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

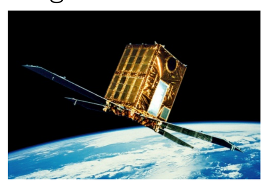
Kiyoshi Hayashida, Tomoki Kawabata, Takashi Hanasaka, Hiroshi Nakajima, Ryo Hosono, Takayoshi Shimura , Hiroyuki Kurubi, Shota Inoue, Hiroshi Tsunemi Hironori Matsumoto (Osaka University)

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 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 selfimage 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 raging 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

Collimator or Telescope	Detector Position Resolution	Field of View	Angular Resolution
Slat Collimators (e.g. Ginga LAC)	**No**	**1~10°**	**1~10°**
Modulation Collimators (Yokoh HXT)	No	~0.5°	~5''
Coded Mask (SwiftBAT)	2D	~70°	17'
Slit(MAXI)	2D	~90°	~0.1°
Grazing Incidence Mirror	**2D**	**0.1~1°**	**0.5''~2'**

Ginga 1987-1991



MAXI 2009- ~1m

10m 0.5'' 5m 2' 6m/12m 1.3'/1.7' 12m 5''

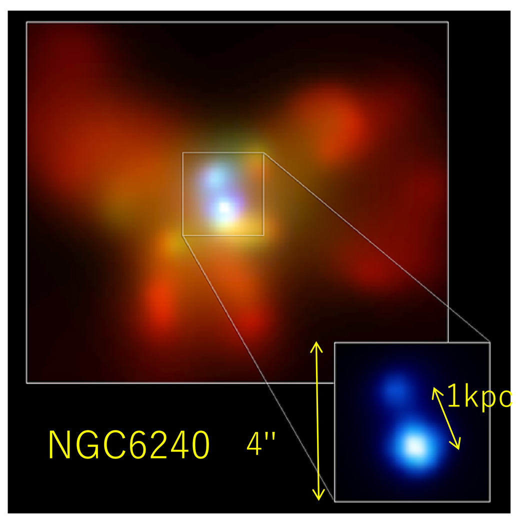
- High angular resolution needs X-ray Mirrors on Big Satellites
- Angular resolution of 0.5'' with Chandra is difficult to reproduce.

Arcsec Sub-Arcsec X-ray Observations Targets

c.f. 0.1 arcseconds resolution for visible, IR and mili-arcseconds or better for radio are common.

SMBH Binaries

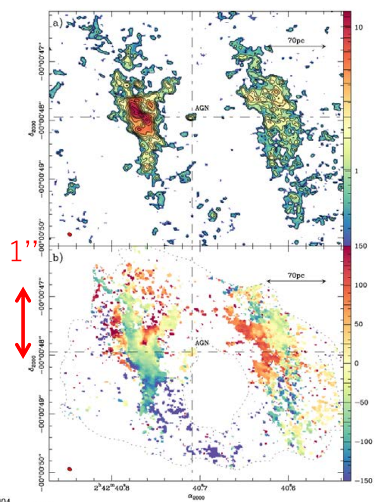
- One of the most important issues on evolution of galaxies
- Related also to gravitational wave
- Only few kpc apart cases (NGC6240, OJ287 etc.) are known.
- There should be more SMBH Binaries
- Angular resolution improvement by factor of 3 will leads to one order of magnitude larger sample.

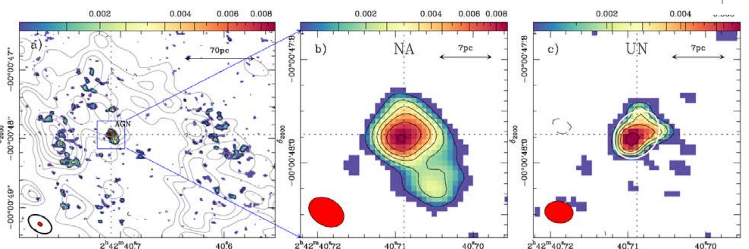


Chandra X-ray image of NGC6240
Credit: NASA/CXC/MPE/S.Komossa et al.

