

# *How and Why to go Beyond the Discovery of the Higgs Boson*

John Alison

*University of Chicago*

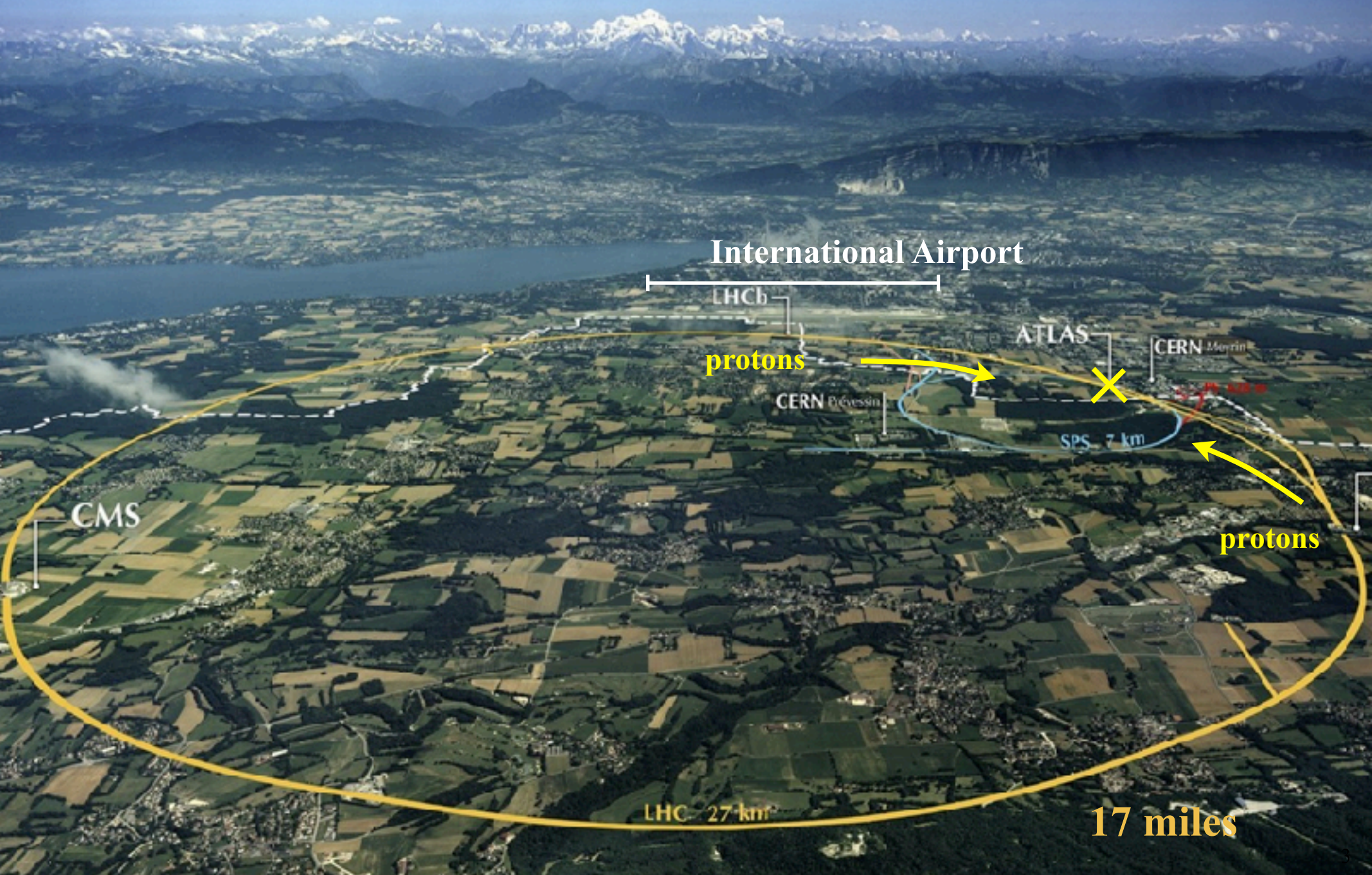
**<http://hep.uchicago.edu/~johnda/ComptonLectures.html>**

# Discovery of the Higgs Boson



**Nobel Prize**

# What it Took: The Large Hadron Collider



International Airport

LHCb

protons

ATLAS

CERN Meyrin

CERN Provesim

SPS 7 km

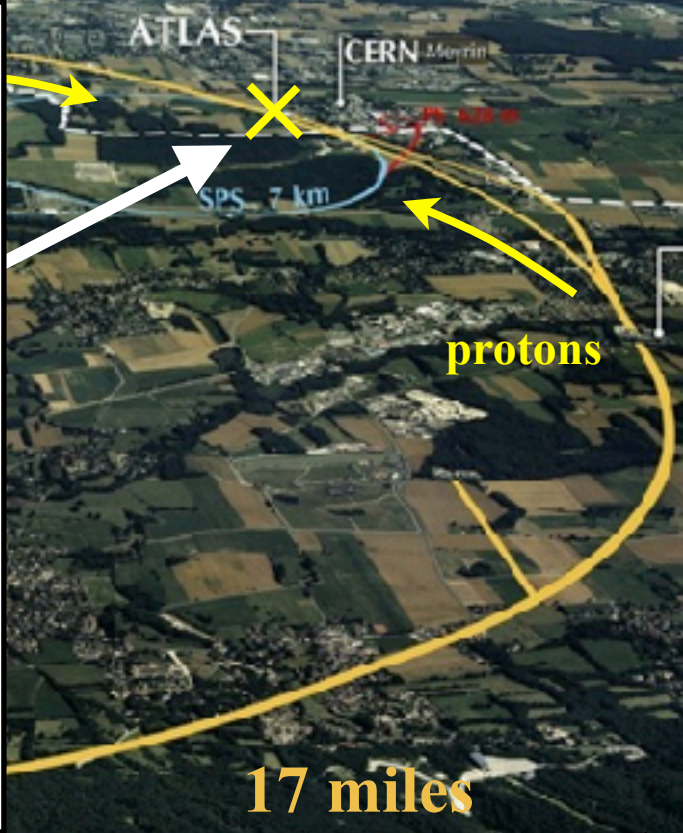
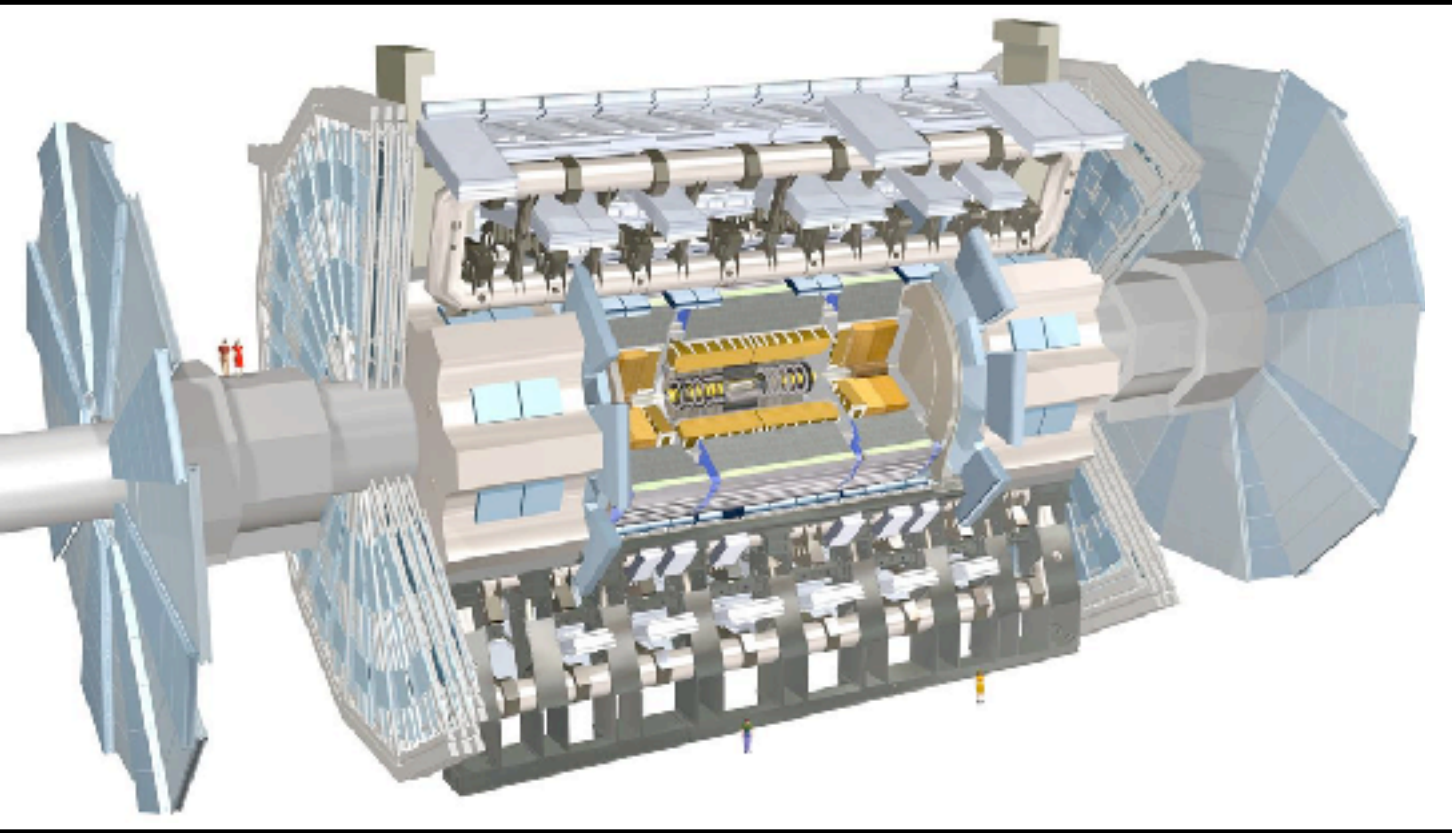
protons

