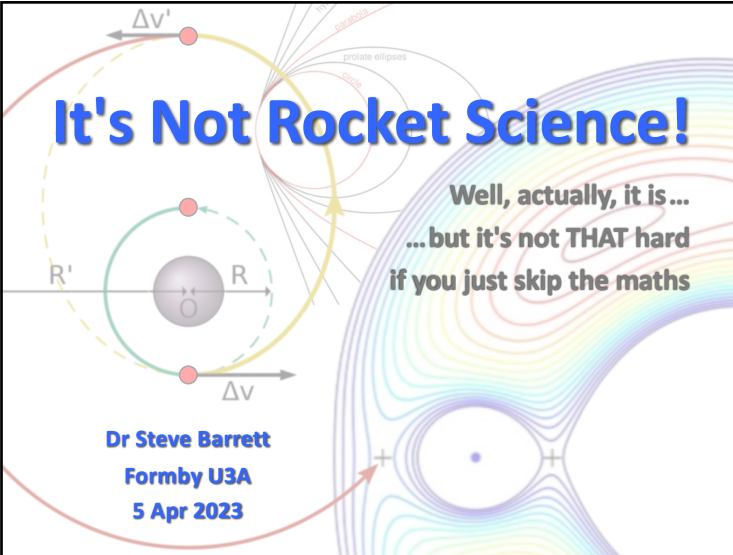


# It's Not Rocket Science!



**It's Not Rocket Science!**

Well, actually, it is...  
...but it's not THAT hard  
if you just skip the maths

Dr Steve Barrett  
Formby U3A  
5 Apr 2023

## It's Not Rocket Science



## Contents

### Rocket Science

What does a rocket do?

### Orbits

Kepler, Newton and Buzz Aldrin  
Circular – elliptical – parabolic – hyperbolic

### Getting From A to B

Earth to Mars  
Gravity assists to the rest of the solar system

### Parking Places

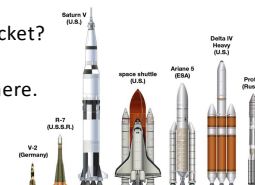
What are Lagrange points all about?

## 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.



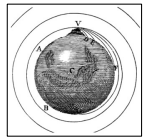
The ISS and the HST are actually still **in** the atmosphere – it's just rather thin up there at an altitude of ~500 km.

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. )

# It's Not Rocket Science!

Newton's Cannonballs



Isaac Newton  
*Principia* 1686

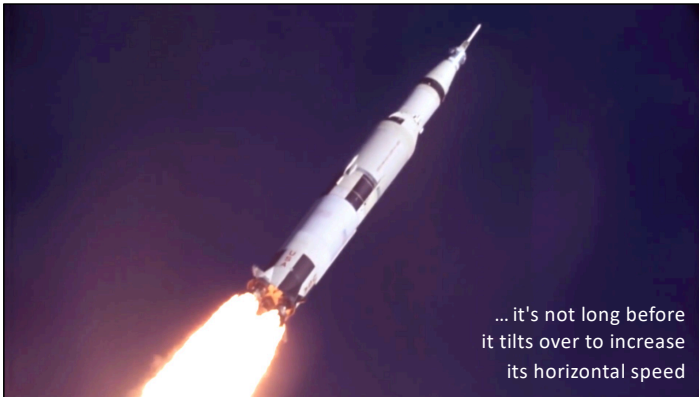
The need for **horizontal** velocity was realised more than 300 years ago

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 ...



It goes vertically up ...  
it comes vertically down

Blue Origin  
New Shepard  
Altitude = 100 km  
Flight time = 10 min

# It's Not Rocket Science!

## Rocket Science

What does a rocket do?

## Orbits

Kepler, Newton and Buzz Aldrin

Circular – elliptical – parabolic – hyperbolic

## Getting From A to B

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## Parking Places

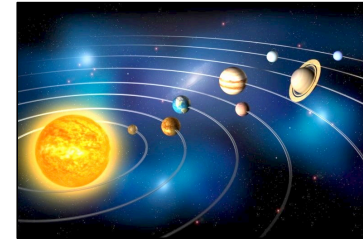
What are Lagrange points all about?

## Orbits

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

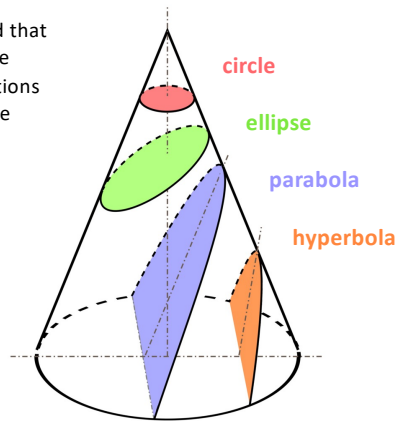
We are all used to the idea of planets in orbit around the Sun, or moons in orbit around their planets.

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



## Conic Sections

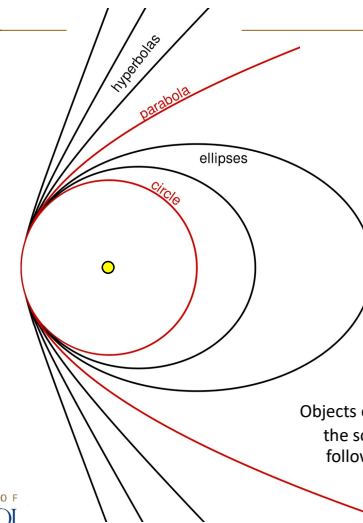
Newton found that orbits have the shapes of sections through a cone



## 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.

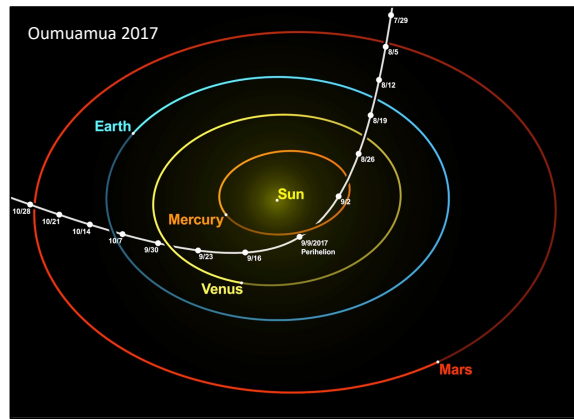


Planets follow closed elliptical orbits, but a comet falling into the solar system from way out in the Oort cloud follows a parabolic path.

