Intro to Celistial Observation Tech

Lec 1 → 5 Aug.

First study the Introduction → Basics.

Astronomy → What is Astronomy? → Study of object beyond earth & their Interaction.
→ It Answers creation, mechanics & behaviour of system.

Challenge in Astronomy As it
How Far / Big / Bright the things are.

Moon & Sun subtend an angle about a half degree.

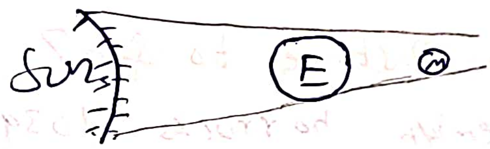
1 AU = 1.5×10^8 Km. Jupyter is at 5.2 AU

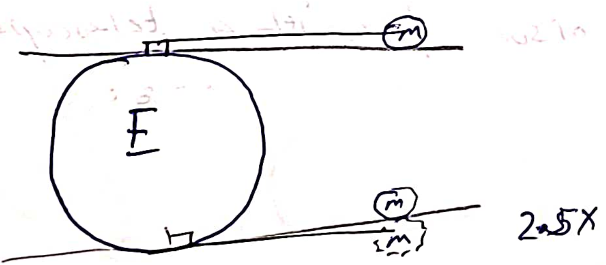
1 LY = 9.461×10^{12} Km 1 PC = 3.26 ly.

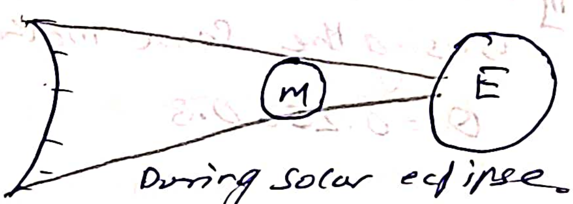
Arestachus 310 - 230 BC.

Q How to measure the size of moon?

During lunar Eclipse.



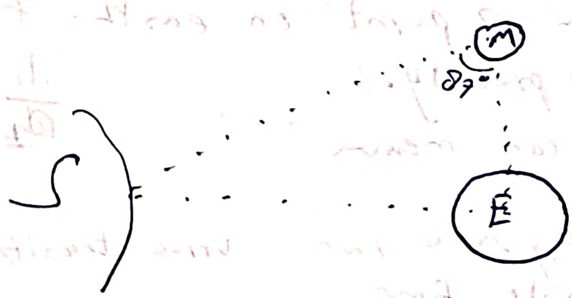




During solar eclipse.

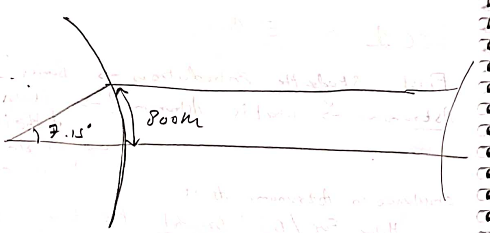
we see the trasition of moon &

How to measure the Diameter of sun?



Eratosthenes (276-194 BC)
-> Estimate circumference of earth.

$$\frac{7.15}{360} = \frac{d}{\text{Circumference}}$$

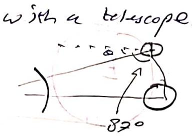


Johannes Kepler 1591.
-> Tycho Brahe (Naked observer).
->. kepler tried to fit circular orbit. latter he did. elliptical.

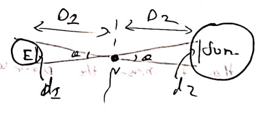
1st Law: The orbit of every planet is eleptical
2nd Law: The Area swept per unit time is equal.
3rd Law: $\text{Distance}^2 = \text{Period}^3$.

What is Distance to Sun?

A] Jeremiah horrucks (1639)
↳ using the Same method of eclipse of sun & with a telescope.
$\theta = 0.25$ to 0.3



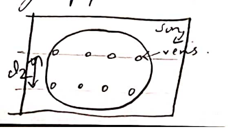
B] using Transite of venus.



Suppose we observe transit of venus from 2 point on earth. & measuring very precisly.
we can measure

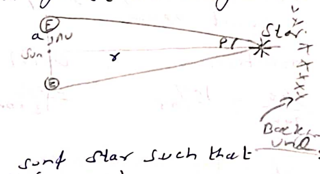
$$\frac{d_1}{D_1} = \frac{d_2}{D_2}$$

The you to map vens trasition on an image pepr of sun & the note time



d_1 -> 2 point where measure from earth
d_2 -> distance /size on sun.
D_1 -> Earth to venus
D_2 -> vens to sun.

Q How to Measure Distance to stars?
-> we use Stellar parallax it is to observe the apperent shift in the position of any nearby star against the background of distant stars.



$\tan p = \frac{a}{r}$. for $p \ll r$.

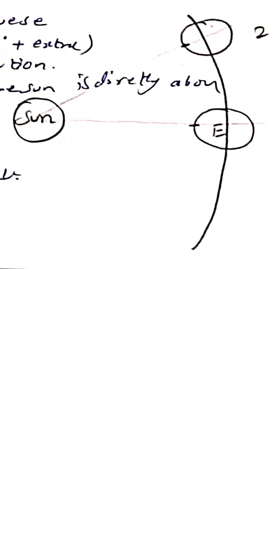
$p = \frac{a}{r}$ $\Rightarrow$ $\boxed{r = \frac{a}{p}}$

Q what is 1 parsec?
1 Parsec -> is a distance between sun & star such that the angle p subtended is about 1'' (arcsec). $1'' = \frac{1}{3600} = \frac{\pi}{3600 \times 180} = \frac{1}{\ }$ rad
$p = 1''$ => $r = \frac{1\,AU}{1''}$
∴
$1PC = 3 \times 10^{16}\,m \approx 3.26\,ly$

Q How to Differentiate between proper motion & parallex?
↳ when we continiously observe using parallex we see the star doesnot keep the same over ~~a to~~ years It will deviate

Understand night sky.
six motion of earth.
1 ~~↳ sidereal, solar~~, Rotation -> Sidereal (23hr, 56min); Solar (24 hr
2 Revolution 365 days
3 Precession ->. 26000 yr.
4 Earth moon Barycenter: Earth & moon orbit a common center of gravity.
5 Milankovitch cycle: Earth orbit goes from elliptical to circular, 1,00,000 yr (causes ice age).
6] Tilt. Changes from 21° to $24\frac{1}{2}$° cycle 41,000 yr.

