Optical and Infrared Detectors

Tim Hardy

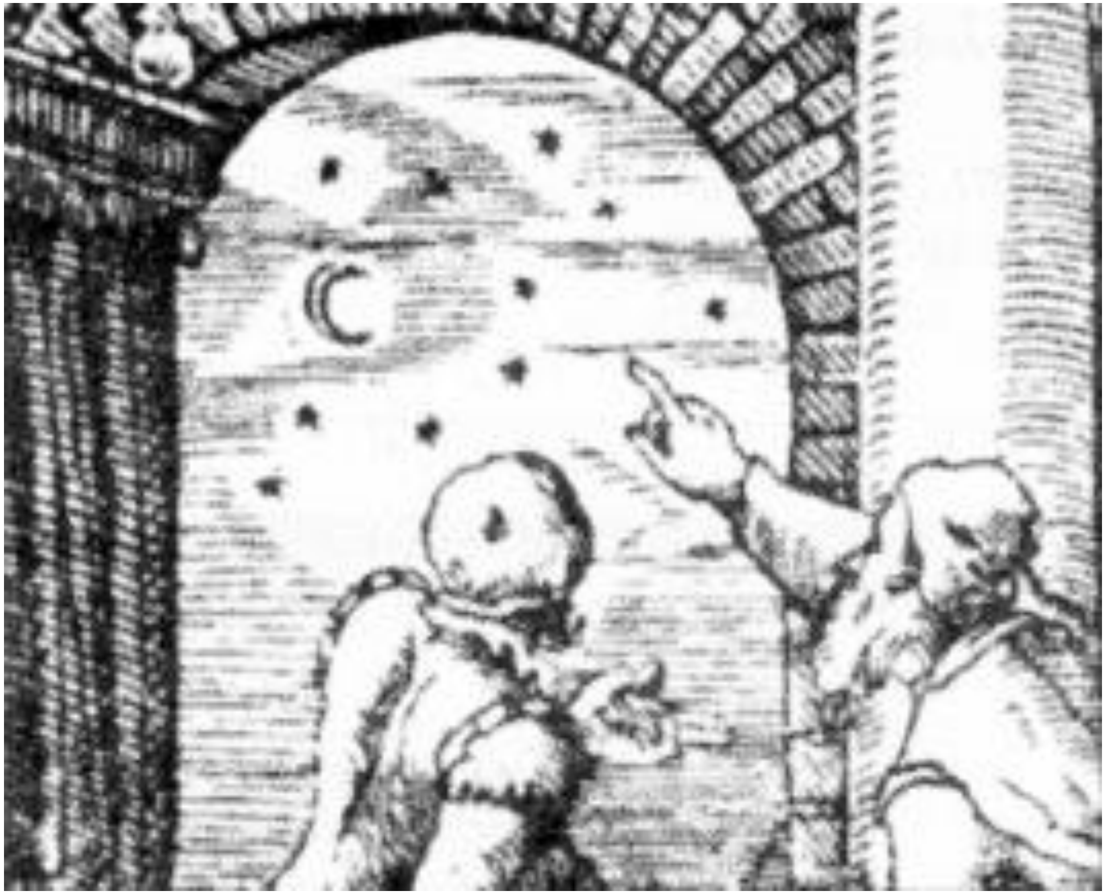
Outline

- Introduction
- History
- Charge Coupled Devices (CCDs)
  - Break
- CMOS imagers
- Hybrid CMOS imagers
- Other

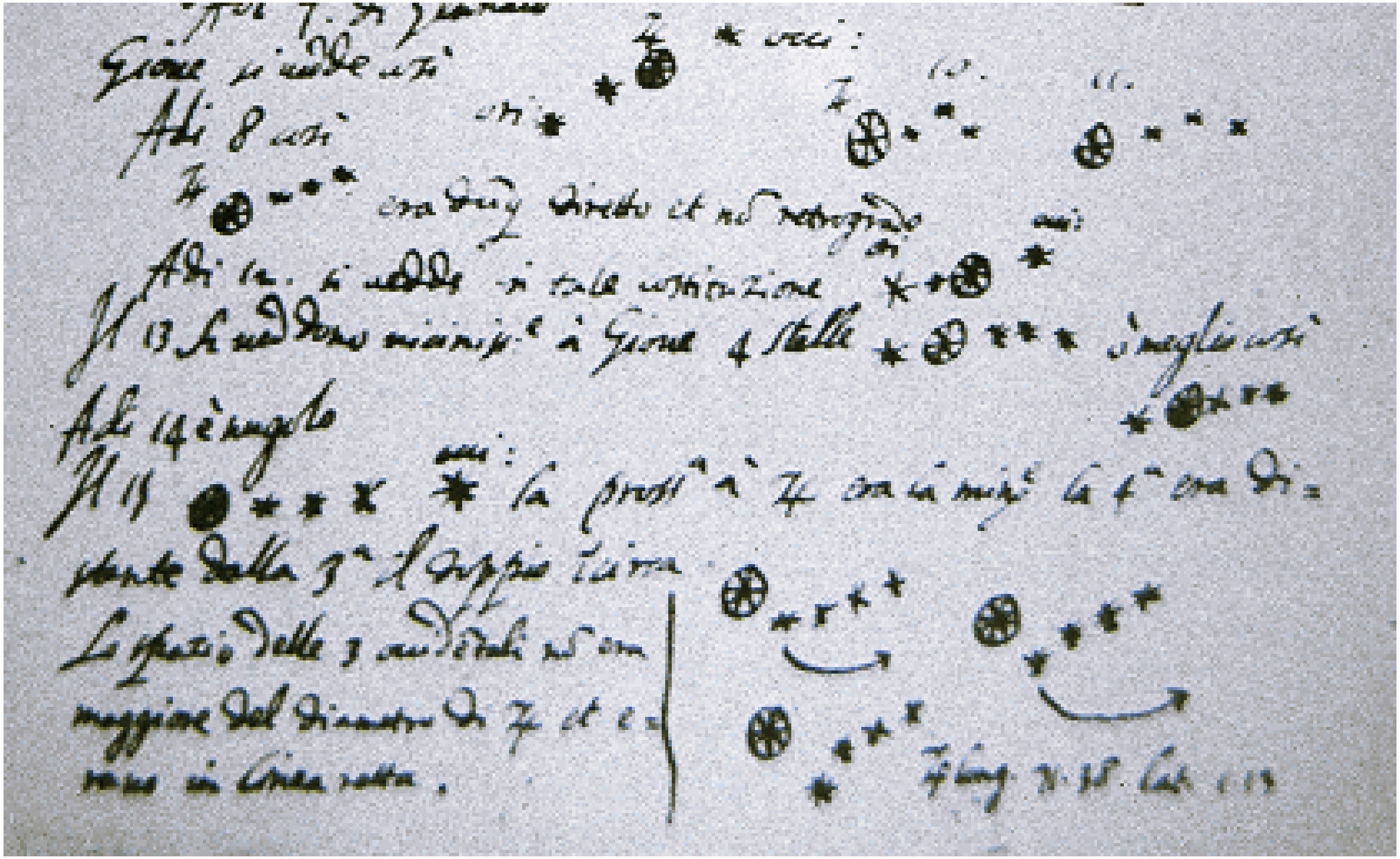
Introduction

- Who am I?
- Why are detectors important?
- What is a detector?
- What information can we get?
- What causes imprecision?

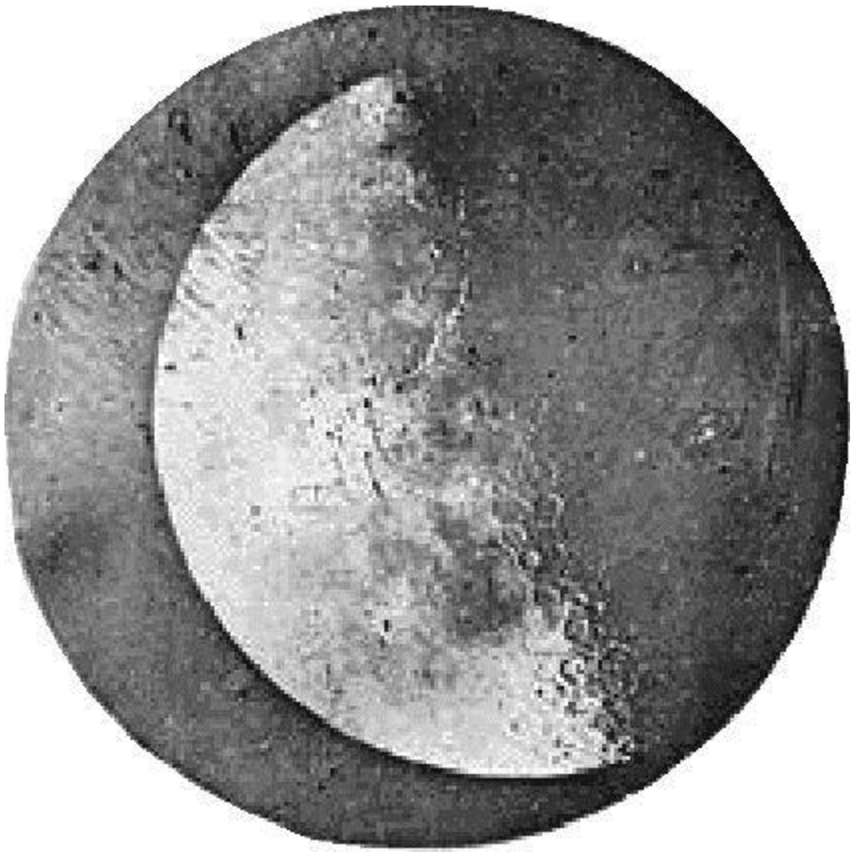
History



History



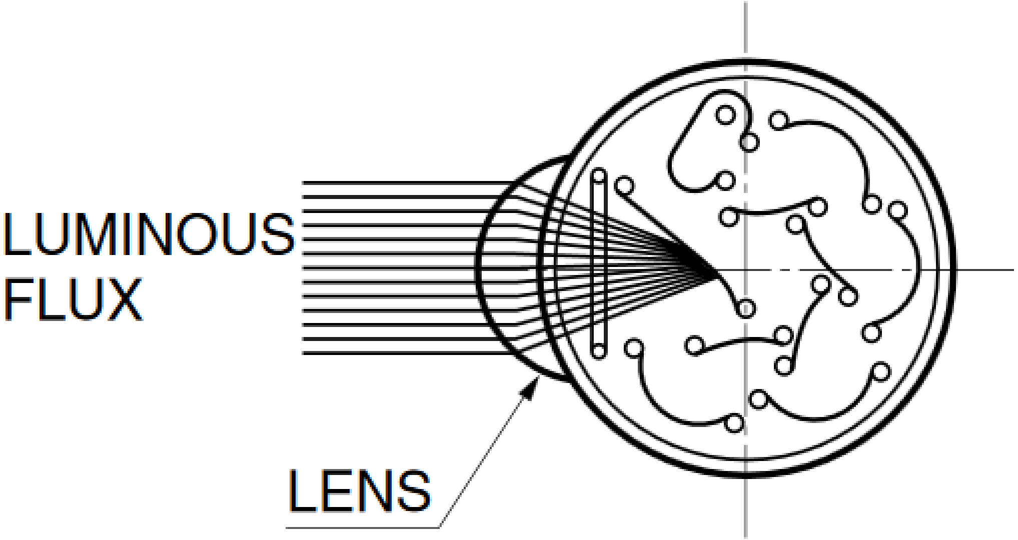
History



Daguerreotype of the Moon taken by John William Draper in 1845.
Source: New York University Archives

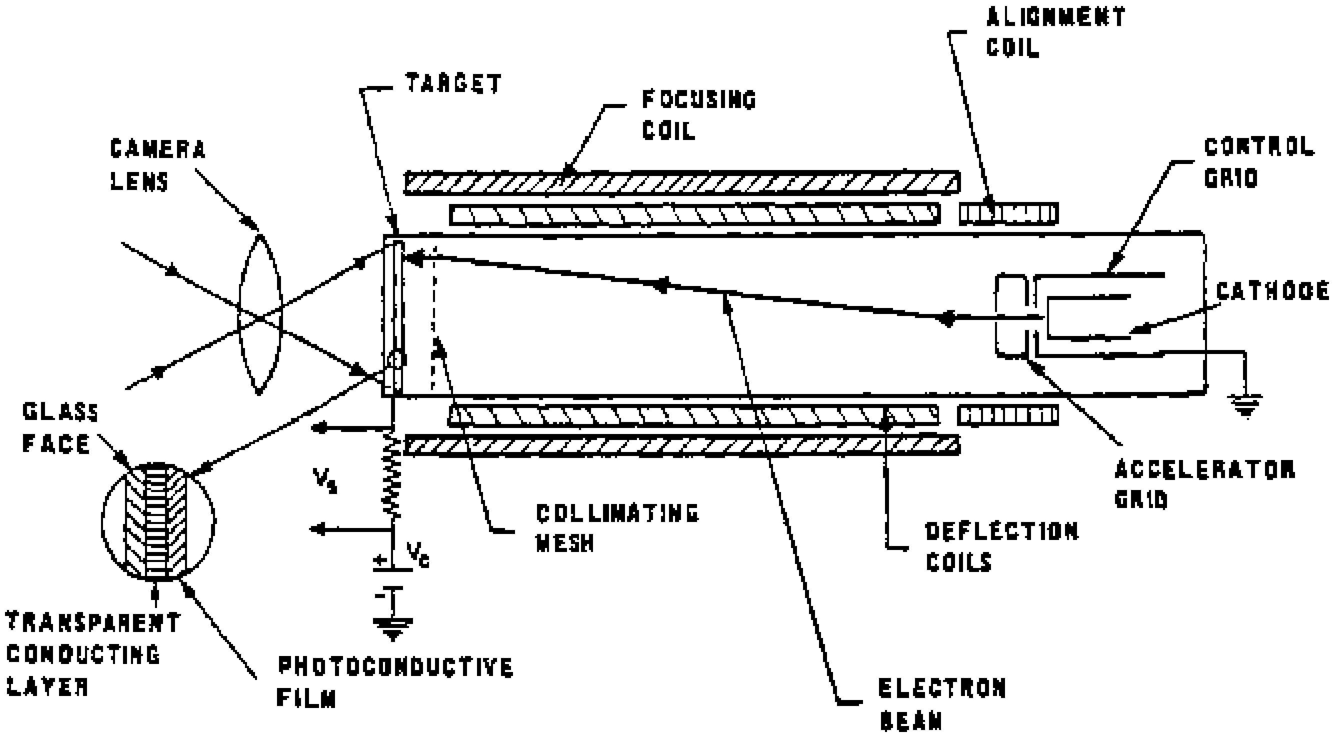
Electronic detectors

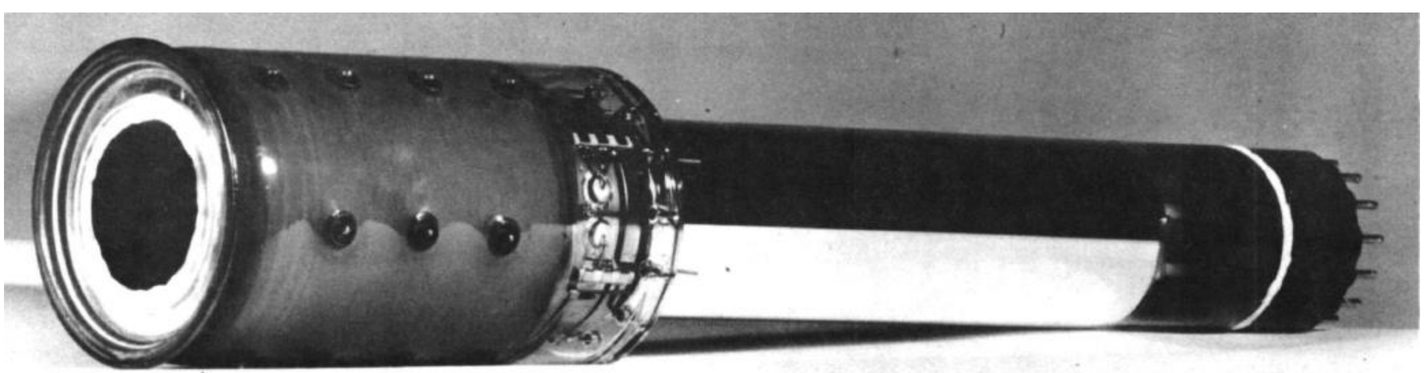
- PMT (photoelectric effect)



