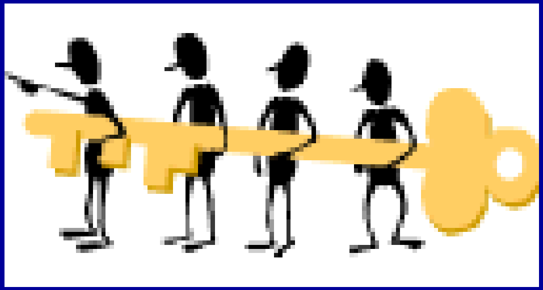
TOPIC # 6
The RADIATION LAWS

The KEY to unlocking the topics of:
The GREENHOUSE EFFECT,
GLOBAL WARMING &
OZONE DEPLETION!



TODAY: Topic #6 – Part I
pp 29-31

$E = \sigma T^4$

$(1/d^2)$

"The equations we seek are the poetry of nature . . . . Why is nature that way?

Why is it possible for these powerful manifestations of forces to be trapped in a very simple, beautiful formula?"

"This has been a question which many people have discussed, but there is no answer."

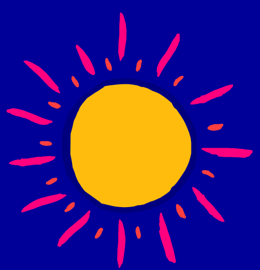
~ Chen Ning Yang (b. 1922) US physicist

$E = h c / \lambda$

$\lambda_m = a/T$

OBJECTIVES FOR TODAY'S CLASS:

To understand the key differences between



Solar radiation

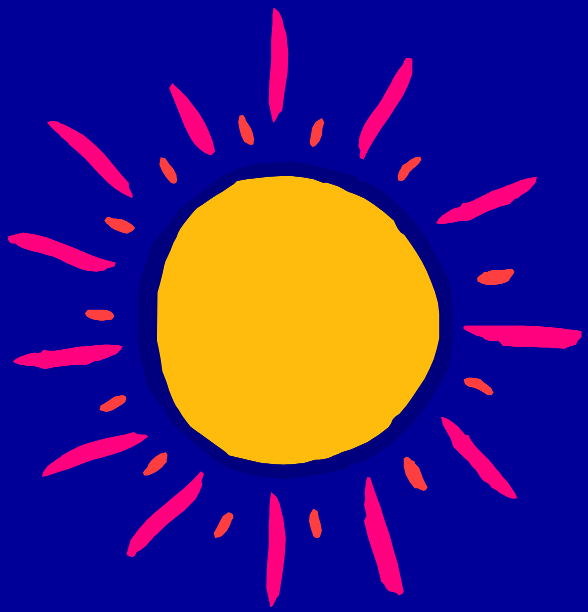
&

Terrestrial radiation

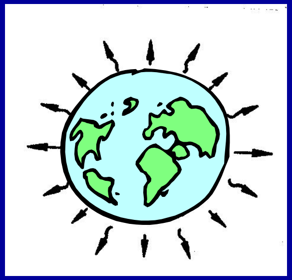
based on the principles of the <u>**"Radiation Laws."**</u>

A "cartoon" view of Solar vs Terrestrial radiation:

Both Sun & Earth are radiating energy . . . .

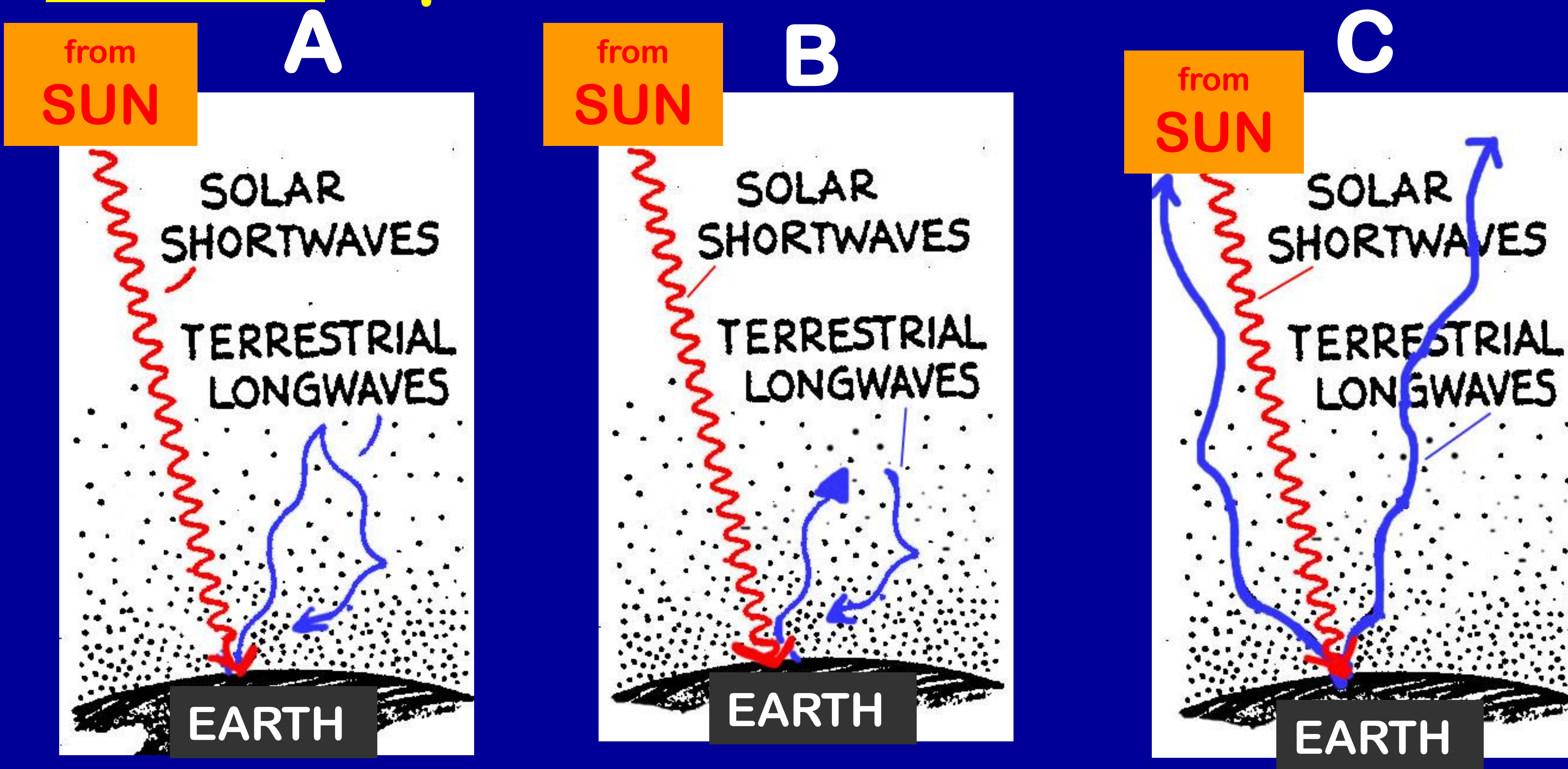


(Sun & Earth are NOT shown in proper scale!)



