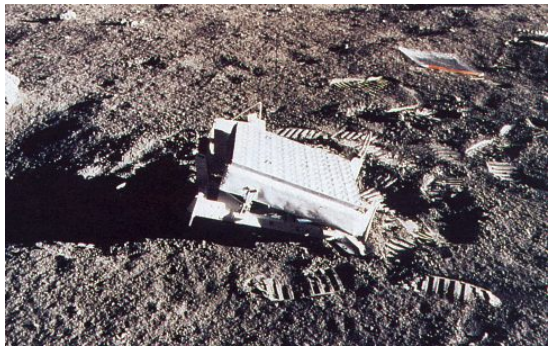
PHYS 408 Group Activities for Feb 3 2011

The ongoing Lunar Laser Ranging Experiment measures the distance between Earth and Moon using laser ranging. Lasers on Earth are aimed at retro-reflectors previously planted on the Moon (Apollo 11) and via the reflected signal the distance is measured.



1-Why would we want to precisely measure the earth-moon distance?

The moon is approx .35 Gm away from earth

2-How could the distance be measured with laser ranging?



Images Source: NASA

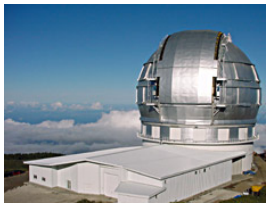
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The ongoing Lunar Laser Ranging Experiment measures the distance between Earth and Moon using laser ranging. Lasers on Earth are aimed at retro-reflectors previously planted on the Moon (Apollo 11) and via the reflected signal the distance is measured.

3-As an optical design engineer on the project you must model the laser beam propagation as a Gaussian Beam and you need to optimize the return signal as measured on earth. The laser (λ=532 nm, 10 Watt) is pointed to the moon through a telescope and you are offered three different telescopes with varying apertures. Via calculations of Gaussian beams, discuss the advantages and disadvantages of each.

Bonus-If the retroreflector is 1m^2 how much total power is reflector to earth?

Gran Telescopio Canarias (10.4 m)



Gran Telescopio
©Pachango,
CC BY-NC-SA 2.0

Hale Telescope (5.1 m)



Hale Telescope
©Matthew Hunt,
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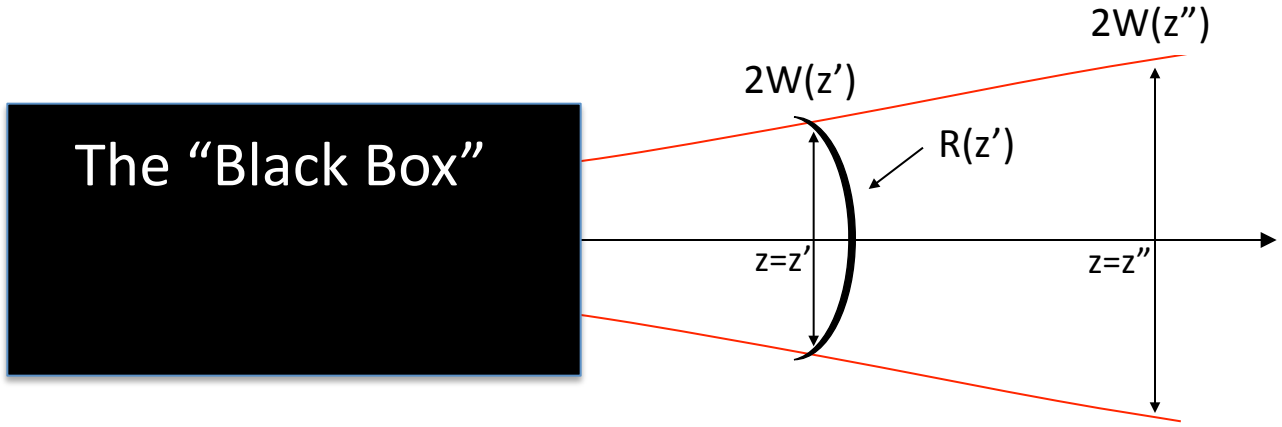
Hooker Telescope (2.5 m)



