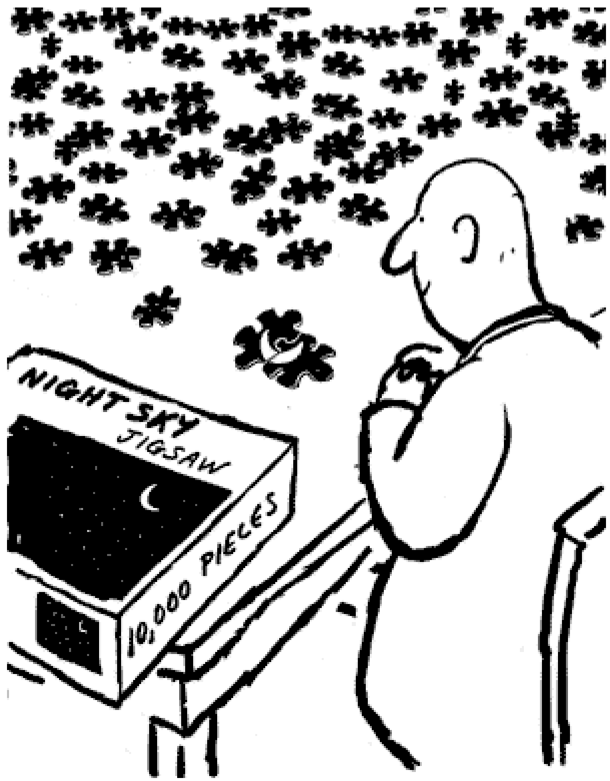
AS750 Observational Astronomy

Prof. Sebastian Lopez
Lecture 8

Observational limitations



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Observational limitations

0) Poisson! (quantum limitation)

