

The Science of Sunshine

By Colin Johnston, Science Communicator

“The sun is dying, and mankind is dying with it. Our last hope: a spaceship and a crew of eight men and women. They carry a device which will breathe new life into the star. But deep into their voyage, out of radio contact with Earth, their mission is starting to unravel. Soon the crew are fighting not only for their lives, but their sanity.”

This is the plot of ‘Sunshine’, the 2007 science fiction film directed by Danny Boyle. The movie is set fifty years in the future. How plausible is this? Could our Sun really fade away in just a few decades?

“If the Sun stopped generating energy our future would look bleak”

In a very simplified nutshell, the Sun, like every other main sequence star generates energy deep in its core by converting hydrogen into helium. Exactly the same process occurs in a detonating thermonuclear bomb, so the core of the Sun can be thought of as one enormous nuclear explosion. This fusing of hydrogen into helium only happens in the core as only there are the pressure and temperature high enough to fuse atoms together. The released energy travels upwards from the core until it eventually escapes the Sun’s surface. It is a long journey, about 700,000 km, or almost twice the distance from the Earth to the Moon. Once it leaves the Sun’s surface most of it shines outwards into empty space but after a journey of about 8.3 minutes a tiny fraction of it falls on the Earth, bringing us light and warmth. If somehow the Sun ceased converting hydrogen into helium, it would stop generating energy and our future would look bleak.

Each nuclear reaction in the core releases its energy as a tiny ‘packet’ called a photon and each

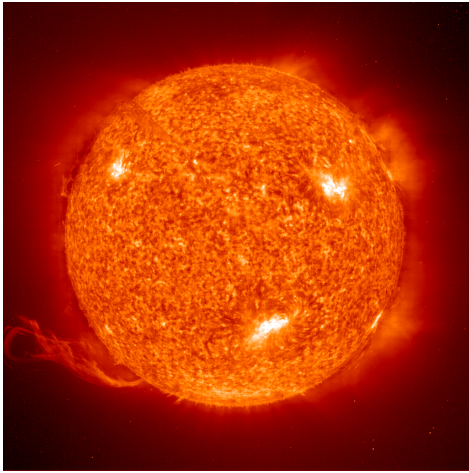


Image Credit: 20th Century Fox

The crew of Icarus II The cast of ‘Sunshine’ includes Rose Byrne, Michelle Yeoh and Cillian Murphy .

photon’s trip upwards is slower than you may imagine. A photon travels at the speed of light (because they are light), but inside the Sun they do not get a clear run. The core is so dense there are atomic nuclei everywhere, so each photon can travel only a short distance before hitting a nucleus and being absorbed. After a short pause the nucleus spits the photon out again in a random direction- which could be back the way it came- and the photon continues on its way until it hits the next atomic nucleus. This happens trillions of times on each photon’s journey through the Sun. Inside the Sun, a photon follows an erratic, meandering route, sometimes doubling back on itself until it eventually blunders into the freedom of space. As a result, the journey time through the Sun can be very, very long indeed. On average, photons of energy may take about 40 000 years to travel from the centre of the Sun to its surface, that is equivalent to about 2cm per hour which is much, much slower than a snail’s pace. The Sun’s surface, by the way, displays many spectacular phenomena such as sunspots and prominences, these will be covered in a future issue of Astronotes.

As a by-product, the fusion reactions in the Sun’s core also generate a multitude of particles called neutrinos. Neutrinos are strange ghostly little beasts; travelling at almost the speed of light they have an extraordinary ability to pass straight



Unquiet Sun Prominences are huge clouds of relatively cool dense plasma suspended in the Sun's hot, thin atmosphere. At times, they can erupt, escaping the Sun's atmosphere as seen in this image from the SOHO spacecraft. Prominences and sunspots are generated far above the sun's core.

through matter. It is has been claimed that a neutrino would have a 50% chance of passing unhindered through a block of lead 50 light years thick! As a result, when each fusion between two hydrogen nuclei occurs, creating a photon of energy and a neutrino, the photons begin aimlessly lurching from one collision to the next. Meanwhile the neutrinos created in the core leave the photons standing as they zip through the Sun's outer layers in just over a couple of seconds and escape into space. A small portion of them reach Earth just over eight minutes later. If we could detect them it would give us nearly instant news on what is going on inside the Sun. Detecting neutrinos sounds impossible since they can pass through virtually anything without stopping but it has in fact been done. The first 'neutrino telescope' was a giant tank of very pure chlorine-based chemicals (located deep underground to shield it from radiation sources). When a neutrino strikes a chlorine atom there is slight chance of it being absorbed, converting the chlorine atom into an atom of argon in the process. This is incredibly unlikely but there is a staggering number of neutrinos emitted by the Sun. Hold the palm of your hand in front of the Sun for a second: six trillion neutrinos have just passed through your

hand. As there are so many neutrinos passing through the tank, after a week there should be a measurable amount of argon in it. The experiment is very difficult to do, requiring great care and the leading researcher who pioneered the technique, Raymond Davis, deservedly shared a Nobel prize for the work.