Hamamatsu R6350 to R6358 series data sheet

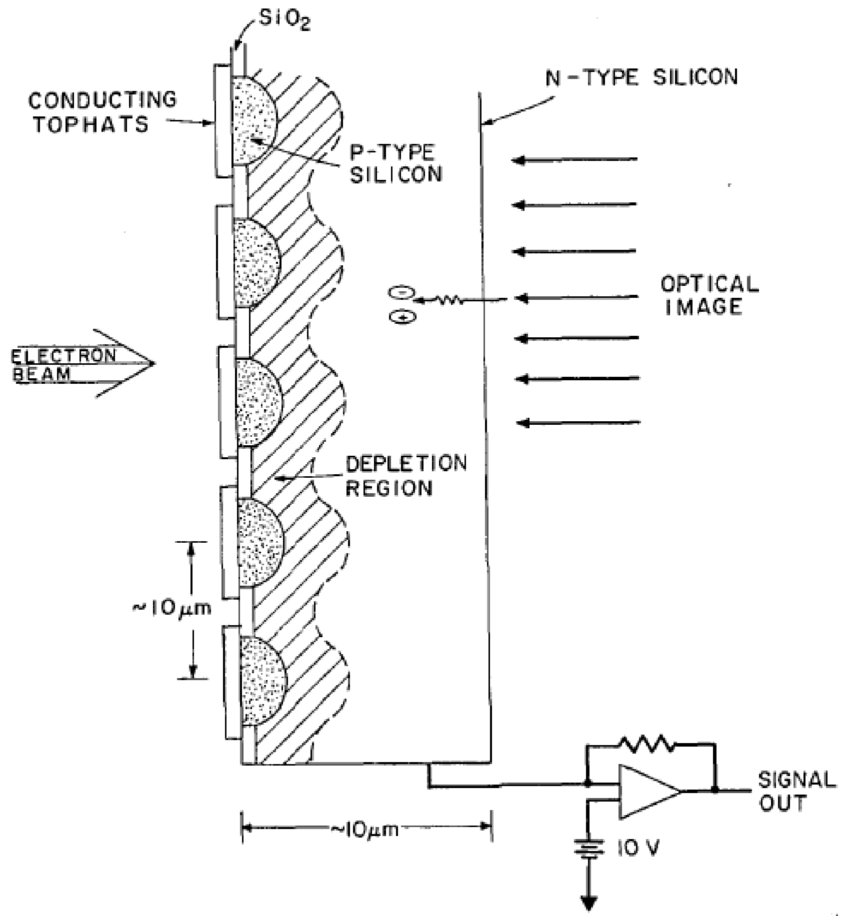
Electronic detectors





Vidicon tube (Zucchino and Lowrance 1971)

Electronic detectors

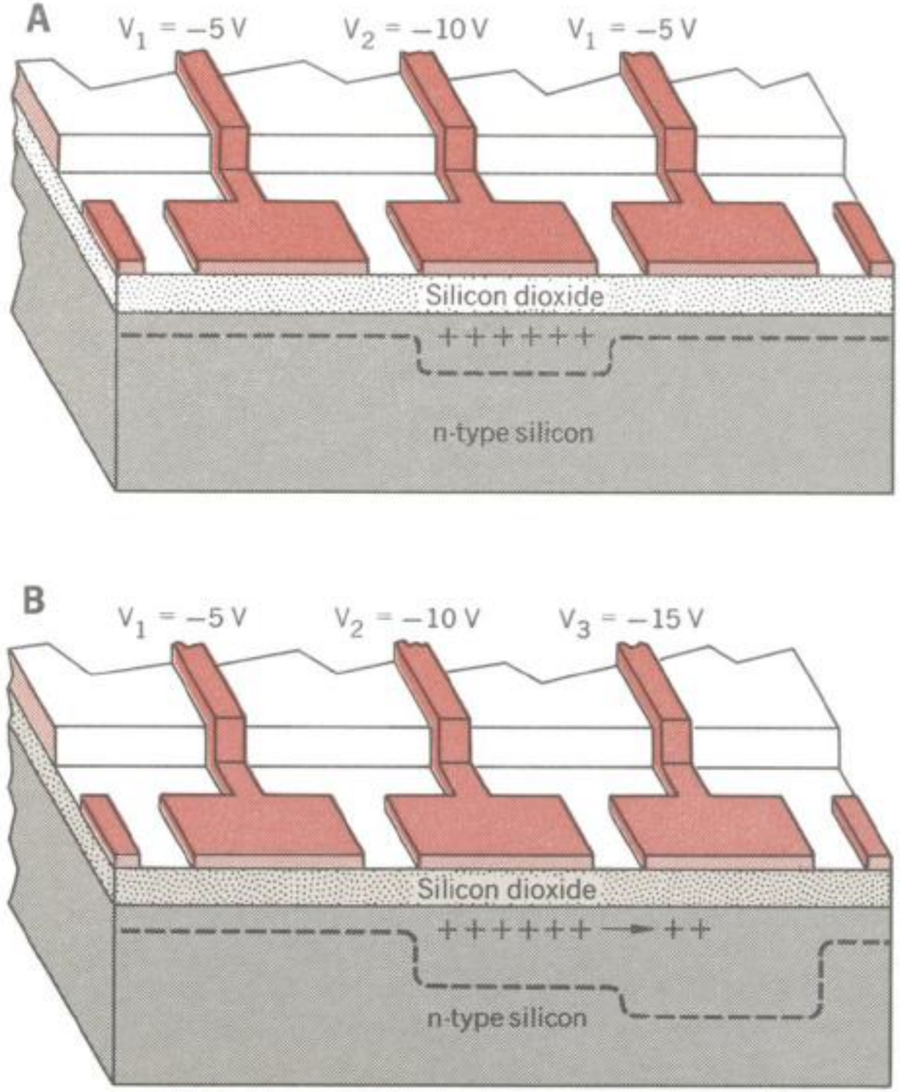


Silicon photodiode vidicon target (McCord & Westphal, 1972)

