Previously on Astro1

- **What is light?** Light is electromagnetic radiation
Homework – Due 01/26/11

• On your own: answer all the review questions in chapter 6
• To TAs: answer questions 6.32 6.36 6.48 6.40
Today on Astro1

• Blackbodies
• Photons
• The color of the sky
• What are stars and interstellar gas made of?
Blackbody
Definition of a blackbody

• A blackbody is an idealized object that absorbs all radiation falling on it. It does not reflect light, instead it re-emits light.

• A blackbody does not have to look black! The Sun is nearly a blackbody.

• Light in thermal equilibrium
Blackbody Curves

Each curve shows the intensity of light at every wavelength that is emitted by a blackbody at a particular temperature. The rainbow-colored band shows the range of visible wavelengths. The vertical scale has been compressed so that all three curves can be seen; the peak intensity for the 12,000 K curve is actually about 1000 times greater than the peak intensity for the 3000 K curve.
Wien’s Law for a blackbody

\[ \lambda_{\text{max}} = \frac{0.0029Km}{T} \]

\( \lambda_{\text{max}} \) = wavelength of maximum emission of the object (in meters)

T = temperature of the object (in Kelvins).

(The K and m above are units of Kelvins and meters).

Example: At which peak wavelength do people radiate?

Human temperature in K = 273+37 = 310K

\[ \lambda_{\text{max}} = \frac{0.0029Km}{310K} = 9.4 \times 10^{-6} m = 9400 \text{ nm} \]

This is in the infrared!
An Infrared Portrait

In this image made with a camera sensitive to infrared radiation, the different colors represent regions of different temperature. Red areas (like the man’s face) are the warmest and emit the most infrared light, while blue-green areas (including the man’s hands and hair) are at the lowest temperatures and emit the least radiation.
Energy flux

Energy is usually measured in Joules (J).

One joule per second is a Watt (W) – a measure of power.

Flux is the amount of energy per second passing through one square meter.

The Stefan-Boltzmann Law gives the flux of a blackbody of a given temperature.  
\[ F = \sigma T^4 \]

\(\sigma\) (a constant) = \(5.67 \times 10^{-8}\) W m\(^{-2}\) K\(^{-4}\)

\(T\) = Temperature in Kelvins
In the movie *The Matrix* – people are used as batteries. If the average human’s bodily surface area is 1.7 m², and has an average temperature of 37°C, how much energy per second (power) does a person radiate?

**Answer.** Treating a person as a blackbody, use the Stefan-Boltzmann law to determine the energy radiated per second per square meter, then multiply by the body’s surface area to get the energy radiated per second.

Human temperature in K = 273+37 = 310K

\[ F = \sigma T^4 = (5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4})(310 \text{ K})^4 = 524 \text{ W m}^{-2} \]

Power = 524 W m⁻² (1.7m²) = 891 W

About the power of a toaster!
A very important blackbody: Cosmic Microwave Background

- The cosmic microwave background was discovered as a background “noise” a real problem for telecommunication satellites
- Wherever Penzias and Wilson pointed their antenna they would detect a microwave signal, very uniform across the sky
- This signal is now called the cosmic microwave background…
Cosmic Microwave Background.
The CMB is a “perfect” Blackbody

COBE FIRAS 1989; T=2.725 K
Question 7.1 (iclickers!)

• If all stars are considered perfect blackbodies, then it should follow that all stars
  • A) of the same composition emit the same energy flux
  • B) of the same size emit the same energy flux
  • C) traveling at the same speed emit the same energy flux
  • D) of the same temperature emit the same energy flux
Light is also a particle: Planck’s Law

\[ E = \frac{hc}{\lambda} \text{ or } E = hv \]

- \( E \) = Energy of a photon
- \( h \) = Planck’s constant = \( 6.625 \times 10^{-34} \text{ J s} \)
- \( c \) = speed of light
- \( \lambda \) = wavelength of light
- \( \nu \) = frequency of light

