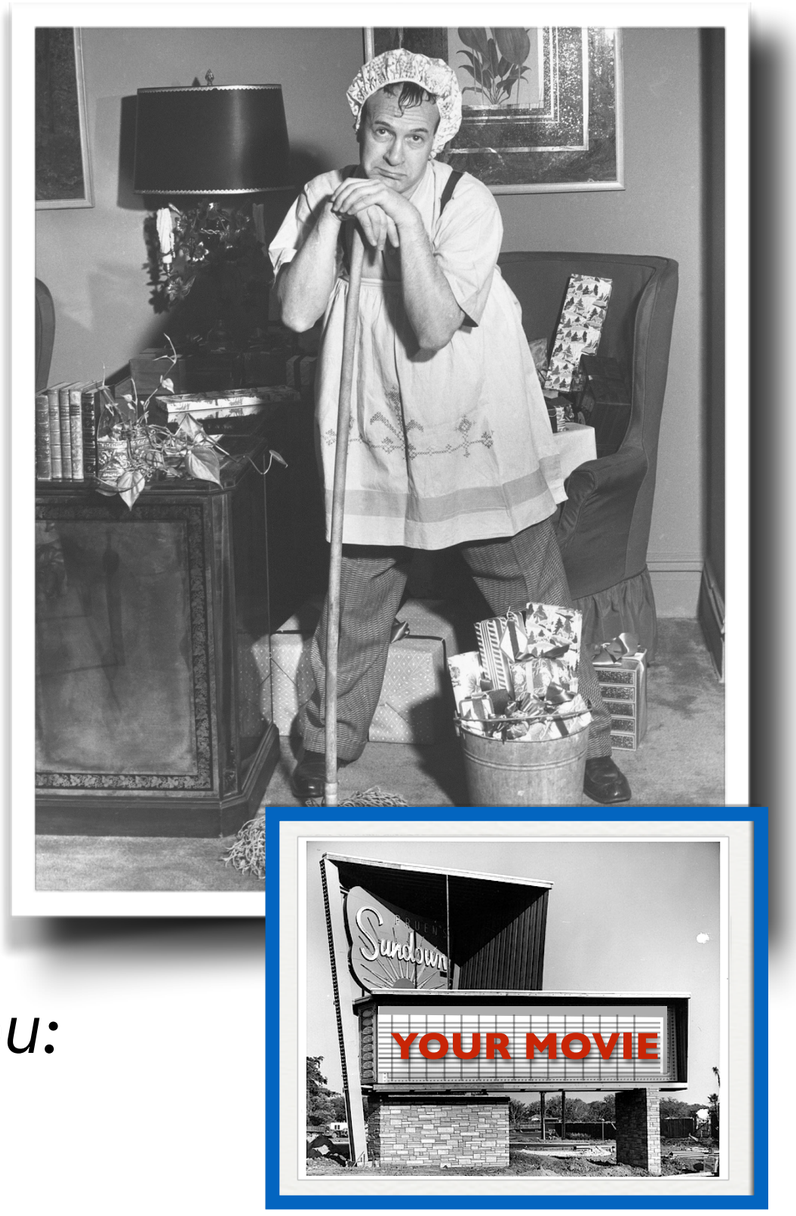
hi

Day 22, 03.04.2018

Quantum Mechanics 1

housekeeping



Gotta come to class

question about anything? I'll make a movie for you:

Quantum Mechanics:

Readings: Oerter, Cosmic Perspective, and Hobson

Hobson_QM1.pdf & Hobson_QM2.pdf are chapters 12 & 13 out of Hobson

Homework #10 is part from MasteringAstronomy and part from MasteringPhysics

honors project began

https://qstbb.pa.msu.edu/storage/Homework_Projects/honors_project_2018/

contains:

- the first instructions: the plan & tutorial
- the second instructions
- the data, assigned by name in the second instructions

dates:

- complete first part, March 16
- analyze data and complete writeup, April 22

relation alert: **Hubble's Law**

refers to: $v = rH$

example:

Speed of a galaxy is proportional to the distance away from any point.

galaxy NGC1832 is 9.57×10^{20} km away, so Hubble's Law says it would be moving at v = 2150 km/s

original results:

$1 \text{ light year} = c \times 1 \text{ year} = 9.5 \times 10^{15} \text{m}$

H = 160 km/sMly

The outstanding feature, however, is the possibility that the velocity-distance relation may represent the de Sitter effect, and hence that numerical data may be introduced into discussions of the general curvature of space.

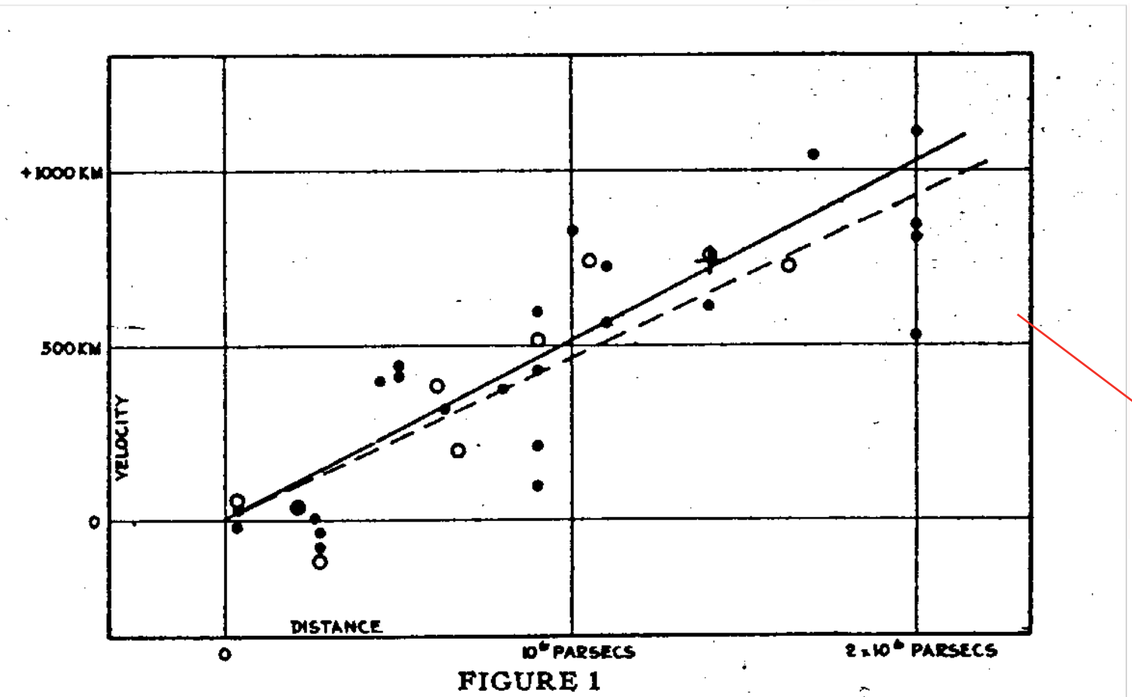
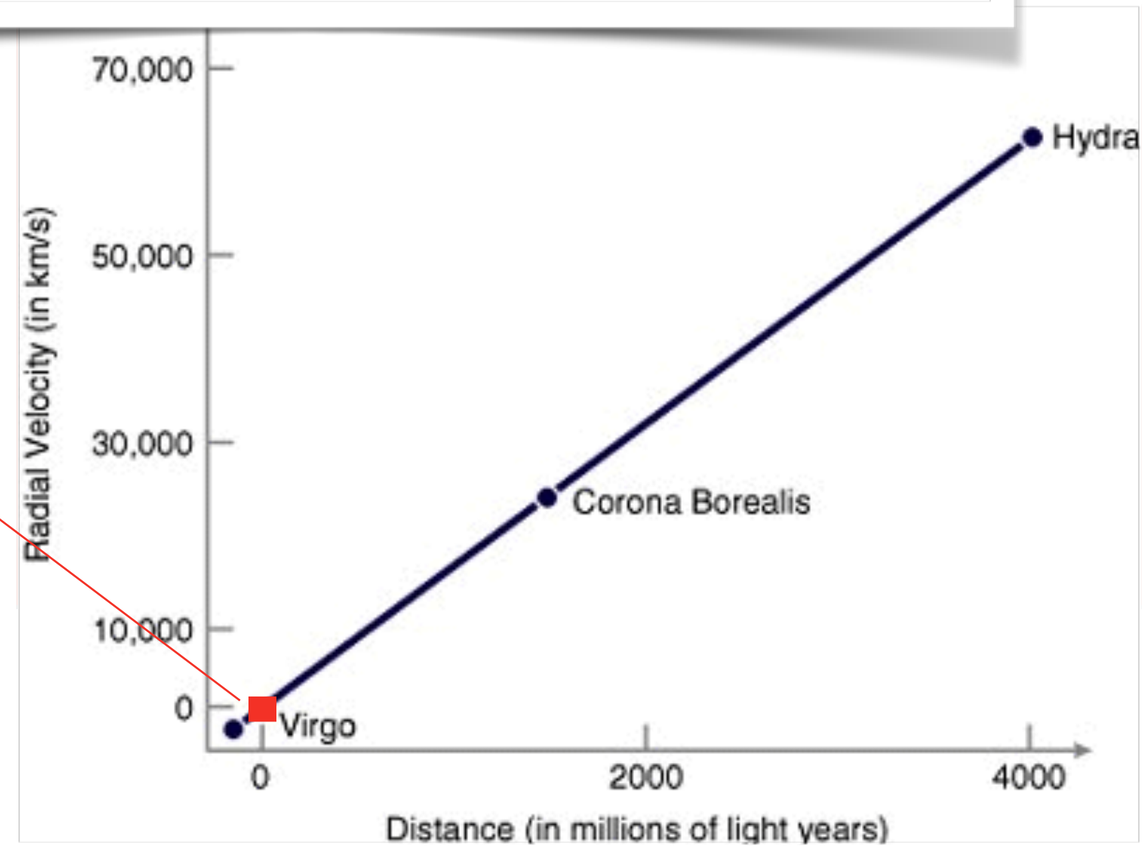


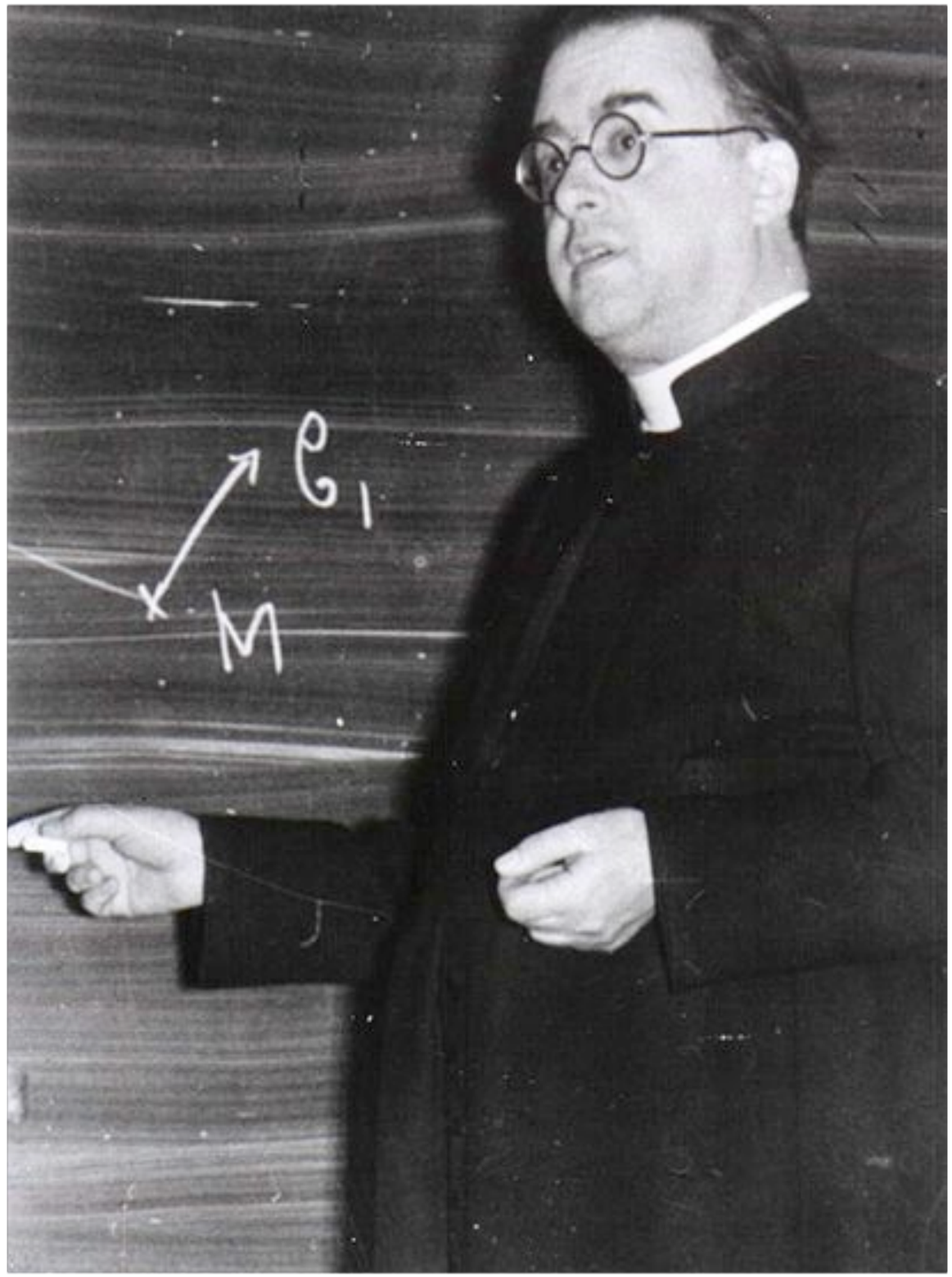
FIGURE 1



Georges Lemaître (1894-1966)

The father of the Big Bang

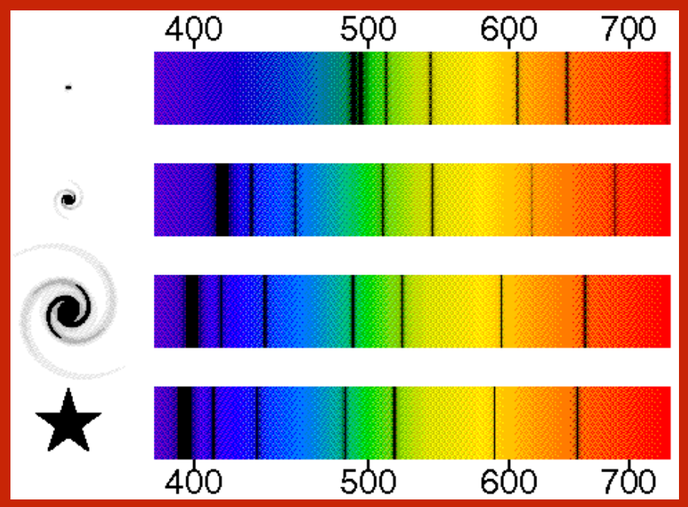
get it?



the “red shift”

