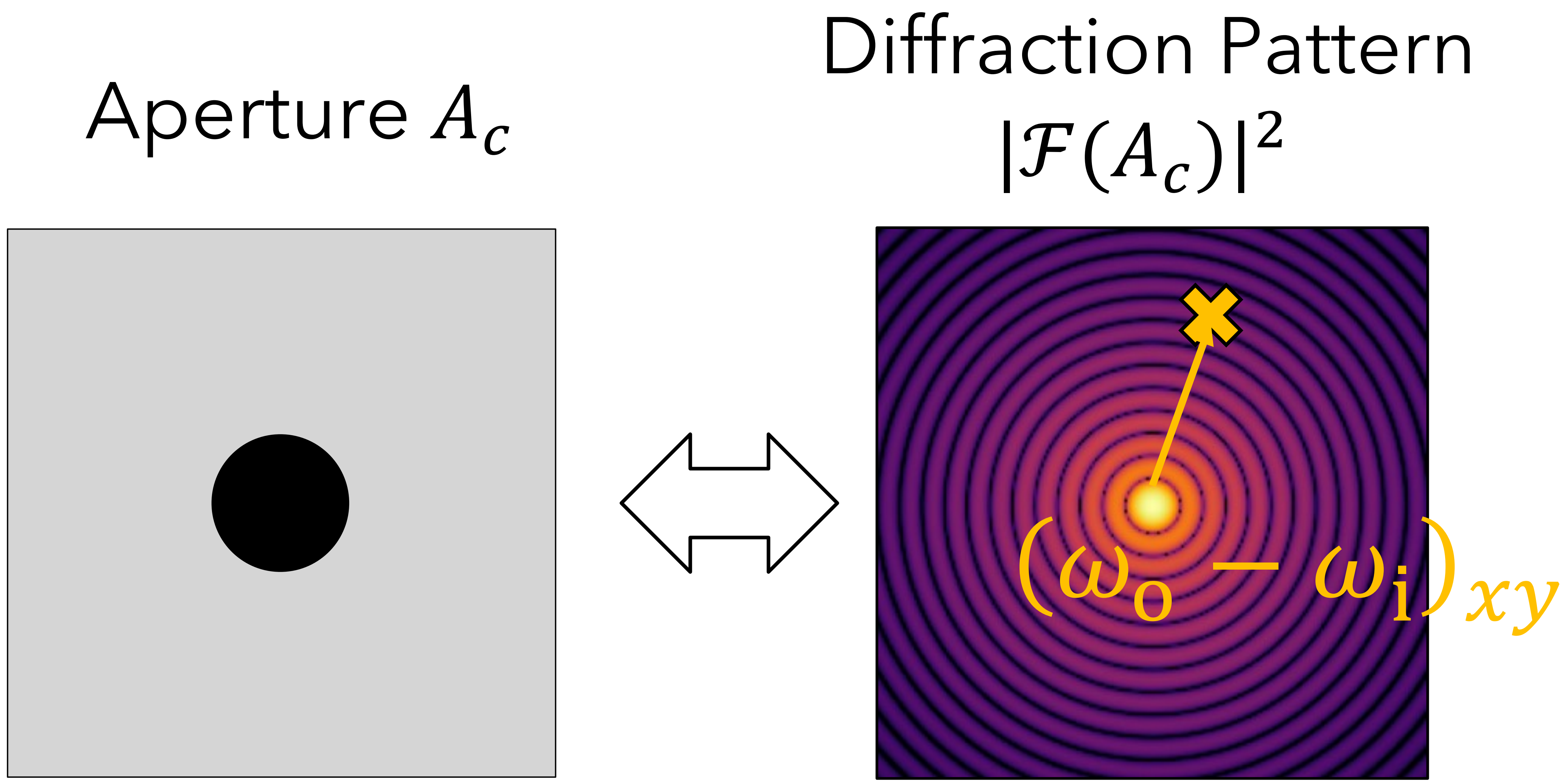


$\mathcal{F}$: Fourier Transform

$$\text{Intensity in } \omega_o = |\mathcal{F}(A_c)|^2[(\omega_o)_{xy}]$$

Diffraction as BSDF



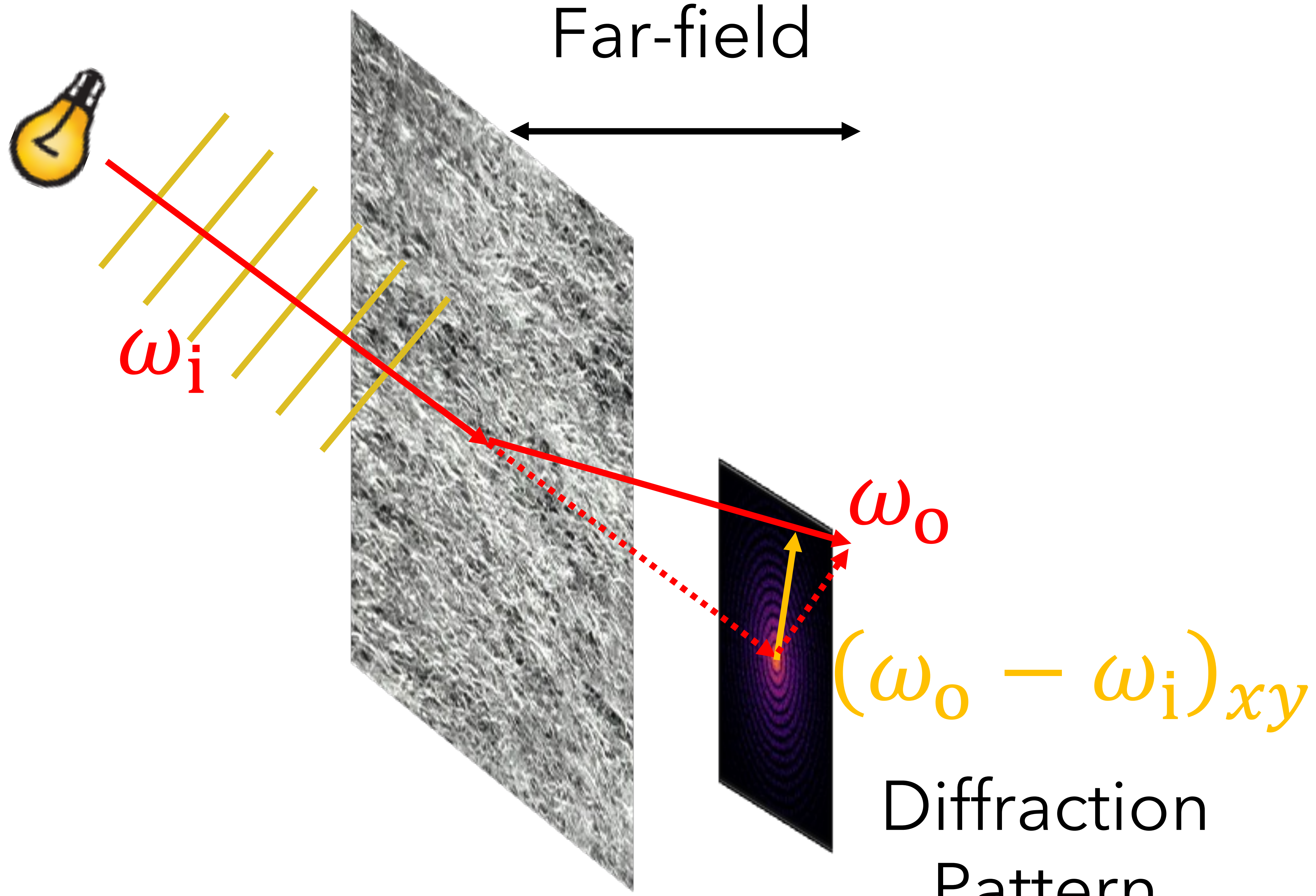


$\mathcal{F}$: Fourier Transform

BSDF Formulation

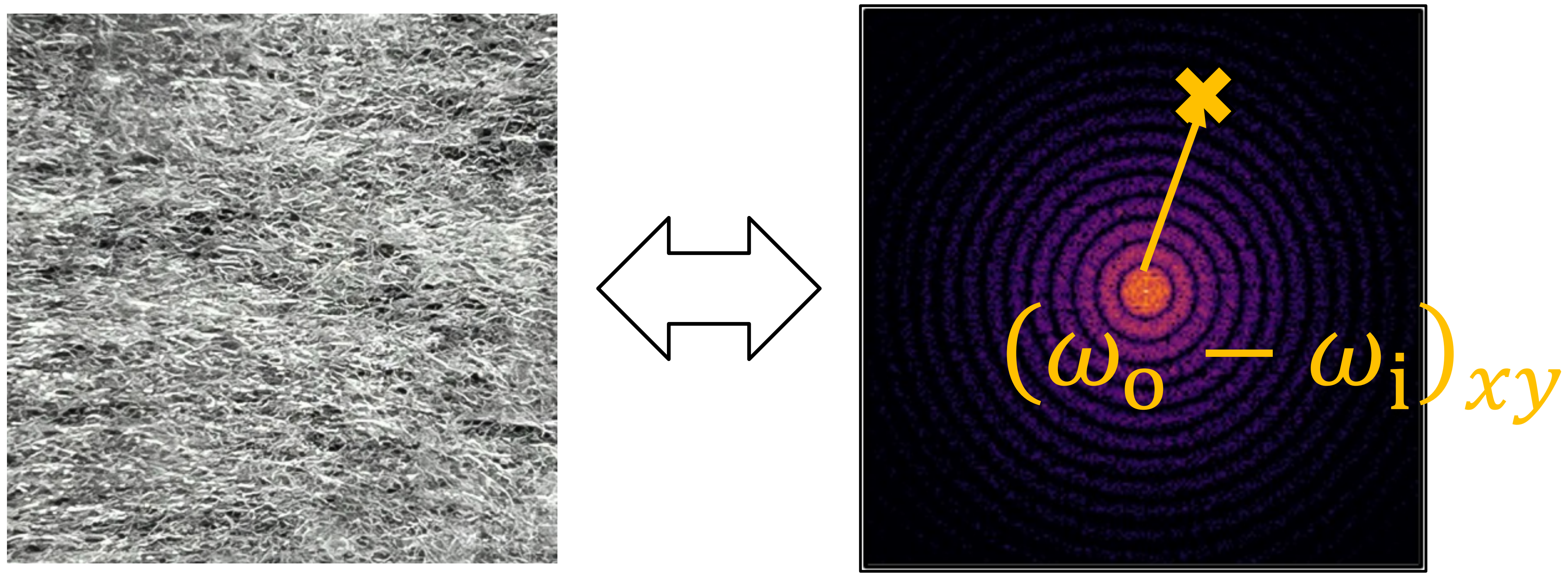
$$f_r(\omega_{\mathrm{i}}, \omega_{\mathrm{o}}) = |\mathcal{F}(A_c)|^2[(\omega_{\mathrm{o}} - \omega_{\mathrm{i}})_{xy}]$$

Diffraction as BSDF



Arbitrary Aperture A_c

Diffraction Pattern $|\mathcal{F}(A_c)|^2$

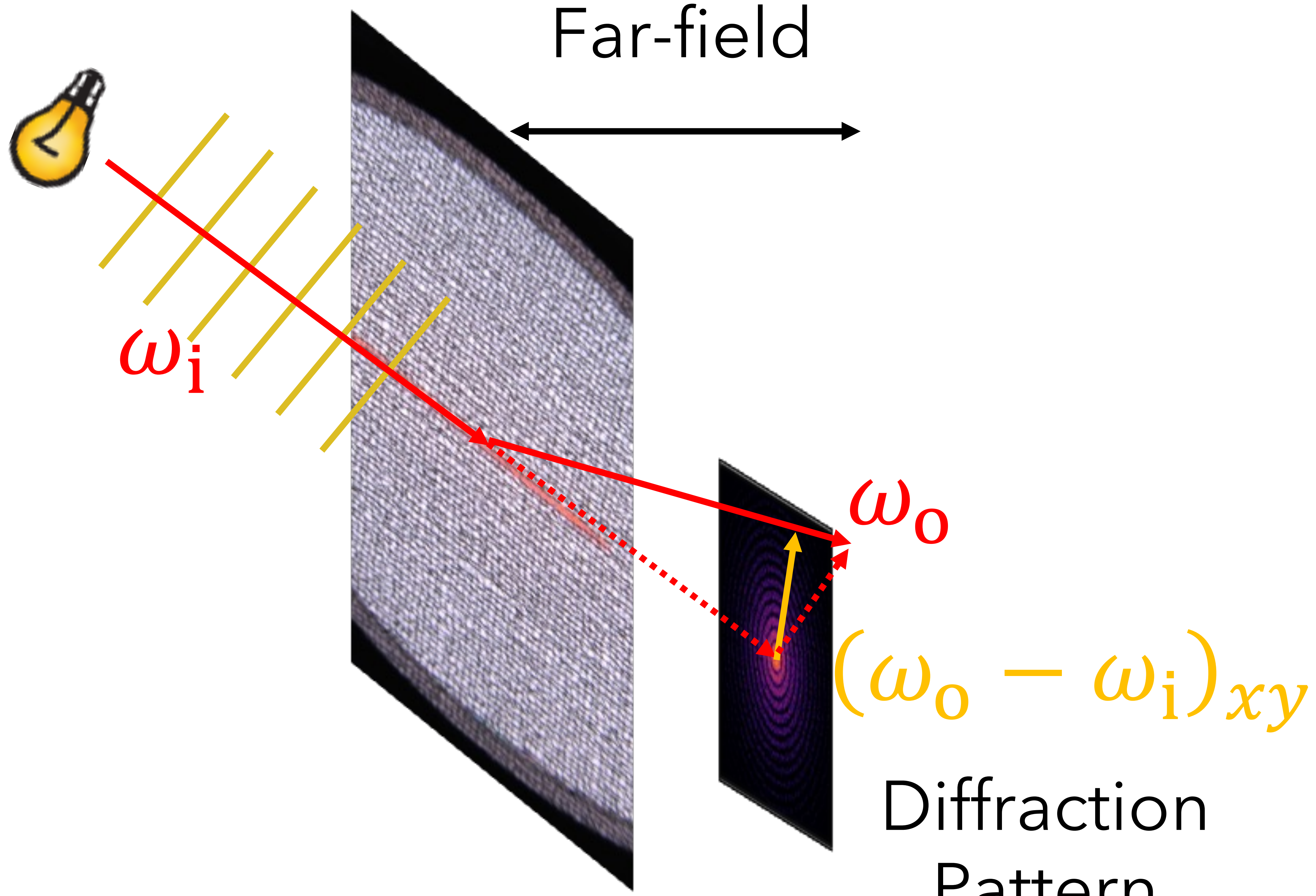


$\mathcal{F}$: Fourier Transform

BSDF Formulation

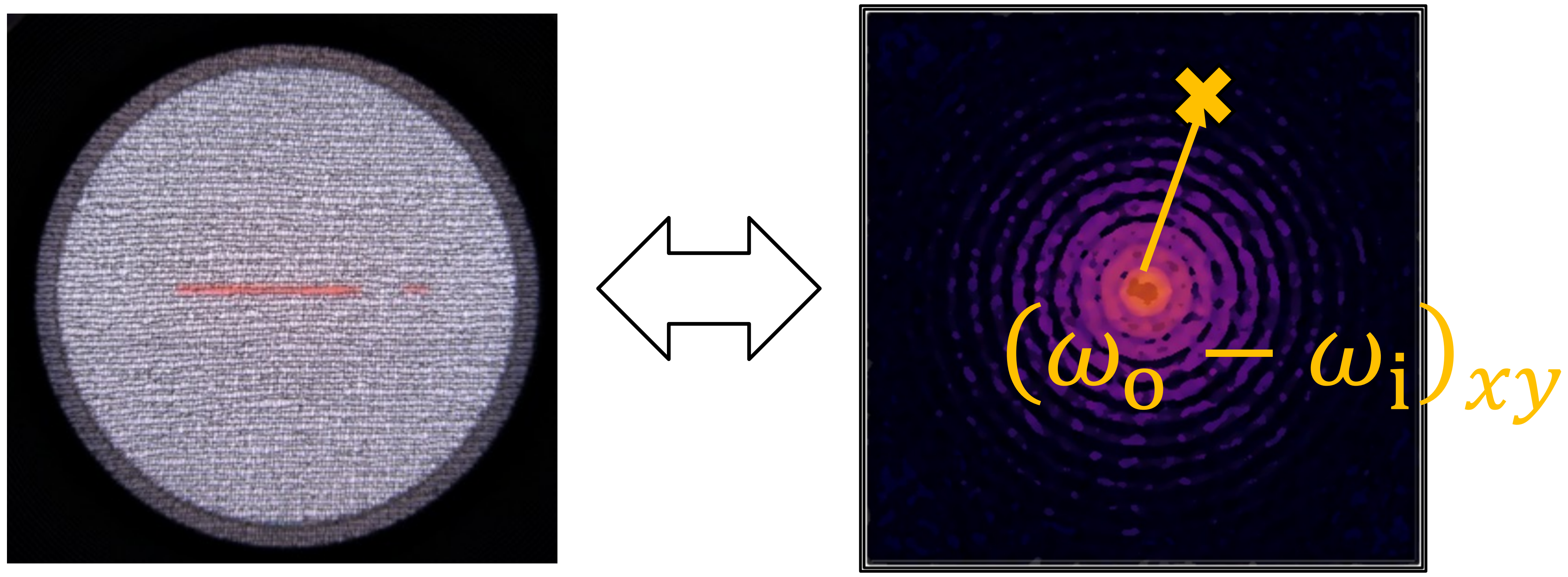
$$f_r(\omega_\mathrm{i}, \omega_\mathrm{o}) = |\mathcal{F}(A_c)|^2[(\omega_\mathrm{o} - \omega_\mathrm{i})_{xy}]$$

