

**NATS 101**  
**Section 13: Lecture 5**

**Radiation**

**What causes your hand to feel warm when you place it near the pot?**

**NOT conduction or convection. Why?**

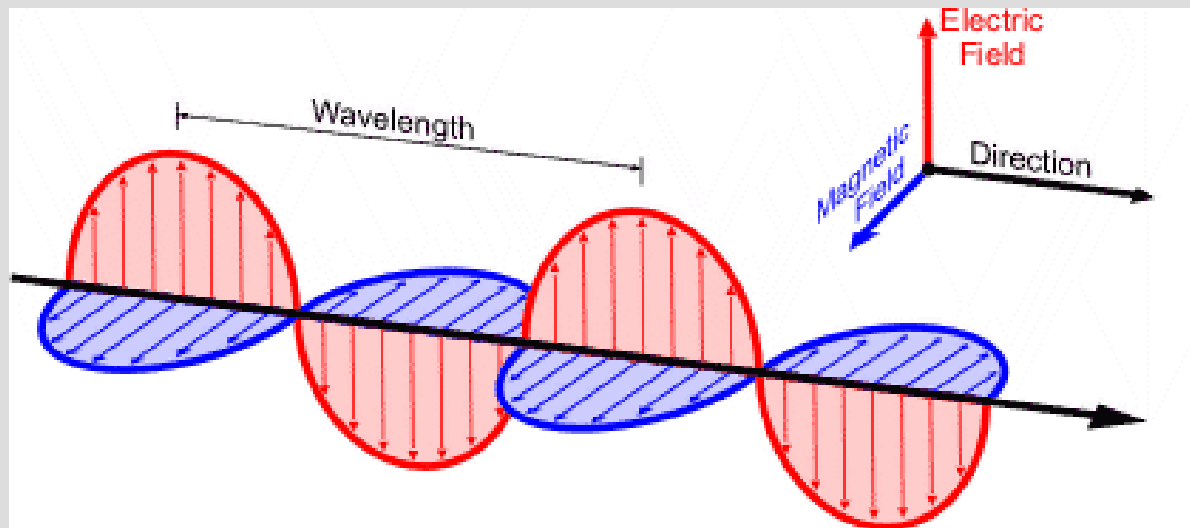


***Therefore, there must be an mechanism of heat transfer which DOES NOT require the presence of molecules.***

# Radiation: Third mode of heat transfer

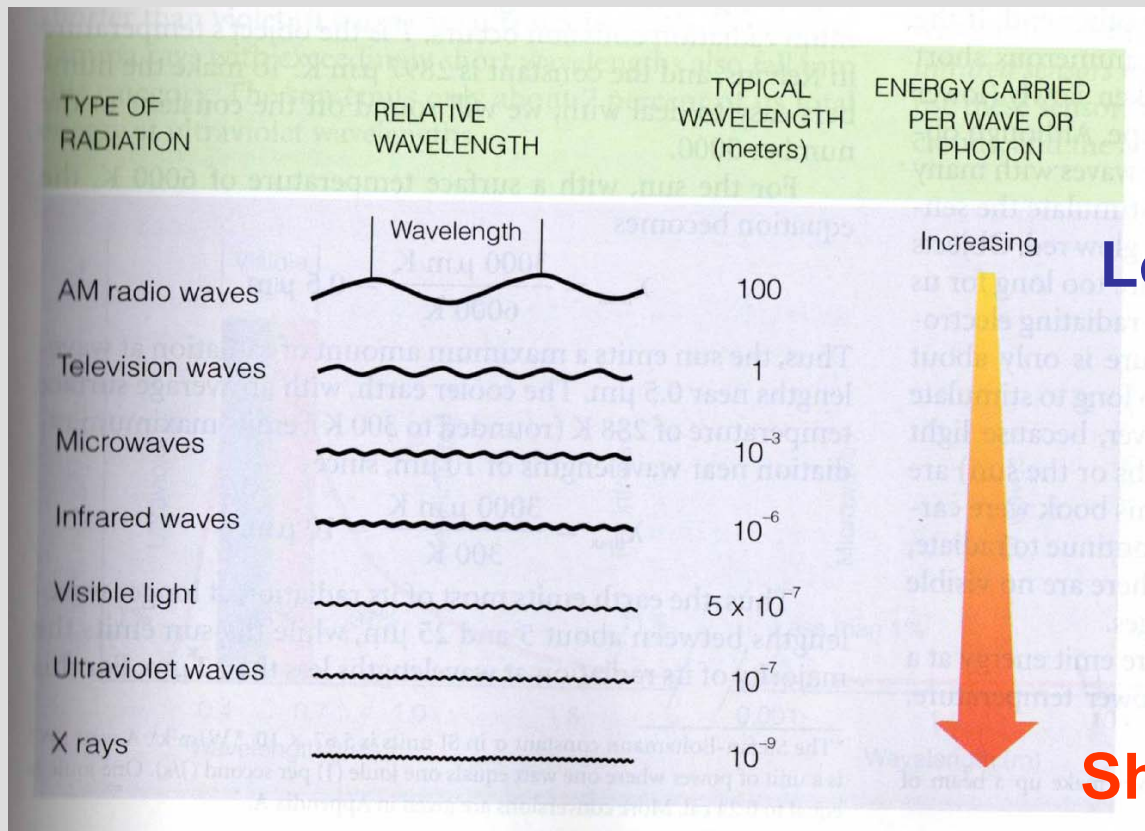
**Radiation**: Energy propagated by electromagnetic waves, which travel at the speed of light ( $\sim 3.0 \times 10^8 \text{ m s}^{-1}$ ) in a vacuum. The electromagnetic waves are caused by acceleration of charges within atoms and molecules.

