TEXAS A&M UNIVERSITY

Relativity Lite

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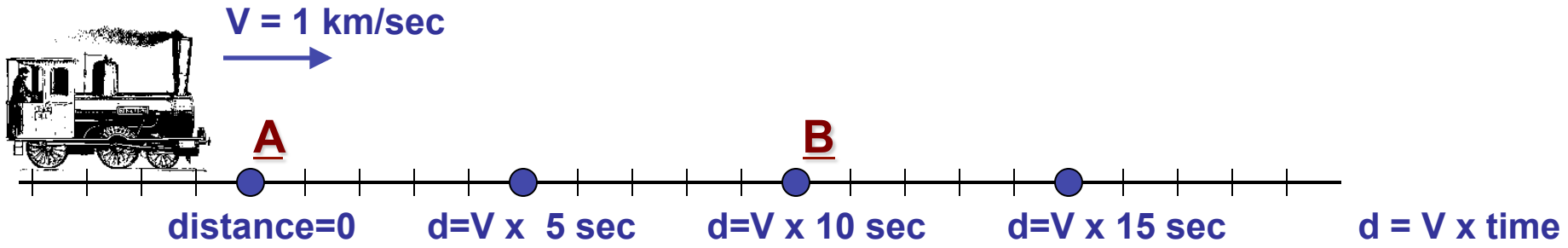
A brief introduction to :

- ***Special Relativity***
- ***General Relativity***

Intuition and common sense in Relativity

- You on land, friend driving train. Tell you friend to turn the lights on 10 seconds after passing stop A.



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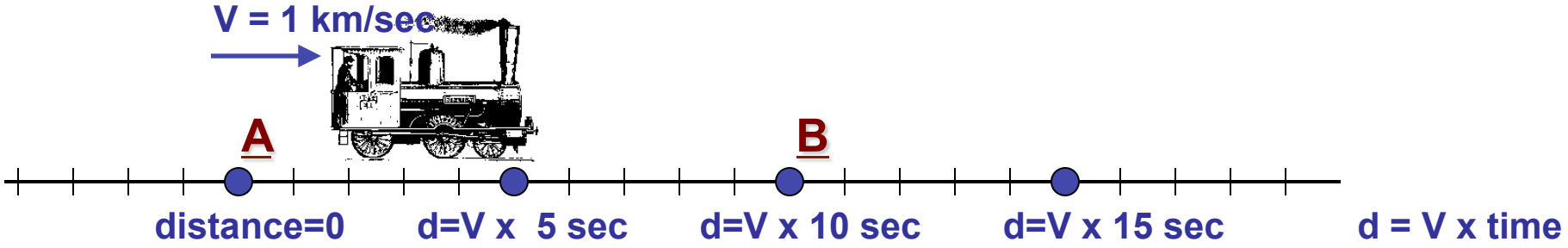

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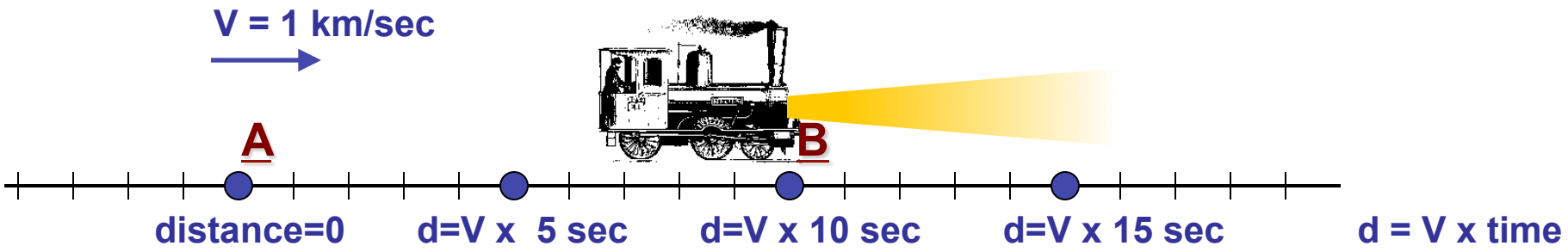

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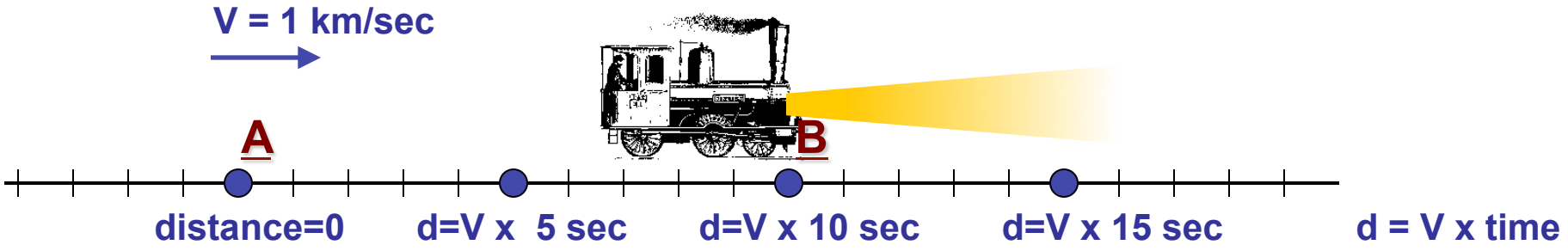

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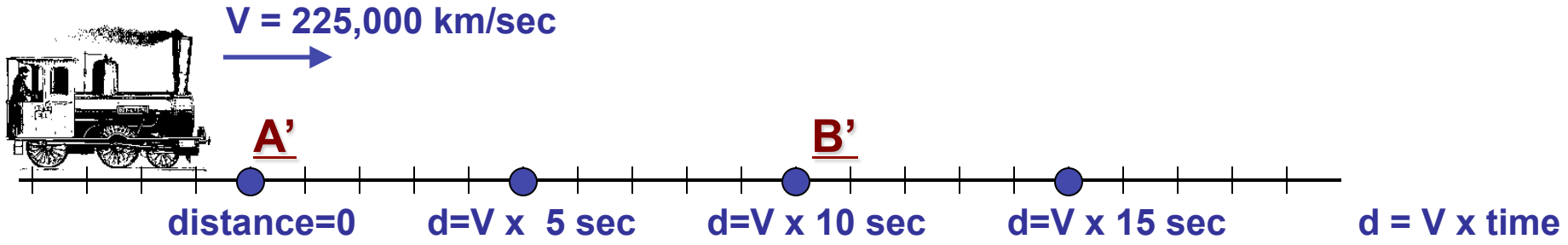

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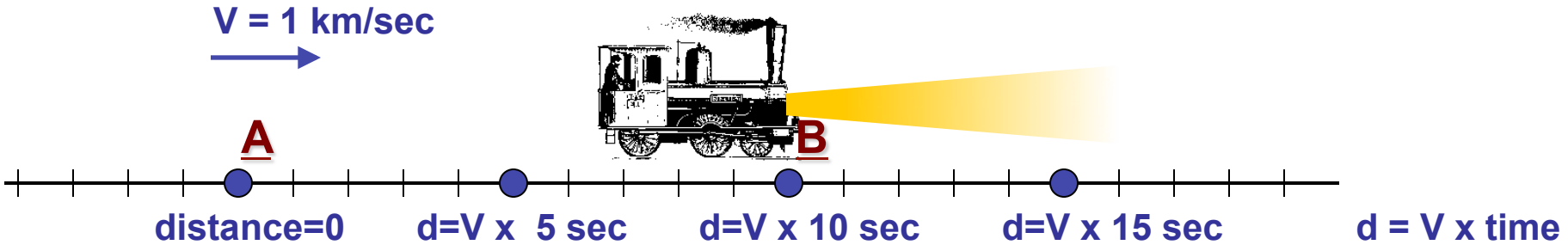

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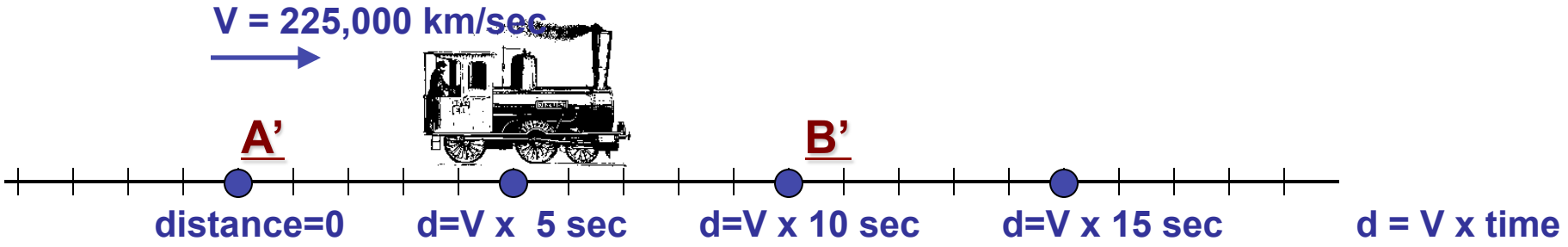

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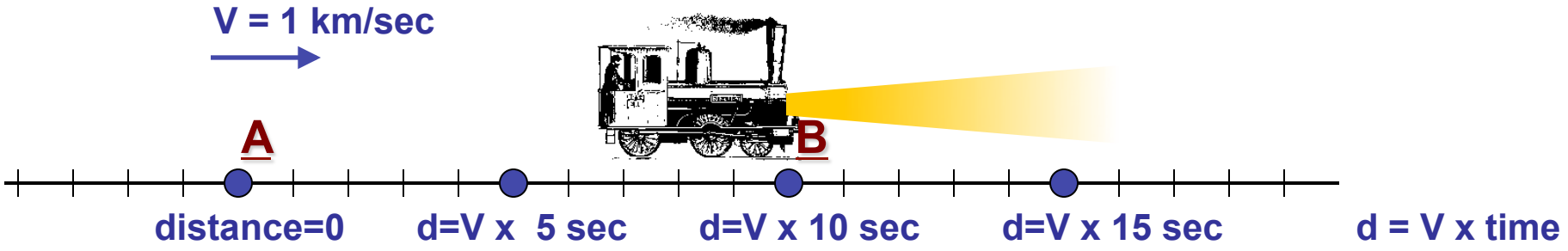

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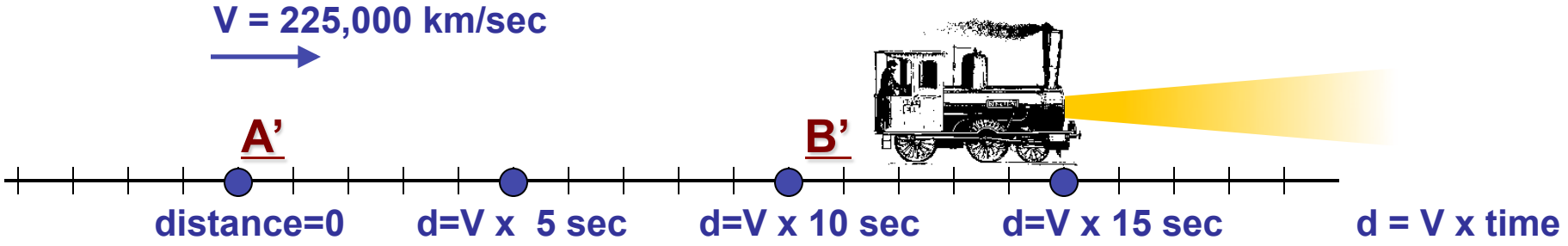
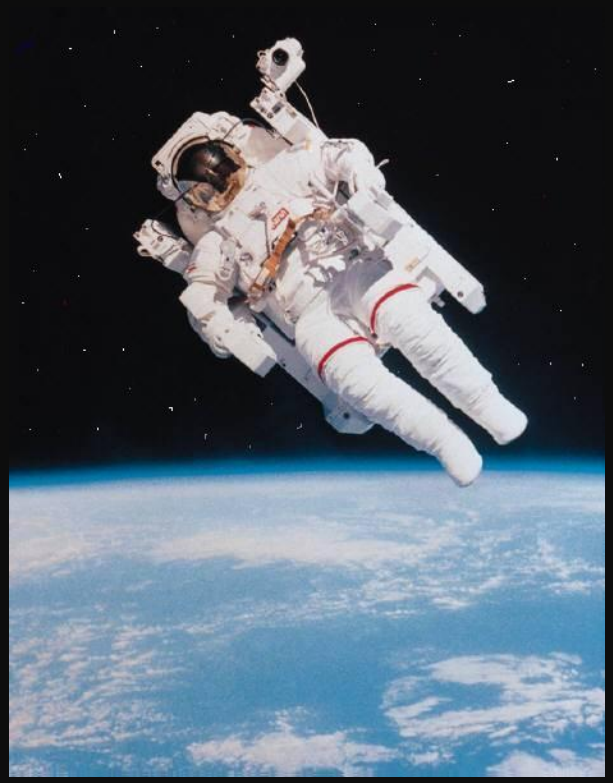


This effect was theoretically predicted before any experiment confirmed it!!
To understand this we need to go back to the times of Galileo

New Chapter

Physics before Einstein

Principle of Relativity



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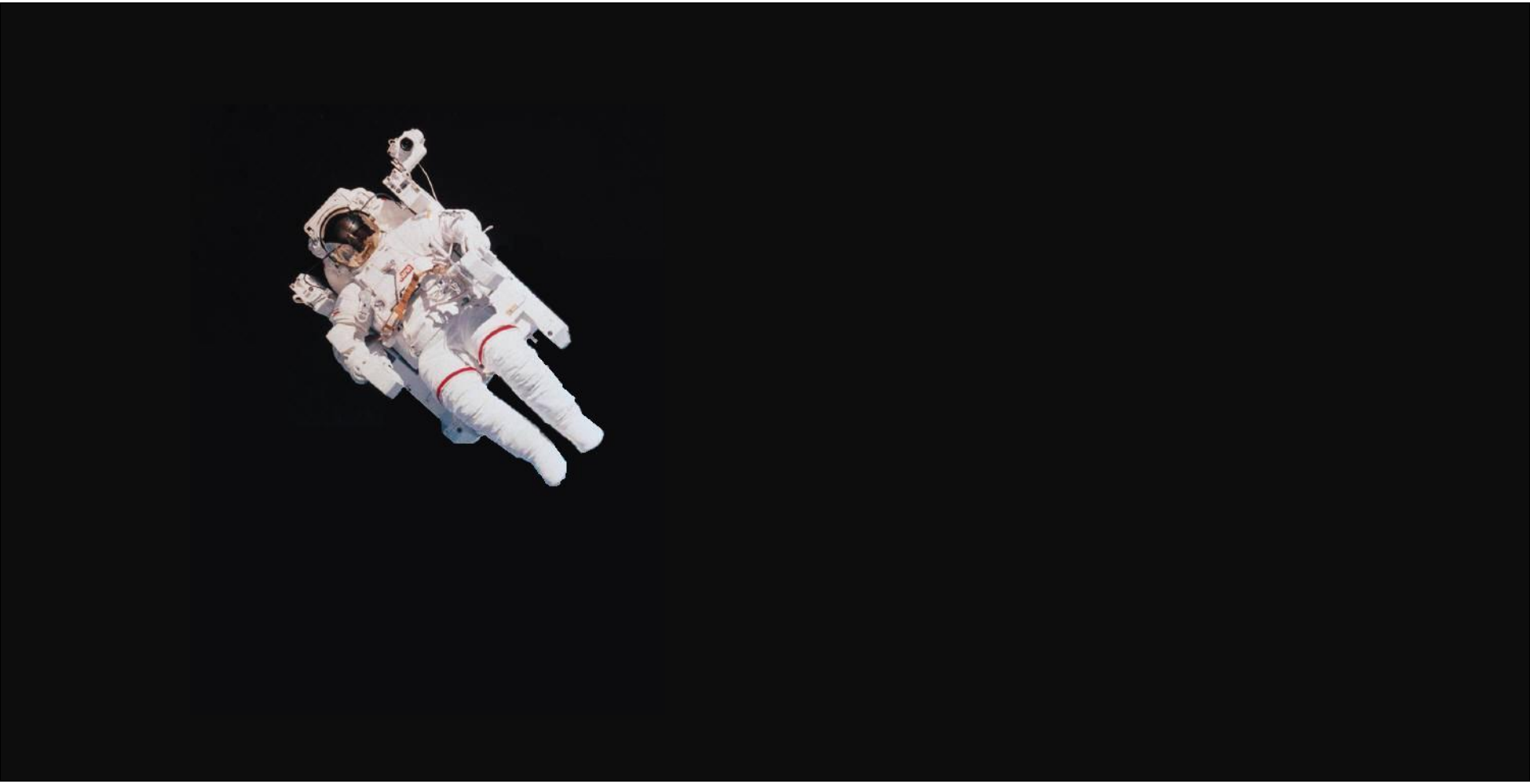


Principle of Relativity: All states of uniform motion are equivalent for the description of physical phenomena

Physics before 1900's:

- **It was assumed:**

$$x' = x - \mathrm{V} \times \mathrm{t}$$

$$t' = t$$

Absolute time !

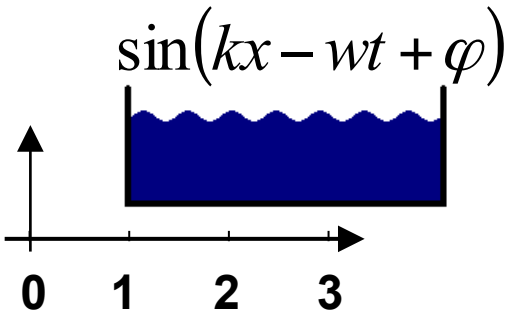
This is a Galilean transformation

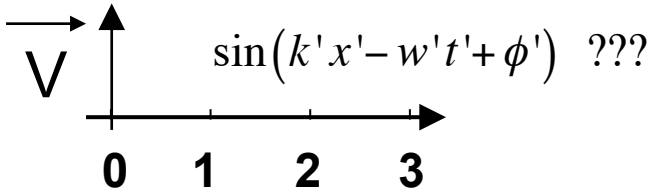
- **Consequences:**
  1. Applying this to a velocity **v'** we obtain:

$$v' = v - V$$

Transformation of velocities
Velocities can go up to infinity!

  2. Waves:





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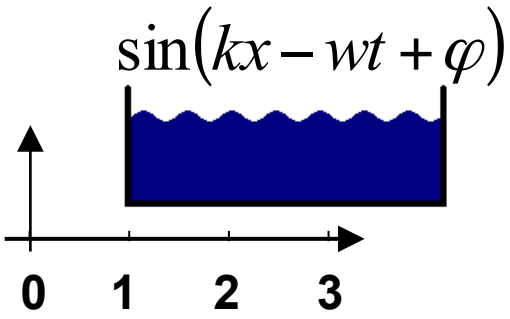
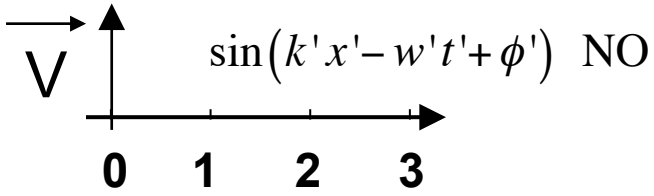




According to Galilean transformations:
-what looks like a wave in one r.f. does not look like a wave in another.
-to talk about waves one must specify a reference frame,

New Chapter

A Problem Arises

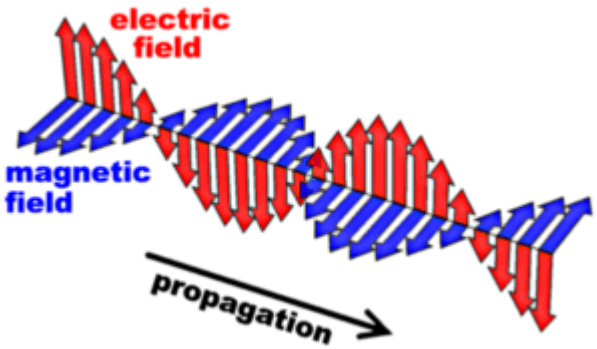
The problem: electromagnetism (light)

- **Electromagnetic waves**
  - Maxwell wrote the basic theory in 1860's
  - Heinrich Hertz sent and received radio waves in 1890's
  - Radio waves predicted and measured to move with the speed of light!

Problem:

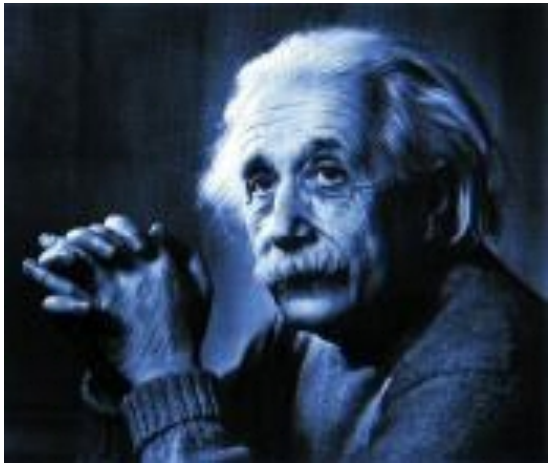
Maxwell equations are not invariant to Galilean transformations of r.f.

- **Three options:**
  - Maxwell equations are wrong.
  - Galilean transformations are wrong.
  - The relativity principle is wrong for light.
    Is there an ether through which light propagates ?



New Chapter

The solution, by Albert Einstein



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- **He postulated:**

  - *Principle of relativity is valid.*
    The principle of Relativity is symmetrically nice. Only ether could violate it, but the ether has not been found.

  - *The velocity of light (in vacuum) is the same in all r.f.'s*
    Maxwell equations predict the velocity of light, which has been measured to be the same as predicted. Maxwell is right and the velocity of light is the same regardless the r.f. from which we look.

