The application of Large Area Active Pixel Sensor (LAS) to high resolution Nuclear Medicine imaging

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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 and have generic benefits of low-power, high-speed, cost-effectiveness, flexibility and high levels of on-chip integration.

Other APS properties

Back thinning allow low energy beta/gamma/X-ray radiation to be detected

Devices can be used either as direct sensors or coupled to phosphors for example.

Devices can be read out through special FPGA based interfaces to allow data acquisition onto a PC or laptop.

Potential for radiation hardness

Potential for ROI read-out

The MI-3 research consortium

MI-3 stands for Multidimensional Integrated Intelligent Imaging

MI-3 was a four-year £4.5m Basic Technology project funded by UK-RC to advance the capabilities and application of APSs for a raft of scientific and technological endeavours

Consortium members

Universities of Sheffield, Liverpool (2 groups), Glasgow, Surrey, York, Brunel, UCL and

Rutherford Appleton Laboratories

MRC Laboratory for Molecular Biology,

Institute of Cancer Research.

MI-3 APS applications

Medical and biological imaging (UCL, Surrey, ICR)

Space science (Brunel)

Bioarray imaging (Liverpool)

Electron microscopy (Cambridge)

Particle physics (Liverpool, Glasgow)

Synchrotron radiation applications (Sheffield)

Materials science (York)

Detector Design and testing mostly done at RAL/STFC

Properties of APSs used in this project

	# Pixels	Pixel size (μm)	System noise (e)	Frames/s
Startracker	525 × 525	25	>100	10
Opic	64 × 72	40	>100	>3700
Vanilla	520 × 520	25	34-52*	1-100**
LAS	1350 × 1350	40	40-62*	20**

*Indicate the noise range which is dependent on the reset type.

