Centrum Wiskunde & Informatica

News from the Ground Floor

Explorative Imaging at the FleX-Ray Laboratory

Sophia Bethany Coban

Centrum Wiskunde & Informatica, Amsterdam, The Netherlands.

CWI Scientific Meeting

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Preamble: Quick introduction to imaging

An inverse problem is

- a problem that fails one or more of **Hadamard's conditions** for a well-posed problem:

    1. A solution to the problem must exist;

    2. The solution to the problem must be unique;

    3. The solution depends continuously on the data.

Considering the continuum and discrete CT problems separately…

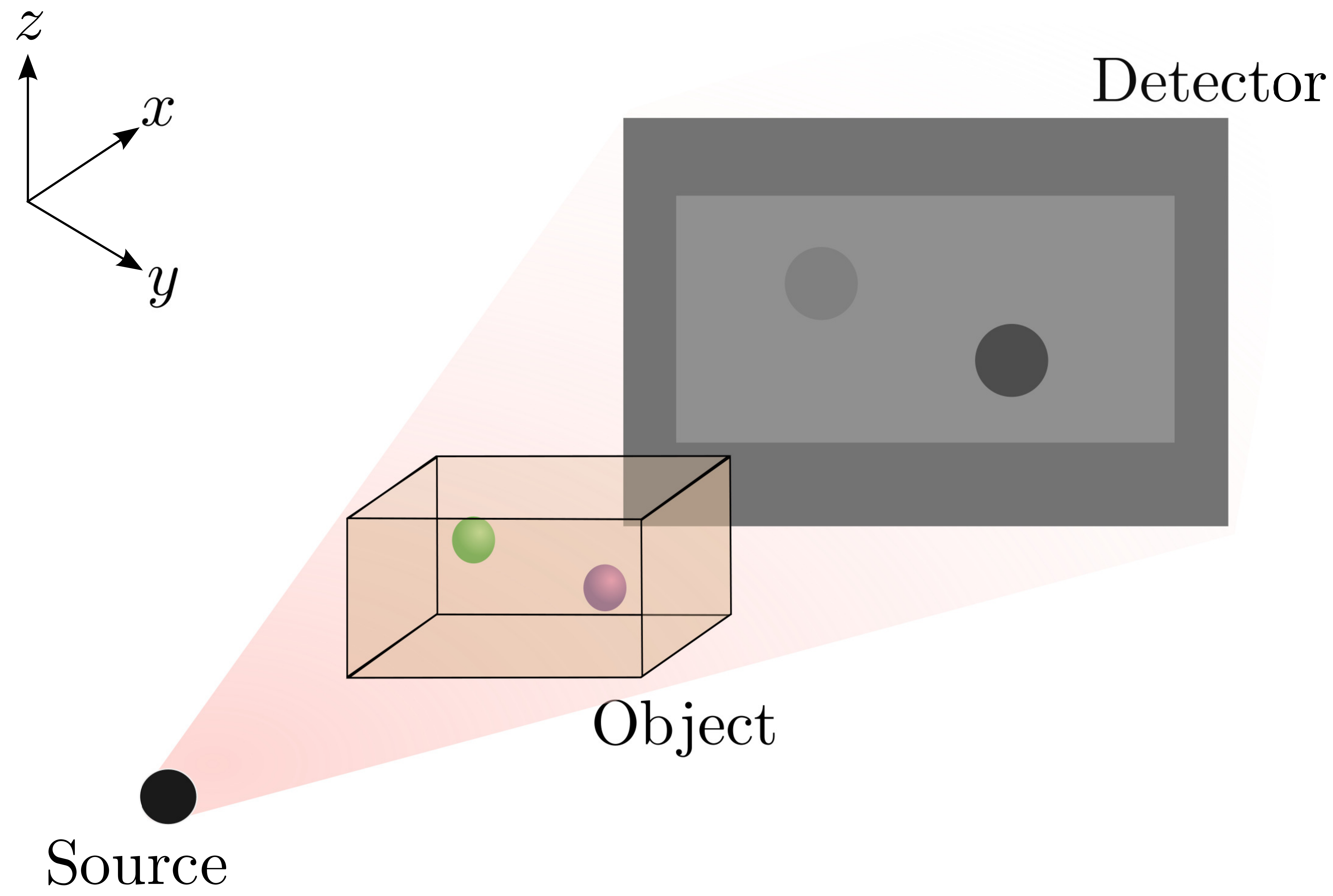
The continuum case:

Can have a unique solution given the *right data*, but the problem can still be unstable in a reasonable norm, meaning a **severely ill-posed problem**.

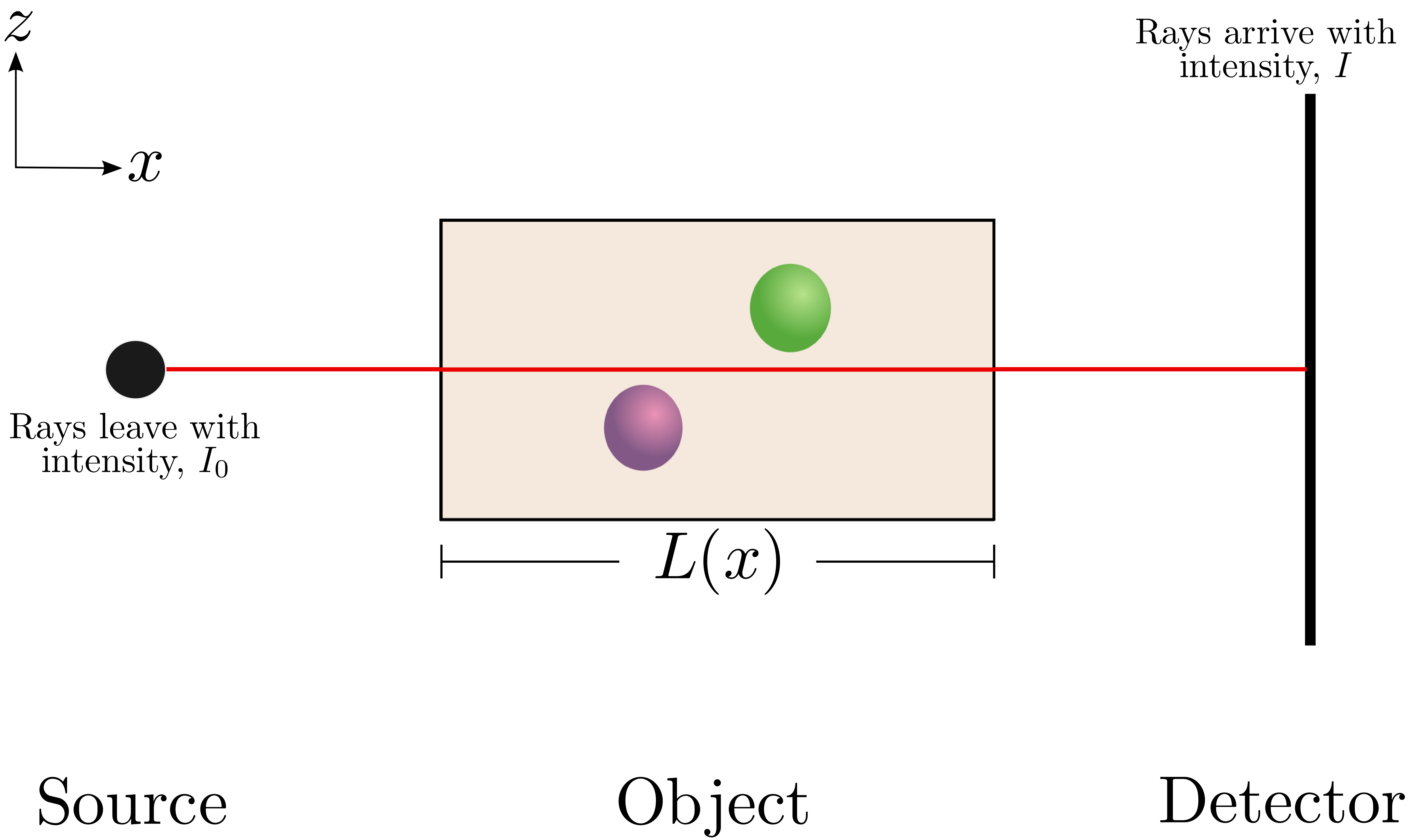
The discrete case:

Cannot produce a unique solution due the *finite set of data* yet *with infinite number of unknowns*, but it can be stable and therefore **mildly ill-conditioned**.

Small changes in the measured data can lead to big changes in the reconstructed image.



3D illustration of a simple apparatus set up for cone beam.



2D (xz-)view of a single ray from a point source with the intensities I0 at the source and I at the detector.

CWI

Consider a single point, dx_L on a monochromatic X-ray beam…

$L(x)$, the length of the X-ray beam travelling through the object,
dI the intensity value at the point dx_L.
At this point dx_L, the beam has lost some intensity proportional to its initial intensity, I_0,

$$dI = -\mu(x) I_0 dx_L.$$

Here, $\mu(x)$ is the attenuation coefficient, i.e. the **rate** at which the **photons are absorbed** (or scattered).

This implies

$$I = I_0 \mathrm{e}^{-\int_{L(x)} \mu(x)\, dx_L}.$$

In physical terms, this describes that the monochromatic beam is **attenuated exponentially** as it travels through an object.

This is commonly referred to as the **Beer-Lambert Law**.

Monochromatic beam is

- an X-ray beam with a single energy (also referred to as a white beam),
- expensive to produce
- need synchrotrons
- not available in a laboratory setting!

Therefore we have to consider X-rays with multiple energies, i.e. **polychromatic beams.**

Since we now depend on varying energy levels as well as the location in the object, the CT model becomes

$$I = \int_{L(x)} I_0(E) e^{- \int_{L(x)} \mu(x,E)\, dx_L} \, dE.$$

Integrating over
all energy levels

Initial intensity of beam
now depends on energy of the beam
as it leaves the source

Attenuation of an object
also depends on the energ
of beam at that location

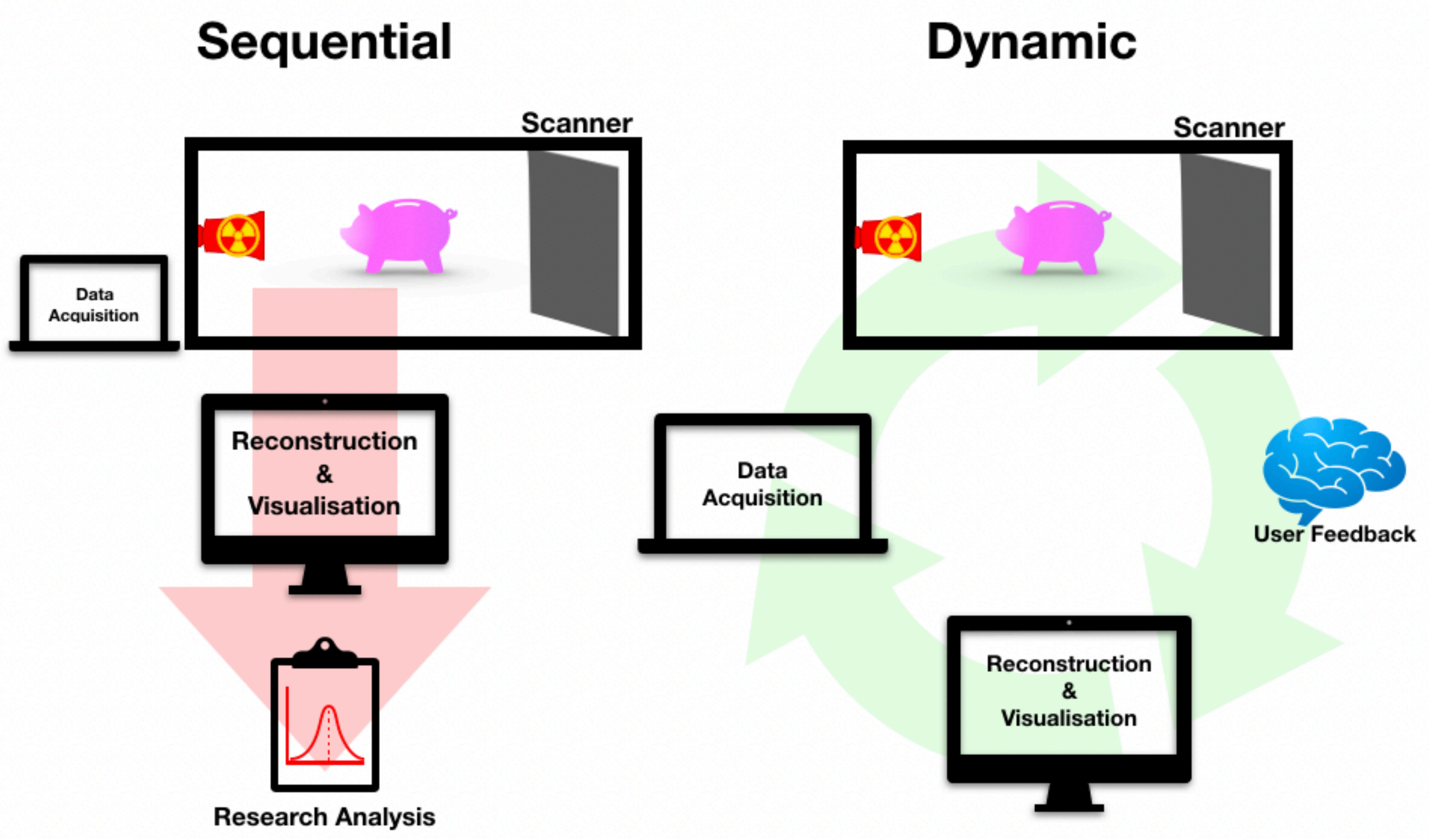
Since we now depend on varying energy levels as well as the location in the object, the CT model becomes

$$I = \int_{L(x)} I_0(E) \mathrm{e}^{-\int_{L(x)} \mu(x,E)\, dx_L}\, dE.$$

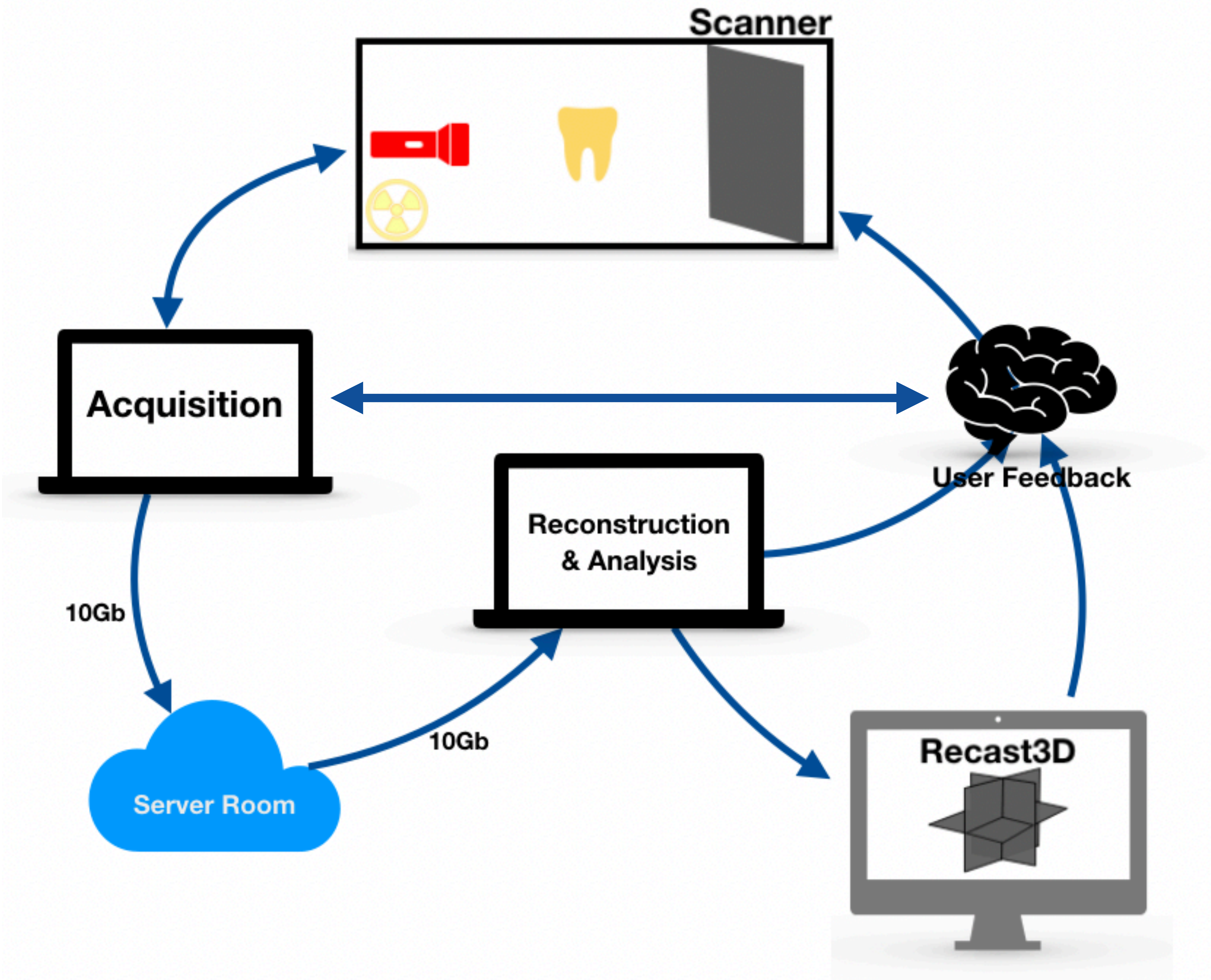
Mathematically, the goal is to recover the **attenuation coefficient** from the **information at detectors.**

