Sub Arc-seconds to Micro Arc-seconds Imaging with Multi Image X-ray Interferometer Modules (MIXIM)

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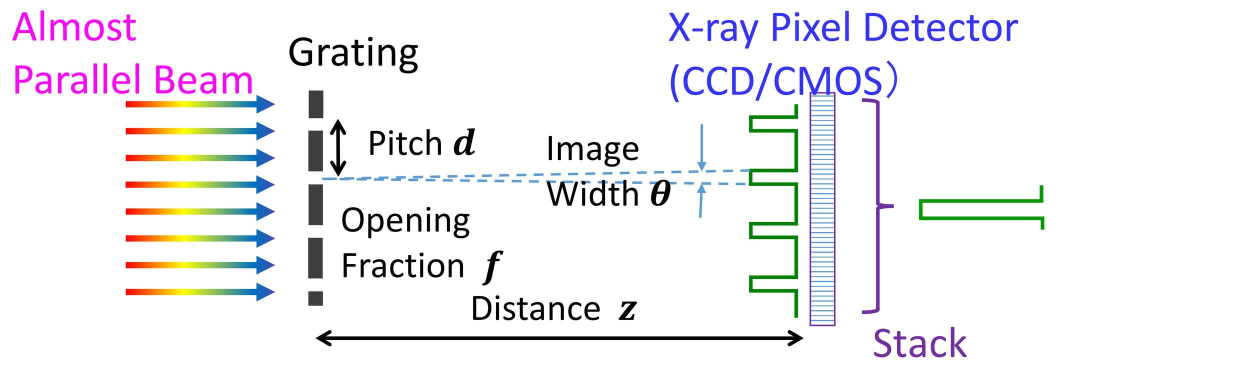
The best and exceptional angular resolution of 0.5″ is realized with the X-ray mirror aboard the Chandra satellite. Nevertheless, further better or comparable resolution is anticipated to be difficult in near future. We propose a new type of X-ray interferometer consisting simply of an X-ray absorption 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 sub-arc-seconds resolution of the X-ray targets with very small satellites of 50 cm size. We in fact obtained ~0.5″ width image in the experiment at SPring8 BL20B2 by introducing small pixel size CMOS detector originally designed for optical imaging but we find capable of X-ray detection. MIXIM is scalable and can be installed on conventional X-ray astronomy observatories with 10 m size, or on free fryer of 100m distance. In the latter case, we expect 0.01″ resolution, AGN torus can be resolved with some polarization information. Ultimate case would be the grating and detector distance of 2.5million km, like LISA. In that case we expect micro arcseconds resolution to resolve blackhole event horizon.

Multi Image X-ray Interferometer

Hayashida+ 2016,2018

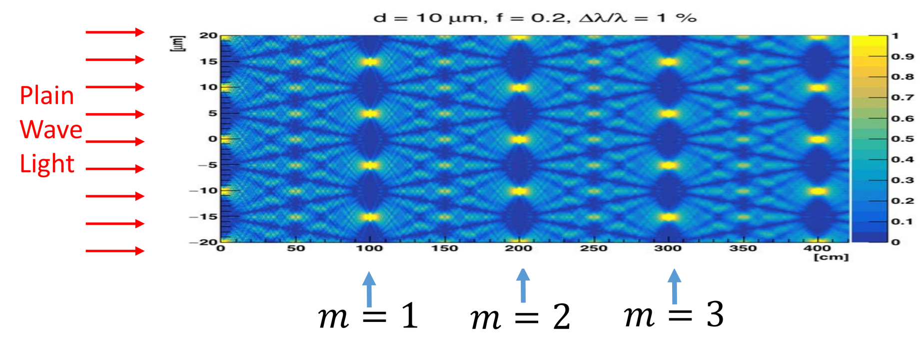


- Only employ a Grating and an X-ray Pixel Detector
- Image profile detected reflects the profile of the X-ray source.
- Stacking the image with a period of d in the analysis, accurate source profile is obtained.
- Diffraction is significant. But, if we select X-ray events that meet the Talbot condition, the self image of the grating is obtained.
- Image Width $\theta = fd/z = 0.4'' \left(\frac{f}{0.2}\right)\left(\frac{d}{5\mu m}\right) / \left(\frac{z}{50cm}\right)$

