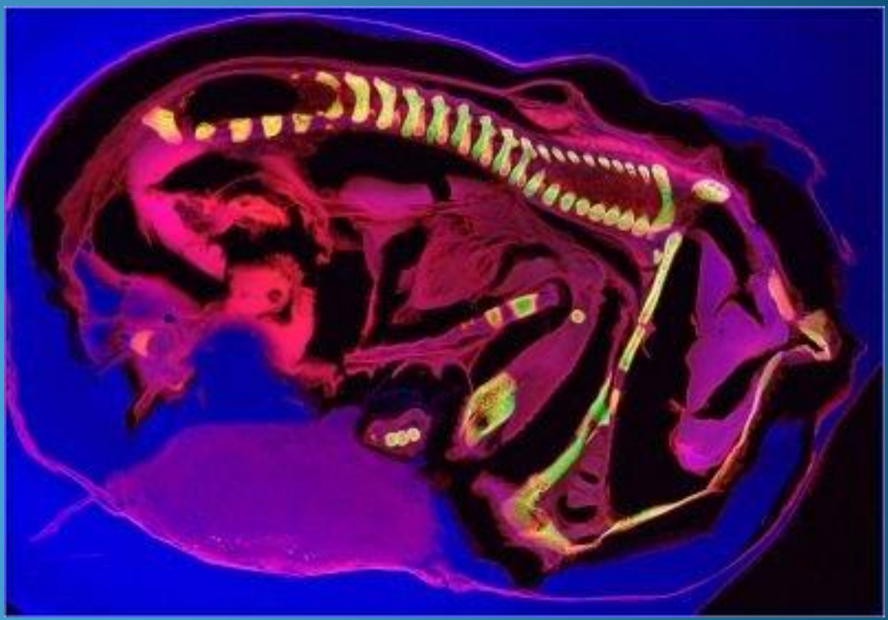
Simultaneous x-ray transmission and fluorescence CT

Chris Hall
Imaging and Medical Beam Line (IMBL)
Australian Synchrotron

Fluorescence imaging and XF microscopy



Optical fluorescence combined with x-ray CT

'FMT-XCT: *in-vivo* animal studies with hybrid fluorescence molecular tomography-x-ray computed tomography', A. Ale et al, 2012, Nature Methods, **9**, pp 615-620

X-ray fluorescence imaging using XFM

Image: Mouse embryo, Euan Smith and Enzo Lombi, CRC CARE, University of South Australia

