General Astronomy (29:61)
Fall 2012
Lecture 24 Notes, October 26, 2012

1 Overview of the Solar System

Haven't we done that already? We are mainly interested in two questions.

1. What makes some planets hot and some planets cold? Same question hold for Moons. ($\longrightarrow$ see online notes and diagrams)

2. Why do some planets (and moons) have atmospheres, while others do not? ($\longrightarrow$ see online notes and diagrams). This question clearly has relevance for life throughout the universe.

We will see that we can employ some of the physics concepts we have already learned to answer these.

2 What Determines the Surface Temperature of a Planet

Yesterday morning when I came into work it was 70 degrees Fahrenheit. When I left to go home, it was 44 degrees Fahrenheit. That seems like a pretty extreme change.

When you use the Kelvin scale, the change seems less extreme; 294.3K $\rightarrow$ 279.8K. But in physics and astronomy we can have much bigger ranges. Why isn't the surface of the Earth 77K (temperature of liquid nitrogen). Or 900K? Objects in the solar system span this range. Now let's find out why.

2.1 Good Day Sunshine

A major source of heating the surface of planets (the only source for most) is sunlight. The *flux* of radiation from the Sun at a distance r from the Sun is (see Equation 8.5 of the textbook).

$$F_\odot = \frac{L_\odot}{4\pi r^2} \tag{1}$$

Where $L_\odot$ is the luminosity of the Sun. $L_\odot = 3.839 \times 10^{26}$ Watts

Let's work out the number.

$$F_\odot = \frac{L_\odot}{4\pi r^2} \tag{2}$$

$$F_\odot = \frac{3.839 \times 10^{26}}{4(3.142)(1.496 \times 10^{11})^2} = 1365 \tag{3}$$

This number is often called the *solar constant*, and is extremely important in climate studies, solar power engineering, etc. $\longrightarrow$ *What are the units?*

This energy is absorbed by the Earth (or another planet) and heats up the Earth. However, every square meter of the Earth doesn't absorb that much power. There are two considerations.

First of all, not all of the power incident on the Earth is absorbed. Some is reflected back into space. Only the rest is absorbed. An important term in astronomy is the *albedo* A. This is the fraction of the power incident on a solar system object that is reflected back into space.

The fraction that is absorbed is $(1 - A)$.

The albedo is definitely a function of wavelength, but for many solar system objects changes sufficiently gradually that we can use one number for visible light.

Question for the learned community. How does the albedo affect the brightness of a solar system object.

Table 8.2 gives some interesting numbers. These are the albedos of some major solar system objects. Note Earth (0.40), Moon (0.07), Mars (0.16) , Jupiter (0.51), and Venus (0.76). Big differences!

The other consideration is that not every square meter on the surface of the Earth is receiving 1365 units of power. The nightime side is getting none. The polar regions are getting less than regions where the Sun is shining straight down. When you do the correction, you find that 1/4 of the surface area of the Earth is absorbing solar power.

So, we have for *total* power input to Earth is

$$W_p = \left(\frac{L_\odot}{4\pi r^2}\right) \pi R_E^2 (1 - A) \tag{4}$$

This is Equation 8.6 of the book.

2.2 The Planck Function Again

The Planck Function says how power radiated away by a blackbody is distributed in wavelength. The meaning becomes clear when we look at the units of the Planck Function, Watts/m^2/m.

This means if you sum up the power radiated in all the infinitesimal wavelength intervals (think calculus: integrate the Planck Function over wavelength) you have a quantity with units of Watts/m^2. This is the total power in electromagnetic radiation per unit area.

If we do the integral of the Planck Function, we get the following formula, which is called the *Stefan-Boltzmann Law*

$$F_{BB} = \sigma T^4 \tag{5}$$

where σ is the Stefan-Boltzmann constant,

$$\sigma = \frac{2\pi^5 k_B^4}{15c^2h^3} = 5.6705 \times 10^{-8} \tag{6}$$

2.3 Blackbody Radiation of a Bald Planet

This sounds like a weird section title, but let's move on. Let's assume that a planet has a uniform temperature. You might say this isn't true for the Earth, but as we so above, what strike us as big temperature changes aren't really all that big. The *total power* radiated to space is

$$L_p = \sigma T^4 4\pi R_E^2 \tag{7}$$

This is Equation 8.7. Astronomers like this equation, but if you want to be precise about it, the right hand side should be multiplied by a constant ϵ which is a measure of how good a blackbody a planet is. For planets this number is usually close to 1, but it isn't exactly 1.

3 Radiative Equilibrium and the Equilibrium Blackbody Temperature of a Planet

Equation (4) gives power coming from the Sun to heat up the Earth. Equation (7) is the power radiated by the Earth as it cools down. In the condition of *equilibrium*, these two balance,

$$W_p = \left(\frac{L_\odot}{4\pi r^2}\right)\pi R_E^2(1-A) = L_p = \sigma T^4 4\pi R_E^2 \tag{8}$$

We can cancel terms to obtain the equilibrium temperature of a planet

$$\left(\frac{L_\odot}{4\pi r^2}\right)\pi R_E^2(1-A) = \sigma T^4 4\pi R_E^2 \tag{9}$$

$$T^4 = \left(\frac{L_\odot}{4\pi r^2}\right)\frac{1-A}{4\sigma} \tag{10}$$

$$T = \left[\left(\frac{L_\odot}{4\pi r^2}\right)\frac{1-A}{4\sigma}\right]^{1/4} \tag{11}$$

Let's work it out for the Earth. This is fun!

$$T = \left[\left(\frac{L_\odot}{4\pi r^2}\right)\frac{1-A}{4\sigma}\right]^{1/4} \tag{12}$$

$$T = \left[1365\frac{1-0.40}{4(5.67\times 10^{-8}}\right]^{1/4} \tag{13}$$

$$T = 245K \tag{14}$$

The real value (global average temperature of Earth) is 290 K (check Table 8.3 of book).

There are two ways of considering the agreement, or lack of agreement, between these two numbers. The first is that the agreement really isn't too bad for a pencil-and-paper calculation. However, the difference, 45K, is the difference between 62 degrees Fahrenheit and -19 degrees Fahrenheit. That is the difference between the Earth as it is, and one locked in pole-to-pole glaciation.