4 The Sun

Now that we have all the theoretic building blocks in place, let's start using them by having a look at our central star, the Sun:

Mass	2×10^{30} kg
Radius	0.7×10^{6} km
Distance	150×10^{6} km
Age	4.6×10^{9} a
Escape velocity	618 km/s

4.1 Structure

Analysis of the Doppler shift of light emitted from the solar surface reveals that the Sun oscillates at a discrete set of eigenmodes, not unlike a ball of jello would; at any one time about 10^7 of these eigenmodes are present on the surface. Comparing the distribution of these eigenmodes with those of models we can estimate the internal density and temperature structure of the Sun, in the same way oscillations from earthquakes reveal details of the Earth's internal structure. Quite adequately, this technique is called helioseismology. The Sun consists of three main layers; the core, the radiative zone, and the convective zone. This structure is shown schematically in Figure 1.

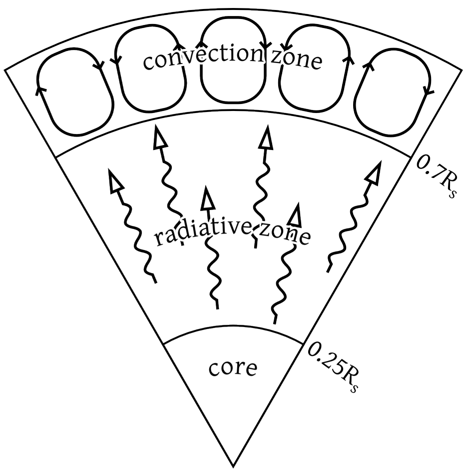

Figure 1: Sketch of the internal structure of the Sun.

From the center of the Sun the core extends outwards to about $0.25R_S$. In the core temperatures reach about 15×10^6 K and the density is about 10 times that of gold (150×10^3 kg/m^3). Under these conditions nuclear fusion occurs; hydrogen is fused to helium. This occurs in the three steps known as the ppI-chain shown in Figure 2.

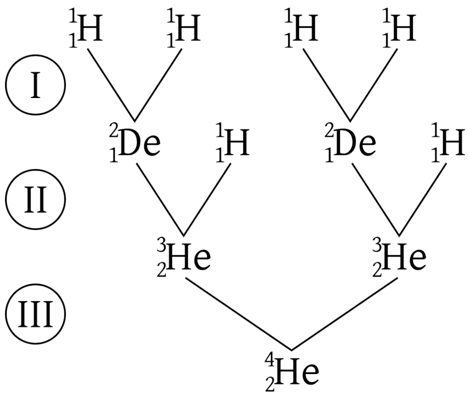

Figure 2: The ppI-chain.

Once all hydrogen inside the Sun is spent, fusion will cease. It is estimated that the Sun is not heavy enough to create conditions under which helium can be fused to even heavier elements.

Between about $0.25R_S$ and $0.7R_S$ lies the radiative zone in which the heat produced by the nuclear fusion inside the core is transported outwards in form of electromagnetic radiation (photons). This process of heat transport can be described as a diffusion process. Because of the short mean free paths of the photons (mostly gamma rays) involved, it is believed that it takes about 150.000 years until a photon created in the core reaches the solar surface.

All material up to the outer boundary of the radiative zone called the tachocline rotates with the same angular velocity; at larger radial distances the solar plasma rotates differentially with higher angular velocities at the

equator than at the poles.
Above the radiative zone the temperature decreases with increasing radial distance in such a steep gradient that the material is unstable with respect to the convective instability. A convection zone is formed in which the hotter material from the inside rises to the Sun's surface, radiates its heat into space and - now colder - sinks back down. Furthermore, in the transition region between radiative and convective zone more and more ions are not fully ionized such that more and more radiation is absorbed which leads to a less effective radiative heat transport. Signs of convection are observed on the surface of the Sun as "granules".
As the Sun is a giant ball of gas it is not immediately obvious where the surface is. We define the surface as that part where most (visible) light is comming from. Consider Figure 3 where several parameters are shown as a function of altitude.

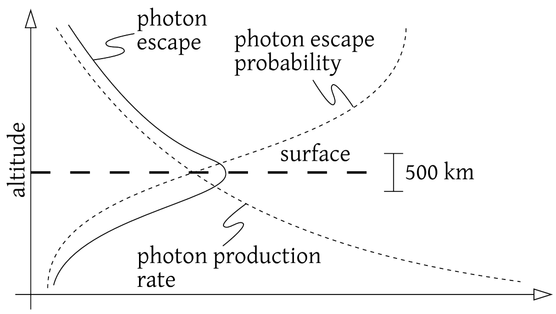

Figure 3: Altitude profiles of photon production rate and photon escape probability.

The density of the material decreases with altitude, which implies that the amount of light emitted (photon production rate) from the higher altitude ranges is smaller than that at lower altitudes. At the same time, due to less material being around, the higher altitude layers will absorb less material whereas most light will be absorbed in the lower layers. The amount of photons reaching us are from that thin region where still a substantial number of photon is created and they are not absorbed in the overlying layers. We called this layer the photosphere. Inside the photosphere the temperature decreases from about 6600 K to 4300 K and it mostly consists of neutral hydrogen and helium.
Above the photosphere the temperatures begins to rise again, probably due to magnetic reconnection and/or the breaking of boyancy waves. This region is about 2000 km thick and called the chromosphere.
At the top of the chromosphere the temperature is about 10.000 K and it increases dramatically thereafter, to about 1.000.000 K in the uppermost layer of the solar atmosphere called the corona. Due to these high temperatures all its main constituents (mostly hydrogen and helium) are fully ionized. This part of the solar atmosphere forms the basis for the solar wind.
The upper layers of the Sun are summarized in Figure 4.

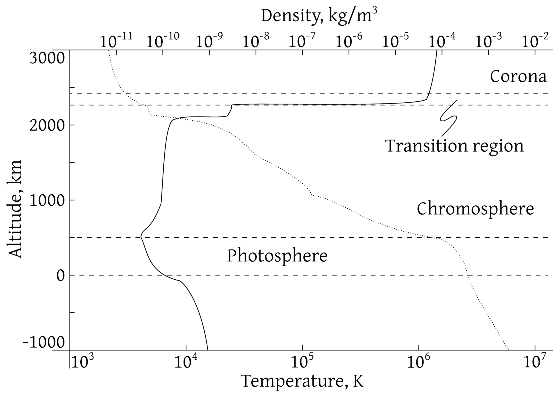

Figure 4: Upper atmospheric structure of the Sun.