Hi this is Steve Nerlich from Cheap Astronomy [www.cheapastro.com](http://www.cheapastro.com) and this is *The interplanetary transport network.*

You know how the word astronaut is just ancient Greek for star sailor and how we talk about the solar wind and we imagine making solar sails as an energy-efficient way to explore space. Anyway, my point is that there's all these nautical analogies used when we talk about space travel. So, would it surprise you to learn that there are all these slow moving currents, washes and eddies of space-time running throughout our dynamic solar system – and that these might offer a very energy-efficient way of exploring space... with or without solar sails.

*So, when you say efficient Steve, you really just mean cheap don't you?*

Exactly. The idea of network of gravitational currents and flows, running throughout the solar system, shouldn't really come as a surprise. If you think about it, the planets are big, round chunks of mass that can warp space-time – and they are all in very rapid motion about an absolutely humungous chunk of mass called the Sun. So the solar system is a very dynamic, even turbulent, place.

You can get a hint of these dynamic effects when you hear NASA talking about gravity-assist manoeuvres. This is where a spacecraft can approach a rapidly moving planet and temporarily get caught up in its space-time wake gaining a bit of a push forward – kind of like a dolphin swimming in the bow wave of a ship. The push or the pull of the planet's gravity can add to, or subtract, from a spacecraft's velocity and even change its course without the spacecraft having to burn any fuel.

In fact, as long as you have an abundance of patience and don't mind taking an often circuitous route to your destination, it is possible to tour the whole solar system with an exceedingly economic use of fuel. If you imagine the whole solar system as a big rubber sheet which is warped by gravity wells that have been created by massive objects...

*Steve if I can break in here. You're saying that even though the solar system looks flat - it's really not flat?*

Well, not through Einstein's eyes – spatially the solar system is a flat disk but really it's a space-time continuum that holds it – and is curved by it. So, the very massive Sun keeps the planets rolling around a steep curve of space-time which we call the Sun's gravity well. Then you should think of the planets as just making small dents pressed into the sides the Sun's overarching gravity well, since the Sun has 99% of the mass of the whole solar system. The planets create their own smaller gravity wells which keep their moons rolling around them. Einstein didn't think of gravity as a real force – it's just consequence of this space-time curvature that shapes the trajectory of massive objects.

*Oh OK. But eh, so what Steve? I mean once you left Earth aren't you just going to roll down the sides of this gravity well of the Sun, unless you fire your rockets?*

Well no, because you have come from Earth you already have the velocity of the Earth's solar orbit (which is 30 kilometres a second). So for example, you can just hover around the outer rim of the Earth's gravity well and follow the Earth all the way around the Sun - or perhaps wait until another planet passes by and hop over onto the rim of its gravity well.

The rim of the Earth’s gravity well is land marked by Lagrange point 1 (or L1) which lies directly between the Sun and the Earth – and also Lagrange point 2 (or L2) on the opposite side of the Earth directly away from the Sun. You can move around the rim of the Earth’s gravity well from L1 to L2 using hardly any fuel - because you are already out of Earth’s gravity well and you’re not on the slope of the Sun’s gravity well. In other words, around the rim between L1 and L2 space-time is fairly flat.

*Oh I see - it is all starting to sound quite cheap then.*

Indeed - very cheap if you just follow three key principles. Firstly, a spacecraft can just hover around a Lagrange point and be carried right around the Sun. Secondly, the Lagrange points represent a junction to transfer between different planetary orbits. So, as though the solar system’s space-time curvature makes a kind of giant skateboard park, it’s possible to step off Earth’s L1 and coast down the Sun’s gravity well to Venus – or you can coast across the flat rim of Earth’s gravity well for about 3 million kilometres to L2 and then with just a modest fuel burn, step off L2 and a follow a spiral path up to Mars’ orbit and hop onto Mars’ L1 as it passes by. And there you might rest again, letting Mars carry you around in its solar orbit before you perhaps shuffle across to Mars’ L2 and to go on to Jupiter.

What helps to make this travel so energy-efficient, is the third key principle, where it’s the constant motion of different planetary gravity wells that creates opportunities for gravity-assist manoeuvres – which means a spacecraft can lose or gain velocity or change its trajectory just by borrowing energy from that passing planet. If you gain velocity from gravity-assist you can start climbing up the Sun’s gravity well to the outer planets – or if you lose velocity you can travel back towards the inner planets.

So if you plan things right, these little kicks of gravity-assist means you’re always moving without burning fuel – as though you are following an ocean current and the Lagrange points of different planets are like little eddies or flat spots where you can rest up. In fact when you do all the orbital mechanics math together, you can find a whole network of interconnecting pathways that are called the Interplanetary Transport Network (or ITN).

*Well, It all sounds a bit like hocus pocus Steve. Surely you've got to burn some fuel.*

Well a tiny bit, but remember if you want to visit the inner solar system, you just ride down the Sun's gravity well – so no need burn fuel to do that. And even though the Sun's gravity well gets steeper as you get closer to the Sun - the inner planets move faster in their orbits. So the inner planets give you a much bigger gravity-assist kick – which helps you get back out again. And as you do move out - you need progressively less energy to keep going out - because the Sun's gravity well becomes less steep the further out you go.

The principles underlying the ITN have been adopted by a number of spacecraft missions to conserve fuel. The *International Sun/Earth Explorer 3* satellite, launched in August 1978 was the first ever spacecraft to go into orbit around a Lagrange point, in this case L1 – from which it collected data about the Sun.

After completing its mission in 1982, the mission planners decided that well, they still had a spacecraft, even if it didn't have much fuel left. So they repurposed it to become the *International Cometary Explorer*. A short thruster burn kicked it out of its L1 orbit and then it followed a complex path around the Earth-Moon Lagrange points – before finally being flung out of the Earth-Moon system altogether in 1984. Once in its own solar orbit, its trajectory then took it through the tail of comet Giacobini-Zinner in September 1984, becoming the first spacecraft to ever visit a comet.

In the 1990's, someone worked out a circuitous trajectory to enable the Japanese probe *Hiten* to get into a lunar orbit in 1991, despite it only having 10% of the fuel required for a traditional trans-lunar insertion trajectory. The whole manoeuvre was successful, although travel time to the Moon was five months instead of the traditional three days.

So, the Interplanetary Transport Network seems most likely to be used by low budget robotic spacecraft – or where there's a change in a spacecraft's mission plan – and there isn't quite enough fuel left to do what you want to do via conventional spacecraft trajectories. With the ITN, you don't need a lot of fuel, all you really need a lot of - is patience.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website trying to make huge expanses of cold, empty vacuum sound interesting. No ads, no profit, just good science. Bye.