Dear Cheap Astronomy - Episode 002

Question 1:

Dear Cheap Astronomy - How do neutrinos fit into the grand scheme of things and can they really move faster than light?

The sub-atomic world is divided into fermions and bosons. Broadly speaking fermions include the main constituents of stable matter, while bosons are mainly force carrier particles - which often have no mass. A photon is a good example of a boson.

Fermions, the matter particles, can be further sub-divided into hadrons - which include protons and neutrons - and leptons, which include electrons and neutrinos.

But... if it were only that simple To complicate the above story you also get things like mesons, which are unstable matter particles called bosonic hadrons. This is because what technically defines a fermion versus a boson split is whether particles have integer spin (bosons) or half-integer spin (fermions) and these unstable mesons do have integer spin. But the general rule that fermions are matter and bosons are forces - does work *most* of the time.

Anyhow neutrinos are definitely leptons and are essentially neutrally charged versions of the other leptons – electrons, muons and taus, all of which have a negative charge. So, we say that neutrinos come in three 'flavors' – electron neutrinos, muon neutrinos and tau neutrinos.

On the anti-matter side of things there are also positively charged leptons - being positrons, anti-muons and anti-taus. There are thought to be anti-neutrinos, but since they are also neutrally charged, some people have suggested that the anti-matter version of a neutrino is ... well, a neutrino.

Anyhow, neutrinos are weakly interacting. That phrase should be taken literally - since neutrinos interact via the weak force and not by the strong or electromagnetic forces. That is why they can zoom straight through a light year of lead as though it wasn't there.

It's generally agreed that neutrinos have mass, but so little mass that no-one has been able to put a figure on it yet. They are often clocked moving at 99.99 per cent of this speed of light - which is also the case electrons which, you might remember, are also leptons - but do have a known mass and a negative charge. However, electrons can only maintain these kinds of speeds within a vacuum. Neutrinos being weakly interactive, can maintain these kinds of speeds while moving through solid objects.

This is the basis of the now-infamous Oscillation Project with Emulsion-Racking Apparatus (or OPERA) experiment, which tracks neutrinos emitted from the CERN Large Hadron Collider. Those neutrinos move in a straight line through the Earth's crust to a detector 730 km away in Italy. Now, no-one would have been the tiniest bit surprised if those OPERA experiment neutrinos had been clocked moving at 99.99 per cent - because that's what neutrinos do.

But, as it happened they were clocked at 100.0025% of the speed of light - so instead of being a tiny bit under, they were a tiny bit over. The smart thing to do under these circumstances is to start checking your equipment for bugs before you start suggesting that you have overturned one of the foundations of modern physics. It doesn't seem likely that this finding will survive further scrutiny - which the OPERA people are half- expecting anyway. They just want to understand how they got the data that they got.

Question 2:

Dear Cheap Astronomy - Do thermonuclear weapons have anything to do with the fusion reactions that drive the Sun?

Well, not much. Human-made thermonuclear explosions and solar fusion both involve thermonuclear reactions - but the underlying principles of these reactions are quite different.

Thermonuclear weapons are built using heavy radioactive isotopes, which being radioactive are already a bit unstable. If you fire a neutron at high velocity at a nucleus of such material, the impact can be sufficient to split the heavy nuclei into two smaller and lighter nuclei. This splitting of an atom (as people sometimes call it) or *fission* releases some of the energy that bound the original heavy nucleus together - and that energetic reaction will fling off a number of particles, including (let's say) two high velocity neutrons.

And if you have packed lots of fissile material together in just the right way, then those two high energy neutrons will each hit two more heavy radioactive nuclei - splitting them, which releases more energy and now *four* high energy neutrons - and if they each strike four more heavy radioactive nuclei then you have the makings of a chain reaction - where the action of two atoms splitting, splits four atoms, which splits eight atoms, then sixteen atoms, then thirty two and so on.

Now, we should explain that the first 'atomic' bombs - including the ones detonated over Japan that killed about 200,000 people, mostly civilians - were really *fission* bombs designed around the chain reaction principle we have just described. Real *thermonuclear* bombs came later, including the hydrogen bomb which does actually include a hydrogen fusion step - although the bomb still requires the fission of heavy radioactive isotopes. Essentially, an initial fission step heats a package of hydrogen isotopes (deuterium and tritium) to temperatures sufficient to enable fusion. That fusion step then fires out high energy neutrons to generate more fission from another package of fissile material.

The advantage of this thermonuclear design is that you can build stages within the bomb - and that allows you to build bombs that are at least an order of magnitude more powerful than the original fission bombs. Fortunately, at least to date, such nightmarish weapons have never been dropped on anyone. Cheap Astronomy suggests that we keep it that way.

So, from all that you hopefully get the picture that enabling such thermonuclear reactions to take place on Earth requires a lot of precision engineering and the careful packing together of enriched fissile materials into some very intricate and artificial patterns that you won't find in nature.

If we now consider what does happen in nature - we find that natural thermonuclear reactions have nothing to do with engineering. The powerful self-gravity created by a star's mass is all that is needed to drive these reactions. If you pack hydrogen together within the dense core of a star, the compression generated from the overlying layers of the star's mass heats the hydrogen protons and forces them together - enabling fusion reactions which create even more heat (remembering that fusion is a thermonuclear reaction) - and this extra heat facilitates more fusion. But you wouldn't call this a chain reaction - it's ultimately the density of the star's core containing the heat that makes stellar fusion possible.

In the Sun's case you never actually *see* thermonuclear explosions. There are lots of conventional explosions on its surface of course - like solar flares and coronal mass ejections - but these are the result of an ongoing, dynamic struggle between gravitation, radiation pressure and the Sun's intense magnetic field.

All the thermonuclear activity within the Sun take place deep within its core and the Sun's powerful self-gravity prevents any chance of an explosion taking place there. The high energy radiation and sub-atomic particles produced by thermonuclear hydrogen fusion have to slowly negotiate their way outwards over hundreds and thousands of years through the dense layers of the Sun until they reach its surface. This is not an explosion.

There are also a huge amount of high energy, though weakly interacting, neutrinos produced by solar fusion. These pretty much shoot straight out of the Sun - from deep within its core out through its surface at close to the speed of light. But this is not really an explosion either. The weakly interacting neutrinos don't blow up the Sun - they just leave.

Of course nature is full of genuine thermonuclear explosions - which are called supernovae. These are seriously stupendous thermonuclear explosions - caused by the collapse of a massive star's core or by a white dwarf exceeding its Chandrasekhar limit. But these supernovae explosions also have almost nothing in common with the relatively tiny chain-reaction-based fission explosions we have managed to artificially create on Earth.

Still, despite their small size, these small terrestrial explosions can still leave deep and prolonged feelings of guilt and regret in their wake. They should be avoided at all costs.