Observational Astrophysics I

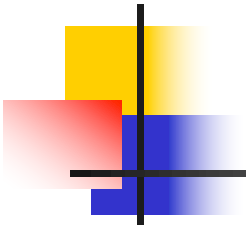
Astronomical Detectors

Kitchin pp. 2-51
Chromey pp. 232-264

Types of detectors

Integrating detectors	Photon counting detectors (PCD)
Accumulate reaction to incoming radiation over time and then digitise	Count (almost) every incoming photon producing digital signal
Example: photographic film, CCD	*Example:* photomultiplier

Technology of integrating sensors



CCD

CMOS

Monolithic CMOS

Hybrid CMOS

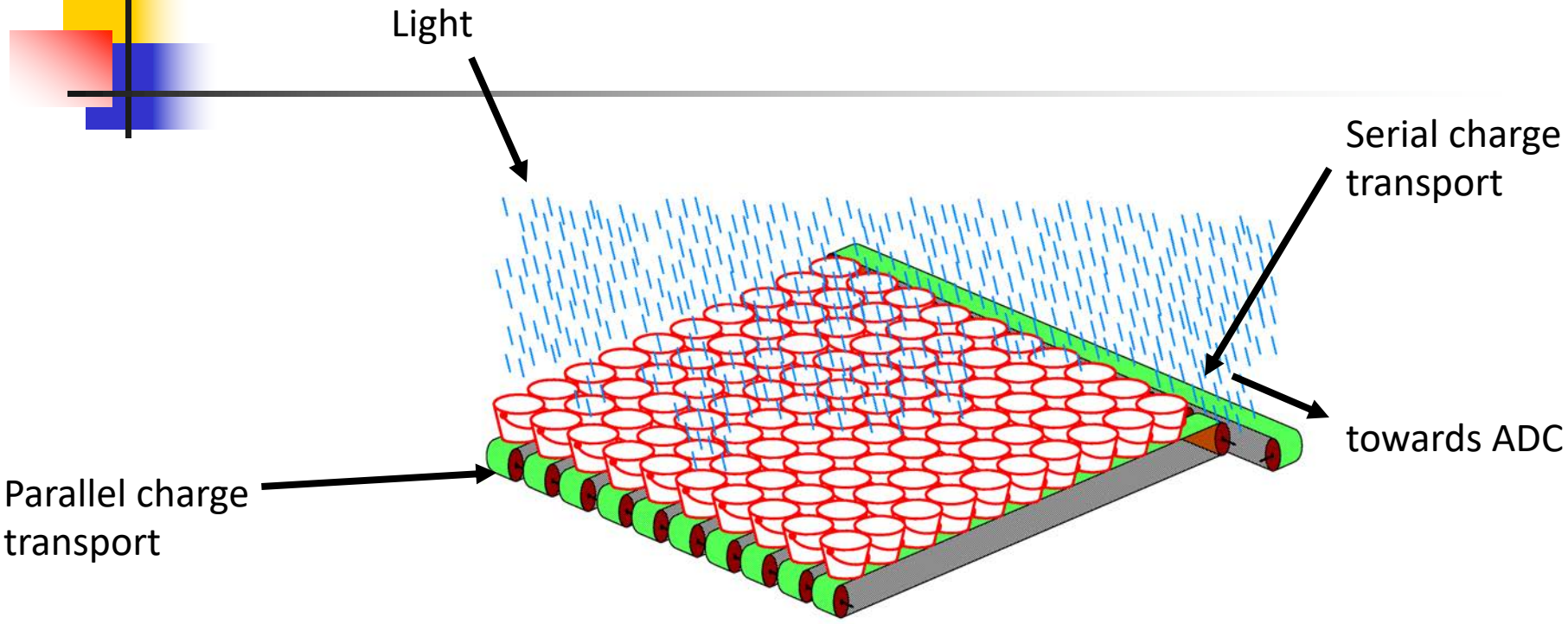
HgCdTe
Visible through IR

Silicon - Visible through near IR

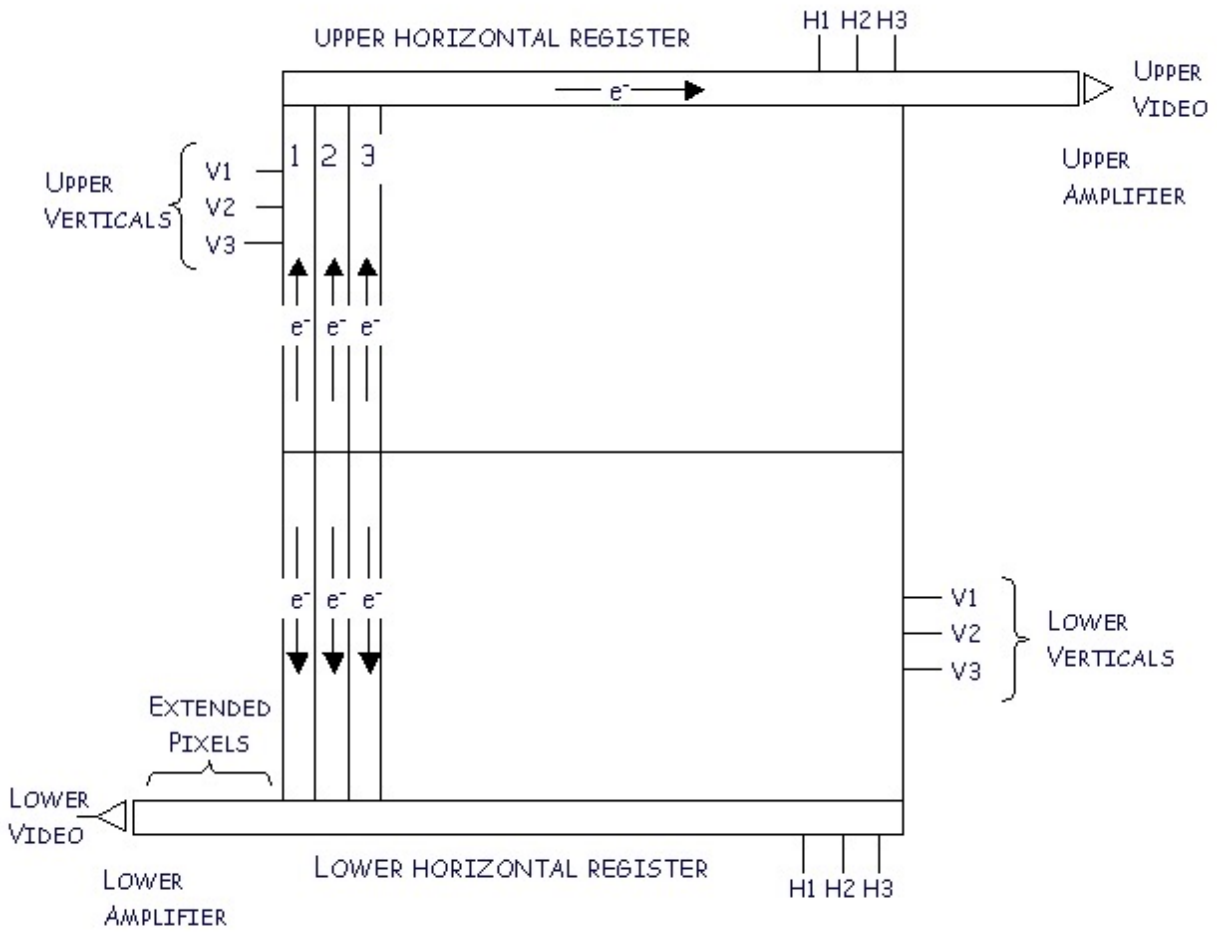
Common parameters of detectors

- Quantum efficiency (QE)
- Spectral response
- Linearity
- Gain
- Dynamic range
- Saturation level
- Cosmic ray sensitivity
- Modulation Transfer Function (MTF)
- Cosmetics
- Noise
  - Shot noise
  - Read-out noise
  - Dark current
- Memory
- Flatness

