

Introduction to visualisation

Paul Bourke

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- Hardware: resolution, stereoscopy, immersion
- Special topics: virtual environments, sonification, haptics, 3D printing, 360 video, gigapixel imaging, multispectral imaging, photogrammetry

Introduction

- Definition: “Visualisation is the process of applying computer graphics to data in order to provide insight into the underlying structures, relationships and processes.”
- “Turning data into images and animations to assist researchers”.
- The key is insight, may be insight to the researcher, their peers, the general public.
- Techniques that find application across a wide range of disciplines.
- Often employs novel capture methodologies, display technologies and user interfaces.
- Frequently requires high performance computing and advanced algorithms.
- Outcomes
 - Revealing something new within datasets.
 - Finding errors within datasets.
 - Communicating to peers (papers, conferences)
 - Communicating to the general public.

Examples: mathematics

- Equations are the Devil's Sentences. (Stephen Colbert)

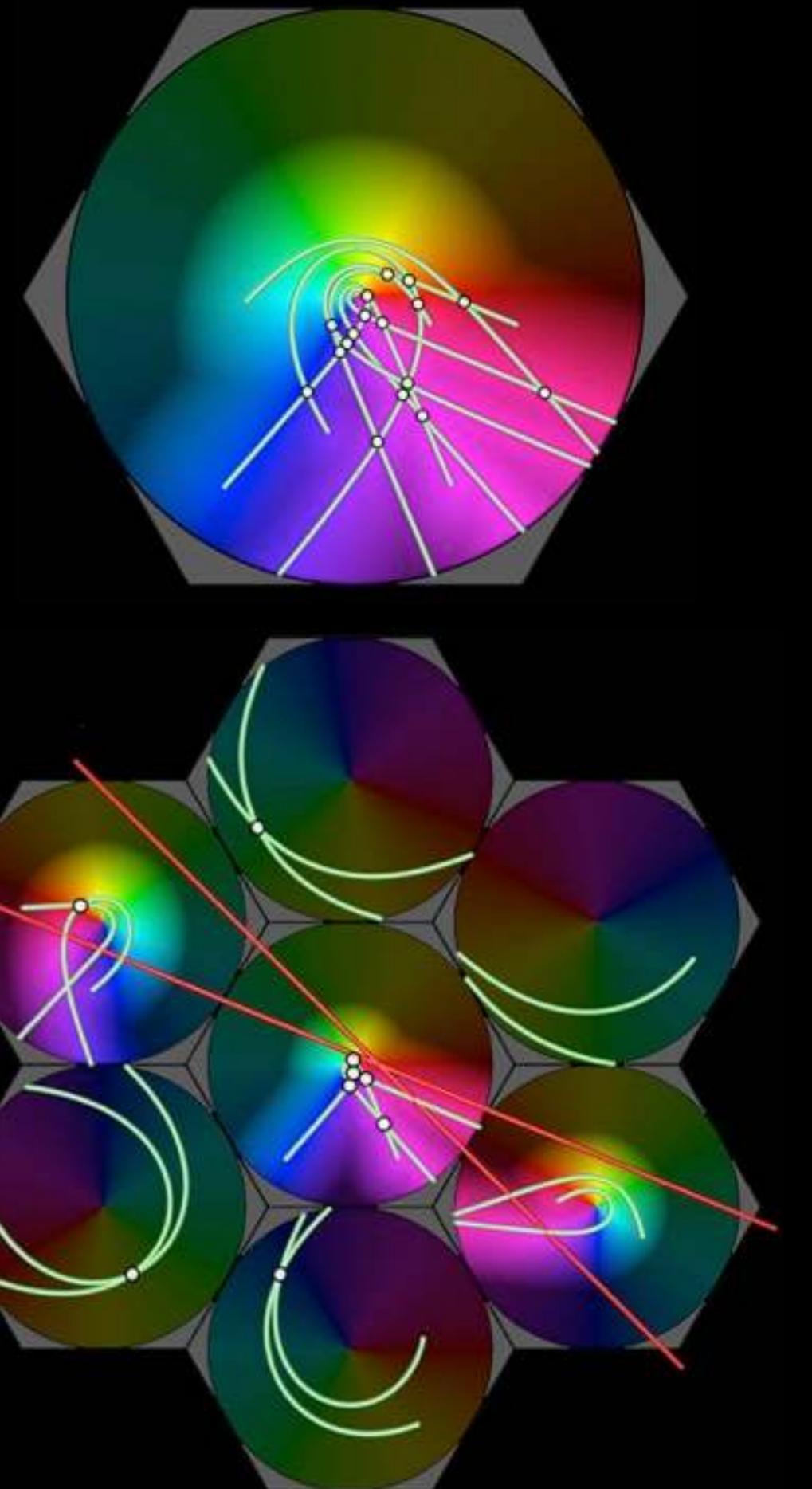
$$\varphi_p^{\mathbf{qr}'}(t) = f_p^{\mathbf{qr}'} \times Q_p \left(\mathbf{r}', t - \frac{|\mathbf{q} - \mathbf{r}'|}{v} \right)$$

$$\psi_p^{\mathbf{qr}'}(t) = M_p^{\mathbf{qr}'} * \varphi_p^{\mathbf{qr}'}(t)$$

$$\Psi_p(\mathbf{q}, t) = \int_{\mathbf{r}'} \psi_p^{\mathbf{qr}'}(t) d\mathbf{r}'$$

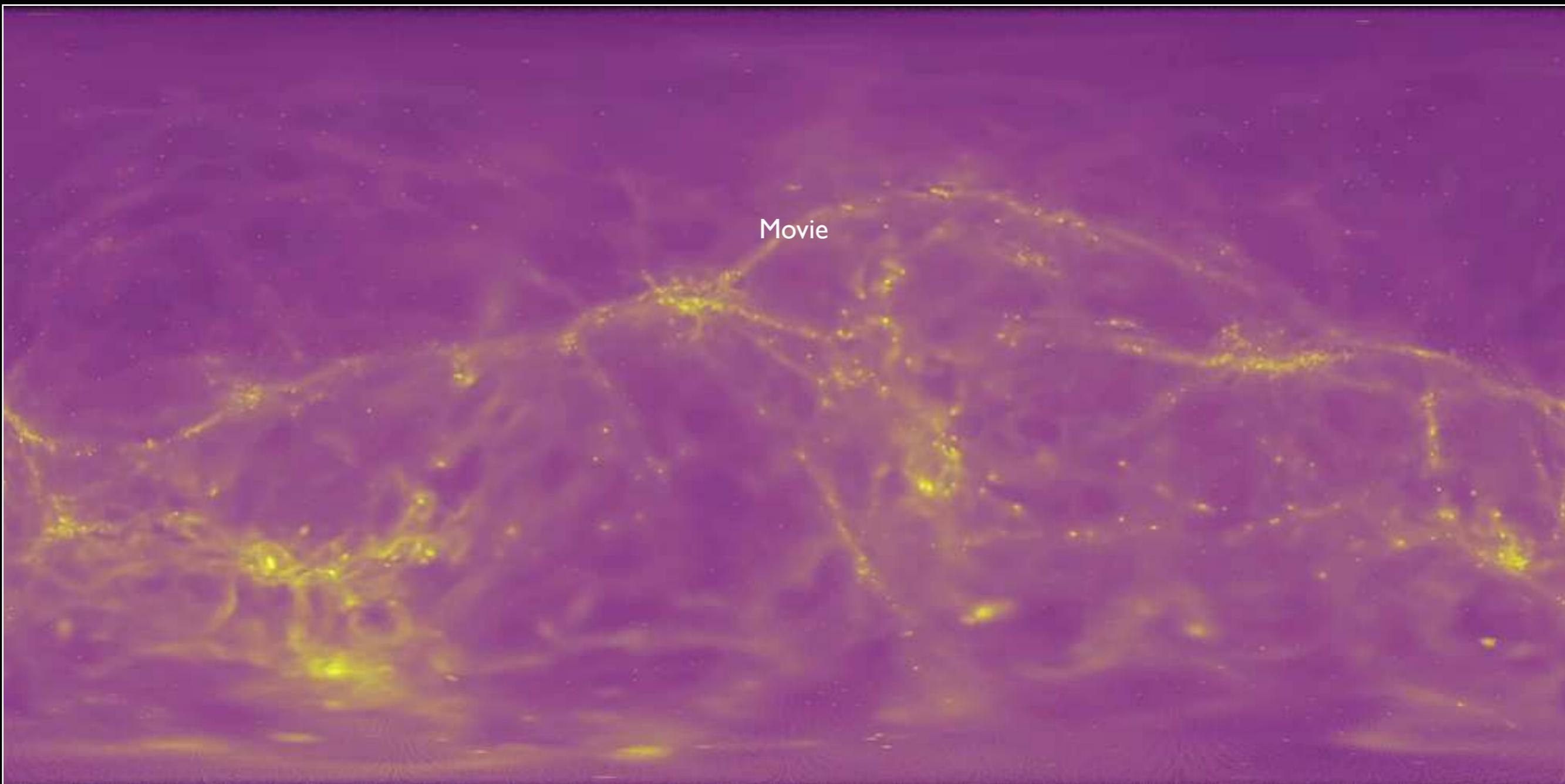
$$V_p(\mathbf{q}, t) = \sum_{p=e \wedge p=i} G_p * \Psi_p(\mathbf{q}, t)$$

$$Q_p(\mathbf{q}, t) = f_\Sigma(V_p(\mathbf{q}, t)) + E_p(\mathbf{q}, t)$$



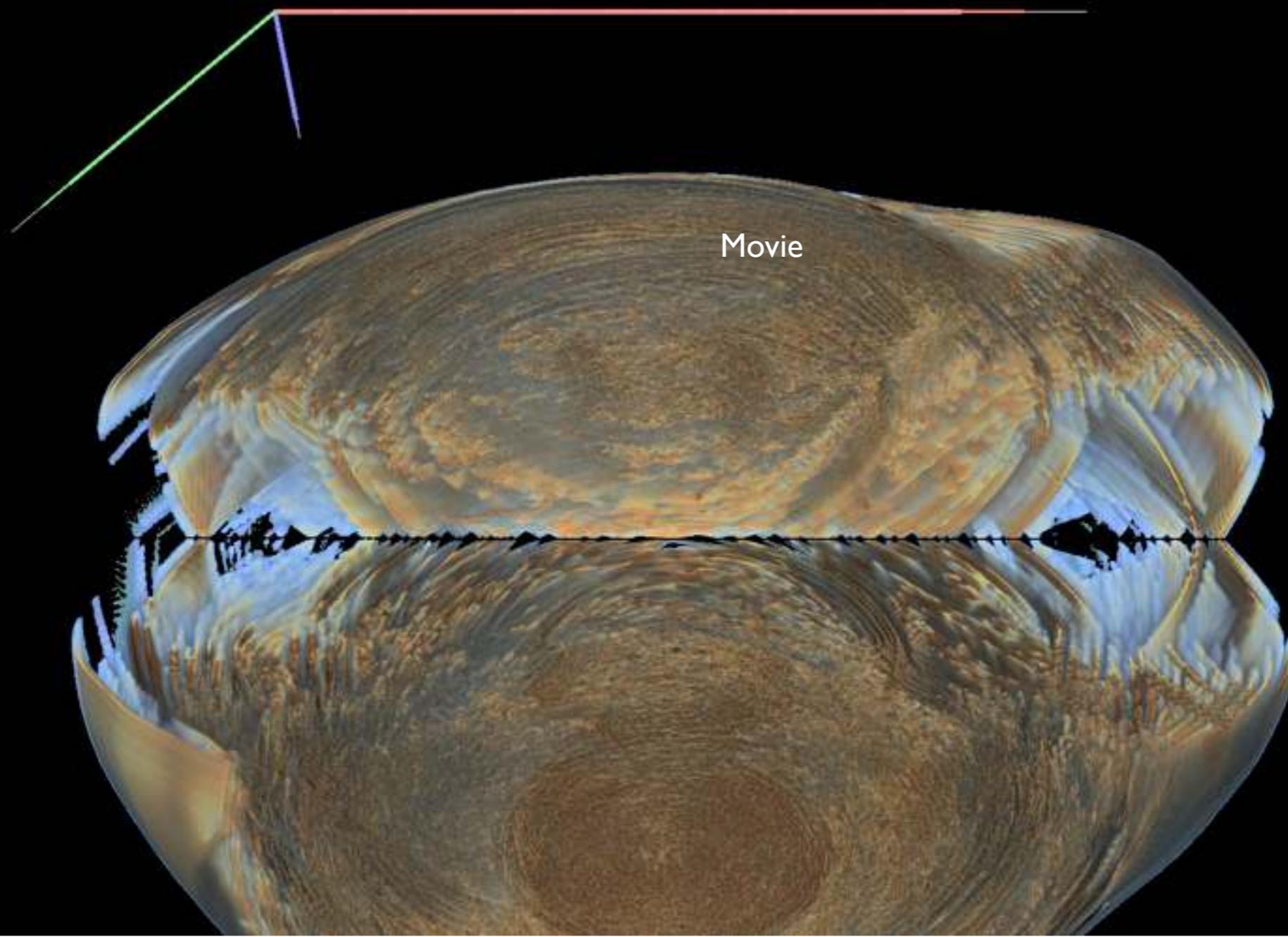
Examples: simulation

- Galaxy formation / evolution. (Allan Duffy, ICRAR)
- Example of visualisation also being performed on the supercomputers doing the simulations.
1/2TB per time step.



Examples: simulation

- Wave propagation in Geoscience simulations.
- ITB dataset but visualisation is interactive on a high end workstation.



Examples: 3D scanning

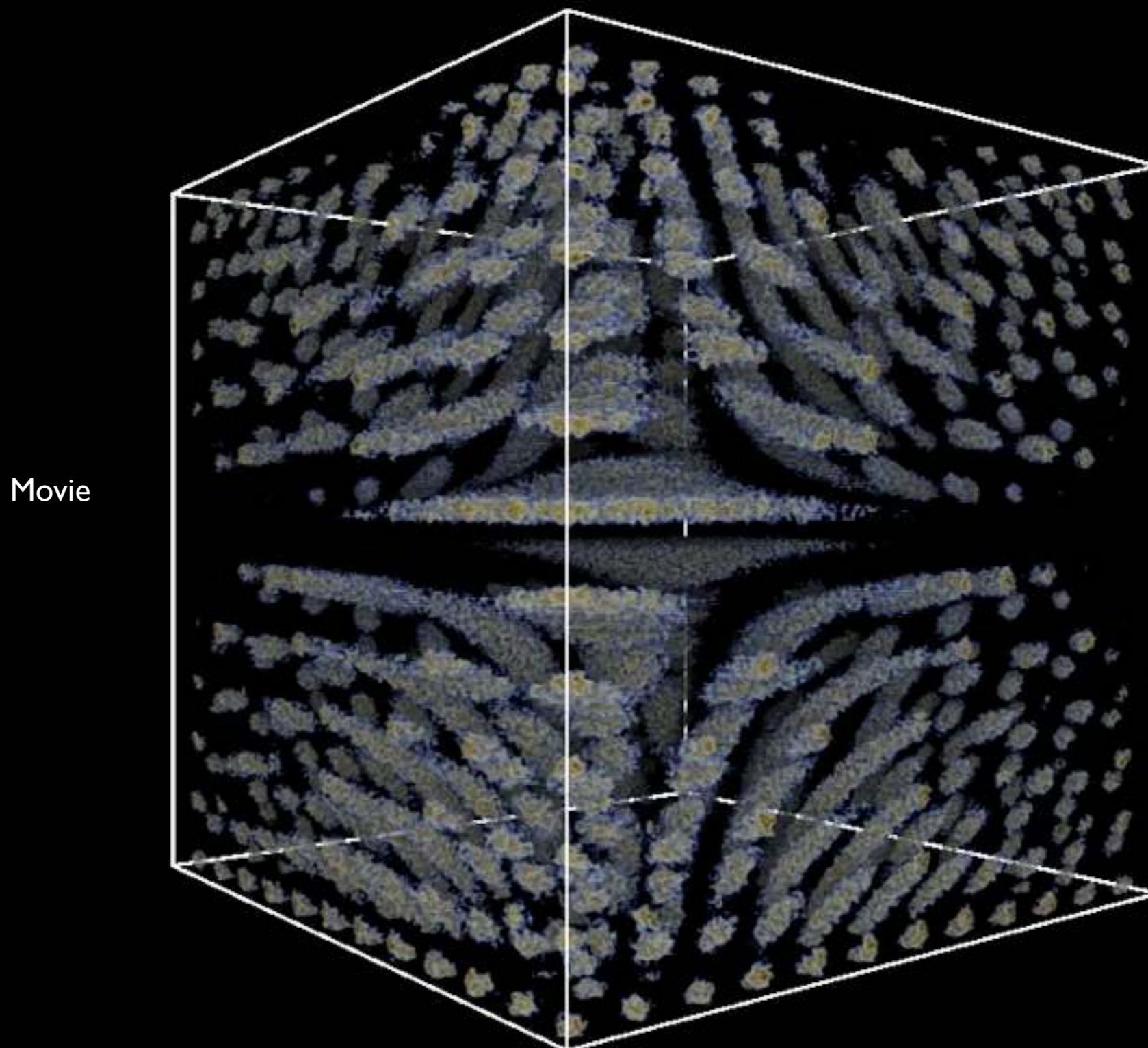
- Medical CT scan at Hobart hospital. (Pausiris mummy)
- The first time the interior of this Egyptian mummy was revealed, designed for forensic purposes but also as a public exhibition.

Movie

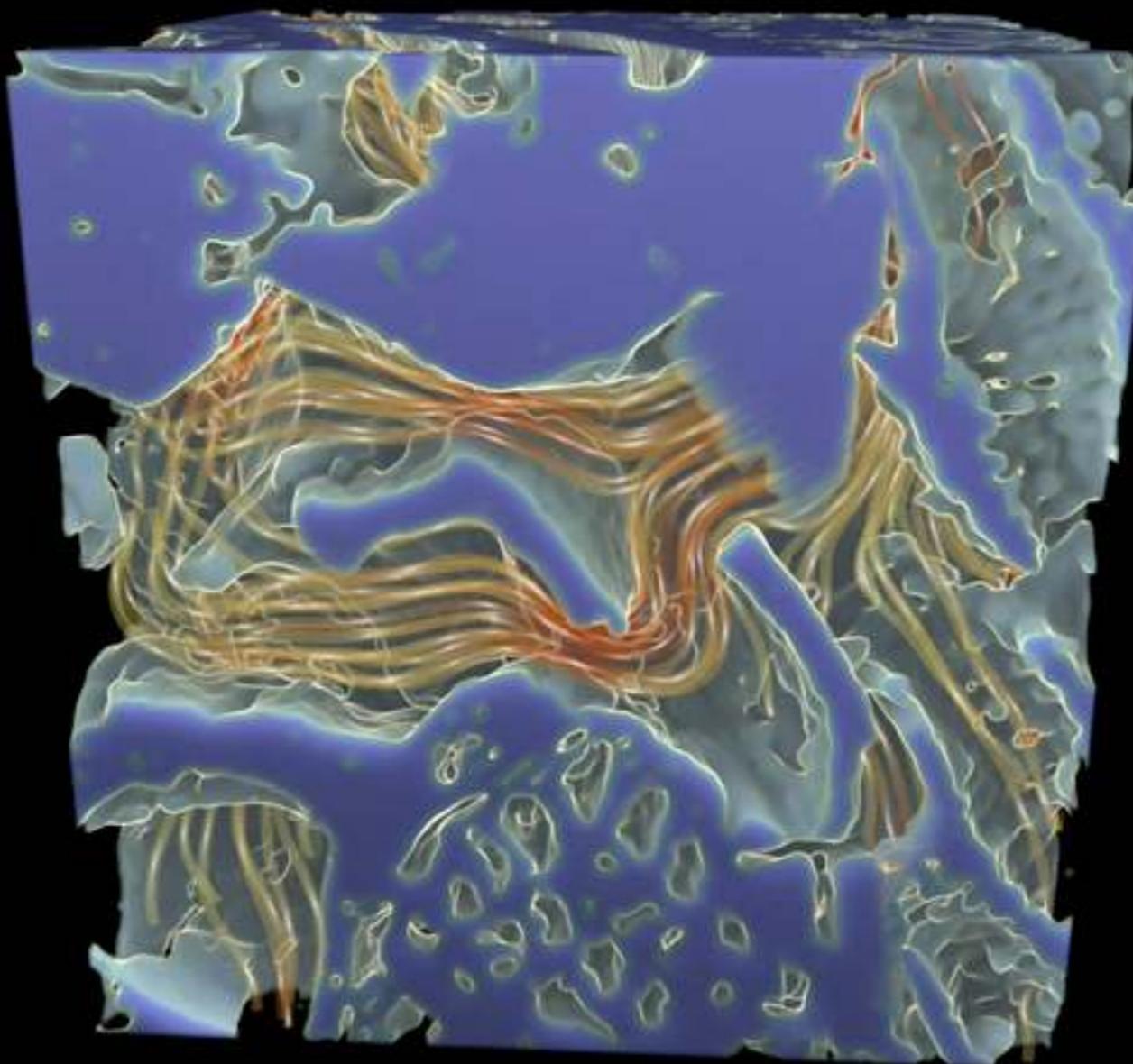


Examples: time varying volumes

- Standing waves in electromaterials.



Examples: flow visualisation



Movie

Examples: illustration

- Illustrative visualisation in medicine. (Drew Berry)
- Visualising a process without there necessarily being data involved.

Movie



Examples: heritage

- Visualising heritage objects.

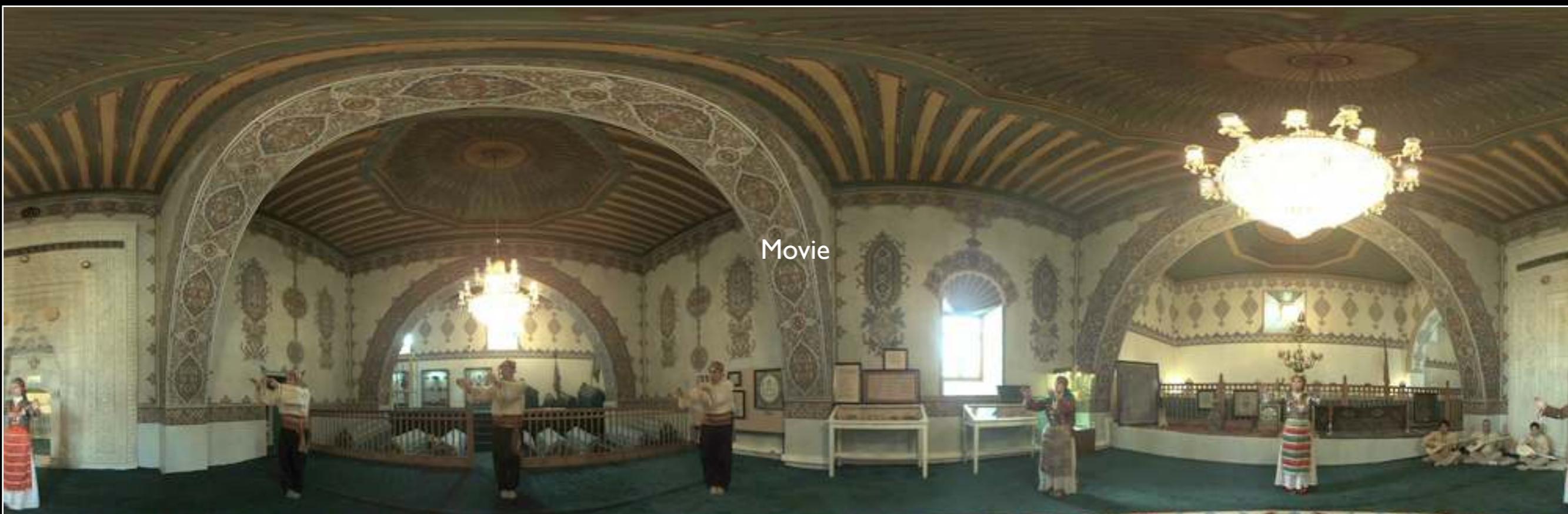


Movie



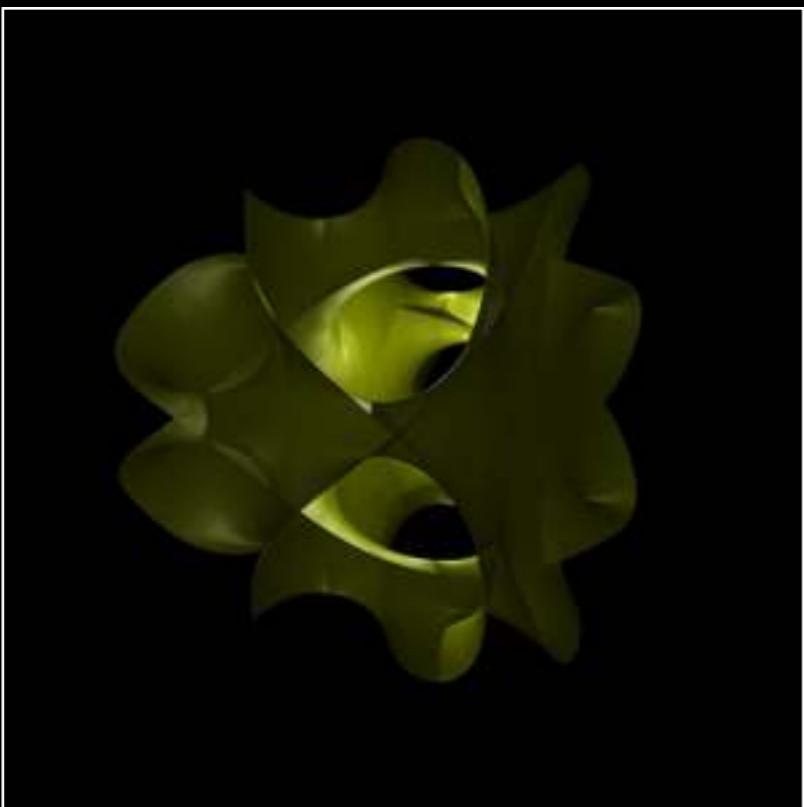
Examples: cultural heritage

- Visualising other cultures, possibly from another time.
- Insight into what it may have been like to live in another culture or time.

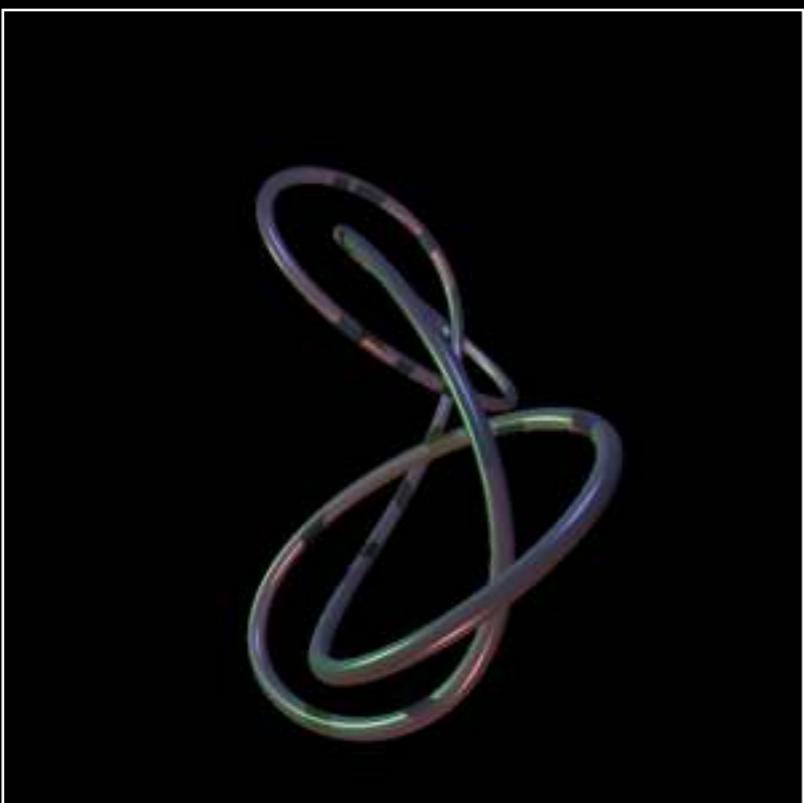
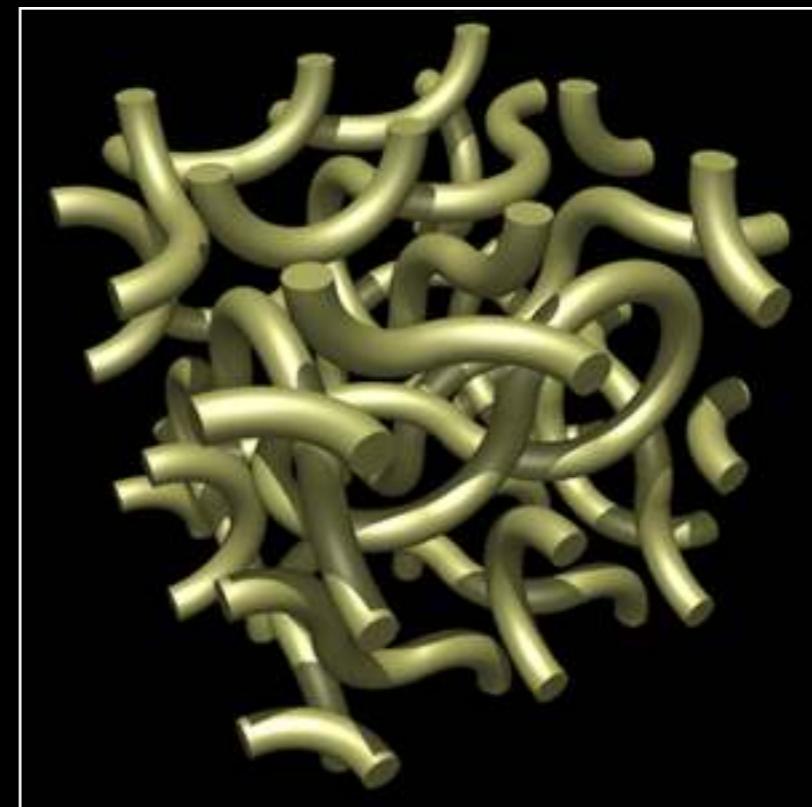


Example: geometry / topology

11 dimensional Calabi-Yau surface



3D Truchet tiles



Knot theory



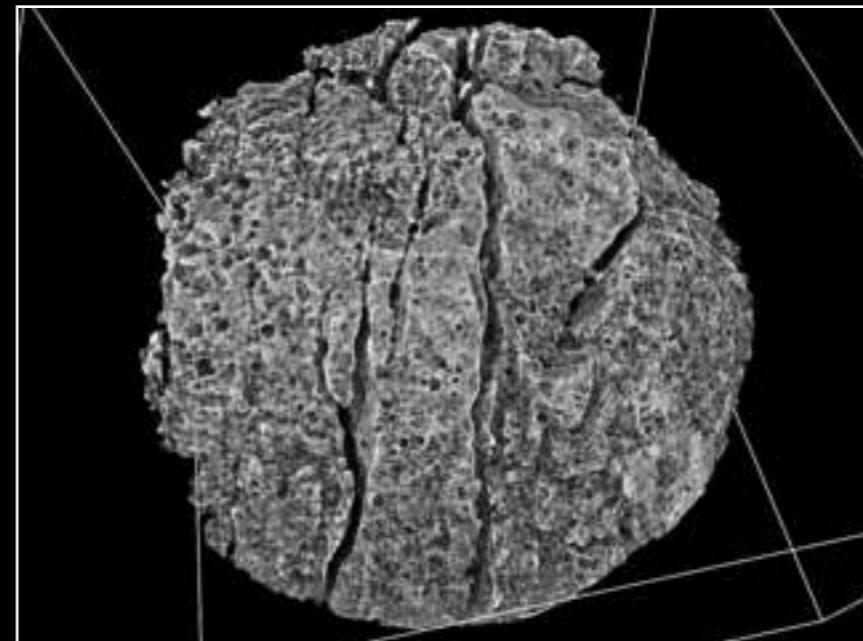
Borromean rings

Categories: volume visualisation

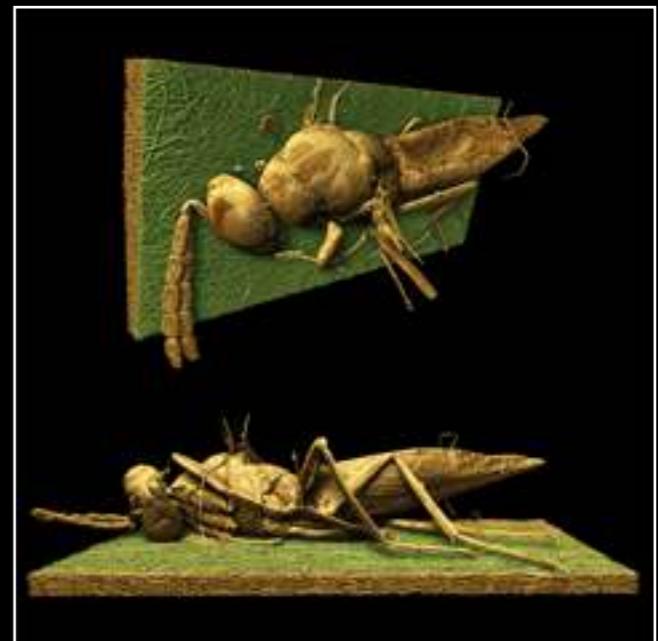
- Very common form of data in the sciences.
- Traditionally one thinks about medical data, for example MRI.
- Other scanning and 3D imaging technologies include CT (MicroCT) and CAT scans.
- Volumetric data also arises from many numerical simulations.
Quite common in astronomy and engineering (finite element calculations).
- In scanned volumetric datasets the quantity per voxel depends on the scanning technology.
For example: MRI essentially gives water content, CT gives density.
- For volumetric datasets derived from simulation there can be multiple variables per voxel.



