

# Lecture 23: Imaging and Rendering in Cultural Heritage

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**CSC 292/572, Fall 2022**  
**Mobile Visual Computing**

# Logistics

Final project due 12/20, 11:30 AM.

- Provide a write-up describing what you have done, along with the code.
- Submit a Jupyter notebook if you code in Python



# The Roadmap

Theoretical Preliminaries

Human Visual Systems

Color in Nature, Arts, & Tech

(a.k.a., the birth, life, and death of light)

Digital Camera Imaging

Modeling and Rendering

**Applications**



**Medical Imaging**

**Cultural Heritage**

AR/VR

Research











# Goals and Where We Can Contribute



More than 90% of the objects in museums around the world will never be seen by the public — lack of display space or damage or fragility.

How can we turn every museum and archive into an open university?

- Making the invisible visible.
- Making the visible accessible.



# The Herculaneum Papyri



Carbonized by the eruption of Mount Vesuvius in 79 CE  
Excavated from the ancient city of Herculaneum in the late 18th century

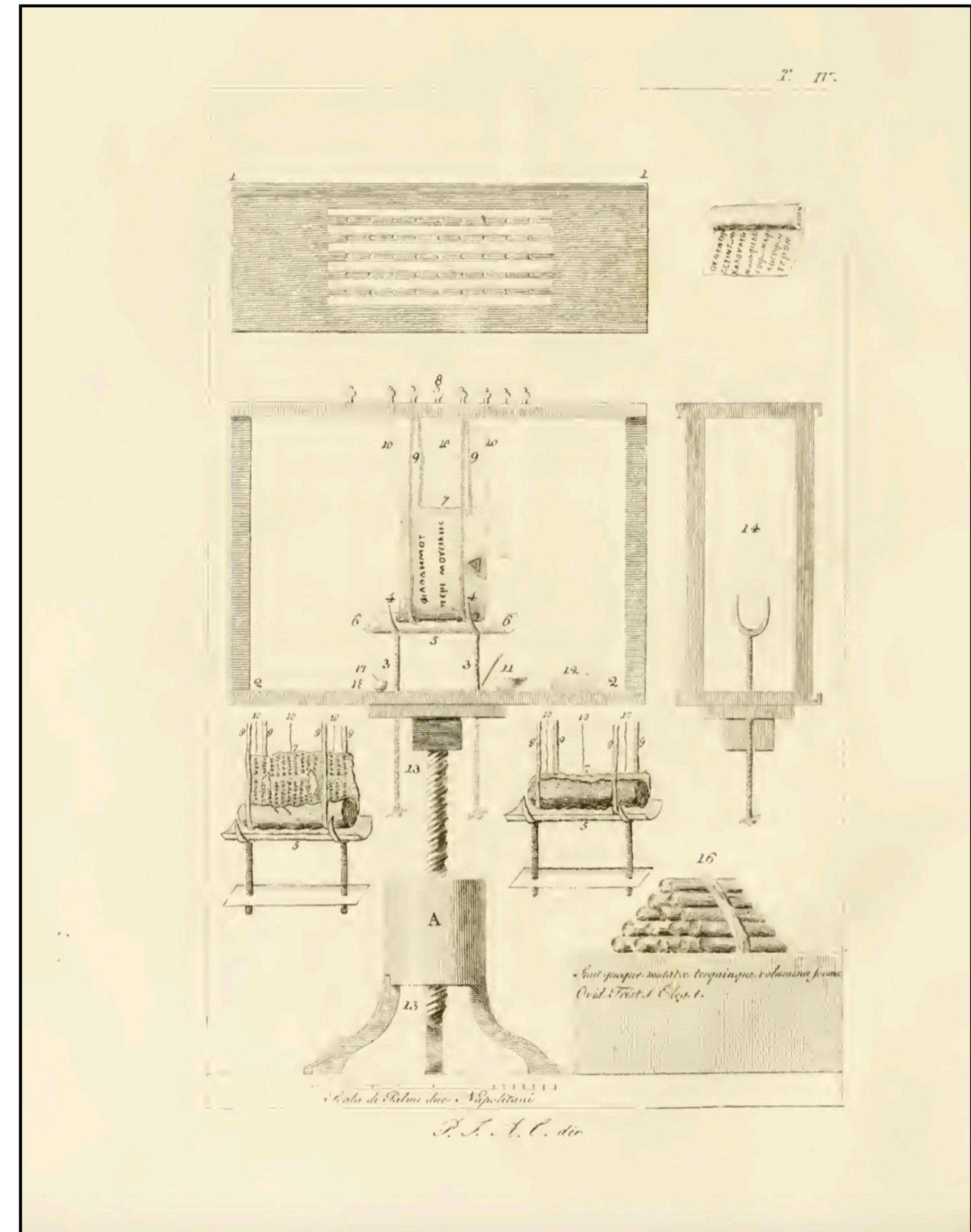


# Destructive Attempts

In the 18th century, scrolls were unwrapped at the rate of a centimeter an hour, using a machine designed by Vatican conservator Antonio Piaggio.

Hundreds of scrolls were pulled apart using Piaggio's machine, but they revealed only limited text.

Tesoro Letterario Di Ercolano, Tavola IV (1858)





# Destructive Attempts

The most successful attempts were made in the 19th century, when about 300 of them were peeled apart by machine.

- This endeavor resulted in fragmented, layered sheets of brittle papyrus with visible, but largely illegible, writing on the black-as-charcoal surface.

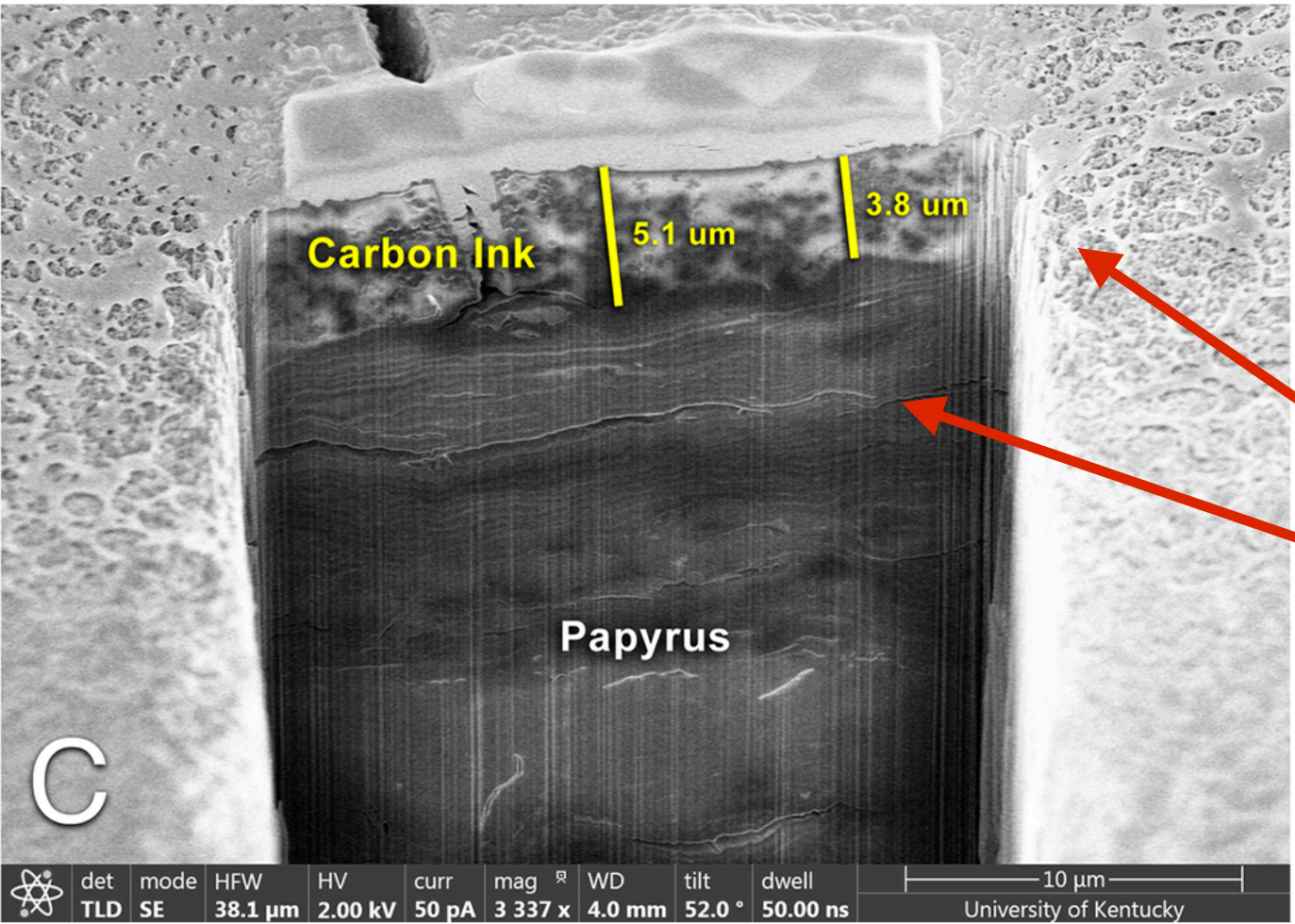
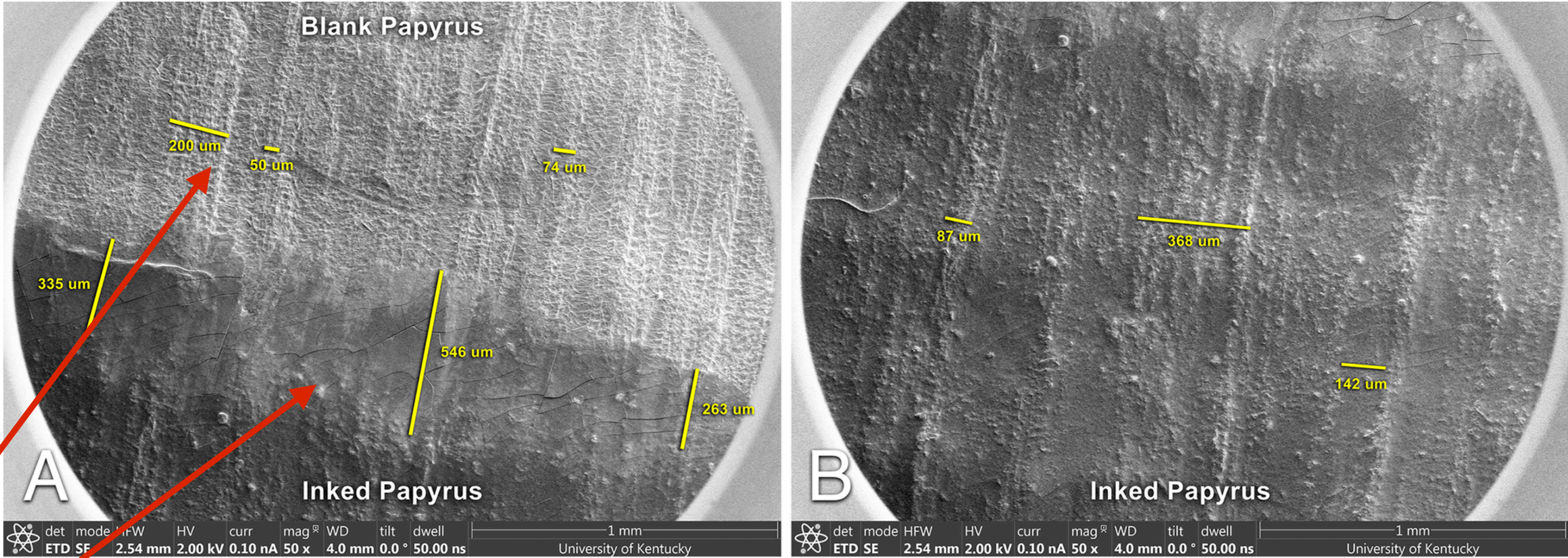








# Measurement and Approach

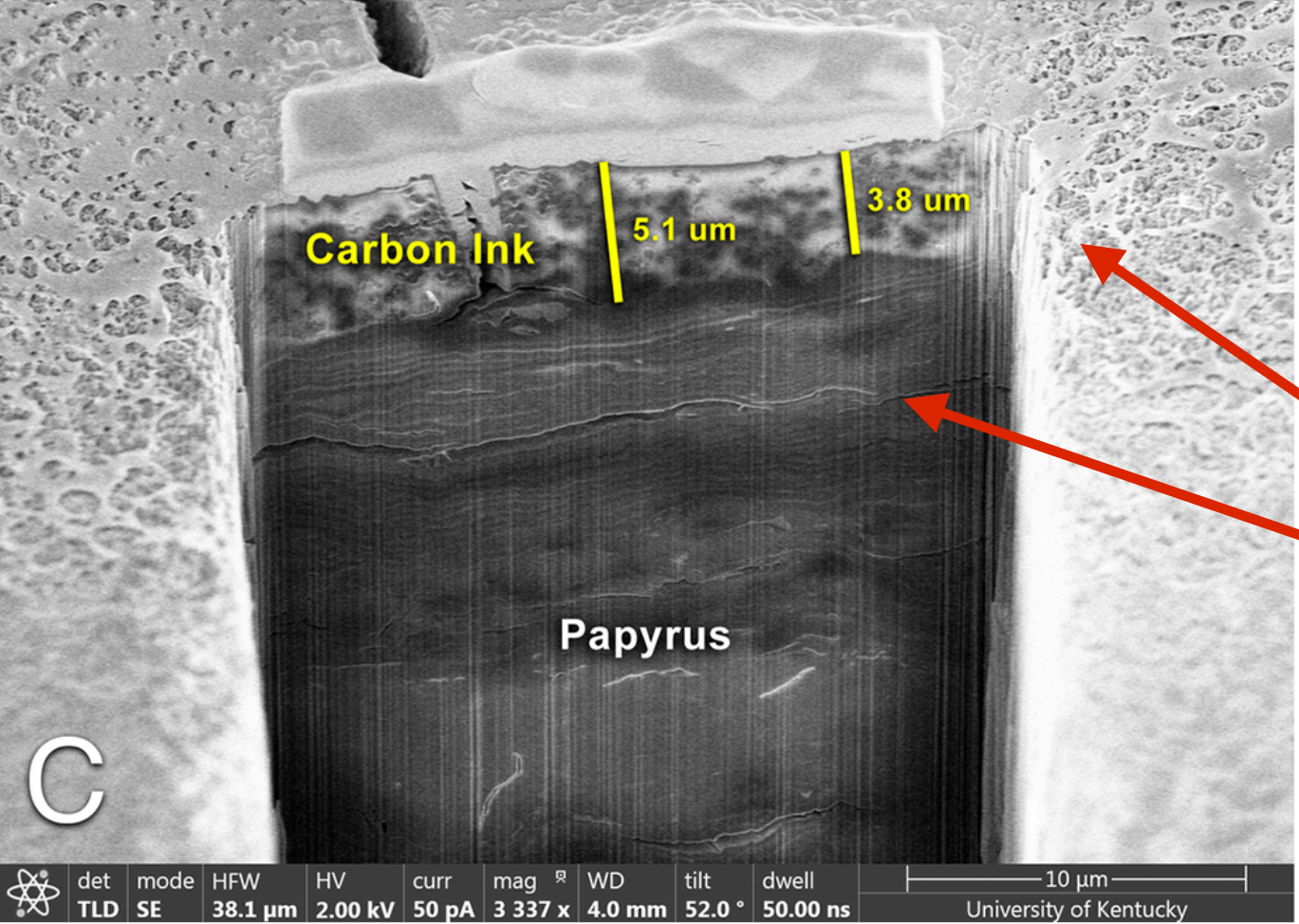
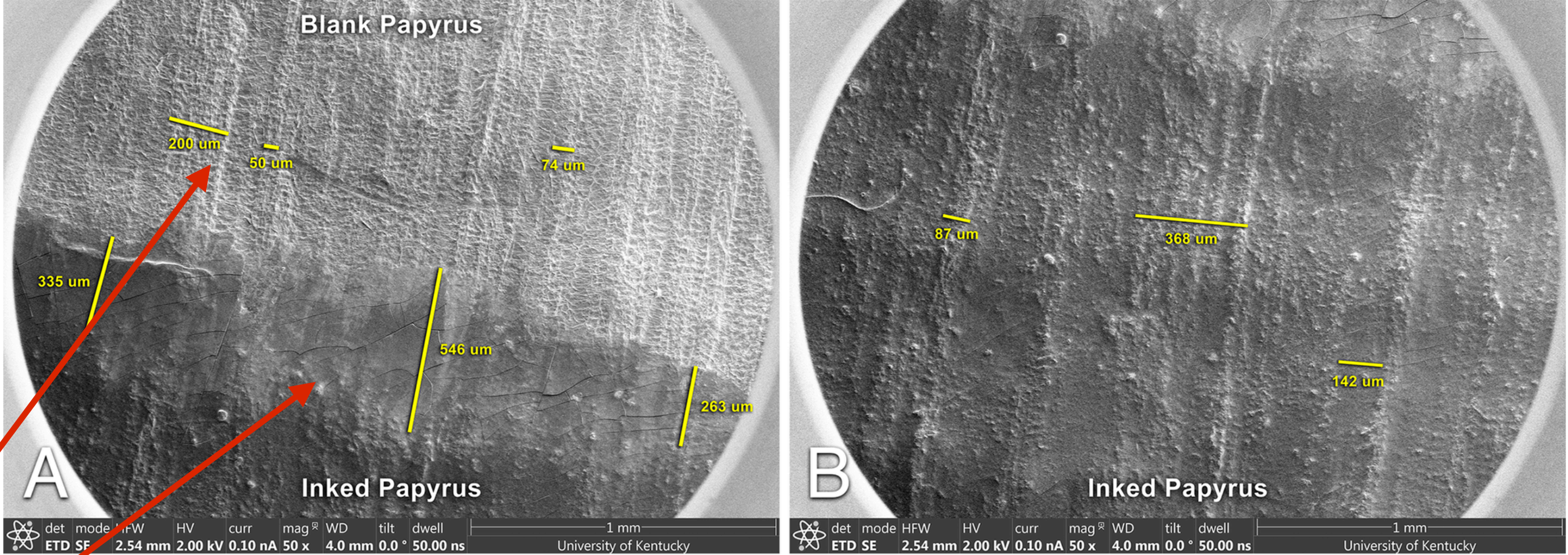


Morphological differences

Intensity difference (not always significant: carbon ink vs. papyrus)

