

# X-ray phase imaging with Talbot interferometer using LUCX source

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# Outlook

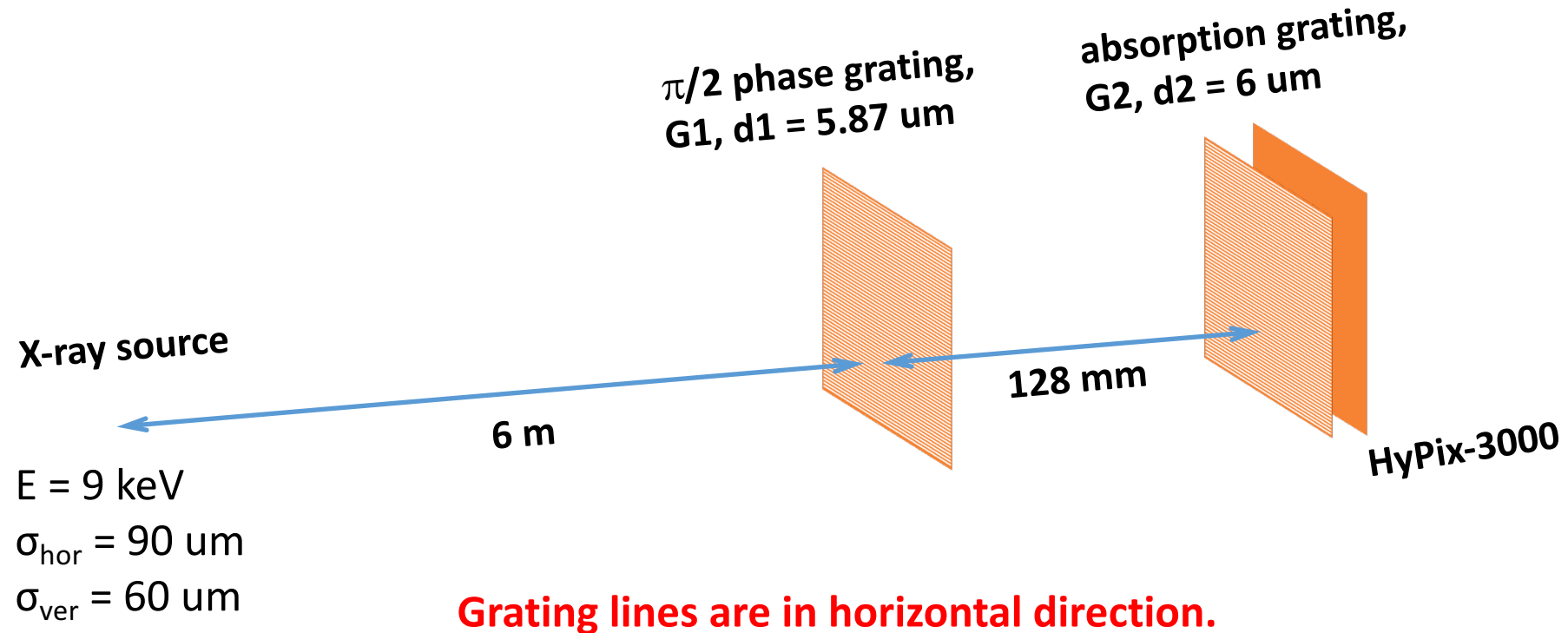
- Introduction
- Experiments (2015)
  - Results and Summary
- Experiments (2017)
  - Purpose and Motivation
  - Experiment I and Results
  - Experiment II and Results
  - Experiment III and Results
- Conclusion

# Introduction

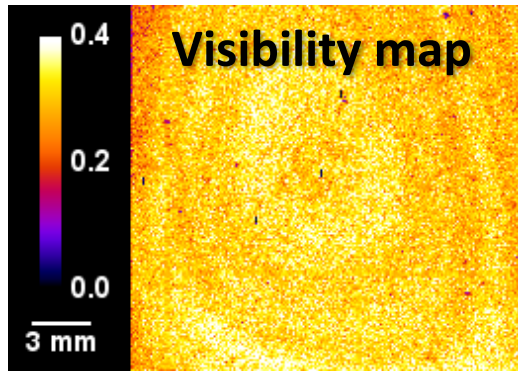
- X-ray phase imaging with Talbot interferometer using LUCX source was demonstrated in 2015, experiments were conducted at 9 keV.
- 33% average moiré fringe visibility was obtained at 5h total exposure time.
- Experiments have been repeated again in 2017 to evaluate the current state of the LUCX source for Talbot interferometry.

# LUCX Experiments 2015

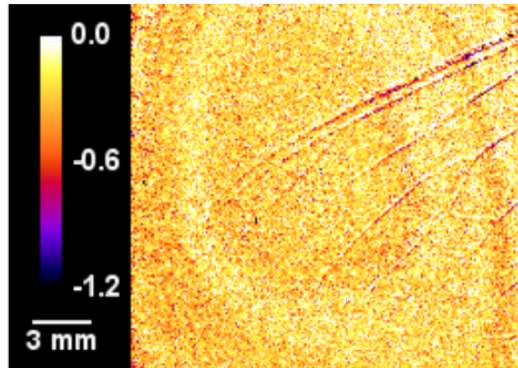
# X-ray Talbot interferometer Set-up (2015)



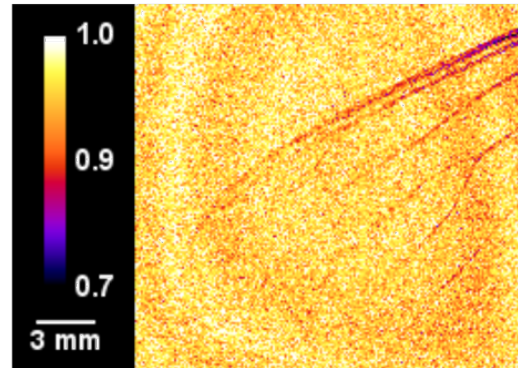
# Results of LUCX experiments, 2015



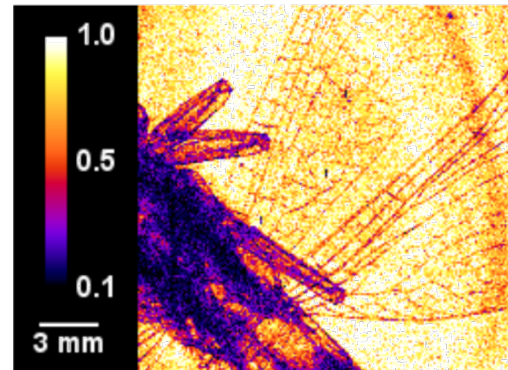
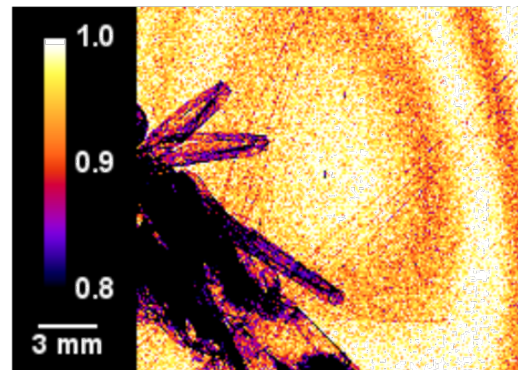
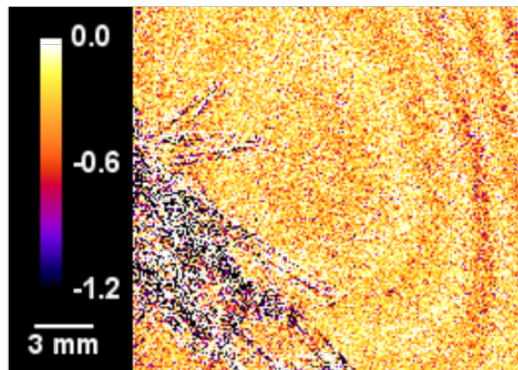
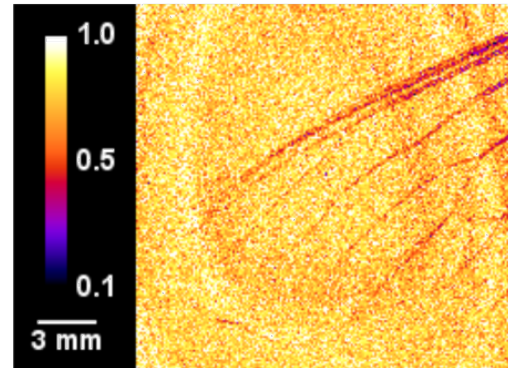
**Beam refraction**