isn’t a Doppler velocity

it’s geometry



close

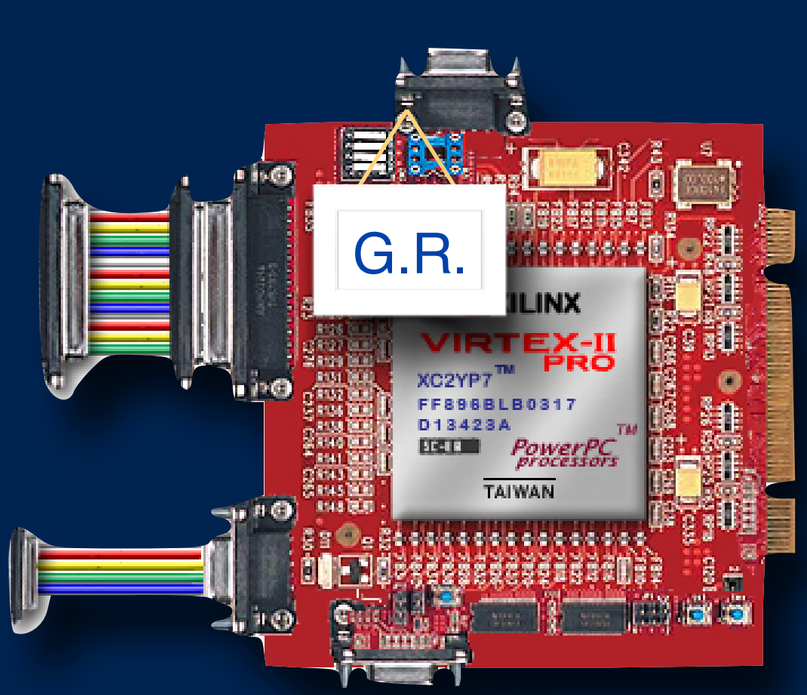
late

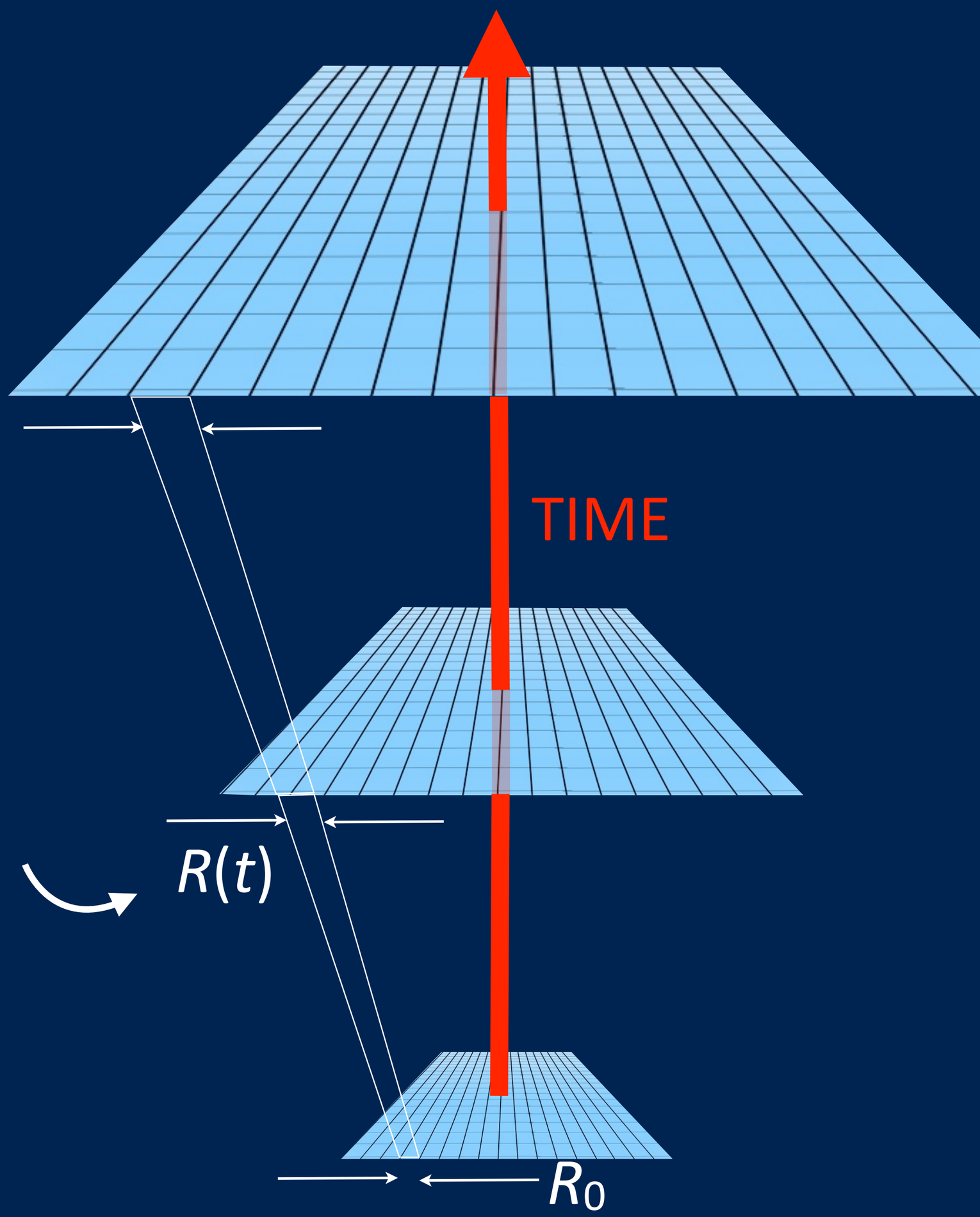
early

energy/mass/pressure

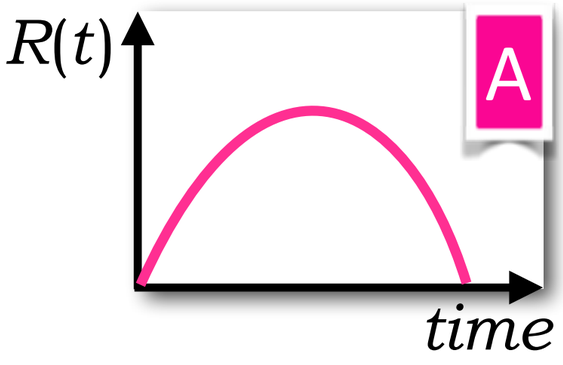
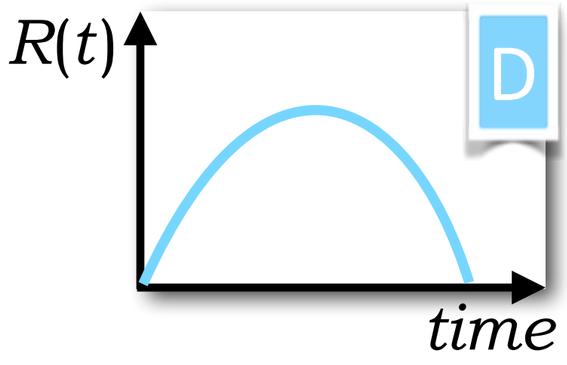
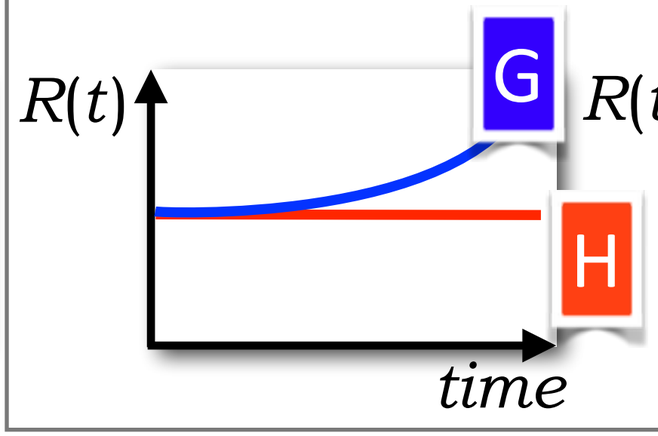
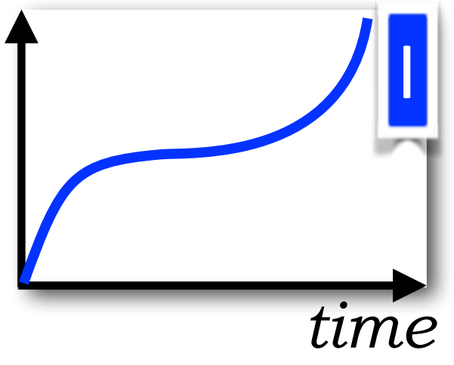
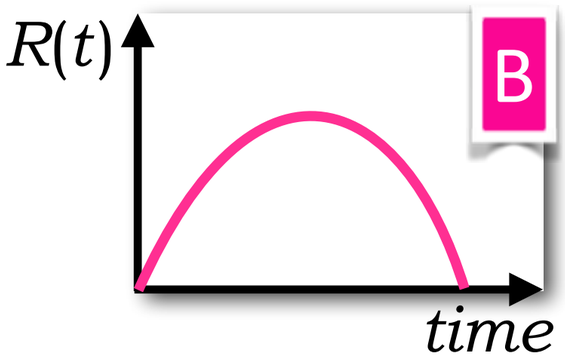
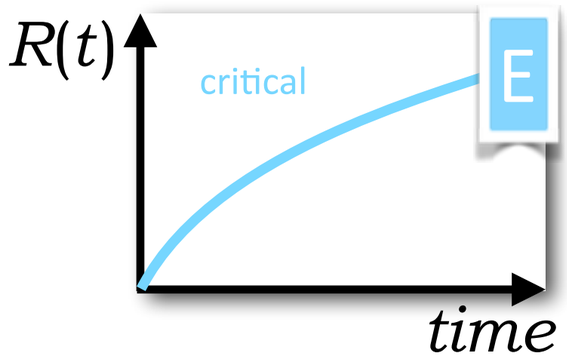
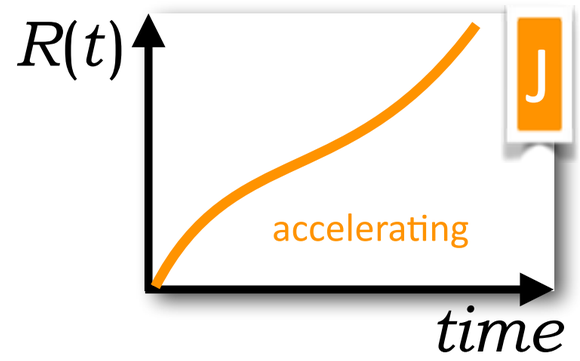
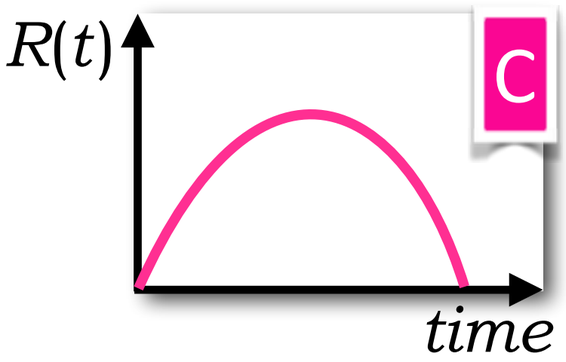
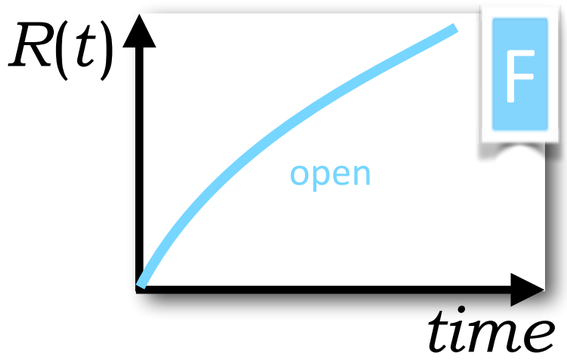
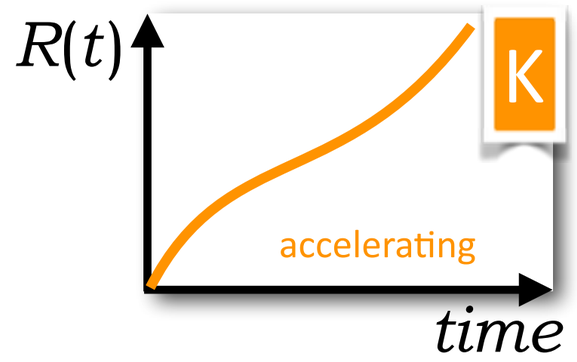
energy/mass/pressure

$$G = T$$





FLRW catalogue of Universes

	$\Lambda < 0$	$\Lambda = 0$	$\Lambda = \Lambda_E$	$\Lambda > \Lambda_E$	$\Lambda > 0$
$k = +1$					
$k = 0$					
$k = -1$					

I see

dead stars

one more tool

waves

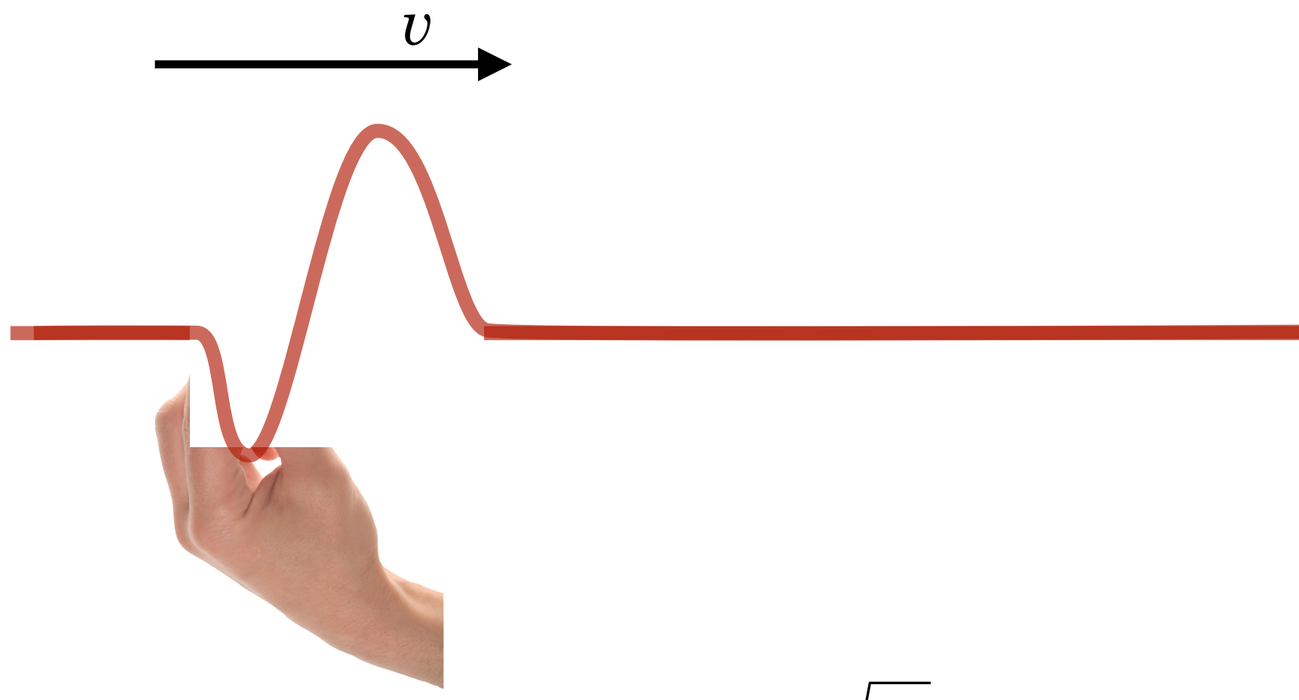
a wave is

a disturbance.

a way to transmit energy

without transmitting matter

one part is stretched, but the rope's tension restores it - and K is passed on to an adjacent part



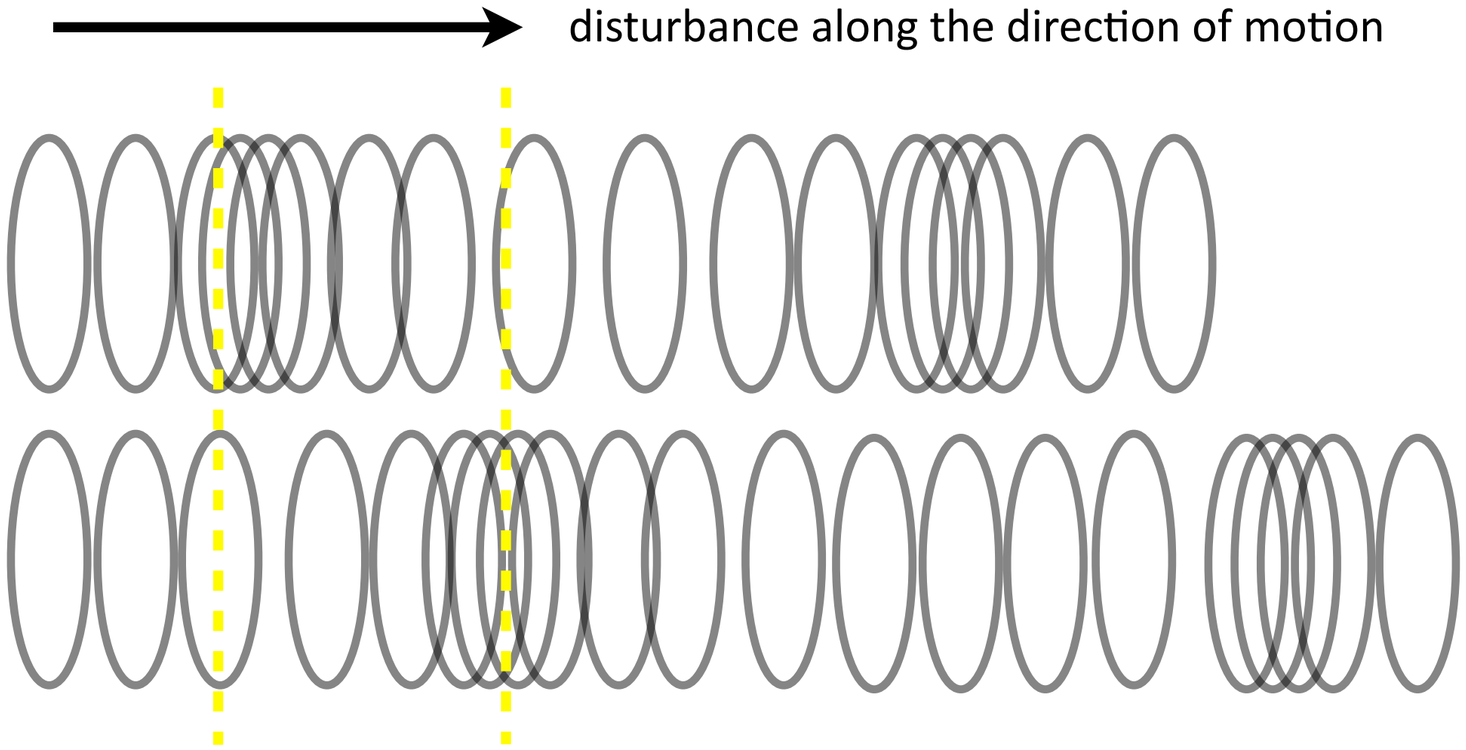
the *disturbance* moves with velocity $v = \sqrt{\frac{T}{\rho}}$

