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Infrared sensors with avalanche gain for radical improvement in sensitivity in space borne instruments

Stuart Cripps, Ian Baker and Keith Barnes

CEOI Innovations in Remote Sensing Event
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Selex ES has a unique 3rd Gen MOVPE HgCdTe technology for science and space applications

MW MERLIN
1024 x 768 pixels, 16 μm pitch
NETD 16 mK

MOVPE grown on GaAs substrates
$100 each for 76mm wafers

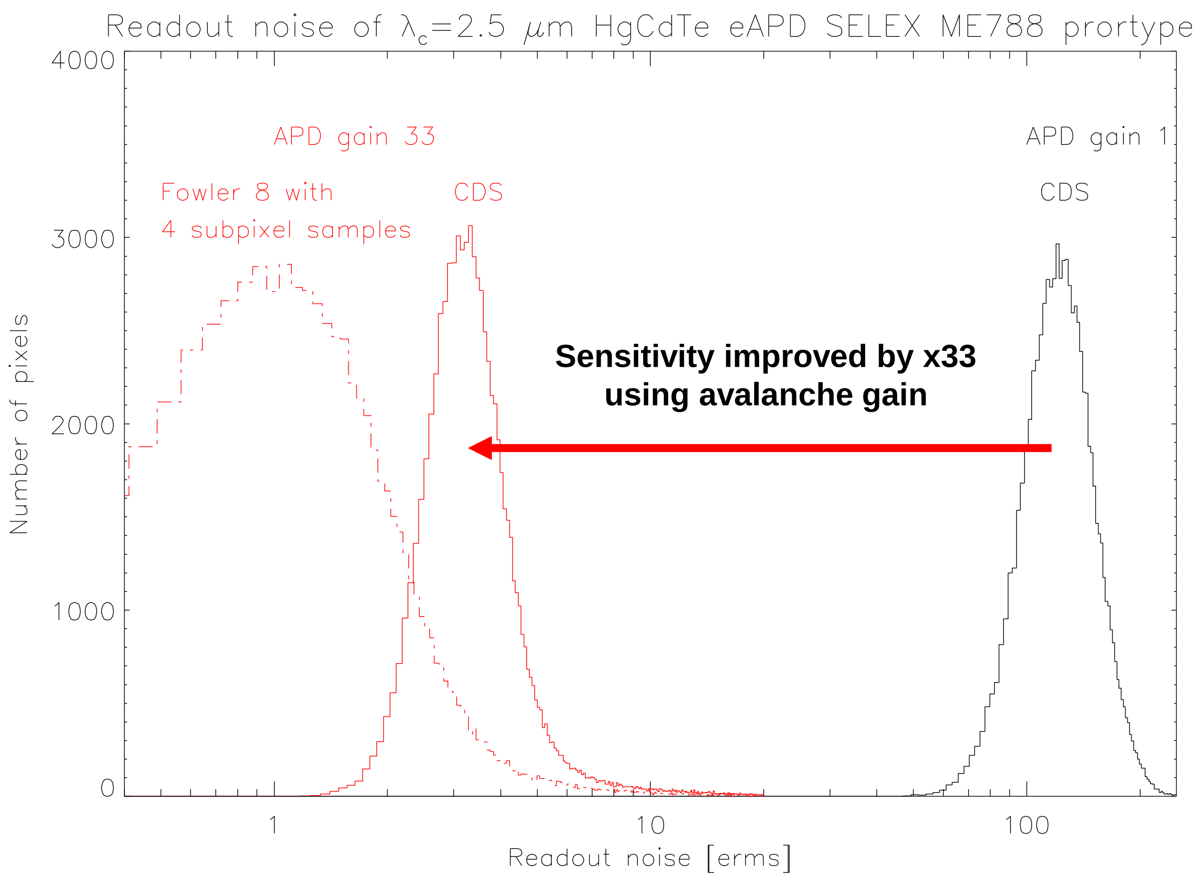
LW HARRIER
640 x 512 pixels, 24 μm pitch
NETD 17 mK (12 mK in binning mode)