**Transmission**



**Normalized visibility**



A dragonfly wing was measured using a 5-step fringe scan, 30-minute exposure time per step.

# Summary, 2015

- Average Moiré fringe visibility was 33% with vertical direction coherence.
- This relatively low value of visibility was expected due to the spatial coherence of the X-rays, the G2 height and duty cycle.

# LUCX Experiments 2017

# Purpose and motivation

- Purpose

- To evaluate the performance of X-ray phase imaging with Talbot interferometer using LUCX source.

- Experiments

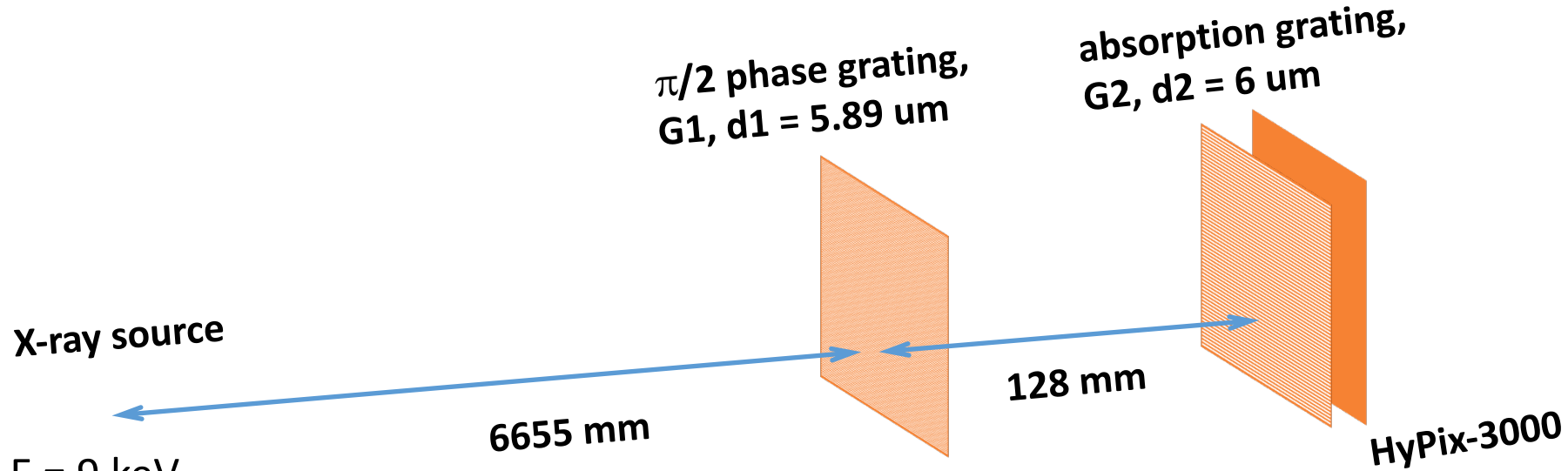
- I. Comparison of X-ray flux to 2015 in the same setup configuration.
- II. To test the horizontal spatial coherence of LUCX.
- III. To achieve wide-field of view with large area gratings.

# Experiment I

Comparison of X-ray flux to the experiments in 2015 in the same setup configuration.

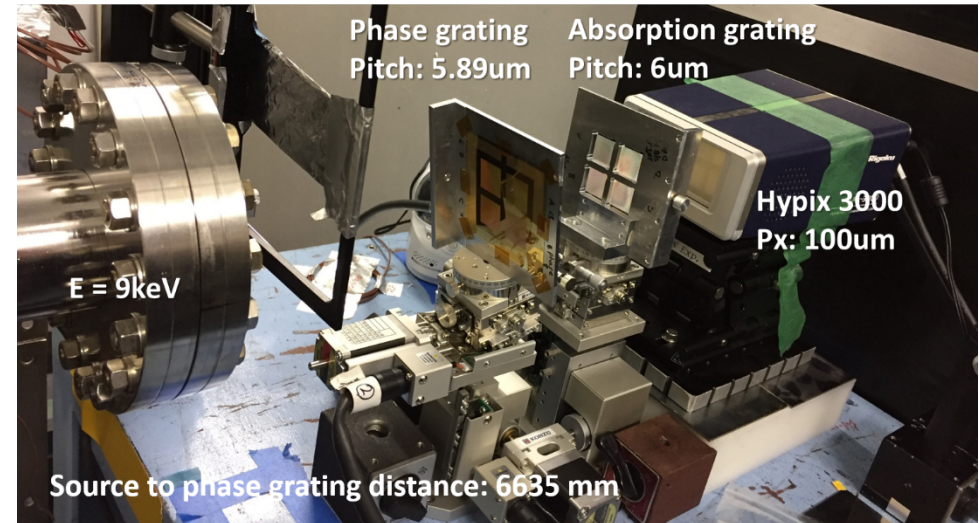
- Gratings
  - Phase grating G1: 5.89  $\mu\text{m}$  (6  $\mu\text{m}$  pitch grating tilted by 11.2 degrees)
  - Absorption grating G2: 6  $\mu\text{m}$
- Detector
  - HyPix-3000 (775 x 385 px), 100  $\mu\text{m}/\text{px}$  from Rigaku
- Horizontal grating alignment.
- 15 step fringe scanning by translating absorption grating.
- Exposure time : 2 min/step
- Samples: Washi in Aluminum foil, cicada wing, spider web

