

The Process of Science

How Do Scientists Think?



CERN HST 2022

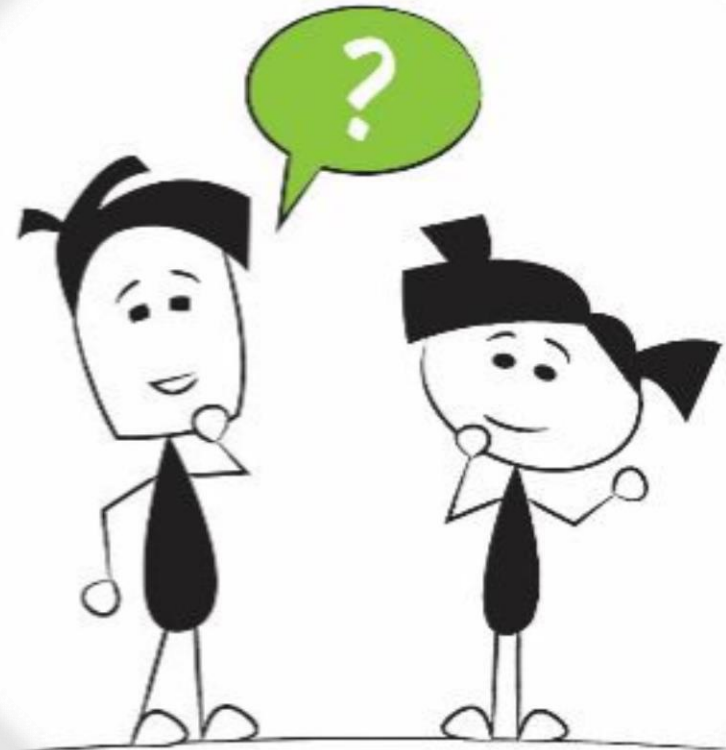
How Do Scientists Think?

Scientists Are
Curious



How Do Scientists Think?

Scientists Ask
Questions



How Do Scientists Think?

Scientists Build
and Revise
Models



How Do Scientists Think?

Scientists Are
Creative



How Do Scientists Think?

Scientists
Collaborate



How Do Scientists Think?

Scientists Look
for Patterns



Looking for patterns

- spin
- electric charge (Q)
- strangeness (S)
- mass
- date

spin $3/2$

$Q = -1$

$S = 0$

mass: 1232 MeV

discovered: 1954

Finding patterns

spin 3/2
Q = -1
S = 0
mass: 1232 MeV
discovered: 1954

spin 3/2
Q = 0
S = 0
mass: 1231 MeV
discovered: 1954

spin 3/2
Q = +1
S = 0
mass: 1235 MeV
discovered: 1954

spin 3/2
Q = 0
S = -2
mass: 1532 MeV
discovered: 1962

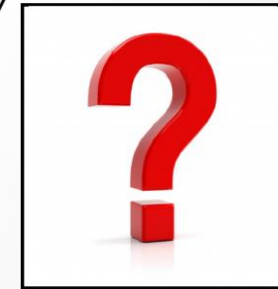
spin 3/2
Q = +2
S = 0
mass: 1231 MeV
discovered: 1954

spin 3/2
Q = +1
S = -1
mass: 1383 MeV
discovered: 1960

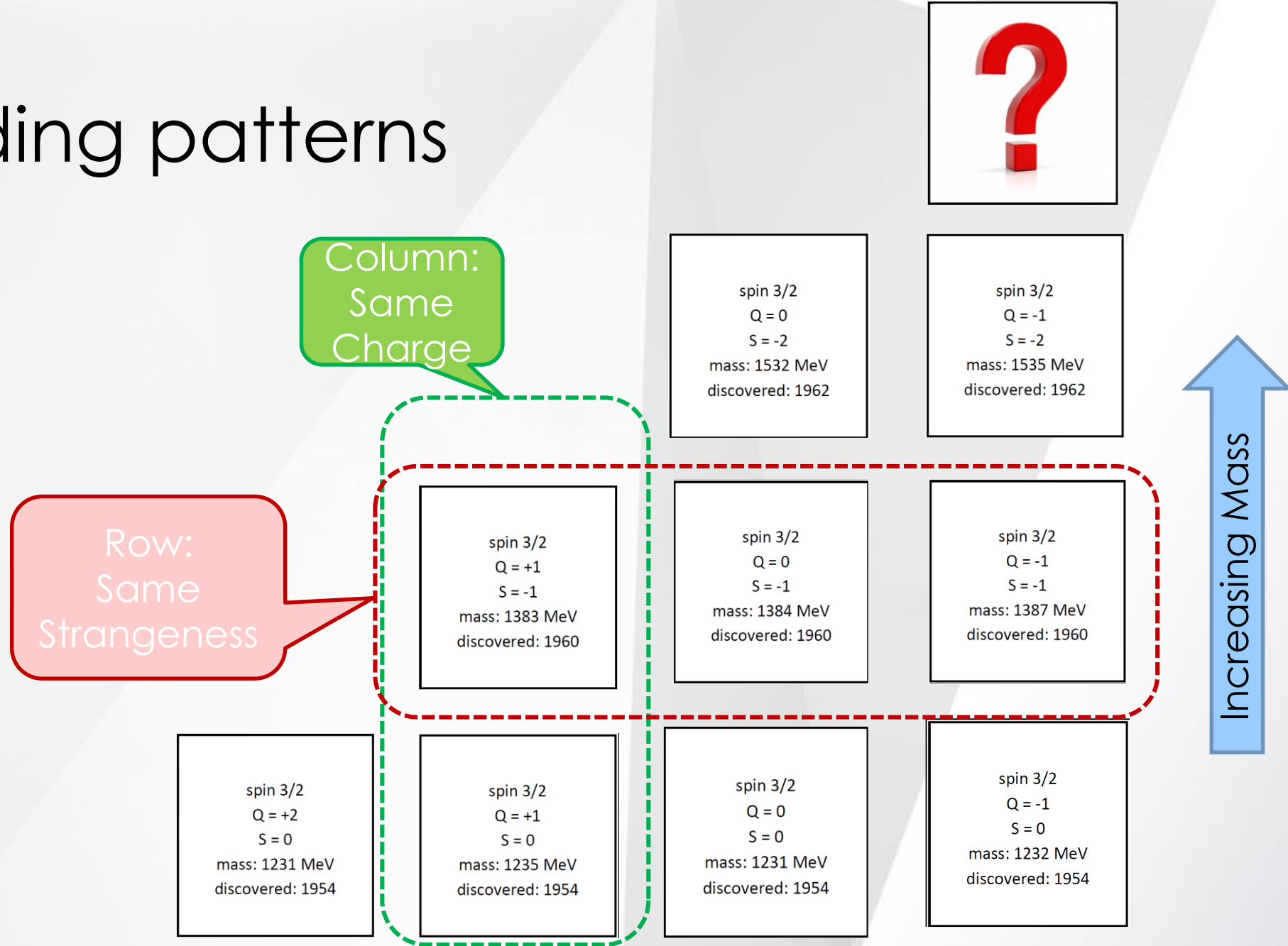
spin 3/2
Q = -1
S = -1
mass: 1387 MeV
discovered: 1960

spin 3/2
Q = 0
S = -1
mass: 1384 MeV
discovered: 1960

spin 3/2
Q = -1
S = -2
mass: 1535 MeV
discovered: 1962



Finding patterns



Particle Prediction

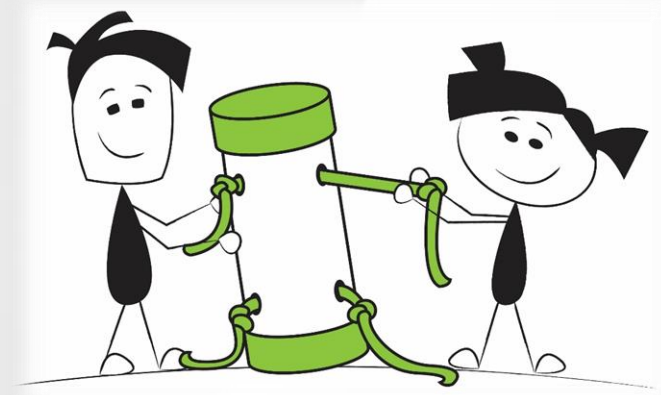
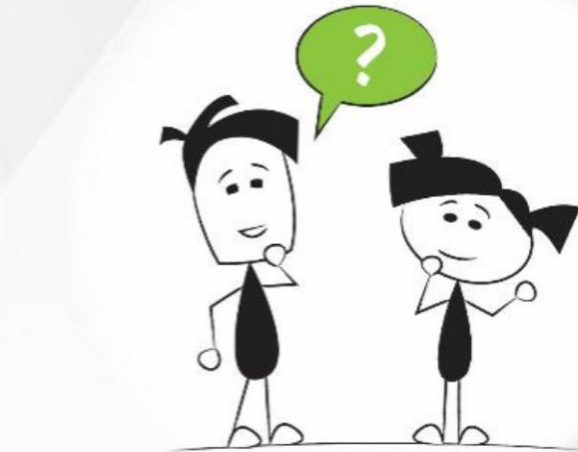
- spin $2/3$
- charge
- strangeness
- mass



1969 NOBEL PRIZE
Murray Gell-Mann

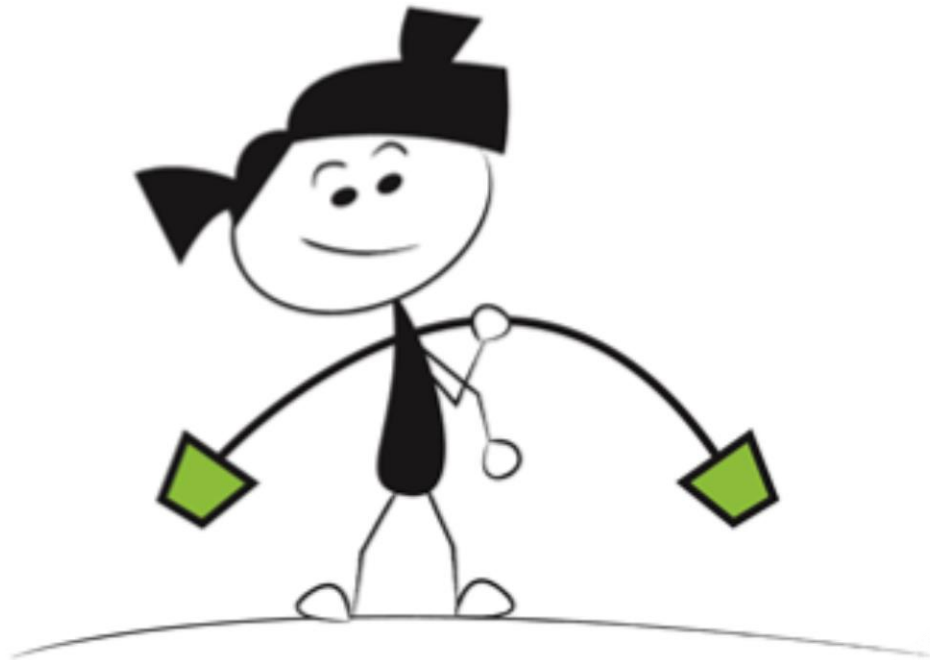
“for his contributions and discoveries concerning the classification of elementary particles and their interactions”