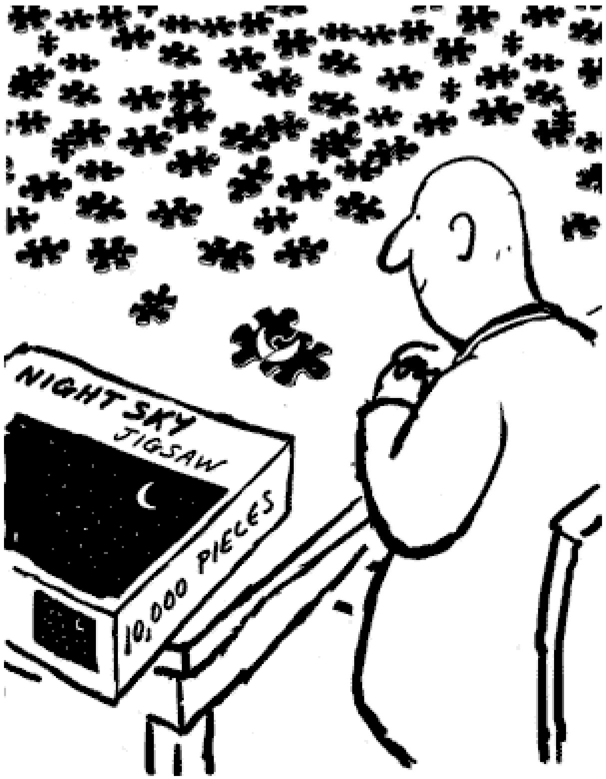
1) Diffraction limit

2) Detection (aperture) limit

   a)Simple case

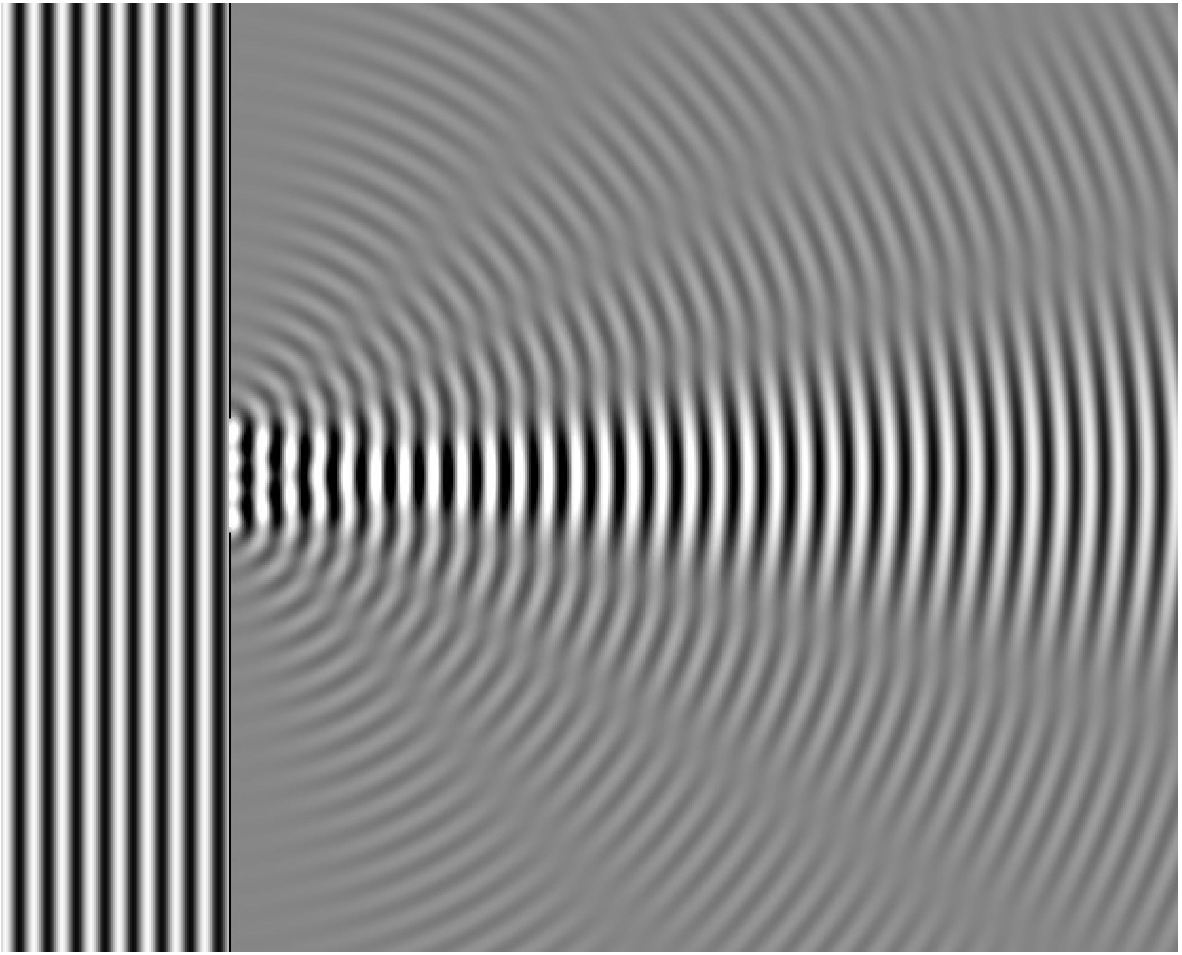
   b)More realistic case

3) Atmosphere



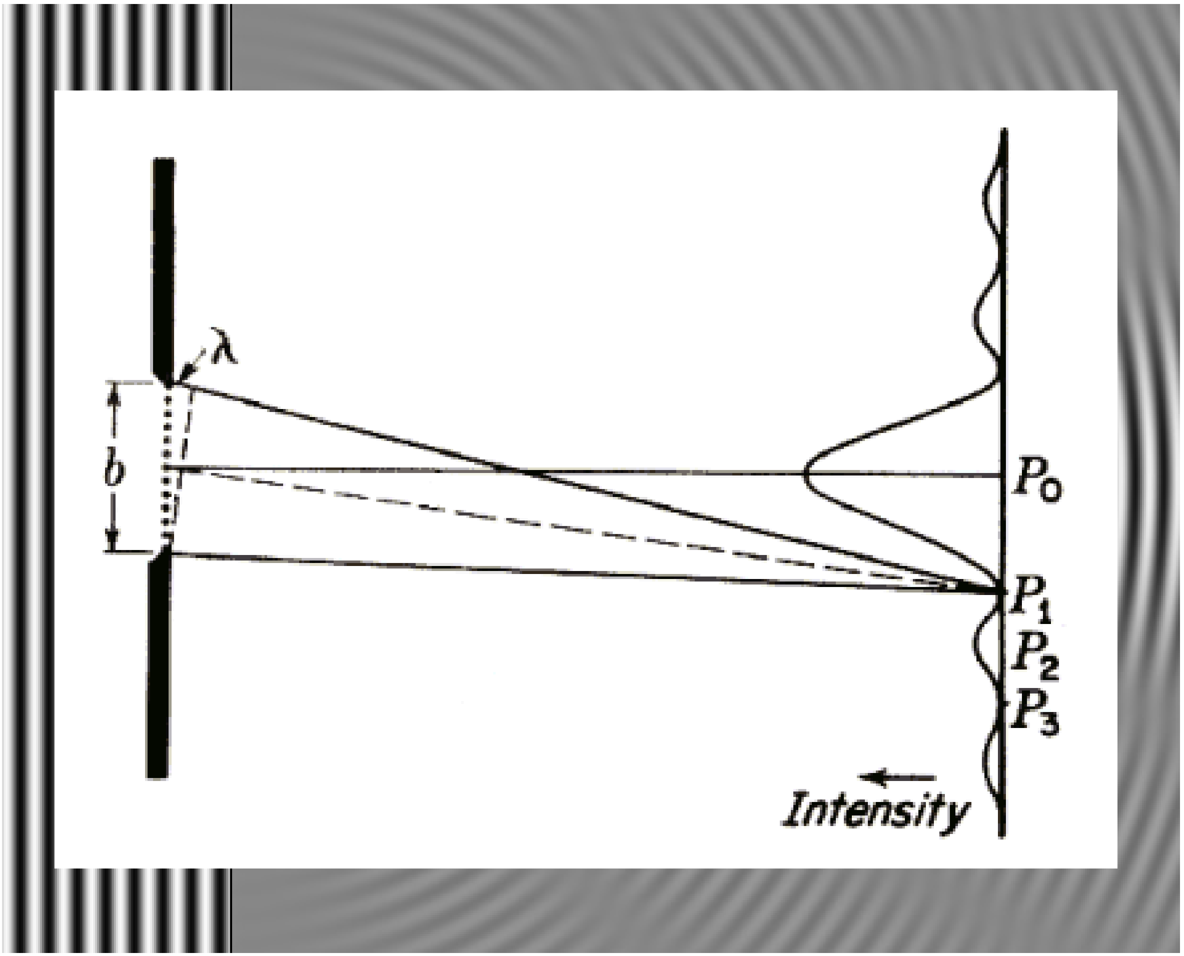
Observational limitations

1) Diffraction limit



Observational limitations

Diffraction limit: if the source is coherent the diffraction pattern is produced by constructive and destructive superposition.



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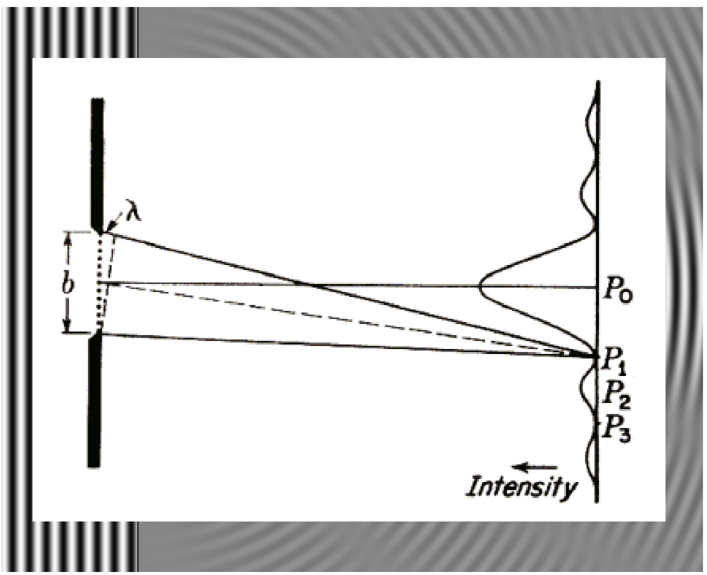

Phase: $\phi = \frac{2\pi}{\lambda} b \sin\theta$

Observational limitations

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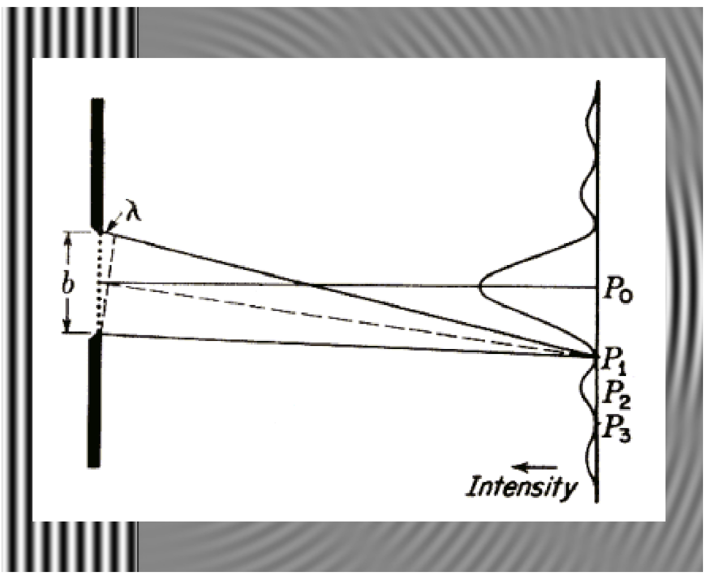


Phase: $\phi = \frac{2\pi}{\lambda} b \sin\theta$

Distribution of intensities is given by the power Spectrum of the Fourier Transform of the pattern:

$$I_\theta = I_0 \frac{\sin^2(\pi b \sin\theta / \lambda)}{\left(\frac{\pi}{\lambda} \sin\theta\right)^2}$$