# X-ray Talbot interferometer Set-up I



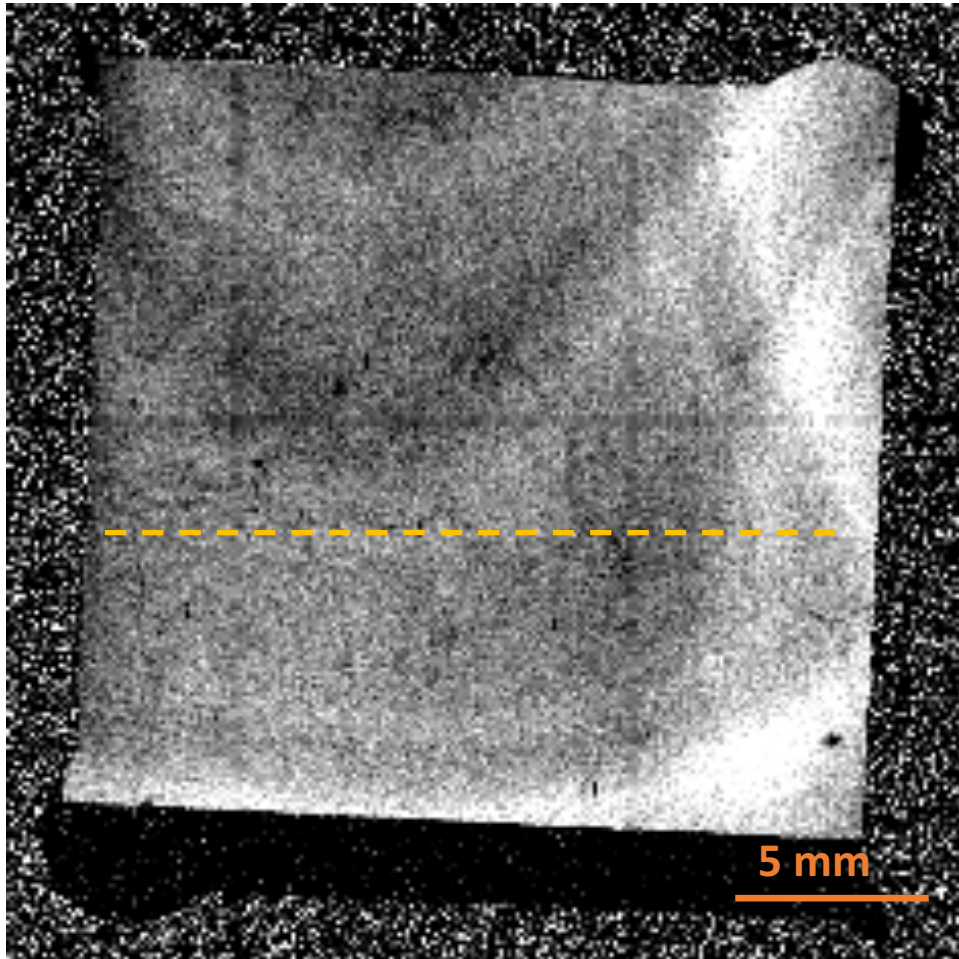
$E = 9 \text{ keV}$   
 $\sigma_H = 60 \mu\text{m} (?)$   
 $\sigma_V = 60 \mu\text{m}$

**Grating lines are in horizontal direction.**

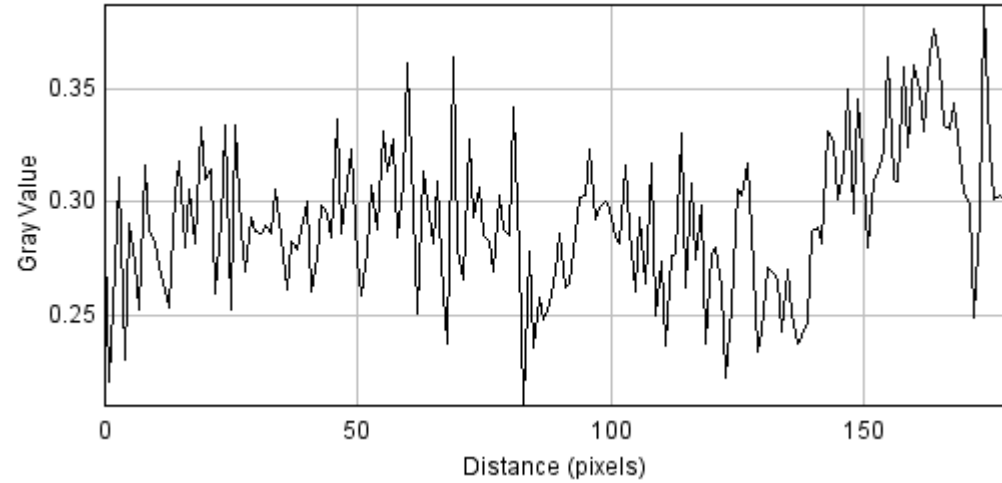


Exposure time: 2min/step x 15step

# Visibility map

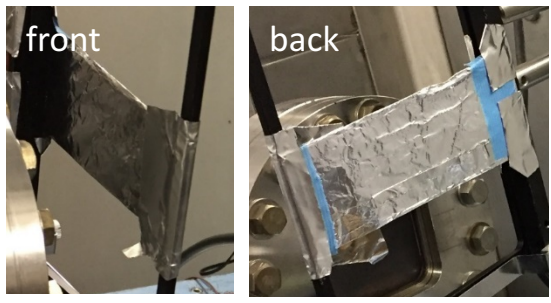


The average visibility was around 30%.

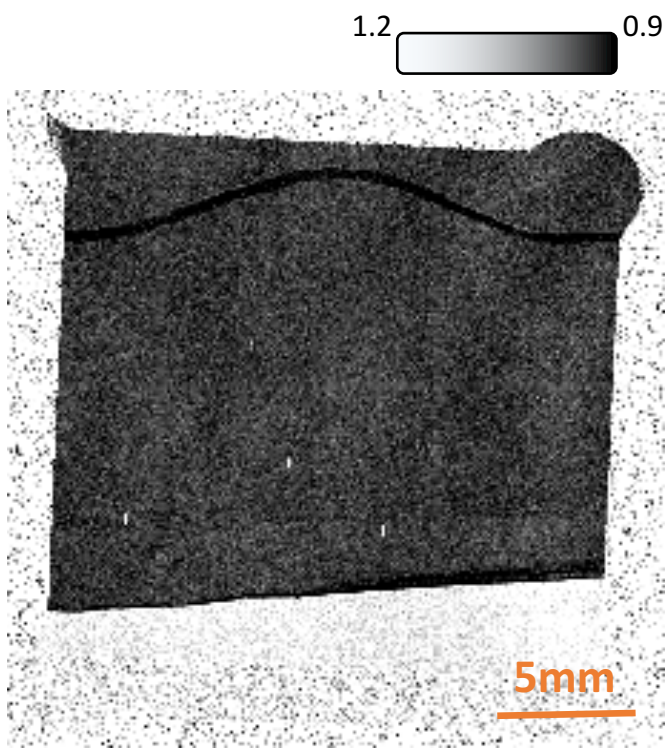


Horizontal direction cannot provide sufficient spatial coherence for Talbot interferometer with 6 $\mu$ m pitch gratings.

