Where was this picture taken?

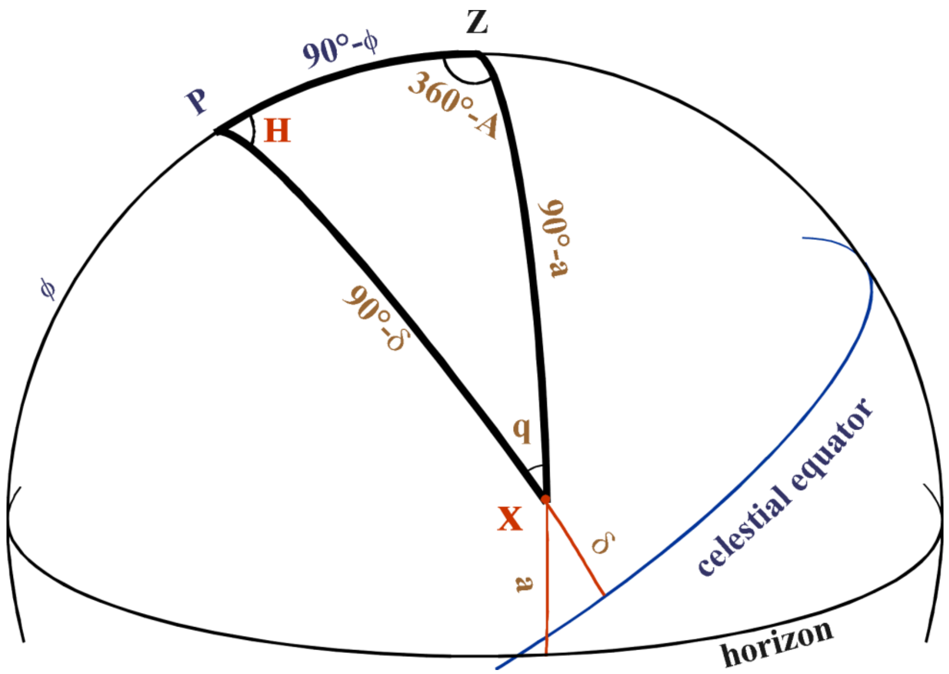
Exposure time = ?

Where's north?

- **Remember to turn in your Doodle sheets at the end of each class!**
- **Install “Stellarium” ?**
- **21” telescope this afternoon (4 pm?)**
  - **Bring the RA and DEC of a favorite object, like your “Star Name”**
- **Today: Coordinate review and “light”**
- **Observe the Moon this week after sunset:**
  - **Brightness, phase, “Earthshine”**

Can you identify the angles shown below?

“spherical trigonometry”



Spherical Trigonometry

To convert from equatorial to horizontal coordinates:

Given RA α and declination δ, we have

Local Hour Angle H = LST - RA, in hours;

convert H to degrees (multiply by 15).

Given H and δ, we require azimuth A and altitude a.

By the cosine rule:

$\cos(90-a) = \cos(90-\delta)\cos(90-\varphi) + \sin(90-\delta)\sin(90^\circ-\varphi)\cos(H)$

which simplifies to:

$\mathbf{\sin(a) = \sin(\delta)\sin(\varphi) + \cos(\delta)\cos(\varphi)\cos(H)}$

This gives us the altitude a.

By the sine rule:

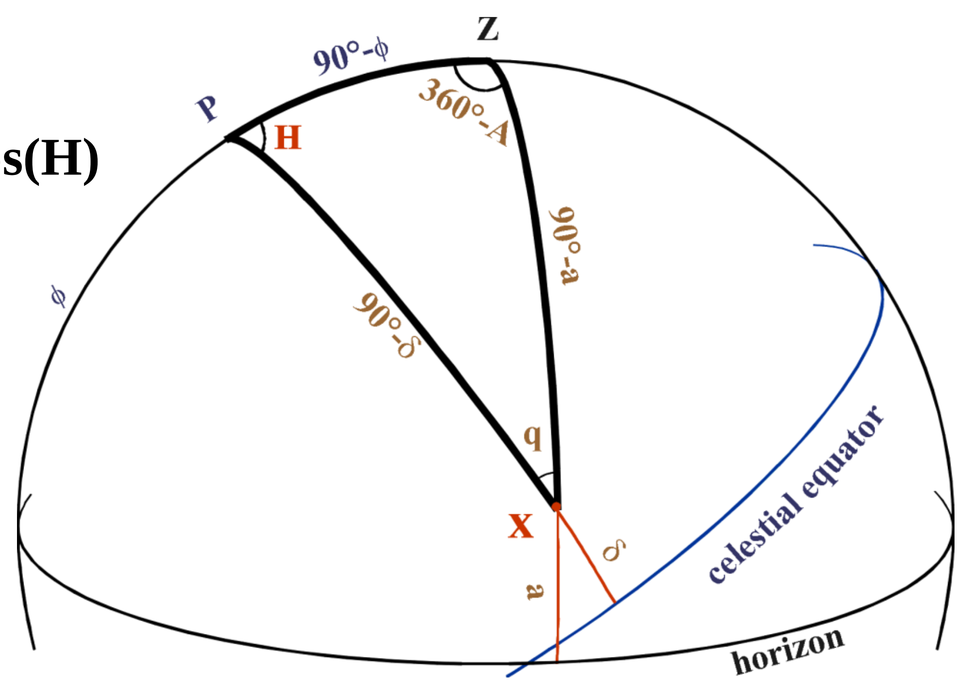
$\sin(360-A)/\sin(90-\delta) = \sin(H)/\sin(90-a)$

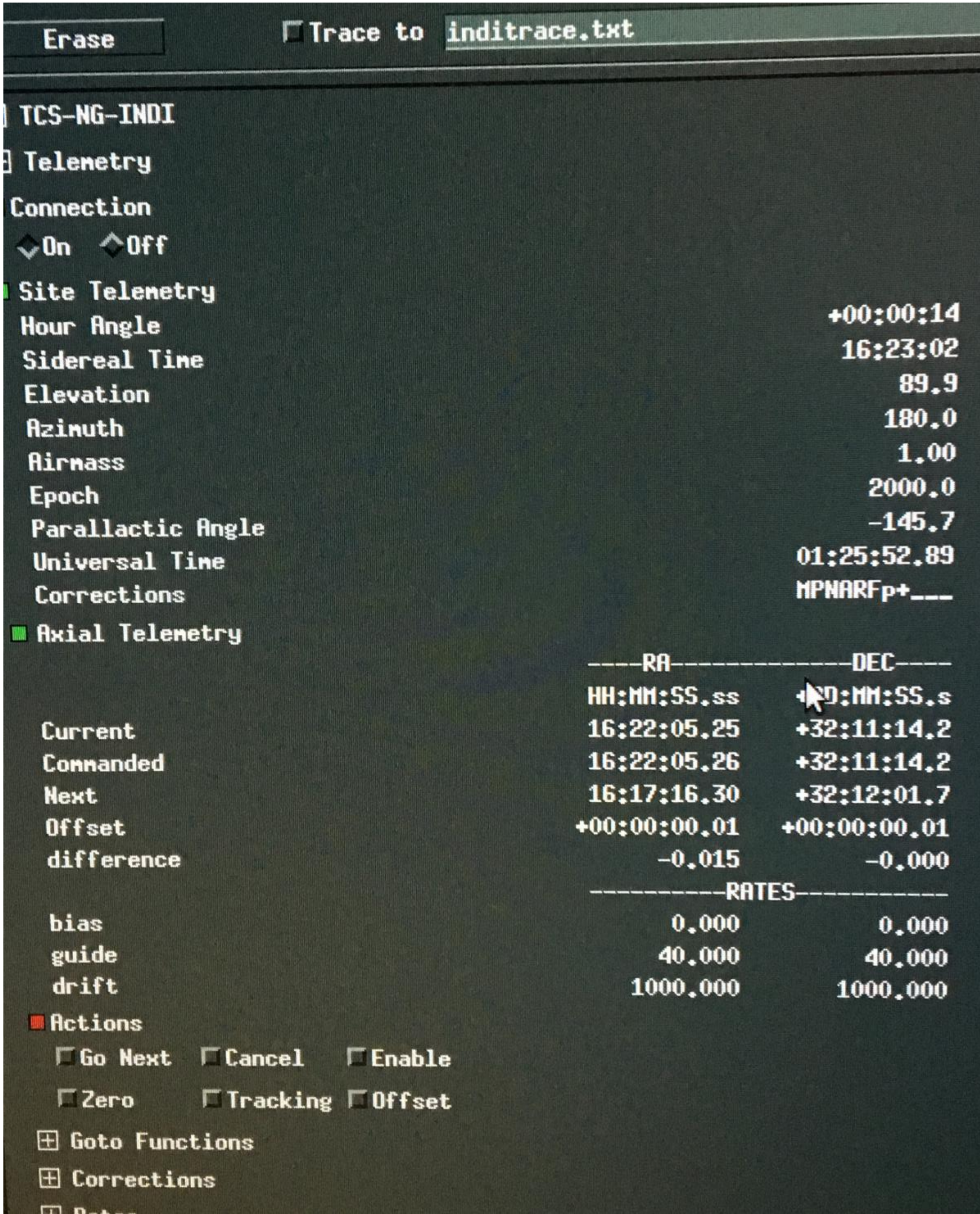
which simplifies to:

$-\sin(A)/\cos(\delta) = \sin(H)/\cos(a)$

i.e. $\mathbf{\sin(A) = -\sin(H)\cos(\delta)/\cos(a)}$

which gives us the azimuth A.





Where is the telescope pointed now?

Small angular corrections are applied

Could you observe this object tonight?

Pretend you are planning to observe at the MMT Observatory tonight and wish to study "Campbell's Hydrogen Star":

$$\alpha = 19^h{:}34^m{:}45^s \qquad \delta = +30^o{:}30'{:}59''$$

The Local Sidereal Time (LST) at midnight will be 8:04:32

The Sun sets at 5:53 pm and rises at 7:19 am.

Could you observe this object within an hour angle of $\pm 2^h$ and hence over a relatively low air mass?

Problem

Friday's optional homework problem

On 17 August 2017, 12:41:04 UT (i.e., Universal Time), the gravitational-wave observatory, LIGO, detected an event (aka, GW170817) from a pair of merging neutron stars. The estimated location had coordinates of (RA: 13:09:48.08; DEC: -23:22:53.3). Quickly, an electronic alert message was sent around the world, encouraging astronomers at observatories around the world to record the event across the spectrum of light. This event provided an opportunity for "multi-messenger" astrophysics.

In Greenwich, the Local Sidereal Time (LST) was 10.35 hours. The 1-meter Swope Telescope in Chile (longitude: 70:42:05.9 W; latitude: -29:00:35.85) was the first facility to observe the object. At the time of the event, what was the object's Hour Angle at the Swope Observatory; in other words, could Swope astronomers have observed the event immediately or did they need to wait some amount of time for the object to rise in their sky? [NOTE that Right Ascension increases towards the east.]

Do you understand the problem?
What do we know?

When: 17 August 2017 at 12:41:04 UT
Where: RA: 13:09:48.08; DEC: -23:22:53.3

In Greenwich, the Local Sidereal Time (LST) was 10.35 hours.

The 1-meter Swope Telescope in Chile:

- **longitude:** 70:42:05.9 W
- **latitude:** -29:00:35.85

At the time of the event, what was the object's Hour Angle at the Swope Observatory?

Solution

- Longitude: 70:42:05.9 W = 70.70 deg

- 70.70 deg / 15 deg per hour = 4.71 hours
- 4.71 hours earlier than Greenwich

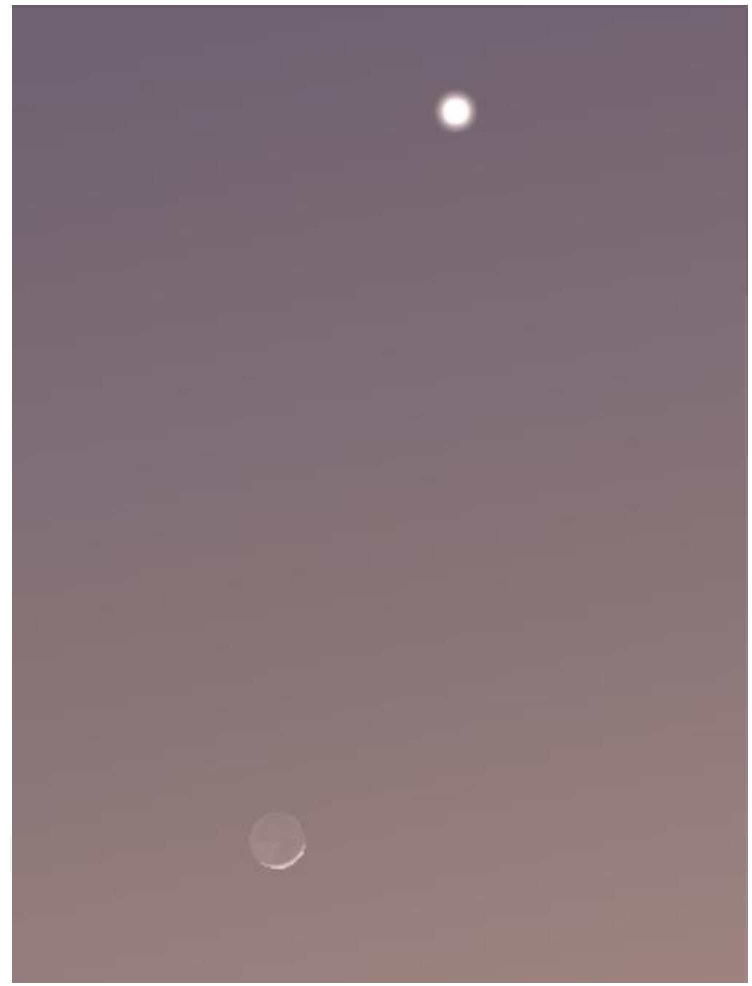
- LST at Greenwich was 10.35 hours at midnight
- At Swope, LST then was 10.35 – 4.71 = 6.54 hours
- So an RA of 6:32:24 was transiting

- Object's RA = 13:09:48.08
- So HA (east) = 6:37:24.08 = 6.62 hours
- So object had not yet risen above Chilean horizon

Tonight's Moon with Venus

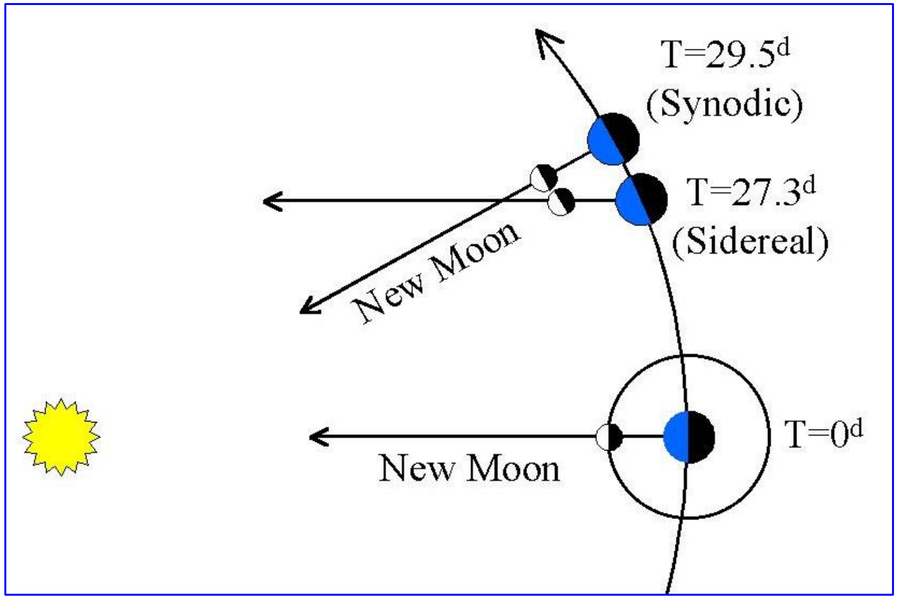
"Earthshine"

