

*Parchment Conservation Workshop - March 2016*

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# Micro-CT of Parchment.

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@dtl

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The Apocalypto Project

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# Introduction

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Sometime in 2006 a question was asked  
*"Can you see ink on parchment with your X-Ray scanner?"*  
- Tim Wess talking to Graham Davis in a taxi.

The answer turned out to be yes, and more besides.

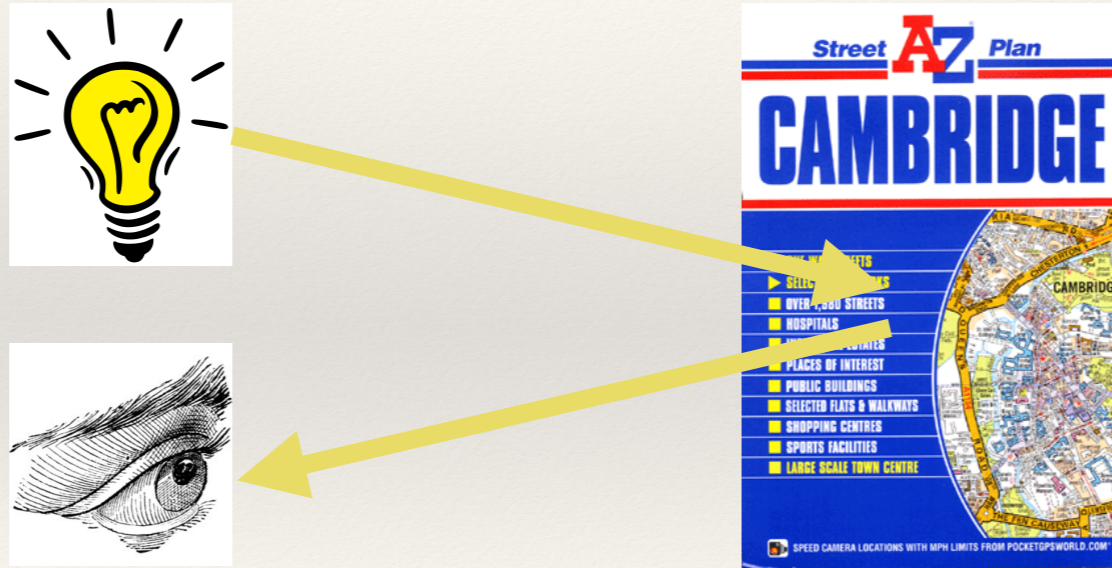
In mid 2009 the Apocalypto Project was born - a collaboration between Conservators, Scientists  
and Computer Vision experts.

This presentation covers some of what we've worked on and learned along the way

How we got started in this - A dental School and an ophthalmology school doing heritage science

# The nature of imaging

In general, how do we image anything?



We shine light on an object and detect what's reflected.

Light areas reflect more, dark areas less. Coloured areas absorb some colours - we see the colours they don't absorb.

# The nature of imaging

At different wavelengths different things become visible

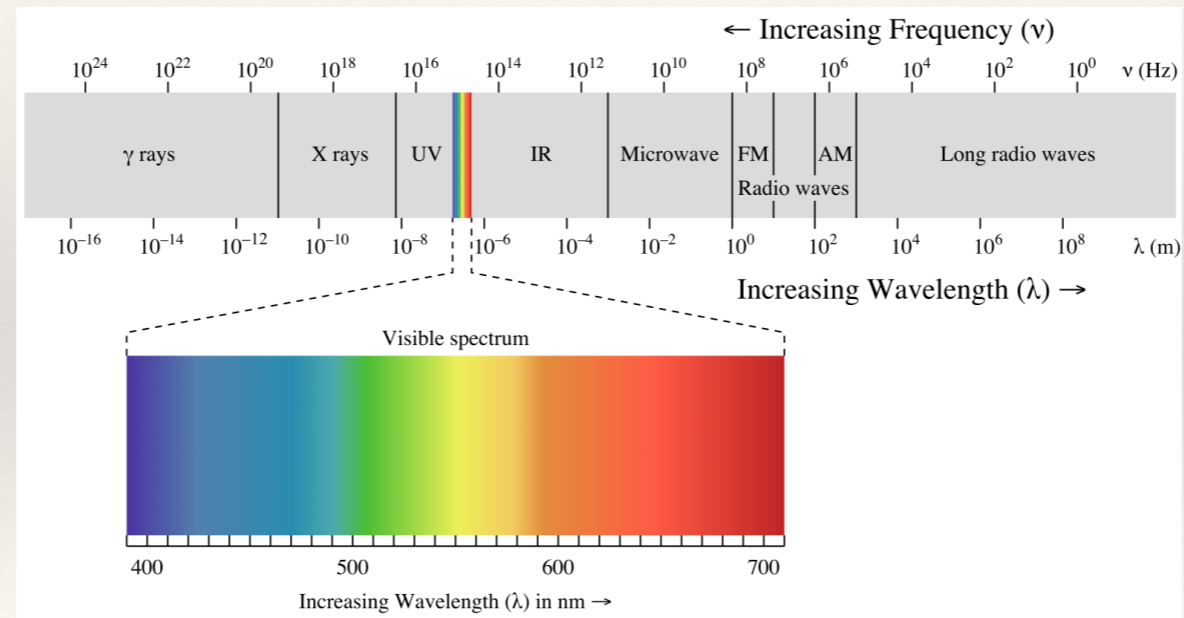


"UV Vis IR Portrait" by Spigget - Own work. Licensed under CC BY-SA 3.0 via Commons - [https://commons.wikimedia.org/wiki/File:UV\\_Vis\\_IR\\_Portrait.jpg#/media/File:UV\\_Vis\\_IR\\_Portrait.jpg](https://commons.wikimedia.org/wiki/File:UV_Vis_IR_Portrait.jpg#/media/File:UV_Vis_IR_Portrait.jpg)

The same person photographed under UV, Visible and IR light shows different features. Sun damage shows up under UV, Skin is more translucent in IR

# The nature of imaging

X-Rays are just shorter wavelength light

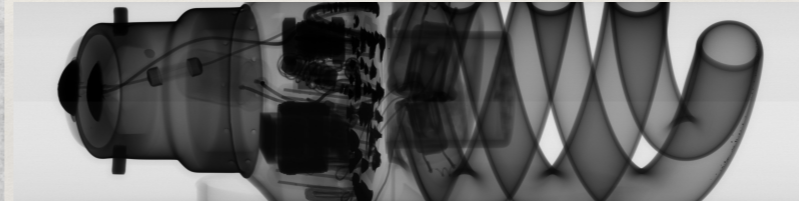


X-Rays are just another form of light.

They are made of the same stuff that the light we're used to is - photons.

# The nature of imaging

Imaging with X-Rays has one major difference...

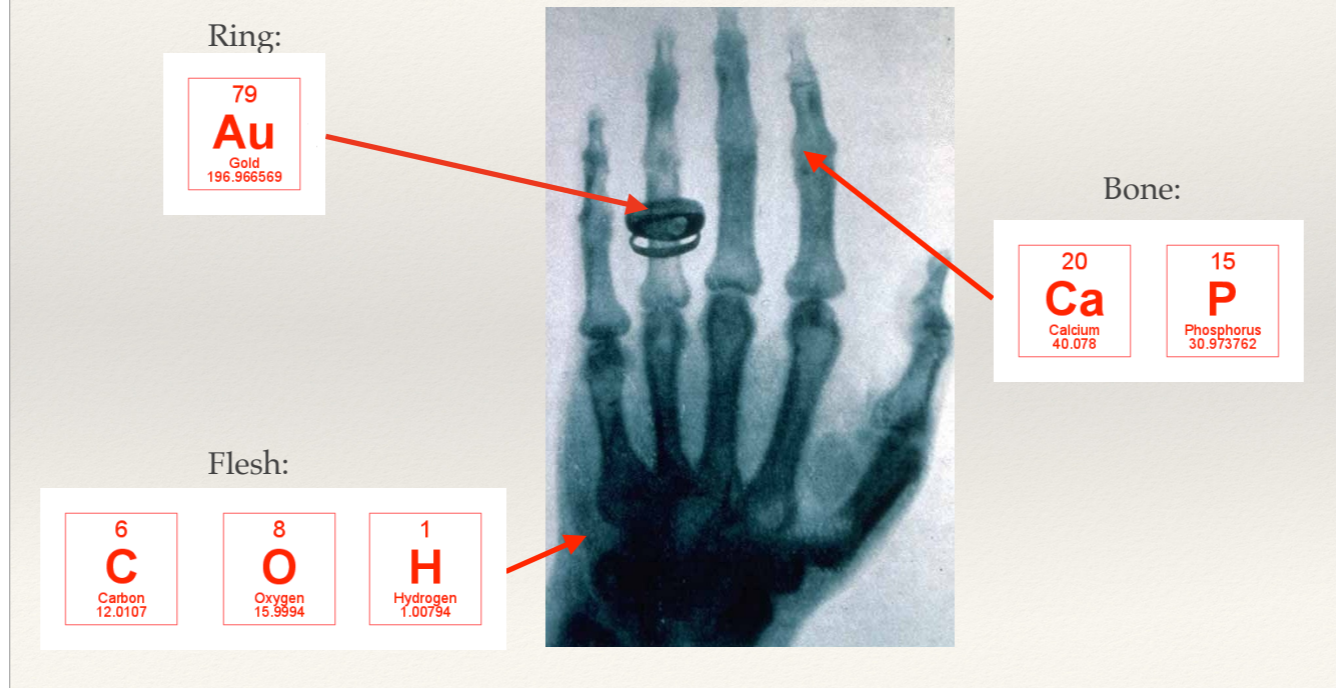


You detect X-Rays that pass through the object, not reflected ones.