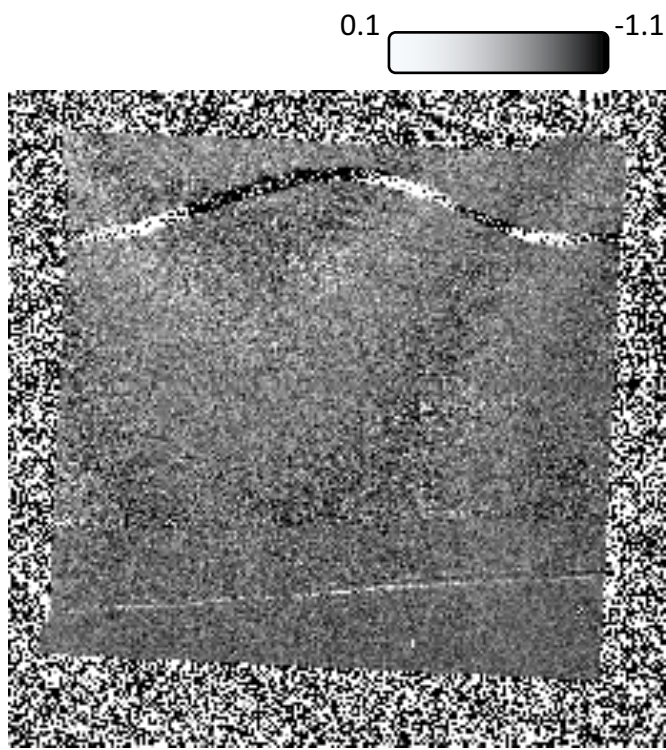
# Results of washi in the aluminum foil



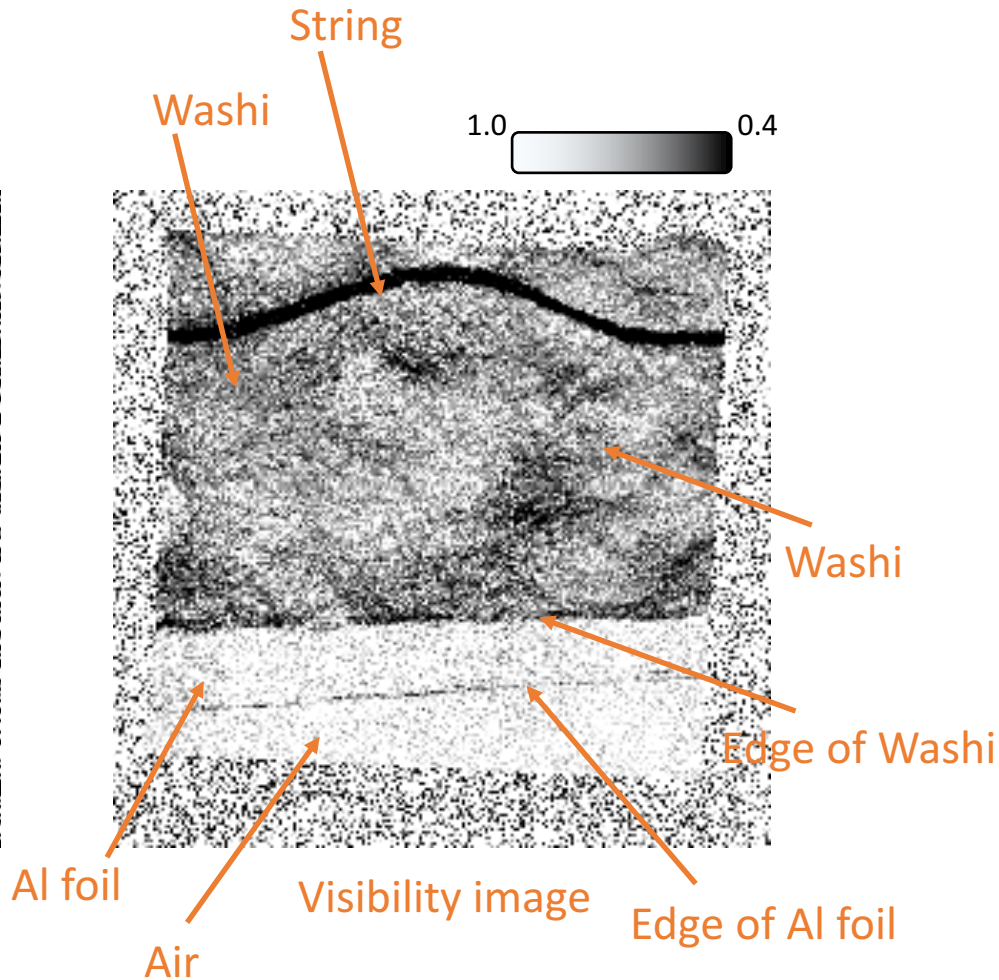
Best contrast and more information were obtained from normalized visibility image. Visibility image provides better contrast at the Washi/Al and Al/air interface than the absorption image.



Absorption image



Differential phase image

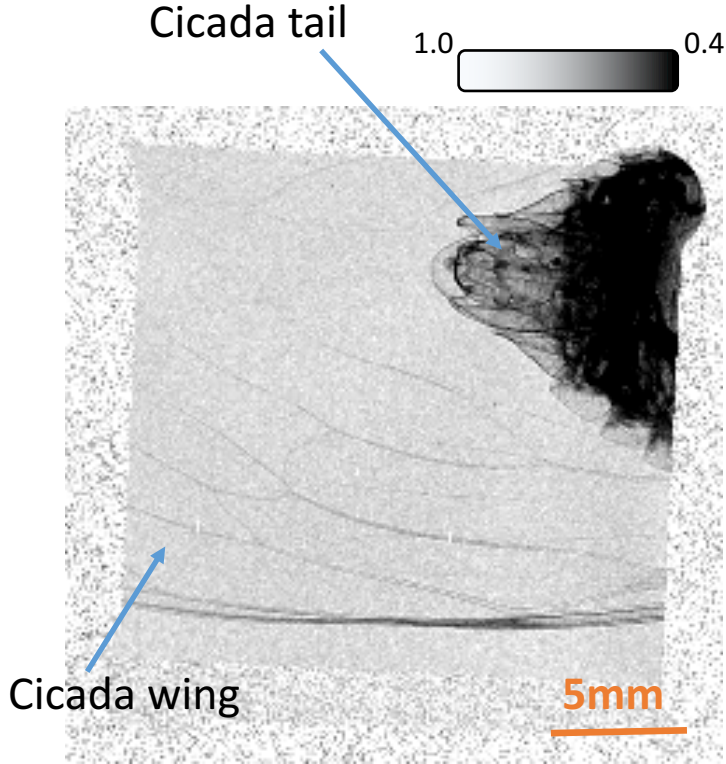


Sample: washi and string were sandwiched in Al foils.