Diffraction as BSDF



Arbitrary Aperture A_c

Diffraction Pattern $|\mathcal{F}(A_c)|^2$

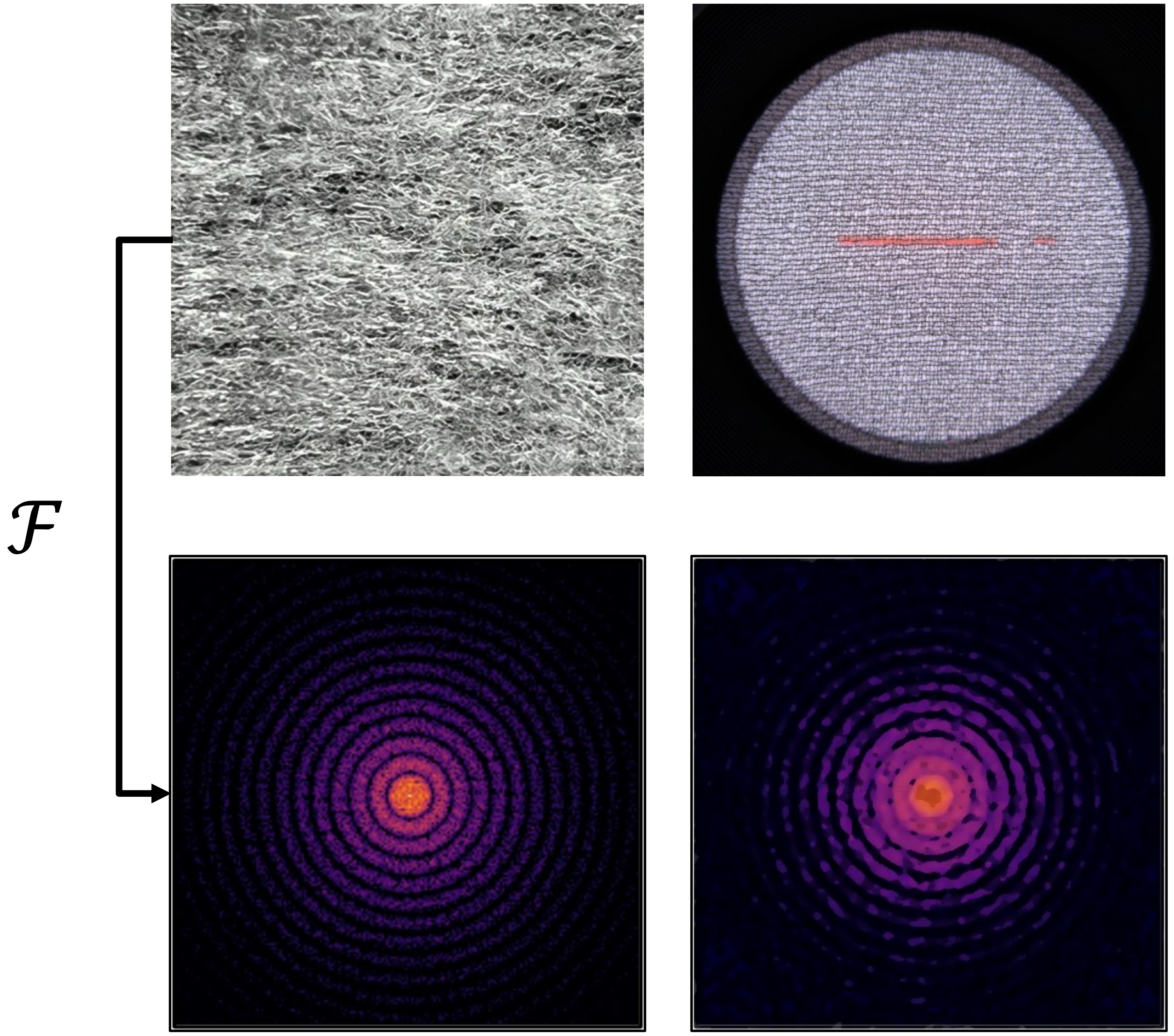


$\mathcal{F}$: Fourier Transform

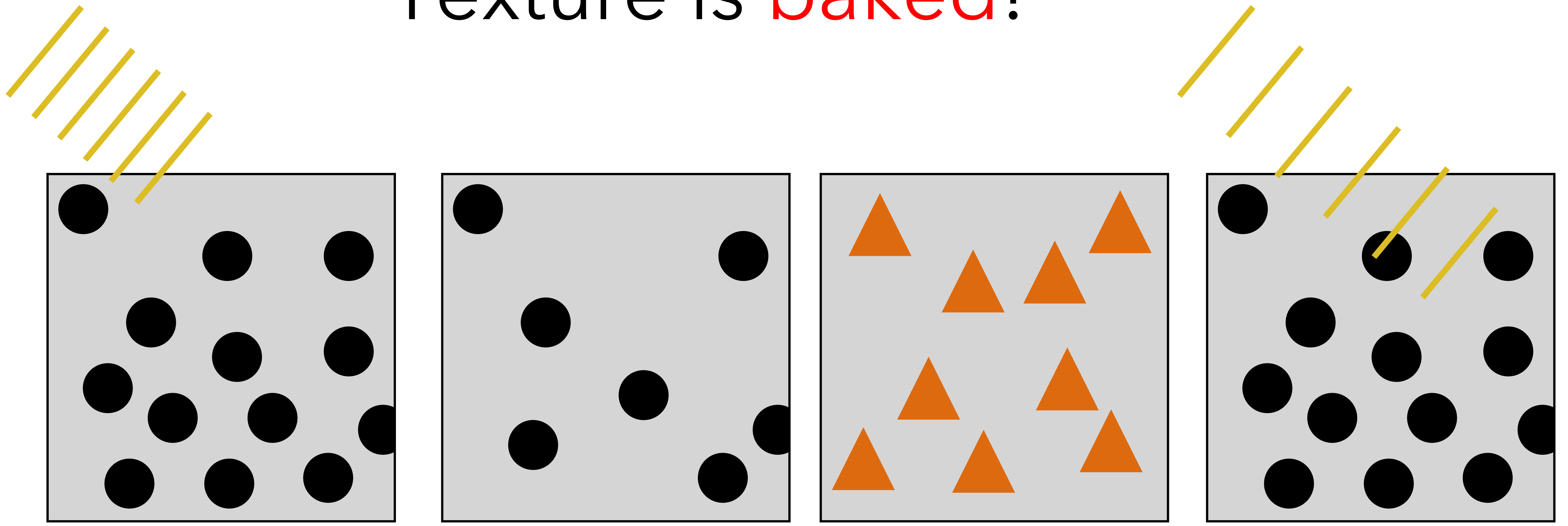
BSDF Formulation

$$f_r(\omega_{\mathrm{i}}, \omega_{\mathrm{o}}) = |\mathcal{F}(A_c)|^2[(\omega_{\mathrm{o}} - \omega_{\mathrm{i}})_{xy}]$$

Diffraction from Arbitrary Aperture



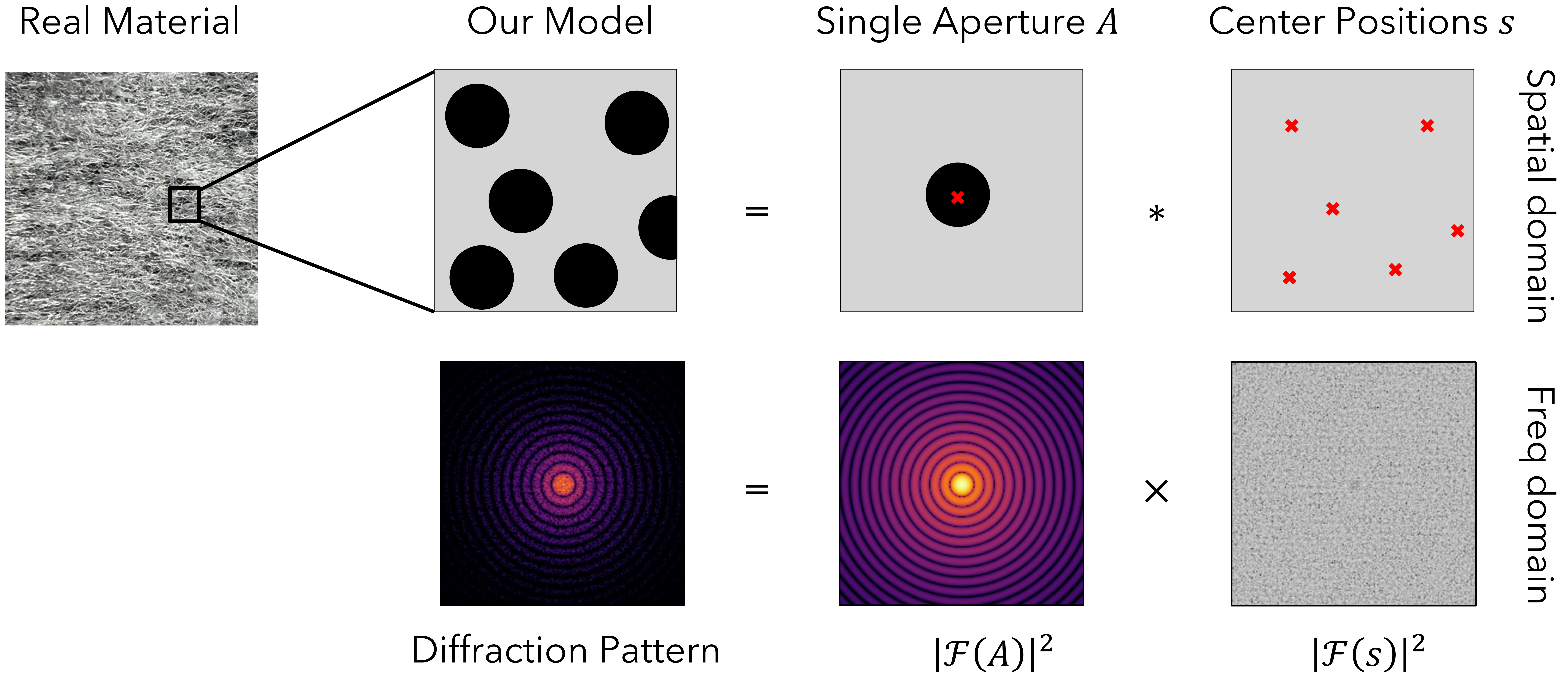
Texture is baked!



