PROJECT REPORT

Instrumentation: CCD and Telescope

Presented by
Anjali Lohani
Amity University
Noida, Uttar Pradesh 201313

Under the guidance
Dr. Biman J. Medhi
(Scientist – E)
ARIES, Manora Peak
Nainital, Uttarakhand, 263002

ABSTRACT

The aim of this project was to gain a first hand knowledge of instruments such as CCD and telescope being used in current astronomy. In this project, I have learnt the basic properties of telescope along with a hands on practice with CCD data.

1. CCD :-

The invention of charge couple device replaced the photographic plate and digitalized the astronomical world. Though it lead to advancement of astronomy but still there are some issue that take CCD onto a backseat. The problem that incur quite often in CCD is due to its temperature dependency ,charge transfer efficiency (CTE) and quantum efficiency(QE). The effect of these enormity can be seen during readout of pixel in form of dark current , non uniform distribution of electron over the array of pixels and degradation of light intensity(e.g.-bright star will appear faint in image).

To understand the problem and its solution I went to dome during observation night to analyze how these problems are minimized. From there I learned how calibration technique like biasing and flat field is performed before taking observation to avoid non uniform distribution in CCD. Afterward I learned IRAF(image reduction and analysis facility) to make master bias and master flat . From the statistical data provided in IRAF I calculated gain, read noise and signal to noise ratio. These parameter were used to make master bias and master flat. I also saw and read about the CCD dewar and analog to digital converter(ADC).

2. **TELESCOPE** :-

I have learnt the basic properties of telescope along with a hands on practice with CCD data. Learnt about the various mounts like equitorial and alt azimuth.

OVERVIEW:-

1.CCD

BASIC PRINCIPLE

- It is a detector that detects the light signals and convert them to digital signal for analysis.
  OR
- It convert optical images to electrical signals

INTRODUCTORY POINTS

- Silicon is the semiconductor material used to make CCD
- Present day CCD come In size ranging from 512*512 to 8192*8192 pixels (square)
- In rectangular 2048*4096 are usually produced for spectroscopic application .

The comparison of CCD's are done on the basis of following properties:-

1.NOISE PROPERTIES

- The electronic noise is measured in electron per pixel.
- The modern device make negligible noise around 2 to 5 electron per pixel .

2.QUANTUM EFFICIENCY

- It is the ability of a detector to turn incoming photons to photo electrons .
- CCD's today are 90% quantum efficient and 60% more quantum efficient over 2/3 of total spectral range.

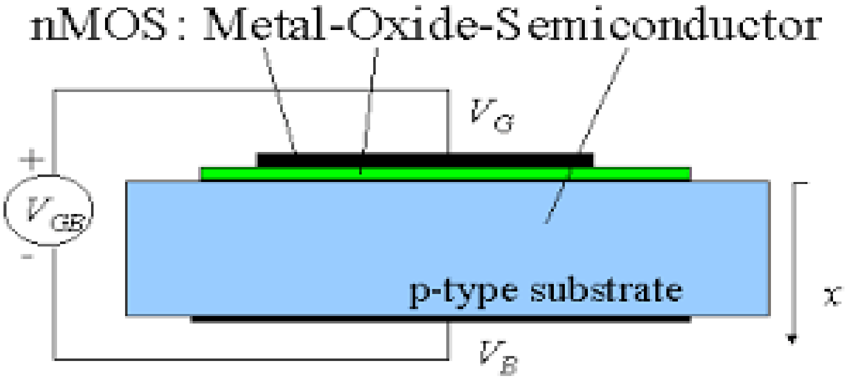
3.BANDPASS

- It means the total spectral range for which detector is sensitive to incoming photons.
- For e.g. our eye have a band pass converging only 2000A of optical spectral range (4500-6500A)
- Dyes and coatings are done to extend the band pass converge

ELECTRONICS OF CCD

BASIC PRINCIPLE

- The produced photo-electron are stored in depletion region of a metal insulator semiconductor (MOS) capacitor.
- CCD array simply consist of many of these capacitors placed in close proximity.
- Voltages are manipulated during readouts in such a way to cause the stored charges to flow from one capacitor to another,hence it got the name charged couple device



- Each cell or pixel of CCD contains MOS capacitor
- CCD are typically fabricated on p type substrate .
- In order to form a buried channel a thin n- type region is formed on its surface.
- An insulator in the form of silicon dioxide layer is grown on top of n region.
- The capacitor is finished by placing electrode also called gates on top of SiO2.

