Topic 2: Detectors

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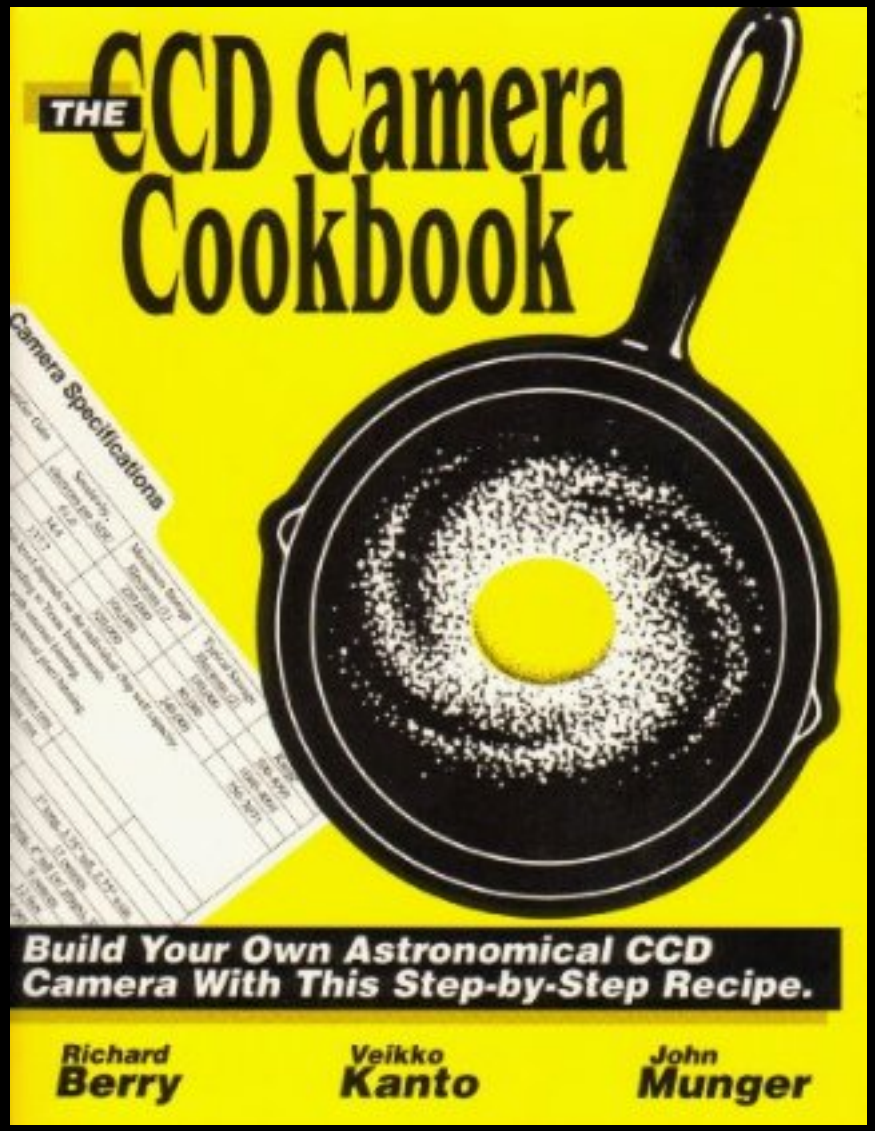


Do-it-yourself CCD camera; 1990's

Other 1990's cameras

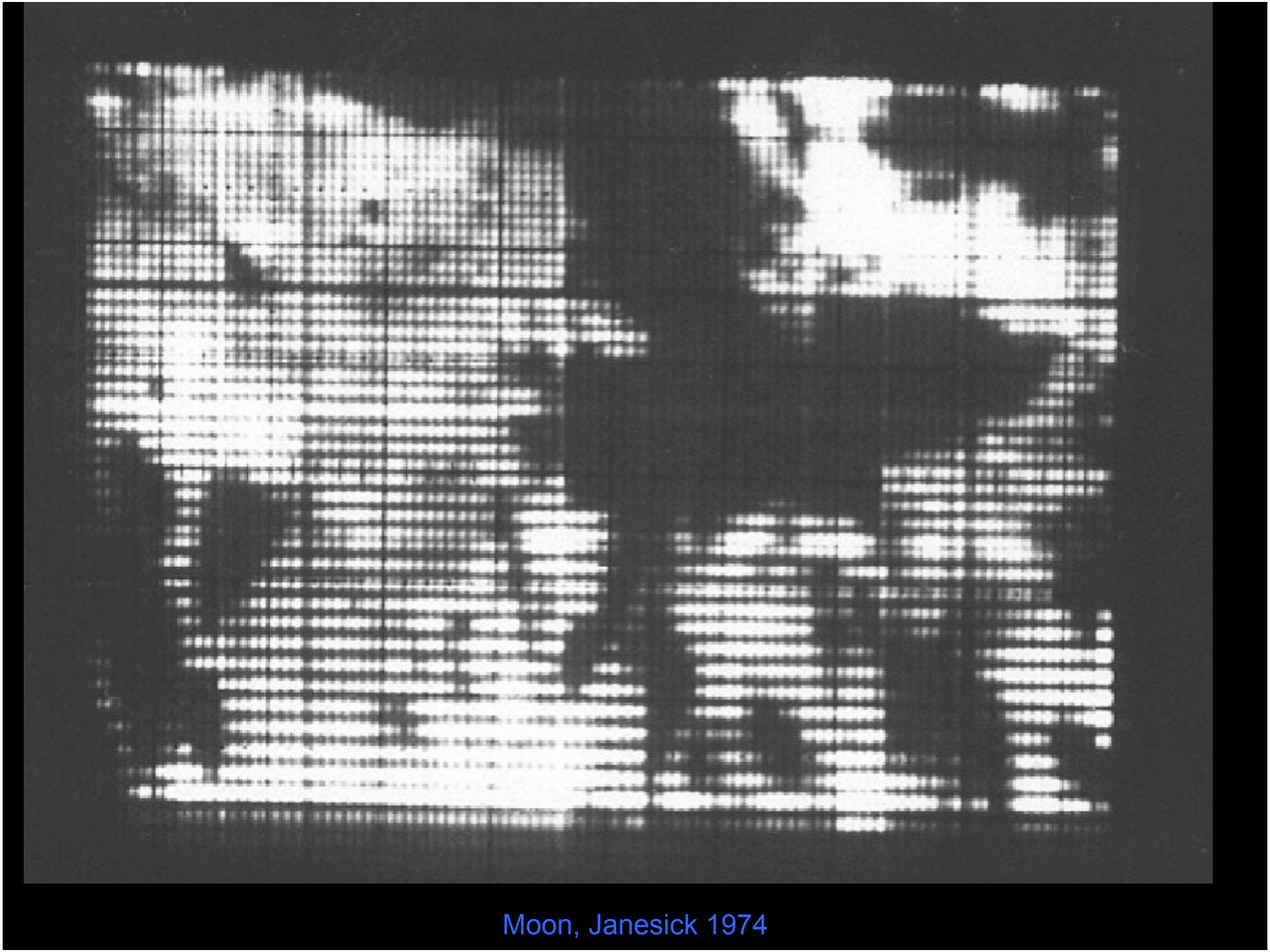
- Spectrasource Lynxx, HPC-1
- SBIG ST-4, ST-6
- Meade Pictor

Sensor types

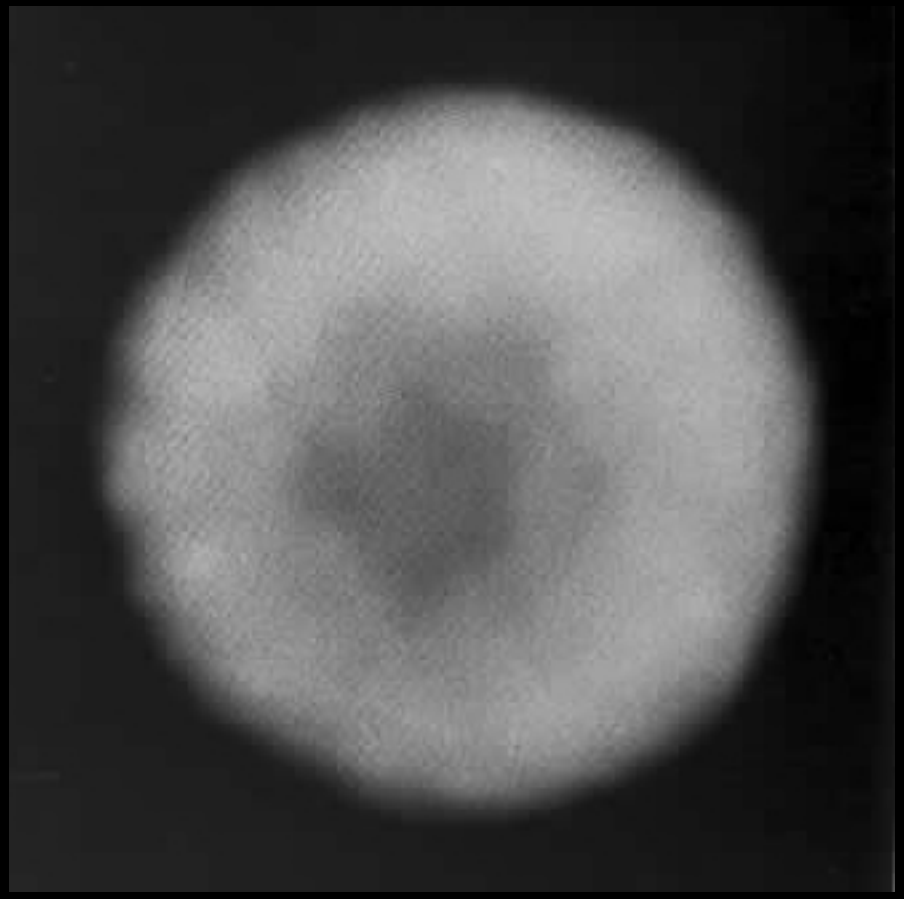
- Charge-Coupled Device (CCD)
  - Full-frame
  - Interline transfer
  - Electron-multiplying
- CMOS
- Hybrid

CCD Sensors

- Invented 1969 Smith&Boyle, Bell Telephone Laboratories
- First used by Jim Janesick 1974 (8” telescope, 100x100 array)
- First professional published image by Brad Smith (Uranus, 1976)
- TI 800x800 for HST proposed in 1976



Moon, Janesick 1974



Uranus (1976, B. Smith; pole-on)

Sensor vendors

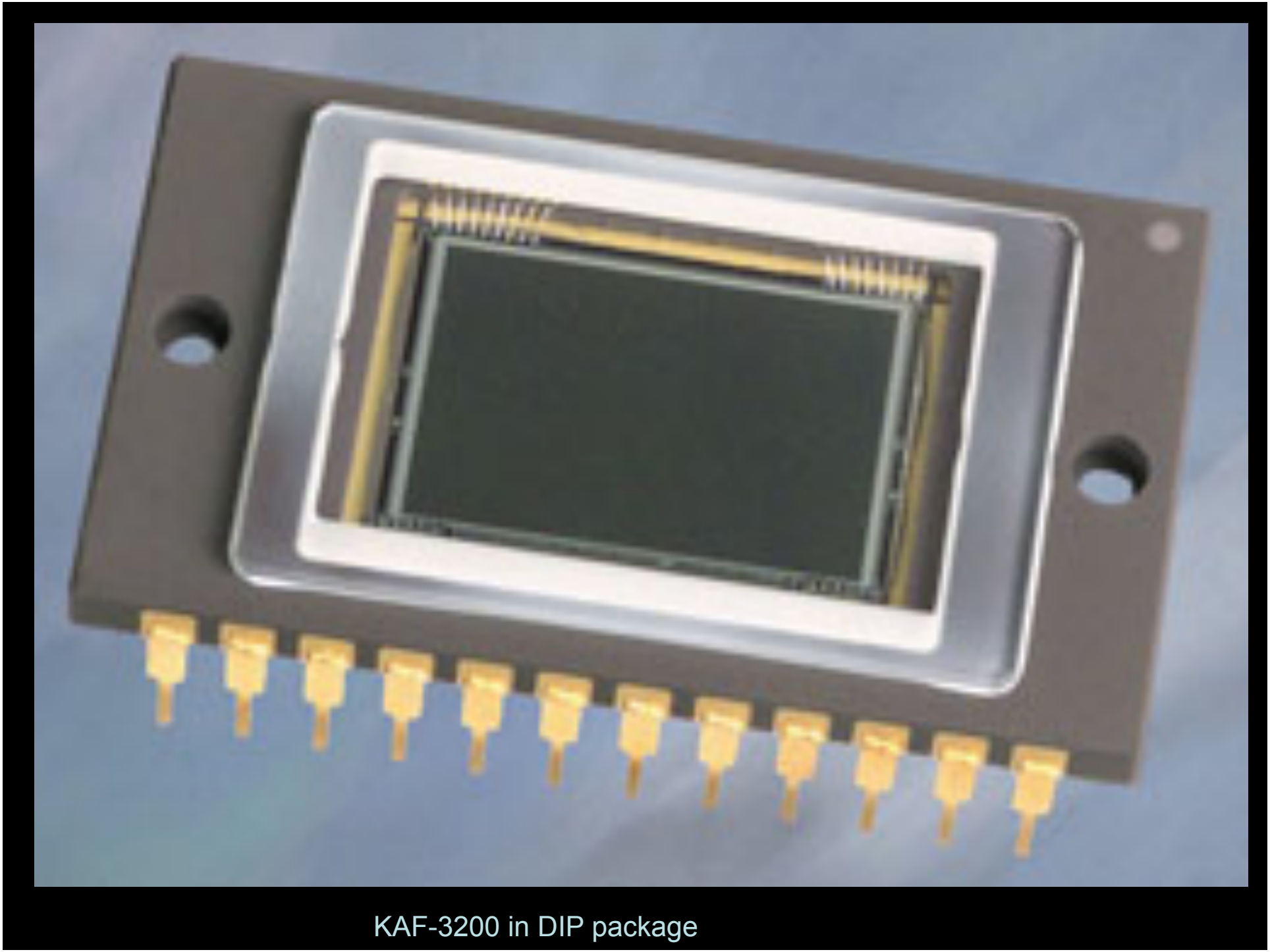
- Texas Instruments
- Kodak
- Sony (Hole Accumulation Device)
- E2V
- STA
- Fairchild/Loral
- Foveon

Kodak

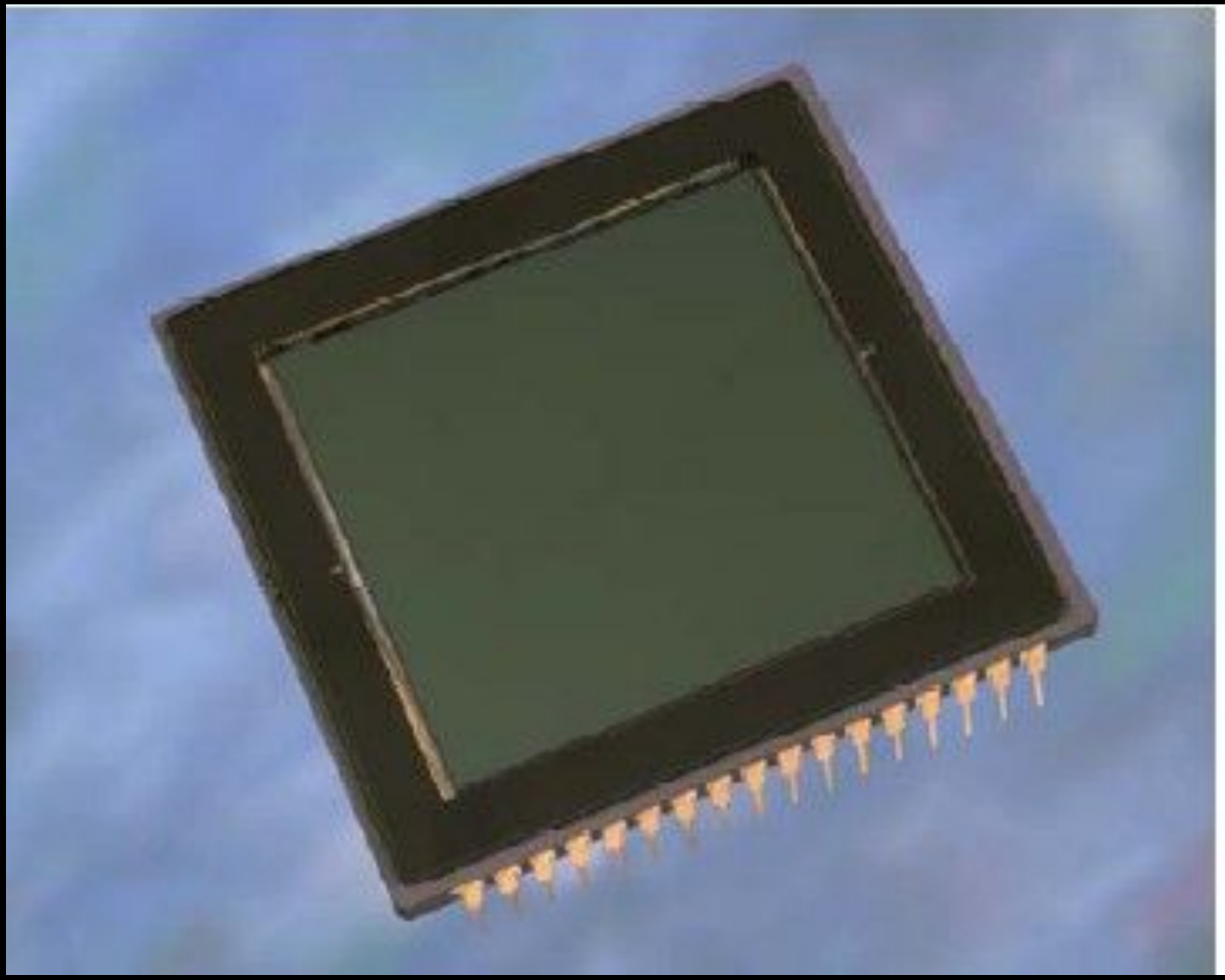
- Now Truesense Imaging
  - http://www.truesenseimaging.com
- Naming convention
  - KA + F(ullframe)/I(nterline) + Mpix + version
- KAF-0400 (0.4Mpix, 00 version)
- KAF-16803 (16.8Mpix, 03 version)
- KAI-29050 (Interline, 29.0Mpix, 50ver)

Sensor grading/classes

- Point defect
  - Dark pixel > 6% weak
  - Bright (hot) pixel ~4000e-/pix/sec
- Cluster defect. Grouping of not more than 5 adjacent point defects
- Column defect. >5 contiguous point defects or a hot pixel along a column
- Defects are usually outside of central zone
- Most commercial sensors grade 0(best)-2(worst)
- Engineering grade sensors sometimes available



KAF-3200 in DIP package

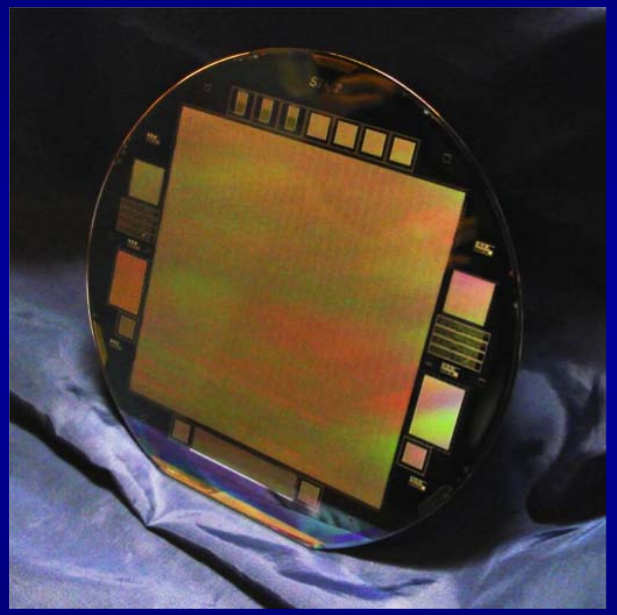


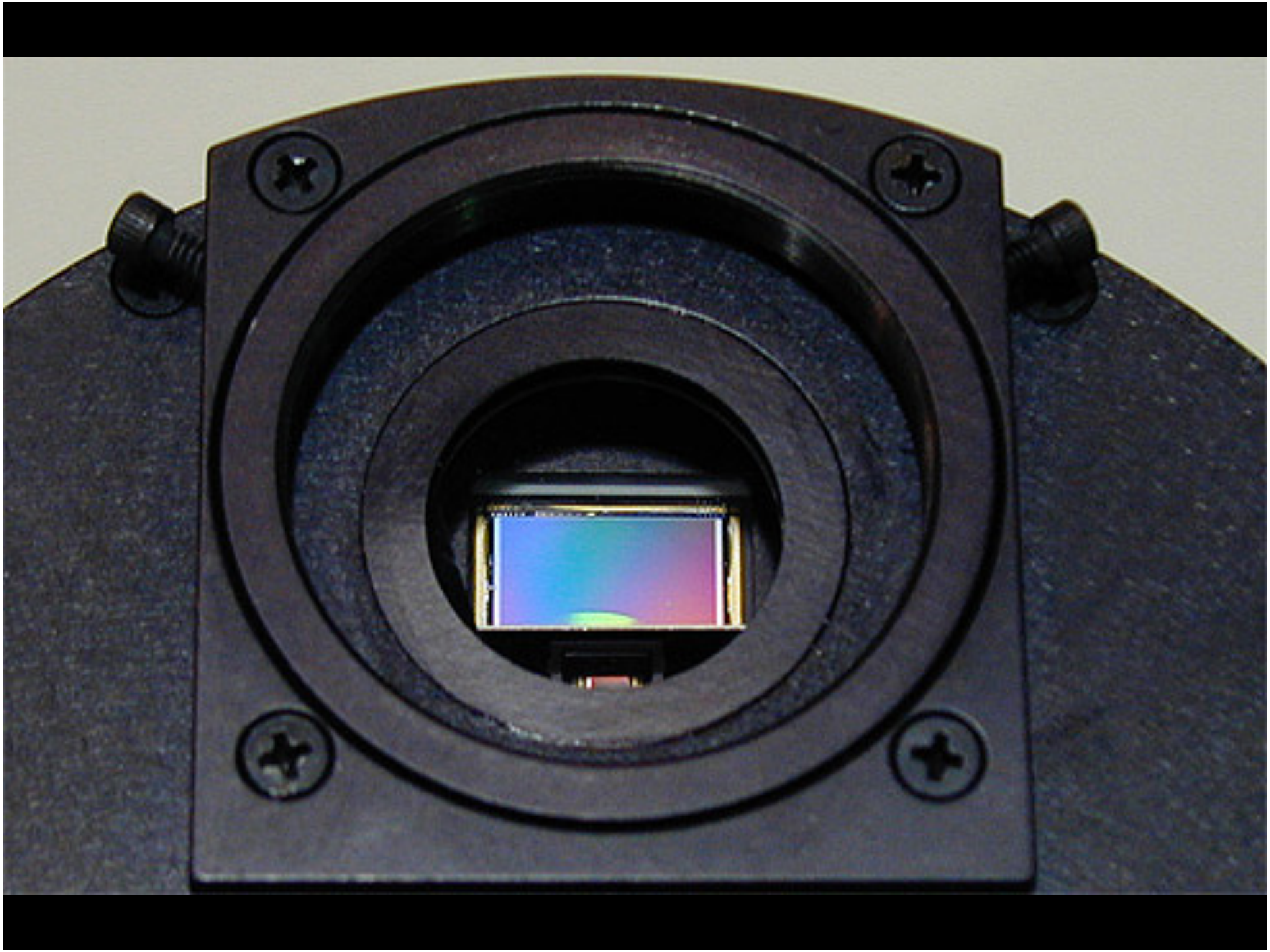
KAF-16803


KAF-50100

STA1600B 111Mega pixel imager

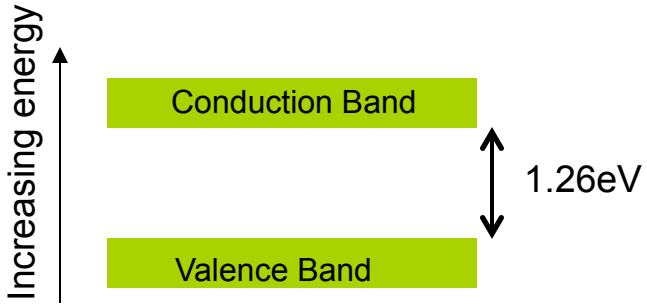
- Full 6” wafer imager
- 10560 x 10560 pixels
- 9 micron pixel
- 111,513,600 pixels per frame
- 16 dual stage high speed outputs
- Backside thinned available
- Acquisition speeds up to 1 frame/sec
- Designed for US Naval Observatory

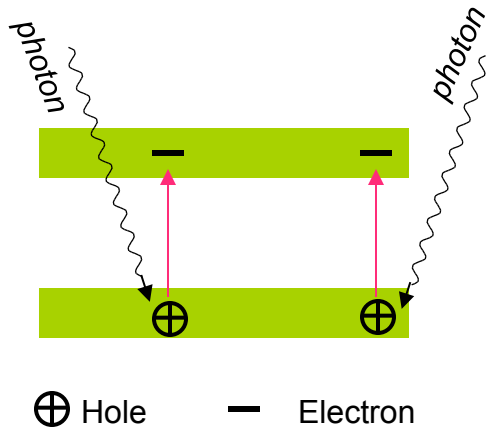




Photoelectric Effect.