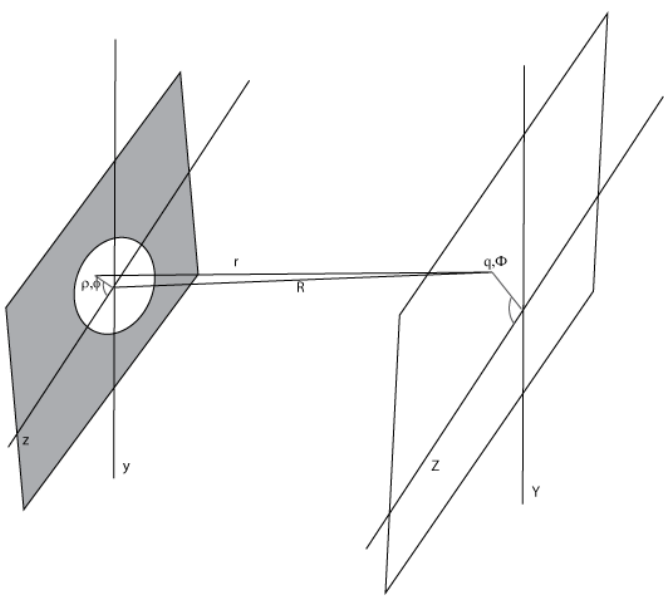
Two parallel slits separated by a distance *d*

Observational limitations

For a circular aperture:

$$I_\theta \propto \frac{\pi^2 r^4}{m^2} (J_1(2\mathrm{m}))^2$$

Where: J is a Bessel function, r the radio of the aperture and:

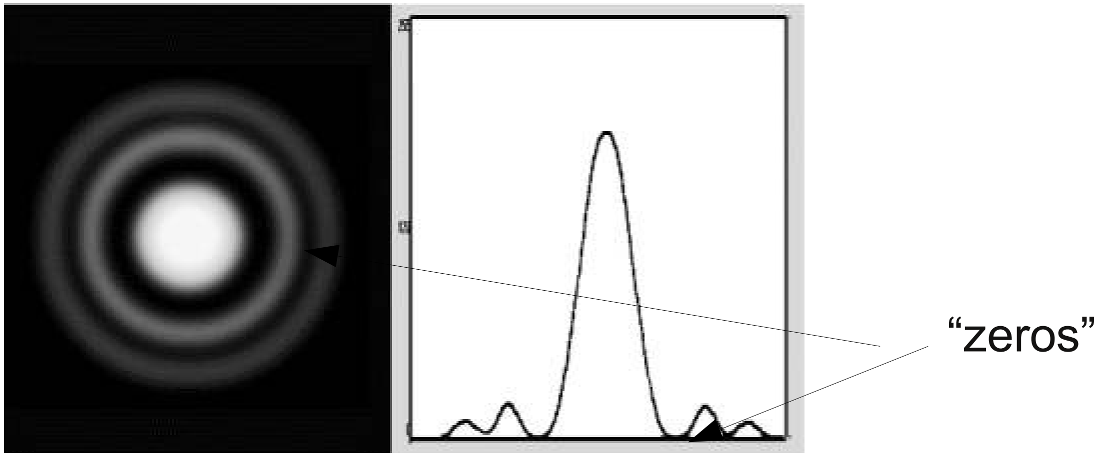


$$m = \frac{\pi r \sin\theta}{\lambda}$$

(see Kitchin, Chapt 1)

Observational limitations

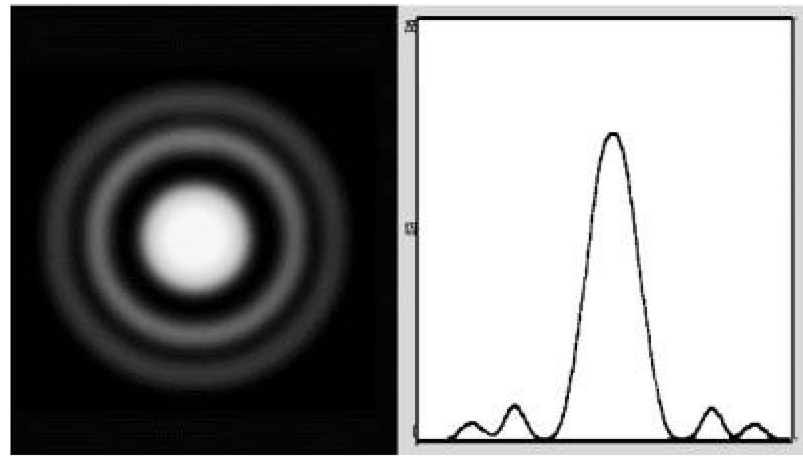
For a circular aperture:



Airy disk

Observational limitations

For a circular aperture:



$$m = 1.916, 3.508, \ldots$$

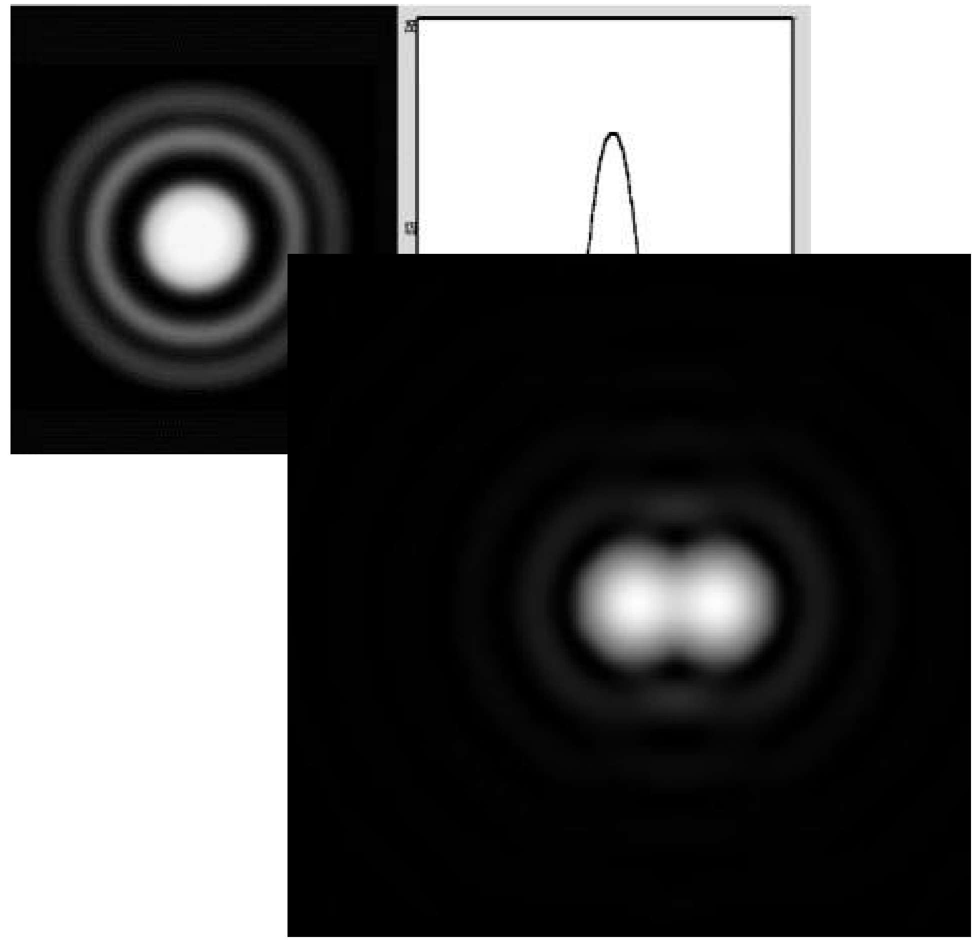
$$\sin\theta = \frac{1.916}{\pi r}\lambda, \frac{3.508}{\pi r}\lambda, \ldots$$

d=2r

$$\theta \approx \frac{1.220}{d}\lambda, \frac{2.233}{d}\lambda, \ldots$$

Observational limitations

For a circular aperture:



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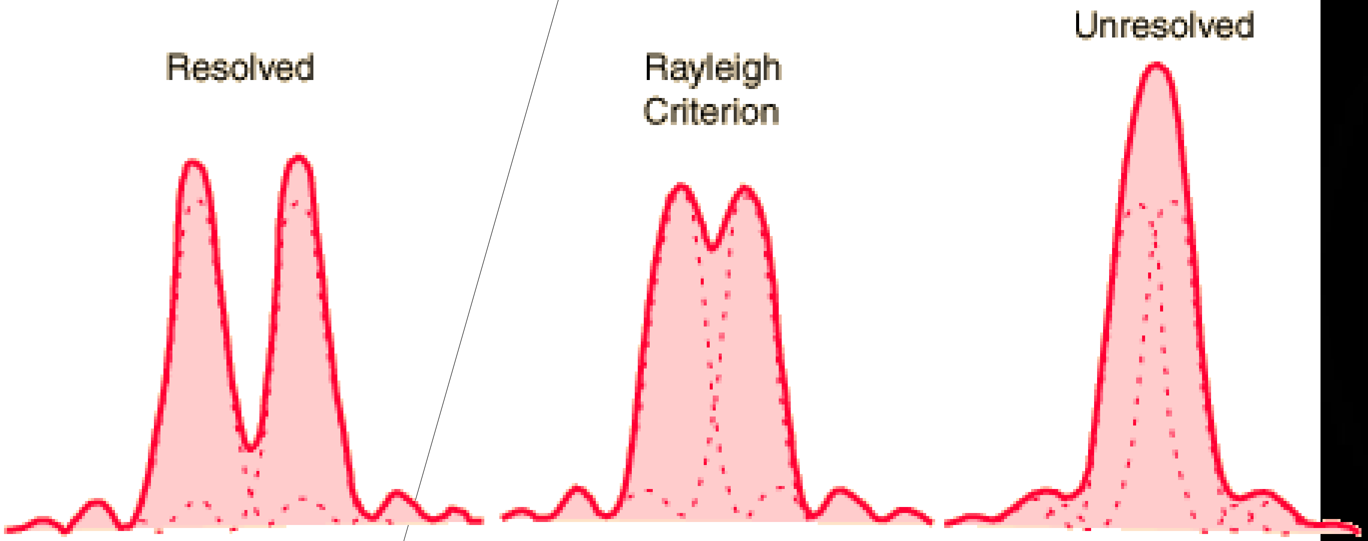
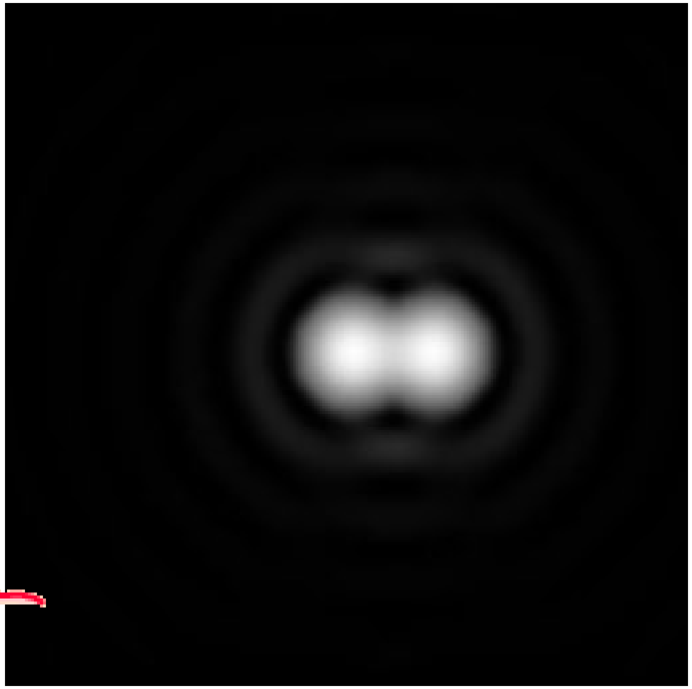
Rayleigh's criterion for resolving two sources.

Observational limitations

Rayleigh's criterion for resolving two sources (circular aperture).





$$\theta \approx \frac{1.220}{d} \lambda$$

Observational limitations

Examples:

- Human pupil: d=8 mm, @ 5000 Å, α = 15 arcsec

Observational limitations

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- Human pupil: d=8 mm, @ 5000 Å, α = 15 arcsec
- Hubble Space Telescope: d=2.4 m, @ 5000 Å, α = 0.05 arcsec

Observational limitations

Examples:

- Human pupil: *d*=8 mm, @ 5000 Å, α = 15 arcsec
- Hubble Space Telescope: *d*=2.4 m, @ 5000 Å, α = 0.05 arcsec
- Gemini telescope: *d*= 8 m, @ 10.,000 Å, α = 0.03 arcsec

