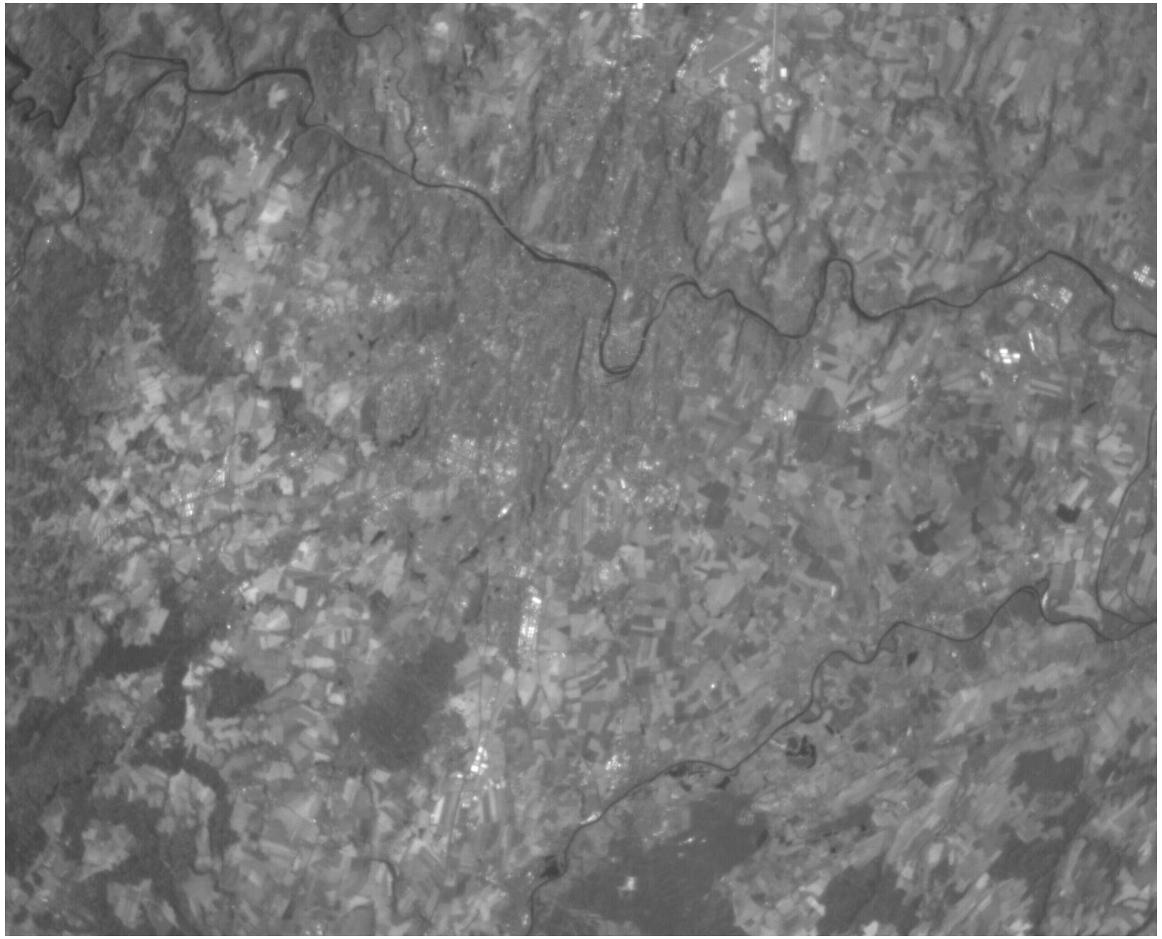
# X-ray optics trade-off for small spacecraft

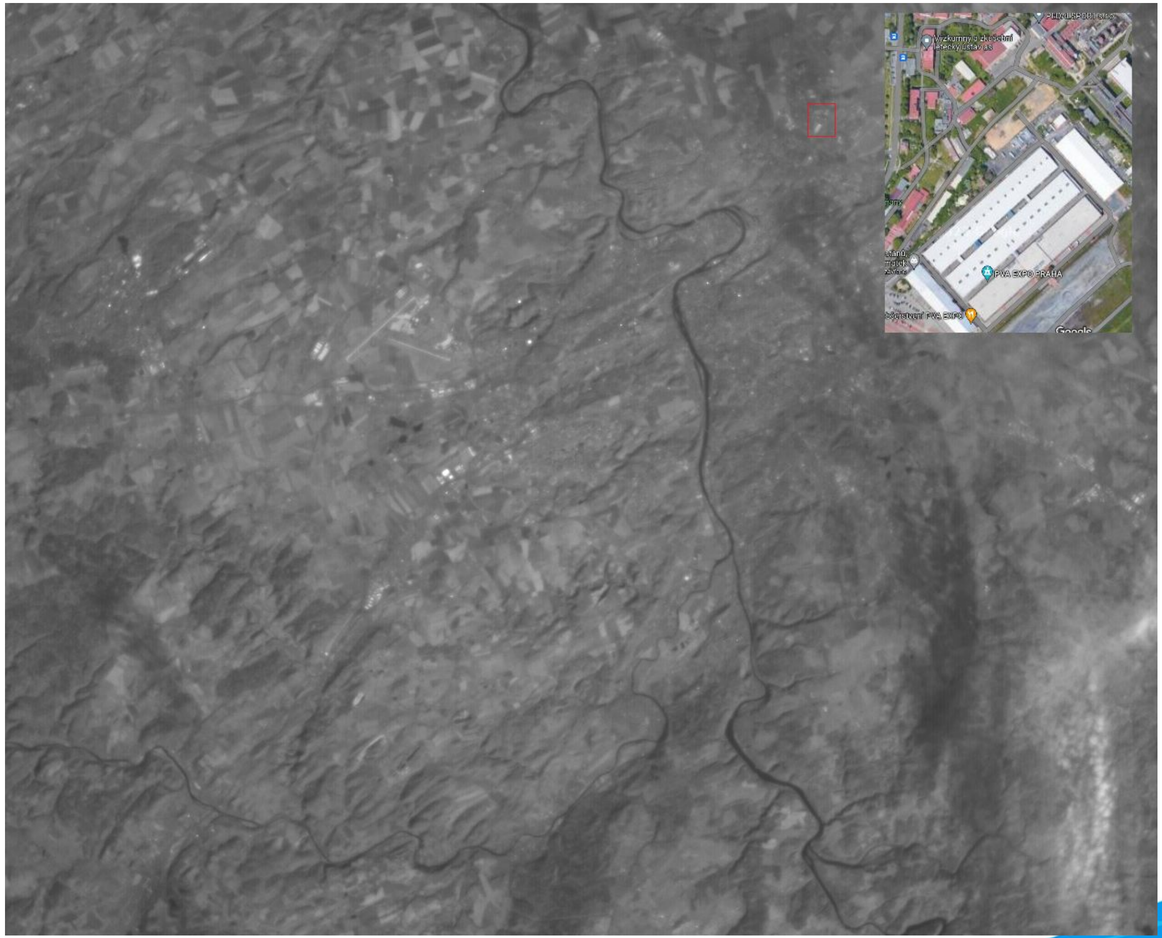
Dániel V., Maršíková V., et al.

