The Multidimensional Integrated Intelligent Imaging Project (M-I^3)

Phil Evans on Behalf of M-I^3 consortium

RESEARCH COUNCILS UK

M-I^3 Multidimensional Integrated Intelligent Imaging

Giving Science a New Image

What is M-I^3?

- Research Councils UK Basic Technology Programme
- £4.4M total budget over 5 years
- Develop active pixel sensors
  - Design and fabrication of sensors
  - Characterisation
  - Application demonstrators
- Collaboration between 11 partners

Consortium Members

Department of Electrical and Electronic Engineering, University of Sheffield, UK
STFC Rutherford Appleton Laboratories, UK

Seminconductor Detector Centre, University of Liverpool, UK
Experimental Particle Physics, University of Glasgow, UK

Radiation Physics, University College, London, UK
Imaging for Space and Terrestrial Applications, Brunel University, London, UK
Laboratory for Environmental Gene Regulation, University of Liverpool, UK
Electron Optics, Applied Electromagnetics and Electron Optics, University of York, UK
MRC Laboratory for Molecular Biology, Cambridge, UK
Centre for Vision, Speech and Signal Processing, University of Surrey, Guildford, UK
Institute of Cancer Research, Sutton, Surrey, SM2 5PT, UK

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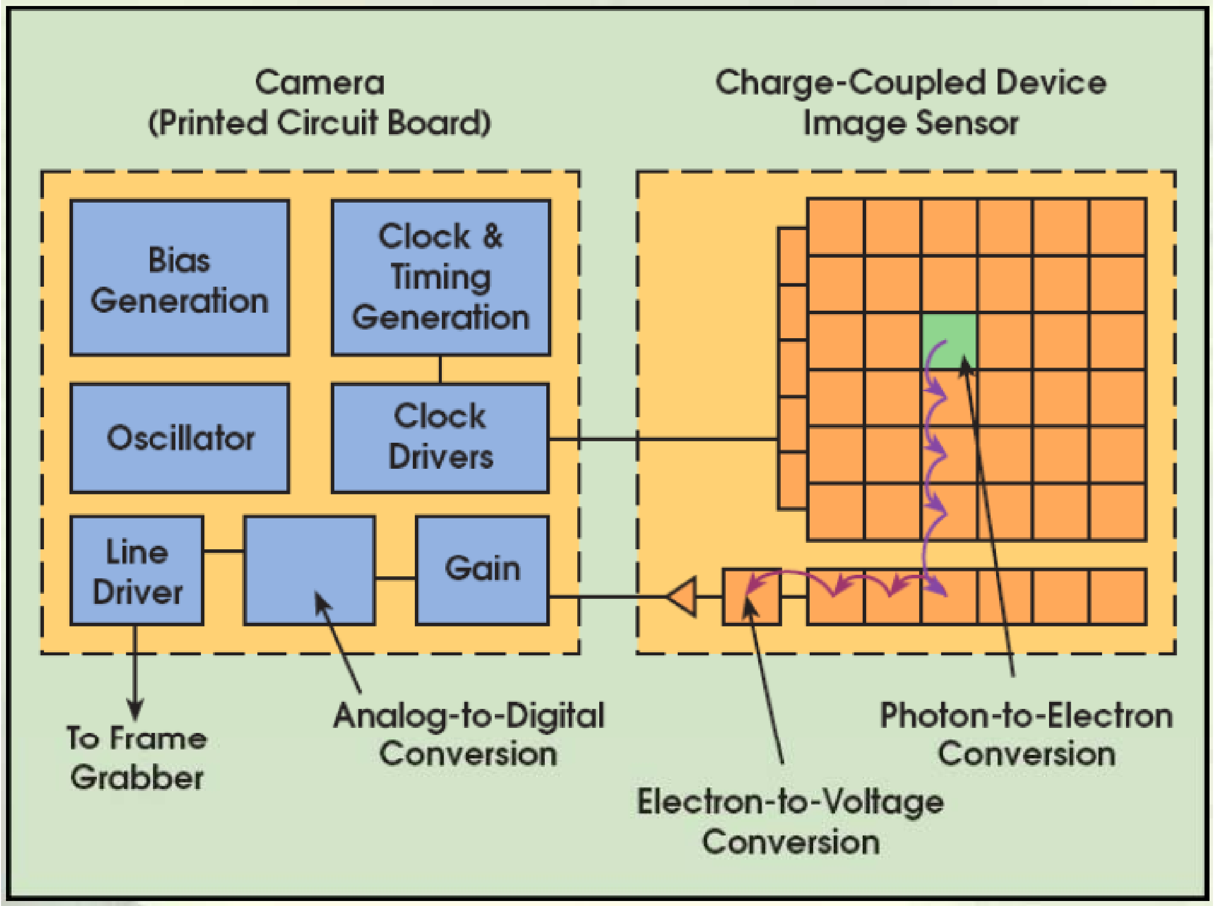
CCD Camera

