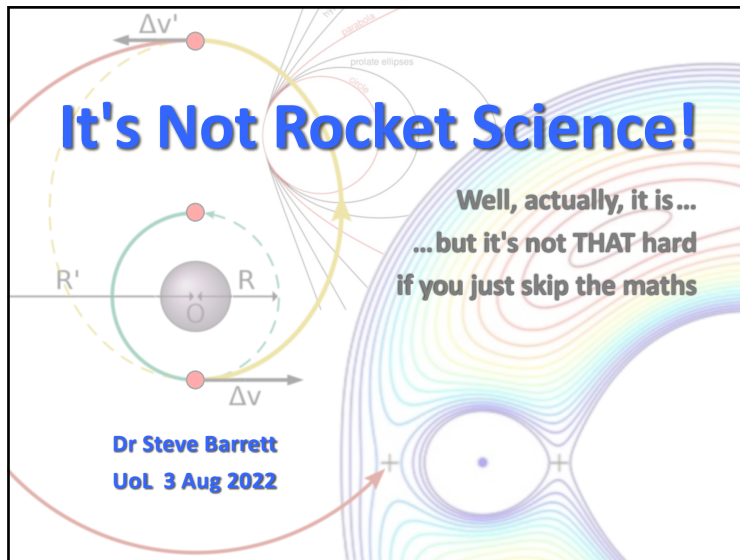


It's Not Rocket Science!



It's Not Rocket Science



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What are Lagrange points all about?

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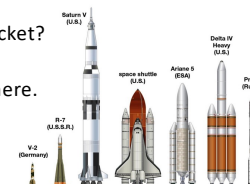
3

What Does a Rocket Do?

Q: What is the primary function of a rocket?

A: To lift objects up above the atmosphere.

Well, yes ... sort of.



The ISS and the HST are actually still **in** the atmosphere – it's just rather thin up there at an altitude of ~500 km.

To put an object into Earth orbit what is needed is **horizontal** speed.

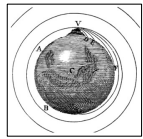
(Getting as high as possible to reduce atmospheric drag is a good idea, but it is not strictly necessary.)

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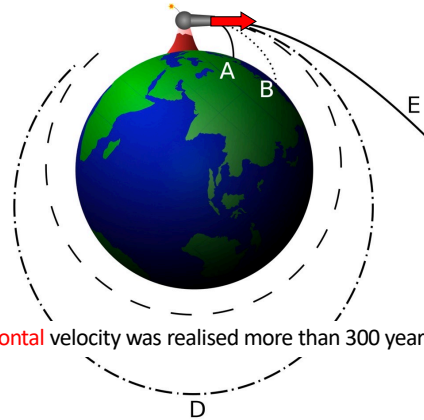
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Newton's Cannonballs



Isaac Newton
Principia 1686



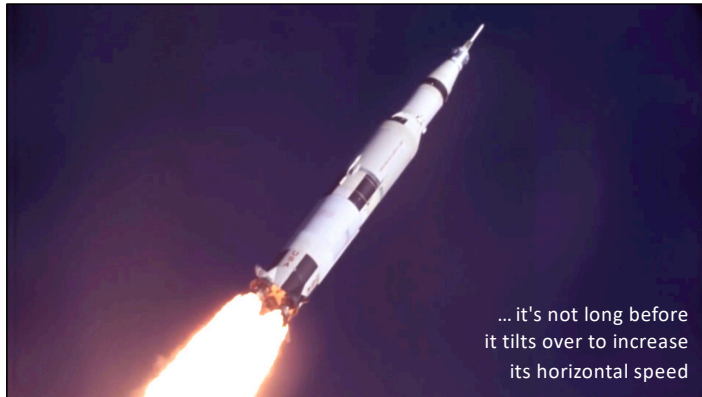
The need for **horizontal** velocity was realised more than 300 years ago

Saturn V Launch



Although initially
the rocket lifts
off vertically...

Saturn V Launch



... it's not long before
it tilts over to increase
its horizontal speed

Otherwise: What Goes Up...



Blue Origin
New Shepard
It goes vertically up ...
it comes vertically down
Altitude = 100 km
Flight time = 10 min

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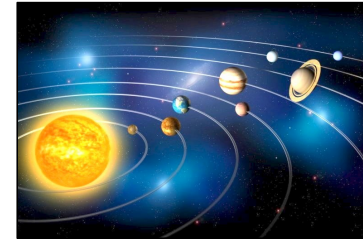
What are Lagrange points all about?

Orbits

Orbit: The path of an object affected by (only) gravity.

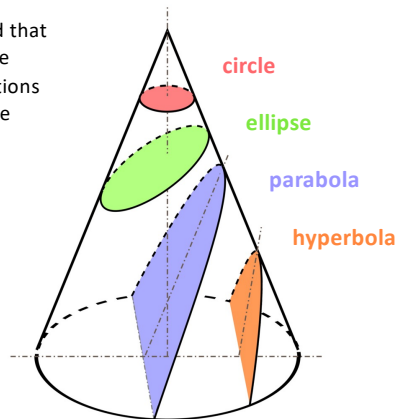
We are all used to the idea of planets in orbit around the Sun, or moons in orbit around their planets.

Kepler observed that the planets orbit in ellipses and Newton figured out why – his law of universal gravitation.



Conic Sections

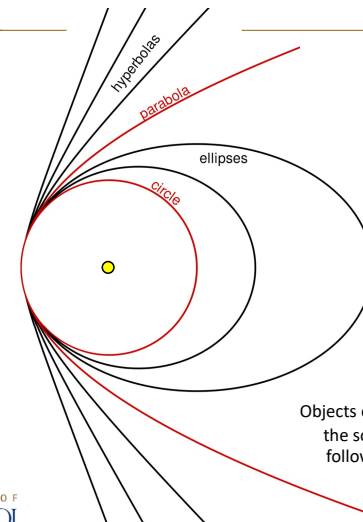
Newton found that orbits have the shapes of sections through a cone



Conic Sections

These curves that describe orbits around the Sun are also the curves that define the shapes of mirrors that are suitable for focusing light.

This is because the maths is basically the same for both.