# Prague city over years

8.9.2024



10.10.2022

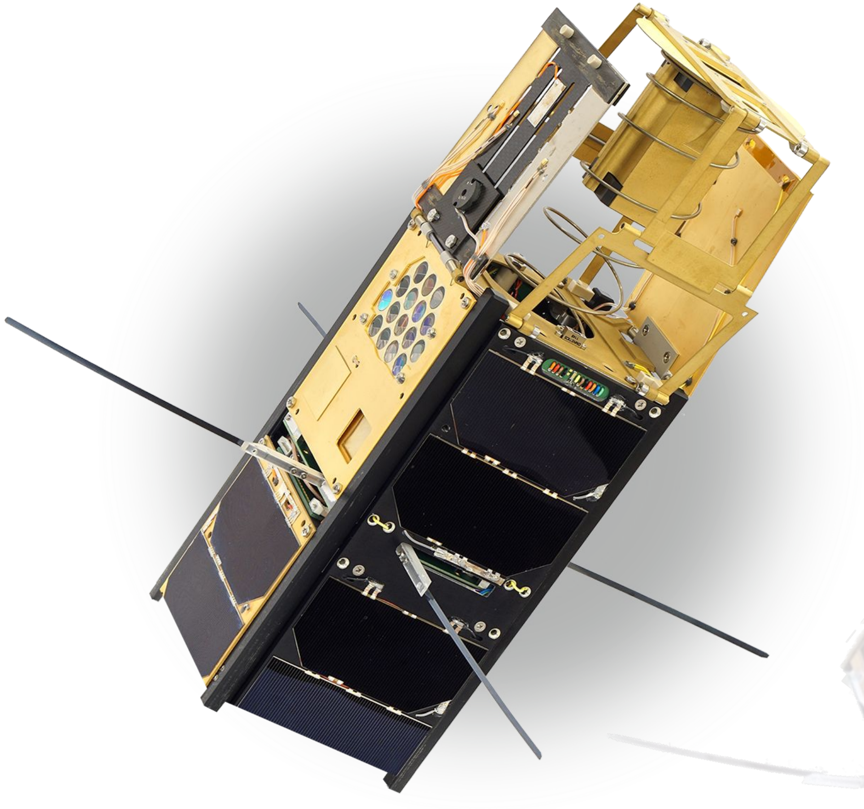


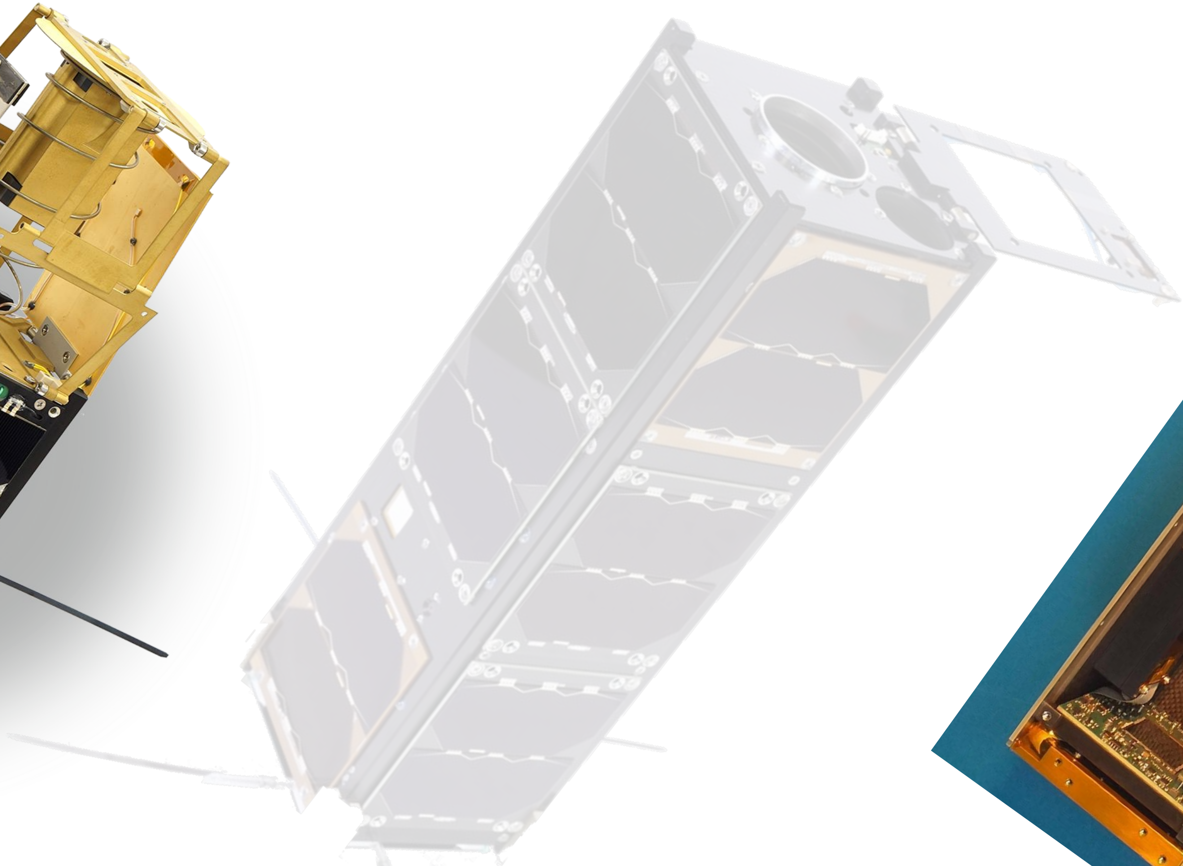
# The X-ray Spectroscopic Telescope Payload