Medical research (MRI)

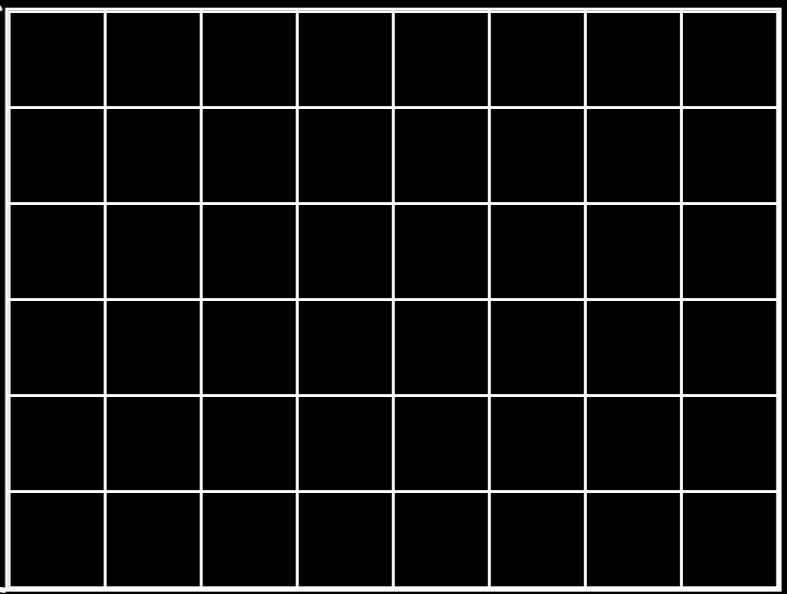
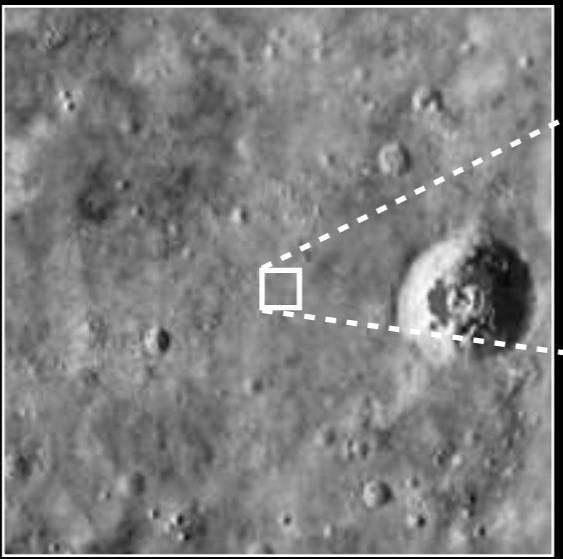


Geology (CT)

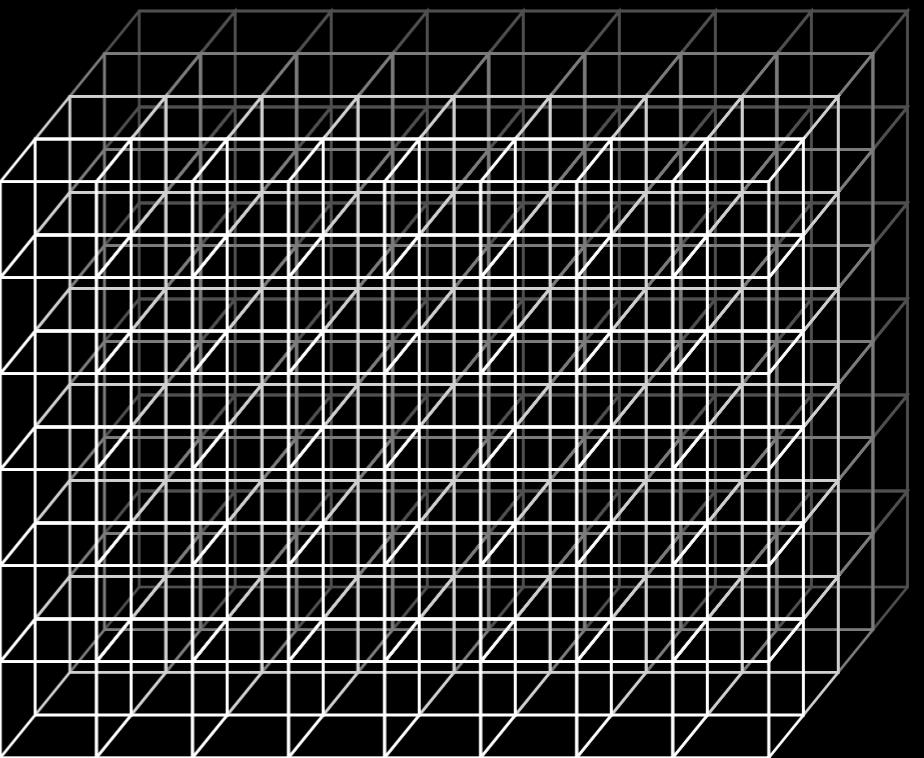
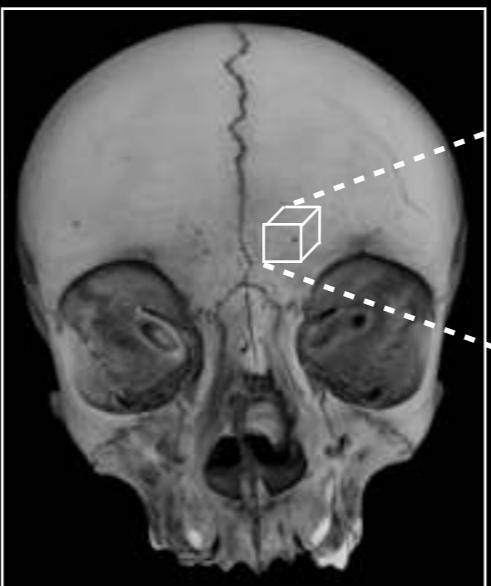


Entomology

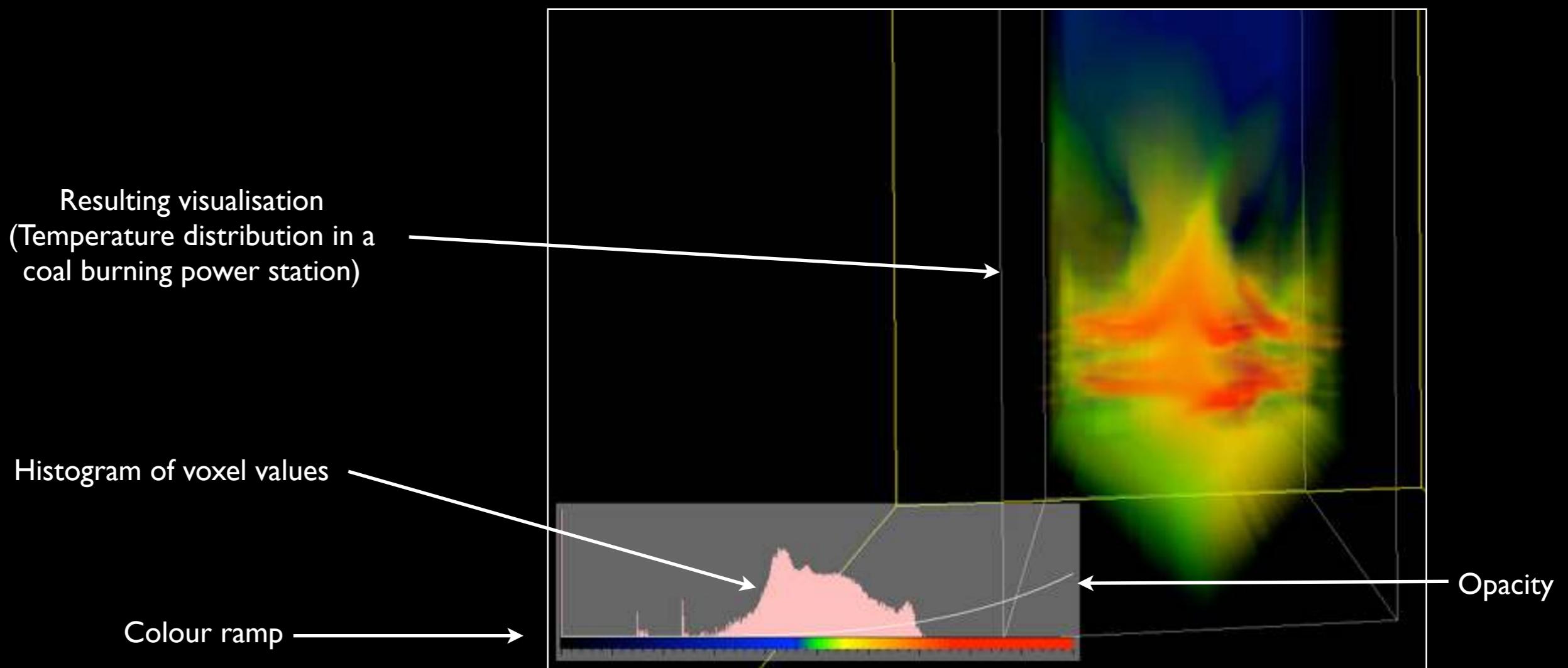
- A digital image contains some quantity sampled on a regular grid on a 2D plane.

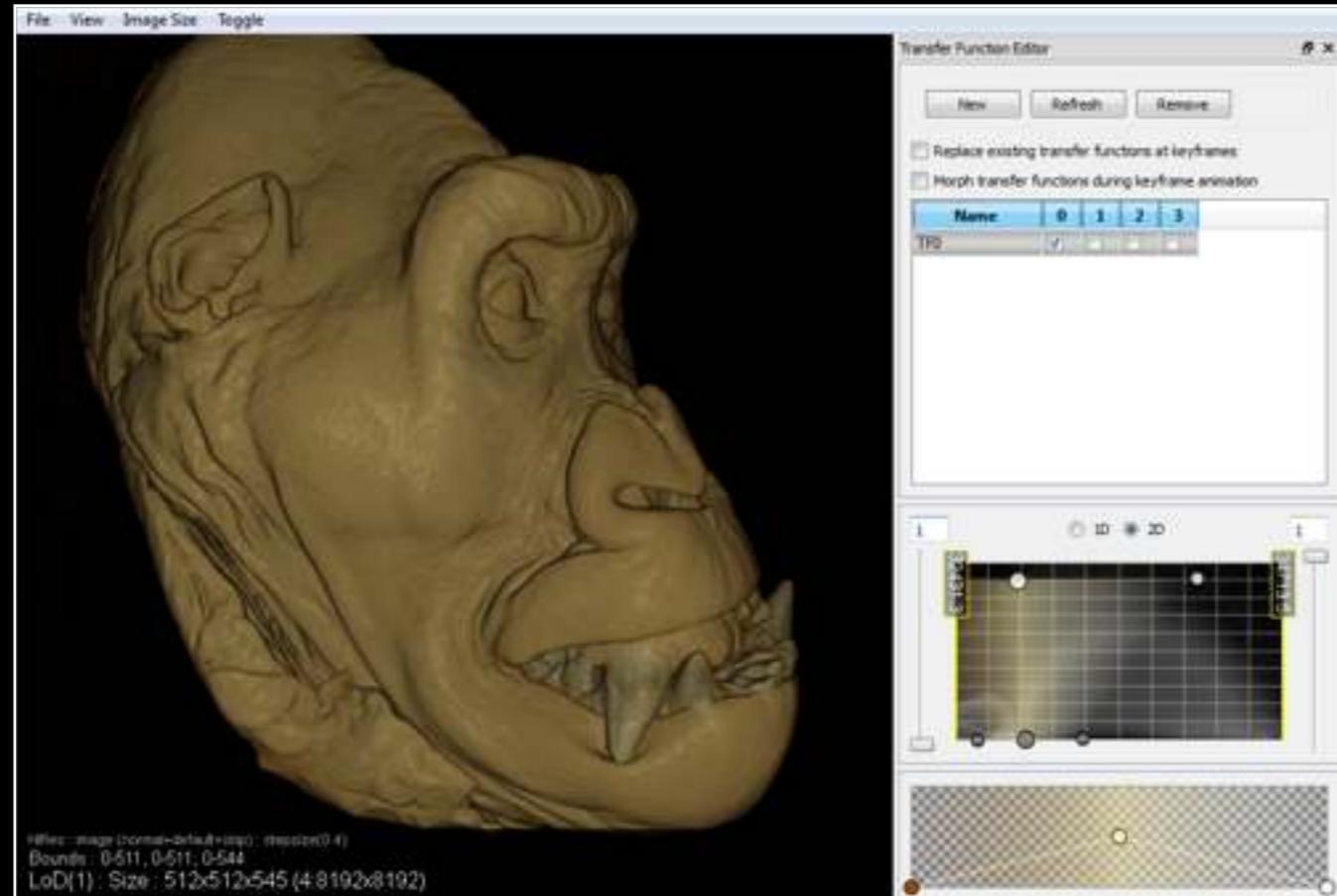


- In a volumetric dataset there is some quantity sampled on a regular 3D grid. Each cell is called a VOXEL (VOlumetric piXEL)

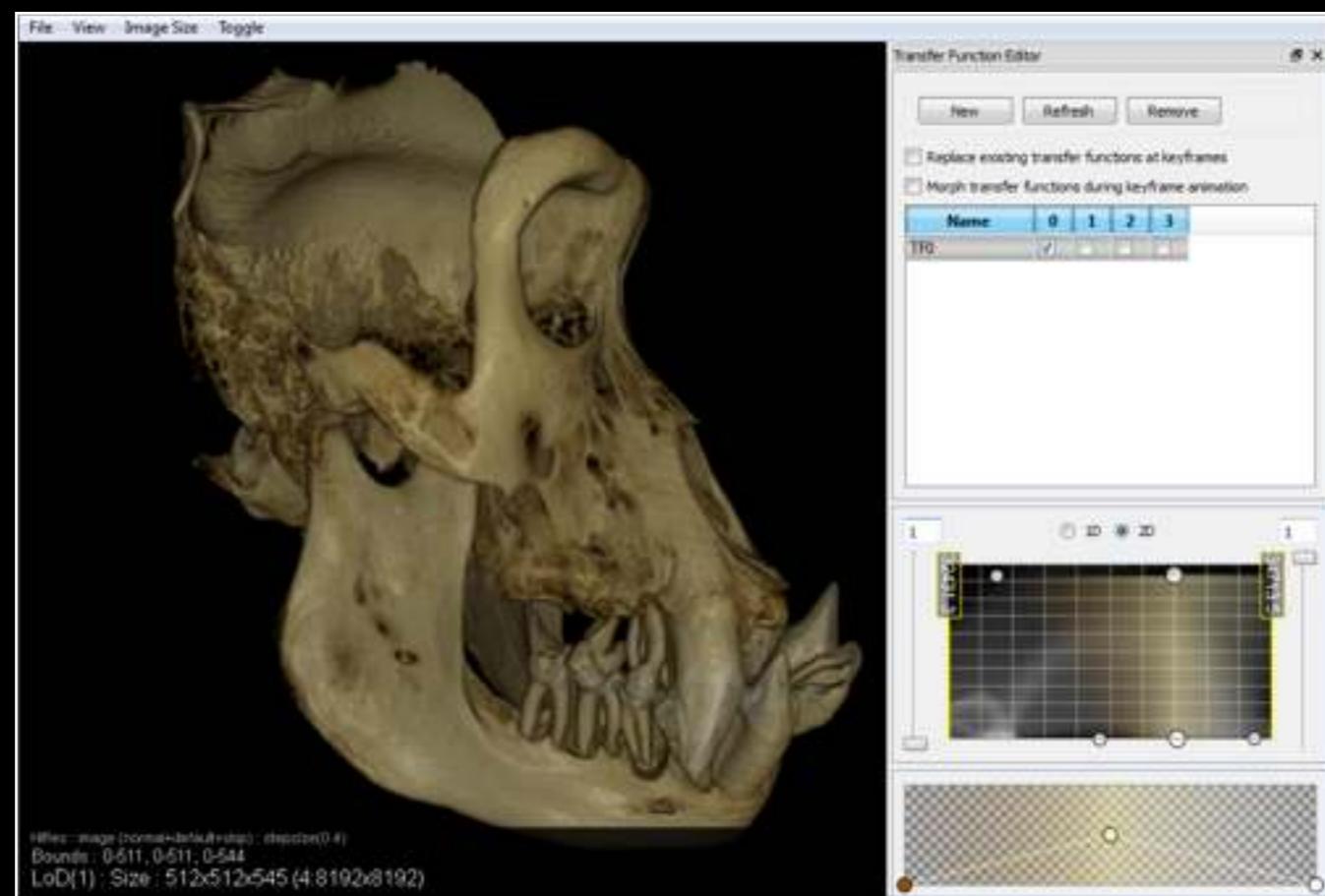


- Volumetric visualisation is the process of exploring and revealing the structure/interior of a volumetric dataset.
- The general approach involves a mapping between voxel values and colour-opacity.
- Realtime volume visualisation generally requires hardware assistance, notably graphics cards.
- Has always been a demanding area in visualisation, the data volumes researchers wish to visualise has always been ahead of the technology.
- Still the case with huge volumes from MicroCT scanners and Synchrotrons.

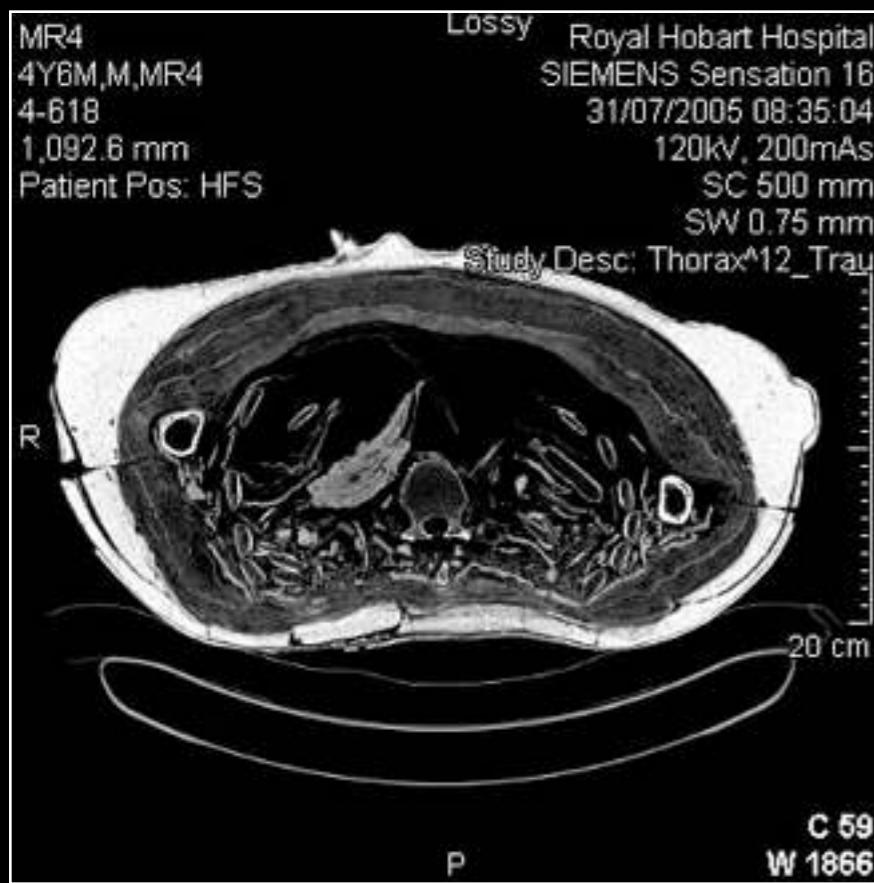




Same data but different transfer functions



- Raw slice data is generally shown as a movie in just the axis of the slices.
- Colours are not real, that is a mapping choice by the person doing the visualisation.
- Can be chosen to enhance features, or based upon expected colour.
- There are volumes where the voxel values are RGB values, for example cryosection volumes.



Slice data from the CT scanner



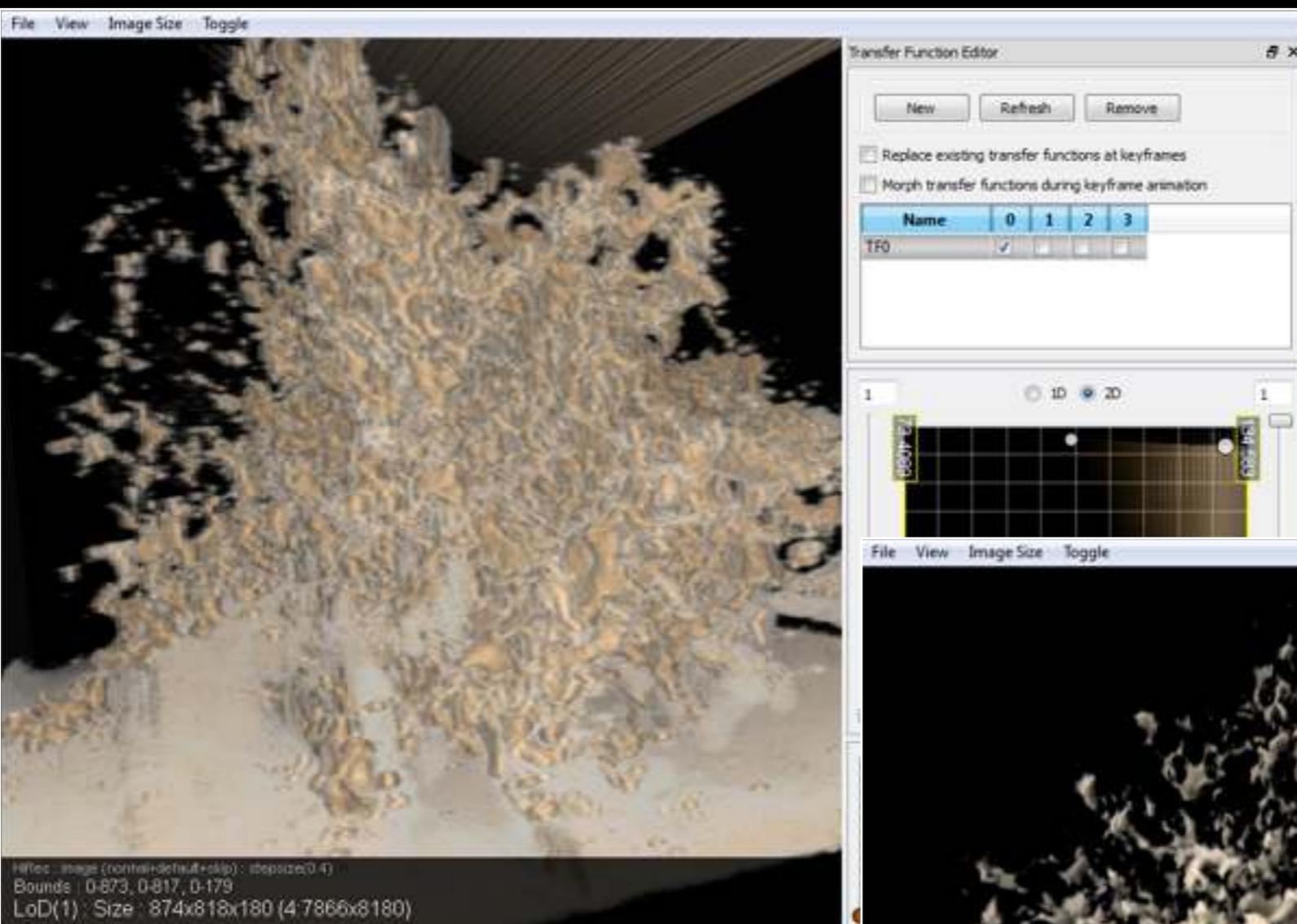
Volume visualisation

- RGB volume generally arise from slice and photograph techniques.
- For example, the visible human dataset)

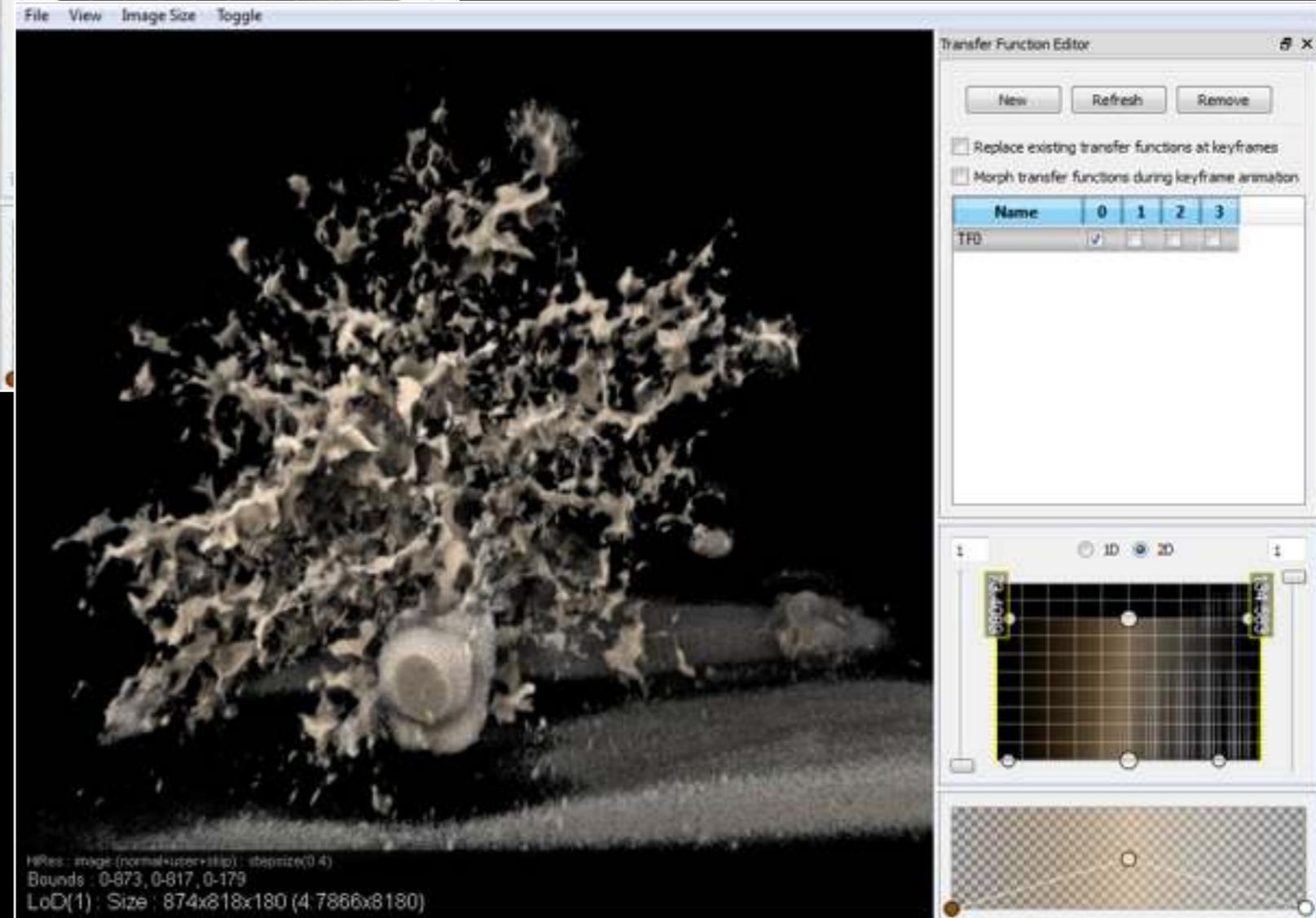
Movie



● Microfossil



The structure is a 1.9 billion year old microfossil from the Gunflint chert of Canada. The image is a reconstruction of c. 180 slices through the microfossil. The slices were c. 15 x 15 microns in size and 75 nm thick. Slicing was achieved using a focused beam of gallium ions, and imaging of successive slices using a scanning electron beam of a Zeiss Auriga Crossbeam instrument at the Electron Microscopy Unit of UNSW.

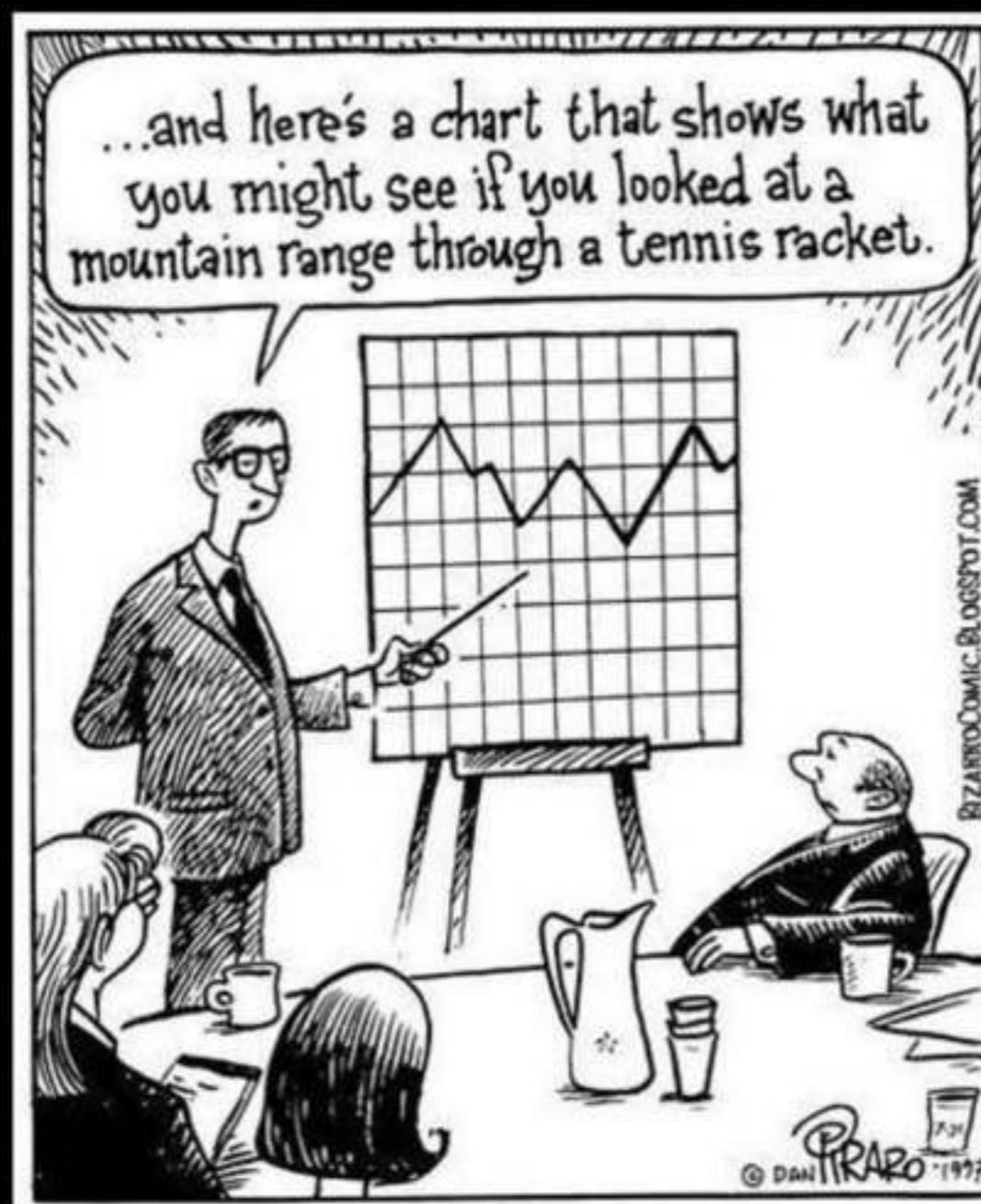




Movie

Categories: geometric representations

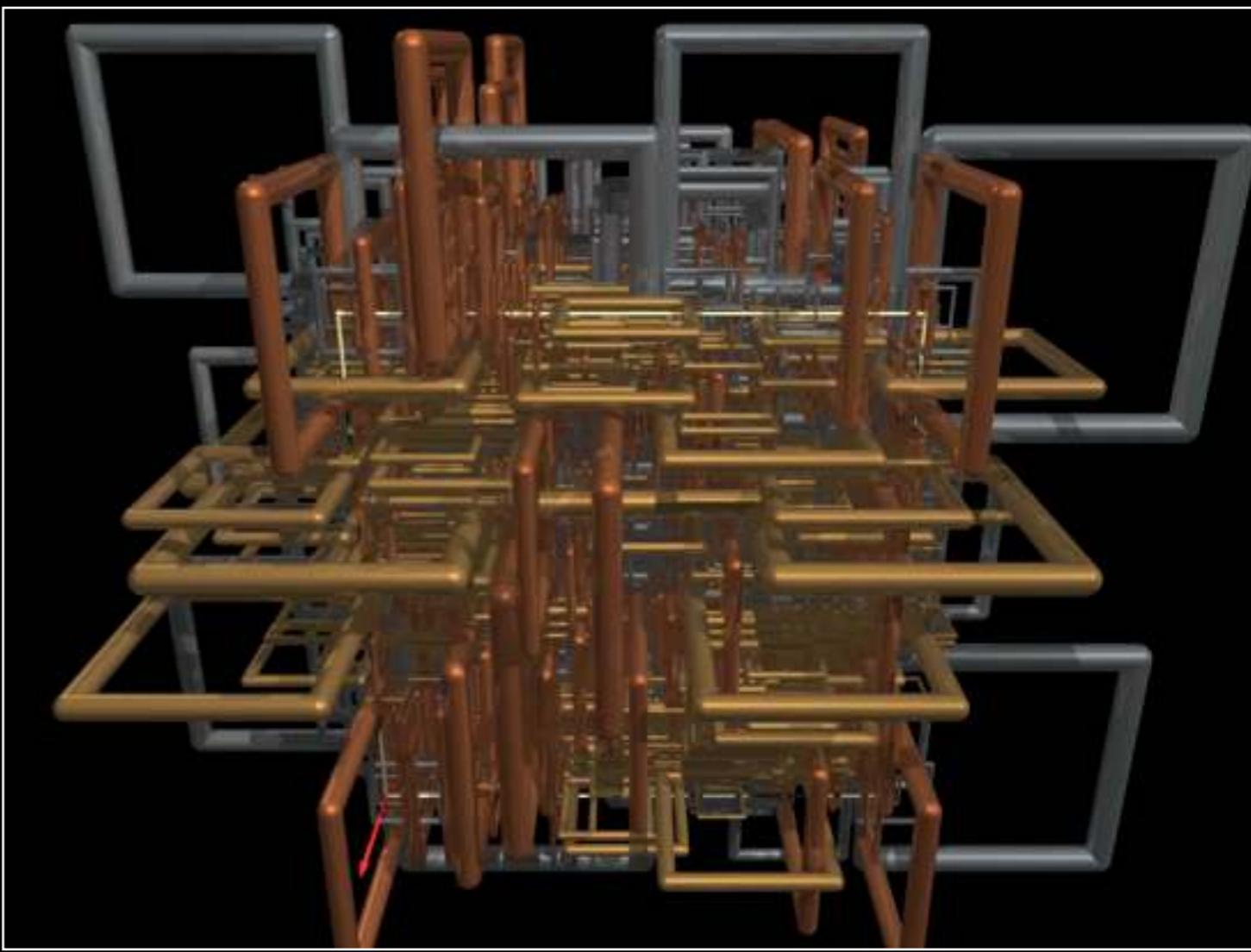
- Visualisation is often concerned about mapping data to geometry.
- The mapping is often obvious, other times not.