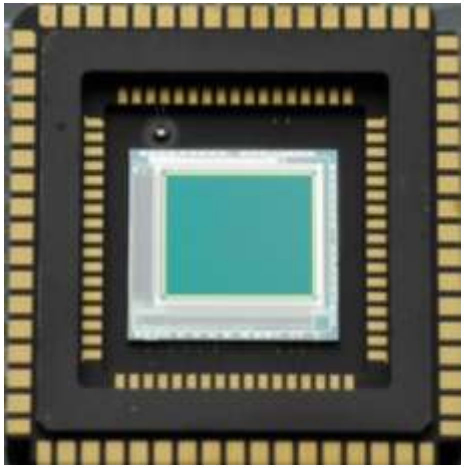
HgCdTe eAPD FPAs in low background flux applications

Earth observation
Astronomy
Wavefront sensors
Spectroscopy
Interferometry
Photon counting
Ultra-fast imaging

eAPDs in HgCdTe

Usually give pro-rata improvement in sensitivity



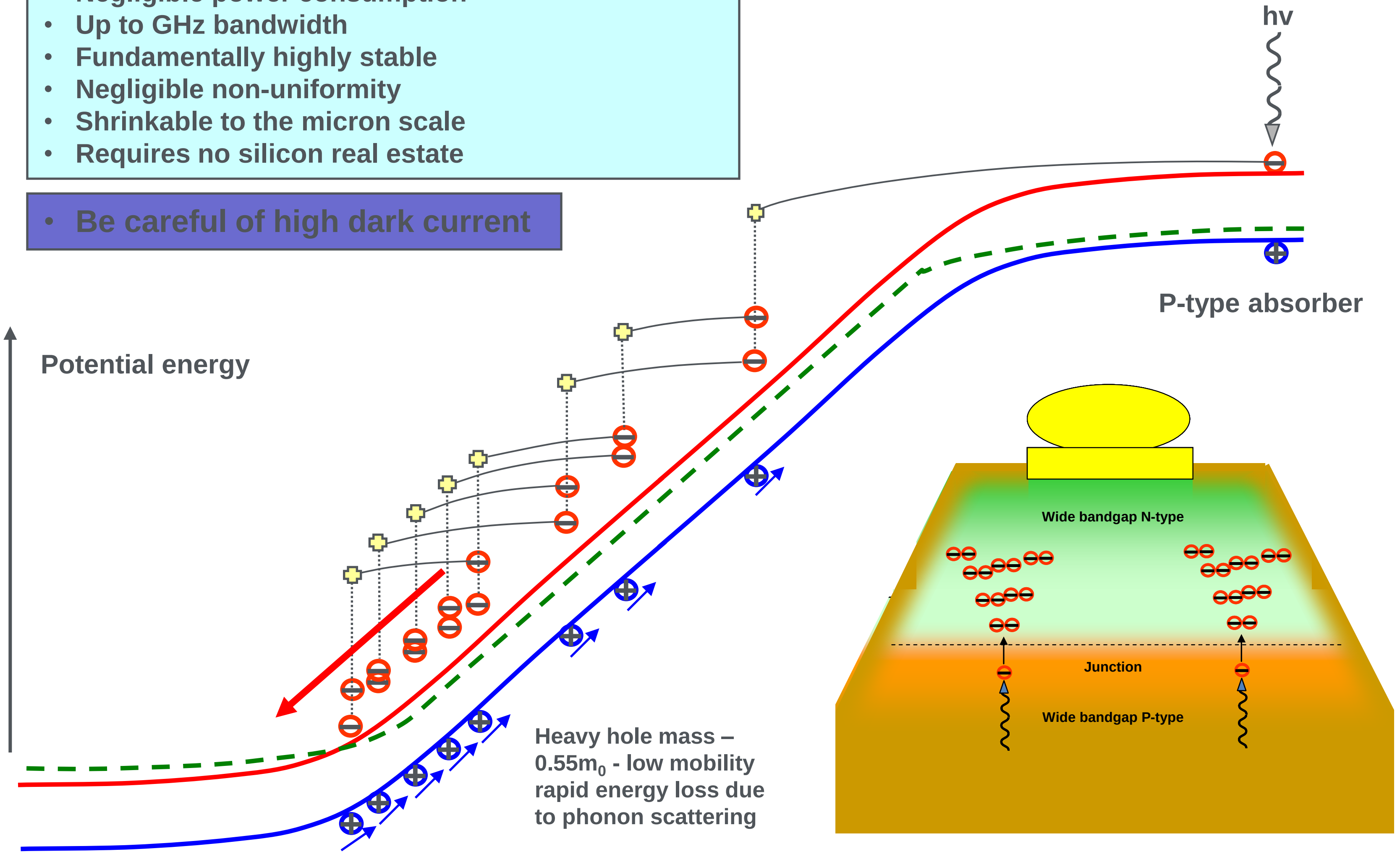


Courtesy of European Southern Observatories, ESO, with special thanks to Dr Gert Finger

Avalanche gain in HgCdTe