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. Cloetens, 1997)
- **Talbot Distance** $z_T = m\frac{d^2}{\lambda}$

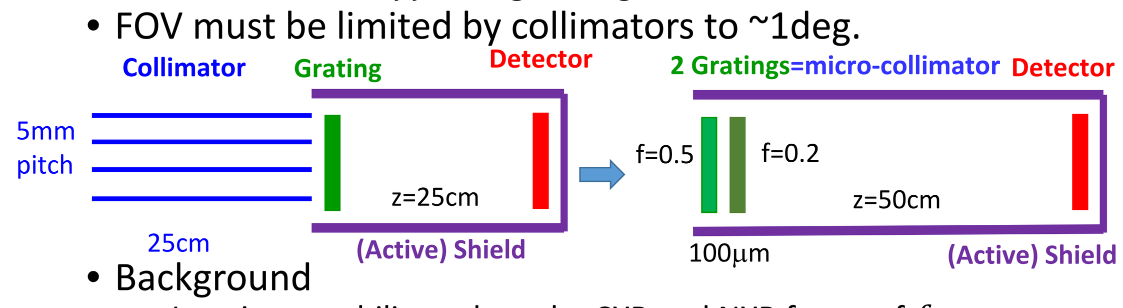


For λ=0.1nm(12keV) X-rays and a d=5μm pitch grating, Talbot distance z_T of m=2 is 50cm

Preliminary Design

θ :Image Width d :Pitch f :Open. Frac. z :Distance m :Talbot Order

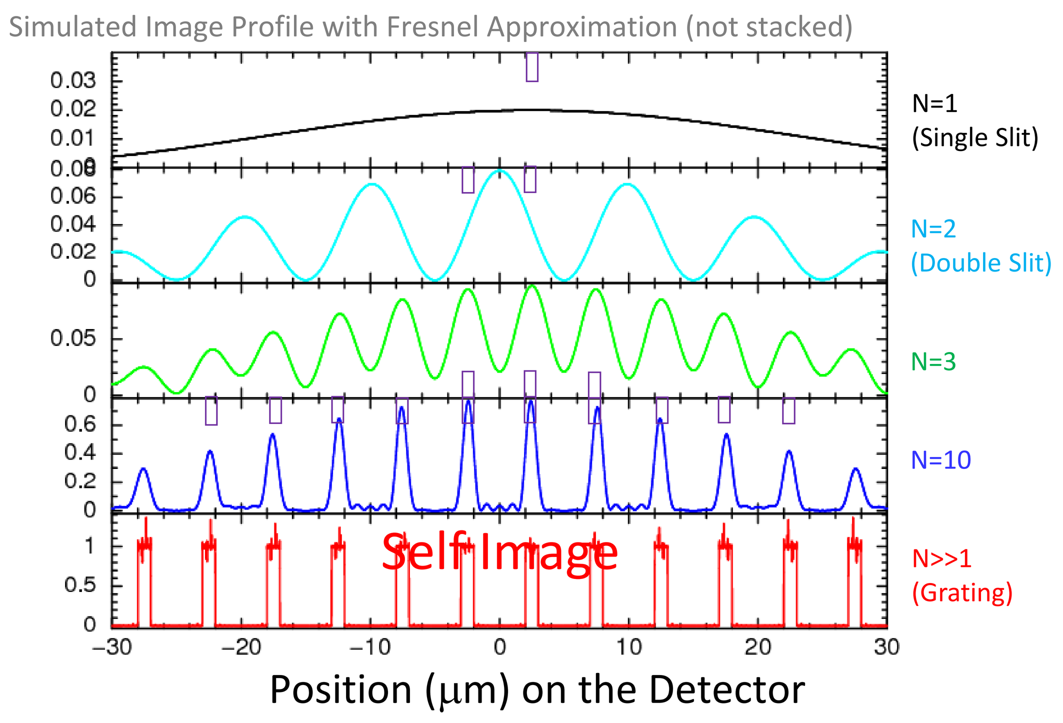
- $z = md^2/\lambda = 50\text{cm}\left(\frac{m}{2}\right)\left(\frac{d}{5\mu m}\right)^2 / \left(\frac{\lambda}{0.1nm}\right)$
- $\theta = \frac{fd}{z} = f\lambda/dm = 0.4''\left(\frac{f}{0.2}\right)\left(\frac{\lambda}{0.1nm}\right) / \left(\frac{d}{5\mu m}\right)\left(\frac{m}{2}\right)$
  - Positional Resolution of Pixel Detector is essential.
- Energy Range 5-20keV
  - Grating transmission η_{gra} at open (Si filled) part, and Detector efficiency η_{det} limits the range.
- Effective Area $A_{eff} = A_{geo} \cdot \eta_{gra} \cdot \eta_{det} \cdot f \cdot \Delta\lambda/\lambda$
- FOV must be limited by collimators to ~1deg.