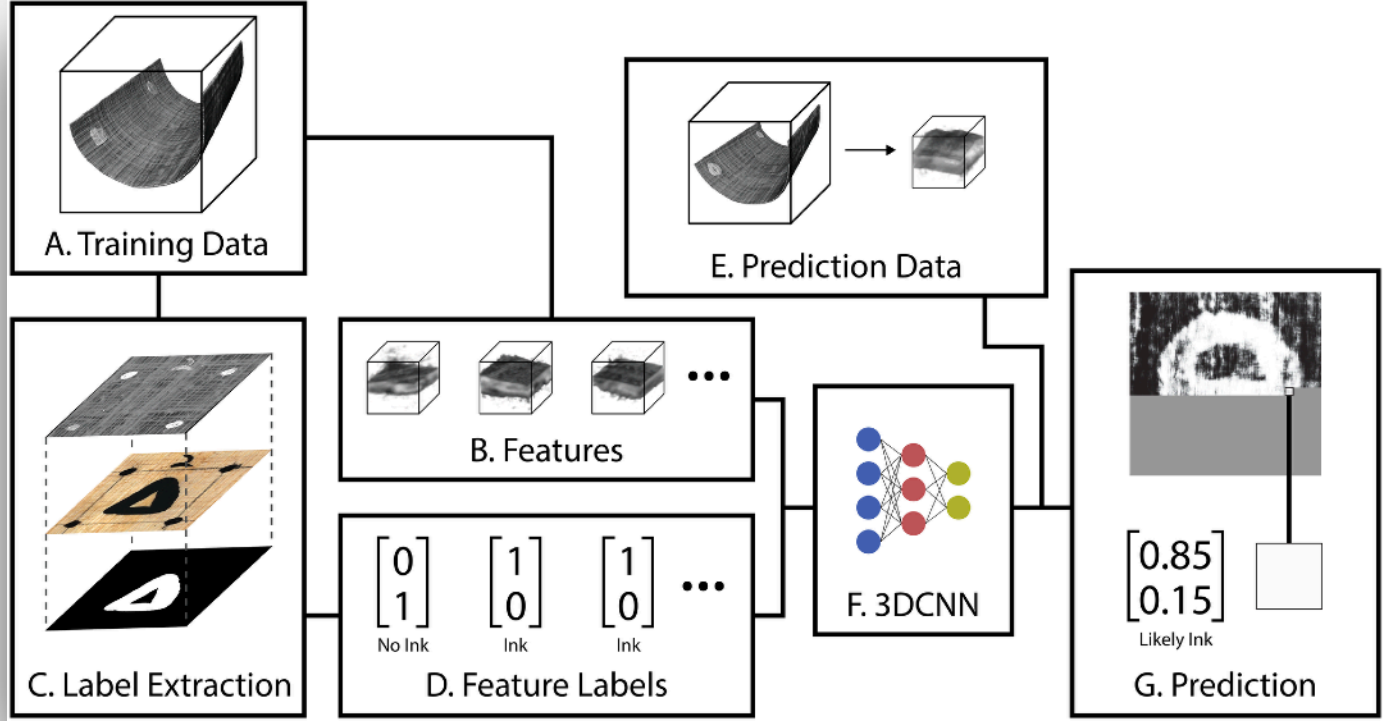


# Measurement and Approach



Morphological differences

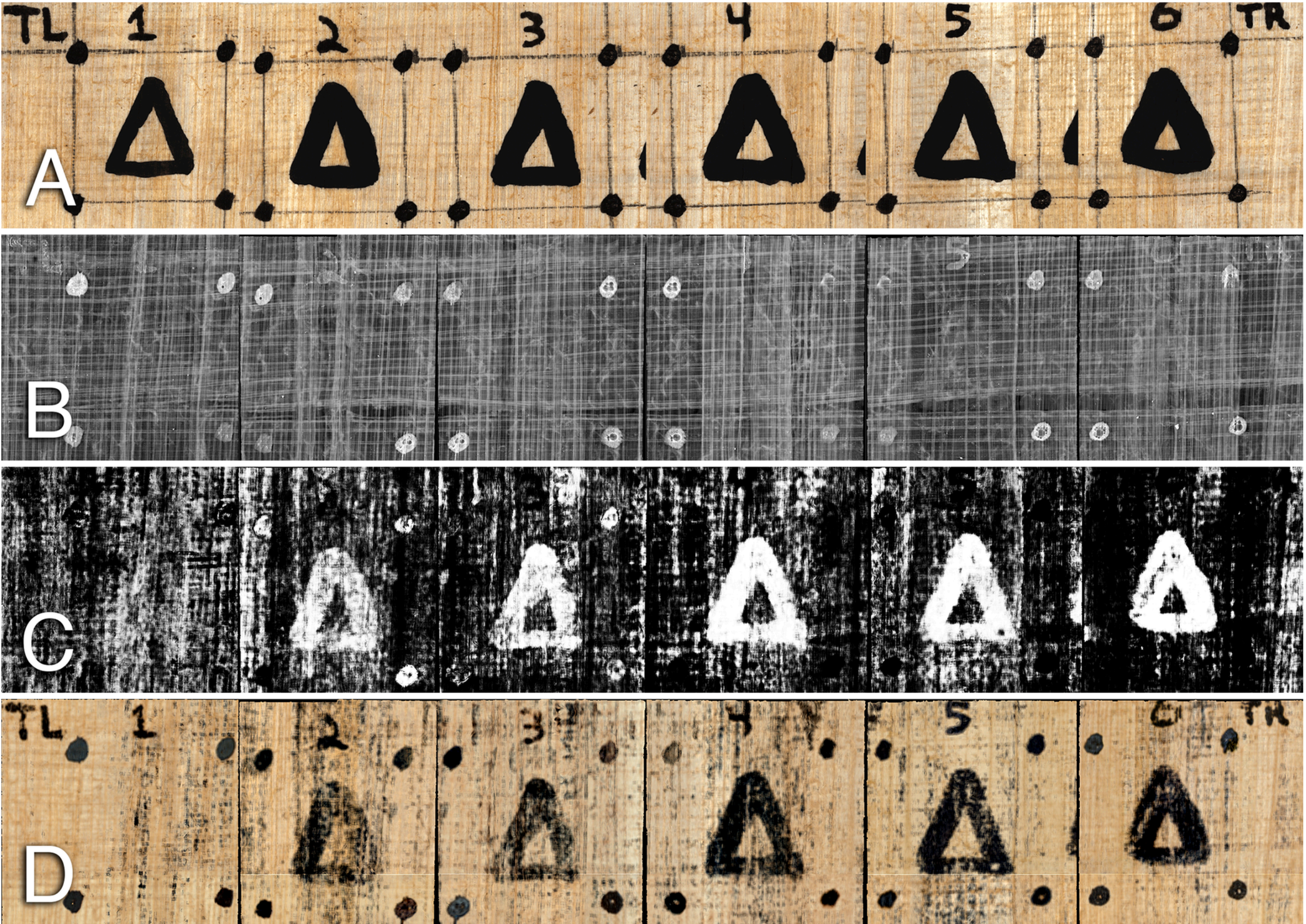
Intensity difference (not always significant: carbon ink vs. papyrus)



CNN used to detect ink and reconstruct images



# Results on an Emulated Setup



Ground truth from writing on a modern papyrus

Raw data from CT

Ink detection

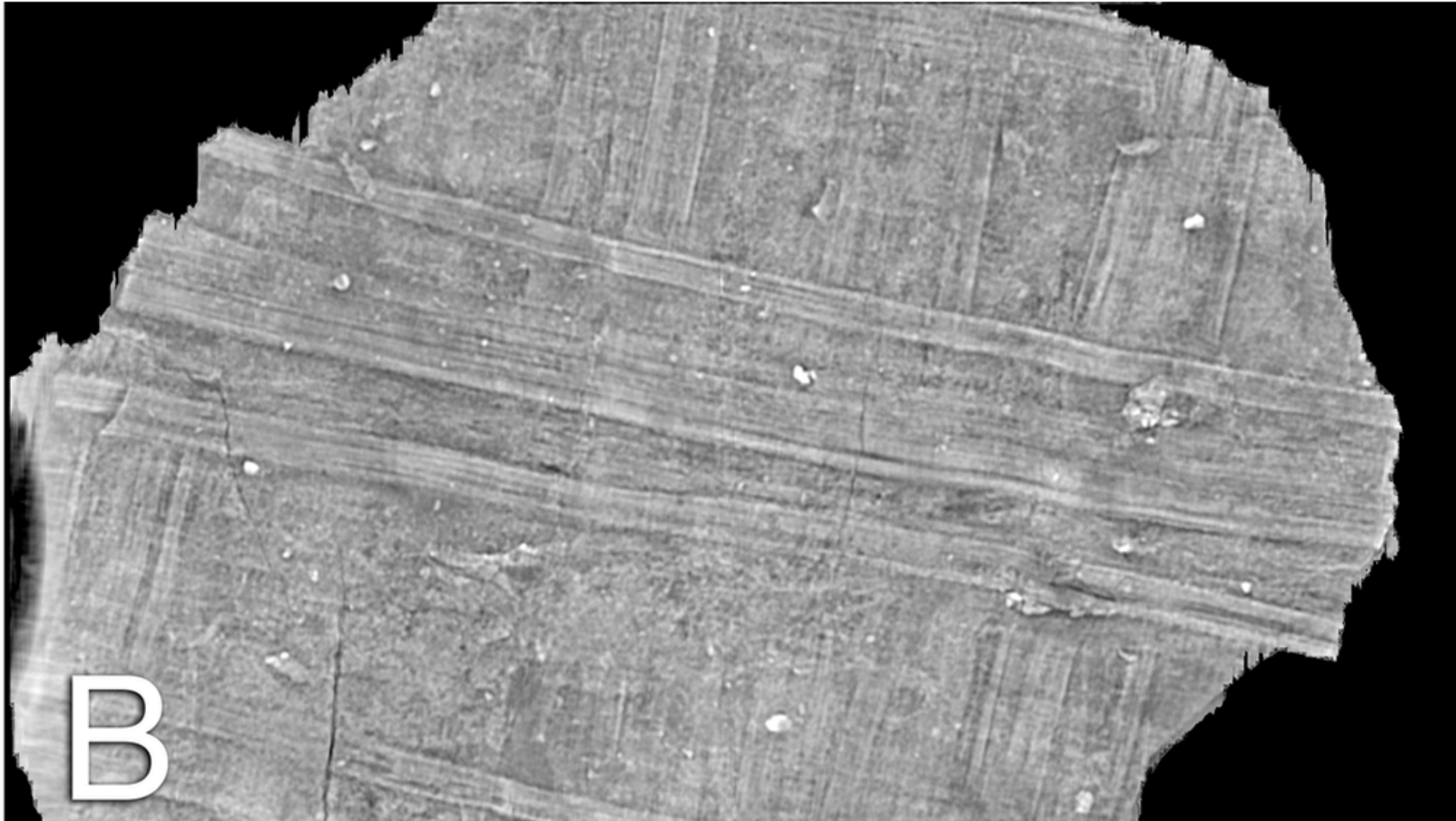
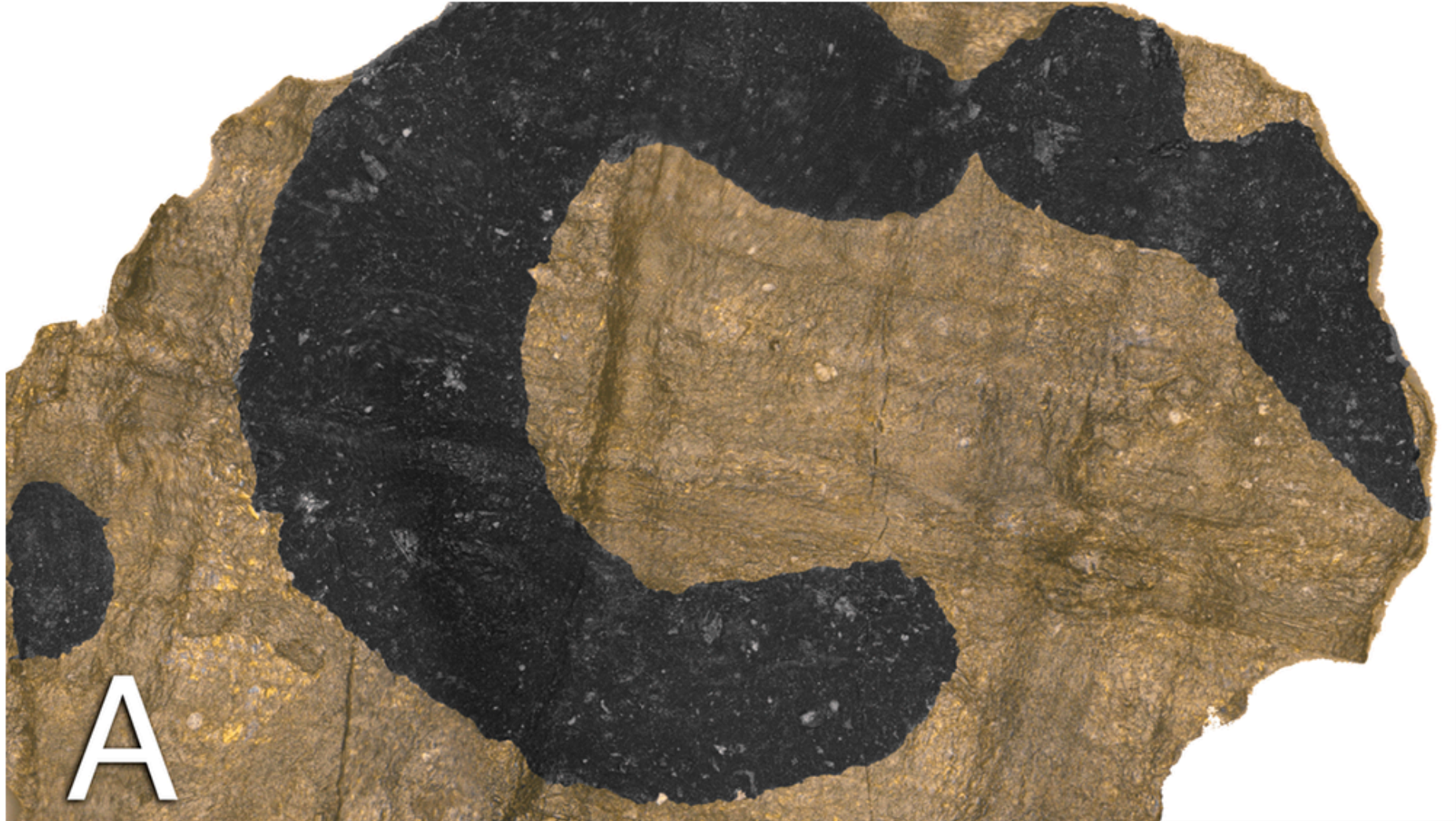
Rendering



