Question 1:

Dear Cheap Astronomy: Is the Universe really a donut?

This idea has been around for a while and Stephen Hawking attributes it to an unexpected source (sound clip). This is one of these areas where you can propose a hypothesis which is totally unmeasurable – and since no-one can prove you wrong, you can get a publication out of it.

But anyway… the donut story arises from studies of the comic microwave background, the CMB. We tend to naturally assume that the universe is an expanding sphere, since the universe started small and has expanded ever since – and since the CMB looks fairly uniform across the sky.

Although… really it would have to be a hyper-sphere. It makes no sense to suggest that the universe has an inner and an outer surface like a beach ball – instead you have to imagine that the inner and outer surface are continuous with each other. So, it is a sphere upon which an ant could walk from the inner surface to the outer surface without crossing an edge. Some people like talking about the old video game Pac-man where your munching Pac-man icon could follow a trail off the edge of the screen and immediately re-appear on the opposite side. It's that sort of idea.

In hyper-geometry, it's better to talk about manifolds rather than surfaces. So, a hyper-sphere has a continuous manifold. Another geometry that has a continuous manifold is a hyper-torus – that is, a hyper-donut. A normal torus – like an inflatable inner tube –has continuous inner and outer surfaces that an ant could walk all over without crossing an edge. In this respect it very similar to a sphere. And a hyper-torus – sorry, hyper-donut – would be just like a hyper-sphere, with a continuous manifold and no edges, anywhere.

But so what? Why should we decide that the universe is a hyper-torus rather than a hyper-sphere? Well, the early universe was a hot, broiling plasma that cooled as the universe expanded – until it was cool enough for protons and electrons to form hydrogen atoms. This made the universe suddenly transparent to radiation, resulting in an energetic flash of light. That flash of light has since cooled to become the cosmic microwave background.

It is thought that concentrations of mass-energy-density in the early universe existed in a dynamic equilibrium. Gravity was trying to collapse them inwards and photons were trying to push them outwards. With the sudden release of those photons when hydrogen atoms were first formed – the remaining density concentrations collapsed inwards. Those sudden collapses produced baryonic acoustic oscillations – which were shock waves, a bit like claps of thunder.

Some people, who have analysed the cosmic microwave data, claim that there is a puzzling limit to the angular size that these oscillations can have. This is what you might expect if we did live in a donut universe. A donut universe will have a diameter that is less than the length of its inner tube – so it would constrain the spread of baryonic acoustic oscillations. However, a spherical universe has a diameter that is as big as itself, and so would not constrain the spread of an oscillation.

So, yes Virginia, the Universe is a donut – at least until someone discovers that it isn't.

Question 2:

Dear Cheap Astronomy - Can dark matter form black holes?

Recent findings from the European Space Agency's Planck spacecraft have provided some minor revisions to the currently accepted parameters of the Universe. As well as it now being 13.8 billion years old, the distribution of our universal knowns and known-unknowns now stand as: conventional matter (5%), dark matter (27%) and dark energy (68%).

The nature of dark energy remains utterly unknown. If it really is energy, it is a kind of energy that is so alien to our current understanding of energy, that it's hardly worth using the word. It's just dark something.

However, dark matter is less troublesome. It does behave in much the same way as matter that we are familiar with. Sure, it's invisible and it's weakly interacting – but then so are neutrinos, billions of which are passing through your body every second. You don't notice them because they are invisible and weakly-interacting.

Although neutrinos have mass, they fly around the universe at close to the speed of light, seemingly wanting nothing to do with each other. However, a key feature of dark matter is that it gravitates. Dark matter particles readily accumulate into big stable clumps, hence providing a gravitational foundation upon which conventional matter can also accumulate into large-scale structures like galaxies and galactic clusters.

So, since a key feature of dark matter is gravitation, shouldn't it have all collapsed down into black holes long ago and gobbled up the rest of the universe's matter in the process? Fortunately, the answer is no.

Getting something to fall into a black hole is not as straight-forward as it might seem. While an exact straight-line trajectory might score a hole-in-one, it is more common that a chunk of matter is drawn into orbit around a black hole. Potentially, such a chunk of matter could then stay in that orbit indefinitely, unless something causes its orbit to decay.

What we see with conventional matter is that orbiting material accumulates into an accretion disk which begins to radiate energy as various interactions and collisions within the disk heat the material within. That electromagnetic radiation is an example of the conservation of energy. Essentially, the interactions and collisions within the accretion disk convert the momentum energy of the orbiting matter into radiation. And as a chunk of matter in orbit loses its momentum energy, its orbit will begin to decay.

But with dark matter, the above scenario never happens. They say it takes a light year of lead to stop a neutrino in its tracks. Presumably a similar principle applies to weakly-interacting dark matter particles. A dark matter particle could be captured in orbit around a black hole, but it will scarcely interact with other matter nor can it radiate away any of its momentum energy. As a consequence, dark matter orbits will not decay and dark matter will not spiral in to be consumed by a black hole.

Observational data seems to confirm this view. There is a strong correlation between the rate of consumption of conventional, visible matter from accretion disks and the consequent estimated mass of feeding black holes. So, unlike the rest of the universe, where dark matter seems to dominate conventional matter by a factor of five, black holes seem to be primarily built from conventional matter.

One troublesome issue is that, since dark matter is so prevalent in the universe, you would think that quite a lot of it should be getting caught in orbit around black holes, even if it is just a loose orbit that never decays. Perhaps, under these conditions, dark matter particles begin to interact with each other and self-annihilate, producing a characteristic positron energy signature that the Alpha Magnetic Spectrometer 2, aboard the International Space Station, may have recently detected.