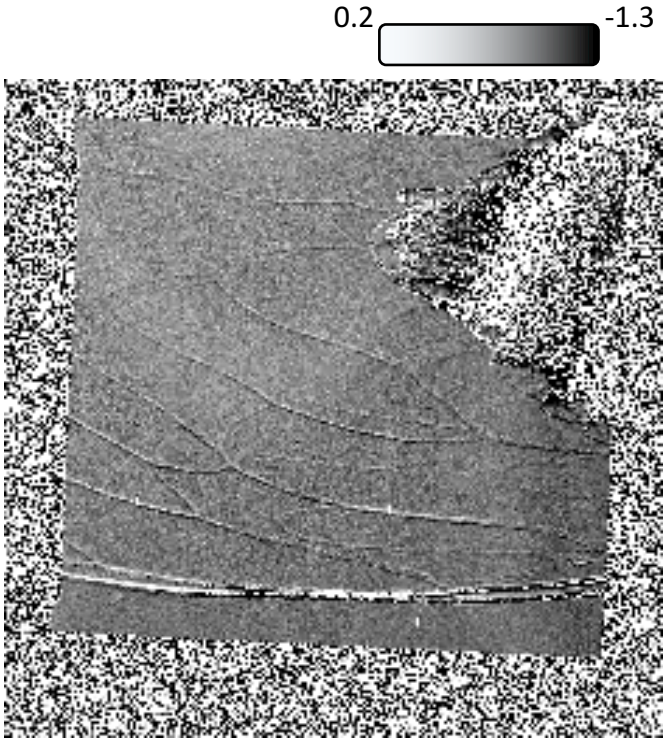
# Results of cicada wing



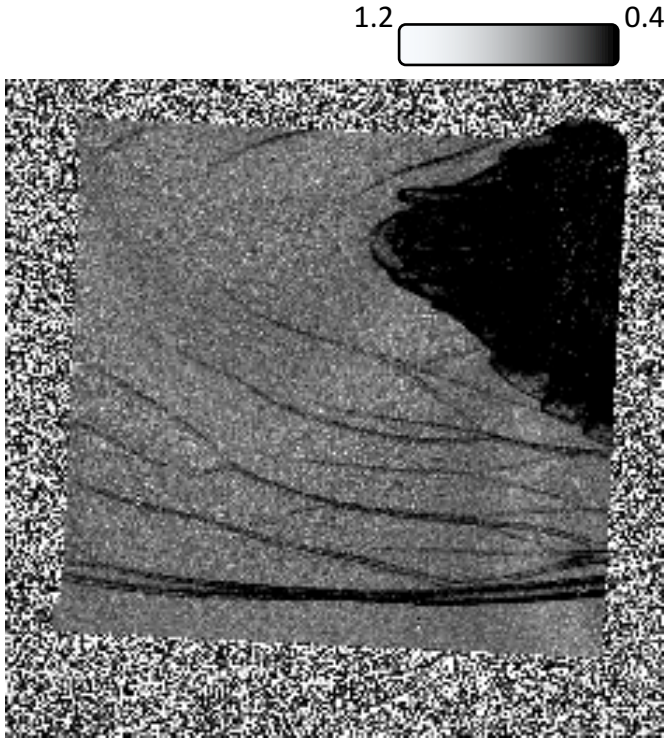
Biological sample is too absorbing at 9 keV, low photon counts result in noisy differential phase image. While the wing of the cicada could be measured at this energy, no new information was available than the conventional absorption contrast.



Absorption image

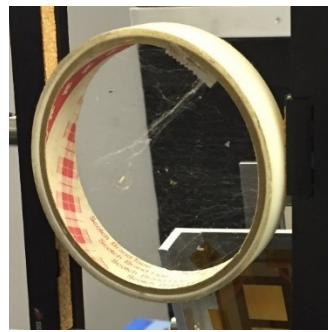


Differential phase image

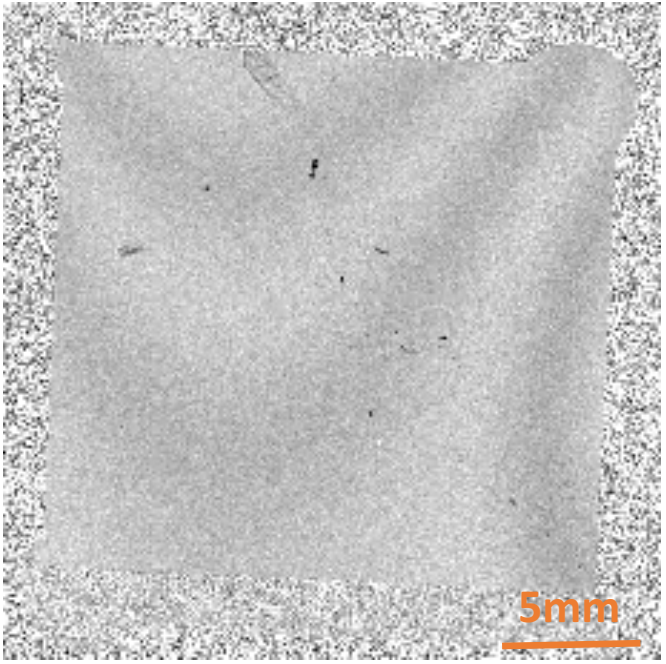


Visibility image

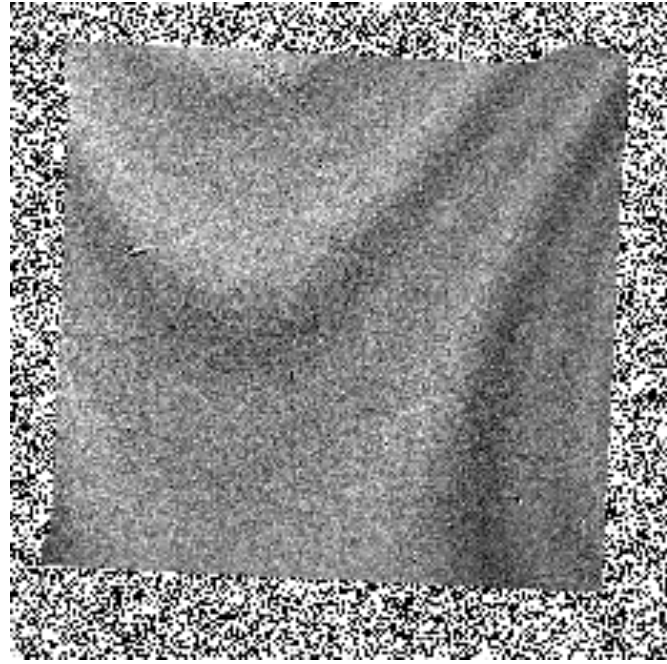
# Results of spider web



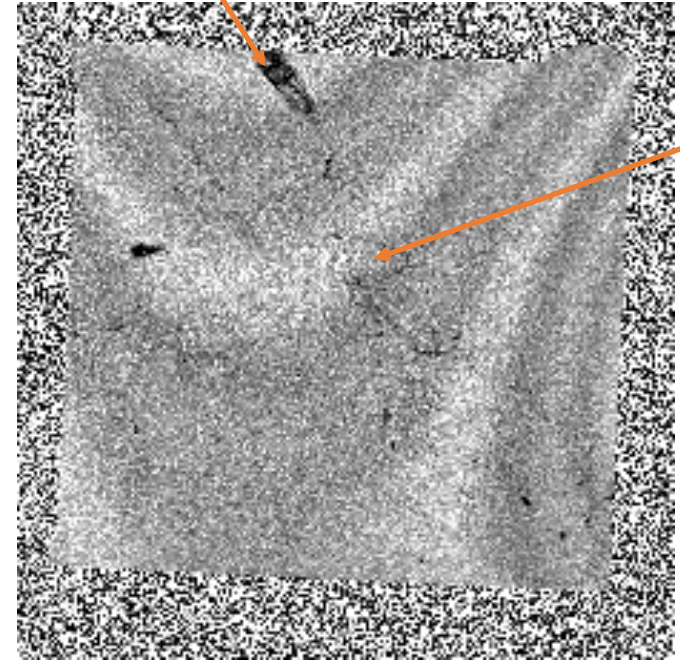
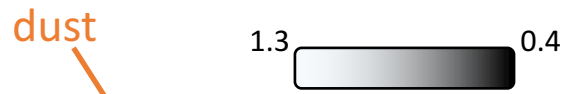
The background region in the images are not flat. This is a phase stepping error caused by movement of moiré fringe during 1h scan resulting in appearance of moiré traces in the results images. Also beam dump happened few times during scan.