Fire up your clickers . . . . Channel 32

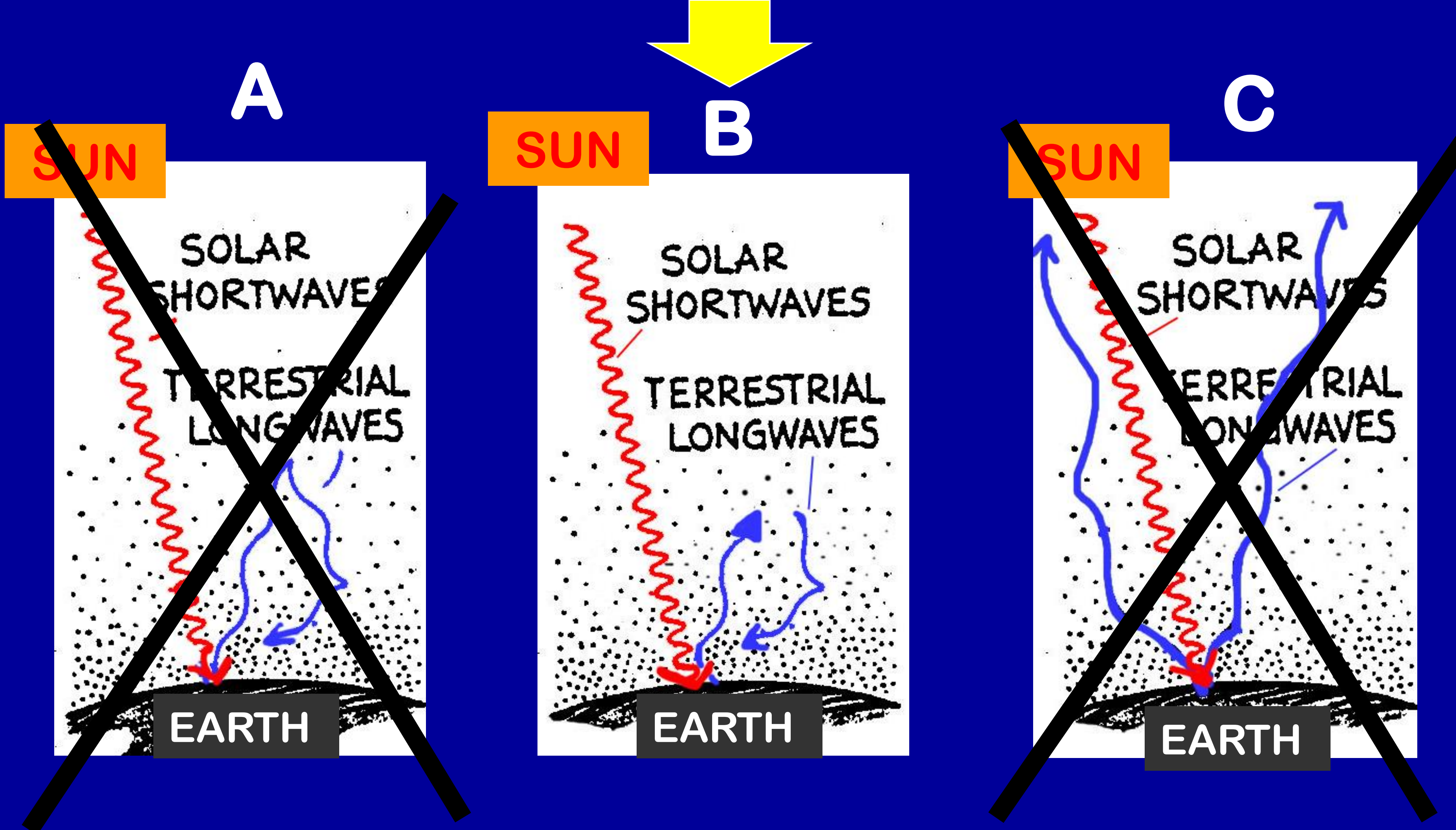
Warm up question: **Which one do you think is the <u>most accurate</u> depiction of the Greenhouse Effect??**



= gases in the atmosphere

= solar (shortwave) radiation (High Energy)

= terrestrial (longwave) radiation (Lower Energy)

