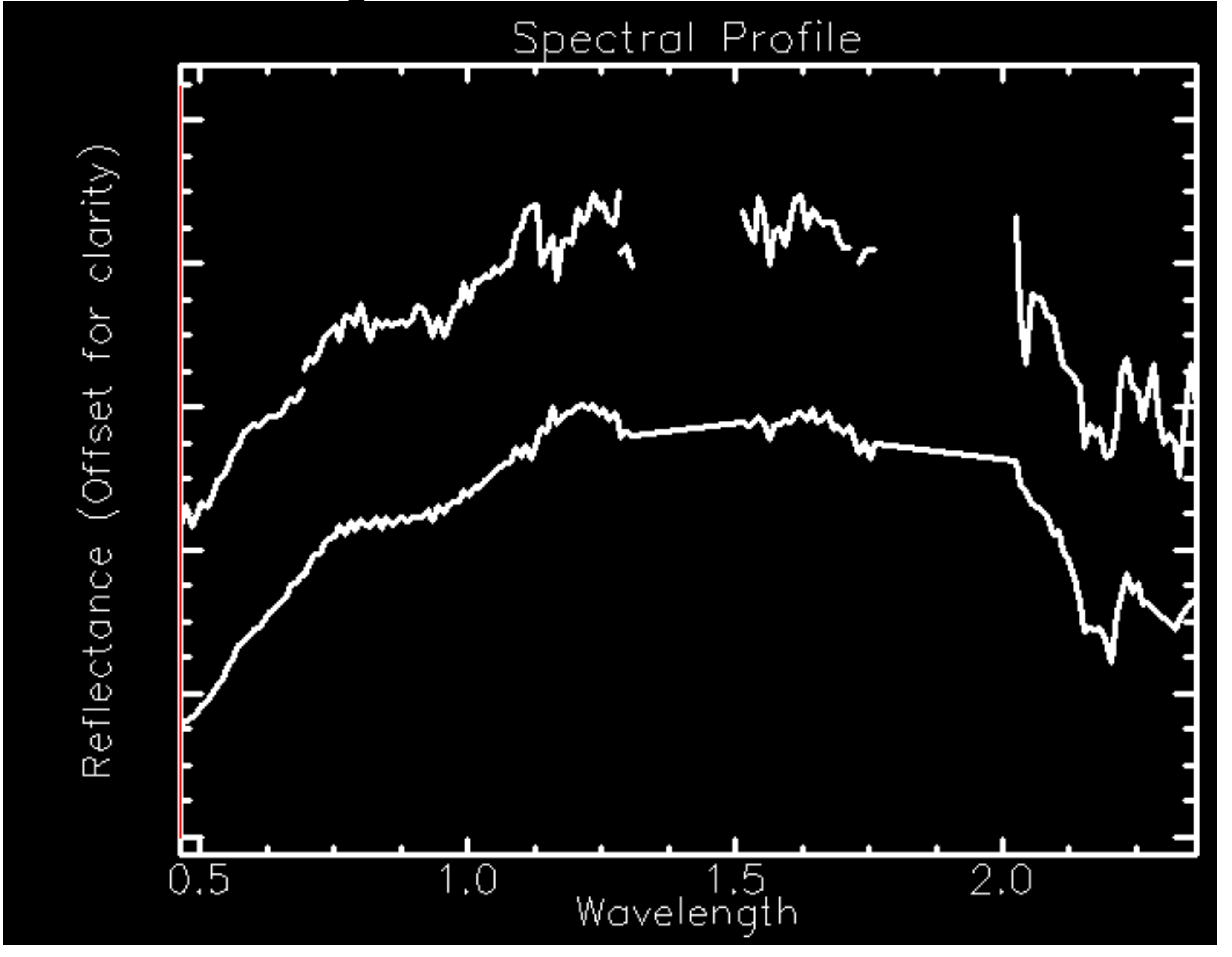
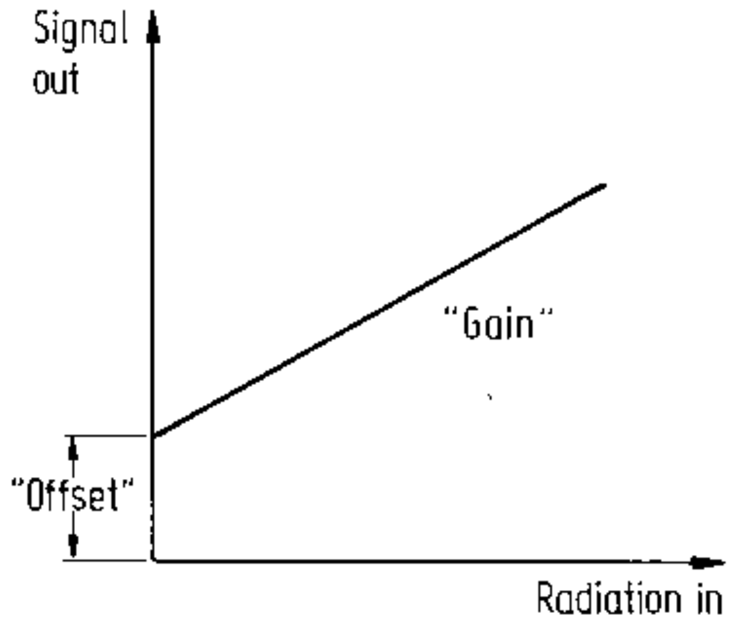
Basic Instrument Parameters

- Radiometric
  - Signal to Noise Ratio (SNR)
  - Dynamic Range
  - Linearity

Signal to Noise Ratio



Linearity



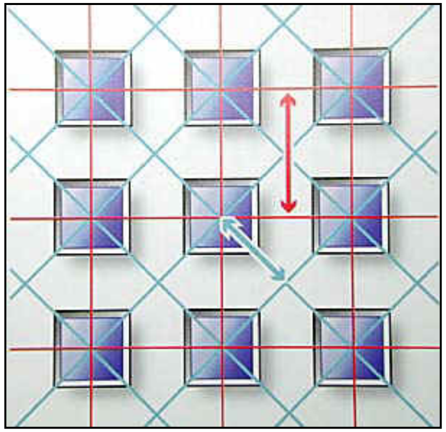
DN = (Radiance)*Gain + Offset

Digital Images

A Charged Couple Device replaces the photographic film.

CCD

- ➢ silicon wafer
- ➢ solid-state electronic component
- ➢ array of individual light-sensitive cells
- ➢ each = picture element ("pixel")



Each CCD cell converts light energy into electrons.

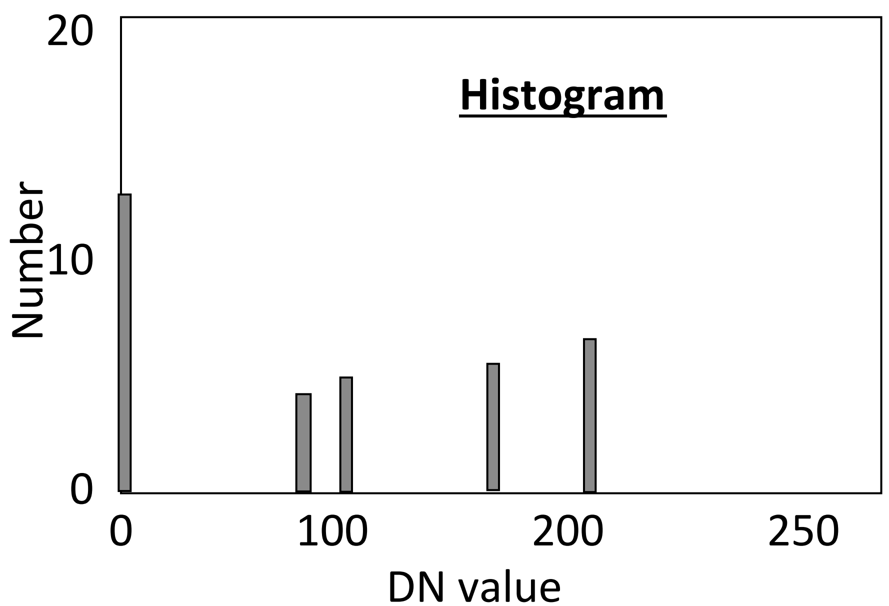
A digital number ("**DN**") is assigned to each pixel based on the magnitude of the electrical charge.

