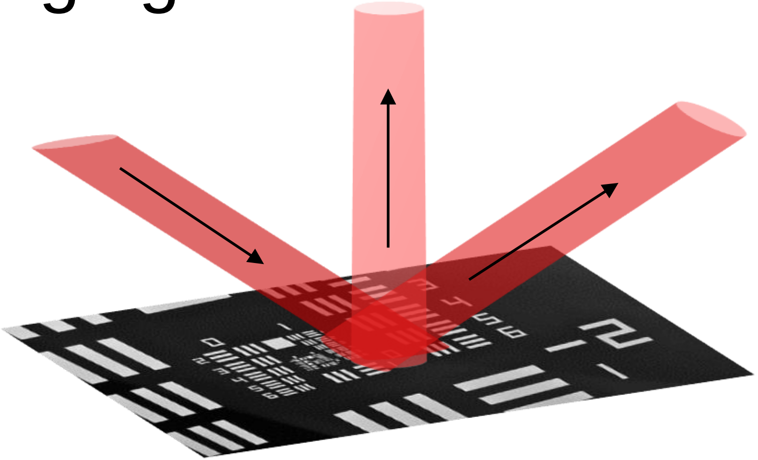
# Improving Optical Overlay Metrology Using Computational Imaging

## via dark-field Digital Holographic Microscopy



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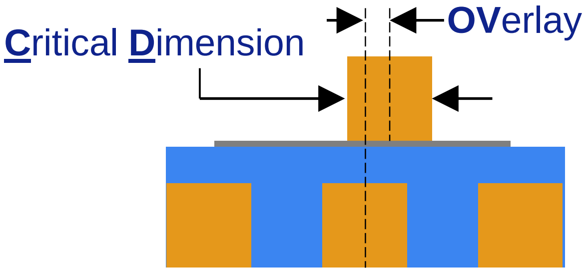
# Modern computer chip have small features...
# ... even quality control is challenging

Nowadays requirements:

- Critical dimension 7 nm
- Overlay metrology << 1 nm



Periodic Structures

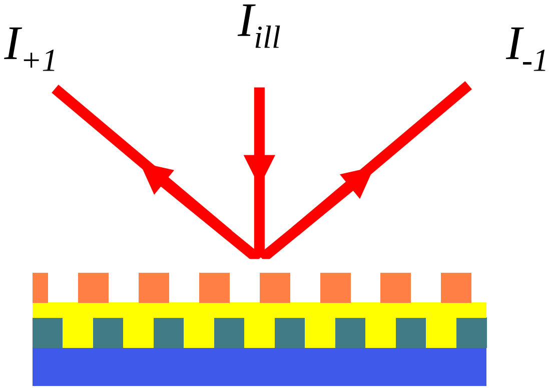
# Optical OV Metrology for future sensors

