Astronomical Techniques I

Lecture 7

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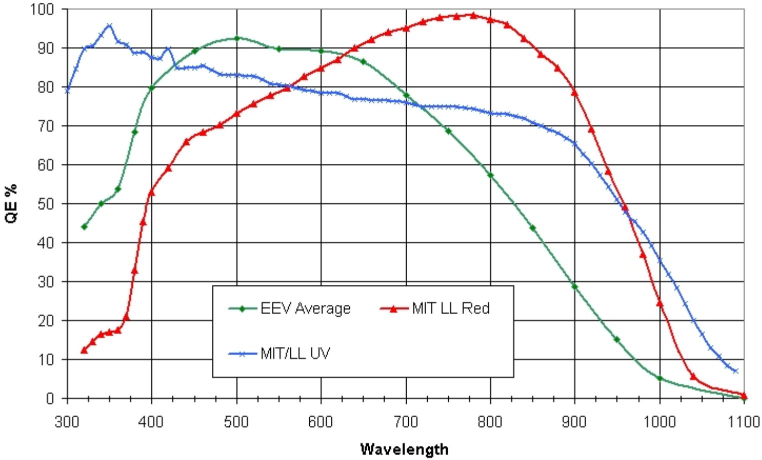
Some comments on the Research seminar

- I expect you to spend $\sim 20 hours$ on the research seminar including time to prepare slides.
- you will need to read and understand your selected paper in detail. You may need to browse through a few related papers.
- I will make time available a couple of days before the seminar to resolve doubts
- Pitch your talk at the level of your colleagues. You may assume as background whatever you have learnt in grad school so far (including in this course).
- Since we have many students, we might have to cut the talk to 25 min + 5 min questions.

CCD Quantum Efficiency



This is why we need 30m class telescopes!

CCD Gain

is number of electrons per ADU (Analog-to-Digital-Unit). Most CCDs have a user settable gain. Why is it very useful to be able to set the gain? What is the equivalent of gain in a digital SLR camera? film camera?

Characteristics of the perfect detector

- 100% QE
- Perfectly Uniform Response
- Noiseless
- Unlimited Dynamic Range
- Completely Understandable Characteristics

Characteristics of CCDs

- High QE compared to photographic media
- High Linearity
- Large Dynamic Range
- Relatively Low Noise
- Digital

applications of CCDs

- video cameras
- digital cameras
- security cameras
- photocopying machines
- scanners

In all these applications, they have been largely replaced by CMOS devices. The largest volume of imaging sensors (in terms of units produced) is now cell phone cameras which are all CMOS.

Some CCD Jargon

- *buried channel* charge transfer from a lower layer than the surface - avoids charge traps, and improves CTE
- *front illuminated*
- *back illuminated* (also called *thinned* devices: $\sim$ 15μm) have higher QE, especially at short wavelengths. Disadvantage: low full well capacity, non-uniform thinning, and more expensive.

Questions

- We noted that modern astronomical CCDs take about a second to read out. How can we build video cameras with CCD sensors?
- CCDs are only measuring photons that hit them. How can one build a digital camera that takes *colour* photos?

Frame transfer CCDs

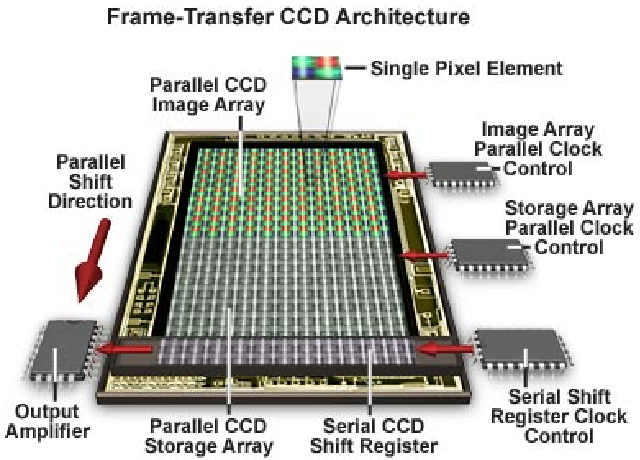
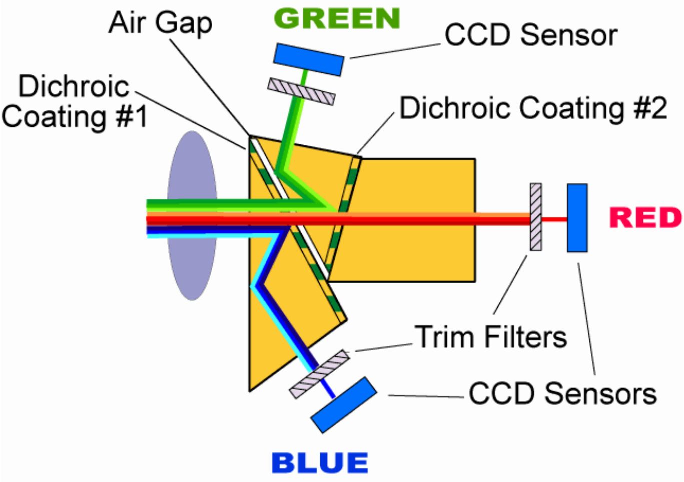
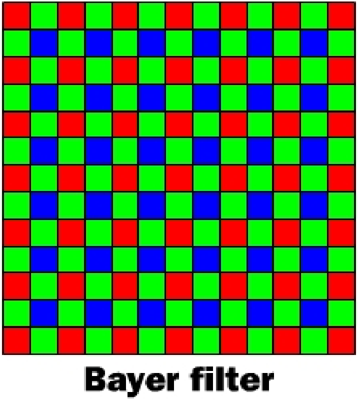


