Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Black holes: Everyone's favourite physics problem*.

This is the first of a two part series on black holes.

Black holes are a bit like dinosaurs – they'll kill you if you ever get near one, but at a distance they're just cool. A black hole is an object which has all of its mass compressed within its Schwarzschild radius - which means that a certain density has been achieved which induces gravity, powerful enough to hold back light.

The Schwarzschild radius of the Sun is 3 kilometres - meaning that if you compressed the Sun into a sphere with a radius of 3 kilometres - you would have yourself a black hole. The Schwarzschild radius of the Earth is 9 millimetres - meaning you would need to compress the Earth to about the size of a grape to get a black hole.

Now, there's two ways to deal with the mass of a black hole mathematically. Some say that once you get whatever mass you are dealing with down to that certain density - it will continue to collapse inevitably into a singularity. Well…that is what the maths says. A naïve definition of a singularity is a point of infinite density within zero volume – which is problematic when you can clearly have small black holes and big black holes - where those big black holes clearly have more mass and hence a bigger Schwarzschild radius - but … are we saying those big black holes with more mass have singularities with an infinity plus one density?

You can be less prescriptive about black holes by just stating that we do know what their volume is – and we do know what their mass is. From there, some simple arithmetic suggests that stellar-sized black hole might have a huge density, but a Solar System sized supermassive black hole only has about the density of water. This is because the Schwarzschild radius is directly proportional to the mass, but the volume of the sphere it occupies is directly proportional to the cube of that radius.

So – really neither the singularity idea, nor the evenly dispersed mass idea really sound right. And this is the whole problem - once a black hole forms and light is held back - that's the end of the story. No-one can know the heck what happens inside a black hole because there is no way to receive information about what's happening within a Schwarzschild radius - because light is the only way to transfer information from there to you - and it can't get out.

What could be going on – is that the material in a black hole achieves some new kind of 'ground state'. We know neutron stars are made of degenerate atomic material where atoms collapse under extreme gravity, by their electrons combining with protons to form neutrons – so that all you have left is well, neutrons – very densely packed together so that a teaspoon-full of neutron star material has the mass of Mt Everest.

Actually my favourite neutron star thought experiment is if you drop something from a height of 1 meter above a neutron star's surface, it will hit the surface within a millionth of a second having been accelerated over that metre to 7 million kilometres an hour. Cool.

Anyway, it’s hypothesised that if you keep compressing a neutron star down it will collapse into a strange star. In a strange star even the neutrons have collapsed, their component quarks have been driven together and all you have left is a very dense collection of strange quarks. Strange stars are hypothesised to be smaller than neutron stars, but with much more mass – so they are kind of a mid-point between a neutron star and a black hole - although since no-one has found one yet, this is just an idea.

But taking this idea a bit further, intensely gravitationally compressing an already dense collection of strange quarks might make them collapse down into some even more fundamental ground state of matter – which we have never, and arguably will never, see - or even know about, because it exists behind a Schwarzschild radius.

Of course the reason we may never know what's inside a black hole, is that the Schwarzschild radius is the event horizon of a non-rotating object. Now black holes probably do rotate, that is spin. Through the principle of conservation of angular momentum, a neutron star spins faster than its progenitor star because its mass is compressed into a smaller volume – which is like ice skaters pulling their arms in. So, you might expect black holes take this principle a step further – and hence spin even faster than neutron stars do.

With a spinning black hole, the event horizon should still be roughly equivalent to the Schwarzschild radius – but the spinning produces unusual equatorial bulges of warped space-time, which is called the ergosphere – from which you could still escape but if you were in it you would be inexorably rotated around the black hole through the process of frame-dragging. The usual analogy used here is that you would have to run, like the Red Queen, faster than light just to stay still.

Anyhow - the event horizon of a black hole is not really its surface, it's just a point in space-time curvature from which nothing can escape. There are various thought experiments involving orbiting the black hole at close to the speed of light while you try to lower a sampling container below the event horizon – which you can do – but no force known would then be sufficient to let you pull it back out again. And if you tried to lower a thermometer or a microphone down there – the electrons needed to bring a signal back along a wire to you also wouldn't be able to escape. It’s all just unknowable – great podcast, huh?

But look, in the theatre of the imagination, where the mass in the black hole is in some new ground state of matter – it might exist as a very condensed sphere lying well within the event horizon. And the surface gravity of this unknowable object might be even more powerful than it is at the event horizon – so think of all the various unknowable effects that might have. And that terribly dense sphere might be radiating energy unknowably too – and also have a stupendously powerful magnetic field. But of course, any electromagnetic radiation produced by these processes is (depending on your preferred physical model) either bent back on itself – or red-shifted into oblivion – long before it reaches your eye.

John Archibald Wheeler, once Professor of Physics at Princeton University, first coined the term black hole in 1967 – in fact after coining the term wormhole in 1957 – neither of which terms Einstein presumably ever heard or used – since he died in 1955.

Wheeler is considered one of the greats in taking general relativity theory forward after Einstein's death – who was at that stage a professor in the Institute of Advanced Studies at Princeton. It's unclear if they both worked together in any real sense, but Wheeler's life was hugely influenced by Einstein, not only because of the relativity physics, but also because he spent much of his time working on the Manhattan project to build the atomic bomb and then the Matterhorn project to build the hydrogen bomb – all of which came about because Einstein wrote to US President Roosevelt in 1939 - worried that the Germans were going to go nuclear. While the cosmological constant might have been his biggest blunder - he called this letter his greatest mistake.

On the bright side though, the Matterhorn project was later renamed the Princeton Plasma Physics Laboratory, presumably after the administrators realised that there might be something in this whole physics lark beyond just building weapons of mass destruction.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website making the unknowable, unknowable. No ads, no profit, just good science. Bye.