Message from the Dark Side there is . . .

The Moon wasn't always so far away. The Moon was formed about 60 million years after the Earth, about 4.5 billion years ago. It was formed when the planet Theia, about the size of Mars, collided with the Earth. The two planets merged, but a lot of the material from both was thrown into space, much of it into orbit around the combined body. Over the next few years, this orbiting debris gathered together to form the Moon. The energy released in this process would have caused the outer parts of both the Earth and the Moon to be glowing liquid magma.

A few million years later, both bodies had solidified – at least on the surface. At that time the Moon was only about 25 000 km from the Earth, one fifteenth of what it is today. So, from Earth the Moon would have been 15 times as wide in the sky and over 200 times as bright. What's more, it would have orbited the Earth in 10 hours, compared to the 28 days at present. In those days, the Earth rotated much faster too – in about 6 hours.

Being so large in the sky would mean that there would be a total eclipse of the Moon every time or nearly every time it went round the Earth – every 10 hours. And, for observers near the equator, there would be a total eclipse of the Sun about every 10 hours too. Of course, in those days, observers were a bit thin on the ground.

With the Moon so close, tides would have been huge (once enough water had accumulated to make an ocean). Tides of up to a kilometre would have been possible.

The gravitational forces that cause the tides also had the effect of slowing down the rotation of the Earth and causing the Moon to move progressively further away. The Moon is still receding at 3.8 cm per year. In the not-too distance future, there will be no more total solar eclipses – the moon will be too small in the sky to completely cover the Sun.

Message from the Dark Side there is . . .

Neutrinos. Neutrinos are sub-atomic particles produced in nuclear reactions. Each time four hydrogen nuclei (protons) and two electrons combine to form a helium nucleus in the Sun, neutrinos are produced and these radiate from the Sun very close to the speed of light. So many nuclei are fused in the Sun that, each second, about 1000 trillion of these neutrinos pass through your body. This sound like it could be harmful, but neutrinos react very little with other matter and so do very little damage. The vast majority of neutrinos will pass right through the Earth without hitting anything.

Message from the Dark Side there is . . .

Dwarves. The universe is full of dwarves. There are billions of billions of them. There are red ones, yellow ones, black ones, white ones and brown ones.

The sun is a yellow dwarf. It is called a dwarf because it's not a giant. Seemingly there isn't much in between. Stars less than half the mass of the sun are red dwarves, so called because they are small and red. The sun's nearest neighbor, Proxima Centauri, is a red dwarf. Stars even smaller than that (less than 8% of the sun's mass) are brown dwarves – they hardly shine at all and in fact are not really even stars in that they don't fuse hydrogen to helium. They are bigger than planets, though.

White dwarves are what the sun will turn into in about 5 billion years' time, after it has been a red giant for a while. White dwarves are very small and very dense (about 1 tonne per cubic centimeter). They are initially very hot (white hot in fact). After a few tens of billions of years, they cool down and stop shining, becoming black dwarves. There aren't actually any black dwarves yet – the universe hasn't been here long enough.

And, of course, there are dwarf planets too – like Pluto.

Message from the Dark Side there is . . .

The smallest stars. The smallest stars in the universe are not called dwarves. They are neutron stars. These are produced when some of the largest stars in the universe, blue giants, end their life as a supernova. The hydrogen in a blue giant burns to helium, then the helium burns to carbon and oxygen, then they burn to magnesium, silicon etc., finally ending up as iron. Once the core of the star is made up of iron, it can't produce any more heat, so it collapses. It collapses so hard that the electrons around the nuclei of the iron atoms get squashed down into the nuclei to make a solid mass of neutrons. The collapse is accompanied by a supernova explosion as a huge amount of energy is released in the collapse.

The resulting neutron star is just 15 kilometers across and one teaspoonful of neutron star has a mass of about a billion tonnes. Neutron stars can rotate at several hundred revolutions per second and can have magnetic fields about a trillion times stronger than the Earth's.

This magnetic field would tear your atoms apart if you landed on a neutron star. But that wouldn't really matter because the gravity would squash you down to a smear on the surface about a thousandth of a millimetre thick anyway.

Message from the Dark Side there is . . .

The Solar Compost Heap. In the core of the Sun, hydrogen is being converted into helium with the release of huge amounts of energy. Even at the distance of the Earth, this amounts to 1366 Watts per square metre. The total output can be calculated by multiplying this number by $4\pi r^2$, the formula for the surface area of a sphere, where r is the Earth-Sun distance, about 150 000 000 000 m. This comes to 4×10^{23} kW. So how much energy is produced by one cubic metre of the Sun's core? The answer is about 250 Watts, about the same as is produced by one cubic metre of fermenting compost. The vast amount of energy produced by the Sun comes from the vast number of cubic metres in the Sun's core. The actual material in the Sun's core is only about as powerful as compost.