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

# It's Not Rocket Science!

## Hyperbolic Orbit



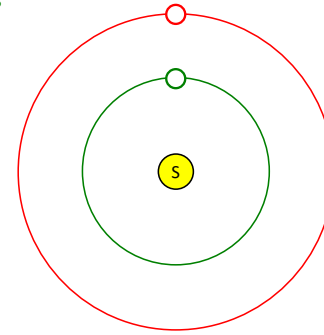
## Orbit Size and Orbit Period

Green planet is closer to Sun

Gravitational pull from Sun is stronger

Planet moves faster to stay in orbit

Shorter period ('year')



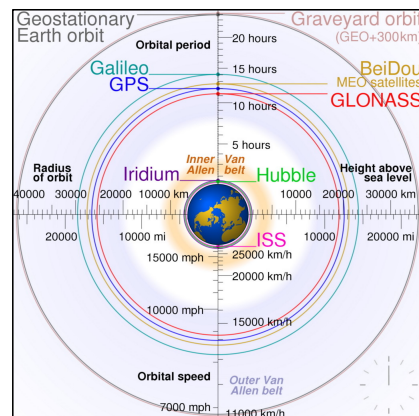
Red planet is further from Sun

Gravitational pull from Sun is weaker

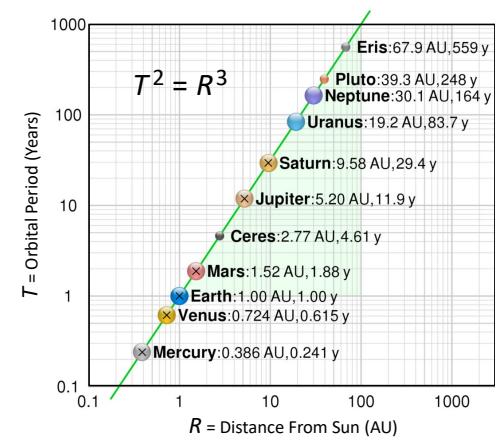
Planet moves more slowly to stay in orbit

Longer period ('year')

## Earth Satellite Orbits




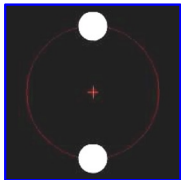
## Planets Orbit the Sun



# It's Not Rocket Science!

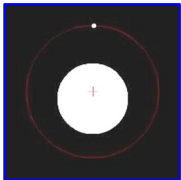
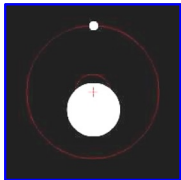
## Circular Orbits

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



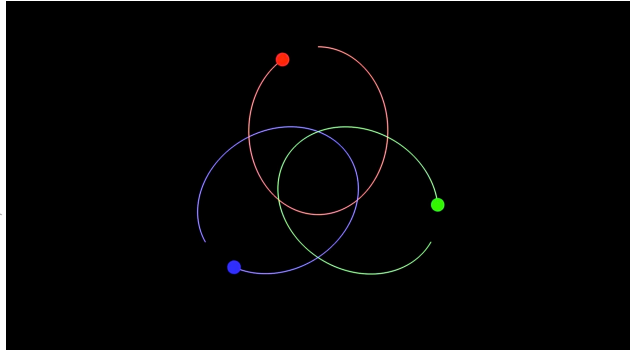
Even a small object (planet) can make a large object (star) wobble – this is how exoplanets can be detected

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## 3-Body Problem

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



Physics Simulations

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

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## Rocket Science

What does a rocket do?

## Orbits

Kepler, Newton and Buzz Aldrin  
Circular – elliptical – parabolic – hyperbolic

## Getting From A to B

Earth to Mars  
Gravity assists to the rest of the solar system

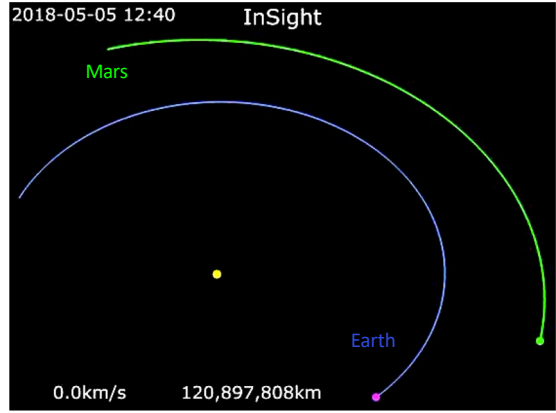
## Parking Places

What are Lagrange points all about?