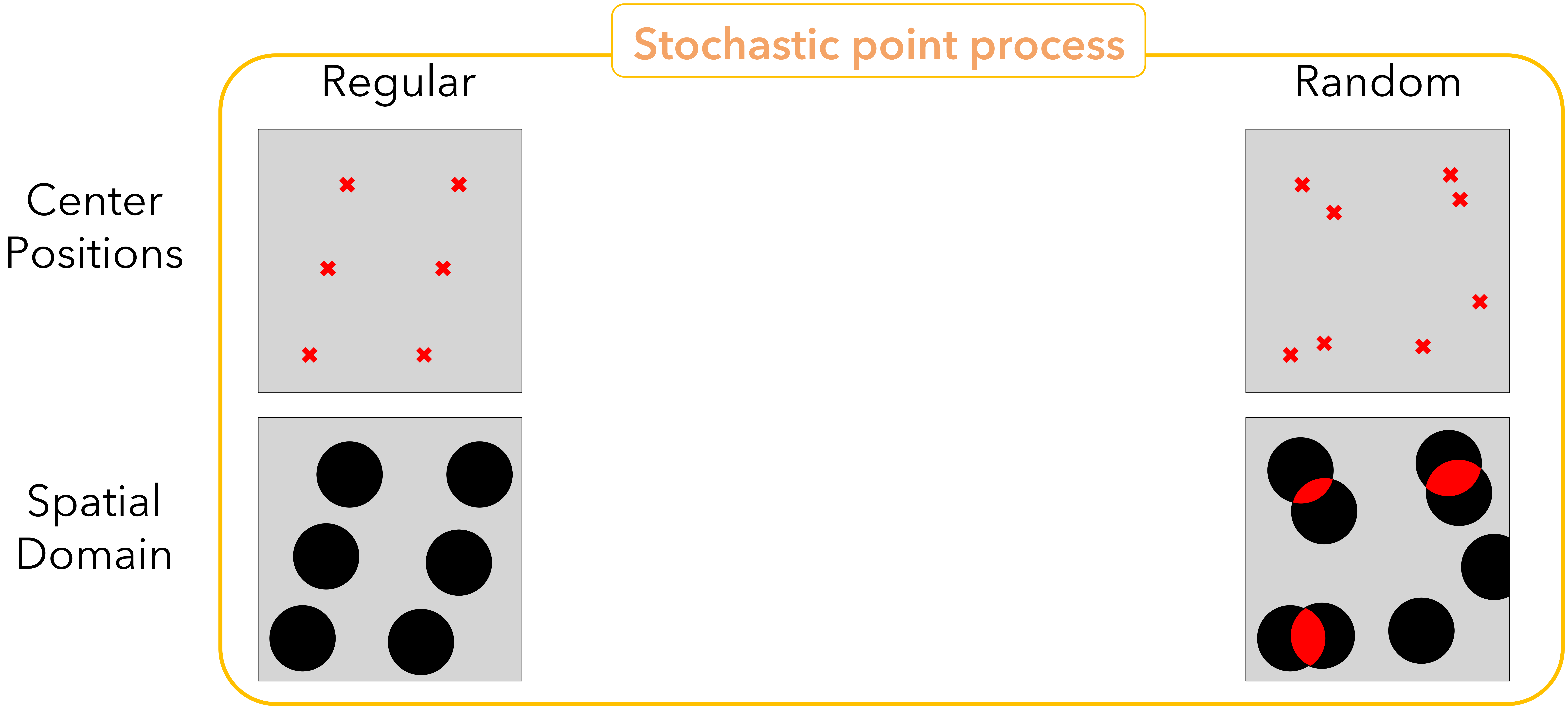
Density Shape Wavelength

→ Need full recalculation of the diffraction pattern

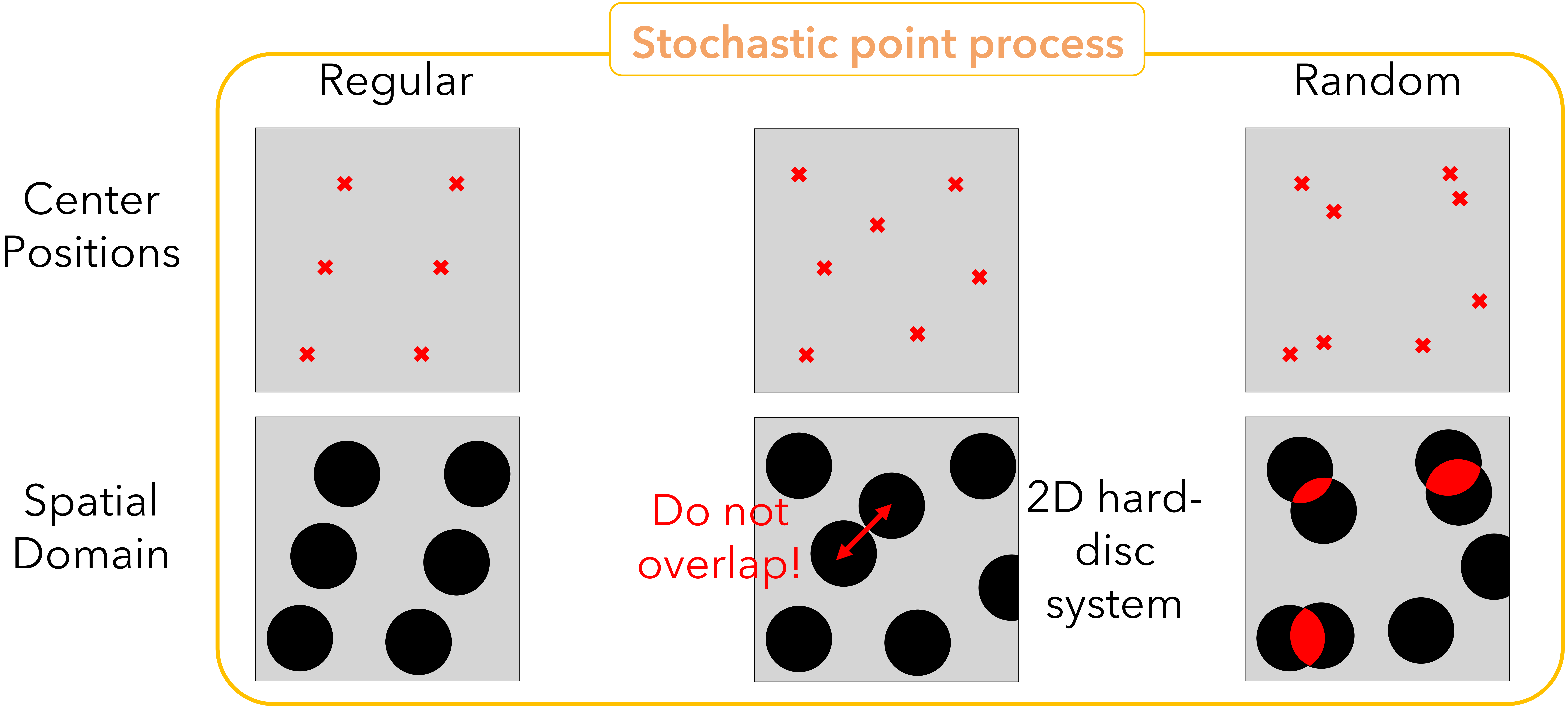
Material Modeling



Aperture Center Distribution



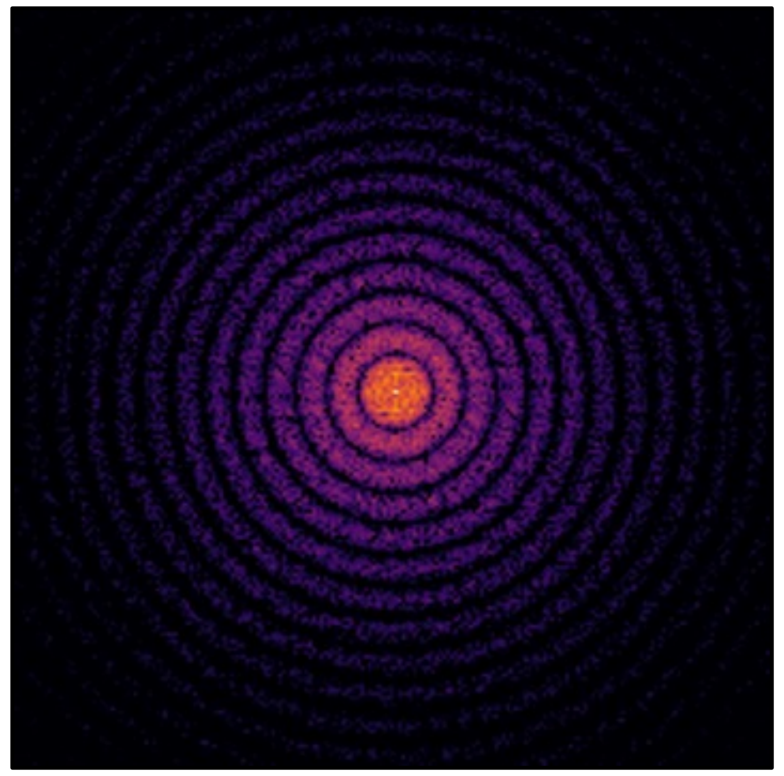
Aperture Center Distribution



Ensemble Averaging

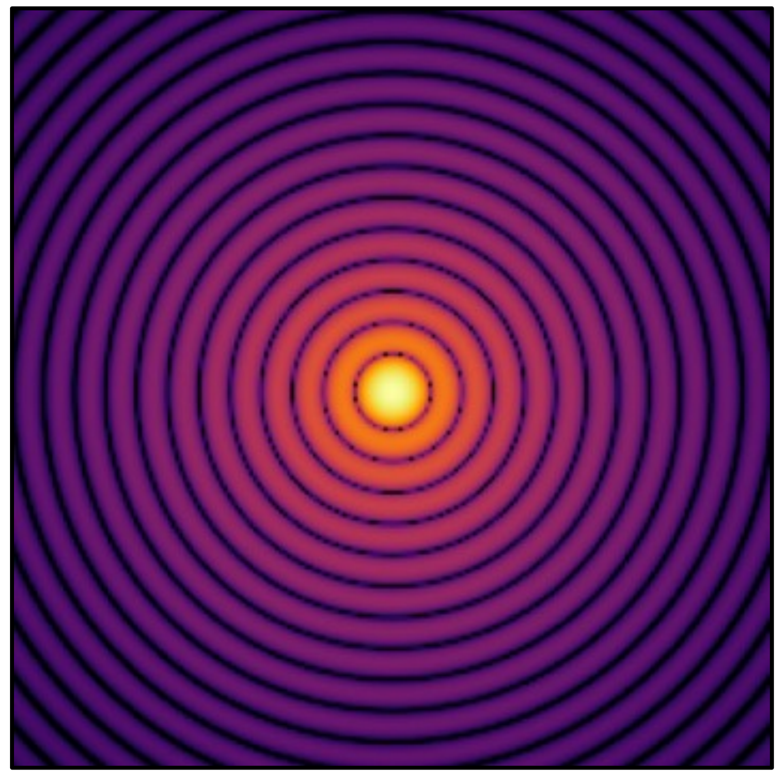
Laser

$|\mathcal{F}(A * s)|^2$



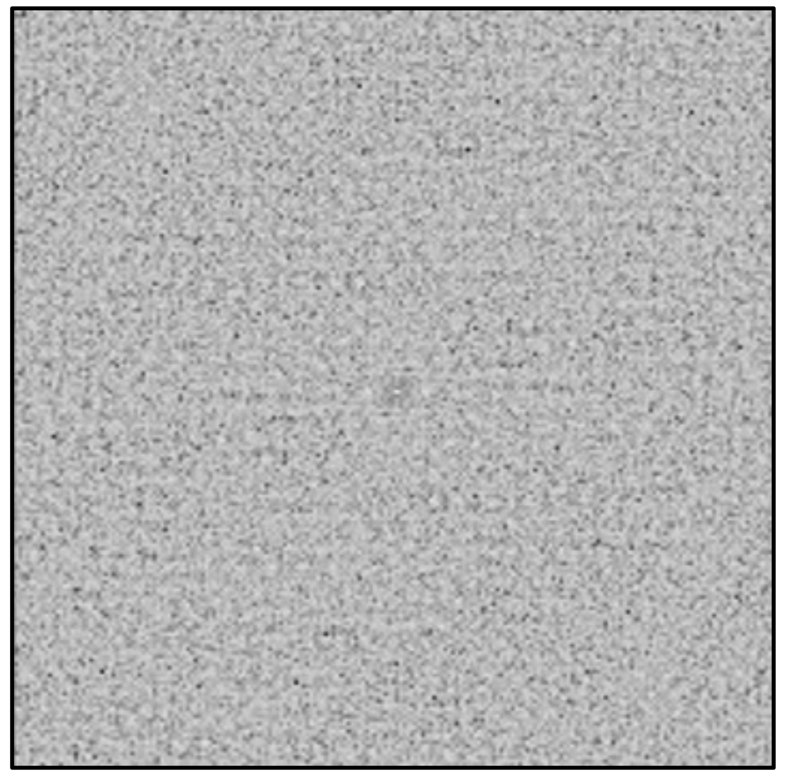
=

$|\mathcal{F}(A)|^2$

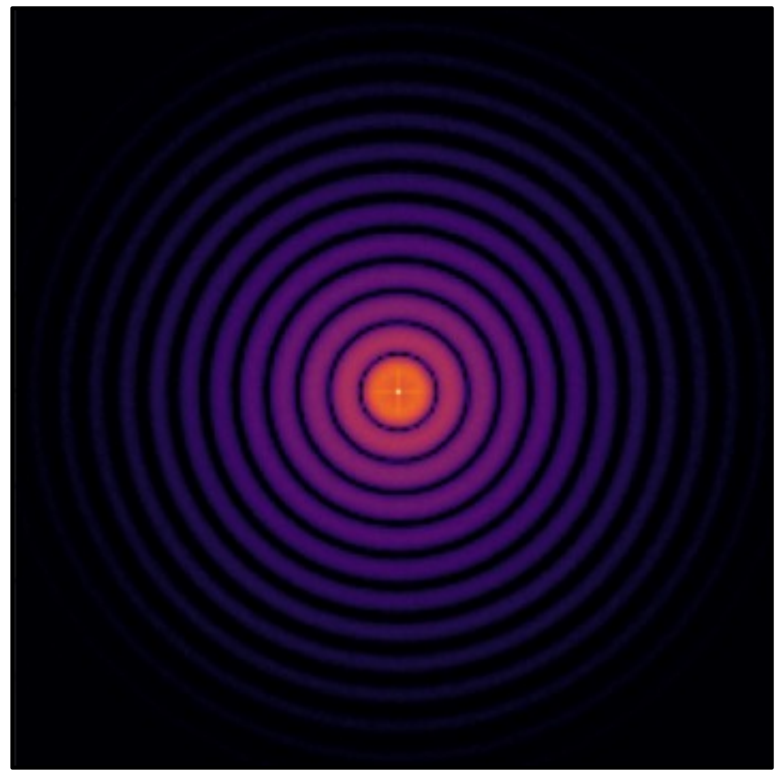


×

$|\mathcal{F}(s)|^2$

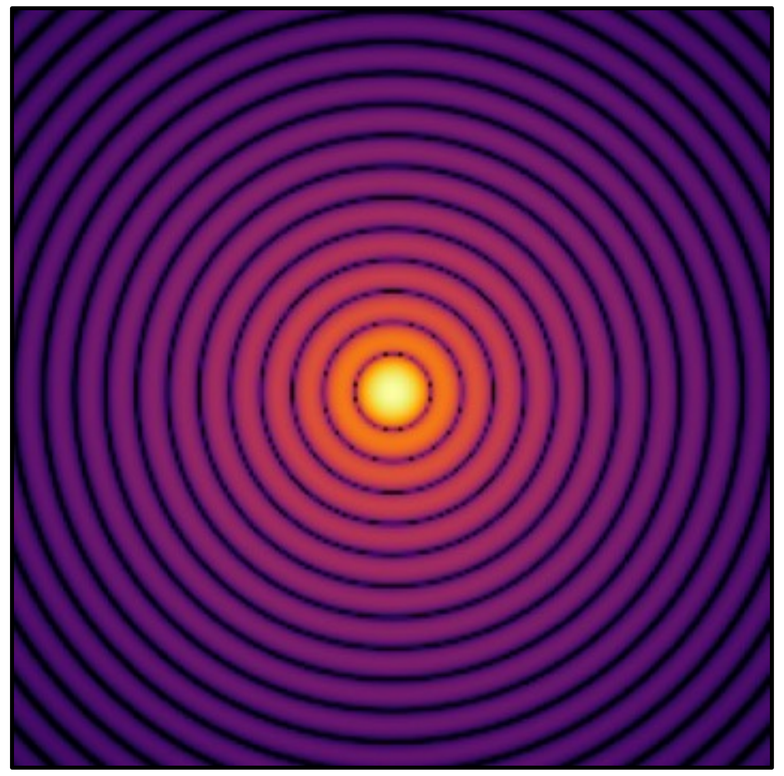


Natural light source



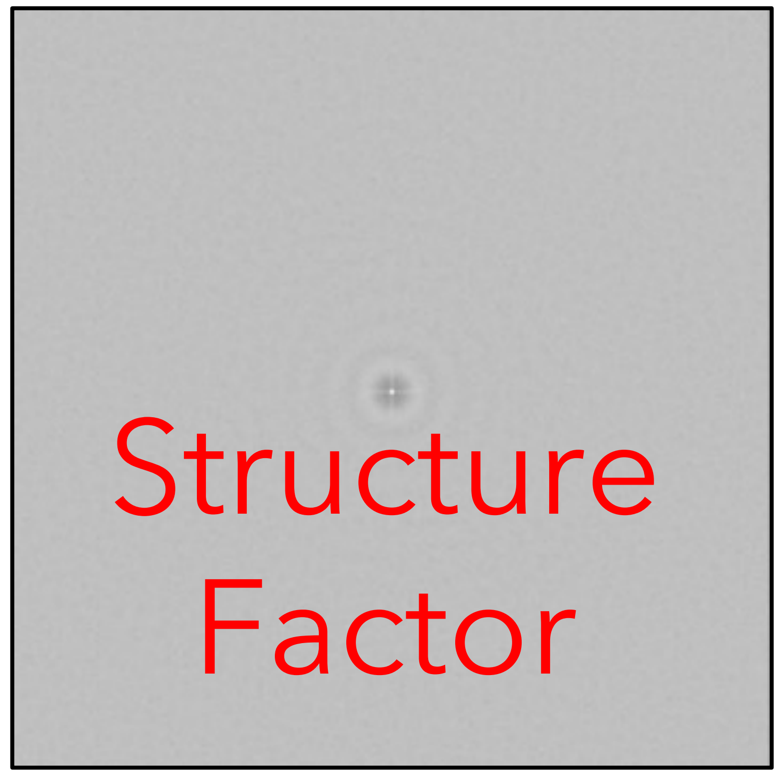
$\langle|\mathcal{F}(A * s)|^2\rangle$

=



$|\mathcal{F}(A)|^2$

×



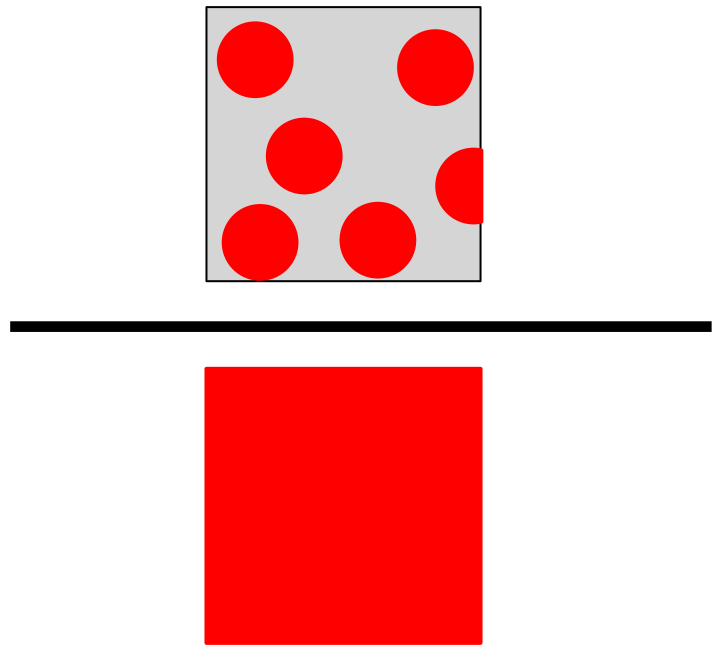
$\langle|\mathcal{F}(s)|^2\rangle$

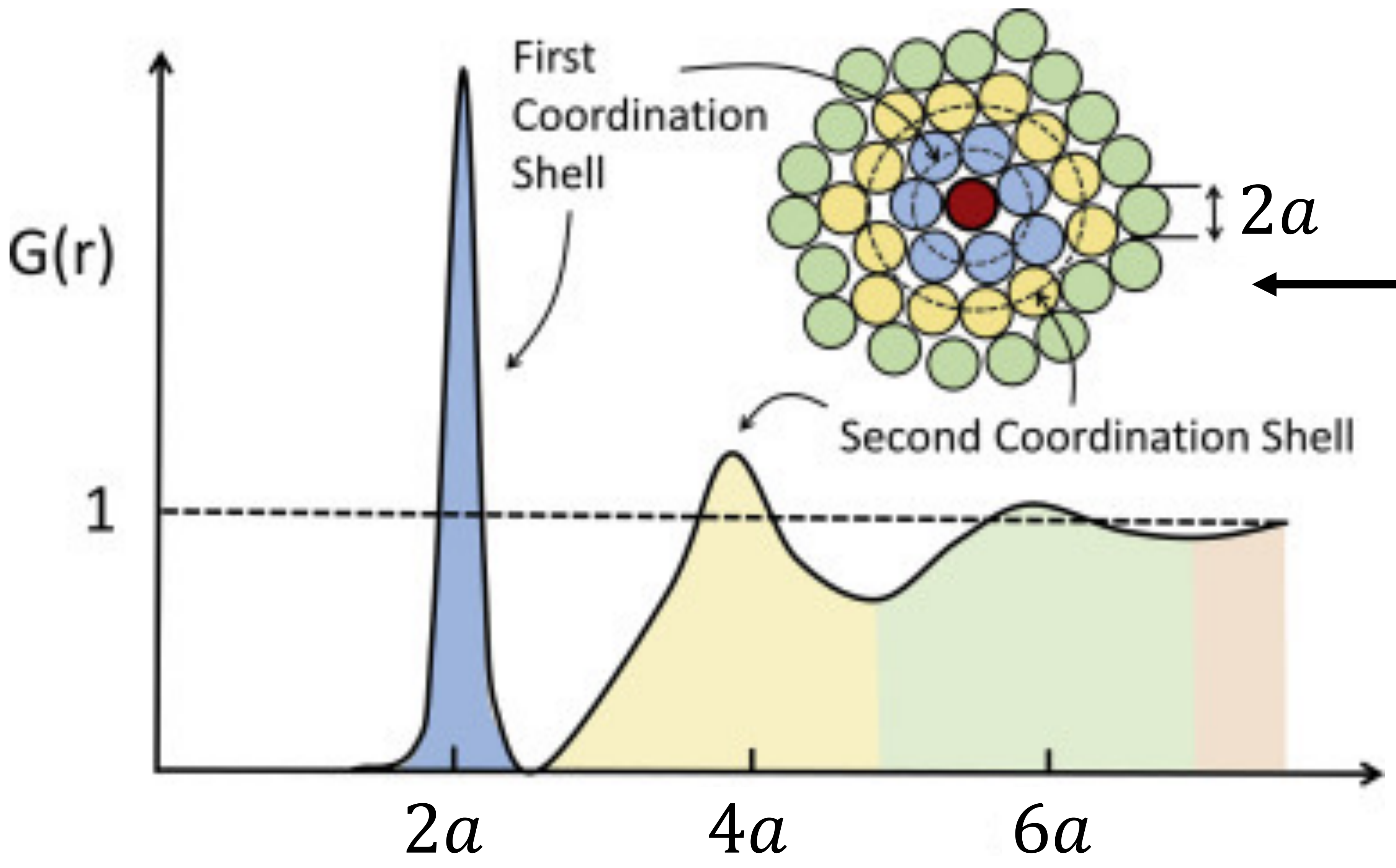
Structure Factor

2D hard-disk system

Structure Factor $= \mathcal{F}$

- Radial distance r
- Area Fraction F_a