## Light scattering from periodic structures

Benefits of DBO metrology

- OV measurement precision < 1nm
- Non-scanning & Non-destructive
- **FAST**

$$OV = \frac{I_{+1} - I_{-1}}{K}$$



Diffraction Grating

Requirements of future sensors

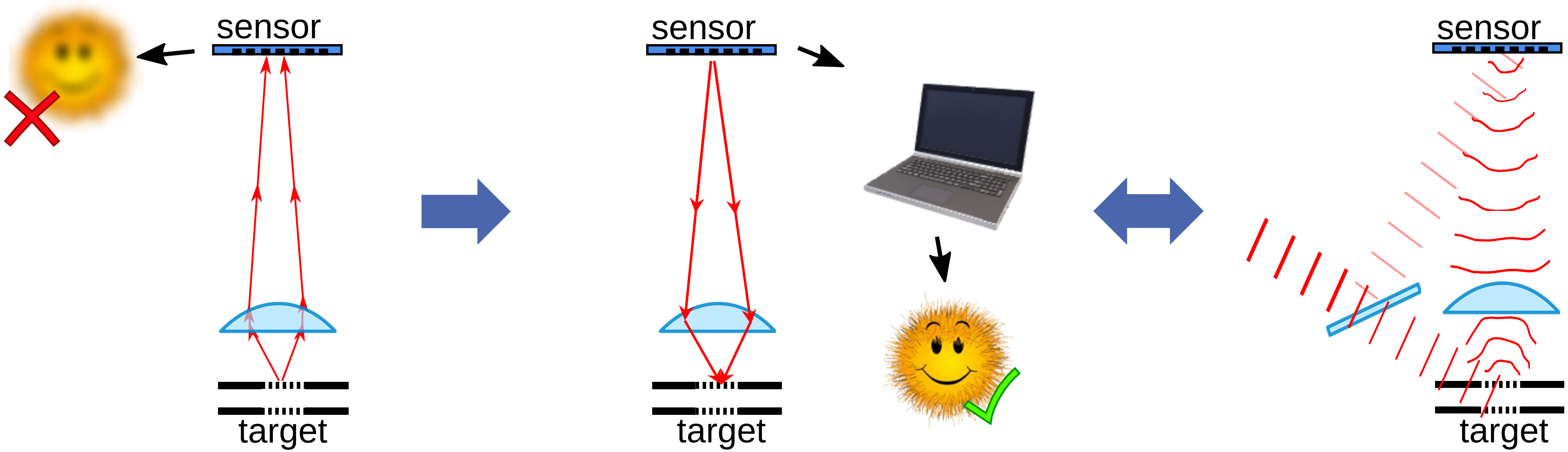
- Detect weak scattering targets (Diff.Eff. < 1%)
- Small sized targets (5x5 um$^2$)
- Longer wavelength ranges
- **Optics with High NAs & low aberrations**
- **Any alternatives???**

