X-ray Universe 2017 @Rome July 09 2017

Arcsecond and Sub-arcsecond Imaging with Multi Image X-ray Interferometer for (Very) Small Satellites

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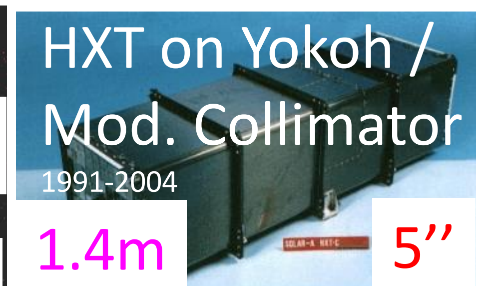
-Instruments for X-ray Astronomy- Agree?

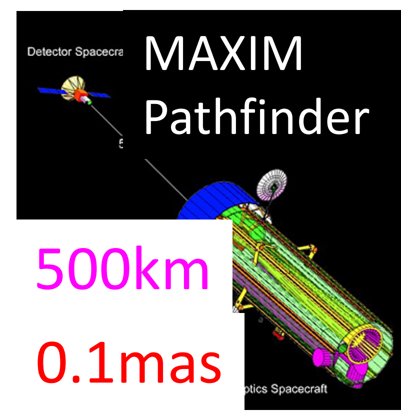
1. Telescopes are build with Grazing Incidence Mirrors with FL of 3-12m plus Pixel Detectors.
2. 0.5'' resolution mirror is exceptional. It is very much difficult to reproduce it now.
3. Slits, Masks or Collimators are primarily used for wide FOV surveys, in which angular resolution is limited to ~10arcminutes.
4. Interferometers have been proposed. Some function in lab, but application in orbit are even more difficult.

NASA / SAO / CXC

ESA



ISAS/JAXA



NASA

Attempt to challenge these common sense

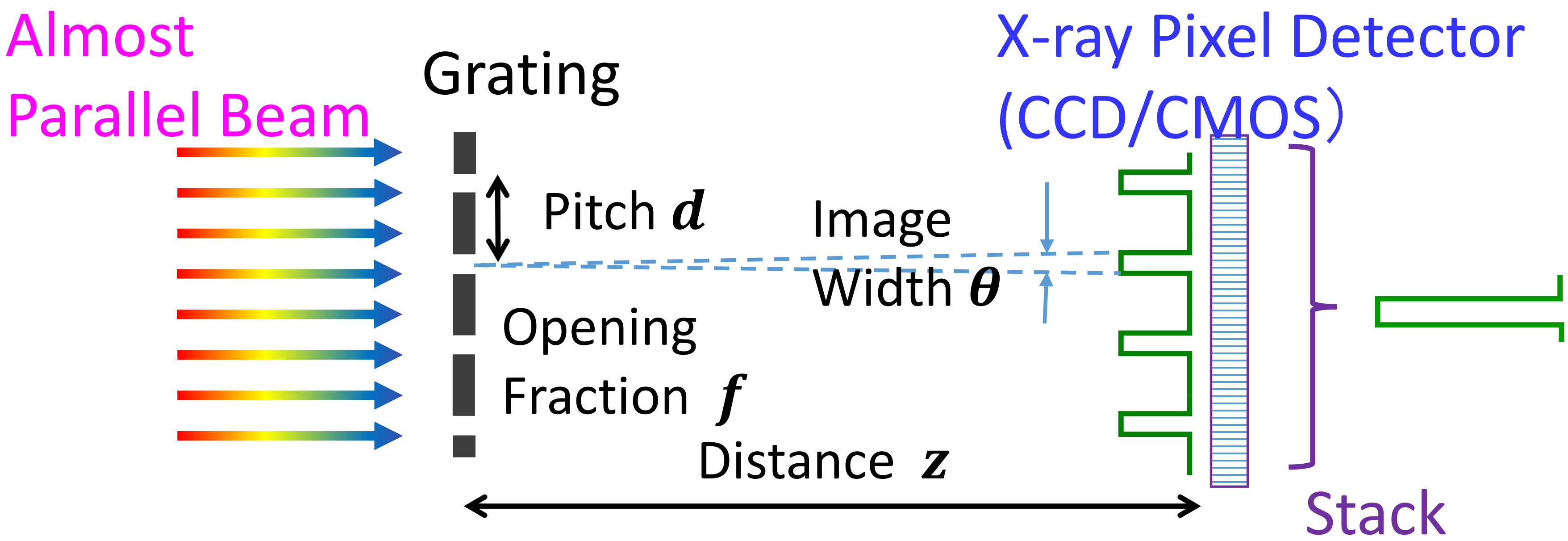
Multi-Pinhole(Slit) Camera is the baseline

http://blog.goo.ne.jp/hanahanaharu04/e/a8ef27218dee3713136a89943109a431

STACK
these multiple images in the analysis

Multi Image X-ray Interferometer/Imager

See Hayashida+ SPIE Proc 2016



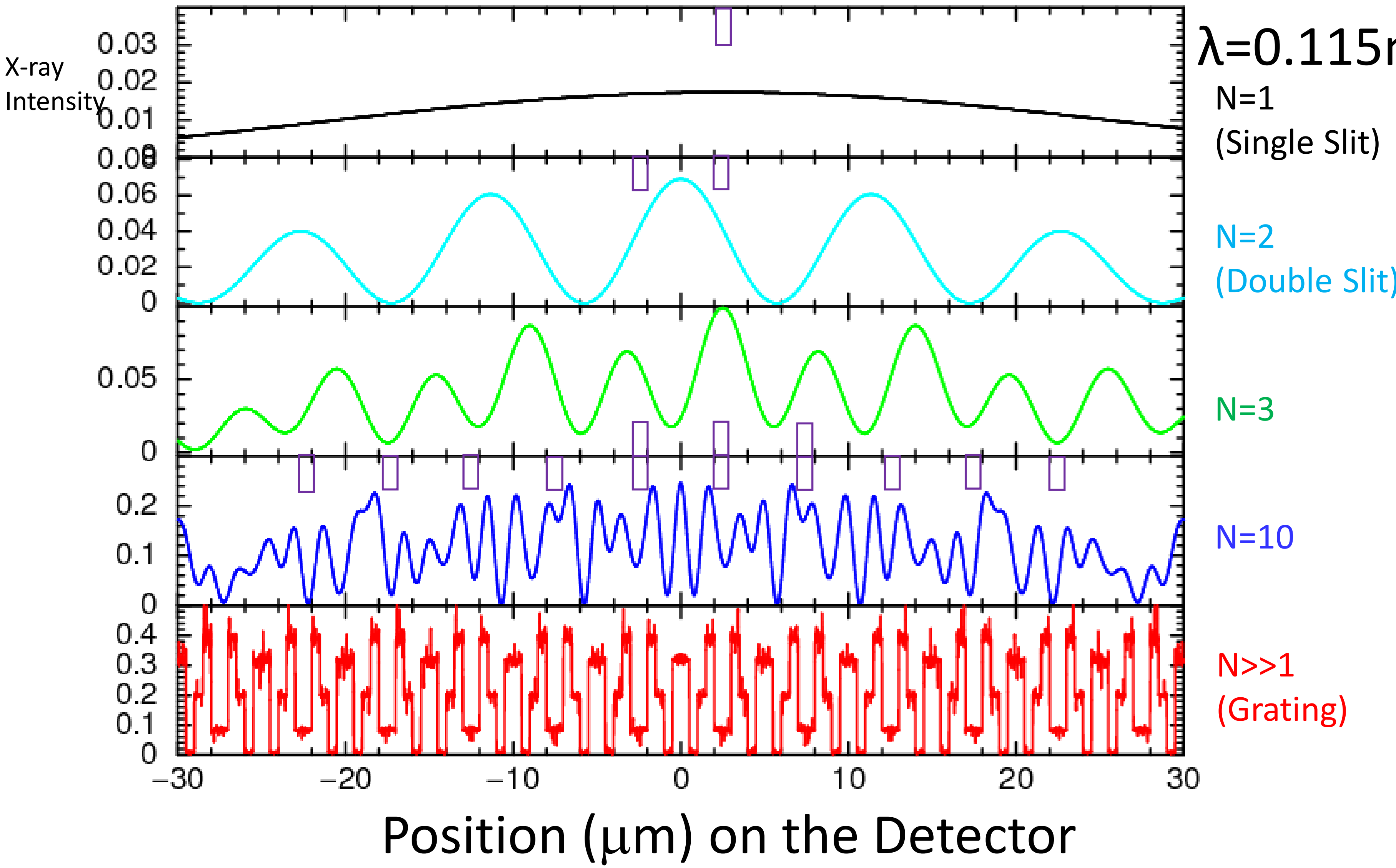
- Only employ a Grating and an X-ray Pixel Detector
- Image profile detected reflects the profile of the X-ray source.
- Stacking the image with a period of d in the analysis, accurate source profile is obtained.
- Image Width $\theta = fd/z = 0.4'' \left(\frac{f}{0.2}\right)\left(\frac{d}{5\mu m}\right)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