CCD OPERATION

I. Charge generation

- Within a pixel the charge is generated by photoelectric effect.
- Incoming photons strike the silicon within a pixel and are easily absorbed if they possess the correct wavelength.

QUE-How we choose a semiconductor material for particular wavelength ?

Ans -Silicon has a band gap energy of 1.14 eV so for photoelectric effect the energy must be greater than 1.14 eV.

For 1.1eV, $\text{wavelength(A)} = \frac{12407}{E(eV)} = \frac{12407}{1.1} = 11279$ A

Silicon has a useful photoelectric range from 1.1 to 10 eV
for 10 eV, wavelength= 1240.7

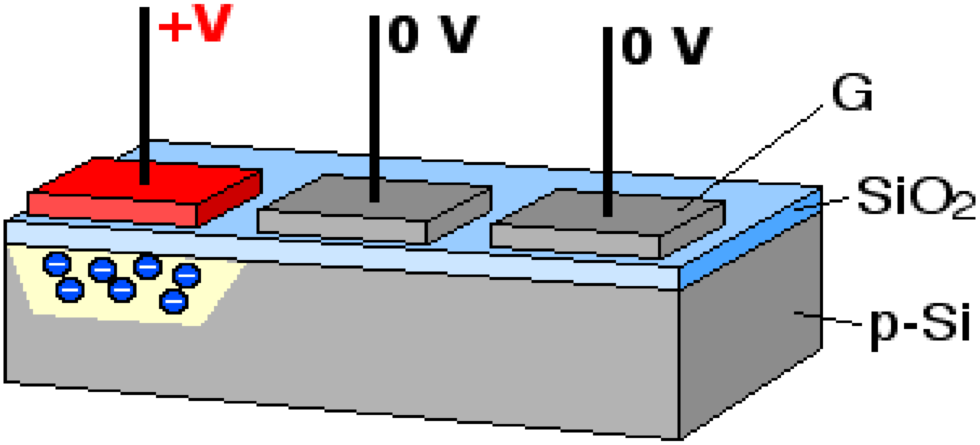
Now if we check the wavelength from table of electromagnetic spectrum:-

	WAVELENGTH(Angstrom)
1.Radio wave	>10^9
2.Microwave	10^9 - 10^6
3.Infrared wave	10^6 - 7000
4.Visible range	7000 - 4000
5.UV wave	4000 - 10
6.X-rays	10 – 0.1
7.Gamma rays	<0.1

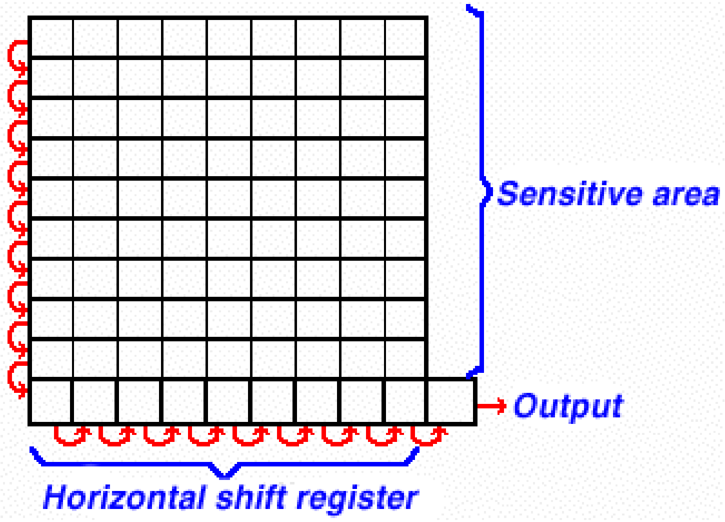
- It means that Si is sensitive to UV, Visible and IR range.