	A	B	C	D	E
1	X	Y	Z	R	Axis
2	3.094771	-2.206173	5.097041	2.910621	0
3	3.094771	7.793827	5.097041	2.910621	0
4	9.114162	2.697415	0.180805	2.828702	1
5	9.114162	12.697415	0.180805	2.828702	1
6	9.114162	2.697415	10.180805	2.828702	1
7	9.114162	12.697415	10.180805	2.828702	1
8	0.118114	2.967826	3.442576	2.754914	2
9	10.118114	2.967826	3.442576	2.754914	2
10	0.427236	-0.258223	6.412867	2.68795	0
11	10.427237	-0.258223	6.412867	2.68795	0
12	0.427236	9.741777	6.412867	2.68795	0
13	10.427237	9.741777	6.412867	2.68795	0
14	1.846255	6.221668	5.500492	2.626783	1
15	5.560567	3.806308	5.693708	2.570595	2
16	5.401607	4.61849	8.86958	2.51872	0
17	4.74108	3.939676	3.870554	2.470614	1
18	-0.058313	1.966198	2.037181	2.425826	2
19	9.941687	1.966198	2.037181	2.425826	2
20	-0.058313	1.966198	12.037182	2.425826	2
21	9.941687	1.966198	12.037182	2.425826	2
22	-0.916052	5.077406	7.016881	2.383977	0
23	9.083948	5.077406	7.016881	2.383977	0
24	8.261508	-2.266257	2.234689	2.344748	1
25	8.261508	7.733743	2.234689	2.344748	1

4978	0.036635	5.538867	6.293864	0.366667	1
4979	6.363881	5.627172	3.737942	0.3666637	2
4980	2.976083	2.336567	9.22129	0.366604	0
4981	7.289498	2.35672	2.288495	0.366572	1
4982	8.17908	4.514182	6.687099	0.366539	2
4983	6.795975	5.465027	6.440717	0.366506	0
4984	2.330369	4.633094	9.5849	0.366474	1
4985	9.152864	2.912539	2.763119	0.366441	2
4986	4.295763	5.213909	0.333169	0.366408	0
4987	7.368822	4.872445	1.572595	0.366376	1
4988	2.326575	8.539257	9.341913	0.366343	2
4989	9.448618	3.542957	8.154446	0.366311	0
4990	1.356728	6.729697	4.519018	0.366278	1
4991	5.096654	3.247994	3.586767	0.366245	2
4992	-0.250326	5.085708	2.532254	0.366213	0
4993	9.749675	5.085708	2.532254	0.366213	0
4994	2.13282	4.316009	4.919343	0.36618	1

Movie

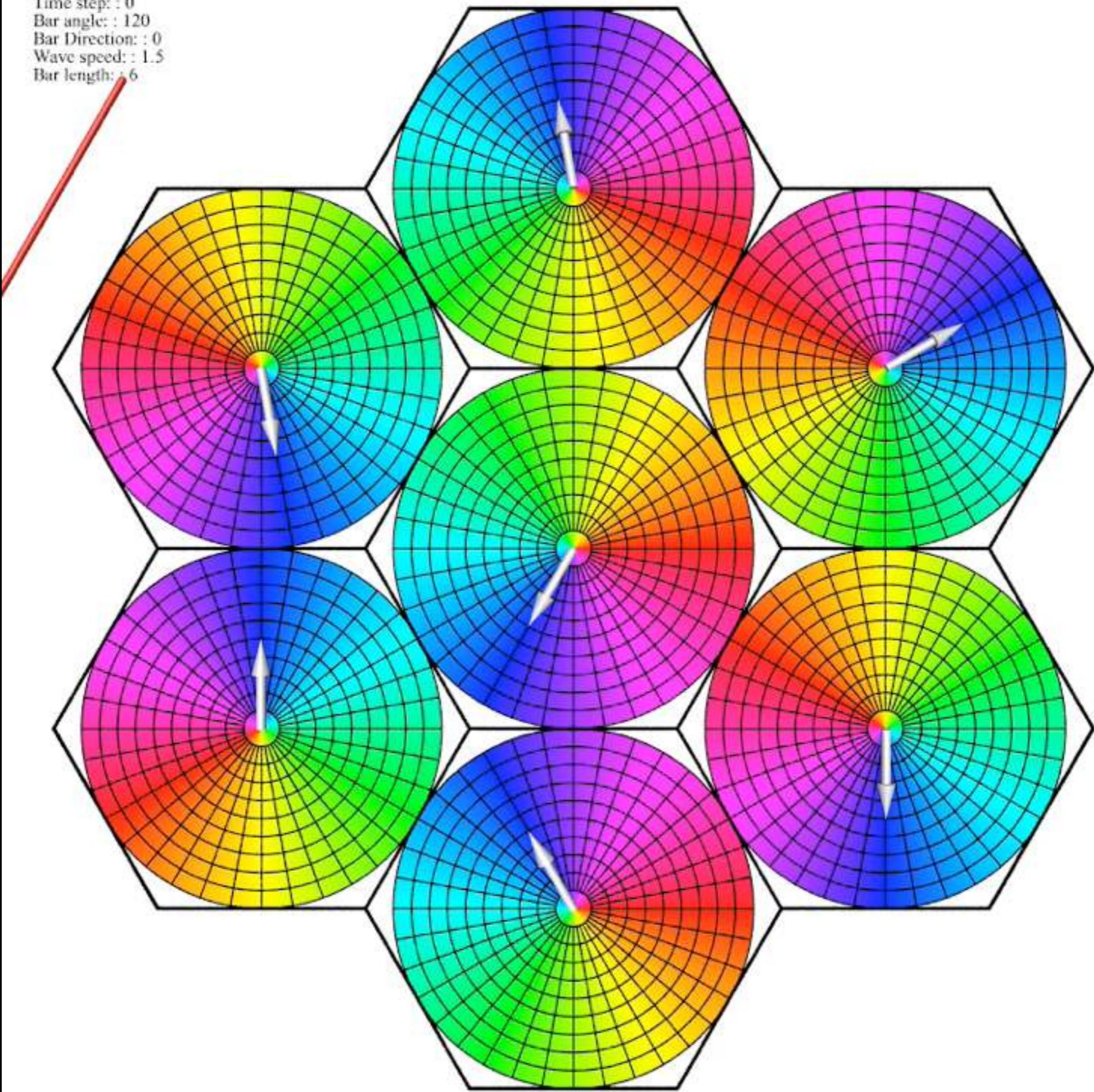




Movie

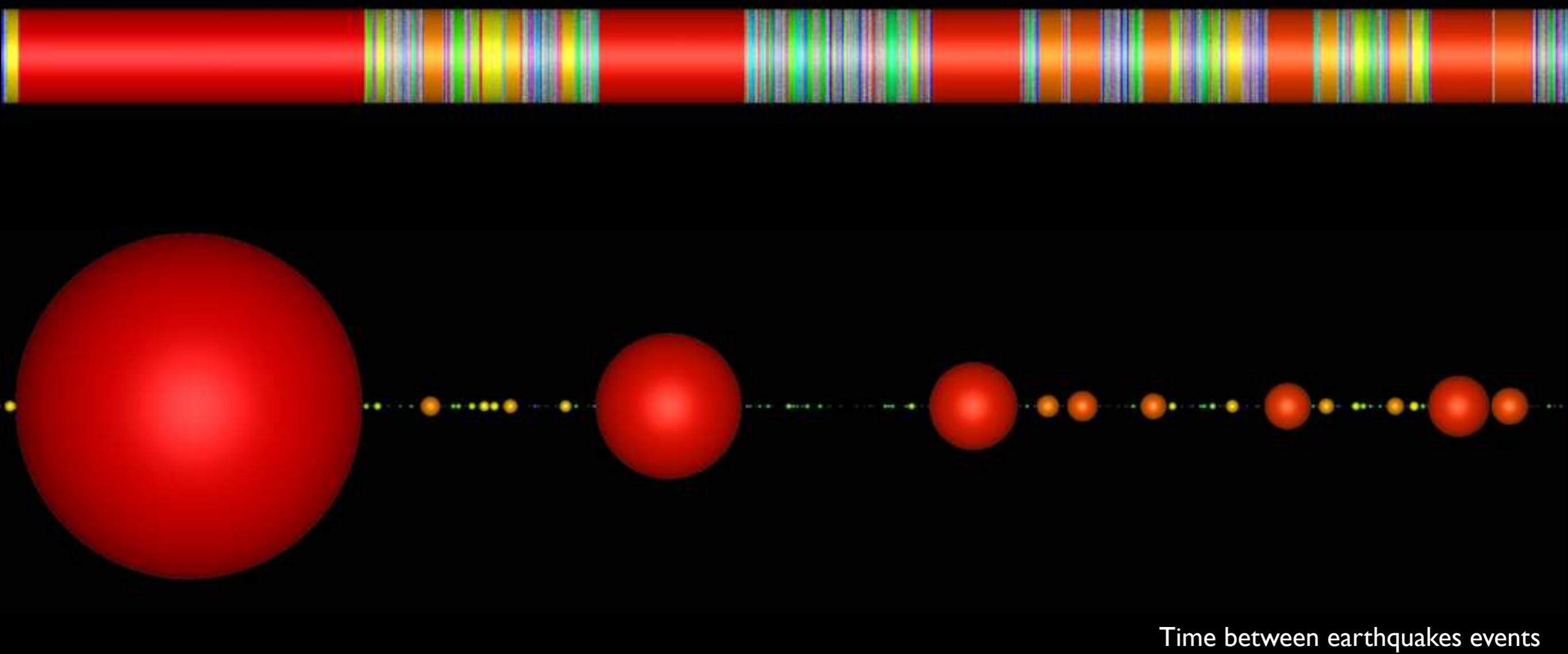
Time step: 0
Bar angle: 120
Bar Direction: 0
Wave speed: 1.5
Bar length: 6

Movie



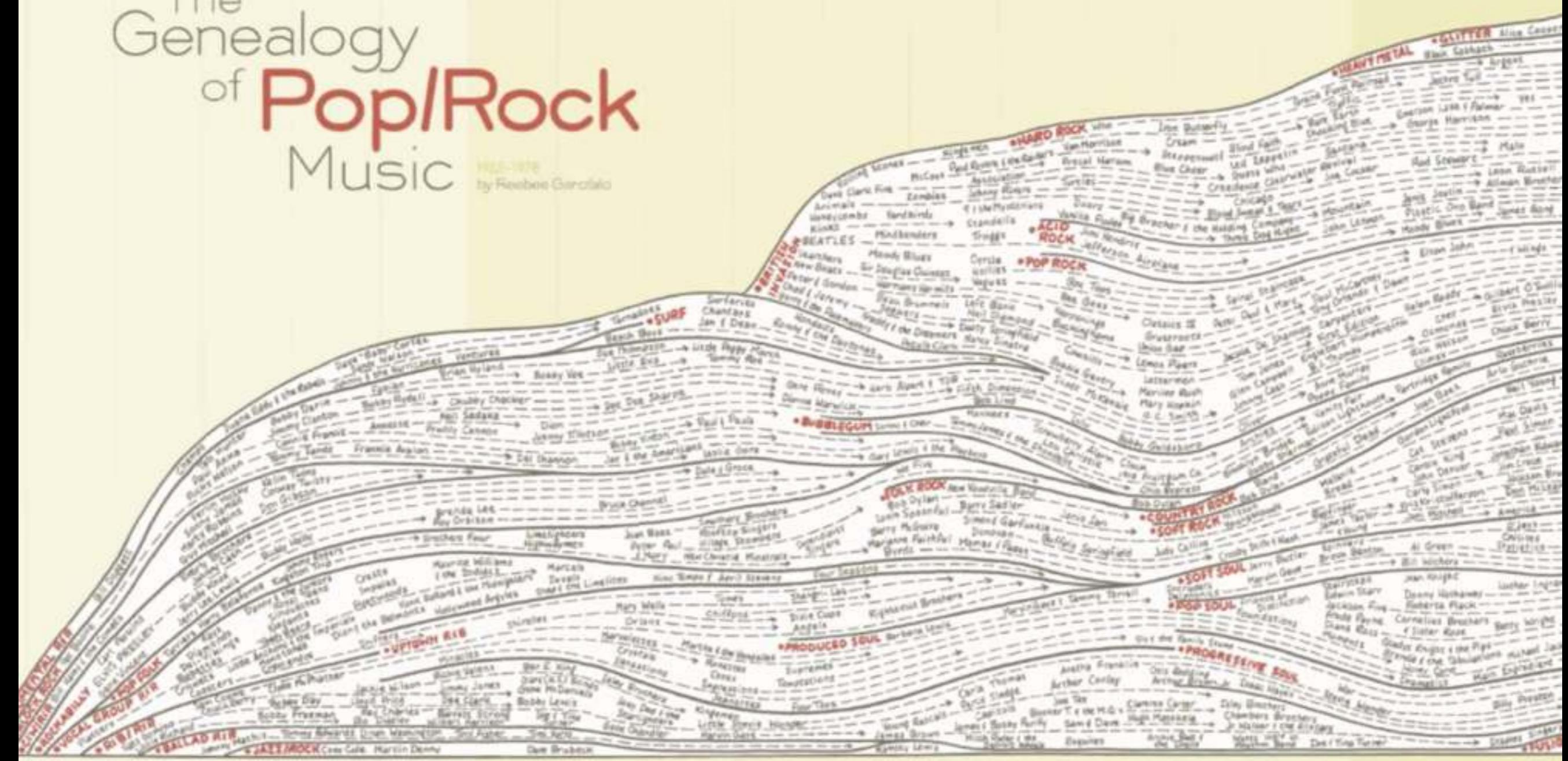
Categories: information

- A whole area of visualisation in itself.
- Often no direct / obvious mappings between data and visual representation.



The Genealogy of Pop/Rock Music

1955-1975
by Frederico Gonçalves

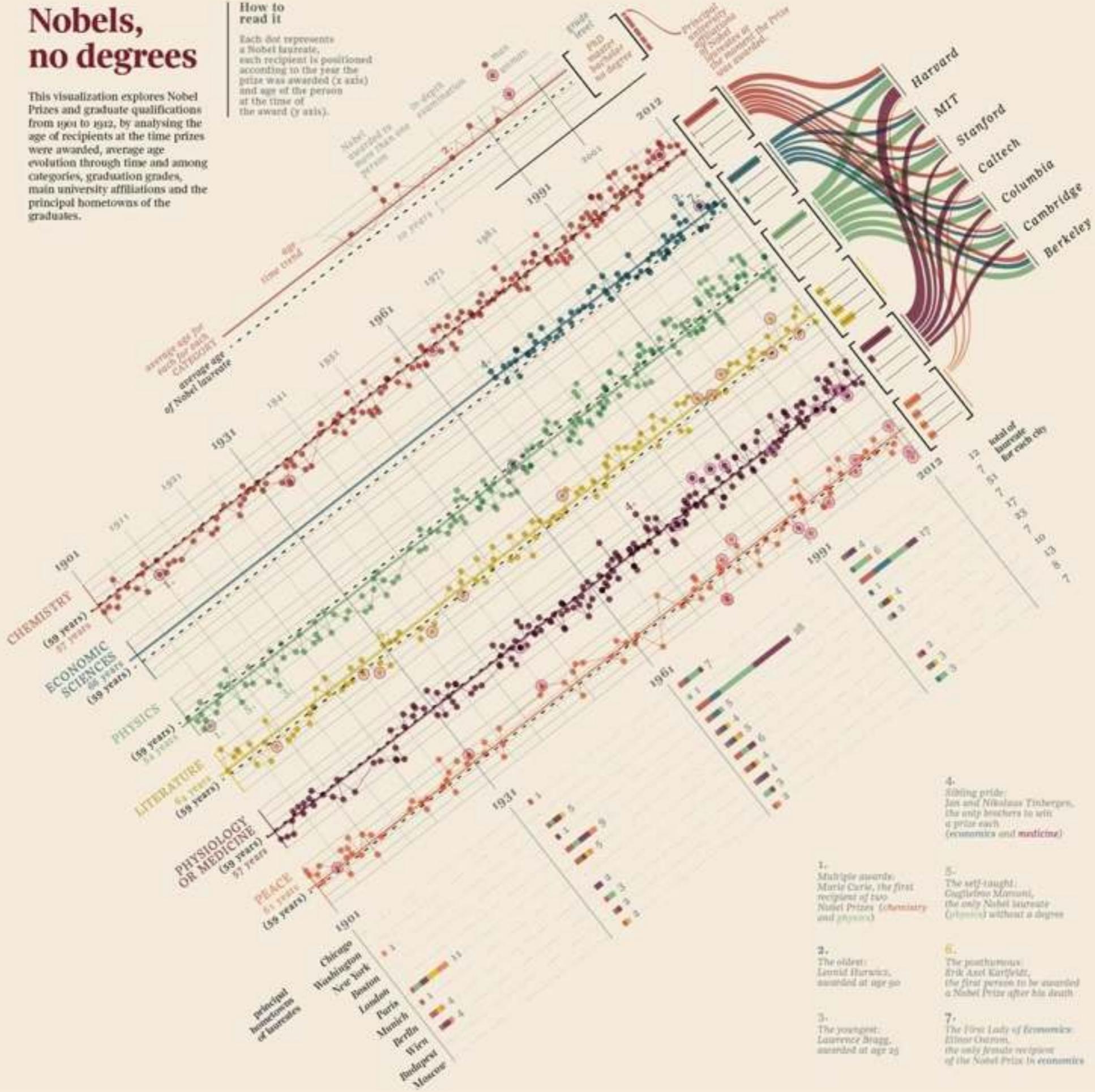


Nobels, no degrees

This visualization explores Nobel Prizes and graduate qualifications from 1901 to 1912, by analysing the age of recipients at the time prizes were awarded, average age evolution through time and among categories, graduation grades, main university affiliations and the principal hometowns of the graduates.

How to read it

Each dot represents a Nobel laureate, each recipient is positioned according to the year the prize was awarded (x axis) and age of the person at the time of the award (y axis).



Health Life expectancy at birth (years)

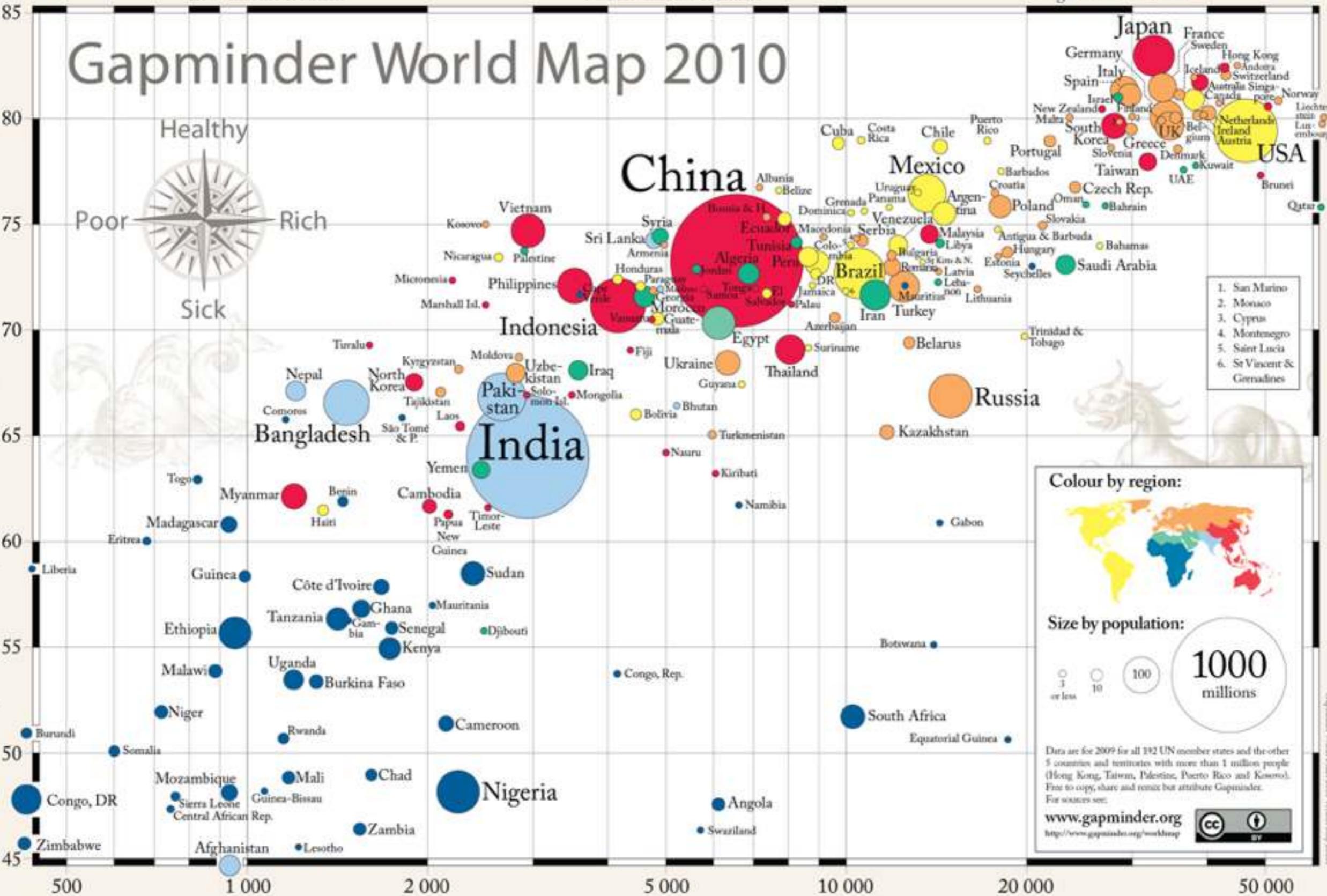
Gapminder World Map 2010

Healthy

Poor

Rich

Sick



Money GDP per person in US dollars (purchasing power adjusted) (log scale)

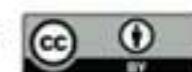
GAPMINDER

Data are for 2009 for all 192 UN member states and the other 5 countries and territories with more than 1 million people (Hong Kong, Taiwan, Palestine, Puerto Rico and Kosovo). Free to copy, share and remix but attribute Gapminder.

For sources see:

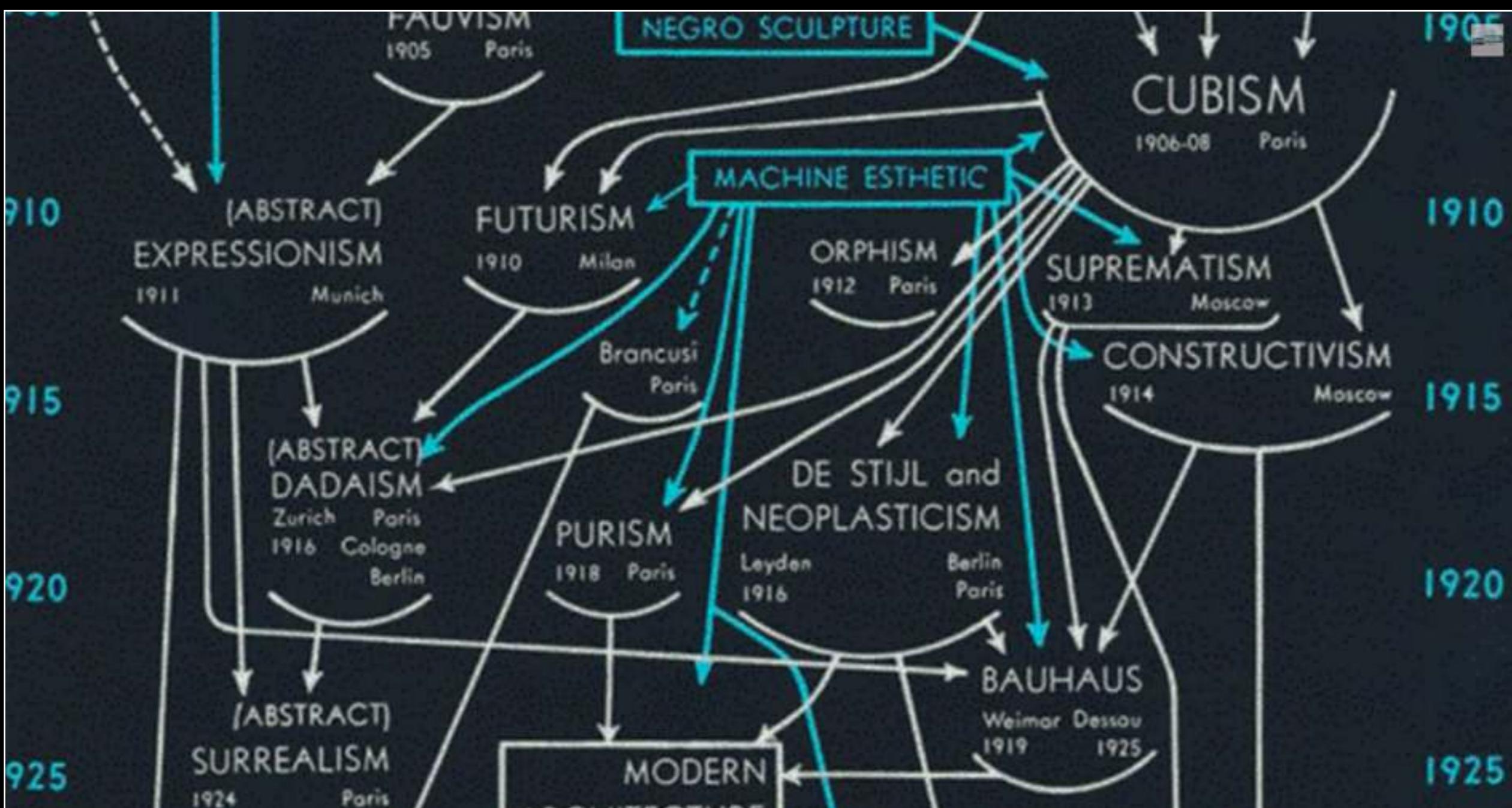
[www.gapminder.org](http://www.gapminder.org/worldmap)

<http://www.gapminder.org/worldmap>



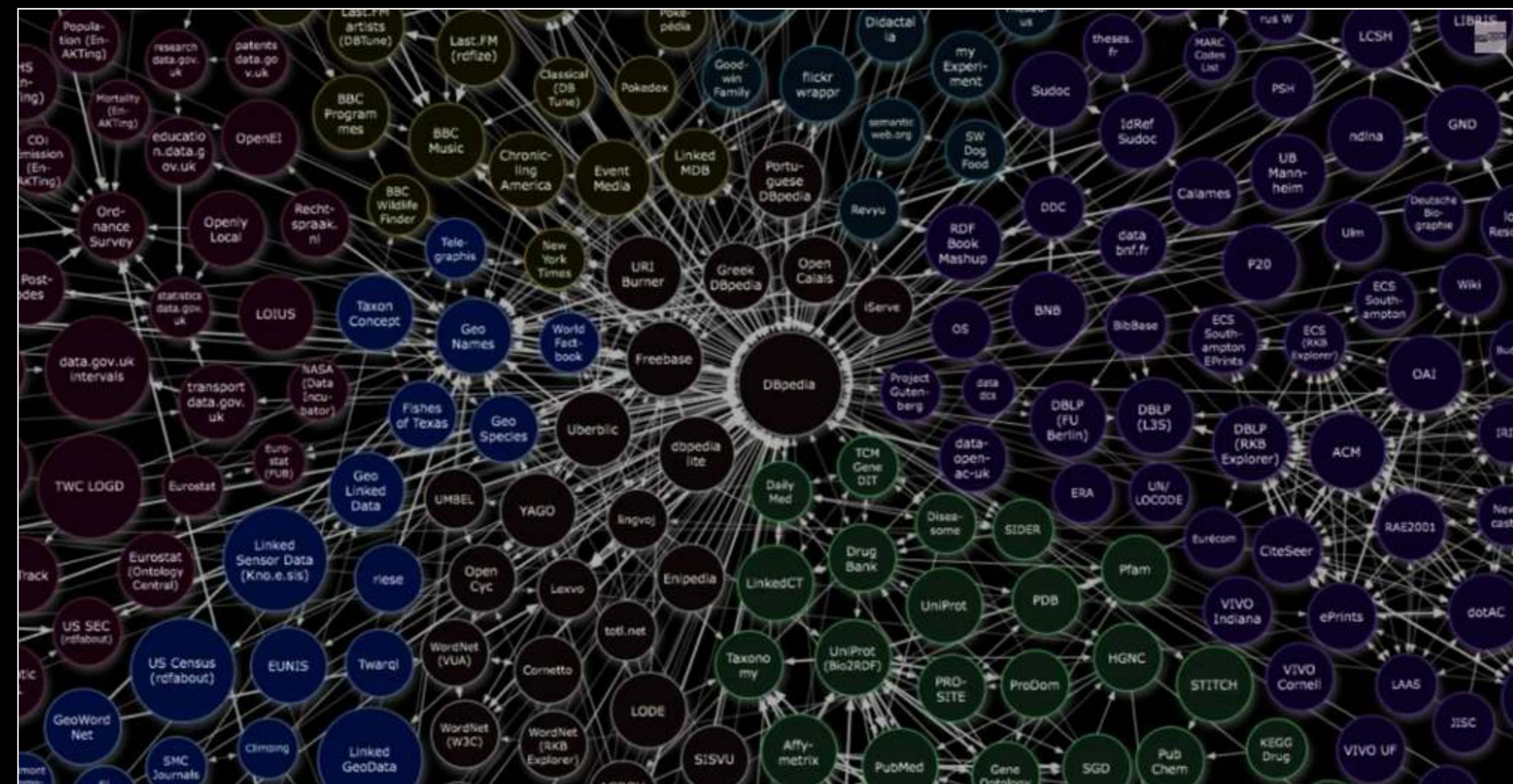
Categories: networks

- Visualising networks is usually about arranging the nodes/connections so as to reveal informative structures.



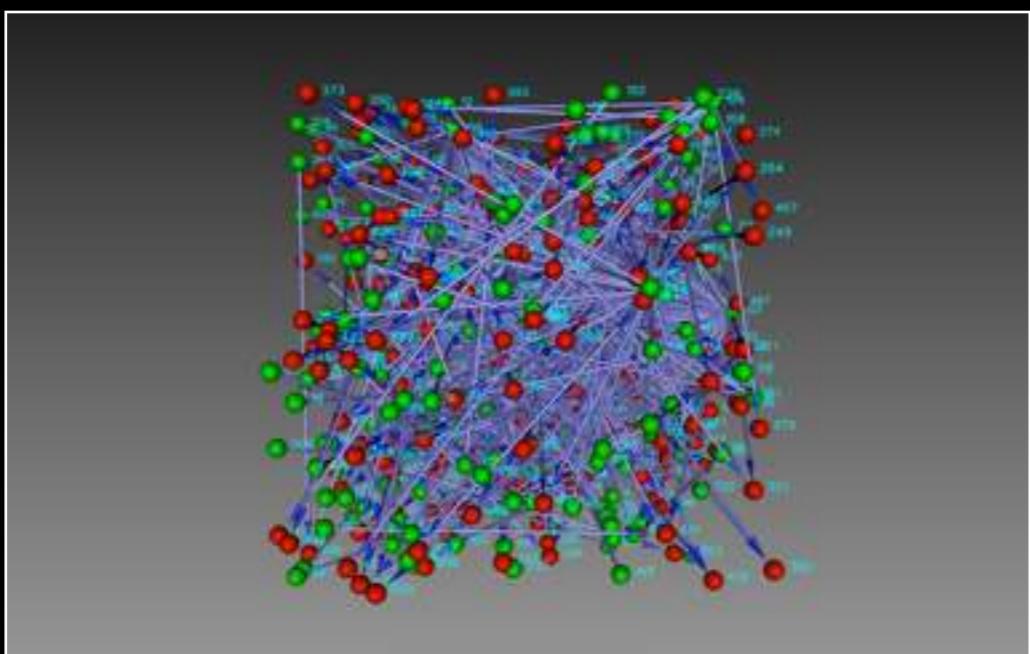


FACEBOOK USERS WORLDWIDE

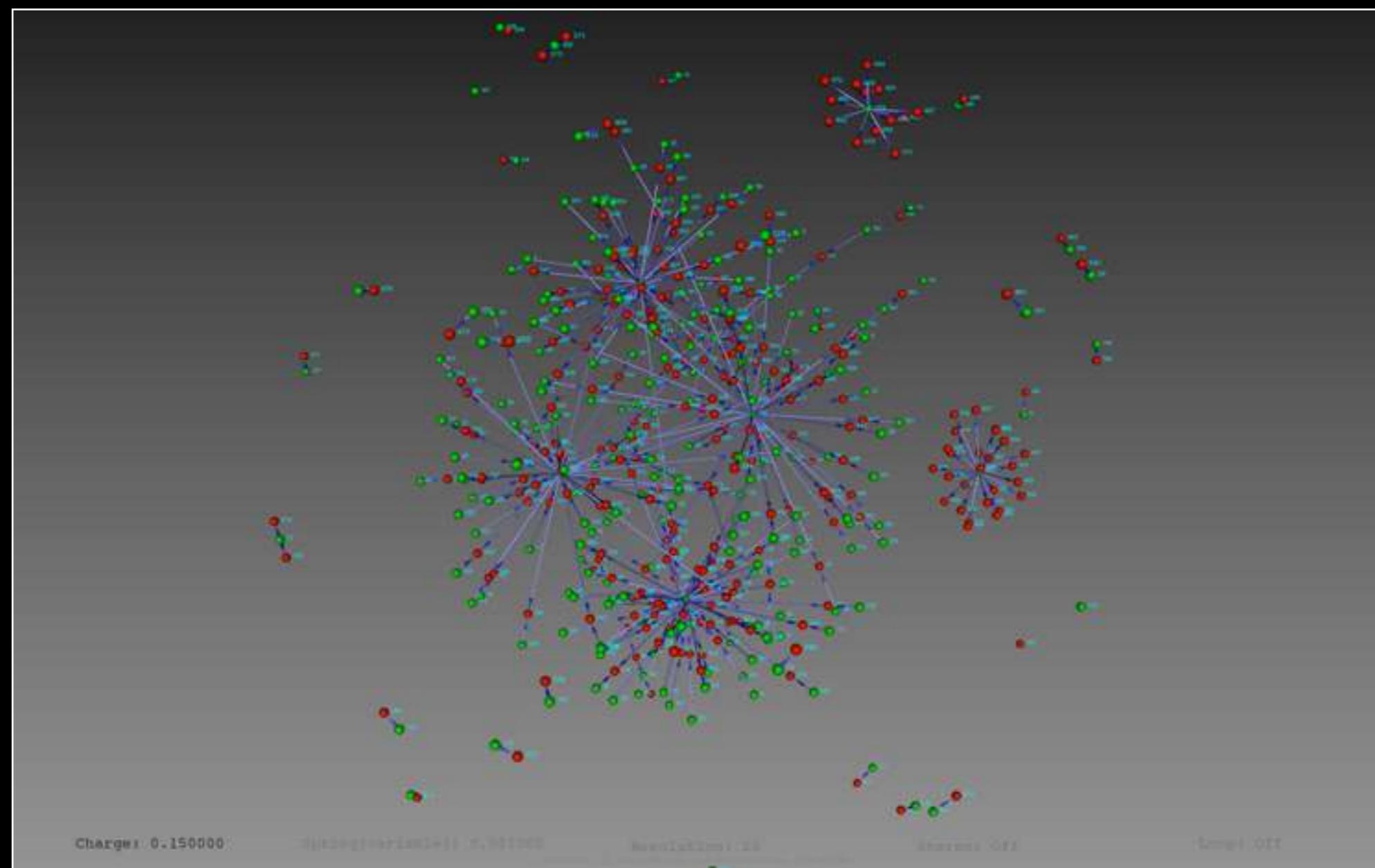


- One approach is to use a physical based system
 - Each node has a positive charge, so repel all other nodes.
 - Each connection between nodes is a spring that attracts connected nodes.
- Provides intuitively right characteristics.
- Run the physics simulations until (if) the structure stabilises.
- No assurance to reach minimum energy state, may be local minima rather than global.