XFCT in practice

Cigar Beetle

100 angles

5 µm steps

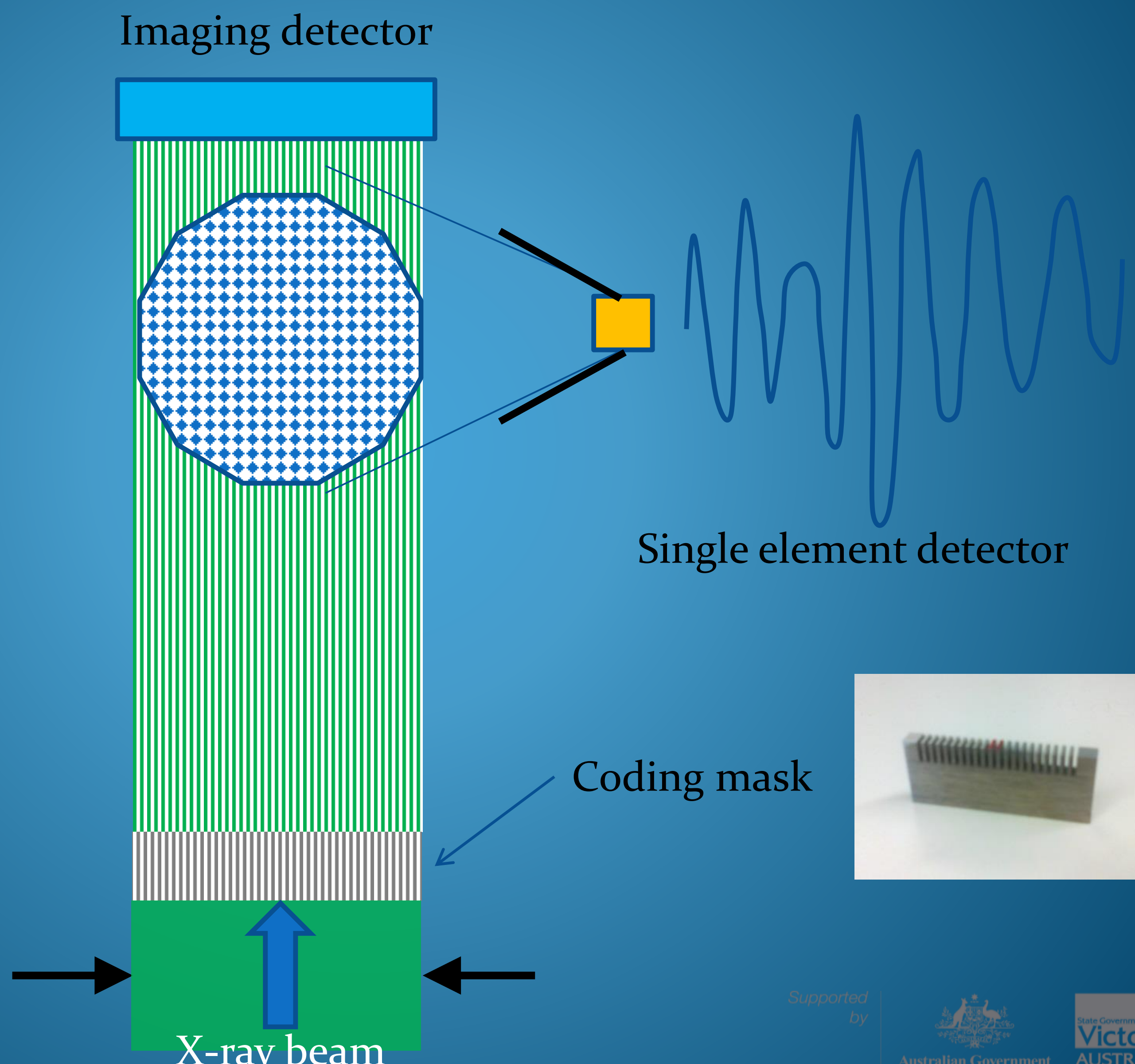
1.25 ms dwell

3 * 2 mm FoV

8 hrs total dwell

Measured in 34 hrs due to line overheads

Coded Beam Fluorescence Imaging (CBFI)



Linear algebra model of an imaging system

$$Ax+n=b$$

System matrix (m x n)

Input signal (n)

Noise (n)

Measurements (m)

But most often:

$Ax-b \neq 0$ (A is not invertible)

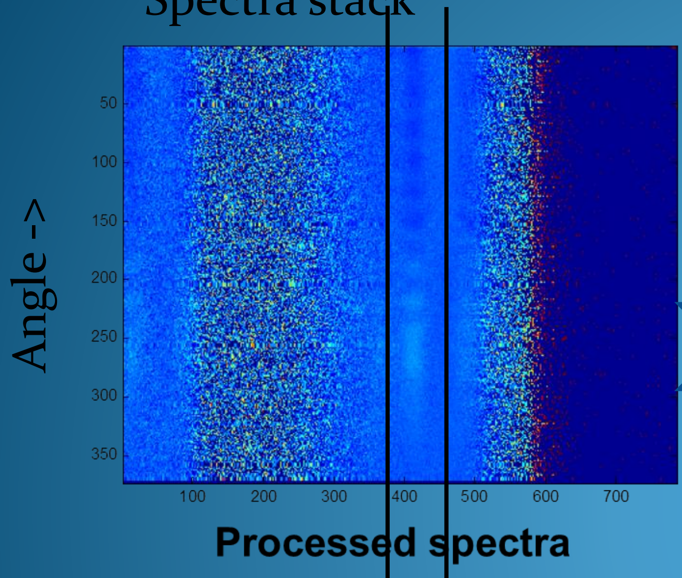
And there are many solutions ($n >> m$).

