The Physics of Science Fiction:
Wormholes to Warp Drive

The Science of Spacetime:

A Physicists Guide to the Galaxy

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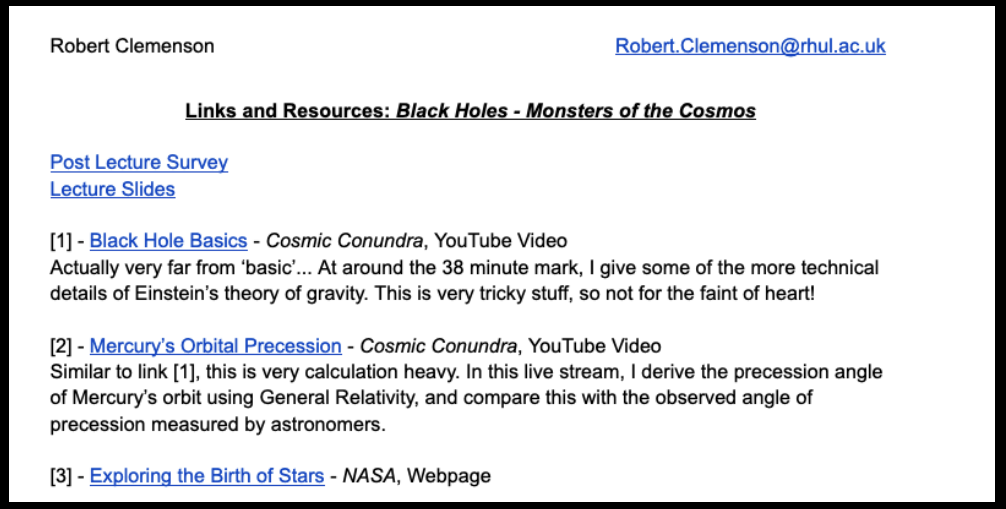
Southend Planetarium – 04.07.2026

Lecture Live Links (LLL)

Throughout the lecture, I will make a couple of references to previous talks, livestreams, and other online materials.

If you would like to check these out after the talk (or view recordings of previous lectures), please feel free to scan the QR code shown here.



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Links and Resources: *Black Holes - Monsters of the Cosmos*

Post Lecture Survey
Lecture Slides

[1] - Black Hole Basics - *Cosmic Conundra*, YouTube Video
Actually very far from 'basic'... At around the 38 minute mark, I give some of the more technical details of Einstein's theory of gravity. This is very tricky stuff, so not for the faint of heart!

[2] - Mercury's Orbital Precession - *Cosmic Conundra*, YouTube Video
Similar to link [1], this is very calculation heavy. In this live stream, I derive the precession angle of Mercury's orbit using General Relativity, and compare this with the observed angle of precession measured by astronomers.

[3] - Exploring the Birth of Stars - *NASA*, Webpage

Scan the QR code above, or simply click the QR code in the PDF of the lecture slides.

Lecture Overview

- The Universal Speed Limit
- Travelling through Space
- Travelling through Time
- Mass Destruction
- Q&A (**Questions welcome throughout the talk!**)

Part I – Universal Speed Limit

The Universal Speed Limit

The Speed of Light is a constant.

No matter who you ask, where you are, how you look at it, or how fast *you* move.

Moreover… *Nothing* can travel faster than the speed of light.

This is a huge problem for Science Fiction writers…

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This is a huge problem for Science Fiction writers…

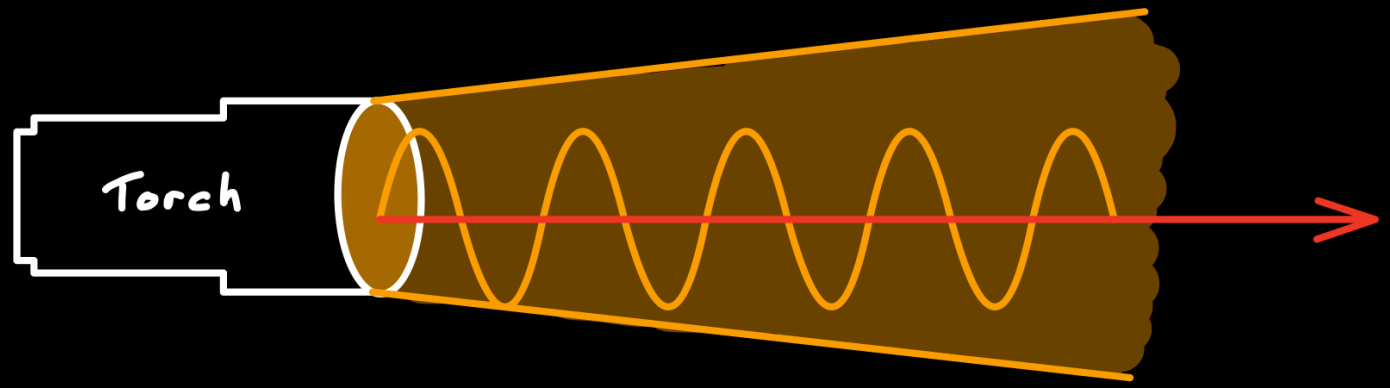
1. It limits distances that can be travelled within a human lifetime.
2. It limits the speed of communication across even quite small astronomical distances.

‘Light Years’

Light is fast

A *light-year* is not a duration of time, but a unit of distance.

One light-year (abbreviated to LY) is the distance travelled by light moving through empty space in one year.



Speed = 300,000,000 Metres per second

or 670,000,000 Miles Per hour

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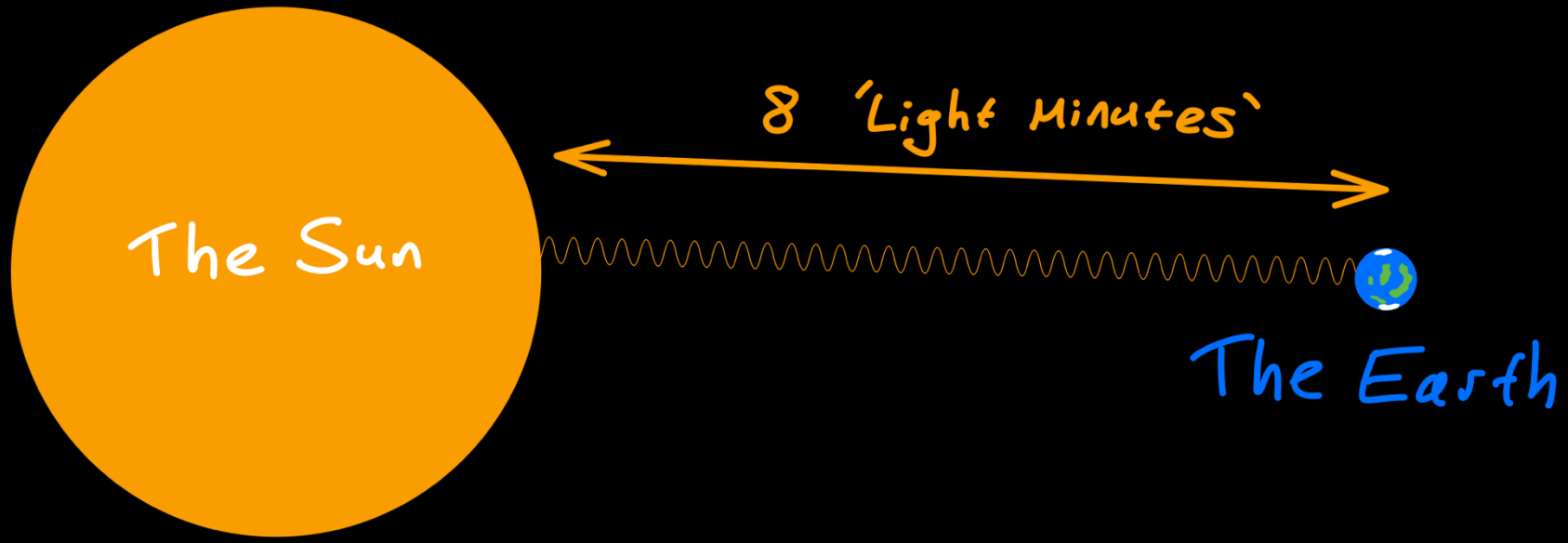
$$1\ LY = 300,000,000 \times (365 \times 24 \times 60 \times 60)$$

$$= 9,500,000,000,000,000 \text{ Metres}$$

$$\underline{\text{or}} \quad 5,900,000,000,000 \text{ Miles}$$

[590 Billion Miles]

‘Light Minutes’



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$\Delta t = 8$ minutes

Though not a common unit, a *light-minute* can be defined as the distance travelled by light in a single minute.

Proxima Centauri

The star closest to our own solar system, is Proxima Centauri.

This is a Red Dwarf Star, with several planets orbiting around it.

Despite being the star nearest to our solar system, Proxima Centauri is still **4.25 Ly** from the Earth.

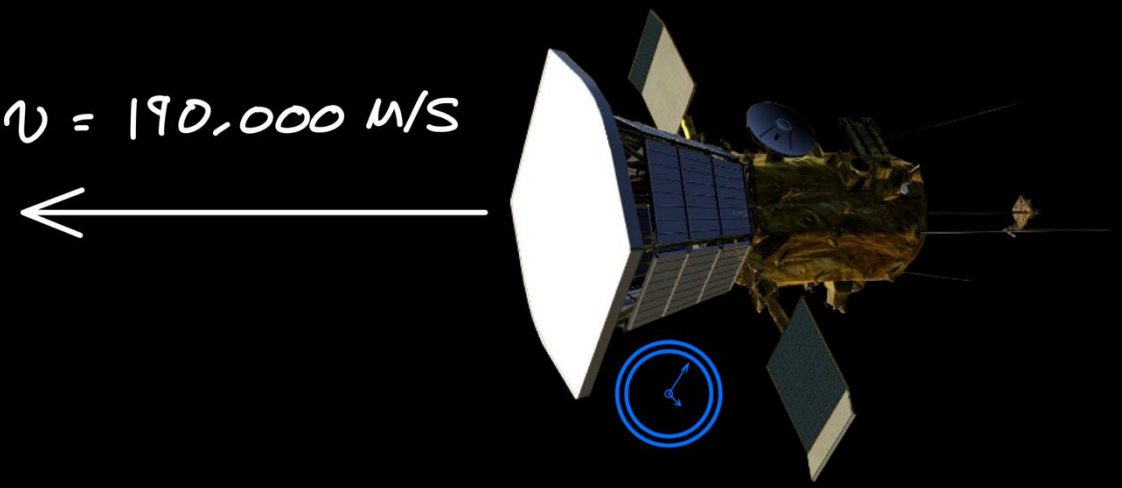
Part II – Travelling through Space

Travelling through Space

Crossing the immense distances of our cosmos requires some imagination on the part of Science Fiction writers.

The fastest moving object ever created by humans, is the Parker Solar Probe.

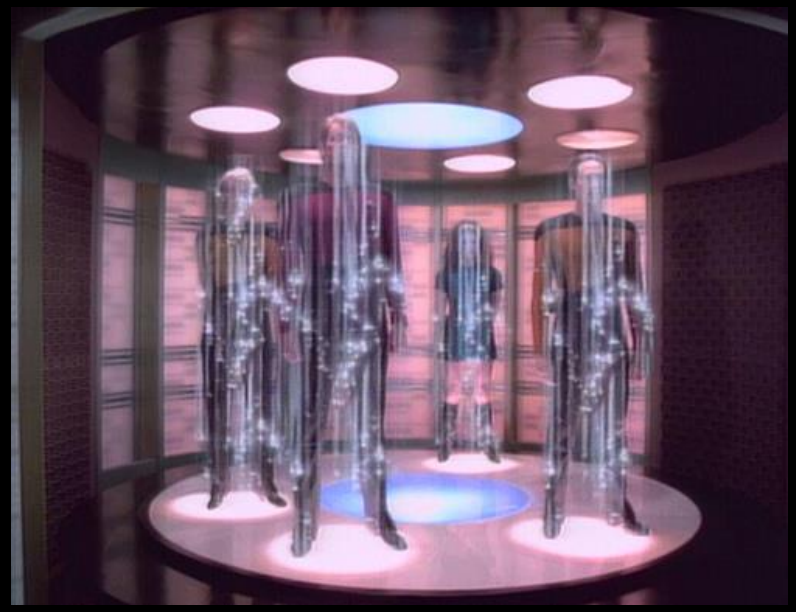
Even at the whopping **190,000** meters per second of the of the Parker Solar Probe, it would still take over **7000 years** to reach Proxima Centauri (our nearest neighboring star).



Breaking the Speed Limit…

In Science Fiction, these distances are traversed in a number of ways, including:

1. Warp Drive / Hyperdrive
2. Wormholes
3. Teleportation



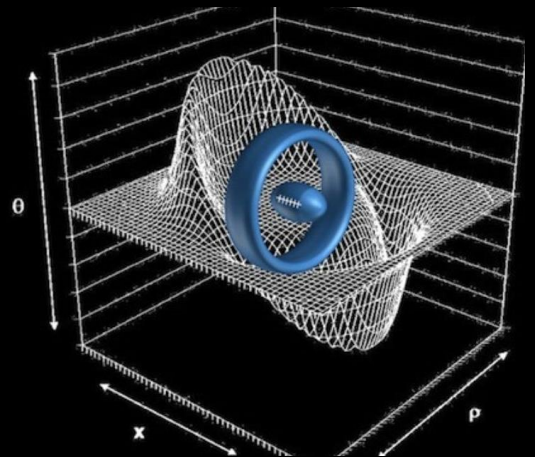
The Alcubierre ‘Warp Drive’

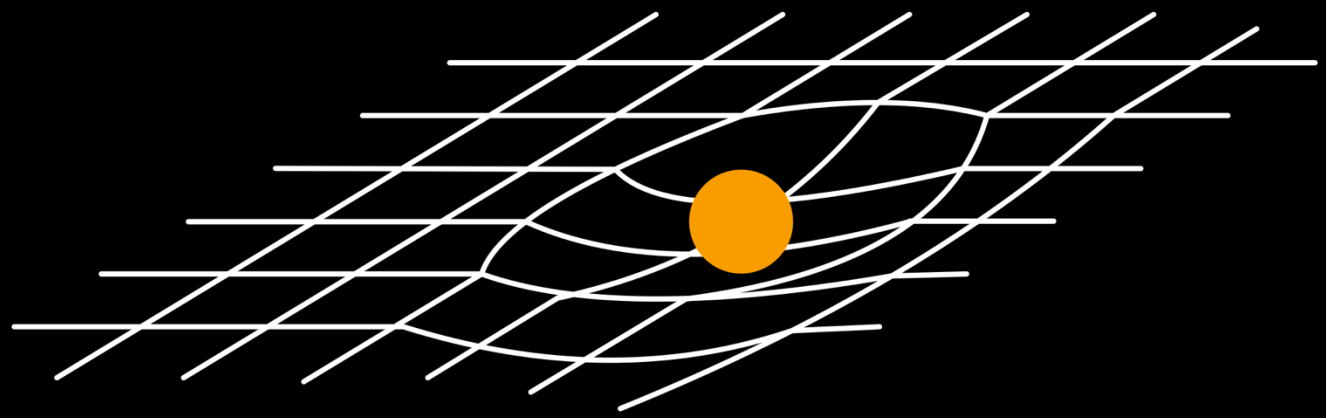
In 1994, Miguel Alcubierre allowed his imagination to wander while watching Star Trek, and laid the foundations for the serious scientific study of faster-than-light travel.

Miguel Alcubierre.

The Alcubierre ‘Warp Drive’

By imagining a configuration of space time, that would allow an observer to ‘surf’ the wake of a super-luminal bubble of space time, Alcubierre showed that faster than light travel is not explicitly forbidden by Einstein’s equations of gravity.





$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Space-time Curvature

Speed of Light

Matter

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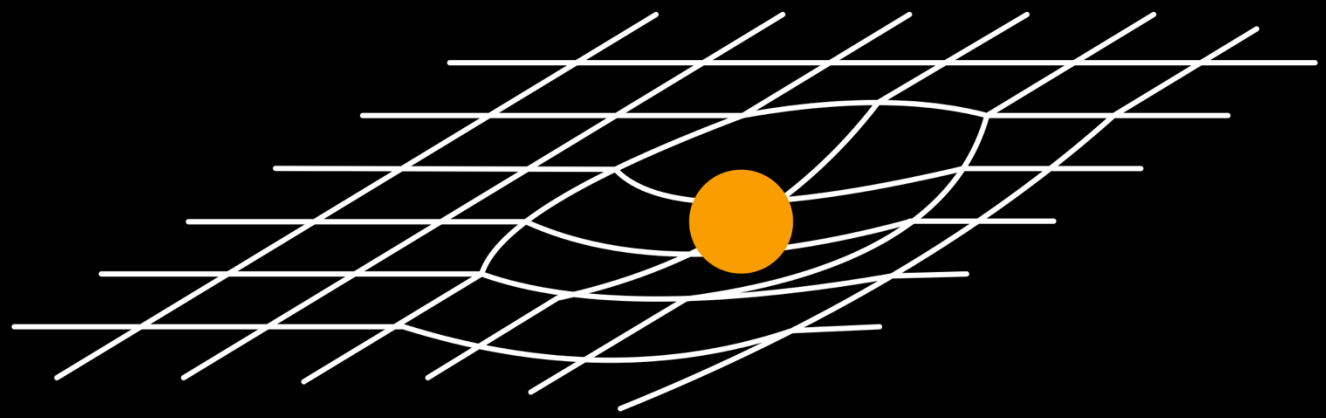

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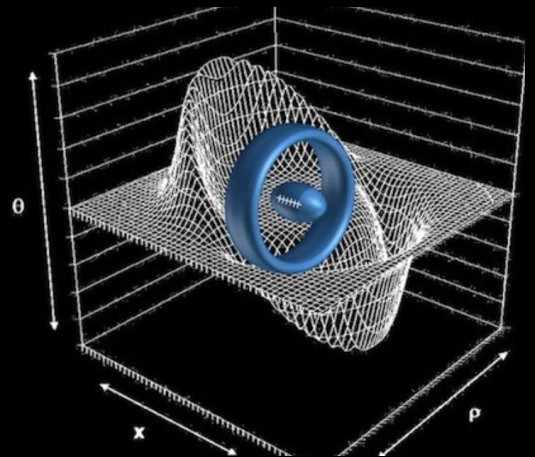
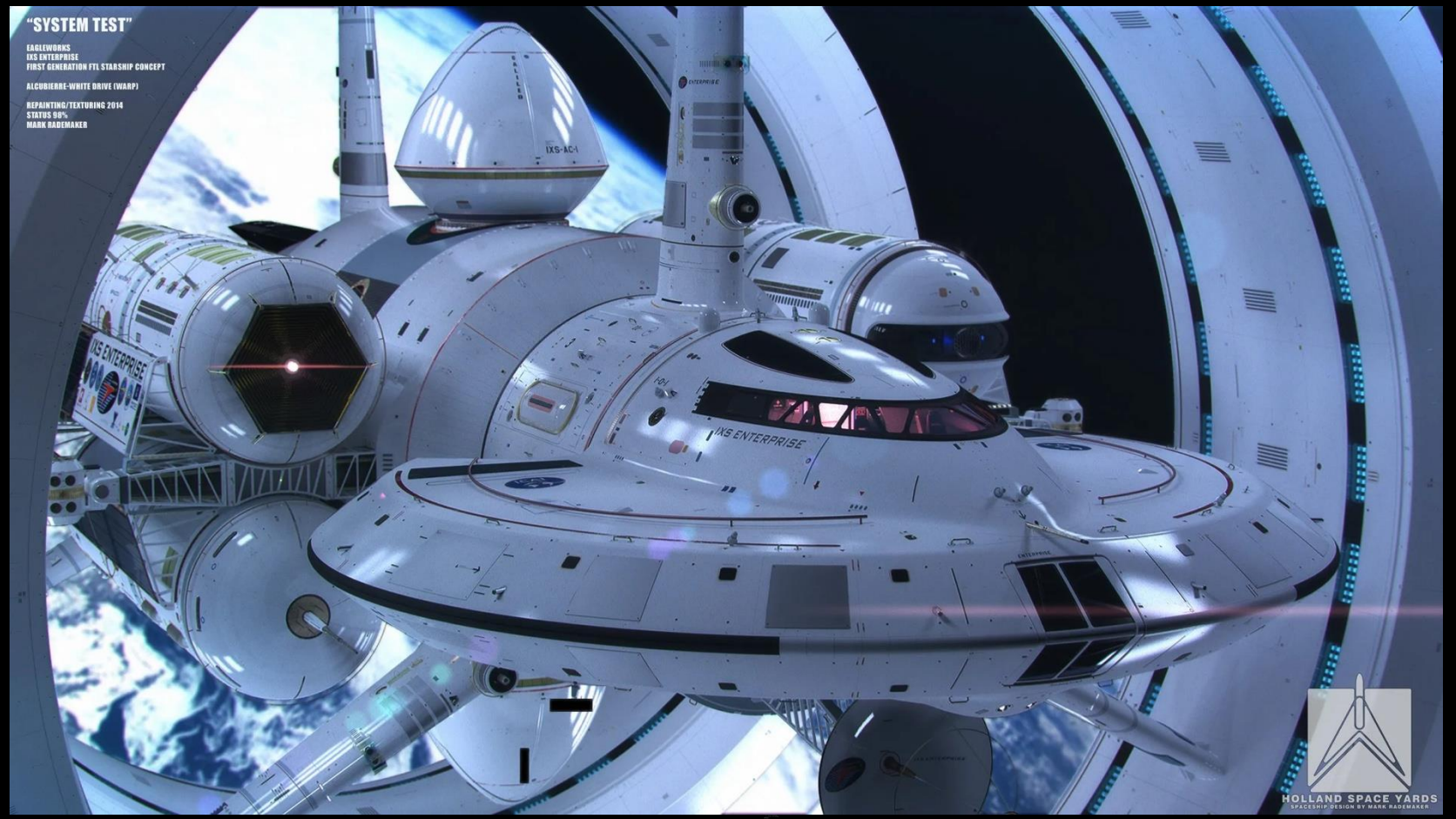


This does not mean other laws of physics won’t kill Alcubierre’s theory!