CMS

LHC 27 km

17 miles

# What it Took: The Large Hadron Collider



# What it Took: In Numbers

- **>10,000** scientists and engineers from **85** countries
- **27 kilometer** particle accelerator
- Protons moving at **99.9999993%** the speed of light
- **~1 billion** proton collisions / second (for 2 years)
- Total budget: **~10 billions dollars**
- Detectors - size of apartment buildings - operating at **40 MHz**
- Generate **80 TB/s** ( $\sim 10 \times$  size of library of congress )
- (Salary of physicist)  $\ll$  (Salary of banker or engineer)

*What is the Higgs boson ???*

*Why did we need such extremes to find it ?*

*Why look for the Higgs boson in the first place ?*

*Are we done now that we have found it ?*

# Lecture Outline

- April 1st:** *Newton's dream & 20th Century Revolution*
- April 8th:** **Mission Barely Possible: QM + SR**
- April 15th:** **Standard Model & Importance of the Higgs**
- April 22nd:** **The Cannon and the Camera**
- April 29th:** **Guest Lecture**
- May 6th:** **The Discovery of the Higgs Boson**
- May 13th:** **Going beyond the Higgs**
- May 20th:** **Experimental Challenges**
- May 27th:** **Memorial Day: No Lecture**
- June 3rd:** **What comes next ?**

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**June 3rd:** **What comes next?**

## Sources:

- Nima Arkani-Hamed
- Steven Weinberg
- ...

*I will keep this list up to date as we go along.*

# Who am I ?



THE UNIVERSITY OF  
CHICAGO



# Today's Lecture

**Newton's Dream:** The direction of science

**20th Century Revolutions:**

- Relativity
- Quantum Mechanics

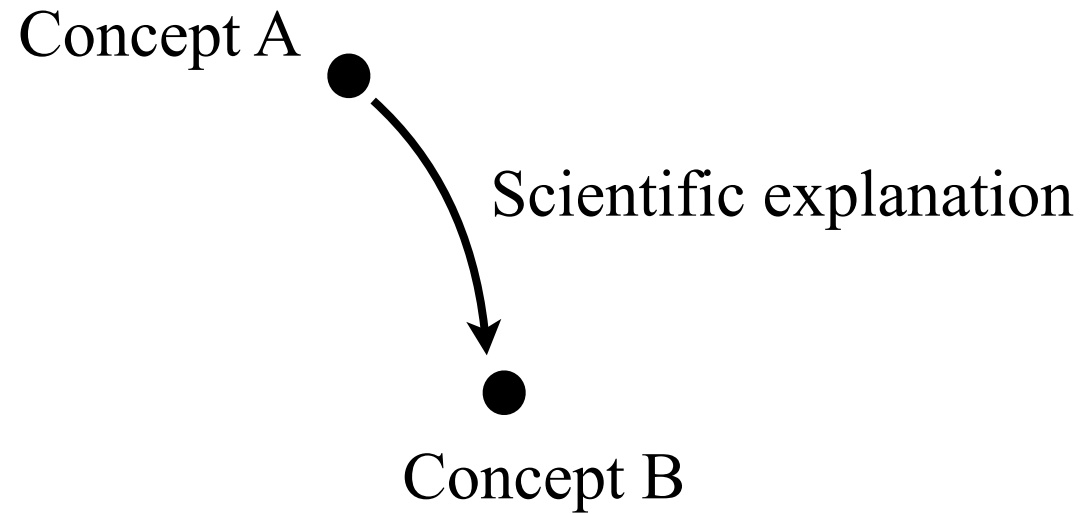
# Scientific Explanation

Notion that diverse natural phenomena can be explained by simpler concepts dates back to the ancients.

Came to life with Newton (Galileo) :

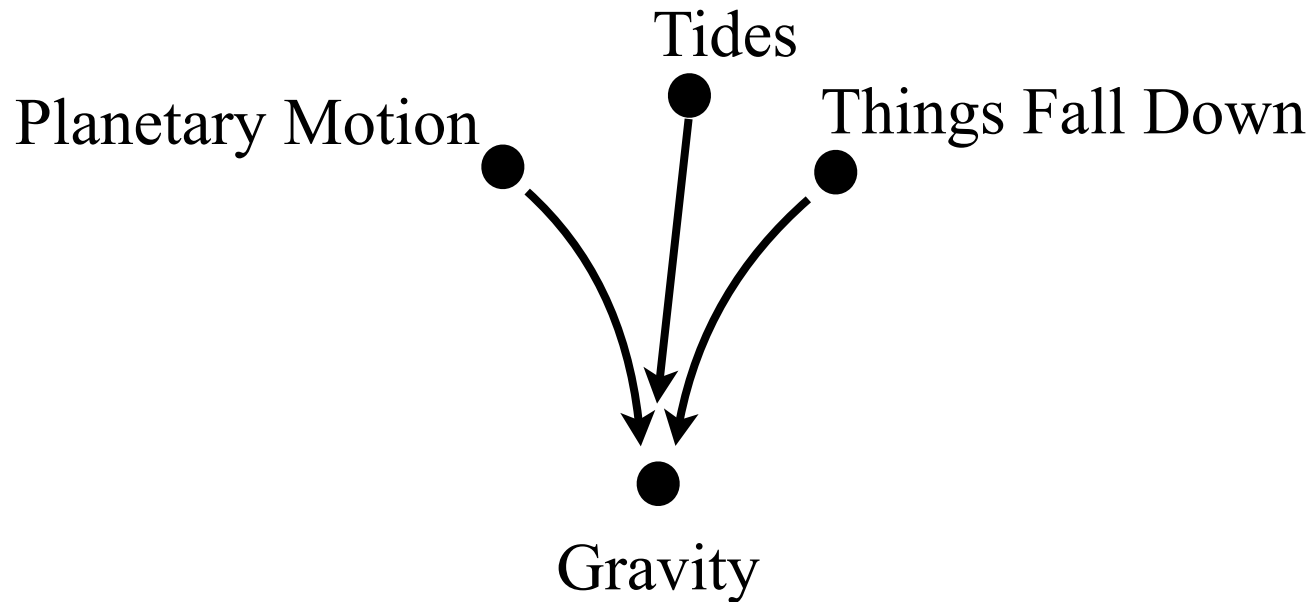
- Mathematics central to describing nature
- Developed new branch of math: calculus
- New laws of motion and gravity
- Biggest advance of all: *“Newton’s Dream”*

# Scientific Explanation



# Scientific Explanation

Newton:

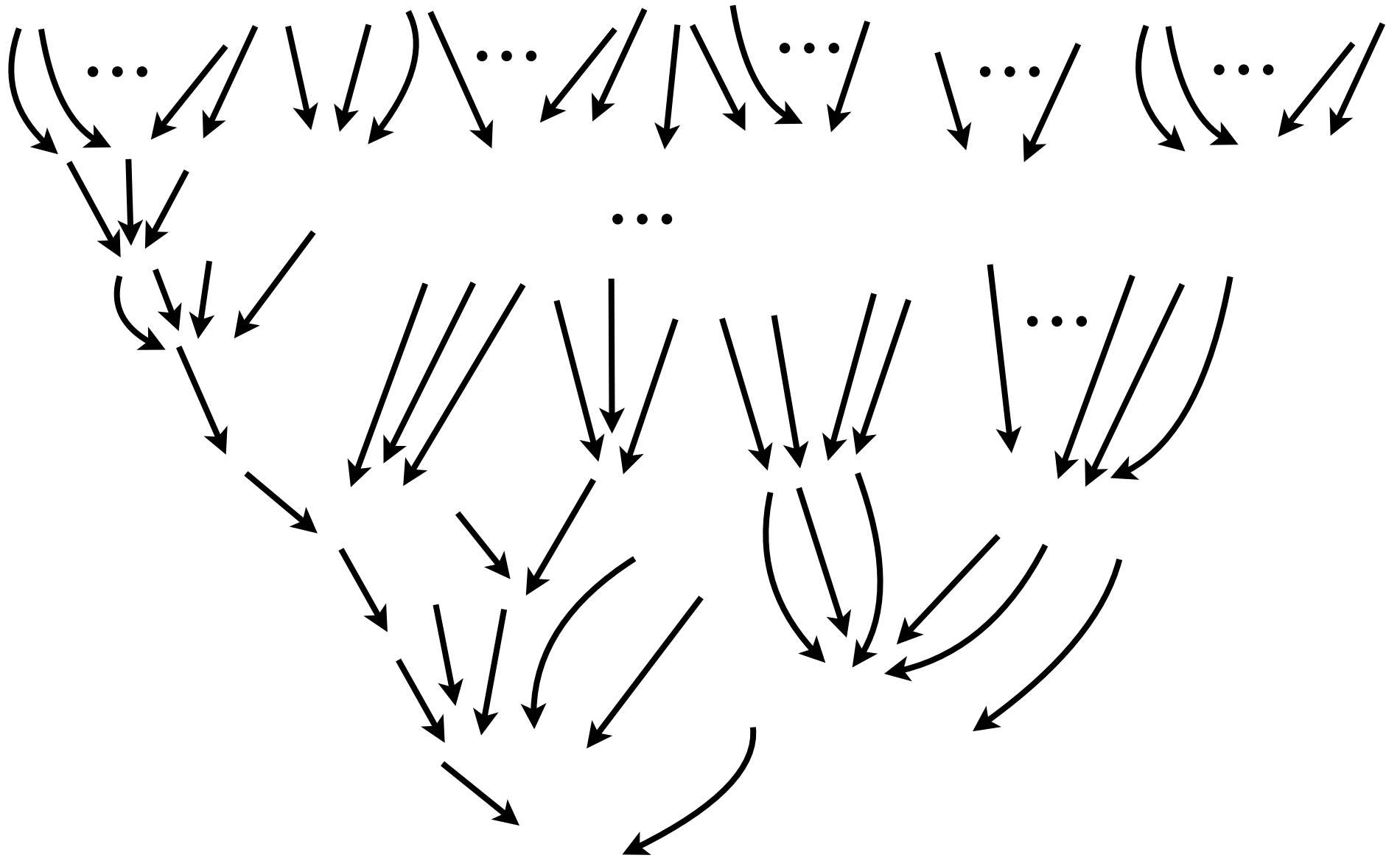


*“I wish we could derive the rest of the phenomena of nature by the same kind of reasoning as for mechanical principles. For I am induced by many reasons to suspect that they may all depend on certain forces.”*