Explorative imaging in a flexible setting

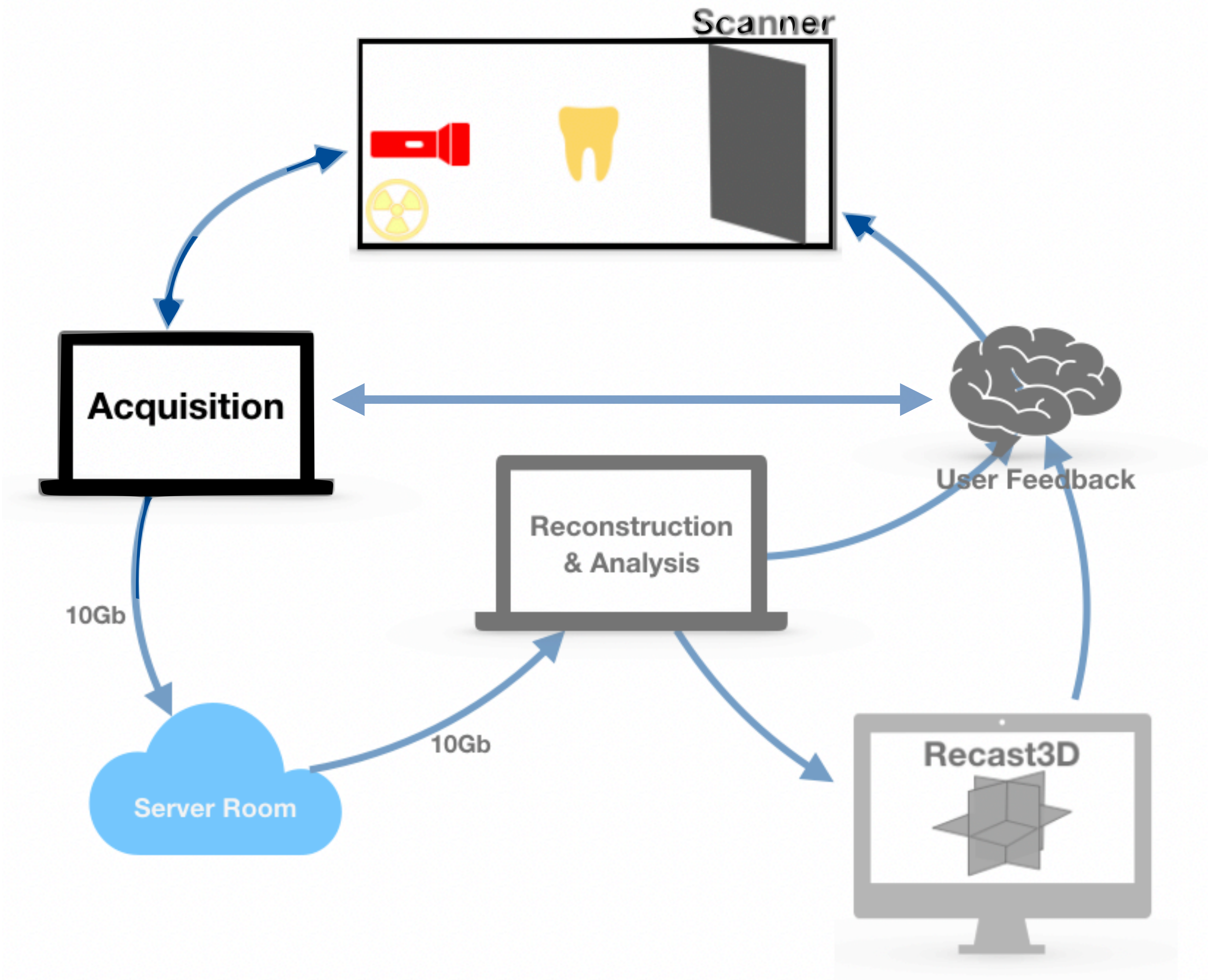
Explorative Imaging



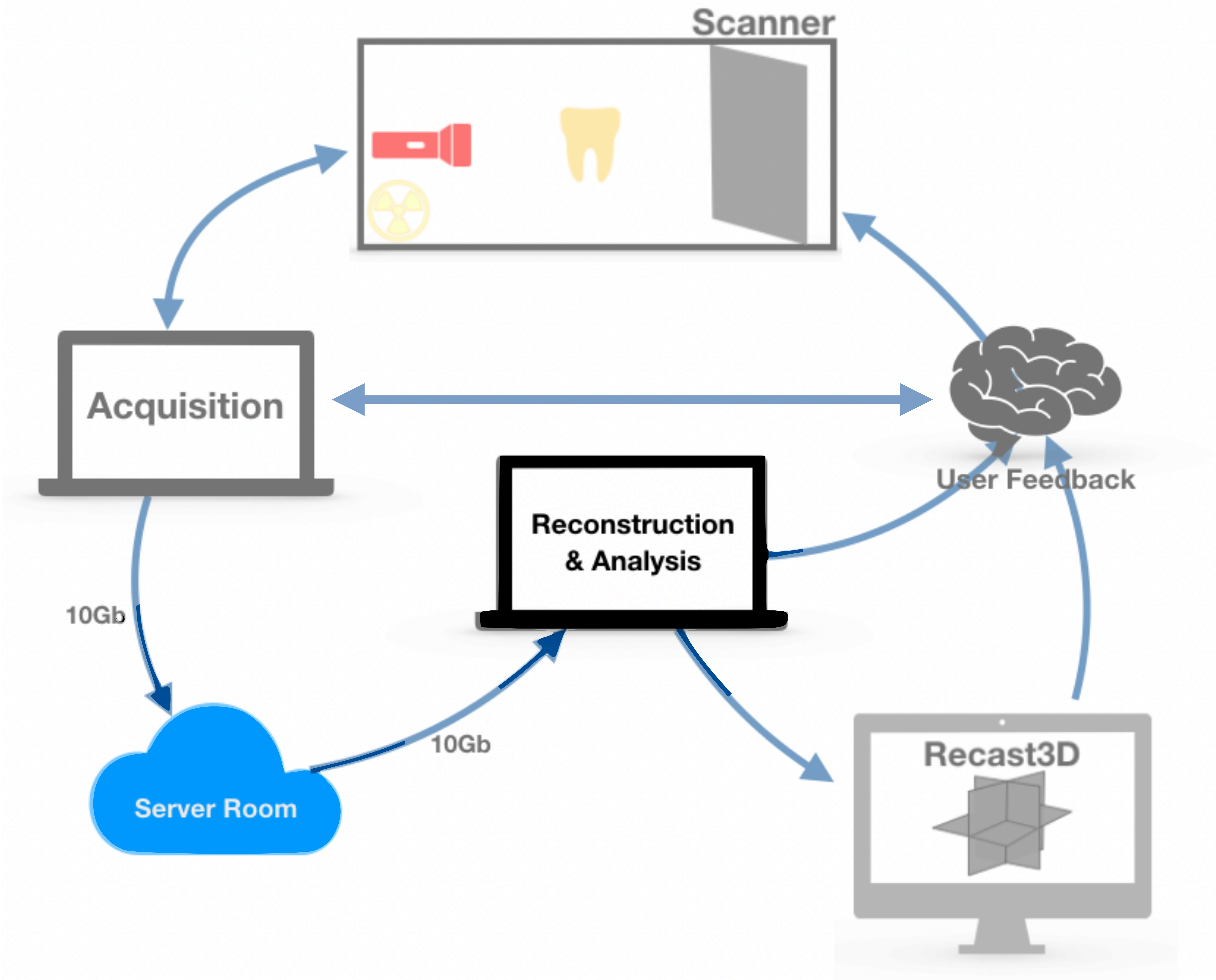
Explorative Imaging



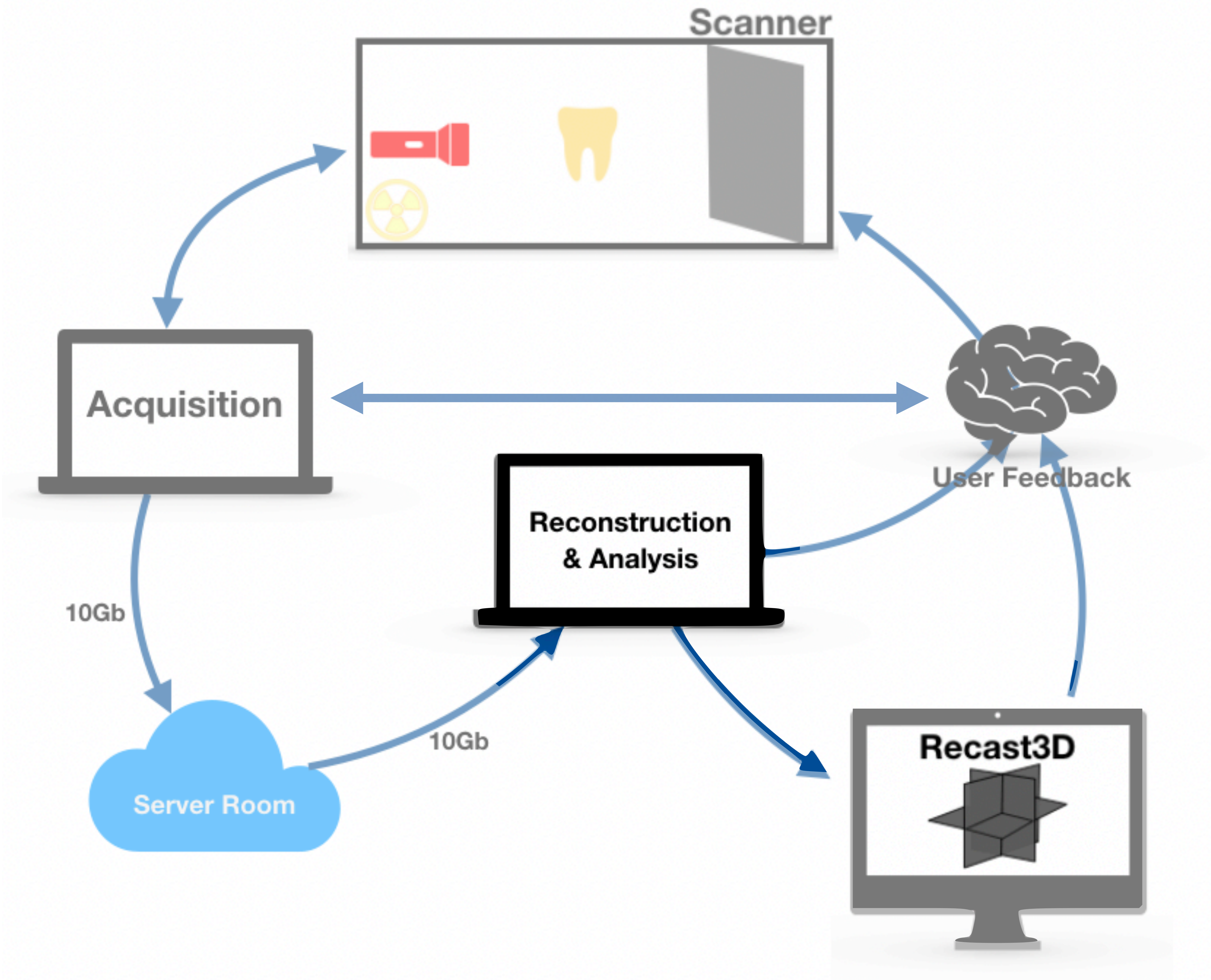
Explorative Imaging



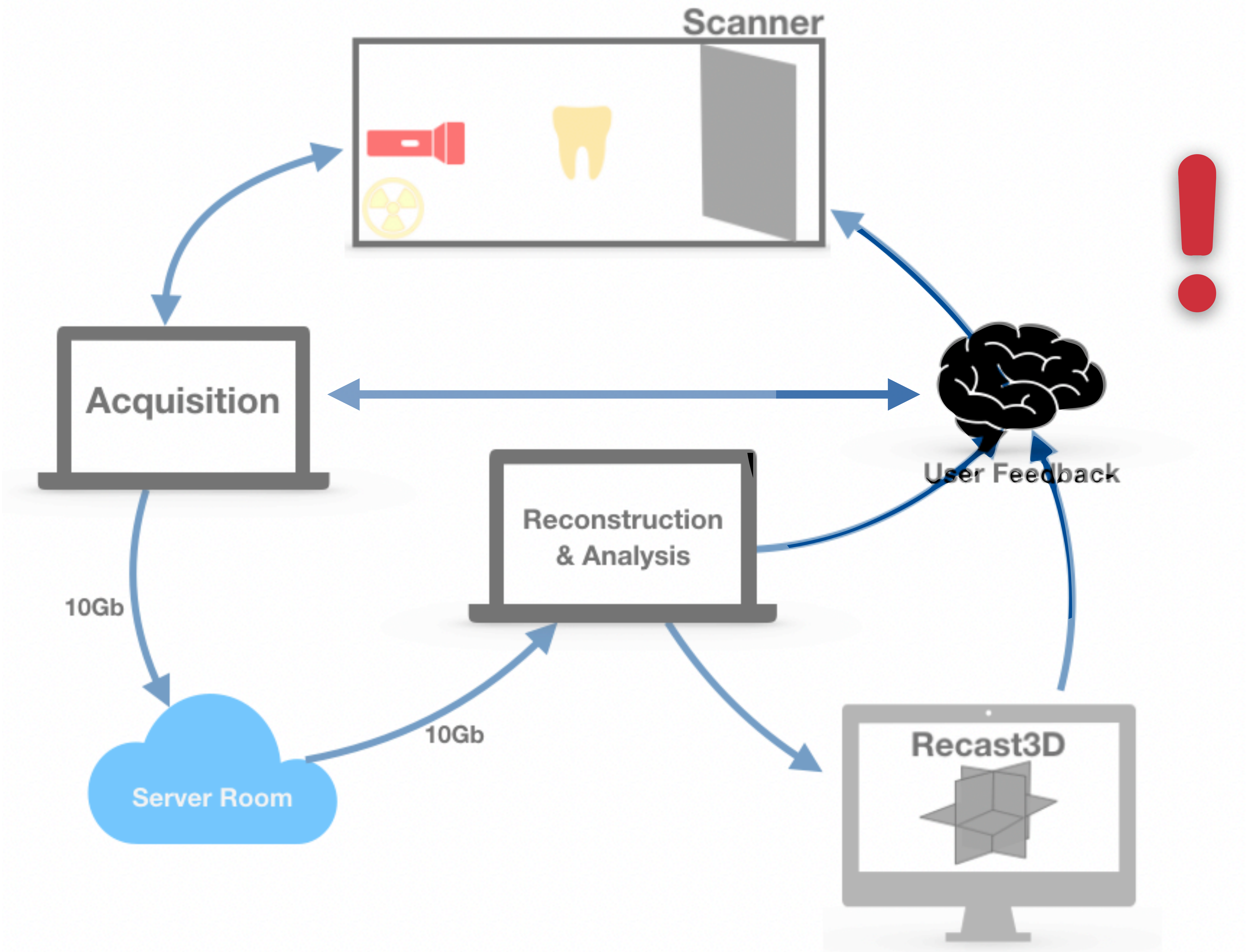
Explorative Imaging



Explorative Imaging

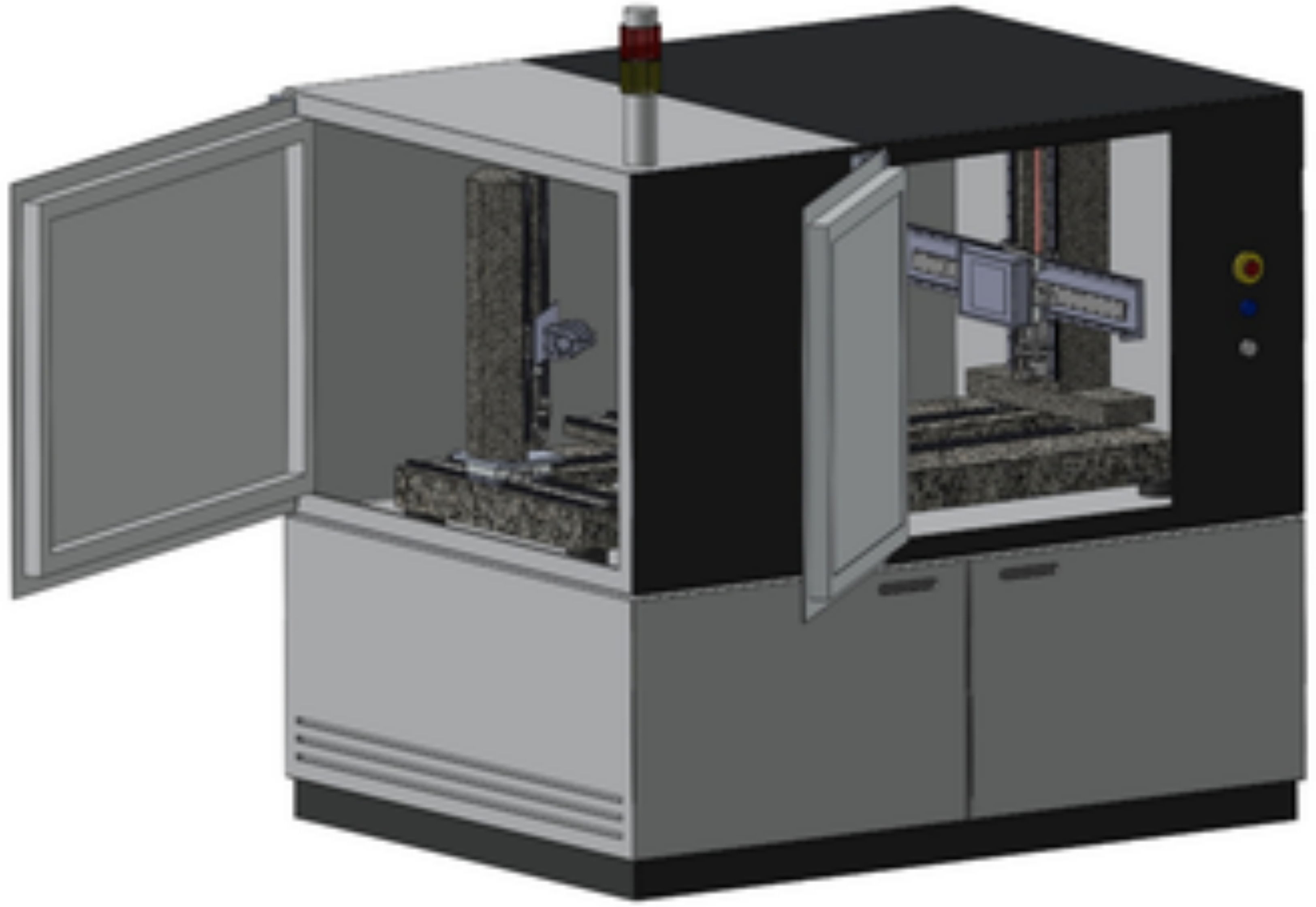


Explorative Imaging



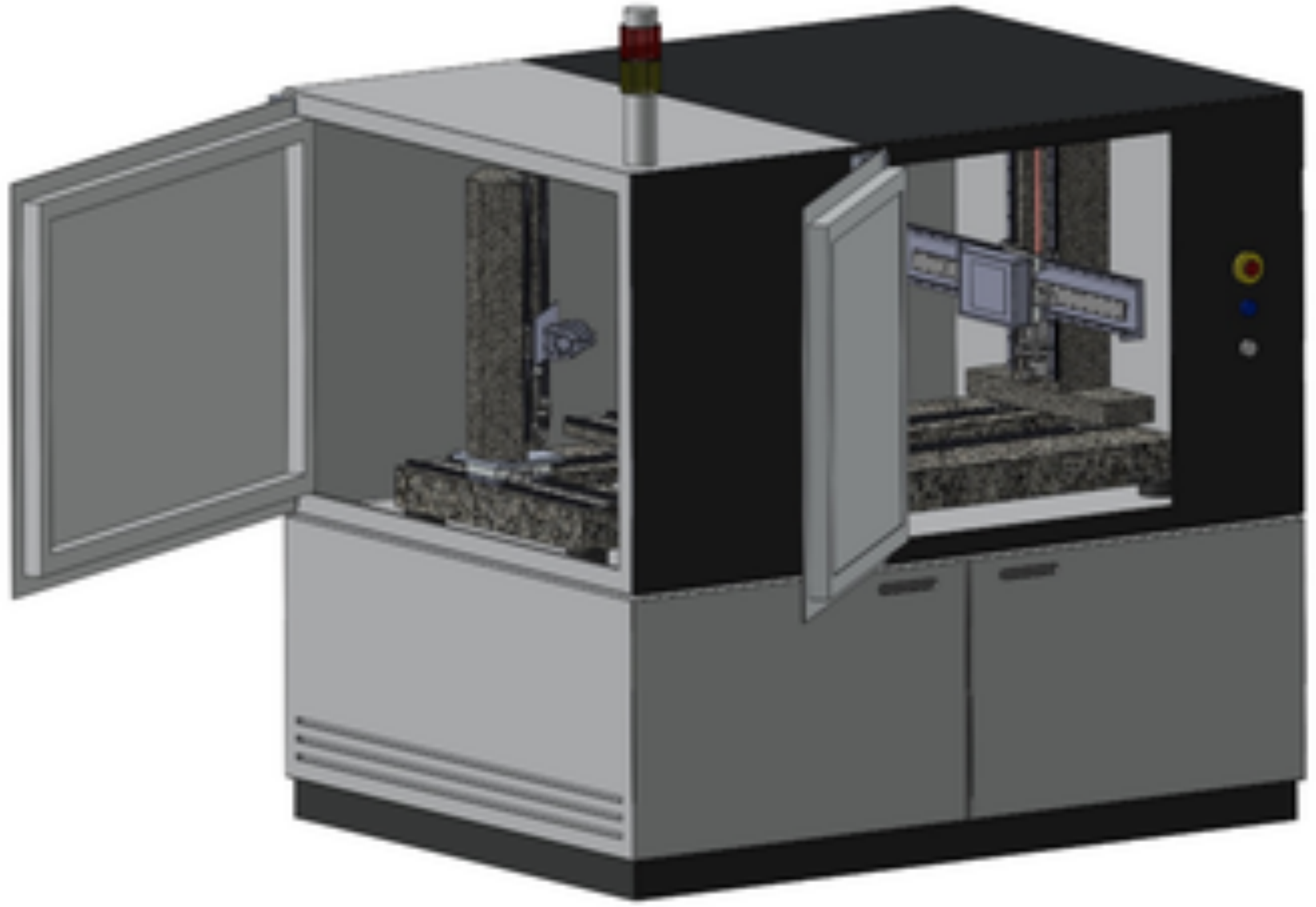
The FleX-Ray Laboratory

Introducing FleX-Ray Laboratory



Ten programmable motors in the full flexible setup.