The Alcubierre ‘Warp Drive’



Artists impression of how a futuristic warp ship might look.

Exotic Matter

On big problem with the Alcubierre Drive, is that it requires *exotic matter* to produce the distortion of space-time required to form and sustain such a '*Warp Bubble*'.

In this context *exotic matter* refers to substances with a negative mass, or a negative energy density.

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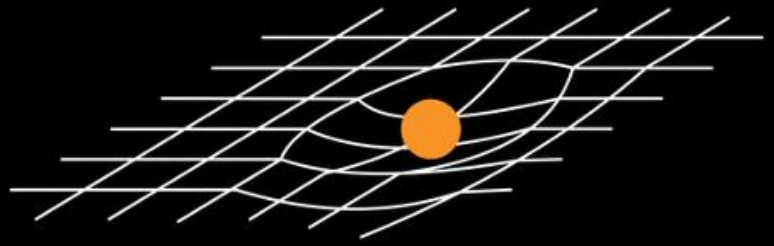

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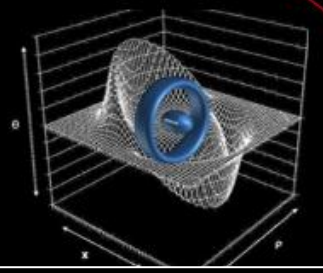

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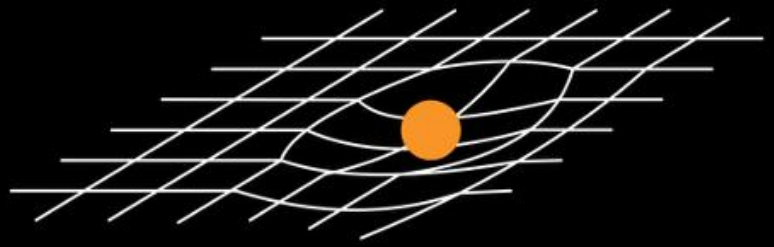

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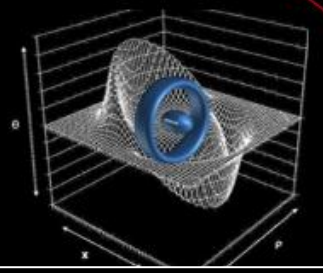
Space-time Curvature — Speed of Light — Matter



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But does *exotic matter* exist??

Or is this the nail in the coffin for Alcubierre's Drive?

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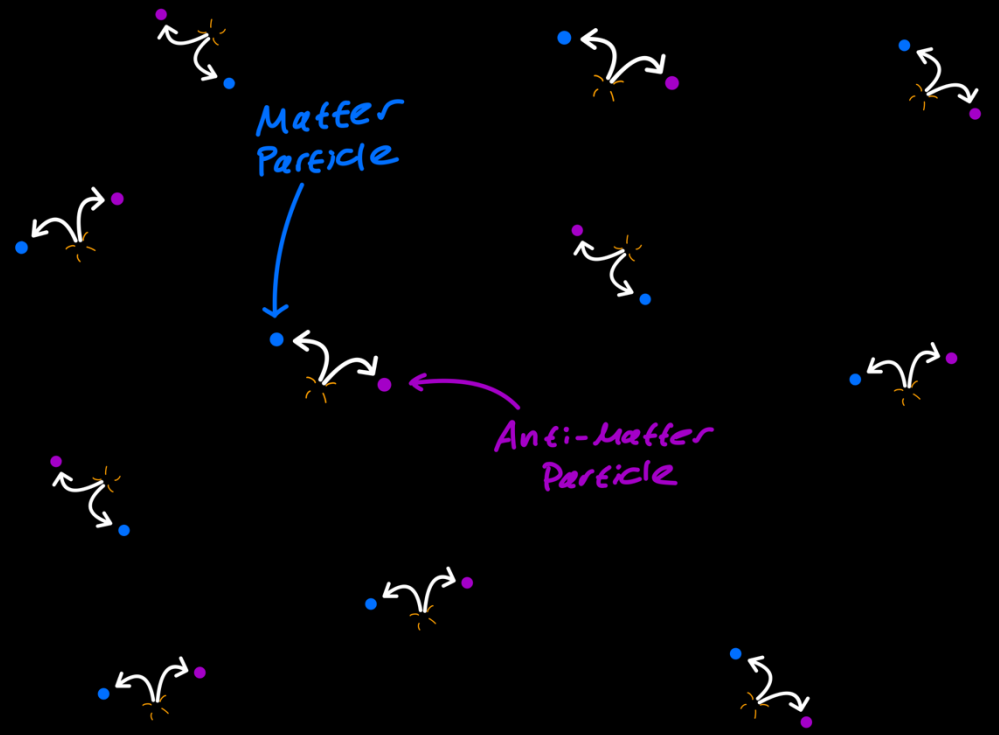
Not in any useful sense, that we know of…

The closest phenomena we know of, which is a result of Quantum Mechanics, is the so called '*Casimir Energy*' present in the vacuum, detectable by measuring the force between two uncharged parallel plates.



Particles pop into existence and dissolve back into the vacuum a short time later.

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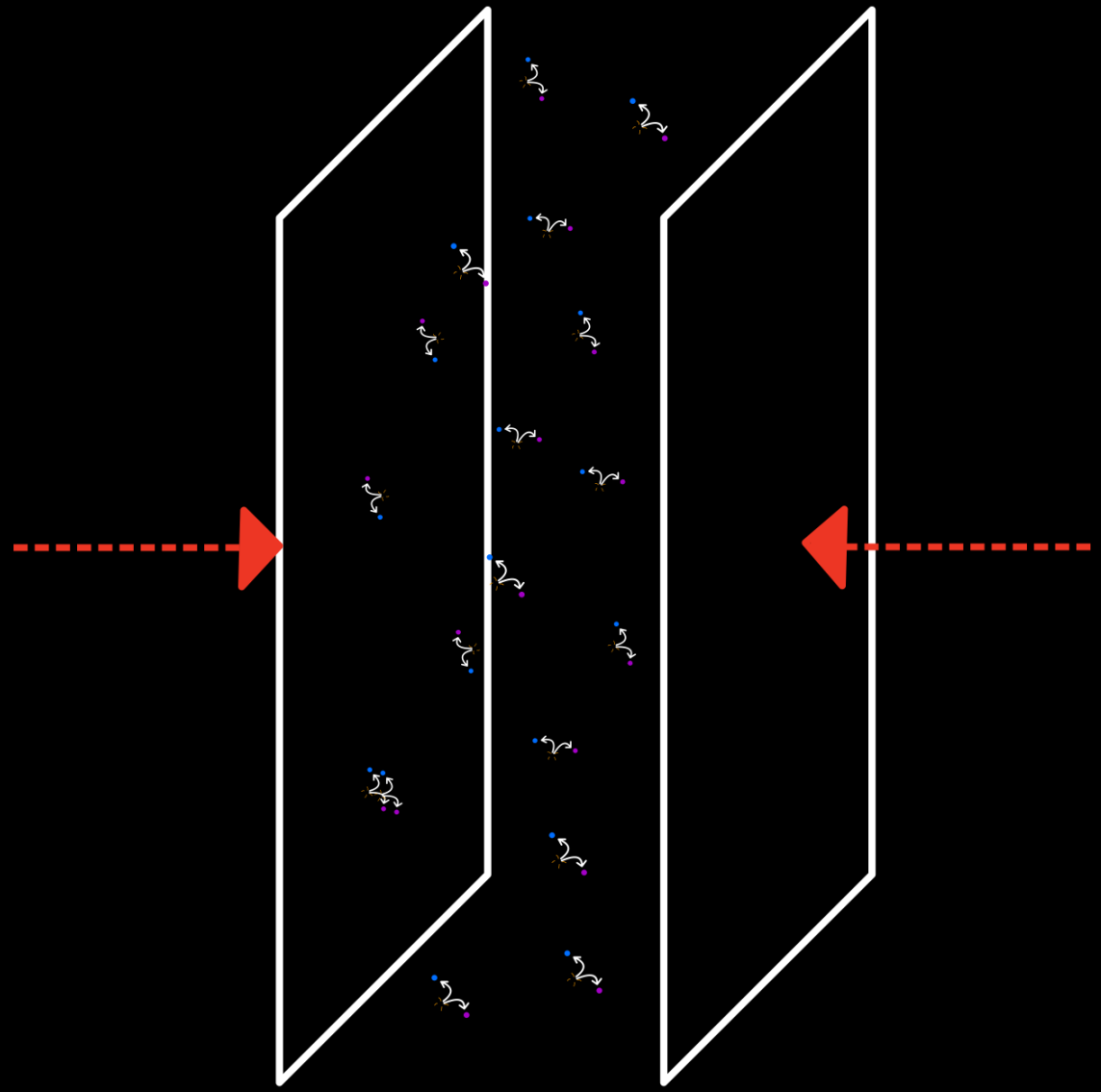

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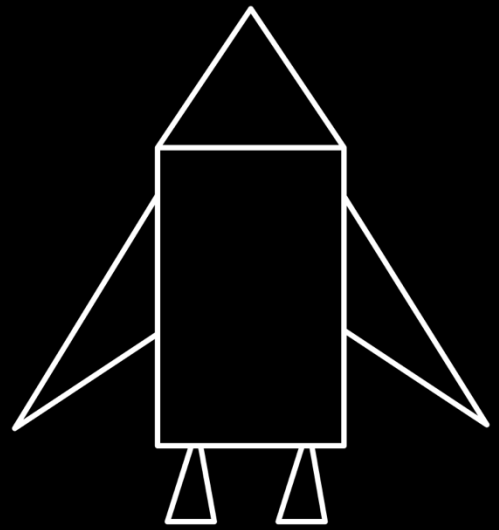
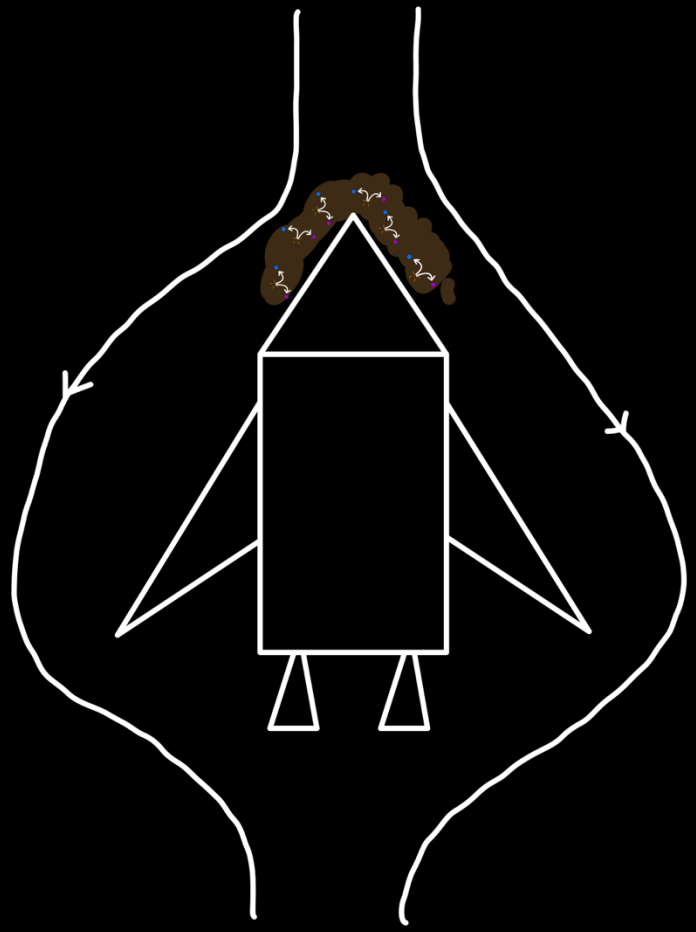
Other Problems…

Suppose we could build such a craft, there are some good reasons you might not want to do so!…



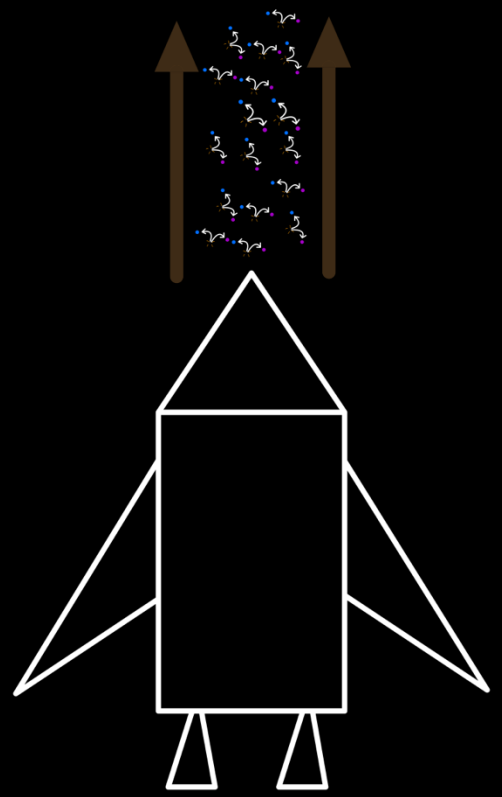
Other Problems…

Due to the super-relativistic speeds of the craft, a collection of very high energy particles would accumulate at the front of the '*warp bubble*'.



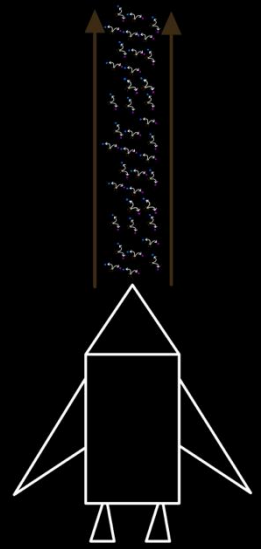
Other Problems…

When the craft decelerates, these high energy particles would continue to move…



Other Problems…

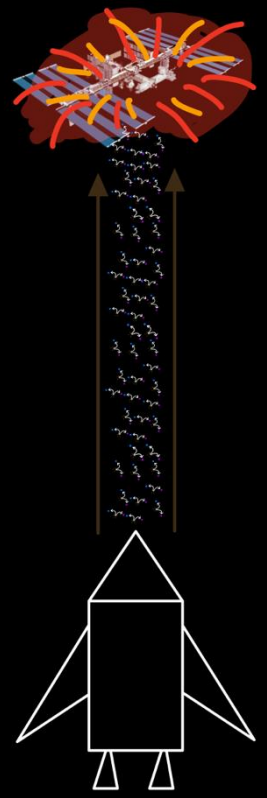
This deadly beam of paired matter & anti-matter particles would propagate forwards as a deadly beam of energy…



Other Problems…

Likely destroying what lay in its path….

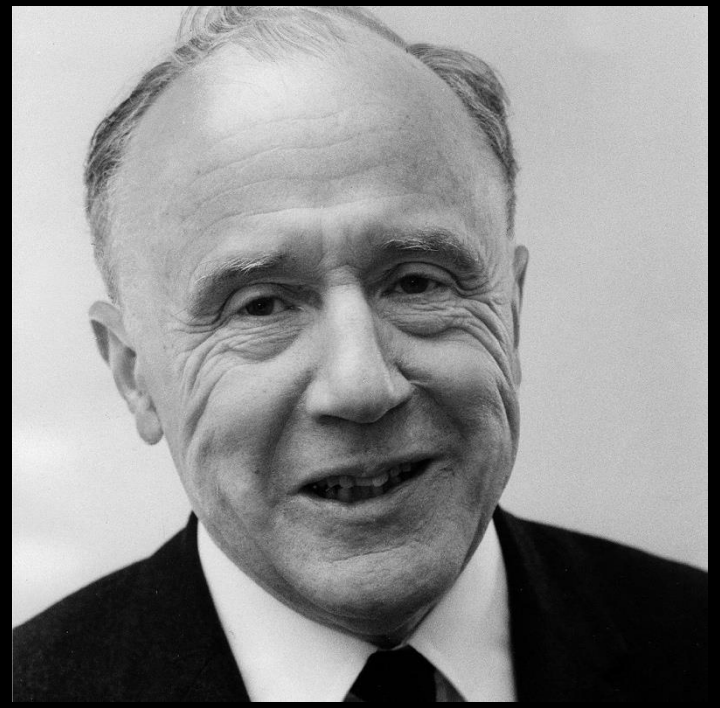
Not the best introduction to other species!



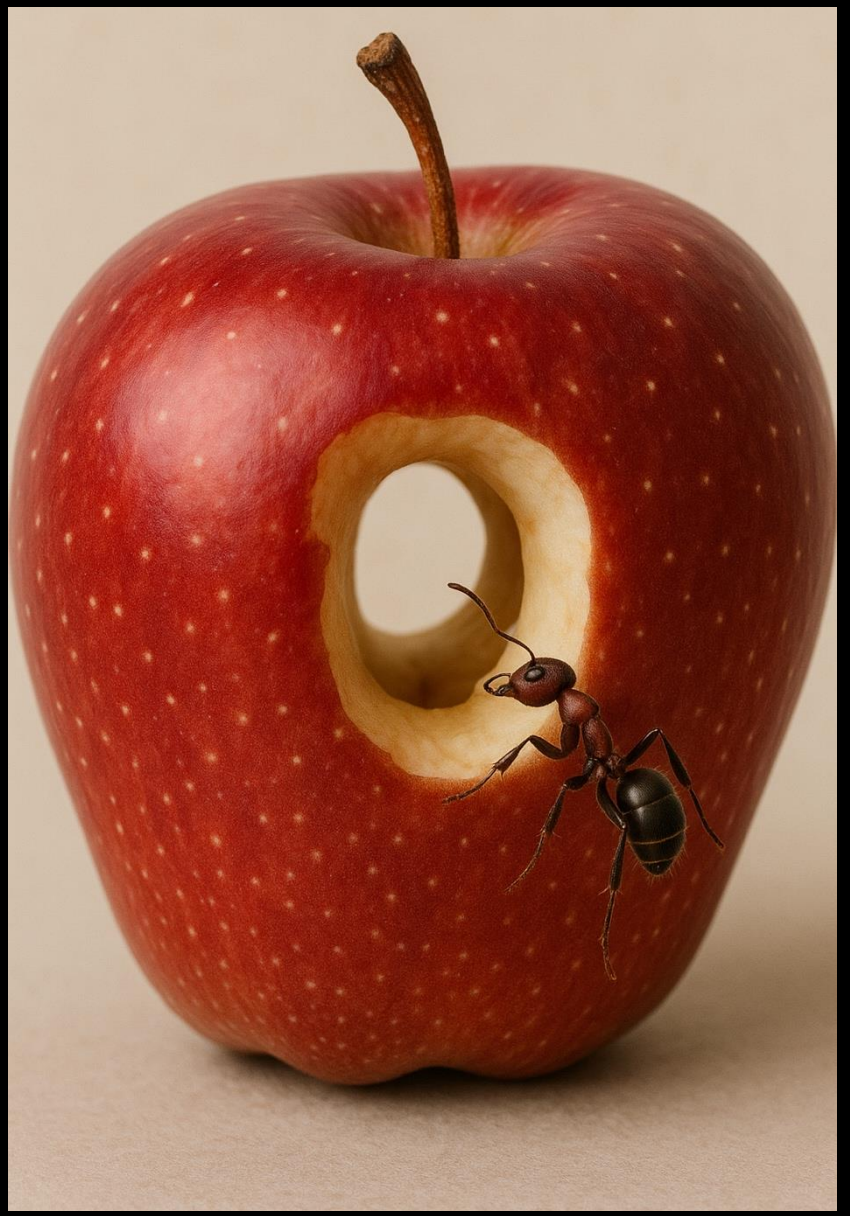
Wormholes

John Wheeler was the first to coin the term ‘*Wormhole*’.