Absorption image



Differential phase image



Visibility image

# Summary I

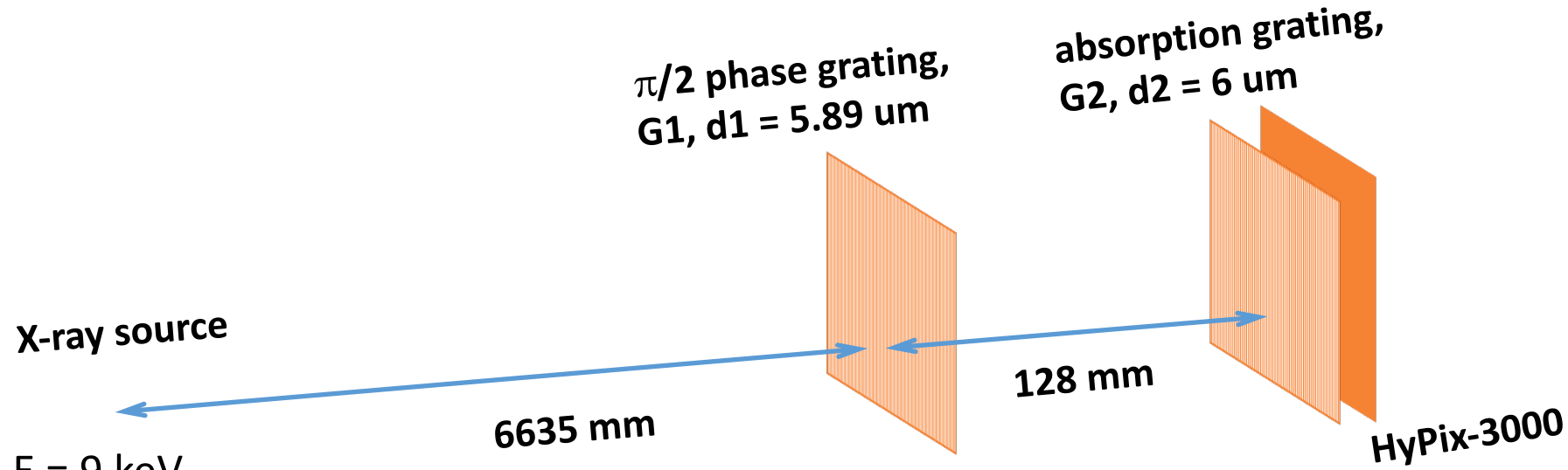
- X-ray phase imaging with Talbot interferometer using LUCX source was performed at 9 keV. The average moiré fringe visibility was 30% when using 6 $\mu$ m pitch gratings (horizontal alignment) in the Talbot interferometer.
- The X-ray flux was improved 11 times than previously achieved, which contributes to increase in image quality.
- Best contrast was achieved from normalized visibility images. Most samples (i.e. biological sample) are too absorbing at 9 keV, lower photon counts result in noisy differential phase image.
- The total exposure time (include foreground and background) was 1h, which is still not practical for X-ray imaging experiments.
- Phase-stepping error occurred due to moiré fringe movement during long scan.

# Experiment II

To test the horizontal spatial coherence of LUCX.

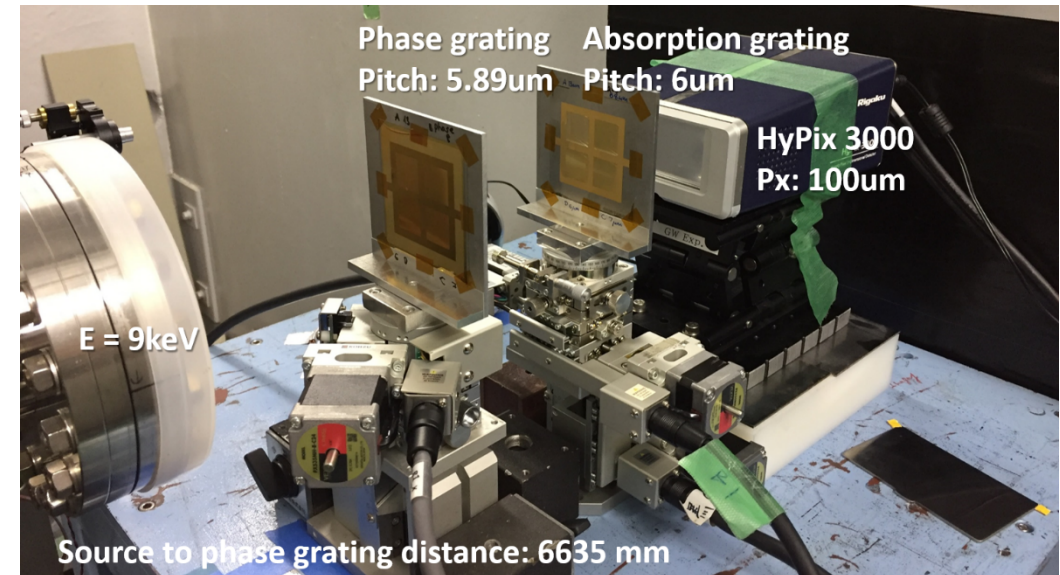
- Gratings
  - Phase grating G1: 5.89  $\mu\text{m}$  (6  $\mu\text{m}$  pitch grating rotated by 11.2 degrees)
  - Absorption grating G2: 6  $\mu\text{m}$
- Detector
  - HyPix-3000 (775 x 385 px), 100  $\mu\text{m}/\text{px}$ , from Rigaku
- 5 step fringe-scanning by translating absorption grating.
- Vertical grating alignment
- Exposure time: 5 min/step

# X-ray Talbot interferometer Set-up II



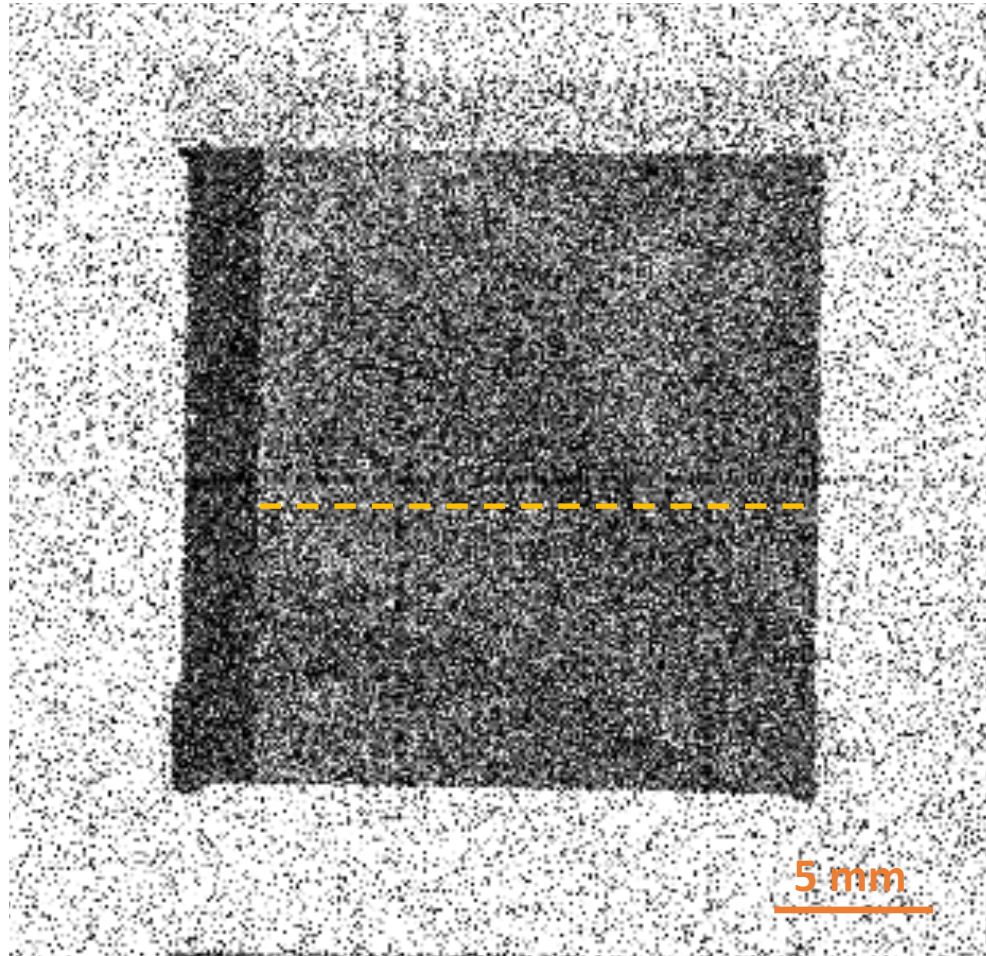
$E = 9 \text{ keV}$   
 $\sigma_H = 60 \mu\text{m} (?)$   
 $\sigma_V = 60 \mu\text{m}$