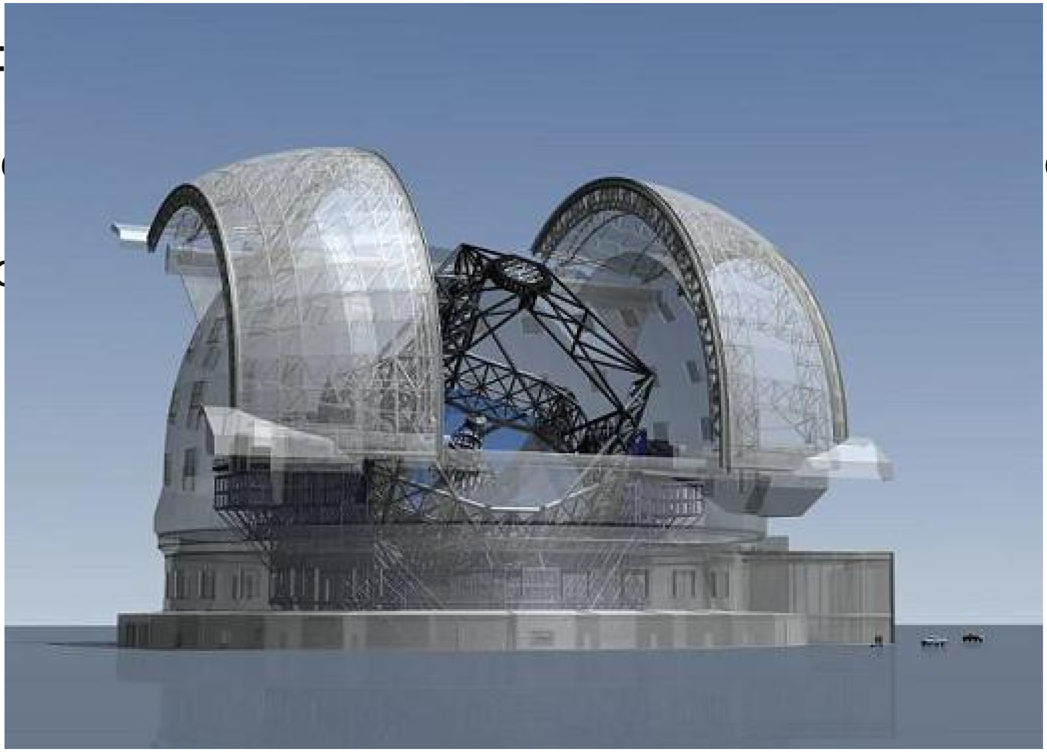
Observational limitations

Examples:

•Human pupil:

•Hubble Spac c

•Gemini telesc



Observational limitations

Examples:

Eye receptors ~ 1 arcmin

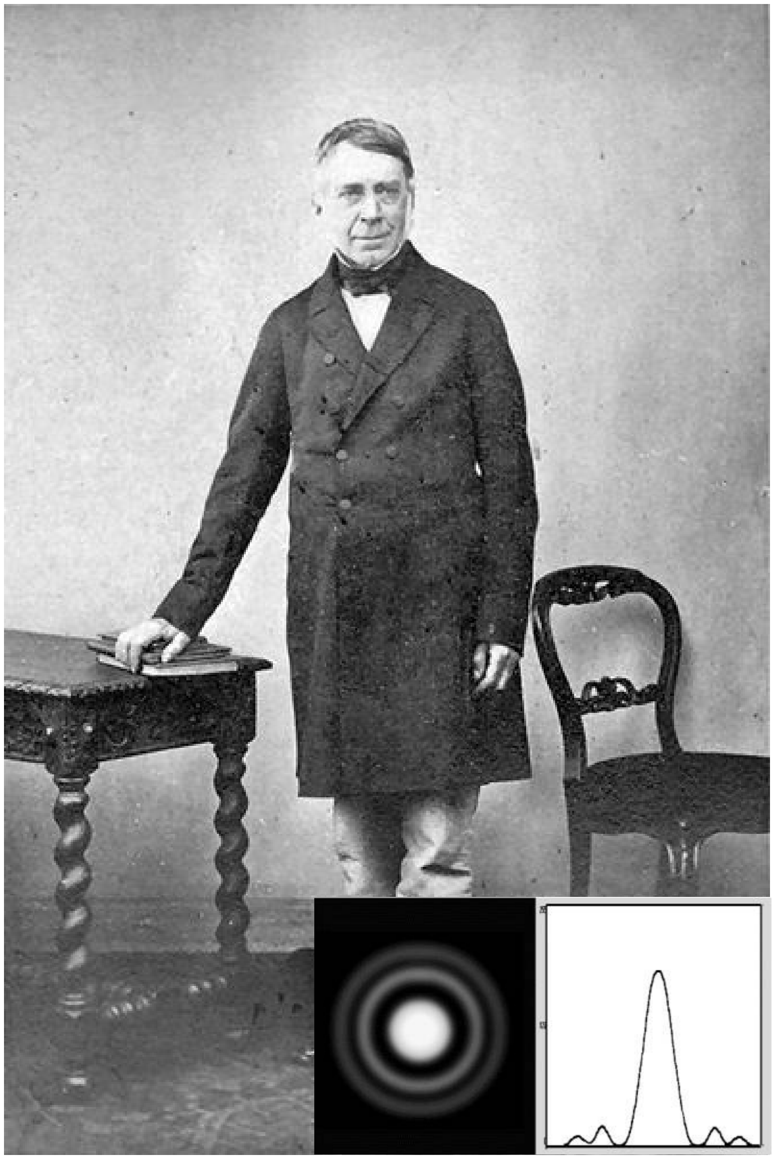
•Human pupil: *d*=8 mm, @ 5000 Å, α = 15 arcsec

