Previous Lecture

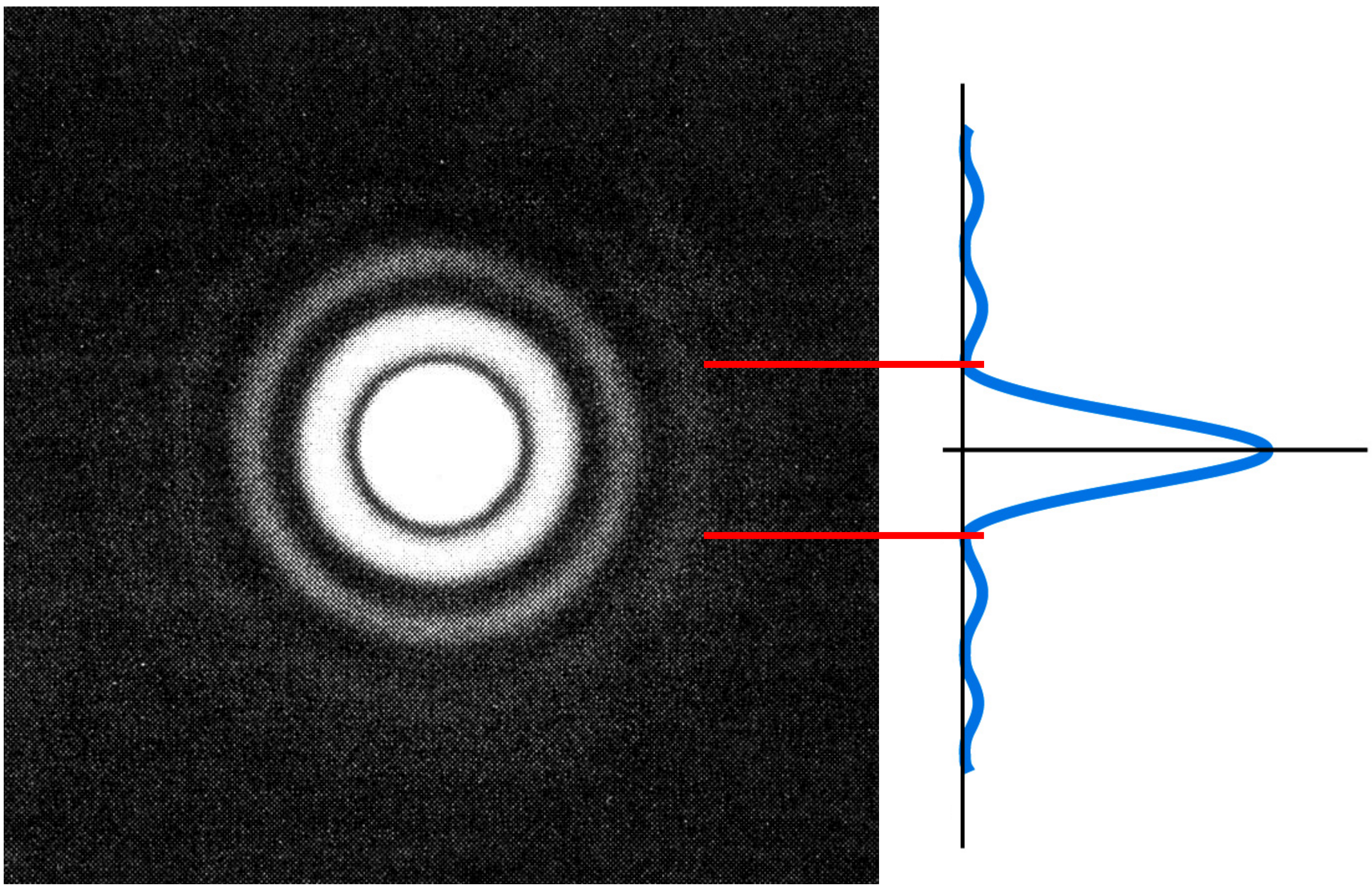
- one slit, two slits
- diffraction pattern from one slit
- diffraction pattern from circular aperture