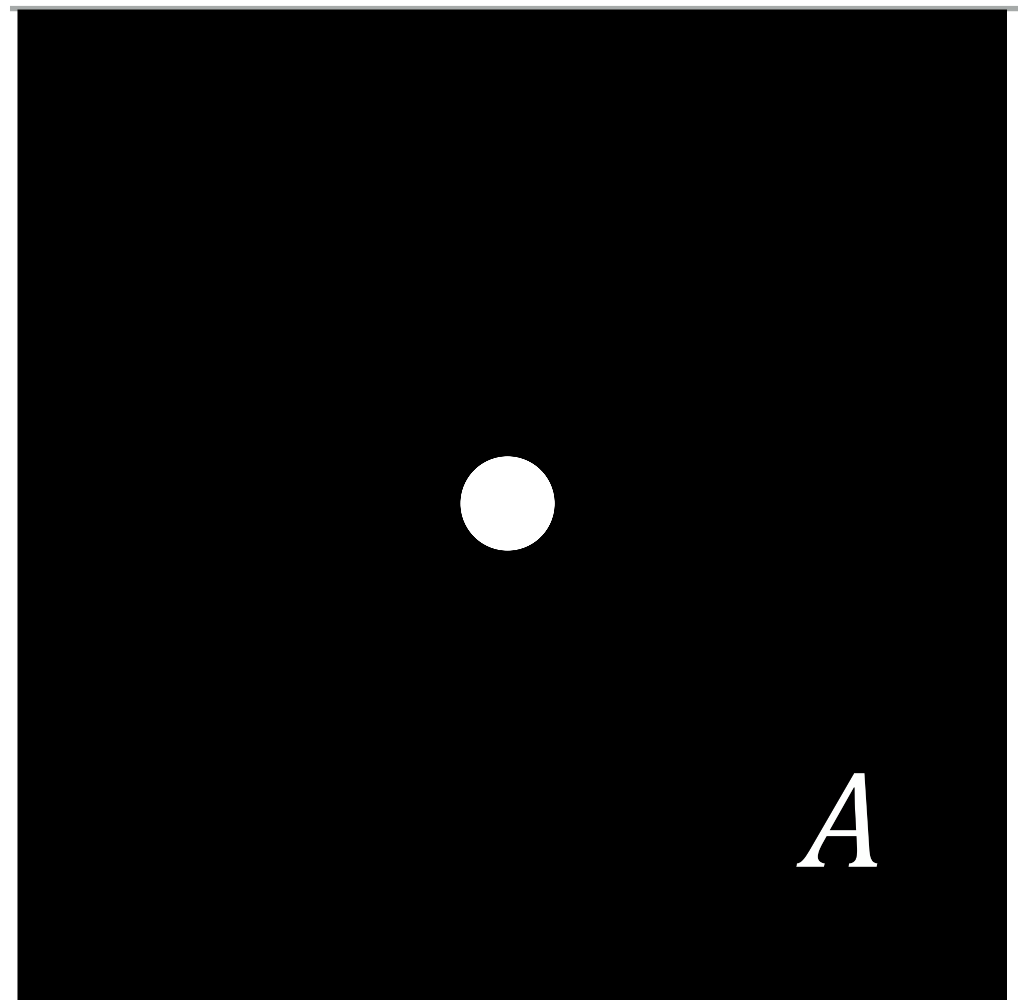
$F_a =$ 



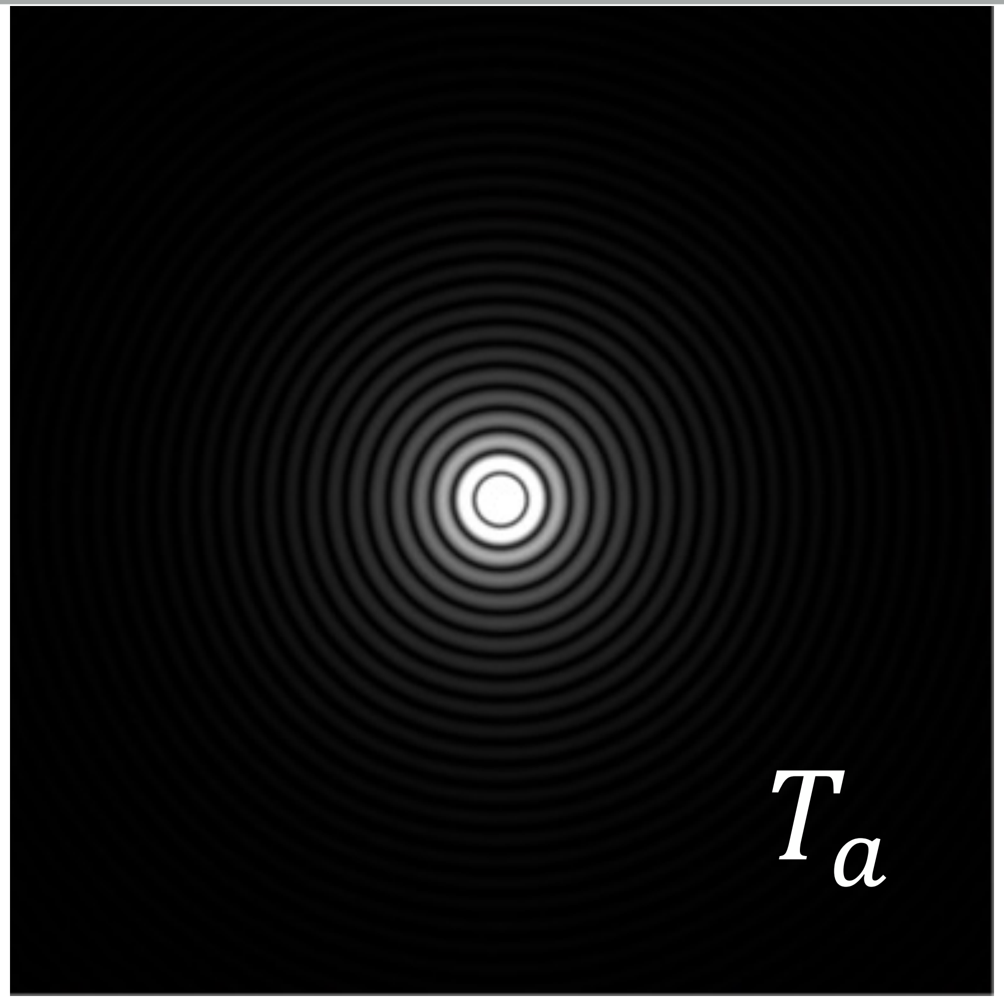
Pair correlation function

: probability of finding other particles at certain distance

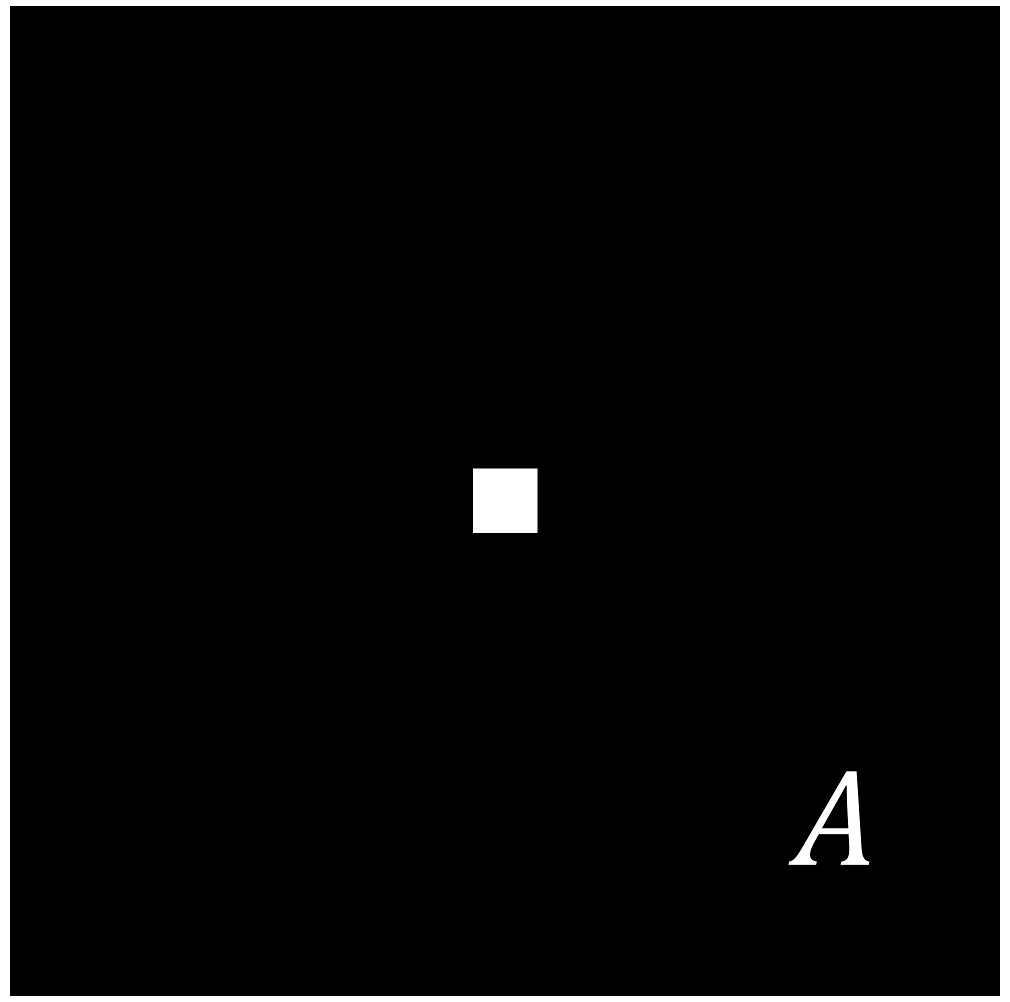
BSDF evaluation



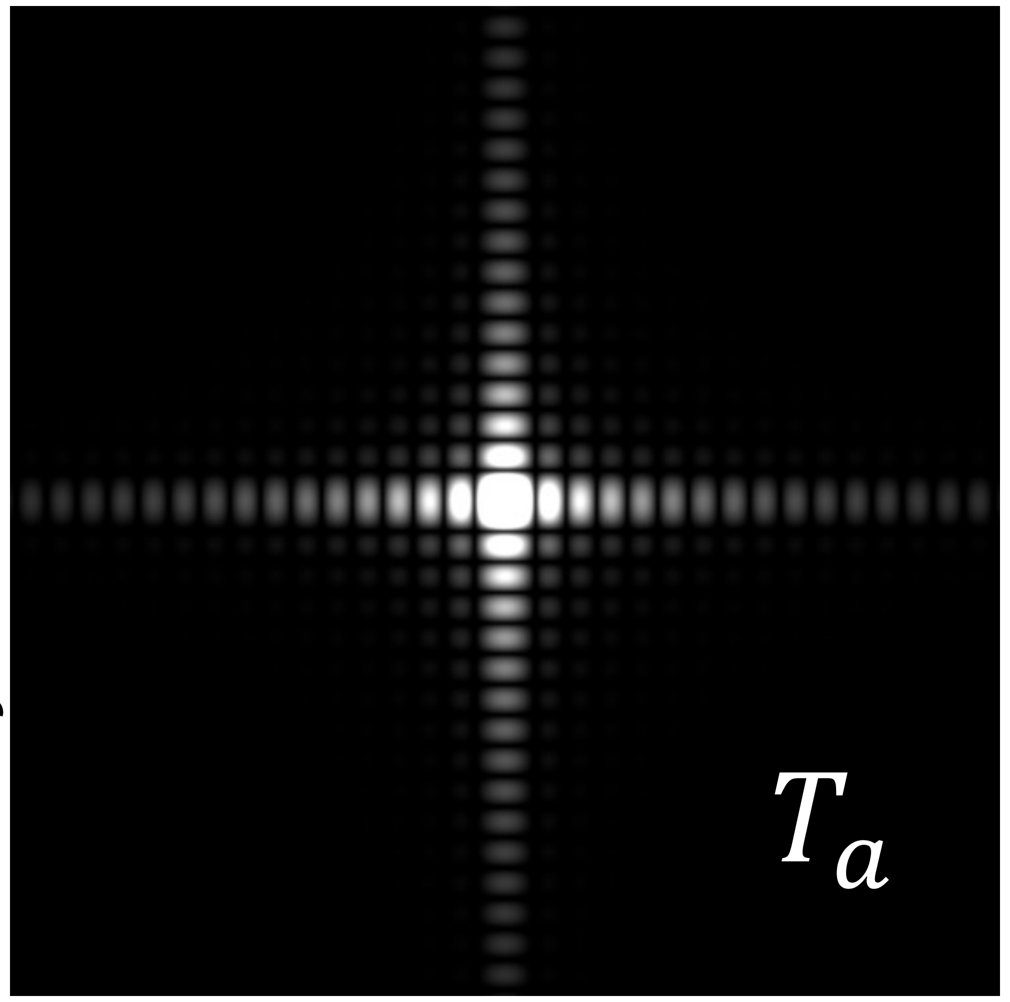
$\mathbf{d}_y \in (-2,2)$



$\mathbf{d}_x \in (-2,2)$



$\mathbf{d}_y \in (-2,2)$



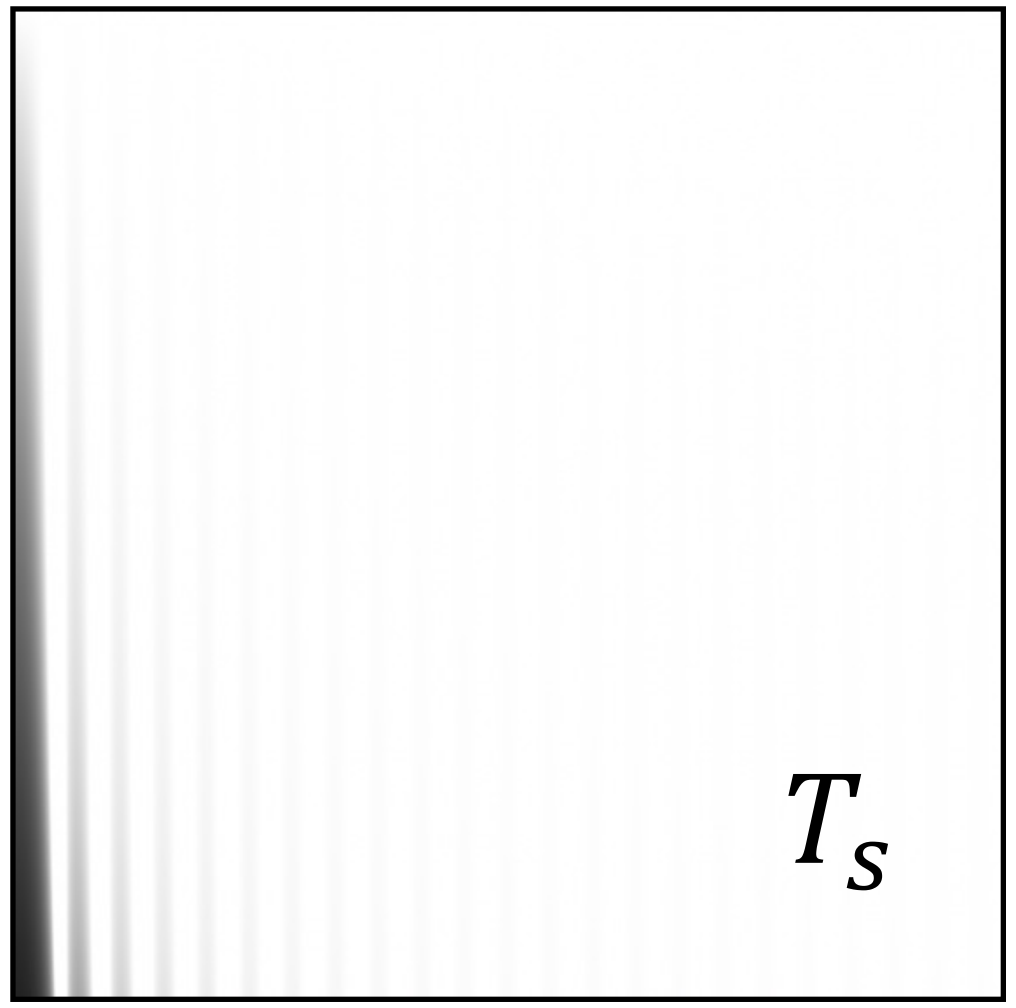
$\mathbf{d}_x \in (-2,2)$

$$\mathbf{d} = (\omega_\mathrm{o} - \omega_\mathrm{i})_{xy}$$

$$T_a(\mathbf{d}) = |A|^{-1} |\mathcal{F}\{A\}(2\pi/\lambda_0 \mathbf{d})|^2 \lambda_0^{-2}$$

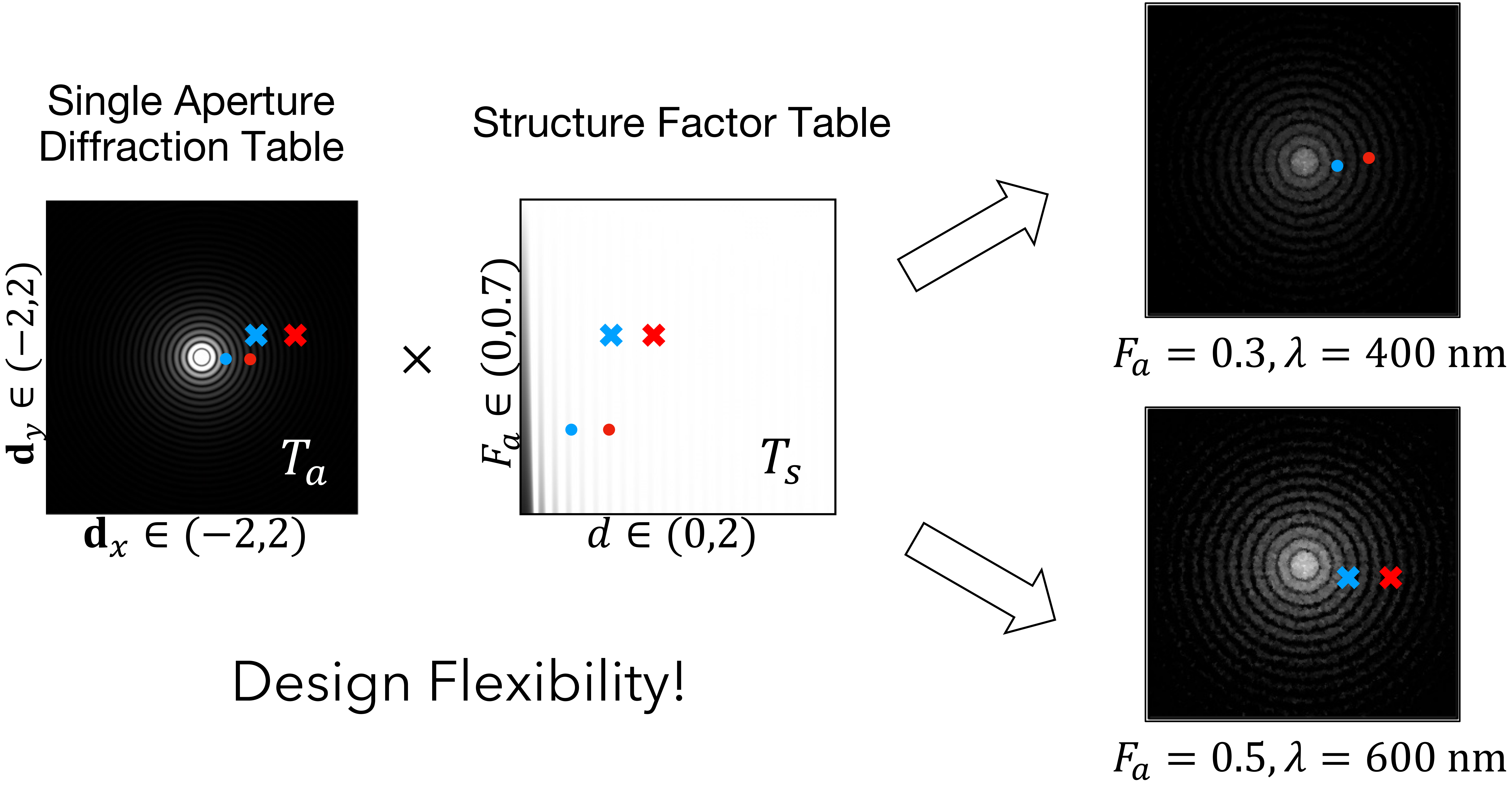
λ_0 : reference wavelength (350 nm)

$F_a \in (0,0.7)$



$d \in (0,2), d = |\mathbf{d}|$

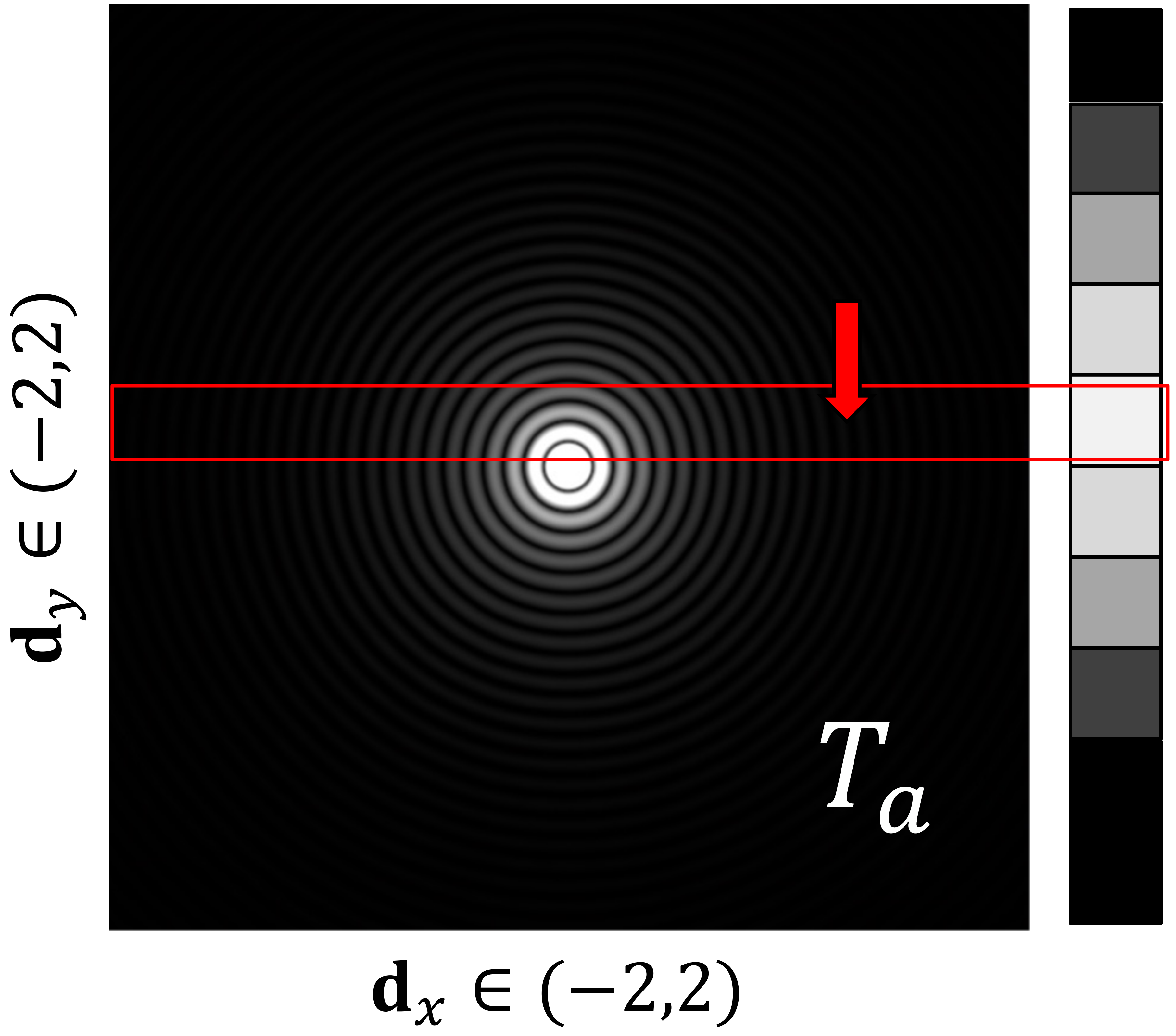
BSDF evaluation

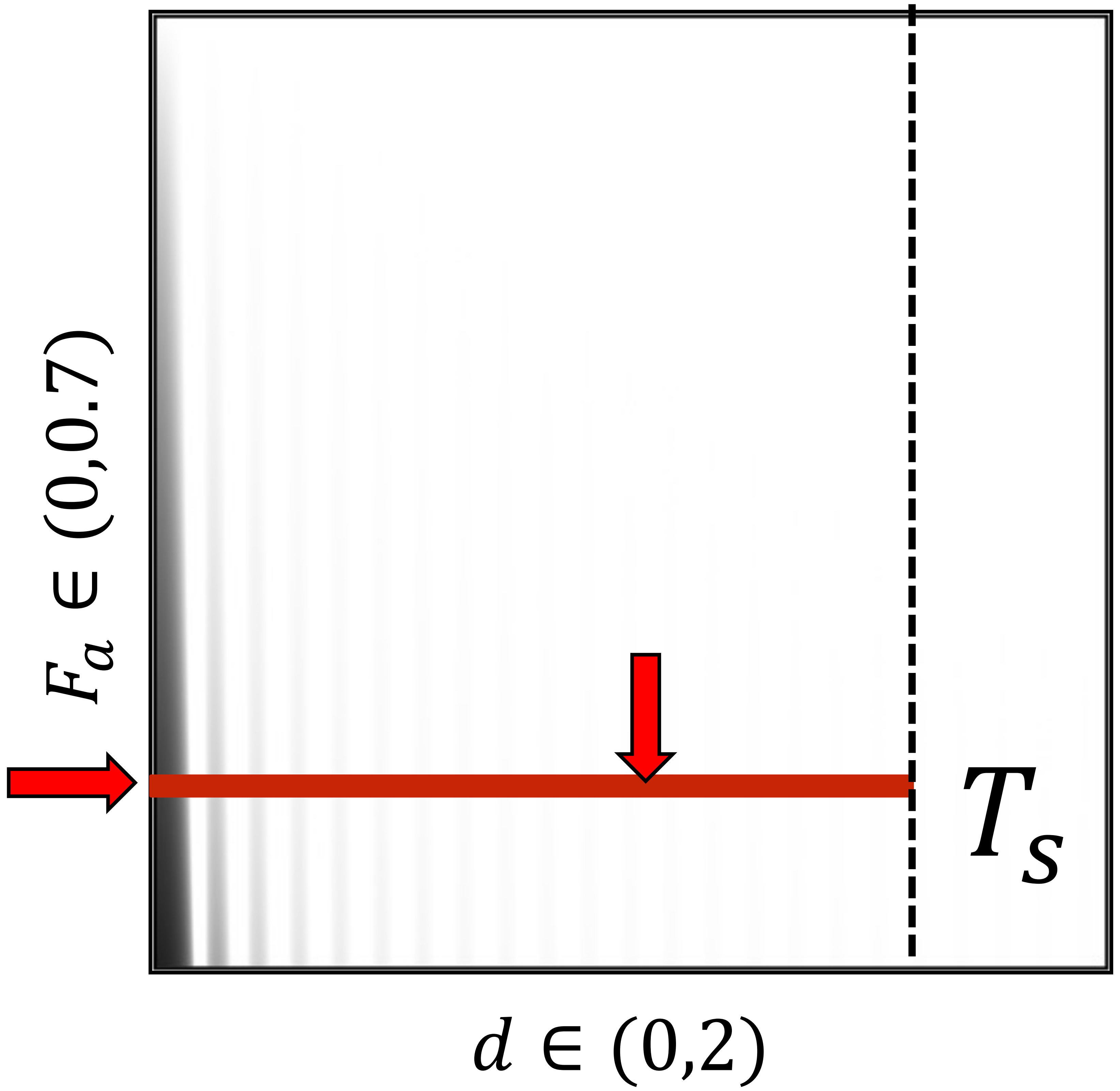


Design Flexibility!

BSDF Sampling with MIS

$$d_{\max} = \frac{\lambda_0}{\lambda}\left(1 + |(\omega_{\mathrm{i}})_{xy}|\right)$$