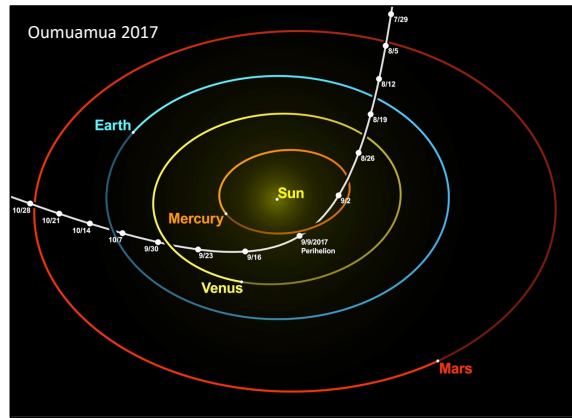


Planets follow closed elliptical orbits, but a comet falling into the solar system from way out in the Oort cloud follows a parabolic path.

Objects entering and leaving the solar system at speed follow a hyperbolic orbit.

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Hyperbolic Orbit



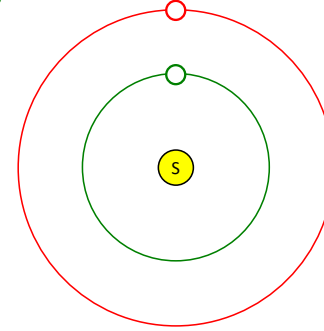
Orbit Size and Orbit Period

Green planet is closer to Sun

Gravitational pull from Sun is stronger

Planet moves faster to stay in orbit

Shorter period ('year')



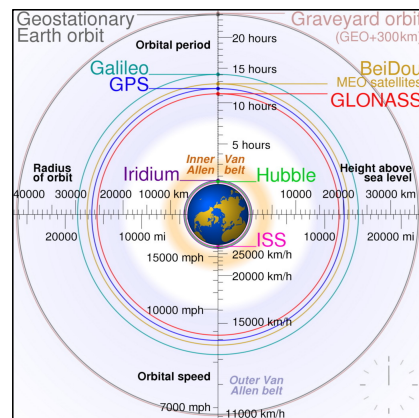
Red planet is further from Sun

Gravitational pull from Sun is weaker

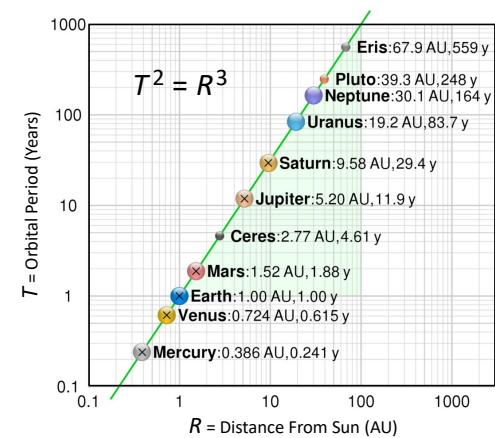
Planet moves more slowly to stay in orbit

Longer period ('year')

Earth Satellite Orbits



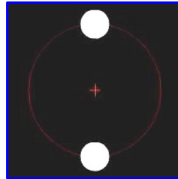
Planets Orbit the Sun



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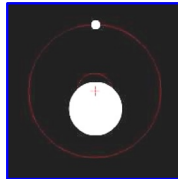
Circular Orbits

Two objects with equal mass orbit around the centre of mass (+)



If the objects have different masses, objects with larger mass move smaller distances

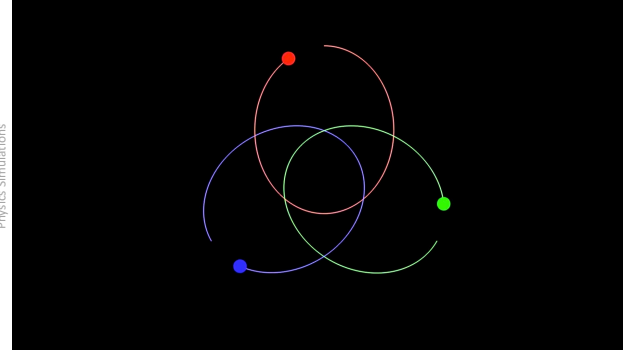
If the masses are very different, the centre of mass (+) may lie within the larger object



Even a small object (planet) can make a large object (star) wobble – this is how exoplanets can be detected

3-Body Problem

Describing the relative motion of **two** objects is a soluble problem



but for **three** or more objects there are very few analytic solutions

Rocket Science

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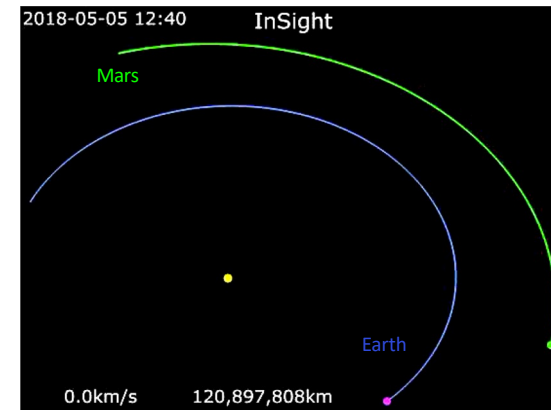
Earth to Mars

