Photon Diffusion for the Sun

You have probably heard that it takes light from the sun about 8½ minutes to reach the Earth. We can confirm this with a quick calculation:

$$Light\ travel\ time = \frac{distance}{speed\ of\ light} = \frac{93{,}000{,}000\ mi}{186{,}000\frac{mi}{s}} = 500\,\text{sec} = \mathbf{8.33\ minutes}$$

But this really doesn't tell the whole story.

Where does the light come from?

The sun is comprised mostly of Hydrogen (about 75%). These hydrogen atoms under high pressure and temperature will undergo a nuclear reaction where 2 hydrogen nuclei will fuse together to form a Helium nucleus. This is called **nuclear fusion**. The result of the reaction is that a tremendous amount of energy is released. Much of it is released in the form of **photons**. A photon is a packet of energy that has zero rest mass and moves at the speed of light. The level of energy of these photons determines what kind of electromagnetic radiation they are. The sun emits a large spectrum of electromagnetic radiation including light, x-rays, inferred, and ultraviolet.

Never yell "Fire!" in a crowded room.

Usain Bolt is considered the fastest man alive. He runs the 100-meter sprint in under 10 seconds. That is approximately the length of a football field! Now, let's take everyone in the stands of a football stadium and bring them down to the field. It would be very crowded. Now let's let Usain Bolt run the length of the field. As we watch him hit the first wall of people, he would lose all his momentum, bounce off individuals, recoil backwards, and be thrown around. He may even lose his sense of direction and aimlessly bounce around people until he luckily found an exit. In the end, it may take hours for the fastest man in the world to traverse the 100 meters. This is same principle for evacuating a room quickly. Slow and orderly usually clears a room faster that panic and pushing. The photons of light born in the center of the sun have this treacherous kind of journey to get to the surface and escape to take the 8.3 minutes to get to Earth. But how long could this possibly take.

A photons long journey.

The sun is a very complex system. We can simplify it dramatically if we consider it as having two major regions; the interior and the solar atmosphere.

Our photon travels through the interior

A photon born in the very center of the sun finds itself in one of the most hostile environments ever conceived. Immense temperature and pressure create a place where the boundaries of atoms become less well defined. Particles are just thrown around and photons are absorbed and re-emitted continuously. As our photon starts to head toward the surface of the sun, it doesn't

get far until it encounters another particle in its way. When a photon passes near an electron, the electron can actually absorb the photon and take its energy. This causes the electron to jump out of its orbit to a new higher orbit. Since the electron can only exist at specific energy levels, this usually results in the electron giving off a photon or photons to release the added energy and the electron goes back down to its stable orbit. So technically, a photon born in the middle of the sun NEVER makes it to the surface. It is always absorbed and re-emitted as another photon. Photons are continually absorbed and re-emitted throughout the interior region of the sun. The re-emitted photons may also leave the electron at a different angle than they came in based on conservation of momentum, mass, spin, etc. So our photon, that was trying to get to the surface, may have just been shot back to the middle of the sun again. This whole process of the photon making its way to the surface is called **photon diffusion**.

Our photon gets to the solar atmosphere.

Once the photon reaches the solar atmosphere, it finds itself in a little different environment. The pressure isn't as great and the density has reduced making it have to travel longer to reach another particle and interact. In contrast to the interior, the outer part of the sun is largely transparent, and if the photon makes it here, it has a good chance of getting away and starting it's trip to Earth. So we can really just look at the photo travel from the center to the start of this zone as the diffusion time.

Exactly how long is the diffusion time?

This is a difficult time to actually pin down to an exact amount. We learn more and more about the sun over time and our understanding of its composition and the nature of its interior has grown dramatically. Let's do a quick calculation to see what the light travel time is from the center of the sun to the outside to get a reference for the shortest straight line distance.

$$Light\ travel\ time = \frac{radius\ of\ sun}{speed\ of\ light} = \frac{432{,}288\ mi}{186{,}000\ \frac{mi}{s}} = \mathbf{2.3\ seconds}$$

So if there were no interactions of our photon, it would take a little over 2 seconds to exit the sun when traveling from the center. Do you have a guess at how much longer that time is when we add in these random interactions?

170,000 years

Yep, it takes 170,000 years for our photon born in the center to reach a place where it can escape and start its journey to Earth. So the next time someone asks how long it takes light to reach Earth from the sun, you will know that eight and a half minutes is only half the story.