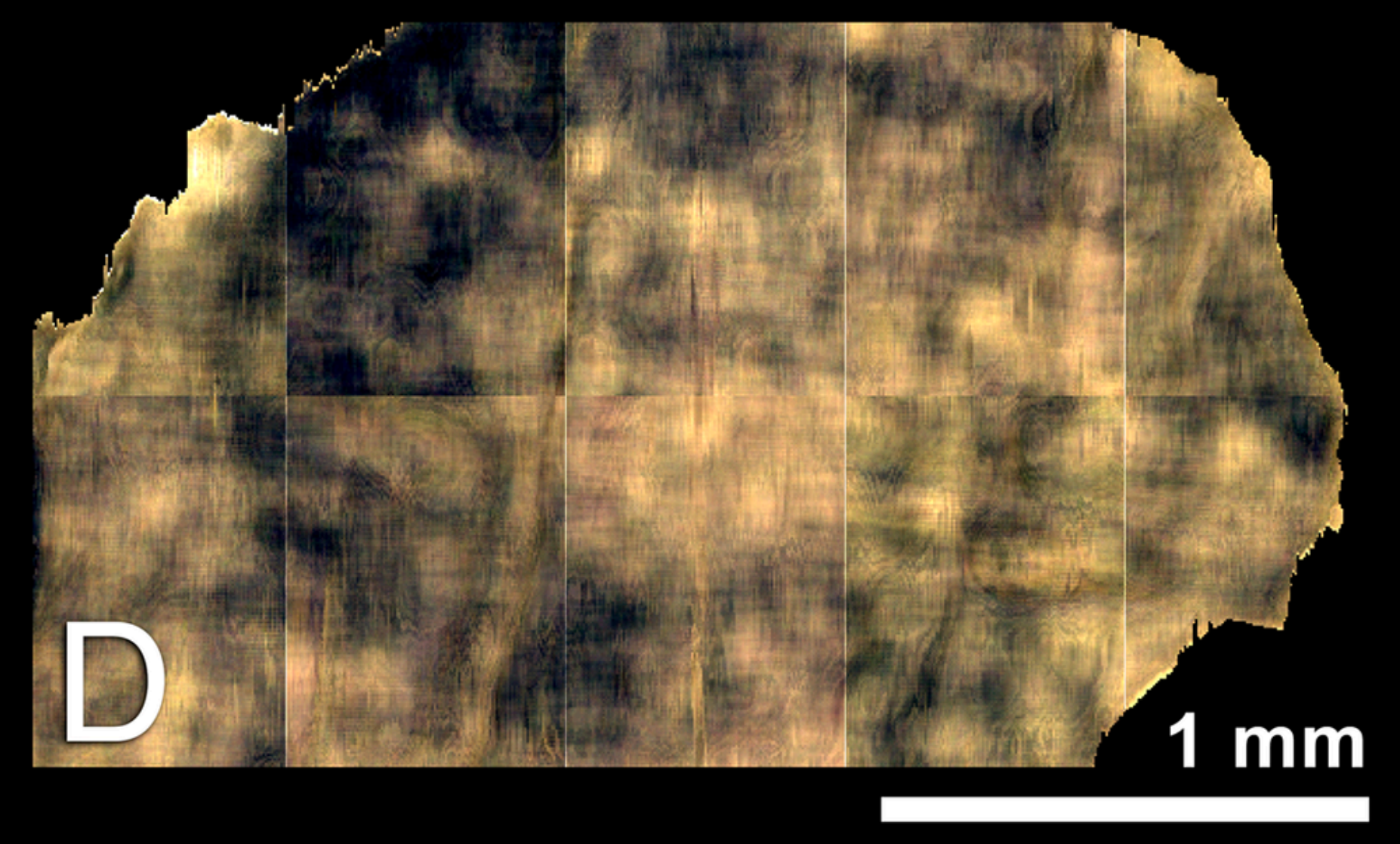
# Results on an Actual Piece

PHerc.118; an intact scroll  
unpeeled by a machine

**A:** Obtained from a  
confocal microscopy,  
which is not feasible for  
the scrolled piece.

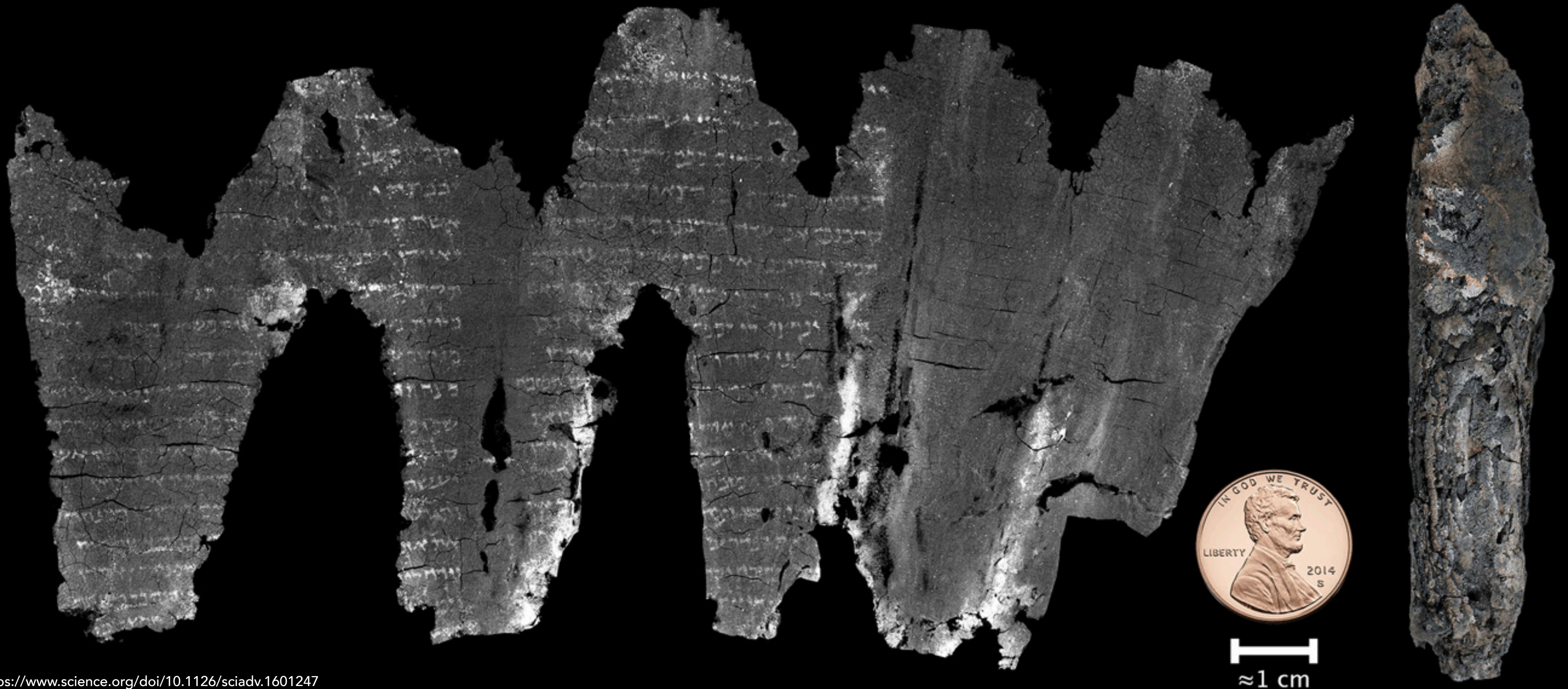


**No one has  
completely digitally  
unwrapped it yet!**





# Reading the Scroll from En-Gedi





# Codex vs. Scroll

15th Century Torah scroll



The Codex Gigas, 13th century, Bohemia

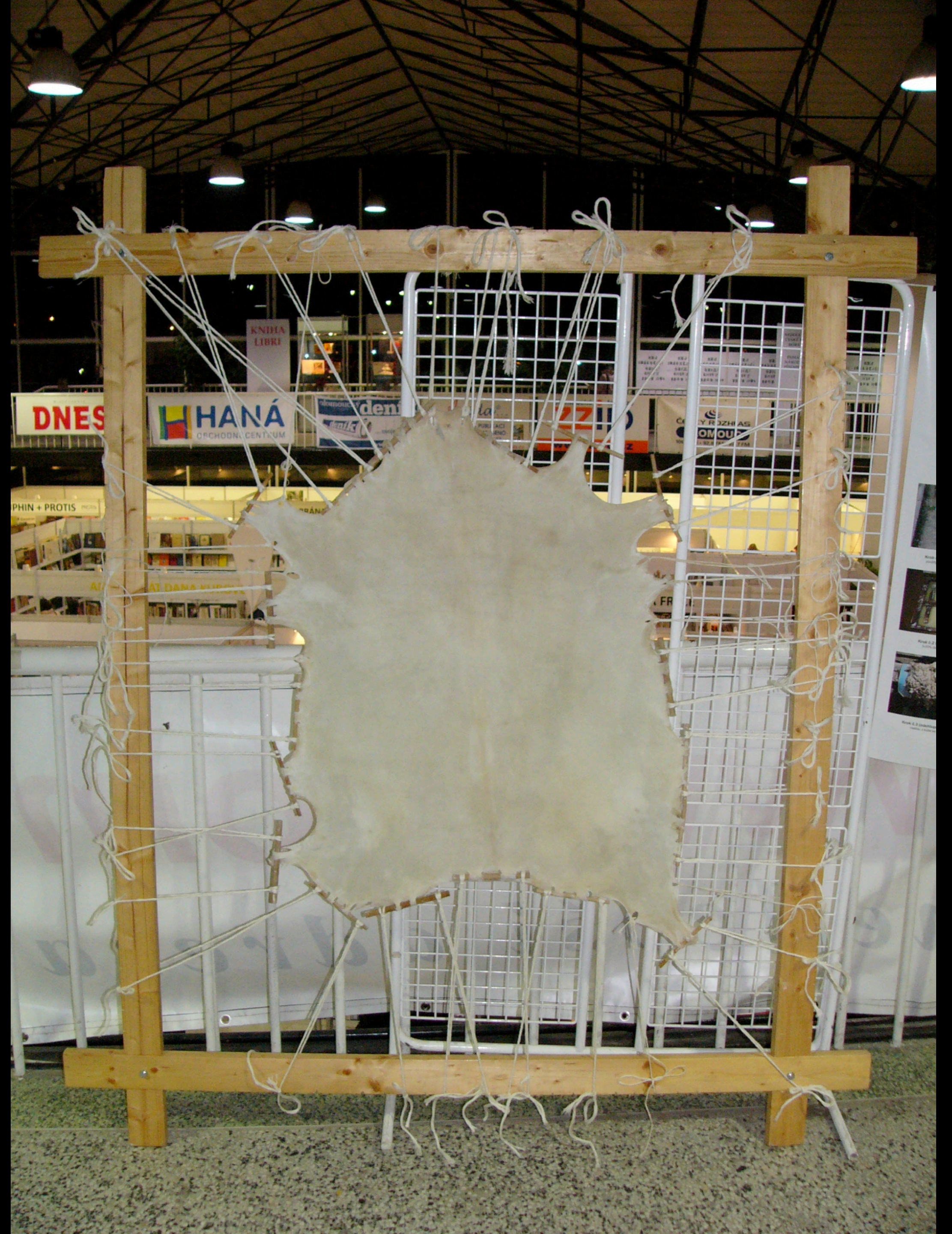








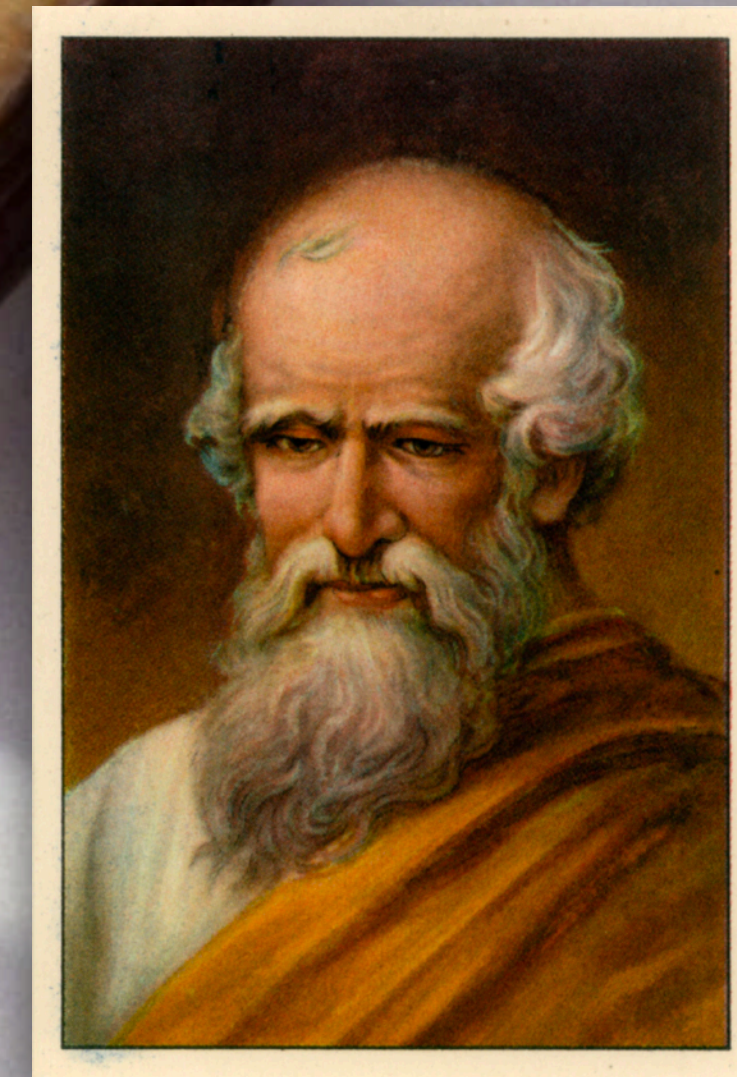
# Parchment





# The Archimedes Palimpsest

Medieval manuscript made from parchments used for other writings. The over-text is a Byzantine prayerbook (1229). The under-texts are mainly from Archimedes and Hyperides; some are unidentified.





Θείως και τοποτηριον εκ του γερηνματος  
της αμπελου χαρην κερασα. ευχαριστη  
σας αγιασα. ευλογησα. ελωκεν τοις αγι  
οις αυτου μαθηταις και απο πολλοις ειπων. **εκφω**

**Π**ιθε εζω παντα του βηντο αιμαμον  
τοτησ και ησ διαθηκησ. τοσρι πολλων  
εκ χρωμηνον εισαφεισ ημαρτι οχλη.

**οι ε ε πειχεται**

**Τ**ουτο ποιητε. ητην βηνμαμαρτι  
ωσακισ γαρ ανωθεν τε τον αρτον του  
ε και τοποτηριον τουτο ωινηται τον  
βηνον θαρρατον και τωβλε. τηνημηρα  
ρασασι μο λογητε. μημηνη βνοι οω  
δωποτα και μη εσ των σριων αυτου πα  
θηματων. του βωσ ποιου φρου. της τρι  
νημου ταφης. της εκ με κρωμαρτασ  
της εσοωσισ αμοδου. της εκ δειωμσ  
του θυ εσρεσ καθεδρας. και της ερδοξ.  
εφοβρασ. δατερασ αυτου παρωσιασ. **εκφ**

**Π**ιασ εκ των σων σοι προσφερον και πα  
οχ **σευ μη εμεν. σεευ. οι ε ε πειχεται**

**Β**ια τουτο δωποτα παμμε. εση εσ οια  
μαρτωλοι. εσ αναζιοι δουλοισου. οικατα  
ζιω θενταλει τοφνην τοφνω σου θισι  
ατηριω. ουδ ιατασ δι και οσωσ ημω  
ουαρ ποιησαμην. τι γαυου βωιτησ.

αλλε διατα ελε εσου και τουσ οικτιρμου  
σου. ουδ εχρασ. αλωπιασ εφημασ. θαρου  
τωσ ομωρεσ εγγισωμην. τοφνω σου θισι  
ατηριω. και παροσ θενταλει τασρι τυσα  
του φνωσ ματοσ του χυσου. σου δωμε  
εσε παρακαλομην. ηε φνω. εδοκισα ησ  
σησ εαυτωπιτοσ. ελε εμ τοσρι σου τοσ  
νιομε φημασ. εβωιτασ προκημ βραιδω  
ρατατα. και ελομησ ατατα. εσ ηασισ  
εσ αναζιασ. **και ανησ ομωσ οι ε ε**

**εφρατζει τε τα ε ε λεγων.**  
**κ**αι ποιησον τον μεναρ του. αυτω τοτημη  
εω του χυσου. **ε ε αμνη.** το δε εμ ποτι  
ριω του. το τιμ ομα αυτου χυσε. **ε ε αμ.**  
**π**ο εκ χυθεν παρτησ του κοσμου ζωησ.

**εστω και ομωσ οι ε ε πειχεται**

**Η**μασ εσ παρτασ τοσ εκ του βμοσ αρτε  
και τουσ οκτηριουμα εχουτασ. βνωσε  
ραλληλοισ. εσ βρωσ παρ φνου κοιρωμιασ.  
και μηδ βρωσ ημωσ εσ κριμελ. εσ κατα  
κριμασ ποιησ εσμε εσ οχημ. του φνωσ  
ματοσ. και εμματοσ του χυσου. αλλιμω  
εσ φωμην ελεσ και χαριμ. εβωιτασ παρ  
τωσ φνωσ. των απαιωμοσ σοι εβωιτασ  
παρ παρωσ παρωσ. παρ αρχων. παρ φητασ  
απο πολλων κηρυκων εβωιτασ.



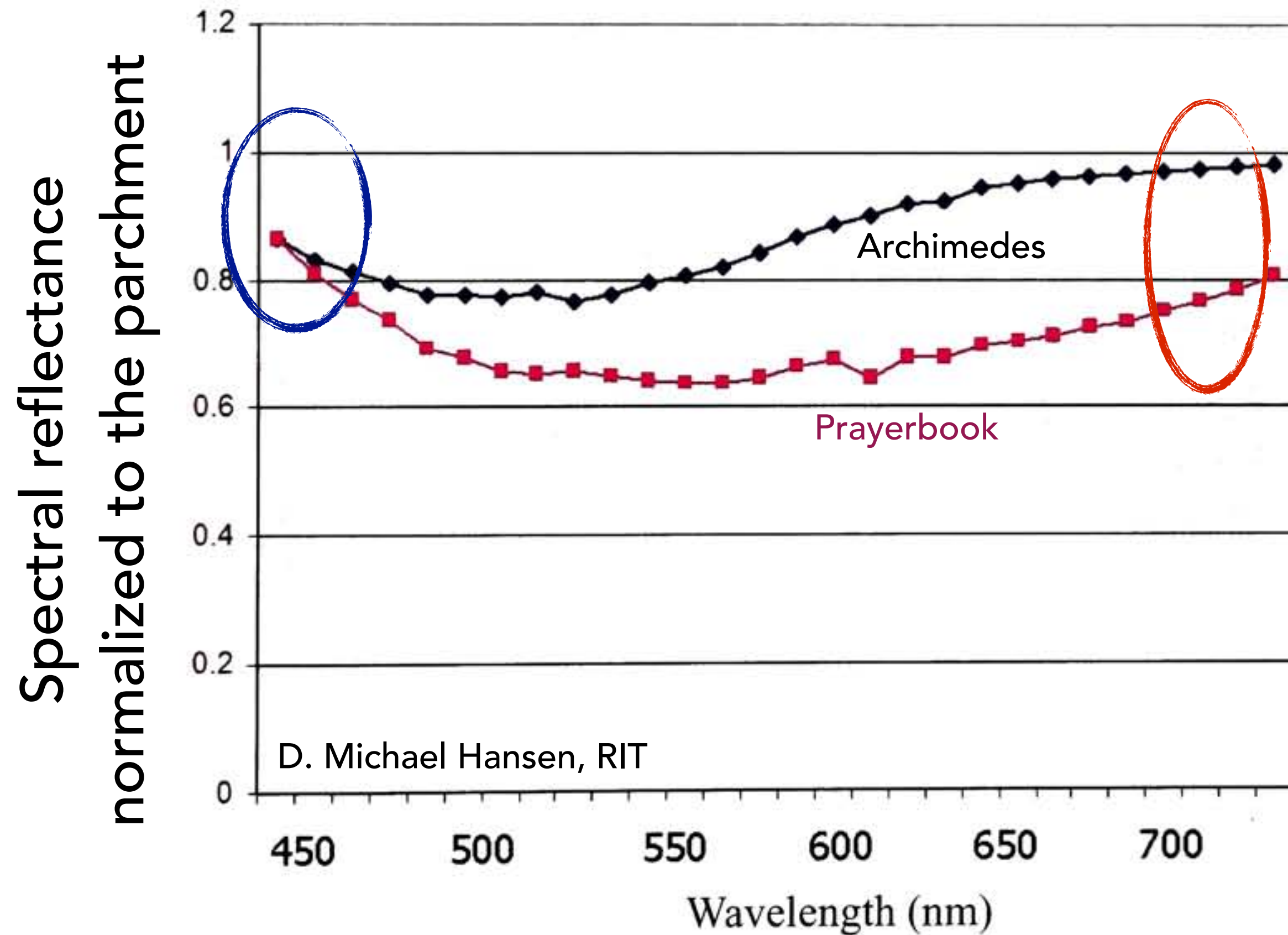








# Spectral Signatures

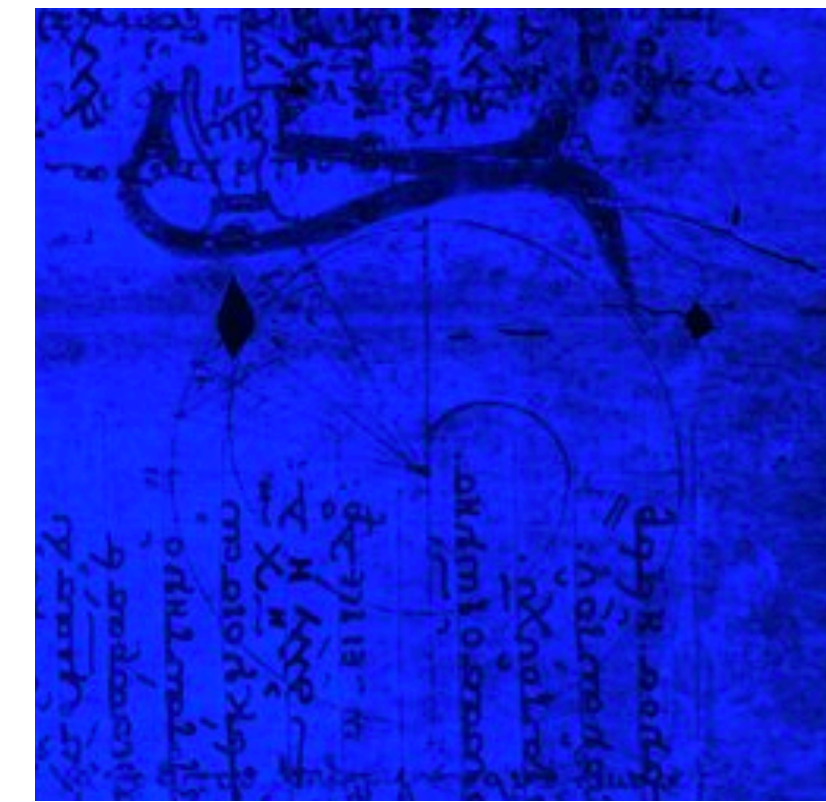
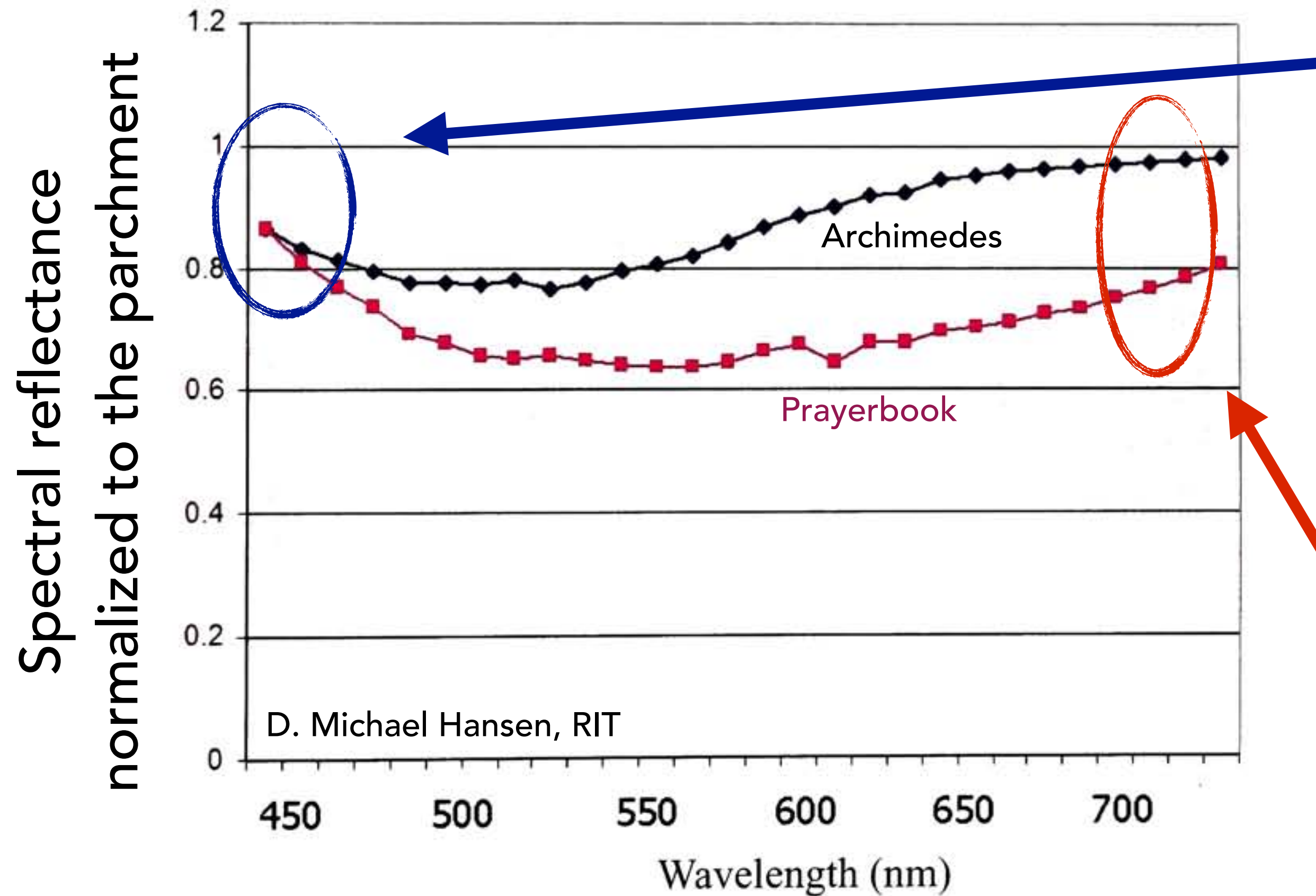


The key to read texts is to find contrast: b/t texts and parchment and b/t over & under texts.

- Texts reflectance is lower than that of parchment; they will look dark.
- If two points have the same reflectance, the one with higher concentration (abundance) will appear darker.

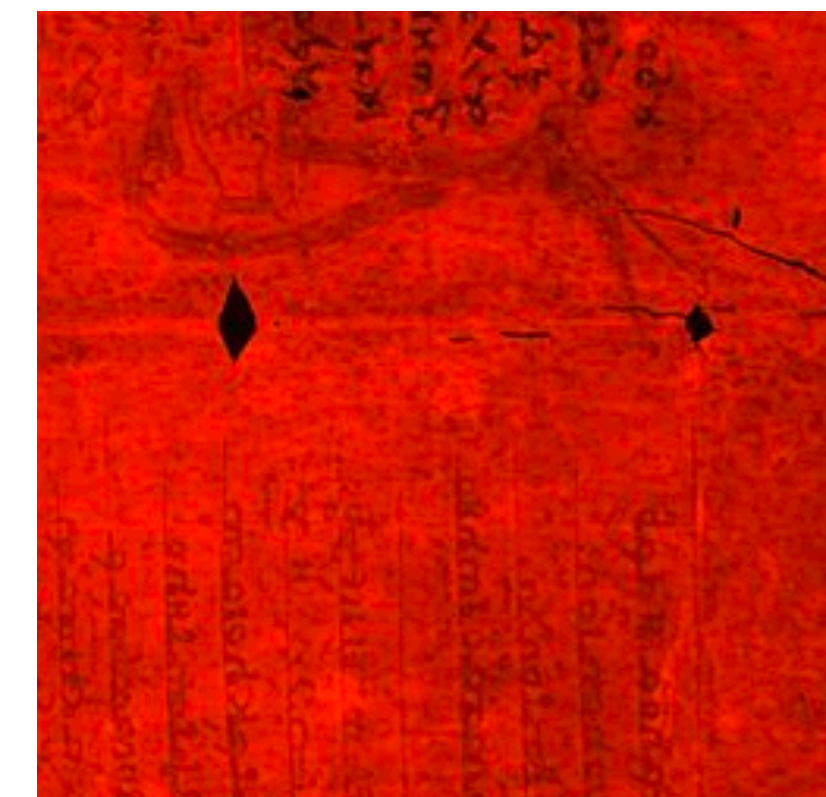
# Spectral Signatures

Drawings are Archimedes (under-texts);  
vertical texts are Prayerbook (over-texts).



445 nm

Over- and under-texts have similar reflectance, but under-texts have lower abundance (scratched!) so they look lighter than over-texts. Both are different from the parchment, i.e., visible.



