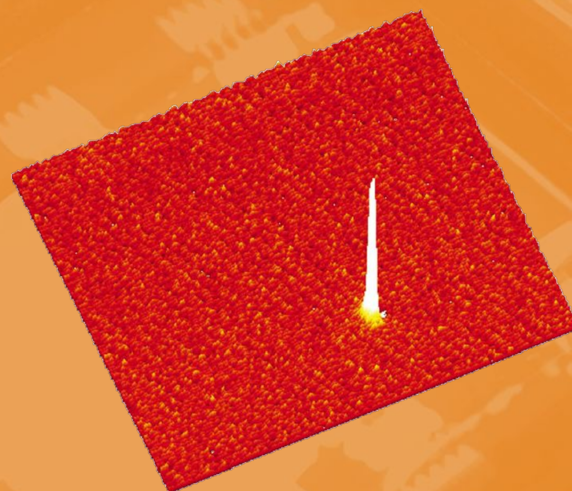
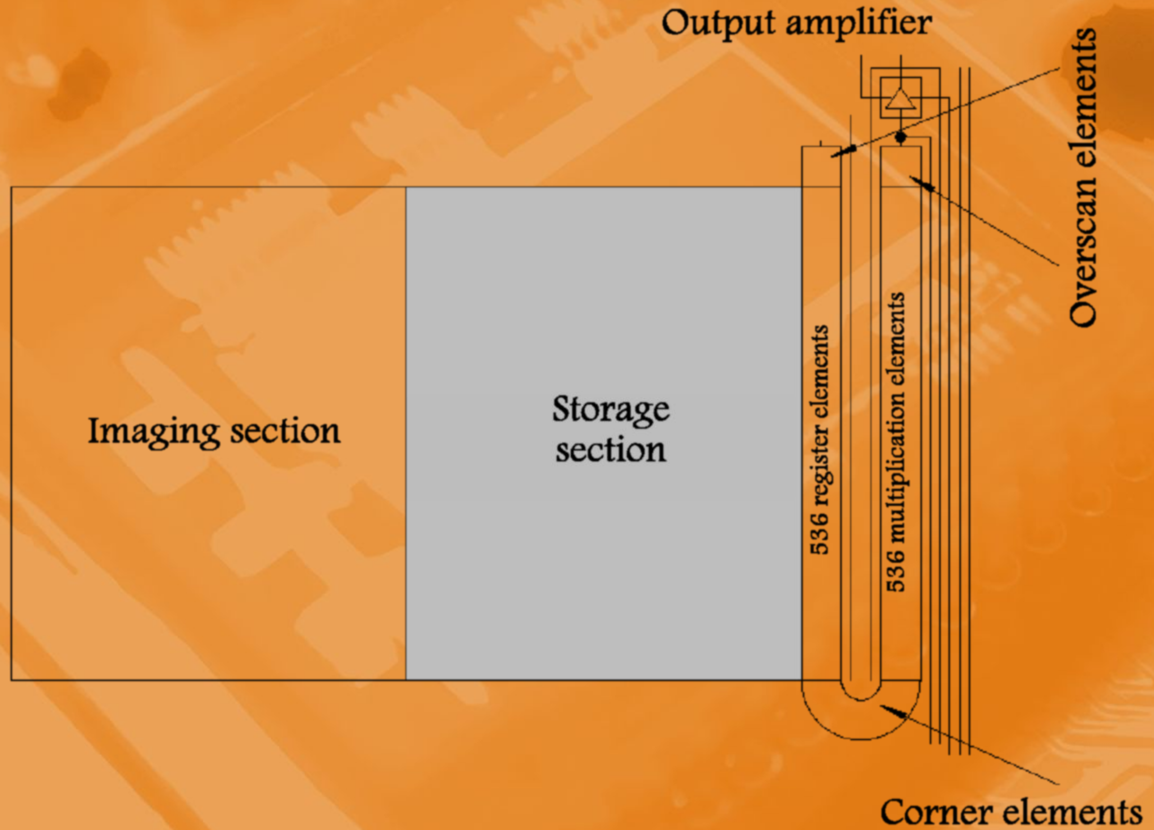
Photon counting with L3CCDs



