Light Microscopy Course 2008

Charge - coupled devices - CCD's

The human eye as a detector of light

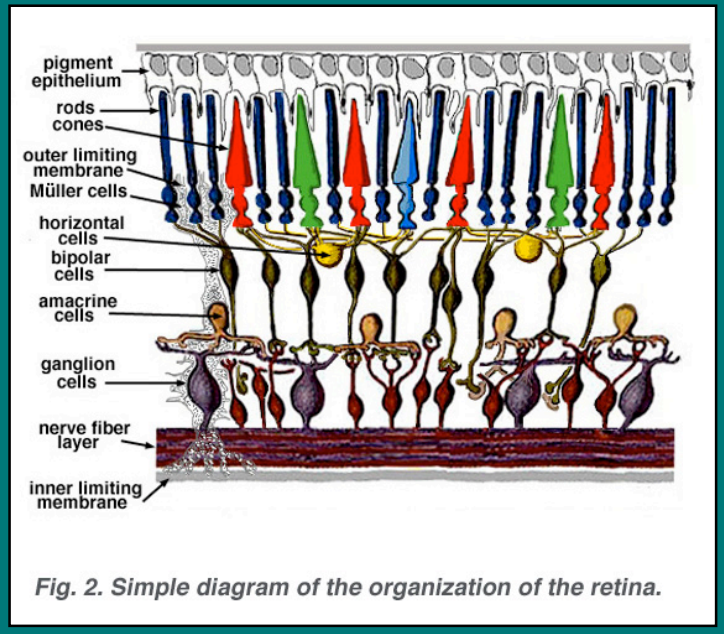


Fig. 2. Simple diagram of the organization of the retina.

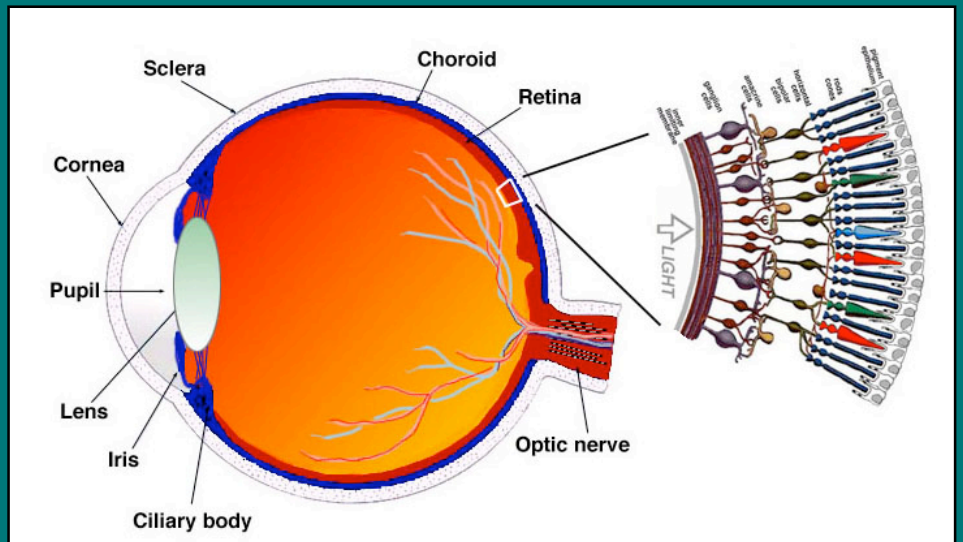
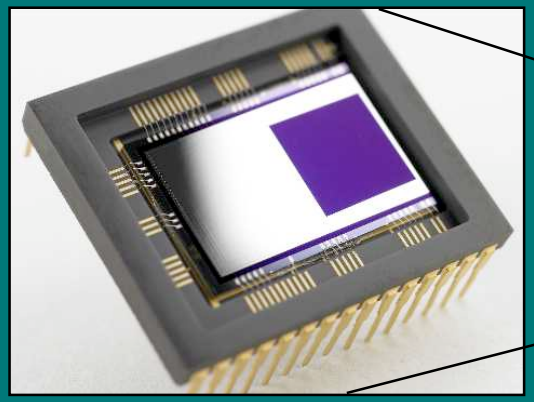


