

**International symposium on the development of detectors**

# **Electron multiplying CCDs**

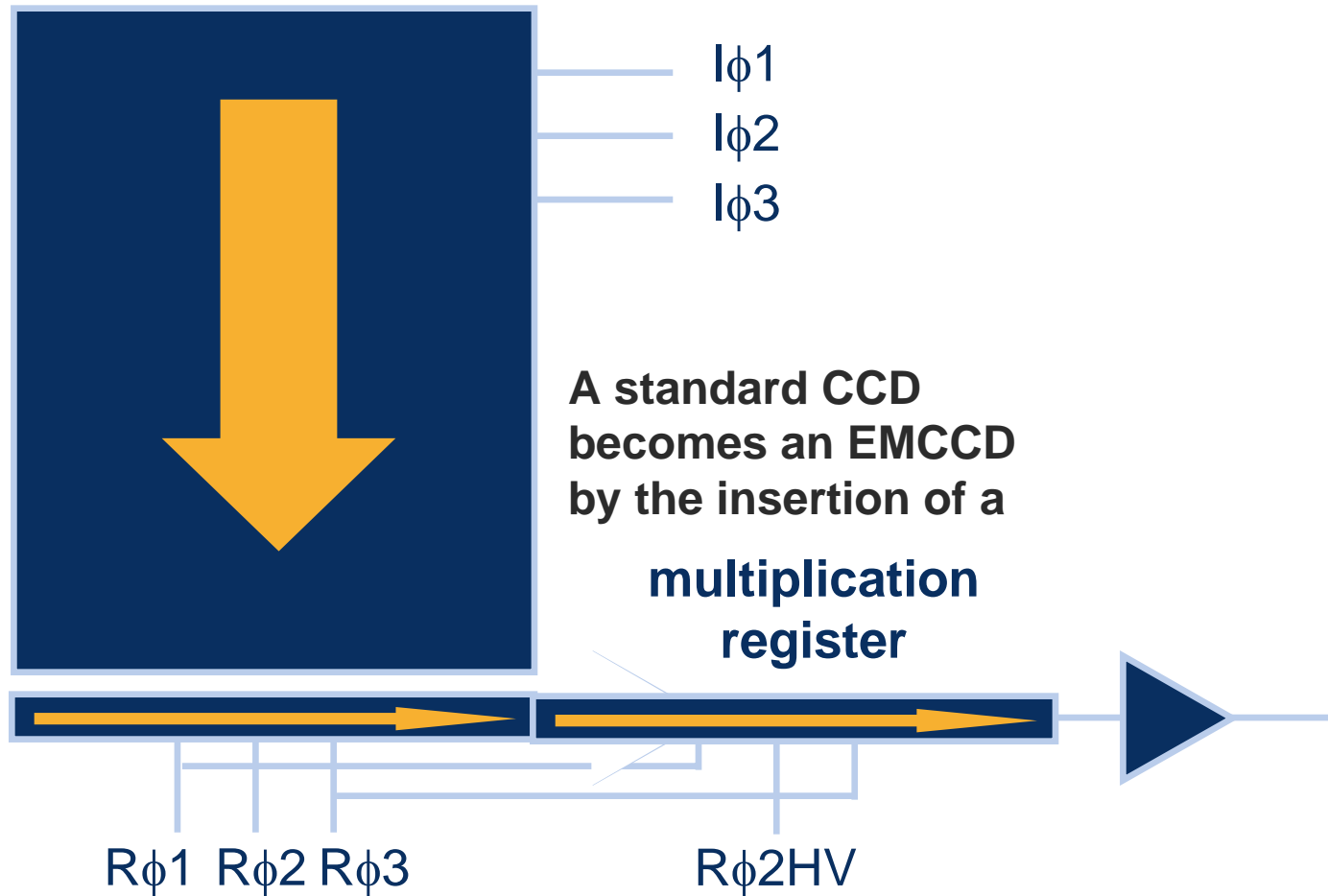
**P.A. Jerram, P. J. Pool, D. J. Burt, R. T. Bell**