Message from the Dark Side there is . . .

Transit of Venus. On 6 June 2012, there was a transit of Venus. Venus passed between the Earth and the Sun so that it could be seen as a black circle on the face of the Sun. The photo is of a projection of the sun using a telescope. It was taken downstairs in the Canterbury secondary library.

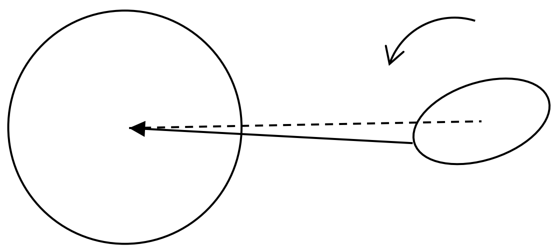
The next transit will be in 2117. So, most of us won't get to see another one in our lifetimes.

Message from the Dark Side there is . . .

The Dark Side of the Moon. People often refer to the side of the Moon which we cannot see from Earth as 'The Dark Side of the Moon'. That side is, however, light just as often as the side which faces us. Most points on the Moon get 14 days of daylight followed by 14 days of night. If you stand on the side of the Moon which faces Earth, you will see the Sun rise and set once every month. The Earth, however, will stay at roughly the same point in the sky all the time. It will never rise or set. Its phase will change as the Sun goes past it each month.

Message from the Dark Side there is . . .

The Captive Moon. From Earth we only ever see one side of the Moon. This is because the Moon is in a captured orbit around the Earth. This means that it rotates once for each time it orbits the Earth. In the early days, the Moon would have rotated faster, so we would have been able to see all sides of it from Earth. But the gravitational force from the Earth causes the moon to bulge towards and away from the Earth (the way the Earth's oceans bulge towards and away from the Moon with the tides). To keep the bulge pointing towards the Earth, the Moon had to constantly change shape. Because this changing of shape takes time, the Earth-side bulge was always slightly ahead of the line joining the centre of the Moon to the centre of the Earth. So, the Earth's gravity tended to pull it back and this slowed it down. Eventually, the Moon's rotation slowed to one rotation per orbit, so now the bulge always points straight towards the Earth.

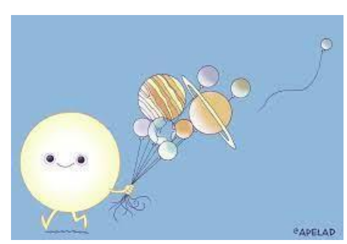


Message from the Dark Side there is . . .

Pluto the Outcast. In 2006, the International Astronomical Union met and cast Pluto out of the set of planets of our solar system. This decision has caused much grief around the world and resulted in abusive letters and even death threats to astronomers. The decision was brought about by the fact that several bodies similar in size to Pluto had been discovered in the outer solar system over the previous few years. These included Eris, Sedna, Haumea and Makemake. It appeared likely that many more would be found over coming years. So, a decision was made to define a planet as a body which:

1. orbits a star
2. is large enough for gravity to make it spherical
3. has cleared its orbit of smaller objects.

Objects like Pluto which meet the first two requirements but not the third were assigned to the new category of 'Dwarf Planets'. It might be said that a dwarf parrot is still a parrot, and so a dwarf planet should still be a planet. Astronomers tend not to see it that way, though.



Message from the Dark Side there is . . .

Super-moons. The Moon's orbit around the Earth is elliptical, not circular. Its distance from the Earth varies from 357 000 km at perigee to 406 000 km at apogee. Its diameter in the sky at perigee is 14% larger than at apogee and its area (and thus brightness) are 30% greater. When the Moon is full at perigee, this is called a super-moon. These happen quite frequently.

Message from the Dark Side there is . . .

Dark Matter. The people, planets, stars, galaxies and gas clouds we see around us are made of protons and electrons in equal numbers. There are also neutrons, but a neutron is made from a proton and an electron. For every proton and electron in the universe, there are about a billion photons (light particles) and about a billion neutrinos. But calculations of the amount of matter in galaxies based on their rotation speeds show that their mass is about 5 times that of the protons etc. in them. The rest of the mass is attributed to dark matter. It seems that dark matter consists of some sort of subatomic particle which we have never observed. It seems to interact with normal matter gravitationally, but not significantly in any other way.

Message from the Dark Side there is . . .

Dark Energy. Another one of these messages talks about dark matter. Even with dark matter, the density of galaxies in the universe is only about a quarter of what is needed to account for the gravitational cohesiveness of the universe as a whole. The remaining mass is thought to be in the form of dark energy. Dark energy seems to be a property of space itself. Space isn't just nothing. The space-time fabric is essentially what the universe is made of. Matter can be seen as local disturbances of this fabric. Space makes up 73% of the mass-energy of the universe, dark matter 23%, and all the matter we can observe makes up just 4%. Of this 4%, 0.4% is in galaxies, 3.6% is in clouds of hydrogen and helium gas between the galaxies.