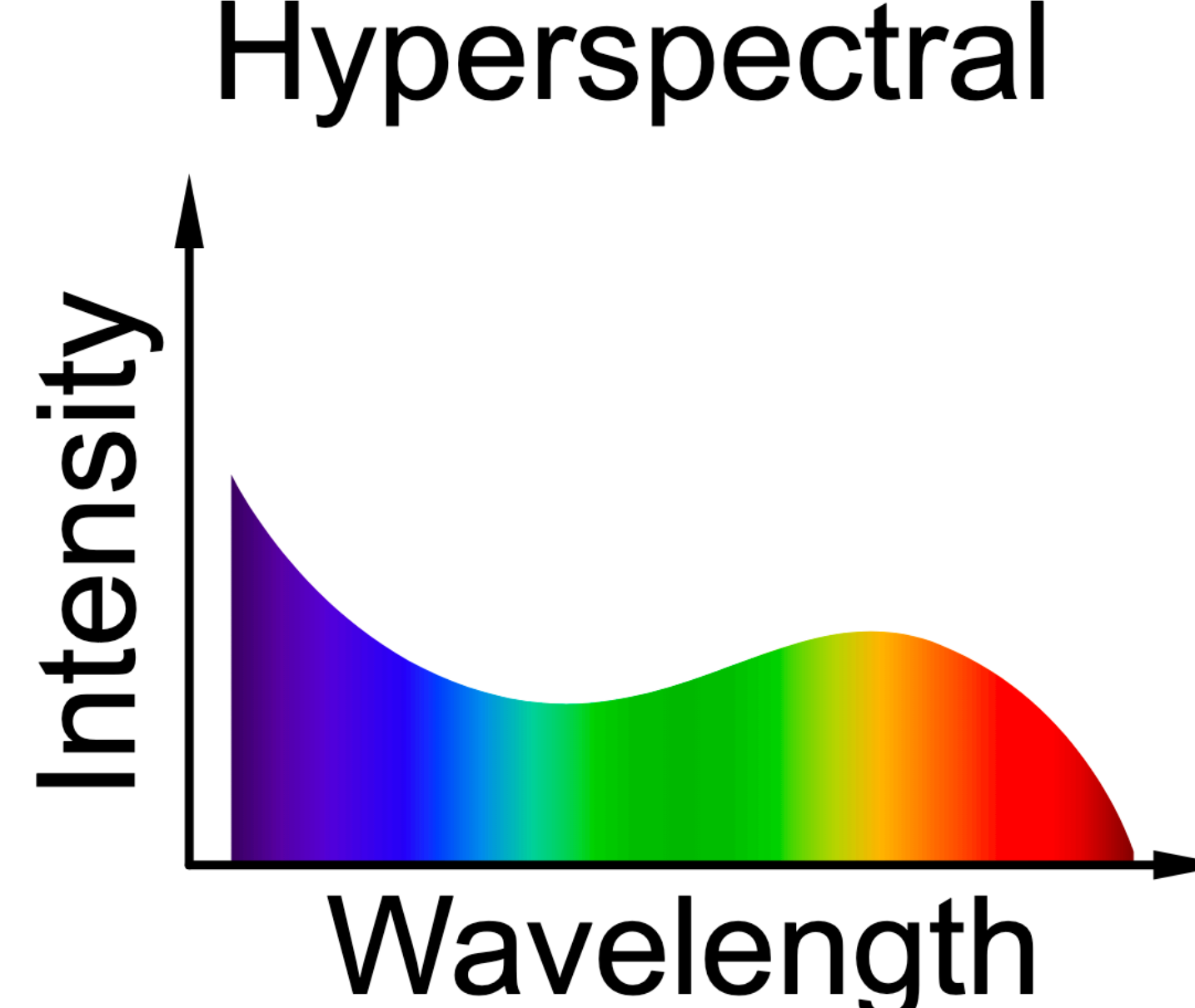
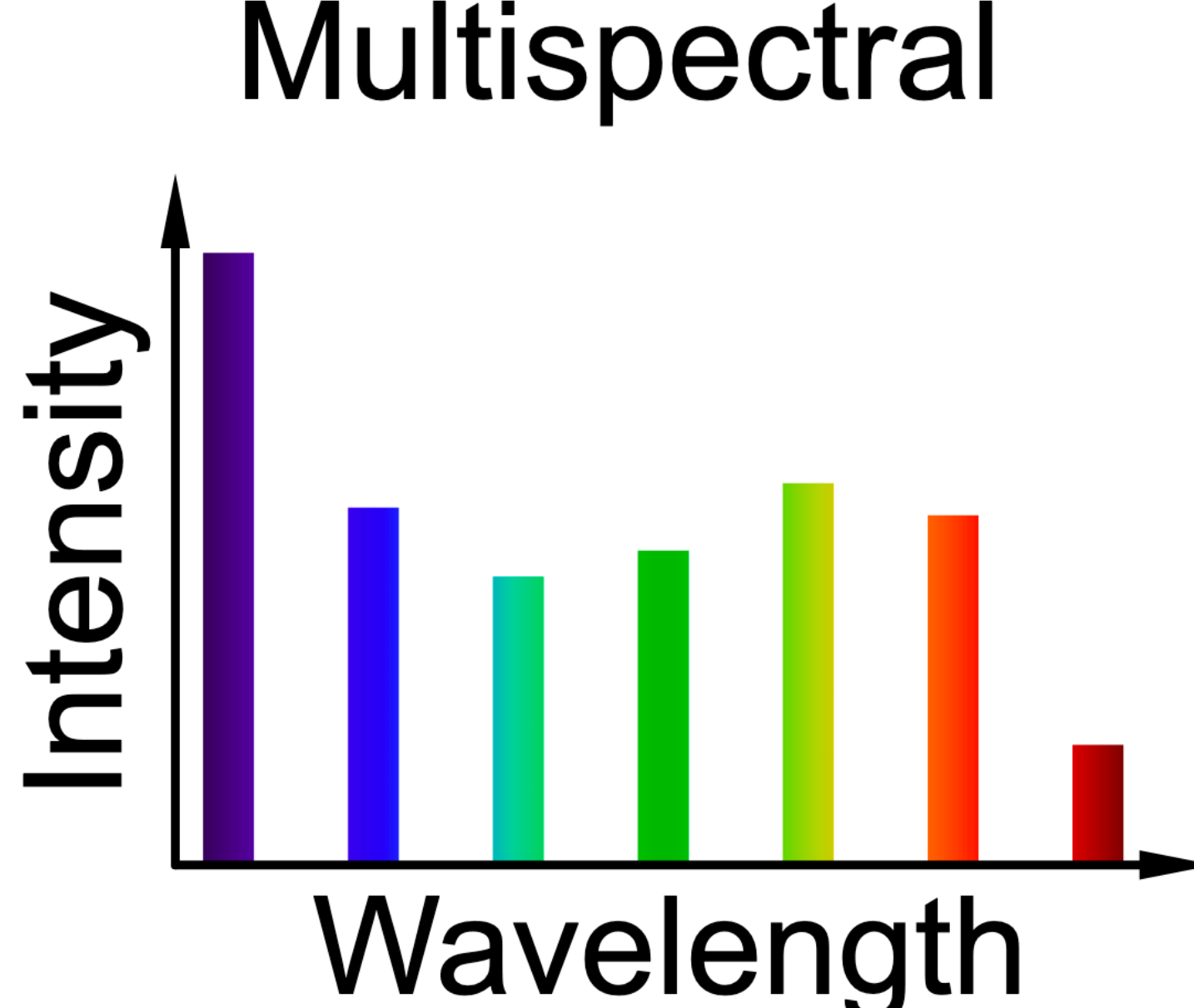
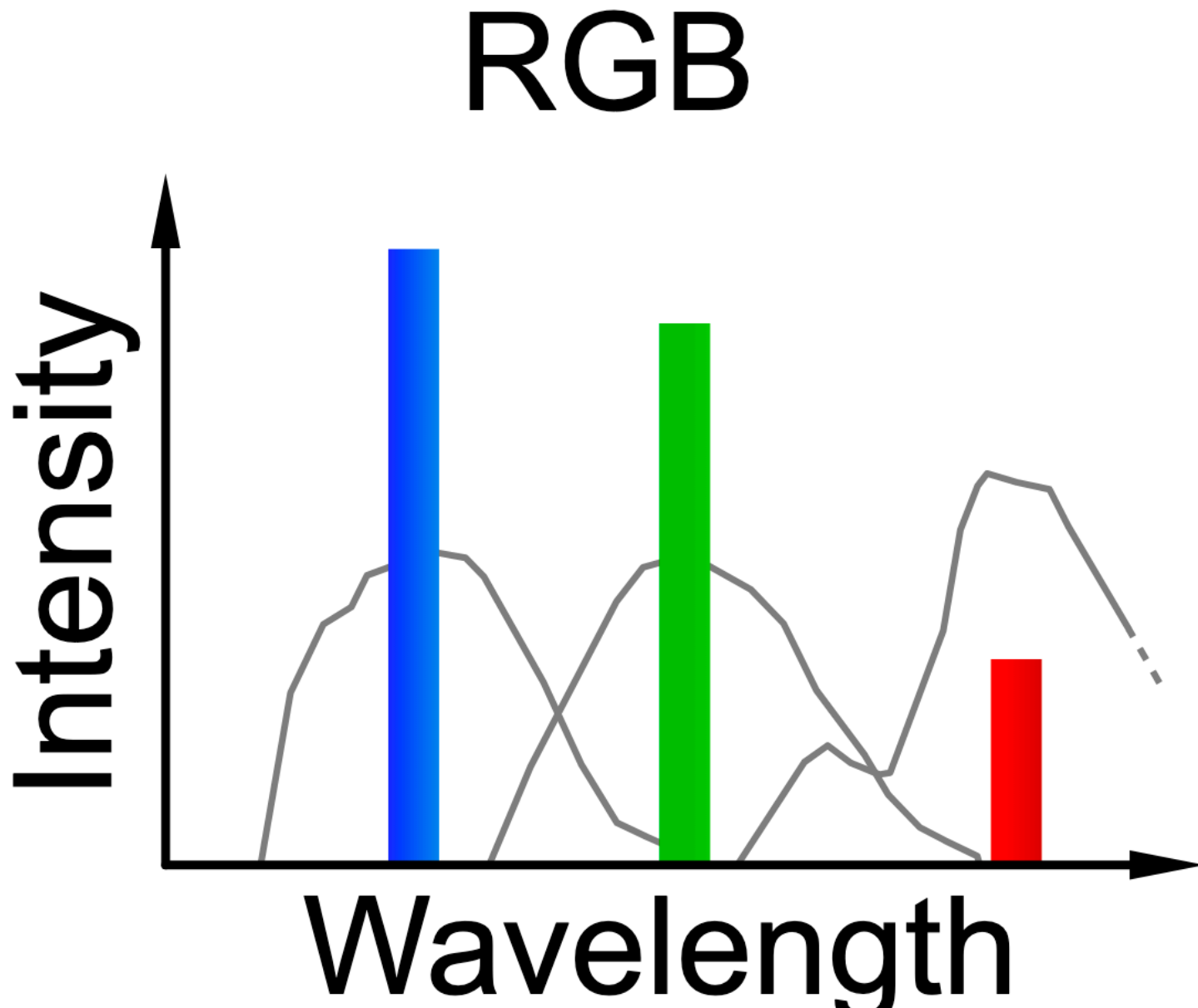
700 nm

Under-texts reflectance is similar to that of the parchment so they are invisible. Over-texts are still somewhat visible.

The spectra here are not obtained in the exactly same setup used to take the images on the right.

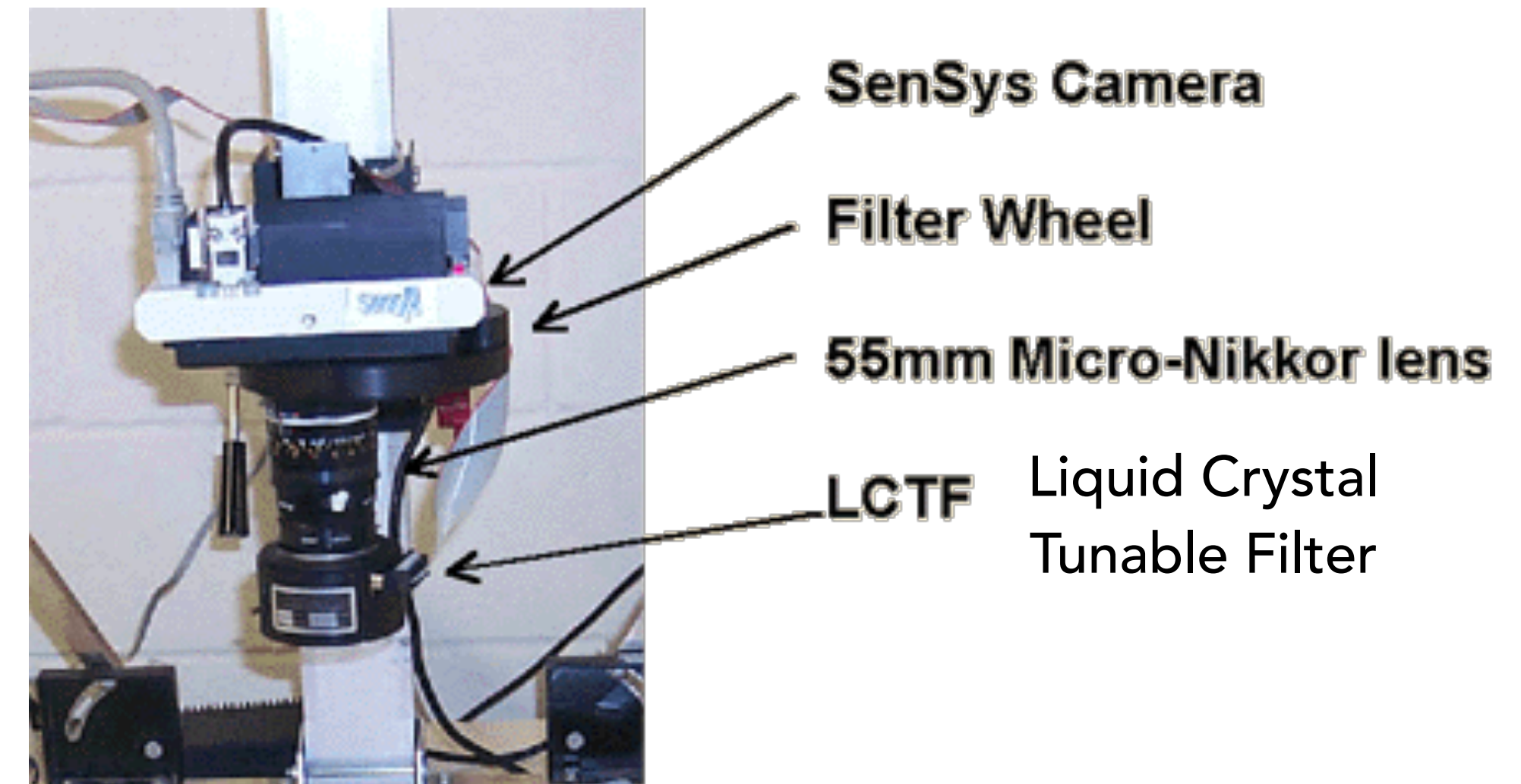
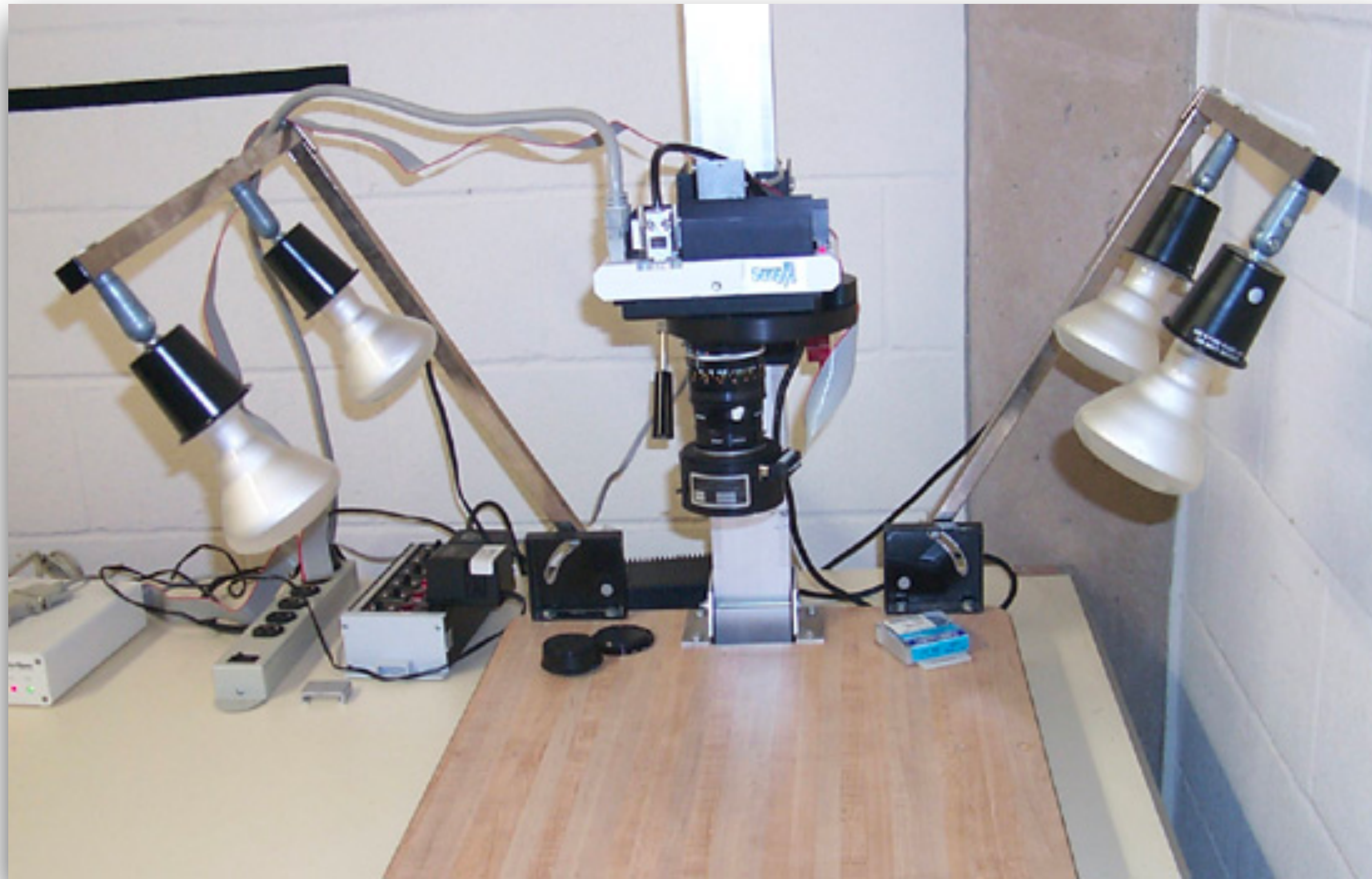


# Multispectral Imaging





# Initial Multispectral Imaging Device



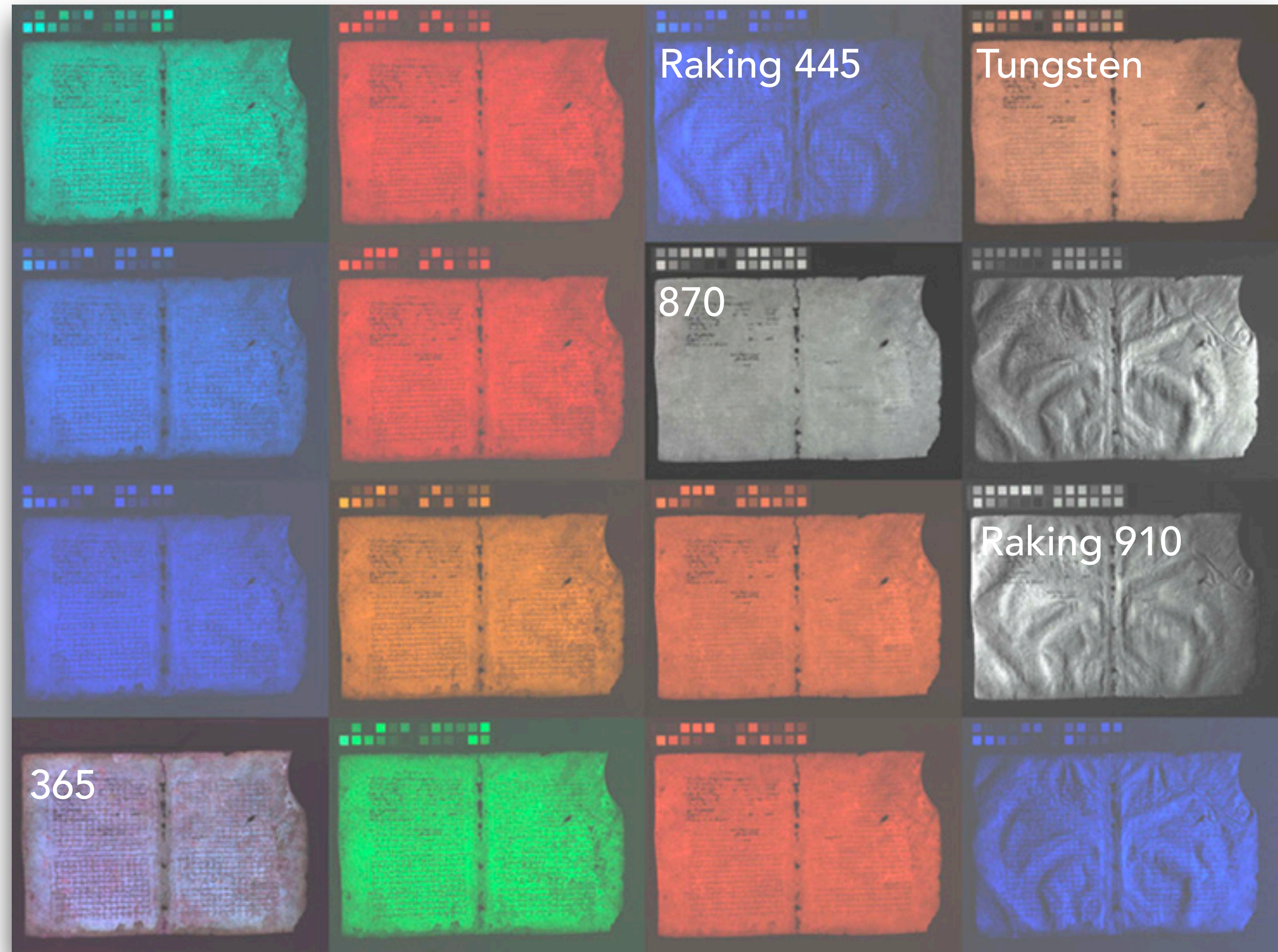
The filters used in the initial imaging are actually the standard astronomical UBVRI filters! They later also used XRF, too.



