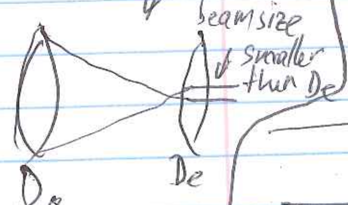
Lecture 3

* Telescopes, aberations, and other problems
* "Beyond" diffraction limit

1) We considered diffraction limit of <u>ideal</u> lens, $\theta_{min} = 1.22\frac{\lambda}{D}$

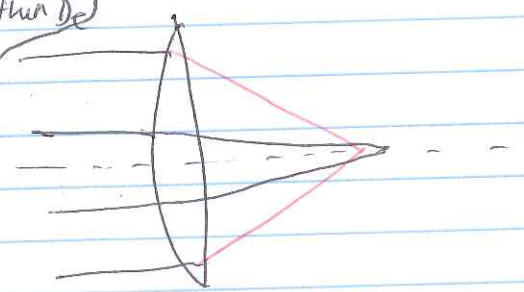
Q: Telescope D_o D_e which D limits?

A: D_o → During derivation we assumed light over <u>all</u> aperture



What problems we might have or what is non-ideal lense i.e. <u>real</u> lens. <u>Imperfections</u> <u>of making</u> $\lambda/20$ required to desired shape

<u>Spherical aberations.</u>



Focus point depends on ray distance from optical axis

Fix: parabolic lenses

<u>Color aberations</u>

$$\Phi = \frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

n is λ dependent i.e. color so different colors focused at different points

<u>easy</u> <u>Quick Fix</u> → Newton reflector
≈1700 year problem: low Reflectivity

Telescopes
1781 - Hershel - new planet Uranus
with reflector telescope

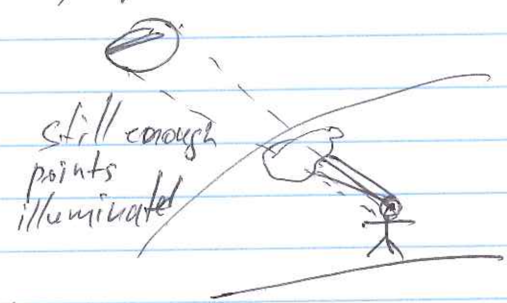
1803-1804 Hershel binary star system
orbiting each other, compared
his 20 year old records

Same guy - map of Galaxy
brightness as a distance estimate

Atmosphere — <u>Huge problem</u>

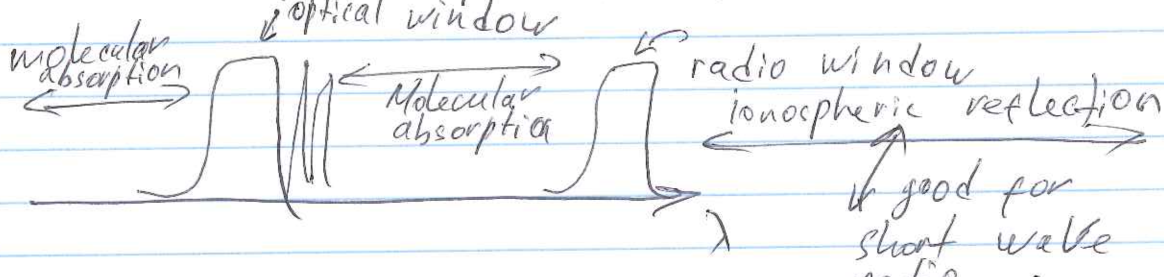
* Why star twinkle $\Leftrightarrow$ scintillation

why planets are not

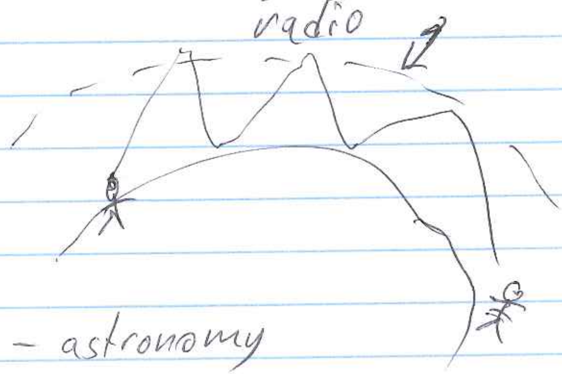


$\Rightarrow$ θ at best $0.25''$
which is smaller then
$1.22\frac{\lambda}{D}$

Windows of transparency of Atmorpere



good for short wave radio



Radio, X-ray, γ-ray — astronomy

Recall that

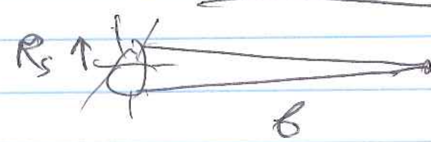
Atmosphere limit $\theta_{min} = 0.25''$