By observing the neutrinos emitted by the Sun, we can monitor the fusion reactions going on inside it in almost real time. If we did not see as many neutrinos as we should, we get alarmed. In fact we have already had this experience. In his measurements, Davis saw only a third of the number of neutrinos from the Sun that theory predicted. Was the Sun going out? Thankfully the answer is no, but it took several decades to find out what was really happening. It was known that there are three types of neutrino. Only one type, the electron-neutrino is produced in the Sun, and the experiment was designed to detect them alone. Later research has discovered that neutrinos can spontaneously change their type as they travel through space. Imagine you 'phone a take-away pizzeria to order a pepperoni pizza, but when it arrives you find it is a ham and pineapple pizza. When you investigate you discover that the toppings on all the pizzas ordered from the restaurant are constantly morphing randomly from pepperoni to ham and pineapple or chicken and sweetcorn from the minute they leave the oven. As a result of these weird goings-on there is only a one in three chance you will receive the pizza you want. In the case of solar physics the pizza oven is the Sun's core and the different topping are the different types of neu-

“The Sun has been in a delicate balance for 4.6 billion years”

trino- it seems strange but it really happens! Newer neutrino detectors can identify all three types of neutrino and once we look for all three, we do indeed see the correct number from the Sun. They were all the same type when they left the Sun but changed en route. If the scenario from the movie really happened- and note that there is no way that we know of that it could come true- the first we would know is when we

saw a lower number of solar neutrinos. The Sun has spent its 4.5 billion years of existence maintaining a delicate equilibrium. The Sun contains a lot of material, equivalent to more than 330 000 Earths. This means its gravitational pull is very strong, if you could stand on the surface of the Sun, you would be nearly thirty times as heavy as you are on Earth. Why does this crushing gravity not collapse the Sun into a denser sphere? Earlier I compared the Sun's core to a nuclear explosion; in the Sun (and other 'normal' stars) the energy unleashed in the core ought to blast it apart- except the enormous gravity is pressing downwards holds it together. In this way the Sun is in a delicate but very stable balance which has remained more or less constant (it is slowly getting hotter through the aeons) for 4.6 billion years. It is now about half way through its life. The Sun has billions of years

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worth of hydrogen left as fuel and will continue to shine throughout that time. Eventually there will be one last perfect day on Earth, then the hydrogen in the Sun's core will be exhausted. Nuclear fusion will trickle to a halt. Less energy will radiate out, so there will be less to oppose gravity's grip. Material from the Sun's outer layers will fall inwards and the Sun's core will contract - getting even hotter and denser than ever before. Under these conditions, new fusion processes can begin as helium is converted into carbon and oxygen, releasing energy and the Sun will swell into a new equilibrium as a bloated red giant star so large that it will almost engulf the Earth. By this time our planet will be a scorched sphere, baked dry of life.

The 'Sunshine' movie's plot raises another interesting issue: it is extremely hard to send spacecraft from the Earth to the Sun. To send a probe diving into the Sun sounds easy, after all it is a huge target, but in practice when the probe is launched it will share the Earth's orbital velocity around the Sun (about 30 km/s). To make it fall sunward we need to cancel this velocity out and

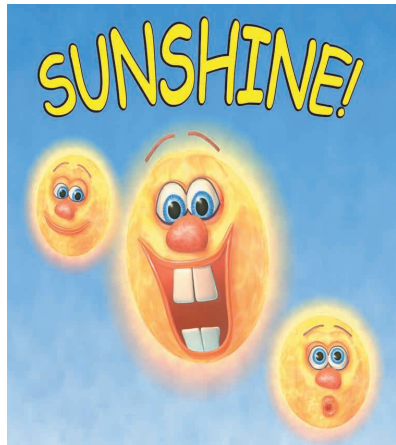


Image Credit: National Space Centre

The Other Sunshine Hopefully no one will confuse Danny Boyle's gritty epic with our show for the under-fives.

there is no existing rocket booster that can do this. This requirement is so demanding that there is nothing on the drawingboard that might do the trick either. It takes less energy to send a probe out of the Solar System than it does to send one into the Sun (and there is no point even considering a return trip). Sending spacecraft close to the Sun requires a powerful booster and multiple gravity assist manoeuvres around planets. In a seven year journey to Mercury NASA's MESSENGER spacecraft will make several fly-bys: Earth, Venus twice, and Mercury three times in order to slow down enough for its engine to be able to put it into orbit around the innermost planets. In the interests of drama, the Icarus II in the film will probably travel by an unfeasibility fast route.

As far as science tells us the Sun will outlive all of us, so no desperate spaceship crew will ever need to re-ignite the Sun. The movie 'Sunshine' is fiction after all, but hopefully it will make the audience think just a little about the delicate balance of forces which sustain our star, and thus us all.