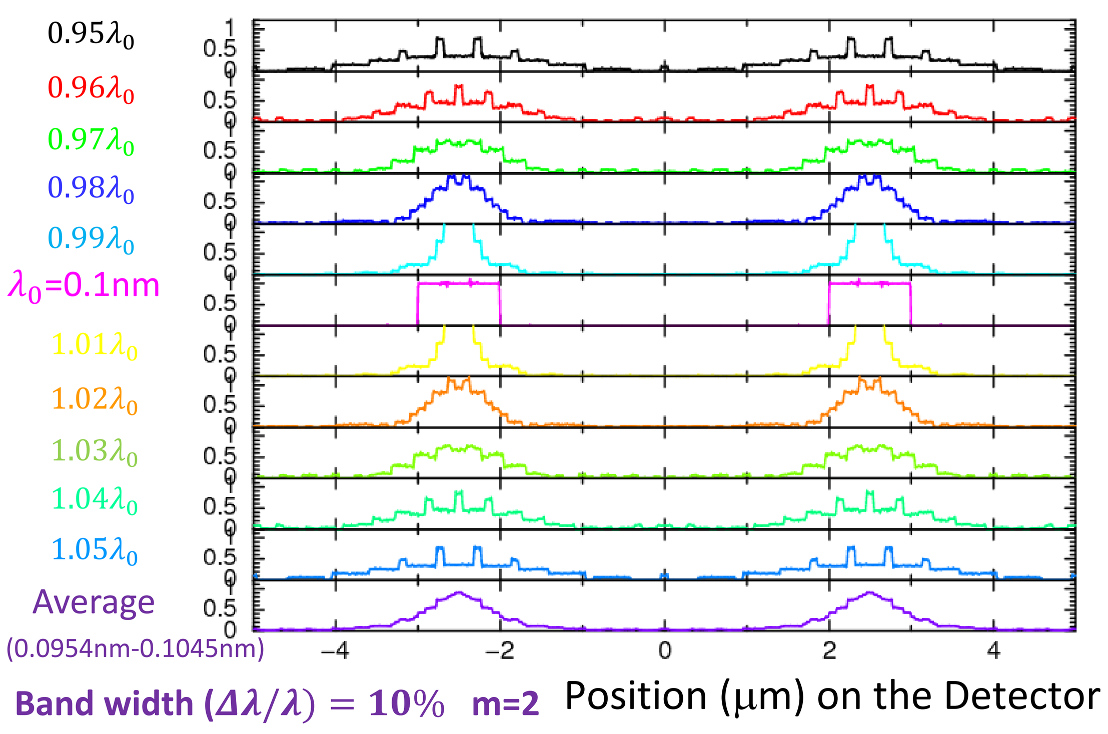
- Background
  - Imaging capability reduce the CXB and NXB factor of f.
  - Rough estimate CXB=0.2 mCrab, NXB=4mCrab Very preliminary

Simulation with Fresnel Approximation Band width of ~10% is available; good for CCD, CMOS