The effect is fundamental to the operation of a CCD. Atoms in a silicon crystal have electrons arranged in discrete energy bands. The lower energy band is called the Valence Band, the upper band is the Conduction Band. Most of the electrons occupy the Valence band but can be excited into the conduction band by heating or by the absorption of a photon. The energy required for this transition is 1.26 electron volts. Once in this conduction band the electron is free to move about in the lattice of the silicon crystal. It leaves behind a 'hole' in the valence band which acts like a positively charged carrier. In the absence of an external electric field the hole and electron will quickly re-combine and be lost. In a CCD an electric field is introduced to sweep these charge carriers apart and prevent recombination.





Thermally generated electrons are indistinguishable from photo-generated electrons . They constitute a noise source known as 'Dark Current' and it is important that CCDs are kept cold to reduce their number.

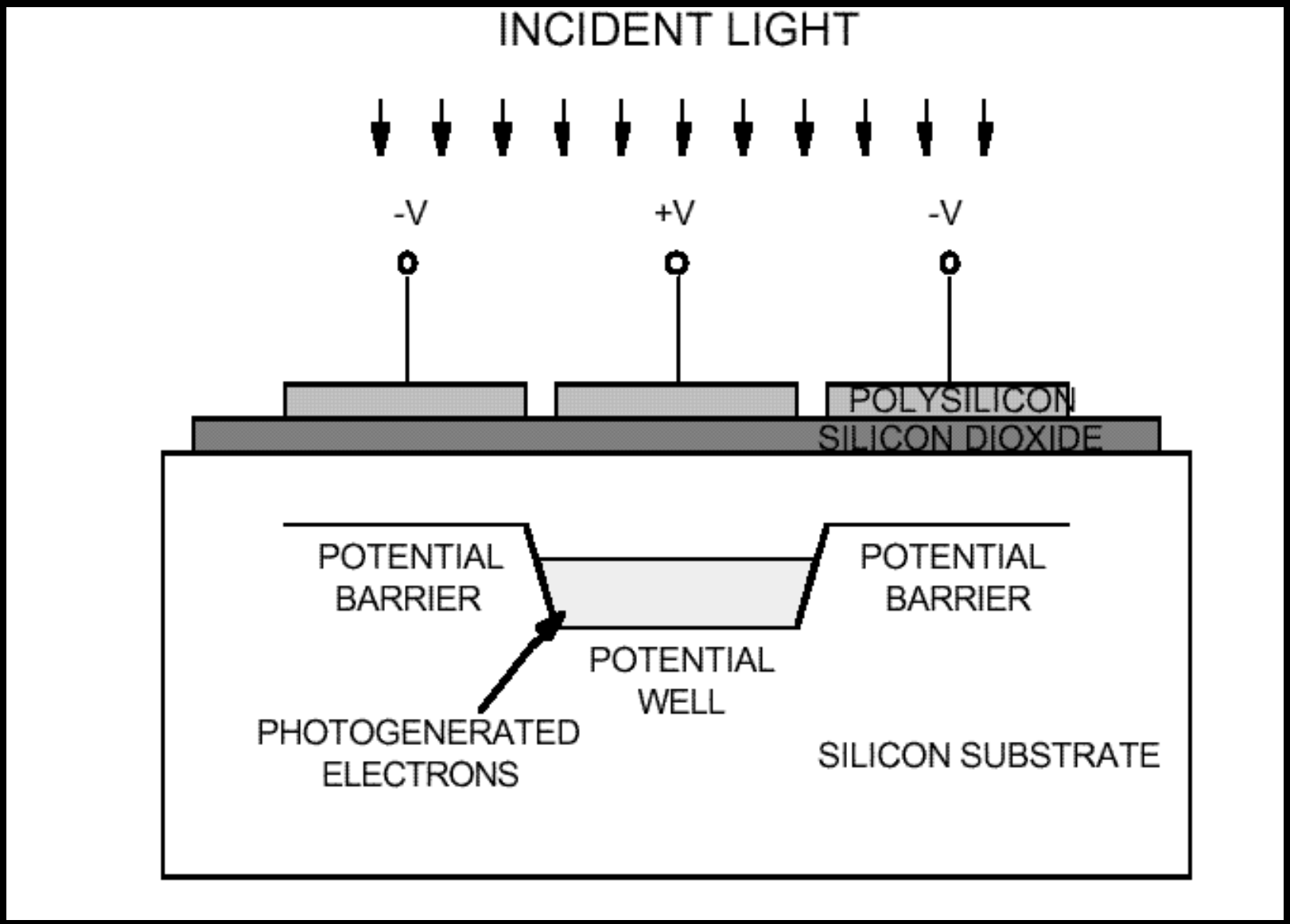
1.26eV corresponds to the energy of light with a wavelength of 1μm. Beyond this wavelength silicon becomes transparent and CCDs constructed from silicon become insensitive.

Sensitivity

- Silicon cutoff wavelength = 1239/E(ev)
- For 1.14eV, lambda = 1086.8nm
- Silicon is transparent in infrared (good lens!)
- 1.2-3.1eV get one electron-hole pair (1086-400nm)
- Can cover 1.1eV-10keV (0.1nm)

Other material

- Germanium 0.66eV bandgap; 1600nm
- However, germanium oxide not good insulator; hard to make germanium CCDs
- Other materials usually manufactured as hybrid detectors


INCIDENT LIGHT
-V
+V
-V
POLYSILICON
SILICON DIOXIDE
POTENTIAL BARRIER
POTENTIAL BARRIER
POTENTIAL WELL
PHOTOGENERATED ELECTRONS
SILICON SUBSTRATE

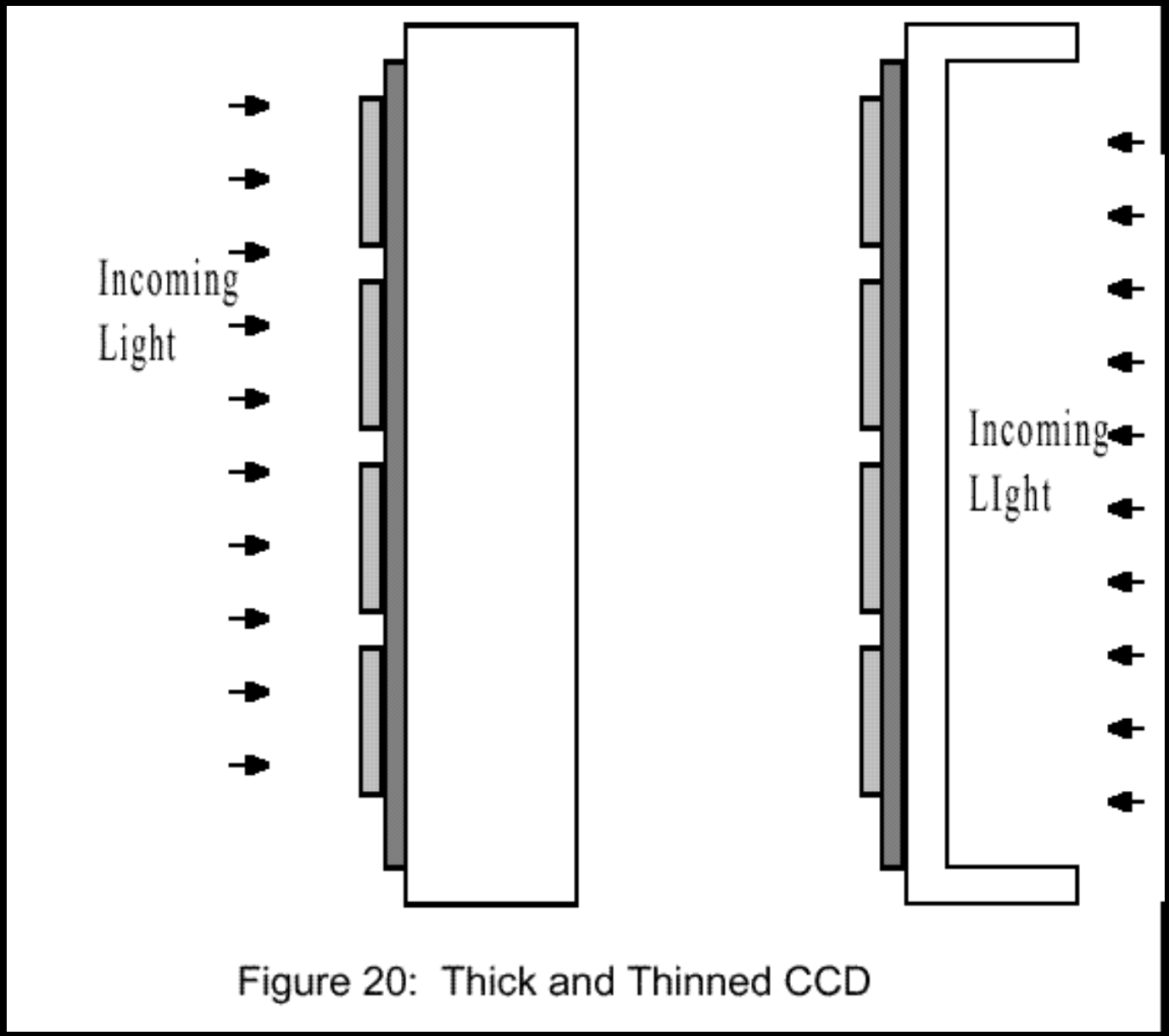


Figure 20: Thick and Thinned CCD

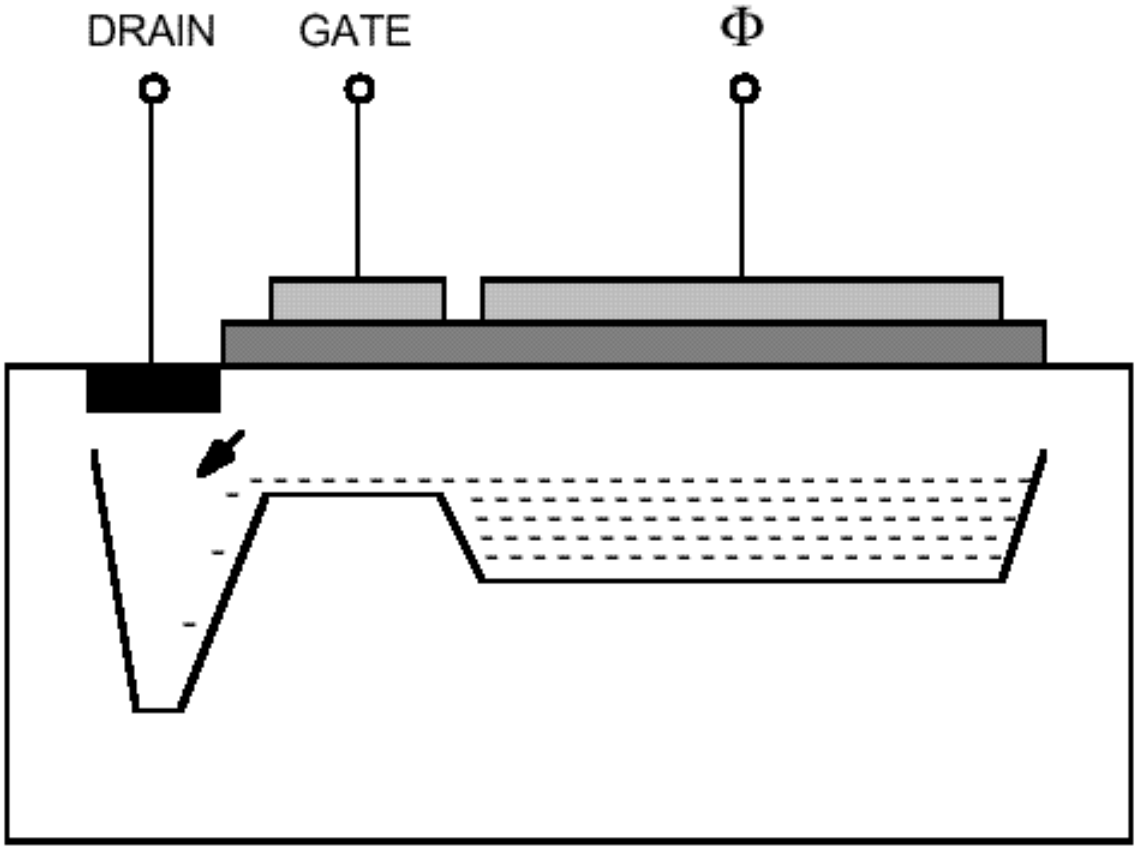
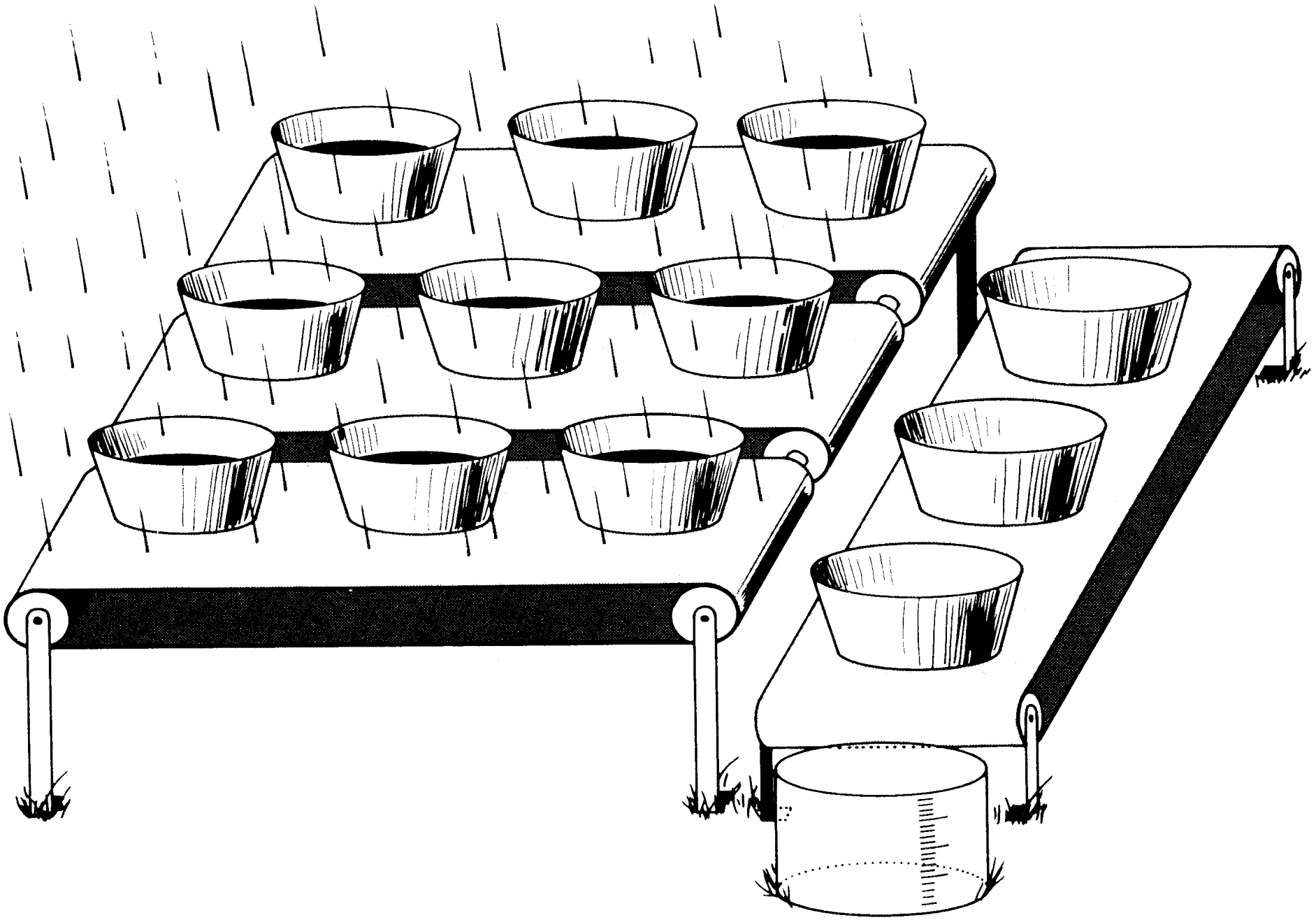
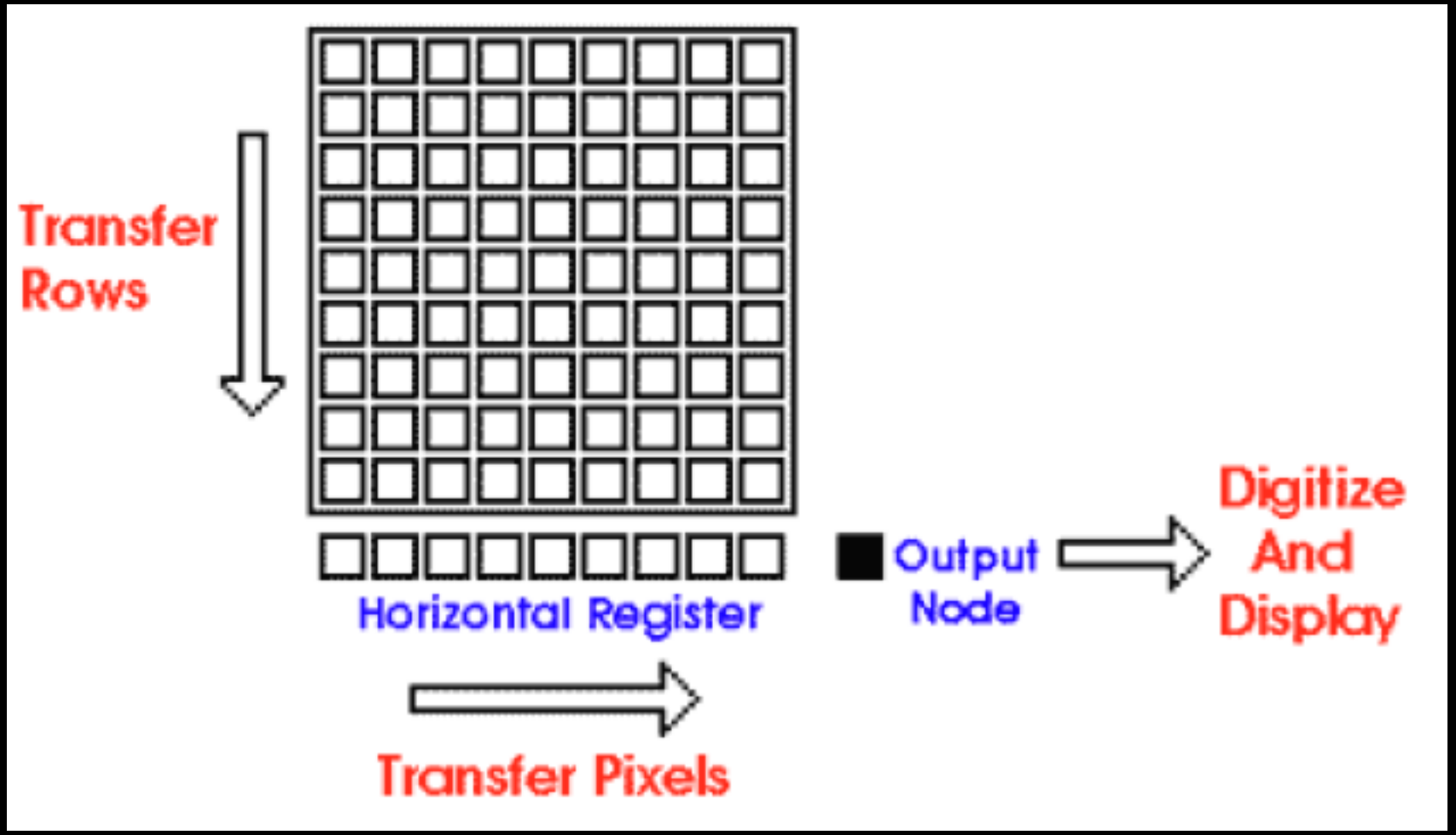
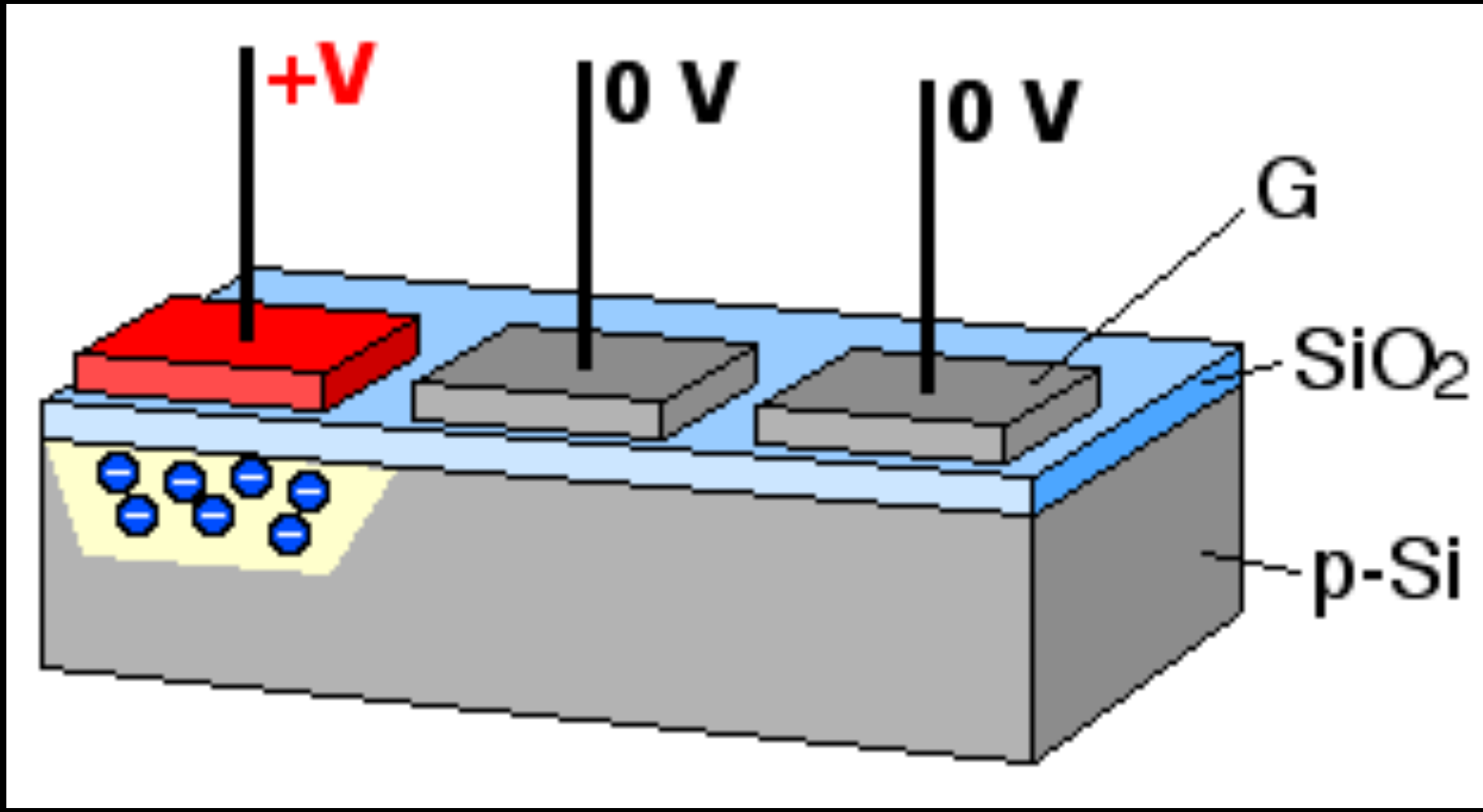


