

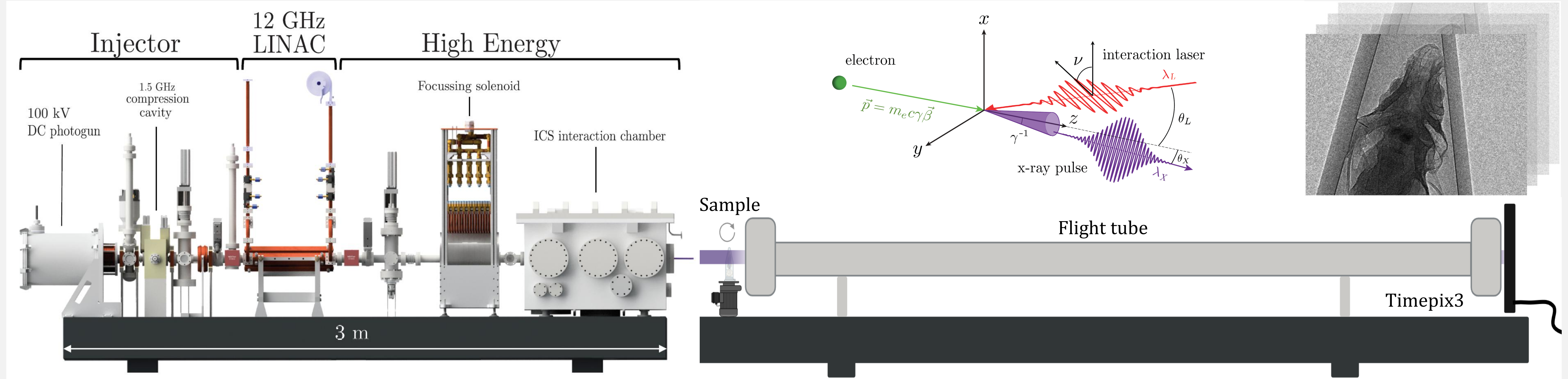
X-RAY COMPUTED TOMOGRAPHY (XCT) OF A ZEBRAFISH USING THE Smart*Light INVERSE COMPTON SOURCE (ICS)

Situation

Inverse Compton scattering (ICS) X-ray sources promise to bridge the gap between synchrotrons and laboratory sources, as the latter are widely available but limited in flux and coherence, whereas the former provide high flux and coherence but remain relatively difficult to access by the general public.

ICS is a process where photons gain energy by scattering off relativistic electrons. In essence, such a conversion is manifested through a double Doppler shift, where relativistic electrons from an accelerator interact with a high-intensity pulsed laser, upshifting the photons into the X-ray regime. The result is a high-brilliance, quasi-monochromatic X-ray beam with tuneable energy.