II.CHARGE TRANSFER

- The goal is to protect the integrity of each charge packet and to move them on down the line.



- Potential well is created for the gate having highest voltage(+) so all electron fall on it.
- One clock cycle moves each row of pixel up one column, with the top row being shifted off the array into what is called output shift register or horizontal shift register.



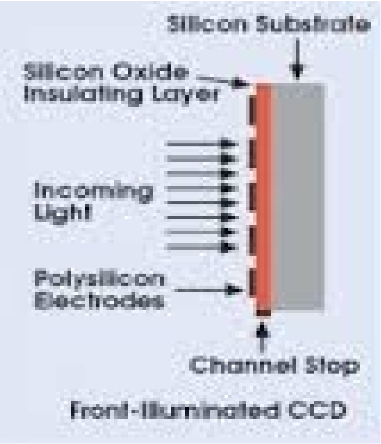
TYPES OF CCD

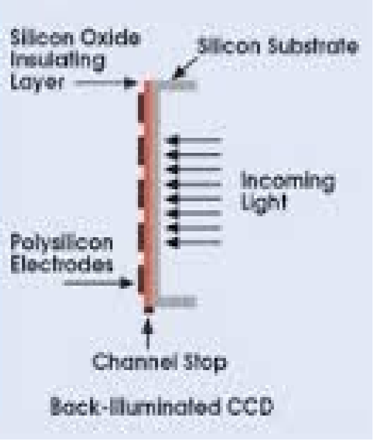
1)FRONT SIDE ILLUMINATED CCD

- In this the illumination occur in front side of CCD with the photons being absorbed by the silicon after passing through the gate structure
- CCD have lower quantum efficiency.
- It provides a flatter imaging surface

2)BACK SIDE ILLUMINATED CCD

- These are known as thinned device.
- Illuminated from behind.
- The quantum efficiency of device is high and response of detector to short wavelength is improved.





ANTIBLOOMING CCD

- Observation of bright stars can lead to collection of too many photo electrons within one or more pixel of a CCD
- The result of such saturation is termed as bleeding.
- A bright streak on CCD image is significance of blooming.
- **CCD can saturate in two different ways** :
  1. Too much exposure.
  2. Collection of more charge in short integration

The image below (M16 - The Eagle Nebula) shows something known as "blooming".

ANTIBLOOMING GATE add electrical structure manufactured into CCD itself.

- These structure allow saturated pixels to be "drained off"
- The offending pixels in such a case are still not usable but neighboring pixels are
- For a CCD with antiblooming gates 30%of the active pixel area is lost which lead to reduction of quantum efficiency.

ANTI REFLECTING COATING CCD

- Silicon has a very high refractive index (n) so photons are strongly reflected from its surface.
- Photons reflected at interface= $\frac{n(air) - n(silicon)}{n(air) + n(silicon)}$
- n(air)= 1, n(glass)=1.46, n(silicon)=3.6
- From this we calculated that glass in air reflects 3.5% and silicon in air reflects=32%
- It means silicon detects 2 out of 3 photons.
- So this refractive index is reduced by depositing a thin layer of transparent material on the surface of CCD.
- The refractive index of this material should be between that of silicon and air and should have an optical thickness 1/4 Of wavelength of light. Typically 550 nm is chosen which is in middle of spectrum.

CHARACTERISTICS of CCD

It is done on the following basis

1. Quantum Efficiency

- QE depend on the thickness of silicon that intercept the incoming photon.
- CCD with high resistivity are preferred as resistivity increases the depletion region increases so more photons can be trapped in each pixel.