The origin of this term comes from the analogy of an insect, wishing to cross from one side of an apple to the other. If there is a literal *worm hole* connecting the two sides, this provides a shorter path for the ant.

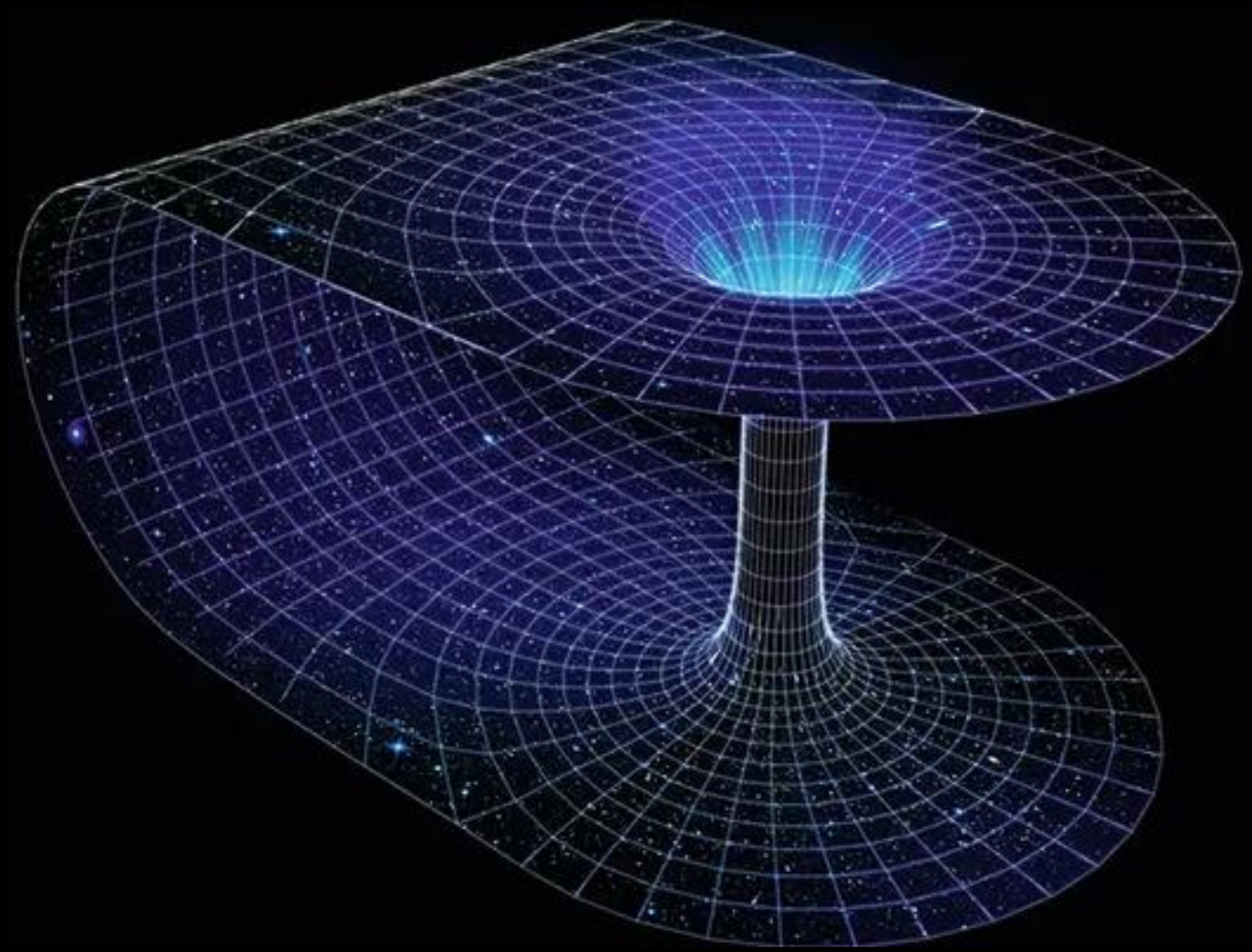


John Archibald Wheeler



Wormholes

In analogy to the literal *worm holes* found in apples (the most consequential fruit in the history of science), astrophysical wormholes would provide shortcuts from one point in 4D space time, to another point in 4D space time by ‘cutting through’ some higher dimensional bulk space.



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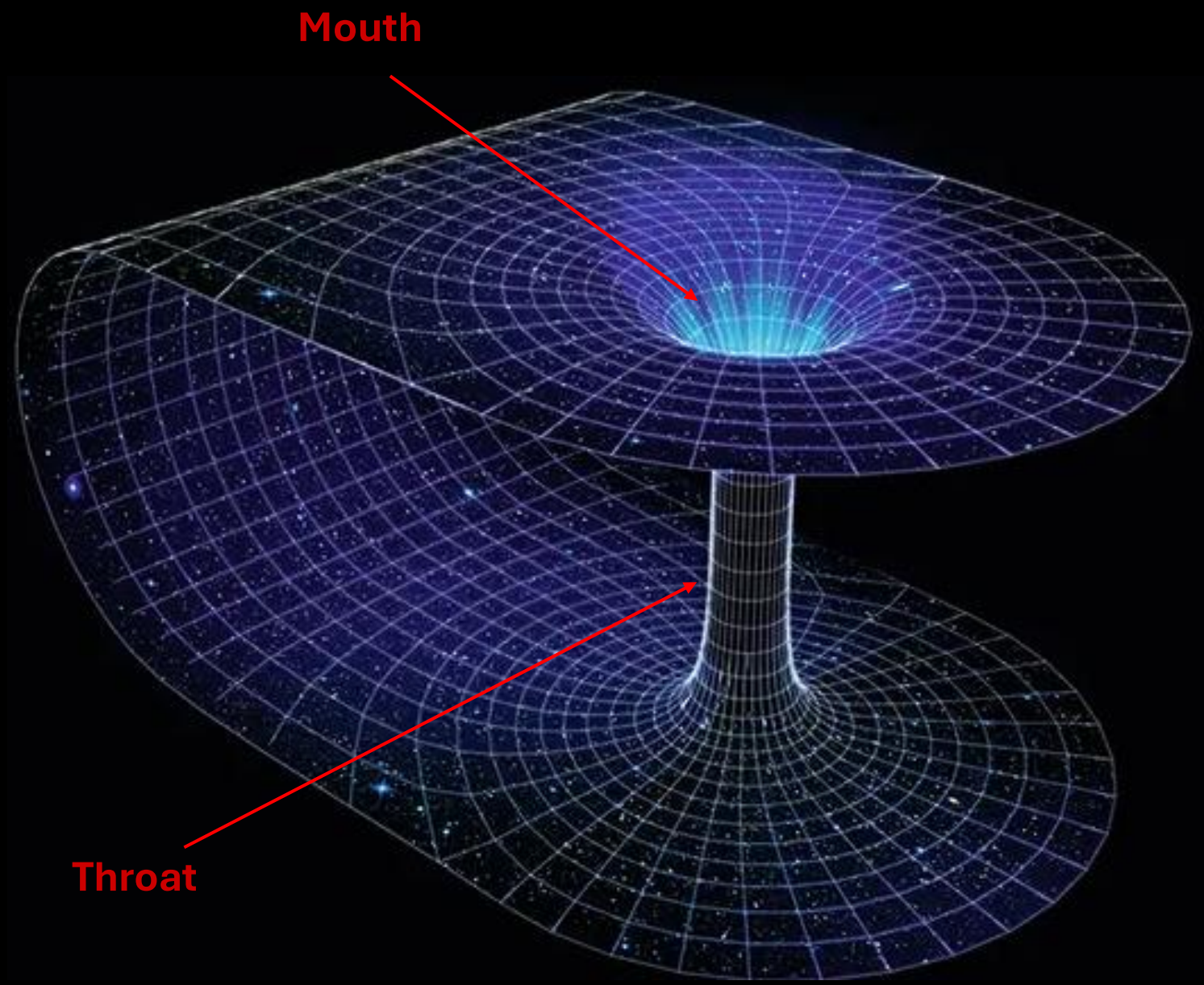
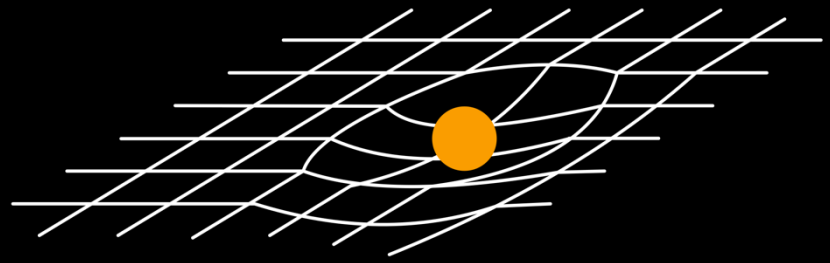


Wormholes

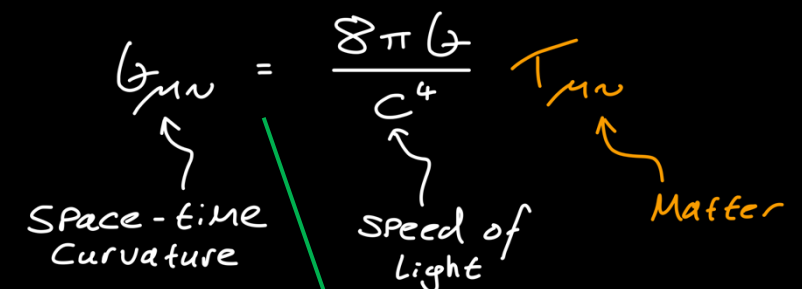


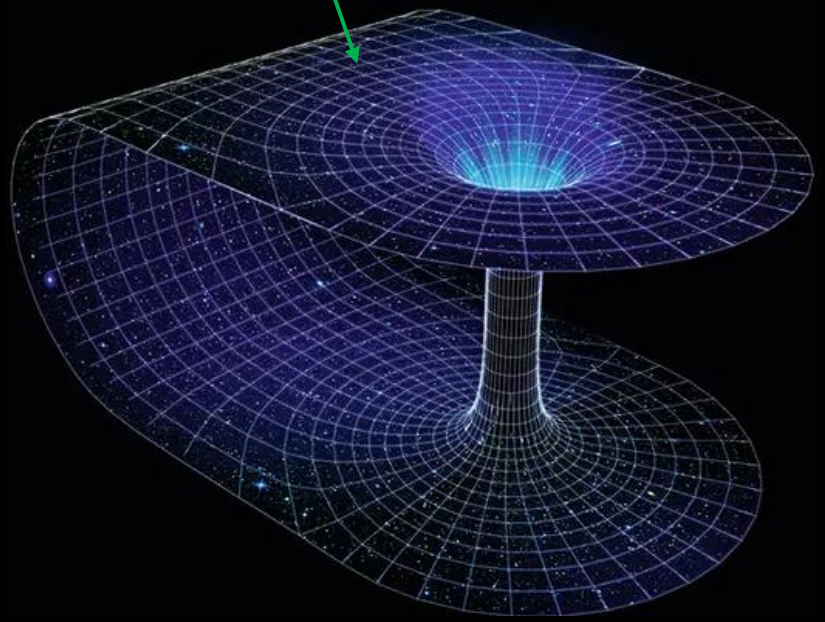
Wormholes aren't just based on a hunch...

They arise as natural solutions to Einstein's equation of gravity.

First noted in 1916 by Ludwig Flamm, they were picked up again in 1935 by Einstein and Nathan Rosen, who speculated about the physical meaning of this abstract mathematical solution.

Ludwig Flamm

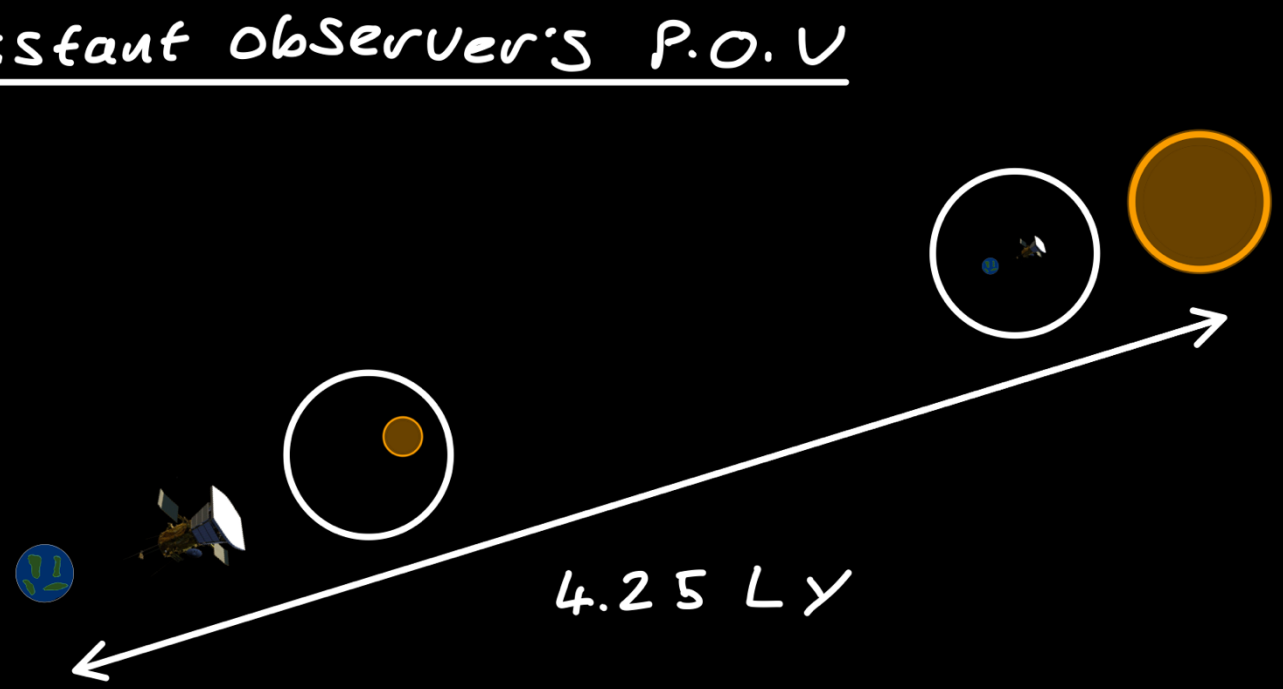




Wormholes

Returning to Proxima Centauri...

Wormholes might provide shortcuts between distantly connected regions of space.

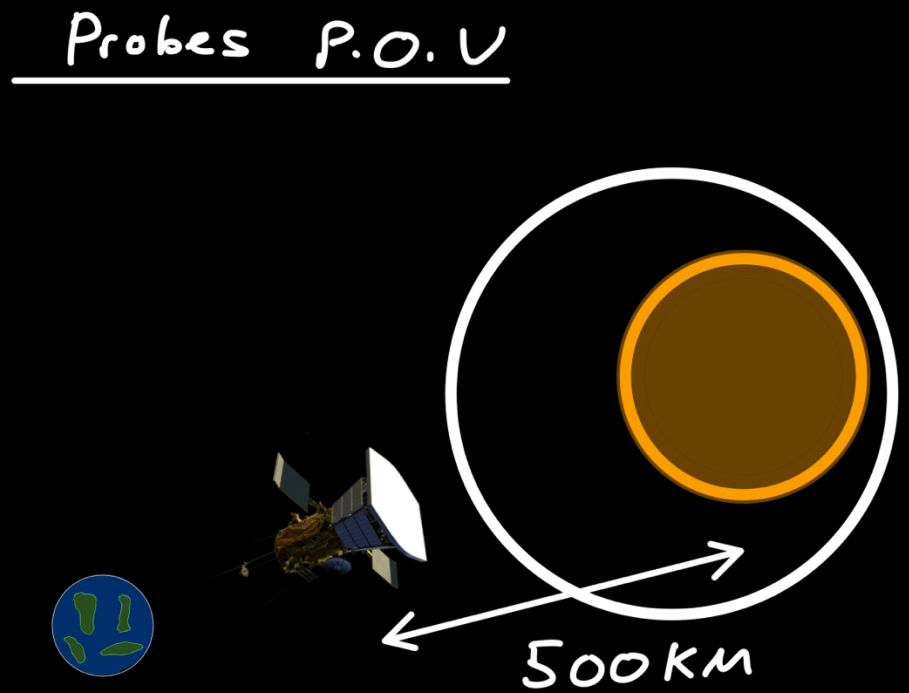


Wormholes

Returning to Proxima Centauri...

Wormholes might provide shortcuts between distantly connected regions of space.

Allowing great distances to be traversed more quickly, via the shortcut of a wormhole.



Exotic Matter Again…

Unfortunately… if wormholes exist, they cannot stay open for long enough for anything to pass through…

Creating a *Traversable Wormhole*, that could be passed through again requires negative energy densities!