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## Earth to Mars



2018-05-05 12:40 InSight

Mars

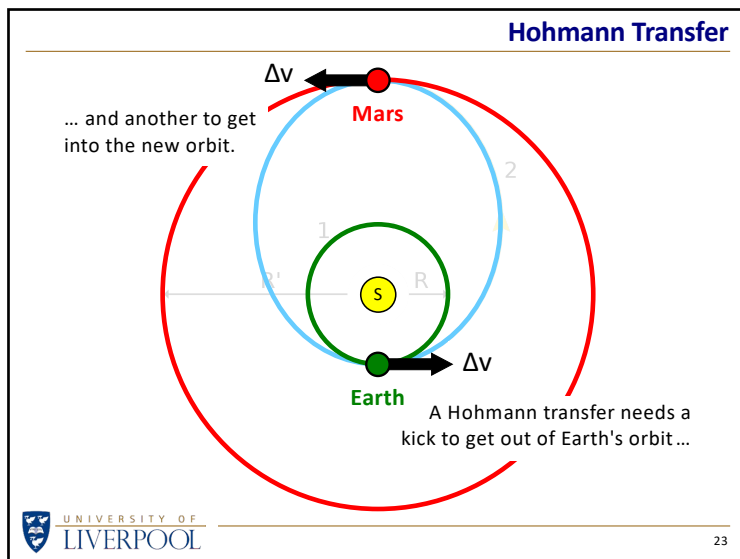
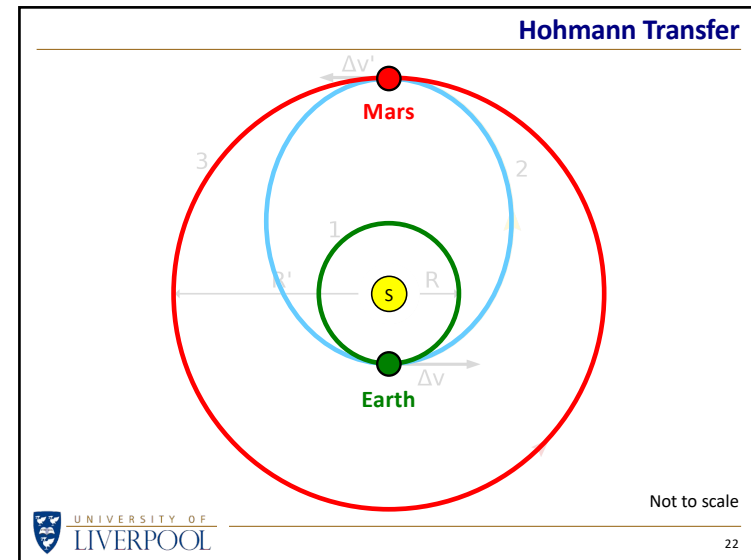
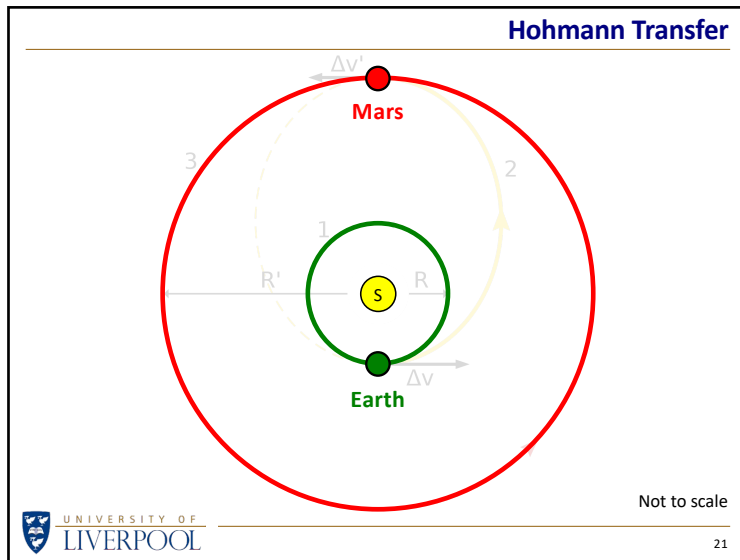
Earth

0.0km/s 120,897,808km

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# It's Not Rocket Science!