In the case of digital cameras: Each pixel on the image sensor has red, green, and blue filters intermingled across the cells in patterns designed to yield sharper images and truer colors.

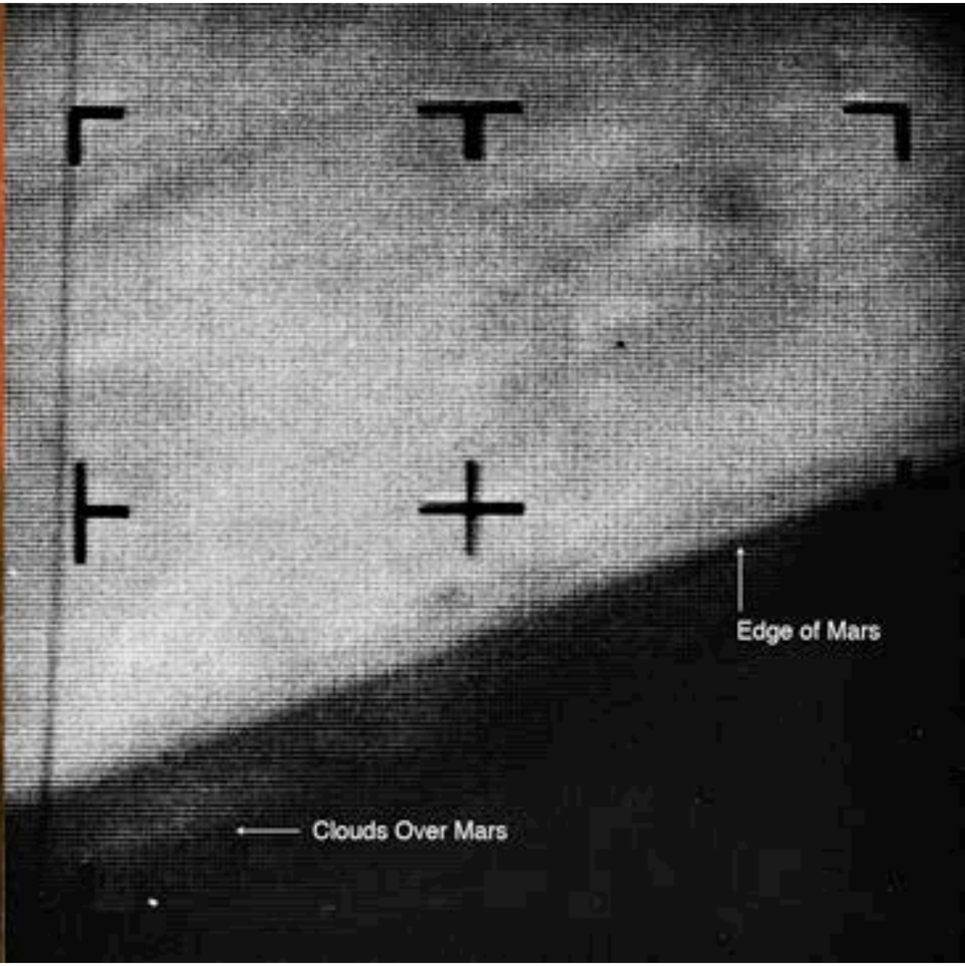
Digital images

Each pixel is assigned a DN

0	0	0	0	200	100
100	0	198	75	0	198
198	0	0	0	100	75
198	0	75	168	75	168
0	0	0	167	168	199



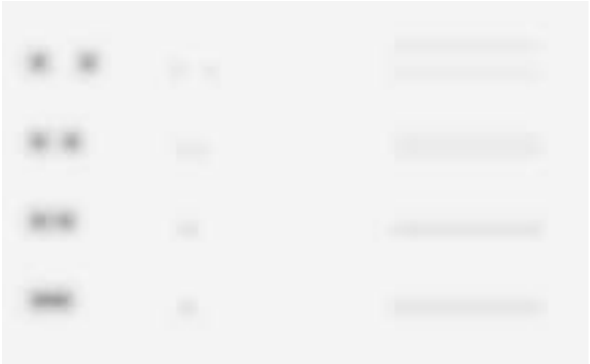
First image from Mars (Mariner 4)



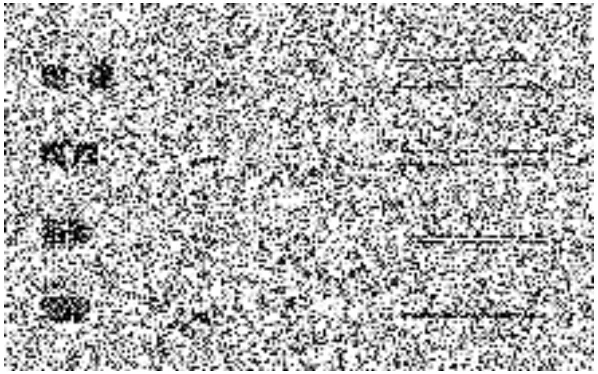
First image from Mars (Mariner 4)