Q what is difference in sideral & solar.



If we time the rotation period wese in 24 Hr the earth has rotated (360° + extra) & for the compensation bcz of revolution.
it is solar time -> As diff in time sun is direcly above
Sideral is 360° rotation.
it is ~4 min less than sun
but ~~it changes As earth orbit is eliptical~~.
$23^h\ 56^m\ 04^s$

Celestial Sphere.

↳ it is an imaginary sphere. on which the astronomical ~~Late~~ object appears.

rotation.

$\frac{360^\circ}{24 hr} \approx 15^\circ/hr$

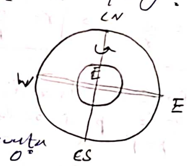
Orbit.

$\frac{360}{12 \text{ month}} \approx 30^\circ/\text{month} \approx 1^\circ/\text{day}$.

RA & dec.

Dec ~ latitude

RA ~ longitude.



Kanpur - lat 26.44 N.
Long 80.33

↳ To get Lat long of star we substract RA & dec from current location.

dec - latitude = will give angle to see.

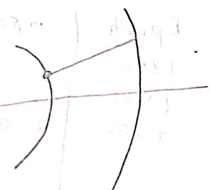
2nd book

Ref $\mathfrak{Sky}$.

Lecture 2 :

$\frac{360^\circ}{24} = 15^\circ/hr$

$\frac{360}{12 m} = 30^\circ/\text{month}.$



Dec. from 26.44 N = current loc ≈ 26.44°N − (star loc.)

=.

RA = No of hr's behind the sun. on March 21 (Vernal Equinox.

NE	E	SE
June 21	March 21 ↳ Sep 21 vernal equinox.	Dec 21.

	March 21	Apr 21	May 21	Jun 21.
RA	6hr	4hr	2hr	~~0hr~~

$30^\circ \Rightarrow 2hr.$

— Explore Stellirium.

Epoch : The fundamental plane & the direction Kai equatorial coordinate system

JD → Julian calendar ⇒ Number of days passed since. 4713 BC. UTC Noon.

e.g. No of days on 0 UTC at aug 15.
2450675.5 JD.

J 2000 1.5 Jan 2000.

MJD = JD = 2400,000.5 = 2451545.

MJD = 51544.5.

— $\alpha = \alpha_0 + (m + n \sin\alpha_0 \tan\delta_0) N$ → to days.

$\delta = \delta_0 + (n' \cos\alpha_0) N.$

m (sec). n (sec) n' arcsec

Epoch	m(sec)	n(sec)	n'(arcsec).
1900			
1950			
2000	3.07313	1.3356	20.034.

Sirius $\alpha(J2000) = 6^{H}\ 45^{m}\ 8.9^{s}$

$\delta(J2000) = -16^{\circ}\ 42'58''$

June 1st 2013 ?

$N = 365 \times 13 + $

EM spectrum :-

Gamma xray, UV, visible IR, FIR, Radiowave.

Lecture - 3.

Black Body Radiation :- Perfect absorber & Emitter.

Each star is assumed to be perfect BB. But there is a slight absorption in photosphere. But still is approx BB.

$$u_\nu = \frac{8\pi \nu^2}{c^3} \frac{h\nu}{e^{h\nu/kT} - 1}$$

$$I_\nu = c \frac{du_\nu}{d\Omega}.$$

$$I_\nu = \frac{c}{4\pi} u_\nu = \frac{2h\nu^3}{c^3} \frac{1}{e^{h\nu/kT} - 1} = B_\nu \quad erg\ s^{-1} cm^{-2} Hz^{-1} steradian^{-1}.$$

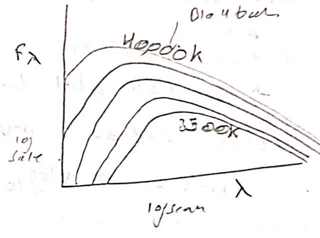
$$L = \int I_\nu d\nu\, d\Omega\, dA. = 4\pi R_*^2 \int I\, d\Omega = 4\pi R_*^2 F.$$

$$\boxed{F = \frac{L}{4\pi R_*^2}}.$$

Q what is the flux at Earth from sun given

$L_\odot = 3.835 \times 10^{26}$ W.

$\rightarrow$ flux $= \dfrac{3.835 \times 10^{26}\ W}{4 \cdot \pi \cdot (\quad)^2}$



1 AU $\rightarrow$ km

$$F(\lambda_1, \lambda_2) = R\lambda \int_{\lambda_1}^{\lambda_2} f_\lambda\, d\lambda.$$

U B V R I

UV, Blue, visual, Red, IR.

JWST is a mid ir to far IR.

$\rightarrow$ we also need to have filter to remove/avoid the absorp/emission [Teluric] lines. to avoid strong lines.

Magnitude system.

$m = -2.5 \log_{10} F + C.$

C defines the zero point of the magnitude. $C = +2.5 \log_{10}(F_0)$.

is the flux density from a m=0 star.