Figure 19: Lateral Overflow Drain

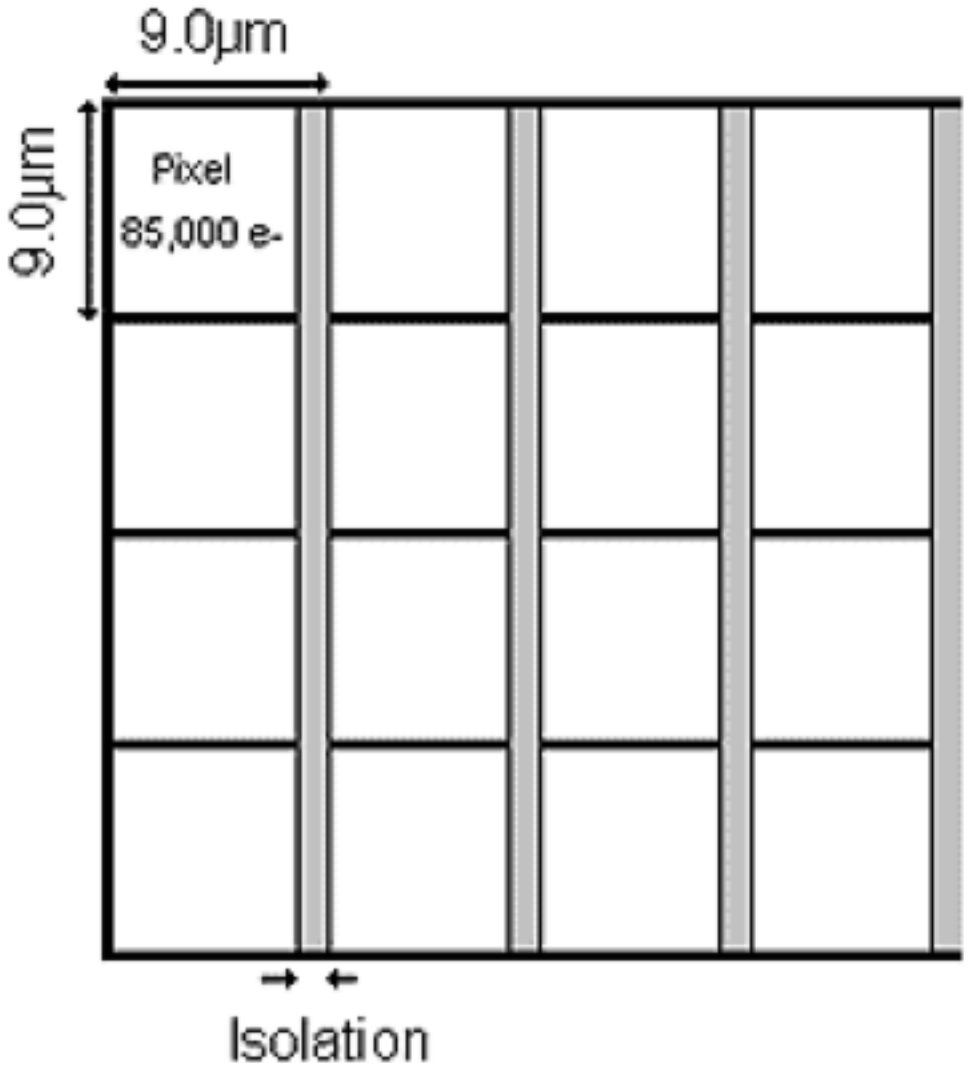




CCD charge transfer



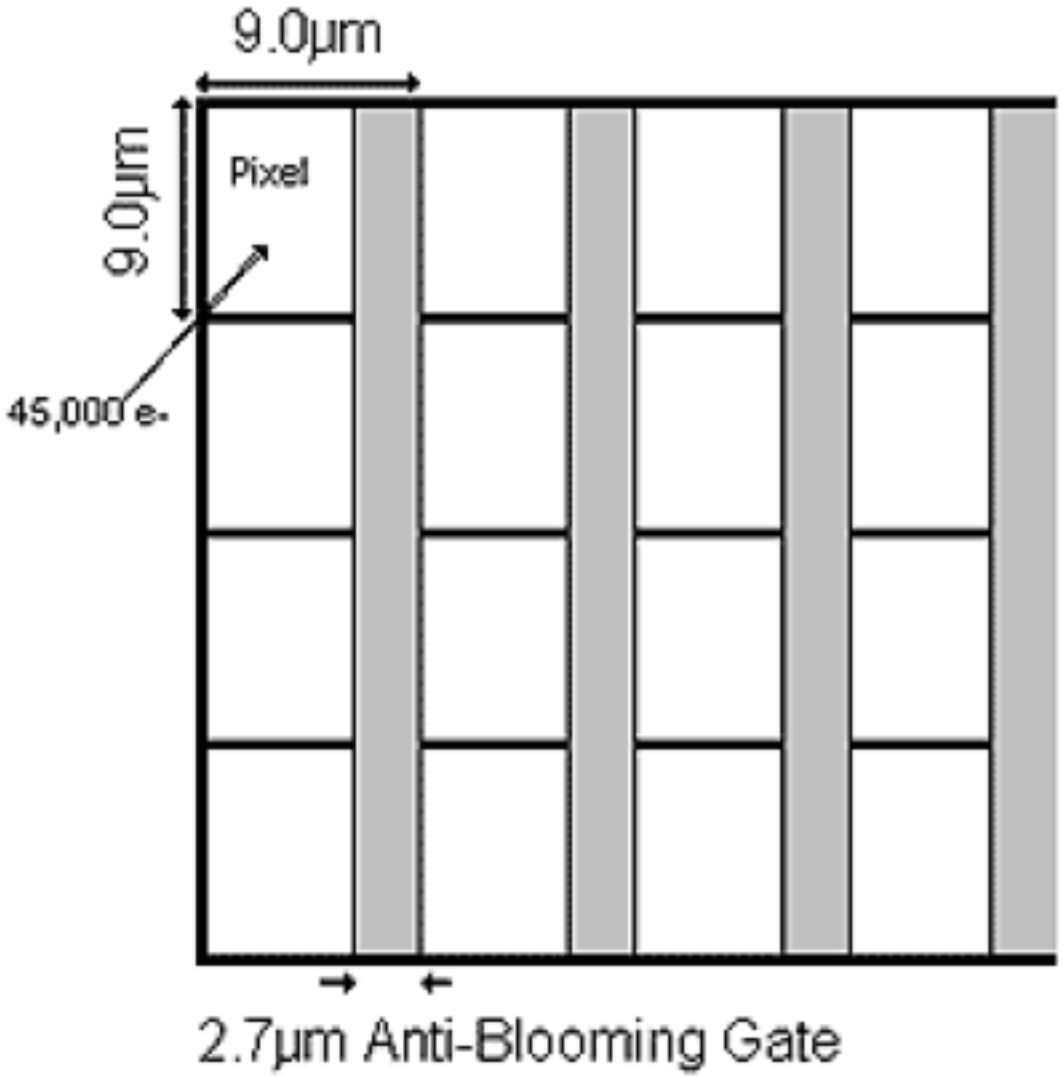
Credit: Schmid



No Anti-Blooming Gate

100% Fill Factor
85,000 electron well depth
Higher Quantum Efficiency
Blooming (Streaking) possible

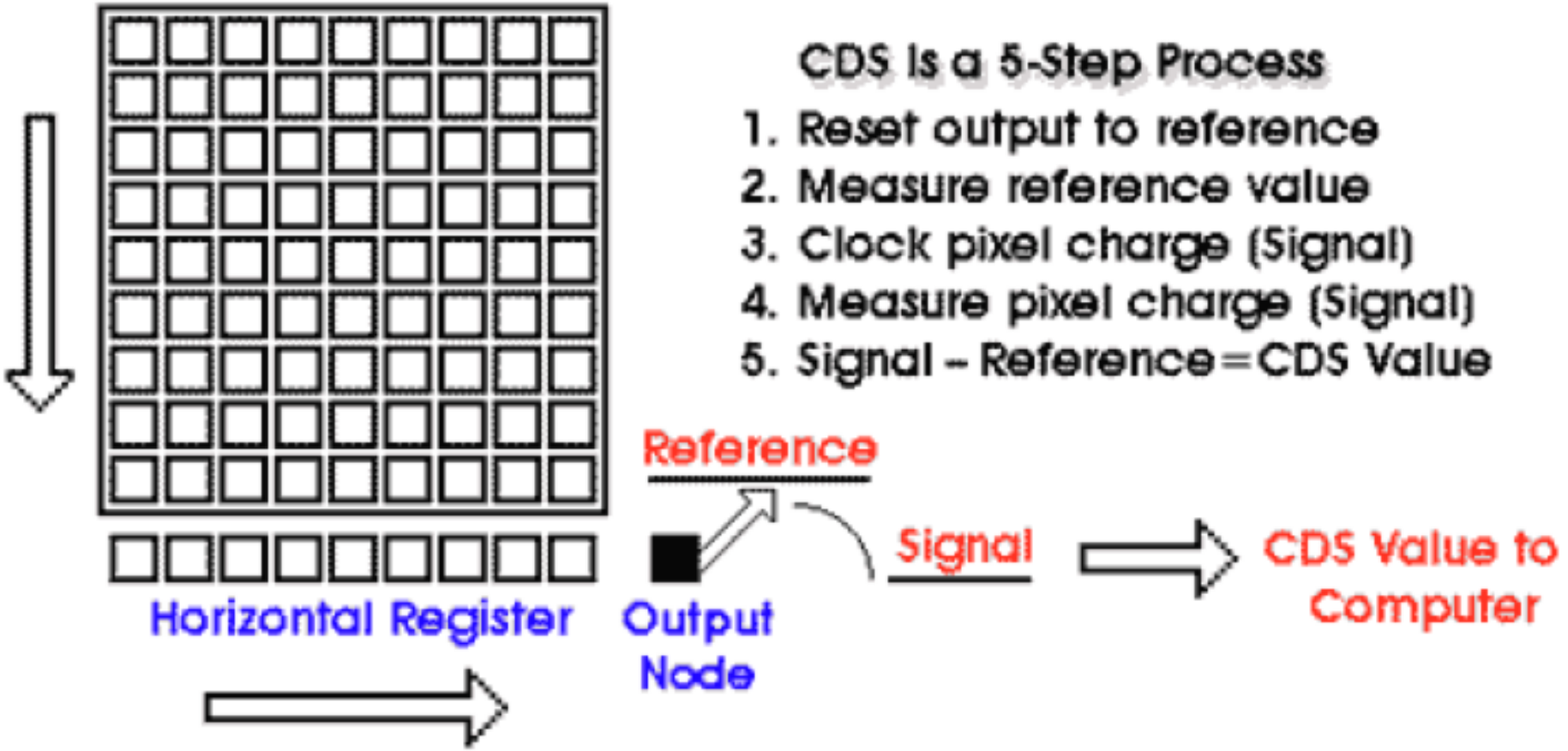
NABG pixel shape



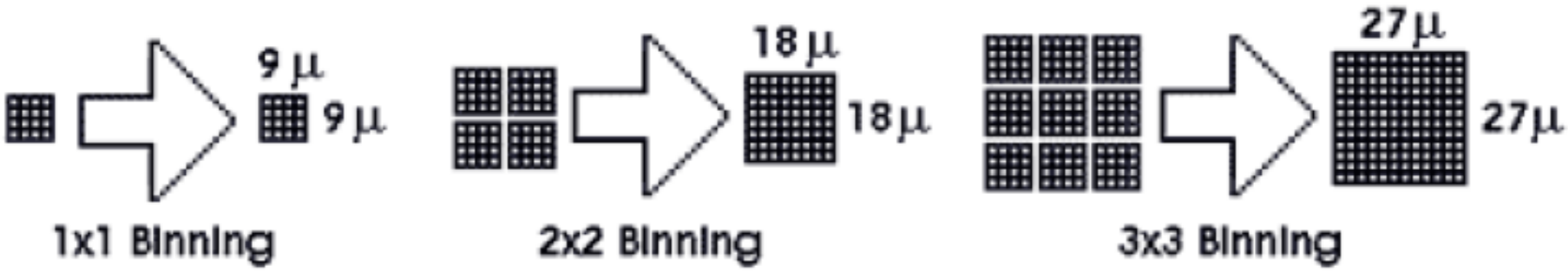
Anti-Blooming Gate

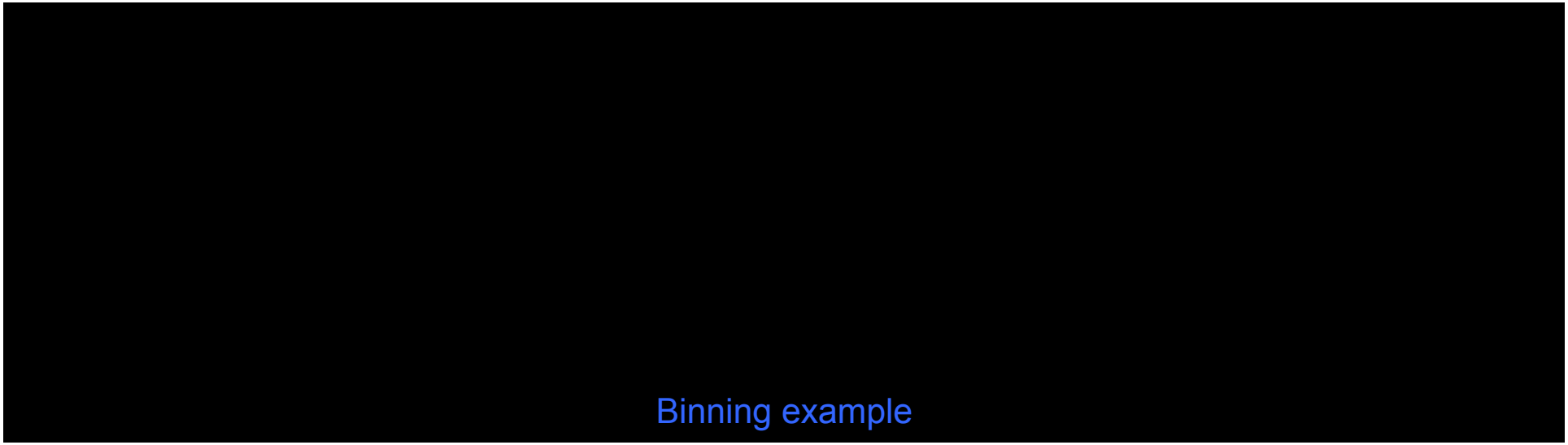
70% Fill Factor
45,000 electron well depth
Lower Quantum Efficiency

ABG pixel shape



Correlated double sampling





Binning example

Camera types

- Monochrome science
- One-shot color
- DSLR
- webcam

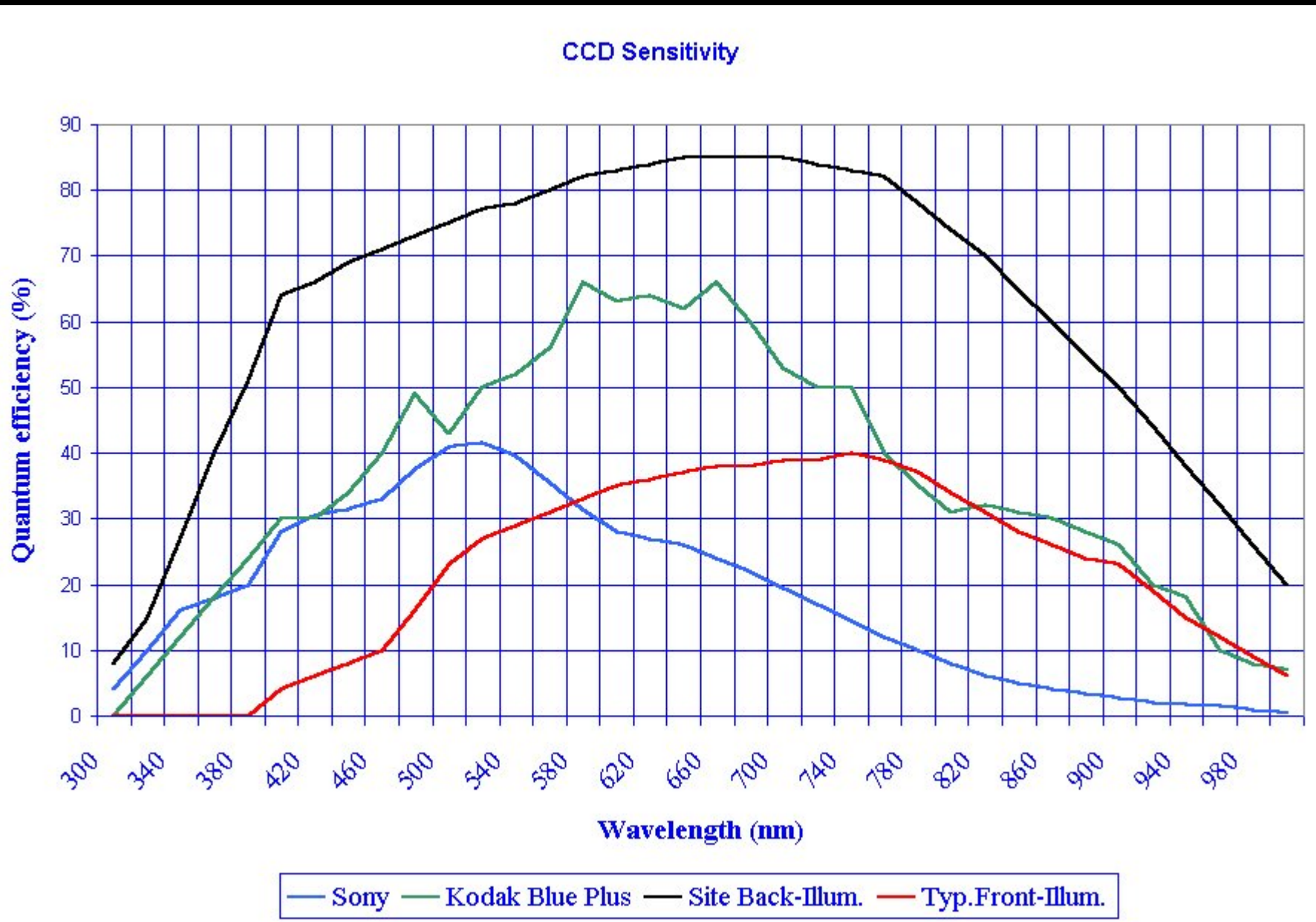

OIII-AXS

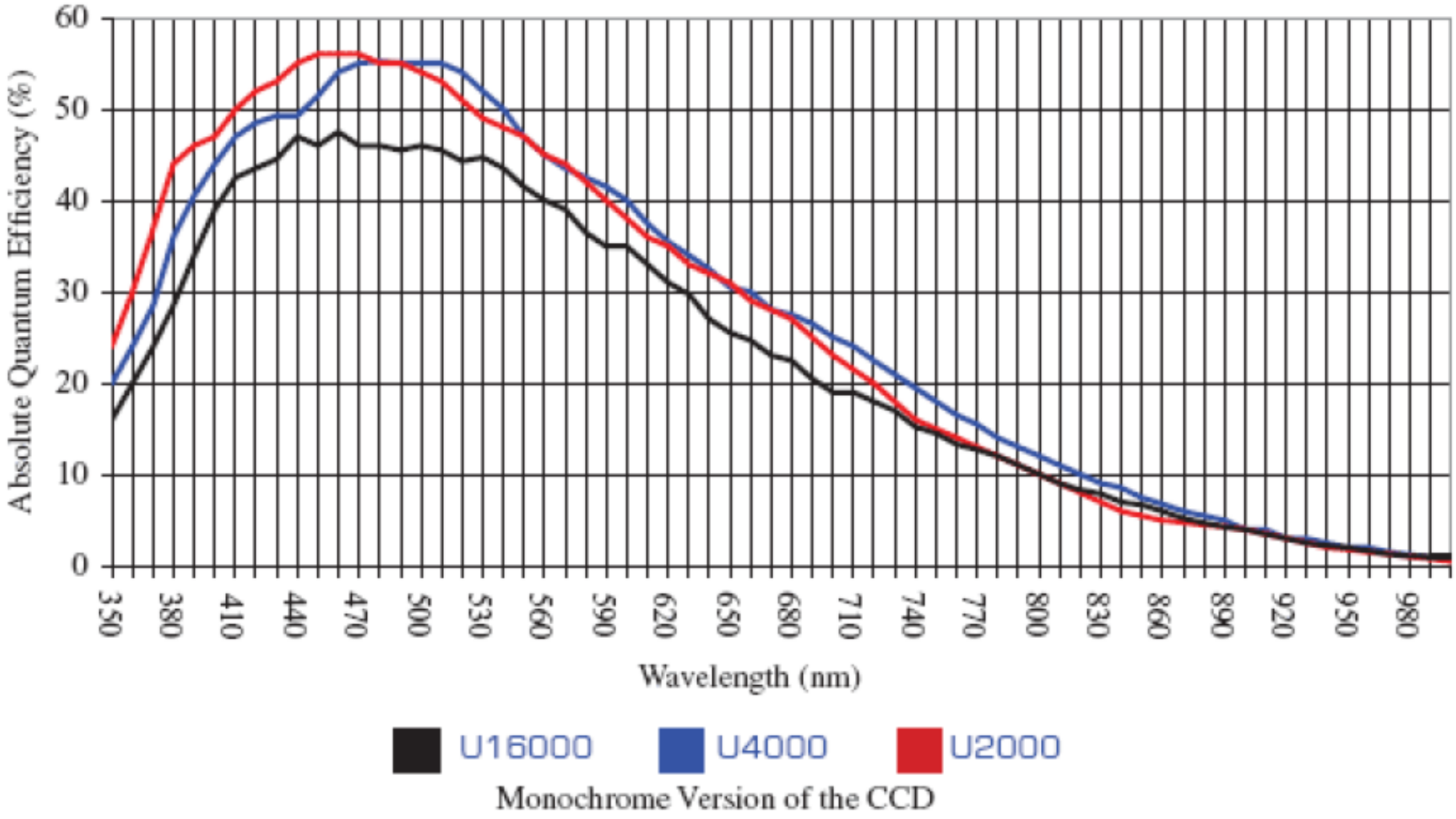
Starlight Xpress

Typical Apogee camera D7 body

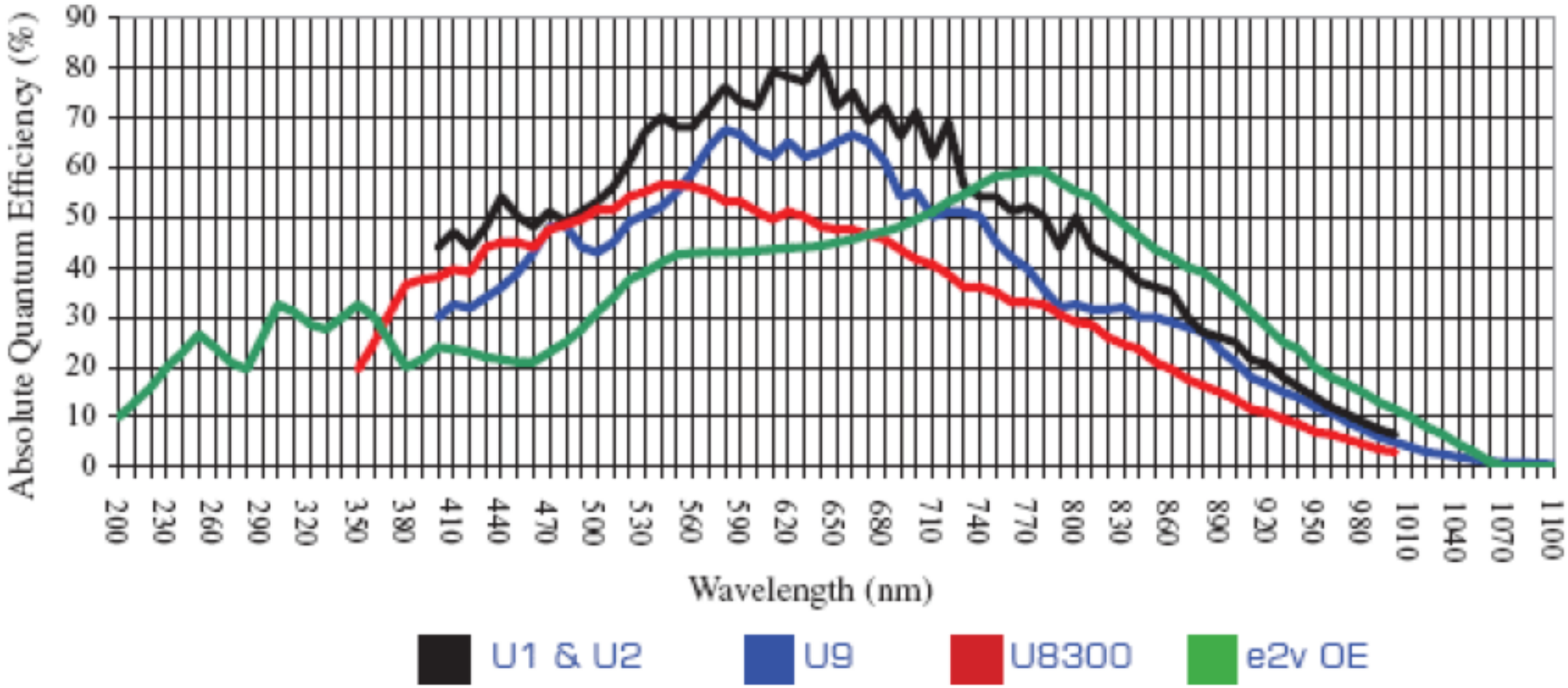

QSI
HOT
PRODUCT
2009
SKY
& TELESCOPE


MEADE

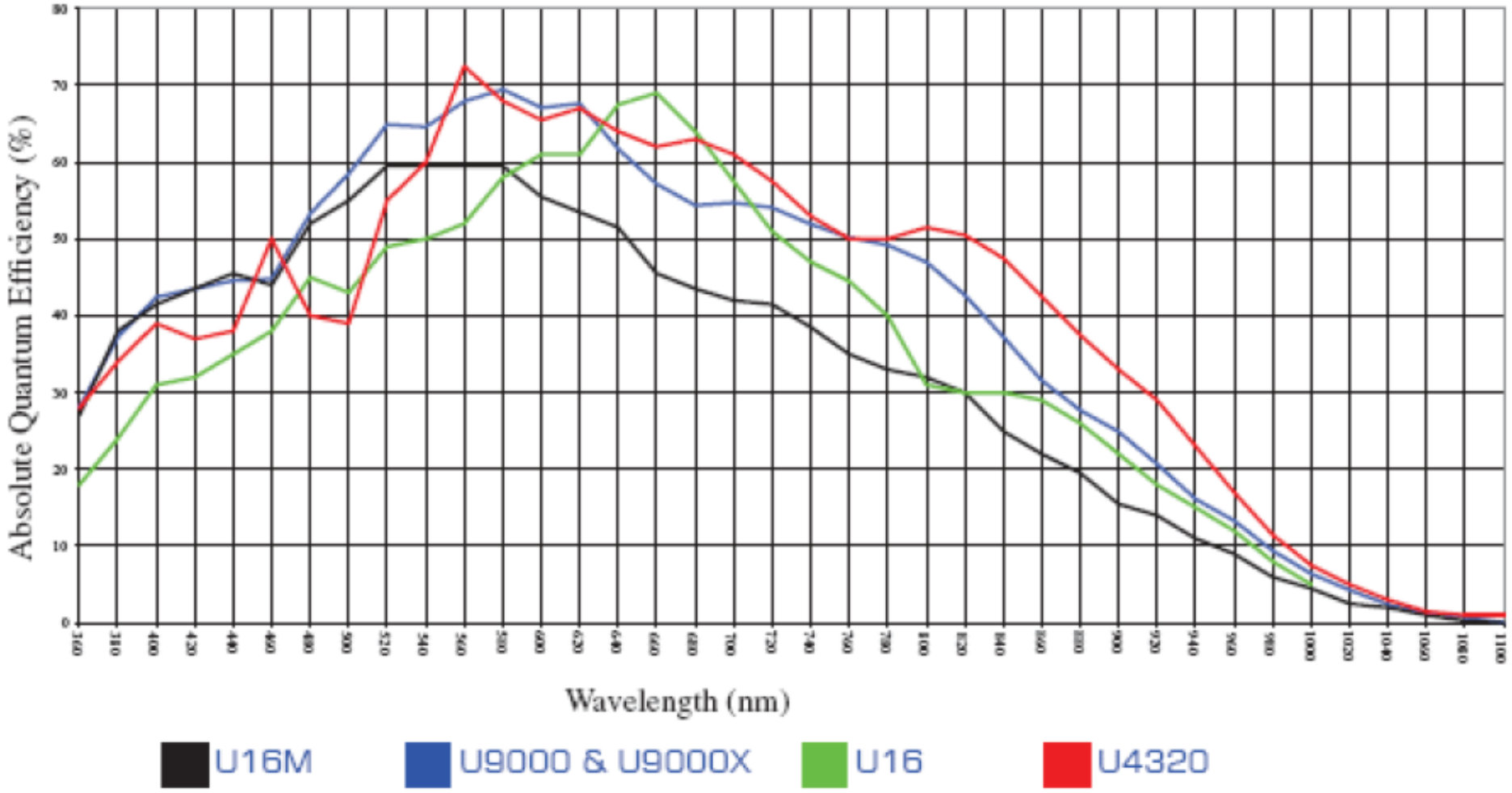

CCD Sensitivity
Quantum efficiency (%)
90
80
70
60
50
40
30
20
10
0
300
340
380
420
460
500
540
580
620
660
700
740
780
820
860
900
940
980
Wavelength (nm)
Sony
Kodak Blue Plus
Site Back-Illum.
Typ.Front-Illum.