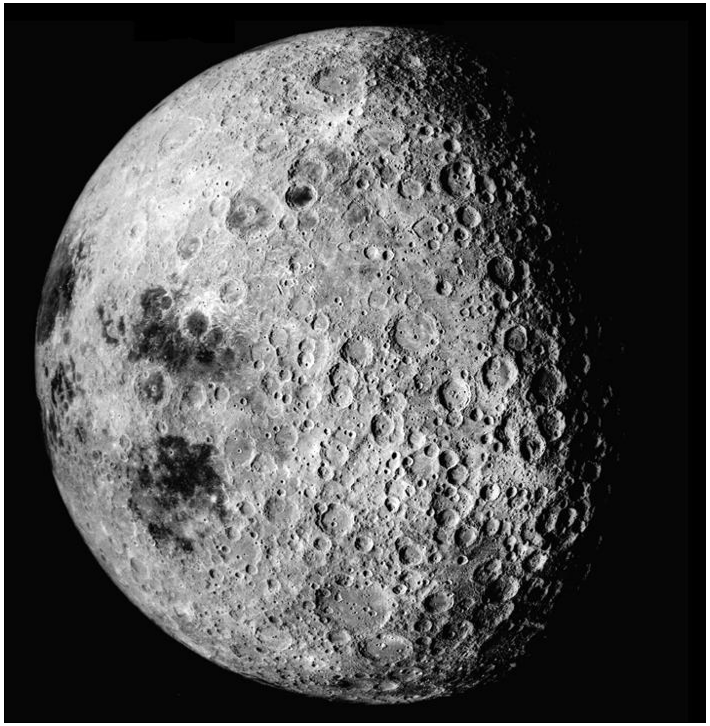
watch throughout this week



What does it mean to "revolve"?
How long are a "month, year"?

- **Synodic period = 29.53 days**
- **Sidereal period = 27.32 days**





You should be able to derive this relationship:
textbook: pp. 17-18

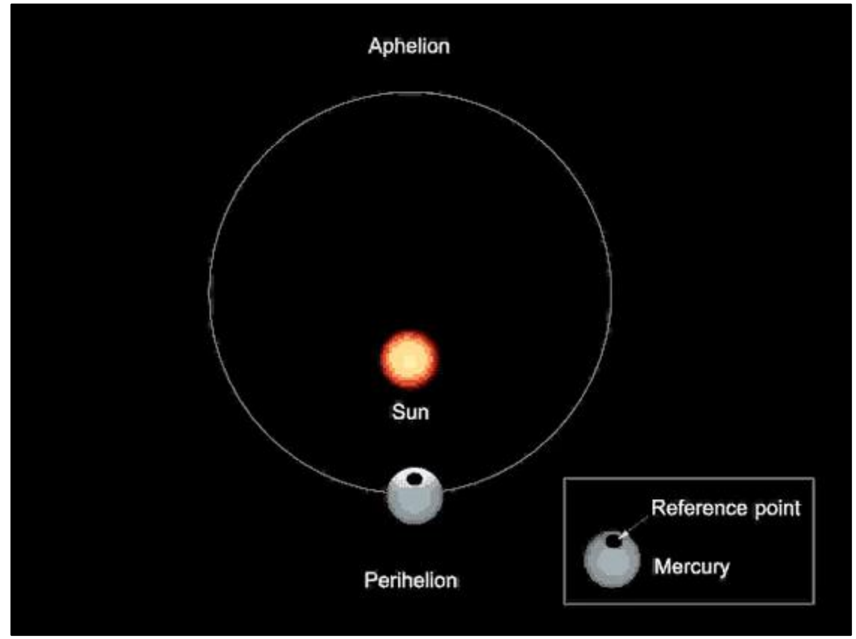
Mercury: Solar vs. Sidereal Day

How long is a "day" on Mercury?

Mercury rotates on its axis exactly 1.5 times for each revolution around the Sun.

Revolution period
87.969 days

Rotation period
58.646 days



Mercury rotates exactly 3 times during two orbits around Sun.

RATIO = 87.97/58.65 = 3:2
["3:2 spin-orbit resonance"]

Maxwell Year 2006
Celebrating the Man who Changed Everything!

James Clerk Maxwell
1873

He described mathematically the relationship between electrical and magnetic fields.

Maxwell's Equations predicted:
electromagnetic waves
(a spectrum of them)

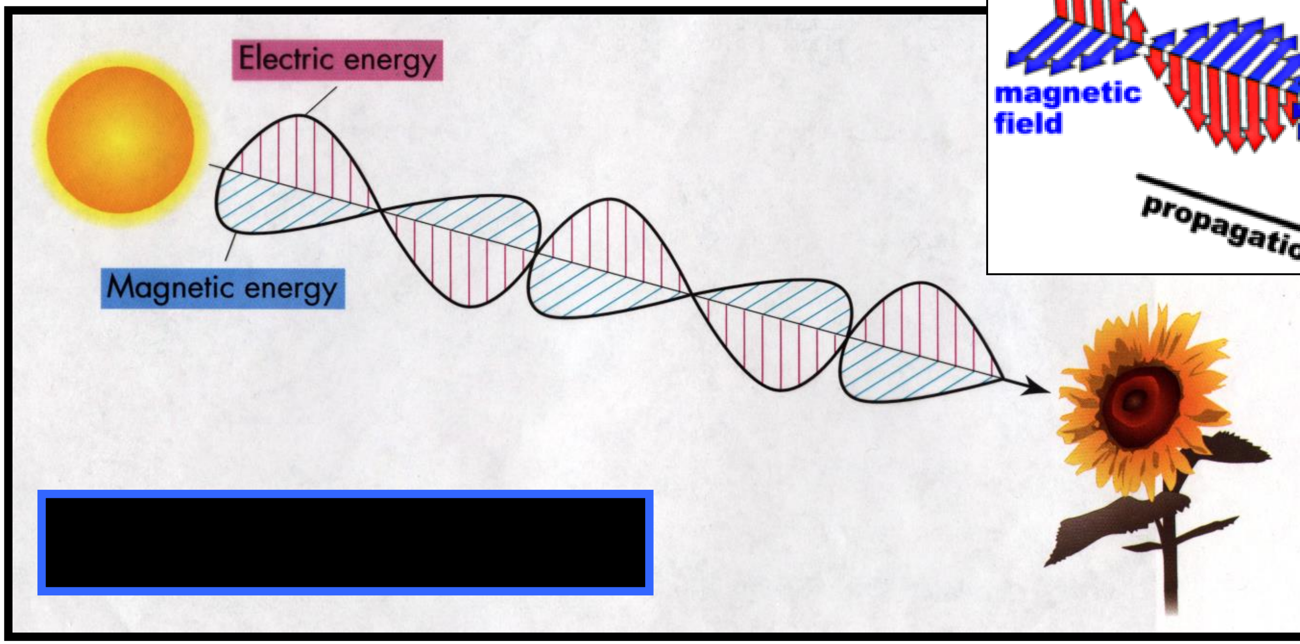
The speed of these waves = c.
These waves (light) carry energy.

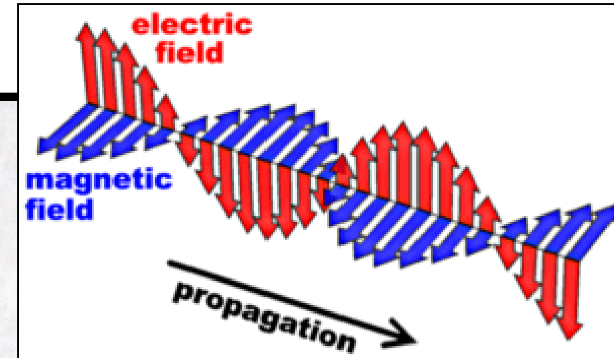
He "unified" electricity, magnetism, and light.