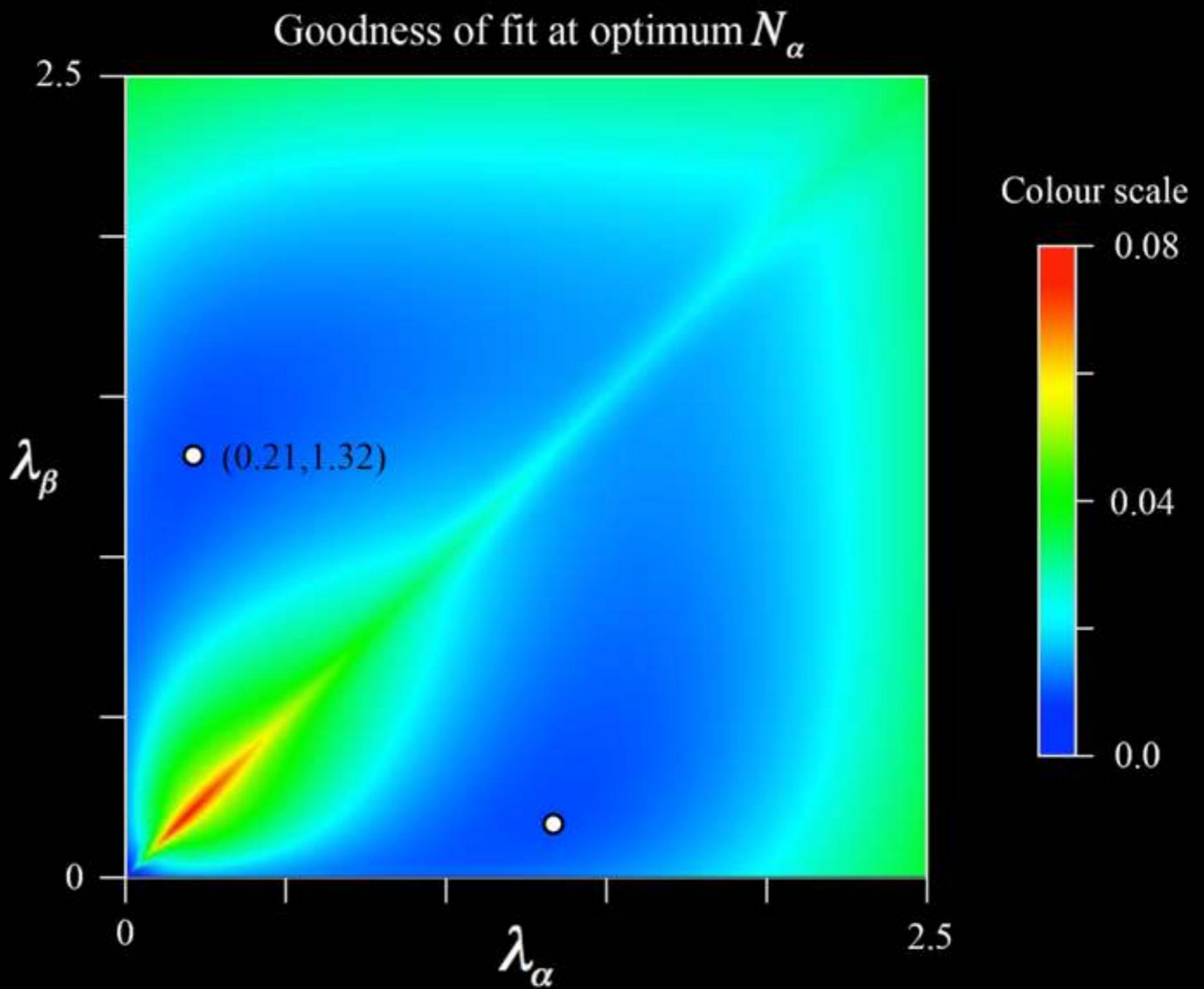
Initial random arrangement
No predefined structure



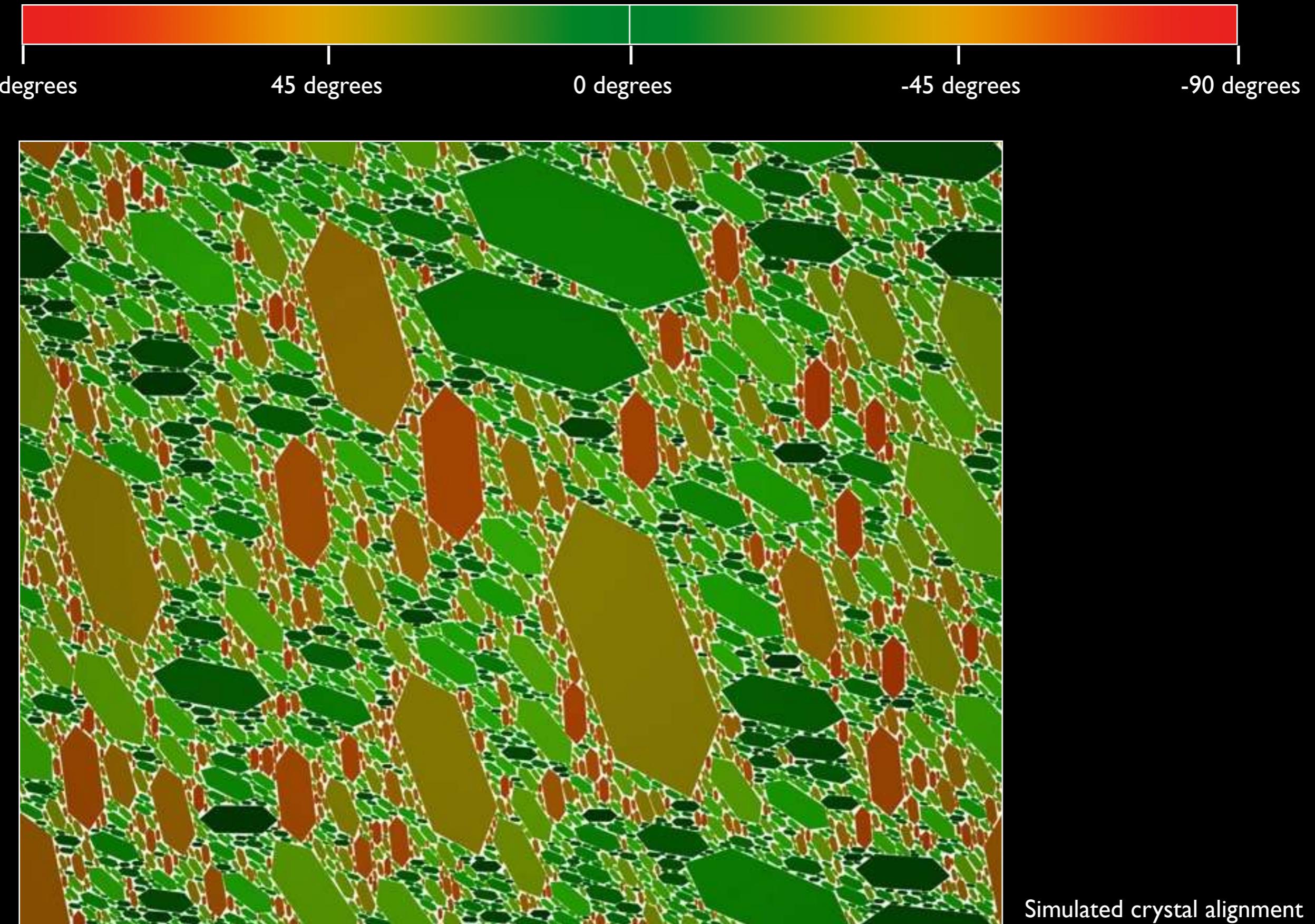
Structure and relationships
evolve based upon the
physics rules.

Techniques: colour maps

- Simplest method of mapping some quantity onto geometry.



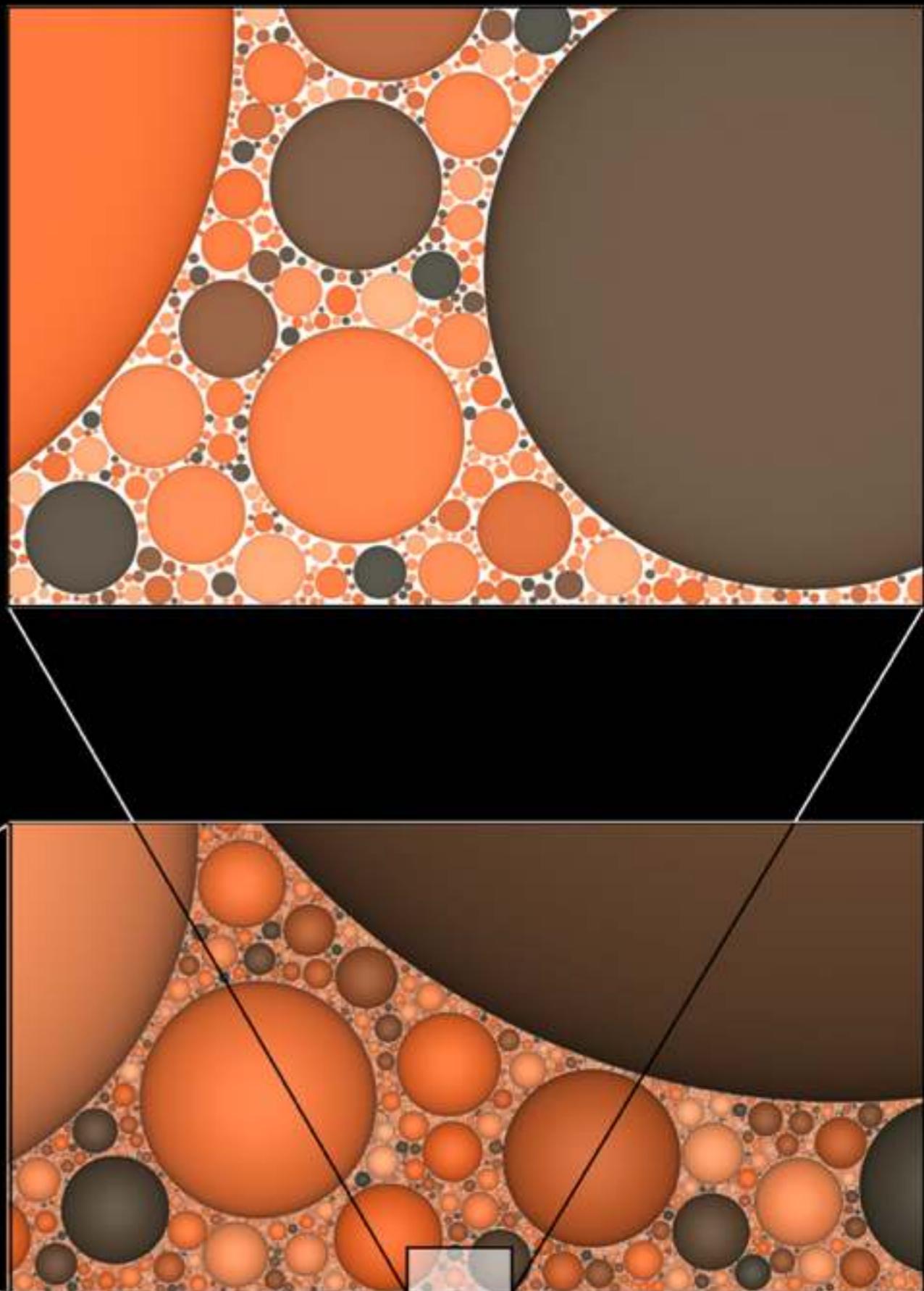
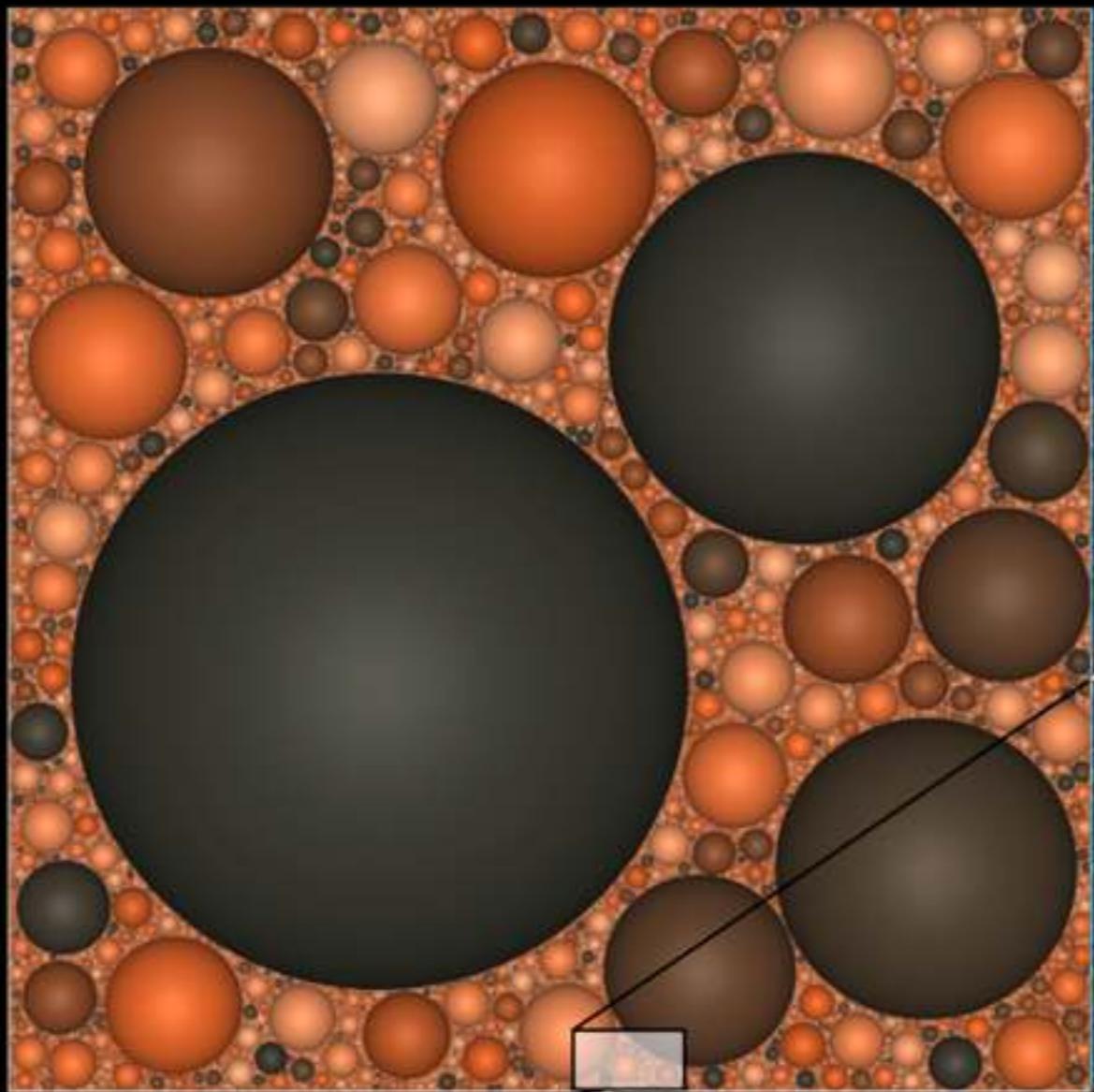
- When an angle is mapped to colour would typically use a circular colour map.



Not uncommon to doubly map variables.

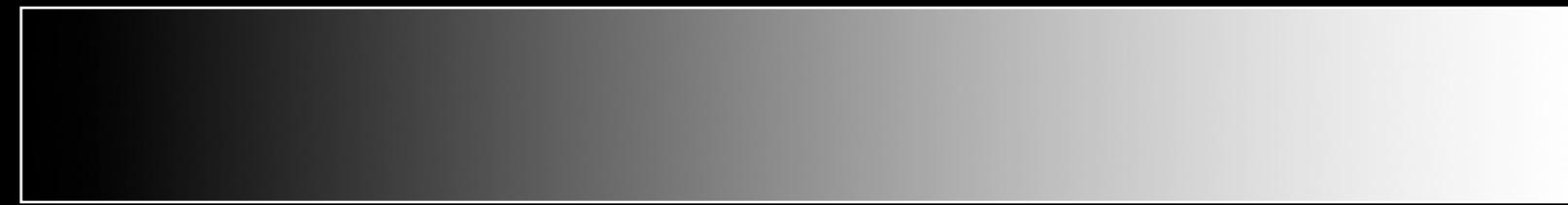
Colour mapped here to size but we can already observe the size.

Have the opportunity to map other dimensions by colour.



- Rainbow colour maps are dangerous.
- Introduce transitions where they don't exist.
- “Everyone” knows they can be misleading but the technique is so engrained.

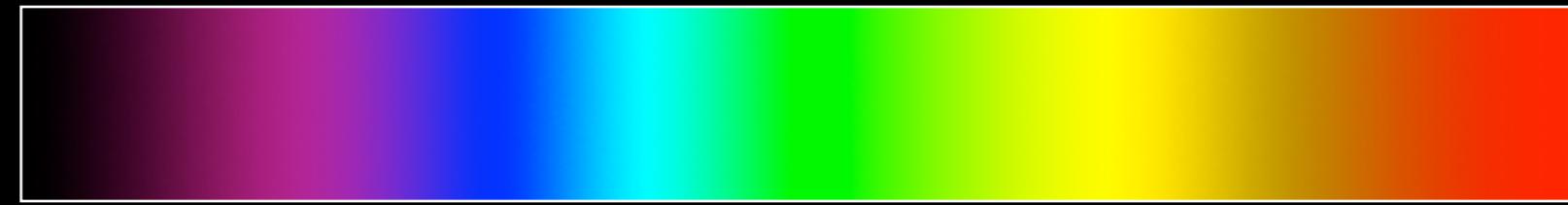
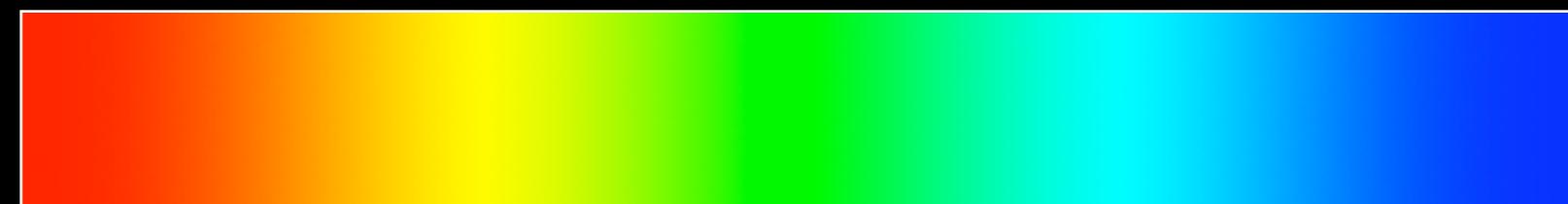
Linear greyscale ramp



Circular rainbow map

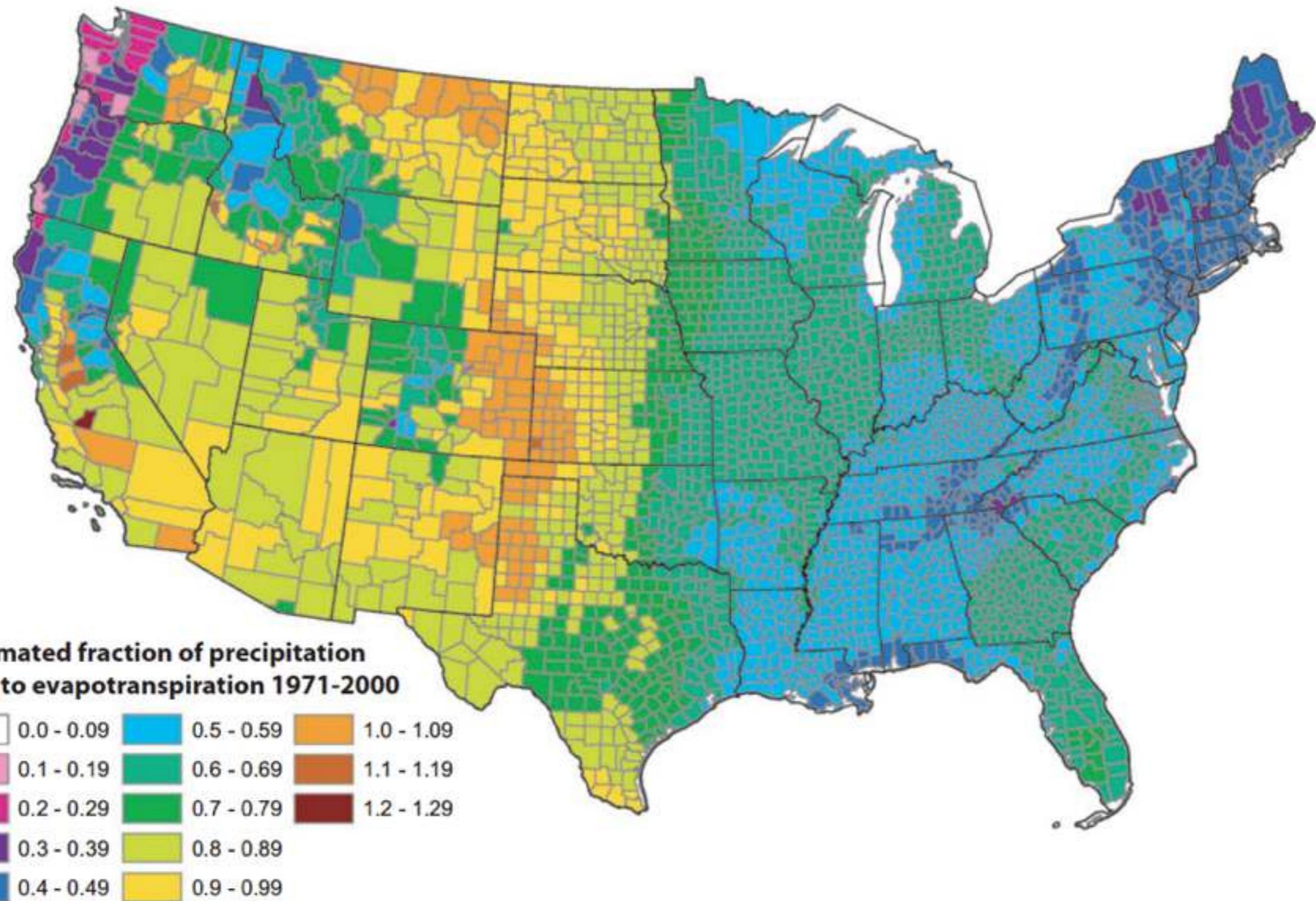


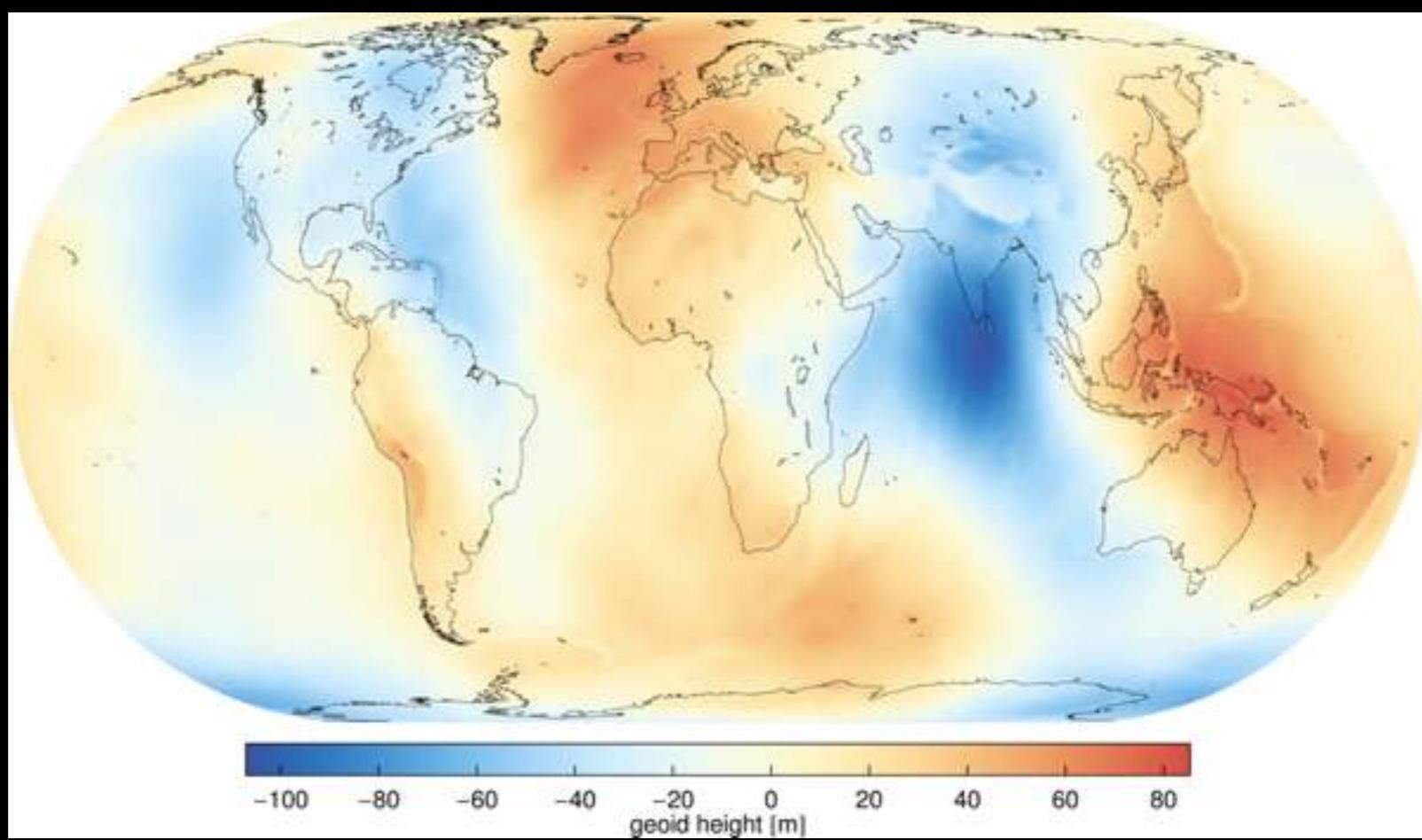
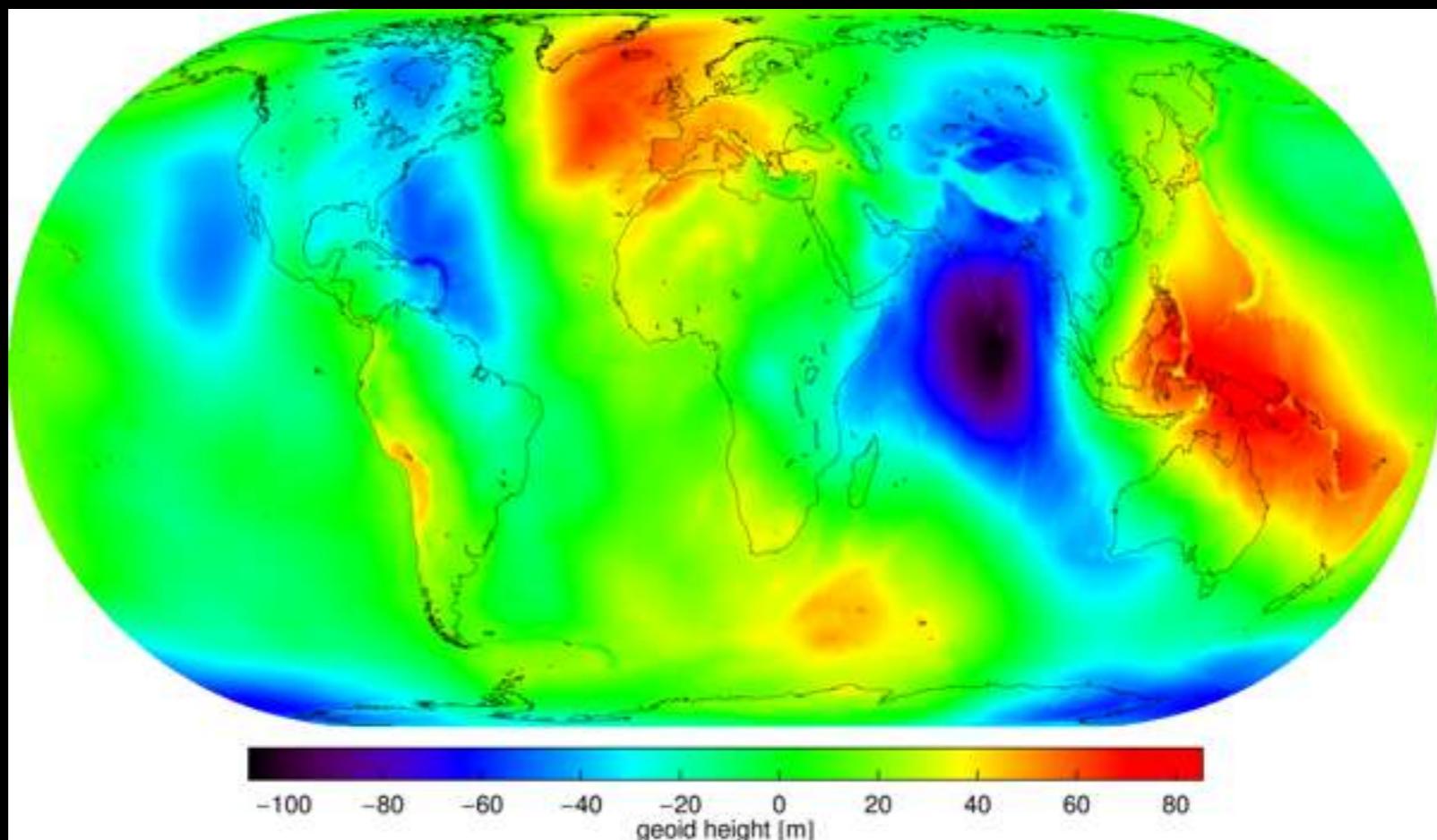
Rainbow map



- Colour is hard, need a knowledge of the human visual system.

