# Active Pixel Sensors in Nuclear Medicine Imaging

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# What is Nuclear Medicine

- The use of radioactive tracers to imaging the function of living tissues
- Whole body imaging performed using gamma cameras and PET cameras with spatial resolutions of >5mm
- High resolution (<1mm) imaging desirable for studying the detail of tracer uptake

# What is an active pixel sensor (APS)

- A silicon wafer based sensor similar to a CCD but with the potential for intelligent processing in each pixel
- APSs are based on mainstream CMOS technology with low-power, high-speed, cost-effectiveness, flexibility and high levels of on-chip integration.
- The sensors used here were developed and funded under the MI-3 research consortium

# The MI-3 research consortium

- **MI-3 stands for Multidimensional Integrated Intelligent Imaging**
- **MI-3 is a four-year £4.5m Basic Technology project funded by RCUK to advance the capabilities and application of APSs for a raft of scientific and technological endeavours**

# Parameters of APS used here

| | Number of pixels per side | Pixel size (μm) | System noise (e) | Frame rates (fps) |
|---|---|---|---|---|
| Startracker | 525 | 25 x 25 | 100-120 | 10 |
| OPIC | 64 x 72 | 40 x 40 | >100 | >3700 |
| Vanilla | 520 | 25 x 25 | ~25 | 1-100 |

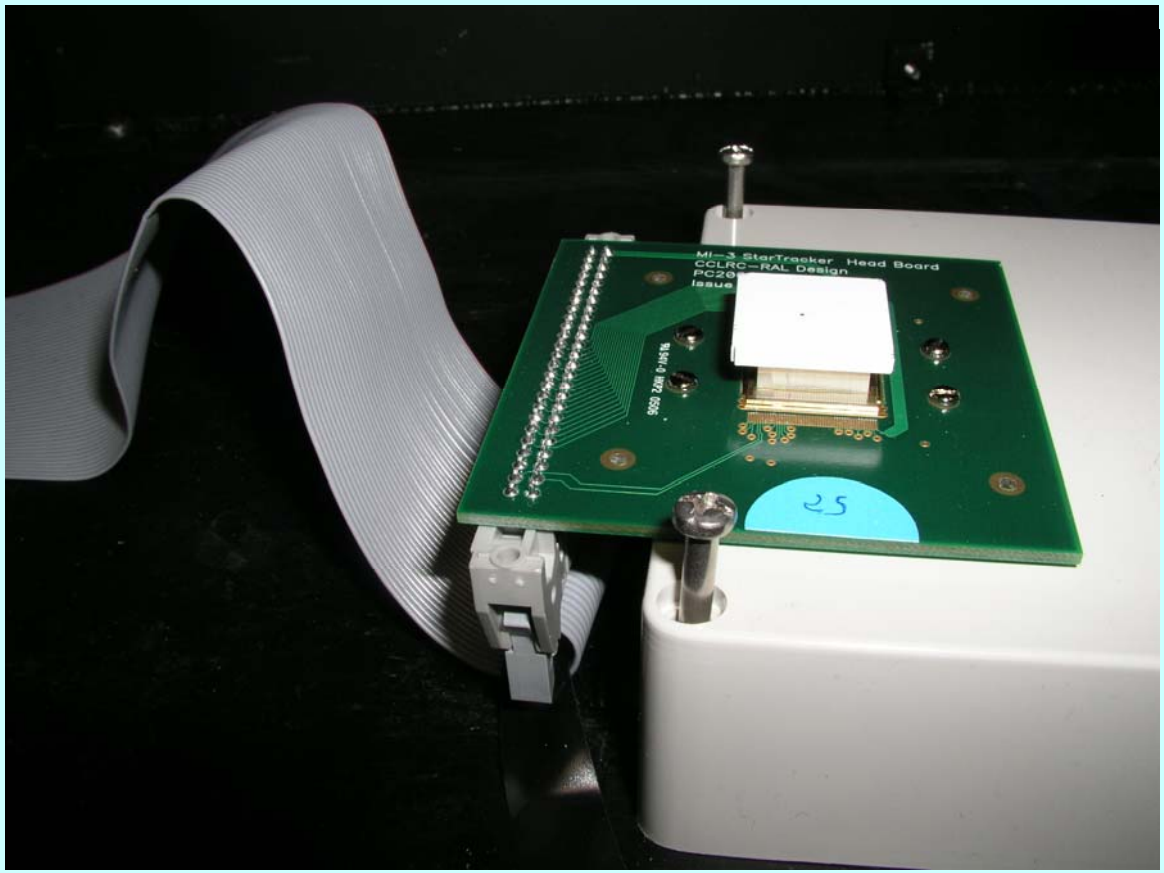
# High-resolution gamma camera wish-list

