Question 1:

Dear Cheap Astronomy – What exactly is vacuum energy?

To paraphrase various physicists and science communicators over the last few decades – anyone who thinks that a vacuum is nothing, just doesn't get it. At the same time though, anyone who thinks they do understand what a vacuum is doesn't get it either. What we think we know about a vacuum is that it's part of the spacetime continuum and when a region of vacuum is removed from significant gravitational influences, it will start expanding – and apparently that expansion will accelerate over time. A vacuum also has a quantum side to it, where the whole idea of vacuum energy is a quantum physics concept. So, a system at its least possible energy state can be said to have zero point energy. But that doesn't mean the system has no energy. There will be an inherent fluctuation in its zero point energy which arises from Heisenberg's uncertainty principle.

Although, there is some debate around this. It's specifically the Heisenberg uncertainty about the complementary variables time and energy, where the longer you measure a system the more reliability you will gain about how much energy it has. This means that if you only measure a system's energy for a fleeting moment, you may well see random energy fluctuations popping out of nowhere. But if you keep on measuring the system for a long time and you might find your energy measurements do start approaching zero. So, you might reasonably conclude that zero is a more reliable measurement of the system's energy, even if you can never absolutely conclude that it's zero. As with many things in quantum theory, it's all a matter of interpretation. You could say that time-energy uncertainty predicts that vacuum energy exists, or you could say it just makes vacuum energy a possibility – and it's a possibility that gets smaller and smaller the longer you keep on looking for it.

Anyhow, whether or not it exists, vacuum energy is often conceptualized as two polarized particles appearing out of nowhere and then annihilating each other and disappearing an instant later – unless of course they appear out of nowhere next to a black hole event horizon and one goes into the black hole and the other one doesn't – that other one then becoming real persistent energy particle that contributes to that black hole's Hawking radiation.

Vacuum energy is also thought to be what underlies the Casimir effect, where two large metal plates positioned parallel to each other and in very close proximity get pushed towards each other – allegedly because the narrow space between them constrains the number of possible vacuum energy states, while outside of the plates the number of states are unrestrained. The Casimir effect is a real measureable phenomenon, but there's ongoing debate about what causes it, so it might not be clinching proof that vacuum energy exists.

Of course, the expansion of the Universe seems like just the thing you could expect to happen if vacuum energy exists. As we noted earlier, in the absence of the constraining effects of substantial mass-energy gravitation, a vacuum will expand. This is a real measureable phenomenon and the bigger that vacuum gets the faster it expands. That seems a compelling argument for the vacuum itself to be the source of whatever is driving the expansion.

But quantum predictions of what vacuum energy should be on a cosmic scale deliver crazily-large values, orders of magnitude larger than the cosmological constant, which is now more commonly referred to as the cosmological parameter, or just dark energy – since, given the Universe's expansion is accelerating, is clearly is not a constant. So, whatever cosmological parameter (slash) dark energy is, is it may not be the vacuum energy predicted in quantum physics. Indeed, as we like to say here at Cheap Astronomy, the only thing about dark energy you can sure about is that it's not energy – since it is apparently both created and then destroyed, it does its work of expansion with 100 per cent efficiency and works its effect on the 3k Kelvin coldness of empty space without the faintest hint of a temperature change. So, if dark energy breaches all the laws of thermodynamics we shouldn't really call it energy, it's just something. Probably not vacuum energy, but probably not something totally inexplicable either, it's just something that we are yet to understand or explain.

Question 2:

Dear Cheap Astronomy – So what do you make of Massive Gravity?

As we've previously discussed on Cheap Astronomy, there are a lot of people out there who want to muck about with General Relativity. After all, it is fantastic physics and a genuine theory that has been tested time and again and it keeps on passing those tests. But with such success comes people who will tell you that if you tweak this one little part of General Relativity then their theory can be made to work brilliantly.

It's not unreasonable to suggest that 90% of the people who make such claims are cranks, but the other ten percent are a bit more careful in their language and do reasonably point out there are areas of reality that general relativity just doesn't cover – notably the physics of the fundamentally small, where quantum mechanics reigns. Some also say that general relativity can't tell you what happens in a black hole, but then neither can quantum physics really, despite what many quantum physicists may tell you. To its credit, General Relativity at least predicted the existence of black holes – and did so well ahead of anyone actually finding one.

Anyway, Massive Gravity deals with a different known unknown - the accelerating expansion of the Universe. This is the realm of dark energy which, as we like to say here at Cheap Astronomy, might be dark, but it's probably not energy. The origin of Massive Gravity lies way back in the 1930s, well before dark energy was a thing, where people used to sit in street-side cafes in Geneva and Copenhagen discussing the fundamentals of reality - and complaining about the Nazis. Bloody Nazis. And during this period, Wolfgang Pauli and Markus Fierz way proposed the startling idea that gravitons might have mass.

So, firstly gravitons themselves are largely hypothetical, proposed to be the force carriers of gravity, in the same way that photons are the force carriers for electromagnetism, but, we are yet to gain definitive evidence of their existence. If they do exist they are generally considered to be massless and hence can move at the speed of light in a vacuum. So, if we instead assume gravitons have mass then they might start struggling to mediate the force of gravity over very long distances.

It's allegedly this effect accounts for the accelerating nature of the universe's expansion, as though over long distances mass-handicapped gravitons can't quite manage to mediate the force of gravity all the way out to the Universe's distant peripheries before those peripheries have started slipping away from them. But it’s not immediately clear why this is a better explanation than what conventional cosmology offers. From observations of the expansion velocity of close and distant objects, we think that for a very long time the Universe’s expansion didn’t accelerate – the acceleration only kicked when the Universe was about 8 billion years old, presumably because its declining mass-energy density couldn’t inhibit the Universe’s expansion as much as it had in earlier times.

So, both conventional cosmology and massive gravity end up saying pretty much the same thing – as the Universe gets bigger it’s going to expanded faster. That then begs the question of why you need such an unconventional explanation like massive gravity.

Further more, Massive Gravity’s claim that it doesn’t need dark energy to explain the Universe’s behaviour fails to deal with a much more fundamental issue – why the heck the Universe is expanding in the first place. Conventional cosmology says that dark energy was there from the start, it just took a few billion years for the Universe’s density to diminish enough so that it could really take off. Massive gravity’s position seems to be that well, everyone knows the Universe expands, so let’s not dwell on that, let’s just talk about why it accelerates.

Both Newton’s and Einstein’s gravitational theories are universal – what happens here happens everywhere. Massive Gravity says that what happens here, does not happen in the same way long distances away, because the gravitons struggle to get out there in a timely fashion. So, we’re not dismissing the idea out of hand, we’re just saying that if things do happen differently way over there then we should be able to observe and measure that.