Message from the Dark Side there is . . .

Starry Starry Night. Omega Centauri is a globular cluster, one of a couple of hundred which orbit our galaxy. Omega Centauri can be seen with the naked eye as a round smudge in the constellation Centaurus. It contains about half a million stars, packed so tightly together that, if Earth were in the centre of it, there would be about 100 000 stars in the sky brighter than Sirius, the brightest star visible from where we are. The night sky would be truly magnificent. The trouble is that life would be very unlikely in a globular cluster because any planets present would be thrown out of orbit by the frequent passage of other stars through their stellar systems. Unlike in the disc of our galaxy, star collisions are quite common in globular clusters.

Message from the Dark Side there is . . .

Light Years and Parsecs. It is often said that a light year is a very long time. But of course it isn't a time at all: it's a distance. It is the distance light travels in a year. As light travels about 300 000 km/s, it is about 10^{13} km or 10 trillion kilometres. Astronomers often use the parsec as a distance unit. A parsec is about 3.26 light years. It is the distance of a star whose parallax against distant stars caused by the movement of the Earth around the Sun is 1 second of arc. A degree is divided into 60 minutes and a minute into 60 seconds.

Message from the Dark Side there is . . .

Red Dwarfs. The closest star to the Sun, Proxima Centauri, lies 4.2 light years away in the constellation Centaurus. But it is much too feint to see without a good telescope. This is because it is a red dwarf. Red dwarfs are stars less than half the mass of the Sun. Because the pressure and temperature at their centres are both quite low (in relative terms – typical values are 10 000 000°C and 500 000 000 atmospheres), they burn hydrogen to helium very slowly and therefore shine only weakly (surface temperatures of less than 4000°C. This means that their lifetimes are generally measured in hundreds of billions or trillions of years rather than the 10 billion years for our Sun. We cannot see any red dwarfs from Earth with the naked eye, even though they make up about 85% of all stars in the galaxy.

Message from the Dark Side there is . . .

Brown Dwarfs. It was mentioned in an earlier message that red dwarfs make up 85% of the stars in our galaxy. When stars form in a nebula from accumulations of gas and dust, they form at all sorts of sizes from blue super-giants over 100 times the mass of the Sun down to red dwarfs. But many gas and dust accumulations aren't big enough to form a star at all. They form brown dwarfs or even smaller objects like gas planets. A star is generally defined as an object that produces heat by nuclear fusion at some stage in its life. Brown dwarfs don't do this and so are not classified as stars. Brown dwarfs can glow for a while from heat released by their gravitational collapse, but cool down after a billion years or so to a temperature at which they do not emit visible light. It is thought that there are at least as many brown dwarfs as stars in our galaxy and probably even more planet-like objects floating freely, not bound to stars. Of course, both are very difficult to find.

Message from the Dark Side there is . . .

The Hairy Dog Theorem. Mathematics is fundamental to astronomy. There are some quite hairy theorems in mathematics, not the least of which is the hairy dog theorem. This states that if you comb the hair on a dog, there must be at least one point where the hair radiates outwards leaving the skin visible. On a real dog, of course, this point is at its nose.

As with many mathematical theorems, you might think that this one is marginally interesting, but totally useless. But you would be very wrong. It is crucial to the design of fusion power generators. In fusion reactors, the reacting plasma has to be kept at about 100 000 000°C. At this sort of temperature it would instantly vaporize a material container. So magnetic containment is used. The container is a 3D space which has the magnetic field lines on its surface everywhere parallel to the surface. Being parallel to the surface stops the plasma from escaping.

But the hairy dog theorem tells us that such a container cannot be built: there must be at least one place where the magnetic field is zero or perpendicular to the surface. The plasma would leak out at this point (squirt out in fact). Now the hairy dog is topologically equivalent to a sphere and the hairy dog theorem applies only to such shapes. A donut has a hole through it and so is not topologically a sphere. Consequently, the hair on a donut-shaped dog can be combed without producing a bald spot – you go up through its hole and down round its outside. In the same way a donut-shaped magnetic fusion container can be made with the magnetic field everywhere parallel to its surface. So fusion containers are always toroidal or donut-shaped.

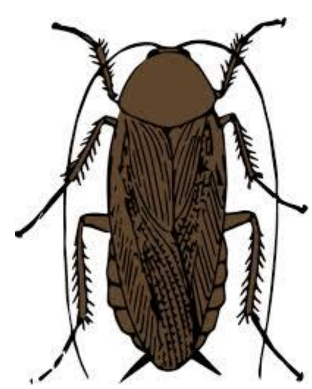
Message from the Dark Side there is . . .