Advantages

- Low noise
- High full-well capacity
- 100% fill factor
- High uniformity

Disadvantages

- Slow readout
- Pixel blooming
- Specialised fabrication
- Low functionality



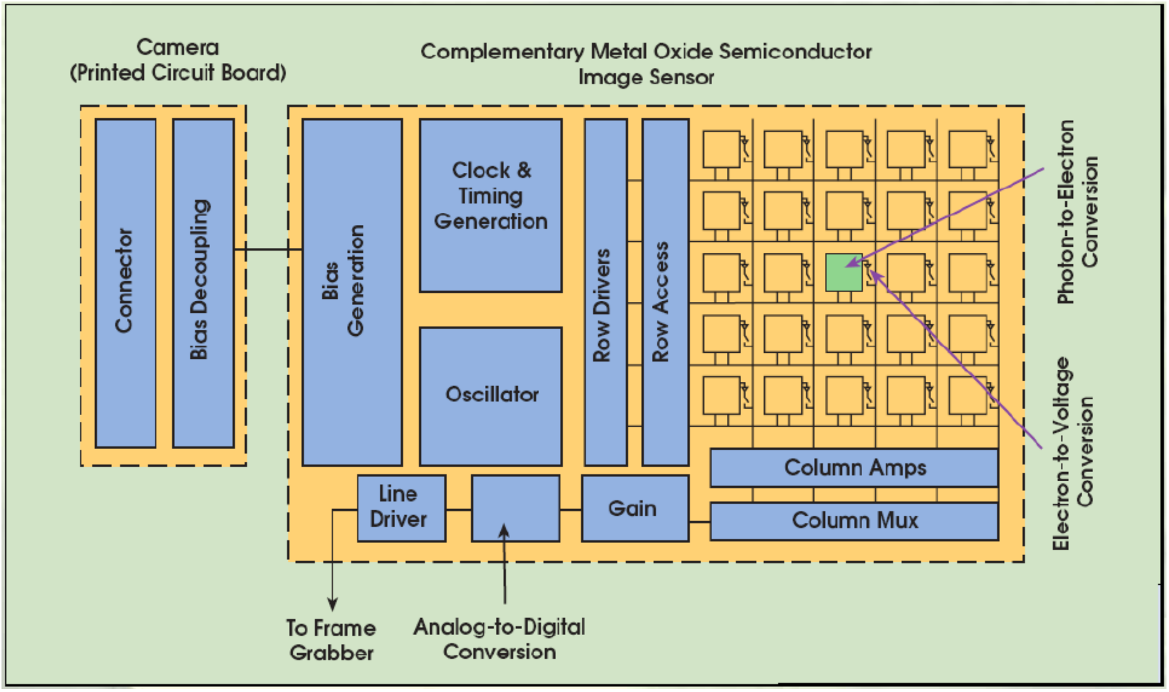
CMOS Camera

Advantages

- Mainstream technology
- High speed readout
- Random access
- On-chip intelligence
- "System on a chip"
- Radiation hard
- Cost

Disadvantages

- High readout noise
- Reduced dynamic range
- Reduced uniformity
- Reduced fill factor



Basic Technology Programme

"The Basic Technology Research Programme will contribute to the development of a generic technology base that can be adapted to a diverse range of scientific research problems and challenges spanning the interests of all disciplines and all the research councils"

EPSRC Grand challenge in Silicon Technology (2008)

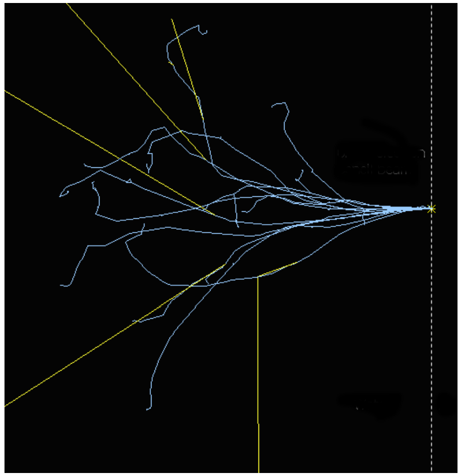
"Large imaging arrays for use in medical applications and imaging of explosives and weapons"