*All matter that has a temperature above absolute zero emits some kind of radiation.*



# Radiation and photons

Radiation can be thought of as a *photon*, or discrete packet of electromagnetic radiation. The energy of the photon corresponds to the type of radiation.



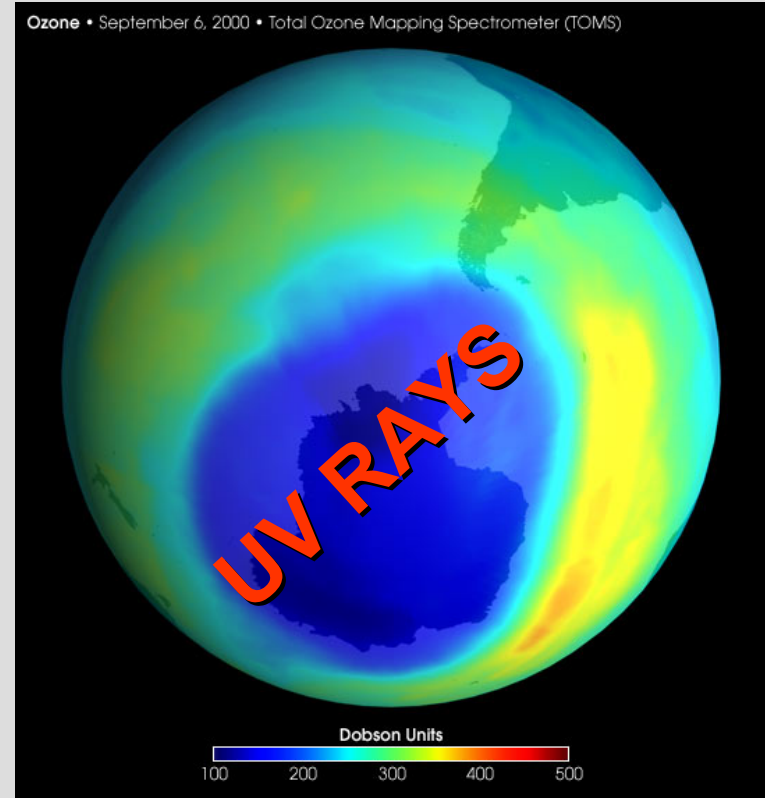
**Longer wavelengths  
→ low energy**

**Shorter wavelengths  
→ high energy**

**High energy radiation certainly can be dangerous!**



**GAMMA RAYS**  
**X-RAYS**



**Why is high energy radiation is hazardous to life?**



**RADIO WAVES**



**MICROWAVES**



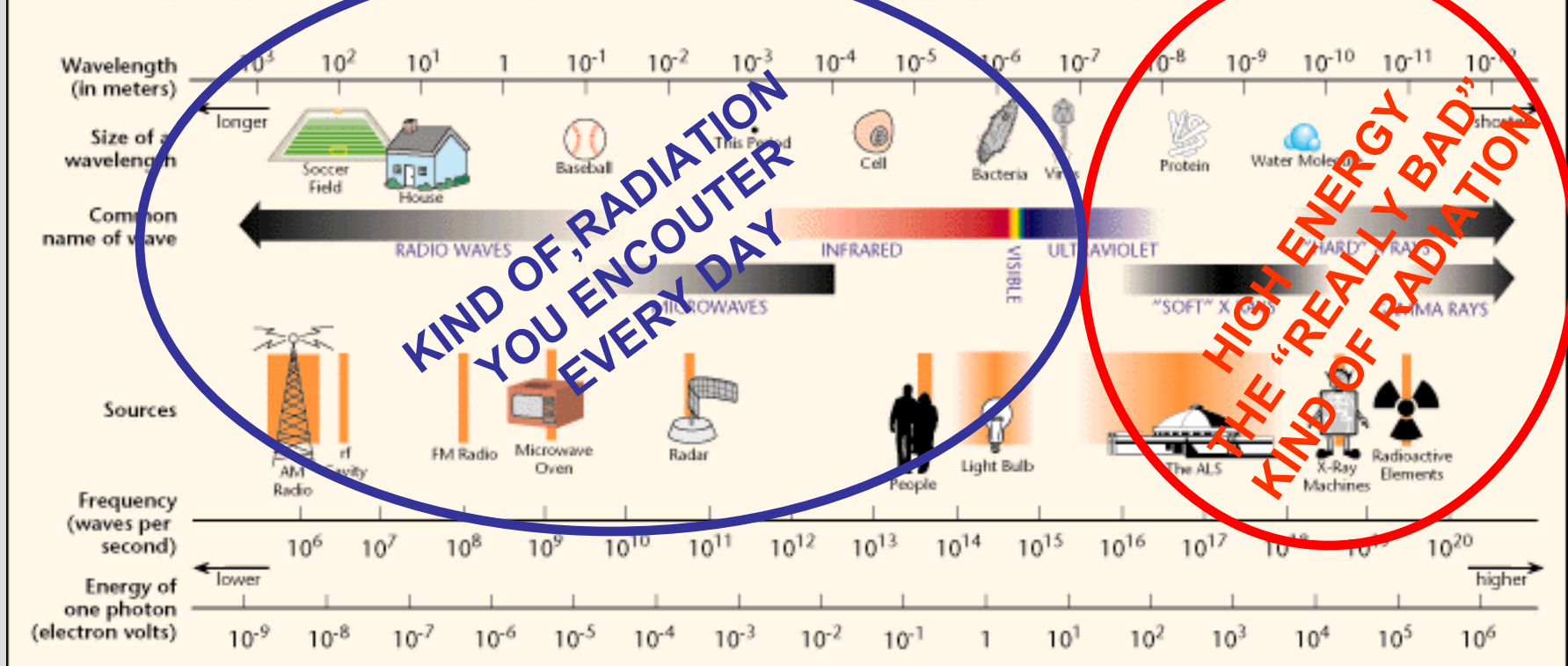