Resolution, contrast & 'noise' affect **detectability**

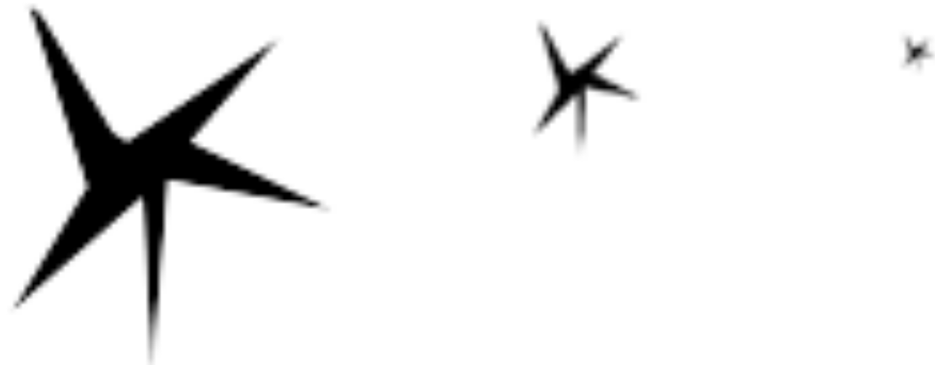
High contrast



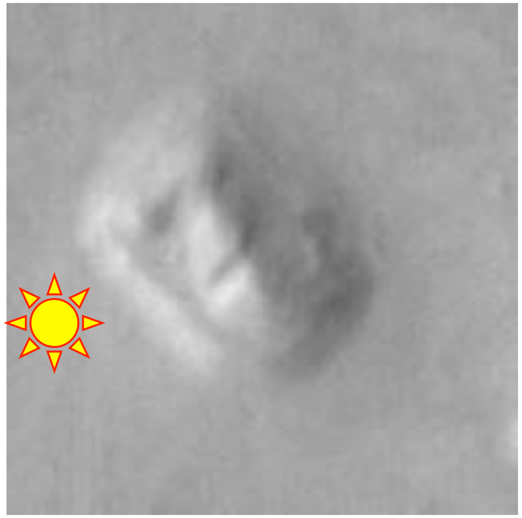
Low contrast & blurred

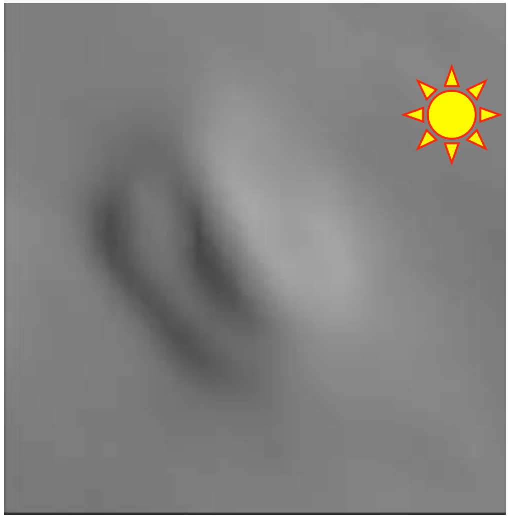


Low signal/noise

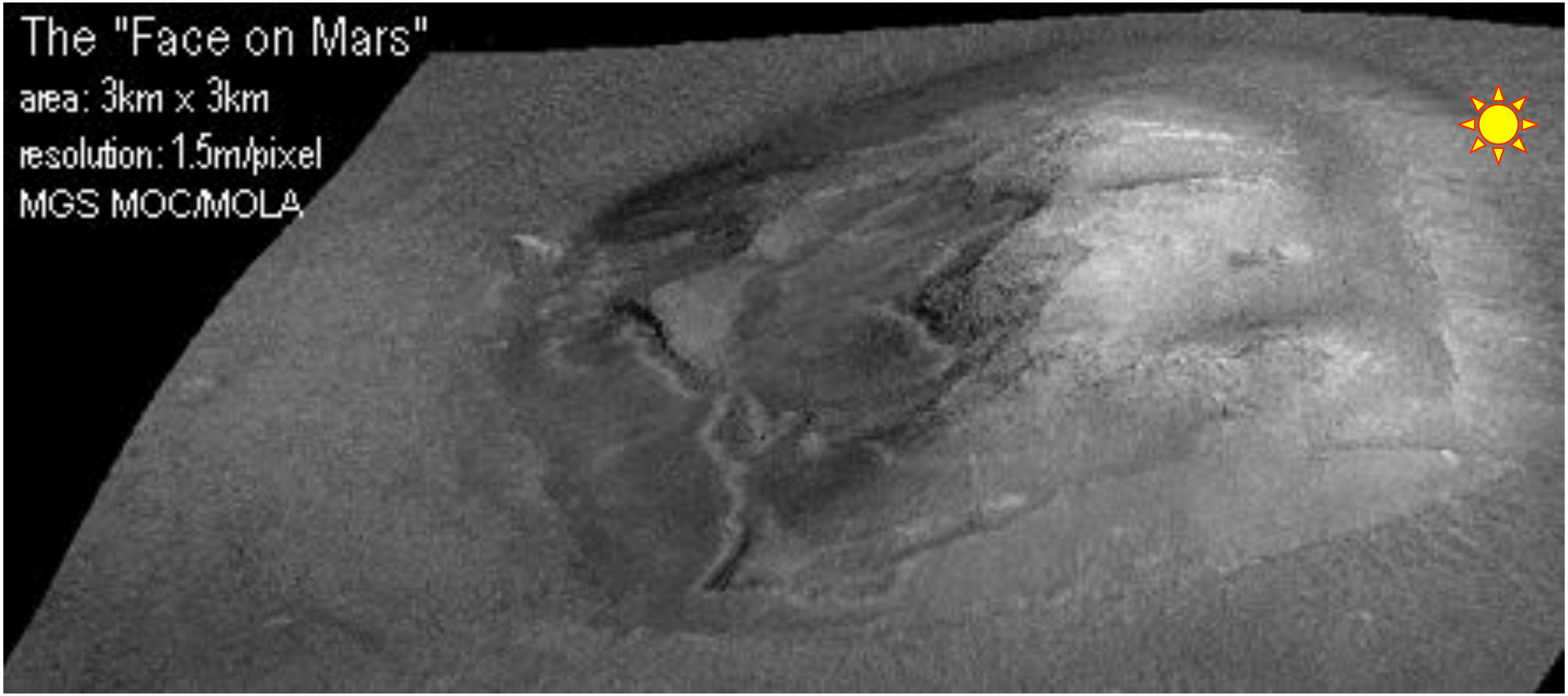


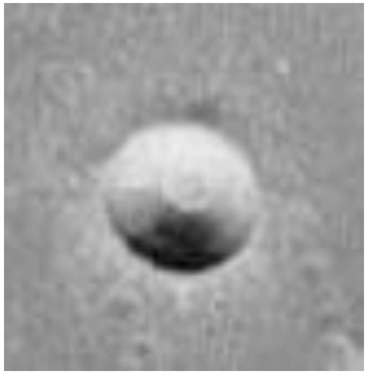
Recognition of shape is affected by resolving power





**Lighting,
viewing geometry,
& resolution**



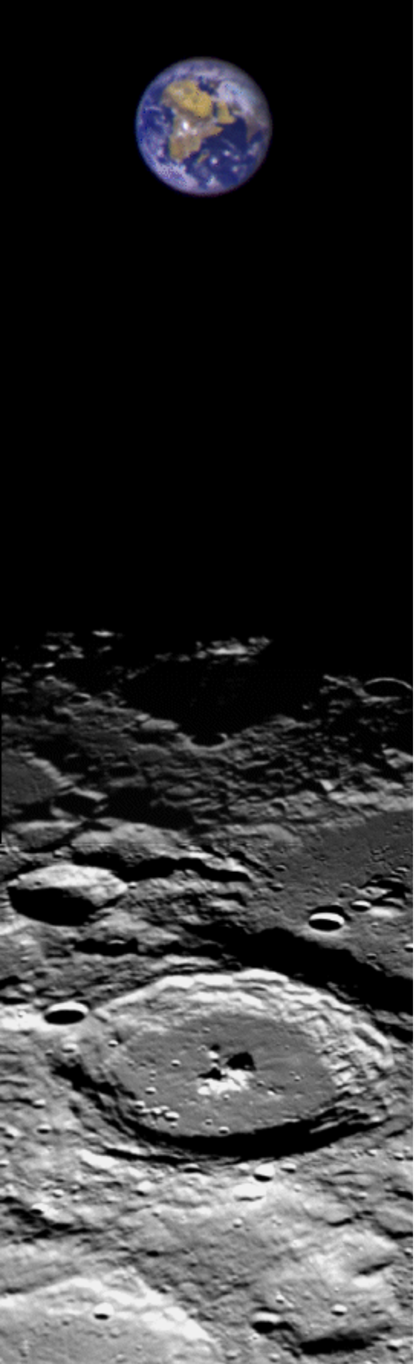


?

Absence of contextual clues permits ambiguity

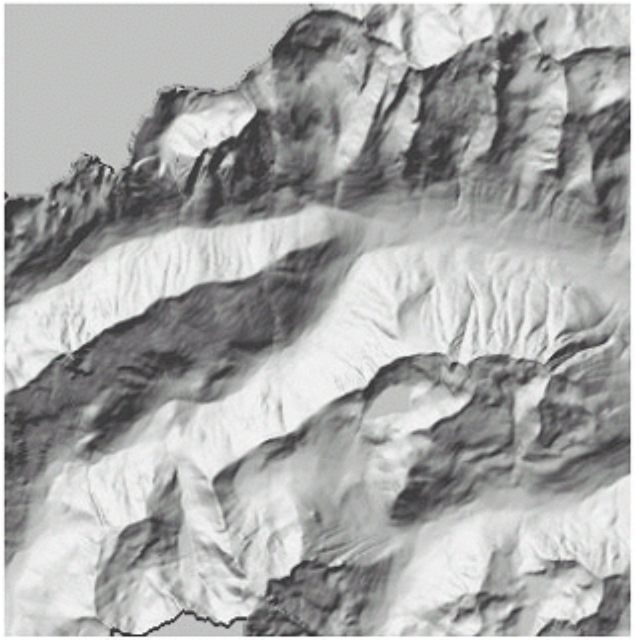
Hill?
Or hollow?

