

Smart*Light: The Synchrotron in the Museum's Cellar

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Motivation

X-rays allow for a non-destructive investigation of objects. This makes them well suited for the investigation of cultural heritage objects that need to be preserved for coming generations. The most informative X-ray techniques, such as XANES or XRD imaging are limited to synchrotron (SR) sources as they require tunable, monochromatic primary radiation of high intensity.

Experiments at SR sources require the transport of objects, which might be prohibited due to the stress they are exposed to in the process. Further, experimental time at SR sources is limited. The Smart*Light (S*L) project aims to bridge the gap between X-ray tubes and SR sources by developing a compact Inverse Compton Scattering (ICS) source that can be installed in a museum's cellar, minimizing the need for transporting delicate artifacts and maximizing accessibility for cultural heritage research.

Inverse Compton Scattering

The Inverse Compton effect describes how laser light is scattered back by relativistic electrons, gaining energy and being promoted to the X-ray regime (s. Fig 1). Inverse Compton Sources feature several **Advantages**:

- **Narrow Bandwidth**: The bulk of the created radiation is in a narrow bandwidth (approximately 1% $\Delta E/E$).
- **Partial Coherence**: The radiation is partly coherent.
- **Narrow Emission Cone**: The radiation is emitted in a narrow cone.
- **Tunable Energy**: The energy of the emitted radiation can be tuned by varying the energy of the electrons or the laser.

Energy and intensity have a peculiar shape, both declining with scattering angle (s. Fig 2). While not competitive to a full SR source in terms of intensity (s. Fig 3), ICS sources are more compact and require a much smaller investment.

The main reason ICS sources have not been established is the high demands to power and quality of laser and electron beam, but most problems have been overcome for S*L.

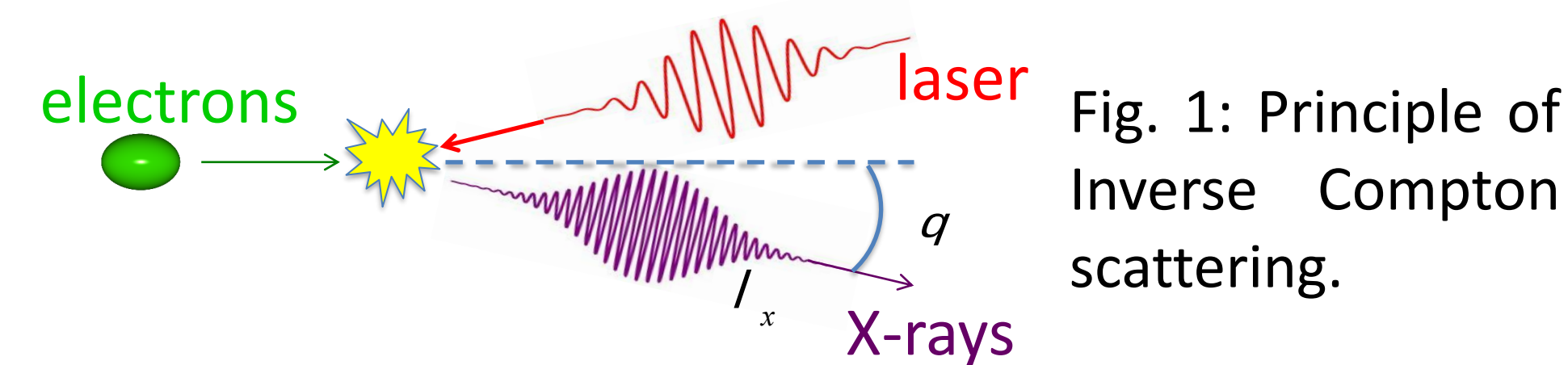


Fig. 1: Principle of Inverse Compton scattering.