Gravity assists to the rest of the solar system

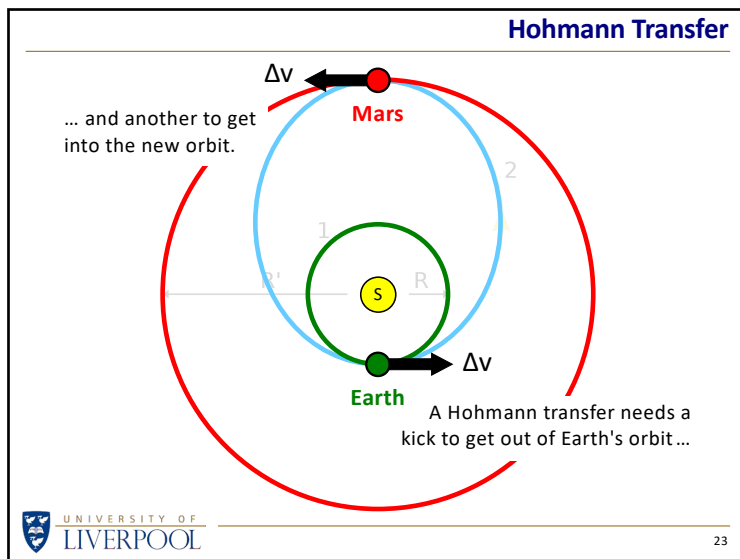
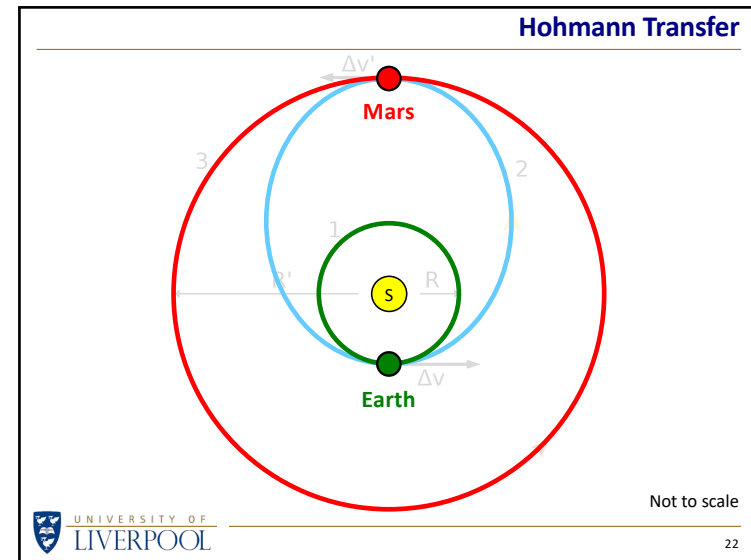
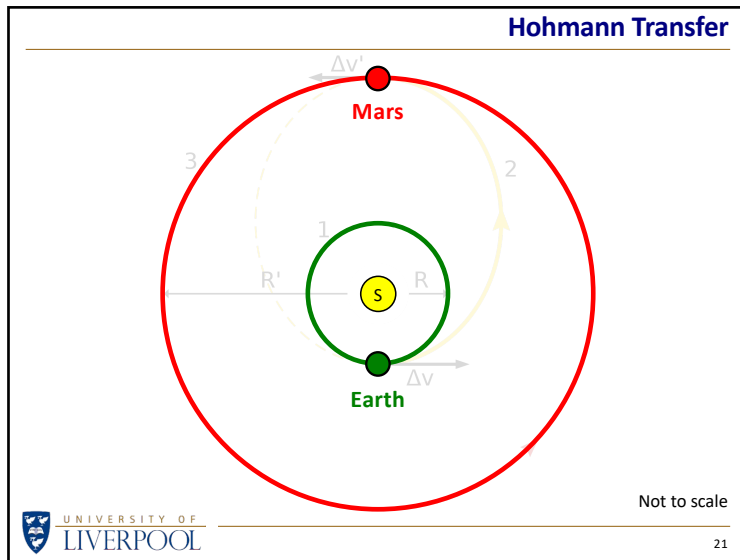
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What are Lagrange points all about?

Earth to Mars



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Gravity Assists

What about getting to other planets in the solar system?

In the 1960s it was realised that flying a spacecraft close to a planet can 'slingshot' it onwards at higher velocities.

Hence exploring the outer solar system can be carried out faster and cheaper.

In effect, the spacecraft robs the planet of some of its momentum.

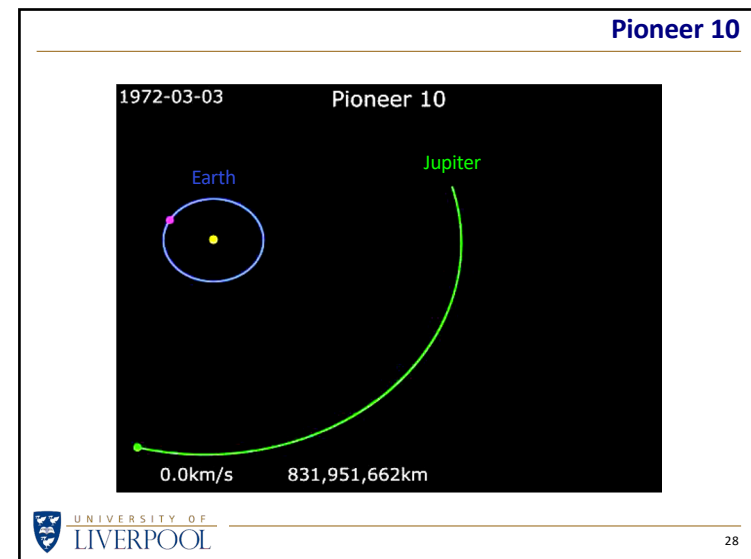
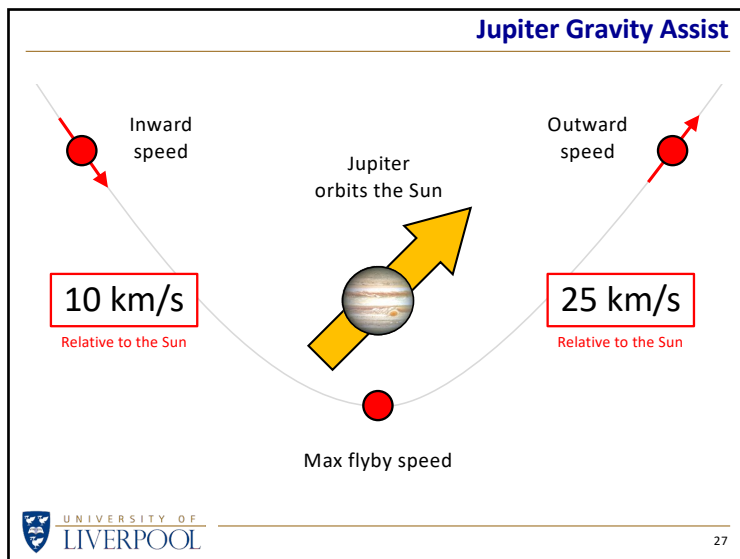
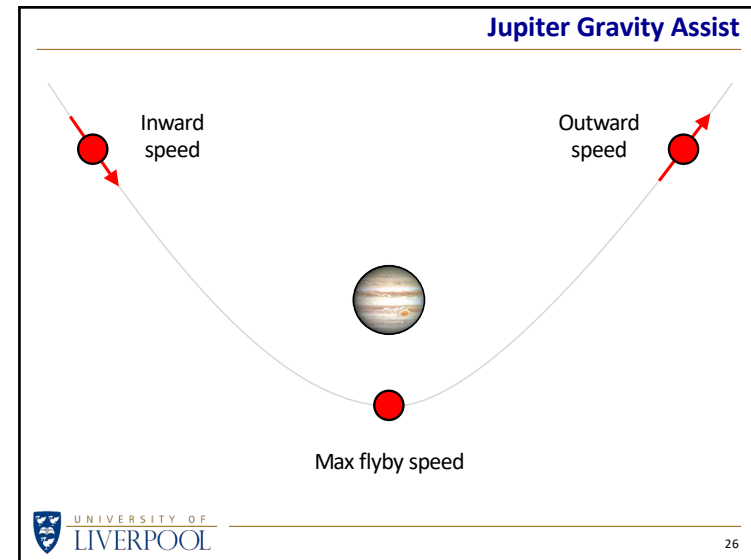
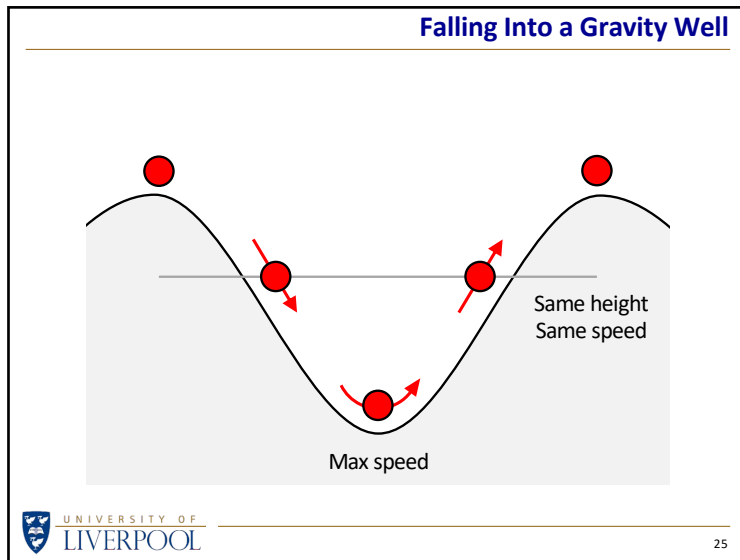
1986-12-08 Voyager 2