The problem is grossly under determined

- But we can use statistical convex optimisation methods to find a best estimate.
- First attempt was with Maximum Likelihood Expectation Maximisation (MLEM)

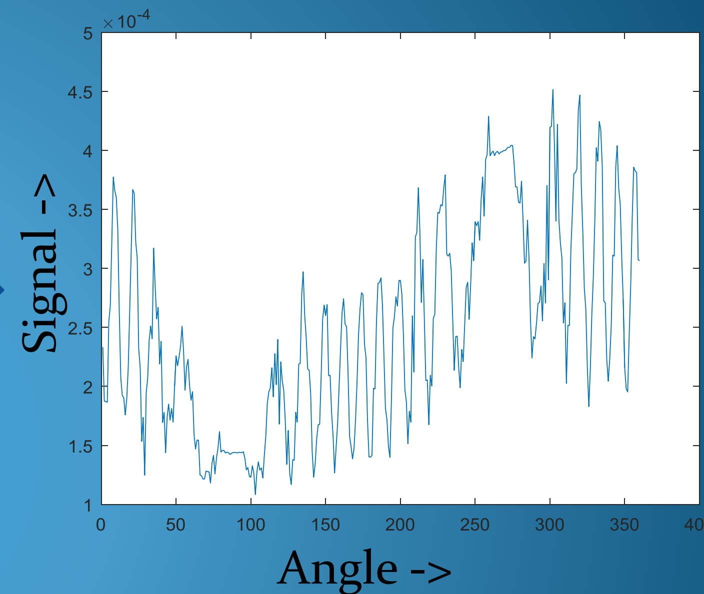
Data

Spectra stack

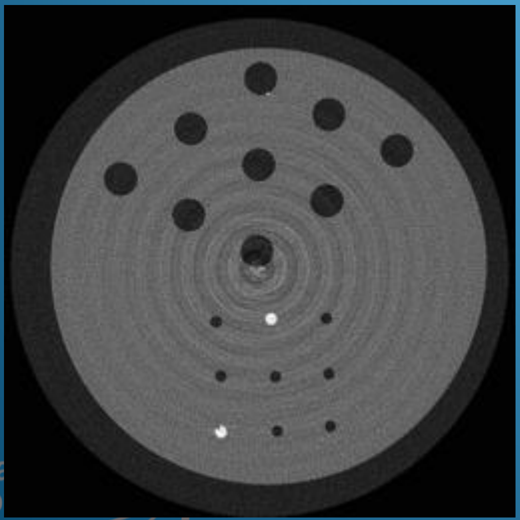


Peak analysis