Jansky.

$1\,Jy = 10^{26}\, W\, m^{-2}\, Hz^{-1}$.

$\Delta m = m_1 - m_2 = -2.5 \log\left[\frac{f_1}{f_2}\right]$.

$\frac{f_1}{f_2} = 10^{-0.4\,\Delta m}$

m → Apperent Flux ← what appears to us.

Absolute Magnitude.

$m - M = 5\log_{10} d - 5$ — d in Pc

Absolute magnitude M is defined as the apperent magnitude a star would have, if observed from a distance of 10 parsec.

~~Q M=0~~,

Bolometric Magnitude.

→ Based on total Luminosity including all wavelength.

Color Indices. B-V V-R.

$B - V = -2.5\log_{10}\left(\frac{F_B}{F_V}\right) + C_{B-V}$.

Bolometric Corrections:

$BC = M_{bol} - V$

Lecture - 4.

Wien's law & Stefan Boltzmann law.

$T = \frac{0.0029\,km}{\lambda}$

$L = 4\pi R_*^2 F$.

$\frac{dQ}{dt} \propto A T^4$.

$\frac{dQ}{dt} = L = e\sigma A T^4$. ($e$ → emissivity).

if we have 2 stars.

$\frac{\text{Flux } A}{\text{Flux } B} = \frac{\text{Luminosity } A}{\text{Luminosity } B}\left(\frac{\text{Distance } B}{\text{Distance } A}\right)^2$

Q

A	10 pc	15 $L_\odot$
B	30 pc	3 $L_\odot$
C	5 pc	0.5 $L_\odot$

$\frac{F_A}{F_B} = \frac{15 L_\odot}{3 L_\odot}\left(\frac{30}{10}\right)^2 = \frac{F_A}{F_B} = 5 \cdot 9 = 45$

$\frac{F_B}{F_C} = \frac{3}{0.5}\left(\frac{5}{30}\right)^2 = \frac{6}{6^2} = \frac{1}{6}$. $\frac{F_B}{F_C} = \frac{1}{6}$.

$F_A = 45 F_B$.

$F_B = \frac{1}{6} F_C$

~~C_A~~ $F_1 = 6 F_B$

Q $T_1 = 5000K$ (R) $T_2 = 10000K$. (2R)

Classification based on Luminosity.

Relation between distance, temp & Luminosity.

Stefan boltzmann Law,

Temp from wien's Law.

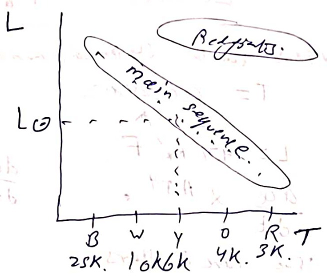
Distance using Parallax.

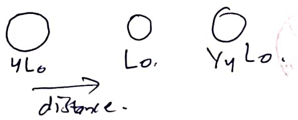
~~from Deepika Thakur~~.

Spectroscopic Parallax.

$L \propto T^4$

$A T^4$ is of Stars should be large.





Q How to measure distance of a star using it's Luminosity?

$S_{ref} = 3K.$ $S_y = 6K$

$L_y = 48 L_R$ $\Rightarrow$ $L = e\sigma A T^4$.

$$48 = \left(\frac{R_*}{R_\odot}\right)^2 \cdot \left(\frac{6K}{3K}\right)^4$$

$$\frac{2\times2\times2\times7}{2^4} = \left(\frac{R_*}{R_\odot}\right)^2$$

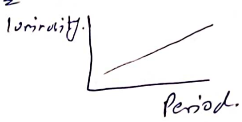
28
14
7×2

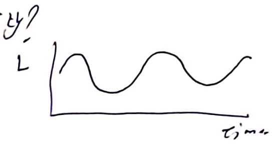
$$\boxed{R\sqrt{\frac{7}{2}} = R_*}.$$

1 Apperent magnitude
2) Based temp → luminosity.
→ distance.

Cepheid variable stars.

Q What's result in the change of luminosity?





Q $T = 3.7d$. $M = -3.1$. $m = 5.5$.

Type Ia Supernovae.
An type Ia $M \sim -19.3 \pm 0.03$.
1 Mpc → to over 1000 Mpc.

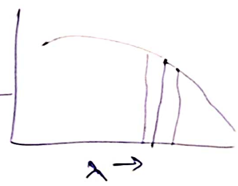
Counting Photons.

$\text{Flux} = 10^{-0.4 \times m} \times \text{flux}_{m=0}$.

$\Delta m = m_1 - m_2 = -2.5 \log_{10} \frac{f_1}{f_2}$
$= f_1 = 10^{-0.4 \cdot m} \times f_{m=0}$.

$1 Jy = 10^{-23} \text{ erg sec}^{-1} \text{cm}^{-2} Hz^{-1}$.

$1 Jy = 1.57 \times 10^7 \text{ photons sec}^{-1} m^{-2} \left(\frac{d\lambda}{\lambda}\right)$.



SNR - signal to noise.
No dector is perfect.
if $n = 10000$ & $n = 100$ $\frac{\delta N}{n}$

$$SNR = \frac{N}{\sqrt{N}}$$

Astronomical optics.

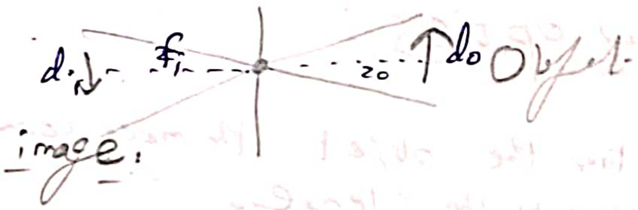
measures → Flux, Position, Spectra, Polarisation
Flux → stellar pulsation, exoplanet transit
Position → astrometry, masses.
Spectra → temp. dynamics, processes, chemical comp. velocimetry.
Polarisation → mf. optical scattering of light

• Telescope.
→ commetbl abrivation.