**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.

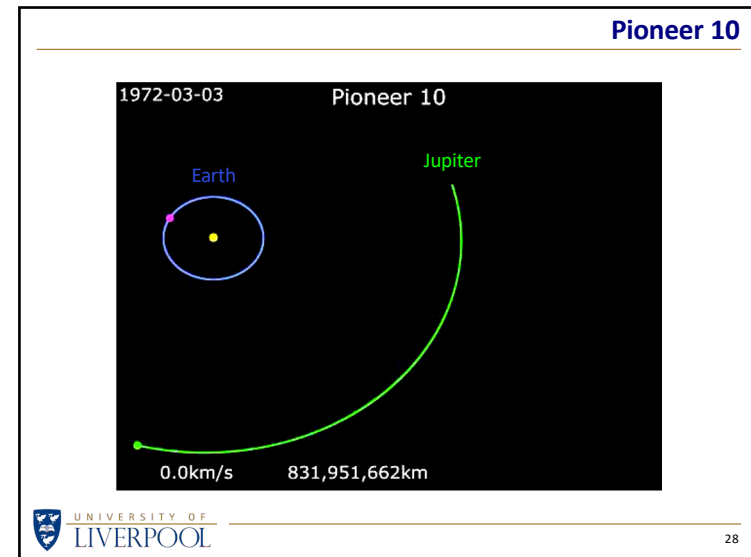
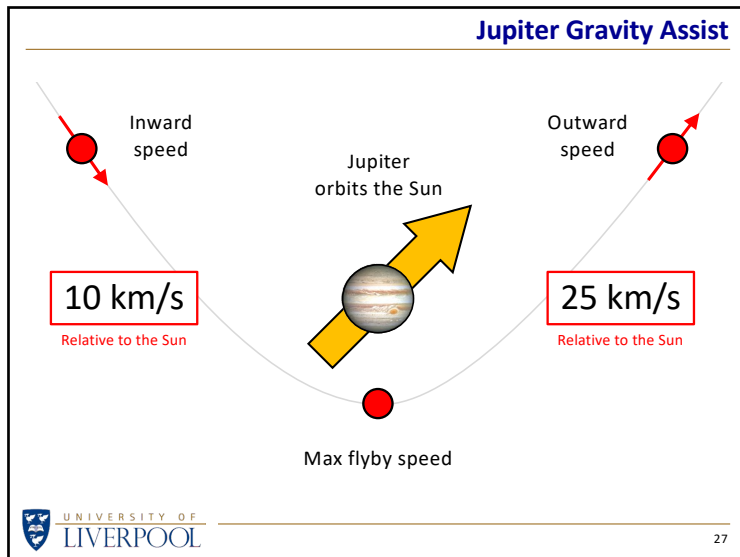
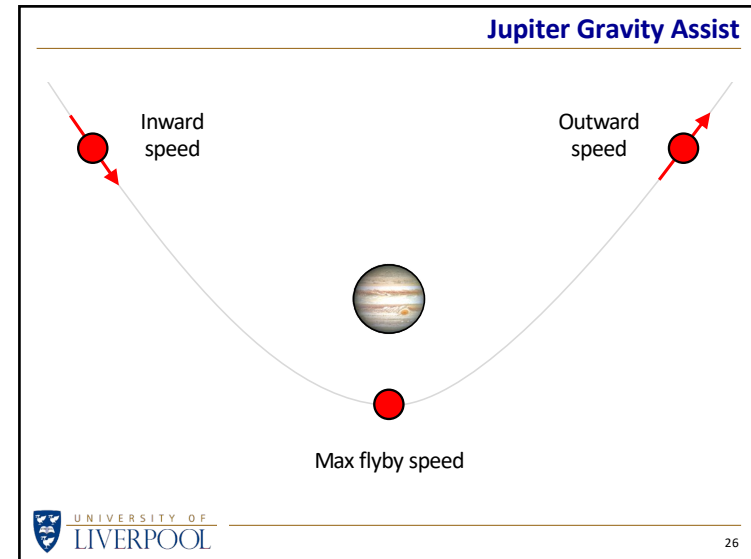
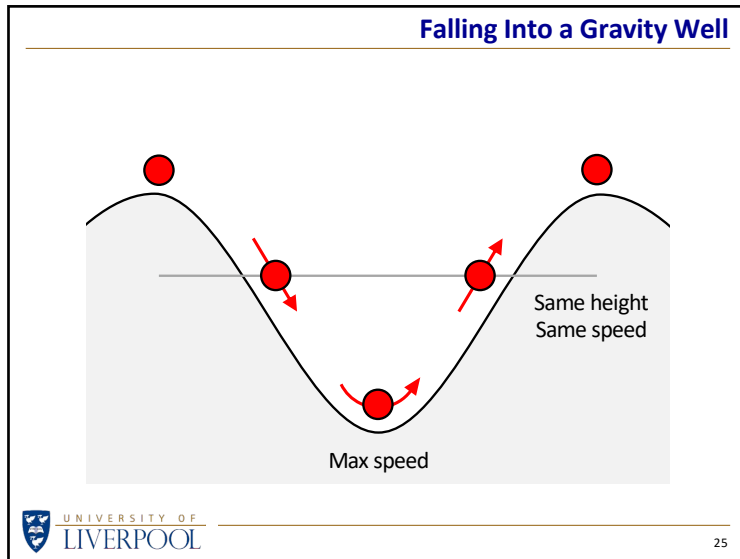
1986-12-08 Voyager 2