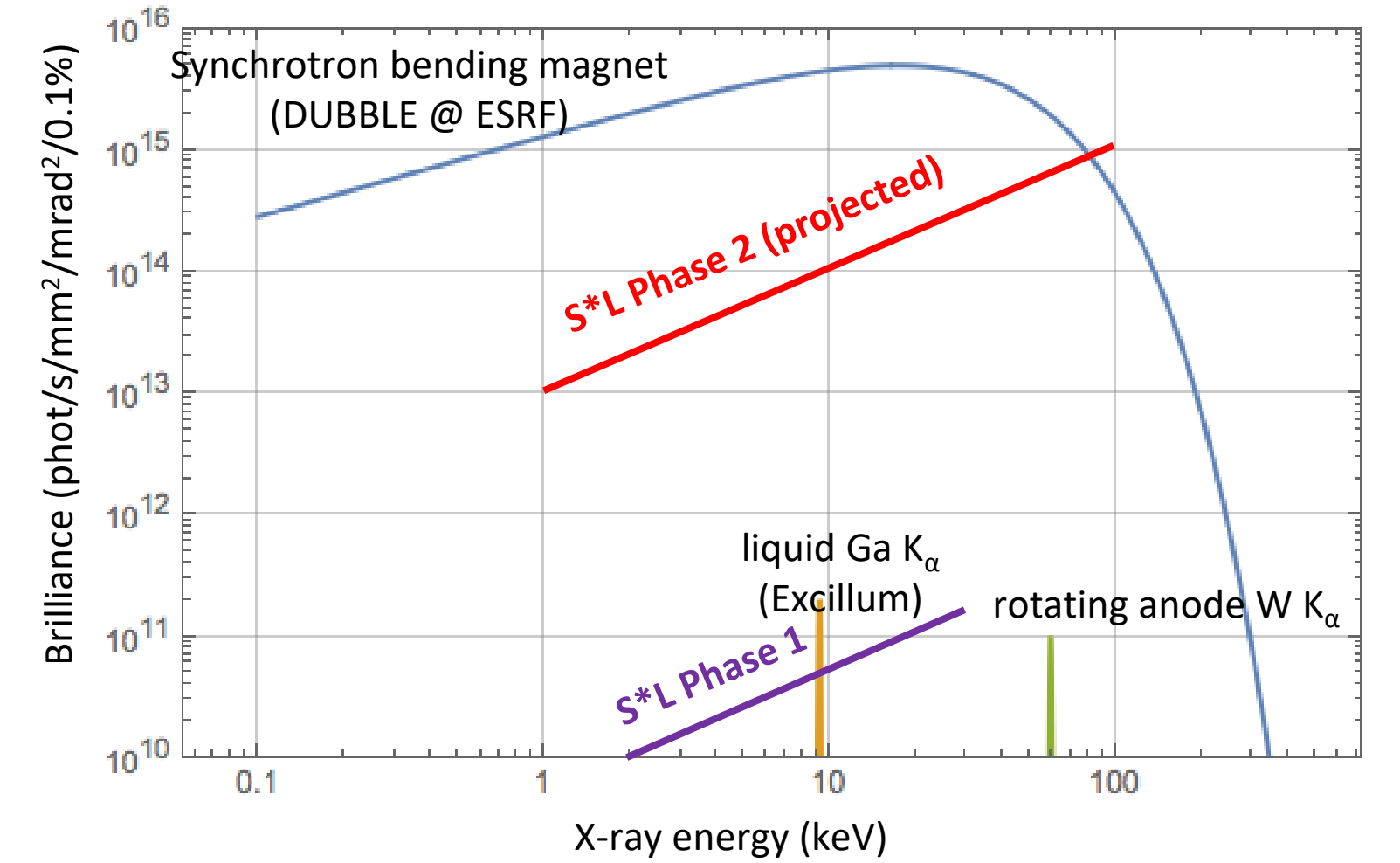


Fig. 3: Expected performance of Smart*Light

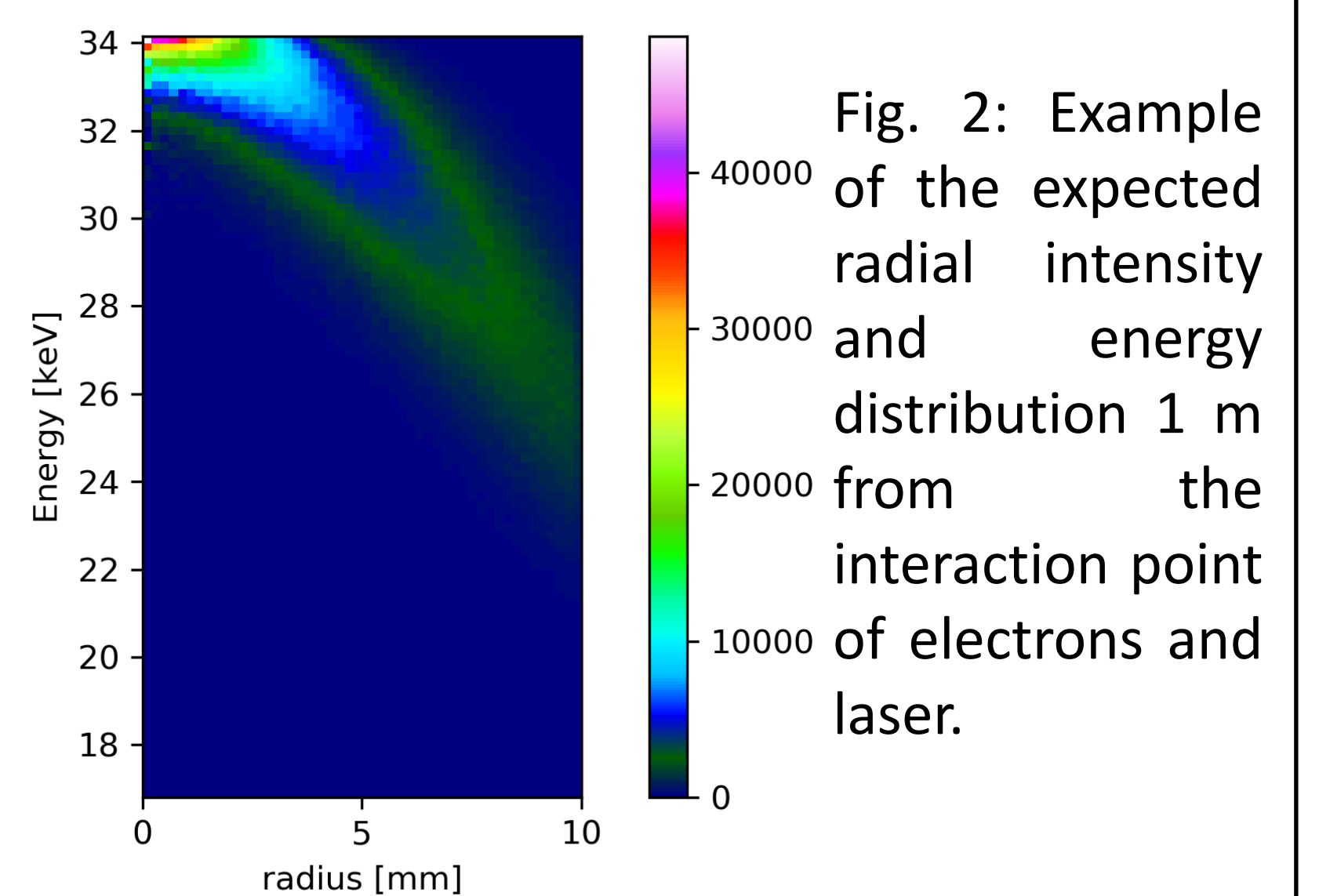


Fig. 2: Example of the expected radial intensity and energy distribution 1 m from the interaction point of electrons and laser.