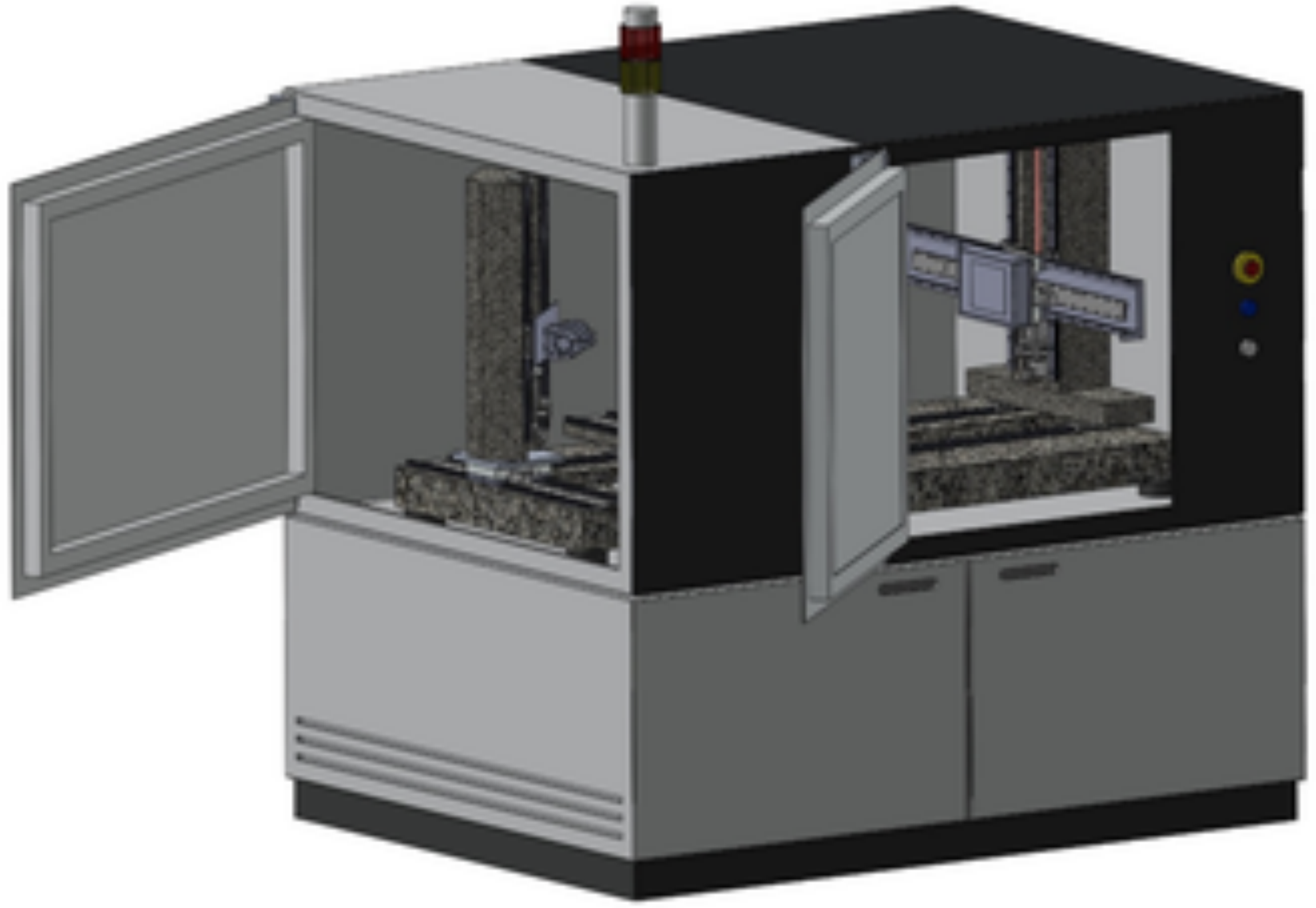
Introducing FleX-Ray Laboratory



XRE CWI NIKHEF

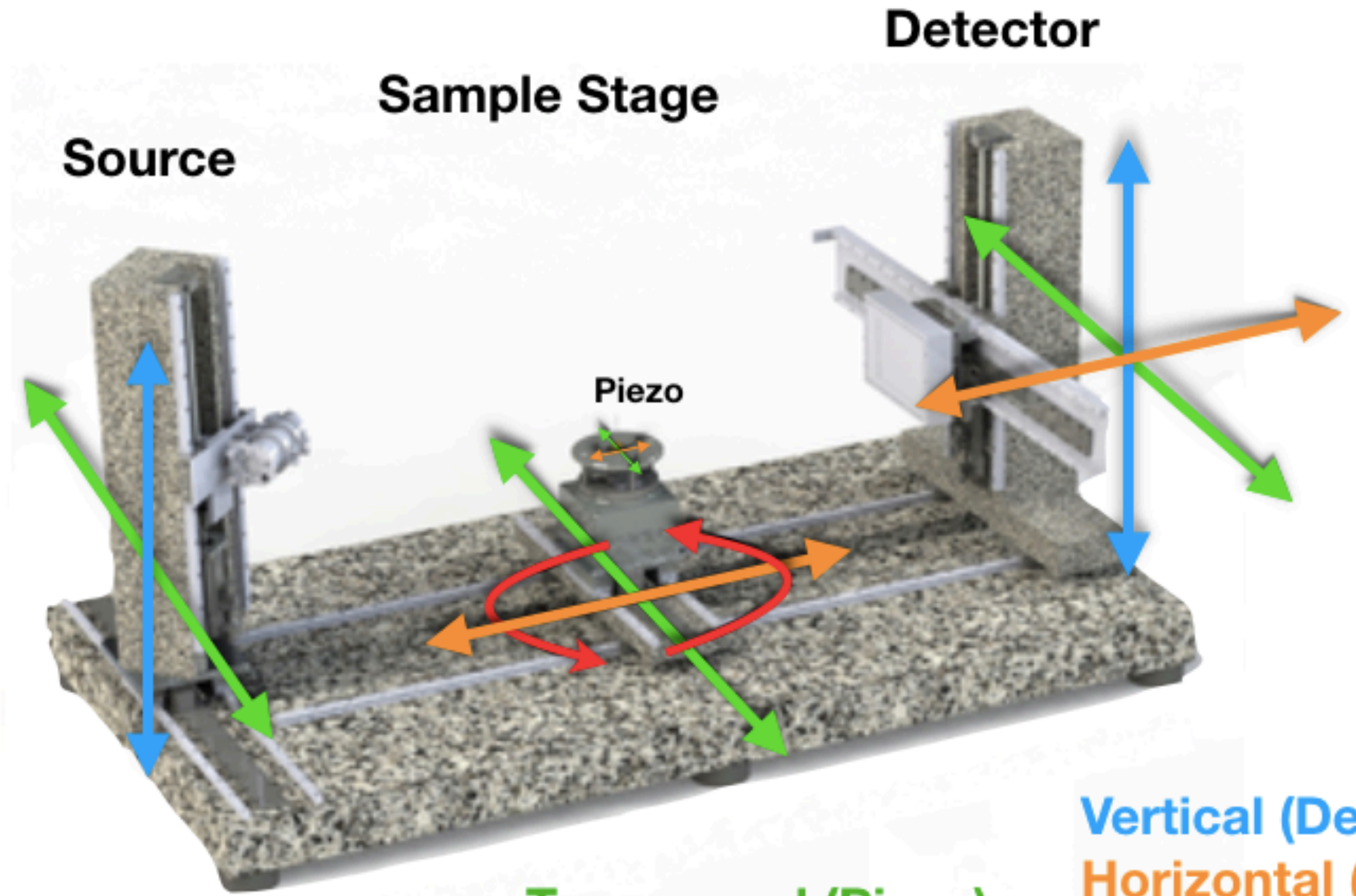
Real-time data streaming and almost-instantaneous reconstructions.

Introducing FleX-Ray Laboratory



Ability to incorporate additional components: Spectral detector.

Motors

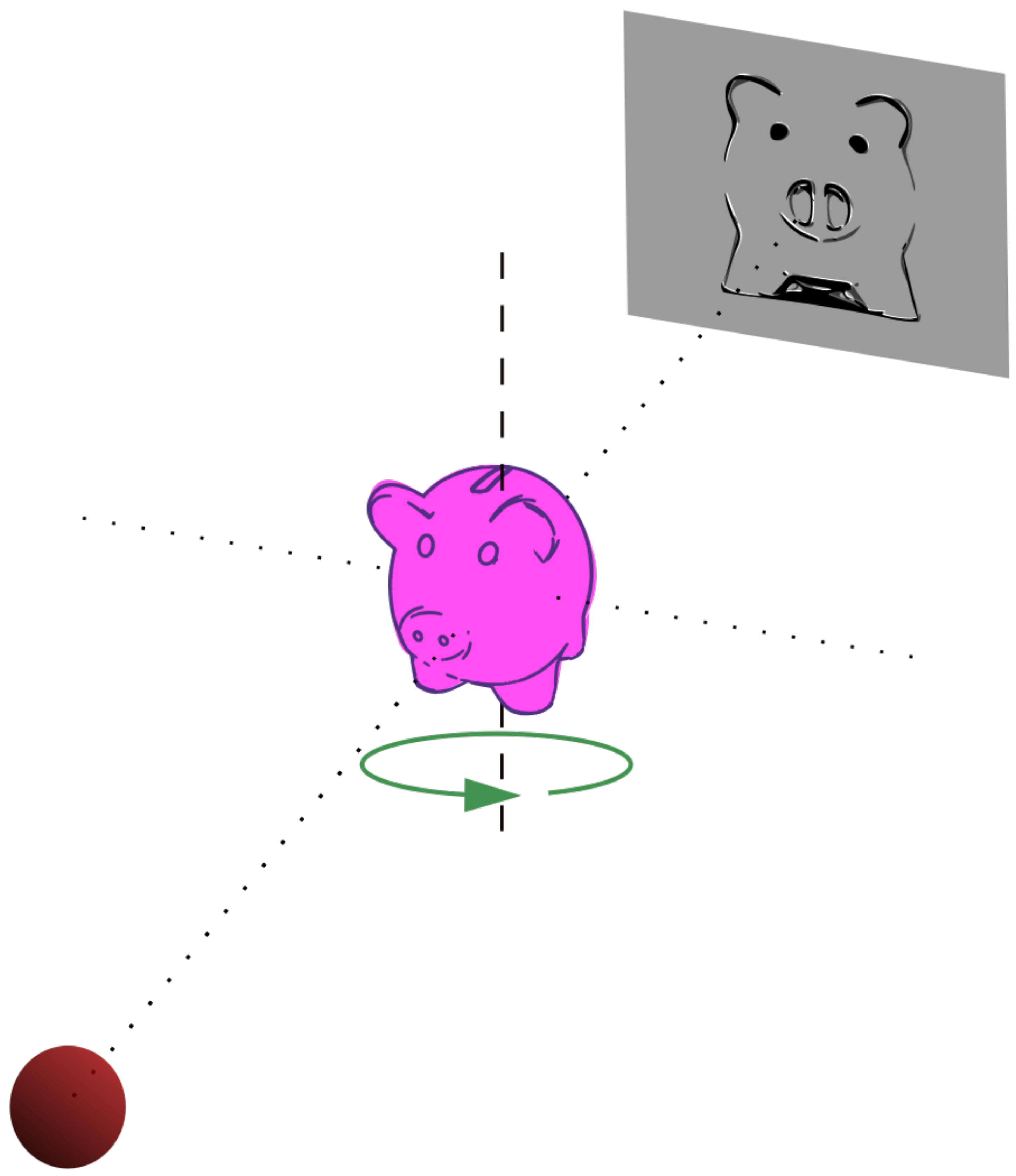


Vertical (Source)
Transversal (Source)

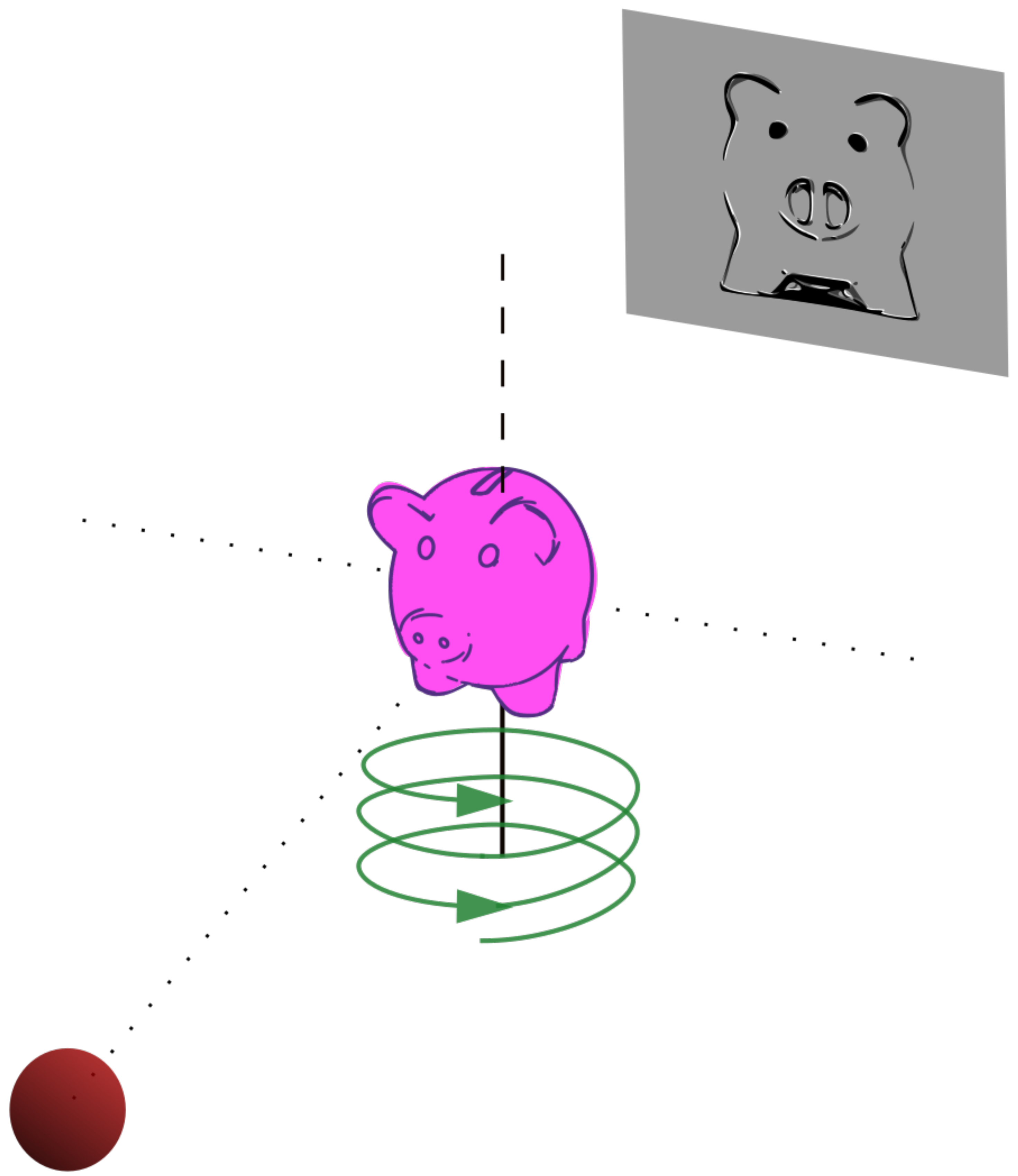
Transversal (Piezo)
Horizontal (Piezo)
Transversal (Sample)
Horizontal (Sample)
Rotational (Sample)

Vertical (Detector)
Horizontal (Detector)
Transversal (Detector)