stiffer - faster

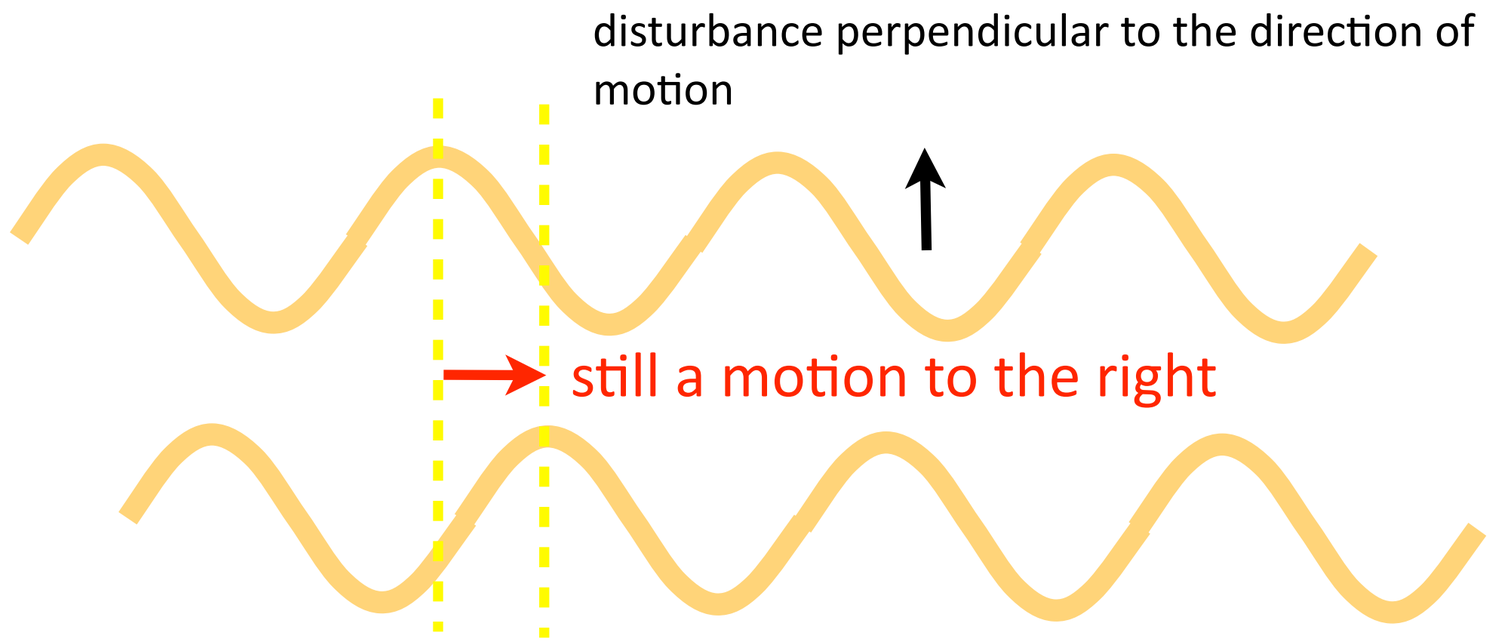
lighter - faster

2 kinds of waves

Longitudinal ***SOUND***



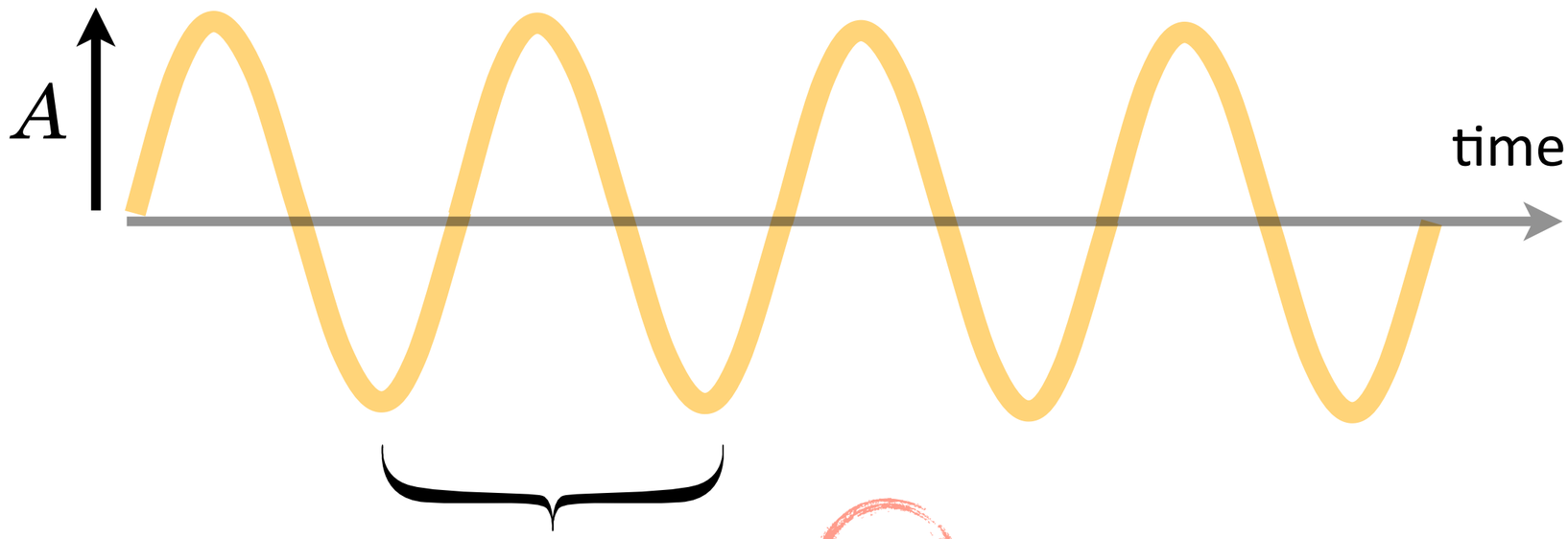
Transverse ***ROPES, WATER***



just some facts, Ma'am

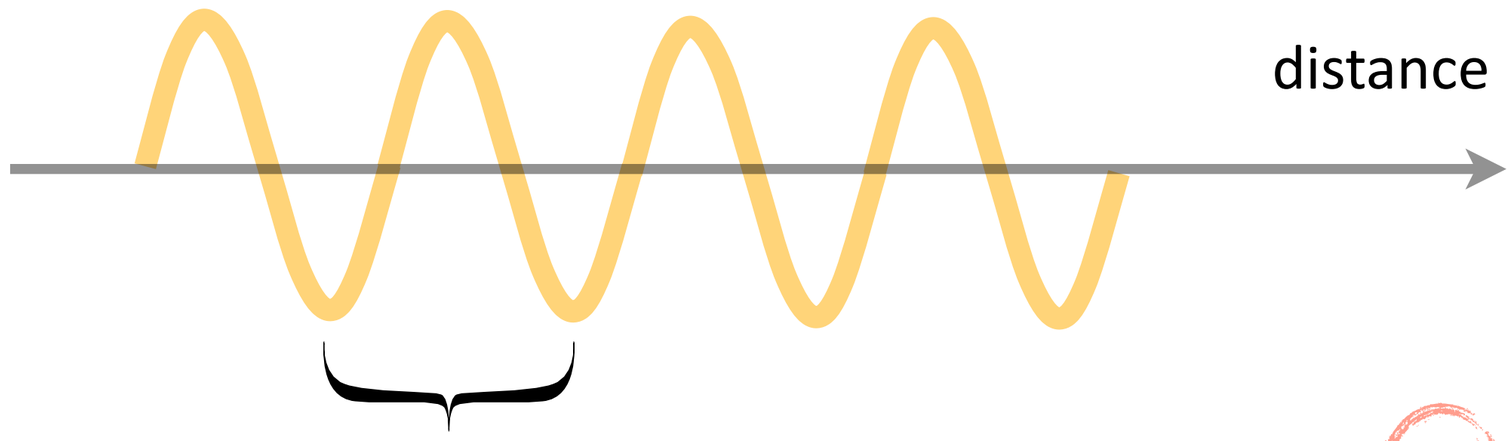
maximum height of the disturbance: "Amplitude," A.

"Intensity" is ~ A^2



time to repeat: "Period," T. seconds

rate of repetition: "Frequency," f. (Hz) $f = \frac{1}{T}$



distance through which it repeats: "Wavelength," λ m

$v = \frac{\lambda}{T}$ $v = \lambda f$

relation alert: **speed of a wave**

refers to: $v = \lambda f$

example: middle C ~ 4 ft (=1.2 m) wavelength

f = 262 Hz, so speed of sound:

$$v = 1.2 \times 262 = 314 \text{ m/s}$$

wave speeds

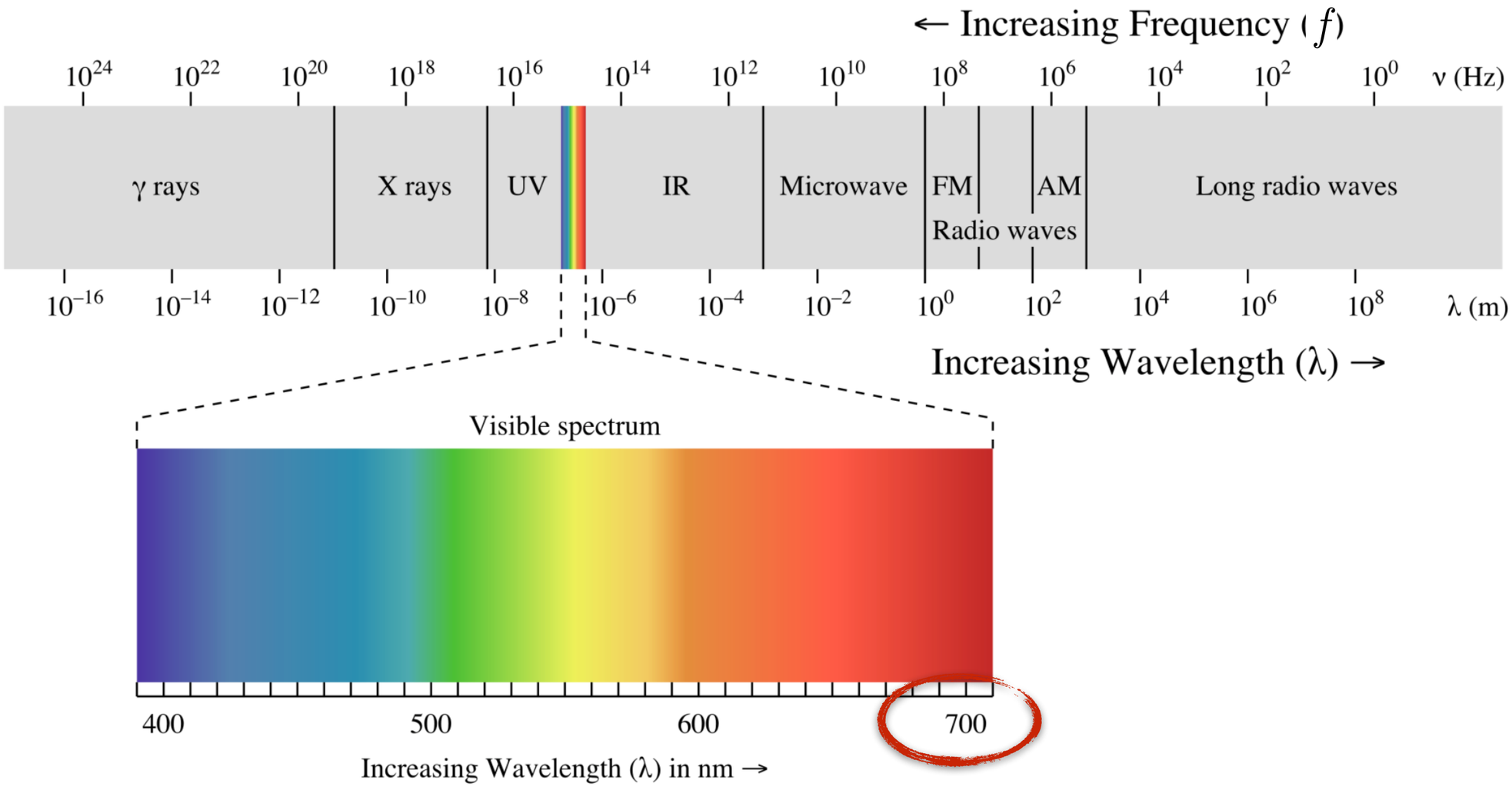
for sound in regular room temperature air?

about 300ish m/s: so about 30 ms to hear me in the back row

for light...anywhere?

$v = c = 3 \times 10^8$ m/s

$$v = \lambda f \rightarrow c = \lambda f$$



frequency and wavelength are coupled for light:

$$c = \lambda f$$

$$c = (700 \times 10^{-9}) f$$

$$\frac{c}{700 \times 10^{-9}} = f$$

$$f = \frac{3 \times 10^8}{7 \times 10^{-7}} = 0.42 \times 10^{15} = 4.2 \times 10^{14} \text{ Hz}$$

what characterizes a wave?

different from a material body?

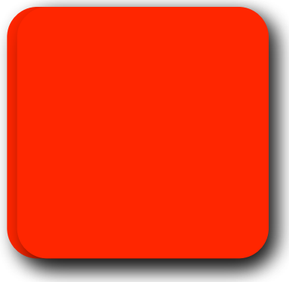
a material object is

here.

a wave is

everywhere.

a material bounces



doesn’t pass through.

?

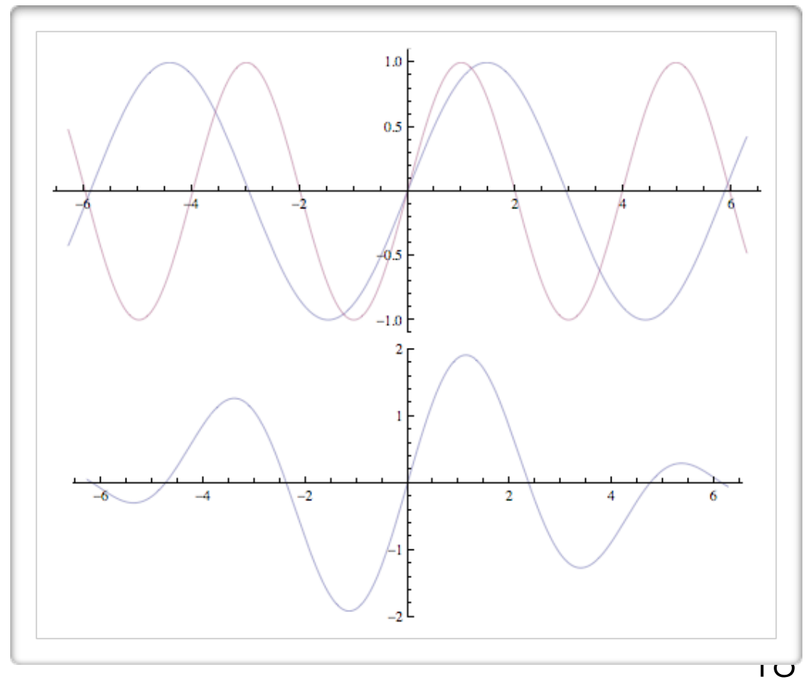
!

waves go right through

one another

blue or red

blue + red

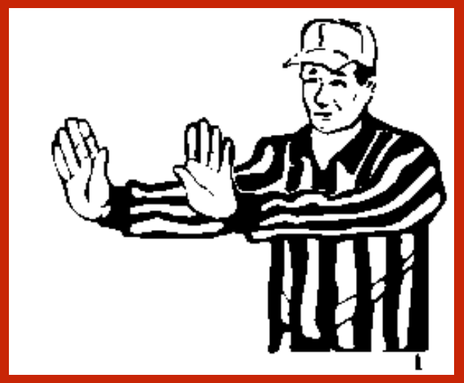


the

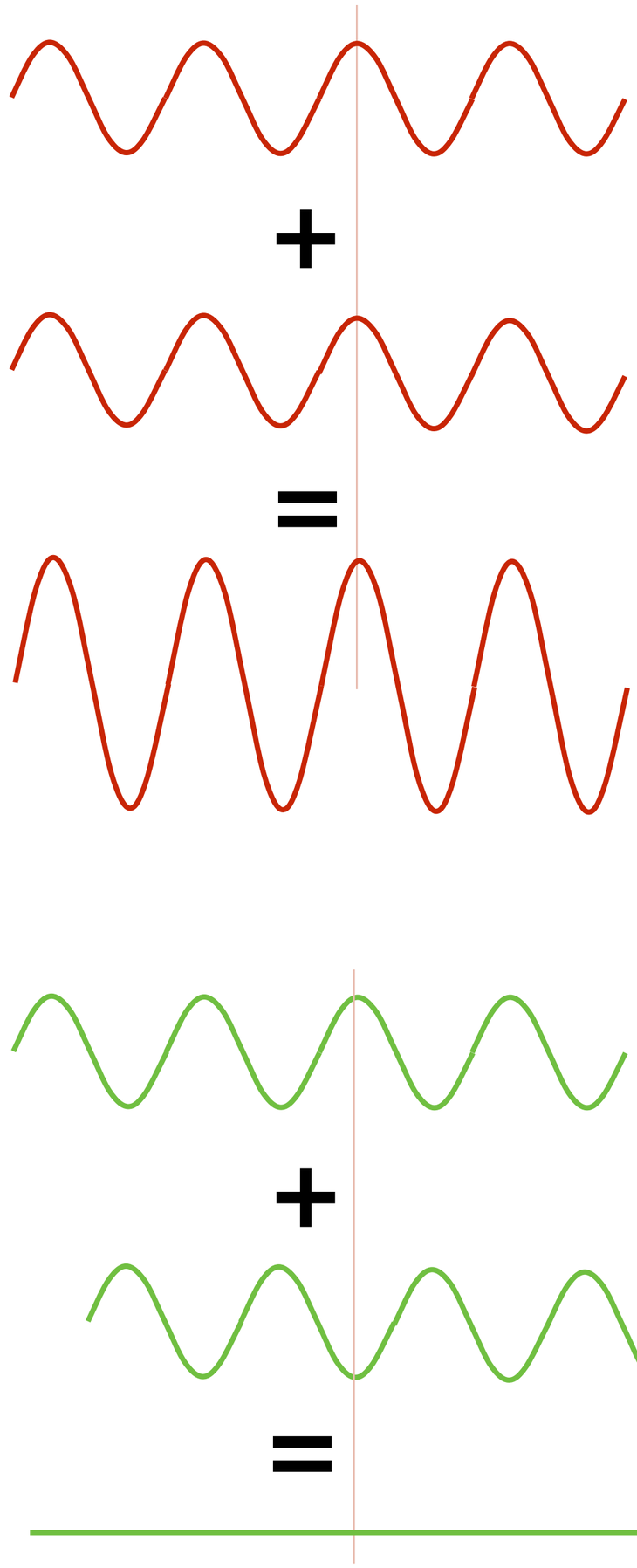
for waves?