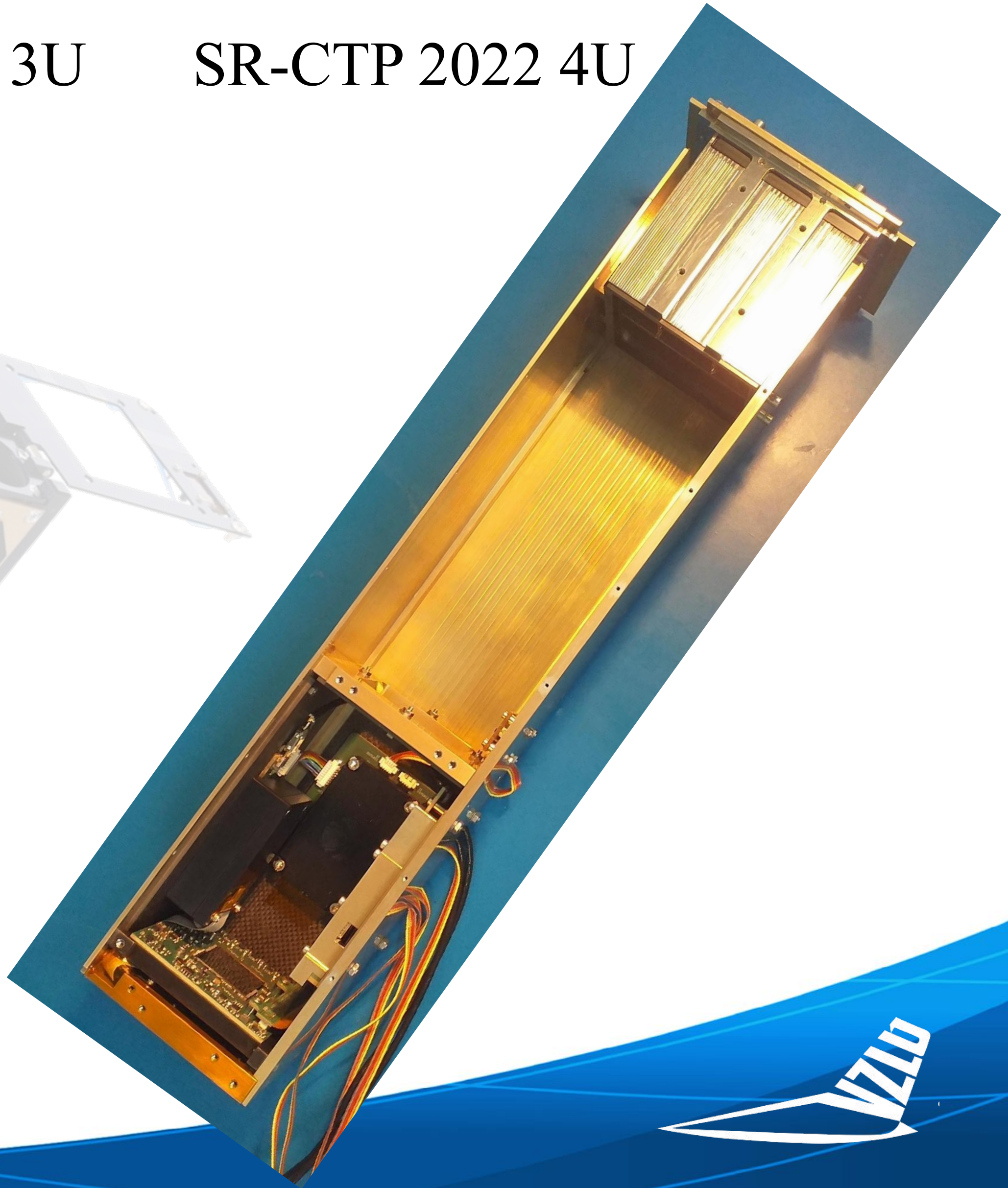
VZLUSAT-1 2017 2U

VZLUSAT-2 2022 3U

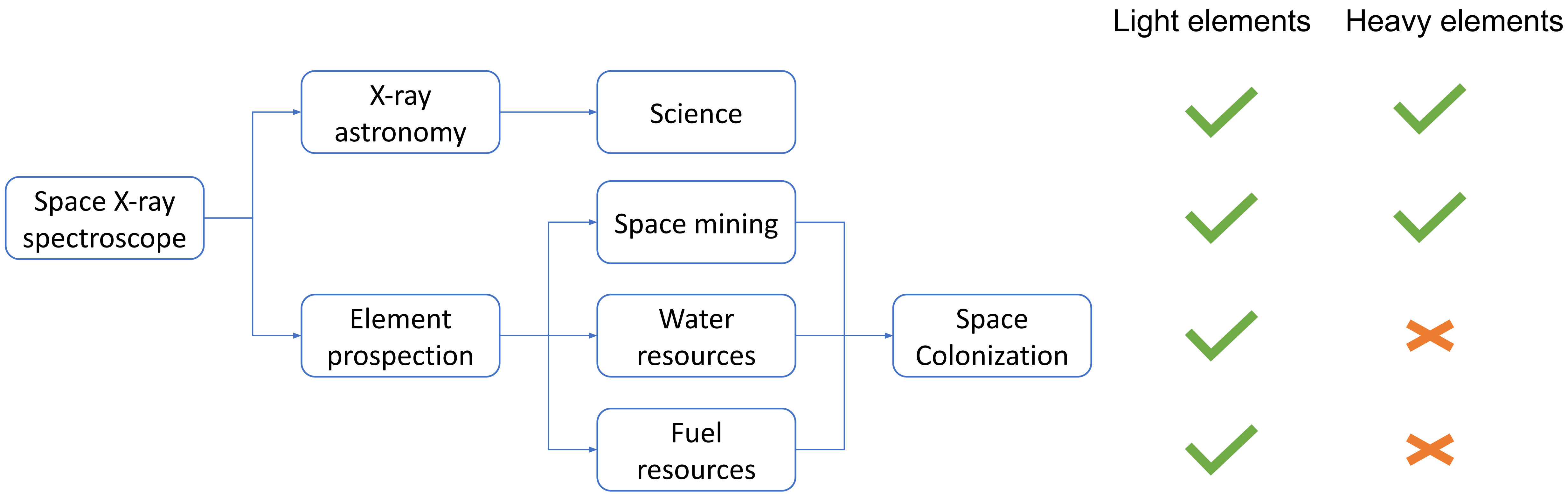
SR-CTP 2022 4U



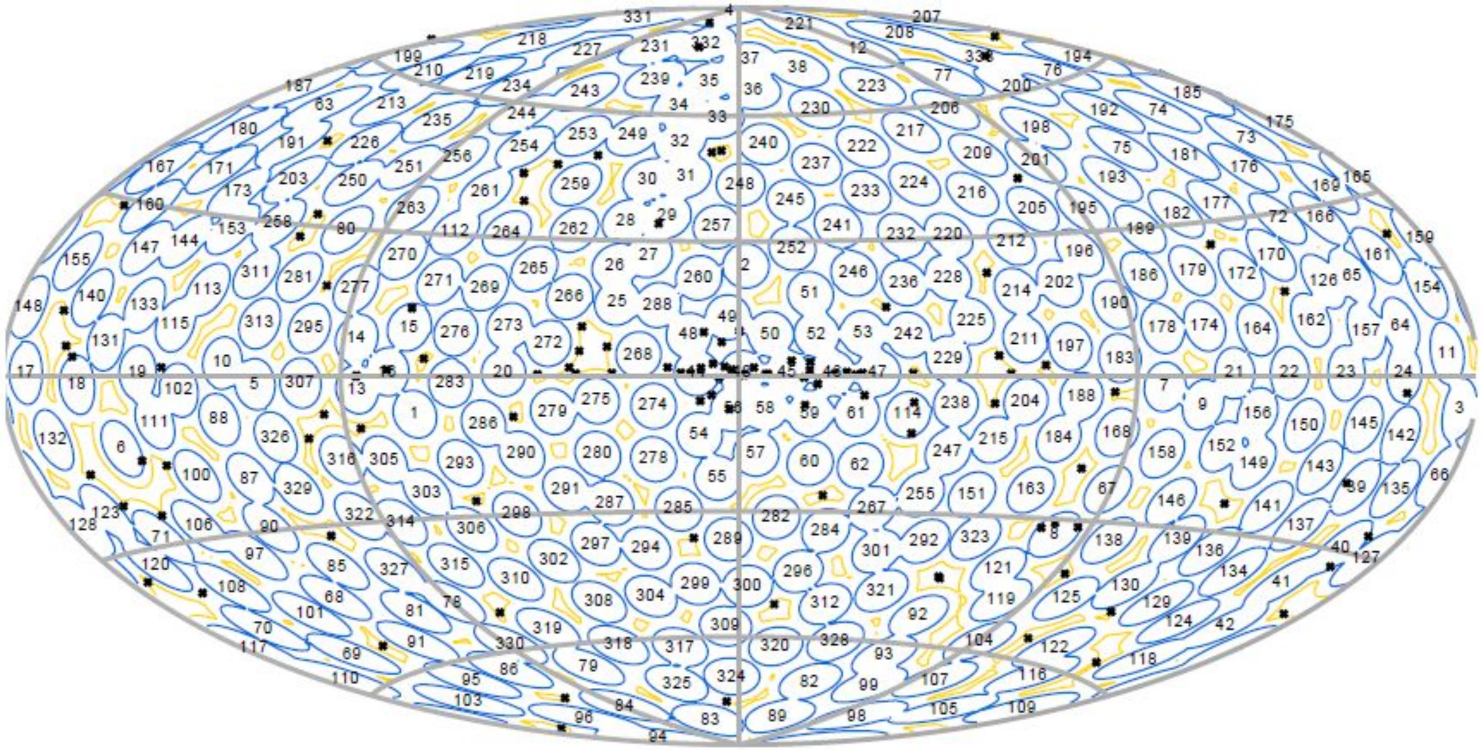




# Spectroscope development targeting



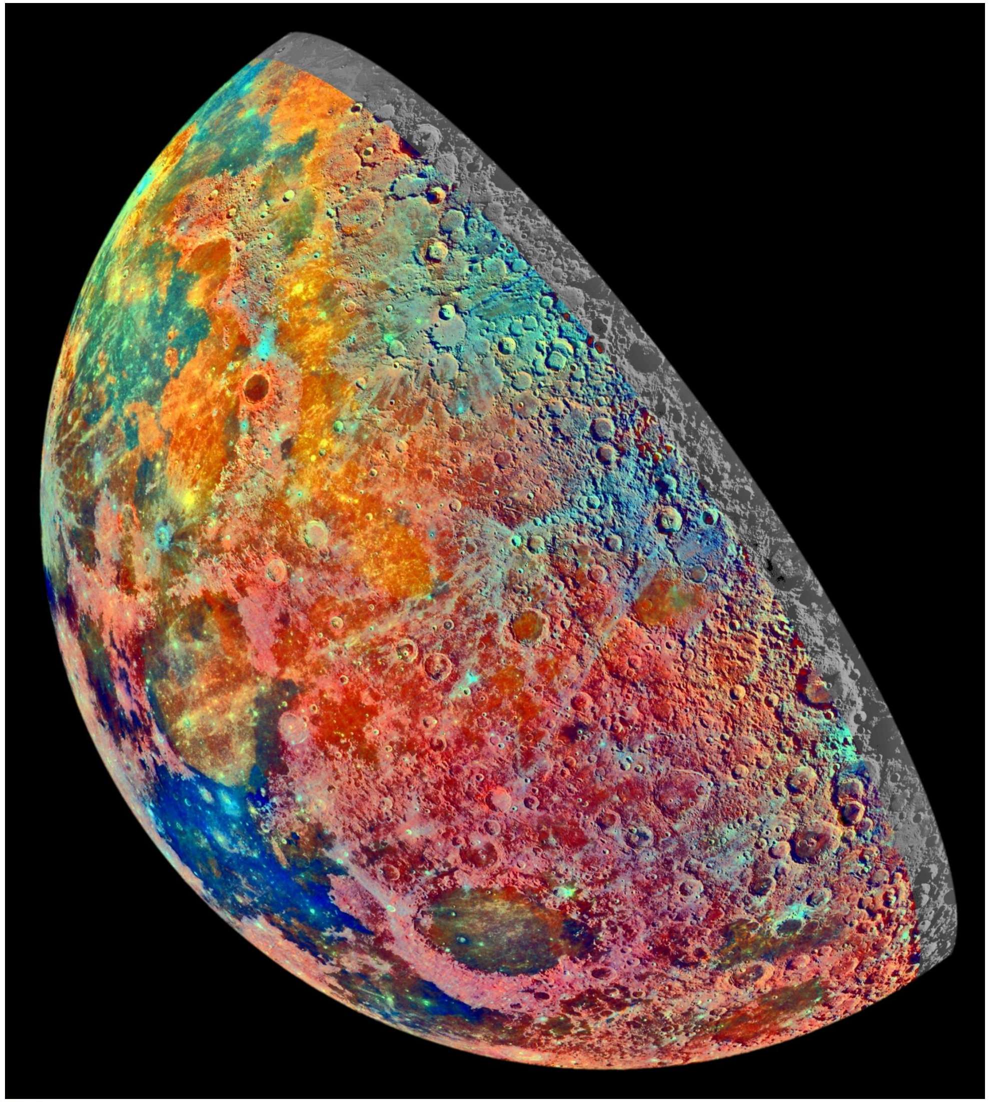
# Hot halo of the Milky Way

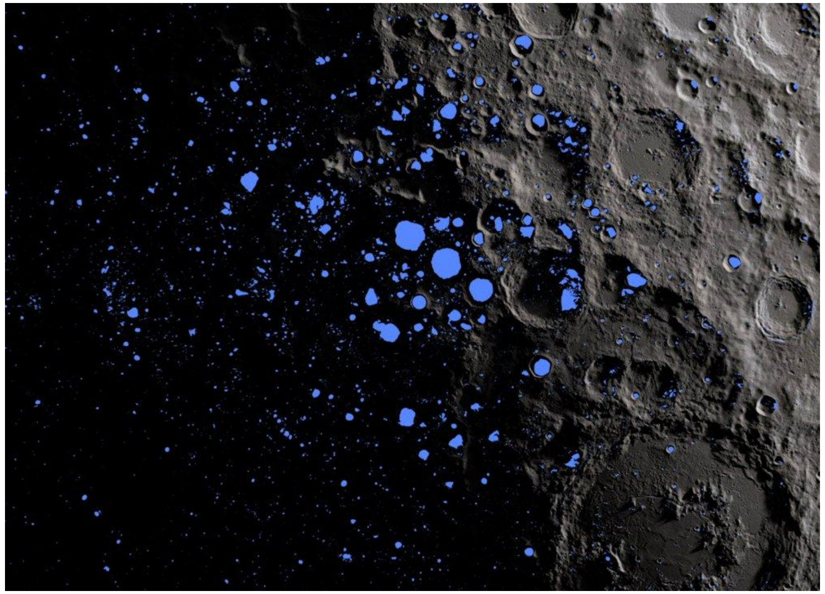


HaloSat targets in Galactic coordinates. The Galactic center is at the center of the image, longitude increases to the left, and latitude increases toward the top. The blue contours show the 10°diameter full-response field of view for each target and the yellow contours show the 14◦ diameter zero response. The black Xs show bright X-ray sources.

HaloSat uses three small detectors that view the sky through mechanical collimators with no optics.
Each detector has an effective area for X-rays of 600 eV of about 5.1 $mm^2$.

# Moon material prospection

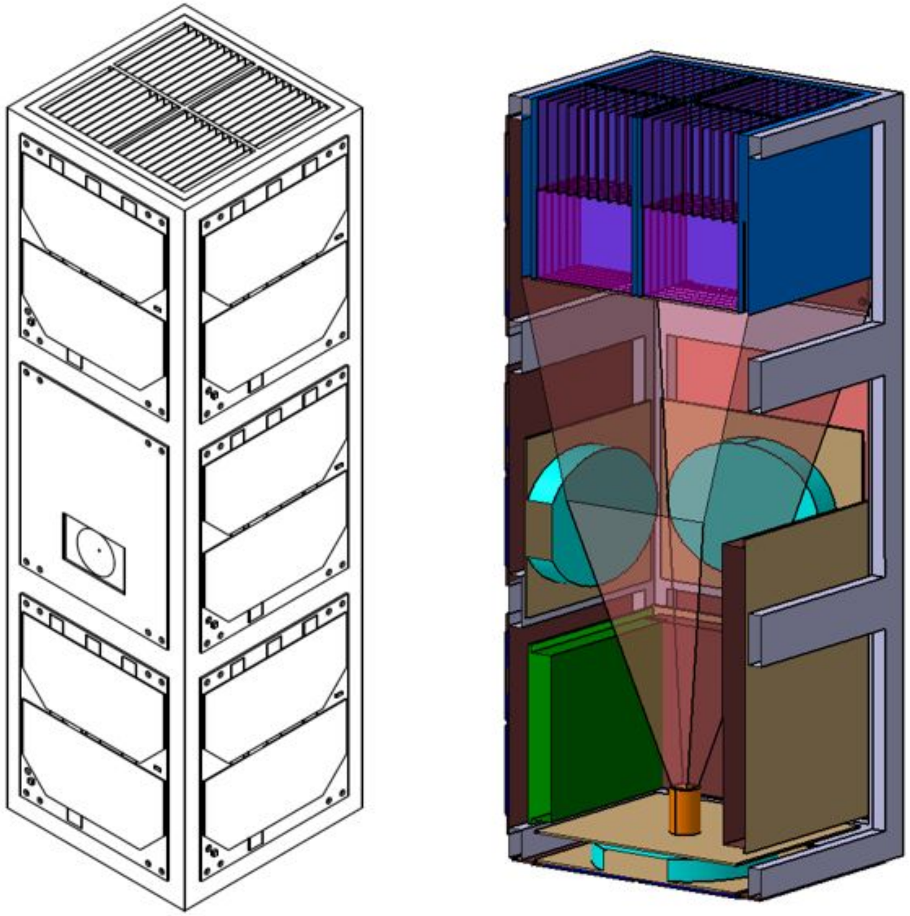