Thinking Like A Scientist



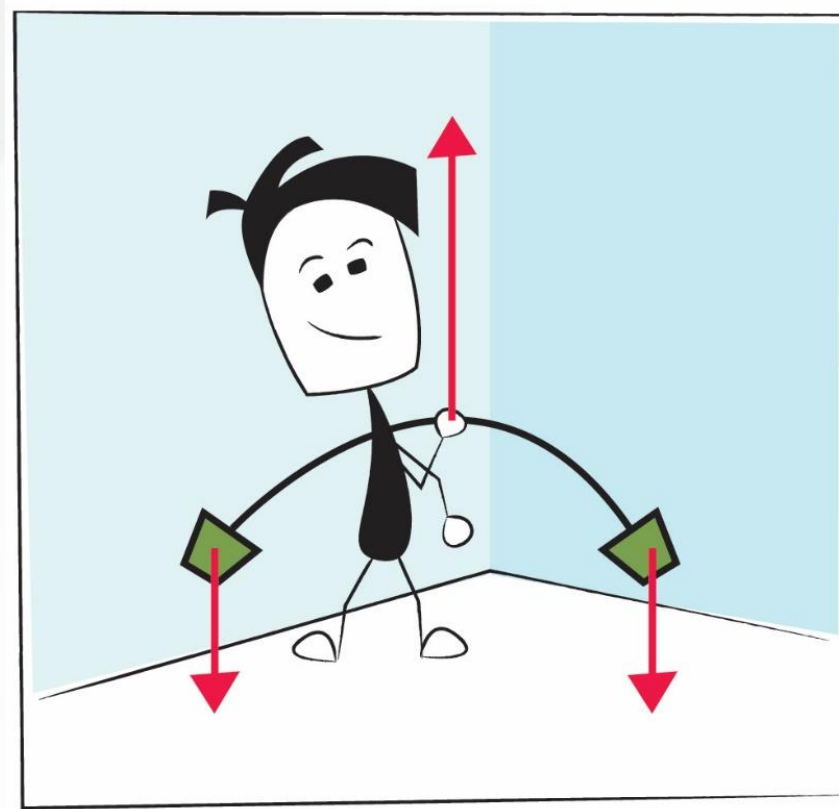
Let's work together to build and revise our model for a simple question.

Why does this rod bend?





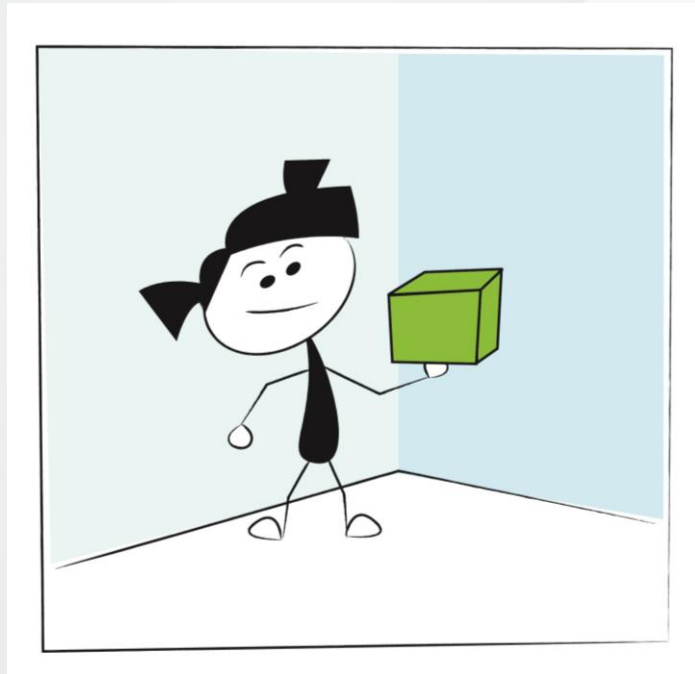
One force pulls down another pushes up



Force Model



Why do objects feel heavy?



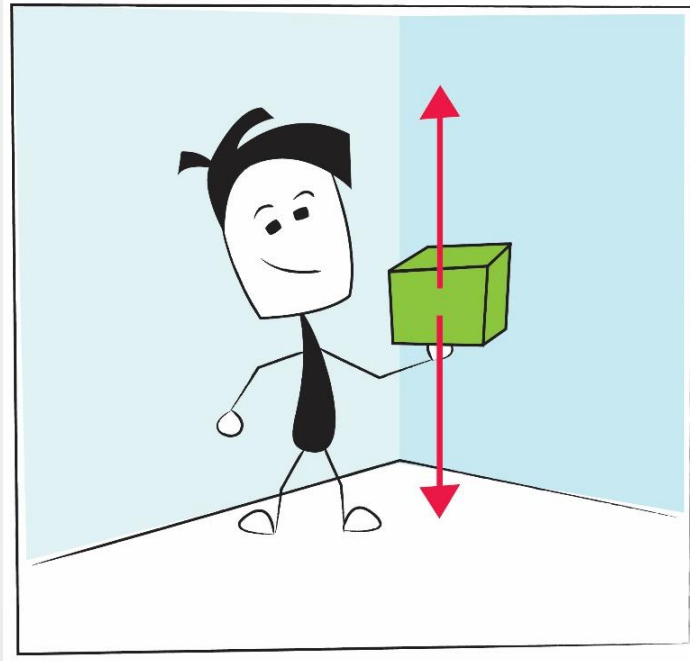
Why do objects fall?



Force Model

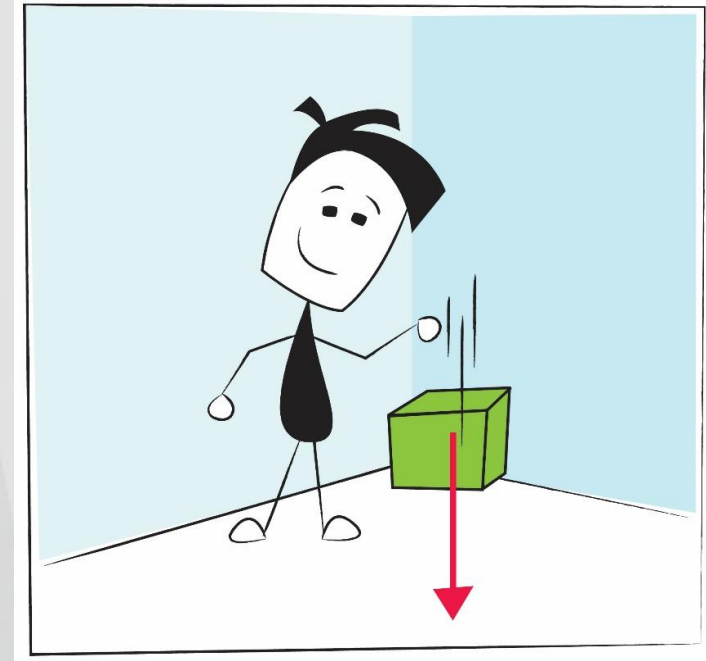


Why do objects feel heavy?



You push up to oppose the force of gravity

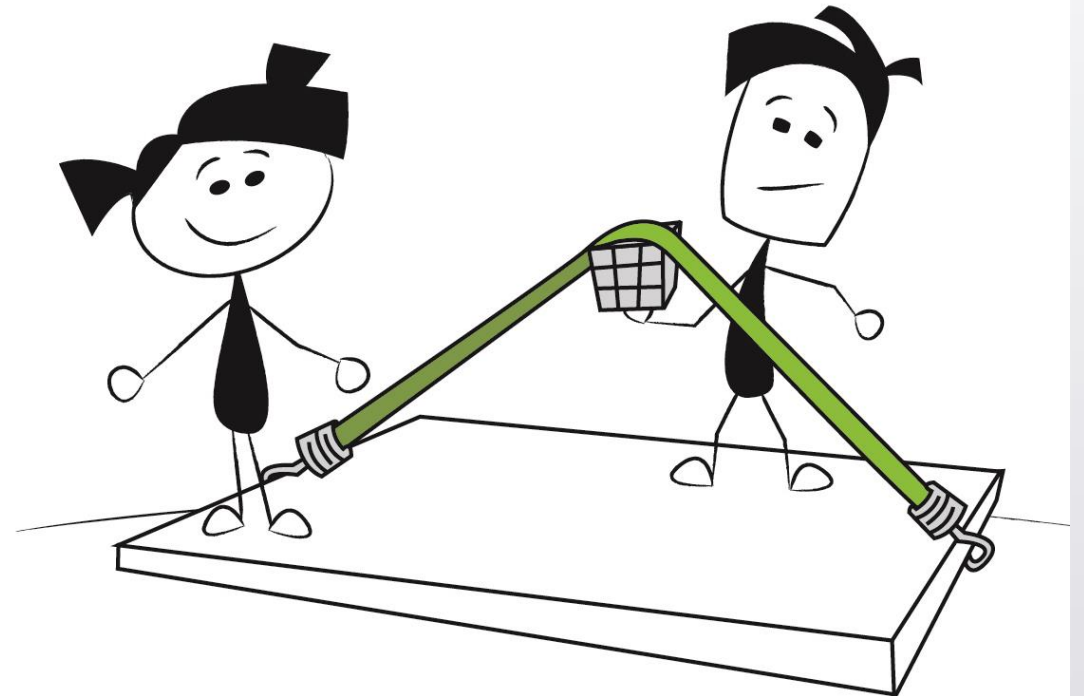
Why do objects fall?



The force of gravity pulls them down

Force Model of Gravity

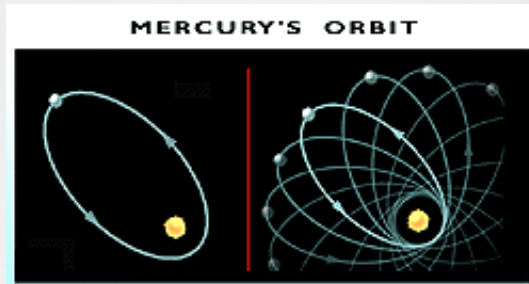
Gravity is like
an Invisible
Bungee Cord



*“That gravity should be innate, inherent, and essential to matter so that one body may act upon another, at a distance through vacuum, without the mediation of anything else...**is to me so great an absurdity**, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it.”*

- Isaac Newton

Newtonian gravity works...right?



