Photon counting with L3CCDs

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L3CCD
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• There is a *probability* \( p \) of multiplication at every shift in the multiplication register (total of \( n \) shifts):
  \[
  G_{\text{eff}} = (1 + p)^n
  \]

• The gain applied in the charge domain lowers the effective readout noise applied to the output signal:
  \[
  \sigma_{\text{eff}} = \frac{\sigma_{\text{real}}}{G}
  \]
L3CCD

- However, the multiplication probability at every shift creates a gain whose behaviour is statistical...
L3CCD

... which affects the resulting SNR by adding a noise factor that scales as

\[ F = \sqrt{\frac{2(G-1)}{N+1} \frac{N+1}{G^N}} + \frac{1}{G}. \]
Thus, the SNR formulae of the system becomes

$$ SNR = \frac{S}{\sqrt{F^2 S + F^2 T + \frac{\sigma^2_{\text{real}}}{G^2}}} $$

When $G$ is large, $F^2 \approx 2$ and the noise factor affects the SNR as if the QE would be halved.

F is neglected if the pixel is considered binary.
Clock Induced Charge

- Spurious charges are generated during the charge transfer operations

Mean signal:
\( 0.01 \, \text{e}\cdot\text{pix}\cdot\text{frame} \)

Sum of 200 dark frames with a CCD87
Clock Induced Charge

- Charge injection rate is dependent of the operation mode of the CCD
  - IMO: $\sim 0.1\,\text{e}\cdot\text{pix}\cdot\text{frame}$
  - NIMO: $\sim 0.003\,\text{e}\cdot\text{pix}\cdot\text{frame}$

- Dark current is also affected by the operation mode of the CCD
  - IMO: $\sim 0.001\,\text{e}\cdot\text{pix}\cdot\text{sec}$
  - NIMO: $\sim 0.1\,\text{e}\cdot\text{pix}\cdot\text{sec}$
  
  } at -50°C 

\{ data from E2V \}
Comparison with other IPCS

GaAs IPCS, 80 fps,  
DQE = 28%

CCD, $\sigma=3\bar{e}$, 5min exposures,  
DQE = 95%, 100kHz readout

L3CCD NIMO, $\sigma=30\bar{e}$, G=3000,  
10 fps, DQE = 95%,  
CIC = 0.003$\bar{e}$·pix·frame

L3CCD IMO, $\sigma=30\bar{e}$, G=3000  
0.1 fps, DQE = 95%,  
CIC = 0.1$\bar{e}$·pix·frame
Comparison with other IPCS

- **GaAs IPCS**, 80 fps, DQE = 28%
- **CCD**, $\sigma = 3\bar{e}$, 5min exposures, DQE = 95%, 100kHz readout
- **L3CCD IMO**, $\sigma = 10\bar{e}$, $G = 1000$, 15s exposures, DQE = 95%
- **L3CCD IMO**, $\sigma = 3\bar{e}$, $G = 2$, 5min exposures, DQE = 95%
What is needed

- GaAs IPCS, 80 fps, DQE = 28%
- CCD, σ=3ē, 5min exposures, DQE = 95%, 100kHz readout
- L3CCD IMO, σ=10ē, G=1000, 15s exposures, DQE = 95%, CIC = 0.1ē·pix·frame
- L3CCD IMO, σ=3ē, G=1000, 5min exposures, DQE = 95%, CIC = 0.003ē·pix·frame

Lowering CIC from 0.1 to 0.003 ē·pix·frame
Readily available packages

• E2V CCD97:
  – 512 x 512 frame transfer
  – 16 μm square pixel (8.2 x 8.2 mm imaging area)
  – DQE max: 93 % at 575 nm (back-thinned)

• TI Impactron:
  – 1000 x 1000 frame transfer
  – 8 μm square pixel (8 x 8 mm imaging area)
  – DQE max: 65 % at Hα.
Conclusions

- As compared to other IPCS, a gain in SNR is possible with L3CCDs at extreme faint flux.

- Clock Induced Charge IS the main issue for faint flux imaging
  - More tests have to be done with CCD97 to lower CIC level

- 8 mm x 8 mm is small!
  - Theoretically, custom sensors up to 1024x1024 frame-transfer (4 outputs, 16 μm pixels, 16.4 x 16.4 mm detector) should have the same amount of CIC