Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *How far is far?*

Something kind of puzzling came up in a recent Cheap Astronomy episode about galaxies. This puzzlement is around the fact that one of the earliest galaxies observable is 13 billion years old, which is actually about 660 million years after the cosmic microwave background flash.

Now determining the age of this galaxy is relatively straight-forward (small cosmology joke there) – we just have to look at its red-shift – since Hubble demonstrated that the further away something is the more its light has been stretched out into longer, redder wavelengths by the expansion of the universe. The puzzling issue comes from a number of commentators describing this galaxy as being about 13 billion light years away – which is actually kind of correct in a way, but kind of not too.

13 billion years ago this early galaxy, which by the way is called A1689-zD1, would have been much closer to the proto-Milky Way – which is also thought to have been born at about the same time.

Because we live in an expanding universe – this gives us three questions to consider: 1) How close were those two galaxies to each other 13 billion years ago? 2) How far has the light from A1689-zD1 had to travel to reach us here in the Milky Way 13 billion years later? And 3) Just how far away is A1689-zD1 now, like today now? While each of these questions may have a factual answer, what that answer is depends upon the observer first being very clear about his or her contextual position in space and time.

So, we know A1689-zD1 is about 13 billion years old – and on that basis alone it's given us a useful picture of what a very early galaxy looks like. Great. But how far away is it? Well, that depends.

Do you mean how far away today is the thing we can visualise today? That's a complicated question since that young galaxy you can see now may have been consumed by a bigger galaxy billions of years ago – or otherwise become a consumer itself and bloated up into an unrecognisable bigger galaxy.

Or do you mean how far away was it when the photons you are seeing left it? Well, that's tricky too, since our current observation point here isn't where it was back then. I mean what the heck does 'here' mean. It only really means something if you also say 'when'.

To get around all this messy semantics – we talk about an objects comoving distance. This places both the observer, like say us on planet Earth and the object observed, like say A1689-zD1 in what's called the Hubble flow, which is the constant expansive motion of all objects within the universe.

So – when you ask how far away is A1689-zD1 – you can ascertain its proper distance which is like running an imaginary tape measure between you and whatever the heck is left of A1689-zD1 now, like today now. When we do that the answer is nearly 30 billion light years away.

Then to make a meaningful statement about the image of A1689-zD1 we can see through a telescope, we just say it has a 13 billion year look-back time – which lets us skirt around the whole issue of how far away it is.

It is all just mathematics though. We have no idea if A1689-zD1 is actually there at its comoving distance of 30 billion light years away and we have no way of finding out for about 17 billion years. And even that's not quite right, since by the time that piece of information arrives here – our current point of reference will have moved a huge distance in the Hubble flow.

This all touches upon the concept of the observable universe. Knowing that the universe is 13.7 billion years old might lead one to propose that we can't observe anything that's more than 13.7 billion light years away – but that would only be true if the universe was static and eternal. In our expanding and ever-changing universe, although 13 billion year old light might appear to coming from a point about 13 billion light years away, we might as well call this an optical illusion because the object that produced that light wasn't 13 billion light years away when those protons were first emitted.

But as we so often must do in cosmology, if we are going to make any headway on this distance problem we need to assume that the universe is isotropic and homogenous at cosmic scales. Even though we can't see further than 13.7 billion light years – it's reasonable to assume that that visible edge of the universe has continued to expand with the known expansion rate of the universe. On this basis, we can say that the edge of the observable universe is actually 46.5 billion light years away – now, like today now.

It sounds like cheating, but remember that any objects that were able to emit light that long ago were actually much closer together when they did emit that light, so saying that the edge of the observable universe is 13.7 billion light years away doesn't make a lot of sense either.

Of course, all we can say is that anything that has happened at a distance of more than 13.7 billion light years is not something we can directly gain any information about – because information can only travel at the speed of light.

In a similar vein, the Sun might have exploded seven and a half minutes ago, but you will know nothing until about eight minutes pass when…. See the observable universe is kind of a known unknown. We are pretty sure it's there, but the further away things are, the less certain we are that they are anything like how they appear in a telescope. Then beyond the edge of the the observable universe are unknown unknowns – there could be more universe there, but it's kind of unknowable.

At the end of the day, it's best just to go along with it – and accept that the edge of the observable universe is 46.5 billion light years away – and since we can look out in all directions, we can say the diameter of the observable universe is actually 92 billion light years.

But look, if this is all too tedious to listen to any more, just go and watch a Star Wars movie. That lead-in *A long time ago in a galaxy far, far away* – pretty much says it all, even if it is a tautology.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where today is only yesterday's tomorrow – except we'll be over there. No ads, no profit, just good science. Bye.