**The rates depend on whether full-frame or ROI read-out is used.

High-resolution Nuclear Medicine imaging requirements

Pixel sizes of 50-100 microns

Coupling to CsI(Tl) phosphors to detect 140keV photons

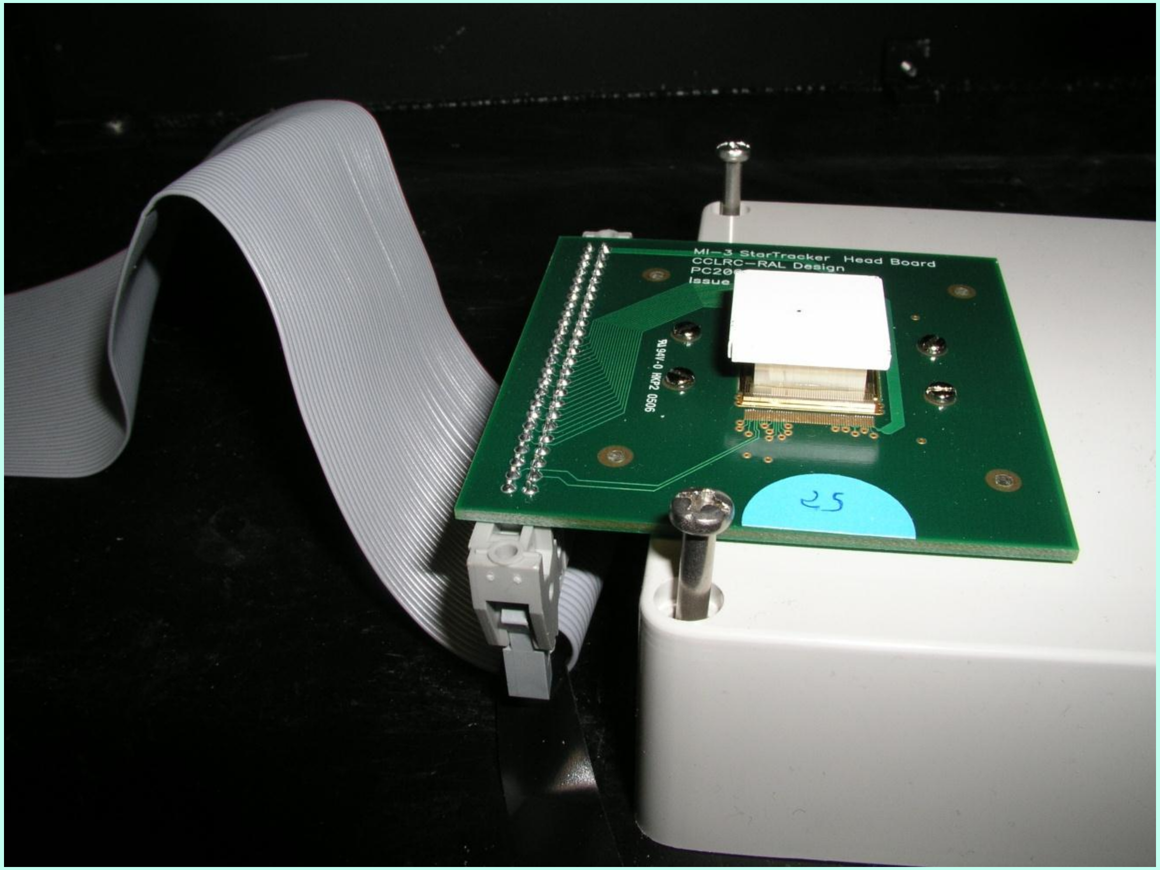
Low noise needed as signal is small

>100 cm^2 sensitive area

Kcps photon counting capacity