# Simple Optics requires digital corrections

Lens Aberrations
Image imperfections

Back Propagation
Data Processing

Digital holography
Complex Field



# Image reconstruction with Digital Holographic Microscopy

- Complex light field acquisition
- Coherently mixed light

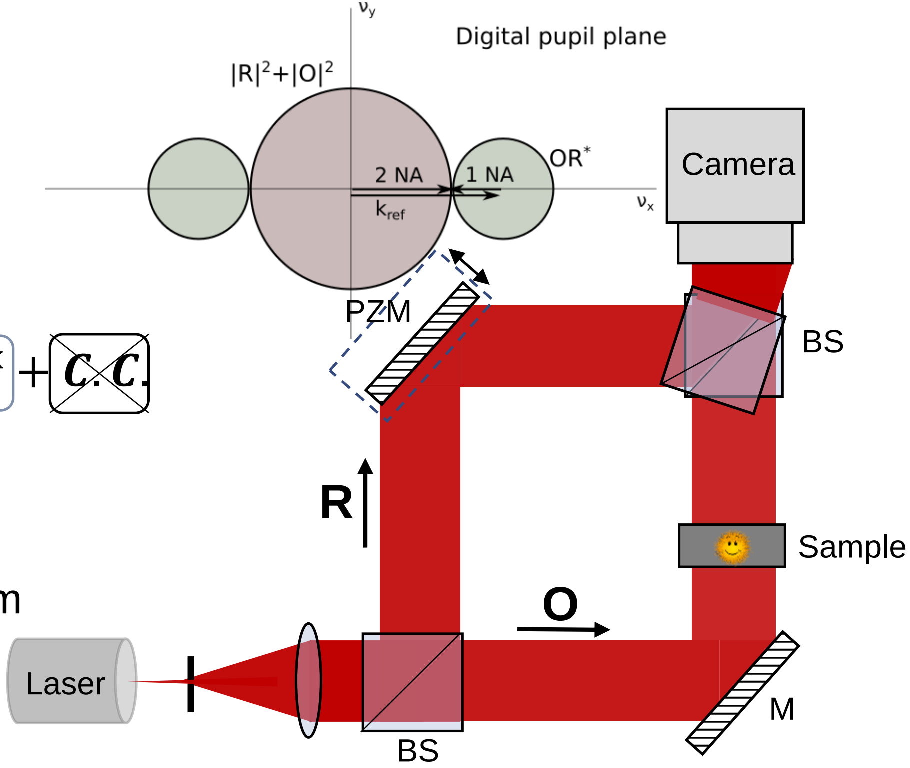
$$I(x,y) = |O(x,y) + R(x,y)|^2$$

$$= \boxed{\xcancel{|O(x,y)|^2}} + \boxed{\xcancel{|R(x,y)|^2}} + \boxed{OR^* e^{i2\pi(\Phi\pm\delta)x}} + \boxed{\xcancel{C.C.}}$$

- Amplifies weak detection signal
- Direct phase measurements

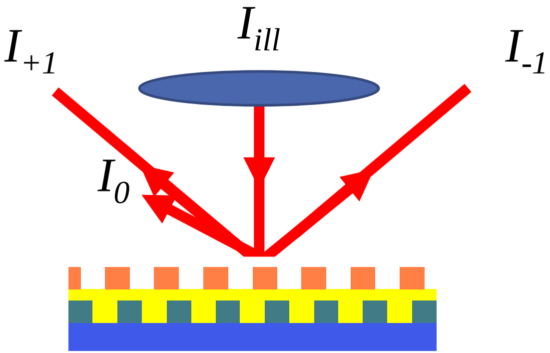
- Off-Axis: extract phase via Fourier Transform
  - Single-Shot Acquisition

- In-line: extract phase via Phase-shifting
  - Multiple Scans



Typical Digital Holographic Microscope

# Dark-Field Holography measures relevant information but has requirements on temporal coherence length

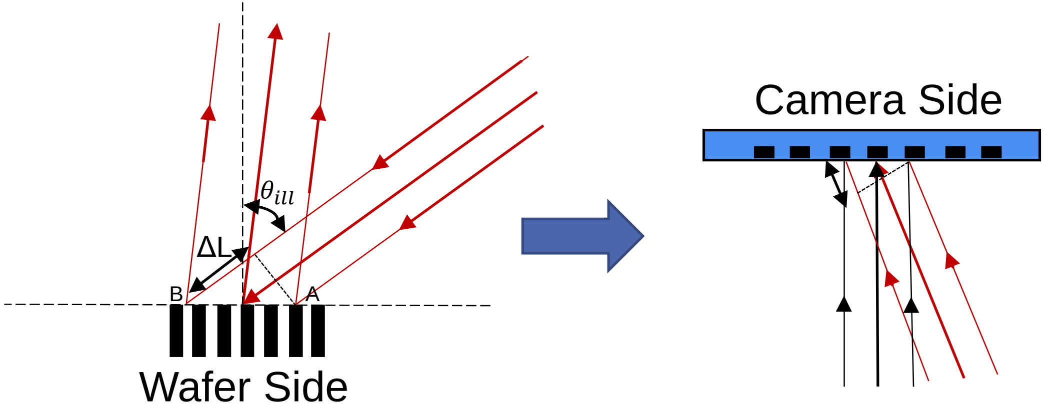


Diffraction Grating

Why dark field?

- Oblique illumination beam
- Discard specular reflection from $I_{ill}$
- Separate illumination & detection optics to reduce stray light

- Delay (ΔL) on the illumination generates
  - Phase difference
  - Limited interference based on temporal coherence
- Derive the requirements for digital holography
  - Balance Bandwidth – Coherence length



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# Solving the impact of coherence