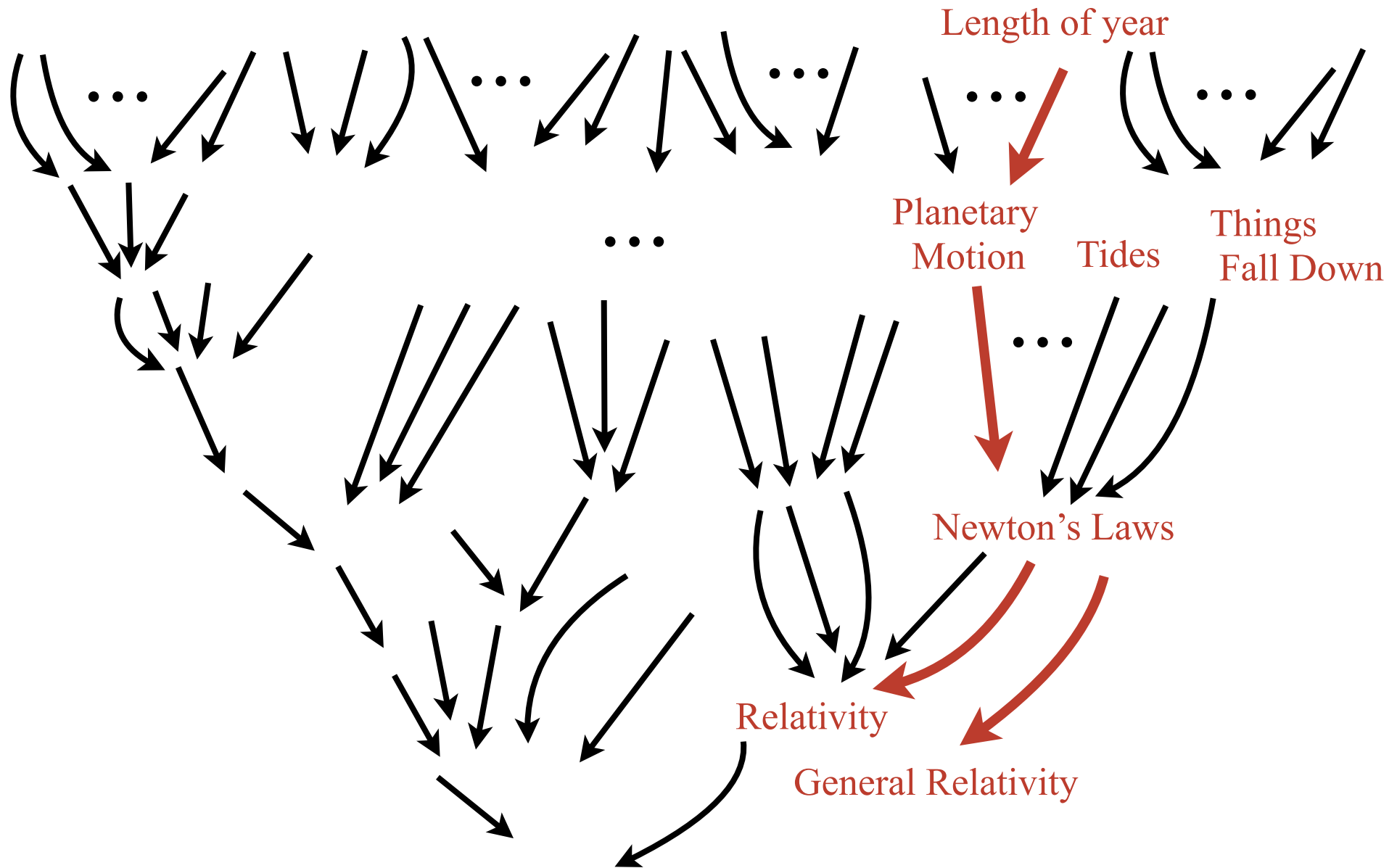
- Newton, Preface to Principia, 1686

**Newton’s Dream:** Understand all of nature terms of simple principles

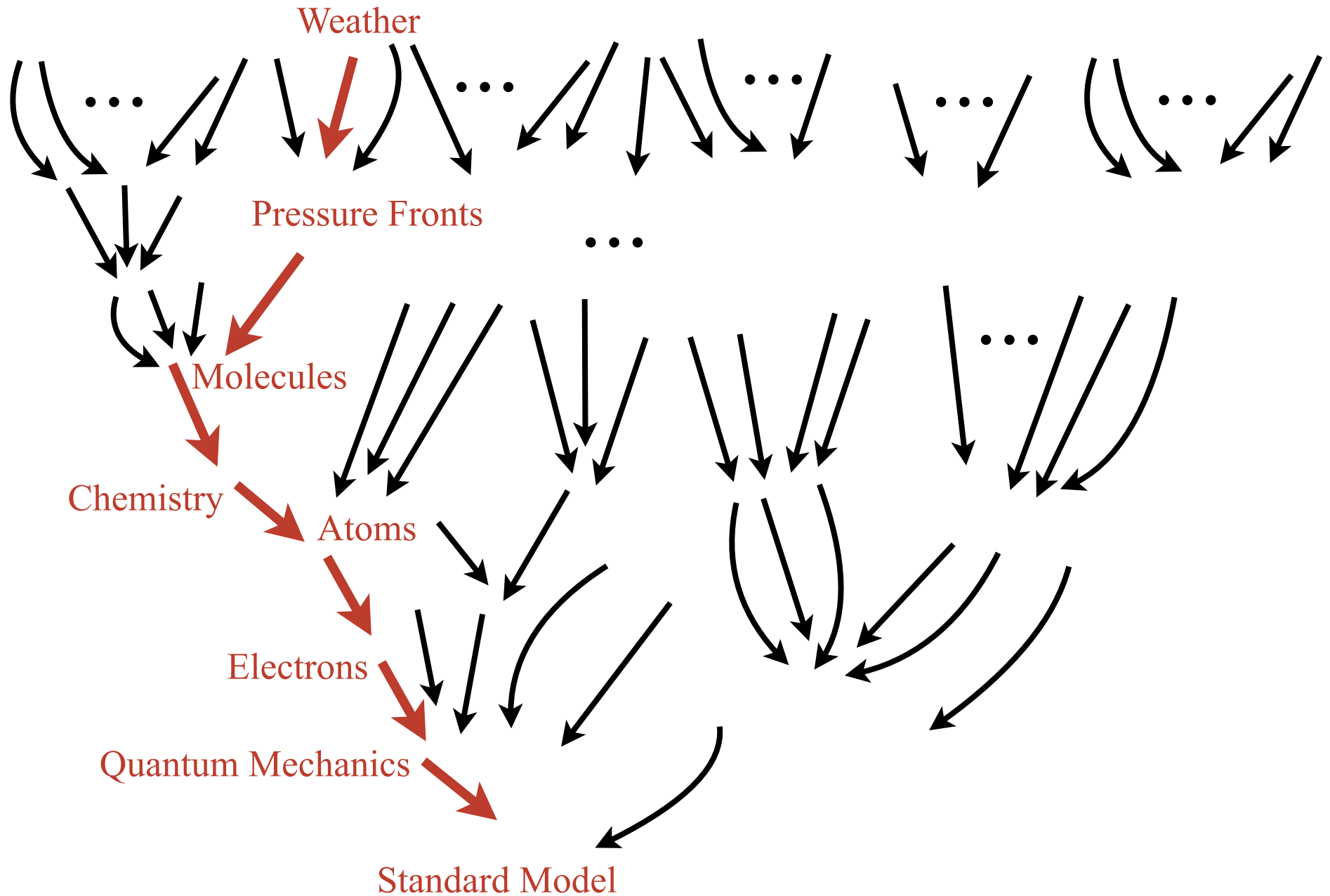
# Realizing Newton's Dream



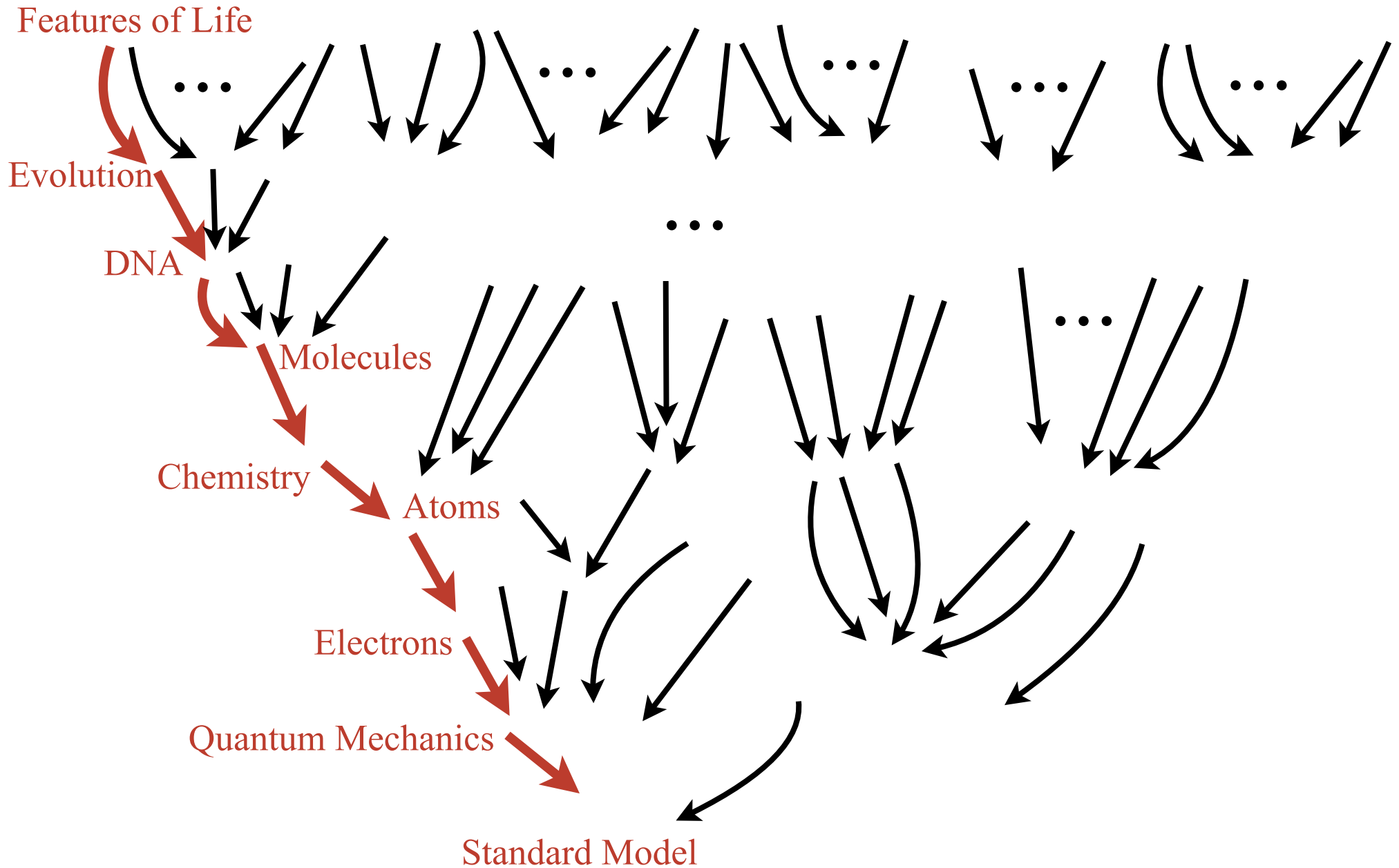
