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	React to (almost) every incoming photon and produce digital count
Example: photographic film, CCD	*Example:* photomultiplier, CMOS

Technology of integrating sensors

CCD

CMOS

Monolithic CMOS

Hybrid CMOS

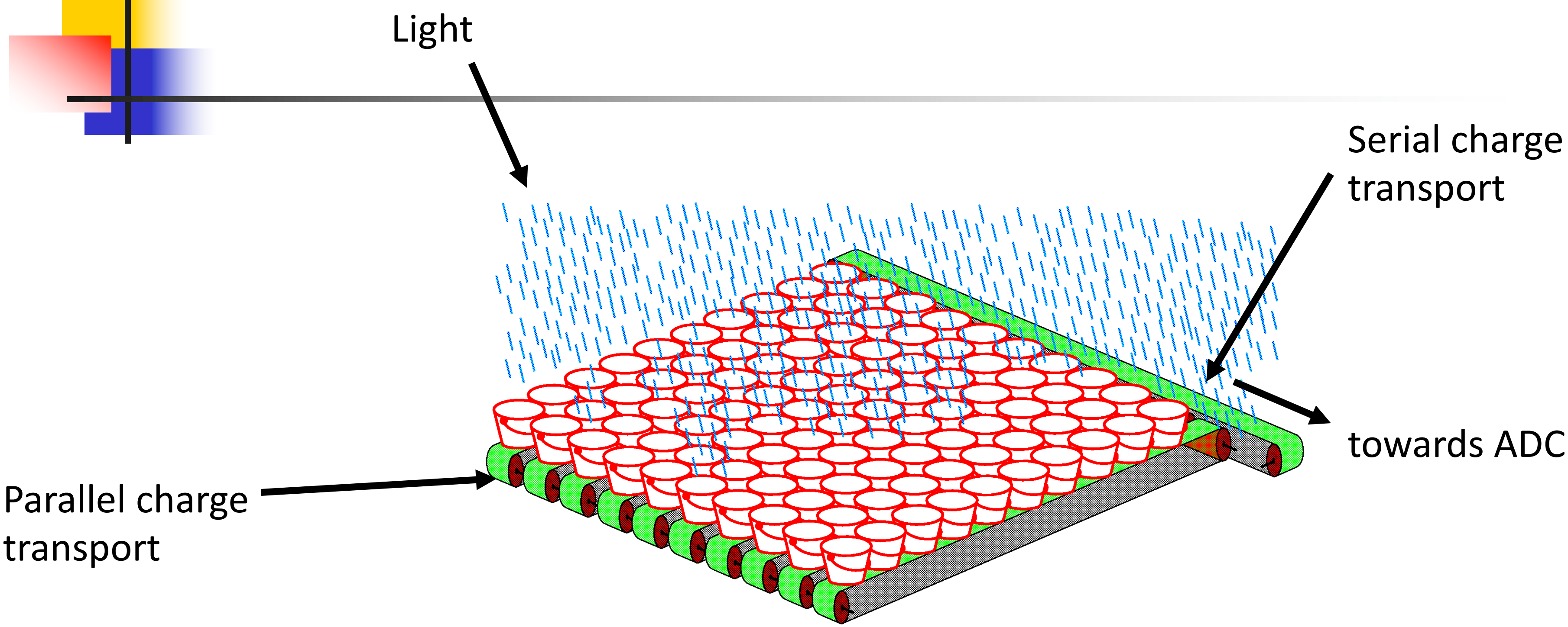
HgCdTe
Visible through IR

Silicon - Visible through near IR

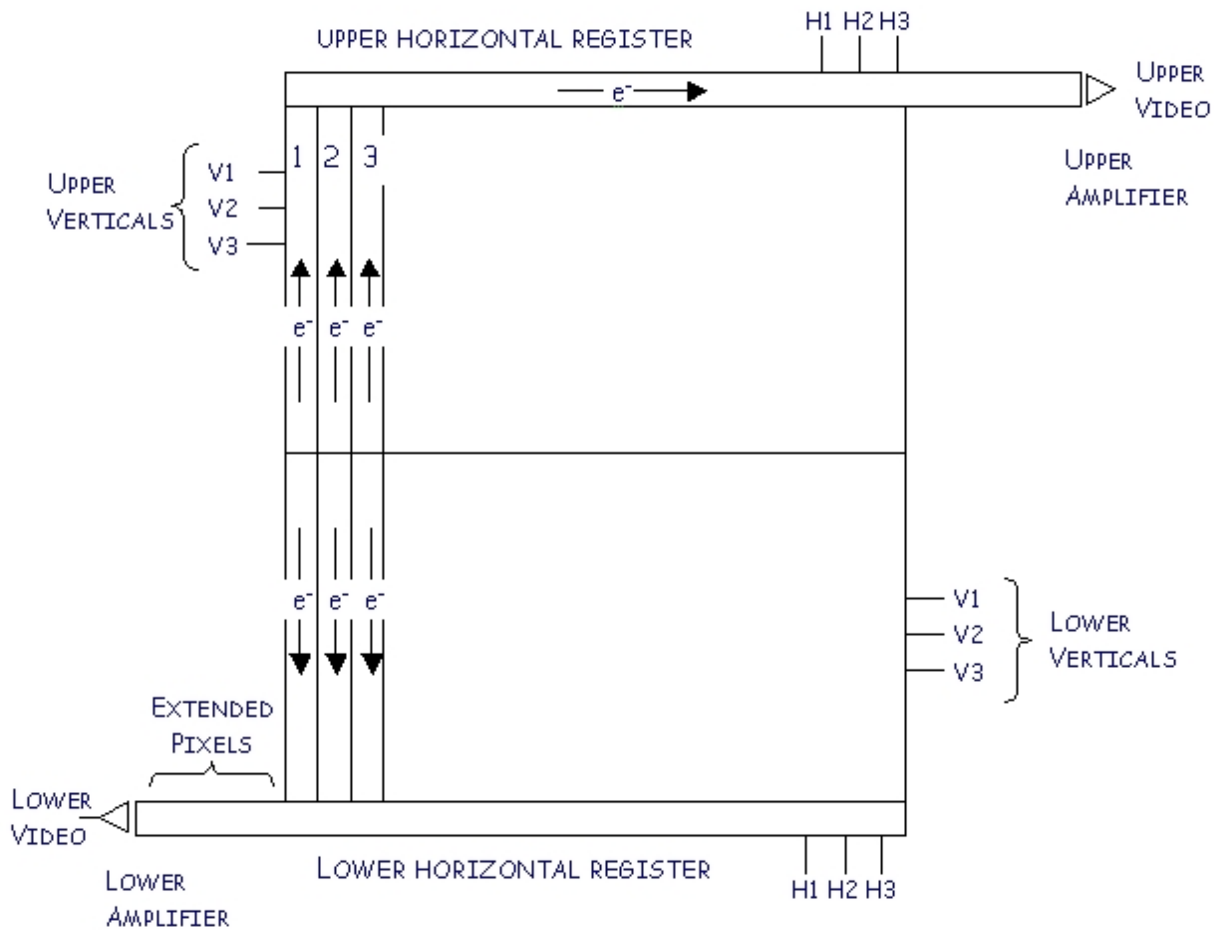
Common parameters of detectors

- Quantum efficiency (QE)
- Spectral response
- Linearity
- Gain
- Dynamic range
- Saturation level
- Cosmic ray sensitivity
- Cosmetics
- Noise
- Persistence
- Flatness

