Question 1:

Dear Cheap Astronomy: Just what the heck is dark matter annihilation

Dark matter annihilation is humanity's latest attempt at hypothesising what might happen if two hypothetical dark matter particles, interacted.

There is quite a long chain of assumptions involved here. Firstly dark matter itself is only assumed to exist on the basis of gravitational phenomena that cannot be explained without assuming the presence of invisible mass. For example, there just isn't enough visible mass to generate the gravitational grip that prevents the outer parts of large spinning galaxies from just flying off. So those galaxies must full of invisible mass, that is dark matter.

The physical nature of dark matter is totally unknown – but when has that ever stopped anyone? There is a branch of hypothetical physics called super symmetry in which hypothetical particles called neutralinos could play the role of invisible massive particles.

Neutralinos are, hypothetically, their own anti-particles. So, hypothetically, if one nuetralino collided with another neutralino then they might self-annihilate in the same way that electrons – and their antiparticles, positrons – annihilate when they collide.

But it is just a theory. Indeed, it's really just a hypothesis, since at this stage there is zero evidence to support the view that neutralinos even exist, yet alone self-annihilate. But again but when has that ever stopped anyone?

We are currently searching for evidence of self-annihilating neutralinos using various detectors in coal mines, Antarctica and even on the International Space Station – although, at least to date, we are not finding any conclusive evidence self-annihilating neutralinos.

If we don't find evidence for their self-annihilation does this mean that neutralinos don't exist? Well, not necessarily, it may just mean they don't spontaneously self-annihilate after all, which will just take us back to the drawing board to look for another way to detect them.

Nonetheless, a range of other predictions proposed by super symmetry have, so far, failed to be realised across a range of different testing environments, including the Large Hadron Collider. This ongoing lack of evidence is leading some to wonder whether super symmetry is still a viable theory. And if people give up on super symmetry, they will probably give up on the neutralino-dark matter hypothesis as well.

A fundamental problem with the dark matter annihilation idea is why a material with such a propensity for self-annihilation still continues to represent 27% of the contents of the Universe, now that the Universe is 13.8 billion years old. Surely, we should have lost a fair chunk of that dark matter to self-annihilation by now, a phenomena that should be clear if we compare why very old galaxies and very young galaxies. And... when we do that, we see no evidence that the Universe has lost any dark matter over its lifetime.

So, if you were a betting person, you probably wouldn't put money on people finding evidence of dark matter annihilation anytime soon. Although this on its own doesn't represent a huge failure in super symmetry theory, it doesn't exactly help it either. So, what is dark matter really made of? No idea really – but then, when has that ever stopped anyone?

Question 2:

Dear Cheap Astronomy: Did the Alpha Magnetic Spectrometer find dark matter?

As we have outlined in previous Cheap Astronomy episodes, there is a hypothesis that you might be able to once-and-for-all prove the existence of dark matter by identifying the by-products of its annihilation. As also discussed in previous Cheap Astronomy episodes, dark matter is by definition weakly-interacting, so about the only thing that is likely to annihilate a dark matter particle is another dark matter particle.

All that said though, it is not immediately clear why two dark matter particles should suddenly decide to end it all by undergoing such mutually-assured destruction. Indeed, if dark matter particles, which make up 80% of all matter in the Universe, are so prone to disintegrating upon bumping into each other – it's surprising that dark matter has managed to remain so prevalent over the last 13.8 billion years of the Universe's existence.

So, just for a moment, let's try running with the idea that maybe dark matter doesn't self-annihilate. Because if it doesn't, then maybe there is some other reason why abundant numbers of antimatter particles, originating from out beyond the solar system, have been detected by the Alpha Magnetic Spectrometer , the AMS, which has been aboard the International Space Station since 2011.

Essentially, the AMS has now confirmed a finding first hinted at by less sophisticated instruments such as PAMELA and Fermi-LAT. The AMS has confirmed that the cold vacuum of space is brimming with antimatter particles, including many high energy ones that no source within the solar system would be able to produce. Furthermore, since no appreciable amount of anti-matter can last for long before colliding with matter and annihilating, all these anti-matter particles must be being constantly replenished.

From its vantage point in low Earth orbit, the AMS found more high energy positrons than low energy positrons. Indeed there seems a rapid increase in the volume of positrons with higher and higher energies until you reach about 250 GeV, after which the numbers drop off sharply. However, it's important to remember that this energy-level distribution is influenced by the solar wind – which resists the inflow of positrons. So, inevitably, more high energy positrons will reach the AMS than low energy positrons, even though there may be a more consistent distribution of positrons at all energy levels out in interstellar space.

It is interesting that the AMS has found no obvious anisotropy in the positrons that reached it – meaning they seemed to be coming from all directions rather than from a specific point source. This is encouraging for dark matter annihilation advocates. Being so prevalent, dark matter should be all over the place and hence it should be producing high-energy positrons all over the place when it self-annihilates. But there are also many other astronomical sources of high-energy positron production that are also all over the place. The high-energy outbursts of neutron star polar jets and black hole accretion disks, which are themselves all over the place, could also be the source of the positrons detected by the AMS.

So, while the latest findings are consistent with the hypothetical idea of dark matter annihilation, they are also consistent with a whole bunch of other ideas that don't get the same prominence, because they don't involve the word 'dark'.

The abstract of the first scientific paper of the AMS findings, by Aguilar et al in Physical Review Letters, sums up the current situation up as follows. Taken together, these features show the existence of new physical phenomena. In other words, while we are not sure yet what these phenomena are – this is no longer just an area for hypothesis. We have data.