CHARGE DIFFUSION

- Once an electron is captured in a CCD pixel it is controlled by voltage to keep in place.
- There are finite probability for given electron to wander out of its collection and into a neighboring pixel. This process is called charge diffusion
- Way by which charge diffusion can occur is
  i) By applying different voltages in gates of front illuminated CCD.
  ii)Impurity in silicon material.
- Electron loss can be mitigated by using higher resistivity Si.

3.Charge Transfer Efficiency

- It is a measure of fraction of charge that is successfully transferred for each pixel transfer.
- It should be 100% in order to preserve the charge in each pixel during readout .
- CCD's with poor CTI generally charge tails in direction opposite readout for bright stars. These tails are basically charge left behind as image is shifted out.
- The CTE of CCD generally degrade with decreasing operating temperature.

4.Readout Noise

- Readout noise is the number of electrons introduced per pixel into final signal upon readout of device.
- Electronics themselves will introduce spurious electron into the entire process , yielding unwanted random fluctuation in output.
- The physical size of on chip amplifier, the integrated circuit construction ,the temperature of amplifier and sensitivity all contribute to the read noise for a CCD.
- The readout speeds ,cause thermal swings in the amplifier temperature which can cause resulting noise level.

5.Dark Current

- It is usually defined as the number of thermal electrons generated per second per pixel.
- Because of this additional,electron within each pixel are added generally.
- Cooling of CCD are generally done via use of liquid nitrogen.
- The CCD and associated electronics are encased in a metal dewar under vacuum.
- The amount of dark current a CCD produces depends primarily on its operating temperature.

6.Pixel Binning

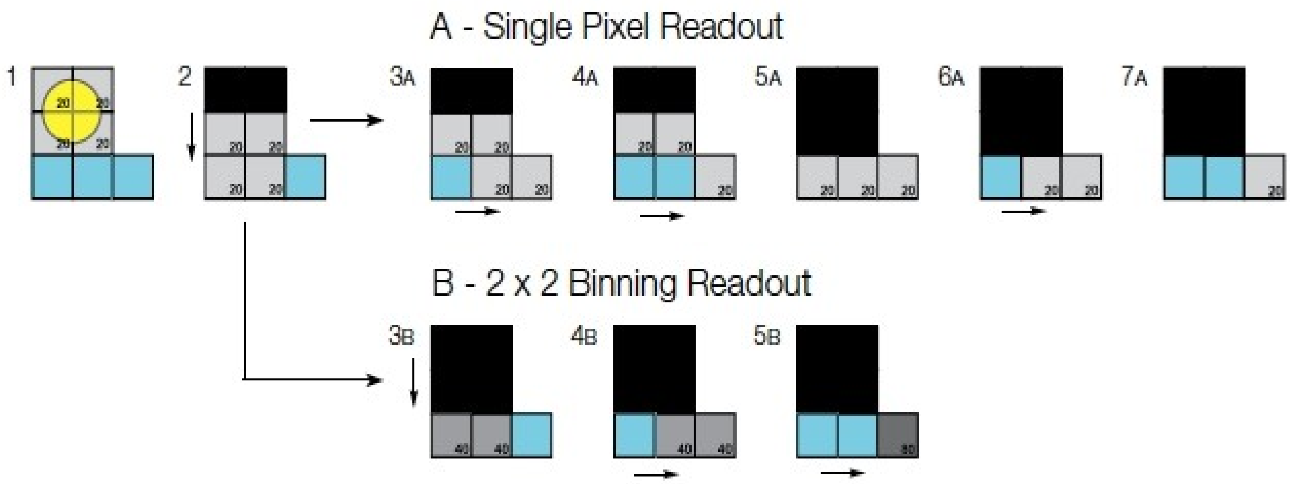
- In this process we usually add rows and column (e.g. 1*1, 2*2, 3*3......) before the are digitalized . As a result we will get the final signal level equal to n times(1,2,3,4...) . This is called on chip binning.
- It occurs prior to readout
- The output register contain 5 to 10 times the charge a single active pixel contains.