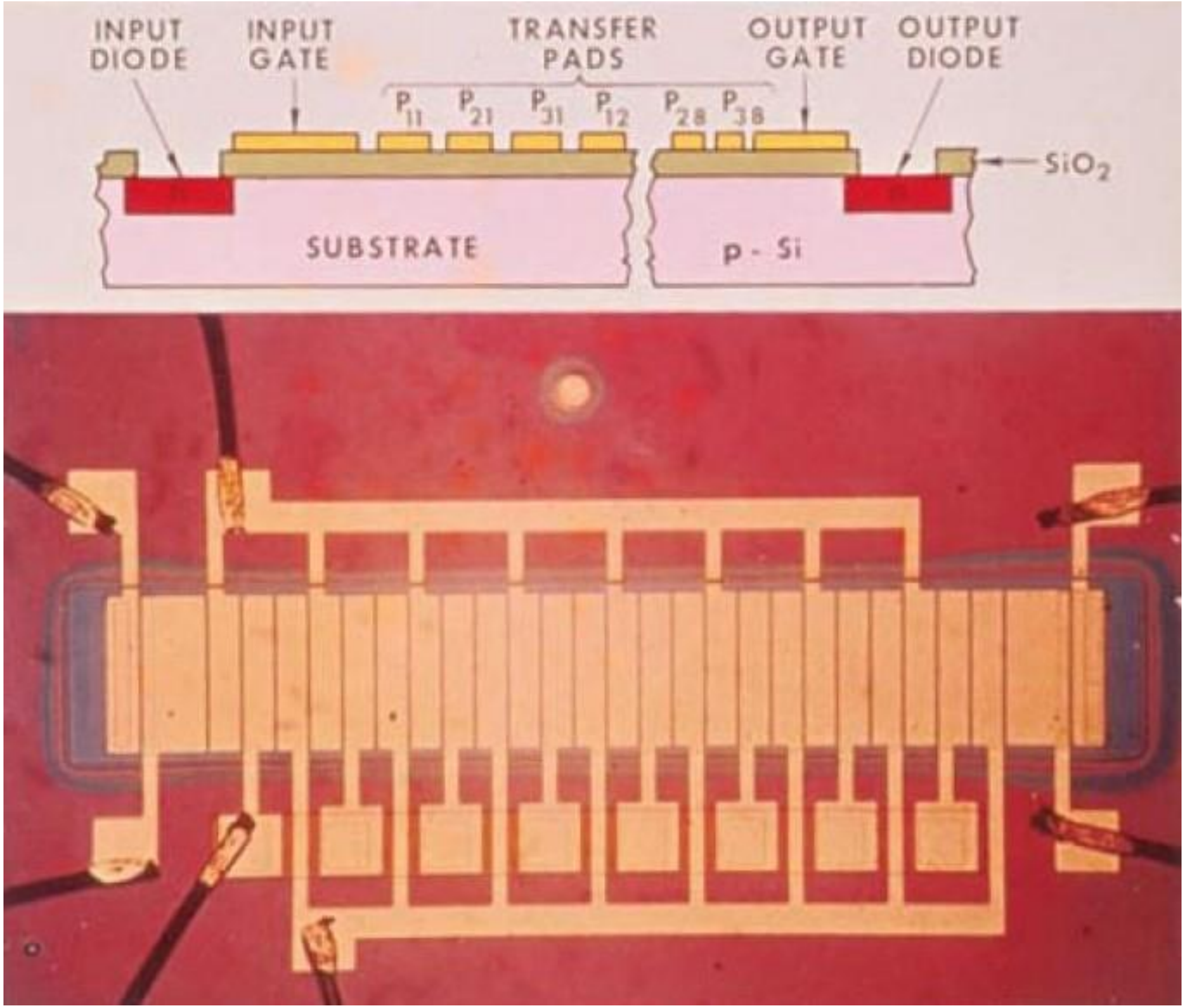
CCDs

Willard Boyle and George Smith at Bell Labs

Charge coupling

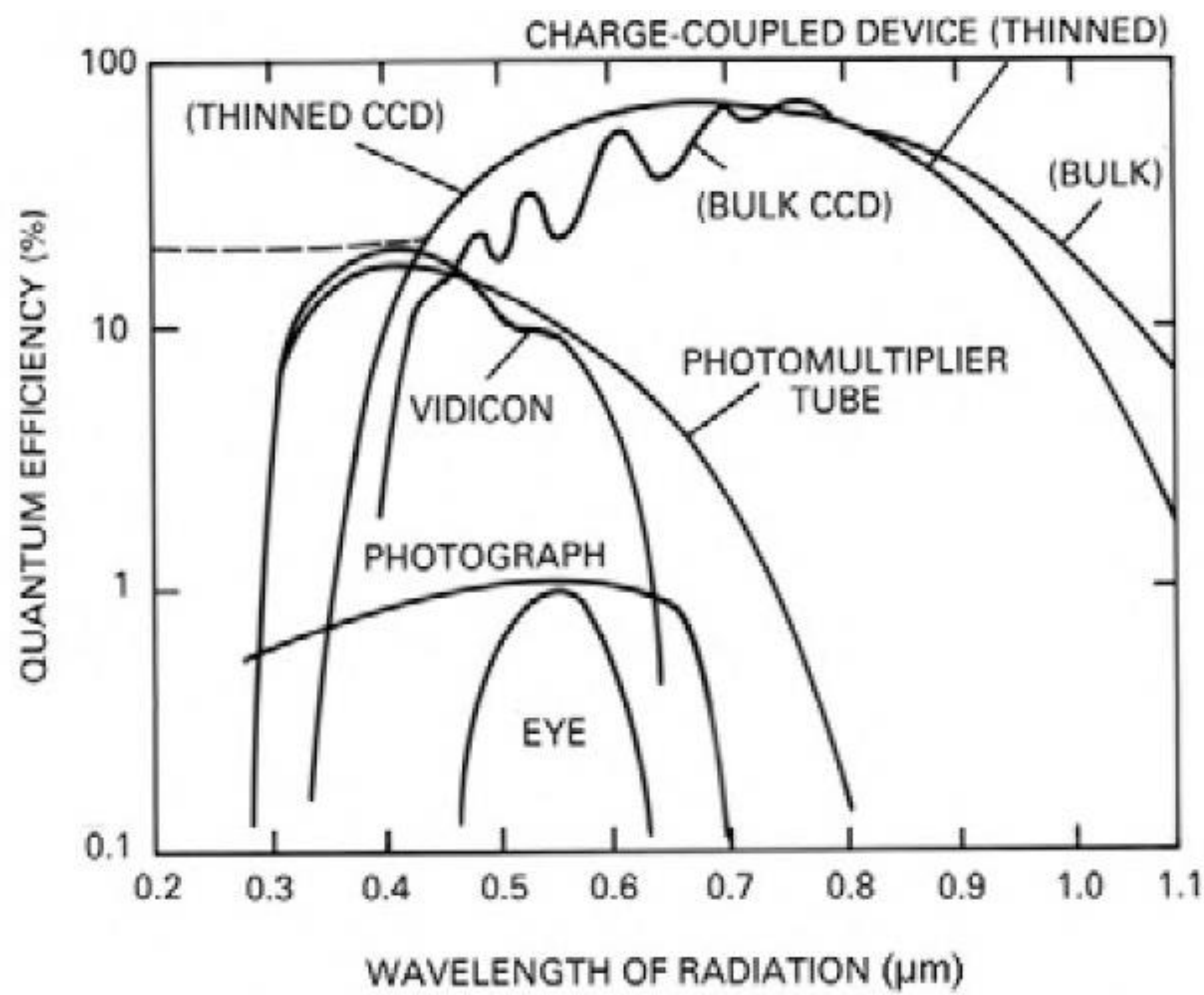


Boyle & Smith, IEEE Spectrum, 1971



Boyle & Smith, IEEE Spectrum, 1971

CCD sensitivity

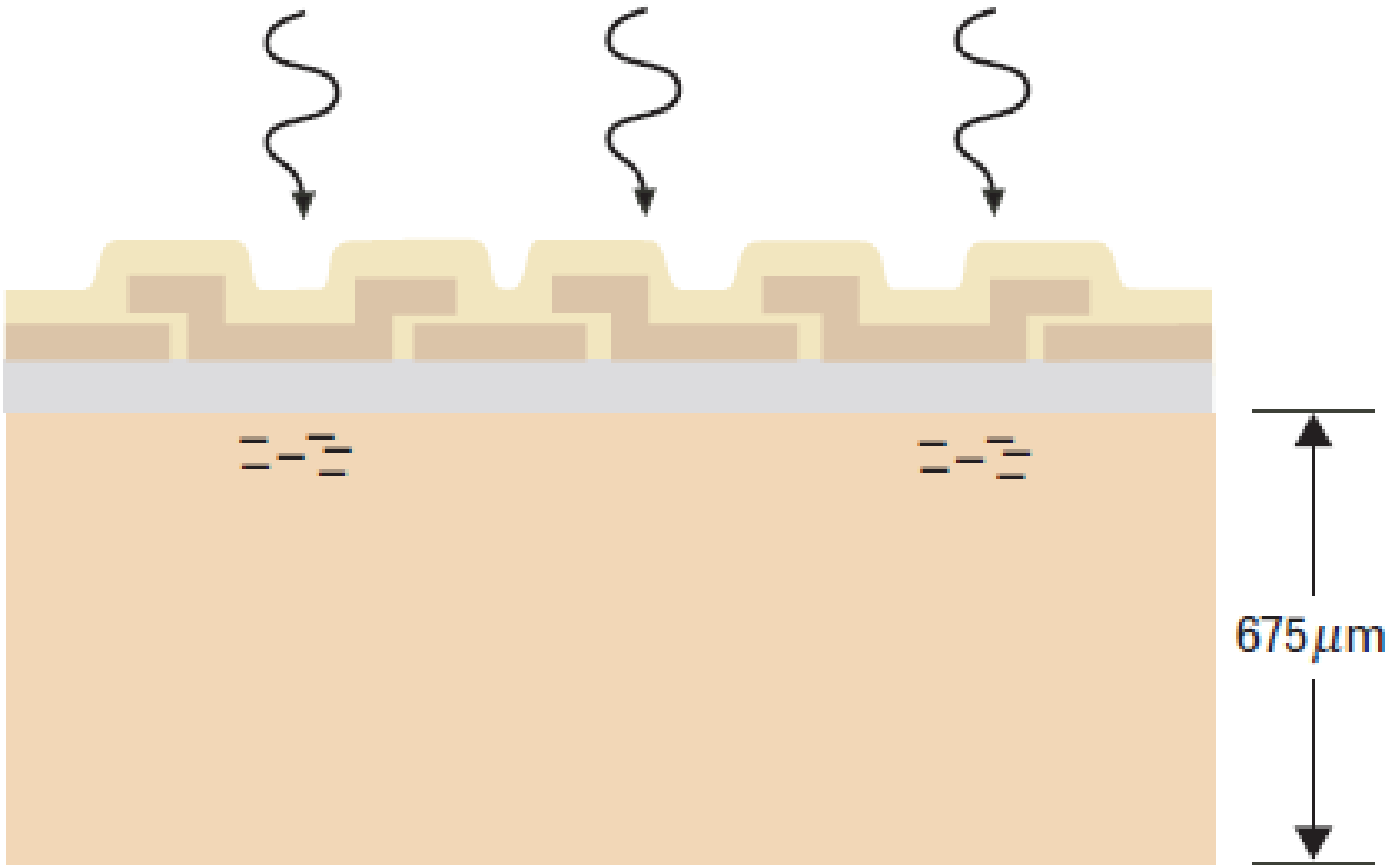


Ian S. McLean, Electronic Imaging in Astronomy

CCD operation

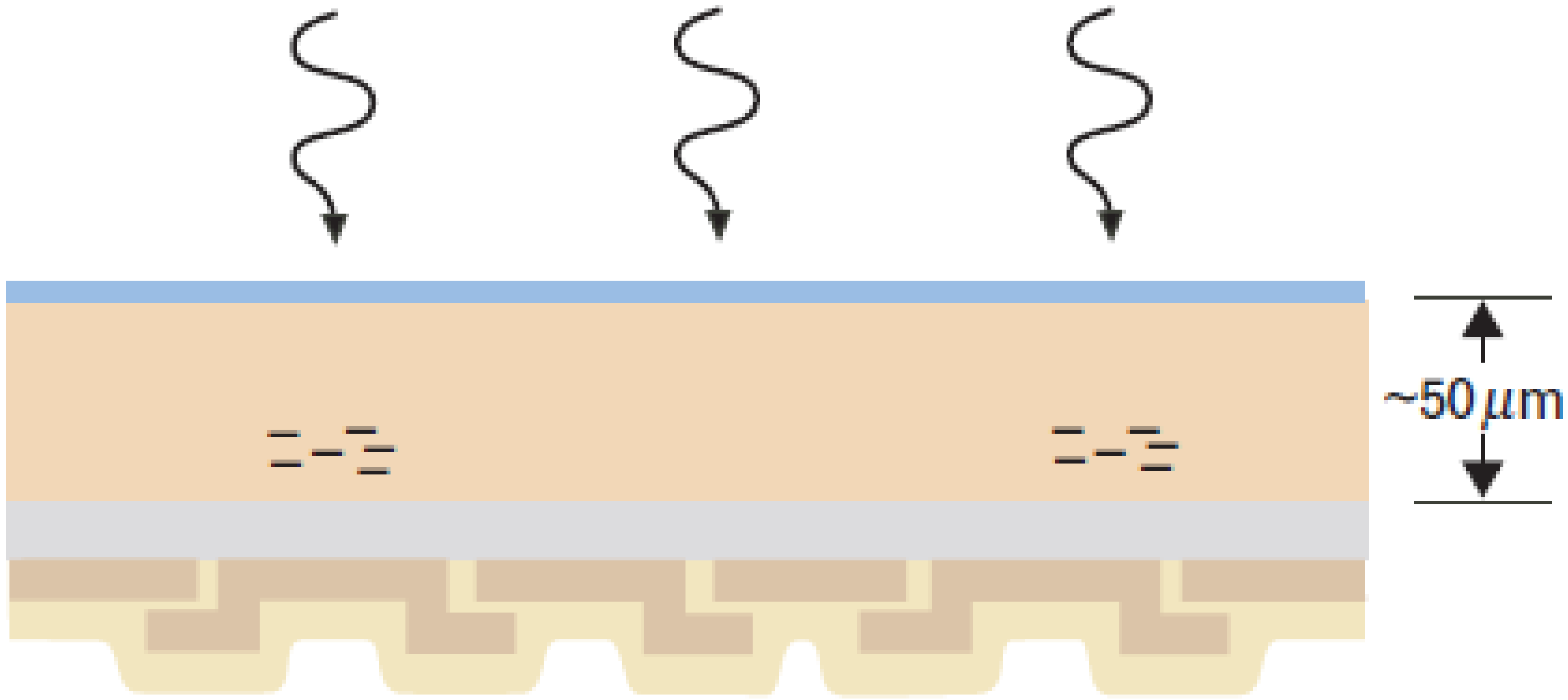
- Charge detection
- Charge collection
- Charge transfer
- Charge measurement