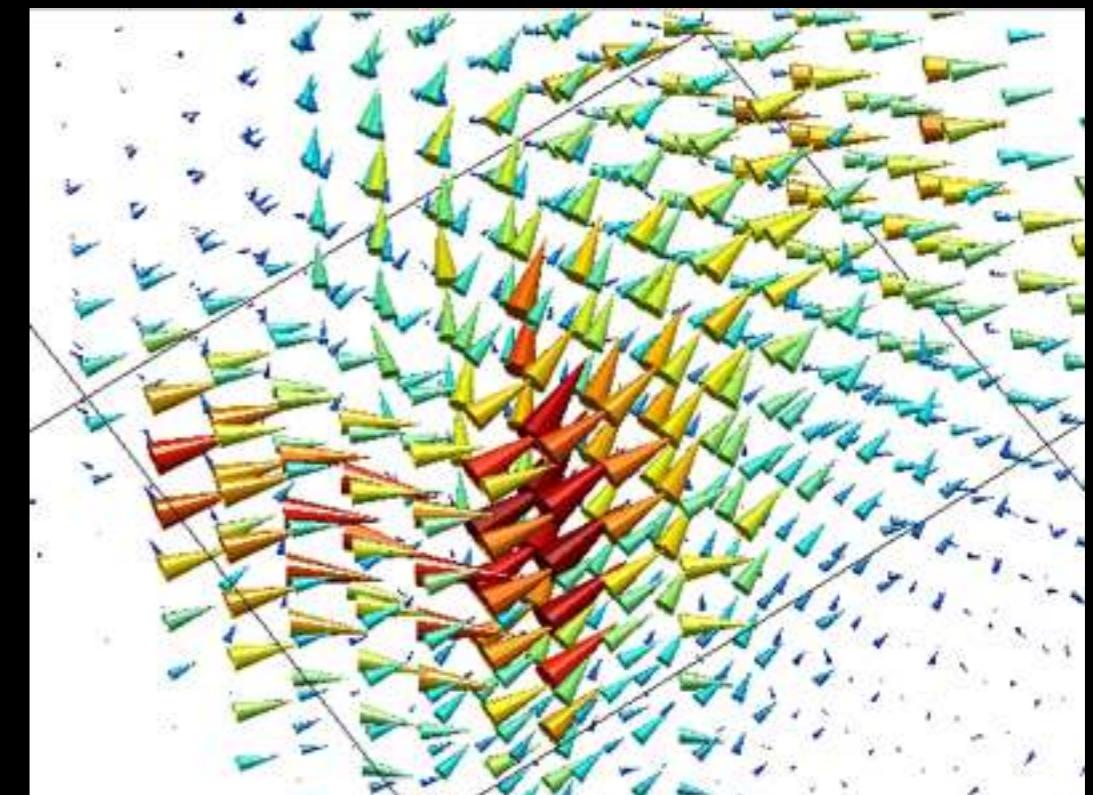
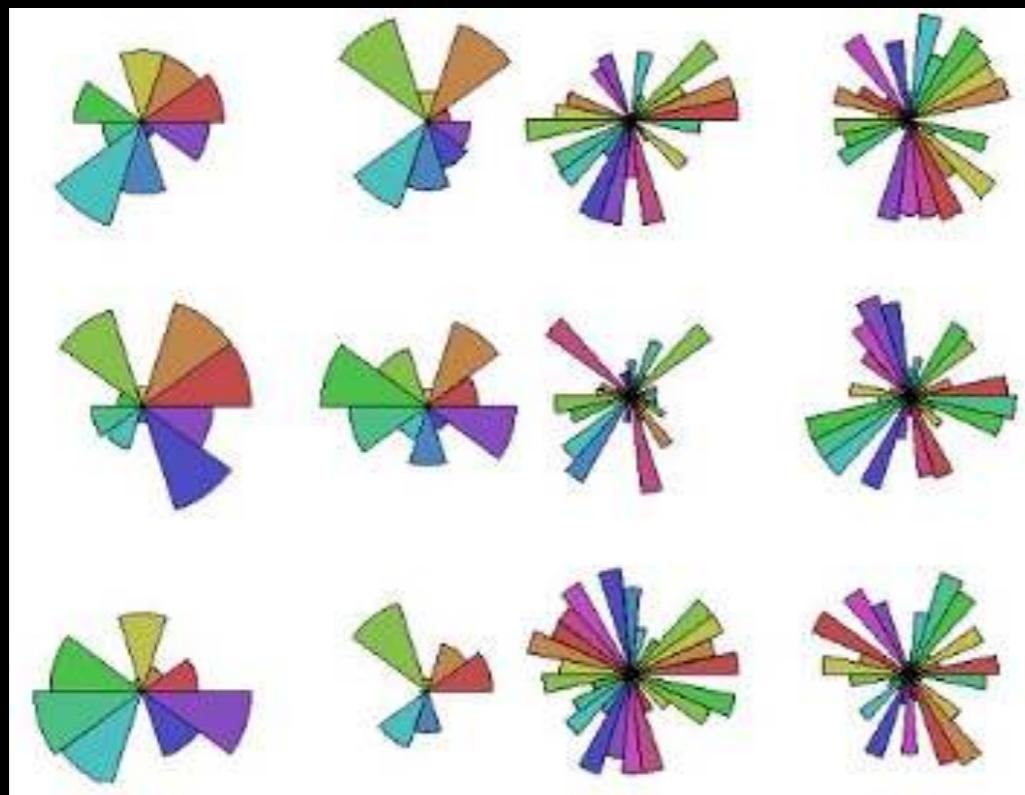
SANFORD AND SELNICK



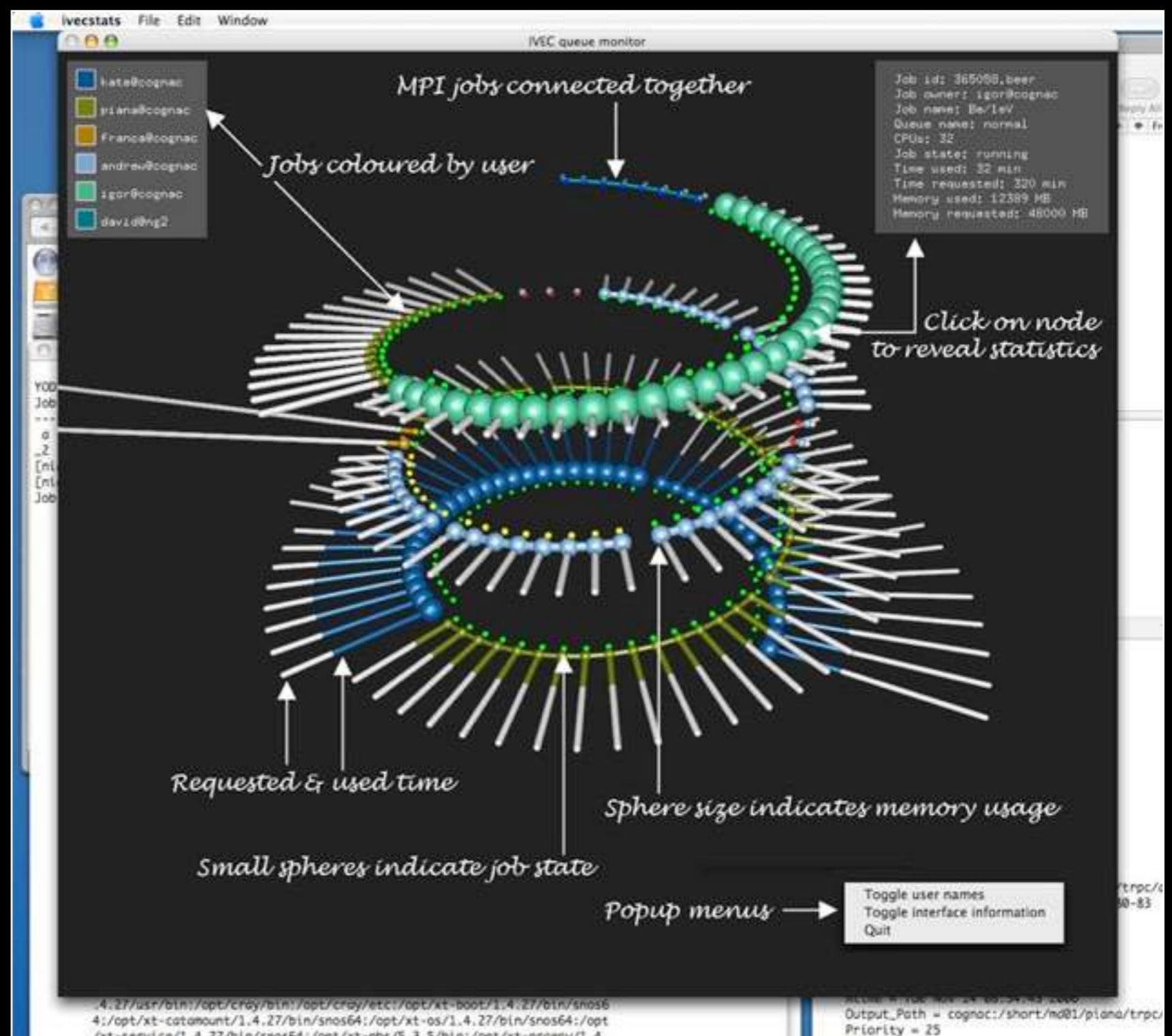


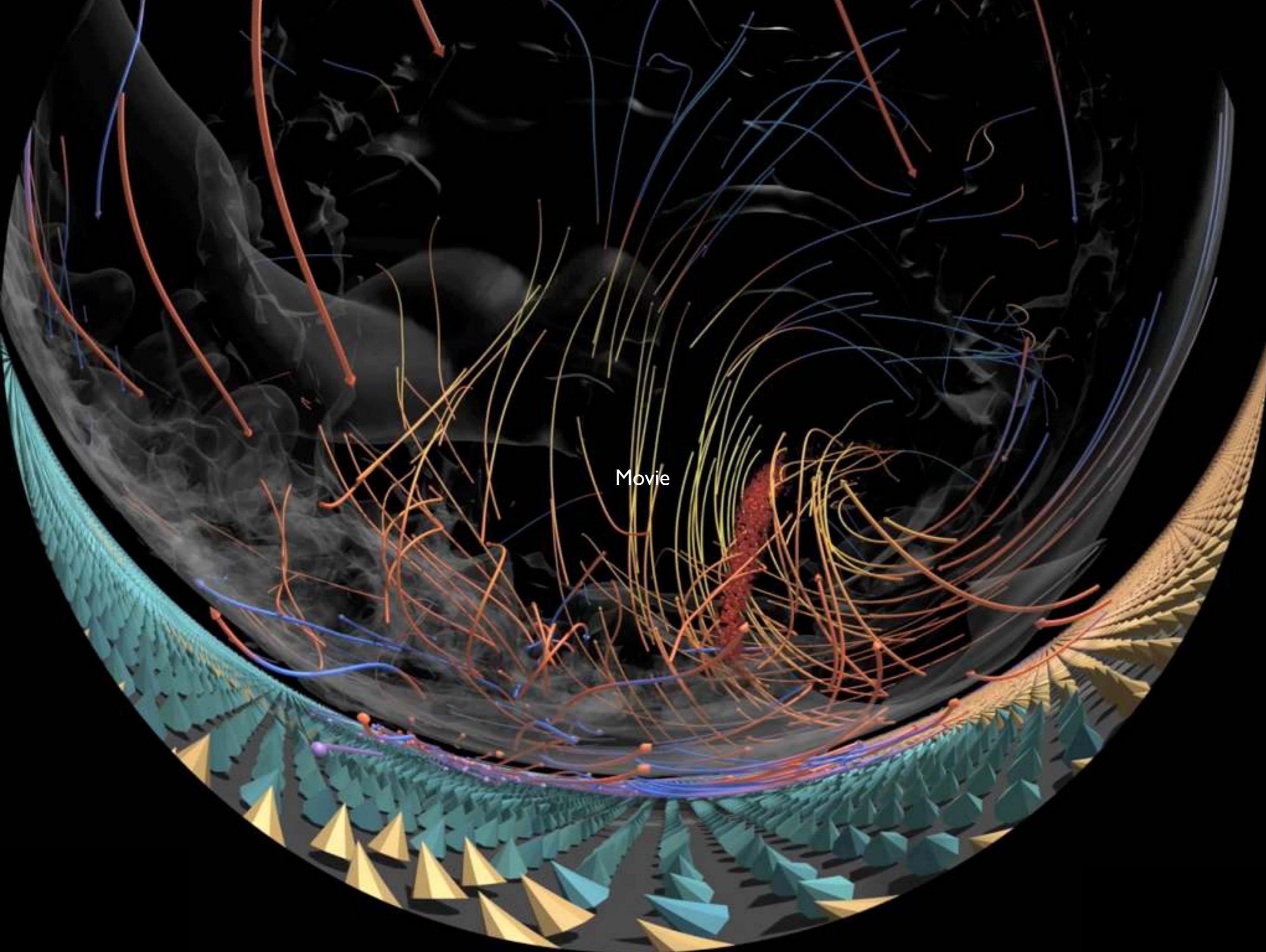
Techniques: Glyphs

- A large part of what occurs in visualisation is mapping variables to 2D and 3D geometry.
- Sometimes the mappings are obvious/intuitive, other times more freedom is possible.
- “Glyphs” is the term given to graphical elements whose characteristics reflect a number of variables. Direction, volume, strength ...



- Ideally the structure/form of the glyph has some intuitive meaning.
 - Common to map a quantity scalar onto the size of the glyph, obvious examples ...
 - Map direction onto arrows.
 - The strength of the direction (eg: velocity) onto length of arrow.
 - Scalars also mapped onto colour.

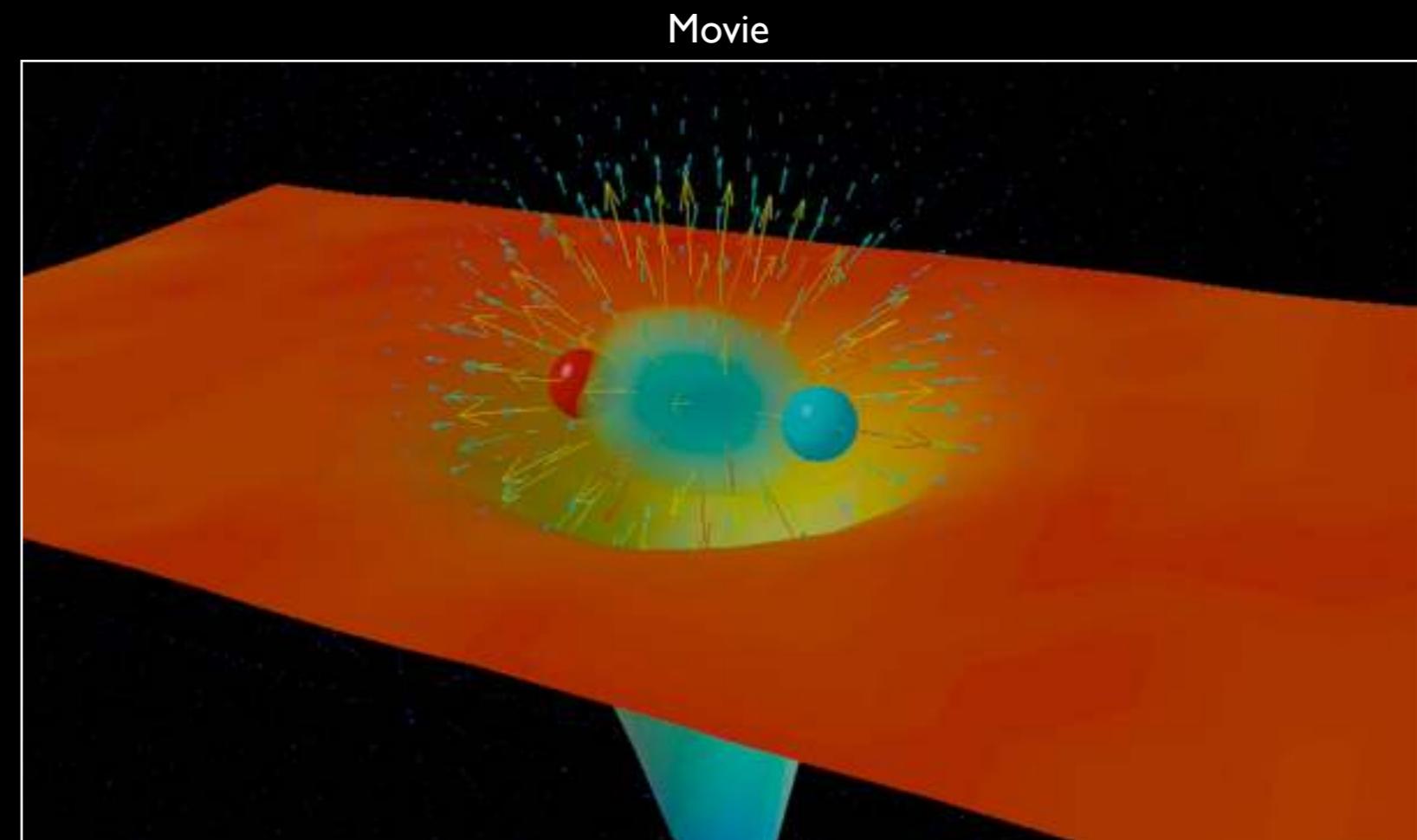
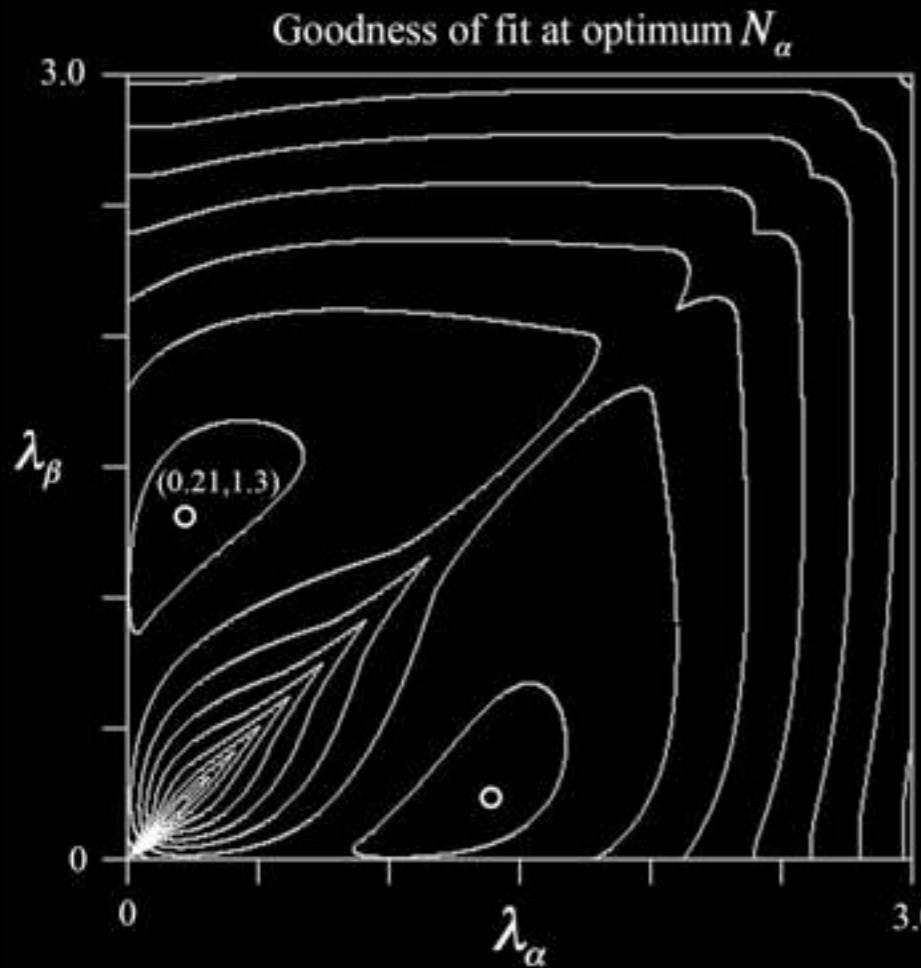




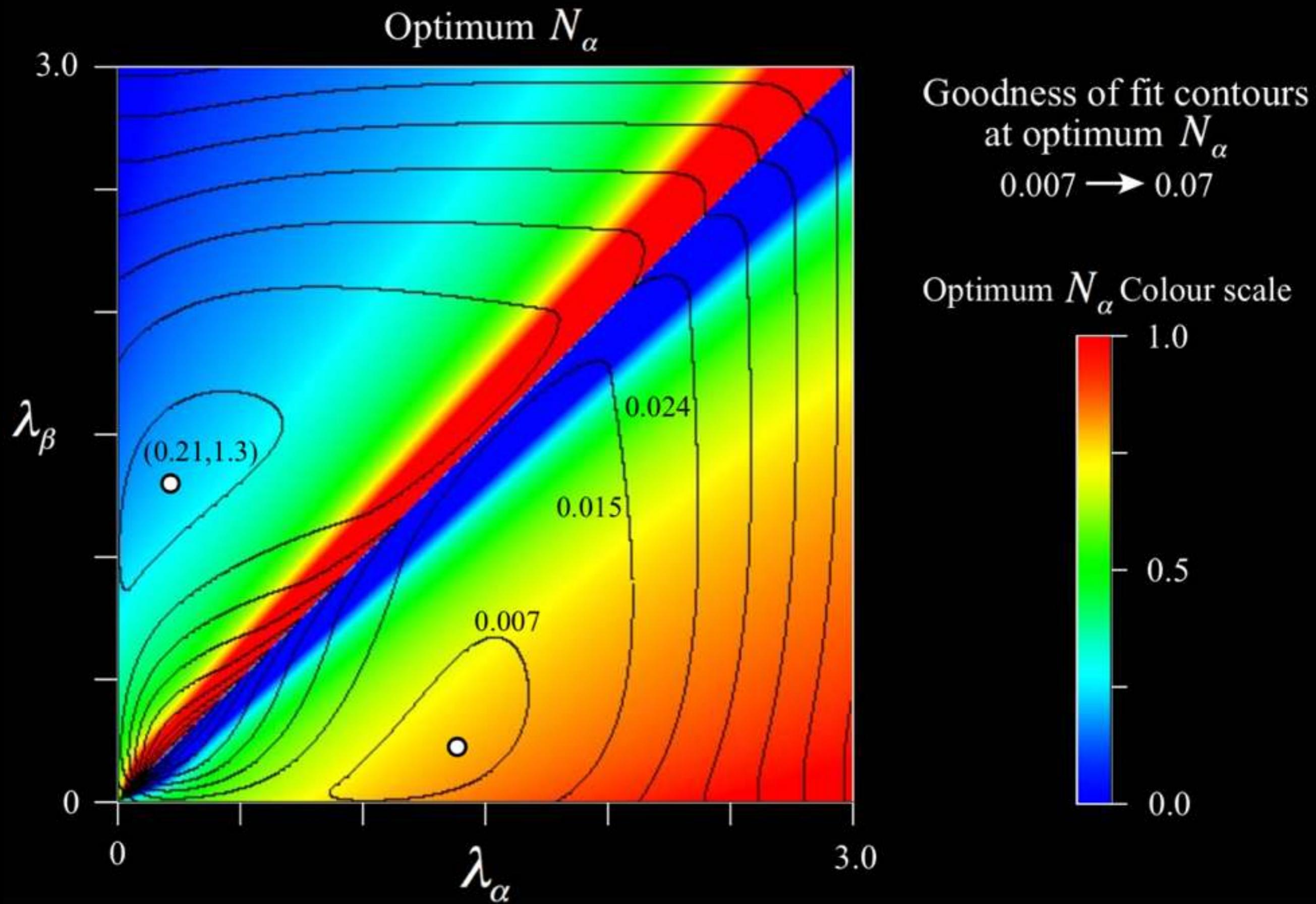
Movie

Techniques: Dimension reduction

- Distinguish between topological dimension and embedded dimension.
- For example air pressure data is a surface (2D) embedded in 3D space.
- Familiar with the idea of reducing the dimension of data.
Contour lines allow the height of a surface to be represented on a plane.
Colour can also be used to represent height: continuous contours.
- Isosurfaces reduce a volume (4D) to be represented in 3D.

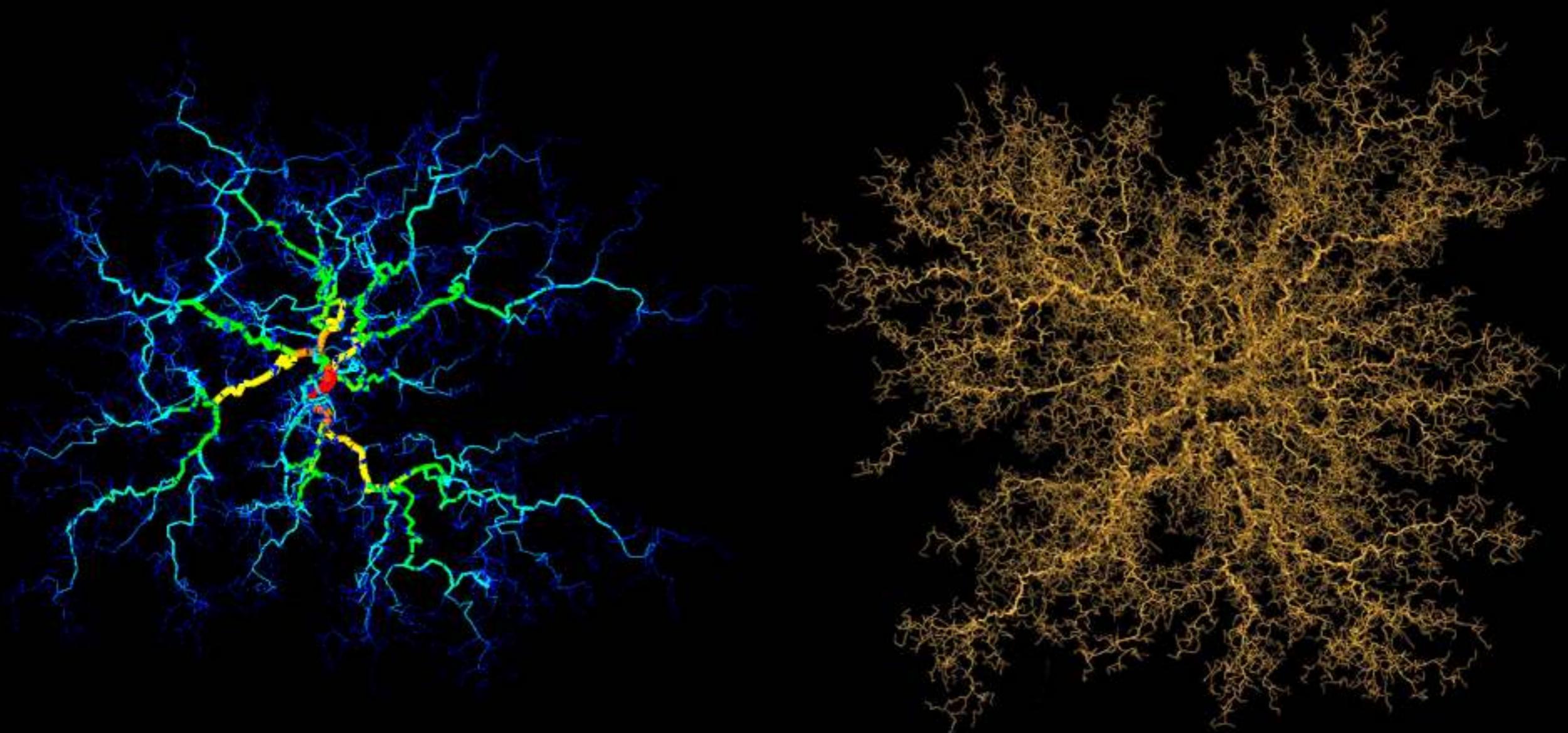


- Dimension reduction provides for increased variable representation.



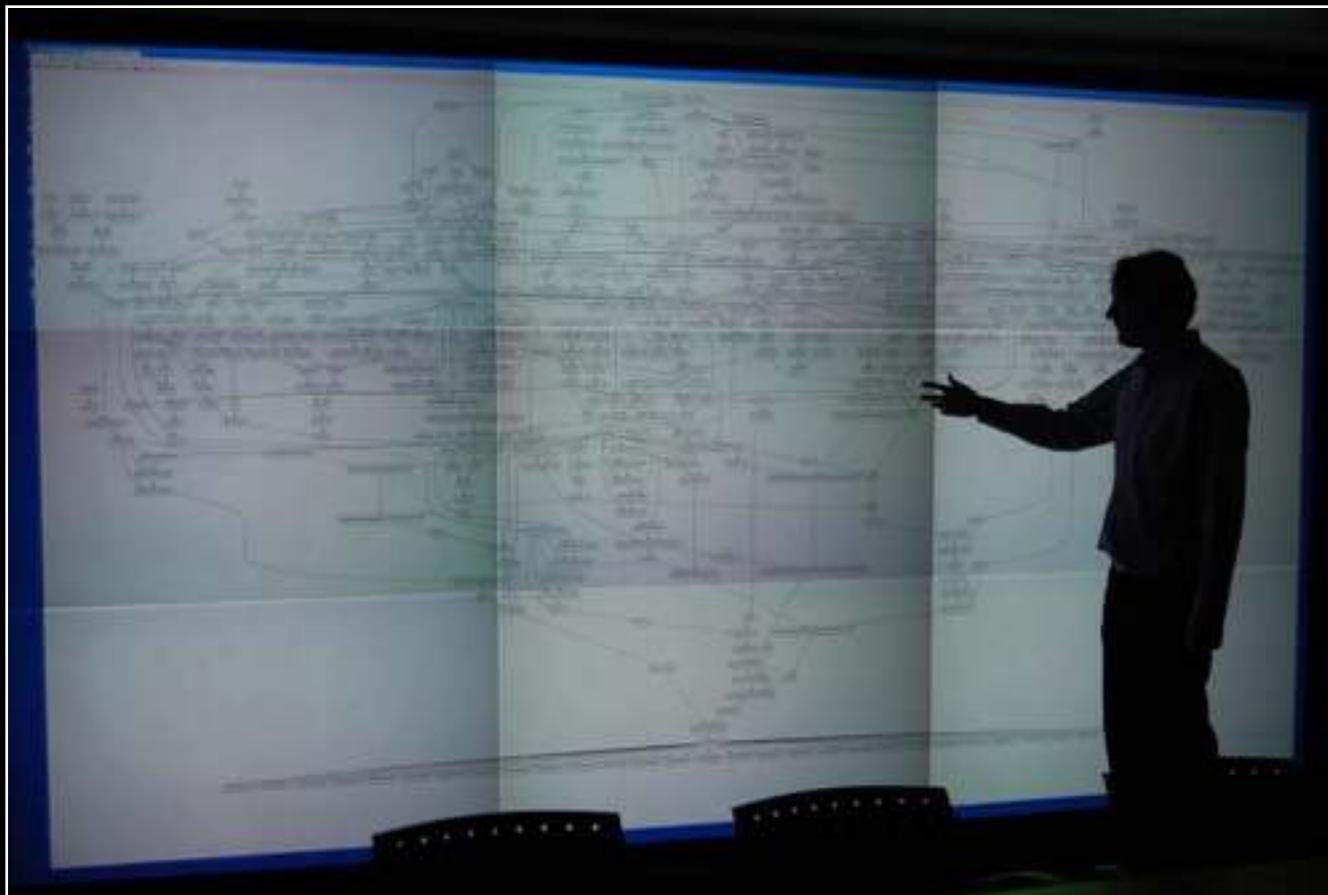
Techniques: rendered vs realtime

- Normally a matter of quality, visual impact.
- Less limited by rendering techniques or model size.



Hardware: resolution

- Often don't have enough pixels.
- HD resolution has about 2 million pixels, what happens if we have more than 2 million objects to represent?
- Constant zooming in and zooming out and one is trading off context for detail.



- A number of displays managed by iVEC
- Pawsey building: 4K x 2K stereoscopic enabled.
- ARRC building and UWA: 6K x 3K stereoscopic enabled.
- UWA: 4K x 3K.
- ECU: 6K x 2K.



UWA

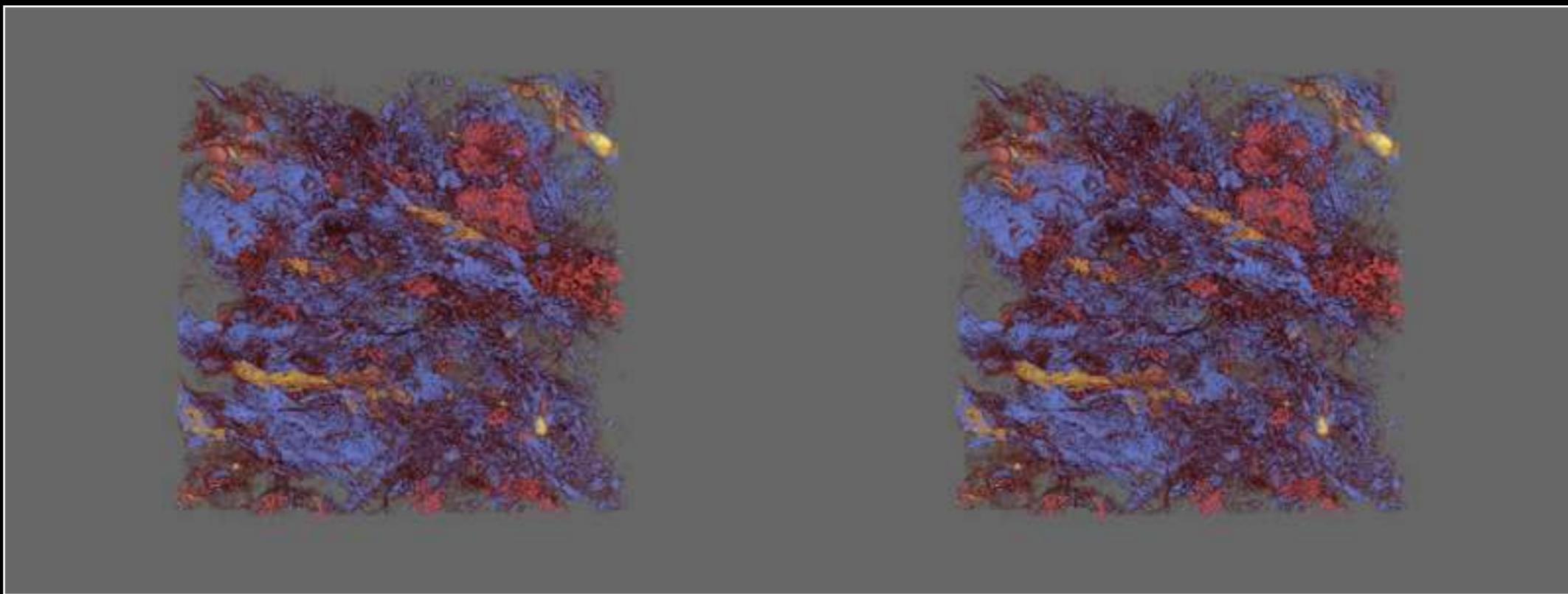


Pawsey building

Hardware: stereoscopy

- We perceive depth largely through stereopsis, having two eyes that get slightly different views of the world around us.
- Easy to imagine that for geometrically complicated relationships that depth perception could be valuable.
- Can obviously simulate those two views by computer rendering.
- The trick then is how to present them independently to each eye.
- Lots of options
 - anaglyph (red-blue) does so by encoding each eyes image by colour and the viewer wears matching colour glasses.
 - polaroid systems encode the left and right eye images by polarisation state of light.
 - active glasses encode the two images in time.
 - autostereoscopic = no glasses required
- In ALL cases there is only one thing going on ... a separate image needs to be presented to each eye. All the technology options are just a means to achieve that.