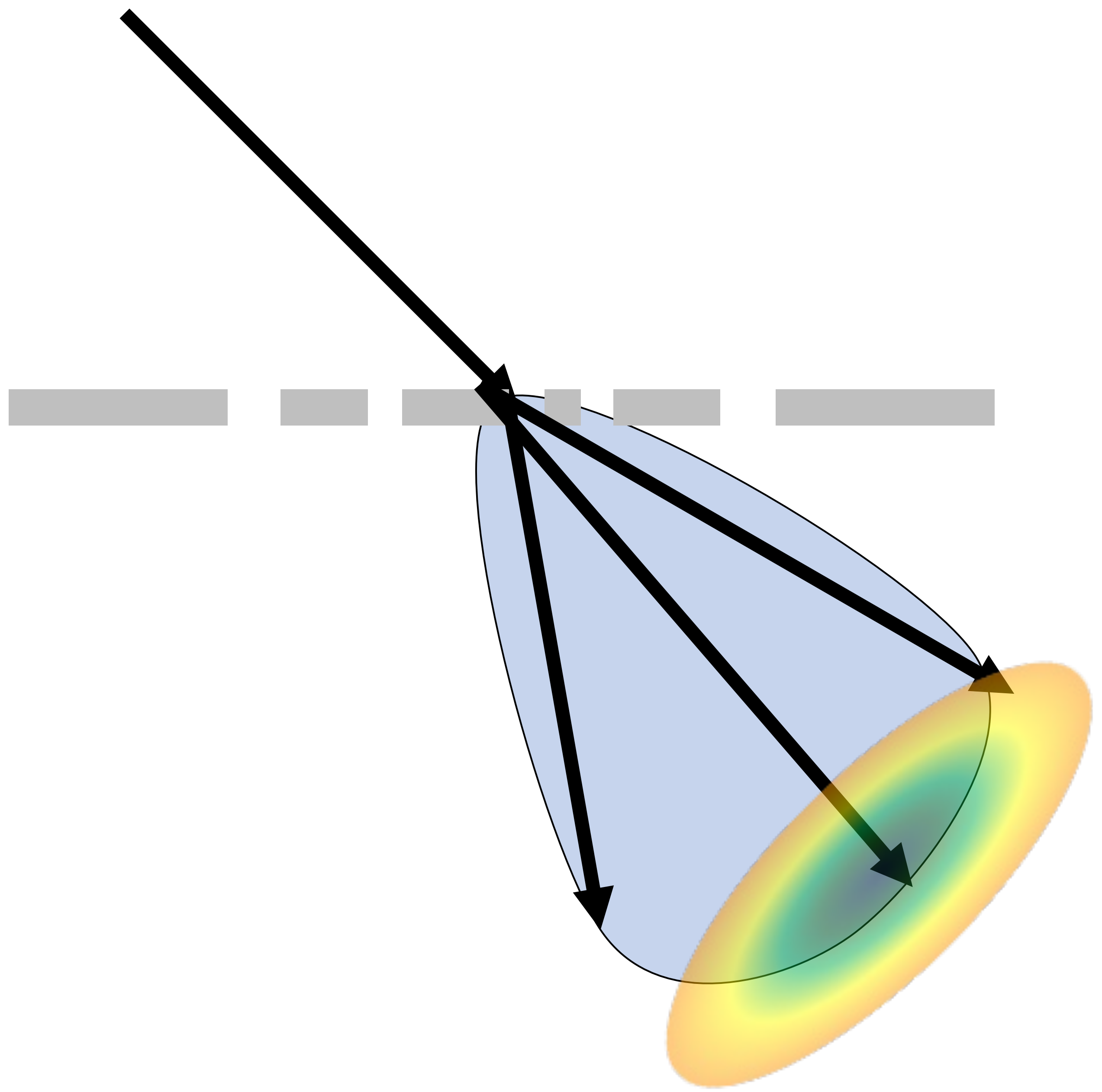




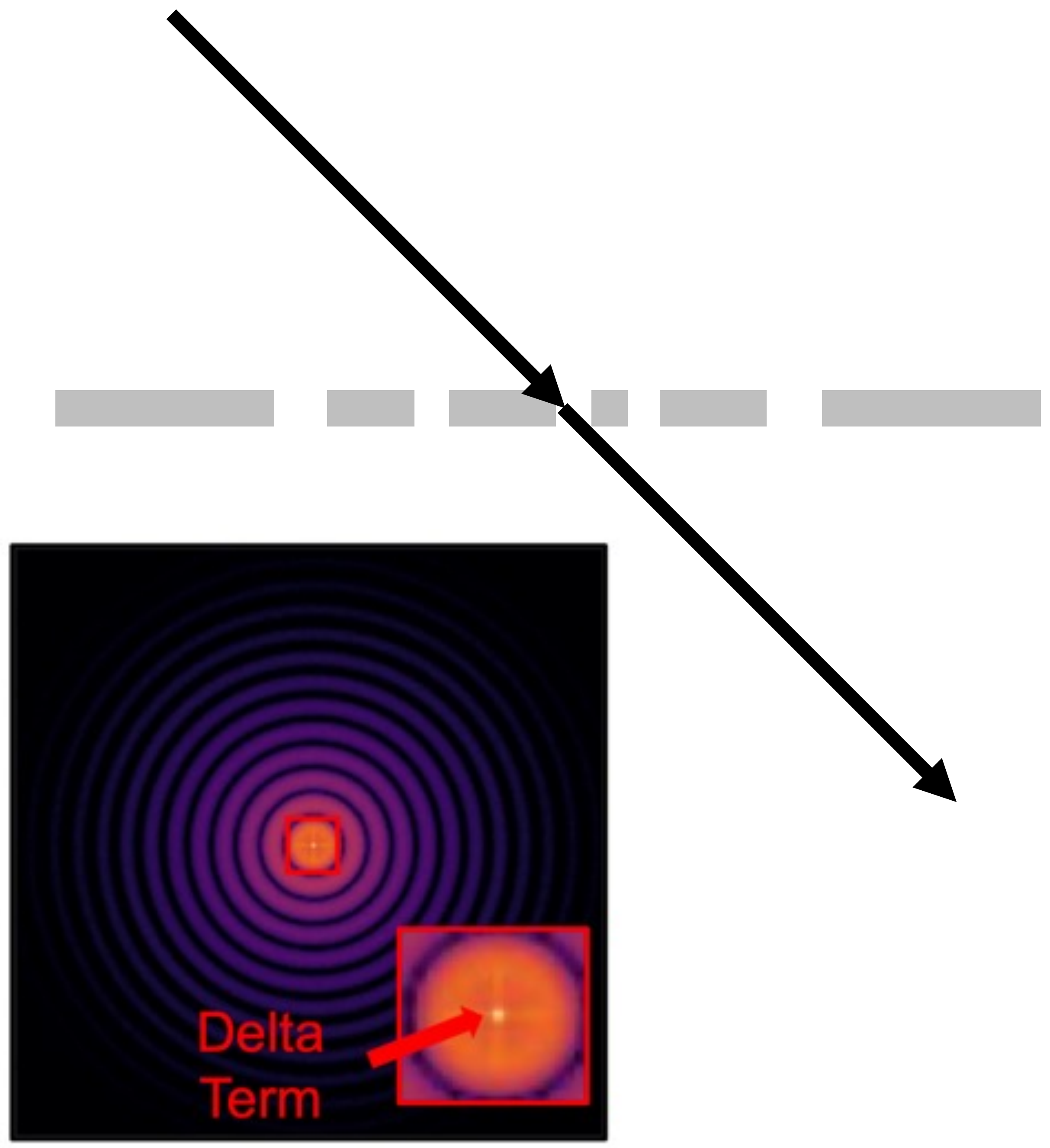
Other Terms in BSDF

$$w_{\text{diffraction}} + w_{\text{delta}} + w_{\text{substrate}} = 1$$

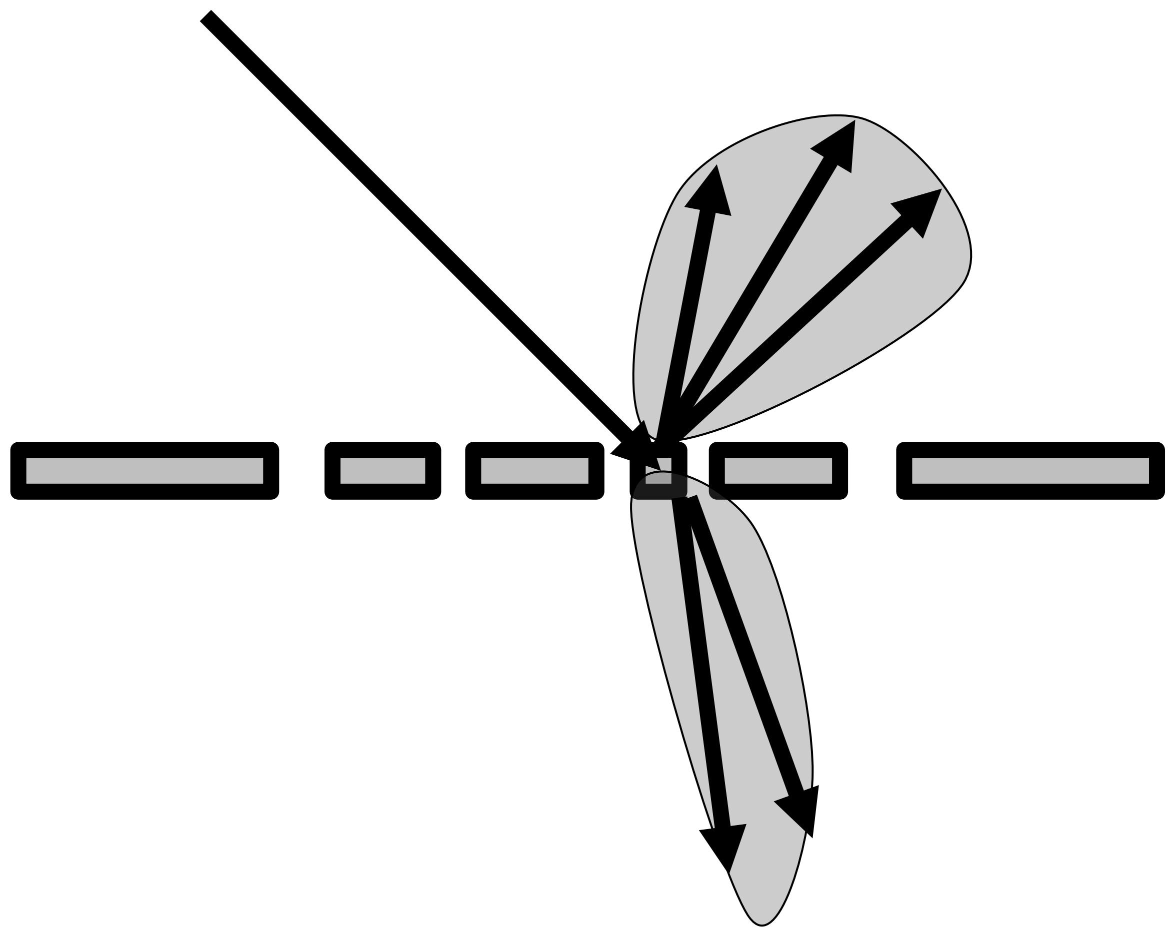
Diffraction



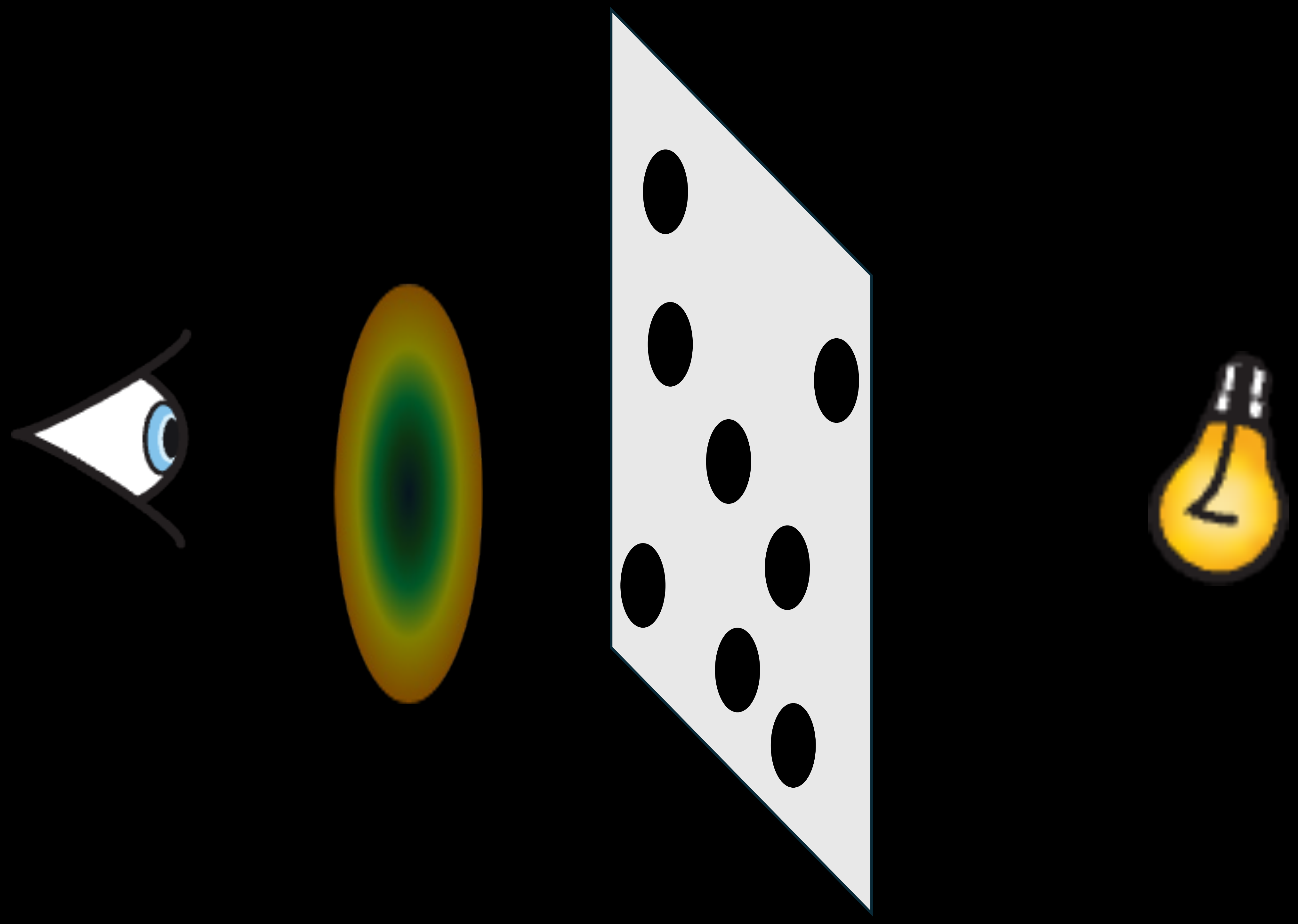
Delta



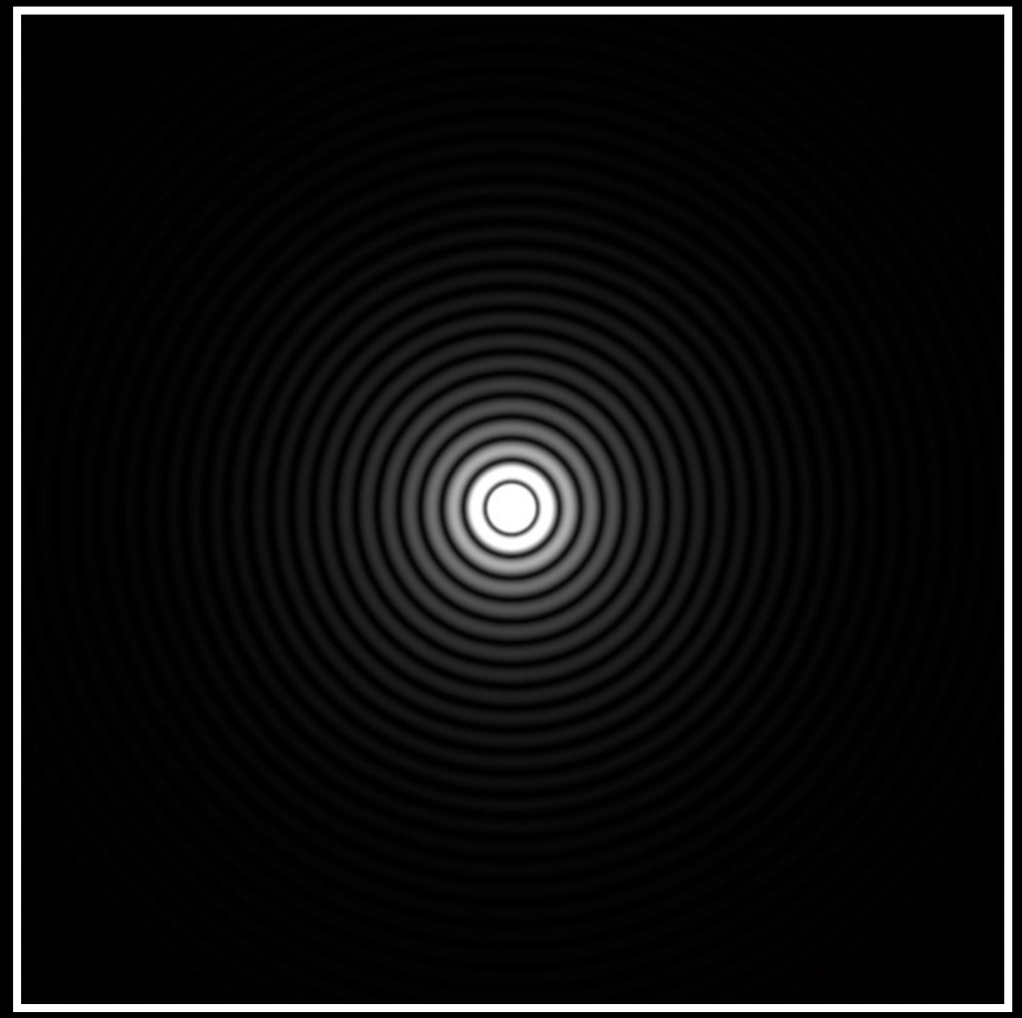
Substrate



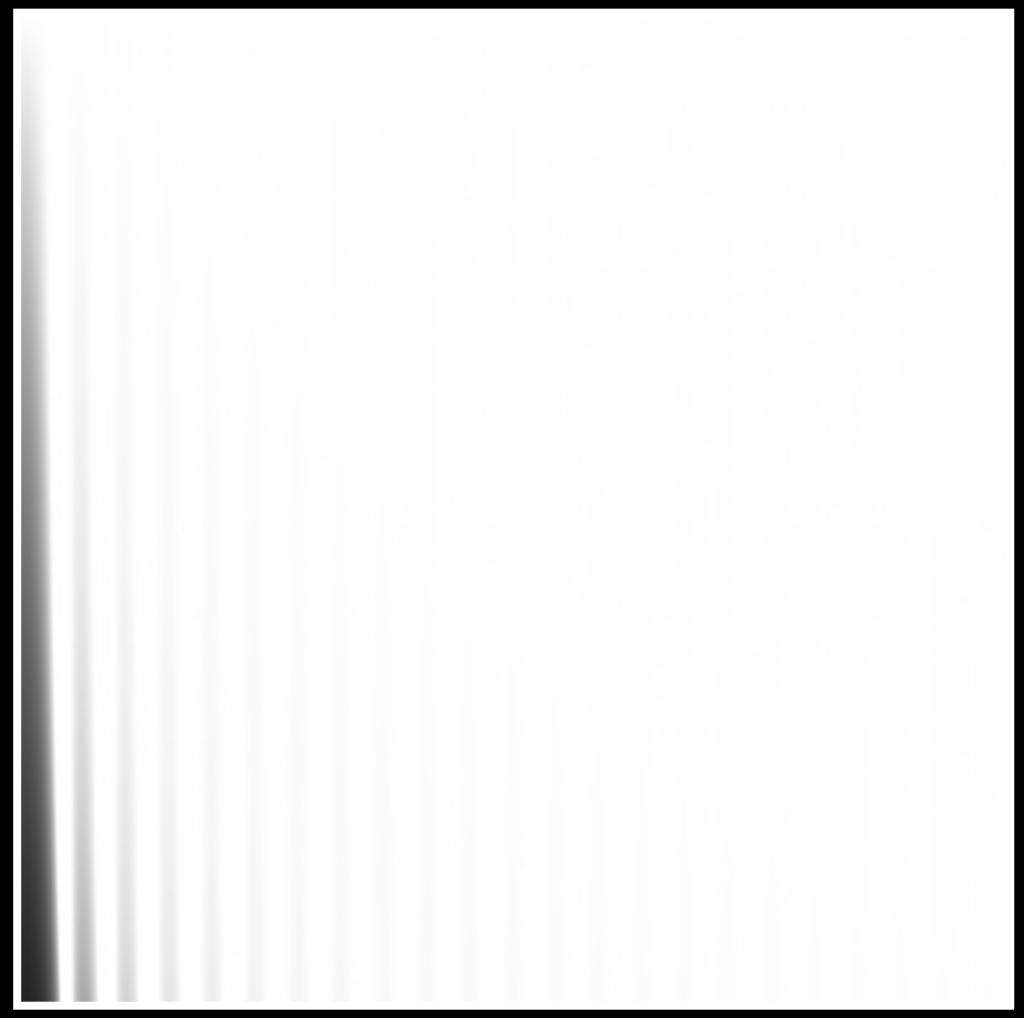
Results

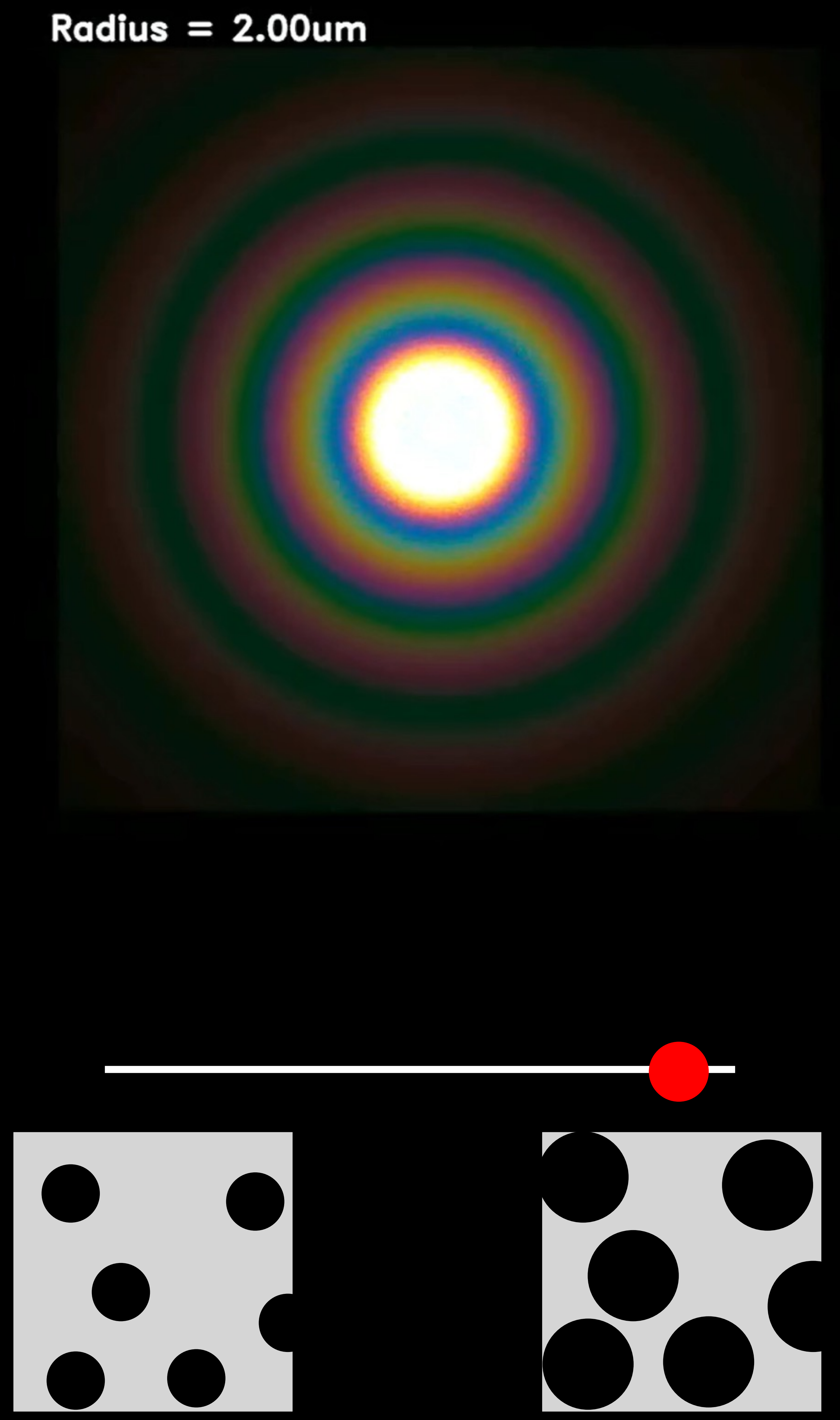


