Introduction to CCD Operations

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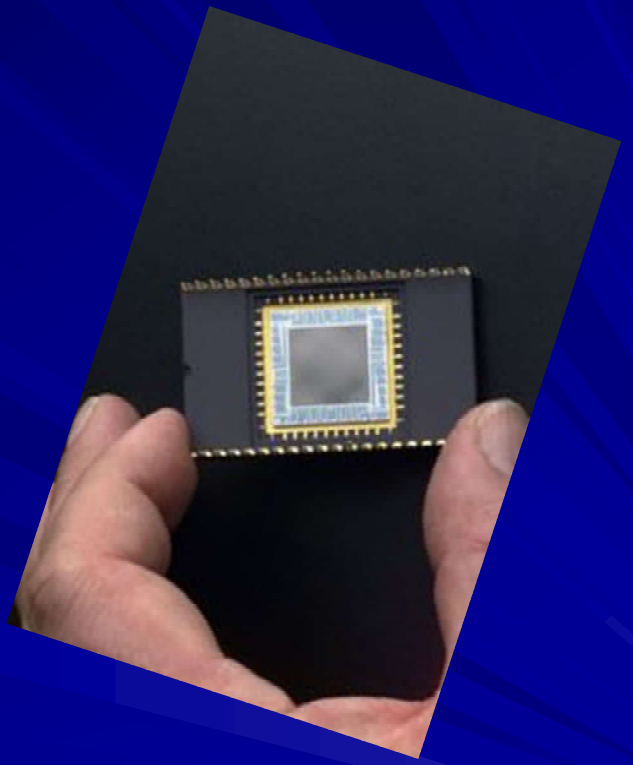
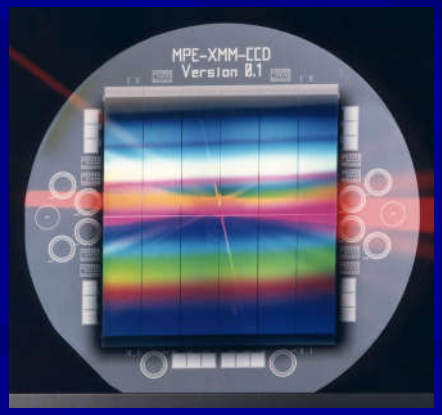
Presentation Layout

- Introduction
- History of the CCD
- Technology of the CCD
- Basic principles of the CCD
- Applications
- Accessories
- Software
- Example
- Conclusion



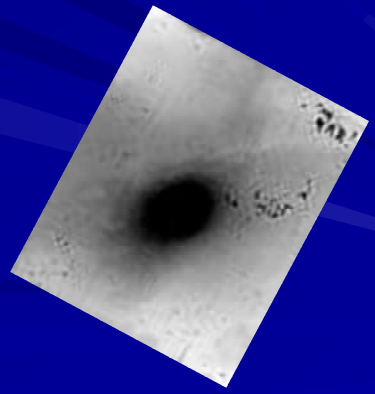


Introduction

- From a early age mankind wanted to see more of the night sky than what was visible through the naked eye. Thus he invented the telescope.
- But then he wanted to preserve what he saw. Thus he invented photography.
- But he also wanted to know. Thus he invented photometry and spectroscopy.

History of the CCD

- Before the advent of digital electronics astronomers used imaging tubes and photographic plates.
- Although plates offered excellent resolution and a choice of detector size, they were also highly non-linear.
- They also had a very low quantum efficiency (the efficiency of a detector in recording radiation).



History of the CCD

- In 1969 W. Boyle and G. Smith invented the Charge-Coupled Device (CCD).
- It was initially developed for the purpose of serving as a serial memory device. It was to be a electronic analogue to the bubble memory used at that time

- It was soon clear however that the CCD could not only be charged via a direct input register, but could also receive charge via the photoelectric effect, thus allowing the creation of digital images.

Basic principles of the CCD

- A CCD consists of a silicon chip containing an array of light sensitive diodes. These diodes which become charged when light falls on them are arranged in rows and columns.
- The columns are then read out column by column to provide a analogue signal, which is then converted to a digital signal for display and storage purposes.
- Current CCD's have a high quantum efficiency (QE) across much of the working spectrum, are highly linear, are responsive and come in a wide range of specifications.