Figure 1

3 CCD imager


Air Gap
GREEN
CCD Sensor
Dichroic
Coating #1
Dichroic Coating #2
RED
Trim Filters
CCD Sensors
BLUE

Bayer filter



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- Photon Shot Noise - longer exposures
- CCD Read Noise - random?
- Electronic Interference - EMI pickup e.g. 50 Hz

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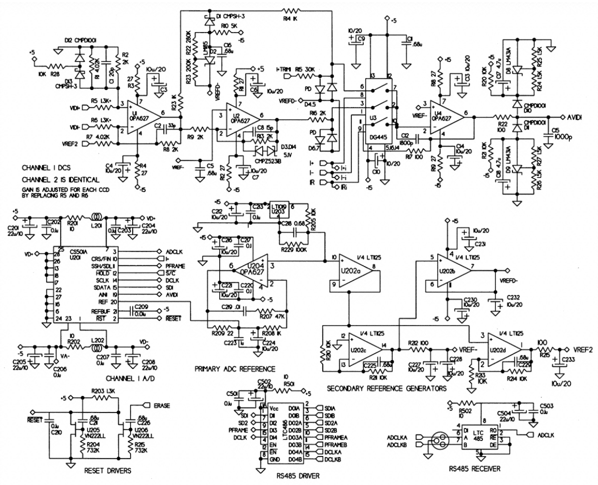
- can be accounted for with a flatfield image - dome/sky flats
- for precision photometry, many factors such as circular shutter closing, flat fielding noise, time variation of the flat field etc. are important.

CCD Read noise

The process of readout introduces many kinds of noise - amplification, discretization noise, EMI pickup (eg. 50 Hz noise). The goal is to reduce random errors and quantify systematic effects so that they can be removed during processing.
Minimizing the impact of these noise sources in the small, confined space of the CCD camera requires sophisticated mixed-signal design techniques including, careful circuit board layout and isolation, shielding, grounding, signal rise-time control, filtering, and considerate timing.

Sloan camera ADC Circuit diagram



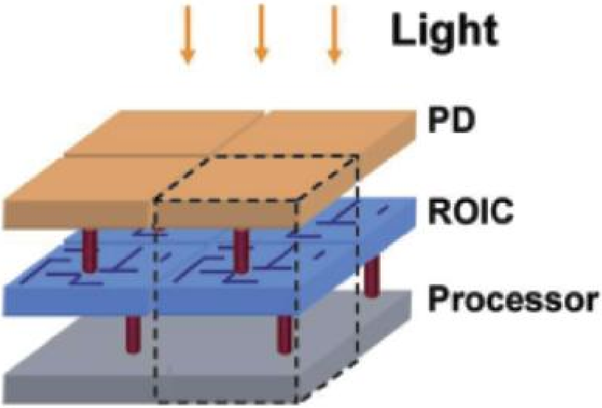
CMOS detectors for astronomy

In terms of manufacturing, CMOS imagers in general benefit from the large availability of foundries worldwide. Using the same foundry resources as microchips guarantees cost-efficient production and highly mature process technology.
A significant advantage of CMOS sensor is flexibility - the ROIC can be as simple as a single integrating capacitor or a complex one with hundreds of transistors.

Why CCDs dominate in astronomy

because volume matters. Although the cost to develop a new CMOS imager is higher, CMOS imagers that can leverage from larger economies of scale will have lower unit cost. With high volumes, a low unit cost (CMOS) can be financially more important than a low development cost (CCD).
But professional astronomy is not a high volume market. Hence, here CCDs still dominate.

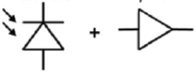
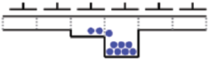
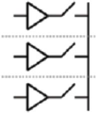
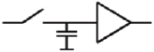
CMOS pixel schematic



Fancy features possible in CMOS devices

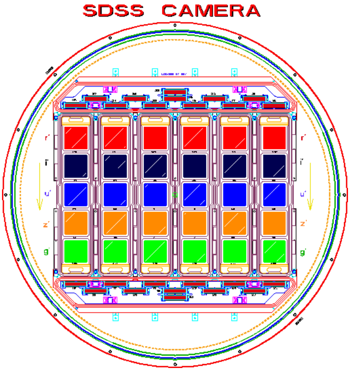
- electronic shutter
- non-destructive read
- random pixel access