Computer generated



Left eye

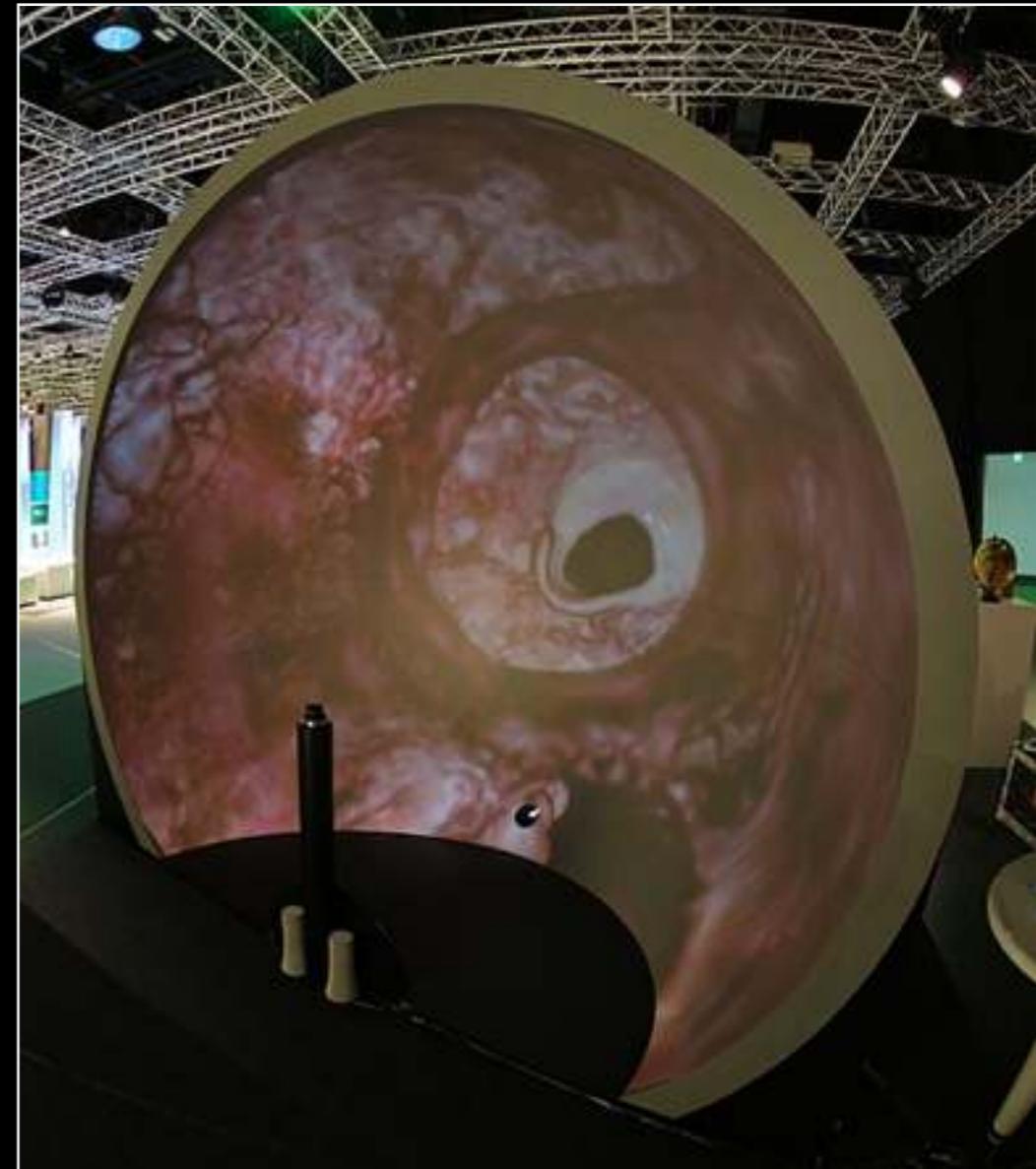
Right eye

Filmed



Hardware: immersion

- Immersion: the sense of “being there”.
- Main contributor is engagement of our peripheral vision.
- Human visual system has a almost 180 degree horizontal field of view and about 100 degree vertical field of view.
- Use perhaps 30 degrees when using a standard flat panel display.
- iDome is one way to engage the entire visual field of view.
- Value for data visualisation is when you are inside the data, the data becomes a virtual world.

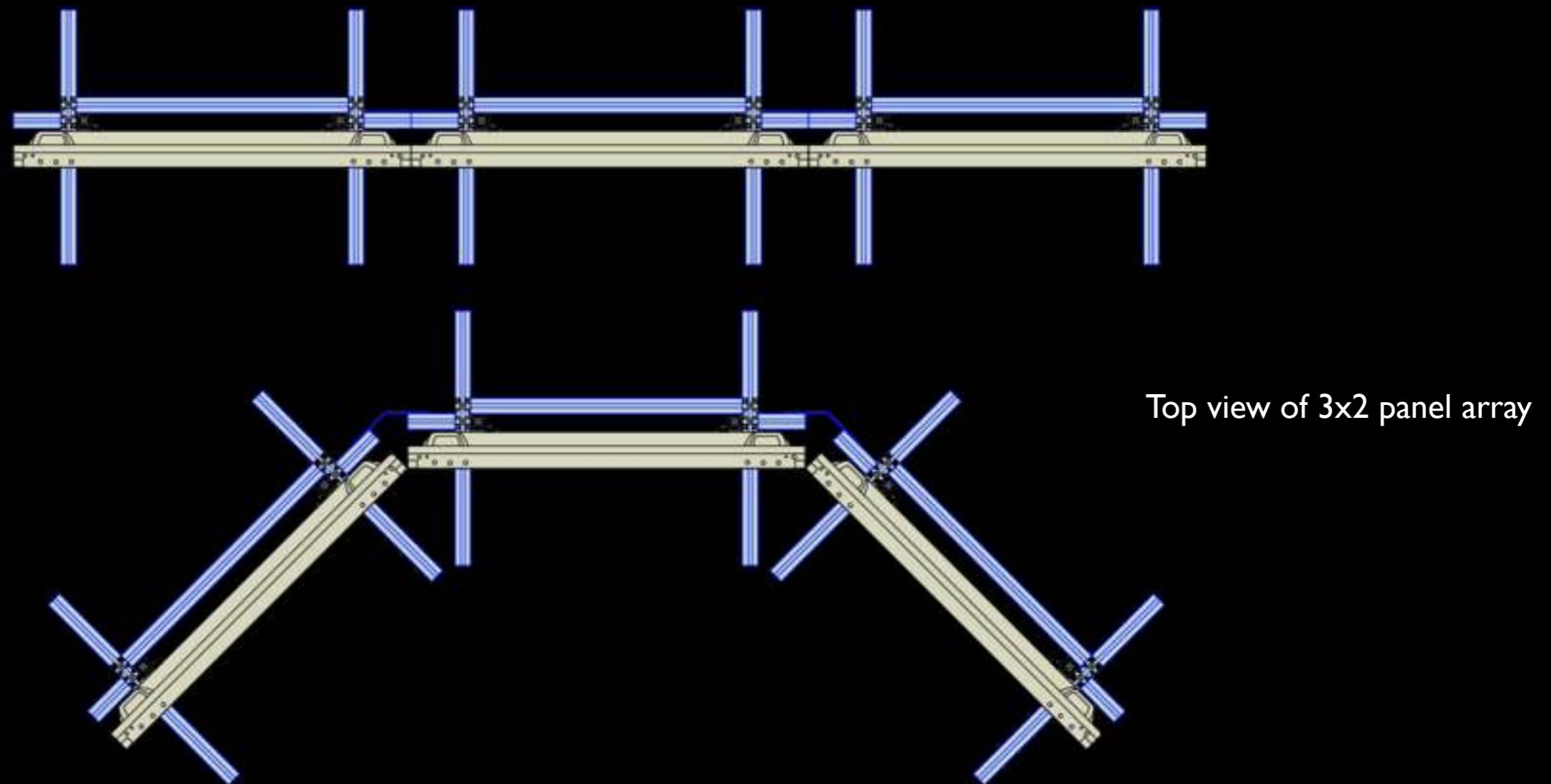


- Head mounted displays are another approach, but rarely engage more than about 100 degrees horizontally.
- Military / simulator HMDs can but they use multiple panels at a high price point.

Movie



- Tiled panels can engage a reasonable horizontal field of view if one can stand close enough.
- Helps if they are curved inwards.
- About to install the following at ECU.



Special topics: virtual environments

- Common to experience visualisations within virtual environments.
- In the context of commodity infrastructure referred to as “serious gaming”.



Movie



Rio Tinto ship loader



Special topics: sonification

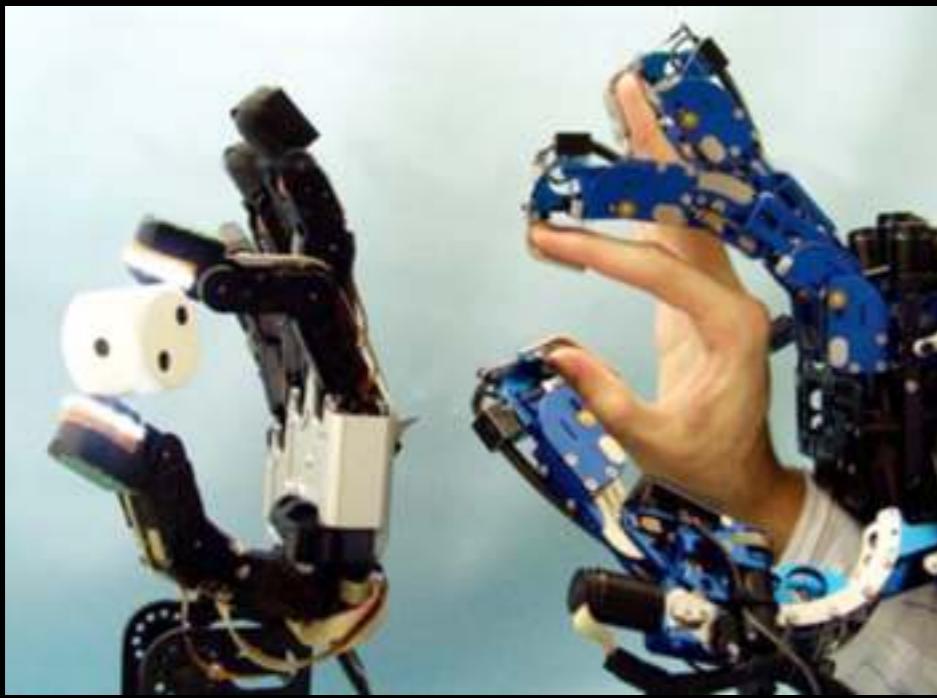
- Sonification is visualisation based upon audio, using our sense of hearing.
- Classic example are Geiger counter, hospital machine that goes “ping”.
- Often a difficult mapping between data and audio/music.
- Two most common approaches are to map some variable to the waveforms (eg: amplitude or frequency modulation) or to map to instruments (eg: midi).
- More common to use audio to compliment visuals.

Direct frequency modulation

Midi instrument, equal tempered scale

Special topics: haptics

- Haptics and force feedback uses the sense of touch to “feel” data or processes.
- Often just pitched as interface devices but can also allow one to “feel the data”.
- Commodity example is joystick vibration in car driving games.
- Used extensively in remote surgery - eg: force feedback scalpel.
- Range of devices/techniques: data gloves, mechanical arms, vibration, temperature ...



Special topics: 3D printing

- Tactile visualisation uses the sense of touch, used here in the context of touching physical models.
- Claim: Insight into the geometry / structure of an object can be assisted if we studying it in the same way as we explore objects in real life.
- 3D printing generally refers to additive processes where successive layers are laid down to form the model.
- Distinct from computer controlled milling or lathes (and others) where material is removed.
- People tend to imagine it is a recent technology, my first 3D prints were done in 1992.



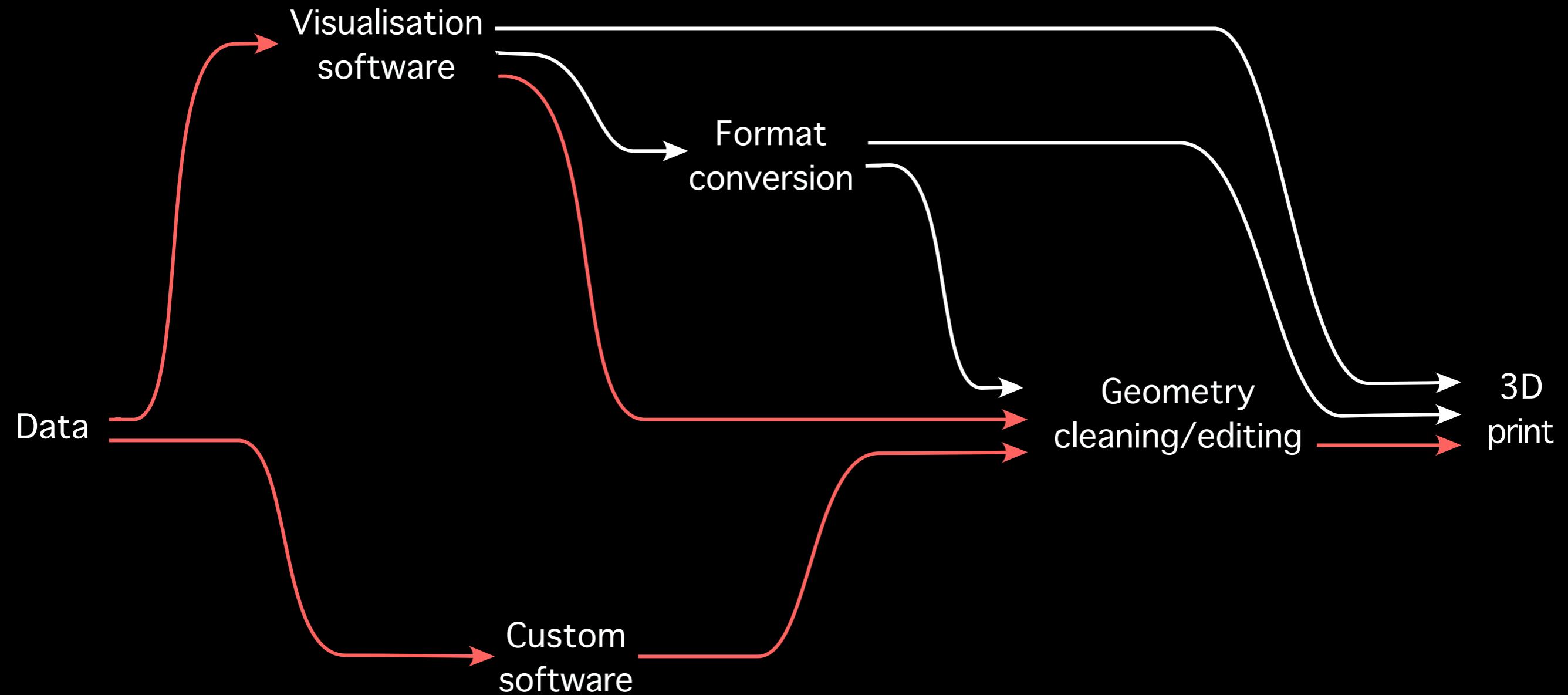
Visualisation in knot theory



Printing in metal



Visualisation in neuroscience



Red shows the most common workflows in my experience.

- Wide range of technologies
 - FDM: Fused deposition modelling
 - EBF: Electron beam freeform fabrication
 - DMLS: Direct metal laser sintering
 - EBM: Electron Beam melting
 - SLM: Selective laser melting
 - SHS: Selective heat sintering
 - SLS: Selective laser sintering
 - PP: Plaster-based 3D printing
 - LOM: Laminated object manufacturing
 - SLA: Stereolithography
 - DLP: Digital light processing
- The key questions for data visualisation are the limitations of a particular technology
 - Ability to create convoluted / concave structures
 - Colour reproduction
 - The finest structures / details that can be represented
- Lots of low cost solution now on the market but they can be limiting.

- Two most useful machines are:
 - ZCorp colour printers
 - ObJet from StrataSys
- ZCorp solved overhanging problem by using powder rather than liquid. Injet printer, prints coloured glue instead of ink onto a rising bed of powder rather than paper.
 - First good colour printer
 - Sandstone like material
 - Finest structures limited
- ObJet lays down one of N materials, photopolymer layers are cured by UV light. One layer may be a water soluble material for creating support layers.
 - Monochrome (until recently)
 - High structural strength plastic
 - Range of materials

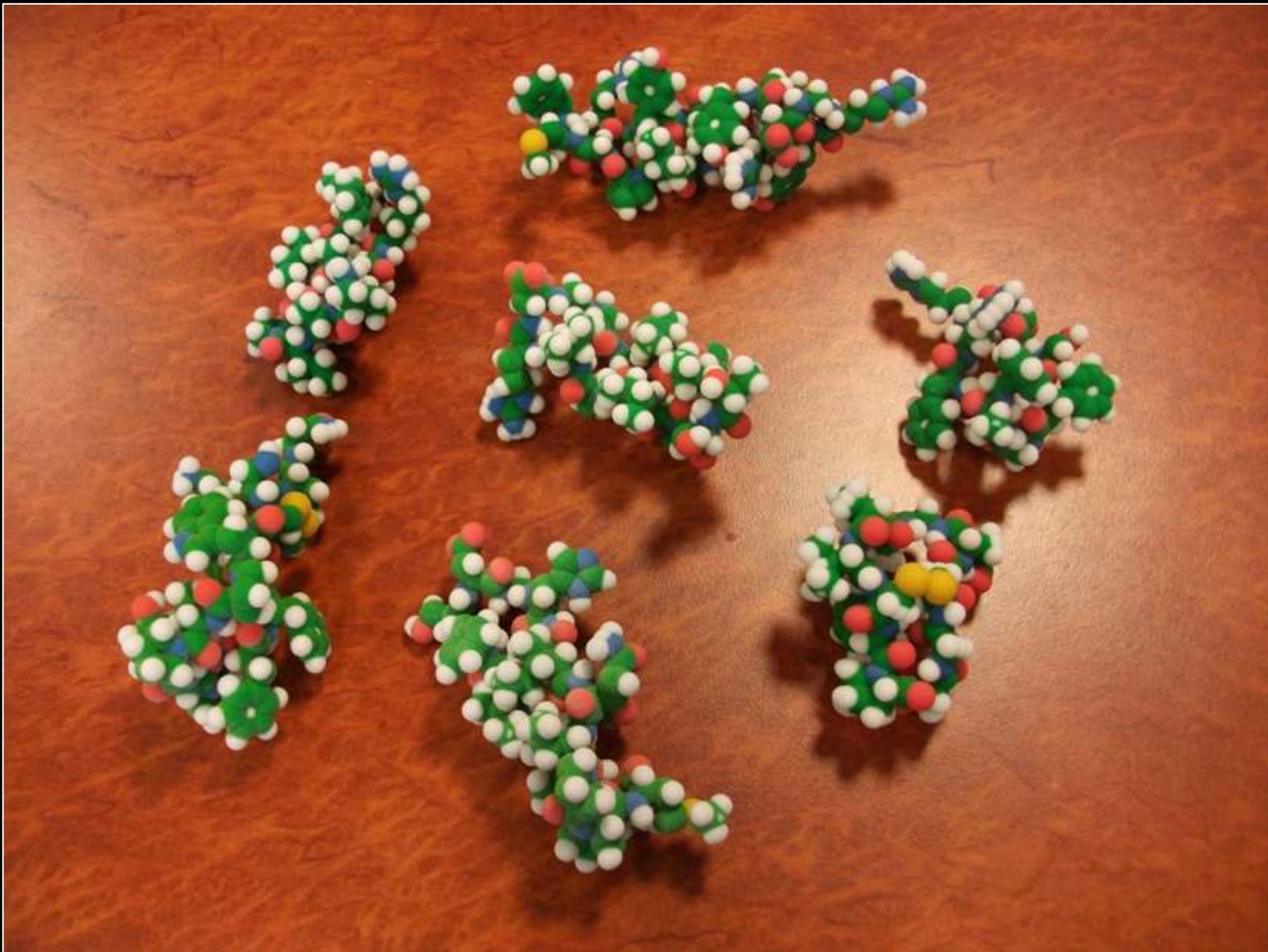


- Examples in geoscience



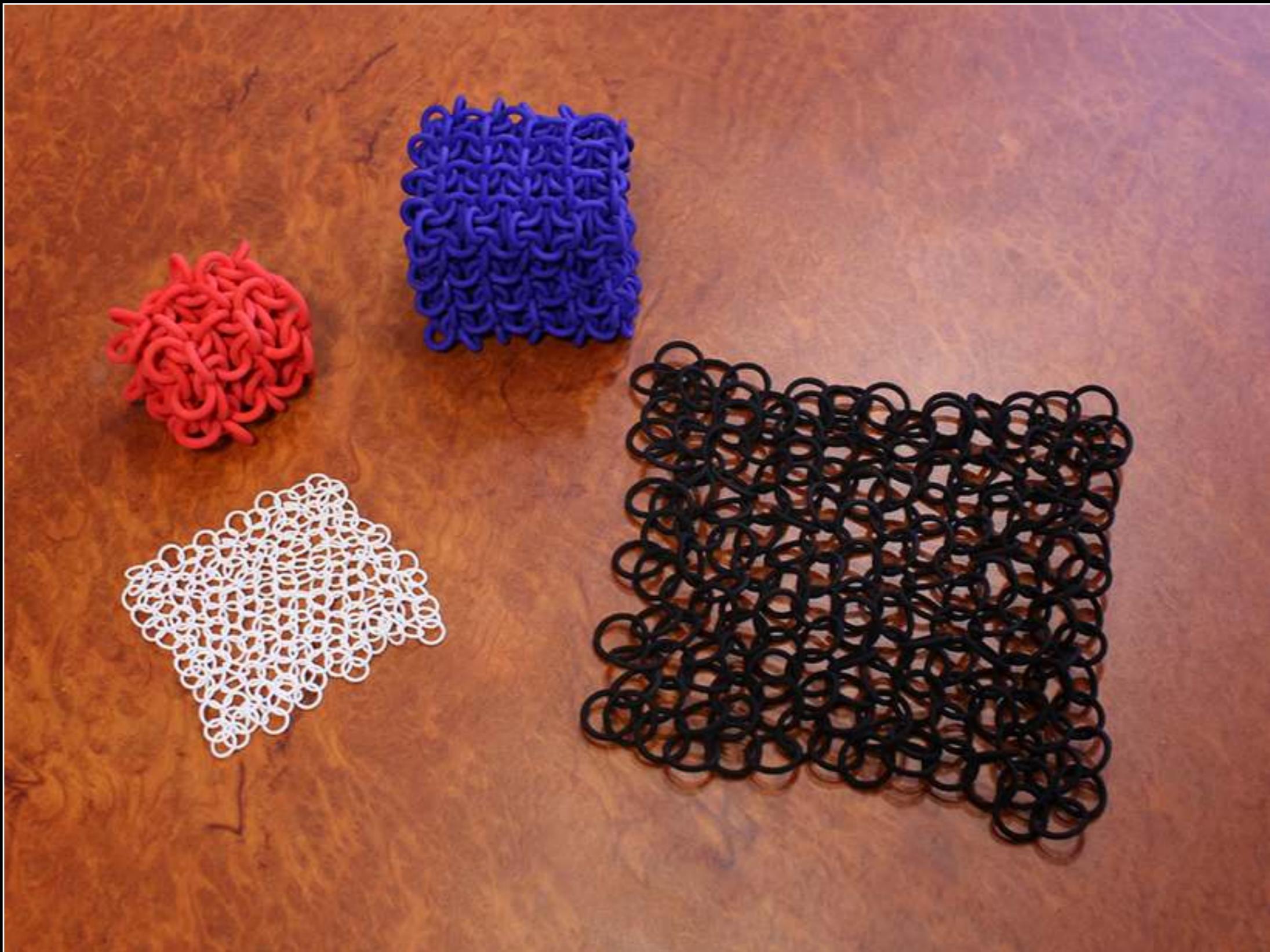
Fossils (Geology)

- Examples in chemistry



Series of peptides (Chemistry UWA)

- Examples in mathematics



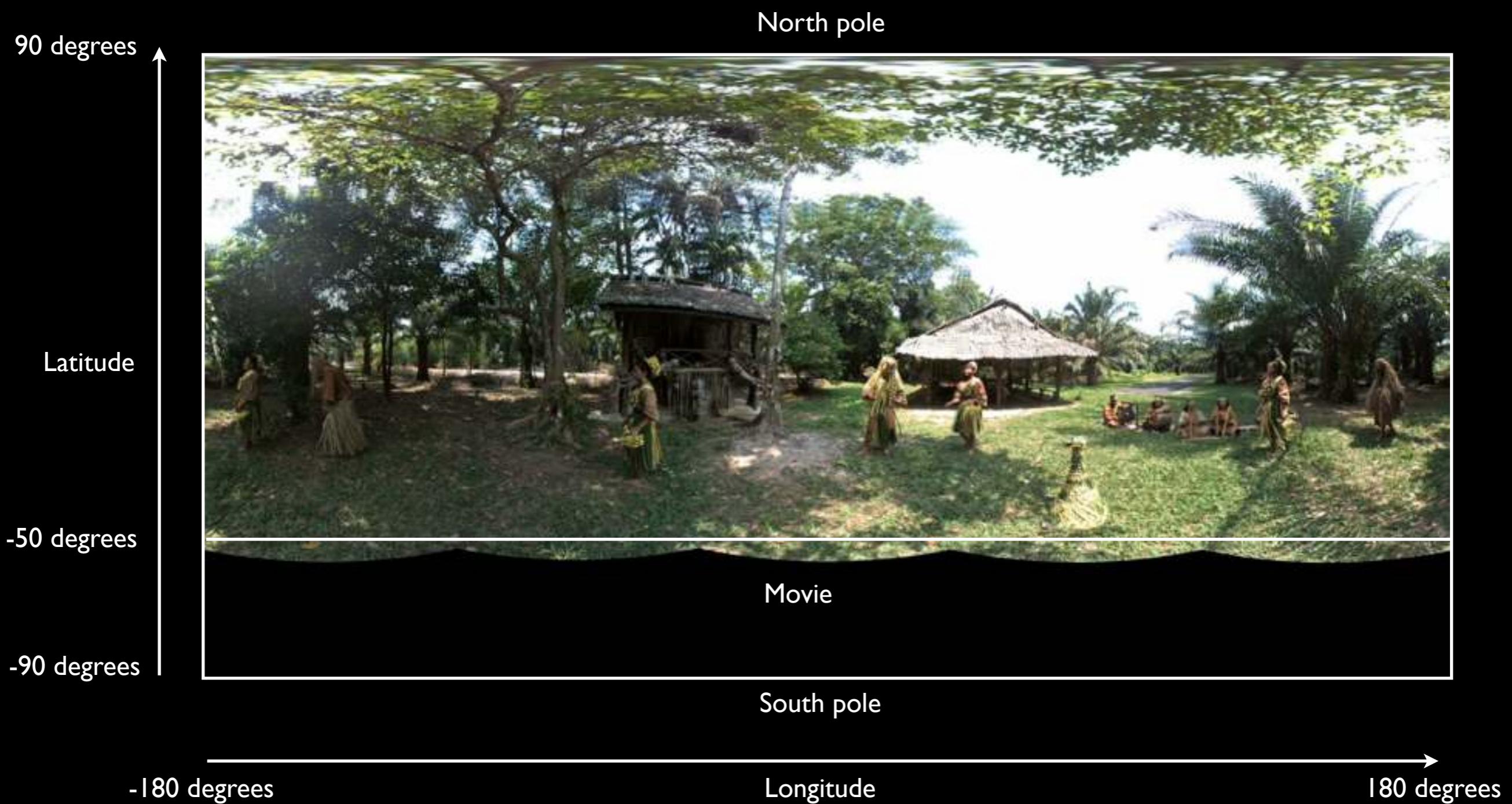
2D and 3D chainmail

Special topics: 360 video

- Largely for projects in cultural heritage.
- Example: Mah Meri, West Malaysia remote tribe.
- Have a healing ceremony involving masks and dance ritual.
- Ceremony occurs around the patient, goal is to capture that perspective, the view from “being there”

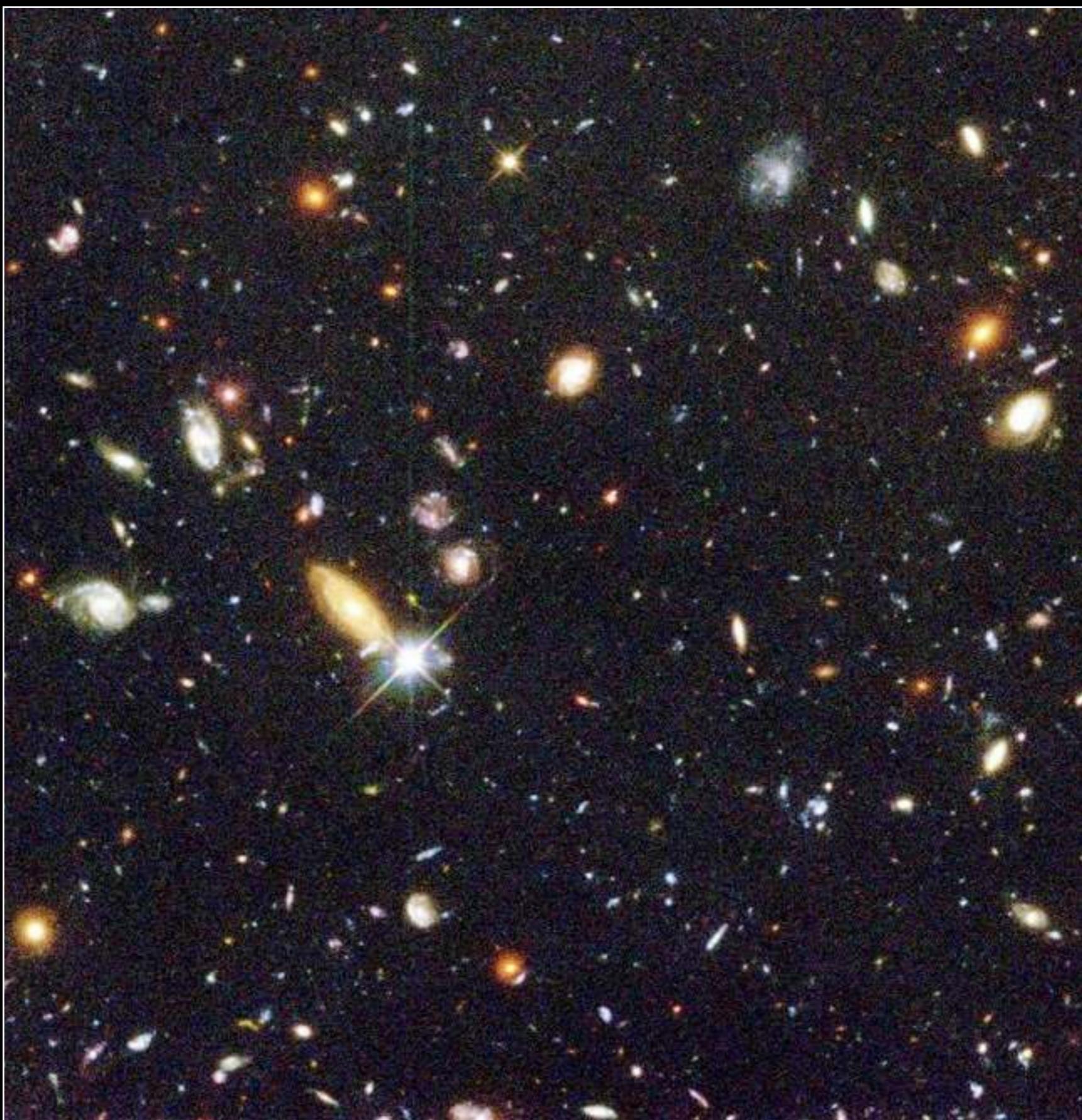


- Spherical panorama, projection onto a sphere unwrapped to form a flat plane.
- 360 video camera captures everything except the lower 40 degrees.



Special topics: gigapixel imaging

- Aim is to capture the context as well as the detail in a single image.
- Result in richer research assets than separate distant and closeup images.
- In the context of remote locations access may be problematic/expensive, goal is to capture as high a value recording as possible.
- For destructive processes one only gets one chance, again, record at as high a resolution possible to maximise future research outcomes.
- One cannot buy a camera with an arbitrarily high resolution sensor, the solution is to tile multiple images together.