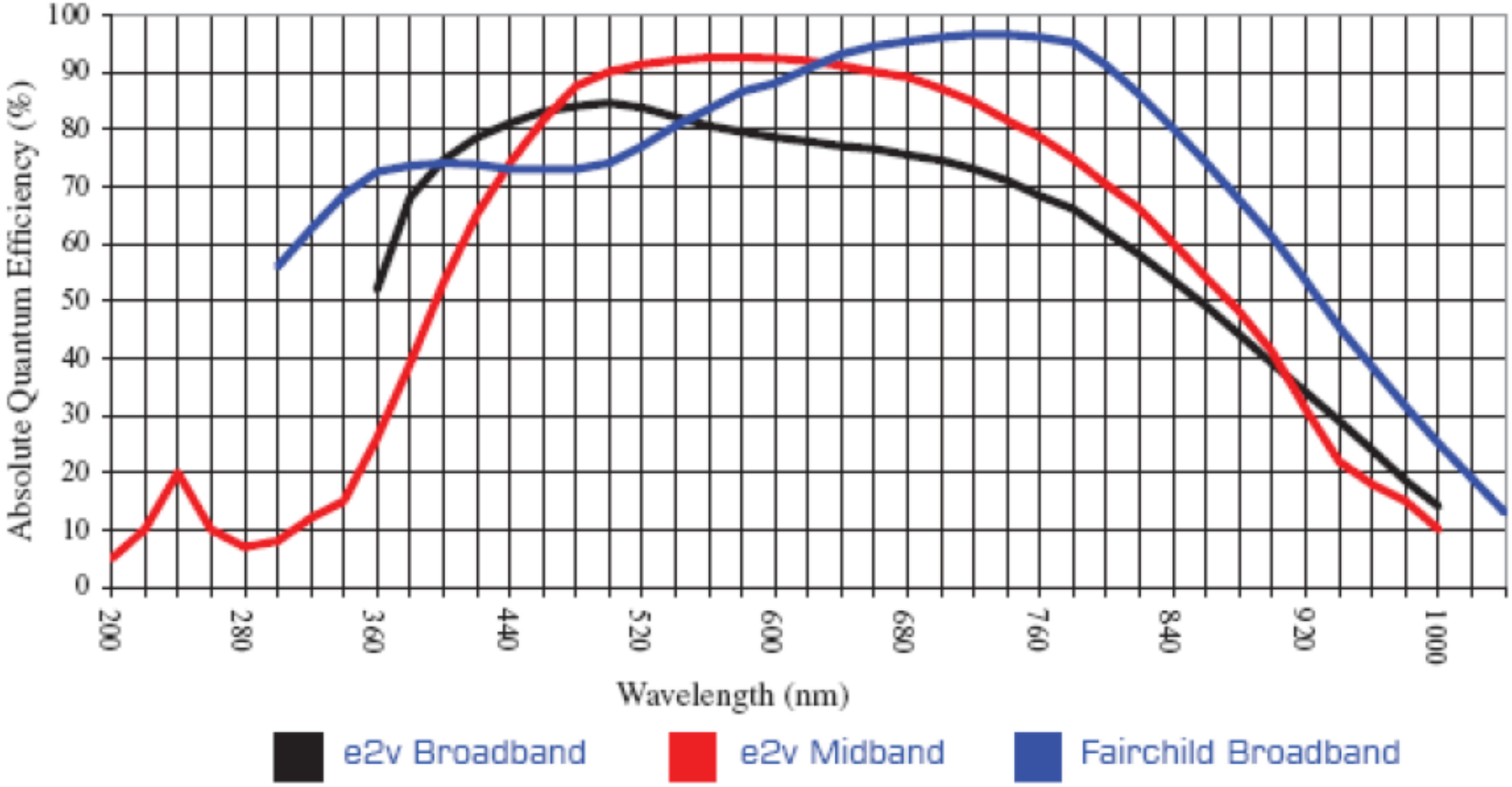
Interline transfer



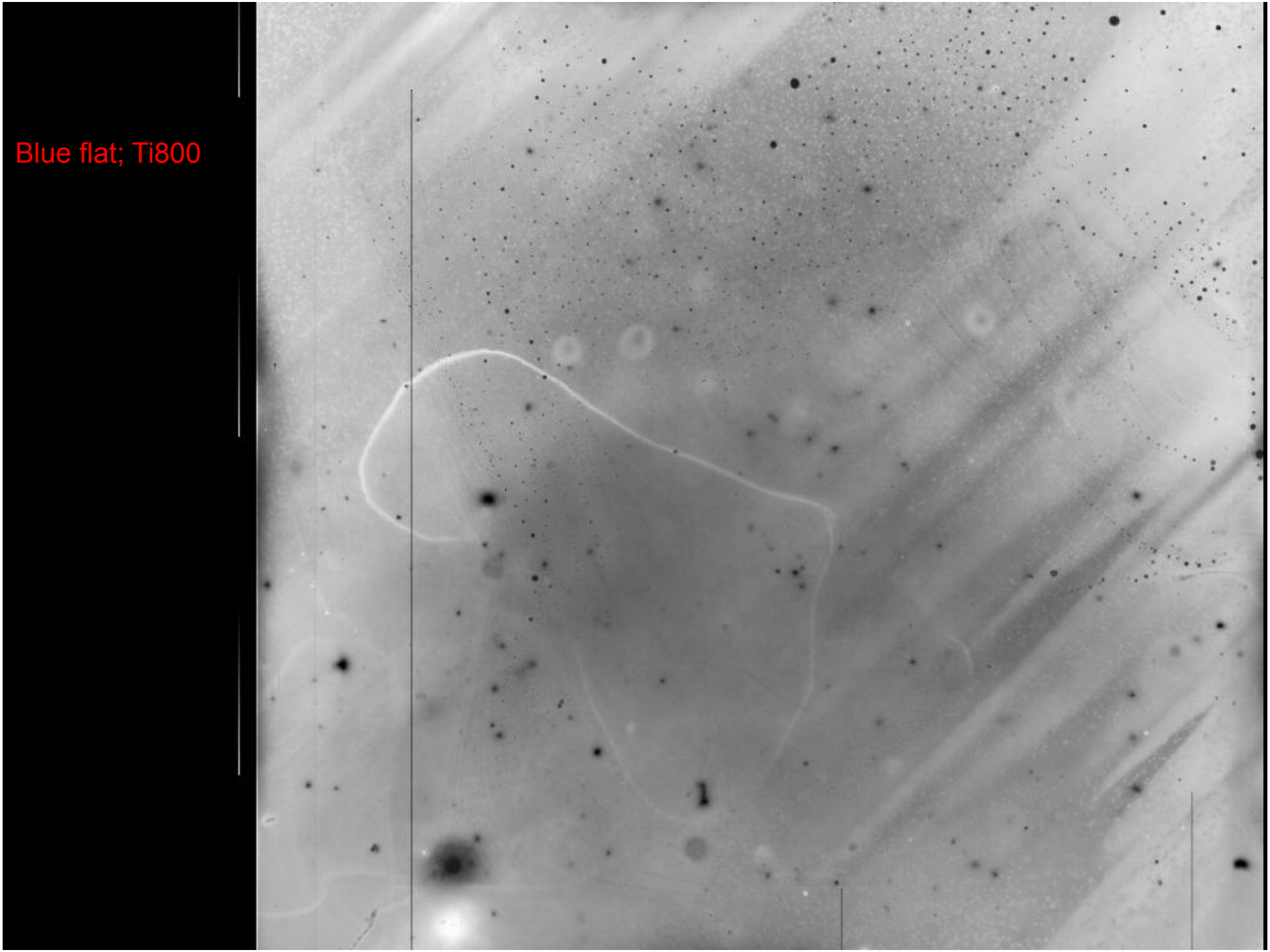
Front illuminated

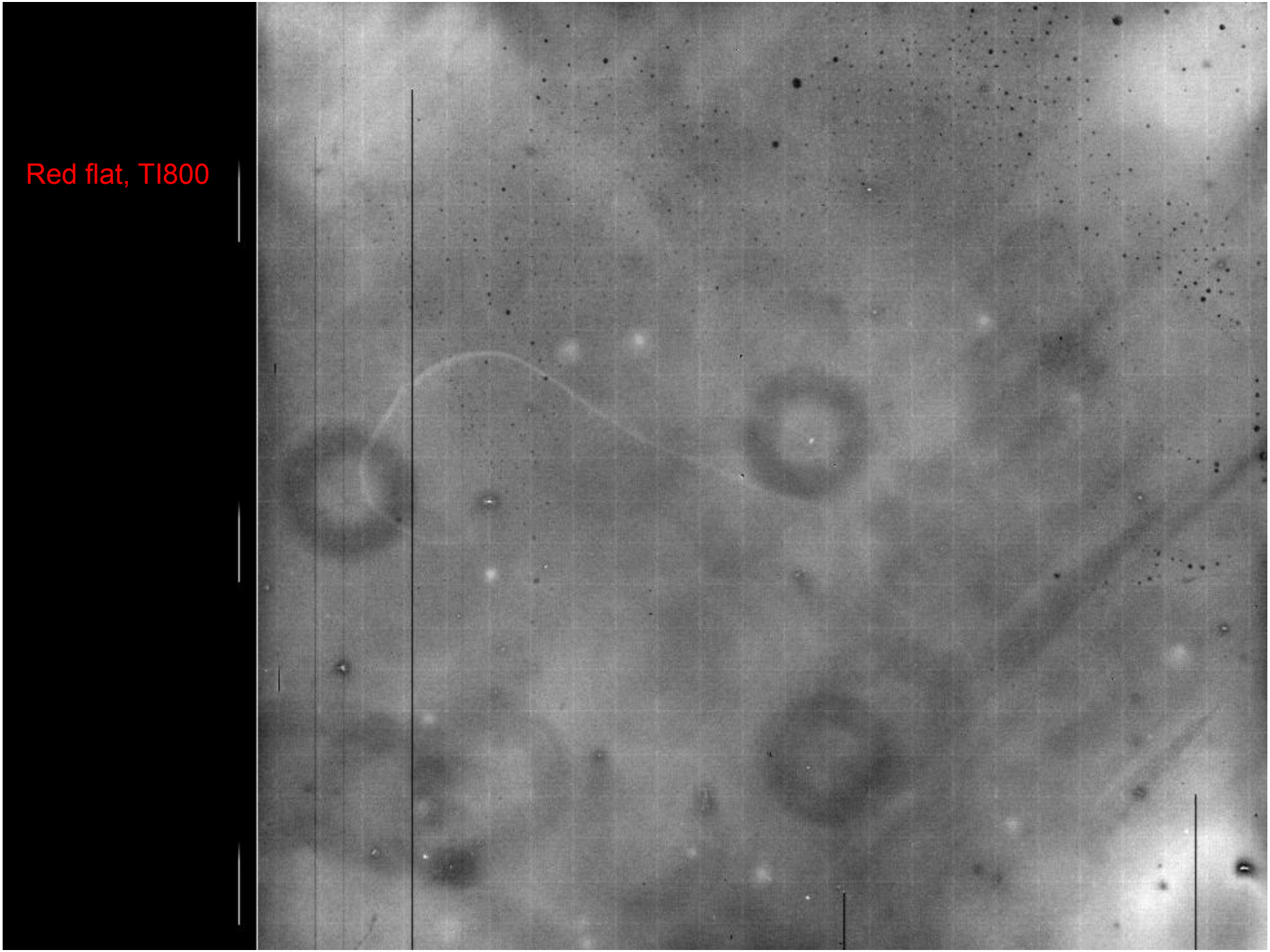


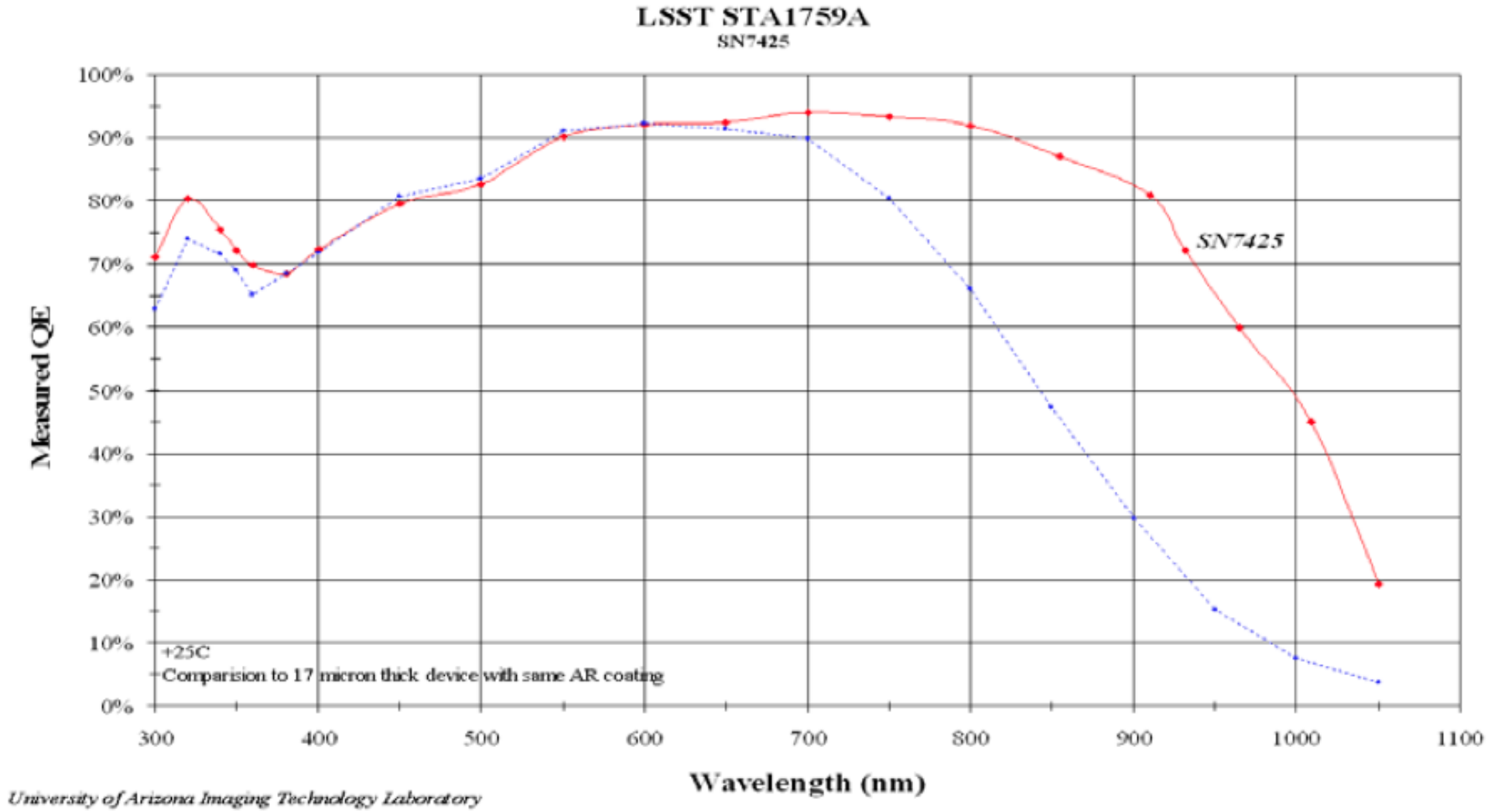
Front illuminated microlens



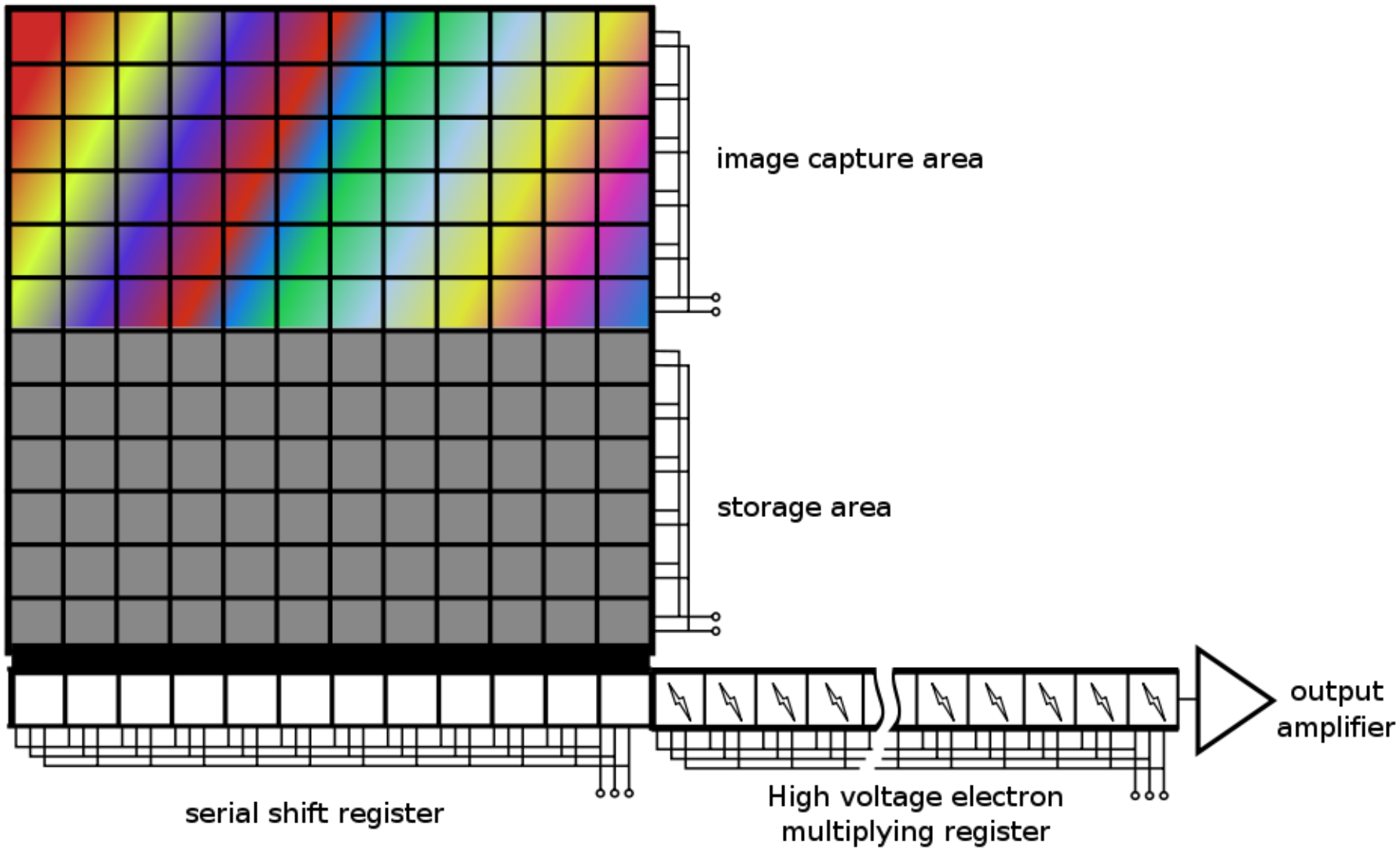
Different AR coatings for back-illuminated


Blue flat; Ti800


Red flat, TI800



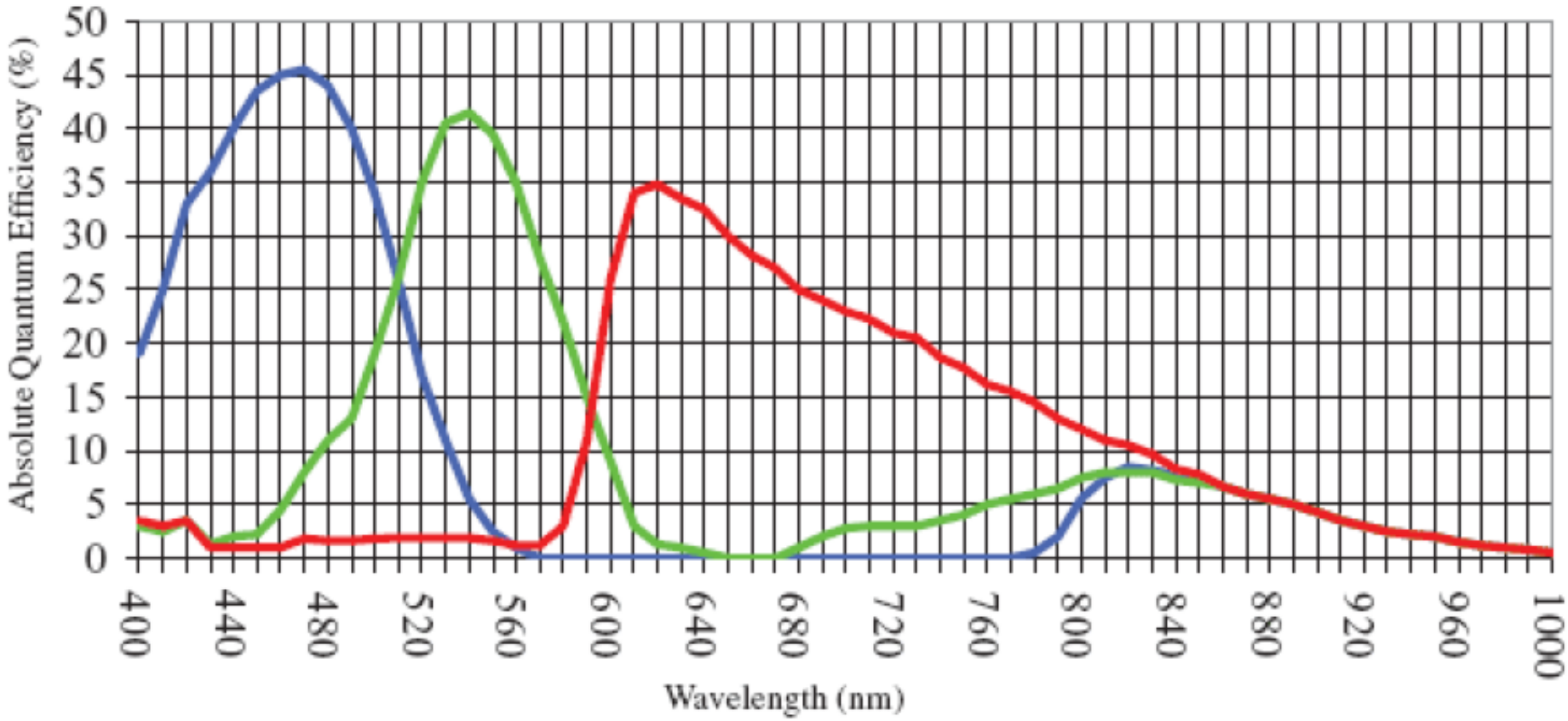
Deep depletion CCD



EMCCD (credit: J. Sanchez)