CMOS Philosophy different

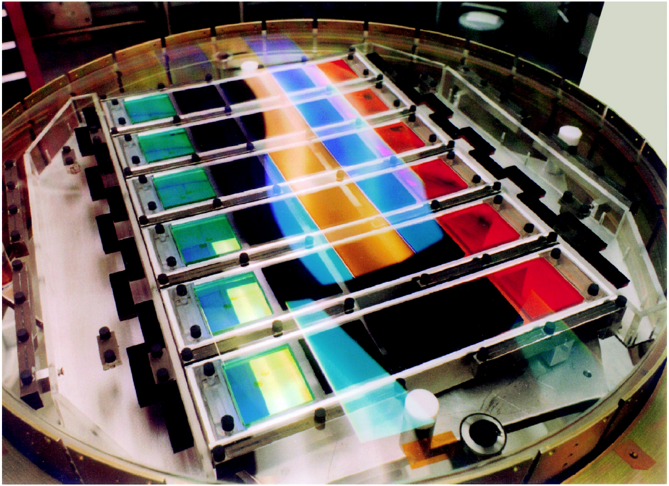
	CCD Approach	CMOS Approach
Pixel	 Charge generation and charge integration	 Charge generation, charge integration and charge-to-voltage conversion
Array Readout	 Charge transfer from pixel to pixel	 Multiplexing of pixel voltages: Successively connect amplifiers to common bus
Sensor Output	 Output amplifier performs charge-to-voltage conversion	Various options possible: - no further circuitry (analog out) - add. amplifiers (analog output) - A/D conversion (digital output)

Multi-CCD Mosaic cameras are now common

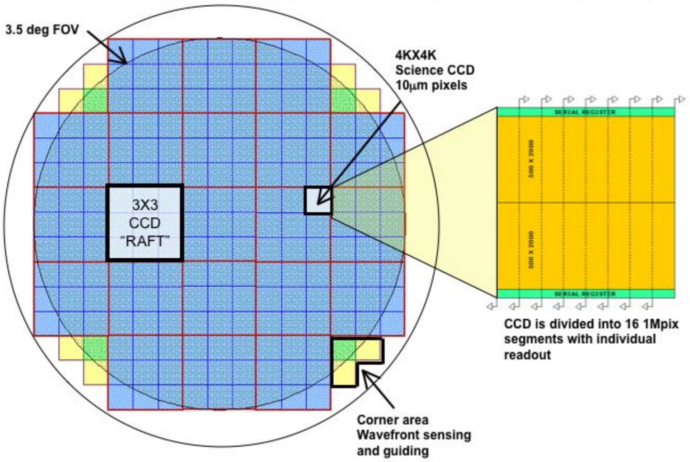
- A drift-scan camera. 54.1 seconds in each filter, in order r,i,u,z,g
- 54 CCDs on focal plane; 145 Mpix.
- Data rate of 5 Mbytes/sec.
- covers sky at 20 sq. deg/hour



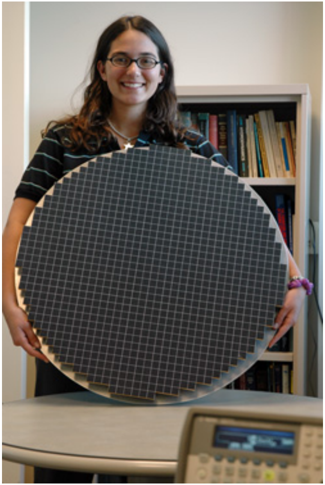
SDSS Imaging Camera



The biggest CCD mosaic of them all!

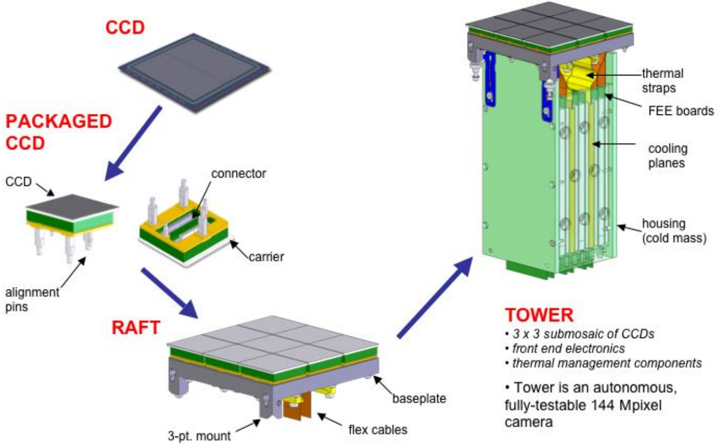


The largest camera ever built - 3.2 Gpixel



Camera size is 1.6 meters by 3 meters (size of a small car). It also will weigh 2800 kilograms.

LSST Raft tower



Types of CCD images

- Bias - Positive bias applied to prevent negative counts. Generates non-zero counts in each pixel. Standard deviation of the counts is called read noise.
- Flat field - dome or sky.
- Object - exposure on astronomical source