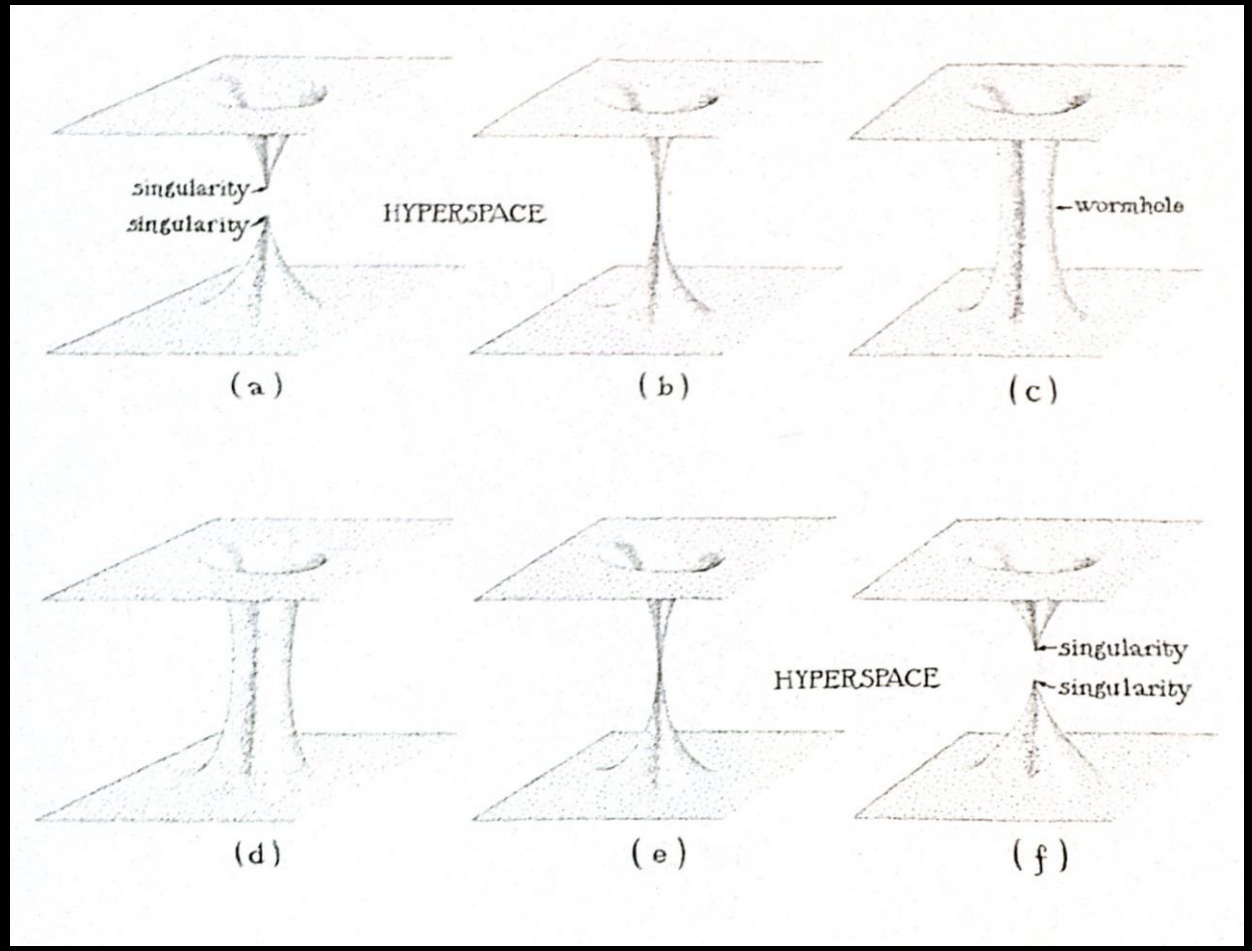


Figure from ‘Time Travel and Wormholes’ – Kip Thorne

Teleportation

The concept of Teleportation in science fiction has some basis in reality, but hits a number of solid brick walls, including:

- Conservation of Momentum / Energy

- The No-Cloning Theorem

Part III – Travelling through Time

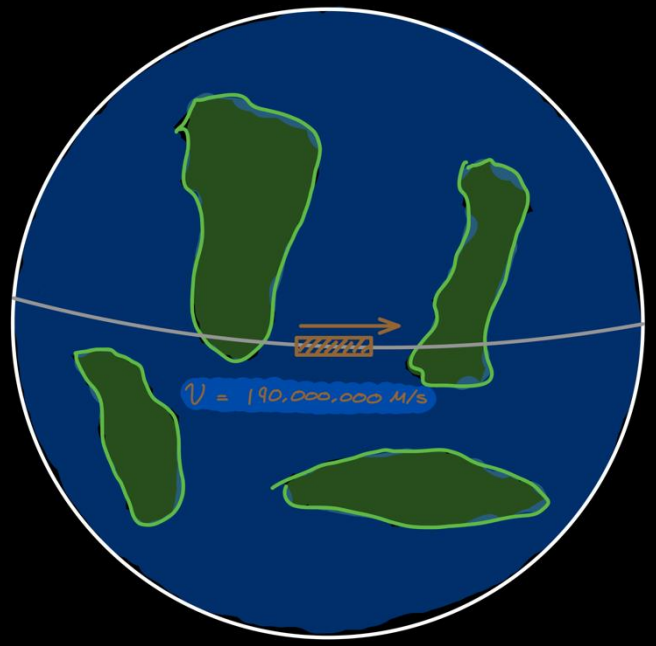
Travelling through Time

Forwards time travel is pretty straightforward, we are all doing it right now, at approximately 1 second per second.

Even travelling forwards through time at a much more rapid pace is well established science.

Backwards time travel is much more controversial...

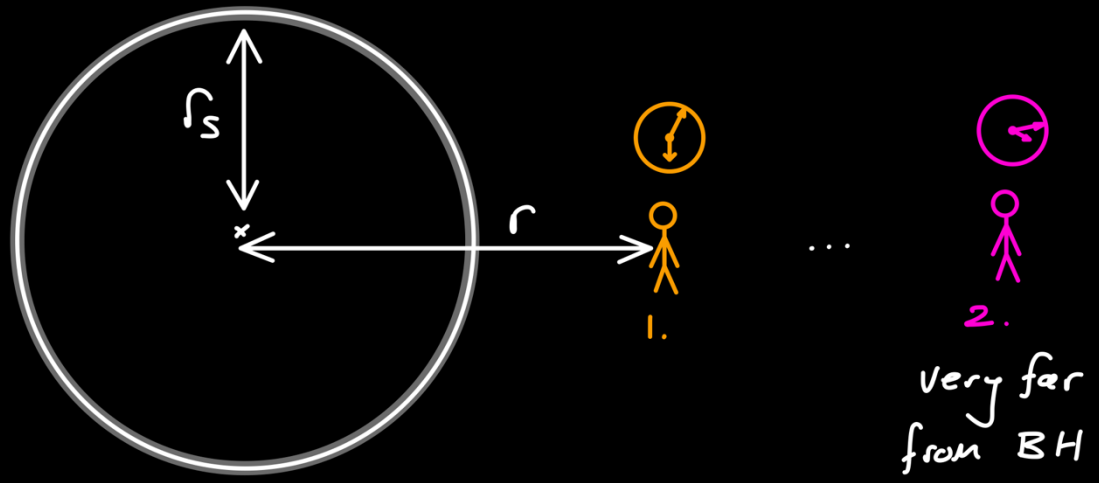
1. Black Holes
2. Wormholes (again!)
3. Travelling Really Fast



Black Holes as Time Machines

Last time, we spoke about the time bending properties of Black holes:

$$\Delta t_{near} = \Delta t_{far}\sqrt{1 - \frac{r_s}{r}}$$



Person 2's clock will tick much faster than Person 1's.

Black Holes as Time Machines

Due to its very fast rotation, the Black Hole in the film *Interstellar* (Gargantua) is a bit more complicated than the example we discussed last time.

As described in the film, 1 hour on Miller's Planet (the planet nearest to Gargantua) is approximately **7 years** back on Earth.

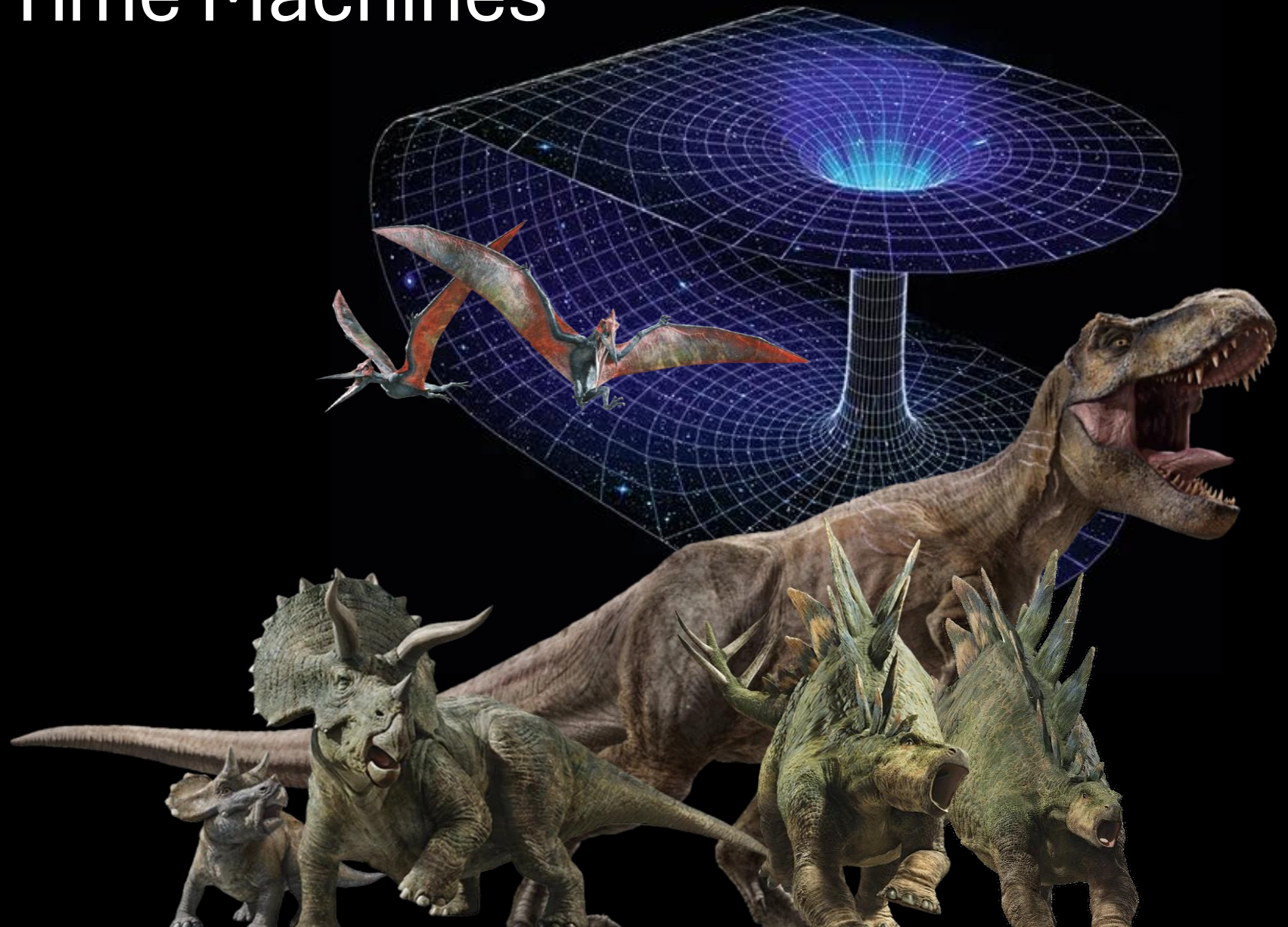
This is completely in line with what we would expect for a close orbit of a 100 million Solar mass Black Hole.

Worm Holes as Time Machines

There are a number of issues with using wormholes for time travel, especially for backwards time travel.

Einstein's theory of gravity (General Relativity) leaves open the possibility of Wormholes, which might connect different regions of space (and moments of time).

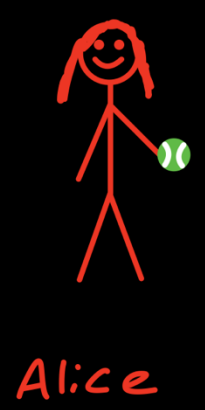
It's thought that when we find the complete theory of Quantum Gravity, something in this theory will rule out backwards time travel.



Galilean Relativity

Relativity is all about translating what one persons observes, to what another person would observe.

This second observer might be located at a different point in space relative to the first observer. They might also be moving relative to the first observer.



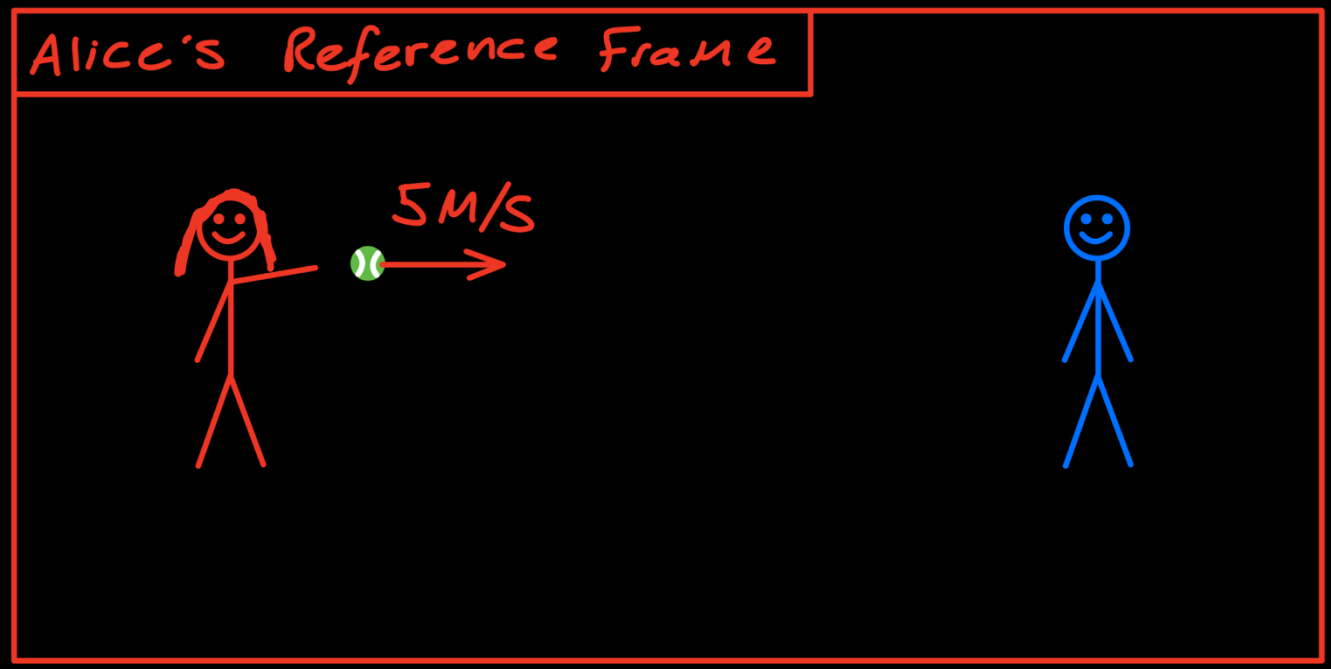
Let's consider what these two observers see when Alice throws a tennis ball at Bob.

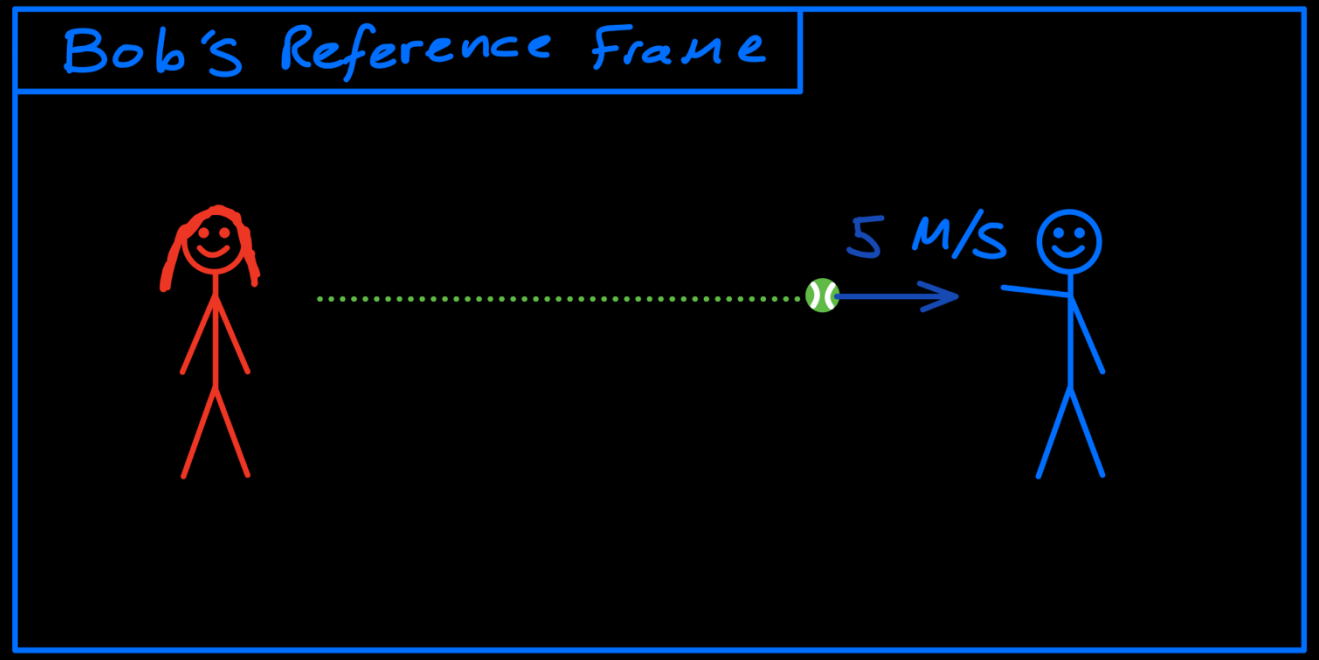
Galilean Relativity

Alice throws the tennis ball towards Bob at a speed of **5 meters per second**.

This is the speed she perceives in her *reference frame*.

In Bob's reference frame, the speed of the tennis ball when it reaches him is still **5 meters per second** (ignoring air resistance).





Galilean Relativity

How about if Bob is running towards Alice?

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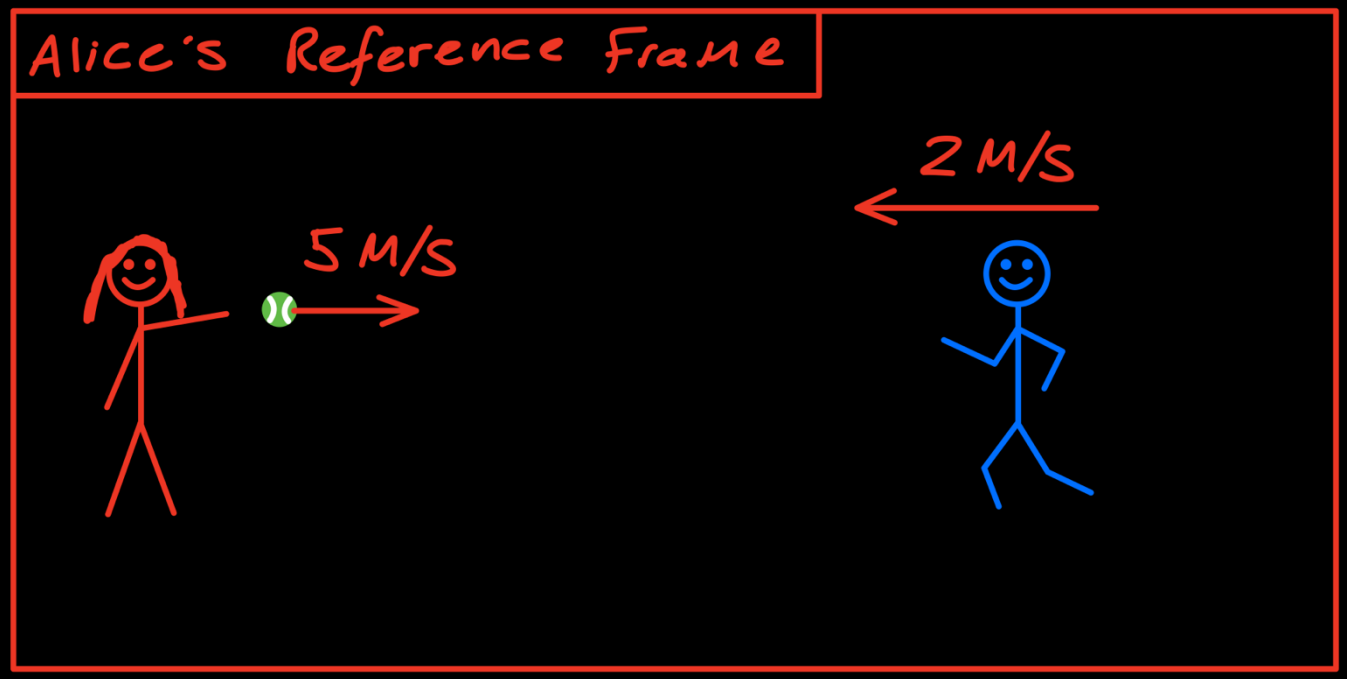

