**General Astronomy (29:61)**
**Fall 2012**
**Lecture 23 Notes, October 24, 2012**

# 1 Other Parts of the Solar Atmosphere

## 1.1 The Solar Chromosphere

During a solar eclipse, one can see a reddish glow in the solar atmosphere, and sometimes what seem to be glowing red clouds.

($\longrightarrow$ look at pictures in the online notes.) These are at higher altitudes than the photosphere, and the gas is deduced to have higher temperature than the photosphere (Didn't I tell you the temperature went down as you go up in the solar atmosphere?) As your book states, the chromosphere is also the place where the element helium was discovered in 1868. You also get a view of the corona in solar telescopes that observe in the Balmer Alpha line of hydrogen. The Physics and Astronomy department has several of these telescopes.

## 1.2 The Solar Corona

During total solar eclipses, one can see a glow around the Sun. This is visible to the naked eye at those times ($\longrightarrow$ look at pictures in the online notes.). With the SOHO spacecraft, an instrument called LASCO allows us to see the solar corona all the time (look at SOHO URL on the course web site. If often shows structure and detail. The intensity of the light of the corona is measured in units of $10^{-6}$ of the brightness of the solar disk.

In the 19th century, astronomers took spectra of the corona during eclipses. An example of an eclipse spectrum is in the online notes. Many of the spectra lines were identified, such as the Balmer Alpha line of hydrogen or lines of helium. However, two bright lines, the "red line" and the "green line" were not identified. This was a big mystery in astronomy until the 1930s, when they were identified as lines from highly ionized ions of iron, FeX and FeXIV.

## 1.3 Question for the Scholarly Assembly

. What does this mean? What is the significance of emission lines of highly stripped ions from the solar corona? What does it tell us about physical conditions in the corona?

**Answer:** The solar corona is extremely hot, with a temperature of $1 \times 10^6 - 2 \times 10^6$. There is all kinds of evidence for this. For example, the Sun is a source of x-rays. For example, a satellite that monitors the Sun keeps track of its x-ray flux in the wavelength range 0.1 - 0.8 nm. ($\longrightarrow$ look at pictures in the online notes. Also GOES x-ray flux on SOHO space weather web page).

## 2 The Temperature Structure of the Solar Atmosphere

One of the amazing discoveries about astronomy is that although the temperature in the solar photosphere is 5800 K, the temperature a few thousand kilometers high (roughly the diameter of the United States) 1 - 2 million K. ($\longrightarrow$ look at pictures in the online notes.) Also look at Figure 7.6 of the textbook.

The region in which the temperature skyrockets in the solar atmosphere is called the "transition region". Read the sentence in the book that says "One question that has puzzled astronomers is what gives the corona its extremely high temperature".

## 3 The Solar Wind

We can pull together some of the physics topics we have discussed this semester to understand one of the most important attributes of the solar system, the *Solar Wind*.

We have seen that the mean squared speed of particles in a gas is directly proportional to its temperature.

$$\frac{1}{2} m < v^2 >= \frac{3}{2} k_B T \tag{1}$$

$$\sqrt{< v^2 >} = \sqrt{\frac{3k_B T}{m}} \tag{2}$$

These equations say that the higher the temperature, the faster the particles are moving around.

Another speed we discussed was the orbital speed of a circular orbit of a small mass $m$ around a large mass $M$.

$$V_c = \sqrt{\frac{GM}{r}} \tag{3}$$

Another related speed which we did not discuss is the escape speed $V_{esc}$. An object with this speed at a distance $r$ from $M$ will be on a parabolic (not elliptic) orbit.

$$V_c = \sqrt{\frac{2GM}{r}} \tag{4}$$

From these equations you can see that as one moves out further from the center of the Sun into the corona

- The thermal speed increases (as the temperature in the corona increases)
- The escape speed decreases.

This means that the further out one is in the corona, the bigger the fraction of the distribution of particles is moving faster than the escape speed. ($\longrightarrow$ Diagram on blackboard). This heated gas flows out through interplanetary space and forms the *Solar Wind*. ($\longrightarrow$ look at pictures in the online notes).

We can measure the solar wind flowing past the Earth (web page for ACE spacecraft; see movies from SOHO).

# 4 Sunspots and Solar Activity

Sunspots are the most conspicuous feature seen on the surface of the Sun. ($\longrightarrow$ look at pictures in the online notes.)

There are some well known features of sunspots.

- They are still regions of hot, incandescent gases. The temperatures in sunspots are of order 4300K instead of 5800K, but that is enough to make them look dark in comparison to the rest of the photosphere.
- They are regions of strong magnetic field, 0.2 - 0.4 Tesla (T).

# 5 Magnetism: the Basic Physics of Sunspots and Solar Activity

A lot of the basic physics of sunspots and solar activity can be understood with just a couple of results from the physics of magnetic fields and charged particles moving in magnetic fields.

## 5.1 The Lorentz Force

A charged particle moving in a magnetic field feels a force called the *Lorentz Force*,

$$\vec{F} = q\vec{v} \times \vec{B} \tag{5}$$

(remember the vector cross product). You can figure out that this means the particle motion projected onto a plane perpendicular to the magnetic field will be a circle. The radius of this circle is called the *Larmor radius*

$$r_g = \frac{mv_\perp}{qB} \tag{6}$$

where $v_\perp$ is the component of the velocity projected onto a plane perpendicular to the magnetic field.

## 5.2 Magnetic Energy Density

In higher level courses in physics, you can show that there is energy in magnetic fields. A convenient way of describing this is in terms of the *energy density*, or Joules/m$^3$. This energy density (which is also a pressure) is given by

$$P_B = \frac{B^2}{2\mu_0} \tag{7}$$

where $\mu_0$ is a fundamental constant of physics called the permeability of free space, and has the value $4\pi \times 10^{-7}$ in SI units.

The basic lesson of this equation is that if you have a strong magnetic field, and it fills a large volume, you have a large amount of energy that can potentially be converted into other forms.