Torus of Active Galactic Nuclei

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

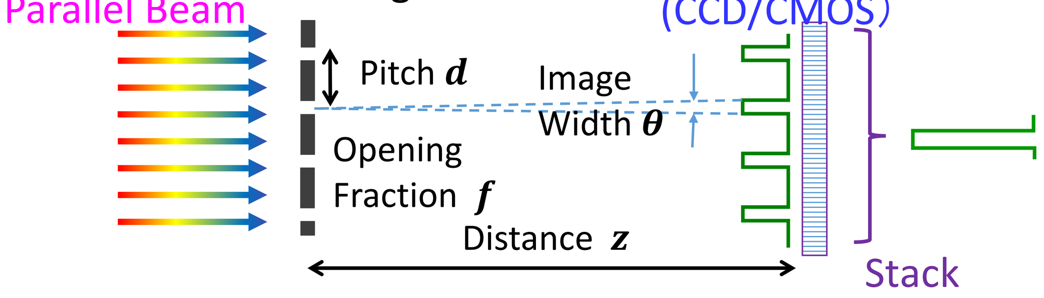




NGC106 8 ALMA (sub-millimeter radio) Image of Tours? Garcia-Burillo et al. 2016

Multi Image X-ray Interferometer

Hayashida+ 2016

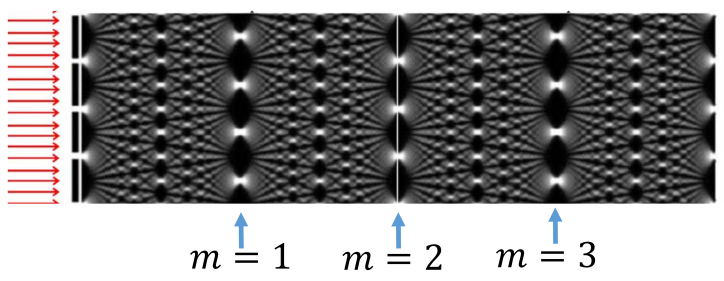


- Only employ a Grating and an X-ray Pixel Detector
- Image profile detected reflects the profile of the X-ray source.
- Stacking the image with a period of d in the analysis, accurate source profile is obtained.
- Diffraction is significant. But, if we select X-ray events that meet the Talbot condition,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

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** $z_T = m\frac{d^2}{\lambda}$

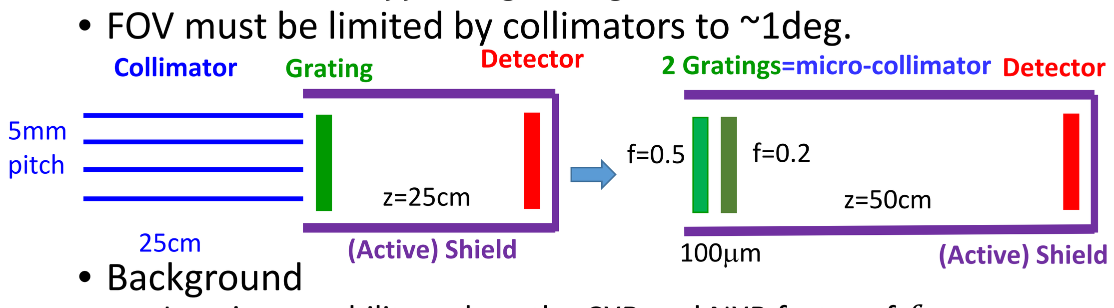


For λ=0.1nm(12keV) X-rays and a d=5μm pitch grating, Talbot distance z_T of m=2 is 50cm