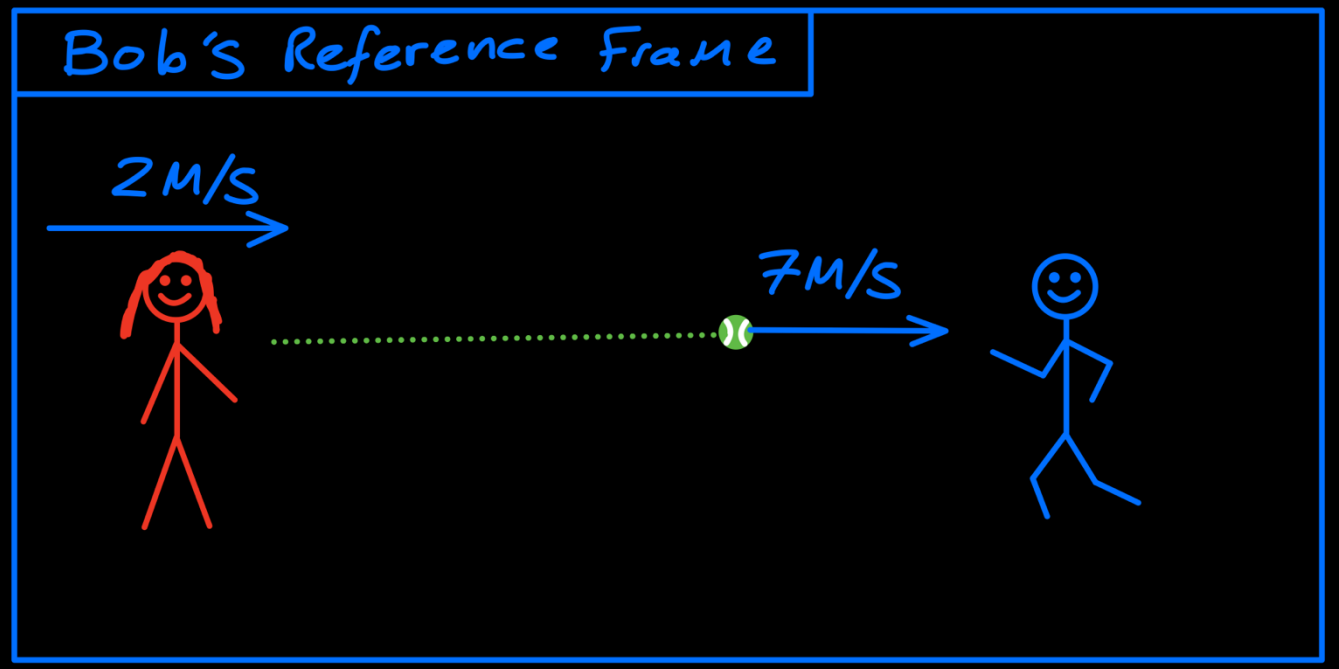

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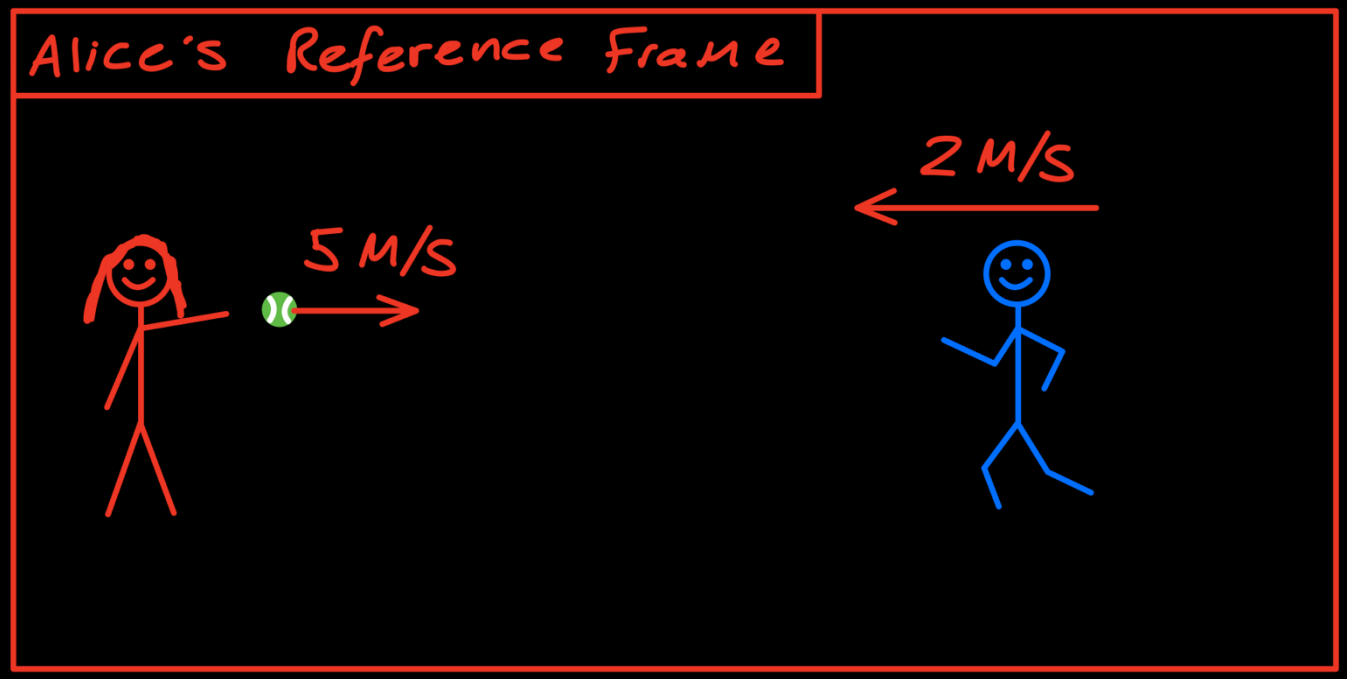

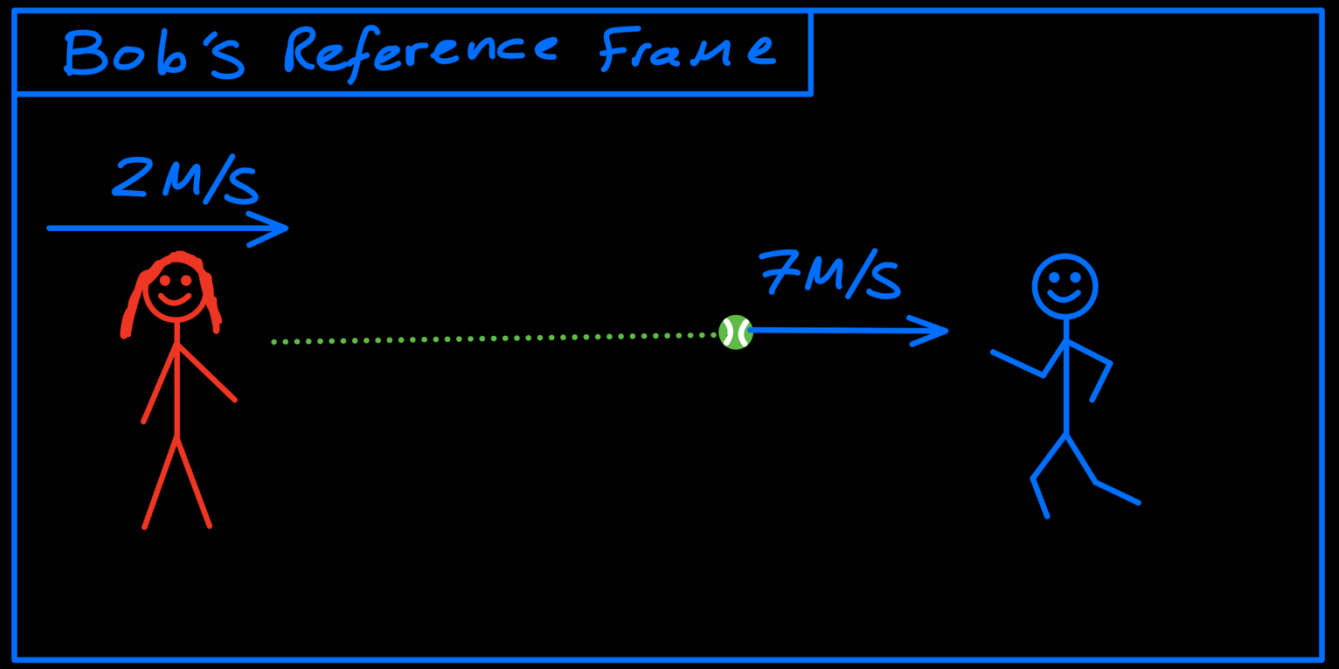

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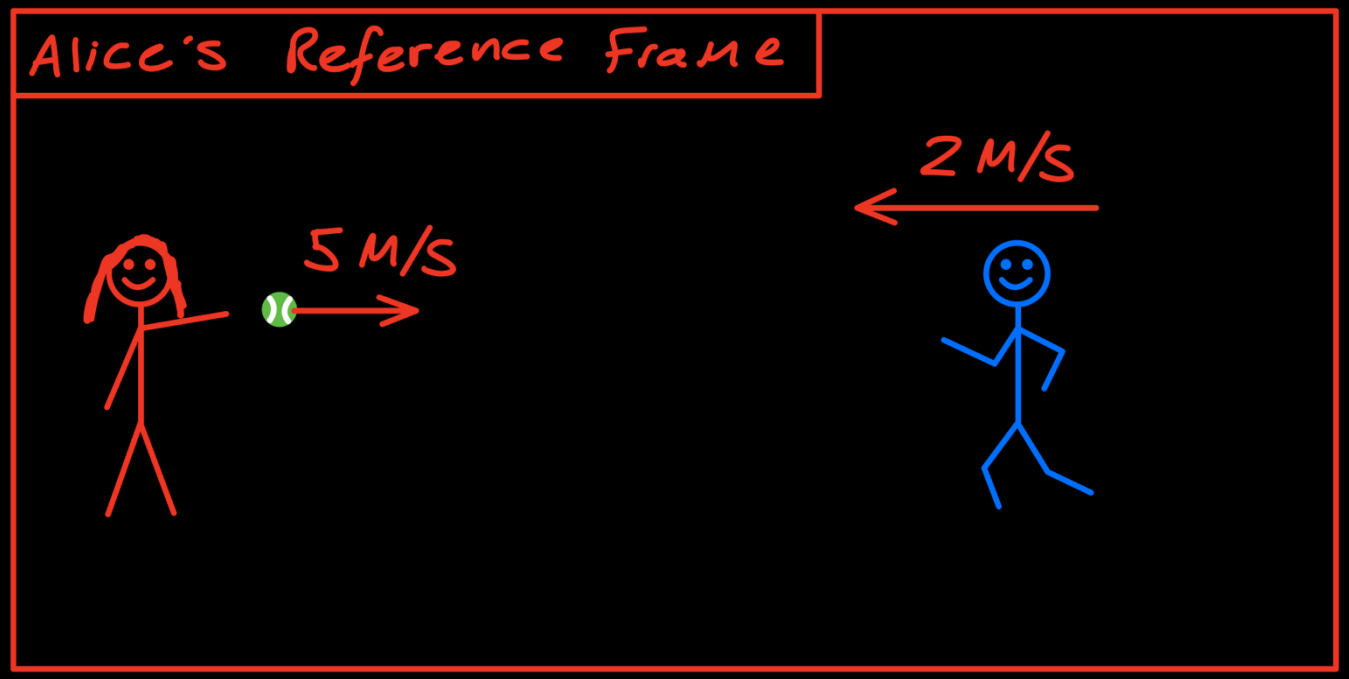
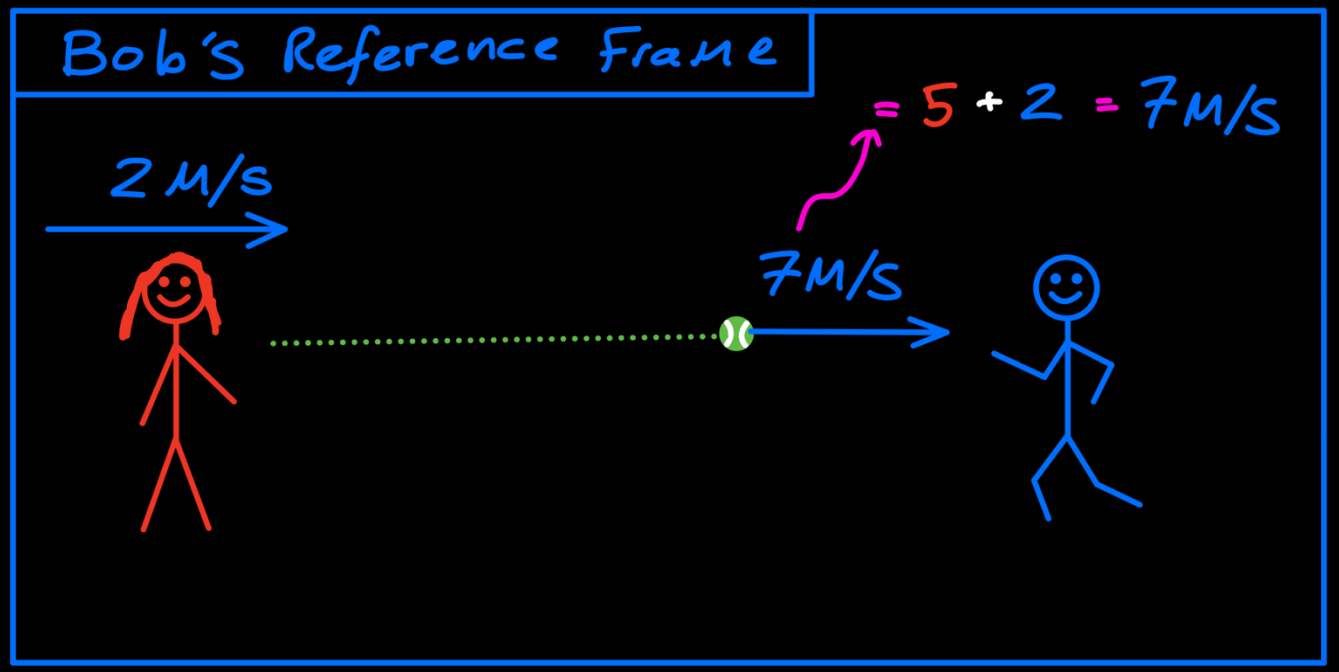
Who is correct?

Nobody is right or wrong! It's relative!

It depends who you ask.





Einsteinian Relativity

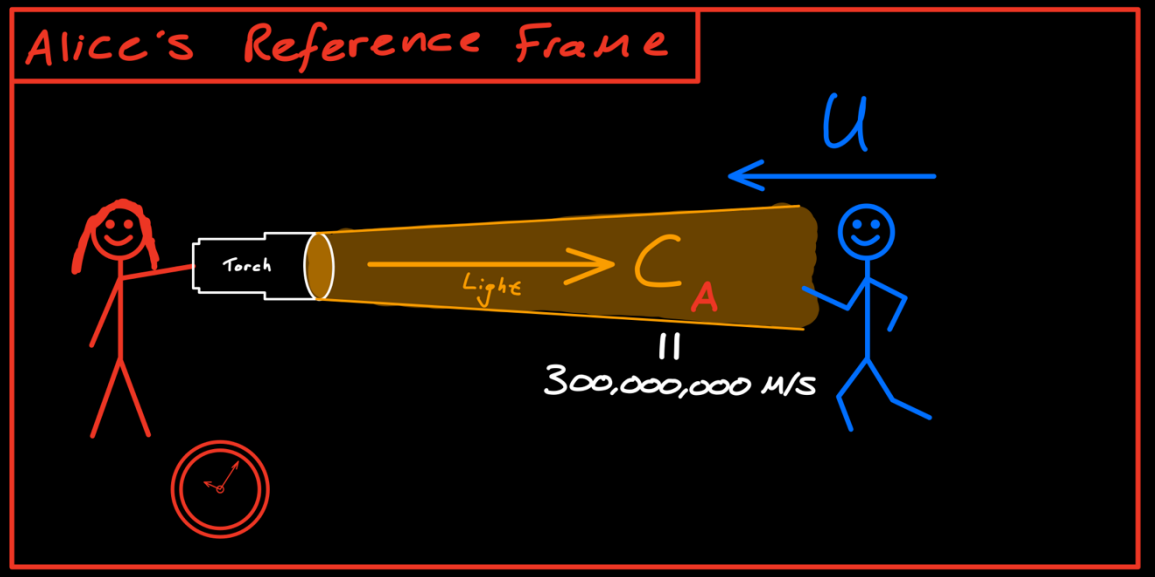
<u>The Laws</u>

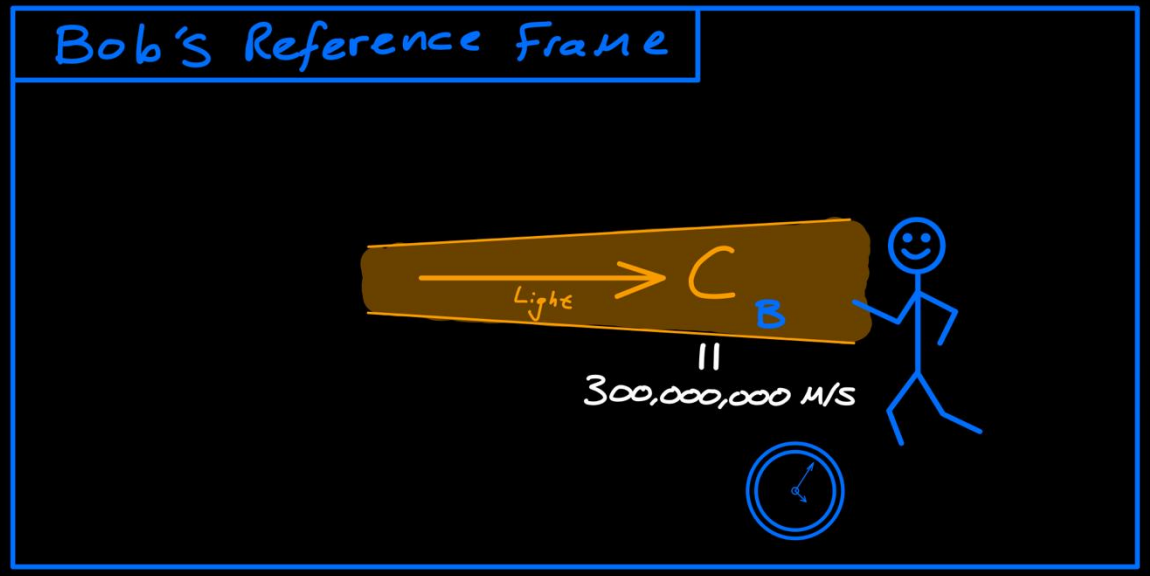
1. All Laws of Physics are obeyed in Inertial Reference Frames.