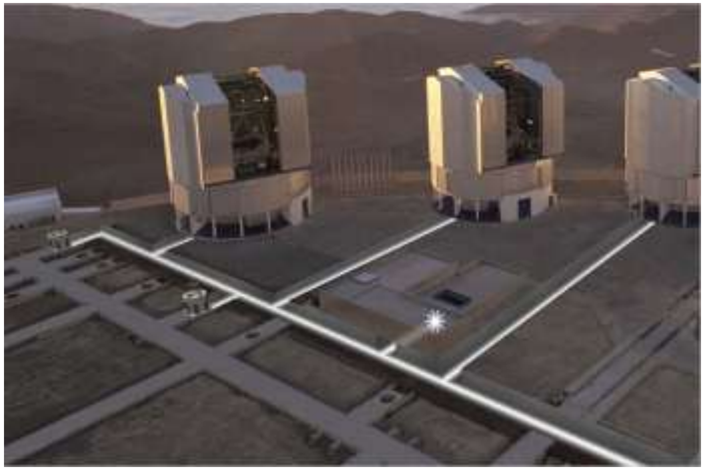
- Voltage controlled gain in depletion region
- Little noise in gain
- Negligible power consumption
- Up to GHz bandwidth
- Fundamentally highly stable
- Negligible non-uniformity
- Shrinkable to the micron scale
- Requires no silicon real estate

- Be careful of high dark current



Astronomy community are using APDs in advanced telescopes i.e. VLT Interferometer