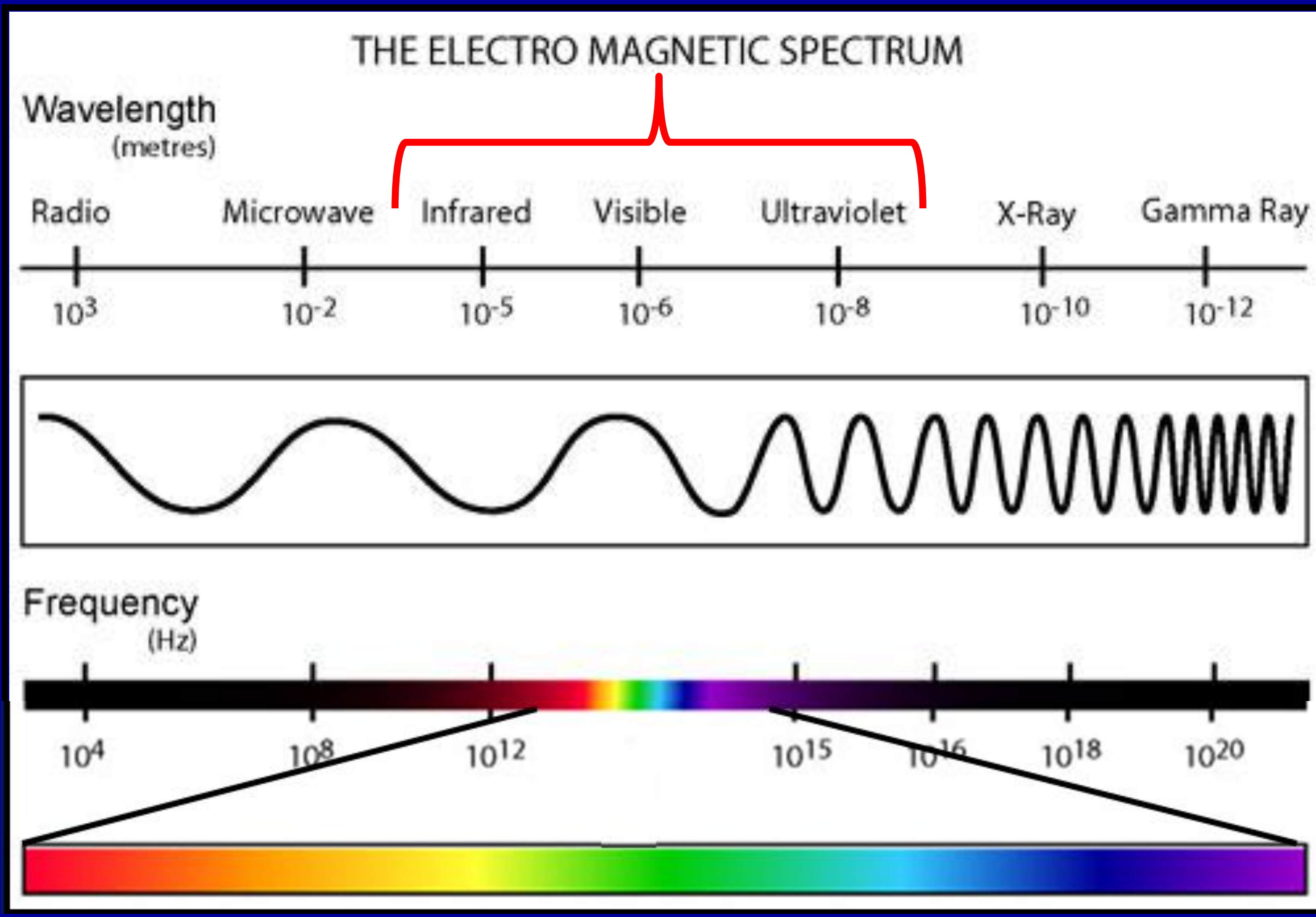


Actually, NONE of these is <u>exactly</u> correct, and we will learn why in a future lecture. . . .

but for now, B is the preferred answer

see the image on bottom of p 27 in Class Notes.

REVIEW . . . .



R O Y G B (I) V

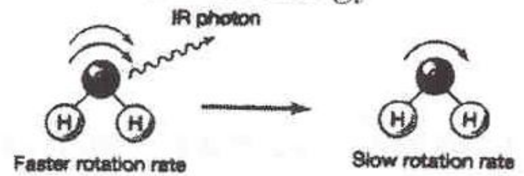
KEY BANDS IN THE SPECTRUM FOR GLOBAL CHANGE:

UV, Visible, IR, NIR,

Type of Electromagnetic Radiation	Range of Wavelengths (in units indicated)	Typical Source
Gamma rays	10^{-16} to 10^{-11} in meters (m) using scientific notation	high-energy processes within nucleus caused by the strong force
Ultraviolet radiation	.0001 to 0.4 in micrometers (µm)	electrons moving (quantum leaps) within individual atoms
Visible light	0.4 to 0.7	
Infrared radiation		chaotic thermal kinetic motion of molecules due to their thermal energy
Near Infrared radiation		
Far Infrared		
Microwaves	10^{-4} to 10^{-2} in meters (m) using scientific notation	electronically produced by microwave oven
AM Radio waves	10 to 10^{2} in meters (m) using scientific notation	electronically produced -- waves vibrate in human-made electrical circuits

Solar SW

Terrestrial LW (IR)



Review p 28

Presenting . . . .

THE RADIATION LAWS !!!

Keys to Understanding the Greenhouse Effect

☺

LAW #1

Emission of radiation

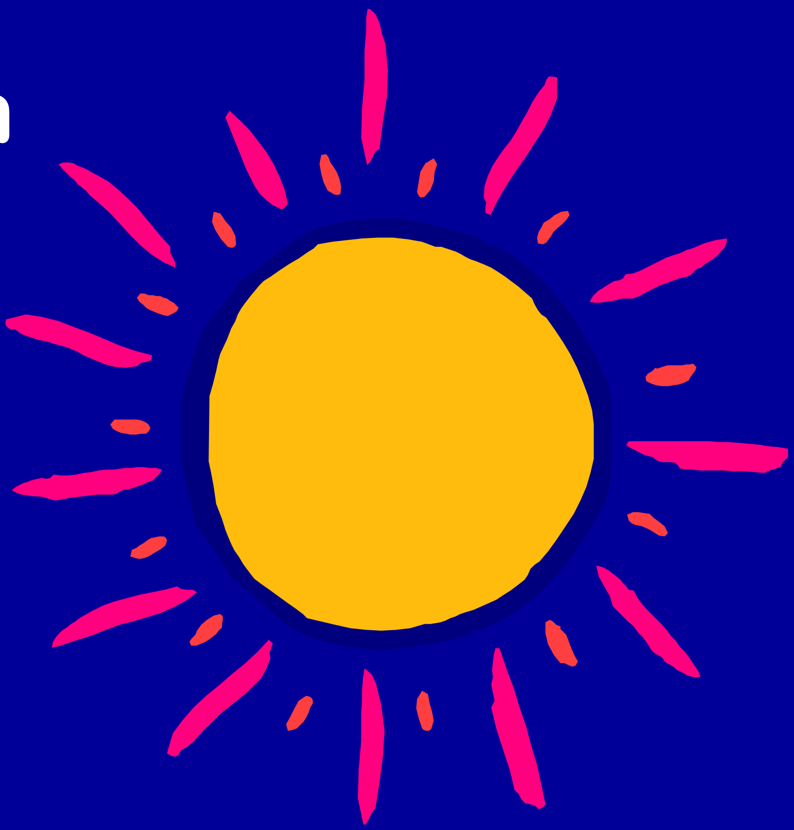
<u>All</u> substances emit radiation as long as their temperature is above absolute zero

(-273.15^{o}C or 0 **Kelvin**).

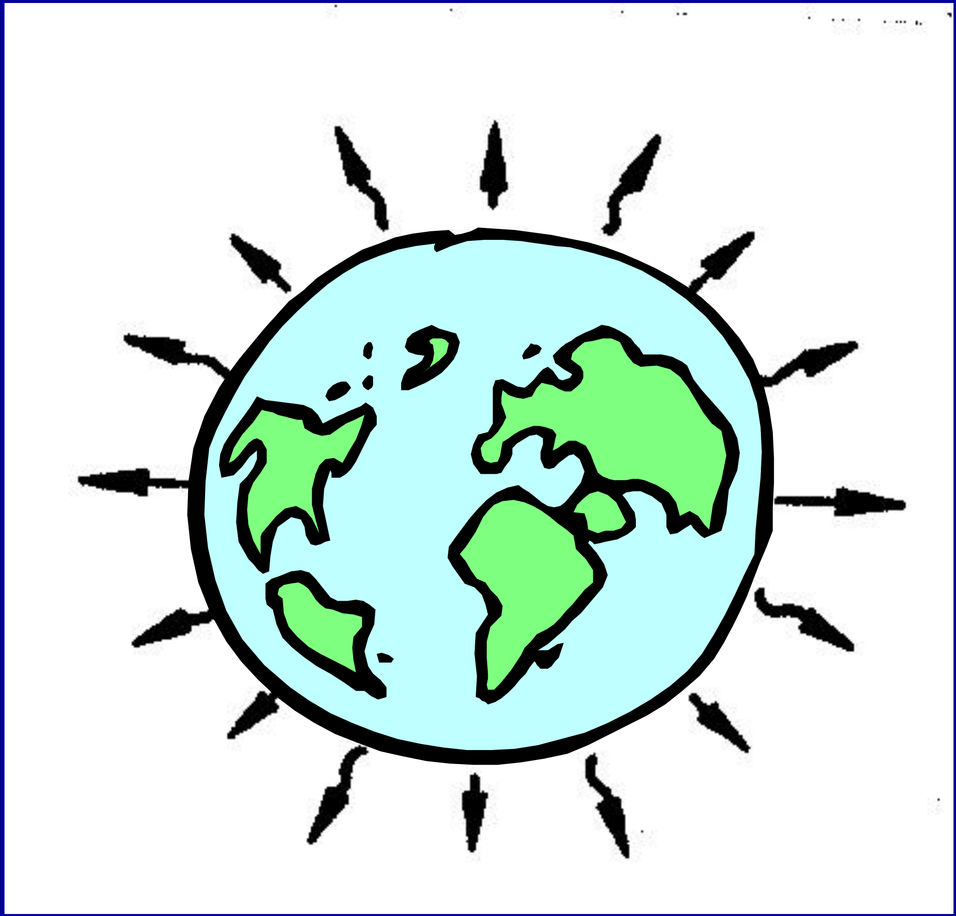
TYING THE RADIATION "LAWS" to GLOBAL CHANGE