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

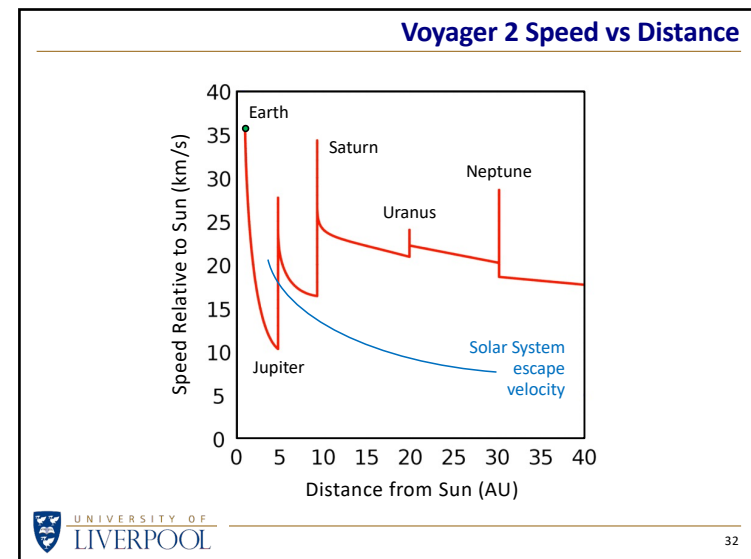
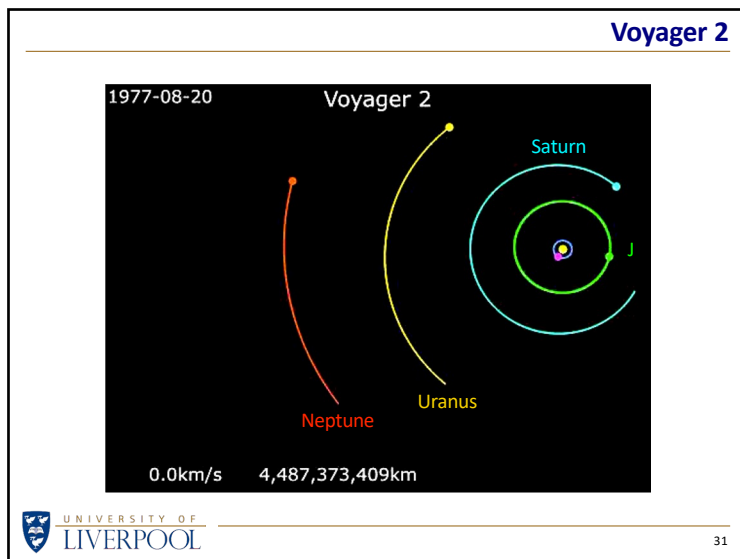
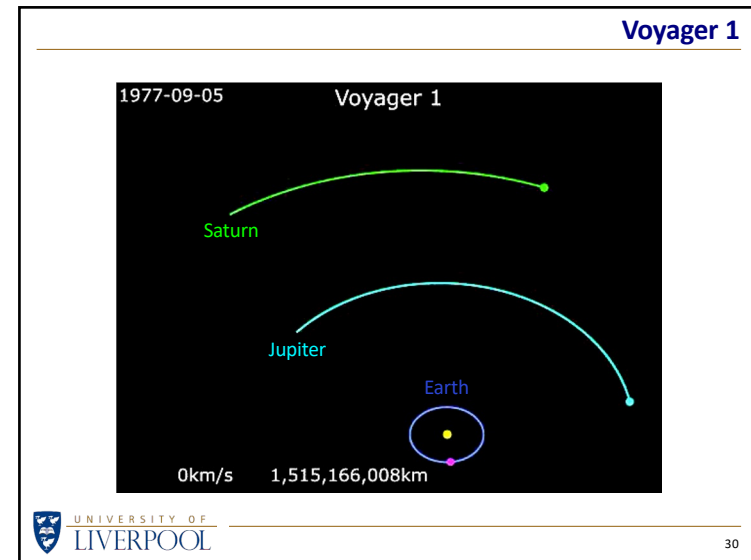
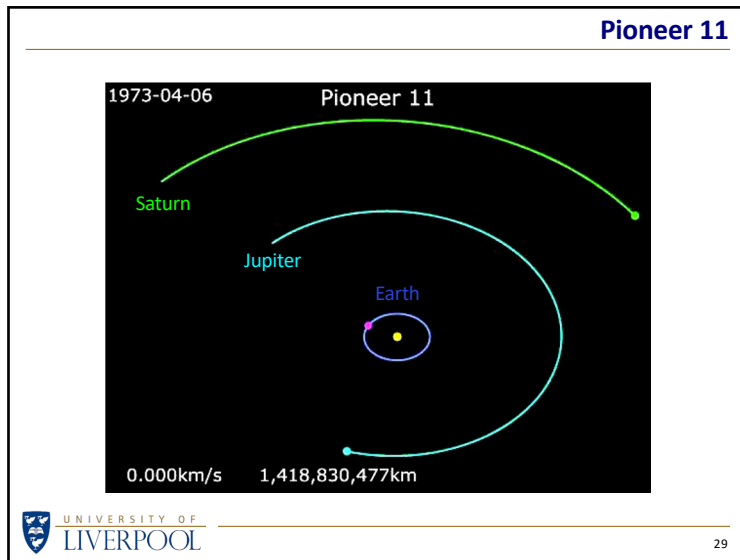
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# It's Not Rocket Science!



# It's Not Rocket Science!



# It's Not Rocket Science!

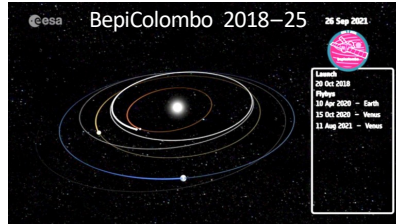
## Gravity Assists

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.

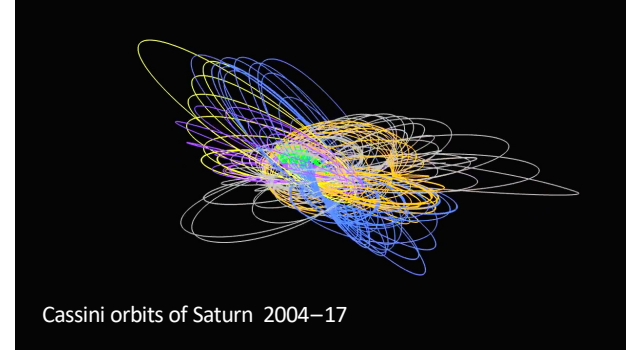
A planet flyby can be used to *lose* speed as a spacecraft 'falls' into the inner solar system.

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

## Rocket Science

What does a rocket do?

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Kepler, Newton and Buzz Aldrin  
Circular – elliptical – parabolic – hyperbolic

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What are Lagrange points all about?

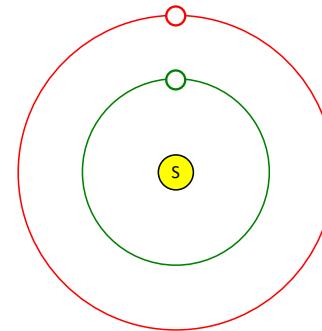
## Orbit Size and Orbit Period

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’)

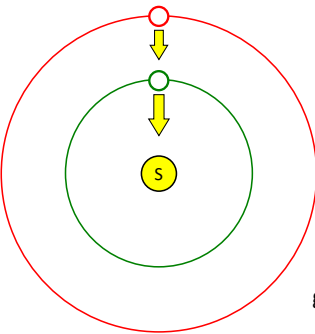
# It's Not Rocket Science!

