

NANOX - proposed nano-satellite X-ray sky monitor

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Science objectives

Primary

- Long-term (months) measurement of light curves of persistent X-ray binary stars in the centre of the Galaxy at soft X-ray energies
- Detection and measurement of light curves of transient events of X-ray binary stars in the centre of the Galaxy at soft X-ray energies

Secondary

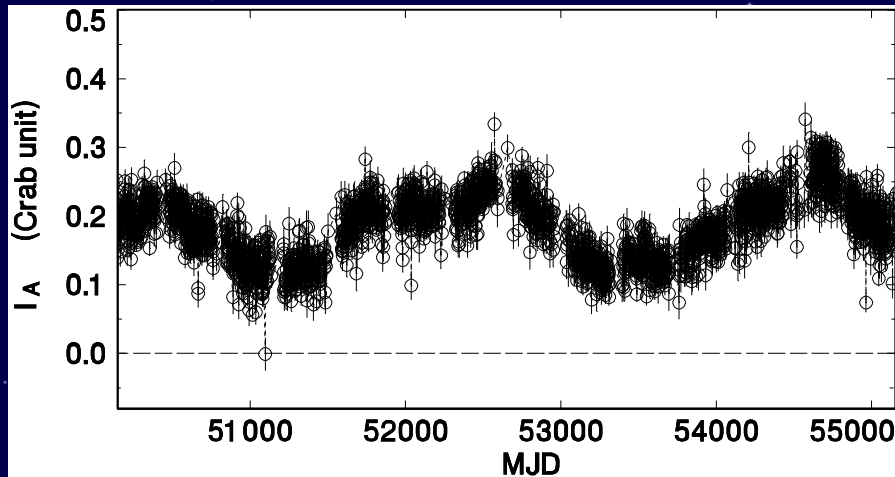
- Discovery of X-ray sources (unknown so far)
- Monitoring of another X-ray sources (to be specified later in detailed observation plan) - ?

Scientific justification

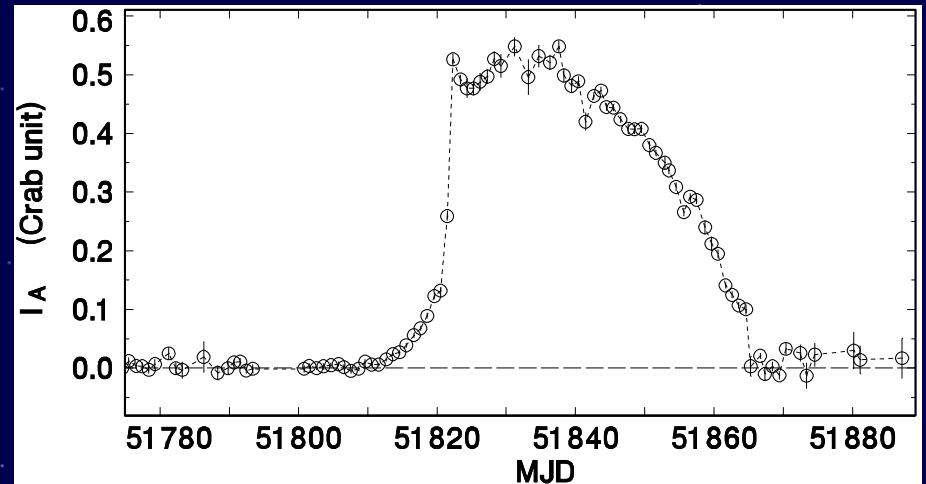
- Most of existing and past X-ray satellites perform pointing to a sample of object with a limited observing time allocated for a given object. This strategy enables to study faint sources with high temporal and/or spectral resolution.
- Mission performing long-term (weeks or months) monitoring of variable X-ray sources is lacking. However, long-term observations are required for better understanding of those sources.
- Galactic nucleus contains plenty of low- and high-mass X-ray binaries (LMXBs and HMXBs). Our idea is to build nano-satellite performing almost permanent monitoring rectangular area around the Galactic center.

Instrument requirements

We assume using of small instrument with field of view in order of square degrees or more. As seen below, its sensitivity has to be sufficient to measure intensity in order of 100mCrab at energies of order of keV with time resolution of days. Instrument has to have sufficient angular resolution to identify the sources.



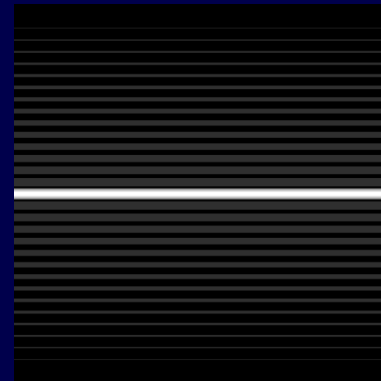
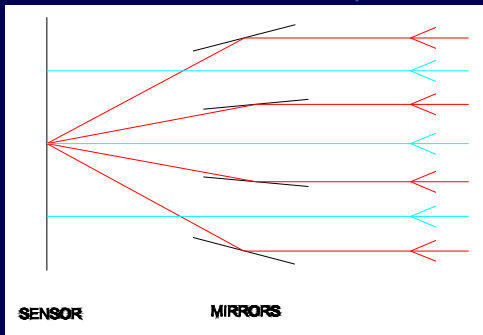
Example #1: The light curve of a persistent source GX 3+1 observed by ASM/RXTE is in the 1.5-3 keV band.



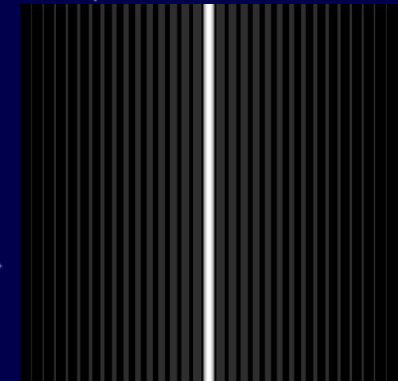
Example #2: The outburst of a transient source Aql X-1 observed by ASM/RXTE in the 1.5-3 keV band.