Fluorescence emission signal



Tomogram



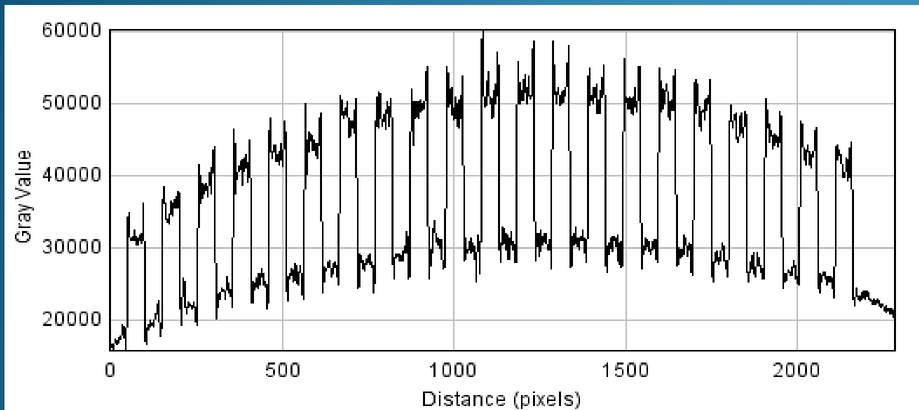
Experiment geometry

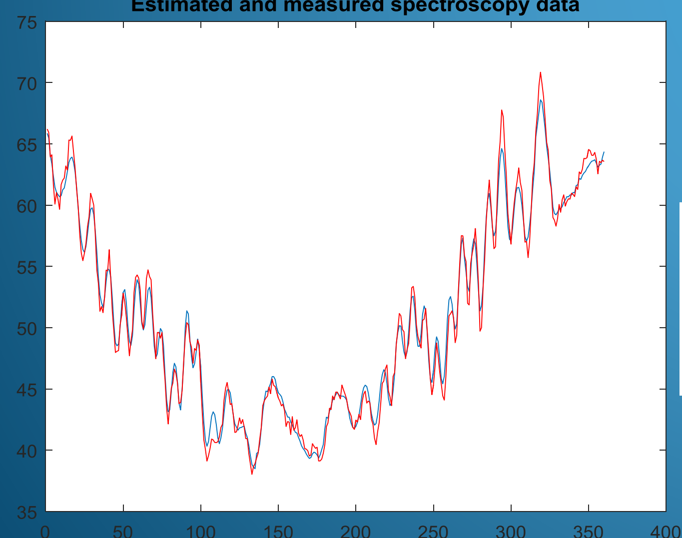
System matrix

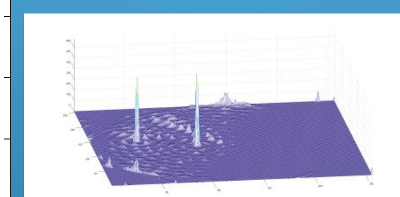
A

Results

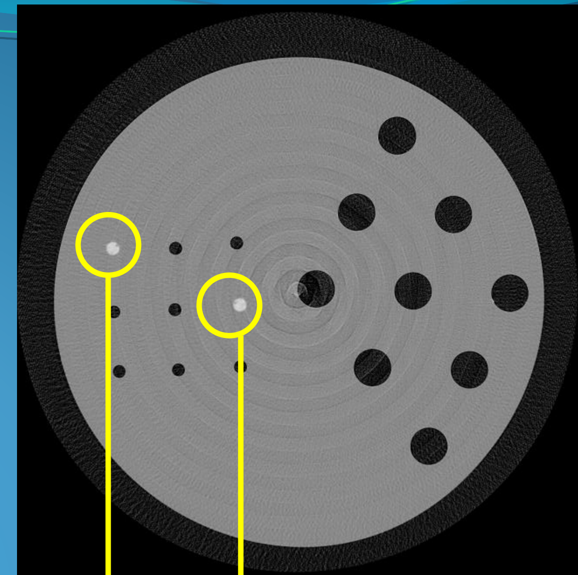
Horizontal profile of beam intensity,
As seen by the imaging detector