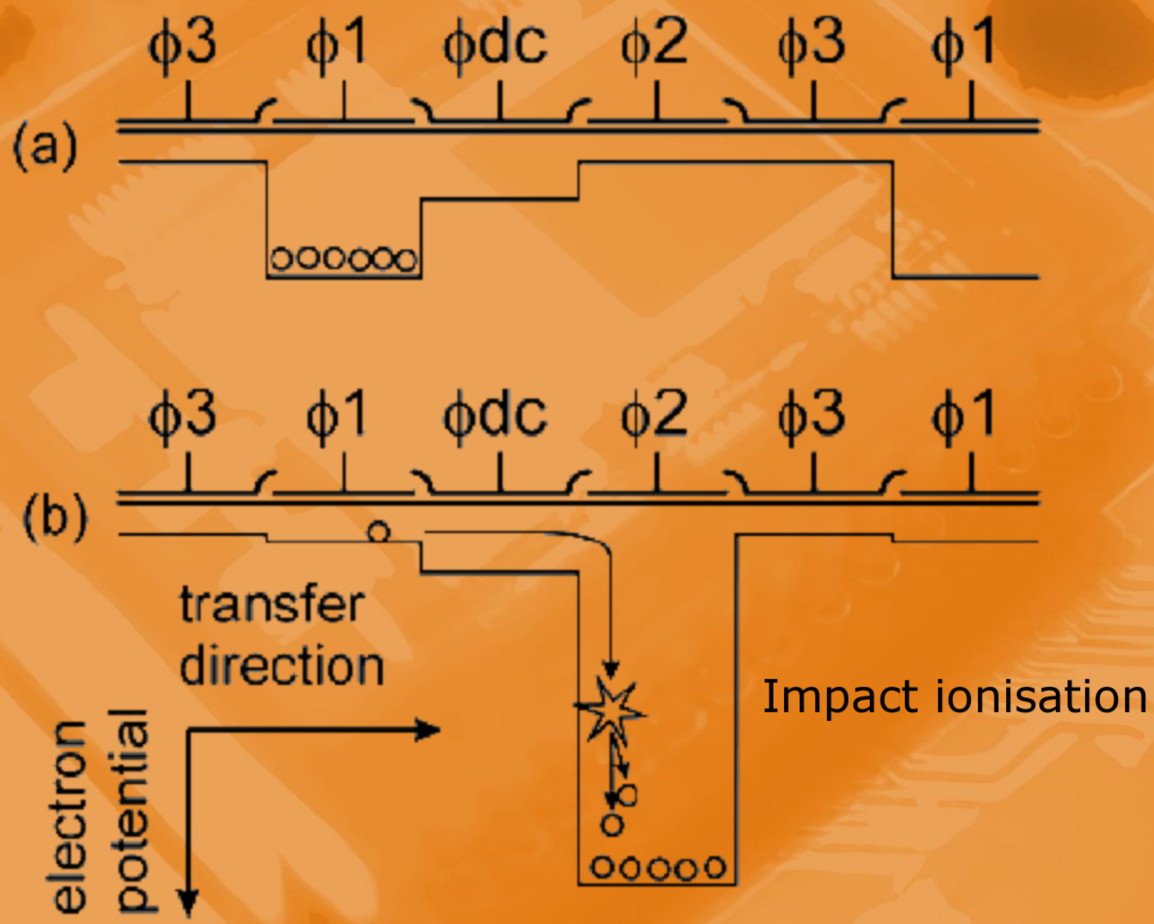
Olivier Daigle
Université de Montréal
Laboratoire d'Astrophysique Expérimentale

3D NTT workshop
Marseille, 16 juin 2005

L3CCD


Output amplifier
Overscan elements
536 register elements
536 multiplication elements
Imaging section
Storage section
Corner elements

L3CCD



ϕ3 ϕ1 ϕdc ϕ2 ϕ3 ϕ1
(a)
ϕ3 ϕ1 ϕdc ϕ2 ϕ3 ϕ1
(b)
transfer
direction
electron
potential
Impact ionisation