Today

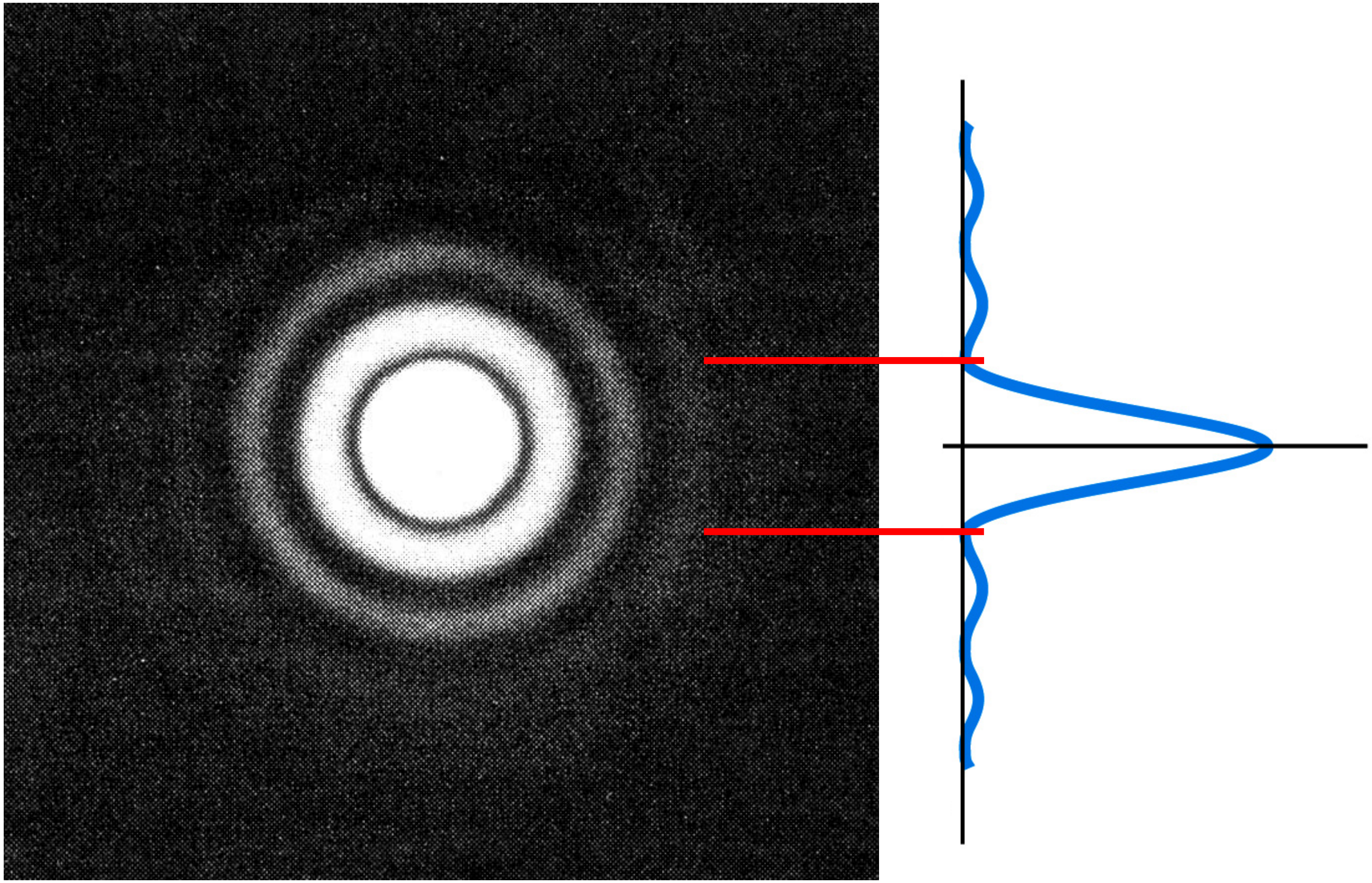
- Resolution of optical instruments
- Polarization
- Quantum mechanics on one page
- Information about the final