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

Charge-coupled devices as detector of light



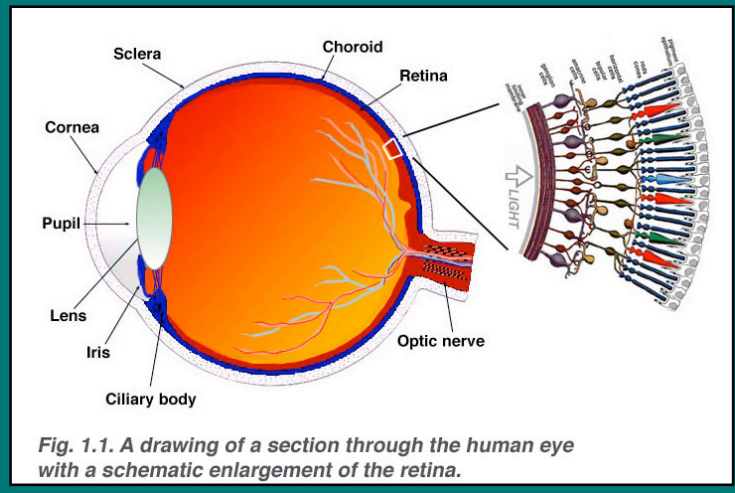
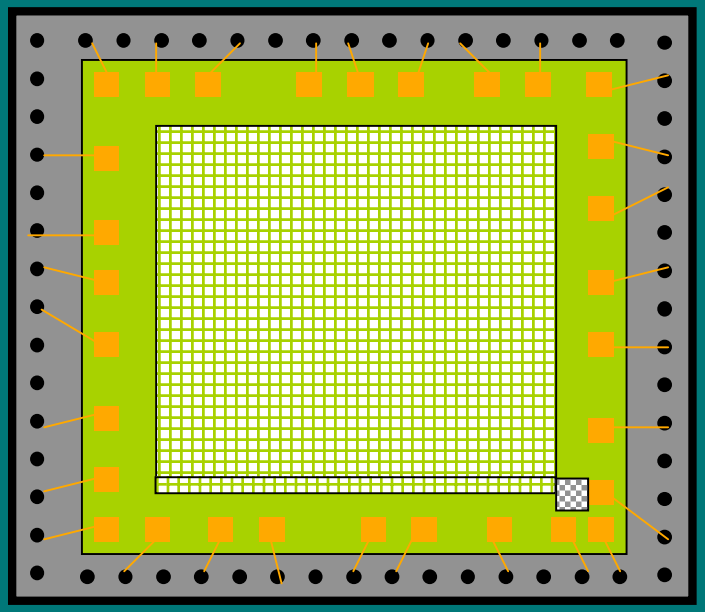
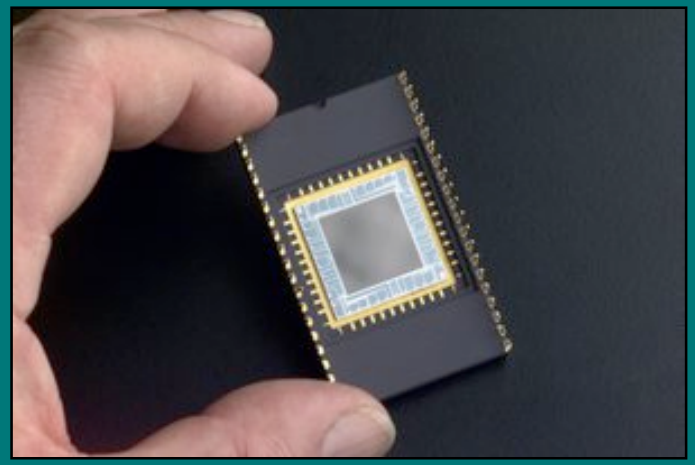
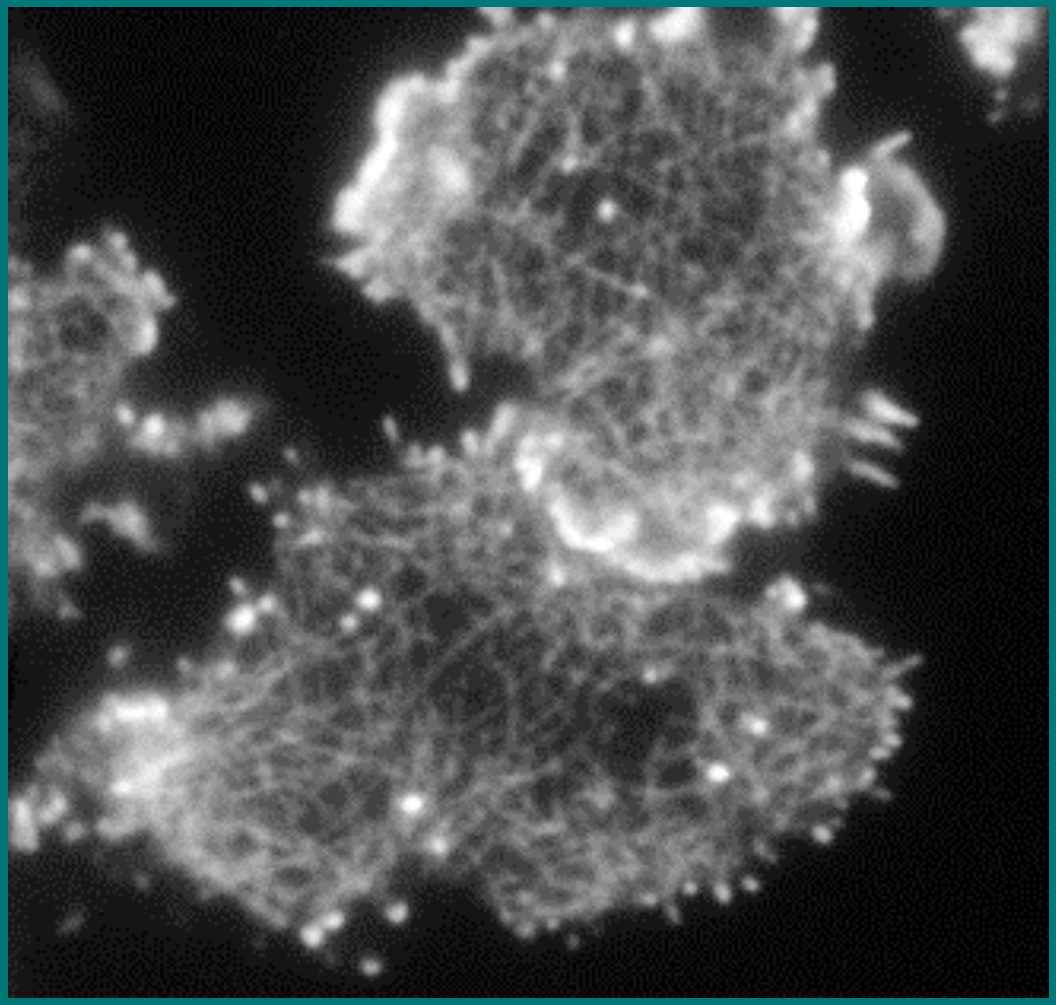


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.