L3CCD

- There is a *probability* (p) of multiplication at every shift in the multiplication register (total of n shifts):

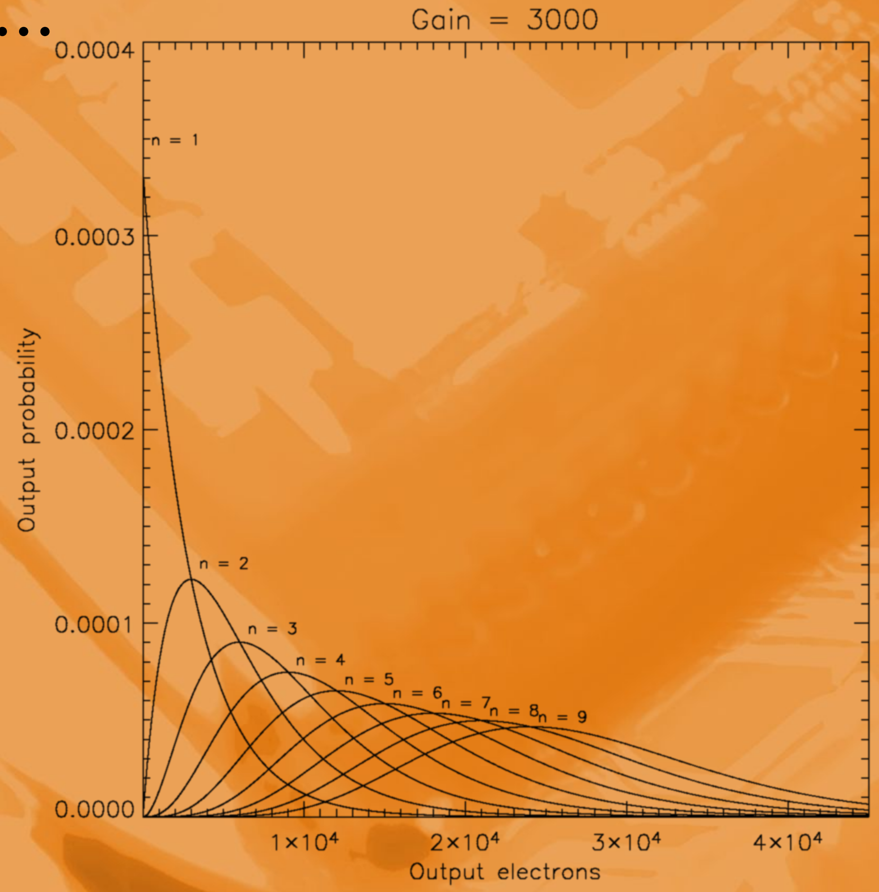
$$\overline{G} = (1 + p)^n$$

- The gain applied in the charge domain lowers the effective readout noise applied to the output signal:

