Basics of Charge Coupled Devices

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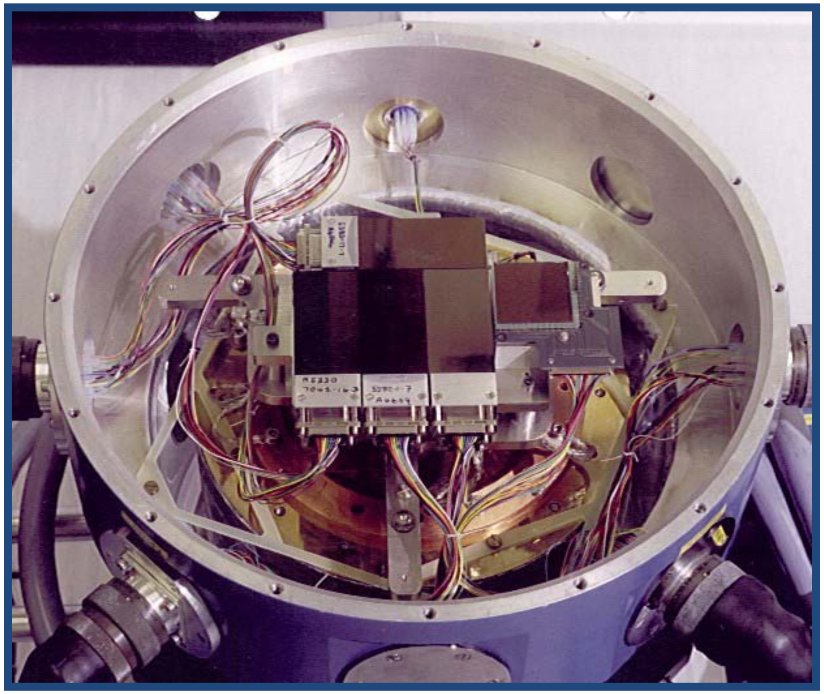
Charge-Coupled Devices

- Introduction
- Mode of Operation
- Characterization
- Basic Reduction
- Use



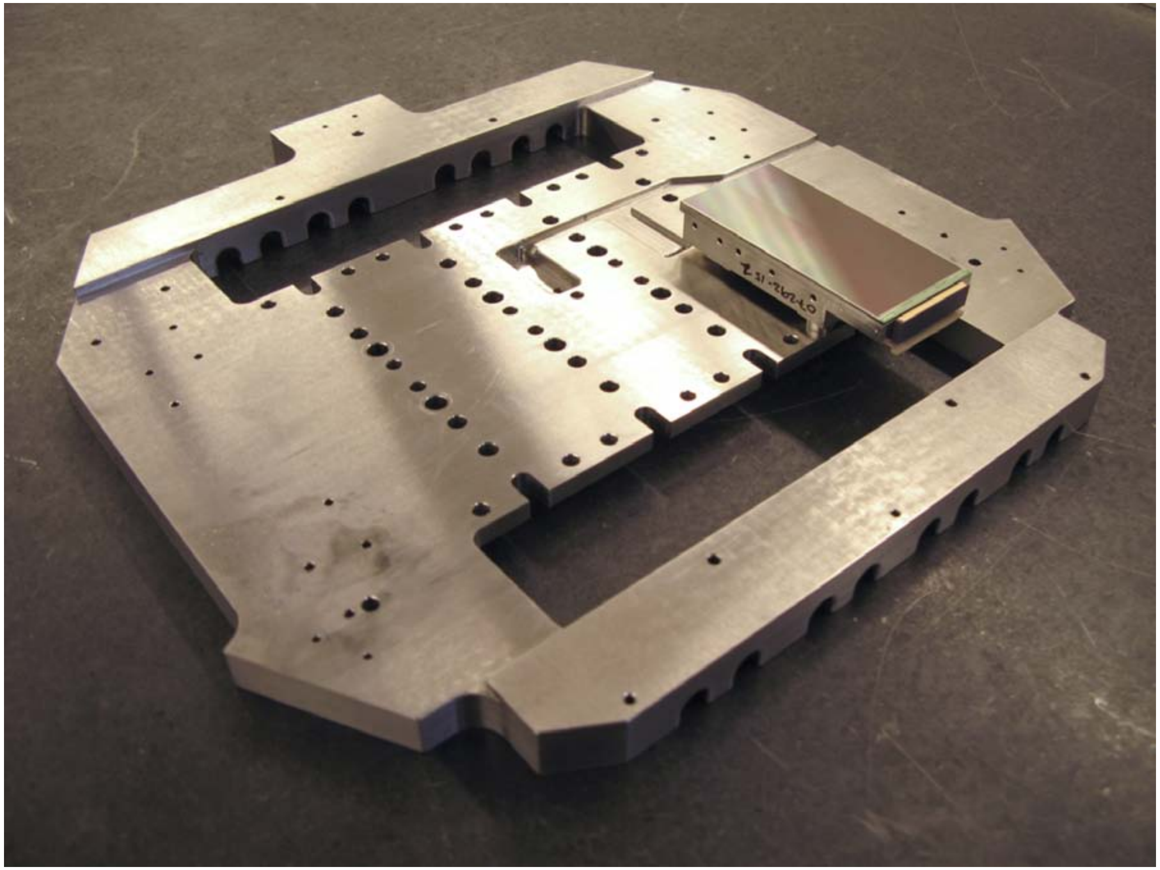
INT 2.5-m Wide Field Imager

CCD Nomenclature: What's in a Name?

- CCD size: 512 X 512, 1024 X 3096, 4096 X 4096
  - Designates the number of pixels in the x by y direction
- CCD Name: Tek2048, T2KB, SITe4096, GMOS
  - Manufacturer, CCD size, instrument specific
- Packaging: many types, sizes & methods
- CCDs are integrated circuits built like computer memory

- Why use a CCD?
  - Analog to digital conversion
  - Quantum efficiency & wavelength coverage (300-1000 nm)