Lecture - 5 . 22- Aug.

Q Why Multiple camera's.
→ Different focus for different purpose.

Q How does pinhole cam - works.
In Pinhole came it dosent focus but we get directionality & it is Projected inverted on the screen.



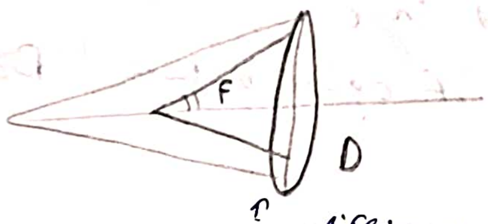
Q what is Magnification?
→ $m = \frac{d_i}{d_o}$ $m = \frac{f}{z_o}$

The closer the screen wider the image. [Field of view is more].
the. focus/magnification.
field of view is not as same as.

Q What is Depth of field?

Q How is fnumber defined?

$$d/\# = \frac{f}{D}$$



fast beam when the focus is small & slow beam the focus len is large.

Fast beam → wide field
Slow beam → focus /magnify more.

Q What is ideal size of pinhole.

$d \sim 2\sqrt{F\lambda}$ f - focus
λ - wavelength.

Large pinhole → One - one maping is lost
Too small → diffraction. start to dominating.

Q what is disadvantage of pinhole.
→ we have a very low exposure. [Apparature is small].
so we use lenses.

Q What is largest telescope?

Refractor → 1 meter Yerkes.

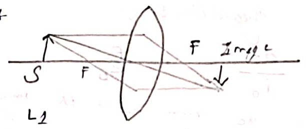
Reflector → . 10 meter. Keck., Hawaii.

↳ has 100 times large, as mus. as 1-meter telescope

Area is 100%. r^2.

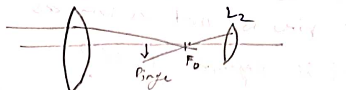
Ray optics :

further the object the image comes closer to the lense.



simple telescope.

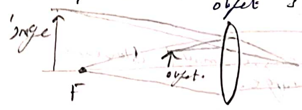
$$M = \frac{f_o}{f_e}$$



The focal length of L1 is between the. Eyepiece & F_o.

virtual image

→ if object between focus of lense, – The image is formed on the object side.



Real image

→ if the object is further than the focal length

→ The image is formed on opposite side.

Q what is LGP.

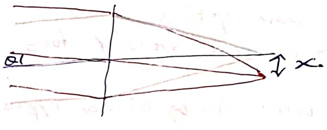
→ Light gathering power it is related to the Area of apperature.

Q What is field of view for a simple telescope.

image formation $x = F \tan \theta$.

$x \approx F\theta$.

The plate scale of a telescope can be described as the angle corresponding to distance at the focal plane.



$$\frac{d\theta \ (\text{rad})}{dx \ (\ )} = \frac{1}{f}$$

$$dx = d\theta \times f \times \frac{1}{57.2958}$$

$dx = 0.0174 \times \delta\theta \times F$.

→ this show how much degree we see per pixel.

Q Solve for the value.

$d = 50$ cm.

$F/10 = 10$.

~~$\frac{dx}{f} = 0.0174 \times$~~ $\frac{d\theta}{dx} = \frac{.1}{0.0174 \times 10}$

$\boxed{\text{focal len} = \text{f-num} \times \text{diameter}}$

$dx = 0.5^\circ \times 0.0174 \times 10 \approx 0.086. \times 50$ cm

$\boxed{dx \approx 4.3 \text{ cm}}$

Energy Density.

Q what is energy density.

$\Rightarrow U = \frac{E}{A}$

As F increase the energy ~~dense~~ density decreases.

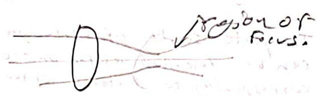
Survey telescope use fast focal length (short).

Image Formation [Isnt Just ray tracing].

: what effect is not consider in rayoptics.? differ then wave optics?

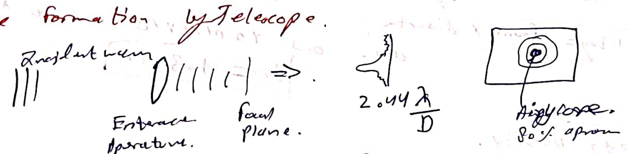
in wave optics.

-> we have a region of focus.



Q Difforation by circular Apperature.

Image formation by Telescope.

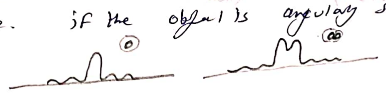


Q why is then this patten by lense?

-> we have the interfarance patten bec we assume every Point on lense to be the Source of spharical wave.

Q What is the Raylaigh condition?

If we want to resolve two sourse seprately ~~have~~ the Resolution crit Q. if the object is angulary separated by



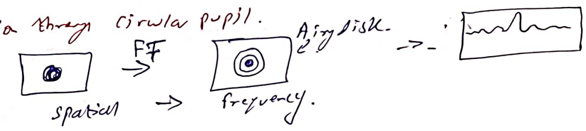
$R = \frac{1.22\lambda}{D}$.

increase λ resolution get poor..
increse D makes the resolution better. .

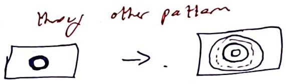
-> the Airy disk is the result of the optics not the source.

& so it is called a point spread function.