Technology of the CCD

- Digital imaging CCD's work on the photoelectric principle. The physics behind this is the creation of a electric current in a light sensitive material when it is irradiated with electromagnetic radiation or photons.
- The architecture of the CCD thus consists of an array of pixels/cathodes on a semiconductor (mostly Si) which when it absorbs a photon can use the energy to release a electron in the semiconductor. With each pixel representing a potential well which must hold the total electric charge generated up until read-out.

Technology of the CCD

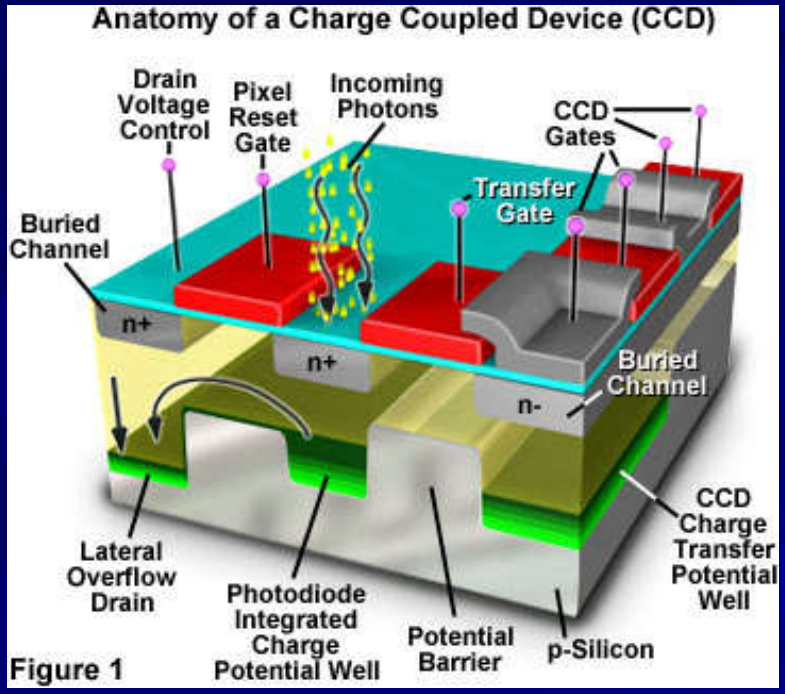


Figure 1

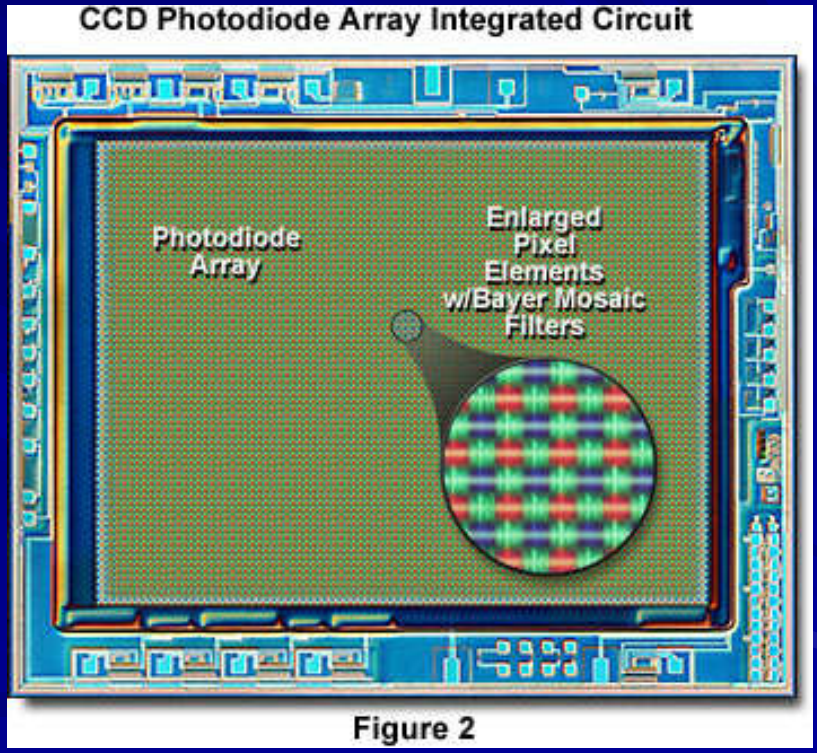


Figure 2

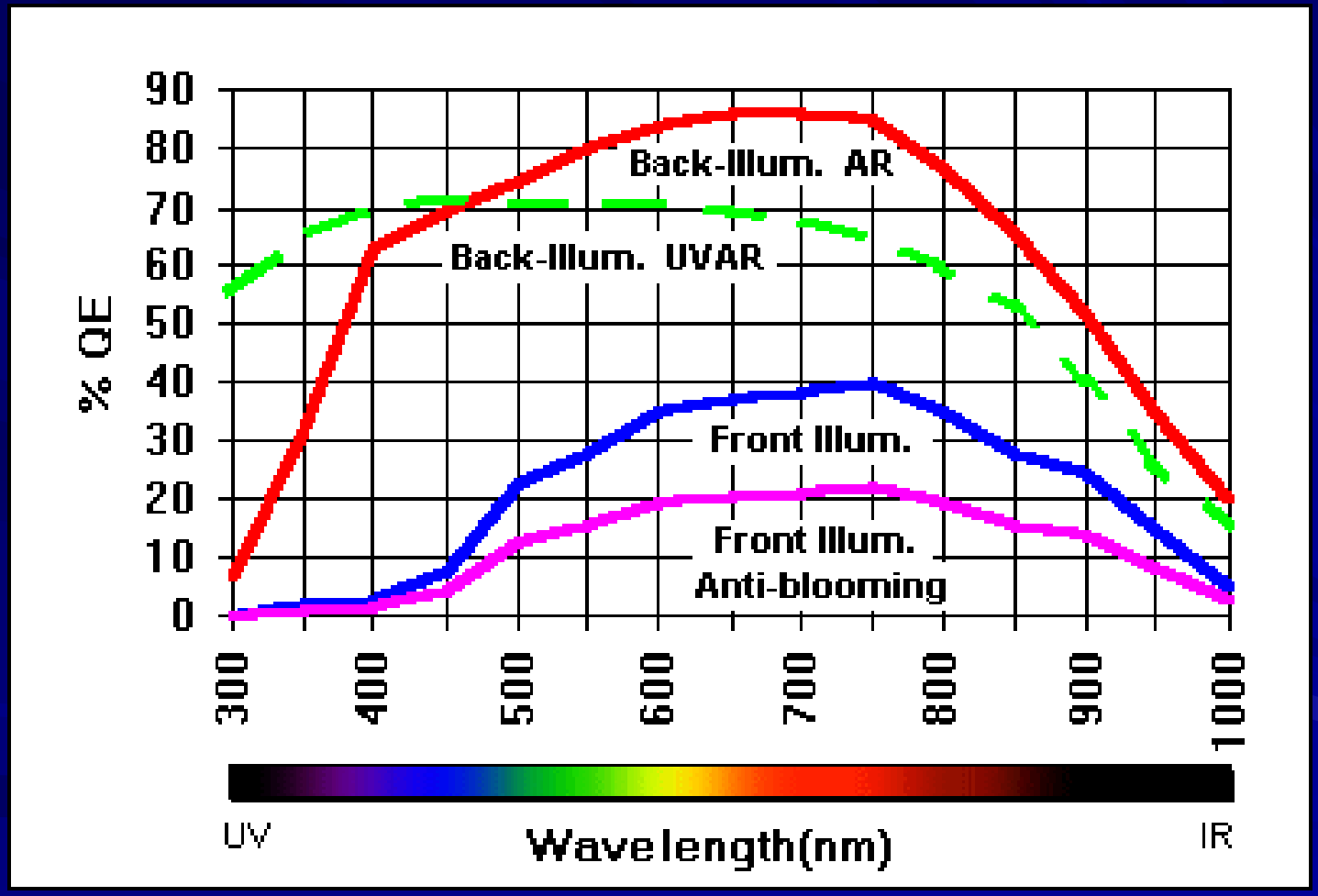
Technology of the CCD

- There are different architectures implemented for CCD construction. The most common are full-frame, frame-transfer and interline.
  - Full-frame: The whole image area is active. Mechanical shutter is needed
  - Frame-transfer: Half of the CCD area is covered by a opaque mask. The image is then transferred to the opaque area from the image area, with acceptable smear. No mechanical shutter is needed