Proposed technological concept: Telescope based on Schmidt multi-foil X-ray optics

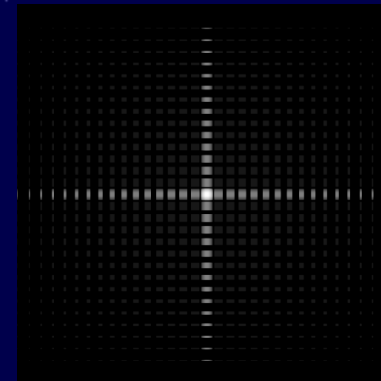
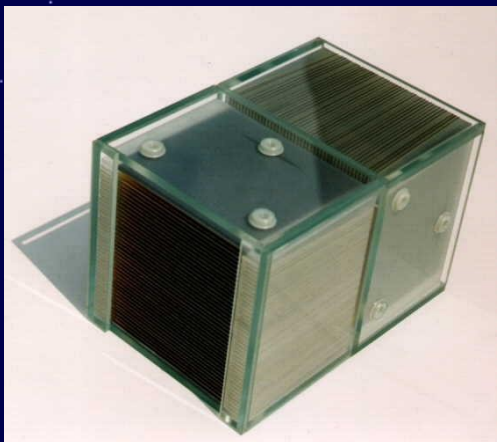
One-dimensional SMFO principle: Flat mirrors are arranged in a uniform radial pattern around the perimeter of a cylinder. X-rays are reflected by total external reflection. This system can provide a field of view up to ~ 100 sq. degrees and can have small mass and dimensions.