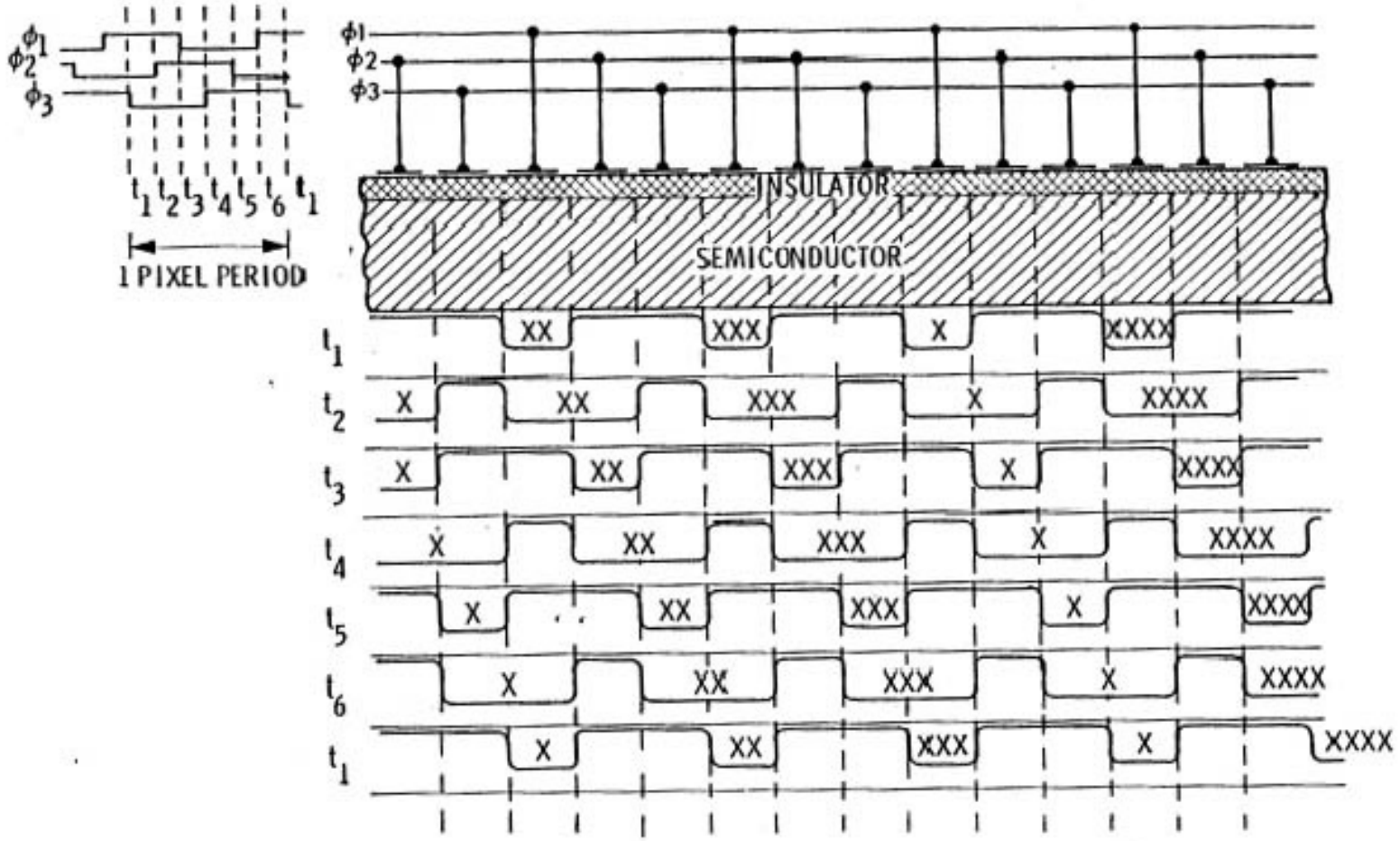
Integrating detector: Charge Coupled Device



