Question 1:

Dear Cheap Astronomy – If the Big Bang happened 13.8 billion years ago how come we can still see it?

What we can see is the cosmic microwave background, the CMB, which was a flash of light that actually occurred about 380,000 years after the Big Bang. For reasons we'll explain, we can't see light from any earlier time. And while you might think that surely there should be some point when all the photons arising from a single event must eventually whizz past you never to be seen again, well not so far – although it is certainly the case that a heck of a lot of them have whizzed past you already.

What we say about the evolution of the early Universe is mostly hypothetical since the first observable data comes from when it was already 380,000 years old. What we hypothesise is that in the very first second, the basics of quantum theory appeared – being the quarks and the leptons and the bosons – and the forces that those bosons mediate – for example, photons mediating the electromagnetic force. Then as the Universe further expanded and cooled, at around three minutes the first nuclei formed from cooled-down quarks, being mostly hydrogen nuclei (that is single protons), but also some deuterium, helium and lithium nuclei.

Then for a further 380,000 years, it was still just too darn hot and free electrons (which are leptons) kept all the photons scattered, that is unable to follow a straight line path for any distance due to ongoing collisions and deflections. But at 380,000 years the Universe's temperature dropped below 3,000 Kelvin, which is the ionization temperature of hydrogen – in other words, it became cool enough for electrons and protons to come together and form the first hydrogen atoms. A similar thing happened with the helium and deuterium and lithium nuclei at slightly different times because of their slightly different ionization temperatures. But it was the hydrogen that made the major contribution towards clearing a path for photons to radiate in straight lines out across the young Universe – producing a flash of light that we now call the CMB. This event happened just once, but it happened everywhere across the Universe at that same time.

So, at 380,000 years photons shot off in all directions in a newly-created vacuum carrying data about the last particle they had interacted with. So every CMB photon we've since detected has been travelling though the vacuum of space for 13.8 billion years. And after that first flash there weren't a lot of new photons being produced until the first stars formed when the Universe was 200 million years old. So, with modern technology the CMB is quite easy to distinguish from other light sources that have subsequently appeared across the Universe.

To understand why we still keep on seeing it, remember it happened at the same time everywhere. So, imagine there's a line of flashlights extending away from you in a straight line for a light year or more. Then imagine they all flash just once, all at exactly the same time, and then they switch off again. You'll see the nearby flashes almost immediately, but you will also keep on seeing progressively distant and dimmer flashes for a year or more - even though all the flashes you see all happened at the same time and in the past. While we don't know how the big the Universe is, we do know that our observable part of the Universe had a radius of about 700,000 light years when the CMB flash was released and it now has a radius of about 47 billion light years, due to more than 13 billion years of subsequent universal expansion. Consequently, the photons that left those distant sources when they were no more than 700,000 light years away have since been travelling through the vacuum of a progressively expanding Universe. The expansion means that not only is the light from those distant places dimmer due to normal attenuation over distance, but its wavelength has also been stretched by the expansion of the Universe into microwaves, carrying a temperature of just 2.7 Kelvin, whereas they originally carried a temperature of about 3,000 Kelvin.

Over the course of your brief lifetime, lots of CMB photons have whizzed past you never to be seen again, but there's still plenty more coming in from progressively further distances out. Of course there were lots of CMB photons never made it this far, if stars or planets or even dust grains got in the way, but the Universe is a very big and very empty place.

Question 1:

Dear Cheap Astronomy – How can we observe things that are receding faster than the speed of light?

So, as is well understood by regular Cheap Astronomy listeners – and OK probably other astronomy podcast listeners as well, the Universe's expansion has an additive effect over distance. So, imagining points a, b and c, the expansion gives point b a certain receding velocity relative to point a- while point c relative to point a, not only has point b's apparent receding velocity but also an additional velocity due to it also receding from point b. Then point d has even more velocity relative to point a and so on. Apply this principle at a universal scale and it's inevitable there will eventually be things moving away from point a faster than the speed of light. Of course they are not themselves speeding through local space faster than light, it's just the cumulative expansion of the Universe at work.

The parts of the Universe that are receding at the speed of light relative to Earth right now all lie beyond what we call the Hubble sphere, which has a radius of about 15 billion light years. Of course, 15 billion light years is well less than the radius of the observable universe which is about 46 billion light years, but when we say observable universe we mean that now, today, we can see photons emitted by objects that are now, today as far away as 46 million light years, although they weren't nearly that far away when they first emitted those photons that we are just now seeing today.

This is all about horizons of observation. The particle horizon is the farthest distance from we can detect photons now, today that were emitted by distant particles in the past – so the particle horizon is the radius of the observable Universe. Conversely, the cosmic event horizon is the farthest distance from which we will ever detect photons emitted by something now, today – even though it may be billions of years in the future before those photons eventually reach us.

So you might think that surely the radius of cosmic event horizon would the same as the radius of the Hubble sphere? But, no – remember the Hubble sphere around Earth is the radius beyond which distant objects are moving away from us faster than light due to the Universe's expansion – and that radius is about 15 billion light years away. But, the radius of the cosmic event horizon is actually about 16 billion light years away. So, it's only a bit bigger than the Hubble sphere, but there is always a slight margin between the two.

Remember the apparent receding speed of distant objects is just the cumulative effect of the Universe's expansion over that distance – so any objects at the Hubble sphere's edge aren't actually moving at the speed of light relative to their local environment. So imagine objects just outside the Hubble sphere that emit photons towards you on Earth. Since those photons do travel at the speed of light they can readily cross from outside the Hubble sphere to inside it, since the objects that emit them aren't receding at anything like the speed of light relative to the Hubble sphere's edge. But this principle only works for objects within a billion or so light years of the Hubble sphere's edge – objects any further out than may still emit photons towards Earth, but the ongoing expansion of the Universe will ensure those photons never reach Earth. That's why we call that 16 billion light year radius the cosmic event horizon.

Complex? Well, yes, but mostly because we struggle with the concept of spacetime. Distances are so small here on Earth's surface that the transmission of information seems instantaneous even though it isn't really. Once you look out into the vast Universe you need to start adjusting your thinking to accommodate the fact that time is distance and distance is time. They're both just two different aspects of the same thing – spacetime.