**Grating lines are in vertical direction.**

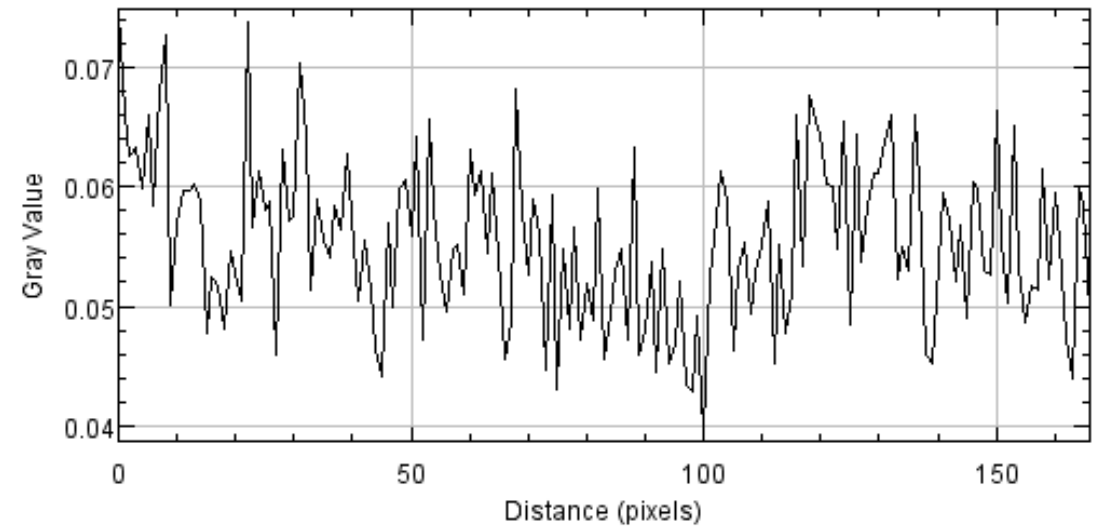


Exposure time: 5min/step x 5step

# Visibility map



The average visibility was around 6%.



For horizontal direction, x-ray source cannot provide sufficient spatial coherence for Talbot interferometer with 6 $\mu$ m pitch gratings.

# Summary II

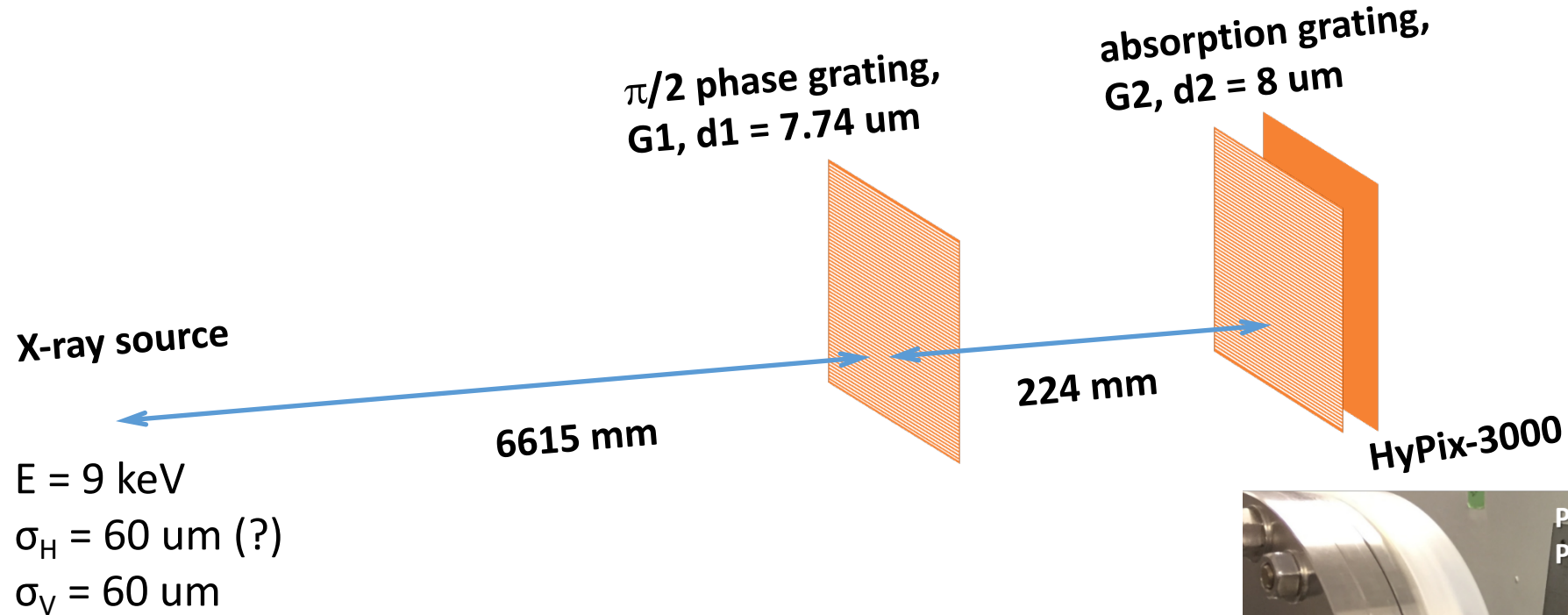
- Since the horizontal beam size was bigger than expected, we could not obtain the expected visibility using 6 $\mu$ m pitch gratings.

# Experiment III

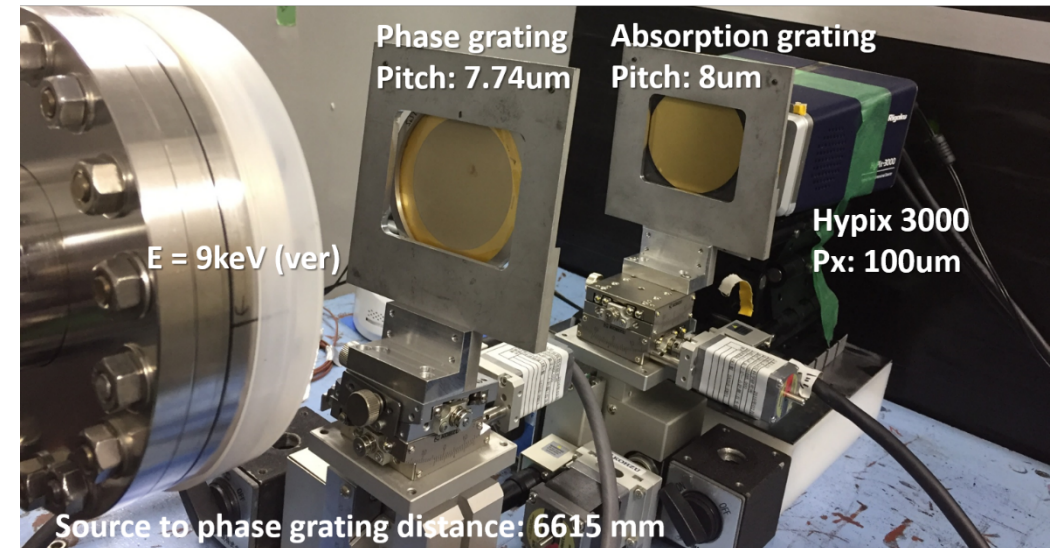
Talbot interferometer with large area gratings to achieve wide field of view.

