Arc-seconds and Sub Arc-seconds Imaging with Multi Image X-ray Interferometer Modules for Small Satellites

Kiyoshi Hayashida, Tomoki Kawabata, Takashi Hanasaka, Hiroshi Nakajima, Ryo Hosono, Takayoshi Shimura, Hiroki Kurubi, Shota Inoue, Hiroshi Tsunemi, Hironori Matsumoto (Osaka University)

The best and exceptional angular resolution of 0.5 arc-second is realized with the X-ray mirror aboard the Chandra satellite. Nevertheless, further better or comparable resolution is anticipated to be difficult in near future. We propose a new type of X-ray interferometer consisting simply of an X-ray absorbing grating and an X-ray spectral imaging detector. The setup is similar to the X-ray Talbot interferometer used for X-ray contrast imaging of light elements, but we measure the comparable X-ray source profile rather than the detailed structure of the specimen set at the grating. We select X-ray events for which Talbot interference condition is satisfied, and stack the self-image of the grating to obtain the source profile. We show the band width of 10% is available, which is suitable for CCD or CMOS resolution of 2-3%. This system, we call Multi Image X-ray Interferometer Module (MIXIM), enables us arc-seconds and sub-arc-seconds resolution of the X-ray targets with very small satellites of 50 cm size. Although the targets of MIXIM are limited to relatively bright sources, as we do not employ collecting mirrors, we propose a new type of X-ray interferometer consisting simply of an X-ray absorption grating and an X-ray spectral imaging detector, The setup is similar to the X-ray Talbot interferometer used for X-ray contrast imaging of light elements, but we measure the X-ray source profile rather than the detailed structure of the specimen set at the grating. We select X-ray events for which Talbot interference condition is satisfied, and stack the self-image of the grating to obtain the source profile. We show the band width of 10% is available, which is suitable for CCD or CMOS resolution of 2-3%. This system, we call Multi Image X-ray Interferometer Module (MIXIM), enables us arc-seconds and sub-arc-seconds resolution of the X-ray targets with very small satellites of 50 cm size. Although the targets of MIXIM are limited to relatively bright sources, as we do not employ collecting mirrors, unique scientific theme, such as, search for super massive black holes and resolving AGN torus would be possible. We introduce the concept of the MIXIM. Satellite plans of MIXIM ranging from arc-seconds resolution with a very small satellite to 10 milli-arc-seconds resolution with a medium size satellite are also shown. Laboratory experiments are presented in P89, in which positional resolution of the detector is essential.

### X-ray Astronomy Satellites

- **Talbot Effect** (H.F. Talbot 1836)
- **Preliminary Design**
- **Multi Image X-ray Interferometer**
- **Arcsec Sub-Arcsec X-ray Observations Targets**
- **Torus of Active Galactic Nuclei**
- **Simulation with Fresnel Approximation**
- **Near Field Case**
- **MIXIM satellite options**
- **Laboratory Experiments**

### References

1. Hayashida et al., 2016, SPIE proc., 9905, 99057
3. Kawabata et al., 2017, P89 this conference

**Multi Image X-ray Interferometer**

Almost Parallel Beam

Grating

Stack

- Only employ a Grating and an X-ray Pixel Detector
- Image profile detected reflects the profile of the X-ray source.
- Stacking the image with a period of d in the analysis, accurate source profile is obtained.
- Diffraction is significant. But, if we select X-ray events that meet the Talbot condition, the self-image of the grating is essentially.
- Image Width \( \theta = f d / z = 0.4(\lambda / d + 1) / \lambda \) (micron)

Chandra Resolution with a 50cm size satellite?

**Talbot Effect (H.F. Talbot 1836)**

- Parallel Light through a grating makes Self Image of the grating at periodic distances. (H.F. Talbot, 1836)
- Explained with Diffraction and Interference (Rayleigh, 1881)
- Hard X-ray Talbot effect in experiment (P. Cplement, 1997)
- Talbot Distance \( z_p = m \lambda / z \)

**Arcsec Sub-Arcsec X-ray Observations Targets**

- One of the most important issues on evolution of galaxies
- Related also to gravitational wave
- Only few kpc apart cases (NGC6240, 0238 etc.) are known.
- There should be more SMBH
- Angular resolution improvement by factor of 3 still leads to open order of magnitude larger sample.