Milky Way on Collision Course with the Andromeda Galaxy. Our galaxy, the Milky Way, is a spiral galaxy containing about 400 billion stars. But it is on a collision course with the larger Andromeda Galaxy. Impact is expected in about 3 billion years. Will this be the end of the world? Almost certainly not. Galaxies contain so much empty (or nearly empty) space compared to the space taken up by stars, planets etc., that it is quite unlikely that there will be even one direct hit between stars. The galaxies will pass right through each other, then be pulled back again by each other's gravity, eventually to coalesce as one large elliptical galaxy. Galaxy mergers are common in the universe and have led to a gradual increase in the size of galaxies over cosmic time.

Message from the Dark Side there is . . .

Pests. Humans are about 300 million years more advanced than cockroaches, in the sense that things like cockroaches were around 300 million years before things like us. Because of this, we consider cockroaches so primitive that, if we find them in the area in which we live, we take steps to eradicate them. We justify this on the basis that they spoil and pollute our environment with their droppings and germs – and on the basis that we just don't like the look of them. We give no thought to how the cockroaches feel about being eradicated.

The universe existed for some 9 billion years before the Earth formed and planets like Earth would have been around long before the Earth. In fact, there would probably be many millions of Earth-like planets considerably older than Earth in our galaxy alone. It is quite probable, therefore, that our galaxy has millions of civilizations at least 300 million years more advanced than us. How would such a civilization view us? Probably the way we view cockroaches.



In the last 100 years we have done quite a good job of spoiling and polluting our part of the galaxy: some space debris has even left the solar system. For that same 100 years, we have been advertising our presence and what we are doing through our radio broadcasts. These messages now fill space for 100 light years around Earth. Here's a sobering thought: if there's a Galactic Pest Control Unit within 100 light years of Earth, they are probably already on their way.

Message from the Dark Side there is . . .

The Ham and Cheese Sandwich Theorem. In another message, we talked about the hairy dog theorem. Another similarly interesting mathematical theorem is the ham and cheese sandwich theorem. This states that if you make a ham and cheese sandwich for two people, it doesn't matter how badly you make it, you will always be able to cut it into two pieces with one planar cut such that both pieces will have the same amount of bread, the same amount of ham and the same amount of cheese. The bread pieces can be any shape and size, the cheese can be put anywhere, for instance all on one side of the sandwich and likewise with the ham – the ham could even be on the floor nowhere near the bread or in pieces all over the wall. You will still be able to find a plane that divides it fairly.

This theorem illustrates the mathematical concept of degrees of freedom. There are 3 degrees of freedom in specifying a plane in 3-dimensional space. There are 3 constraints in having to fairly divide the bread, the ham and the cheese. So, there is one way to choose a plane that does the job. What relevance is this to anything that concerns us? Absolutely none.

Message from the Dark Side there is . . .

The Oxygen Catastrophe. In the early days the Earth's atmosphere was largely nitrogen and carbon dioxide with a bit of methane and other gases. It is thought that the earliest life gained its energy from chemicals emanating from underwater volcanic hot springs. Later, around 3 to 2.5 billion years ago, bacteria evolved that could gain energy from the sun by photosynthesis.

Photosynthesis produces oxygen as a waste product and these early bacteria hadn't learnt how to use the oxygen for respiration. So, the oxygen produced reacted with the ferrous iron dissolved in the oceans to produce iron oxides which then deposited on the bottom to produce the banded iron formations which now provide most of the world's iron ore. By about 2.3 billion years ago, the iron dissolved in the water had been largely precipitated. Free oxygen then started to accumulate in the ocean and, soon after, in the atmosphere.

But oxygen was actually a poison to life at the time and it killed over 99% of all living species – the species that had produced it in the first place. This was the oxygen catastrophe. It was a bit like asphyxiating on one's own flatulence. But a few fortunate mutations produced organisms that could survive in the oxygen and actually get energy from it. These organisms spread and diversified and eventually gave rise to nearly all the species alive today. Catastrophes aren't always bad in the long run.

Message from the Dark Side there is . . .

Snowball Earth. In another message, we talked about the oxygen catastrophe that killed nearly all living things around 2.3 billion years ago. But there was another consequence of the accumulation of oxygen. It oxidized the methane in the atmosphere to carbon dioxide.

Methane is a greenhouse gas about 80 times as effective as carbon dioxide. So, with the depletion of methane, the Earth got a lot cooler.

Today we are warm enough without the methane, but back then the sun produced only about 75% of the heat that it does today. (Stars like the sun get gradually hotter as they use up their hydrogen fuel.)