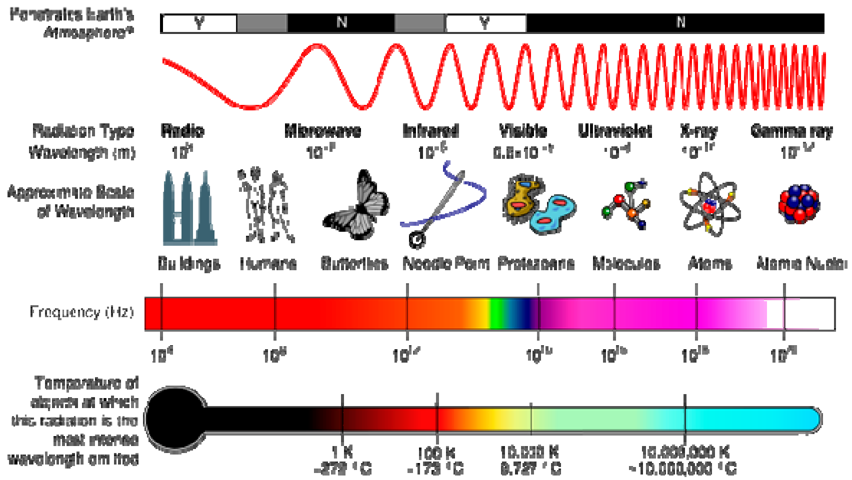
Project Goals

- Develop spectrum of radiations for which APS is used
  - High energy γ-rays to infrared, e^-, hadrons
- Develop on-chip intelligence down to pixel level
  - Adaptive signal processing
  - Pattern recognition
  - Data volume reduction

Imaging Requirements

- Low noise
- Large dynamic range
- Linear
- Large size
- High speed
- Ease of data manipulation
  - Data volume reduction
- Broad spectrum of radiations

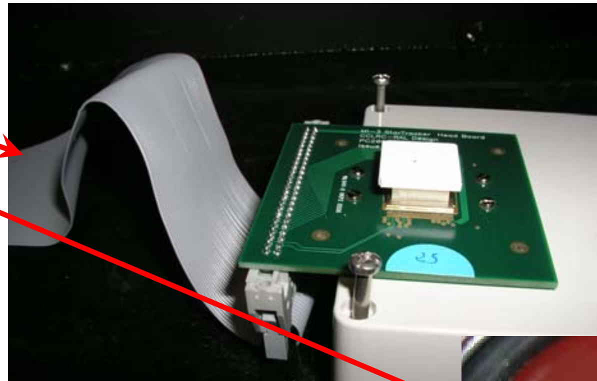


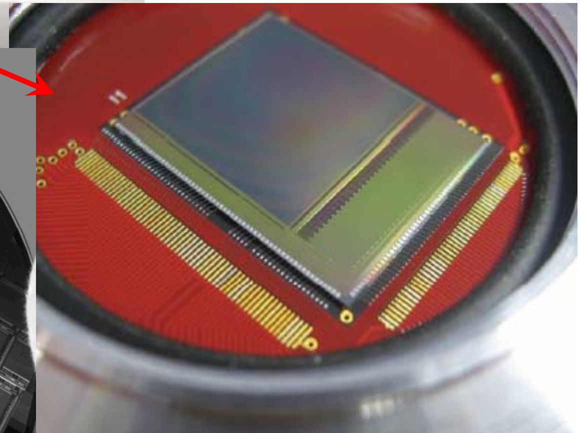


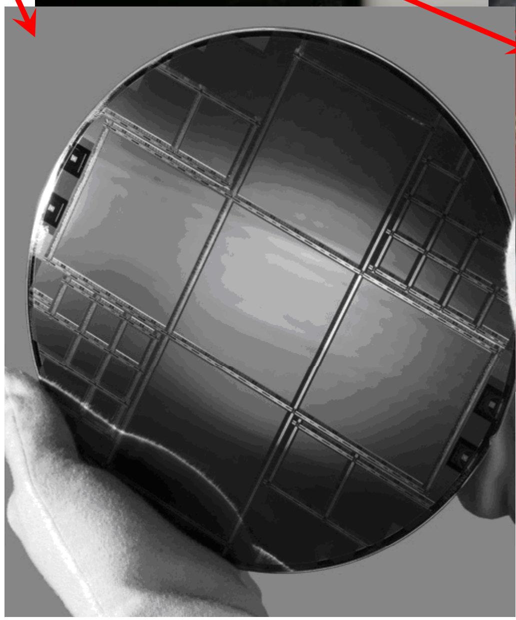
http://en.wikipedia.org/wiki/Electromagnetic_spectrum

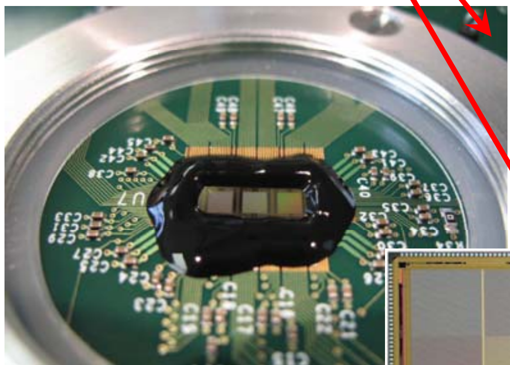
Range of Sensors

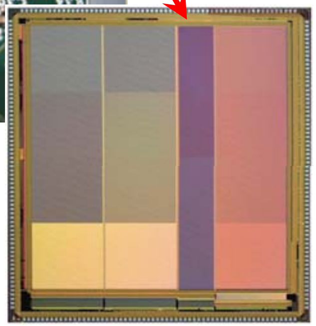
- Startracker
- Vanilla/PEAPS
- Large Area Sensor
- OPIC
- eLeNA