X-Rays are usually detected in transmission mode - you shine them through an object and detect what gets through. First medical X-Ray of Roentgen's Wife

# The nature of imaging

What's the contrast mechanism?



In this image we see flesh, bone and gold. Contrast comes from the stuff - elements the object is made from. Metals show up better than non-metals, but non metals can still be imaged.

# The nature of imaging

## Heavy and light elements

hydrogen 1 H 1.00794																	helium 2 He 4.0026	
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180	
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948	
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selecnium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80	
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29	
cesium 55 Cs 132.91	barium 56 Ba 137.33	* 57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	* 89-102 *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	unnilium 110 Uun [271]	ununium 111 Uuu [272]	ununium 112 Uub [277]	ununquadium 114 Uuq [289]					
* Lanthanide series			lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04		
** Actinide series			actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [269]	nobelium 102 No [269]		

The common elements in materials and inks are shown in the periodic table.

Paper, parchment, organic materials are essentially made of the Orange elements - they don't image well unless there is a great thickness of them, blue is medium and pink is everything else.



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## What does this mean?

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- ❖ If you want to use X-Ray imaging to look inside an object for obscured writing or images
  - ❖ The substrate needs to be material that doesn't show up too strongly (paper, parchment, wood, bark, etc)
  - ❖ The ink should contain heavier elements (iron, copper, gold, silver, mercury, etc)
  - ❖ You're very unlikely to be able to see carbon ink or graphite on paper

# Hot Off The Press

The image shows two mobile phone screens side-by-side, both displaying news articles. The left screen shows a BBC News article titled "Ancient scrolls give up their secrets" by Helen Briggs, published 6 hours ago. The article discusses the discovery of metallic ink on ancient scrolls, which pushes back the date for the first use of metallic ink by several centuries. It mentions that the scrolls are the only library known to have survived from classical times and that the Herculaneum scrolls were buried by the eruption of Mount Vesuvius in AD79 and are charred and fragile. The right screen shows a continuation of the article, discussing the task of reading the surviving scrolls, which has fallen to scientists using technology such as the European synchrotron. It mentions that last year, physicists used the 3D X-ray imaging technique to decipher writing in the scrolls. Below the text, there are three small images labeled 'a', 'b', and 'c', showing curved letters 'A P N', 'H E Y', and 'K I' respectively. A scale bar indicates 1 mm. The article concludes by stating that now they have gleaned that the papyrus contains high levels of lead, which they say could only have come from its intentional use in the ink. A quote from Dr Emmanuel Brun of the European Synchrotron is also visible.

**Ancient scrolls give up their secrets**

By Helen Briggs  
BBC News  
6 hours ago | Science & Environment

**Metallic ink was used to inscribe scrolls regarded as an archaeological wonder, according to scientists.**

The discovery pushes back the date for the first use of metallic ink by several centuries.

The scrolls are the only library known to have survived from classical times

The Herculaneum scrolls were buried by the eruption of Mount Vesuvius in AD79 and are charred and fragile.

The task of reading the surviving scrolls has fallen to scientists using technology such as the European synchrotron, which produces X-rays 100 billion times brighter than the X-rays used in hospitals.

Last year, physicists used the 3D X-ray imaging technique to decipher writing in the scrolls.

1 mm

a A P N b H E Y c K I

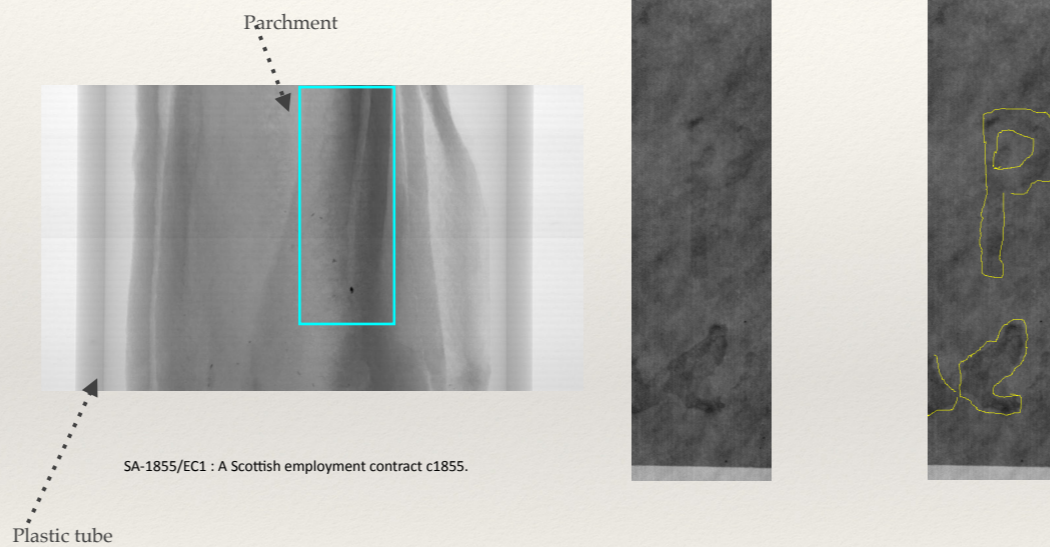
Curved letters have previously been identified on the papyrus

Now they have gleaned that the papyrus contains high levels of lead, which they say could only have come from its intentional use in the ink.

"We found some metal - some lead - in the ink, which is supposed to come four centuries after," said Dr Emmanuel Brun of the European Synchrotron in Grenoble, France

Hot off the press this morning

# What do you see if you X-Ray parchment?



Single image, 6s exposure 25kV X-Rays

Take a standard X-Ray

Ink is visible in this flat X-Ray image, but the text isn't really readable.

Proves that high contrast TDI imaging can see ink.

# One X-Ray Isn't Enough

*Ei alienum epicurei sit, nec feugait offendit mnesarchum at. No eum  
legimus intellegat elaboraret, eu vide semper suavitate has. Pri clita  
Habitat in ista dicitur et quid feugait in officio habita. In quo  
per se non est dolor sit quod, cui est quem alterum salutatis  
vituperatoribus vel ne, te nonnulla phlogia vel. Augue appetere sea  
Eum elit summo mucius ex, eum vidisse adipiscung id, usit summo  
eu, sea id constituam temporibus, per duis senserit argumentum qui.  
impedit singulis at. Ea sudas utinam per, mel inermis ponimus qualisque  
Eum elit summo mucius ex, eum vidisse adipiscung id, usit summo  
ea. Accusans offendit ei has. In pro, fuisse recusabo, illud habemus  
impedit singulis at. Ea sudas utinam per, mel inermis ponimus qualisque  
impedit singulis at, ea sudas utinam per, mel inermis ponimus qualisque  
Mel ex detraxit aliquando similique. In, aequo noster mentitum est. Ad  
ea. Accusans offendit ei has. In pro, fuisse recusabo, illud habemus  
reque vitae adipiscung vint. Exerci appetere et nam, id duo eimod  
Mel ex detraxit aliquando similique. In, aequo noster mentitum est. Ad  
reque vitae adipiscung vint. Exerci appetere et nam, id duo eimod  
malorum. Ipsum viris alterum ea qui.*