The result of the methane depletion was an ice age. The ice age age was so intense that the ocean froze right down to the equator. The whole earth was covered in ice – the snowball Earth. Ice reflects the sun's heat much better than rock and water, so that just made things worse. There was seemingly no way for the Earth to warm up again and, in fact, it stayed frozen for about 200 million years. The oceans weren't frozen right through though because the pressure at depth lowers the freezing point of water and geothermal heat was still coming out from the Earth. So life survived in the ocean.

Volcanoes produce carbon dioxide. This normally reacts with life and rocks to produce limestone and the like. This couldn't happen during the snowball Earth, so carbon dioxide accumulated in the atmosphere. Eventually, there was enough CO_2 to produce a sufficient greenhouse effect to melt the ice and to return things to normal. There were ice ages later, but none as severe.

Message from the Dark Side there is . . .

The Great Dying. There have been a number of mass extinctions during the history of the Earth. The Great Dying happened about 250 million years ago. It is thought to have been caused by a massive and prolonged burst of volcanic activity in Siberia. This put vast amounts of carbon dioxide into the atmosphere. The consequent temperature increase combined with the extra CO_2 caused bacteria and algae to proliferate in the world's water bodies, making them poisonous to most more advanced life forms as well as reducing the amount of light that could penetrate the waters. 95% of all species became extinct.

This took a couple of million years, though. At no time during the Great Dying was the rate of extinction anything like what it is today.

Message from the Dark Side there is . . .

The Unlikely Universe. The amount of gravitational attraction between bodies in the universe is determined by the universal gravitational constant, G, which is about $6.67408 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$. This seems to be something which is the same at all places and at all times in the universe. There are other constants which determine the intensities of the other forces – electromagnetic, strong nuclear and weak nuclear.

Had any of these constants been different by just 1%, then matter as we know it would not have existed and therefore neither would life, or us.

Perhaps more significantly, given the values of these constants, if the density of matter and energy in the universe one nanosecond after the big bang had been one part in a million trillion higher, the universe would have quickly collapsed in on itself because of the extra gravitational attraction; had it been one part in a million trillion lower, the universe would have spread out too quickly for any galaxies, stars or planets to form. It seems to be a very unlikely coincidence that we are here.

Three possible explanations for this are:

- God made the universe and ensured that it was exactly right for life to exist.
- There are a large or infinite number of universes, all with different values of the fundamental constants and different initial densities of matter. Life would only be possible in the ones which were just right and so any life would have to see a universe that was just right. This is called the anthropic principle.
- Something we don't fully understand about how the universe was formed meant that it had to be this way. That something might be inflation, the exponential growth of the universe between 10^{-36} seconds and 10^{-33} seconds after the big bang which caused the observable universe to increase from less than the size of a proton to the size of a grapefruit.

Message from the Dark Side there is . . .

The Most Fundamental Question. What is the meaning of life? Why do I exist? Do I actually exist? Why is the universe the way it is? These are fundamental questions to which some people feel they have answers and some people don't.

The most fundamental question, though, has to be 'Why is there something rather than nothing?' Mankind's knowledge is constantly advancing, but it's not clear whether it will ever even be possible to answer that question.

Message from the Dark Side there is . . .

How Big is the Universe? The observable universe is the part of the universe from which light has had time to reach Earth so we can observe it. The universe is 13.8 billion years old, so one might think the radius of the observable universe would be 13.8 billion light years. But it's not: it's 46.1 billion light years. This is because the universe is expanding. As the light from distant sources travels towards Earth, the space behind it expands (as does the space in front of it). By the time it arrives, the space behind it has expanded to more like 46.1 billion years.

That's the observable universe; it's not the whole universe. The cosmic horizon is a spherical shell 46.1 billion light years in radius centred on the Earth. It is the places from which light emitted just after the big bang would be reaching Earth now. It is the edge of the observable universe. There is no reason to believe that the galaxies stop at the cosmic horizon and there is in fact good reason to believe that the whole universe is at least a hundred billion trillion times as big as the observable universe.

The curvature of the universe is important here. Consider the surface of the Earth as a 2D analogy of the 3D universe. If the surface of the Earth is curved downwards (positively), then if you walk far enough in one direction, eventually you will come back to where you started. Even though the surface doesn't have an end, it is finite in size.

But suppose the surface was totally flat. Without an end you would go on for ever without ever going over the same ground twice. It would be infinite in size.

3D space can be curved too. On a flat Earth all triangles would have the sum of their internal angles equal to 180°. On a curved Earth (with positive curvature) the sum of the angles in a triangle is more than 180°. If you need to be convinced, think of the triangle formed by going straight from the North Pole to the equator, then turning 90° to the right, walking the same distance along the equator, then turning 90° to the right again and going back to the North Pole. The triangle you formed has three 90° angles.

In the same way, if space has a positive curvature, then a very large triangle in space would have the sum of its angles >180°; if it has zero curvature (i.e. is flat), then all triangles will have angles adding to 180°. As with a flat Earth, flat space must be infinite.

