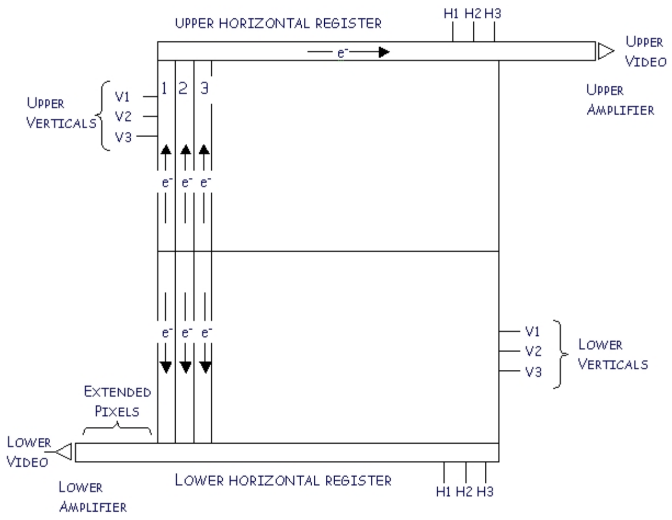
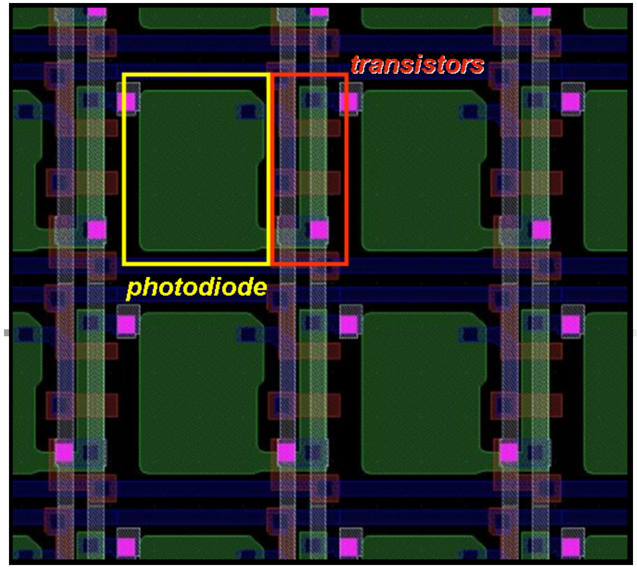
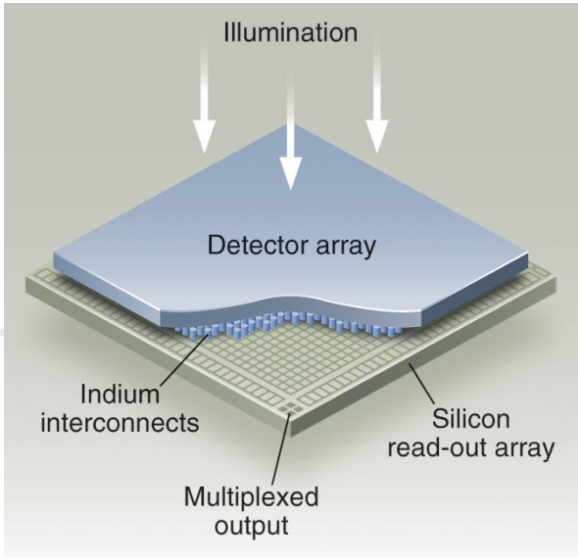
Observational Astronomy