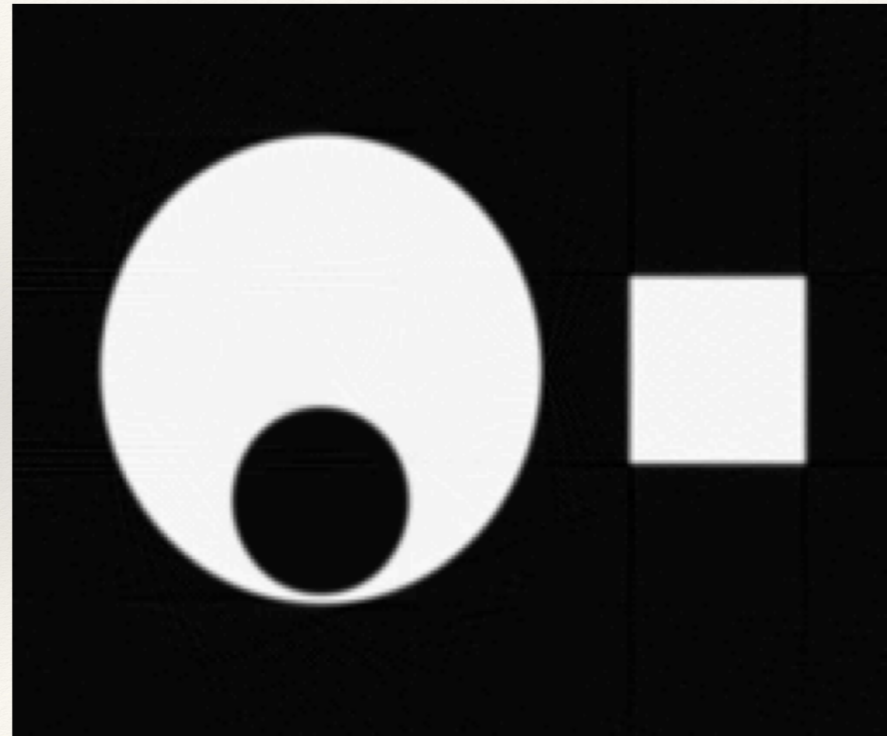
One X-Ray just gives you all the text on top of each other. Assuming you can see anything anyway. What you need is a 3-D Xray

# 3-D X-Rays

We call these CT Scans

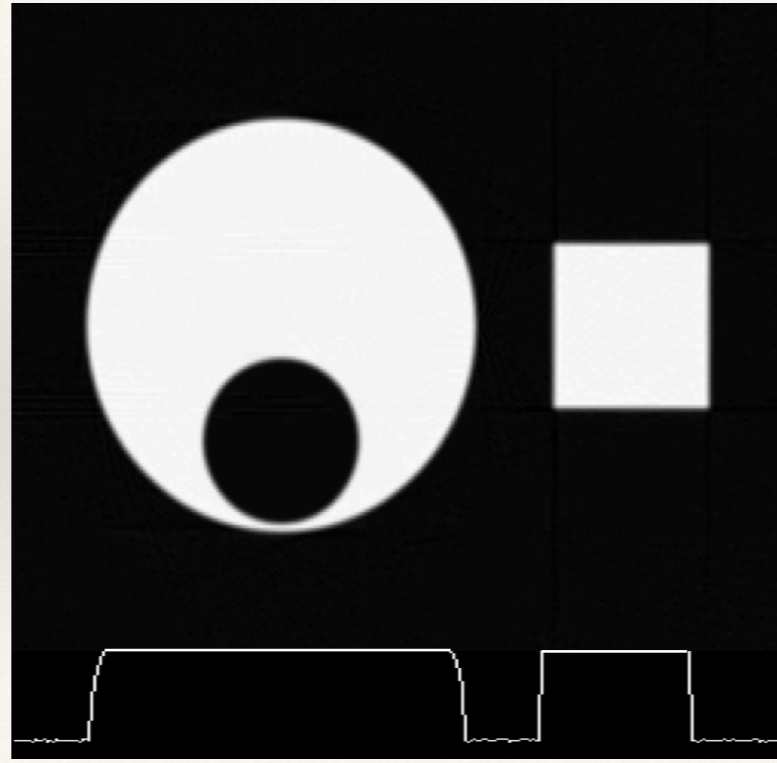


## CT Scans Need Lots Of X-Ray Images



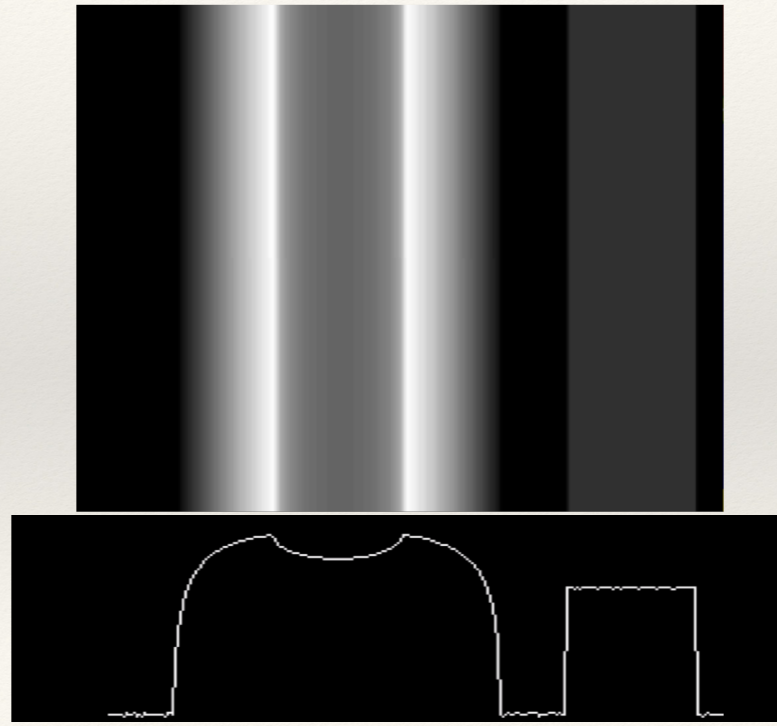
This is an X-Ray Phantom - just an example image, to reproduce it, how many X-rays do we need?

# Projection



One X-Ray gives us the line profile shown

# Back Projection



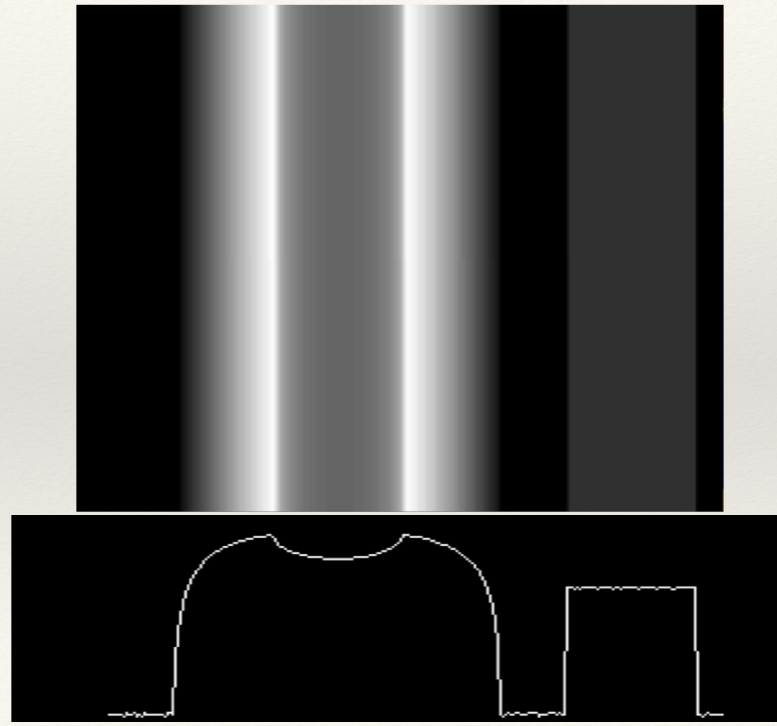
To make our 3-D Xray we need many 2-D X-rays taken at different angles around the object.

Smear the line profile backwards and you get a 1-xray image of the phantom

This back projection is known as Reconstruction.

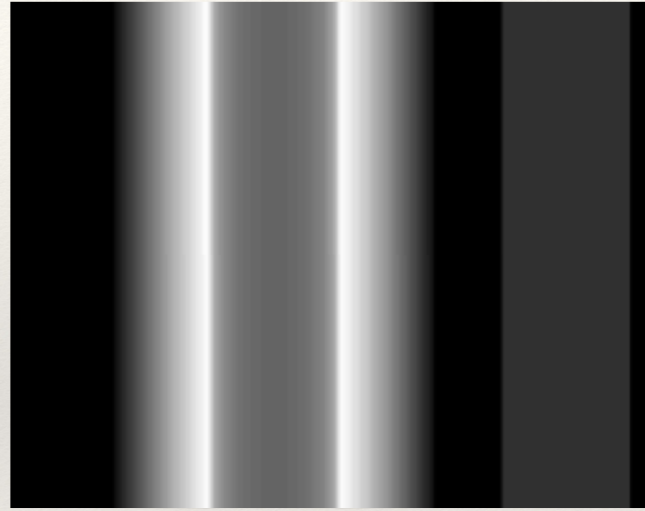


# How Many Images? (1)



One X-ray isn't enough.