# Data

## Illuminations:

- 365 nm — 870 nm (11)
  - 365 nm is longwave ultraviolet, which induces fluorescence
  - 700 nm+ is NIR
- 1 broadband tungsten light illumination
- 2 raking illuminations
  - 445 nm and 910 nm
  - From both left and right
- X-ray fluorescence for some leaves (not shown here).



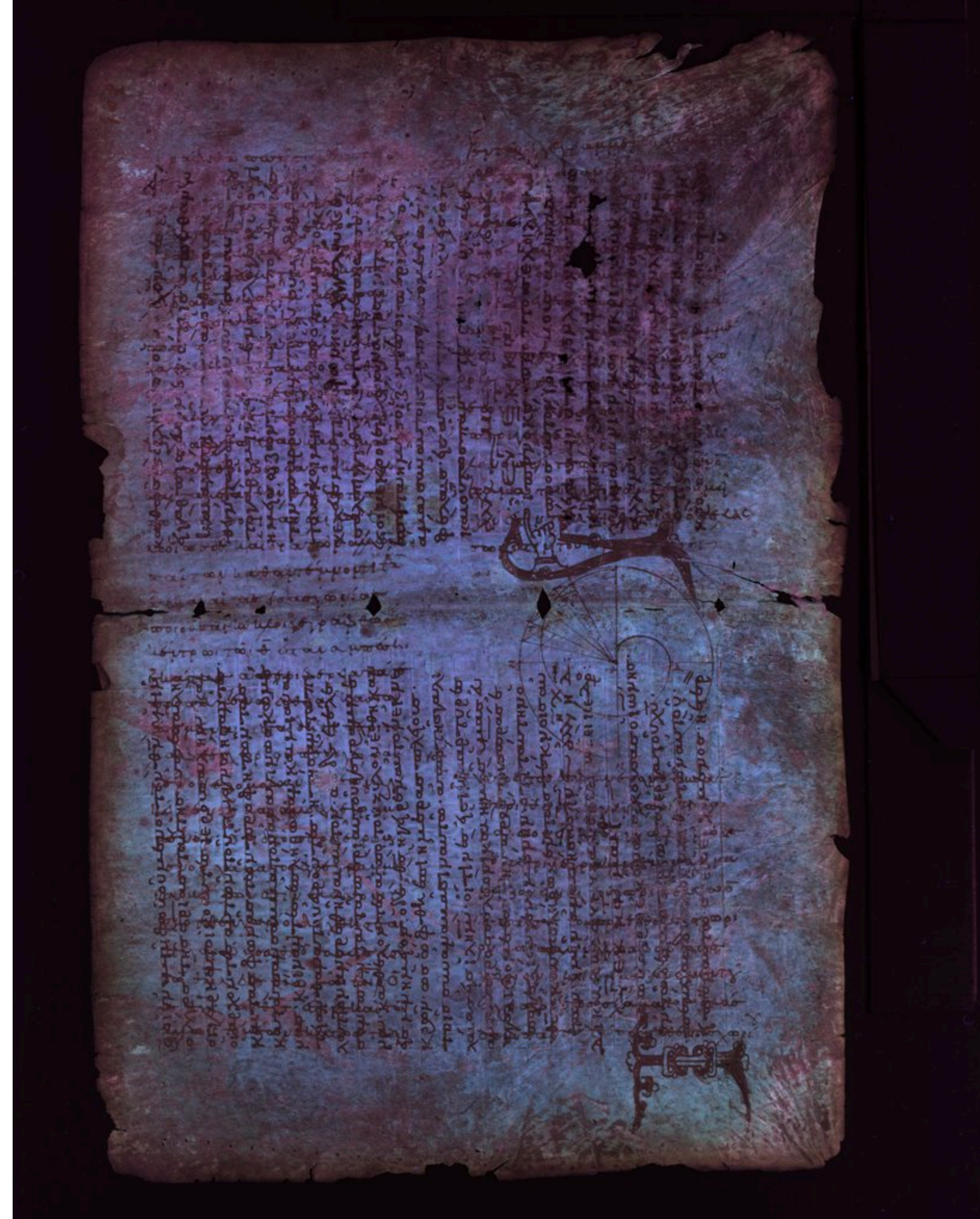


# LWUV Fluorescence

365 nm (LWUV) imaging best distinguishes the texts (both under and over) from the parchment.

LWUV generates visible fluorescence. Both LWUV and the fluorescence are absorbed by the ink but not by the parchment.

- See the [AIPR 2003 paper](https://www.archimedespalimpsest.net/Data/102r-098v/102r-098v_Arch39r_Sinar_LED365_01_pack8.jpg).



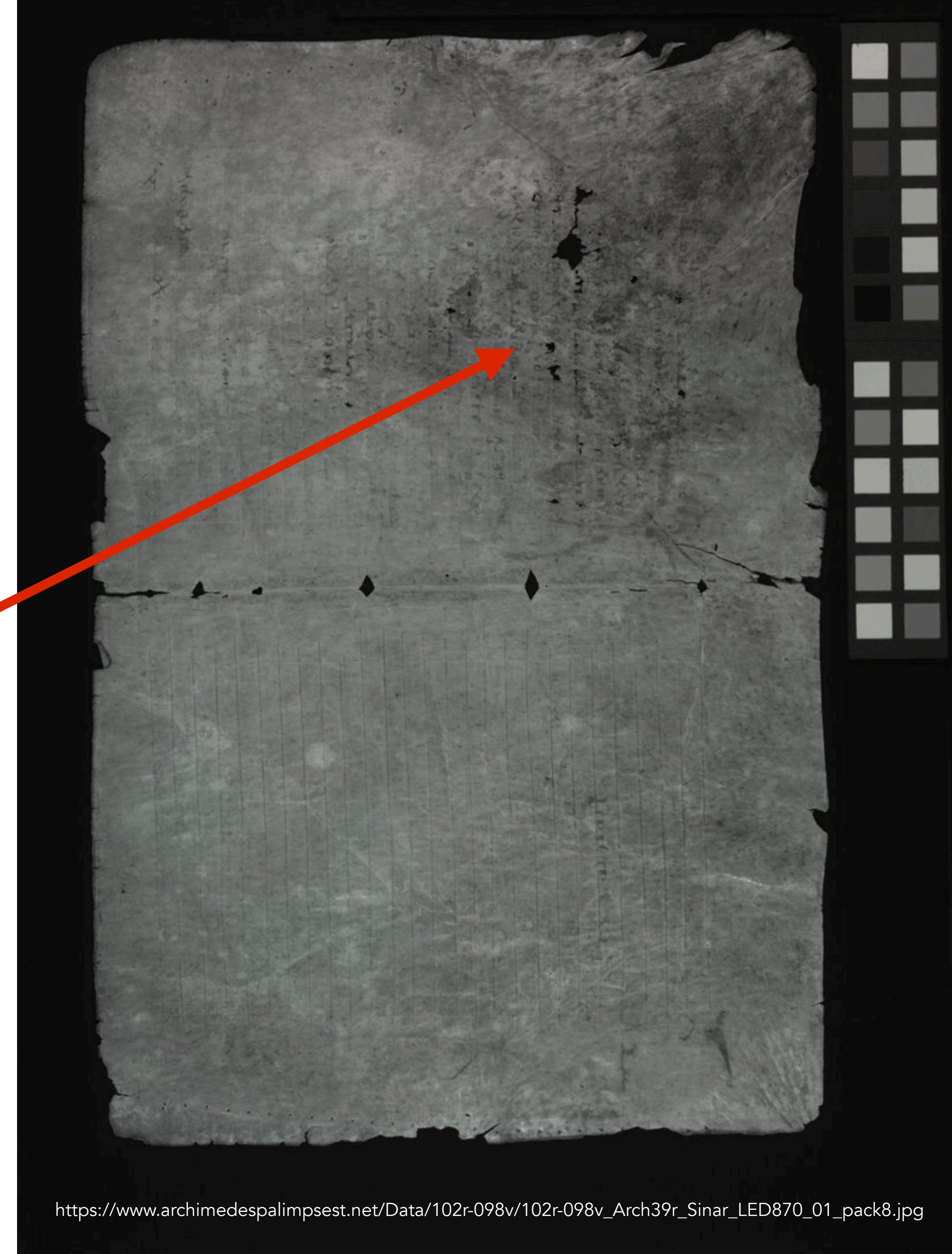


# 870 nm (NIR)

Very little text, both under and over, can be seen.

Presumably at 870 nm, the reflectances of the texts and the parchment are very similar.

- So texts will only be visible when the abundance is very high.



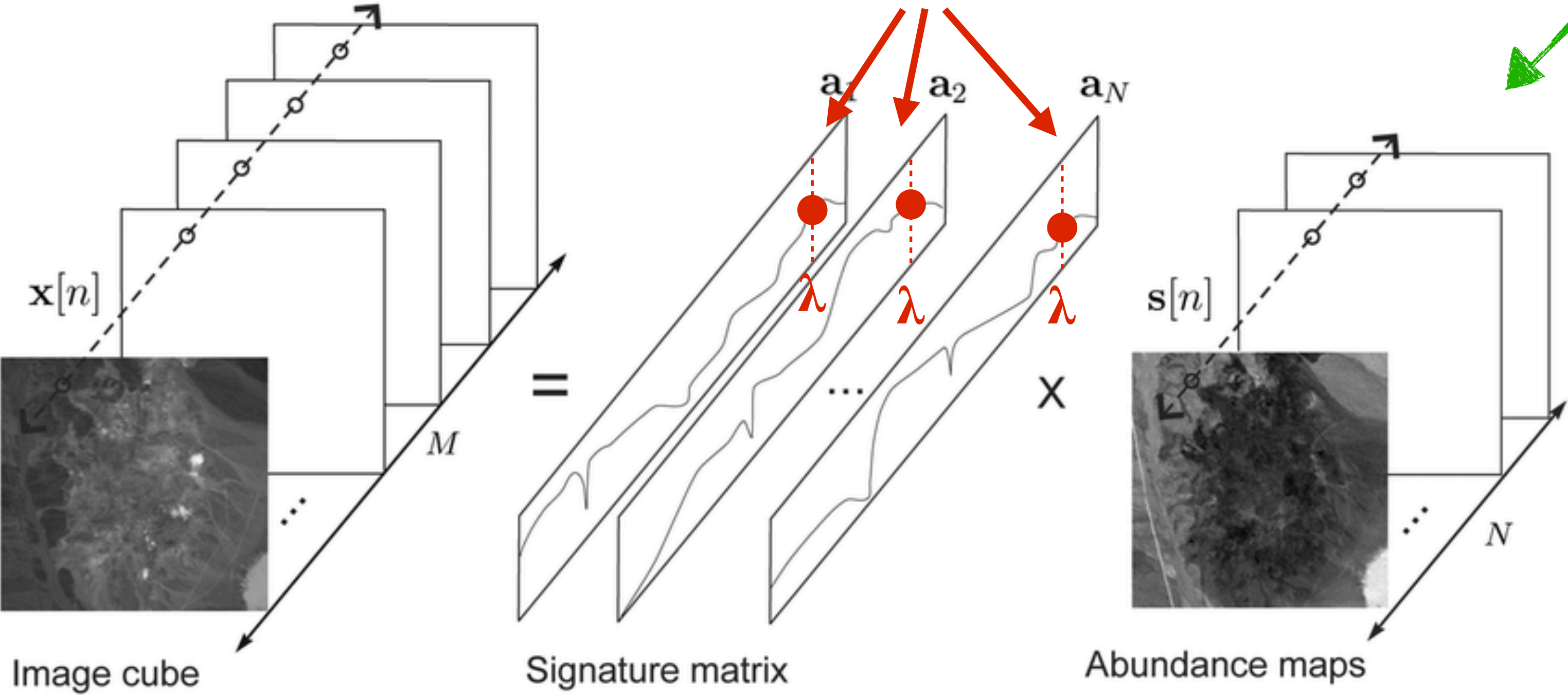


# Linear Mixing Model (Originally Used in Remo)

M: # of spectral bands

Contributions of different layers at  $\lambda$

The goal is to calculate these images



N: # of layers

Spectral reflectance of each layer

Over-determined system:  $N < M$ ; solve by minimizing least squares error.



## News in focus



The library of St Catherine's Monastery on the Sinai Peninsula in Egypt yielded a palimpsest containing stellar coordinates by Hipparchus.

### FIRST KNOWN MAP OF NIGHT SKY FOUND HIDDEN IN MEDIEVAL PARCHMENT

Fabled star catalogue by ancient Greek astronomer Hipparchus had been feared lost.

By Jo Marchant

A medieval parchment from a monastery in Egypt has yielded a surprising treasure. Hidden beneath Christian texts, scholars have discovered what seems to be part of the long-lost star catalogue of the astronomer Hipparchus – believed to be the earliest known attempt to map the entire sky.

Scholars have been searching for Hipparchus's catalogue for centuries. James Evans, a historian of astronomy at the University of Puget Sound in Tacoma, Washington,

describes the find as "rare" and "remarkable". The extract was published online last week in the *Journal for the History of Astronomy* (V. Gysembergh *et al.* *J. Hist. Astron.* 53, 383–393; 2022). Evans says it proves that Hipparchus, often considered the greatest astronomer of ancient Greece, really did map the heavens centuries before other known attempts.

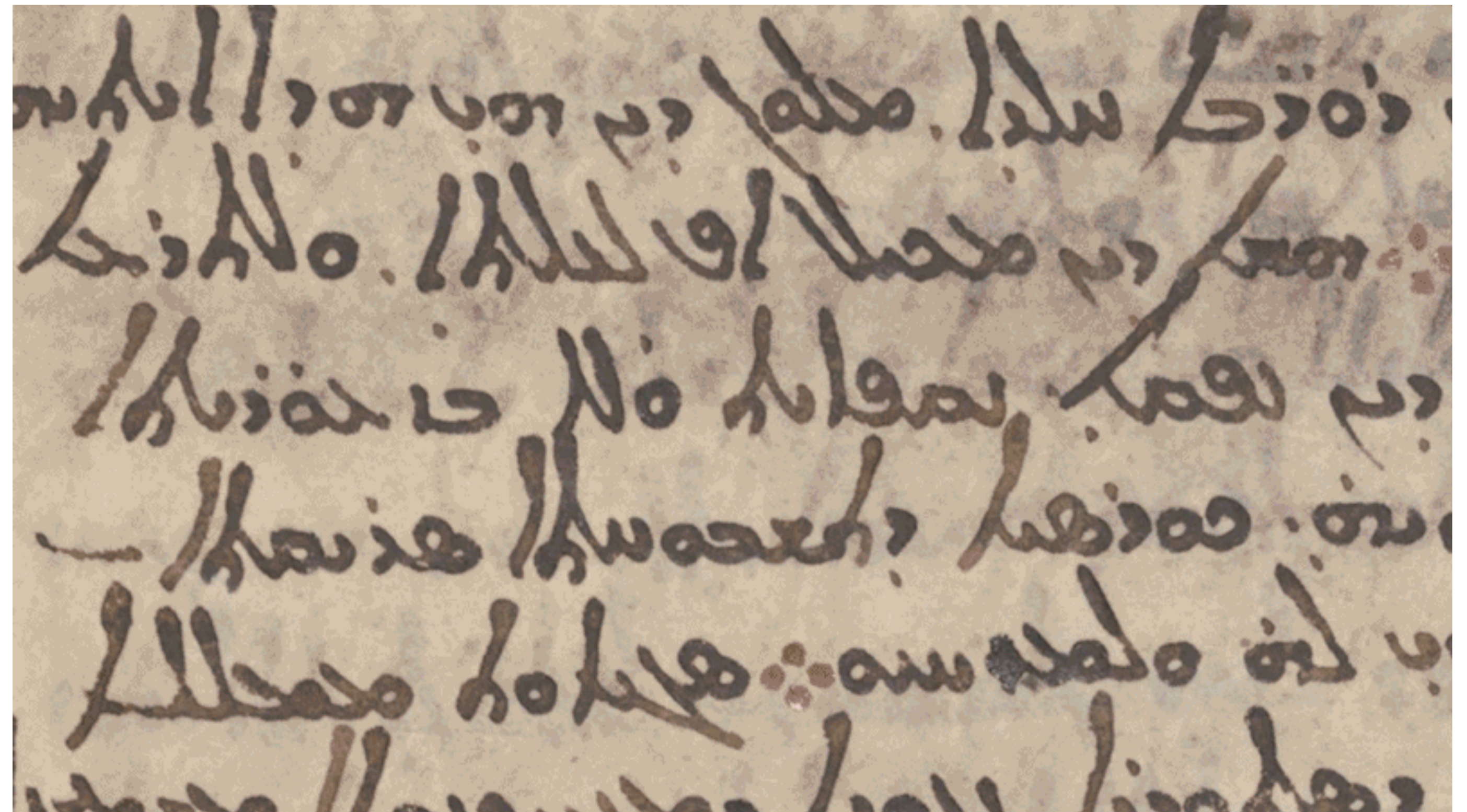
The manuscript came from the Greek Orthodox St Catherine's Monastery on the Sinai Peninsula, Egypt, but most of its 146 leaves, or folios, are now owned by the Museum of the Bible in Washington DC. The pages contain the

*Codex Climaci Rescriptus*, a collection of Syriac texts written in the tenth or eleventh century. But the codex is a palimpsest: parchment that was scraped clean of older text by the scribe so that it could be reused.

The older writing was thought to contain further Christian texts and, in 2012, biblical scholar Peter Williams at the University of Cambridge, UK, asked his students to study the pages as a summer project. One of them, Jamie Klair, unexpectedly spotted a passage in Greek often attributed to the astronomer Eratosthenes. In 2017, the pages were reanalysed using state-of-the-art multispectral imaging. Researchers

# Hipparchus's Star Catalogue

Recently discovered; believed to be the long-lost, earliest mapping of the entire sky by Hipparchus. We imaged it using multi-spectral imaging and are working on revealing the hidden texts.





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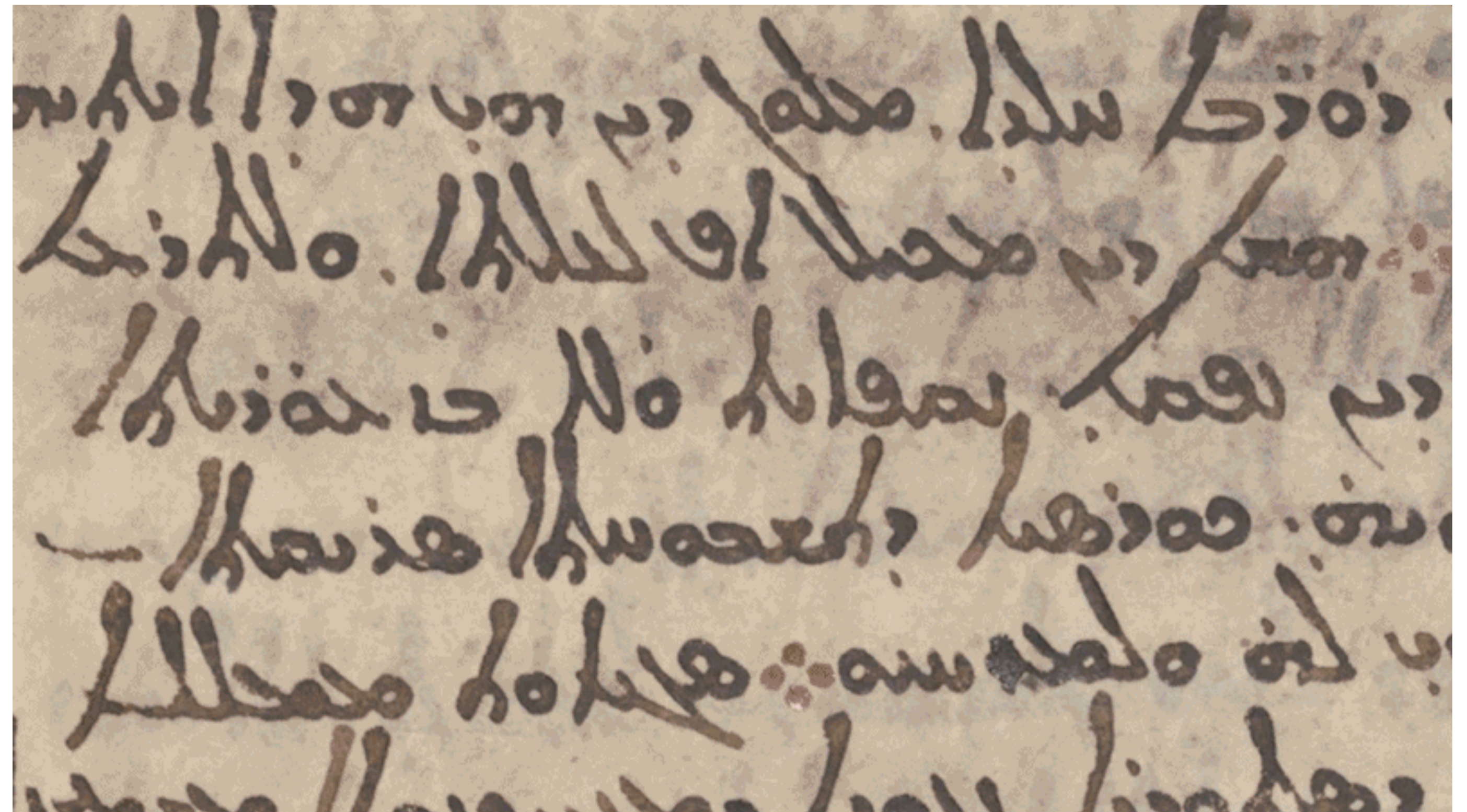
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# Pentimento

The presence/emergence of earlier paints that have been painted over.