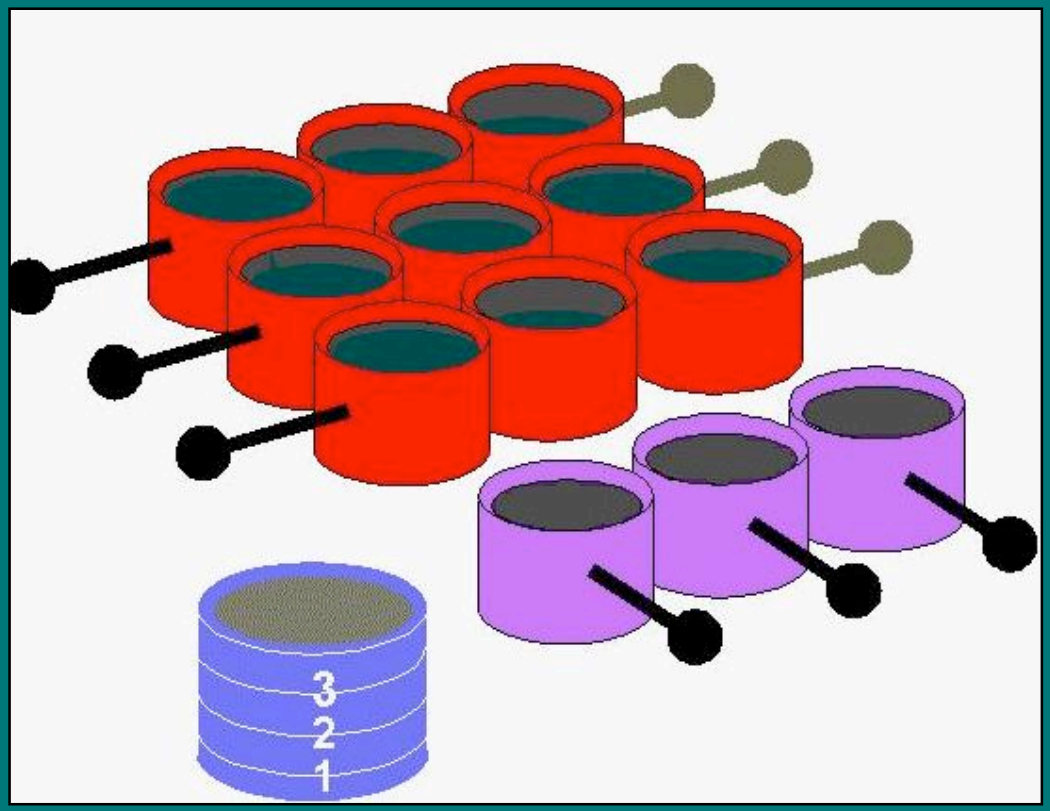


Charge-coupled devices as detector of light



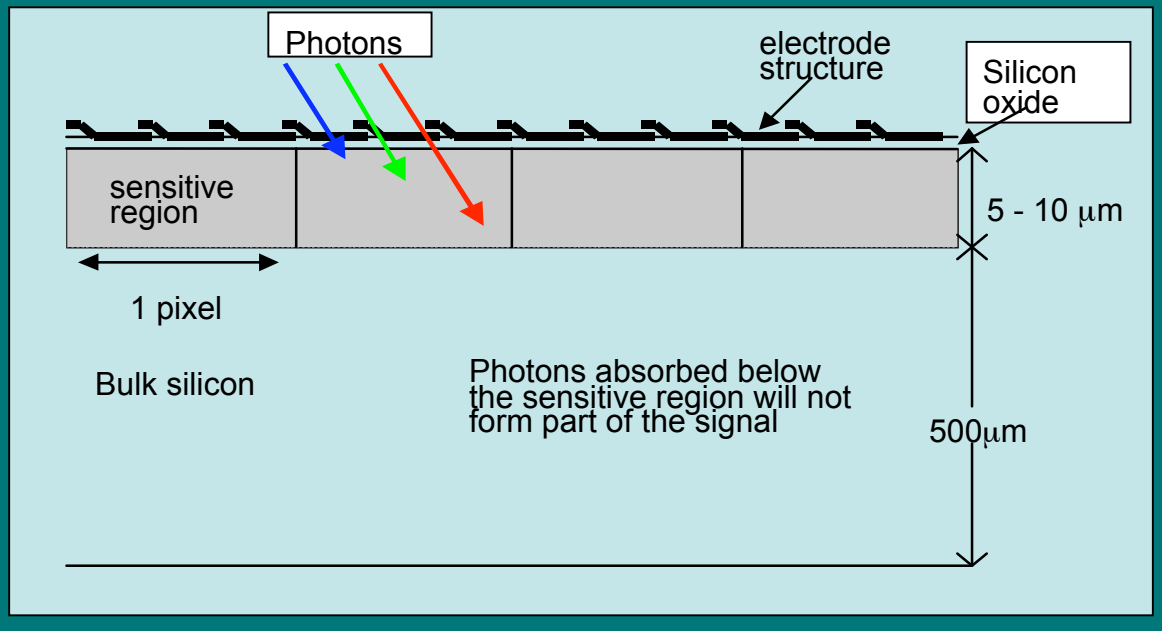
How a CCD works - basic principle

- The bucket array analogy



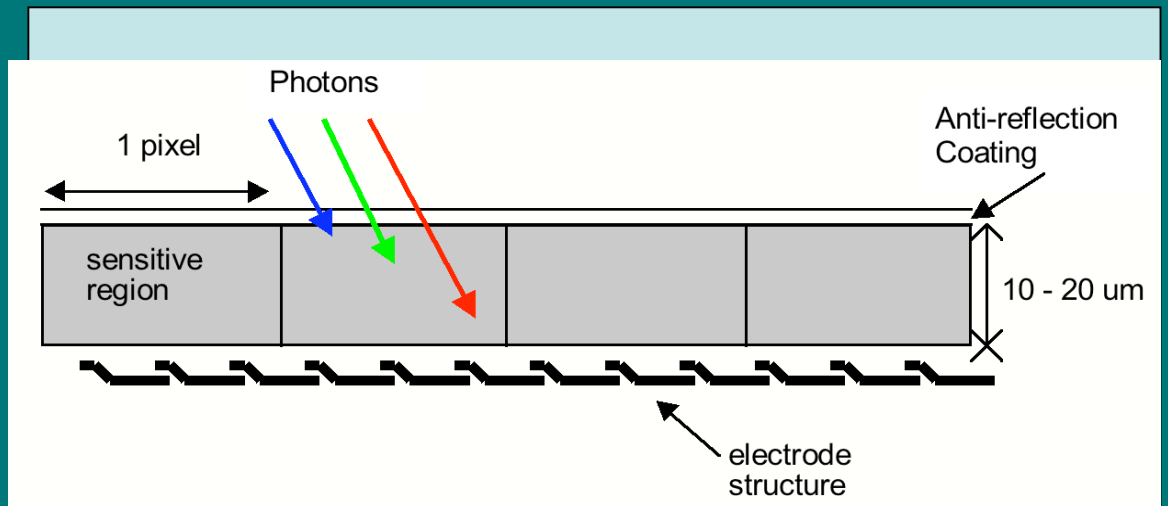
How a CCD works

- Photons incident on sensitive region of CCD generate electrons or photoelectrons
- Photoelectrons are stored in regions called Pixels
- Photoelectrons kept in pixels by an electric field
- Storage capacity of pixels ranges from 10,000 electrons to 1,000,000 electrons
- Electrodes enable the photoelectrons to be moved around the CCD



How a CCD works - back-thinned CCD

- The CCD is turned upside down and the bulk silicon is ground down
- The back side of the CCD can be more readily anti-reflected coated to reduce surface reflection losses (~4% per surface)