Single Aperture Diffraction Table

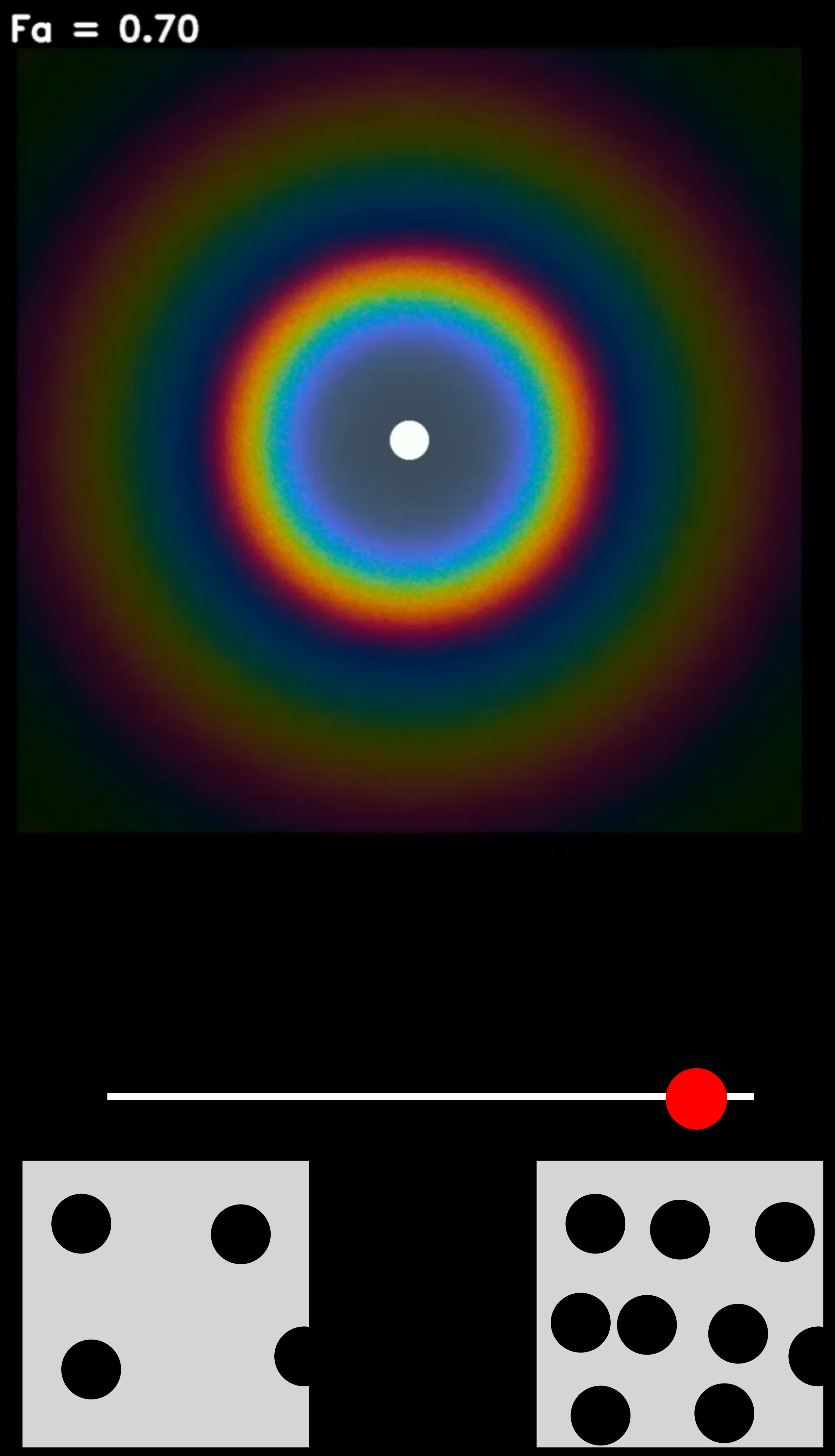


Structure Factor Table

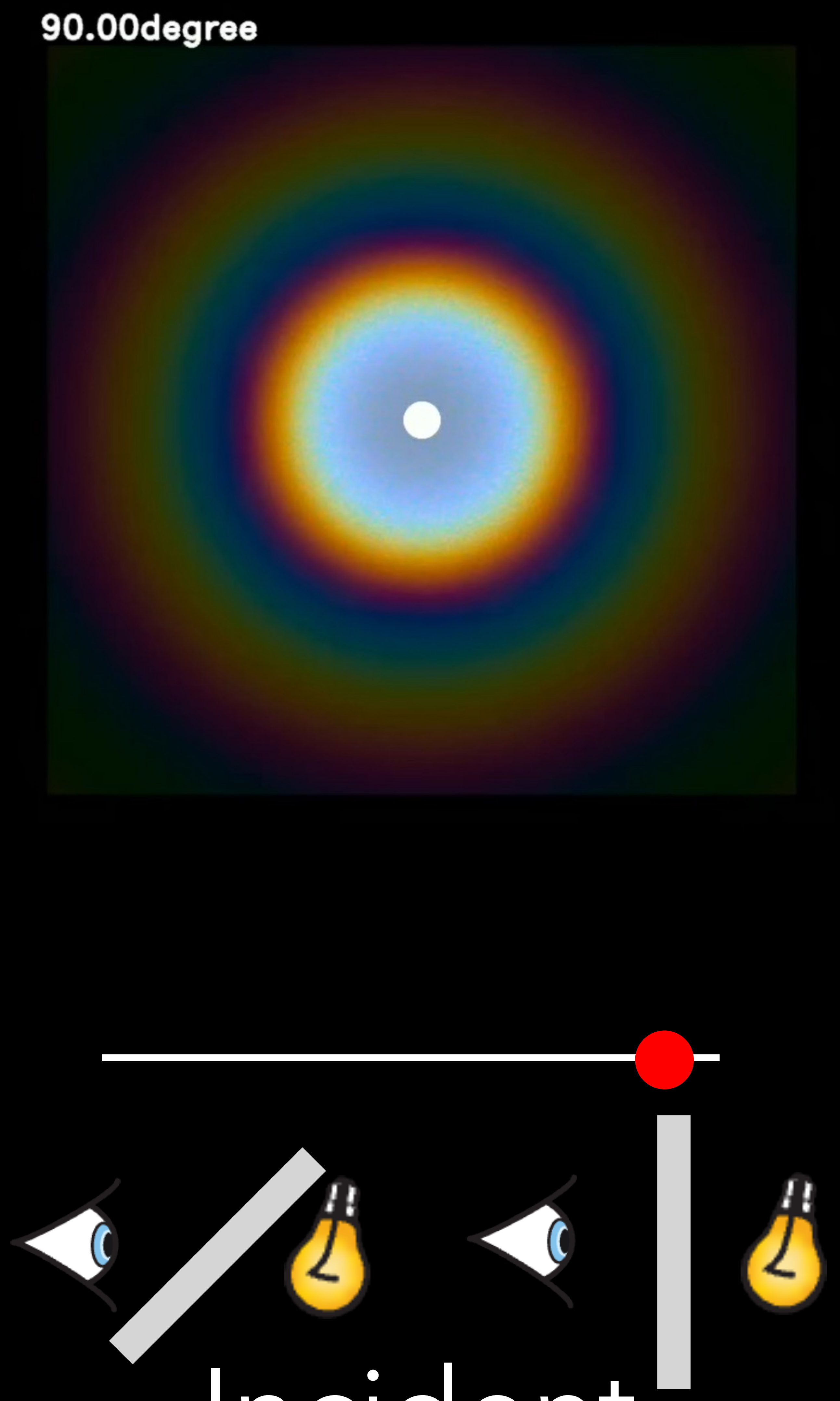




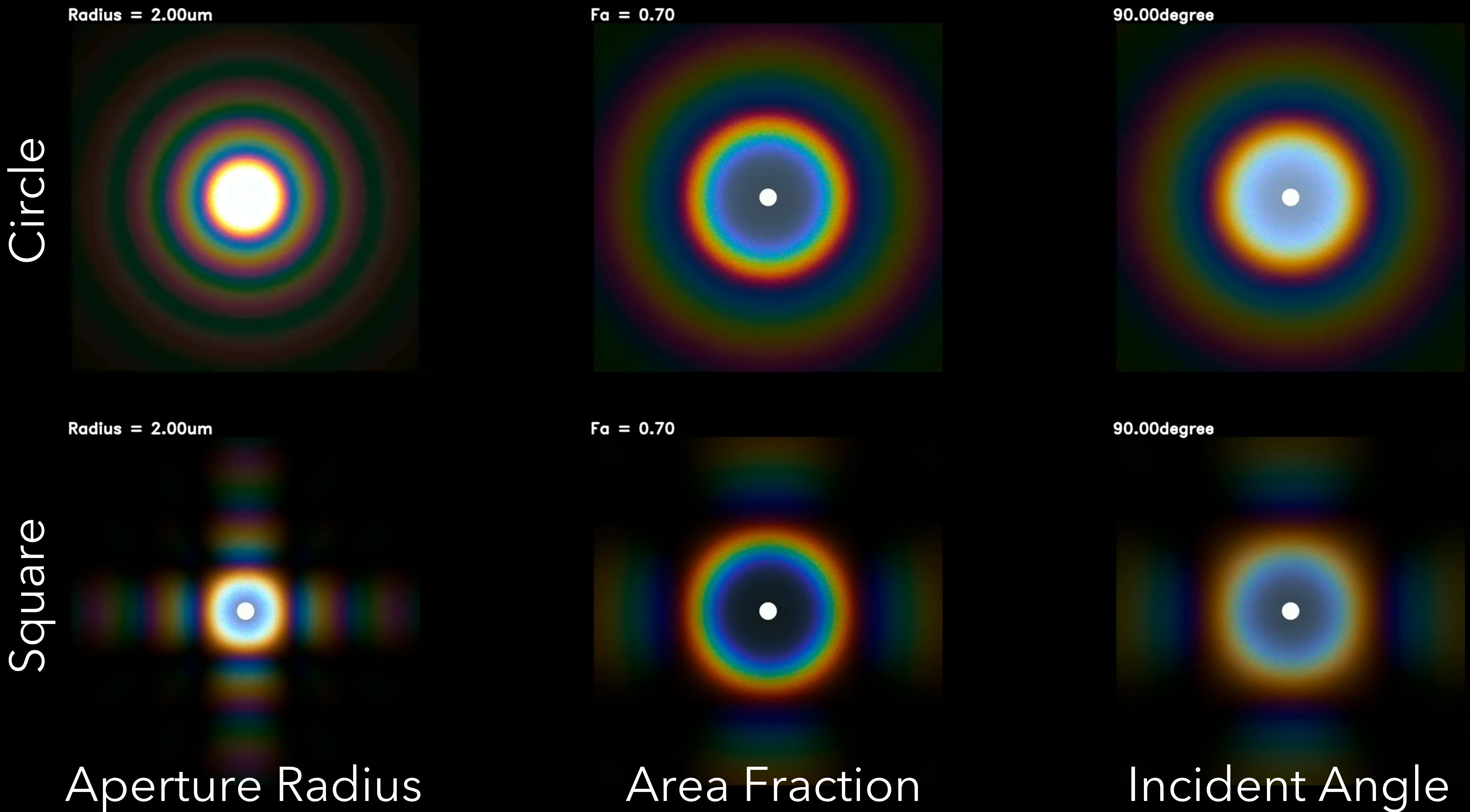
Aperture Radius



Area Fraction

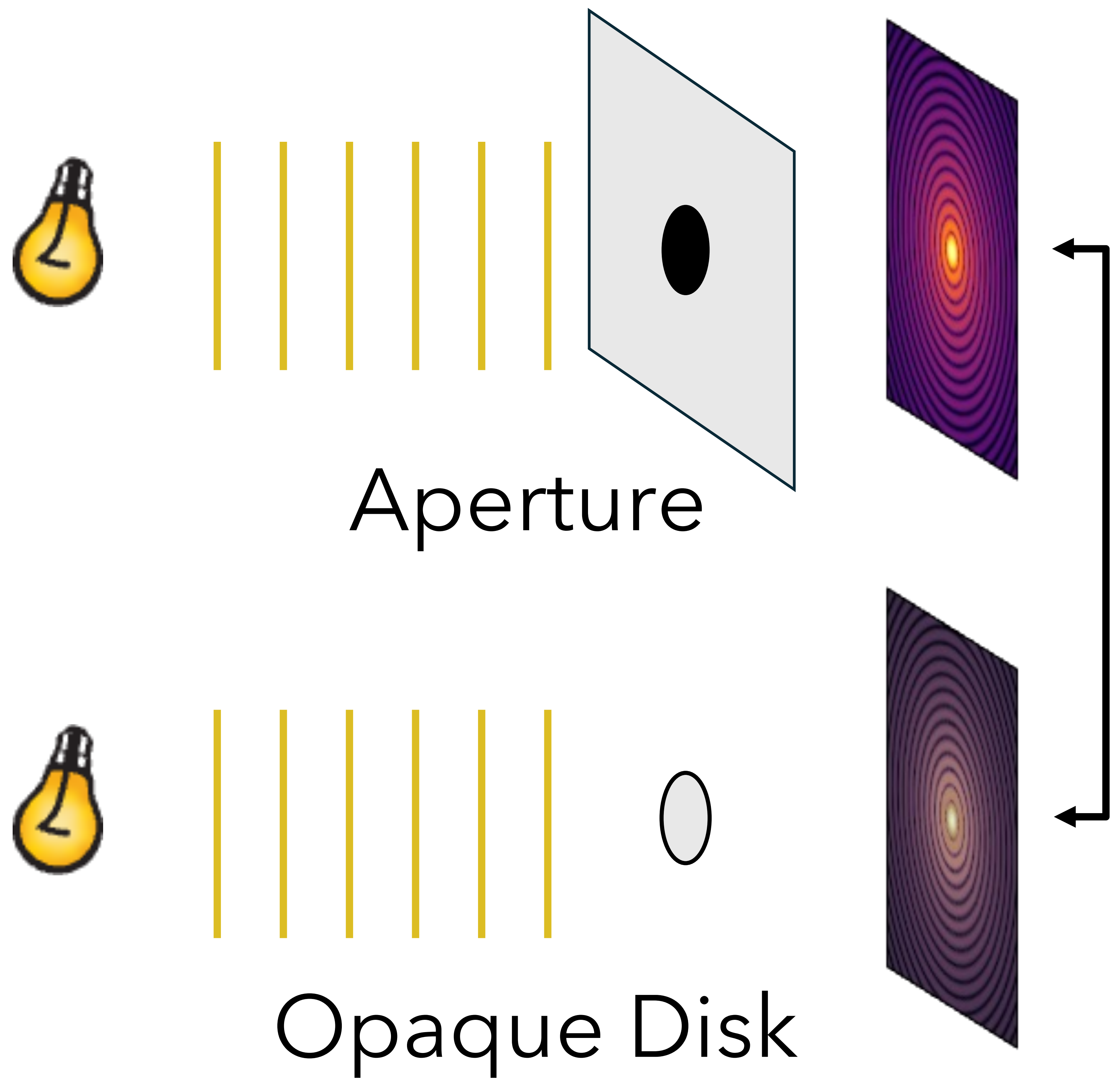


Incident Angle


Radius = 2.00um
Fa = 0.70
90.00degree
Radius = 2.00um
Fa = 0.70
90.00degree
Circle
Square
Aperture Radius
Area Fraction
Incident Angle