Mosaic 1.1 focal plane

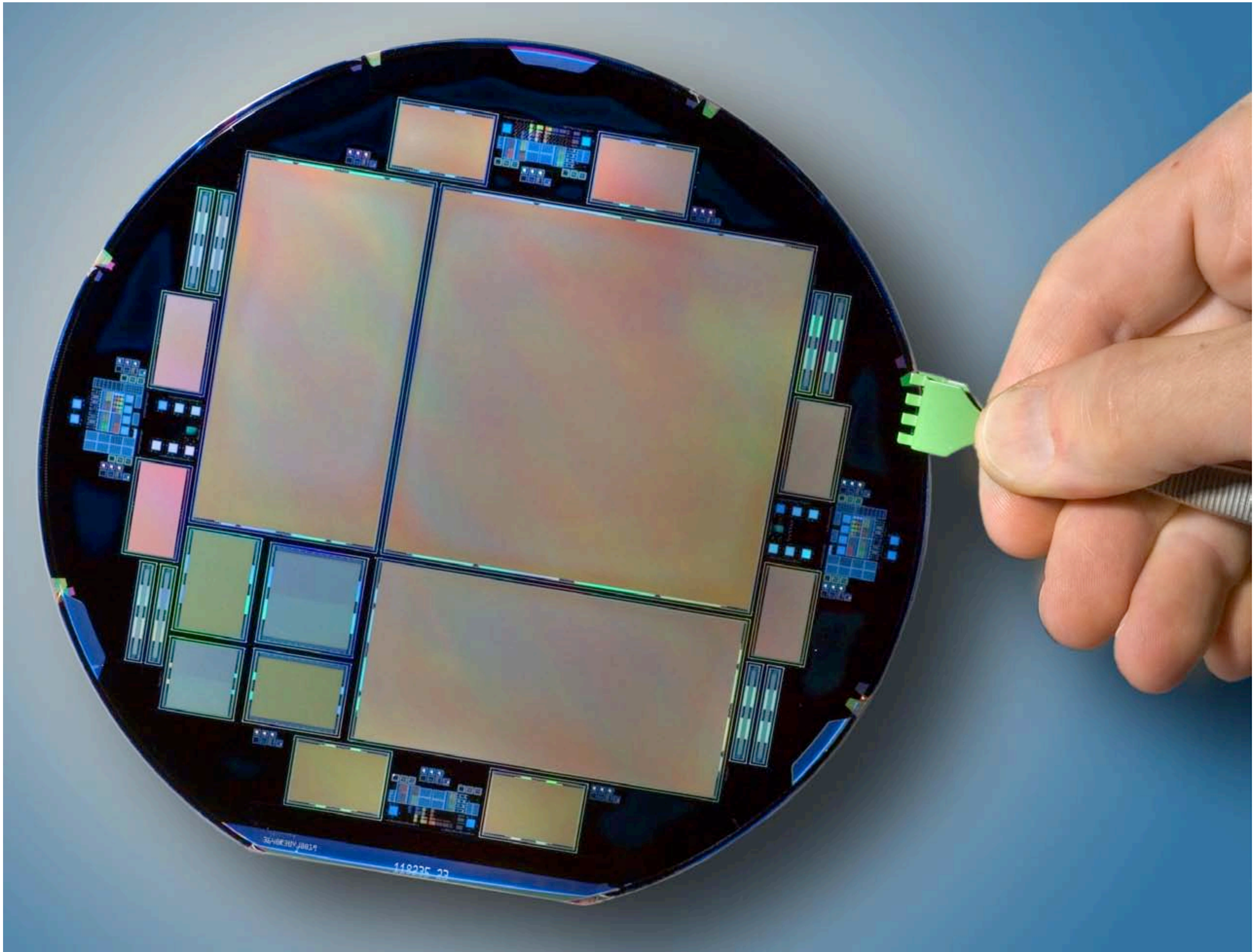


Mechanical sample e2v 2048X4096 CCD in package and sitting in focal plane assembly. Seven more will be added in the final 8K by 8K imager.

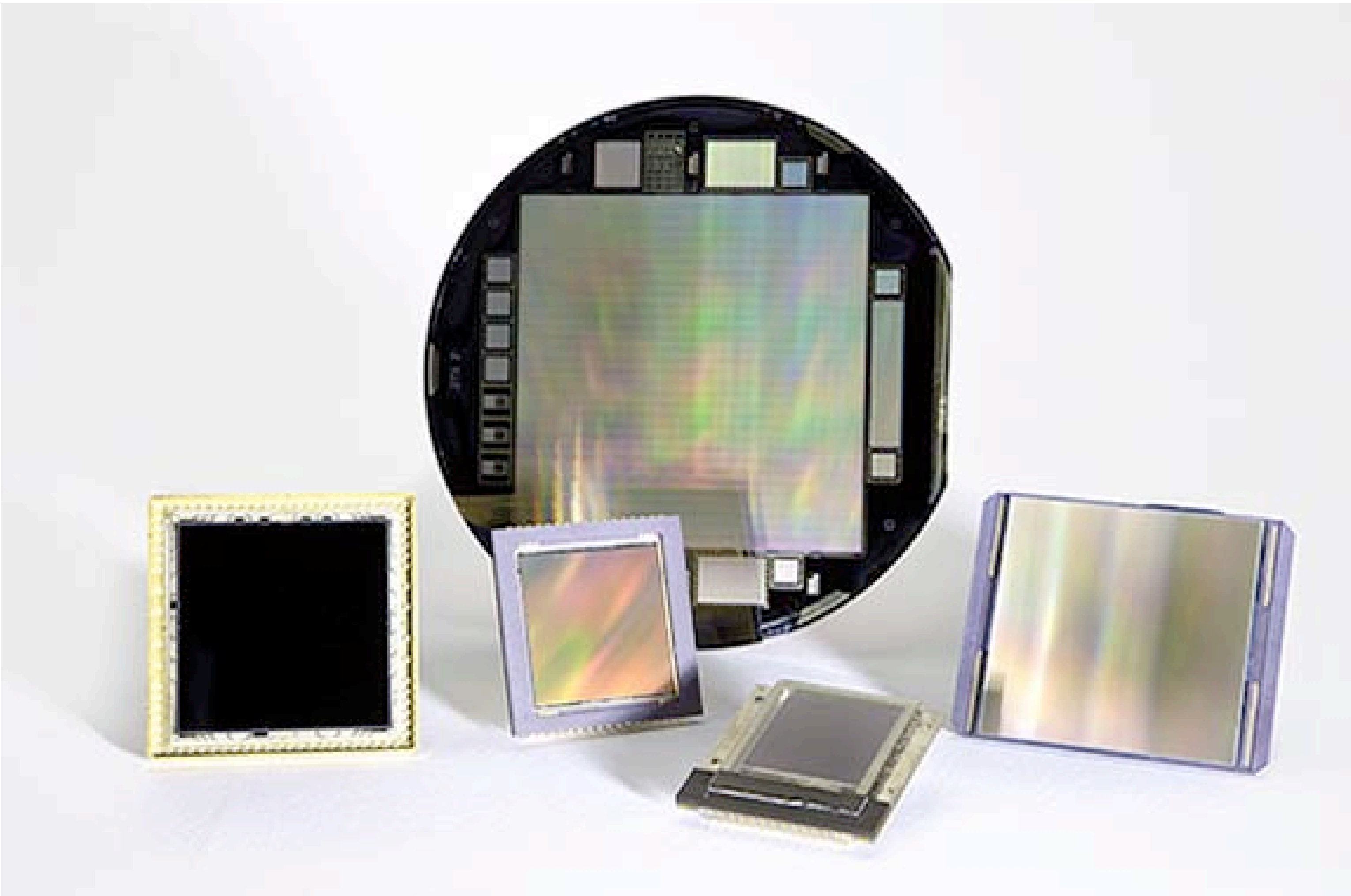
CCD Types:?

- CCDs come in a variety of types:
  - Specific types are made/used for specific applications
  - Application examples: fast readout, large area coverage, high QE, cheap price, dynamic range, radiation hard, good cosmetics, low noise, on-chip AO, etc.
- Astronomical CCDs are usually thinned, back side illuminated, slow readout, buried channel devices
- Others types: front side illuminated, interline, frame transfer, surface channel, anti blooming, MPP, OT, low light level (EMCCD), CMOS, STJ, etc
- CCD properties depend on the CCD and the readout electronics ("controller")
  - Controllers: Leach, MONSOON, Princeton Inst., IR labs, etc.
  - Readout: CCD and analog-to-digital converter