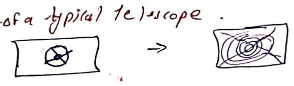
• Difraction throgh cirular pupil.



• Difraction throgh other pattern



• PSF of a typical telescope.



Lecture - 6 . 29 Aug.

D. $\frac{\lambda}{D}$

Q why not ~~solve~~ resolve with 1 pixel.
→ we wont be able to distinguish between noise & signal.

Q why do. PSF of telescope ..

Q The point spread fn is a fn of the .. optical. instrument.
The difraction limit.

• If we have a. high PSF the. image quality is bad
& low PSF the image quality is ~~bad~~ good.

• Fourier Transform of the image optics:

$$I_i(x) = \left| \text{Fourier} \{ P(x) \, e^{i\phi(x)} \} \right|^2 \otimes I_g(x).$$

→ Phase Abberation is the efeis.. pupe.. glasses.
→ glucoma is the Amplitude. Aberration.

-Just
In image from Just we see the hexagonal abberation of the. poinsource

Abberration.

→ Chromatic [colour & wavelength.
→ monochromatic Abberration.

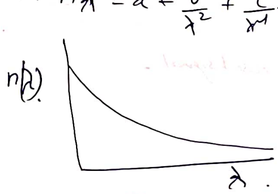
[Spherical
Coma.
Astigmation] deteriorate the image

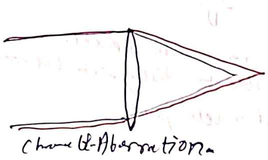
Field] destort.

Chromatic Abberation.

glass eqn

↳ $n_\lambda = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4} + \ldots$ ← Cauchy's transmission eqn





Chromatic Aberration.

How to solve?

→ by combining glass.

4 different wave lengths can have focus: using 3 lenses.

← Achromatic lenses.

Monochromatic Aberrations.

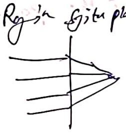
1] spherical Aberrations.

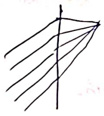
$x = B_1 r^3 \sin\theta$

$y = B_1 r^3 \cos\theta$.

2] Coma →
coarse from offaxis sepration.

Region of the plan





3] Astigmation.

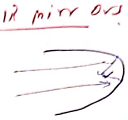
4] Field curvature / Petzval field curvature.
Small focal length big field of view.

5] Distortion.
→ geometrical.
pincusion, Barrel.

- Keplerian telescope.

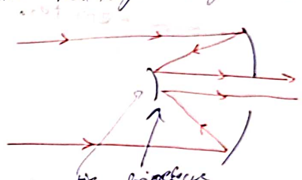
→ Newtonian. Reflector.
↳ Mirror we do not have chromatic Abberassion.
Parabolic mirror → No spherical Abberassion - good for ~~offaxis~~/ On axis.

- Parabolic mirrors



Hyperbolic & Ellipsoidal mirror.

Cassegrain telescope.
→ Higher focal length & higher magnification.



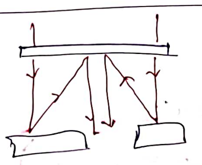
Lecture - 7.

Abberations:

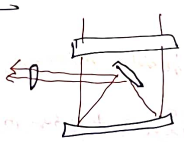
Chromatic [color / λ dependence on. refractive index]

Monochromatic Aberrations. [Seidel]:

- Spherical Aberration.



Cassegrain reflector



Newtonian Refractor.

-> . Telescope Evol.

-> Refractors.

-> Spherical mirror

-> Parabolic.

-> . Ritchey - Chretien - Cassegrain telescope

-> most modern telescope.

-> Fig 4 Fast. RC required featury.

-> Correcting Aberrations.

- Parabolic correct - spherical aberration only.

- Cassegrain. correct.

-> Classification.

-> wiki list of optical type.

-> For optical -> we should avoide light pollution 4.

Atmospheric effect.

Telescope Mirrors.

Vera . C. Rubin observatory.

Classical   Honeycomb

Meniscus.   Segmented   dilute aperture.

As the Large mirror can result in stress strain on mirror.

Honeycombed -> Structure provides most stability

B. The layer is made on top of a honeycomb structure.

Active optics.

The mirror is placed on the support structure which is.

Actuated. electronically.

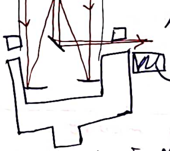
Differnt Focus.

-> Primary focus.

-> Cassegrain focus

-> Nasmyth focus.

- Coude focus.



The Advantage is Nasmyth focus is fixed & make it easy to put heavy instruments.

Primary A -> using secondary mirror

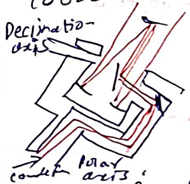
Segmented mirrors.

It's tricky to manufacture big mirrors.

So we make segmented mirror.

by stacking small mirror.

Coude focus



The amp fixed.

-> used for high precision

-> useful in radial measurement of exoplanets.

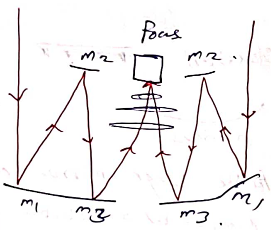
-> Need heavy spectrograph with temperature controle.

-> Also in optical interferometry

-> Need very stable focus point.

LSST

→ It's a survey astronomy.
→ using a wide field of view
→ make 3D map.
Asteroid survey.



LLST

→ For survey telescope - Large field of view
& large collecting power.

Etendue = collecting area(m^2) X field of view [deg^2].

Indian optical telescope

1] Devasthal optical [ARIES]. 3.6m [Alt-Az]
2] Vainu Bappu 2.3m [Equatorial]
↓ Easy to operate.

