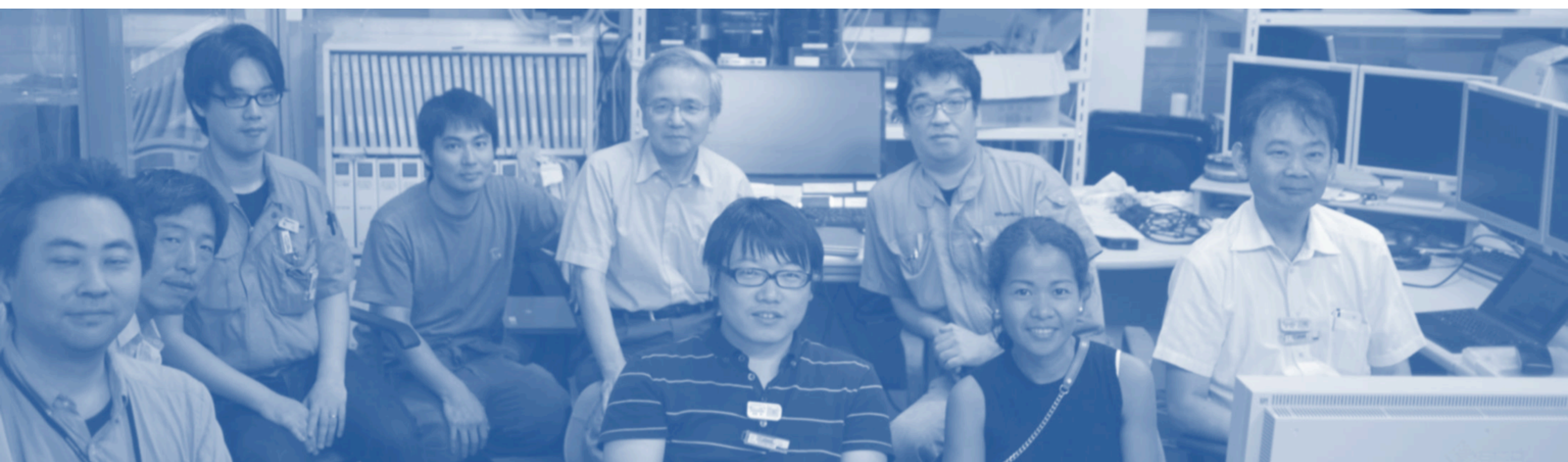
Development of X-ray phase imaging method using a compact high-brightness X-ray generator

Sub-theme: X-ray phase imaging using the LUCX source at KEK

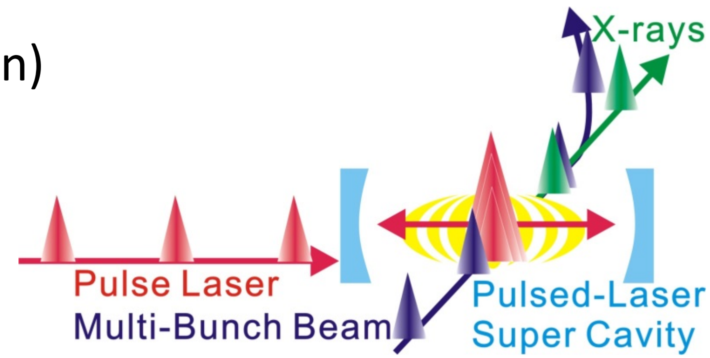
Report by: Margie P. Olbinado IMRAM, Tohoku University
Experiments were performed in collaboration with
Sakae Araki, Masafumi Fukuda, Nobuhiro Terunuma, Junji Urakawa (KEK), Yoshitaka Taira, Ryunosuke Kuroda (AIST), Masashi Kageyama, Masaru Kuribayashi (RIGAKU), Kazuyuki Sakaue (Waseda University), Yanlin Wu, Atsushi Momose (Tohoku University)



Purpose and Motivation

- Purpose
  - To evaluate the performance of X-ray phase imaging with grating interferometry using the KEK LUCX source (operated at 9 keV)
- Motivation
  - The measured X-ray flux at the detector (using Rigaku HyPix-3000) was 23 times better than previously achieved at AIST.
    - Laser power was intensified by an optical enhancement cavity so that X-ray flux is increased without increasing the background Bremsstrahlung radiation