- Pixel sizes of 100 microns or more
- Coupled to thin inorganic phosphor such as CsI(Tl) to allow detection of 140keV photons
- Low noise (few electrons) needed
- >100 $cm^2$ sensitive area
- Kcps photon counting capacity
- On-chip pulse and cluster analysis for signal selection and noise reduction

# High-resolution gamma camera (what we have so far)

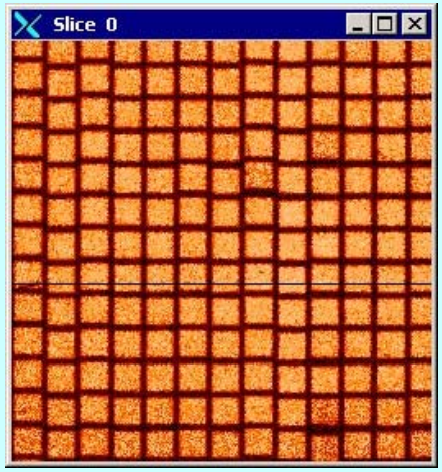
- Pixel sizes of 25-40 microns
- Coupled to 2mm thick CsI(Tl) phosphor segmented into 400 micron elements
- 25-120 electrons noise
- ~2 $cm^2$ sensitive area
- A few 10s of cps photon counting capacity
- Off chip data analysis