# Realizing Newton's Dream



# Realizing Newton's Dream

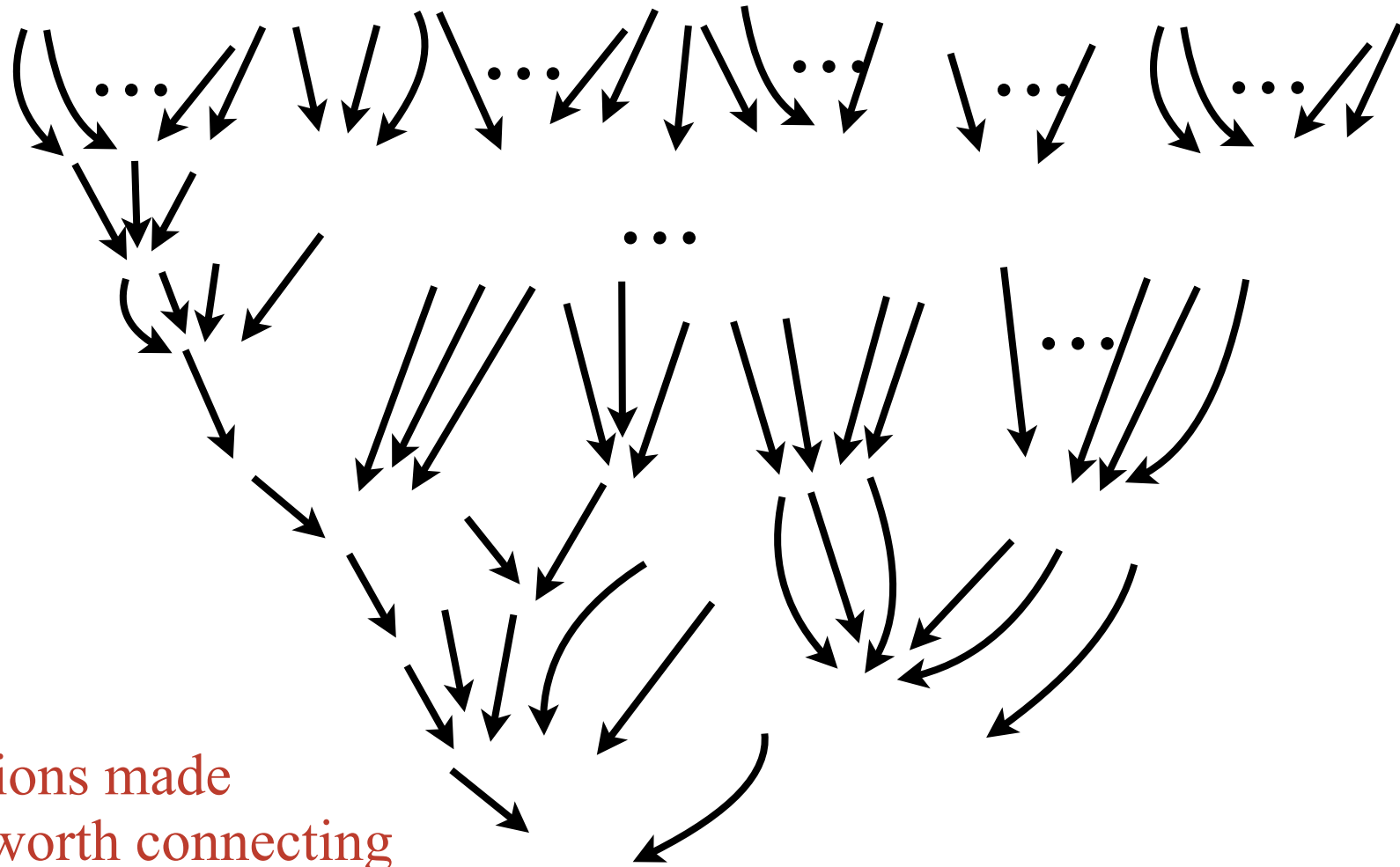


# Realizing Newton's Dream





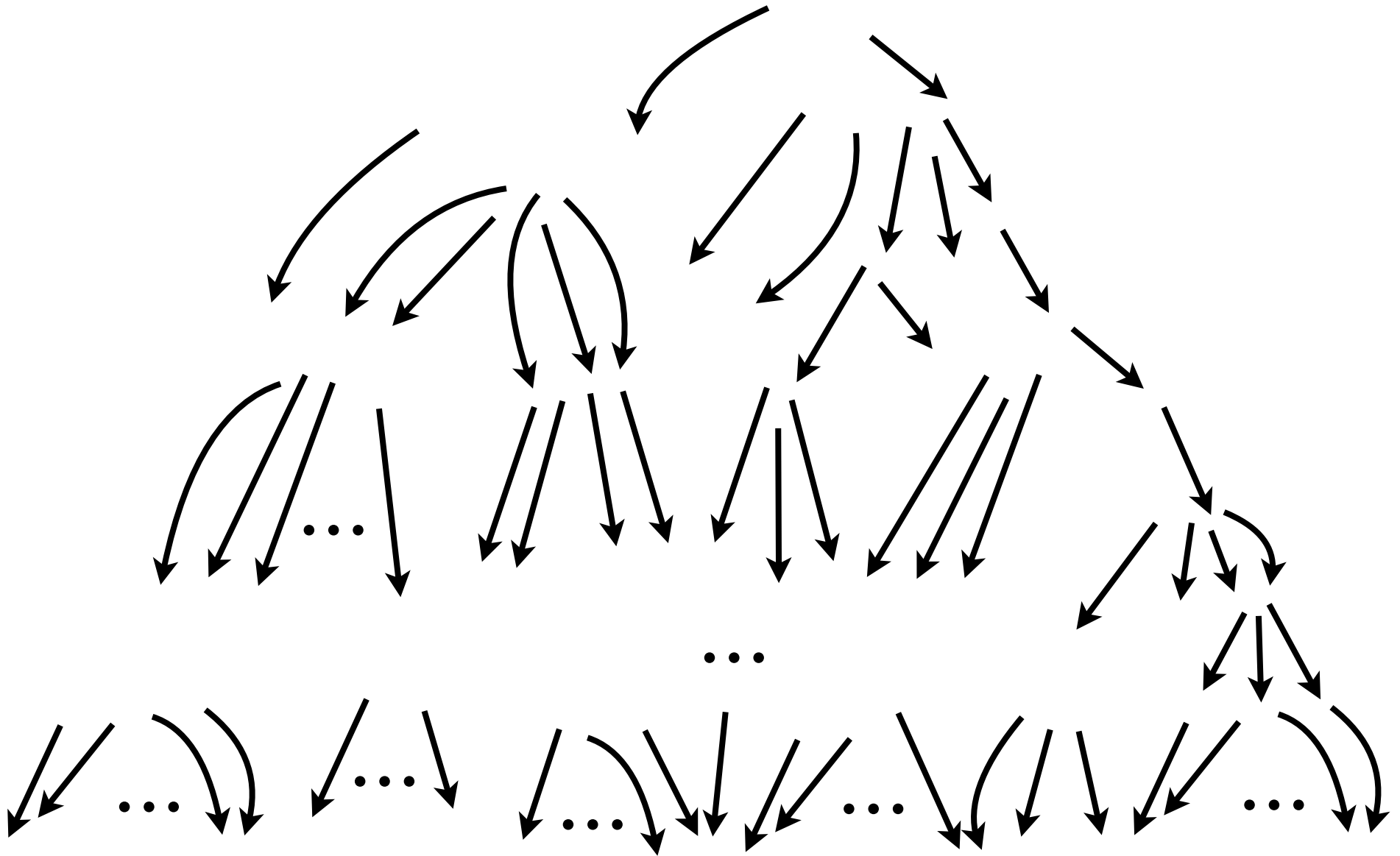
# Sense of Direction in Science



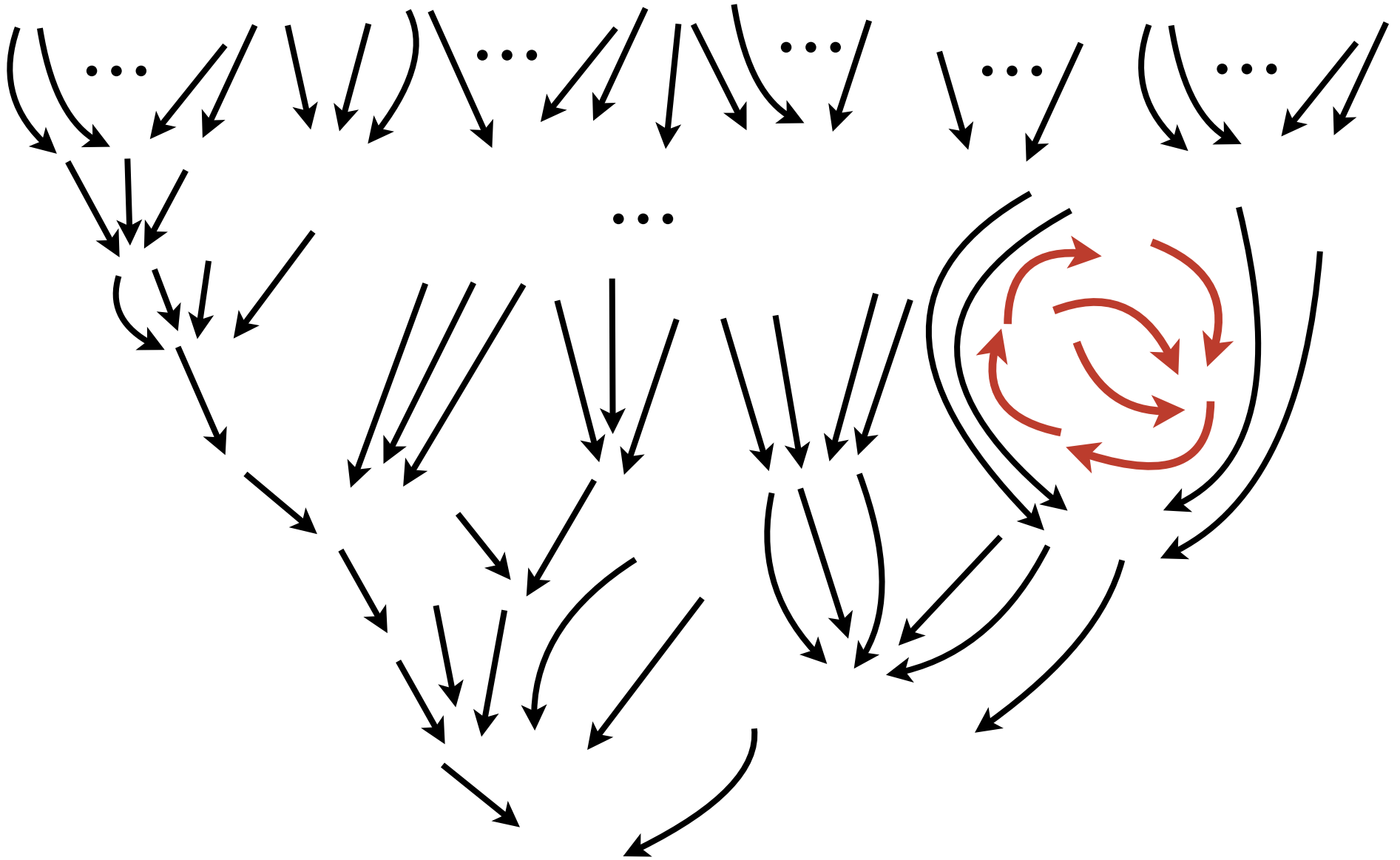
- Not all connections made
- Not all arrows worth connecting
- Direction/Convergence
- Fact about nature