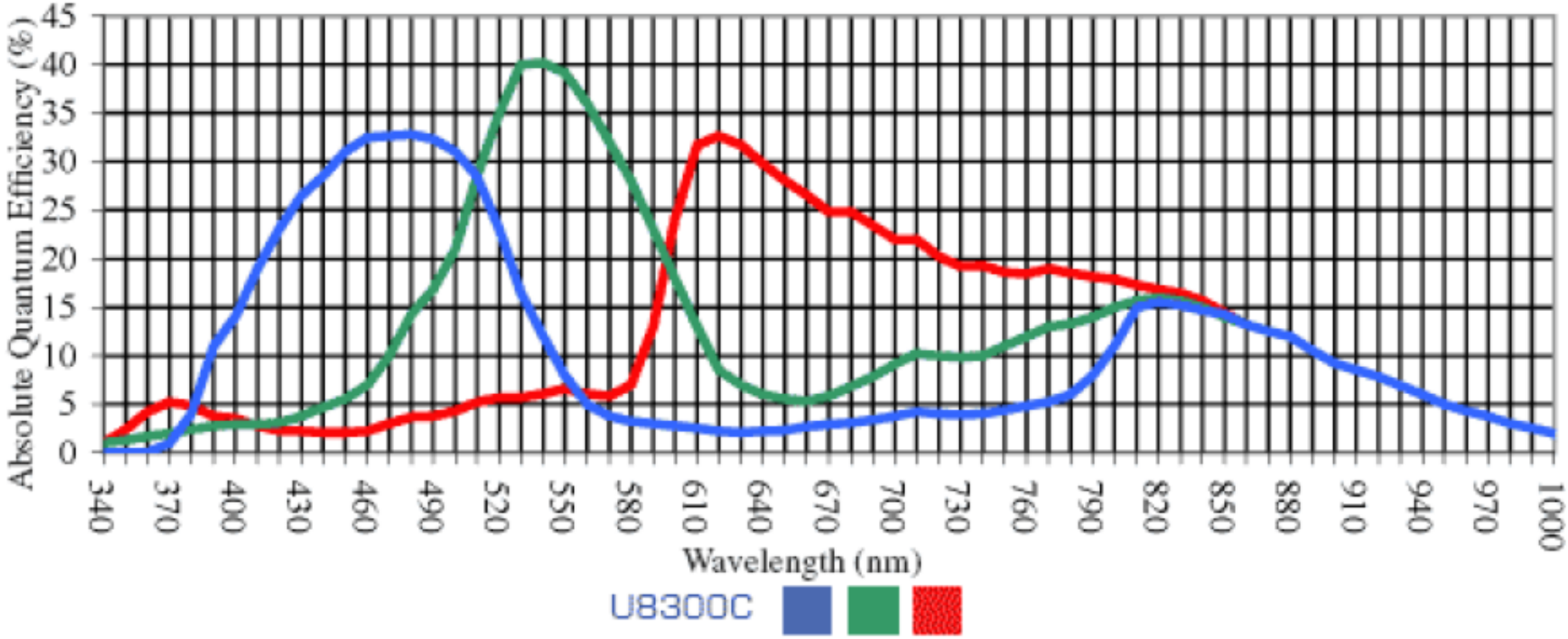
Color CCD

- Monochrome CCD with colored layers added
- One-shot color is like science CCD (cooled, 16-bit ADC, etc.)

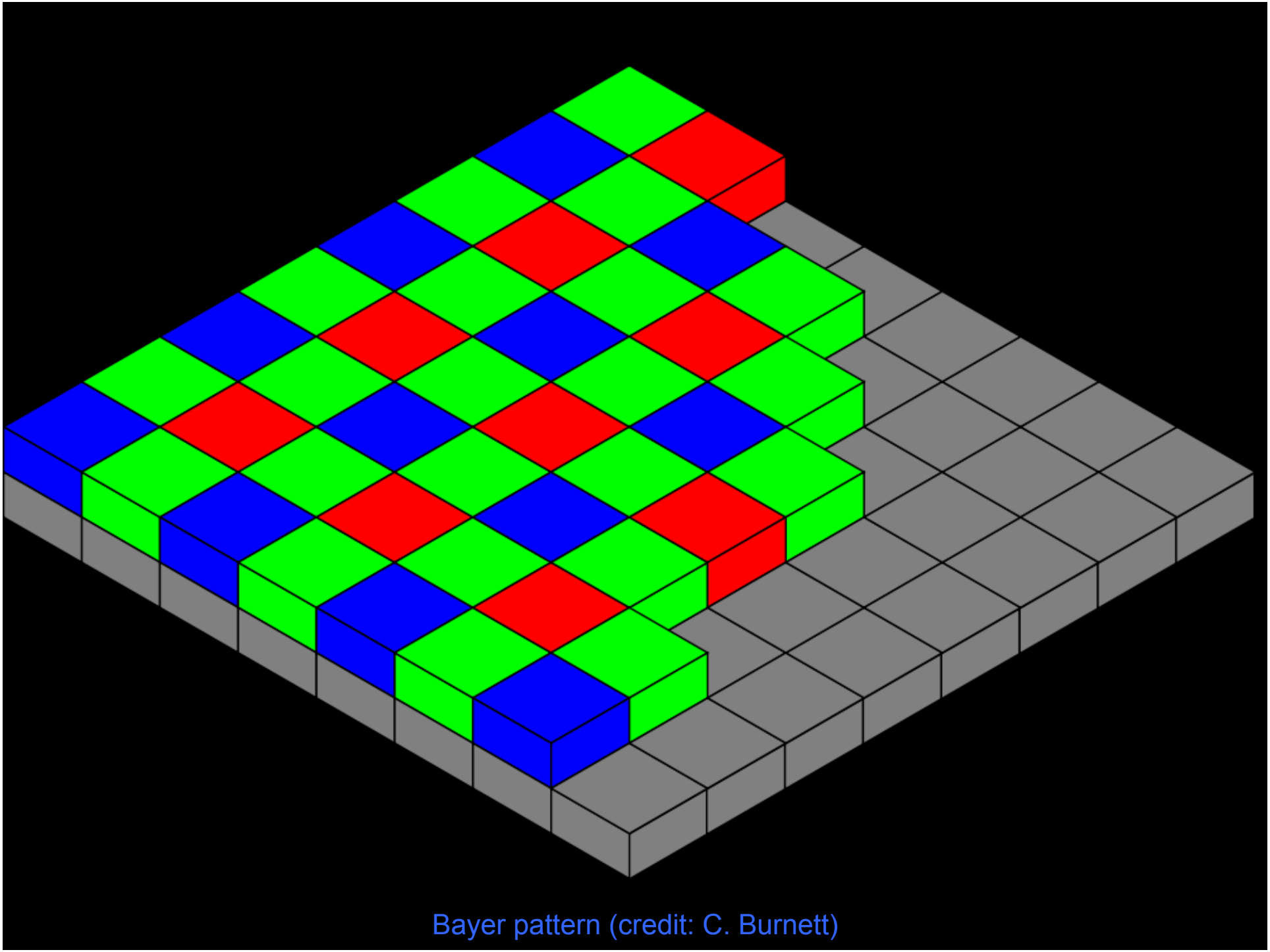


U16000, U4000, & U2000 Color

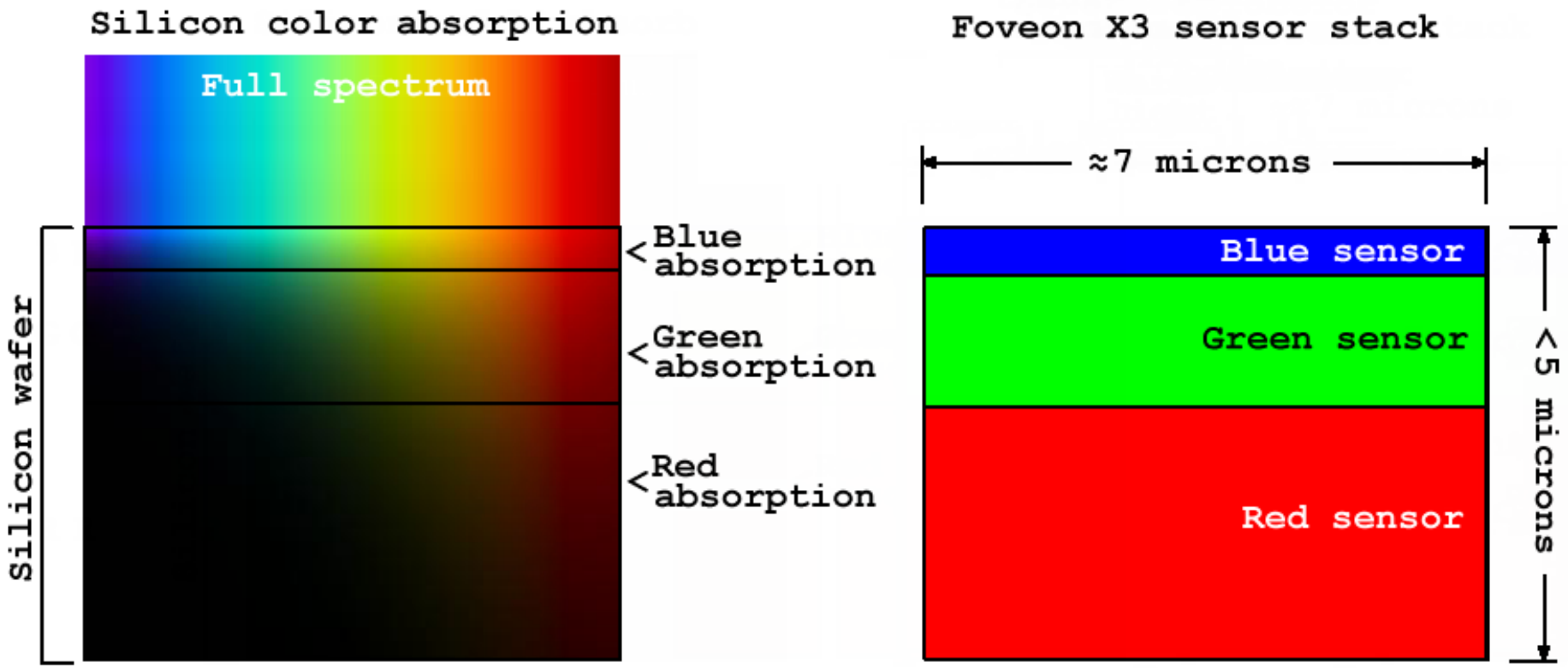
Color CCDs, note red leak



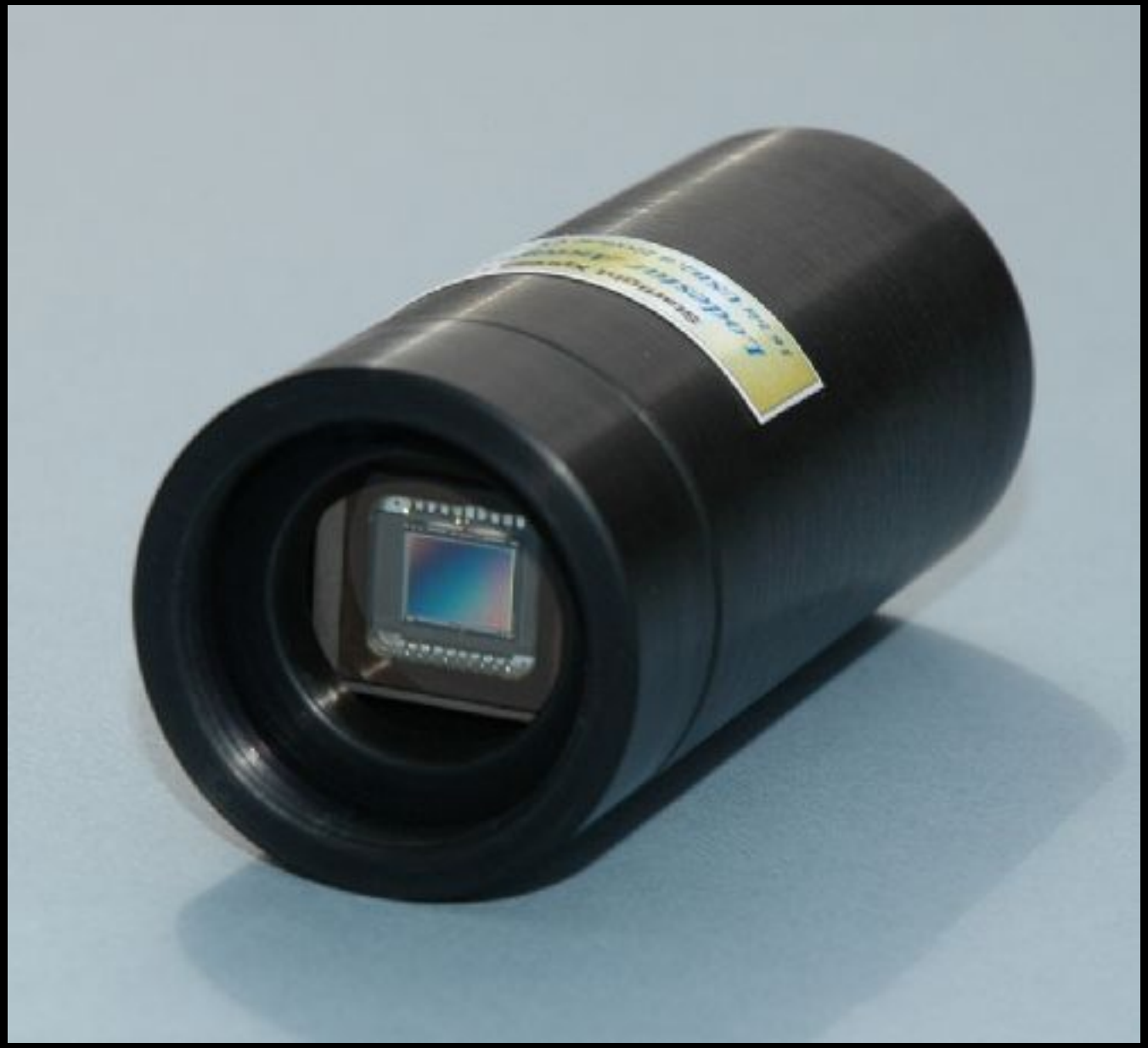
KSF8300C, note red leak



Bayer pattern (credit: C. Burnett)

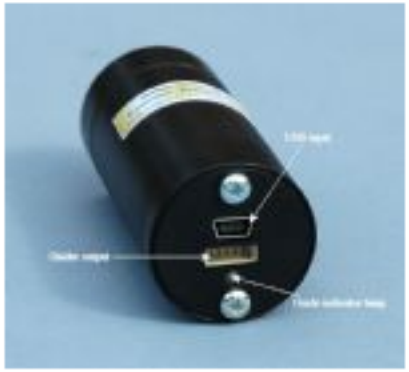


Foveon X3 sensor (Sigma)



Lodestar guider

Starlight Xpress Lodestar Autoguider Specifications...



- CCD type: ICX429AL Sony Exview interline CCD with low dark current and vertical anti-blooming.
- CCD Full resolution Pixel data: Pixel size: 8.2uM x 8.4uM, Image format: 752 x 580 pixels
- CCD Image area: 6.4mm (Horizontal) x 4.75mm (Vertical).
- CCD quality: Grade 1
- Spectral Response: QE max at 620nM (~65%), 35% at 400nM and 770nM.
- Readout Noise: Less than 15 electrons RMS - typically only 10 electrons.
- Full-well capacity: Greater than 50,000 e- (unbinned)
- Anti-blooming: Overload margin greater than 1000x.
- Dark current: Dark frame saturation time greater than 1 hour. Less than 0.1 electrons/second @ + 10C ambient.
- Data format: 16 bits.
- System gain: 0.9 electrons per ADU
- Computer Interface: Built-in USB 2.0 compatible interface.
- Image download time: Typically 0.2 seconds at full resolution using USB 2.0.
- Power requirements: USB powered.
- Cooling system: Ambient air cooling.
- Size: 32 x 72mm black anodised aluminium barrel with 25 x 0.75mm 'C mount' thread at the CCD window end & input/output plugs at rear.
- Weight: approx. 50g

Lodestar specifications

Super Low Light B/W Video Security Camera

Multiple lens options, small form factor, and amazing low lux

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- Compact form factor accepts any CS-mount lens

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SHIPS: Same business day when ordered by 3:00pm CT
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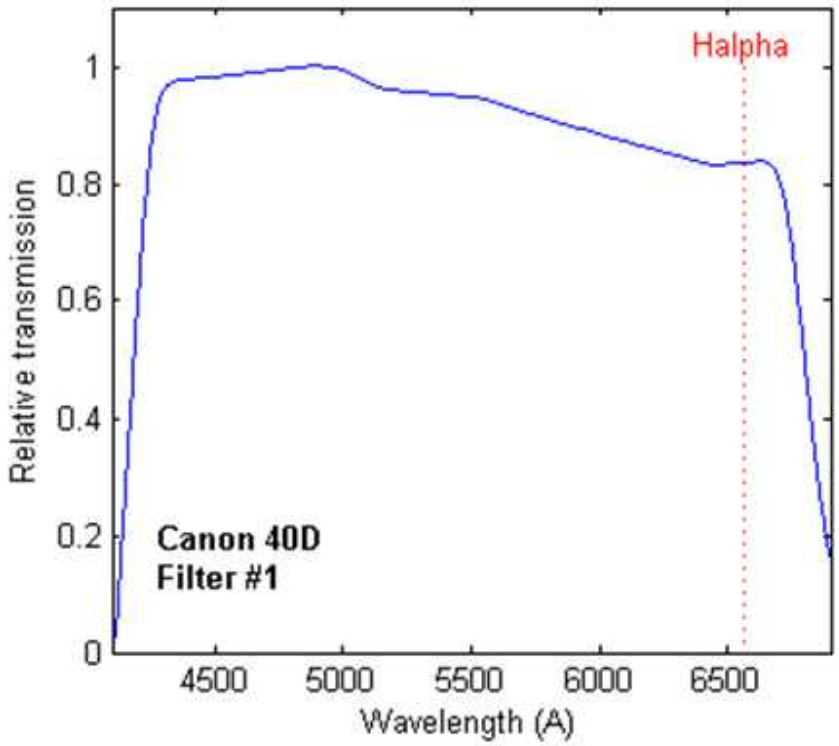
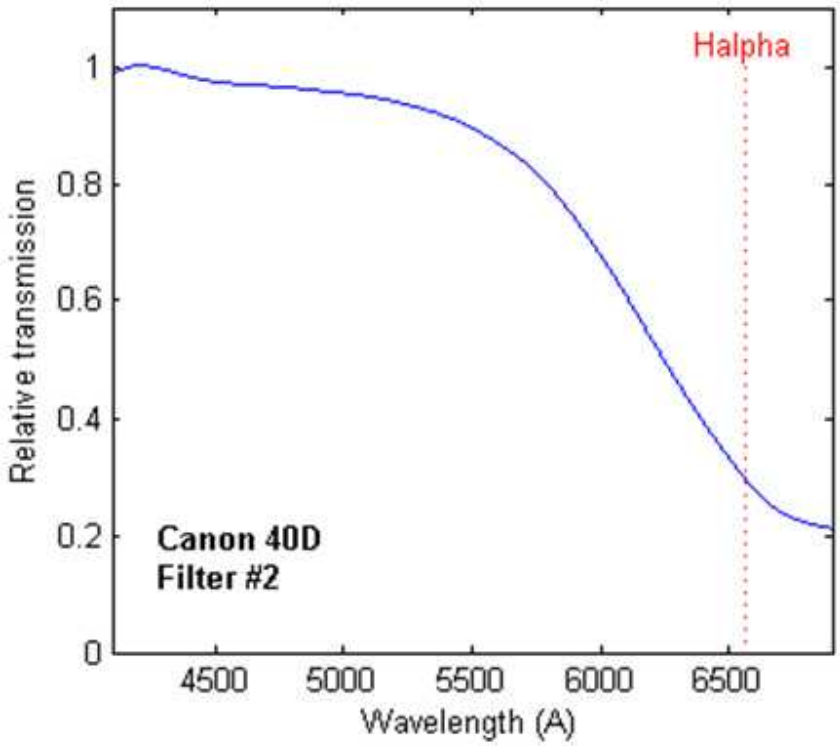
Low Light Video