Astronomical Detectors

Kitchin pp. 1-44







CCD

Monolithic CMOS

Hybrid CMOS

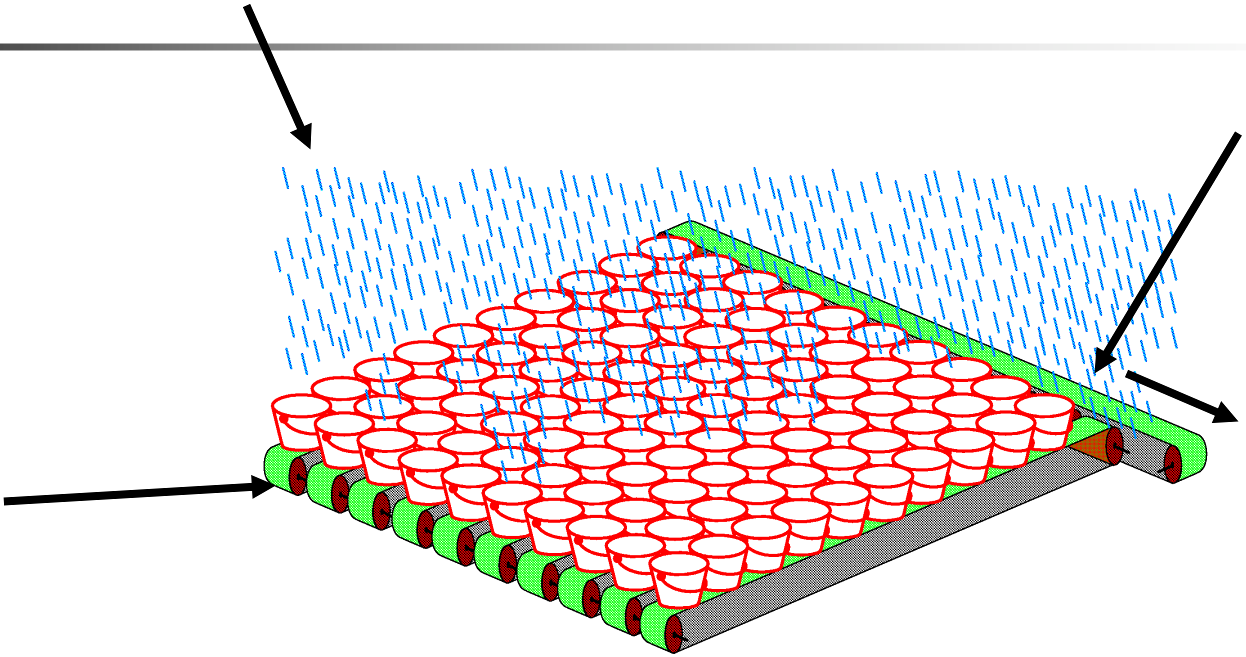
HgCdTe
Visible through IR

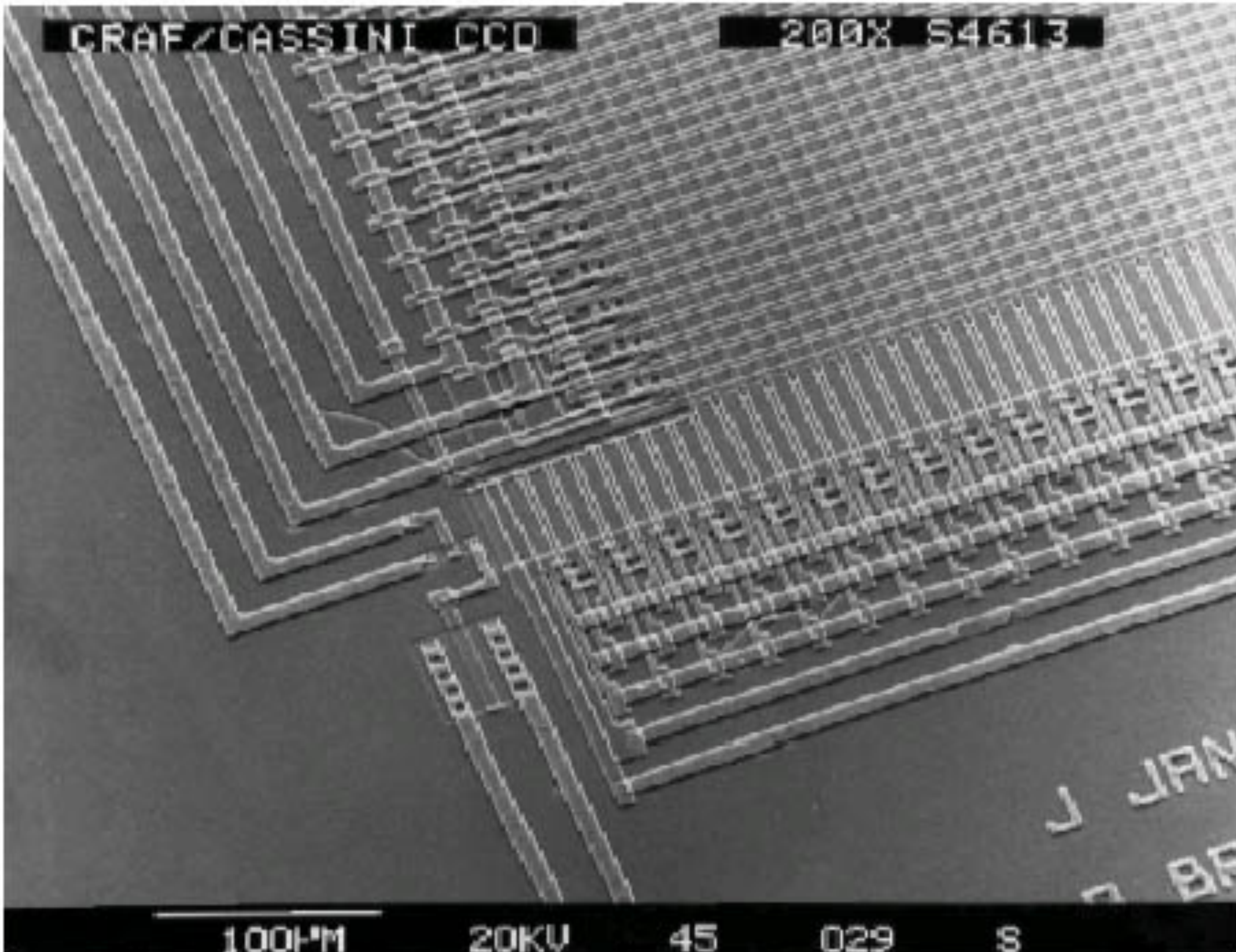
Silicon - Visible through near IR

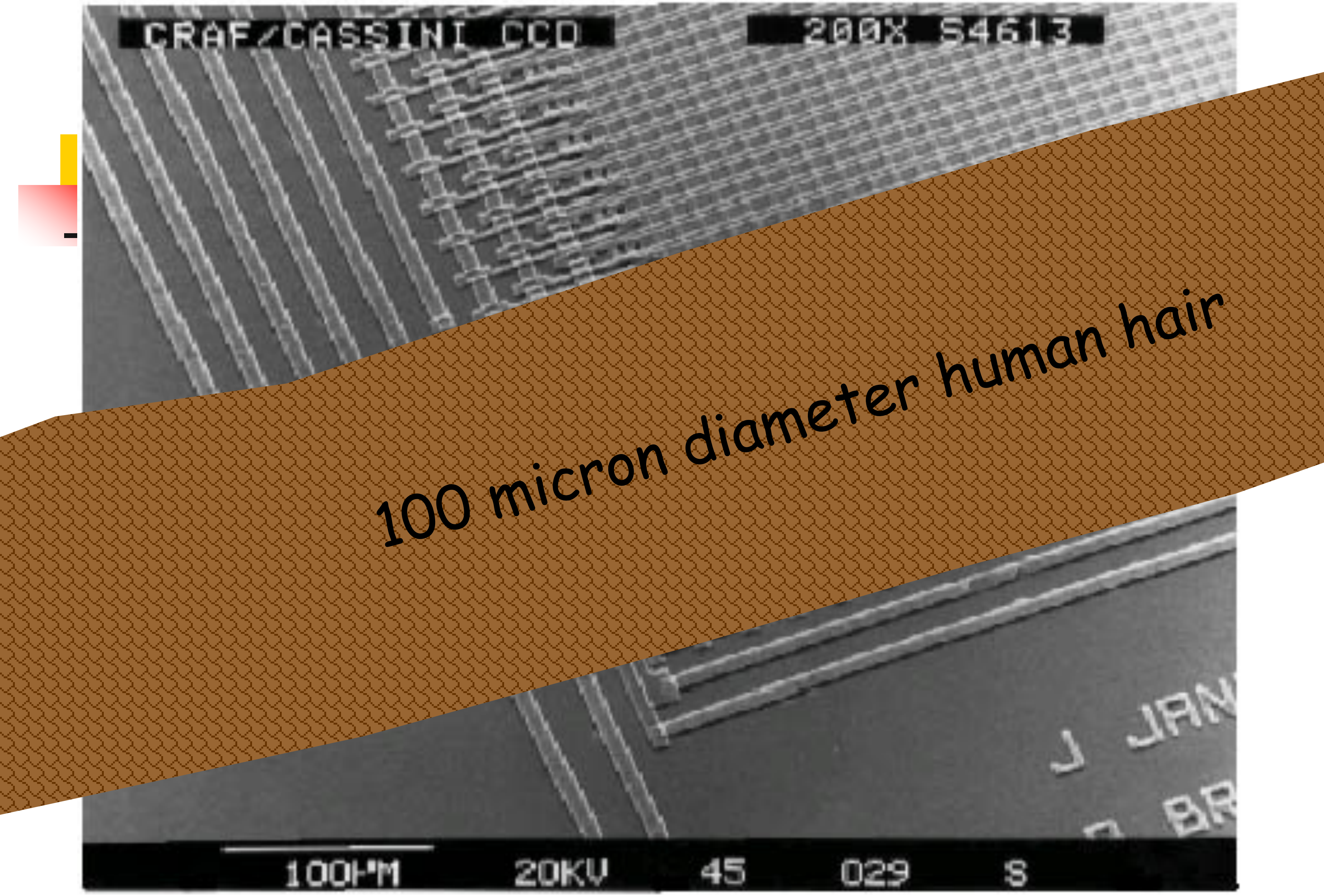
Common parameters of detectors

- 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

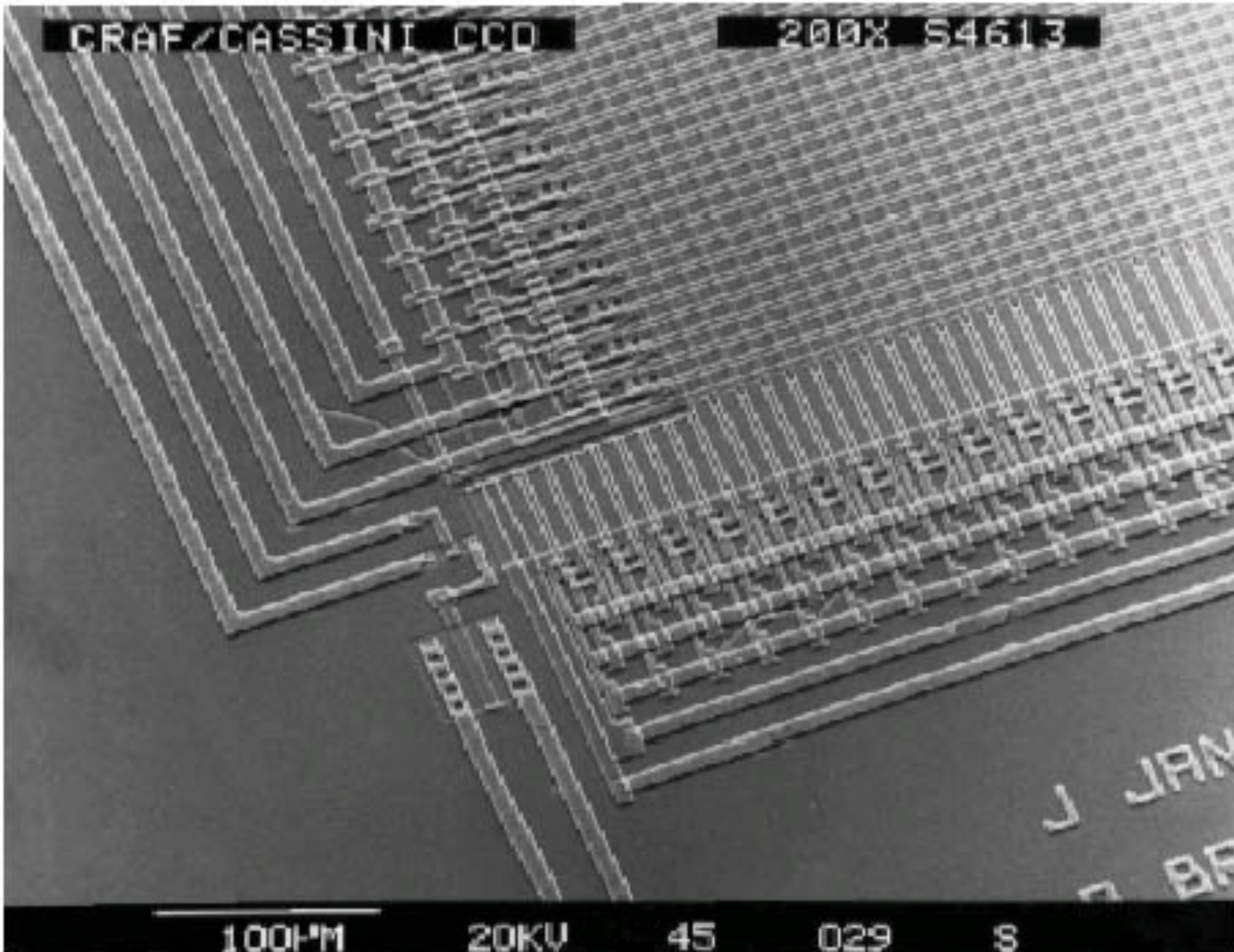
Optical: Charge Coupled Device

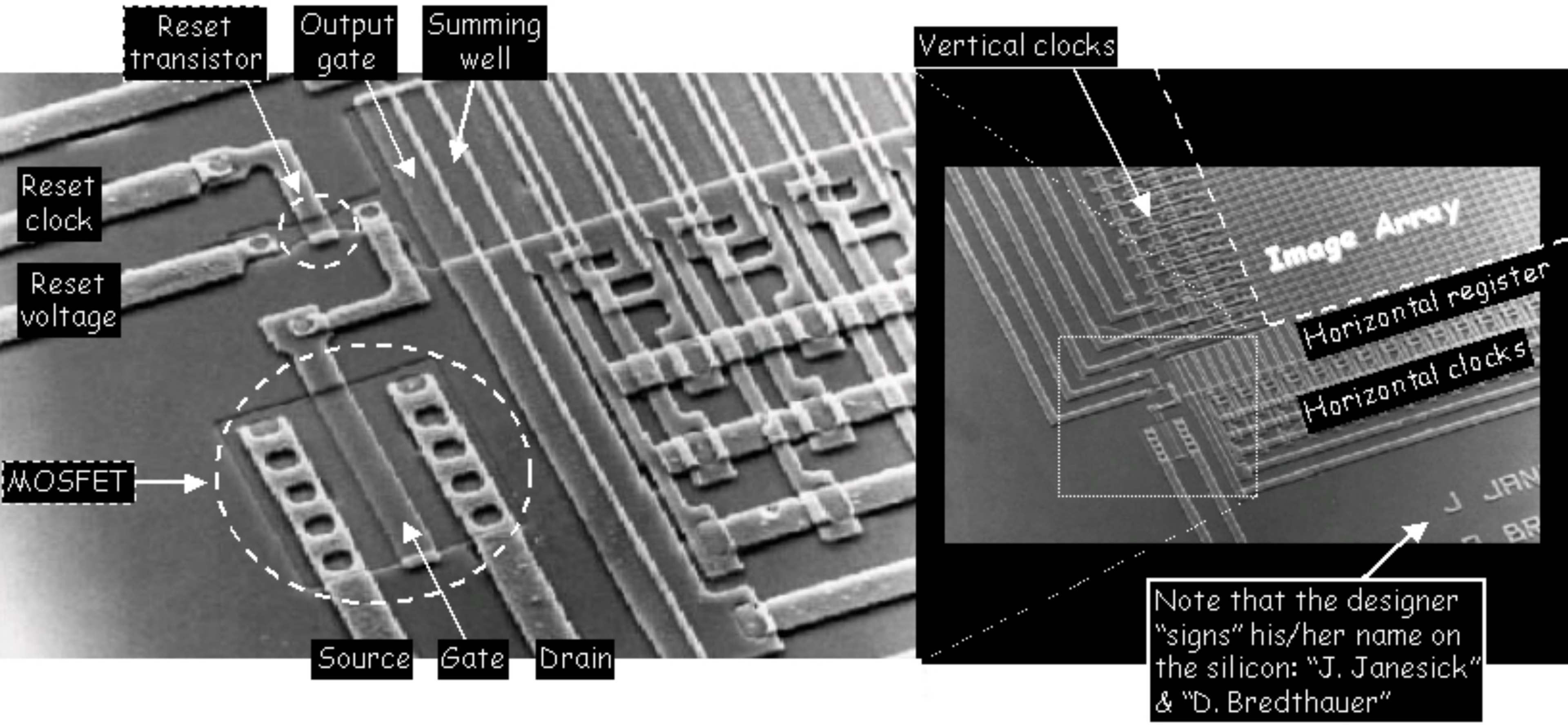


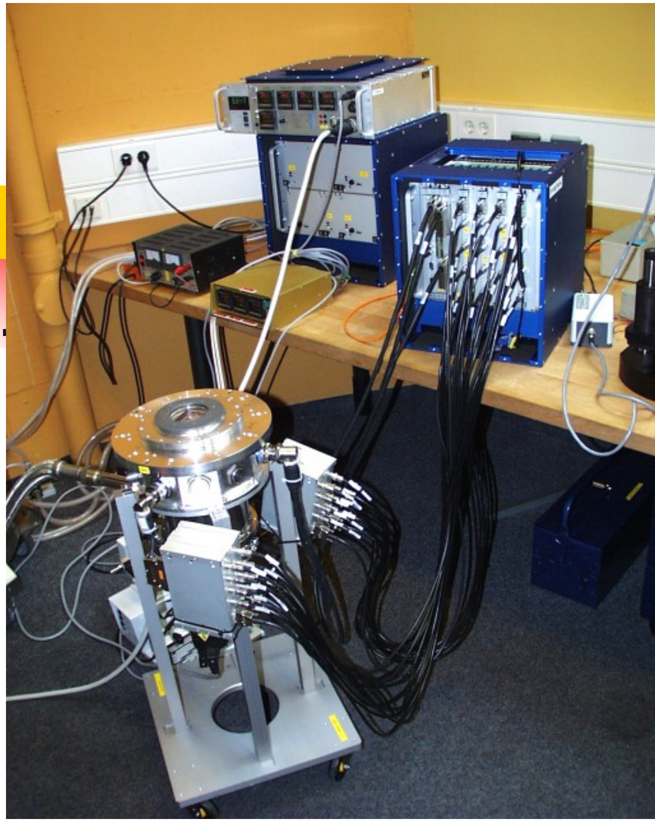

CRAF/CASSINI CCD