  - Interline: Every other column is covered, thus serving as storage. 50% of image area is lost however, but smear is essentially eliminated. The fill problem has been addressed in modern designs.

Technology of the CCD

- Back-Illuminated (BI) vs Front-Illuminated (FI)
  - Front: Because of their physical thickness (200-300 microns), FI CCD's are more sensitive in the RED than BLUE. This is because the absorption depth of blue photons in Si is 2000 Å, while the insulation gates of the electrodes are 5000 Å thick. Thus many blue photons are absorbed before they could penetrate the gates. FI CCD's was used throughout the 80's.
  - Back: BI CCD's are produced by thinning the CCD from 300 microns down to 10 microns. The backside is then exposed to blue photons, allowing the photons to reach the electrode without being absorbed by the gate. This greatly increases QE of the CCD in the B and U, without much sacrifice to the QE in the R. Most modern CCD's are BI.

Technology of the CCD



Applications

- Astronomical CCD's
  - CCD Spectrometer
  - CCD Photometer
- Digital and Video Cameras
  - Security Cameras, Night Vision devices, Infrared imaging, Commercial Cameras
- Optical Scanners, Photocopiers, Fax Machines
- Colour Cameras: Uses a Bayer mask over the CCD.

Accessories

- Image Reducer lens: Increase FOV
- Port Accelerators: Increase speed of image download
- USB 2.0 Interfaces: Allows direct USB connection
- Auto-guider CCD camera's
- Filter's, Filter-wheels
- Cooling Units
- (*etc* …)

Software

- AIPS – Astronomical Image Processing System
- AstroArt
- CCDSoFT
- IRAF – Image Reduction and Analysis Facility
- MaximDL
- Picture Window Image Editing Software
- The Sky
- Starry Night
- (*etc* …)

An Astronomical CCD system.

- The Boyden 60-inch Telescope is a prime example of a fully implemented and modern astronomical CCD system.

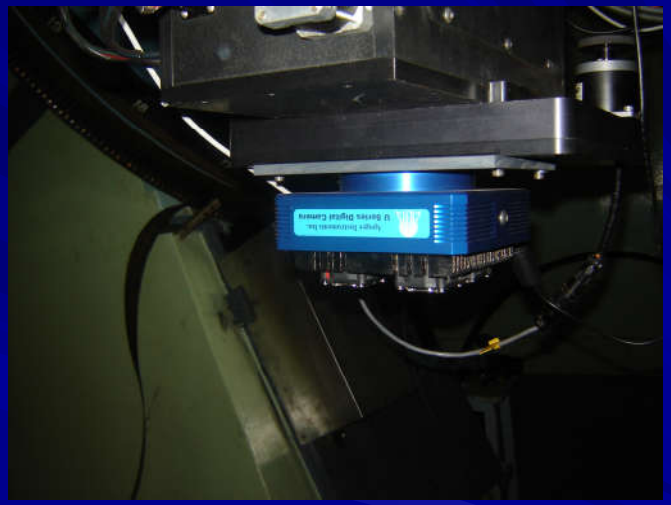
Instrumentation: Telescope

- Equatorially mounted cassegrain.
- Primary mirror diameter is 60 inches (1.5 meters).
- Computer controlled
- F-ratio of approximately 15.
- CCD based photometric system, with a filter-wheel controlling the filters used during photometric study.