Smart*Light (S*L) and its Cultural Heritage & Characterisation (CH&C) endstation

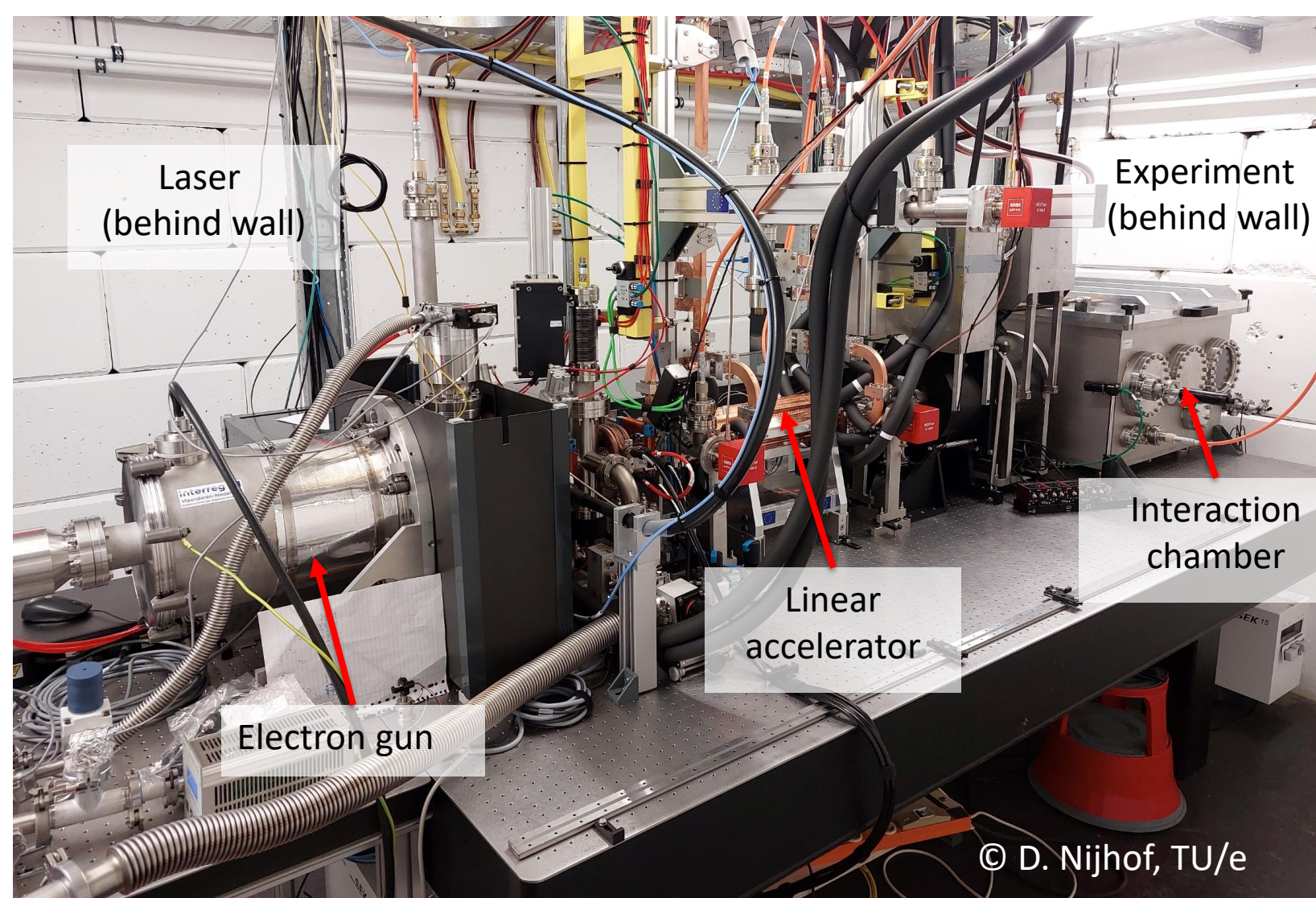


Fig. 4: Smart*Light (S*L) prototype at the TU/e. Experiment and Laser are covered by brick walls.

Smart*Light (S*L, Figure 4):

Electrons are emitted from the electron gun and accelerated towards the interaction chamber, where they scatter the laser light under inverse Compton conditions, before being diverted into the beam dump. The X-rays pass then through a beamline in the wall to the experiment.

Cultural Heritage & (Beam) Characterisation endstation (CH&C, Figure 5):

The beam enters from the right, is collimated by flexible (JJ) slits, optionally focused by an optic on the hexapod, before interacting with the object on the sample stage. Behind the object is a transmission detector.

Testing and Results (Figure 6):

As S*L is not yet operational, the CH&C endstation was tested with an X-ray tube to demonstrate the feasibility of simultaneous acquisition of XRF and transmission data from a 19th century painting. The results are compared to data acquired with the M6 Jetstream.