- Painter changing mind (pentimento is from “pentirsi” in Italian, which means repentance)
- Underdrawing

Can be identified using imaging techniques (e.g., X-ray), or from paint composition changes (previous slide).



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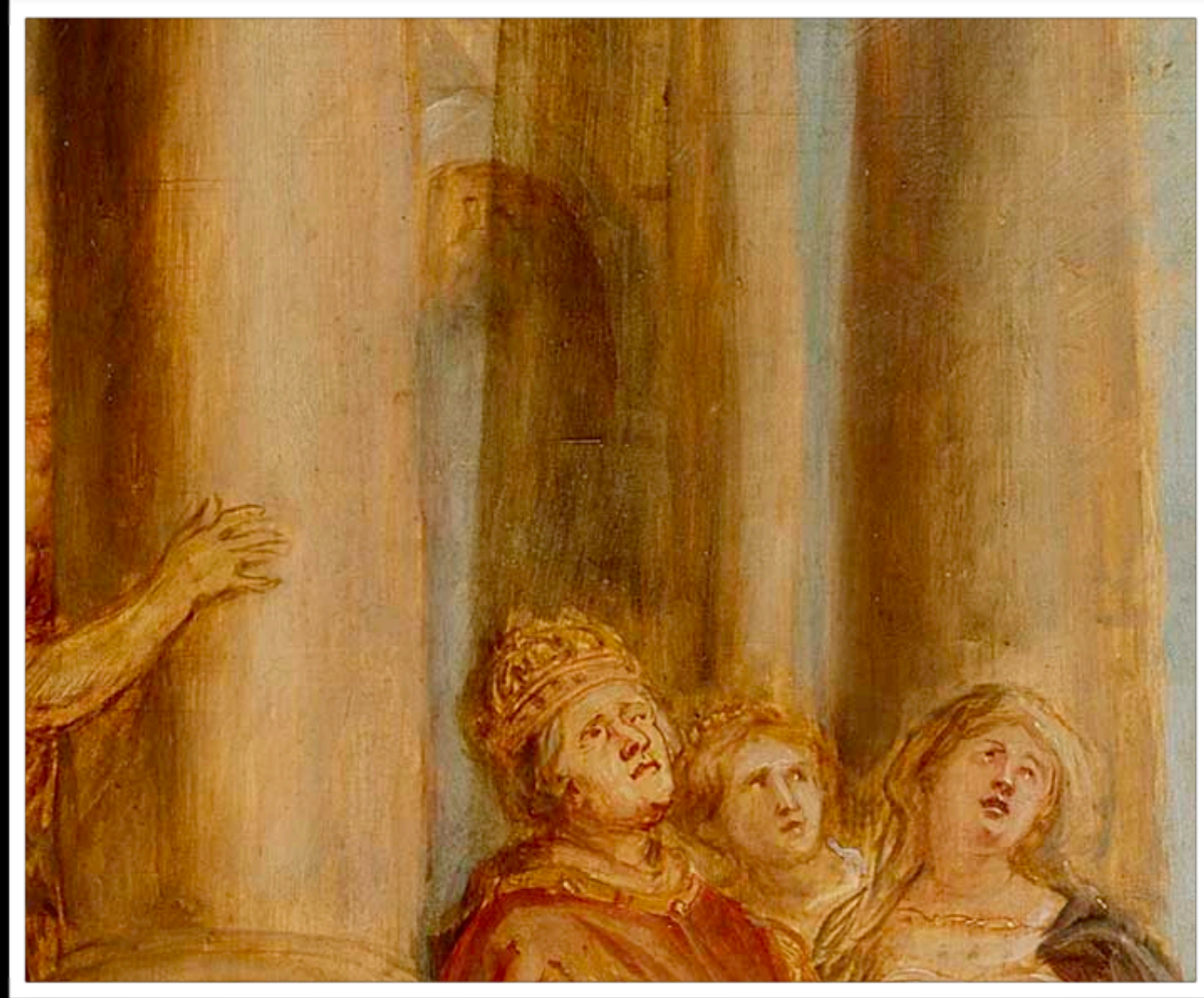
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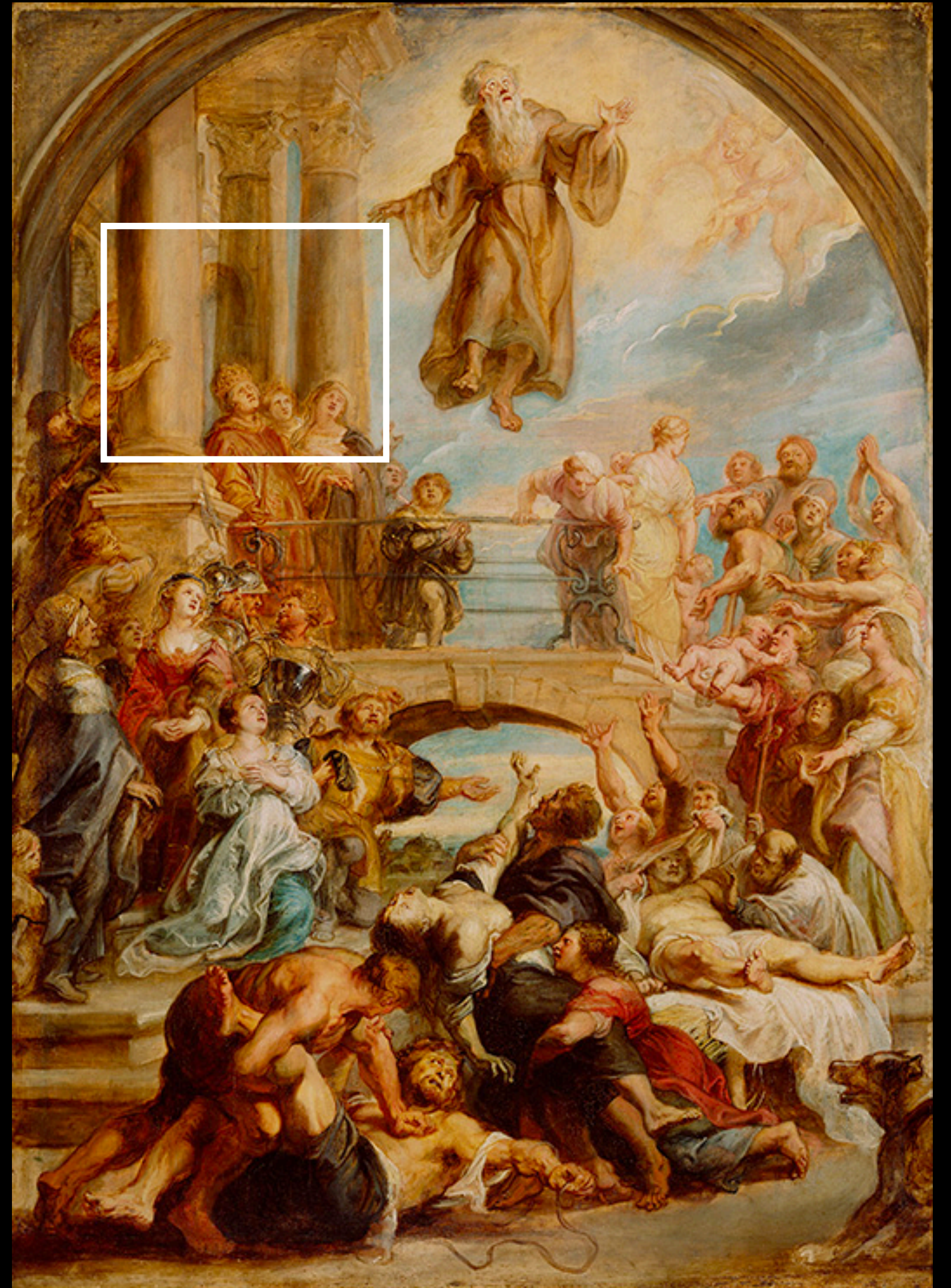




*The Miracles of Saint Francis of Paola, P. P.*  
Rubens, 1627–8. J. Paul Getty Museum.



The refractive index of the linseed oil in the paint increases over time and matches that of the pigment. The paint layer becomes transparent, revealing the pentimento underneath.