**e2v Technologies, Chelmsford, Essex, UK**

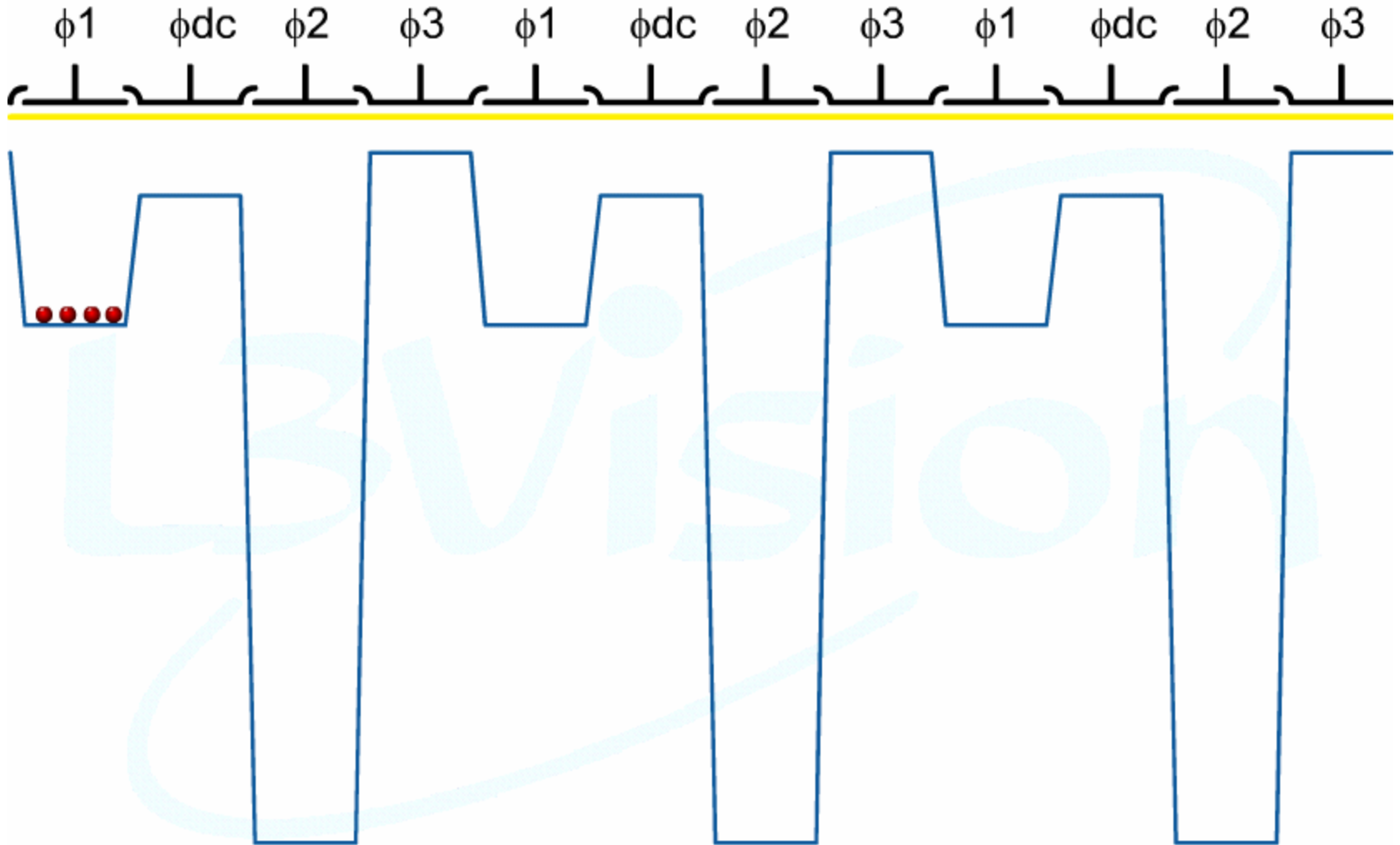
- **Brief Introduction to the EMCCD Structure**
- **Performance requirements**
- **Overview of non-space applications**
- **Possible applications in Particle, Astro-particle and synchrotron radiation detection**

All performance data derives from e2v L3Vision CCDs

# L3Vision CCD

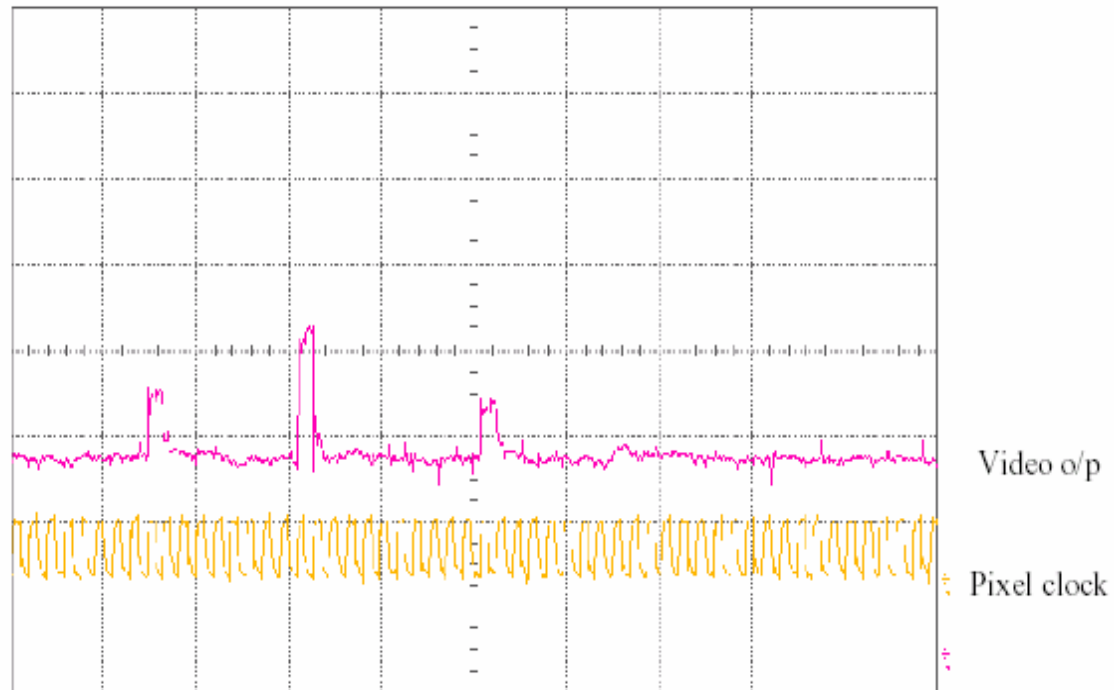


# Operation



# Operation

Signal 0.05 electrons/pixel



...and this is the signal out from the device from single electrons. If you have spent your life looking at CCD waveforms this is really exciting.

