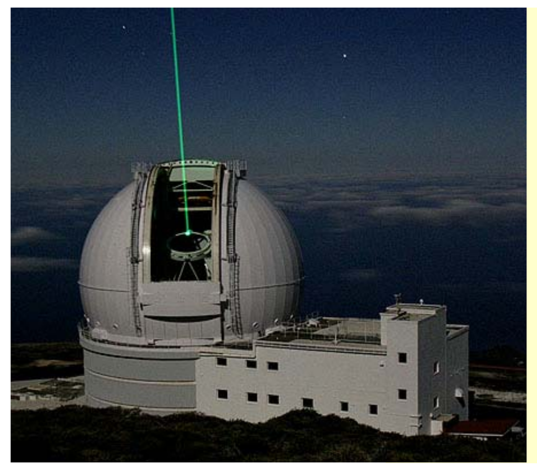

# *Monte Carlo Modeling of L3 Detectors in High Time Resolution Applications*


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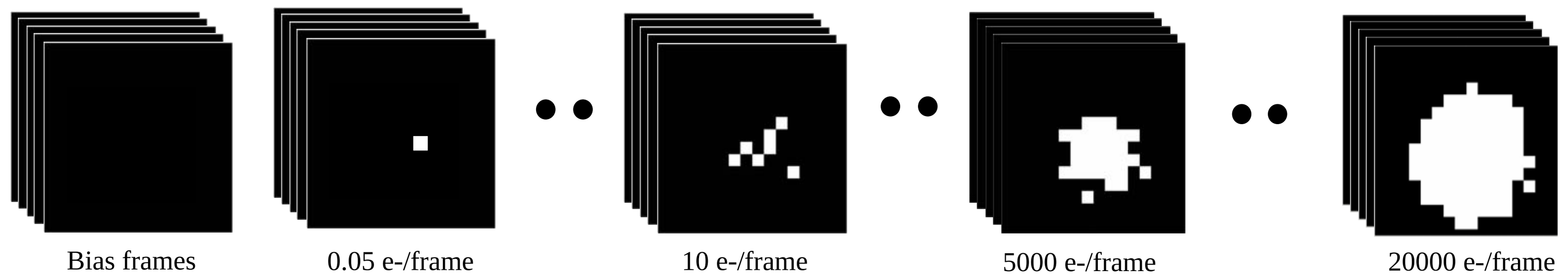
I have developed an IDL simulation of an electron multiplying L3 (low light level) technology CCD that includes the effects of clock induced charge and multiplication noise. This model allows observers interested in obtaining high time resolution photometry and spectroscopy of faint sources to compare more easily the gains in performance that can be expected by switching to an L3 detector. The model has been used to generate synthetic image sequences of stars and emission lines. The stellar images are analysed to show how the measured centroid noise of the star varies with the source brightness. In the case of the synthetic spectra the analysis determines how the SNR of a Gaussian line fit varies with the source brightness. In order to provide points of reference, the results are compared with both an ideal detector and a conventional CCD with various levels of read noise. The results show how closely an L3 CCD can approach to an ideal detector in various observing regimes. The performance of an L3 detector in photon counting mode is also investigated.


**Choose image parameters :**

1. Normal CCD with 2.2e- noise
2. Normal CCD with 3e- noise
3. Normal CCD with 5e- noise
4. Normal CCD with 10e- noise
5. Normal CCD with 20e- noise
6. L3 CCD with gain of 1000, CIC=0.03e- pix$^{-1}$
7. L3 CCD with gain of 1000, CIC=0.006e- pix-1

**Generate Synthetic Image stacks , 5000 deep, 30 stacks in all of varying exposure levels**

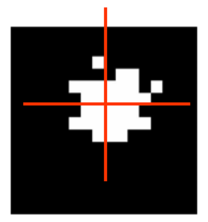



WFS Application

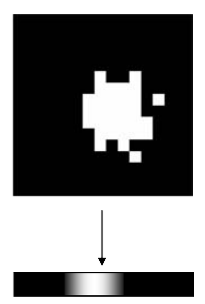
Spectroscopy Application (proportional)

Spectroscopy Application (photon counting)