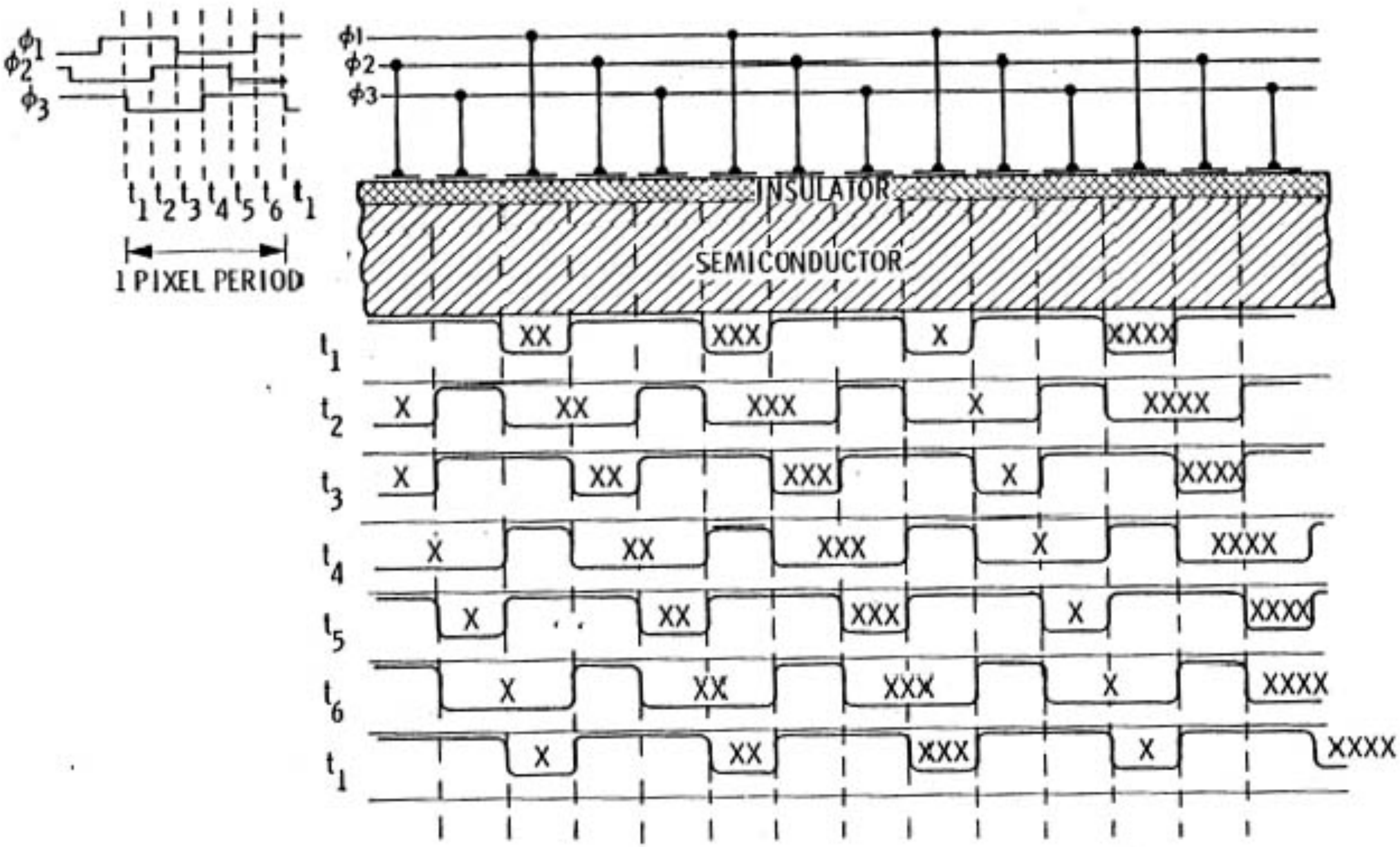
Integrating Detectors: Charge Coupled Device (CCD)



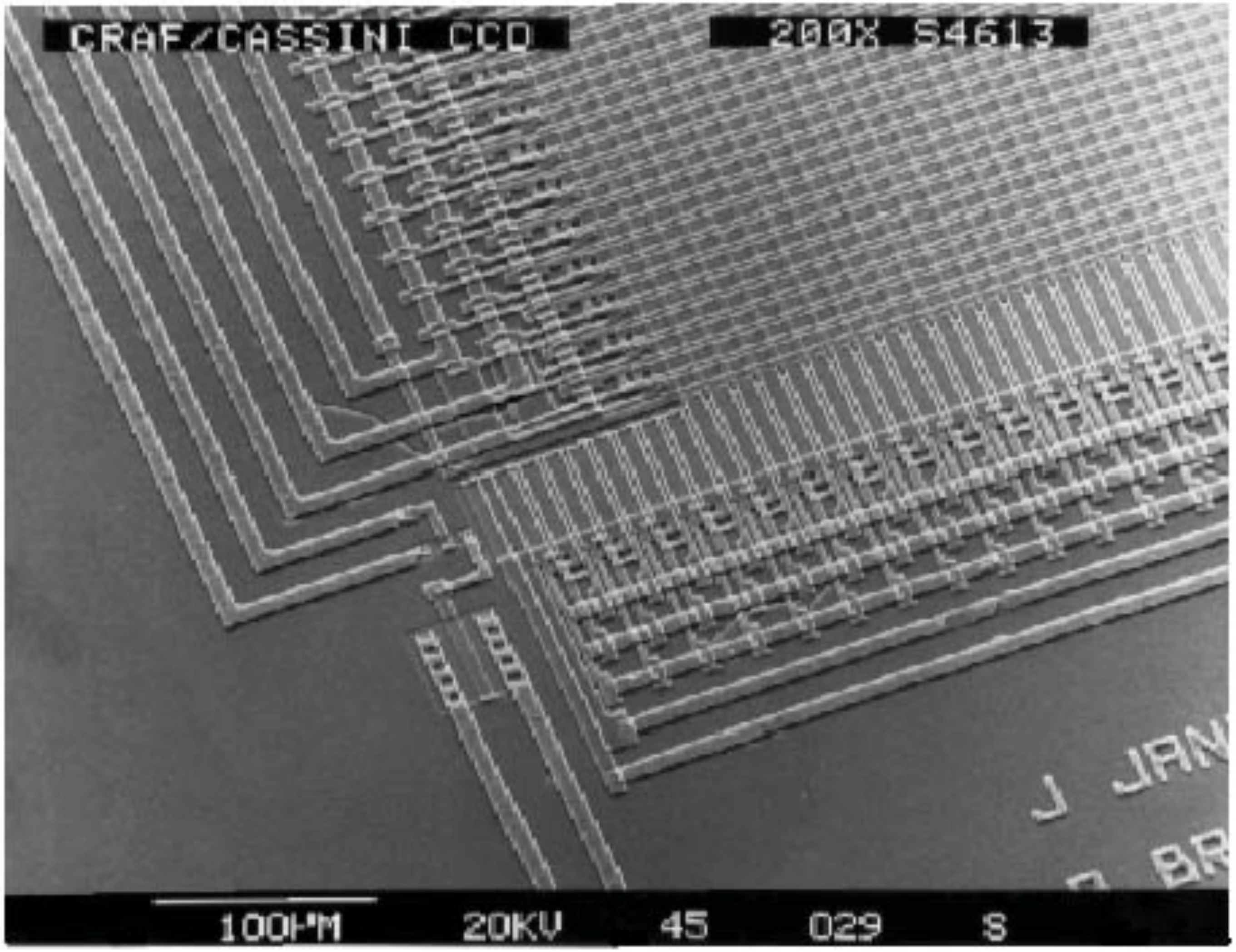
2-serial register detector



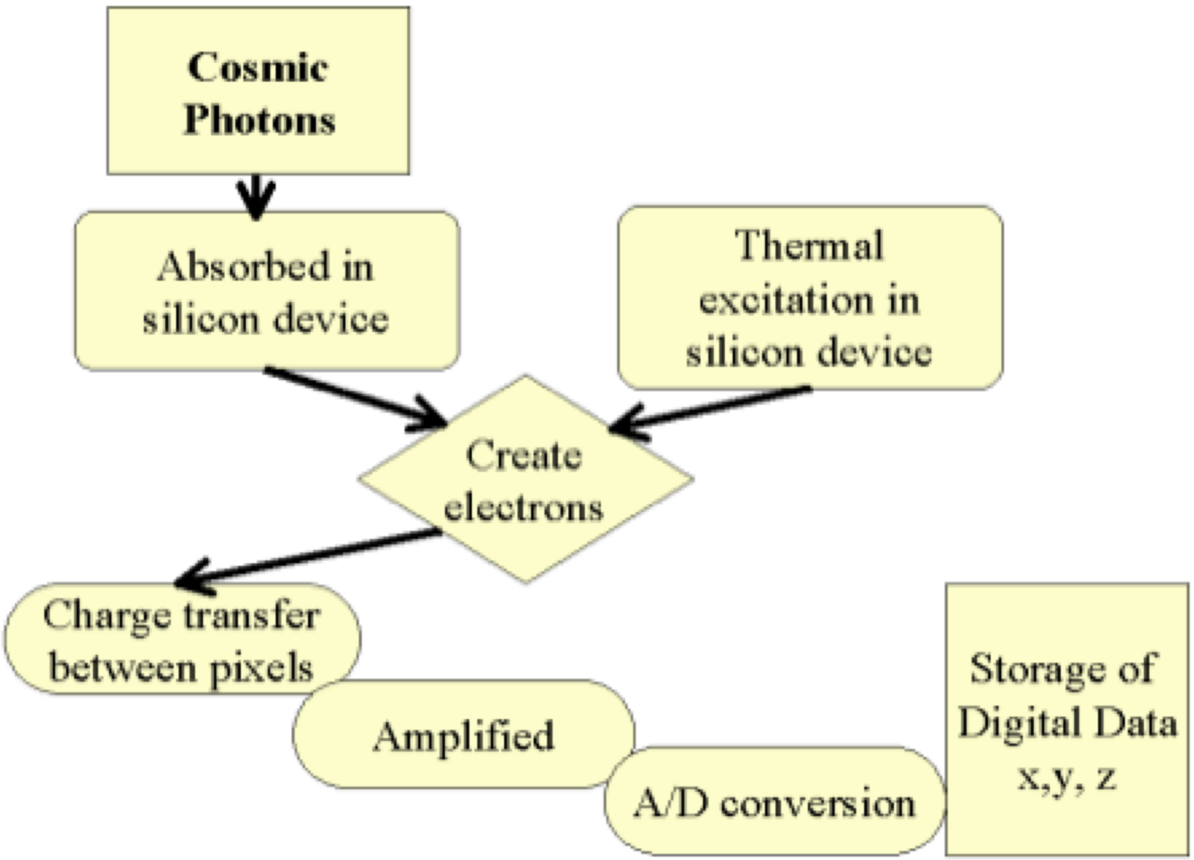
Readout voltage timing diagrams (6 electrodes)