?



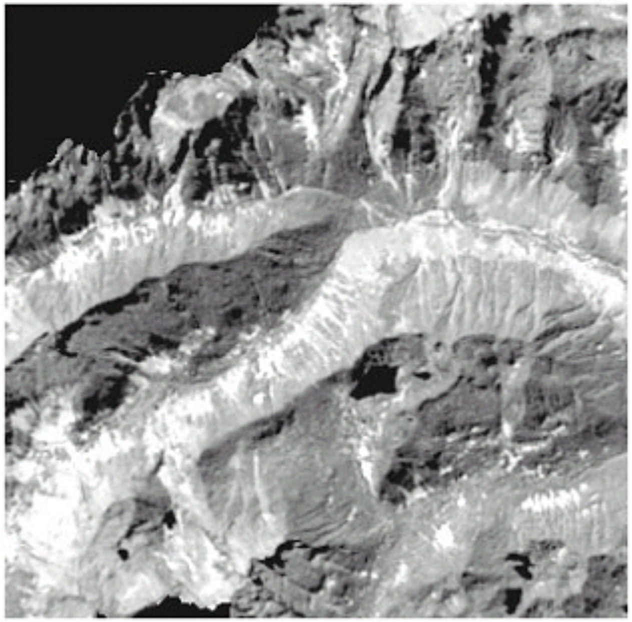
Expand the FOV for more contextual clues

