We can also do detection with non-optical X-ray, radio, X-ray, infrared, ultraviolet, etc. If the atmosphere has only few windows, it can be mitigated with adaptive optics (10 years).

Resolution is 
\[ \frac{\lambda}{D \sin \theta} \]

Closest star at 1.26 ly.

Star scintillation, turbulence, and planets don't let us see. We can only see some, so far.
Star size diameters

Betelgeuse larger than Earth orbit

\[ R_{st} = 1000 \text{R}_\odot = 10^3 \times 7 \times 10^8 \text{m} \]

Distance \( \theta = 200 \text{pc} = 200 \times 3 \times 10^{16} \text{m} \)

\[ \theta_{\text{disk}} = \frac{R_{st}}{\theta} = \frac{7 \times 10^{18}}{6 \times 10^{18}} \approx 10^{-9} \text{m} \]

So it can be done with telescopes with \( \theta \) of about 5-10 m

But the atmosphere ruins it.

The answer is differential measurements.
Michelson setup

- screen with 2 slits at distance $2d = D$
- focusing lens
- viewing screen

We are concerned with interference so total path difference between path 1 and 2 is $\Delta l = l_2 + l_4 - l_1$

- due to diffraction

Note that blue parts are equal (lens focusing property) for beams which are parallel.
\[ l_1 = \sqrt{b^2 + (d + \alpha)^2} \]
\[ l_2 = \sqrt{b^2 + (d - \alpha)^2} \]
\[ l_d = 2d \cdot \sin \theta_d \]

\[ \Delta l = l_1 + l_d - l_2 = \]
\[ = \sqrt{b^2 + (d + \alpha)^2} + 2d \sin \theta_d - \sqrt{b^2 + (d - \alpha)^2} = \]
\[ \approx b \left( 1 + \frac{(d + \alpha)^2}{2b^2} \right) + 2d \sin \theta_d - b \left( 1 + \frac{(d - \alpha)^2}{2b^2} \right) = \]
\[ = \frac{2d \alpha}{b} + 2d \sin \theta_d = \]

recall \( \frac{\alpha}{b} = \theta_s \) angle to the star, \( 2d = D \) separation between slits

\[ \Delta l = \theta_s \cdot D + D \sin \theta_d \]

condition for interference maxima
\[ \Delta l = n \lambda \]

\[ n = 1, 3, 5 \text{ etc.} \]

minima
\[ \Delta l = \frac{1}{2} + n \lambda \]
Let's be concerned with maxima only

\[ \Delta l = \Theta_s D + D \sin \Theta_s = \lambda m \]

\[ \sin \Theta_{\text{max}} = \frac{\Delta m}{D} - \Theta_s \]

\[ \Theta_{\text{max}} = \frac{\lambda}{D} m - \Theta_s \]

Interference pattern

Suppose we are observing two stars at \( \Theta_{s1} \) and \( \Theta_{s2} \). Each of the stars will form the following patterns on the screen.

If we decrease \( D \), we can't separate fringes.

\[ \Theta_{s2} - \Theta_{s1} = \frac{\lambda}{D} \]

Resolution of this Michelson setup

\[ I_{\text{total}} \]

\[ I_f = I_2 + I_1 \]
Wait a second our resolution is still no better than one of original telescope, i.e. \( \frac{\lambda}{D} \).

But we've got an advantage: contrast of the pattern (i.e. do we see fringes or not) is not affected by the atmosphere any more.

But there is one more trick to use.

So we can separate slits by a larger distance.

It sounds easier than it is:

We need to move mirrors without affecting their alignment i.e. position of reflected spot need to be controlled with better than \( \lambda \) precision.

So at the time of Michelson the largest telescope had \( D \geq 5 \text{ m} \),

Michelson used \( D = 6 \text{ m} \) (recall it need to be scanned!)

In 1891 Jupiter moons diameters

In 1920, he measured diameter of the Betelgeuse star with its angular size \( \leq 0.014'' \). Note a difference that a star can be considered as bunch of point sources \( *** \ldots \star \)
Beyond standard telescope resolution and mitigation of atmospheric effects.

Key idea: we will do differential measurement, so objects might appear to shift/wobble/twinkle, but resulting measurement will not.
Alignment problems limit practical size of D setups with D = 18 m are known though.

The next idea we will use intensity (vs. more well-known field) interferometer

Hanbury Brown, and Twiss experiment 1956

\[ C = s_1 \cdot s_2 \]

correlator

\[ \text{two separated telescope collected light, they do not need to be good. HBT used war time (WWII) search light (P = 165 cm, f = 65 cm)} \]
Light intensity seen by one detector is delayed with respect to the other one due to optical path difference \( \Delta l \).

So for the first source signal from 1st detector

\[ S_1 = I_1(t) \]

on a 2nd detector it is \( S_2 = I_1(t - \Delta l/c) \)

\[ \Delta l = \frac{D}{2} \frac{\gamma}{L} \quad \text{(see Michelson exp.)} \]

Similarly for the 2nd star

So

\[ S_1 = I_1(t) + I_2(t) \]

\[ S_2 = I_1(t - \frac{\Delta l}{c}) + I_2(t - \frac{\Delta l}{c}) \]

\[ C = <S_1, S_2> = \left( \gamma_1 + \gamma_2 \right) \]

\[ = <I_1(t) + I_2(t), I_1(t - \frac{\Delta l}{c}) + I_2(t - \frac{\Delta l}{c})> \]

\[ = <I_1(t), I_1(t - \gamma_1)> + <I_2(t), I_2(t - \gamma_2)> \]

\[ + <I_1(t), I_2(t - \gamma_2)> + <I_2(t), I_1(t - \gamma_1)> \]

\[ \text{Note} \quad <..> = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} \ldots \mathrm{d}t \]
We assume that all light sources have the same $g_2$ behavior

$$C = g_2(\tau_1) + g_2(\tau_2)$$

A typical thermal light source has the following $g_2(\tau)$

Let's for simplicity chose $\tau_1 = 0$
then $\tau_1 = 0 \rightarrow$ always

no we move detectors to change $D$

$C$ similar to $g_2(\tau)$ shape

$g_2(0) \rightarrow$ due to 1st star

$D$ when we lose correlation, i.e. visibility

$$D \leftrightarrow \frac{\Delta L_2}{C} = \tau_0$$

$$\Rightarrow \frac{D \cdot T_2}{\sigma C} = \tau_0 \Rightarrow$$

$\Delta L_2$ star separation

$$\tau_2 = \frac{\tau_0 \cdot C \cdot \theta}{D}$$

$\theta_s = \frac{\tau}{\theta} = \frac{C \tau_0}{D}$

Note that angular resolution