- Signal processing

Charge detection

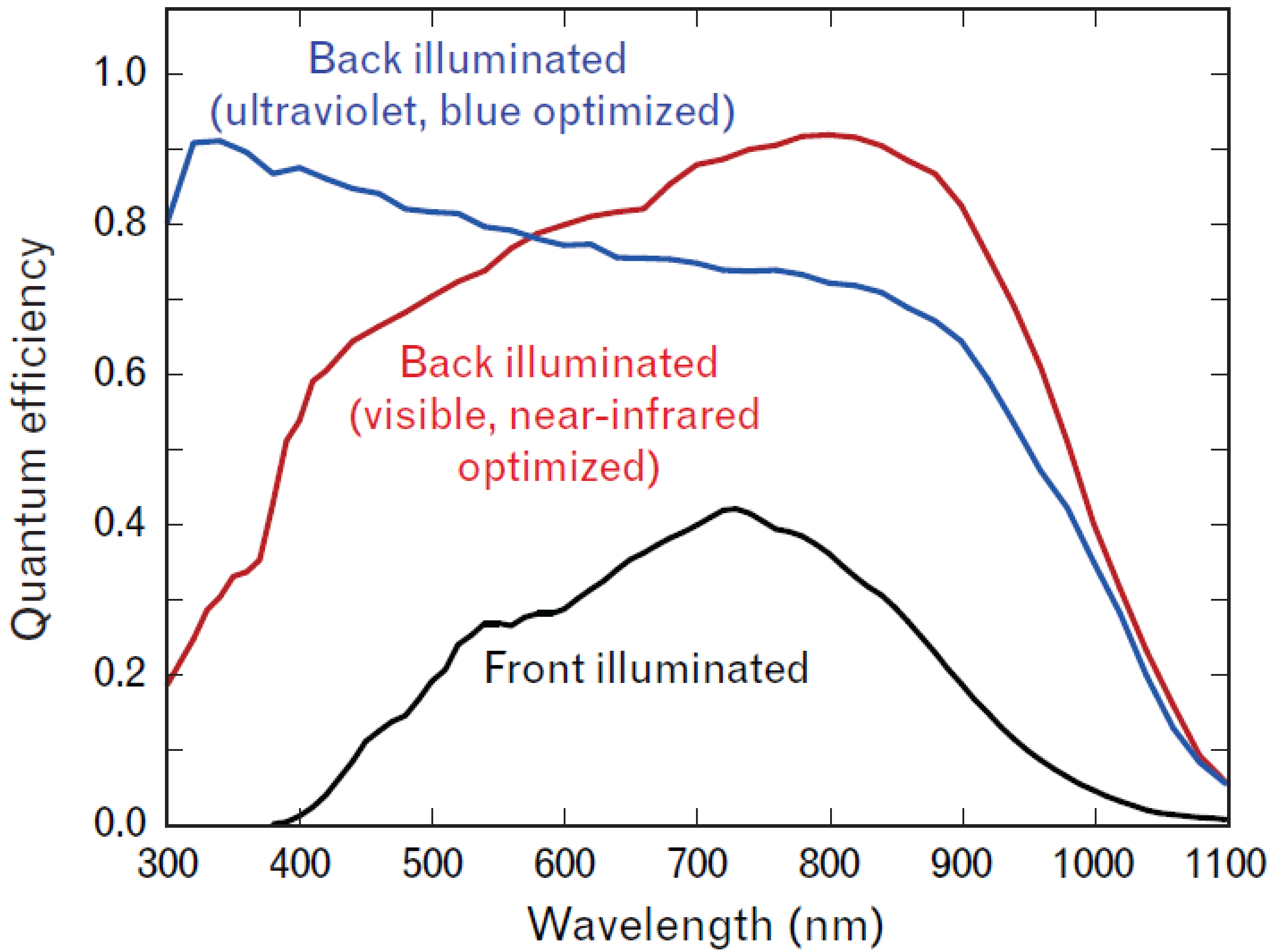


Burke et al, Lincoln Laboratory Journal, 2007

Backside illumination

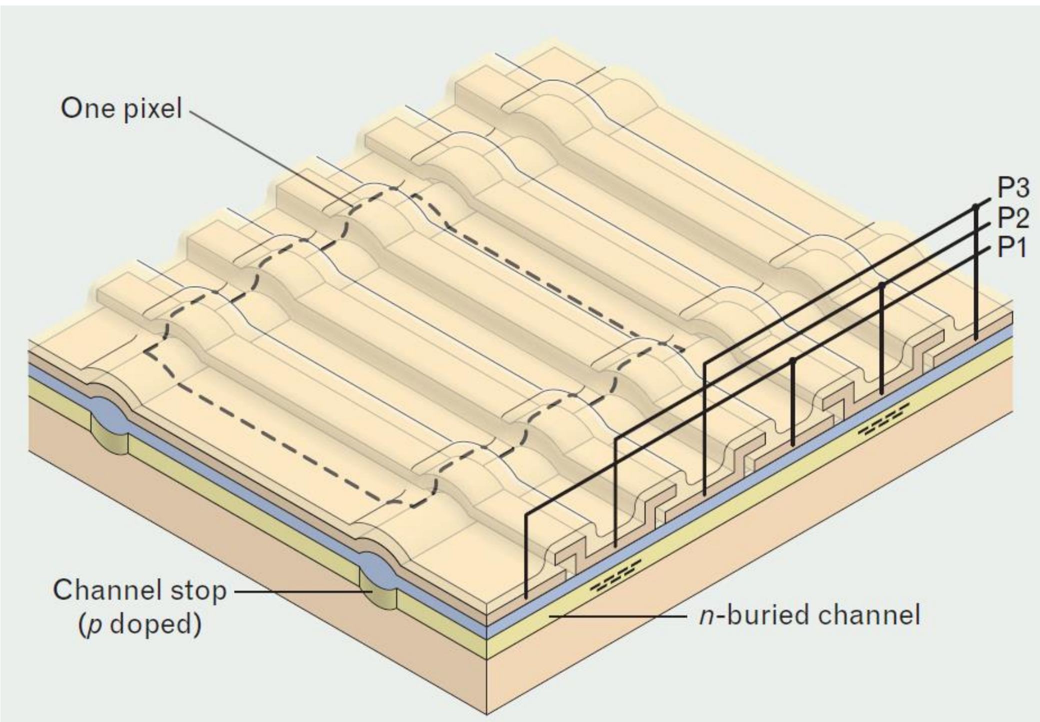


Burke et al, Lincoln Laboratory Journal, 2007

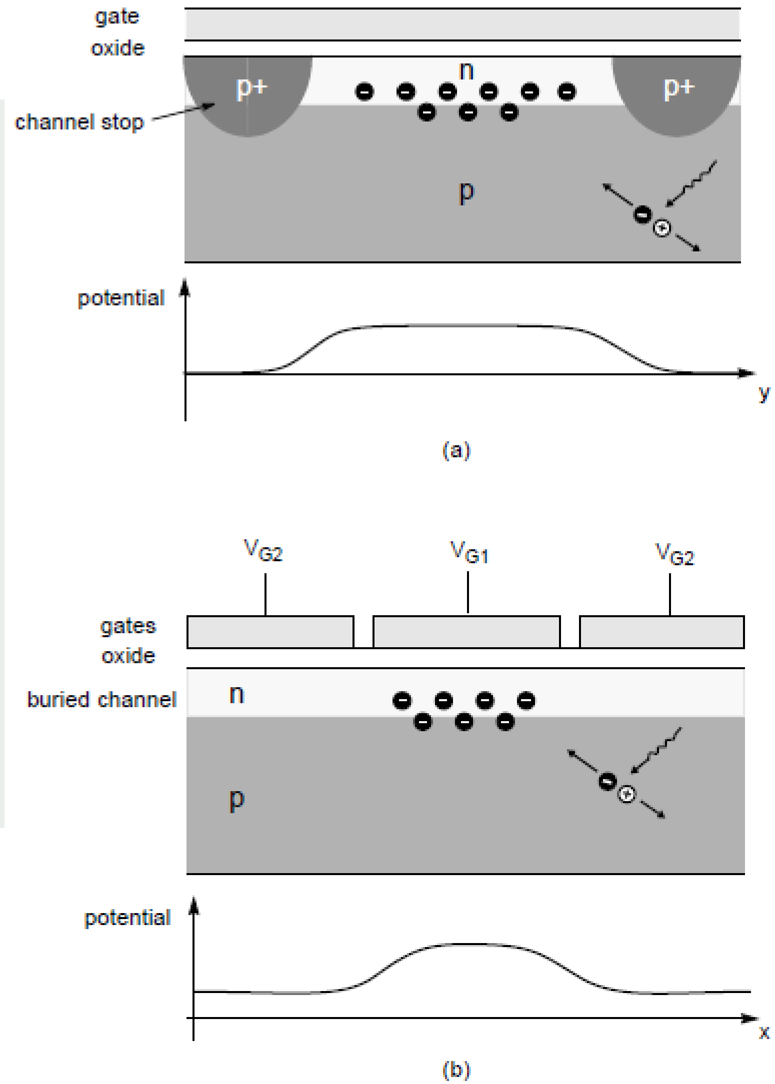


Burke et al, Lincoln Laboratory Journal, 2007

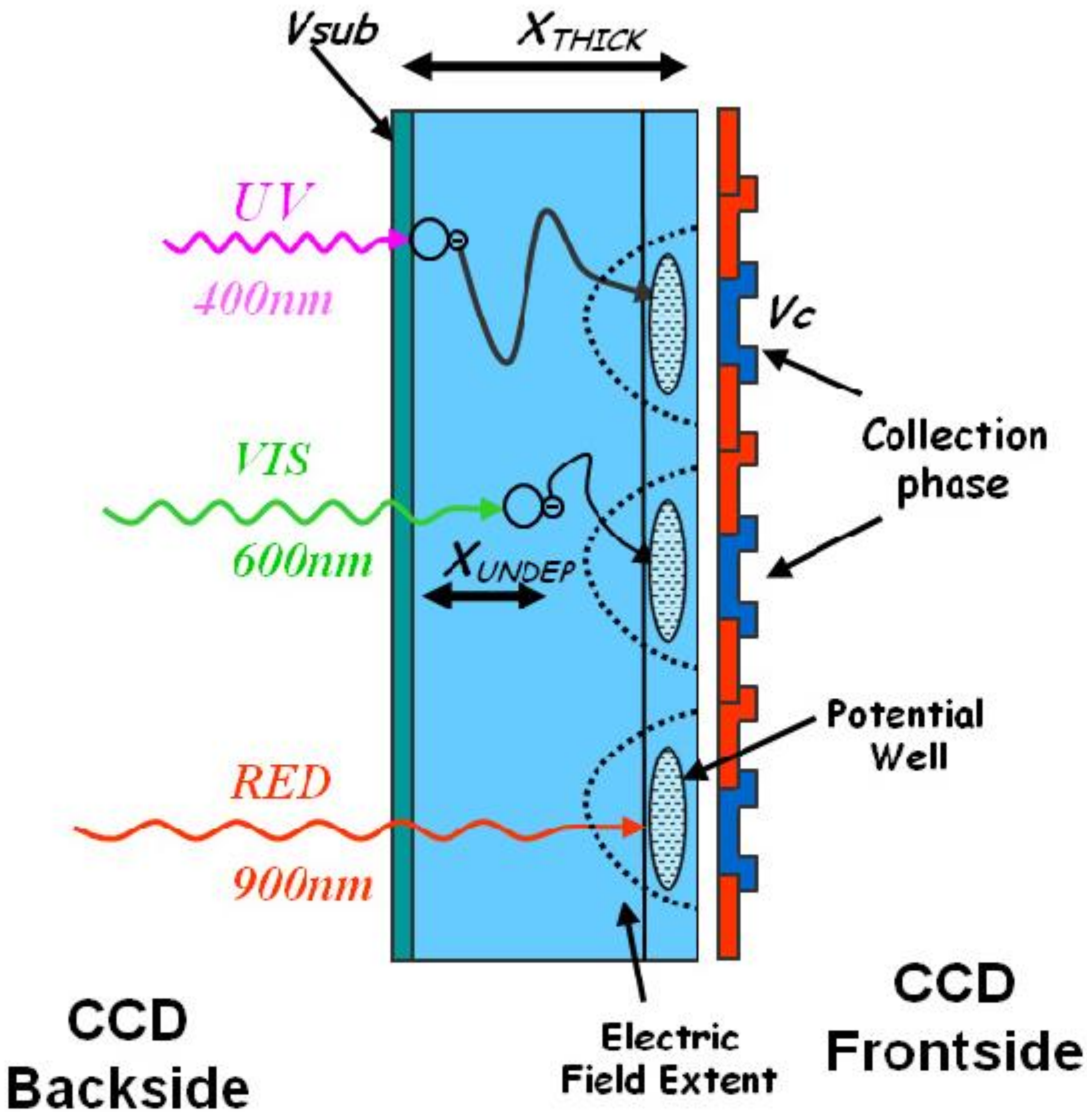
Charge collection



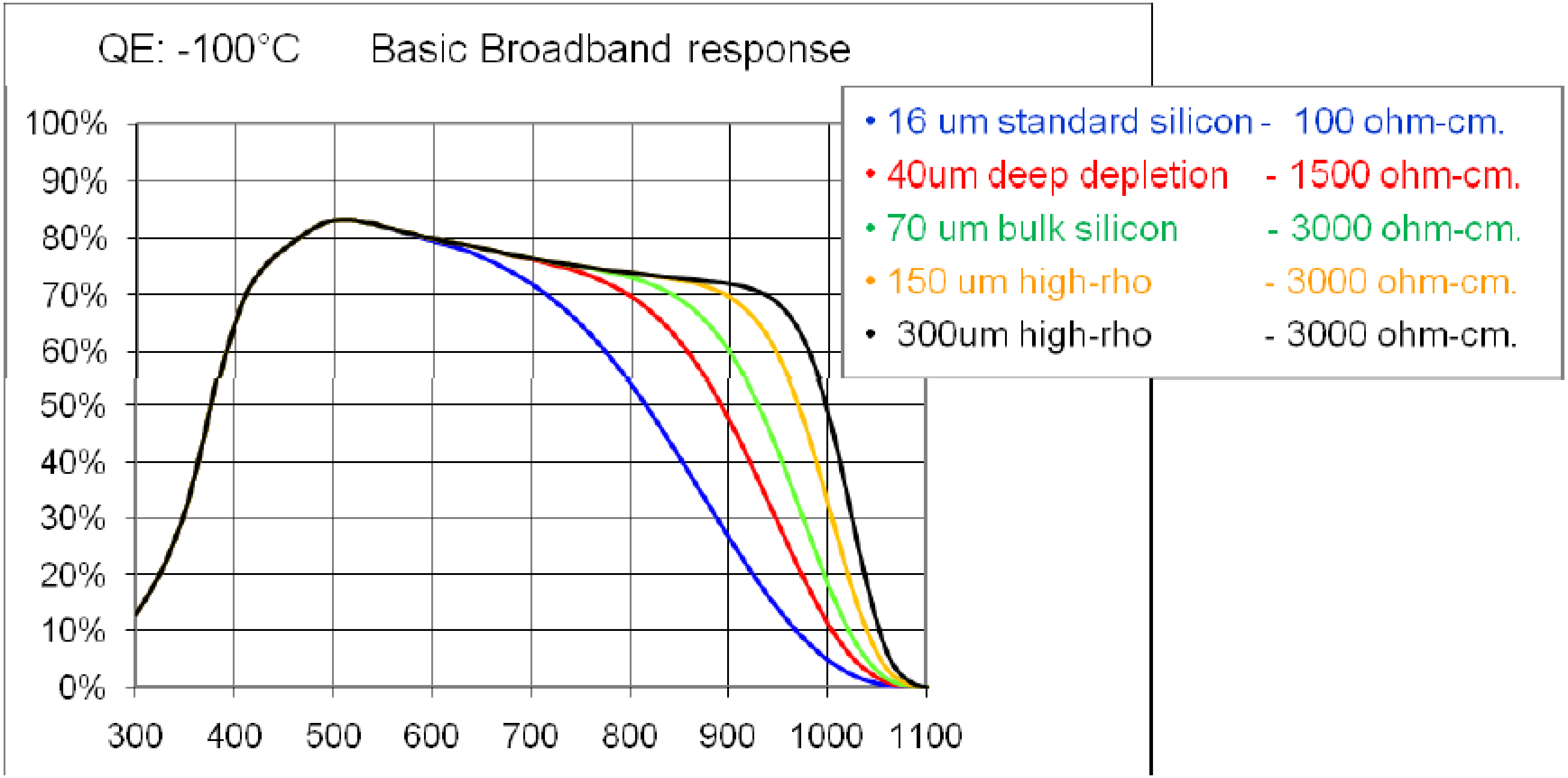
Burke et al, Lincoln Laboratory Journal, 2007