$$\sigma_{eff} = \frac{\sigma_{real}}{G}$$

L3CCD

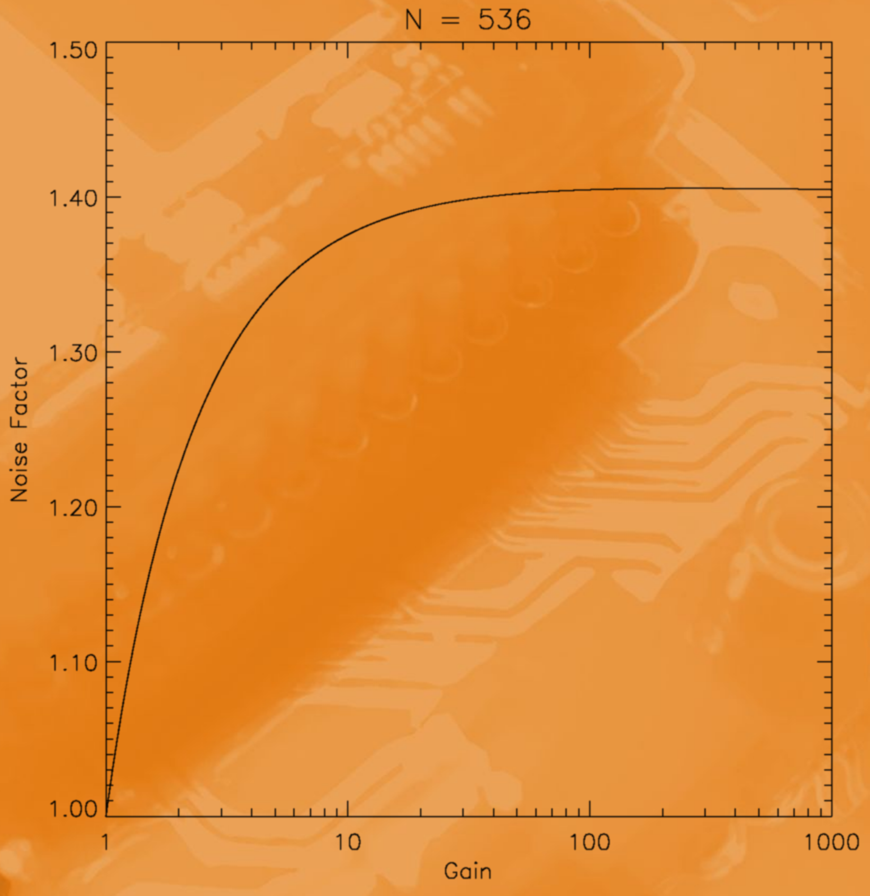
- However, the multiplication probability at every shift creates a gain whose behaviour is statistical...



L3CCD

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

$$F = \sqrt{\frac{2\left(G-1\right)}{G^{\frac{N+1}{N}}} + \frac{1}{G}}.$$



L3CCD

- Thus, the SNR formulae of the system becomes

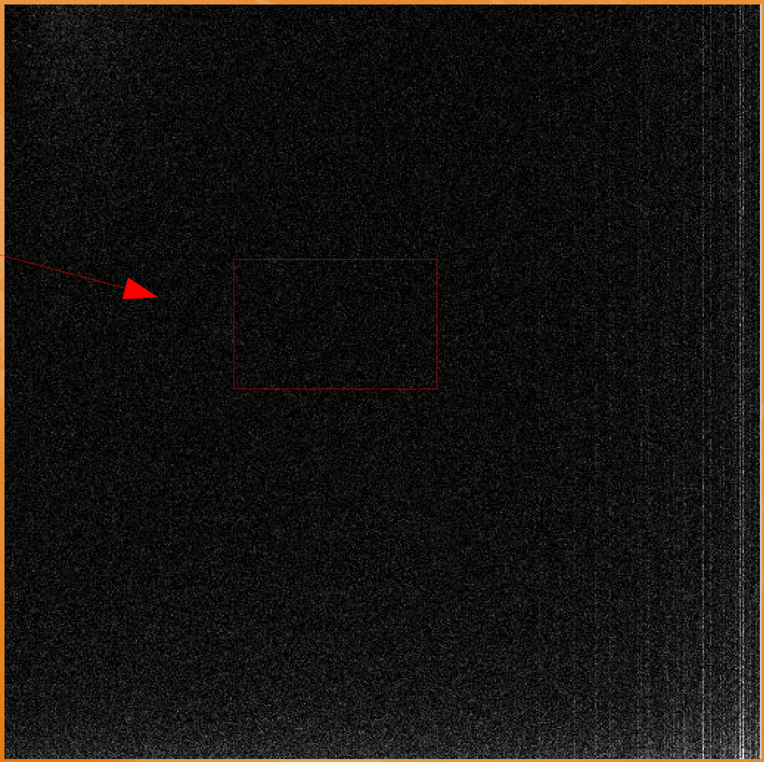
$$SNR = \frac{S}{\sqrt{F^2 S + F^2 T + \frac{\sigma_{real}^2}{G^2}}}$$