Observations (1859)

Force model predicts the wrong orbits

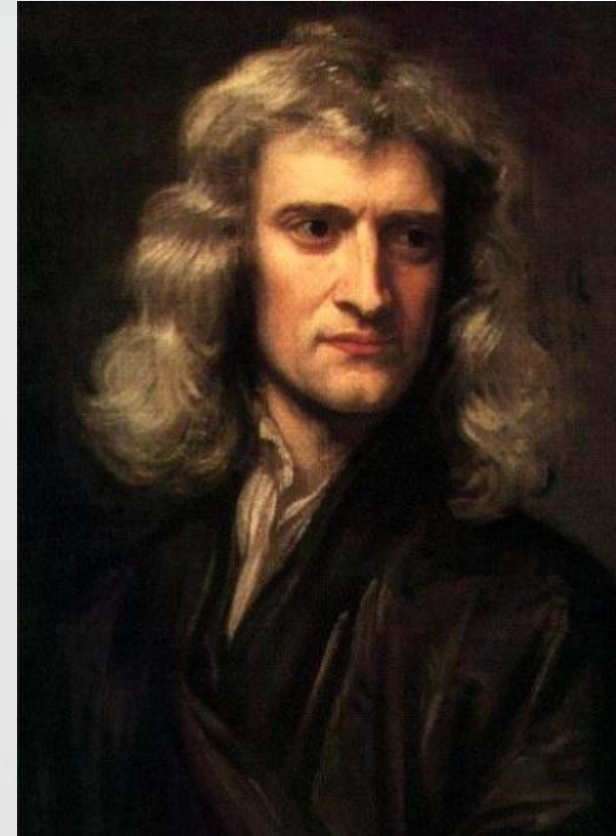


Theory (1905)

Force model violates speed of light limit

Newton: Gravity is a force

FEELS RIGHT, but
doesn't survive
experimental tests



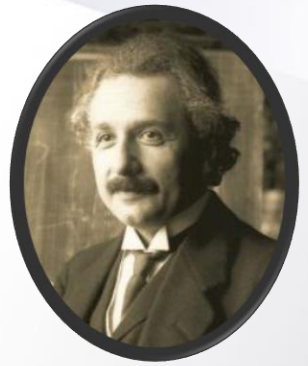
SO....

something is **wrong** with our
force model for GRAVITY

How else can I make this rod bend?



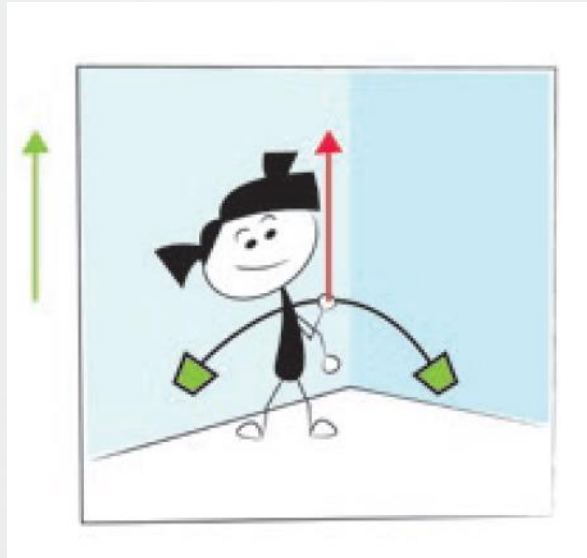
Acceleration Model



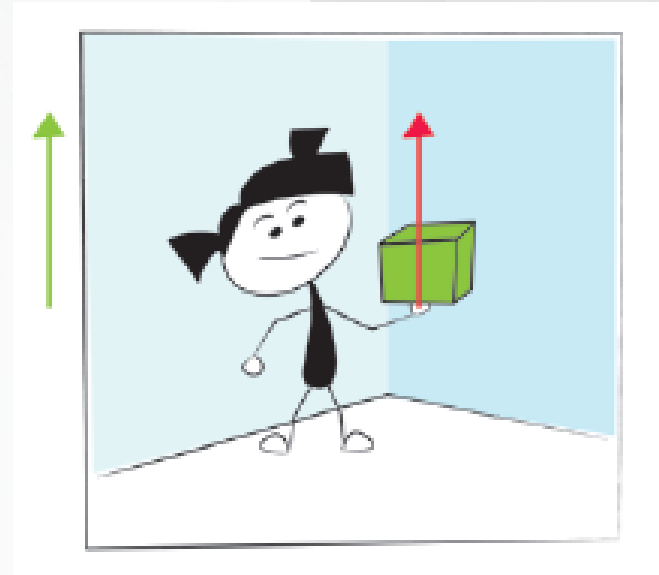
Acceleration Model



Bendy Rod



Weight



Freefall

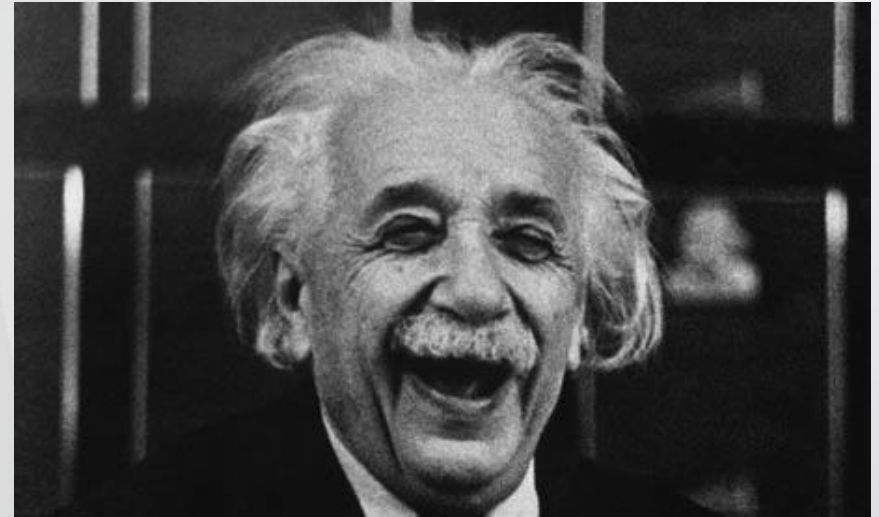


Acceleration Model of Gravity

Acceleration in one direction is identical to a force in the other direction!
-Einstein's "happiest thought"

Gravity isn't a force pulling us down.

We are accelerating UP!



The **BIG** Question

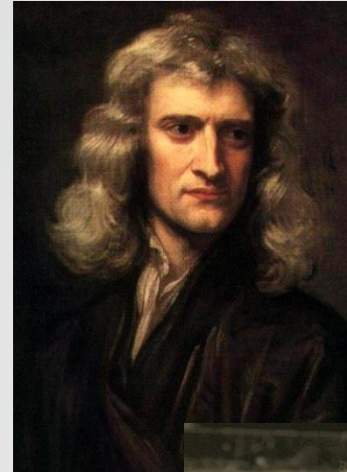
How can the ground be *accelerating up*
without *moving up*?



Two Models

Newton: Gravity is a force

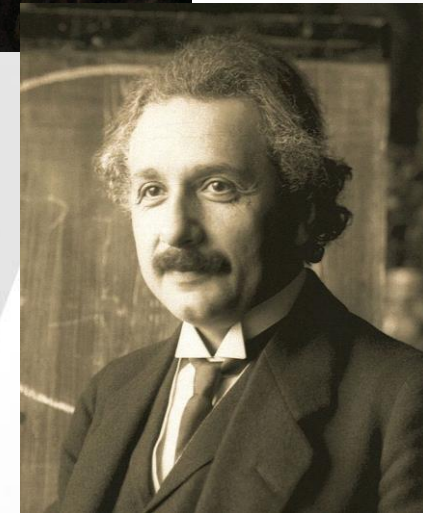
FEELS RIGHT, but doesn't survive experimental tests.



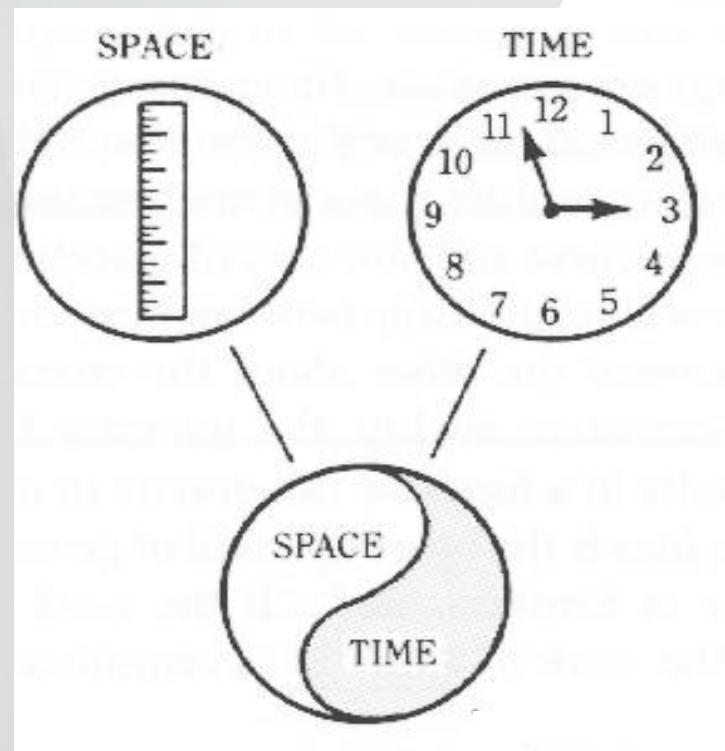
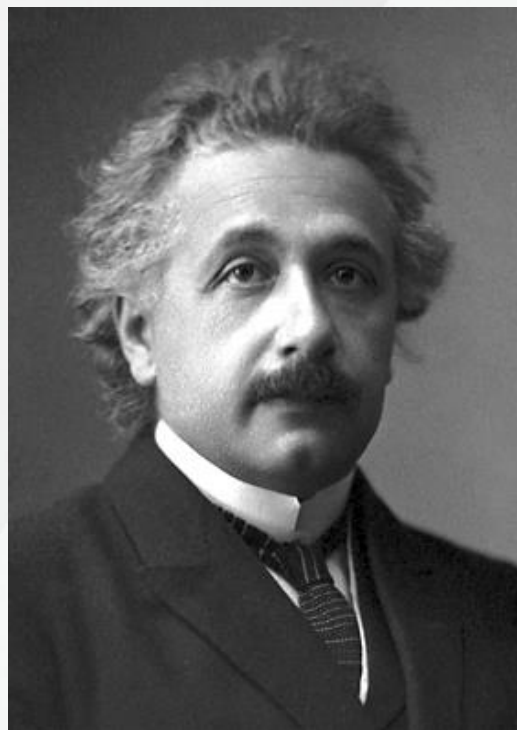
Einstein: Acceleration Model

FEELS WEIRD but could work...