**In a CCD, charge transfer is noiseless, so the only remaining noise source is in the charge detection circuit.**

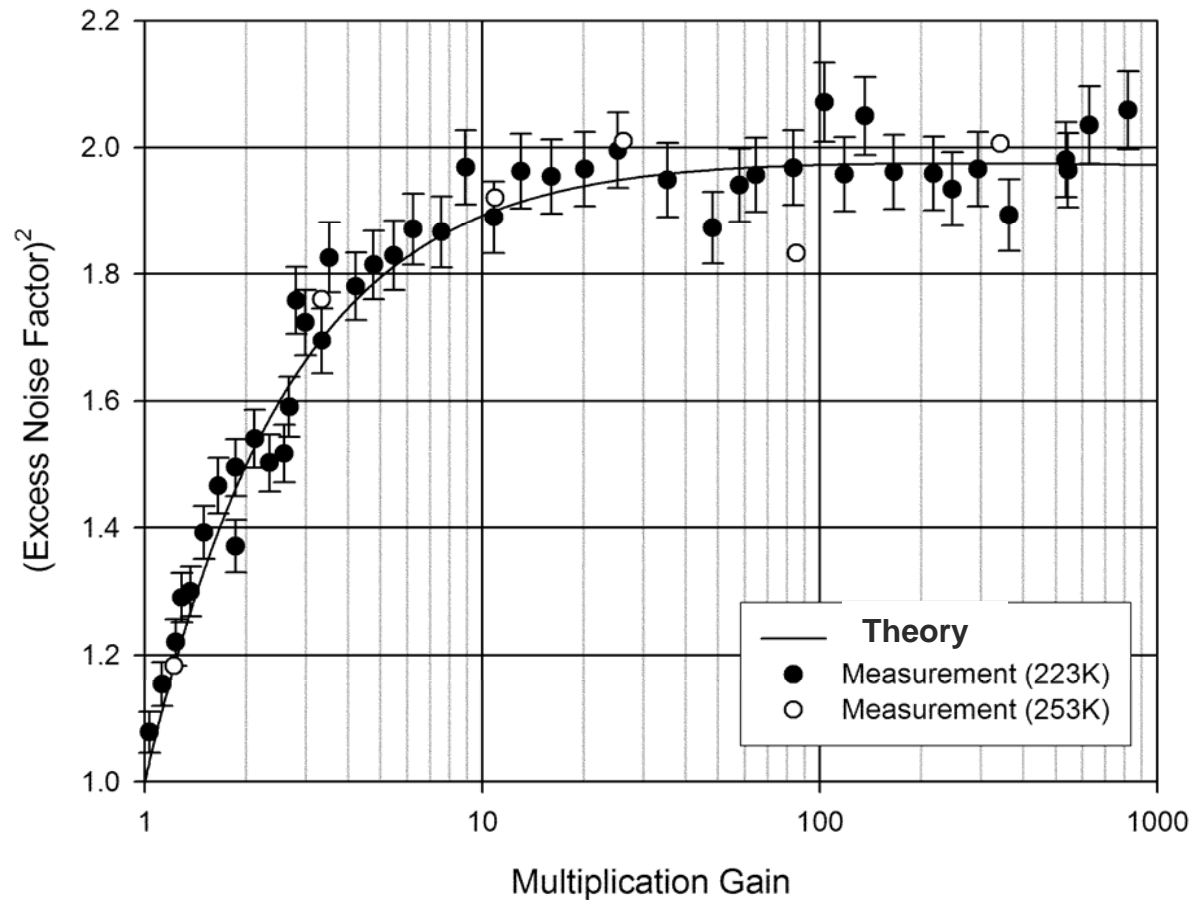
**In the EMCCD impact ionisation in silicon provides gain in the charge domain before detection. This gain effectively reduces the read noise by the gain factor.**

**However, for high gain values, the gain is subject to statistical fluctuations which appears as noise of  $\sqrt{N}$  electrons, where N is the input signal (electrons).**

**The combination of this excess noise factor, together with shot noise, results in a noise on the signal of  $\sqrt{(2N)}$  :**

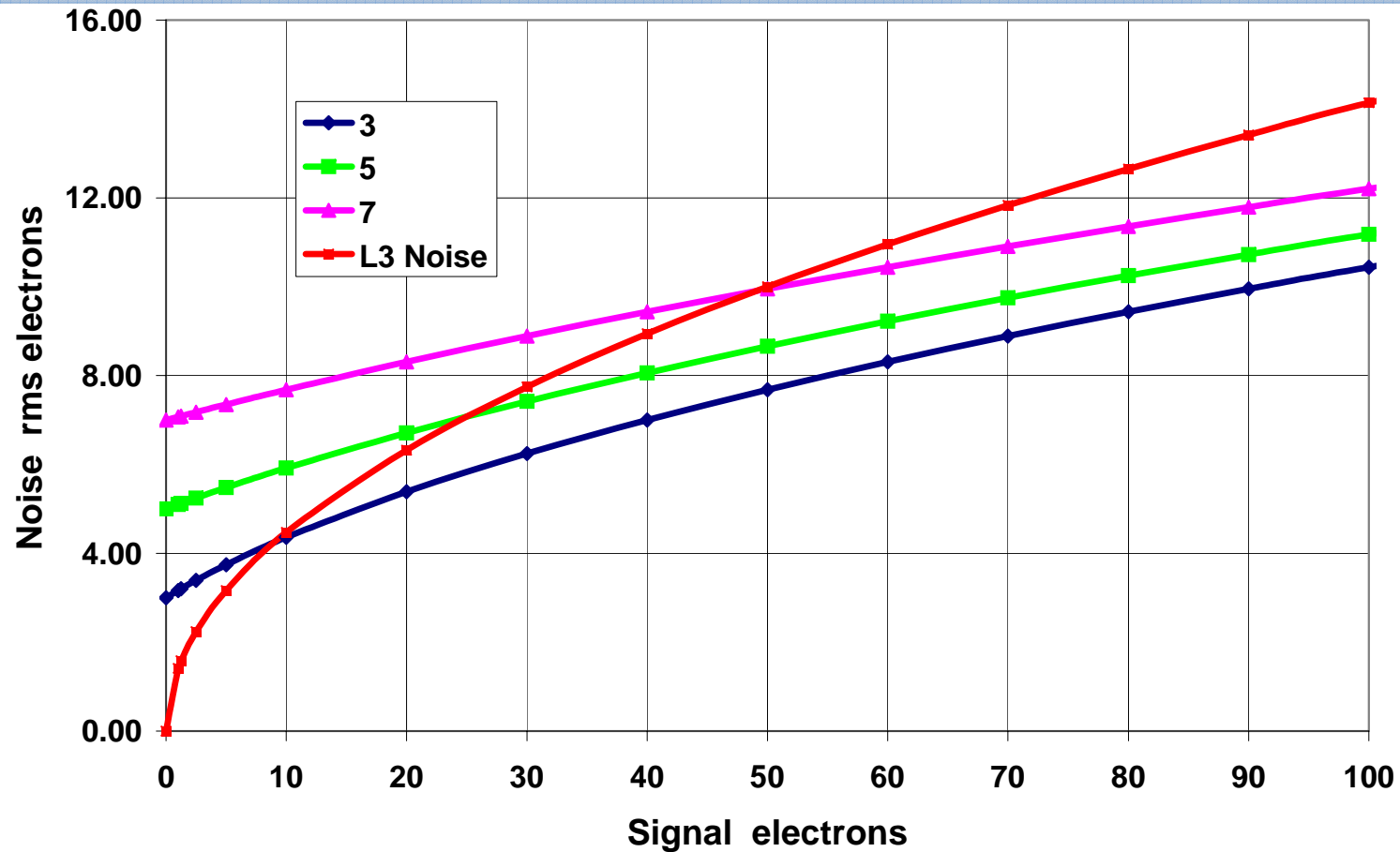
**an excess noise factor of  $\sqrt{2}$**