Chandra Resolution with a 50cm size satellite ?

But, in reality Diffraction is significant.

d=5μm
f=0.2
z=0.5m
λ=0.115nm

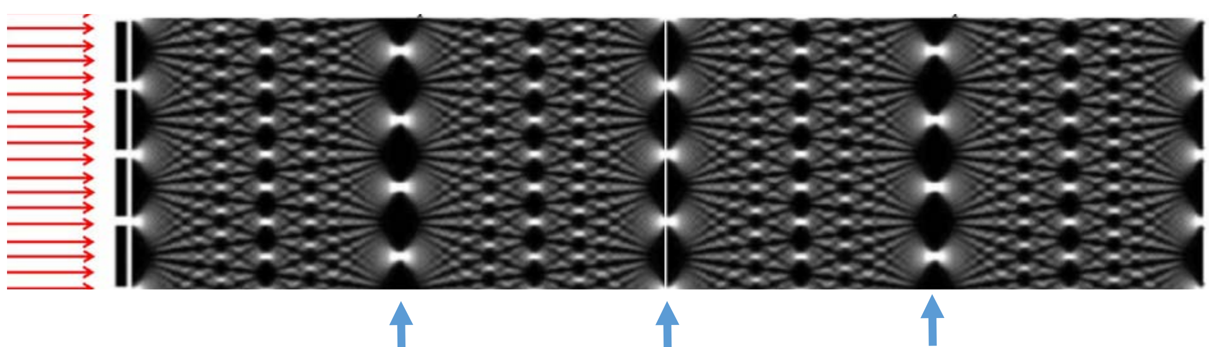
Simulated Image Profile with Fresnel Approximation (not stacked)



But, but, Talbot Effect can be employed

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

Plain Wave Light



$m = 1$ $m = 2$ $m = 3$

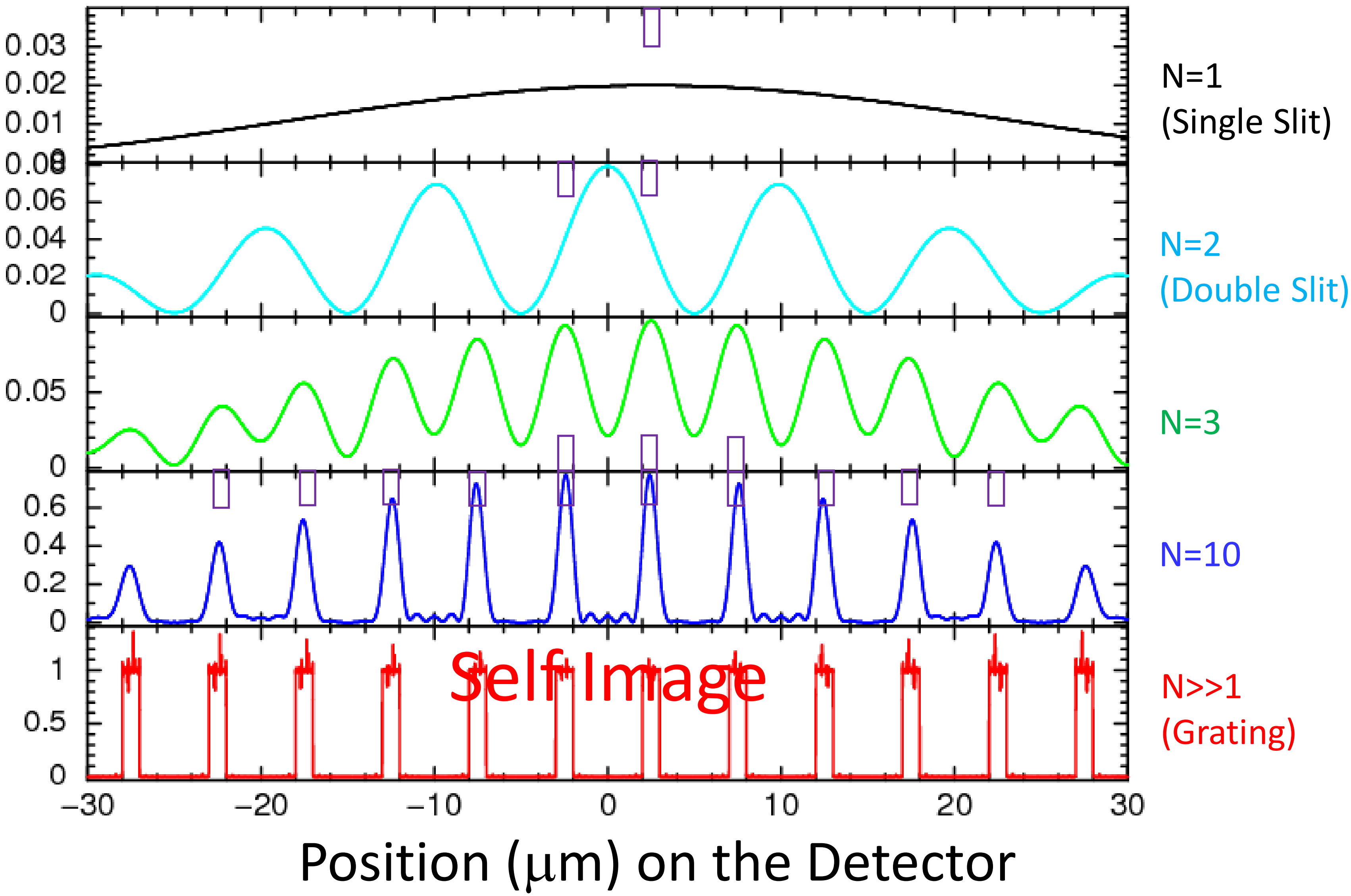
Talbot Carpet
Image from Wen et al. Advances in Optics and Photonics 5, 83-130 (2013)