Familiar scenes are interpreted more easily

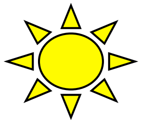


“Illuminated” DEM

Albedo variations, shape & lighting both contribute to B/W images

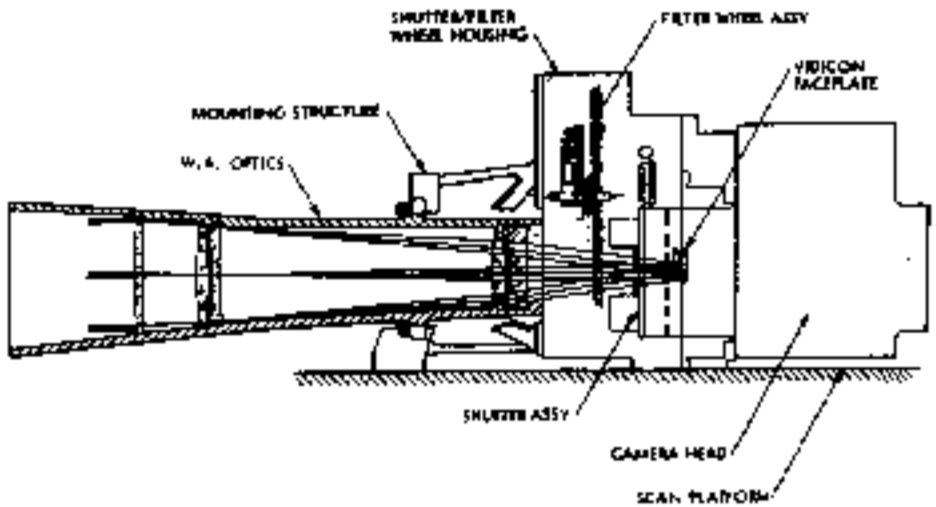


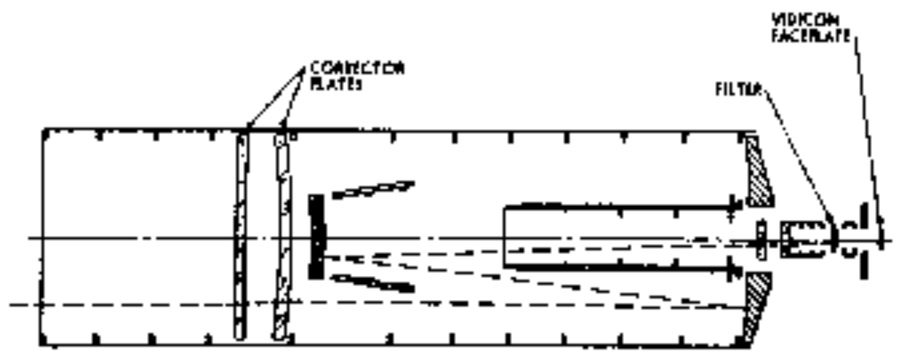
grayscale image



Voyager Imaging Science Subsystem

"Vidicon" video camera tube with selenium-sulfur photoconductor detector





CCDs have many advantages

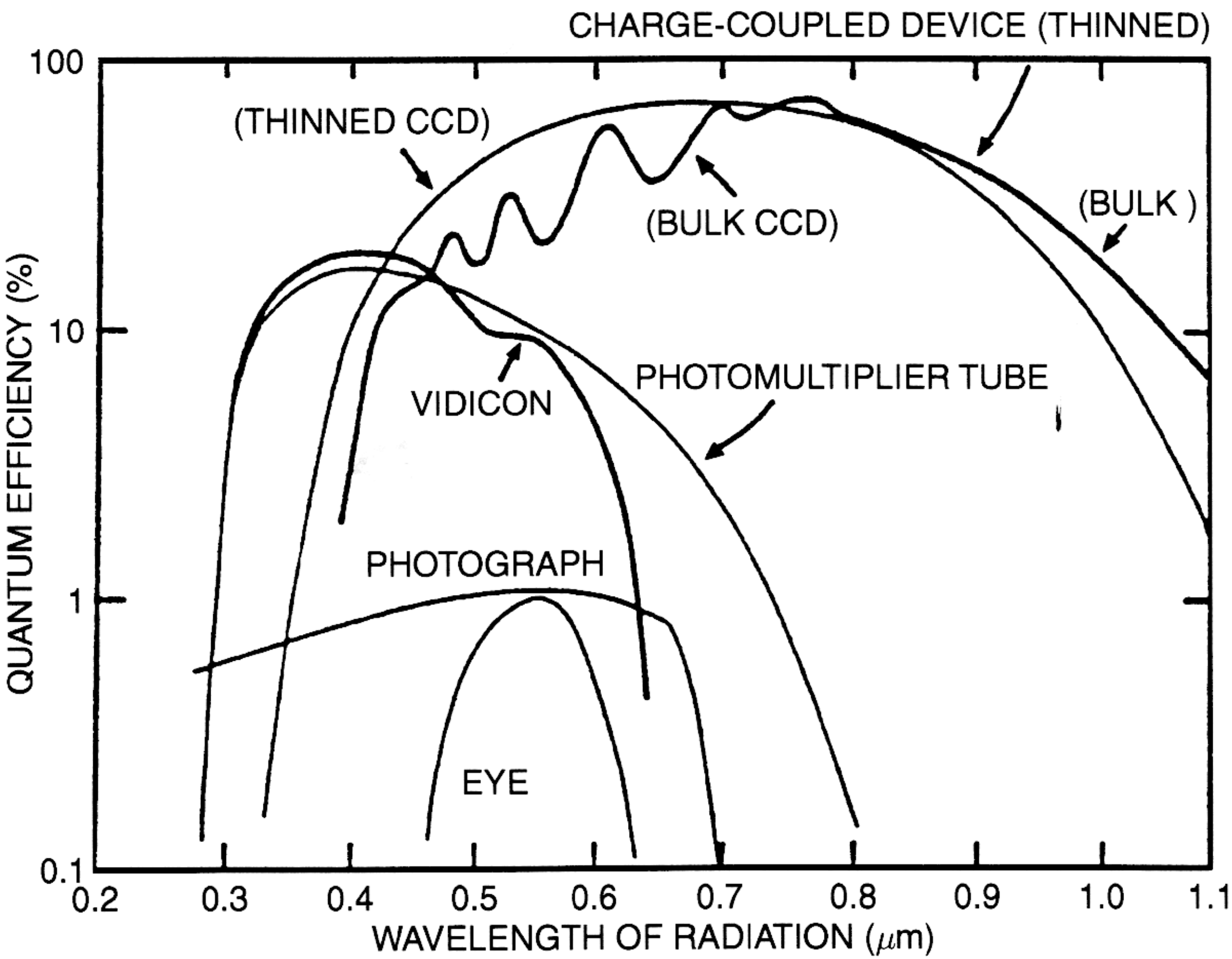
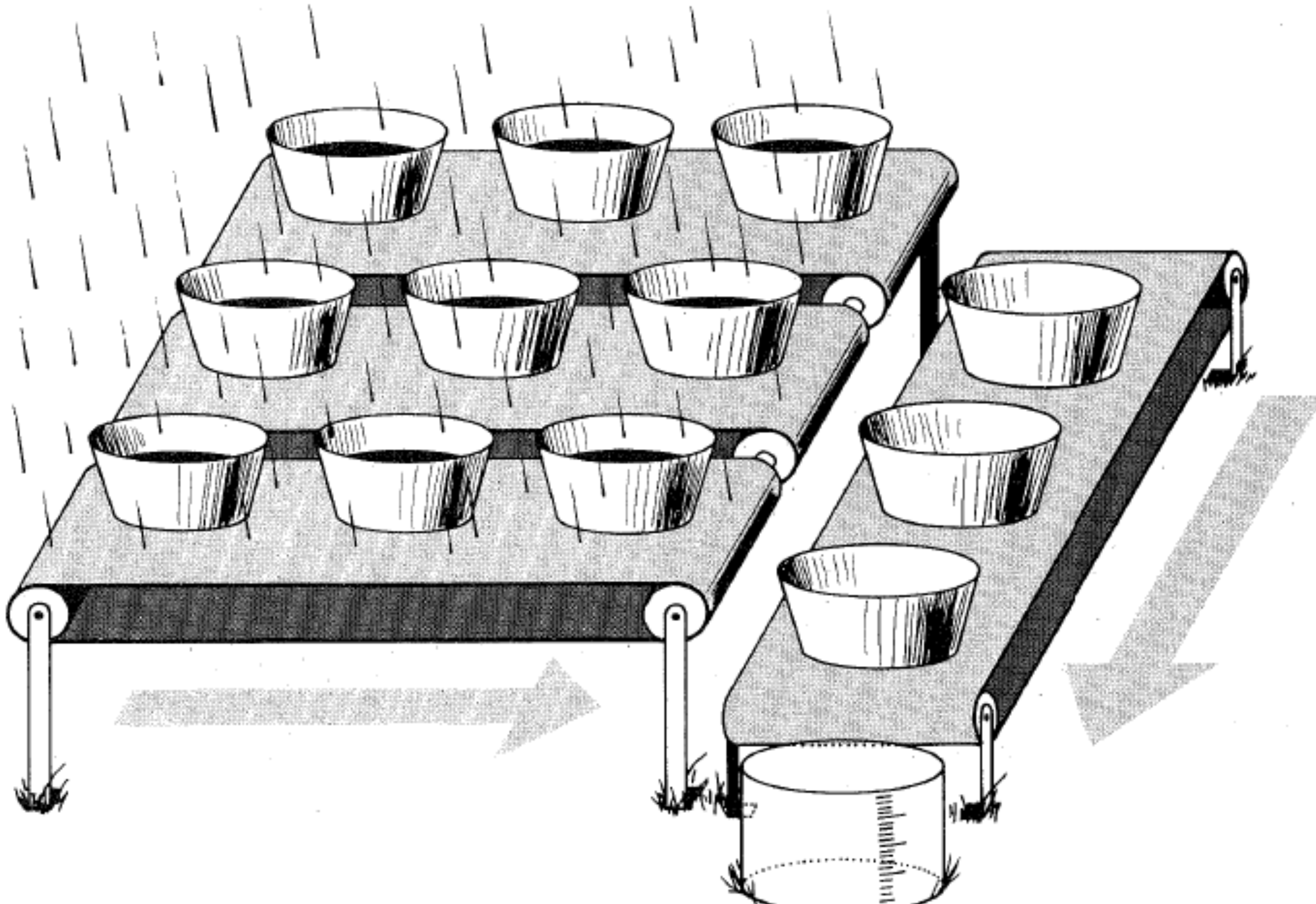


Fig. 3.2. QE curves for various devices, indicating why CCDs are a quantum leap above all previous imaging devices. The failure of CCDs at optical wavelengths shorter than about 3500 Å has been essentially eliminated via thinning or coating of the devices (see Figure 3.3).

- High QE = fraction of incoming photons that are actually detected
- Broad spectral response