- 1D implementation of df-DHM model

$$\sin(\theta_n) + \sin(\theta_{ill}) = n\frac{\lambda}{P}$$

- Detected intensity for Quasi-Monochromatic Source

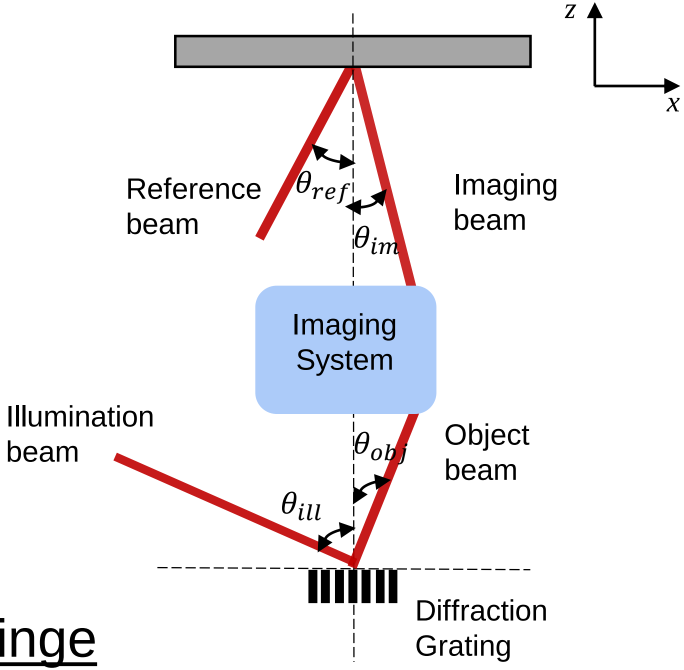
$$I(x;\lambda_c,B) = 1 + \cos\left[2\pi\left\{\frac{n}{M}\frac{1}{P} + \frac{1}{\lambda_c}S_\lambda\right\}x\right]\boxed{\mathrm{sinc}\left(\pi\frac{B}{\lambda_c^2}S_\lambda x\right)}$$

Outcome:

- Field-of-View is limited by the bandwidth (B)

$$FOV < \frac{1}{B}\frac{2\lambda_c^2}{\sin(\theta_{ill}) - \mathrm{M}\sin(\theta_{ref})}$$

**Fringe Contrast**



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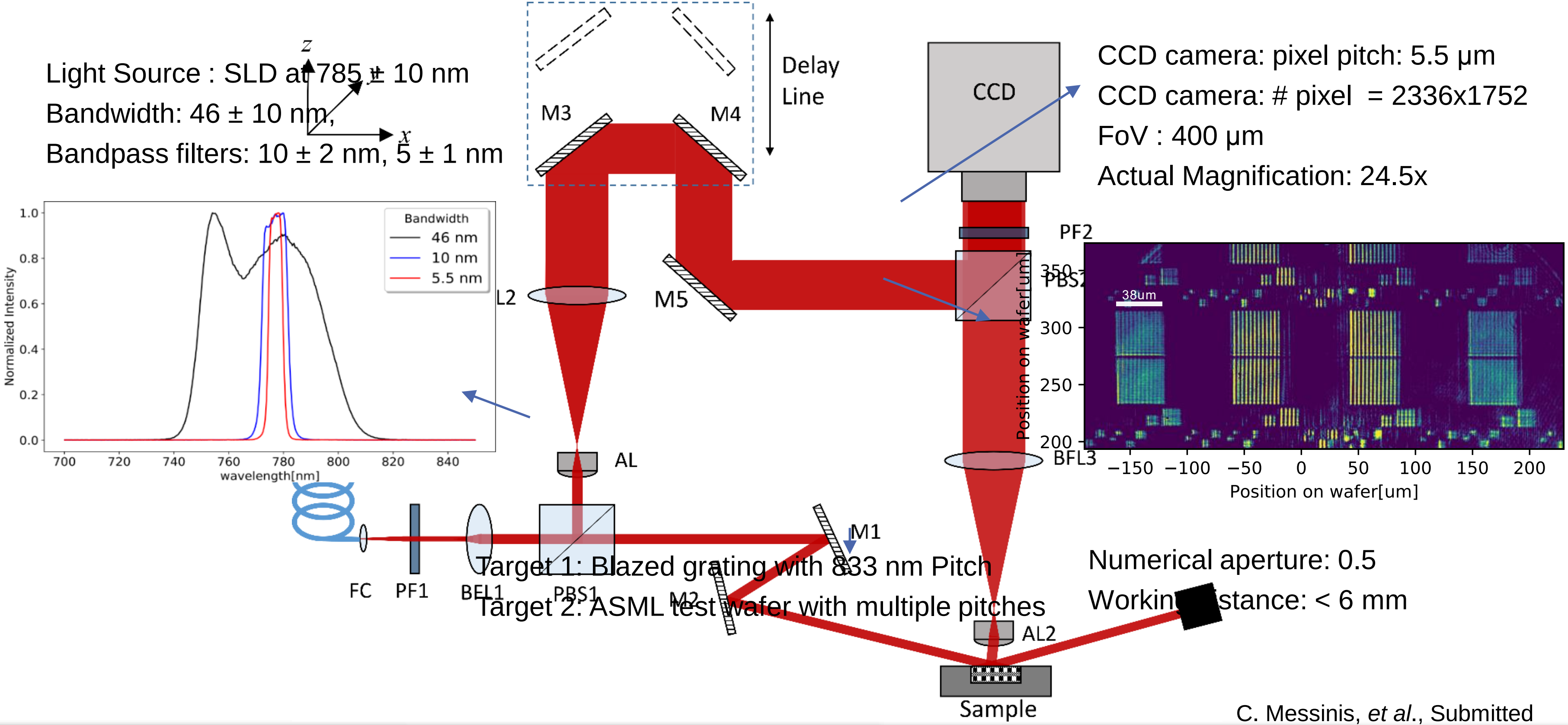
# Dark-Field Holographic Microscope