Example: DNA molecules are easily broken when hit with ultraviolet light at 260 nm (why you get cancer from sunburns). How much energy does a single photon at this wavelength have?

\[ E = \frac{hc}{\lambda} = \frac{(6.625 \times 10^{-34} \text{ Js})(3.00 \times 10^8 \text{ m/s})}{2.60 \times 10^{-7} \text{ m}} = 7.64 \times 10^{-19} \text{ J} \]
In what way does a photon of blue light not differ from a photon of yellow light in a vacuum:

A) wavelength
B) color
C) energy
D) speed
Why is the sky blue and the sunset red?
The atmosphere scatters blue light more effectively than red light — hence mostly blue light reaches your eye when you look at the sky.

Why the sky looks blue
The atmosphere scatters blue light more effectively than red light — hence mostly red light reaches your eye when you look through a thick slice of atmosphere at the setting Sun.

Why the setting Sun looks red
Spectra as the “fingerprints” of nature
The Sun’s Spectrum

In 1814 Joseph von Fraunhofer magnified the solar spectrum seen through a prism, and found hundreds of dark lines.
1. Add a chemical substance to a flame

2. Send light from the flame through a narrow slit, then through a prism

3. Bright lines in the spectrum show that the substance emits light at specific wavelengths only
Kirchhoff’s Laws

1. A hot, dense object such as a blackbody emits a continuous spectrum covering all wavelengths.
2. A hot, transparent gas produces a spectrum that contains bright (emission) lines.
3. A cool, transparent gas in front of a light source that itself has a continuous spectrum produces dark (absorption) lines in the continuous spectrum.
(a) Continuous spectrum (blackbody emits light at all wavelengths)

(b) Absorption line spectrum (atoms in gas cloud absorb light of certain specific wavelengths, producing dark lines in spectrum)

(c) Emission line spectrum (atoms in gas cloud reemit absorbed light energy at the same wavelengths at which they absorbed it)
The energy output of the sun.
(a) Continuous spectrum (blackbody emits light at all wavelengths)

(b) Absorption line spectrum (atoms in gas cloud absorb light of certain specific wavelengths, producing dark lines in spectrum)

(c) Emission line spectrum (atoms in gas cloud reemit absorbed light energy at the same wavelengths at which they absorbed it)
Figure 5-15
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The glowing gas cloud in this Hubble Space Telescope image lies 210,000 light-years away in the constellation Tucana (the Toucan). Hot stars within the nebula emit high-energy, ultraviolet photons, which are absorbed by the surrounding gas and heat the gas to high temperature. This heated gas produces light with an emission line spectrum. The wavelength of red light emitted by the nebula is 656 nm, characteristic of hydrogen gas.
The Ring Nebula is a shell of glowing gases surrounding a dying star. The spectrum of the emitted light reveals which gases are present.
For each emission line of iron, there is a corresponding absorption line in the solar spectrum; hence there must be iron in the Sun’s atmosphere.
Atomic number is the number of protons in an atom.
Question 7.3 (iclickers!)

• If light from a hot, dense star is viewed through a cool cloud of gas,
  • A) the spectrum of the star will be seen unchanged because the gas cloud is cool
  • B) only specific wavelengths of light will be removed from the spectrum
  • C) the whole spectrum will be reduced in intensity
  • D) the atoms of the gas cloud will add energy to the overall spectrum, producing emission at specific wavelengths
Summary

• **What is a blackbody?**
  - **Wien’s law:** $\lambda_{\text{max}}$ (in meters) = \((0.0029 \text{ K} \cdot \text{m})/T\).
  - **The Stefan-Boltzmann law:** $F = \sigma T^4$.

• **What are photons?**
  - Light can have particle-light properties. The particles of light are called photons: $E = h\nu = hc/\lambda$

• **Why is the sky blue and sunsets red?**
  - Interaction between light and atmosphere

• **Kierchoff’s Laws**

• **What are stars and interstellar gas made of?**
  - The same elements we see on Earth, mostly Hydrogen, He, Oxygen, Carbon
The End

See you on Friday (midterm)!