Motors

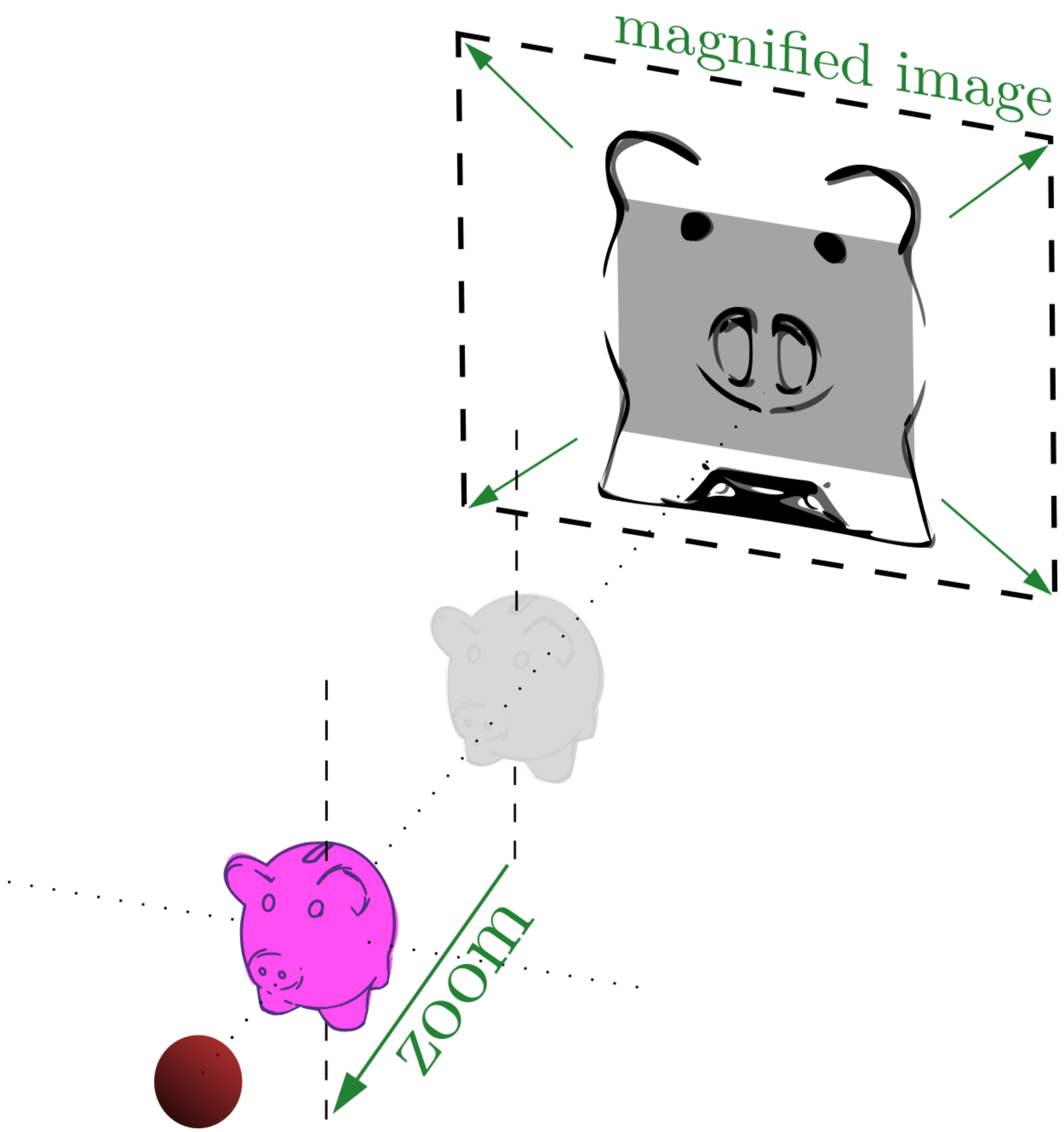


Circular

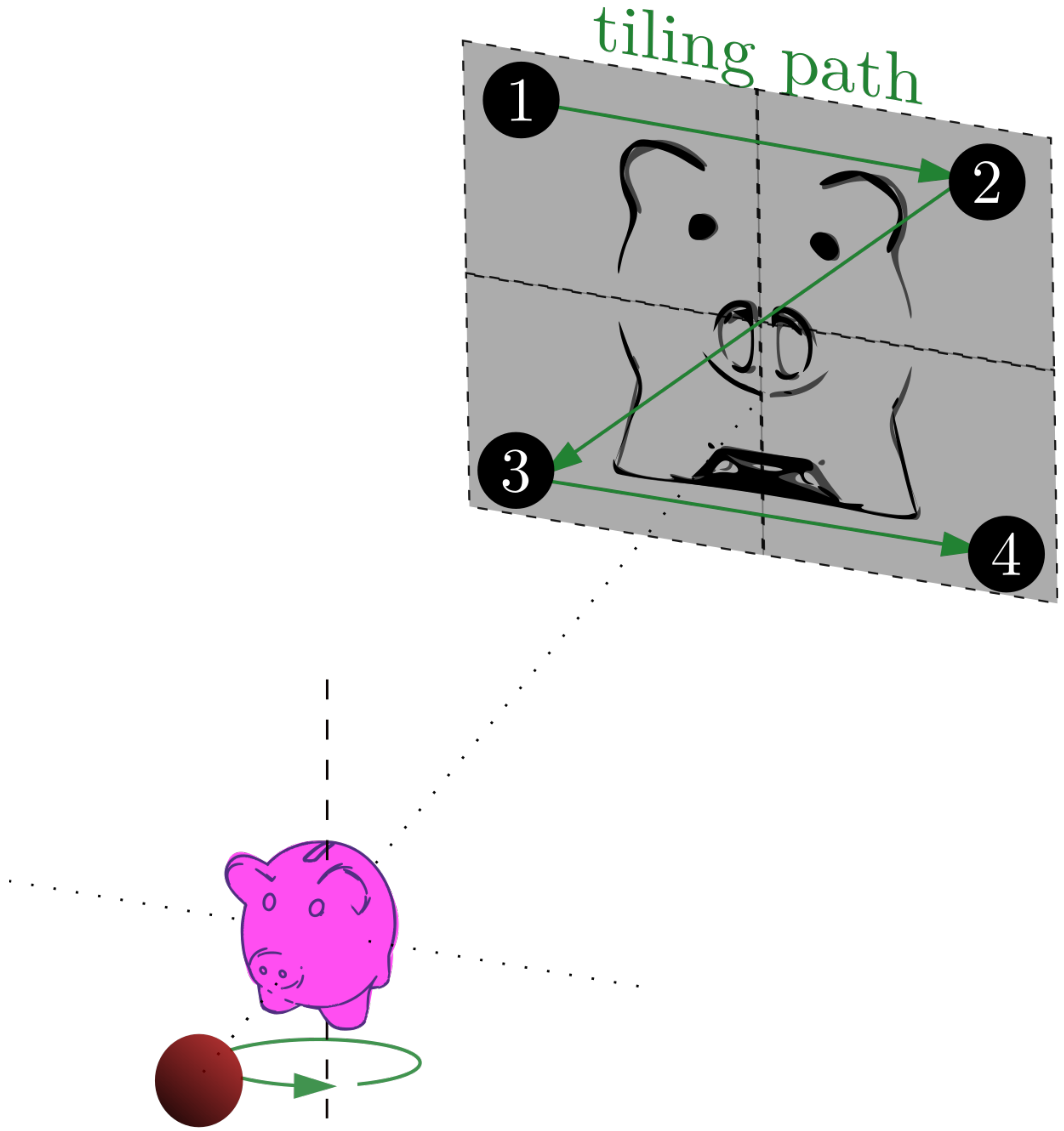


Helical

Motors

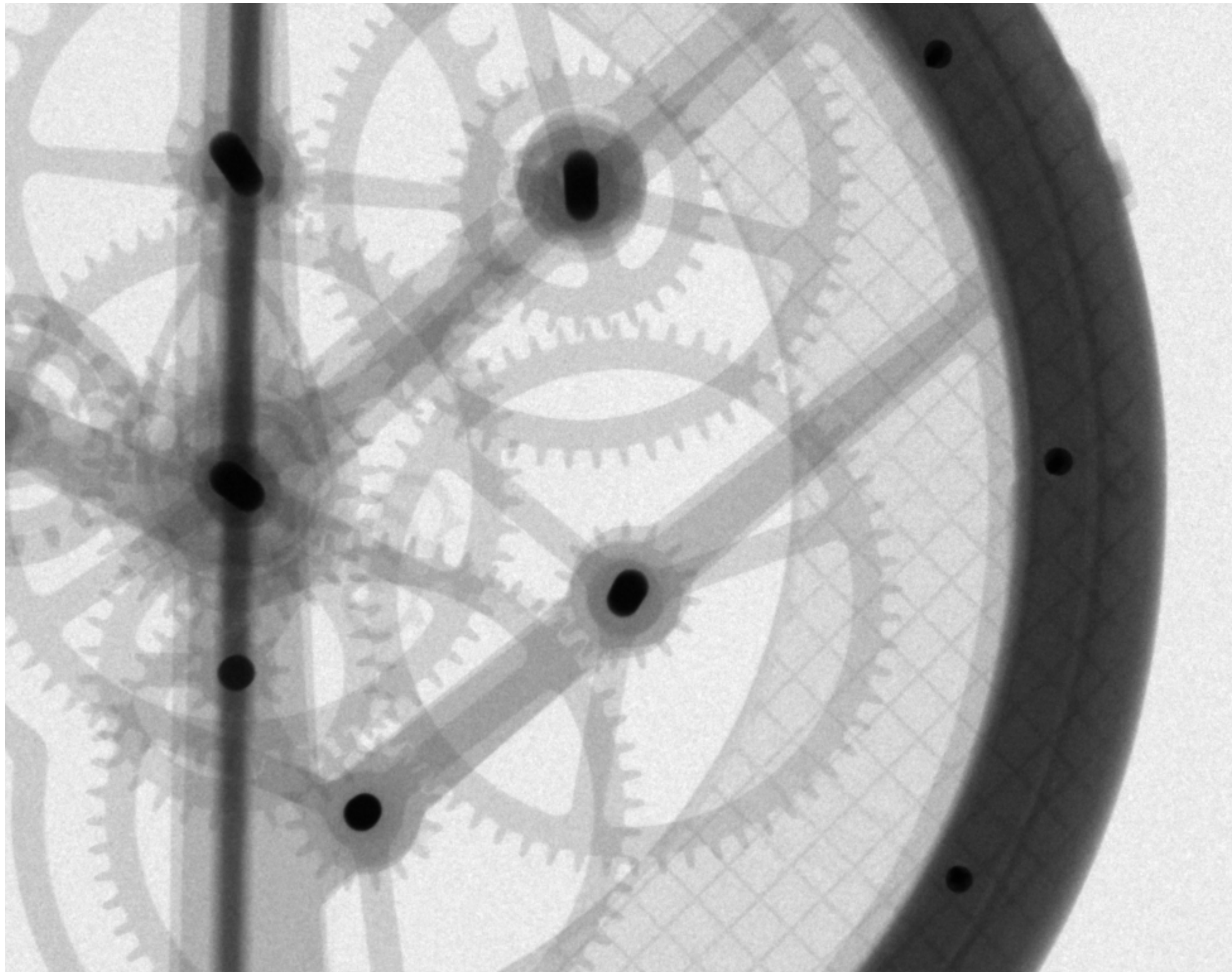


Zoom in



Tile in detector plane

Motors

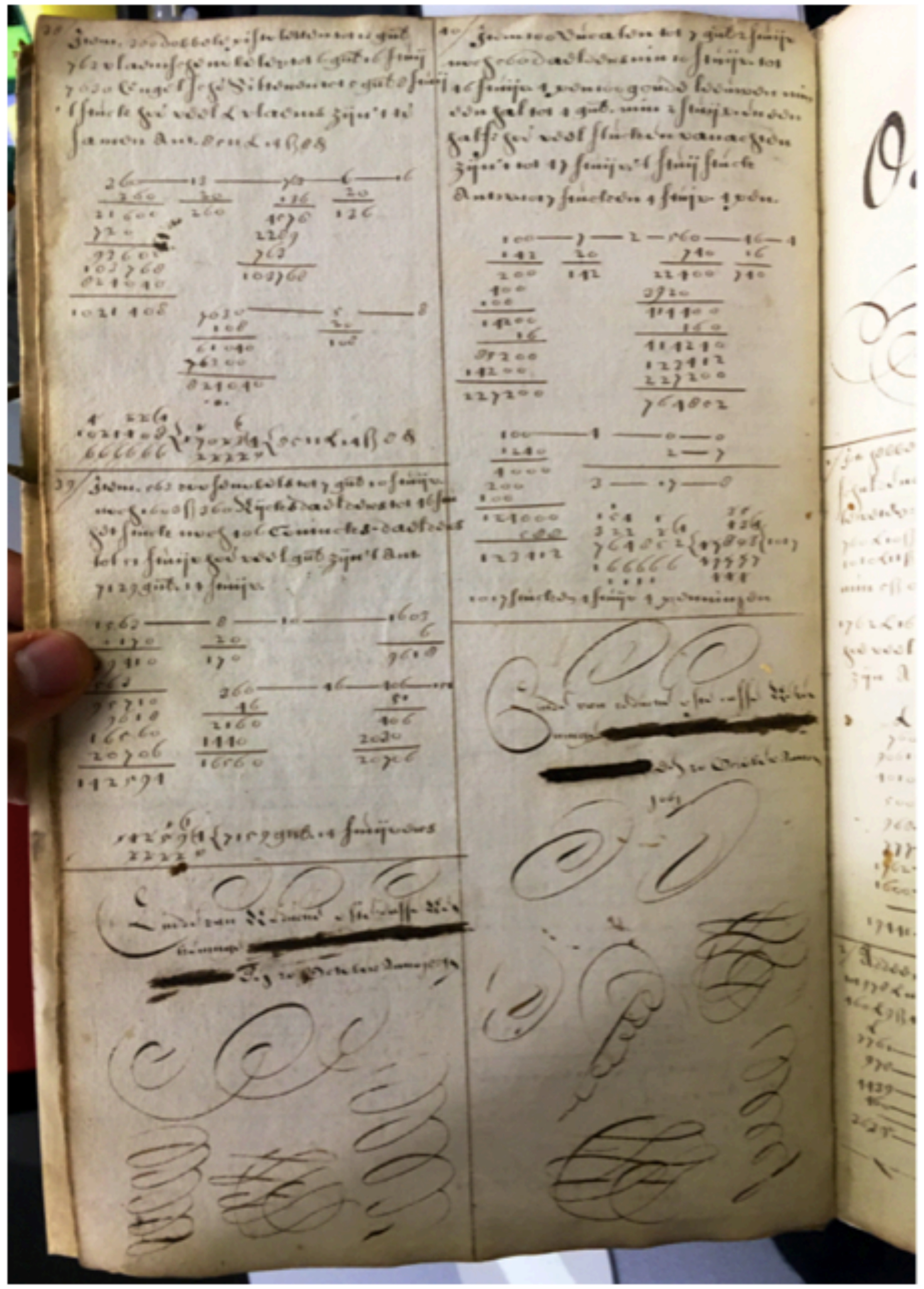


Latest imaging news from the ground floor


CWI
Kinder

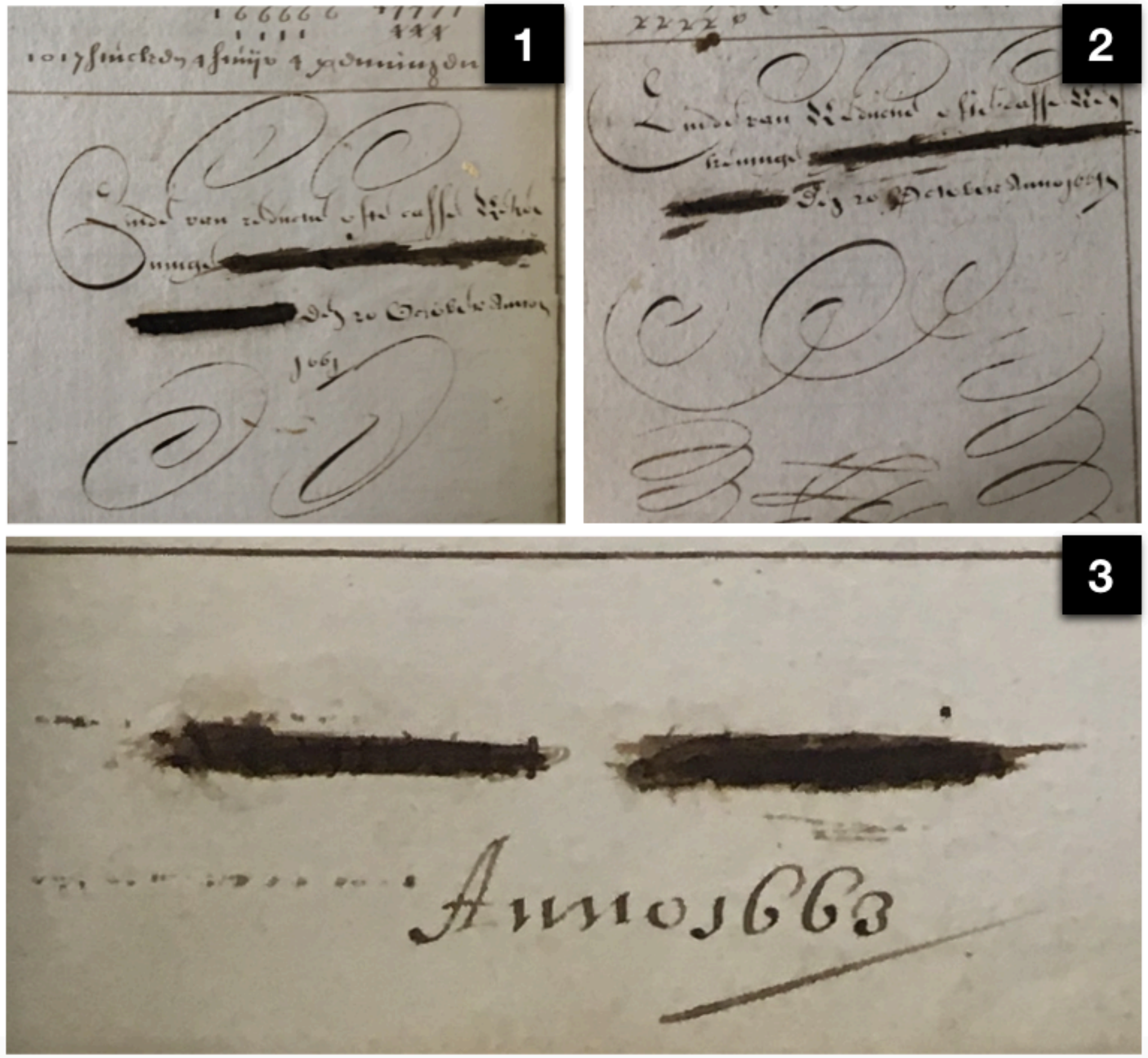
Recovering the name of an author

Problem Description

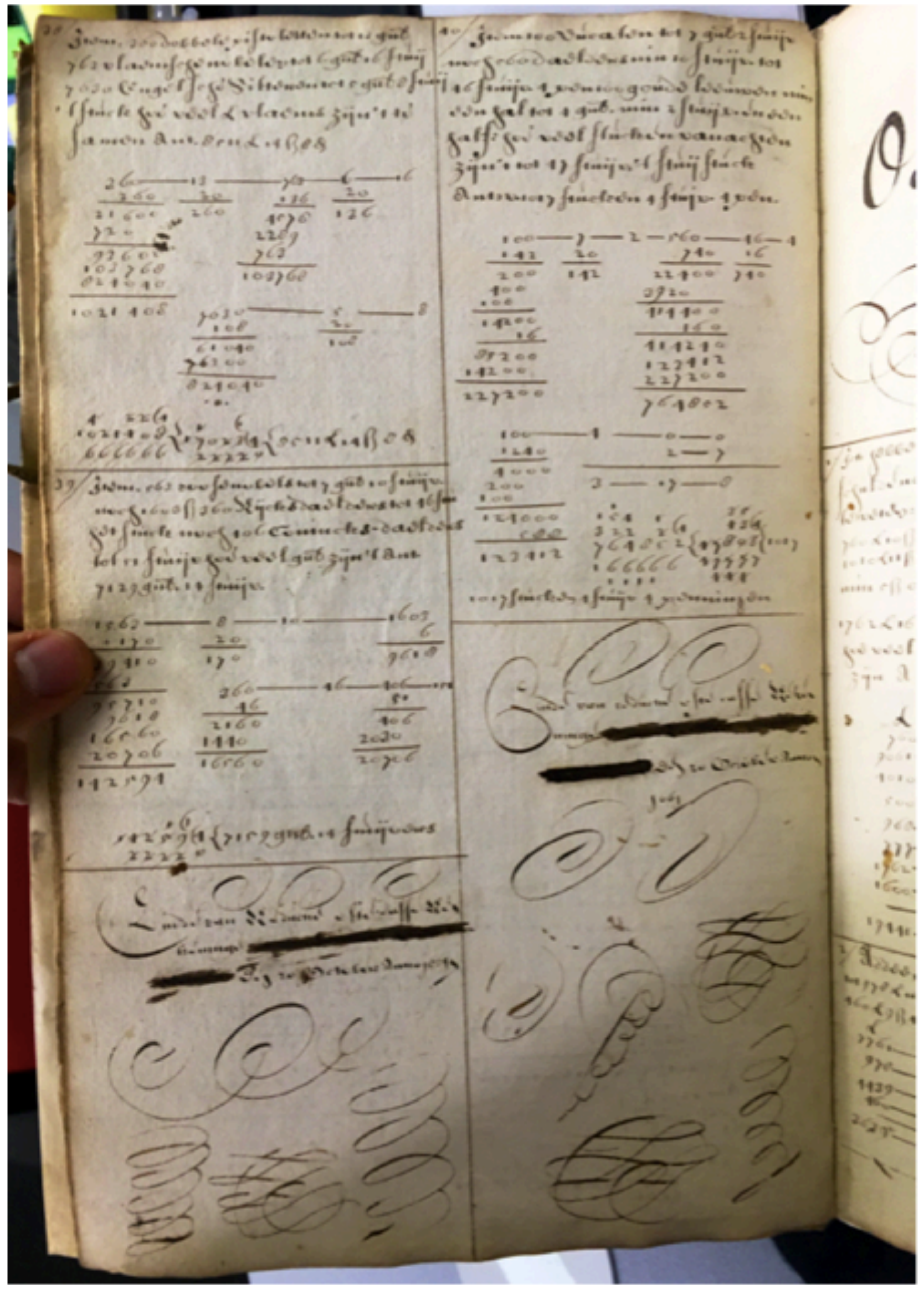


The dating of chapters and the consistent handwriting suggests a single author, produced between 1661 and 1664.

