Question 1:

Dear Cheap Astronomy – I still don’t get Lagrange points, particularly L4 and 5.

Most explanations of Lagrange points are a bit idealised. For example, explanatory diagrams show Earth’s orbit as a perfect circle around the Sun, which isn’t right, it’s really an ellipse. Similarly all the diagrams about spacetime curvature, where the Lagrange points are presented as flatspots in intersecting gravity wells, aren’t really right either since they show a 2 dimensional surface being curved and warped, whereas the reality is a three dimensional volume being curved and warped and also undergoing continual dynamic changes as Earth orbits the Sun.

So half the problem with understanding Lagrange points may be that the visual analogies people use aren’t perfect and the other half of the problem maybe that they were first identified, or at least predicted, through some high-level mathematics – which is probably the best way to explain them.

Lagrange points are often described as points where the forces of gravity reach equilibrium in a simple two body orbital system, for example the Earth orbiting the Sun. The makes sense for L1 – which lies between the Earth and the Sun, but is harder to grasp in the cases of Ls 2 to 5.

A better way to think about the whole problem may be to consider why we care about Lagrange points – and that is all about spacecraft positioning. So for example, the James Webb Space Telescope needs a place from where it can observe the Universe and also needs a place from where it can send the data it collects back to Earth. While an Earth orbit worked well for the Hubble Space Telescope, James Webb is an infrared telescope and needs to keep itself cool, which it will achieves by always keeping its sun shield facing the Sun. This would hard to achieve if it orbited the Earth every 95 minutes as the Hubble does. It’s easy to achieve in a solar orbit, but it will have to be a solar orbit where it remains equidistant with the Earth. If it doesn’t keep pace with the Earth, its orbit will either lag or advance meaning there will be times when it’s the other side of the Sun, which will put it completely out of contact with Earth.

So how do you get a spacecraft to keep pace with Earth? It’s not hard in principle, you just need the spacecraft to adopt the same orbital velocity as the Earth which is largely a matter of tweaking since it already will have a very similar orbital velocity, having been launched from Earth. But remember the Earth’s orbit is elliptical, so it speeds up around aphelion and slows down around perihelion and while a small mass spacecraft would naturally orbit the centre of the Sun, the much larger mass Earth really orbits the Earth-Sun barycenter, which is about 500 km out from the centre of the Sun. So a solar-orbiting spacecraft would need to regularly adjust its speed and trajectory to keep pace with Earth.

Or of course, you could just fly to a Lagrange point, which will do most of that work for you. L2 is the chosen destination for the James Webb, since it’s on the other side of the Earth from the Sun. So, it’s a bit cooler, plus an object at that point orbits the combined mass of both the Sun and the Earth – so even though it’s in a higher orbit than the Earth is, which would normally have a slower orbital velocity, it will move at the same orbital velocity as the Earth.

L3 is not much use for spacecraft parking being on the opposite side of the Sun to the Earth and hence of out of radio range, unless you also positioned a relay spacecraft above or below the orbital plane. Such a mission has been proposed to observe the other side of the Sun, in order to provide early warning of solar flare activity that might later be rotated around to face Earth – remembering the Sun rotates on its axis once every 27 days. A spacecraft at L3 would also orbit the combined mass of the Earth and the Sun, just in the opposite order, and so its orbit would also be slightly higher than the Earth's but nonetheless match the Earth's orbital velocity.

And then your last two other options are Lagrange points 4 or 5. These points are in line with the Earth's orbit and always remain at 150 million kilometres to either side of the Earth – where 150 million kilometres is also the average distance between the Sun and the Earth. So these points experience the same gravitational influences that keep the Sun and the Earth in orbit around their mutual barycenter. So if you put something at either Lagrange point 3 or 4 they will also match Earth's orbital velocity.

Question 2:

Dear Cheap Astronomy – Can neutrinos predict supernova explosions?

We've previously expressed doubts that the recent dimming of Betelguese suggests it is about to go supernova. Since Betelguese is an irregularly variable star, the recent dimming just means it's being true to form. We then ended that episode by saying that perhaps if we could observe enough supernovae all the way from pre- to post-blast, we might be able identify some genuine signals of a pending supernova blast. And so to the topic of today's episode, supernova neutrinos.

Neutrinos are so named because they are neutrally-charged and have a very small mass – hence inos. They are produced in nuclear reactions, for both fission and fusion pathways – so many neutrinos that come to us on Earth are from the Sun and there are some man-made ones from nuclear fission reactors and there are also a lot from other non-solar astronomical sources. These range from high energy extragalactic neutrinos which are pumped out in the jets of galactic nuclei – that is active supermassive black holes found in the centres of many galaxies. At the other end of the scale there are very low-energy neutrinos that arose from fusion reactions in the very early universe, where all hydrogen that appeared after the first three minutes began fusing to form helium and a bit of lithium and a bit of beryllium before the Universe had expanded and cooled sufficiently to prevent any further such wide-scale fusion. About mid-way across that neutrino energy spectrum from big bang to extragalactic neutrinos are supernova neutrinos, which have distinctive energies in the 10-30 mega electron volt range.

Supernova neutrinos are produced en masse in the final gravitational collapse of a giant star. During the collapse, the force of infalling matter overcomes electron degeneracy pressure in its core, hence driving protons and electrons together to form a much denser core of neutrons. Since the neutrons cannot be compressed further, the collapse stops short producing a bounceback shock wave that then blows out the rest of the star. But remember this is a giant star, which may have the diameter of Mars' orbit around the Sun, so it can take several hours before that core-generated shock wave emerges from the star's surface accompanied by a burst of photons that is bright enough to be seen from other galaxies. However, the neutrinos released at the moment of the collapse almost immediately shot out of the star since they only interact weakly with other matter.

So, for example, in 1987 supernova SN1987a exploded in the Large Magellenic Cloud. The optical detection of the event was preceded by a neutrino burst around 18 hours earlier. So, even though once they've left the star, the photons were moving at the speed of light in a vacuum, the earlier-departing neutrinos were moving at nearly the speed of light in a vacuum and so still arrived at Earth first. So there you go. Forget all the dimming stuff, if you want early signs of pending supernovae, it's all about neutrinos. Many of the major neutrino observatories across the world are currently engaged in SNEWS, the Supernova Early Warning System, which is scanning the skies for supernova-heralding bursts of neutrinos. If SNEWS detects a strong signal both electromagnetic and gravitational wave observatories across the world will lock onto that point of origin waiting to collect data from the light burst and gravitational wave burst generated by the emerging shock wave.

Of course, 18 hours isn't much warning. It has been proposed that there may be earlier telltale signs, at least for Type 2 core collapse supernovae, in the form of smaller neutrino bursts, that correspond with the final steps in element burning where hydrogen fusion, switches to helium and then carbon fusion, then neon, oxygen and silicon fusion, until it's all over at iron. It's possible that each of these steps produces a characteristic burst of neutrinos, which could give very accurate predictions of the expected time of the explosion. We can only say it's possible since we're still waiting for the opportunity to properly monitor a supernova event to test this hypothesis – and it has to be a reasonably close one to get the amount of data resolution that we'd like. The 1987 supernova we mentioned earlier was in the Large Magellanic Cloud, which is kind-of next door, but we really want one that's inside the Milky Way. The last observed supernova in our galaxy was in 1680 – plus there's been a few since which no-one observed directly. But it's really now that we're scanning the skies with the right technology that we want a star in our galaxy to go kablooey so we can observe it with our multi-messenger array of light, gravitational and neutrino observatories. So, as usual, watch this space.