Summary of Laser-Electron Beam Parameters
at the photon-electron collision point (by Sakaue-san)



LASER

Wavelength	Repetition	Power	Pulse energy
1064nm	357MHz	214kW	600uJ

Size(H)	Size(V)	Pulse duration	Col. angle
89um	85um	7ps	7.5°

9keV LCS X-ray Energy

ELECTRON

Energy	Repetition	Charge	N. bunch
23-28MeV	357MHz	0.6nC	1000

Size(H)	Size(V)	Bunch length	Emi (H)	Emi (V)
85um	95um	15ps	10πmmmrad	7πmmmrad

Prepared by MP Olbinado, July 15, 2015

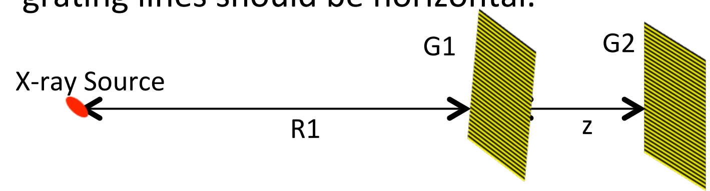
Considering a Talbot Interferometer for LUCX at 9

1. Calculation of the X-ray Spatial Coherence

$$L = \lambda R_1 / 2\pi\sigma_{source}$$

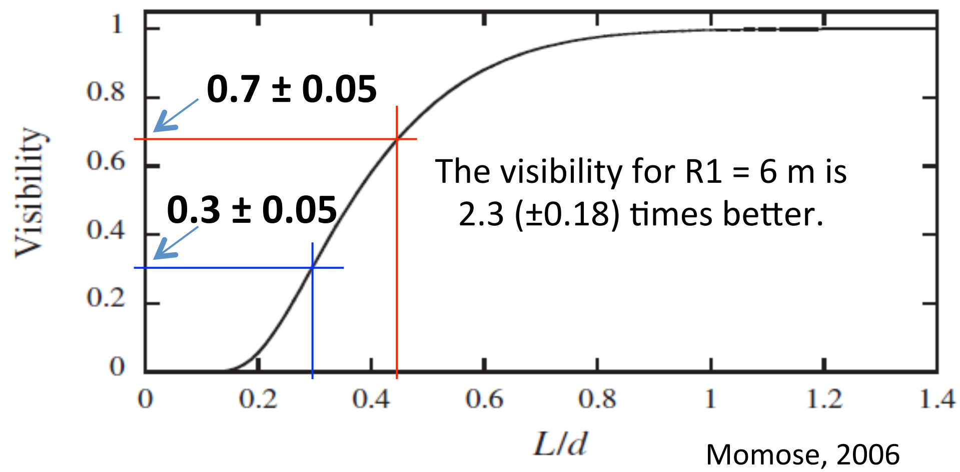
	Horizontal	Vertical
FWHM_source	180 µm	120 µm
L at R1 = 4 m	1.14 µm	1.72 µm
L at R1 = 6 m	1.72 µm	2.58 µm

The spatial coherence is better along the vertical; the grating lines should be horizontal.



2. Calculation of L/d1 and considering the visibility of the self-image at R2 = R1 + z.

	d2	6 µm
R1 = 4 m	z	126.4 mm
	d1	5.82 µm
	L/d1	0.30
	Visibility of self-image	0.3 ± 0.05
R1 = 6 m	z	127.7 mm
	d1	5.87 µm
	L/d1	0.44
	Visibility of self-image	0.7 ± 0.05



Momose, 2006

3. Which R is better for more sensitive phase imaging?

$$\text{sensitivity} = 1/\Delta\varphi_{sample} \propto V\sqrt{I_{det}}$$

$$\text{sensitivity}_{R=6\text{ m}} / \text{sensitivity}_{R=4\text{ m}} \propto (0.7 \pm 0.05)/\ldots$$

The visibility for R1 = 6 m is 2.3x better. But the photon count for R1 = 4 m would be 2x more.

Sensitivity for R1 = 6 m is 1.6 (±0.18) times better. We set up the interferometer at R1 = 6m.