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

At Talbot Distance

d=5μm f=0.2
z=0.5m **λ=0.100nm (m=2)**

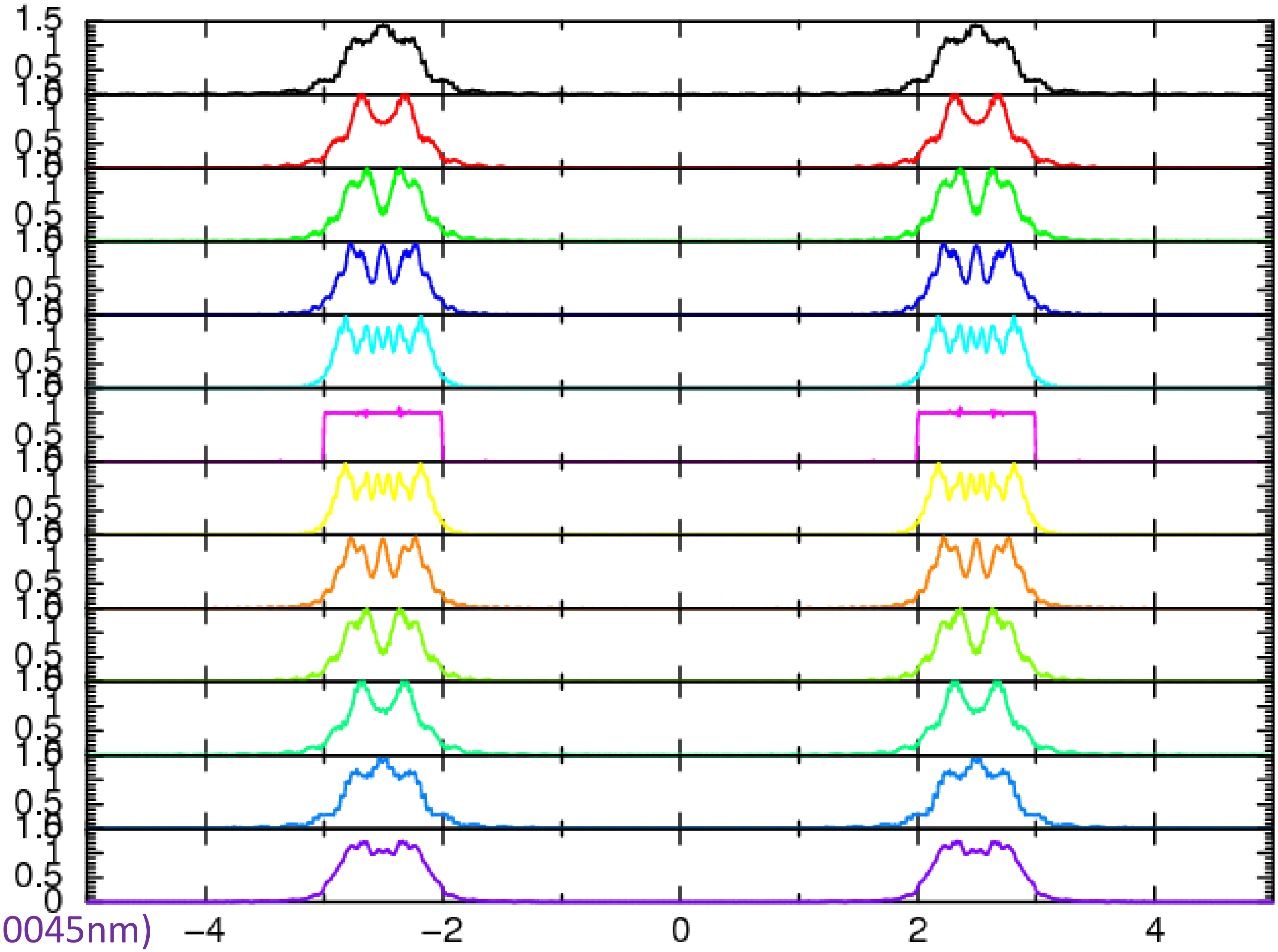
Simulated Image Profile with Fresnel Approximation (not stacked)



λ dependence at a fixed setup

d=5μm f=0.2
z=0.5m (m=2)

$0.995\lambda_0$
$0.996\lambda_0$
$0.997\lambda_0$
$0.998\lambda_0$
$0.999\lambda_0$
λ_0=0.1nm
$1.001\lambda_0$
$1.002\lambda_0$
$1.003\lambda_0$
$1.004\lambda_0$
$1.005\lambda_0$
Average
(0.09954nm-0.10045nm)