Light Source : SLD at 785 ± 10 nm

Bandwidth: 46 ± 10 nm,

Bandpass filters: 10 ± 2 nm, 5 ± 1 nm

CCD camera: pixel pitch: 5.5 μm

CCD camera: # pixel = 2336x1752

FoV : 400 μm

Actual Magnification: 24.5x

Target 1: Blazed grating with 833 nm Pitch

Target 2: ASML test wafer with multiple pitches

Numerical aperture: 0.5

Working distance: < 6 mm

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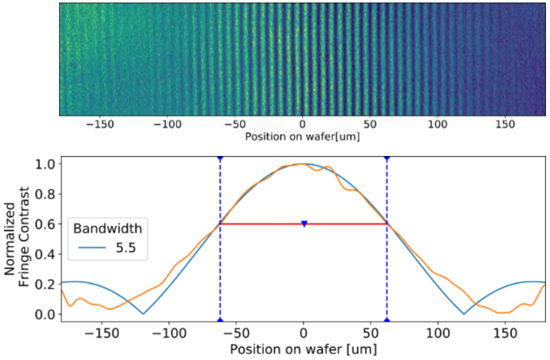
# Solving the impact of coherence

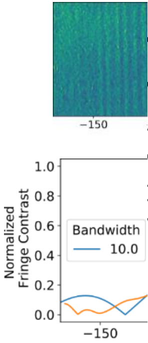
- Field-of-View is limited by the bandwidth (B)
- Synopsis for in-line DHM
  - From $\theta_{ref}$ = 5.2 mrad

$$FOV < \frac{1}{B}\frac{2\lambda_c^2}{\sin(\theta_{ill}) - \mathrm{M}\sin(\theta_{ref})}$$