**Torus of Active Galactic Nuclei**

- Spatial resolved X-ray spectrum and polarization
- Where the reflected components comes from?
- Ring like image and circular pattern of polarization for Type 1 AGN?

**Simulation with Fresnel Approximation**

Band width of ~10% is available; good for CCD, CMOS

**Near Field Case**

\[ z = \frac{\lambda}{2d} \]

\[ \lambda = 0.1 \text{nm} \]

\[ z = 50 \text{cm} \]

\[ \lambda / d = 0.2 \]

\[ z = 0.5 \text{m} \]

\[ \lambda / d = 0.1 \]

\[ z = 0.6 \text{m} \]

\[ \lambda / d = 0.2 \]

\[ z = 1.1 \text{m} \]

\[ \lambda / d = 0.1 \]

\[ z = 5 \text{m} \]

\[ \lambda / d = 0.5 \]

\[ z = 25 \text{m} \]

\[ \lambda / d = 0.02 \]

\[ z = 1 \text{km} \]

\[ \lambda / d = 0.01 \]

\[ z = 10 \text{km} \]

\[ \lambda / d = 0.01 \]

\[ z = 100 \text{km} \]

\[ \lambda / d = 0.02 \]

\[ z = 1 \text{Mm} \]

\[ \lambda / d = 0.1 \]

\[ z = 0.1 \text{Mm} \]

\[ \lambda / d = 0.2 \]

\[ z = 0.2 \text{Mm} \]

\[ \lambda / d = 0.01 \]

\[ z = 0.01 \text{Mm} \]

\[ \lambda / d = 0.01 \]

\[ z = 0.01 \text{Mm} \]

\[ \lambda / d = 0.2 \]

\[ z = 2 \text{Mm} \]

\[ \lambda / d = 0.1 \]

\[ z = 1 \text{Mm} \]

**MIXIM satellite options**

- **Multi Image X-ray Interferometer Module** or **MIXIM**

**Laboratory Experiments**

- We started experiments with micro-focus X-ray sources in our laboratory. We obtained the X-ray Talbot interference fringe with a 4.8 µm grating and 30 µm pixel XRPIX2b with a magnification factor of 40.
- We also introduced a CMOS sensor GSENSE5130 at open (Si filled) part, and Detector efficiency \( \eta \) limits RXB range.
- Effective Area \( A_{eff} = \int_{\lambda_1}^{\lambda_2} A(\lambda) \frac{\lambda}{\sqrt{2\pi \sigma^2(\lambda)}} \)
- FOV must be limited by collimators to 1-3 deg.
- Calibrator Grating mask - 2 Gratings mask - Detector

**Near Field z << z_T**

\[ d = 25 \text{m} \]

\[ f = 0.2 \]

\[ \lambda = 0.1 \text{nm} \]

\[ z = 0.5 \text{m} \]

\[ \lambda / d = 1 \]

\[ z = 0.25 \text{m} \]

\[ \lambda / d = 2 \]

\[ z = 0.125 \text{m} \]

**Position (\mu m) on the Detector**

\[ \lambda = 0.1 \text{nm} \]

\[ z = 0.5 \text{m} \]

\[ \lambda / d = 1 \]

\[ z = 0.25 \text{m} \]

\[ \lambda / d = 2 \]

\[ z = 0.125 \text{m} \]

\[ \lambda / d = 4 \]

\[ z = 0.0625 \text{m} \]

\[ \lambda / d = 8 \]

\[ z = 0.03125 \text{m} \]

**Position (\mu m) on the Detector**

\[ \lambda = 0.04 \text{nm} \]

\[ z = 0.5 \text{m} \]

\[ \lambda / d = 1 \]

\[ z = 0.25 \text{m} \]

\[ \lambda / d = 2 \]

\[ z = 0.125 \text{m} \]

\[ \lambda / d = 4 \]

\[ z = 0.0625 \text{m} \]

\[ \lambda / d = 8 \]

\[ z = 0.03125 \text{m} \]

**Position (\mu m) on the Detector**

\[ \lambda = 0.02 \text{nm} \]

\[ z = 0.5 \text{m} \]

\[ \lambda / d = 1 \]

\[ z = 0.25 \text{m} \]

\[ \lambda / d = 2 \]

\[ z = 0.125 \text{m} \]

\[ \lambda / d = 4 \]

\[ z = 0.0625 \text{m} \]

\[ \lambda / d = 8 \]

\[ z = 0.03125 \text{m} \]