ADVANTAGE

- It increases final signal to noise ratio.
- Reduces total readout and final image size.

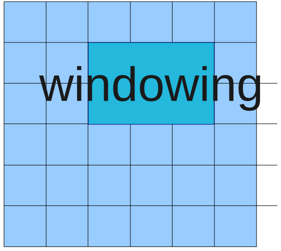
DISADVANTAGE

- It decreases the final image resolution.



7.Windowing

- It allows user to choose a specific rectangular region within the active area of CCD to be readout upon completion of integration
- For e.g. using a 2048*2048 CCD to make high speed imaging observation would be dificult but windowing the CCD would allow for first 512 rows and column much faster readouts and far less storage for image data.



CCD in which Binning is done

8.CCD gain

- CCD gain means how the amount of charge collected in each pixel will be assign a digital number in the output image.
- It is basically electron needed to produce one analog to digital unit (ADU). So its unit is electron /ADU.
- The largest output number that a CCD can produce

depends on the number of bits in A/D converter e.g.14bit

- A/D converter have 0 to 16383 range or would be able to hande a no as large as 16383.

CCD Imaging

Plate Scale

- Plate Scale is defined as the number of arc seconds that each pixel of the CCD spans.
- It is given by-

$$P= \frac{206265 * s}{1000 * f} \quad \text{(arcsecond /pixel)}$$

where,
f is focal length in mm
s: CCD pixel size(microns)
1 radian = 206265 arcseconds

Flat field

- This is basically a calibration technique used to make each pixel of CCD uniformly illuminated.
- It is done before take observations .In this we basically remove pixel to pixel variation.
- There are two methods of doing it
  1)Illuminate inside dome
  2)Exposure during twilight

READ NOISE

Consider two bias and two flat images .See the mean pixel value within each image .Then we see the standard deviation of these images (all the information is present in IRAF)

$$\text{GAIN}= \frac{(F1 + F2) - (B1+B2)}{[\sigma(F1-F2)]^2 - [\sigma(B1-B2)]^2}$$

and read out noise can be calculated from

READ NOISE = GAIN * $\sigma(B1-B2)/\sqrt{2}$

Signal to Noise ratio

The equation for the S/N of a measurement made with a CCD is given by-

$$\frac{S}{N} = \frac{N^*}{\sqrt{N^* + n(N_s + N_d + N_r^2)}}$$

where N* (signal term) = total no. of photons collected from object of interest

n :- no. of pixel under consideration

Ns:- total no. of photons from background or sky

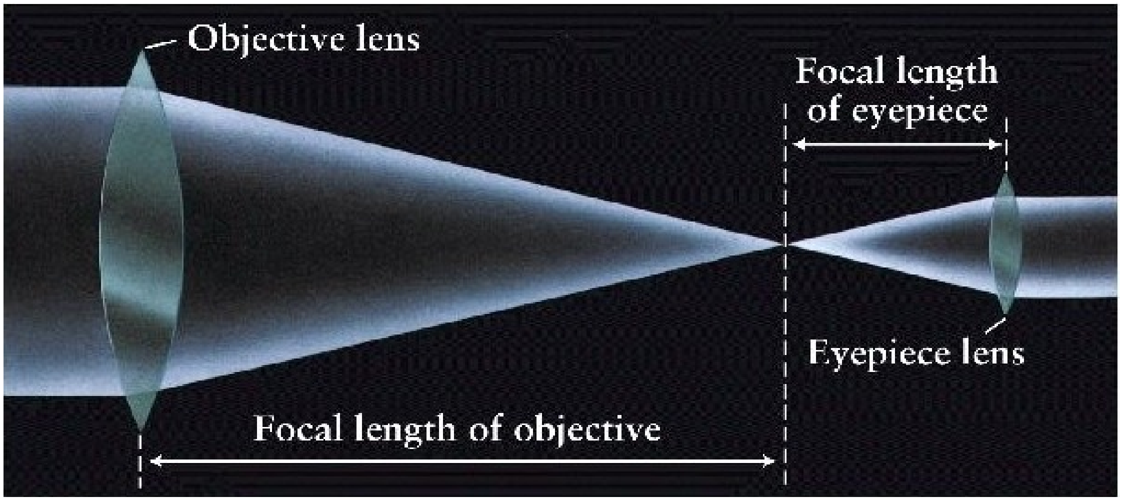
Nd :- total no. of dark current electron