18 signatures, all crossed out.



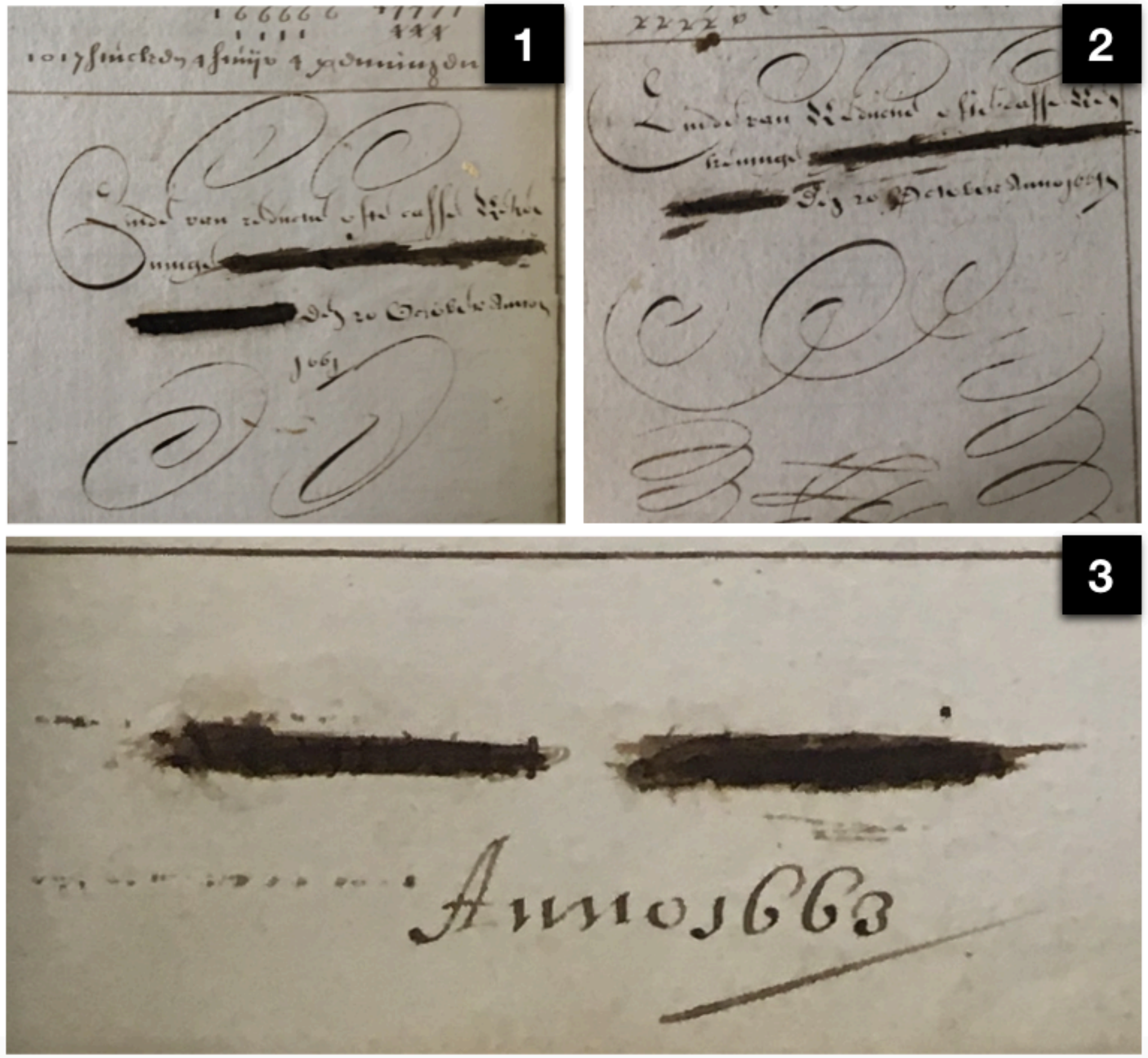
Problem Description



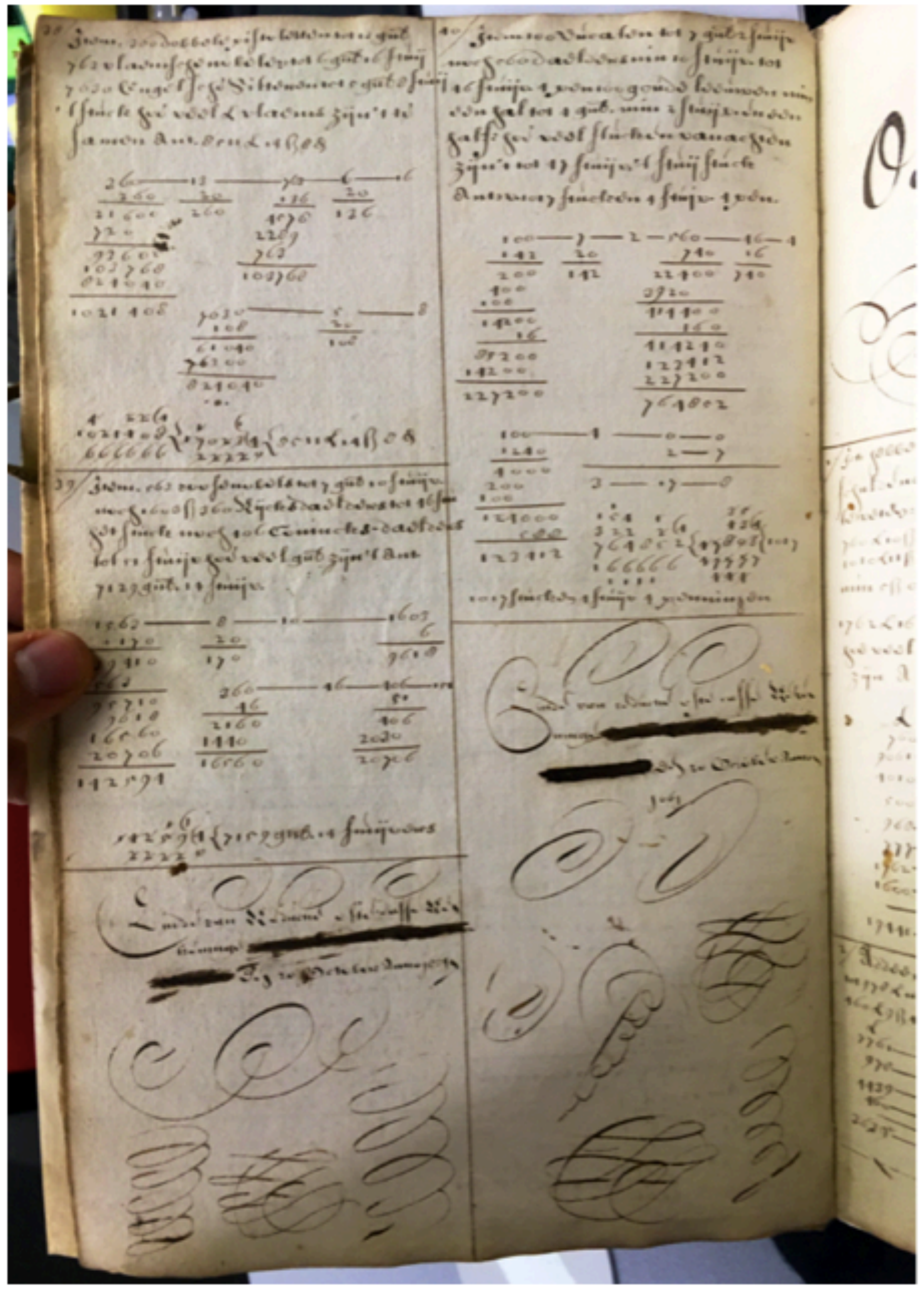
Two different iron gall inks.

Differing chemical compositions: second is from late 18th to early 20th century.

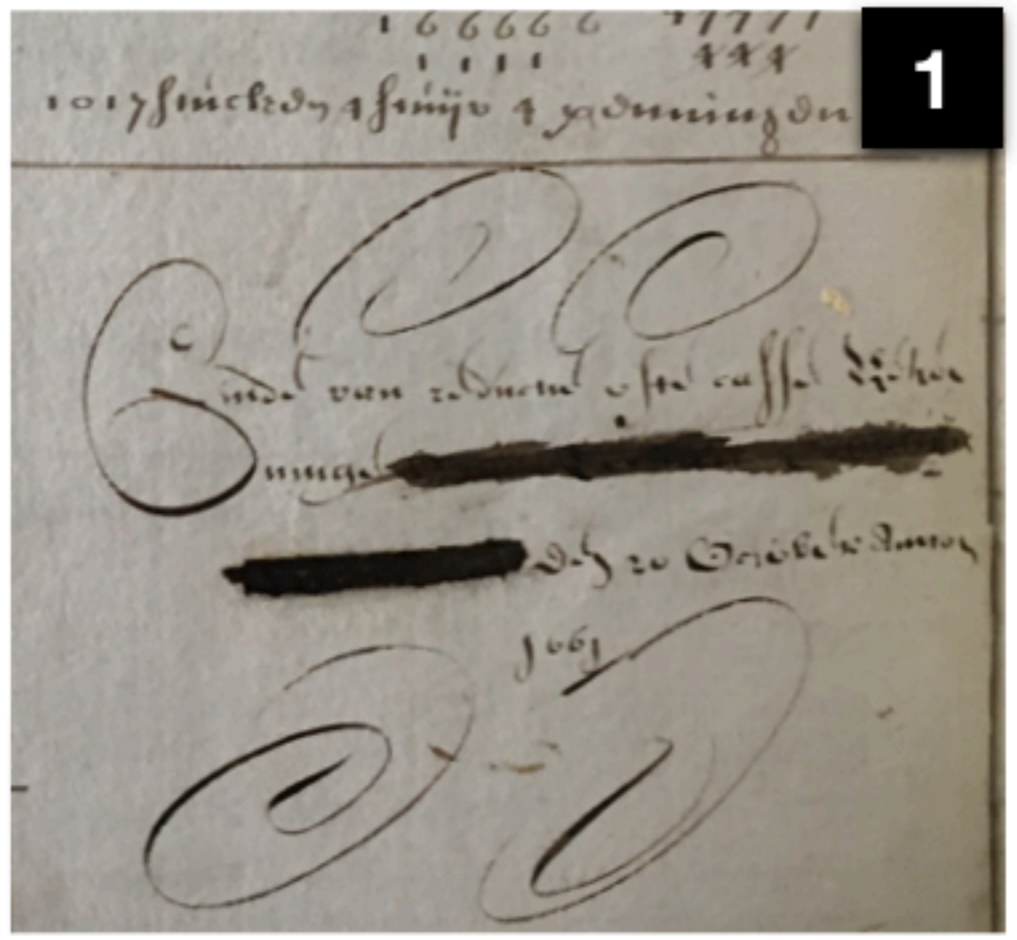
Original ink contains more metal, coincides with the usage in 17th century.

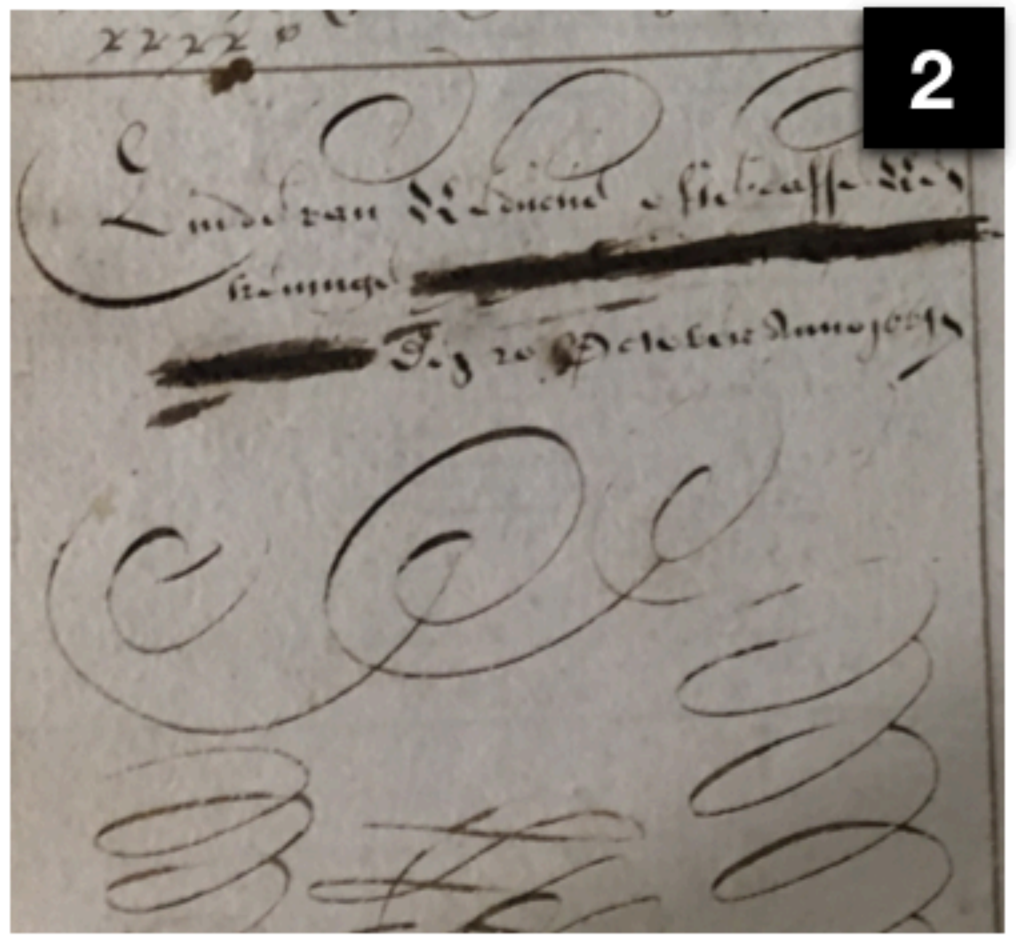


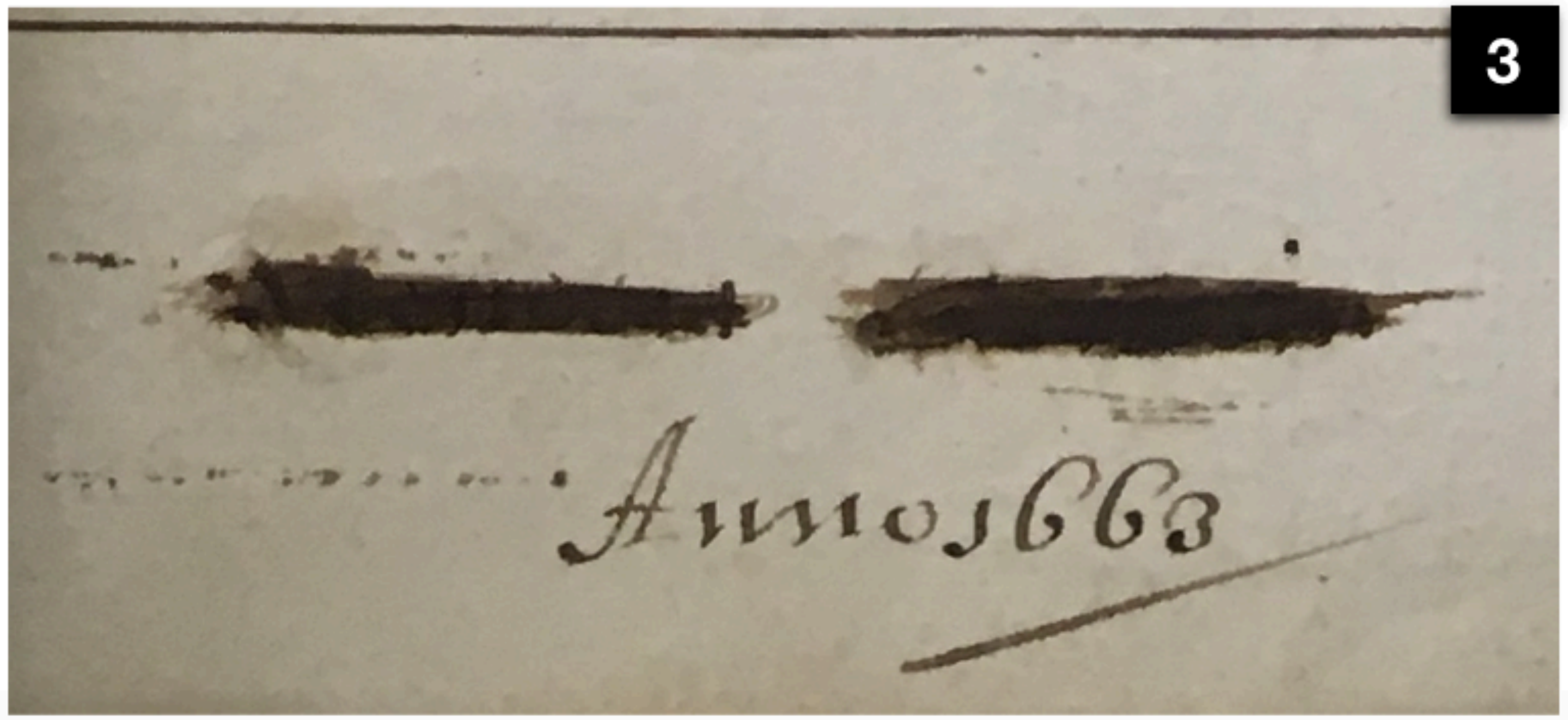
Problem Description



In contrast we have two layers of ink, and a laboratory X-ray absorption imaging...

