Question 1:

Dear Cheap Astronomy – How much can we learn from New Horizons quick fly-by of Pluto next year?

We say Pluto was discovered in 1930, although it was actually observed fifteen times prior to 1930, the earliest-recorded observation being in 1909. But, since none of the people making those observations realised that the small white dot they had observed was a dwarf planet, those 15 episodes are now known as ‘prediscoveries’.

At the time of Clive Tombaugh’s discovery in 1930, it was estimated that Pluto was about the size of Earth. Then, as technologies improved, we began to realise it was a lot smaller than that. Indeed, we are now pretty confident that Pluto is about one sixth the size of Earth, making it smaller than the smallest planet, Mercury. Indeed it is smaller than the moons Ganymede, Titan, Callisto, Io, The Moon, Europa and even Triton.

New Horizons will approach Pluto in early 2015 and fly-by it in July 2015, coming to within about 10,000 kilometres of Pluto’s surface. That’s pretty close to an object which is only about 2,300 kilometres in diameter. The first thing New Horizons may be able clarify is exactly how big Pluto is and finally settle the issue of which is bigger, Pluto or Eris. Pluto is estimated to have a diameter of 2,306 kilometres plus or minus 20 kilometres. Eris is estimated at 2,326 plus or minus 12 kilometres. So for the moment we can’t fully differentiate them, although if you were a betting person you’d probably put your money on Eris.

But if it turns out that we find Pluto’s diameter is between 2,314 and 2,338 kilometres, then all bets are off since that is within Eris’ current plus or minus 12 kilometres error bars. If that is the case, we’ll need a New Horizons 2 to fly to Eris in order to finally settle the matter.

Now, this all assumes that Pluto – and indeed Eris – are round. Both objects are much too far away to confirm their geometry by direct observation. Being round is all about hydrostatic equilibrium – the balance between gravity and the mechanical resistance of the materials that are being gravitated together. The point at which an object becomes round is partly about its mass, but it’s also about the volume that the mass is concentrated into – in other words, it’s about density.

It’s been easy enough to work out the mass of Pluto and Eris, by looking at the way they both interact with their moons – Dysnomia in Eris’ case and Charon in Pluto’s case, being the biggest of Pluto’s five known moons known so far.

We could tell you the actual masses of Pluto and Eris, but both of those figures are largely meaningless, being something times ten to the power of something else. When considering the mass of celestial bodies, it’s much easier to talk about them in relative terms. So, Eris is 23% of the mass of the Earth’s Moon, while Pluto is only 18% of the mass of the Earth’s Moon. This means that Eris is 27% more massive than Pluto – which is quite a lot really.

But remember it’s not just about mass, it’s about density. Given Pluto and Eris are about the same size and Pluto is 27% less massive, it works out that Pluto should be around 12% less dense than Eris. So, is that enough density to make it round? Well, yes, it probably is.

Some reassurance is gained by considering Mimas, the so-called Death Star moon, which is one of the smallest, but readily-observable moons in the Solar System - being a moon of

Saturn and readily observable by the Cassini spacecraft. Mimas is unarguably round, although it has several hundred times less mass then Pluto and is about a sixth of Pluto's size. The overall density of Mimas works out to be less than Pluto's density too. So, if you were a betting person, you'd probably put your money on Pluto being round and you'd probably put double stakes on Eris being round.

Apart from confirming Pluto's size and shape, we expect that New Horizons will be able to confirm the chemical make-up of Pluto's tenuous atmosphere – which we think is principally nitrogen and methane. And we might also get to the bottom of Pluto's highly-contrasted surface, which has a puzzling mix of very light and very dark patches all over it. There's a whole bunch of hypotheses as to what underlies that phenomenon, but since we will probably find out for sure in July next year, why don't we just wait and see?

In the absence of real data, a whole bunch of stuff is possible. In the presence of real data, a whole bunch of stuff becomes utter bollocks.

Question 2:

Dear Cheap Astronomy – Is the Dragon version 2 landing procedure physically plausible?

The Dragon Version 2, or V2, is Space-X's proposed new manned capsule for seven astronauts. To date, we have only seen a full scale mock-up and an animated video of what the real spacecraft might do. Perhaps its most remarkable feature is that it can land by powered descent.

From orbit the craft will shed much of its velocity during atmospheric re-entry, aerobraking with an ablative heat shield. This will not be much different from an Apollo or a Soyuz re-entry, though the craft is expected to be more manoeuvrable during re-entry, to maximise its aerobraking, while also lining itself up for a pinpoint landing.

As the capsule aerobrakes into thicker atmosphere, it will reach terminal velocity - a constant velocity arising when the spacecraft's acceleration due to gravity balances with the resistance of the atmosphere. From here an Apollo or a Soyuz capsule might deploy parachutes to further slow the craft and then land. However Dragon Version 2 will fire retro-rockets to slow its descent all the way down to a soft-landing, without using parachutes.

And Dragon V2 has unusual retro-rockets. They don't fire straight down, since the rockets jets would need to project through the heat shield to do that. Instead they fire diagonally from four equidistant points above and around the heat shield.

This is a curious solution. Even 1950s science fiction retro-rockets fired straight down. After all, it's all about Newtons second law of equal and opposite reactions. Firing diagonally to your direction of motion will not give you an opposite, or an equal, reaction.

Based on the demonstration video, the angle used ofr rocket firing used means that only 70% of the rockets output will effectively contribute retro-thrust to the capsule's direction of motion. It may be that firing diagonally from four points will give the craft more stability on descent. However, there is some risk involved too. If one or two of the engines fail on the same side, the whole craft could be flipped upside down. That would be, what is commonly-known, as a mission failure.

But a lot of very smart people with PhDs worked on the design, so we might assume that it will all go smoothly. In this podcast, we just want to investigate the physical plausibility of the landing procedure – and that is just a question of mathematics.

If the Dragon V2 aerobraking procedure is as effective as claimed, it could slow the capsule to a falling terminal velocity of around 300 kilometres an hour. The super-Draco rocket specs say they can deliver thrust of around 8,000 kilometres an hour. That sounds like a lot of thrust, but we need to think in terms of momentum, not just velocity. The downward momentum of the falling spacecraft is a product of its mass and its velocity.

The rockets can expel propellant at a speed that is about 25 times faster than the fall of the spacecraft. But remember the rockets fire diagonally, so about 30% of that reverse thrust is wasted since the vector of thrust is not opposite to the vector of descent.

But it is probably still enough thrust. The effective reverse thrust of the rockets is a product of the mass and velocity of their propellant fuel – a hypergolic nitrogen tetroxide hydrazine mix, if you really want to know.

It works out that if 10-15% of the spacecraft's initial falling mass was rocket fuel and that 10-15% mass was then retro-thrust at 8,000 kilometres an hour, you could bring the spacecraft to a gradual halt, despite the 30% efficiency loss due to the diagonal thrust vector.

The exact mathematics require calculus since the loss of fuel progressively robs the spacecraft of some of its momentum, so it gets progressively easier to slow with the same force of retro-thrust as it approaches the end of its fall. You also have to account for the reduction of speed from terminal velocity, which returns the capsule to an accelerating fall in a gravity field – but, trust me, I'm an astronomy podcaster… the math works.

Some may still argue that the retro-rockets are just an exorbitant and inefficient luxury that will further pollute the atmosphere, but it is nice to know that the math works.

And just in case it all goes pear-shaped, Dragon V2 will carry parachutes anyway.