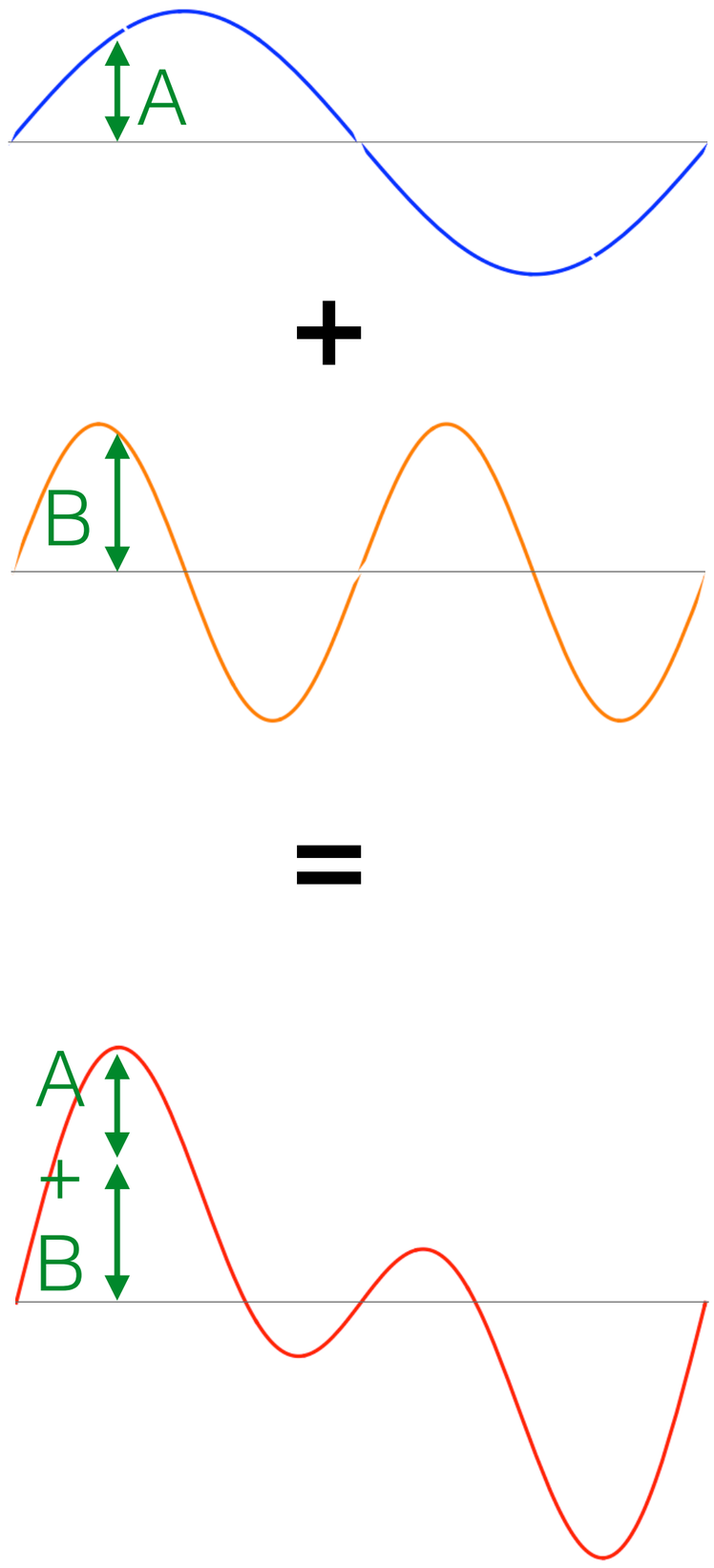
that's right

interference



can always make a third wave out of the sum of two waves





for us, two kinds

traveling waves

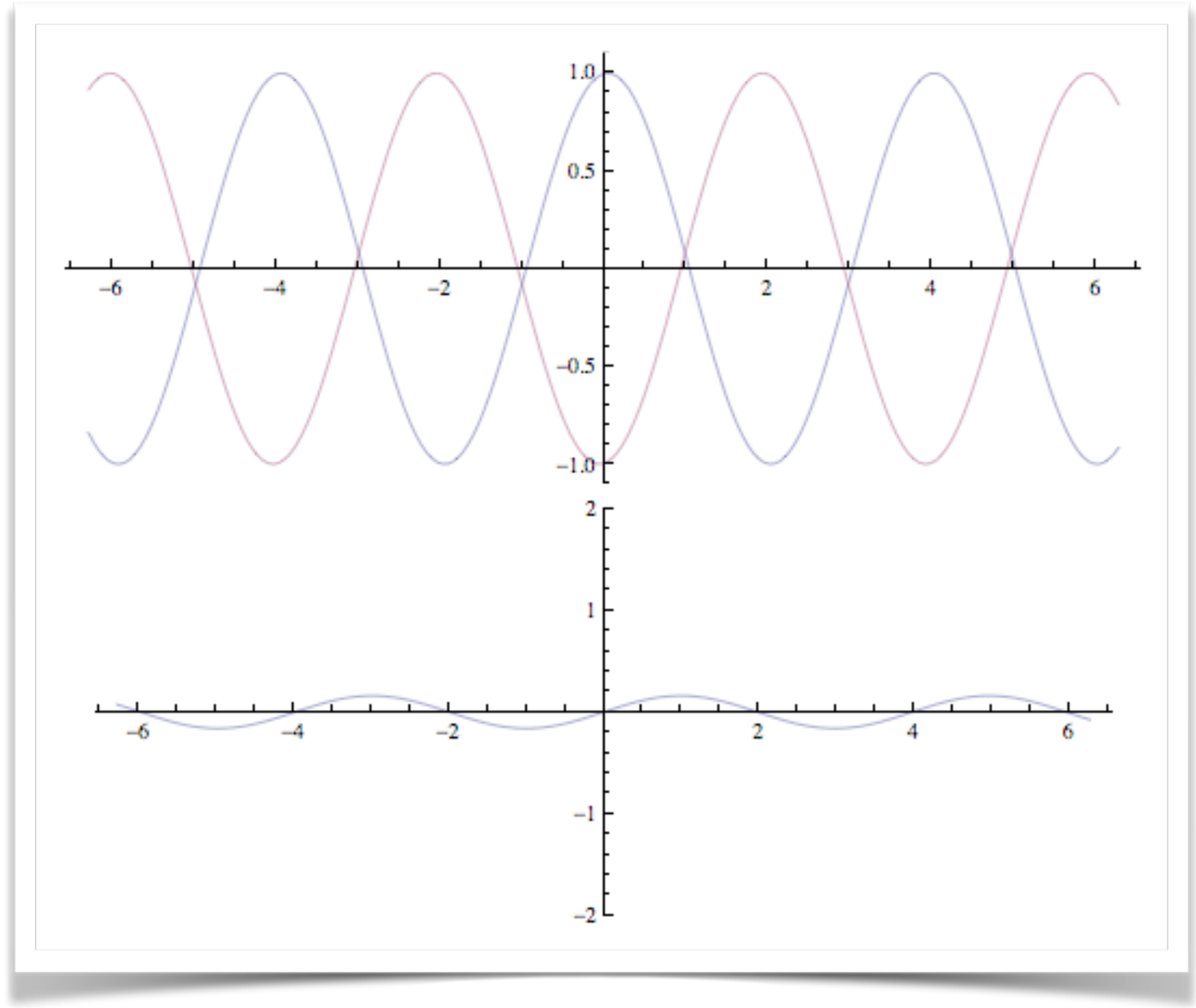
the disturbance translates

standing waves

the disturbance marches in place

Standing room only

"standing wave pattern"



Quantum Mechanics

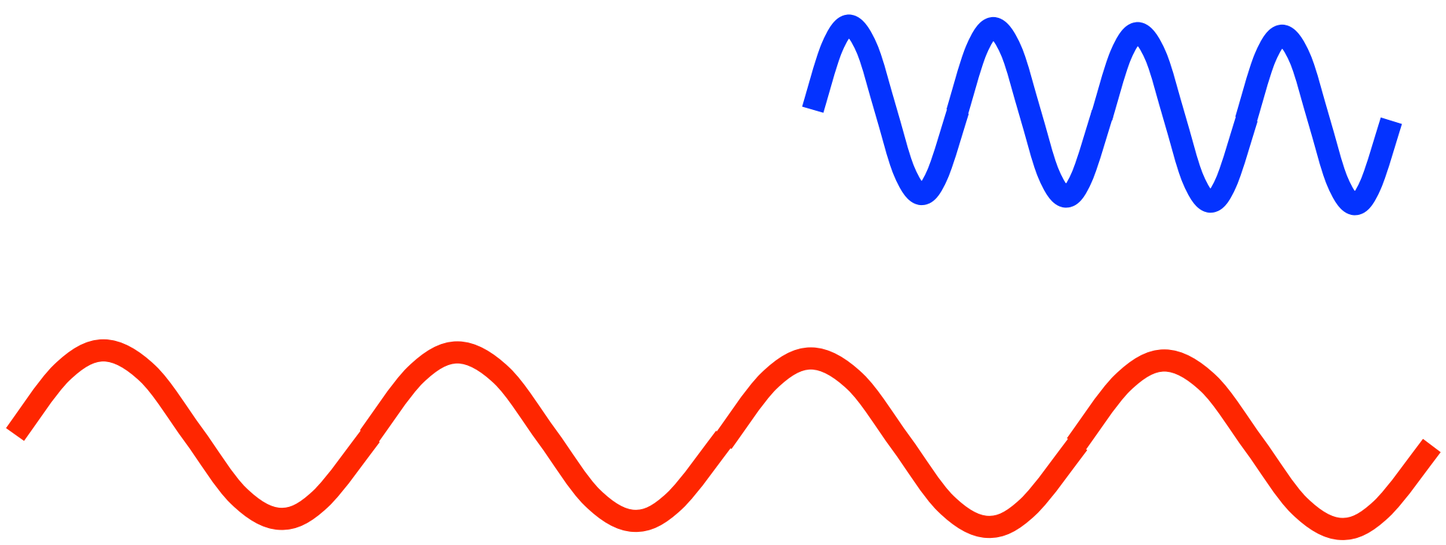
in the 1890's things were heating up

I mean, literally.

color = temperature

why?

Gassan Sadatoshi

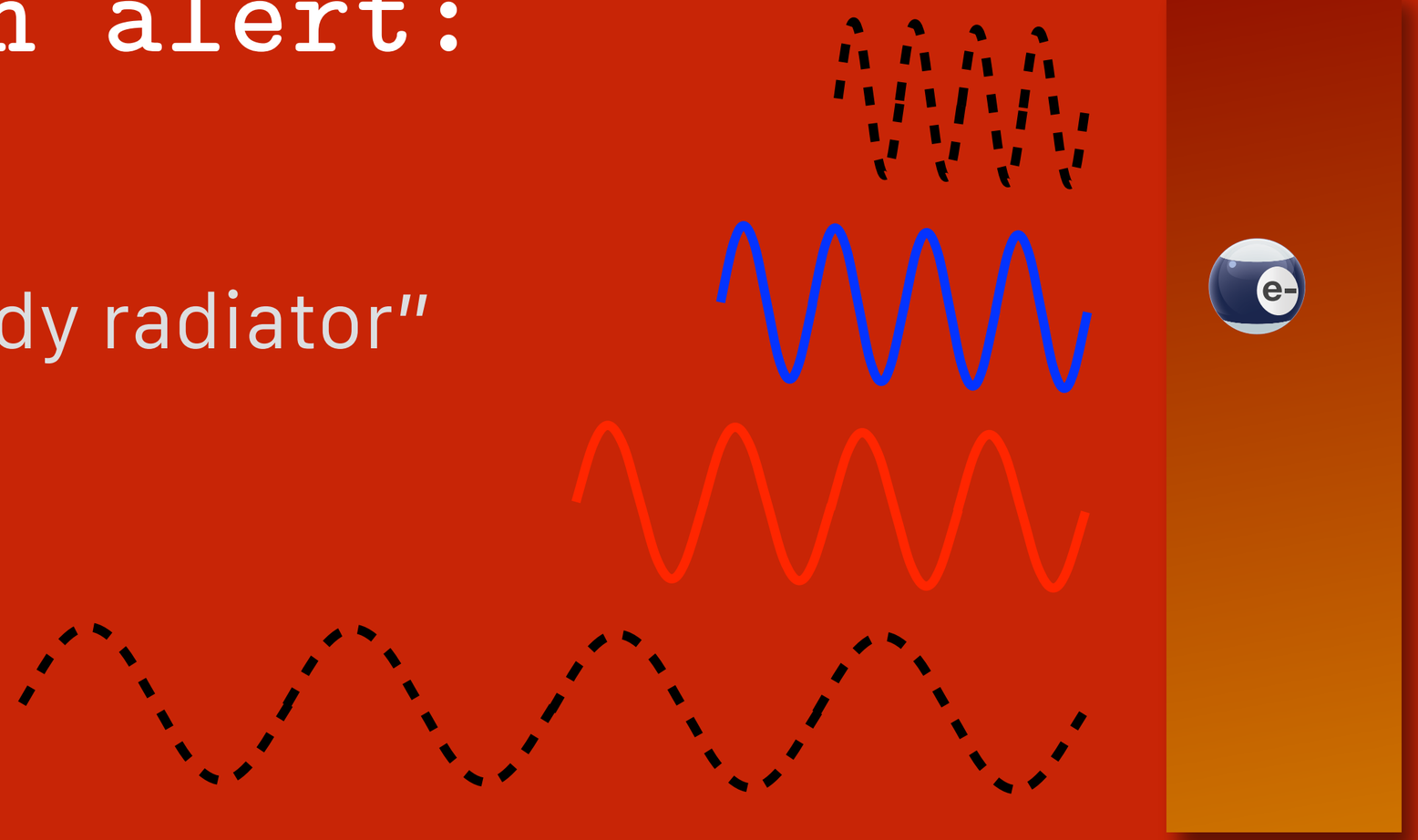


http://www.howstuffworks.com/sword-making.htm/printable

amount of each wavelength: depends **ONLY** on temperature

jargon alert:

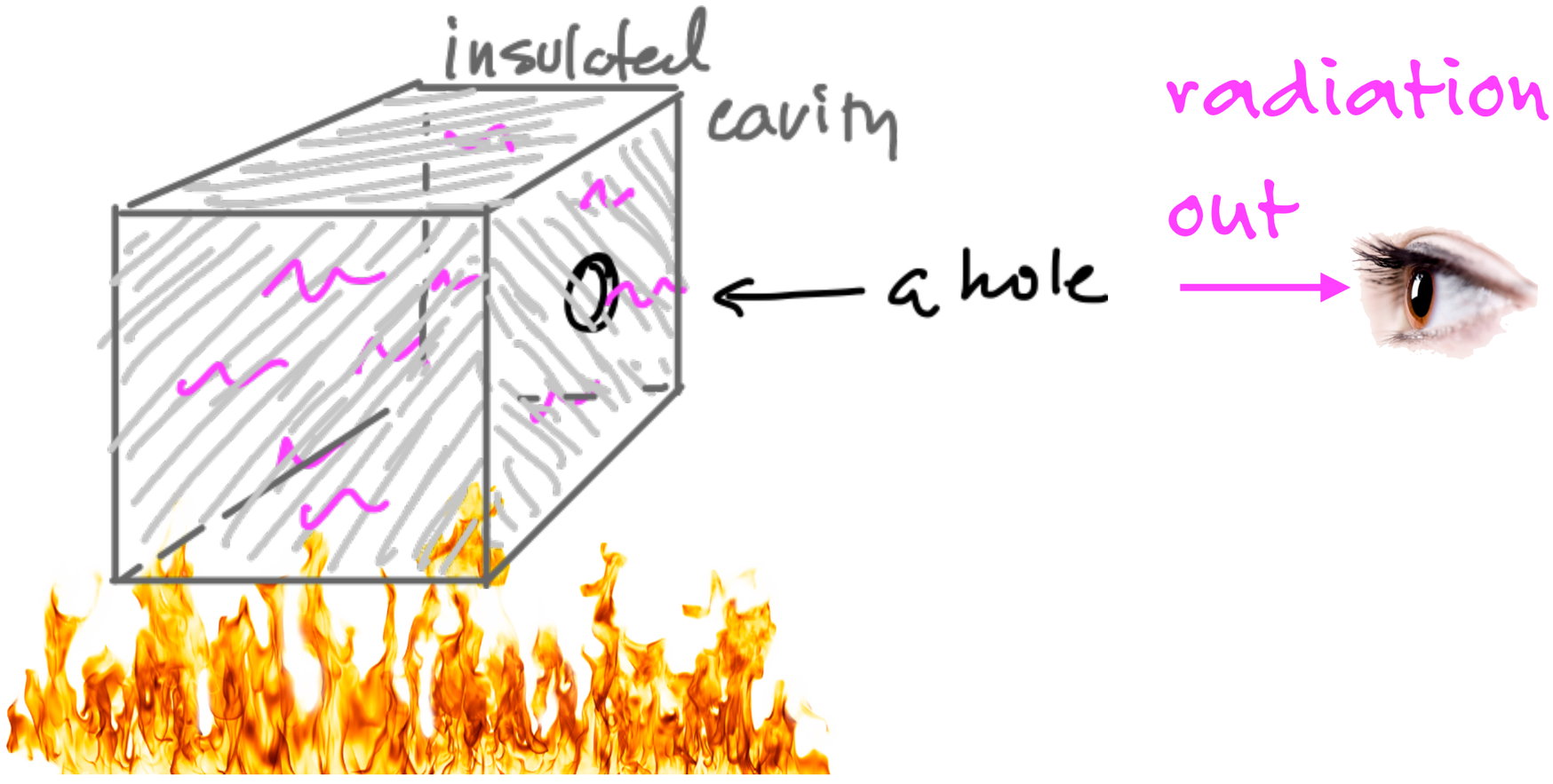
"Blackbody radiator"