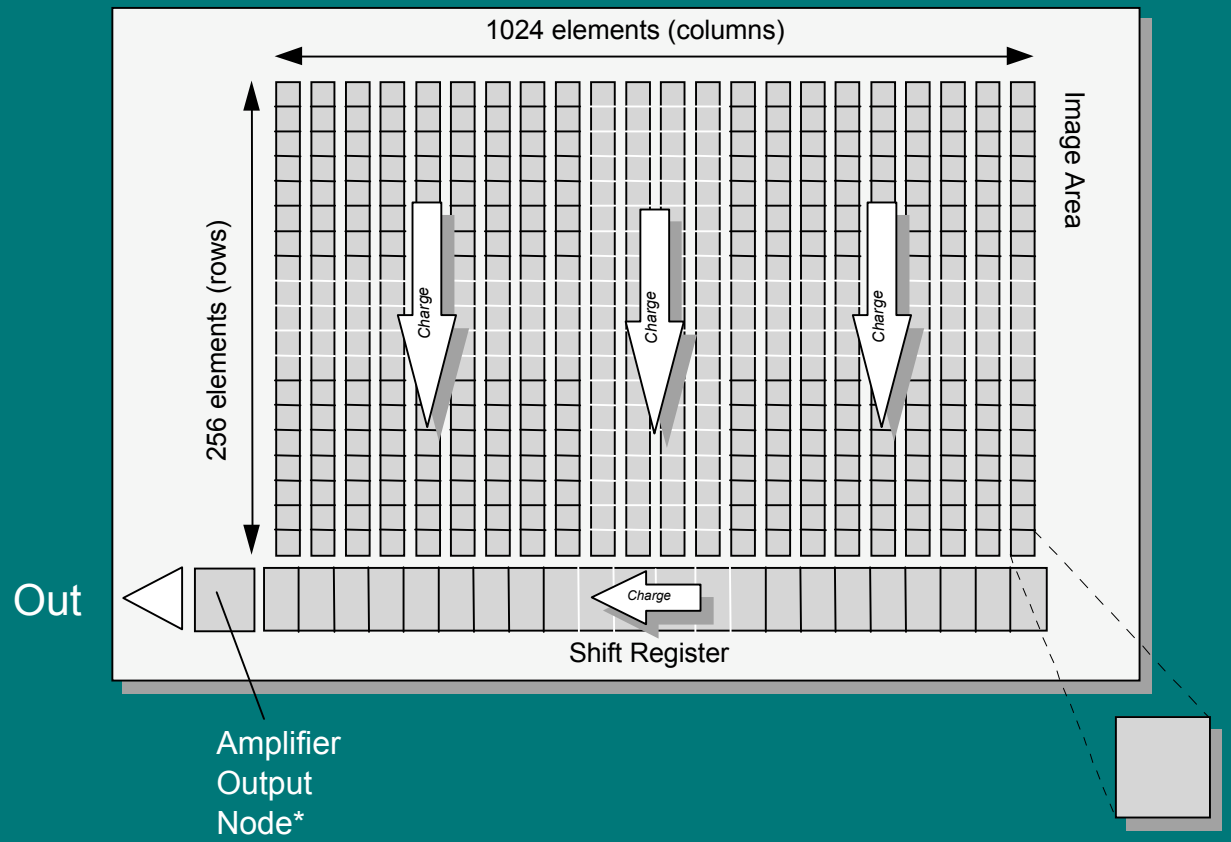


CD

CCD 2D-Structure

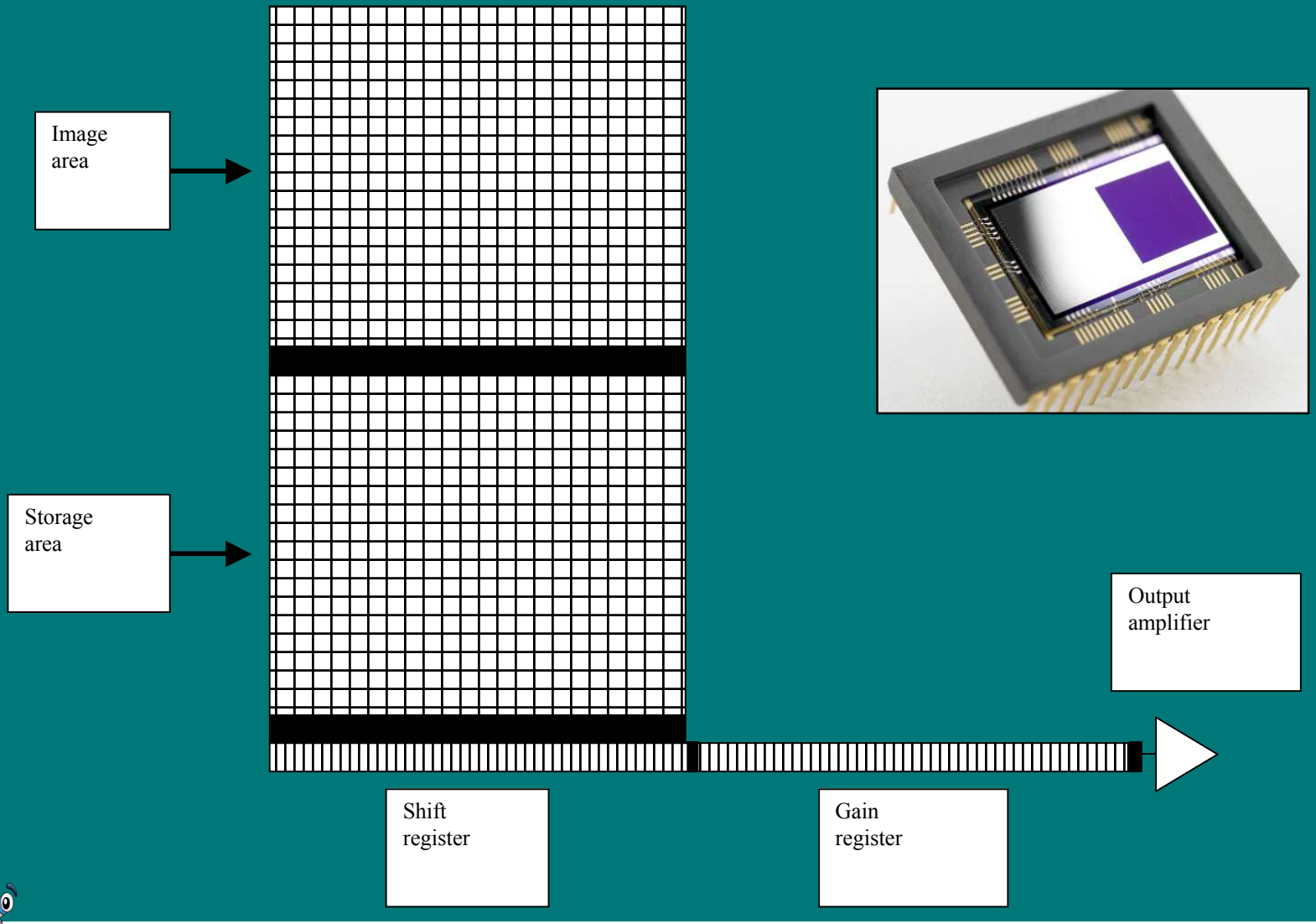
Typical CCD Chip

Specification (no./size of pixels, etc.) varies according to chip model



**Charge that is output from the shift register may be summed either on- or off-chip, depending on the chip model.*

Frame Transfer CCDs



What makes a detector sensitive?