We can determine the curvature of space quite accurately using observations and the theory of general relativity and, as far as we can see, it seems to be exactly flat. This would make it infinite in size.

Now an object of finite size cannot expand into something of infinite size. Therefore, if the universe is infinite, it must always have been infinite, even at the time of the big bang. The observable universe would have been a tiny spot, but the whole universe would have been infinitely large.

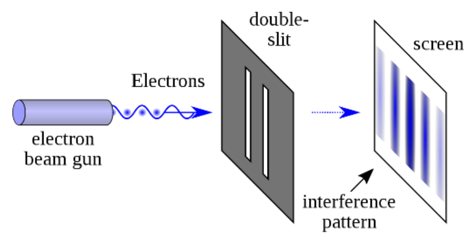
Message from the Dark Side there is . . .

Schrodinger's Cat. Most people have heard of Schrodinger's cat. In fact it's probably about the most famous cat of all history, even though it was only hypothetical. Erwin Schrodinger didn't actually own a cat.

For those who don't know the story, Schrodinger put a cat in a box with a radioactive isotope with an unpredictable decay. If it decayed, it would cause poison to be released from a bottle, killing the cat. If it didn't, the cat would be ok (though maybe a little cross).

The idea was that, after some time, the box would be opened and the cat would be seen to be either dead or alive. But before the box was opened, it would be both and dead alive – in a superposition of the two states.

This scenario was put forward in a paper by Schrodinger on quantum theory in 1935. It was actually put forward, not to explain what would happen to such a cat, but to ridicule the Copenhagen interpretation of quantum mecanics by which if something with more than one possible outcome occurred, it remained in a superposition of all possible outcomes until it was observed.



The double slit experiment illustrates this. Electrons were fired at a barrier with two slits in it. As electrons behave as waves, those passing through the left slit interfered with those passing through the right slit to produce an interference pattern when they hit the screen behind. Surprisingly it was found that if just one electron was fired at a time towards the slits, the same interference pattern still resulted, indicating that the electrons interfered with themselves. This could only happen if each electron passed through both slits.

The same experiment was then conducted with a detector at each slit which could detect whether the electron went through that slit. In that experiment, there was no interference pattern. Each electron went through either the left slit or the right slit, not both.

The interpretation was that the electron was in a superposition of the two states (passing through the left slit and passing through the right slit) until it was observed. Then it collapsed to just one of those states.

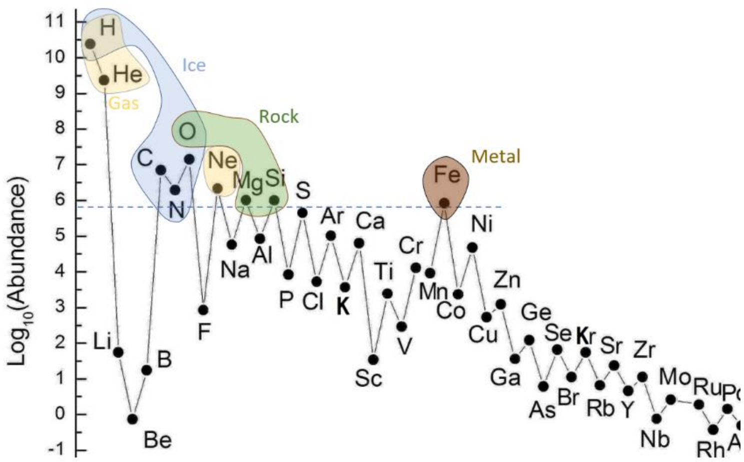
Schrodinger didn't like this interpretation and came up with the cat story to ridicule it. One obvious problem with the interpretation is deciding what constitutes an observer: does it have to be a human, or could it be the cat itself? Or a machine? If it had to be a human, that would mean that nothing actually happened in the universe until a human came along to observe it.

A modified interpretation is that particles remain in a superposition of all possible states until they interact with another particle.

Message from the Dark Side there is . . .

The Earth is made of Oxygen, Silicon, Magnesium and Iron. The big bang produced just hydrogen and helium (and a trace of lithium). All other elements have been produced by nuclear fusion inside stars, then scattered through the universe by red giant outbursts and supernovas.

The present make-up of the universe is roughly as shown in this diagram. The abundances are on a logarithmic scale, so each unit upwards means a 10 times increase in abundance.



The top 9 elements (those above the blue dashed line) are hydrogen, helium, carbon, nitrogen, oxygen, neon, magnesium, silicon and iron.

