Question 1:

Dear Cheap Astronomy – How does the galaxy rotate?

There is something weird about how stars rotate in the Milky Way Galaxy – and probably in any other rotating galaxy. If you think about a standard disk galaxy, it certainly looks like all the stars are rotating about the centre – and to all intents and purposes they really are. But the physics of it is totally different to how things work in, say, our Solar System. In our Solar System around 99% of the entire Solar System's mass in the Sun – so it's hardly surprising to find that the motion of few planets that's orbit it are dominated by the gravitational influence of that Sun.

But, in the Milky Way, everything is different. By and large, the orbital velocities of all stars at all different distances out from the centre are all about the same – that is, about 230 kilometres a second. There are exceptions – stars right close-in to the centre don't move fast. But, once you get outside those dense inner regions the speed goes up to 230 kilometres a second – and it stays there, consistently right out to the edge, although the outermost stars do tend to move a tiny bit faster, maybe up to 250 kilometres a second. It's important to remember that this is only a general tendency, but these tendencies do hold across most of the galactic disk.

Of course, having the same orbital velocity doesn't mean that all stars in the galaxy keeps pace with each other. If all the stars in the galaxy really did have the same periodicity – then stars near the centre would have to move very, very slowly and stars near the edge would have to move very, very fast so that they all kept pace with each other.

In a nutshell, the motion of stars in the galaxy is not mediated by gravity generated from the centre, the way that it is in the Solar System. So, it's best just to forget about Kepler. What actually does mediate the motion of stars in the galaxy is still a bit of a mystery. The motion of the outer stars are the most puzzling since the galaxy just doesn't have enough visible mass to produce a gravity well that could keep those outer stars locked into the circular orbits that we observe, given the orbital speeds that they are moving at.

So, we invoke dark matter to explain it all. And we mostly need that dark matter in the outer parts of the galaxy. The dense inner and visible parts of the galaxy look like they might have enough mass density to hold inner stars in orbit, but the outer ones clearly need some kind of invisible mass to explain why their orbital speeds don't fling them out into the void.

But the dark matter we need to invoke to explain what we observe must be pretty weird stuff. It's invisible, which technically means it's transparent to visible light, but in fact it's also transparent to any wavelength of light, from infra-red, to x-ray and to gamma. And if you are imagining that dark matter is some kind of invisible dust that visible stars have to push through in their orbits, then their orbits should start decaying the same way the orbit of a satellite around Earth under goes decay when it comes into contact with the Earth's atmosphere – and, nope that doesn't happen either.

So, for now it probably is fair to say that dark matter is and does whatever it has to do to explain the motion of visible matter in a rotating galaxy – and when you dig into that idea, dark matter works out to be pretty strange stuff – not only does the experience being invisible and untouchable, but apparently measuring Neutrinos could fit the frame since they are largely invisible and untouchable.– and only just barely detectable, but they don't seem to have either the numbers or the mass to explain the behavior of star's orbits in galaxies.

Here at Cheap Astronomy we have no answers to offer, we just like to remind people that cosmology's appeals to either dark matter or dark energy are in no way satisfactory explanations of cosmological phenomena. They are just a way of acknowledging that there's something going on out there that we can't explain yet.

Question 2:

Dear Cheap Astronomy – *What is intergalactic dust made of?*

So firstly, hooray for intergalactic dust. Traditional estimates of how much known baryonic matter there is (that is, light not dark matter) never quite matched calculations of how much baryonic matter there should be given the expected amount of nucleosynthesis that should have happened within the first three minutes after the Big Bang. But now, according to a 2018 article published in Nature, the missing 40 per cent of the expected visible mass of baryonic matter has now been identified in what is known as the WHIM – the Warm-Hot Intergalactic Medium.

Of course we can only hypothesise how much baryonic matter should have been created in the first three minutes – and the 2018 Nature article acknowledges that the large majority of the proposed WHIM must be in the form of ionized hydrogen, which is beyond our current technology to reliably detect way out there in intergalactic space. What the research team did detect, and in substantial volumes, was a particular kind of ionized oxygen, from which they have concluded that – well if ionized oxygen is there in substantial volumes, there must be absolute truckloads of ionized hydrogen along with it. And just to get the terminology clear, we generally talk of empty space as containing traces of gas and dust, where the gas is mostly hydrogen and helium and the dust is mostly carbon, silicon and oxygen – and there's always a lot more gas than there is dust – even though there's not actually much of either.

Anyway, what we call the WHIM (the Warm-Hot Intergalactic Medium) is somewhat distinct from the much larger and much emptier voids that are also out there. The WHIM is in the space between galaxies, but when we talk about all the matter in the Universe being a thin web of connected filaments, the WHIM is all the loose connective stuff that makes that work. So, in between the dense structures of galaxies and the less dense structures of galaxy clusters, there's a tenuous, whispy WHIM that's loosely interconnects all the galaxies and clusters. And while the galaxies are much denser, the WHIM extends over some gargantuan distances between those galaxies. So, even though it's thin and it's whispy, it fills a vastly greater volume of space and so ends up having nearly as much cumulative mass as all the more compact and more visible galaxies.

Nonetheless, this relatively new finding doesn't change the current hypothesised distribution of light and dark matter. To recap, we think the Universe started from a single point and then everything that was in that point spread outwards very quickly – thus ensuring that the total contents of the Universe is now very evenly spread out. But all the while, the Universe has kept expanding and because of gravity any particles that have mass tend to congregate together. This includes both light and dark matter- and since dark matter is thought to make up 85% of all matter, it's dark matter that determines how light matter gets distributed. In any regions were matter is concentrated, those regions tend to resist the natural expansion of the Universe – so most of the Universe's expansion occurs in regions where matter and gravity have lost hold. So most of the Universe's overall expansion now occurs within the accelerating volumes of vast and mostly-empty voids. So, we think all the visible (that is, light) matter and all the invisible (that is, dark) matter takes the form of a thin web of interconnected filaments of matter separated by huge and growing voids of empty space.

Although, even the great voids are not completely empty – they do contain the odd particle that didn't get caught up in the early matter clumping that happened across the Universe. And we shouldn't assume that intergalactic space just contains gas and dust either. Just as intra-galactic space maybe filled with rogue planets thrown out of their stellar system, inter-galactic space may be contain rogue stars that were tossed out of their galaxy, usually due to a galactic collision of some kind. So, there is actually all sorts of stuff out there in intergalactic space, although it is rare and hard to find in amongst all that vast emptiness.