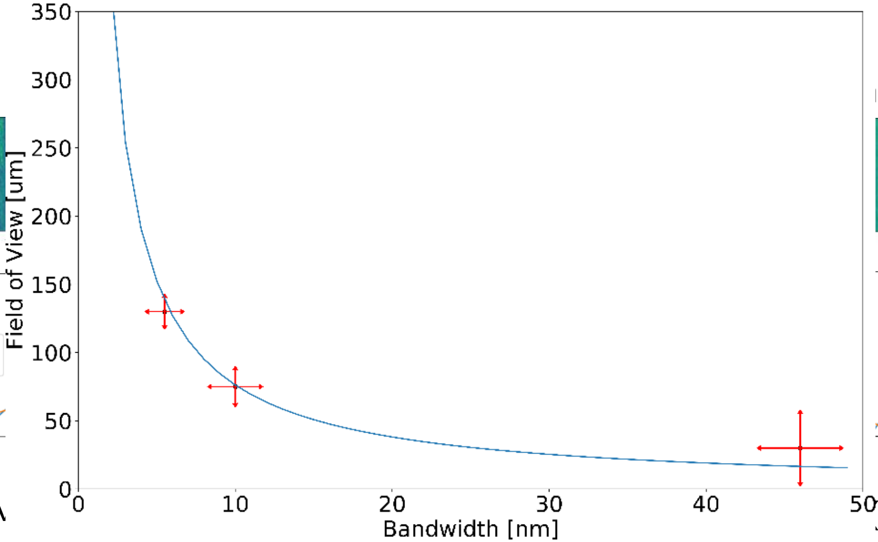
Bandwidth : 5.5 nm

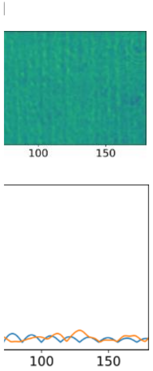


FoV with fringes: 130 (±10) um



Fo





±25) um

Target 1: Blazed grating with 833 nm Pitch

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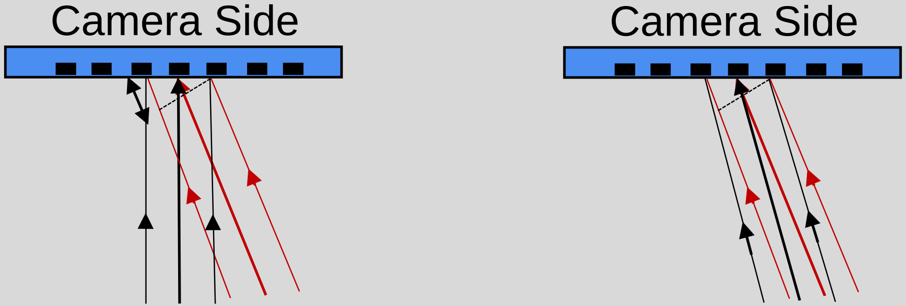
# Off-axis df-DHM

FoV = 210 um

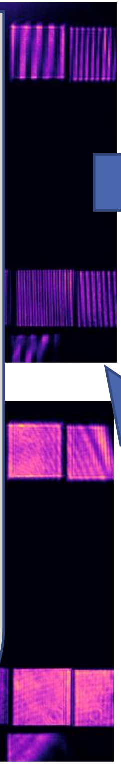
Introduced delay due to oblique illumination