Two key parameters:

- **Quantum Efficiency**

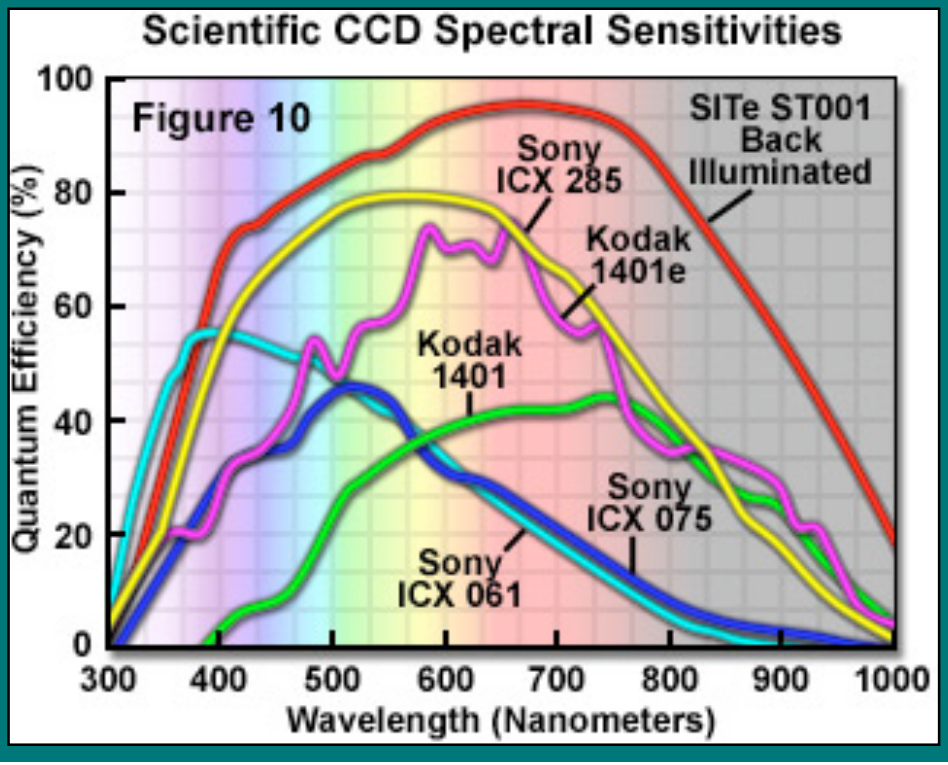
- **Noise**

✓ ***Camera must be <u>designed</u> to ensure these parameters are optimised.***

Quantum efficiency and Spectral response

- QE: measure of a detector's ability to produce an electronic charge as percentage of the total number of incident photons detected