**VISIBLE LIGHT**



**INFRARED**

**Much of the technology of our present age has developed because of our understanding of the nature of radiation during the past century!**

# THE ELECTROMAGNETIC SPECTRUM



Note that for electromagnetic waves:

$$c = f\lambda$$

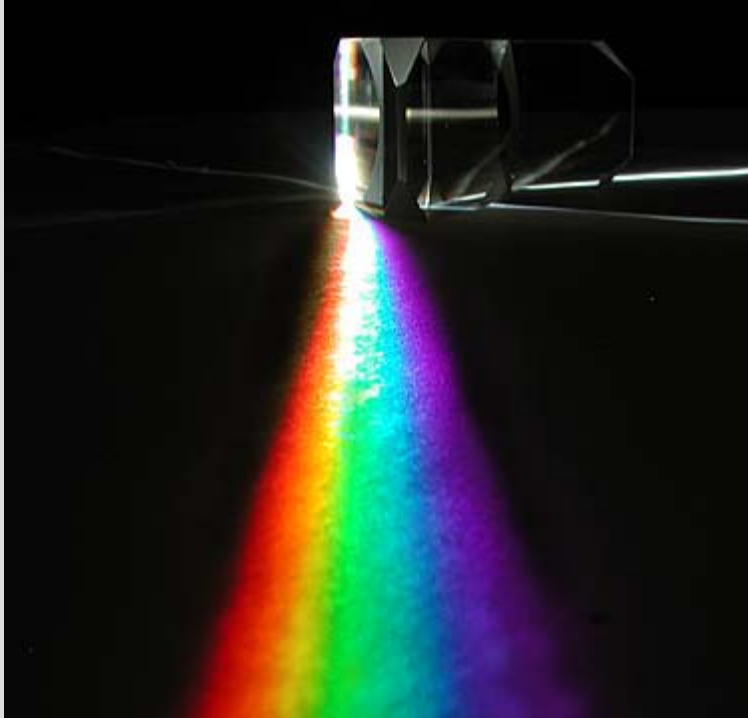
Speed of light = frequency X wavelength

$c$  = speed of light

$f$  = frequency ( $s^{-1}$  or Hertz)

$\lambda$  = wavelength (m)

# Visible Spectrum through a Prism



0.7  $\mu\text{m}$

0.4  $\mu\text{m}$

Longer  
wavelength

Shorter  
wavelength

Visible part of the  
spectrum:

0.7 to 0.4  $\mu\text{m}$

1  $\mu\text{m} = 10^{-6}$  m



# Rainbow: Nature's Prism



***Rainbows occur as a result of sunlight being reflected within raindrops.***

***Each wavelength of the visible spectrum is reflected at a slightly different angle.***

# The Human Eye: Sensor of the Visible Spectrum



**Human eyes detect radiation in the visible part of the spectrum:  
(0.4 – 0.7  $\mu\text{m}$ ).**

**Typically, this radiation is reflected off objects, not generated by them.**

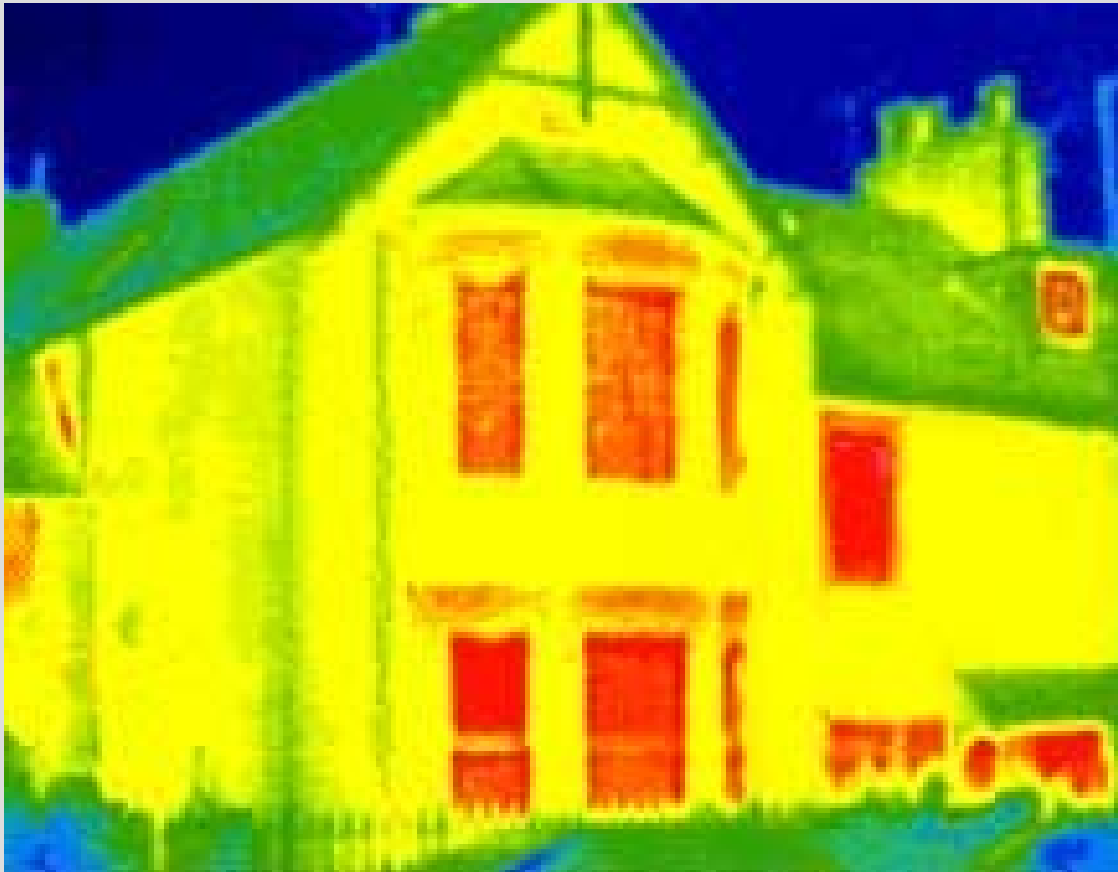
# The Human Skin: Sensor of the Infrared Spectrum



**Our touch is designed to sense the infrared part of the spectrum (around 5 – 15  $\mu\text{m}$ ) and gives us our sense of “hot” and “cold.”**

# What if we could “see” in infrared?

*This is what a house on a cold winter day might look like...*



**Hot areas appear in red and orange**

**Cold areas appear in blue and purple.**

**Areas in between relatively hot and cold appear green.**

# Planck Function

*The intensity of radiation as it relates to the frequency (or wavelength) and temperature of a body was first described by Max Planck in 1900*