December 7, 2011

Diffraction by a circular aperture

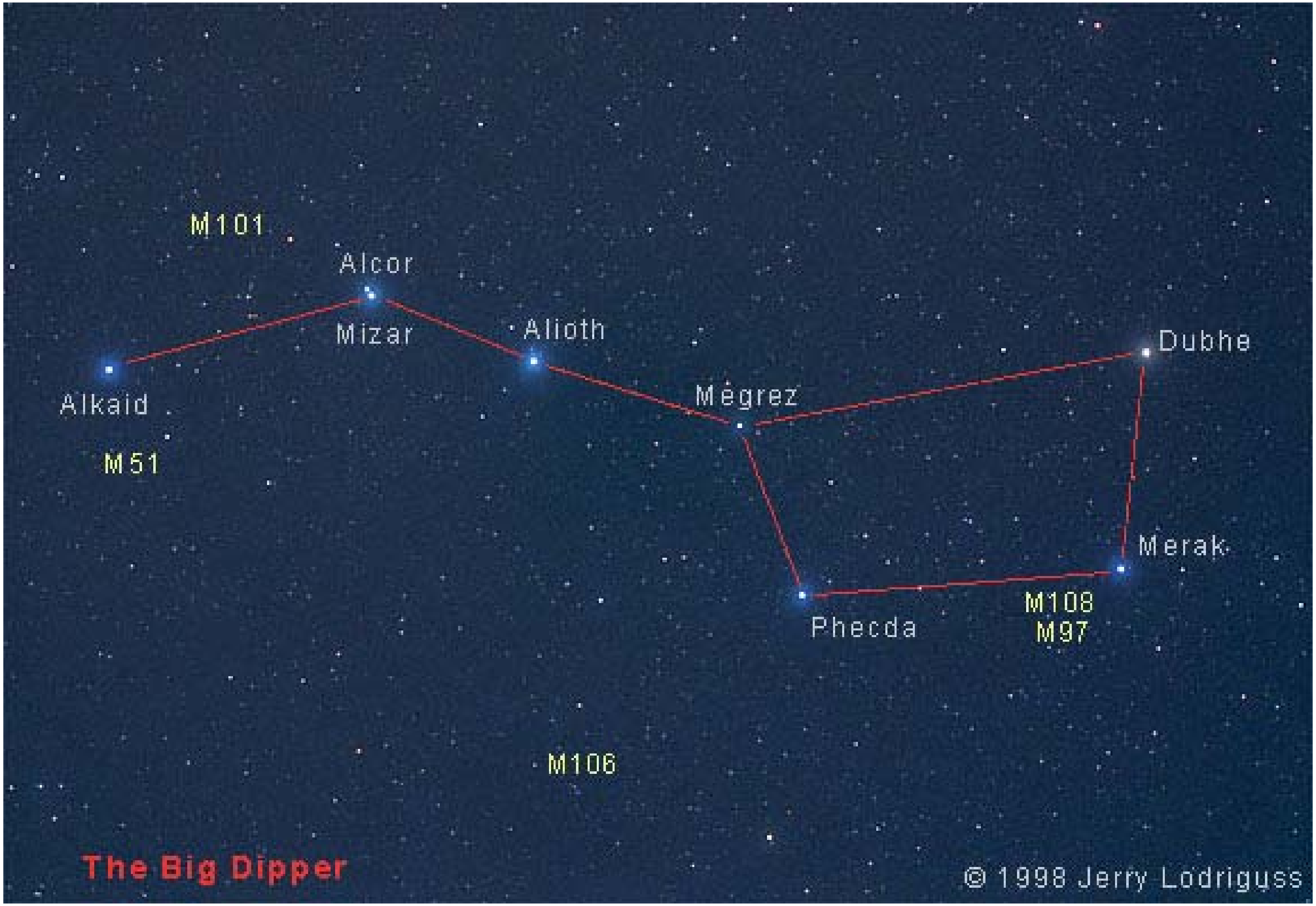


Diffraction by a circular aperture



When light goes through a hole, diffraction makes it spread out.

Resolution of Optical Instruments



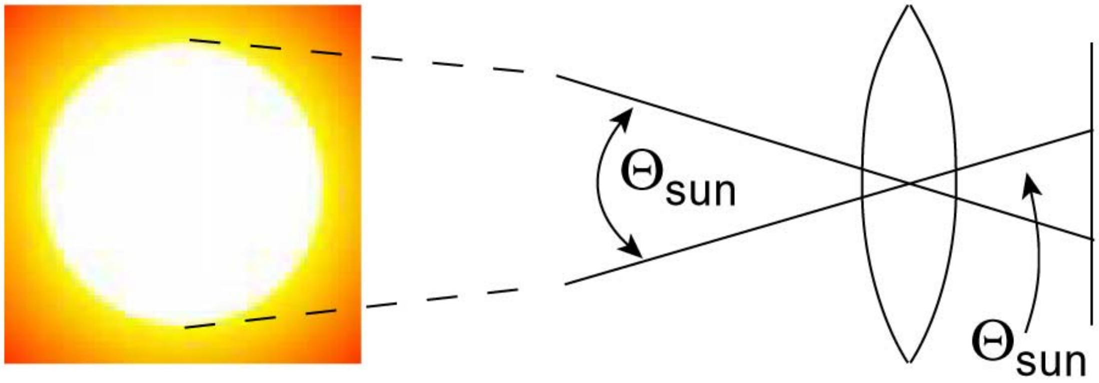
Imaging Binary Stars

When we use a telescope to form an image of a star, there are two competing effects:

- Geometric optics makes the lens focus the light rays to a point.
- Diffraction makes the light wave spread out.

The interplay of these effects controls our ability to distinguish fine details in images.