At Talbot Distance

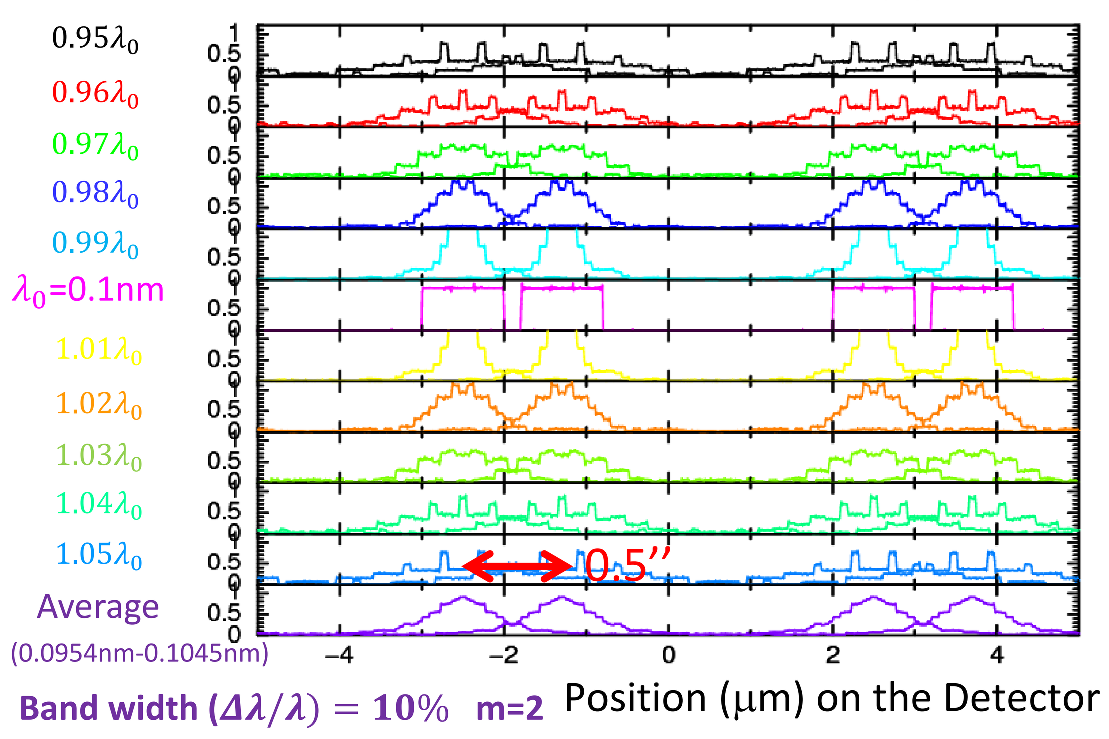


λ dependence at a fixed setup d=5μm f=0.2 z=0.5m m=2



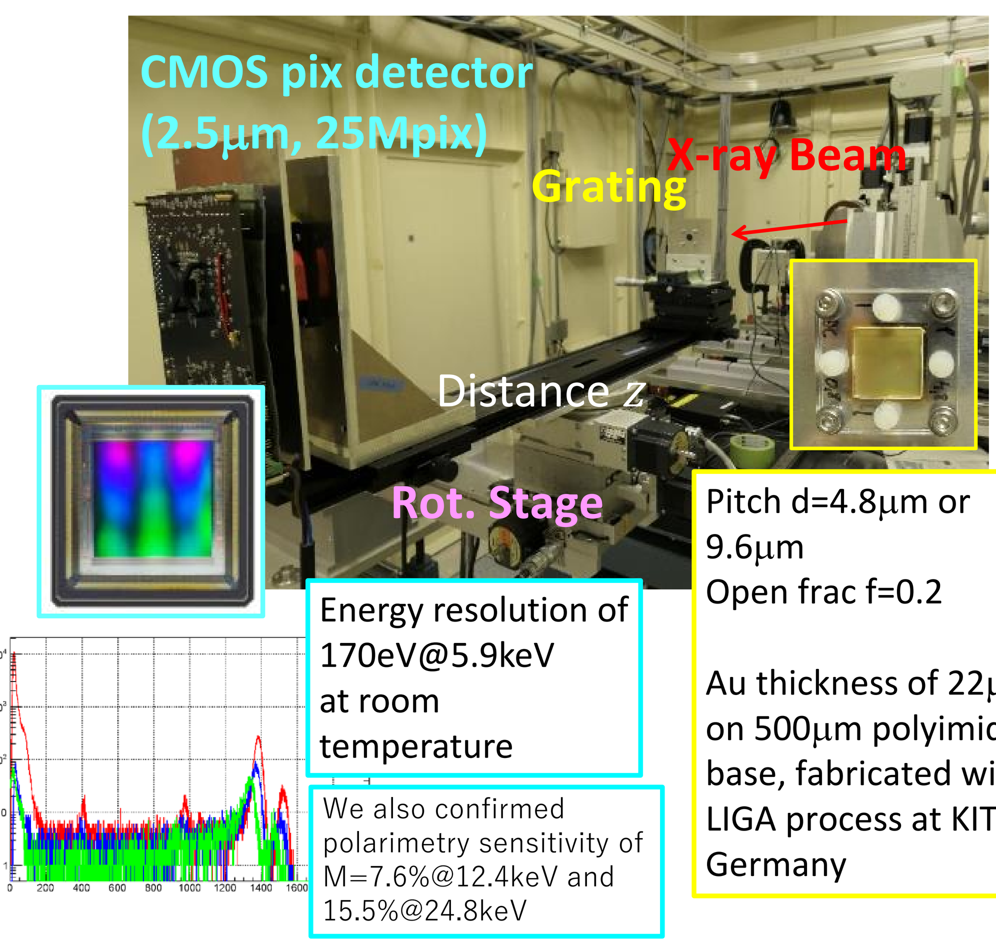
Band width $(\Delta\lambda/\lambda) = 10\%$ m=2

Another X-ray beam incidence from 0.5arcsec offset direction d=5μm f=0.2 z=0.5m m=2



Band width $(\Delta\lambda/\lambda) = 10\%$ m=2

Experiments at SPring8 BL20B2 200m beamline; Succeeded in Obtaining Sub-Arcsec Images



Energy resolution of 170eV@5.9keV at room temperature

We also confirmed polarimetry sensitivity of M=7.6%@12.4keV and 15.5%@24.8keV

Pitch d=4.8μm or 9.6μm
Open frac f=0.2

Au thickness of 22μm on 500μm polyimide base, fabricated with LIGA process at KIT, Germany