Hubble deep field
340 image composite

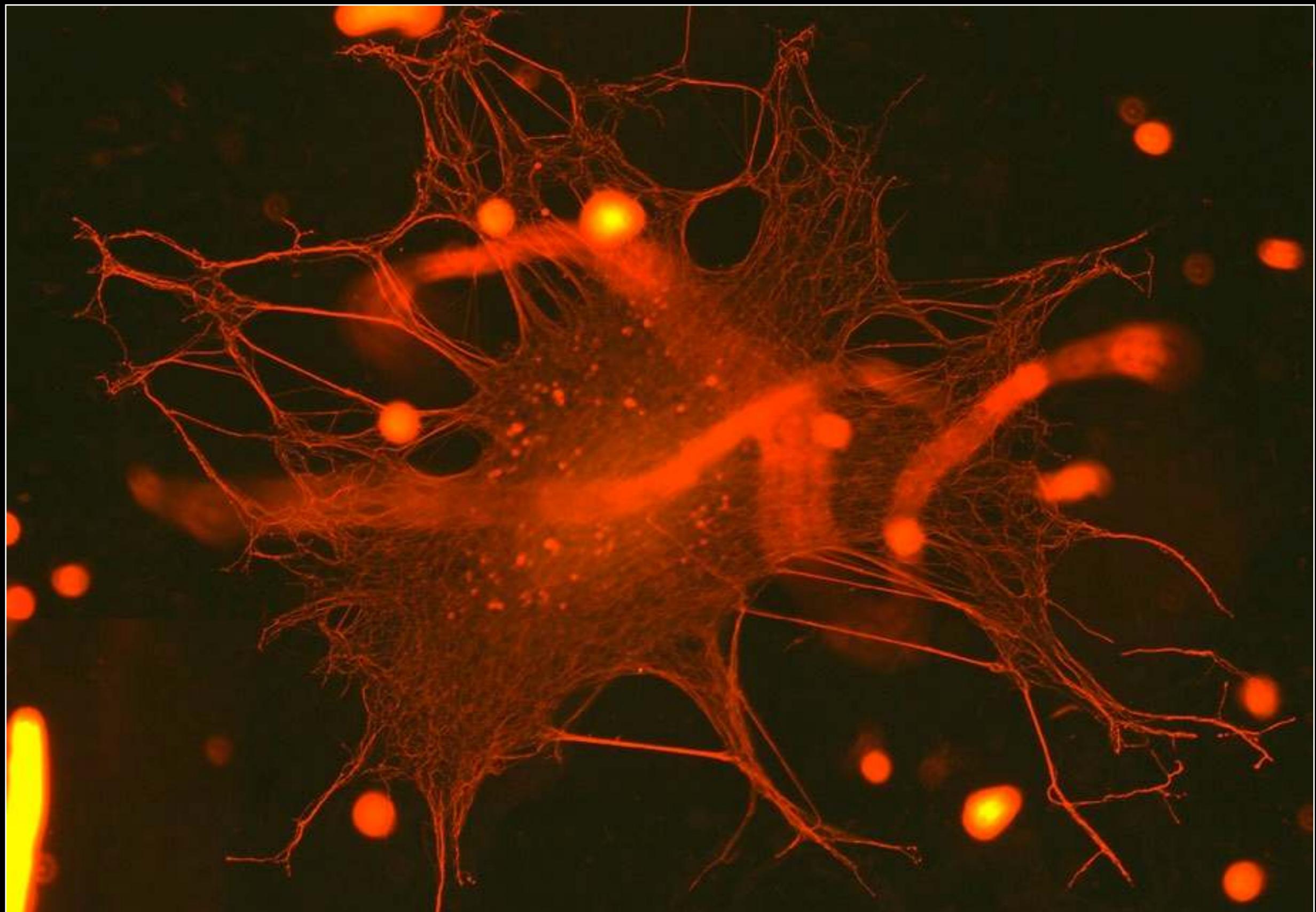


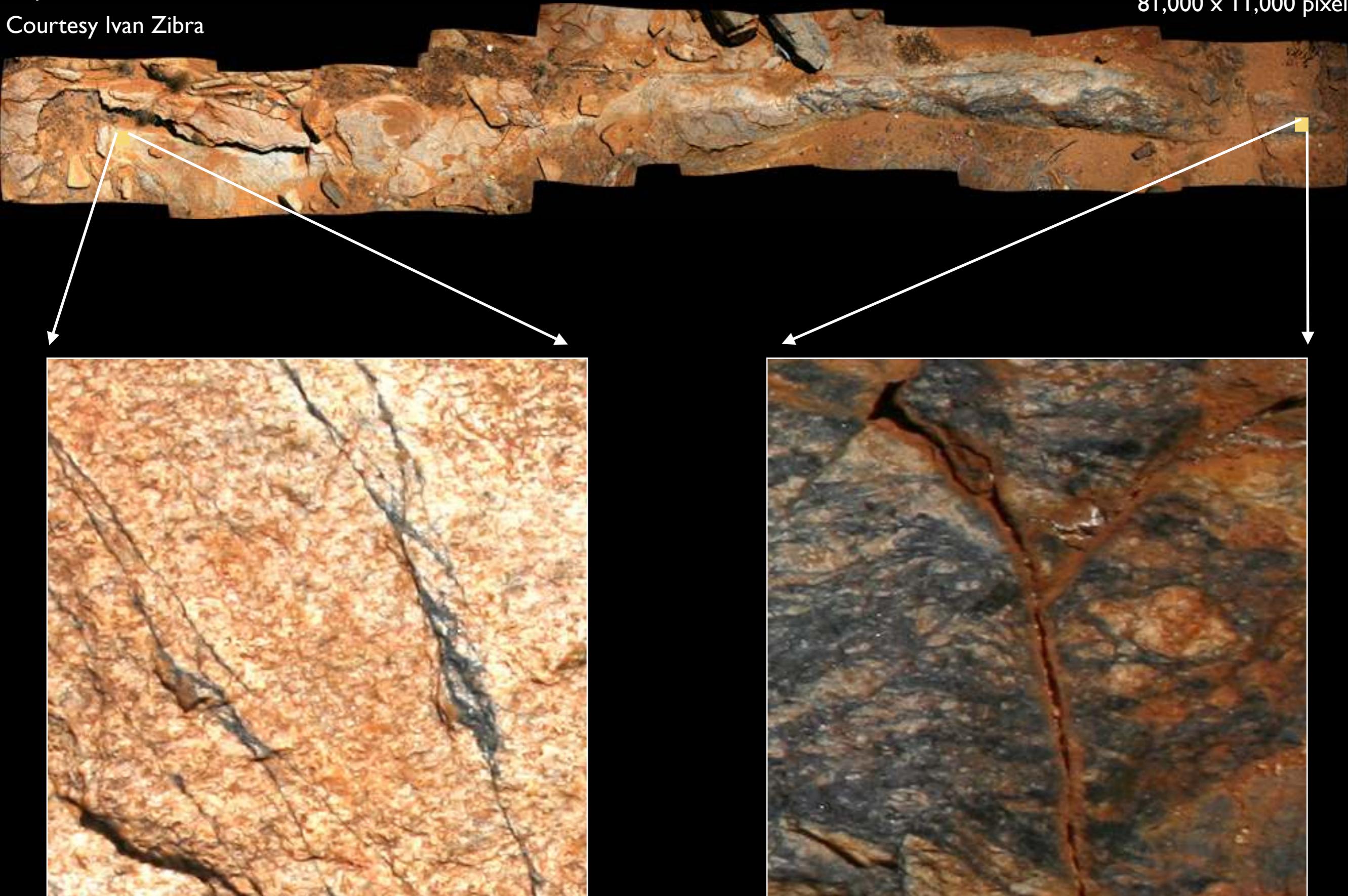
Image courtesy CMCA, UWA

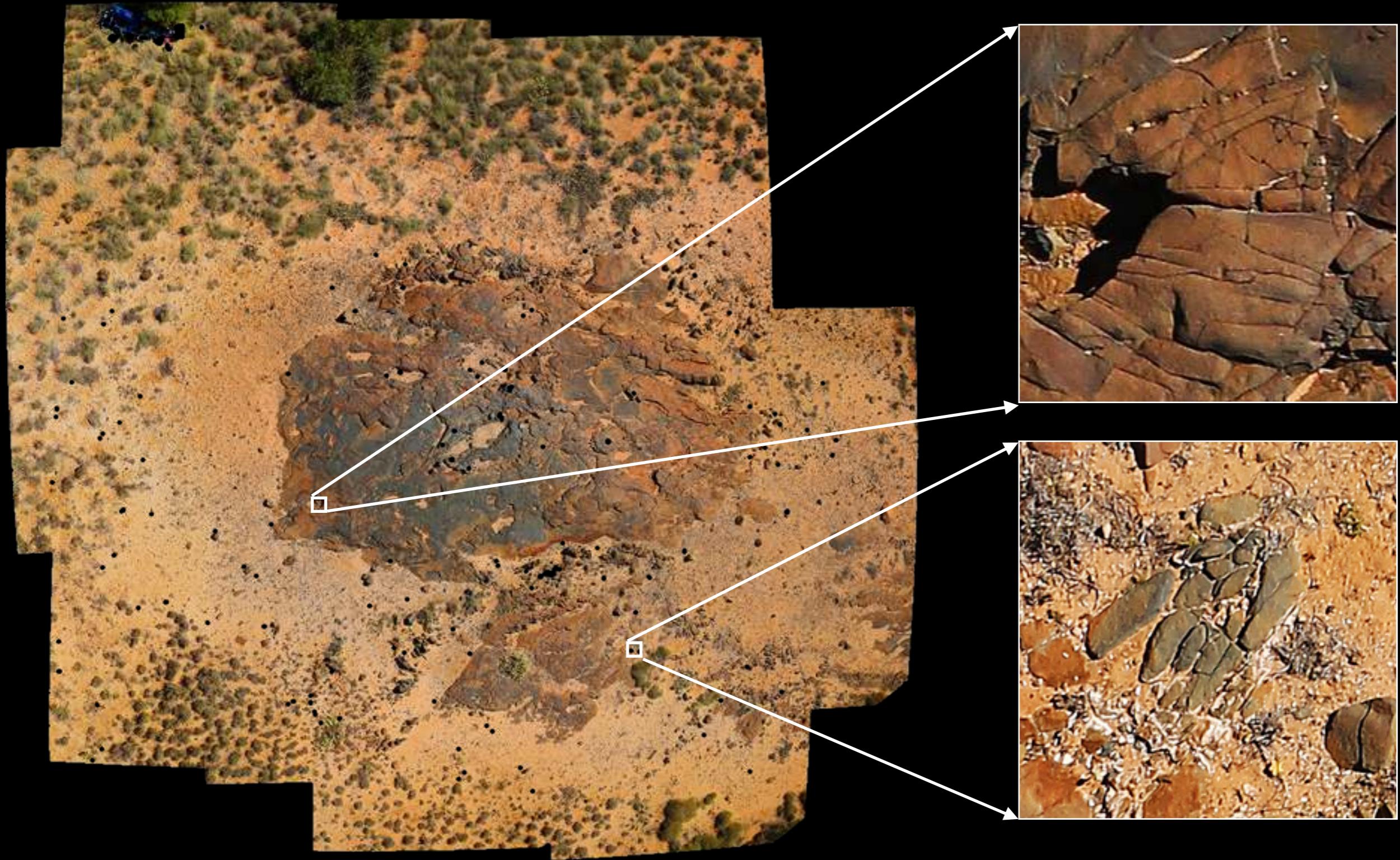
31,000 × 26,000 pixels

Department of Mines and Petroleum

Courtesy Ivan Zibra

81,000 x 11,000 pixels

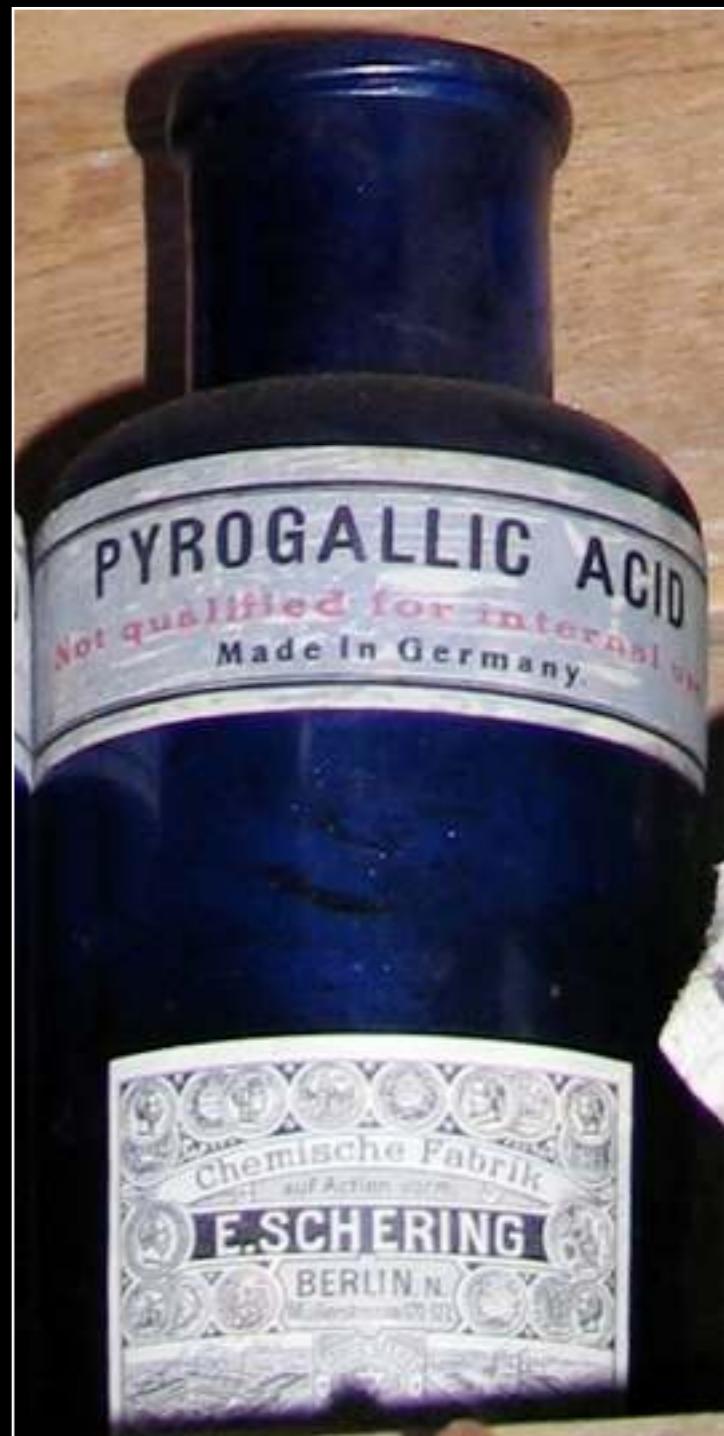




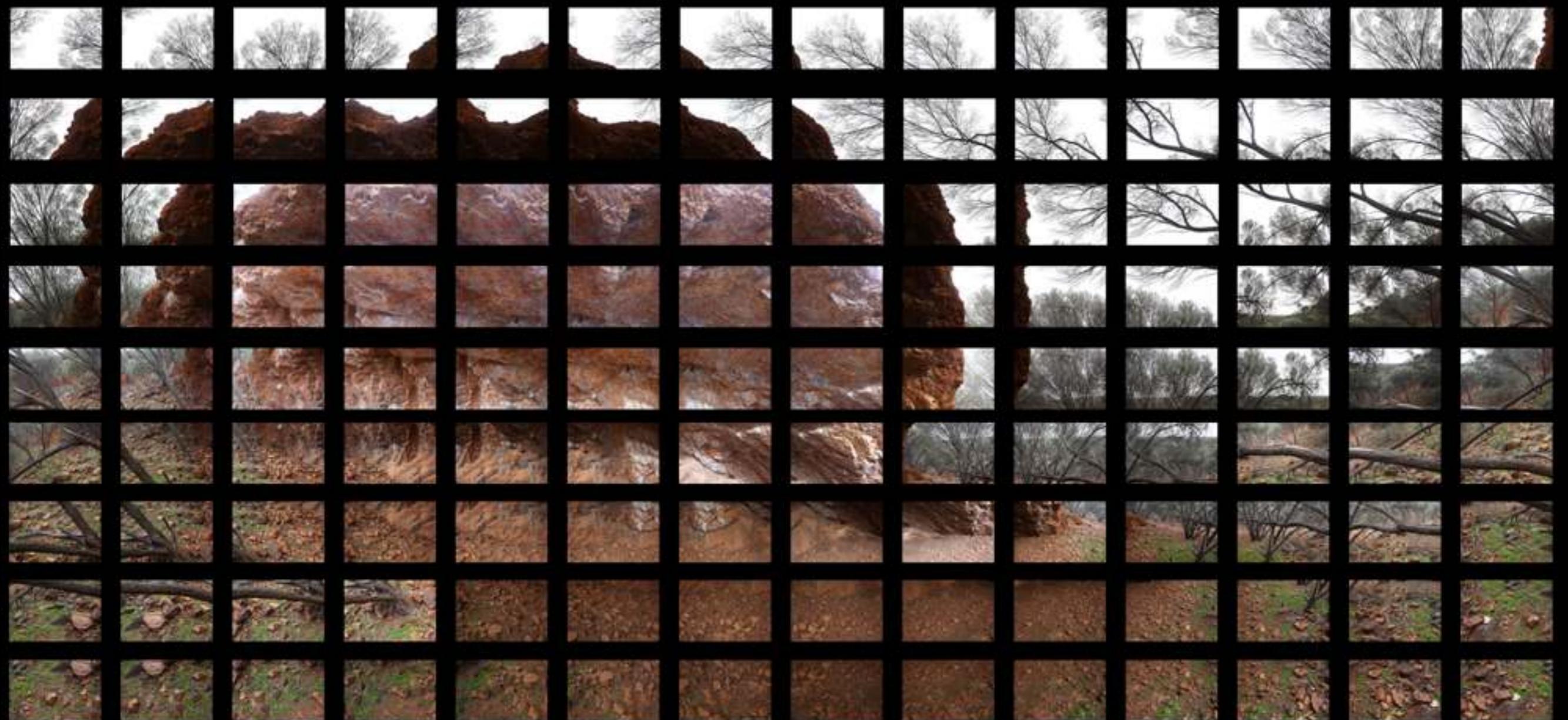


Wanmanna, Archaeology, UWA

40,000 by 20,000 pixels



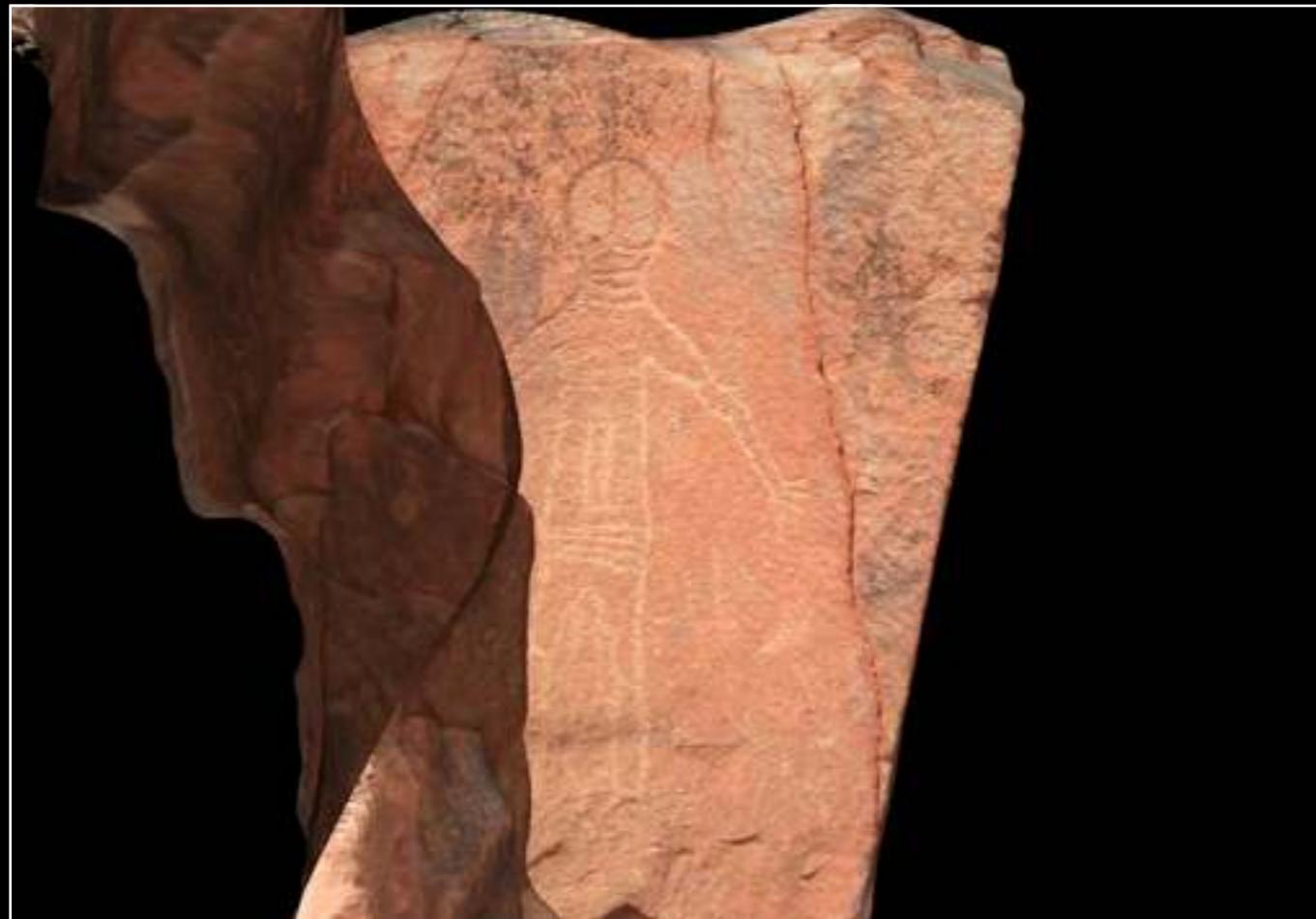
Hurley's darkroom, Mawson's hut (Antarctica)
Courtesy Peter Morse



A photograph of a large, rounded rock formation with distinct horizontal sedimentary layers. A small, brown lizard is visible on the upper left side of the rock. The ground in front is covered with reddish-brown rock fragments and sparse green grass. Bare trees are in the background.

Movie

Special topics: multispectral imaging

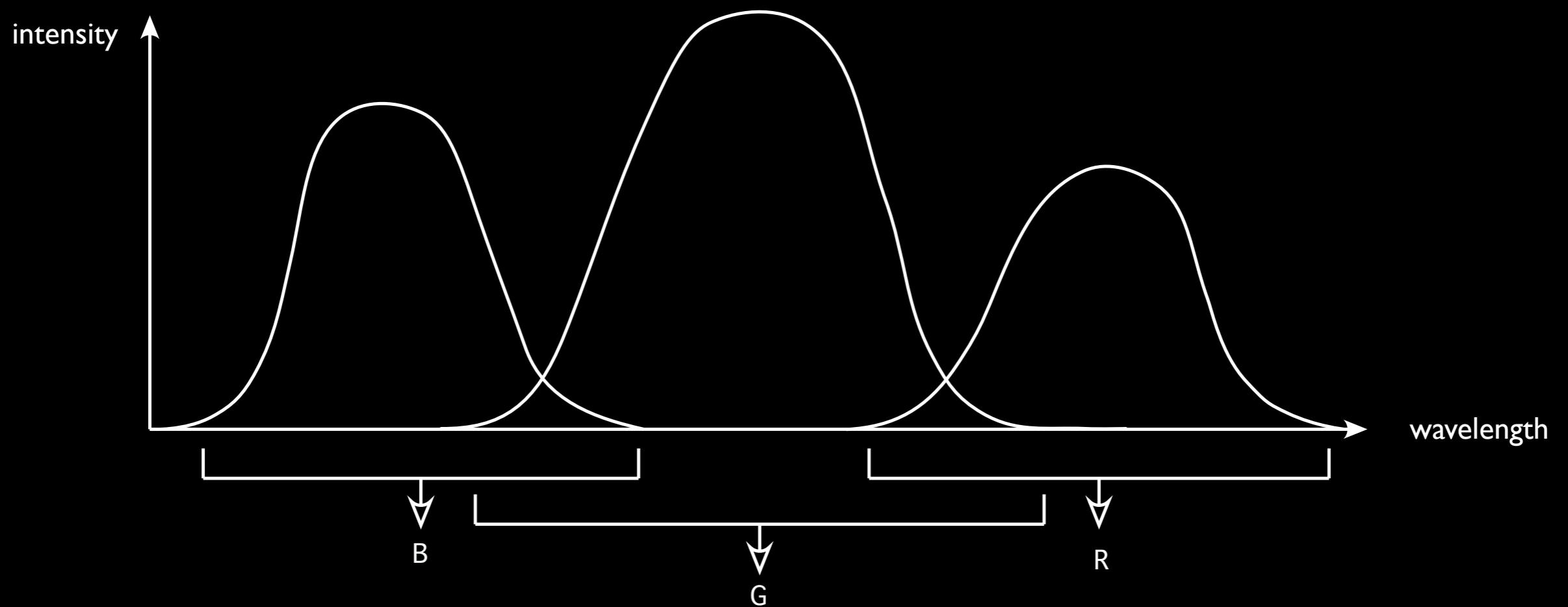


Rock art is often very obvious and interesting



Other times less so

- A normal photograph is throwing away a huge amount of information.
- The energy across a range of wavelengths is being (weighted summed) into just 3 numbers, single R,G,B values.
- Can imagine materials that reflect strongly in different wavelengths but appear to be the same colour.

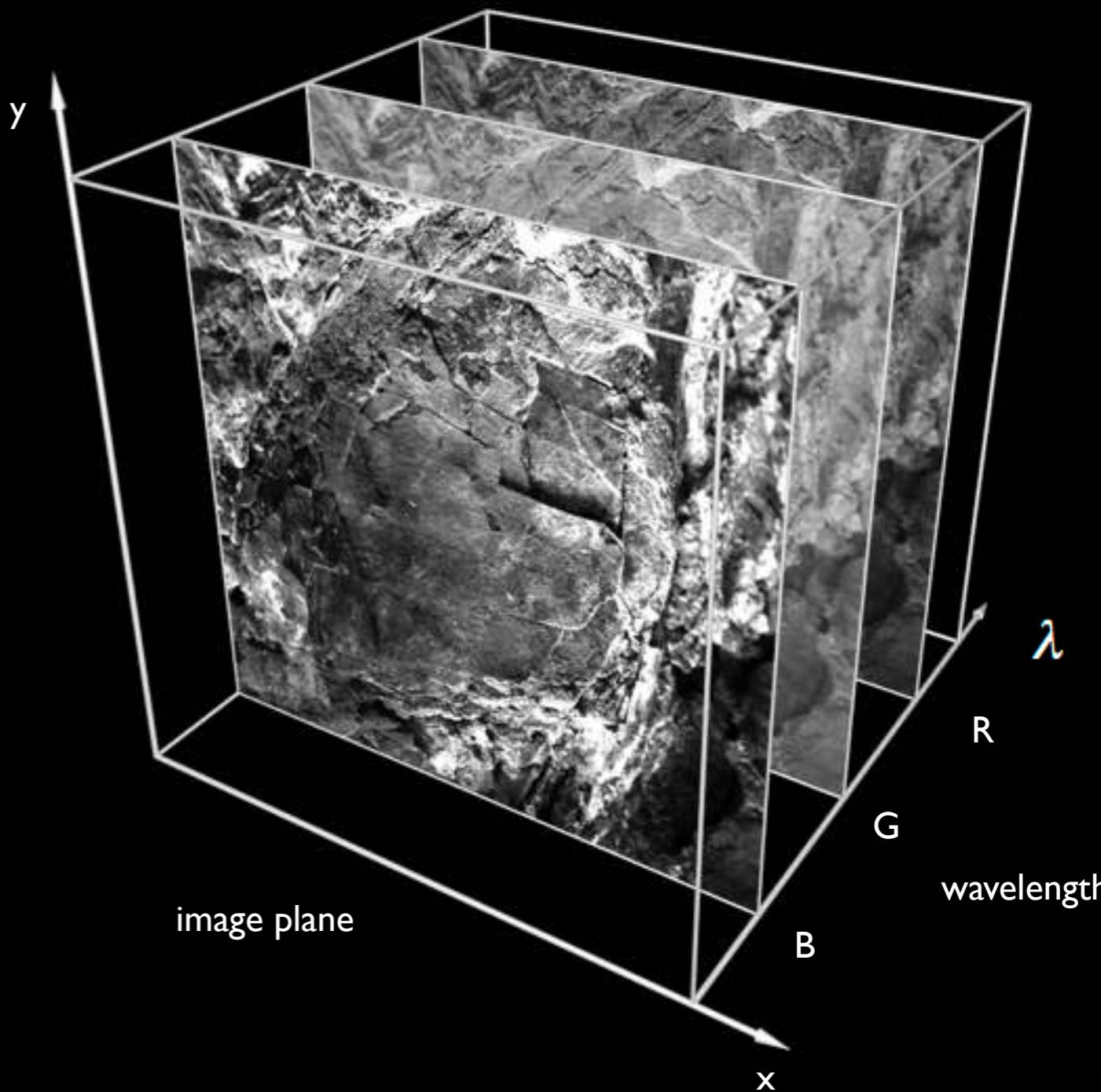


- Image cube (x, y, λ)

y

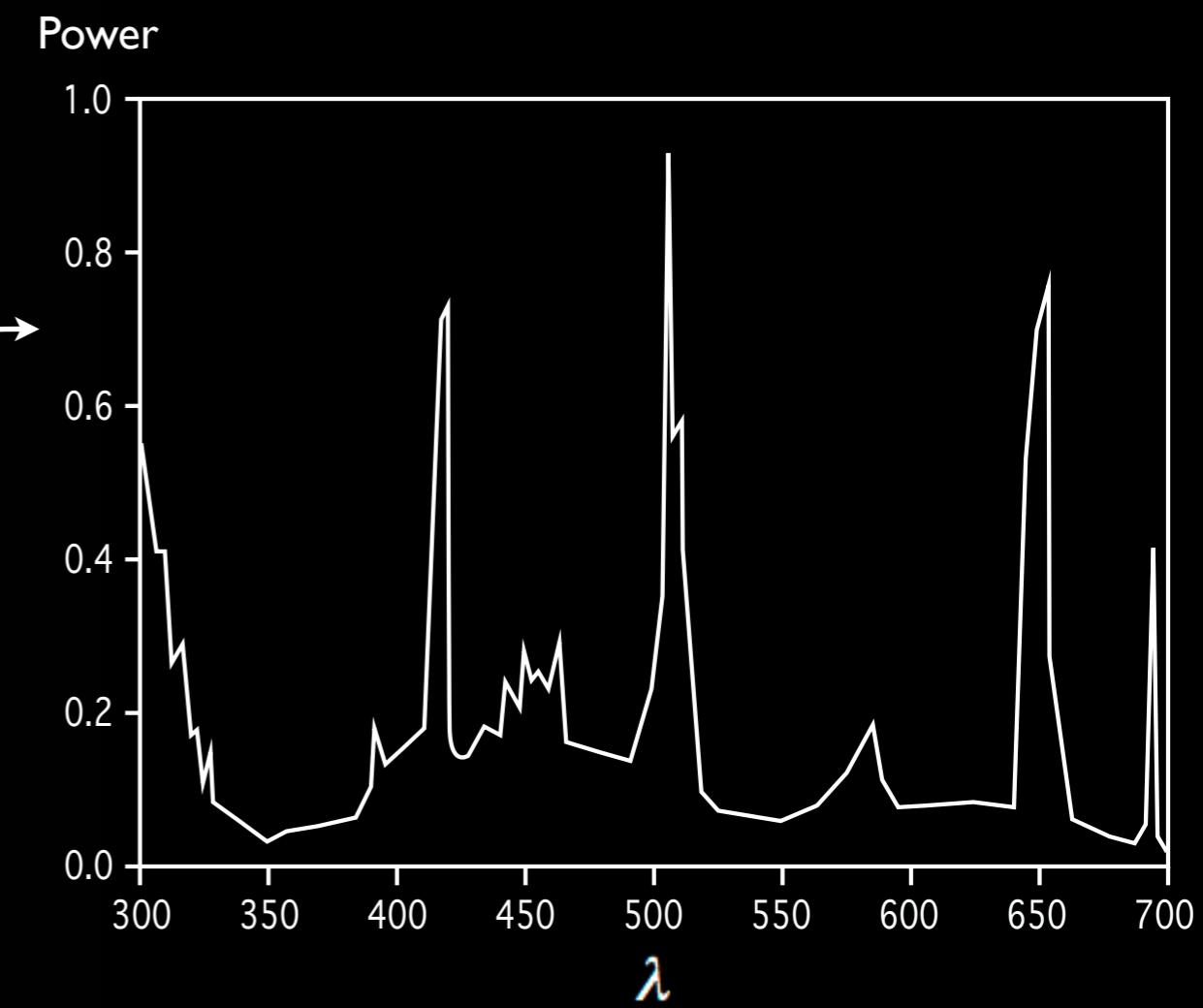
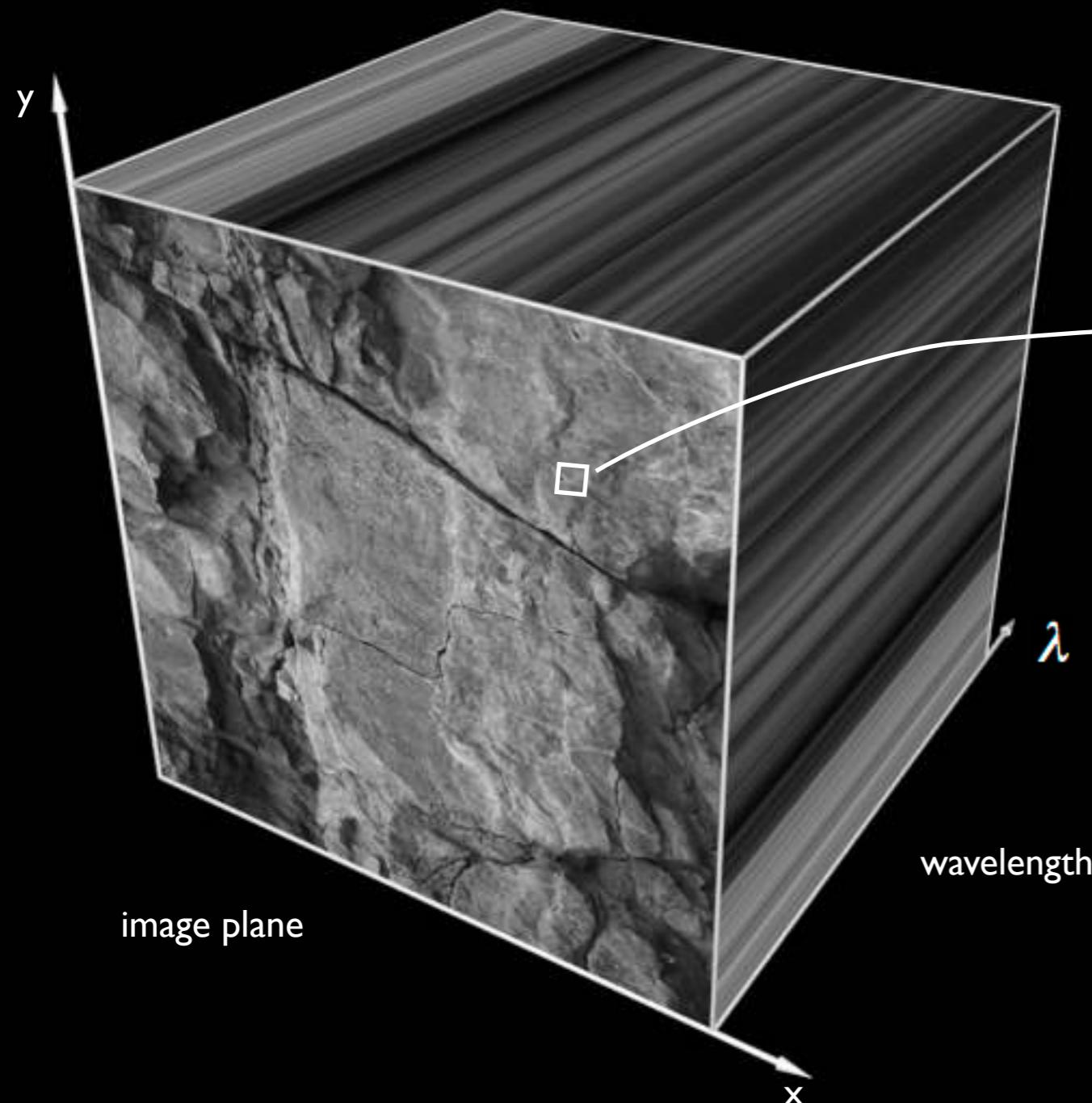


x

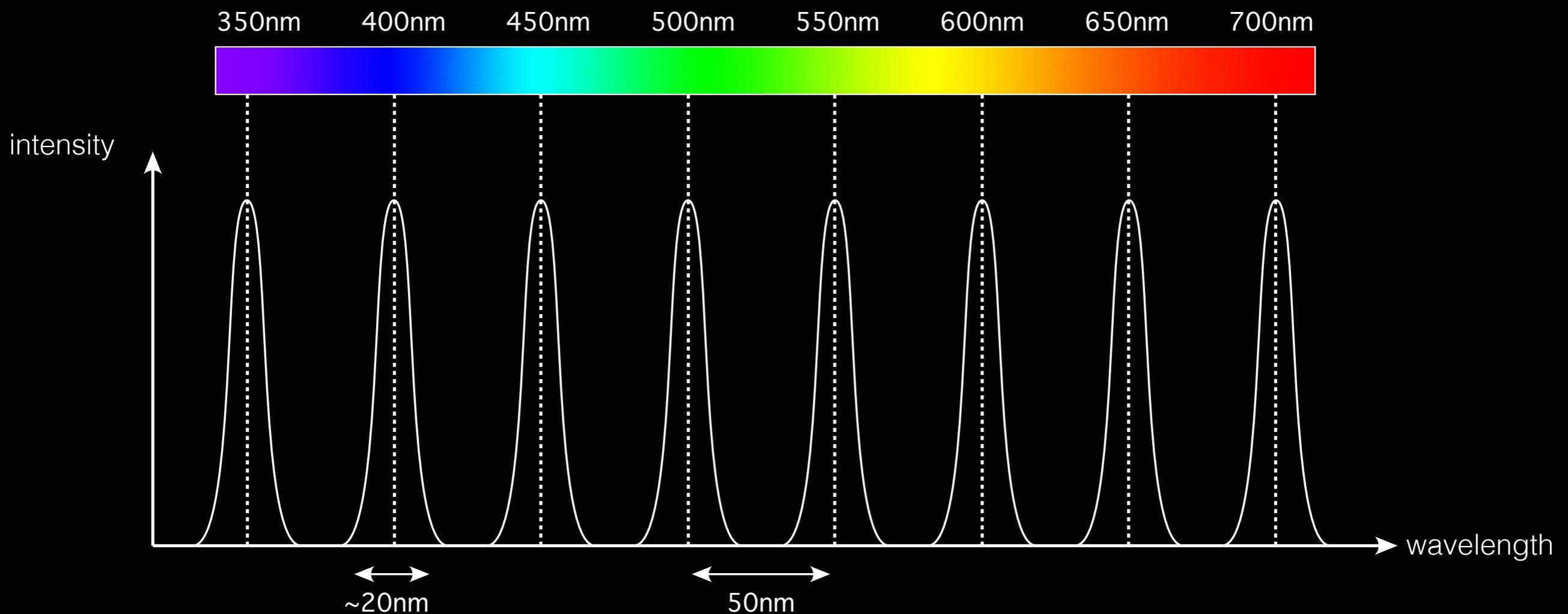


Hand print, West Angeles rock shelter.