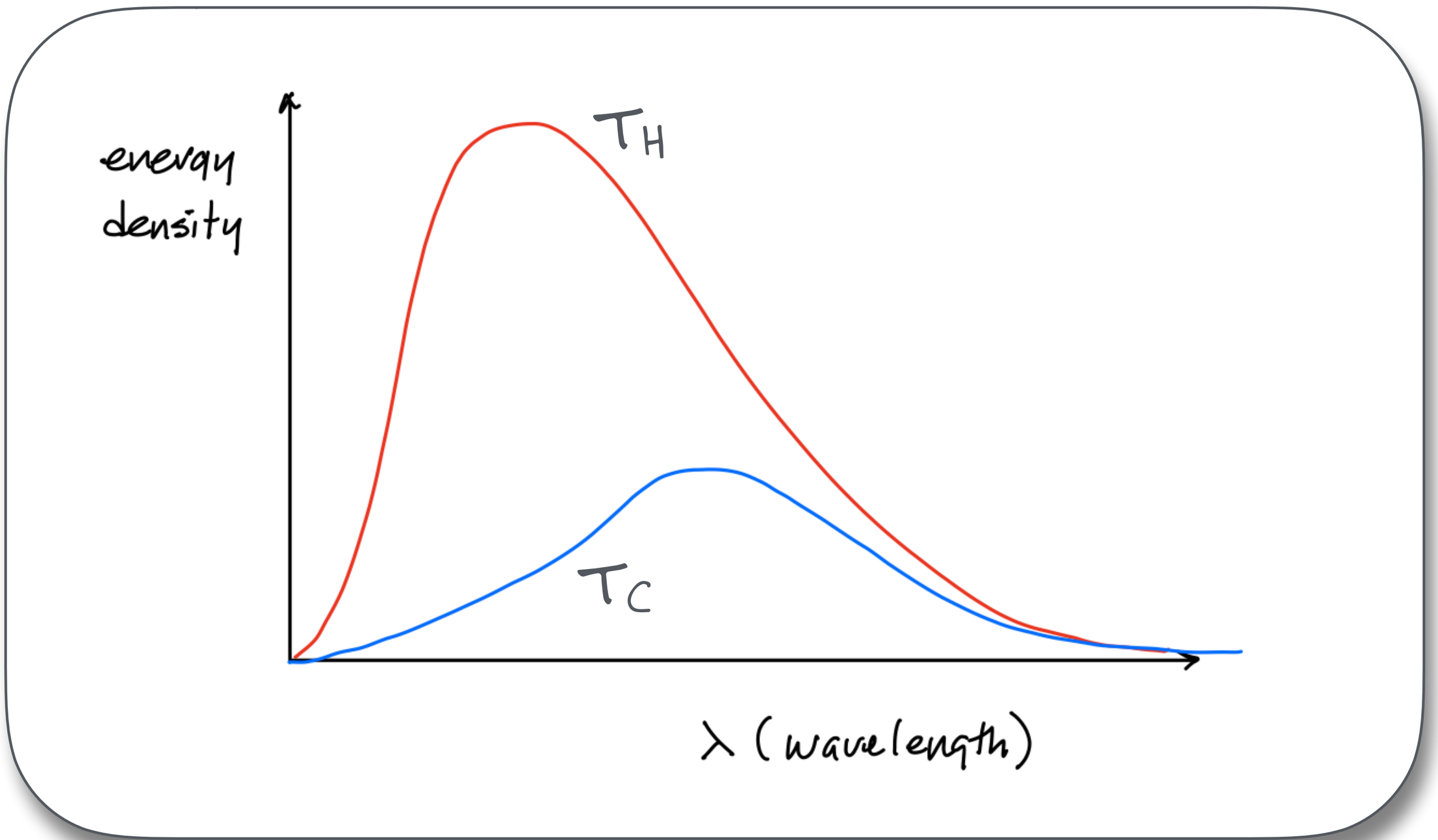
A little more complicated - glass, metals, soot...all behave differently

Basically think of a "Blackbody Radiator" as a perfectly absorbing, perfectly radiating substance.

what people measured:



make your fingers think



jargon alert:

Black Body Radiation

refers to:

A thermal absorber that perfectly absorbs all wavelengths of EM radiation and emits according to its temperature

entomology:

“black” in the sense of a perfect absorber...no reflection

example:

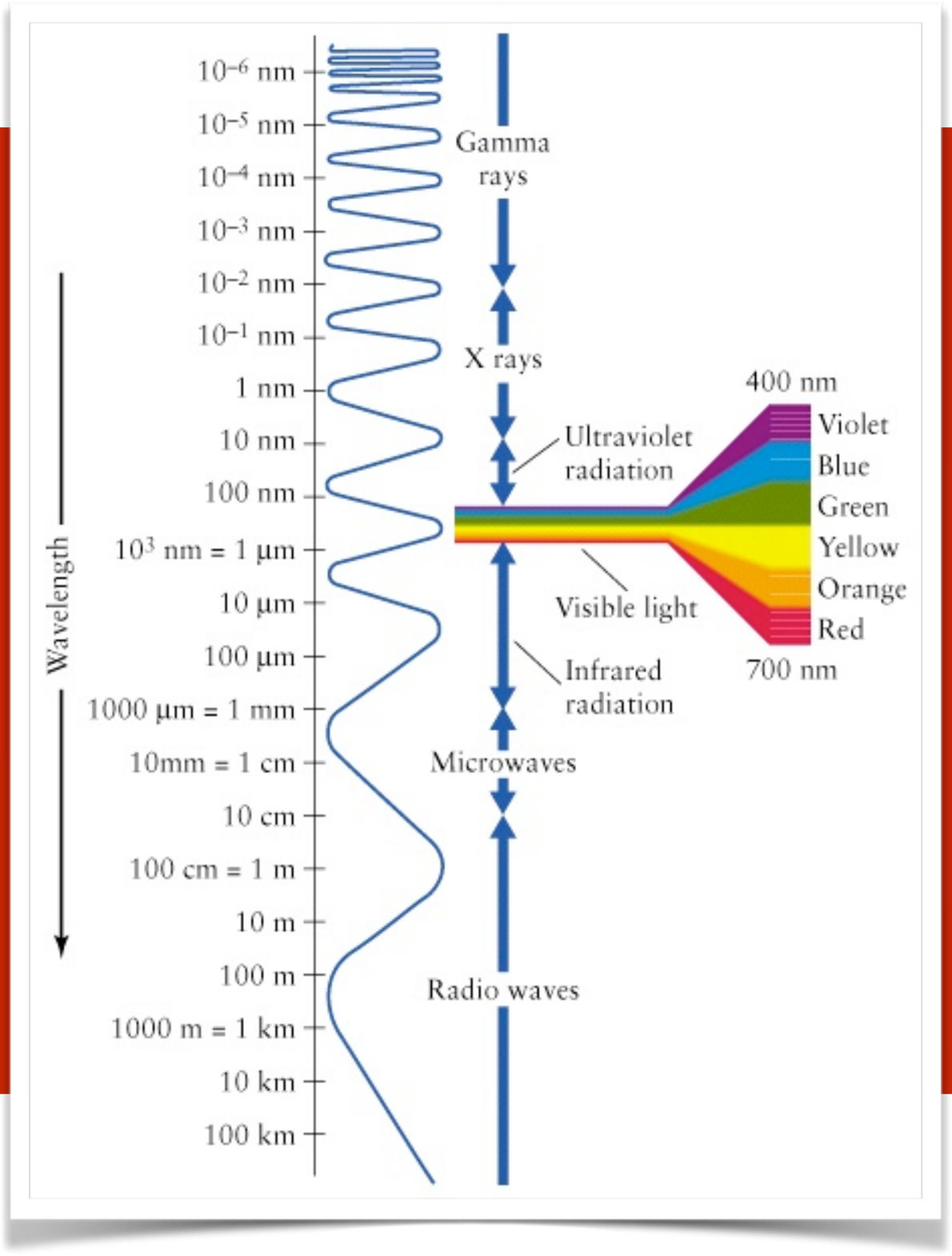
A cavity with a hole, a near-black object, a star...

everything radiates

everything.

Many objects approximate Blackbody radiators:

- stars
- you, me
- heated metal
- stuff...



temperature scales

water freezing - boiling - absolute zero

The US go-it-alone scale: Fahrenheit

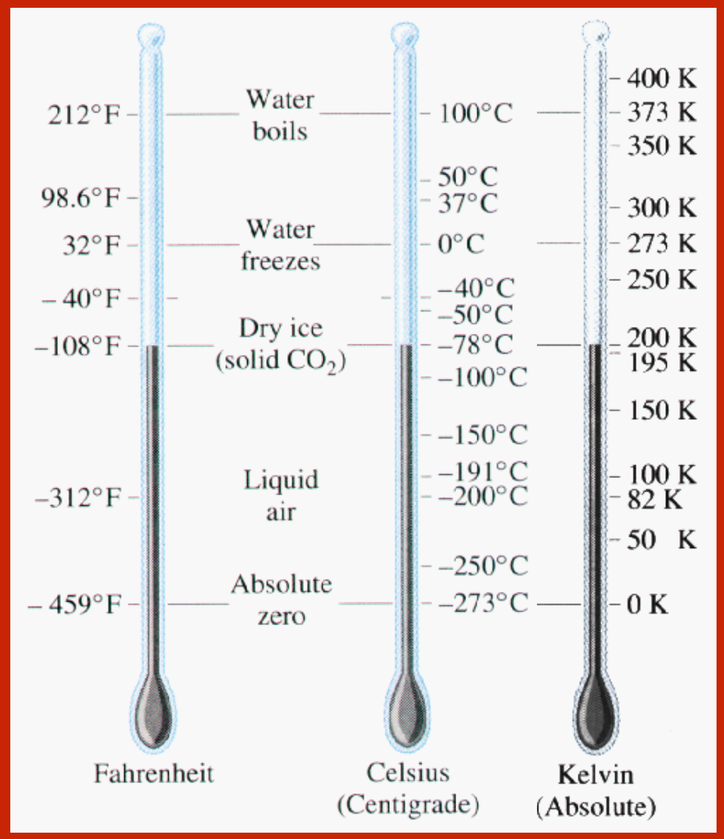
- (32°F - 212°F - –459°F)

The rest of the world: Celsius (or Centigrade)

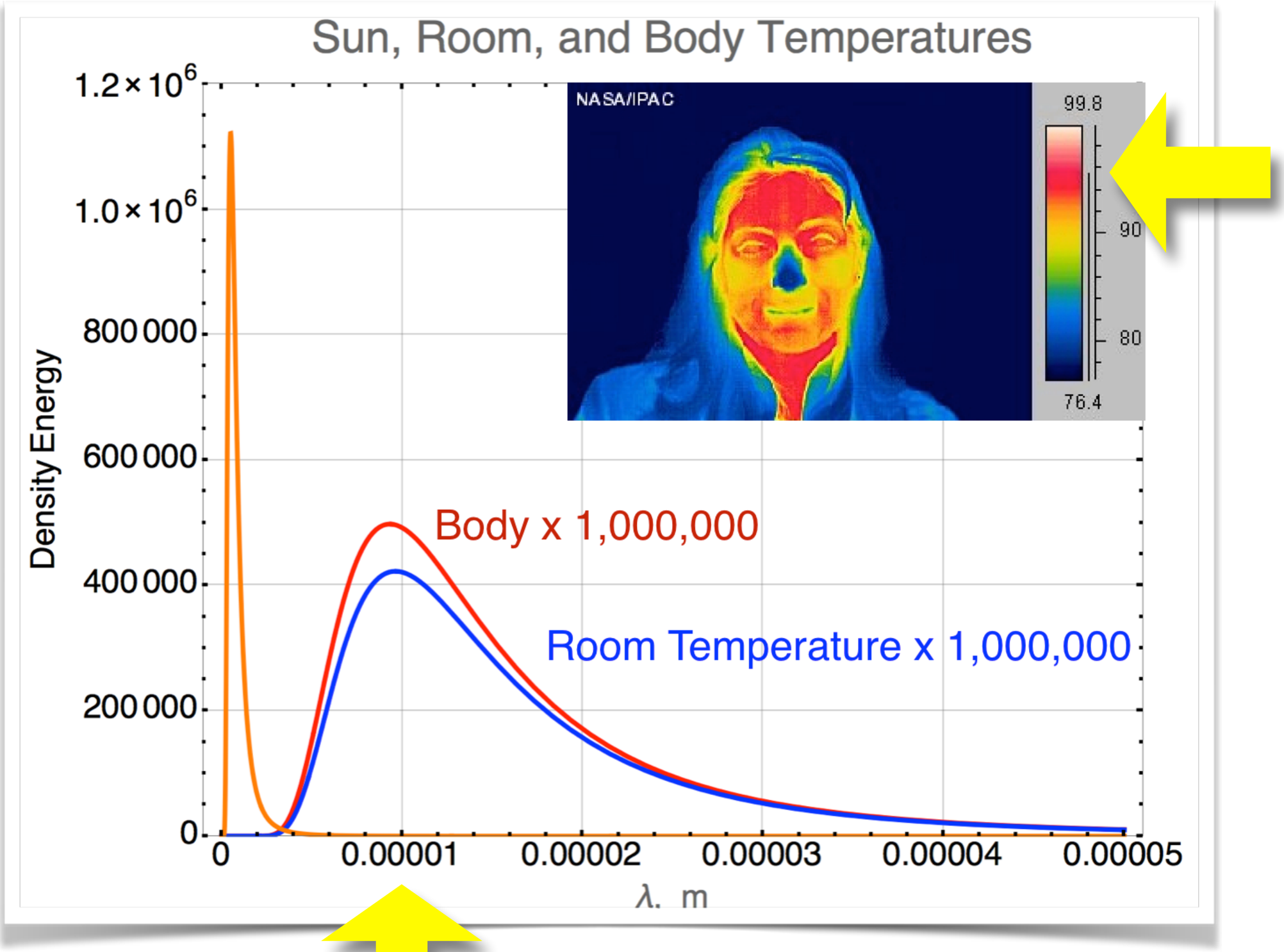
- (1°C - 100°C - –273°C)

The scientific community: Kelvin

- (273 K - 373 K - 0 K)



everything with a temperature radiates electromagnetic waves

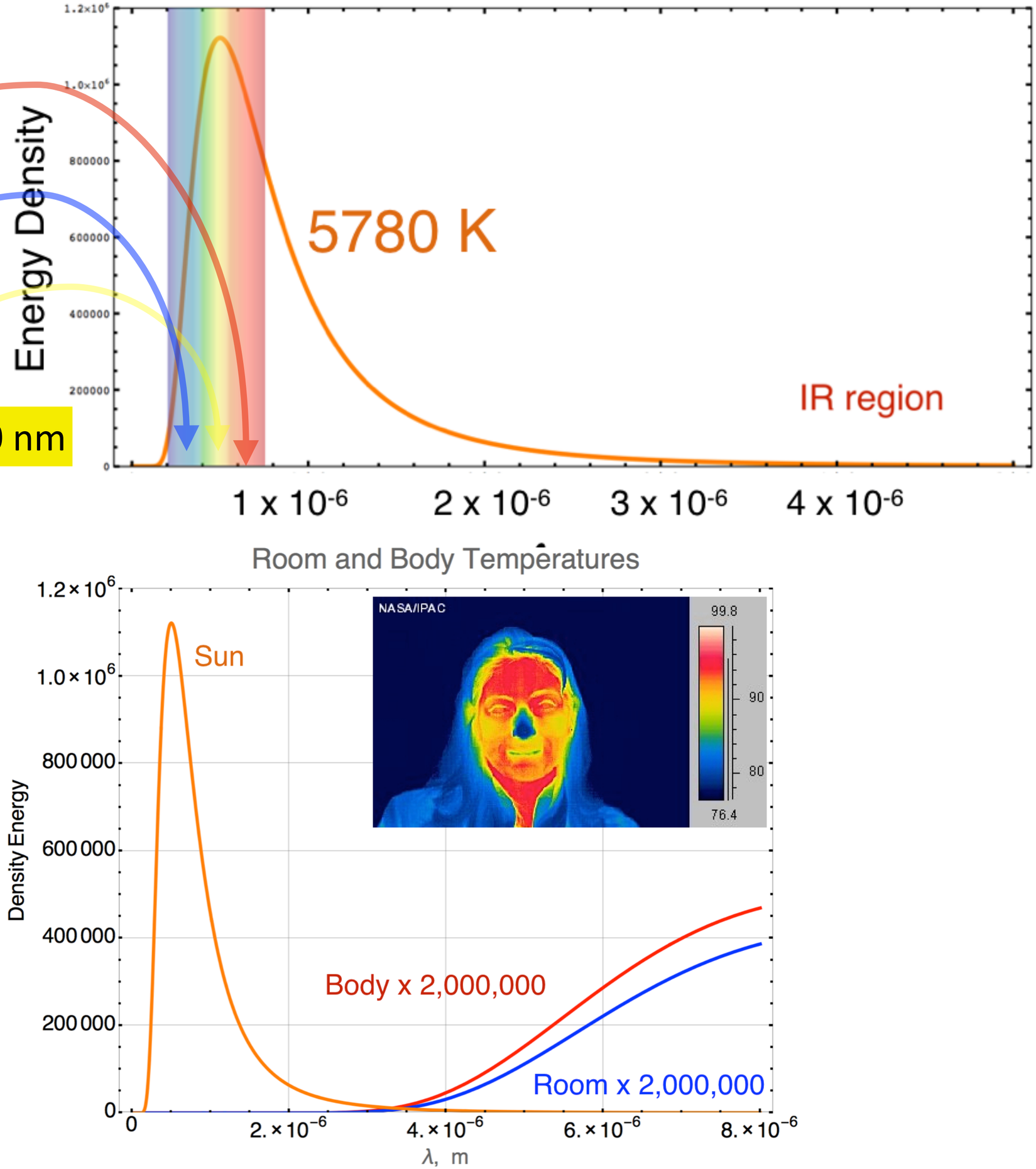


about 1 x 10^{-5}m, 10 microns: infrared

red light: 650 nm

blue light: 475 nm

yellow light: 570 nm



sun

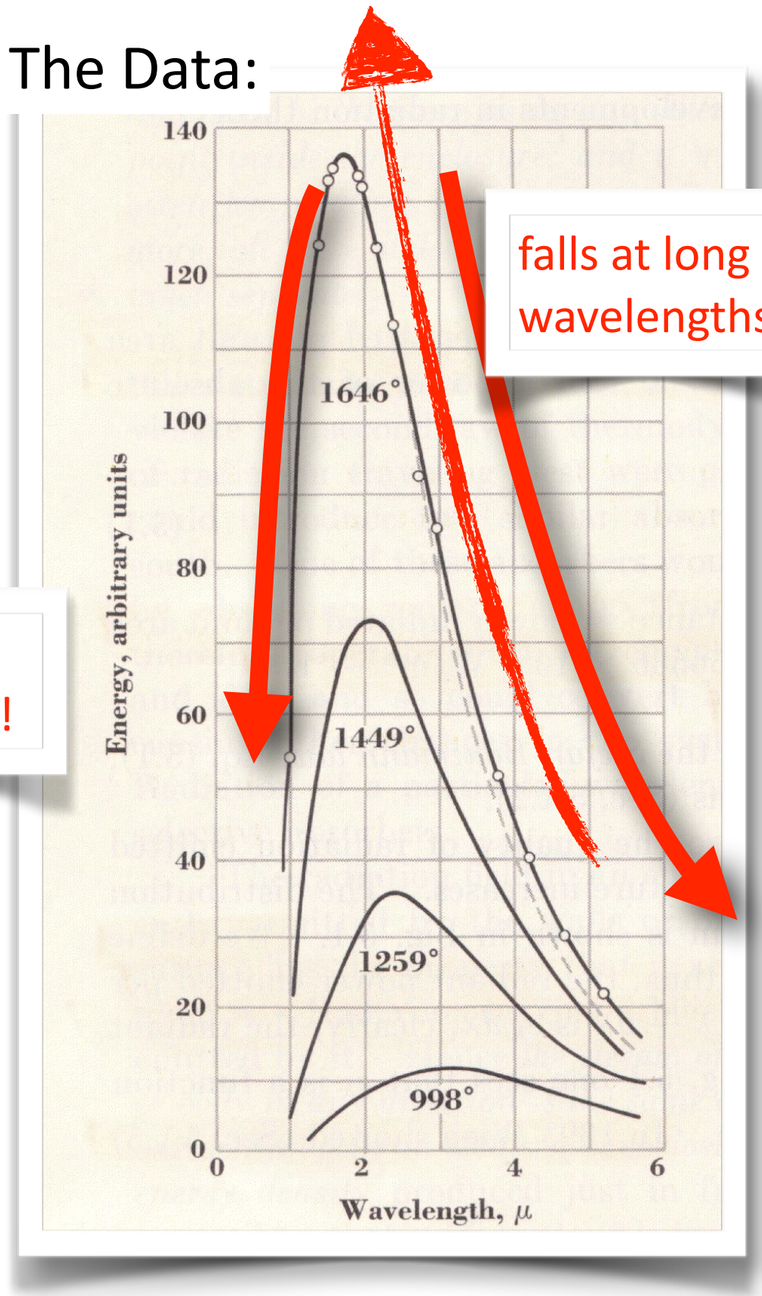
what would Maxwell's theory say?