## 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.

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## Lagrange Points

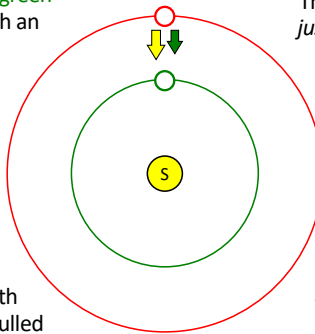
Let's assume that **green** is planet **Earth** with an orbital period of exactly 1 year.

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.

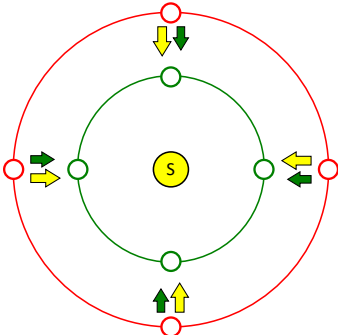
That would mean that the **red** object would orbit the Sun 'with' the **Earth**.



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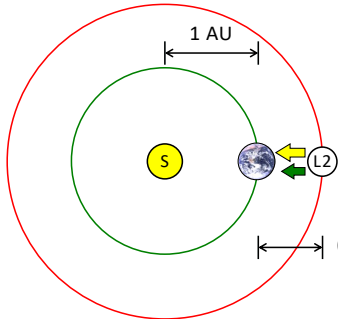
## Lagrange Point L2



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## Lagrange Point L2



1 AU

0.01 AU

Not to scale

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# 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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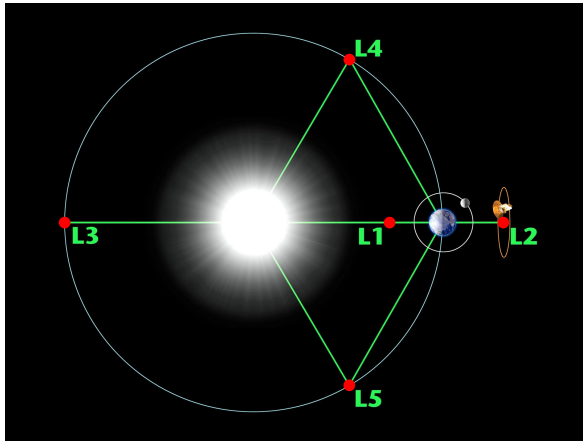
Just solve for  $r$ . Simple!

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

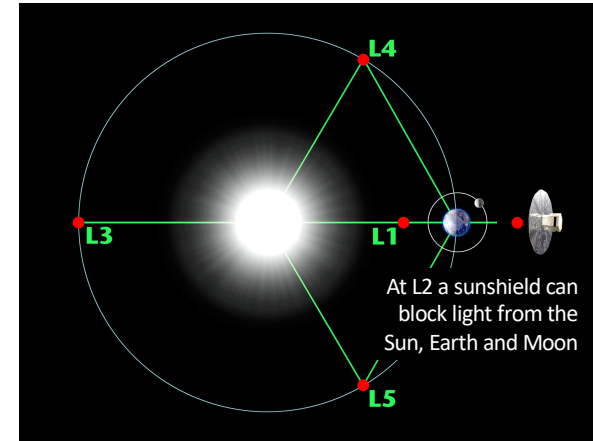
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# It's Not Rocket Science!

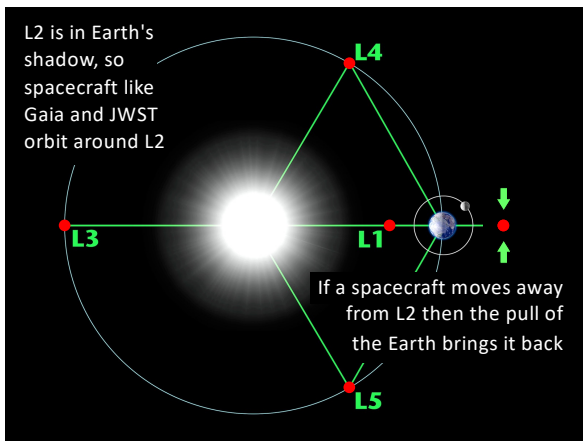
Lagrange Points 1–5



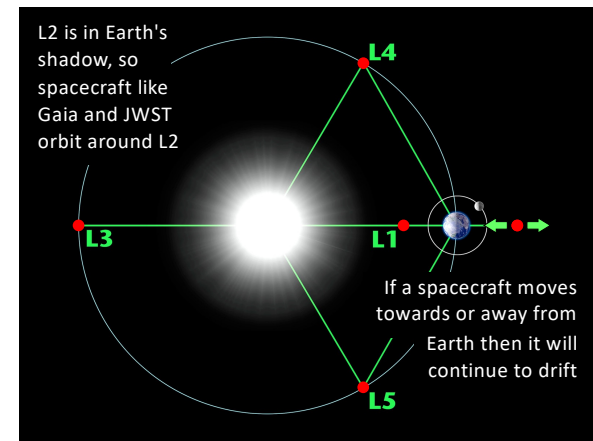
Why Park at L2?