200X S4613
100µM
20KV
45
029
S

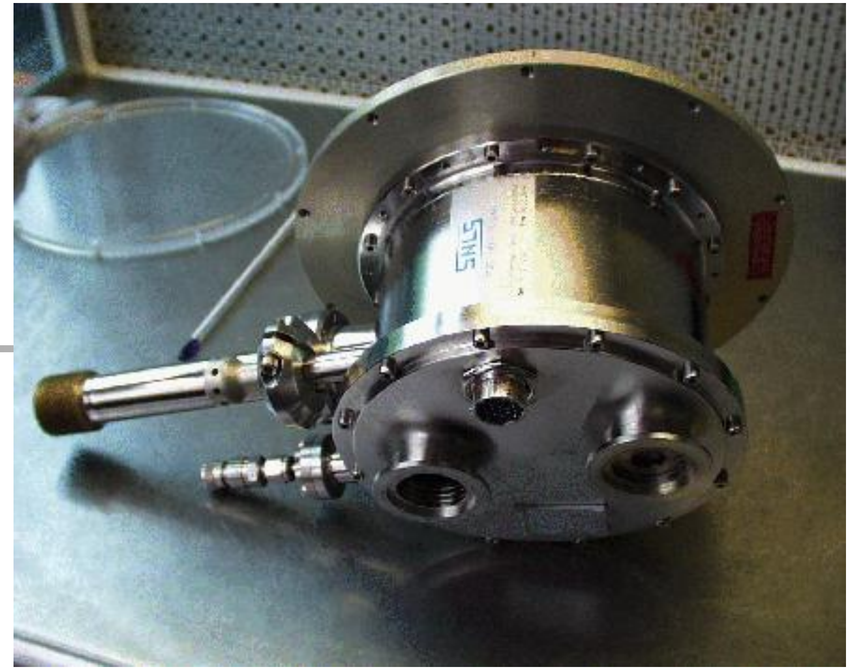


CRAF/CASSINI CCD
200X S4613
100 micron diameter human hair
100µM
20KV
45
029
S

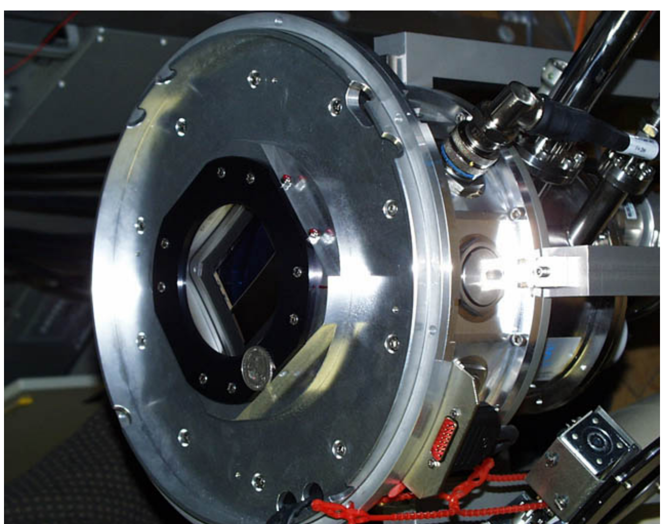

CRAF/CASSINI CCD
200X S4613
100µM
20KV
45
029
S

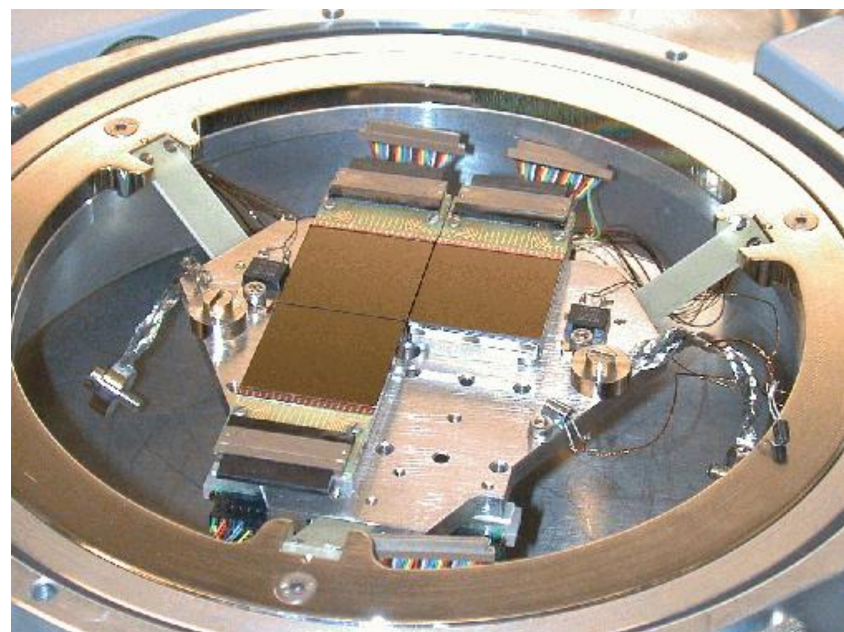

Reset transistor
Output gate
Summing well
Reset clock
Reset voltage
MOSFET
Source
Gate
Drain
Vertical clocks
Image Array
Horizontal register
Horizontal clocks
Note that the designer "signs" his/her name on the silicon: "J. Janesick" & "D. Bredthauer"