nonsense.

a major problem.

imagine a cavity with radiation inside

The Data:

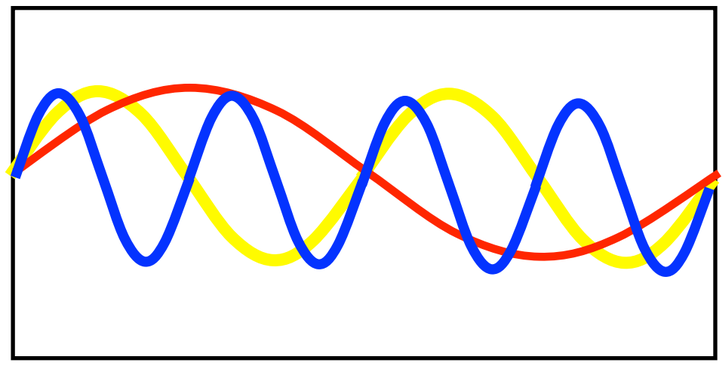


falls at short wavelengths!

falls at long wavelengths

long wavelength →

← high frequency



Maxwell-like theory:
no limit to the number of different short wavelengths (= high frequencies) that could fit

a universal phenomenon...

Why is there such a strict relationship between temperature and color?

Heat seems to be related to Electromagnetism...independent of the material.

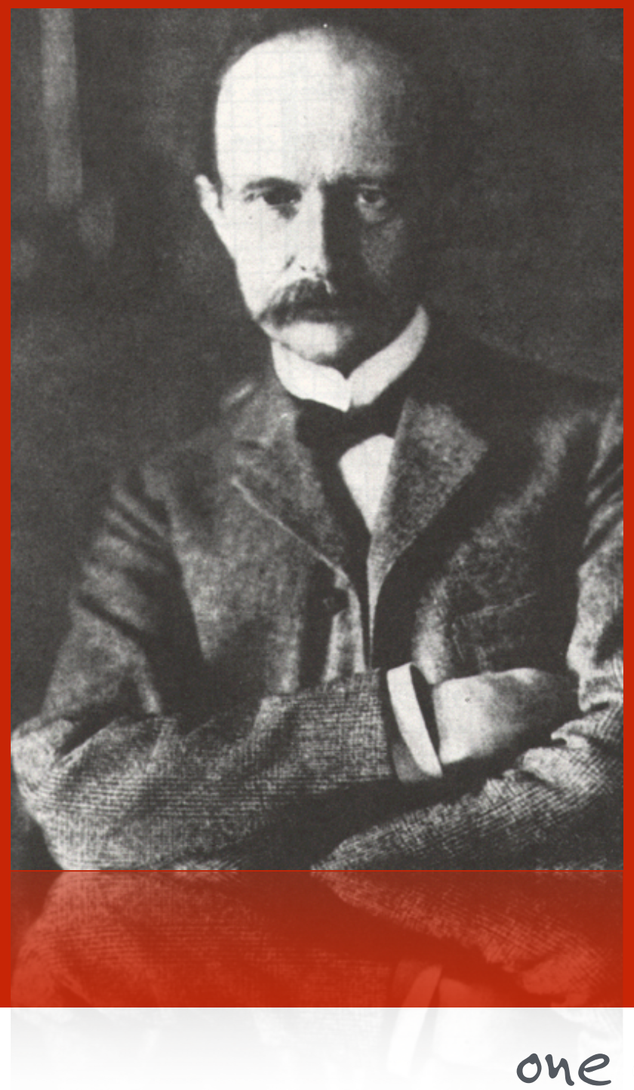
Why?

Was a major late 19th century question.

the solution to heat radiation

came in 1900

and then expanded in 1905



Max Planck
1858-1947

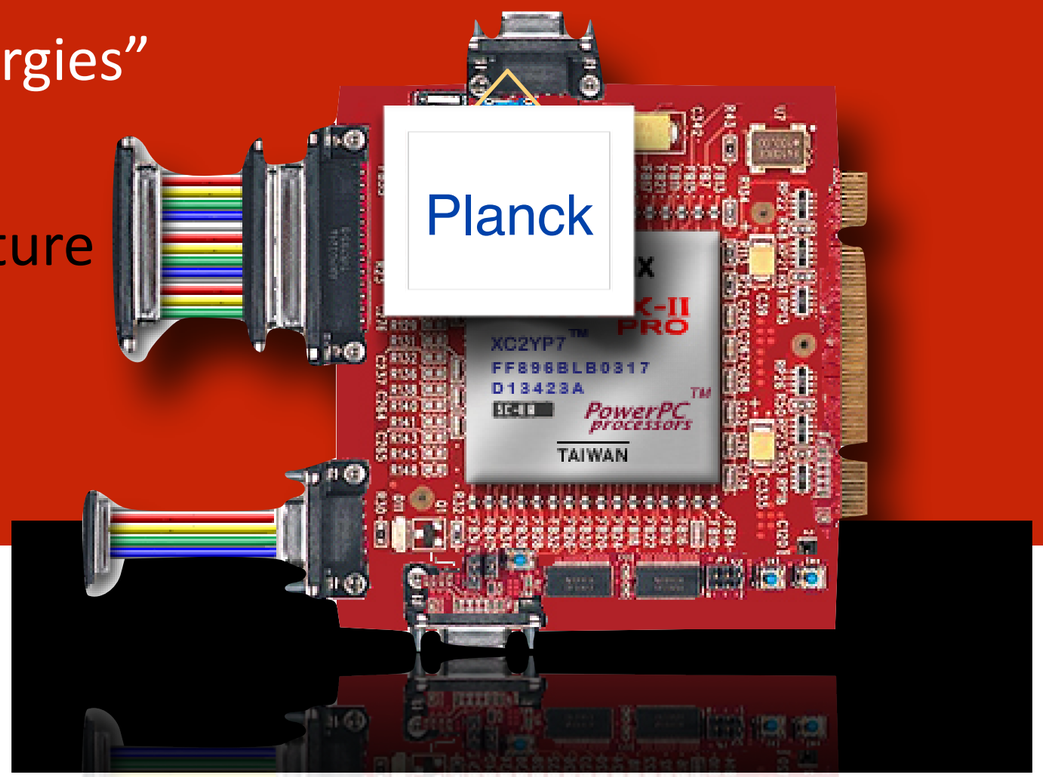
one of the good guys

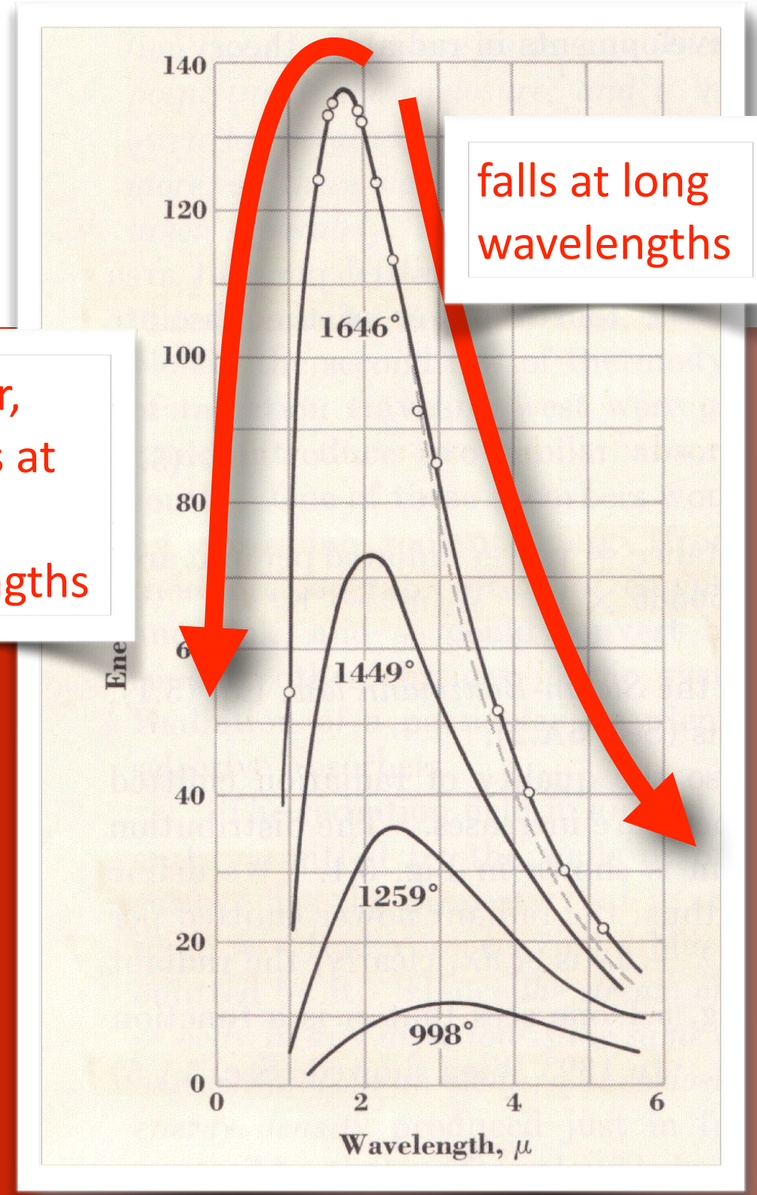
Planck could only get a solution

if he restricted energies of emitted electromagnetic radiation

"**bundled** energies"

temperature





long wavelength → ← high frequency

$$v = \lambda f$$

what in the world does that mean?

Good question:

“It was an act of desperation. For six years I had struggled with the blackbody theory. I knew the problem was fundamental and I knew the answer. I had to find a theoretical explanation at any price...”

Energy of radiation is parceled in particular amounts

Planck: “bundles

Philip Lenard 1902: "quanta"

Planck’s Law: $E = nhf$

$h = 6.62606896(33)\times10^{-34}$ J-sec

Planck’s Constant - itsy bitsy... n is an integer

energy of an electromagnetic wave

classically

and

Planck

before 1905 physics is often called "classical physics"

Before Planck:

2 "E's" going on...this one's "**energy**"

$$E(\text{classical}) \sim \mathbf{E}^2$$

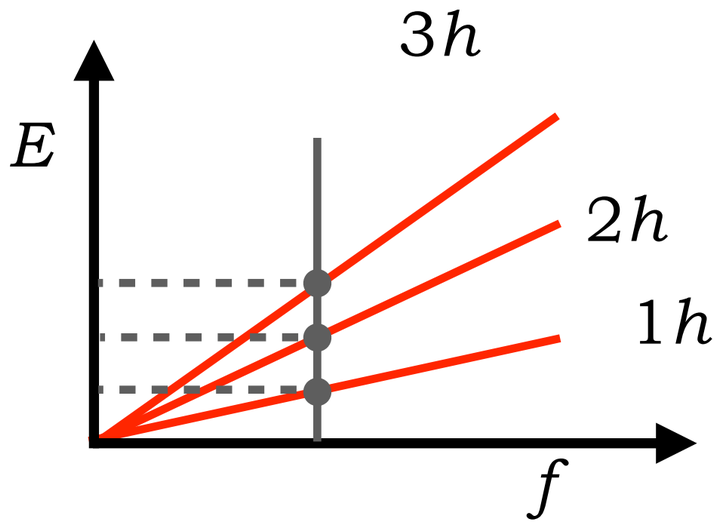
2 "E's" going on...this one's **Electric Field** vector

electric field vector magnitude $\mathbf{E}$ could be any amount

After Planck:

1 "E" going on...just "**energy**"

$$E(\text{modern}) = nhf$$



relation alert: **Planck's Law**

refers to: $E = hf$

Energy of radiation comes in a discrete amount for each frequency

example: photoelectric effect

constant of nature:

Planck's Constant, h

value: $h = 6.62606896(33)\times10^{-34}$ J-sec

units: Energy - time

usage: everything at atomic and smaller sizes

$$c = \lambda f$$

$$f = \frac{c}{\lambda}$$

for a given frequency (wavelength)

$$E = nhf$$

the only energies that can be radiated:

1hf, 2hf, 3hf, 4hf....

So, for 10 micron infrared wave, E = n(3 x 10^{-13}J)

E's must be = 3 x 10^{-13} J, 6 x 10^{-13} J, 9 x 10^{-13} J...

that is: 5 x 10^{-13} J, 7.8 x 10^{-13} J, etc are not possible

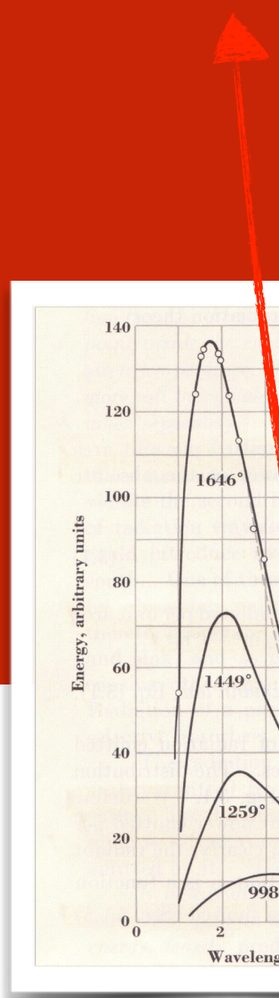
it’s as if

no matter how hard you pump

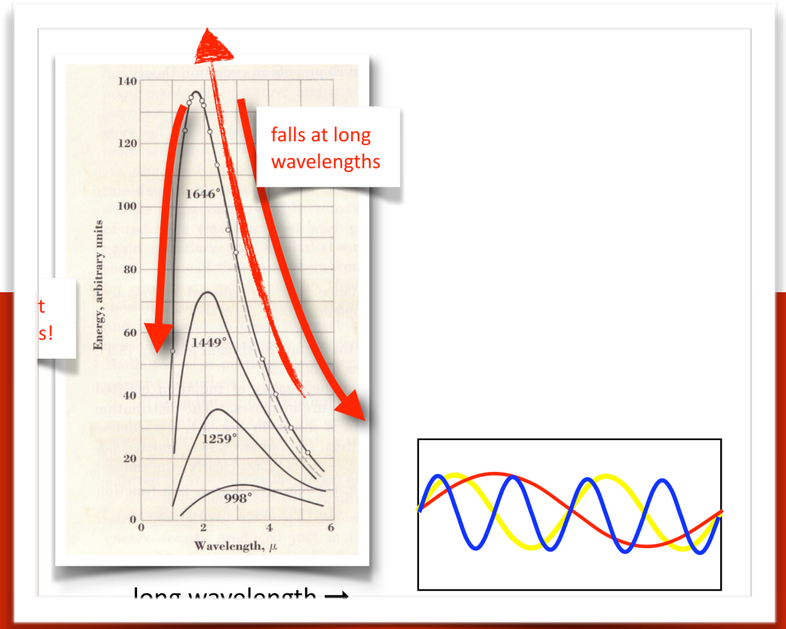
your amplitude is choppy

the lack of light at the short wavelengths

= high frequencies?