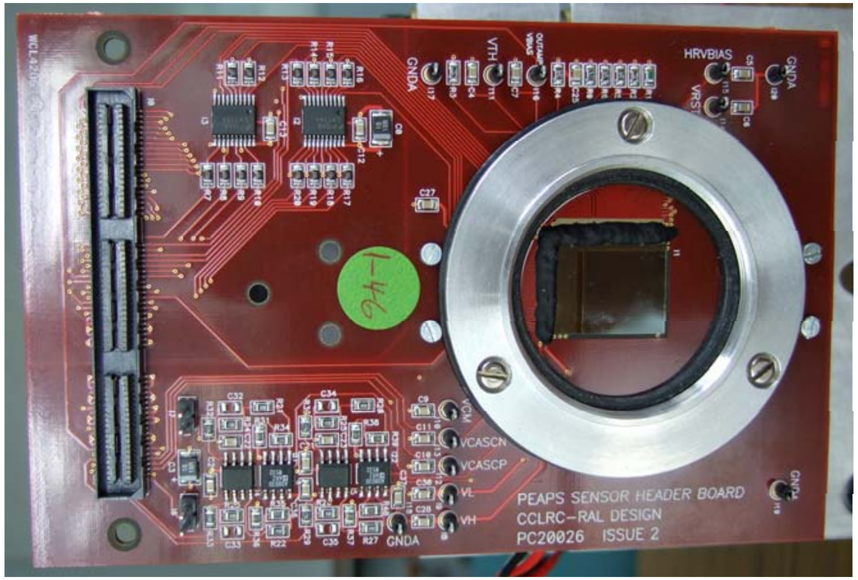






Vanilla/PEAPS

- 520 x 520 array
- 25 μm pixels
- 100 frames/s
- 12 bit digital o/p
- 6 regions of interest
  - (20 kHz analogue)
- 85% fill factor
- Two-sides buttable
- Back thinning being studied



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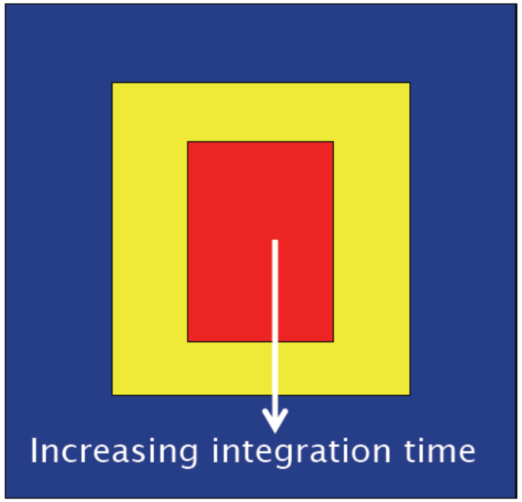
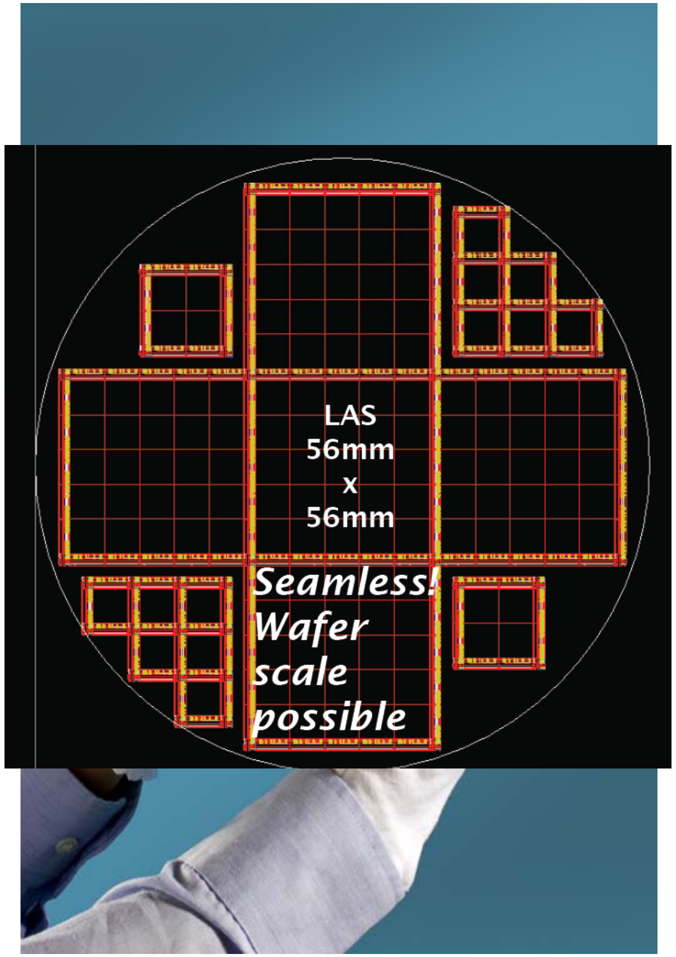
Large Area Sensor (LAS)