When the solar system condensed from a cloud of gas and dust, these elements behaved in different ways. Magnesium and silicon reacted strongly with oxygen to form magnesium silicate dust (mostly Mg_2SiO_4 - olivine). Carbon, nitrogen and the left-over oxygen reacted with hydrogen to produce methane, ammonia and water. Near the sun, in the region where the Earth formed, these gases were blown outwards by the solar wind. They collected as ice in the outer planets, particularly Uranus and Neptune, and in dwarf planets, comets etc. The left-over hydrogen, along with the inert gases helium and neon were also blown to the outer parts of the solar system and collected in the gas giants or left the solar system altogether. This left the iron, which formed dust. The earth formed from the silicate and iron dust. So, the Earth was essentially magnesium silicate and metallic iron.

At first these were mixed. But the gravitational collapse of the dust cloud into a solid planet released a lot of gravitational energy. Iron has a lower melting point than magnesium silicate, so it melted. Being denser, it also started to sink towards the centre of the Earth. This released more gravitational energy, causing a run-away melting of the iron (and much of the silicate). The result was that the iron sank to form the core, while the silicate formed the rock mantle.

Thus the core is made of iron while the mantle is magnesium, silicon and oxygen.

That is all very simple, but, of course, the separation of the elements wasn't perfect, so the core contains some silicon and the mantle contains some iron. Furthermore, there are lots of other elements in smaller quantities with different chemical affinities. For instance, argon, being an inert gas, went with the helium and neon; calcium, aluminium and sodium, reacting with oxygen and silicon, went into the rocky mantle forming garnet and feldspar; and sulphur and nickel went mostly with the iron into the core.

Message from the Dark Side there is . . .

Subatomic Particles – A Crash Course. The visible matter in the universe is made of protons, neutrons and electrons. Protons and neutrons form the nuclei of atoms and electrons orbit the nucleus.

Electrons are elementary particles, not made of anything smaller. But protons and neutrons are made of quarks. A proton is made of two up quarks (each with electric charge $+^2/_3$) and a down quark (with charge $-^1/_3$, making a total charge of +1). A neutron is made of one up quark and two down quarks, thus having a total charge of 0. Electrons have a charge of –1. Un-ionised atoms have equal numbers of protons and electrons making them electrically neutral.

There are 4 other types of quarks – charm, strange, top and bottom. These are unstable and very short-lived and occur only in very high-energy situations, like in a particle accelerator. There are also anti-matter counterparts, anti-quarks, to each of these 6 quarks. Electrons are leptons and there are also 6 types of lepton (electron, muon, tau, electron neutrino, muon neutrino and tau neutrino) and their anti-particles. The muon and tau are unstable. Neutrinos are stable, but don't interact much with other particles and always move very close to the speed of light. So they aren't a component of normal matter. There are, however, about a billion neutrinos for every proton, neutron and electron in the universe.

All the above are fermions. They have non-integer spin and two fermions cannot occupy the same location. This is why matter has size and can be somewhat rigid.

As well as the fermions, there are bosons. These have integer spin and can occupy the same location. The bosons are the force-carrying particles. The photon carries the electromagnetic force; the graviton carries the gravitational force; the W^+, W^- and Z^0 bosons carry the weak nuclear force (involved in nuclear reactions) and 8 types of gluons carry the strong nuclear force which hold the protons and neutrons together in the atomic nucleus against the electromagnetic repulsion between the positively charged protons. There is also the Higgs boson which gives mass to other particles and causes them to travel at less than the speed of light and therefore to travel through time as well as space.

Actually, the Higgs boson is hard to find because it is very rare. How then does it give mass to all matter? The Higgs particle is actually a quantum excitation of the Higgs field. The Higgs field is present everywhere, even if there isn't a particle present. According to quantum field theory, all particles are just quantum excitations of omni-present fields. These fields are what make up space. Space isn't just nothing. It has mass and dark energy and can be curved, causing gravity.

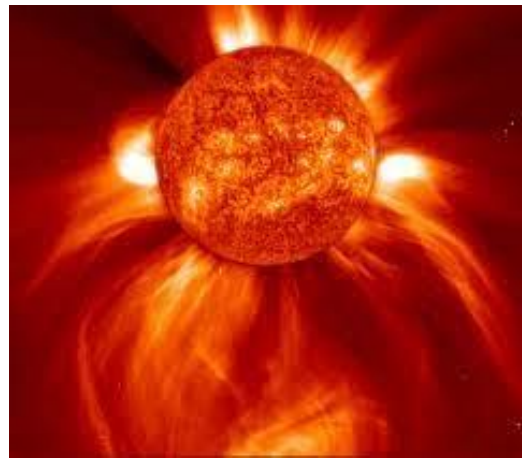
The above explains the stuff we can see – visible matter. There is also dark matter – about 5 times as much as there is visible matter. Physicists think it's probably made of particles we haven't observed yet.

Three other common terms are *hadron*, *baryon* and *meson*. A hadron is a particle made of quarks and/or anti-quarks: a baryon has 3 quarks or 3 anti-quarks; a meson has one quark and one anti-quark.