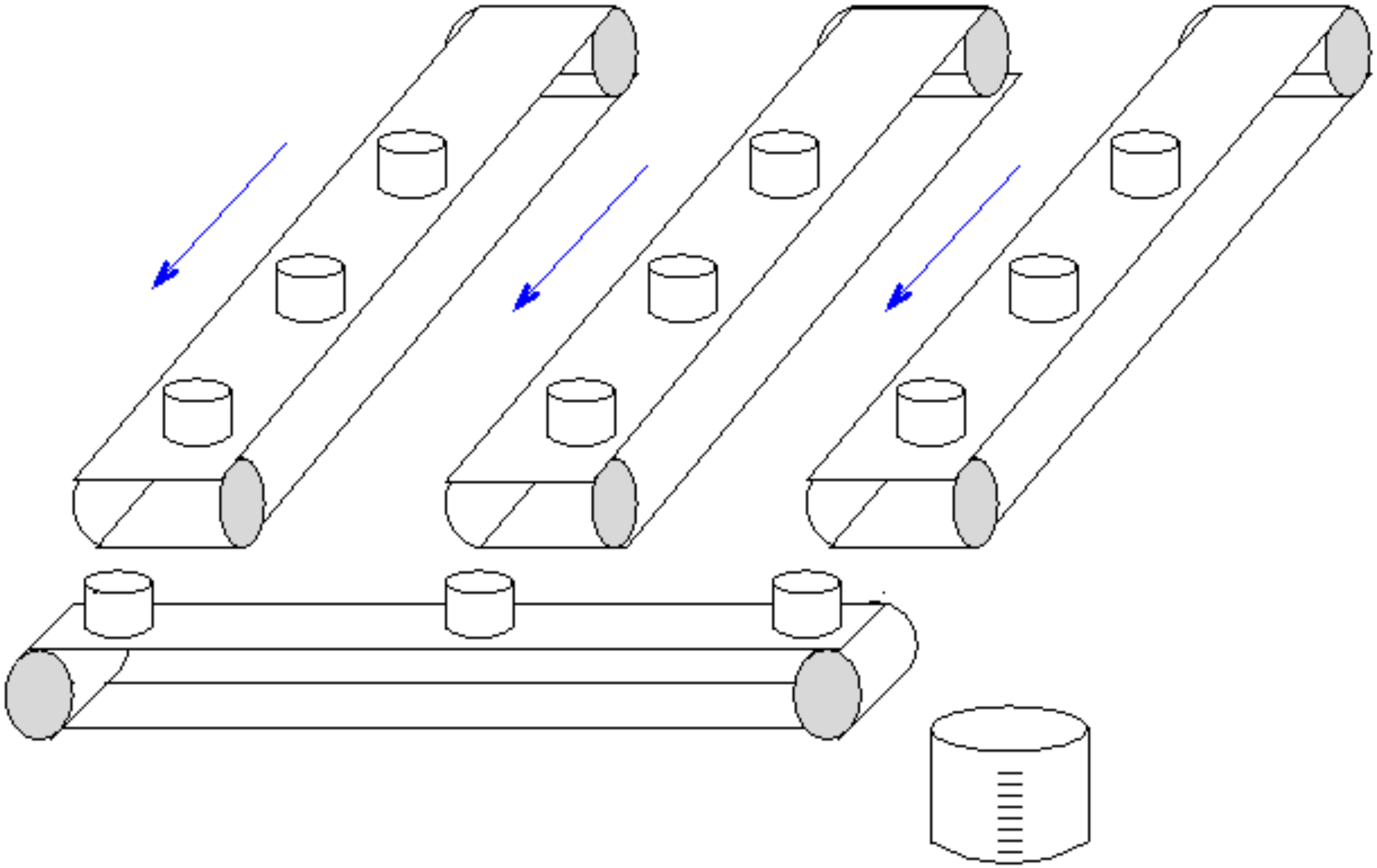
CCDs: A Nobel-worthy innovation

CCDs: rows of buckets on conveyor belts



Determining the brightness distribution in a celestial object with a charge-coupled device can be likened to measuring the rainfall at different points in a field with an array of buckets. Once the rain has ceased, the buckets in each row are moved horizontally across the field on conveyor belts. As each one reaches the end of the conveyor, it is emptied into another bucket on a belt that carries it to the metering station where its contents are measured. Artwork by Steven Simpson.

CCDs: rows of buckets on conveyor belts



- Each “bucket” is a pixel
- They are actually (in simple CCDs) directly adjacent to each other (no space between)
- Buckets are stationary during image integration, then transfer occurs along rows
- After each pixel-width transfer, the output shift register must empty, one row at a time

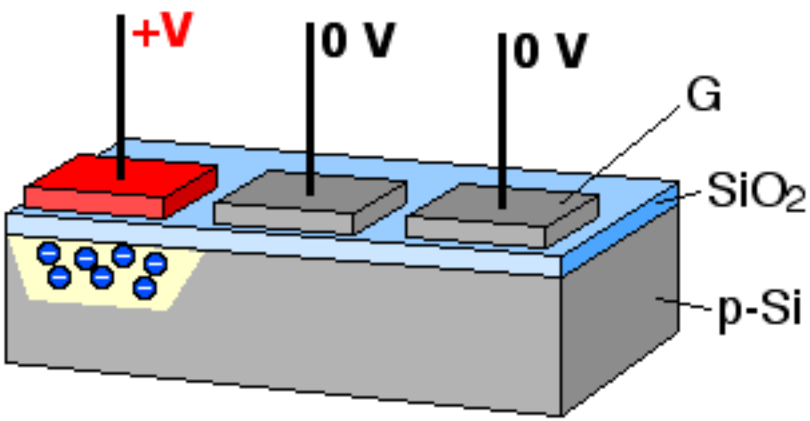
CCDs: what's really going on

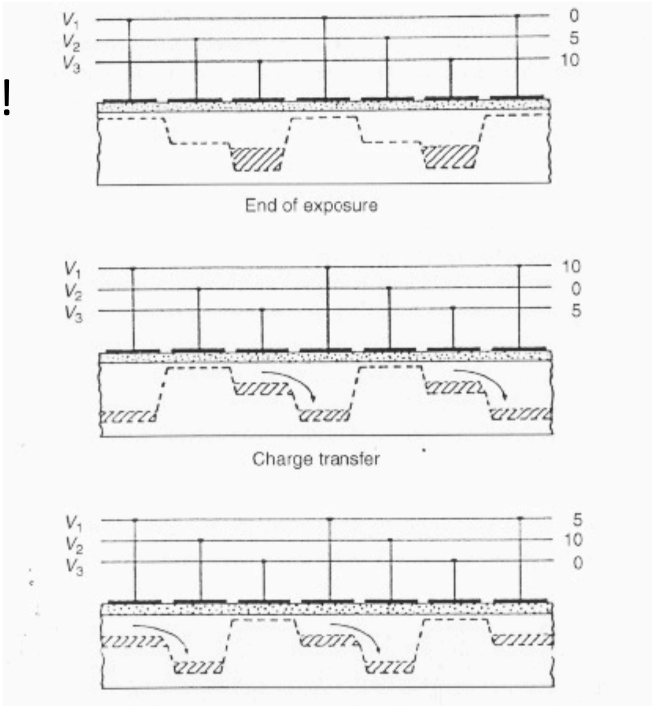
- Every photon ~300-1100 nm has 1 to a few times silicon's bandgap energy; absorption causes an electron to move from valence to conduction band
  ➔ *photoelectric effect*

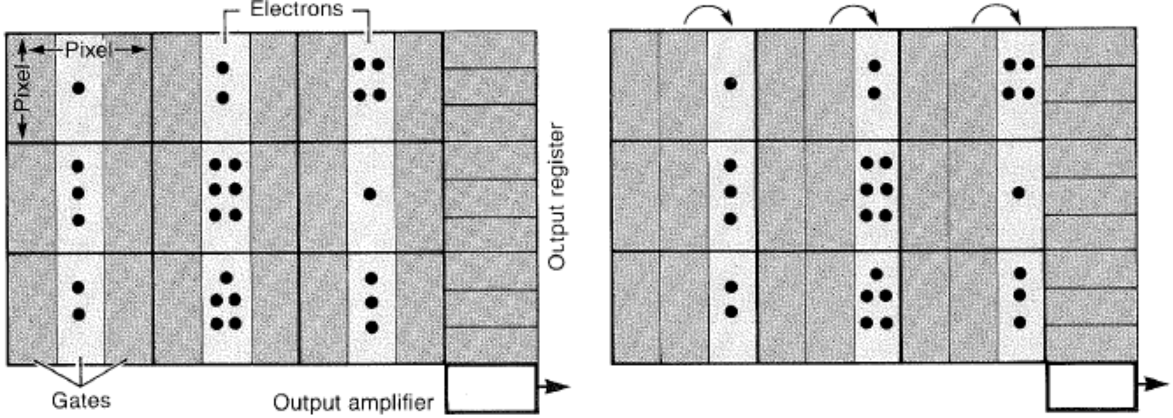
- Freed electrons collected in "gate" structures (specifically, in 1 of 3 per pixel)

- After imaging, gate voltages are varied to shift electrons in controlled manner

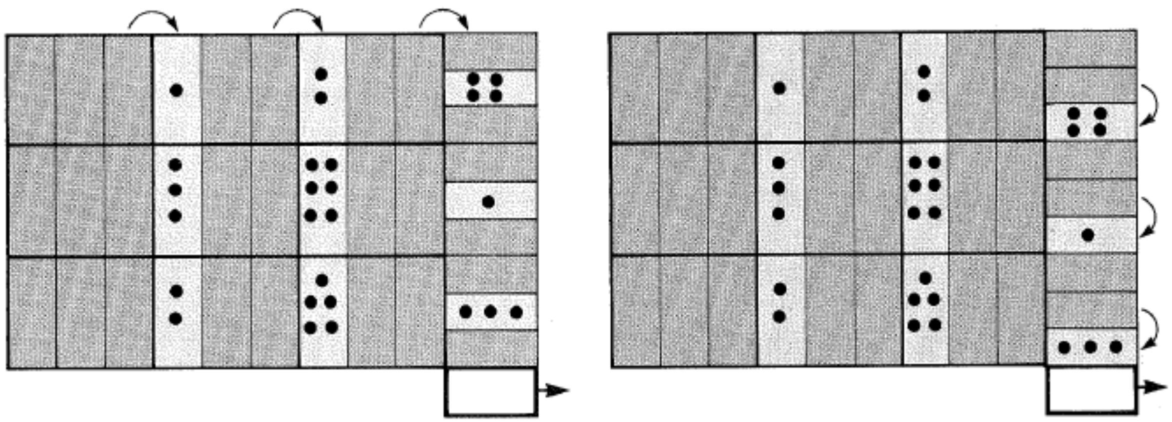
- *Charge transfer efficiency* (CTE) per pixel >99.9995%!