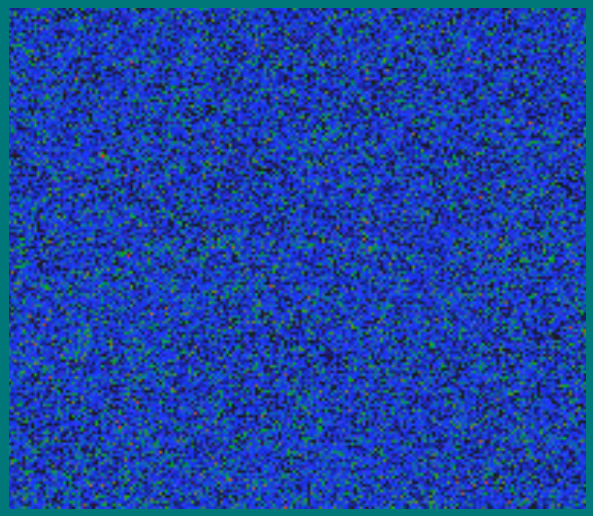
- SR: detected signal response as a function of wavelength of light

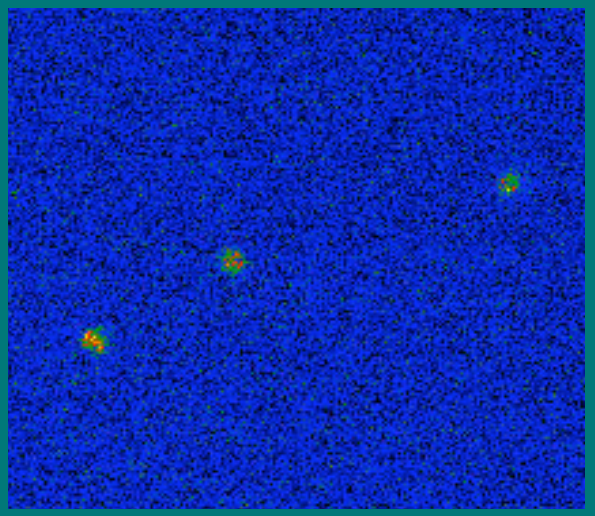


Camera sensitivity and noise

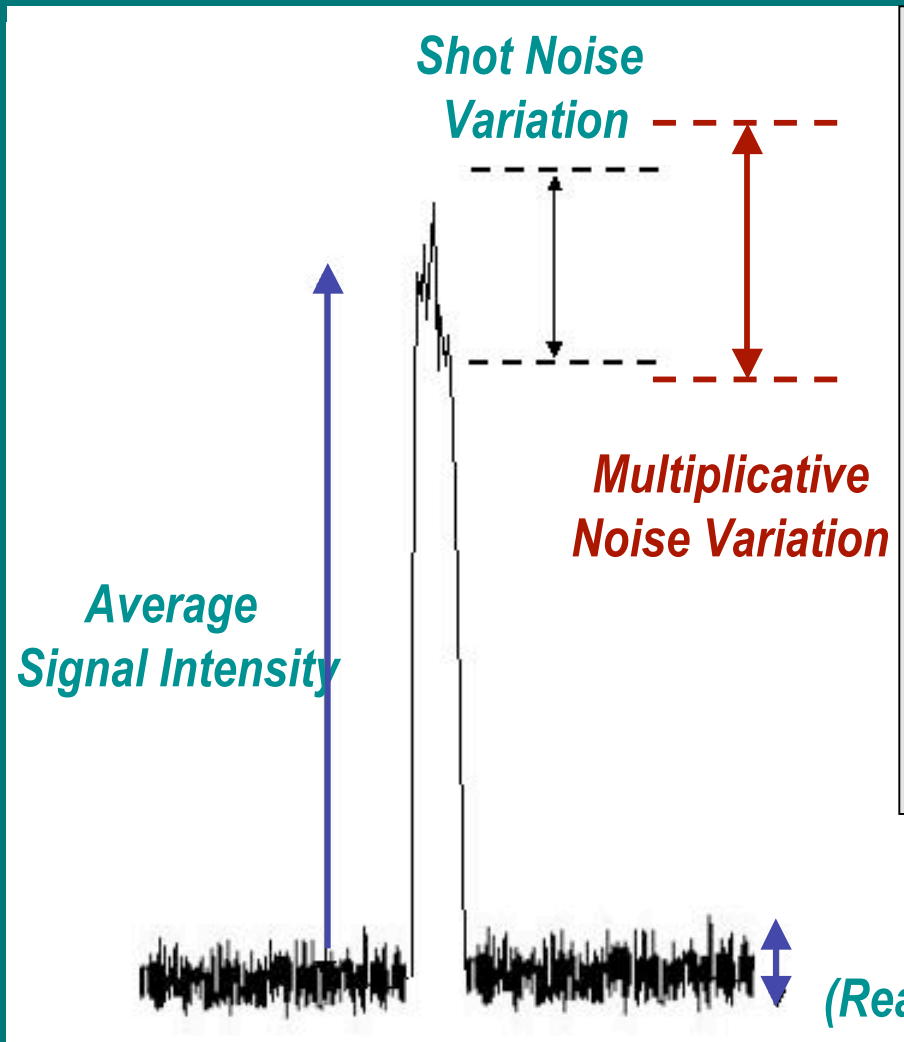
- C. S. lowest detectable light signal

- depends on Q. E. and noise





Principle Noise Sources



- **Read noise**

  True CCD detection limit.

- **Dark current**

  Dependent on temperature

- **Shot Noise**

  QE and signal dependent.