Nr^2:- total no. of electron / Pixel resulting from read noise

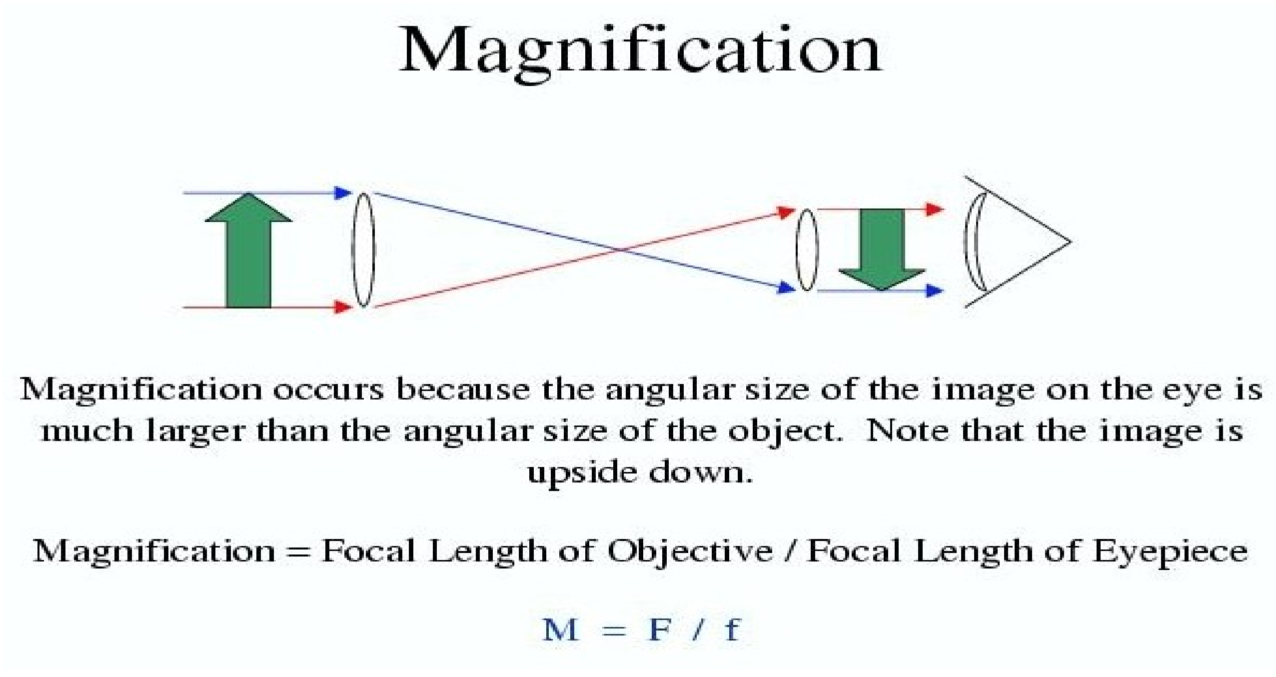
Telescope

General types of Telescopes

- Refracting
- Reflecting
  a)Newtonian
  b)Cassegrain
- Catadioptrics
- Schmidt-Cassegrain
- Maksutov-Cassegrain