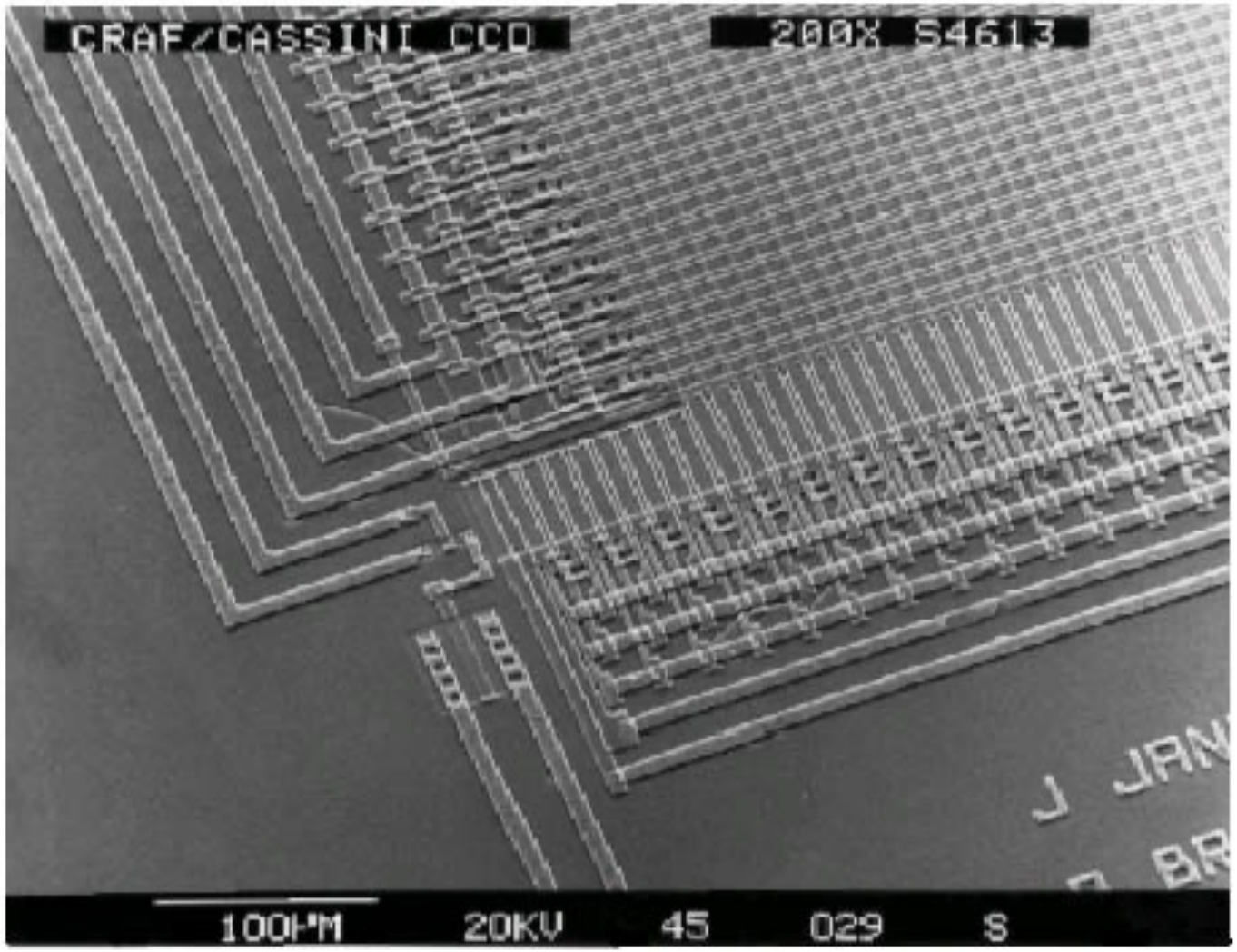
CCD with 2-shift registers

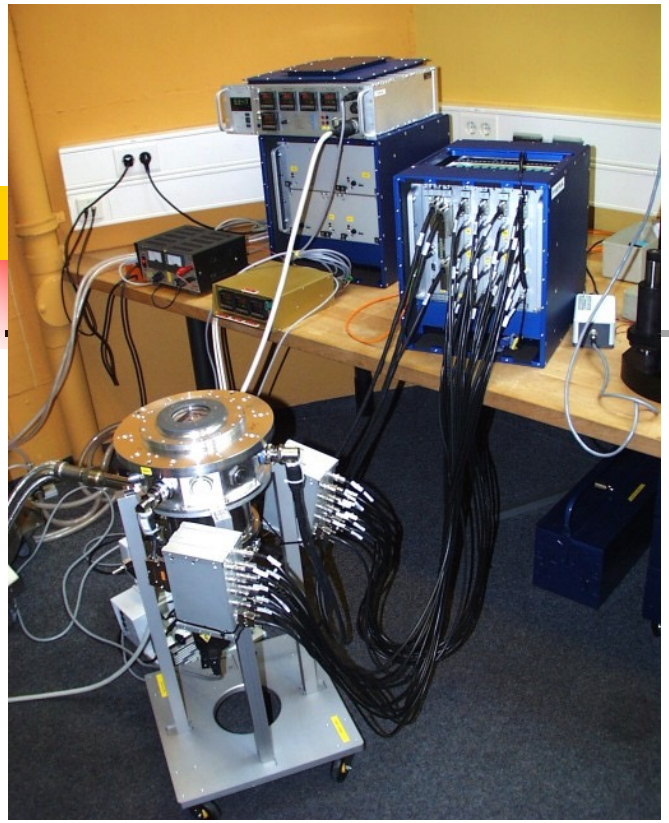


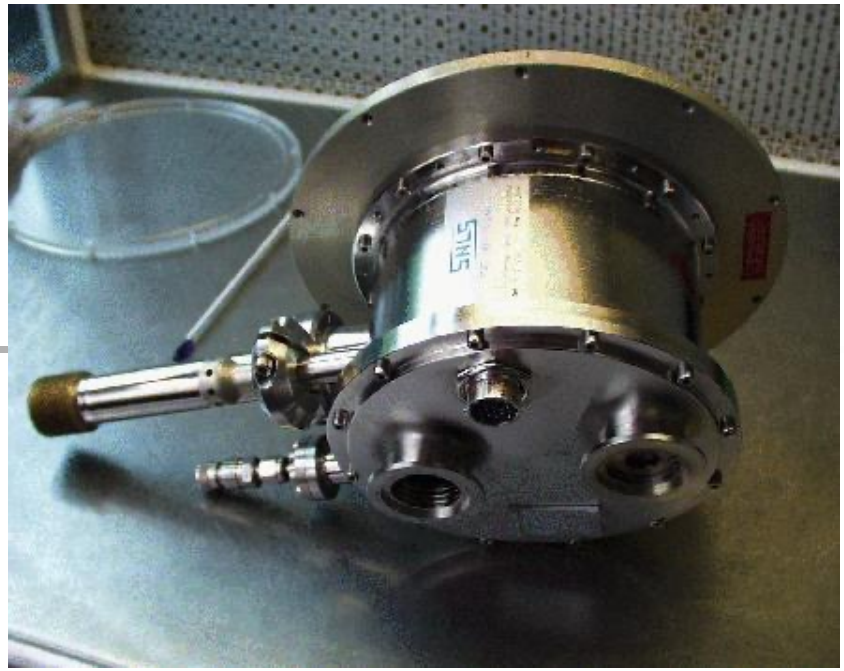
Voltages to pixels during readout



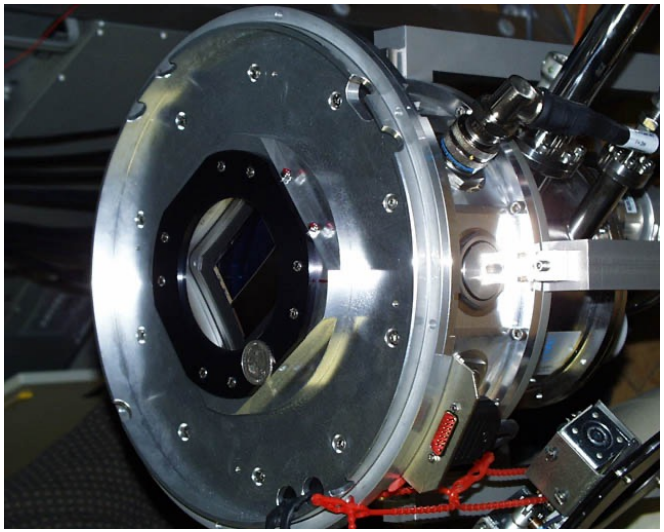
Logarithmic amplifier Technology is spectacular!