19.5km/s 1,438,307,736km

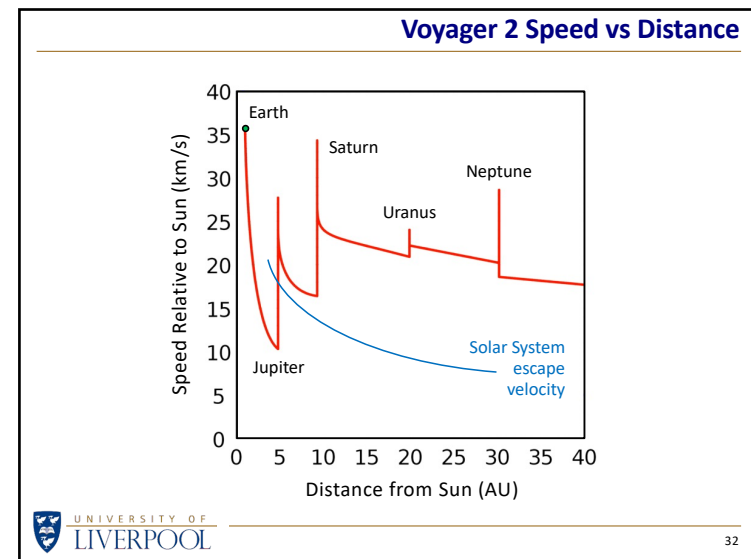
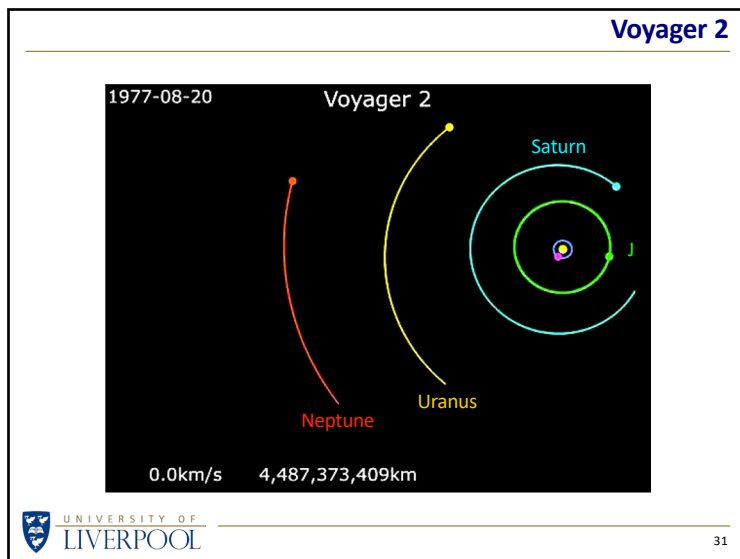
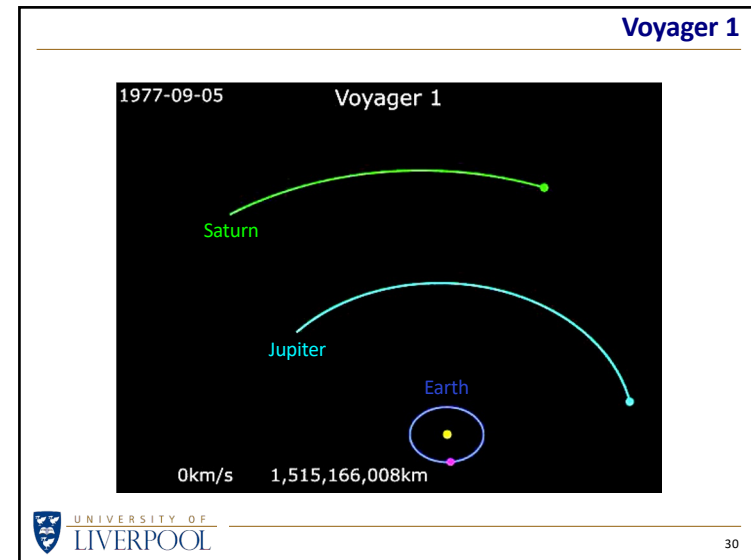
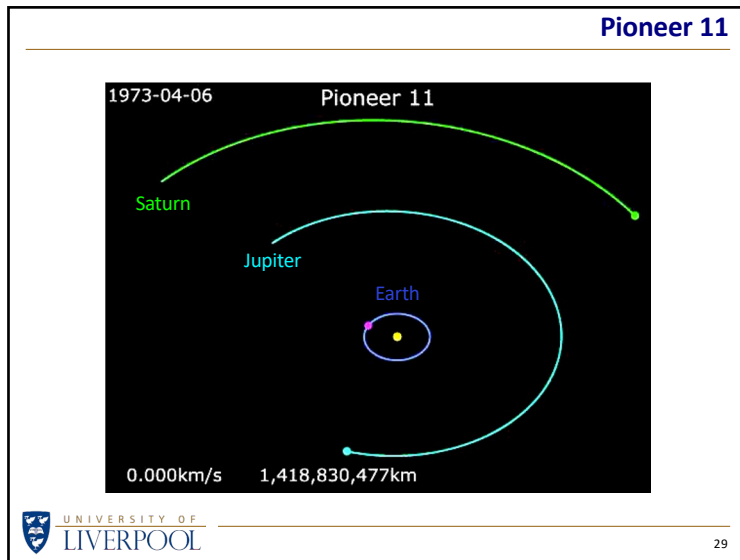
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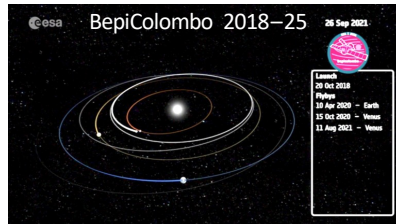
Gravity Assists