Alt Az mount → is compact.

Indian Radio Telescope.

- GMRT. Pune.

Alt-Az

→ Easy to ~~operate~~ manufacture
→ compact size.

N→. AI
→. Field change.

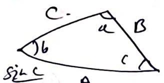
Equatorial mount.

→ Easy to operate.
→ field does not change
→ [illegible]
→ match earth rotation.

Field Rotation.

in Alt Az → The field change.
in Equatorial → The field does not change.
↳. Alt Az ← need computational resource.

→ Sine Law

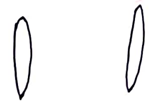


$$\frac{\sin a}{A} = \frac{\sin b}{B} = \frac{\sin c}{C}.$$

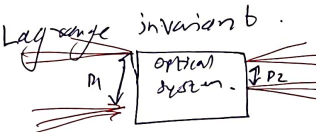
Star-WV st-and. ar.uu Chp 7- nf/wetnote.

Telescope Pupils

entrance pupil & exit pupil.



∘ Lagrange invariant.



$D_1 \theta_1 = D_2 \theta_2$.

We cannot have a small exit pupil. The D_2 needs to be big else rays will Diverge.
& so the exit optics system will also be big.

Small-beam →. compress propagation distance, lot of beam walk & Diffraction effect.

• Earth Atmosphere.

→ Biggest disadvantage for a telescope.

invisible → Airglow 100km.
In IR →. BB of water vapour

wavefront distortion →. function of refractive index.
Atmospheric turbulence →.
Atmospheric refraction.

Rayleigh scatter

↳ Sky looks blue bec of ~~scat~~ scattering from the water vapour.

Transmission & Emission in near IR.

Optical Emission - Airglow.

eg OH. line. Emission from OH - [red & near ir], O [visible green light]

O_2 - [near Blue light].

→ gain is minimal for ground based telescope. Integrating for a long time is not much helpfull..

→ Hubble deep field.

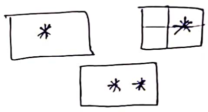
Lecture . 8

Atmospheric Extinction.

Observation in mid IR.

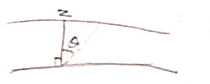
↳ There are too many photons. & we need to use chopping to minimize the thermal background.

→ using chopping on binary one is +ve & other is -ve.



chopping can be done up to 10 HZ.

Airmass . = sec(zenith angle).



Atmospheric effects.

- Refraction -
- Diffraction -
- Scintillation -
- Dispersion -

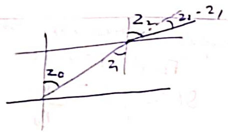
Green flash → during sunset green light

Atmospheric Refraction. & Dispersion.

→ Apparent position changes.

ADC - Correction using 2 prisms.

Plane Parallel Model.



Change in apparent position = $z_2 - z_1$

$n\sin(Z_1) = \sin(Z_2)$

$\varepsilon = z_2 - z_0$

$n\sin(z_1) = \sin(z_0+\varepsilon) = \sin z_0 \cos\varepsilon + \cos z_0 \sin\varepsilon$

$\simeq \sin z_0 + \varepsilon\cos z_0 = n\sin(z_1)$

$$\varepsilon = (n(\lambda)-1)\tan(z_0)$$

$$\frac{n\sin(z_1) - \sin z_0}{\cos z_0} = \varepsilon$$

$$\varepsilon = (n(\lambda)-1)\tan(z_0)$$

For large Angle spherical shell model.

$\varepsilon =$

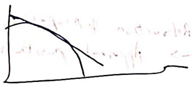
Wave front abrassion.

Adaptive optics

~~Atmospheric~~ Atmospher cause distortion in signal.

Atmospheric turbulence.

Spatial freq vs An.



Imaging the presence of turbulence

Fried parameter

$$\theta(\text{Seeing}) = \frac{\lambda}{r_0}$$

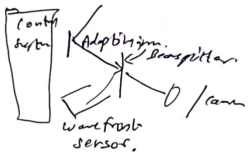
$$r_0 \propto \lambda^{6/5}$$

if Diameter of tels is $> r_0$.

$D > r_0$.

Effect of Atmospheric seeing.

& what is Ao system.



The observation is done at shorter wavelength & the correction done at longer wavelengths.

Deformable mirror

→ there are Actuators to modify the membrain.

piezo based ← is good for small scale

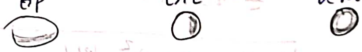
voice coil based ←. for large scale.

Wavefront Sensing:

Shack-hartman wavefront sensor.

consist of small lense & letarrays.

wave front correction by parameterization.



Adaptive optics. Error Budget.

$$\sigma^2_{DM\,fit} = \mu\left(\frac{d}{r_0}\right)^{5/3}$$

$$\sigma^2_{temporal} = 0.28\left(\frac{\tau}{t_0}\right)^{5/3}$$

wavefront se σ^2_{WFS}

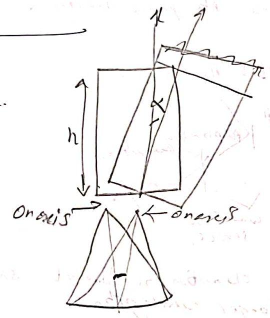
$$\sigma^2_{\phi} = \sigma^2_{DM\,fitting} + \sigma^2_{temporal} + \sigma^2_{WFS} + \sigma^2_{align}.$$

Lecture - 9

Atmospheric extinction.
- Mid-IR observation ten.
-

Isoplantic Angle

→ it's Angle over which we have a uniform turbulence.



$S = \text{signal} = \frac{\pi D^2 \lambda}{4\, hc} F_\lambda t Q$

$Q \rightarrow$ quanity factor = Efficiency.
t = time.
F_λ = Flux.