•Hubble Space Telescope: *d*=2.4 m, @ 5000 Å, α = 0.05 arcsec

•Gemini telescope: *d*= 8 m, @ 10.,000 Å, α = 0.03 arcsec

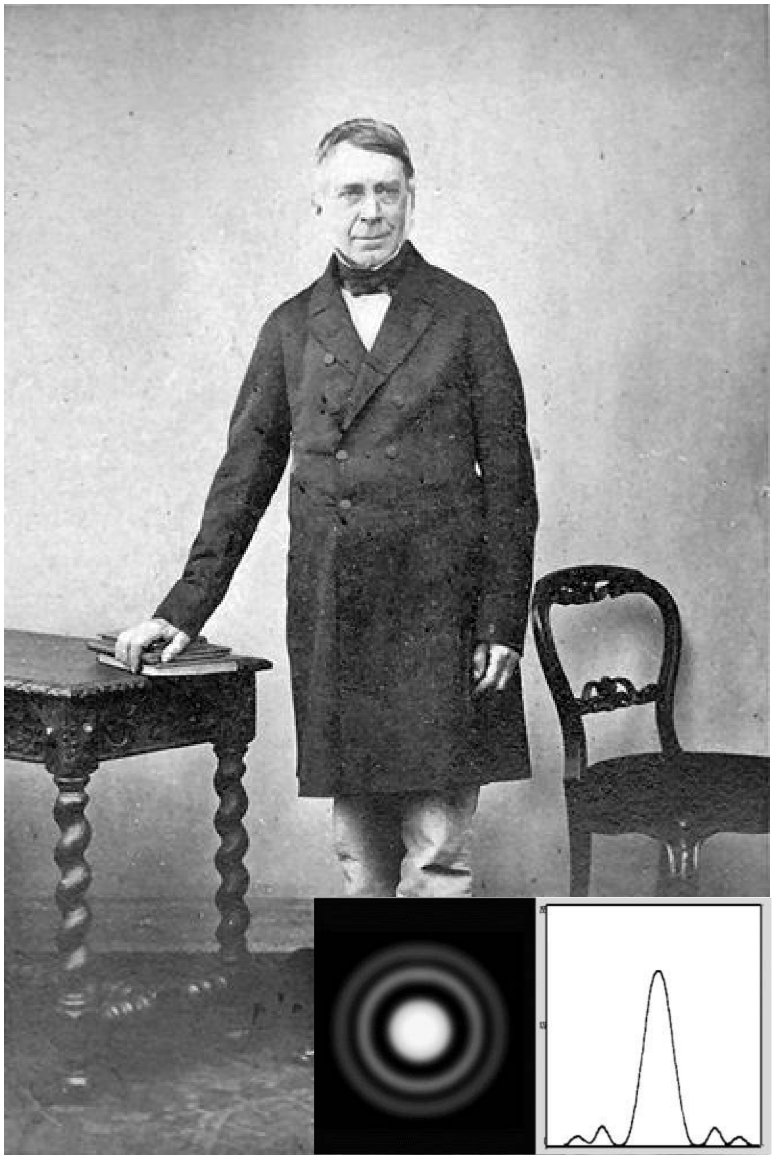
Atmospheric seeing ~0.5 arcsec

Observational limitations

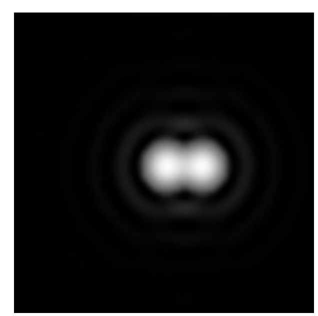


George Airy

Observational limitations



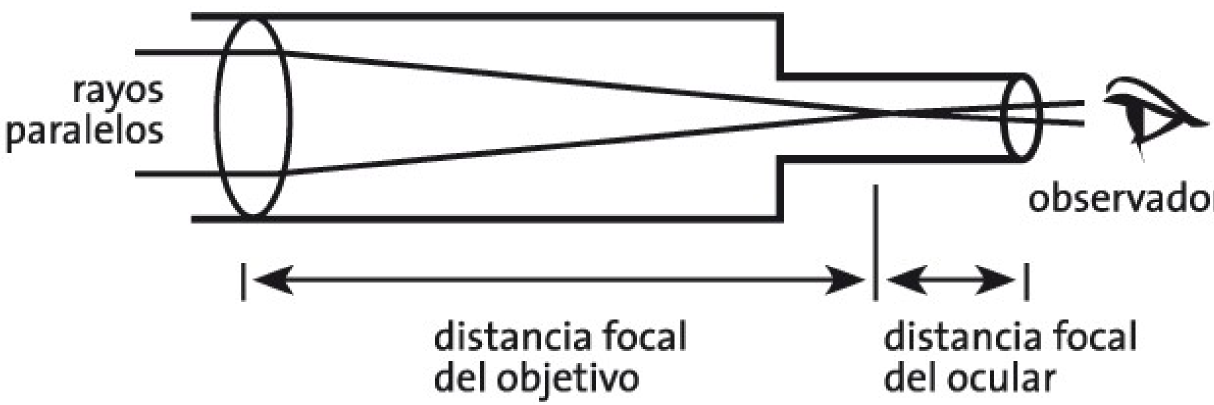
George Airy



John Strutt
(Lord Rayleigh)

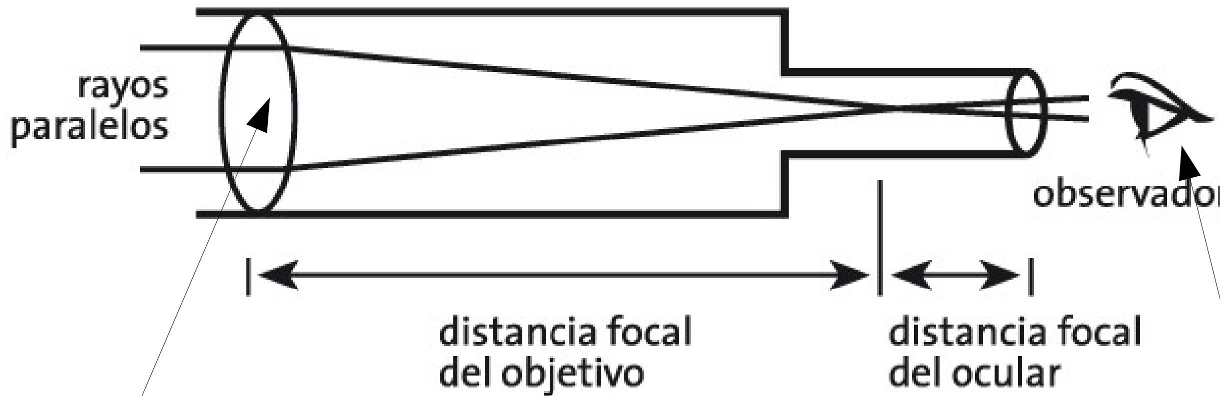
Observational limitations

2) Aperture limit



Observational limitations

2) Aperture limit

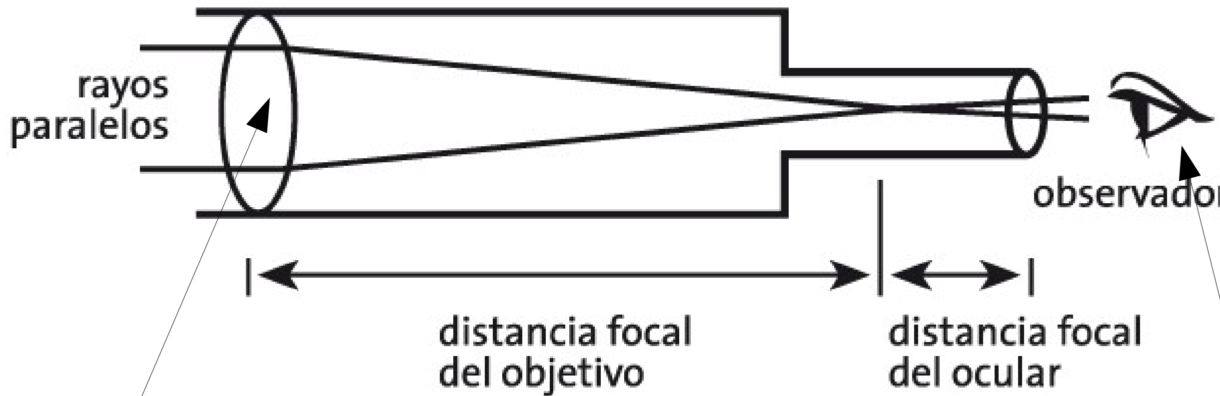


Aperture with diameter *D*

Aperture with diameter *d*

Observational limitations

2) Aperture limit



Aperture with diameter *D*

Aperture with diameter *d*

Flux received by naked eye

$$\frac{f_0}{f_T} = \left(\frac{d}{D}\right)^2$$

Flux received with the help of a telescope

Observational limitations

2) Aperture limit

$$\frac{F_T}{F_0} = \left(\frac{d}{D}\right)^2$$

Limiting flux received with Telescope aid (F_T)

Limiting flux received by naked eye (F_0)