or

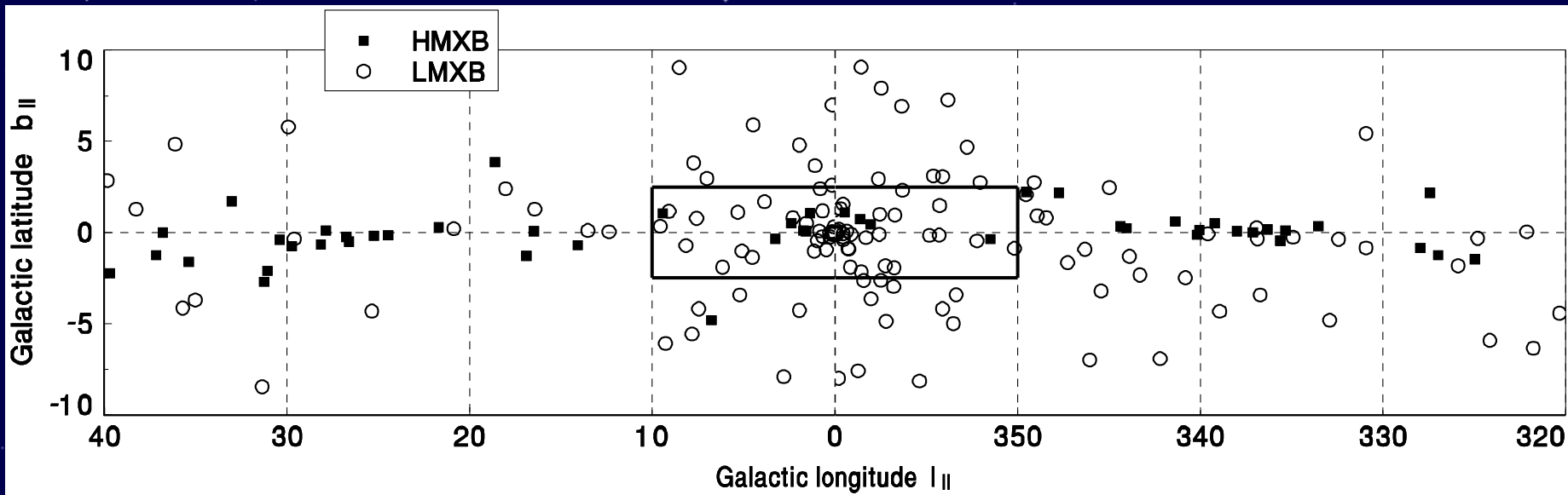


Two orthogonally arranged systems in sequence form a double-focusing device

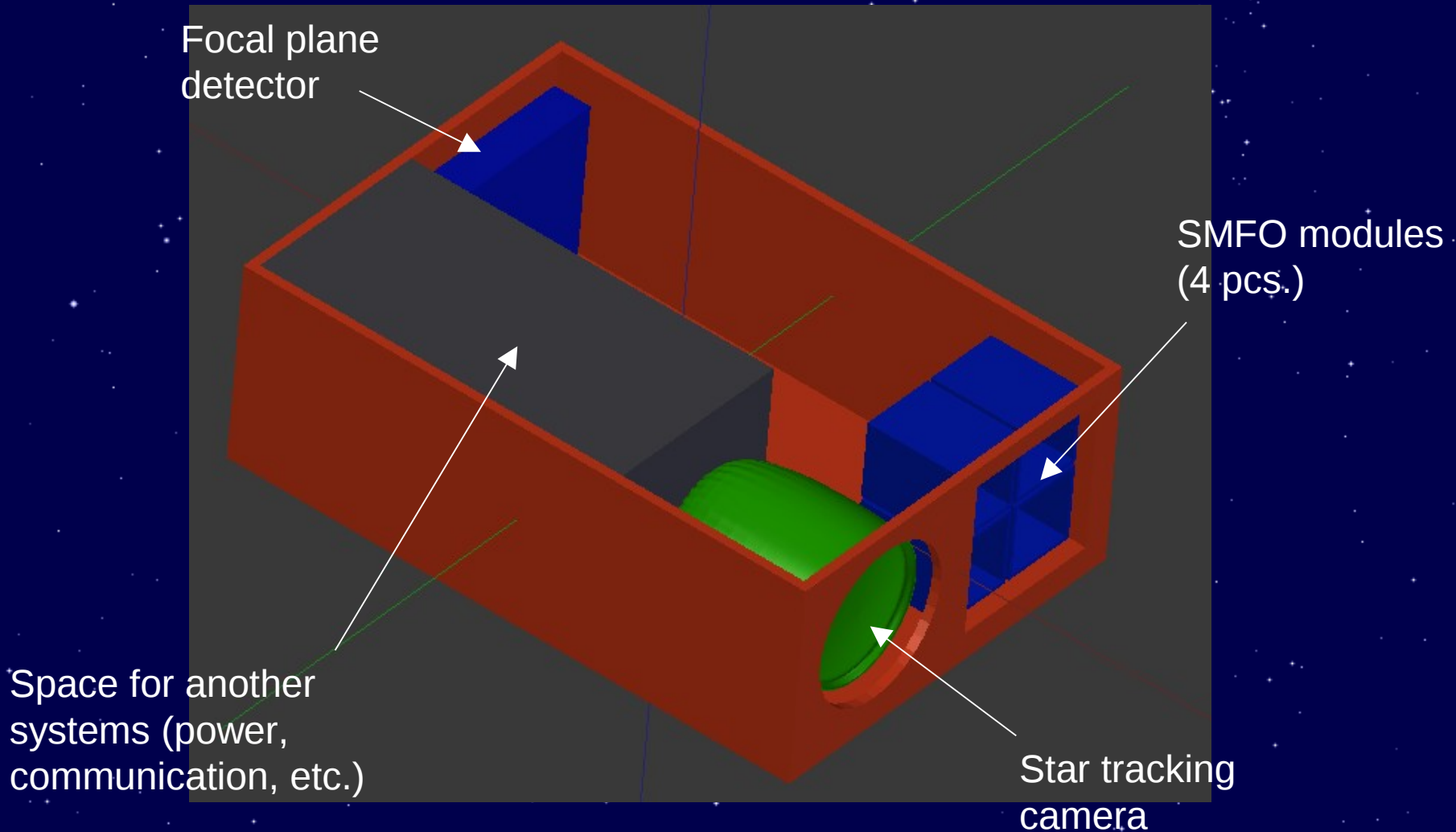


Area to be monitored

- Four SMFO modules of focal length 250mm are supposed to be used.
- Each of these SMFO's permanently monitor field of $4G4^\circ$. Fields are arranged in a line.
- Supposing overlaps, the total field of ca. $14G4^\circ$ is permanently monitored.



Spacecraft – 6U CubeSat

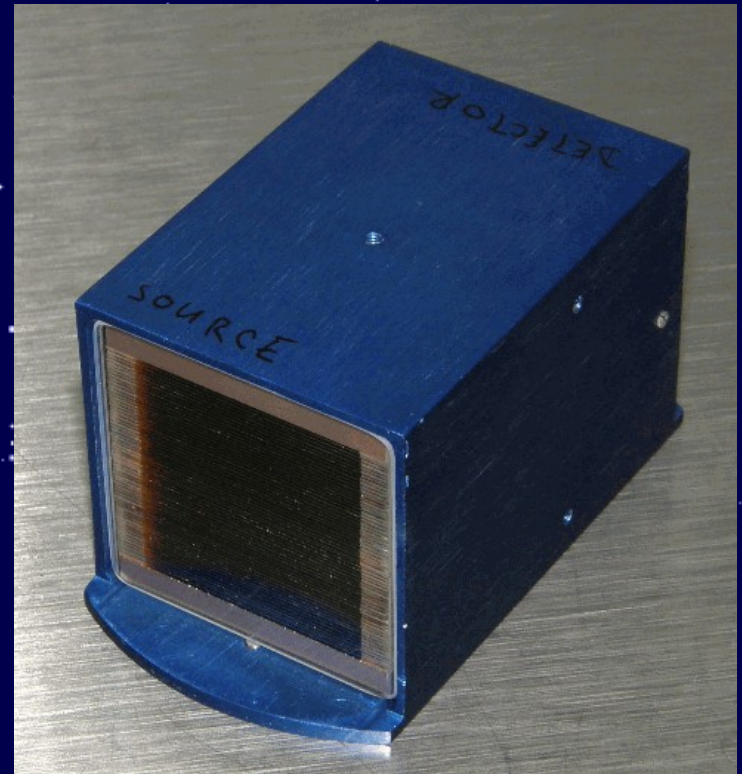


- Attitude control and sensing of accuracy in order of arcmins is necessary
- Data rate ca. 1MB per orbit – deconvolution can be performed on Earth

Prototype SMFO P-25

To verify that idea of nano-satellite SMFO X-ray monitor is feasible, we did tests on prototype lobster eye P-25. Tests were compared to simulations.

