Review

Last time we

• Finished talking about star formation.

• Discussed how the collapse of a gas cloud into a star can be induced by shock waves from forming stars, young stars, or supernovae.
Star Clusters

I. Open Clusters
   A. Hundreds to tens of thousands of stars in the space of a few parsecs.
   B. Usually fairly young (less than 100 million years).
   C. Wisps of leftover gas are often present.

II. Globular Cluster
   A. Roughly spherical.
   B. Hundreds of thousands to millions of stars spread out over many many parsecs.
   C. Fairly old (10 billion years old on average).
The Sun: Basic Information

- Radius: $7 \times 10^5$ km (109 Earth Radii)
- Mass: $12 \times 10^{30}$ kg (330,000 Earth Masses)
- Surface Temperature: 5,800 K
- Core Temperature: 15,000,000 K
- Average Density: 1.409 g/cm$^3$ (Similar to Kevlar)
Solar Atmosphere

We know that the surface of the Sun has a temperature of 5,800 K based on the thermal radiation we detect. This raises some important questions:

- What is this so called surface of the Sun, if the Sun is a ball of gas?
- What makes the Sun so hot?

A major triumph of astronomy in the 20th century has been the ability to answer these questions. We start, as they did, with what we can see.
Solar Atmosphere

The Solar atmosphere is divided into three parts

1. The Photosphere
2. The Chromosphere
3. The Corona

The separation between these parts of the Sun is not a strict line or elevation. They tend to flow one into the other, but each has defining characteristics which we will discuss.
The Solar Photosphere

The photosphere is the “surface” of the Sun.

- The photosphere is not solid like the surface of the Earth.
- The photosphere is approximately 500 km thick.
- The photosphere is a region of the Sun in which radiation can escape to space.
- The photosphere is low in density (3,000 times less dense than air).
- The photosphere looks fairly smooth, with the exception of a few dark sunspots.
Granulation

The photosphere varies a bit in brightness and color. A close look reveals bright spots surrounded by dark lines called *granules*.

- Granules appear bright because they are \( \sim 100 \) K hotter than the surrounding gas.
- Granules are about the size of Texas.
- Granules last about 10-20 minutes.
- Granules rise up from deeper within the Sun.
- Granules are the result of *convection* within the photosphere.
The Chromosphere

Just above the photosphere lies the chromosphere.

- The chromosphere has an irregular depth on the order of Earth radii.
- The chromosphere looks pink, as a result of spectral line emission from Hydrogen.
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- The chromosphere has an irregular depth on the order of Earth radii.
- The chromosphere looks pink, as a result of spectral line emission from Hydrogen.
- The chromosphere is $10^8$ times less dense than air.
- The temperature rises up to $10^6$ K at the top of the chromosphere.
Filtergrams

How do we study a region so close to the photosphere? Using a filtergram. We observe the light in an absorption band where the photons from the photosphere are absorbed. This reveals

- Supergranules that are several times as large as the Earth.
- Long dark filaments extending over much of the Sun’s chromosphere.
- Spicules of gas which rise up into the lower reaches of the Corona and tend to last for 5-15 minutes.
The Solar Corona

Above the chromosphere is the hottest part of the solar atmosphere, the corona.

- The corona extends to several times the radius of the Sun.
- The temperature in the corona is 1 to 2 million Kelvins.
- There are no absorption lines in the corona.
- The gas in the corona is very hot, but not very bright, because there is so little of it (1-10 atoms per cubic centimeter).
- Heated by magnetic fields looping up through the photosphere.
Helioseismology

Although we cannot see into the Sun’s interior, we can begin to probe the interior of the Sun much the same way we probe the interior of the Earth, through seismic waves.

- As the Sun moves it vibrates in specific patterns.
- We can detect these vibrations not with seismographs, but by observing Doppler shifts on the surface of the Sun.
- The patterns we see tell us about the density and temperature beneath the solar photosphere.
Sunspots

Sunspots were observed by Galileo and are easy to detect through a small telescope. *Never look directly at the Sun, or look through a telescope at the Sun unless it has a solar filter.*

- Sunspots rotate across the surface of the Sun, indicating that the Sun itself is spinning.
- Sunspots follow an 11 year cycle in which they subside or strengthen in ways that affect the Earth’s atmosphere as well as electronic devices.
- Sunspots trace regions of magnetic activity on the Sun’s surface.
Link to Earth Climate
The Magnetic Cycle of the Sun

The cycle of sunspot activity indicates that there is a magnetic cycle in the Sun. What causes this cycle? To understand that we need to look at how the Sun rotates.

- The Sun's equator is rotating faster than higher or lower latitudes.
- This type of rotation is called *differential rotation* because different parts of the Sun rotate at different speeds.
Babcock Model

The solar magnetic cycle is not well understood, but we believe that the following sequence of events occurs.

- The magnetic fields of the Sun are frozen into the ionized gas of the Sun.
- Differential rotation tends to tangle the magnetic fields into tight loops.
- After approximately 11 years the magnetic fields begins to quickly rearrange itself into a new, simpler configuration of opposite polarity.
- The tangling process begins again.