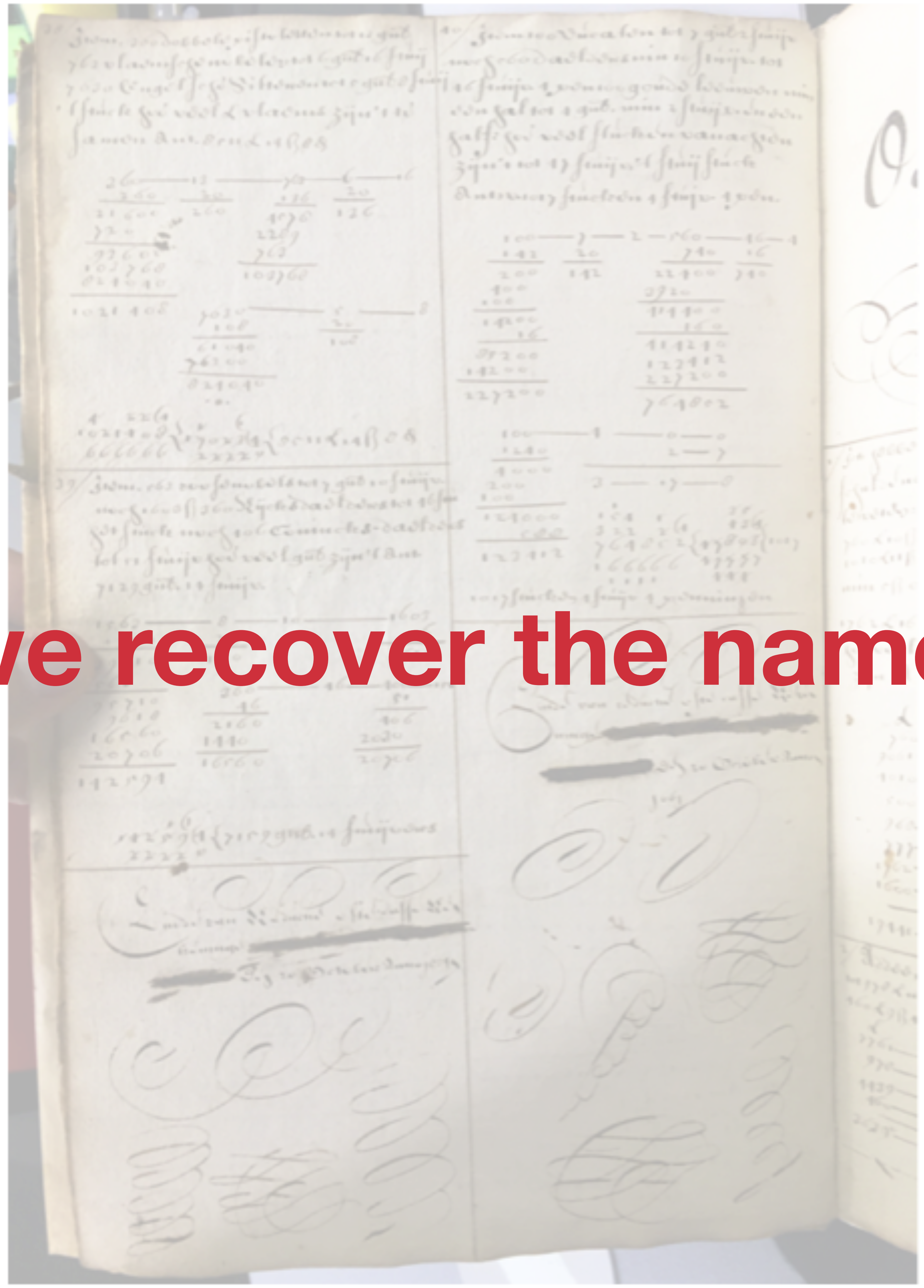


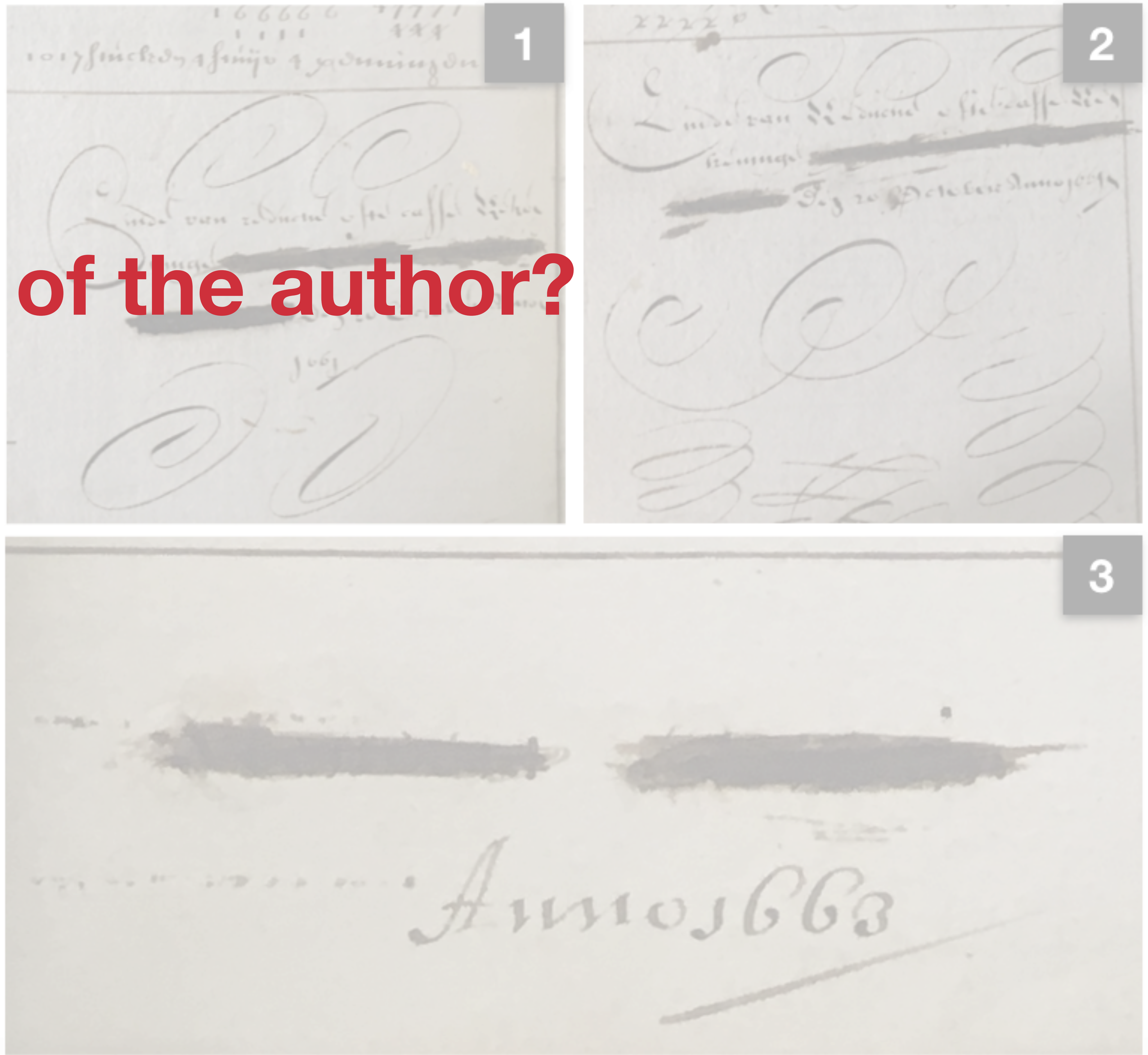




Uncovering writings in old manuscripts is done using X-ray florescence or phase contrast in synchrotrons.

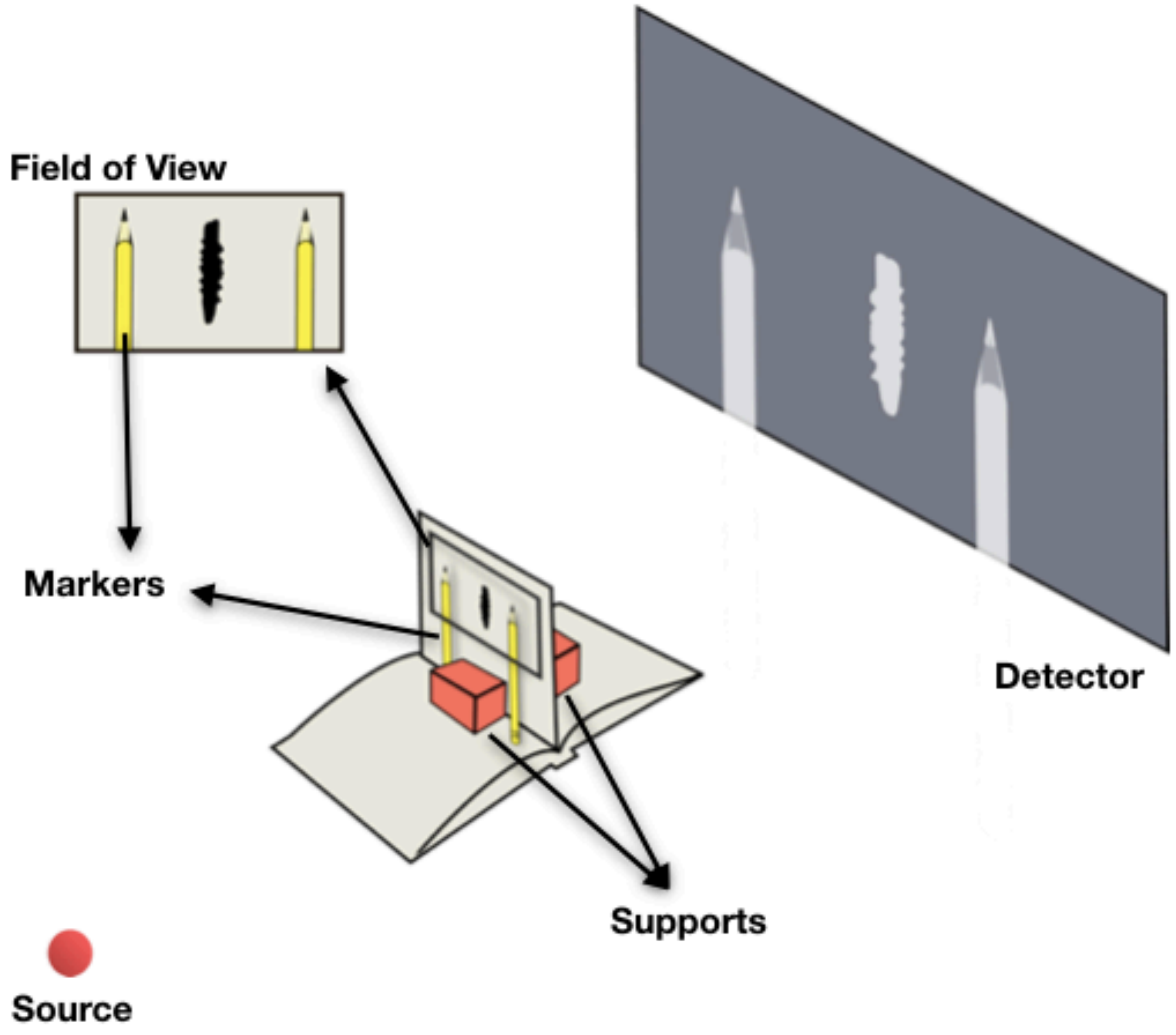
Problem Description

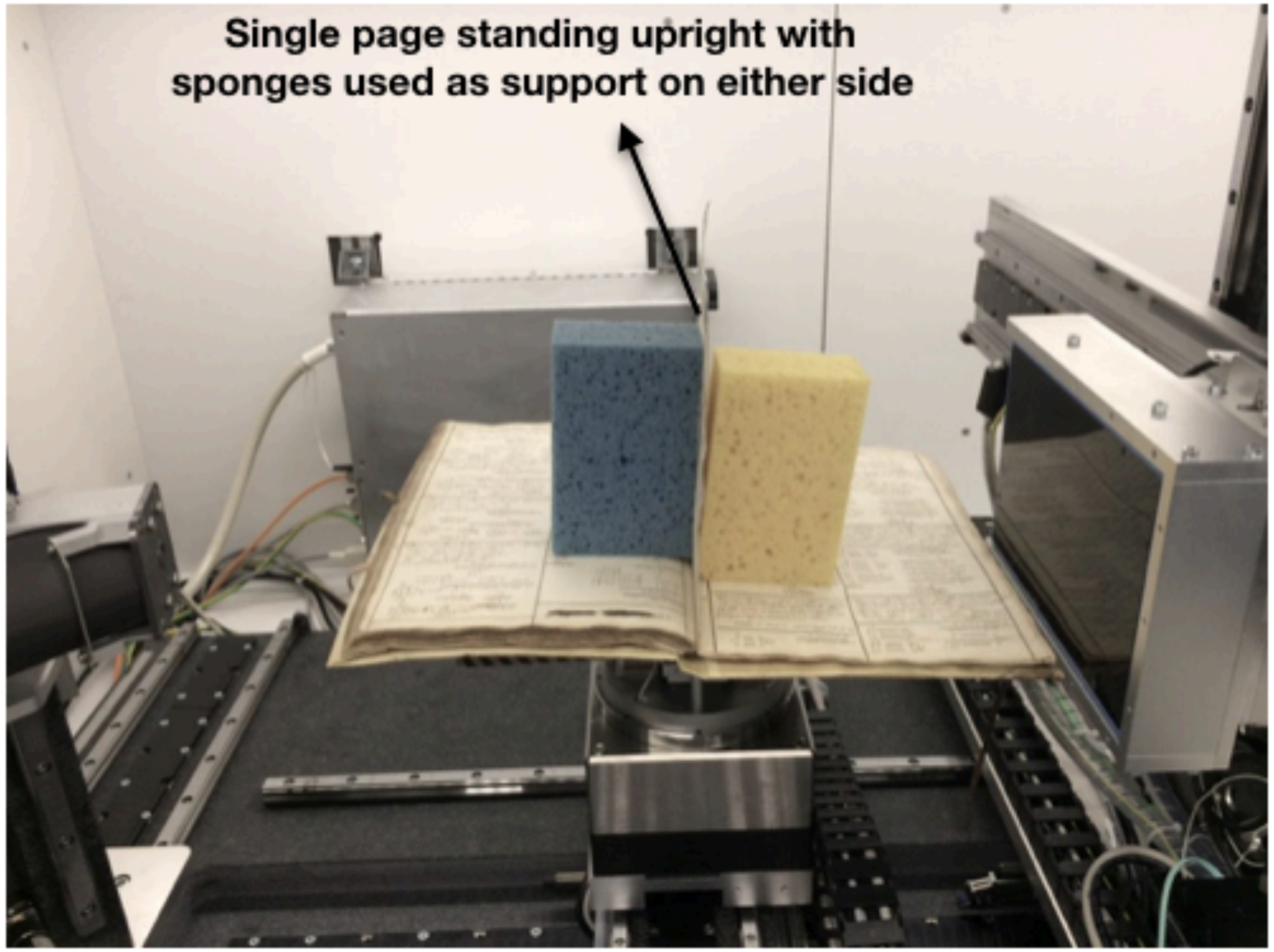




Can we recover the name of the author?

