Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *The shape of space: Dark energy or geometry?*

This is the first of two podcasts on some interesting aspects of Einstein's general relativity field equations featuring my Dad, who is also Professor Graham Nerlich Emeritus Professor of Philosophy, University of Adelaide and previously Professor of Philosophy at the University of Sydney.

I know you wrote a book called The Shape of Space. So, what is the shape of space?

Well, the book didn't aim to tell you what the shape of space is, so much as to tell you that as far as general relativity is concerned whenever you have gravitational phenomena to explain, the right way to do it is to appeal to the particular shape of space-time that does that job as a curved geometry.

So, once you start asking what the shape of space-time is, you are going away from pure theory really, into cosmology and cosmological models. The theory itself never tells you what there is in the world, certainly doesn't tell you that there's a solar system. It just tells you that if you've got a solar system, then this is what will happen to it.

So that's the difference between pure theory and applied theory. Now in general relativity if you look at it from the point of view just of the pure theory that Einstein came out with in 1915, it just tells you that whenever you've got gravitational phenomena, you can forget about the force of gravitation and just substitute for that the geometry. The geometry won't be Euclid's geometry, it will be geometry of curved space-time – that is to say, it will be a matter of the shape of that local area of space-time.

Then you look out and you see, as Einstein knew you would, if you look at the sky at the right time and the right place, you will see the planet Mercury. And Einstein noted that when people had tried to work out in terms of Newton's physics just what that the orbit of that planet was – it was not what the theory predicted. So he thought, I will apply my pure theory to this bit of observational knowledge and see what the theory says we should get. And what the theory says we should get is exactly what had been observed. So that oddity in the observations was now explained by pure theory.

That's the precession of Mercury's orbit.

Now, when you say what is the shape of space, that becomes a combination between the pure theory of general relativity and the observational knowledge of what there is out there, which the astronomers give us. You put these two things together – then you get some model of cosmology, some account of what the universe is like at large. Now general relativity doesn't tell you that. Once Einstein invented general relativity – it became immediately clear that the number of shapes that you can get for space-time is simply huge.

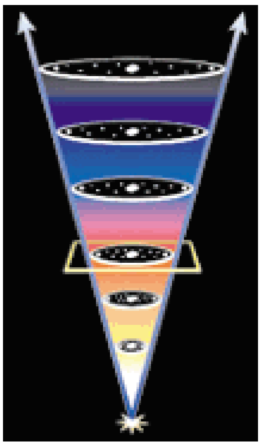
You need both general relativity and the observational knowledge and apply the one to the other. Then you may be able to get a picture of what the shape of space-time is in our universe. And at the moment it looks a bit as if it's the shape of what's called a De Sitter space-time, which is, from the spatial point of view, like an expanding universe and one that accelerates in its expansion – and that‘s what’s recently been observed. So, what shape space has is not just a matter of the pure theory. But when I wrote the book and called it *The Shape of Space*, I wanted to talk really about the pure theory rather than about the cosmology and the observational stuff – because I don’t know anything about it.

You’ve suggested to us that the De Sitter space theory would fit quite well with observational data which seems to - at the moment - require astronomers to start talking about this mysterious dark energy to explain the acceleration rate that we see. So how does an accelerating expansion fall out of De Sitter space.

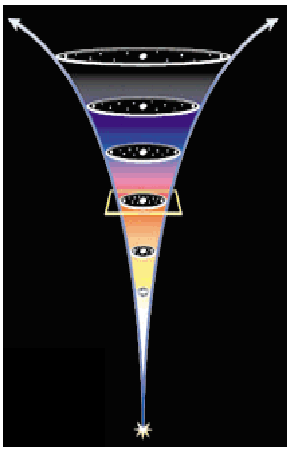
Well, it's like the surface of a hyperbola. What shall I say. If you look at an ordinary flat Minkovski space-time and you consider the light cone - you usually draw it on the page just as a couple of intersecting lines at right angles to each other. If you try to do a perspective drawing of it – then you put a little circle joining the two lines, so you can see that as time goes on, you've got an expanding circle of light rays moving out. Are you with me?

Now that is an expanding light cone. It expands not at an accelerated rate, but at a steady rate. If you draw a similar kind of picture of De Sitter space-time – instead of drawing those straight lines and a circle moving up the page, so to speak. You draw two hyperbolae, a sort of hyperboloid (a hyperbola of rotation really). And if you take the spatial cross-sections of that - once again you get something like a circle, but as you go up, it not only gets bigger, it gets bigger, faster.

So that's the way in which De Sitter space-time is different in its geometry, different in its shape, from Minkovski space-time. Without the drawing it might not make too much sense, but I hope it does.



A universe expanding linearly



A universe with accelerating expansion

I'm picturing a hyperbola being a convex sort of surface, as opposed to a…

You should really draw the hyperbola as a sort of pair of lines - in the way that the light cone is a pair of straight lines, the hyperbola if you drew it on the two-dimensional page would be a pair of curved lines.

Curving outwards like a vase, say.

Right. You can easily find a picture of a hyperbola if you look a bit. So, you've got the hyperbola pair – and as you go up the page, the horizontal cross-sections are giving you the total volume of the universe. You see, not just that as you go up the page the universe is getting bigger (just as the light cone gets larger), the universe is getting bigger, faster. So that the expansion is an accelerated expansion.

OK - wow. Is there a brief way of defining what De Sitter space is, as a theory? What is it attempting to outline?

Well, De Sitter came up with it as an empty space-time, a matter-empty space-time - which had according to the equations of general relativity, a quite simple geometry. I mean curvature is naturally built in to the very structure of general relativity, so it was a fairly simple solution to the equations. I think it's probably round about 1920 or 21 - you know, a quite early discovery after Einstein and De Sitter just put it out as a solution and it was interesting because it was simple - and in its cute, queer way *natural*.

Nobody paid a huge amount of attention to it but recently of course, there have been cosmological observations which suggest that is actually what's happening. I think at the, I think it's the supernova evidence isn't it - that the red shift suggests that the universe is not just expanding - it's expanding faster all the time.

The type 1a supernova.

Yep.

Well, thanks Dad - great.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where developing a warped mind is actually a good career move. No ads, no profit, just good science. Bye.