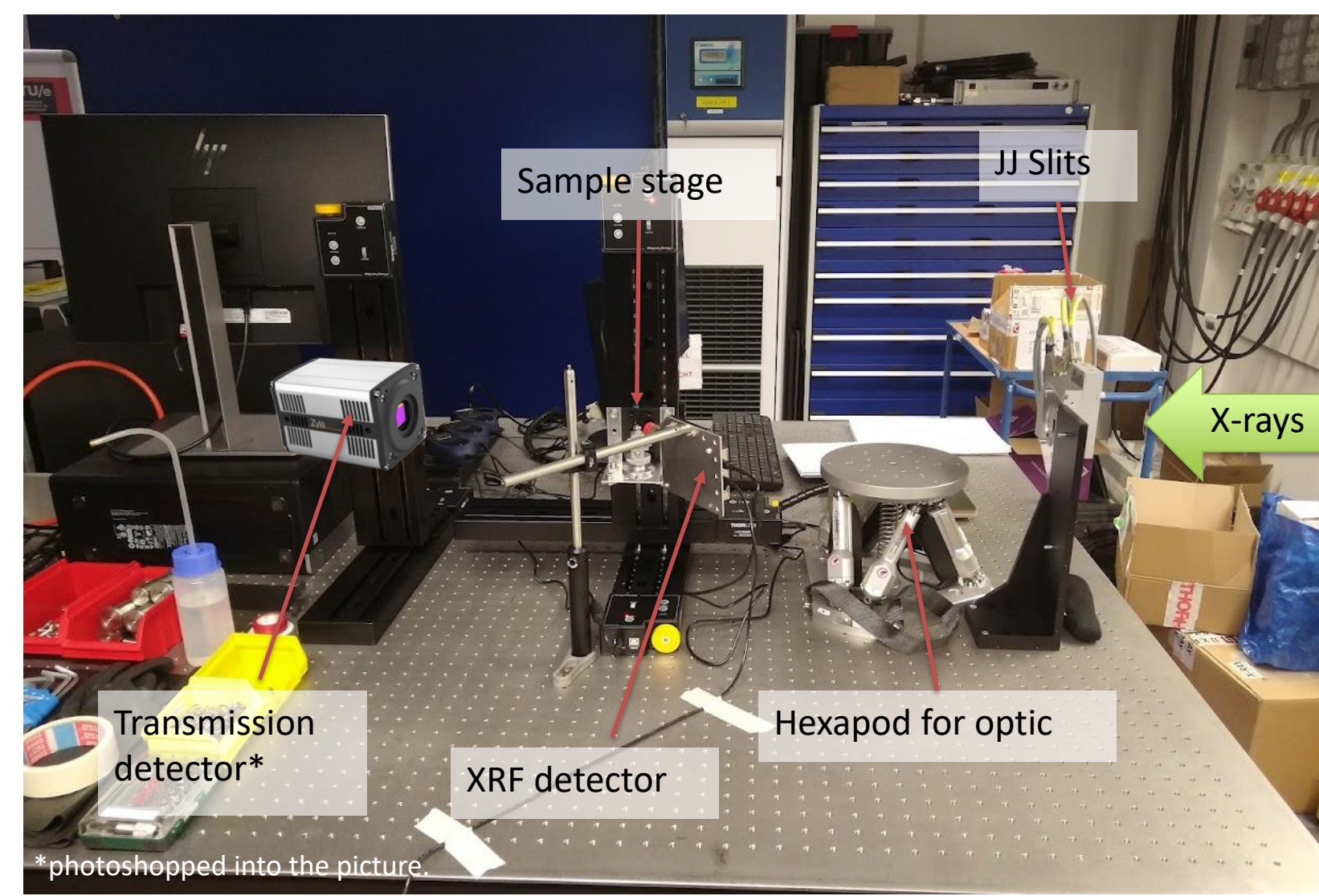


Figure 5: stage test of CH&C endstation of S*L with beam entering from the right,