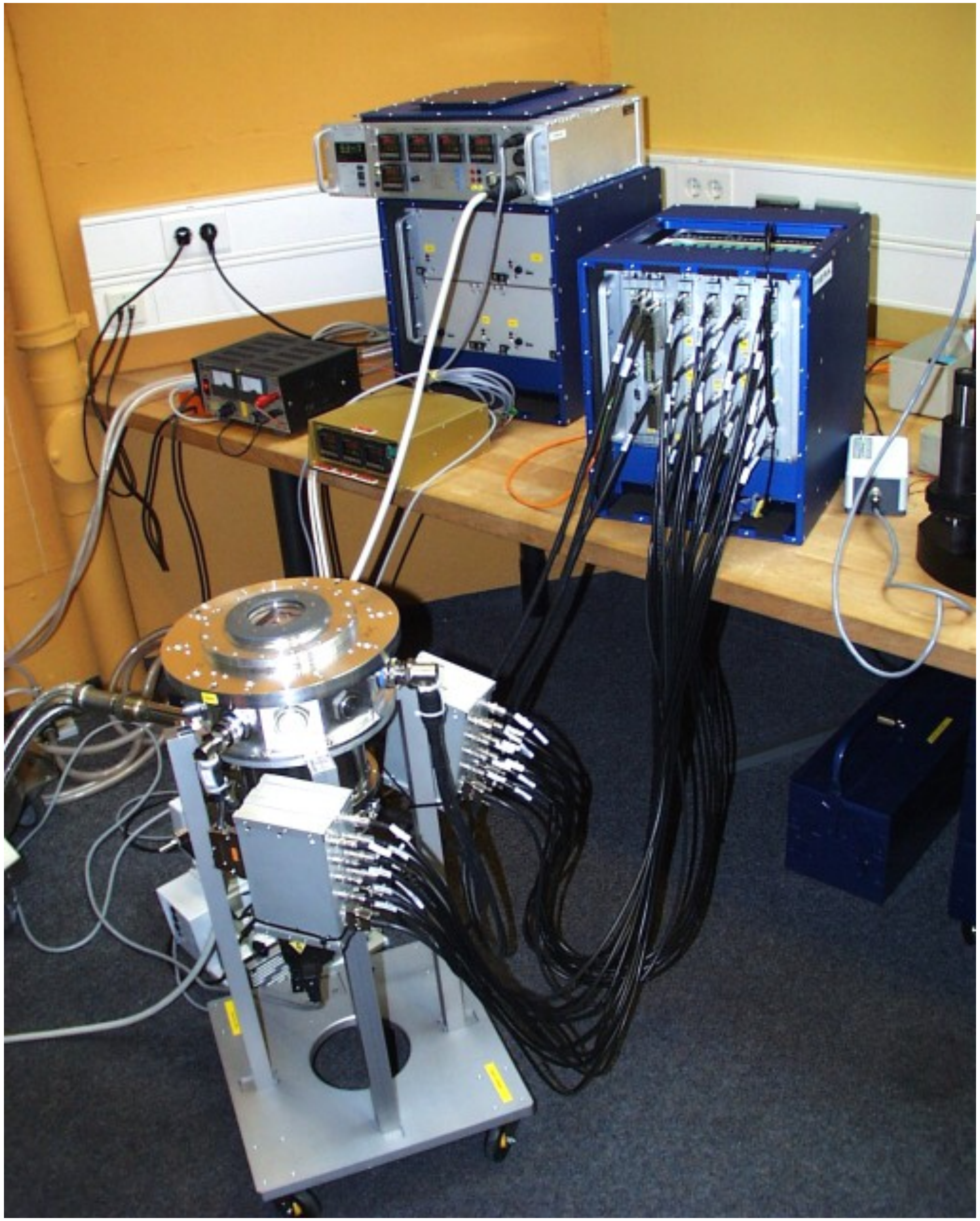
Technology is spectacular!

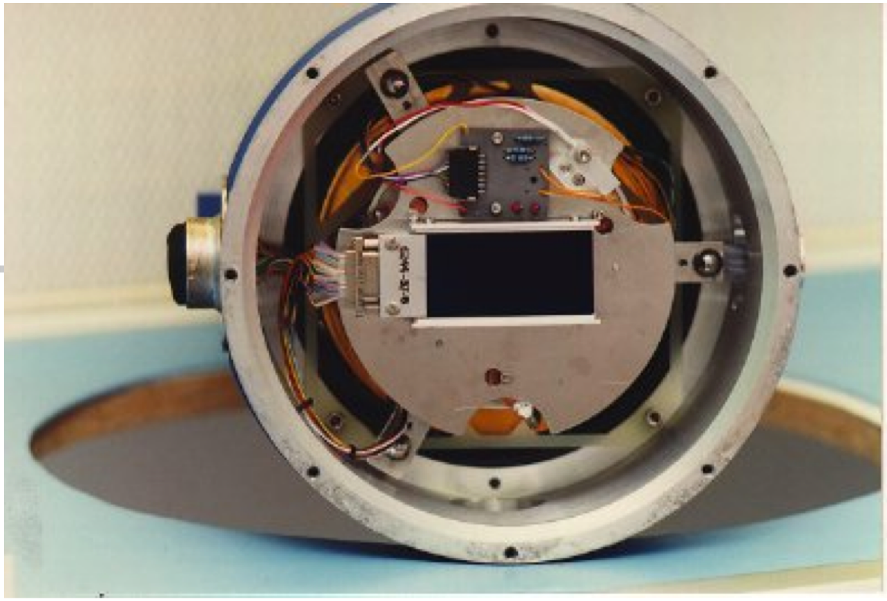


Photon registration path



Liquid Nitrogen cooling





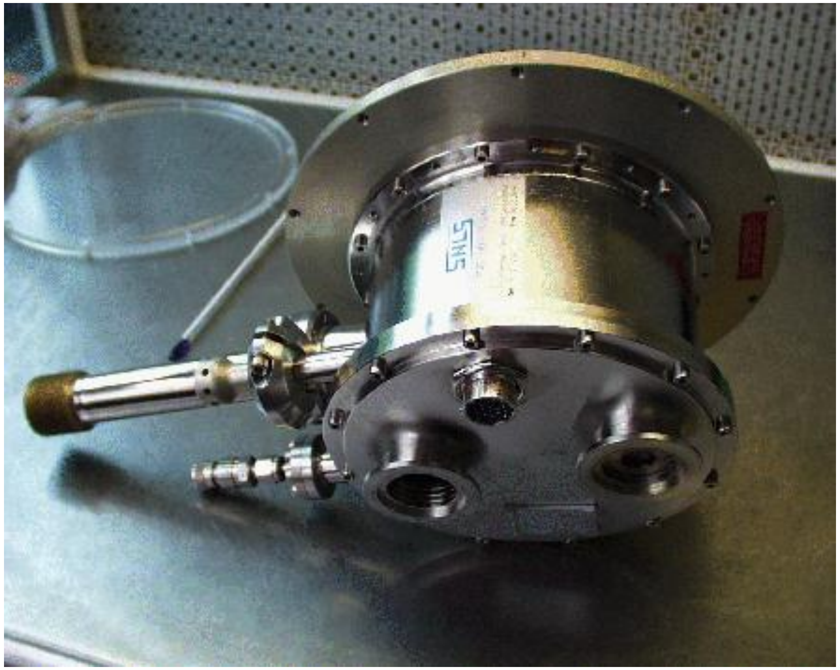
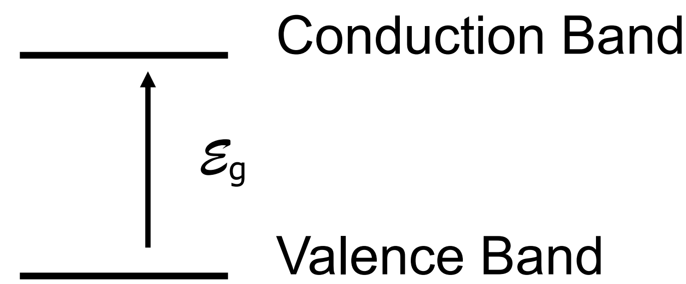