The **Sun**'s energy **(solar)** is emitted in the form of electromagnetic radiation.

mostly
Shortwave (SW)
(but also some LW)



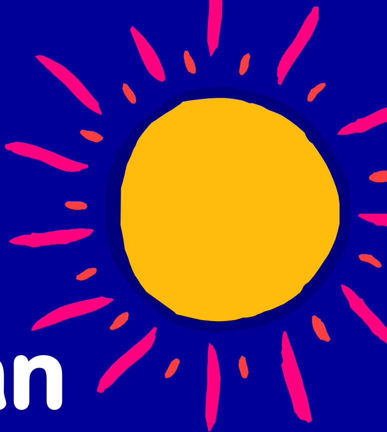
The Earth's energy (terrestrial) is also emitted in the form of electromagnetic wavelengths . . .



but in LW INFRARED (IR) wavelengths

☺

LAW #2 BLACKBODY & PLANCK FUNCTION CONCEPT



The Sun is very similar to an "ideal emitter" (or "Black body")

(NOTE: the Earth is NOT as good a "black body" as the Sun)

Black body (def): a body that **emits** equally well at **all wavelengths**

(i.e. radiates with 100% efficiency)

It also **absorbs** equally well at all wavelengths and is a **"perfect absorber"**

(hence described as "black")

Blackbodies ("ideal emitters") exhibit a *defined relationship* between:

the intensity of radiation energy (E)
(i.e. amount of radiation flux) they give off
&
the wavelength of that radiation.

This relationship is called the Planck function :

E = h * speed of light / wavelength

Where (h) is Planck's constant.

or

$$E = h\,c / \lambda$$

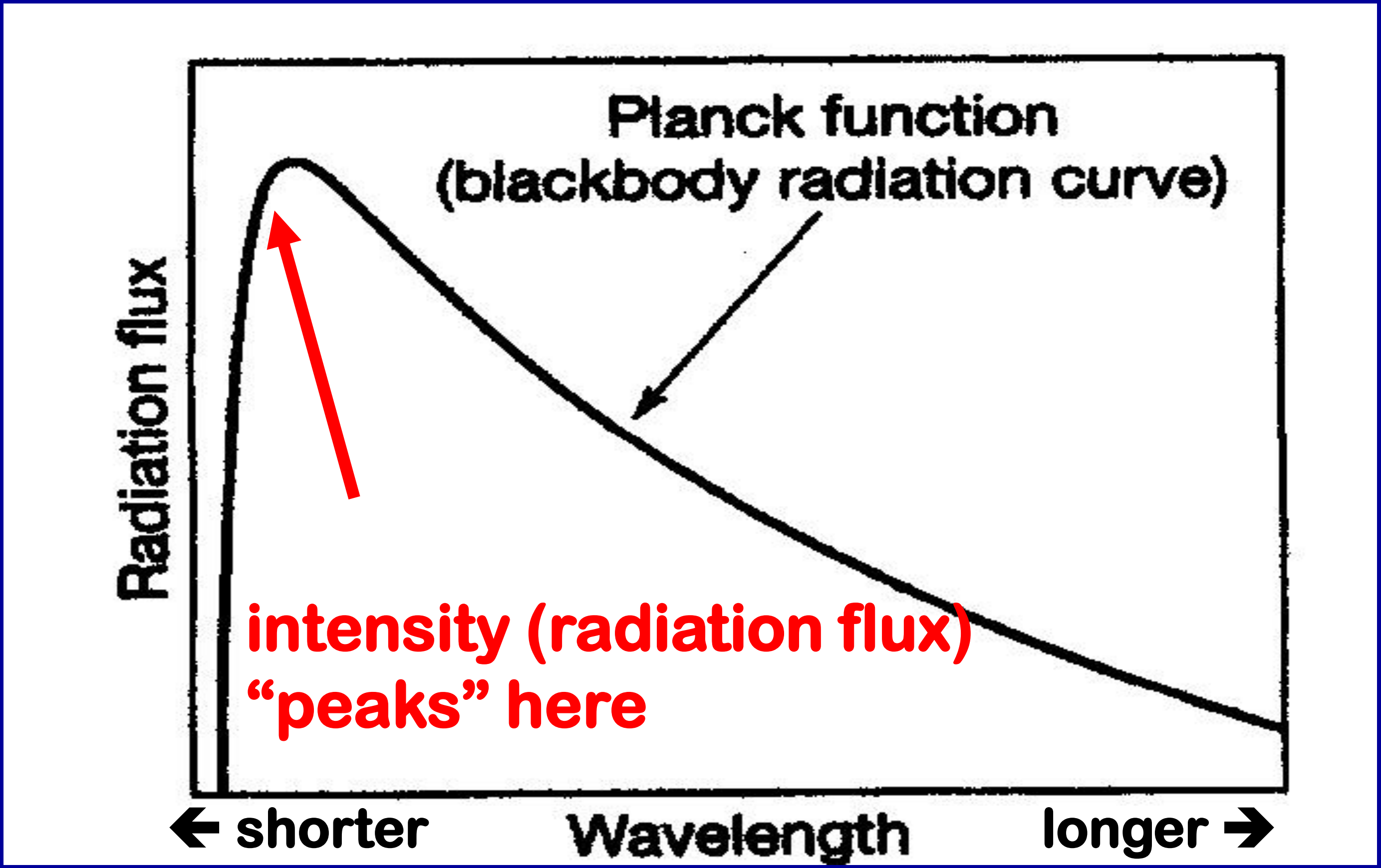
Planck Function:

The Sun emits energy at ALL wavelengths . . .

but the **amount** of **Energy** emitted is **inversely related** to the wavelength of emission

"I radiate at the speed of light like a blackbody; but my energy flux is GREATEST at SHORTER wavelengths"

This can be depicted in a graph:



An emitting blackbody's SHORTER wavelengths have HIGHER intensity radiation (and greater energy flux) than the LONGER wavelengths

Easy way to remember the PLANCK FUNCTION / BLACKBODY concept:

“The shorter the wavelength, the GREATER the intensity of the energy flux”

☺

Q1 - Gamma radiation involves a greater energy flux than microwave radiation.