Particle vs. Aperture

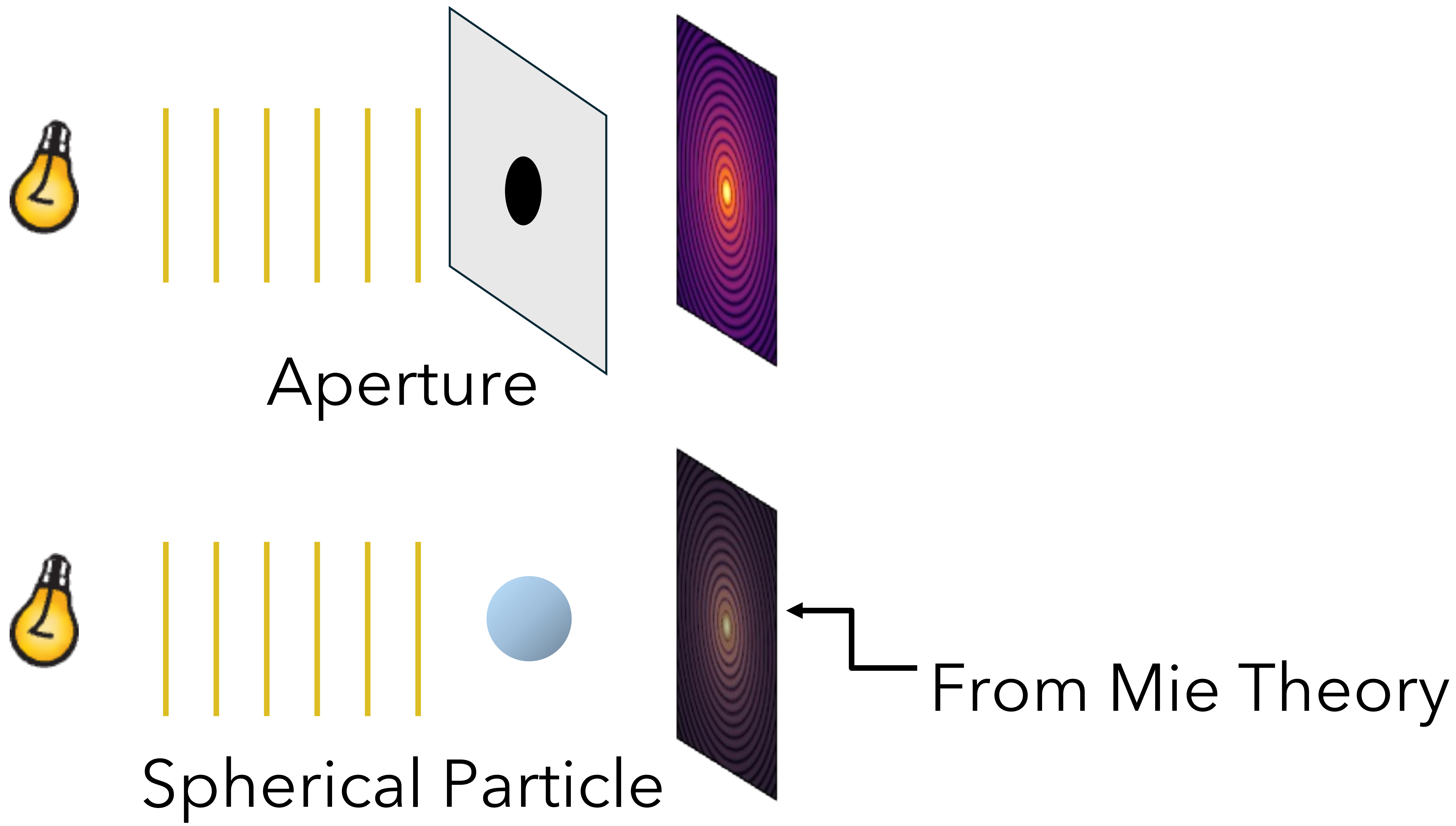
Babinet's principle



Diffraction patterns are equal, except overall brightness

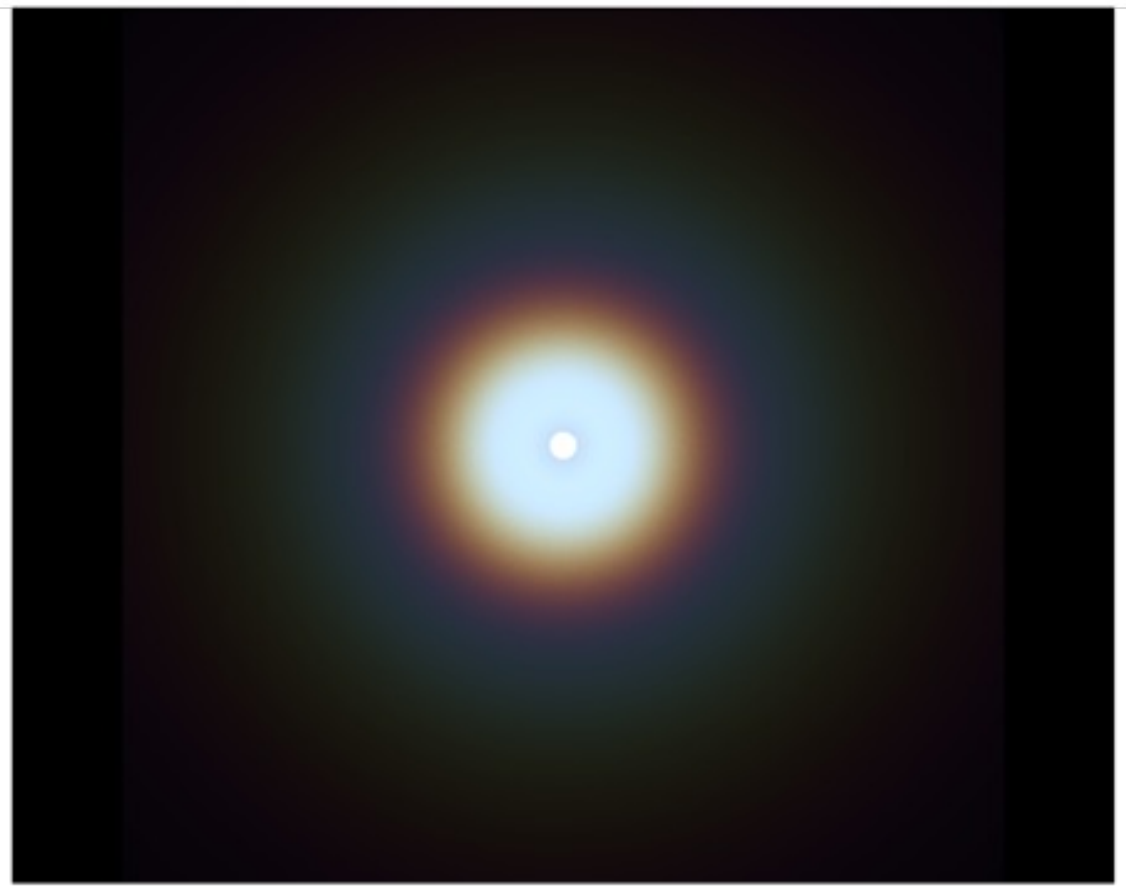
Particle vs. Aperture

Babinet's principle

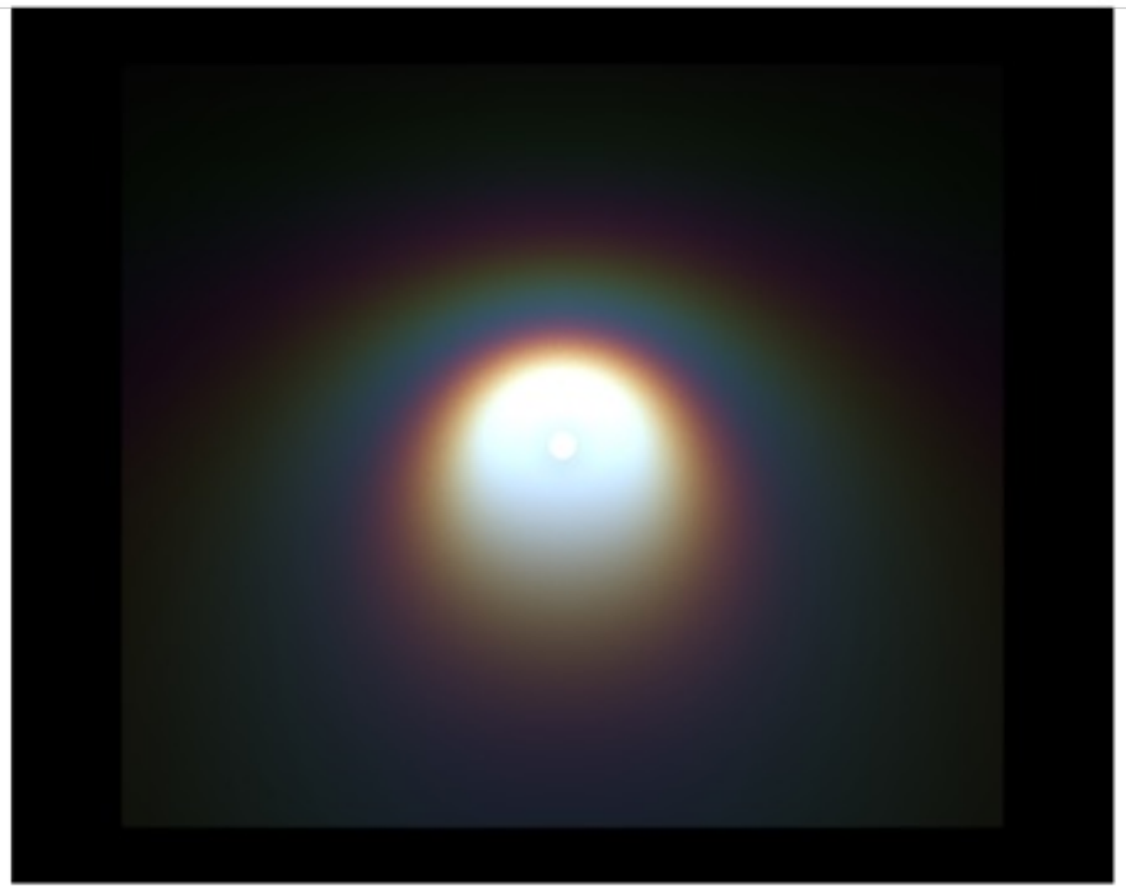


Particle vs. Aperture

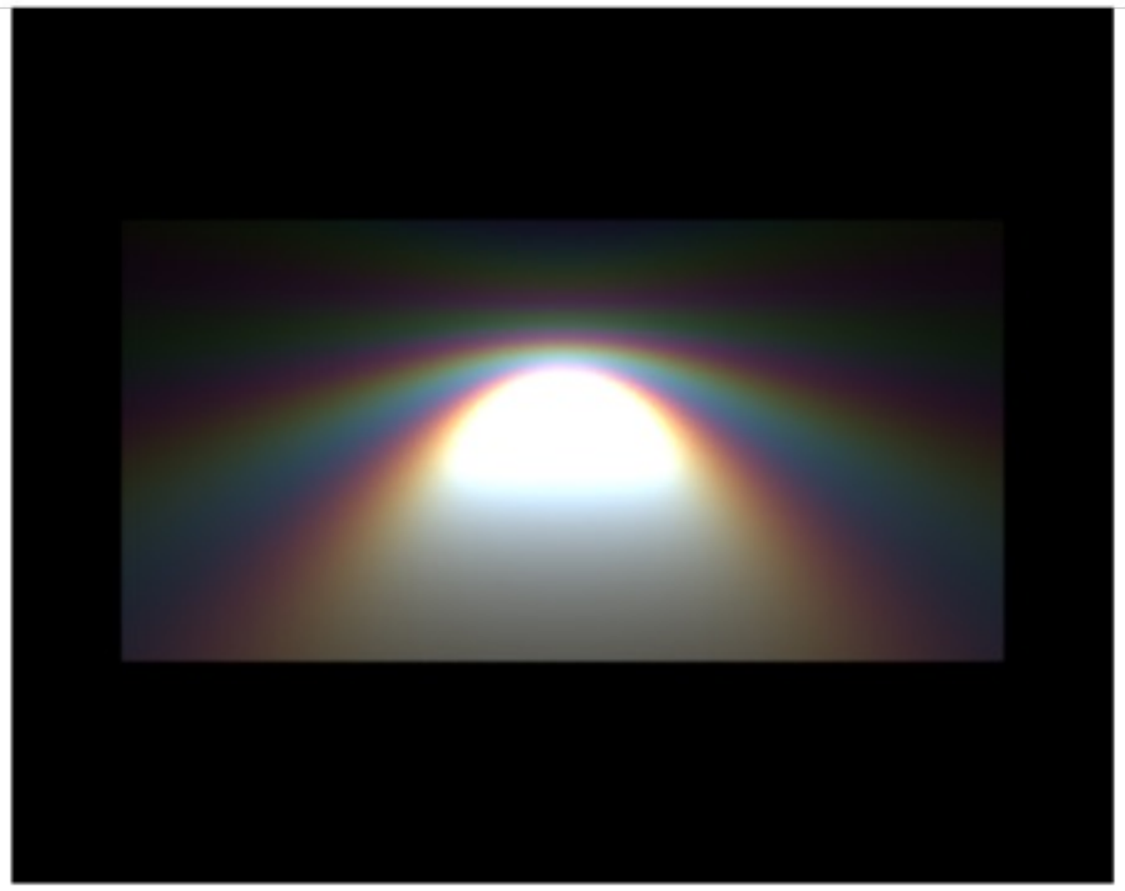
particle



Particle: $f = 0.3, r = 0.5um, 90^{\circ}$

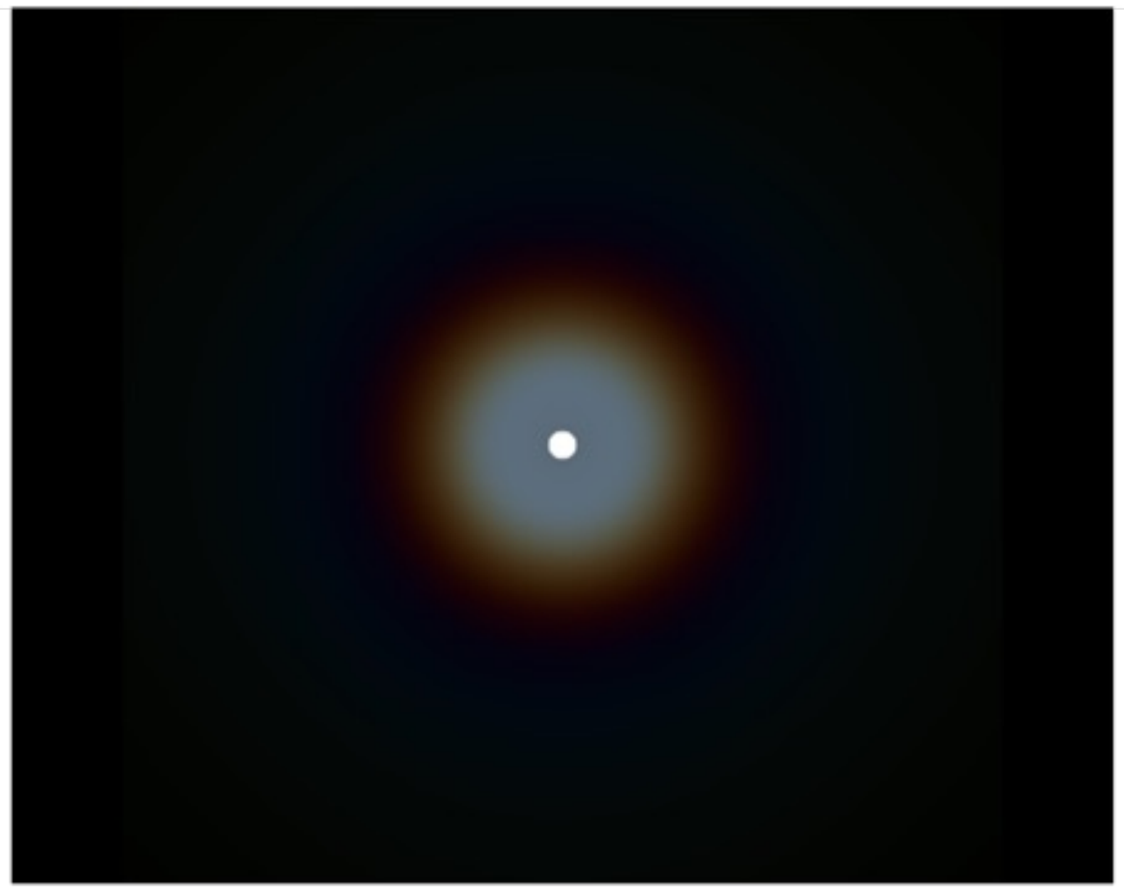


Particle: $f = 0.3, r = 0.5um, 60^{\circ}$

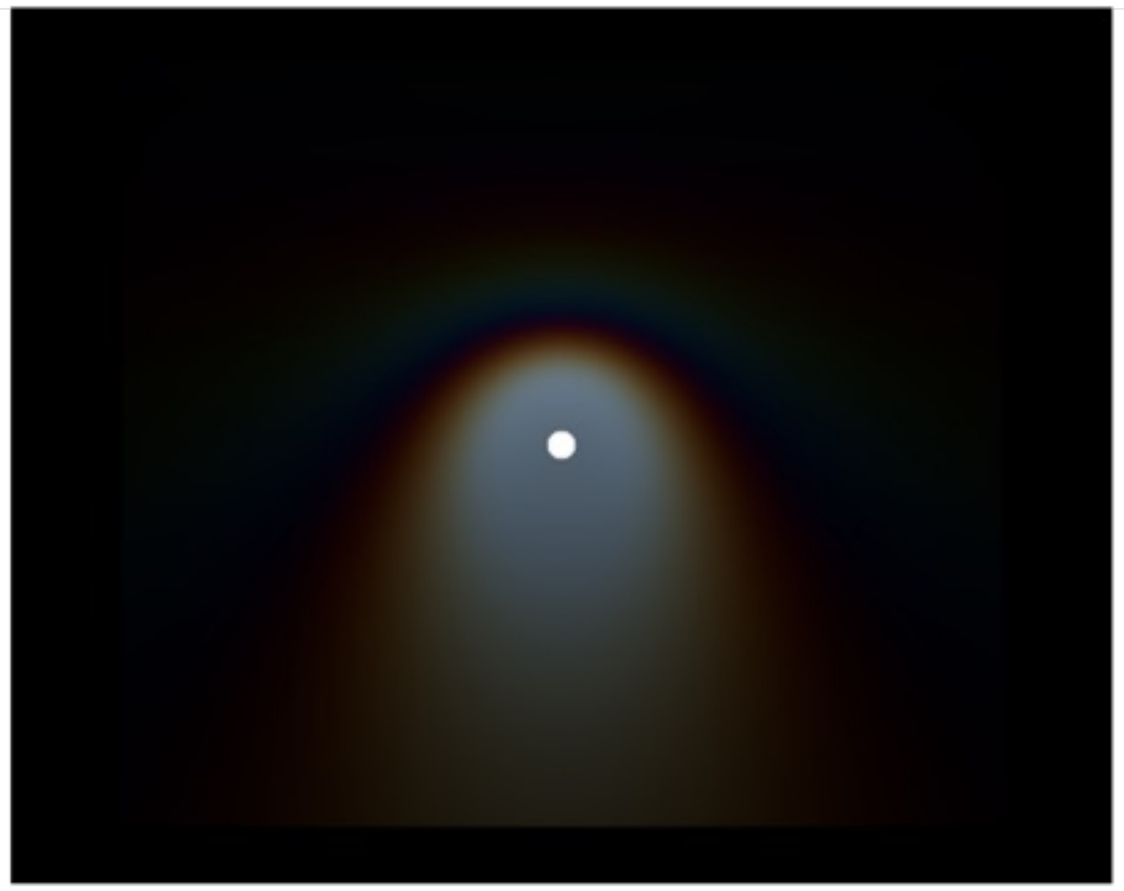


Particle: $f = 0.3, r = 0.5um, 30^{\circ}$

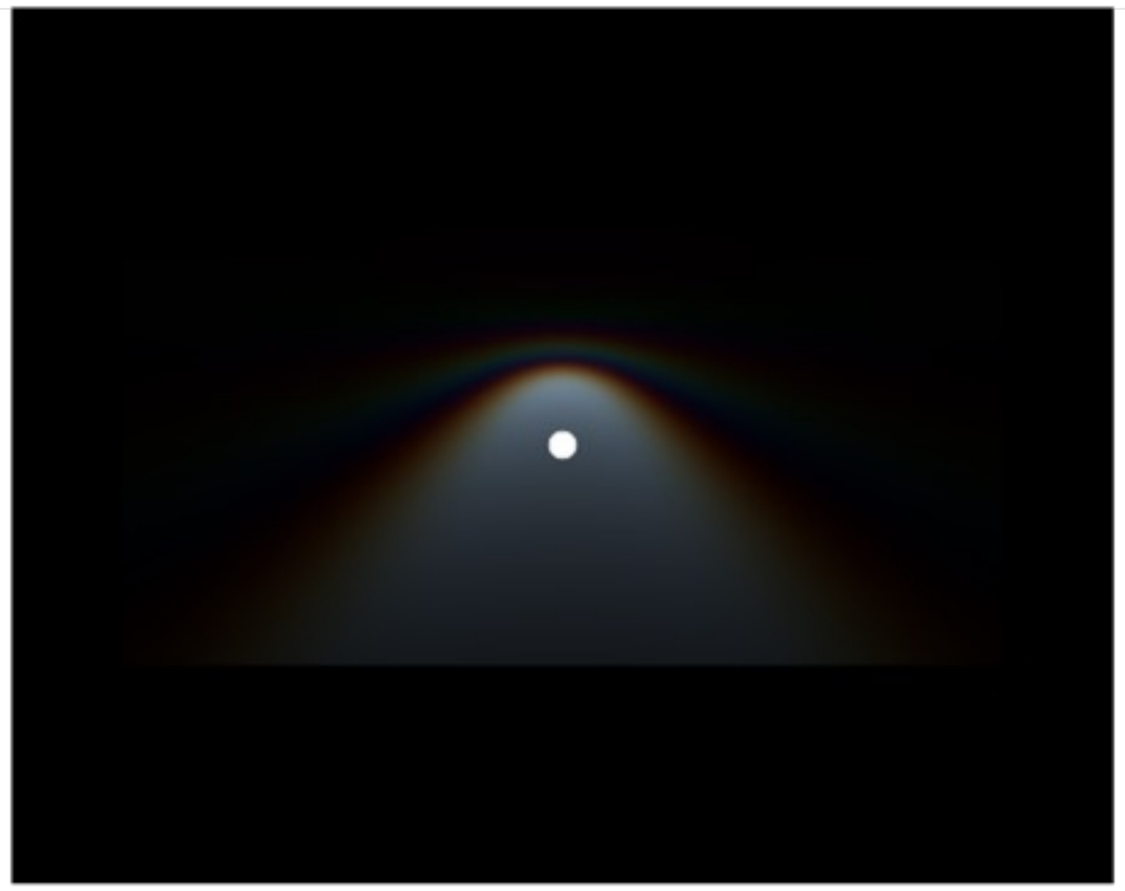
aperture



Aperture: $f = 0.3, r = 0.5um, 90^{\circ}$

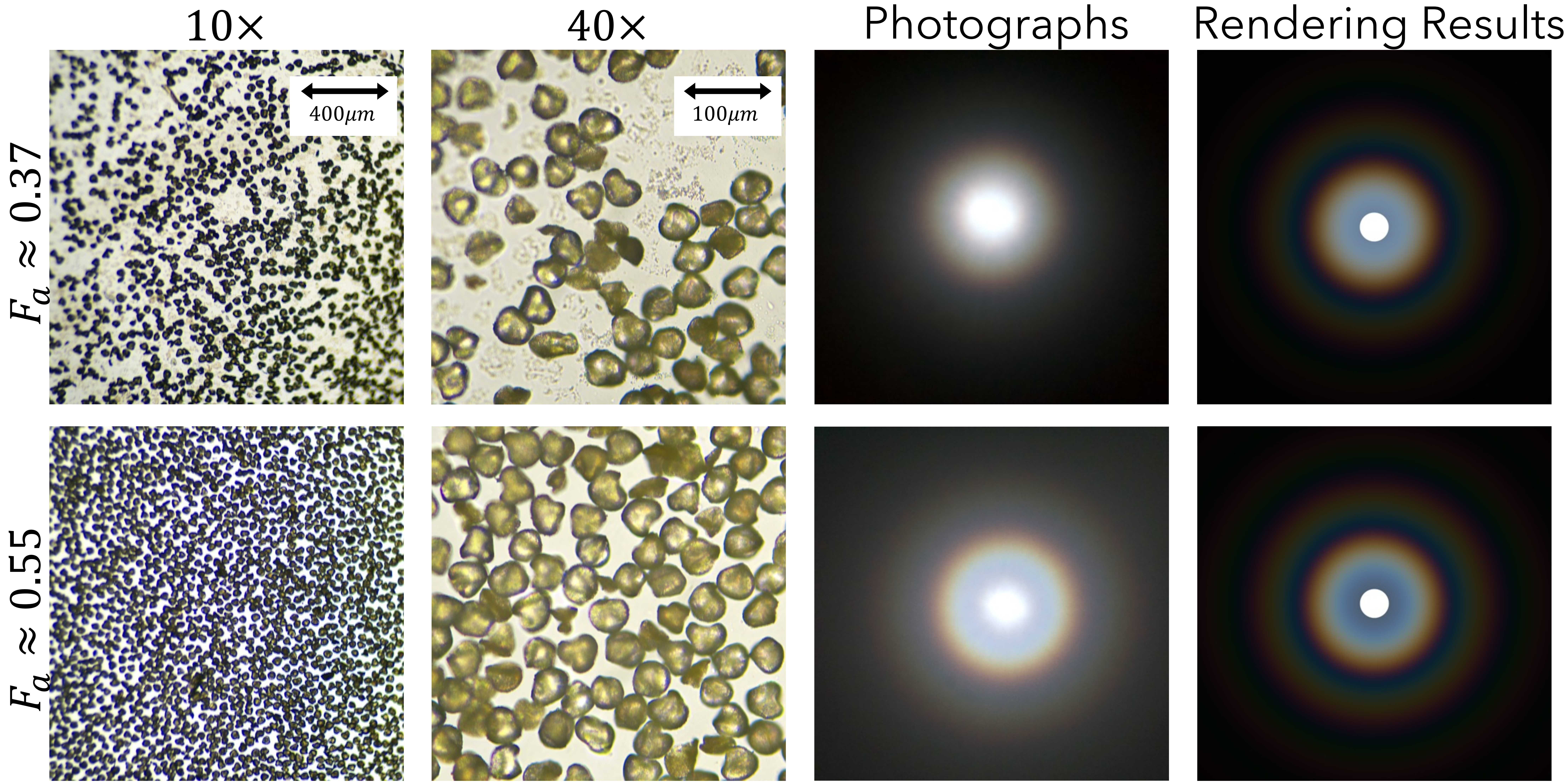


Aperture: $f = 0.3, r = 0.5um, 60^{\circ}$



Aperture: $f = 0.3, r = 0.5um, 30^{\circ}$

Lycopodium powder

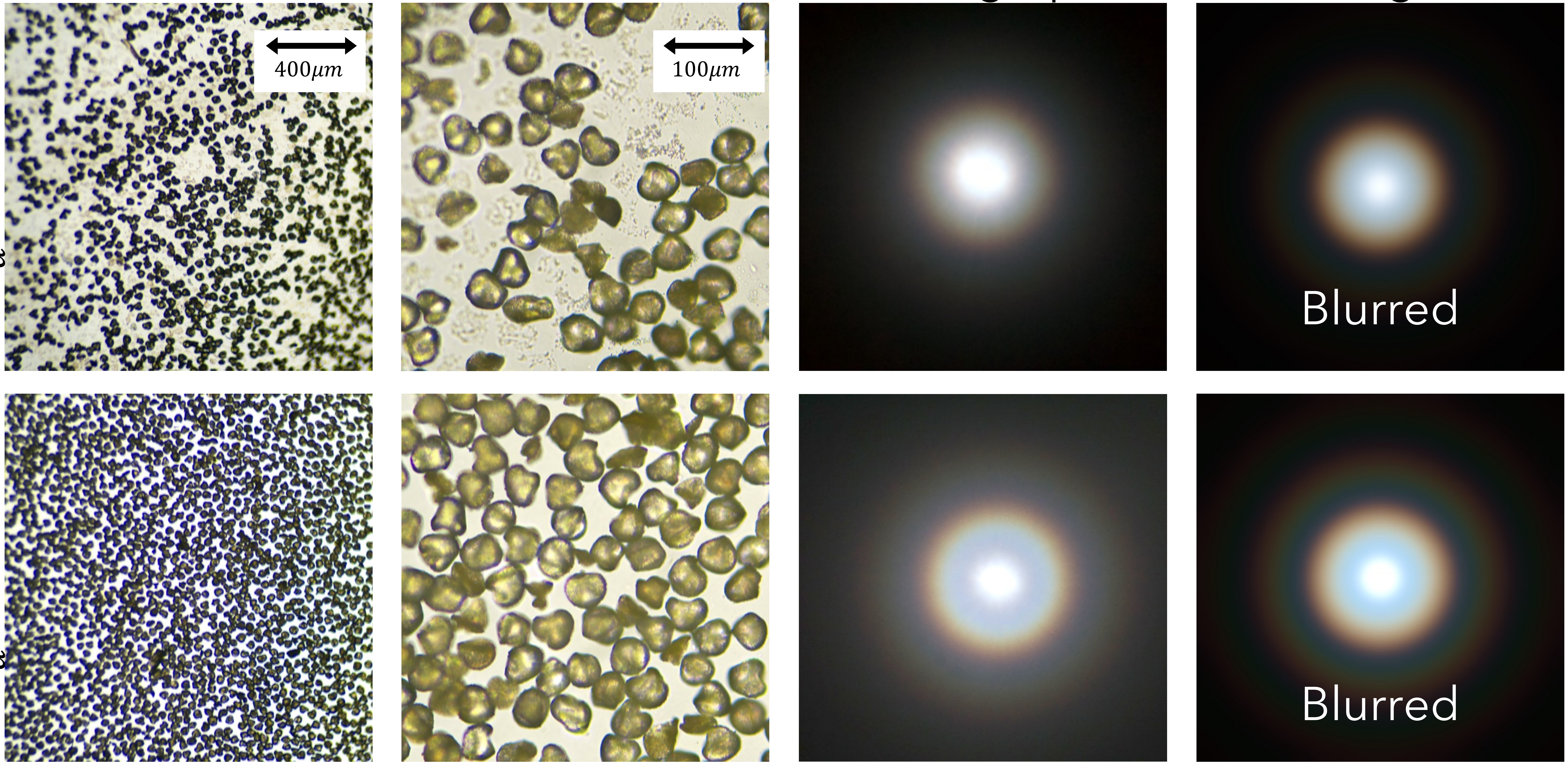