Classical radiation theory predicted an infinite amount of energy at high frequencies....the “Ultraviolet Catastrophe”



a maximum E, depending on temperature

Energy

classically,
all frequencies are probable

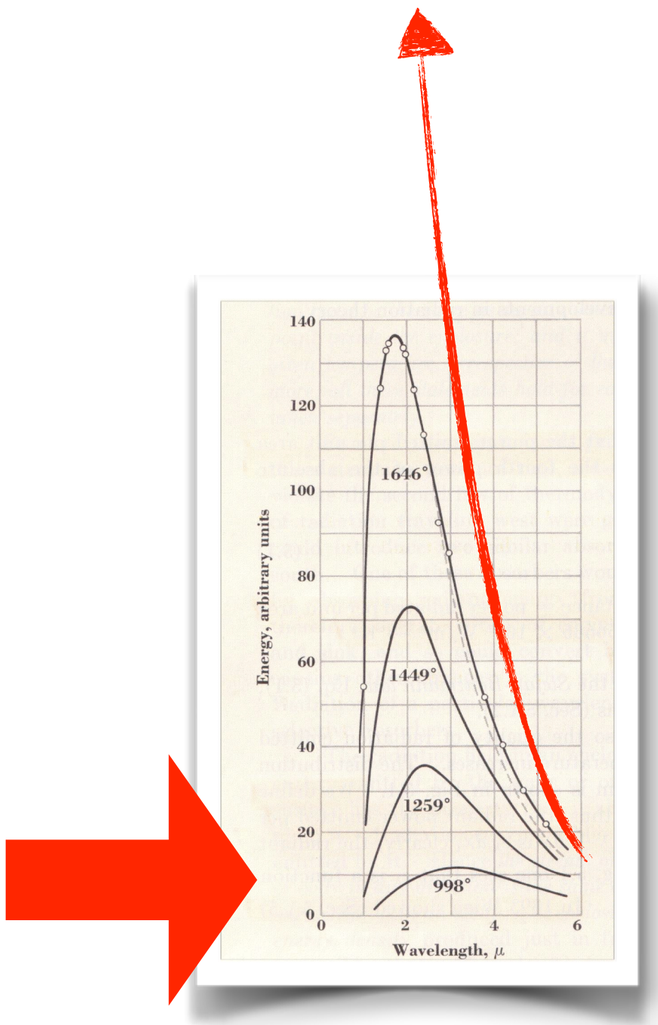
frequency

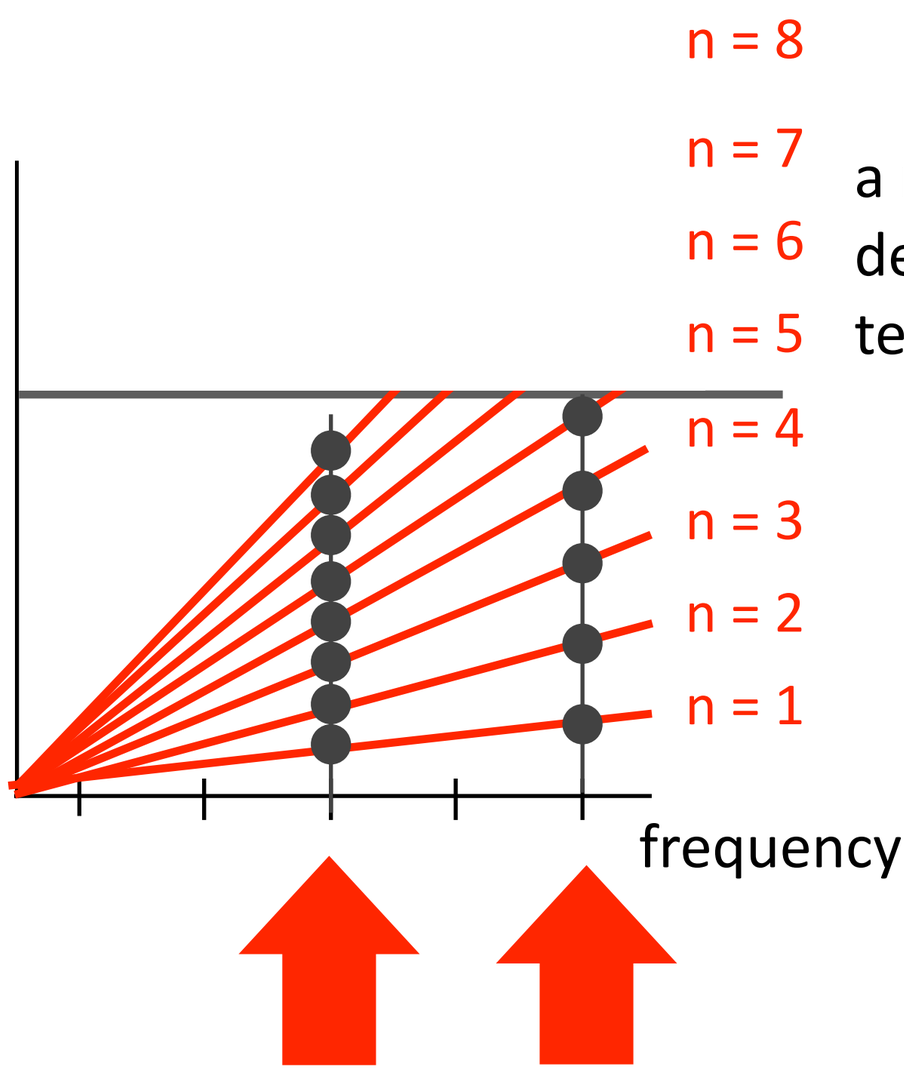
the lack of light at the short wavelengths

= high frequencies?

But, for Planck:

$$E = nhf$$





a maximum E, depending on temperature

The number of high frequency oscillations are much fewer than low frequencies:

each quantum has <u>more</u> <u>energy</u>...but there are <u>fewer of them</u>.

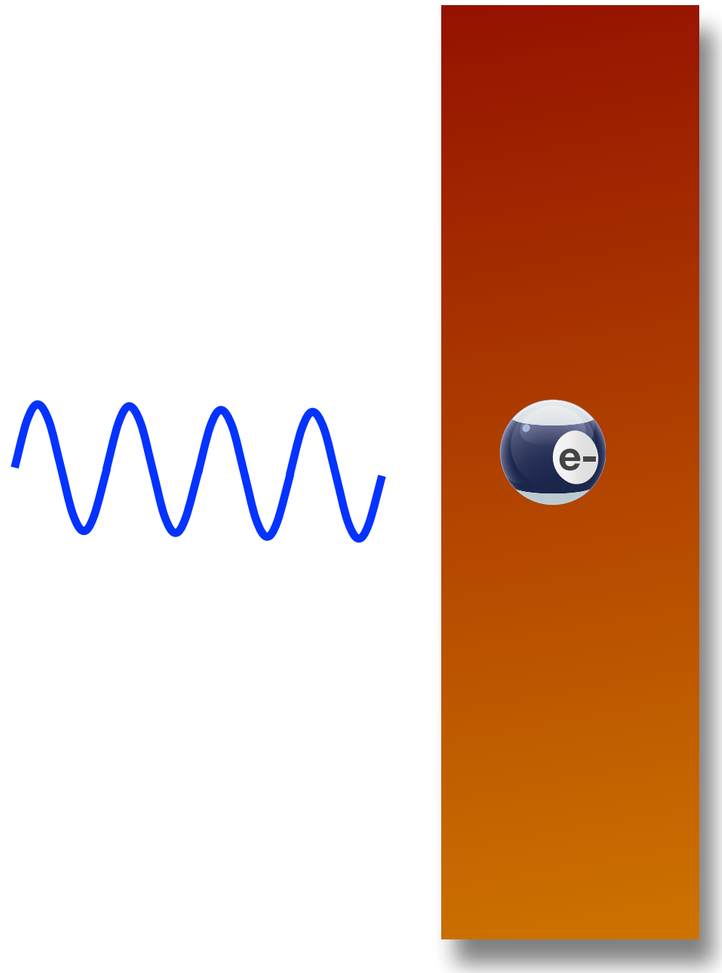
for Planck

electromagnetic waves

can still be anything

the radiator walls "quantize" emission

EM can be any frequency radiator (the container wall) can produce only particular frequencies



Not a statement about EM!
A statement about the material radiators of energy!

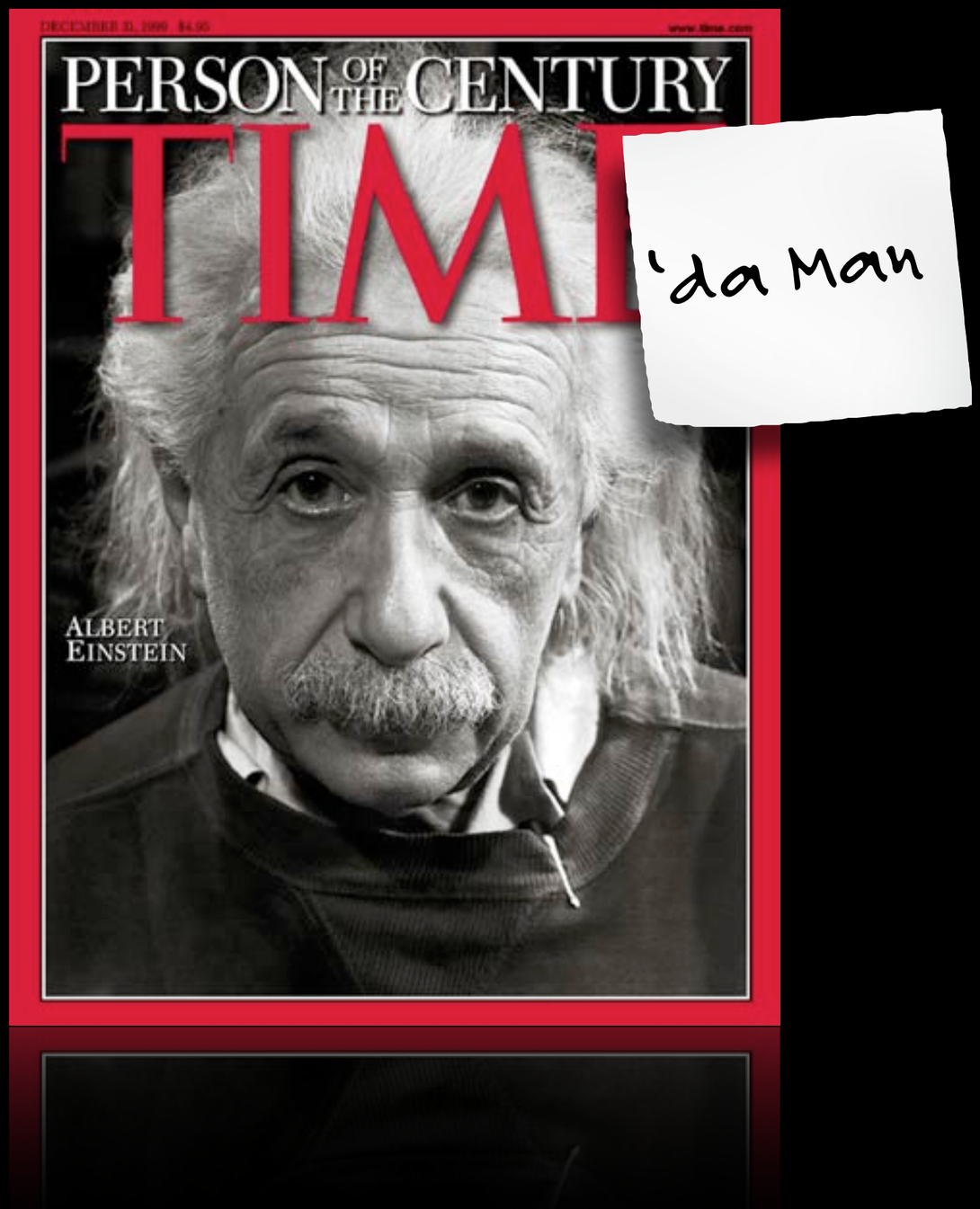
perfect analogy

sound

piano

sound can be any frequency
piano can produce only particular frequencies

Not a statement about sound!
A statement about pianos!



'da Man

He's Back

perfect analogy

sound

piano

sound can be any frequency

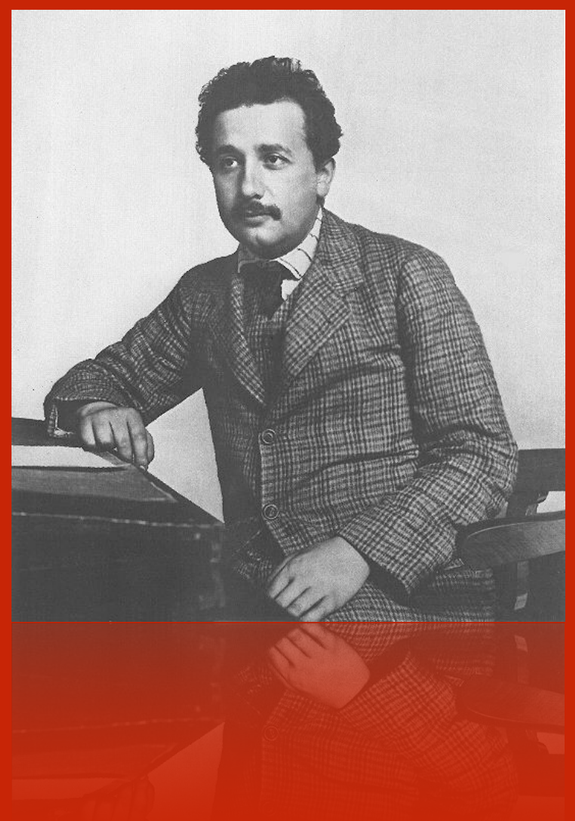
piano can produce only particular frequencies

Not a statement about sound!

A statement about pianos!

Einstein said:

in that famous 1905 year



Planck's bundles are not about the walls...the radiators

It is a statement about light (electromagnetism)

Light is itself "quantized"

....as particles:

these particles are called:

"photons," γ

they have no mass

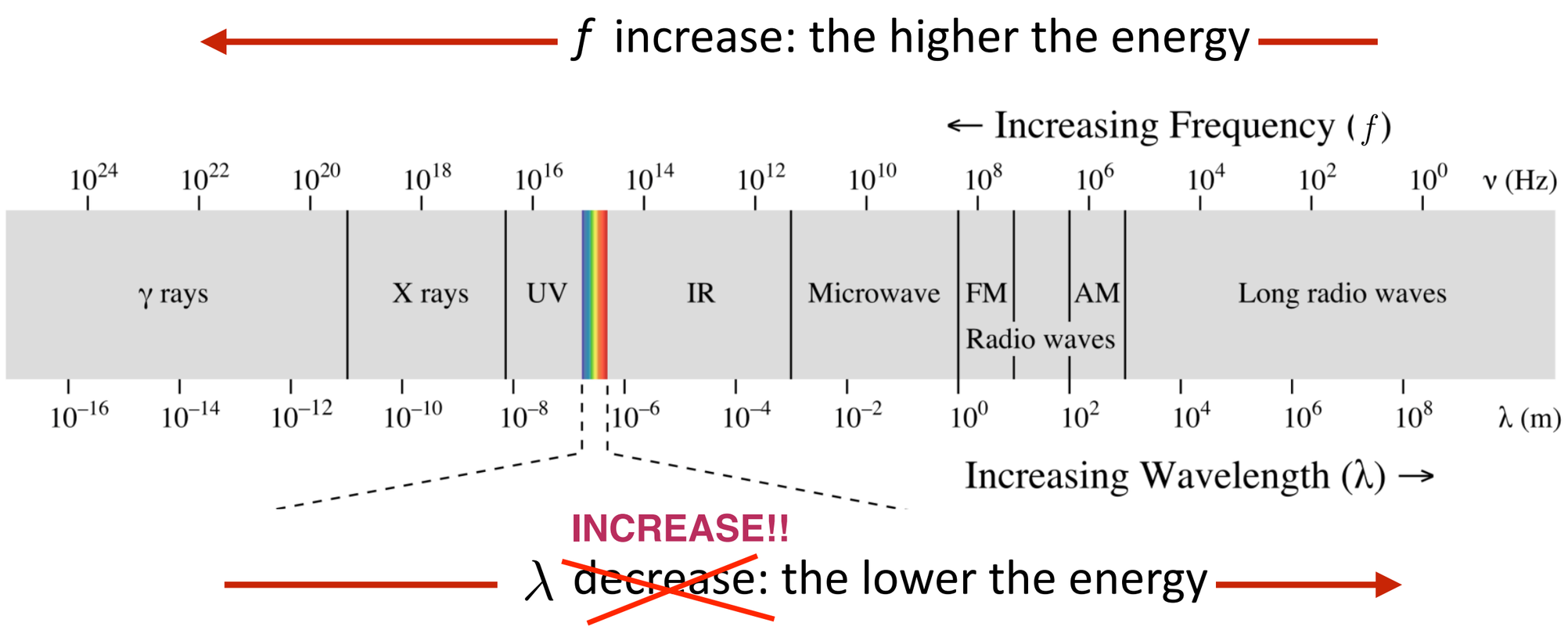
light particle energies

$E = hf$ the lower the frequency the lower the energy

the higher the energy the higher the frequency

$E = \dfrac{hc}{\lambda}$ the larger the wavelength the lower the energy

the higher the energy the smaller the wavelength



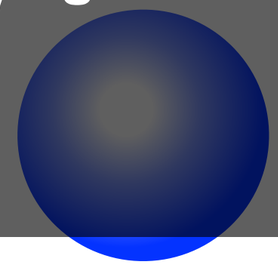
hold the phone.

A wave is EVERYWHERE

& light is a wave!

How could things so opposite be combined into one reality?