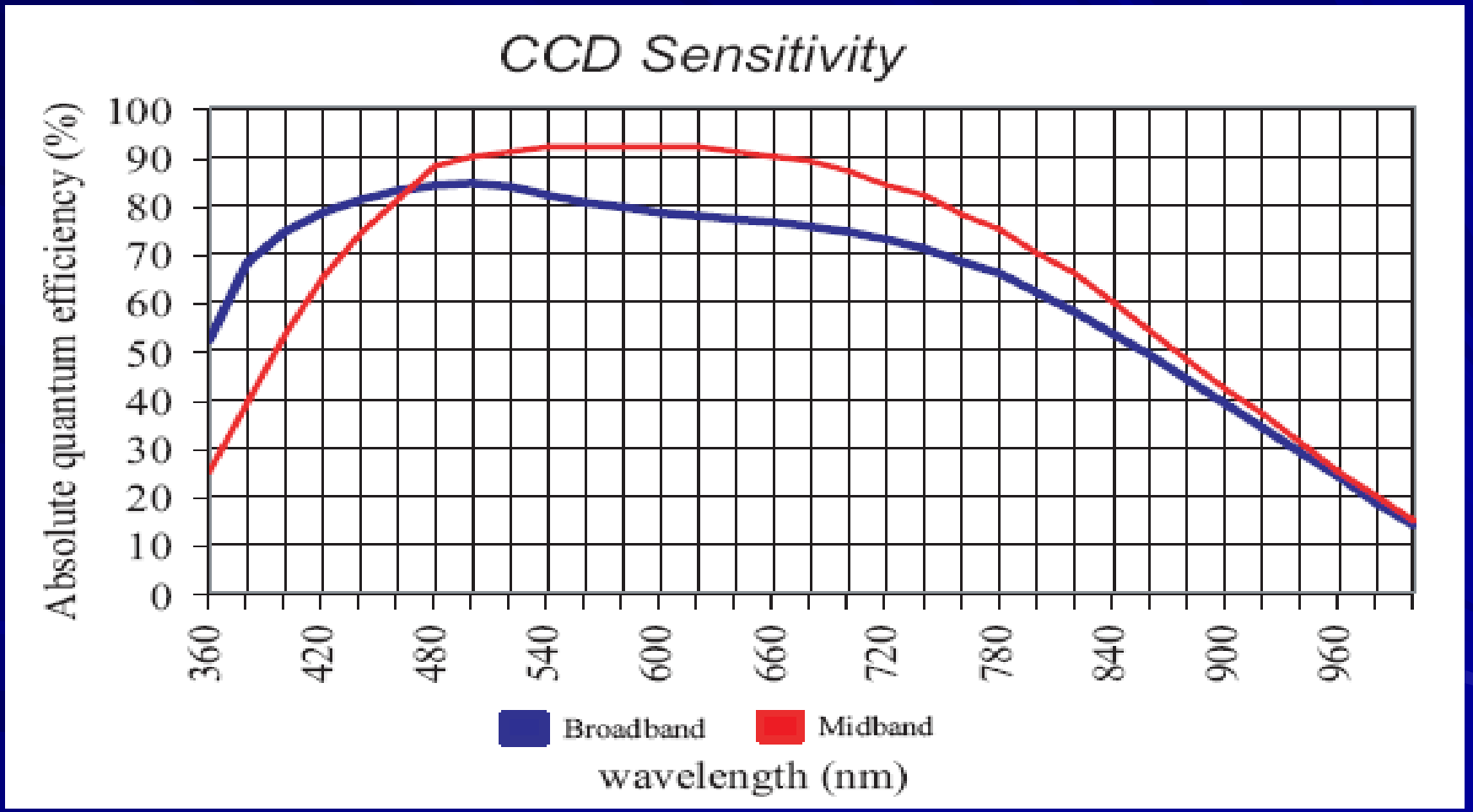
Instrumentation: Camera

Alta U55 CCD Camera specifications:

- **CCD:** E2V CCD55-20 Back-illuminated
- **Array Size (pixels):** 770 x 1152
- **Pixel size:** 22.5 x 22.5 microns
- **Imaging area:** 17.3 x 25.9 mm (448 mm^2)
- **Imaging diagonal:** 18.83 mm
- **Linear Full Well (typ.):** 450,000 e-
- **Dynamic Range:** 93 dB
- **Plate Scale:** 8.59”/mm
- **Field Size:** 2.5’ x 3.7’