**Centroid the star and analyse the error as a function of brightness**

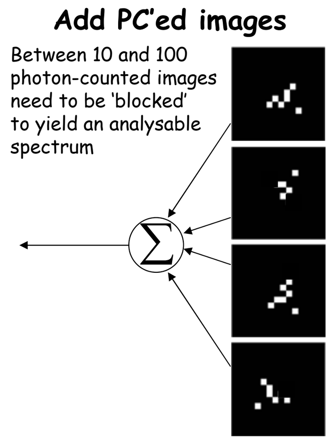


**Bin across slit i.e. interpret as an emission line**

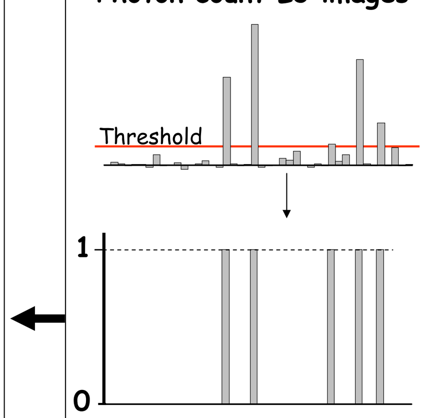


**Add PC'ed images**

Between 10 and 100 photon-counted images need to be 'blocked' to yield an analysable spectrum



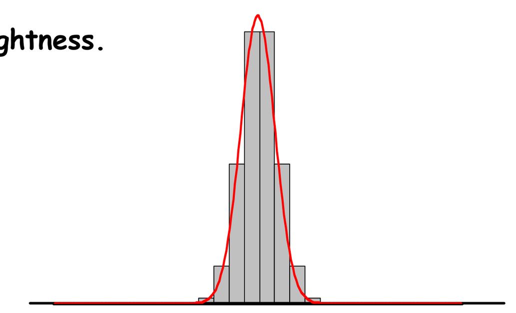
**Photon count L3 images**



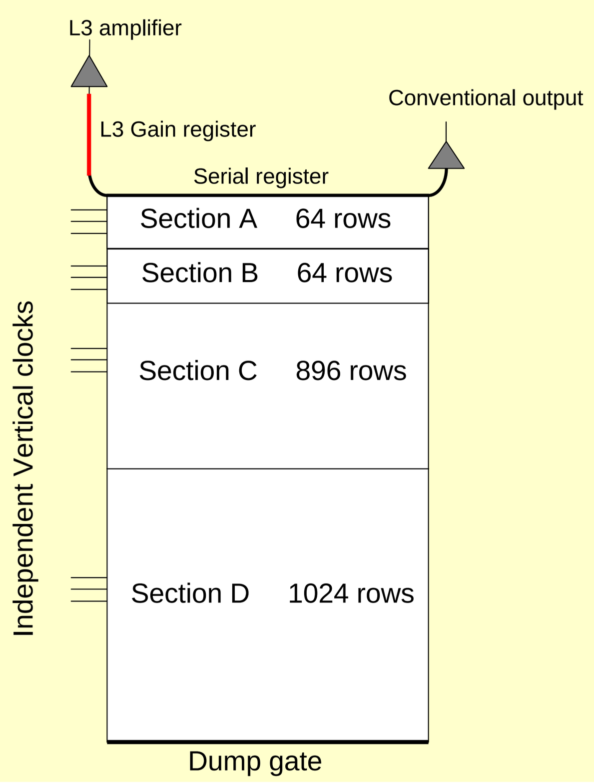

**Analyse the signal to noise ratio of the emission line as a function of brightness.**

The 1-D spectral image is analysed in 2 steps. First a constant line is fitted, secondly a Gaussian profile is fitted. The Chi$^2$ of these two fits is then combined using the equation below to yield the SNR of the line.

$$SNR = \sqrt{\chi^2_{CONST} - \chi^2_{GAUSS}}$$



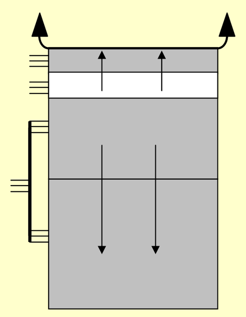
## Proposed flexible Geometry L3 CCD for spectroscopy




Option of using an L3 or conventional output depending on signal levels and frame rates. L3 amp for low signal level – high frame rate, conventional amp for high signal level –low frame rate. CIC is proportional to number of vertical transfers so for photon counting it makes sense to restrict the CCD's vertical dimension.