- 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:
0.01ē·pix·frame



Sum of 200 dark frames
with a CCD87

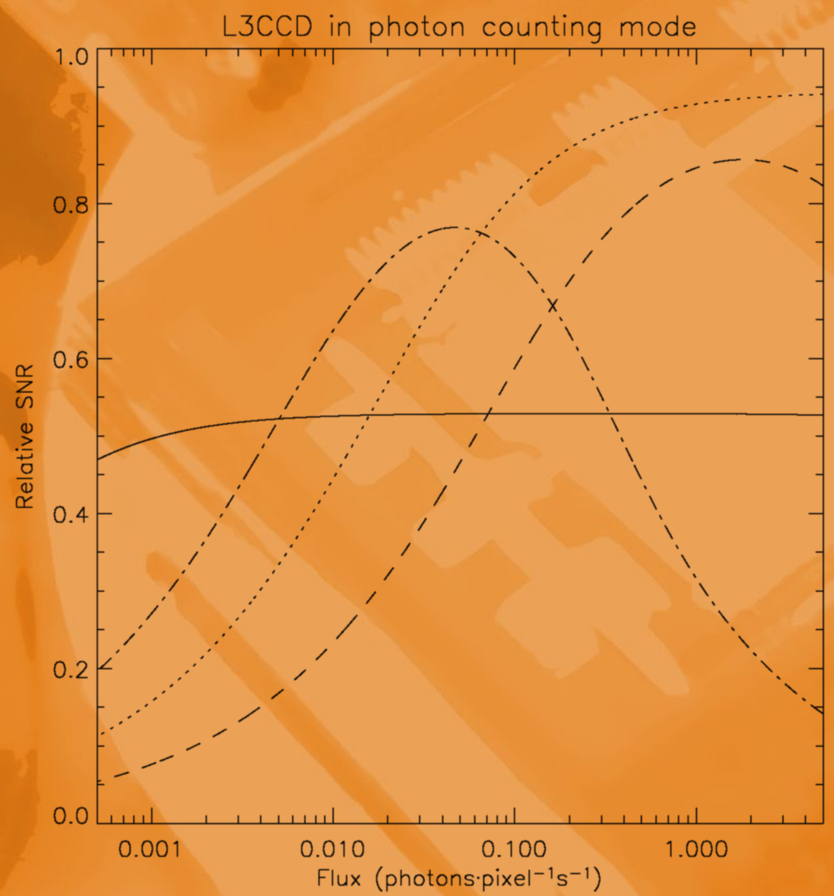
Clock Induced Charge

- Charge injection rate is dependent of the operation mode of the CCD
  - IMO: ~ 0.1ē·pix·frame
  - NIMO: ~ 0.003ē·pix·frame

  } data from E2V
- Dark current is also affected by the operation mode of the CCD
  - IMO: ~ 0.001ē·pix·sec
  - NIMO: ~ 0.1ē·pix·sec