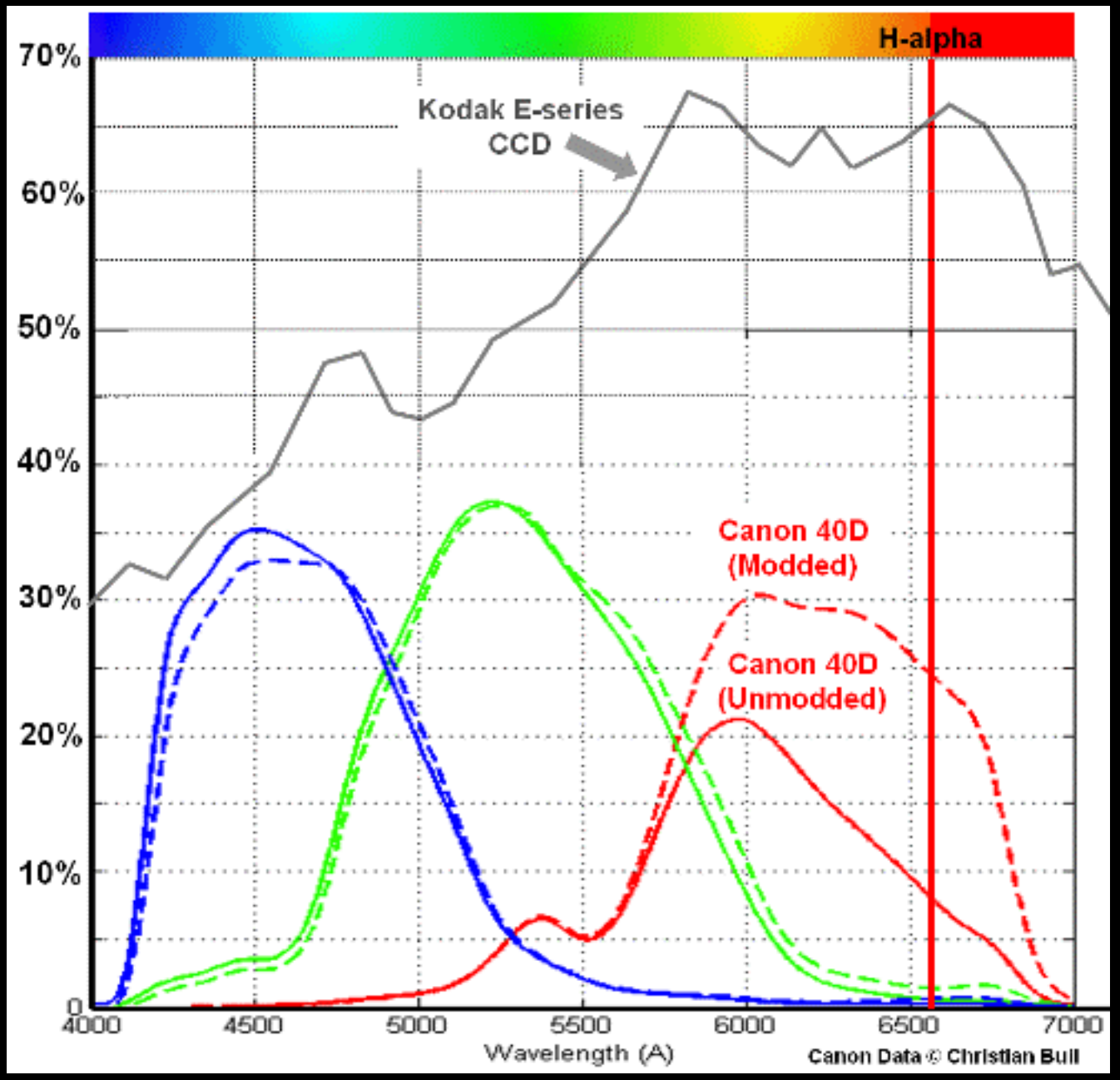
PC-164 webcam/videocam

Typical DSLR Camera





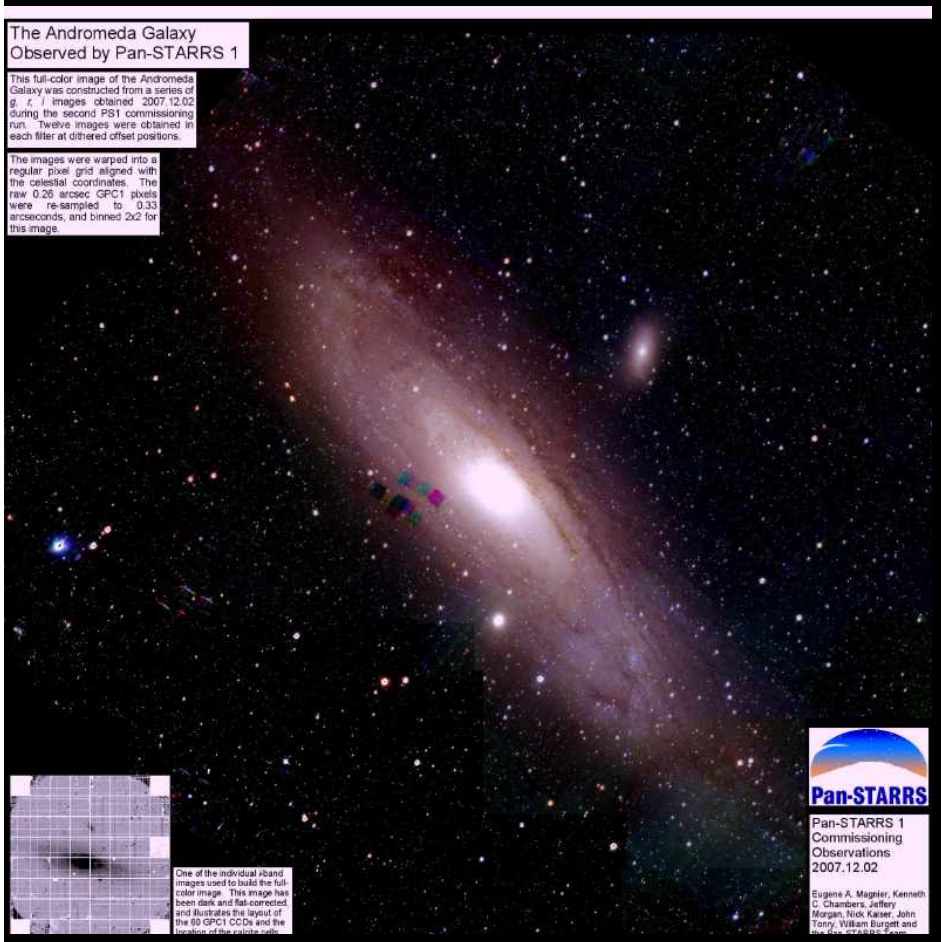
Cover glass comparisons

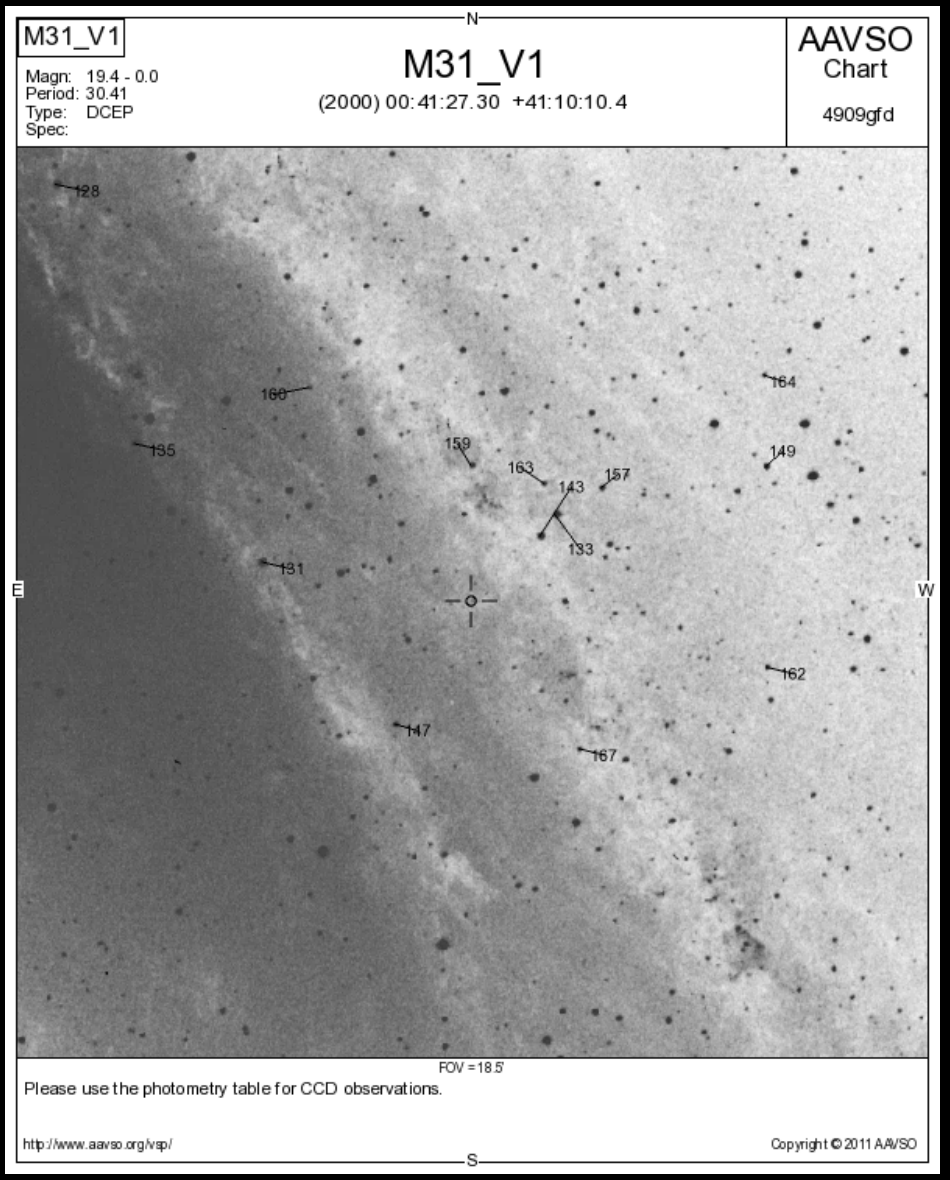


Canon RGB response

LSST Detectors

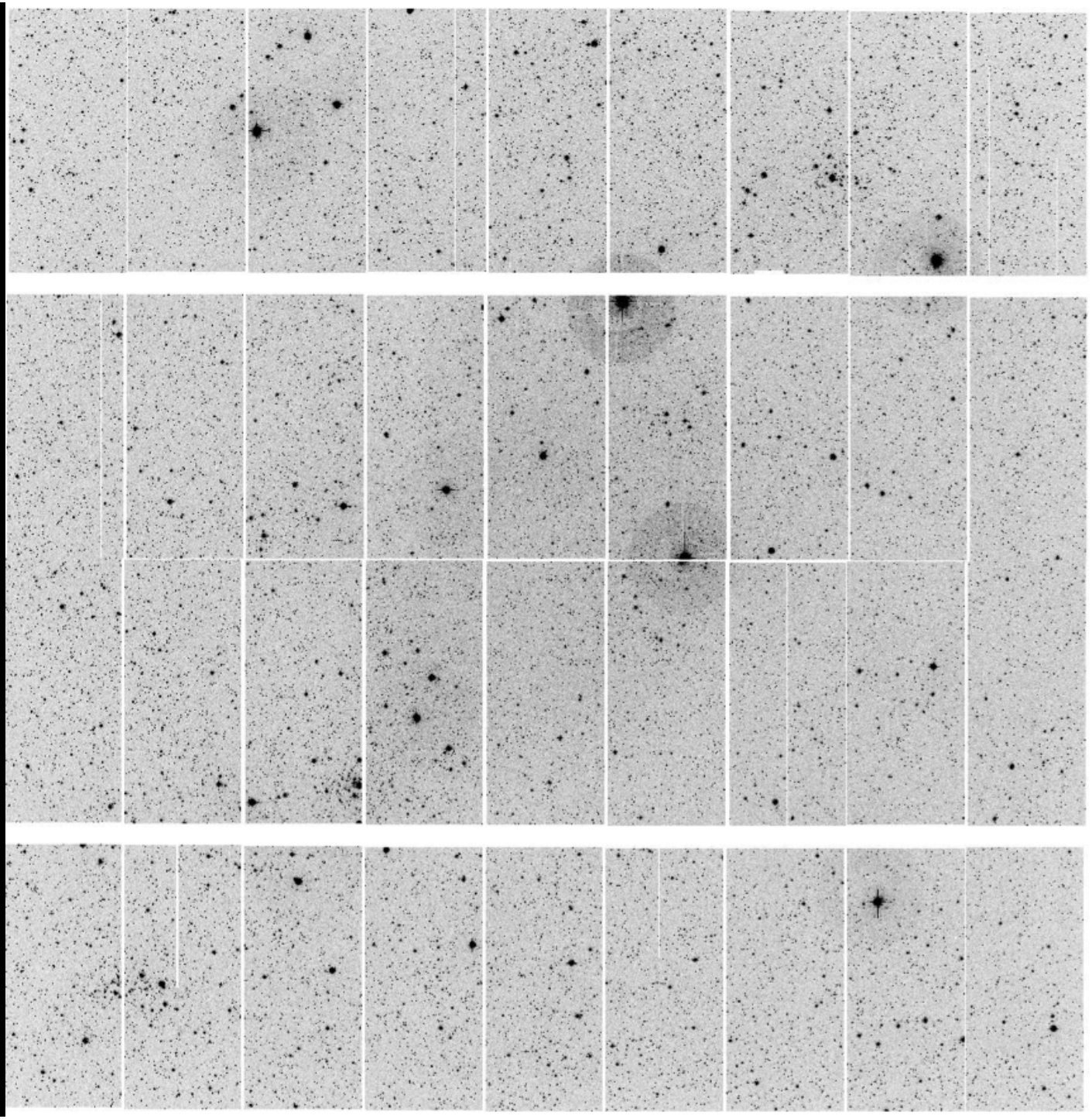
Hubble's Variable in M31



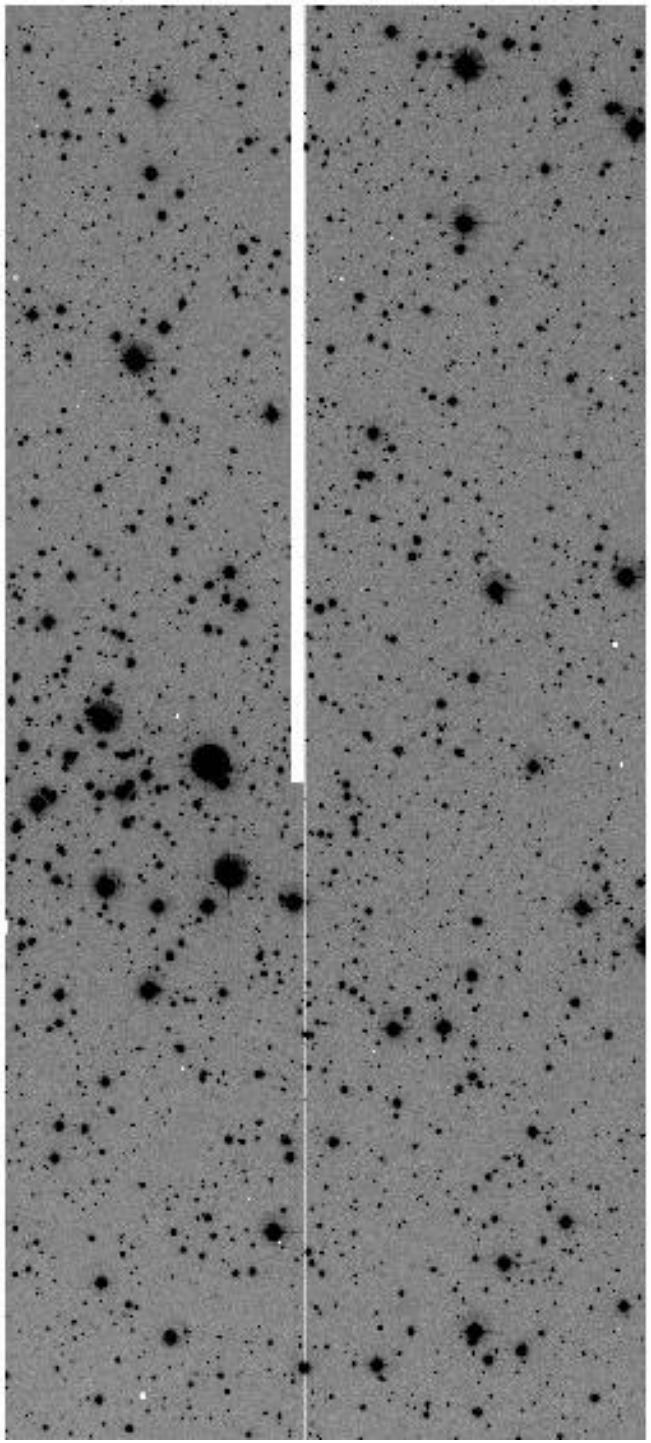


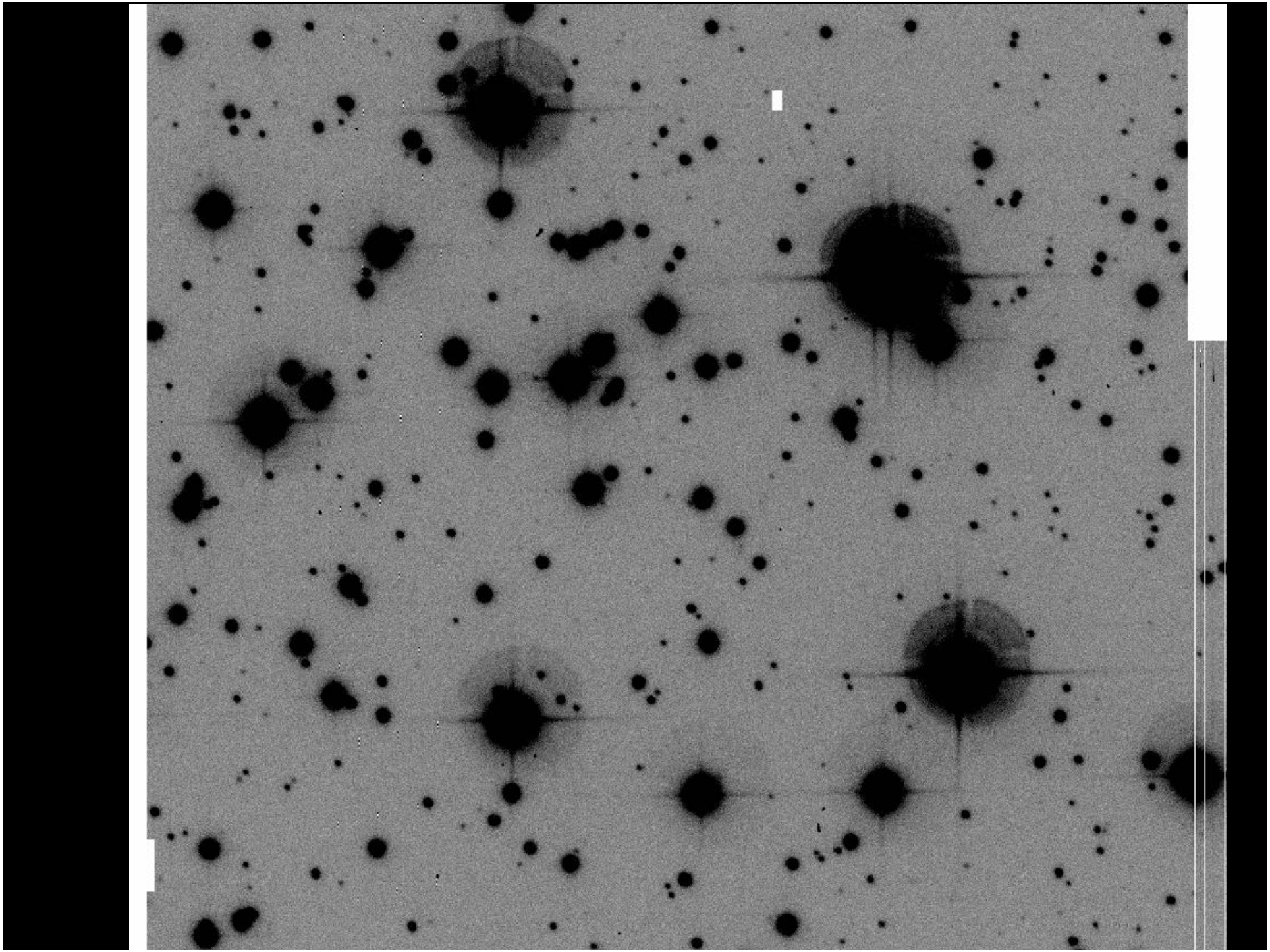
Note size of PanSTARRS
Gpix camera

CFHT MegaPrime
36 2kx4k CCDs



Closeup of one CCD; note poor quality. Next slide is portion of this; note good images





Near Infrared Arrays

- First InSb 58x62 1990's
- Now 4kx4k
- VERY expensive
- Comsumer-level 640x480 available due to telecommunications industry

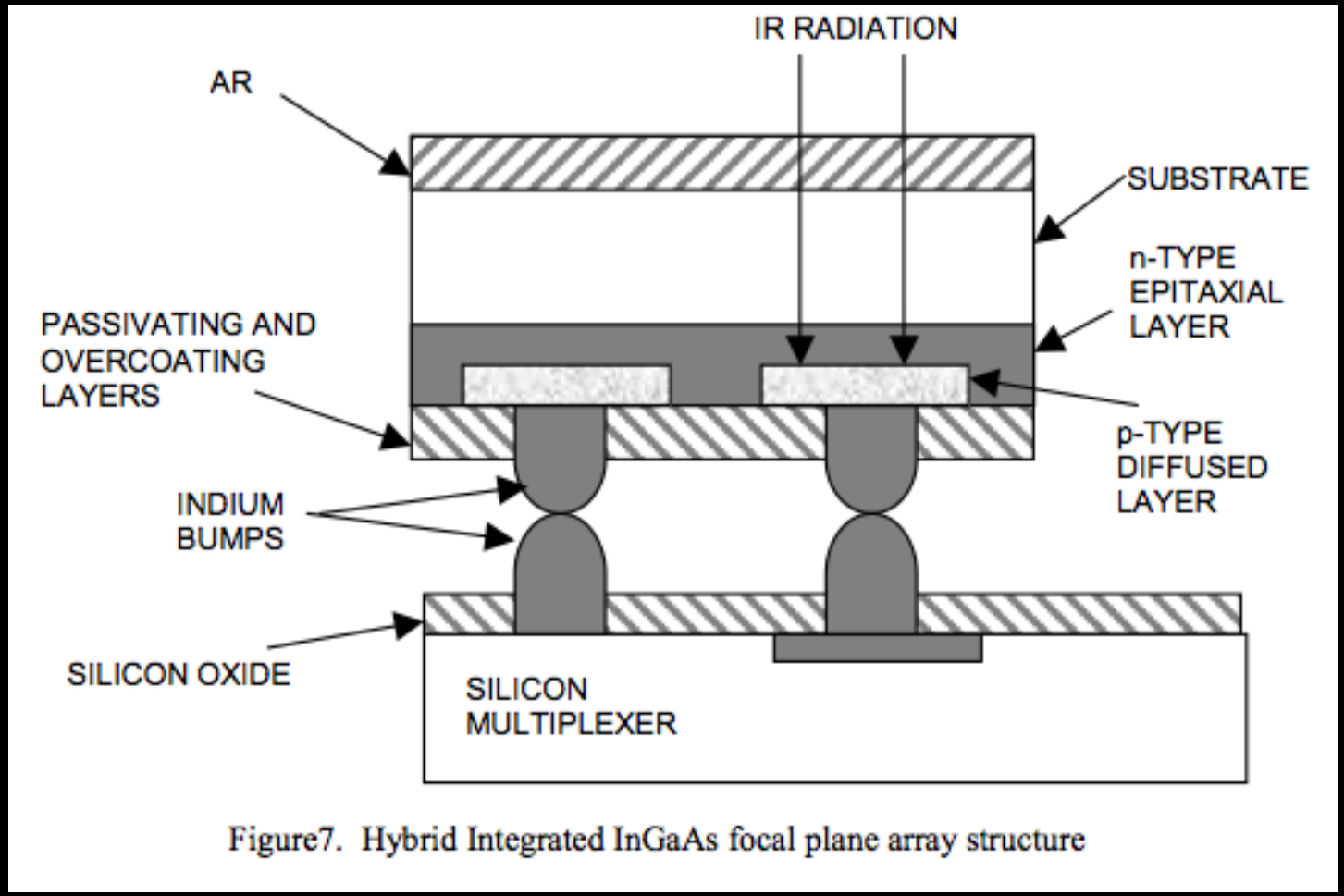
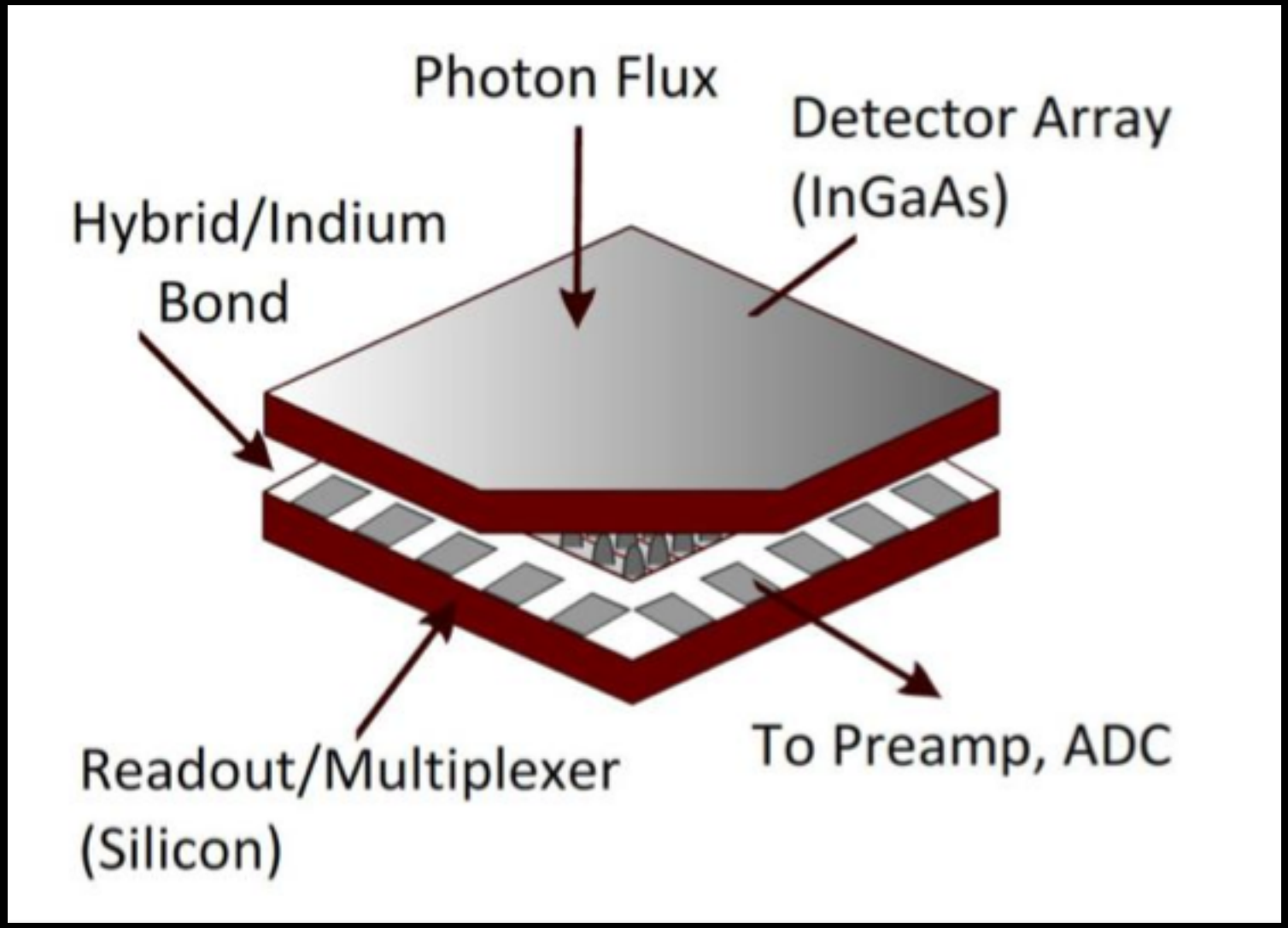
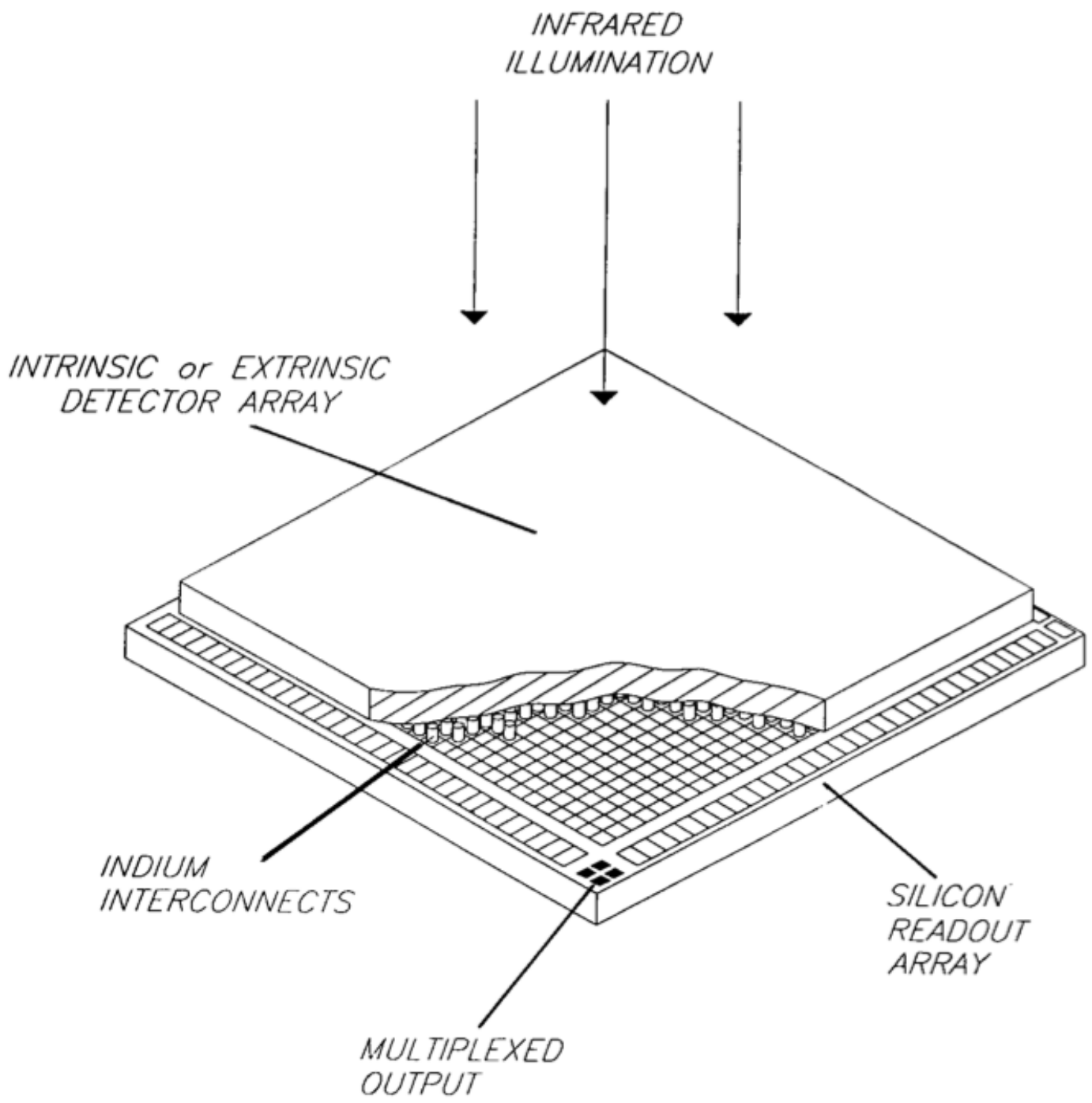