- P-25 was provided by *Rigaku Innovative Technologies Europe, s.r.o.*
- Focal length 250mm
- Outer dimensions 35G35G50 mm
- Consists of 2G60 mirrors of diameters 24G24G0.1 mm
- Optimal efficiency at 1 keV X-ray photon energy
- Similar parameters we suppose for SMFO for nano-satellite

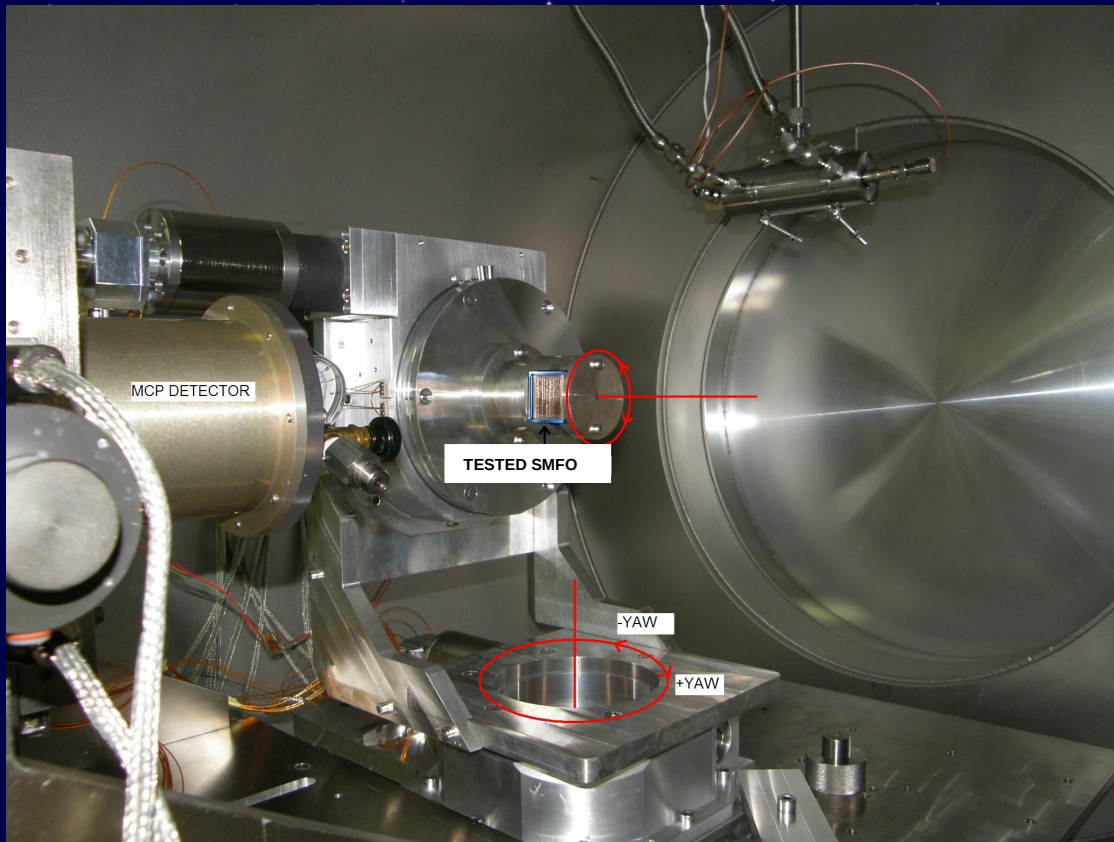


Tests of P-25 in X-rays



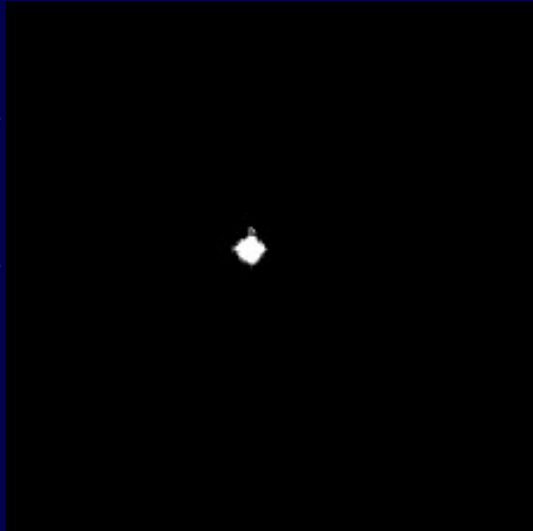
Lobster eye P25 was tested in quasi parallel beam full imaging mode using the 35 meters long X-ray beam line in XACT facility of *INAF-Osservatorio Astronomico di Palermo* (Italy). X-ray images at the focal plane have been taken with a MCP detector with spatial resolution $100\mu\text{m}$.

Experimental setup

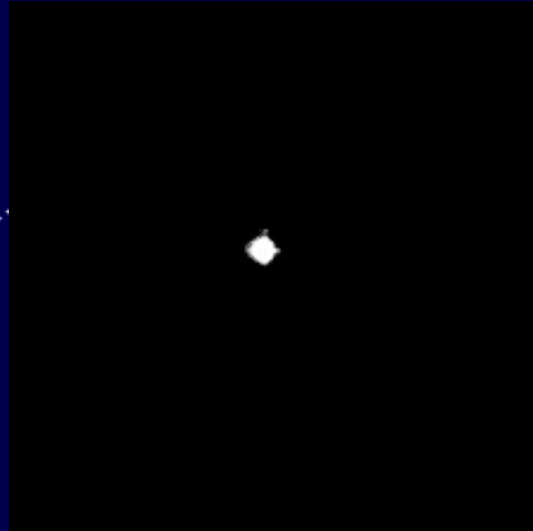


Tested SMFO was placed on device allowing remote controlled rotations figured by red color. MCP detector was placed on device allowing remote controlled translations in all directions.