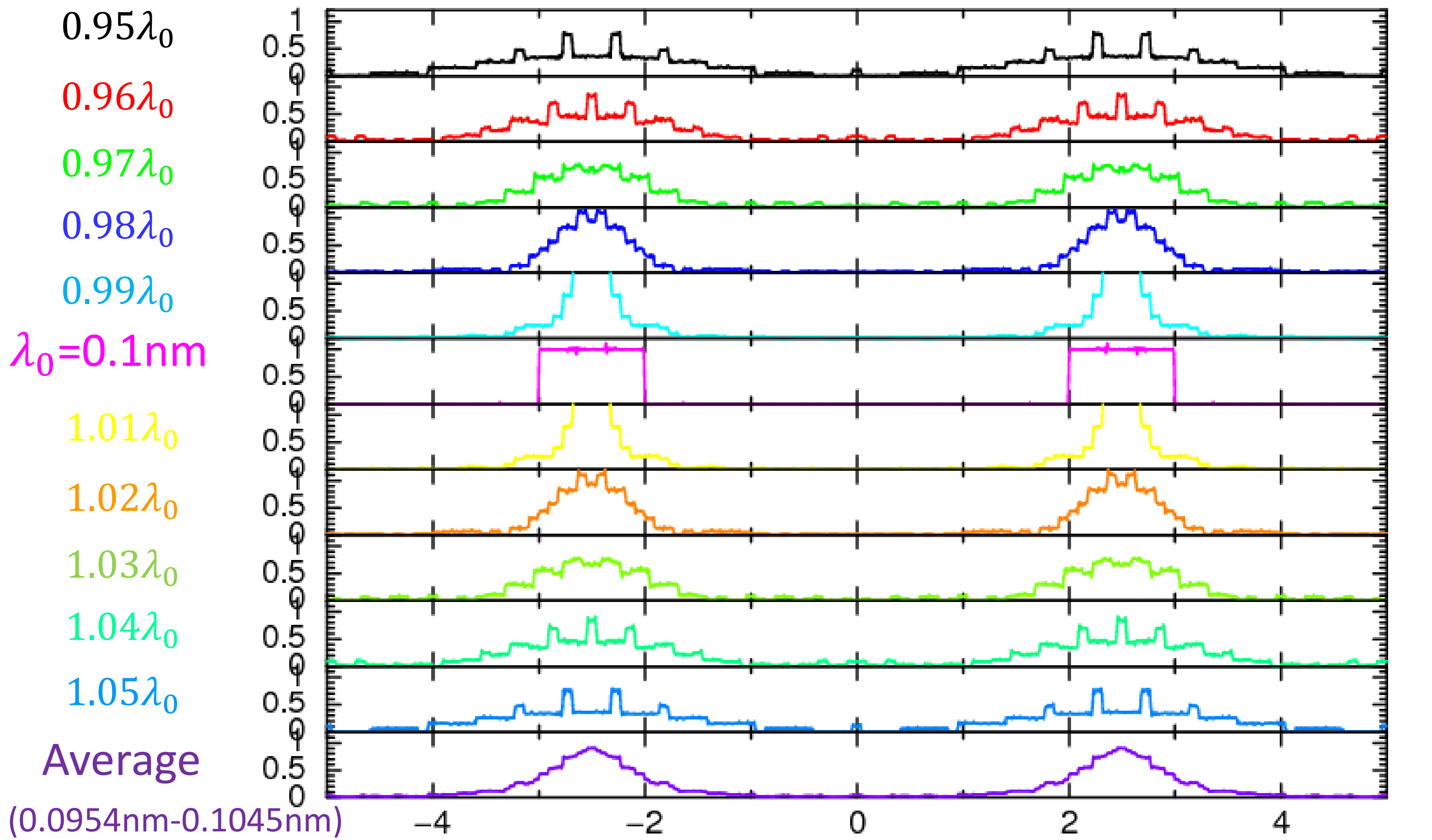


Position (μm) on the Detector

Band width $(\Delta\lambda/\lambda) = 1\%$

λ dependence at a fixed setup

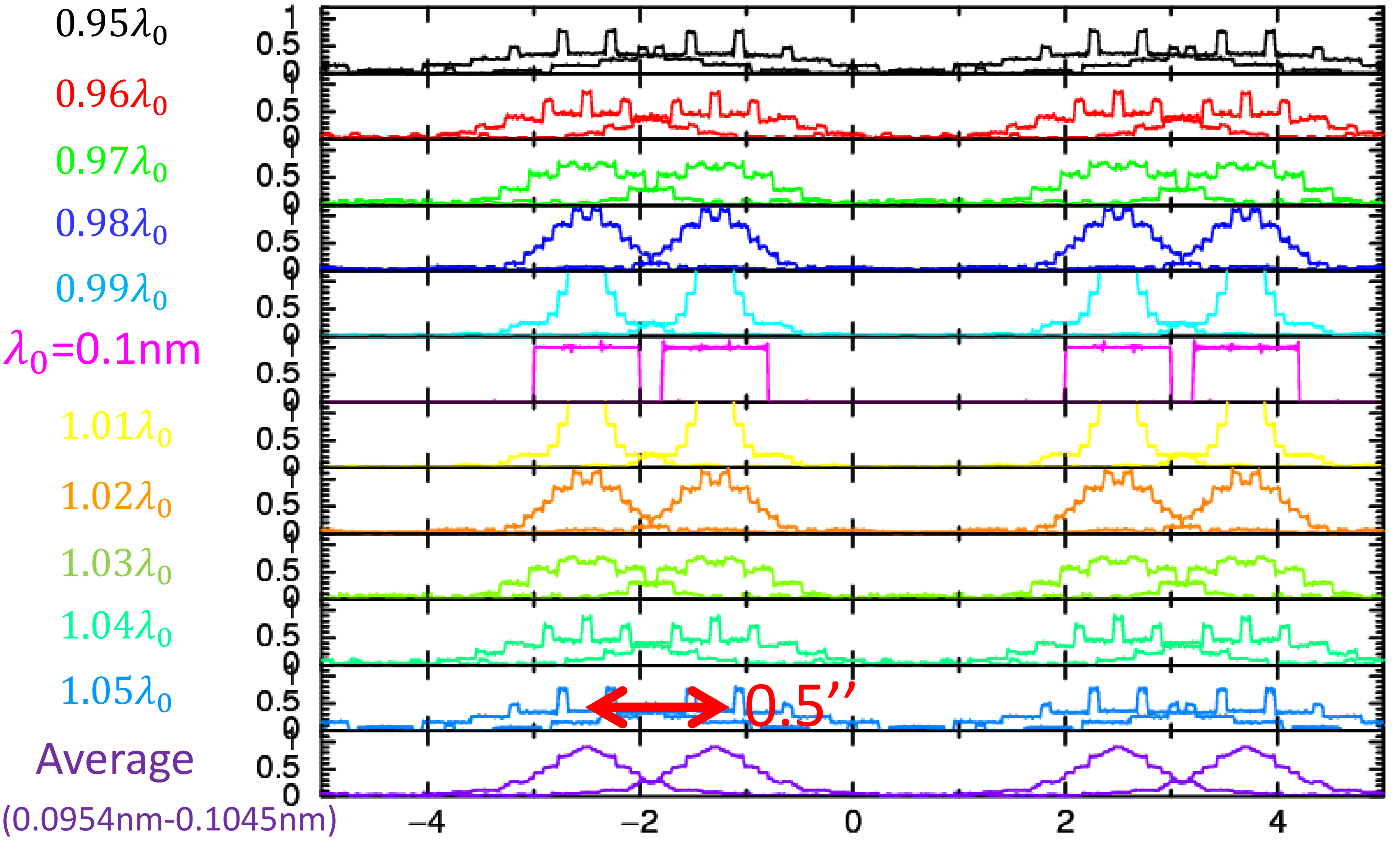
d=5μm f=0.2
z=0.5m m=2



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

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

Hayashida+ SPIE Proc 2016

- X-ray Grating with a few~10's μm pitch and X-ray Imaging Spectrometer
- Select X-ray Events of which energy is within specific band around the Talbot condition.
  - Band-pass $\Delta\lambda/\lambda$ of about 10% (for m=2; 20% for m=1) can be utilized. Wider than Si-detector energy resolution of 1~2%. Good for X-ray CCD and X-ray CMOS.
- Stacked Image tell us the X-ray source profile

c.f. **X-ray Talbot (-Lau) Interferometer** Momose+(2003), Pfeiffer+(2006) for Phase Contrast X-ray Imaging of Light Material