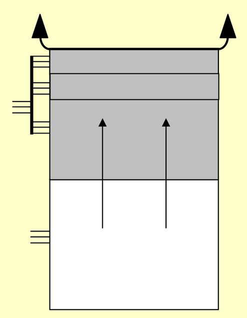
### Low CIC mode

Number of vertical transfers is minimised. Spectrum imaged into Section B. Section A functions as an image store. Sections C and D clocked in reverse direction and dumped.



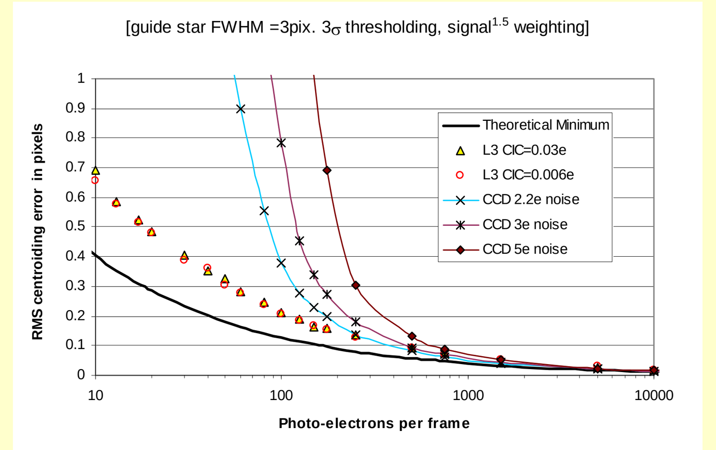
### Long slit mode

Sections A,B,C clocked together and function as a frame store. Spectrum imaged into section D. CIC high in this mode so photon counting does not perform optimally.



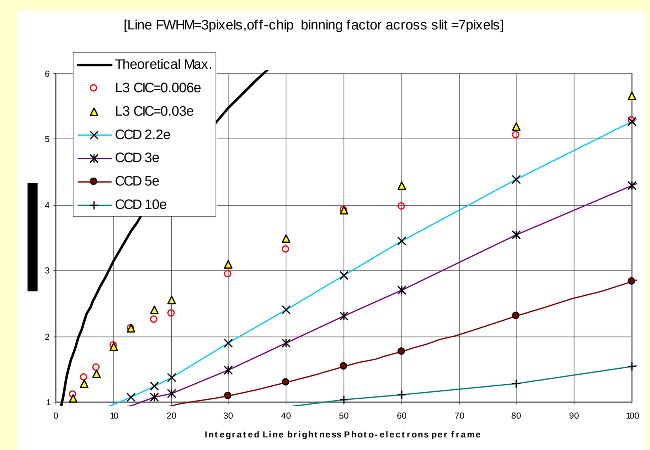
## Shack-Hartmann Wavefront sensing

L3 can approach to within a factor of 1.5 of theoretical minimum centroiding error. Centre of Gravity centroiding algorithm used. Pixels below 3 x read noise are not considered. Pixels above threshold are weighted to the power of 1.5. Clock Induced Charge (CIC) has little effect on result.

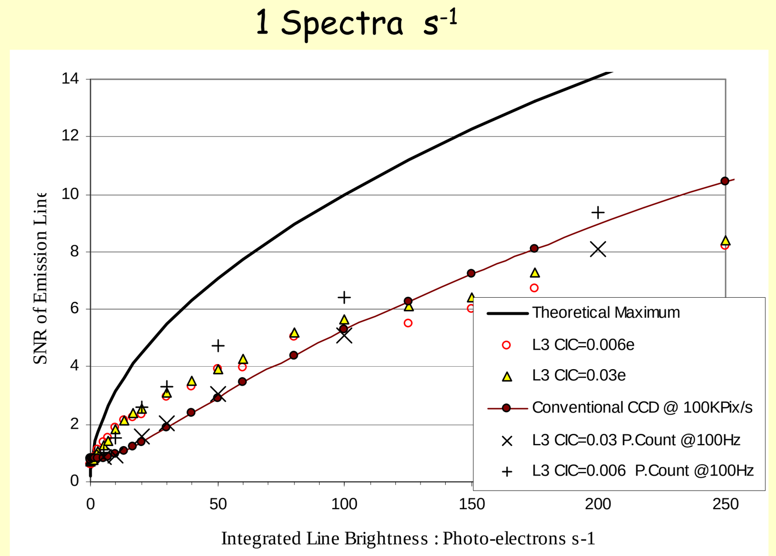



## Emission Line Spectroscopy

At low signal levels L3 is a clear winner. Low Clock Induced Charge (CIC) is a necessity. The plot below includes performance for two different CIC levels.