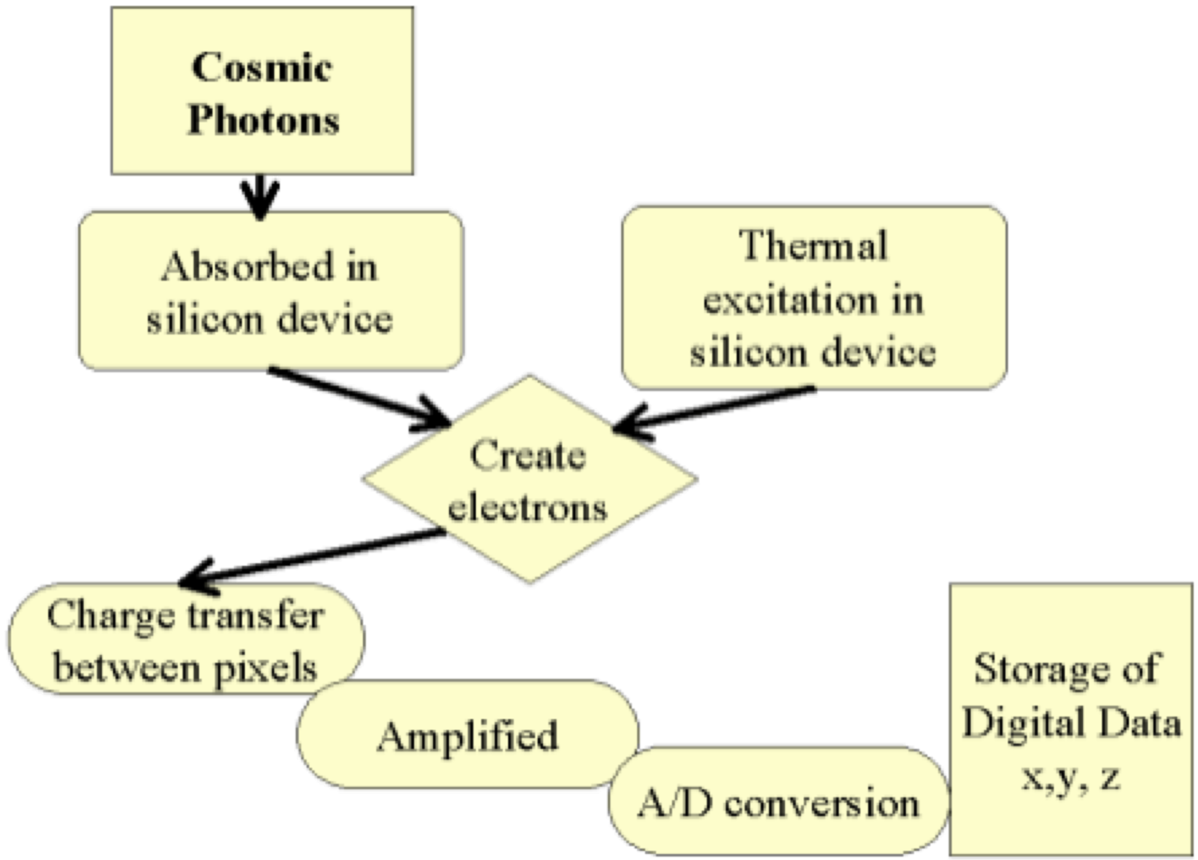


Continuous flow cryostat

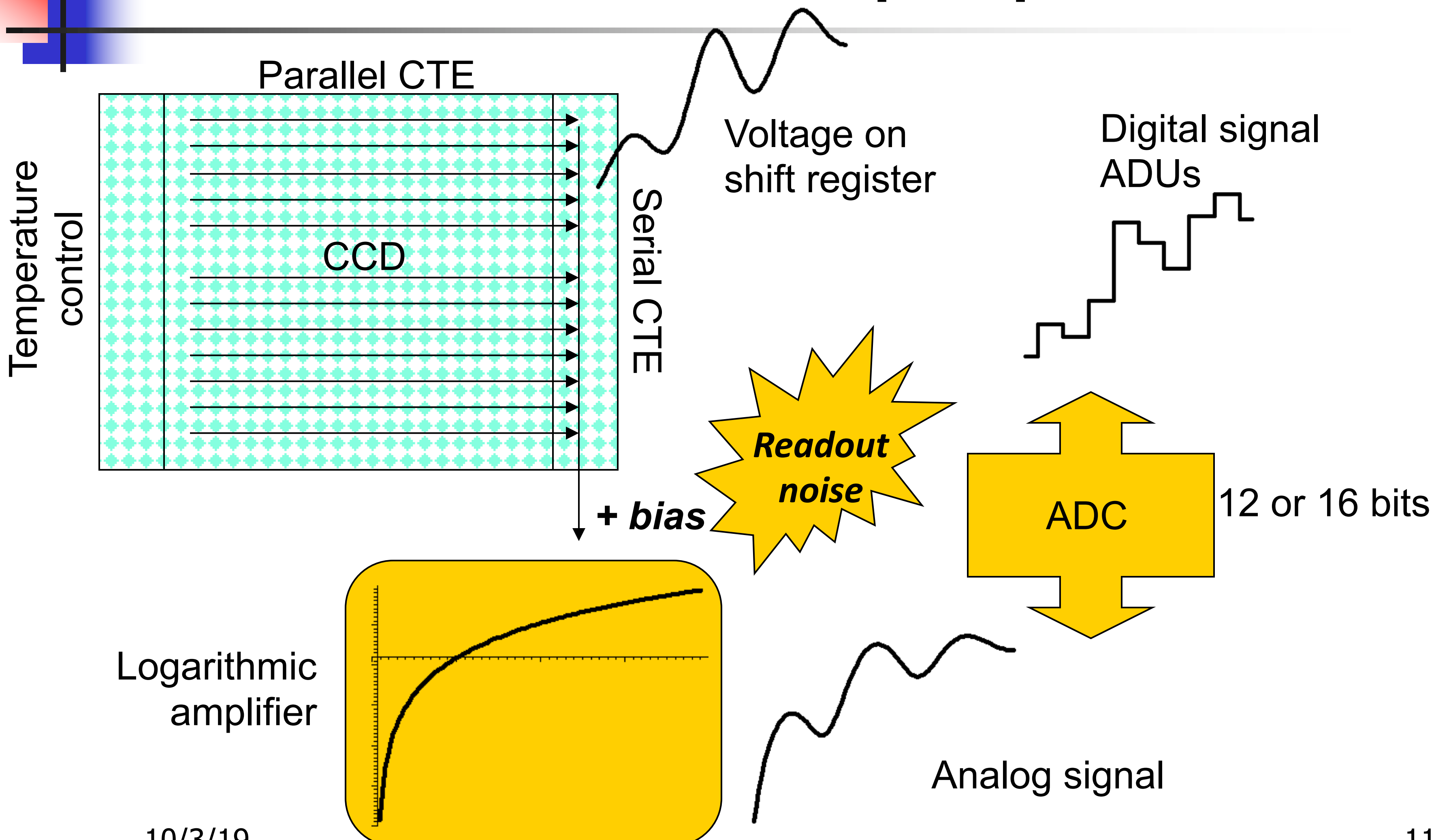




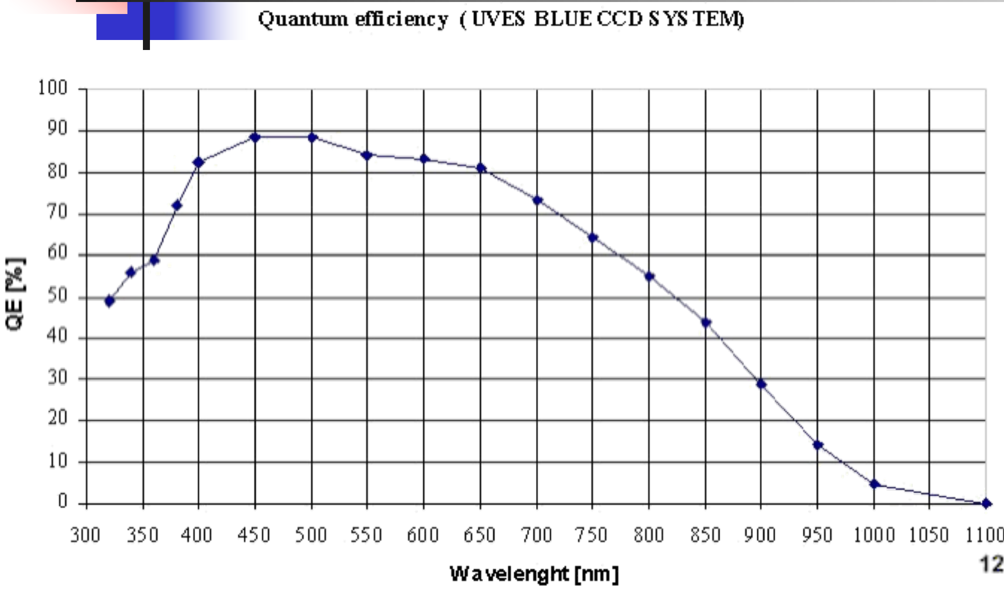
Electron trail

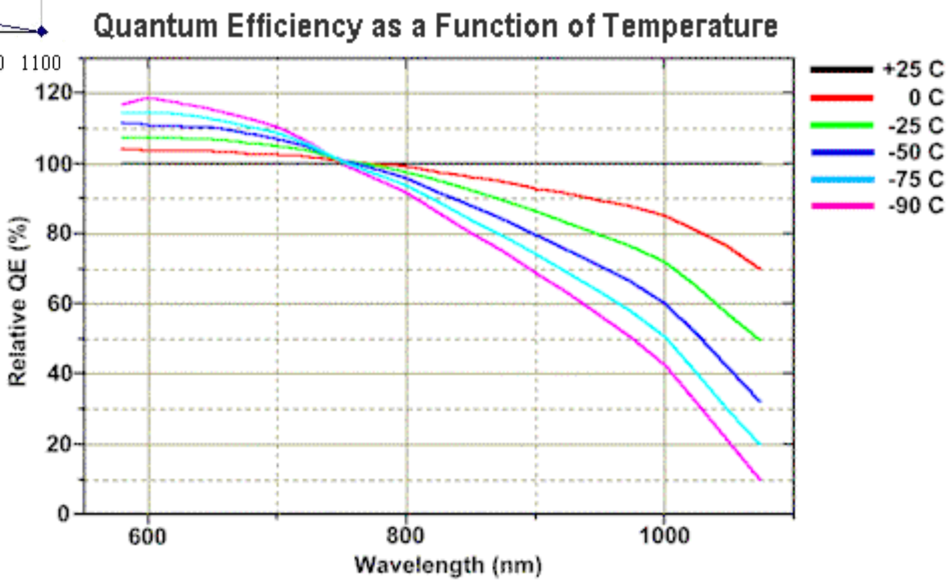


Critical data flow properties



Quantum Efficiency





Improving spectral range

- QE drops in the blue because the top layer (electrodes) is non-transparent. One way to improve it is the remove extra silicon substrate from the back (thinning) and use back side to detect the light (back-illumination).
- Consumer CCDs avoid thinning by making transparent electrodes.
- QE drops in the red because photons have too low energy. Warming up CCD improves response in the red but also increases the noise.