Image of Sun on Film



Angular size of image according to geometric optics:

$$\Theta_{\rm sun} = \frac{\text{Diameter of Sun}}{\text{Distance to Sun}} = \frac{1.4 \times 10^{9}\,\text{m}}{1.5 \times 10^{11}\,\text{m}} \sim 10^{-2}\,\text{rad}$$

Diffraction:

$$\Theta_{\rm d} = 1.22\frac{\lambda}{D} \sim 1.22\frac{500\,\text{nm}}{50\,\text{mm}} \sim 10^{-5}\,\text{rad}$$

Because $\Theta_{\rm d} \ll \Theta_{\rm sun}$, it's easy to image the sun's disk. We can see sunspots and other features on the surface.

Image of any other star

Estimate the angular size of another star:

$$\Theta_{\mathrm{star}} = \frac{\mathrm{Diameter\,of\,Star}}{\mathrm{Distance\,to\,Star}} = \frac{1.4 \times 10^{9}\,\mathrm{m}}{4\,\mathrm{light\,years}} \sim 4 \times 10^{-8}\,\mathrm{rad}$$

The spread of the image due to diffraction is

$$\Theta_{\mathrm{d}} = 1.22\frac{\lambda}{D} \sim 1.22\frac{500\,\mathrm{nm}}{0.25\,\mathrm{m}} \sim 2.5 \times 10^{-6}\,\mathrm{rad}$$

In this case $\Theta_{\mathrm{d}} \gg \Theta_{\mathrm{star}}$.

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In this case $\Theta_{\rm d} \gg \Theta_{\rm star}$. This relation implies that for stars other than the sun, the diffraction pattern is larger than the image predicted by geometric optics. What you see through a telescope is not the disk of the star; it is the diffraction pattern of an infinite plane wave squeezing through a lens of finite diameter.