Stacked Profiles for Ex=12.4 keV

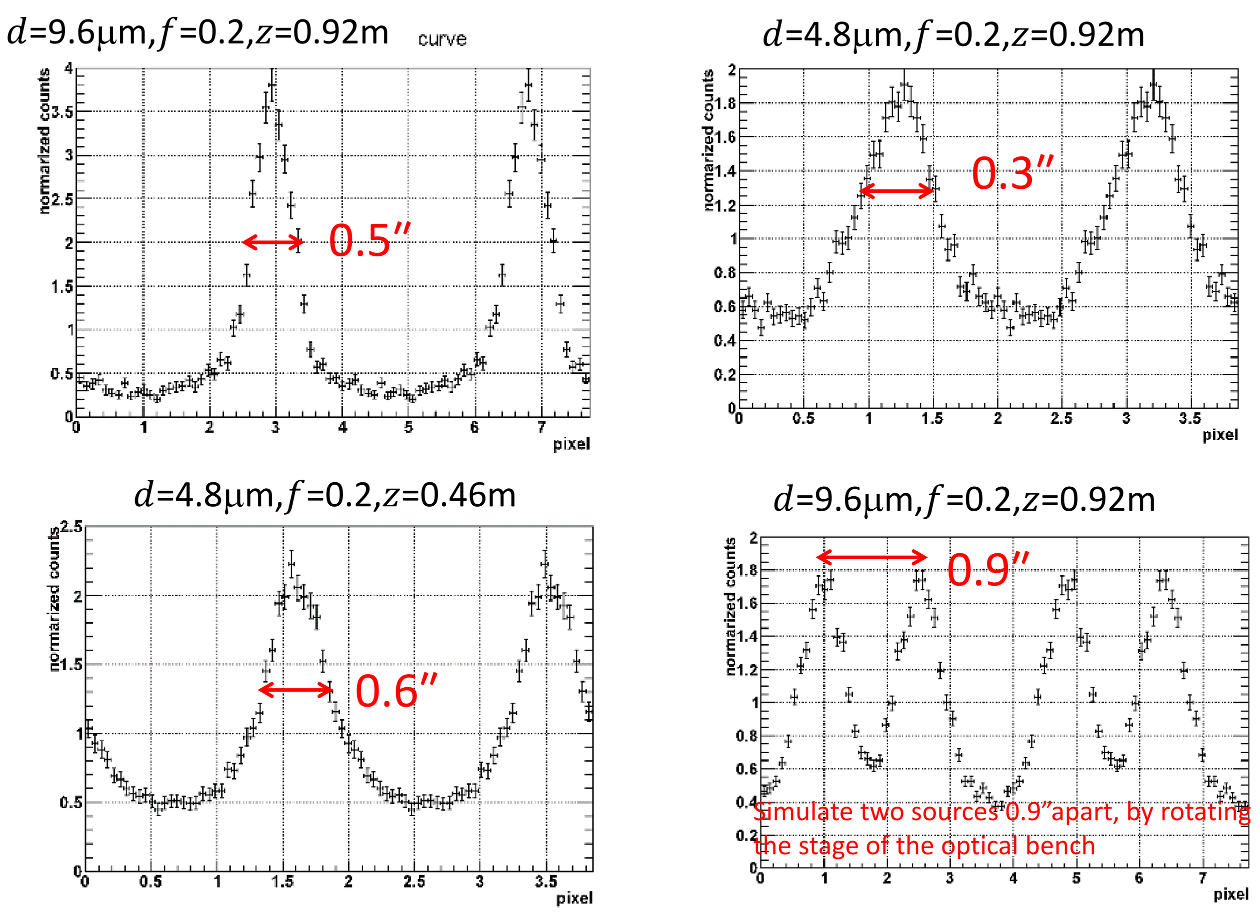
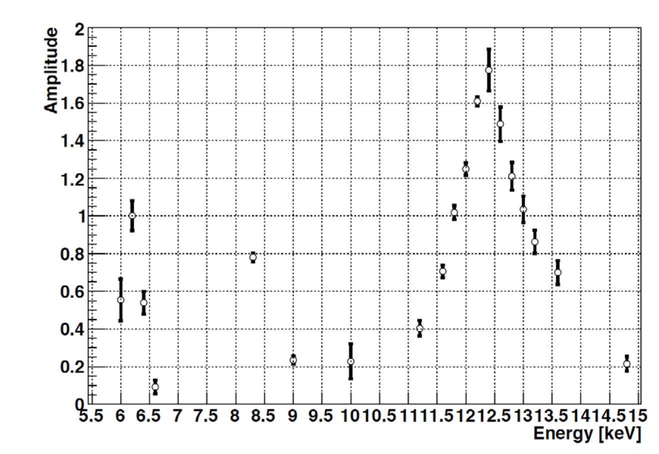
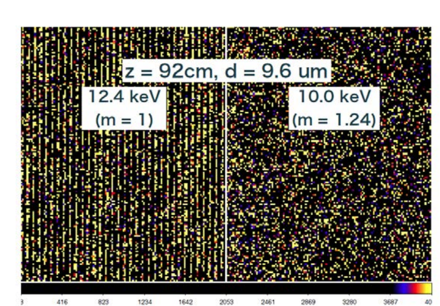