1. True
2. False
3. Both wavelength bands have the same energy flux
4. We haven't learned enough yet to answer this!

☺ **Record your Q1 answer now**

Q1 - Gamma radiation involves a greater energy flux than microwave radiation.

1. True
2. False
3. Both wavelength bands have the same energy flux
4. We haven't learned enough yet to answer this!

LAW #3: THE STEFAN-BOLTZMANN LAW:

If the substance is an ideal emitter (black body),

The total **AMOUNT** of radiation given off is proportional to the fourth power of its absolute **TEMPERATURE.**

$$E = \sigma T^4$$

where σ is a constant (the Stefan-Boltzmann constant) which has a value of

5.67×10^{-8} W/m^{-2}

(or 5.67×10^{-8} J / m^2)

and *T* is the absolute temperature

(in Kelvin)

$$\text{Energy} = \sigma T^4$$

Stefan-Boltzmann Law (easy way)

This law links:

(E) the total amount of energy flux that is emitted by a blackbody & (T) the body's temperature

(specifically, the 4th power of the body's absolute temperature)

"the hotter the body, the (much) greater the amount of energy flux or radiation"

The **total amount of energy** flux described by the Stefan-Boltzmann Law is proportional to the **area under the Planck function curve**

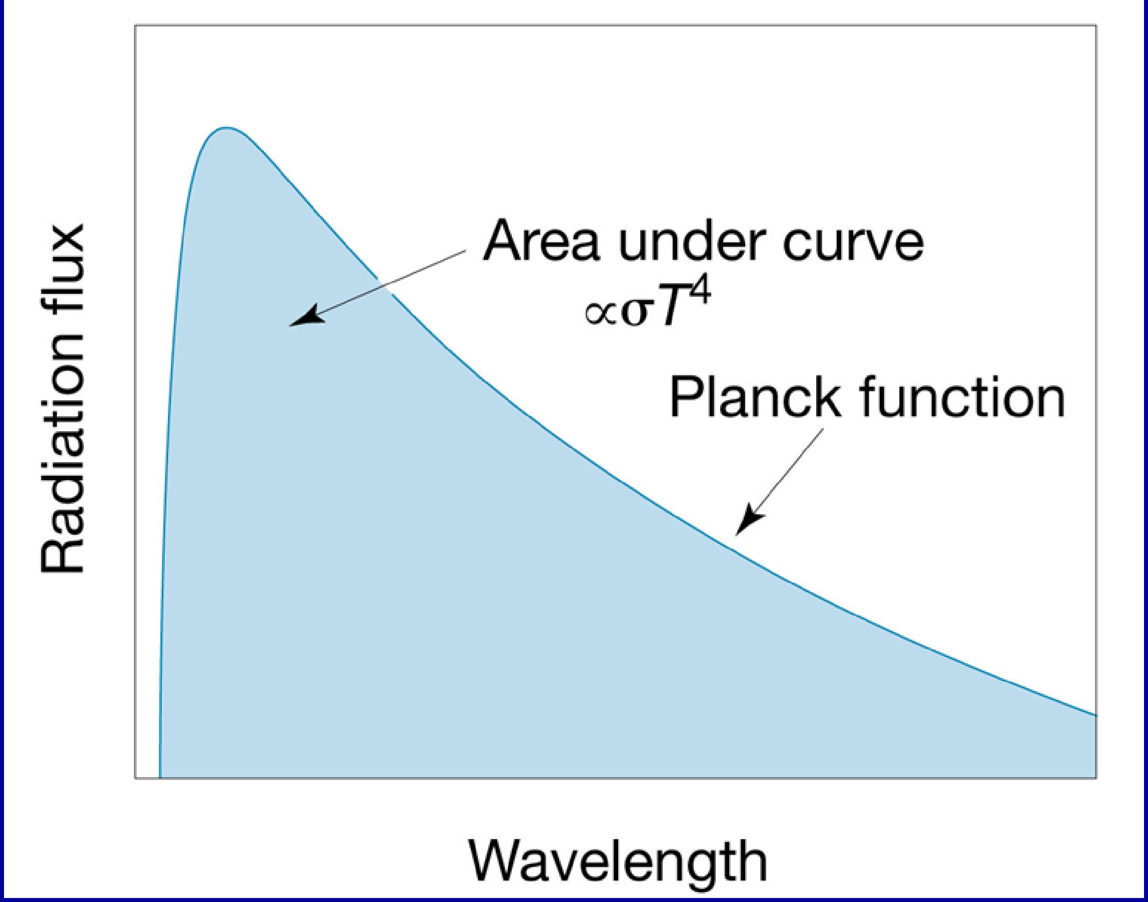


Figure on p 42 in SGC E-text

Stefan-Boltzmann Law:

"I'm HOT, so I emit LARGE amounts of high intensity energy"

"I'm COOL, so I emit much LESS energy . . .AND <u>MY</u> energy is at a lower intensity than Mr. Sun over there!"

Why is this concept important?

Because it means that:

the **amount** of radiation
given off by a body
is a very *sensitive* function
of its **temperature**

Therefore . . . small changes in temperature can lead to BIG changes in the amount of radiation given off.

$$E = \sigma T^4$$

Q2 – Which would you use:
the Planck Function or the Stefan-Boltzmann Law
to accurately compute
the total amount of ENERGY
emitted to space by planet Earth?

1. The Planck Function
2. The Stefan Boltzmann Law
3. Both of them together
4. Neither one is appropriate because the Earth is NOT a blackbody

☺ **Record your Q2 answer now**

Q2 – Which would you use:
the Planck Function or the Stefan-Boltzmann Law
to accurately compute
the total amount of ENERGY
emitted to space by planet Earth?

1. The Planck Function
2. The Stefan Boltzmann Law
3. Both of them together
4. Neither one is appropriate because the Earth is NOT a blackbody

Q3 – Which would you use:
the Planck Function or the Stefan-Boltzmann Law
to compute the total amount of energy
emitted to space by planet Earth,
IF you assume the Earth emits like a blackbody
& you know the Earth's temperature?