Experiment Details

- Gratings:
  - G1 period: 6.0 μm (tilted by 11.72° to achieve a smaller period)
  - G2 period: 6.0 μm
- Detector: Rigaku HyPix-3000 (775 x 385 pixels), 100 μm/ pixel
- 5-step Fringe scanning by translating G2
- Exposure time/step: 30 minutes = 30 frames x 1 minute, (1 scan has 150 frames)
- Samples: dragonfly wing, cicada wing, chicken wing bone (too absorbing at 9 keV, results are not presented)

Image Processing

Subtraction background Bremsstrahlung radiation counts

↓

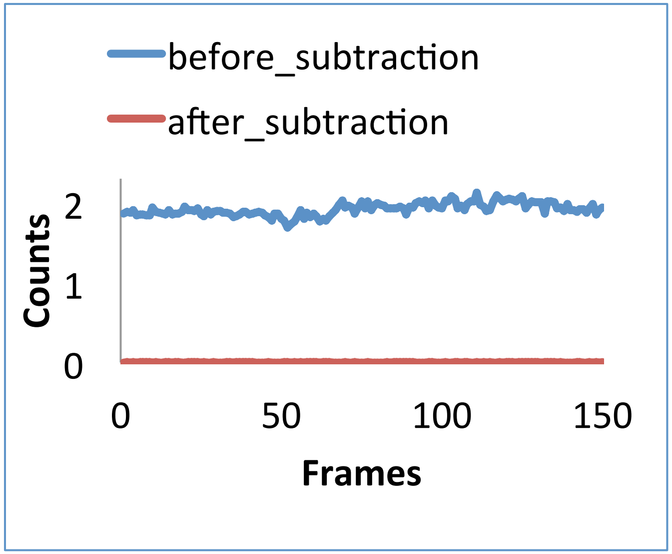
Normalization by fluctuating LCS X-ray counts