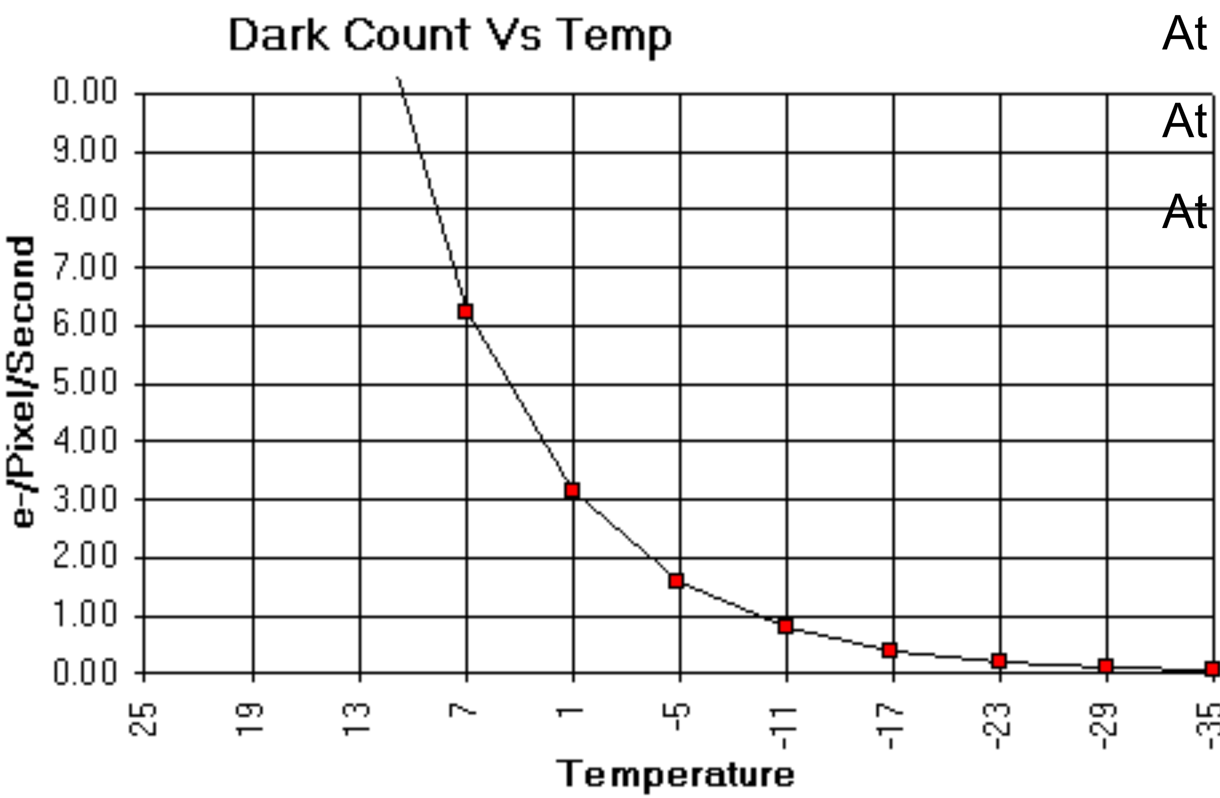
Dark current

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

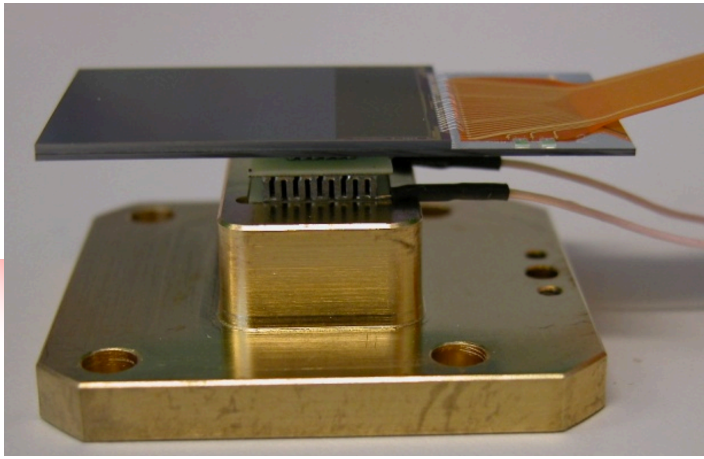
At T=230 K DC 0.1 e^-/pixel/s

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

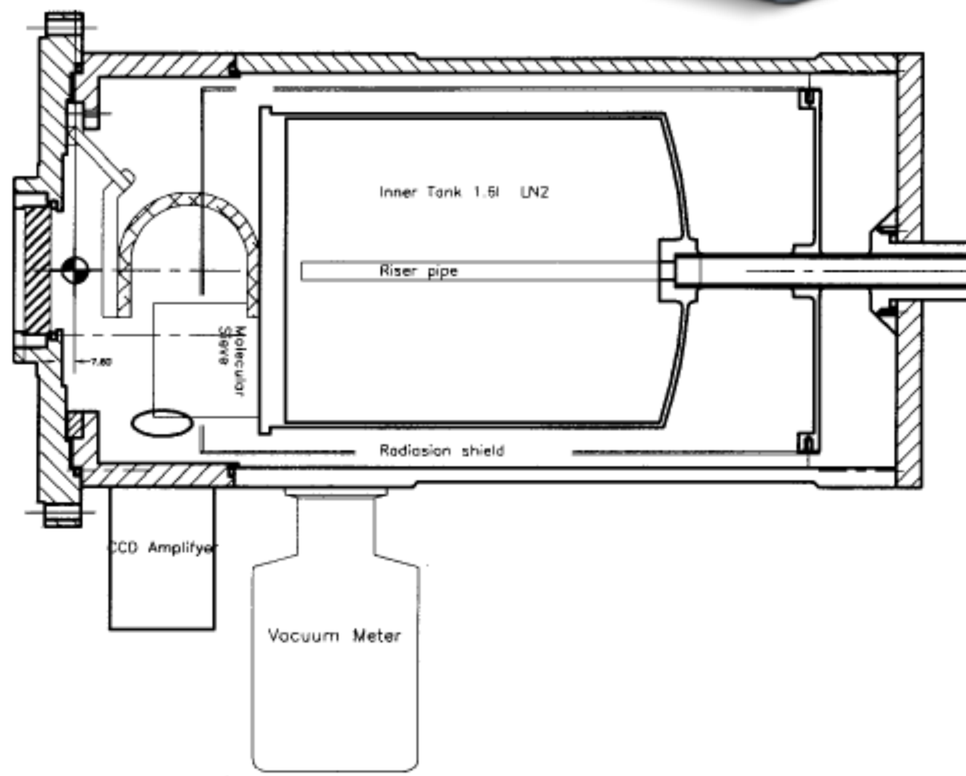
At T=120 K DC 1 e^-/pixel/hour



Cooling

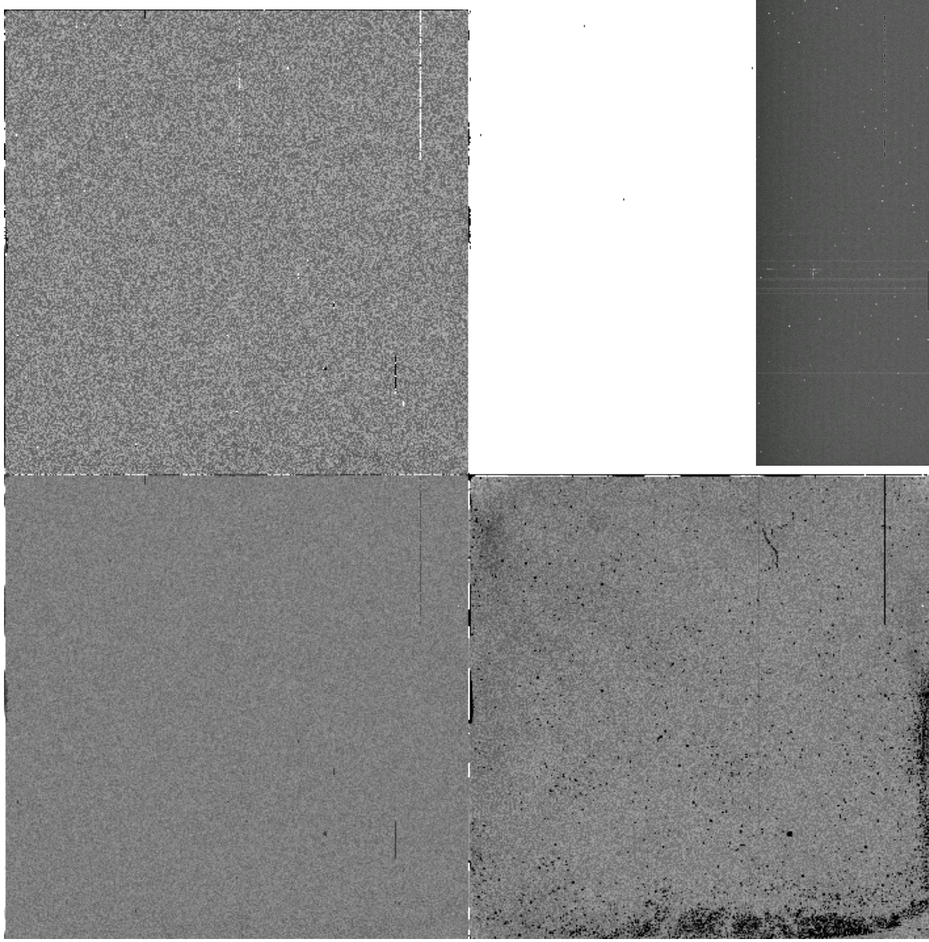


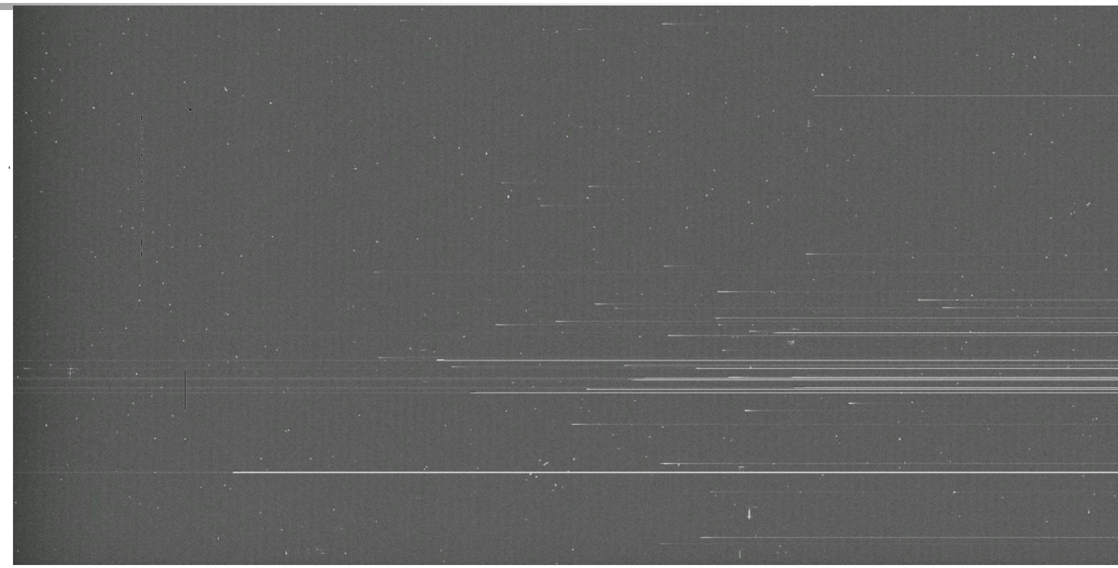
Thermoelectric cooler: -20° ÷ -60° C



Liquid N_2: 125 ÷ 150 K

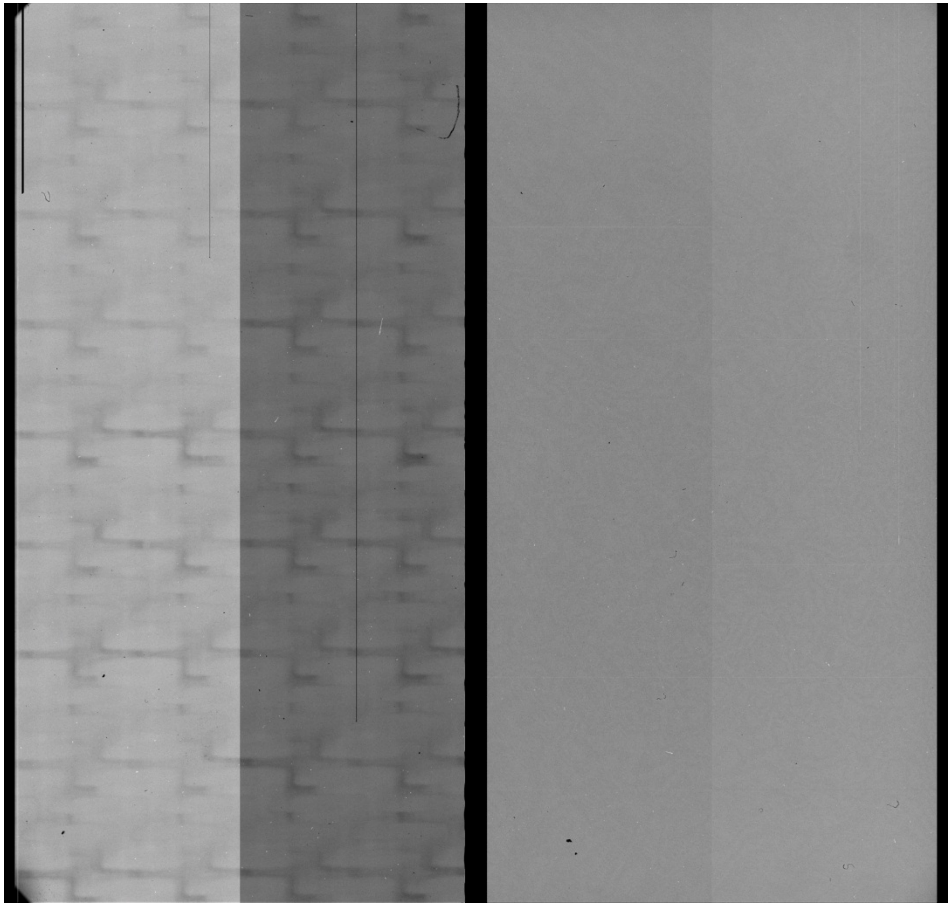
Cosmetics



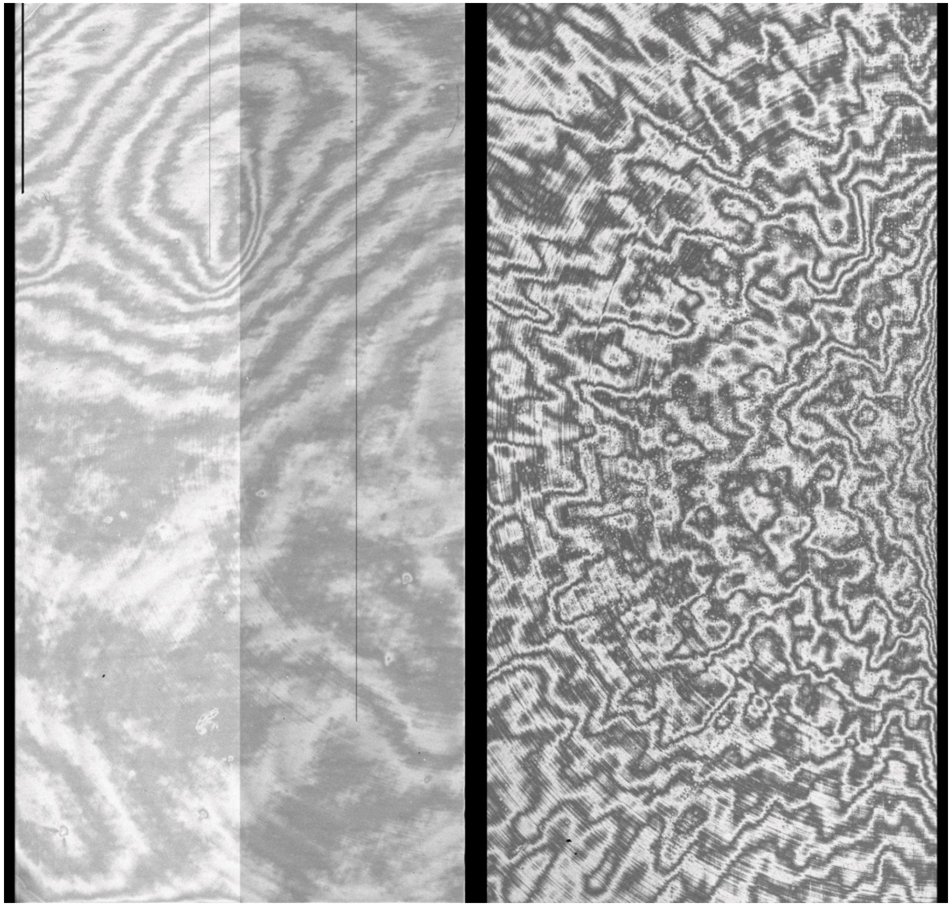


Fringing

λ=650 nm