1. The Planck Function

2. The Stefan Boltzmann Law

3. Neither one is appropriate because you would need to know the wavelengths of radiation the Earth emits

4. Don't know

☺ **Record your Q3 answer now**

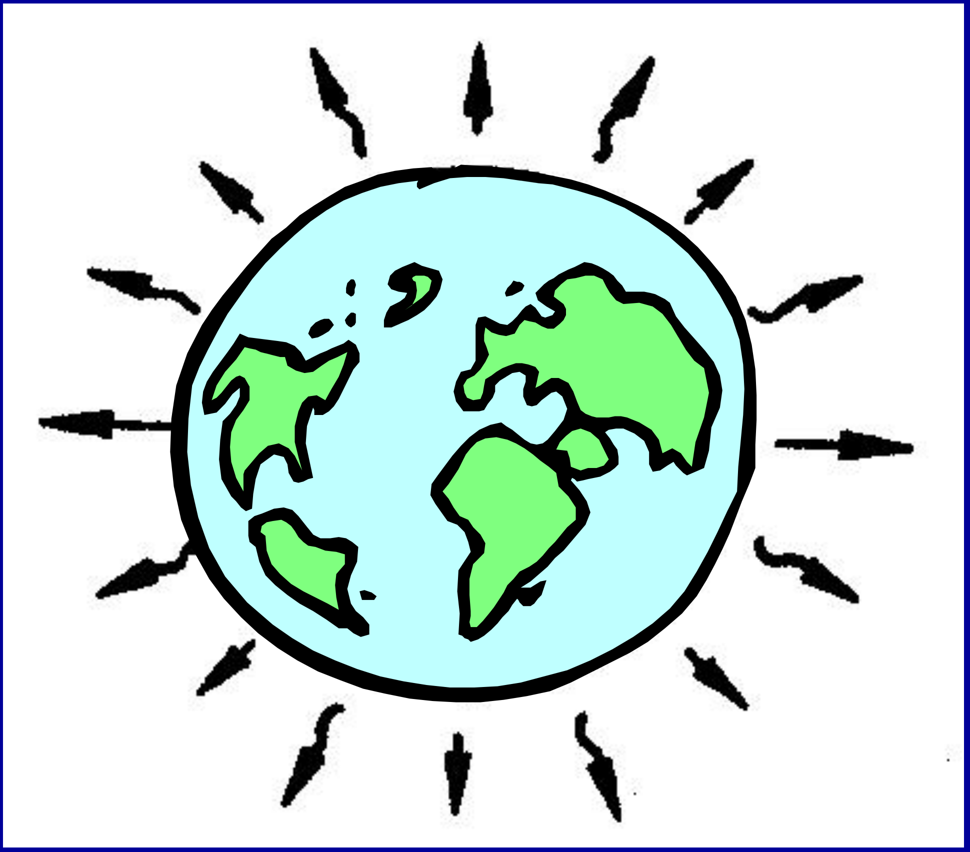
Q3 – Which would you use: the Planck Function or the Stefan-Boltzmann Law to compute the total amount of energy emitted to space by planet Earth, IF you assume the Earth emits like a blackbody & you know the Earth's temperature?

1. The Planck Function
2. The Stefan Boltzmann Law
3. Neither one is appropriate because you would need to know the wavelengths of radiation the Earth emits
4. Don't know

How to do it:

$$E = \sigma T^4$$

E = **Energy per unit area**, so all we need to know is the **AREA** of the emitting Earth's surface + what T is.



From geometry:
Do you remember the formula for computing the area of a sphere?

The area of a sphere of radius R is

$$4 \pi R^2$$

$$E = 4 \pi R^2 \times \sigma T^4$$

See box on p 44 in SGC E-text for more details

10 minute
SUSTAINABILITY SEGMENT

more of:

Then . . . MORE CLICKER PARTICIPATION POINTS

LAW # 4: Temperature and wavelength

As substances get HOTTER, the wavelength at which radiation is emitted will become SHORTER.

This is called Wien's law.

Wien's Law can be represented as:

$$\lambda_m = a/T$$

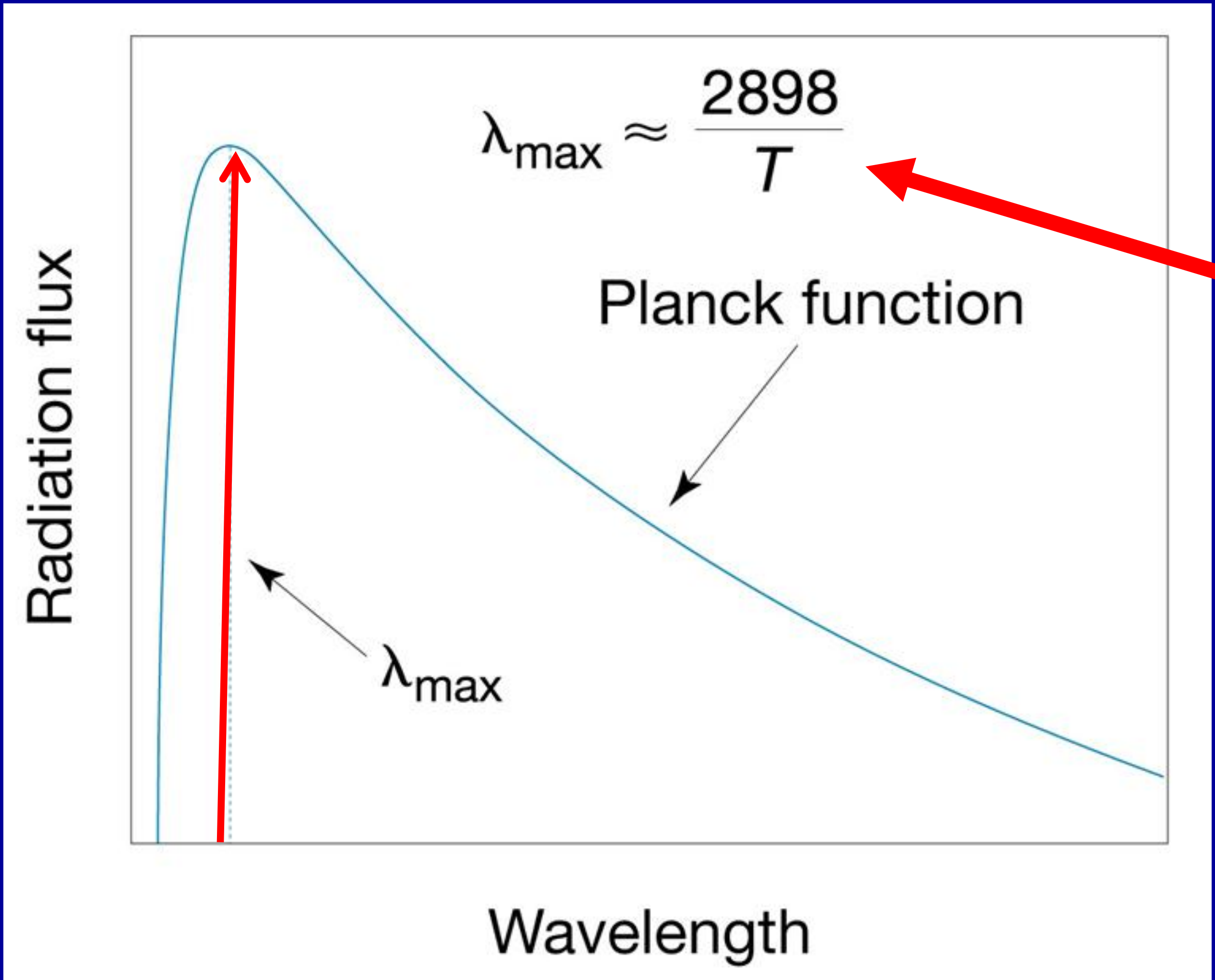
where λ_m is the **WAVELENGTH** in the spectrum at which the energy peak occurs,

(m indicates "max")

T is the absolute **TEMPERATURE** of the body, and

a is a **constant** (with a value of 2898)

(if λ_m is expressed in micrometers.)