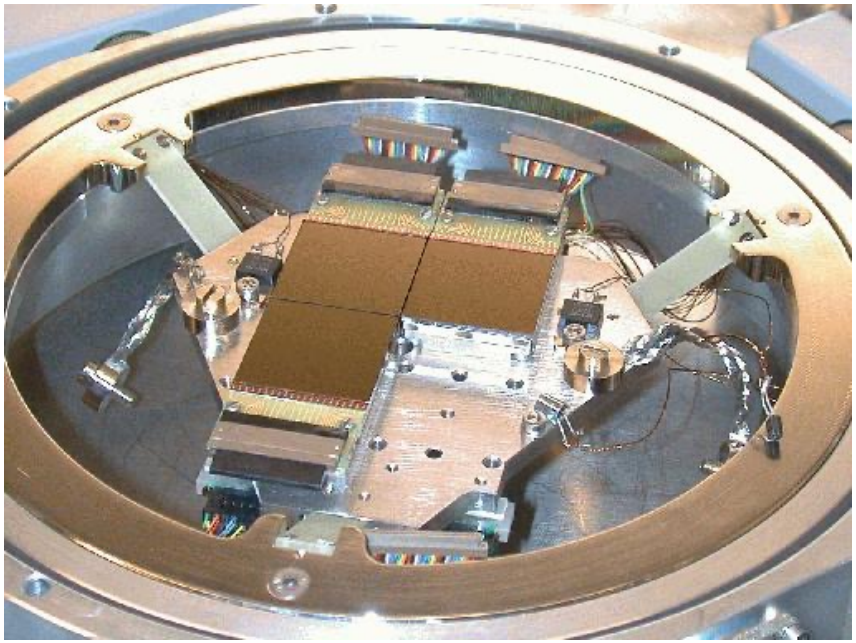




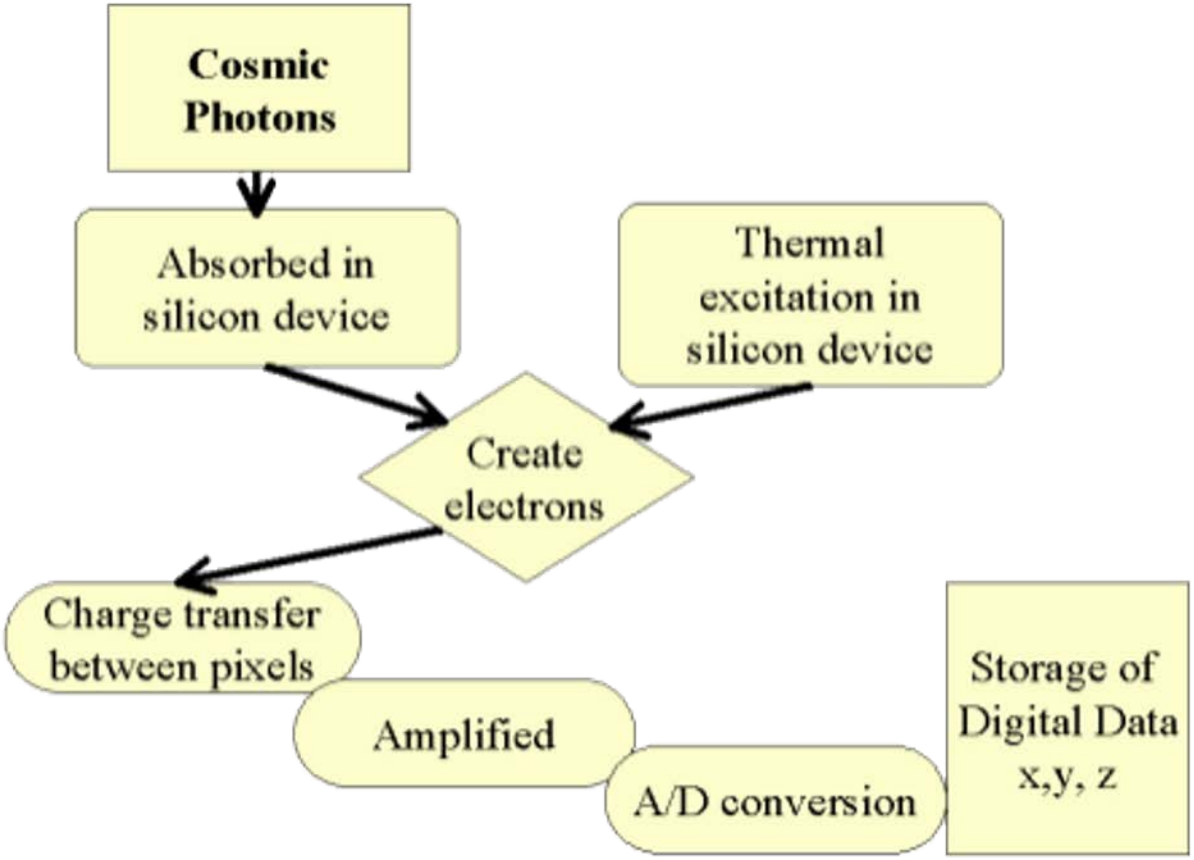


Continuous flow cryostat





Electron trail

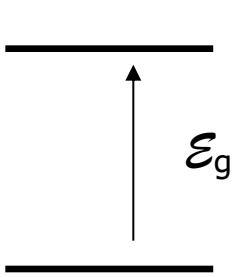


Photon detection

For an electron to be excited from the conduction band to the valence band

$$h\nu > \mathcal{E}_g$$

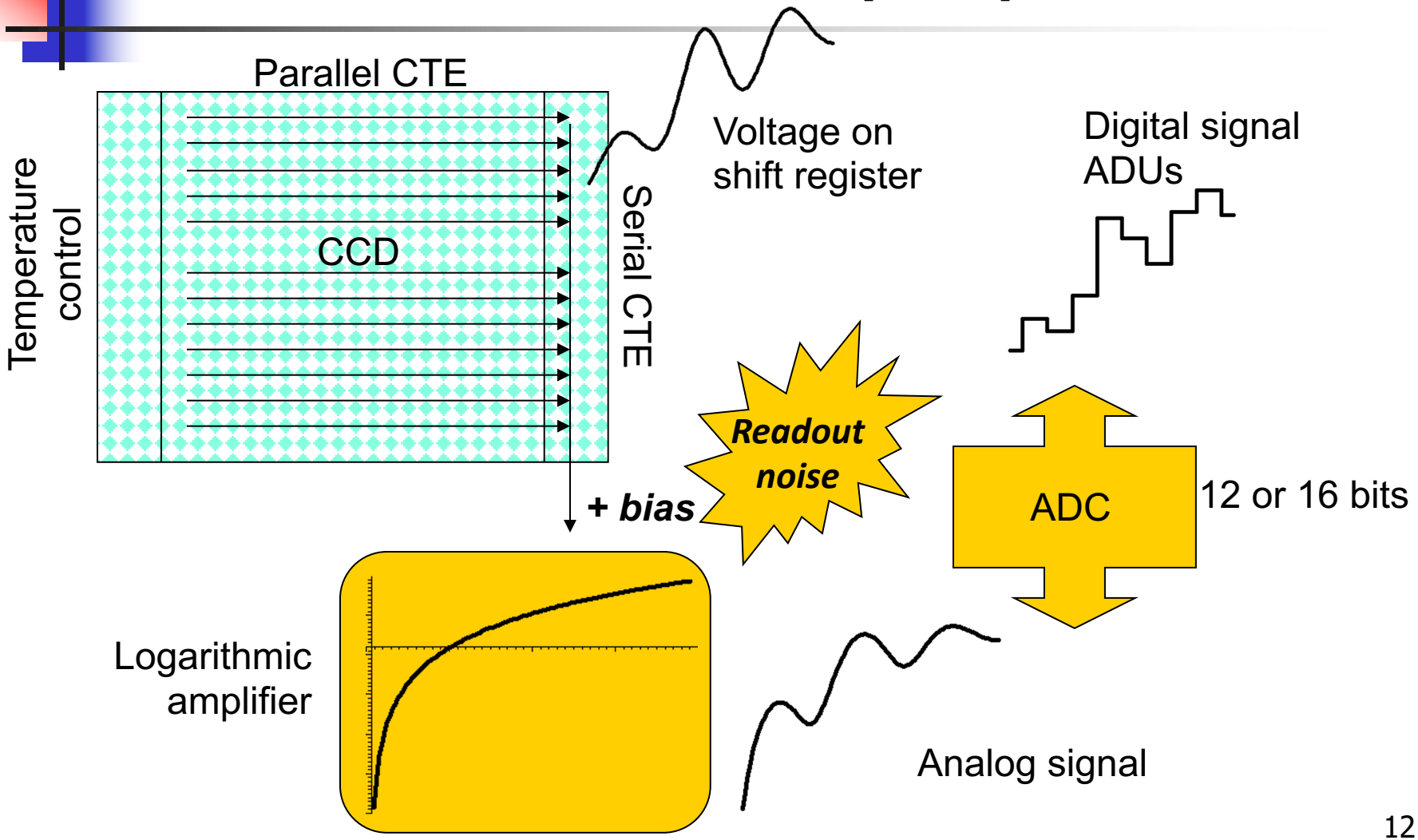
h = Planck constant (6.6310^{-34} Joule•sec)
ν = frequency of light (cycles/sec) = λ/c
$\mathcal{E}_g$ = energy gap of material (electron-volts)



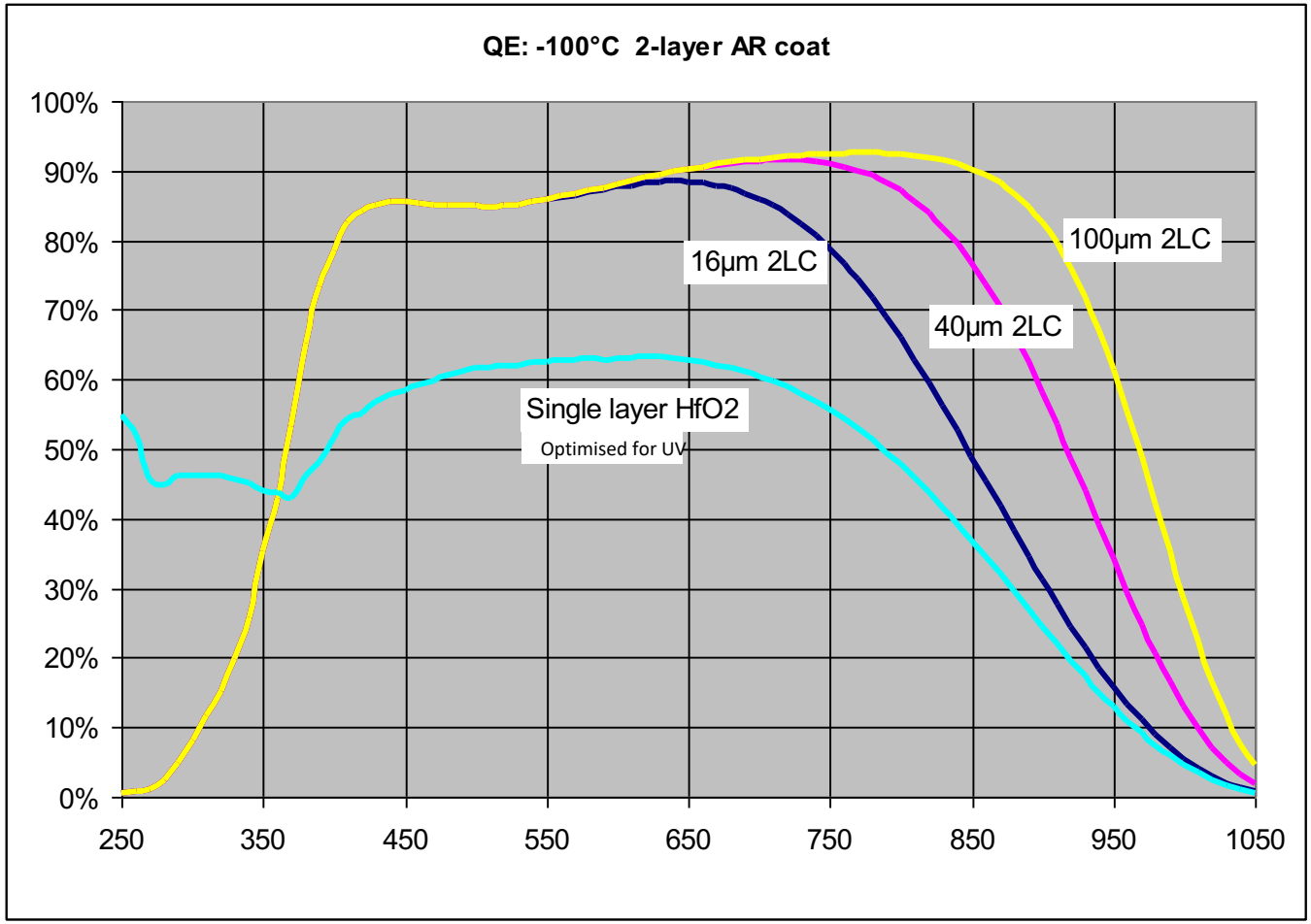
$$\lambda_c = 1.238 / \mathcal{E}_g \text{ (eV)}$$