Image of a Single Star

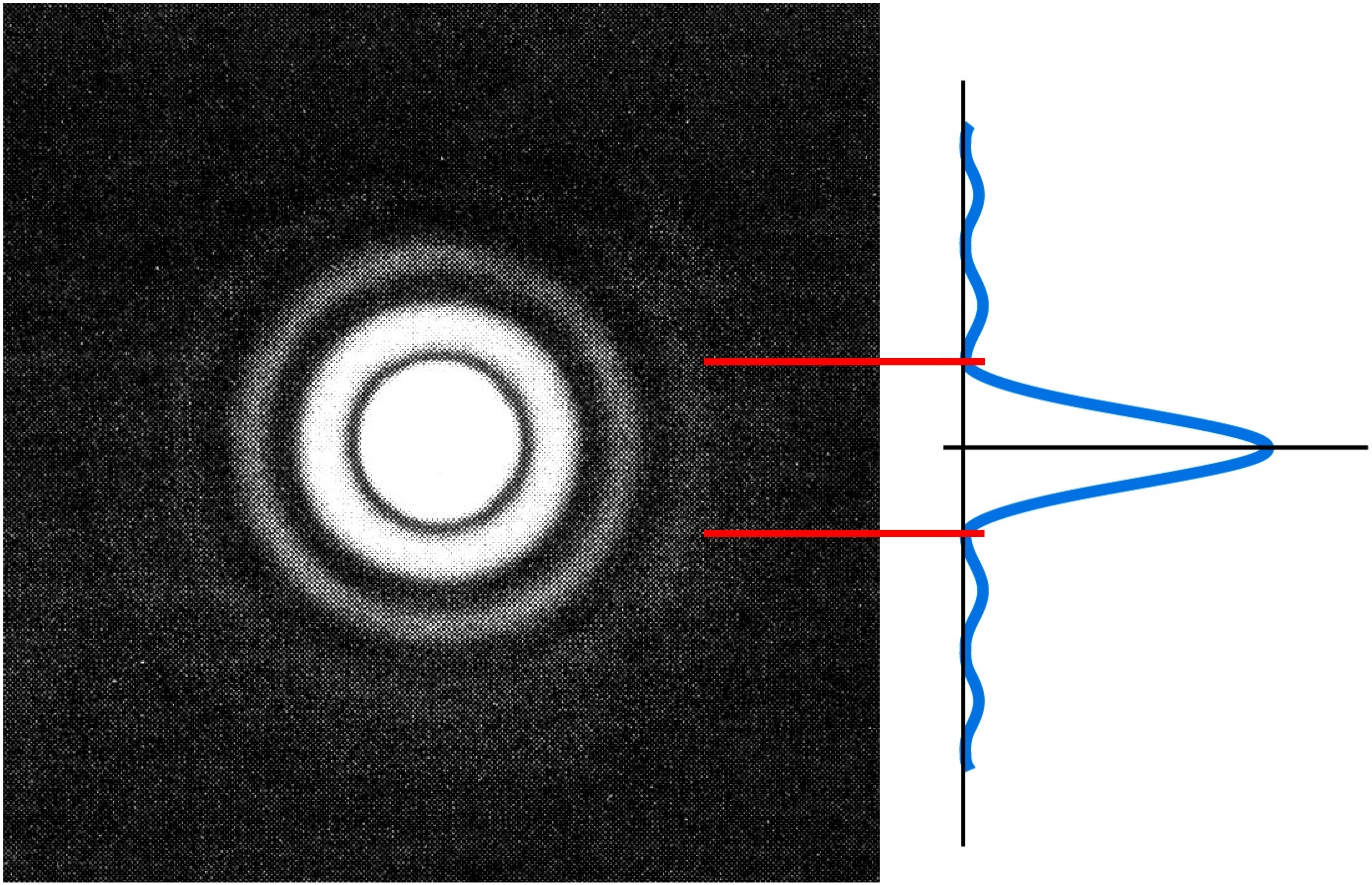
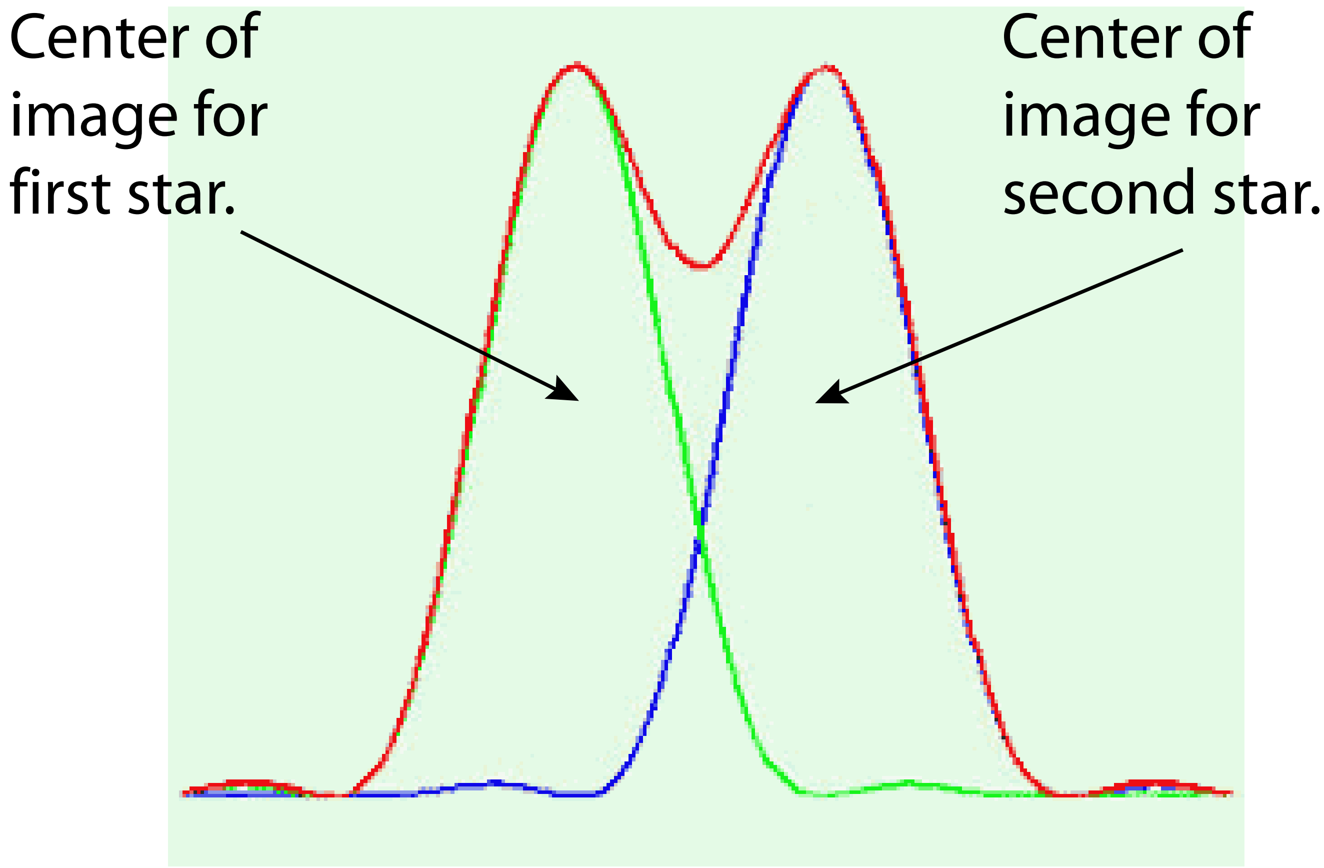


image of point source has angular spread $1.22\lambda/D$.