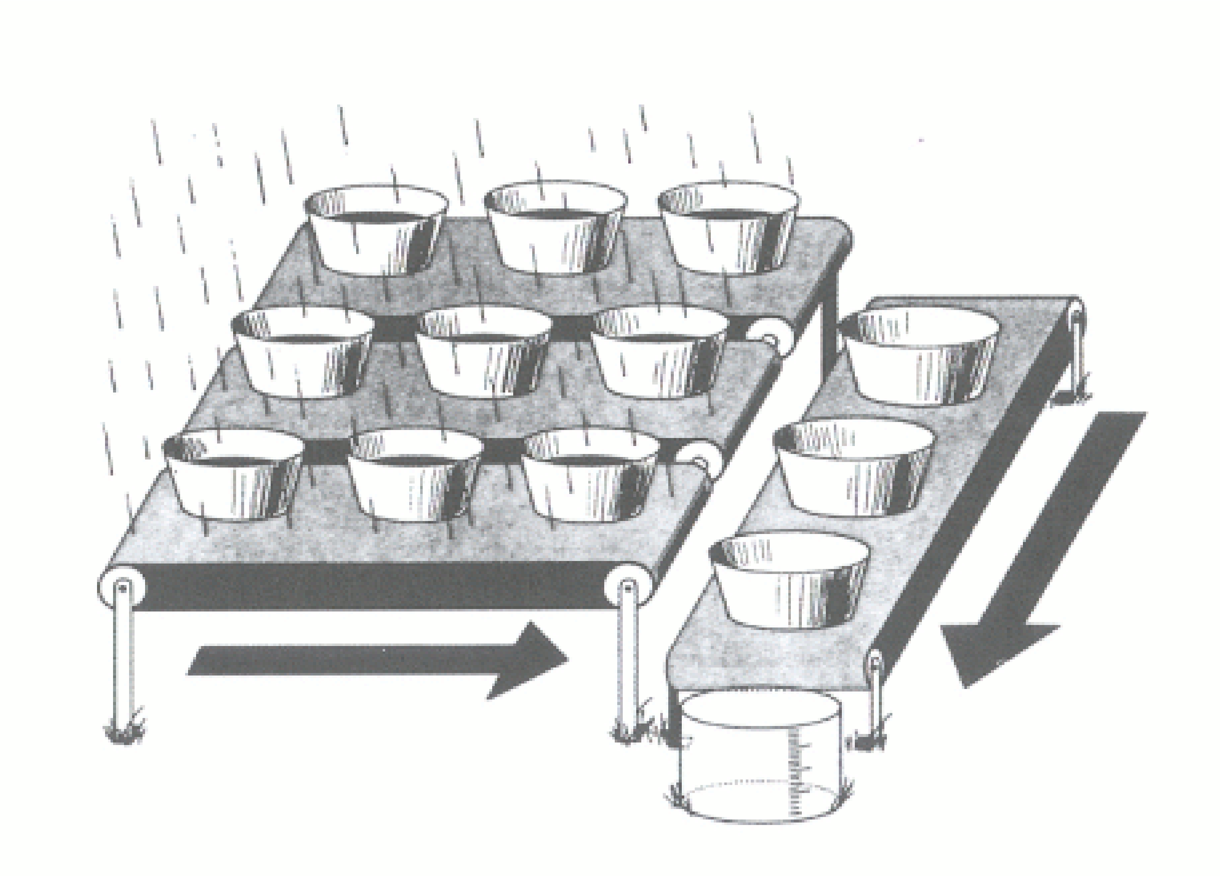
CCDs Galore



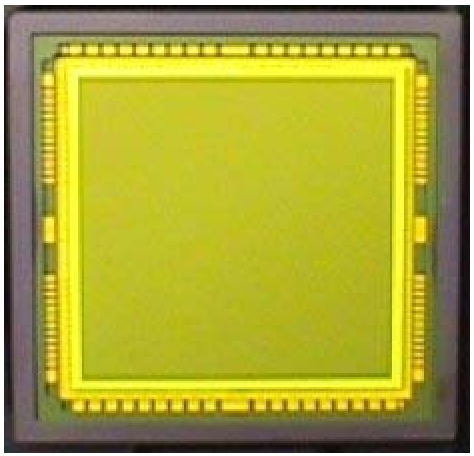
CCDs Galore



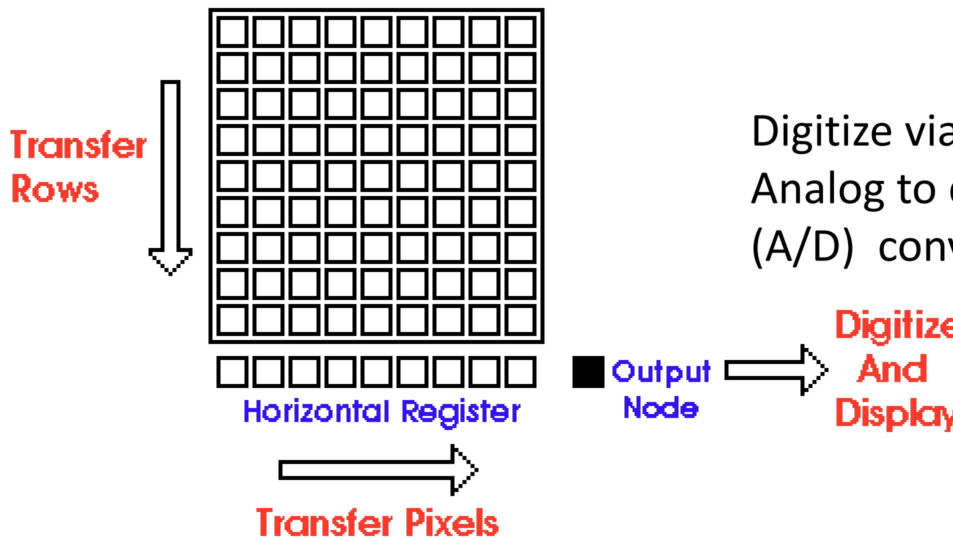
Rain Bucket CCD readout



CCD Readout



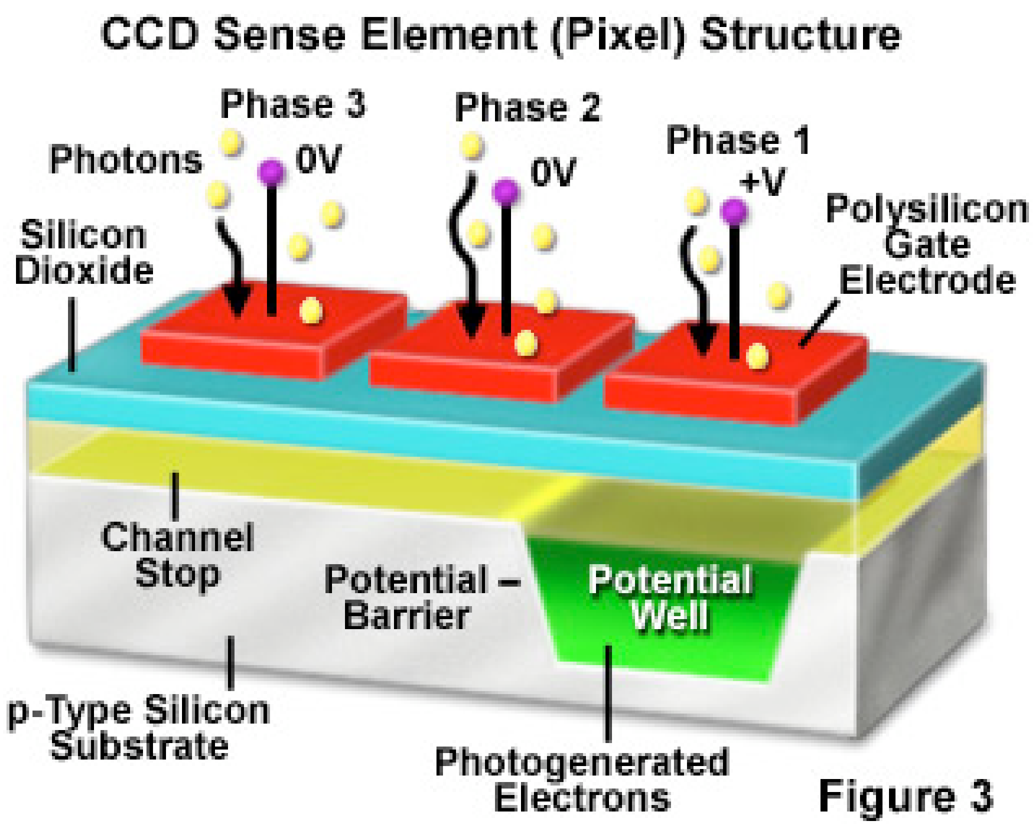
Thomson
2048 X 2048
CCD



Digitize via
Analog to digital
(A/D) converter

Horizontal register = Serial register

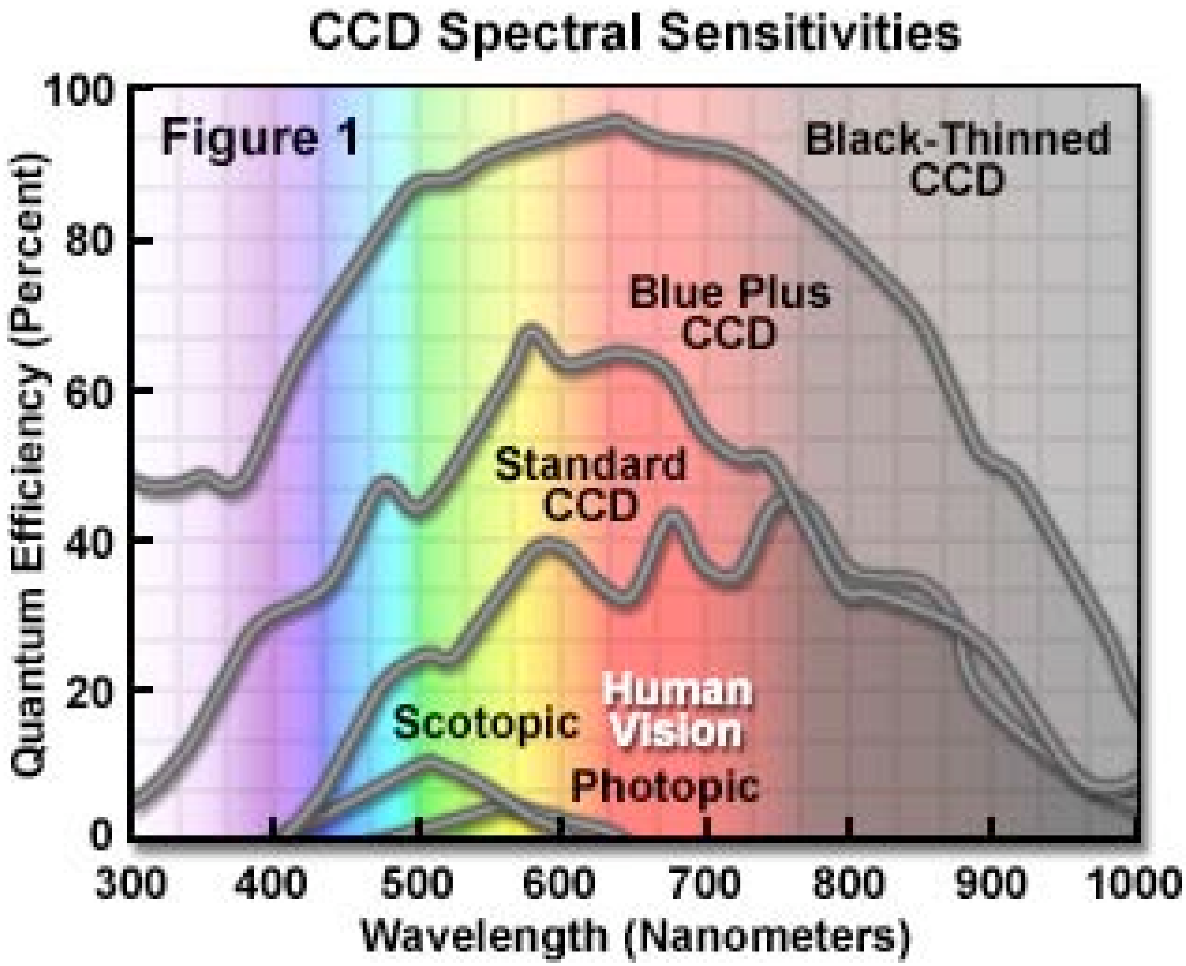
CCD readout