Water prospection through Carbon

An artificially colored mosaic constructed from a series of 53 images taken through three spectral filters by Galileo's imaging system as the spacecraft flew over the northern regions of the Moon on 7 December 1992. The colors indicate different materials. (Wikipedia)

# Asteroid material prospection

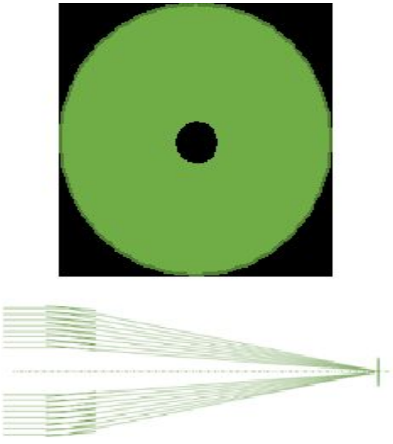


Layout of the nanosatellite

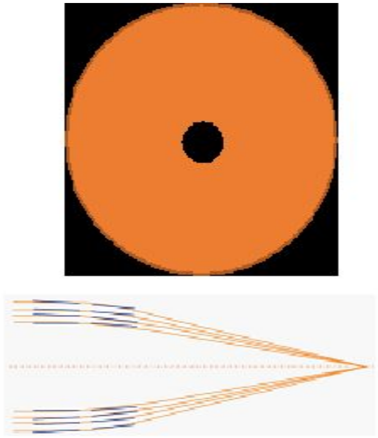
Proposed to ESA by **VZLU+CTU+RIGAKU** in 2015
for Asteroid Impact Mission (AIM) Cubesat
Opportunity Payloads (COPINS) – Not selected

„The mission scope is to observe the X-ray fluorescence spectrum of Didymos, secondary to measure asteroid elemental composition before and after the impact and to measure the spectrum of impact X-ray flash. To realize this primary mission objective it is necessary to get to the close position to the Didymos secondary asteroid in short time before the DART impact.“