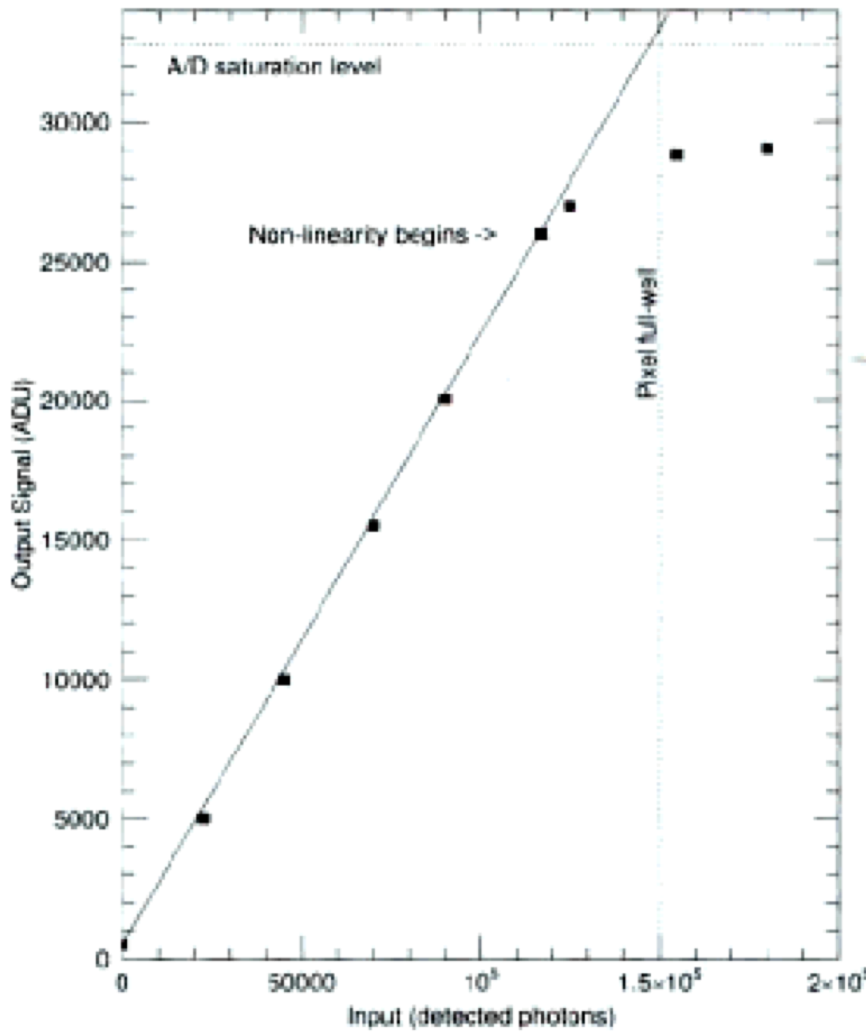
λ=900 nm



Linearity

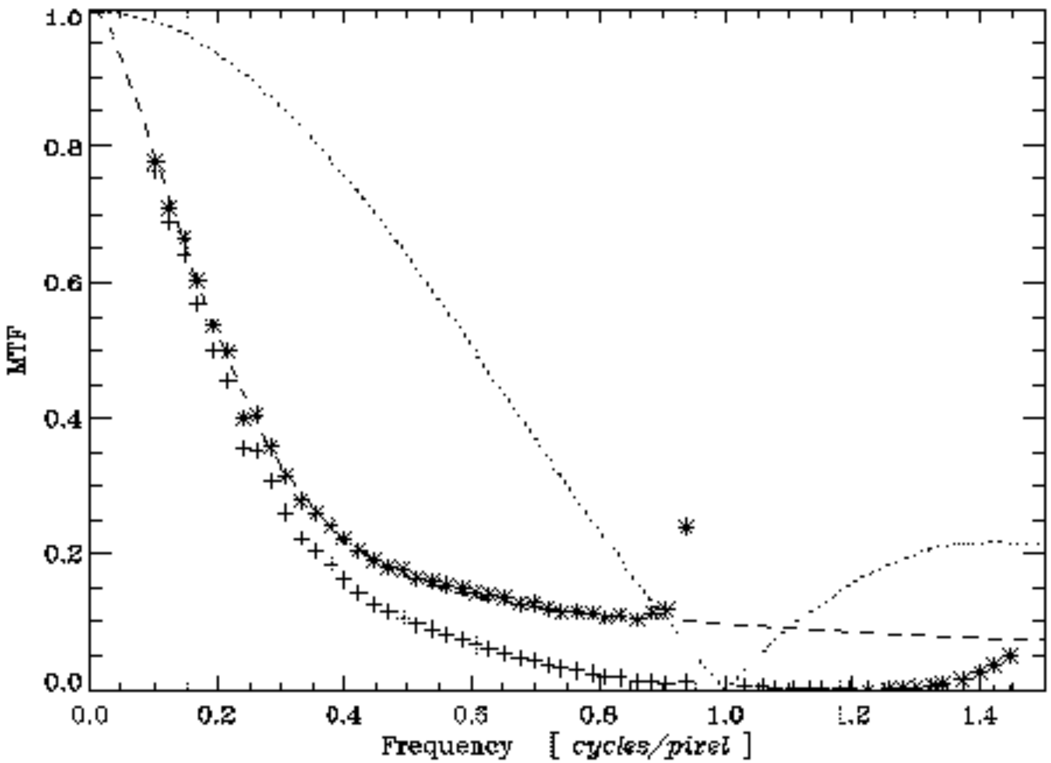
CCD full well is the number of electrons which can be stored in one pixel (height of energy barrier between pixels).

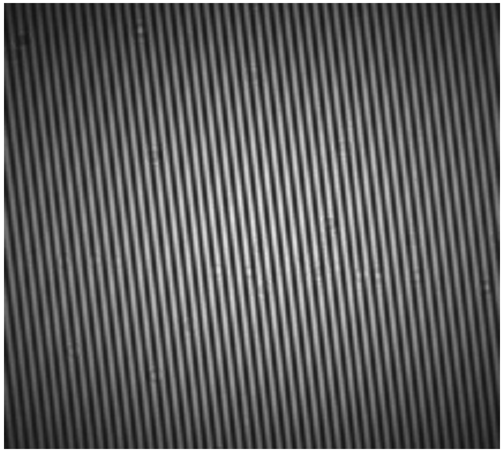
Typical values are between 30000 and 1000000 which also where the CCD goes non-linear.



Modulation Transfer Function

MTF characterizes interplay between contrast and spatial sampling





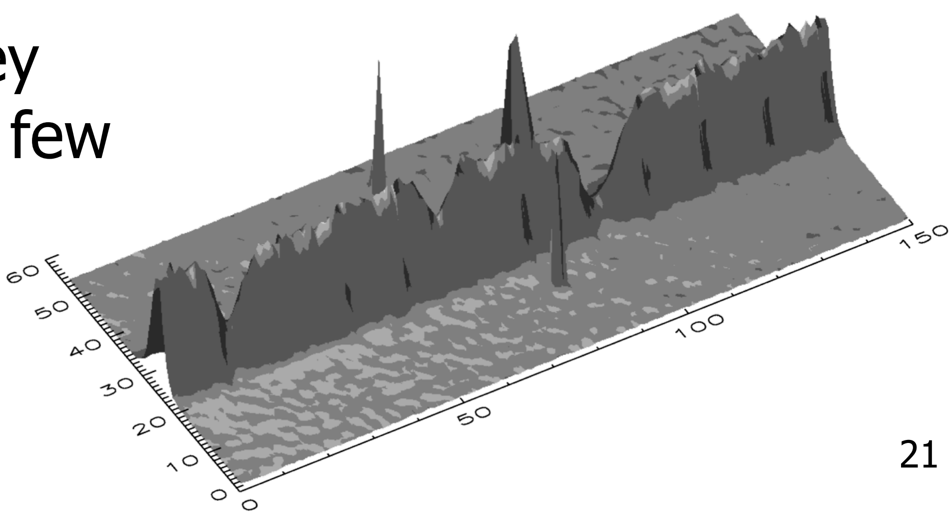
Charge Transfer Efficiency/Gain

- 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.