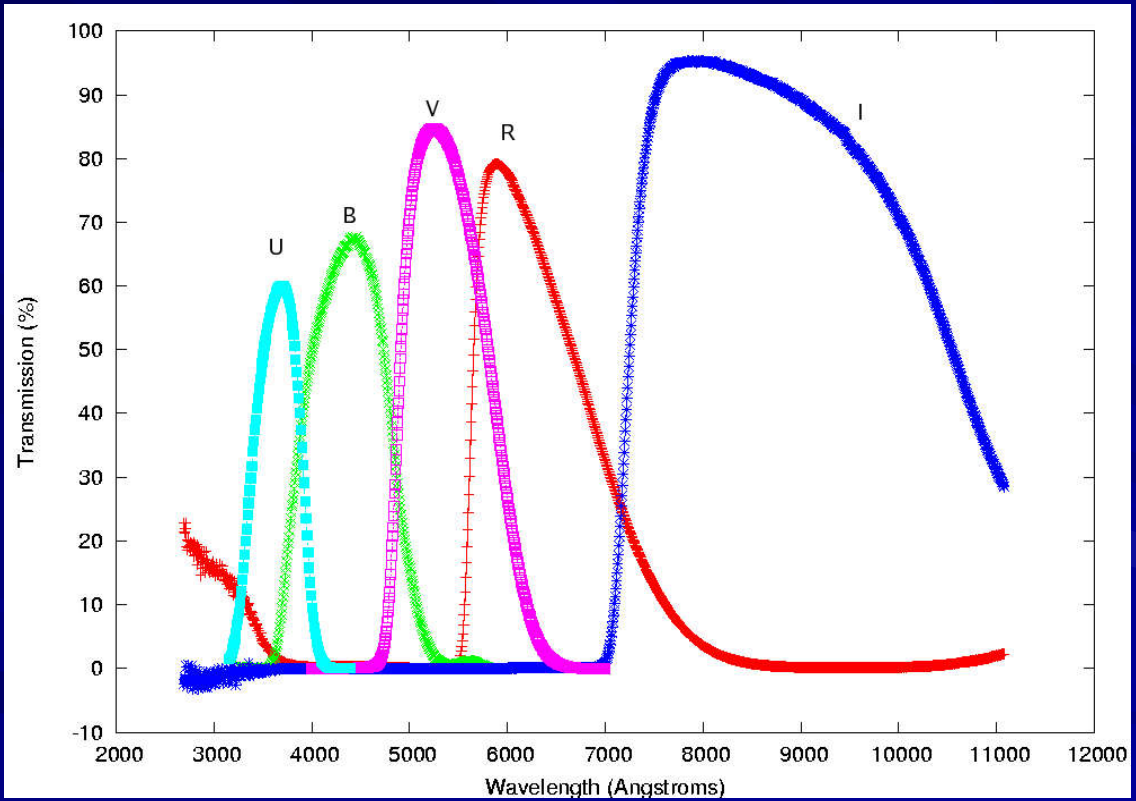


Instrumentation: Camera



Instrumentation: Filters

- **Filter-wheel:** Bessel filters representing Kron-Cousins for **R & I** and Johnson / Kron-Cousins for **U, B and V.**



Instrumentation: PC Control

- The telescope is controlled by an set of computers.
  - One running on PC-Dos is used to control's the telescope drives, tracking and dome systems.
  - Another running under Windows is used for software and general interaction with the telescope system. It runs the filter-wheel interface program "ACE", the planetarium program "The Sky" for telescope connection and star search, and the digital imaging software "SPICA" used to take the photos/images, which is saved in FITS format for further analysis and use.
  - A third running under Red Hat Linux is used for data reduction and analysis, using software like IRAF.

Conclusion

- CCD's are currently the most widely used imaging technology
- It has a wide range of applications and uses
- With the improvement of current material science technology the CCD is close to becoming an ideal detector.

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