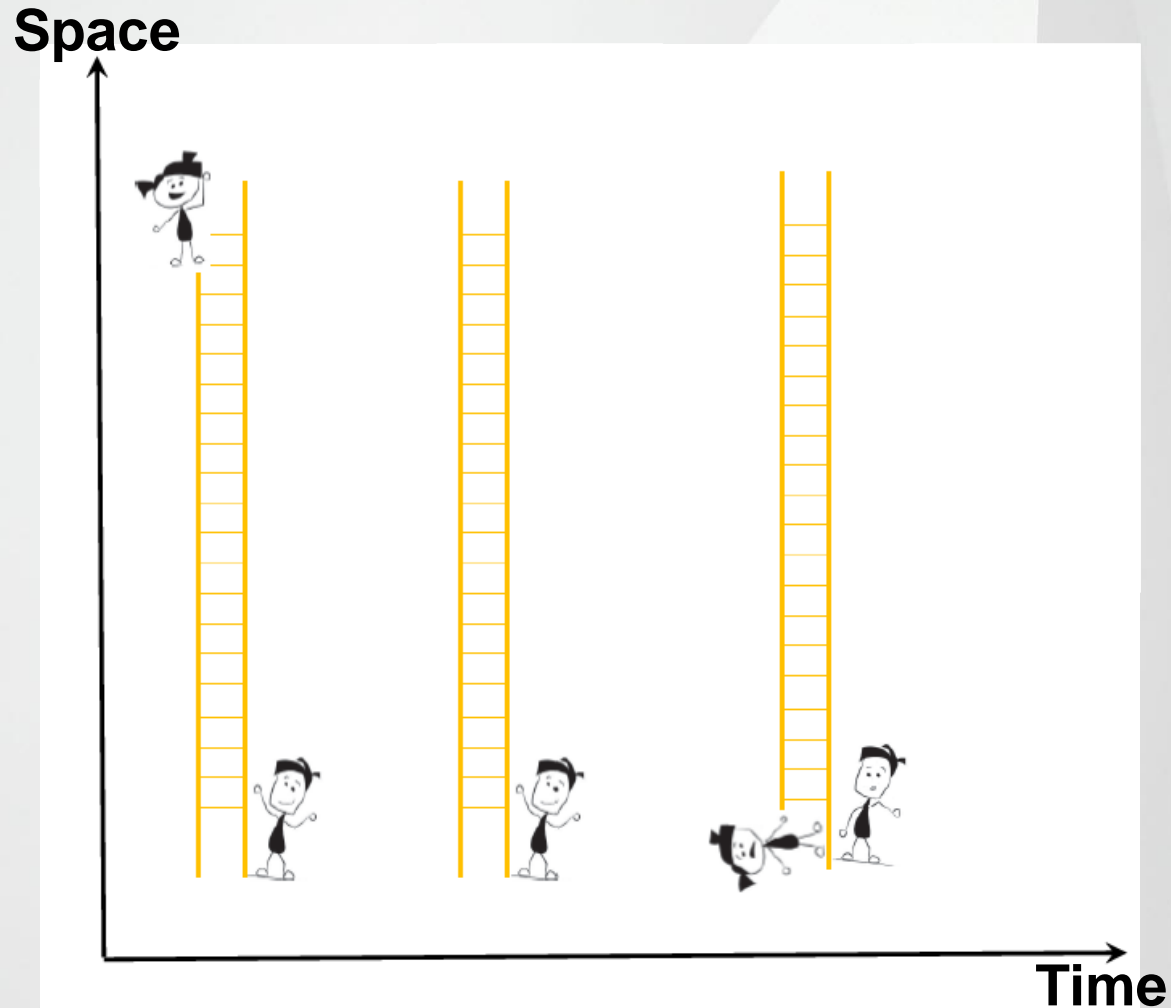
... But earth isn't expanding!



Special Relativity



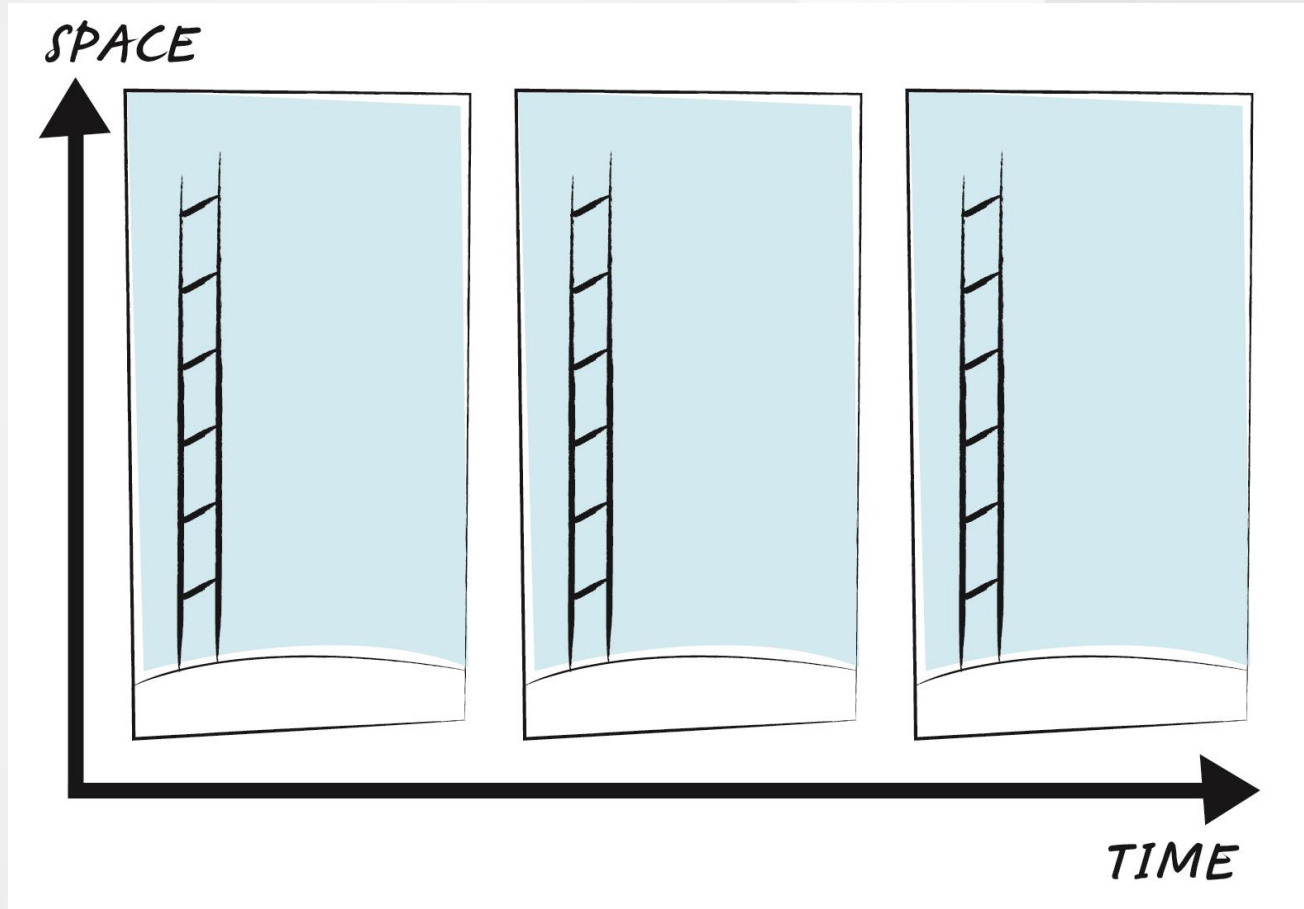
Force Model: Falling Off a Ladder



Curved lines on spacetime diagram mean the object accelerated.

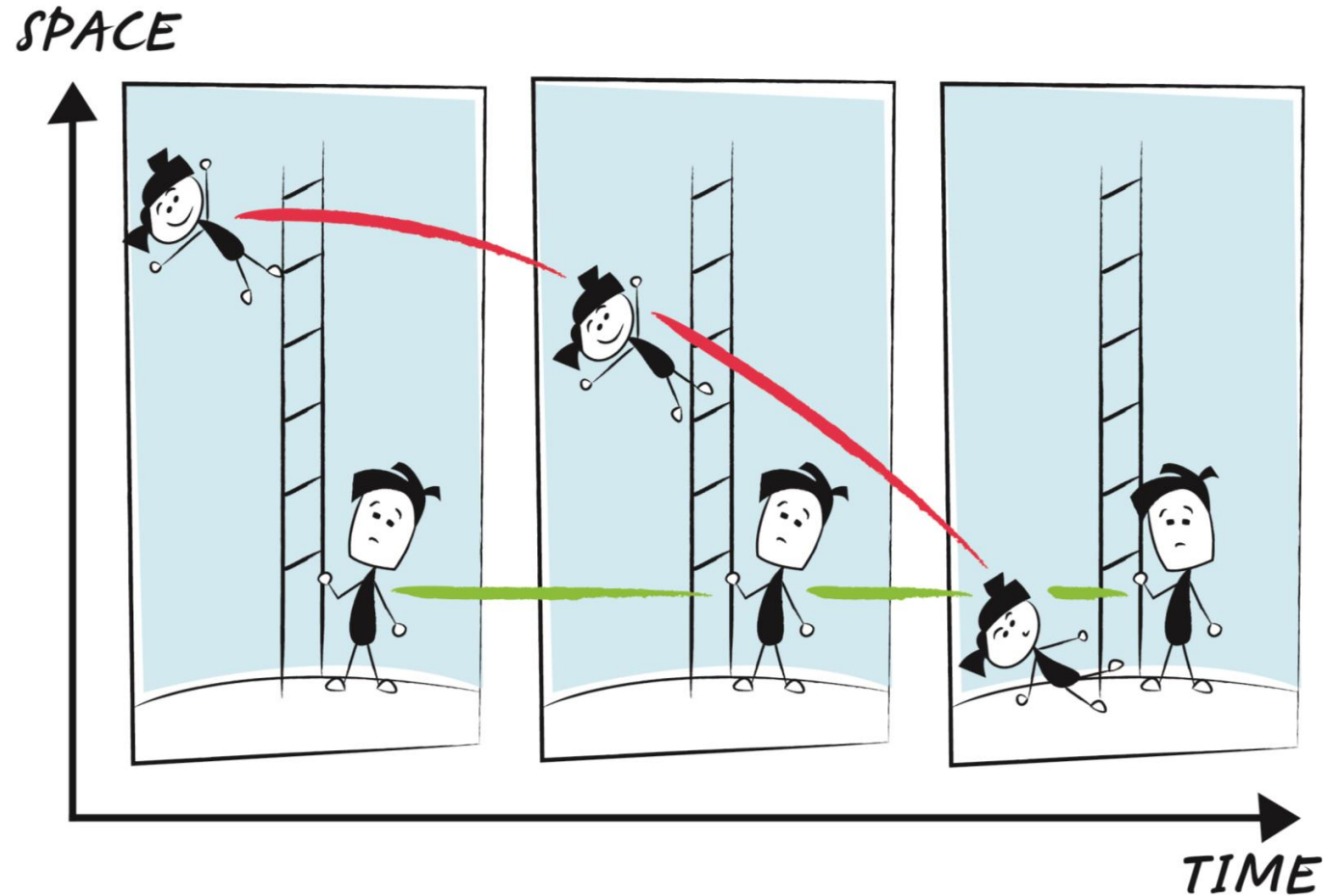
Spacetime Diagram

Curved lines on a spacetime diagram mean the object accelerated.