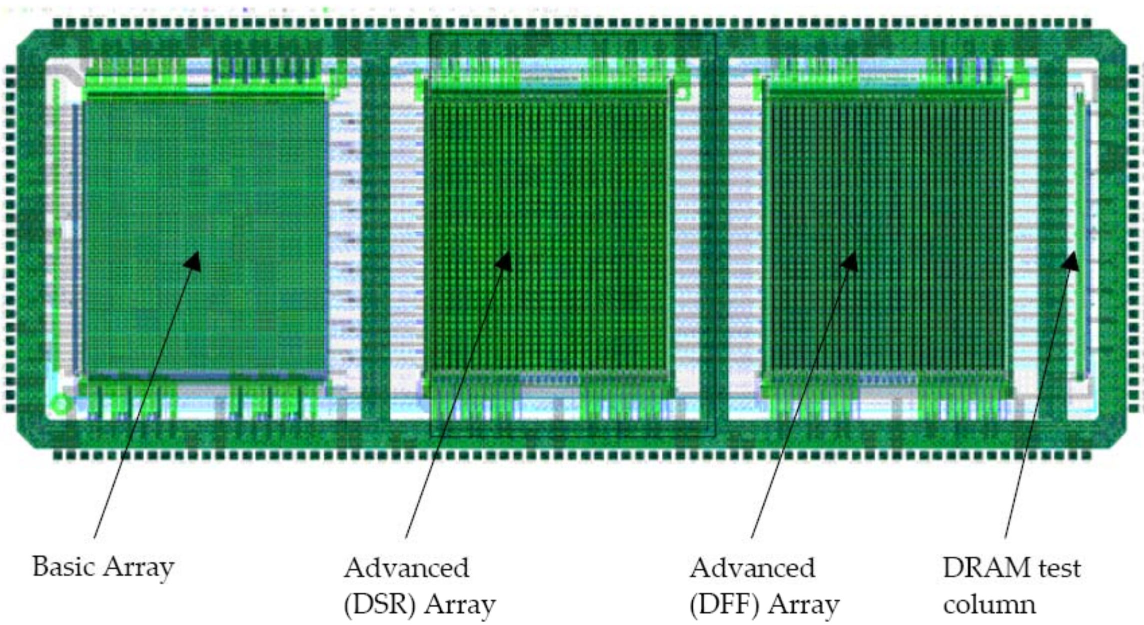
- 1400 x 1400 array
- 40 µm pixels
- 56 mm x 56 mm active area
- Stitched design
- Multiple integration times within frame





On-Pixel Intelligence CMOS (OPIC)

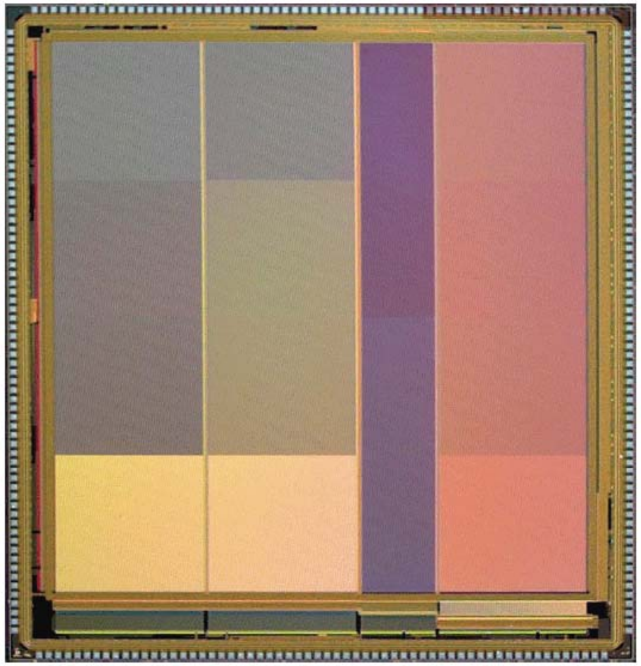
- Test array
- 64 col x 72 row
- 30 µm pixels
- 2 mm x 2.16 mm
- Sparse readout
- On-pixel storage
- Thresholding



DSR – dynamic shift register
DFF – D-type flip-flop

Low Noise APS (eLeNA)