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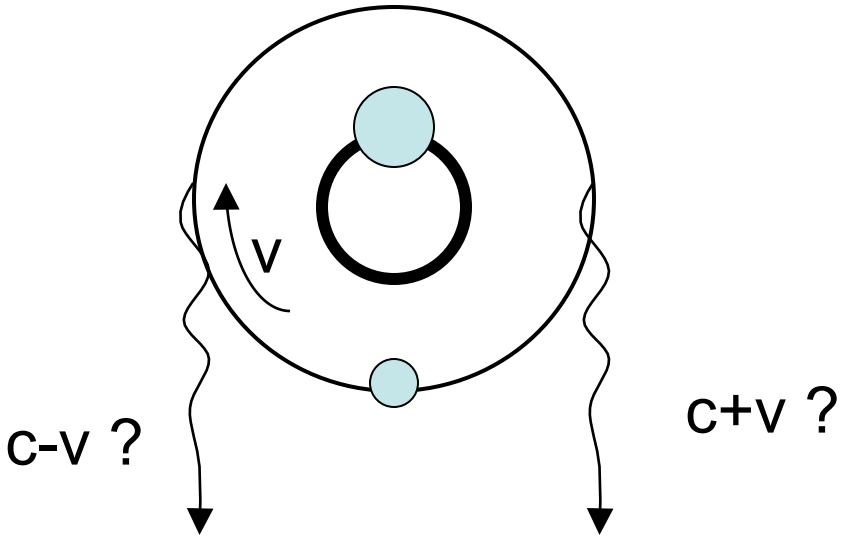

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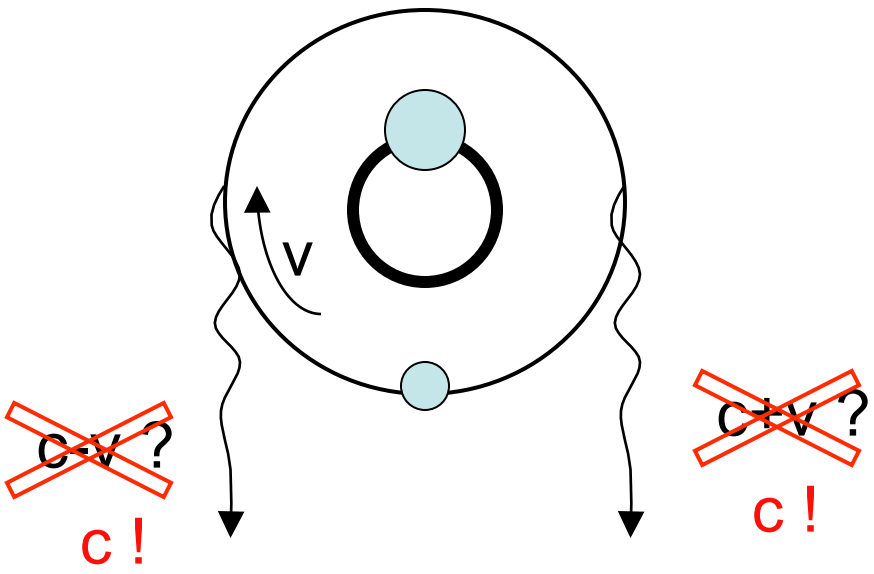
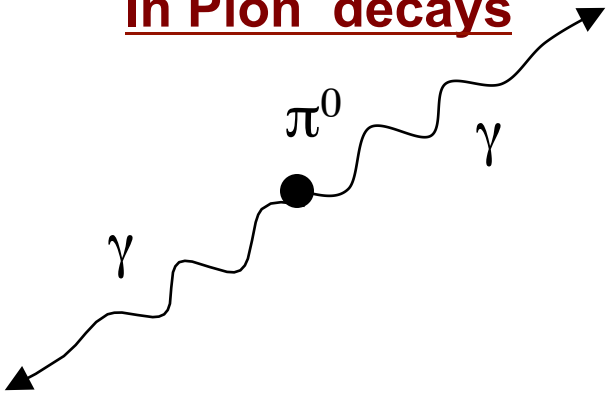


In Pion decays



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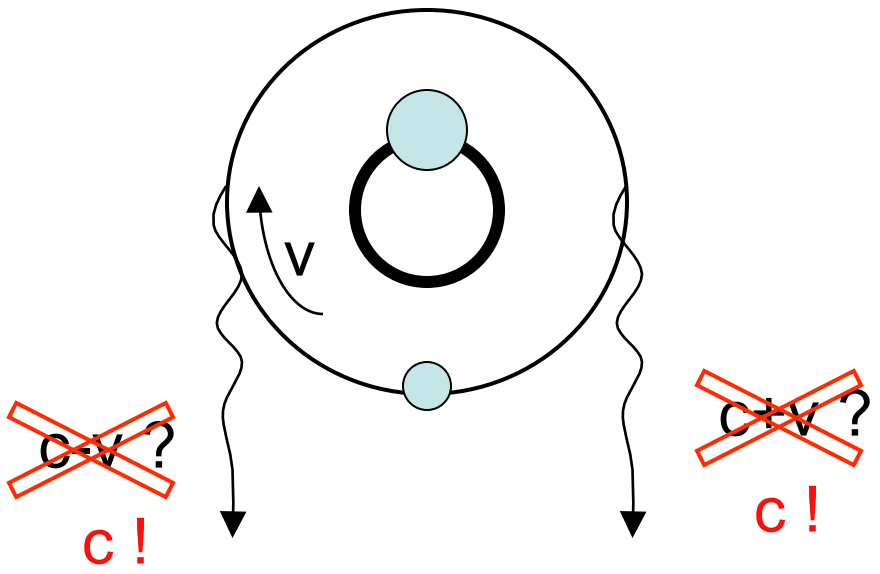

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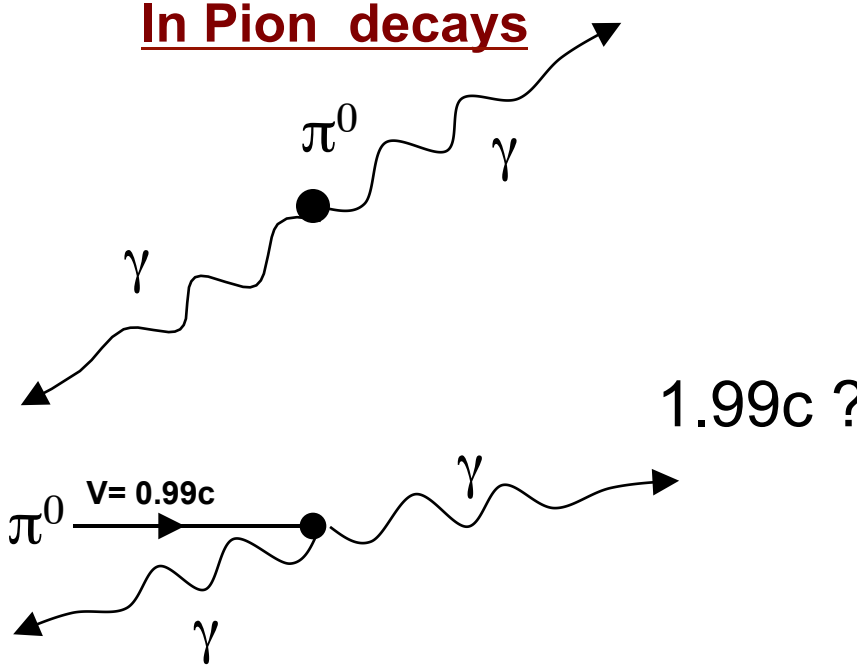

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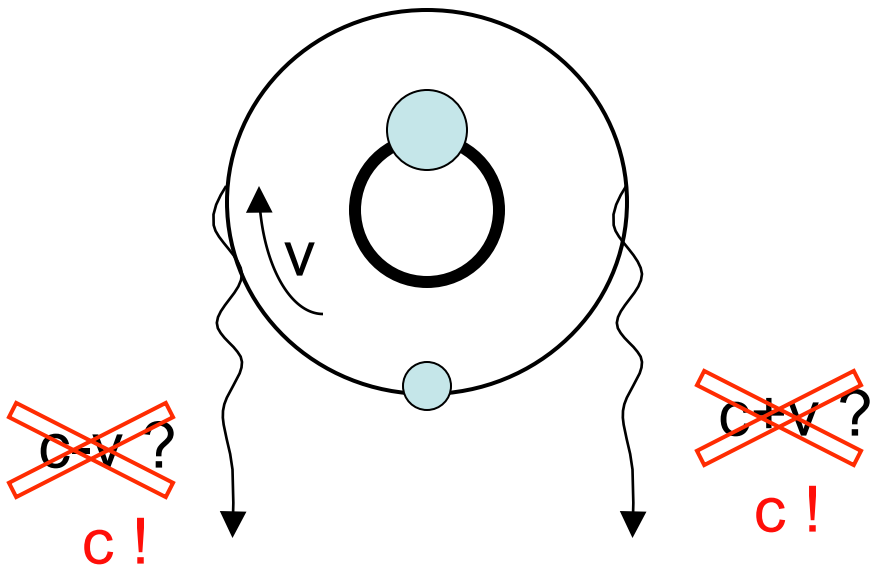

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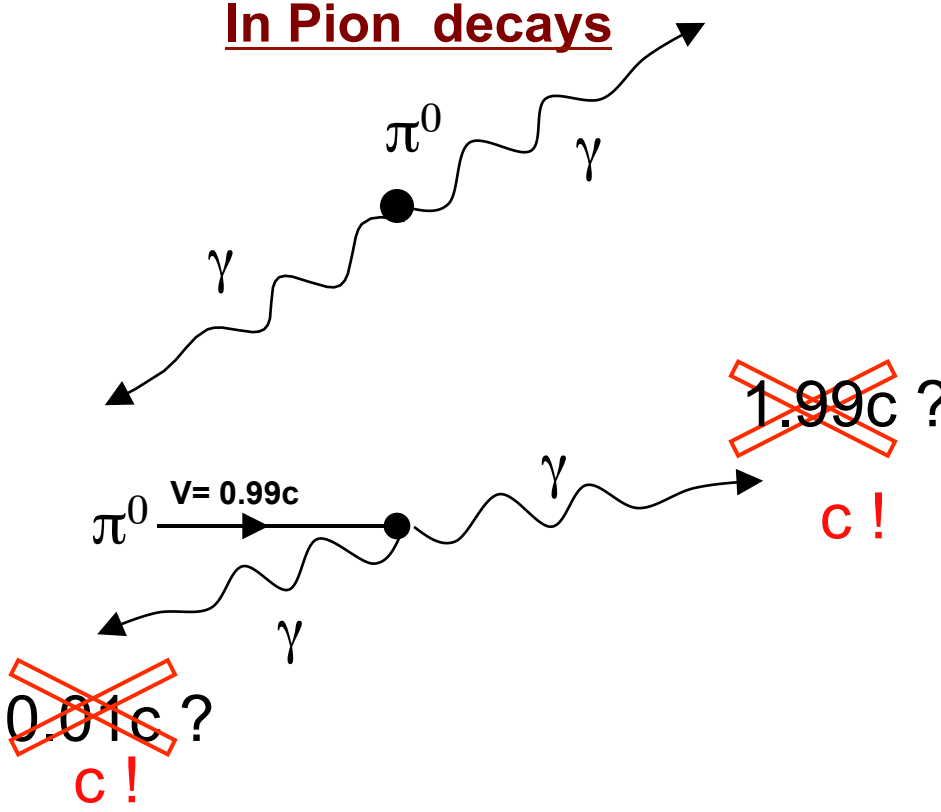
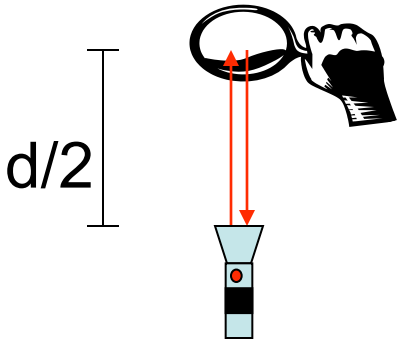


Time in Relativity

- In r.f. S' we make a clock based on light.



$\Delta t' = d/c$

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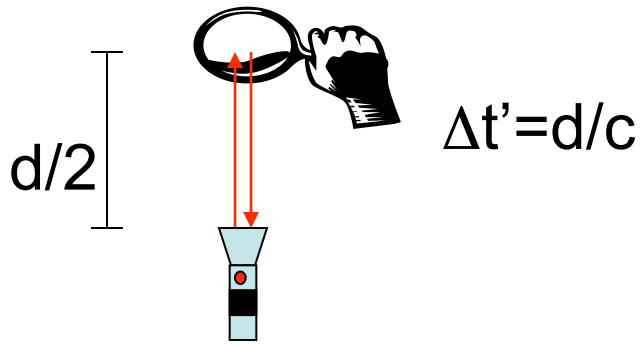

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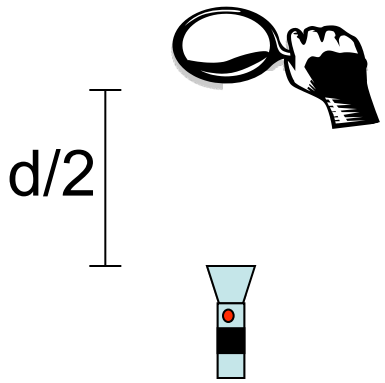

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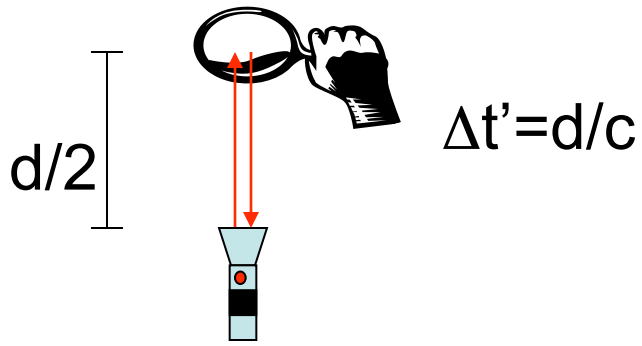

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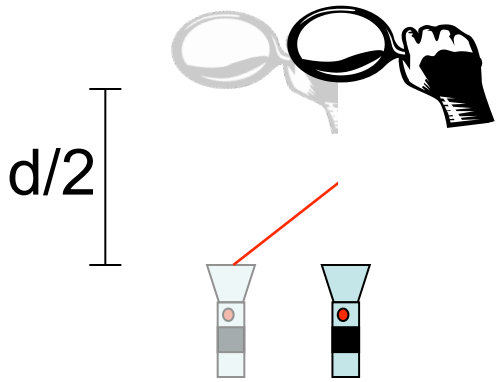

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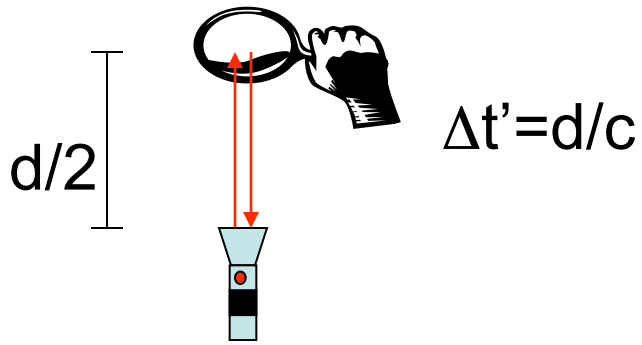

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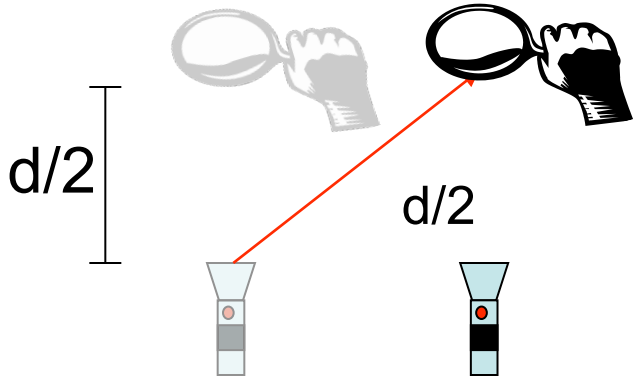

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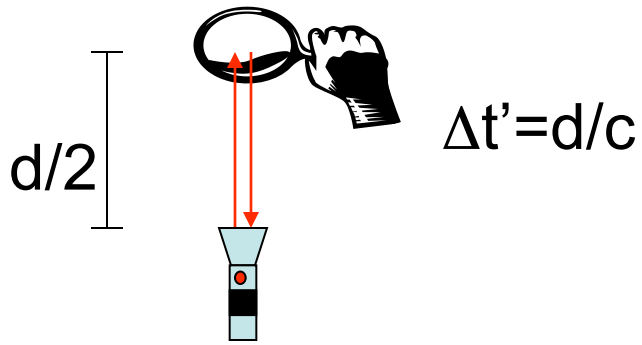

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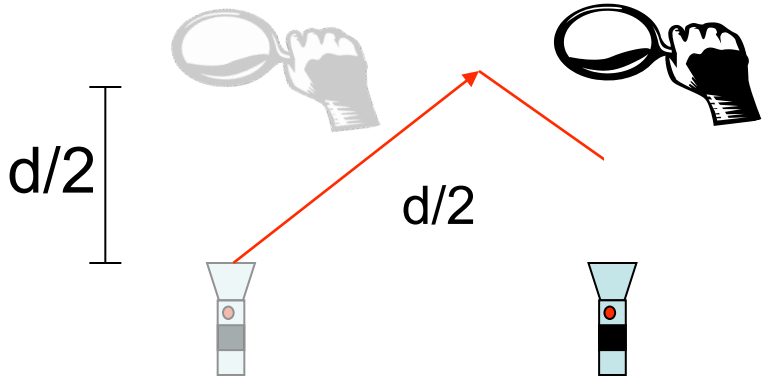

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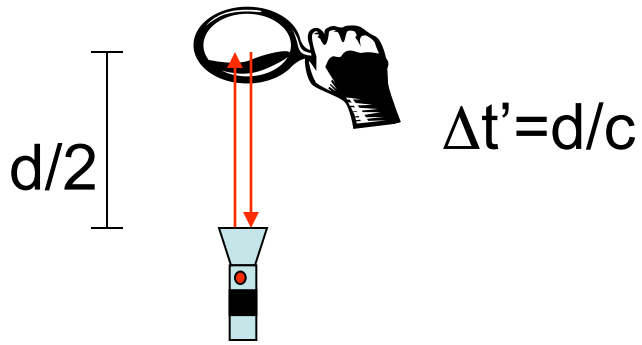

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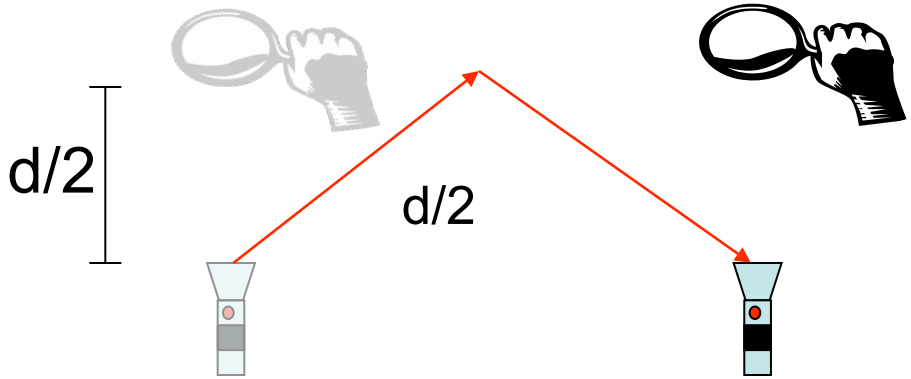

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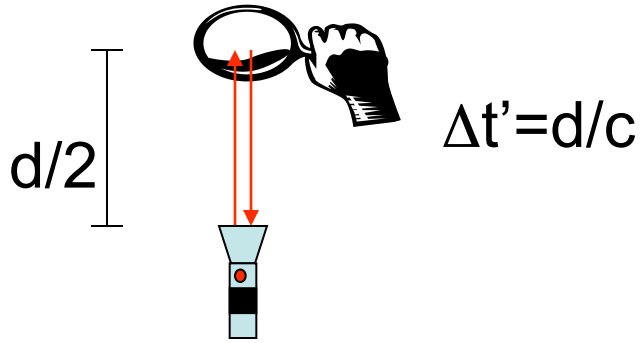

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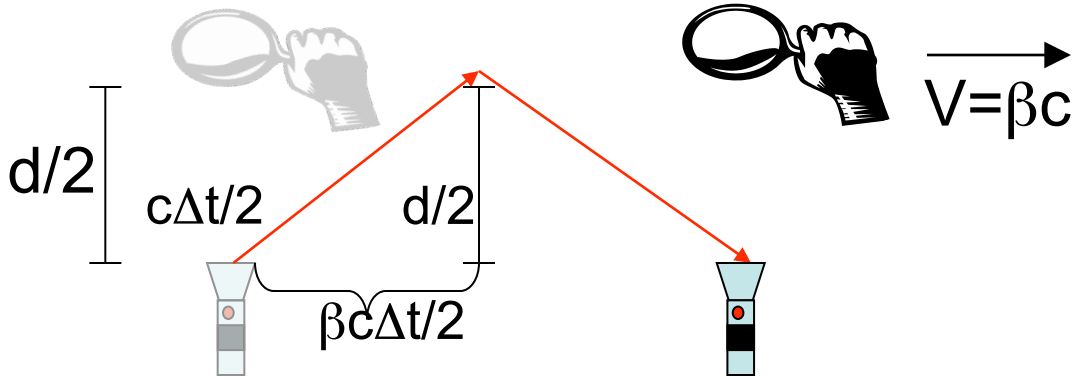

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$$\Delta t^2 (1-\beta^2) = \frac{d^2}{c^2}$$

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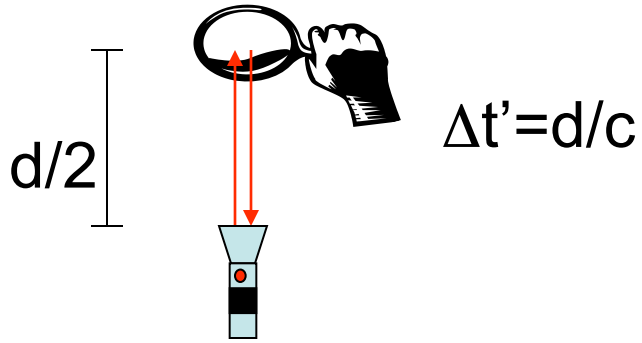

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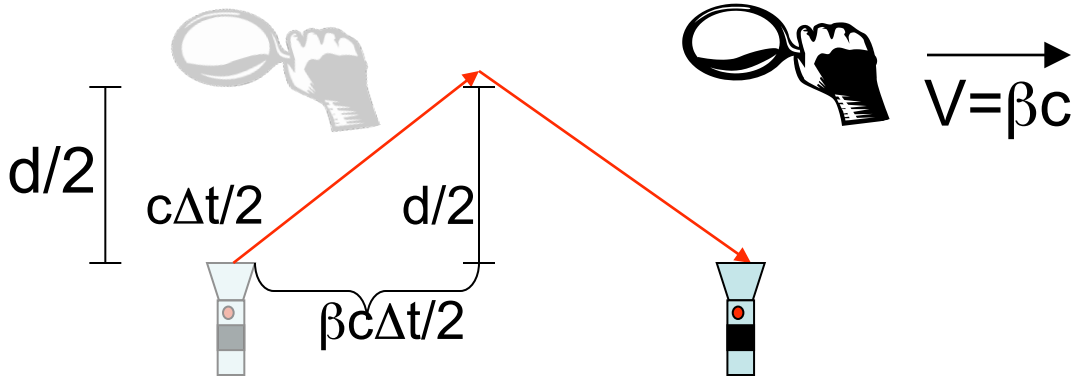

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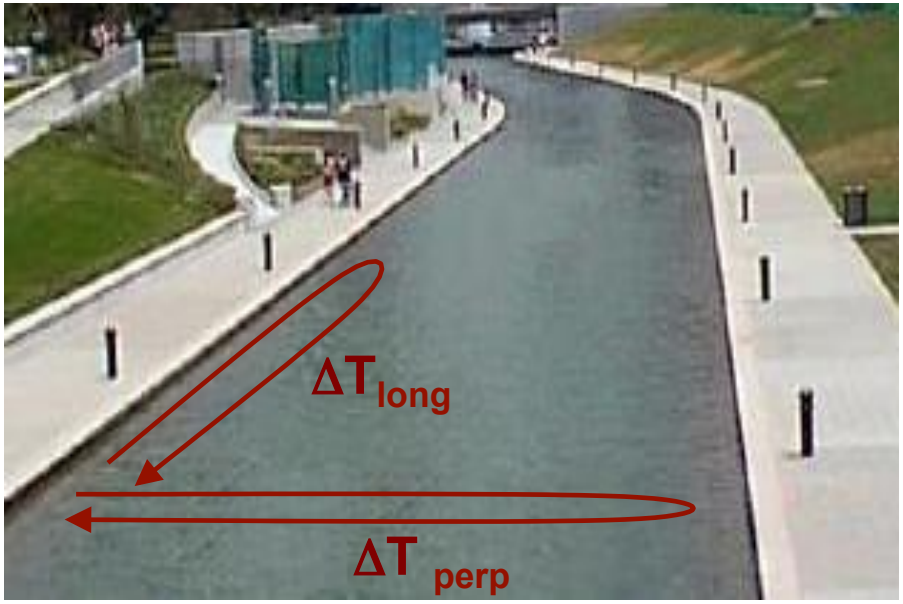
Moving clocks run slower than to non-moving clocks !!!

