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 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 km/sec. 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 230km/sec 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 km/sec. 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 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 being invisible and untouchable, but apparently unmeasurable 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 stars' 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 – why doesn't the image of the black hole in M87 look like the image of the black hole in Interstellar?

Ok, so the back story here is that astronomers recently imaged the black hole within the elliptical galaxy M87 although when we say imaged it's really radio telescope data converted into a visual light approximation, but it's still an image – perhaps just not exactly what you'd see if you parked your spacecraft out at a safe distance and took a peek. Of course we say that because the image of Gargantua, the black hole visualized in the movie Interstellar, was intended to mimic exactly what you would see if you you'd parked your spacecraft out at a safe distance and took a peek. And the way it looks was as advised by Nobel Prize winner Kip Thorne, who you'd think would know how it should look.

In fact everyone was right, Kip Thorne and the Event Horizon telescope team, it's just that black holes will look different depending on which angle you view them from. But let's step our way through that. Firstly, black holes are black. They suck in light and don't let any of that light back out. So, the only black holes we've been able to visualize so far are black holes with accretion disks. There are almost certainly many black holes out there without accretion disks.

Even when a black hole has an accretion disk it's still the case that you won't see anything unless light can escape from it. So, visually even outside the event horizon, there is a gap where both material and light are inexorably fall inwards so no light will come from there back to your eye. This region extends out 2.6 Schwarzchild radii from the black hole's centre where 1 Schwarzchild radius is where the event horizon is. The actual size of the Schwarzchild radius is determined by the mass of the black hole – at least, will for a black hole that's not spinning. If a black hole does spin and most probably do, then those ratios won't be quite so exact, but the general principle will still applies. In this region, where an external observer sees nothing, but it' still outside the event horizon light spirals into a spherical orbit at about 1.5 Schwarzchild radii from the centre, so if you were there you could look at the back of your head if you got all the angles just right. Further in, light and matter are curved into tighter paths, which ultimately take them down past the event horizon and that's that.

Further out though – and the accretion disk does become visible to a distant observer at about 3 Schwarzchild radii from the black hole's centre, but its appearance is affected by spacetime curvature. Remembering that an accretion disk is a disk, if you see it edge on you will see the disk's proximal edge crossing the black hole that's behind it. But you'll also see all the disk's distal parts, that are actually behind the black hole, because the light emitted from those distal parts is being bent towards an orbit around the black hole. So all that light comes around the black hole and back to you, because it's not quite close enough to be caught into an orbit, it just tends towards an orbit and is consequently bent around back towards you, the distant observer. So you see two semicircles on either side of the black hole, one above the black hole representing the upper surface of the disk that's behind it and another semicircle below the black hole, representing the lower surface of the disk that's behind it. And this is what you see in Interstellar – you see the front edge of the disk cutting across the black hole then the two surfaces of back of the disk showing around either side the black hole – and forming a rough circle.

The M87 Event Horizon Telescope image looks different to the Interstellar image because from Earth we are seeing its accretion disk face on rather than edge on. So there is no part of the disk that's behind the black hole and you just see what you'd expect an accretion disk to look like, a ring of bright material surrounding a black hole although the area of black in the middle is much bigger than the actual event horizon, because there's also that 2.6 Schwarzchild radii region where you can't see anything in the process of being sucked down into the event horizon, even though it hasn't actually got there yet.

It's also a common feature with these disks that one side looks brighter than the other. That's because everything in the disk is moving close to the speed of light, so the side where material is coming towards you will look brighter due to relativistic Doppler beaming, which you won't see on the other side, where it's all going away from you. They may have skipped over this bit with Interstellar, but this does explain the bright splotches clearly visible on one side of the M87 image – a real image, not a movie.