Using gravity assists to help cover the enormous distances between planets in the outer solar system seems like a very sensible idea.

What is not so obvious is that gravity assists are also used to visit the *inner* planets.

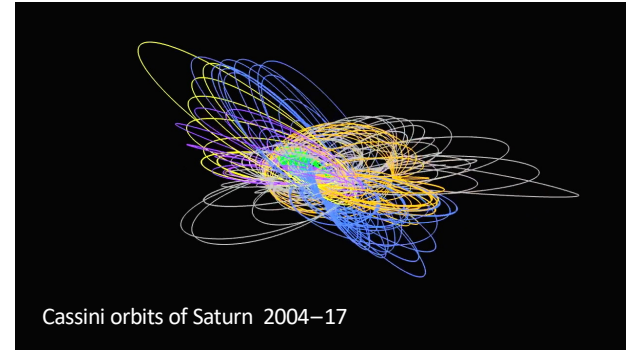
A planet flyby can be used to *lose* speed as a spacecraft 'falls' into the inner solar system.

A flyby can accelerate *or* decelerate, but in both cases fuel is saved.



Changing Orbits Uses Fuel

Some spacecraft go into orbit around their target planet



Any orbital changes require fuel which reduces the mission lifetime

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Green planet is closer to Sun

Gravitational pull from Sun is stronger

Planet moves faster to stay in orbit

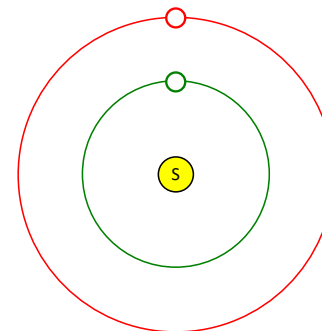
Shorter period ('year')

Red planet is further from Sun

Gravitational pull from Sun is weaker

Planet moves more slowly to stay in orbit

Longer period ('year')



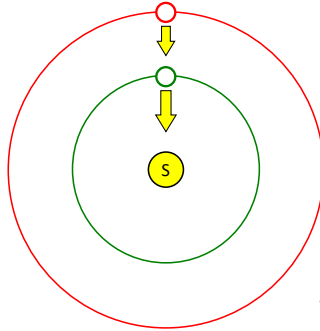
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Orbit Size and Orbit Period

The arrows show the gravitational force of the Sun on each planet.

At a greater distance, the force is less.

Is that always the case?



We can't change the gravitational pull of the Sun...

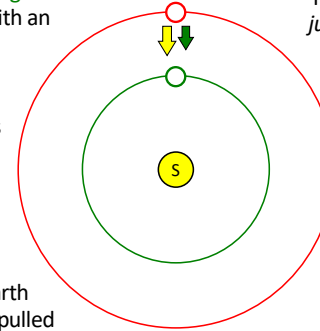
...but we can arrange it so that an object in the red orbit feels an additional gravitational force.

Lagrange Points

Let's assume that green is planet Earth with an orbital period of exactly 1 year.

The red orbit has a period of *more* than 1 year.

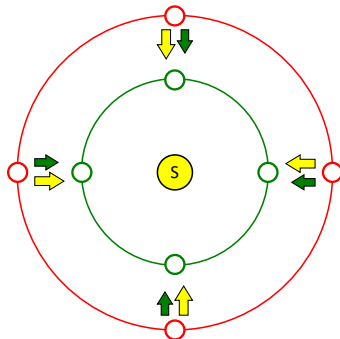
What if the red orbit is close enough to the Earth that an object is pulled by both the Sun **AND** the Earth?



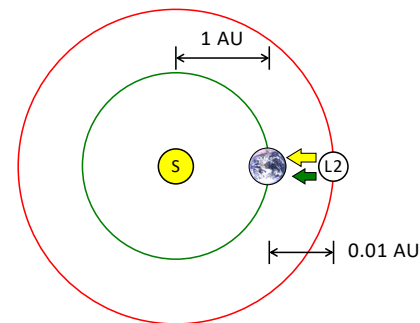
There is a red orbit at just the right distance such that the extra pull from the Earth makes the red object orbit faster with a period of 1 year.

That would mean that the red object would orbit the Sun 'with' the Earth.

Lagrange Point L2



Lagrange Point L2



Not to scale

It's Not Rocket Science!

Lagrange Point L1

The idea is conceptually the same for L1 *inside* the Earth's orbit, but this time the Sun and the Earth pull in opposite directions.