## 1 Spectra s$^{-1}$

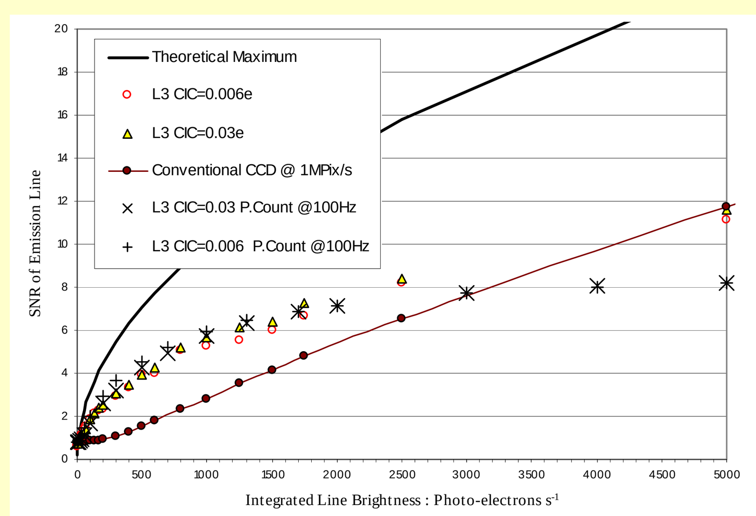



A window of 1000 x 100 pixels on the CCD is assumed. This would be a typical window for spectroscopy. For such a window size the pixel rate is 100 kPixs$^{-1}$ to give 1 spectra s$^{-1}$ . A conventional CCD is capable of 2.2e- noise at this rate.

For this relatively low spectral rate we can also consider photon counting. If the photon counting frame rate is 100Hz we need to block up 100 photon counted frames for each spectrum. This graph shows the importance of low CIC if such a large blocking factor is to be used (If CIC=0.03e- then the L3 is no better than a conventional detector ).

Note that above 250 e- s$^{-1}$ the conventional detector is actually better than L3.

## 10 Spectra s$^{-1}$

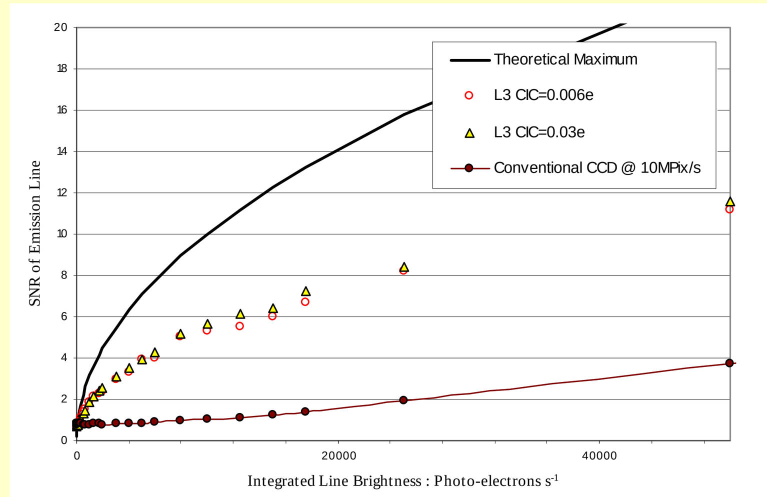



The pixel rate now needs to be 1MPixs$^{-1}$ to give 10 spectra s$^{-1}$ . A conventional CCD is capable of 5e- noise at this rate. The advantage of using L3 now becomes clearer.

We can still use photon counting but only with a blocking factor of 10. The graph shows clearly the effect of coincidence losses which limit the SNR of the photon counting observations to 8.

Photon counting gives little advantage over an L3 detector in proportional mode (i.e. where signal is interpreted as being proportional to pixel value) at these levels of CIC.

## 100 Spectra s$^{-1}$




The pixel rate now needs to be 10MPixs$^{-1}$ to give 100 spectra s$^{-1}$ . A conventional CCD is capable of 20e- noise at this rate. L3 now the obvious choice

Not possible to photon count at these high spectral rates.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High Time Resolution Astrophysics. Edinburgh Sep 2007


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