EMCCD Photometry

Alejandro Ferrero
School of Physics
University College Dublin
alejandro.ferrero@ucd.ie

13/08/2008

EMCCD vs CCD

- EMCCD allows higher temporal resolution than CCD.

EMCCD vs CCD

- EMCCD allows higher temporal resolution than CCD.
- Readout noise is negligible in EMCCD.

EMCCD vs CCD

- EMCCD allows higher temporal resolution than CCD.
- Readout noise is negligible in EMCCD.
- Dynamic range depends on gain. The dynamic range is better for slow scan. Lower dynamic range than CCD.

EMCCD vs CCD

- EMCCD allows higher temporal resolution than CCD.
- Readout noise is negligible in EMCCD.
- Dynamic range depends on gain. The dynamic range is better for slow scan. Lower dynamic range than CCD.
- A noise factor ($\sqrt{2}$) is introduced by the additional multiplication channel. This factor does not affect readout noise, but photon, dark and CIC noises.

EMCCD vs CCD

- EMCCD allows higher temporal resolution than CCD.
- Readout noise is negligible in EMCCD.
- Dynamic range depends on gain. The dynamic range is better for slow scan. Lower dynamic range than CCD.
- A noise factor ($\sqrt{2}$) is introduced by the additional multiplication channel. This factor does not affect readout noise, but photon, dark and CIC noises.
- Not cooled below $-95^o C$, the limiting noise source is readout darkcurrent, which is not important in conventional CCDs. Cooled below $-95^o C$, the limiting noise source is CIC.

EMCCD vs CCD

- EMCCD allows higher temporal resolution than CCD.
- Readout noise is negligible in EMCCD.
- Dynamic range depends on gain. The dynamic range is better for slow scan. Lower dynamic range than CCD.
- A noise factor ($\sqrt{2}$) is introduced by the additional multiplication channel. This factor does not affect readout noise, but photon, dark and CIC noises.
- Not cooled below $-95^{o}C$, the limiting noise source is readout darkcurrent, which is not important in conventional CCDs. Cooled below $-95^{o}C$, the limiting noise source is CIC.
- When photon noise limited, SNR in EMCCDs is half that in CCDs, because of the noise factor.

EMCCD in Photometry

- Temporal resolution improves by a factor $1/G$, if readout time negligible with respect to the integration time.

EMCCD in Photometry

- Temporal resolution improves by a factor $1/G$, if readout time negligible with respect to the integration time.
- The advantage disappears when limiting uncertainty is not due to sensitivity of the detector (readout, dark, charge transfer or spurious charge noises), but to the light level of the source.

EMCCD in Photometry

- Temporal resolution improves by a factor $1/G$, if readout time negligible with respect to the integration time.
- The advantage disappears when limiting uncertainty is not due to sensitivity of the detector (readout, dark, charge transfer or spurious charge noises), but to the light level of the source.
- When source is bright and shot noise higher than the detector noise; EM unable to overcome the noise and puts an additional noise in the measurement.

EMCCD in Photometry

- Temporal resolution improves by a factor $1/G$, if readout time negligible with respect to the integration time.
- The advantage disappears when limiting uncertainty is not due to sensitivity of the detector (readout, dark, charge transfer or spurious charge noises), but to the light level of the source.
- When source is bright and shot noise higher than the detector noise; EM unable to overcome the noise and puts an additional noise in the measurement.
- When the source is faint and shot noise of the background makes the source undetectable; EM useless, because the multiplication does not distinguish between source and background photo-electrons.

EMCCD in Photometry

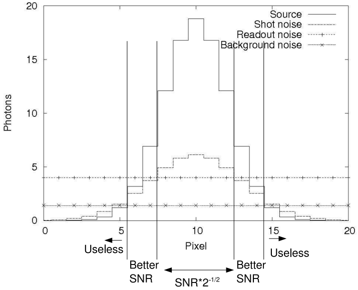

Figure: Different illumination levels in a source. Some pixels are favoured by EM, whereas the SNR of other pixels may decrease due to the EM.

EMCCD in Photometry

- In any case, the SNR of the brighter sources will be always higher than the SNR of the fainter sources.