# The Old Guitarist (Picasso 1903)





# The Old Guitarist (Picasso 1903)

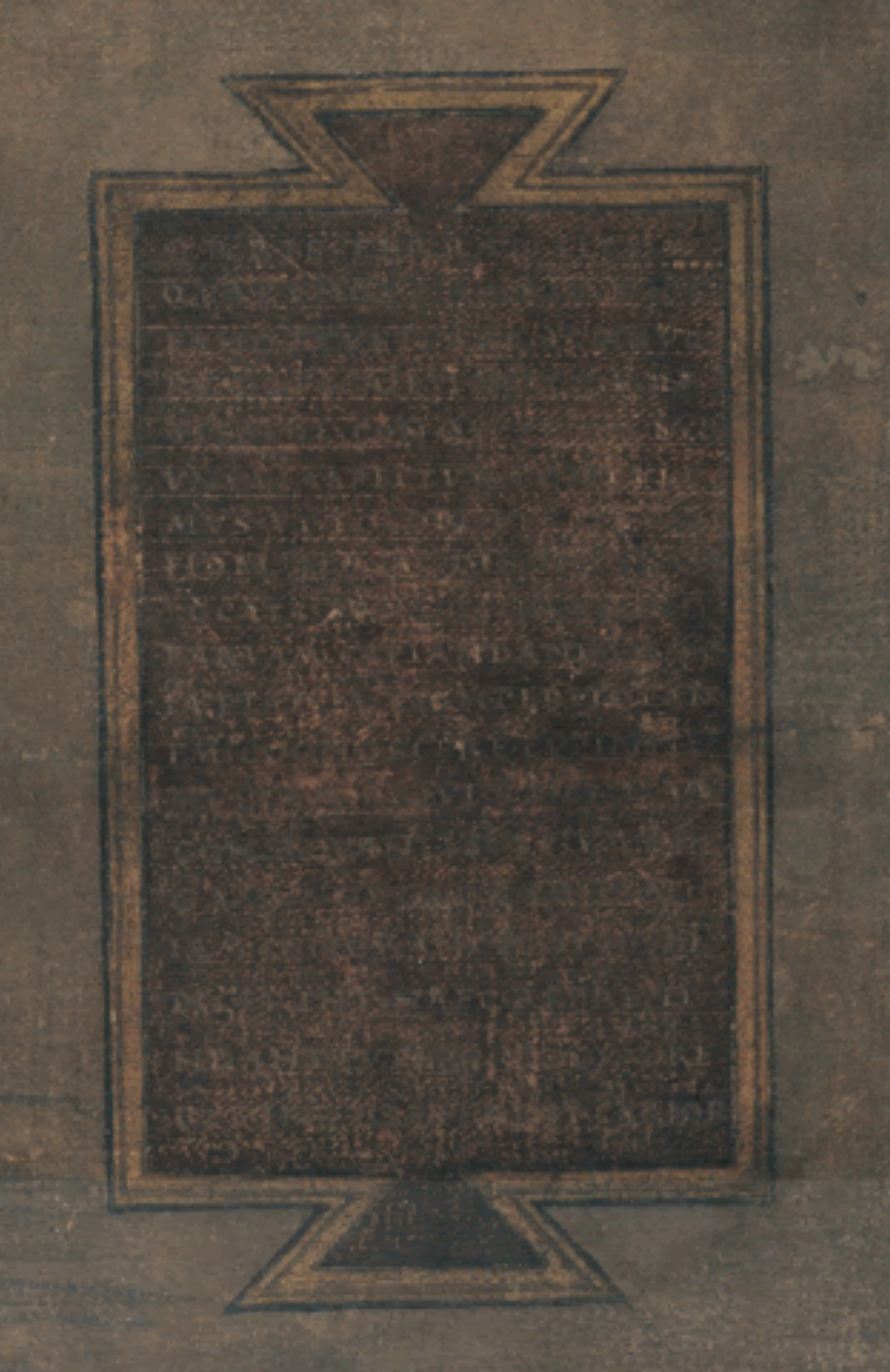




# The Martellus Map

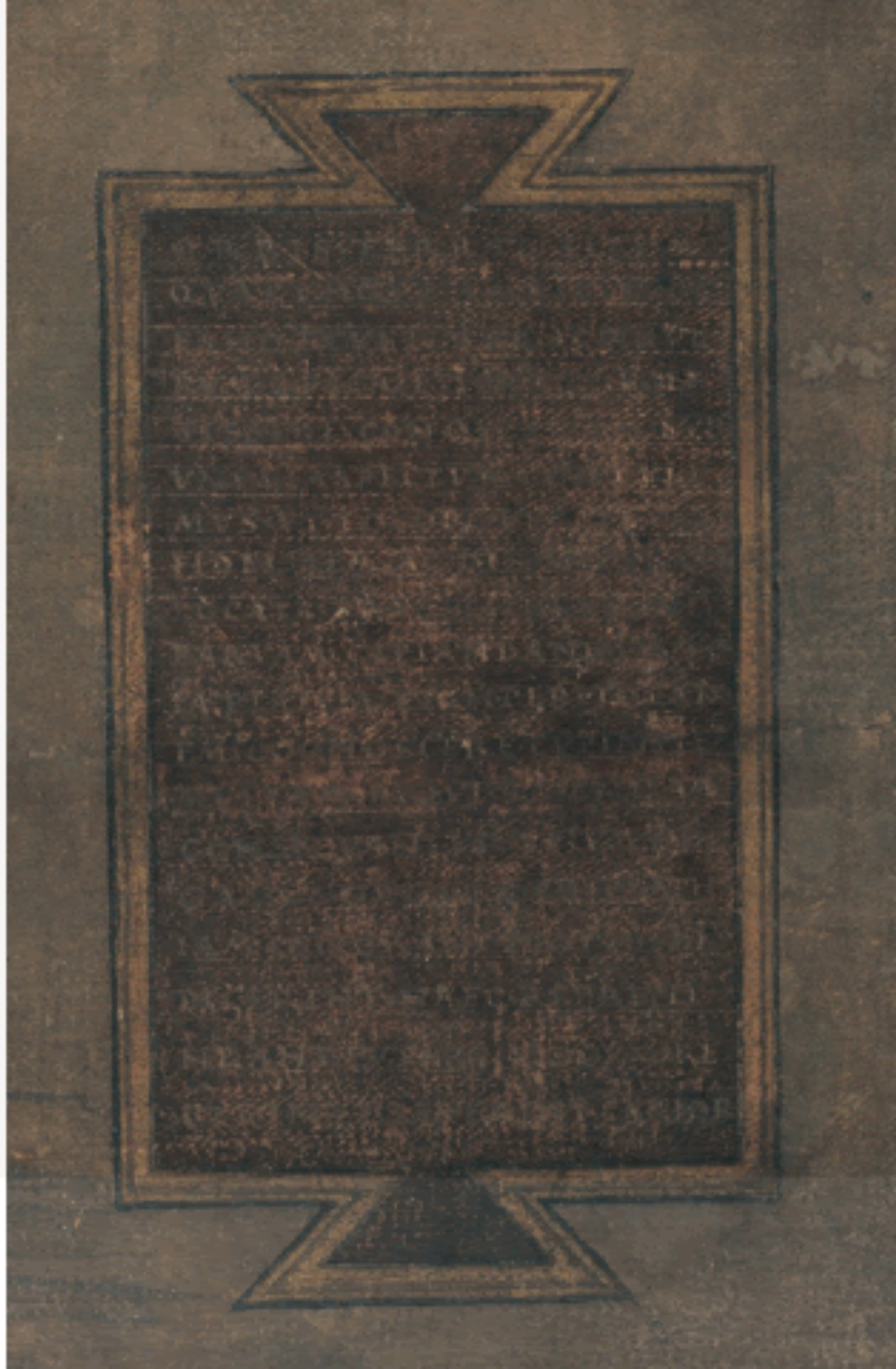






The text-block  
in natural light





The text-block  
in natural light

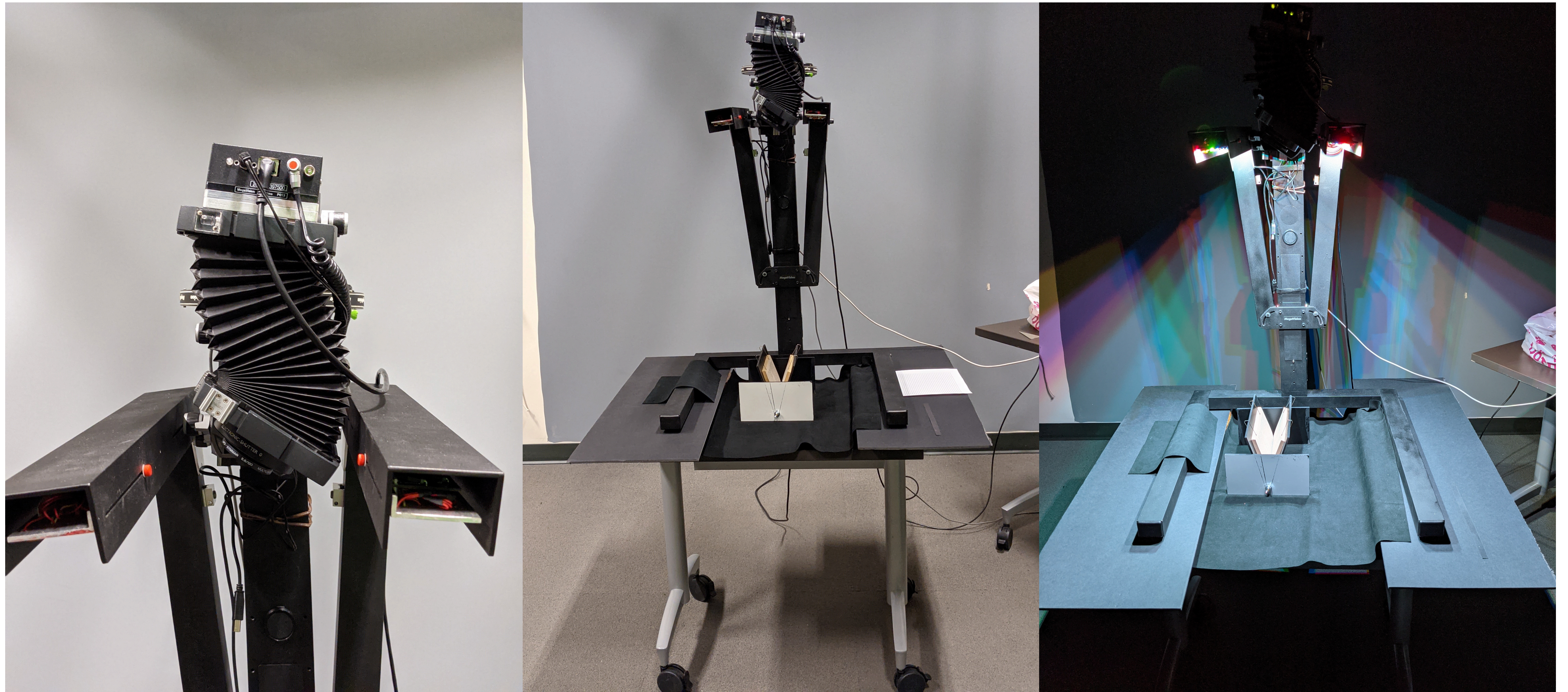


# Tightly Bound Books and Manuscripts

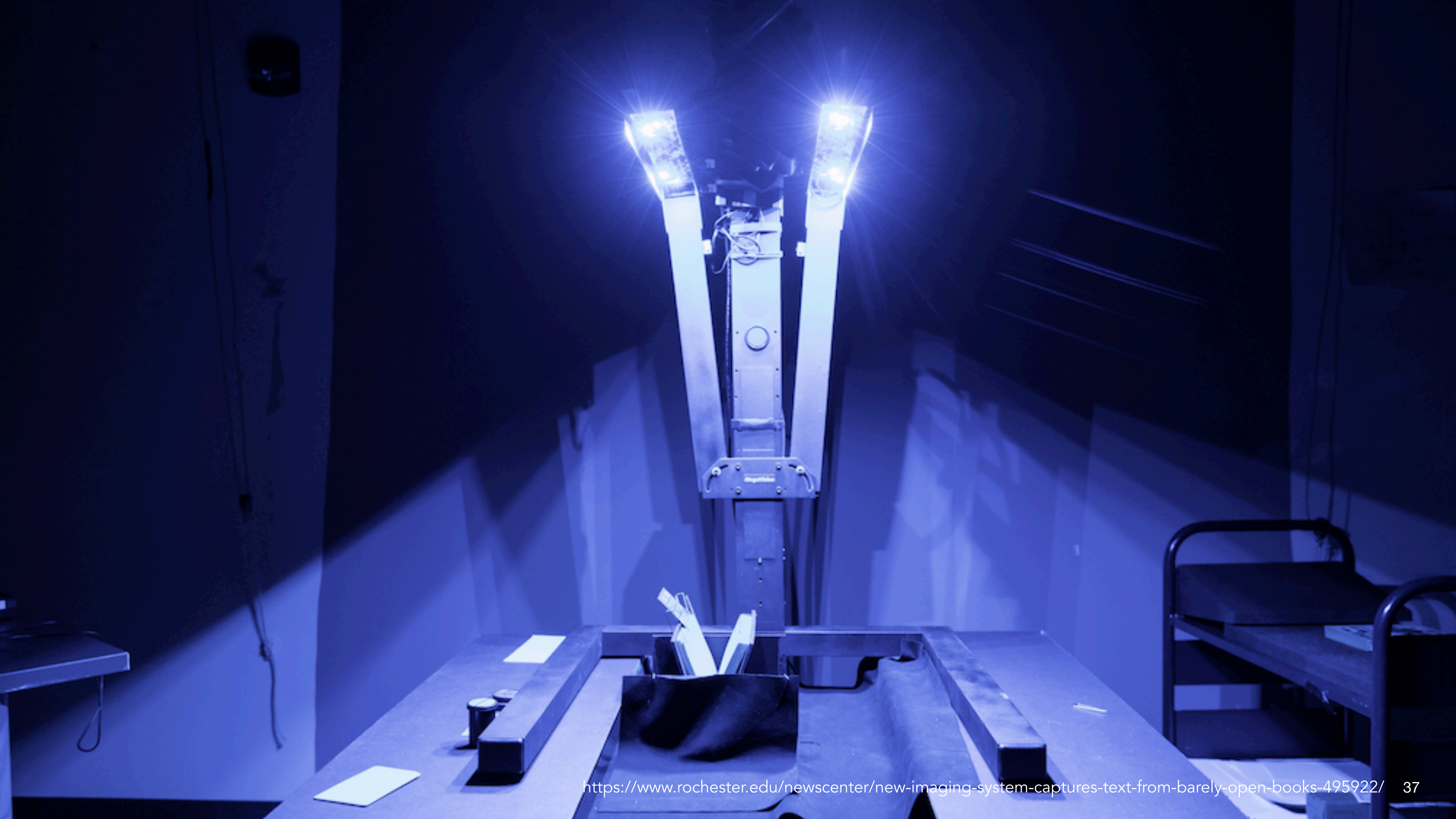




# Scheimpflug Imaging

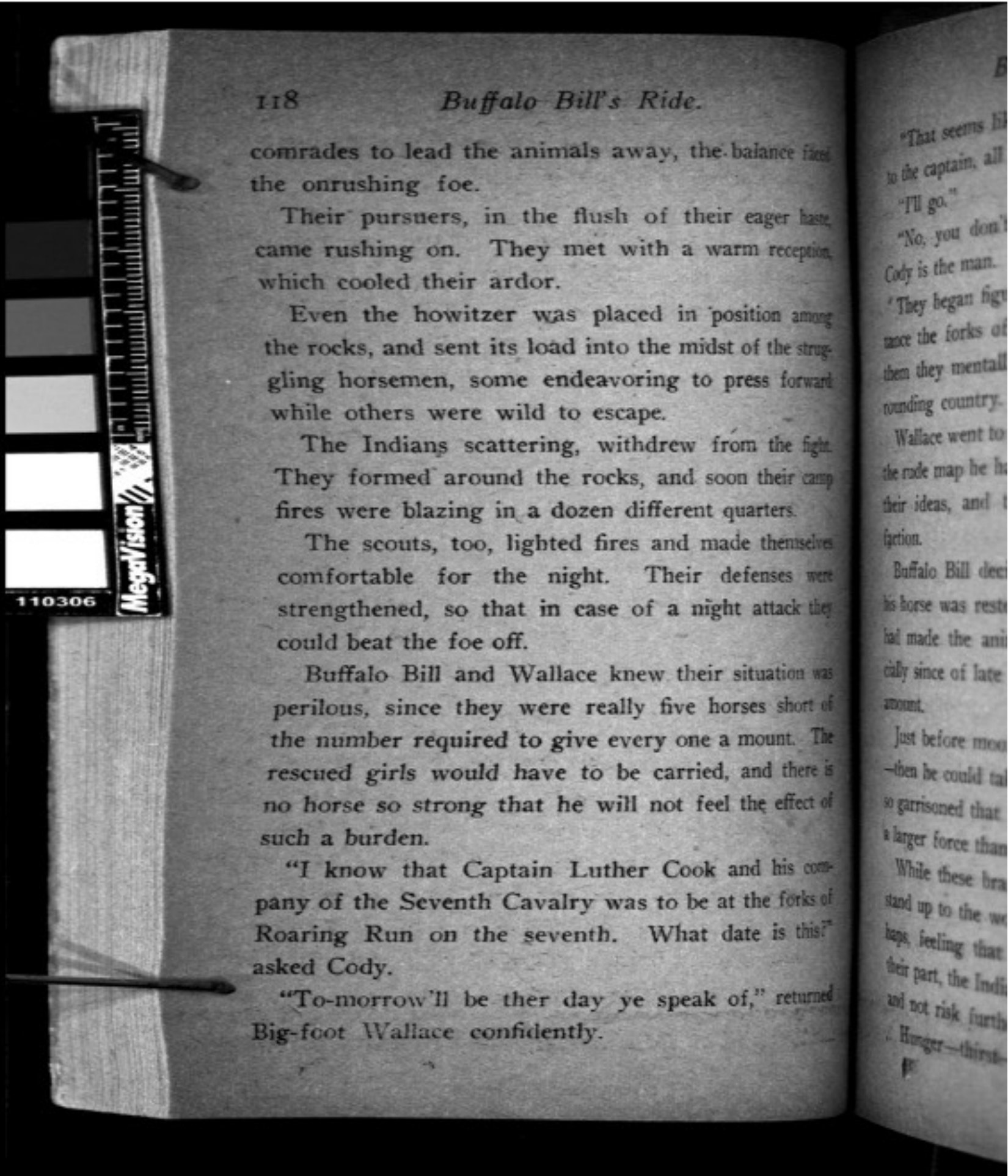
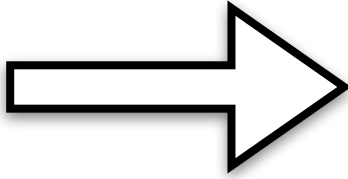
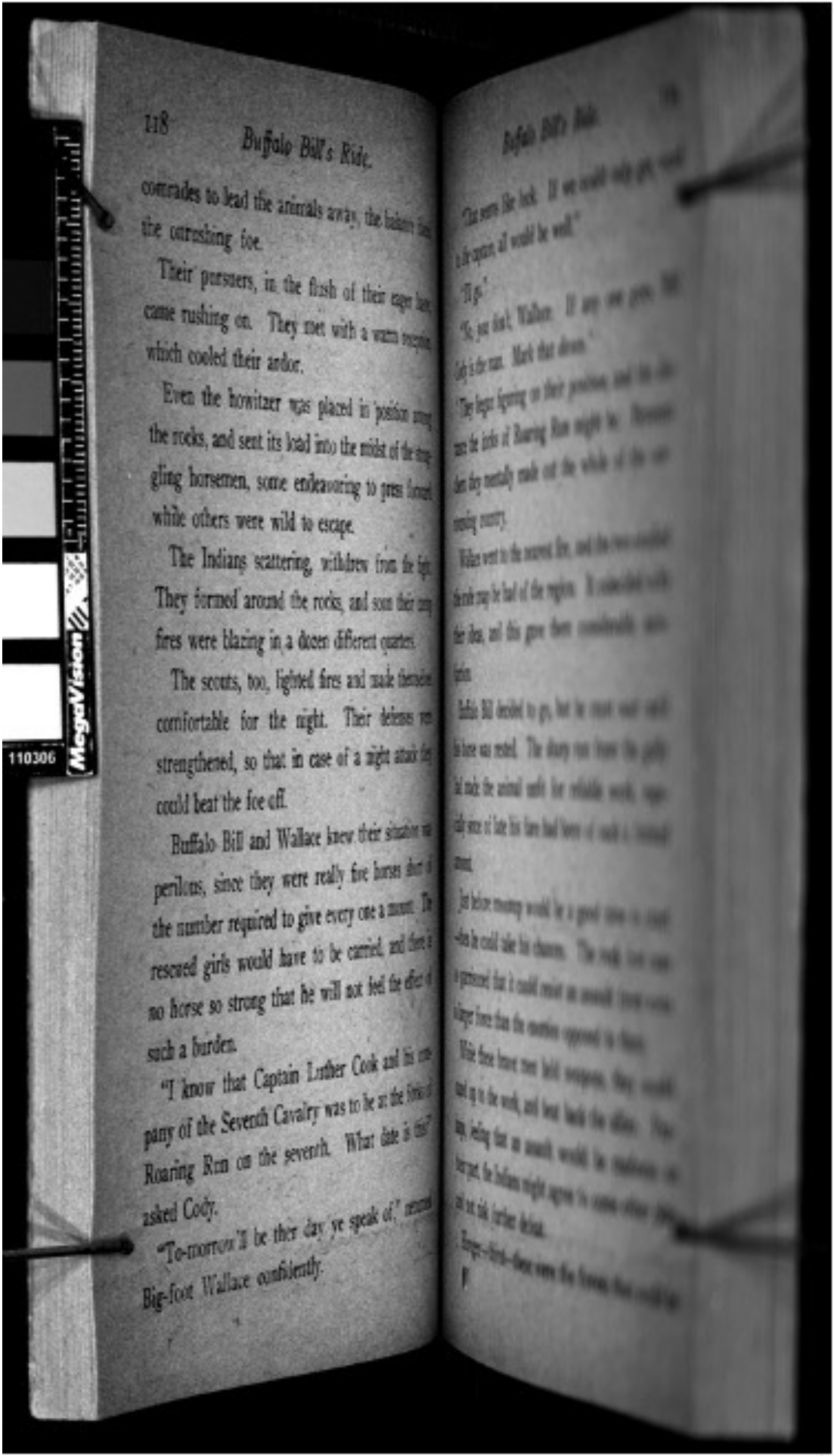








# Post-Imaging Correction





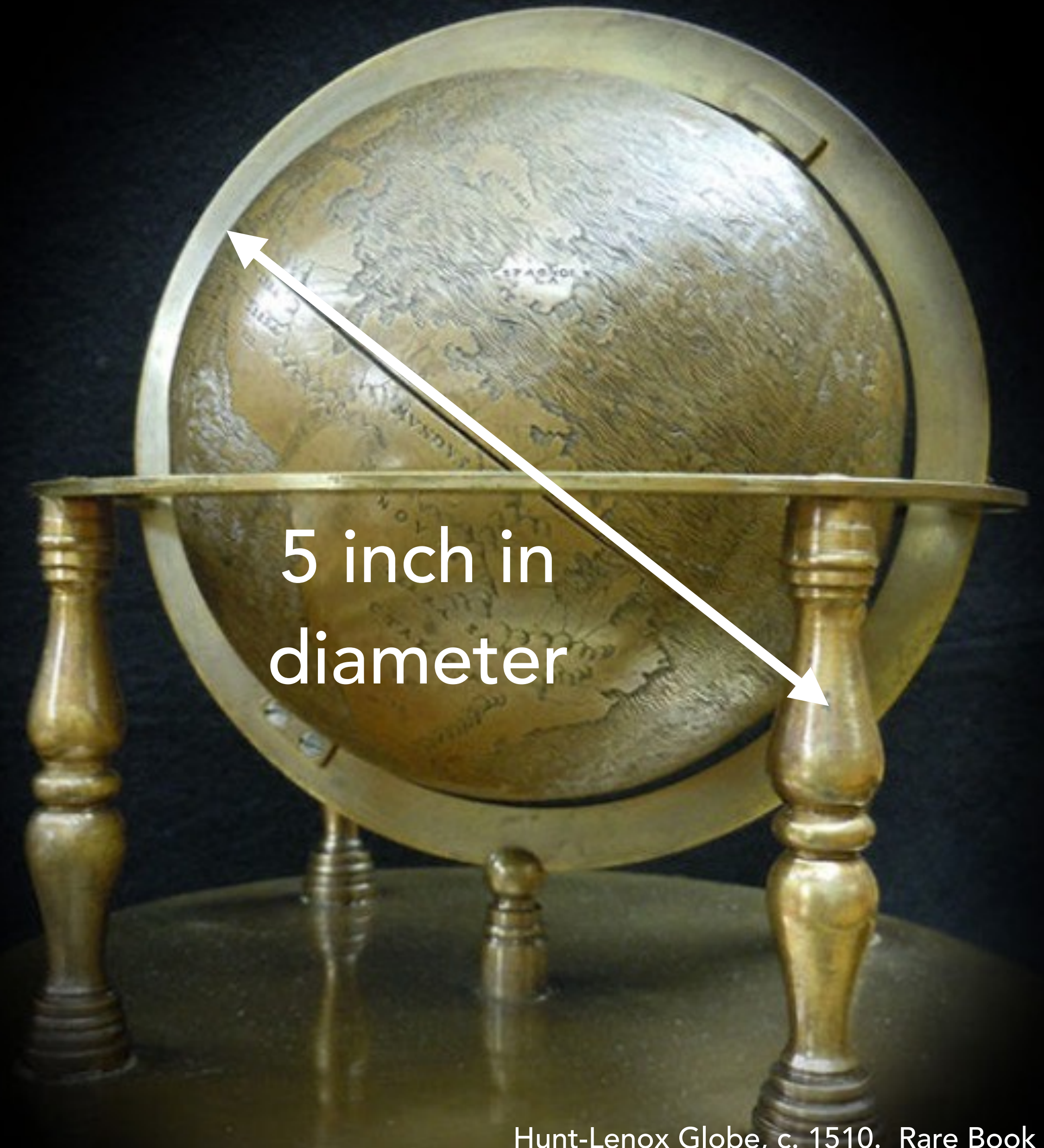
# The Hunt-Lenox Globe



Hunt-Lenox Globe, c. 1510. Rare Book Division. The New York Public Library.



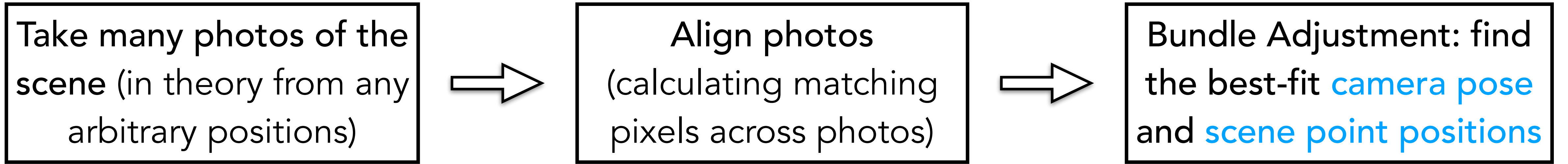
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Hunt-Lenox Globe, c. 1510. Rare Book Division. The New York Public Library.



# Recall: Photogrammetry (Structure from Motion)



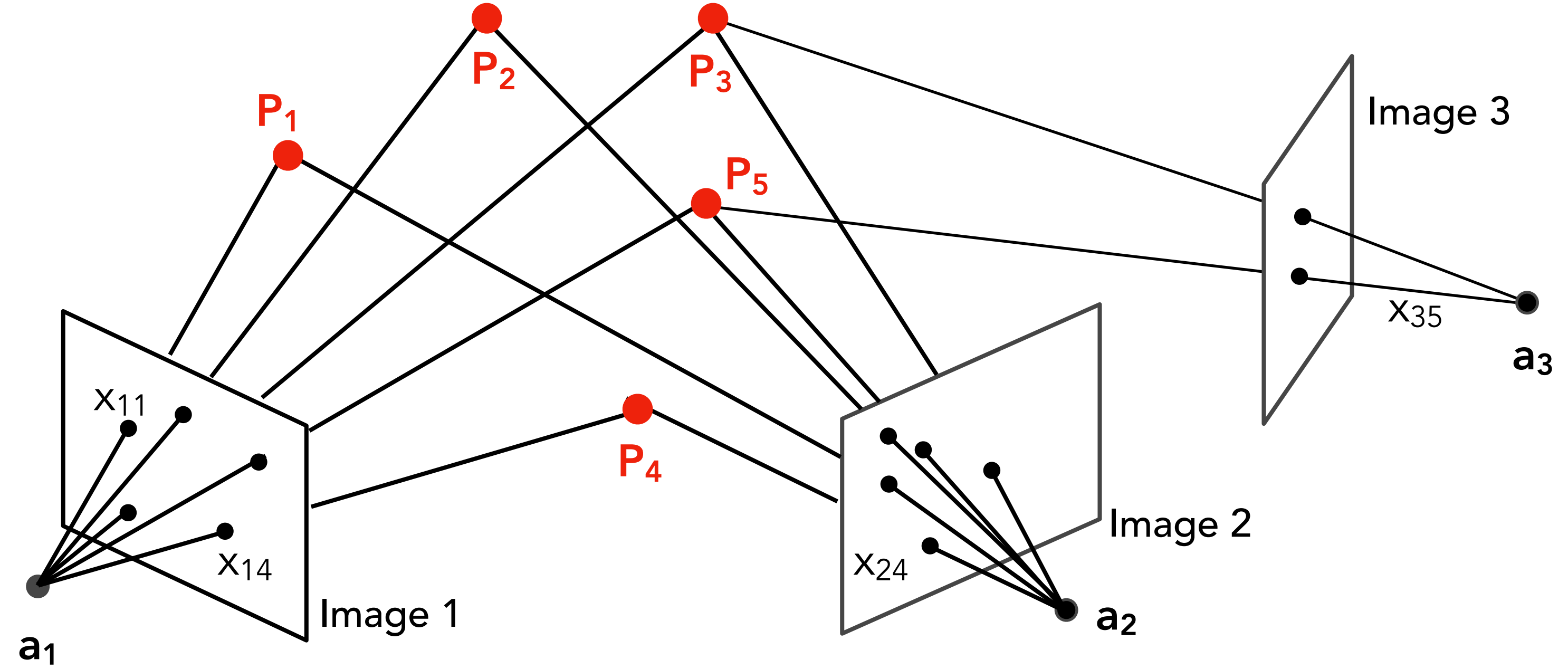
Perspective projection of point  $P_j$  to camera  $a_i$

$$\min_{a_i, P_j} \sum_{i=1}^m \sum_{j=1}^n v_{ij} \| \mathbf{Q}(a_i, P_j), x_{ij} \|$$