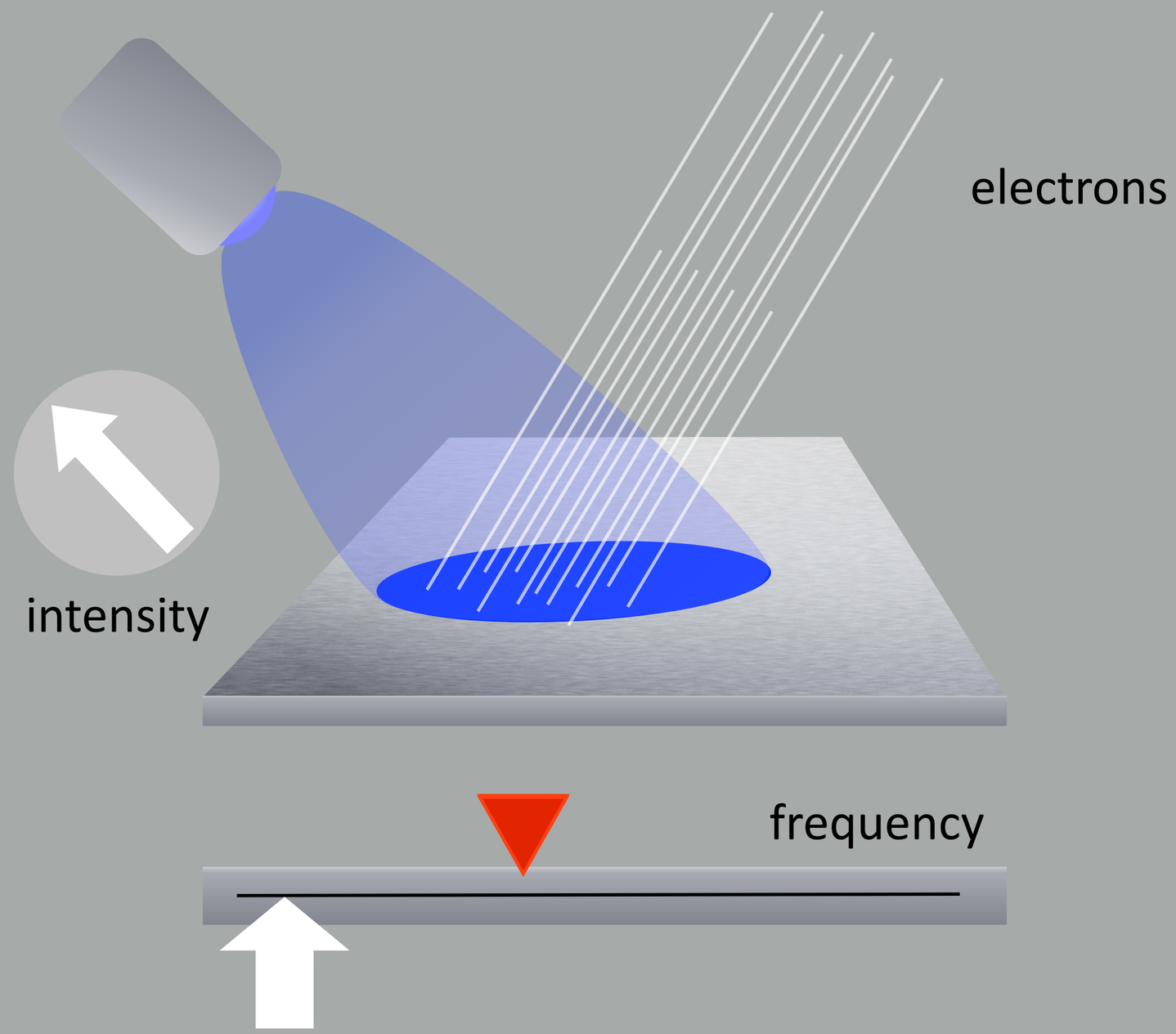
A particle is HERE:



Einstein was motivated by experiment: "photoelectricity"

found by Hertz in his confirmation of Maxwell's waves

Ultraviolet light causes electrons to stream from surface of some metals



The facts:	**The light-wave expectation:**
1. no electrons <u>until a particular frequency</u> *then, with higher frequency they come out with more energy*	huh?
2. raise the intensity...get <u>more</u> electrons	expect <u>higher energy</u> electrons

Using Planck's formula

E = hf

it makes sense.

the electrons are bound a little...so, they get released above a particular f - a particular E is required

The intensity is just more and more photons kicking more and more electrons

photoelectric effect

everywhere:

photodiodes

smoke detectors, CD players, remote controls...

photocells

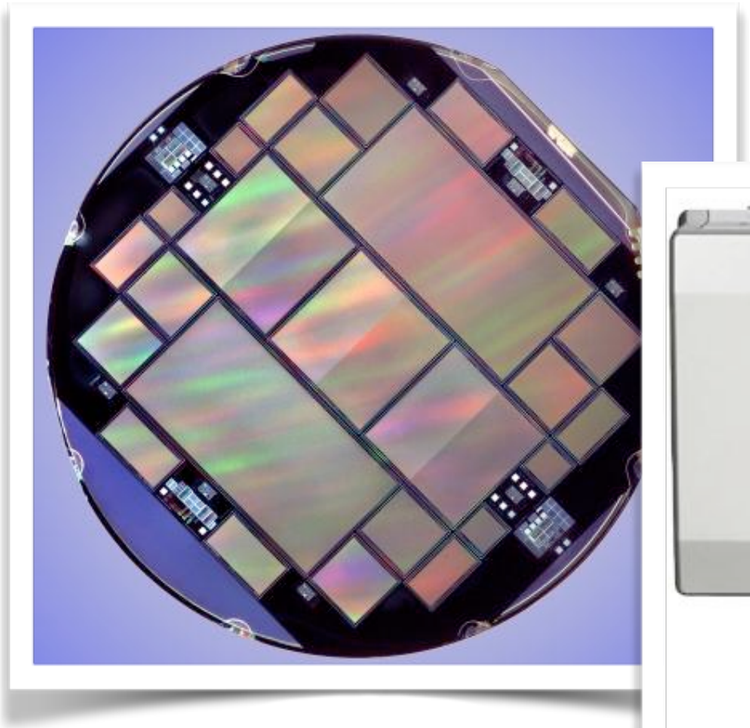
packed into "pixels" and arrays of pixels:

CCDs (charged coupled devices)

The facts:	The light-wave expectation:
1. no electrons until a particular frequency *then, with higher frequency they come out with more energy*	huh?
2. raise the intensity...get more electrons	expect higher energy electrons

53

that's a current



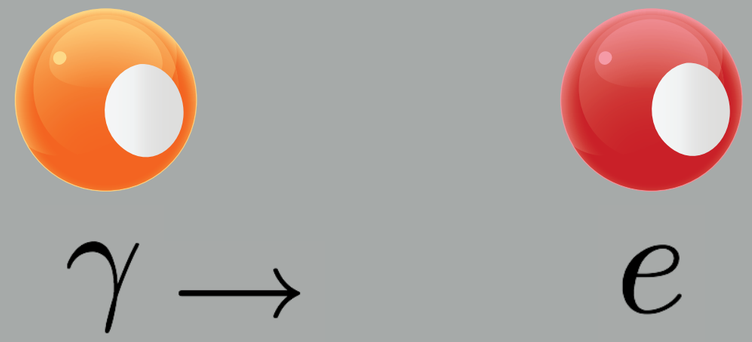
Einstein made a prediction: treat light like billiard-balls

and cause collisions

like particles

the photon loses energy γ

$$\gamma + e \rightarrow \gamma' + e'$$



$\gamma \rightarrow$ e

the electron gains energy e

this seals the deal

"Compton Effect"

measured in 1923

longer wavelength - lower energy

$$E = \frac{hc}{\lambda}$$

E_A

E_B

γ

e-

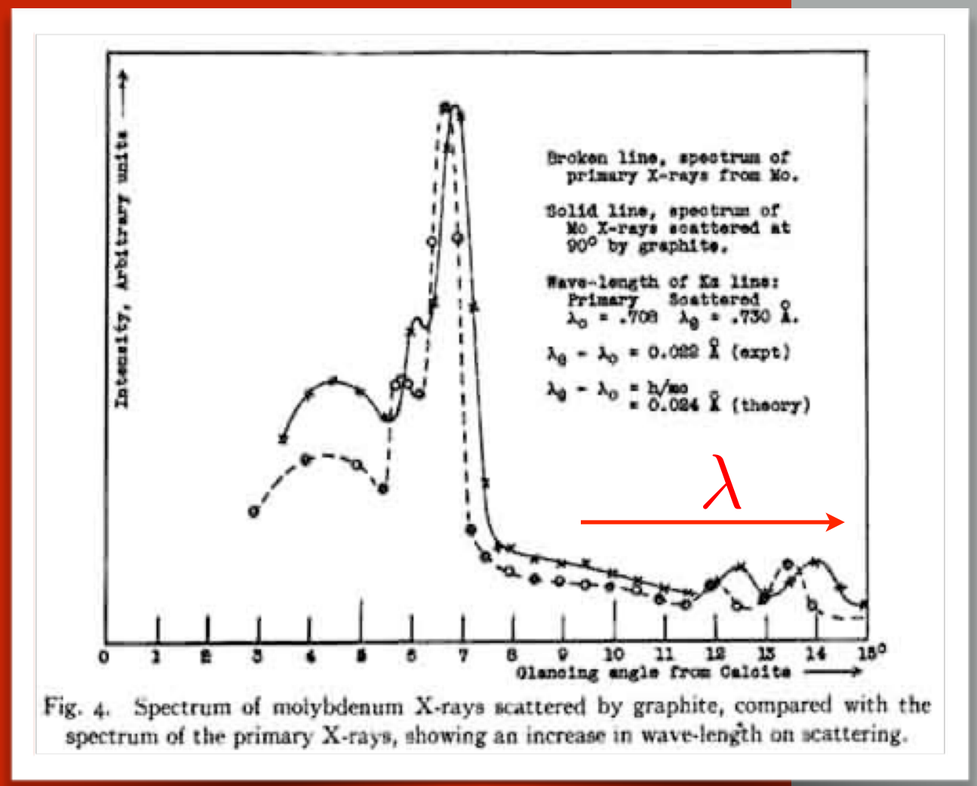


Fig. 4. Spectrum of molybdenum X-rays scattered by graphite, compared with the spectrum of the primary X-rays, showing an increase in wave-length on scattering.

$$\gamma + e \rightarrow \gamma' + e'$$

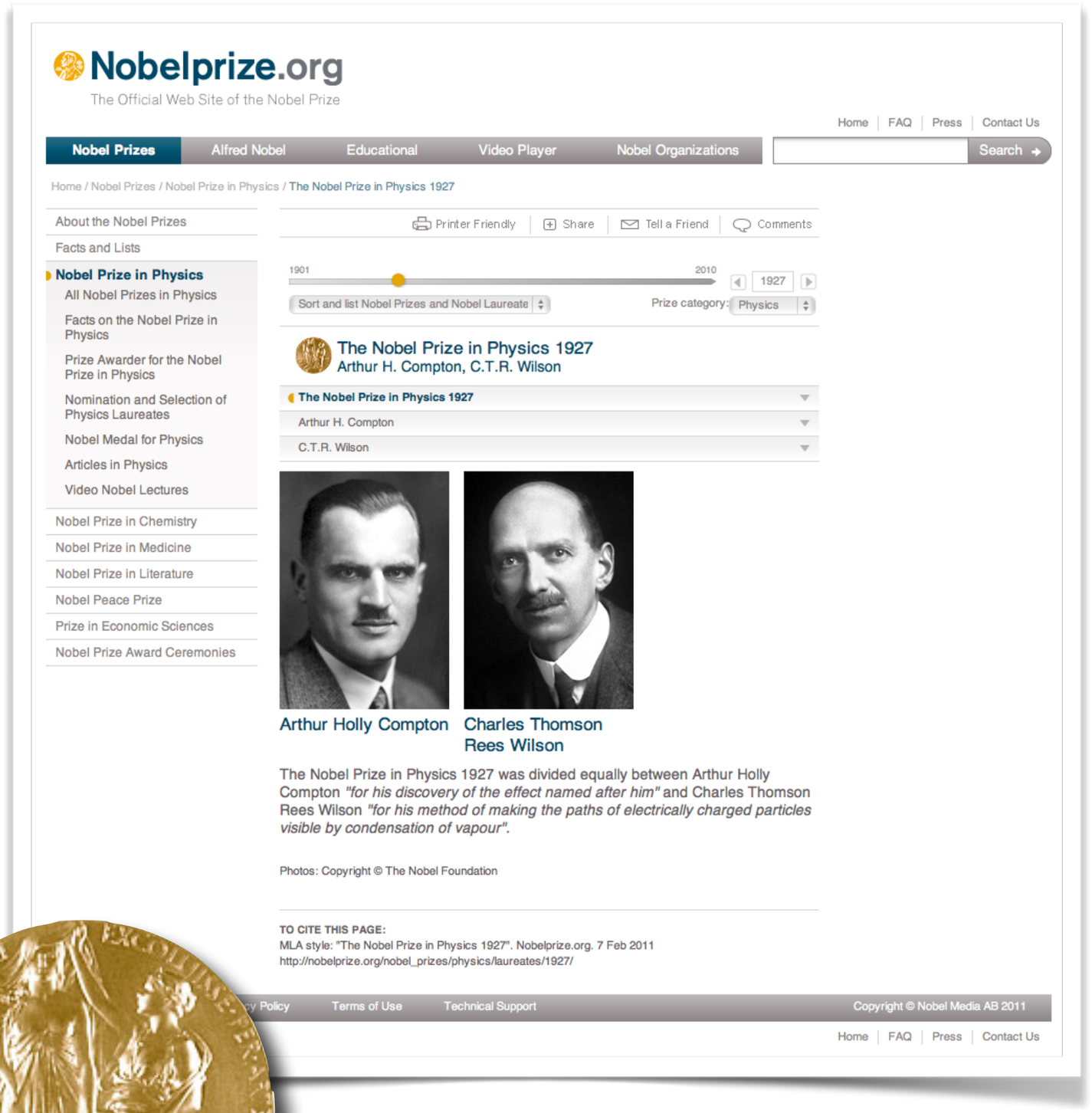
Called: Compton Scattering

E_A should be < E_B so $\lambda_A > \lambda_B$

‘‘Compy’’

I played with his grandson as a kid

which I find absolutely bizarre



our second elementary particle, 1923

the photon (aka “gamma”)

γ

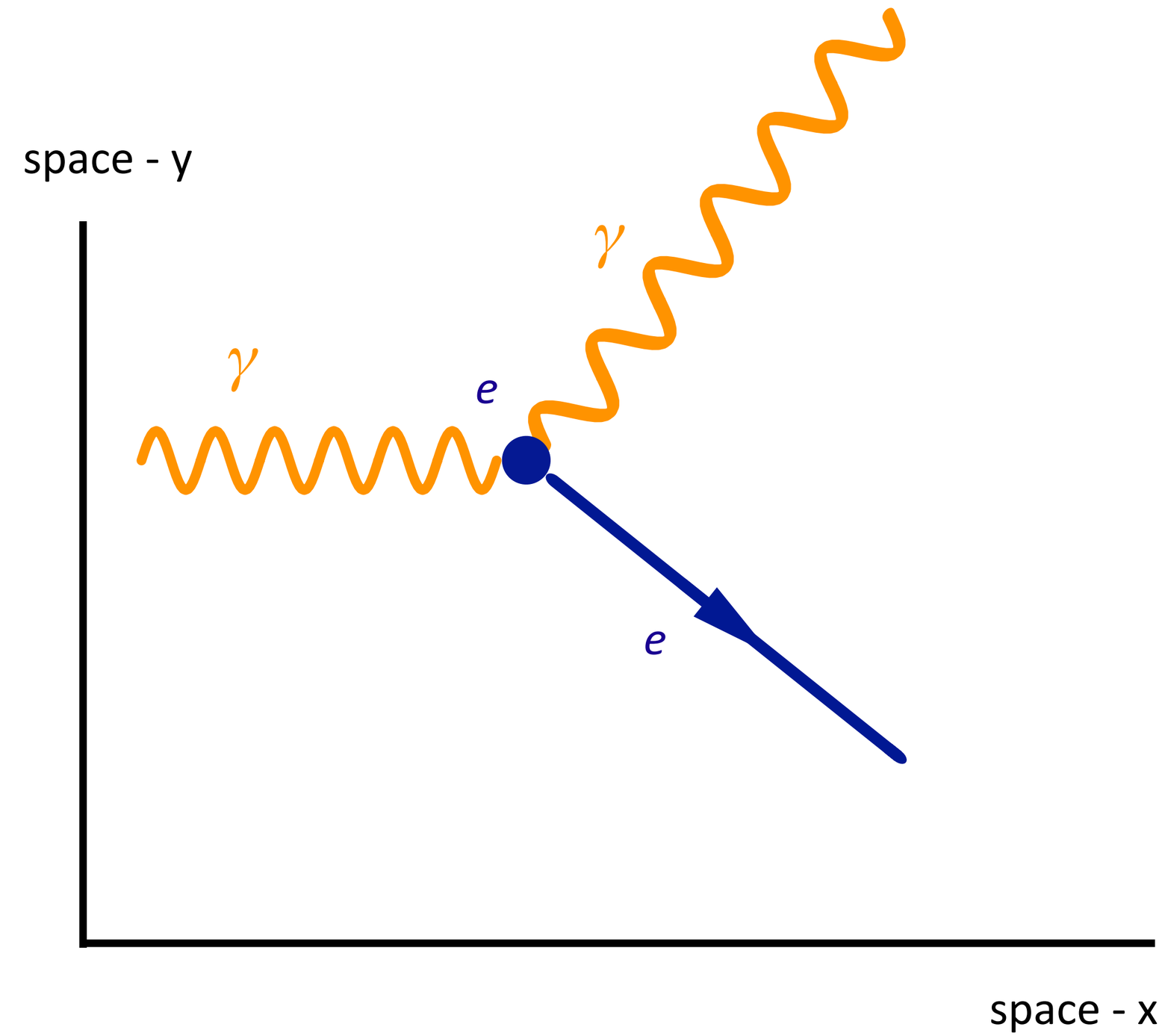
massless

particle:	**photon, γ**
symbol:	γ
charge:	0
mass:	0
spin:	1
category:	an intermediate vector boson, a messenger particle

Compton scattering

Space diagram

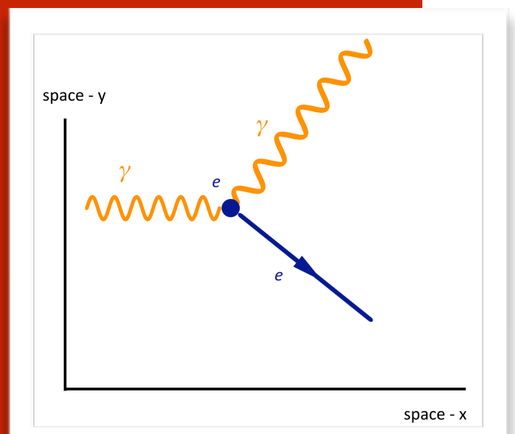
$$\gamma + e \rightarrow \gamma' + e'$$



Compton scattering

spacetime diagram

aka, *Feynman* diagram



draw the Feynman diagram for Compton Scattering

$$\gamma + e \rightarrow \gamma' + e'$$