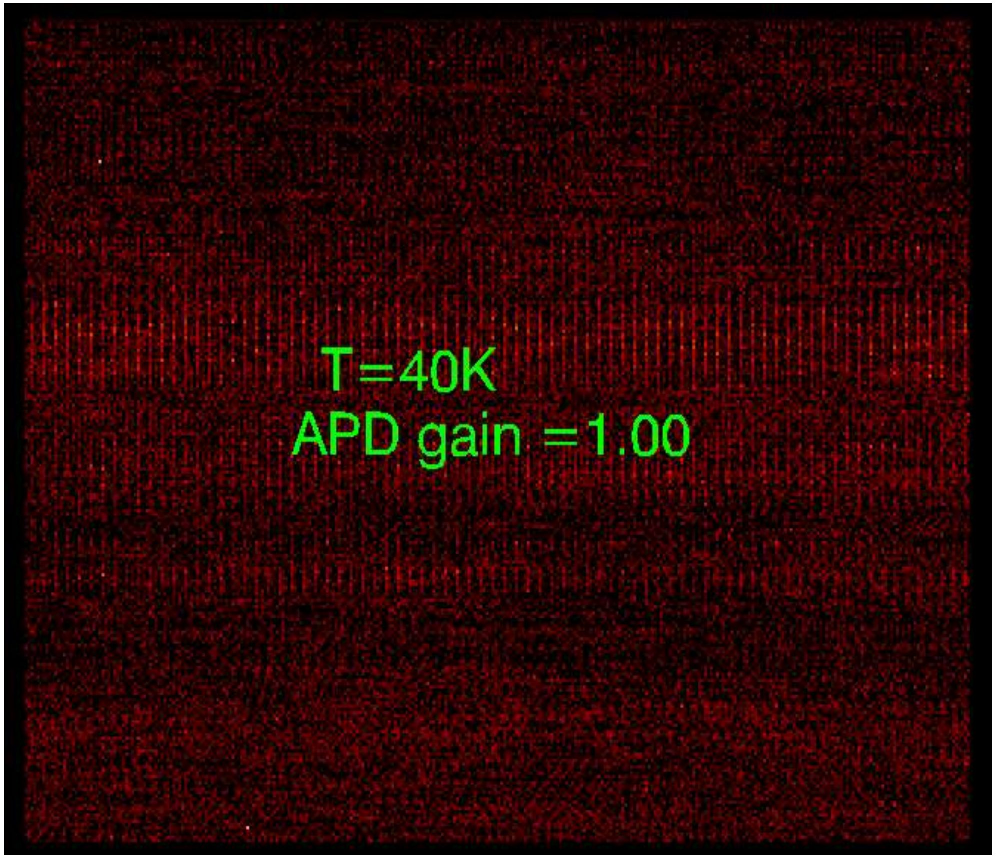
European Southern Observatories, ESO
Very Large Telescope, VLT – cluster of four 8.2m unit telescopes