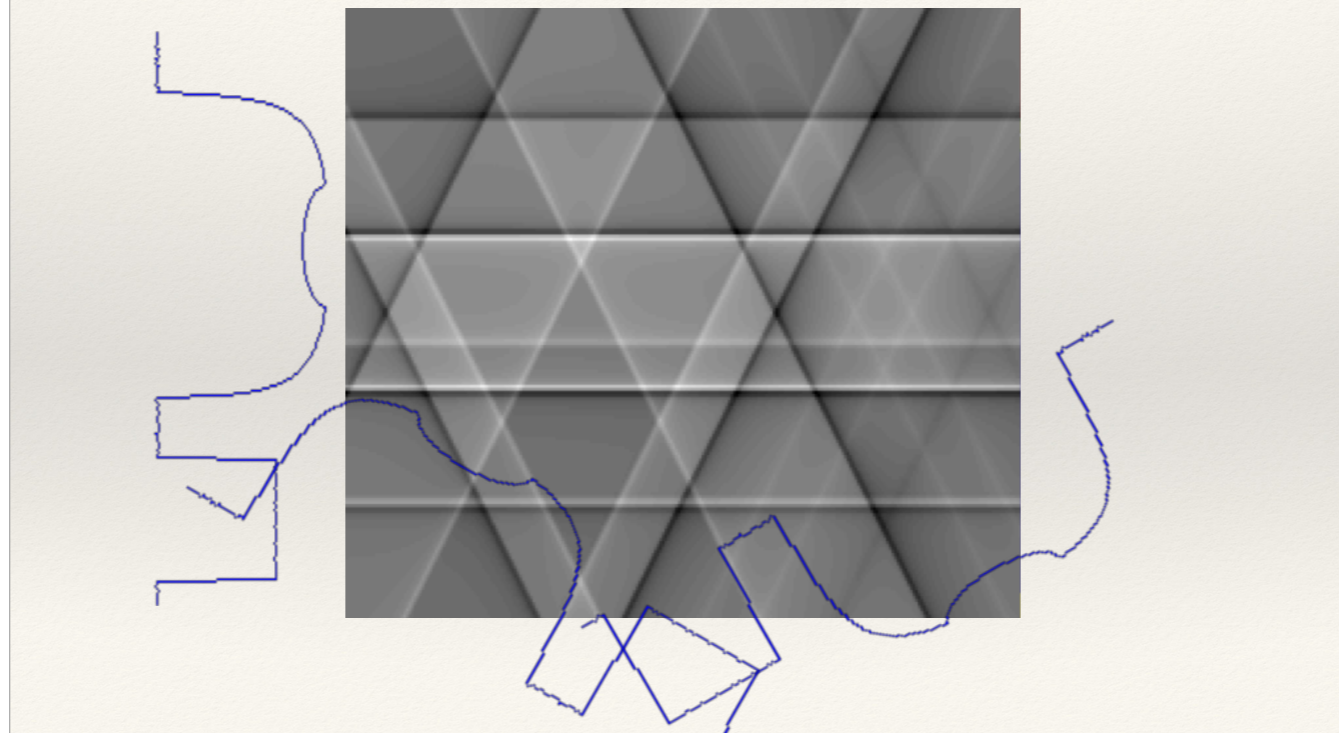
## How Many Images? (3)



What if we take three images at 120 degree separation?

Three images aren't enough

## How Many Images? (3)



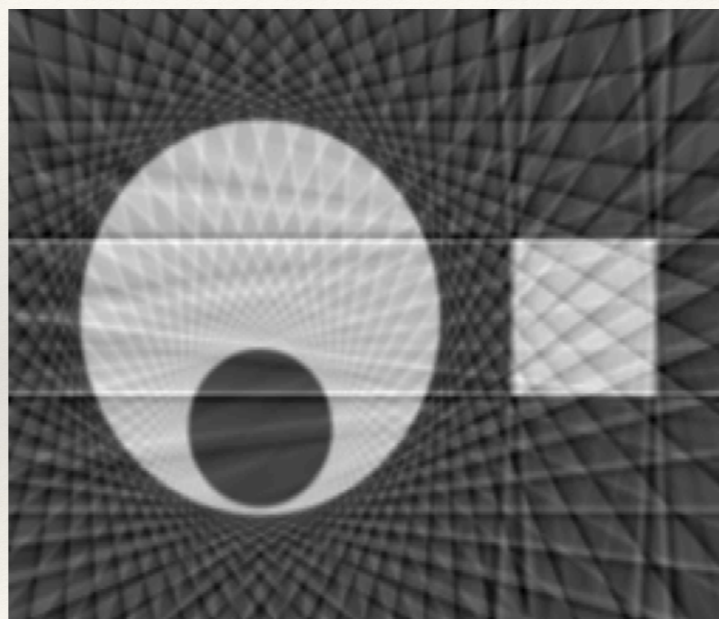
What if we take three images at 120 degree separation?

Three images aren't enough

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## How Many Images? (27)

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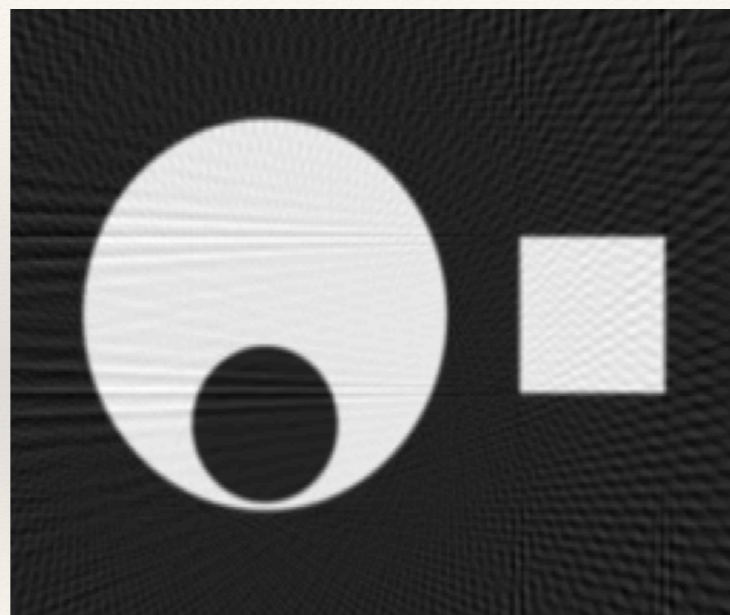


Getting better, but contrast is still low

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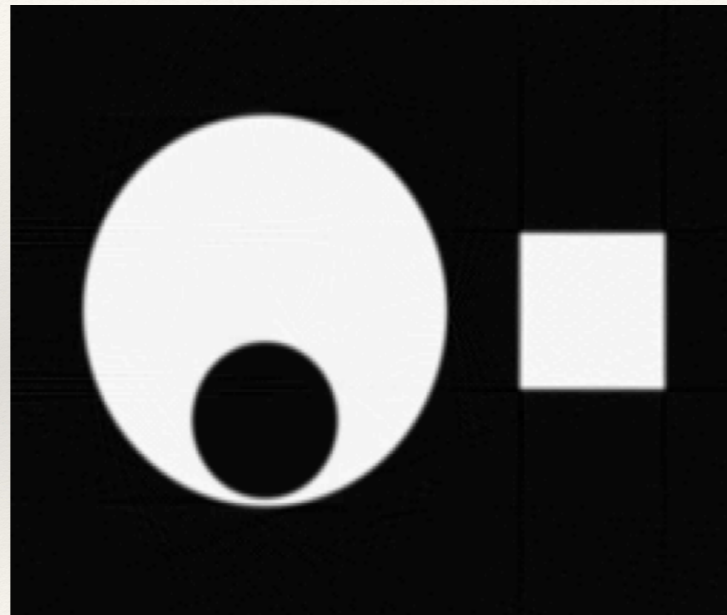
# How Many Images? (80)