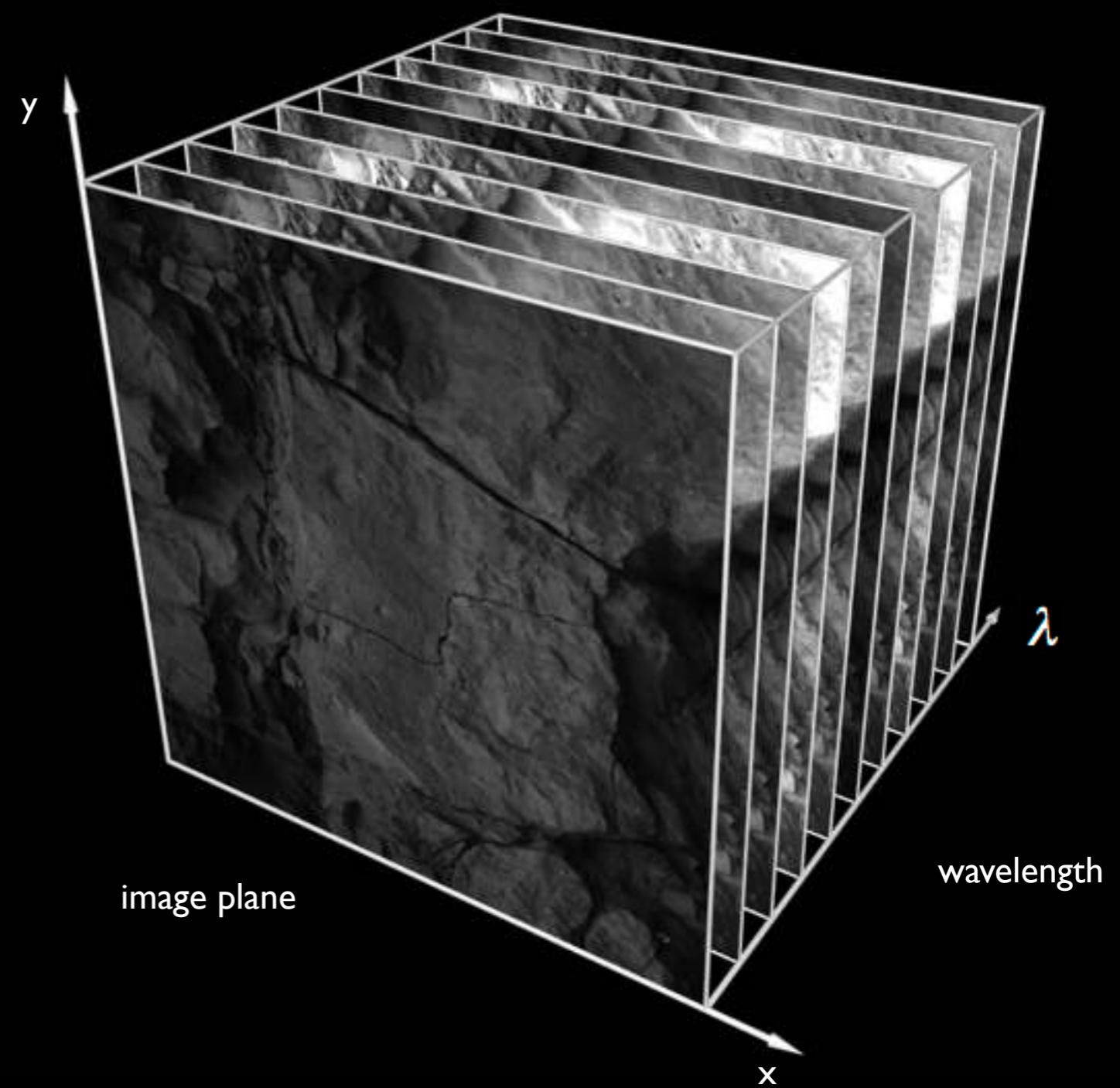
- Continuous image+wavelength cube



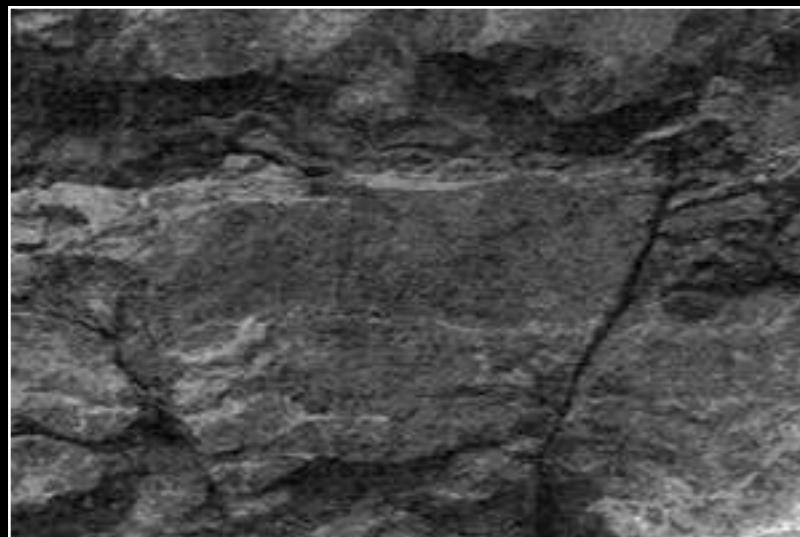
- Low cost alternative
- N filters across the visible spectrum
- Capture narrow wavelength ranges.
- For this initial experiment used 8 interference bandpass filters across the visible range. 350nm to 700nm.
- Filter banks 50nm apart and 20nm wide.



- 8 slices of the image cube



- Example



400nm



450nm



500nm



550nm



600nm



650nm

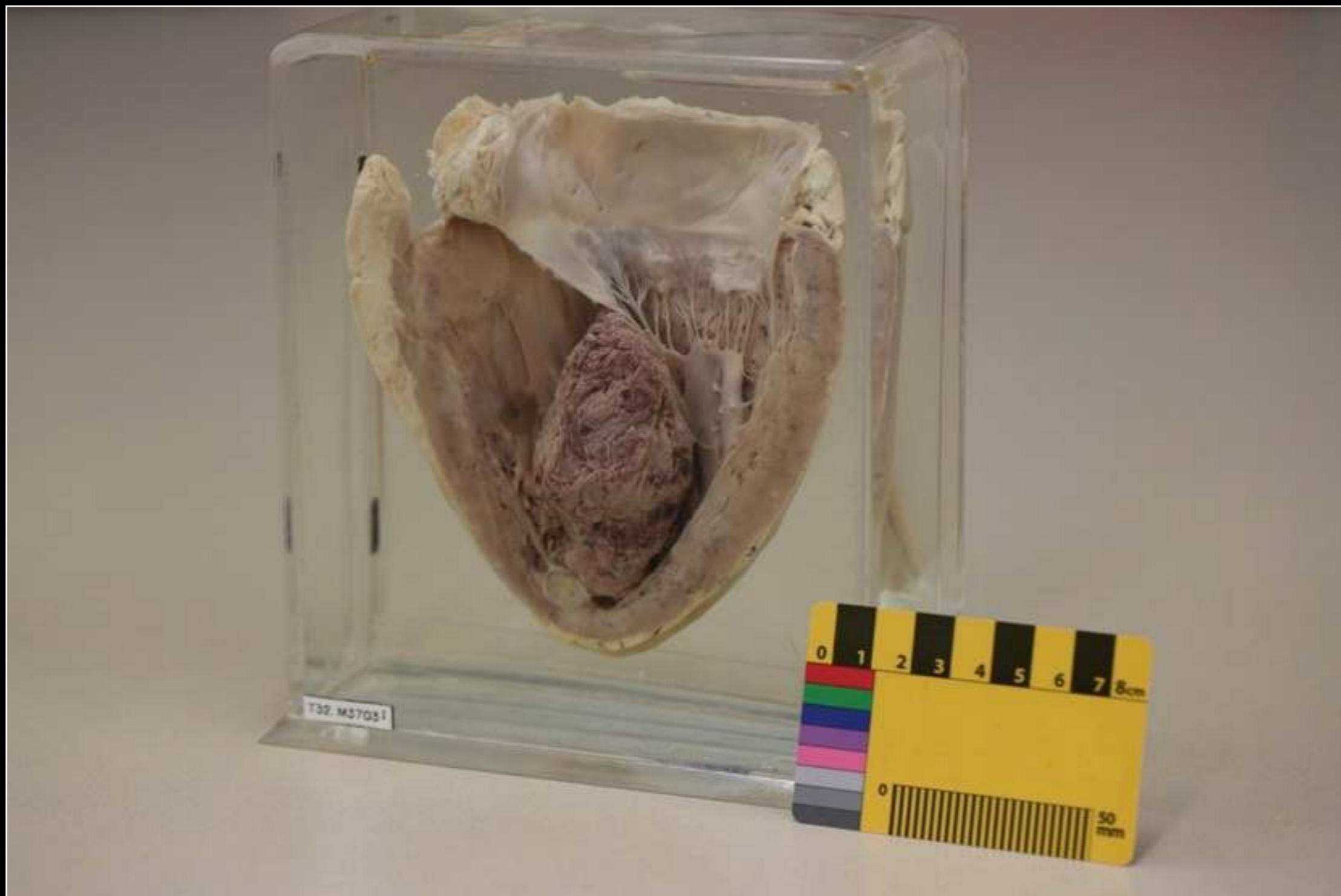
- Might imagine multiplying 500nm and 550nm and subtracting 650nm.
- Note that here we are interested in identification, much of multispectral imaging is more about quantitative analysis.

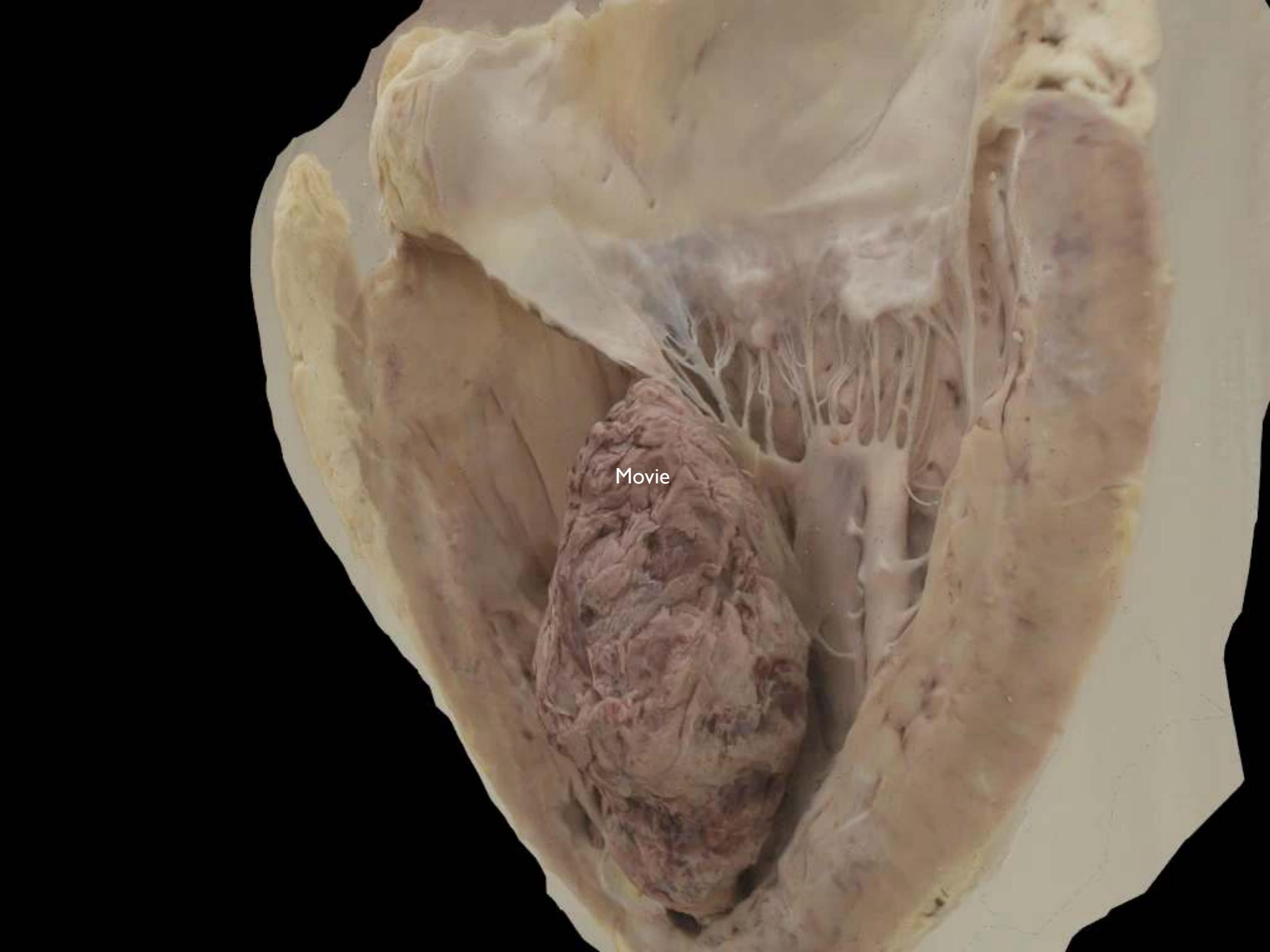




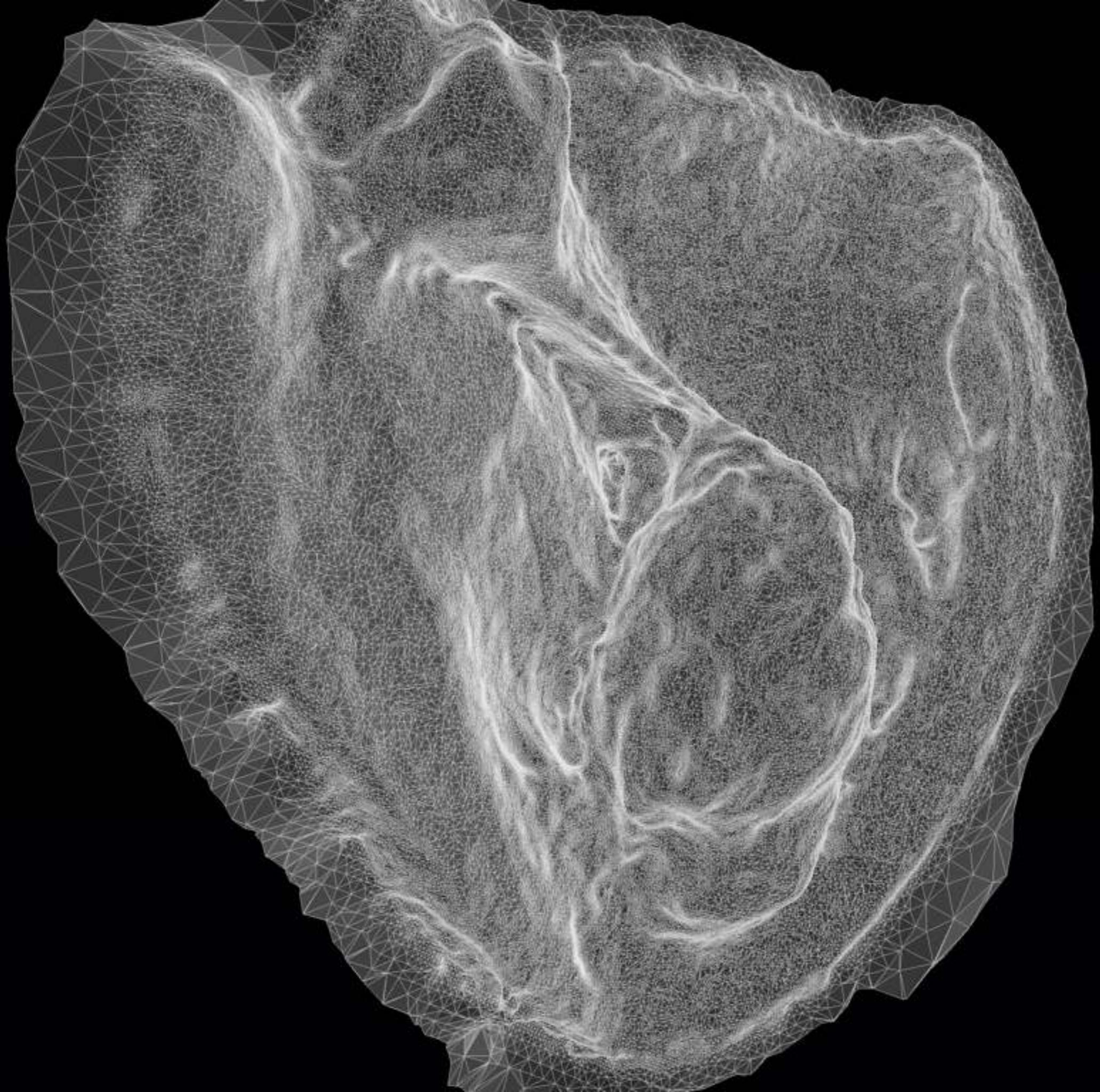
Special topics: Photogrammetry

- Process of deriving some 3D quantity solely from photographs.





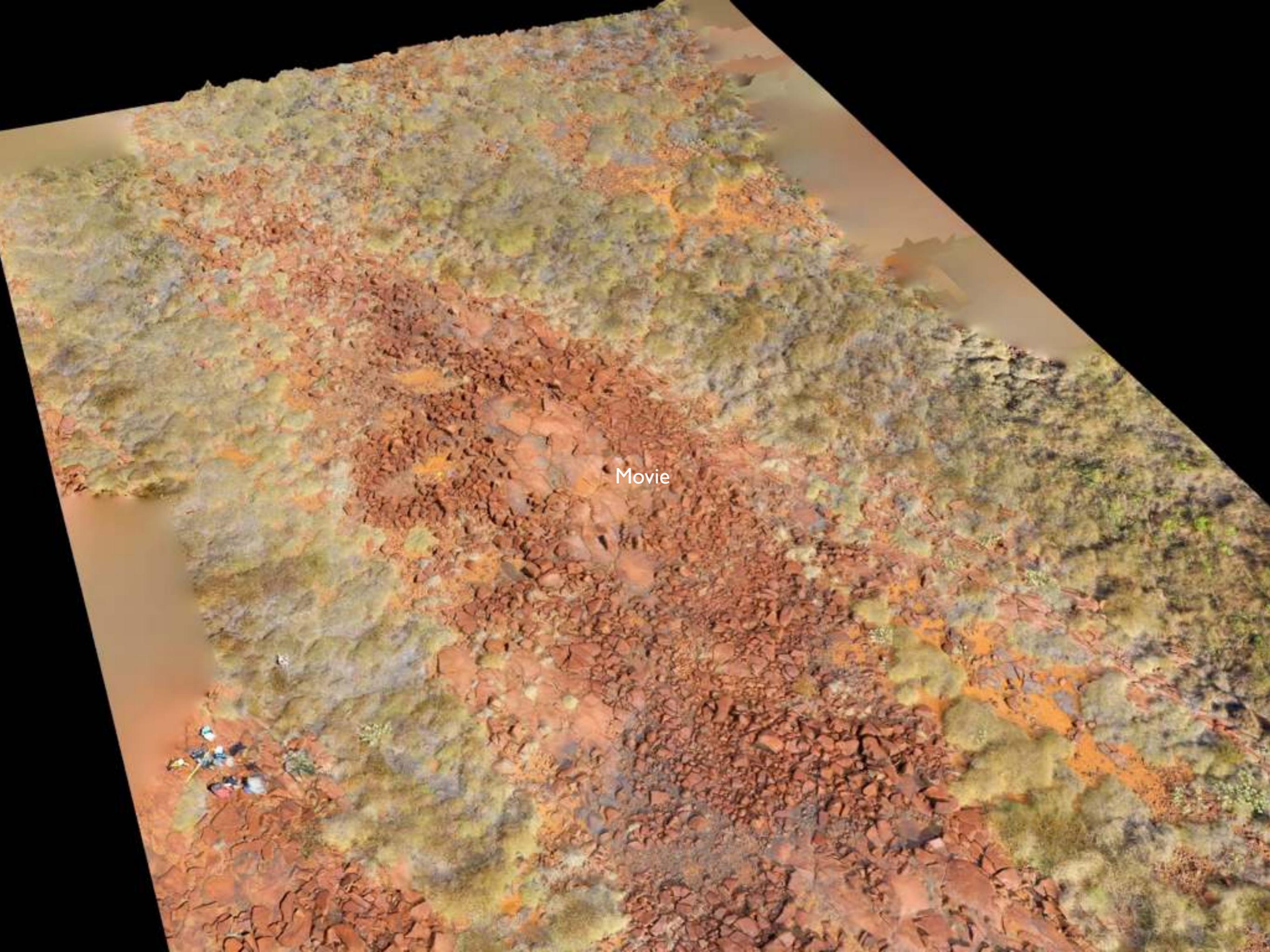
Movie







Movie

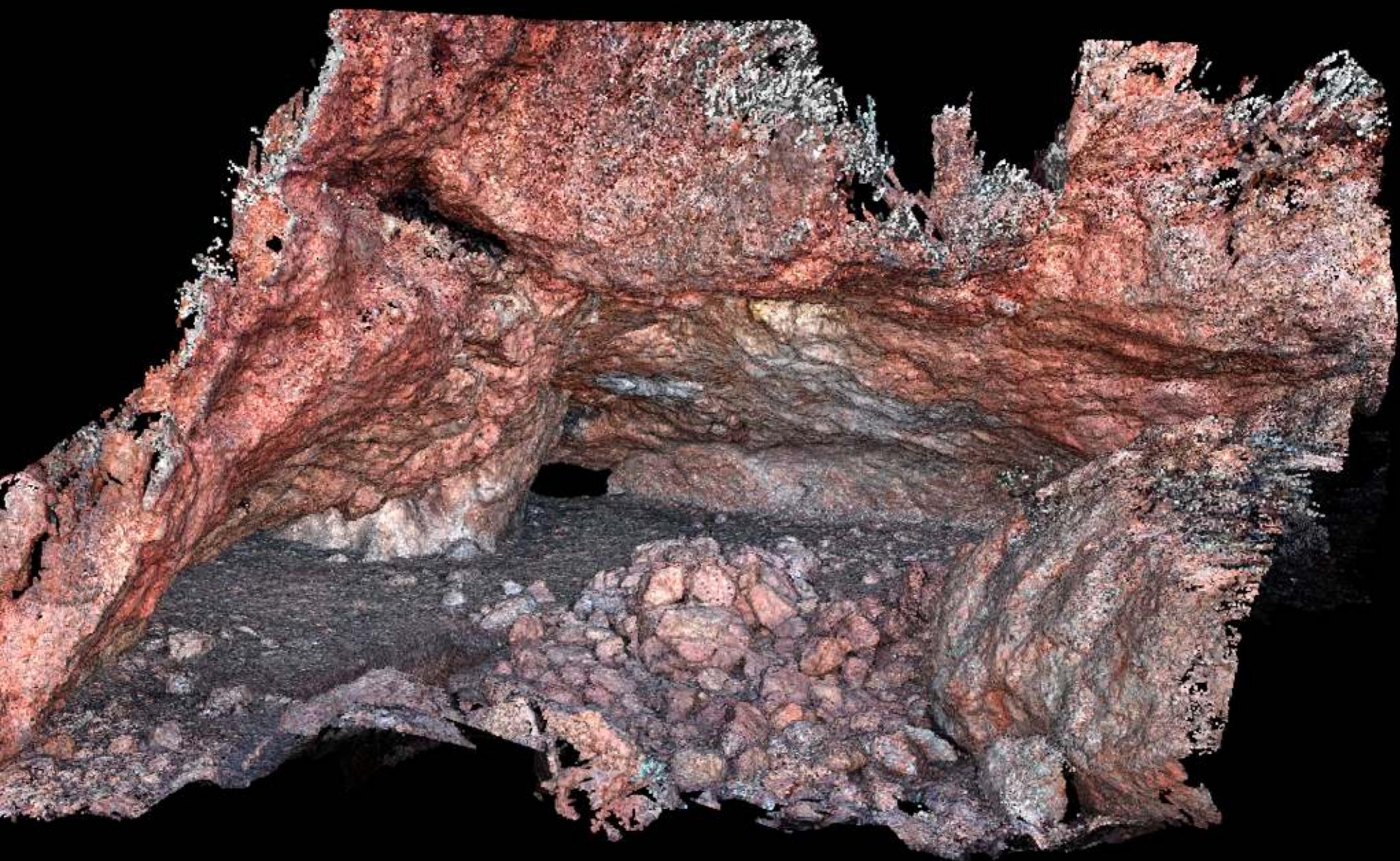


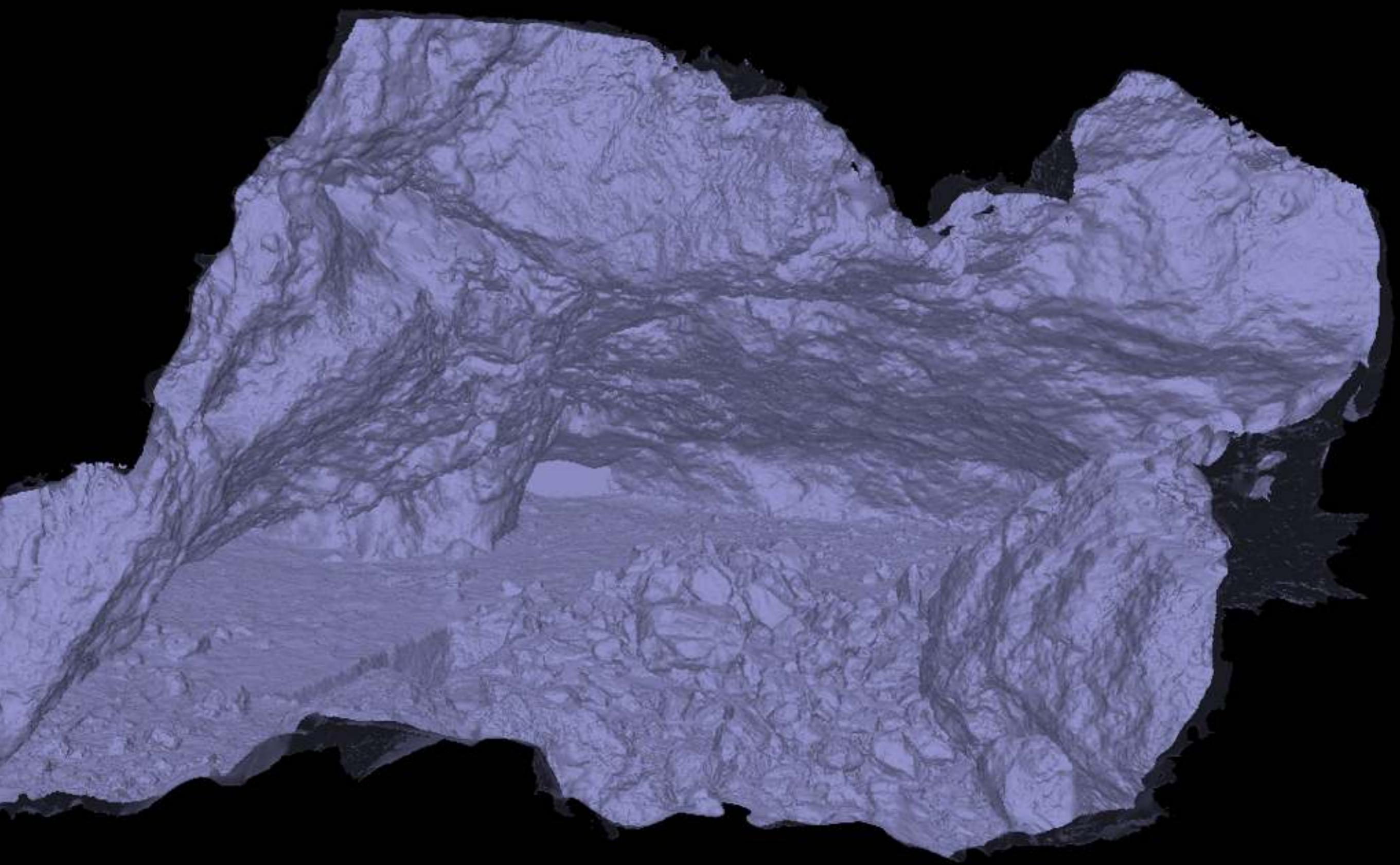
Movie

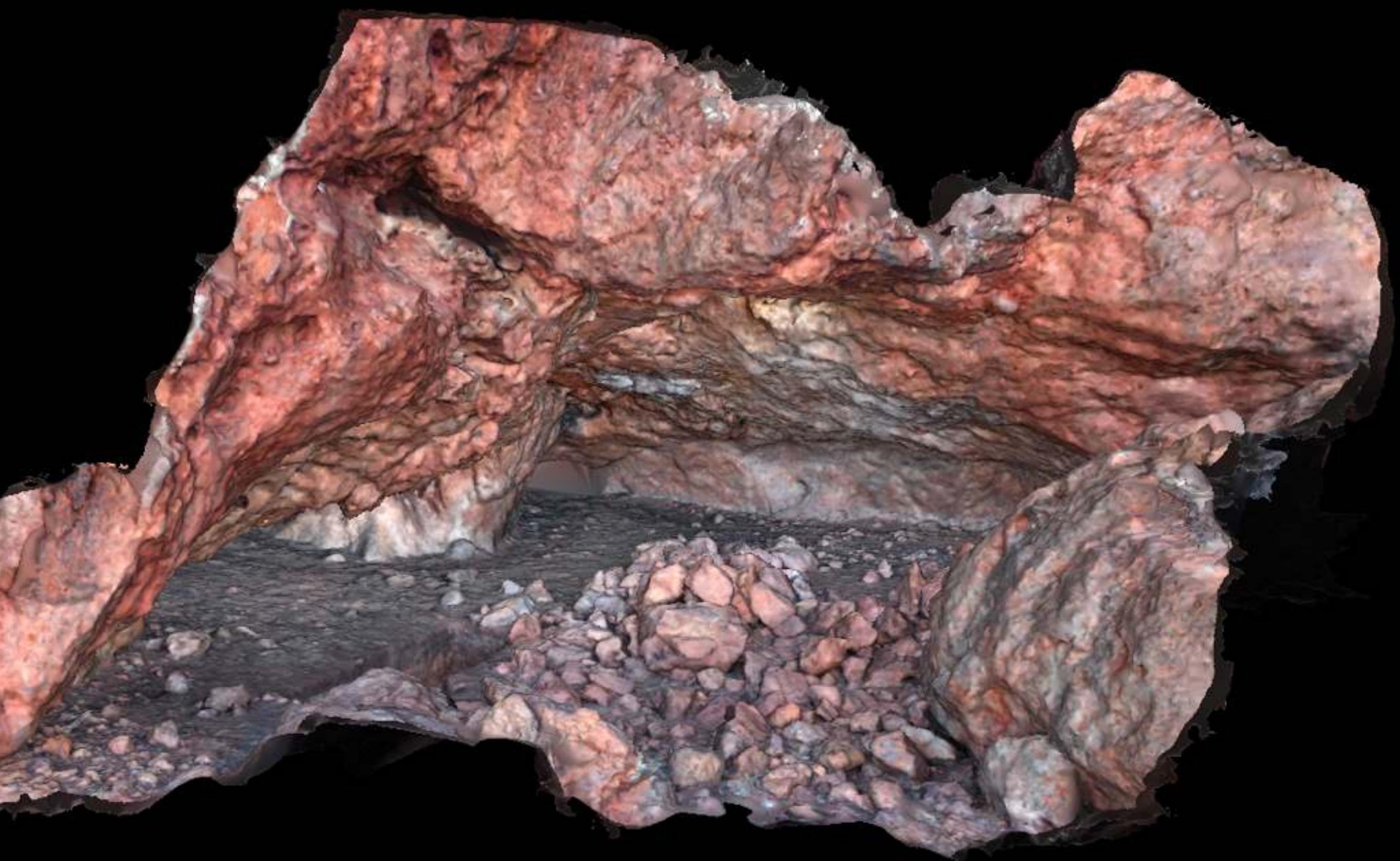


350 x 22MPixel photographs











Questions?