Observational limitations

2) Aperture limit

$$\frac{F_T}{F_0}=\left(\frac{d}{D}\right)^2$$

Limiting flux

$$m_T-m_0=-2.5\log(F_T/F_0)$$

Limiting magnitude

Observational limitations

2) Aperture limit

$$\frac{F_T}{F_0} = \left(\frac{d}{D}\right)^2$$

Limiting flux

$$m_T - m_0 = -2.5 \log(F_T / F_0)$$

Limiting magnitude

$$m_T - m_0 = -2.5 \log(d / D)^2$$

Observational limitations

2) Aperture limit

$$\frac{F_T}{F_0} = \left(\frac{d}{D}\right)^2$$

Limiting flux

$$m_T - m_0 = -2.5 \log(F_T / F_0)$$

Limiting magnitude

$$m_T - m_0 = -5 \log(d / D)$$

If we set m=6 for the limiting magnitude of the naked eye, the last equation becomes:

$$m_T = m_{lim} = 6 + 5 \log(D / d)$$

Observational limitations

2) Aperture limit

$$\frac{F_T}{F_0} = \left(\frac{d}{D}\right)^2$$

Limiting flux

$$m_T - m_0 = -2.5 \log(F_T / F_0)$$

Limiting magnitude

$$m_T - m_0 = -5 \log(d/D)$$

If we set m=6 for the limiting magnitude of the naked eye, the last equation becomes:

$$m_T = m_{lim} = 6 + 5 \log(D/d)$$

For d=8mm (pupil diameter), this equation reads:

$$m_T = m_{lim} = 16.5 + 5 \log D[m]$$

Observational limitations

2) Aperture limit

$$m_T = m_{lim} = 16.5 + 5\log D[m]$$

Could be 16.0 considering inefficiency of the optics

Example 1 telescope amateur, D=0.3m: m_{lim}=13.4

Observational limitations

2) Aperture limit

$$m_T = m_{lim} = 16.5 + 5\log D[m]$$

Could be 16.0 considering inefficiency of the optics

Example 1 telescope amateur, D=0.3m: m_{lim}=13.4

Example 2 GOTO, D=0.4m: m_{lim}=14.0

Observational limitations

2) Aperture limit

$$m_T = m_{lim} = 16.5 + 5\log D[m]$$

This limiting magnitude is constrained by the sampling rate
of the human eye. If we now consider an integration factor that is higher by a factor of "f":

$$\frac{fF_T}{F_0} = \left(\frac{d}{D}\right)^2$$

Observational limitations

2) Aperture limit

$$m_T = m_{lim} = 16.5 + 5 \log D[m]$$

This limiting magnitude is constrained by the sampling rate of the human eye. If we now consider an integration factor that is higher by a factor of "f":

$$\frac{fF_T}{F_0} = \left(\frac{d}{D}\right)^2$$

$$m_T = m_{lim} = 16.0 + 5 \log D[m] + 2.5 \log f$$

Observational limitations

2) Aperture limit

$$m_T = m_{lim} = 16.0 + 5\log D[m] + 2.5\log f$$

Assuming a sampling rate of 1/30 s, the above equation becomes:

$$\boxed{m_T = m_{lim} = 19.7 + 5\log D[m] + 2.5\log t[s]}$$

Observational limitations

2) Aperture limit (Simple case)

$$m_T = m_{lim} = 16.0 + 5\log D[m] + 2.5\log f$$

Assuming a sampling rate of 1/30 s, the above equation becomes:

$$m_T = m_{lim} = 19.7 + 5\log D[m] + 2.5\log t[s]$$

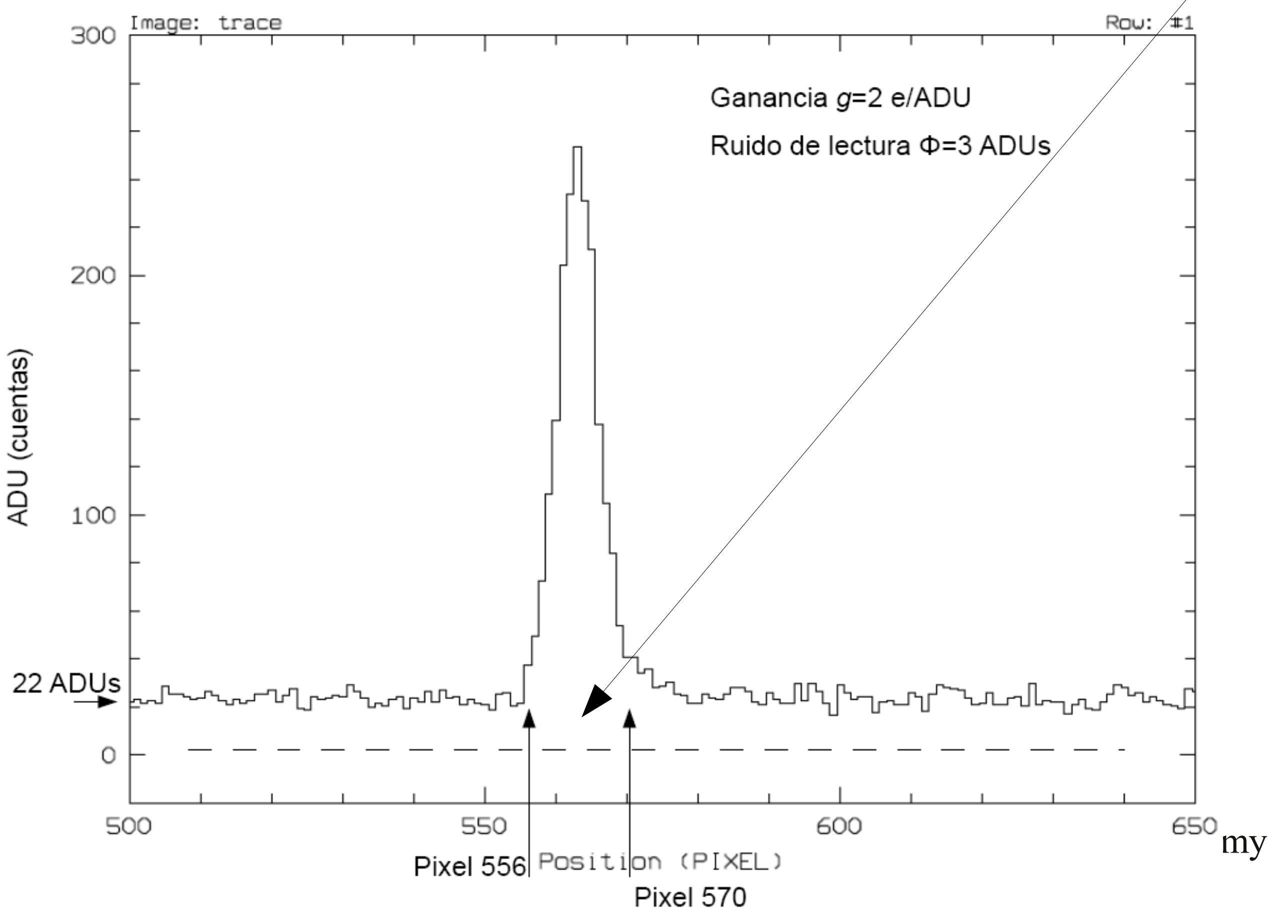
Example: 3.6m telescope at La Silla, *t*= 1800 s gives *m*=29!

However, this limiting magnitude is highly over-estimated. It neglects the effects of the detector noise, the sky background, and the seeing.