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Lagrange Point L1

L1 is a good location for spacecraft that observe the Sun, as the Earth never gets in the way.

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Calculating Lagrange Points

Gravitational forces between two bodies fall off as the square of the distance between them, so we can use that to calculate the distance from Earth to L1 or L2:

$$\frac{M}{(R \pm r)^2} \pm \frac{m}{r^2} = \left(\left(\frac{M}{M+m} \right) R \pm r \right) \left(\frac{M+m}{R^3} \right)$$

M = mass of Sun R = distance Sun–Earth
 m = mass of Earth r = distance Earth–L1/2

Just solve for r . Simple!

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Calculating Lagrange Points

Gravitational forces between two bodies fall off as the square of the distance between them, so we can use that to calculate the distance from Earth to L1 or L2:

$$\frac{M}{(R \pm r)^2} \pm \frac{m}{r^2} = \left(\left(\frac{M}{M+m} \right) R \pm r \right) \left(\frac{M+m}{R^3} \right)$$

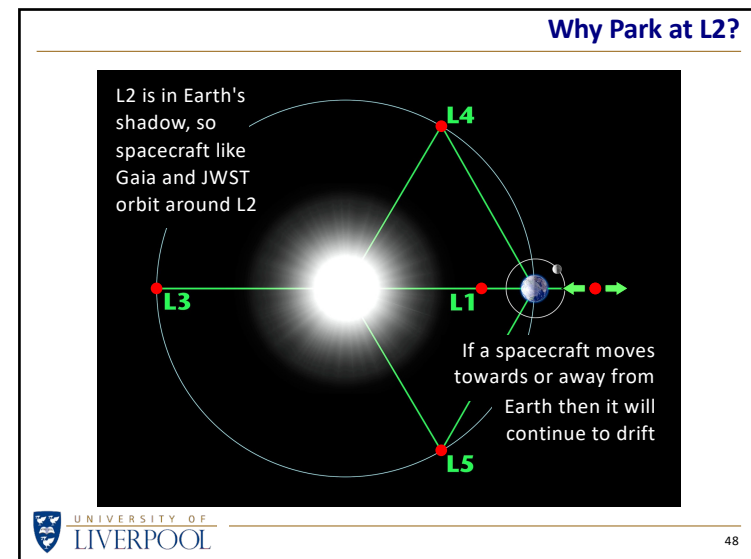
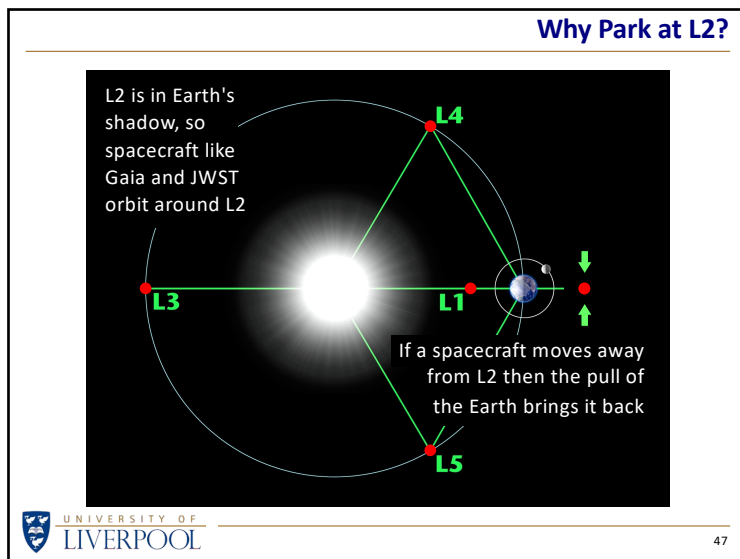
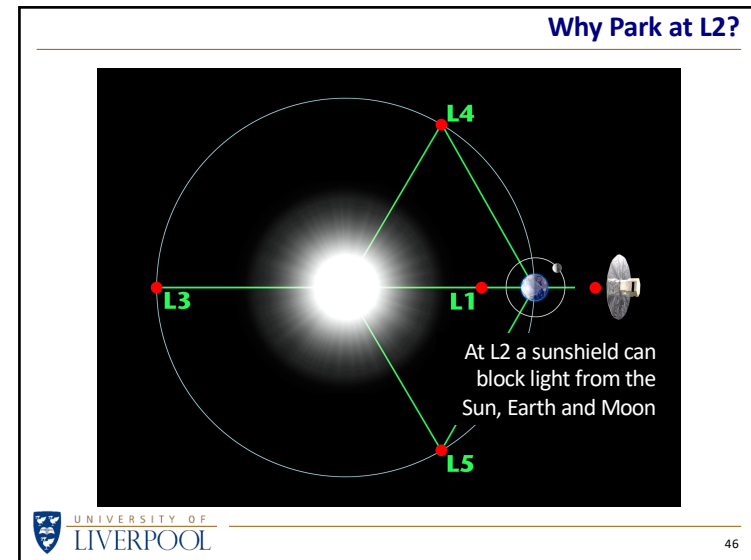
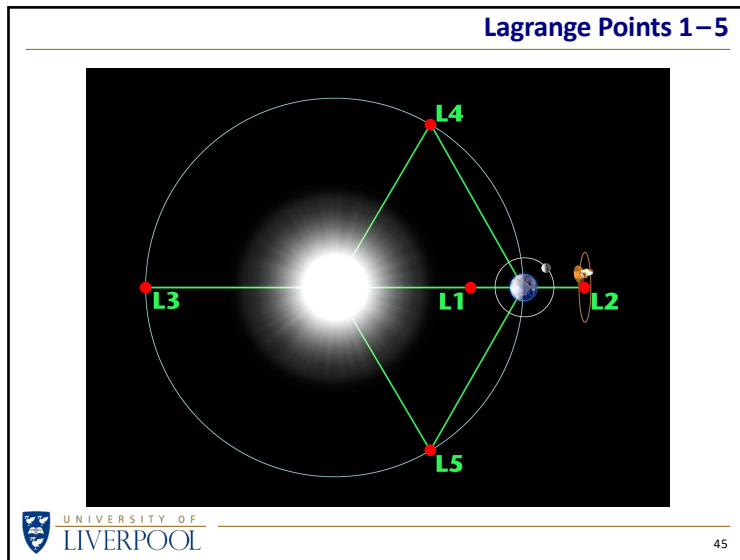
M = mass of Sun R = distance Sun–Earth
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Just solve for r . Simple!