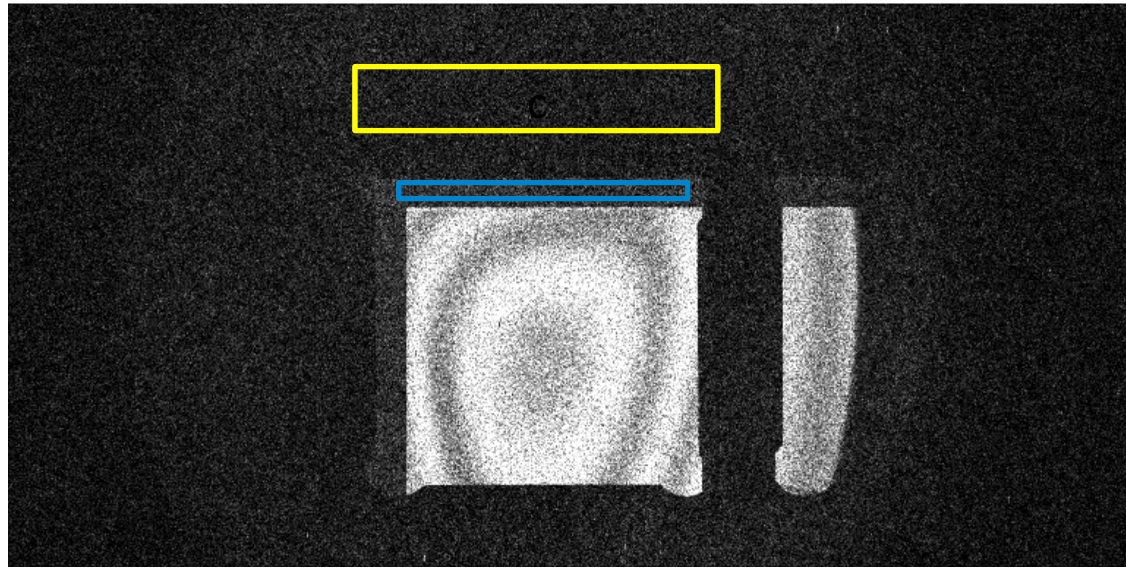
↓

Phase-stepping calculation of Visibility, Transmission and Differential Phase

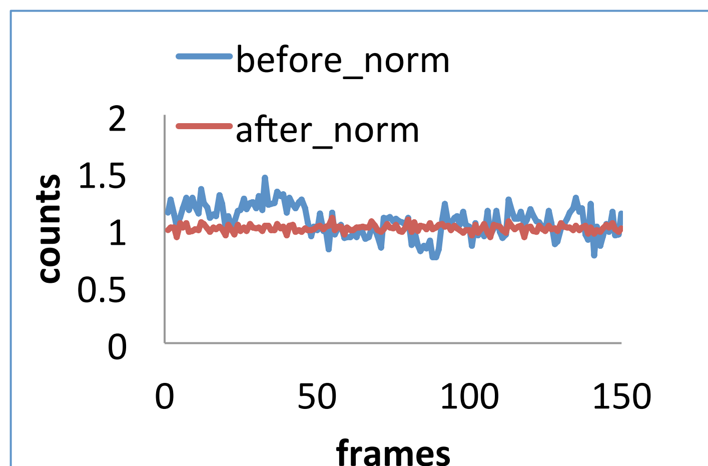
Background Subtraction and X-ray Count Normalization

1. counts of background Bremsstrahlung radiation at each frame was estimated at the yellow rectangle region and then subtracted





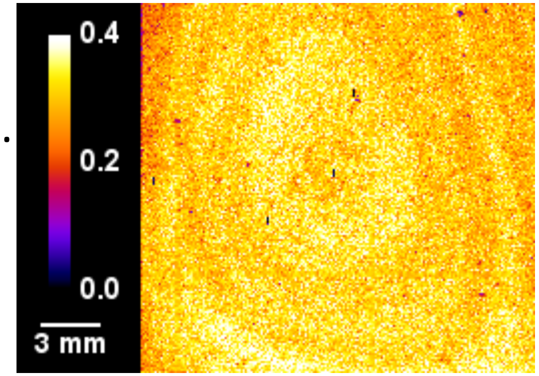
2. The laser intensity fluctuates and so the LCS X-ray counts. The counts at a region without Moiré fringe (blue rectangle) was estimated. Each frame was normalized by counts.