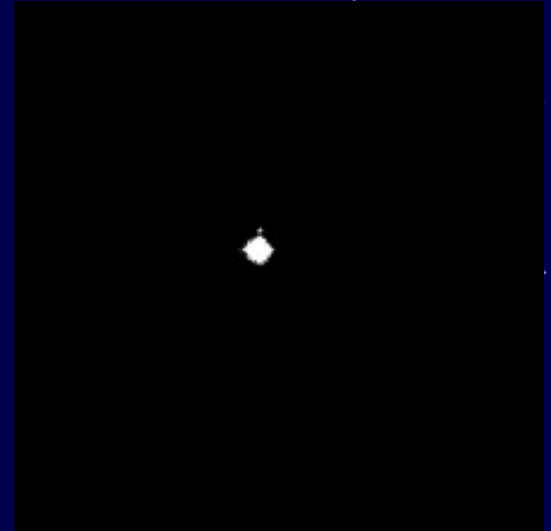
Basic images



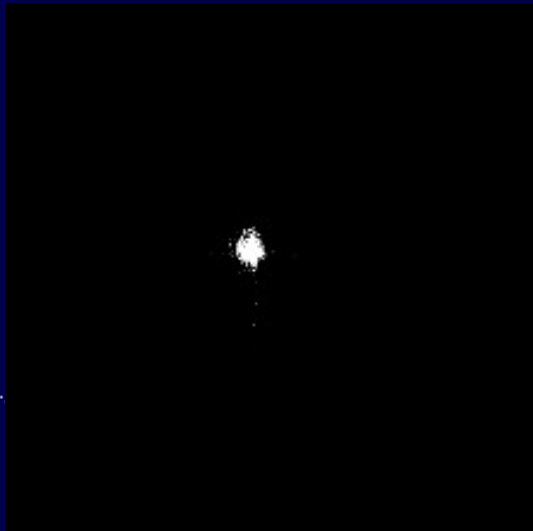
280eV



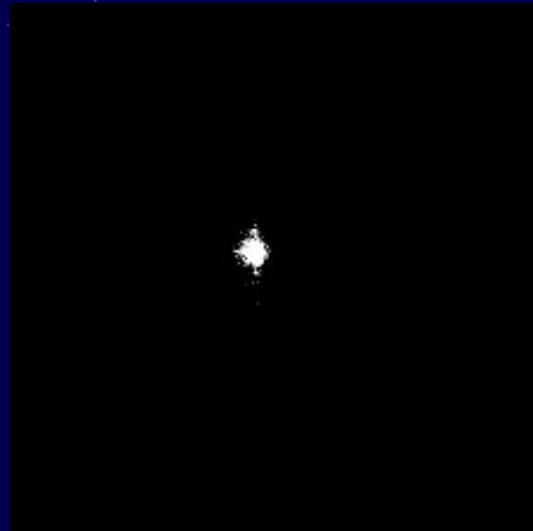
930eV



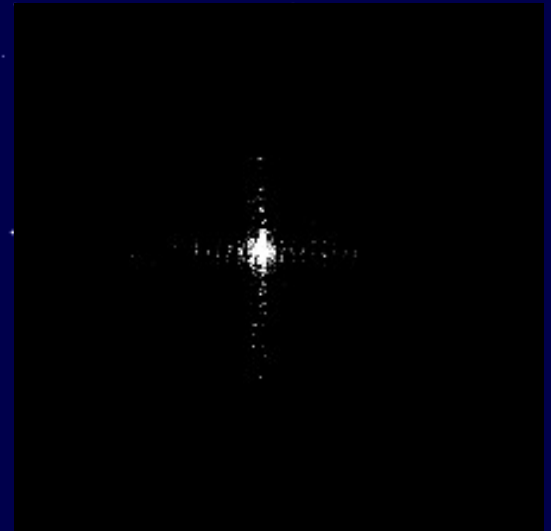
1500eV



2900eV



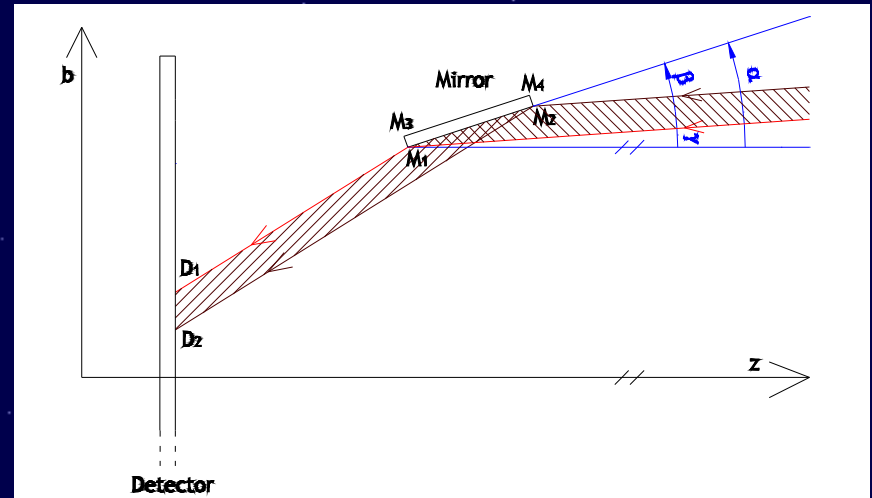
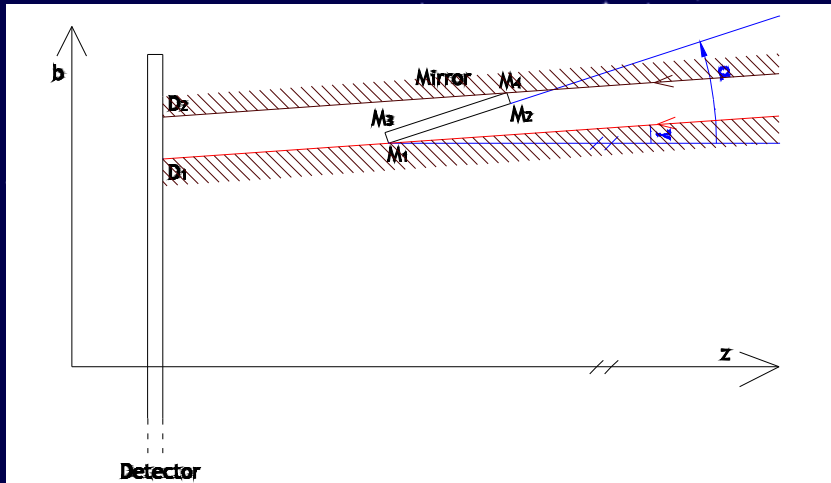
4500eV