- 0.18 μm CMOS INMAPS with deep P-well
- 15 μm pixel pitch
- 5 and 12 μm epitaxial layer
- 512 rows
- 448 columns in 4 sections
  - 4 architectures with dedicated analogue output
- Target noise few e^- rms



Applications

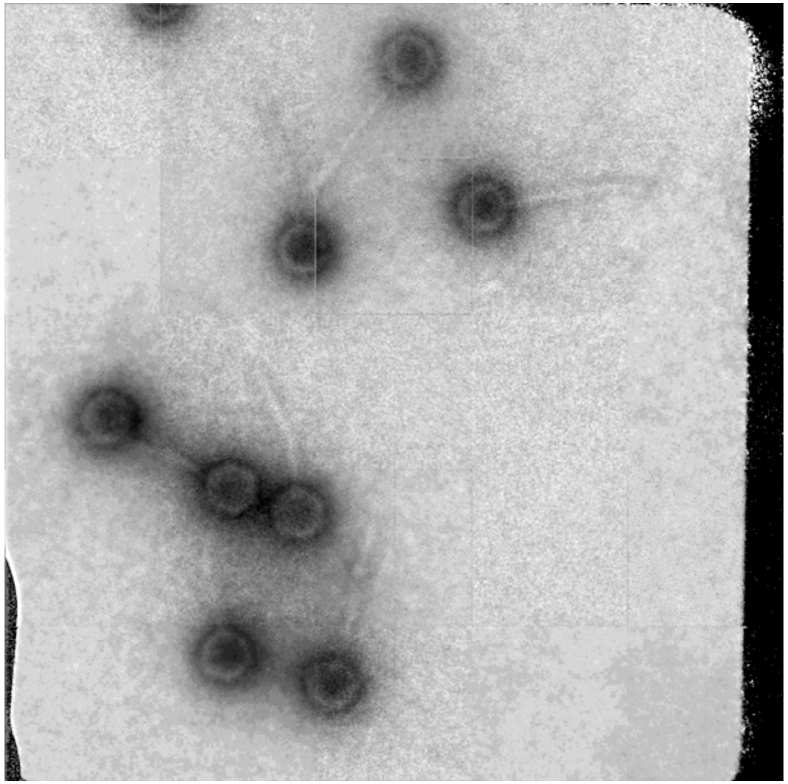
- Electron Microscopy
  - York
  - MRC, Cambridge
- Biology
  - Liverpool
- Particle Physics
  - Glasgow
  - Liverpool
- Space science
  - Brunel
- Biomedical imaging
  - Surrey
  - UCL
  - ICR

Electron Cryo-Microscopy in Structural Biology (MRC Cambridge)

Three main types of EM analysis (and the resolution attained in the analysed structures):

Single Particle Analysis (molecule level),	4-10 Å
Electron Crystallography,	2-3Å …near-atomic resolution
2-D crystal Electron Tomography	50-70 Å … cellular level

To replace film we need electronic detectors with high DQE and MTF, with radiation hardness and with 4kx4k pixels

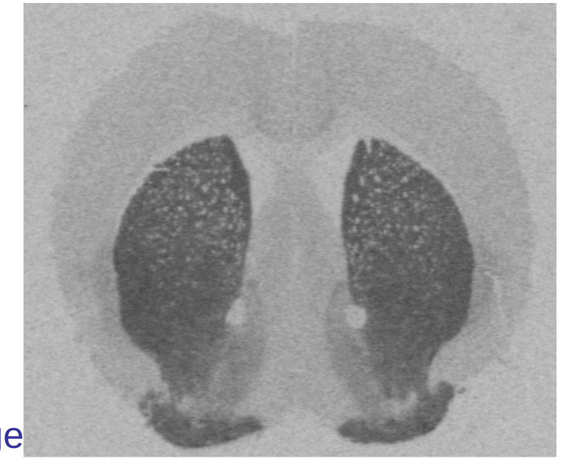


Negatively stained lambda phage Imaged at 120 keV with a MAPS sensor

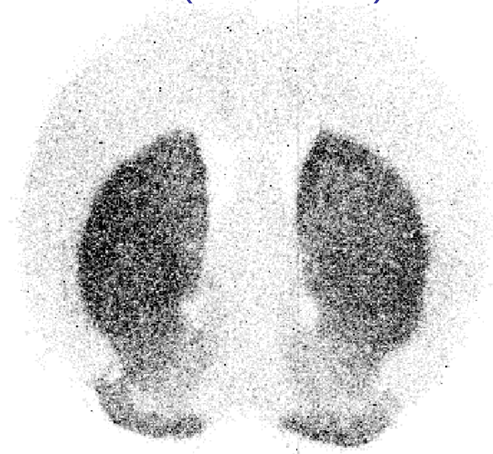
Autoradiography (Surrey, RAL)

- Measure uptake distribution of radio-labelled compound in excised tissue
- Beta emitter in contact geometry (e.g. ^{3}H, ^{14}C, ^{35}S)
- Film detector traditionally
  - Large area, high spatial resolution
  - Poor linearity, dynamic range, sensitivity

Tritiated ligand binding to D1 receptors



^{3}H tissue image
tritiated Hypersensitive film (Amersham)
4 weeks.