Material Name	Symbol	$\mathcal{E}_g$ (eV)	λ_c (μm)
Silicon	Si	1.12	1.1
Indium Antimonide	InSb	0.23	5.5
Mer-Cad-Tel	HgCdTe	1.00 – 0.07	1.24 – 18

Critical data flow properties



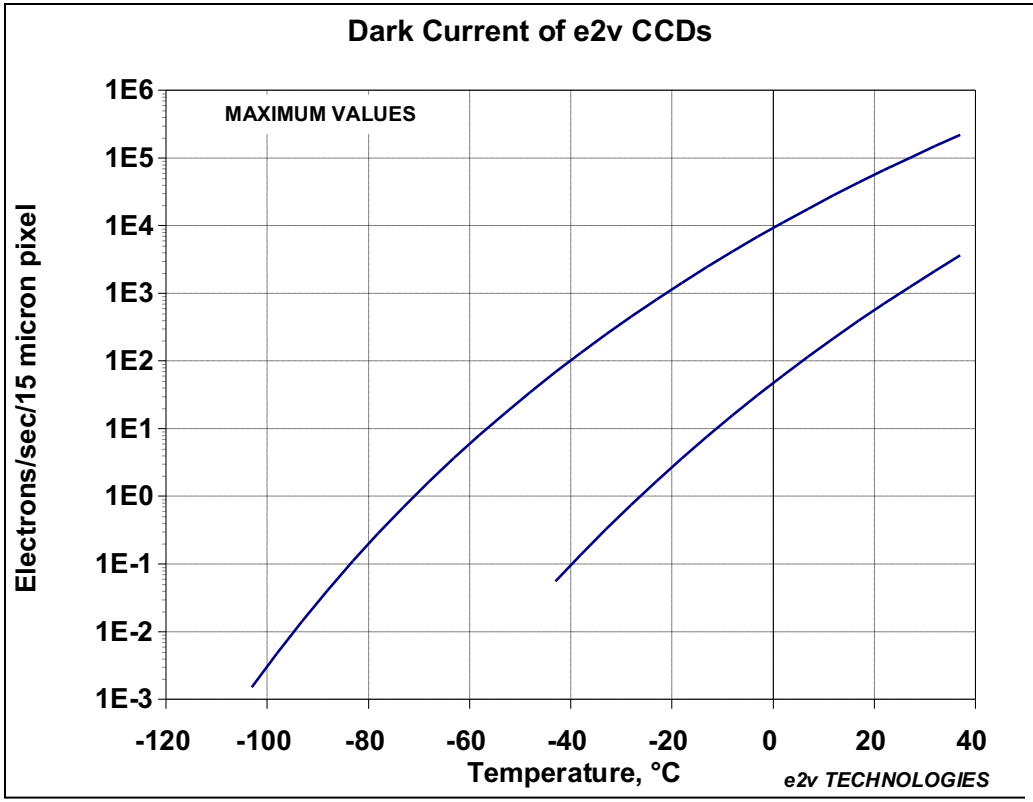
Quantum Efficiency



Limits to the spectral range

- QE drops in the blue because the top layer is covered with SiO film, opaque for UV photons. One way to improve QE in the blue is the remove extra silicon substrate from the back (thinning) and use this side to detect the light (back-illumination) avoiding exposing it to air.
- QE also drops in the red because photons have not enough energy to quick electrons to the valence band. Warming up CCD enhances excited level population and thus improves response in the red but also increases the noise.

Dark current (thermal electrons)

