# Brightness vs. Distance

"The Inverse Square Law"

# The Factors that affect Brightness

- The power of the source
- The distance from the source
- The intervening medium

# The POWER of the source

- Definition: the total amount of <u>energy emitted by the source per second.</u>

- For a star this is called “LUMINOSITY”.

- The unit of Energy:  JOULE.

- The unit of Power:  WATT = 1 joule/sec

# Power of Light Bulbs

Some confusion here….

Example: A 40 watt light bulb consumes 40 watts of electrical power, but most of this energy goes into HEAT energy.

The remaining energy is converted to light. The unit used for light in this case is the “lumen”.

A 40 watt bulb emits about 505 lumens of light.

# The “intervening medium”

- Inside:  No major issue when we’re using light bulbs….unless we’ve just burned something in the oven and the room’s full of smoke!

- We can usually assume that the air acts pretty much like a vacuum with little absorption of light

# The Atmospheric medium

- Outside measuring the sun or the stars: Many possible conditions --clouds, fog, water vapor, air pollution, smoke. All absorb or scatter light which decreases the amount that comes through.

- Also, sunlight and starlight reflect off the "top" of the atmosphere and never reach the Earth. For the sun this may be as much as 25%.

# Brightness

- Definition for a STAR: the amount of energy that lands on a square meter of Earth every second.

- Unit: watts/square meter (W/$m^2$)

- Similar for a light bulb: The unit is lumen/sq. meter which is called a LUX

# Converting Lux to $W/m^2$

- There is no simple conversion….it depends on the wavelength or color of the light.

- However, for the SUN, there is an approximate conversion of 0.0079 $W/m^2$ per Lux.

- Example: We read 75,000 Lux on our light sensor.  We can convert that reading to $W/m^2$.

$$75{,}000 \times 0.0079 = 590\ W/m^2$$

# Summary so far for Stars

- The LUMINOSITY of a star is the total amount of Power (Energy/sec) emitted by the star.
- Unit: WATT

- The BRIGHTNESS of a star is the amount of that Energy that lands on a square meter of Earth every second.
- Unit: $WATT/m^2$

# From the Star to the Earth

- The Energy that leaves the star spreads out uniformly in all directions.
- Imagine a sphere surrounding that star some distance from it. (Observe the example of the expanding balloon or the "Hoberman Sphere".)
- All the Energy that has left the star has to pass through that spherical surface.

# Star to Earth (2)

Suppose the sphere has a radius of r. Then the surface area of that sphere is $4\pi r^2$.

The total energy/second leaving the star is flowing through that area of $4\pi r^2$.

# Star to Earth (3)

Summarizing:

Energy/sec = power = the "Luminosity" of the star, L.

Total area of the sphere = $4\pi r^2$

So the energy flowing through each square meter of the sphere every second is

$$L/4\pi r^2$$

# Star to Earth (4)

Now extend the sphere to reach the Earth. That makes r = d (the distance to Earth from the star)

The energy landing on a square meter of the Earth is now $L/ 4\pi d^2$. We call that the star's brightness, B.

# Star to Earth (final result)

The final equation becomes:

$$B = L/4\pi d^2$$

B = Brightness of the star in <u>$w/m^2$</u>

L = Luminosity of the star in <u>watts</u>

d = distance to the star in <u>meters</u>

# The "Inverse Square Law"

The equation, $B = L/4\pi d^2$

is called the "Inverse Square Law".

Inverse: B gets smaller as d gets larger

Square: the relationship goes by $1/d^2$, not just $1/d$.

# Inv Sq Law for Lightbulbs

Same law we just change the units:

For L, luminosity, we use lumens.

For B, brightness, we use lumens/$m^2$ or lux.

For d, we still use meters.

# Basics of the Inv Sq Law

- If the distance, d, is doubled then the brightness, B, decreases by a factor of 1 divided by $2^2$ or _ the brightness.
- If d is tripled, then B decreases by a factor of 1 divided by $3^2$ or 1/9 the brightness.
- Etc.

# Sample problem

A light bulb with L = 505 lumens
What is its brightness 1 m. away?

$B = 505/4\pi(1)^2 = 40$ lux

How about 2 m. away?

$B = 505/4\pi(2)^2 = 10$ lux = _ as much!

# Forms of the Inv Sq Law

$$B = L/4\pi d^2$$

$$L = 4\pi d^2 B$$

$$d = \mathrm{sqrt}\ (L/4\pi B)$$

# More examples

- Jupiter: $L = 10^9$ watts, d = 4.2 AU, B = ?
- Saturn: $L = 4 \times 10^8$ watts, $B = 2 \times 10^{-17}$ $w/m^2$, d = ? (in AU)
- Star: $L = 2.8 \times 10^{26}$ watts, d = 2500 LY, B = ?
- Star: $B = 8.2 \times 10^{-16}$ $w/m^2$, $L = 5.6 \times 10^{30}$ watts, d = ? (LY and pc)