8000eV

Simulations

■ One-dimensional system: The sufficient problem is to calculate shades and reflections of individual mirrors



$$D_1 = M_{1b} - (M_{1z} - D_z) \tan(\gamma)$$

$$D_2 = M_{4b} - (M_{4z} - D_z) \tan(\gamma)$$

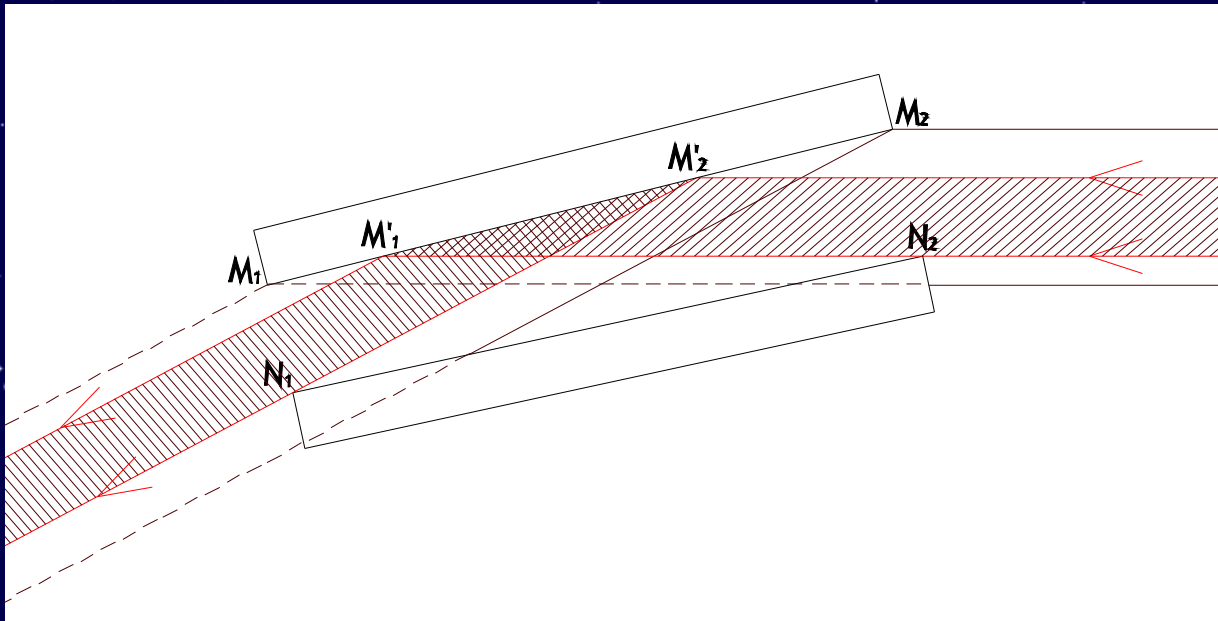
$$D_{1b} = M_{1b} - (M_{1z} - I_{1z}) \tan(2\beta + \gamma)$$