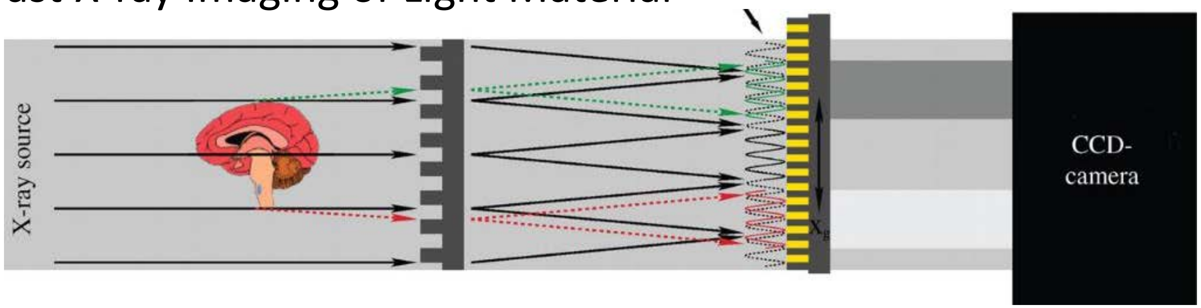
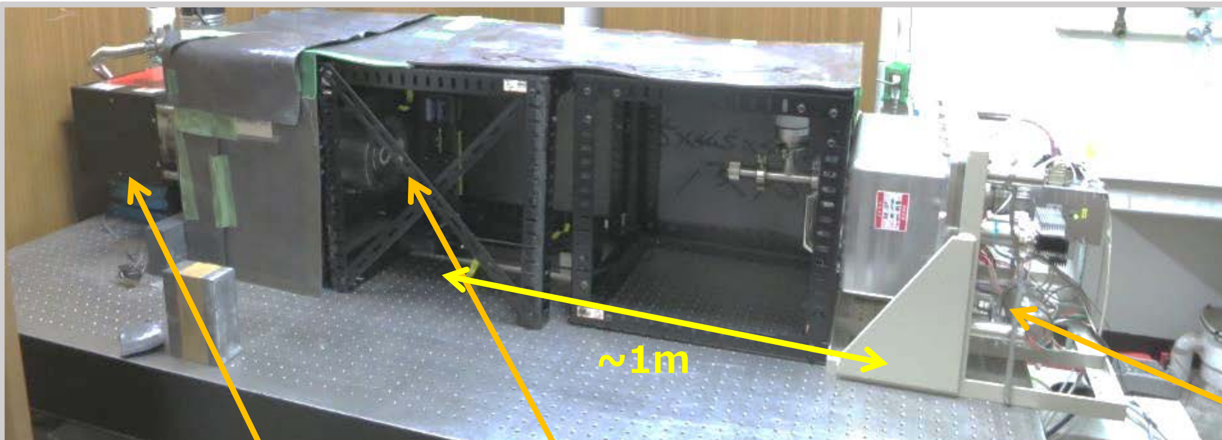


Figure from http://rsif.royalsocietypublishing.org/content/7/53/1665

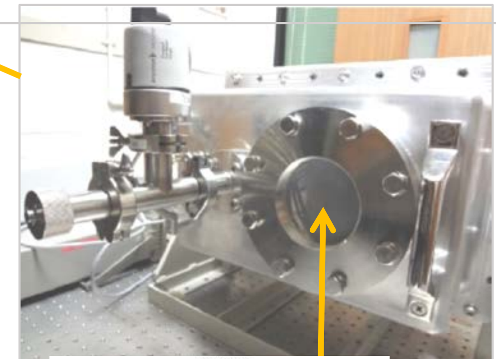
Hoshino+ 2014 KONICA MINOLTA TECHNOLOGY REPORT Vol11

Lab. Experiment with Spherical Wave



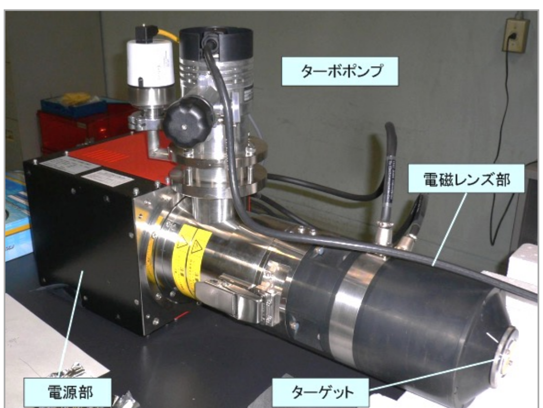
X-ray CMOS (XRPIX2b)

inside Vacuum Chamber
Cooled -40degC
Window=0.2mm Thick Al



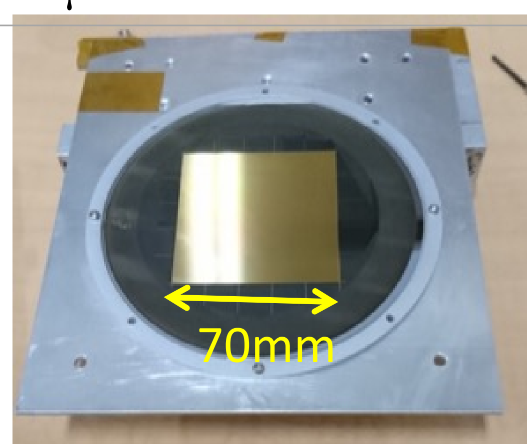
microFocusX-ray

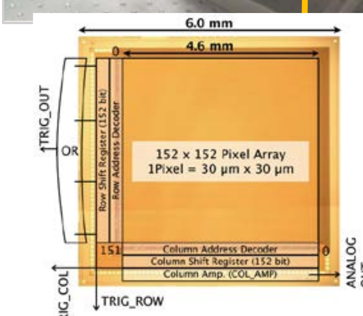
60kV, 100μA, Target=W
Source Size=3~5μm



X-ray Grating

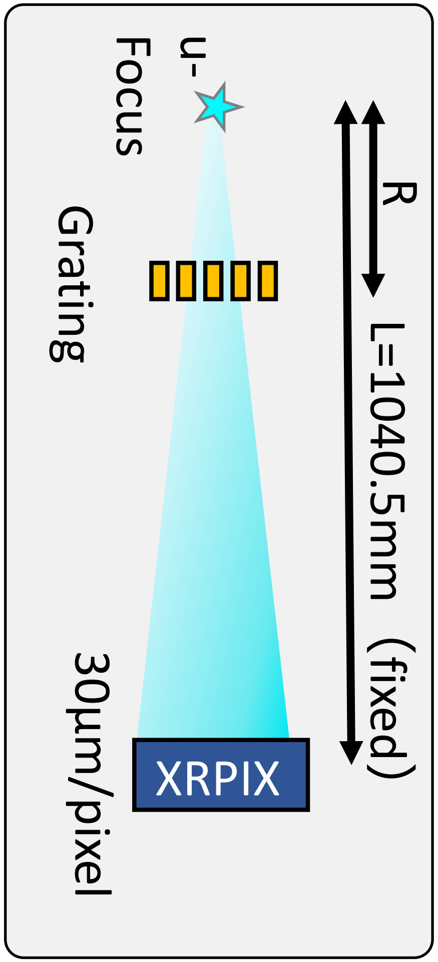
Pitch d=4.8μm
Open frac. f=0.5
17μm thick Au on Si