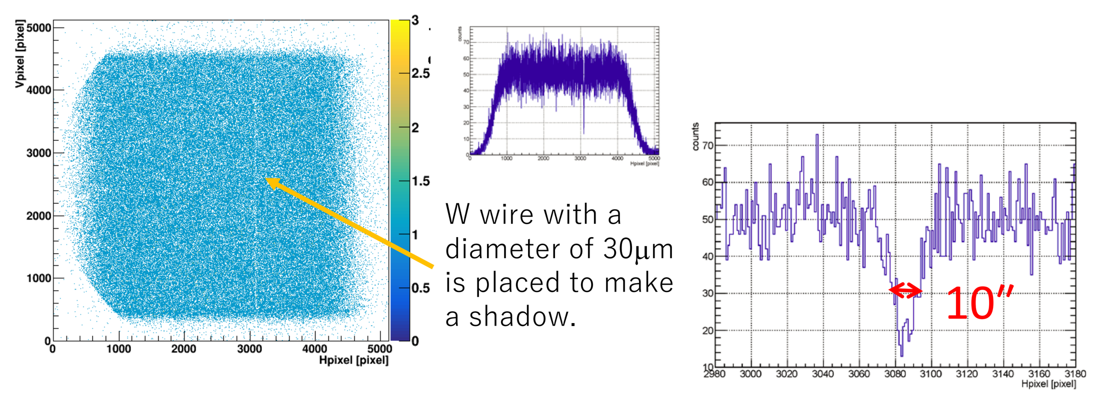
Image Contrast vs Ex



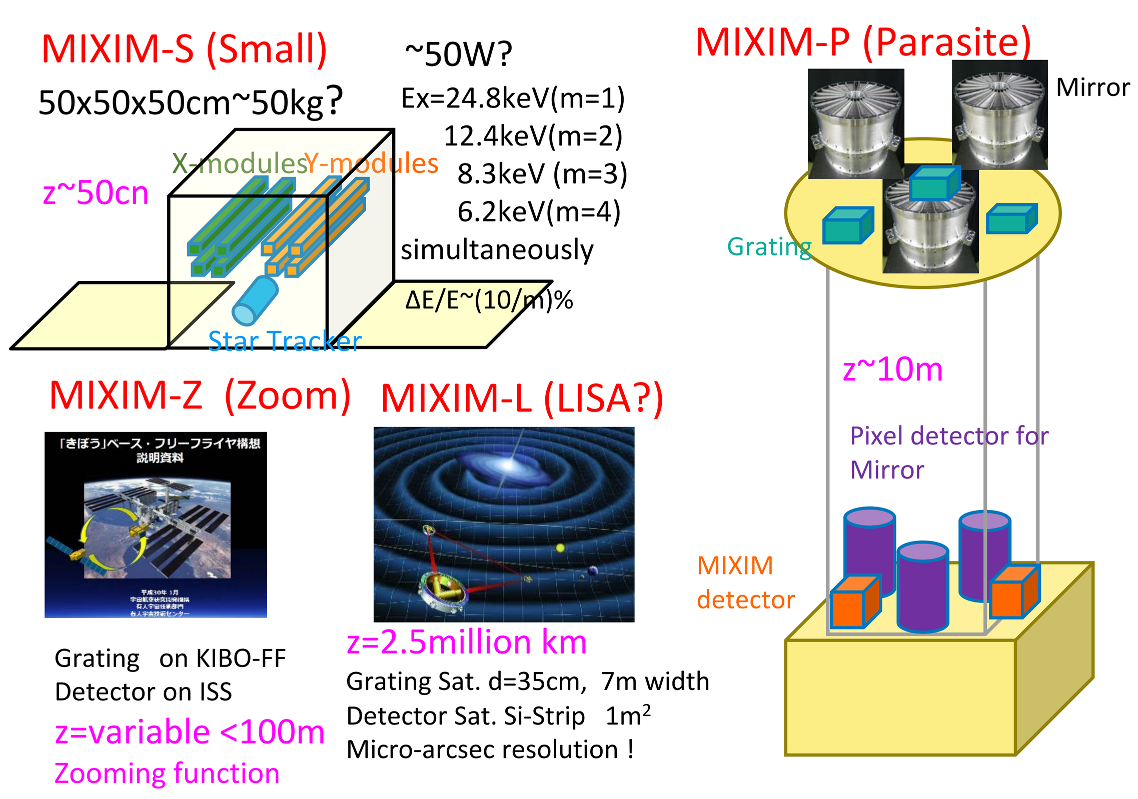


X-ray interference fringes are also visible in the Raw frame images with a long exposure time .