About swimming on the water

- Basic idea: swim 20 meters (measured from ground) back and forth
  - Still waters: $T_{long}=T_{perp}$



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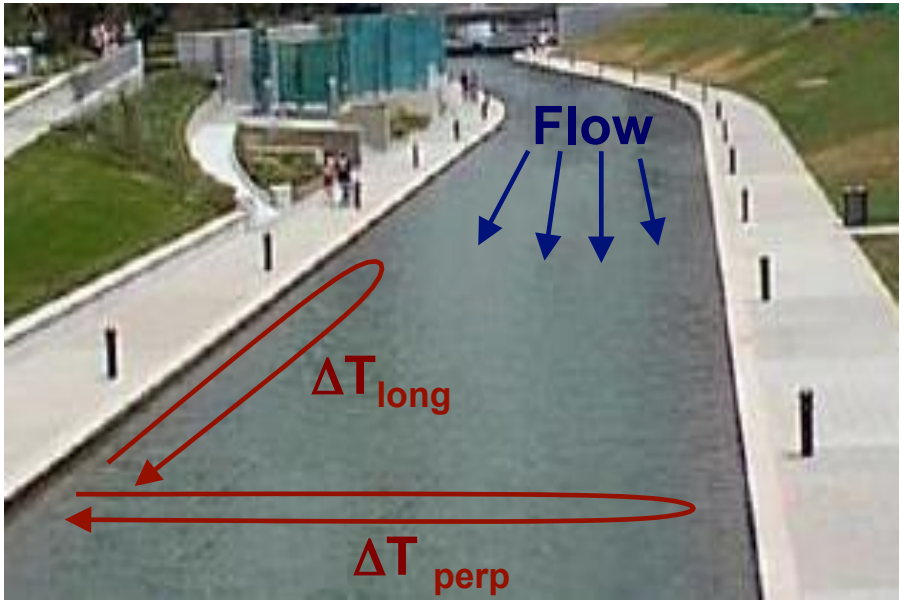

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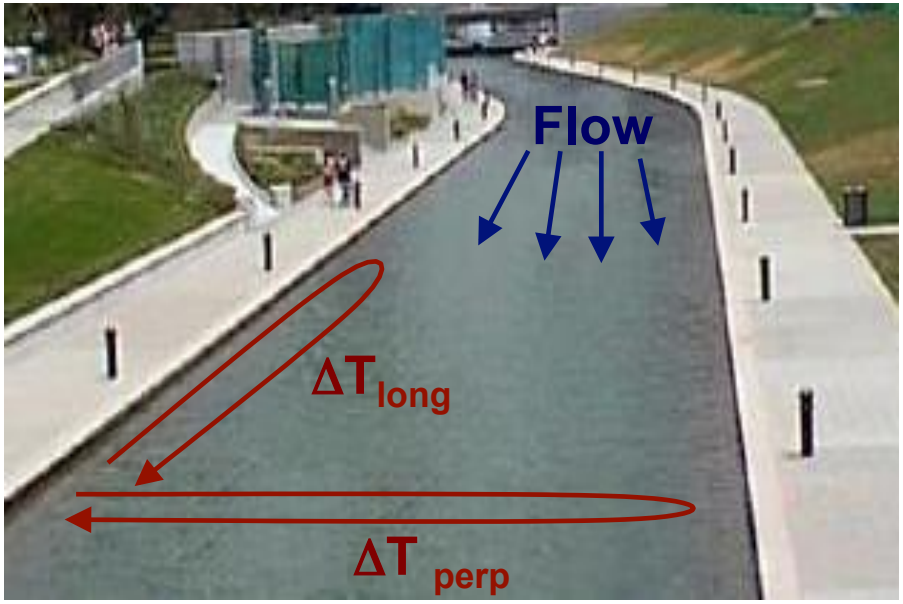
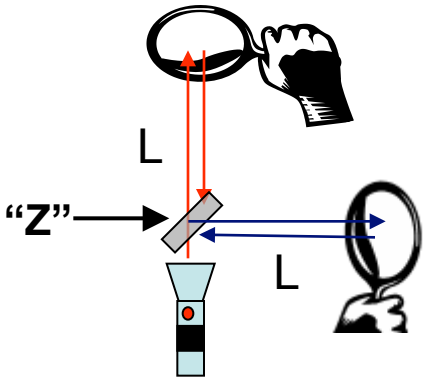


If two identical swimmers were to reach the original position at the same time it would mean that swimmer going longitudinally travelled a smaller distance!

Space in Relativity

- Clock with two arms of the same length.



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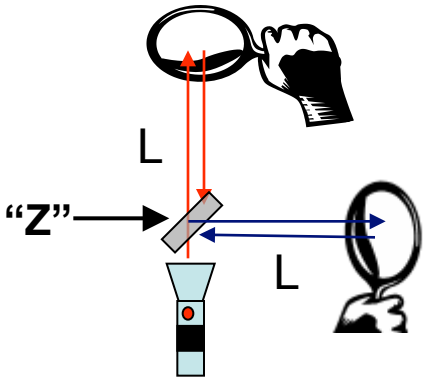

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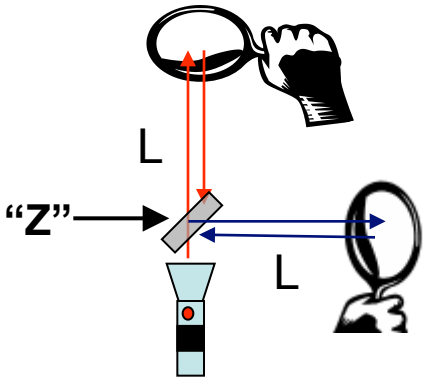

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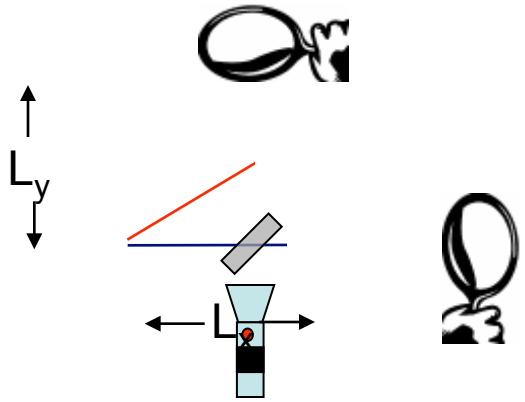

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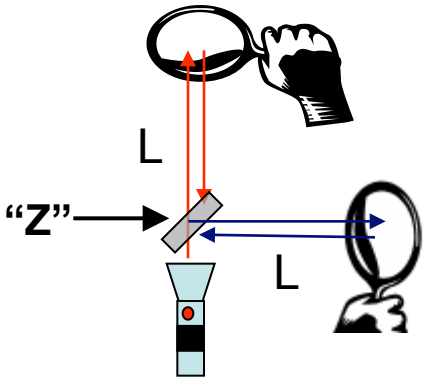

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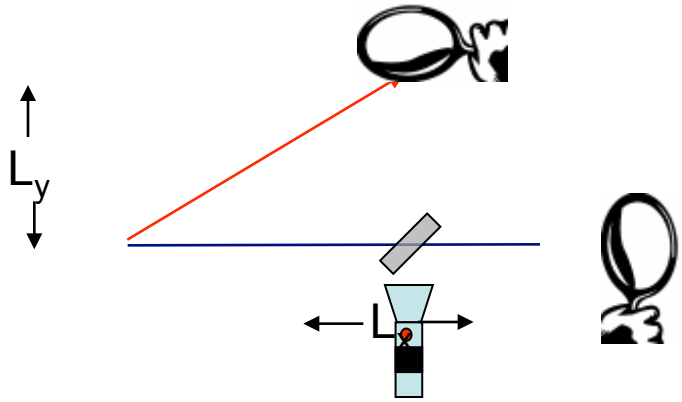

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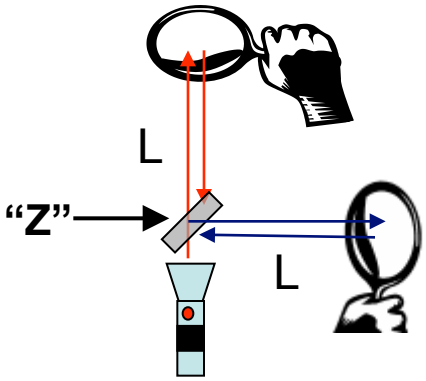

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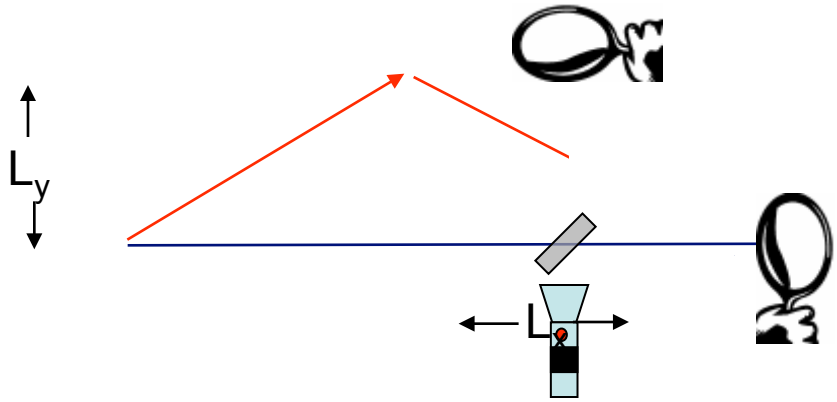

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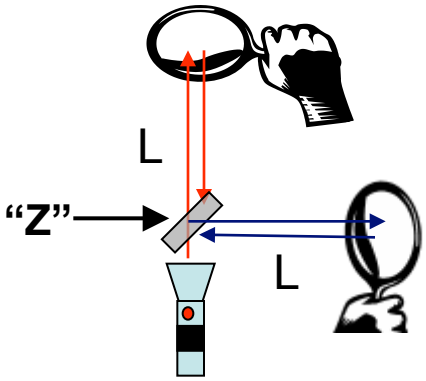

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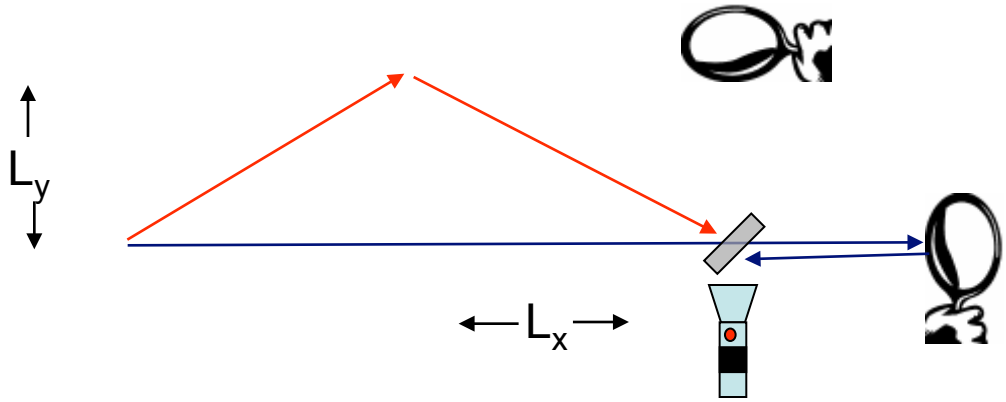

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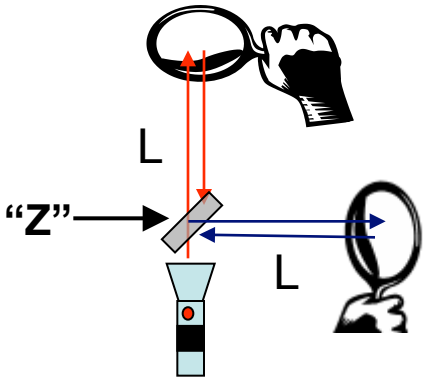

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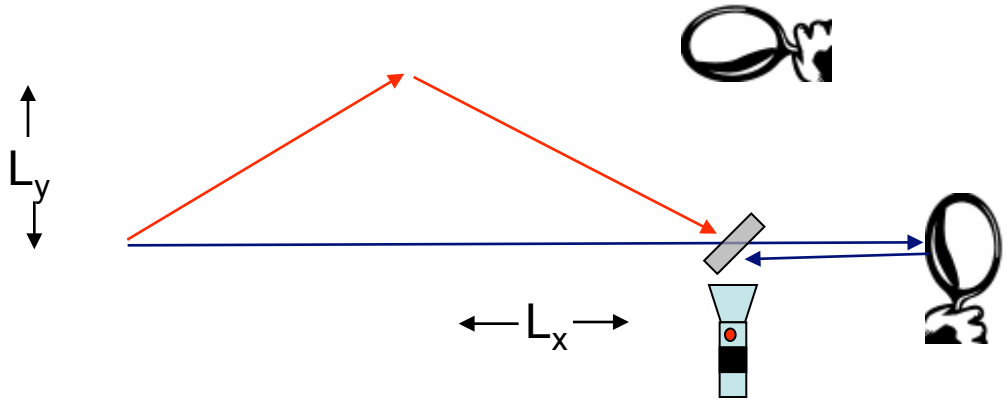

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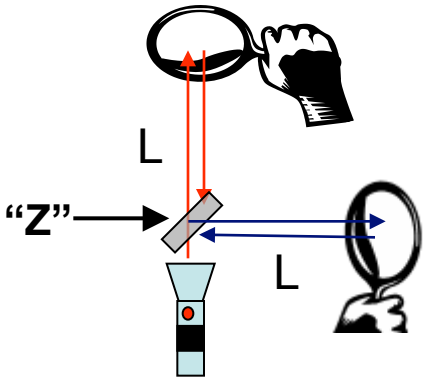

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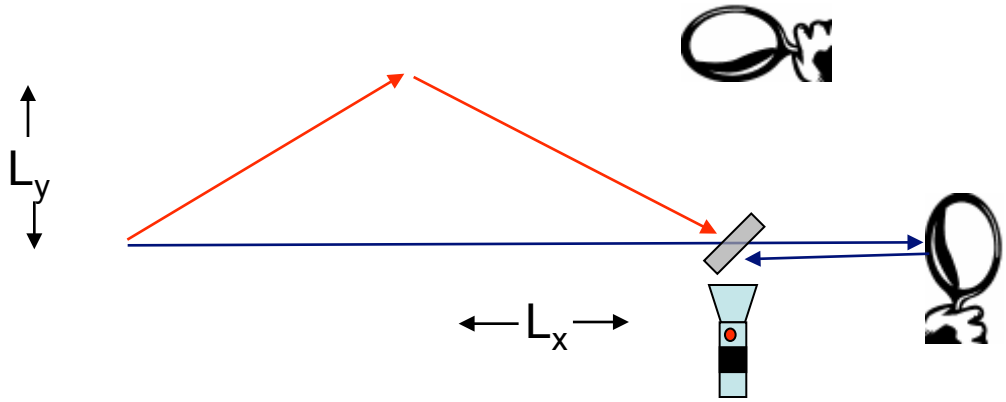

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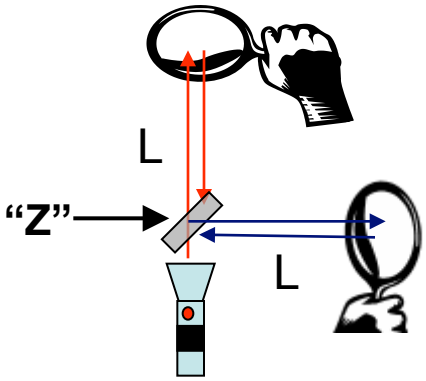

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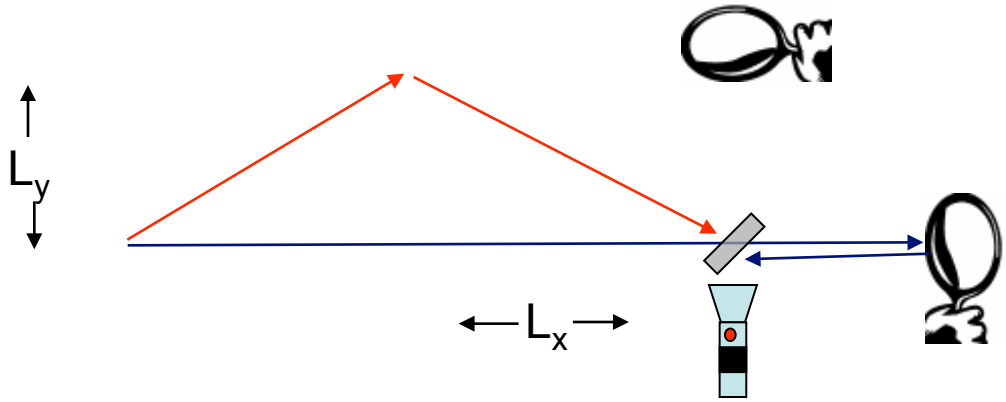

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Moving Lengths look shorter !!!

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- Muons are particles that decay (on average) every 2 μs.
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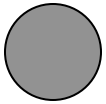

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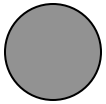

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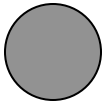

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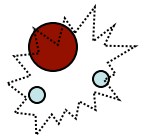

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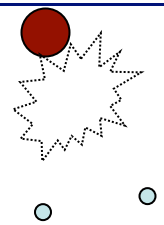

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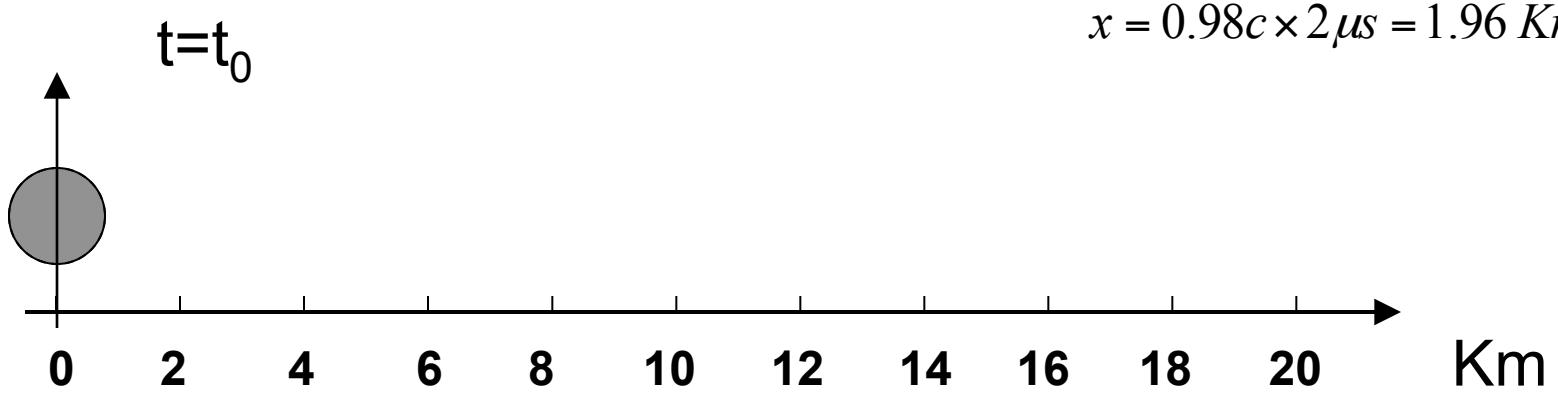
$$x = 0.98c \times 2\mu s = 1.96\ Km$$



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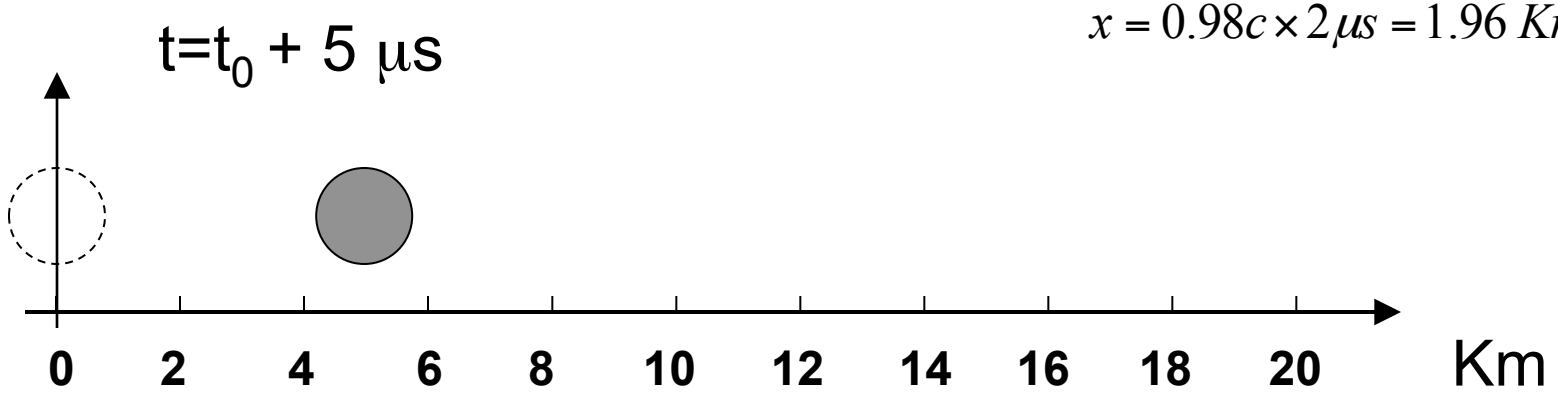