$$D_{2b} = M_{2b} - (M_{2z} - I_{2z}) \tan(2\beta + \gamma)$$

$$\beta = \alpha - \gamma$$

$$\alpha = \arctan[(M_{2b} - M_{1b}) / (M_{2z} - M_{1z})]$$

Shading between mirrors



$$M'_{1z} = (N_{2b} - q_1)/t$$

$$M'_{1b} = M_{2b}$$

$$M'_{2z} = (q_1 - q_2)/t$$

$$M'_{2b} = t M'_{2z} + q_1$$

$$t = (M_{2b} - M_{1b})/(M_{2z} - M_{1z})$$

$$q_1 = M_{1b} - t M_{1z}$$

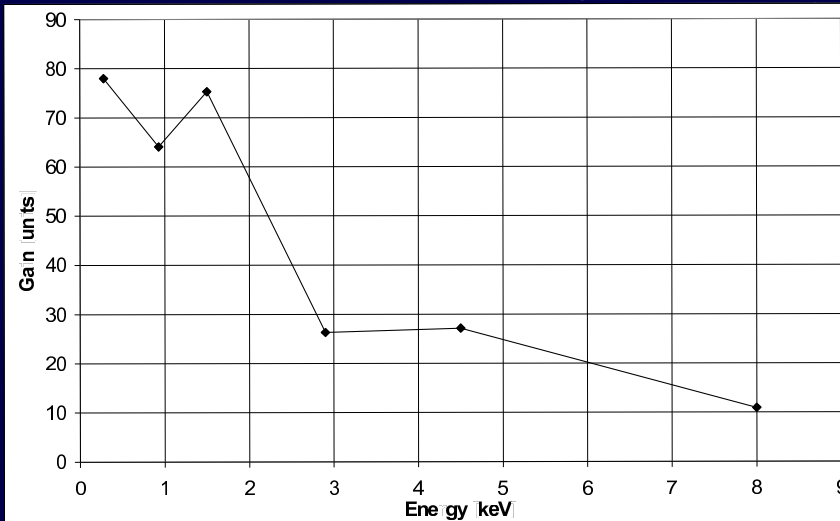
$$q_2 = N_{1b} - 2t N_{1z}$$

One-dimensional system \Rightarrow one-dimensional matrix

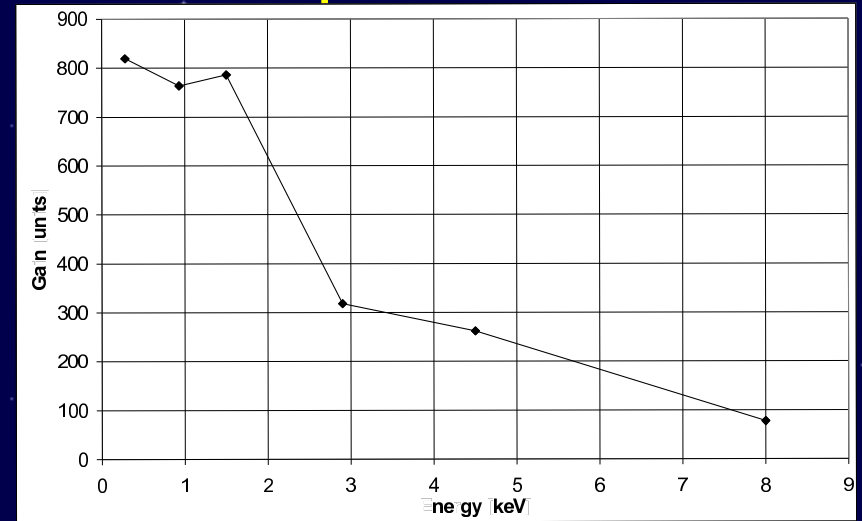
Two-dimensional system \Rightarrow outer product of these matrices

Gain

- Calculated as measured ratio between the flux incoming to LE and the measured average flux of X-rays measured in the projection of the central chamber of size $300 \times 300 \mu\text{m}$

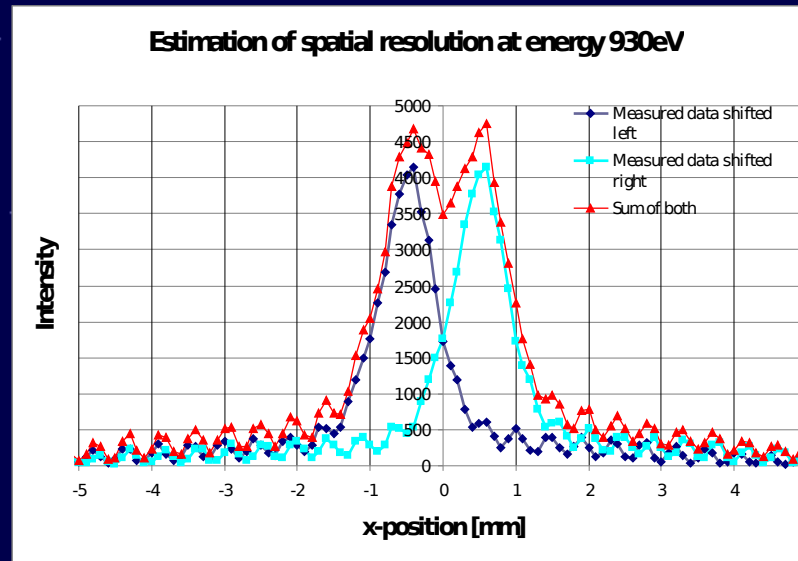


Experiment



Simulations

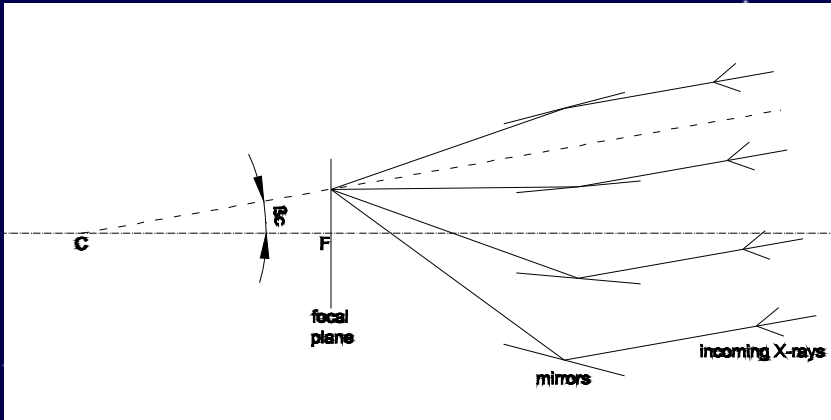
Spatial resolution



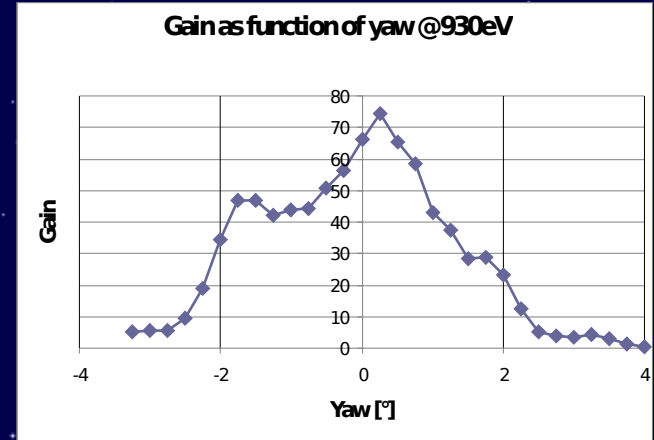
Estimated FWHM spatial resolution 13 ± 1 arcmin.

If sum profile of the image with the shifted one to simulate profile of image of two point sources and if we find the limit when the intensity between peaks fall to 80% of intensity of peak level, we get the same value. Theoretical value is 5.5 arcmin.