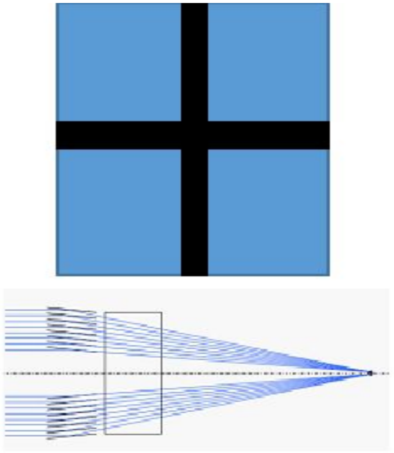
# X-ray optics trade-off



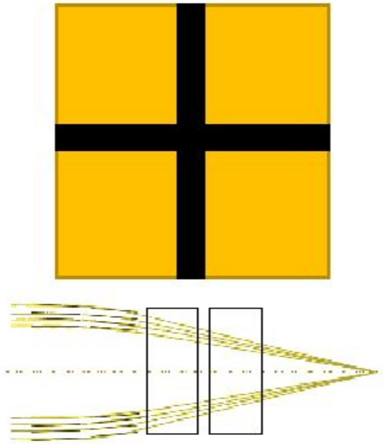
Concentrator optics



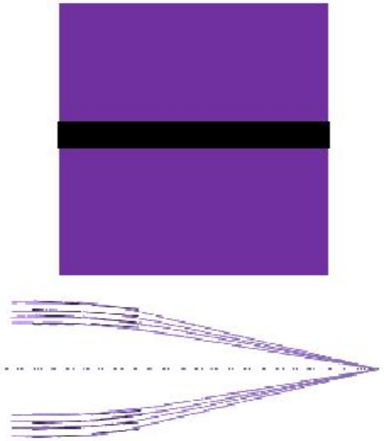
Wolter I optics



Lobster Eye optics



WMFO
Four reflection multifoil optics



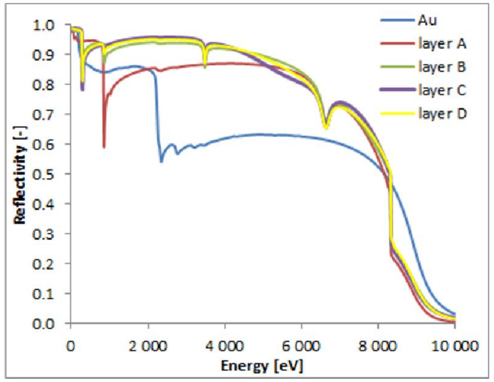
1DWMFO
Two reflection multifoil optics

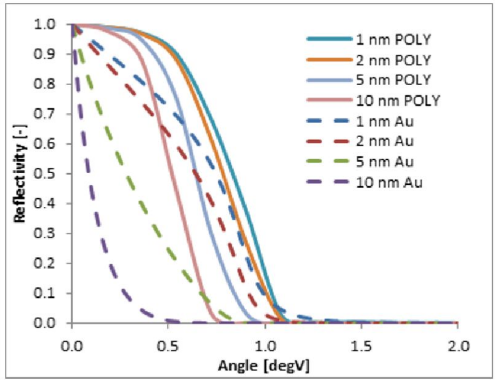
Small satellites such as cube satellites usually have limited focal length and also limited aperture. To fit the 16U CubeSat, a focal length no longer than 400 mm is to be used. We provide the trade-off of five different types of optics.

| Property | Value |
|---|---|
| Telescope outer dimension | $100 \times 100 \times 450$ mm$^3$ |
| Focal length | 355 mm |
| Optical aperture | $69 \times 69$ mm$^2$ |
| Aperture area | 43 cm$^2$ |

- Condenser similar to NICER design (Concentrator)
- Wolter I optics
- Two-dimensional LE optics
- Four reflection multifoil optical system (WMFO)
- 1-dimensional, two-reflection WMFO (1DWMFO) concept

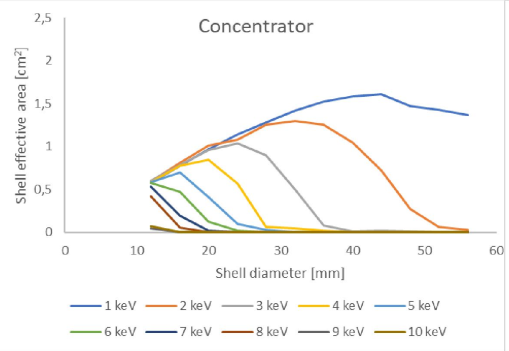
# X-ray optics trade-off

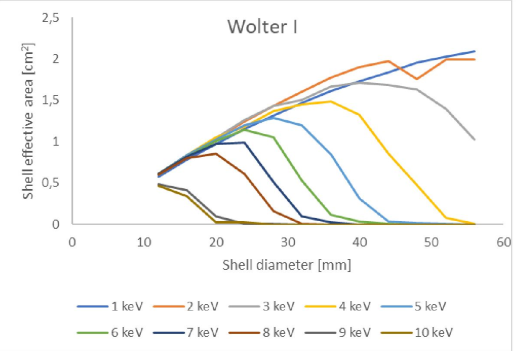


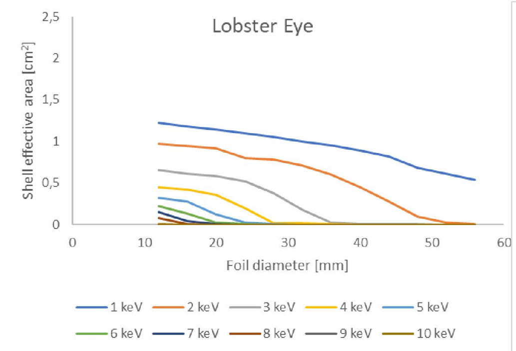



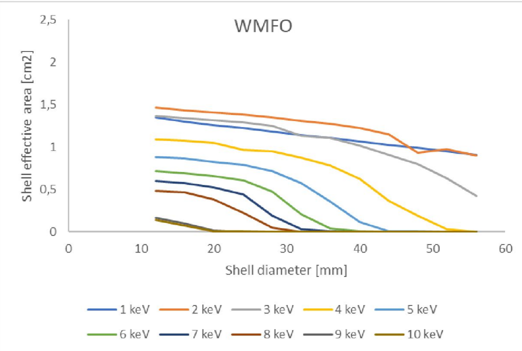

The reflectivity dependence on the incident angle for different multi-layers - RMS = 2nm (left). The reflectivity at incident angle of non-periodic multi-layers for 4.5 keV (right).

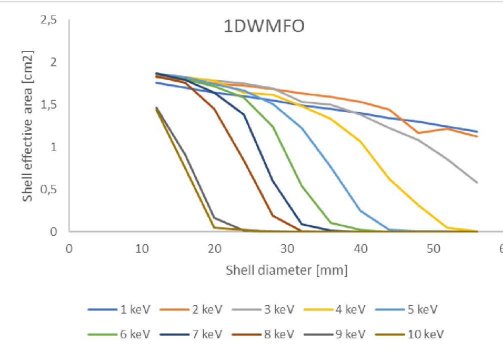
The X-ray spectrometer optics effective area calculation for particular shell of diameter/dimension respective to the optical axis. The final optics properties such as the effective area for particular energy are then represented by the combination of all shells. In fact total effective area is represented by the simple sum of effective areas of all shells.



# X-ray optics trade-off - results

| | Concentrator | Wolter I | LE | WMFO | 1DWMFO |
|---|---|---|---|---|---|
| System | 1 reflection | 2 reflections | 2 reflections | 4 reflections | 2 reflections |
| Incident angle | alpha/2 | alpha/4 | alpha/2 | alpha/4 | alpha/4 |
| Foil convergence | | | | | |
| length [mm] | 776 | 1552 | 776 | 1552 | 1552 |
| Focal length [mm] | 388 | 388 | 388 | 388 | 388 |
| Diameter [mm] | 16 to 56 | 16 to 56 | 8 to 56 | 8 to 56 | 12 to 56 |
| Effective area [$cm^2$] | | | | | |
| @1keV | 14.02 | 16.44 | 11.17 | 13.49 | 15.87 |
| @2keV | 8.17 | 16.96 | 6.59 | 14.77 | 16.62 |
| @3keV | 3.57 | 14.60 | 2.97 | 12.55 | 15.16 |
| @4keV | 1.56 | 9.43 | 1.46 | 7.99 | 11.71 |
| @5keV | 0.54 | 6.02 | 0.76 | 5.12 | 9.00 |
| @6keV | 0.14 | 3.95 | 0.39 | 3.40 | 6.99 |
| @7keV | 0.02 | 2.62 | 0.19 | 2.36 | 5.51 |
| @8keV | 0.00 | 1.65 | 0.08 | 1.60 | 4.23 |
| @9keV | 0.00 | 0.11 | 0.00 | 0.28 | 1.08 |
| @10keV | 0.00 | 0.05 | 0.00 | 0.22 | 0.82 |

- Condenser similar to NICER design (Concentrator)
- Wolter I optics
- Two-dimensional LE optics
- Four reflection multifoil optical system (WMFO)
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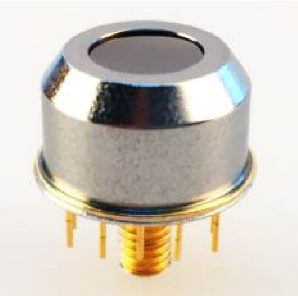
The X-ray spectrometer optic concepts trade-off, maximum theoretical effective area versus energy calculation. The aperture area 23 cm2, focal length 388 mm. Note that the real effective areas will be at least by one third smaller. This reduction is caused by mechanical mounting design and the related shell edges at the aperture surface.

# Spectroscope detector

## KETEK detector

Space heritage from 2012, on board of Mars rover Curiosity and as part of a X-ray spectrometer.
Currently is already the third mission a VITUS SDD has been chosen by the NASA as XRF detector.