*“Perhaps greatest scientific discovery of all”* - Steven Weinberg

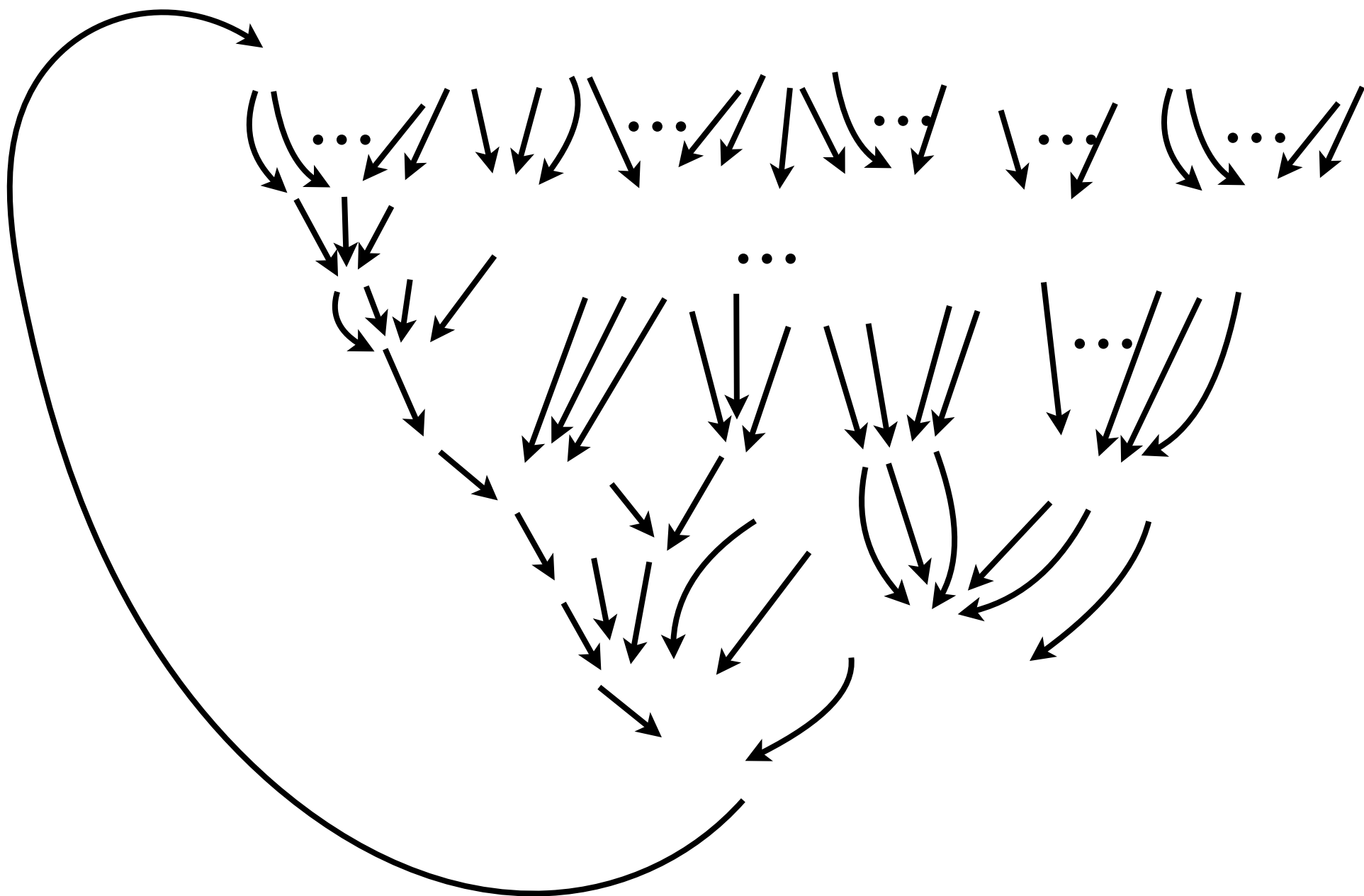
It could have been different.



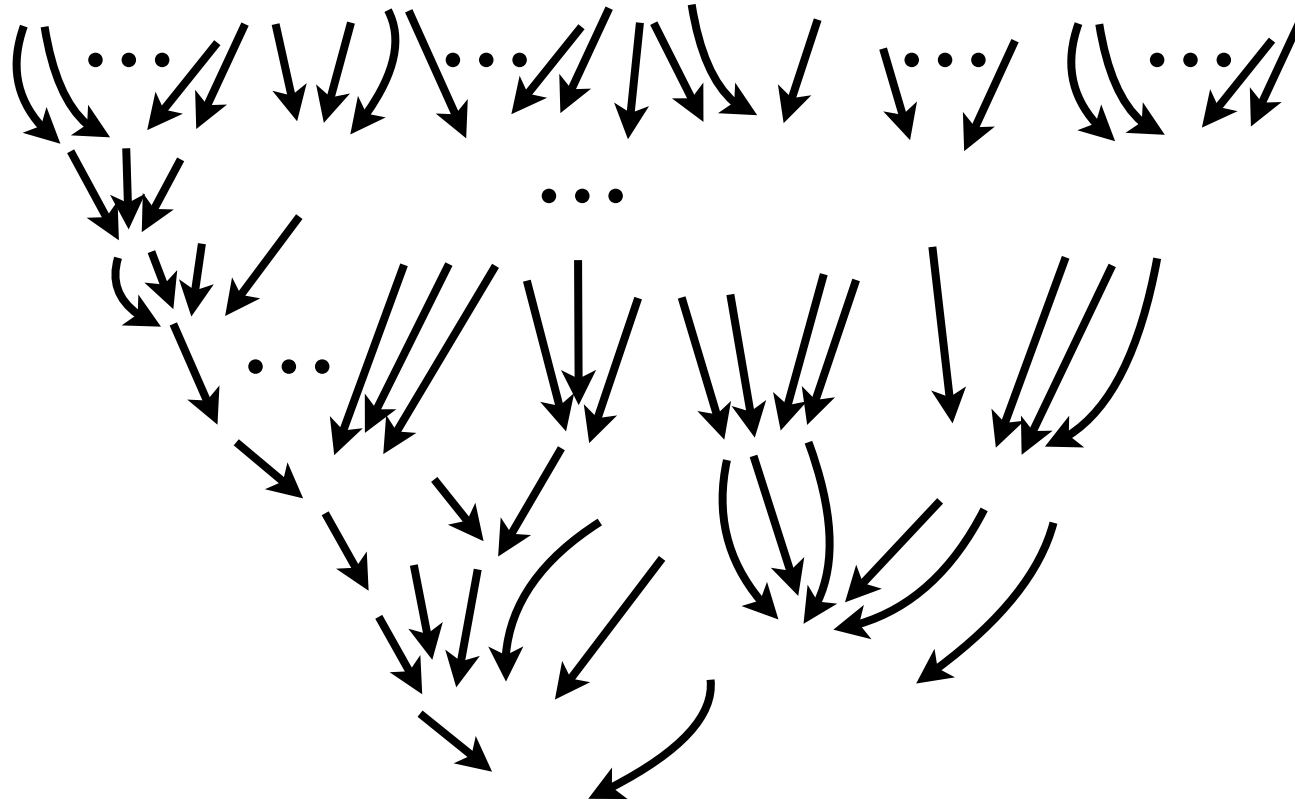
It could have been different.



Could have been different.



# Newton's Dream Realized



Can answer all basic questions of everyday world, w/simple principles

Particle physics probing deepest level

Hints that we are approaching the final explanation

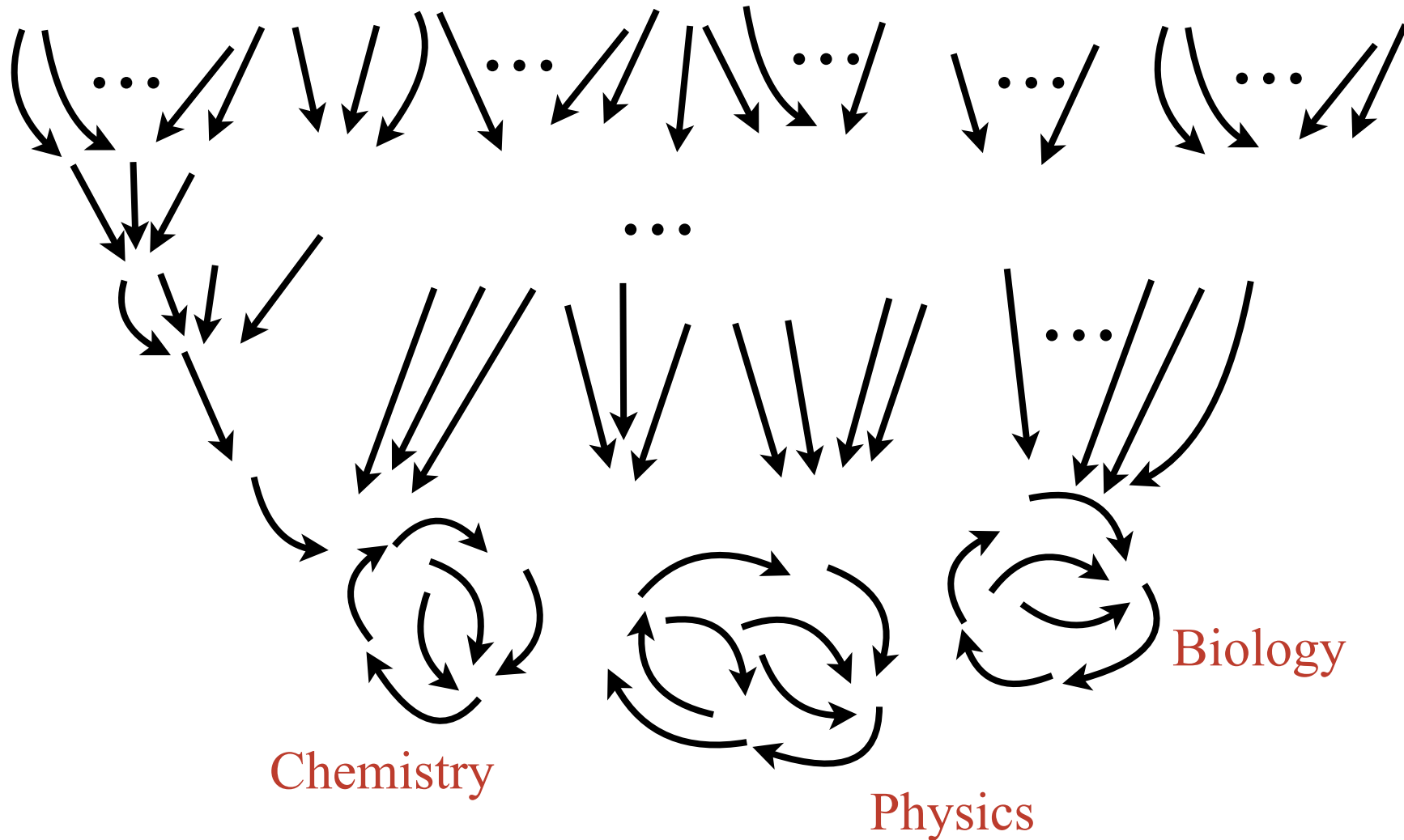
Principles get simpler (not the mathematics!)