$$I(f, T) = \frac{2hf^3}{c^2} \frac{1}{e^{hf/kT} - 1}$$



**Max Planck**

## Variables

$I(f, T)$  = Intensity of radiation

$f$  = frequency

$T$  = Temperature

## Constants

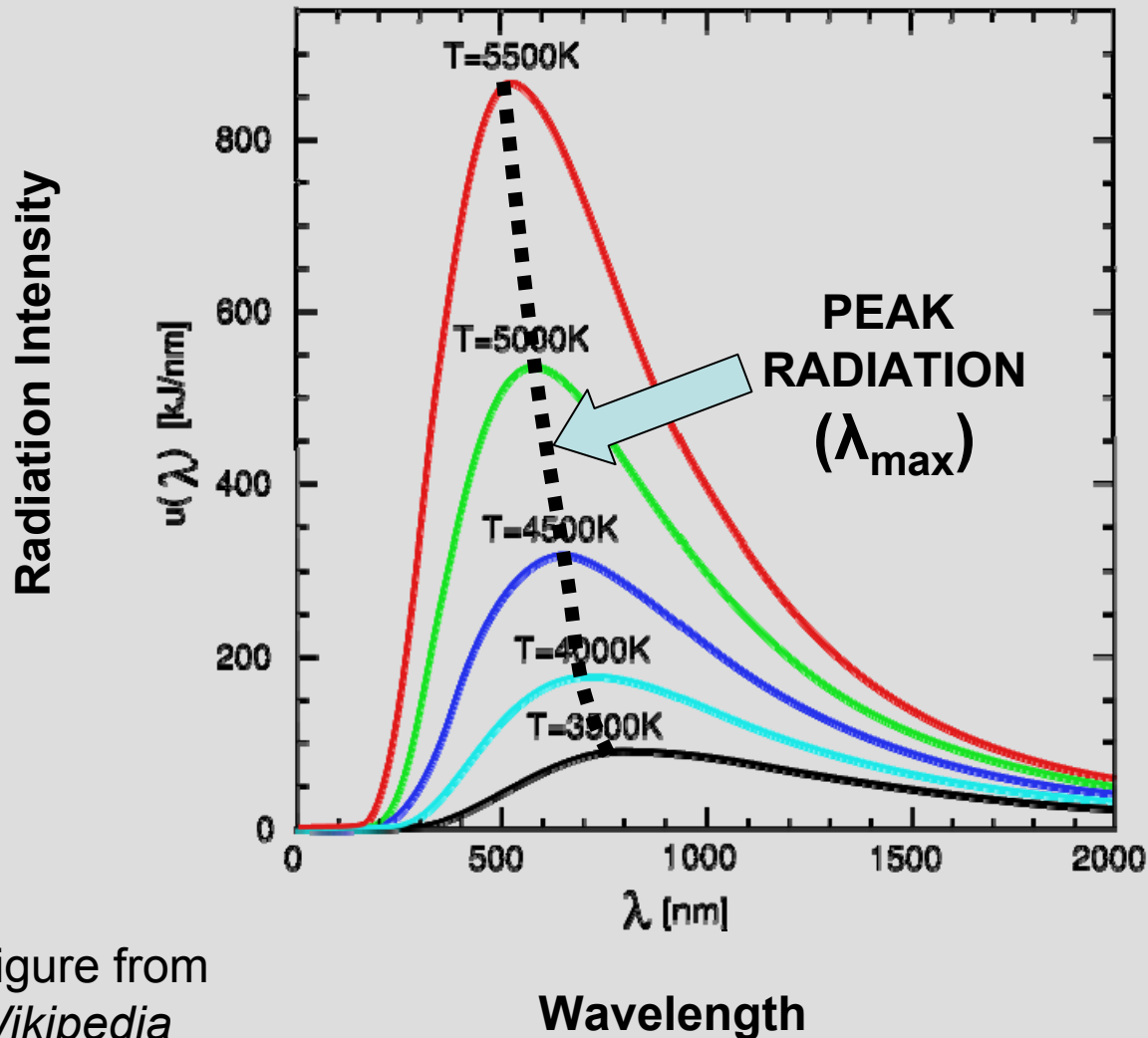
$h$  = Planck's constant

$k$  = Boltzmann's constant

$e$  = natural logarithm

$c$  = speed of light

# Planck Function Characteristics



Peak radiation intensity is *inversely* related to the wavelength and temperature.

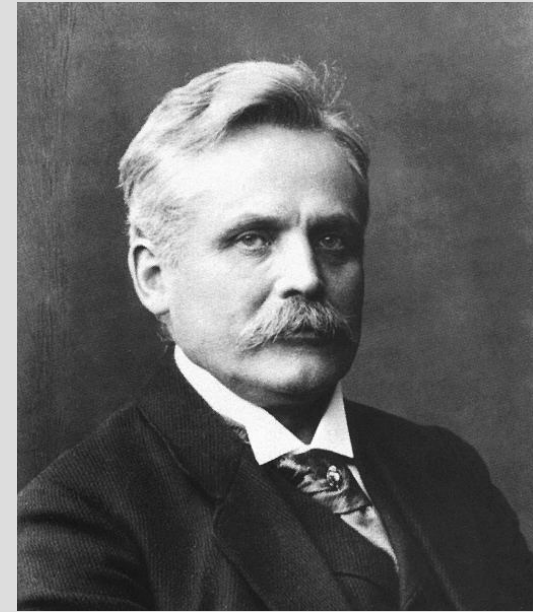
Greater intensity with \_\_\_\_\_ wavelength and \_\_\_\_\_ temperature

Figure from  
*Wikipedia*

# Wien's Displacement Law

*Gives an expression for the wavelength  
at which peak radiation emission occurs*

$$\lambda_{\max} = \frac{2897 \mu\text{m K}}{T}$$



*Wilhelm Wien*

Reflects the characteristics of the Planck curve we just observed:

**The wavelength of maximum radiation emission is inversely proportional to an object's temperature.**

## Total Radiant Energy per unit area: Stefan-Boltzmann Law

*The total radiant energy per unit area (E) is obtained by integration (or computation of the area under the curve) the Planck function (I) over all wavelengths over a half sphere.*

$$E = \int_0^{\infty} \int_0^{2\pi} \int_0^{\pi/2} I(f, T) (\cos \theta) (\sin \theta) d\theta d\phi df$$