Wire-Mark as a coarse direction measure



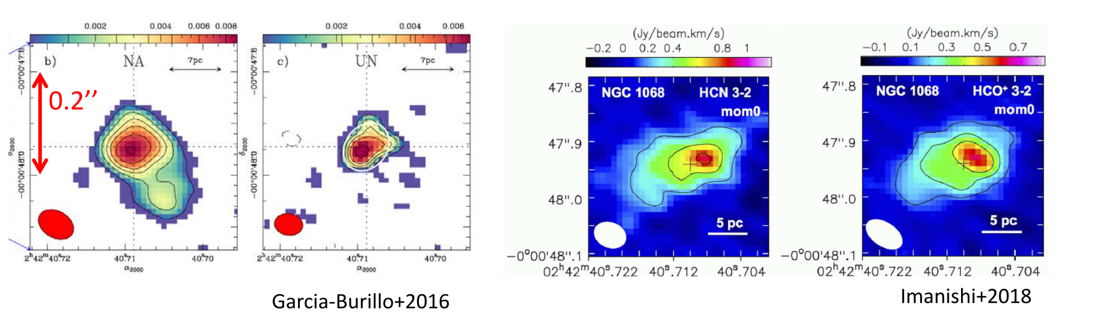
MIXIM is Scalable S,P,Z,L



Mission Format	S	P	Z	L
Distance z	0.5m	10m	100m	2.5x10^{6}km
Pitch d	5mm	22mm	100mm	35cm
$\Delta\theta$	0.4″	0.09″	0.01″	2.9μarcsec
$\Delta\lambda/\lambda$	0.2	0.2	0.2	0.2
No. of X+Y unit (A_{geo}=10cm^2/unit assumed)	4+4	3	25+25	1m^2+1m^2
Eff Area (@10keV) 200um Si assumed	2.5cm^2	1cm^2	8cm^2	312cm^2
Pros、Issues	For Very Small Sat Polarimetry is possible. We need further improvement in pixel size and detection efficiency for CMOS.	Current X-rat pixel detectors can be employed. Can parasite on Conventional X-ray observatories。	Current X-ray pixel detectors are enough for this .	BH event horizon is one of the goal of X-ray astronomy. Various X-ray detectors can be employed for this.
	We need to know the direction of the grating from the detector with better accuracy than the image width. (positional			

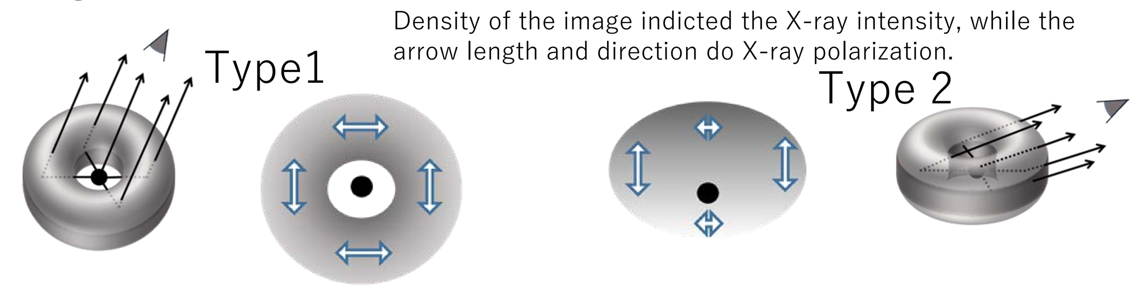
Recent ALMA Observations of nearby AGNs have been revealing the distribution of molecules at the size of putative Torus …. NGC1068 (D=14Mpc,0.1″ corresponds to 7pc)

N-S elongation in CO、E-W elongation in HCO, HCN



If we obtain X-ray intensity and polarization map of similar angular resolution with MIXIM-P or Z

Density of the image indicted the X-ray intensity, while the arrow length and direction do X-ray polarization.



→MIXIM-Z or P can provide direct test of AGN unification model

We can do MIXIM with any form of platforms above. If you are interested in MIXIM or have a room to install MIXIM in your own mission, please contact to us.

References

[1]Hayashida et al., 2016, SPIE proc., 9905, 99057
[2]Hayashida et al. 2017, X-ray Universe 2017
https://www.cosmos.esa.int/documents/332006/1402684/KHayashida_t.pdf
[3] Hayashida al. 2018, SPIE proc., 10699, 106990U [4] Asakura et al., P062