Fewer and fewer moving parts

*This, deep down, is the why!*

# 20th Century Revolutions

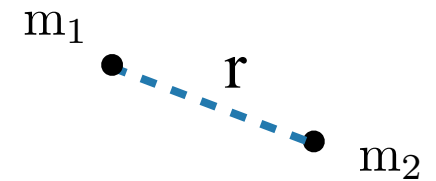
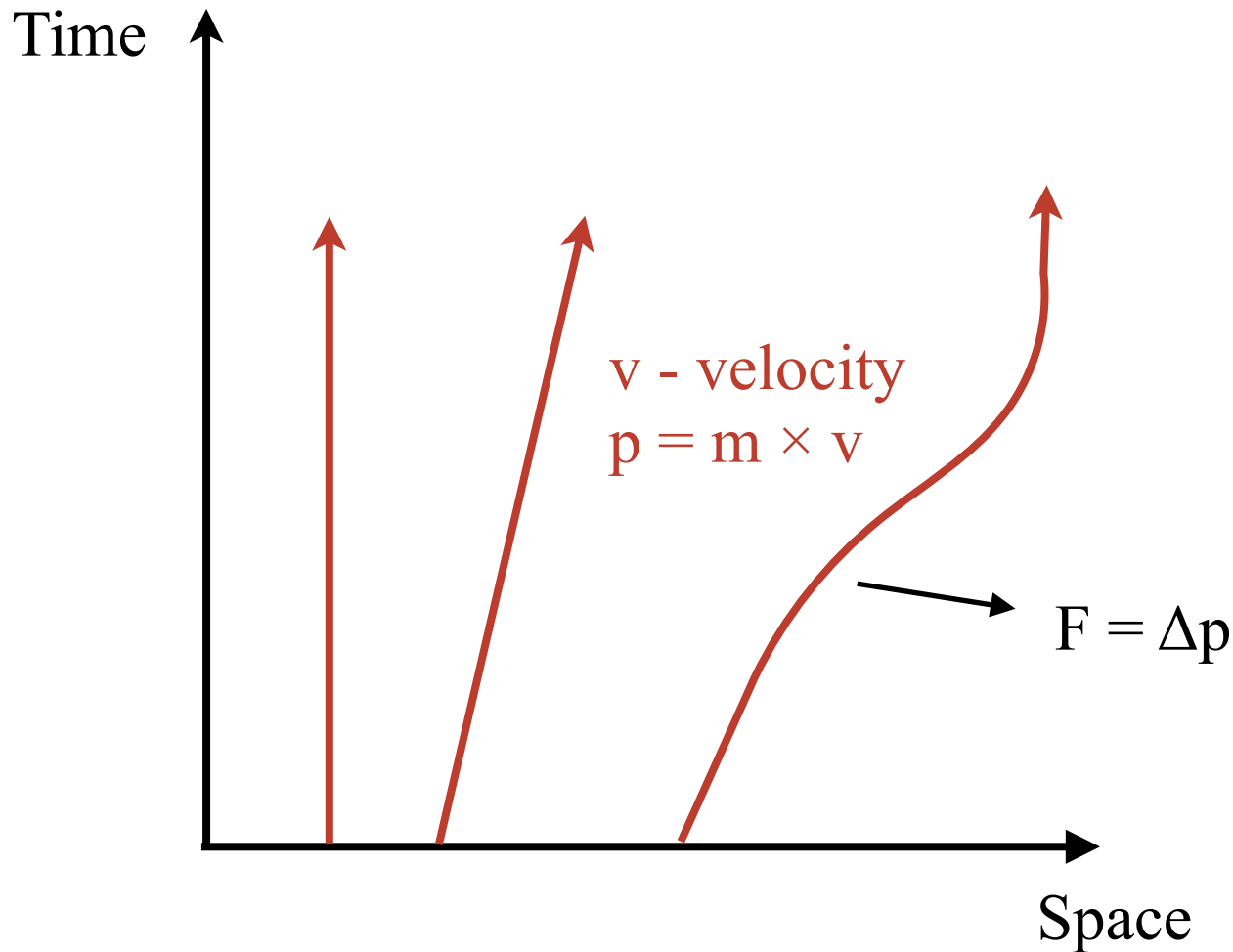
# Science at turn of 20th Century



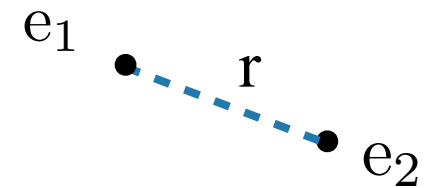
*Nothing new to be discovered in physics* - Albert Michelson

Radically changed by two revolutions: **Relativity and Quantum Mechanics**

# Physics Before the Revolution



$$F = G_N \frac{m_1 m_2}{r^2}$$



$$F = \frac{1}{4\pi} \frac{e_1 e_2}{r^2}$$

- In principle can predict everything!
- Action at a distance

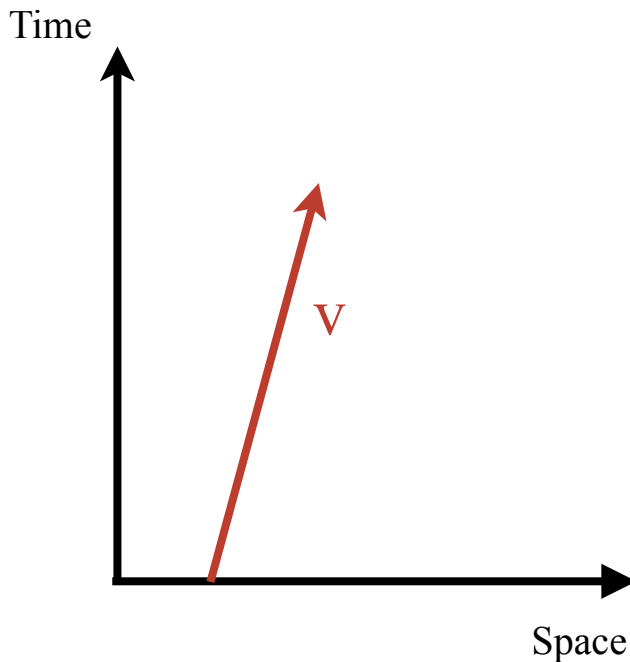


# Principle of Relativity

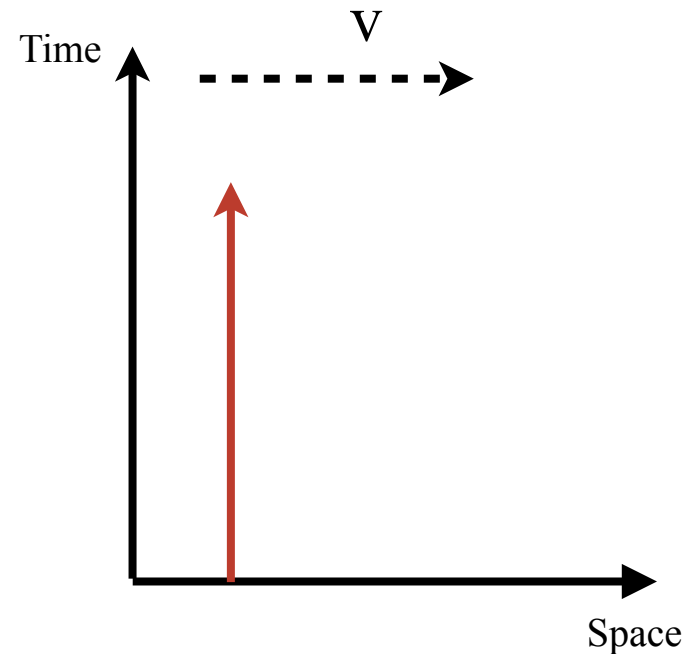


# Relativity before Einstein

Notion of relativity present in Newtons laws. Goes back to Galileo.