Blooming

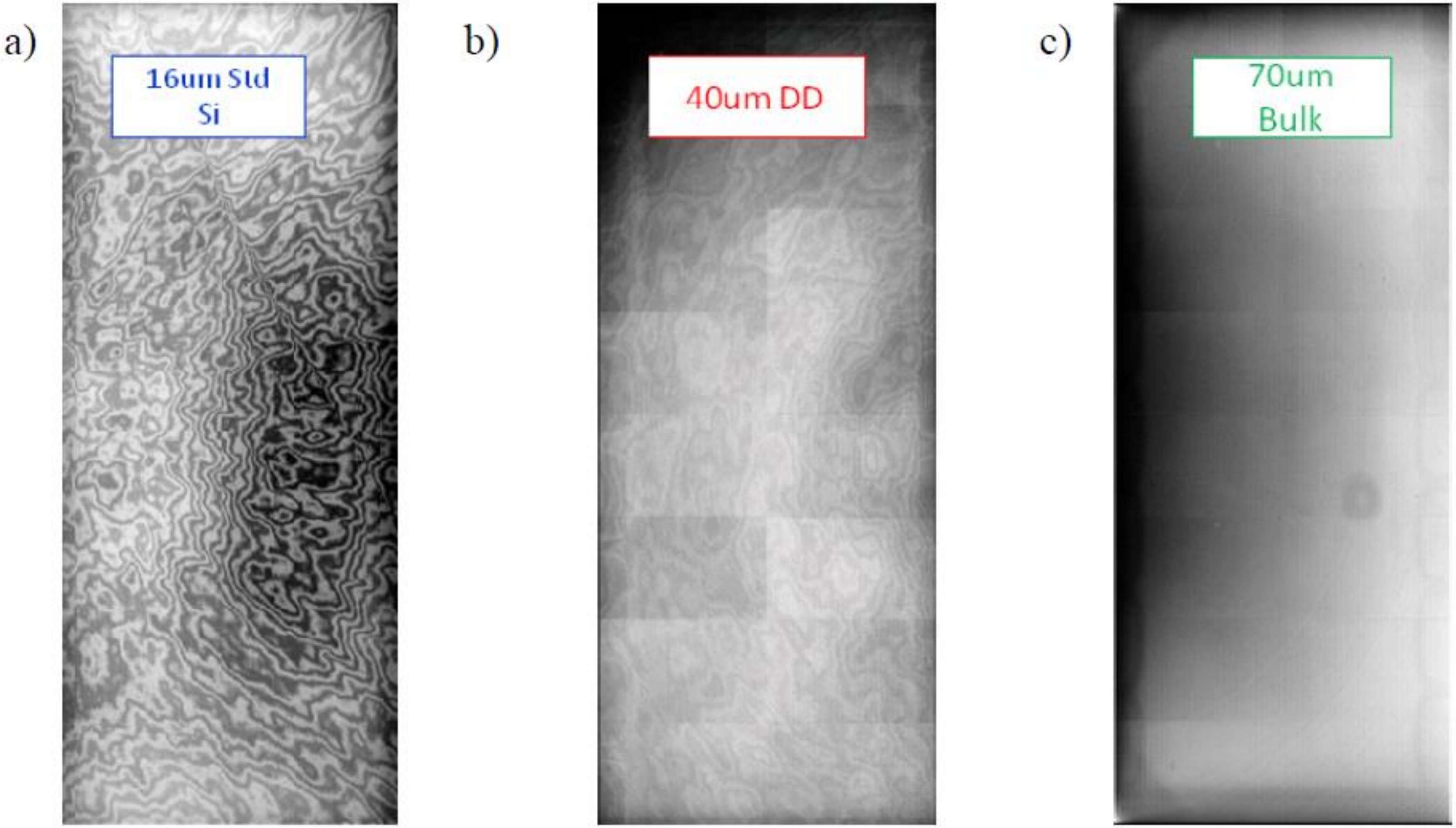


Downing, 2009



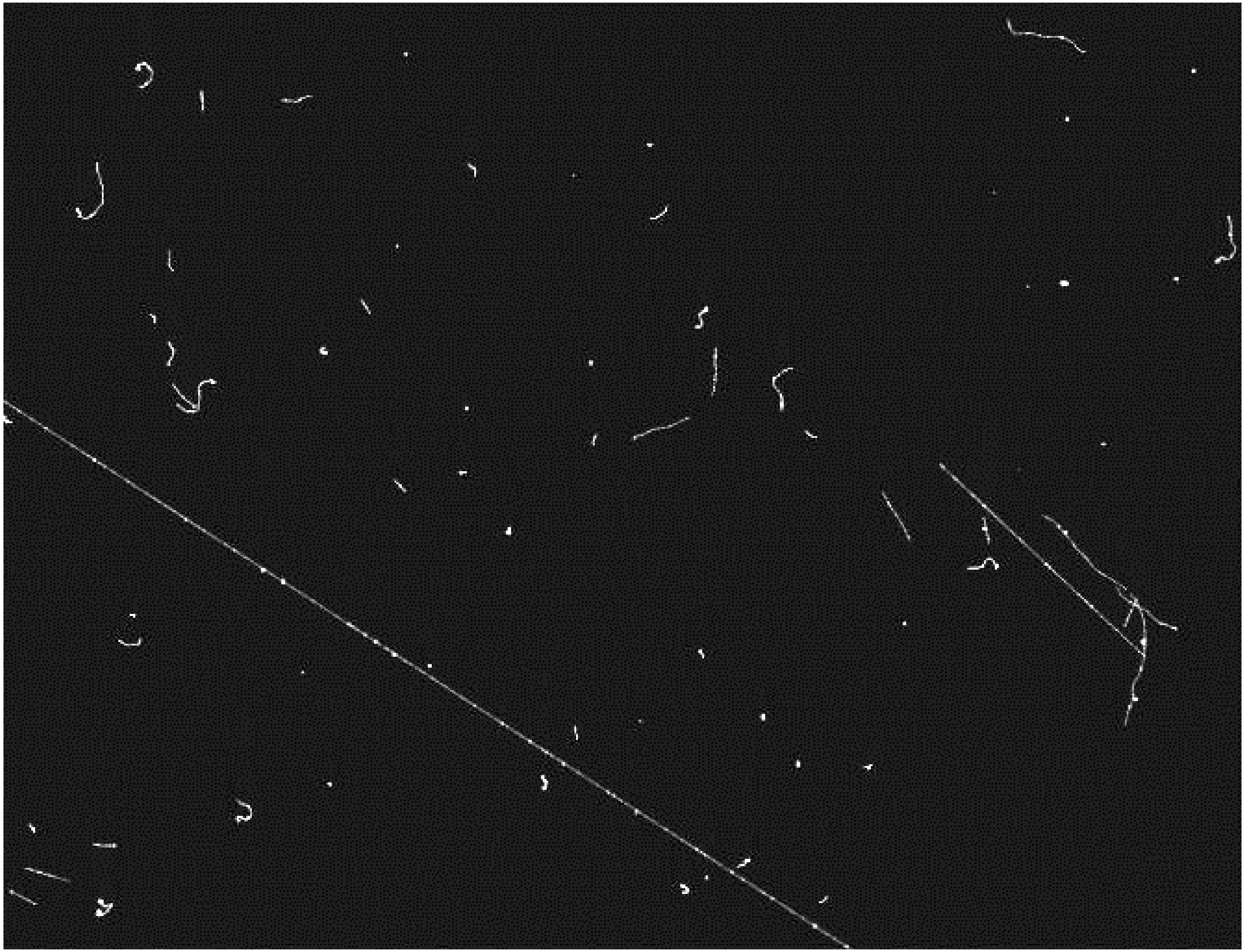
Downing, 2009

Fringing



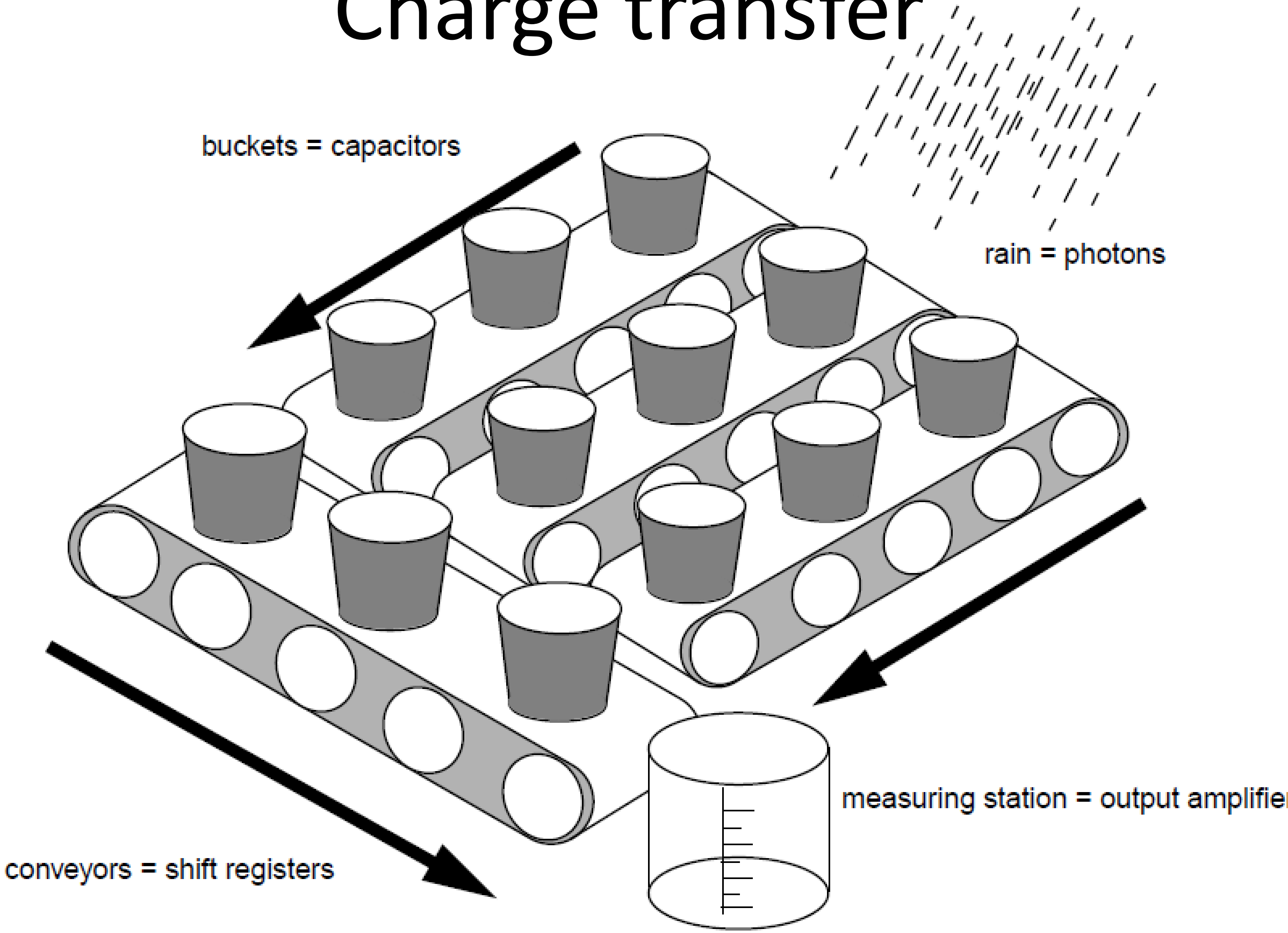
Downing, 2009

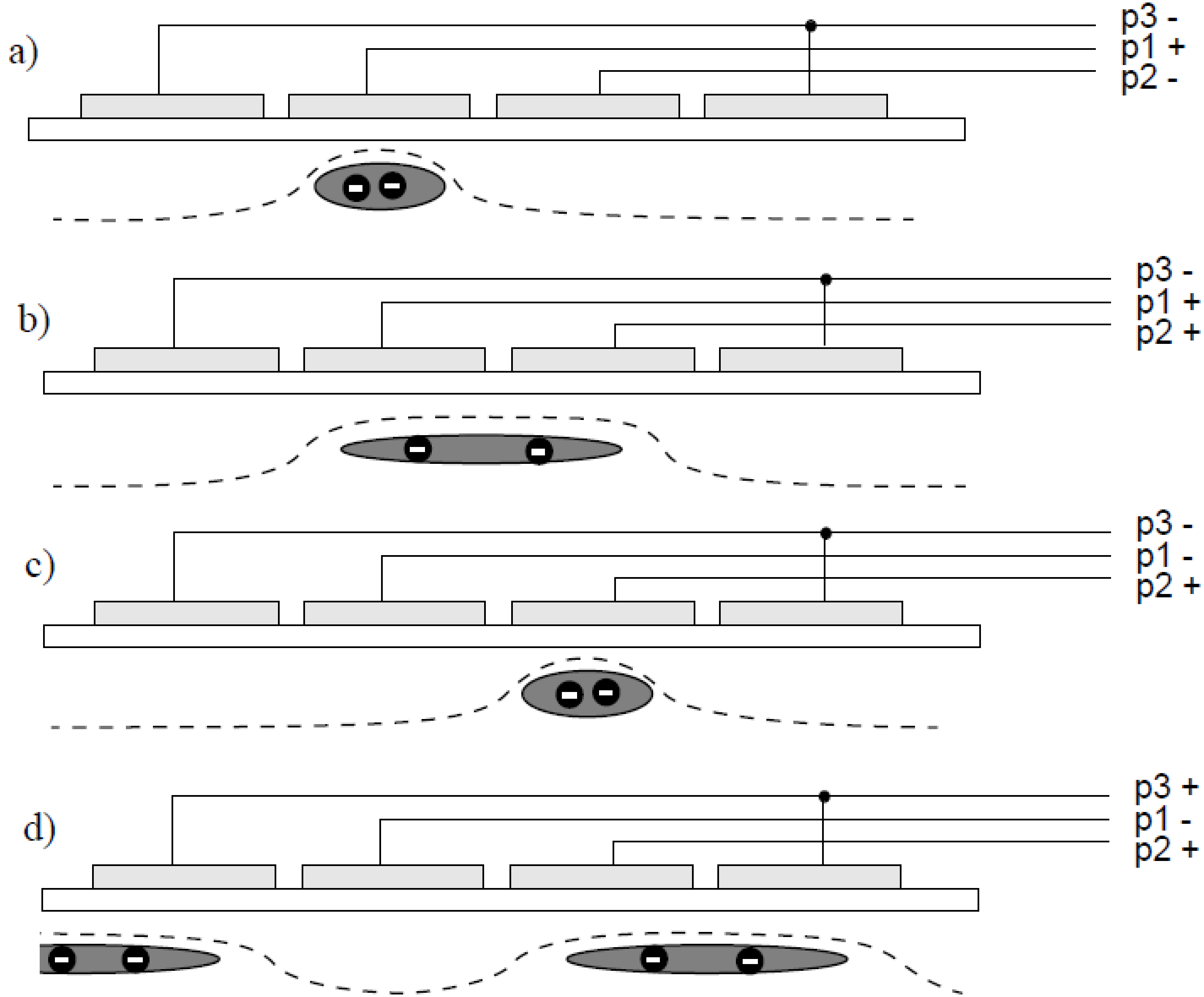
Cosmic rays

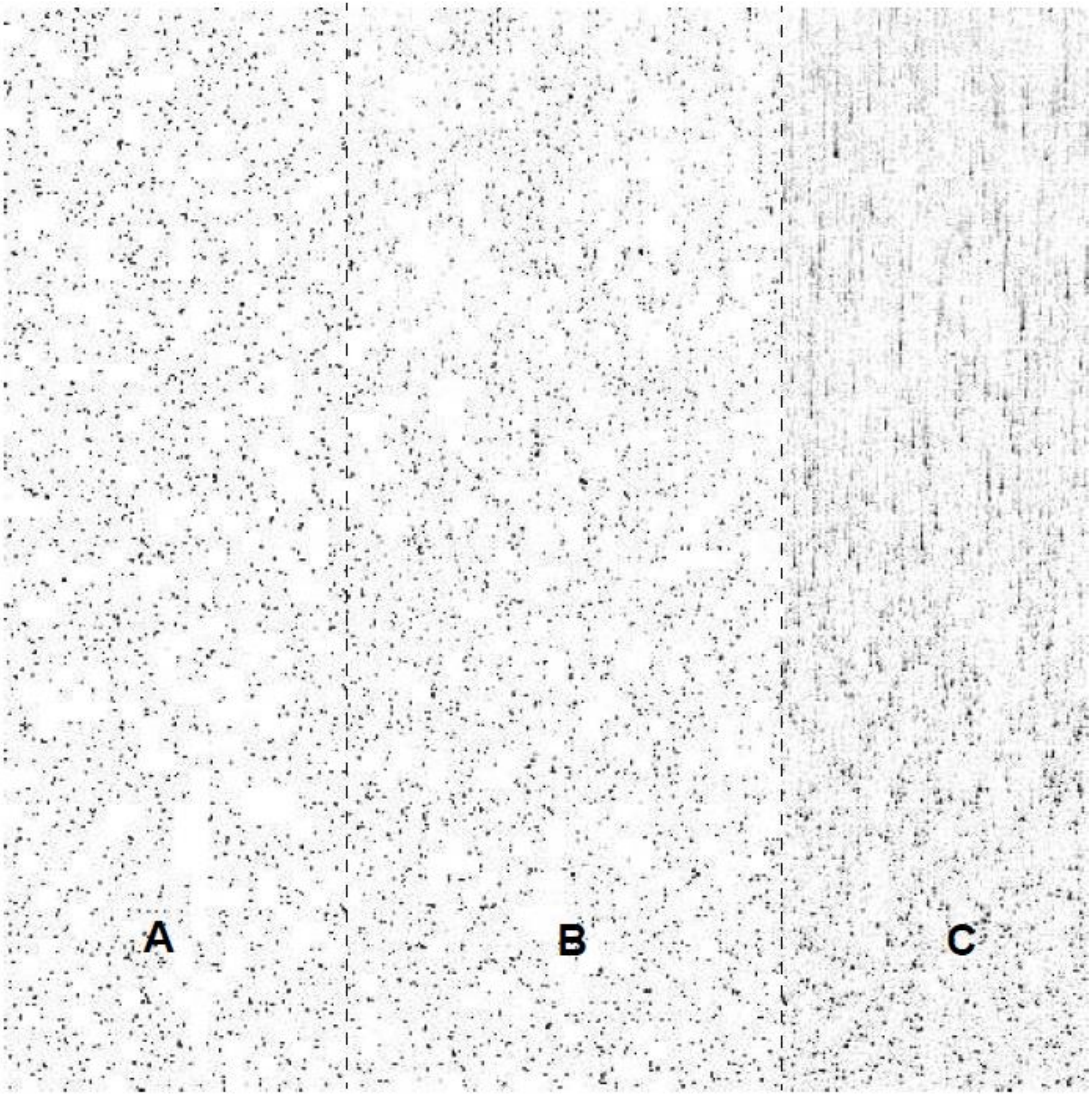


20 minute dark exposure with Hamamatsu fully-depleted CCD

Charge transfer

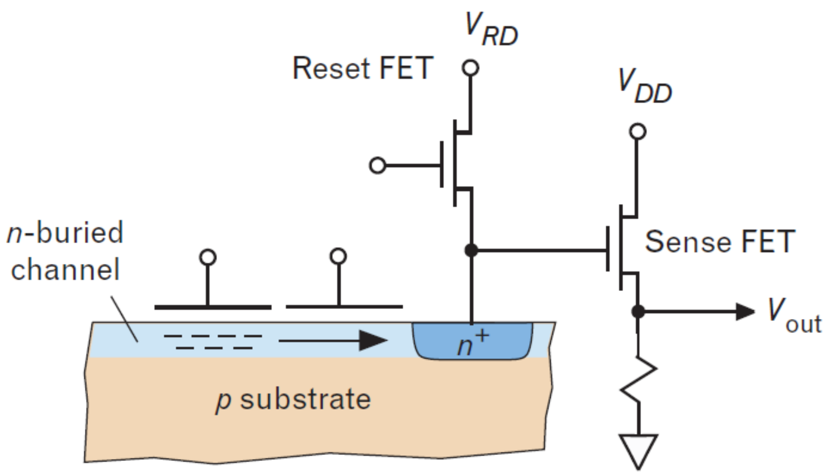



a)
p3 -
p1 +
p2 -
b)
p3 -
p1 +
p2 +
c)
p3 -
p1 -
p2 +
d)
p3 +
p1 -
p2 +



Radiation damaged CCD showing CTE problems

Charge measurement



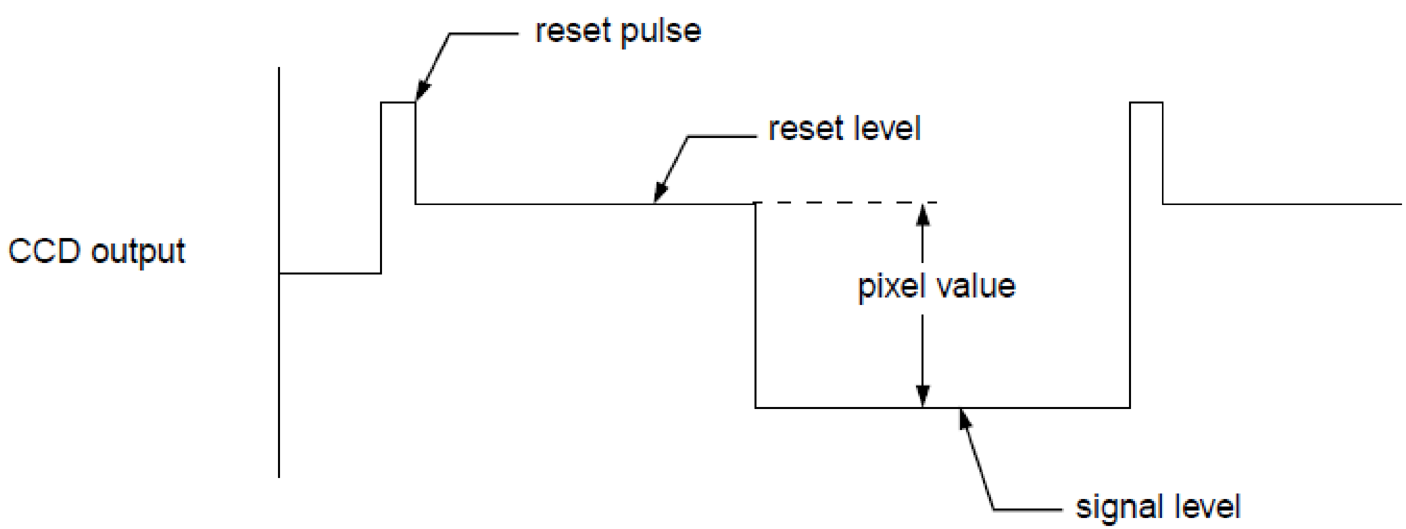
Burke et al, Lincoln Laboratory Journal, 2007

$V_{out} = A(q/C_s)$

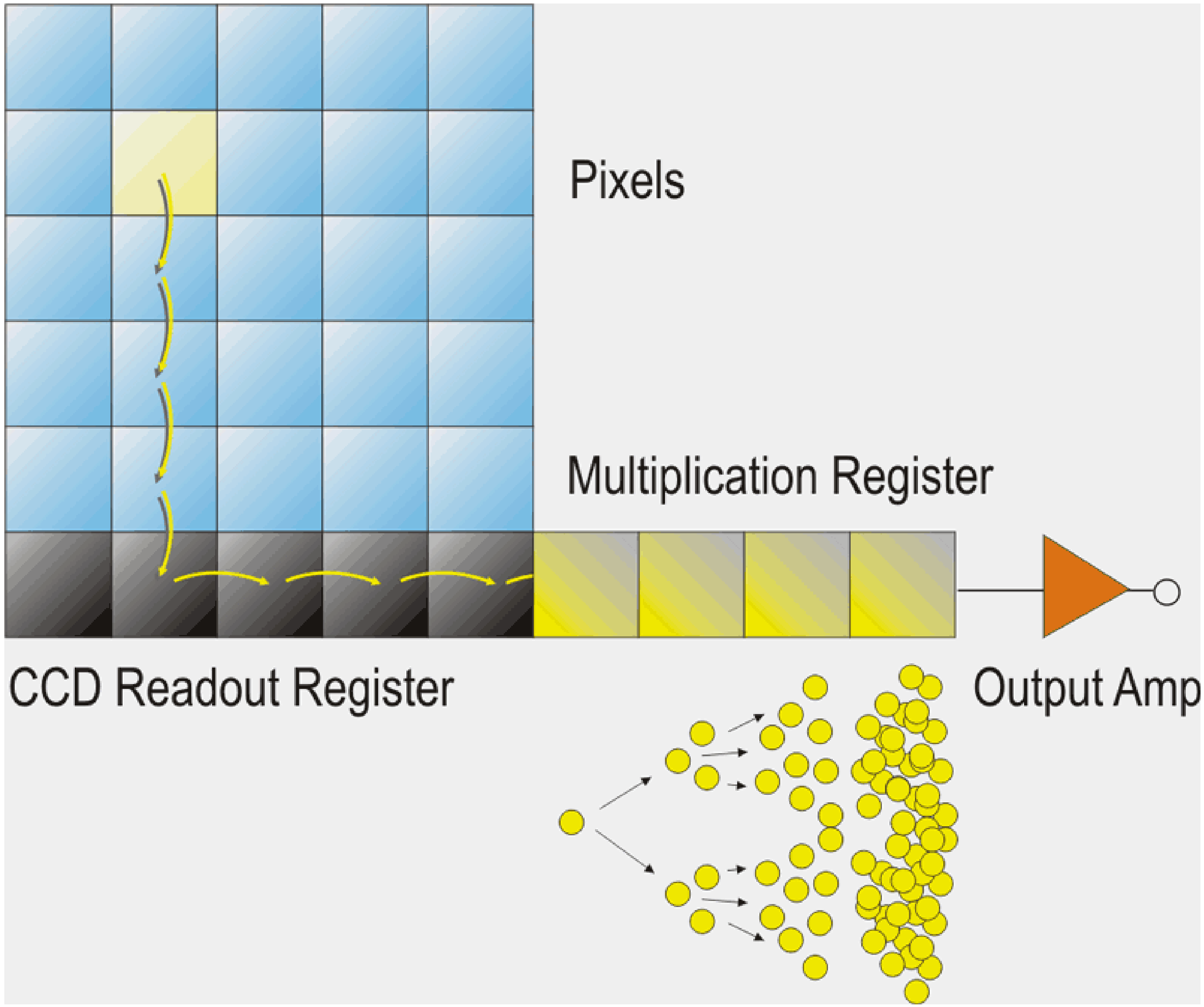
A = gain of transistor

q = charge

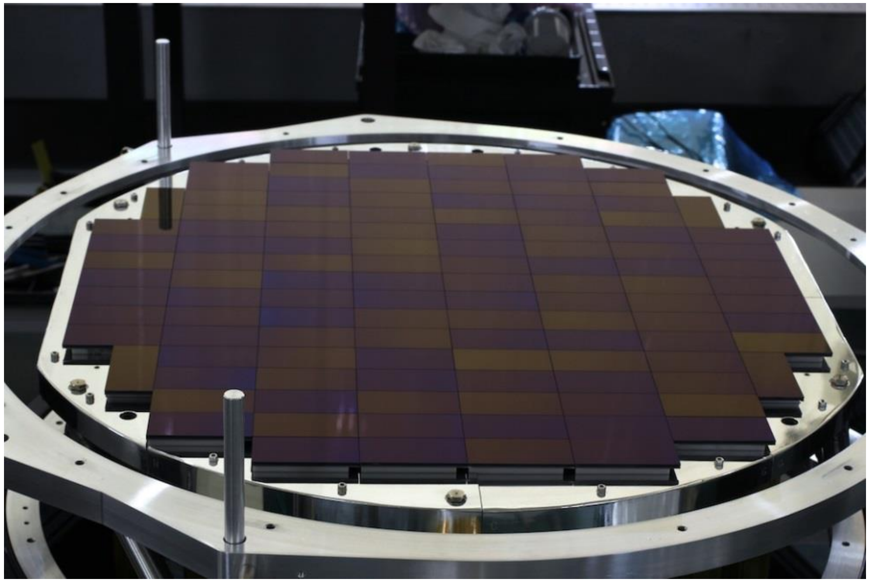
C_s = capacitance of sense node



Electron-multiplying (EMCCD)