On-chip pulse and cluster analysis for signal selection and noise reduction

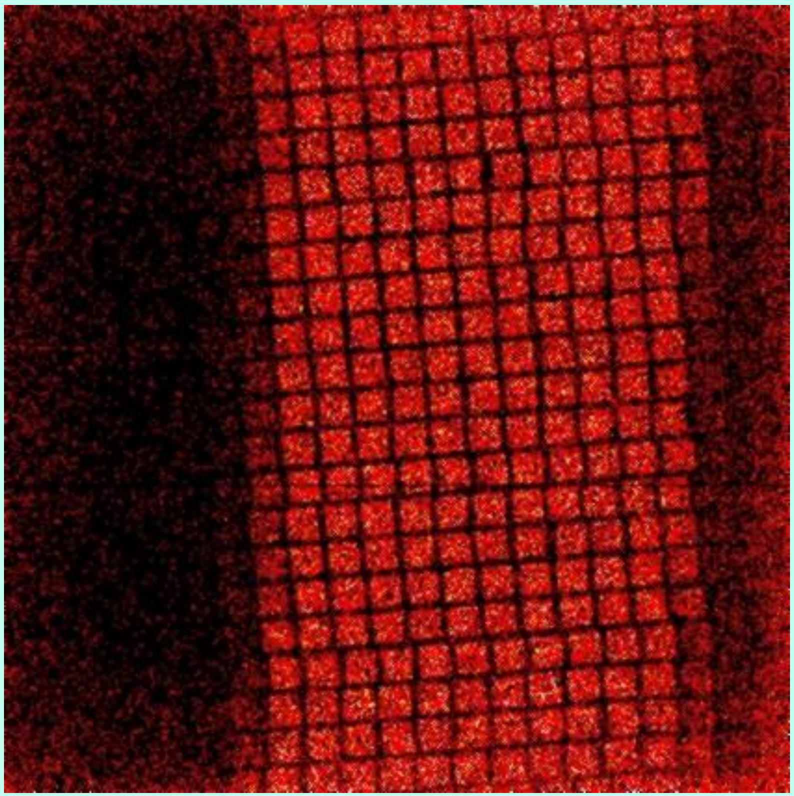
High-resolution gamma camera

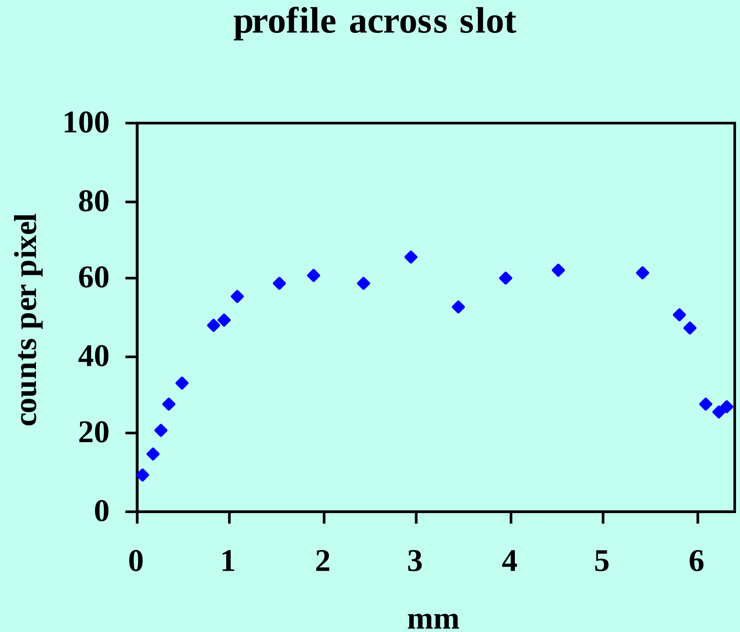


APS coupled to pixelated CsI(Tl) phosphor via optical fibre stud

High-resolution gamma camera

5mm wide slot





System resolution is ~1mm FWHM