Photo-effect for various materials

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

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

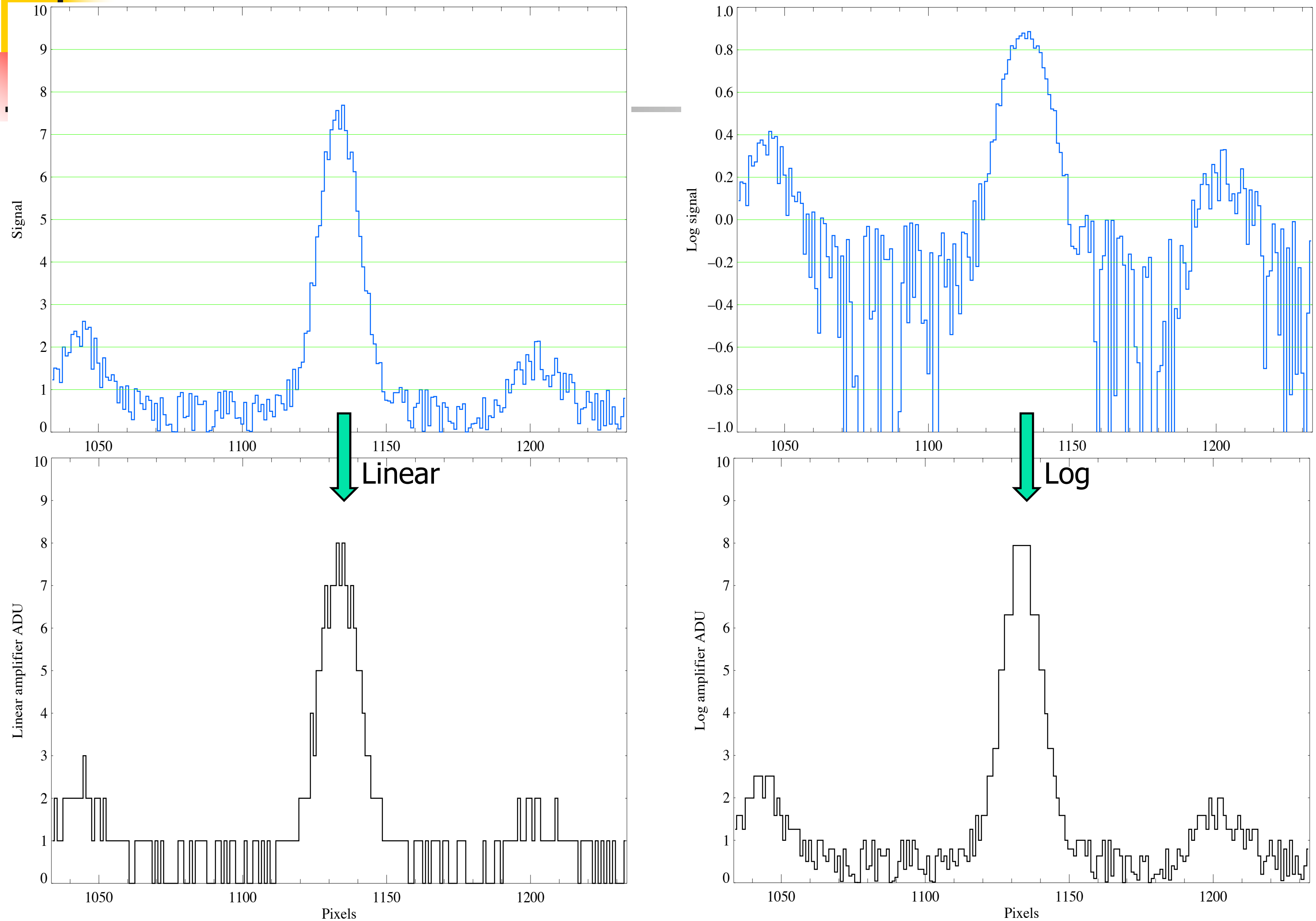
h = Planck constant (6.6310^{-34} Joule•sec)
ν = frequency of light (cycles/sec) = λ/c
$\mathcal{E}_g$ = energy gap of material (electron-volts)



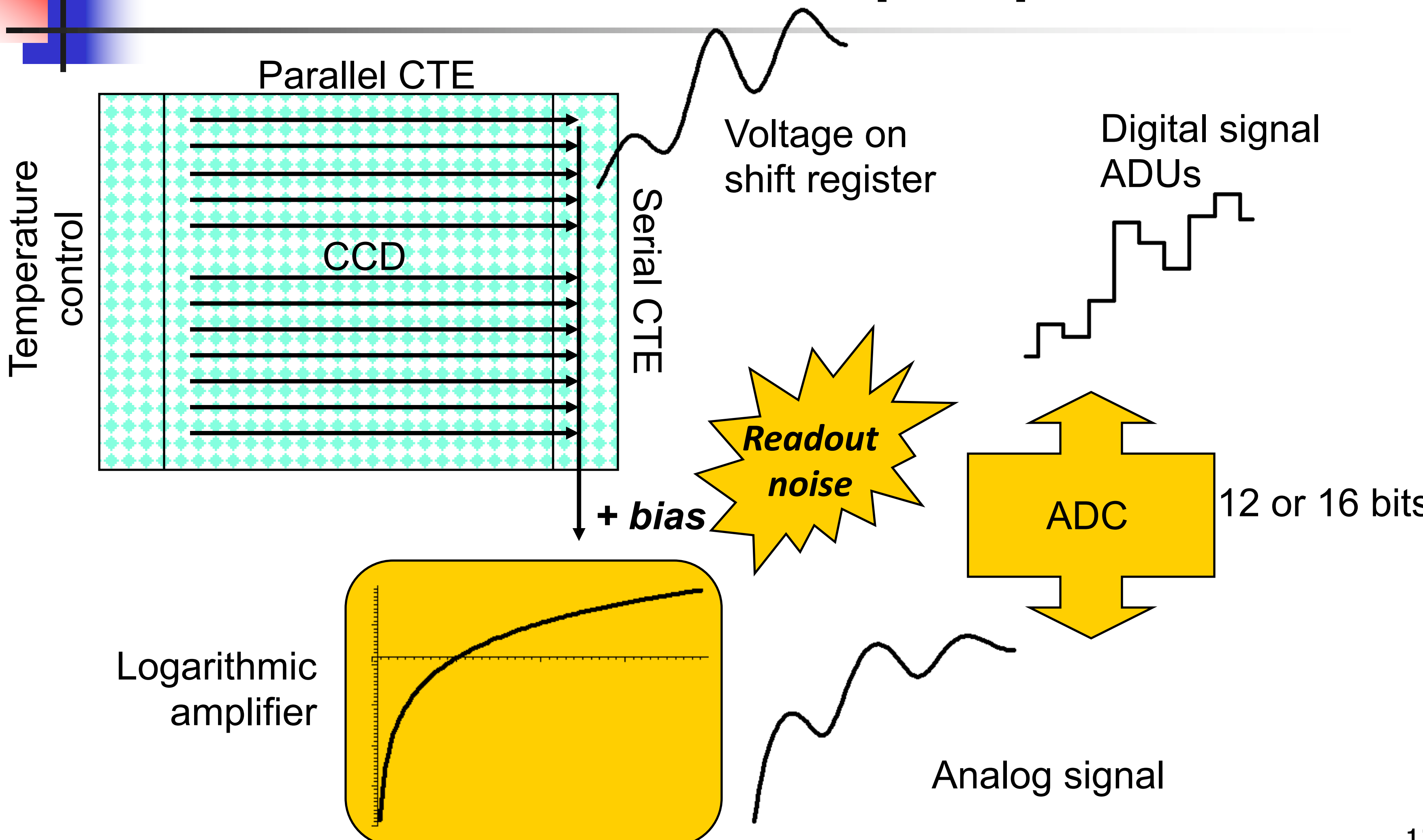
$$\lambda_c = 1.238 / \mathcal{E}_g \text{ (eV)}$$