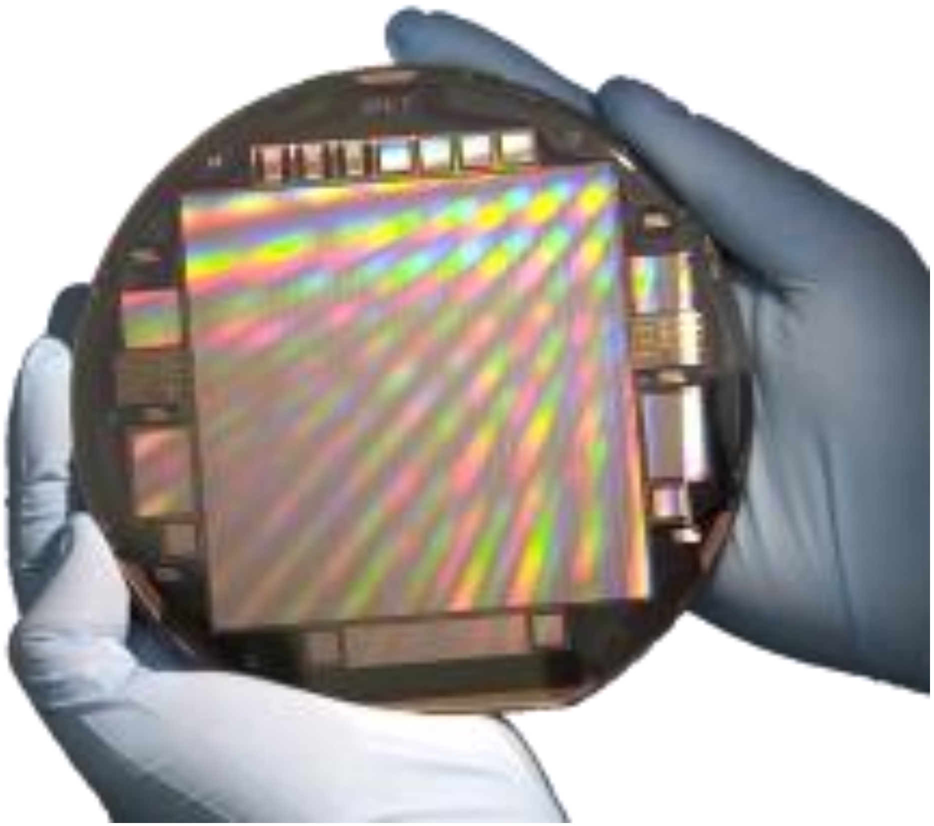
Large mosaics



HyperSuprimeCam
116 CCDs
60cm focal plane

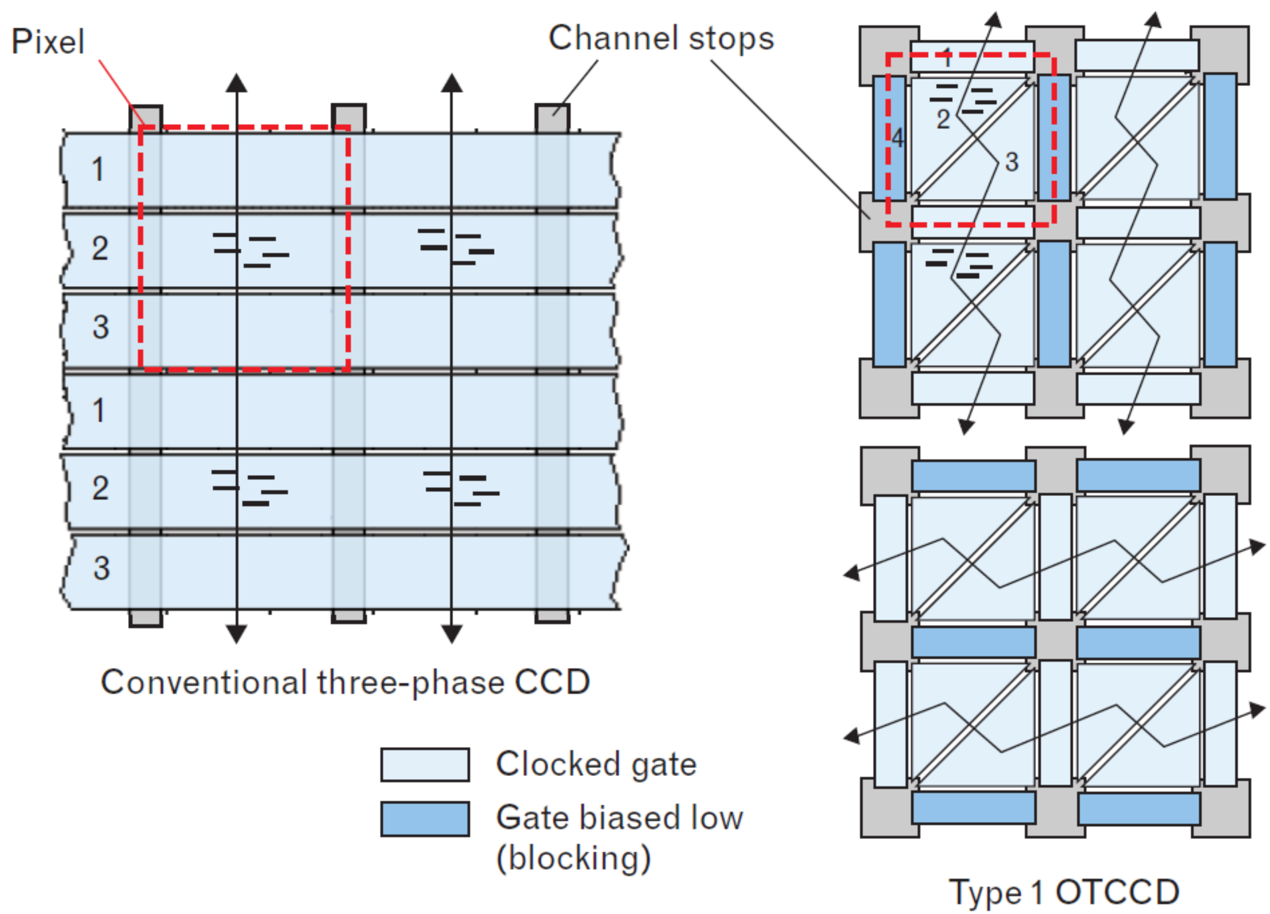
LSST
201 CCDs
64cm focal plane
3.2 GPixels

Large format CCDs



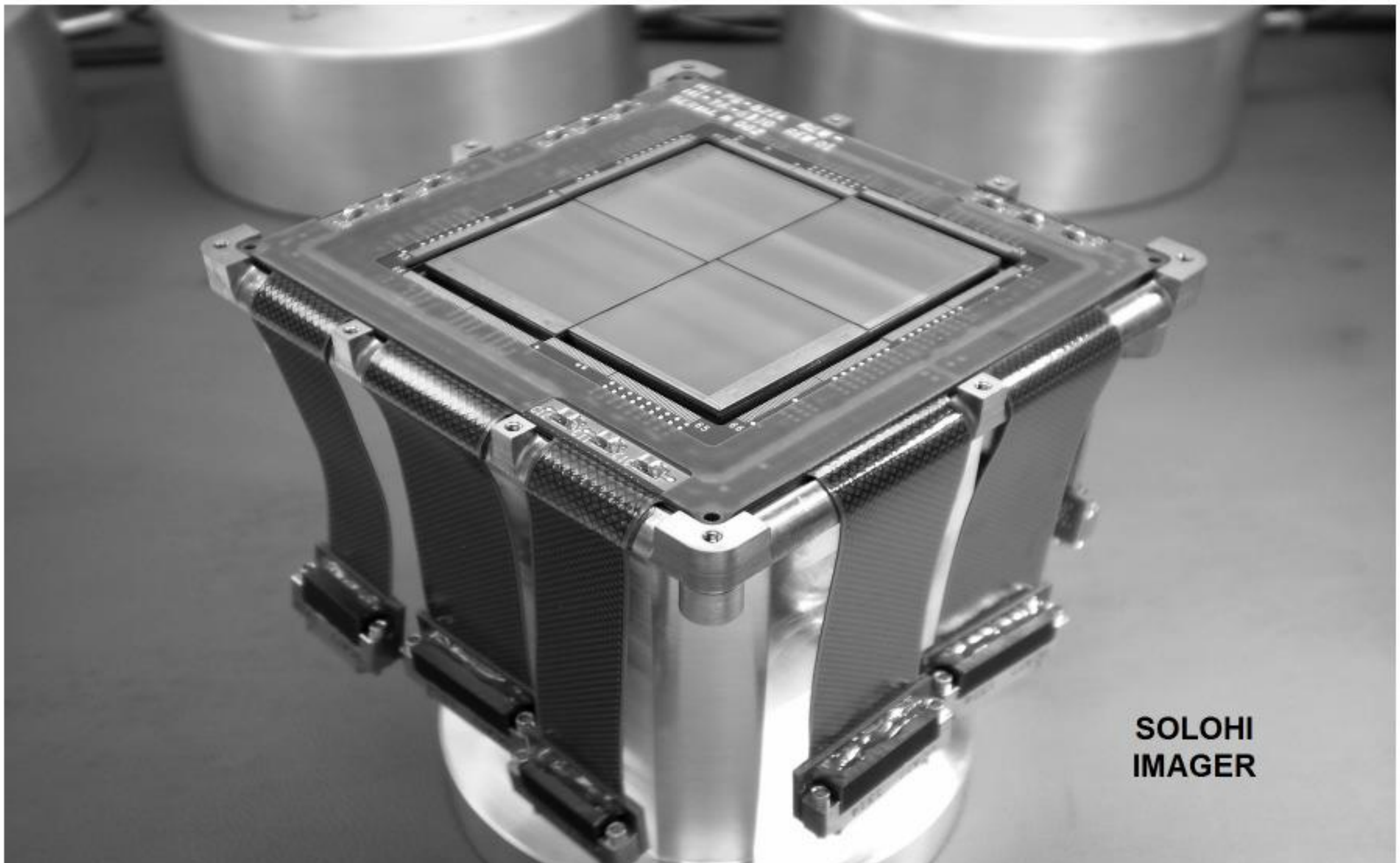
Semiconductor Technology Associates
10kx10k pixels
125mm wafer

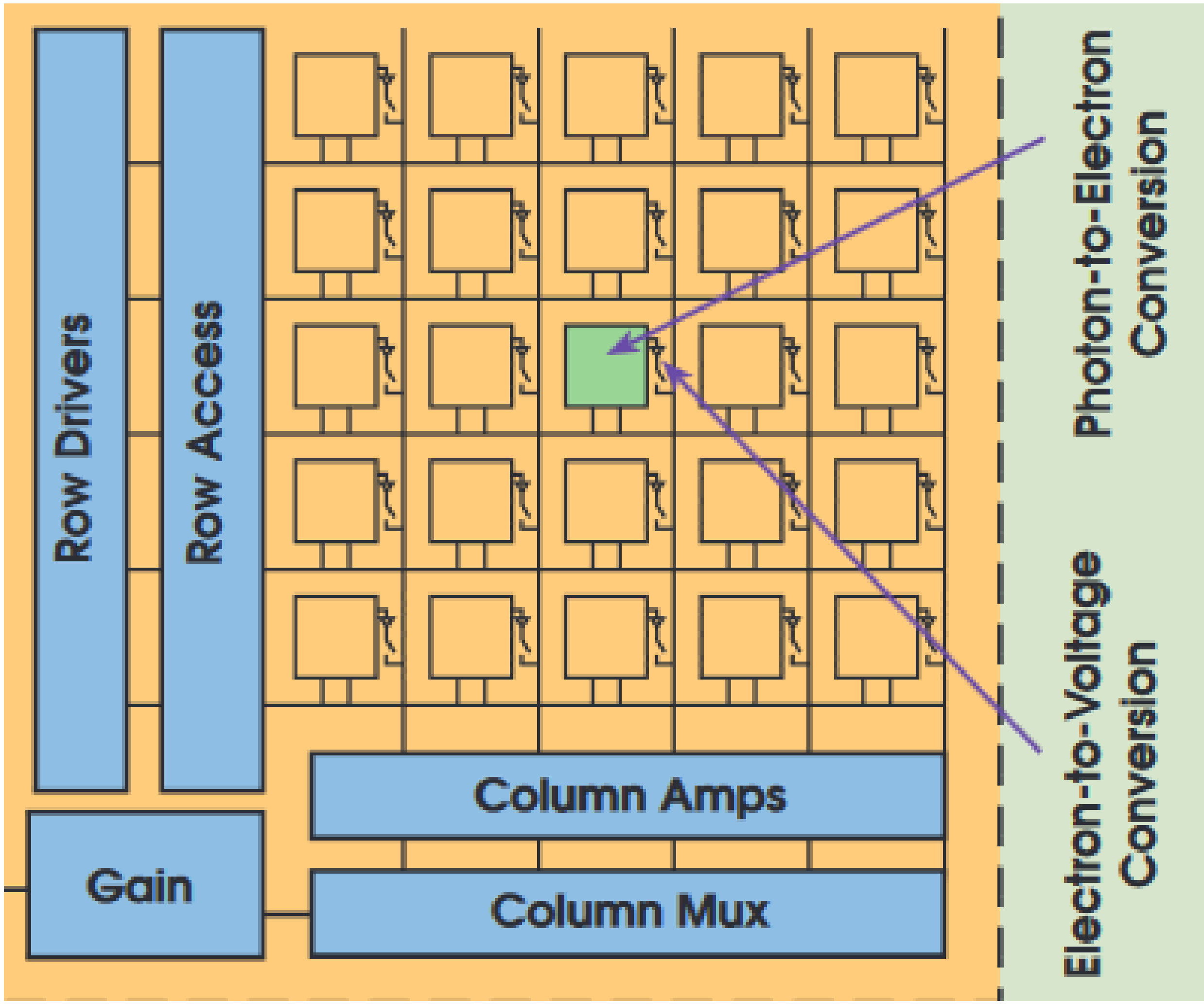
Orthogonal transfer CCD



Burke et al, Lincoln Laboratory Journal, 2007

CMOS imagers





Row Drivers
Row Access
Photon-to-Electron Conversion
Electron-to-Voltage Conversion
Column Amps
Gain
Column Mux

Anatomy of the Active Pixel Sensor Photodiode

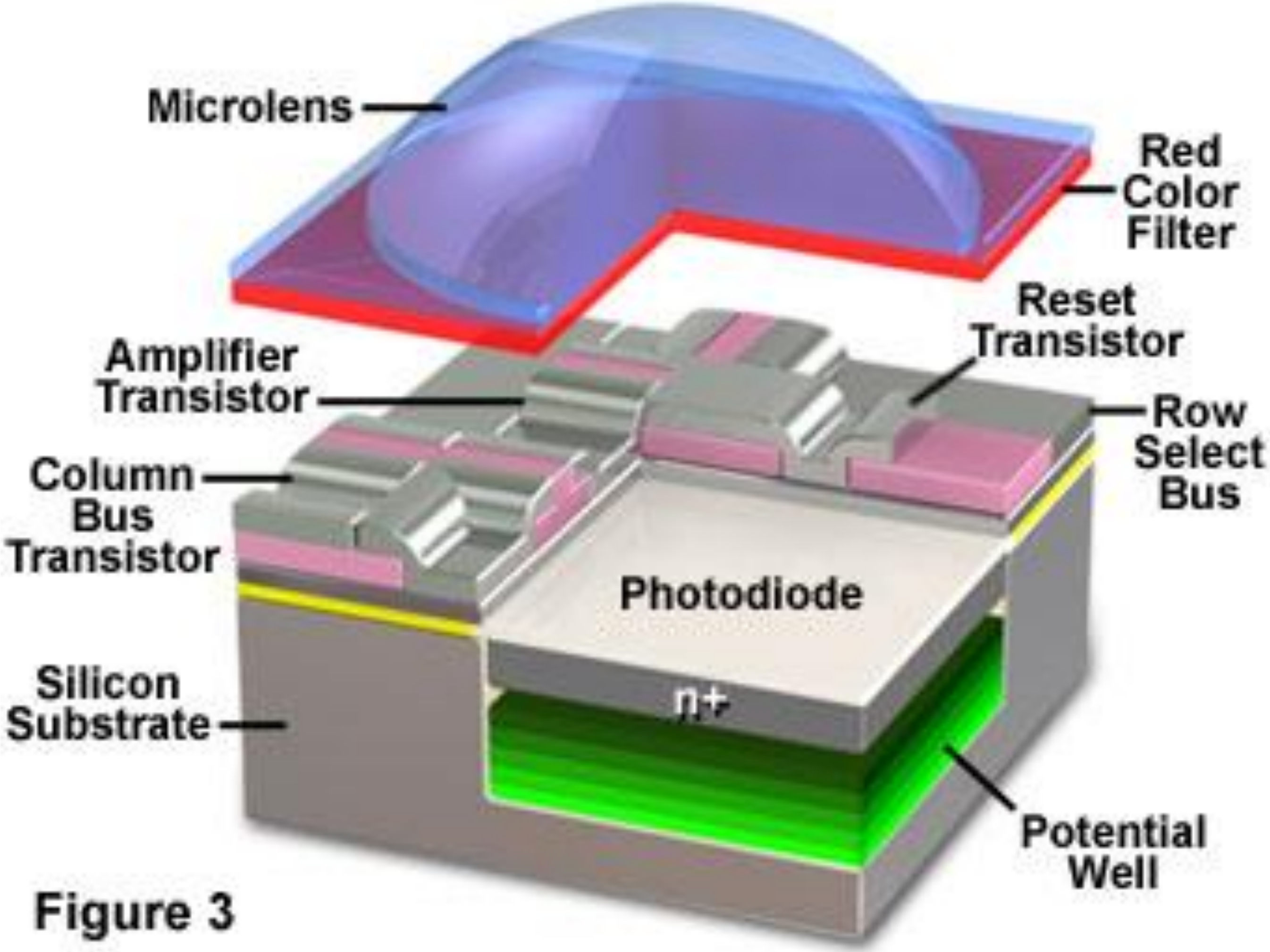
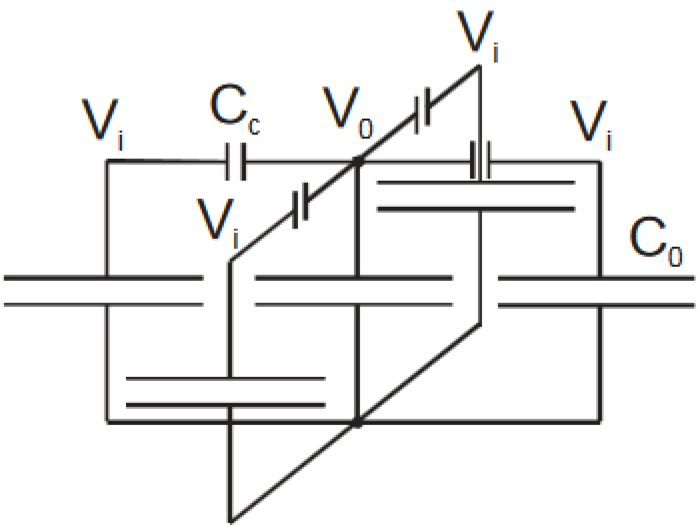
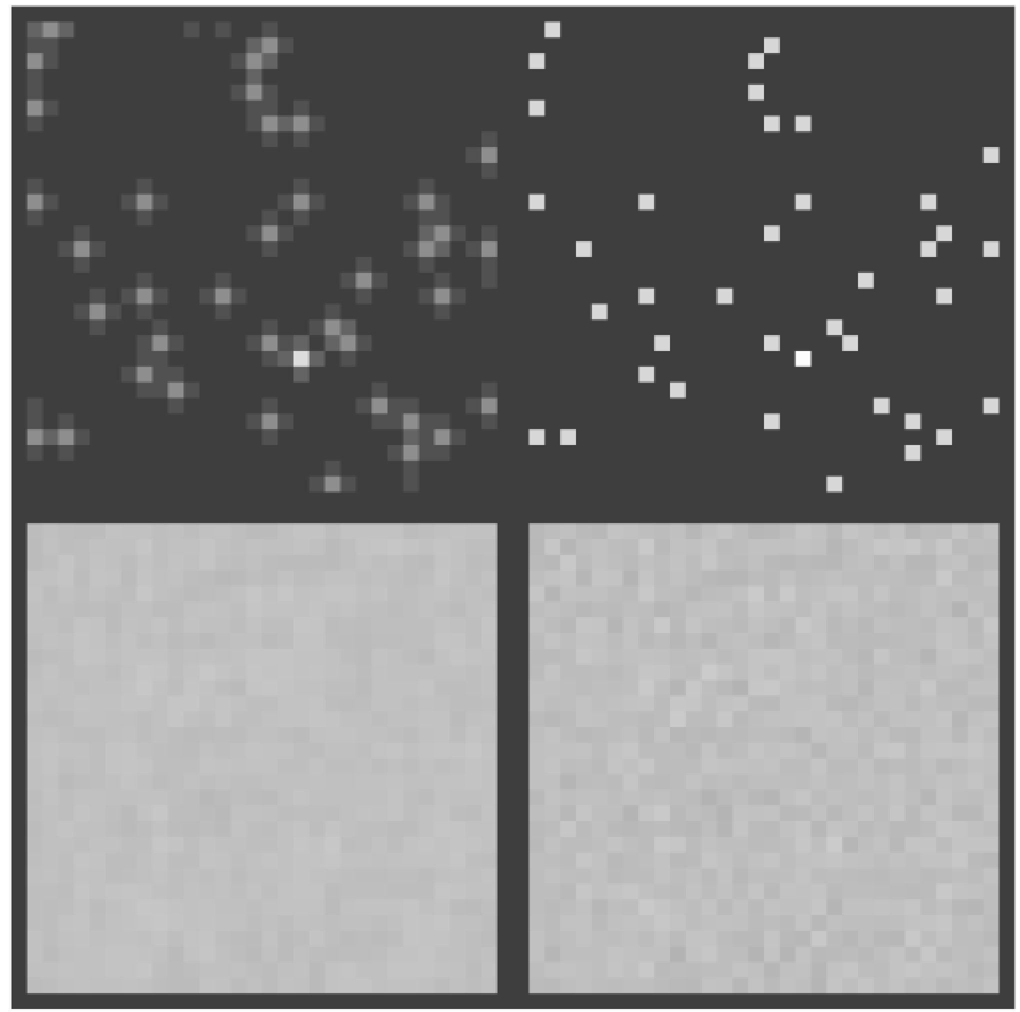