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A noisy image

## How Many Images? (300)

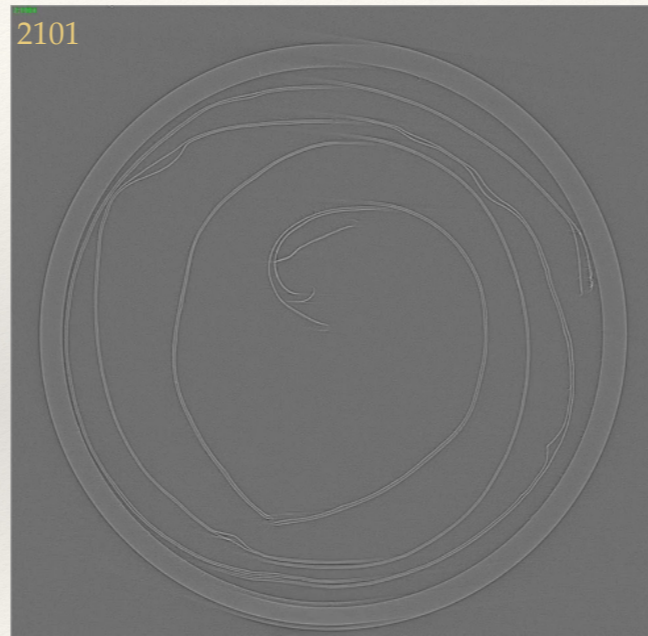


300 X-Rays gives a pretty good image in this case where there is 100% contrast between the two elements (black and white). What about when we have much less contrast - such as ink against paper?

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# For Real Items - Thousands

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Video showing reconstruction of birch bark scroll from 2101 images.

# Damage?

Dental X-Ray - Dentist  
wears lead apron



CT Scan - Technician is in a  
separate lead lined room

We know X-rays damage living things - what about non living things?



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# Damage?

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Is there evidence for change to collagen within parchment samples after exposure to an X-ray dose during high contrast X-ray microtomography? a multi technique investigation

Article in Heritage Science 1(22) · January 2013

DOI: 10.1186/2050-7445-1-22

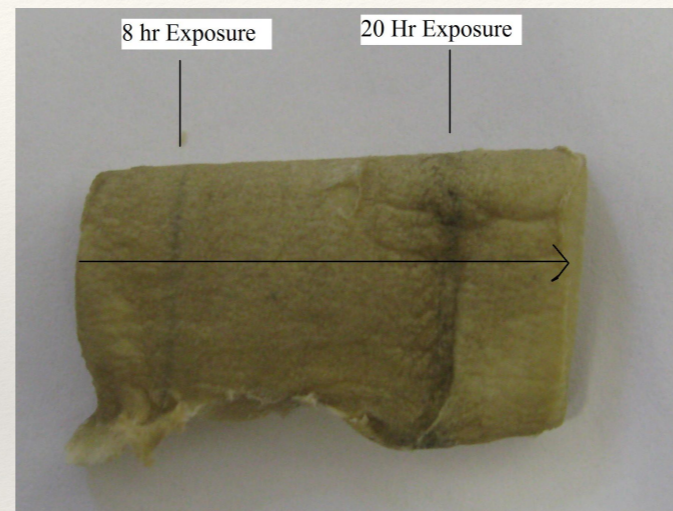
## Conclusions

*“Our overall impression from the techniques used shows that we cannot detect a systematic change to the collagen chemistry or structure that is an effect of XMT radiation we are using to read documents.”*

We know X-rays damage living things - what about non living things?

The technique is really only applicable to damaged material anyway.

# Damage?



This was soaking wet parchment - not the type of material we'd usually scan anyway

Soaking wet, rotting parchment was the only case where we saw visible damage after a scan. This isn't material we'd scan.

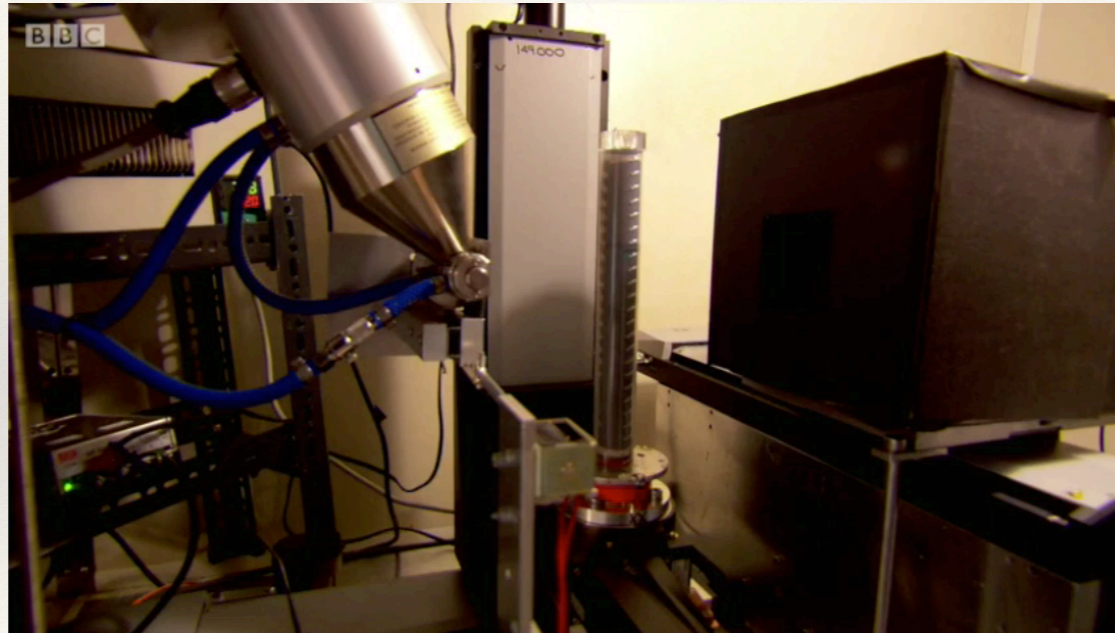
# Let's use a machine built for the job



MuCAT - 2 at Queen Mary University of London

This is one of our three machines, imaginatively named MuCAT 1 to 3. It's a CT scanner rather like you get in hospitals, but aimed at scanning smaller objects at much higher resolution with much better contrast.

## Let's use a machine built for the job



MuCAT - 2 at Queen Mary University of London

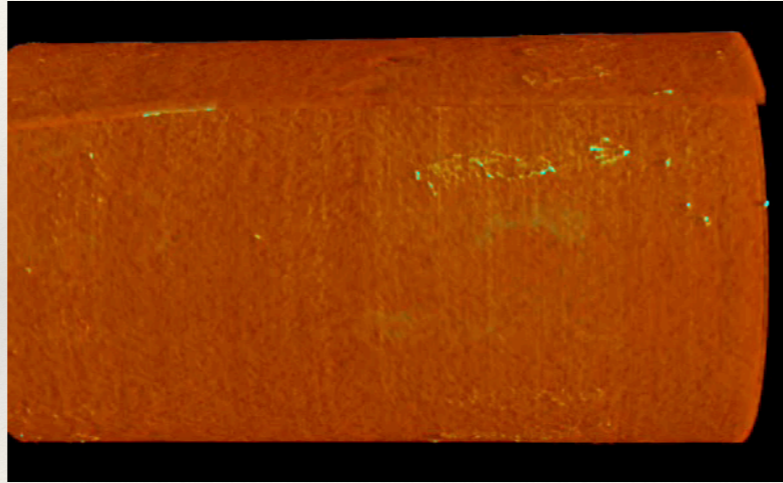
This was filmed by the BBC for The One Show. It shows a greatly speeded up scanning process.

The silver tube to the left is the X-Ray source - the black box on the right is our camera and the vertical tube in the middle is the scroll being scanned.

