A Novel Method for Sub-Arcsec to Micro-Arcsec X-ray Imaging : MIXIM

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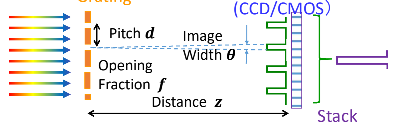
We invent a new type of X-ray imaging system, Multi Image X-ray Interferometer Module (or Method or Mission) : **MIXIM**. MIXIM employs only a grating and a pixel detector, not mirrors. Baseline is a multi-slit camera. Stacking the multi-image provides the profile of the source. Key of the concept is to select the X-ray events of which energy satisfies the Talbot interference condition. We succeeded in obtaining the 1D image profiles for the X-ray energy meeting the Talbot interference condition at experiments in Synchrotron facility SPring-8. The image profile width obtained was **0.55'' at z (grating-detector distance) of 46cm**, suggesting Chandra resolution with a very small satellites. The width obtained is **0.08'', the best angular resolution so far achieved with astronomical X-ray imagers (to our knowledge).** We also succeeded in obtaining the **2D image** at z of 8.67m.

Important aspect of MIXIM is its **scalability**. We show possible examples of the mission format, from Sub-arcsecond X-ray imager on very small satellites, 0.01 arcseconds X-ray imager parasite on 10m satellite or 10-100m free flyer for direct imaging of AGN torus, and **micro-arcsecond X-ray imager** to obtain **color-images of black hole event horizon** with million km formation flight.

Multi Image X-ray Interferometer Method (MIXIM)

Hayashida+ 2016,2018

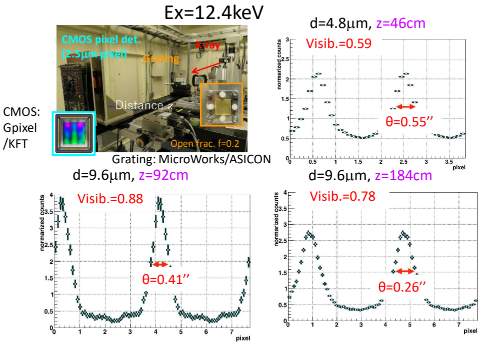
- Multi slit (pin-hole) camera using the Talbot effect.
- Only employ a Grating and a pixel detector. No mirror.
- Select X-ray events of which λ meets the Talbot interference condition $z = m\frac{d^2}{\lambda}$
  - Band width $\Delta\lambda/\lambda \sim$ 10-20% ; good for Si detectors 2-3% resolution
- Stacked Image = Profile of X-ray source
- $z = md^2/\lambda = 50\text{cm}\left(\frac{m}{2}\right)\left(\frac{d}{5\mu m}\right)^2/\left(\frac{\lambda}{0.1nm}\right)$
- $\theta = \frac{fd}{z} = f\lambda/dm = 0.4''\left(\frac{f}{0.2}\right)\left(\frac{\lambda}{0.1nm}\right)/\left(\frac{d}{5\mu m}\right)\left(\frac{m}{2}\right)$



Experiment 2018Nov-Dec at SPring-8 BL20B2

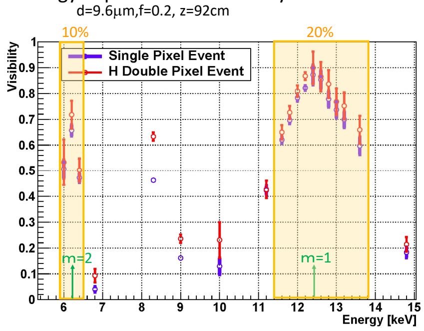
Stacked Images of Talbot interference fringe

Ex=12.4keV



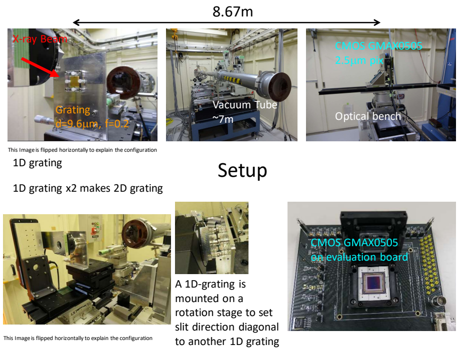
Energy dependence of visibility → Band width

d=9.6μm,f=0.2, z=92cm

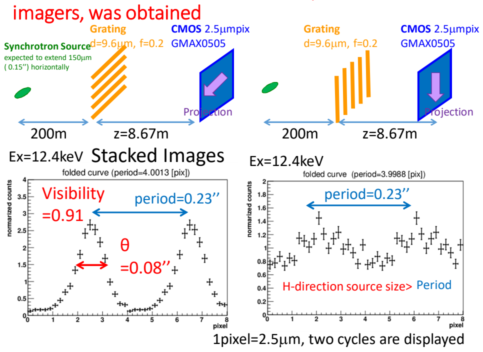


Two cycles are displayed.
Visibility is a measure of image contrast

Experiment 2019/7/13-16 @SPring-8 BL20B2



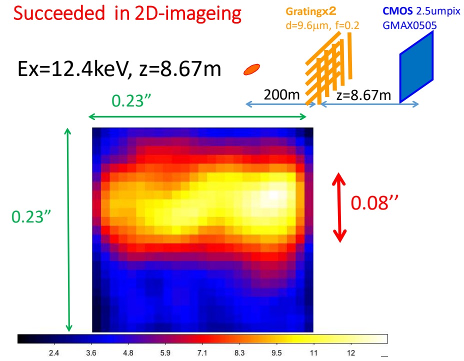
0.08'' resolution, the best with X-ray astronomical imagers, was obtained