EMCCD in Photometry

- In any case, the SNR of the brighter sources will be always higher than the SNR of the fainter sources.
- Therefore, if a chosen gain allows to detect a faint star, it should be never a problem the detection of brighter sources, although the relative uncertainty will increase a factor $\sqrt{2}$ for these sources.

EMCCD in Photometry

- SNR is proportional to $\sqrt{Gt_{int}}$.

EMCCD in Photometry

- SNR is proportional to $\sqrt{Gt_{int}}$.
- The lower limit of t_{int} depends on the photon flux, but above all on the CCD, because the accuracy decreases below 0.1 sec of integration time. In addition, below $t_{int} << t_{readout}$ temporal resolution can not be improved.

EMCCD in Photometry

- SNR is proportional to $\sqrt{Gt_{int}}$.
- The lower limit of t_{int} depends on the photon flux, but above all on the CCD, because the accuracy decreases below 0.1 sec of integration time. In addition, below $t_{int} << t_{readout}$ temporal resolution can not be improved.
- The upper limit of G is imposed by the aging. The higher G, the more the aging. Very high gains decrease the dynamic range of the detector. Since the sources are distributed in a wide range of irradiance levels on the EMCCD, the largest dynamic range gain should be chosen.

EMCCD noise

$$\sigma^2(n_{pe}) = \sigma_r^2(n_{pe}) + n_{pe} + n_d \tag{1}$$

$$\sigma^2(n_{ae}) = \sigma_r^2(n_{ae}) + 2G(n_{ae} + n_{ad}) \tag{2}$$

$$\sigma^2(N) = \sigma_r^2(N) + 2GKN \tag{3}$$

$$GK = \frac{\sigma^2(N) - \sigma_r^2(N)}{2N} \tag{4}$$

Theoretical effect of EM on a source

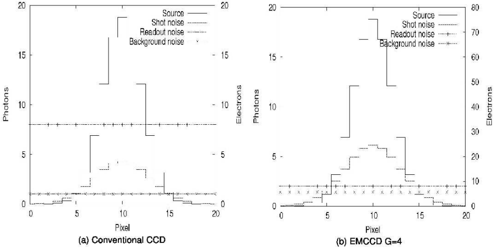

Figure: Theoretical effect of EM on a source in the border of the detection (SNR∼3).

EMCCD vs CCD in Photometry

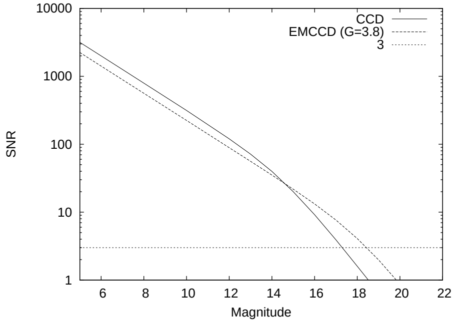

Figure: EMCCD (G=3.8) SNR vs conventional mode CCD SNR.

Experimental setup

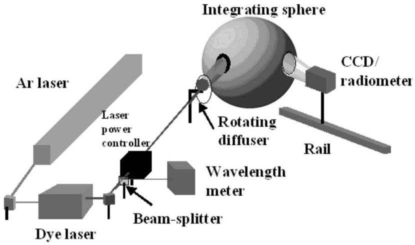

Figure: Radiant source for radiometrical calibration.

Andor IXON DU-897 EMCCD: Parameters choice

- Integration time $> 0.05sec$.
- Vertical Pixel Shift: Shift Speed 2.2 μs, Vertical Clock Voltage *Normal*
- Horizontal Pixel Shift: Readout rate 1MHz@16bits, Preamplifier Gain $\times$ 1.
- Temperarature $-80^o C$.

Stabilization

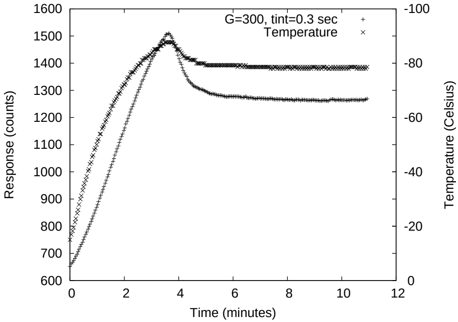

Figure: The response of the EMCCD is clearly temperature dependent and it is stabilized at 0.16% after around 5 minutes.