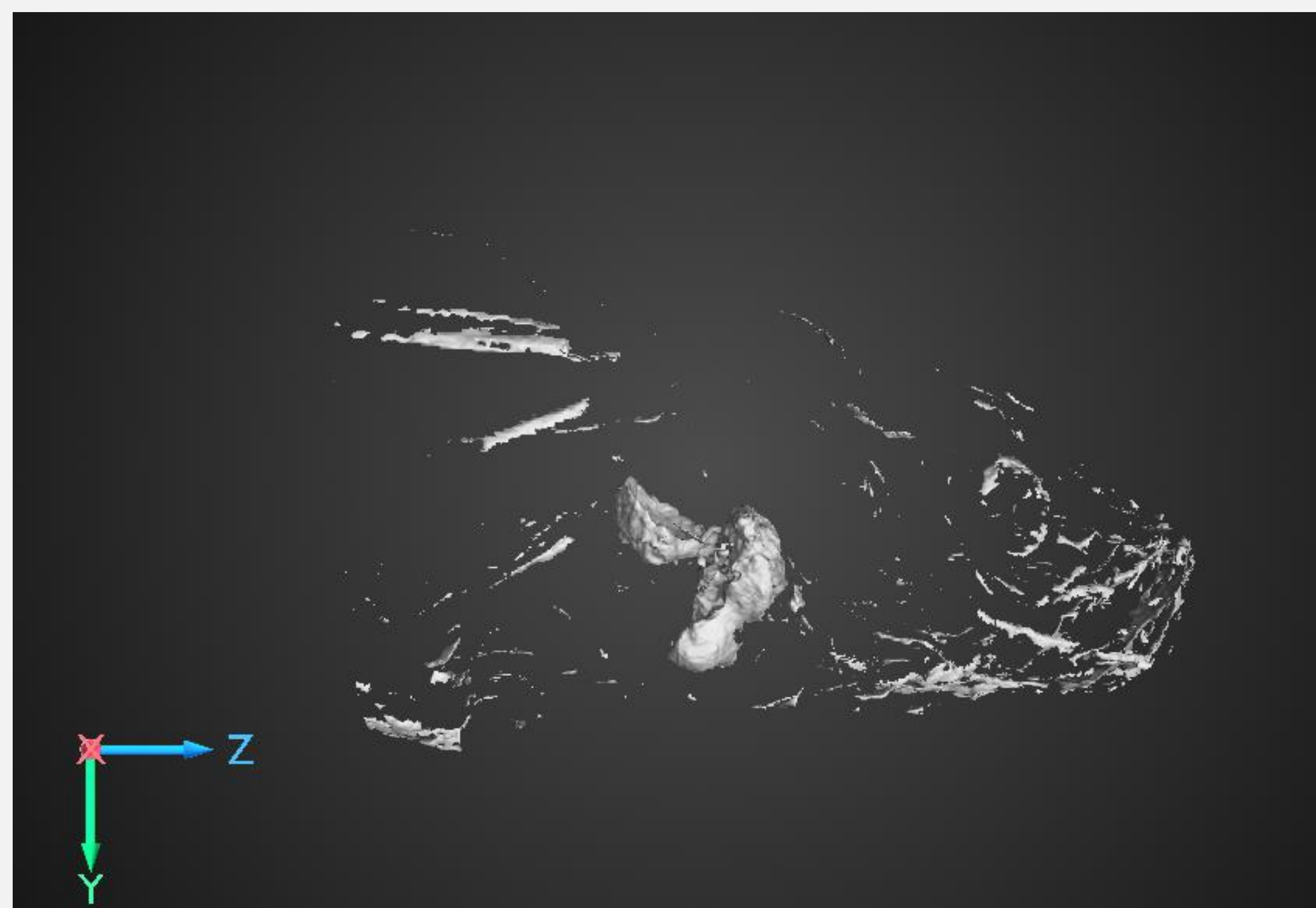
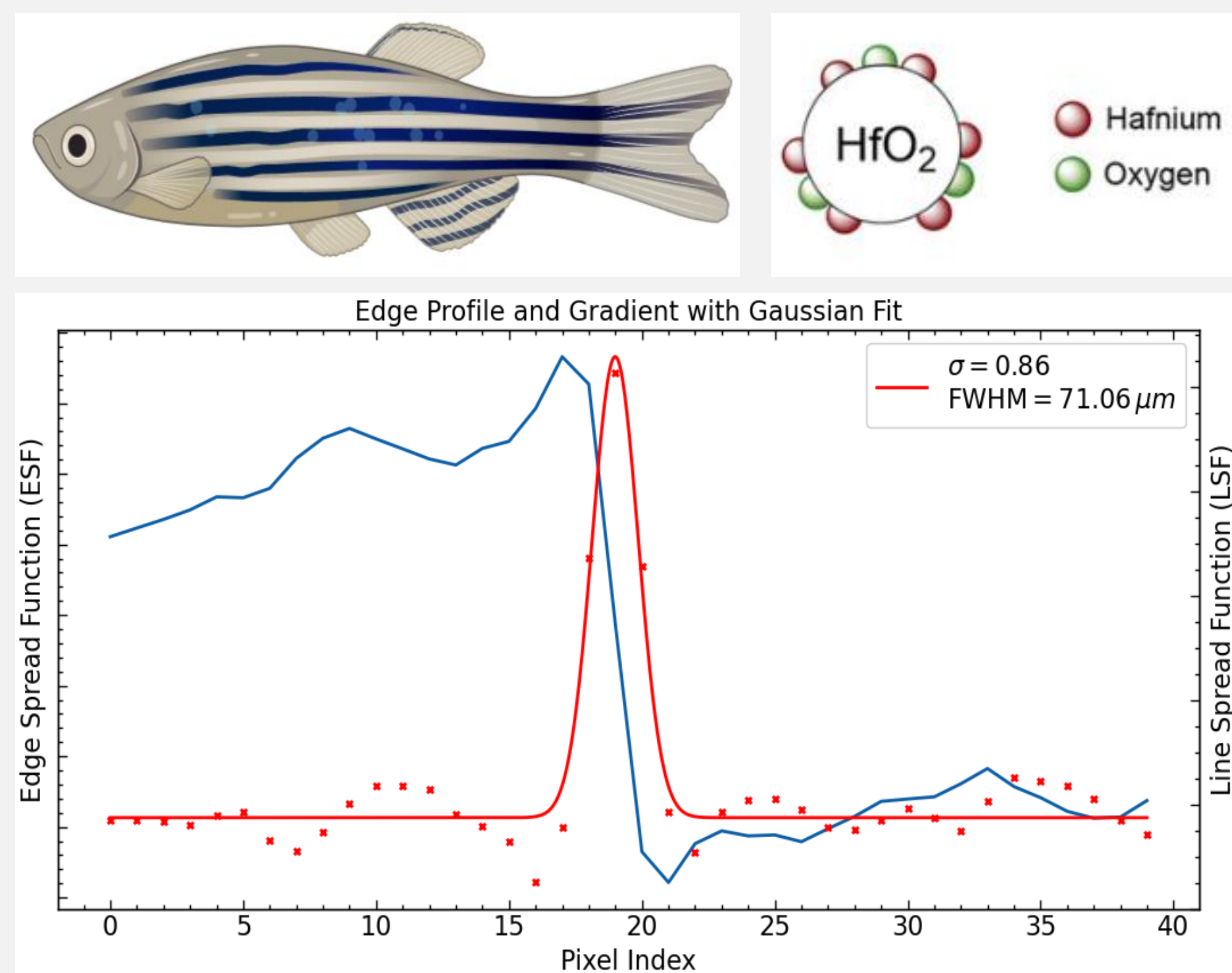
The Smart*Light source is a LINAC-based ICS source, delivering these X-rays in a relatively compact format. However, its low flux and instabilities have so far kept it from routine application and full potential.