The VLT Interferometer and GRAVITY instrument

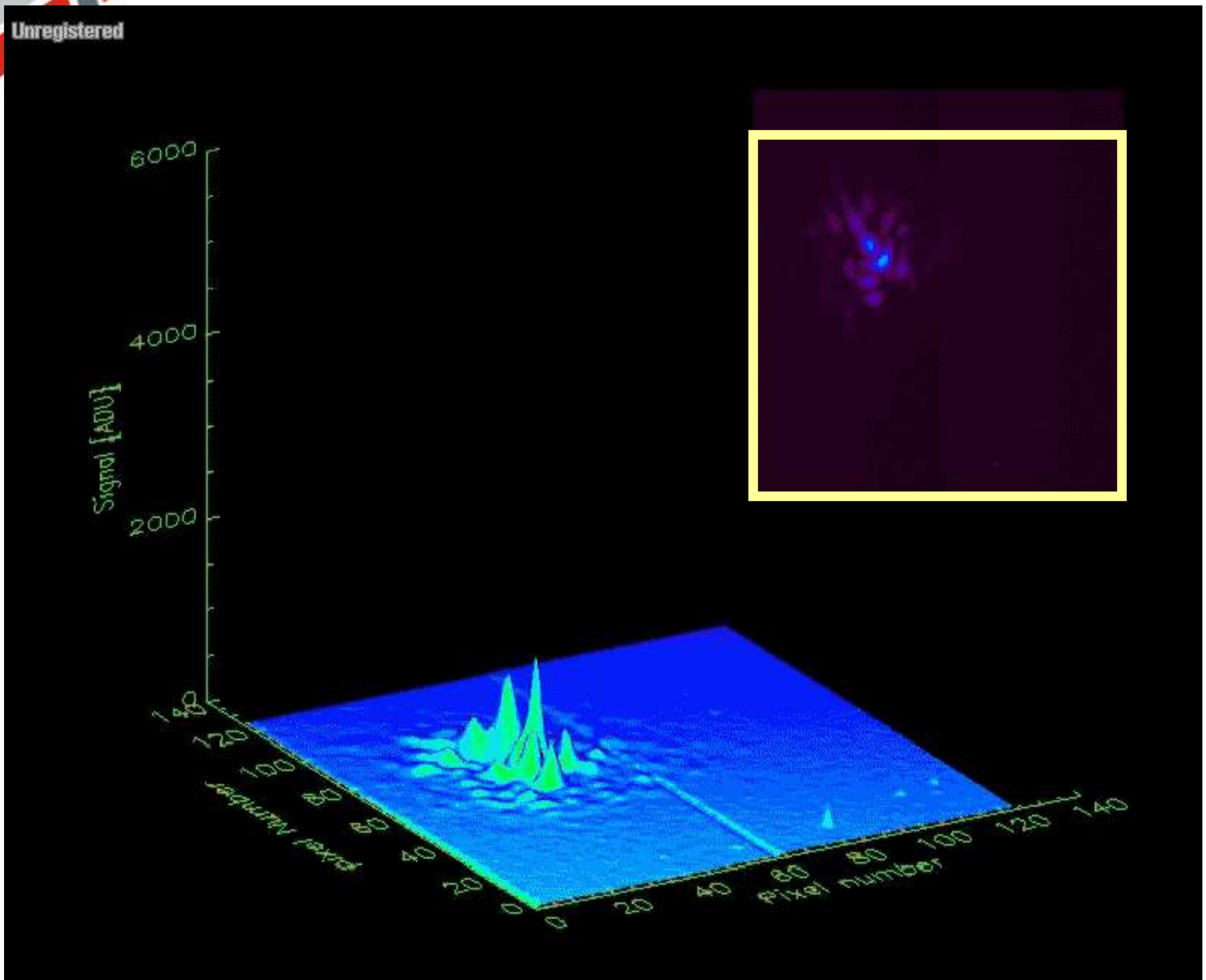
- GRAVITY will combine the signals of four 8.2 metre telescopes to achieve the sensitivity and resolution of a 200 m telescope.
- Narrow angle astrometry with an accuracy of < 10 micro-arcseconds.
- Interferometric imaging for objects as faint as K = 11.
- Pioneering research at the event horizon of black holes, resolution of exo-planets and the origin of protostellar jets.

Signals can be resolved deep in the noise by avalanche gain



Pattern contrast – 14 ph/pixel

eAPDs are used for wavefront sensors using dim stars within the field

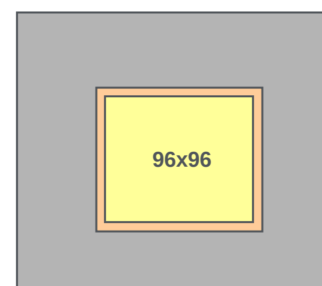


VLTI requirements

- Adaptive optics needed to correct for atmospheric distortion using embedded sources (galactic center).
- The IRIS instrument is used for simultaneous first order wavefront corrections (tip-tilt) of all 4 telescopes on a single detector

APD wavefront sensor:

- 256x256 array at K band
- Frame rate >10KHz
- Sensitivity <3e rms at 5MHz
- 32 parallel outputs
- 24µm pixel size
- Non-destructive readout



Work Conducted Under The UKSA Future Technology Pathfinder Programme

- Selex ES were awarded a contract under the FTPP to investigate the reliability and performance of HgCdTe electron avalanche gain photodiode (eAPD) focal plane array (FPA) detectors for short wave and near infrared space sensing and other low-flux imaging applications

- The highlights of this work are reported here

Extended lifetime testing of eAPDs in HgCdTe

- HgCdTe eAPDs are exposed to high voltages and the space community wish to be assured that these components can operate reliably over long periods.

