Question 1:

Dear Cheap Astronomy – Is space really empty?

Well, the universe is filled with stars, planets and galaxies, but sure all the big gaps between those things are mostly empty. Although, let's not forget dark matter. It's likely to have a wider and denser distribution than visible matter, since we think there's four times more of it than there is of light matter - but all we can really say is 'we think' since we can't see dark matter and we don't actually know what it is.

Anyhow, space is mostly empty, but not a total vacuum. A good rule of thumb is that in very empty intergalactic space, you might find an average of one particle of visible matter per cubic metre of space. Interstellar space within galaxies might contain a few more than that. These particles would be mostly hydrogen and helium – in the forms of ions, atoms or small molecules – and sometimes you might find heavier elements, perhaps flung out from a supernova or some cosmic collision. In interplanetary space, such as within the solar system, you also find additional particles in the form of stellar wind.

But despite all that and even with dark matter included, space is still pretty-darn empty, and we can say with a high degree of confidence that if you are in space and you step outside your spaceship without a space suit, you'll die. Not just from the lack of breathable gas, but also the close to zero pressure which will make your body fluids boil as all the dissolved gases bubble out – so you really do need a pressure suit, not just an oxygen mask to survive.

So again, space is very nearly empty and even if it's not quite empty is that a problem? Well, the folks at Breakthrough Starshot think it is, where they are trying to come up with a plan for how we could send observation probes to Alpha Centauri within a lifetime, by aiming for a speed of around 20% of the speed of light in order to get there in twenty years followed by another 4.4 years to send the data back to Earth. The plan is to use tiny spacecraft attached to laser-propelled sails, which have no other means of propulsion – so it's pretty much just a camera and a transmitter on a sail. But, if space isn't completely empty, then colliding into something at 20% of the speed of light can't be good, but apparently it may not be catastrophic.

The modelling done by the Breakthrough team suggests that the main damage caused by collisions with hydrogen and helium will just be heating – where the collision ionizes atoms and dissociates small molecules releasing their binding energy. Essentially a spacecraft travelling at 20% of SoL acts like a particle collider, smashing atoms as it goes. Of course, that atom-smashing involves both what the spacecraft hits and the spacecraft itself, so such collisions do cause minor surface degradation down to maybe a tenth of a millimeter, which should be within tolerable limits. However, if the little spacecraft hit a speck of dust bigger than 15 microns – which is about the size of a red blood cell – there would be surface destruction down to a depth of 1-2 millimetres, with more melting beneath that – so for a small compact bundle of high technology, that could be game over.

However, on the bright side, while collisions with tiny hydrogen and helium particles are almost inevitable over light years of distance, it's estimated that hitting an actual speck of dust is quite unlikely – apparently 10 to the power of fifty to one against over the distance between Earth and Alpha Centauri.

But – there's always a but – the collisions with the tiny hydrogen and helium particles are still a problem since each collision and the tiny particulate explosions that result imparts a tiny change

in momentum and over a twenty-year trip covering more than four light years of distance that could start adding up to a significant change in trajectory. Lots of little collisions across different parts of the spacecraft might all even out to not that much, but they might not too. Breakthrough Starshot's best risk mitigation strategy is to send a fleet of the little spacecraft in the hope that at least one gets through. That sounds like a plan, but the biggest challenge here is getting someone to foot the multibillion-dollar price tag that might deliver an outcome twenty-five years later.

Question 2:

Dear Cheap Astronomy – Just how strange is reality?

So, this is an unusual question insofar as the word strange implies a divergence from normal - whereas reality is by definition normal. Therefore, whatever strangeness it may possess is mostly defined by our own subjective expectations. Every day the Sun comes up and when we make a cup of tea, the water still boils the way that it has ever other day and the tea bags and milk you bought the day before haven't spontaneously dematerialized overnight. These are things we consider normal and indeed represents the apparent blandness of reality - something that can only be spiced up by the application of our imagination.

But ask a physicist and they're likely to tell you that reality is not only stranger than we imagine, but stranger than we can imagine. This statement was likely first made by JBS Haldane, who was actually a geneticist though also a bit of a poly math. The statement has been subsequently adopted by physics writers, particularly those working in the quantum physics field.

Quantum physics has lots of strange predictions and many have been kind-of sort-of been tested and confirmed. Most of the apparent weirdness stems from the wave-particle duality behaviors of small particles like photons and electrons, as well as the inability to measure all aspects of such small particles simultaneously, being Heisenberg uncertainty principle. These seemingly odd behaviours of very small things can lead to a view that the fundamental structure of matter is probabilistic in nature and even that nothing is real until you observe it. You could also turn to the Schrodinger's cat story and deduce that all possible outcomes of every event in the Universe do all happen and hence resulting in the branching of new realities in a multiverse.

But we should take a deep breath there. Of course you could deduce all that, but you don't have to, and perhaps you shouldn't. There should always be some limit to a reasonable extrapolation of assumptions arising from a known point. It's also the case there's a long list of historical figures who have declared that we now know everything there is to know about a particular subject, shortly thereafter followed by some groundbreaking discovery which opens up vast new areas of research. search and discovery.

So it's absolutely true that there *could be* a multiverse of all possible outcomes, but it's only absolutely true that there could be. A multiverse is just one of several possible interpretations that arise from different findings in quantum physics. Scientific progress often involves running with a whole set of theoretical explanations for an observed phenomenon and then knocking out some of those potential explanations through further experimentation and measurement until you've constrained all the possible explanations down to just one or maybe two.

It is unlikely any future explanations for quantum behaviours will be any less weird than they are now, but Cheap Astronomy is choosing to hold on to the hope that those future explanations might not involve multiverses or faster-than-light communication being something often called upon to explain various aspects of quantum entanglement. But at the same time, Cheap Astronomy is not expecting that it will turn out that the quantum physicists got it all wrong, and subatomic particles are just little round things that you stick together like Lego pieces to make up the world as we know it.

So far, we've mostly dwelt on quantum physics, but there's no shortage of other apparent weirdness in our reality. Who would have thought that time would run differently in fast-moving vehicles and near massive objects, at least when measured relative to an observer in a different frame of reference? And who would have thought that a universe could pop into existence out of nowhere? But before concluding this is all weird, we should first be asking ourselves what we might consider not weird. A universe made-up of indivisible Lego pieces that has existed forever and that allows things to travel within it at unlimited speeds is kind of weird anyway. Notwithstanding it conflicts with a large body of evidence we've already accumulated about our real universe.

When we say all this stuff is weird, we are perhaps not acknowledging that pretty much everything we look into turns out to have all sorts of unexpected complexities and complications. It would be uncharitable to declare it weird that many people never really consider the complexity of the reality they exist in. Lots of people have lots of complex issues to deal with, and they may only have time to acknowledge the universe as a backdrop to the various dramas of their life. But perhaps it is appropriate to say that's a bit of a shame. And to acknowledge it's never a wasted effort to educate people about the reality of reality.