Camera 6 DoF pose

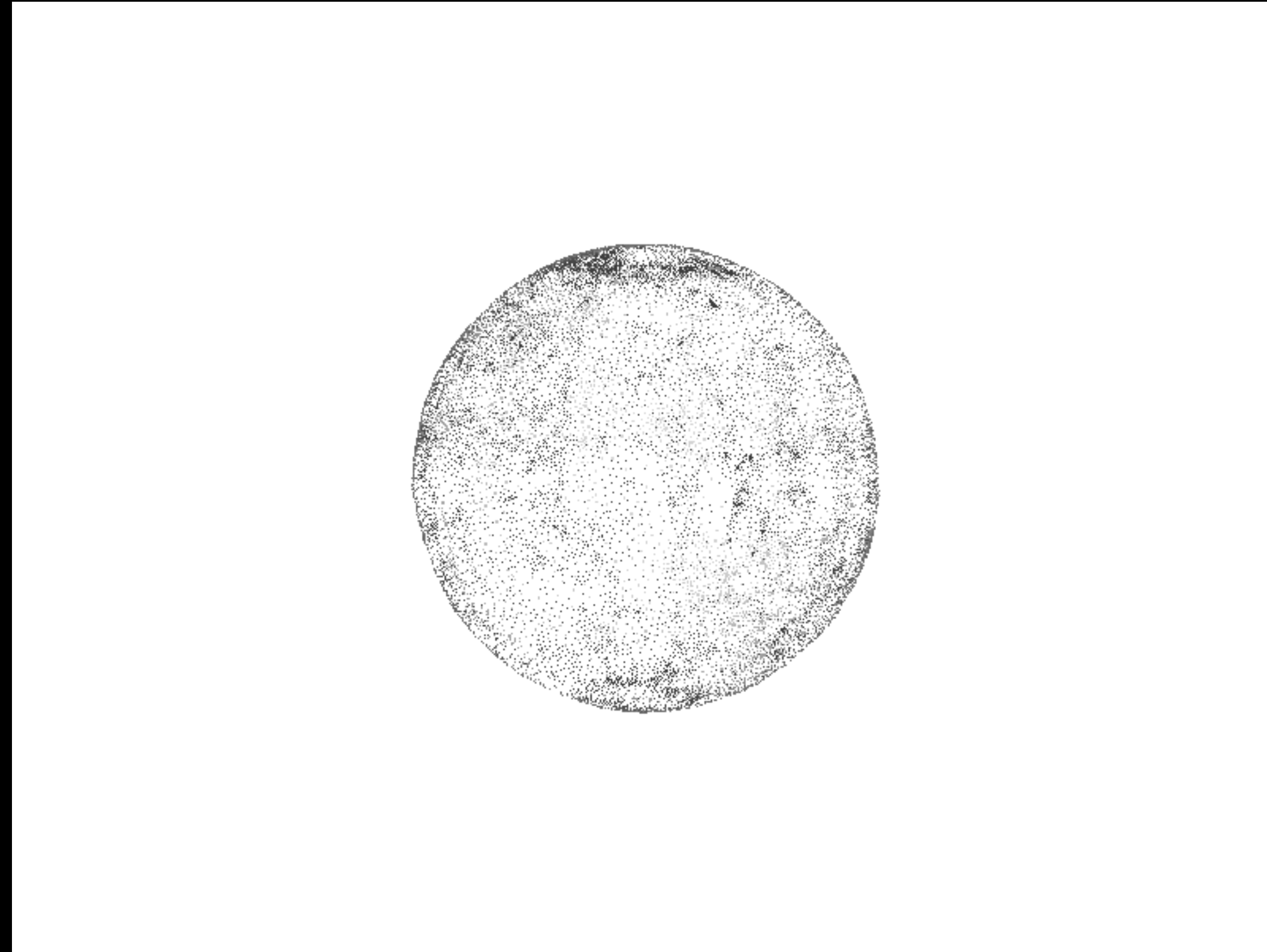
Scene point coordinates

Whether point  $P_j$  is scene by camera  $a_i$



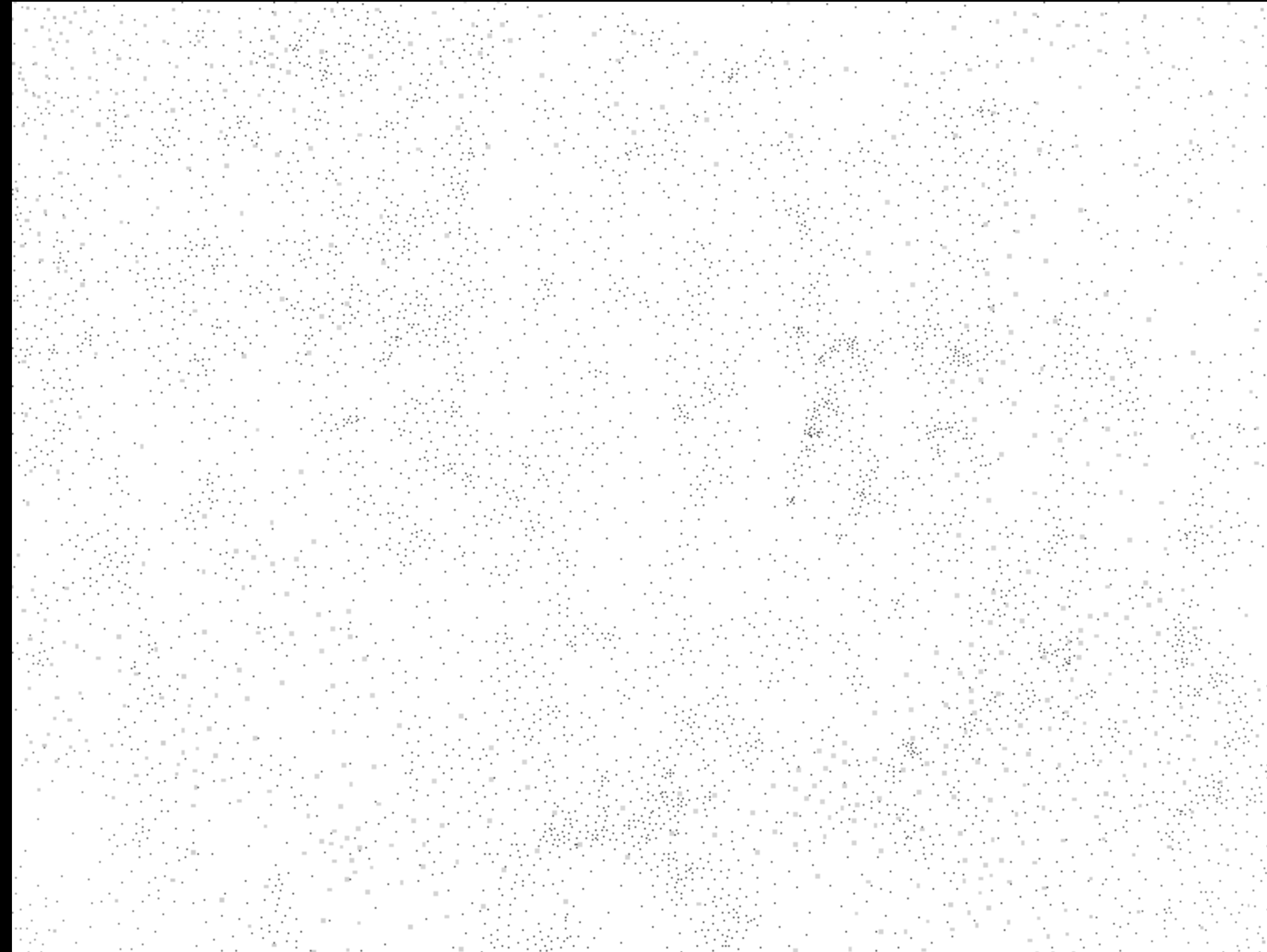


# Point Cloud from SfM



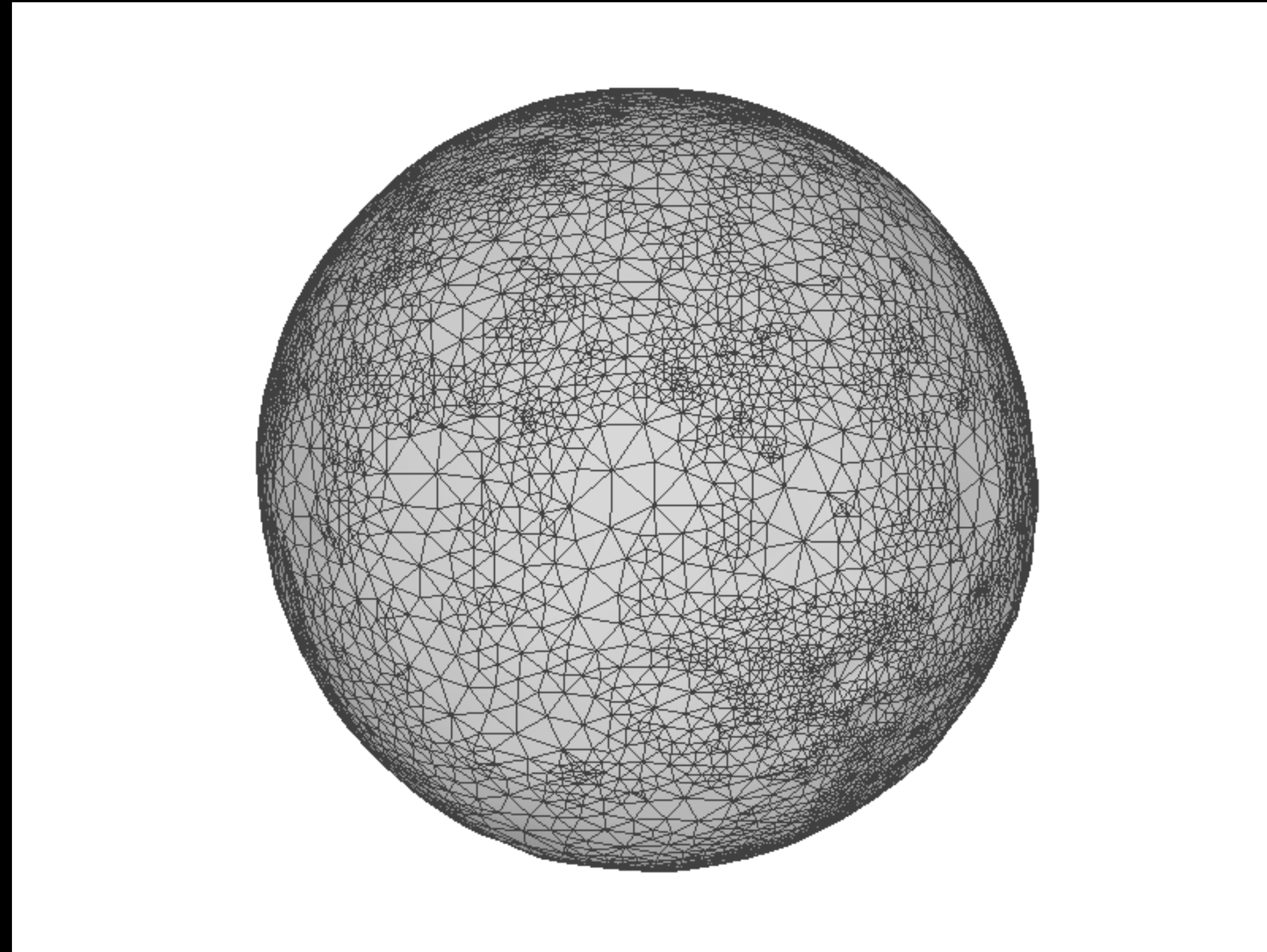


# Point Cloud from SfM



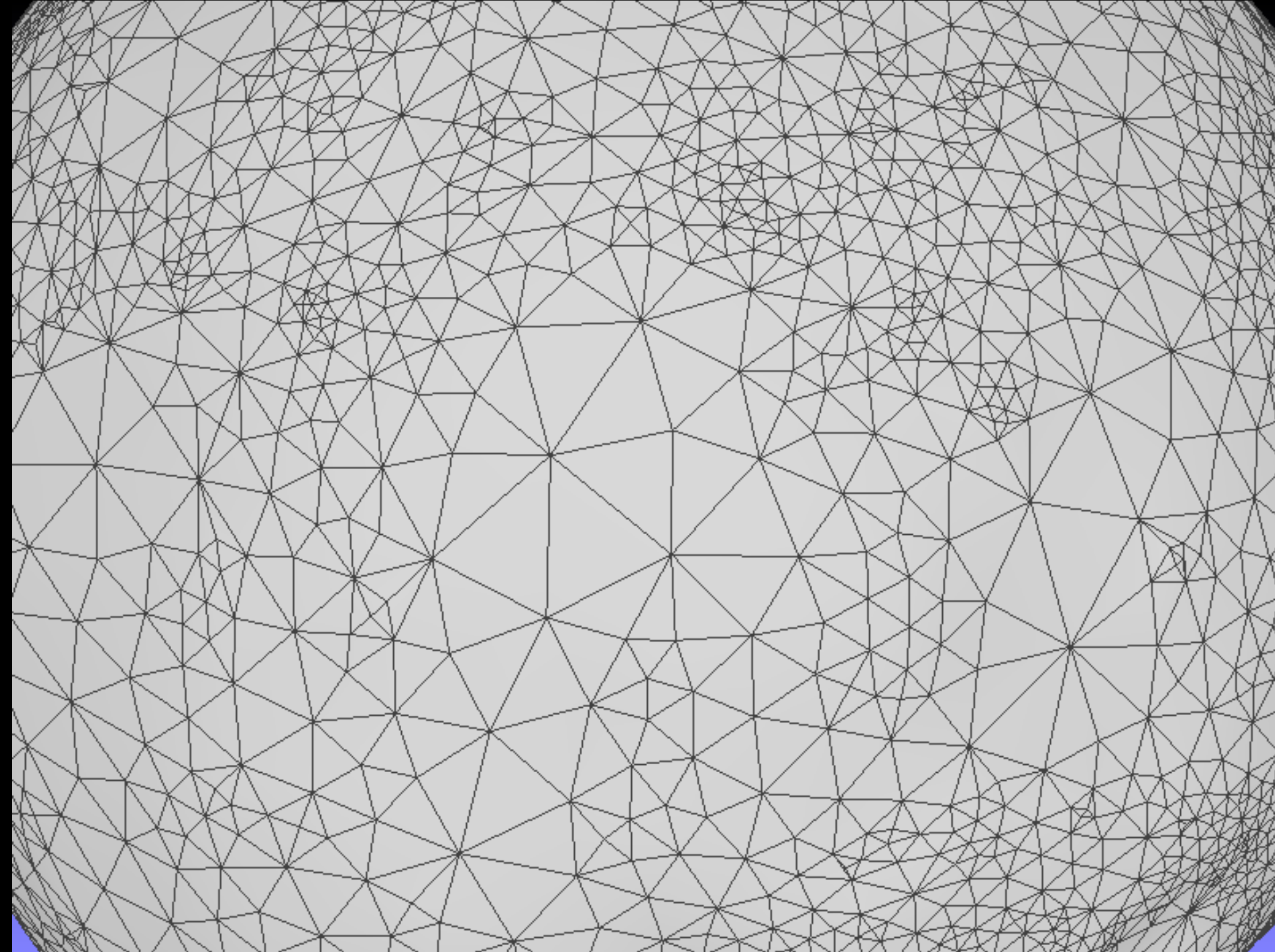


# Mesh From Point Clouds



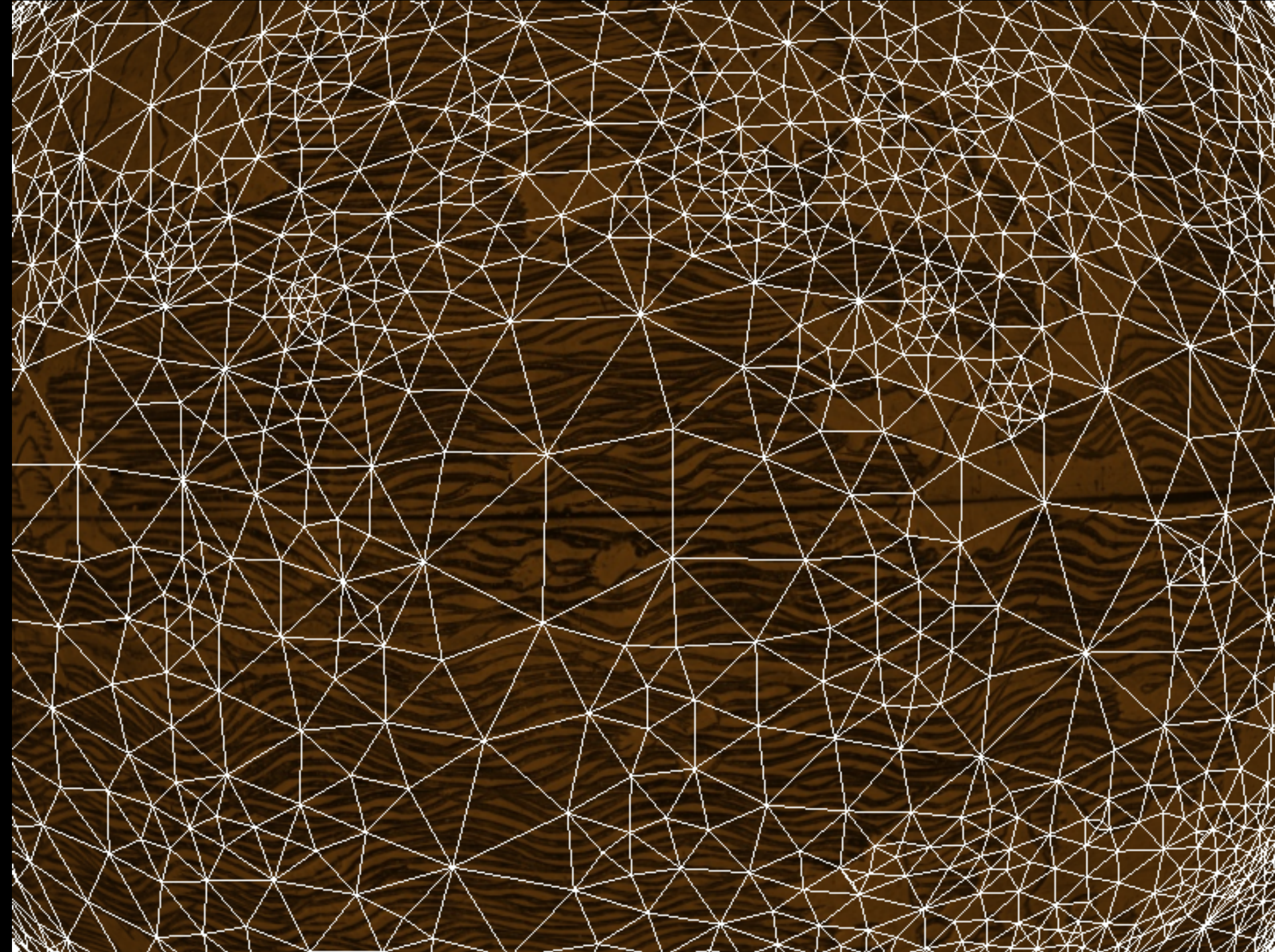


# Mesh From Point Clouds





# Mesh From Point Clouds









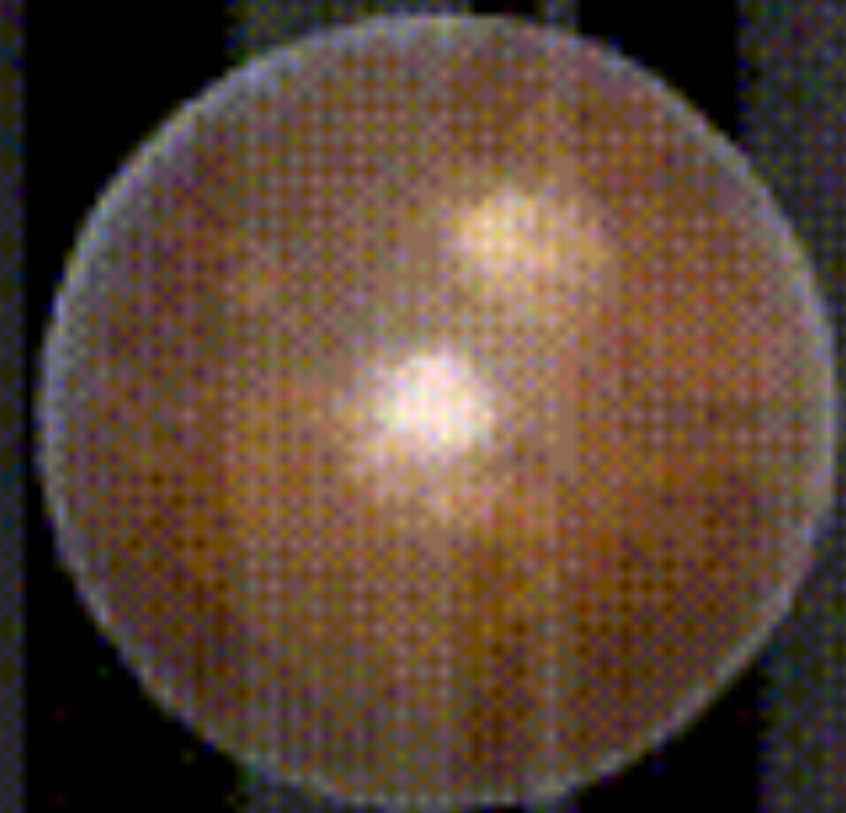




# Future Goals



Active

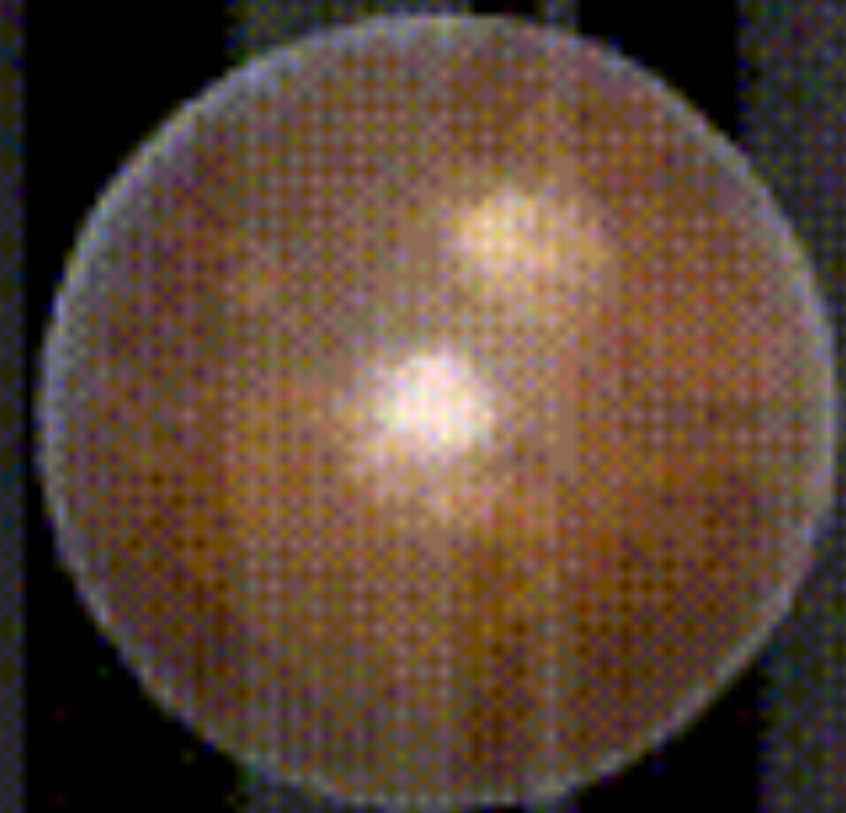




# Future Goals



Active





# References

## Virtual unwrapping:

- From damage to discovery via virtual unwrapping: Reading the scroll from En-Gedi, *Science Advances*, 2016
- From invisibility to readability: Recovering the ink of Herculaneum, *PLOS One*, 2019
- A computational platform for the virtual unfolding of Herculaneum Papyri, *Scientific Reports*, 2021
- Revealing metallic ink in Herculaneum papyri, *PNAS*, 2016

## Archimedes Palimpsest

- Data: <https://www.archimedespalimpsest.net/>
- Data: <https://www.cis.rit.edu/people/faculty/easton/manuscripts-short.html>
- Talk: <https://www.youtube.com/watch?v=gME6fsCvonU>



# References

## Archimedes Palimpsest (cont.)

- Talk: <https://youtu.be/z3fZdlw-s-E?t=790>, shows the SPD of the illuminations
- [Multispectral Imaging of the Archimedes Palimpsest](#), IS&T PICS 2001.
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- Camps-Valls G (2014) [Hyperspectral Image Processing](#). Good reference.