$\text{Background} = \frac{\pi D^2}{4} \frac{\lambda}{hc} \frac{\pi \theta^2}{4} b_\lambda t Q$.

Bodly is indep of this - diameter for large SSZ

Q How big should telescope be for SNR = 5

$m_V = 28.98$ $\qquad Z_p = 1.7981 \; Ph/hr/m^2$

∴ Q = log R.

$21 \frac{mag}{arcsec^2} = \frac{(21)}{(\frac{1}{3600} \cdot \frac{27}{360})} 27$

=

~~28.98~~ + 8.9 = ~~37.88~~

21 + 8.1 = 29.9

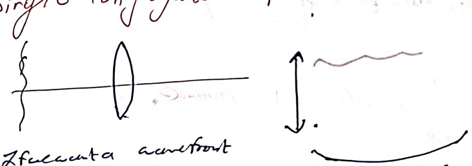
$N_* = Z_p \times 2.512^{-28.98}$ = 45.9 m.

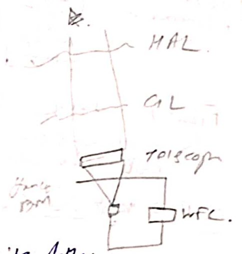
$N_B = Z_p \times 2.512^{-29}$.

$S = 36 D^2$ (P3).
$N_{bg} = 36 D^2 + 559\, \text{rad}\, D^2$.

$S.R = \frac{PSF}{PSF+} = 100\%$

Single Conjugate Adaptive optics.





If we want a wavefront in a collimated beam it has to be compressed.

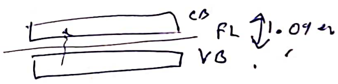
Artificial laser star for AO.
Atmosphere has high sodium and excite to emit light. Laser > 20 W.

Seeing vs AO
→ convolution
coherent ≥ 1 millisec. For better image.
we need fast correction.

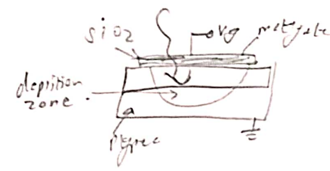
Using Astrometry found orbit & then found the better range of inner (Black BH].

CCD's - Charge Coupled Devices.

Band theory.

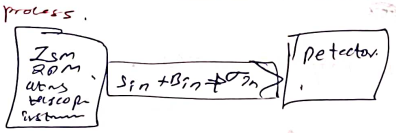


$\lambda < 1 \mu m$. (near IR).
will excite this.



Detection process.

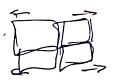
Source + background



Front & Back illumination → difficult to produce.
↳ easy to manufacture
but lower sensitivity

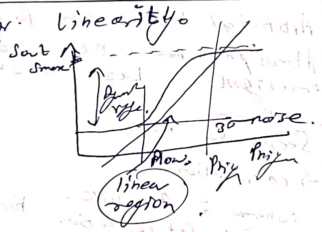
CCD → very slow.

mosaic CCD.



~~Cookrusdo~~

Detector linearity.

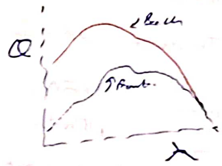


QE is λ dependent.

Lecture 10.

Adaptive optics.
→ Isoplanatic Angle.
→ Detection limit with & without AO.
→ Different flavors of AO system.

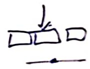
Quantum efficiency.
→ The Backside illuminated ~~ccd~~ ~~ccd~~ has better QE value than Frontside illuminated.



Amplifier:
→ Convert eV → milli-volts.

ADC
- digitizes voltage measurement.

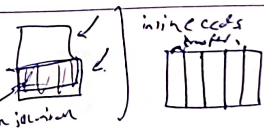
Bleed trail / blooming →.
neighboring pixels get a trail of light
bec of charge leakage..
only happen in CCD
→ As they can hold fixed no of electron before it spill into next row.



CTE → charge transfer efficiency.
CTE ≈ 1 is impossible but CTE close to 1 [modern ccd]

CMOS ← Detector are fast.

CCD
frame transfer.
illumination



For areal frontsensing.

Noise in image sensor,

1] Photon shot noise.
- → Quantum nature of light.
- → Random arrival of photons.

2 Read noise:

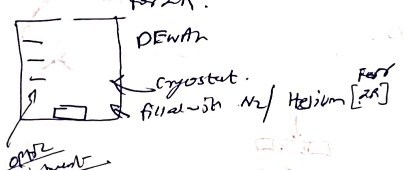
3] other sources,

Thermal noise → follows poison distribution.

Read noise → follows gaussian stats.

The noise add's in ~~[illegible]~~ Z sign..

For ZR.



Infrared Detectors

L - 11 . 4 Sep.

Summary: Detectors, Noise in Image, Image processing.

CCD Calibration: Preprocessing data.

Explore Astropy library for photometry.

Bias: The +ve expose At zero level.

Dark Response: If kept in dark for long time; it start to response for dark env. So $r[x,y]$ is zero..

Linearity: Response of a linear detector is α.

Fringing: Monocromatic light producing bright pattern in CCD.

Flat field Response: All pixels response differently.

So we use 3 object as flat field target.

Just before sunset & sunrise / Dark night sky / Dome flats [Artificial light].

The sky is almost uniform.

→ The Bias is need not be the same sign.

→ we are observing the effect of light on the

→ It has to be a Broad Band do the Dome. flats.

it's tough to reproduce.

$$Rp_i = \frac{lin(R_i) - Z_i - t_i D}{F}$$

lin → is a linear function to take linear part of R_i.

→ Need to do flat field Response every day.

Combine images.

→ combining image is better using the com/ centroid. function.