Q: How do we measure star parallax, if closest one has $\theta_p \simeq 0.768''$

A: Differential measurements

Well but what about stars diameters

$$\frac{R_{st}}{b} = 1.22\frac{\lambda}{D}$$



Betelgeuse $R_{st} = 1000\,R_\odot = 10^3 \cdot 7 \cdot 10^8\,m$

$b = 200pc = 200 \cdot 31 \cdot 10^{15}\,m$

$\lambda = 500\,nm$

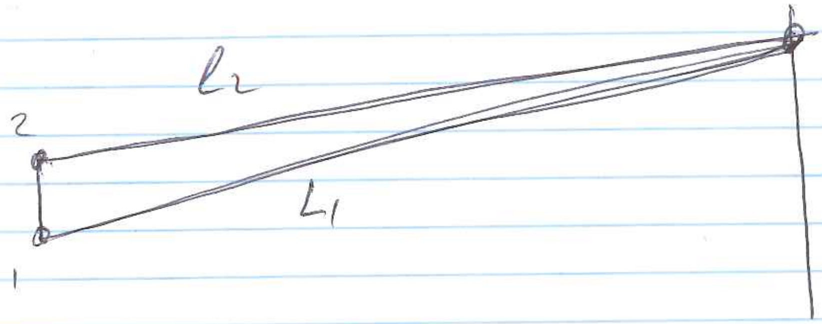
~~Rst~~ $D \simeq 500 \cdot 10^{-9} \cdot \frac{b}{R_{st}} = \approx 4.42\,m$

but $\theta_{st} = \frac{R_{st}}{b} = 0.02''$

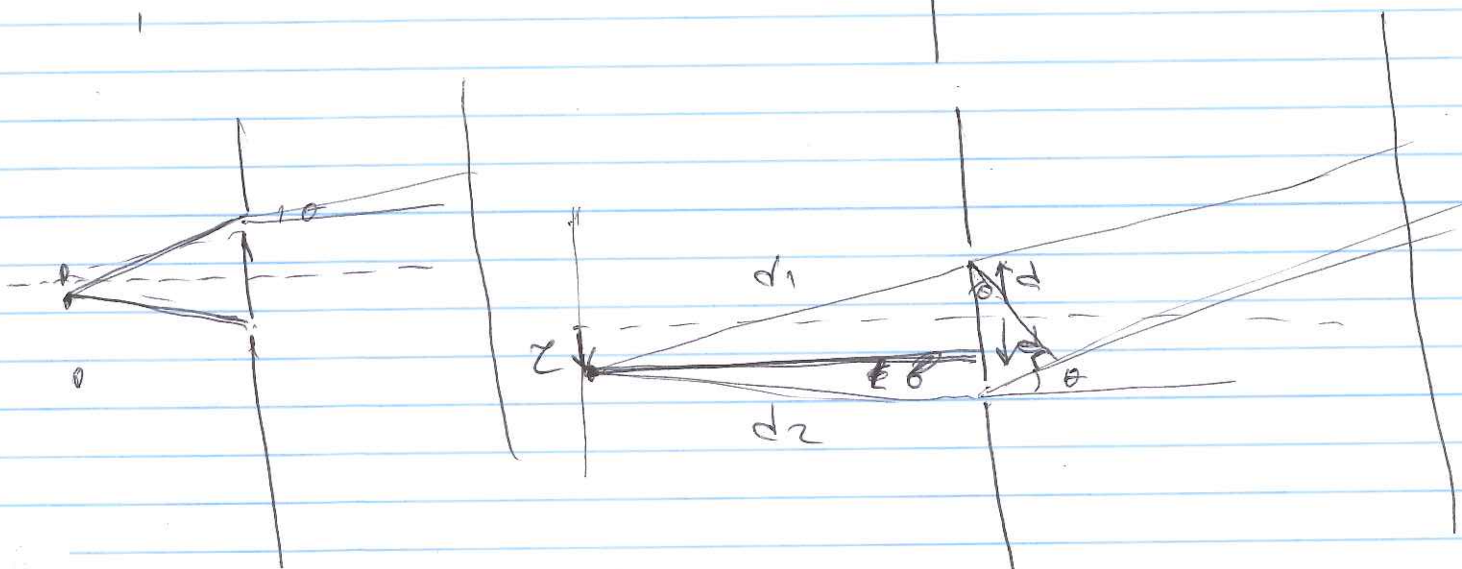
no way due to atmosphere since it is a single measurement.