Preliminary Design

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

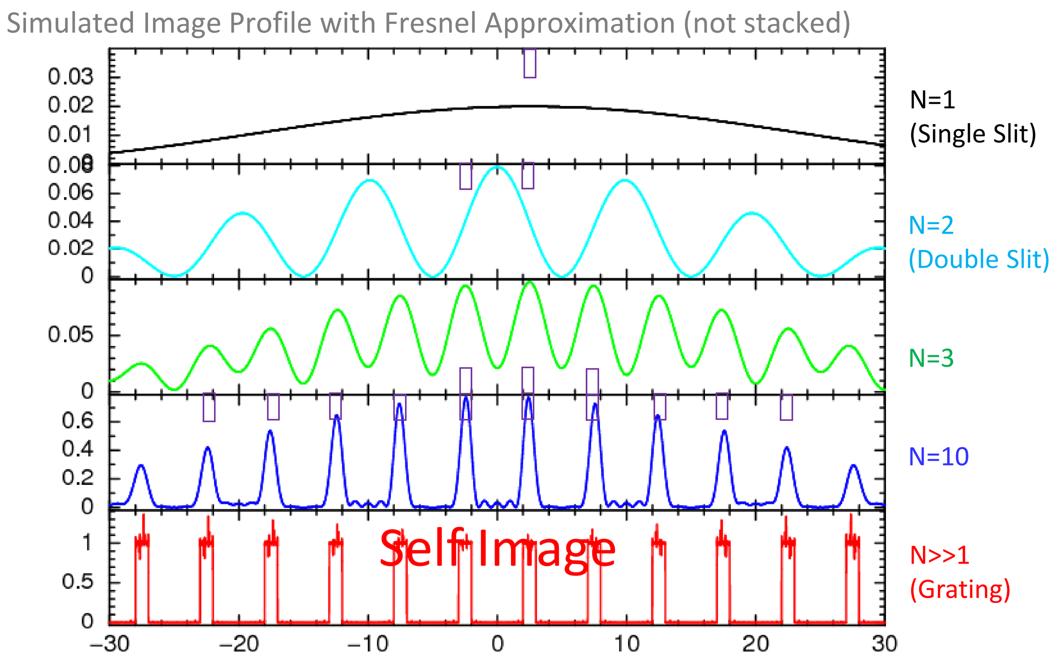
- $z = md^2/\lambda = 50\text{cm}\left(\frac{m}{2}\right)\left(\frac{d}{5\mu m}\right)^2/\left(\frac{\lambda}{0.1nm}\right)$
- $\theta = \frac{fd}{z} = f\lambda/dm = 0.4''\left(\frac{f}{0.2}\right)\left(\frac{\lambda}{0.1nm}\right)/\left(\frac{d}{5\mu m}\right)\left(\frac{m}{2}\right)$
  - Positional 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

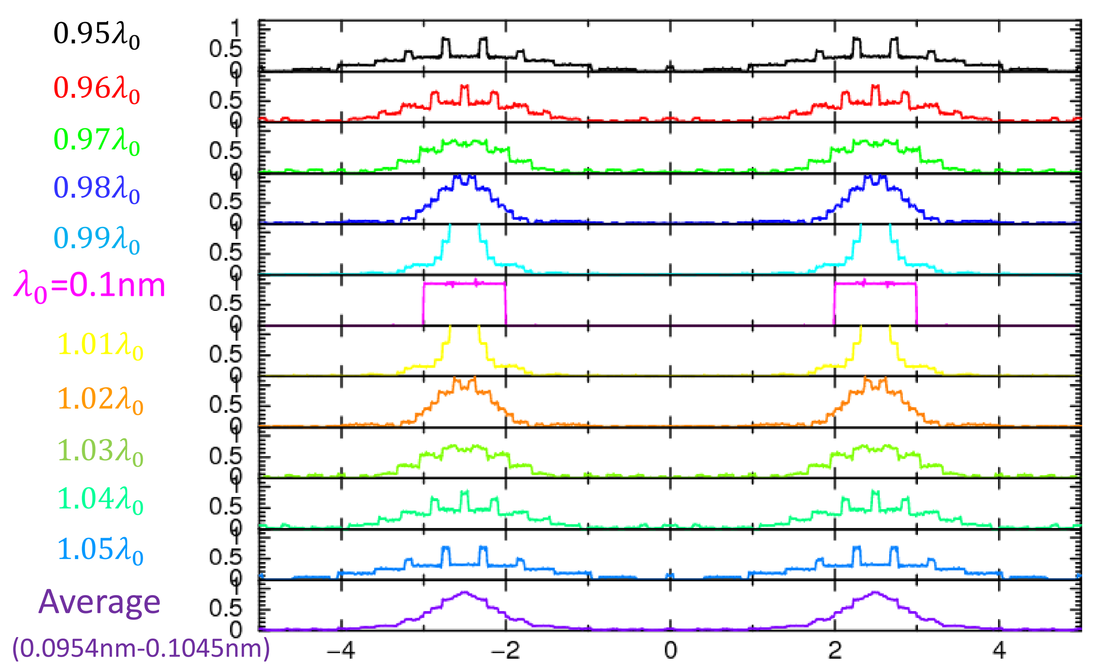
Simulation with Fresnel Approximation Band width of ~10% is available; good for CCD, CMOS