# Read Noise



The excess noise factor of  $\sqrt{2}$  has been shown to be present for the gain factors used in most applications.

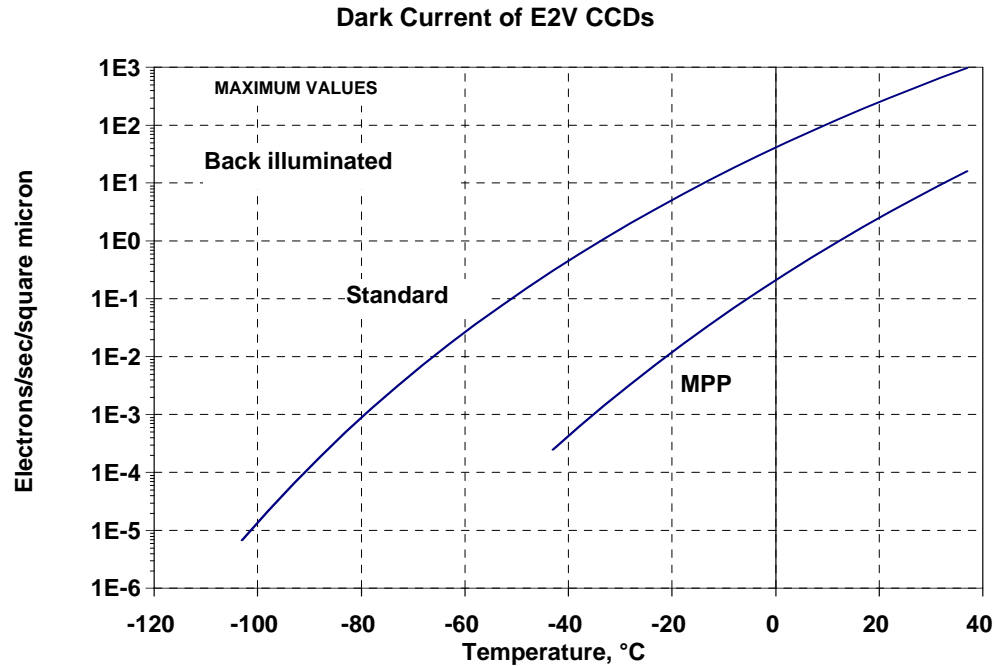
# Noise v signal



Consequently, EMCCD Noise is low for small signals, but higher for large signals.

However, EMCCD noise can be independent of pixel rate

# Dark Noise



Having lost read noise, an EMCCD should be operated under conditions in which the dark charge/pixel does not contribute significantly to the noise.