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

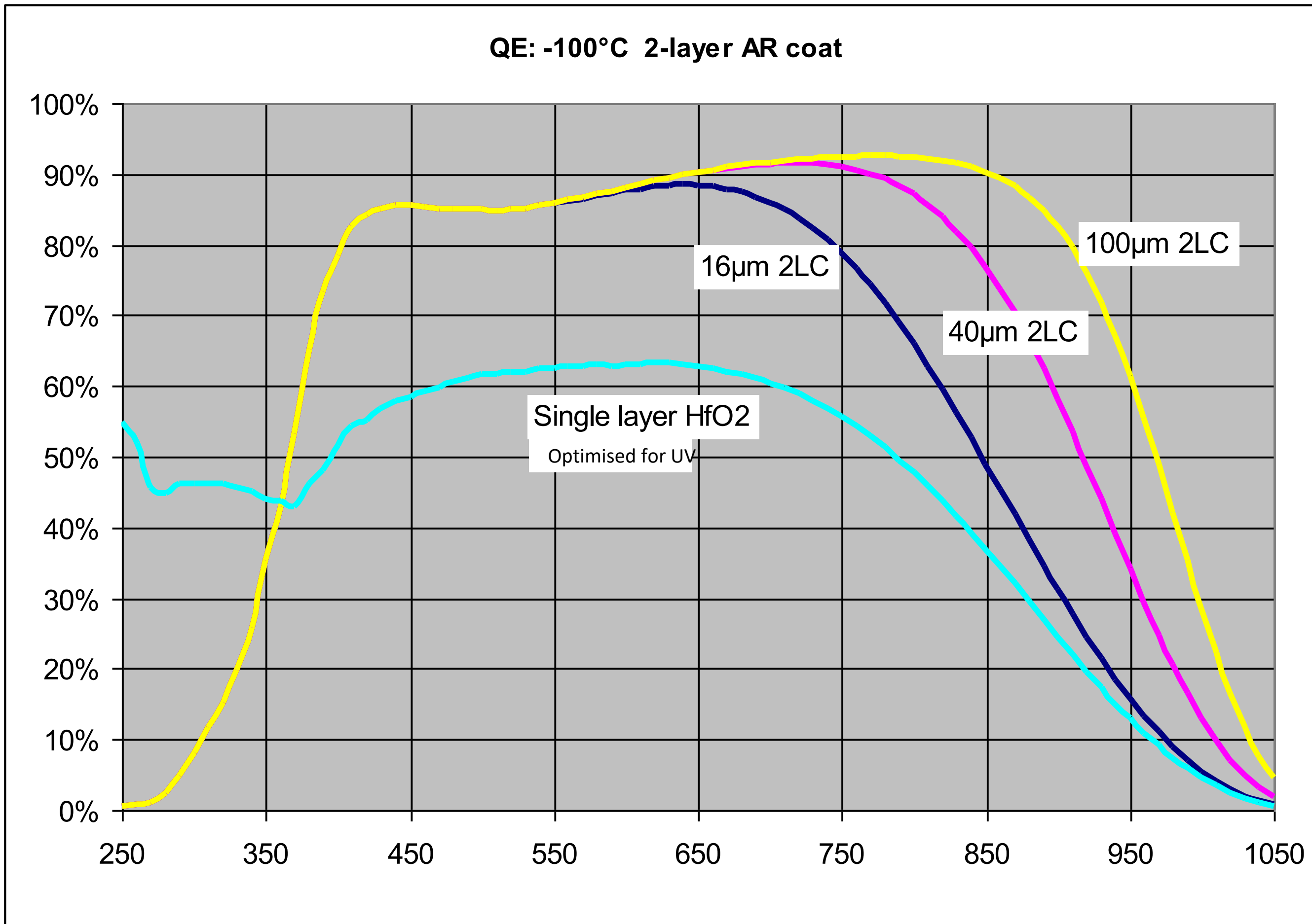
Log amplifier -> Dynamic range



Critical data flow properties



Quantum Efficiency



Improving spectral range

- QE drops in the blue because the top layer is too thick and covered with SiO. To improve excess of silicon substrate is removed from the back (thinning) and back side is used to detect light (back-illumination).
- QE drops in the red because photons have too low energy. Warming up CCD improves response in the red at a cost of increased dark current.
- Anti-reflective coatings help throughout the whole range.