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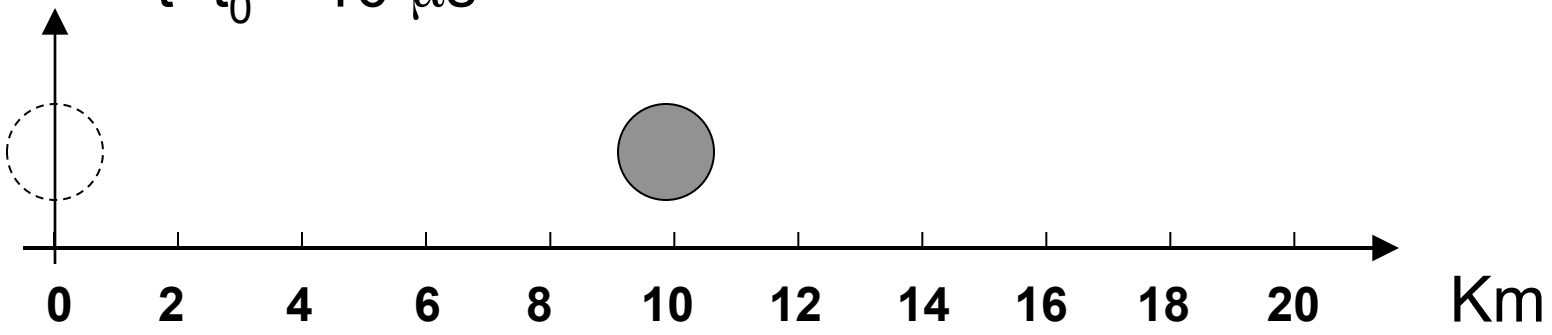

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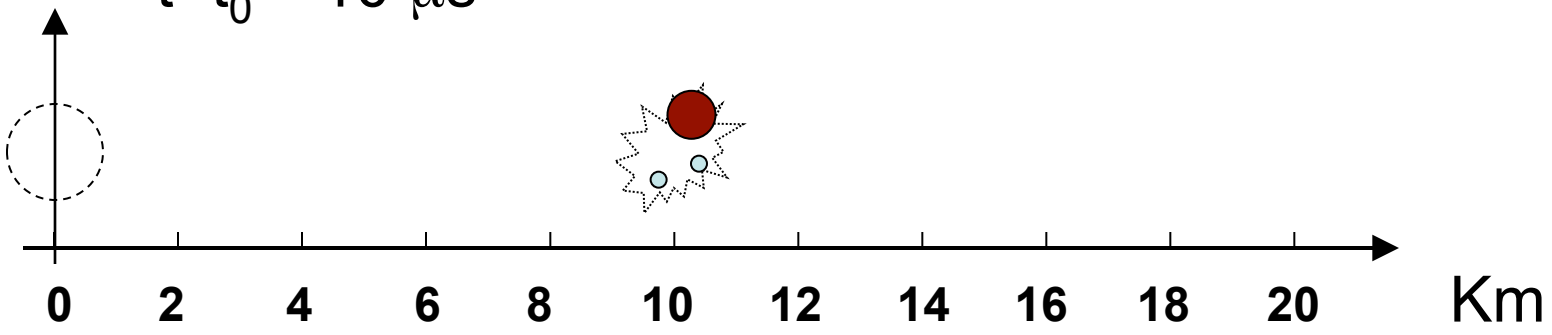

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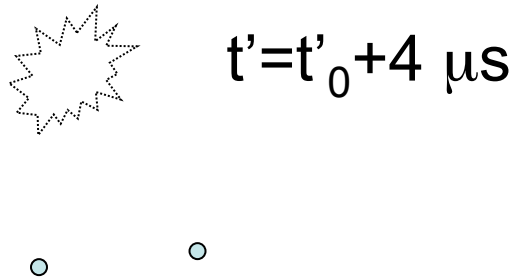

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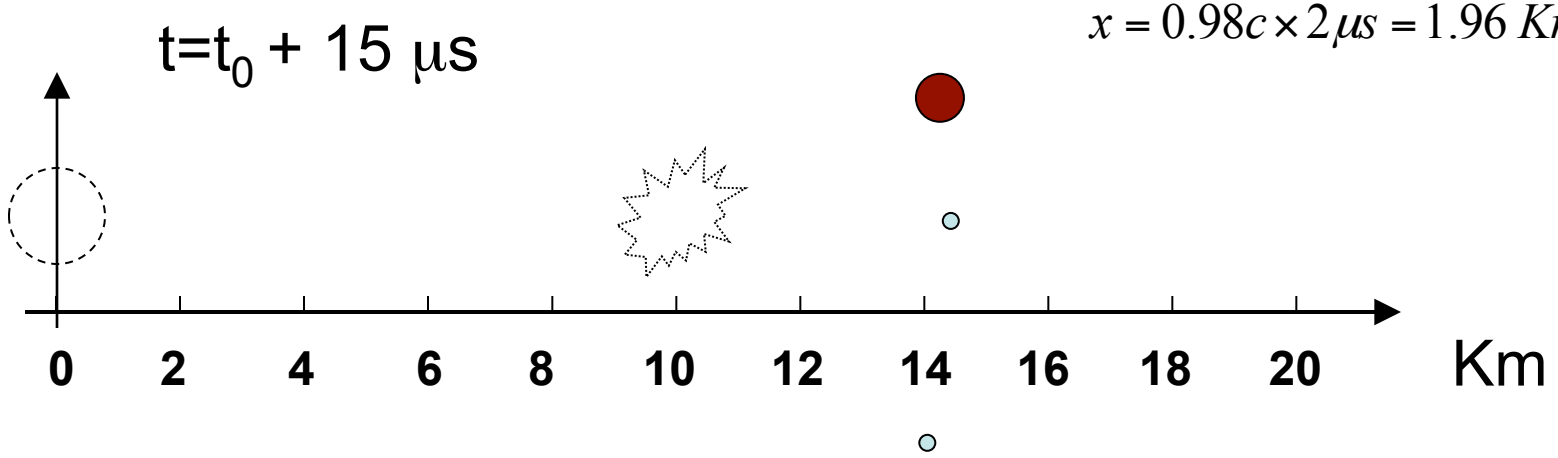

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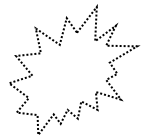

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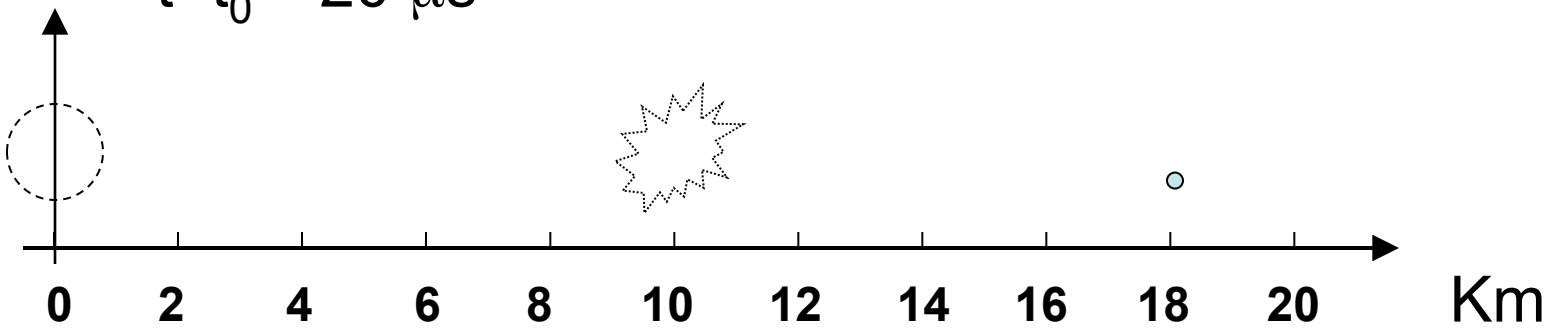

Time dilation in muons

Muon traveling at 0.98c down the atmosphere

- **As viewed in the earth reference frame**
  - The landscape has it's normal size.
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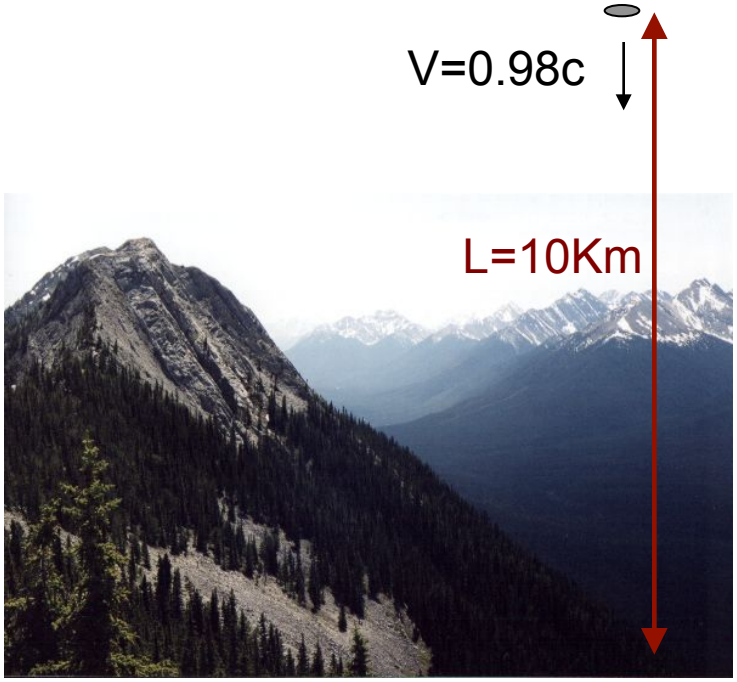
  - Muon's clock run 5 times slower.



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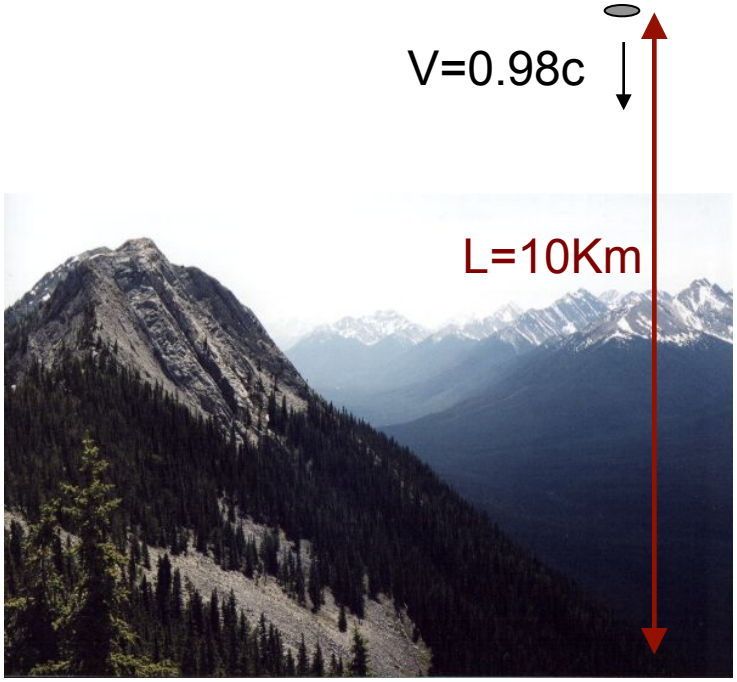

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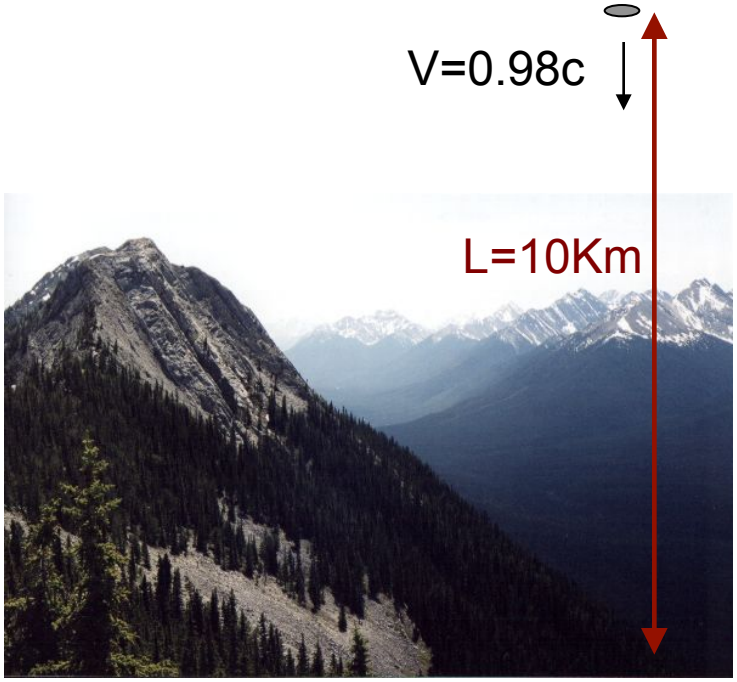

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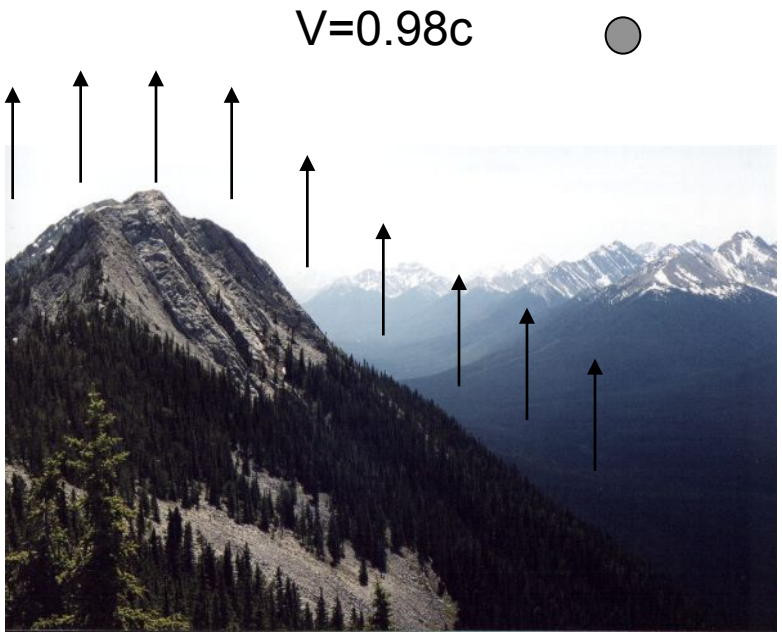

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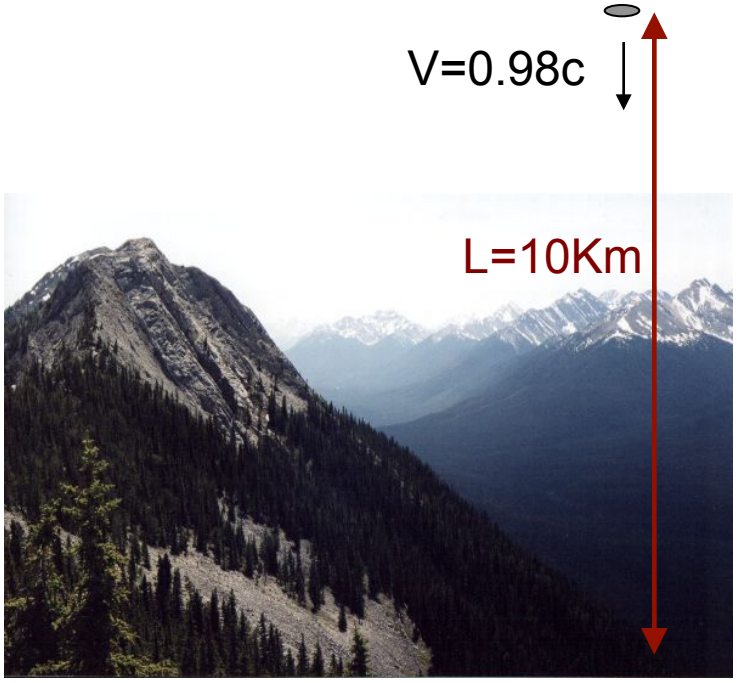

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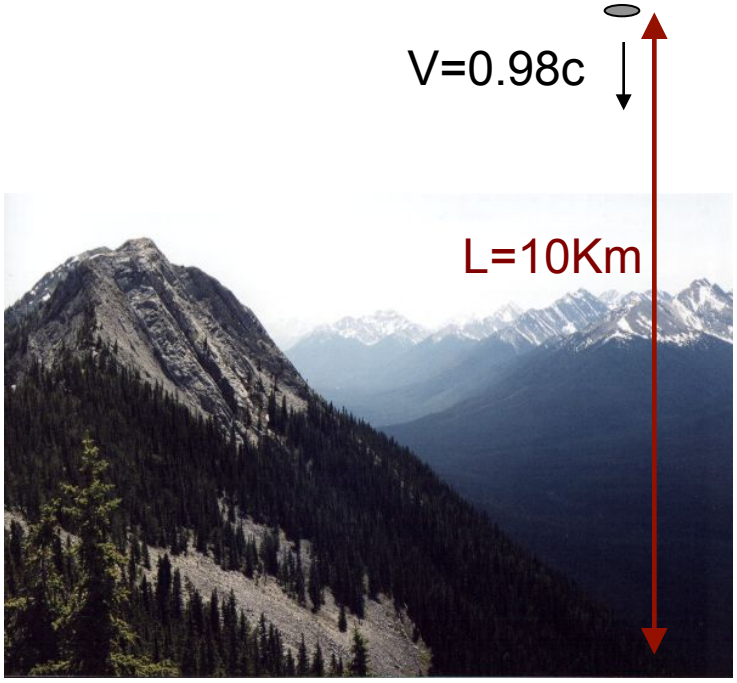

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Both frames predict the same results: muon decays at the base

Light carries momentum

- **Shooting a pulse of light to a cannonball**

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What is going to happen ?

- Let's find out. Rules of the game
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    - Photons have intrinsic momentum
    - Momentum of massive particle: mass x velocity

- Given these two rules, only one thing can happen…

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- In r.f. S' we shoot energy towards a ball

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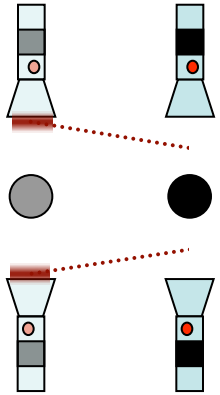

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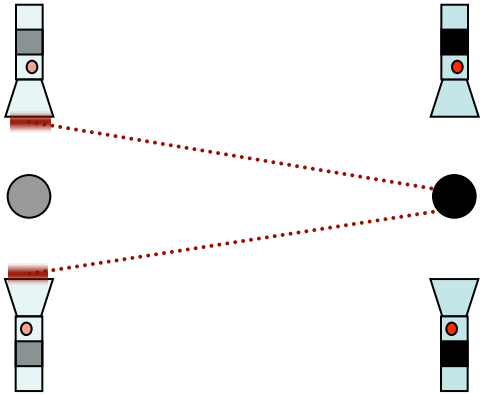

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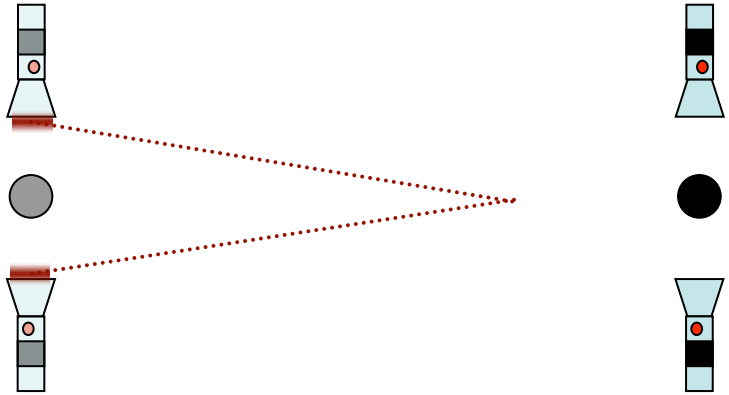

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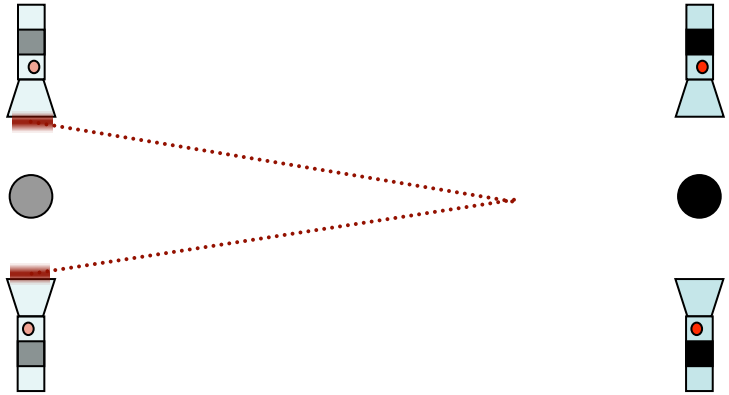

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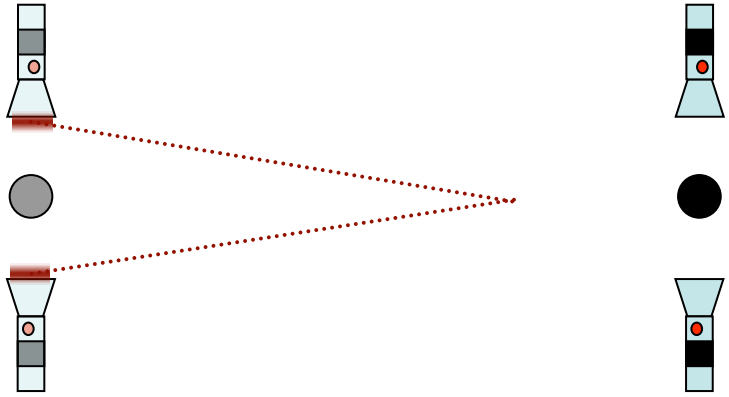