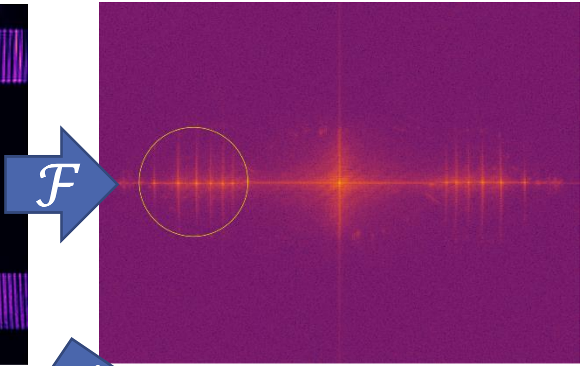
Off-axis adds delay to reference arm

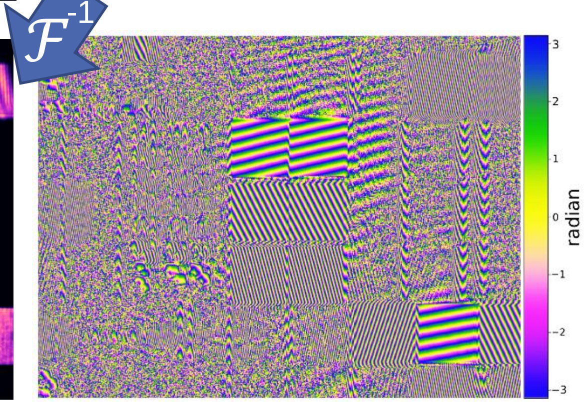
$$FOV < \frac{1}{B}\frac{2\lambda_c^2}{\sin(\theta_{ill}) - \mathrm{M}\sin(\theta_{ref})}$$



In-line df-DHM vs Off-Axis df-DHM



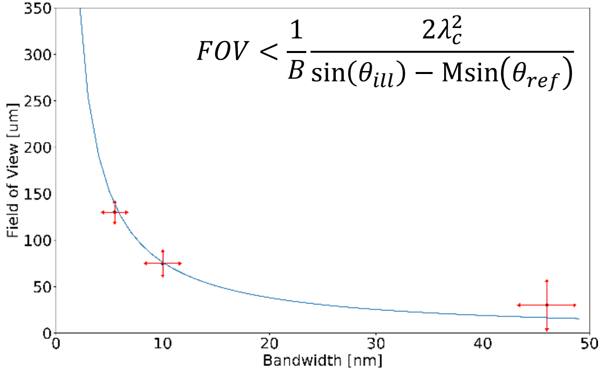




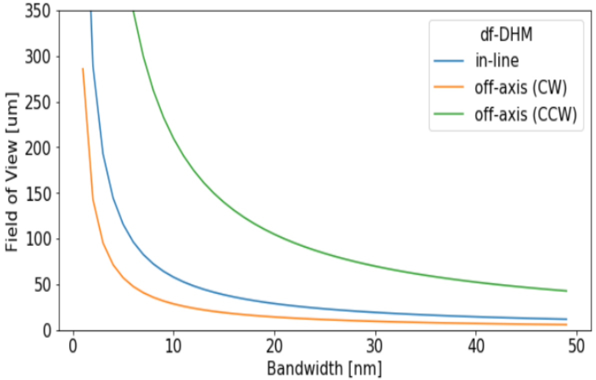
# Summary

- Derived a model that describes the impact of coherence length on the FoV for df-DHM
- This model provides requirements for parameters to design and predict the limitations of a setup

- Off-axis df-DHM offers some advantages over in-line DHM:
    - Enlarges the FoVs
    - Offers single shot reconstruction



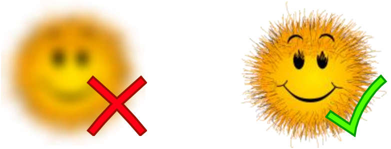
$$FOV < \frac{1}{B}\frac{2\lambda_c^2}{\sin(\theta_{ill}) - M\sin(\theta_{ref})}$$



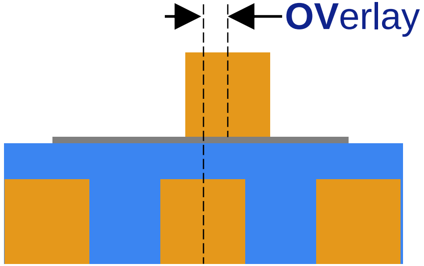
# Directions – Future plans

- Improve the capabilities of df-DHM – meet industrial requirements
  - Increase magnification to image smaller targets (5x5 um$^2$)
  - Use high power light sources for targets with low diffraction efficiencies
  - Demonstrate OV errors for large wavelength range

- Demonstrate proof of principle aberrations correction



- Measure OV error with our setup



Periodic Structures

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Thank you for your attention!!!