Using 2mm thick CsI(Tl) scintillator with 400μm elements coupled to Vanilla

LAS

Pixel size 40 μm x 40 μm

1350 x 1350 pixels

54 mm x 54mm stitched sensor

Read-out noise between 40e and 62e

73% fill factor

Region of interest read-out available

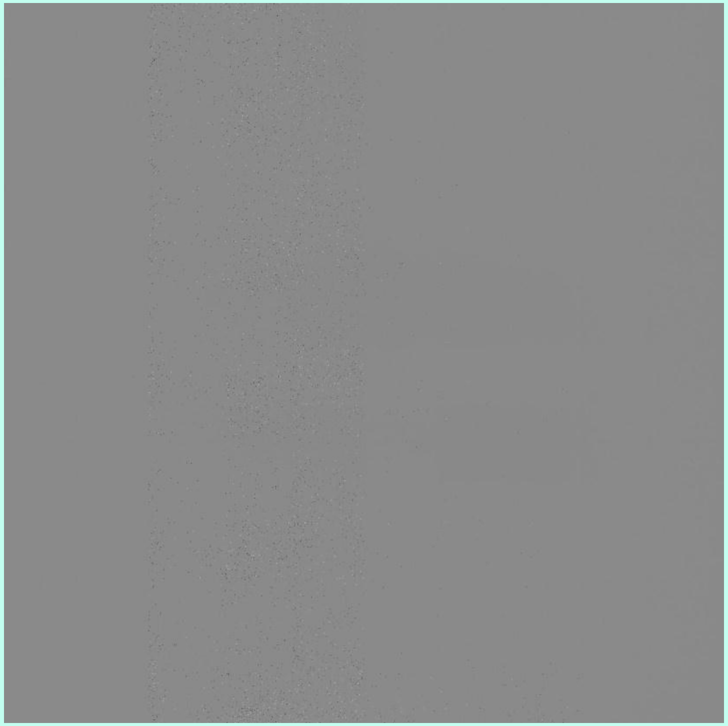
Maximum frame rate $20s^{-1}$

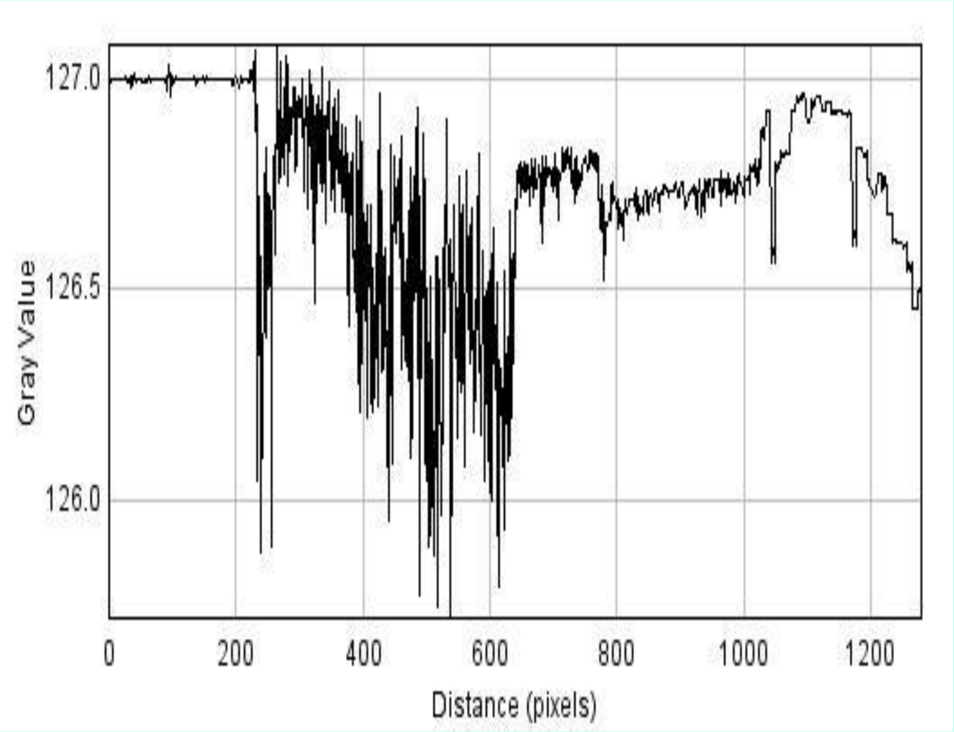
QE at 520 nm ~22% (Vanilla >60%)