**Josef  
Stefan**



**Ludwig  
Boltzmann**

Solution:

$$E = \sigma T^4$$

$\sigma$  = Stefan-Boltzmann constant

$$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$$



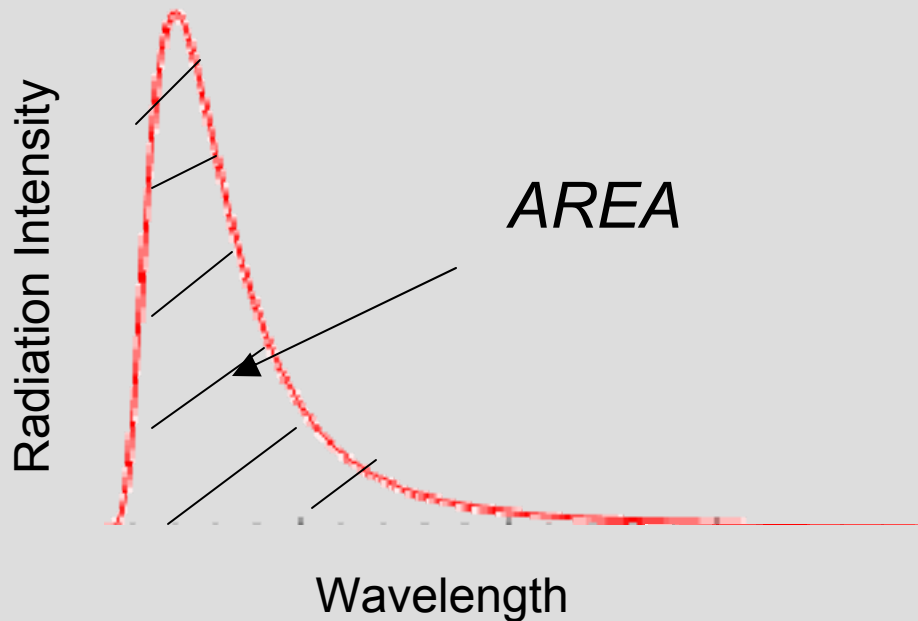
# Total Radiant Energy per unit area: Stefan-Boltzmann Law



*Josef  
Stefan*



*Ludwig  
Boltzmann*



Main point I want you to remember...