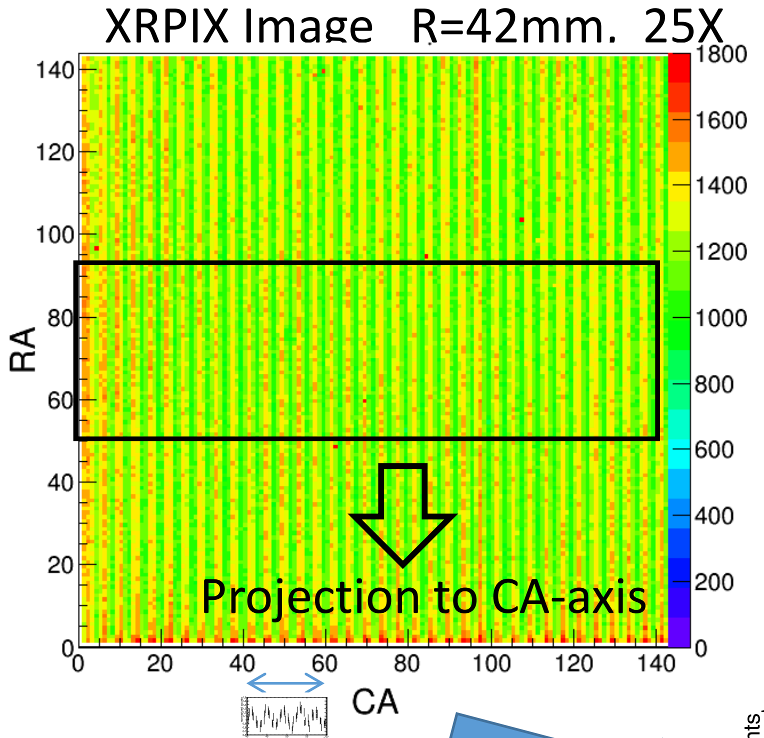


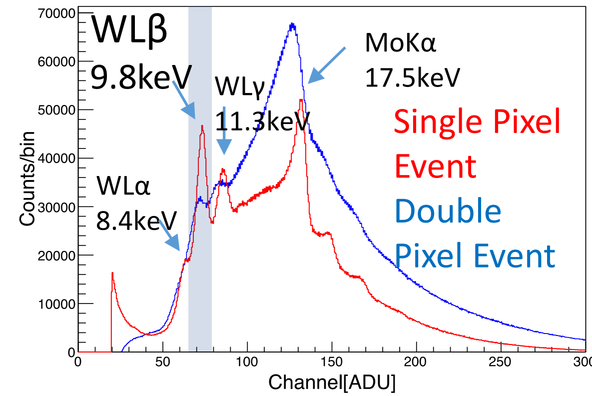


XRPIX2b (Tsuru+2014)
pixel size 30μm
152x152 pix

Lab. Experiment Result 1/2

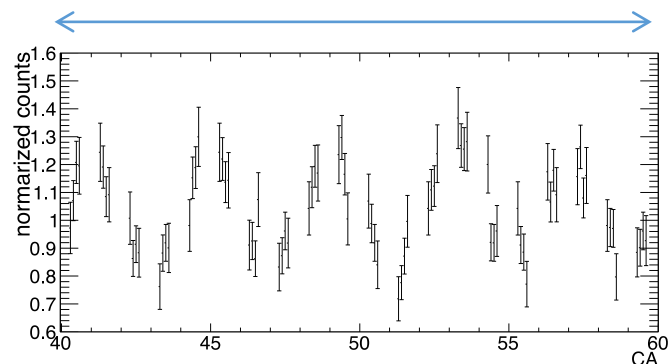




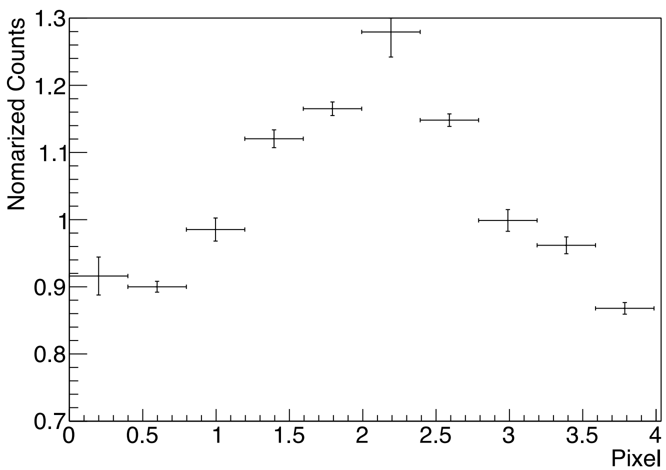


※Only Double Events（split along CA direction）are employed

Projected Profile



Stacked Profile



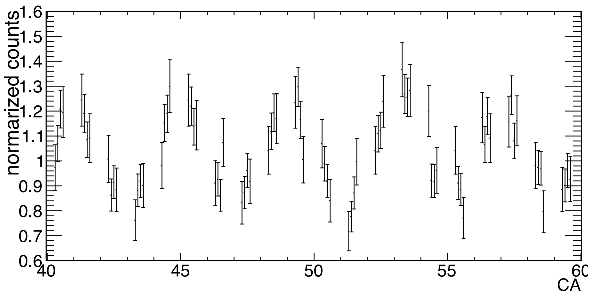
Lab. Experiment Results 2/2

Talbot Distance for a Spherical Wave

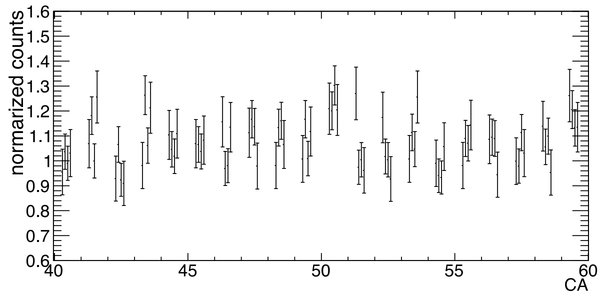
$$z_T = \frac{L}{2}\left(1 - \sqrt{1 - \frac{4md^2}{\lambda L}}\right)$$

Projected Profile (One Part)