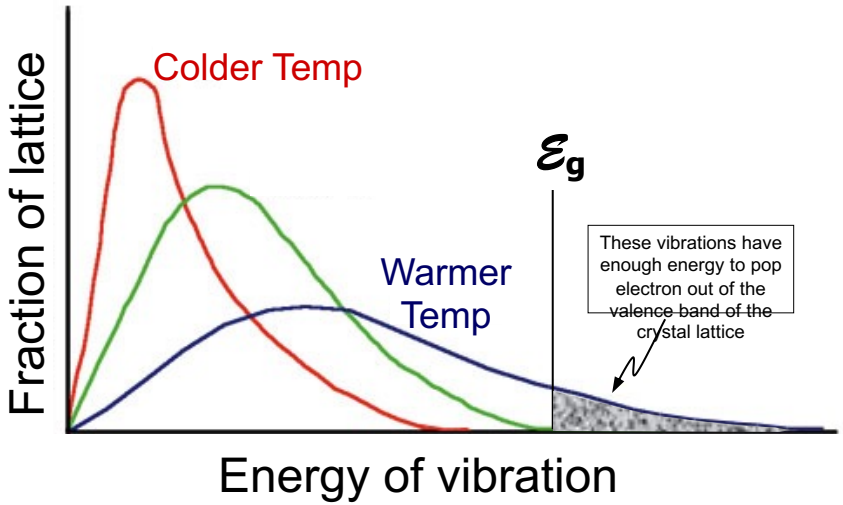


At T=270 K DC 10 e^-/pixel/s

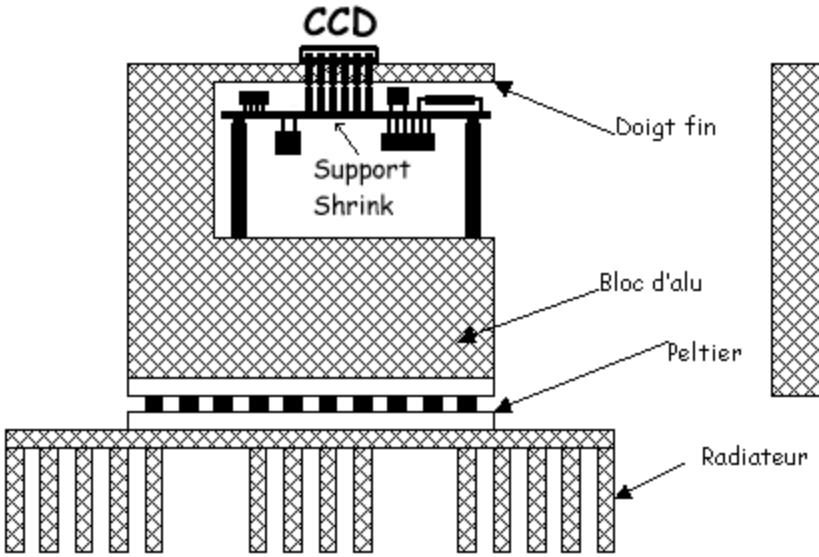
At T=230 K DC 0.1 e^-/pixel/s

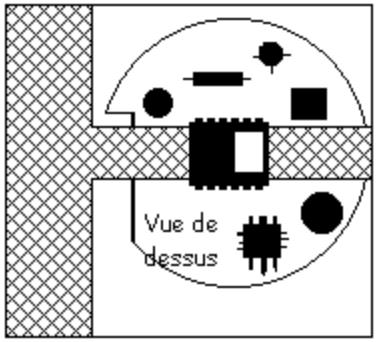
At T=170 K DC 10 e^-/pixel/hour

At T=120 K DC 1 e^-/pixel/hour



Cooling



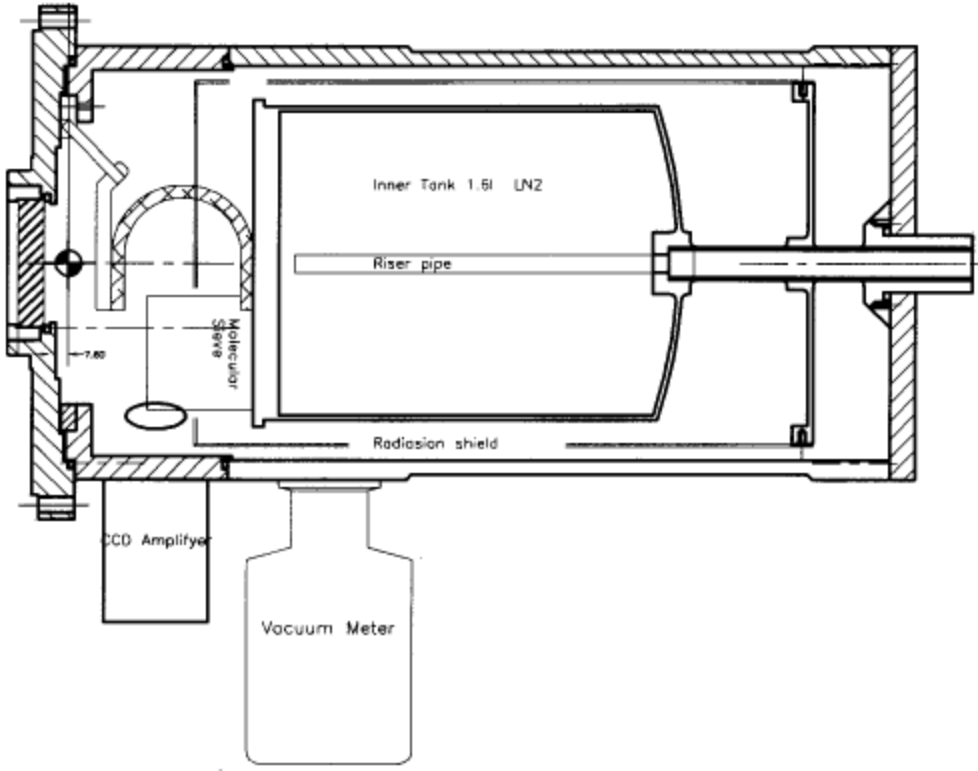


Semiconductor cooling

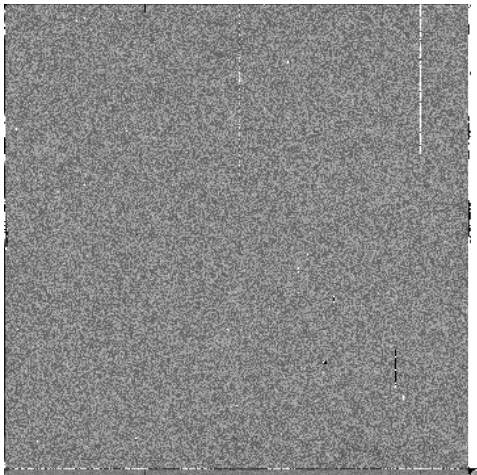
Peltier cooler: -20° ÷ -60° C

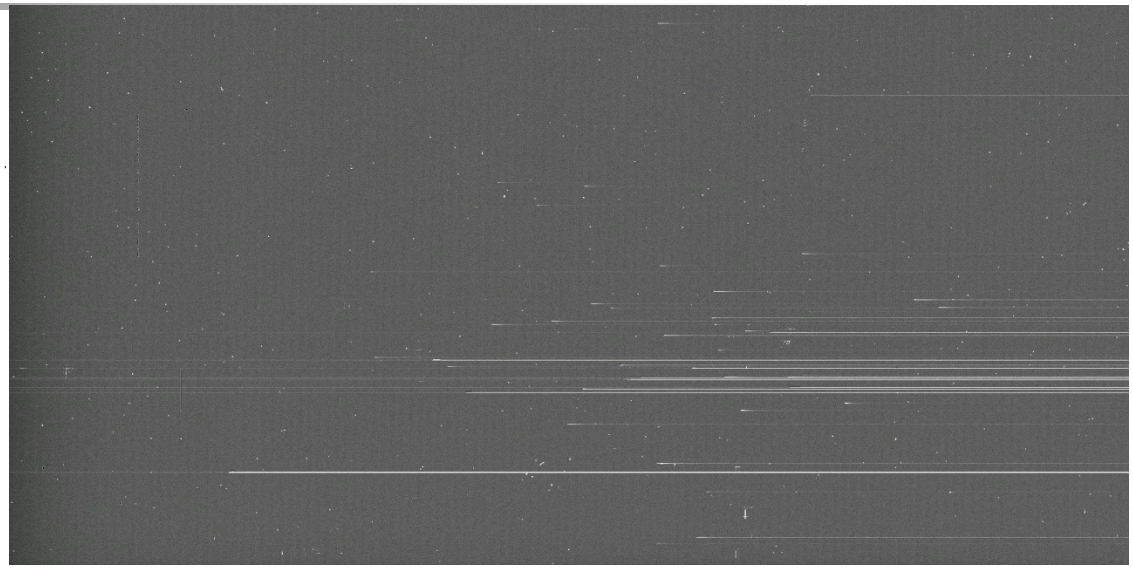
Cryogenic cooling

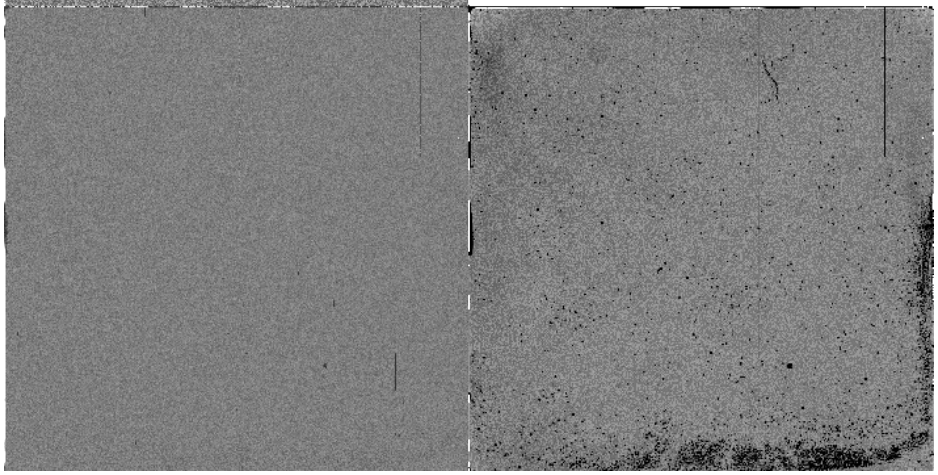
Liquid N_2: 100 ÷ 150 K



Cosmetics (manufacturing defects)