Two Closely Spaced Stars

A Just-resolved Binary Star



The Rayleigh criterion: Two stars are just resolved if the center of the diffraction pattern for the first star coincides with the first dark ring from the second star.

Problem

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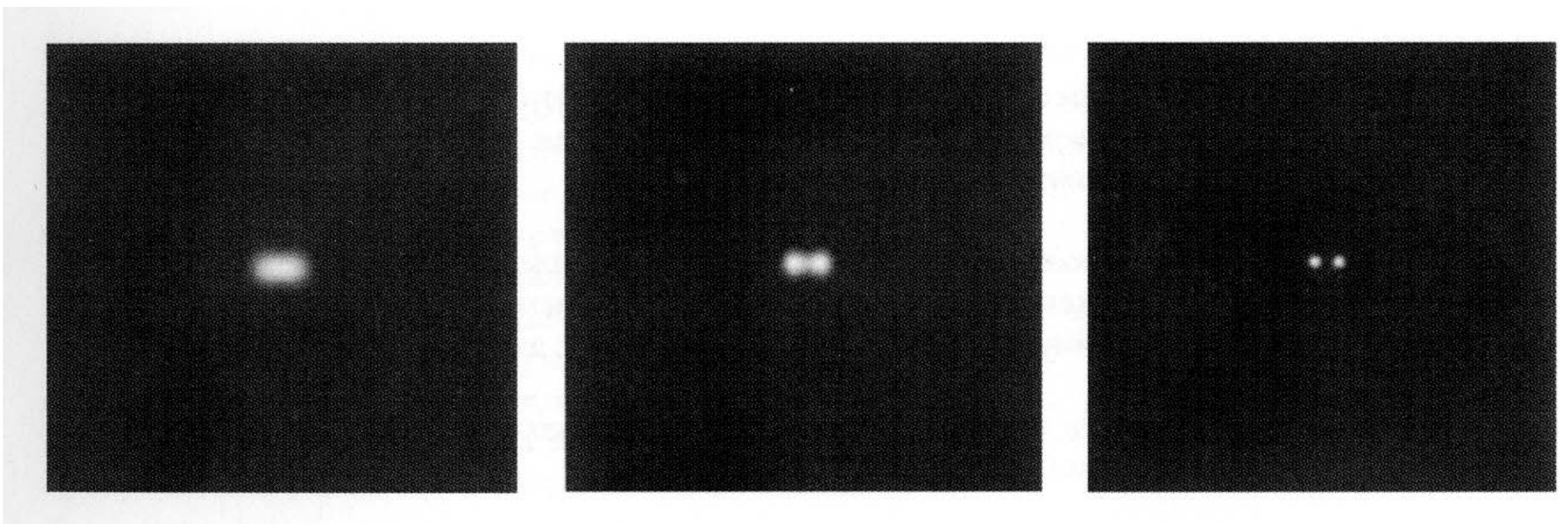
Solution: Use the Rayleigh criterion:

$$\theta = \frac{1.22\lambda}{D} \quad \Rightarrow \quad D = \frac{1.22\lambda}{\theta}$$