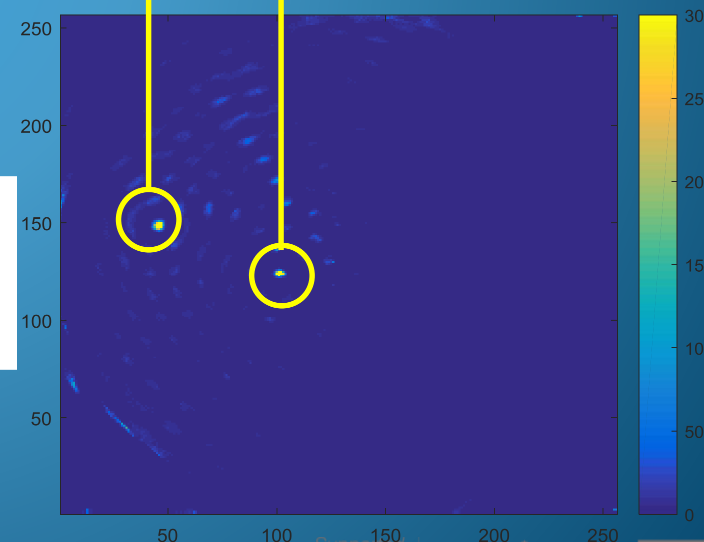




Reconstructed CT slice

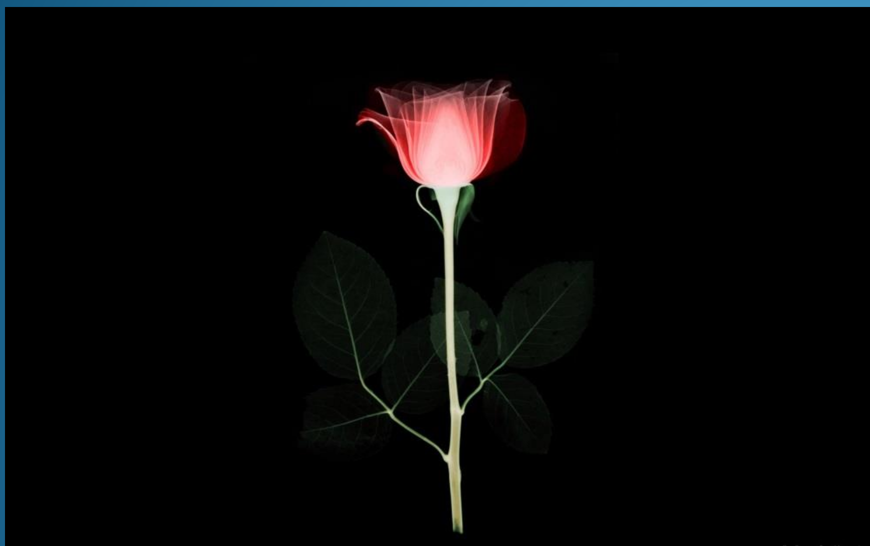


Reconstructed fluoresence map



See Alex Winnett's poster IM-03 for more information.

Compressed Sampling



This image is 1470 x 919 pixels (=1.35×10^6)
Each pixel uses 3 bytes (Red, Green, Blue)
=> 4.05×10^6 bytes

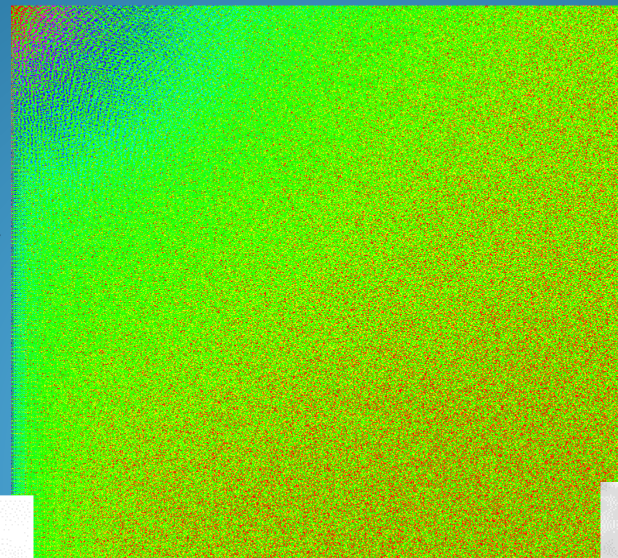
The .jpg file for this image is 122,022 bytes long
=> Compression ~33:1

“The world must not only be interpreted, it must be transformed”