Note the INVERSE relationship between wavelength and temperature

See figure on p 42 in SGC

Wien's Law (easy way)

λ_{max} = constant / T

(Inverse relationship between wavelength and temperature)

"The <u>hotter</u> the body, the <u>shorter</u> the wavelength"

"The <u>cooler</u> the body, the <u>longer</u> the wavelength"

Wien's Law -- Why is this concept important?

Because it means that very HOT objects (like the sun) that radiate like blackbodies will radiate the maximum amount of energy at SHORT wavelengths,

while COOLER bodies will radiate most of their energy at LONGER wavelengths.

p 30

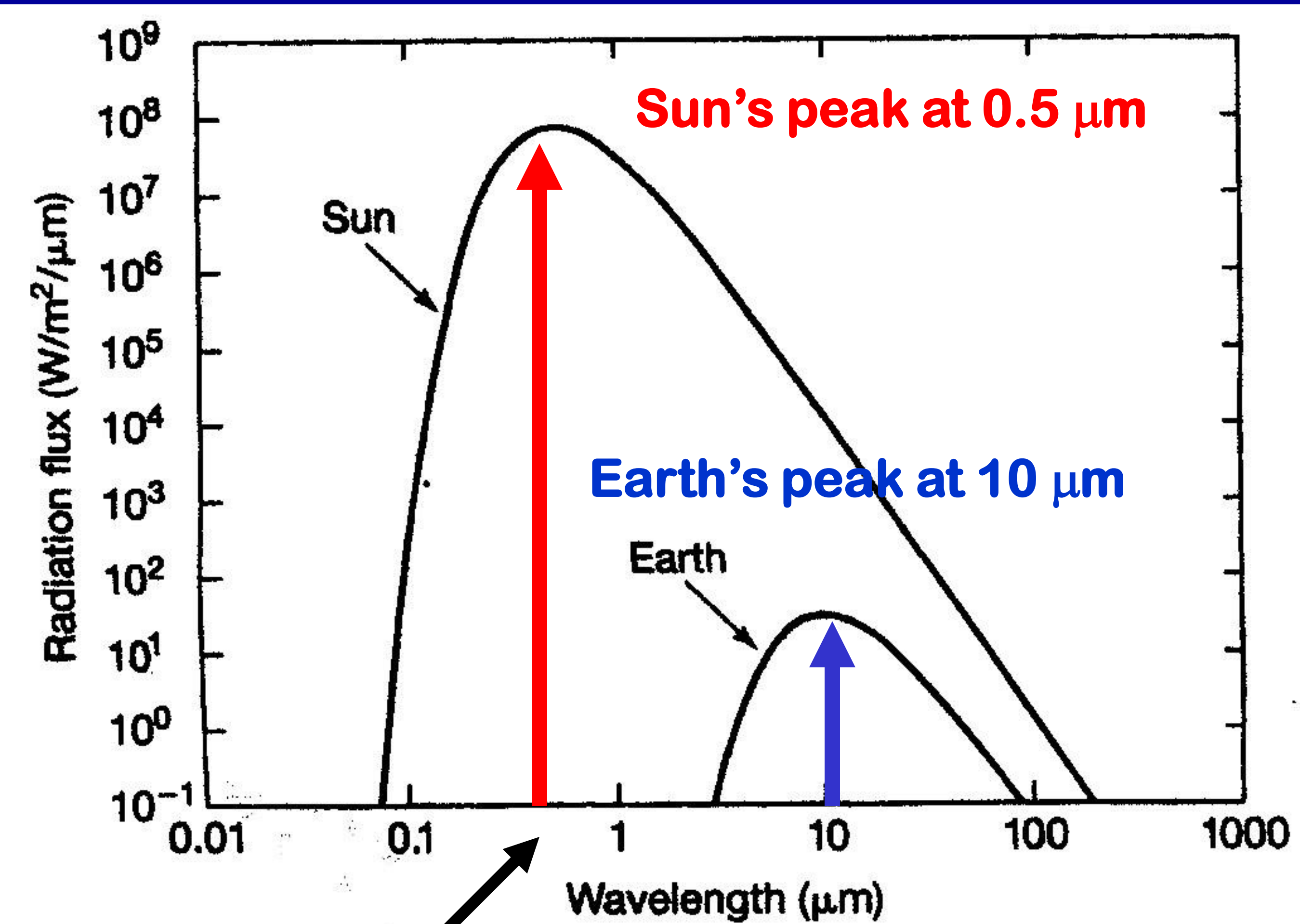
Wein's Law:

"I'm HOT, so I emit my maximum amount of radiation at SHORTER wavelengths"

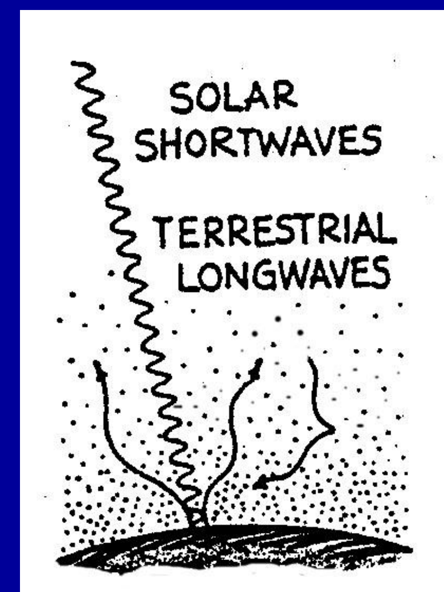
SW = visible (VIS) & ultraviolet (UV)

"I'm COOL, so I emit my maximum amount of radiation at LONGER wavelengths"

LW = infrared (IR)