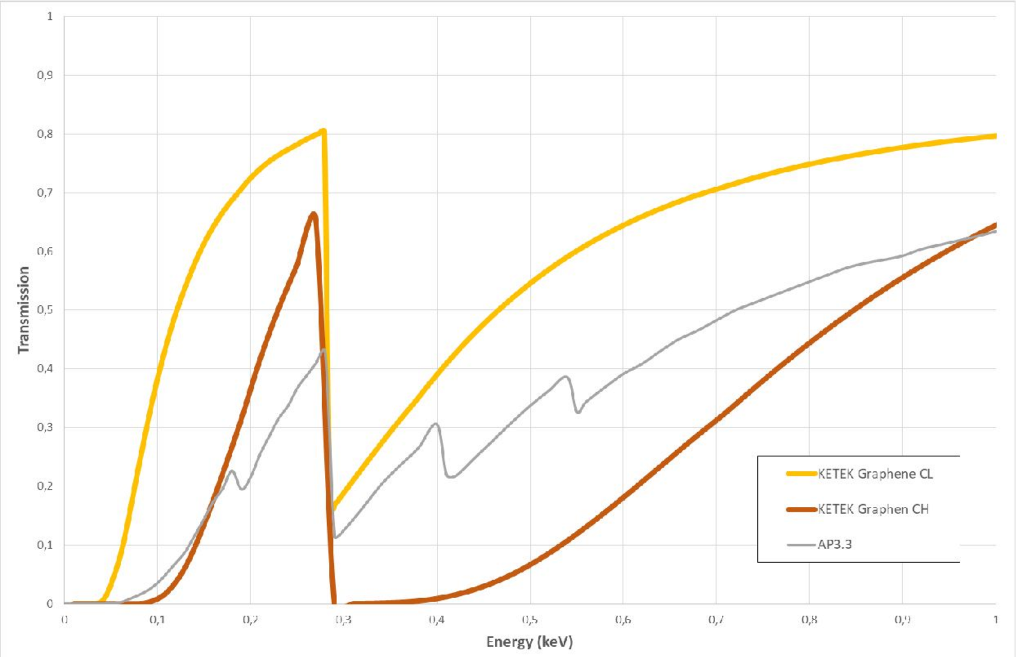


KETEK Silicon Drift Detectors (SDD)

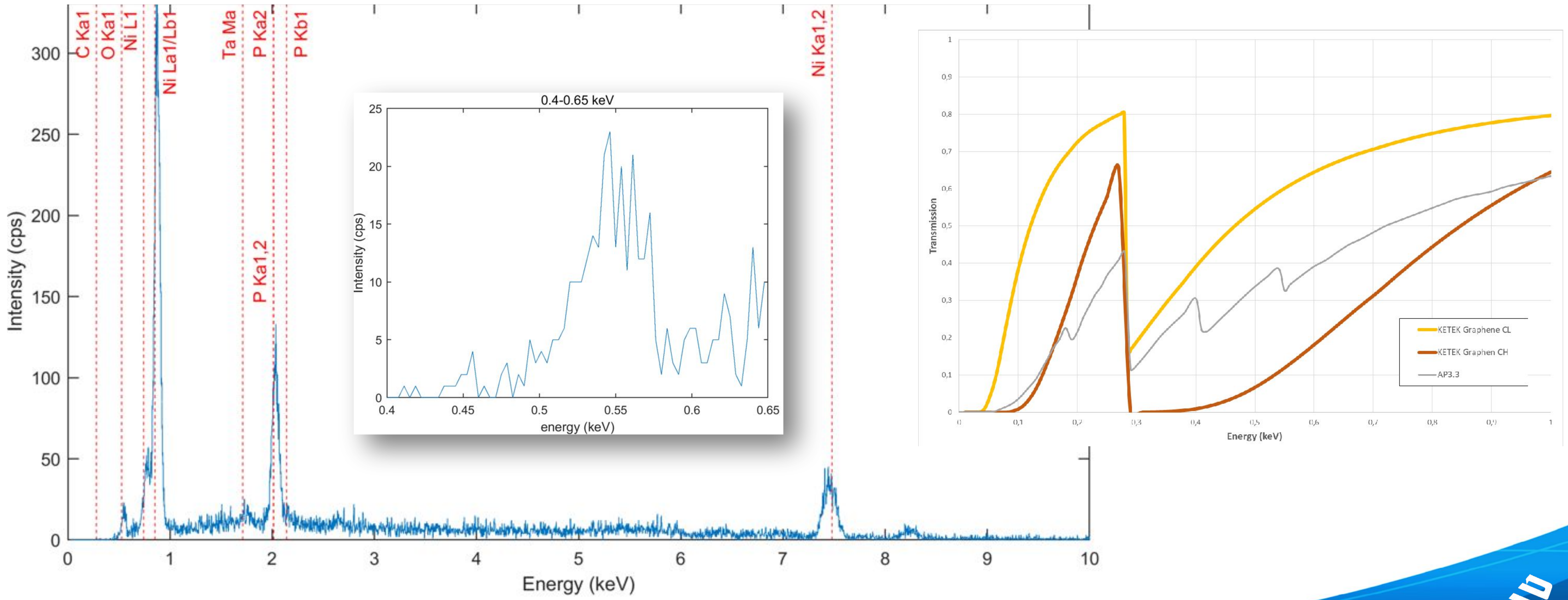
- 7 mm² (H7)
- KETEK Low Energy Graphene Window
- Active cooling
- FWHM<=133eV at 5.9keV