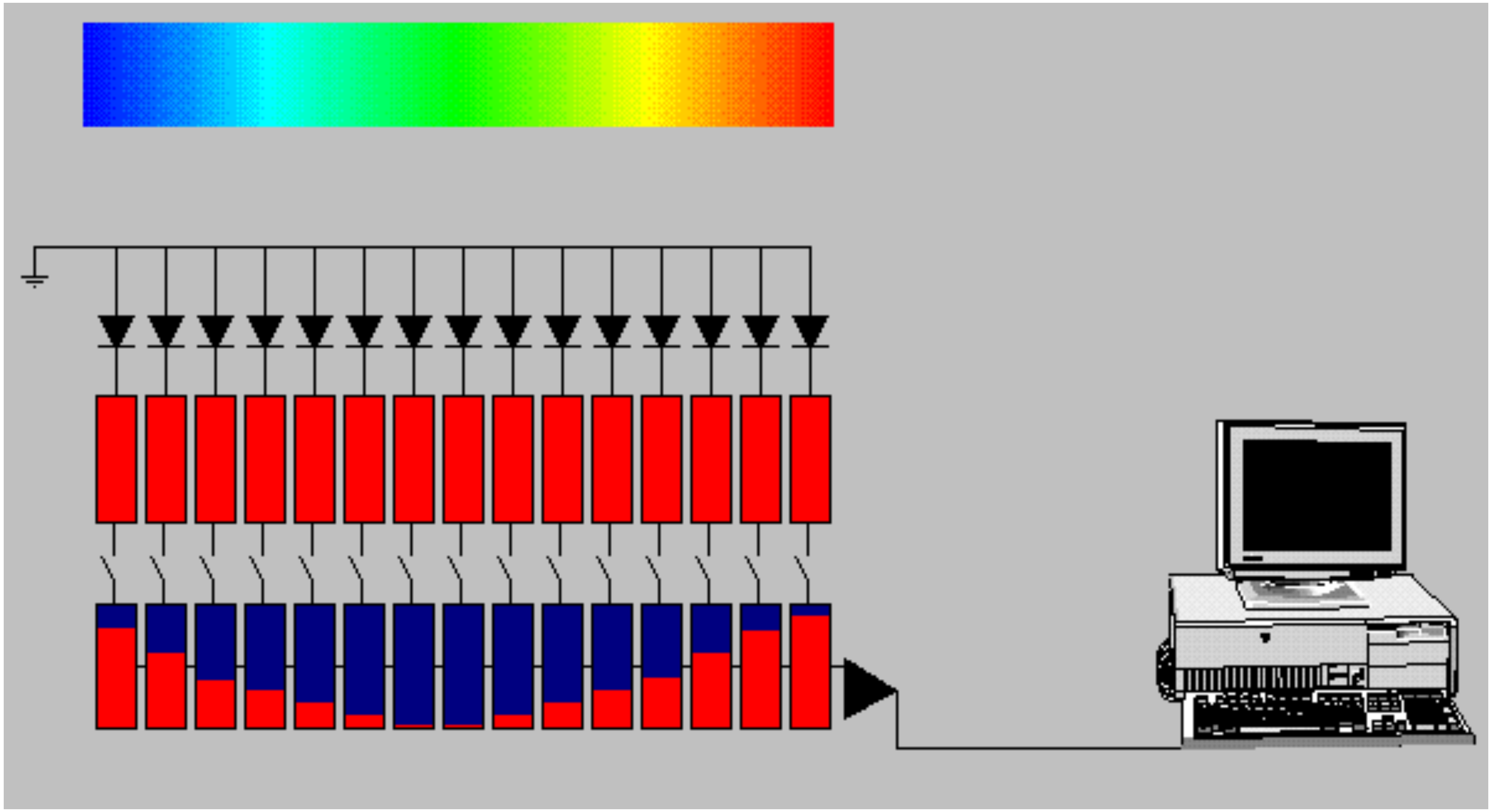


The operation of a CCD is illustrated schematically by this simplified chip consisting of nine pixels, an output register, and an amplifier. Every pixel is subdivided into three regions, or gates; each is an electrode whose voltage can be varied. *Left:* During an exposure the central gate of each pixel is "on" (yellow areas) and its neighbors are "off" (green areas). This creates "electron buckets" under the middle electrodes and barriers between adjacent pixels. *Right:* At the end of the exposure the gate voltages are changed and electrons shifted one gate to the right as new potential wells are created and old ones are destroyed.



Left: As the voltages are cycled again, electrons flow from the right-most gate of one pixel to the left-most gate of its neighbor. The electrons in the right-hand pixels are transferred to the output register. *Right:* Before the pixel array can be shifted again, charge must be transferred, one pixel at a time, through the output register and amplifier. When this register has been completely emptied, another cycle of pixel-array transfers is executed. These steps continue in a systematic way until every charge packet has moved horizontally along its row, vertically down the output register, and into the amplifier, where it is measured. In a real astronomical CCD, this process can take as long as 10 seconds.

CCDs: what's really going on



- Each pixel's accumulated charge must eventually pass through amplifier and A/D converter (converts voltages to DNs)