Average QE between 500nm and 800nm ~16%

Bohndiek et al, IEEE TNS, 56, 2938-2946, 2009

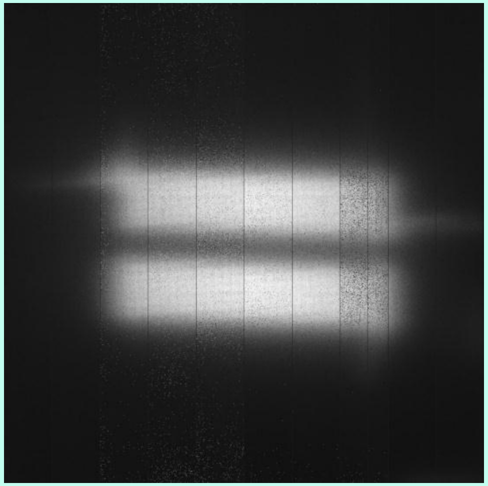
Dark image taken with LAS

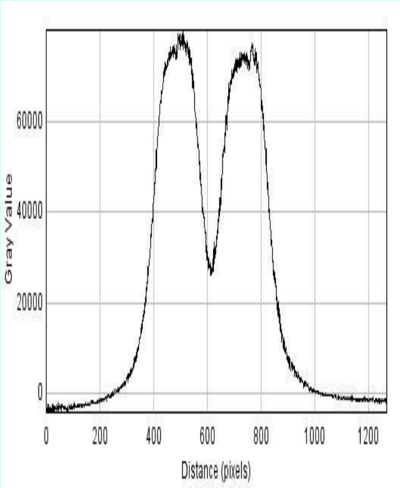




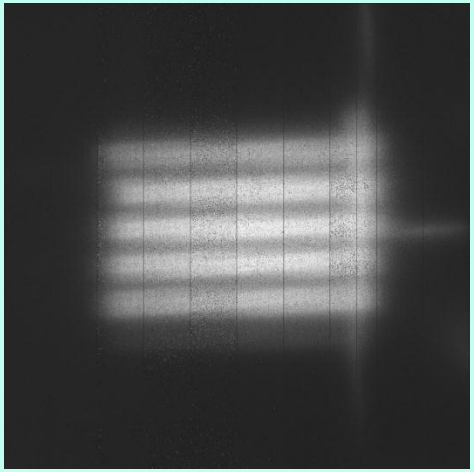
Horizontal profile

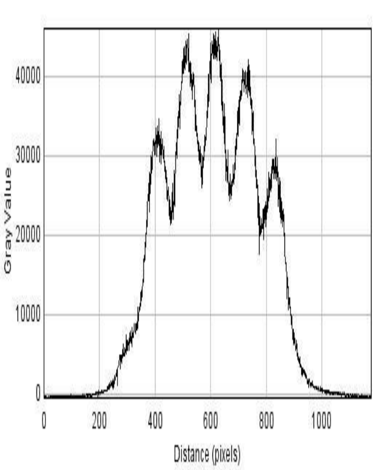
X-ray resolution phantom imaging





0.1 lp mm-1

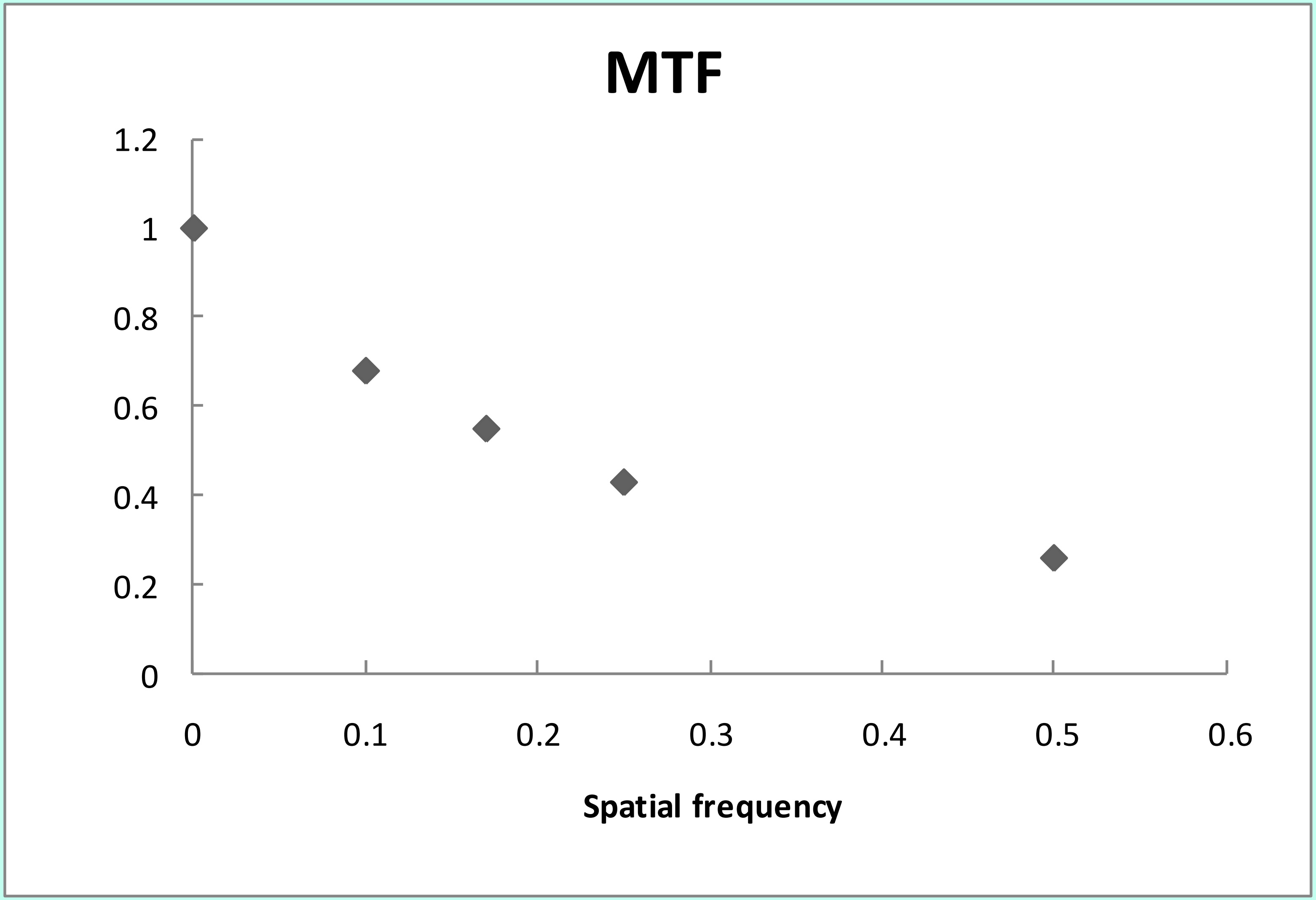




0.25 lp mm-1