Refracting Telescope



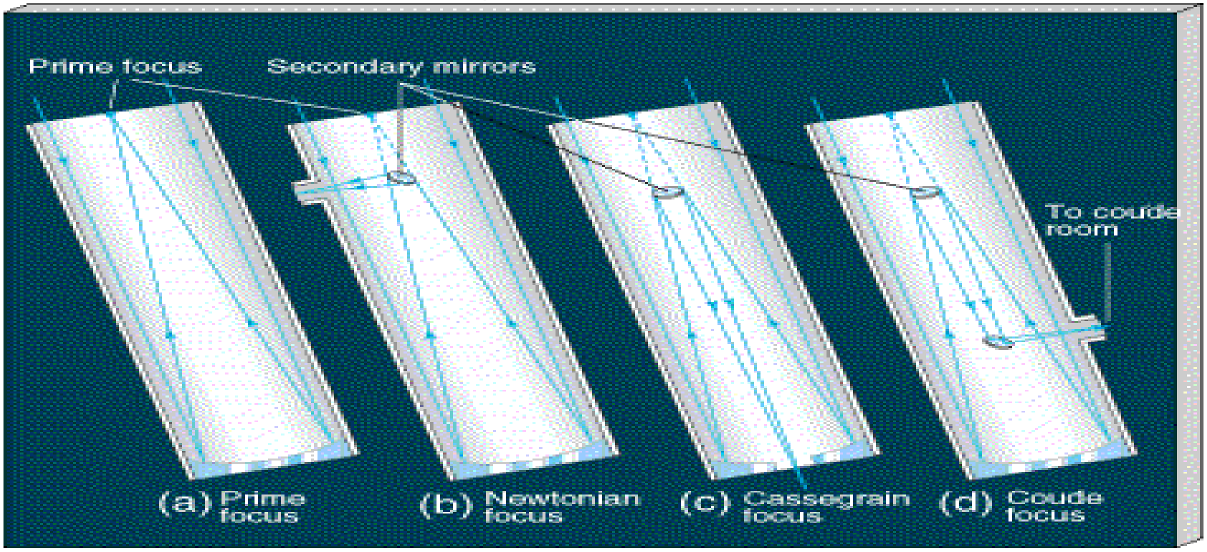
Magnification

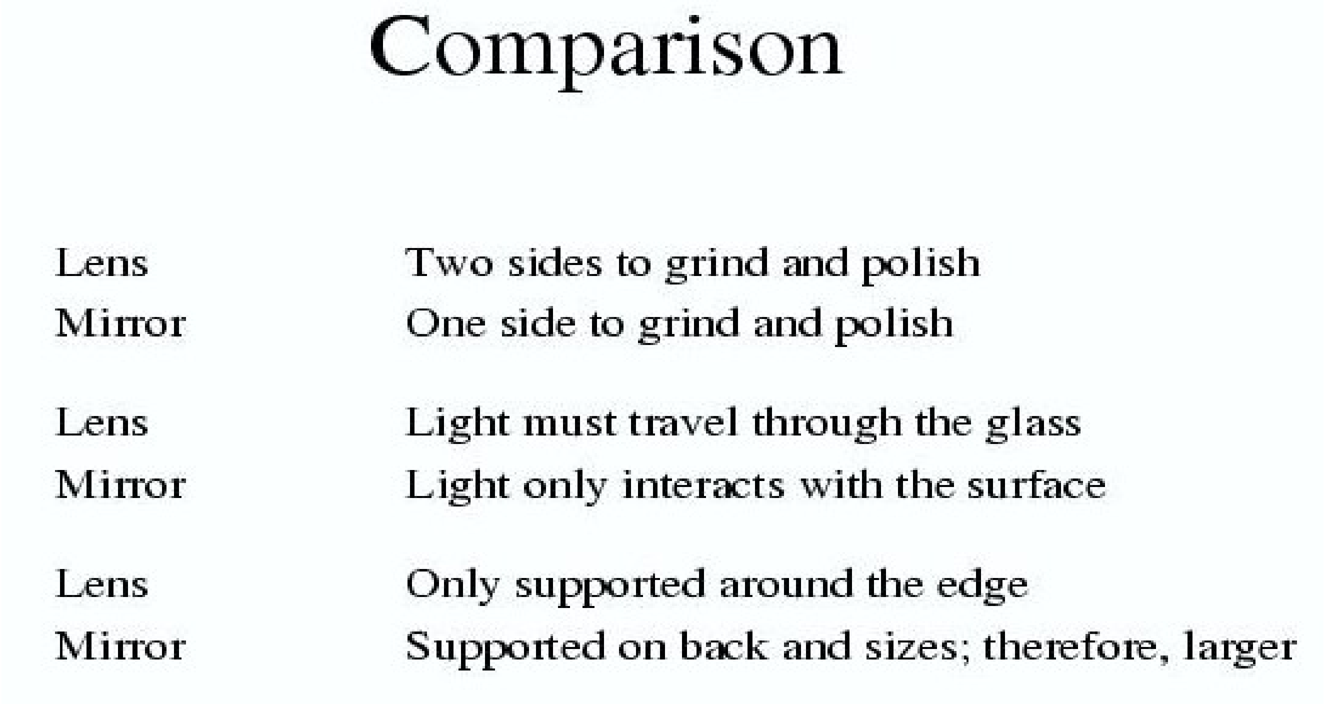
Magnification occurs because the angular size of the image on the eye is much larger than the angular size of the object. Note that the image is upside down.