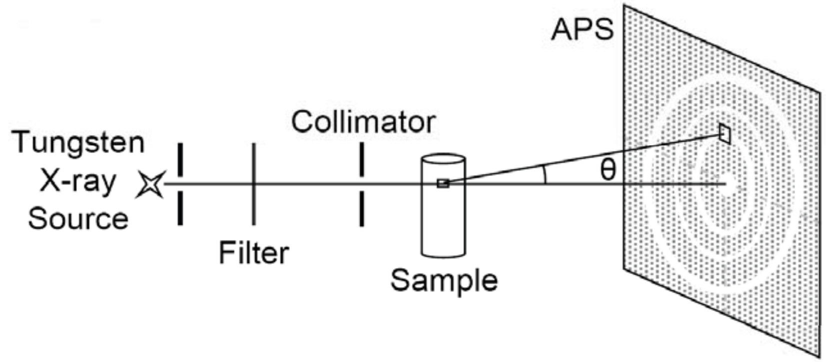


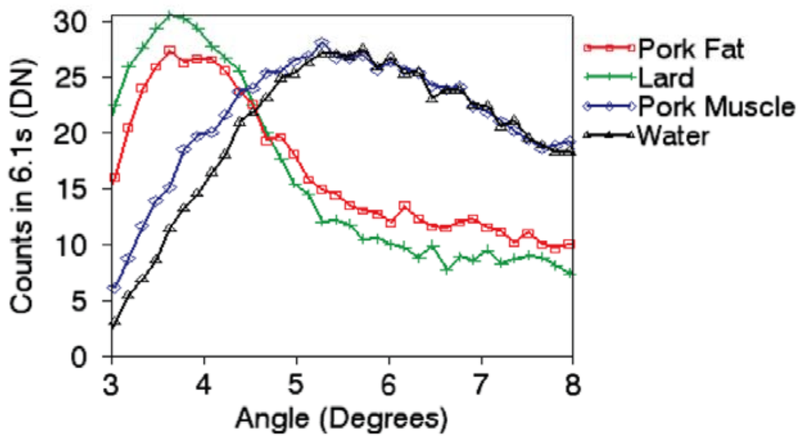
^{3}H tissue image
Back-thinned Vanilla at room temperature
36 hours

Cabello et al. IEEE Nucl. Sci. Symp. Hawaii 2007

X-ray Diffraction Imaging (UCL, RAL)

- Measure diffraction signature of tissue sample
- Allows distinction between tissues
  - Normal vs. diseased
- Large area sensor
  - Multiple integration time
  - Combined transmission and diffraction image



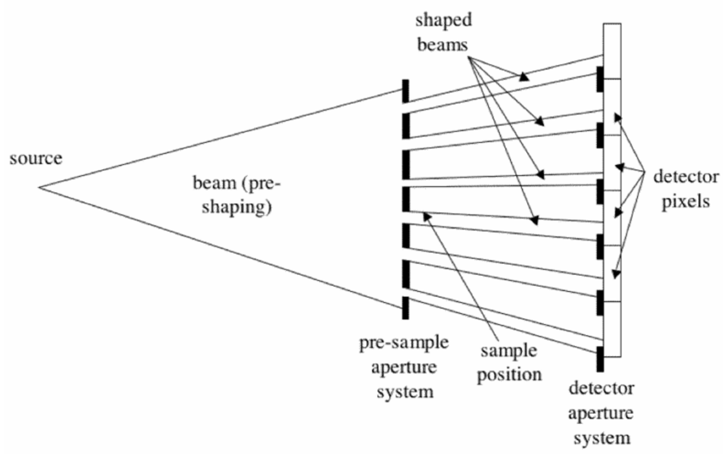


Vanilla results

Bohndiek et al. Phys. Med. Biol. 53 (2008) 655-672

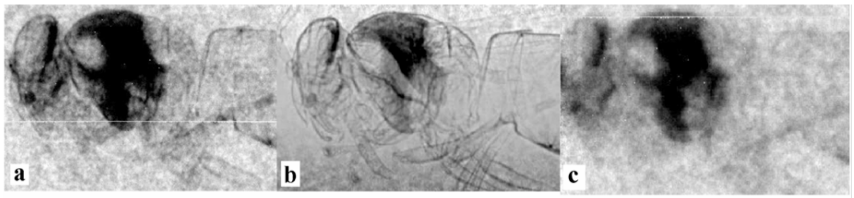
X-ray Phase Contrast Imaging (UCL, RAL)