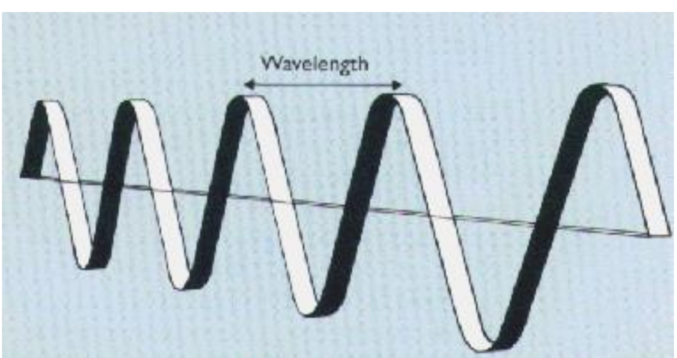
"electromagnetic" waves
electromagnetic fields

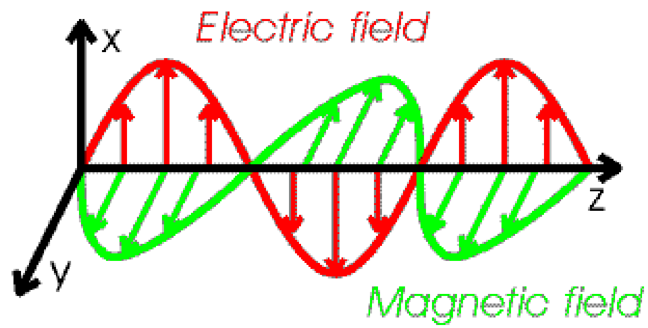
$$
\begin{aligned}
\nabla \cdot \vec{E} &= \frac{\rho}{\epsilon_0} \\
\nabla \cdot \vec{B} &= 0 \\
\nabla \times \vec{E} &= -\frac{\partial \vec{B}}{\partial t} \\
\nabla \times \vec{B} &= \frac{\vec{j}}{\epsilon_0 c^2} + \frac{1}{c^2}\frac{\partial \vec{E}}{\partial t}
\end{aligned}
$$

Electromagnetic Vibrations





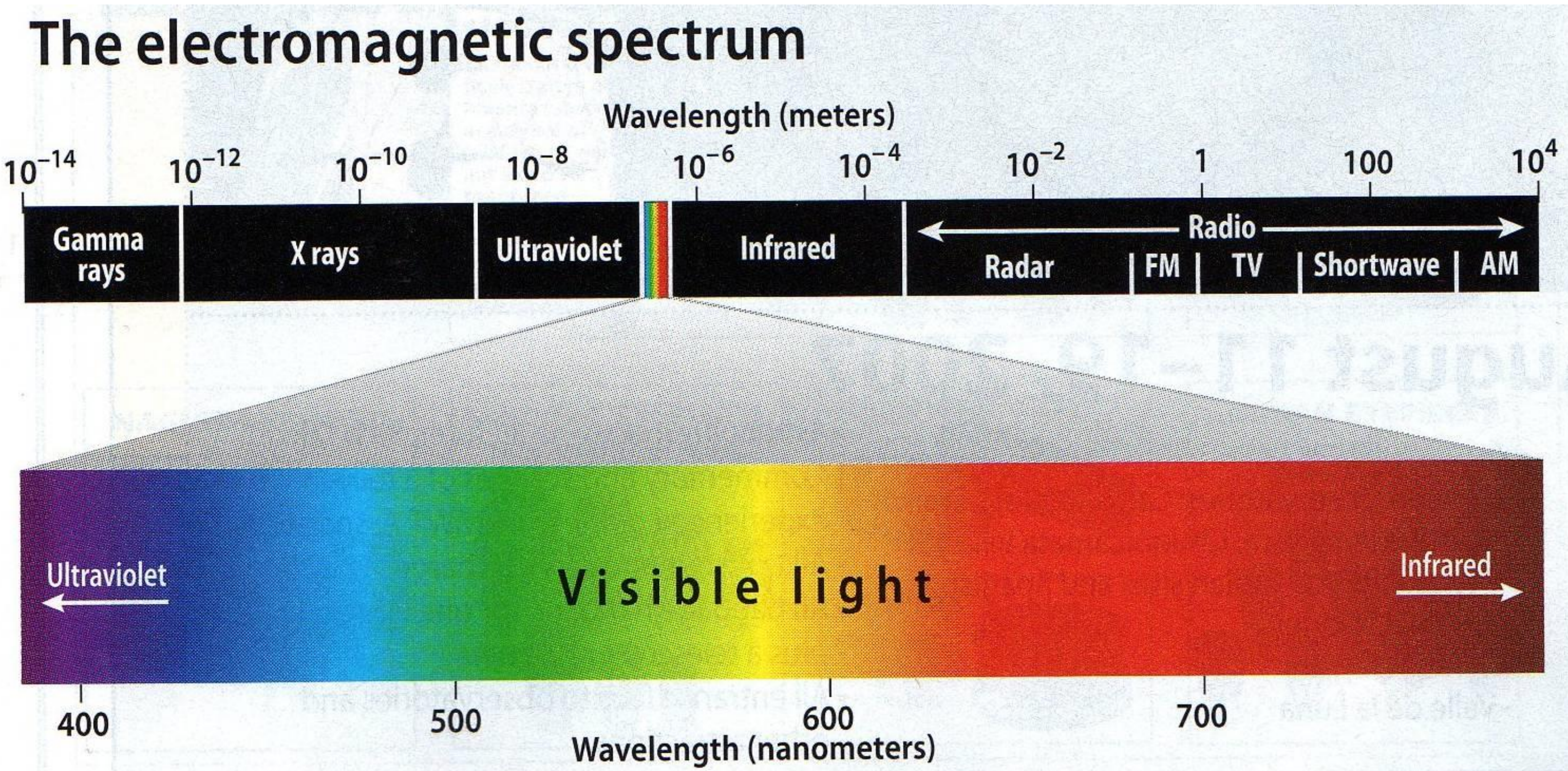




Maxwell's Equations Predicted a Speed (c)

- c = speed
  - 3×10^5 km/sec   or   186,000 miles/sec
- But speed relative to what?
- Scientists thought the speed would be measured with respect to a "medium" like water or air
  - called it "aether"
    - They predicted it must have unique properties:
      - stiff to be consistent with high speed of light
      - tenuous because Earth and planets would move through it
- This "aether" would be an absolute reference.

Maxwell’s Equations <u>Predicted</u> a “Spectrum” of Light



VISIBLE LIGHT contains a rainbow of colors. Green light falls near the middle of the spectrum. At this wavelength, your eyes see white instead of green. *ASTRONOMY*: ROEN KELLY

Describing Light
speed, wavelength, frequency
$c = \lambda \times \nu$

Speed (c) = **Wavelength (λ)** × **Frequency (ν)**

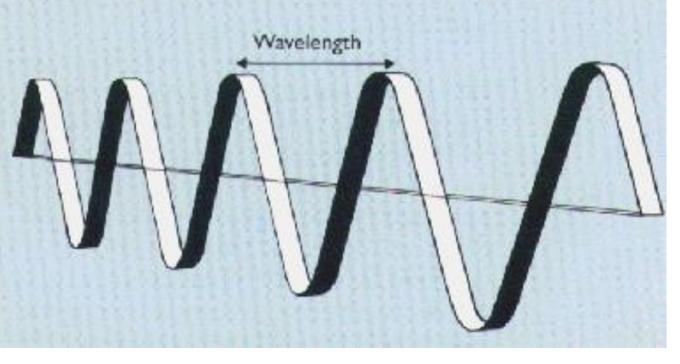
3×10^8 m/sec

The distance between two successive peaks.

Units:
Angstrom (Å = 0.1 nm)
nanometer (nm)
meter (m)
kilometer (km)

The number of wave peaks arriving each second.

Units:
Hertz (Hz = cycles/second)



Arizona Daily Star

front page news (Sep 14, 2016)

terahertz frequencies

New device can read pages of a book without opening it, find hidden images

By Michael Casey
THE ASSOCIATED PRESS

Leave it to the great minds at MIT and Georgia Tech to figure out a way to read the pages of a book without actually opening it.

A team of researchers from the two institutions pulled it off with a system that looks like a cross between a camera and a microscope.

They said it could someday be used by museums to scan the contents of old books too fragile to handle or to examine paintings to confirm their authenticity or understand the artist's creative process.

Writing in the latest issue of the journal Nature Communications, the scientists explained how they used terahertz waves — a type of radiation situated on the electromagnetic spectrum between microwaves and infrared light — to read a stack of papers with a single letter handwritten on each page.

The device, called a terahertz spectrometer, managed to clearly read only nine pages, though it could see writing on up to 20.