Electronics OEM solution

- Ultra-low-noise preamplifier
- VIAMP-KC preamplifier module

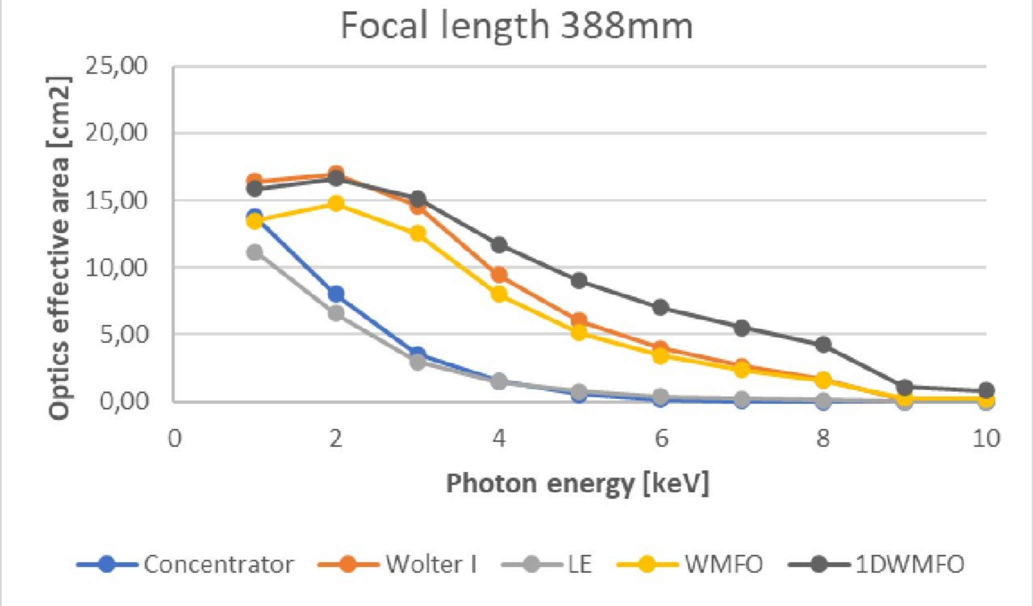


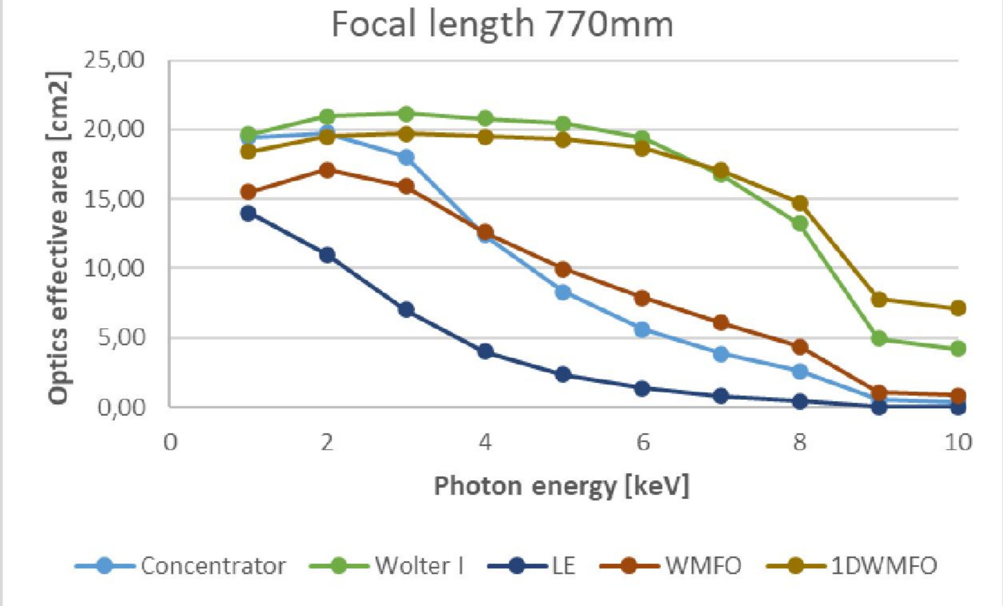
# Spectroscope detector measurement

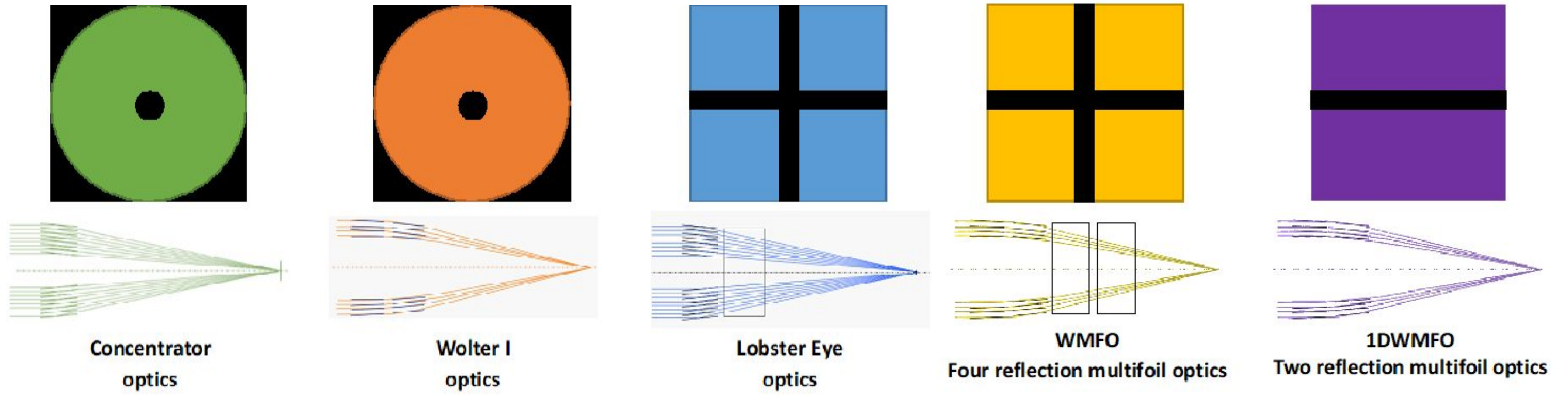


# X-ray optics trade-off - summary

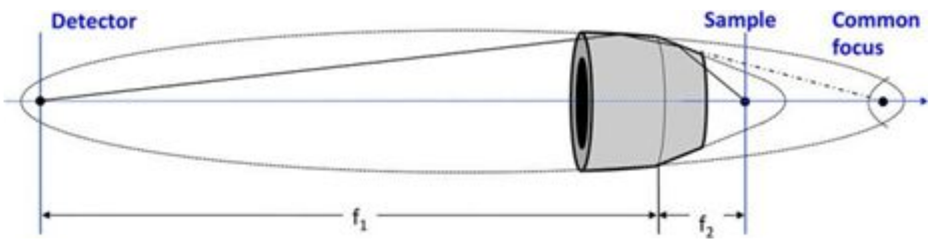
The X-ray spectrometer optics potential maximum effective area calculation.



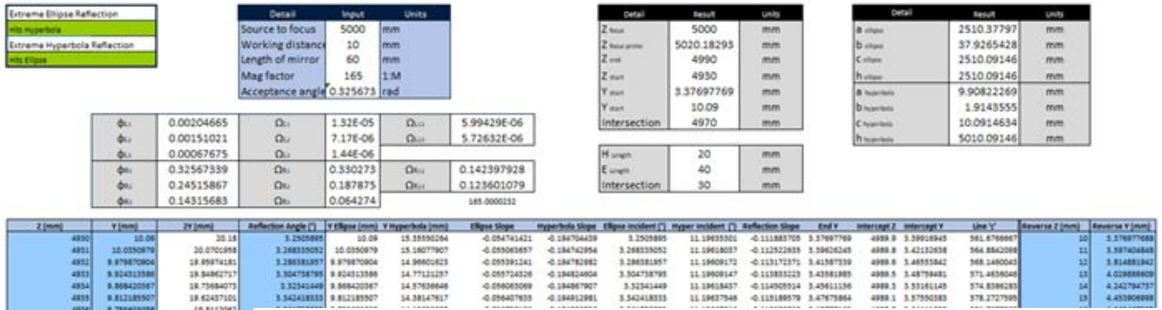



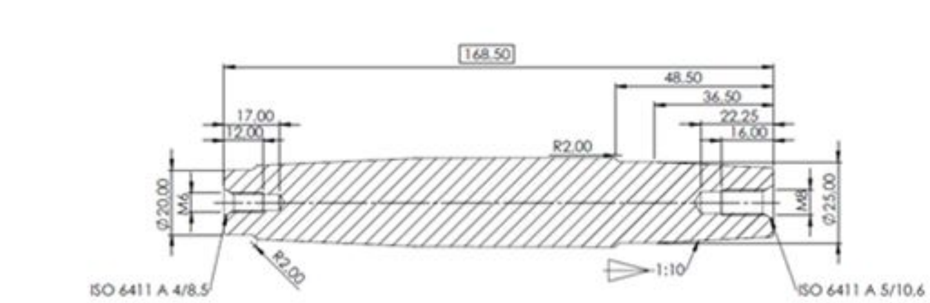
# X-ray optics - Wolter I - proof of concept

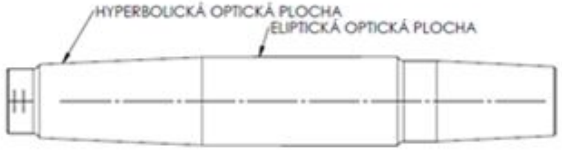



- the Solution Concept has been verified (design concept and simulation program)
- Eliptical and hyperbolic mirror (point - to - point)

The design concept processes input parameters, calculates the basic parameters of the X-ray optics and produces a table of coordinates [z, y] of the X-ray optics, which serve as input parameters for the simulation programme, and at the same time the data can be used to produce a CAD model and a drawing of the Wolter I X-ray optics.