Hooker Telescope
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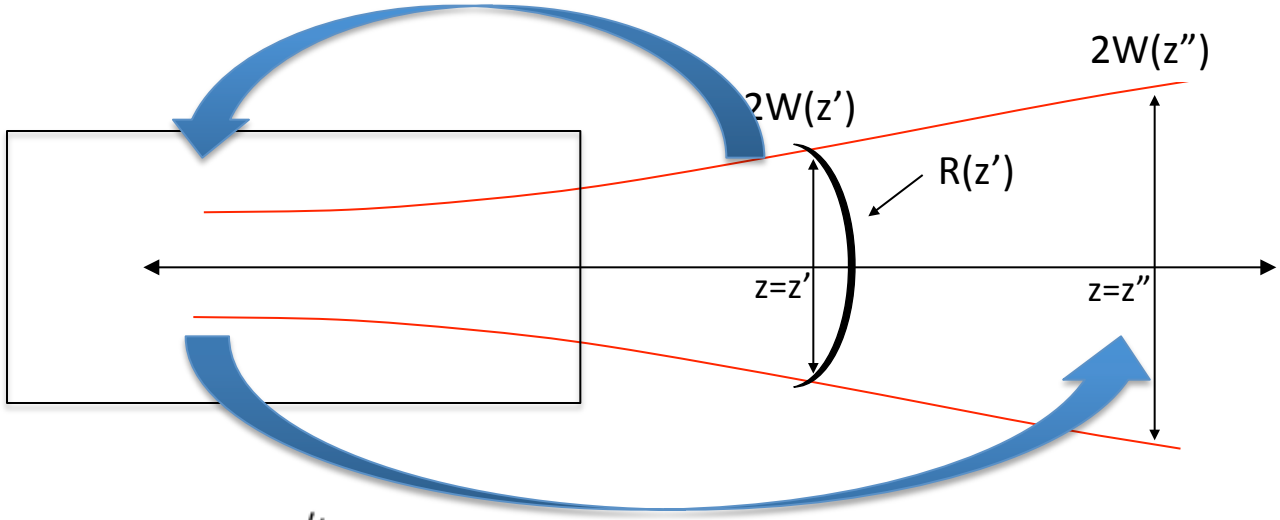
PHYS 408 Group Activities for Feb 3 2011

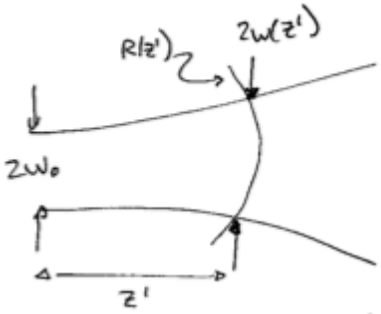
Please complete these exercises without opening the textbook. If you have questions talk with your group mates or raise your hand and Kirk or Ellen will come to help



A laser located somewhere in a black box shines a beam out. Say you have measured the beam width W(z') and radius R(z') at z=z' (note that you don't know what z' is).

5-Write a step by step recipe for your lab partner to calculate the (new) beam diameter at z=z". I'm looking for a qualitative recipe here.





$$\begin{cases} w(z') = w_0\left[1 + \left(\frac{z'}{z_0}\right)^2\right]^{1/2} & (1) \\ R(z') = z'\left[1 + \left(\frac{z_0}{z'}\right)^2\right] & (2) \end{cases}$$

Two equations, 2 unknowns [z' & w_0 or z_0]

1.) Plan is to calculate $2w_0$ & z'

$2w_0$ → minimum waist; z' → location of

2-) Calculate $w(z'')$ via (1)

do it by inverting (1) & (2)

$$\Rightarrow \quad z' = \frac{R(z')}{1 + \left[\frac{\lambda R(z')}{\pi w(z')^2}\right]^2} \qquad w_0 = \frac{w(z')}{\left[1 + \left[\frac{\pi w(z')^2}{\lambda R(z')}\right]^2\right]^{1/2}}$$

given $R(z')$ & $w(z')$ find w_0 & its location z'

So to keep track of beam we need to keep track of W(z) and R(z) and to use

$$R(z) = z(1 + z_o^2/z^2)$$

$$W(z) = W_o\sqrt{1 + z^2/z_o^2}$$

$$W_o = \sqrt{\lambda z_o/\pi}$$

to use these eqns we must first find z_o and location of minimum waist…loads of algebra, but there is an easier way…using the "q parameter.