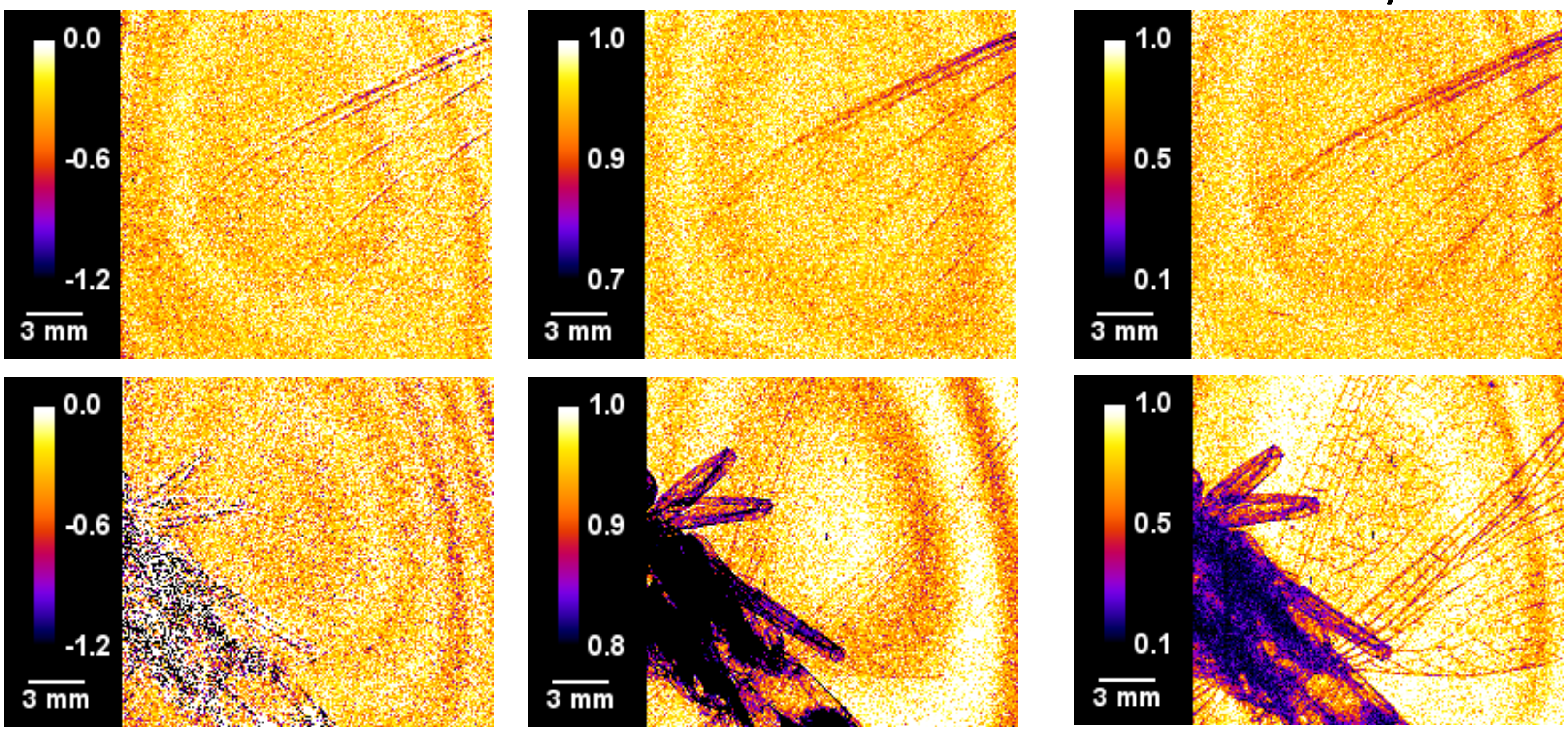
Results

Average Moiré fringe visibility was 33%.
Best contrast was achieved from normalized visibility images.
These biological samples are too absorbing for 9 keV X-rays; too little photon counts result to noisy differential phase image.

Visibility Map



Beam refraction | **Transmission** | **Normalized visibility**

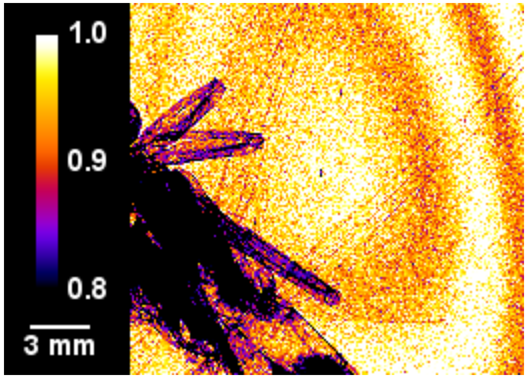


Cicada (above) Dragonfly (below)

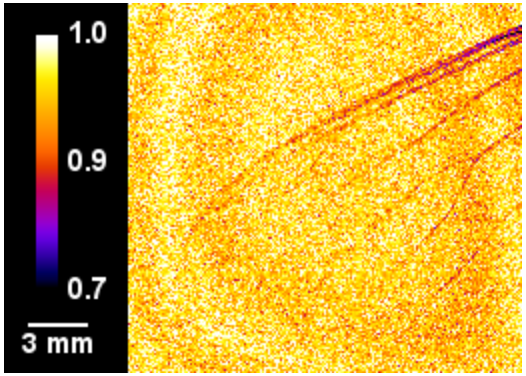
Error Analysis in the Experiment

The background region (without sample) in the Differential Phase, Transmission and Visibility images is not flat. This is a phase stepping error caused by the movement of the Moiré fringe during the 2.5 hour scan. The Moiré fringe movement was observed when the hutch was opened for tuning during a scan.

(Representative Transmission images image to illustrate the error)



Large error



Minimal error

RECOMMENDATION: Put an airflow shielding around the interferometer.

Conclusion

X-ray phase imaging using grating interferometry has been demonstrated using the LUCX Source at KEK operated at 9keV.

The average Moiré fringe visibility was 33%.

The 2.5 - hour exposure time per scan was still not practical for imaging. Further improvement to increase the X-ray flux is necessary.

Phase stepping error occurred due to Moiré fringe movement during long scan (probably due to air flow). Air tight box for the interferometer is recommended.