- Based of refraction/interference
  - Shows details normally transparent
- Often Synchrotron radiation source
  - Coded aperture and polychromatic source
- Vanilla images of common wasp



Conventional source XPCi

Conventional image

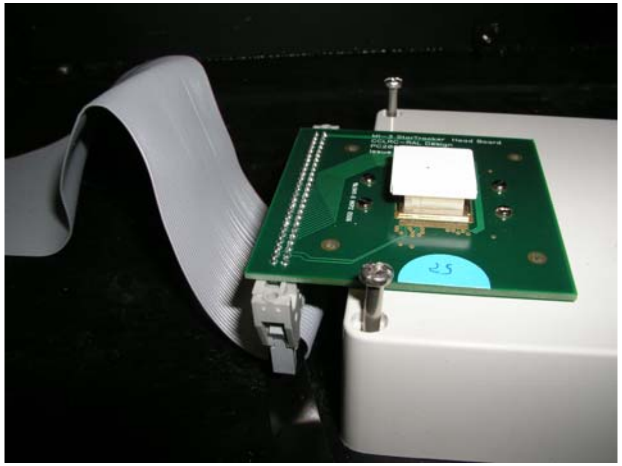


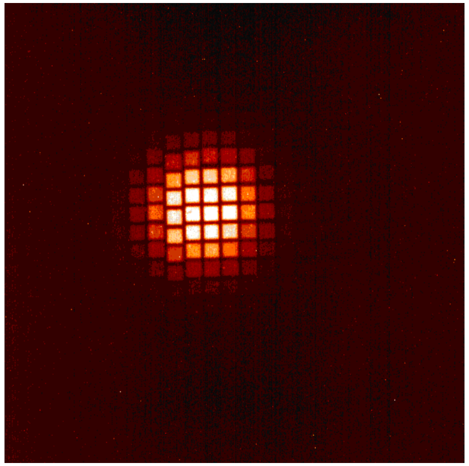
SRS XPCi

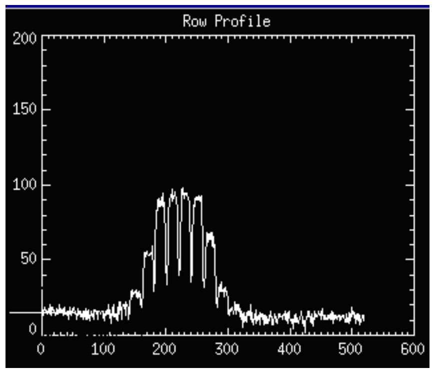
Olivo et al. NIM A581 (2007) 776-782

An APS Gamma Camera (ICR, Brunel, RAL)

- Gamma camera imaging
  - Image activity in body
  - Typically ^{99m}Tc, ^{131}I
- Detector technology
  - NaI crystals, position sensitive PMT array – large
- APS gamma camera
  - Segmented CsI array
  - Vanilla APS
  - Smaller
  - On-chip processing?







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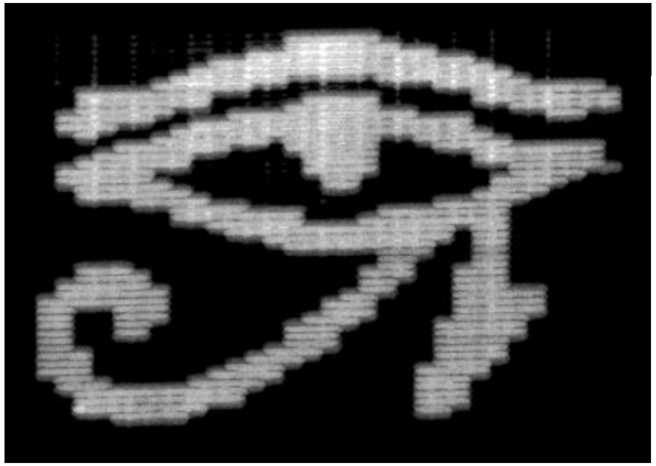
Radiotherapy Verification (ICR, Brunel, RAL, Sheffield)

- External beam radiotherapy
- X-rays – 1 to 10 MeV
- Intensity modulated radiotherapy
  - Scan "multiple finger" aperture across patient
  - Complex dose distribution
  - Complex verification



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CANCER RESEARCH UK

Osmond et al. Phys. Med. Biol. 53 (2008) 3159-3174

MI3 References

This meeting

- Blue – Monday 15.10
- Faruqi – Thursday 15.10
- Osmond – Tuesday 14.50
- Ott – Tuesday 14.30

Refereed papers

- Arvanitis
- Blue x 2
- Bohndiek x 2
- Cabello x 2
- Olivo
- Osmond
- Turchetta

http://mi3.shef.ac.uk/presentation.html

Acknowledgements

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OPIC: 'We would like to thank the CCLRC-Center for Instrumentation which funded the feasibility study for the OPIC sensor.'

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