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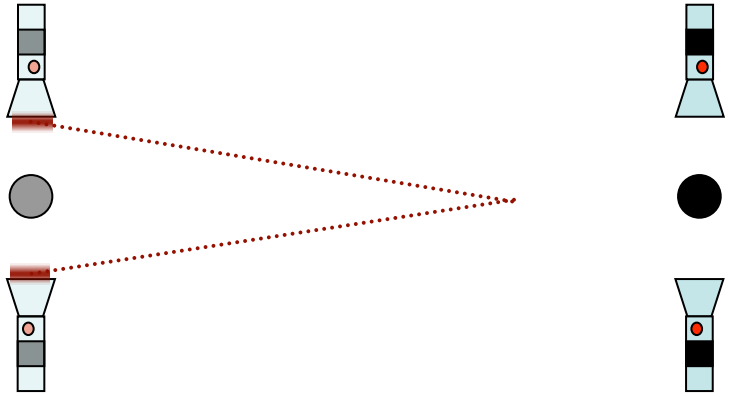

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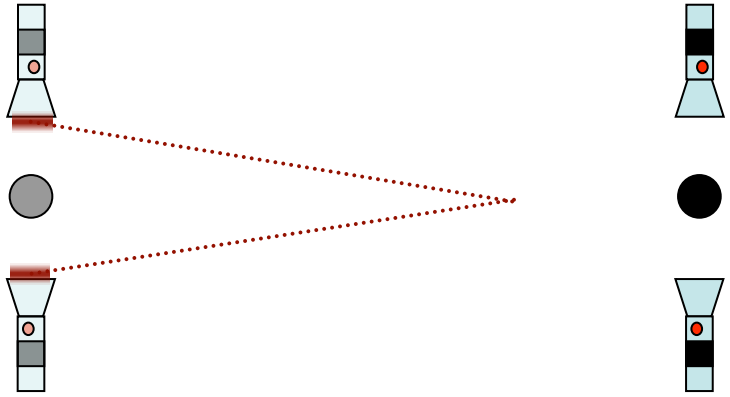

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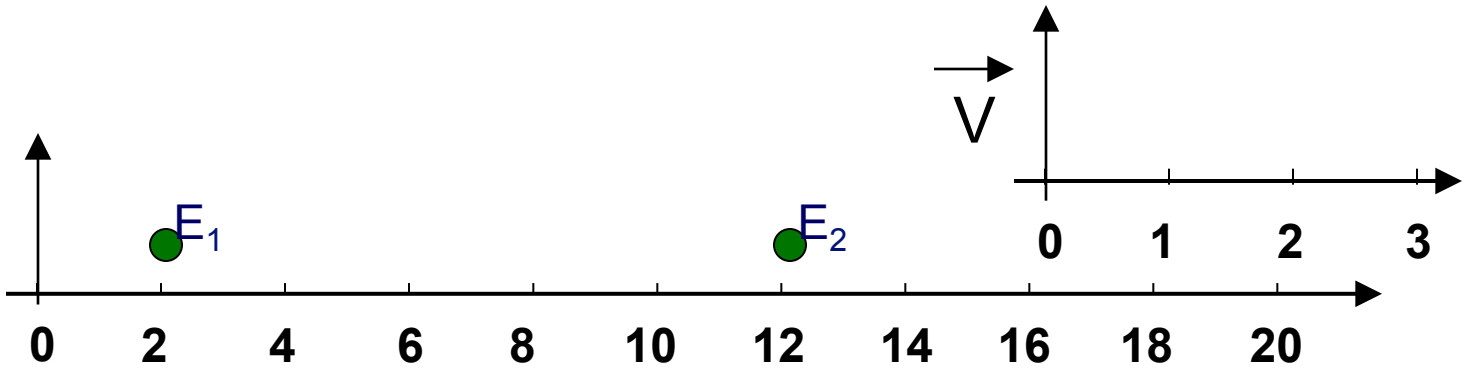
Mass changed!. Mass and energy are related! Einstein found that $E=mc^2$!

Simultaneity in Relativity

- Assume E_1 and E_2 are simultaneous (or $t_1 = t_2$)



- In the moving reference frame:

$$\Delta x' = \gamma \Delta x$$

$$c\Delta t' = -\gamma\beta\, \Delta x$$

The two events are not seen as simultaneous!

- **If V>0 (as drawn) E_2 happens first, later E_1**
- **If V<0 E_1 happens first, later E_2**
- **Event in the direction of the moving r.f. happens first, in this case E_2**

- Can these two events be related, can one be the cause of the other one ?

No! There is no signal that can cover the distance ΔX in no time!

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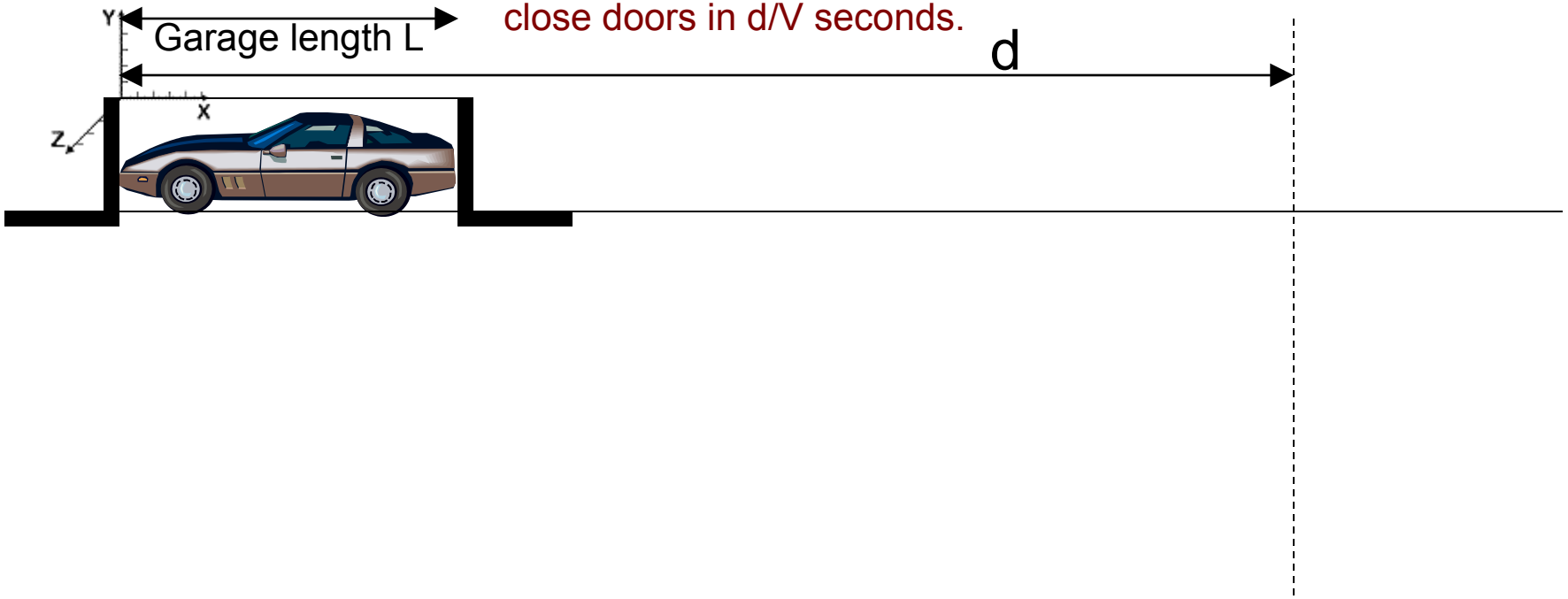

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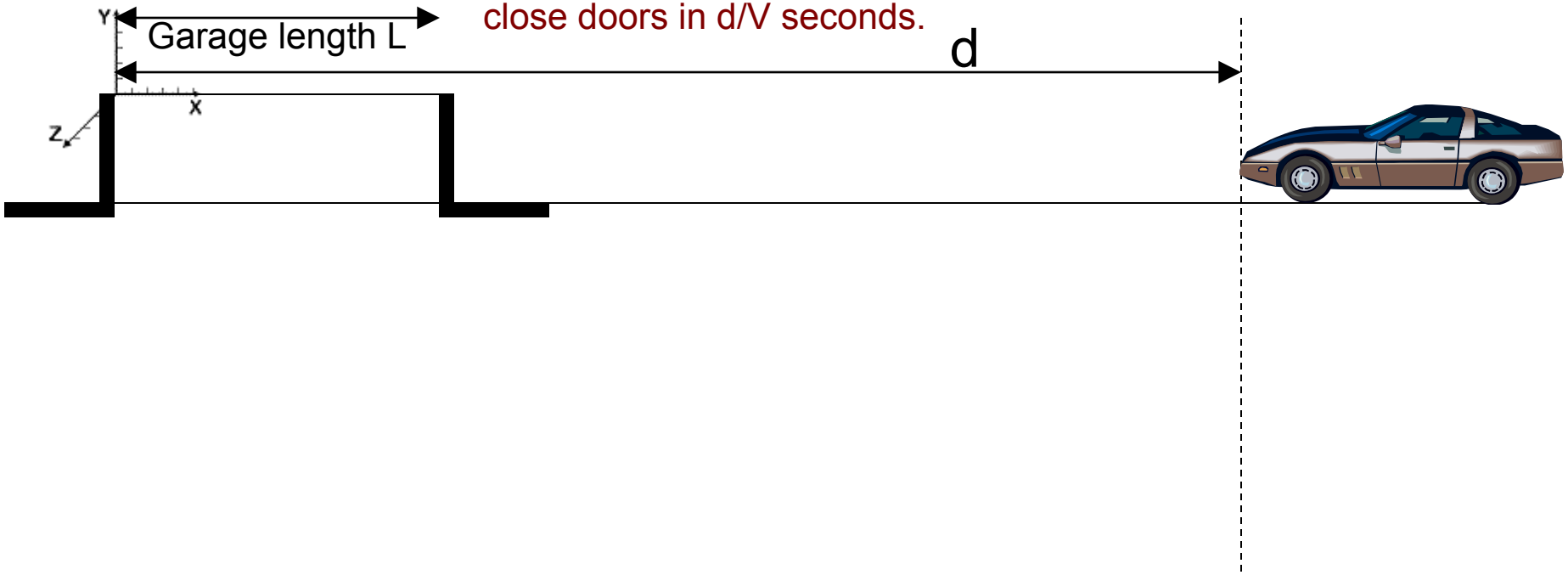

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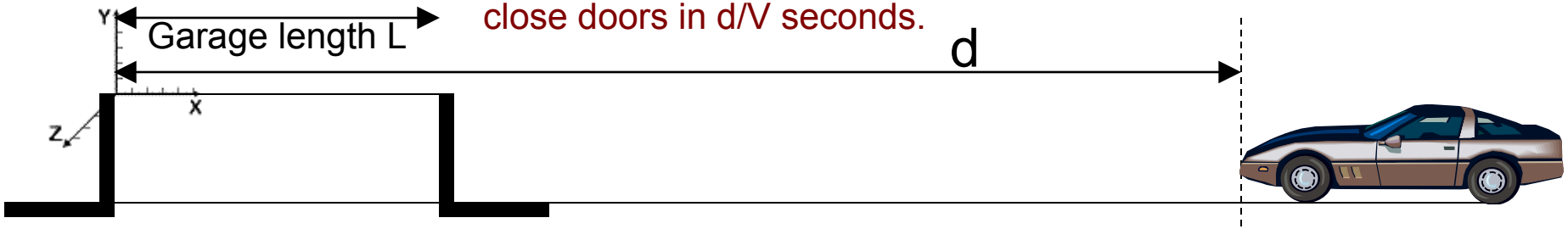

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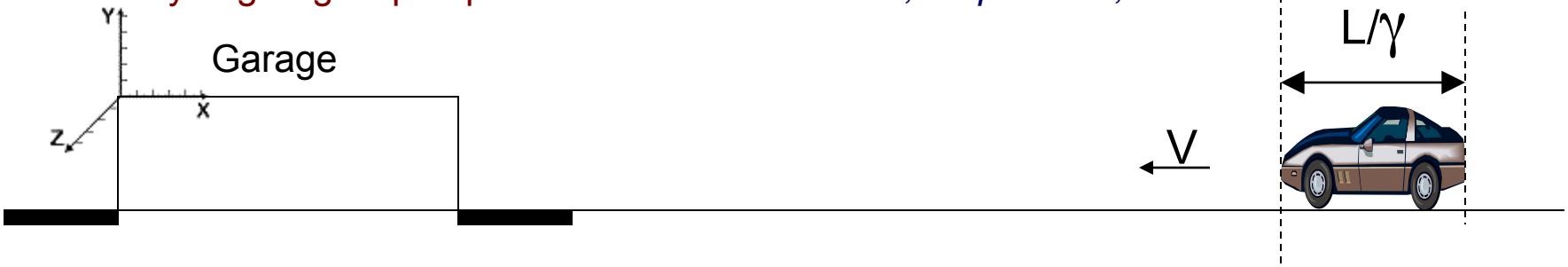

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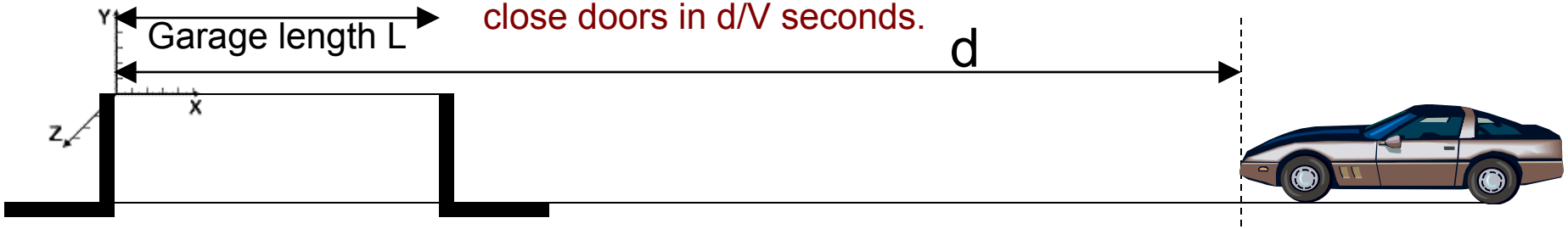

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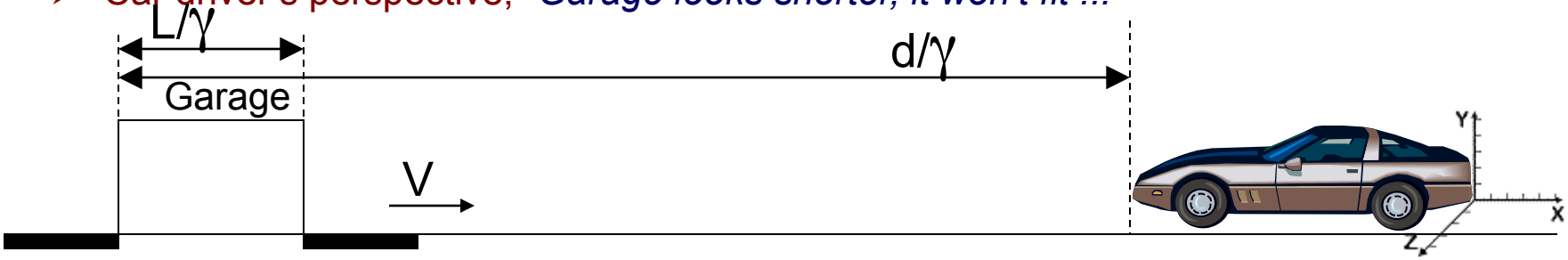

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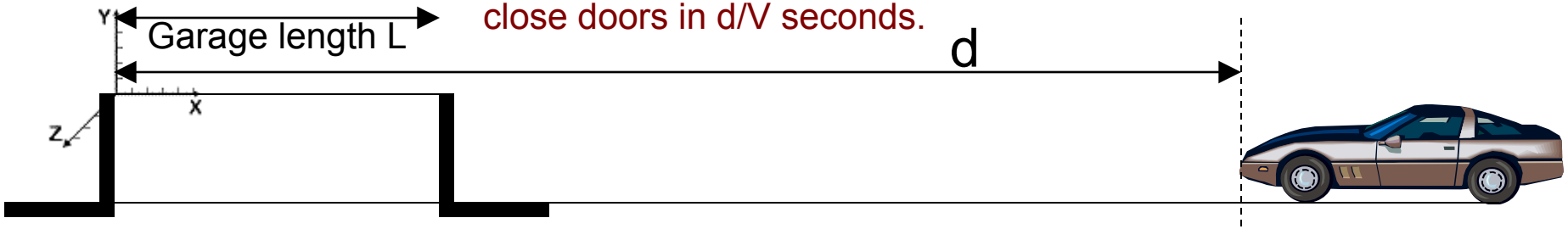

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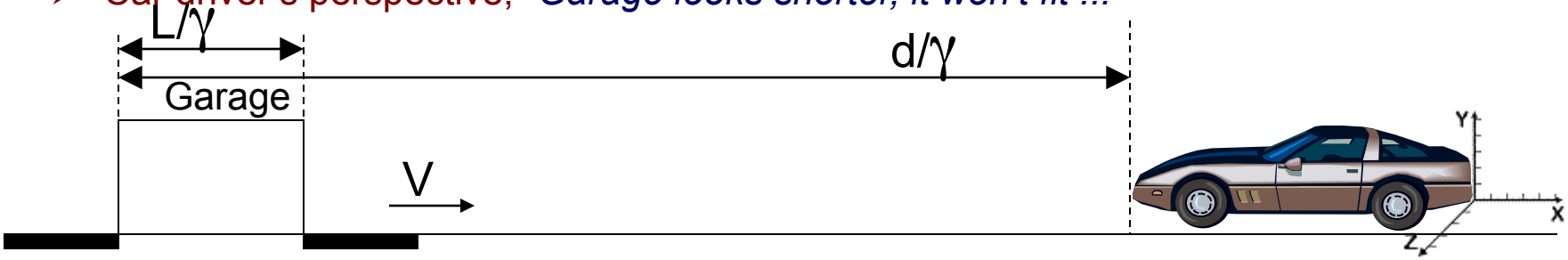
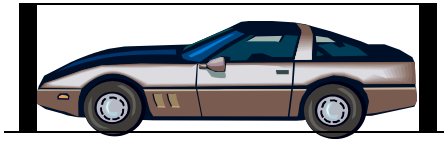


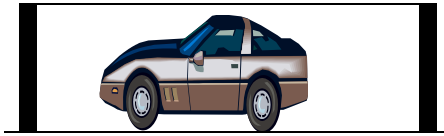
Who's right ? The guy in the garage or the driver ?

Paradox #1: Car and garage (1)

- Both sentences are right. The car "**will fit**" and "**will not fit**" in the garage.
- What's the definition of fit ?

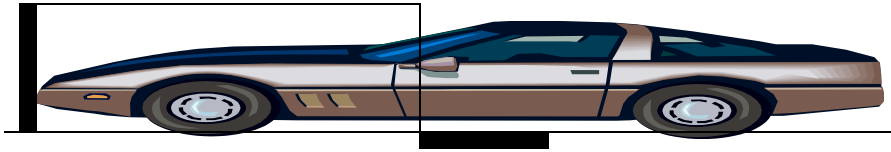


This definitely fits!



This too!

- Does this fit ?



This definitely No

•The car fits in the garage if: the car is within the doors when both doors have been closed SIMULTANEOUSLY .

•"Fit" requires the concept of simultaneity.

•Simultaneity is a frame-dependent concept.

•The "**fit**" mentioned by the driver and the garage-guy represent different things!