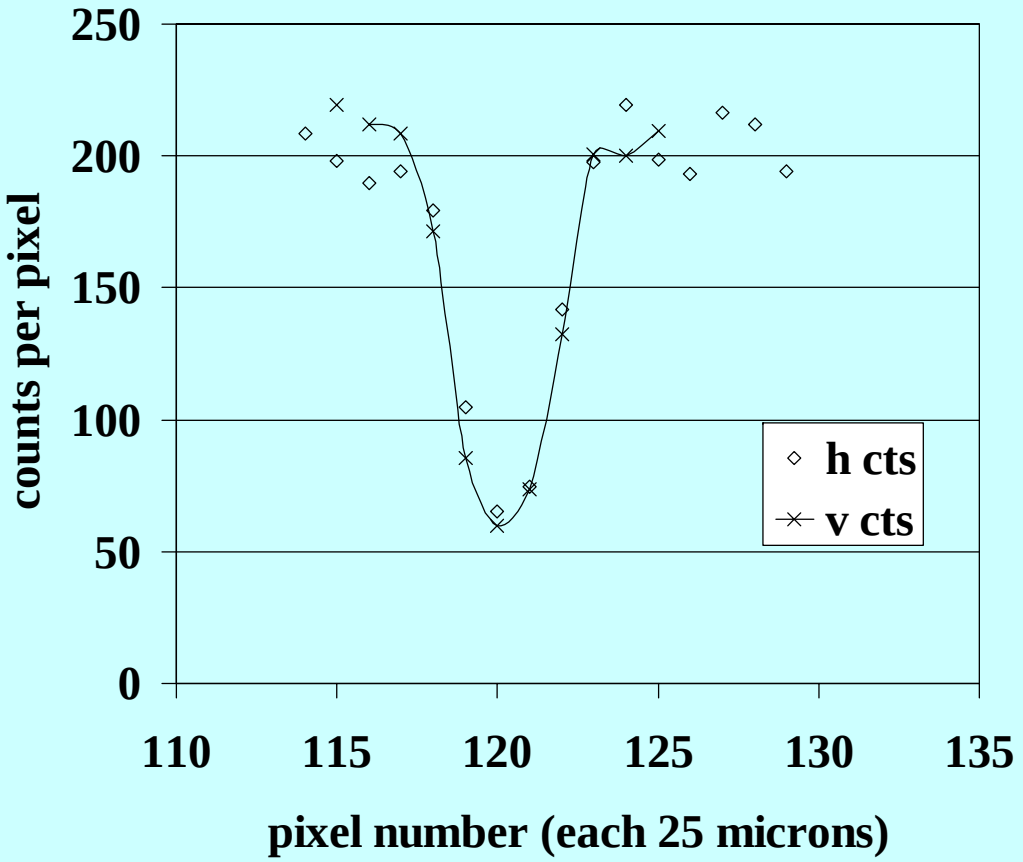
# The Startracker imaging setup




**APS coupled to pixelated CsI(Tl) phosphor via optical fibre stud**

# Intrinsic spatial resolution measured with Startracker

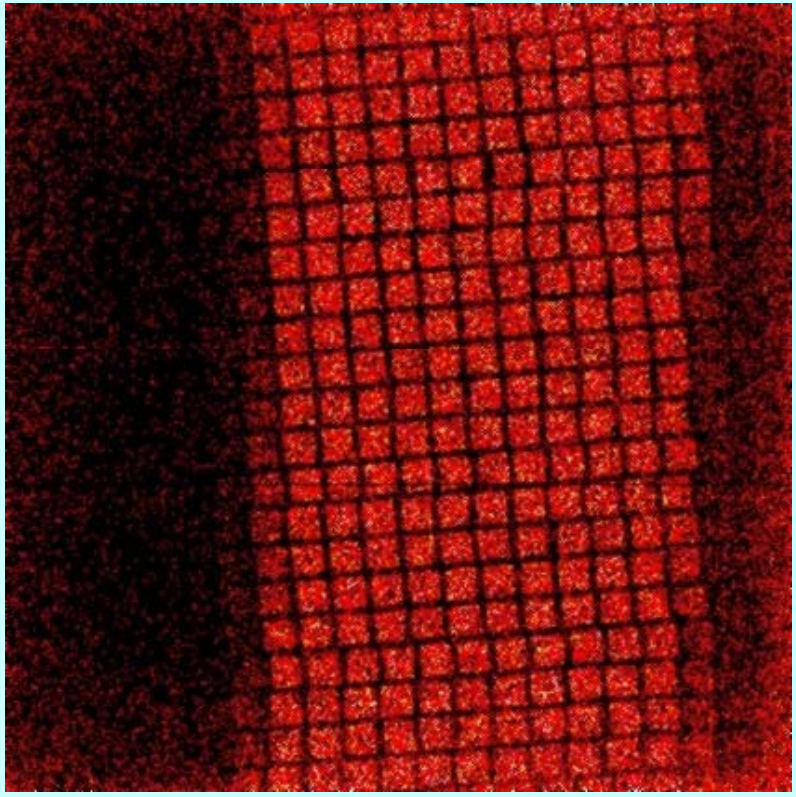


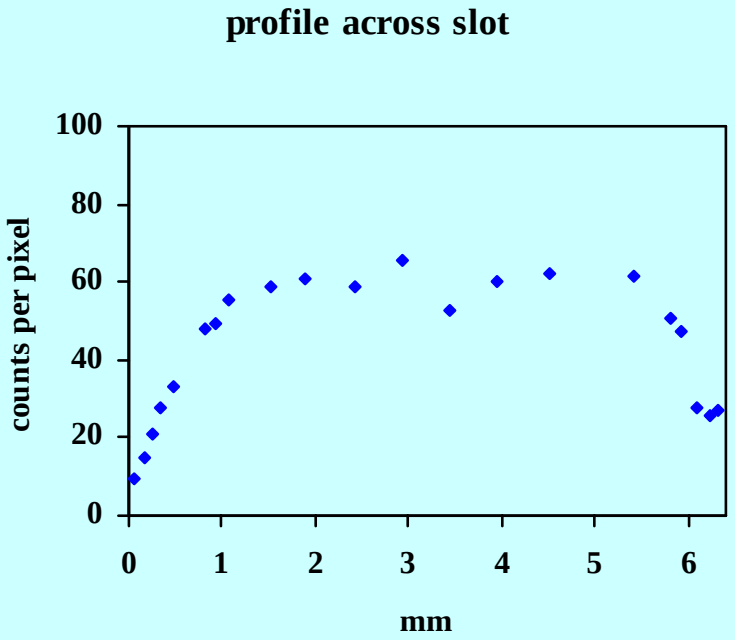




**Spatial resolution ~80 microns FWHM**

# Startracker system resolution measurements

5mm wide slot



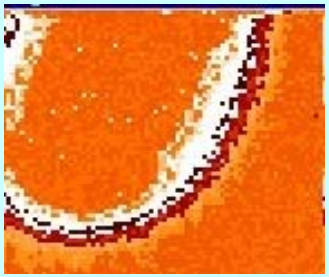



System resolution is about 450 microns

# Conclusions from Startracker studies

- Pixel sizes are smaller than needed reducing signal to noise by splitting signal
- Overall background is too high requiring noise removal
- Background is dominated by ‘fixed pattern noise’ which can be ‘subtracted.
- Thermal noise reduction makes only a small contribution for this sensor

