LIGHT VS. DISTANCE

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What is light?
Discussion # 1

* What can you learn from this movie? What are some aspects of light that are true or untrue?
What are the factors that affect brightness
What are the factors that affect brightness

- The power of the source
- The distance from the source
- The intervening medium
What is power of the source?
What is power of the source?

Definition: the total amount of energy emitted by the source per second.

For a star this is called “LUMINOSITY”.

The unit of Energy: JOULE.

The unit of Power: WATT = 1 joule/sec
Where does the power of light bulbs come from?

* 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.
What’s the “intervening medium?”

- Inside: No major issue when 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
What are some intervening factors that hinder light in the atmosphere?

* Outside measuring the sun and 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%.
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
How do we convert lux to W/m²

※ 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/m² per Lux.

※ Example: We read 75,000 Lux on our light sensor. We can convert that reading to W/m²

※ 75,000 x 0.0079 = 590 W/m²
Summary so far for Stars

- The LUMINOSITY of a star is the 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/m²
The Energy that leaves the star spread 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.
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 $4\pi r^2$. 

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Star to Earth, Part 2

Discussion

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**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 \( \frac{L}{4\pi r^2} \).
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, $B$. 
The final equation becomes:

\[ B = \frac{L}{4\pi d^2} \]

- \( B \) = Brightness of the star in \( \text{w/m}^2 \)
- \( L \) = Luminosity of the star in watts
- \( d \) = distance to the star in meters
What is this equation called?
What is this equation called?

- $B = \frac{L}{4\pi d^2}$ is called the “Inverse Square Law”.
- Inverse: $B$ gets smaller as $d$ gets larger
- Square: the relationship goes by $1/d^2$, not just $1/d$. 
Let’s see this in action in an experiment...
Exploration of Inv. Square Law...
Exploration of Inv. Square Law...
Exploration of Inv. Square Law...
Inv. Square Law Problems

☆ What would happen if the distance, d, is doubled?

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

☆ How about 2m away?
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)
Inverse Square Law

The brightness of an object varies inversely as the square of the distance. This is a geometric consequence of the fact that light moves outward in a spherical fashion.

\[ \text{brightness} \propto \frac{1}{\text{distance}^2} \]

Example: What is the apparent brightness of the Sun as seen from Jupiter?

\[ \frac{b_{\text{Jupiter}}}{b_{\text{Earth}}} = \frac{D_{\text{Earth}}^2}{D_{\text{Jupiter}}^2} = \frac{1^2}{5^2} = \frac{1}{25} \]
Results

What does this graph reveal? What are some experimental errors you have encountered?
Gamma Ray Bursts!

* With measuring light intensity we can measure such phenomenon as gamma ray bursts!
The “Gamma ray” song

We know that gamma ray explosions happen randomly all over the sky

(It's like a lottery: a ticket for each square degree)

You see a FLASH! and then there's not another till about a day has gone by

(But that depends upon detector sensitivity)

In just a moment they spew energy worth (That's pretty fast)
A value we can't even fathom on Earth (It's really vast!)
But just what's giving rise to gamma ray sparked skies?
Is it the death cry of a massive star or black hole birth?
(Or both, or both? or both!)

Chorus:
Swiftly swirling, gravity twirling
Neutron Stars about to collide
Off in a galaxy so far away
Catastrophic interplay
A roller coaster gamma ray ride
Superbright explosion then
Never to repeat again
How are we supposed to know?
How about a telescope rotation
Swiftly onto the location
Of its panchromatic afterglow?

In just a moment gamma ray bursts reach a peak and swiftly fade from view

(It's like a beacon shining clear across the Universe)
But they leave embers in the longer wavelengths fading for a day or two

(It's exponential -- it decays forever)
To solve this space age mystery is why (We wanna know)
We want to catch a thousand bursts on the fly (What makes 'em go?)
Their X-ray light disperse unlock the Universe
Measure their distance from their redshift mark their spot on the sky
(They're where? They're here! They're there! They're everywhere!)

(Chorus)
Swiftly swirling, gravity twirling
Neutron stars about to collide
Off in a galaxy so far away
Catastrophic interplay
A roller coaster gamma ray ride
Superbright explosion then
Never to repeat again
How are we supposed to know?
Swift is the satellite that swings
Onto those brightly bursting things
To grab the multiwavelength answer to what makes them glow

It's like a lottery - a ticket for each square degree
It's like a beacon shining clear across the Universe
Swift is the satellite that swiftly swings all over the sky
Swift is designed to catch a burst of gamma rays on the fly
What are some questions we can further ask?
Let’s play a game!