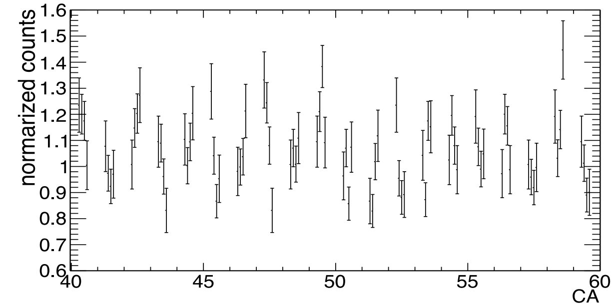
R=42mm, Mag. =25x



R=102mm,Mag.=10x

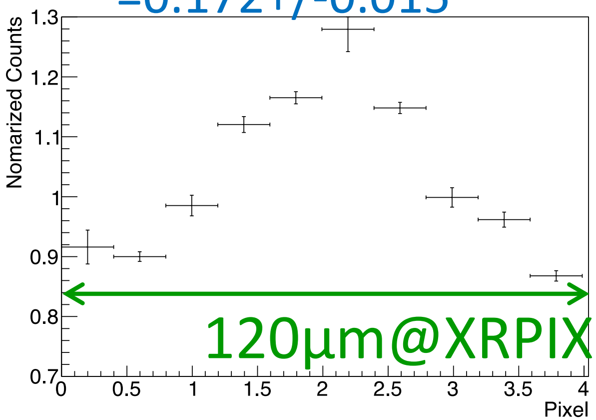


R=235mm（correspond to **Talbot Condition**）, Mag.=4.4x

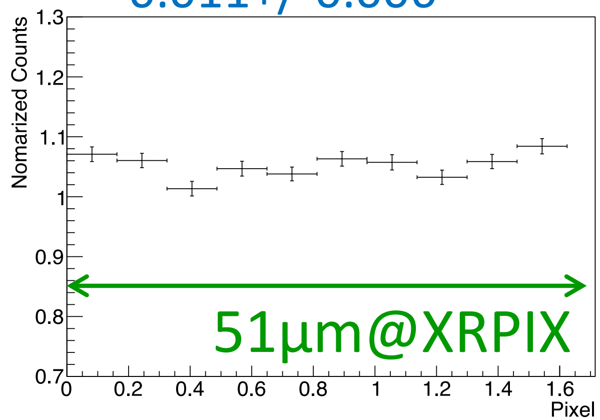


Stacked Profile

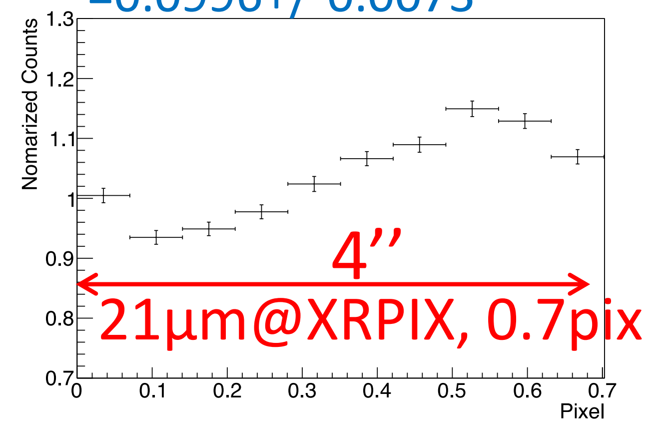
Fractional Amplitude =0.172+/-0.015



Fractional Amplitude =0.011+/-0.006



Fractional Amplitude =0.0996+/-0.0073

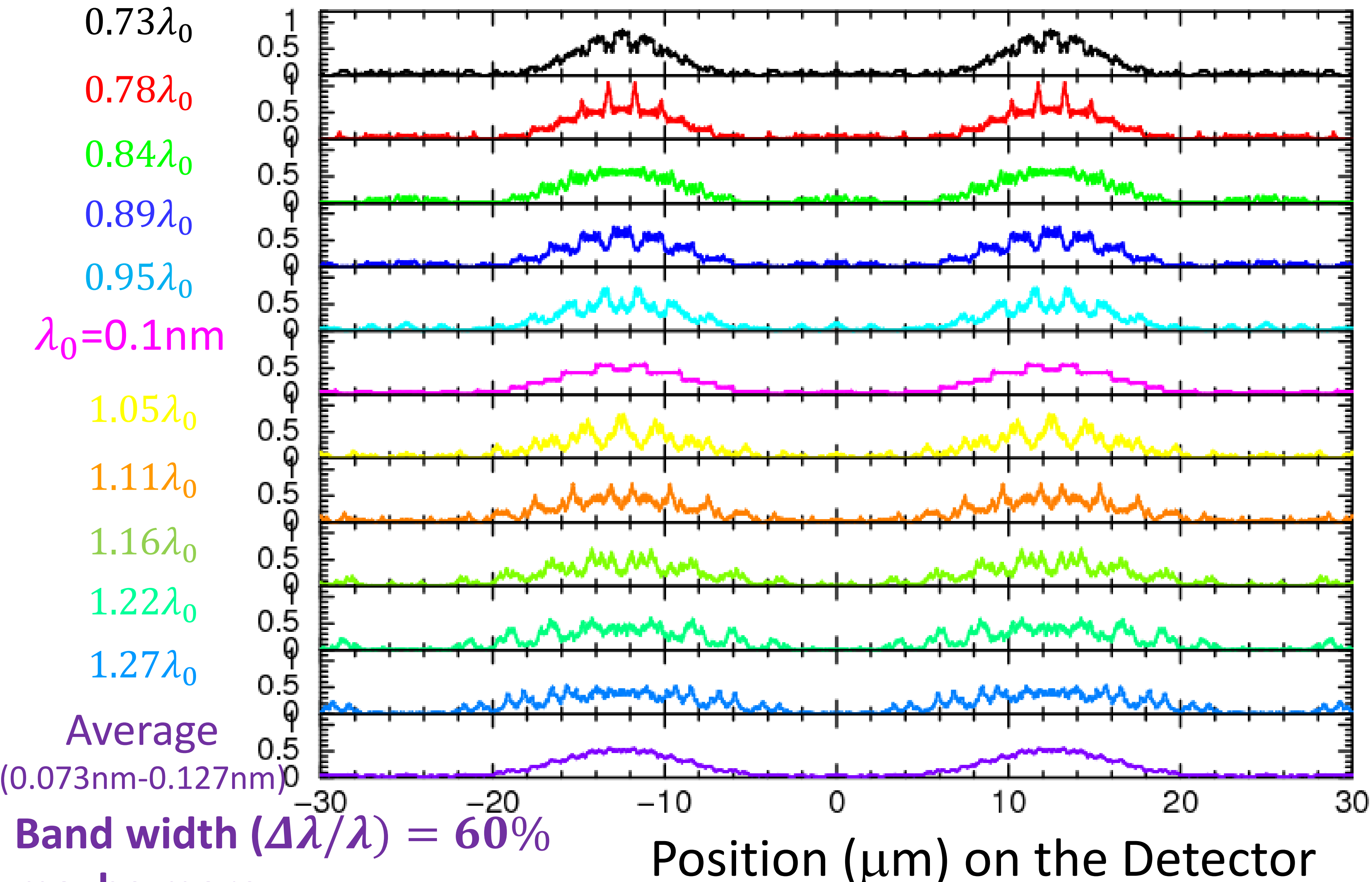


- micro-Focus source size of 3-5um is not small enough to be regarded as a point source as illustrated in the Stacked profile.