**The total radiant energy is proportional to the AREA UNDER the Planck function curve.**

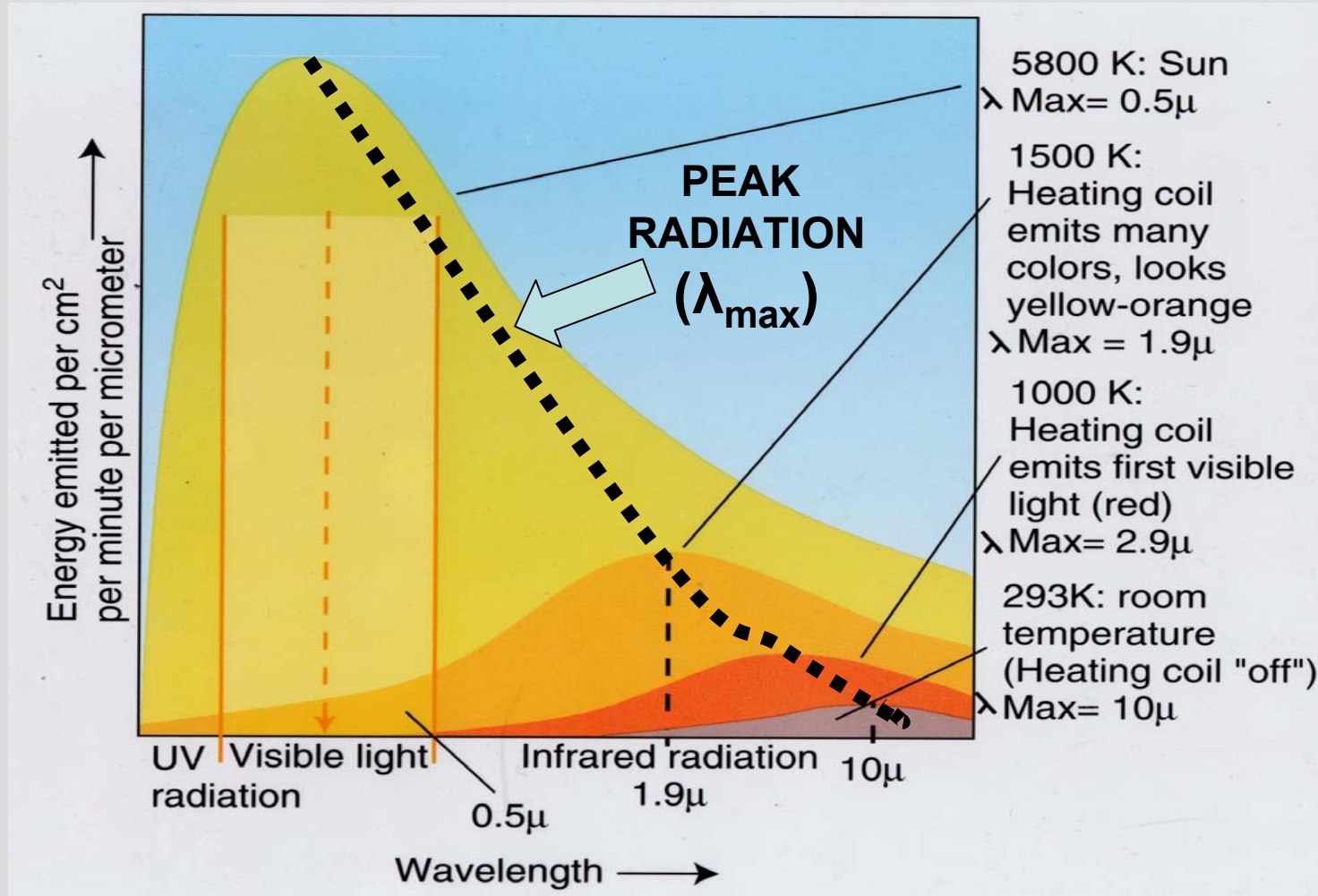
**More area  
→ more radiant energy!**

# **Total Radiant Energy per unit area: Stefan-Boltzmann Law**

$$**E = \sigma T^4**$$

**Relatively SMALL changes in temperature cause  
LARGE changes in the total radiant energy**

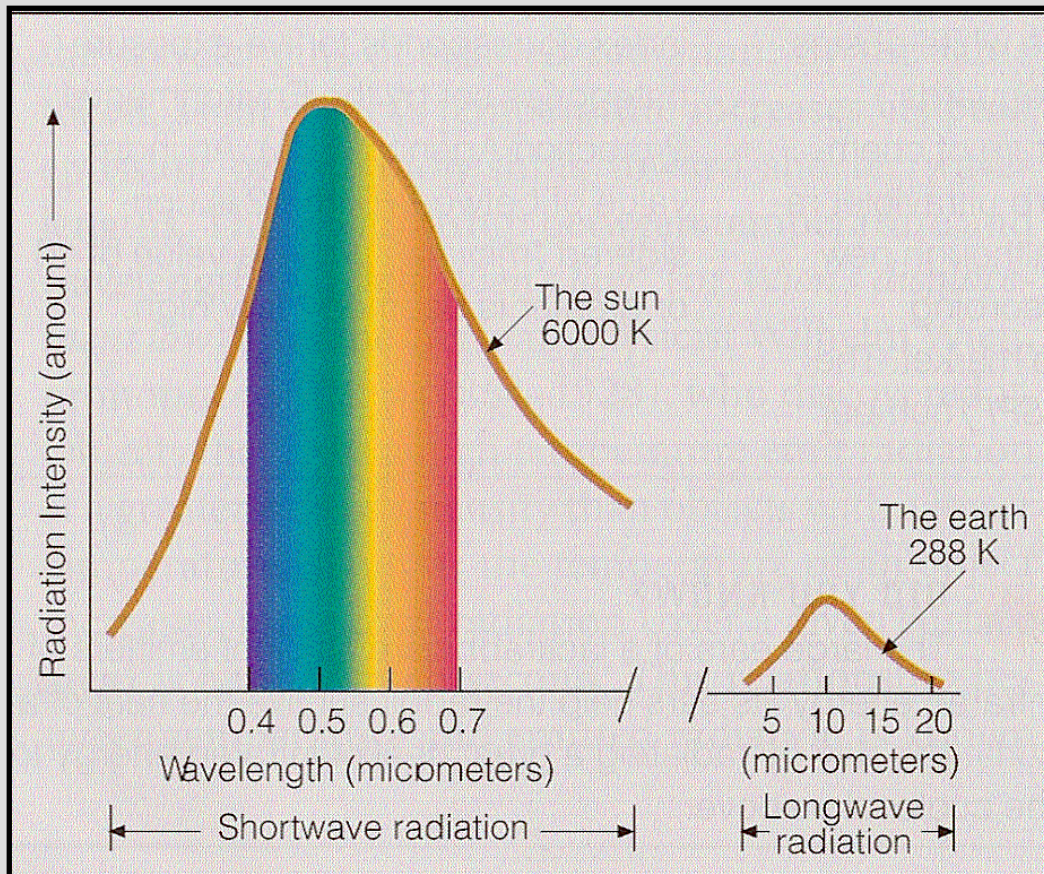
**How does energy change with a doubling of  
temperature?**



**NOTE: More shaded area underneath the curve**

- 1.
- 2.

# Solar and Terrestrial Radiation



**SOLAR**  
 $\lambda_{\max} = 0.5 \mu\text{m}$

**TERRESTRIAL**  
 $\lambda_{\max} = 10 \mu\text{m}$

*The Planck curves based on the emission temperatures of the Sun and Earth define the range of solar and terrestrial radiation.*

**By application of Wein's law, we can obtain  $\lambda_{\max}$ . This is shown in the textbook.**

**How much more radiant energy per unit area does the sun emit compared to the Earth?**

***Answer: About 160,000 times more!***

***How can we use the concepts we've discussed so far to determine that answer?***

# Total radiant energy per unit area: Sun vs. Earth

Sun: T = 5800 K

$$E_{Sun} = \sigma T_{Sun}^4$$

$$E_{Sun} = (5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4})(5.8 \times 10^3 \text{ K})^4$$