Resolving Binary Stars

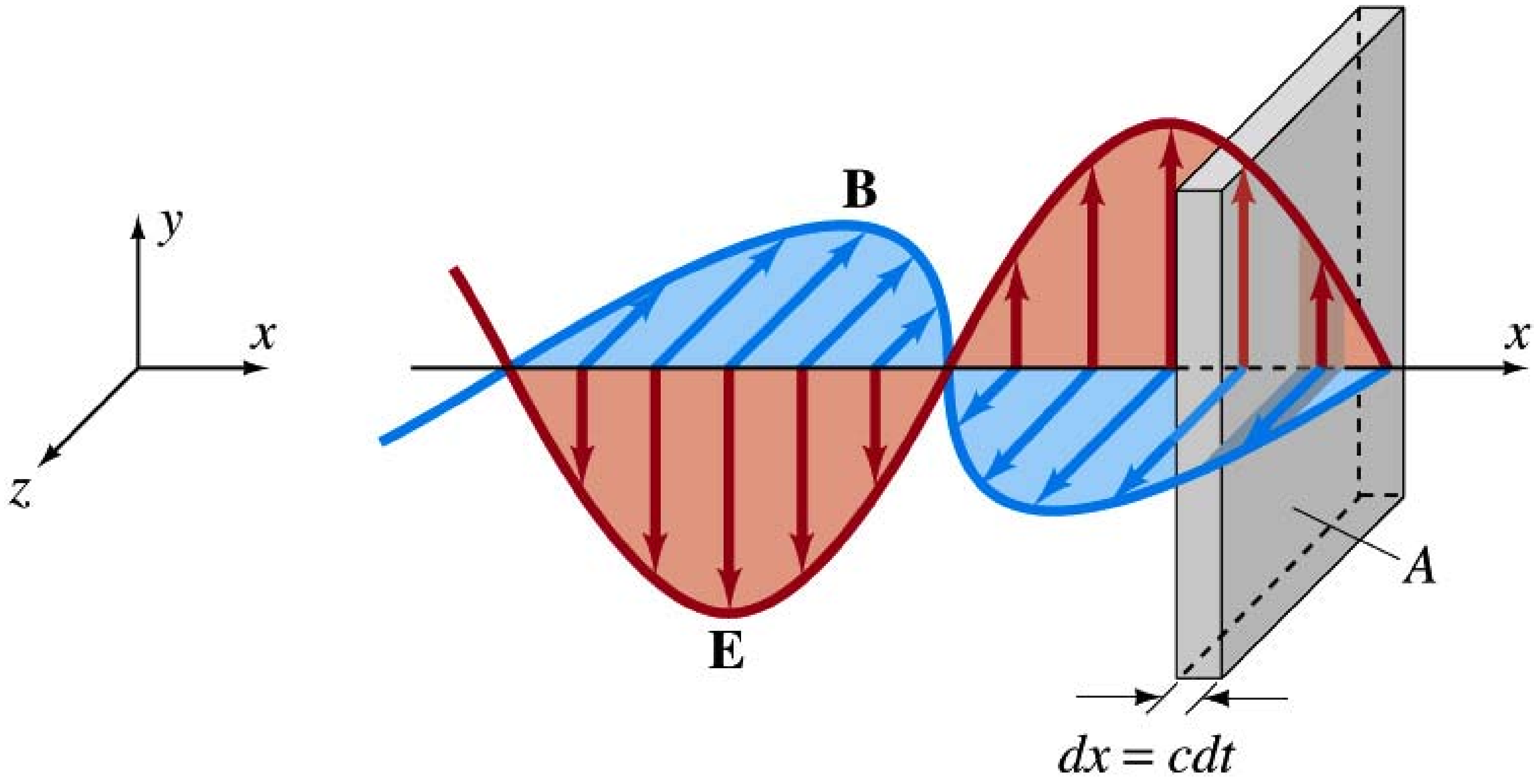
Image of 1.5 arcsecond binary star



60 mm   102 mm   200 mm

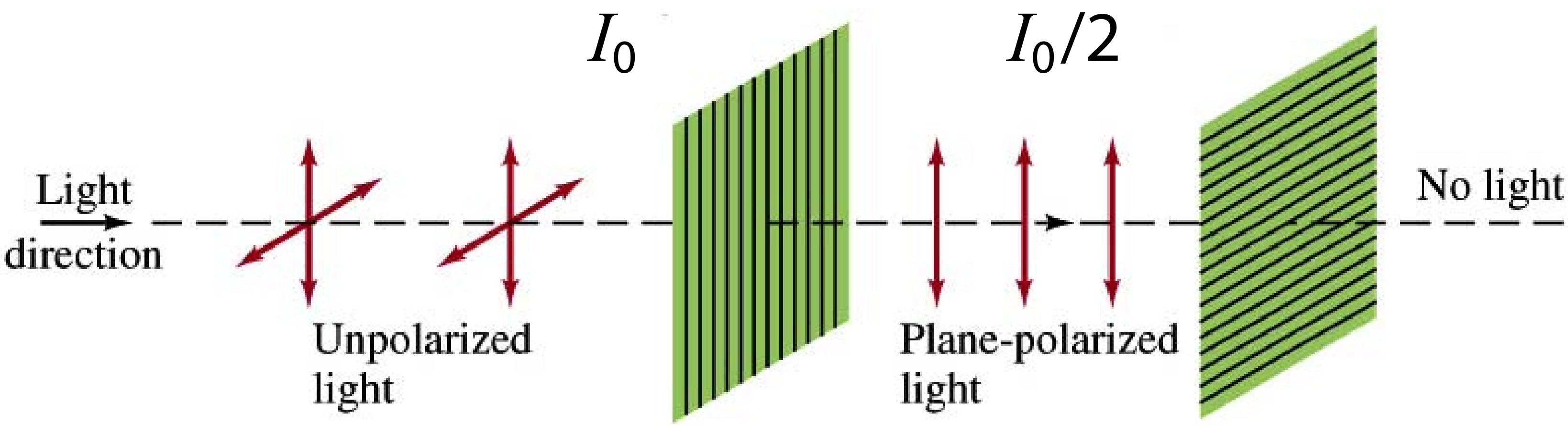
Diameter of objective lens

Polarization

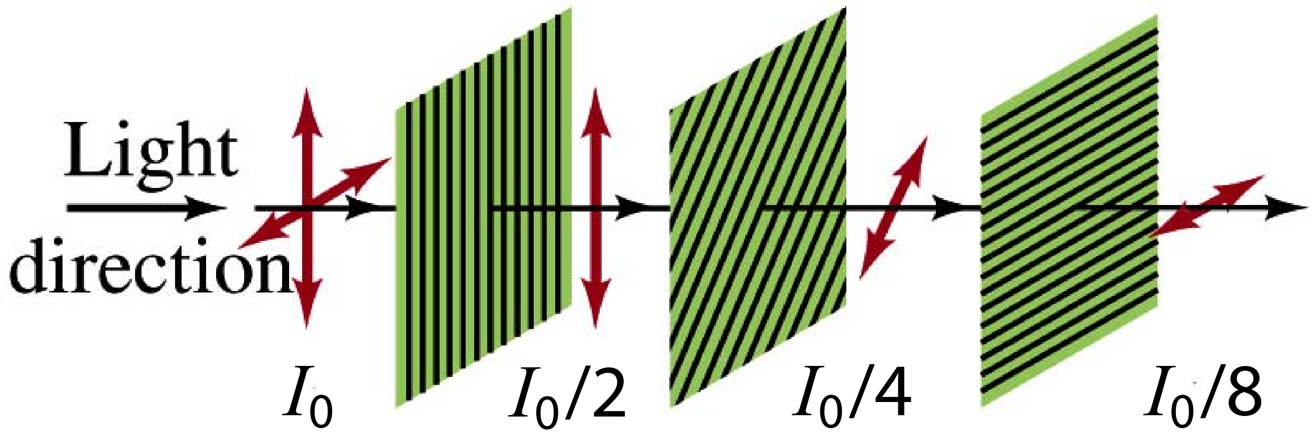


This wave is polarized in the y direction. (Fig. 32-14)

Polarization Effects



Figures 36-35, 36-37

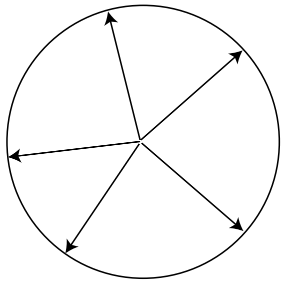


Example

Two polarizers are oriented at 34.0° to one another. Light polarized at a 17.0° angle to each polarizer passes through both. What reduction in intensity takes place?

Polarization Filter

Why does a polarization filter pass 50% of unpolarized light?



If the light is unpolarized, then all polarization directions are equally likely. In that case, we average over θ.

$$\langle E_0^2 \cos^2\theta \rangle = E_0^2 \underbrace{\frac{1}{2\pi}\int_0^{2\pi} \cos^2\theta \, d\theta}_{1/2} = \tfrac{1}{2} E_0^2$$

Remember that $\langle \cos^2\theta \rangle = \langle \sin^2\theta \rangle = \frac{1}{2}$. The integrals involved are the same ones we used to relate the rms value to the peak value of an oscillating electric field.

Quantum Mechanics–Highlights

- Particles the size of atoms or electrons must be described using waves.
- We find the wave by solving Schroedinger's Equation.
- Everything you have learned about waves is valid in quantum mechanics.
- Some of what you have learned about particles is not true in quantum mechanics.
- It's hard to tell what's a particle and what's a wave.
- For more information, take Physics 31.

Final Exam

- Thursday, Dec. 15, 2011, 7:10–10:10 pm in PA 101 (EXTRA TIME STUDENTS TAKE THE ENTIRE EXAM IN LL221 STARTING AT 5:30 PM)
- Covers entire semester:

  $\sim$ 50% E&M $\sim$ 50% waves & optics
- Equation sheet, handout on optics supplied on exam
- A question or two from material covered only in lecture
- Study guide and review questions on optics will be posted on the class web site
- Saturday, Dec.10, 9:20 a.m. and 10:45 a.m.: RCS in LL270 or LL404
- Monday, Dec. 12: RCS for recitation