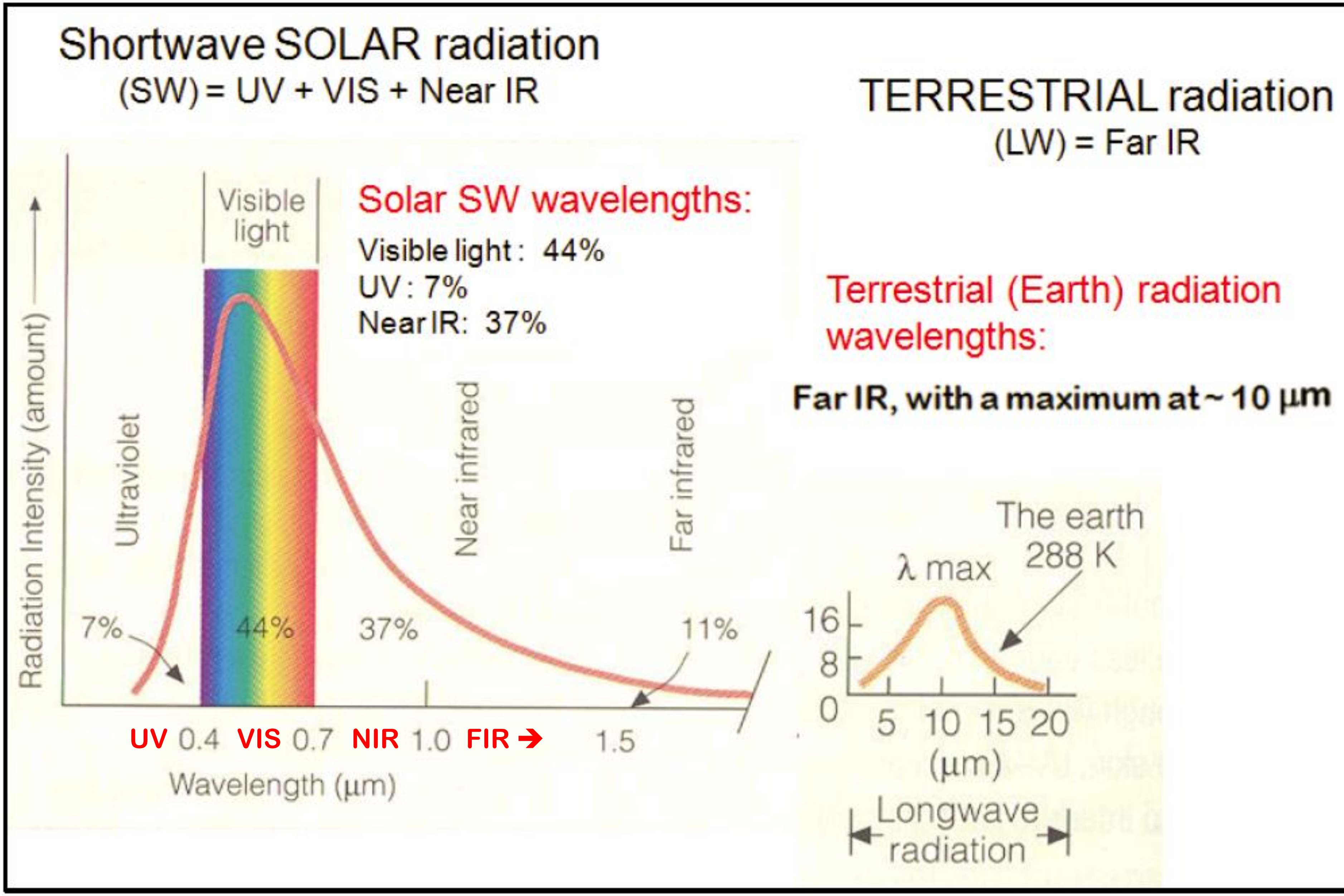


Wein's is the law behind this cartoon **(back on p 27)**



NOTE: this is a logarithmic scale -- values increase exponentially to the right

Another view of the same concept:



Know & understand what this figure is illustrating!

THE RADIATION LAWS

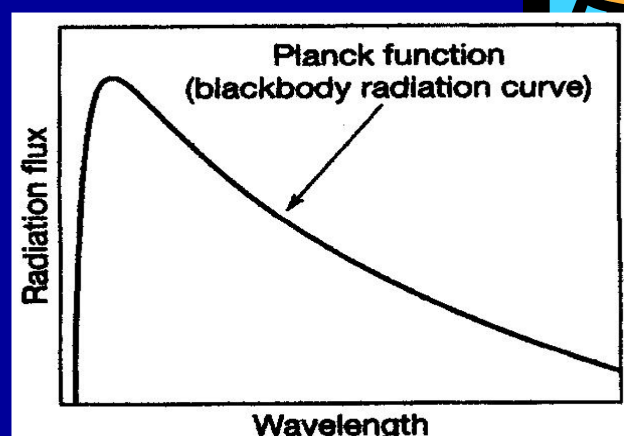
Re-cap of Laws # 2 - 4

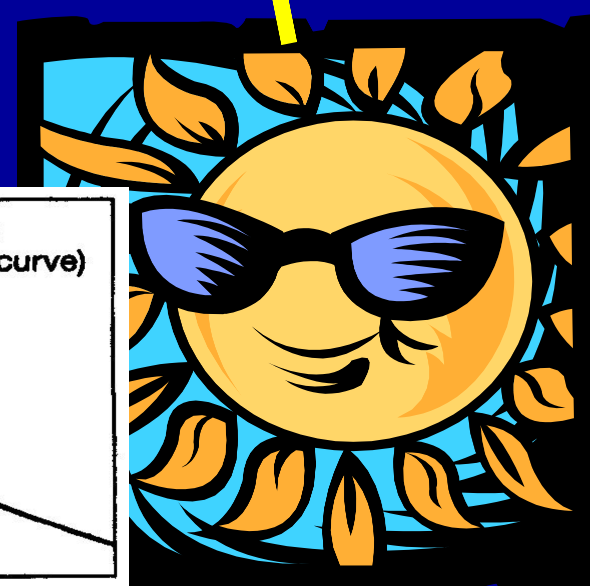
Planck Function:

$$E = h\,c\,/\,\lambda$$

"I radiate at the speed of light like a blackbody; most of my energy is emitted at shorter wavelengths "

The Sun can emit energy at ALL wavelengths, but the <u>amount</u> of energy emitted is inversely related to its wavelength.





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Stefan-Boltzmann Law:

$$E = \sigma T^4$$

"I'm HOT, so I emit LARGE amounts of high intensity energy"

"I'm COOL, so I emit LESSER amounts of energy; *plus* my ENERGY is at a lower intensity than Mr. Hotshot over there!"

Wein's Law: $\lambda_m = a / T$

"I'm HOT, so I emit my maximum amount of radiation at SHORTER wavelengths"

"I'm COOL, so I emit my maximum amount of radiation at LONGER wavelengths"

SW = visible & ultraviolet (UV)

LW = infrared (IR)

☺

Q4 – Which choice correctly matches the Stefan-Boltzmann LAW with its "mantra" (A, B, C):

A "The hotter the body, the shorter the wavelength"
The cooler the body, the longer the wavelength"

B "SHORTER wavelengths have HIGHER intensity radiation than LONGER wavelengths "

C "The hotter the body, the (much) greater the amount of energy flux or radiation"

☺ Record your Q4 answer now

Top of p 31

(A) Wein's Law: $\lambda_m = a / T$

"The hotter the body, the shorter the wavelength"
The cooler the body, the longer the wavelength"

(B) Planck Function: $E = h c / \lambda$

"SHORTER wavelengths have HIGHER intensity radiation than LONGER wavelengths"

(C) Stefan-Boltzmann Law: $E = \sigma T^4$

"The hotter the body, the (much) greater the amount of energy flux or radiation"

RADIATION LAWS # 5 and #6

to be continued . . . . .