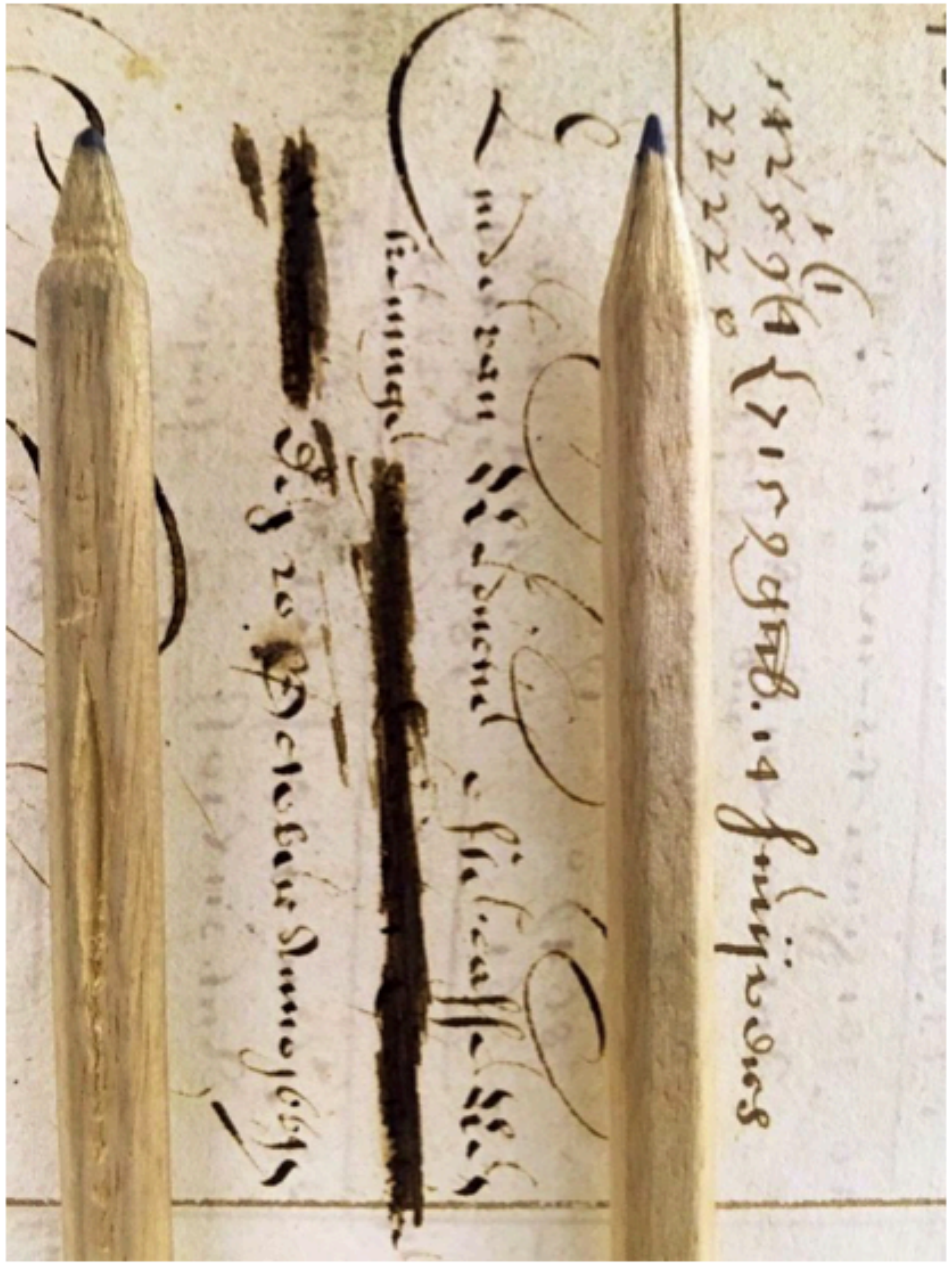
Experimental Plan

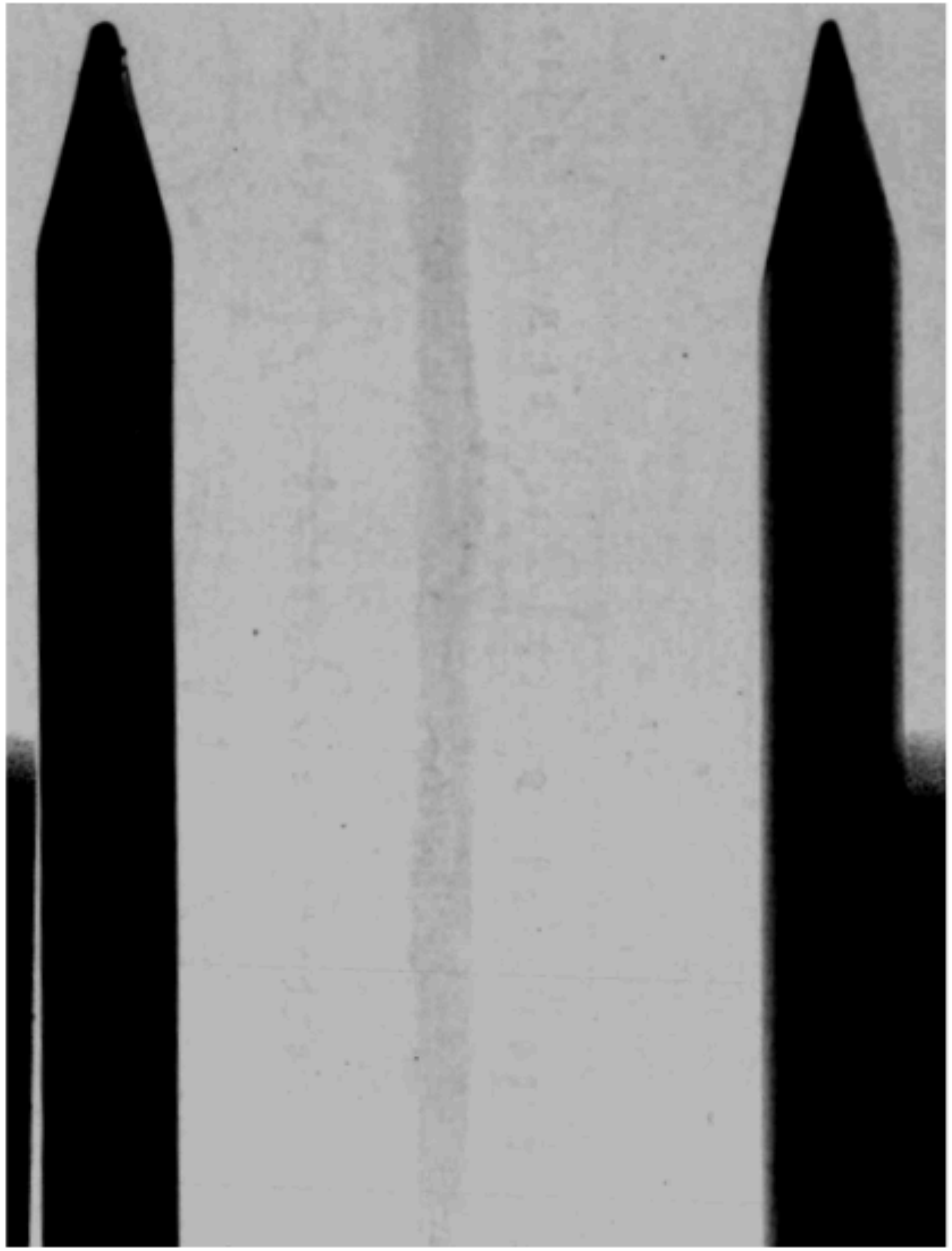




Only allowed to move the tube and detector up/down or sideways.

Experimental Plan





Action Plan

Due to sample fragility, take 2D radiographs of 18 locations.

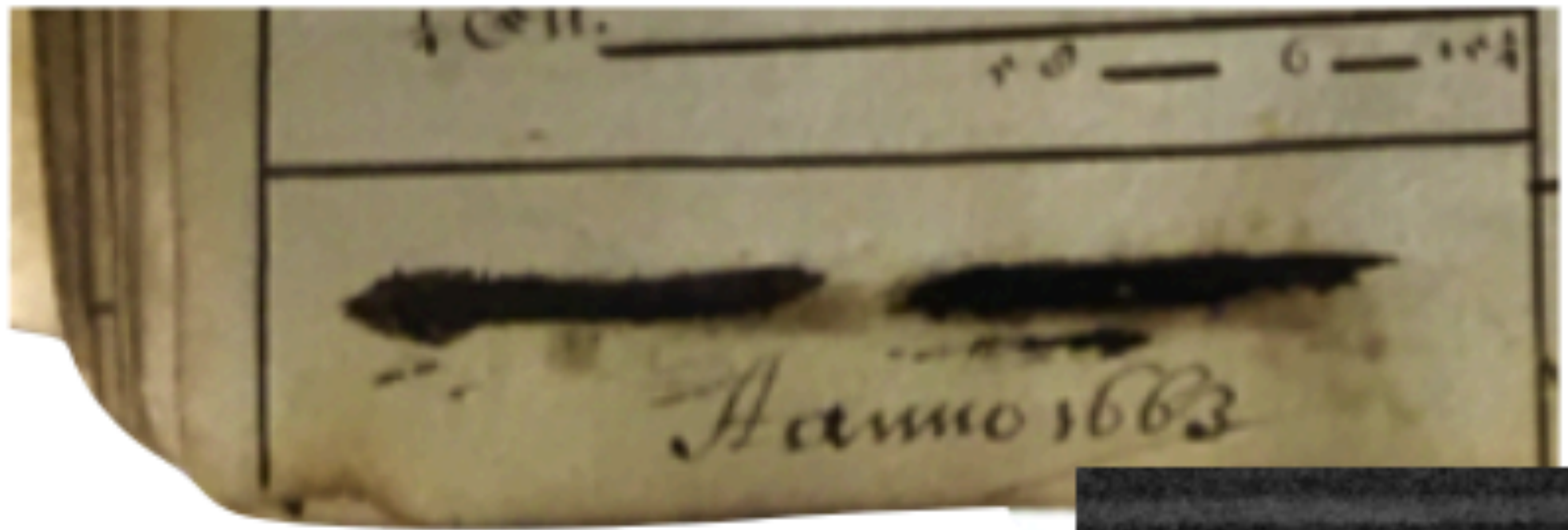
Collect high quality radiographs at various energy levels and exposure.

Automate the image processing, extract information from processed radiographs.

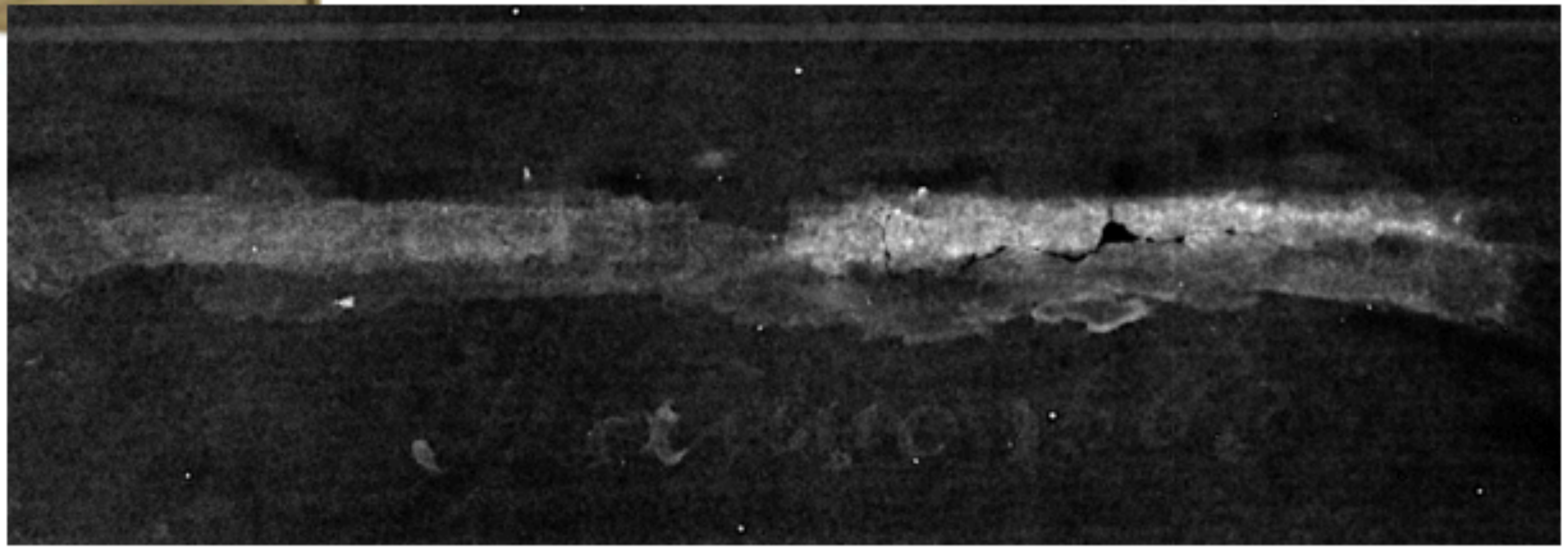
Correlate corresponding letters to recover full name of author.

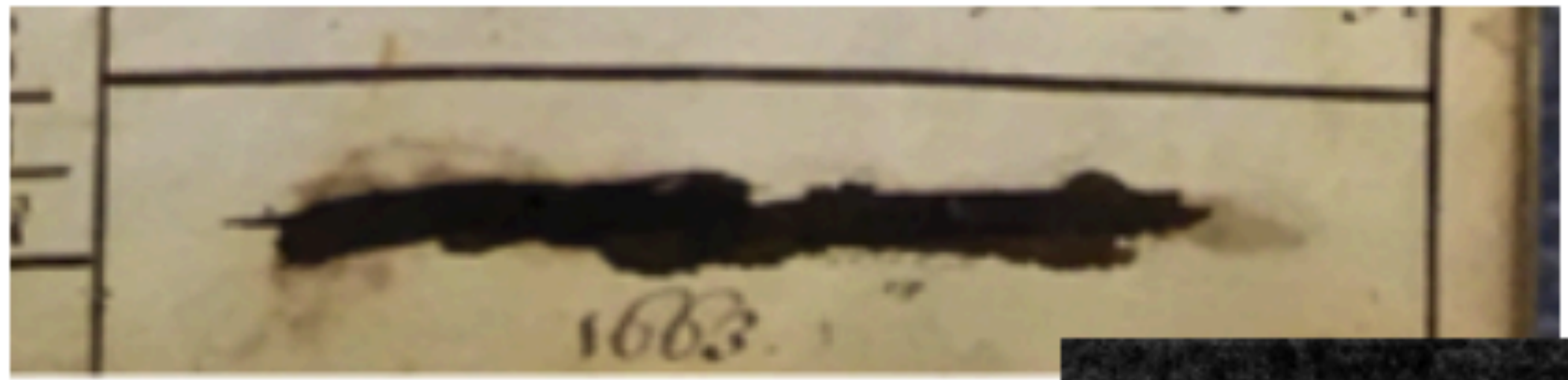
A fun inverse problem in itself: **Relies heavily on quality of input data...**

False positives?