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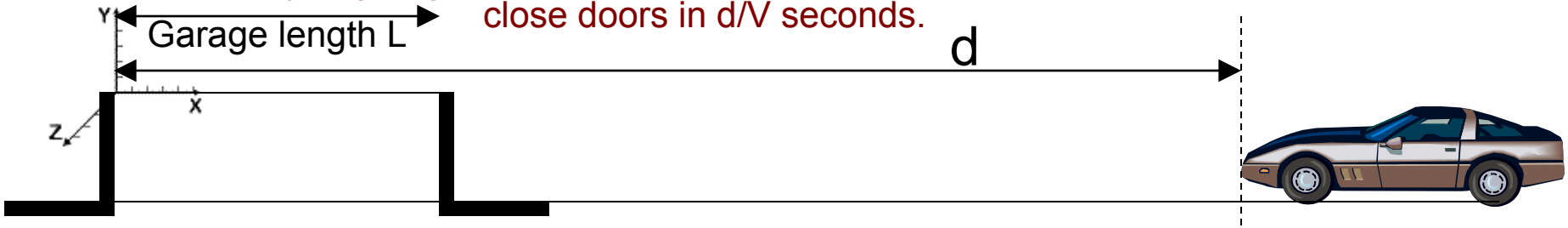

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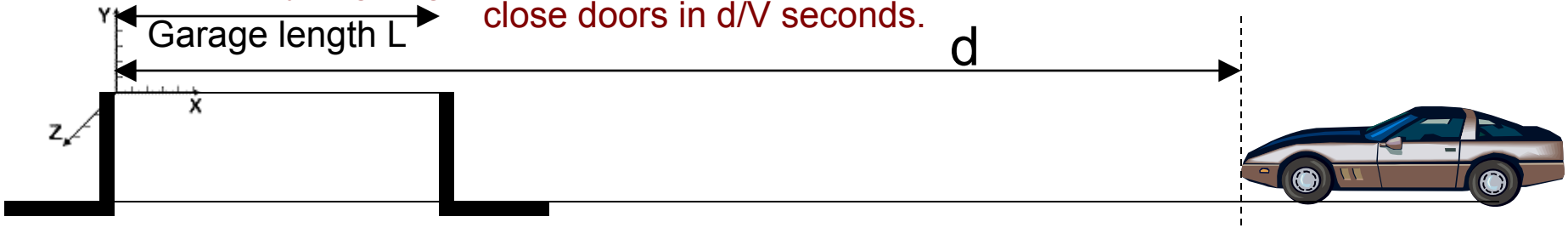

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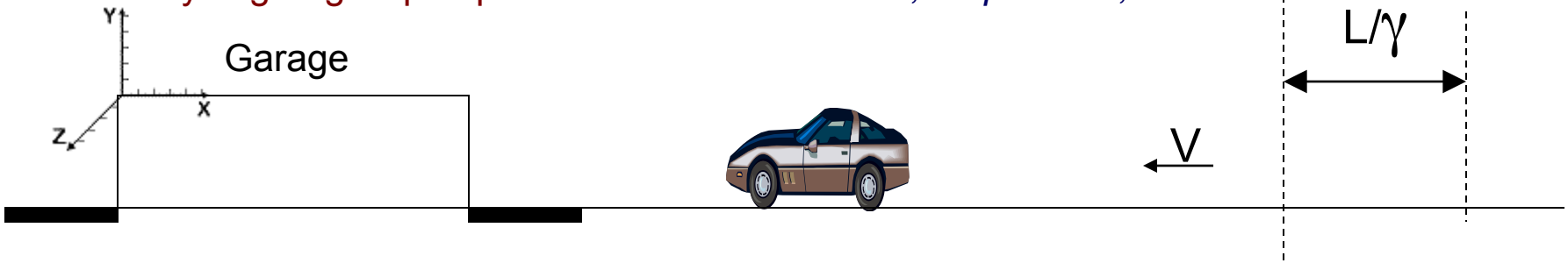

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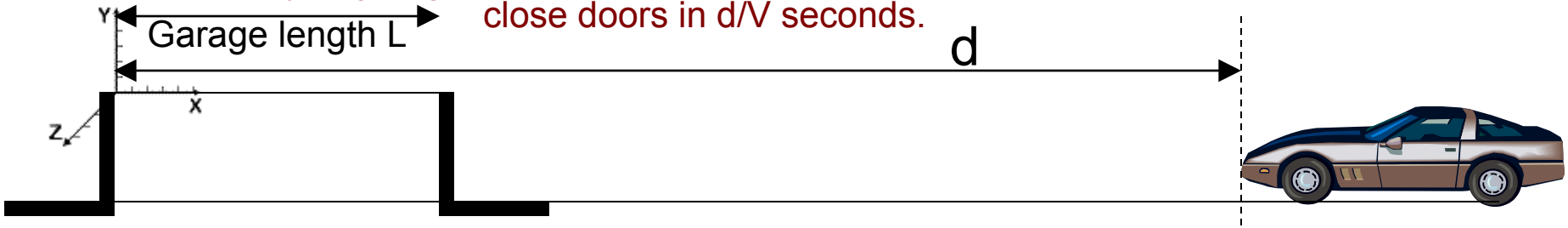

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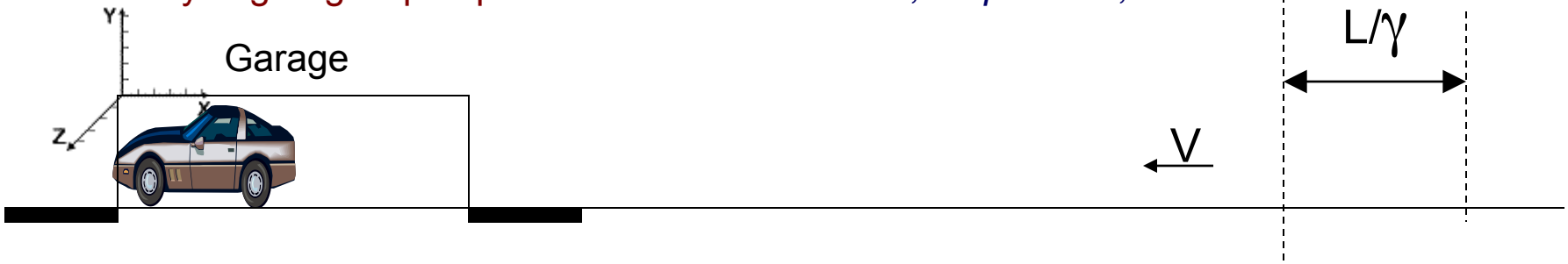

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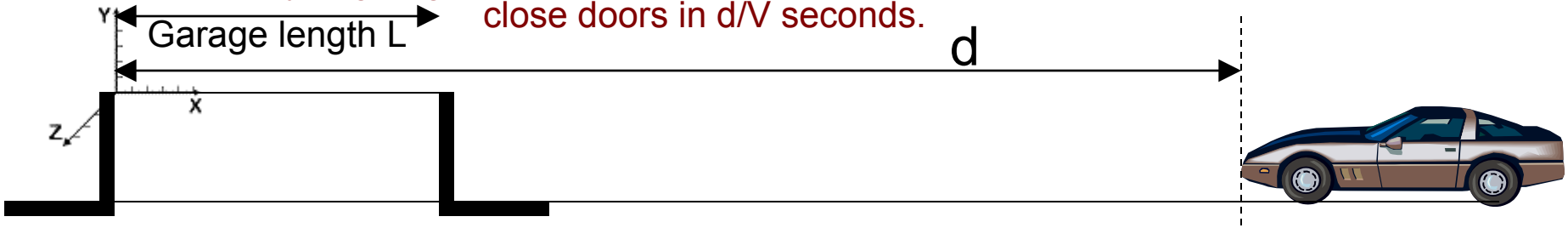

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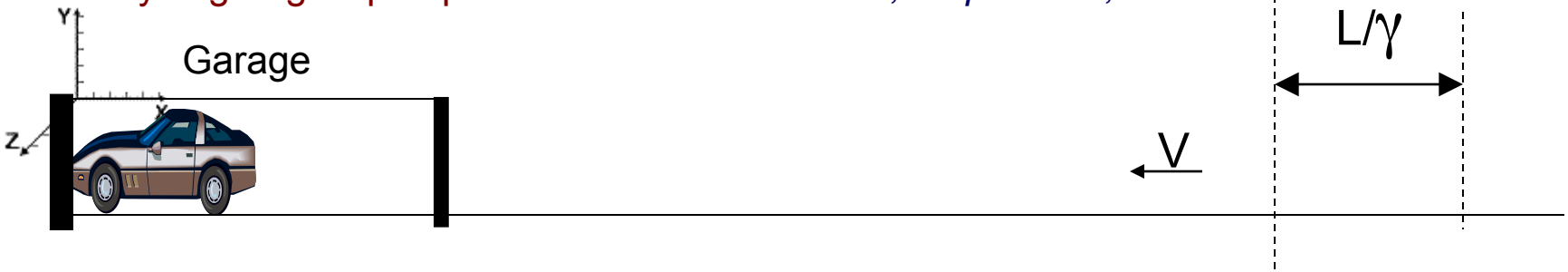

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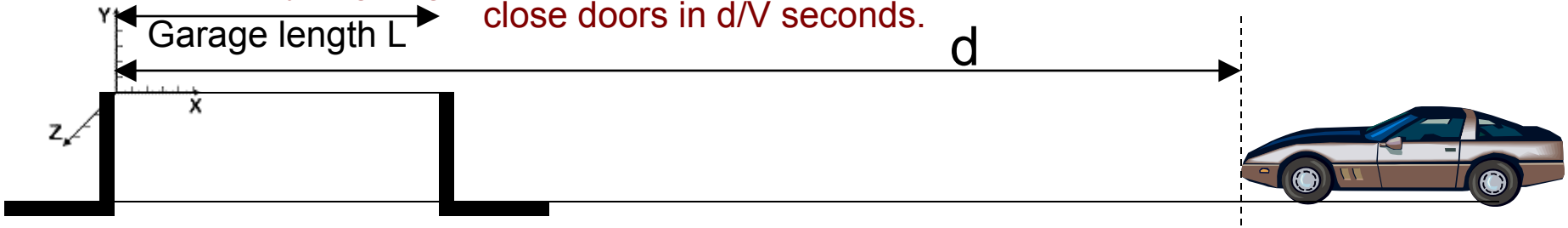

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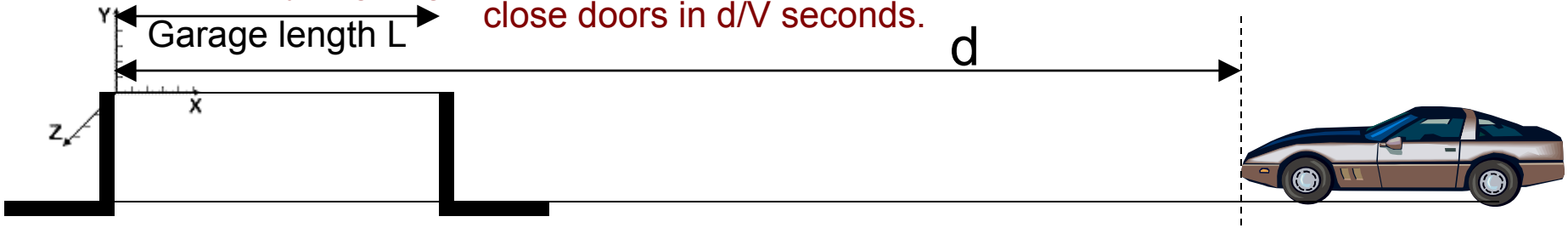

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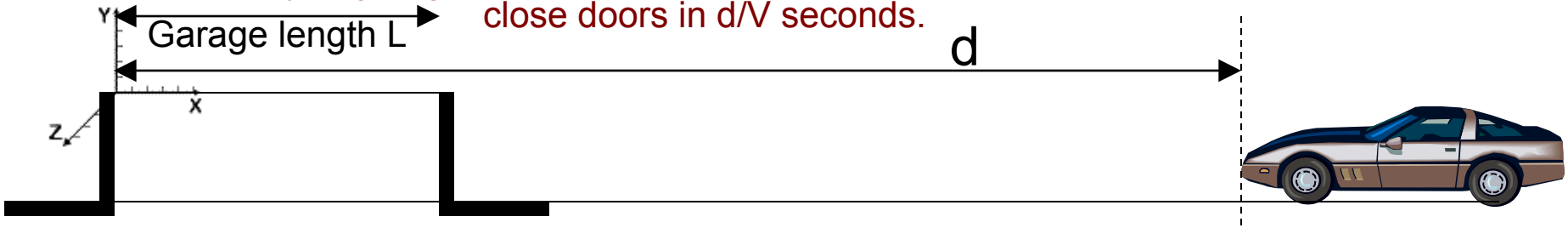

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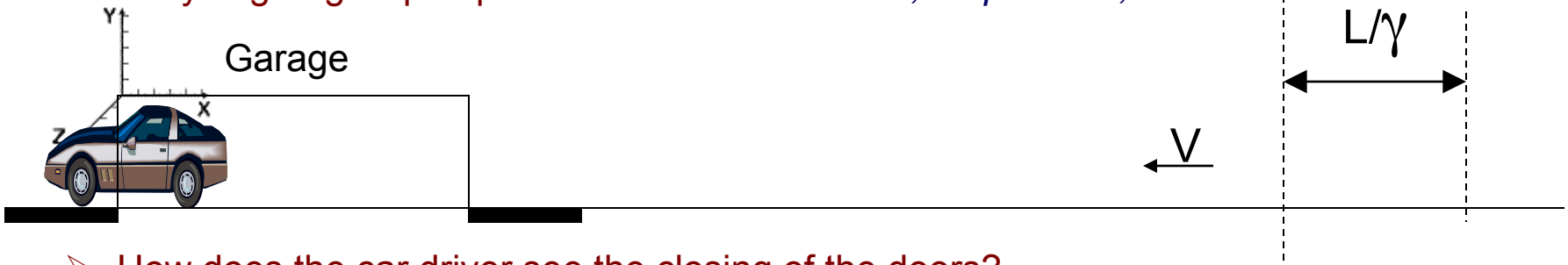

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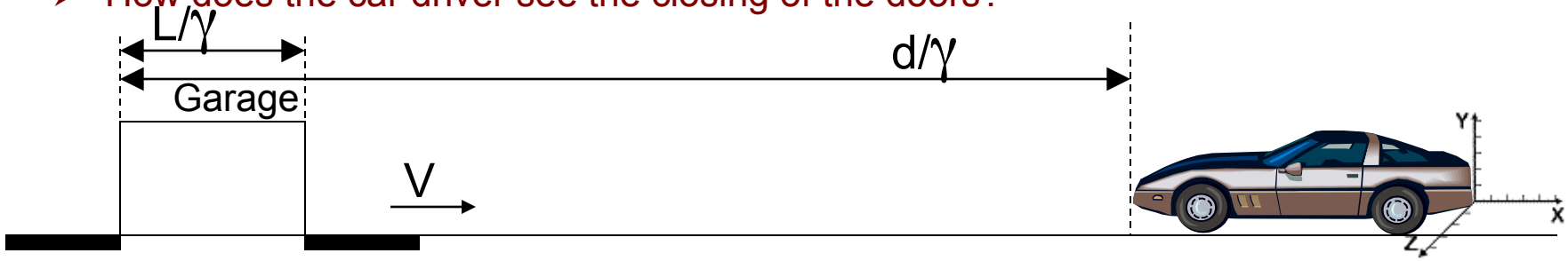

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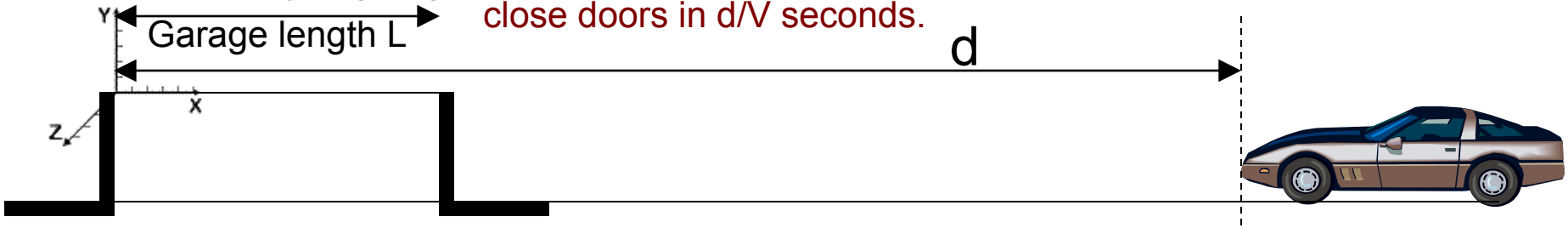

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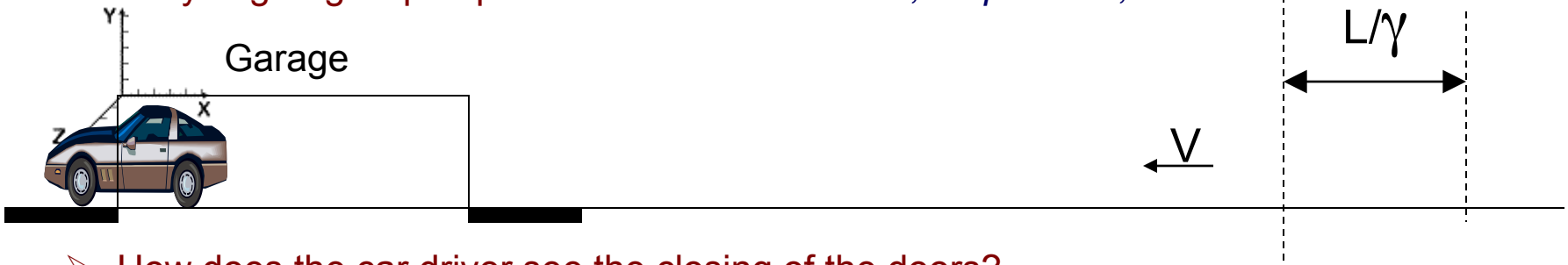

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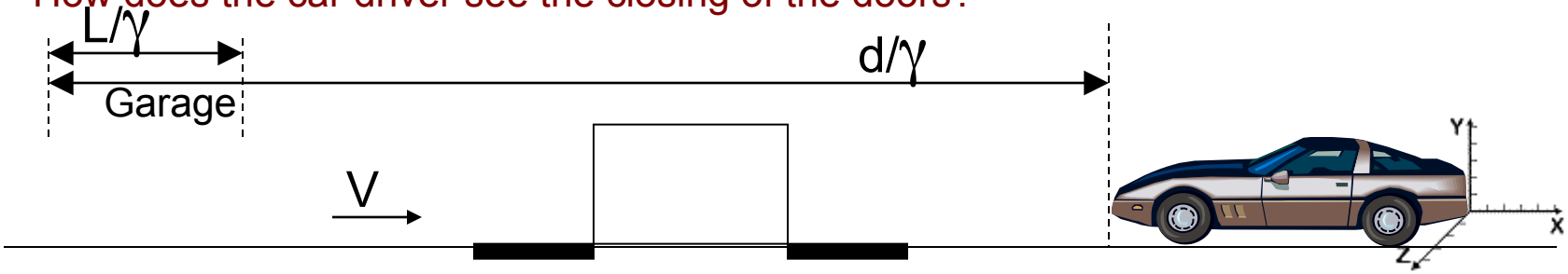

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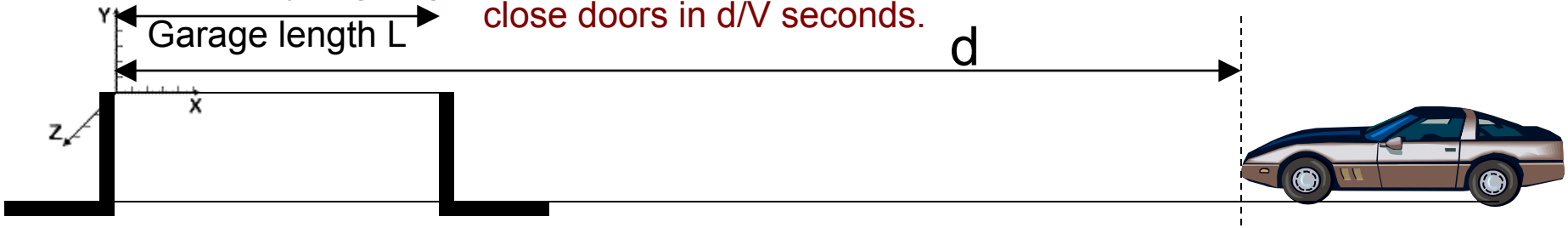

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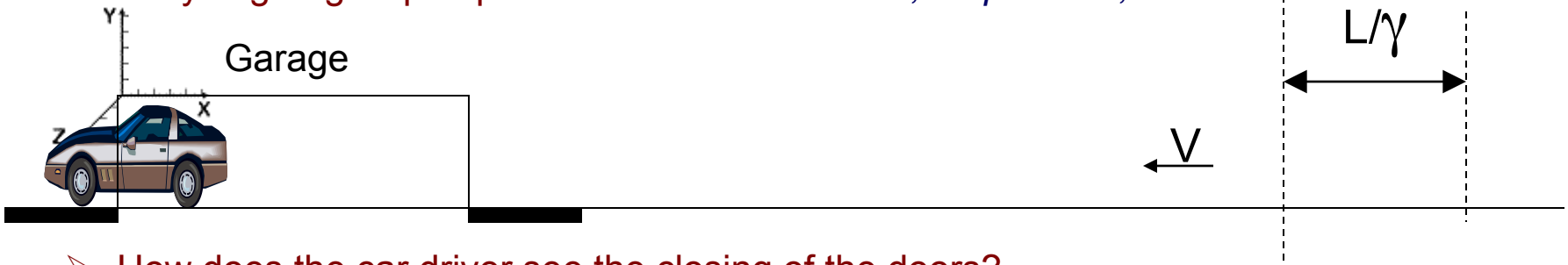

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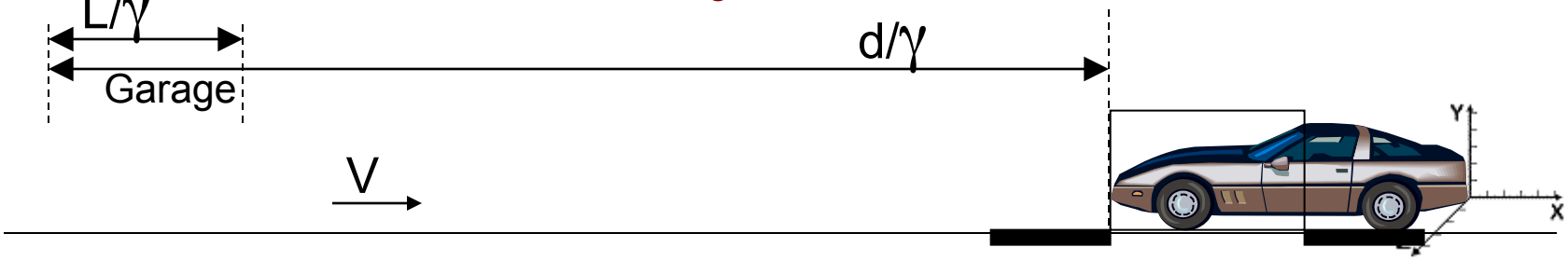

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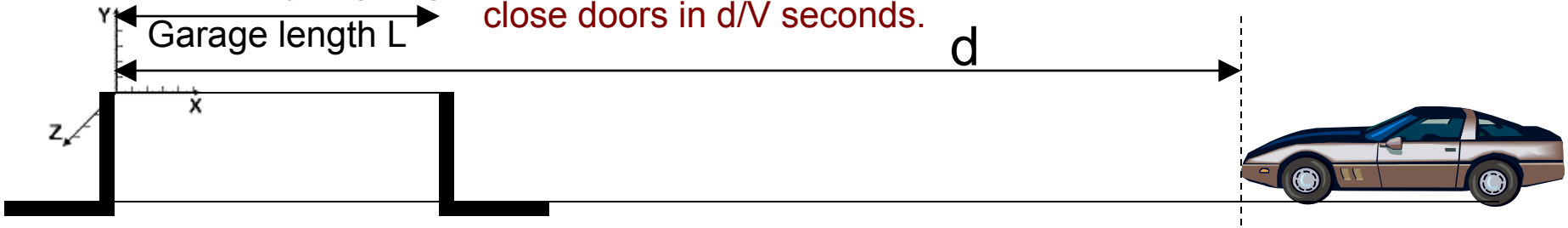

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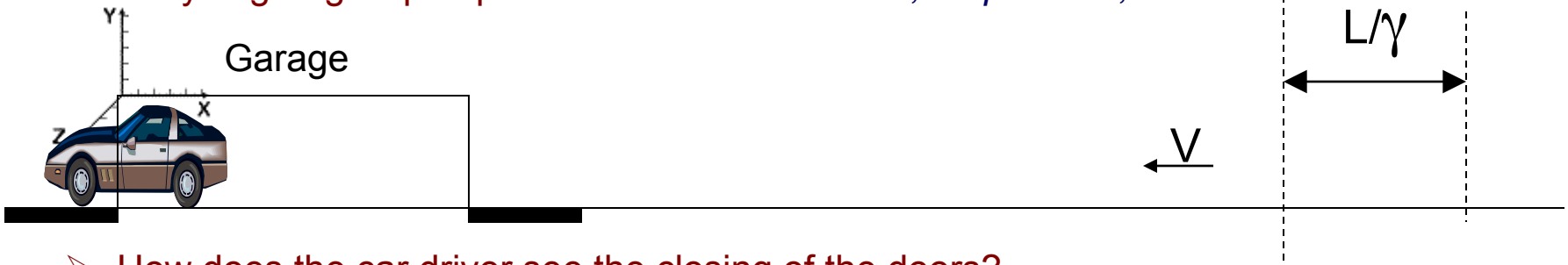