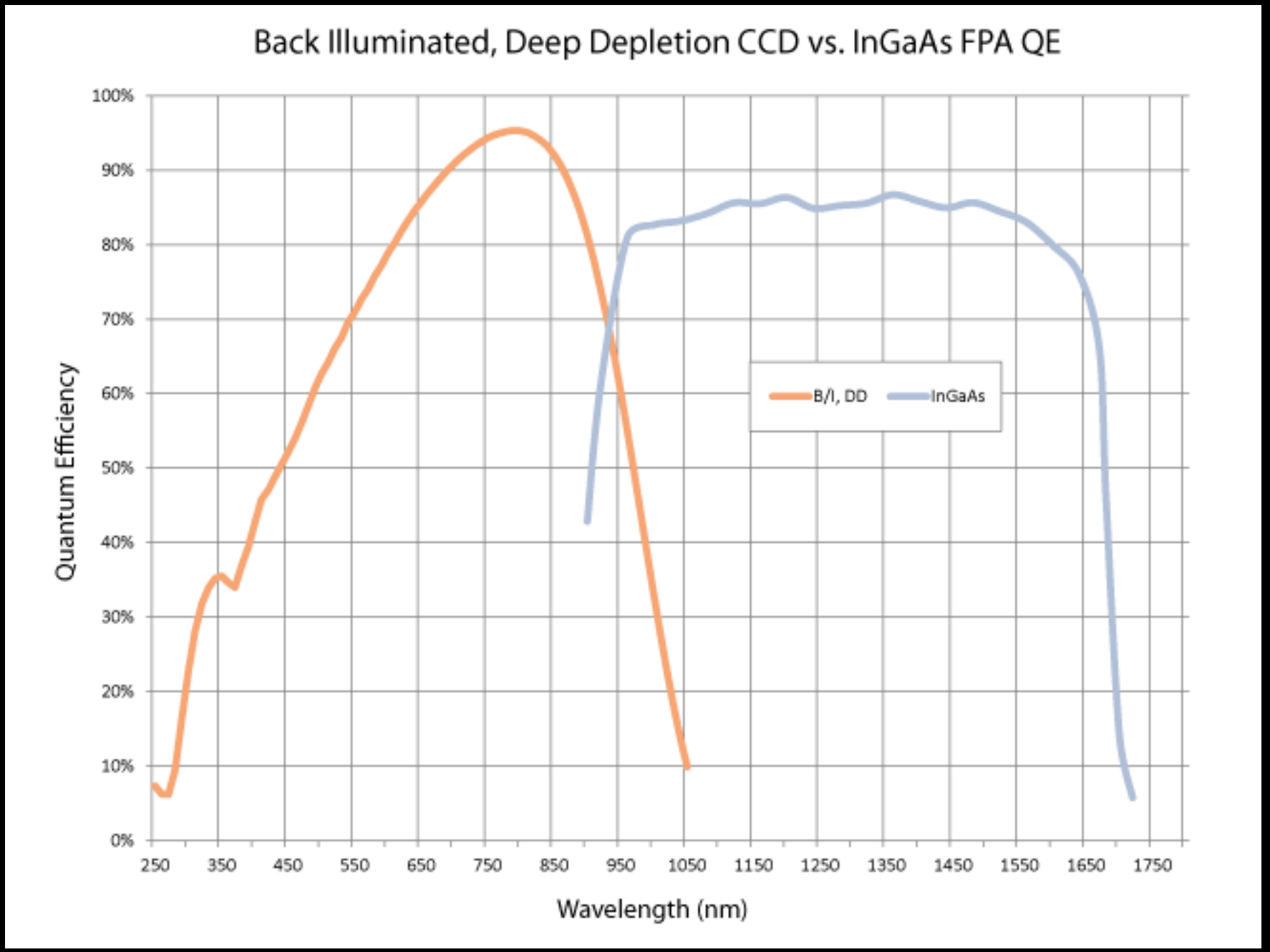
Figure7. Hybrid Integrated InGaAs focal plane array structure

Side view of indium bumps/hybrid

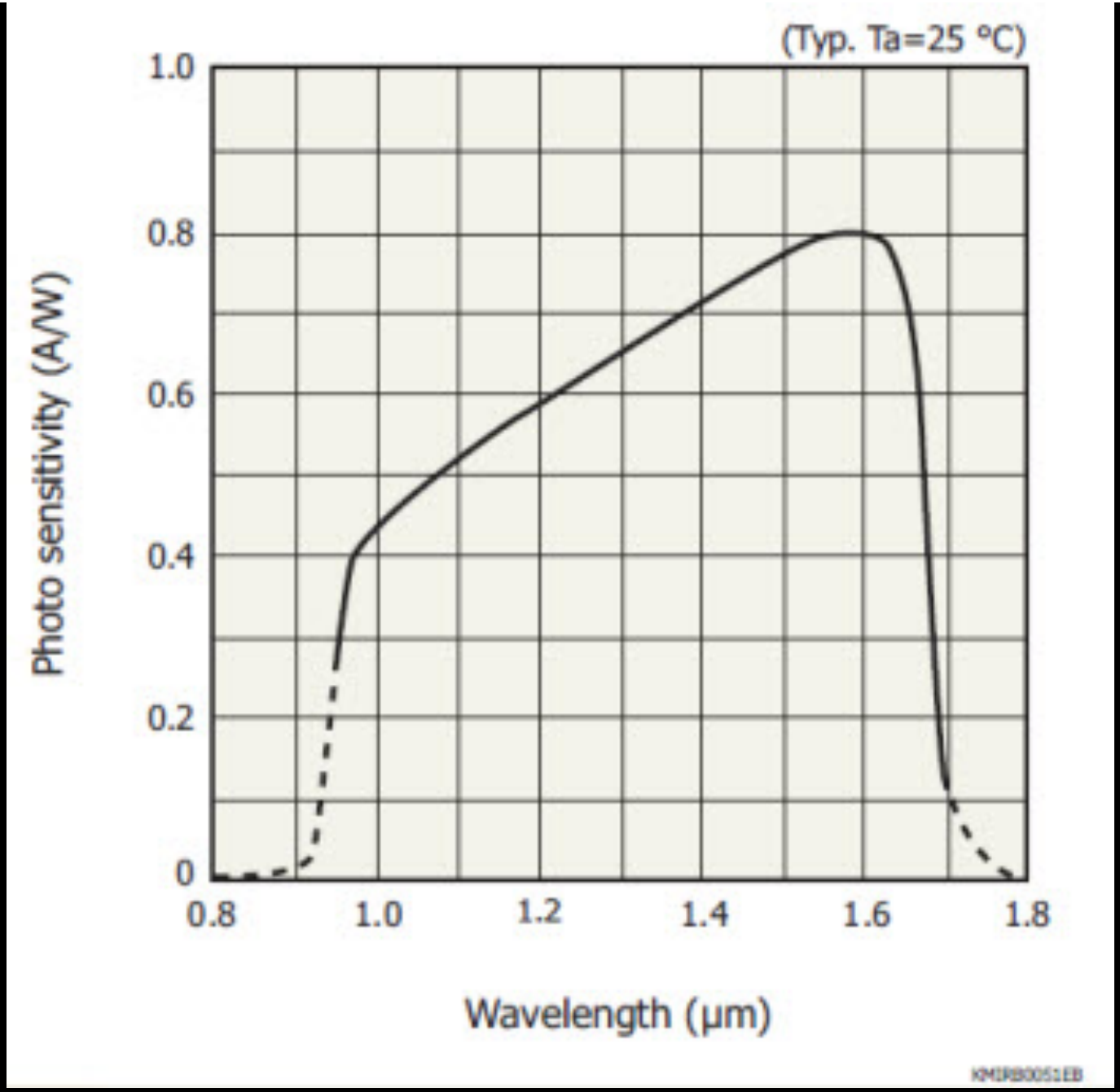


Bump-bonding cartoon

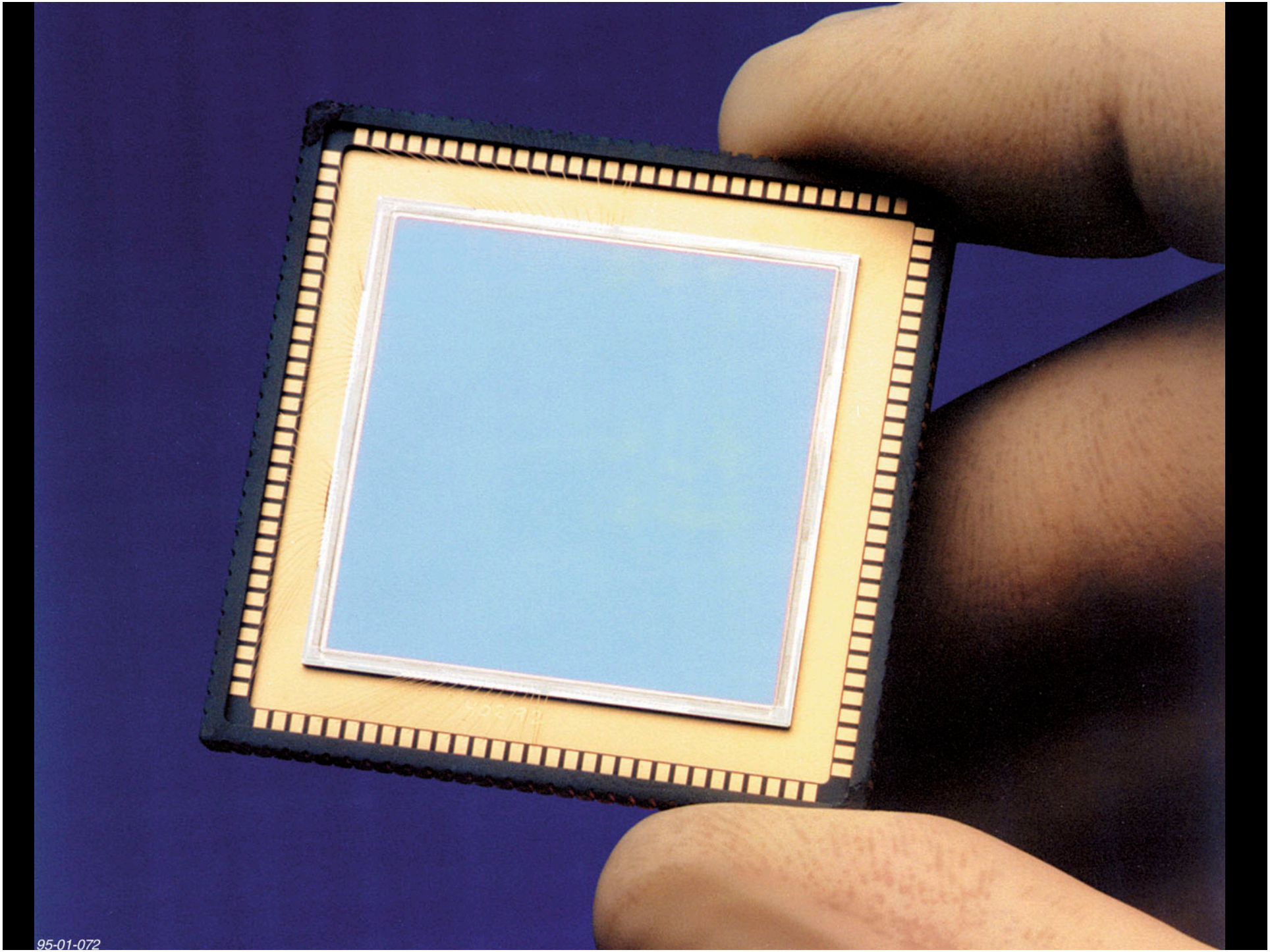

INFRARED
ILLUMINATION
INTRINSIC or EXTRINSIC
DETECTOR ARRAY
INDIUM
INTERCONNECTS
SILICON
READOUT
ARRAY
MULTIPLEXED
OUTPUT