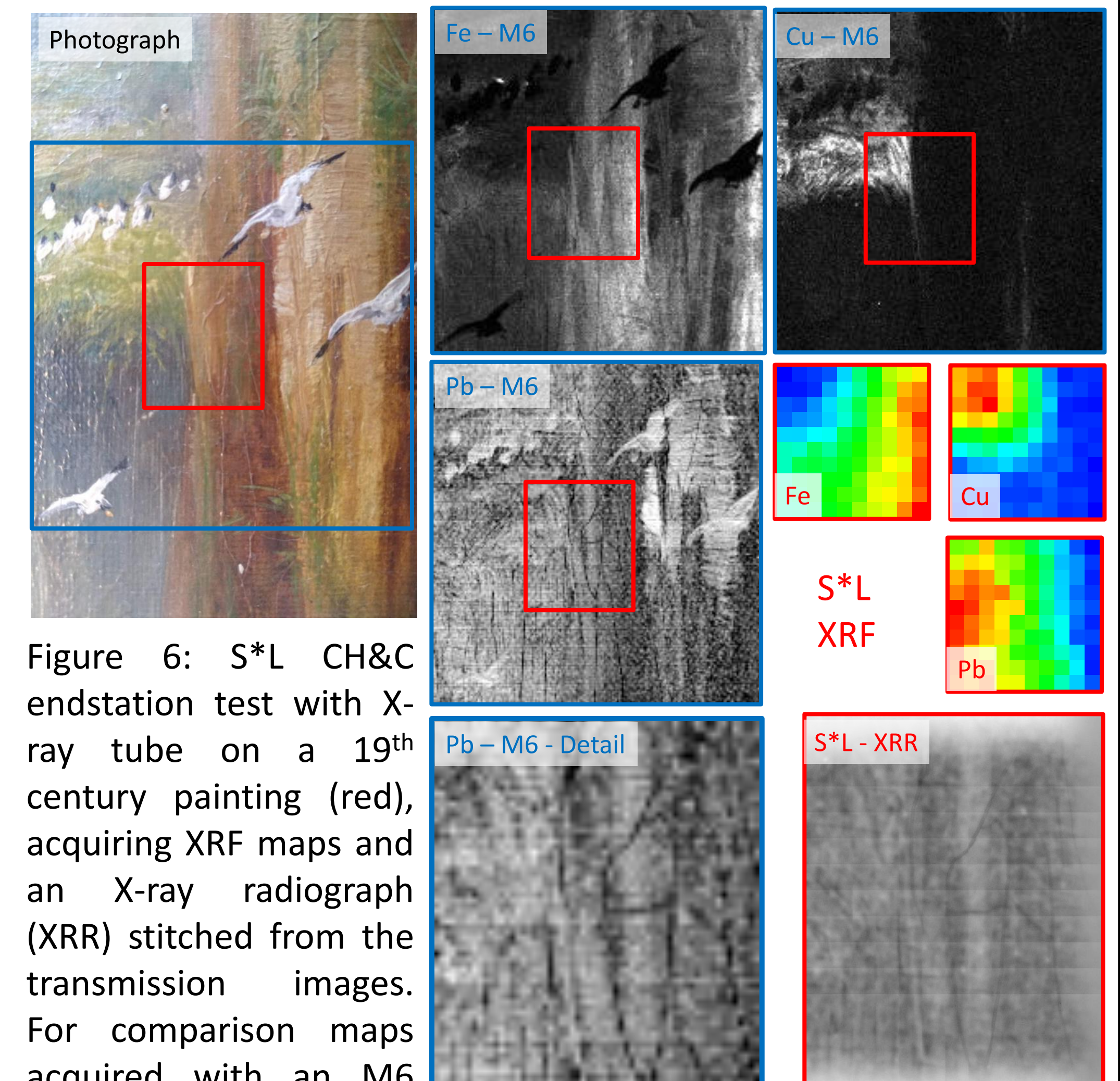


Figure 6: S*L CH&C endstation test with X-ray tube on a 19th century painting (red), acquiring XRF maps and an X-ray radiograph (XRR) stitched from the transmission images.

For comparison maps acquired with an M6 Jetstream of the same area were added. Note how the cracks in the paint are visible in M6 – Pb image and the S*L XRR. Experimental parameters: S*L: 2x2 mm beam, 1x1 mm pixels, 10x10 pixels. For comparison M6 Jetstream data (50 kV, 0.6 mA, 30 ms) with 200x200 pixels of 300 μ m size.

Perspective

The first experiments scheduled later this year will focus on the characterisation of the X-ray beam, its size, intensity, energy distribution and stability.

These initial findings will serve as the basis for selecting appropriate monochromator and optics for the subsequent project phase. The aim is to enhance Smart*Light's capabilities for high-resolution X-ray Diffraction (XRD) and X-ray Absorption Near Edge Structure (XANES) measurements following planned upgrades to its energy range and brilliance.

Concurrently, our initial experiments will be studies to showcase the diverse capabilities of this novel X-ray source. These studies will encompass phase- and absorption-based radiography and tomography, as well as the integration of low-resolution X-ray Fluorescence (XRF) and XRD mapping with high-resolution K-edge imaging. These combined techniques will facilitate the examination of historical documents with unprecedented clarity and detail. Advanced sources like Smart*Light hold significant promise for revolutionizing the investigation of cultural heritage artifacts using X-rays. The prospect of installing such sources in or near museums presents an opportunity to apply advanced X-ray methodologies across a broader spectrum of objects, thereby alleviating the demand on Synchrotron Radiation (SR) facilities.

Acknowledgements

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