2. The Speed of Light is invariant. It is the same in all reference frames.

$$c_B = c_A$$

3. Clocks tick at different rates for different observers.





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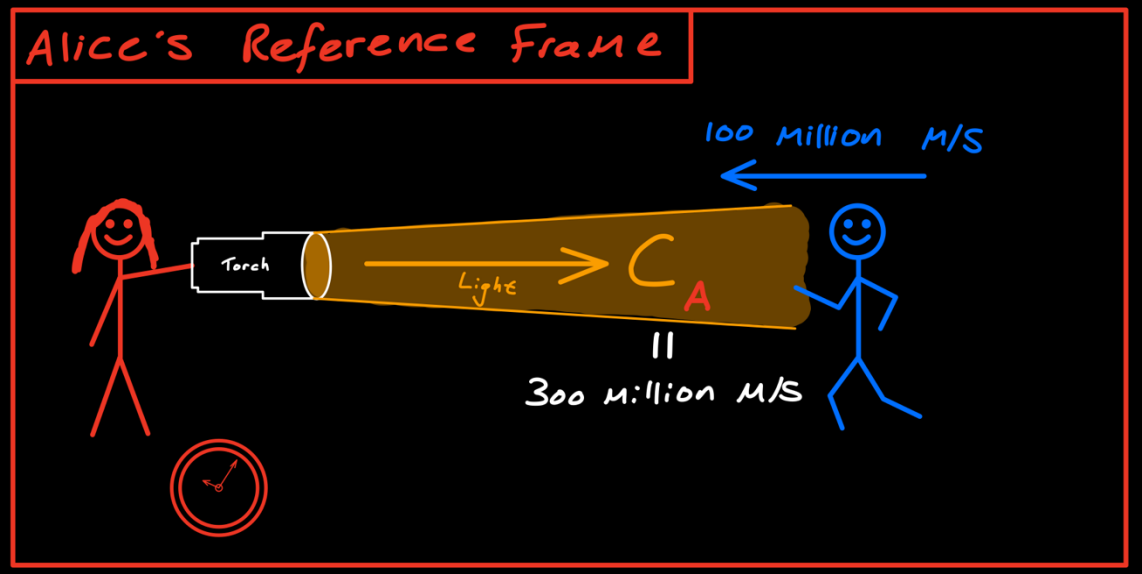

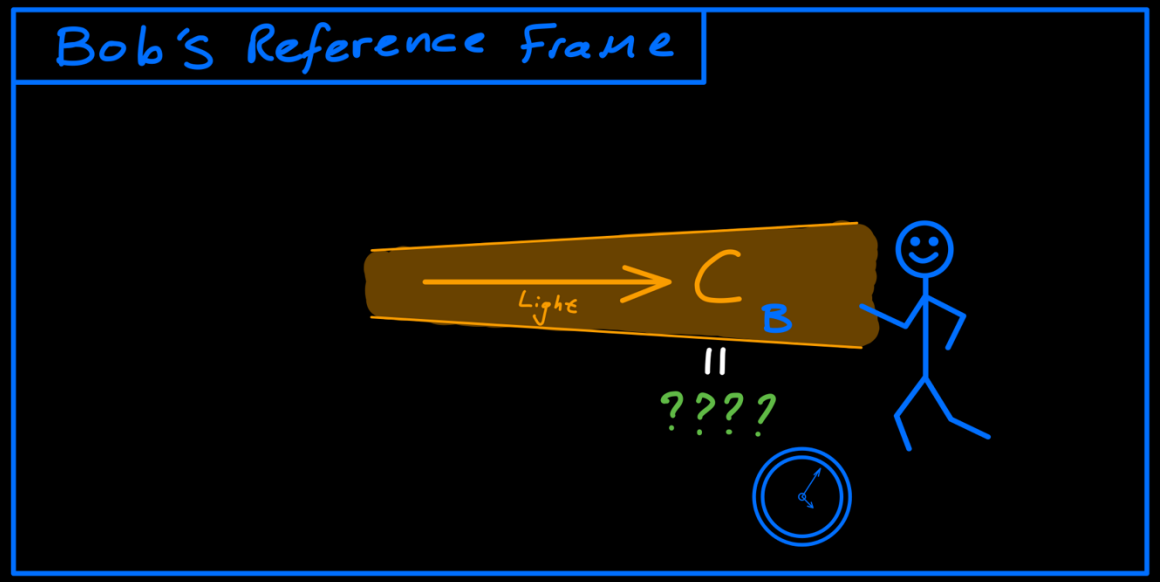

What do you think the speed of light seen by Bob should be?

Einsteinian Relativity

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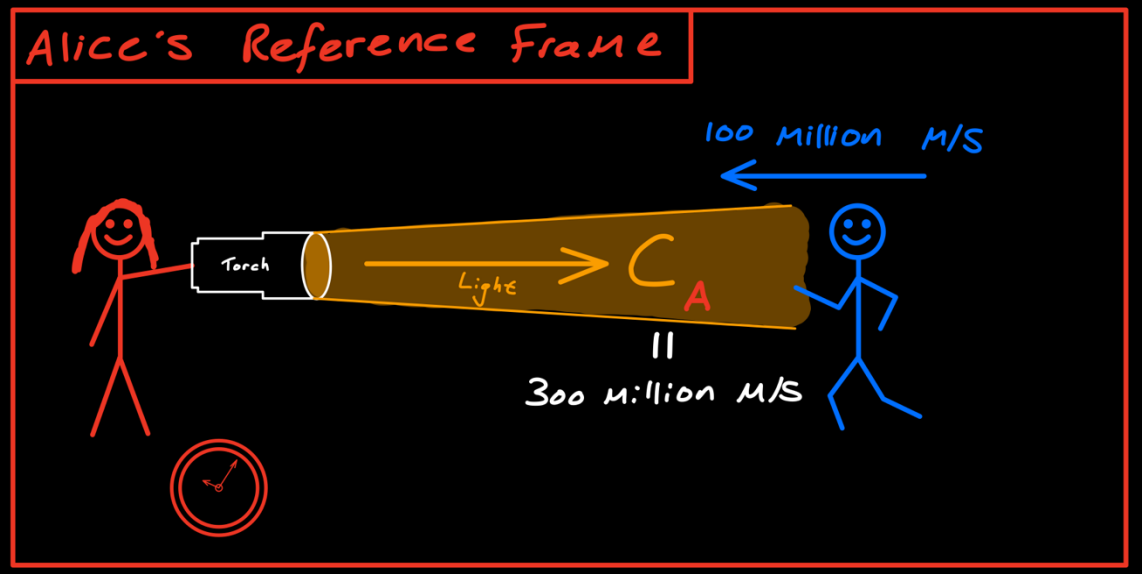
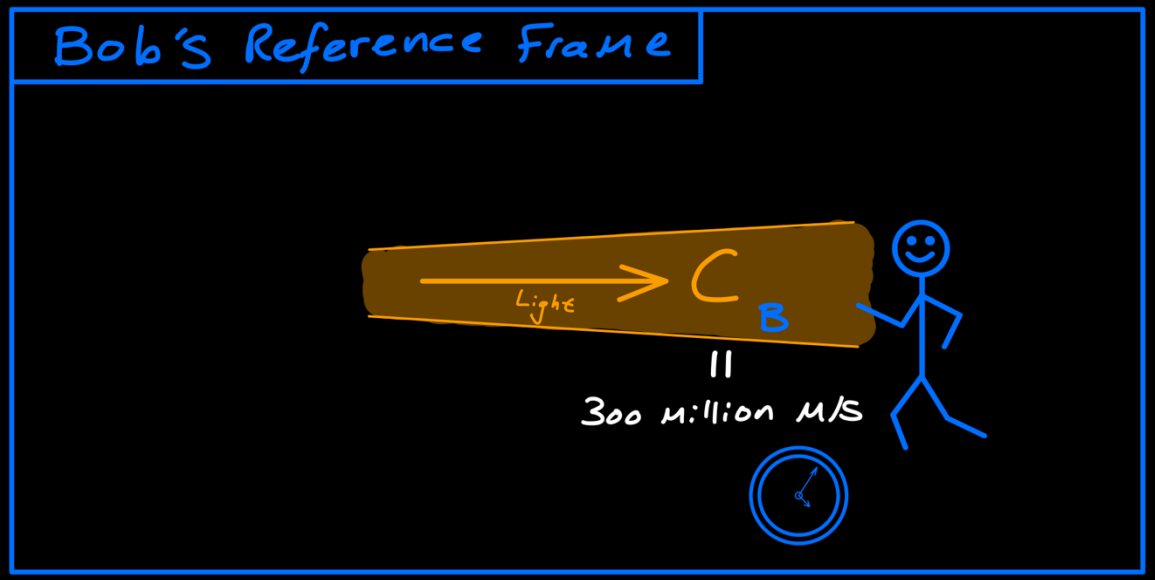
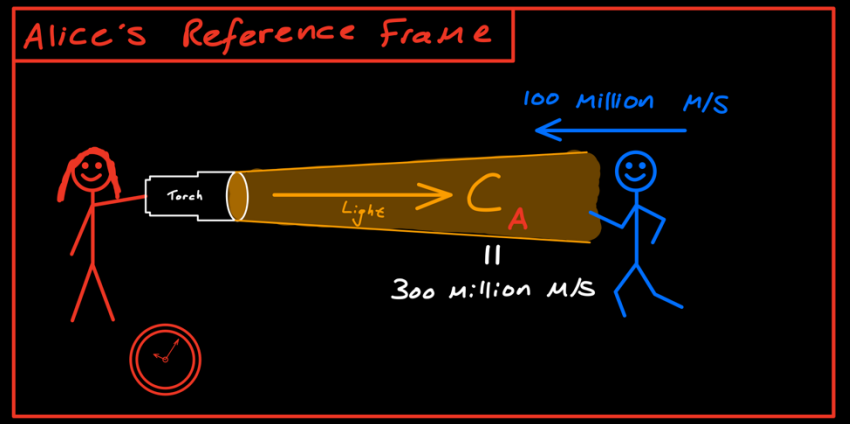
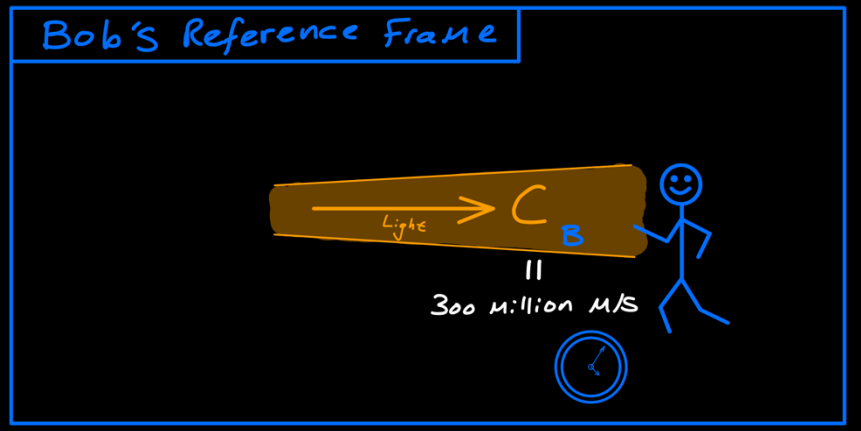




The Speed is unchanged! Light ALWAYS travels at the same speed, in any reference frame.

Einsteinian Relativity





From the invariance of the speed of light, all of the bizarre consequences of Einstein's theory of Special Relativity can be worked out.

This is BY FAR, the most bizarre consequence of Einstein's postulates of relativity.

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Why does the invariance of the speed of light mean moving clocks tick more slowly?

This makes some intuitive sense.

If you run at a light ray at head-on, something about your perception of time must shift for the speed of light to remain the same as if you were standing still.

But… It's deeper than just 'perception'. The passage of time ***really does*** change.

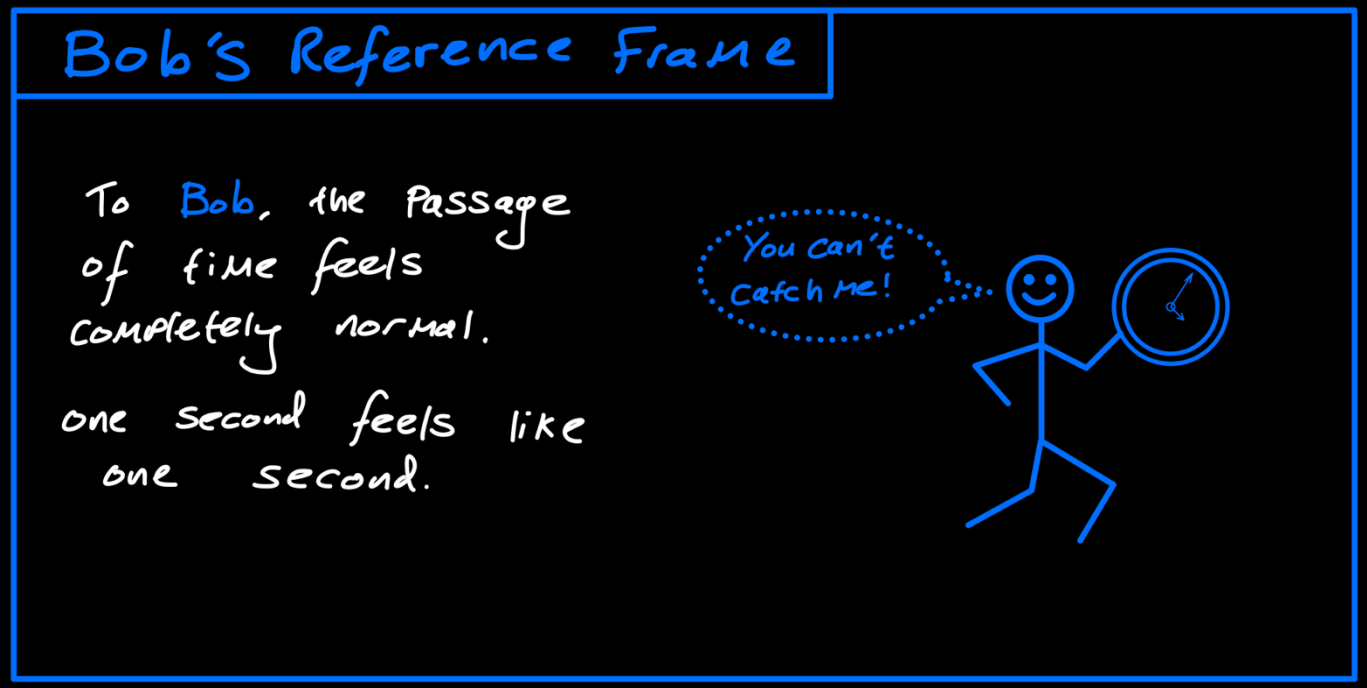
Plants growing on a highspeed rocket will germinate later than they would at rest on the Earth. Grey hairs will not appear as numerous, food will not spoil, clocks will not tick as far ahead.

Time Dilation

First, let's think about how time passes for Bob while he runs away from Alice.

Bob's clock ticks once every second *from his point of view*, as expected.

What would Bob's clock look like, as seen by Alice?

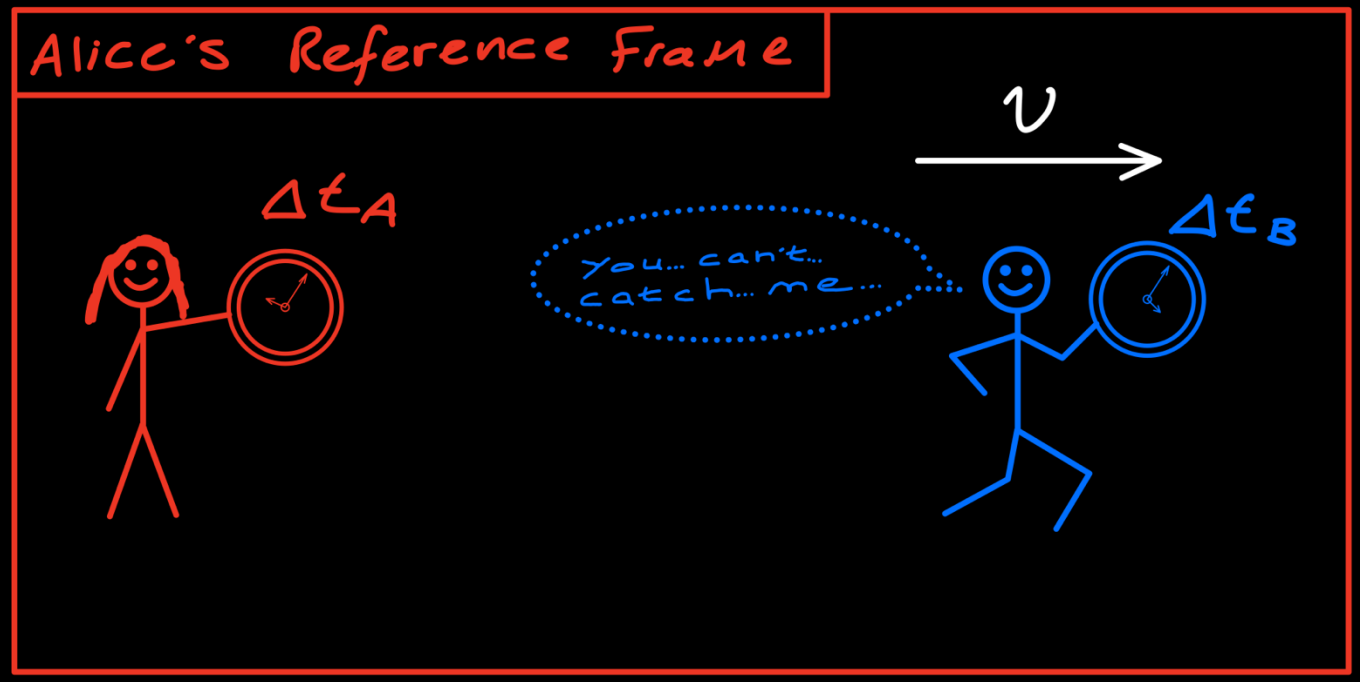


Time Dilation

When Alice looks at Bob's clock, it appears to tick more slowly than her own.

Bob shouts back at Alice as he runs away, and his speech appears drawn out, like slow motion...

These two observers experience the passage of time differently, due to their relative motion.



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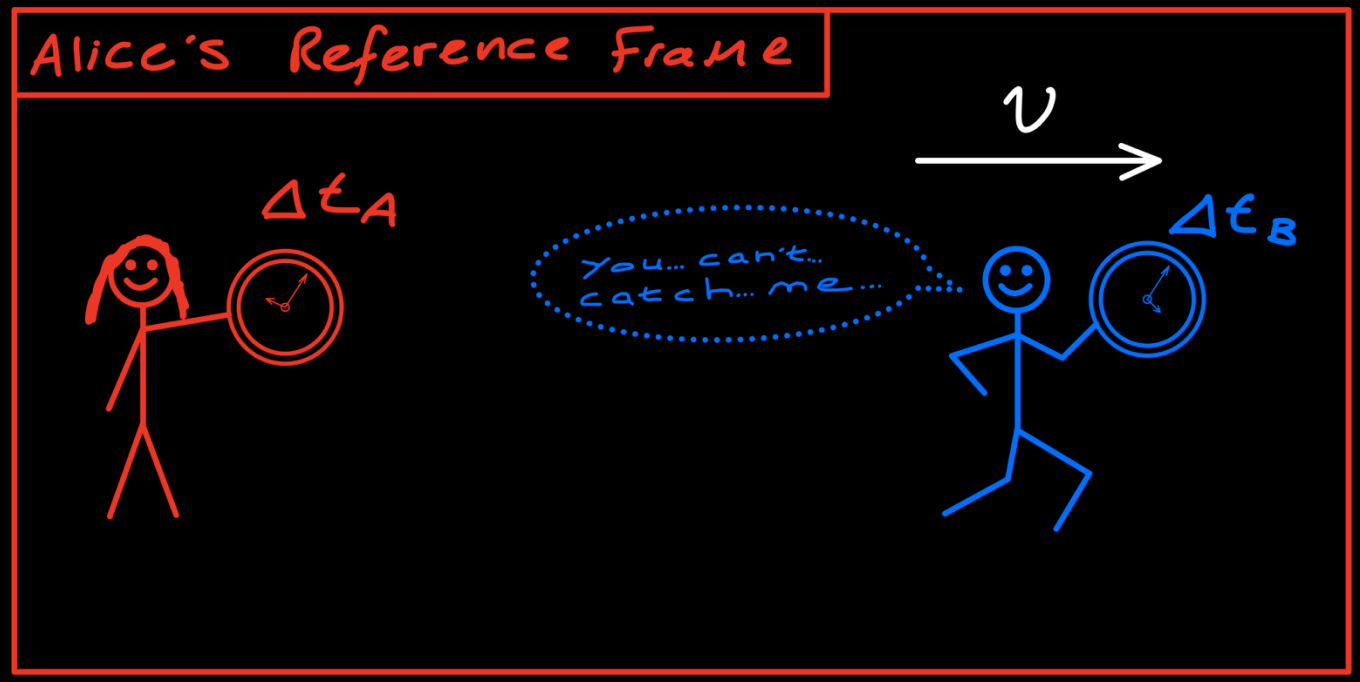


Hang on... Why do we not observe this phenomena in our every day lives?