The .jpg file for this image is 22,544 bytes
Compression 9.4:1

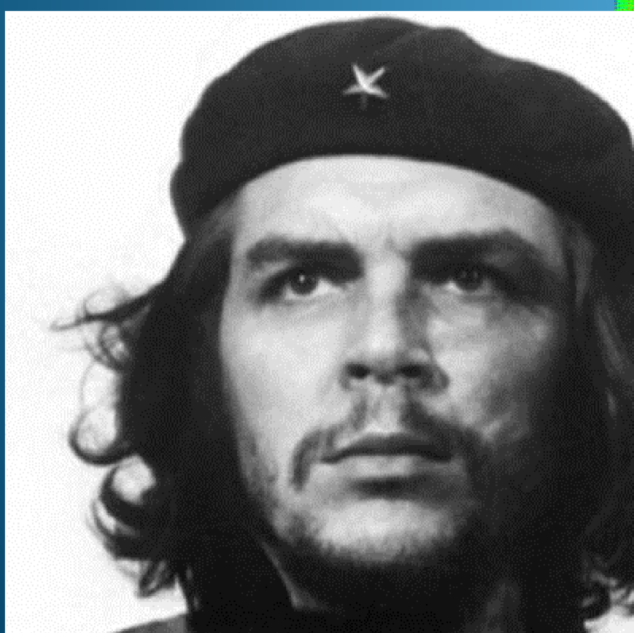
Information sparsity in real images

DCT representation



Using a different basis to represent an image.
In Fourier space – the vector is sparse (lots of zeros, or near zeros)

Original image



99% of the sorted DCT coefficients set to zero

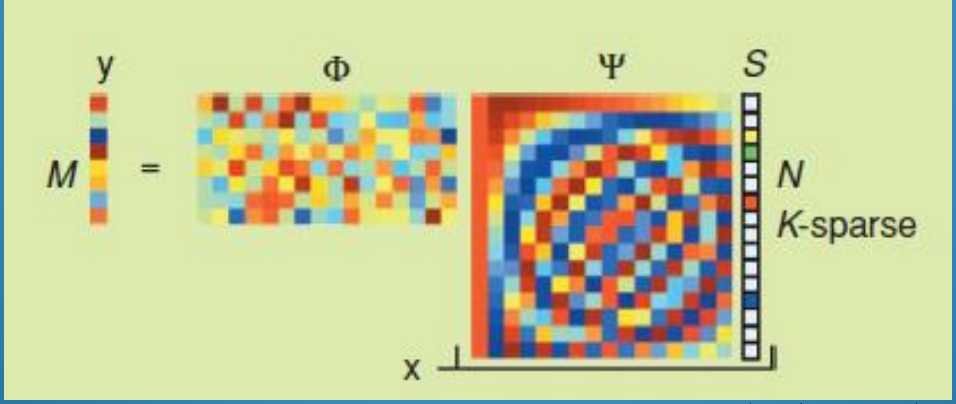
Compressed image

Compressive *Sensing*

Making a measurement means taking an inner product between some measurement matrix and a **sparse** representation of our image x (e.g. using a DCT basis). Then solve for the best solution using convex optimisation.

The L1 norm is minimised.

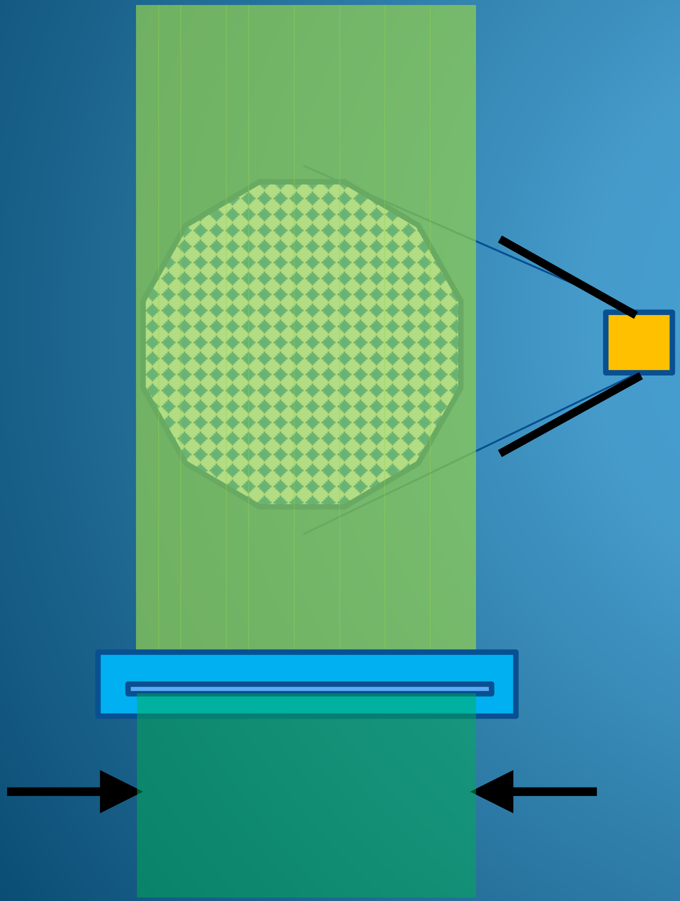
The resulting vector (y) can be shown mathematically to be a very good approximation of S, even if M << N