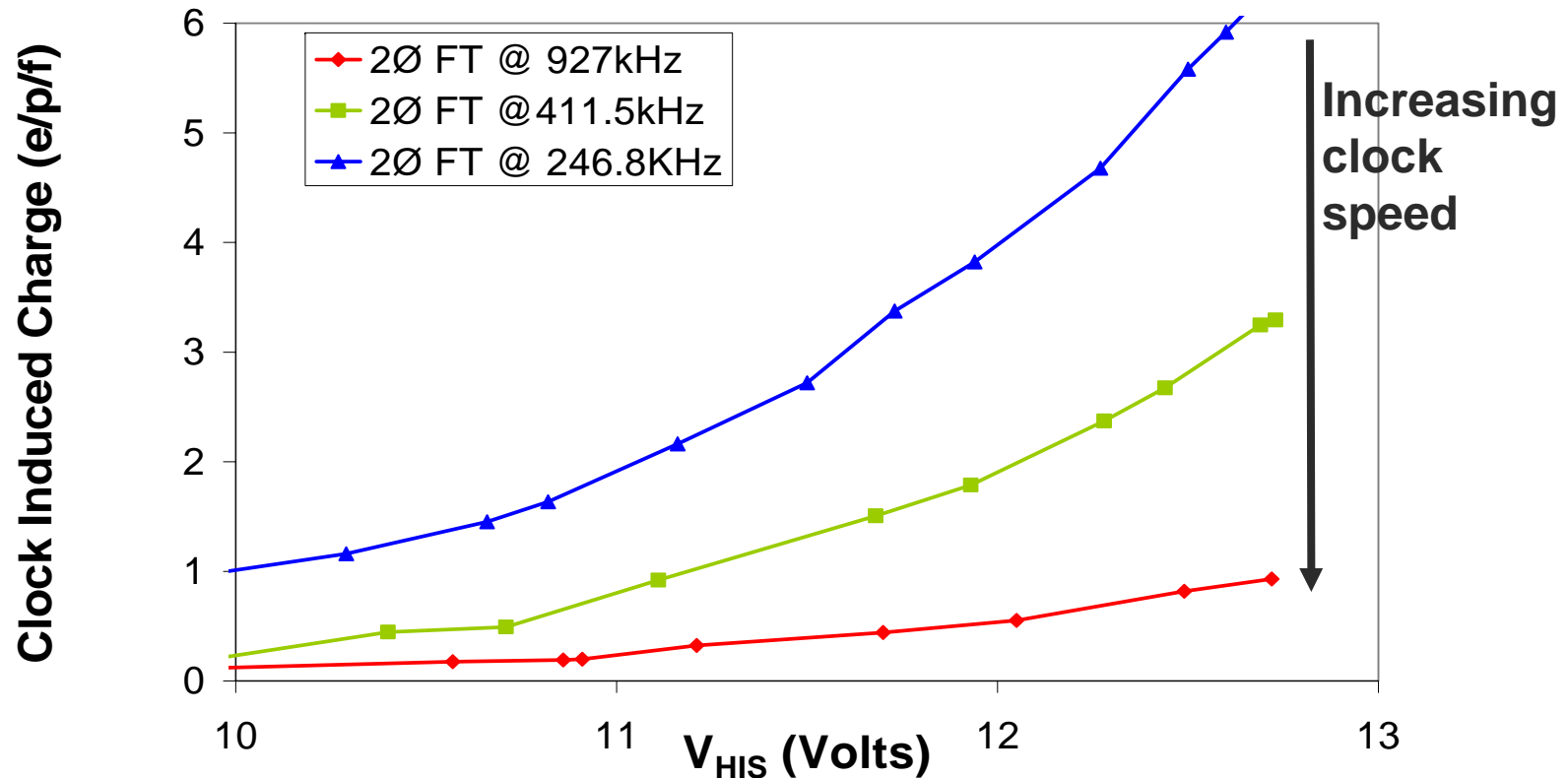
# Clock Induced Charge (CIC)

If sufficient cooling is not available, multi phase pinned (MPP) operation can be used. This makes the system susceptible to CIC, but this can be minimised by careful choice of operating conditions.

In MPP operation, the low clock inverts the silicon surface, saturating it with holes.

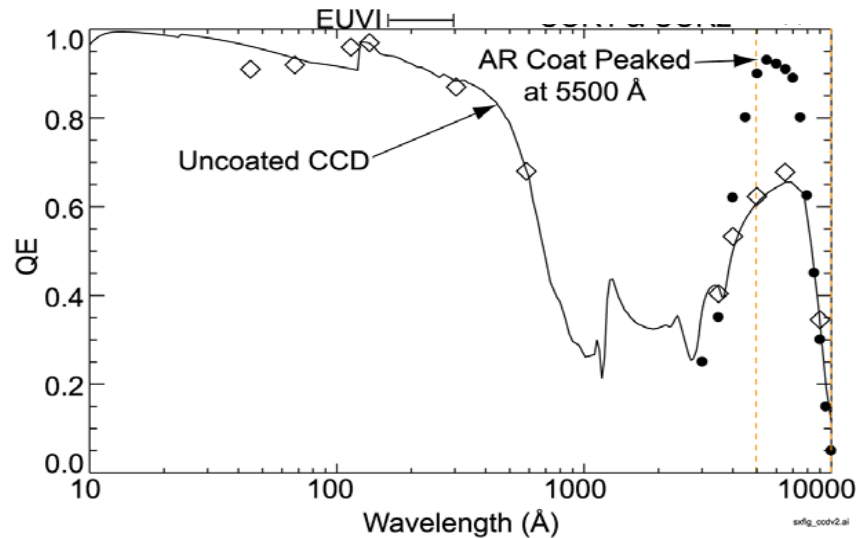
- CIC is caused by impact ionisation of the holes as they move in and out of the Si/SiO<sub>2</sub> interface during clocking.
- The charge generated is dependent on the number of transfers through the CCD and not the integration time.
- Dependent on clock amplitude, transfer rate, and clock timing

# Clock Induced Charge (CIC)



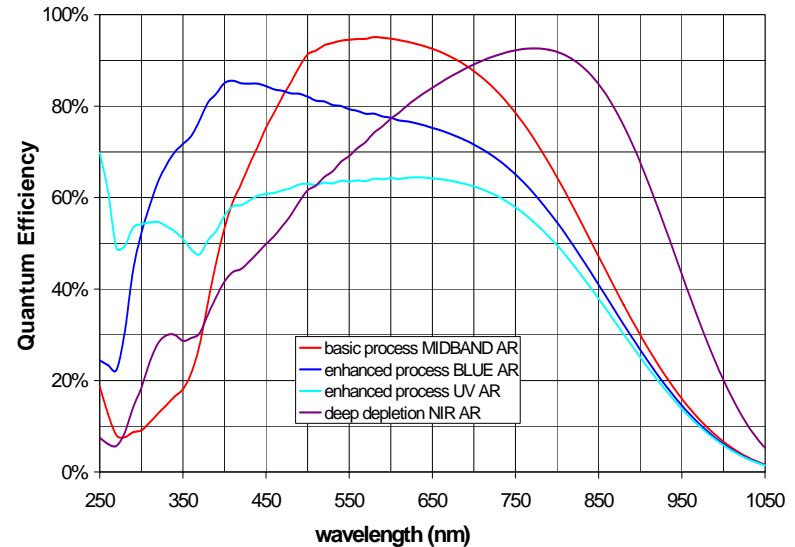
CIC minimised by low clock swing and high clock speed, in particular minimising the time a clock is held high.