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## An initial result

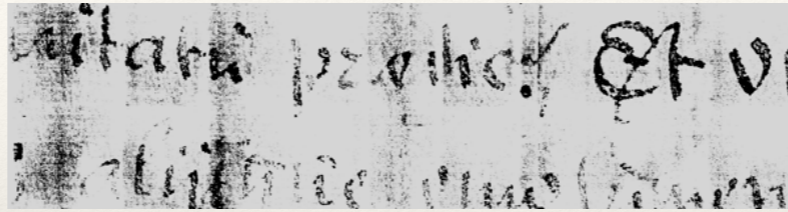
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A scrap of parchment with Iron Gall Ink

Small parchment roll and cross section view (video)

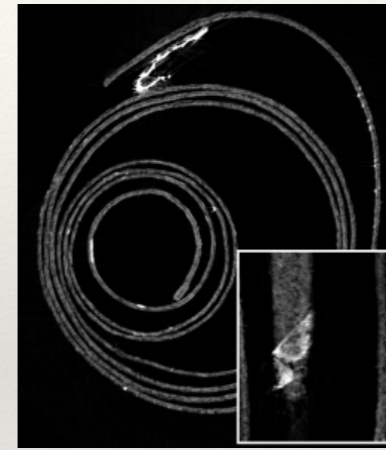
## An initial result



Virtual unrolling

Virtually unrolled

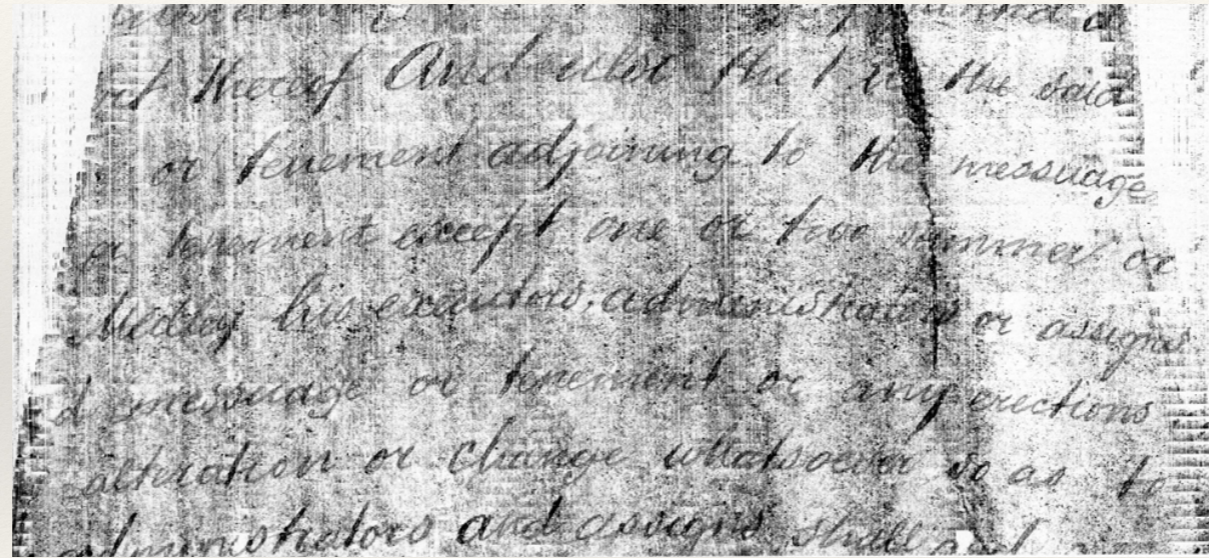
# Unknown Text Experiment



The small scroll was obtained from the Norfolk Archives teaching collection. It was very stiff, difficult to unroll without causing damage and the textual content was unknown.

Small parchment roll and cross section view

# Virtual Unrolling

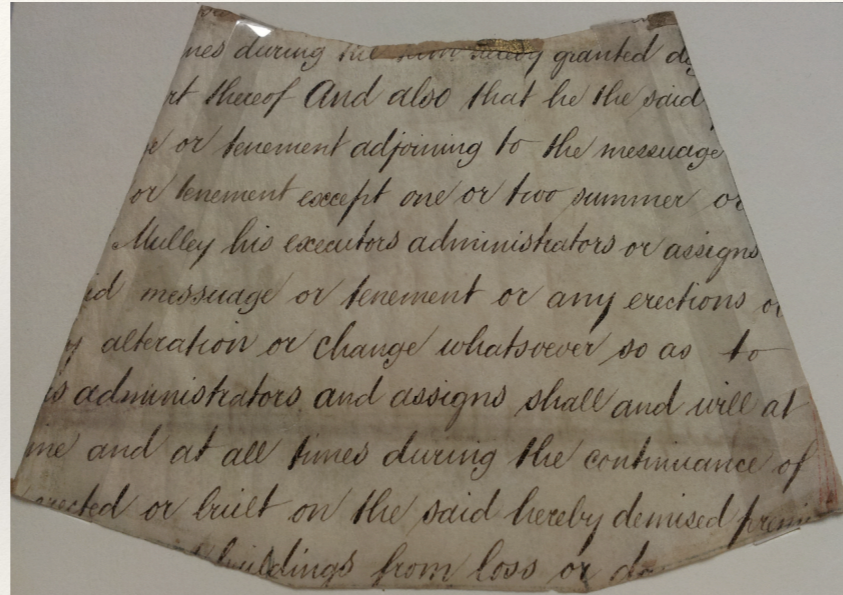


Algorithms developed by colleagues in the school of computer science at Cardiff University, were able to “unroll” the XMT data, making the writing visible

Virtually unrolled



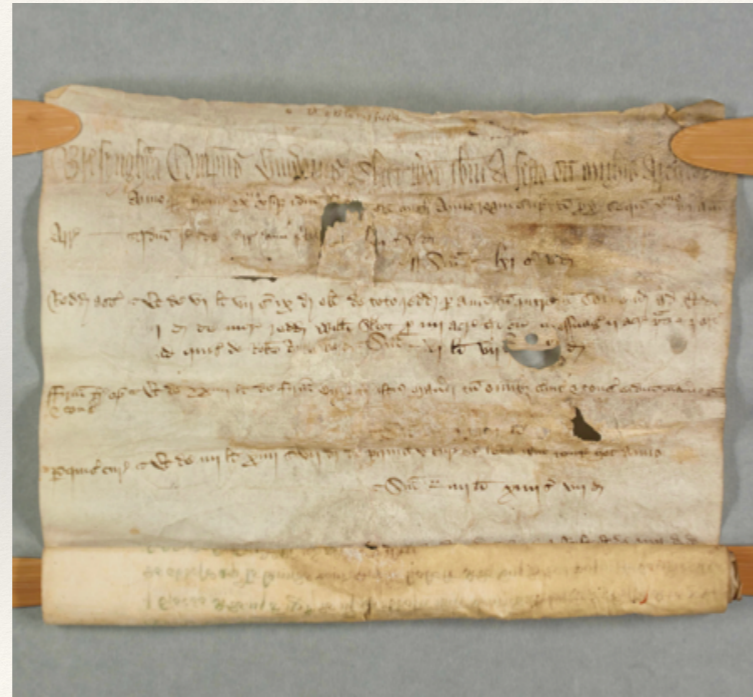
# Comparison



Our conservation consultant on the project, Meagen Smith, was able to unroll the scroll for verification purposes.

Meagen Smith used a combination of humidification and pressing to unroll and flatten the scroll. Was cut to this shape to be used as part of a lamp shade.

# The Bressingham Roll



Parchment roll c1409

Detailing annual accounts of the manor of Bressingham in Norfolk UK.

Approximately 70% of the roll is inaccessible due to water damage to the parchment.

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# The Bressingham Roll

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## Ready for scanning

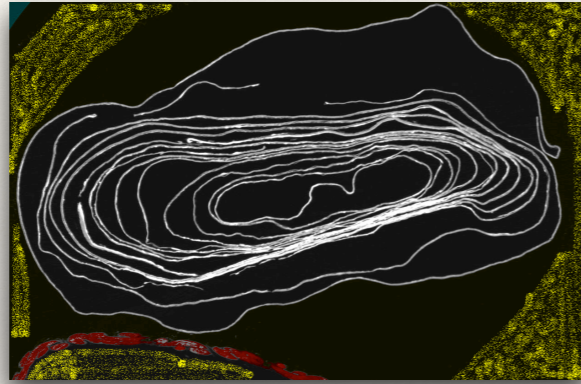
Prior experiments had shown that Plastizote was stable in X-Rays, allowing the roll to be packaged for transport and safe handling by non-conservators