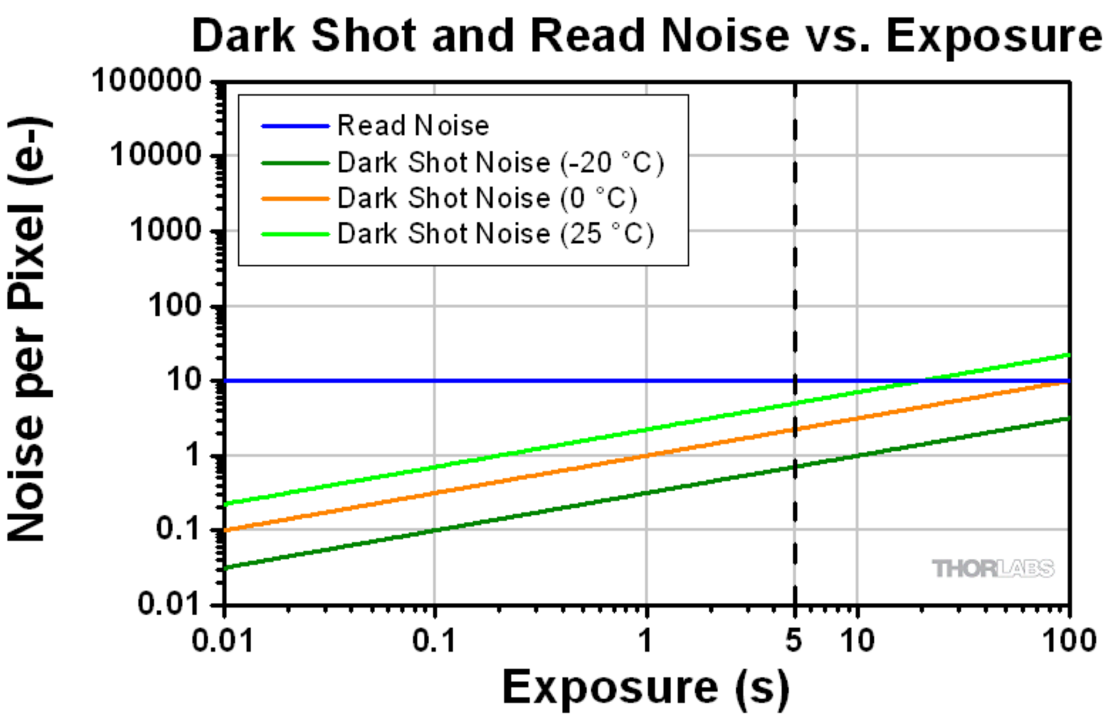
Dark current

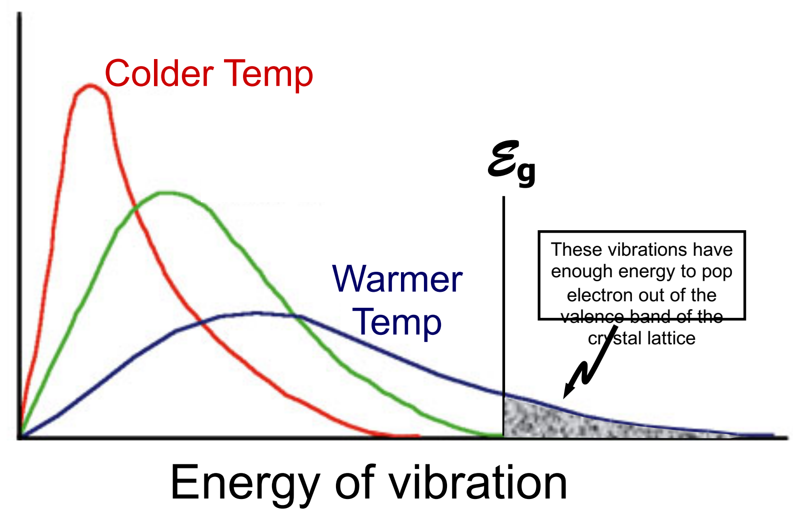
At T=300 K DC 10 e$^-$/pixel/s

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

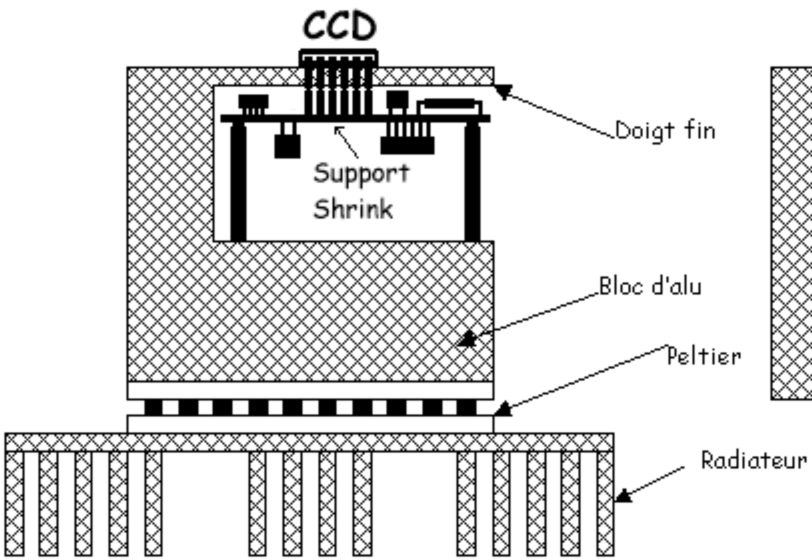
At T=170 K DC 10 e$^-$/pixel/hour

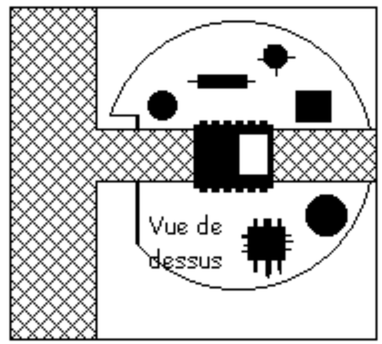
At T=120 K DC 1 e$^-$/pixel/hour



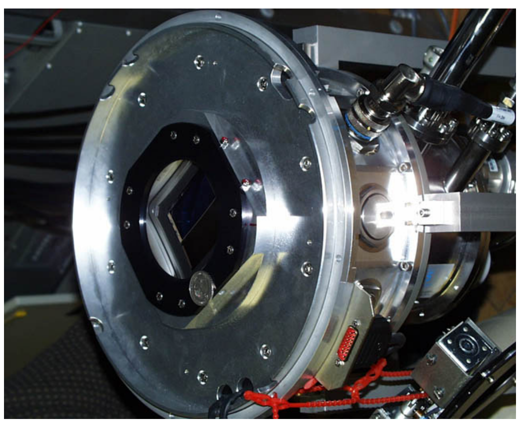


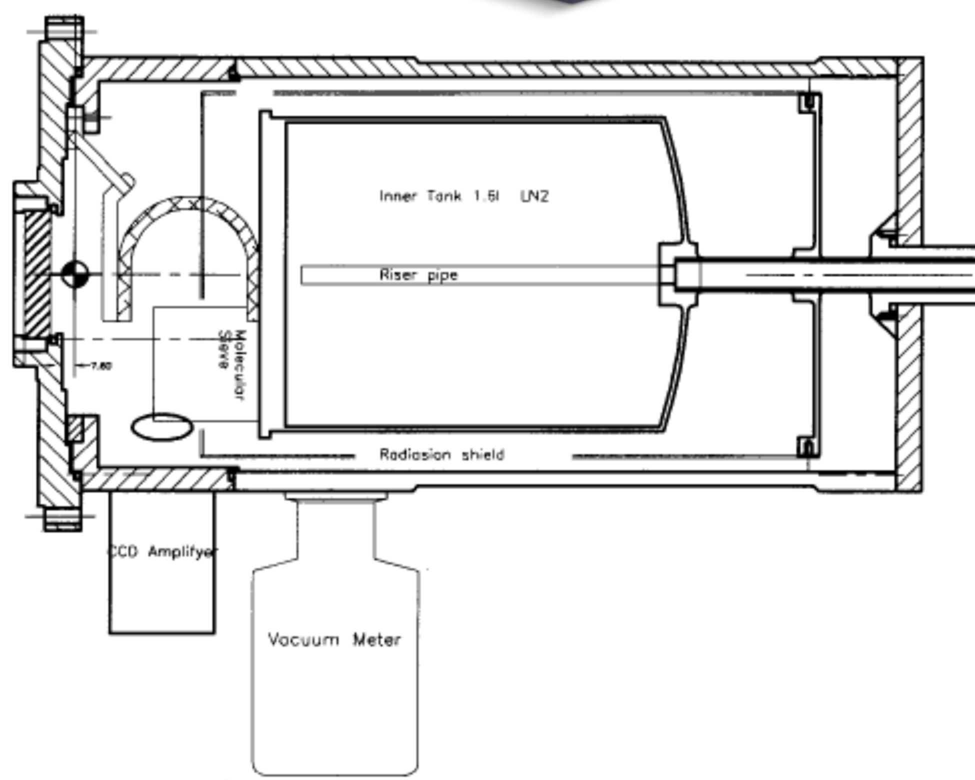
Peltier vs. LN2 cooling





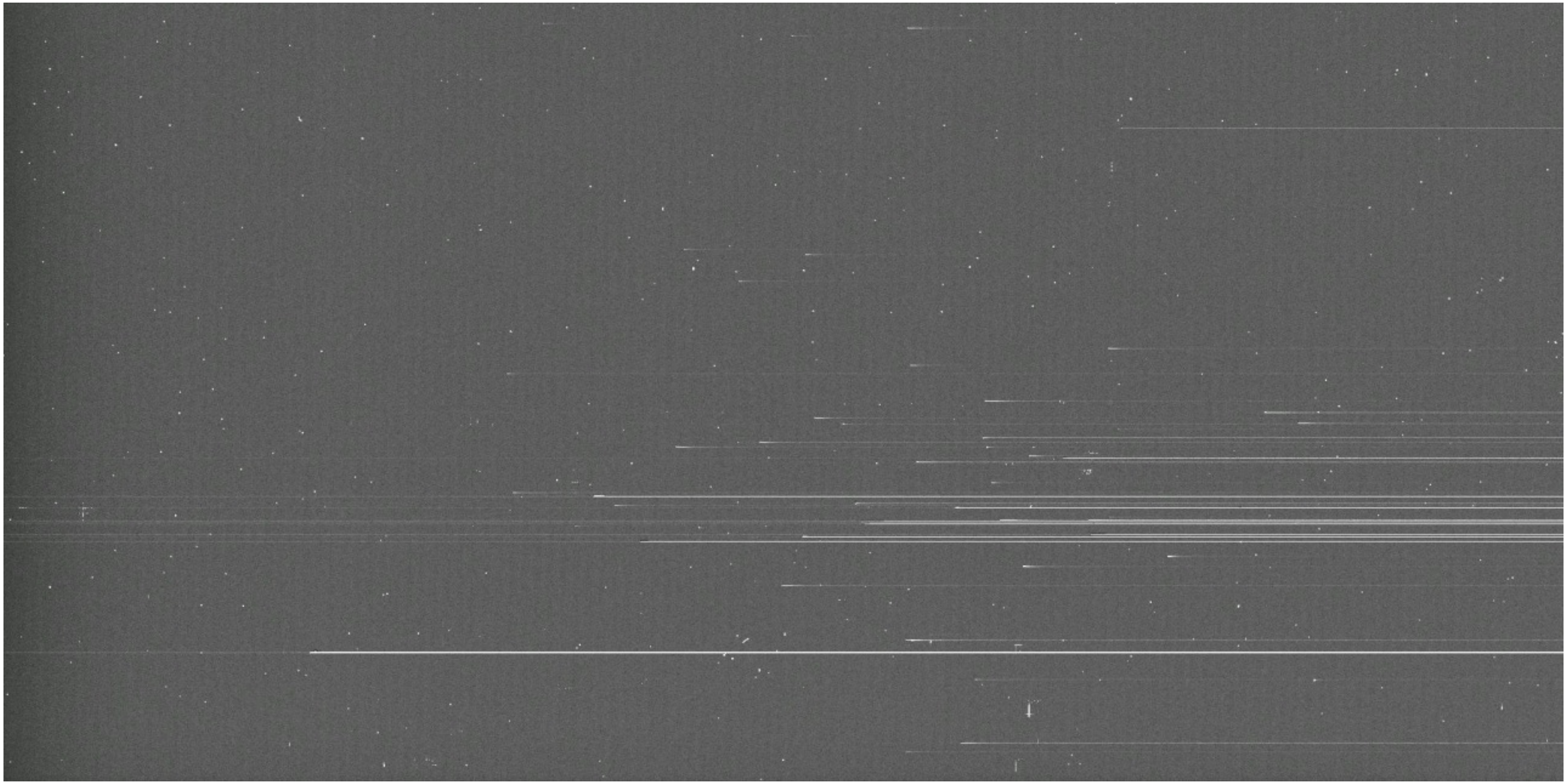
Peltier cooler: -20° ÷ -90° C