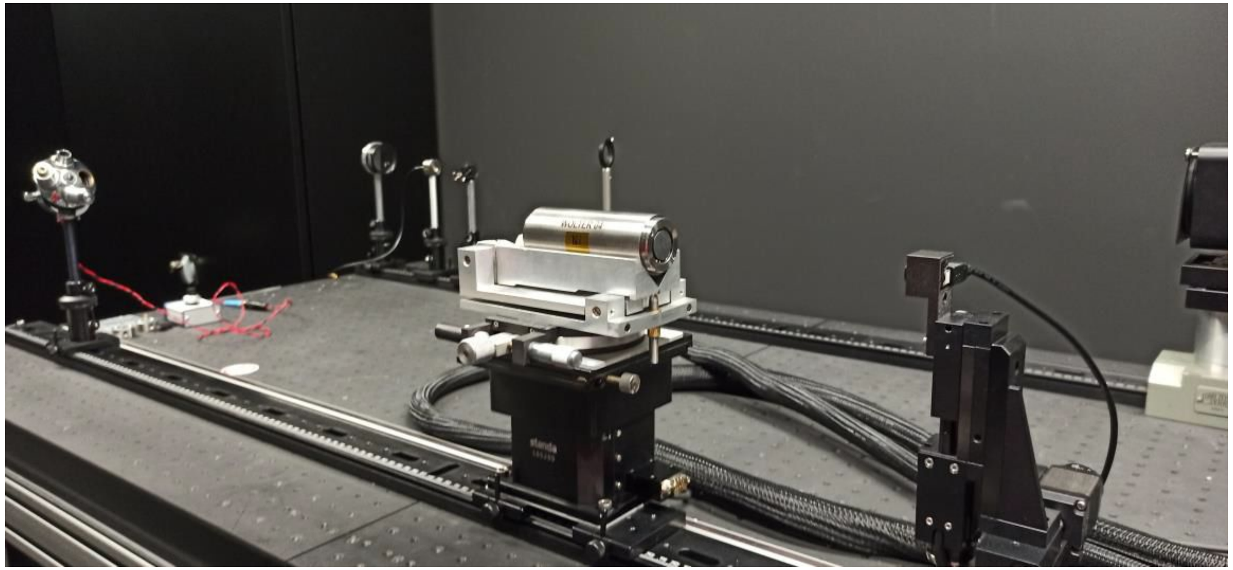



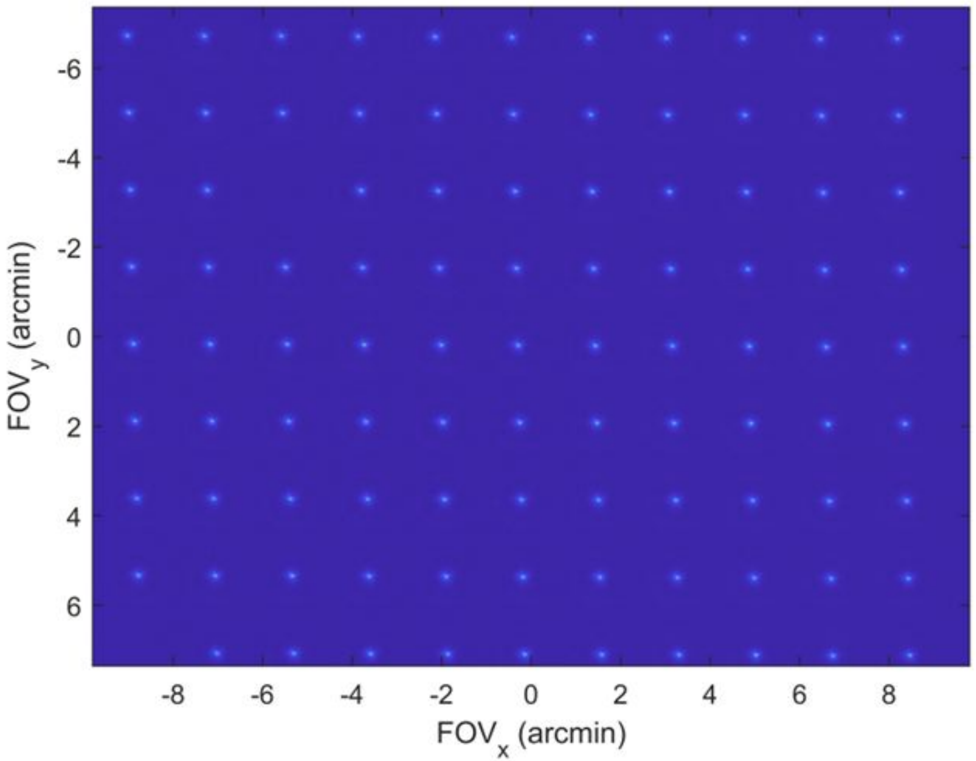



# X-ray optics - Wolter I - manufacturing

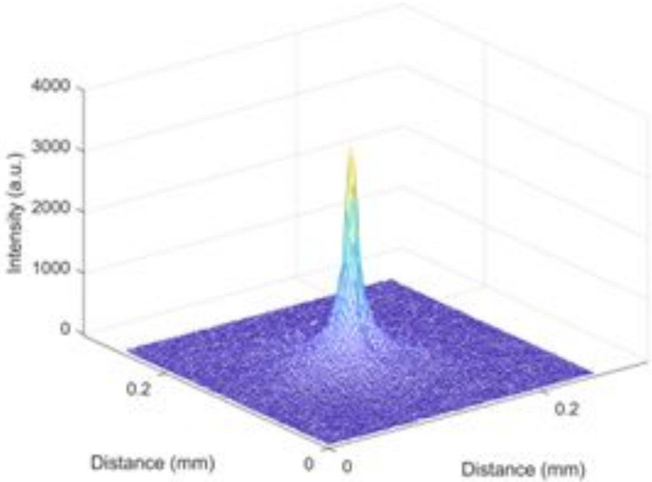
Manufacturing process of Wolter I X-ray optics - raw form, precise form, metallization, polishing, separate and reflective layers, application of electrochemical nickel and replication.

# X-ray optics - Wolter I - testing (VIS)



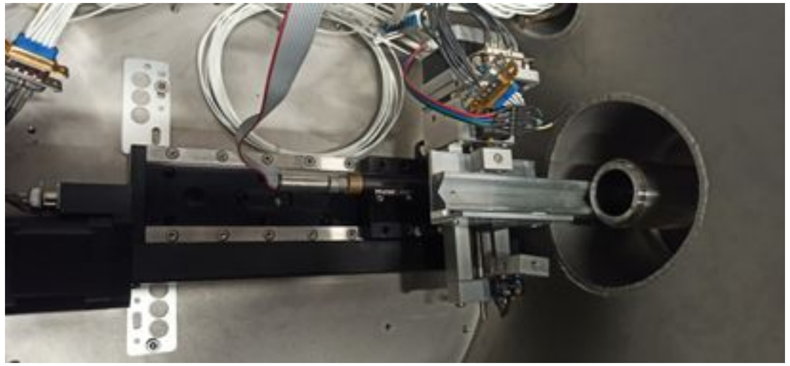


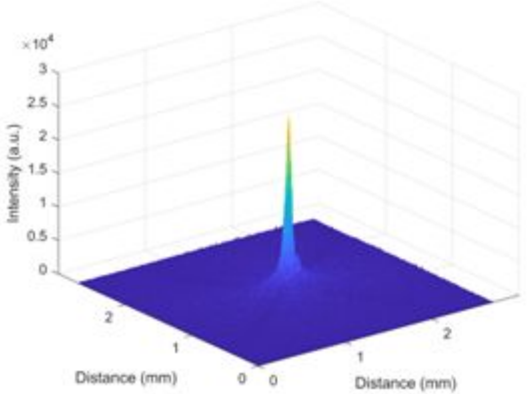

| | |
|---|---|
| source | white LED |
| | 35 x 35 µm |
| detector | XIMEA (MU9PC-MH) |
| | 1944x2592 px |
| | 2.2 µm pixel size |

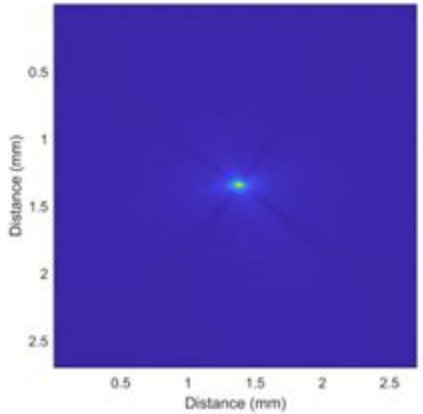



The field of view (FOV) is 17.2 x 13.8 arcmin, which corresponds to the size of the selected detector.

# X-ray optics - Wolter I - testing (X-ray)



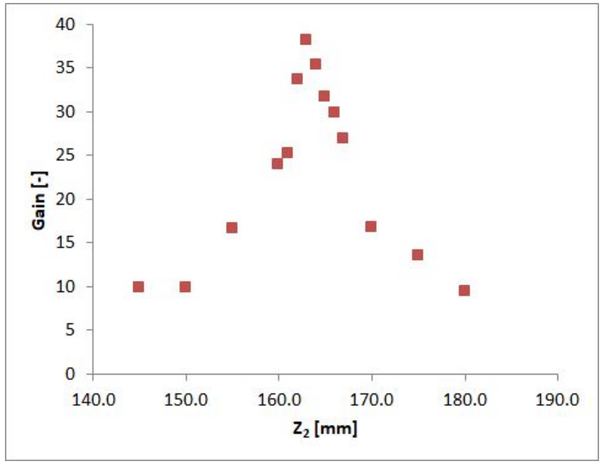


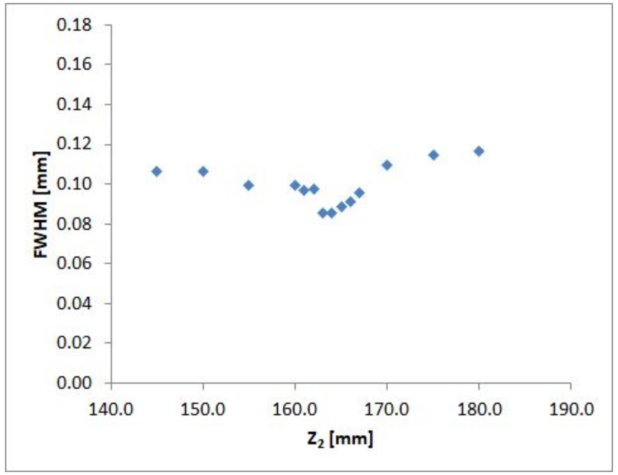



source NiP target
250 um
E =0.86 and 2.0 keV

detector Rigaku CCD kamera
3326 x 2504 px
5.4 µm pixel size

spot size 80 um
(It complies with the assumption)





Rigaku

# Thank you for attention

VZLÚ