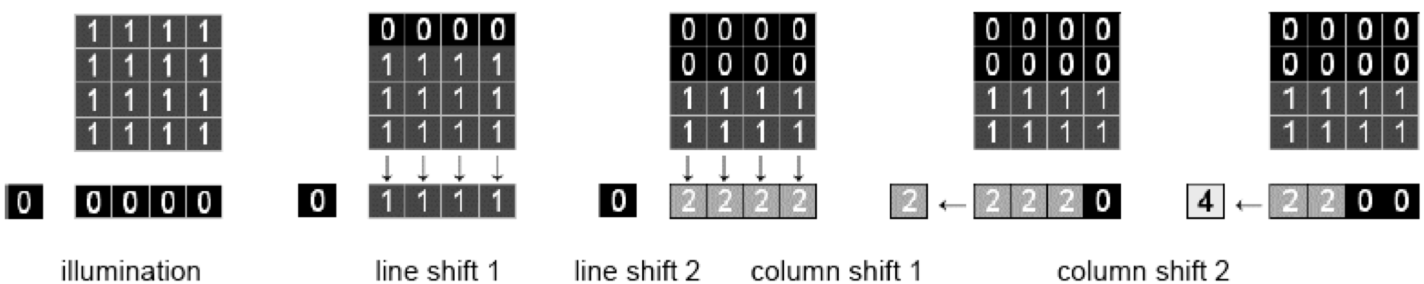
- The same experiment establishes the relation between ADU and number of photoelectrons (gain). Same CCD may use more than one gain (e.g. 1.1 and 9).

CCD noise

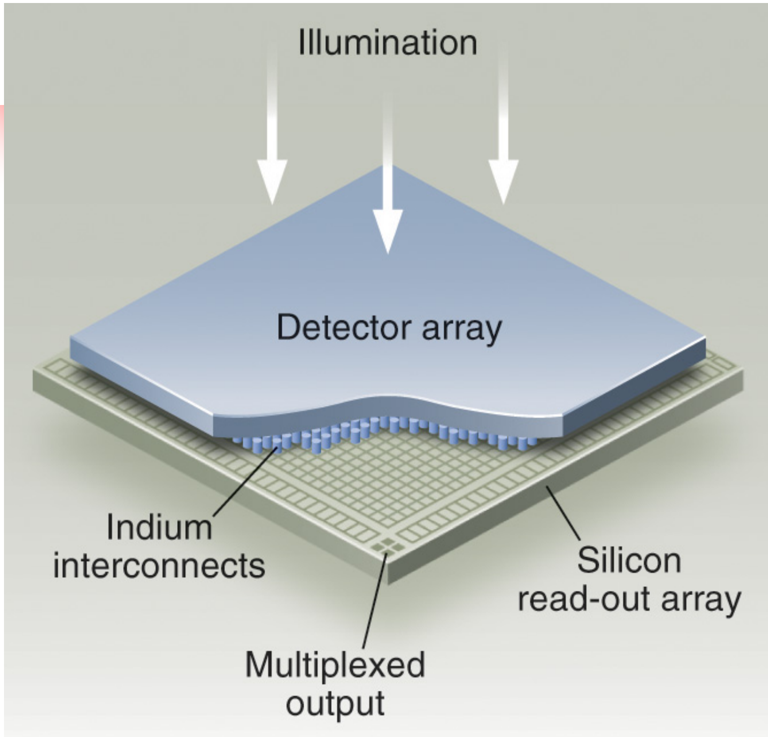
- Shot noise (Poisson distribution σ ≈√N)
- Dark current is proportional to time, depends on temperature
- Readout noise, depends on the temperature, read speed and amplifier(s) used
- Cosmic rays are not exactly noise but they destroy content of a few pixels

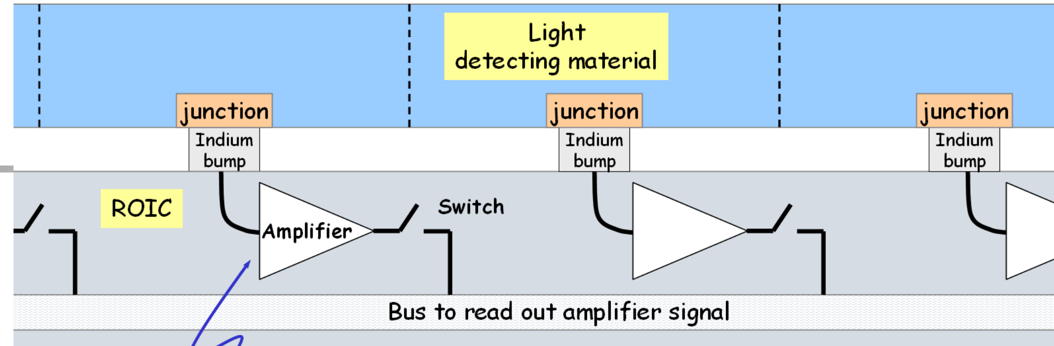


Binning


1 1 1 1
1 1 1 1
1 1 1 1
1 1 1 1
0
0 0 0 0
0 0 0 0
1 1 1 1
1 1 1 1
1 1 1 1
0
1 1 1 1
0 0 0 0
0 0 0 0
1 1 1 1
1 1 1 1
0
2 2 2 2
0 0 0 0
0 0 0 0
1 1 1 1
1 1 1 1
2
2 2 2 0
0 0 0 0
0 0 0 0
1 1 1 1
1 1 1 1
4
2 2 0 0
illumination
line shift 1
line shift 2
column shift 1
column shift 2

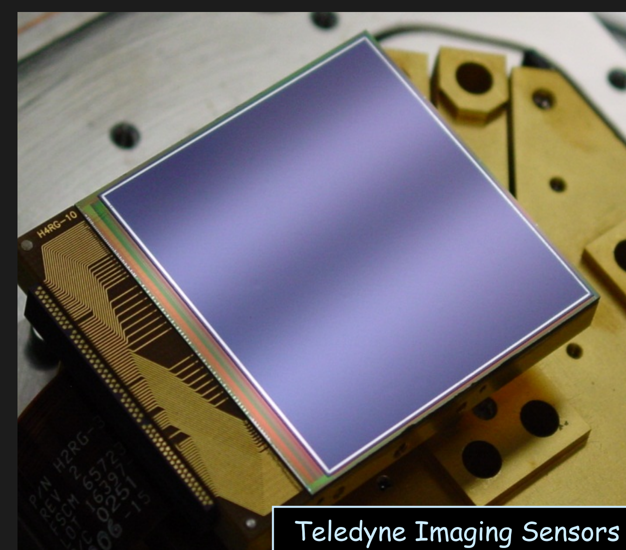
Infrared: Hybrid Imager Architecture





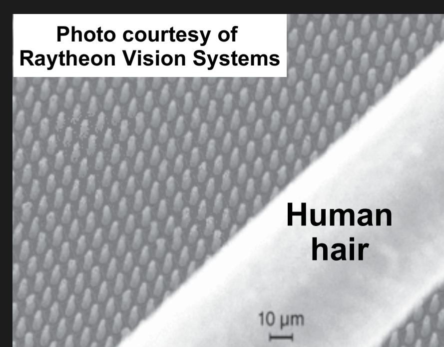
This amplifier contains one or more MOSFETs
MOSFET = metal oxide semiconductor field effect transistor

H4RG-10
4096x4096 pixels
10 micron pixel pitch
HyViSI silicon PIN

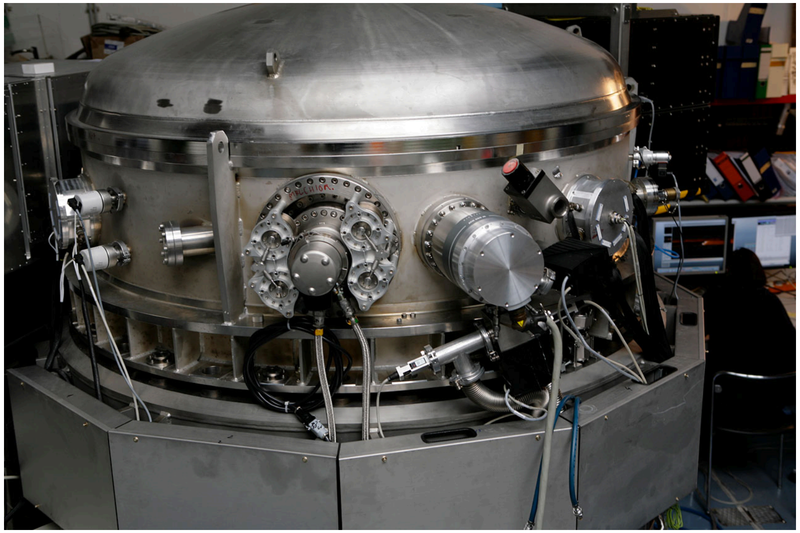


Mature interconnect technique:

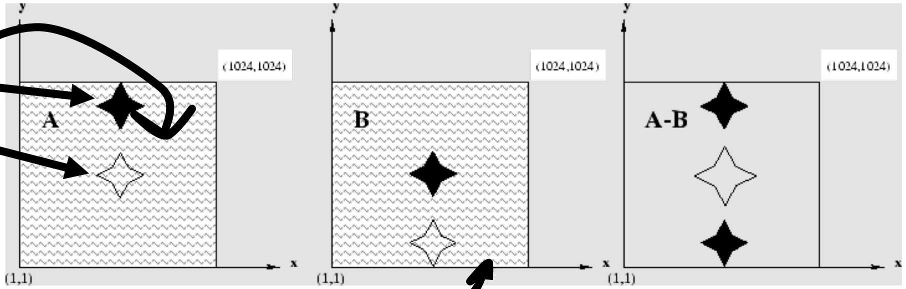
- Over 16,000,000 indium bumps per Sensor Chip Assembly (SCA) demonstrated
- >99.9% interconnect yield