Observational limitations

2) Aperture limit (More realistic case)

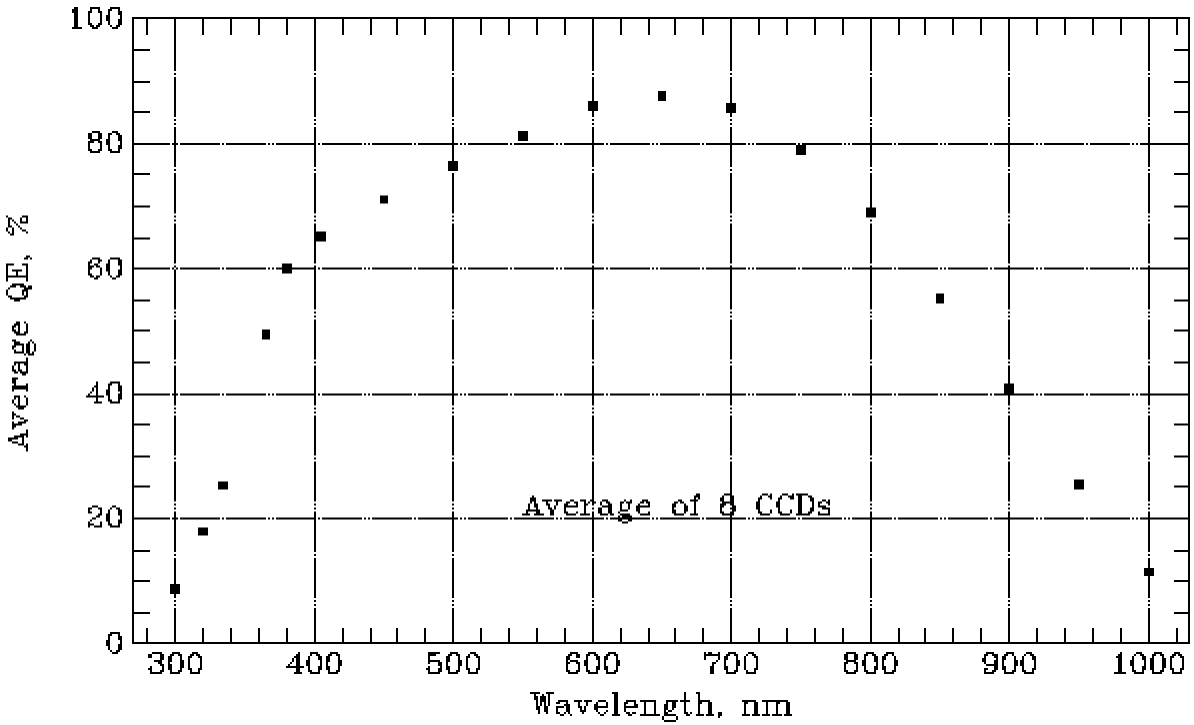
•Aperture has *m* pixels



Observational limitations

2) Aperture limit (More realistic case)

- Aperture has *m* pixels
- Detector has Quantum Efficiency QE



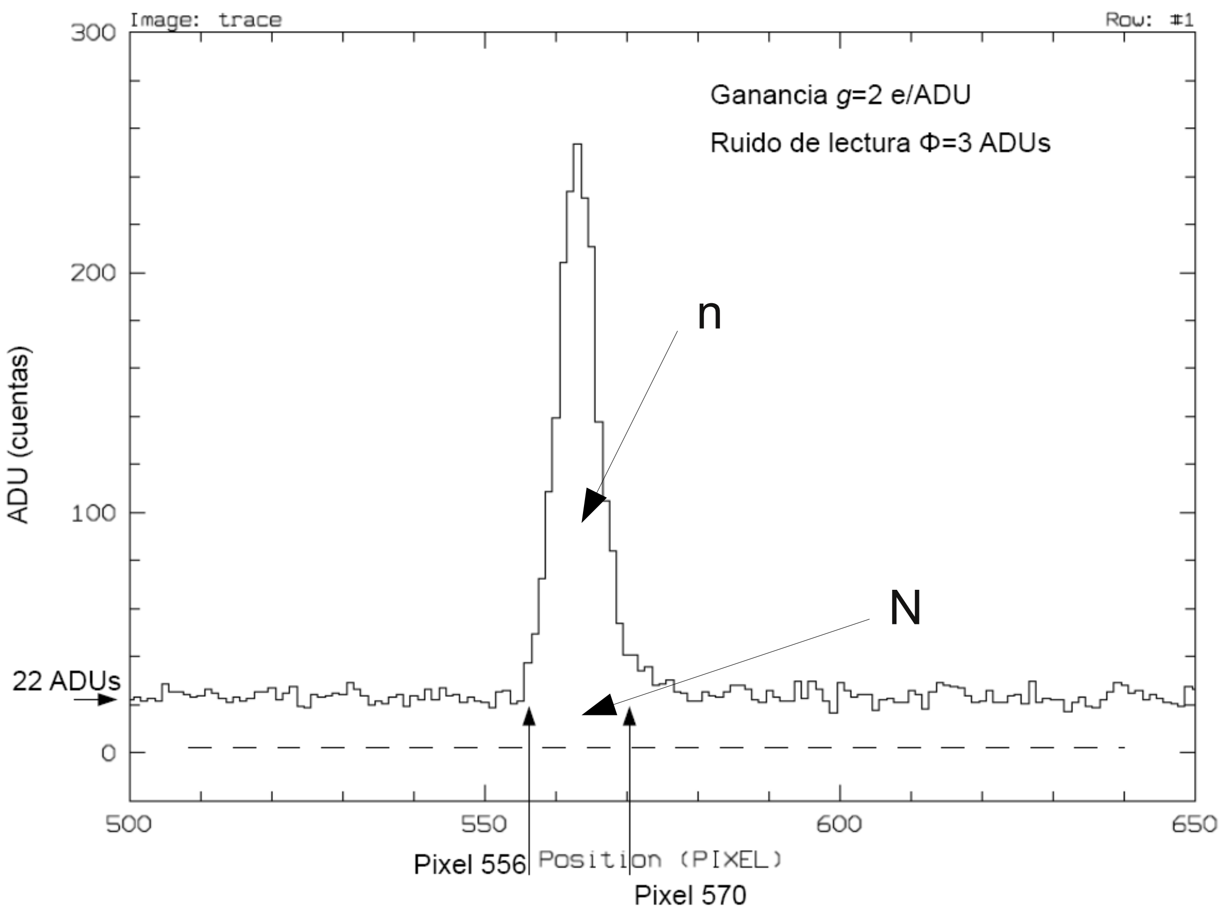
QE: percentage of photons that will produce a photo-electron on the CCD

QE of the red camera of the MIKE spectrograph on Clay @ LCO

Observational limitations

2) Aperture limit (More realistic case)

- Aperture has *m* pixels
- Detector has Quantum Efficiency QE
- Read-out noise "Φ"



my

$$\frac{S}{N} = \frac{nq}{\sqrt{nq + Nq + \phi^2 m}}$$