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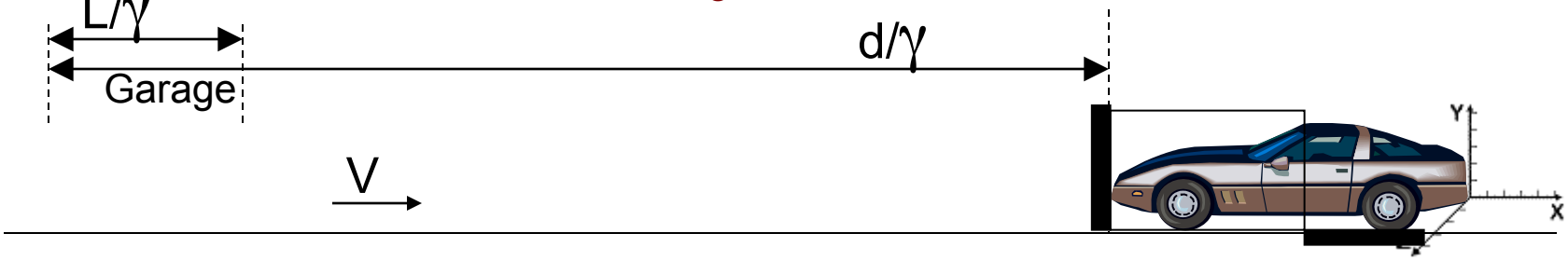

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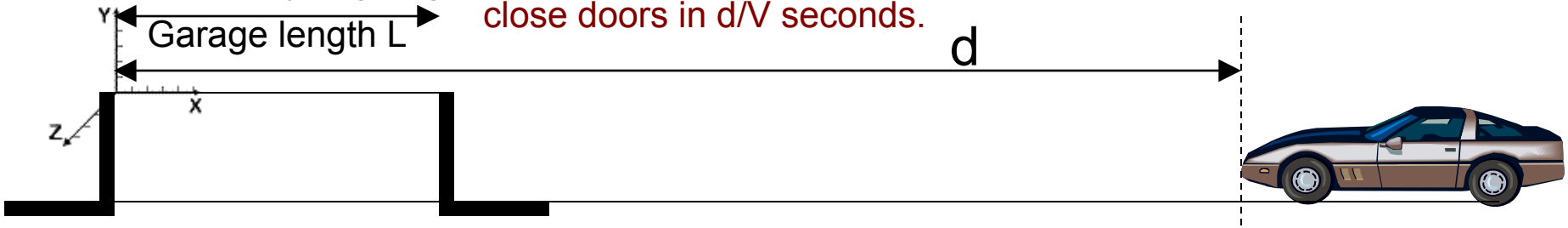

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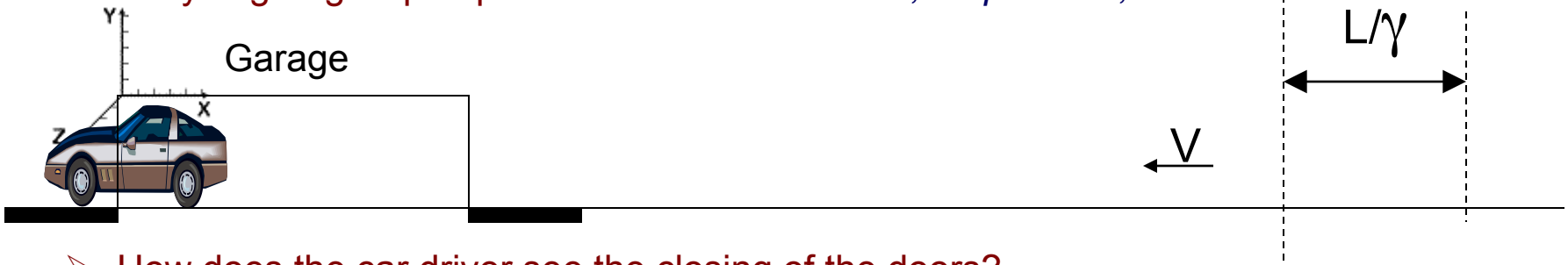

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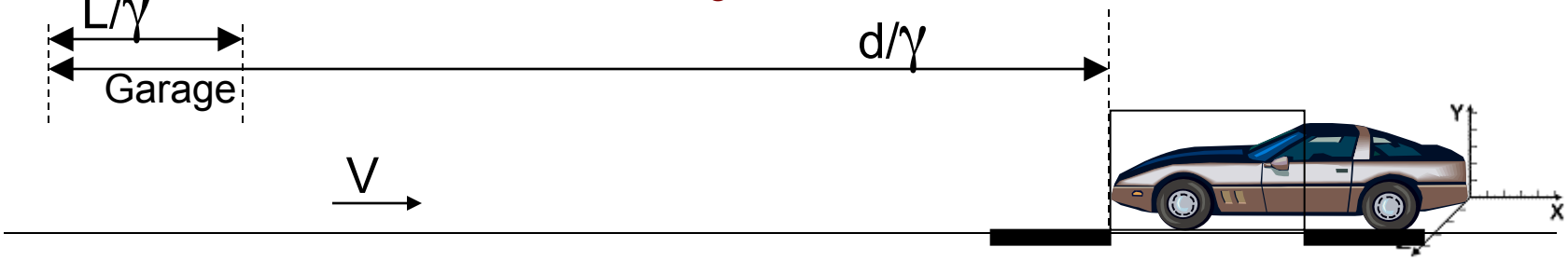

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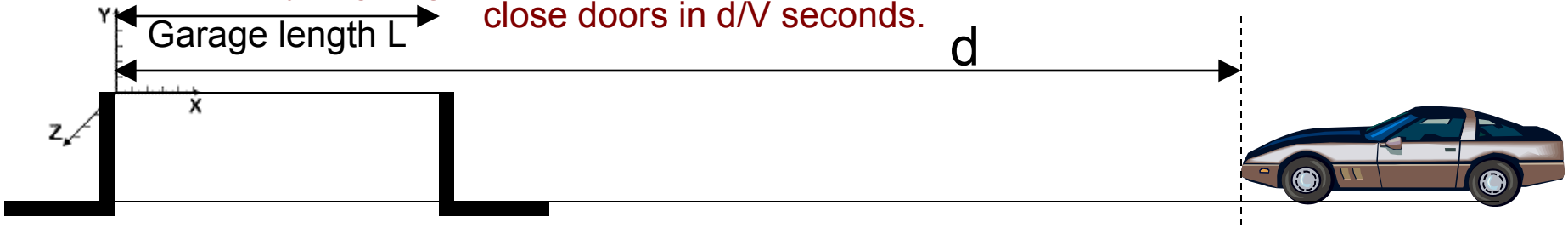

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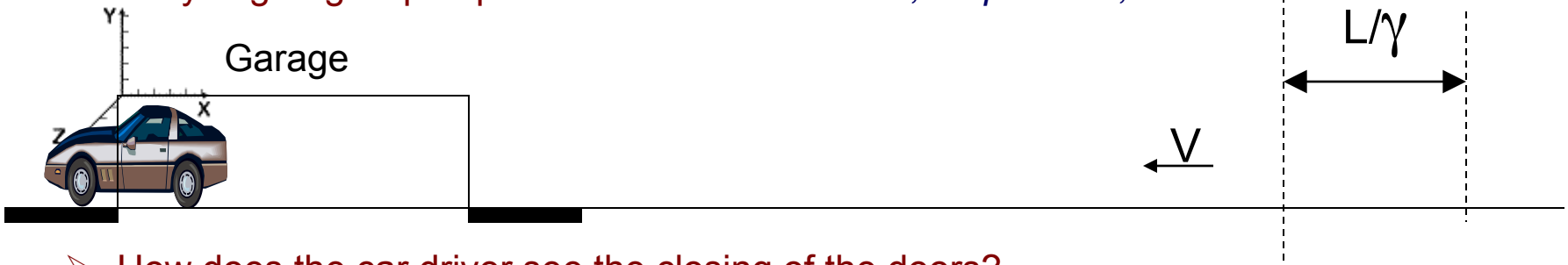

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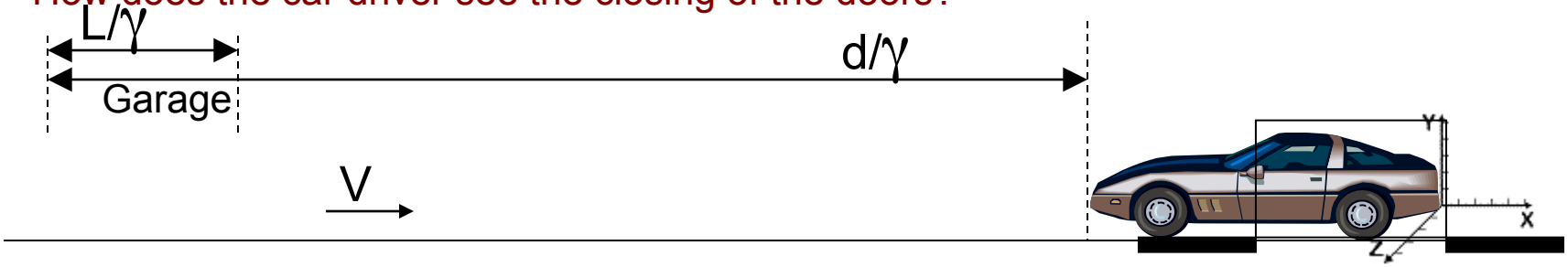

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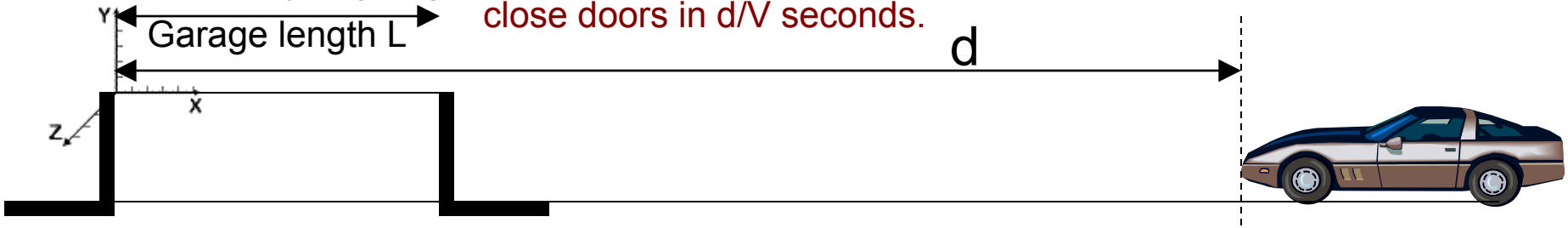

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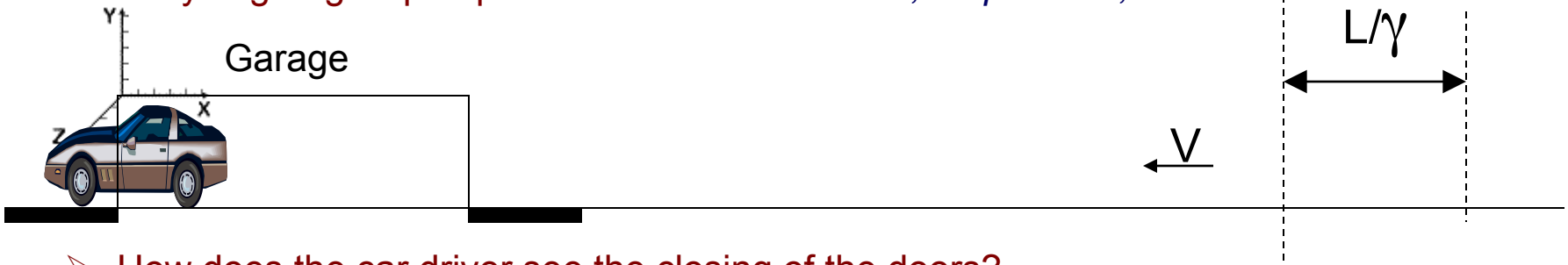

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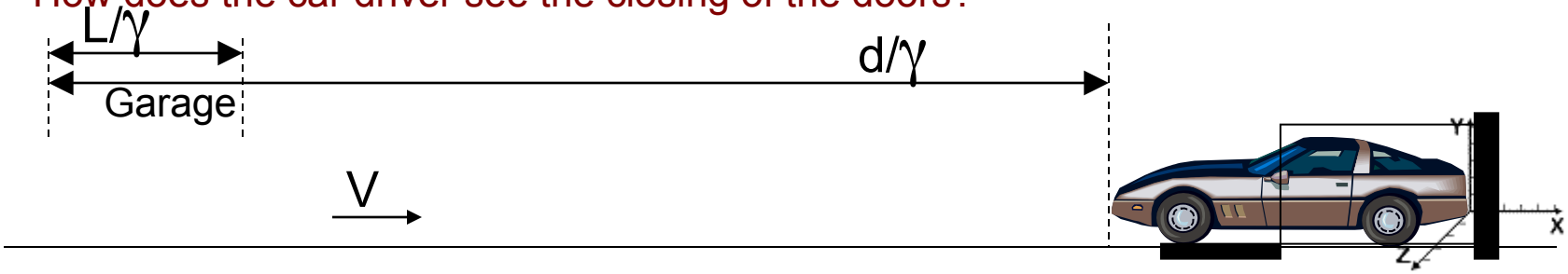

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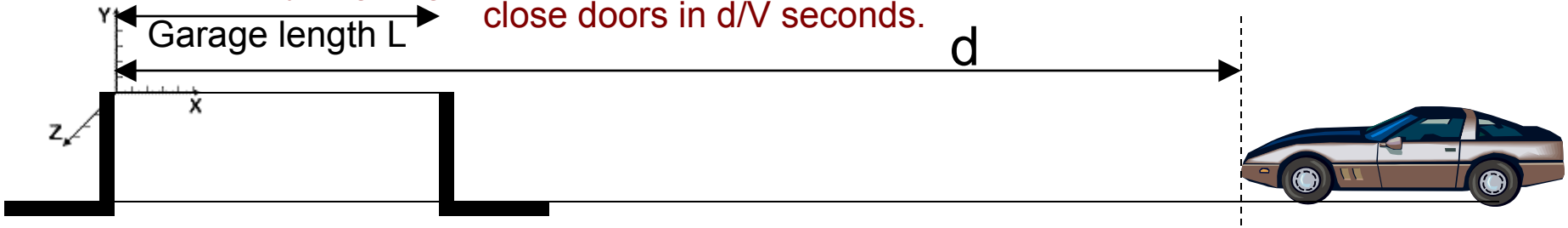

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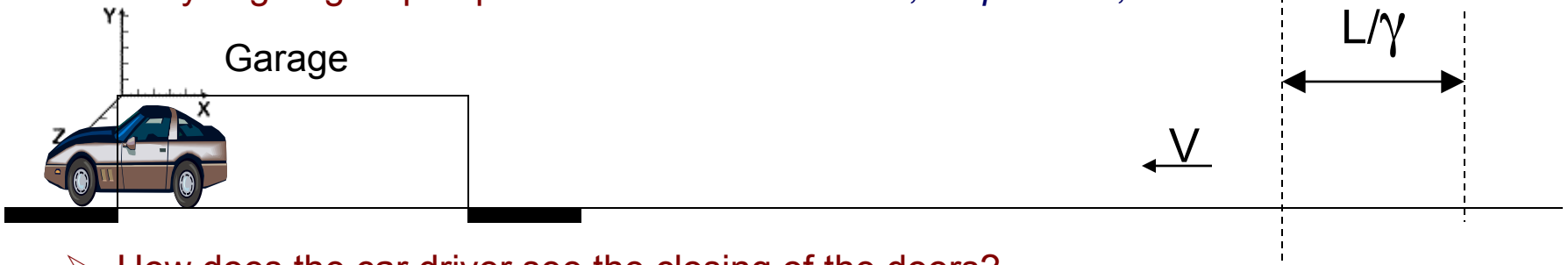

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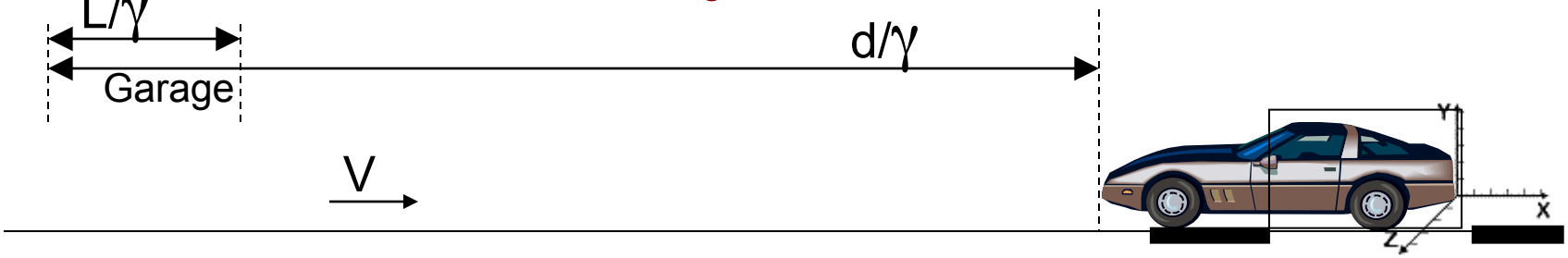

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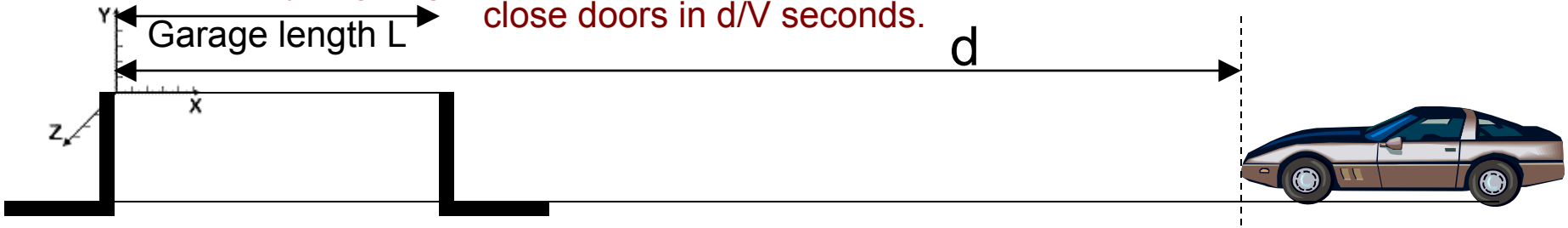

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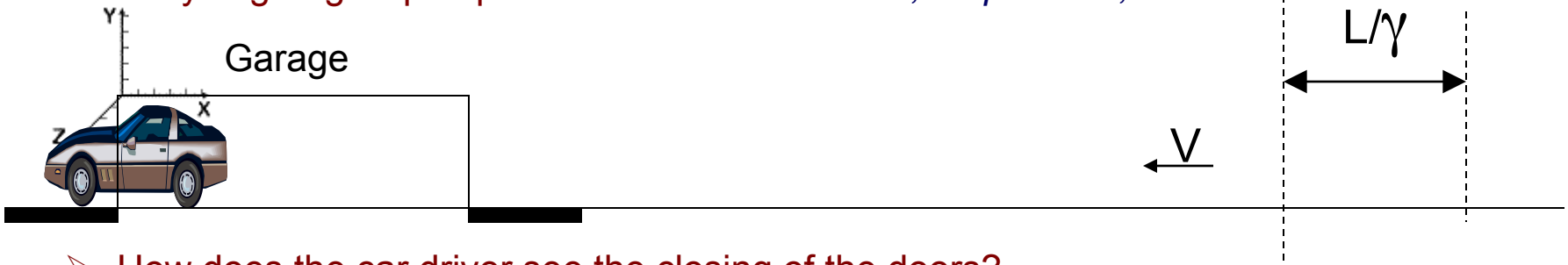

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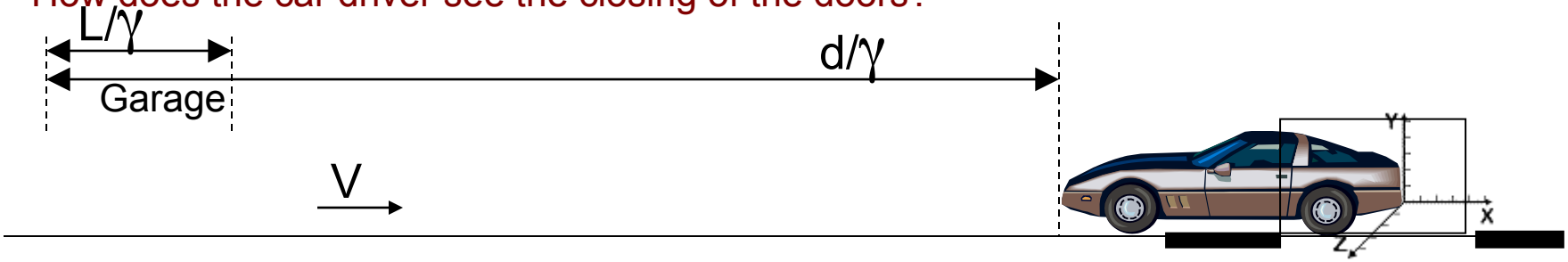

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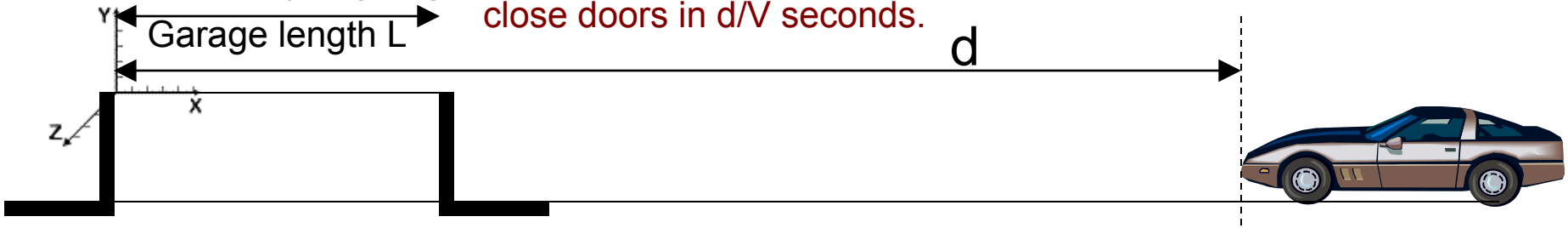