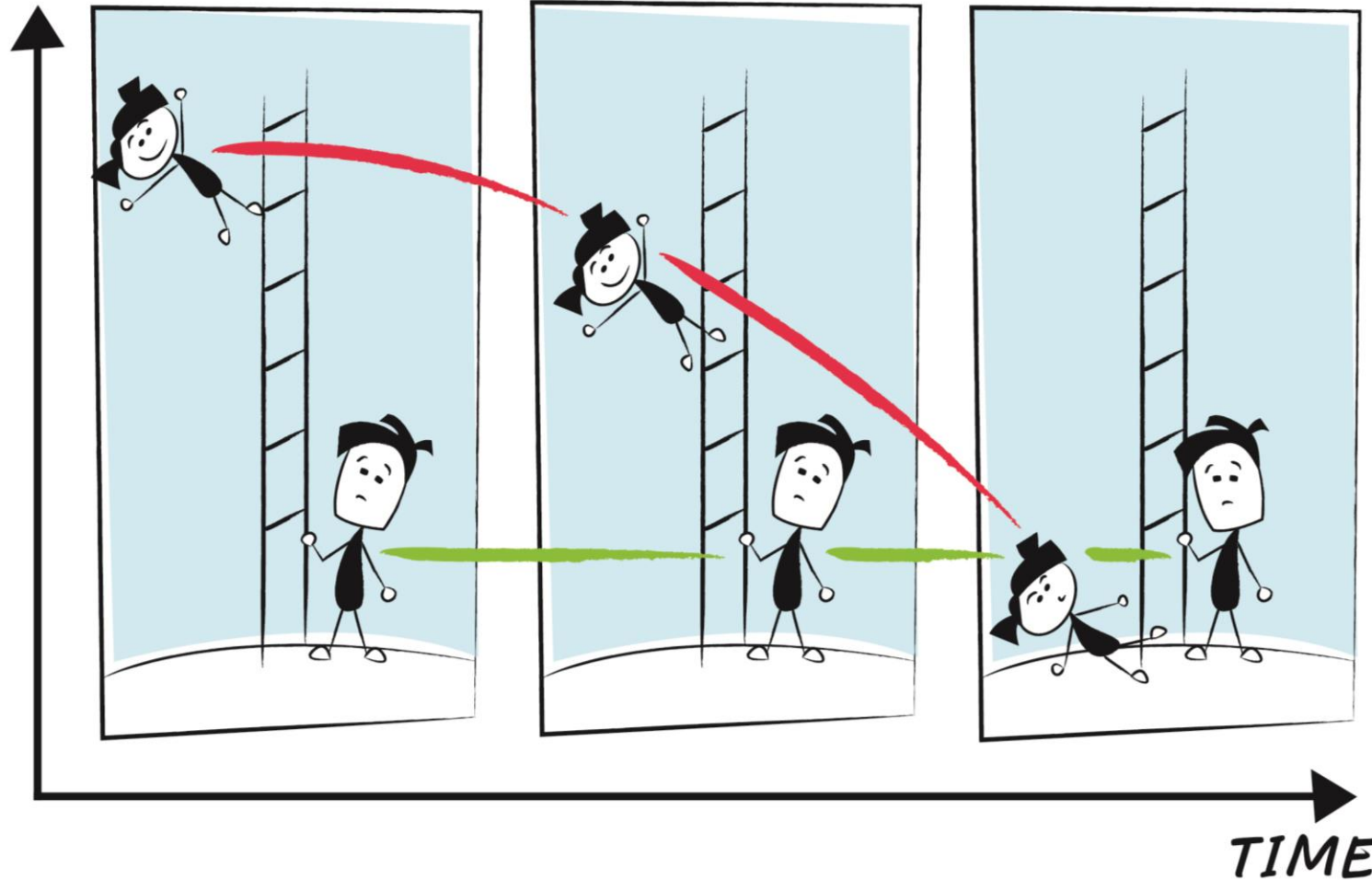
Create three 'snapshots' of Alice as she falls.

Spacetime Diagram



Spacetime Diagram

SPACE

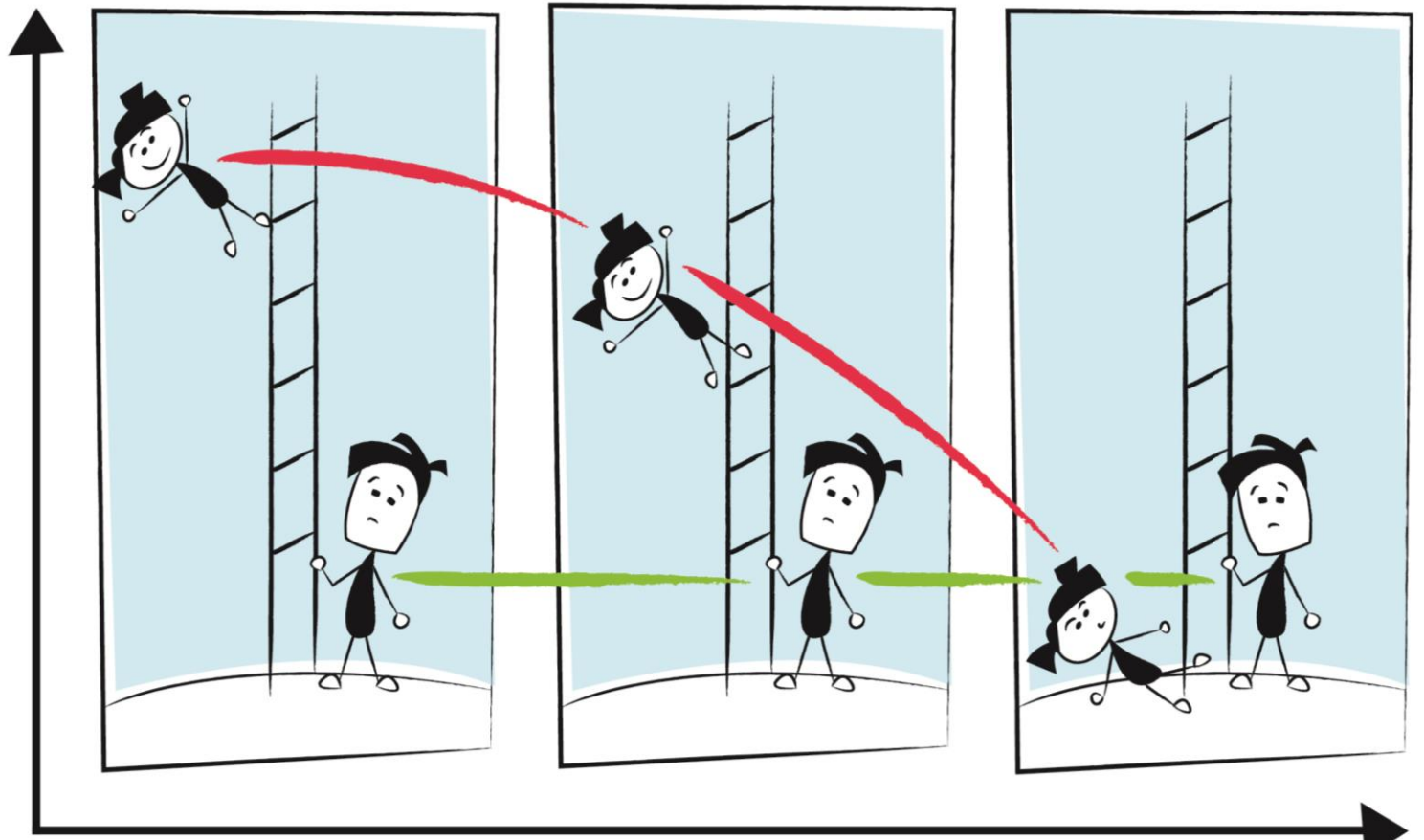


Curved lines on spacetime diagram mean the object accelerated.

Einstein's acceleration model needs to have Alice's line flat and Bob's curved, while Bob remains the same distance from the x-axis...

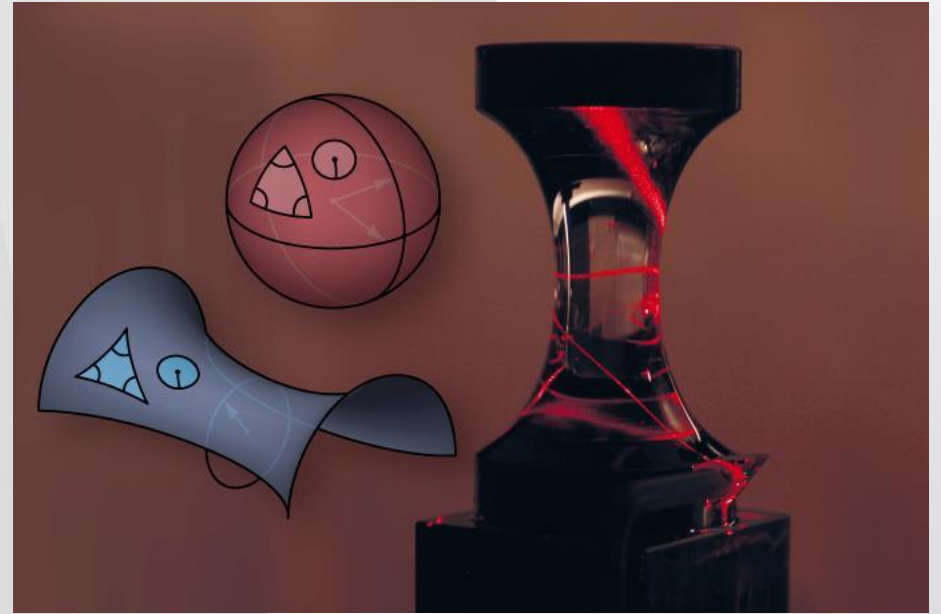
How can Bob be made to accelerate?