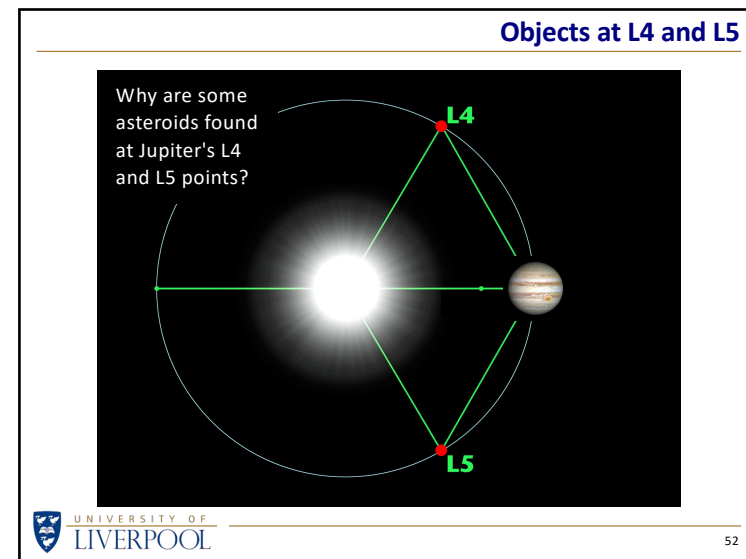
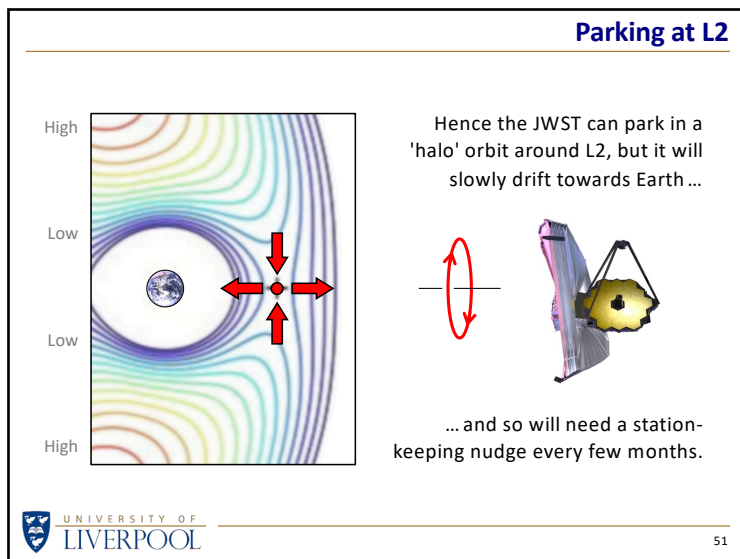
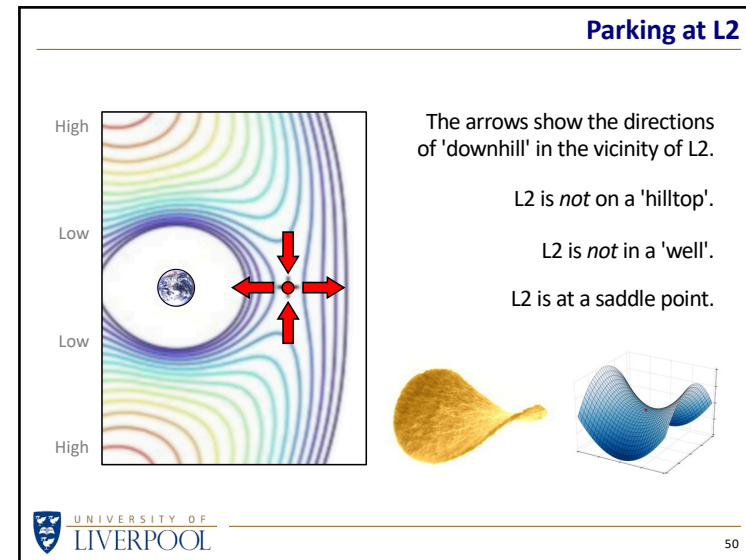
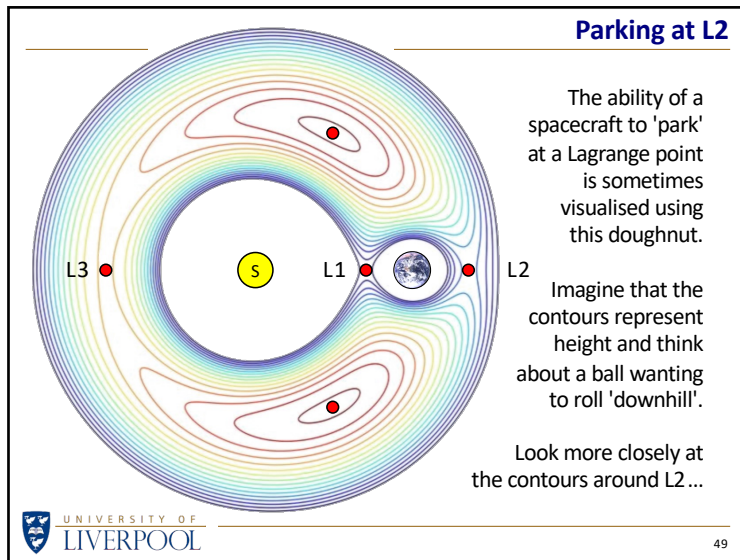
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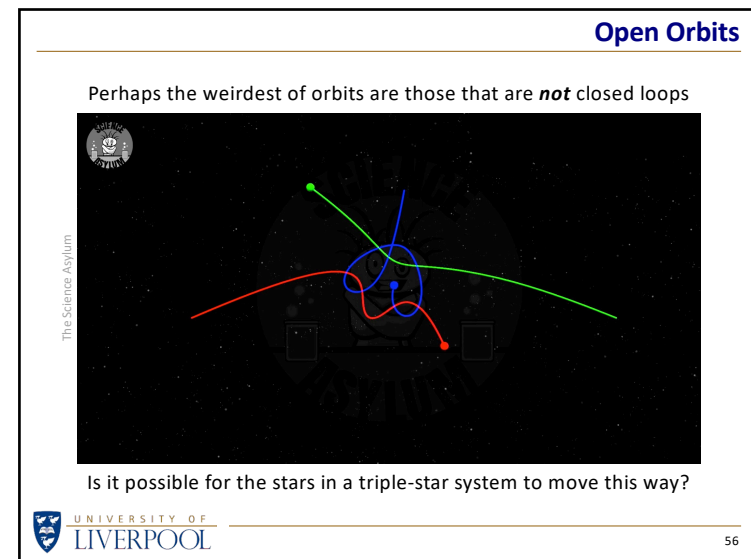
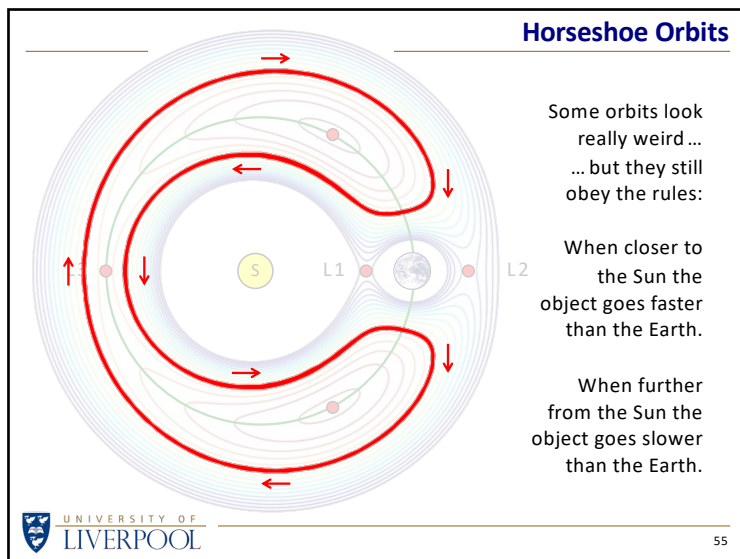
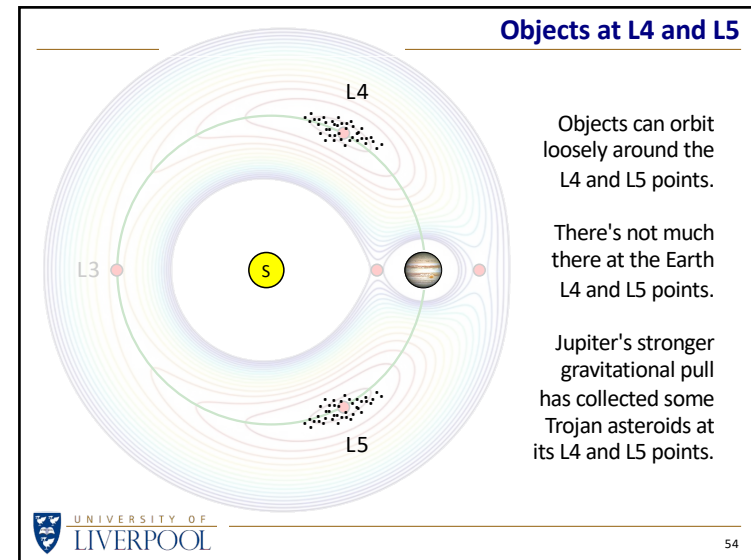
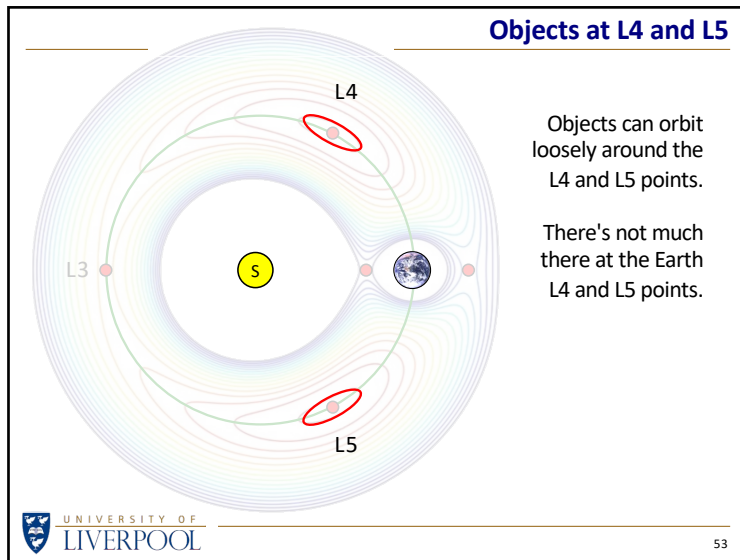
Why Park at L2?