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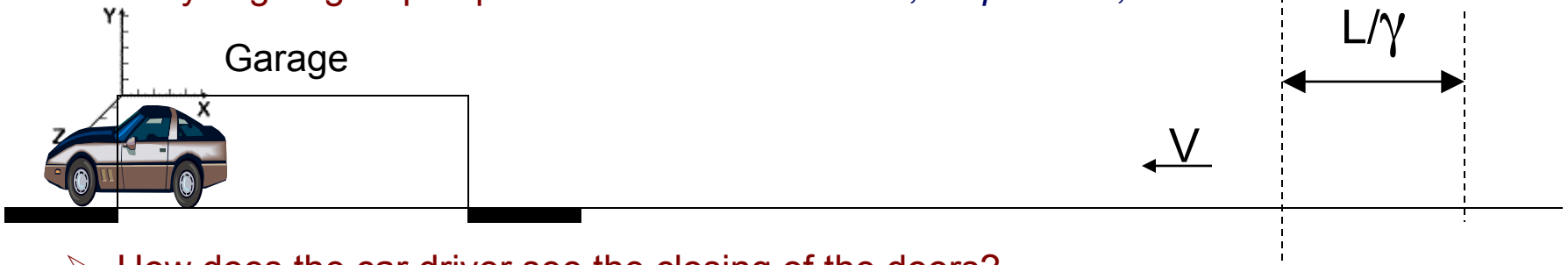

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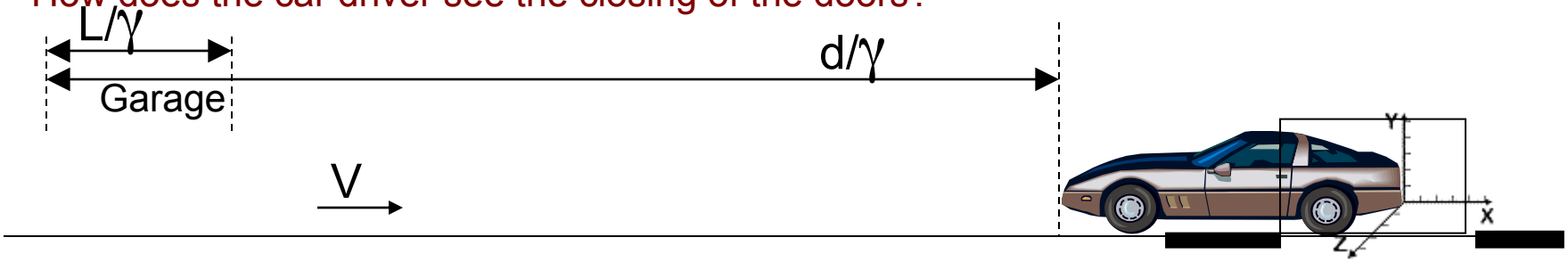


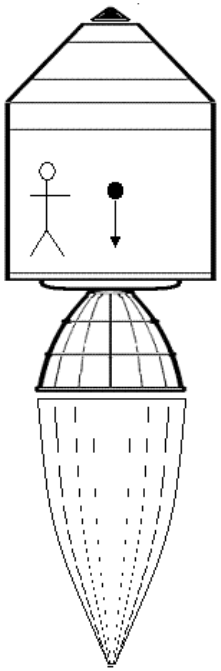
No matter where you see it from the results are the same

New Chapter

Hints of General Relativity

General Relativity: Principles

- Special relativity is valid only in Inertial reference frames.
  - Einstein wasn't happy with that. He sought to extend the principle of relativity to ALL frames of reference. He noticed :



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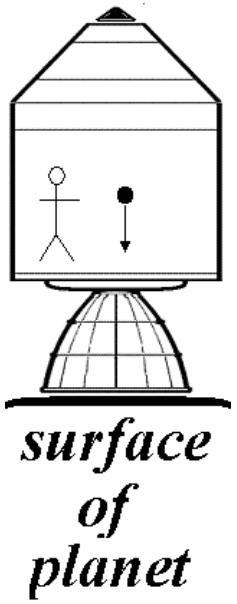
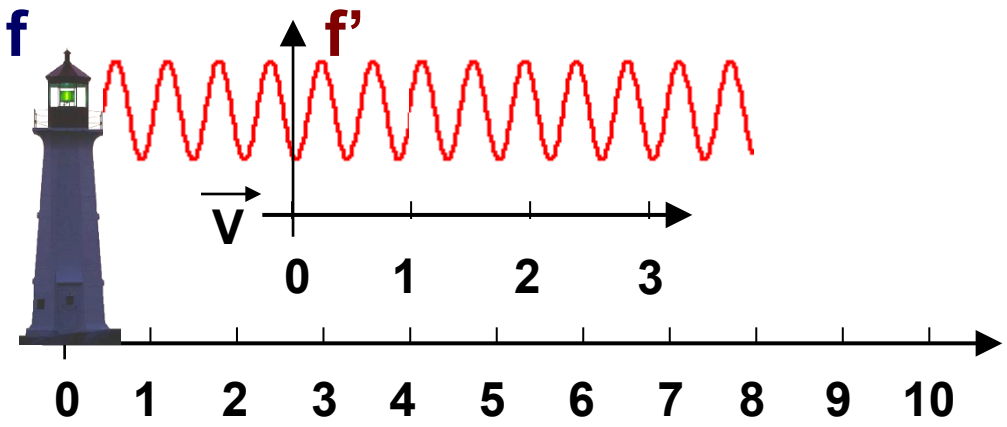
It is impossible to distinguish between accelerated r.f. and the frame at rest with a gravitational pull.



Principle of equivalence

Accelerated frame and frame at rest with a gravitational pull are equivalent in every respect

Doppler effect

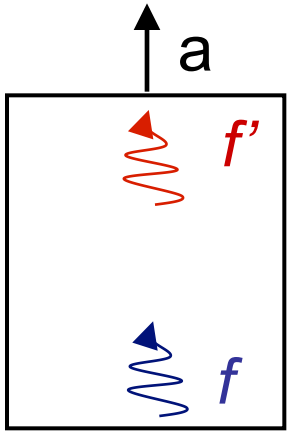


- **Non relativistic Doppler effect:**
  - $f' = f / (1 + V/c)$
- **Relativistic Doppler effect:**
  - Include that the moving observer's clock runs slower by γ
  - $f' = f / [\gamma (1 + V/c)]$

Light frequency is relative to the observer!

General Relativity: Clocks in gravity fields

- Let's consider an **accelerated** frame. From doppler effect
  - A photon of frequency *f* is emitted from the floor.
  - It is detected in the ceiling with frequency *f'*<*f*



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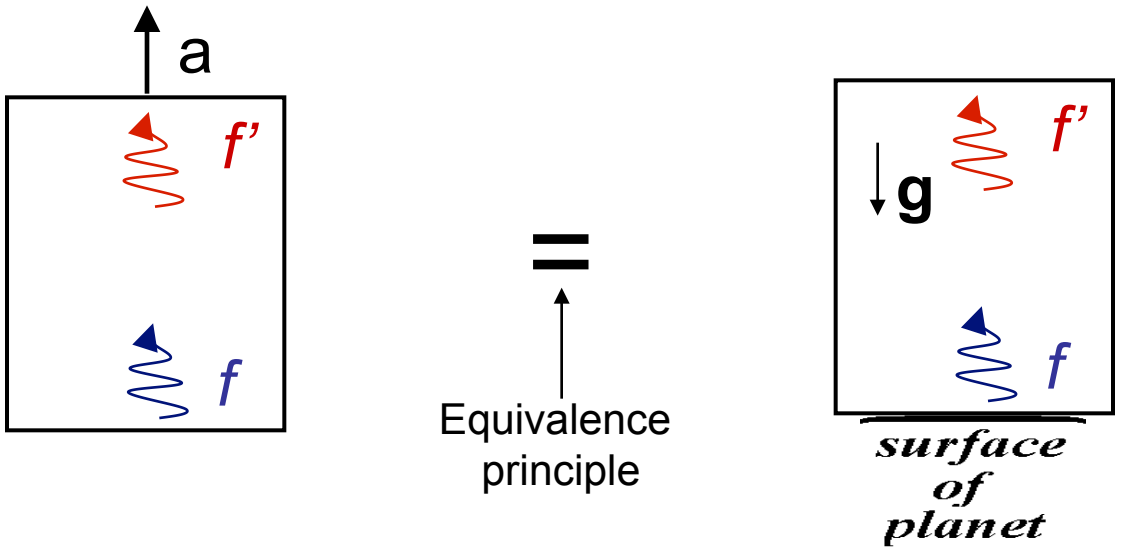

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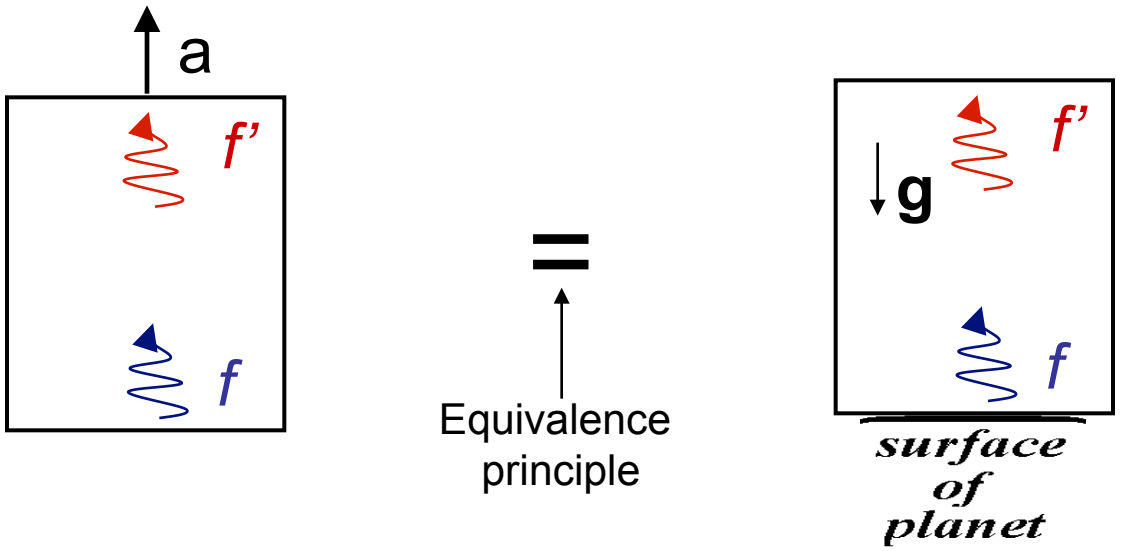

Clocks close to a massive body run slower than clocks farther away

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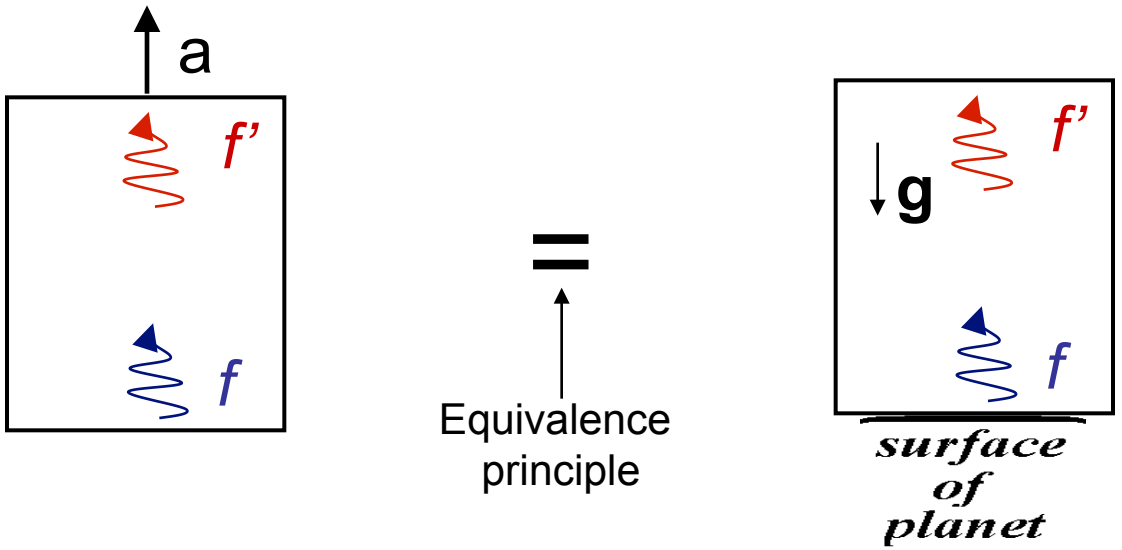


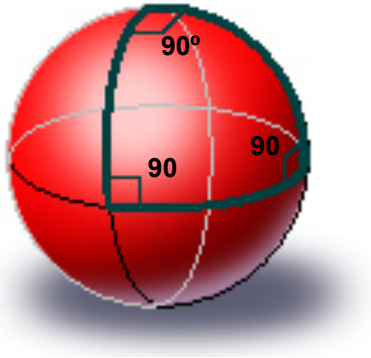
Clocks close to a massive body run slower than clocks farther away

Experimentally verified by many "Tower Experiments"

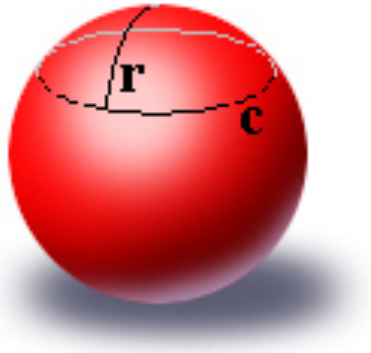
General relativity: the bending of space

- **Is the space curved ?**

Q: is earth curved ?



A1



A2

General relativity: the bending of space

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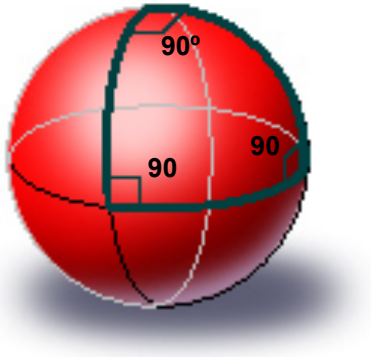

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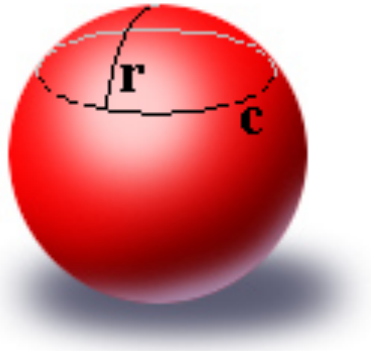


A2

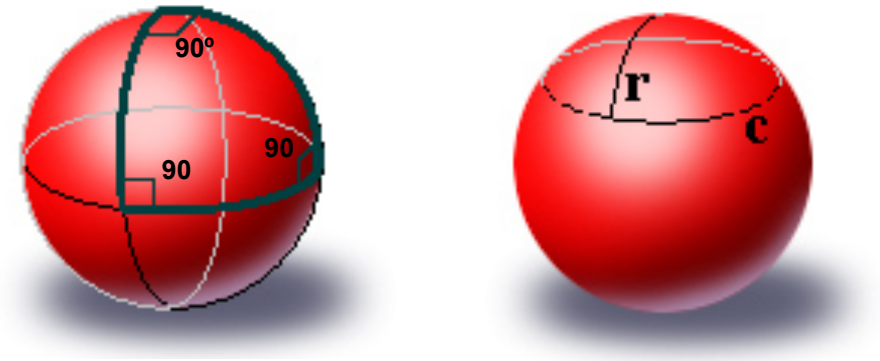
A1: Sum internal angles of triangle greater than 180.

A2: Circumference c of a circle is less than $2\pi r$

General relativity: the bending of space

➢ Is the space curved ?

Q: is earth curved ?



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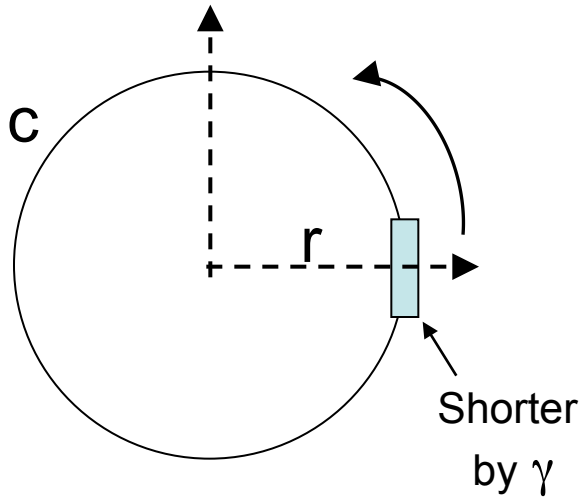
Q: is space-time curved ?



A: circumf. of circle is not $2\pi r$!!

General relativity: the bending of space

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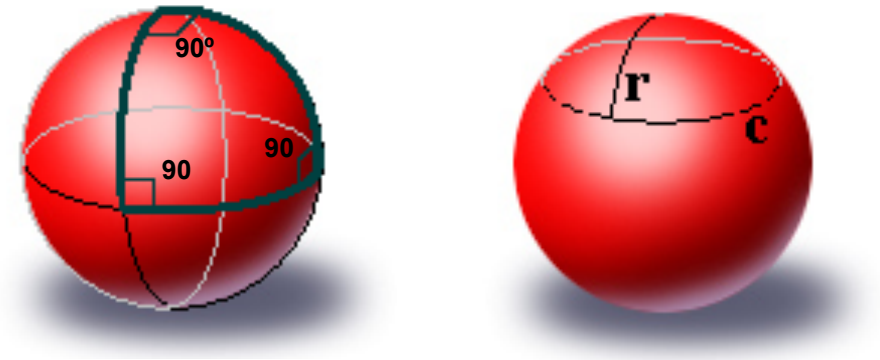
Q: is earth curved ?



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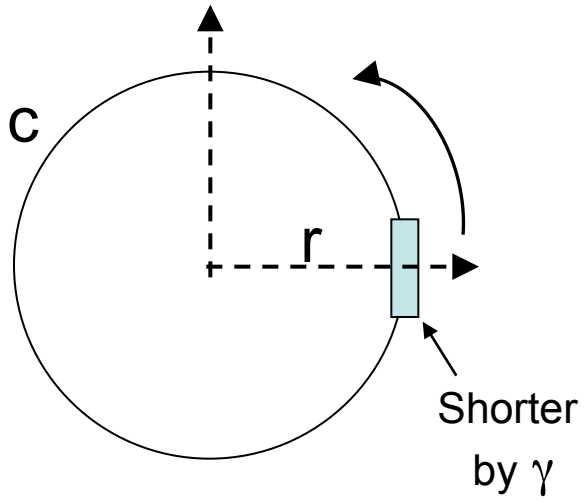

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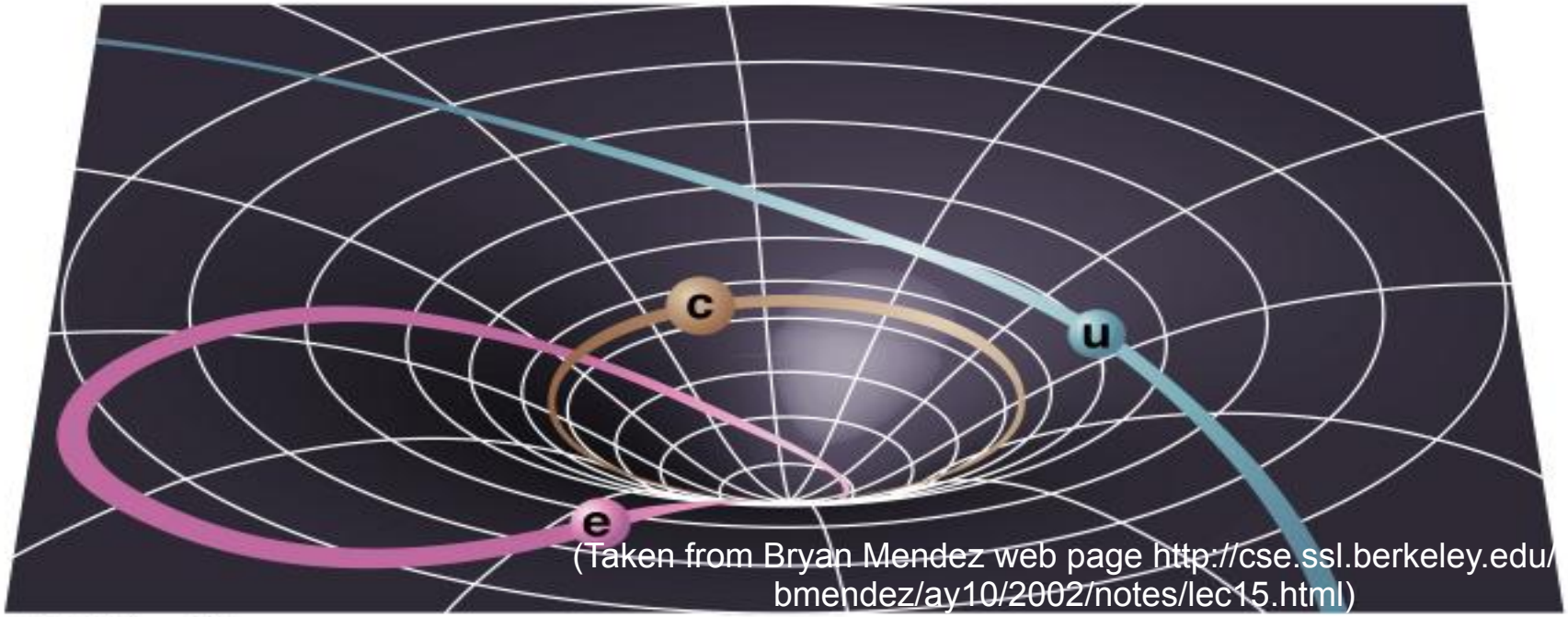
Einstein concluded: Space-time must be curved !

General Relativity: in a nutshell

- **Massive objects curved space-time.**
  - The more massive the greater the curvature.
  - The greater the curvature the more intense the gravity.

- **Objects move following the shortest path in curved space-time.**



(Taken from Bryan Mendez web page http://cse.ssl.berkeley.edu/bmendez/ay10/2002/notes/lec15.html)

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Thank you very much.

Questions ?