Image of an actual CCD

Low light level CCD (L3CCD) has extended *gain register*

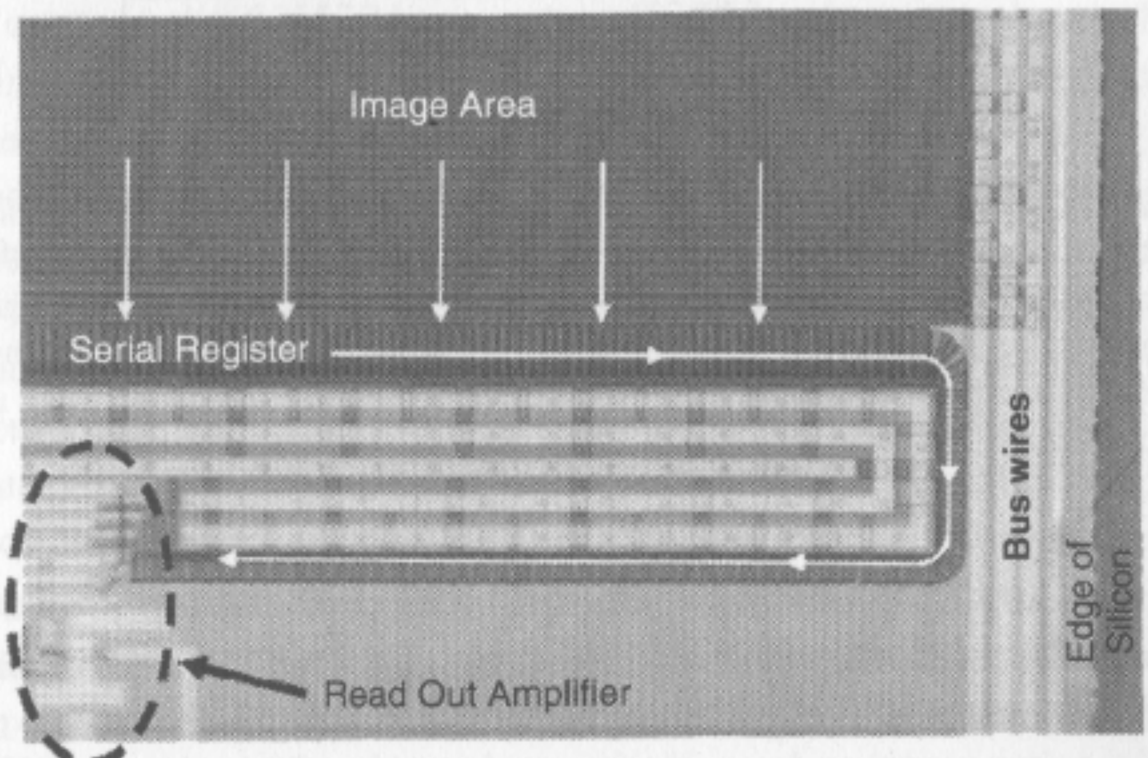


Fig. 2.3. Microphotograph of a E2V L3CCD (see Section 2.2.7) showing the image area (pixels), the serial register, and the on-chip readout amplifier. The other wiring and the bus wires are electrical connections that carry the clock signals and bias voltages to use. Added on to the normal CCD components is an extended serial register through which the readout occurs (the arrow indicates this flow) where the half after the bend is the gain register.

Case study: Mars Reconnaissance Orbiter *HiRISE*

Figure 2. HiRISE instrument inside a clean room tent at Ball Aerospace and Technology Corporation in Boulder, Colorado.

Case study: Mars Reconnaissance Orbiter *HiRISE*

Table 1. HiRISE Camera Capabilities at 300 km Altitude

Parameter	Characteristics
Ground sampling dimension	30 cm/pixel (1 μrad IFOV)
Resolution	~90 cm (3 pixels across an object)
Swath width (RED CCDs)	6 km (1.14° FOV)
Color swath width	1.2 km (0.23° FOV)
Maximum image size (pixels)	20,000 × 63,780 (14-bit data)
SNR (anywhere on Mars in the optimal season)	From 90:1 to 250:1 in RED channels with TDI 128 and full resolution
Color band passes (at half maximum of Mars- and solar-weighted spectral response; see Figure 12)	RED: 570–830 nm BG: <580 nm NIR: >790 nm
Stereo topographic precision	~25 cm vertical over ~1 m^2 areas
TDI lines	8, 32, 64, or 128
Pixel binning	none (1 × 1), 2 × 2, 3 × 3, 4 × 4, 8 × 8, 16 × 16
Bits per pixel	14, can be compressed to 8 via look-up tables (LUTs)
Compression (8-bit images only)	FELICS, compression >1.6:1

McEwen et al. (2007, JGR)

Ground sampling slightly finer than true resolution

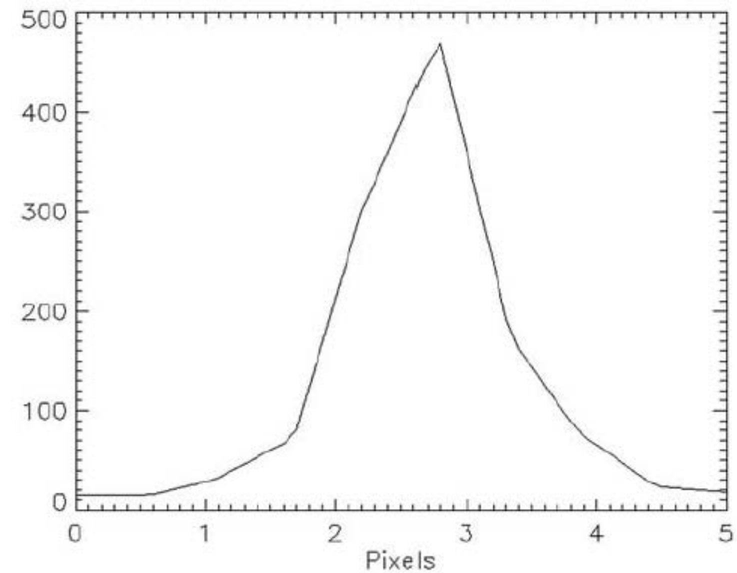


Figure 9. Typical Point-Spread Function (PSF) for a HiRISE pinhole image, acquired at Ball Aerospace with a 30-inch collimator.

Case study: Mars Reconnaissance Orbiter *HiRISE*

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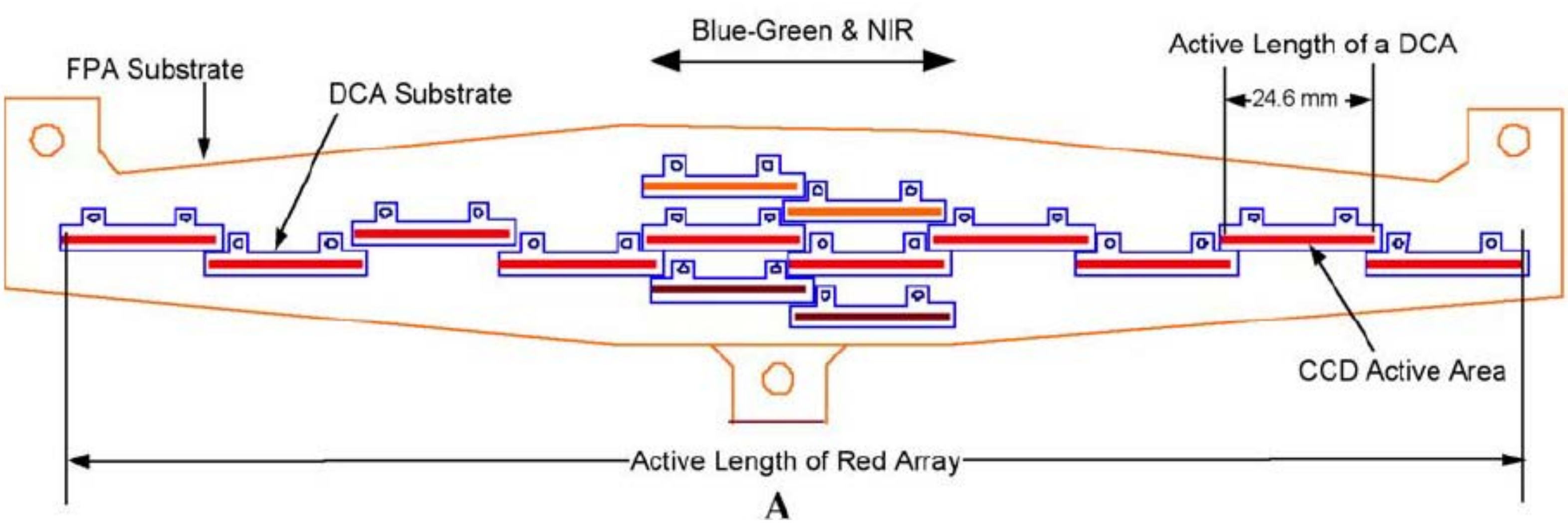
Compression (8-bit images only)	FELICS, compression >1.6:1

Not a single 20,000-pixel detector! (for which readout would take forever);
20 separate output registers (2 per CCD) across the array



Case study: Mars Reconnaissance Orbiter *HiRISE*

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12 µm-wide pixels for HiRISE;

can be as small as 2 µm when compactness/resolution are key

BUT capacity scales with $(\text{width})^2$, so e.g. Kepler has 27 µm pixels to maximize dynamic range (full well capacity ~10^6 electrons)