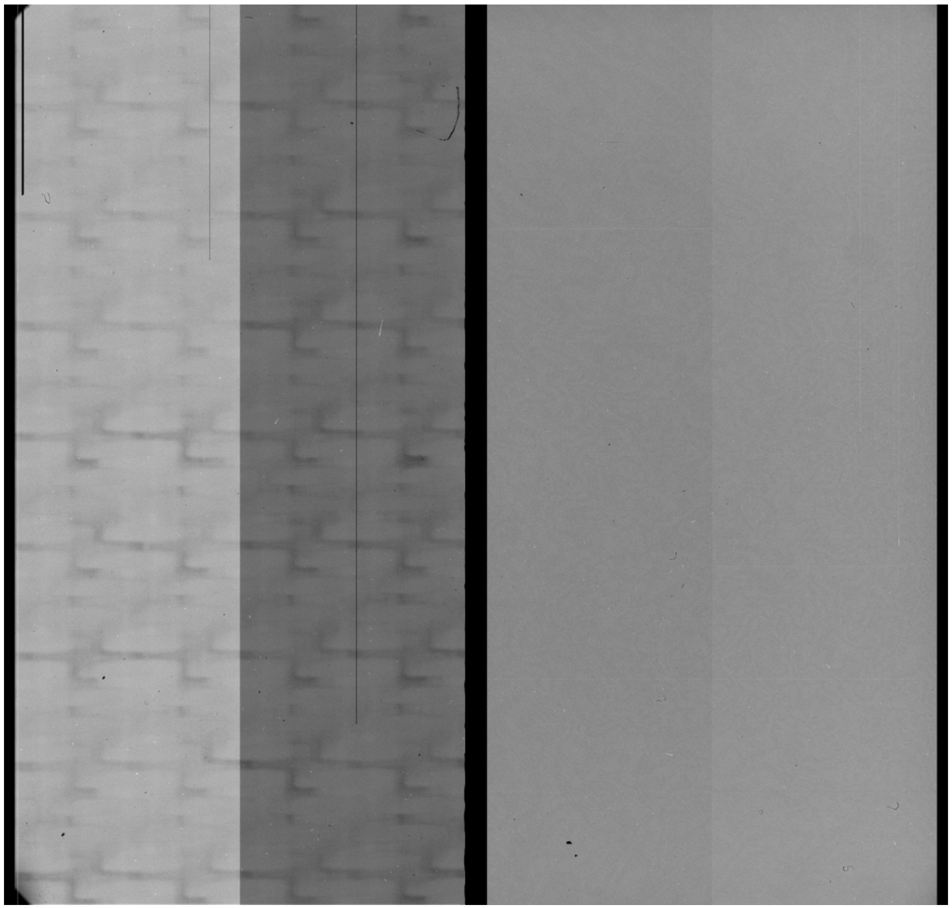
Liquid N_2: 125 ÷ 150 K

Cosmetics: pixel defects

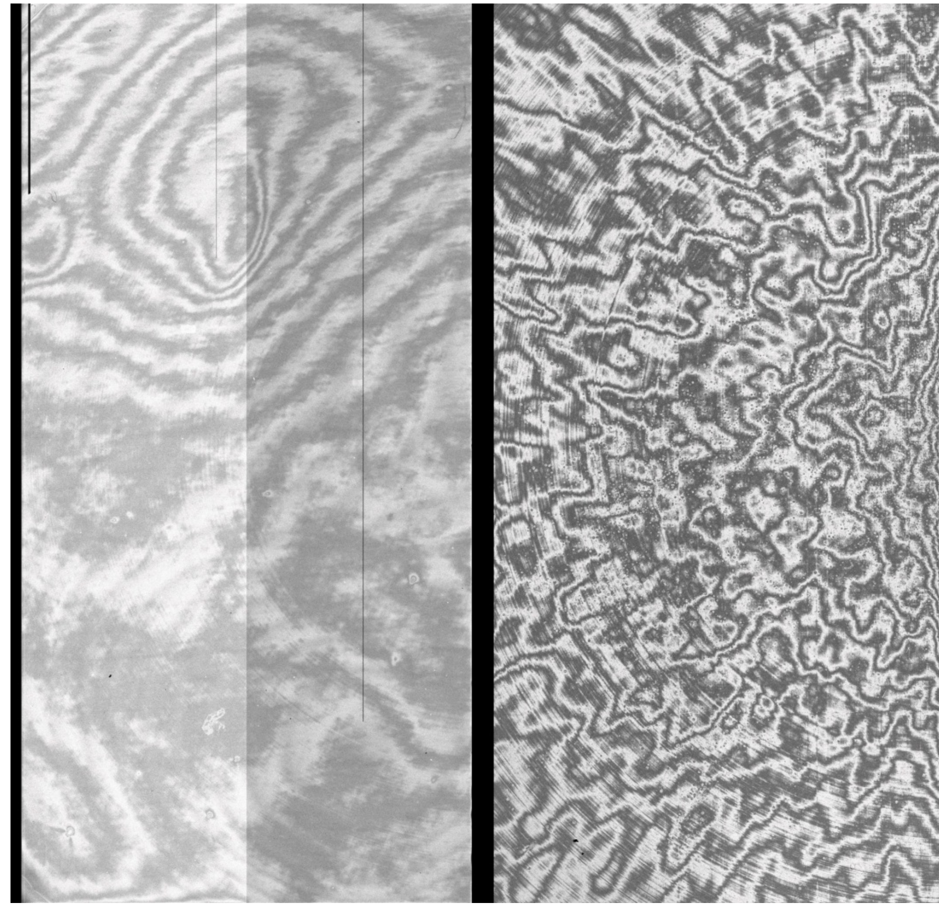


Fringing (interference)

λ=650 nm

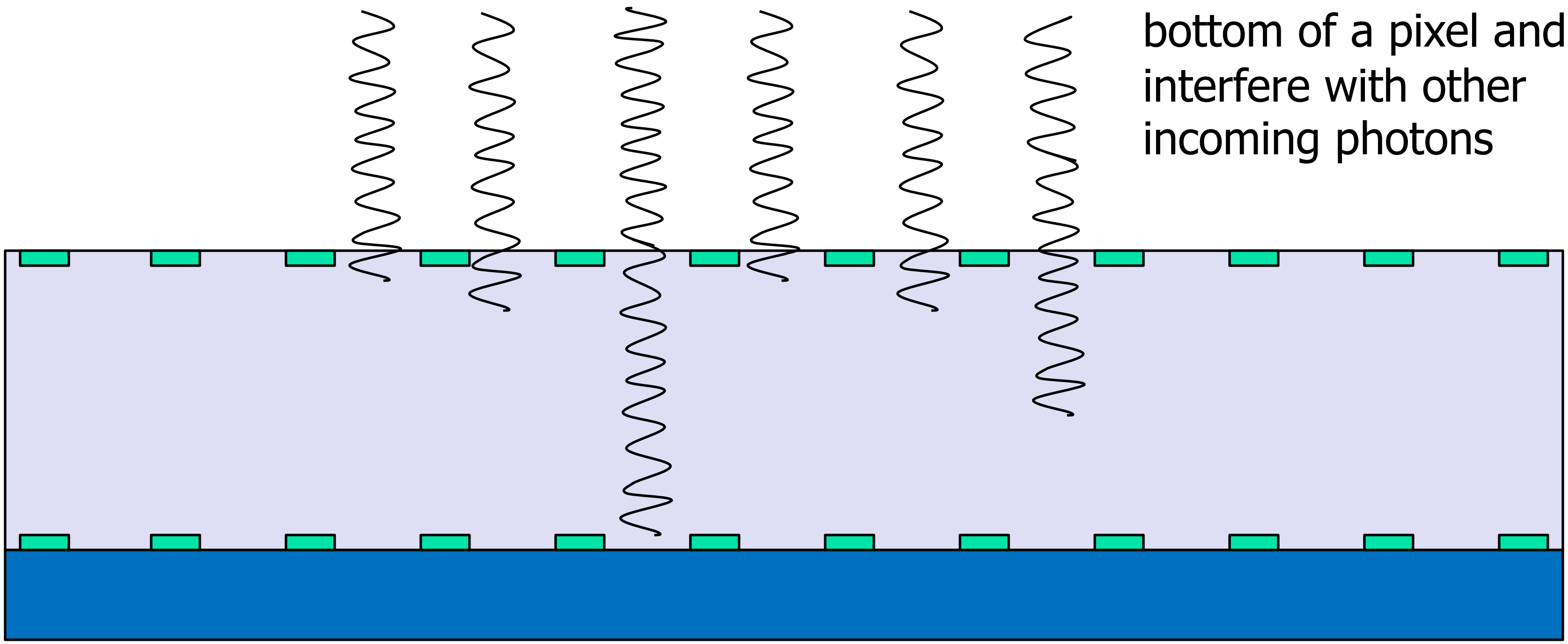


λ=900 nm



Fringing explained

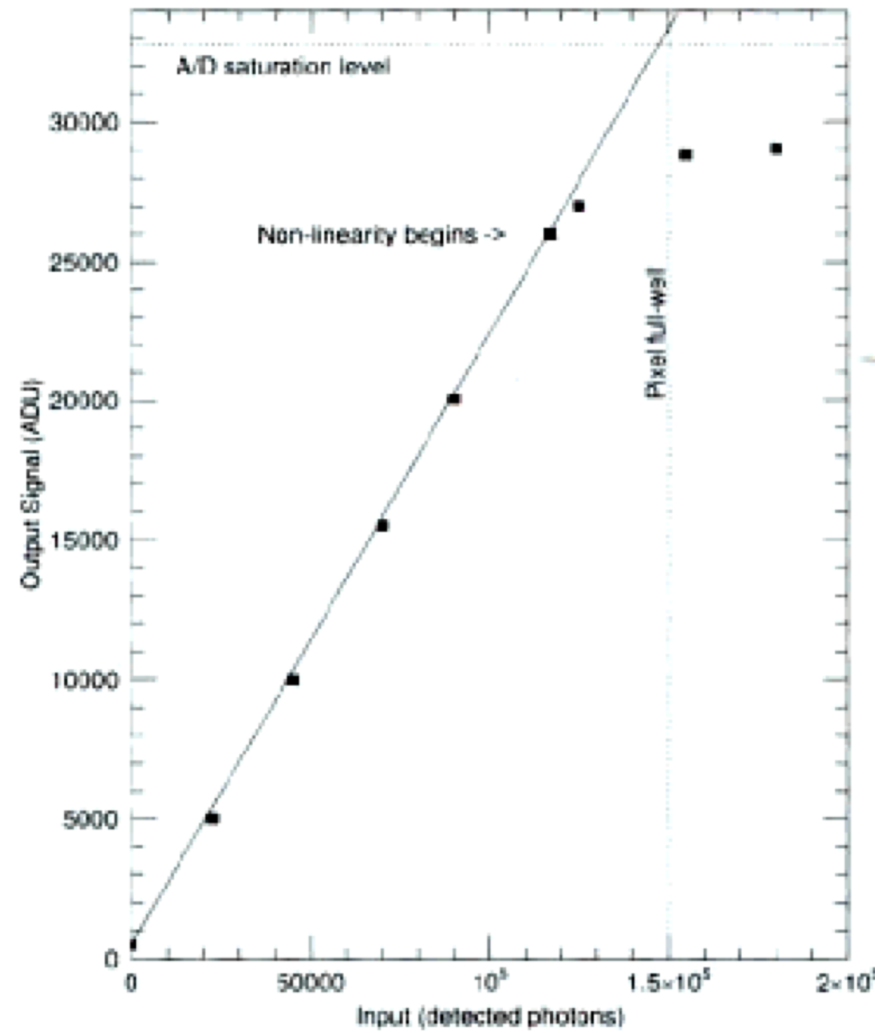
Photons have a chance to bounce from the bottom of a pixel and interfere with other incoming photons



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 200000, which also where the CCD goes non-linear.