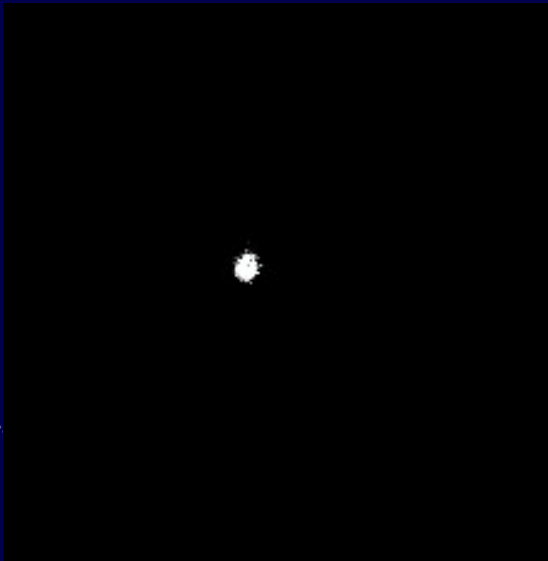
Field of view



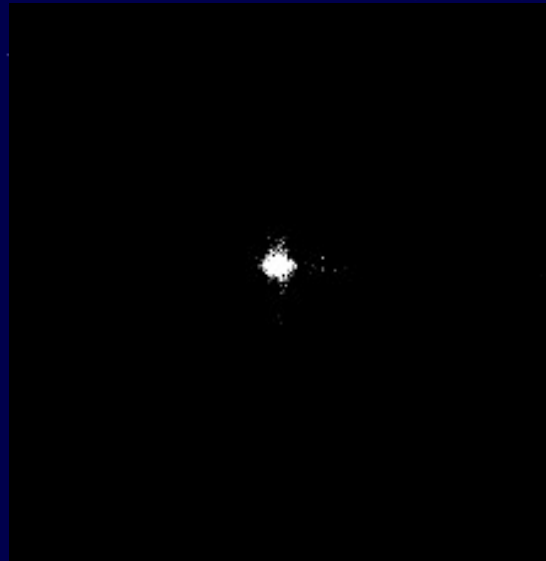
Angle between boundary chambers is 2.8°



At the boundary positions, gain is decreased to approx. 1/2



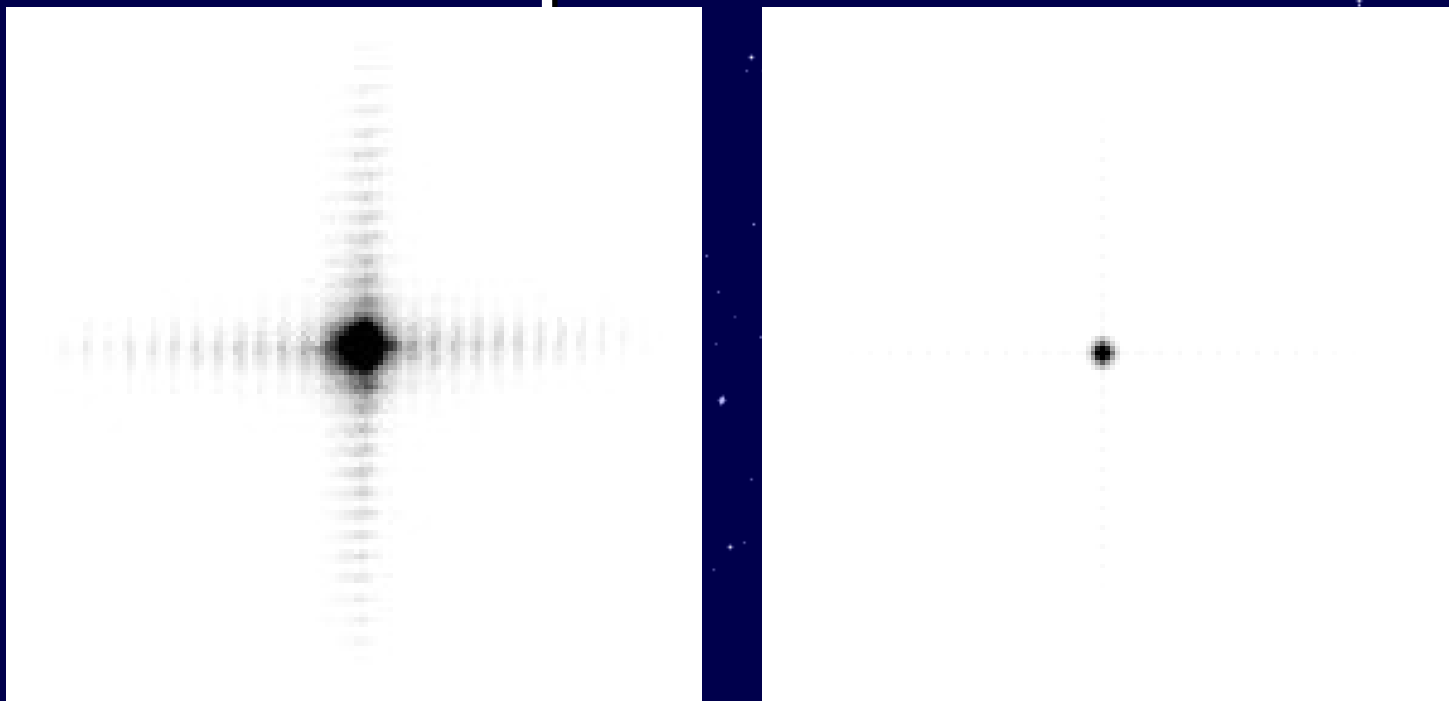
Yaw = -1.4°



Yaw = $+1.5^\circ$

Experimentally found
boundary positions =>
 $FOV = 2.9 \pm 0.1^\circ$

Explanation



There are some manufacturing deviation causing the smearing of the image. It is a common problem of any technology.

However, supposing 90% quantum efficiency of the detector, simply supposing the object is detected if at least 100 photons are focussed into spot, the resulting sensitivity for one-day monitor is

0.23 10.46 mCrab (depending on dead-time)

Conclusions

- The proposed mission can acquire scientifically important data of X-ray binaries for low prize.
- Although we reported differences between the theoretical and measured values, measured optical performances of tested SMFO specimens are sufficient for the mission. So, the proposed nano-satellite mission is feasible.

Acknowledgments

- Thanks to Rigaku Innovative Technologies Europe s.r.o. for providing of the SMFO specimen
- Thanks to INAF-Osservatorio Astronomico di Palermo for allowing X-ray tests on XACT

Thank you for
your attention