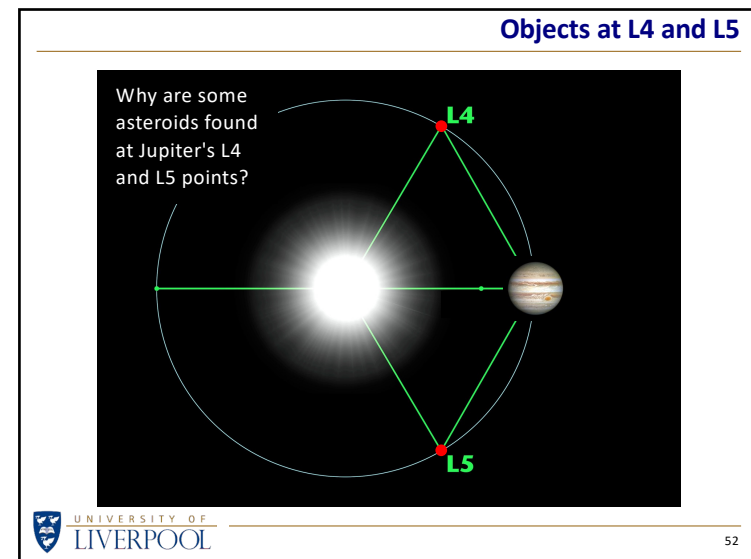
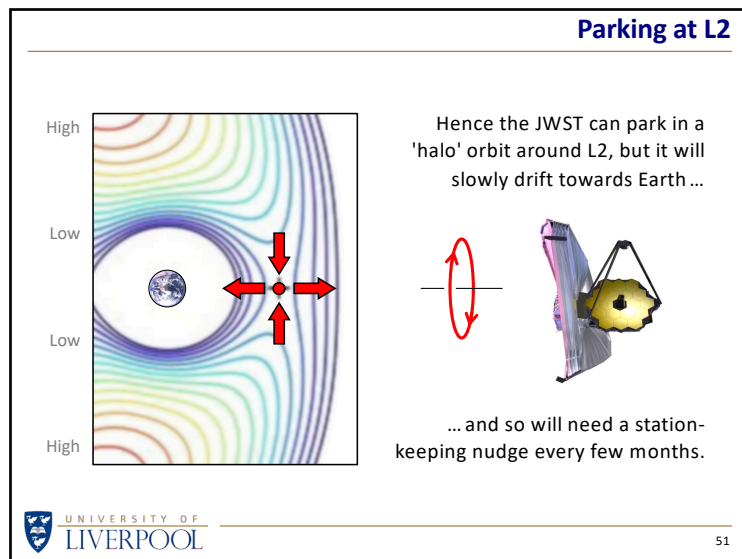
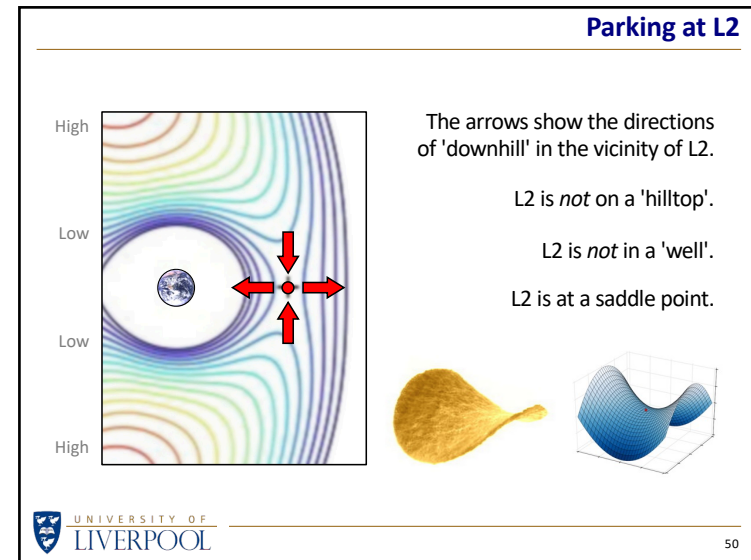
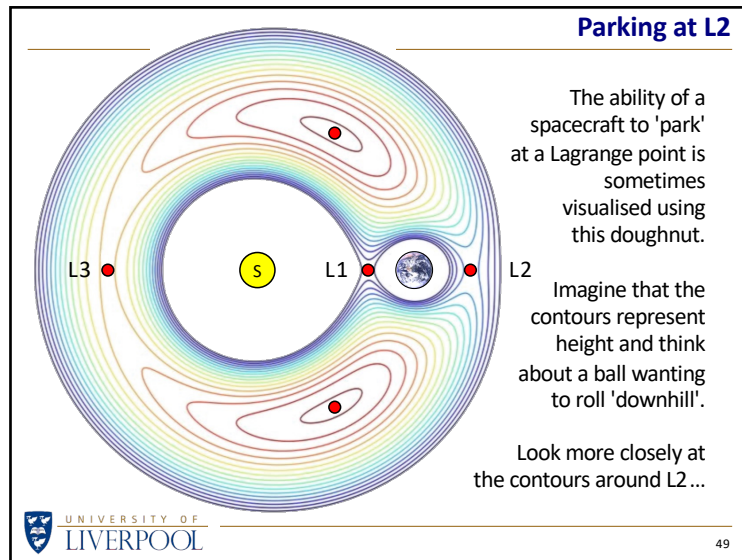
**...but it's not THAT hard
if you just skip the maths**