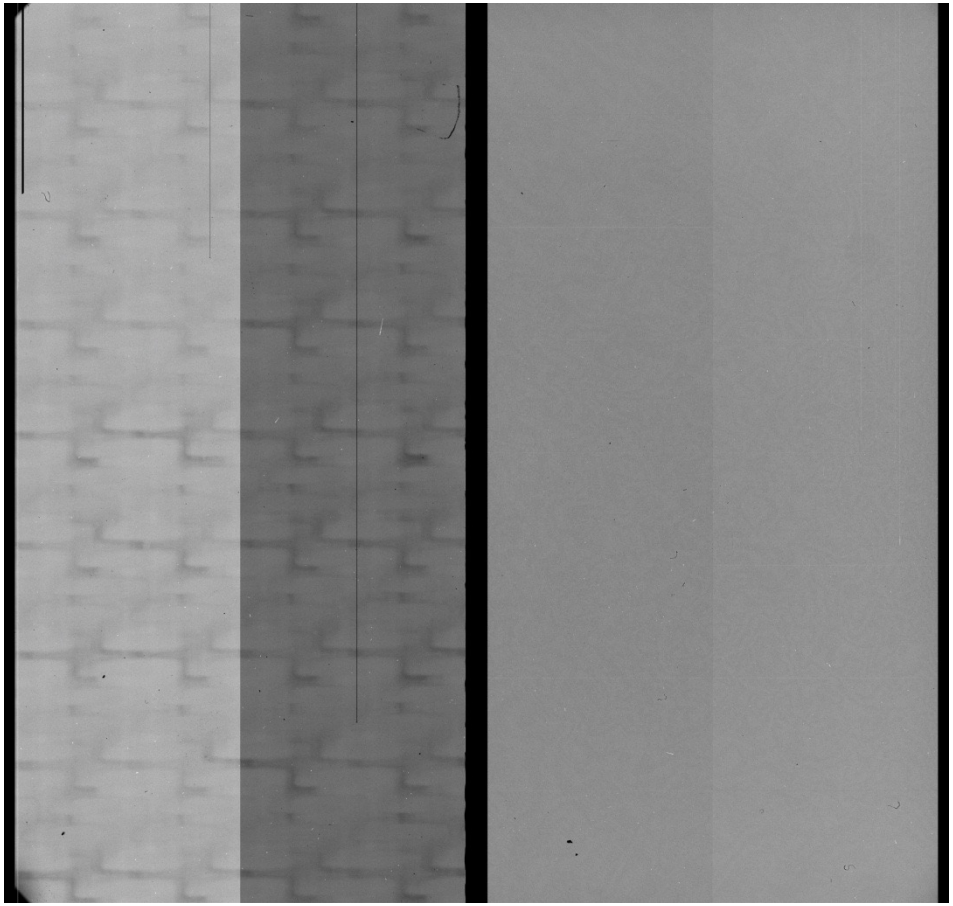




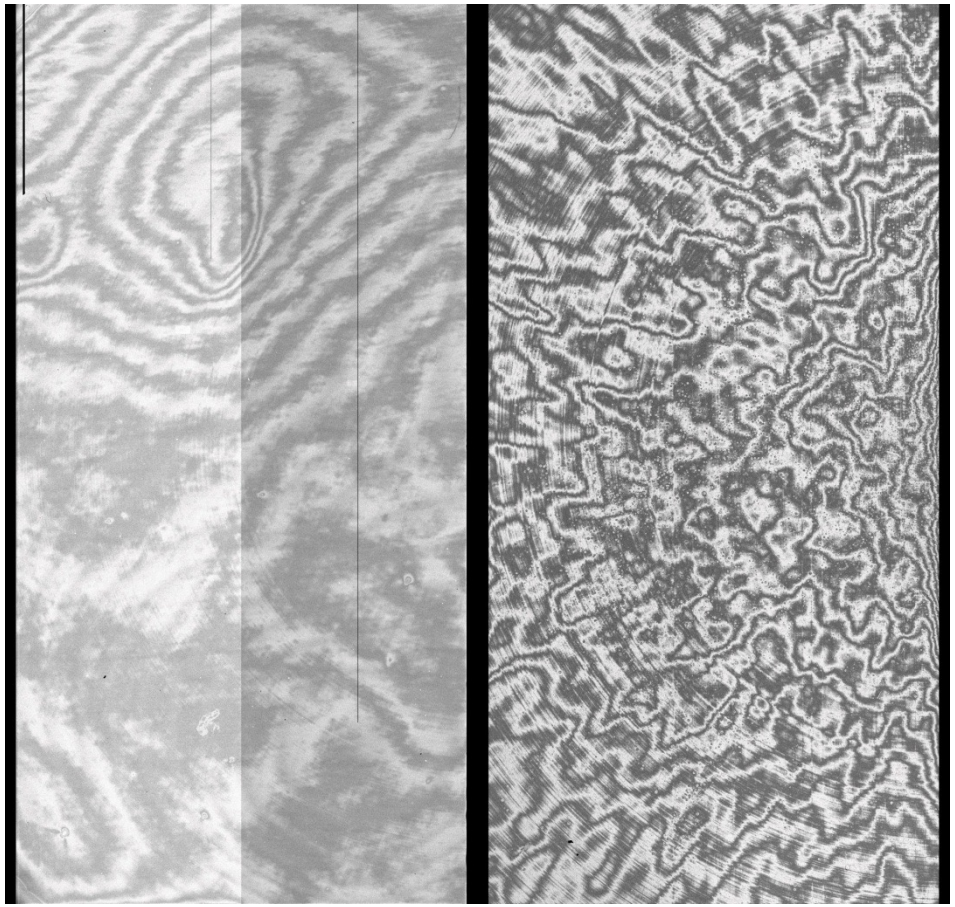


Fringing (interference)

λ=650 nm



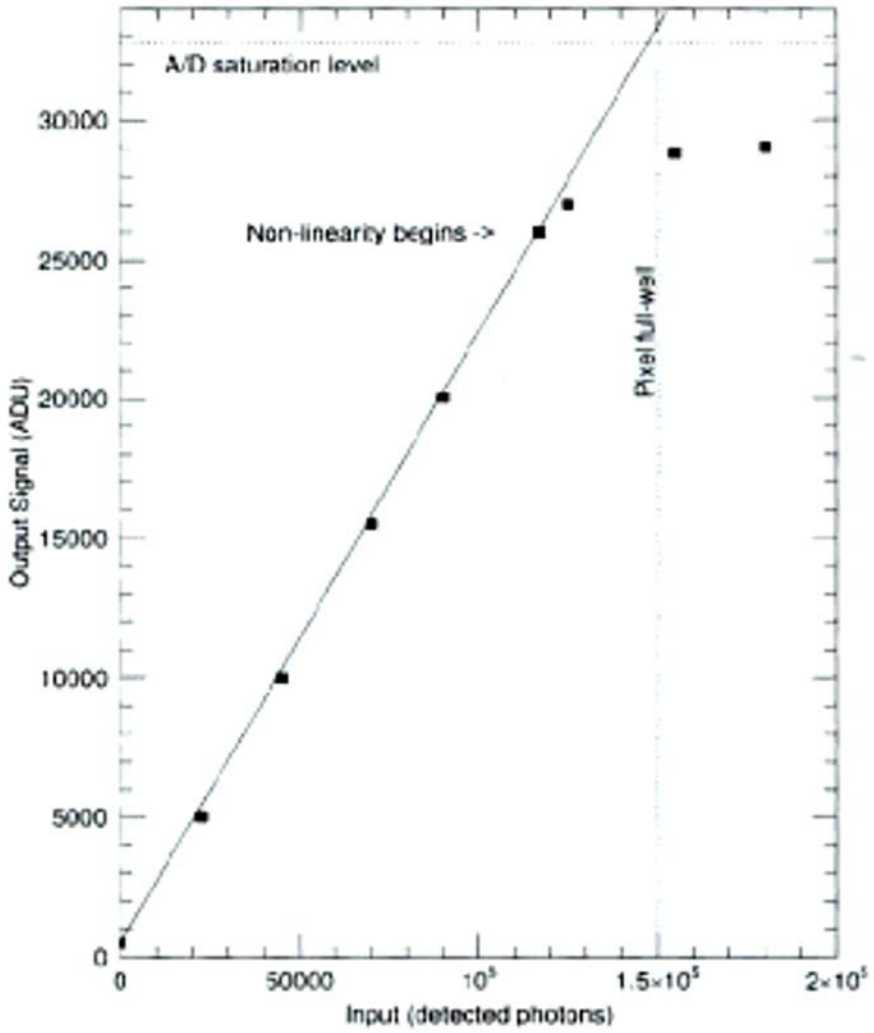
λ=900 nm



Linearity

CCD full well is the number of electrons which can be stored in one pixel (height of energy barrier between pixels).

Typical values are between 30000 and 1000000 which also where the CCD goes non-linear.