"We were very excited because we didn't think we would be able to see as deep as we did," said Barmak Heshmat, a research scientist at the MIT Media Lab.

While the device is still a long way from reading an entire book, Heshmat said the team is already talking with the Metropolitan Museum of Art in New York about using it to inspect some of its artworks and antique volumes. The museum did not immediately respond to a request for comment.

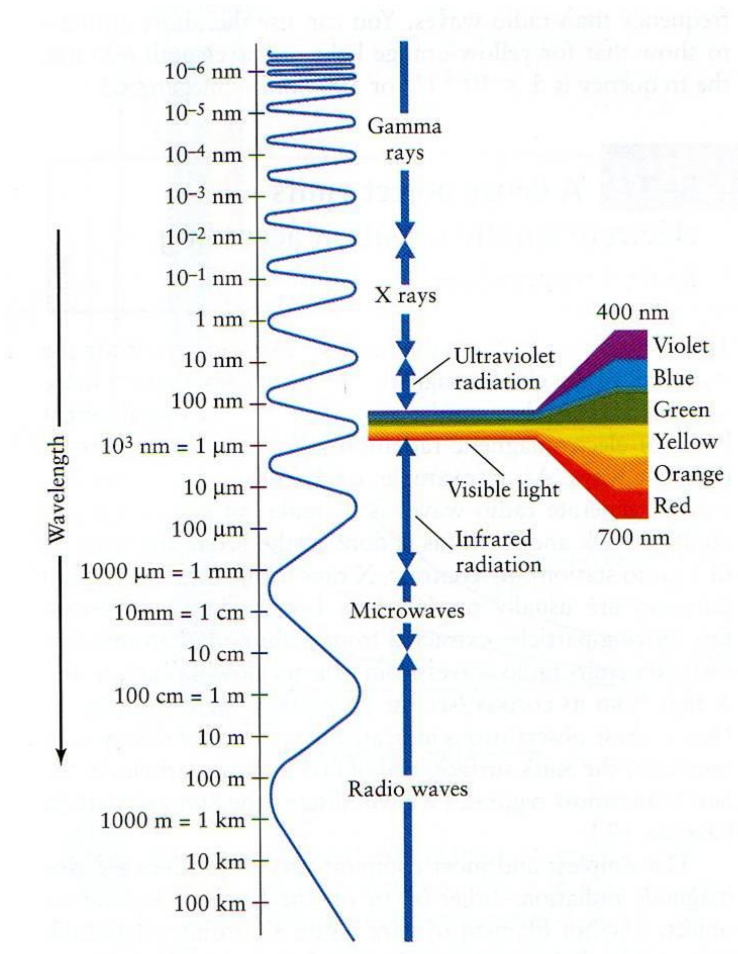
He said it could also be used in industry — for example, to see whether there are cracks or other defects beneath the paint on an

See TERAHERTZ, A4

wavelength = ?

$$\lambda = (3\text{x}10^{8}\ \text{m/sec}) / 10^{12}\ \text{cycles/sec} = 3 \times 10^{-4}\ \text{m} = 0.3\ \text{mm}$$

How many times longer is a wavelength of radio light (500 m) compared to a wavelength of blue light (500 nm)?

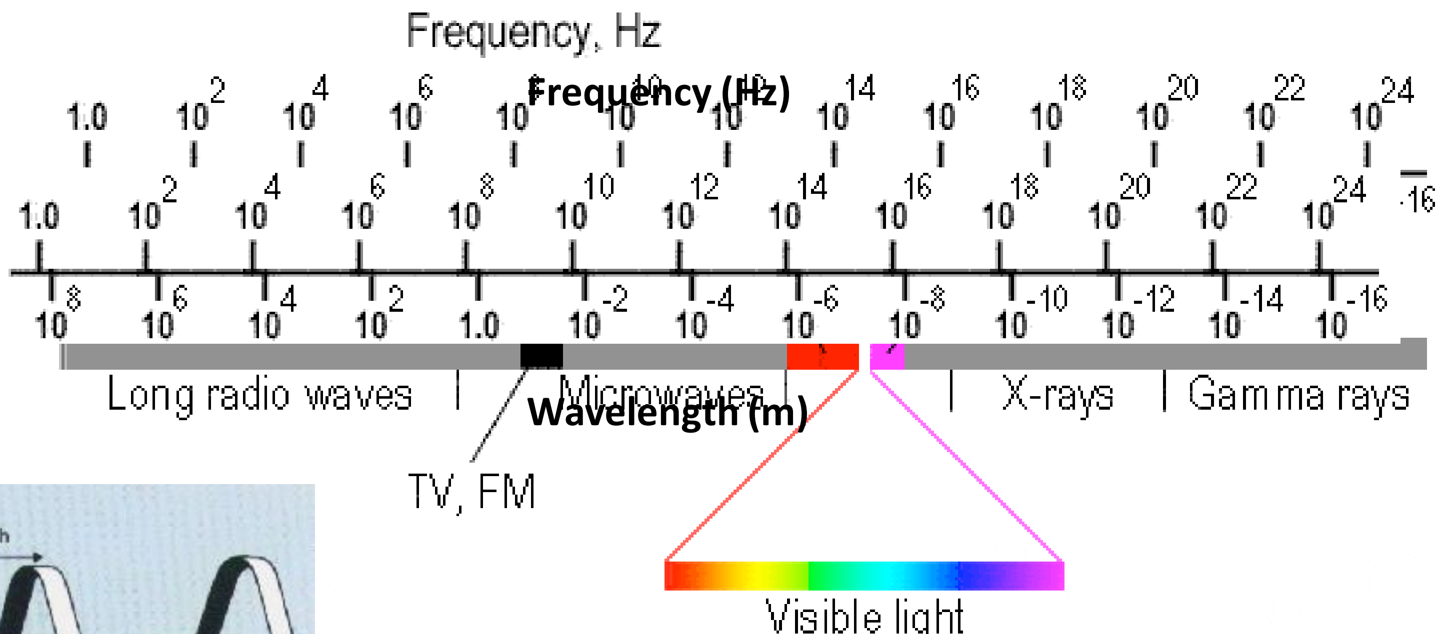


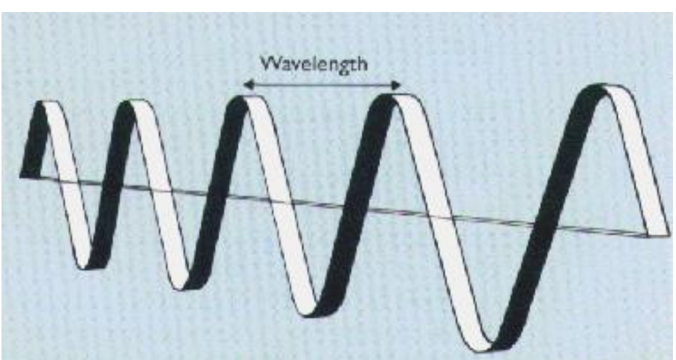
A. 500x
B. 1 billion times longer
C. 1 million times longer
D. 10^9x shorter

Work together!

λ= wavelength (meters)
ν = frequency (waves/sec = Hz)
c = speed of light (meters/sec)