- Gratings
  - ✓ Phase grating G1: 7.74  $\mu\text{m}$  (7.8  $\mu\text{m}$  pitch grating tilted by 7.5 degrees)
  - ✓ Absorption grating G2: 8  $\mu\text{m}$
- Detector
  - ✓ HyPix-3000 (775 x 385 px), 100  $\mu\text{m}/\text{px}$  from Rigaku
- Horizontal grating alignment
- 5 step fringe-scanning by translating absorption grating.
- Exposure time : 2 min/step

# X-ray Talbot interferometer Set-up III



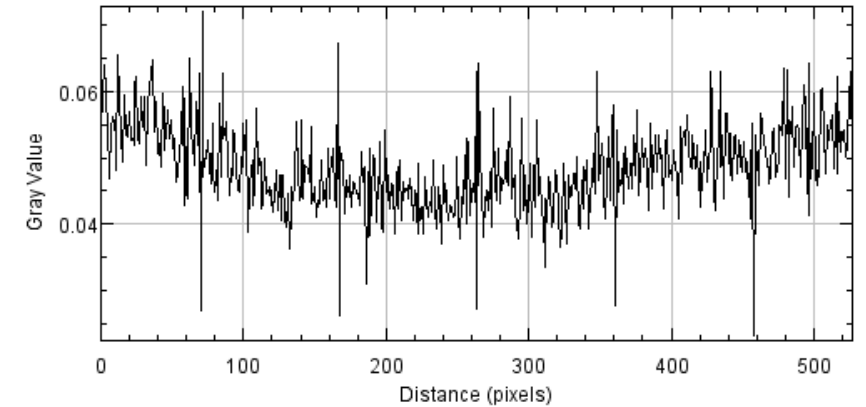
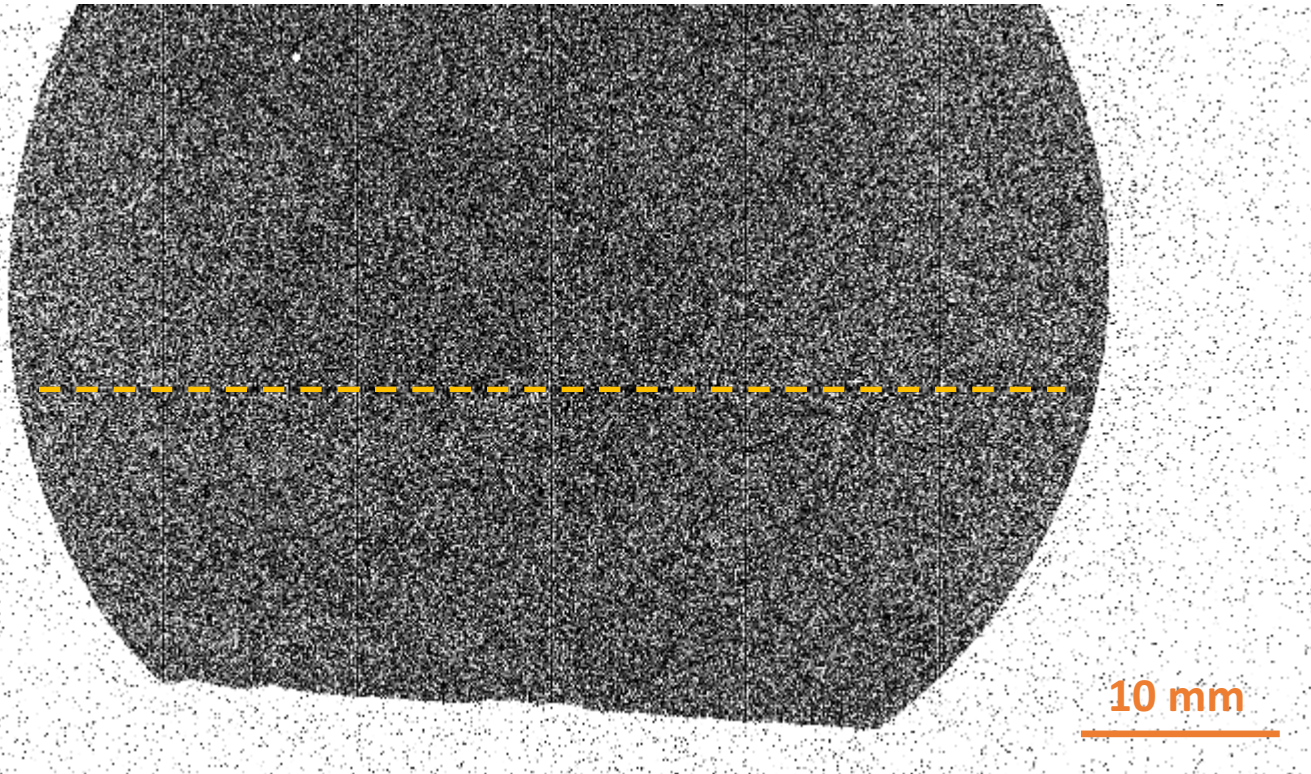
**Grating lines are in horizontal direction.**



Exposure time: 2min/step x 5step

# Visibility map

The average visibility was around 5%.



For vertical direction, the source size and distance between source and phase grating cannot provide sufficient spatial coherence for Talbot interferometer with 8 $\mu$ m pitch gratings.

# Summary III

- Vertical direction spatial coherence provides 30% visibility, but when using broad pitch grating (7.74 $\mu\text{m}$ ), which has wide field of view, we cannot obtain high visibility due to limited spatial coherence in the vertical direction and the limited experiment conditions (distance between source and phase grating, source size).

# Conclusion

- Experiment 2015

- ✓ X-ray phase imaging with Talbot interferometer using LUCX source was first demonstrated in 2015, 33% average moiré fringe visibility was obtained at 5h total exposure time at 9 keV.

- Experiment 2017

- ✓ X-ray phase imaging with Talbot interferometer using LUCX source was performed at 9 keV.
- ✓ It was observed that the X-ray flux has improved 11 times in comparison to the experiments in 2015. Improved flux contributes to increase in the image quality and significant decrease in the total exposure time (1h).
- ✓ Since the horizontal beam size was bigger than expected, we could not obtain the expected visibility using 6 $\mu$ m pitch gratings aligned vertically.
- ✓ 30% visibility was obtained with 6  $\mu$ m pitch gratings in the horizontal configuration but the visibility dropped for 7.74  $\mu$ m pitch gratings. This suggests limited spatial coherence of the LUCX in the vertical direction.

- Requirement

Improvements to increase the X-ray flux, stability and spatial coherence are recommended.