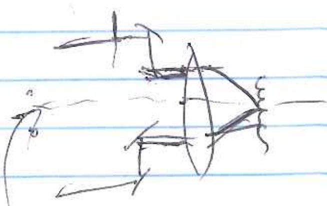
Star separation and diameter

see lecture 4 for cleaner derivations



Michelson interferometer





spherical aberations ⇐ must be symmetric

$$\Delta l = d_2 + 2d \cdot \sin\theta - d_1$$

$$= d_2 - d_1 + 2d\sin\theta =$$

$$d_2 = \sqrt{b^2 + (r+d)^2} \approx b\sqrt{1 + \left(\frac{r+d}{b}\right)^2}$$

$$d_1 = \sqrt{b^2 + (r-d)^2} \approx b\sqrt{1 - \left(\frac{r-d}{b}\right)^2}$$

$b \gg r,d$

$r \gg d$

$$d_2 - d_1 \approx \frac{b}{2}\left(\frac{(r+d)^2}{b^2} - \frac{(r-d)^2}{b^2}\right) =$$

$$= \frac{b}{2} \cdot \frac{r^2}{b}\left(\left(1 + \frac{d}{r}\right)^2 - \left(1 - \frac{d}{r}\right)^2\right) = \quad (1+x)^2 \approx 1+2x$$

$$= \frac{r^2}{2b}\left(4\frac{d}{r}\right) = \frac{2rd}{b}$$

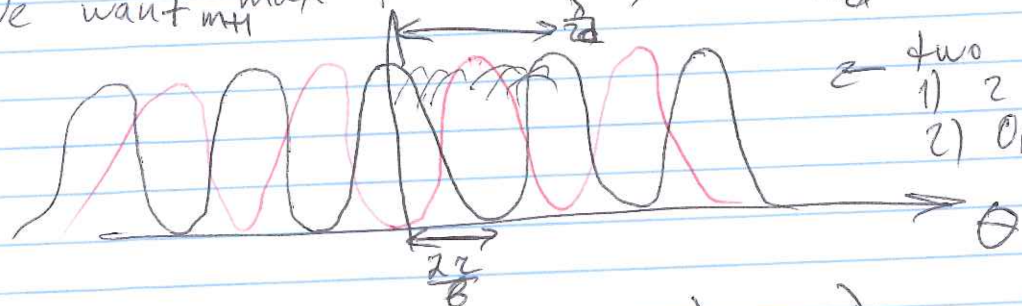
$$b^2 + (r+d)^2 = b^2 + r^2 + 2rd + d^2$$

$$\Delta \ell = \frac{2dr}{b} + 2d\sin\theta = 2d\left(\frac{r}{b} + \sin\theta\right) =$$

$$= 2d\left(\frac{r}{b} + \sin\theta\right) = m\lambda \quad \text{max cond}$$

$$\left(\frac{r}{b} + \sin\theta\right) = \frac{m\lambda}{2d}$$

we want max_{m+1} from $+r$, and max_{m} from $-r$



two situations
1) 2 separate stars
2) One large star

$$\left(\frac{r}{b} + \sin\theta\right) = \frac{m\lambda}{2d} + \frac{\lambda}{2d} \quad \text{max } (m+1)$$

$$\left(-\frac{r}{b} + \sin\theta\right) = \frac{m\lambda}{2d} \quad \text{max 'm'}$$

$$\Rightarrow \frac{2r}{b} = \frac{\lambda}{2d} \qquad \boxed{2d = D_{separation}}$$

Lecture 3 stoped here

$$\frac{2r}{b} = \theta_{source} = \frac{\lambda}{2d} = \frac{\lambda}{D} \quad \text{no interference contrast}$$

Betelgeuse ~~Betlergese~~: $r \simeq 1000 R_\odot = 1000 \cdot 7 \cdot 10^8$ m

$b \simeq 200$ pc $= 200 \cdot 3.1 \cdot 10^{15}$ m

$$\Rightarrow \frac{r}{b} \approx 10^{-6} \approx \frac{10^{-4}}{1.12 \cdot 10^{-7}} \simeq 0.023''$$