$c = \lambda \times \nu$





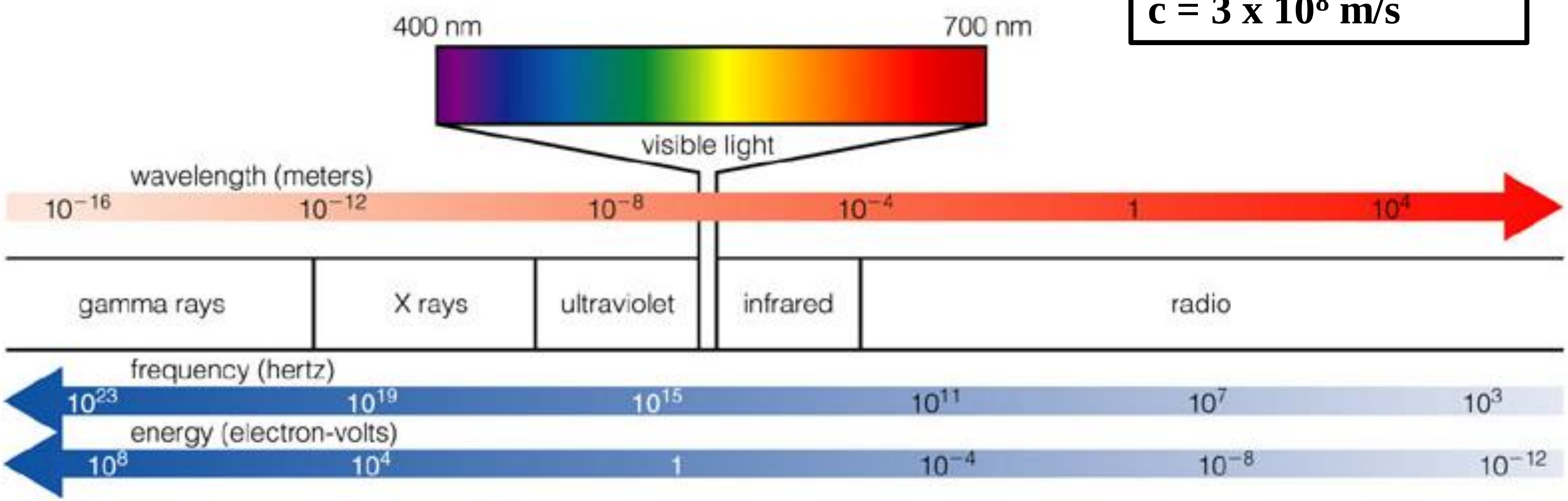
Describing Light

a traveling vibration of pure energy

$$E = hc/\lambda = h\nu$$

Energy (E)	=	**Constant**	÷	**Wavelength (λ)**
Energy (E)	=	**h = Planck's constant**	×	**Frequency (ν)**
		c = speed of light		

h = 6.626 x 10^{-34} J s
c = 3 x 10^{8} m/s



Interactive Problems about Light

$E = h\nu = hc/\lambda$

1. **Assume that all the energy from a 100 Watt light bulb is associated with photons of λ = 600 nm. How many photons per second are emitted by the bulb?**
   a. 1 Watt = 1 Joule/sec = 1 kg m^2 /sec^3
   b. h = 6.6 x 10^{-34} kg m^2 /sec

2. **A common unit of energy is the electron-volt (ev) = 1.6 x 10^{-19} Joules. One ev is the energy equal to the work done on an electron in accelerating it through a potential difference of one volt. Express the energy of the 21 cm line of the hydrogen atom in units of electron-volts.**

$$\# \text{photons} = \frac{100 \text{ Watts}}{hc/\lambda}$$

$$= \frac{100 \left(\frac{\text{Kg m}^2}{\text{sec}^3}\right)}{\left(6.6 \times 10^{-34} \frac{\text{Kg m}^2}{\text{sec}}\right)\left(3 \times 10^8 \frac{\text{m}}{\text{sec}}\right)} \times \left(6 \times 10^{-7} \text{m}\right)$$

$$= \frac{(6) 10^{-5}}{(6.6)(3) \times 10^{-26}} \quad \text{per sec}$$

$$= 3.0 \times 10^{20} \text{ photons/sec}$$

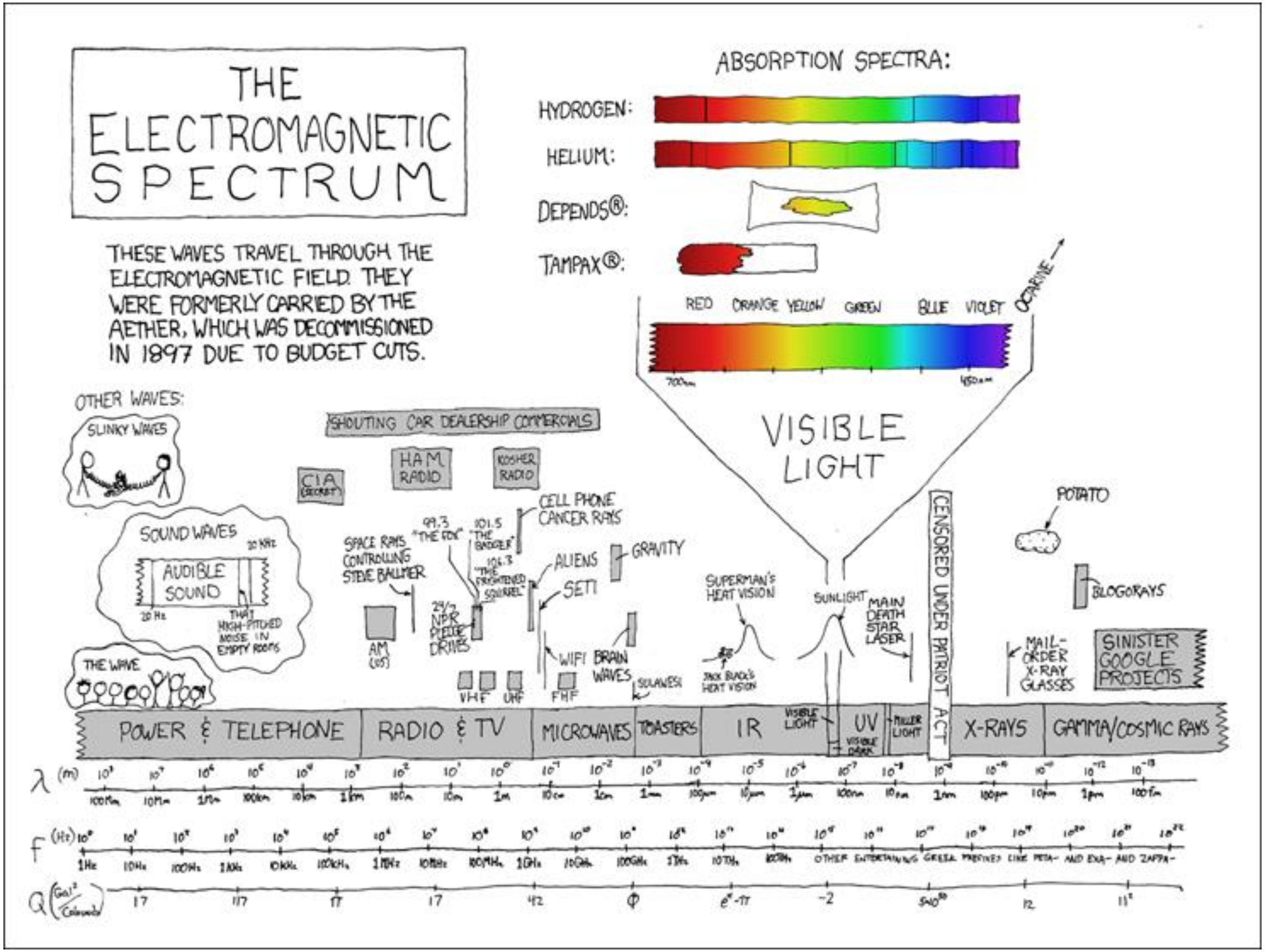
$\lambda = 21\,cm$

$$E = \frac{hc}{\lambda} = \frac{\left(6.6\times10^{-34}\,\frac{kg\,m^2}{sec}\right)\left(3\times10^{8}\,\frac{m}{sec}\right)}{2.1\times10^{-1}\,m}$$