Schematic of typical 3-phase operation.
Charge is held by voltage potential until end of integration, then shifted, one pixel at a time, row by row to output.
Large CCDs move charge through thousands of pixels (c.f., CTE, multiple amplifiers)

CCD Properties

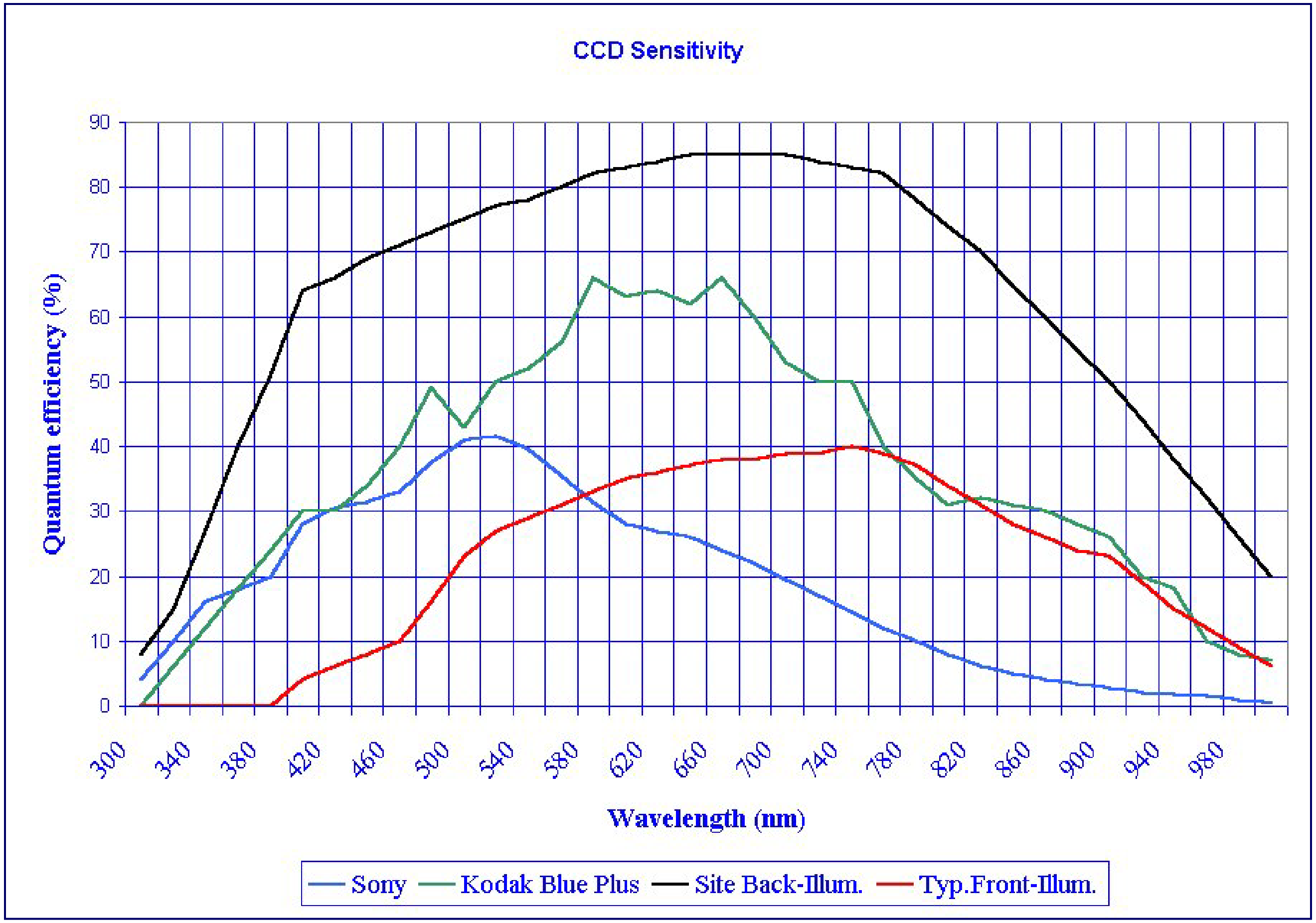
- Quantum Efficiency is the percentage of photons striking the CCD that are actually collected.