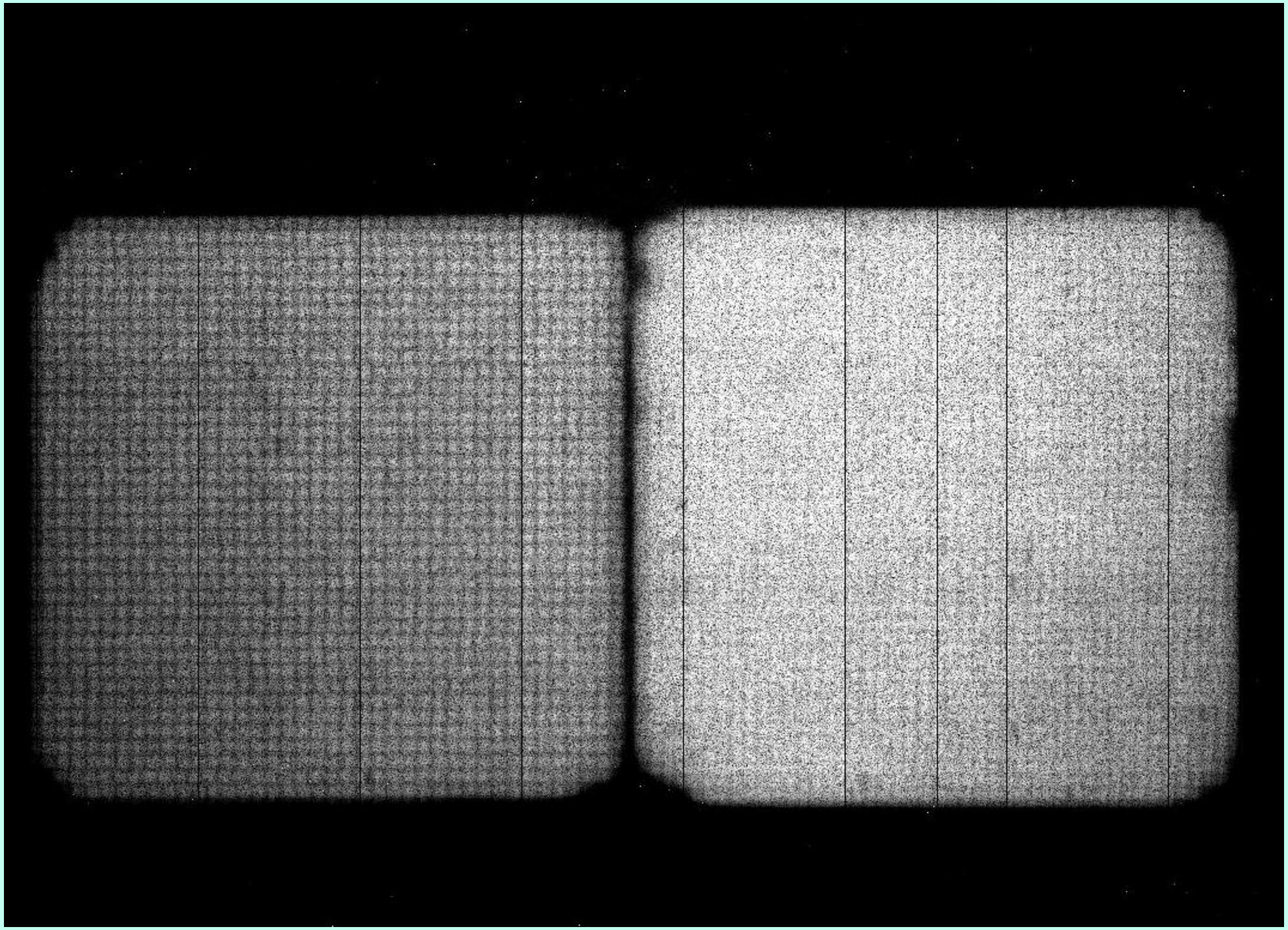
Taken with a ^{99m}Tc flood source

LAS coupled to unsegmented 2mm thick CSI(Tl) flood source



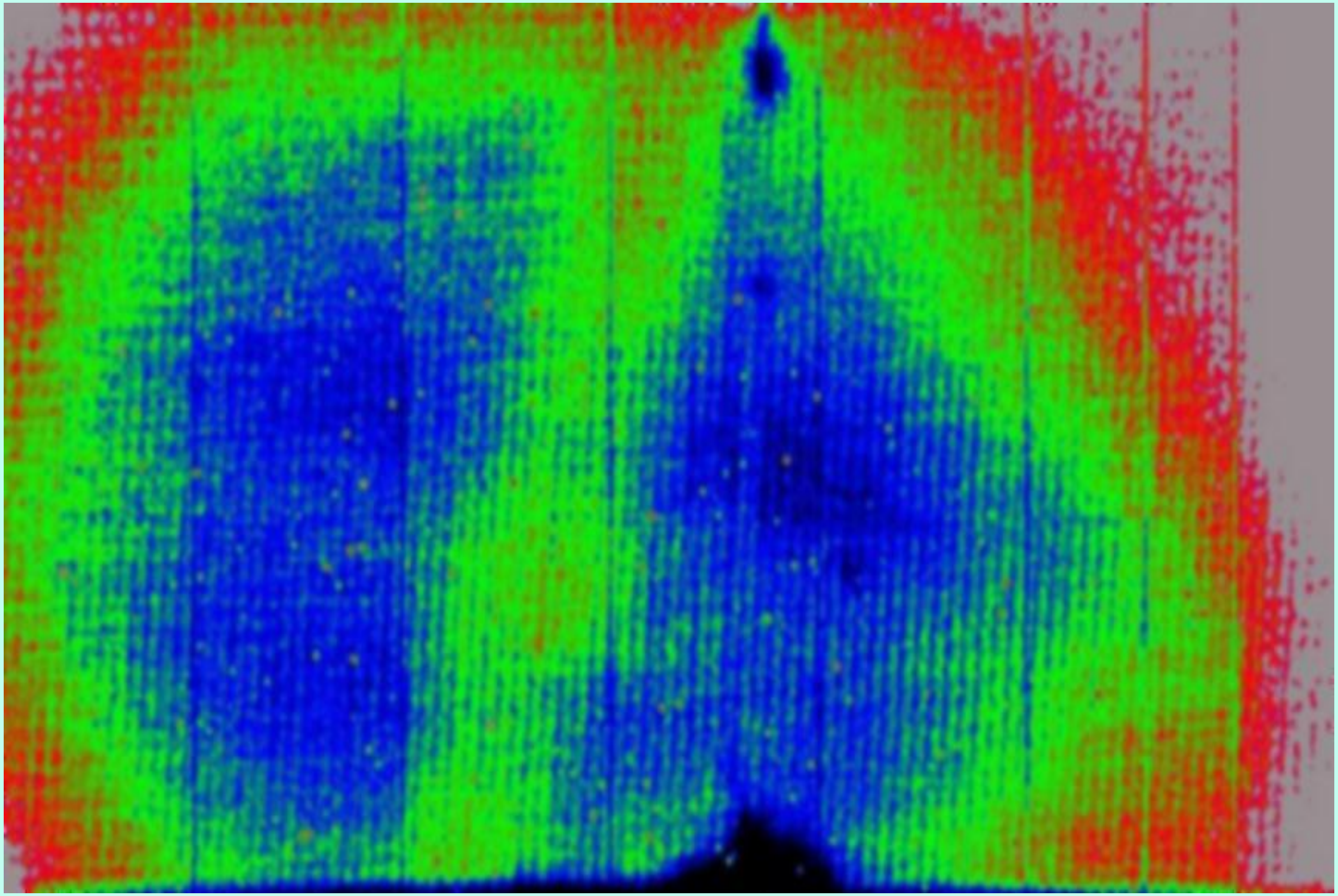
FWHM of ~ 2.5mm

LAS flood image of 20mm x 20mm segmented CsI(Tl) scintillators

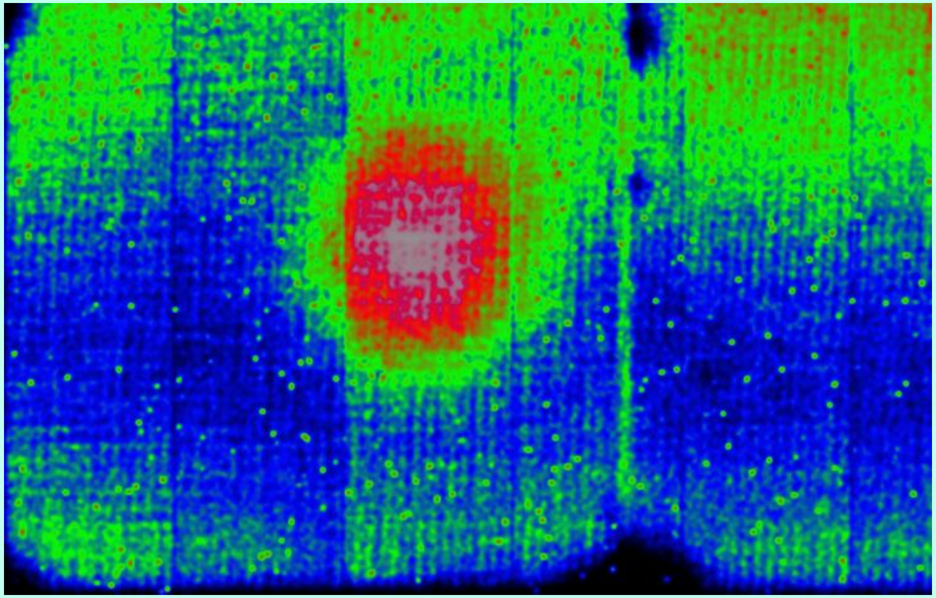


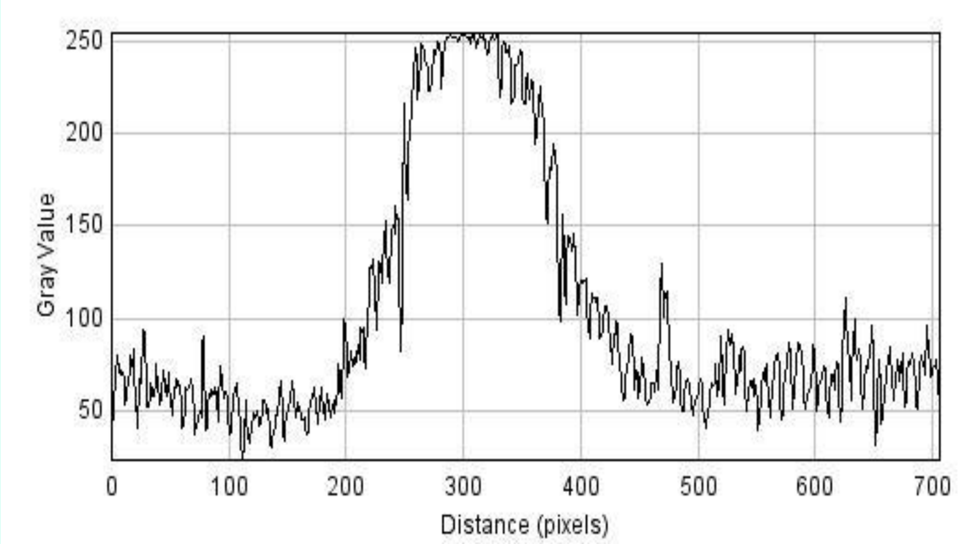
400µm elements **350µm elements**

LAS image of crossed lines thru 3mm pinhole



LAS image of 5mm diam sphere thru 3mm pinhole





Problems and solutions

- The signal from Tc-99m is small so that segmented CsI (Tl) is important
- Higher QE (from <20% to >60%) essential
- Processing to remove fixed pattern noise improves image quality
- Larger CMOS pixels with low noise preferred
- Larger area than LAS needed – see Dynamite

Dynamite – coming soon

Active area 120 mm x 120 mm

Two pixel sizes – 50 µm and 100 µm

15 frames/s for full read-out

Faster for ROI read-out

Pixelated CsI(Tl) scintillator available

Conclusions

APSs could make a contribution to Nuclear Medicine imaging

Noise level requirements are similar to CCDs but with faster readout speed

Fixed pattern noise dominates over thermal noise

On-chip intelligence for noise filtering and allow ROI selection

Large area devices essential for this application

Dynamite will be very interesting