Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Gravity wells – and how to get out of them*.

A gravity well is what we call that field of force created in the fabric of space-time by a massive object, for example a planet. Just like a well, if go too close to one you are likely to fall into it. Unlike a well, once you are in it there are no walls to help you climb back out again.

Barring a TARDIS or some other trans-dimensional travel device, the only way out is up (baby) and there are only four ways you can do that.

Firstly you can build your way out – also known as the Tower of Babel method. Given the strength of Earth's gravity well, this is unlikely to be successful using any known construction material on the planet. There's a reason why Mt Everest is the tallest mountain on Earth – anything bigger, made of a similar silicon-based material (rock), starts collapsing under its own weight once it gets that high. Everest is nearly nine kilometres up from sea level, but to give some perspective to the problem, the International Space Station, considered to be in a low earth orbit, is over 300 kilometres up from sea level.

The ISS is well above the atmosphere, but nowhere near what we might consider to be the edge of the well. In fact, the strength of the Earth's gravity at 300 kilometres up is still about 80% of what it is at sea level. The ISS is falling back to Earth as we speak, it's just falling so fast, and at such an angle, that it keeps missing the ground. Geostationary satellites are 36,000 kilometres above sea level and even they are constant state of slipping back down to Earth – but being higher up they only have to move at the same speed the Earth spins in order to miss the ground.

Anyway, we are not going to build our way out.

The second way to get out of a gravity well is to get someone to throw you a rope. Not as silly as it sounds, this is the idea behind the hypothetical space elevator, built of an extruded carbon nanofibre we haven't invented yet, which is lowered from a space platform in geosynchronous orbit we haven't invented yet – and there's a whole other problem with this plan. We have to get into orbit first.

So, until we have friends in high places, the rope plan isn't going to work.

The third way out of a gravity well is the projectile method, which essentially means being fired from a cannon. Again, not as silly as it sounds, but there is no way any kind of delicate instrumentation, let alone biological tissue, is going to survive the G forces generated from firing something from zero km/h up to the Earth's escape velocity of 11.2 kilometres a second if this acceleration is generated along the length of a cannon barrel. And even 11.2 kilometres a second won't be enough – as you will need even more momentum than that to push through the Earth's atmosphere. Shooting through the atmosphere at these kind of speeds will superheat whatever materials may have survived the initial cannon blast.

So, all this approach will achieve is sending up a mangled, superheated and very dead glob of stuff.

But this does brings us to the fourth way to get out of a gravity well. If you can find some way to slowly and steadily accelerate an object carrying a human being, or a delicate instrumentation package, it is feasible that payload will leave the Earth's gravity well without being squished, mangled or burnt to a crisp. In fact you don't have to get to 11.2 kilometres a second since that is the escape velocity for an object propelled from the Earth's surface. The higher you go, the weaker the gravity, the less velocity you need to escape the well.

But finding a way to achieve that slow and steady acceleration all the way up to the edge of Earth's gravity well has taken us quite a while. It's thought that Homo sapiens left our home country of Africa about 60,000 years ago. As we spread out in all directions across the planet's surface a lot of thought went into how we might extend our success into that other direction – up.

Apart from a few people managing to blow themselves up, the first real successes were the Montgolfier brothers at the end of the eighteenth century and then the Wright brothers at the start of the twentieth century. But these approaches involved making use of the atmosphere – either using atmospheric pressure to push up a lower density gas in a bag (also known as a balloon), using aerodynamic principles to lift a fast-moving object with wings (also known as a plane) or to suck air in one end of a engine and blast it out the other (also known as a jet).

Well before the Wright brothers took off, Konstantin Tsiolkovsky – who incidentally first thought up the space elevator – started thinking about rockets as a way to keep going steadily up and past the atmosphere. Tsiolkovsky spent most of his life in a log cabin somewhere south of Moscow, but there managed to work out most of the fundamental principles of modern spaceflight. In 1903 he published what is commonly referred to as Tsiolkovsky's Rocket Equation.

The Rocket Equation describes the balancing act between having a powerful enough engine to actually launch the mass of your fuel tank – while having enough fuel in the tank to get it and the engine into space before the fuel runs out. A certain proportion of the rocket blast is required to just overcome the inertia of your rocket's mass while the rest has to overcome the force of gravity. The bigger the engine and the bigger its fuel tank, the more inertia there is to overcome.

On the positive side, if you can actually get moving, your rocket will starting losing mass – being all that fuel you are burning up as you go, so it gets easier and easier the higher you go. It's also the case that the higher you go, the weaker the gravity field you have to overcome – but most of the hard work is over by the time this becomes noticeable.

Tsiolovsky's equation led to the use of staging in modern rocketry. The Saturn V rocket which took astronauts to the moon, weighed over 3 million kilograms when fully fuelled. The first stage burned about 2 million kilograms of fuel getting 70 kilometres of altitude, achieving a speed of 10,000 kilometres an hour and clearing most of the thick lower atmosphere. 10,000 kilometres an hour sounds fast, but it is less than 4 km a second and hence nowhere near the escape velocity it needs. But this is where the second and third stages come in. The second stage pushes the remaining 1 million kilograms of mass to a higher altitude and a faster speed and then drops away leaving less than half a million kilograms to continue on. The third stage then does one two minute burn to get into a low earth orbit of 180 km altitude and a speed now approaching 8 km/sec, then it does a longer 6 minute burn to get a three-moduled Apollo spacecraft (weighing about 50,000 kg) on its way to the Moon – which, even at 380,000 kilometres away, is still in Earth's gravity well.

The real edge of Earth's gravity well is something in the vicinity of 1.5 million kilometers away and astronauts are yet to get there. Passing over some highly apocryphal tales of manhole covers being blown into space during the nuclear tests of the 1950's, the first man-made object to leave Earth's gravity well was the small 40 kilogram Pioneer 5, launched on the 11th of March 1960 to explore interplanetary space between Earth and Venus.

It's conceivable, and likely, that astronauts will one day soon climb right out of our well. It's unlikely this could ever have been achieved with a single Saturn V, since the extra mass required for life support and return fuel for the longer trip means more mass to be lifted off the Earth's surface. A more feasible plan might have been to use two rockets to fly up two halves of a spacecraft which are then joined up in Earth's orbit to continue on as one heavier object. Currently this is a part of the developing strategy for getting the new NASA Orion spacecraft to the Moon with six astronauts, rather than Apollo's three astronauts.

I hope this podcast has shown that the term *gravity well* isn't just a cute bit of astronomical jargon. We really do live in a well and it's very, very hard to get out of it.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where you're only as cheap as the telescope you're looking through. No ads, no profit, just good science. Bye.