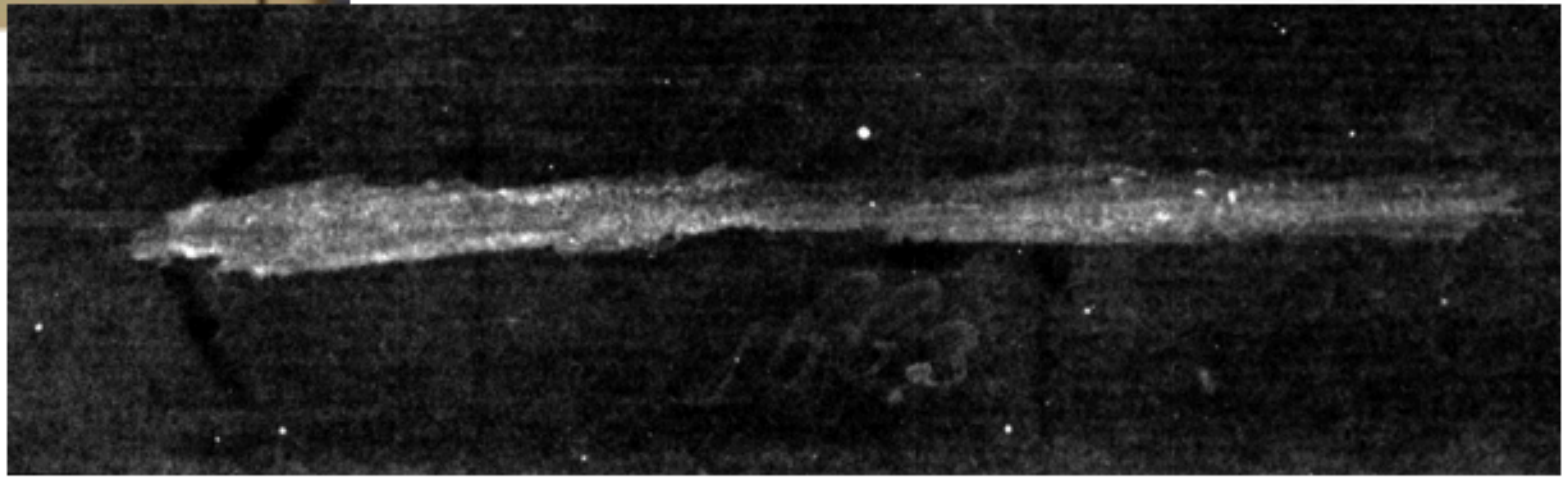


Torn or damaged pages

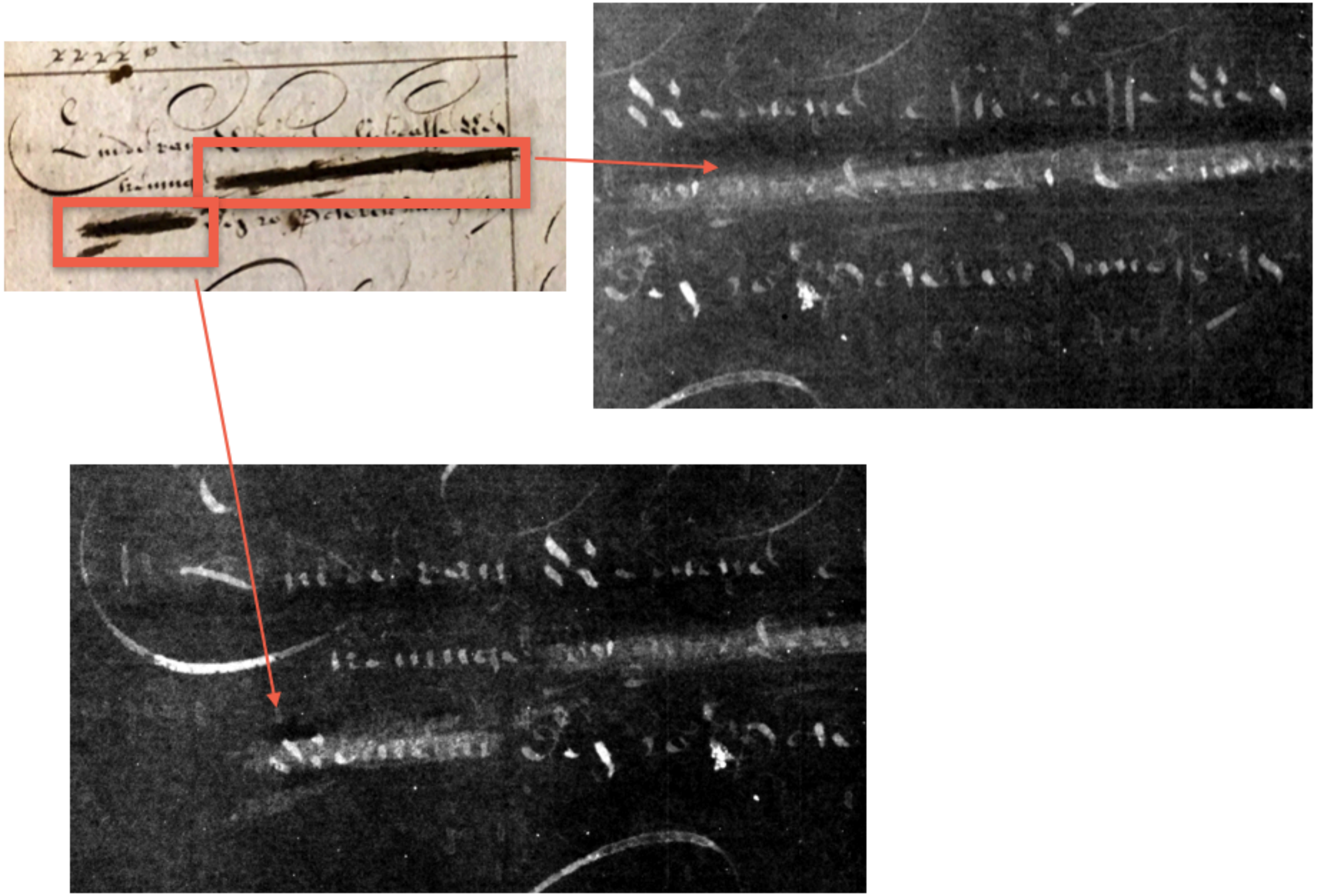


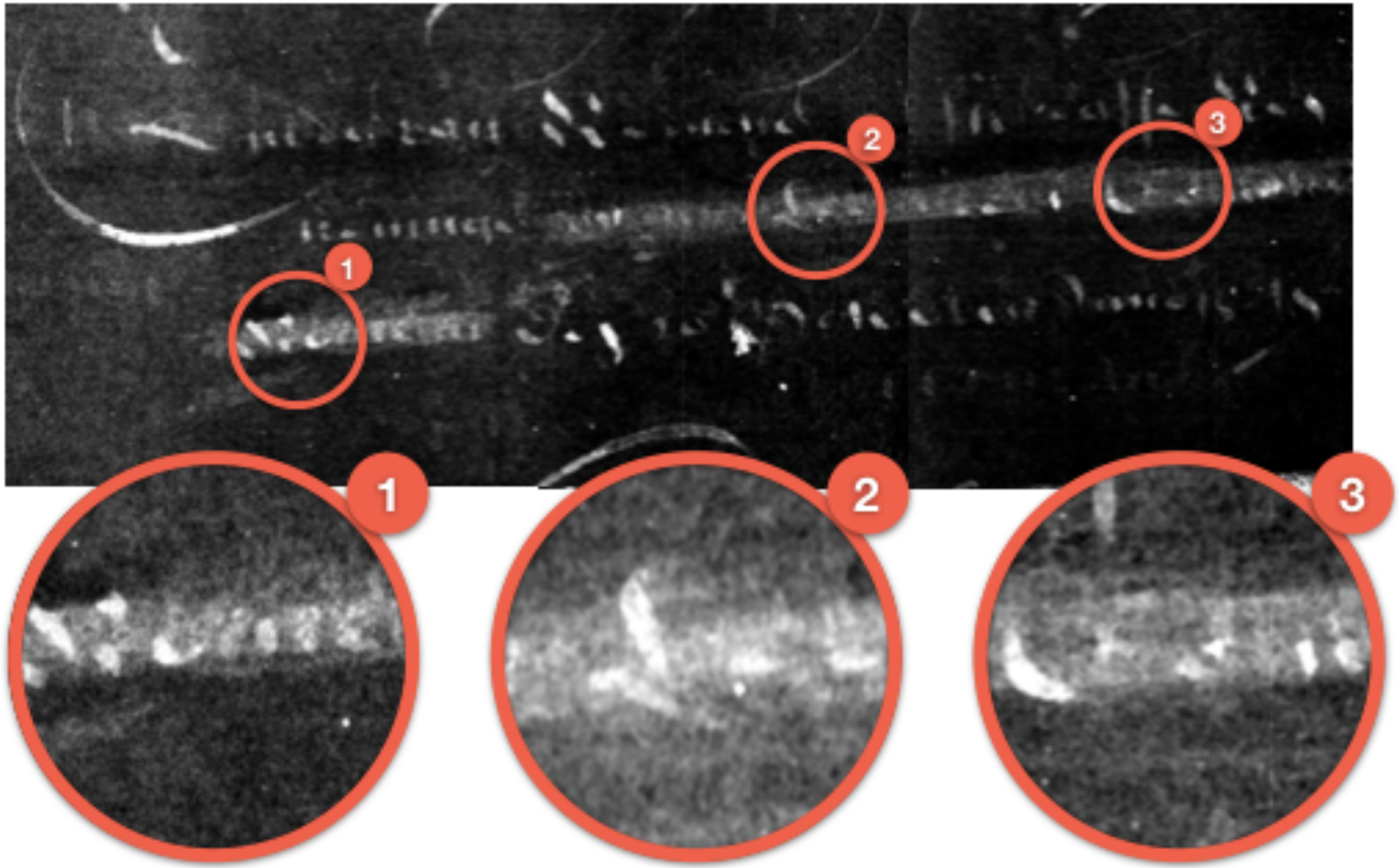


No signatures



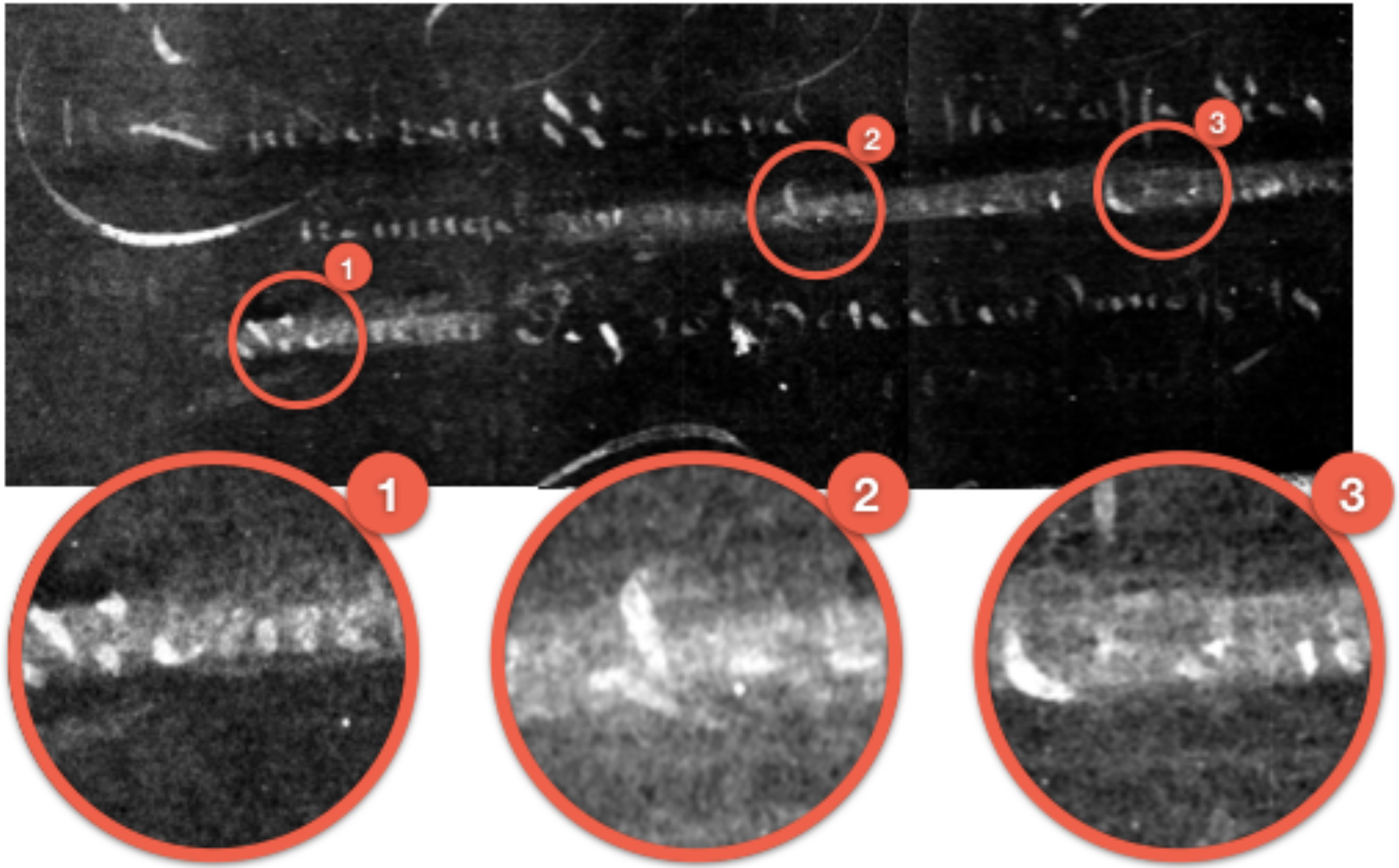
Results





Mon or Rom *Lea or Lee* *Cor or Coe*

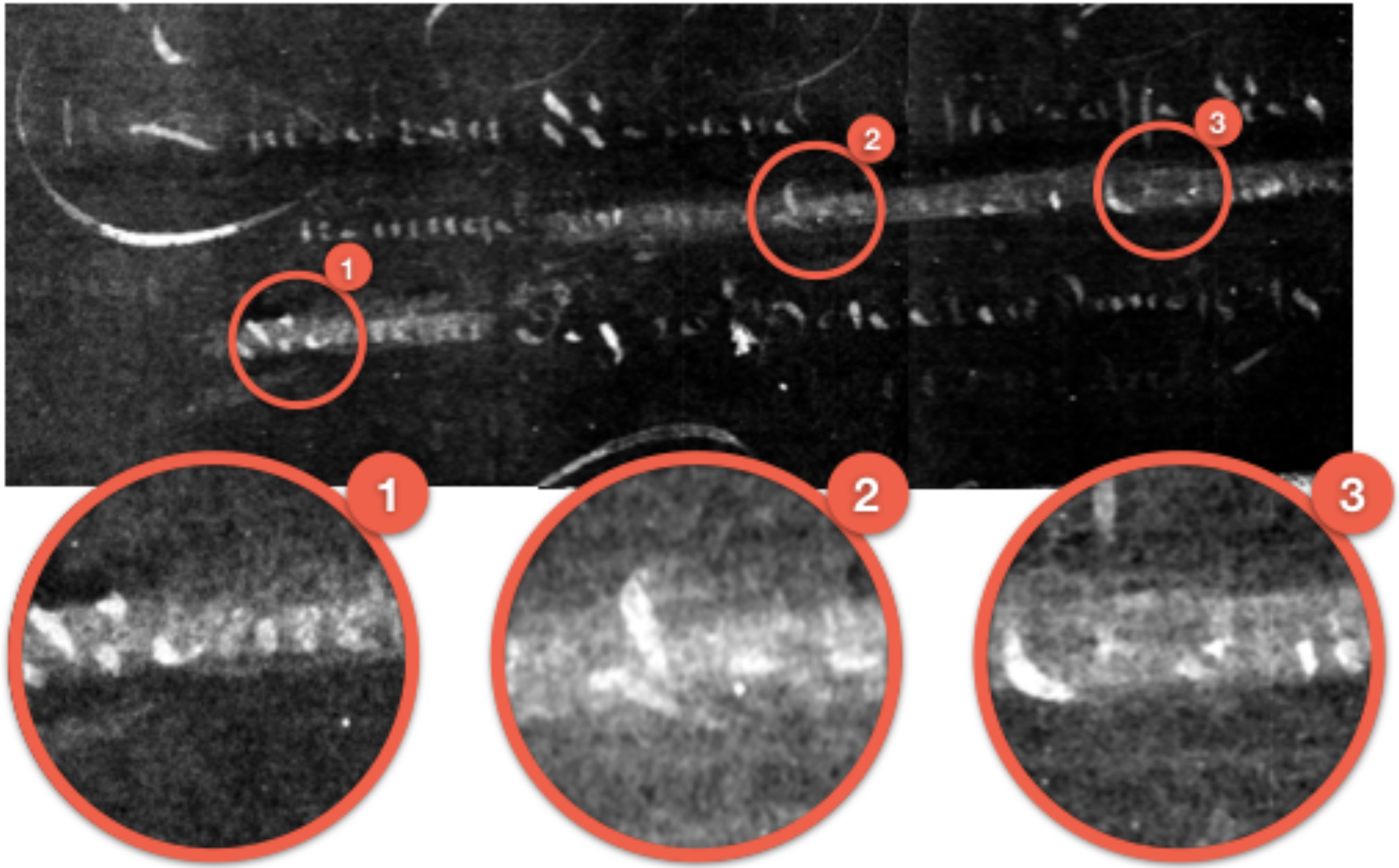
Leendert Cornelisse Romeijn



The national archives contain a certain individual with the name **Leendert Romeijn**.

Leendert lived in Rotterdam and had 6 children. One of his sons was named *Cornelis Romeijn*!

Leendert was a trader.



Expert feedback invaluable.

Could automation have been viable in the absence of expert feedback?

Could a machine learn to rule out a false positive?

Adapting geometry during acquisition

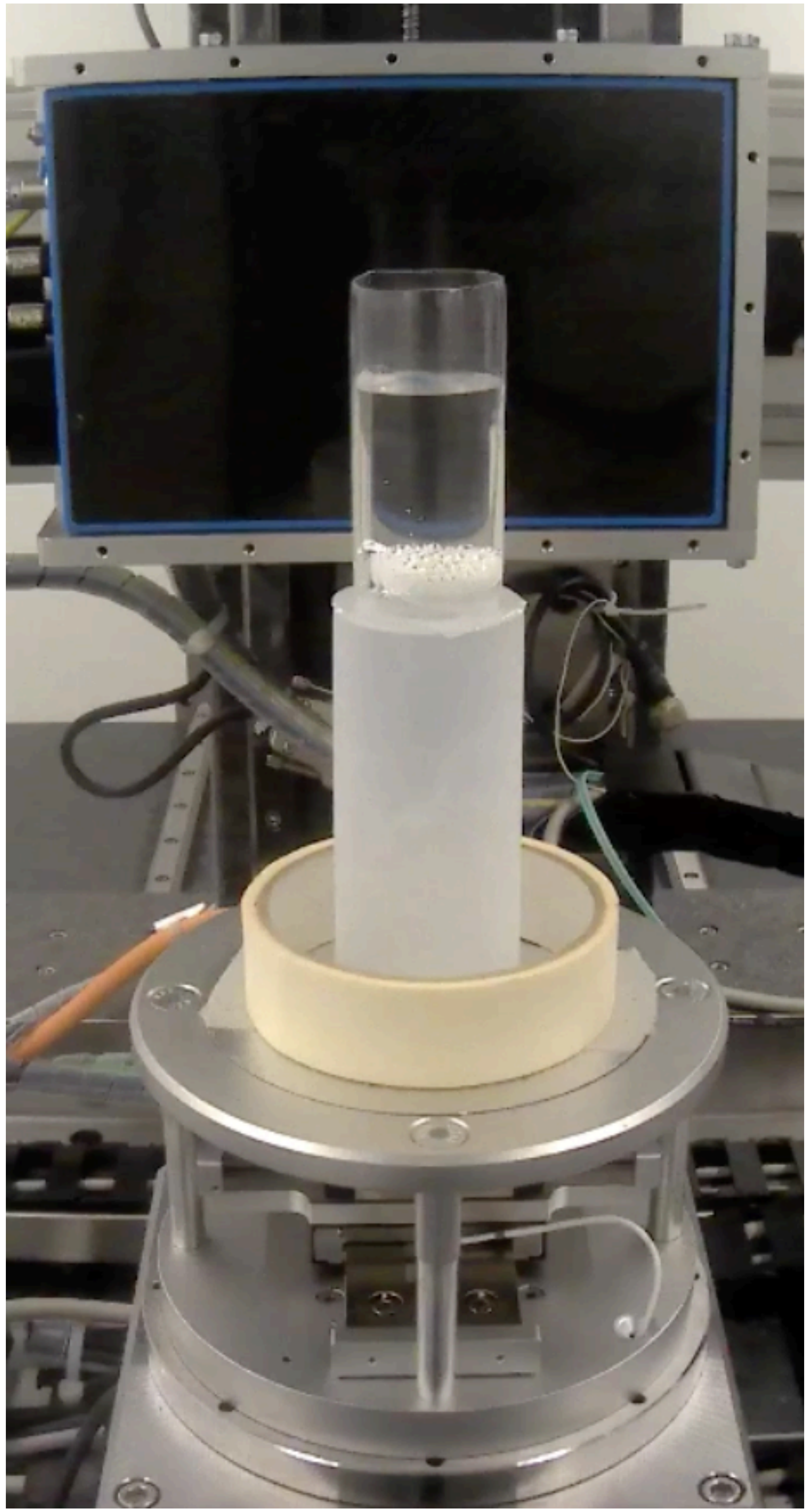
Experimental Setup

Tablet is placed at the bottom of a clear cylindrical plastic container. Gel decanted prior to data acquisition.

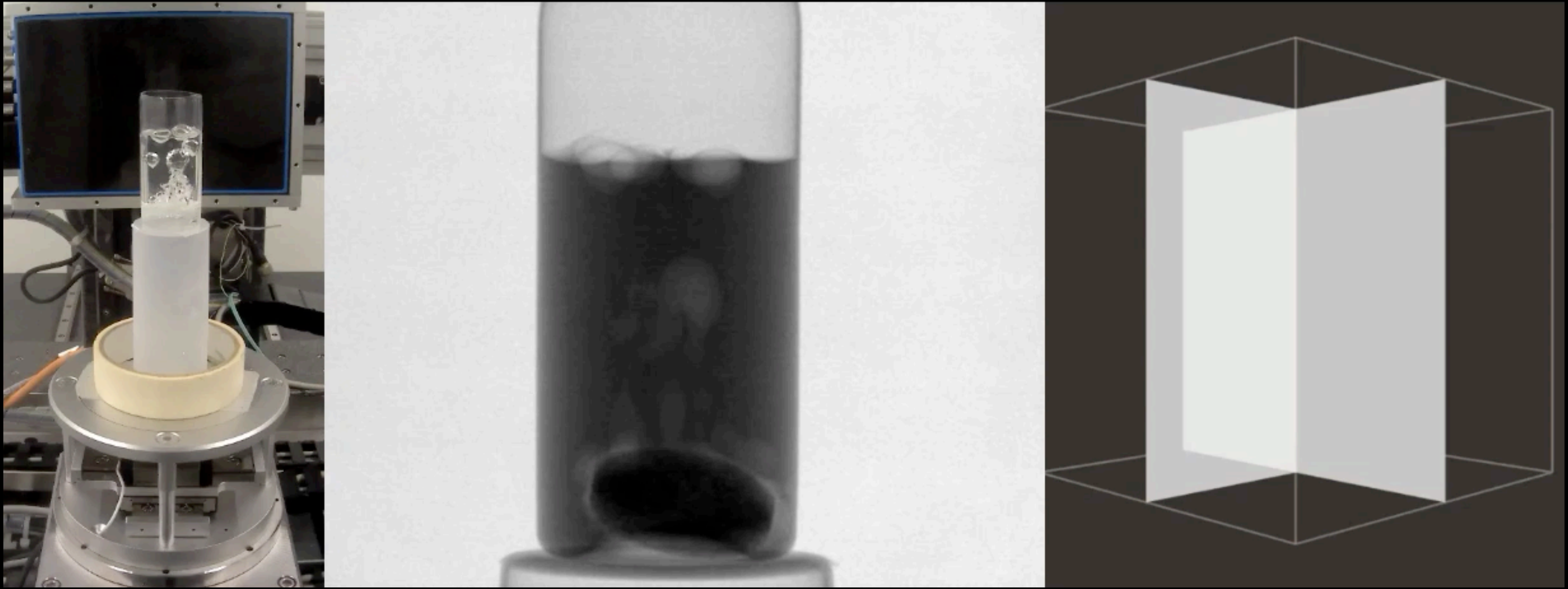
Rotation is 200 deg/s with 150 projections per 360 degrees with 12ms per projection: a total of 166 rotations, i.e. 5 minutes acquisition time.

Each projection is binned but not cropped, (size 487px x 385px). The spatial resolution at the beginning of the experiment is 193μm, at the zoom it is 76μm.

Action camera mounted on top of the source, tilted downwards to capture the entire setup.



Results



Towards a smarter future?

The future of CT acquisition experiments

What can we teach the system?

Can we teach the system to make simple decisions?

Can we teach the system to make *difficult* decisions?

Should AI be involved fully in the process and operator made redundant?

References

Thank you for your attention!

Coban, S.B.; Lucka, F.; Palenstijn, W.J.; Van Loo, D.; Batenburg, K.J. Explorative Imaging and Its Implementation at the FleX-ray Laboratory. *J. Imaging* **2020**, *6*, 18.

Buurlage, J.W.; Kohr, H.; Palenstijn, W.J.; Batenburg, K.J. Real-time quasi-3D tomographic reconstruction. *Meas. Sci. Technol.* **2018**, *29*, 064005.

van Aarle, W.; Palenstijn, W.J.; Beenhouwer, J.D.; Altantzis, T.; Bals, S.; Batenburg, K.J. Sijbers, J. The ASTRA Toolbox: A platform for advanced algorithm development in electron tomography. *Ultramicroscopy* **2015**, *157*, 35–47.

Coban, S.; Lucka, F.; Palenstijn, W. Dynamic 3D X-ray Micro-CT Data of A Tablet Dissolution in A Water-Based Gel With Dynamic Changes in the Scanning Geometry. Available online: **https://doi.org/10.5281/zenodo.3675371**

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April 28, 2020 (v1.1.0) Software Open Access

View

RECAST3D

Buurlage, Jan-Willem; Palenstijn, Willem Jan; Hendriksen, Allard; Pelt, Daan; Graas, Adriaan; Kohr, Holger;

Full-stack implementation of a real-time tomographic reconstruction and visualization pipeline. Source code Documentation

Uploaded on April 28, 2020

April 23, 2020 (v1) Dataset Open Access

View

High-resolution cone-beam scan of twenty-one walnuts with two dosage levels

Lagerwerf, Marinus Jan; Coban, Sophia Bethany; Batenburg, K. Joost;

We release tomographic scans of 21 walnuts with two levels of radiation dosage for noise-level comparative studies in data analysis, reconstruction or segmentation methods. The dataset collected with higher dosage is referred to as the "good" dataset; and the other as the "n

Uploaded on April 23, 2020

https://zenodo.org/communities/ci-cwi/

April 10, 2020 (v1) Dataset Open Access

View

A five-tile tomographic micro-CT dataset of the oak sculpture "Holy woman with lantern" - part 2 of 2

Francien G. Bossema; Alexander Kostenko; Sophia Bethany Coban;

New upload

Community

CWI COMPUTATIONAL IMAGING

Computational Imaging -- Centrum Wiskunde & Informatica

Welcome to the Zenodo community for the Computational Imaging at Centrum Wiskunde & ... a (CI-CWI).

This community, created and maintained by the CI-CWI, is a collection of the research materials produced by its members.

Here, you can find various dataset collected by our