- To study the robustness of HgCdTe APDs several arrays were subjected to extended lifetime testing which involved:

  - Prolonged **high temperature** baking (equivalent to many years at normal temperature)

  - Testing under **high flux** conditions (equivalent to many years cooled and operating)

- Typical results from the study are highlighted here

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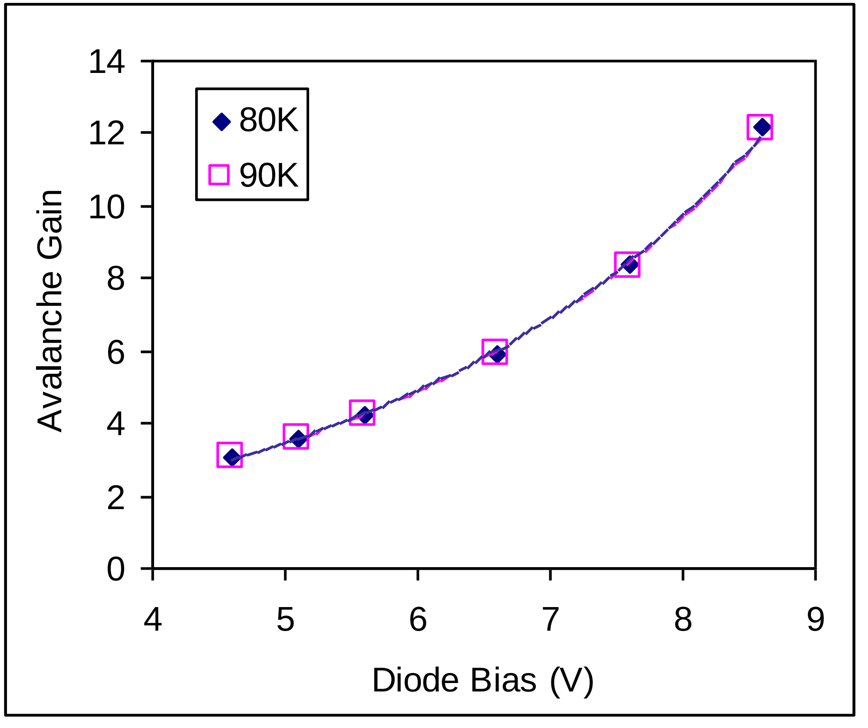
Avalanche gain stability with respect to operating temperature

- A 2.5μm (cut-off wavelength) HgCdTe eAPD array was tested at 80K and 90K operating temperature and the avalanche gain was measured as a function of applied diode bias

- The graph shows excellent consistency between the two operating temperatures
  - This indicates any system with reasonable control over the FPA temperature will have stable performance in low flux conditions where avalanche gain is required