Methods

Recent advances and gain in flux and stability now bring imaging within practical acquisition times. Here we demonstrate that the current Smart*Light source provides sufficient flux for low-energy X-ray computed tomography (XCT). Using an 11.0 keV photon beam, we image a formaldehyde-fixed zebrafish with a heart doped with the contrast agent (HfO₂). This sample is a popular and reliable model for the studies of cardiovascular network, diseases etc. The acquisition comprises five interlaced scans over 0° - 190°, resulting in a total exposure time of 18300s (≈ 5.1 hrs), with the interlacing guarding against potential instabilities.

The projected frames were all flat-field corrected using one master-flat frame. Outliers such as hot- and dark-pixels were corrected for by replacement with a local mean. A built-in Paganin phase filter was applied to all the images, which were then reconstructed in Octopus using the cone-beam geometry. The reconstructed volume was then further analysed using VGSTUDIO MAX and Fiji.

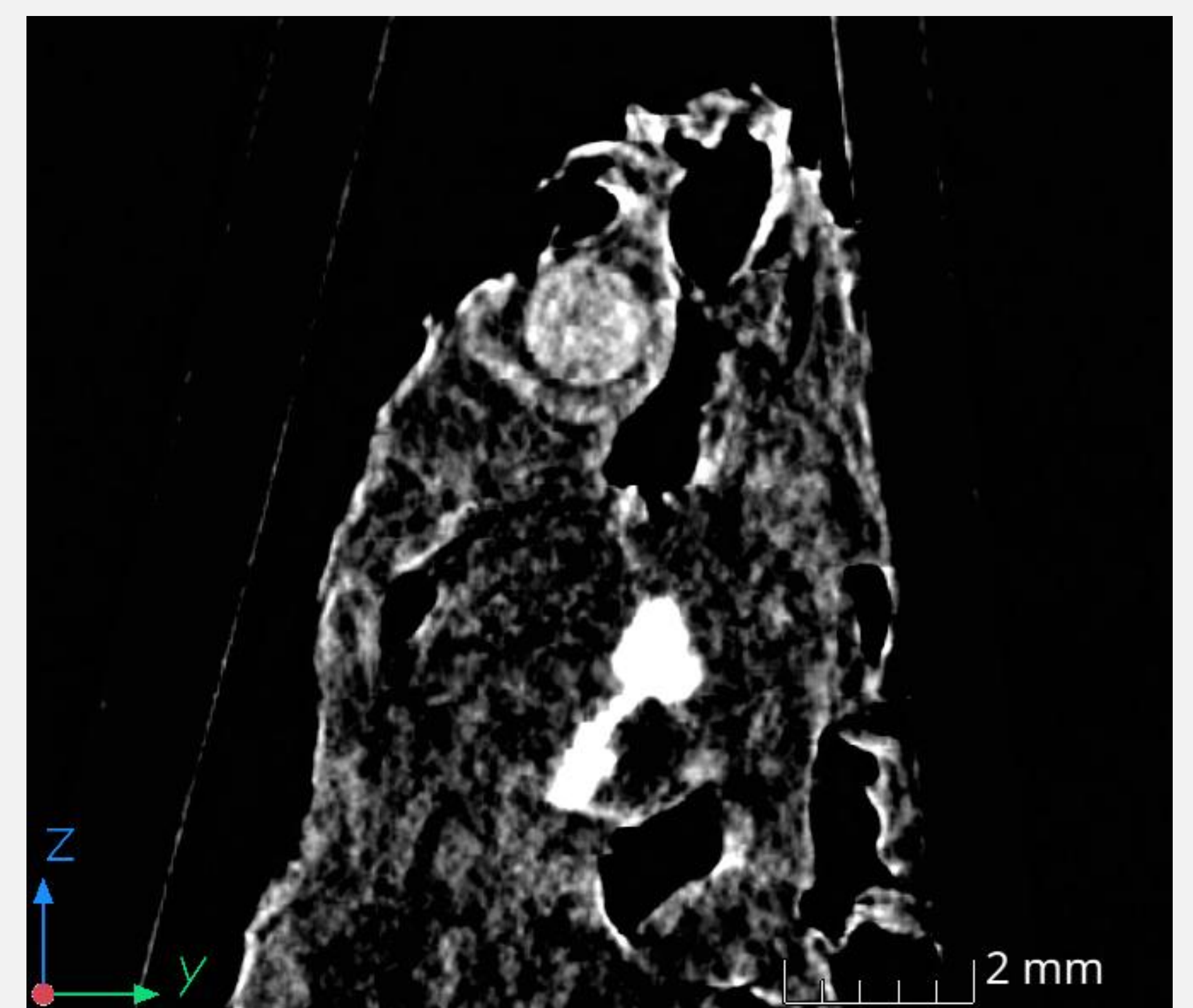
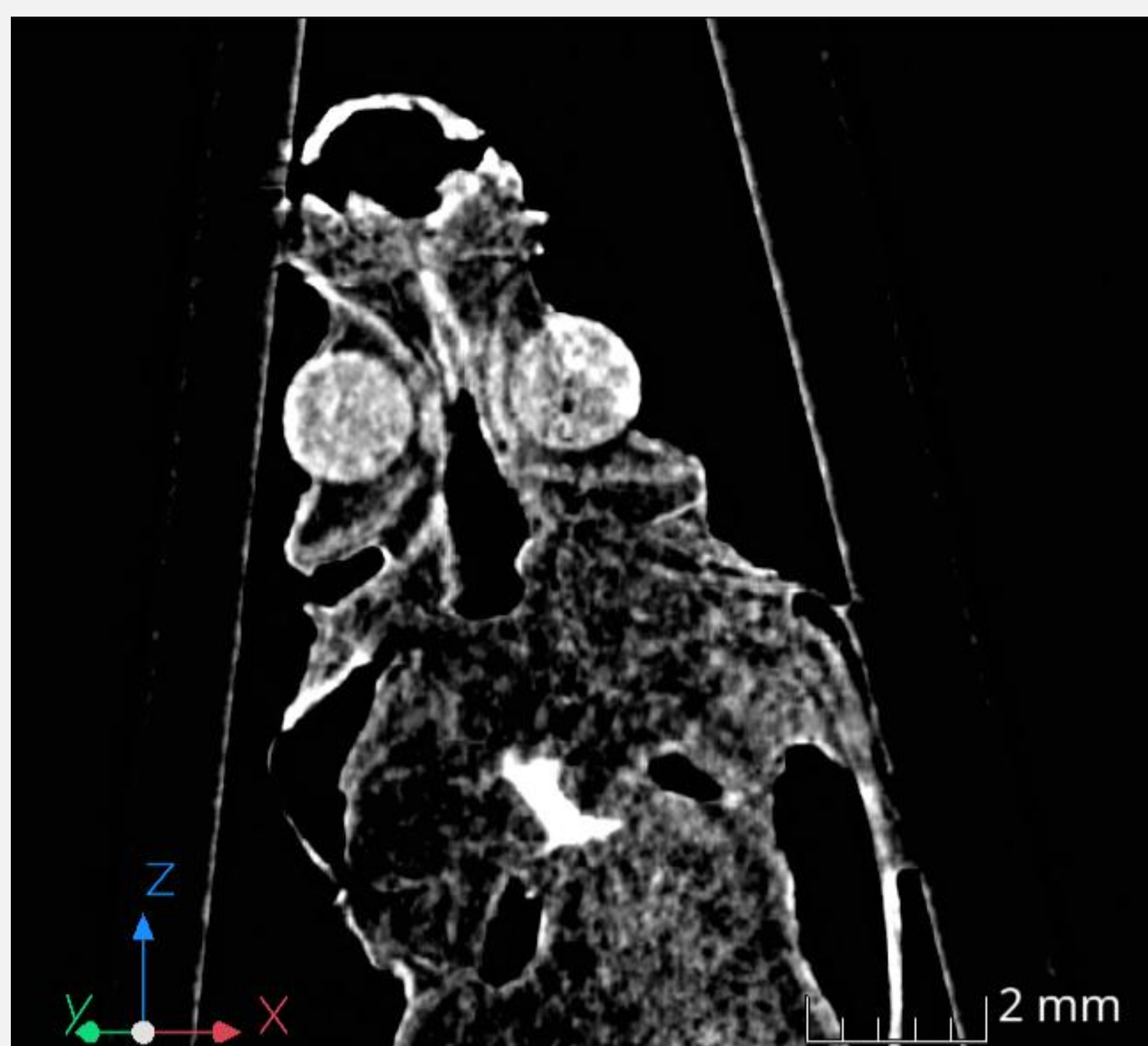
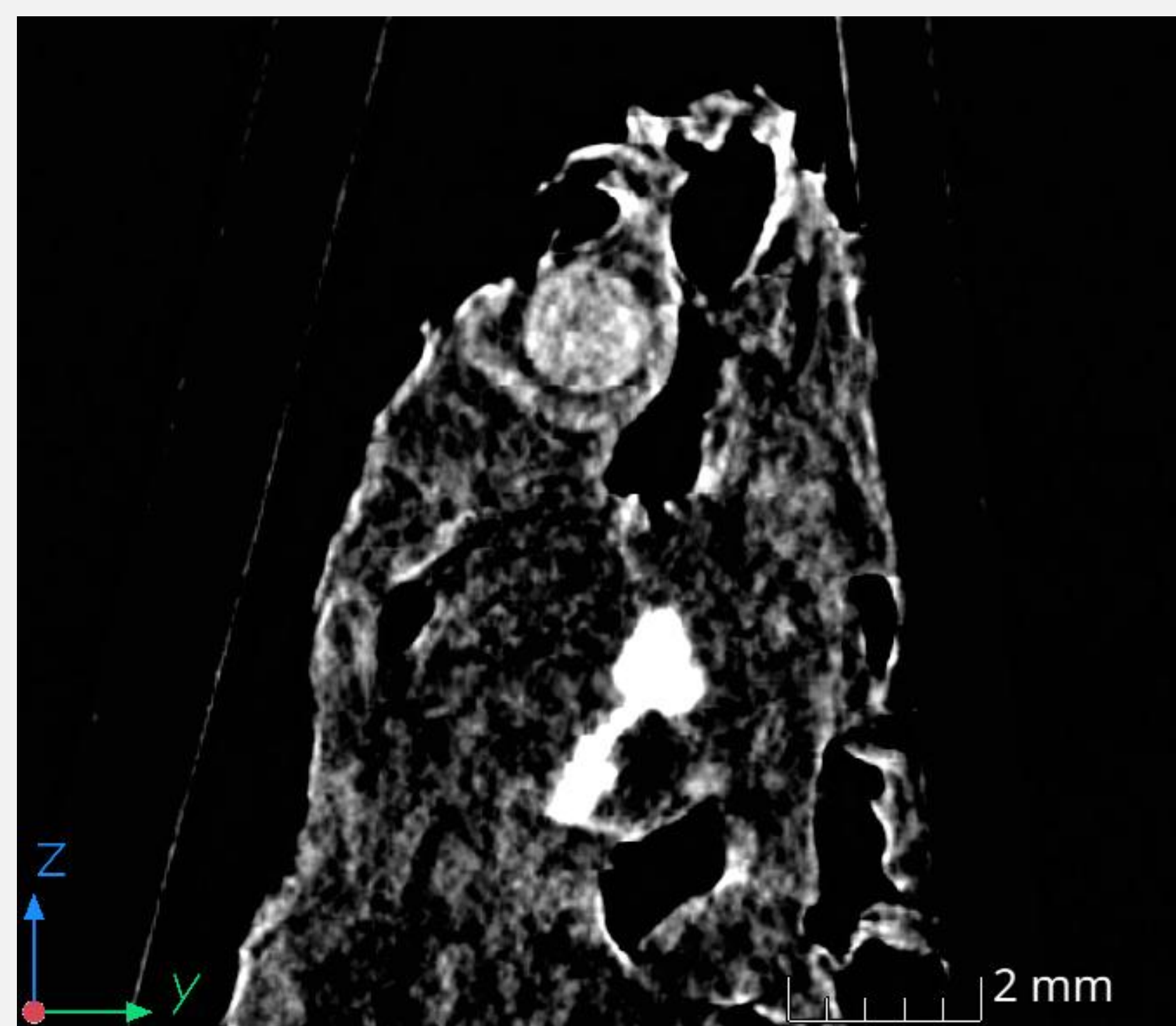