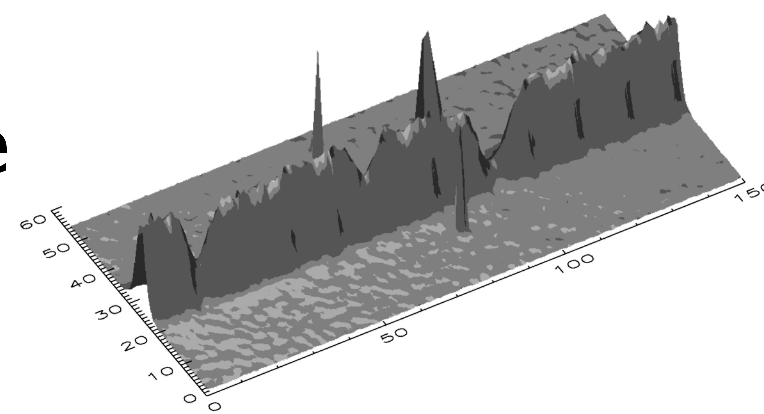
Charge Transfer Efficiency

- 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.

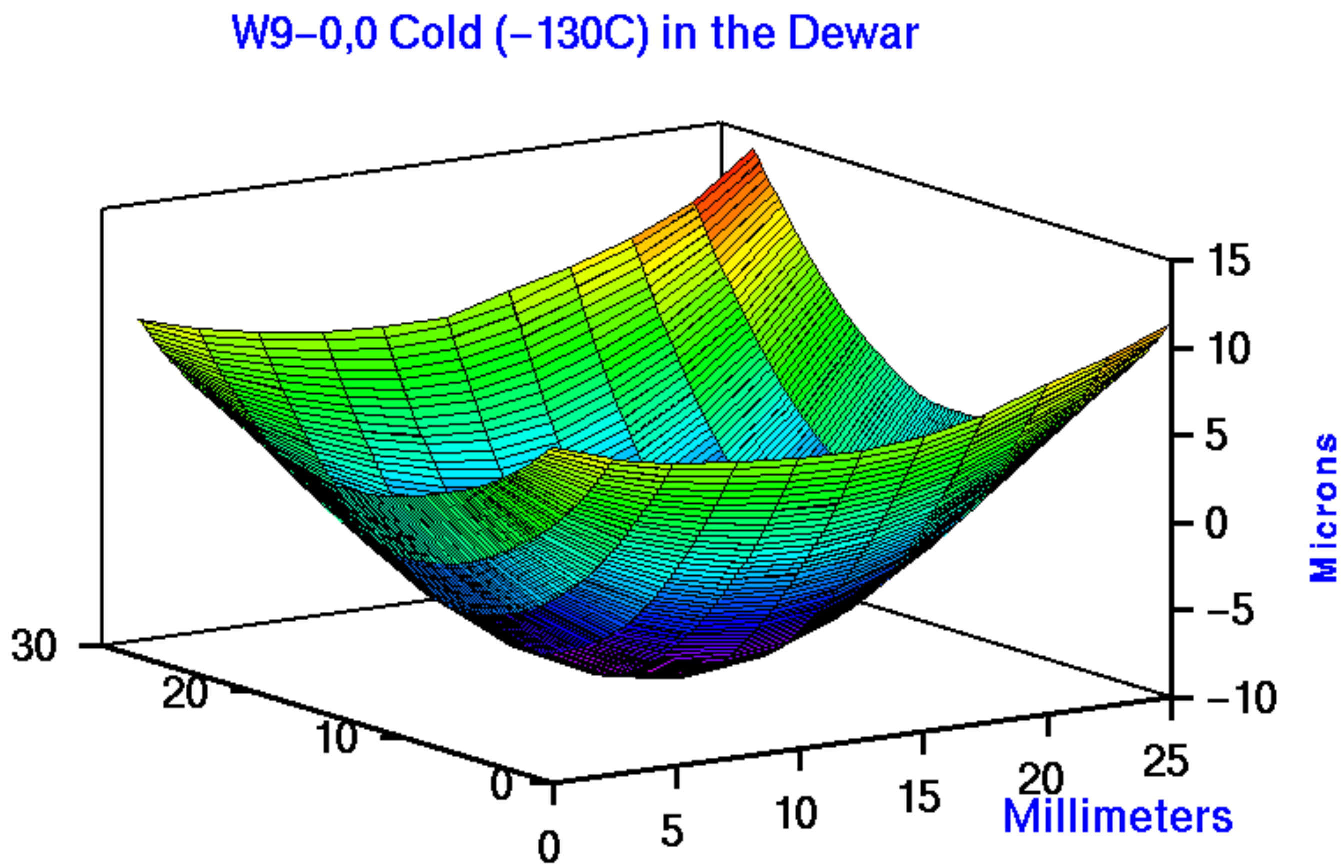
- The same experiment establishes the relation between ADU and number of photoelectrons (gain). Same CCD may use more than one gain (e.g. 1.1 and 9).

CCD noise

- *Shot noise* (Poisson distribution σ ≈√N)
- *Dark current* is ∝time, depends on temperature
- *Readout noise*, depends on the temperature, read speed and amplifier(s) used
- Cosmic rays destroy the content of a few pixels (not the pixels!)



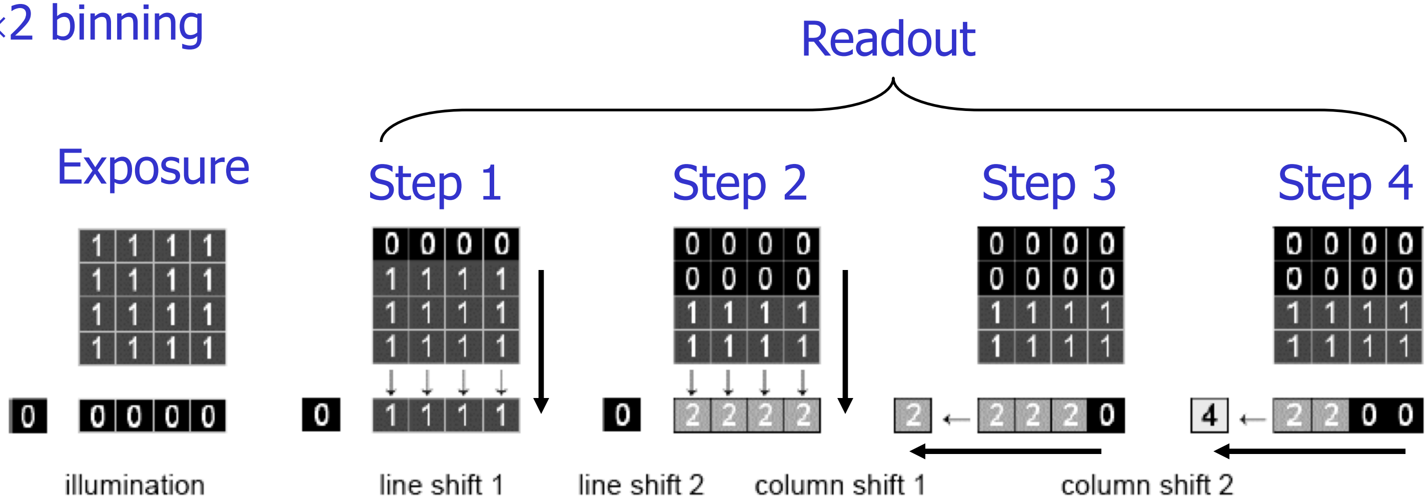
Flatness



W9–0,0 Cold (–130C) in the Dewar
15
10
5
0
–5
–10
Microns
30
20
10
0
0
5
10
15
20
25
Millimeters

Binning

Example: 2×2 binning



Next time…

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