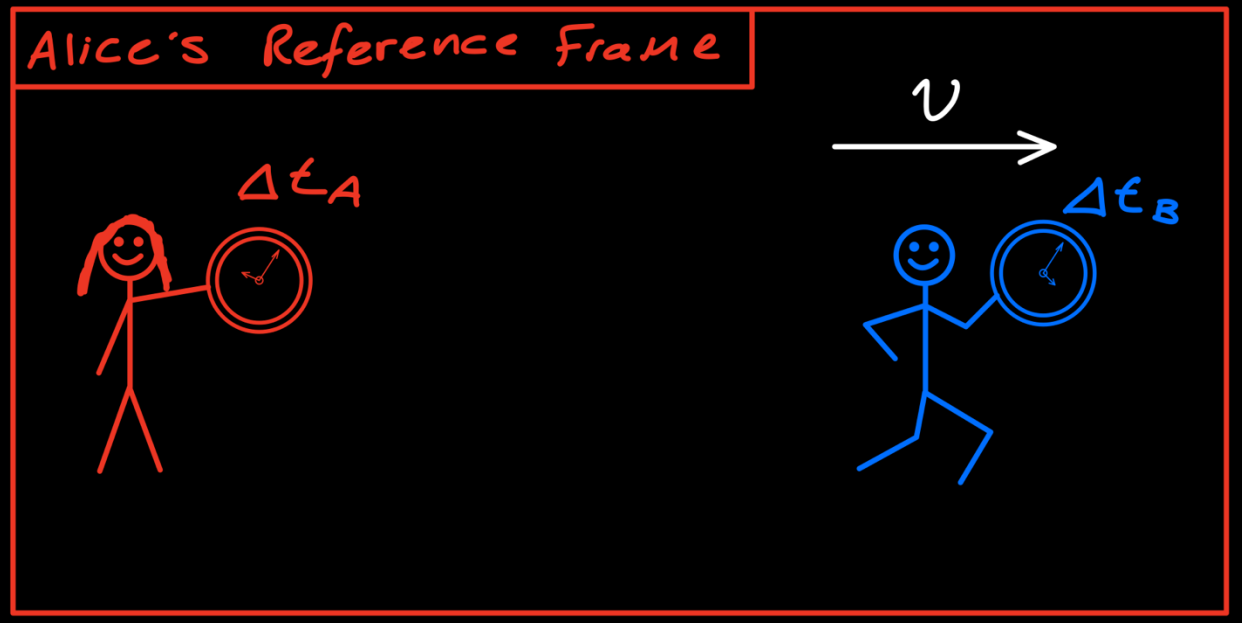
Not every jogger that runs past us moves in slow motion!

Time Dilation

Let's look at Einstein's Time Dilation formula...

Bob's velocity appears in the formula as a ratio of the speed of light.

This means the passage of time on changes significantly when moving at speeds close to the speed of light.



Length of time recorded by Bob.

Length of time recorded by Alice.

$$\Delta t_B = \frac{\Delta t_A}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Speed of Bob, seen by Alice.

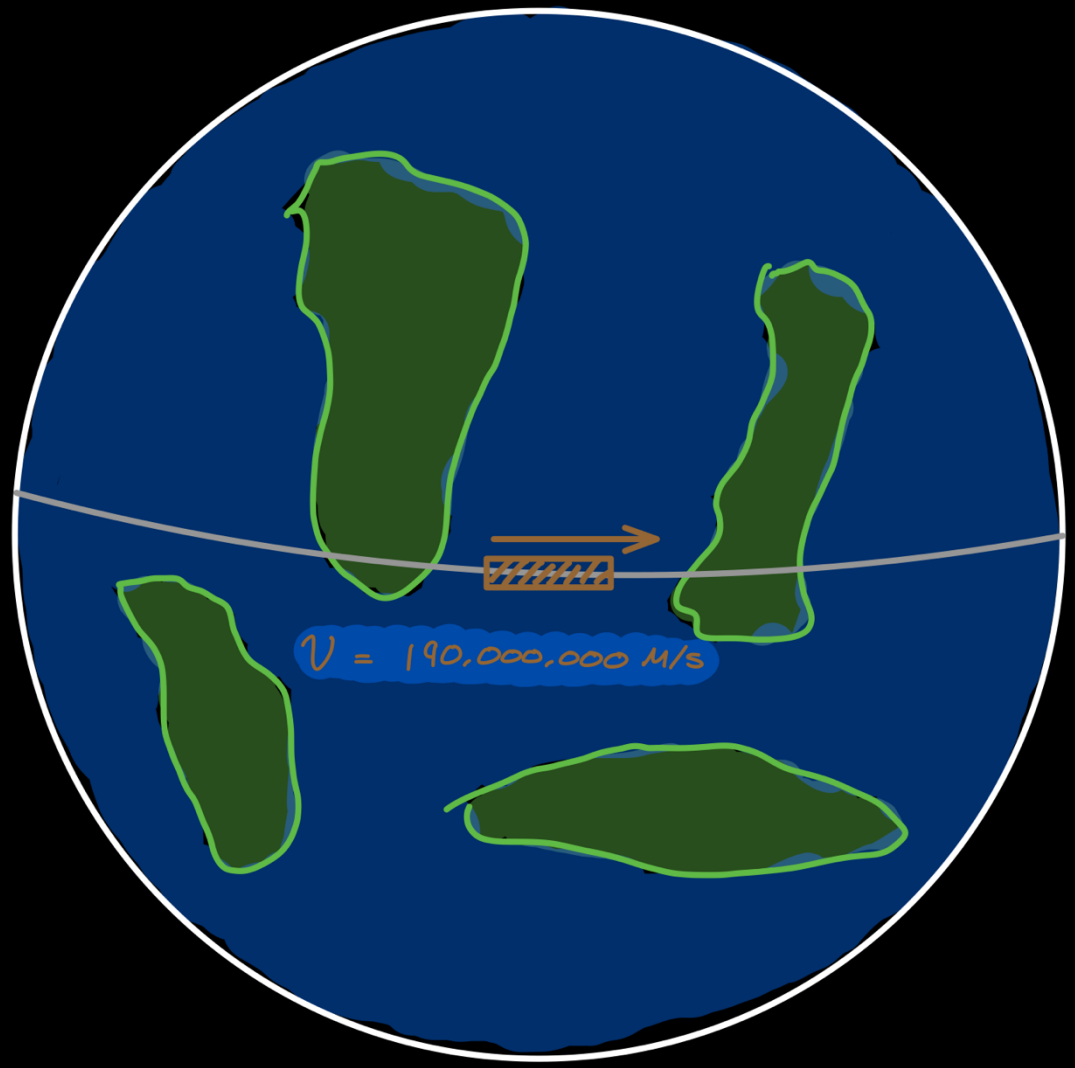
Speed of Light (300 million m/s).

Forwards Time Travel

Suppose we could construct a trainline that spans the Earth's equator.

If a train could travel one thousand times faster than the Parker Solar Probe, the time dilation effects would become significant.

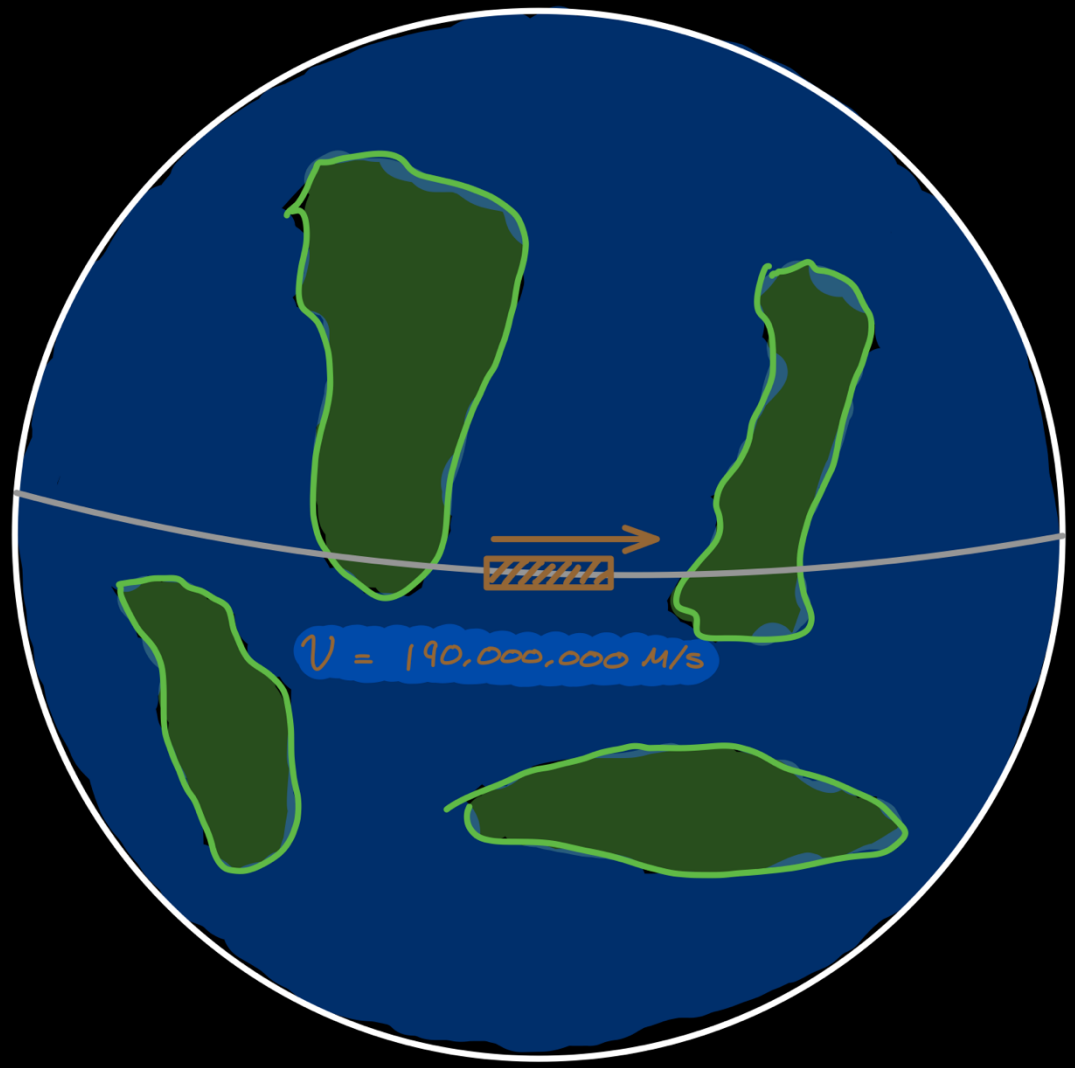
At this speed, the train moves at about **63%** of the speed of light.



Forwards Time Travel

At this speed, the train would make a full rotation around the Earth in just 0.2 seconds.

I.e. It would **make five full rotations** every single second.



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At this speed, the train would make a full rotation around the Earth in just 0.2 seconds.

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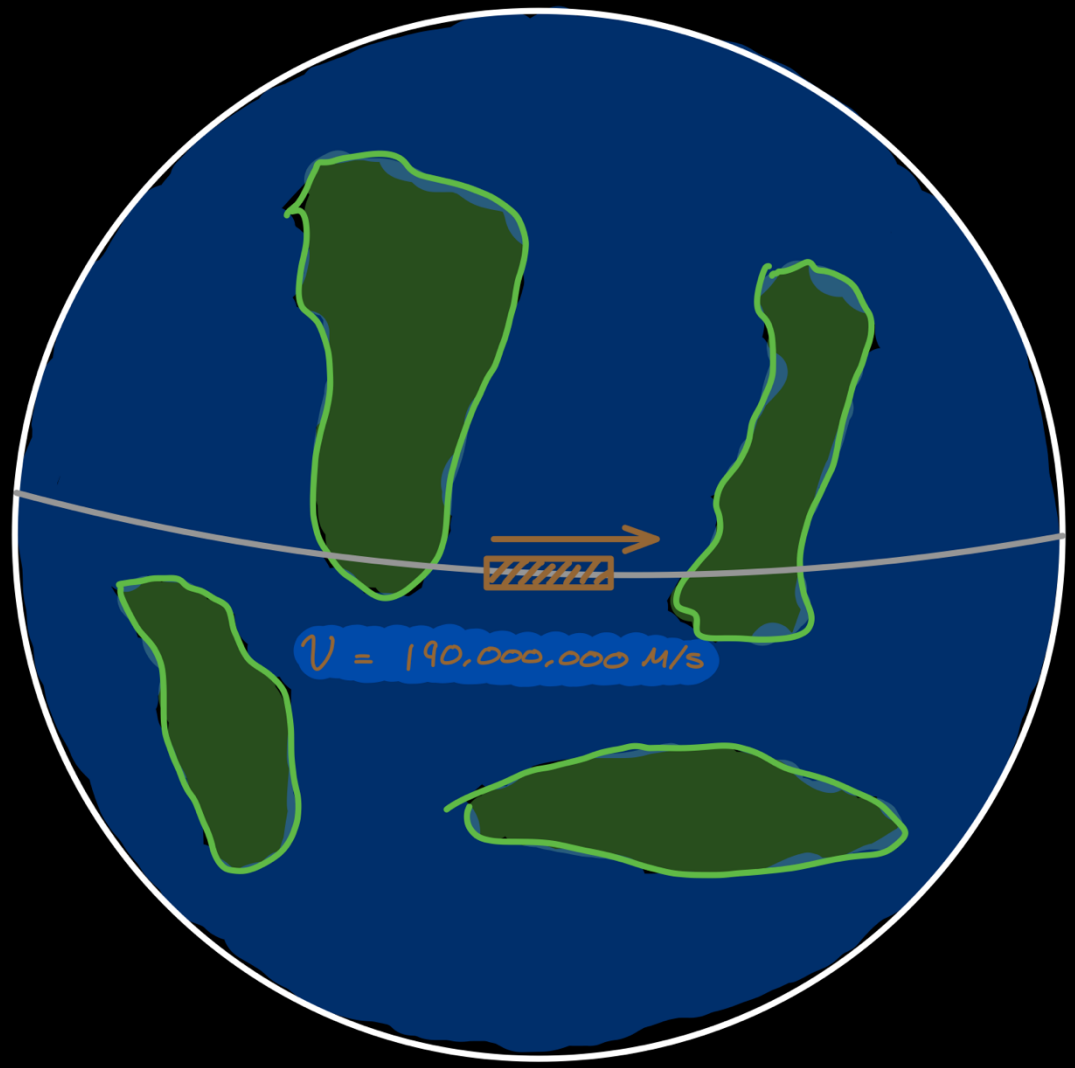
For each of these full rotations, the passengers on the train experience only 0.15 seconds.



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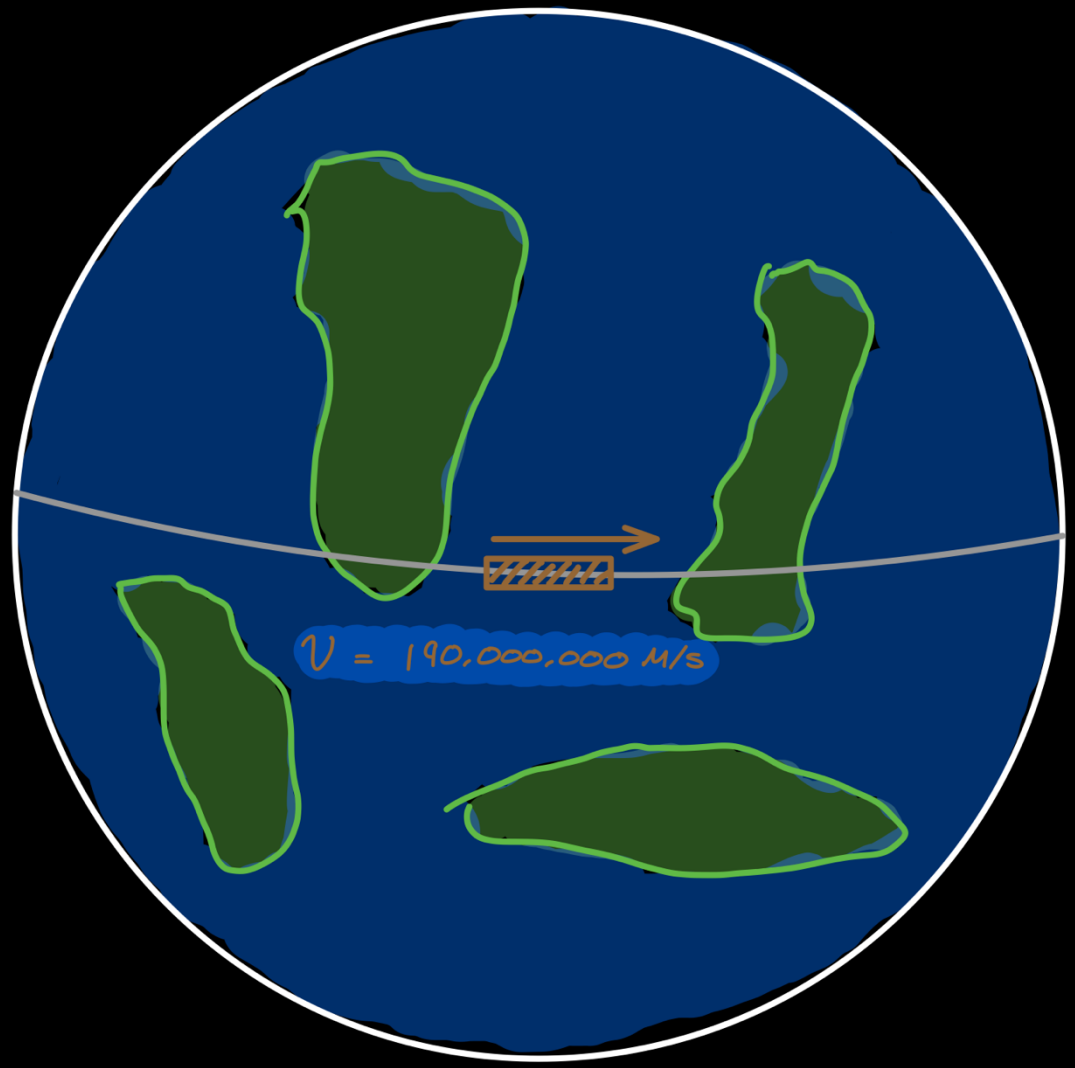
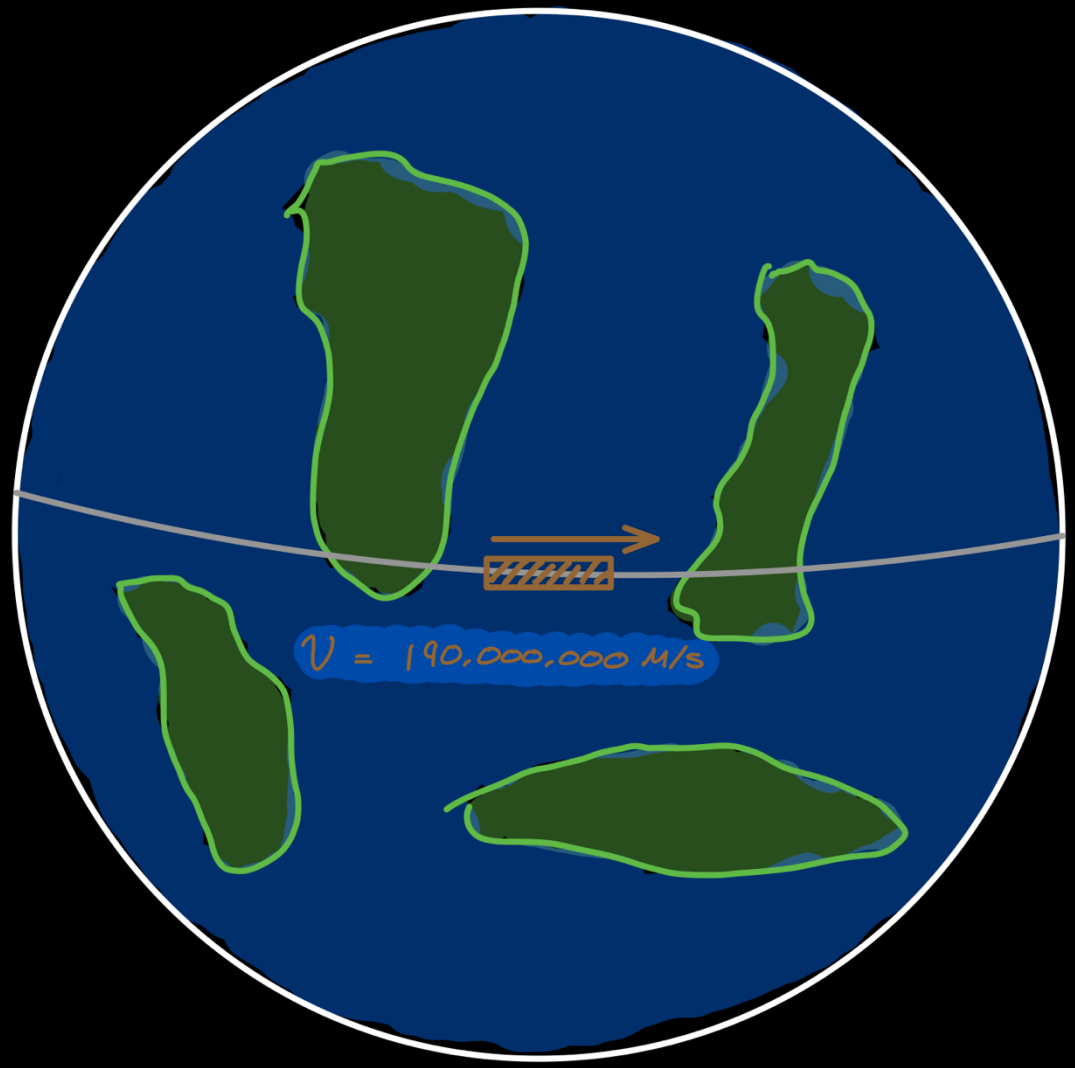


Forwards Time Travel

If the passengers remained on the train for ten years (recorded by everyone else on Earth), they would only experience about 7 years 9 months.