Avalanche gain stability after high temperature baking

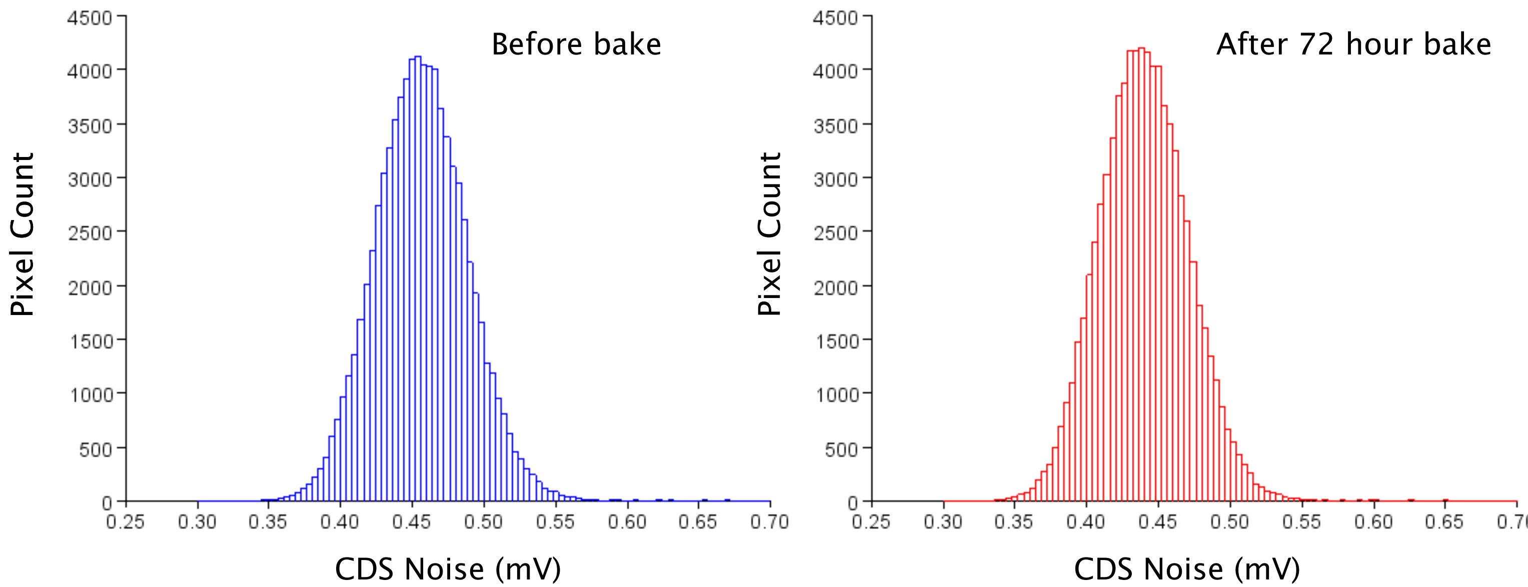
- The HgCdTe APD array was subjected to two high temperature bakes and the performance was measured before and after

- The results show that the avalanche gain process in the HgCdTe array is unaffected by the high temperature bakes, indicating that the APD array is robust

	Avalanche Gain		
Diode Bias (V)	Initial Measurement	After 72hr Bake at +70°C	After a further 24hr Bake at +70°C
4.6	2.7	2.7	2.7
5.1	3.2	3.1	3.1
5.6	3.7	3.7	3.7

Noise performance after high temperature baking

- The dark current in eAPDs in HgCdTe is more sensitive to crystal imperfections than conventional detectors (due to the high bias voltage) and an extremely sensitive test of any degradation mechanism is the noise.
- The graph below shows the measured noise of the array before and after a 3 day bake at high temperature showing no discernable increase. This shows that there are no significant deterioration mechanisms in HgCdTe eAPDs under normal use.



Defective Pixels

- A further test of the robustness of the eAPD array is the increase in noise in individual pixels leading to “defective” pixels
- The number of defective pixels* in the 320x256 FPA was measured before and after high temperature baking. No significant increase was seen in the number

	Initial Measurement	After 72hr Bake at +70°C	After a further 24hr Bake at +70°C
NUMBER OF DEFECTS	2245	2254	2241

*A defective pixel is one that:
- breaks down under applied bias voltage (high leakage current)
- is open/short circuit (poorly formed diode/contact)
- has abnormally high noise (poor contact/unstable leakage)

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Conclusions

- The work conducted under the UKSA FTPP contract to study the robustness of Selex ES HgCdTe APDs has shown that:
  - The avalanche gain process in 2.5µm arrays is insensitive to drift in the operating temperature
  - Arrays are not degraded by subjecting them to extended high temperature baking
  - Arrays are not degraded when run at high gain in high flux conditions
- These results give evidence of the maturity of the technology and indicate that Selex ES HgCdTe eAPD FPAs are suitable for space borne missions where they can significantly enhance the sensitivity of infrared instruments.

Future Work

- To further verify the suitability of Selex ES HgCdTe FPAs for space borne missions it is recommended that future work to prove the performance during/after exposure to radiation is conducted