# Quantum Efficiency



Data from the SECCHI programme (US Naval Research Laboratory)

## BI QE Curves at -50 °C



**To complement low read noise and minimal dark noise, EMCCDs benefit from the high quantum efficiency (QE) available from back illumination.**

**Appropriate processing promotes useful QE anywhere in the wavelength range 1 Ångstrom to 1 micron**

# Overview of three current applications

**Surveillance**

**Ground-based Astronomy**

**LIDAR**

**e2v**

e2v technologies

# 24 Hour Surveillance Daylight

e2v  
e2v technologies

**With variable gain and resistance to overload damage, the EMCCD is ideal for 24 hour surveillance applications.**

**As expected the EMCCD outperforms an intensified CCD in daylight, because gain can be turned down, so it's like a standard CCD.**



# 24 Hour Surveillance Overcast Starlight

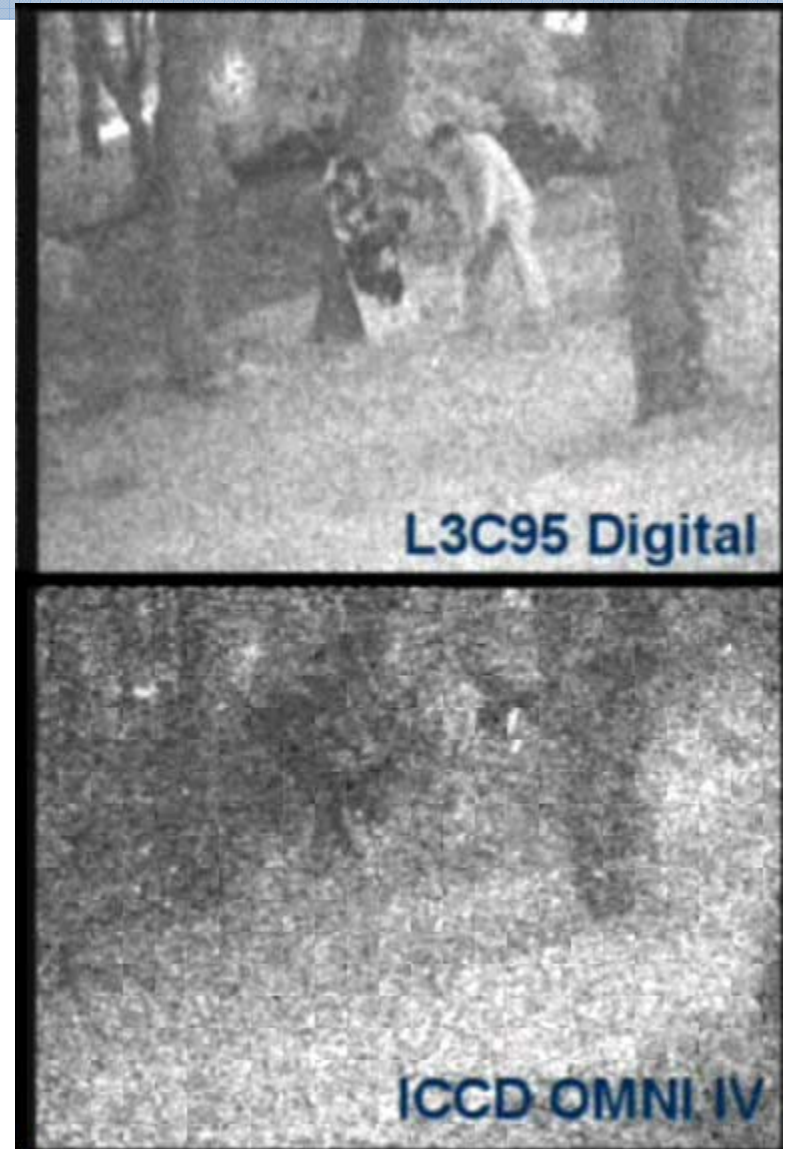
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When it's seriously dark, the gain can be increased, so it still does the job.

This image represents  
~1 electron/pixel/frame.

Some of you may have concluded that this does not show a real golfer.

Nobody has a good swing when it's this dark, so he was the only volunteer



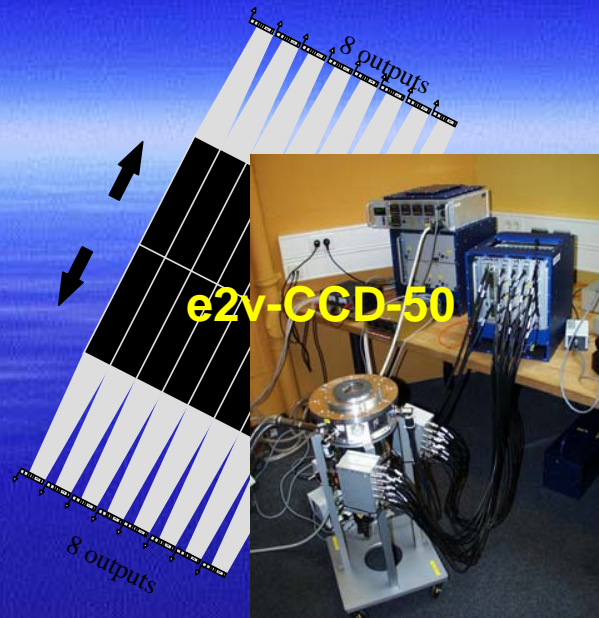
# Ground-based Astronomy. Road-map for ESO adaptive optics