# Noise studies with OPIC



Single frame illumination with laser pointer

Template produced from pixel variance analysis of multiple frames

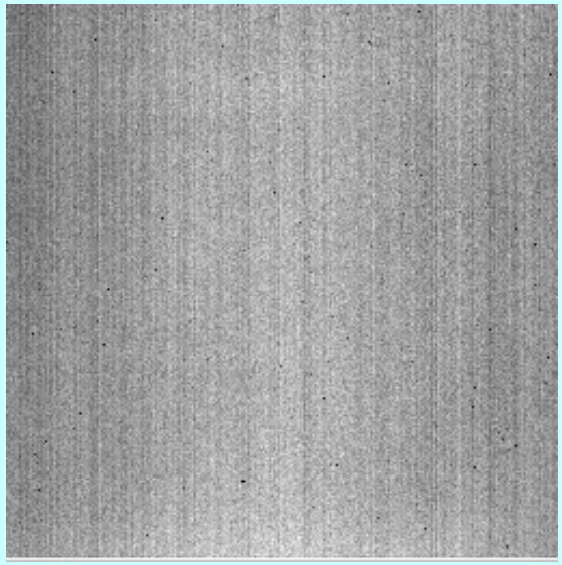
Fixed pattern noise

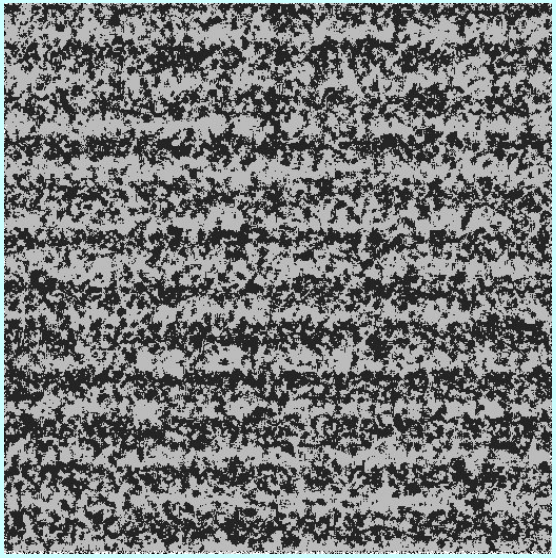
Statistical noise

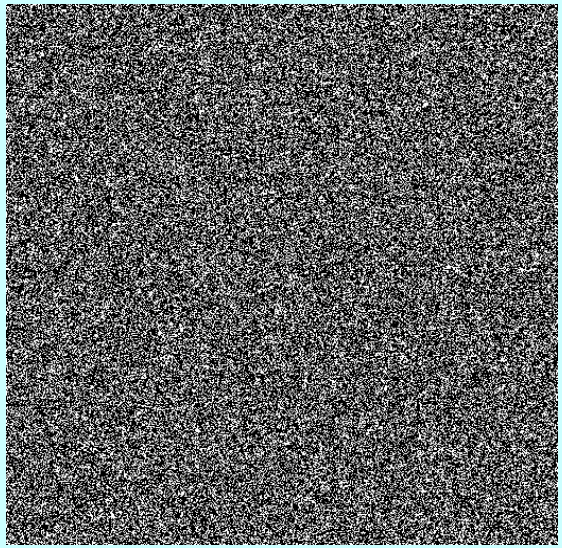
# Conclusions from noise studies with OPIC

- Pixel noise is dominated by 'fixed pattern noise'
- By studying the variance of pixel noise in multiple frames it is possible to differentiate between statistical noise and fixed pattern noise.
- A simple method of noise 'subtraction' can be used to remove fixed pattern noise from pixels