Overall CCD Noise

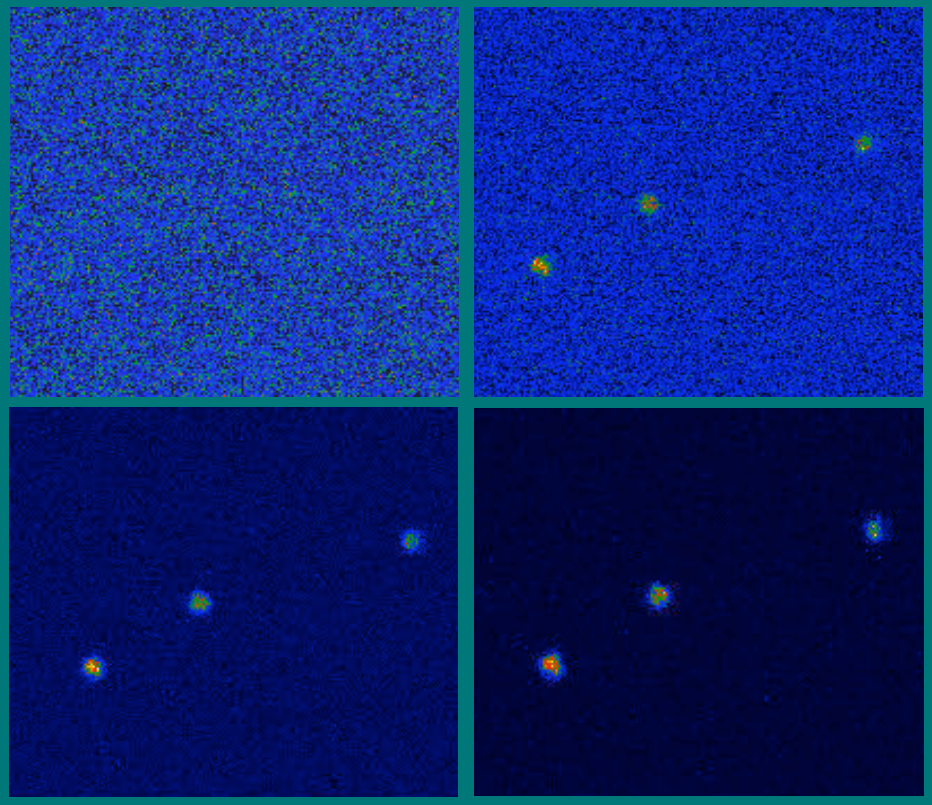
$$\sqrt{(\mathrm{Re}\,adNoise)^2 + (DarkNoise)^2 + (ShotNoise)^2}$$

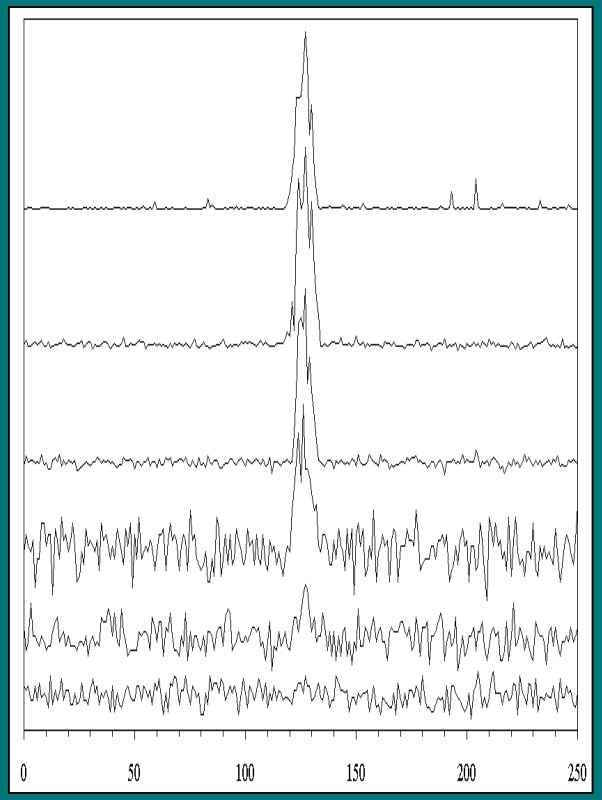
- **Read noise** – given in CCD specs, higher at faster pixel readout rates.
- **Dark Current** – given in CCD specs, reduces with sensor cooling. Depends on exposure time (e^-/pixel/sec)
- **Shot Noise** $= \sqrt{Signal}$