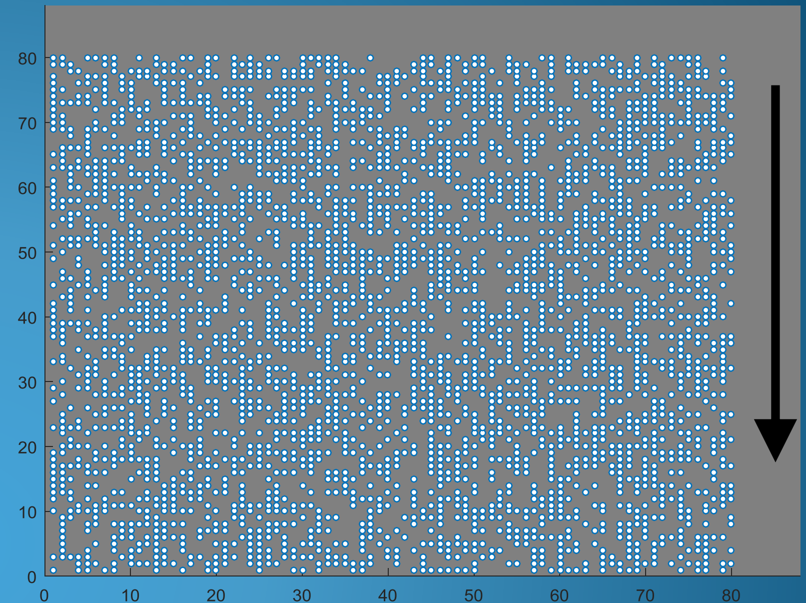
Courtesy Richard Baraniuk

- It turns out that the measurement matrix should be random!

One way forwards for X-rays

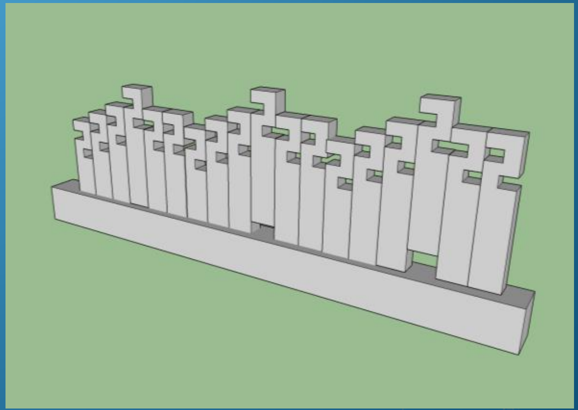


Fixed pattern, multi-row mask



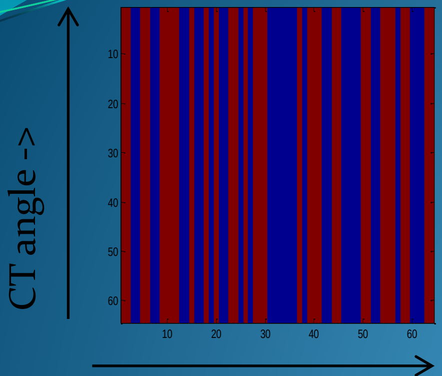
Move through beam, one row at a time.