Key figures

Energy : 11.0 keV, FWHM : 500 eV
Focal spot : ≈ 8.5 μm
Opening angle : $\theta_x = 1.5$ mrad
Pixel pitch : 55 μm (Timepix3 detector)
Pixel count : 512 x 512
Source-to-detector distance : 3.15 m
Source-to-object distance: 0.9 m
Exposure time per projection : 60 s
Paganin phase filter : $\mu = 0.5 \text{ cm}^{-1}$, $\delta = 1 \times 10^{-5}$
Reconstruction software : Octopus (cone-beam)
Voxel size : 34.92 μm

Results

The reconstruction resolves features down to 71.1 μm (FWHM) and yields a contrast-to-noise-ratio (CNR) of 8.4 dB between the heart region (contrast agent) and a reference polypropylene (Eppendorf tube, (C₃H₆)_n). The surrounding tissue has a CNR of 4.1 dB with a signal-to-noise-ratio (SNR) of 13.6 dB. These results mark a step toward routine biological and quantitative imaging applications with the Smart*Light compact ICS source.



Outlook

Due to the relatively good contrast but coarse voxel size, future application will aim for finer pixel- and voxel size, approaching orders of approximately 10 μm to 15 μm and eventually the focal spot limit.

Funding

Interreg Vlaanderen-Nederland (Smart*Light project, Smart*Light project 2.0).