Signal/Shot Noise ratio $= \dfrac{Signal}{\sqrt{Signal}} = \sqrt{Signal}$

Signal-to-noise ratio: S/N

- Ratio of detected light signal to system noise





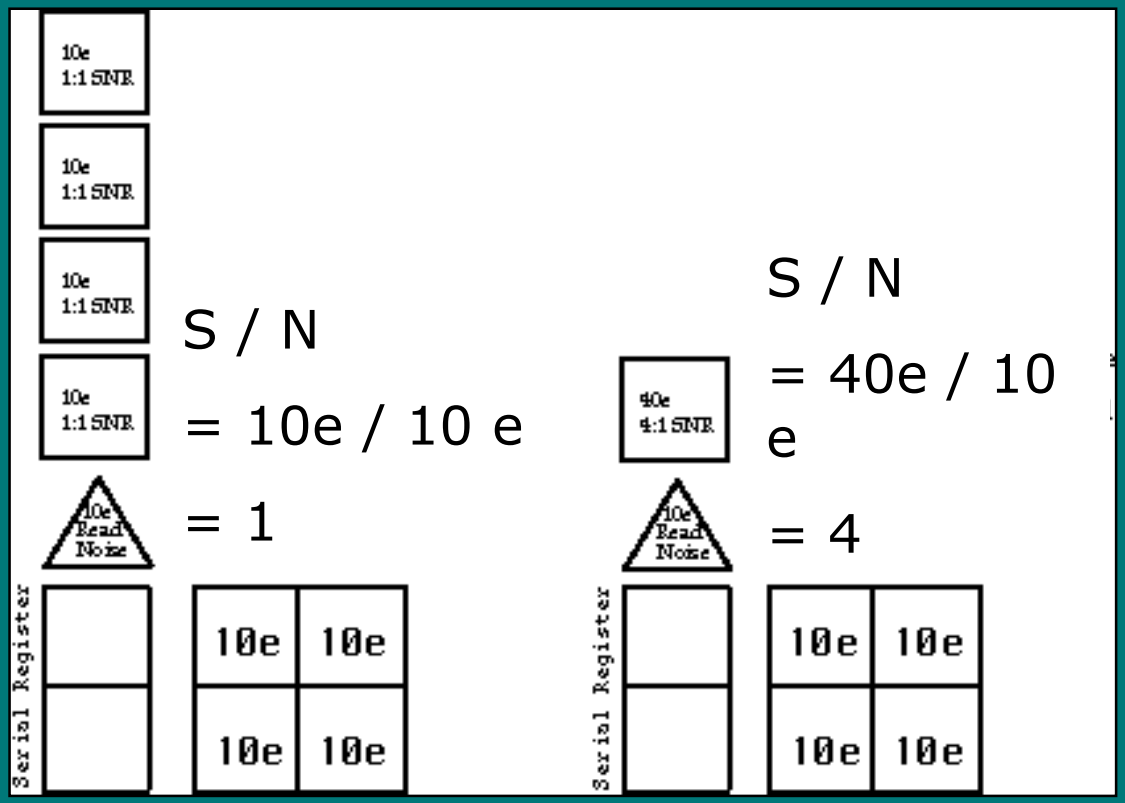
Full well capacity and dynamic range

- FWC: maximum number of electrons a pixel can store
- D.R. = FWC / detection limit (ie read noise)

Pixel size in um x um	Full well capacity	Read noise electrons	Dynamic range
8 x 8	40 000	20	2 000
10 x 10	35 000	12	2 917
16 x 16	200 000	7	28 571
26 x 26	510 000	4	127 500

Binning

- reading out adjacent pixels as one
- decreases # of pixels and spatial resolution
- increases S/N and speed



More CCD vocabulary

- ROI, sub-array, sub-window
  - Region of interest: selected subset of a sample

More CCD vocabulary

- ROI, sub-array, sub-window
- Exposure time: time for collecting photons

More CCD vocabulary

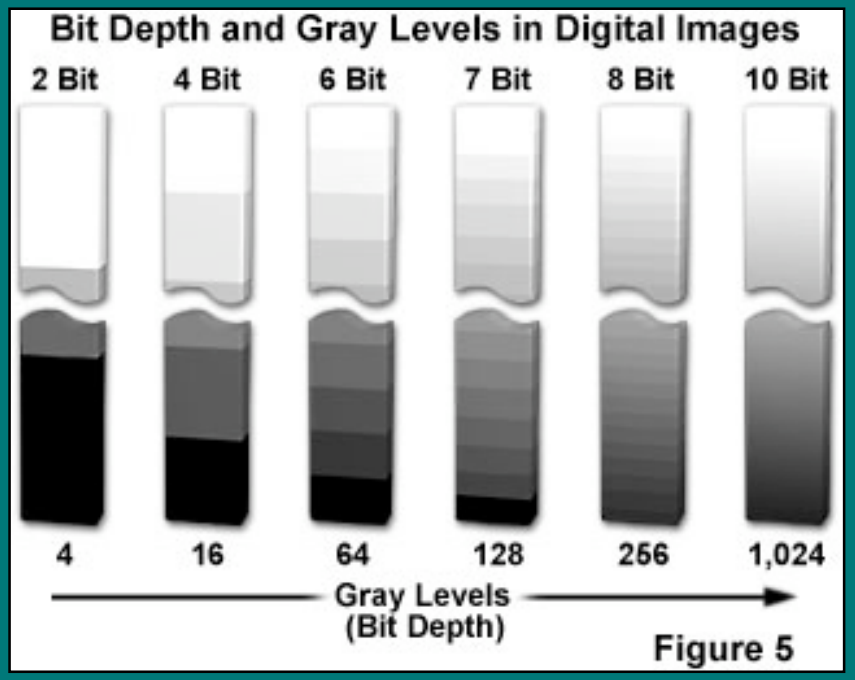
- ROI, sub-array, sub-window
- Exposure time: time for collecting photons
- Read out time: time for reading out charge
  - Depends on # of pixels and digitization speed

More CCD vocabulary

- ROI, sub-array, sub-window
- Exposure time: time for collecting photons
- Read out time: time for reading out charge
- Frame rate: number of frames/second

More CCD vocabulary

- ROI, sub-array, sub-window
- Exposure time: time for collecting photons
- Read out time: time for reading out charge
- Frame rate
- Bit depth:
  - max. possible number of gray levels given by detector



More CCD vocabulary

- ROI, sub-array, sub-window
- Exposure time: time for collecting photons
- Read out time: time for reading out charge
- Frame rate
- Bit depth
- Gain: intensity resolution
  - electrons per intensity count

More CCD vocabulary

- ROI, sub-array, sub-window
- Exposure time: time for collecting photons
- Read out time: time for reading out charge
- Frame rate
- Gain: intensity resolution
- Bit depth
- Defects: hot pixel, dark pixel, trap

More CCD vocabulary

- Let’s see what that all means in practice!

What is the ideal detector for your application?

- Sensitivity
- Frame rate
- Number of pixels
- Pixel size
- Dynamic range
- Wavelength range
- Binning / ROI options
- Flexibility of read out options
- Software
- Price / performance

Take home message:

- Know your CCD detector!