# It's Not Rocket Science!



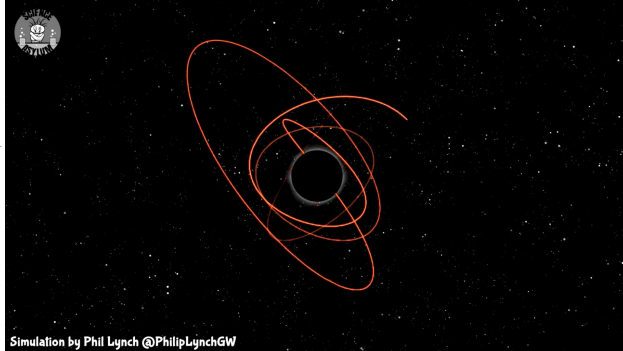
# It's Not Rocket Science!



# It's Not Rocket Science!

## Open Orbits

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



## Summary

### Rocket Science

What does a rocket do?

### Orbits

Kepler, Newton and Buzz Aldrin

Circular – elliptical – parabolic – hyperbolic

### Getting From A to B

Earth to Mars

Gravity assists to the rest of the solar system

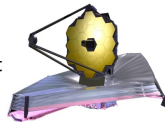
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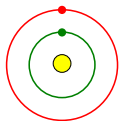
## Summary

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!