SPACE

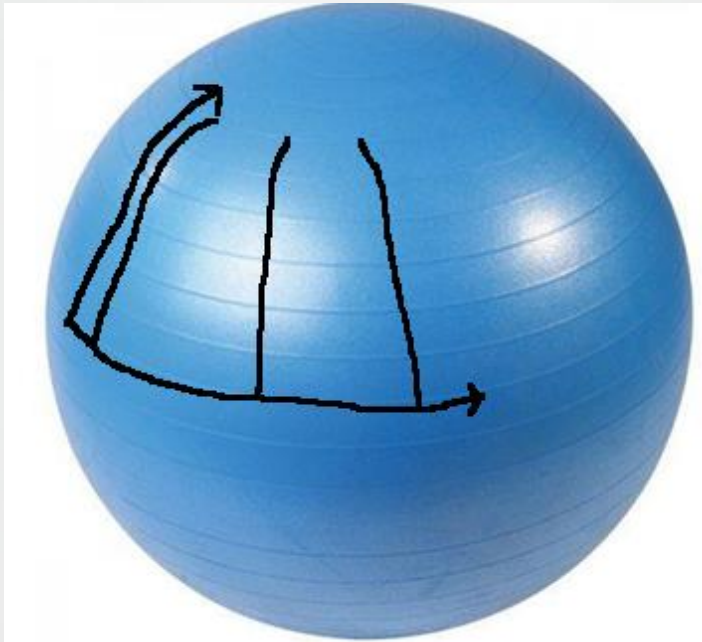


TIME

Einstein's Solution: Spacetime is not flat!

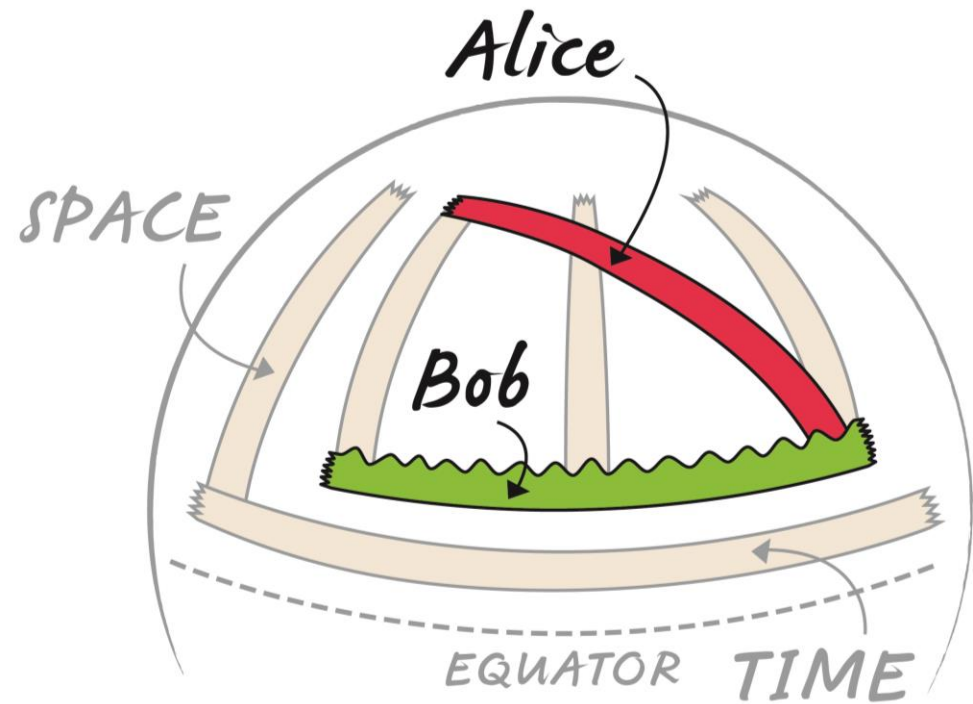
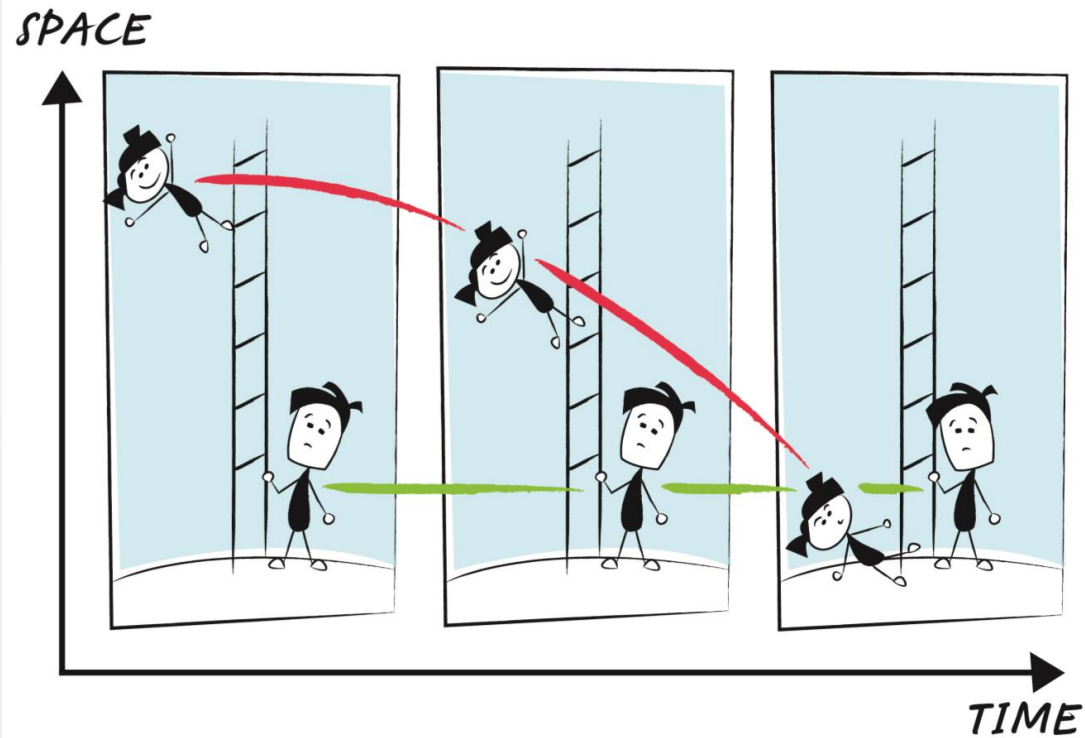


Repeat the same steps on the balloon

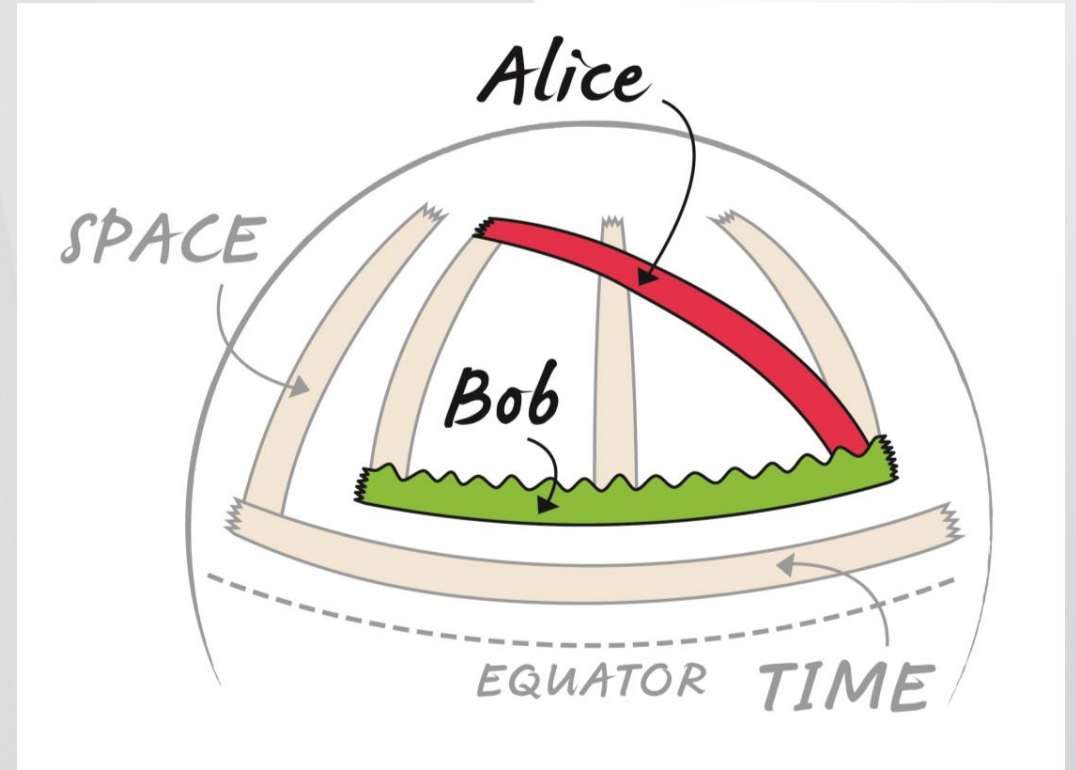
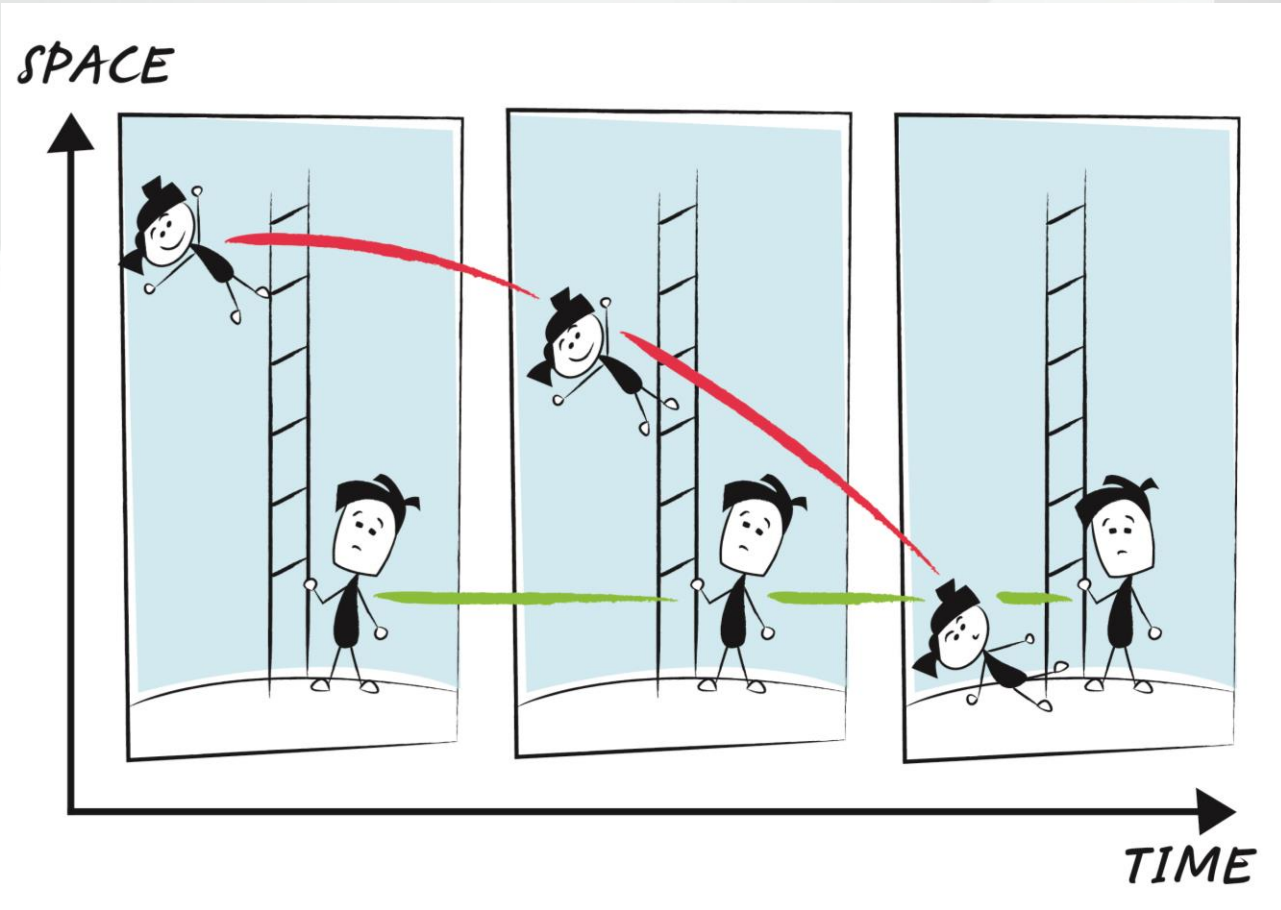