# Noise images taken with Vanilla



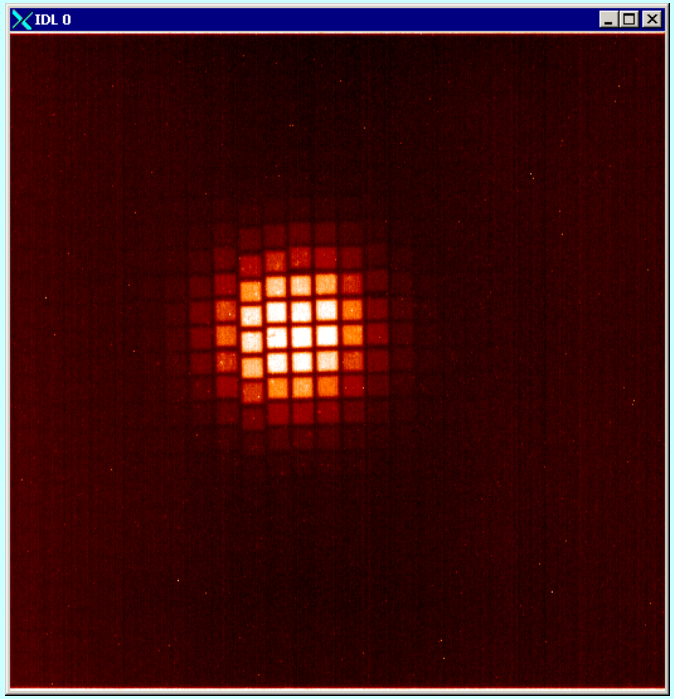


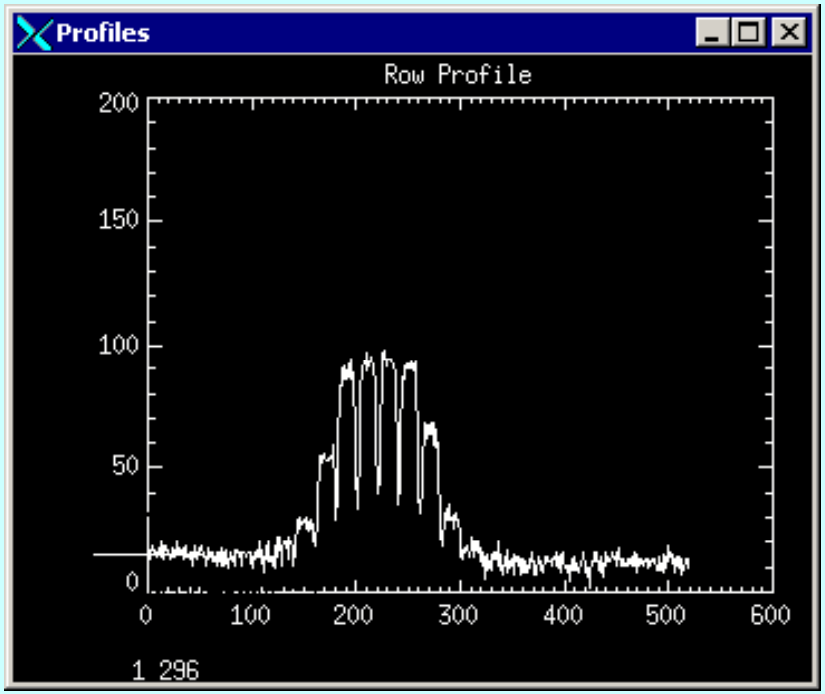


**Total noise** **fixed pattern noise** **statistical noise**

**Data from dark frame images**

# Images taken with Vanilla

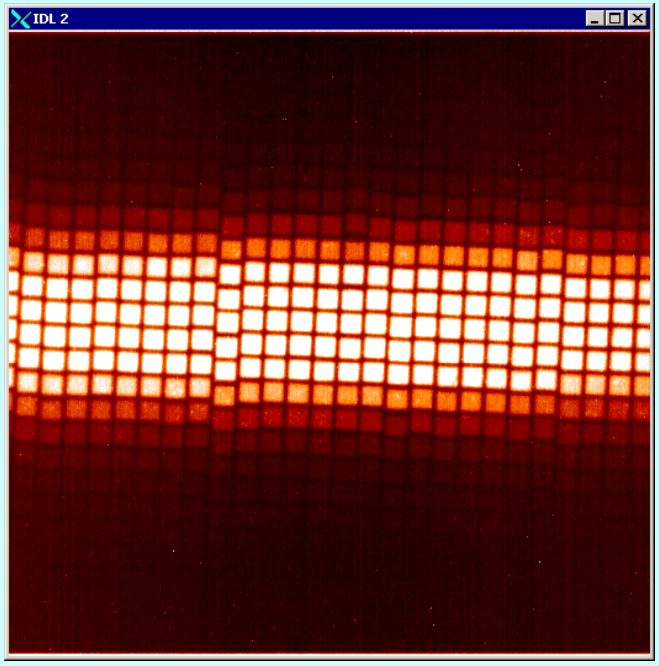


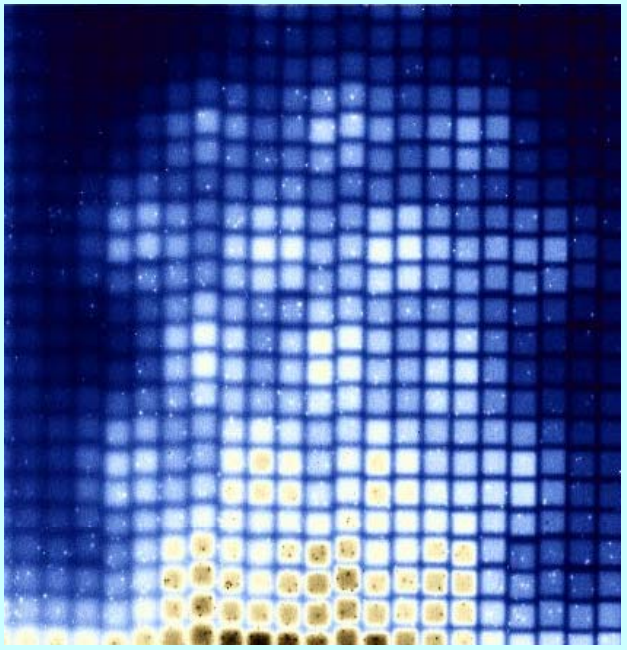




**2mm wide illuminated hole** **horizontal profile**

**Multi-frame acquisitions after fixed pattern noise removal**

# Images taken with Vanilla



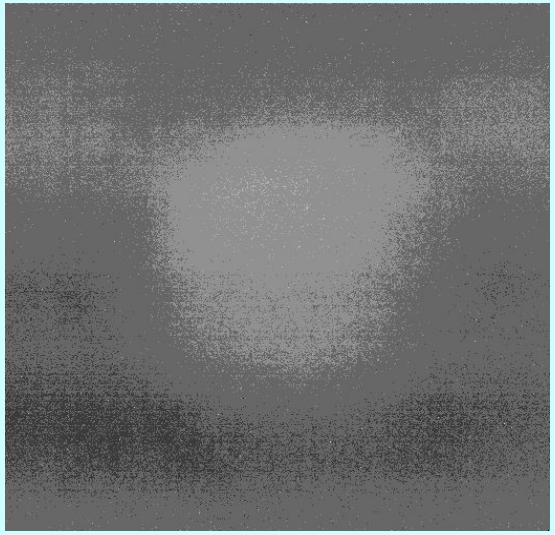



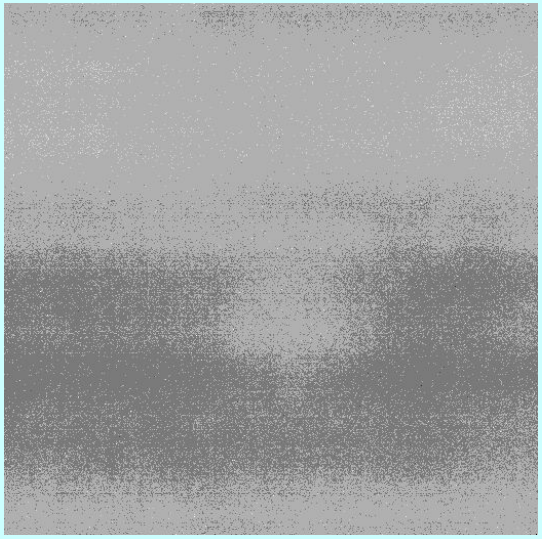
5mm wide slot

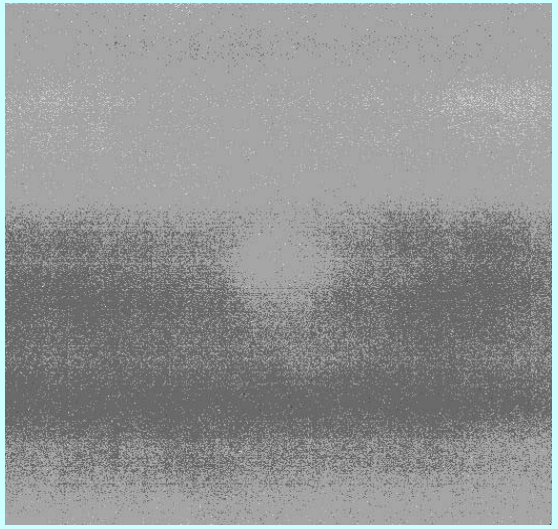
1mm holes on 2mm centres

Multi-frame acquisitions after fixed pattern noise removal

# Images taken with Vanilla using thin non-segmented CsI(Tl)







6mm wide hole

3mm holes

2mm wide hole

Multi-frame acquisitions after fixed pattern noise removal

# So where are we at?

- Tc-99m gamma rays produce ~7000 optical photons in CsI(Tl)
- Number of optical photons reaching sensor is probably ~600-800
- Area of sensor sensing each event ~400 μm (size of phosphor element)
- With 40 μm pixels the signal is spread over 100 pixels (25 micron pixels are worse)
- Hence even for 100% QE the signal per pixel will often be less than the noise
- Use of thin, non segmented phosphor might help but the detection efficiency is much lower
- Larger area sensor with larger pixels (>100 μm) and lower noise would work

# Conclusions

1. APS Devices with the right parameters could make a contribution to high resolution Nuclear Medicine Imaging

2. Noise levels are still a problem for this application

3. Fixed pattern noise dominates over thermal noise making noise removal easier

4. On-chip intelligence to filter out noise would be useful

5. Larger area devices with larger pixels essential.

# Future

Large area sensor is now being released by RAL

Sensitive area of 56mm x 56mm in area with 1400 x 1400 pixels

Pixel sizes 40μm

Pixel noise levels ~**e

# Acknowledgements

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the MI-3 consortium for scientific discussion and input

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