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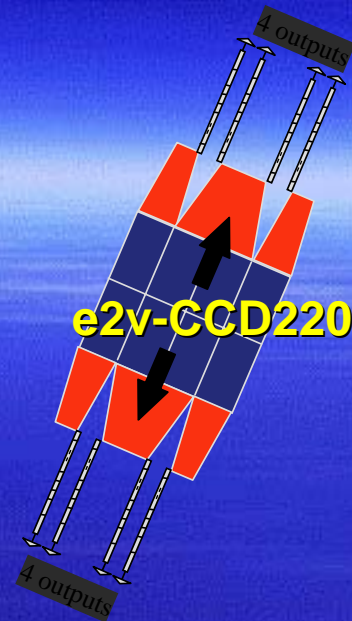
## MAD-WFS CCD

80x80 pixels  
4 outputs  
500Hz frame rate  
Noise: 8-6 e<sup>-</sup> rms



## NAOS-WFS CCD

128x128 pixels  
16 outputs  
25-600 Hz frame rate  
Noise: 2.5-6.5 e<sup>-</sup> rms

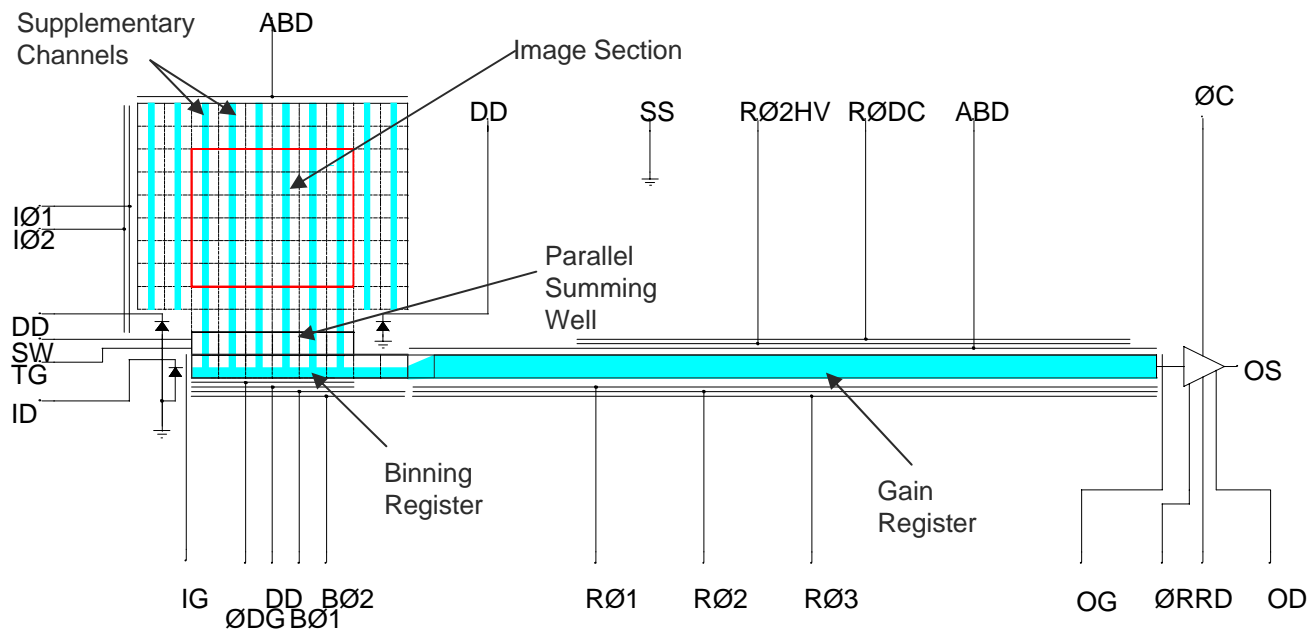


## Future-WFS CCD220 CCD

240x240 pixels  
8 L3 outputs  
0.25-1.2 kHz frame rate  
Noise: < 1 e<sup>-</sup> rms

# Single pixel CCD for LIDAR

To operate at even higher rates – for example to look at the output from a single fibre a single pixel CCD could be used. A structure of the type below is currently being developed by e2v for LIDAR with ESA funding.