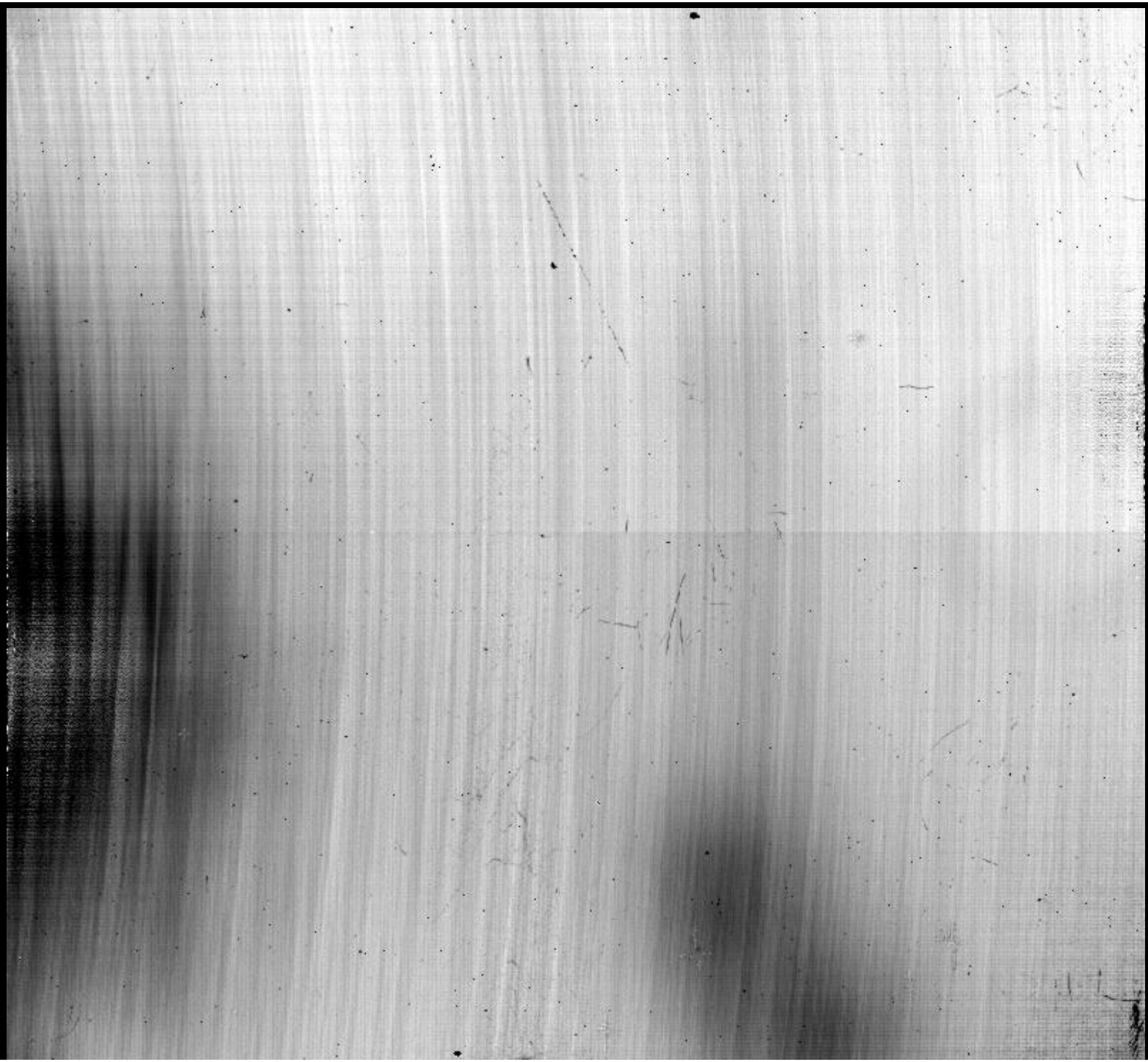


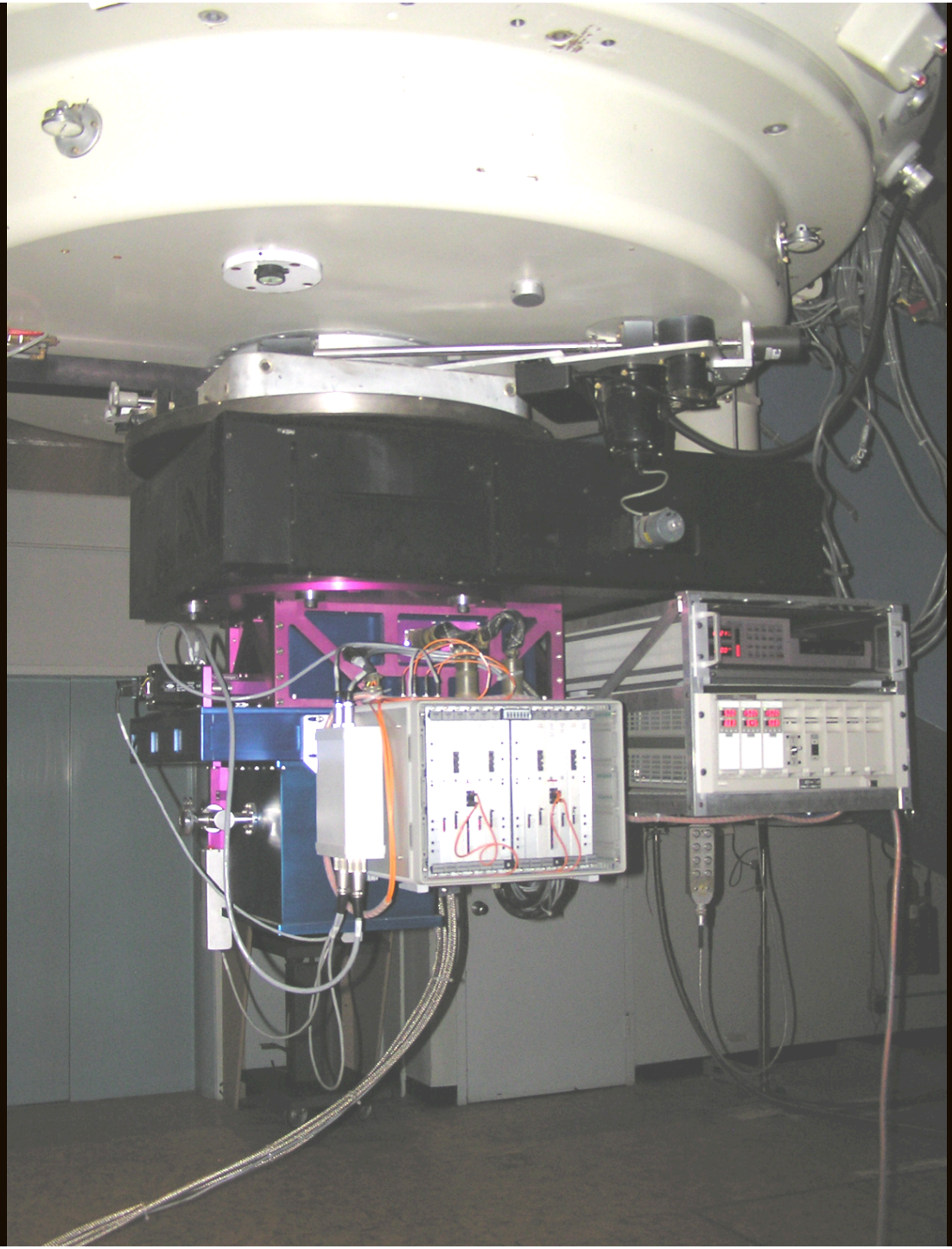
CCD vs. InGaAs

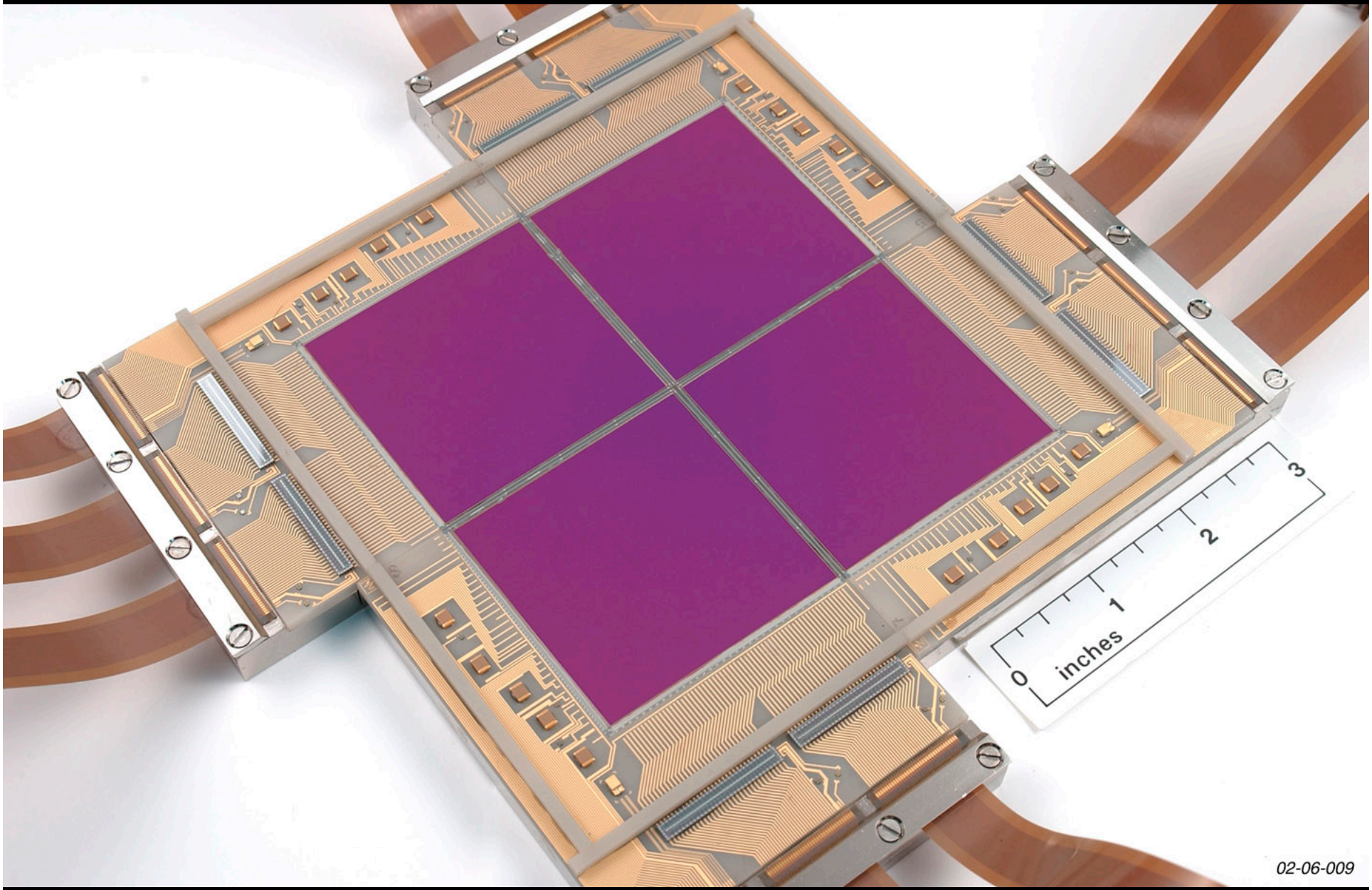


Typical InGaAs photodiode response

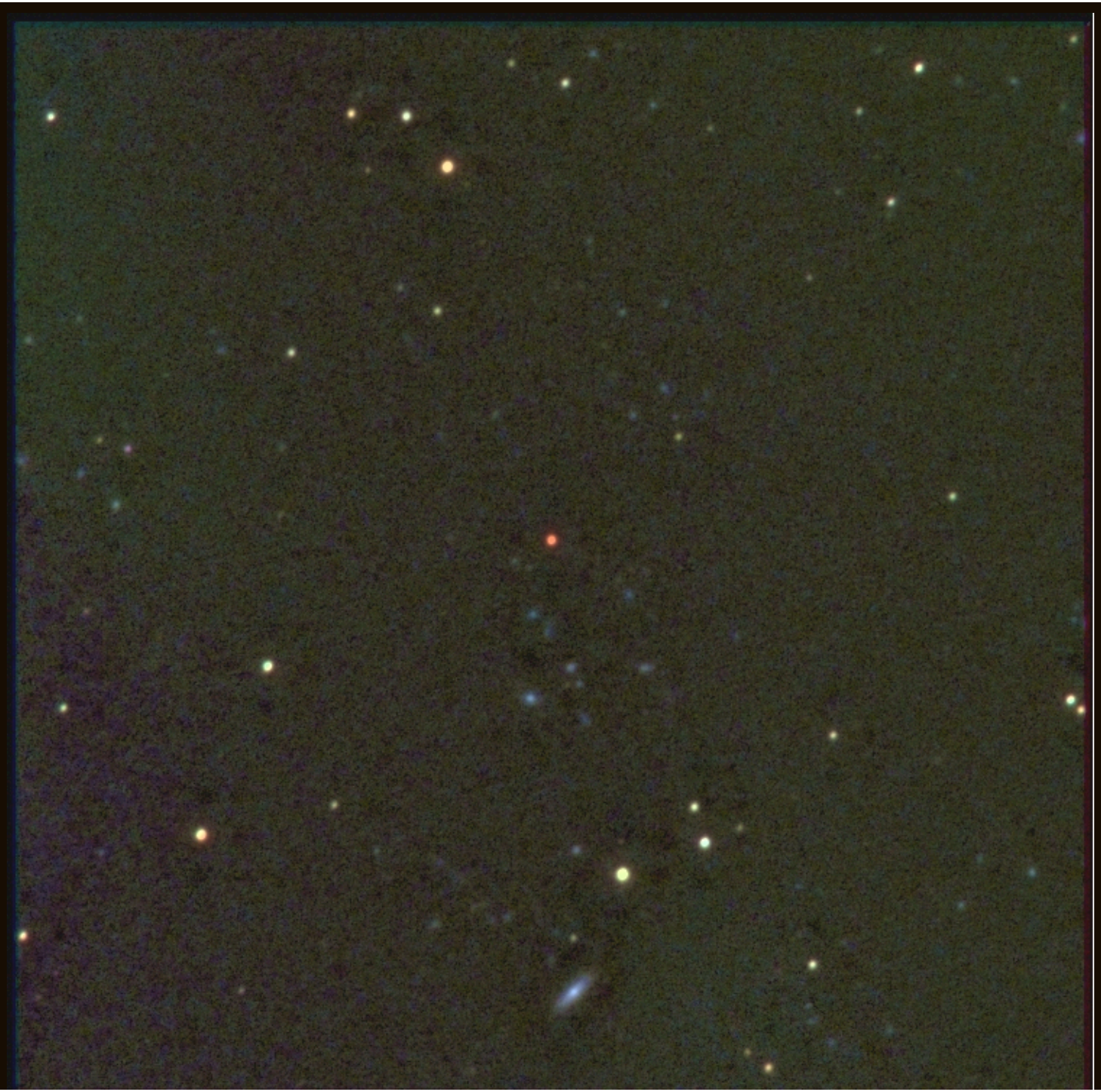

95-01-072





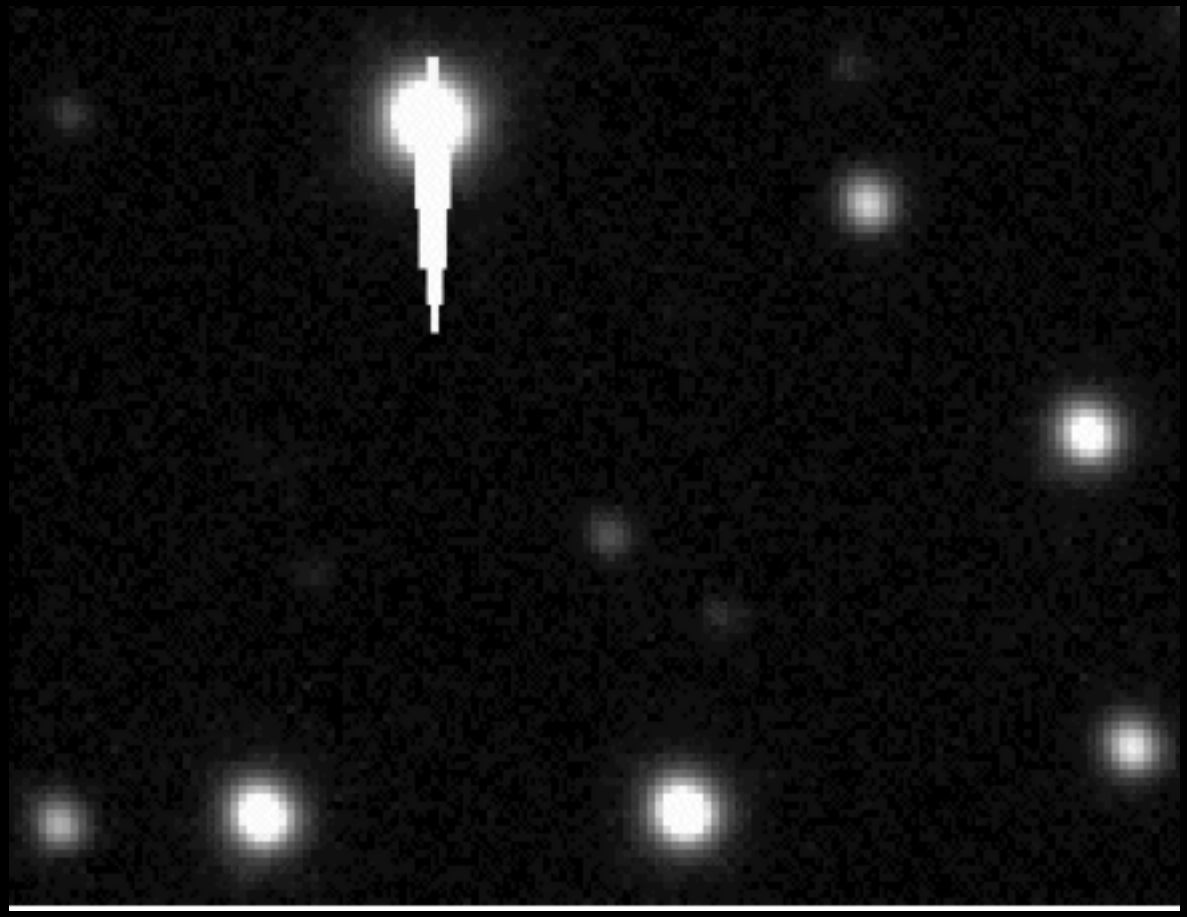

0
inches
1
2
3
02-06-009

2m0415 brown dwarf



Observing defects

- Blooming
- Fringing
- Cosmic rays
- Saturation (watch binning)
- Airplanes/satellites



Typical blooming

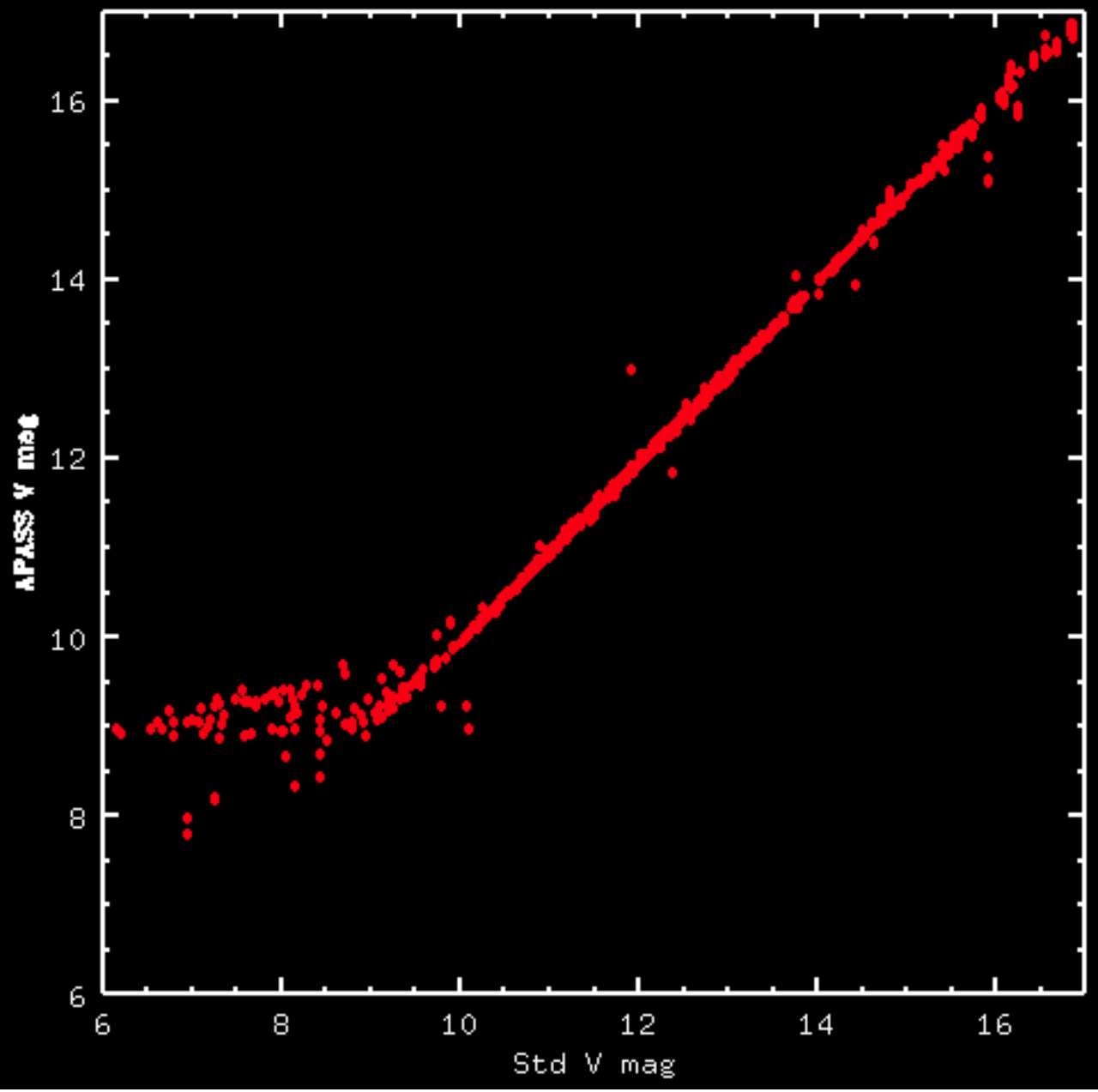
Vapass vs. Vlandolt

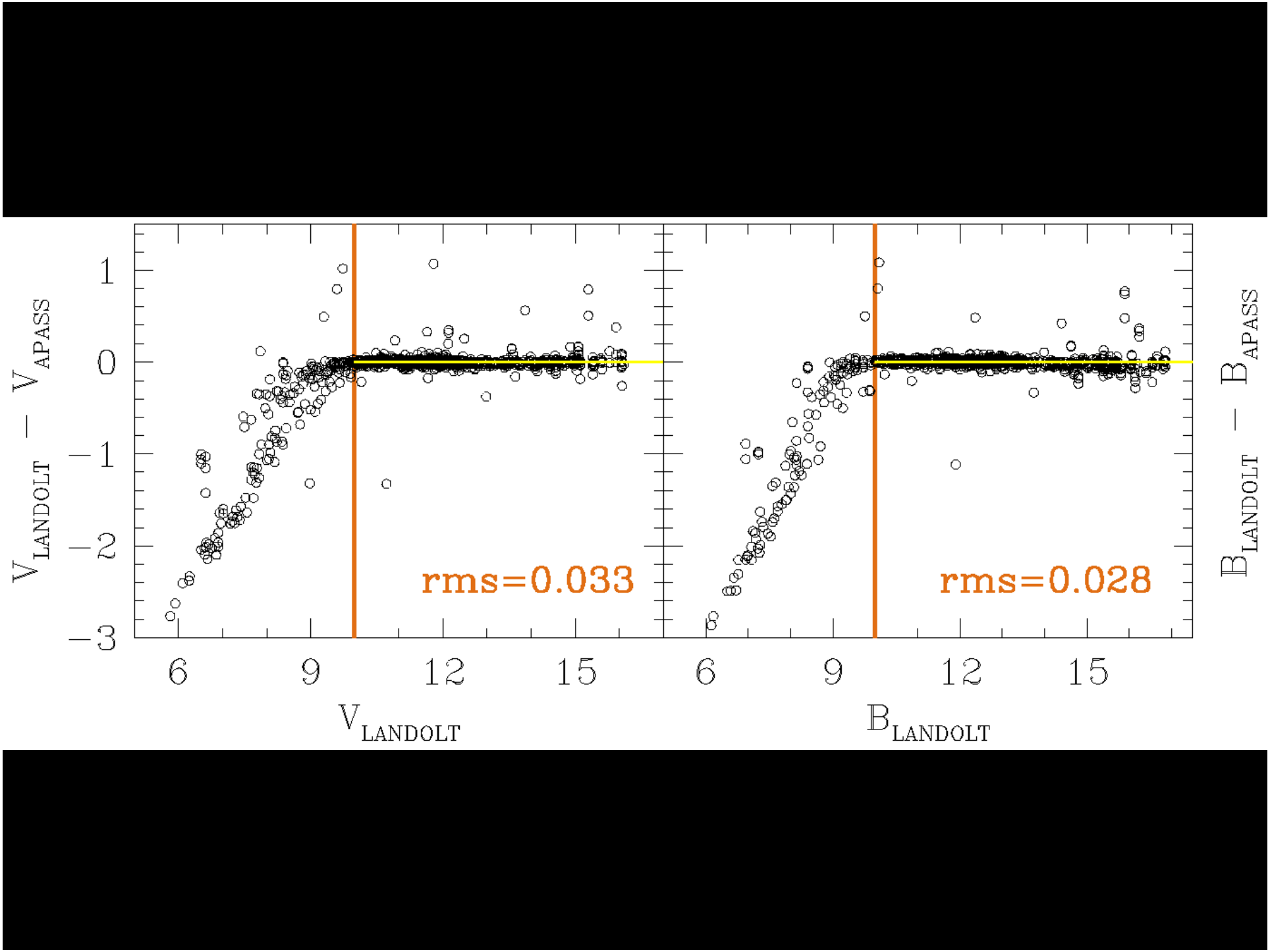
ABG means all saturated stars have ~same mag

Faint limit 16.5 for Standard fields (short exposure)

Some blends, mis-identified stars

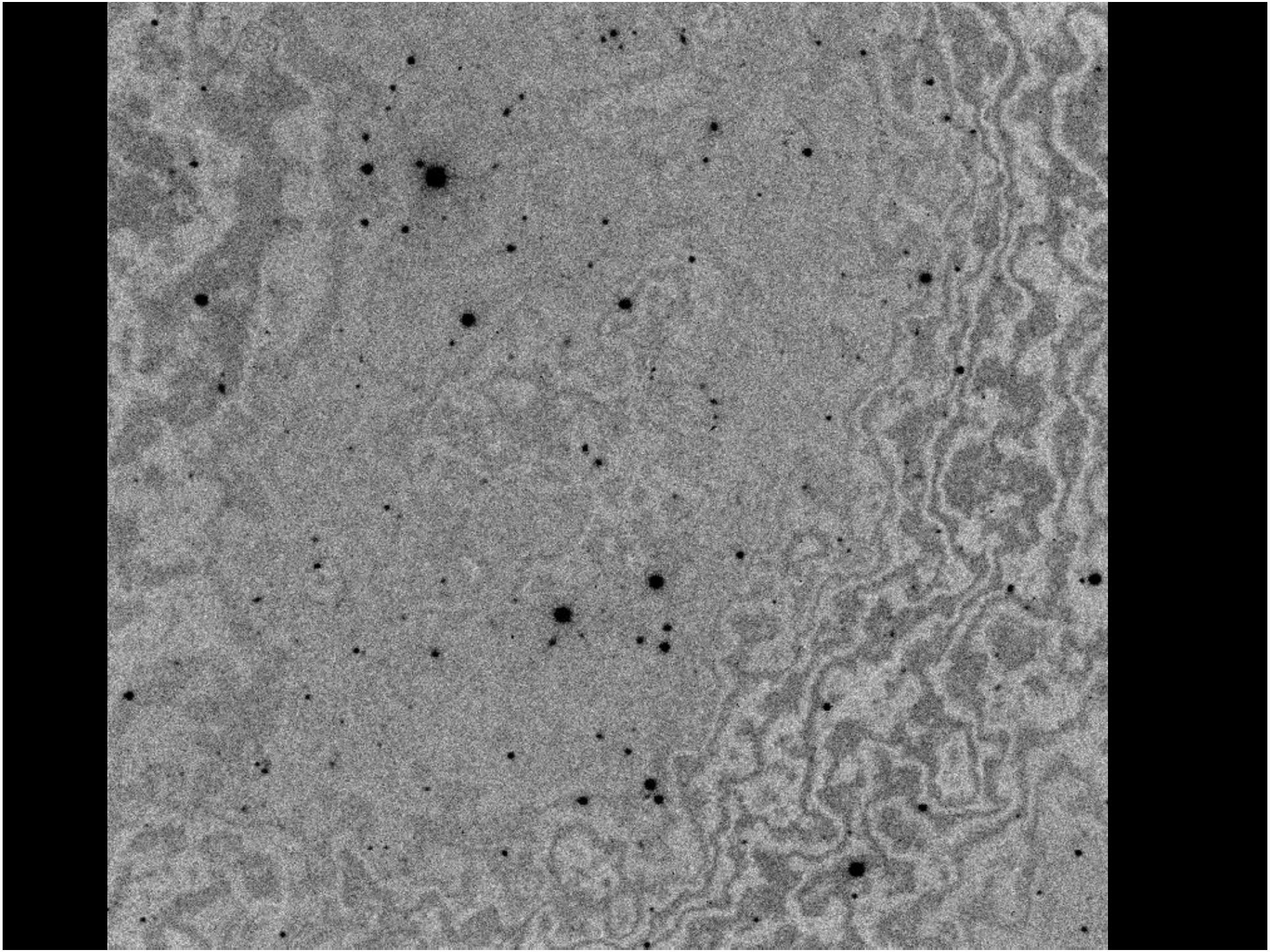
These are all transformed magnitudes; all DR5 is on standard system

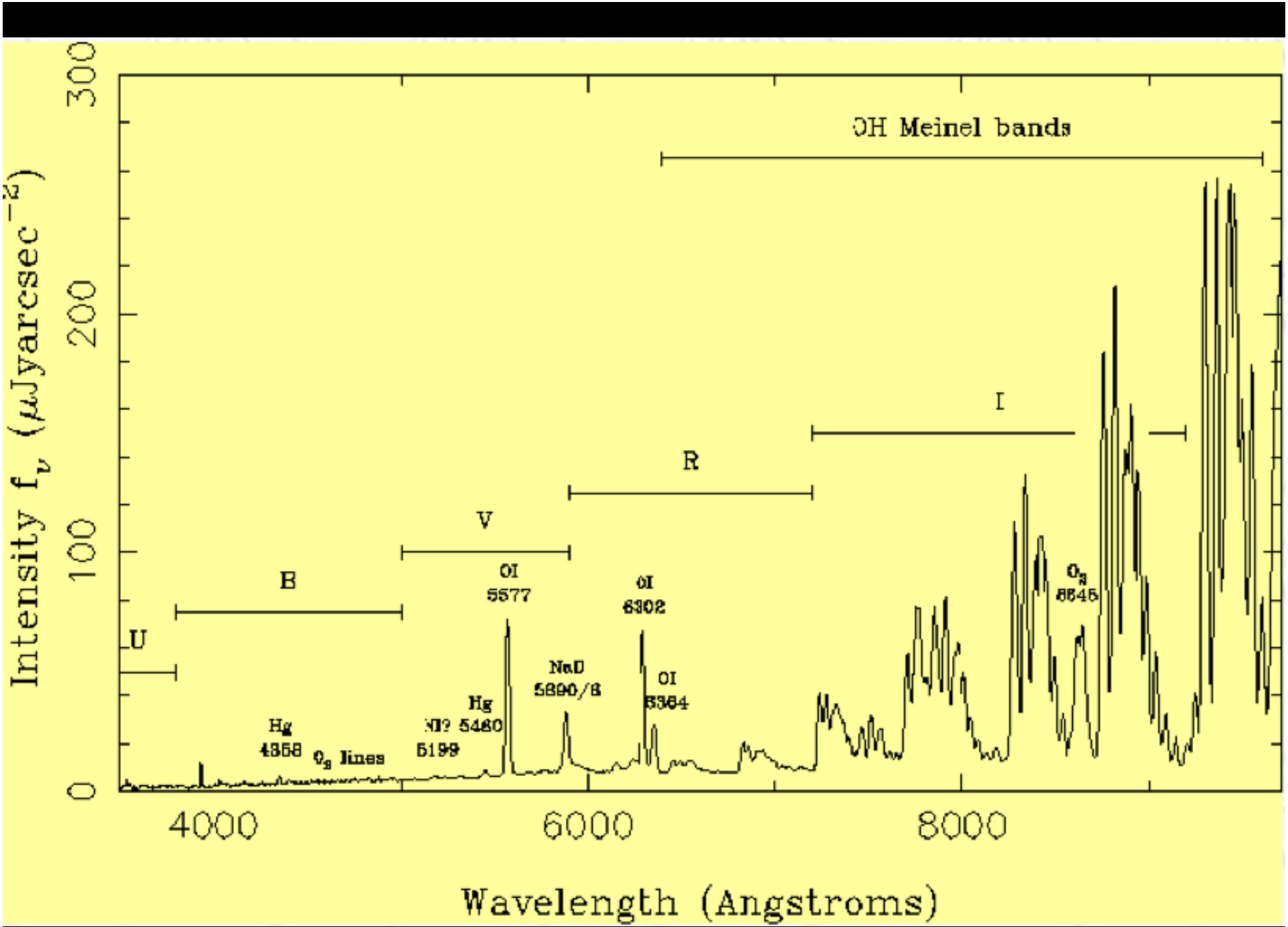



rms=0.033
rms=0.028
V_LANDOLT − V_APASS
B_LANDOLT − B_APASS
V_LANDOLT
B_LANDOLT
1
0
−1
−2
−3
6
9
12
15

Fringing

- Due to interference effects
- Primarily seen on back-illuminated CCDs
- Primarily seen at longer wavelengths
- Night sky lines, aurora




OH Meinel bands
U
B
V
R
I
OI
5577
OI
6302
NaD
5890/6
OI
6364
O2
6545
Hg
4358
O2 lines
NI? 5460
5199
Hg
Intensity f_ν (μJyarcsec^-2)
0
100
200
300
4000
6000
8000
Wavelength (Angstroms)

Cosmic Rays

- Really radiation events; true cosmic rays penetrate meters of material
- Typically 200 events/cm2/hr
- Typically few pixels involved
- Can be enhanced by beta rays from high potassium glass (BK7), radioisotopes in concrete
- Non-gaussian profile, don’t look like stars
- Remove by median filter or point filters