Near Field $z \ll z_T$

d=25μm, f=0.2, λ_0=0.1nm

z=0.5m <<$z_T(m=1)$ =6.25m



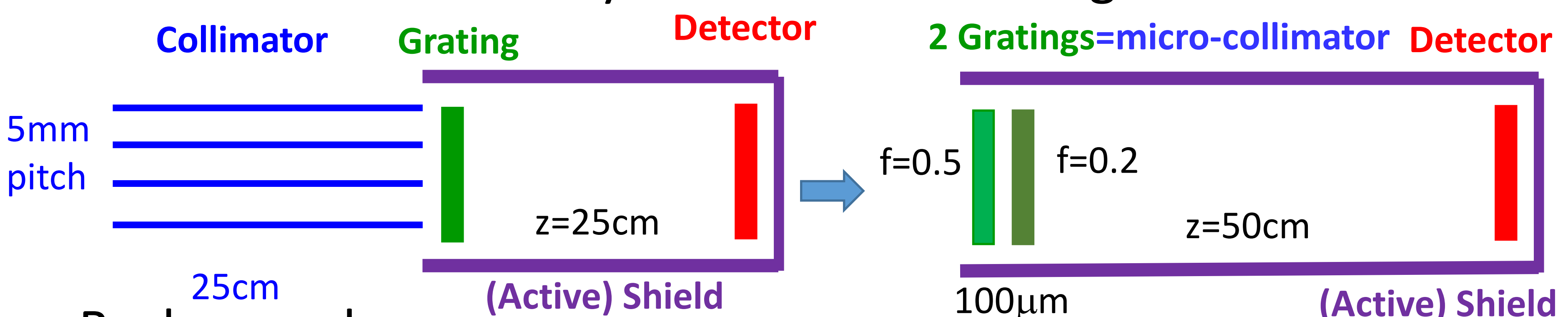
Band width $(\Delta\lambda/\lambda) = 60\%$
maybe more

Hayashida+2016SPIE Proc. and Updates

Very 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

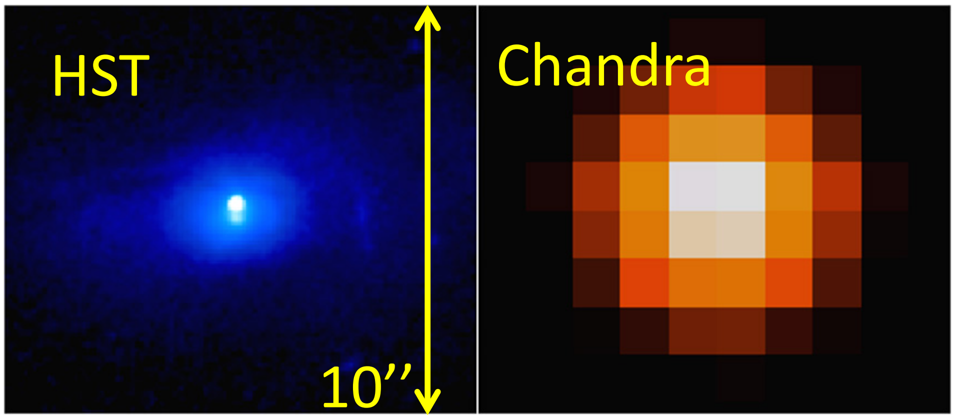
MIXIM options

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 ($Ageo$=10cm^2/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)	3cm^2	2.5cm^2	16cm^2	31cm^2

Targets : e.g. Structure of Relatively Bright Point-like Sources, i.e., (SM)BH and NS

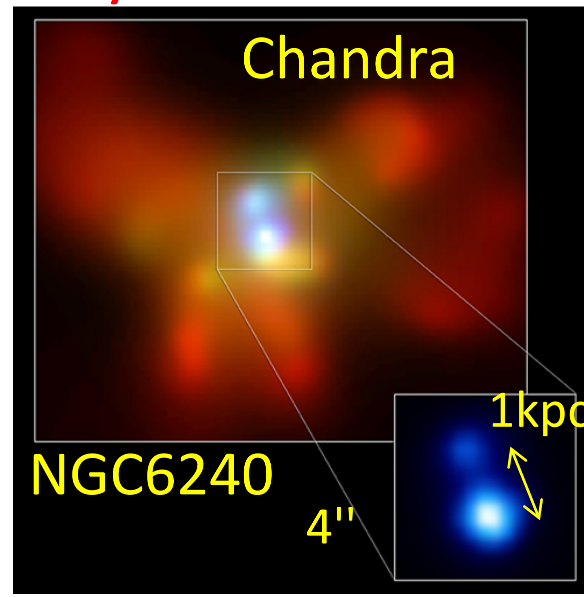
Recoiled SMBH candidates

CXO J101527.2+625911



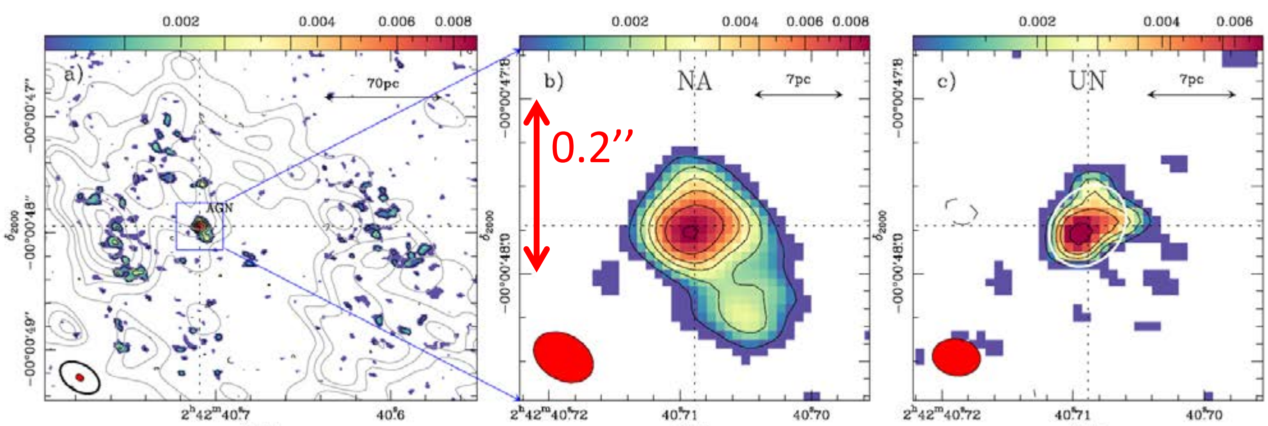
(X-ray: NASA/CXC/NRAO/D.-C.Kim; Optical: NASA/STScI)

Binary SMBHs



NASA/CXC/MPE/S.Komossa et al.

Torus Type2 and 1 AGNs



NGC1068
ALMA image

Garcia-Burillo+2016

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primarily

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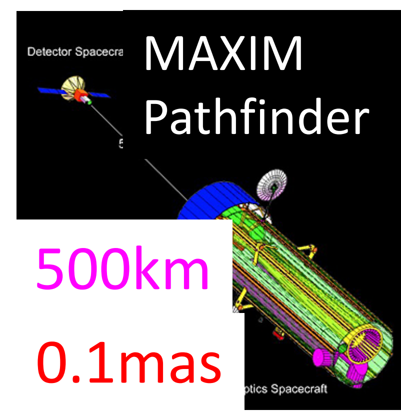

NASA

No, in future, with MIXIM or any other methods.