Reproducibility

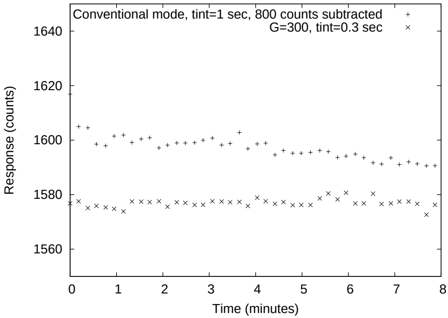

Figure: At G=300 and at conventional mode the stability was 0.1% and 0.2%, respectively.

Photon Transfer Technique

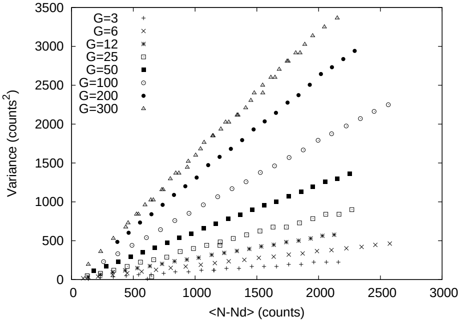

Figure: Photon transfer technique result.

GK product

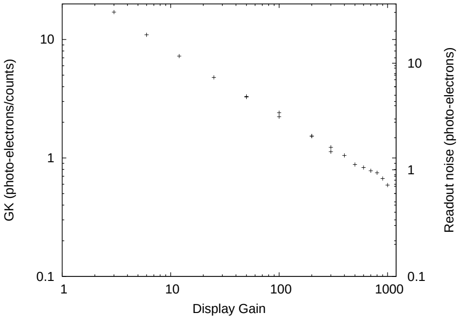

Figure: GK product and readout noise as a function of the software displayed gain.

Actual Gain

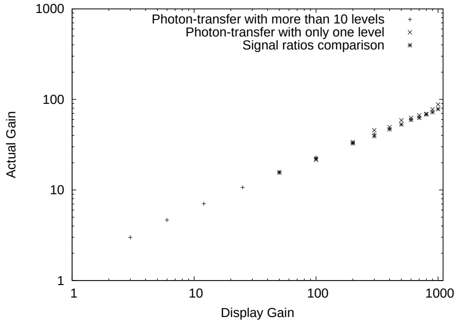

Figure: Actual gain as a function of the software displayed gain, assuming that they are identical at G=3.

Saturation

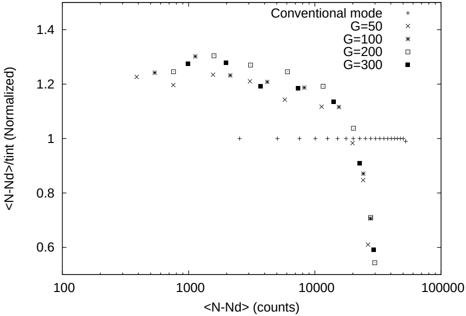

Figure: Saturation of EMCCD at several gains.

Linearity

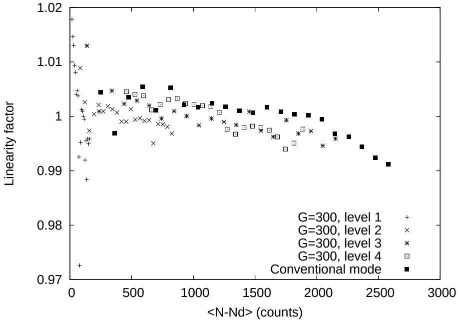

Figure: EMCCD linearity.

Spectral responsivity and external quantum efficiency

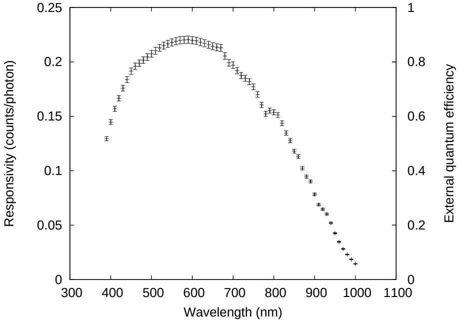

Figure: Spectral responsivity and external quantum efficiency.

Alejandro Ferrero

School of Physics
University College Dublin
alejandro.ferrero@ucd.ie