Lycopodium powder

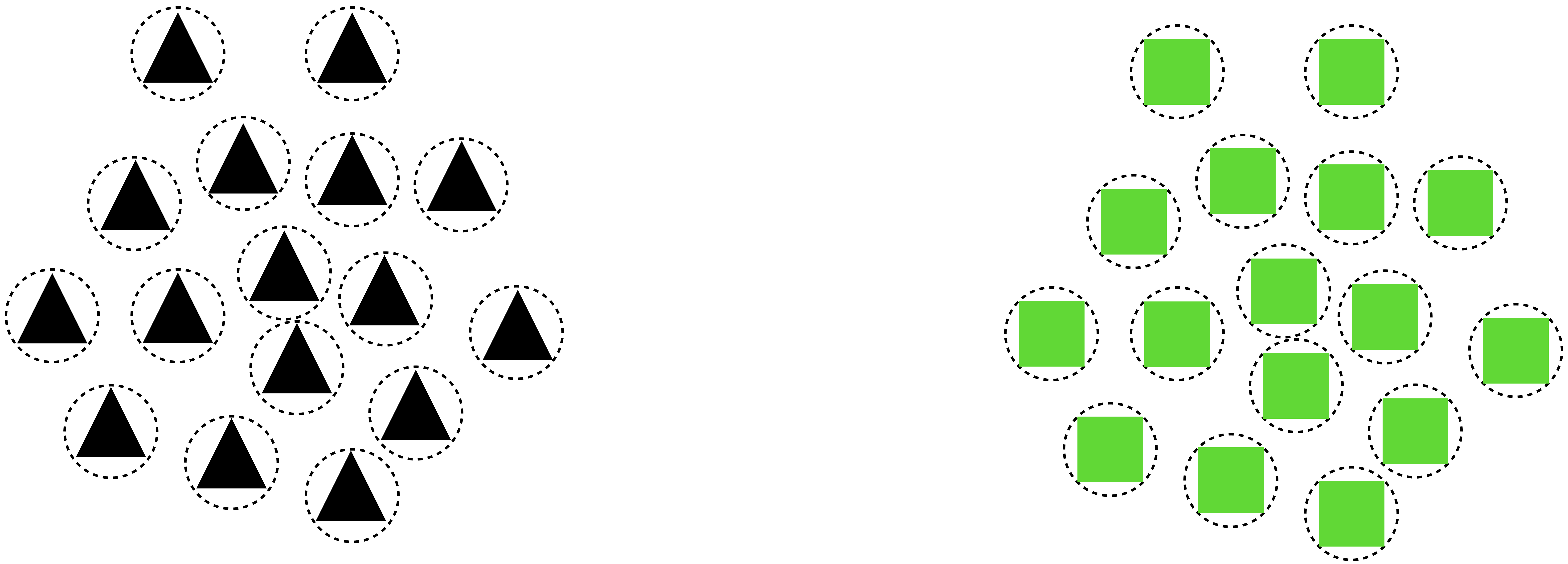
10× | 40× | Photographs | Rendering Results

$F_a \approx 0.37$

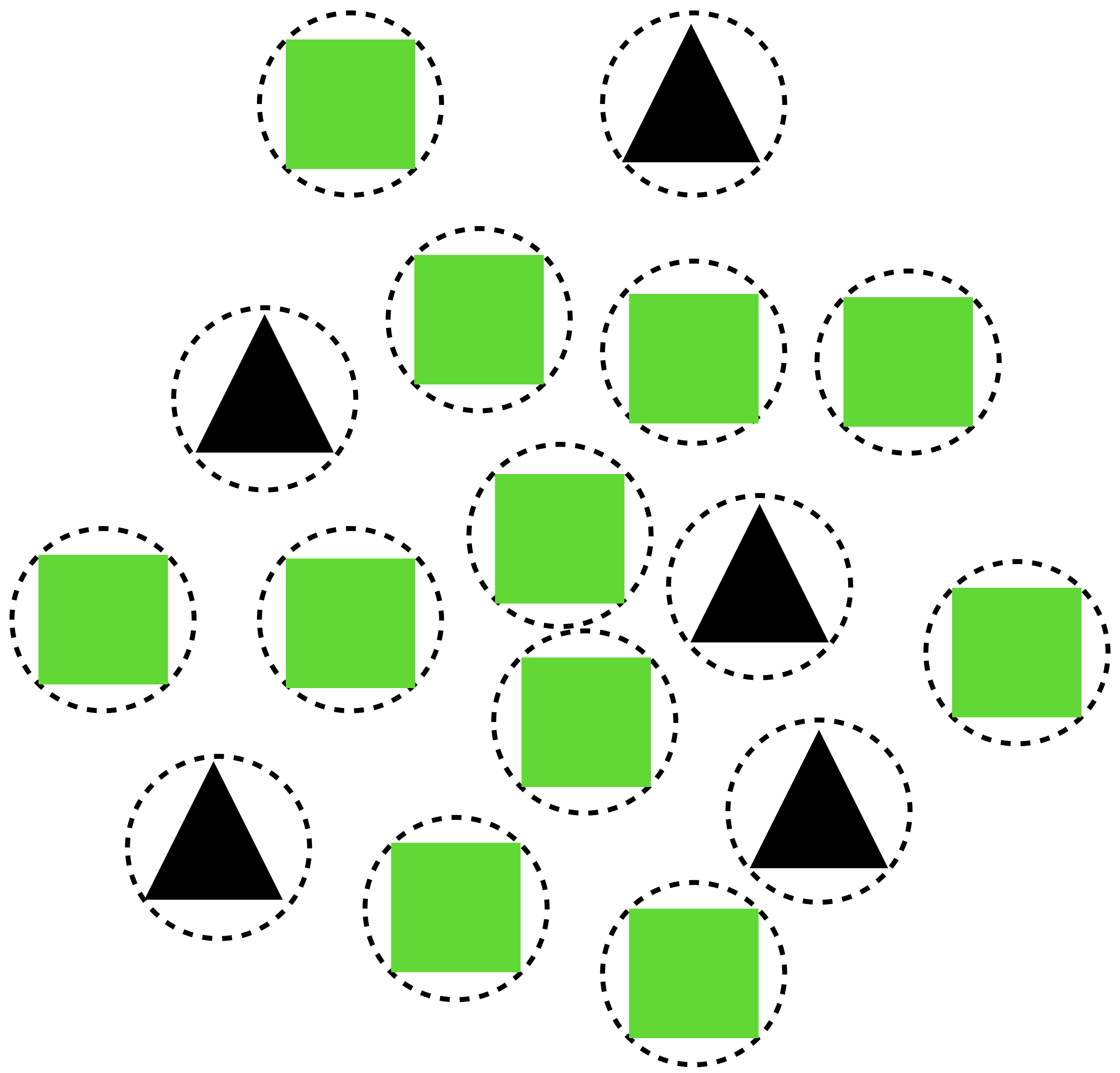
$F_a \approx 0.55$



Mixed aperture types



Mixed aperture types



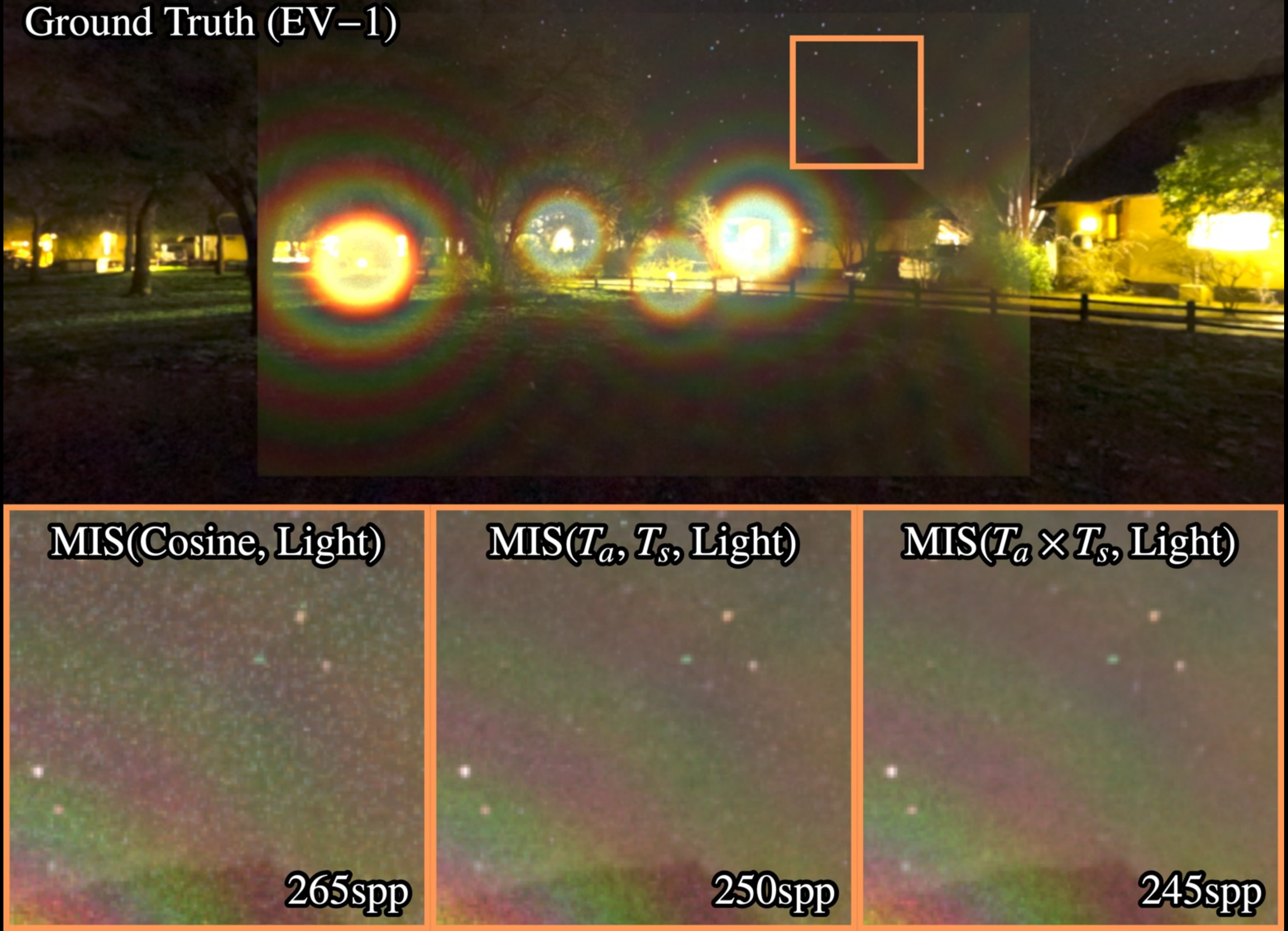
100 %

■ 75 % ▲ 25 %


50 %
50 %


25 %
75 %

100 %


Ground Truth (EV−1)
MIS(Cosine, Light)
265spp
MIS(T_a, T_s, Light)
250spp
MIS($T_a \times T_s$, Light)
245spp

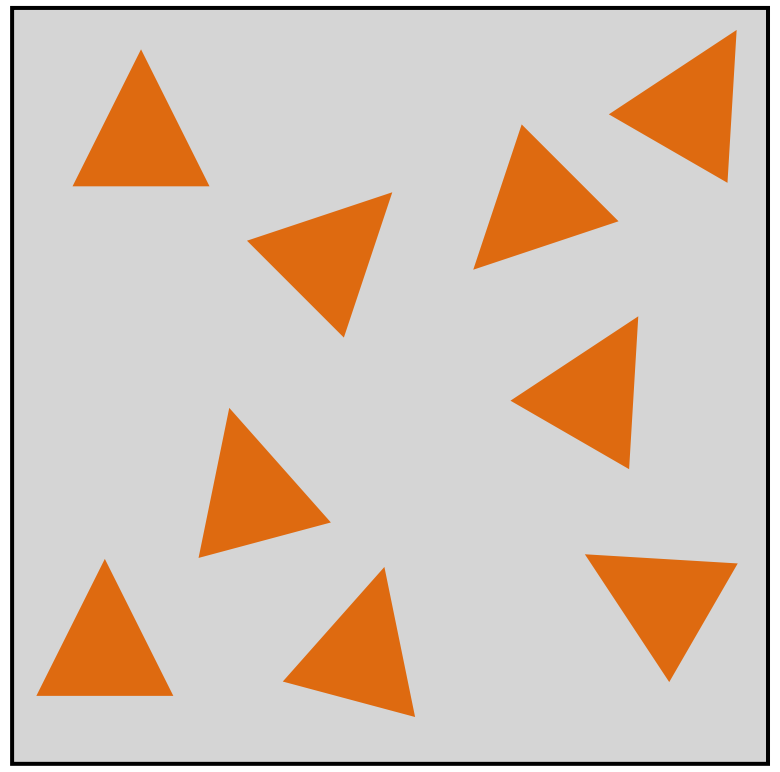
Conclusion & Future Work

A wave-optics-based BSDF for simulating the corona effect

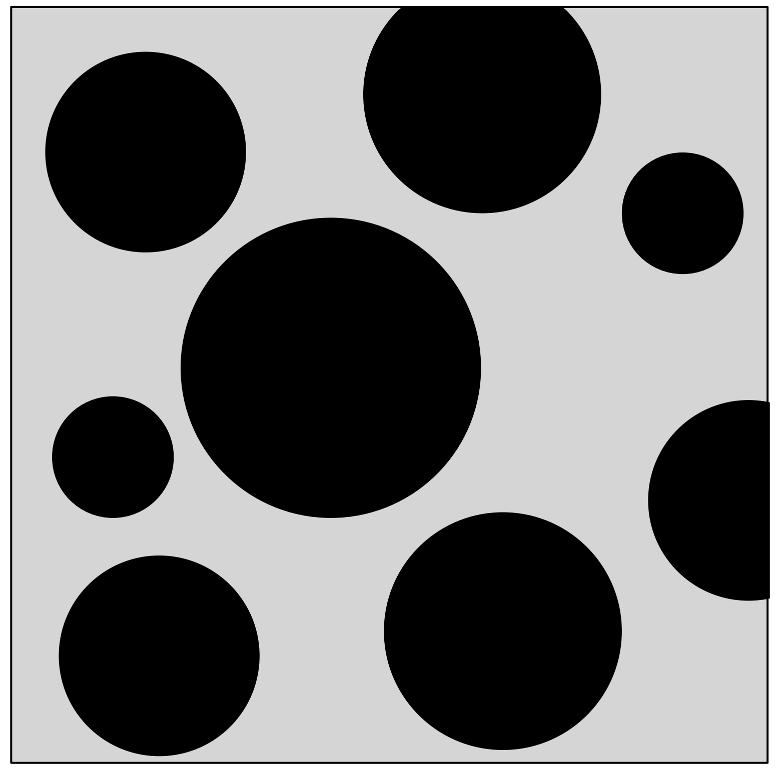
Decoupling the spatial distribution and diffraction of individual scatterers provides design flexibility.

Future works :

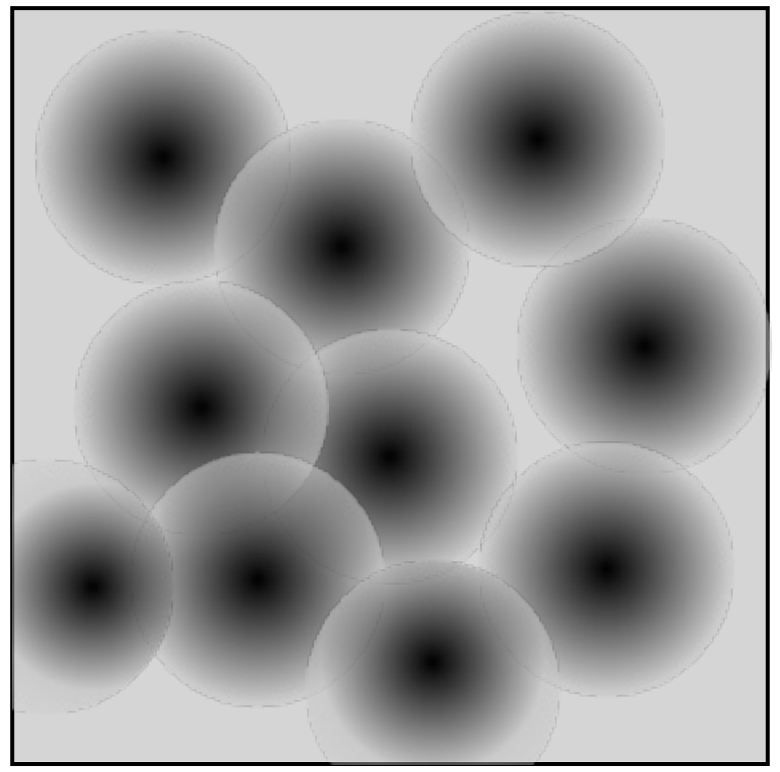
Random orientation



Mixed aperture size



Soft bound





Thank you for listening!