Aperture Photometry:

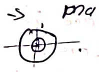
SADU = total − sky.

Too small → loose star light

Too big → more Background.

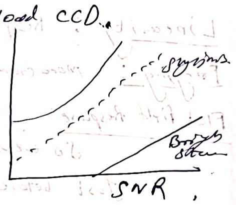
A] digital Aperture

B] Sky annulus → make circle on star &, also take mode of surrounding



If we observe too bright we can overload CCD.

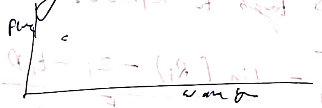
SNR above 10 is good.



Spectroscopy:

Spectra can give info about - Temp, composition, line of sight velocity.

Spectrum of a star-forming Galaxy.



$R = \frac{\lambda}{\Delta\lambda}$ [Spectral Resolution].

$\Delta\lambda$ is diffn in wavelength that can be distinguished.

To make spectrograph:

A]. Dispersion light

1] Prism 2] Grating 3] grisms [gratings + prism].

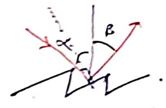
Prism.

$$\theta_D = A\left(\frac{n_1}{n_0} - 1\right) = A(n-1),$$

$$\frac{d\theta_D}{dn} = \frac{\theta_D}{n_1 - 1}.$$

Gratings.

→ use periodic structure to diffract light.



$m = 0$ order at $\alpha = -\beta$.

$$\frac{m\lambda}{d} = \sin\alpha + \sin\beta.$$

Blazed Gratings.

Maximize the diffraction in one particular order.

called [echelette Grating].

Also rotating grating can be used to collect light one wavelength at a time.

Grisms.

Accurate velocity.

$$\frac{d\lambda}{\lambda} = \frac{v}{c}.$$

10 cm

Stellar classification spectra

AGN spectra.

Nuclear

→ How differ types of spectrographs are used in Astronomy.

Multi object Spectrograph.

→ Many object at same time.

→ Pre-image.

Mask-design.

Make sure there is no slit overlap?

→ The signal overlap will have cross talk.

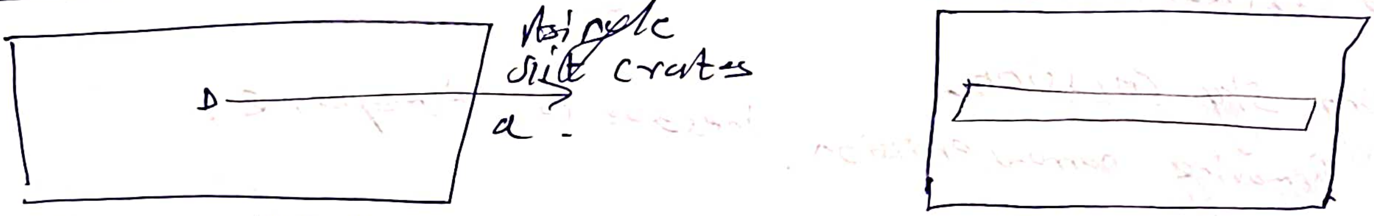


Image plane. Spectroscopic plane.

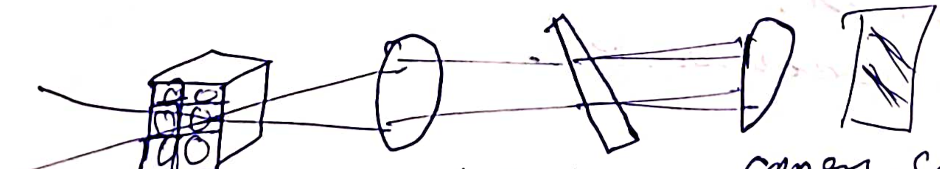
Fiber Spectrograph.

↳ The fiber are controlled by pizeo element & the light source is selected.

IFU → Integral field unit.

↳ we divide the image in sub part. & then

lense slit → fiber → disperse. → Spectra.



↑ each is lenslit Array.

collimator dispersion camera. Screen.

All this inside a cryostat to reduce the thermal noise.

CHARIS

Satelite spots → used to Align the object. 137/150

When we change λ everything Scales.
If the object does not scale it is not a part of the Star we are observing.

Image Slicers.
Use Stack of mirror to slice 2D image in 1D slit array.

Supressing Sky emission.
→ Removing narrow emission lines due to Atmosphere.

→ Multiwavelength Astronomy.

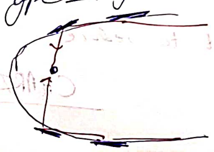
X RAY.

→ X Ray Astronomy How?
→ ~~...~~ It penetrate & material is thick
→ X rays reflect if small grazing angle
→ $\theta_c \propto \sqrt{Z}/E$.

Coded Mask.

→ Small tile of lead.
depend on where source located.

→ Xray optics.
Wolter type 1 xray mirror. using grazing angle to focus the light to a focus point



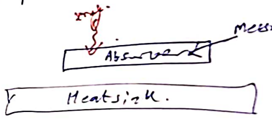
→ The Angle should be small to reflect the xray.
NuStar.
We get a zoomed in image.
→ the collecting area is very small.

→ For soft x ray angle is $1 \to 2^\circ$.

→ How is Spectroscopy done in x Ray?
→ Grating is used to seprate x-ray photons.

→ Xray detector
→ First High energy → to low energy.
→ faster read out [As very small Array].
→ The xray photons are very rare so the high readout use to spatially resolve.

Micro calorimeters.
Proportional counter.



Astrometry over years.

• Hipparcos → Based on Parallax.
→ measures the proper motion of stars.

• GAIA
→ find reference star.
→ Has better relative Accuracy.