44

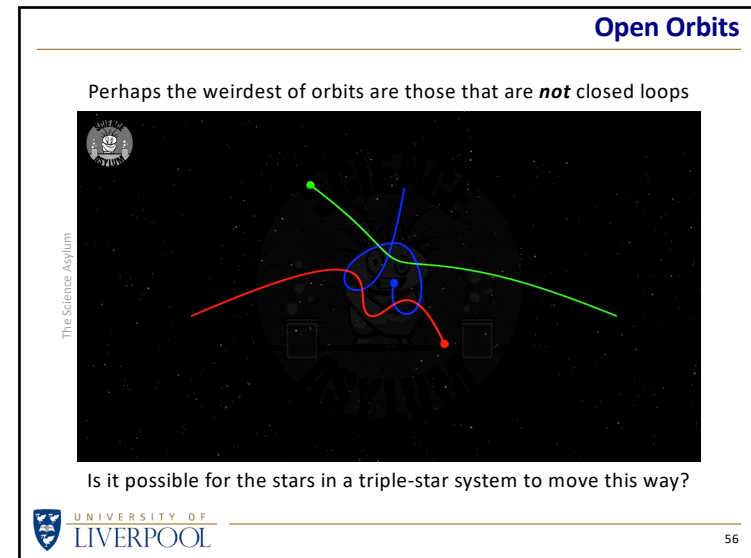
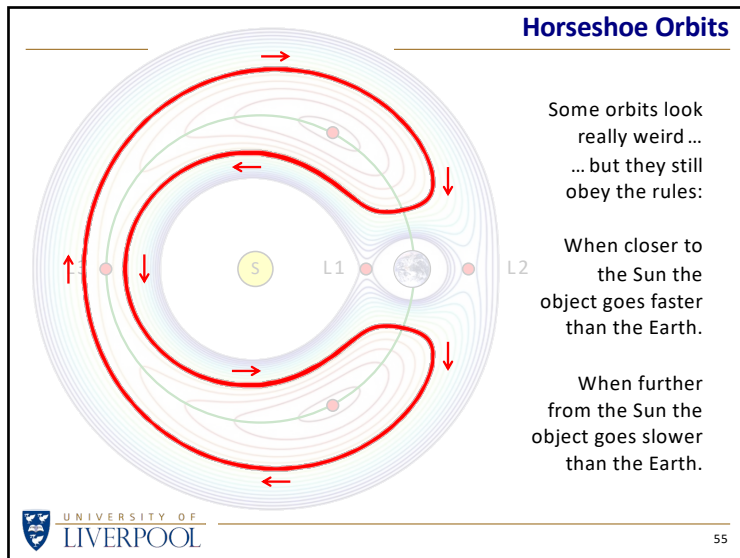
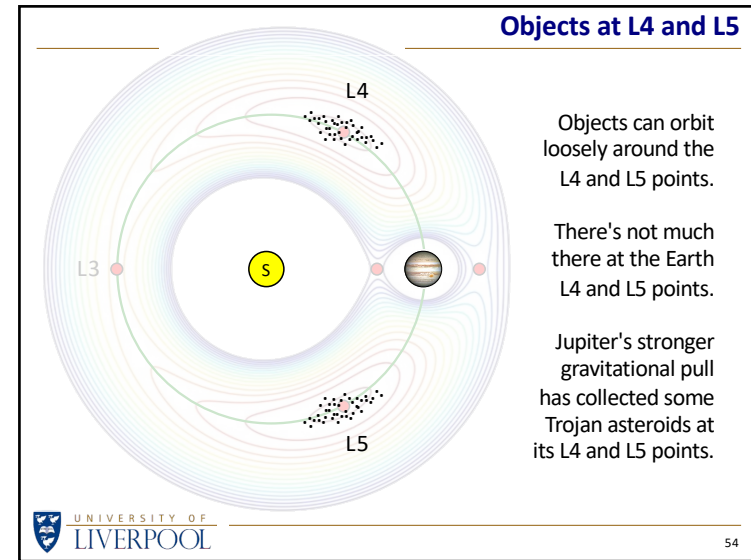
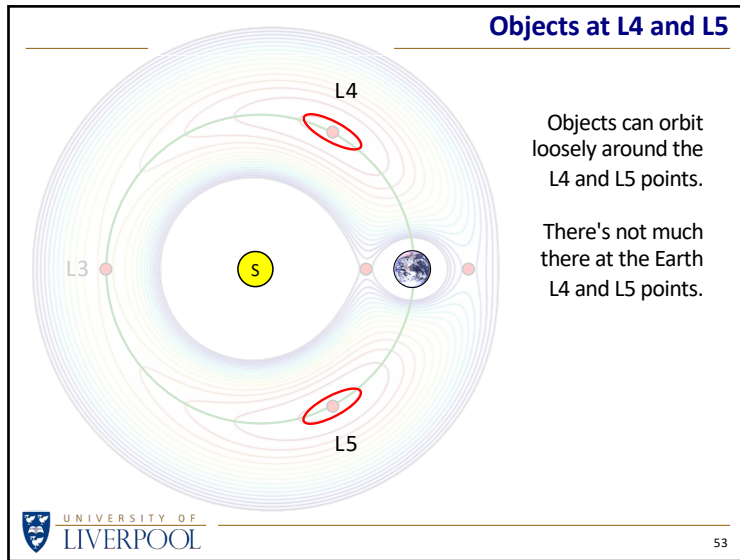
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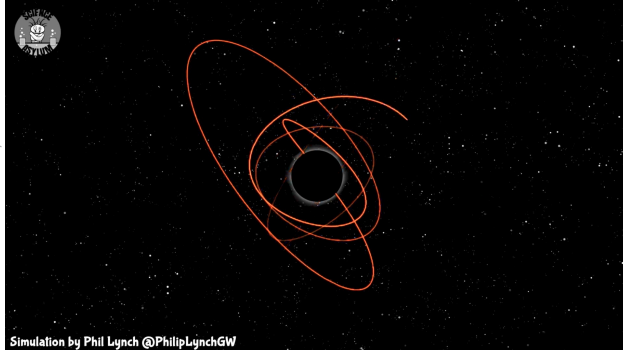
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It's Not Rocket Science!

Open Orbits

...and don't get me started on orbits around black holes



Summary

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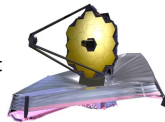
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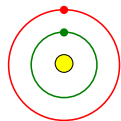
Summary

Why is "rocket science" considered to be so hard?

Yes, there are some objects in the solar system that move in ways that are not, at first sight, intuitive.



Yes, calculating how to put the JWST into orbit around L2 was not trivial (especially given the accuracy achieved).



But the underlying idea is straightforward enough: stronger gravitational pull leads to faster motion. (The Earth moves around the Sun faster than Mars)

That's really all there is to it. The rest is **just** maths.

After all ... it's not rocket science!