Curved lines on spacetime diagram mean the object accelerated.

Curved Spacetime

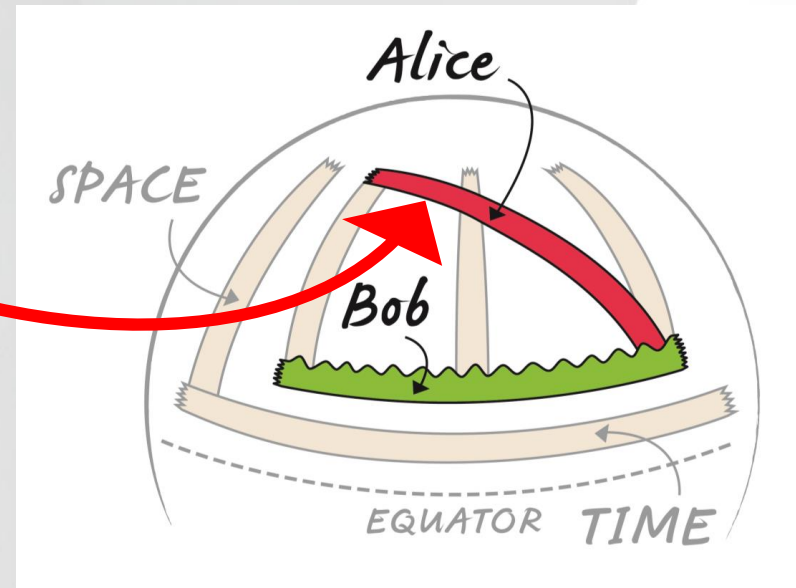
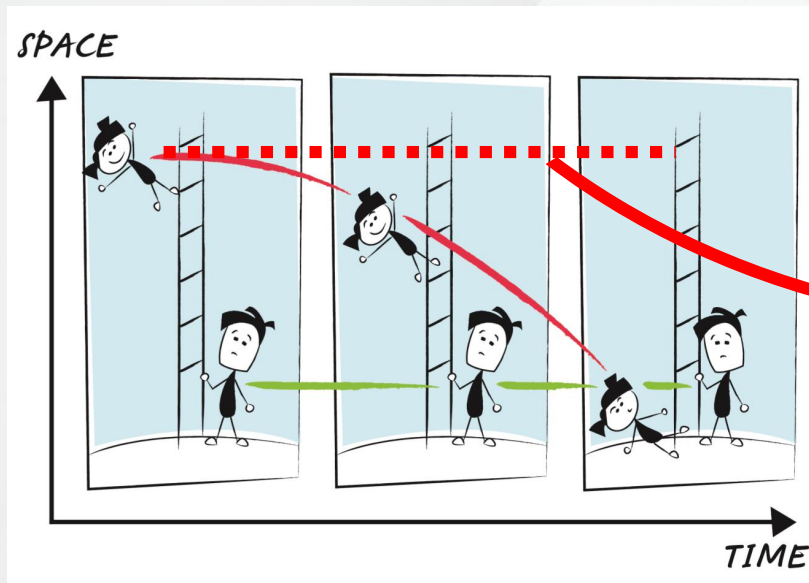


Curved Spacetime

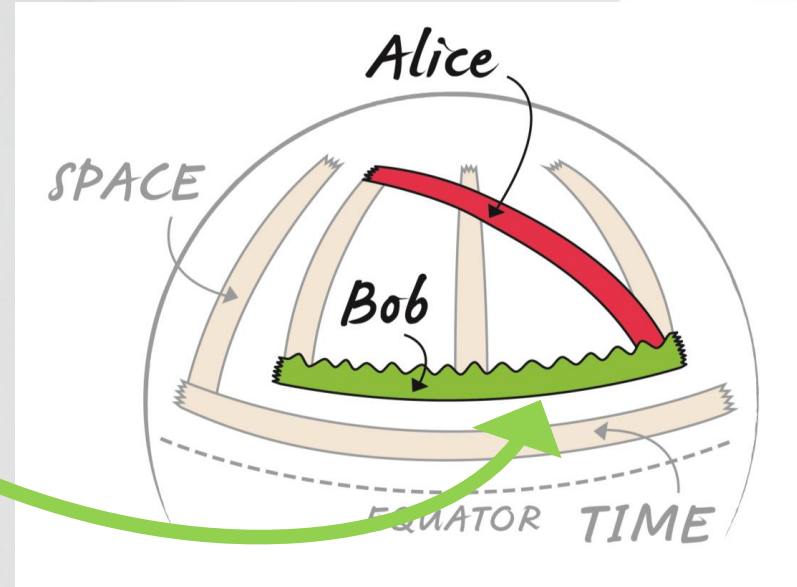
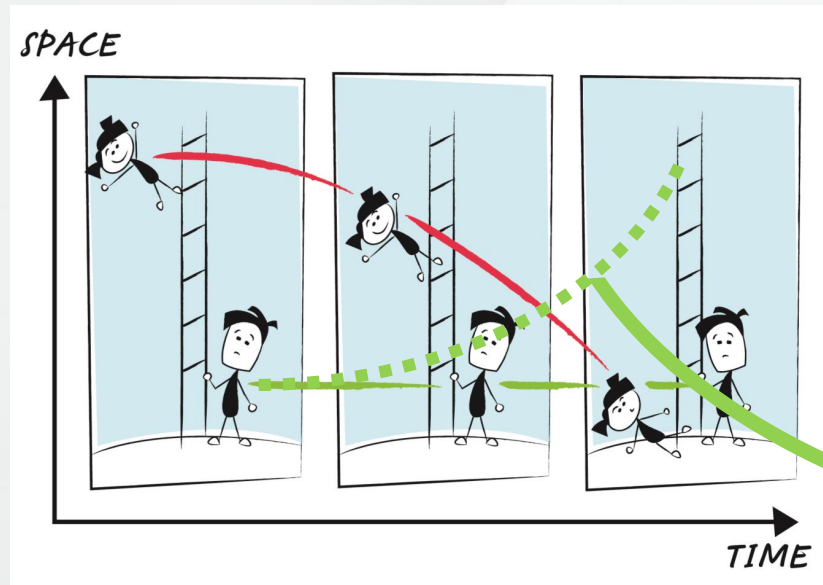


Alice's path stays straight (no force, no acceleration)

...and yet she is falling from the top of the ladder to the bottom!



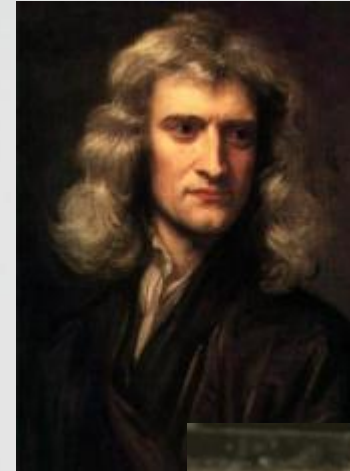
Bob's path *curves up* (he feels upward force and acceleration)
...and yet he is not *moving up*!