$$E = \frac{(6.6)(3)}{2.1}\times10^{-25}\,\frac{kg\,m^2}{sec^2} =$$

$$E = \frac{9.4\times10^{-25}\,joule}{1.6\times10^{-19}\,joule/ev}$$

$$E = 5.9\times10^{-6}\,ev$$


THE ELECTROMAGNETIC SPECTRUM
THESE WAVES TRAVEL THROUGH THE ELECTROMAGNETIC FIELD. THEY WERE FORMERLY CARRIED BY THE AETHER, WHICH WAS DECOMMISSIONED IN 1897 DUE TO BUDGET CUTS.
ABSORPTION SPECTRA:
HYDROGEN:
HELIUM:
DEPENDS®:
TAMPAX®:
RED
ORANGE
YELLOW
GREEN
BLUE
VIOLET
OCTARINE
700nm
450nm
VISIBLE LIGHT
OTHER WAVES:
SLINKY WAVES
SOUND WAVES
AUDIBLE SOUND
20 KHz
20 Hz
THAT HIGH-PITCHED NOISE IN EMPTY ROOMS
THE WAVE
SHOUTING CAR DEALERSHIP COMMERCIALS
CIA (SECRET)
HAM RADIO
KOSHER RADIO
SPACE RAYS CONTROLLING STEVE BALLMER
99.3 "THE FOX"
101.5 "THE BADGER"
106.3 "THE FRIGHTENED SQUIRREL"
24/7 NPR PLEDGE DRIVES
CELL PHONE CANCER RAYS
ALIENS
SETI
GRAVITY
AM (US)
VHF
UHF
FHF
WIFI
BRAIN WAVES
SOLAWESI
SUPERMAN'S HEAT VISION
JACK BLACK'S HEAT VISION
SUNLIGHT
MAIN DEATH STAR LASER
CENSORED UNDER PATRIOT ACT
POTATO
BLOGORAYS
MAIL-ORDER X-RAY GLASSES
SINISTER GOOGLE PROJECTS
POWER & TELEPHONE
RADIO & TV
MICROWAVES
TOASTERS
IR
VISIBLE LIGHT
VISIBLE DARK
UV
MILLER LIGHT
X-RAYS
GAMMA/COSMIC RAYS
λ (m)
f (Hz)
OTHER ENTERTAINING GREEK PREFIXES LIKE PETA- AND EXA- AND ZAPPA-
Q (Gal²/Colorado)

Inverse-square law example

What do you see happening in this picture?

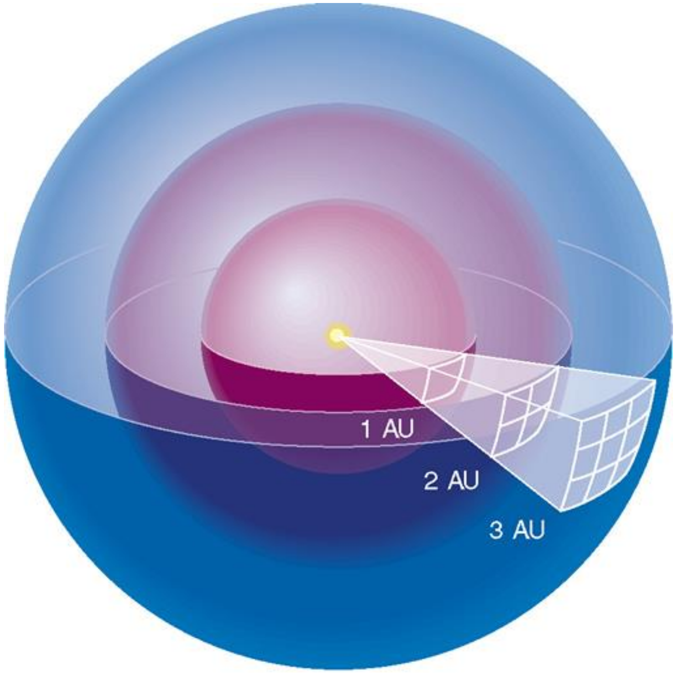
The bulb emits light in all directions. Its light carries energy.

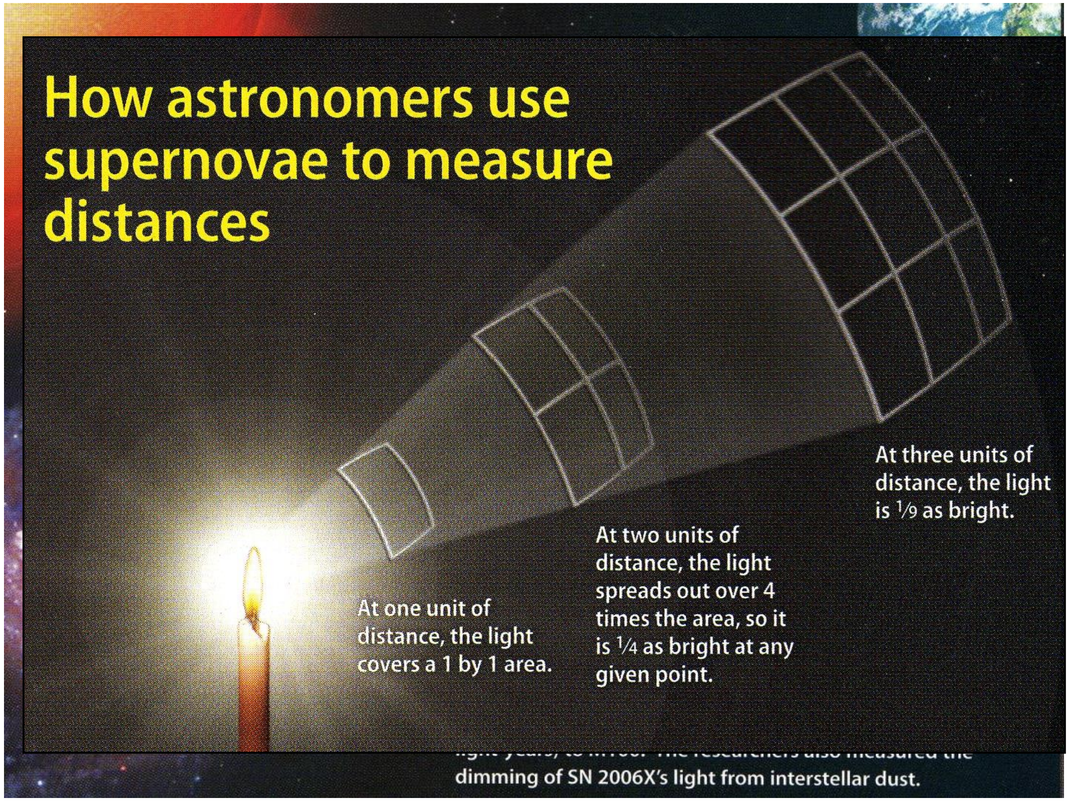
200 Watts is a certain amount of energy per second.

How determine the total energy hitting a person's face in an hour?