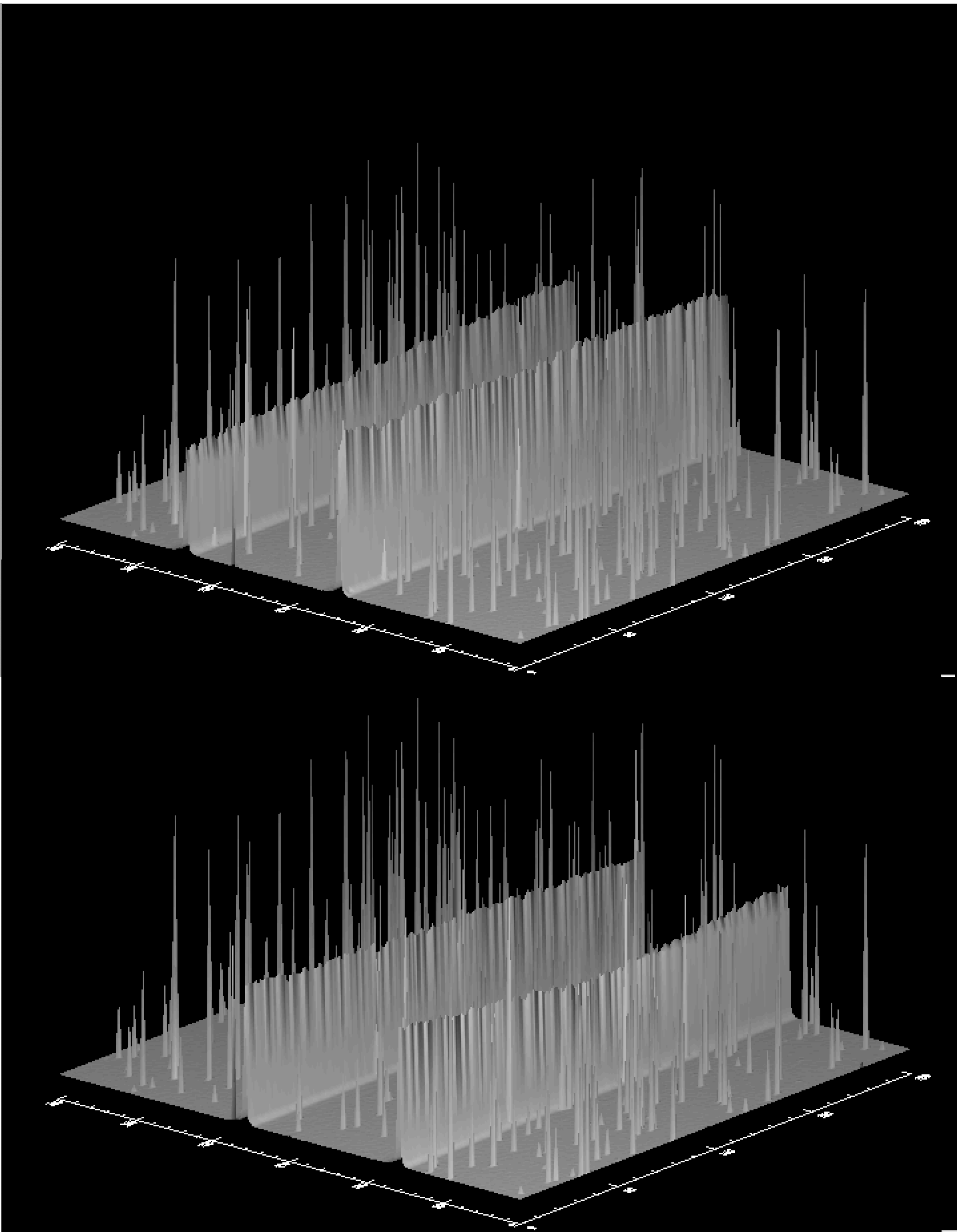
Fighting bad pixels and thermal background

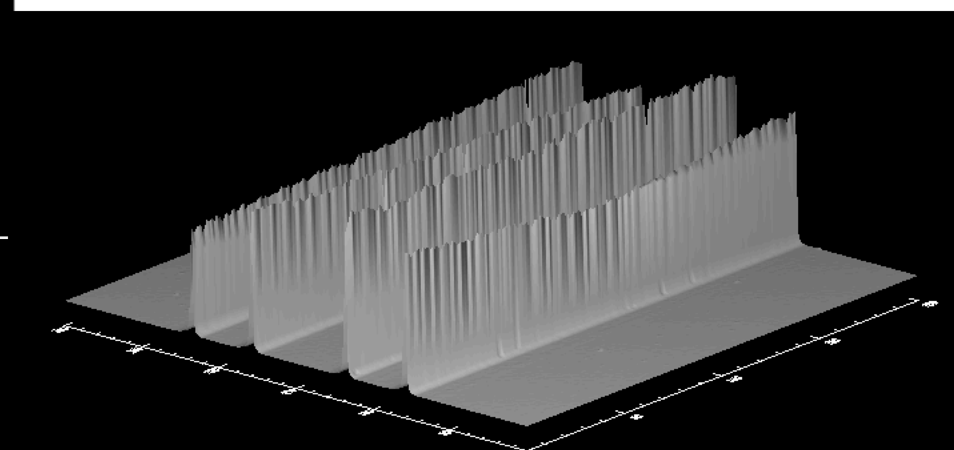


- Cooling the whole instrument
- Taking short exposures
- Chopping and nodding the telescope
- Non-destructive readout



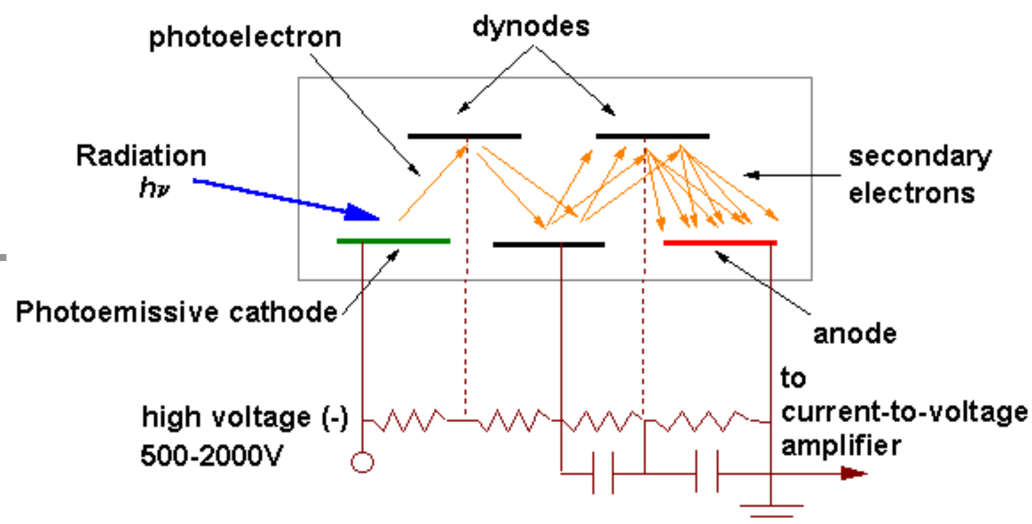
This is how it works in practice



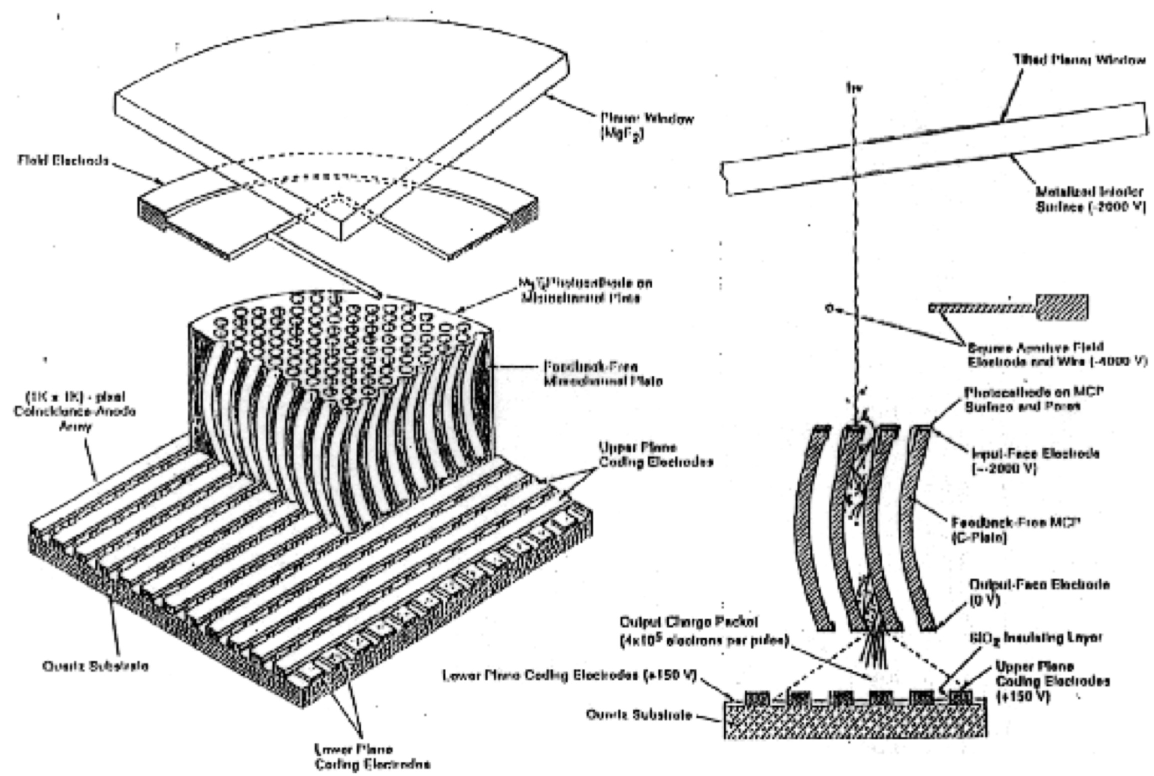


PCD

- Photomultiplier



- Multi-anode microchannel array (MAMA)



PCD properties

- Noise sources: shot noise and dark current
- No readout noise (since there is no ADC)
- Cosmic rays are minor concern – detector of choice for many space missions
- Limited dynamic range (why?)
- Linearity problem
- Can easily be tuned to any spectral range, no need for thinning or other risky operations
- Maximum QE is about 50% (why?)
- MAMA allows reading 2D frames

Comparison

CCDs

- Large dynamic range
- Large QE
- Extremely linear
- Large sizes (4k×4k)
- Sensitivity drops sharply in the blue and the red
- Readout noise
- Cosmic rays
- Cooling

PCD

- Digital output in real time
- No readout noise
- Insensitive to cosmic rays
- No need for deep cooling
- Much easier to make and therefore much cheaper
- Small dynamic range
- Small QE
- High voltages