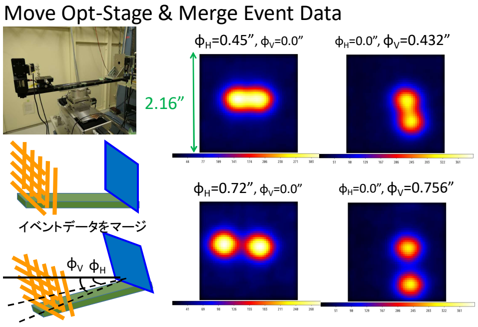
1pixel=2.5μm, two cycles are displayed

Succeeded in 2D-imageing

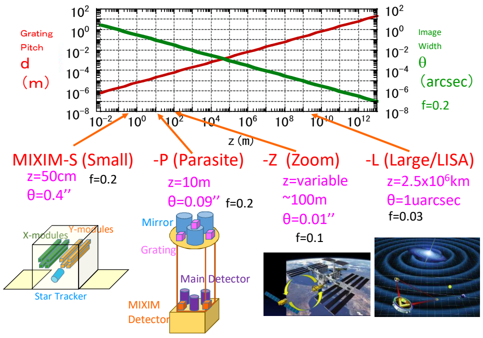
Ex=12.4keV, z=8.67m



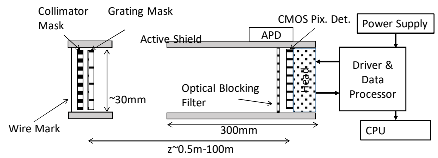
z=0.92m simulate observations of 2 sources
Move Opt-Stage & Merge Event Data



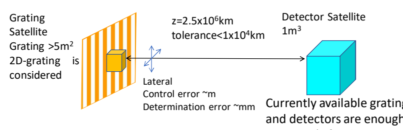
MIXIM is Scalable



MIXIM-S,P,Z module



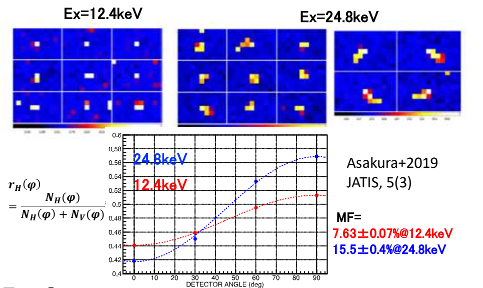
MIXIM-L Configuration



Currently available gratings and detectors are enough for MIXIM-L (c.f. Utley+ 2019)

Targets >mCrab nearby AGNs Imaging+Polarimetry

MIXIM experiment is first enabled with introduction of small pixel size (2.5μm) CMOS detectors, which were originally designed for visible light, but we found they can be used for X-ray detection, surprisingly at Room temperature.
Small pixel size also enables us to use them for Photo-electron-track X-ray polarimeter.



Asakura+2019 JATIS, 5(3)

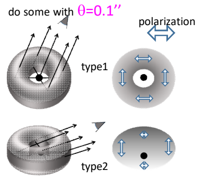
MF=
7.63±0.07%@12.4keV
15.5±0.4%@24.8keV

MIXIM does not have collecting power.
Targets are limited to bright sources.

X-ray Imaging and Polarimetry of AGN putative Torus

→Final Answer to AGN Unified Model

θ=0.01'' is goal but we can do some with θ=0.1''



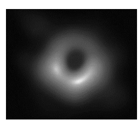
X-ray Image of EH

(Temperature/Abundance/ Polarization)

First Color Image of EH

θ=μarcsec

c.f. EHT image is B/W



MIXIM FAQ

1. Is MIXIM interferometer?
   In the sense that the Talbot Interference condition is the key. Multi slit camera employing the Talbot interference may be appropriate.
2. What is the FOV of MIXIM.
   Folded image within the (additional) collimator is obtained. FOV is thus 0.1-1deg, while 1-folding-period is very narrow. If we use f=0.2 grating, just 5 times of q.
   One bright point-like source within 0.1-1deg FOV is expected.
3. Effective Area of several cm² is too small, isn't it?
   People observe >uCrab (Suzaku) >10nCrab (Chandra) sources with Telescopes with 100-1000cm² effective area.
   For MIXIM targets >mCrab, it should be enough
   cf. We roughly estimate 0.1 c/MIXIM-unit/Crab with technical enhancement in next few years. 5 units, 5mCrab source need 1Ms to collect 10³ counts.
4. How can you obtain 2D image? Multi-Pin-Hole?
   1D units placed X and Y are baseline. 2D mask with larger opening is being designed.

References

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[2] Hayashida, K. et al. 2018, SPIE proc. 10699, 106990U
[3] Momose, A. et al., 2003, JJAP, 42, L866
[4] Asakura, K. et al. 2019, JATIS, 5(3)
[5] Utley, P. et al., 2019, Voyage2015 White Paper
[6] Hayashida et al. 2019, X-ray Astronomy 2019