Figure 3

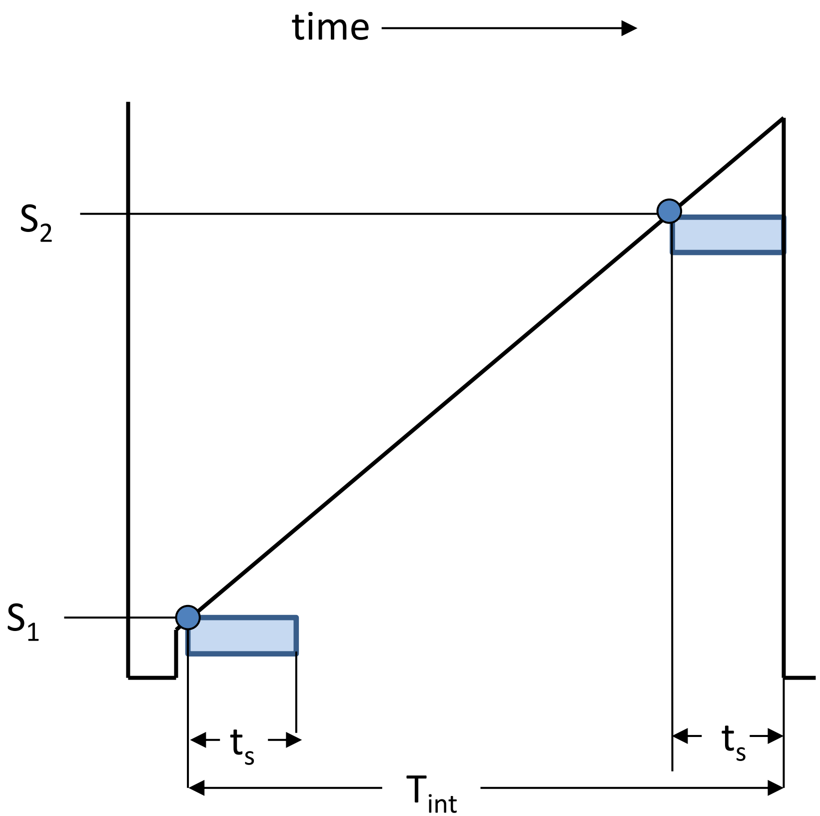
Inter-Pixel Capacitance (IPC)





Finger et al. 2005

Correlated double sampling



signal = S_2-S_1 = $(T_{int} - t_s) \cdot F$

F = flux (e/s)

T_{int}= total integration time

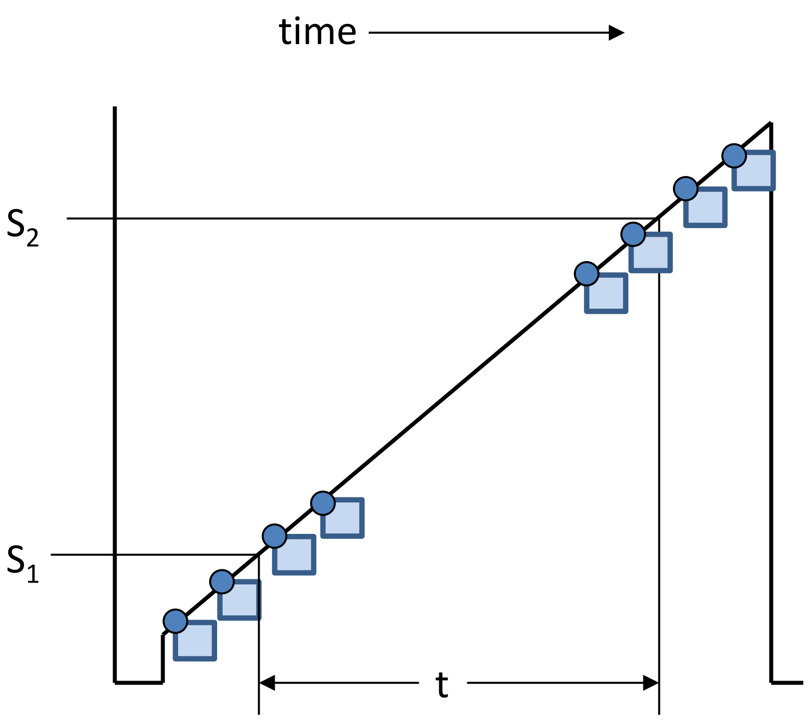
t_s= sample time

$$t_s = \frac{pixels}{outputs \times pixel\,rate}$$

noise = $\sqrt{2\sigma^2}$

σ = read noise (e)

Fowler sampling



signal = S_2-S_1 = $(T_{int} - nt_s) \cdot F$

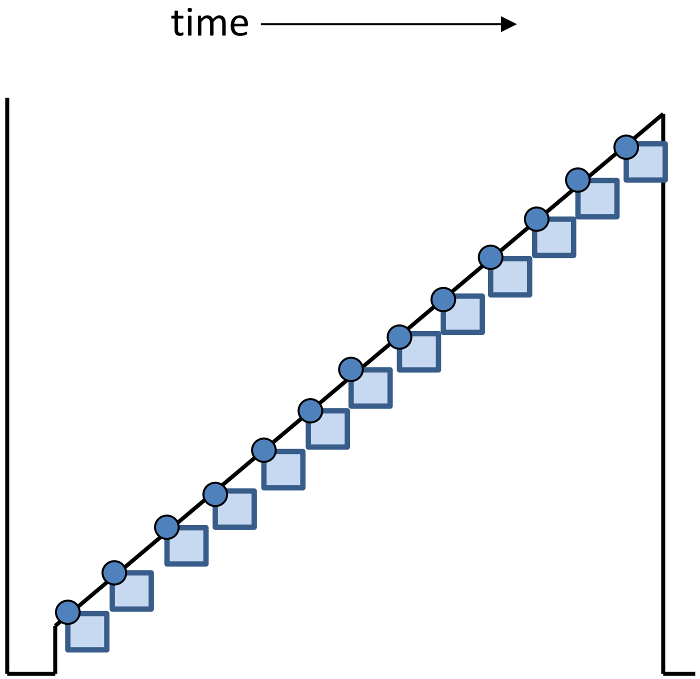
F = flux (e/s)

n = number of samples (4)

noise = $\sqrt{\frac{2\sigma^2}{n}}$

σ = read noise (e)

Up-The-Ramp sampling



signal = F

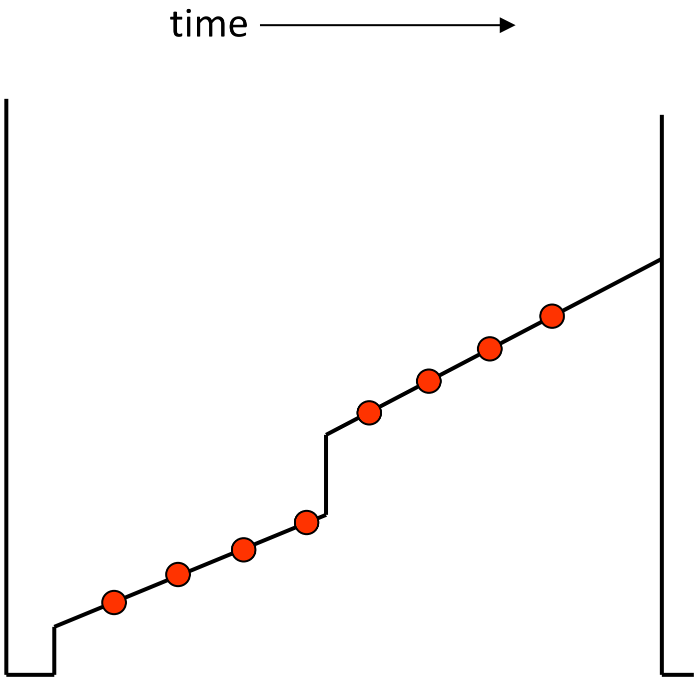
F = flux (e/s)

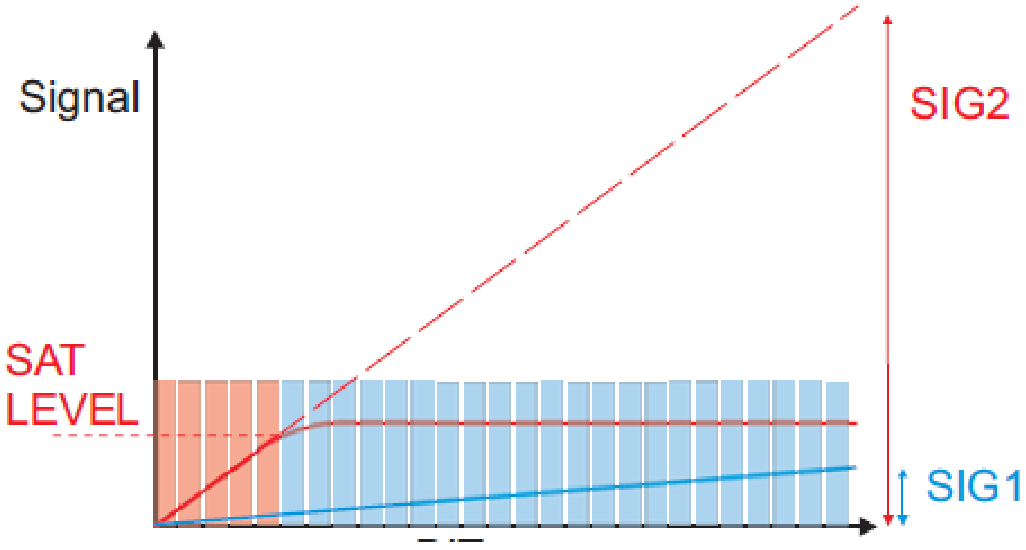
noise = $\sqrt{\frac{12N}{N^2-1} \cdot \frac{\sigma^2}{{T_{int}}^2}}$

σ = read noise (e)

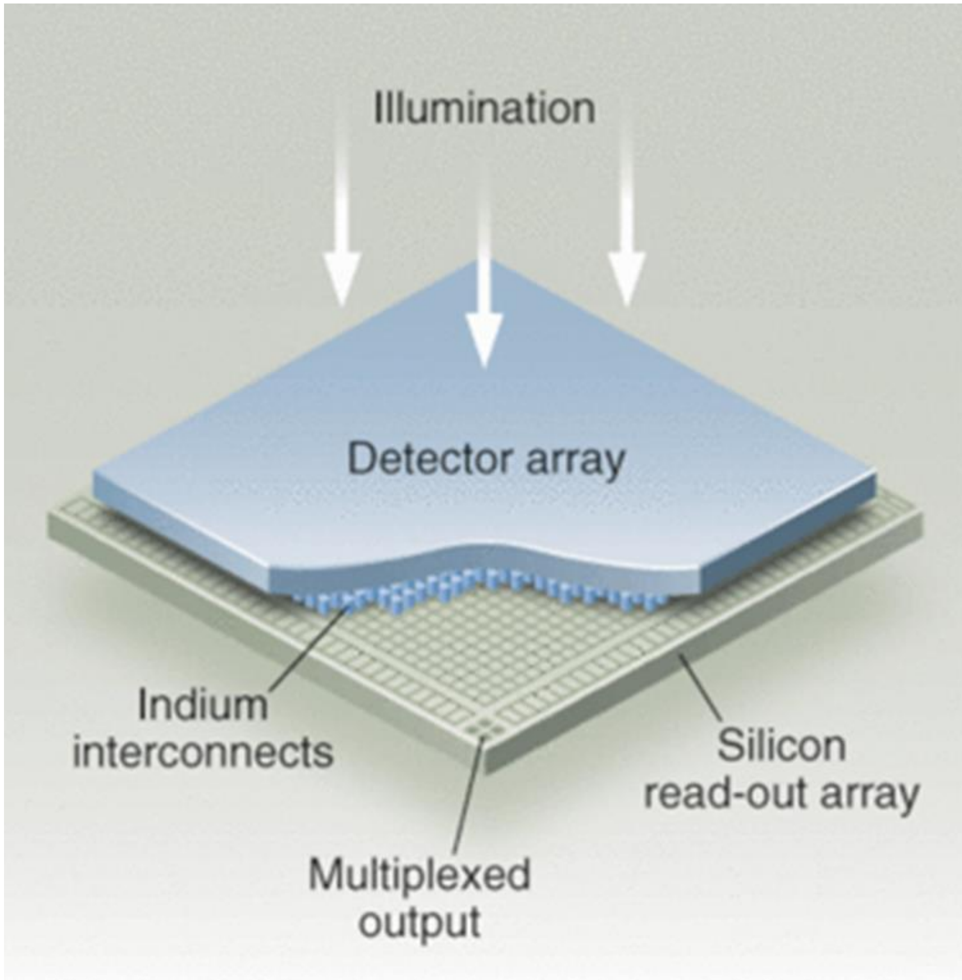
N = number of samples (13)

