Question 1:

Dear Cheap Astronomy – Did the Universe really start from a single point?

The observable expansion and cooling of the Universe over time does lend itself to the idea that if you wind the clock back far enough then everything must have started from a single point. It's sometimes described as a single point possessing infinite density that was all packed up tight within a zero volume singularity.

As we often say here at Cheap Astronomy any explanation that relies on an appeal to infinity is probably bollocks. There is never a point at which you can say you've reached infinite – it's a concept of endlessness, it's not a state that can be reached. Similarly the quantum concept of Planck scales, which include scales of volume and temperature, require that there are fundamental limits to indivisibility and they are limits that can't be breached. So the fact that there is, clearly and obviously, a Universe now means there can't have possibly been a past Universe that was all packed up tight within a zero volume.

There are observable features of the Universe that tell us things about its past. As we said earlier, it is expanding, so it was obviously smaller in the past. And with respect to energy per average unit volume it's cooling, so it was obviously hotter per average unit volume in the past. And while mass and energy are equivalent and interchangeable, the total mass energy content of the universe doesn't change, so the Universe must have also been denser in the past.

Of course we have to pause here to deal with the concept of dark energy, which allegedly increases as the volume of the universe's increases, since it is allegedly an energy that appears out of nowhere to drive the accelerating expansion of the Universe. Here at Cheap Astronomy we acknowledge that the Universe is undergoing accelerating expansion, but we are pretty confident that it has nothing to do with energy, with respect to how humanity describes and measures energy in any other context. Sometimes it's OK to acknowledge you have no clue why something is happening, even though it is obviously happening.

Anyhow, parking dark energy to one side, the Universe of the past was clearly smaller, hotter and denser. But extrapolating that understanding to its extreme by saying the Universe was once all packed up within a zero-volume singularity is probably a step too far. But, really the best thing to say is we just don't know – which is not so say that we'll never know, we just don't know yet.

Probably the most baffling aspect of the very early Universe is that it must have had the energy-mass content of the current Universe, but compressed within a small volume. So why didn't it all just collapse into a black hole there and then? Clearly it didn't, because here we are. Our best guess is that this has something to do with entropy, though don't push us too hard on that point, because we have no clue, really. It does seem as though when the Universe was young and hot and uniform –and its energy-mass equivalence was mostly in energy rather than matter, it naturally inflated. But now when everything is spread out in a larger volume and pockets of energy-mass density have cooled down into conventional matter, that matter can collapse down under its own self-gravity into the irretrievable state of a black hole.

So how big was the Universe in its first instant? Almost certainly it was bigger than one Planck unit of volume and hence not a single point, but how much bigger we can't really say. Current physics doesn't give us much insight into the state of the Universe prior to their being quarks, that is the quark epoch, a split second when the Universe was probably already as big as the solar system, subsequent to early rapid inflation. How big it was before that inflation, no idea, how and why it inflated, no idea. Nonetheless, we really are pretty sure it was never a single point – well, sort of sure.

Question 2:

Dear Cheap Astronomy – How unusual is the Earth?

It's probably best to start by asking how unusual the Solar System is. The many stellar systems with orbiting exoplanets we are finding out there are mostly nothing like it. Many have gas giants in the range of Mercury's orbit and the ones that have Earth-like planets are mostly red dwarf systems. But this is probably just a selection bias effect. Exoplanets are right at the limits of our current detection systems. So the exoplanets we find around large stars are usually close-in gas giants - and the terrestrial planets we find are usually around small stars. Detection via the transit method mostly finds planets that are proportionally large compared to their star and detection via the wobble method mostly finds planets that are either proportionally large and massive or otherwise very close to their star. So while the exoplanets we've found so far have a preponderance of close-in gas giants and terrestrial planets around red dwarves, that's just because these are easy to find.

So, while we yet to prove it, Earth may well be a common and unremarkable planet orbiting a common and unremarkable star. The chemical make-up of the Solar System is composed of elements that are ubiquitous and found in similar proportions across the Universe. Hydrogen and helium arising from post big bang nucleosynthesis are still the dominant elements but 13.8 billion years after the Big Bang, lots of other elements are now in abundance, notably carbon and oxygen which are the next major products of stellar nucleosynthesis after helium. So there's nothing remotely unusual about a planet and a solar system that contain lots of hydrogen, helium, oxygen, water and carbon-based molecules, including CO_2. Indeed it would be unusual if this were not the case.

Of course in any stellar system including ours most of the hydrogen and helium is found in the overwhelming mass of the central star. Once nuclear fusion kicks off and that star generates outward radiation pressure any nearby volatiles, like hydrogen and water are pushed out past the frost line, where the water forms ice rocks alongside carbon dioxide ice rocks which then aggregate and self-gravitate and capture the surrounding hydrogen – thus forming gas giants. Within the frost line the remaining volatile-depleted material aggregates to form smaller and rocky planets. The self-gravity of these rocky planets will drive differentiation of its material composition so it ends up with an iron-nickel core, surrounded by a molten mantle and cooled crust of oxygenated silicon and carbonaceous minerals.

So, perhaps the only thing that is unusual about Earth is that it teems with life. Earth does receive a lot of life-supporting energy in the form of stellar radiation, but that doesn't seem to have helped Venus and Mars. Perhaps we will find floating microbes in Venus cloud tops and fossils of past life on Mars, but clearly neither planet are teeming with life in the way that

Earth is. What sets Earth apart from planets like Mars and Venus is its substantial magnetic field. Without a magnetic field, the solar wind would have stripped Earth of most of its light volatiles, notably its nitrogen atmosphere and its water, leaving behind heavier CO2, which is the primary component of Venus' and Mars' atmospheres. The magnetic field arises from Earth having a somewhat molten iron-nickel core and also a fast spin. The smaller Mars spins about as fast as Earth but its core has cooled and gone solid – and while Venus still has a molten core, it has a very slow spin.

In conclusion then there is nothing particularly unusual about the Earth, although it does have a particular set of conditions that allows it to teem with life. The early collision between the proto-Earth Mark 1 and the Mars-sized Thea may have been key to all this, where Thea added more iron and nickel to Earth Mk 2's core and also gave us an unusually large Moon, remembering that Venus and Mercury have no moons at all and Mars just has a couple of big rocks. So, while Earth might be entirely ordinary as a planet, it does have an unusual Moon, which may have contributed to Earth's habitability by helping to stabilize Earth's spin. And of course, our unusual Moon also gives us a stepping stone into the cosmos.