Scotopic vision is low light conditions (rod cells) , Photopic is daytime (cone cells)

CCD Properties

- CCD Quantum Efficiency is determined by CCD type (front/back side, resistivity of Si, and temperature of operation) and CCD coating



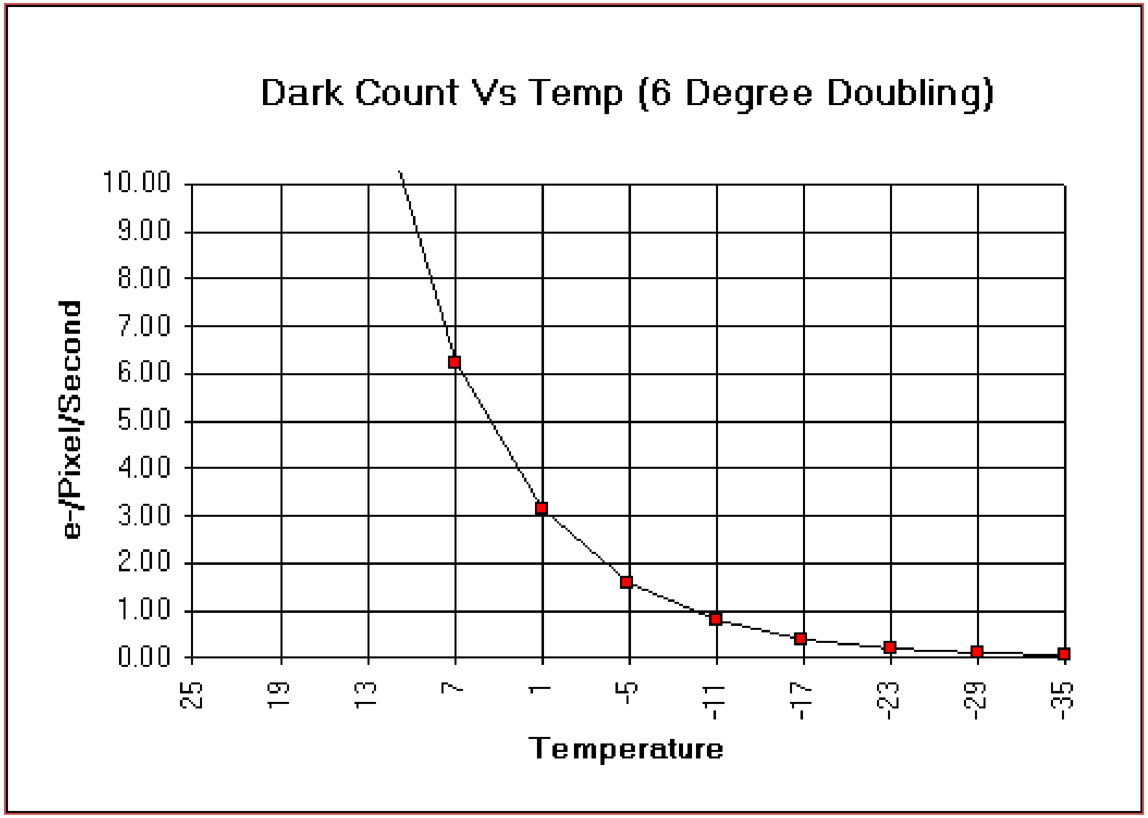
CCD Properties

- Read Noise
  - The level of noise present in a "no exposure" readout of the electronics
  - Use a zero second "Bias" or "Zero" exposure to measure
  - 3-10 electrons per pixel per read are typical today

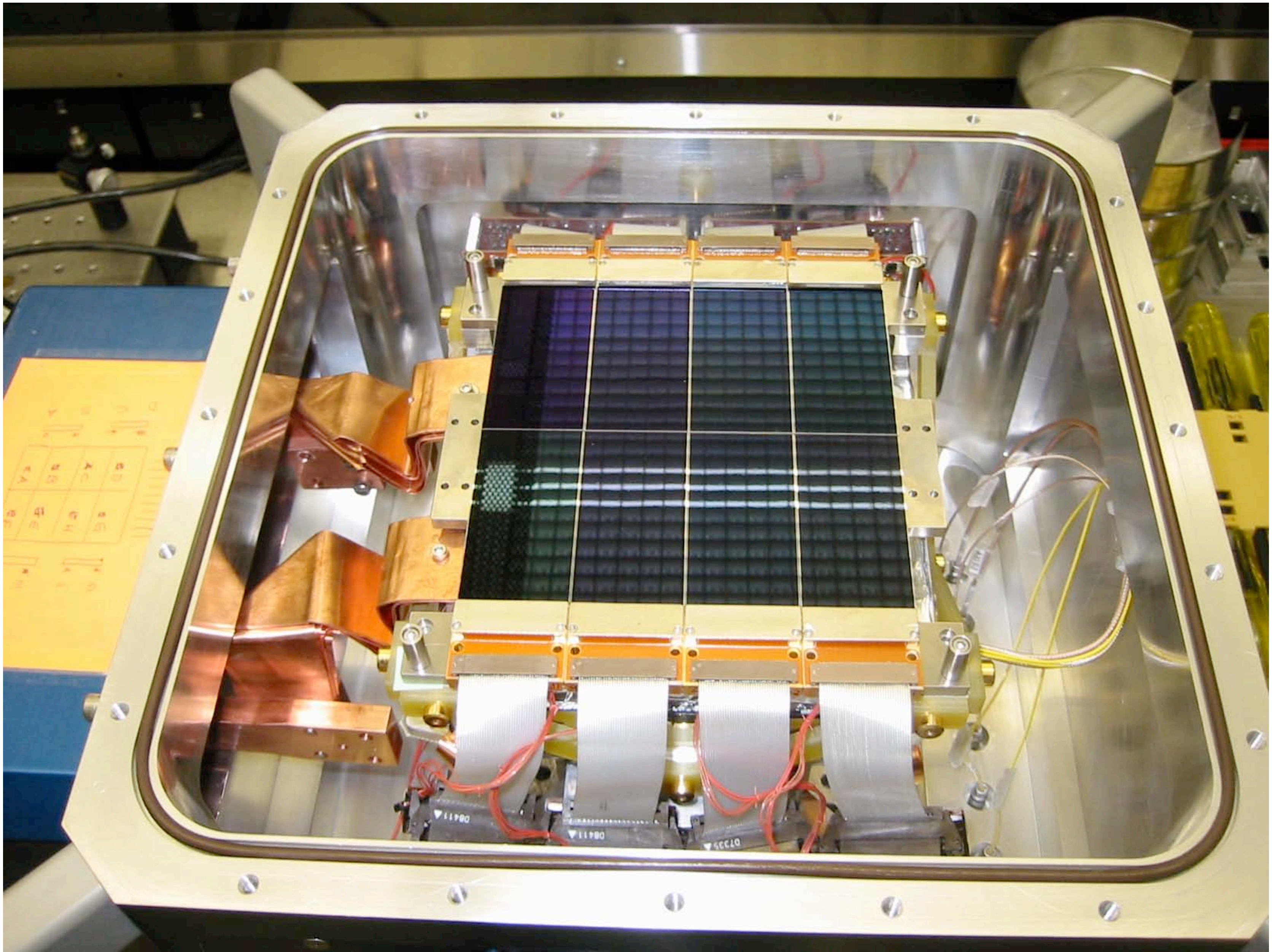
Read Noise acts as a shot noise, that is it enters the noise budget as R^2

CCD Properties

- **Dark Current**
  - Thermal noise (Thermal electrons)
  - Strong function of temperature
  - Essentially zero in research quality CCDs operated near -100 C