  } at -50°C

Comparison with other IPCS



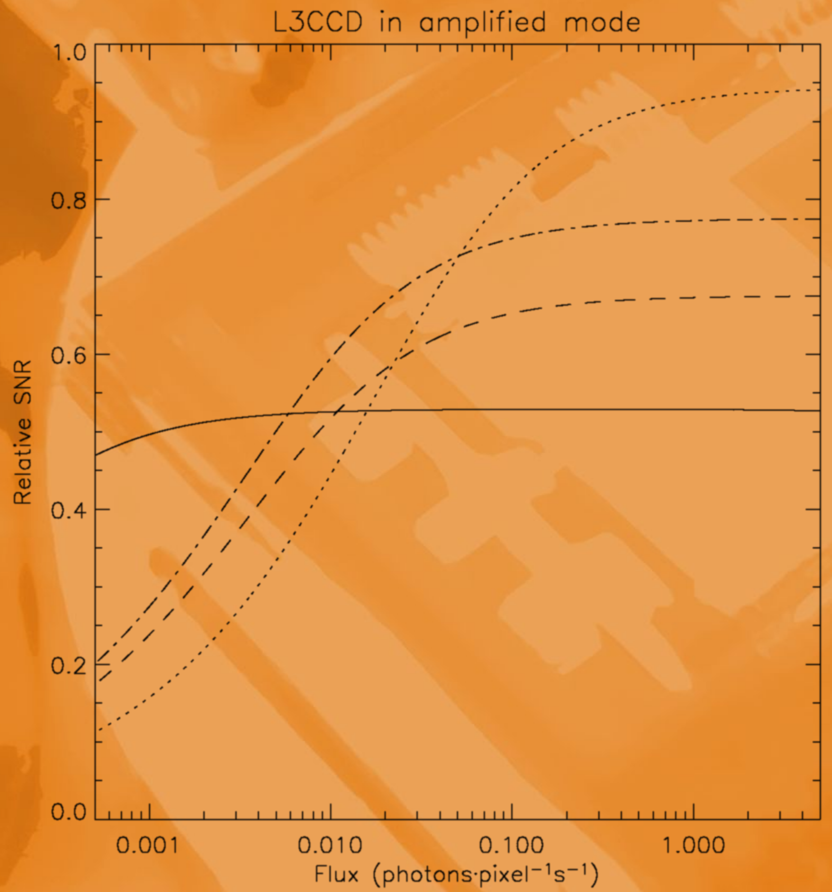
GaAs IPCS, 80 fps, DQE = 28%

CCD, σ=3ē, 5min exposures, DQE = 95%, 100kHz readout

L3CCD NIMO, σ=30ē, G=3000, 10 fps, DQE = 95%, CIC = 0.003ē·pix·frame

L3CCD IMO, σ=30ē, G=3000 0.1 fps, DQE = 95%, CIC = 0.1ē·pix·frame

Comparison with other IPCS



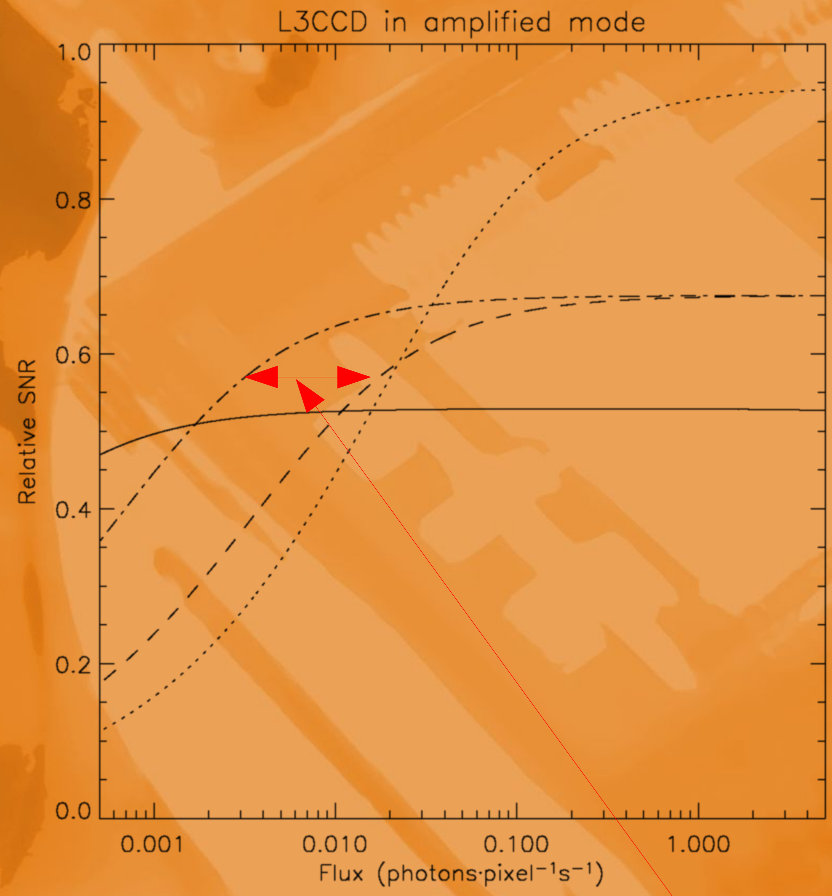
GaAs IPCS, 80 fps, DQE = 28%

CCD, σ=3ē, 5min exposures, DQE = 95%, 100kHz readout

L3CCD IMO, σ=10ē, G=1000, 15s exposures, DQE = 95%

L3CCD IMO, σ=3ē, 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