The passengers have therefore travelled forwards in time by about 2 years and 3 months.

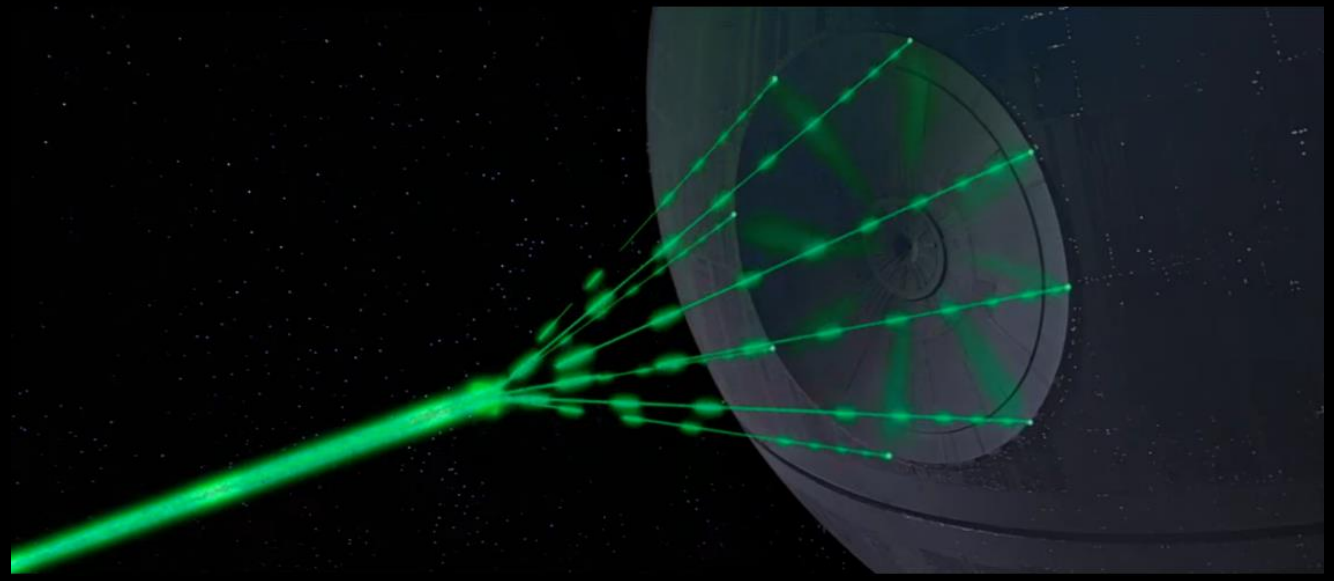


Part IV – The Physics of Mass Destruction

Blowing up a Planet

Science Fiction writer love to blow up planets!

One of the most famous examples, is the scene in *Star Wars Episode IV A New Hope*, where the Death Star is used to destroy the planet Alderaan.



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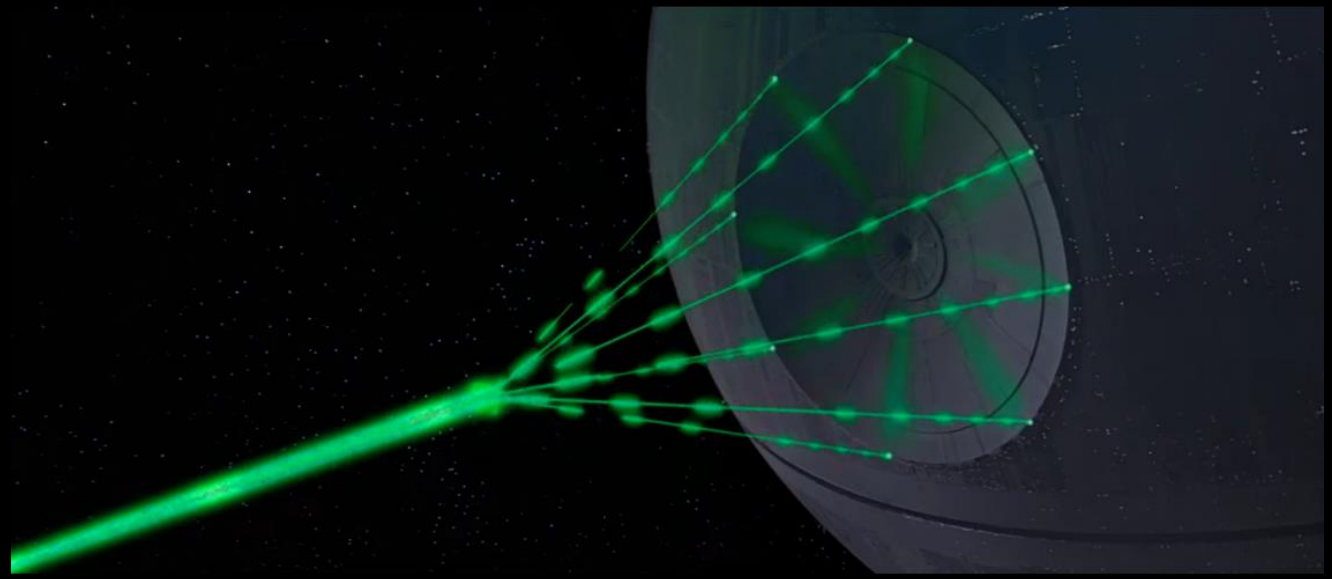
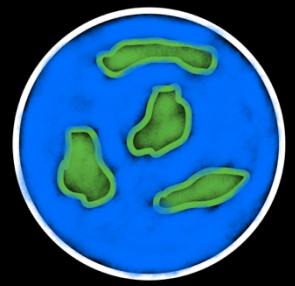


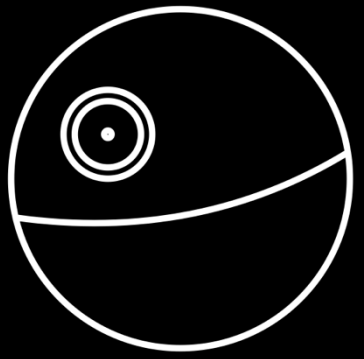
My Question....

What is the Death Star's energy bill?

Blowing up a Planet

Let’s try and calculate this….





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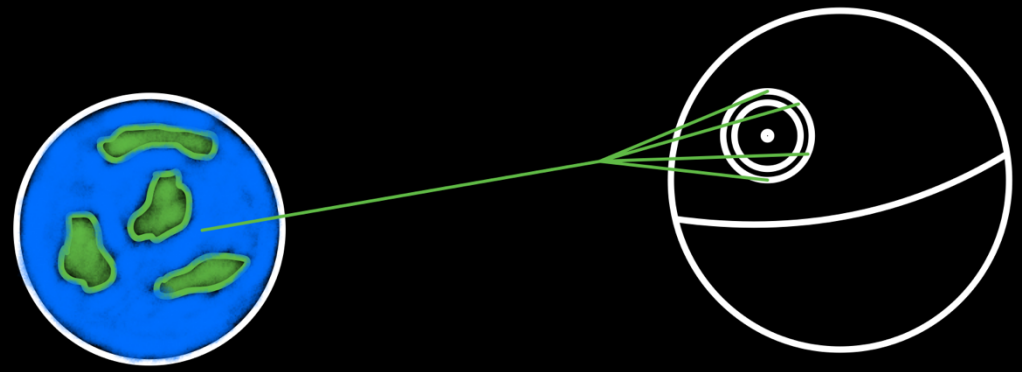

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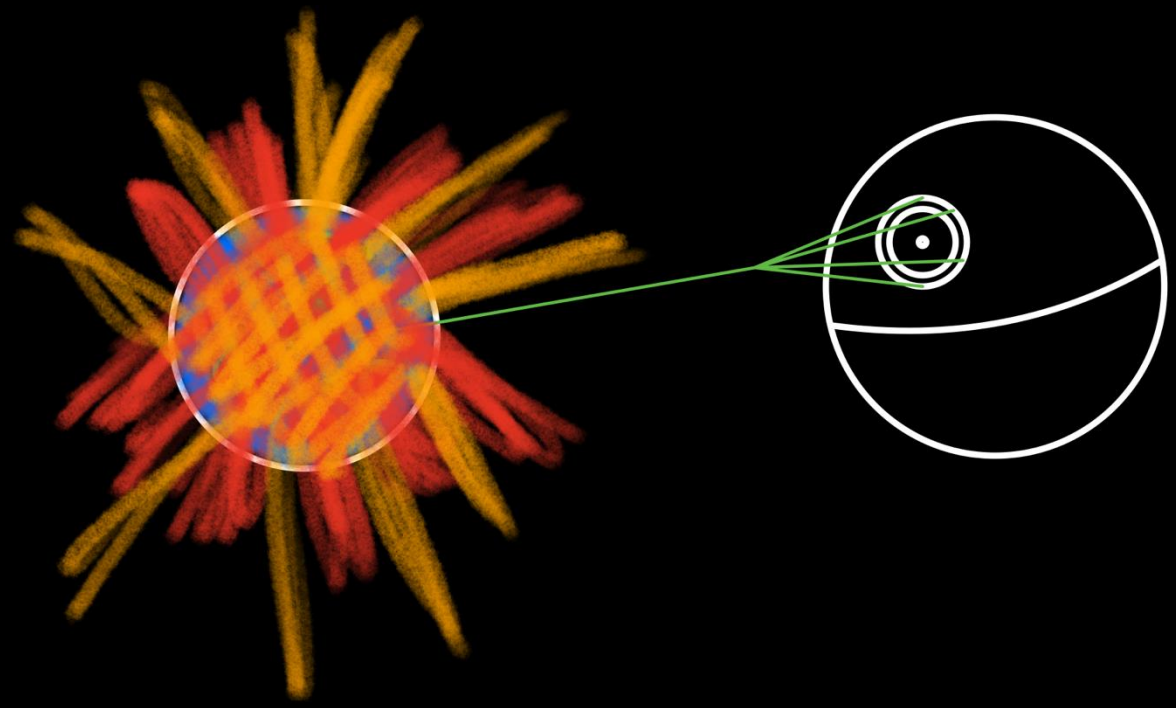
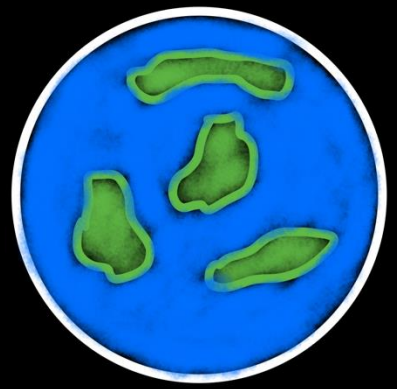


Blowing up a Planet

Mathematically… The energy needed to ‘blow up’ a planet, can be calculated as the energy required to disassemble the planet piece by piece, working against the force of gravity from the remaining mass of the planet:



$$E = \int \frac{GM(r)}{r}\,dm$$

$$= \frac{G\rho^2 4\pi}{3}\int_0^R \frac{r^3}{r} 4\pi r^2\,dr$$

$$= \frac{G\rho^2(4\pi)^2}{3}\int_0^R r^4\,dr$$

$$= \frac{16G\rho^2\pi^2}{15}R^5$$

$$\Rightarrow E = \frac{16}{15}G\left(\frac{3M}{4\pi R^3}\right)^2\pi^2 R^5$$

$$= \frac{3}{5}\frac{GM^2}{R}$$

$$\Rightarrow E_{\text{Blow-up}} = \frac{3}{5}\times\frac{6.67\times10^{-11}\times(5.97\times10^{24})^2}{(6400\times10^3)}$$

$$= 2.23\times10^{32}\ \text{J}$$

$$= 232,000,000,000,000,000,000,000,000,000,000\ \text{J}$$

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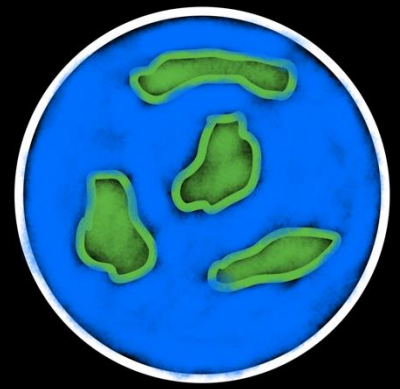

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For an Earth sized planet, this turns out to be 232 thousand billion billion billion Joules of Energy.

= 232,000,000,000,000,000,000,000,000,000,000 J

Blowing up a Planet

Assuming the Ofgem price cap applied beyond out solar system, the cost of blowing up a single Earth sized planet is approximately:

1.62 Billion Billion Billion Pounds

Energy cost = 26.11p per kWh

$1\,kWh = 3.6 \times 10^6\,J$

$\Rightarrow 1\,J$ costs $£7.25 \times 10^{-8}$

So... The cost of Blowing up an Earth sized Planet $\simeq £1.62 \times 10^{25}$

or...

£1,620,000,000,000,000,000,000,000

[1.62 Billion Billion Billion Pounds]

Questions!

Spacetime Sundays

Southend's First Science Community Drop-in:

part office-hour, part lecture, part book club

Approximately every other Sunday 11am-12pm in the Beecroft Gallery Foyer

Upcoming dates:

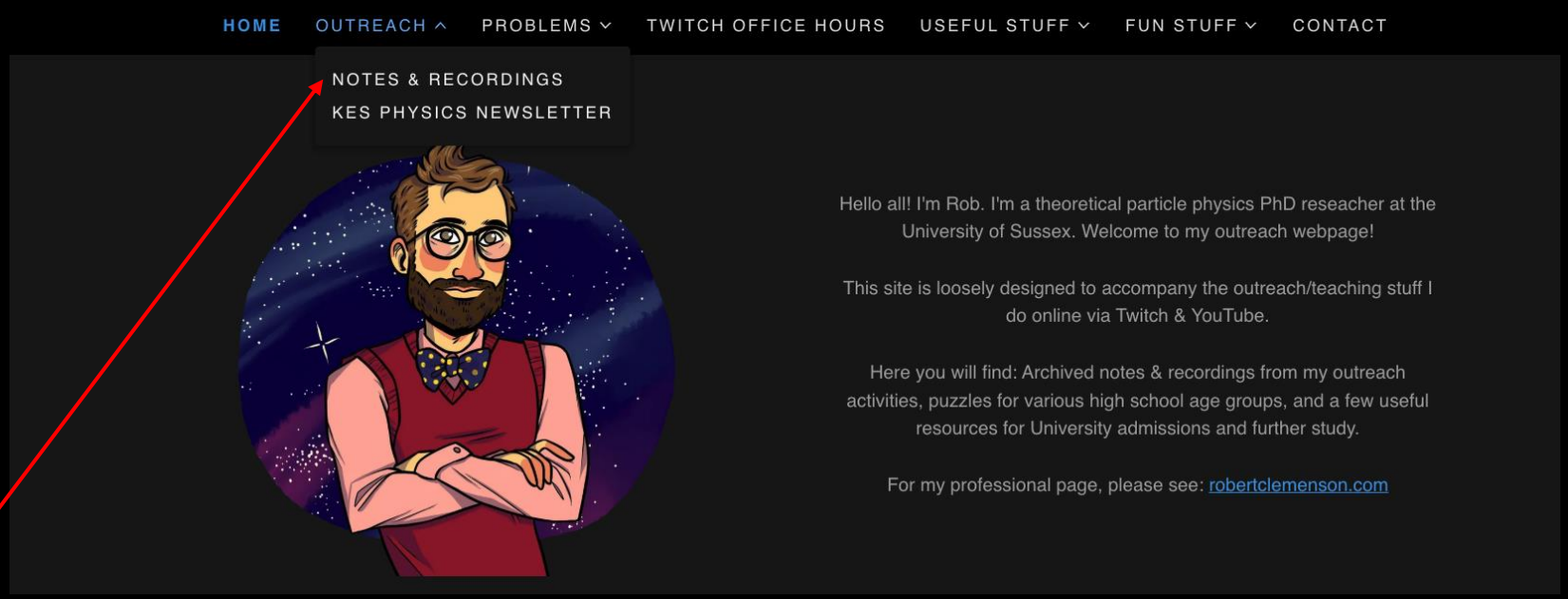
19/07

02/08

Join the Mailing List for Updates!

Visit: Spacetime-Sundays.com

Lecture Slides



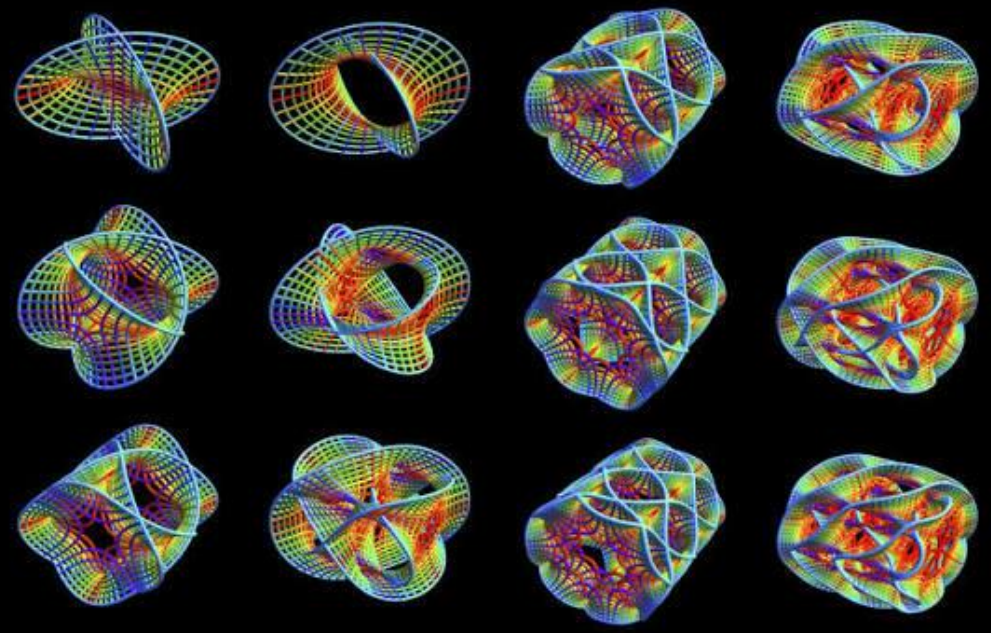
These lecture slides are available on my outreach website:

CosmicConundra.com

Coming Up...

The Science of Spacetime:
A Physicists Guide to the Galaxy

Every other Saturday 11:30am in the Beecroft Gallery Lecture Theatre



~~*Building a Universe from Scratch (06/06)*~~

~~*Black Holes: Monsters of the Cosmos (20/06)*~~

~~*The Physics of Science Fiction: Tardises, Teleports, and beyond… (04/07)*~~

“Not Even Wrong”: The Strangest Ideas in Theoretical Physics (18/07)