Message from the Dark Side there is . . .

Cosmic Rays. Cosmic rays are particles travelling at high speed through space. About 90% are hydrogen nuclei (protons), about 9% are helium nuclei (alpha particles) and the others are a mixture of things including electrons, positrons, antiprotons and nuclei of heavier atoms.

Three sources are recognized.



Solar cosmic rays come from the sun. They form the solar wind: both the background wind and bursts from flares and coronal mass ejections which can increase their number and energy many-fold.

Earth's magnetic field provides considerable protection from these rays by deflecting them from direct impact. The atmosphere then provides a second line of defense as the particles collide with air molecules, transferring much of their energy to these molecules, which can then break up to produce secondary particles with less energy and less penetrating power. Astronauts in the International Space Station do not have the protection of the atmosphere; those going to the Moon or Mars do not have any protection. It was more luck than judgment that there were no solar storms during any of the manned lunar missions. Solar cosmic rays typically have energies of 10^7 to 10^{10} electron volts (eV).

Galactic cosmic rays come from outside the solar system and typically have energies from 10^{10} to 10^{15} eV. They are thought to originate mostly from supernovas. Because the galaxy has a strong magnetic field, these cosmic rays don't travel in straight lines, but spiral around, entering the solar system roughly equally from every direction.

Extra-galactic rays come from outside the galaxy and have energies typically from 10^{15} to 10^{20} eV. They are thought to originate mainly from super-massive black holes at the centres of active galaxies (quasars).

The solar wind provides a fair bit of protection from galactic and extra-galactic cosmic rays, stopping most from getting past the termination shock which is beyond the orbit of Pluto. The stronger the solar wind, the more protection it provides.

Most cosmic rays that approach the Earth are from the sun. There are typically about 10 000 per square metre per second. Galactic cosmic rays come in at about 1 per square metre per second, extra-galactic rays about 1 per square meter per year. The most energetic recorded was the OMG particle in 1991 with an energy of 3×10^{20} eV, about the same as a bullet fired from a .22 rifle. Particles like that can produce up to 10 billion secondary particles as they interact with the atmosphere.

Message from the Dark Side there is . . .

But where is everybody? This is a famous quote from Enrico Fermi, the Italian-American physicist who created the first nuclear reactor, the Chicago Pile-1. Talking with colleagues one day in 1950 he asked this question during lunch. It wasn't because the canteen was unusually empty. He was wondering why the place wasn't swarming with extra-terrestrials.

Fermi wasn't actually the first to come up with the following logic, though the Fermi Paradox is named after him.

In the universe there are billions of galaxies, each with billions of stars. Many of those stars would be similar to the Sun with planets around them like the Earth capable of supporting life. Many of those planets would have been there millions or billions of years longer than Earth and so should be expected to have life millions or billions of years more advanced than us and capable of exploring and settling the whole of their galaxy at least. Earth should be swarming with extra-terrestrials like in the famous Star Wars bar scene. But it's not. There's no good evidence that any have ever visited or that any even exist.

We still haven't resolved this paradox. Quite a few suggestions have been put forward, including that all civilisations that become sufficiently advanced wipe themselves out in a nuclear war.

A more feasible resolution might be that aliens are here or at least have been here, but that they are quite capable of visiting without us noticing. We search the skies for radio transmissions, something that humans have been producing for a hundred years or so. Civilisations millions of years ahead of us would probably have found something better than radios.

If cave men were searching for evidence of extra-terrestrials, they might have thought 'If they'd been here, surely they would have left a few stone tools or cave paintings around.' Is our thinking any better?

Images

Yoder: pixabay.com
Pluto: flickr.com
Dog: maxpixel.net
Cockroach: publicdomainvectors.org
Double-slit experiment: en.wikipedia.org
Alien: pixabay.com
Earth: nara.getarchive.net
Moon: flickr.com
Galaxy: commons.wikimedia.org
Sandwich: flickr.com
Sun: pxhere.com

Message from the Dark Side there is . . .

The Power of the Sun's Core. I find it amazing that a thousand trillion solar neutrinos pass through my body every second. If you multiply that by the number of bodied that would be needed to make a spherical shell around the sun at the distance of the Earth, it turns out that the sun produces a stupendous number of neutrinos each second.

Each neutrino is the result of a nuclear fusion reaction fusing hydrogen nuclei to helium nuclei in the sun's core. Such a reaction produces a lot of energy (0.7% of the mass of the hydrogen is converted to energy).

So how much energy does a tonne of the sun's core produce per second, in other words, how many Watts does it produce?

The answer is a somewhat surprising (to me at least) 2 Watts, enough to light a small torch bulb.

By contrast, the metabolism of a tonne of human bodies produces about 1500 Watts. So we produce 750 times as much heat (kilo for kilo) as the core of the sun.