Cosmic rays/saturation

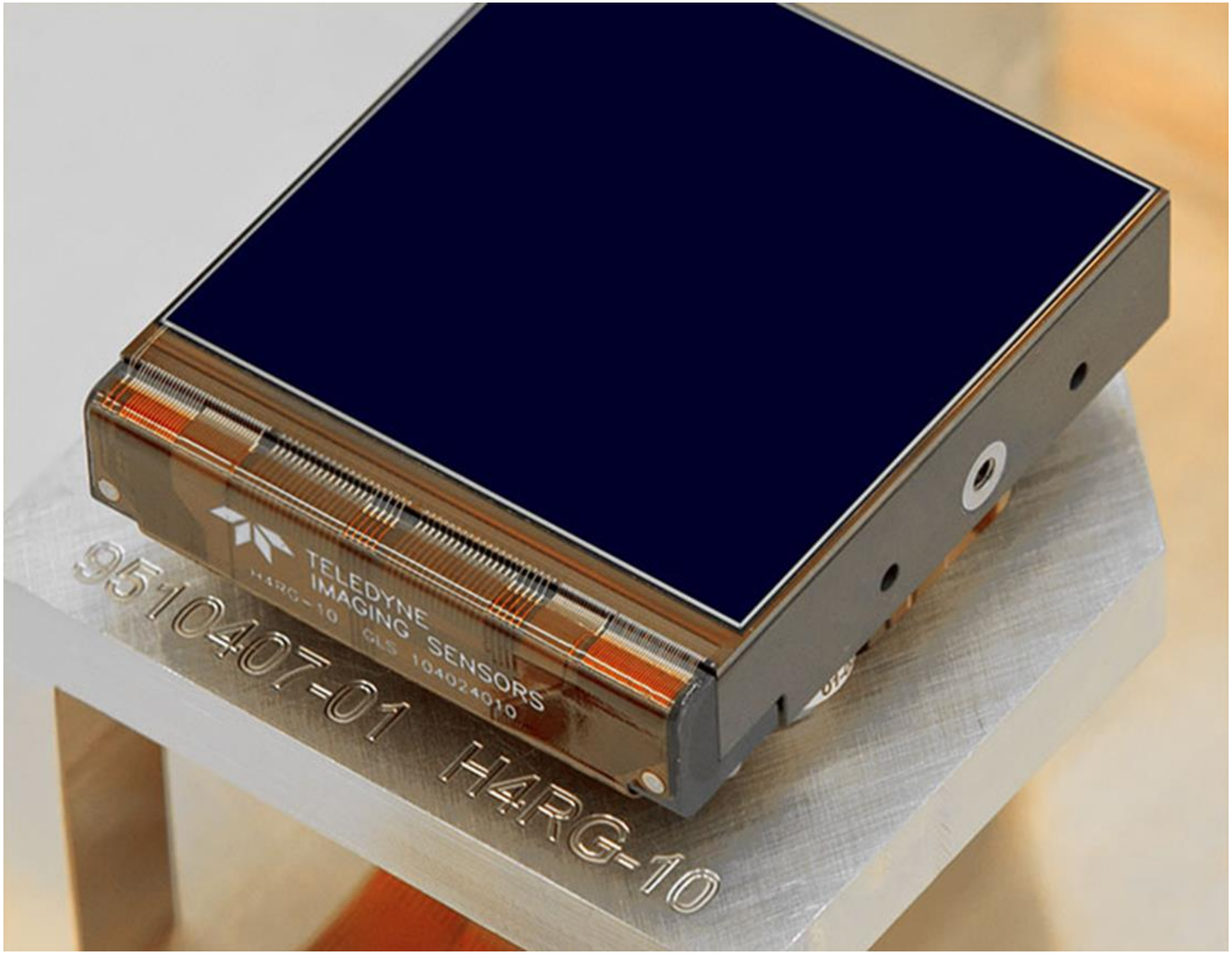


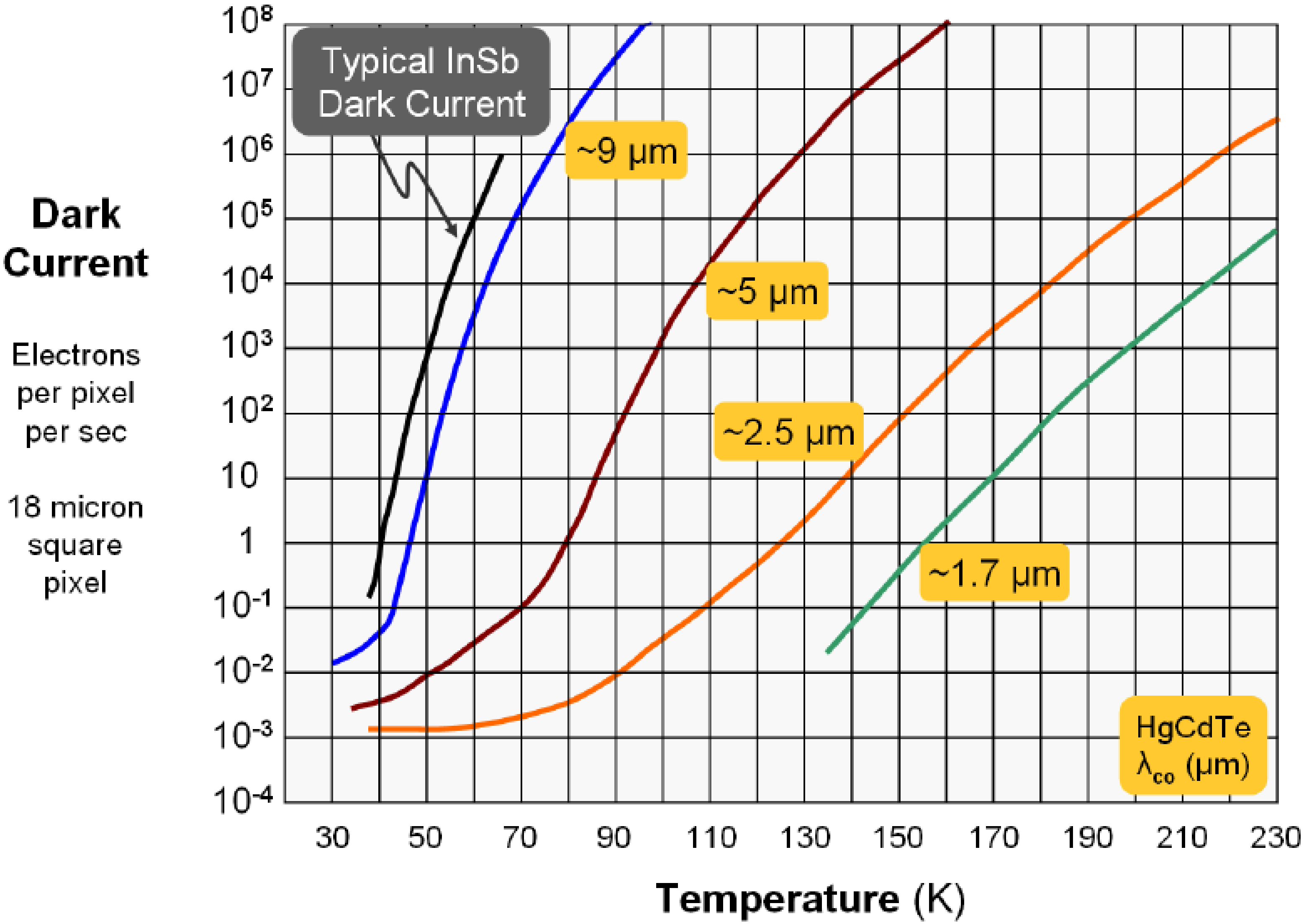


Hybrid CMOS

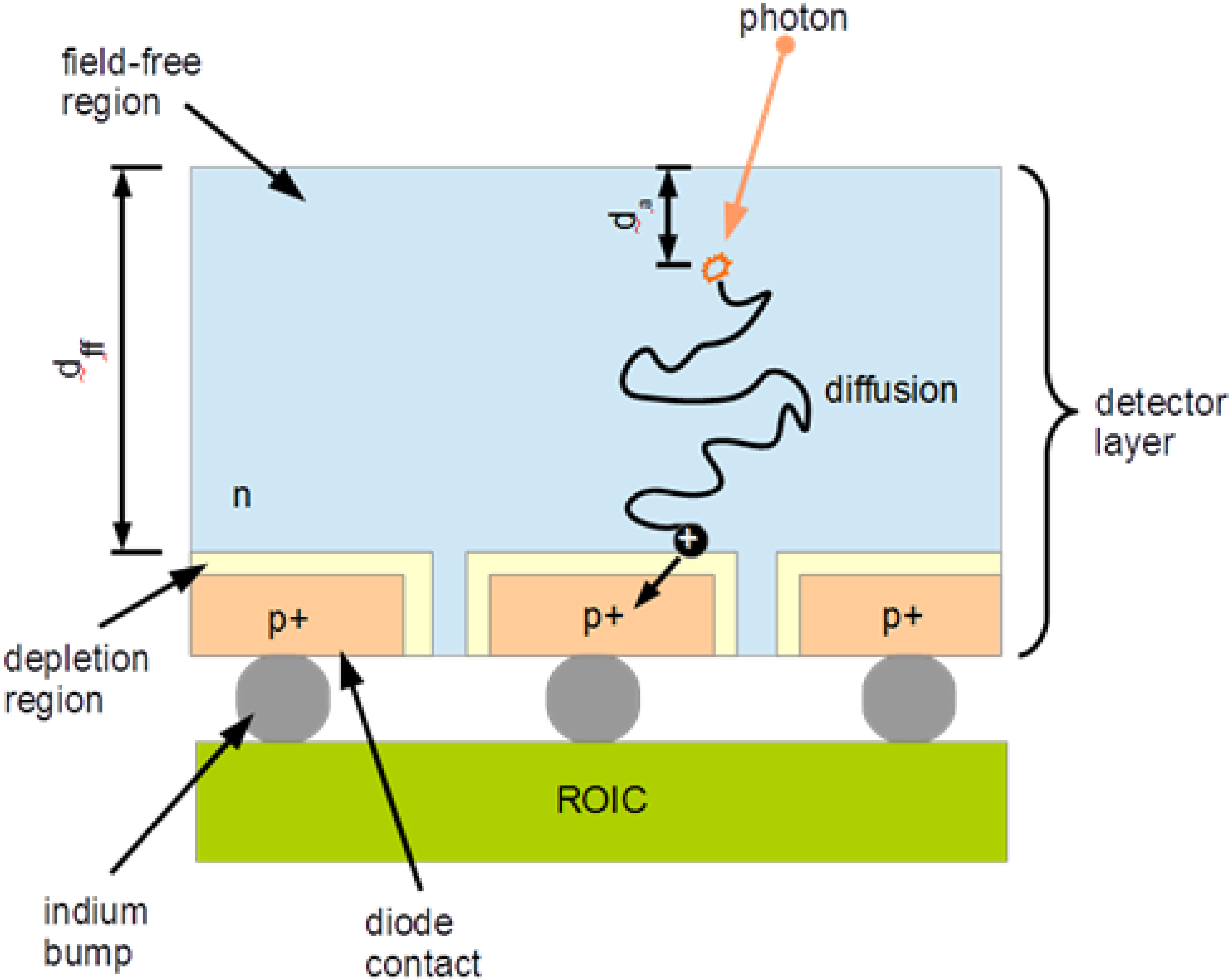


ReadOut Integrated Circuit (ROIC)
Multiplexer (mux)

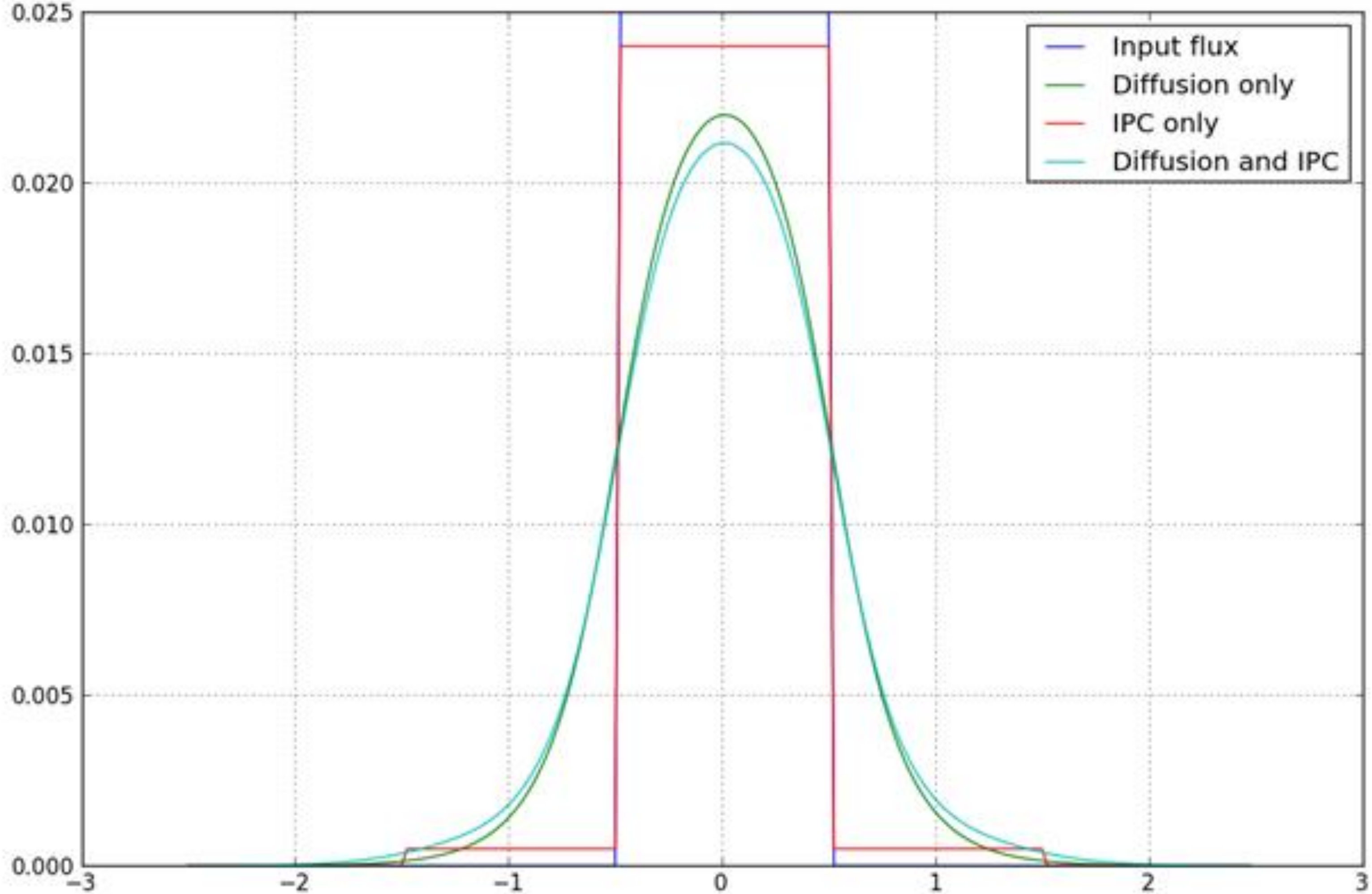

TELEDYNE
IMAGING SENSORS
H4RG-10 CLS 104024010
9510407-01 H4RG-10


Dark Current
Electrons per pixel per sec
18 micron square pixel
Typical InSb Dark Current
~9 µm
~5 µm
~2.5 µm
~1.7 µm
HgCdTe λco (µm)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
30
50
70
90
110
130
150
170
190
210
230
Temperature (K)

Diffusion

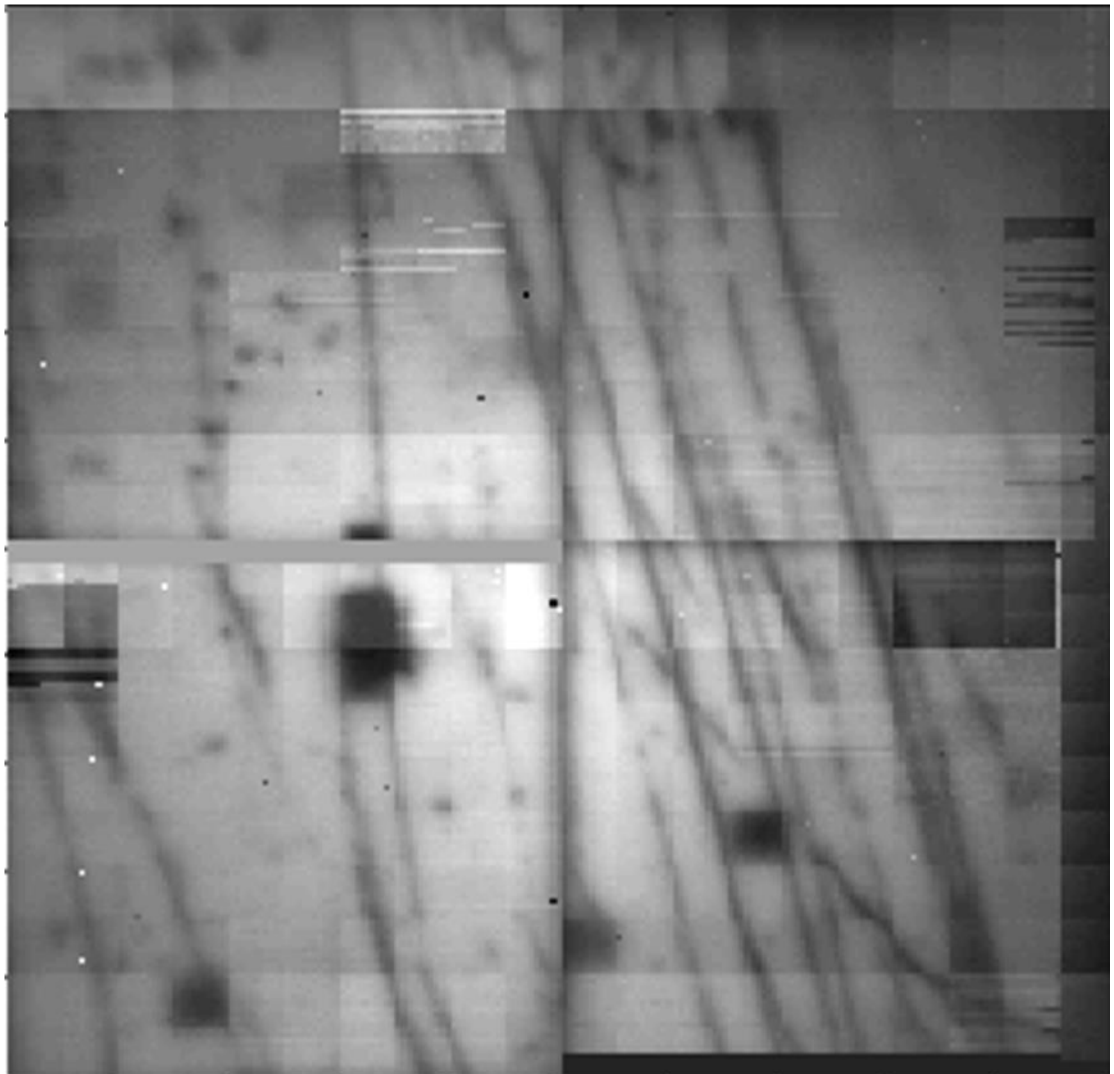


photon
field-free
region
d_a
d_{ff}
diffusion
detector
layer
n
p+
p+
p+
depletion
region
ROIC
indium
bump
diode
contact



Input flux
Diffusion only
IPC only
Diffusion and IPC
0.025
0.020
0.015
0.010
0.005
0.000
−3
−2
−1
0
1
2
3

Sub-pixel scale defects



SAPHIRA IR APD