Variable electro-mechanical mask – using a microcontroller and a lot of micro servos.

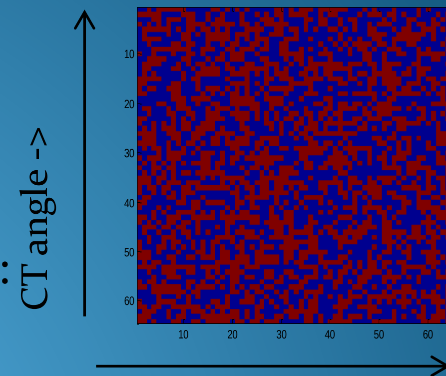


CS Modelling

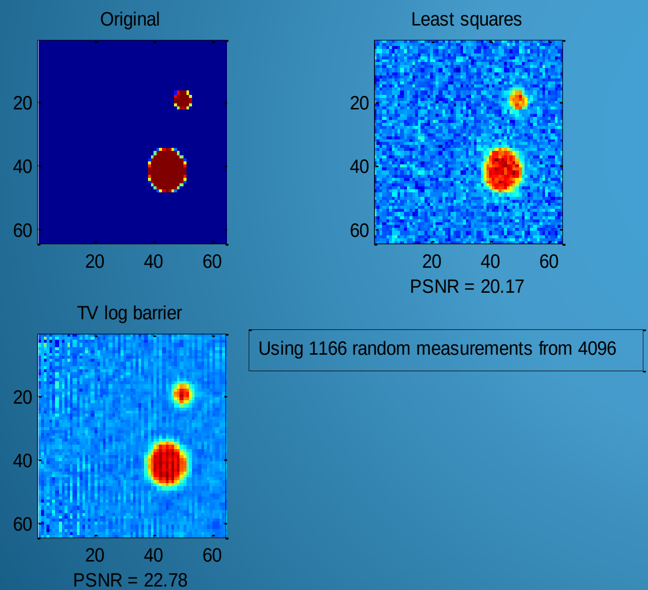
Fixed random mask

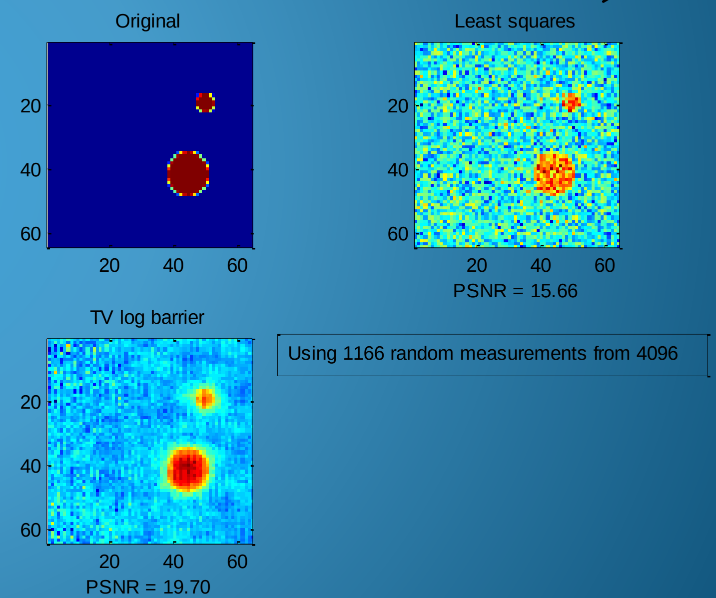


Variable random mask



The reconstructions shown here used the ‘L1-Magic’ Matlab convex function library from Emmanuel Candes*. In particular the simplest: Basis Pursuit algorithm.





Using a 50% transparent fixed pattern mask a peak signal to noise ration (PSNR) of 22.8 was achieved. The test image was 64 x 64 pixels with two regions of fluorescence, each a different size.

For a 50% transparent variable pattern mask the calculated PSNR was 19.7.

*Emmanuel Candes, L1-Magic home page, http://statweb.stanford.edu/~candes/l1magic/