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# The Bressingham Roll

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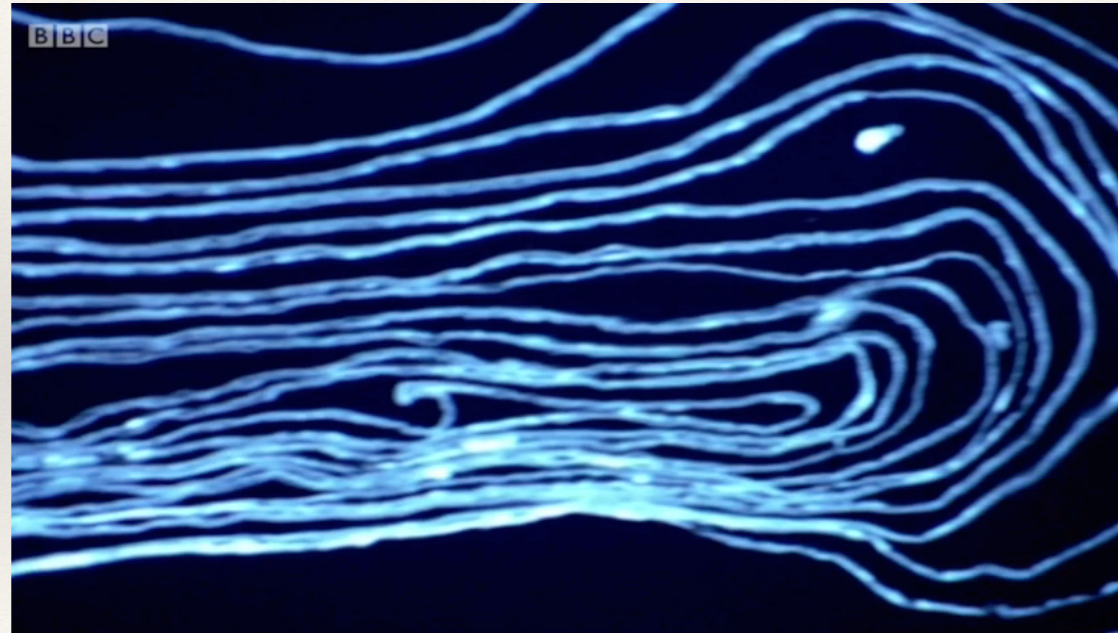
## A virtual slice



A virtual transverse slice through the roll shows how the layers of parchment have stuck together

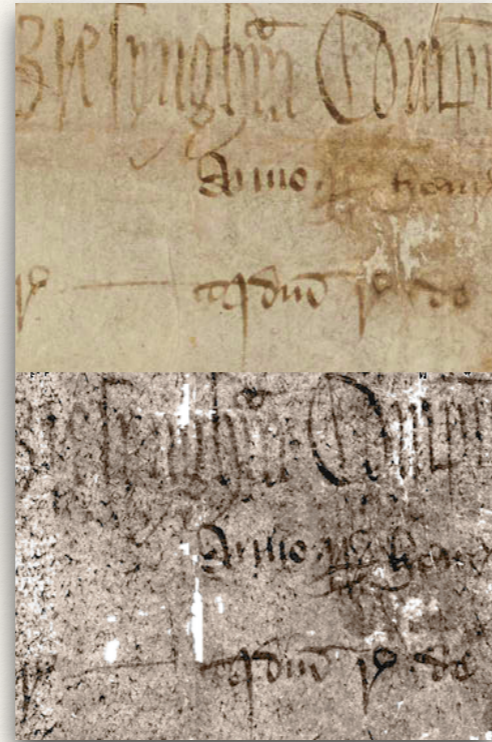
The white material in the image is the parchment. You can see that in places it is totally merged together, rendering physical unrolling impossible. Just seeing this was useful to the conservators, proving physical intervention would be damaging at best.

# The Bressingham Roll



Unrolling (video)

# The Bressingham Roll



Comparing the X-Ray and visible images

Checking the accuracy the top image is a photograph, the lower is the X-Ray result. You can see that in places where the ink seems faded in the photograph, there is still good contrast in the X-Ray image.



# The Bressingham Roll

## Results so far

So far we've revealed the lefthand third of the full length of the roll.

Work in progress to develop new methods to access the other two thirds. All the information exists in the dataset from the scan. No other scanning or access to the roll is needed for this.

<https://www.youtube.com/watch?v=FXkQz9fOafU>

Mills, *et al.* *IADA Journal of Paper Conservation* (October 2014)

Unrolling

# Burned Title Court Roll



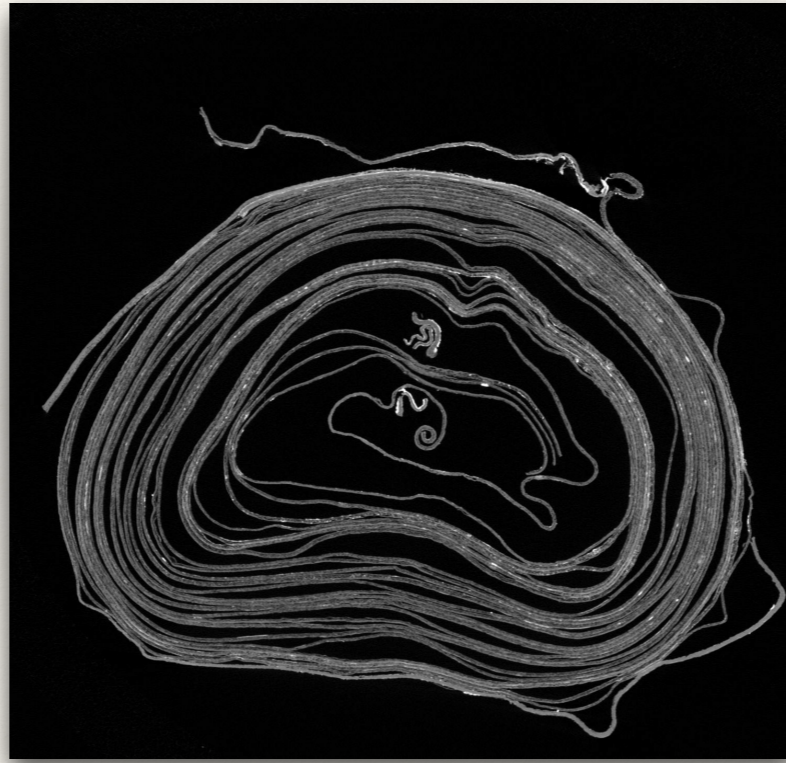
Fire damaged parchment roll c1500  
Details ownership of land and buildings in Diss-Heywood area of Norfolk, UK.  
Burned sometime before 1800s  
Shrunk to ~60% of former size

Another roll from the NRO.

Burned and shrunken. No hope to physically unroll this.



# Burned Title Court Roll



Central slice shows just how bad the roll is.

Work in progress to produce an unrolled version. We've been able to see individual letters, but no full words or lines of text yet.

# Burned Title Court Roll



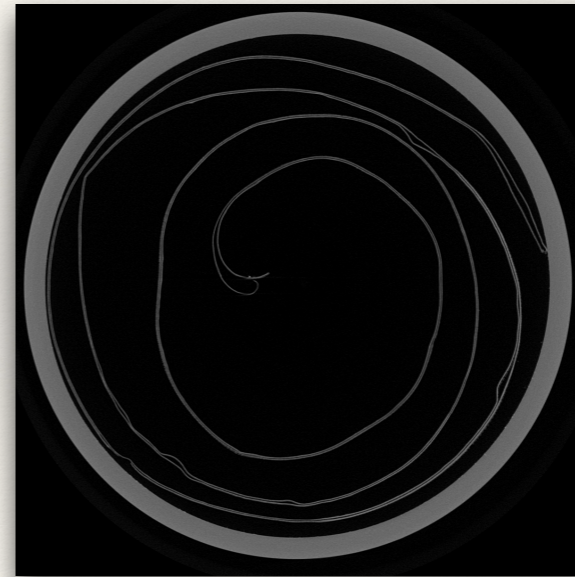
Central slice shows just how bad the roll is.

Work in progress to produce an unrolled version. We've been able to see individual letters, but no full words or lines of text yet.

# Birch Bark Roll



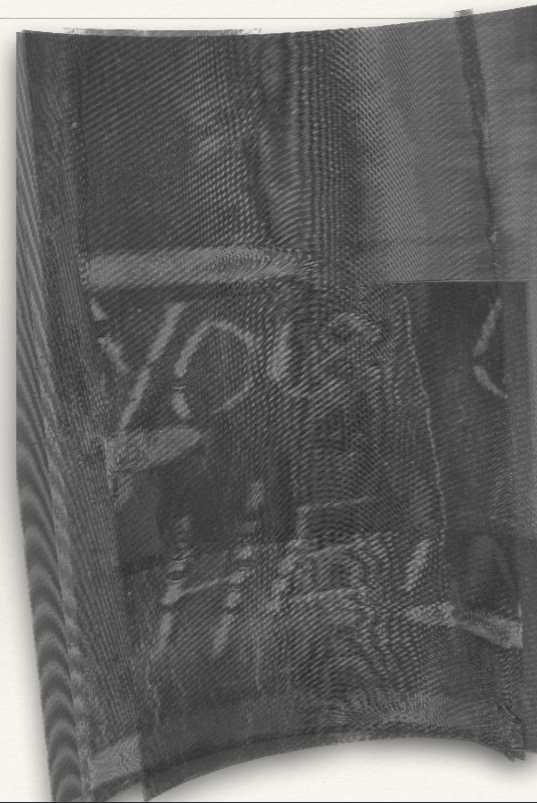
European Silver Birch bark.  
September 2009.  
No ink. Inscribed with blunt stylus



Can we image text when there's no ink / pigment?