$$E_{Sun} = 6.41 \times 10^7 \text{ W m}^{-2}$$

Earth: T = 288 K

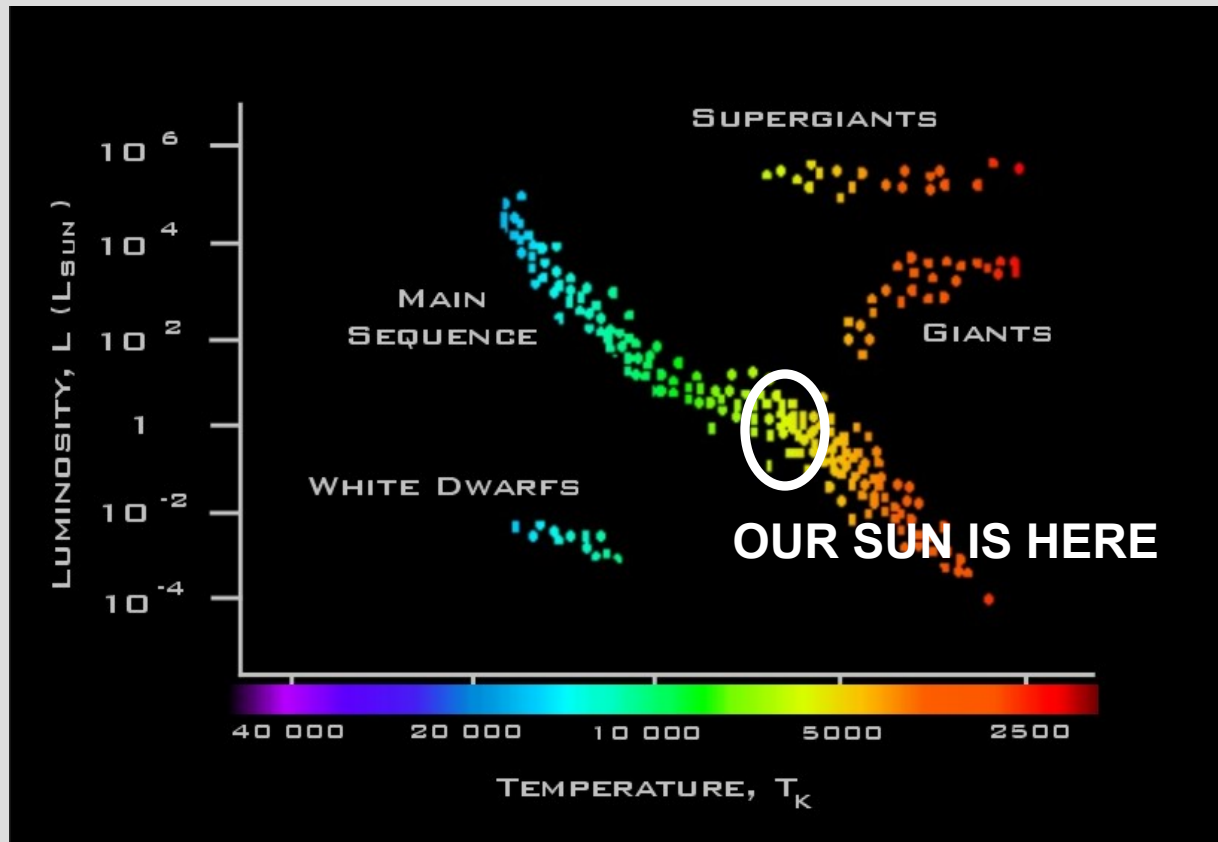
*Do this part on  
your own and  
confirm the  
answer from the  
ratio*

$$\frac{E_{Sun}}{E_{Earth}} = 1.64 \times 10^5 \approx 160,000$$

**Keep in mind that we're talking about  
the total radiant energy  
PER UNIT AREA.**

***Accounting for the area of the  
Earth and the Sun, the Sun emits  
almost 2 billion times the amount  
of energy as the Earth!***

# Not all stars are created equal in the universe!



Source: *Faulkes Telescope Educational Guide*

[http://www.le.ac.uk/ph/fulkes/web/stars/r\\_st\\_evolution.html](http://www.le.ac.uk/ph/fulkes/web/stars/r_st_evolution.html)



# Summary of Three Modes of Heat Transfer

**CONDUCTION**



**Molecule to molecule within a substance**

**CONVECTION**



**Mass movement of a fluid or gas**

**RADIATION**



**Electromagnetic waves**

# Summary of Lecture 5

The three modes of heat transfer are *conduction*, *convection*, and *radiation*. Radiation is energy propagated by electromagnetic waves and is emitted by all objects so long as they have a temperature.

The type of radiation an object emits is dependent on its temperature. The smaller the wavelength of radiation, the greater the energy and the higher the temperature. The entire range of radiation types is given by the EM spectrum.

The total radiant energy emitted by an object is described by the *Stefan-Boltzmann law*.

The wavelength of maximum radiation emission is described by *Wien's law*.

*Solar radiation*, or shortwave radiation, is that which comes from the sun and is most intense in the visible part of the spectrum.

*Terrestrial radiation*, or longwave radiation, is that which comes from the Earth and is most intense in the infrared part of the spectrum.

# Reading Assignment and Review Questions

Ahrens, Chapter 2, pp. 40-51 (8<sup>th</sup> ed.)  
pp. 40-52 (9<sup>th</sup> ed.)

## Chapter 2 Questions

Questions for Review: 4c,7,8,9,10

Questions for Thought: 6

Problems and Exercises: 2,3