How did we get here?

$$E(x,y,z) = \frac{A}{z} e^{ik(\frac{x^2+y^2}{2z})} \xrightarrow{z \to z - iz_o} E(x,y,z) = \frac{A}{z - iz_o} e^{ik(\frac{x^2+y^2}{2(z-iz_o)})}$$

$$U(x,y,z) = \frac{A_o}{\sqrt{(z^2 + z_o^2)}} e^{i \tan^{-1}(z/z_o)} e^{ik\left(\frac{x^2+y^2}{2z(1+z_o^2/z^2)}\right)} e^{-\left(\frac{x^2+y^2}{\lambda/\pi(z^2/z_o+z_o)}\right)} e^{ikz}$$

$$U(x,y,z) = \frac{A_o}{\sqrt{(z^2 + z_o^2)}} e^{i \tan^{-1}(z/z_o)} e^{ik\left(\frac{x^2+y^2}{2R(z)}\right)} e^{-\left(\frac{x^2+y^2}{W^2(z)}\right)} e^{ikz}$$

We keep track of the beam via R(z) and W(z)…consider $q(z) = z - iz_o$

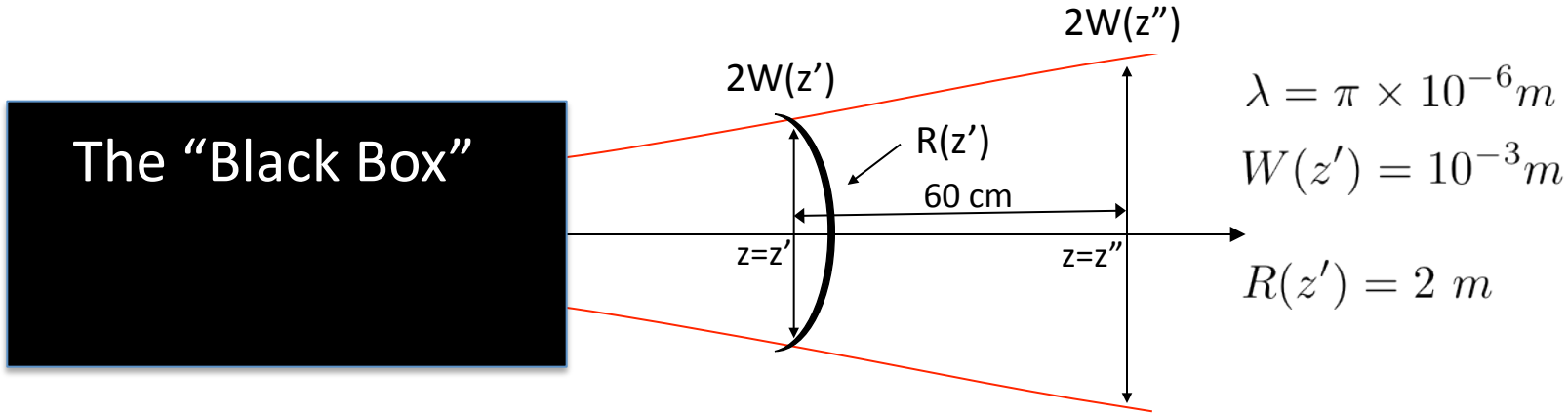
$$U(x,y,z) = \frac{A}{q(z)} e^{ik\left(\frac{x^2+y^2}{2q(z)}\right)} e^{ikz}$$

6- Express q(z) in terms of R(z) and W(z)

7- How many free parameters are in the q(z)? What are they and explain how it is enough to fully describe a Gaussian beam at any location

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A laser located somewhere in a black box shines a beam out. Say you have measured the beam width W(z') and radius R(z') at z=z' (note that you don't know what z' is).

8-Using the q(z), find the location of the minimum waist (z')

9-Using the q(z), find the beam width 60 cm away [W(z")]