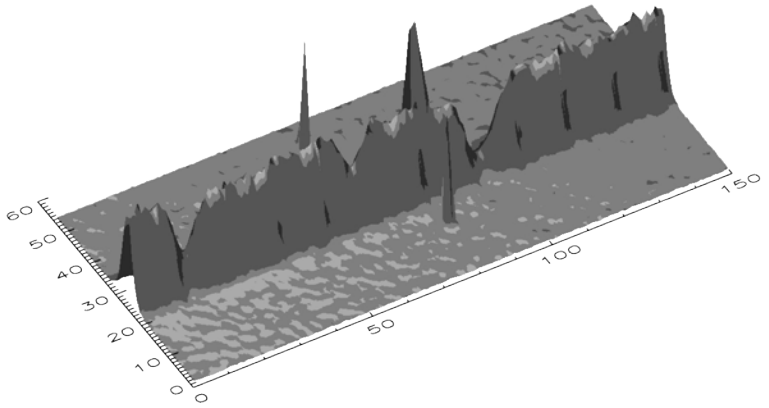
Charge Transfer Efficiency

- This is examined by measuring the amplitude of bright points left by a γ–ray source. Amplitude dependence in the direction of parallel read gives parallel CTE, while the other direction reflects serial CTE. Good CTE is >0.99999.

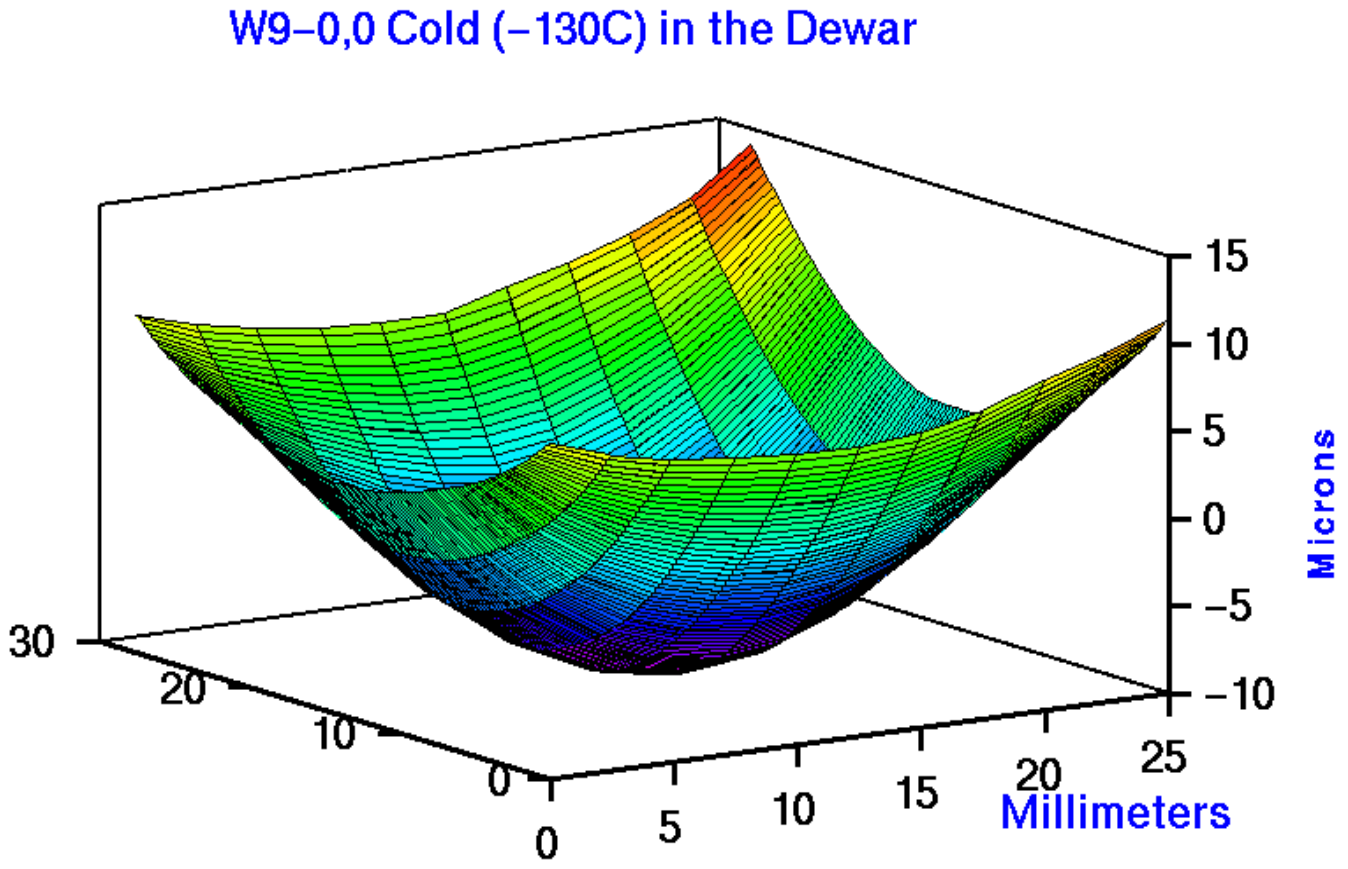
- The same experiment establishes the relation between ADU and number of photoelectrons (gain). Same CCD may use more than one gain (e.g. 1.1 and 9).

CCD noise

- Shot noise (Poisson distribution $\sigma \approx \sqrt{N}$)
- Dark current is $\propto$time, depends on temperature
- Readout noise, depends on the temperature, read speed and amplifier(s) used
- Cosmic rays destroy content of a few pixels

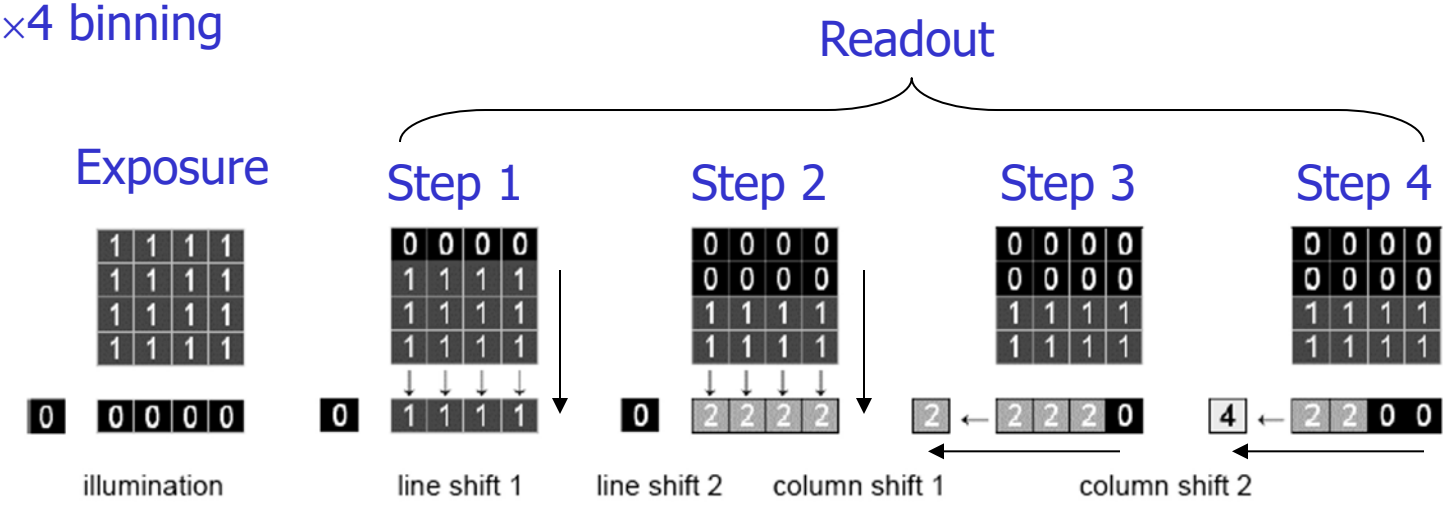


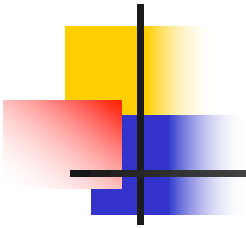
Flatness (thermal stress)



Binning

Example: 4×4 binning





Next time…

- Hybrid detectors
- IR detectors
- Photon counting detectors
- Calibrations