Magnification = Focal Length of Objective / Focal Length of Eyepiece

$M = F / f$

Reflecting telescope





Comparison

Lens	Two sides to grind and polish
Mirror	One side to grind and polish
Lens	Light must travel through the glass
Mirror	Light only interacts with the surface
Lens	Only supported around the edge
Mirror	Supported on back and sizes; therefore, larger

Telescope Properties

1. Light gathering power < how faint an object you can study

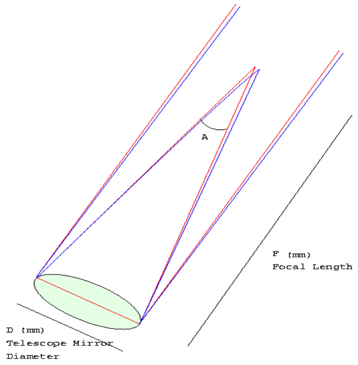
2. Resolving power < how fine a detail you can distinguish

3. Plate scale < how much angle you can imaged

Plate scale

tan A = D/F
or A=D/F radian
or A=206265 D/F arcsec

Plate Scale P=A/D arcsec



Telescope Optics

One of the most important number that characterize a telescope is its focal ratio (or, f/ number)
Focal Ratio = f/D)

*e.g;

Telescope’s aperture diameter = 5 cm

Focal length of primary = 25cm

Focal ratio = 25cm/5cm = 5 (a f/5 telescope)

FAST telescope (<~ 6)

- Small focal ratio (or, small f/ number)
- So, short telescope for fixed aperture
- Wide field of view (with same eyepiece)
- Excel at low power (low magnification) views of deep sky objects, e.g. galaxies, nebula, or open clusters

SLOW telescope (>~ 6)

- Large focal number
- Narrow field of view (with same eyepiece)
- Good for high power (magnification), small field observing, e.g. planets, double stars .
- Most large research telescopes are slow,

  Hubble Space Telescope (f/24)

REFERENCES:

BOOKS-

1.Steve B. Howell- “Handbook of CCD”

2.Pierre Y.Bely - “The Design and Construction of Large Optical Telescopes”

3.Chris Kitchin - “Telescopes and Techniques”

JOURNAL:

1.Jon Holtzman, The performance and calibration of WFPC2 on the Hubble space telescope, 1995 February, 107:156-178

2.Jon A. Holtzman, The photometric performance and Calibration of WFPC2, 1995 November, 107:1065-1093