At Talbot Distance



λ dependence at a fixed setup

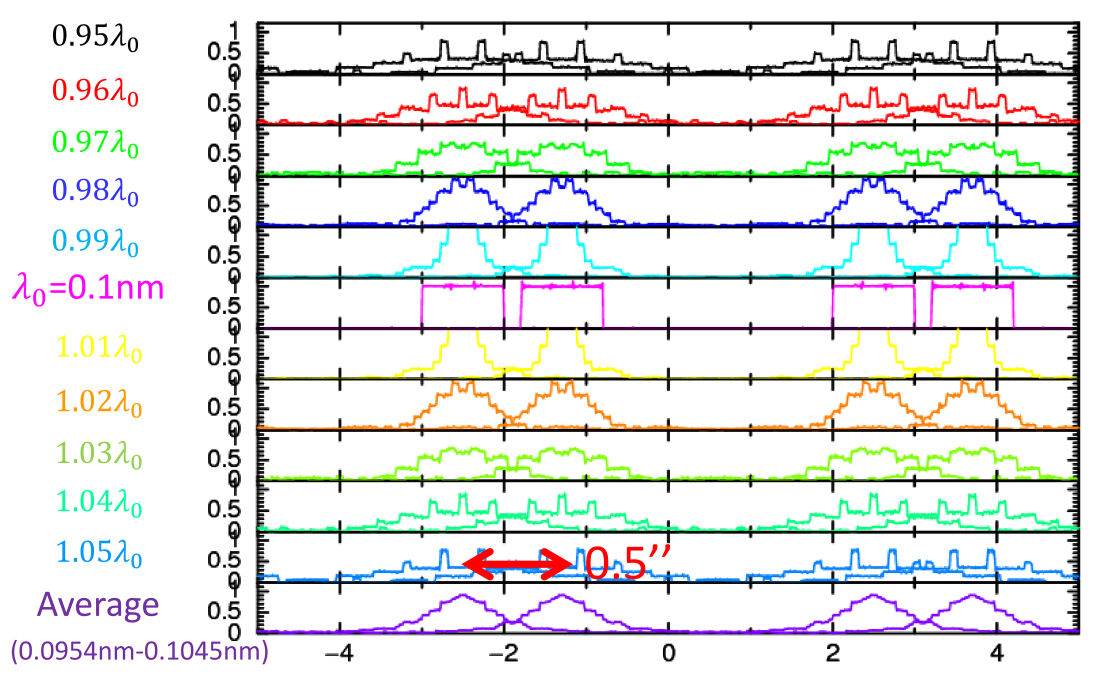
d=5μm f=0.2 z=0.5m m=2



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

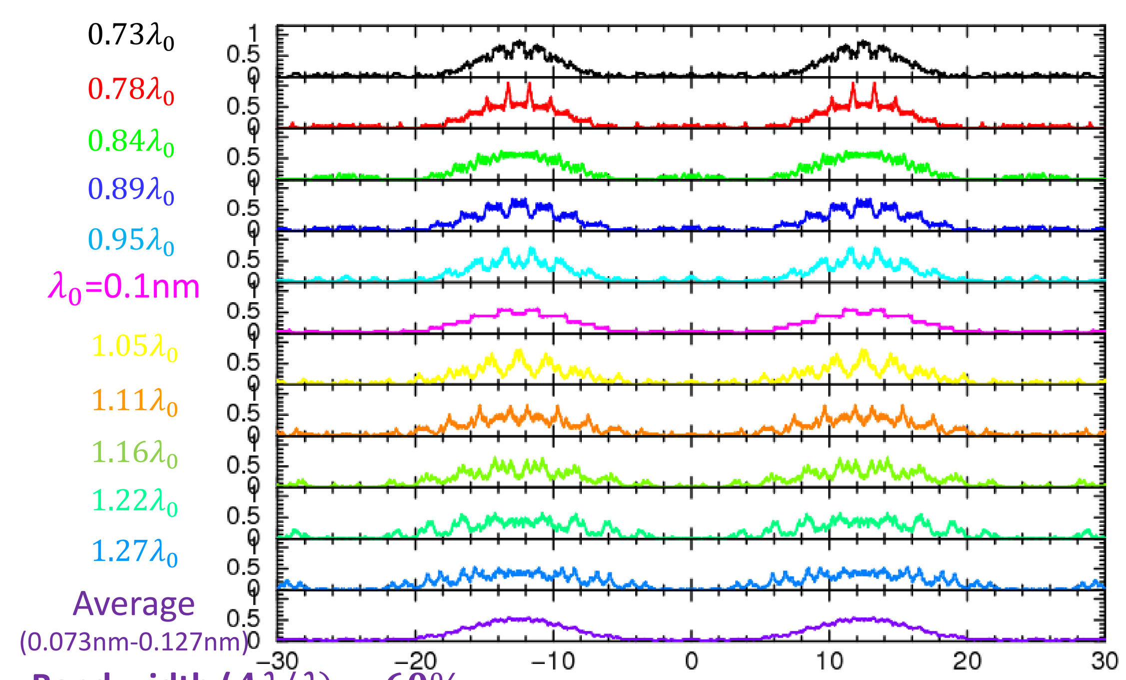


Band width $(\Delta\lambda/\lambda) = 10\%$ m=2

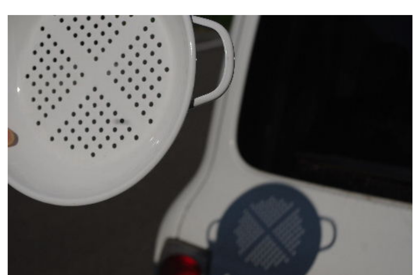
Near Field Case

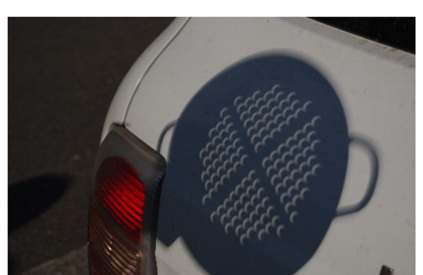
Near Field $z \ll z_T$

d=25μm, f=0.2, λ_0=0.1nm
z=0.5m <<$z_T(m=1)$ =6.25m



Band width $(\Delta\lambda/\lambda) = 60\%$ maybe more





c.f.
Multi-Pinholes Image During a solar eclipse
http://blog.goo.ne.jp/hanahana haru04/e/a8ef27218dee371313 6a89943109a431

MIXIM satellite options

Multi Image X-ray Interferometer Module (or Mission) = MIXIM

Mission Size	Sampler	Short	Tall	Grande
Distance z	0.5m	0.5m	2m	10m
Pitch d	25μm	5μm	10μm	10μm
Open. Frac. f	0.2	0.2	0.2	0.1
Talbot Order m (for 0.1nm X-ray)	(0.1)	2	2	10
θ	2''	0.4''	0.2''	0.02''
$\Delta\lambda/\lambda$	1	0.2	0.2	0.2
No. of X+Y unit (A_{geo}=10cm²/unit assumed)	1+1	4+4	25+25	100+100
η_{det} at 10keV (200um Si assuemd)	0.78	0.78	0.78	0.78
Effective Area (@10keV)	3cm²	2.5cm²	16cm²	31cm²

Laboratory Experiments

See Poster 89

- 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 4.4.
- We also introduced a CMOS sensor GSENSE5130 with a small pixel size of 4.25 μm. GSENSE5130 can detect X-rays at room temperature. The energy resolution is 240eV@5.9keV for single pixel events. We obtained X-ray images through the grating using GSENSE5130.
- We have performed parallel X-ray beam irradiation to GSENSE5130 plus grating at BL20B of SPring-8. X-ray polarimetry was also tested. The results will be shown later.

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]Kawabata et al. 2017, P89 this conference