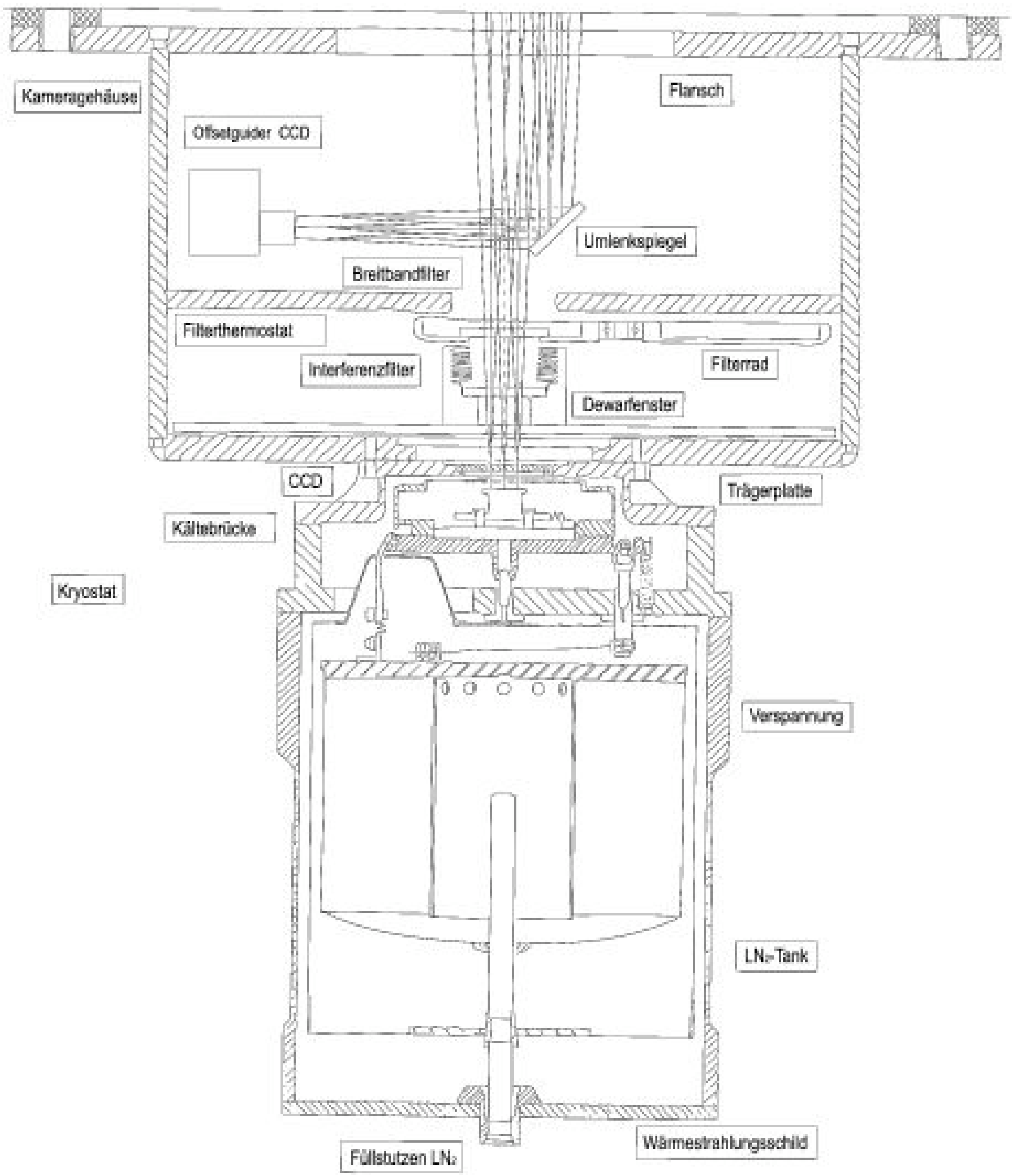
CCDs mounted in a dewar



CCD Dewar

OPTIC OTCCD Camera

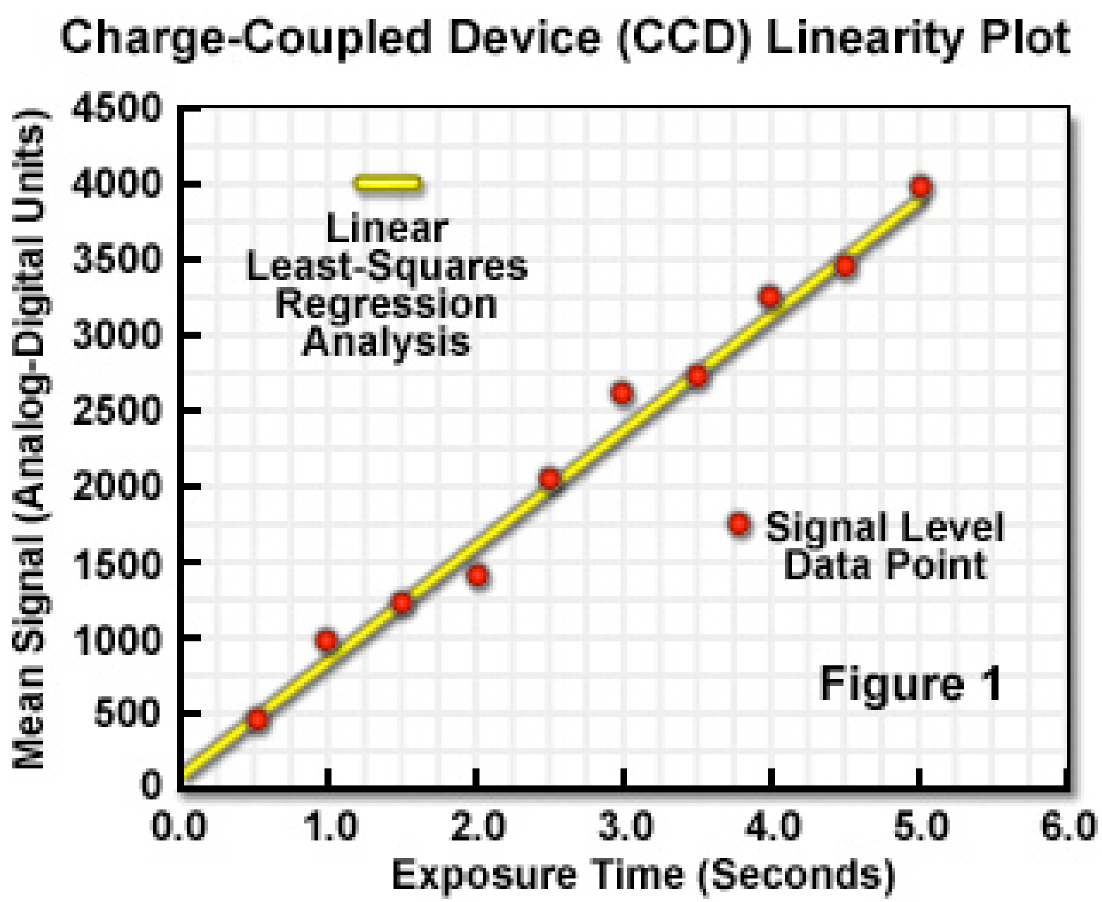
- CCDs are kept cold in dewars; “thermos bottles” filled with liquid nitrogen (LN2)
- CCDs are operated at temperatures near -85 to -100C
- Temperature control to +/-0.1 C is desired



- Schematic CCD Dewar

CCD Properties

- Linearity
  - Relationship between photons in and DN out
  - In-Out related by Gain of CCD (e.g., 3 electrons/ADU)
  - <1% deviation over full range is good
  - Depends on CCD and A/D



Useful CCD Stuff

- CCD pixel scale (Plate scale)
  - given in arcsec/pixel
- CCD Binning
  - How many pixels are co-added on-chip prior to readout. (e.g., 2X2, 3X1)
- CCD windowing
  - What rectangular region of the CCD is in use
- Full well capacity
  - How many photoelectrons can a single pixel hold before saturation (charge spills out to nearby pixels)

Useful CCD Stuff

Signal-to-Noise is a quantitative measurement of data quality. Observers desire high signal and low noise. S/N values are quoted as a number such as S/N = 100 or S/N = 3.