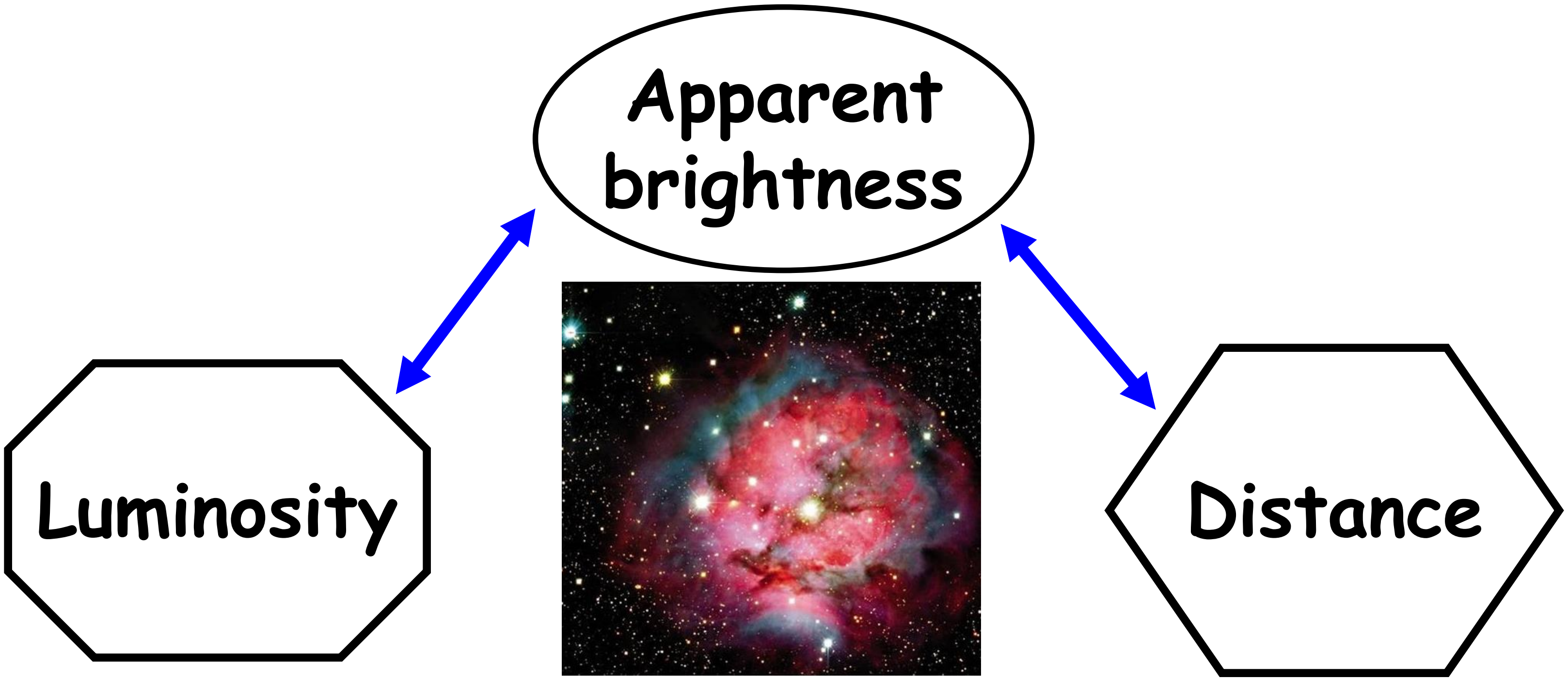
The "Inverse-Square Law" of Light

Light expands spherically away from its source.
Brightness decreases as the square of the distance.





An object's brightness depends on its distance and how bright it really is.

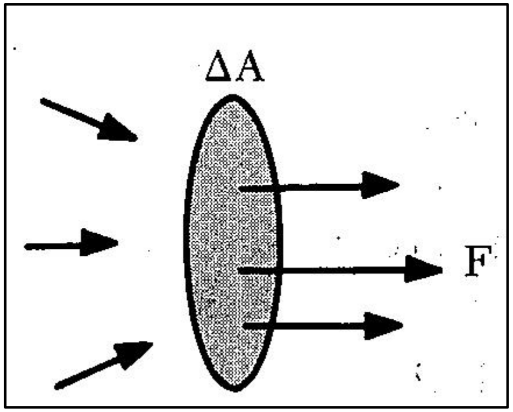


If we know two of these characteristics, we can determine the third.

“Flux”
this quantity can be measured by detectors

The <u>rate</u> of energy passing through a differential area:

$$F = \text{Flux} = \frac{dE}{dA\,dt}$$



What are the units of Flux?

ergs cm^{-2} sec^{-1} = W m^{-2}
1 Watt = 10^7 erg/sec

“Luminosity”

L = flux integrated over the surface area of the object

$$L = \int_{surface} F \, dA$$

If F is constant and the surface is spherical (radius = R), then

$$L = 4\pi R^2 \cdot F$$

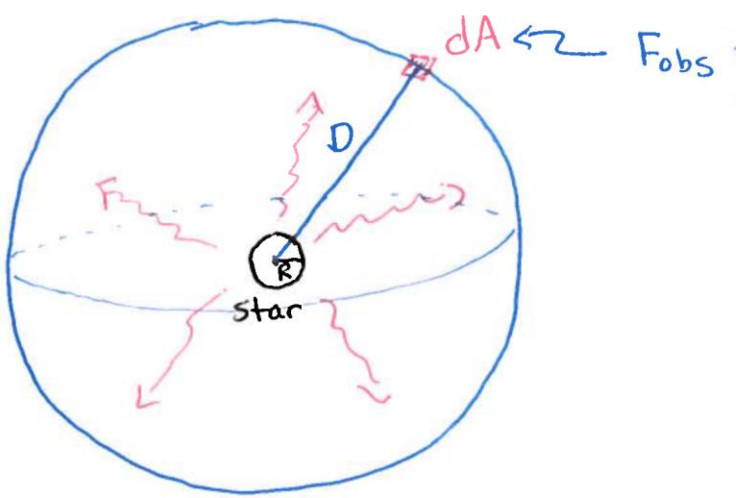
where F is flux at the surface and $4\pi R^2$ is surface area of the sphere

The "inverse-square law"
apply energy conservation

For a star of radius (R_*) and luminosity (L_*):

$$L_* = 4\pi R_*^2 \cdot F_* = dE_*/dt$$

For an observer far away, the same rate of energy will expand outwards and flow through a larger sphere surrounding the star



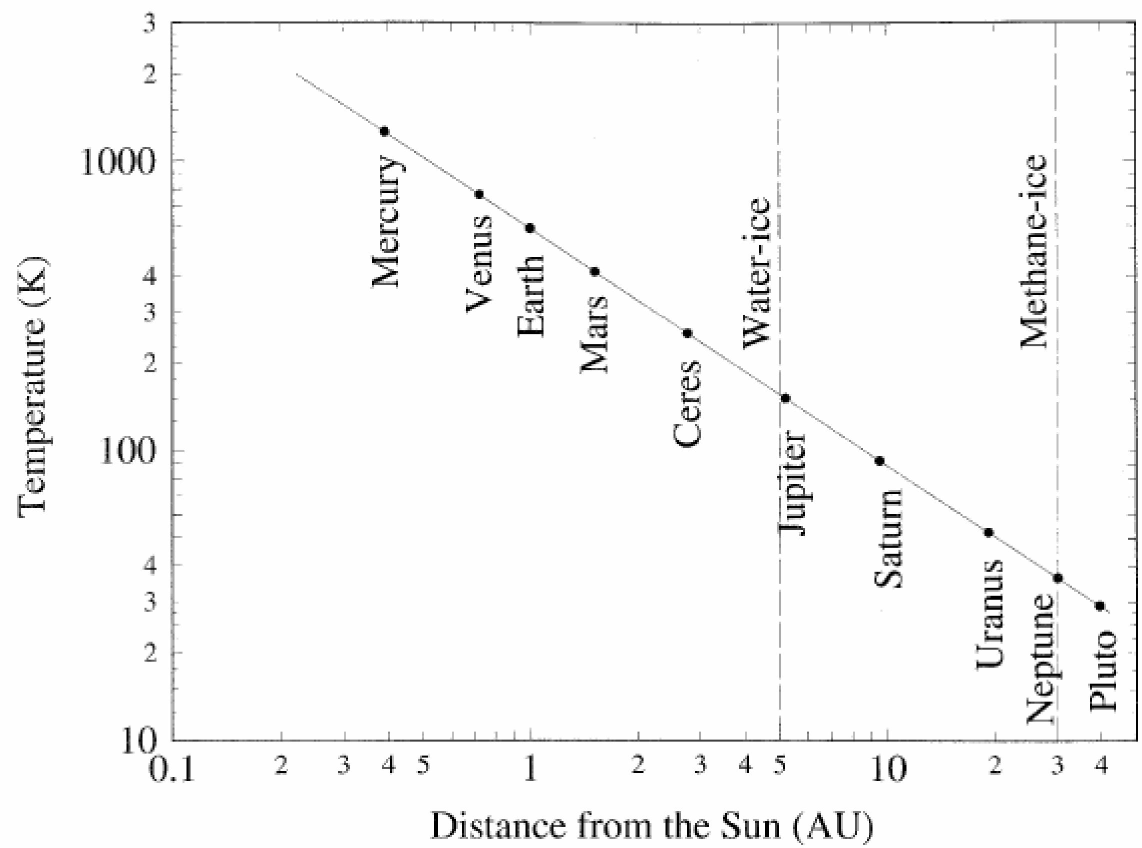
$$L_* = dE_*/dt = 4\pi D^2 \cdot F_{obs} = 4\pi R_*^2 \cdot F_*$$

$$F_{obs} = F_* (R/D)^2$$

So, $F_{obs} \propto 1/D^2$

i.e., "inverse-square" law

Why Do Planets Become Colder with Distance From the Sun?



The graph uses a 'logarithmic' scale.

Radio “Light”

What concepts about light are relevant to cellphones?

What happens when you change channels on your radio?

- Uses electromagnetic radiation
  - radio waves
- Signal travels at the speed of light
  - 3 x 10^8 m/sec
- Light travels in a straight line in a vacuum
  - need antennas to relay signal
- Signal strength decreases as inverse-square distance
  - need antennas to relay signal
  - some dead zones
- Light carries energy is transferred in differer forms:
  - sound to mechanical to light and back again