Blunt stylus used to make impressions and cause some discolouration of the bark. Nothing added or subtracted from the bark

# Birch Bark Roll

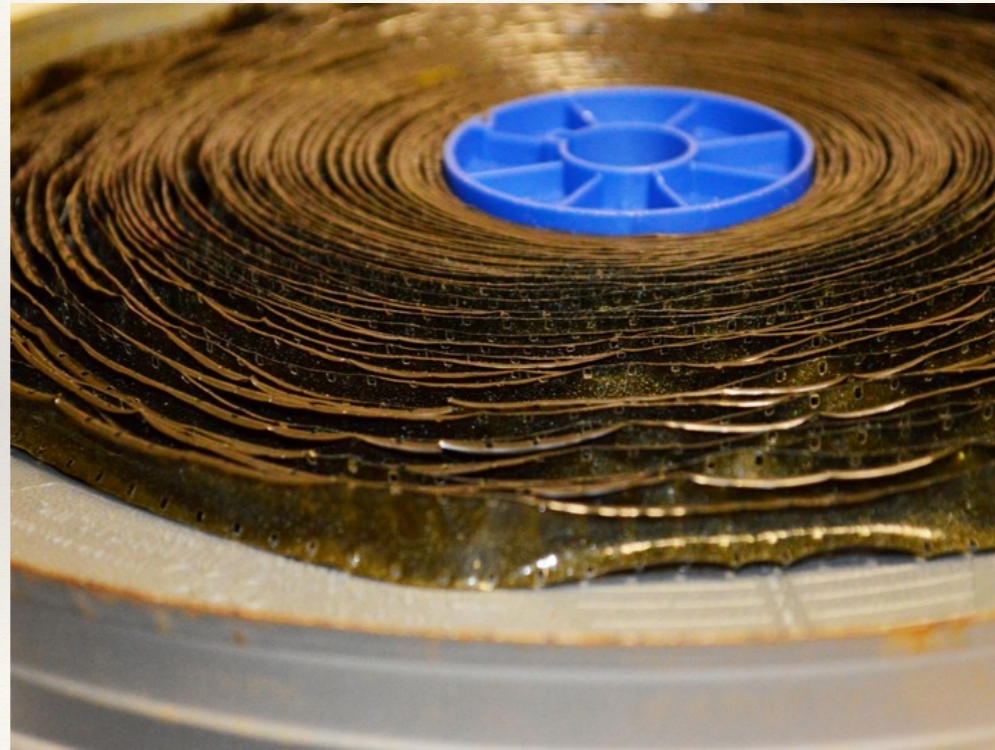


Using a volume render technique we can visualise portions of the writing

Contrast is due to stylus pressure collapsing porous structure of the bark, giving a local increase in density

Yes, we can. The stylus compresses the porous nature of the bark, the X-rays see this as an increase in density, so there's a fraction of a percent more contrast. Our sensitive scanners can see this.

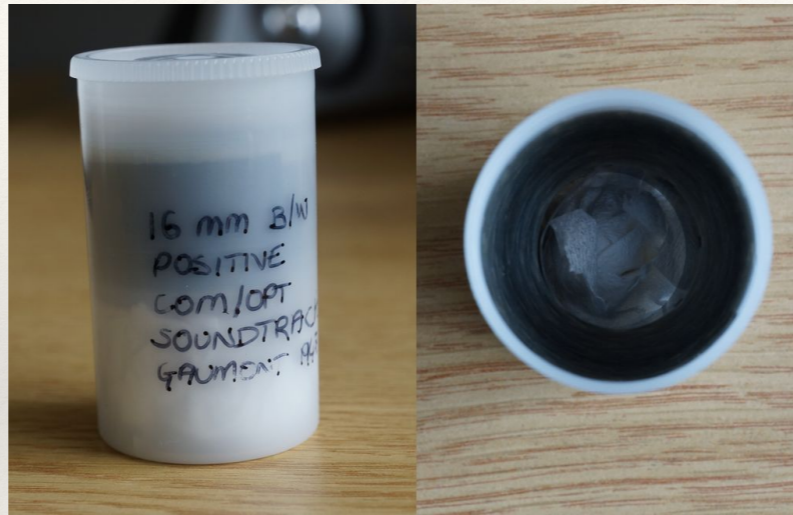
## Something Different



After the BBC made the short film about the Bressingham roll, we were contacted by Charles Norton (freelance writer for BBC archives) to ask if we could unroll film.

It's rolled up and there's silver in it, so would we see anything in X-Rays

# Proof Of Concept



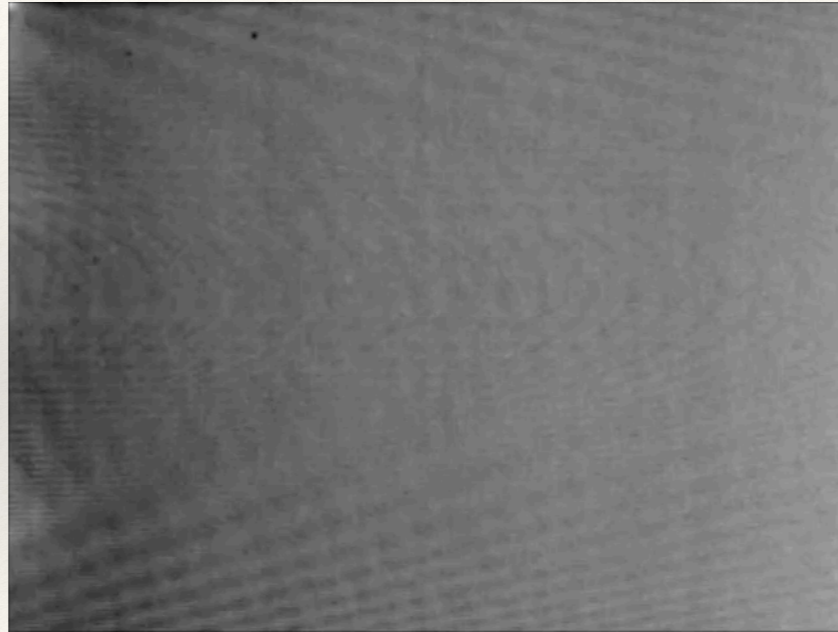
16mm acetate stock positive film "Gaumont British News"

As a proof of concept test we acquired some 16mm acetate stock and scanned it rolled up in a 35mm film can.

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# Proof Of Concept

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(Video)

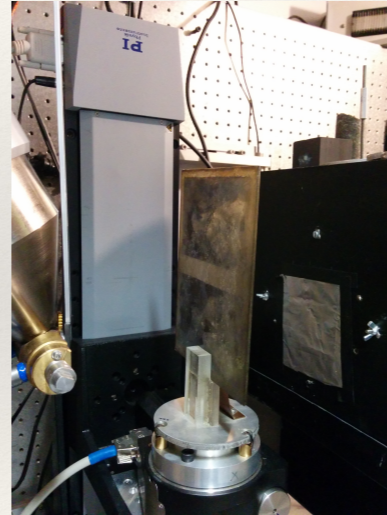
A lot of processing later...

Remember this was pristine film, no detectable damage to deal with at this point.

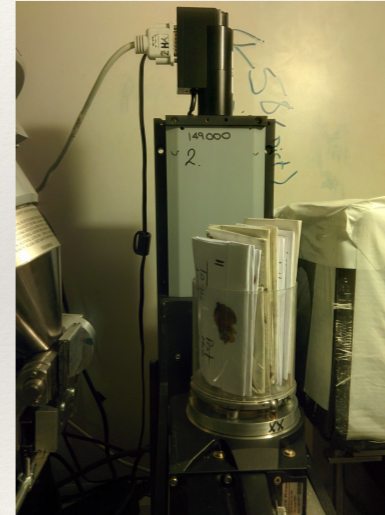
## Some other projects...



Mamluk Cap with writing on internal paper



Glass plate photographs



Bundle of letters

Cap is held by textile archive at Leeds

Glass plates from London Metropolitan archive

Letters from Leiden - technology demonstrator at the moment.



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# How can we help you?

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What do you have in your collection that's inaccessible?

website : <http://apocalypto.org.uk>

email : [d.mills@qmul.ac.uk](mailto:d.mills@qmul.ac.uk)

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# Acknowledgements

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Graham Davis, Paul Rosin and Yukun Lai

Antoinette Curtis, Jana Dambrogio , Jacqui Hyman, Meagen Smith, Caroline De Stefani,

Charles Norton & the BBC