Two Models

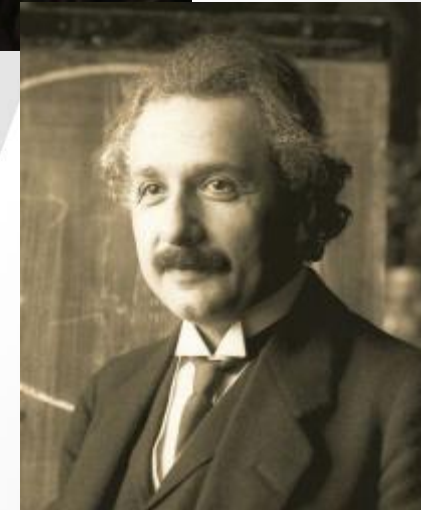
Newton: Gravity is a force

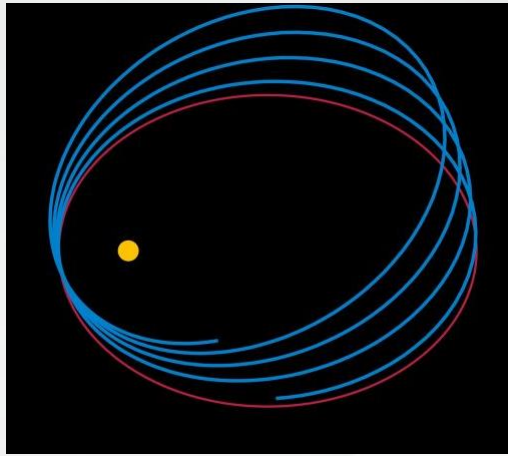
FEELS RIGHT, but doesn't survive experimental tests



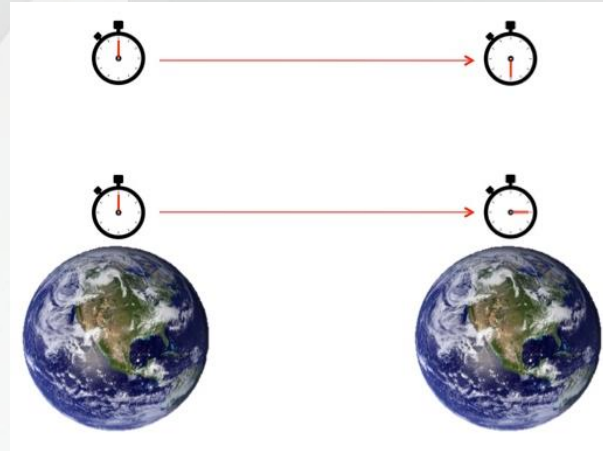
Einstein: Spacetime is curved

FEELS WEIRD but explains what we see (so far)

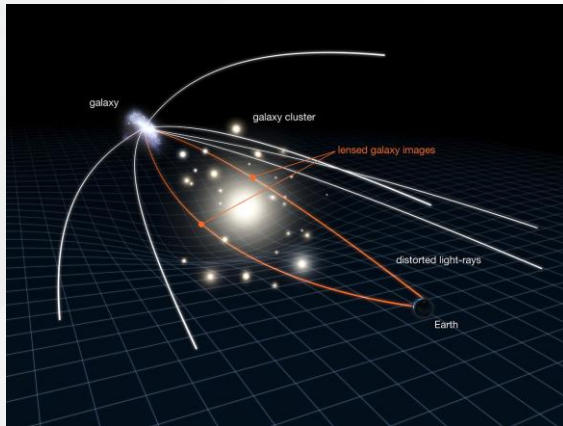
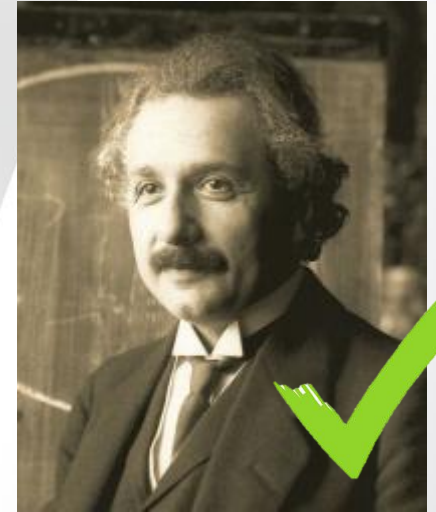




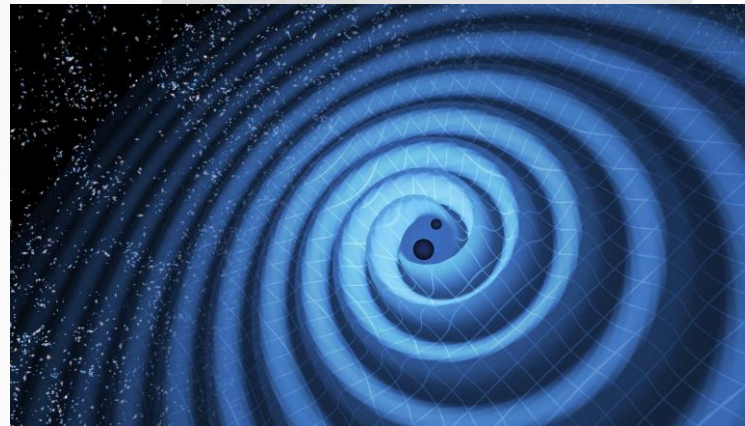
Mercury's Orbit



Time Dilation

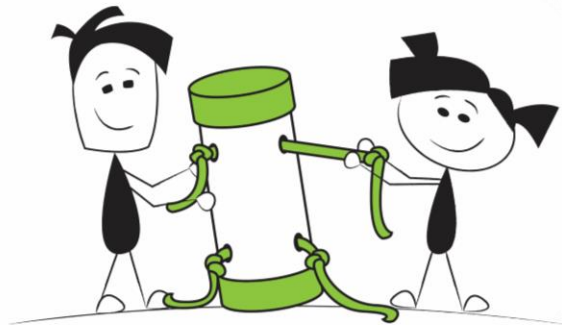


Lensing

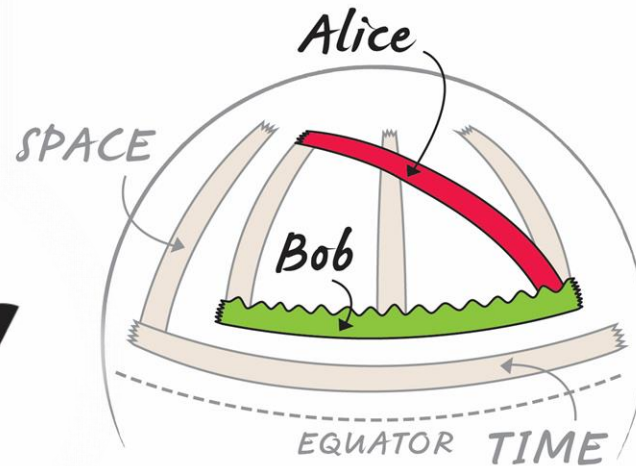


Gravitational Waves

Science is a powerful way of thinking



Curiosity

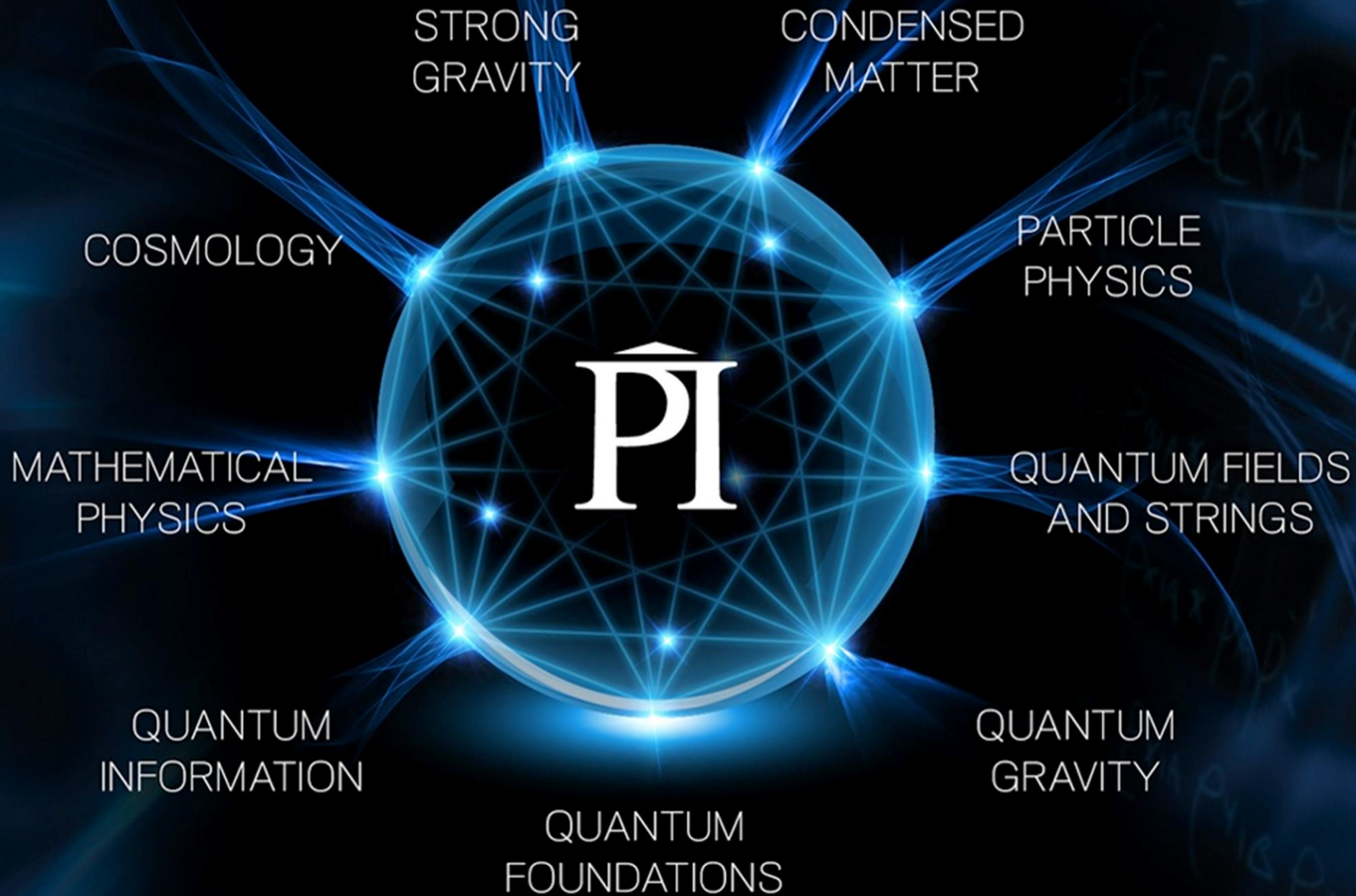


Creativity



Collaboration





Teacher Programs

www.perimeterinstitute.ca/outreach/teachers



IN-CLASS RESOURCES



Experienced
teachers

Perimeter
researchers

Pedagogy and
teaching strategies

<https://resources.perimeterinstitute.ca/>

High School Student Programs

www.perimeterinstitute.ca/outreach/students

Go Physics!

1-day workshops (online)



ISSYP



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By Perimeter Institute

Free Educational Resources for Teachers

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