For a zero noise observation of an astronomical object, the S/N = SQRT(N) where N is the total signal received (i.e., total photons from source). [Poisson Statistics]

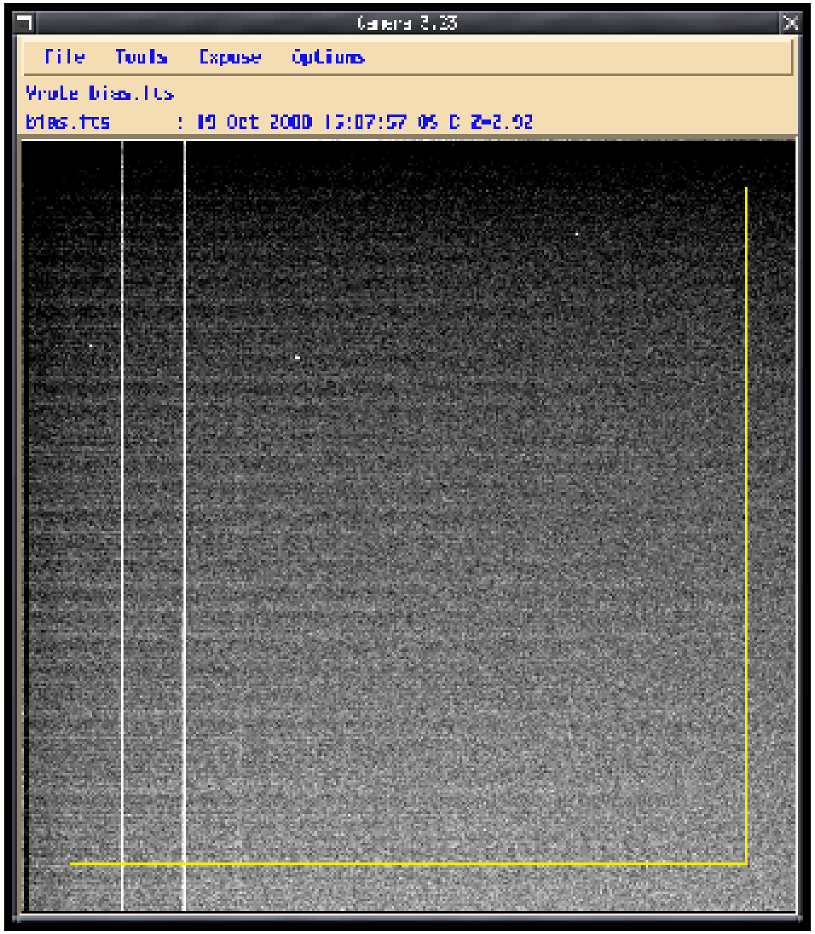
In reality,

$$S/N = \frac{R_* \times t}{[(R_* \times t) + (R_{sky} \times t \times n_{\rm pix}) + (RN^2 + (\frac{\mathcal{G}}{2})^2 \times n_{\rm pix}) + (D \times n_{\rm pix} \times t)]^{1/2}}$$

CCD Observations

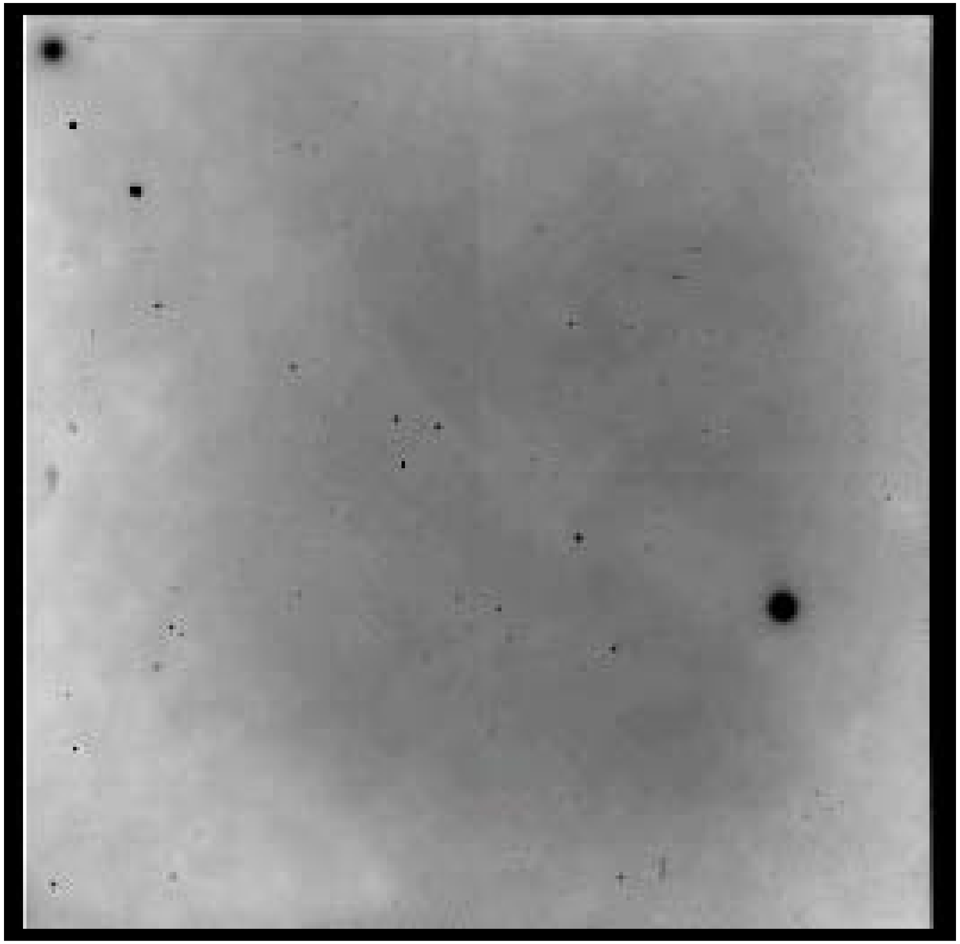
- CCDs are used in astronomy for three major applications:
  - **Imaging**
  - **Photometry**
  - **Spectroscopy**
- Used in optical and outside optical bands (e.g., x-ray, UV, EUV)

CCD Image Types



- BIAS - calibration
  - A bias (or zero) is a zero second exposure used to measure the "no signal" noise level of the detector.
  - Note the two bad columns in this CCD and cosmic rays

CCD Image Types

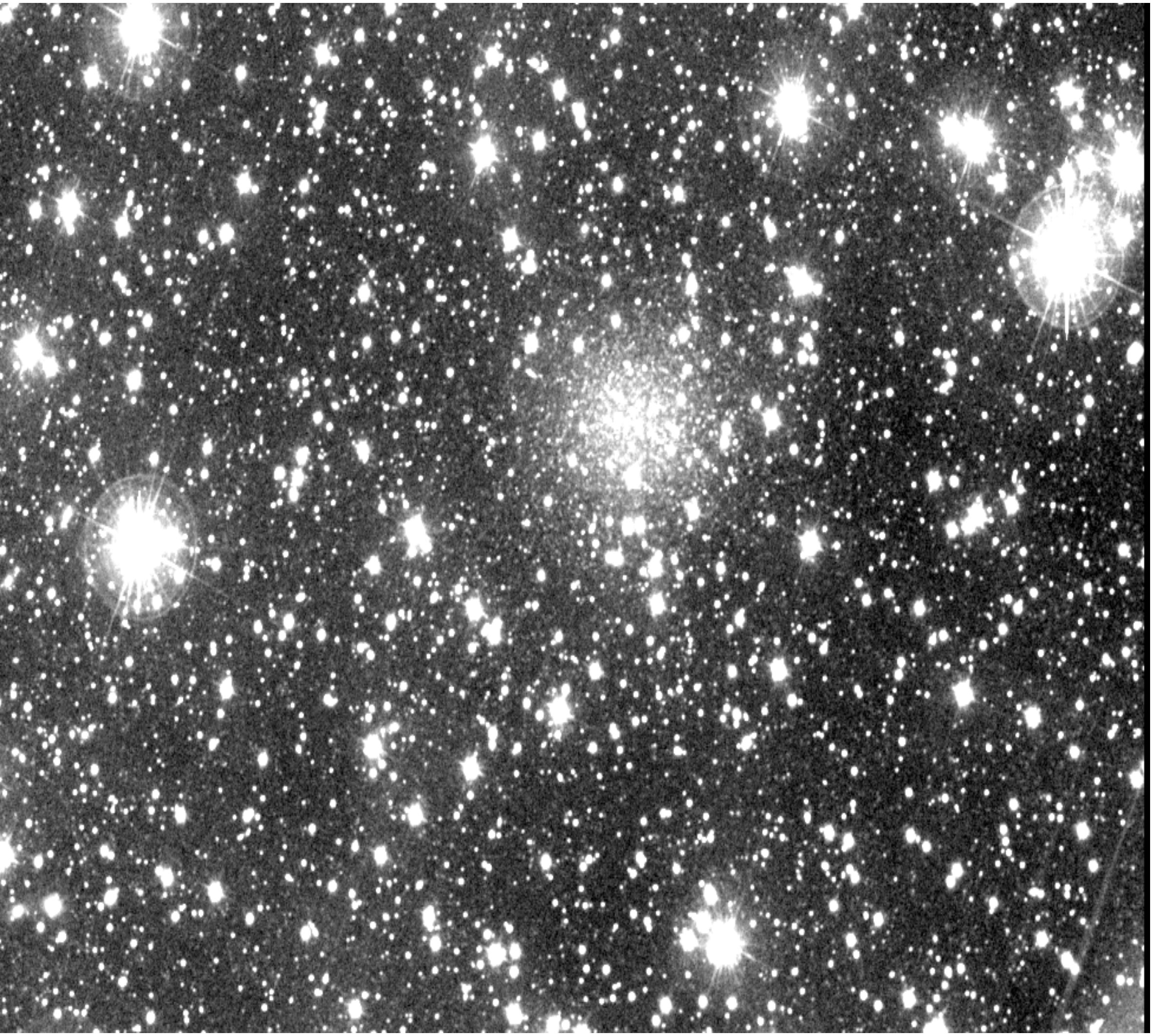


- **FLAT FIELD - calib.**
  - A flat field image is used to determine the relative QE of each pixel in the array
  - Flat field images are obtained from dome screens, the sky, or quartz lamps projected in to a spectrograph