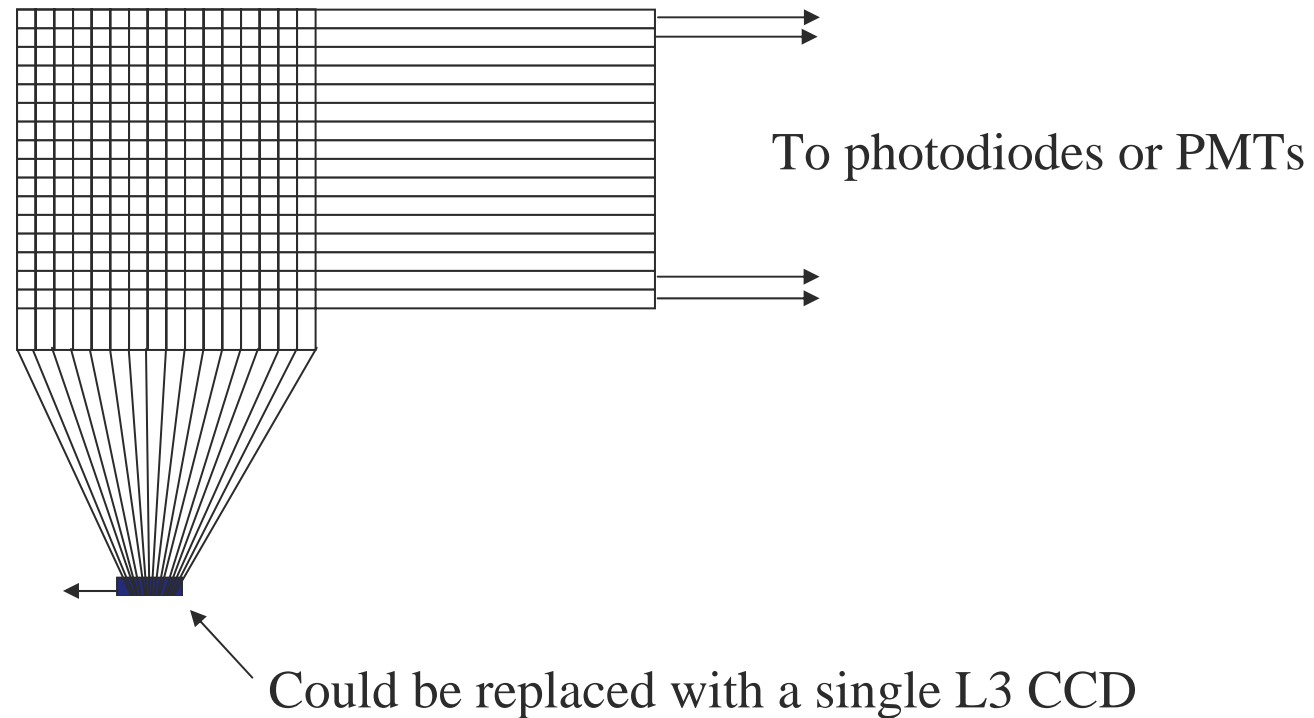


# Particle and Synchrotron radiation detectors

- **L3 devices provide significant advantage when:**
  - A high frame rate is required at low noise
  - The signal is very low – single photons
  - Frame rate can be  $>1\text{kHz}$  with an equivalent noise of  $<1$  electron
  - Single pixel frame rate can be  $> 1\text{MHz}$
- But give no advantage – or degrade performance when noise is dominated by shot noise

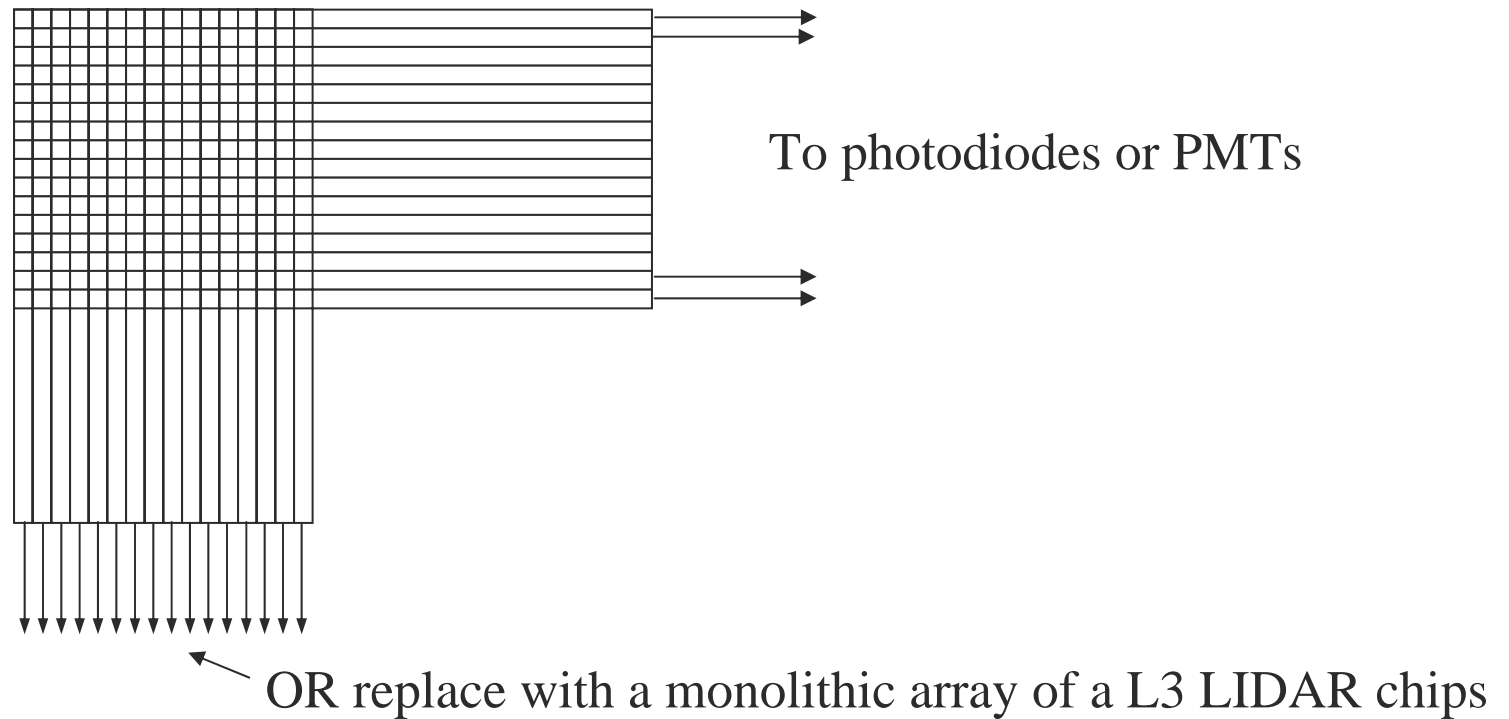
# Particle Detection

For example for the detection of light from scintillating fibres in a positron detector. The photodiodes could be replaced by an L3 CCD with the fibres bundled onto the CCD.



# Particle Detection

For example for the detection of light from scintillating fibres in a positron detector. The photodiodes could be replaced by an L3 CCD with the fibres bundled onto the CCD or with LIDAR devices.



**.....any other applications?**

**Thanks for your attention**

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**UK**

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