Basic CCD data reduction

- Minimal set of images: bias, flat, and object
- Darks needed if dark current an issue
- All frames include overscan
- Additional steps needed for specific CCDs and specific observations – instrument manuals should provide details
- Basic reduction
  - (Object – Mean Zero) / Mean Flat
- LOOK AT YOUR DATA – Does it make sense?

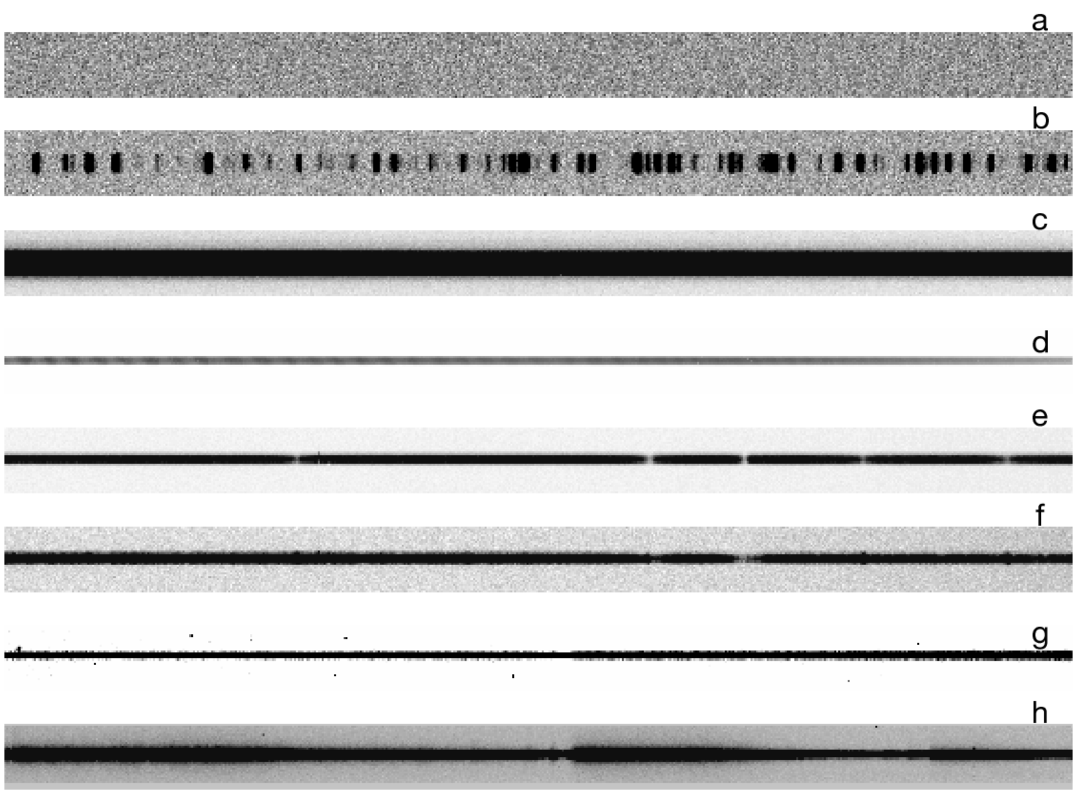
CCD Image Types



Object

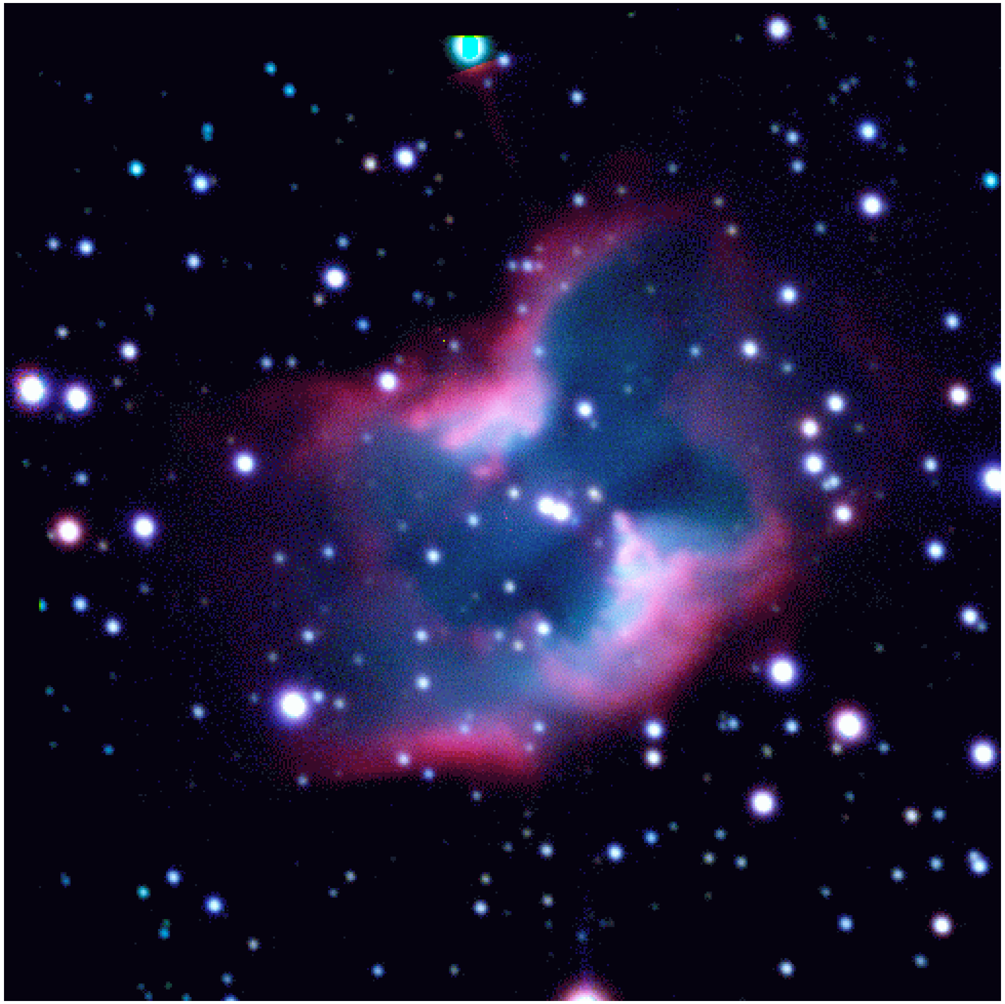
- CCD images are grey scale representations of the collected and stored ADUs.
- To perform imaging or photometry, observers use these types of CCD data.

CCD Image Types



- **SPECTROSCOPY**
  - Spectra are the result of an object's light being dispersed into its component colors.
  - These examples show calibration and object spectral images

CCD Image Types



COLOR IMAGE

– Color images are produced using three (or more) individual grey scale CCD images obtained in different filters.
– These filters generally define special wavelength regions and/or features in the astronomical object