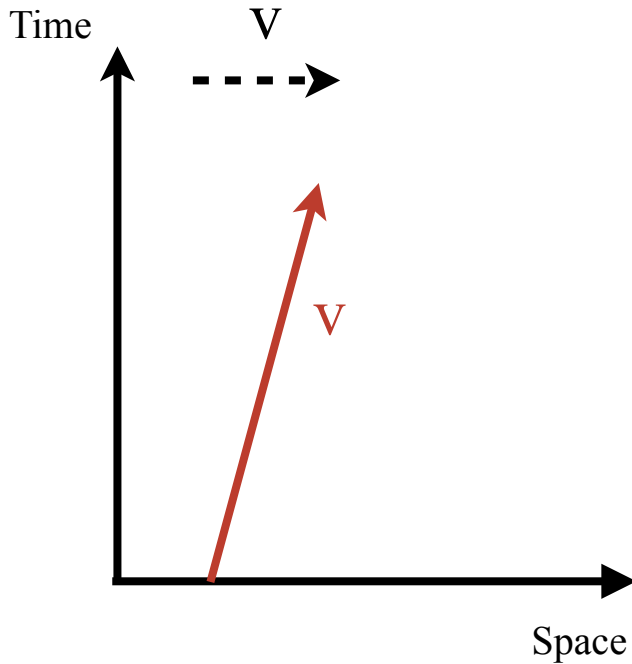
Some body standing still.  
("observer at rest")



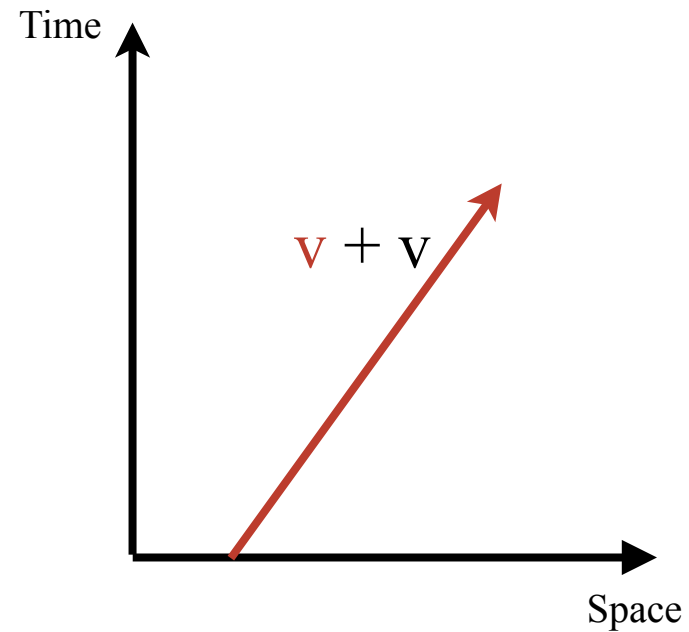
Observer moving at  $v$   
in the same direction

# Relativity before Einstein

Another example



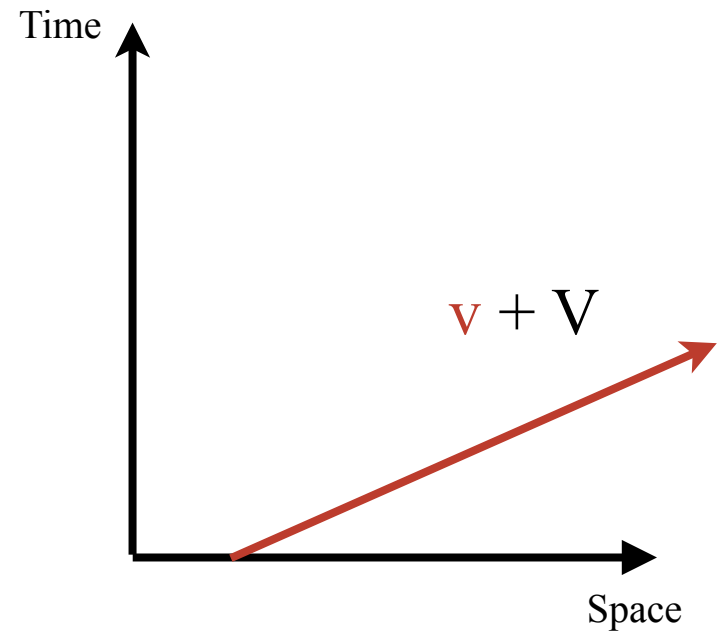
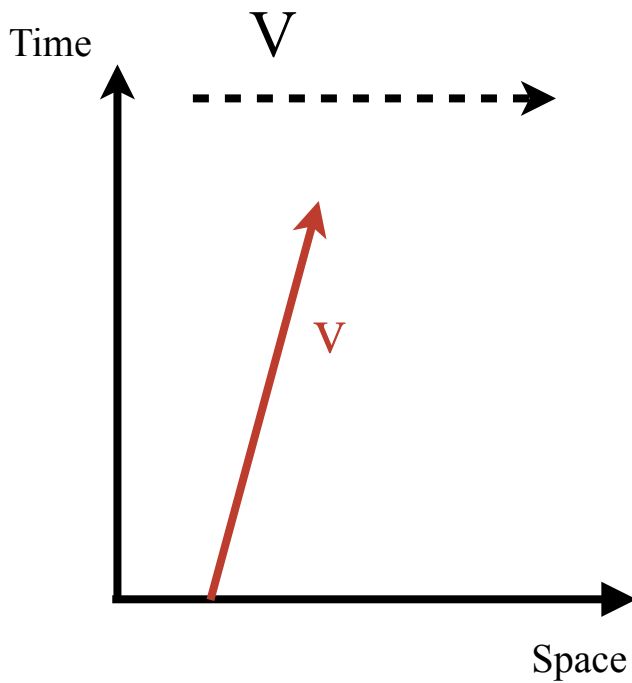
Observer in motion throws something



Observer at rest

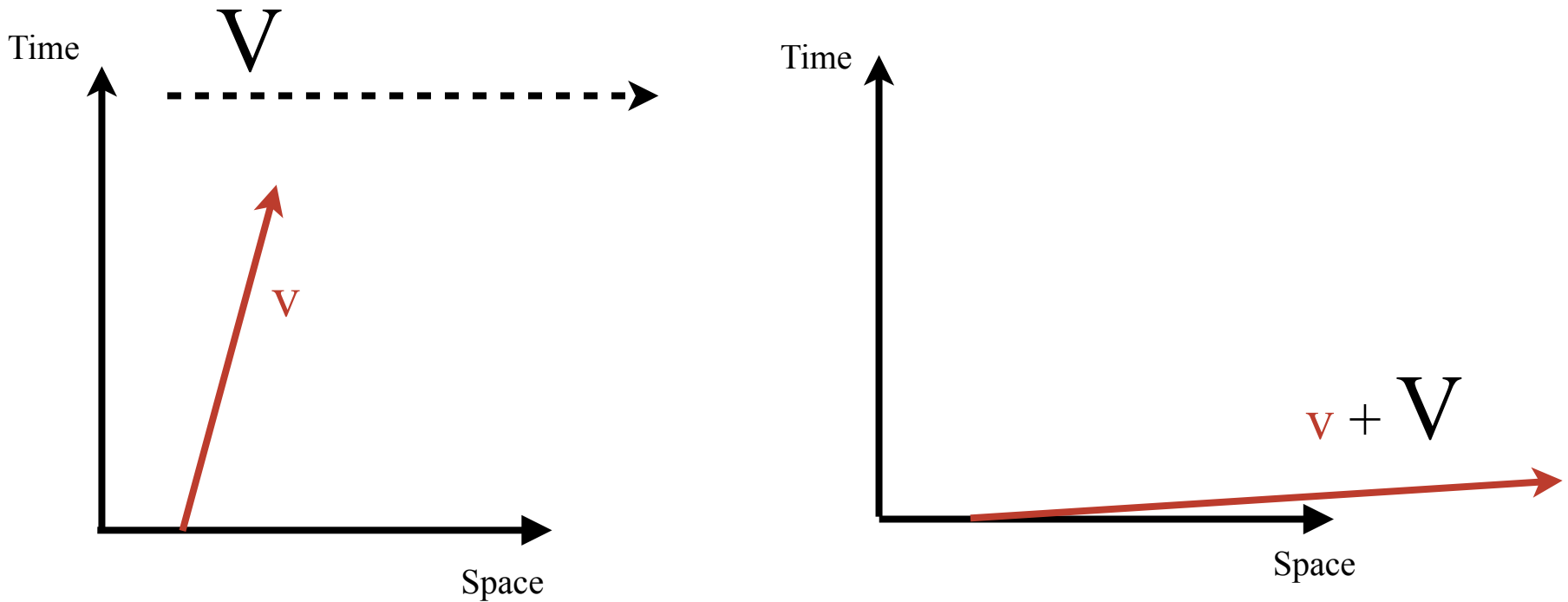
# Relativity before Einstein

Another example



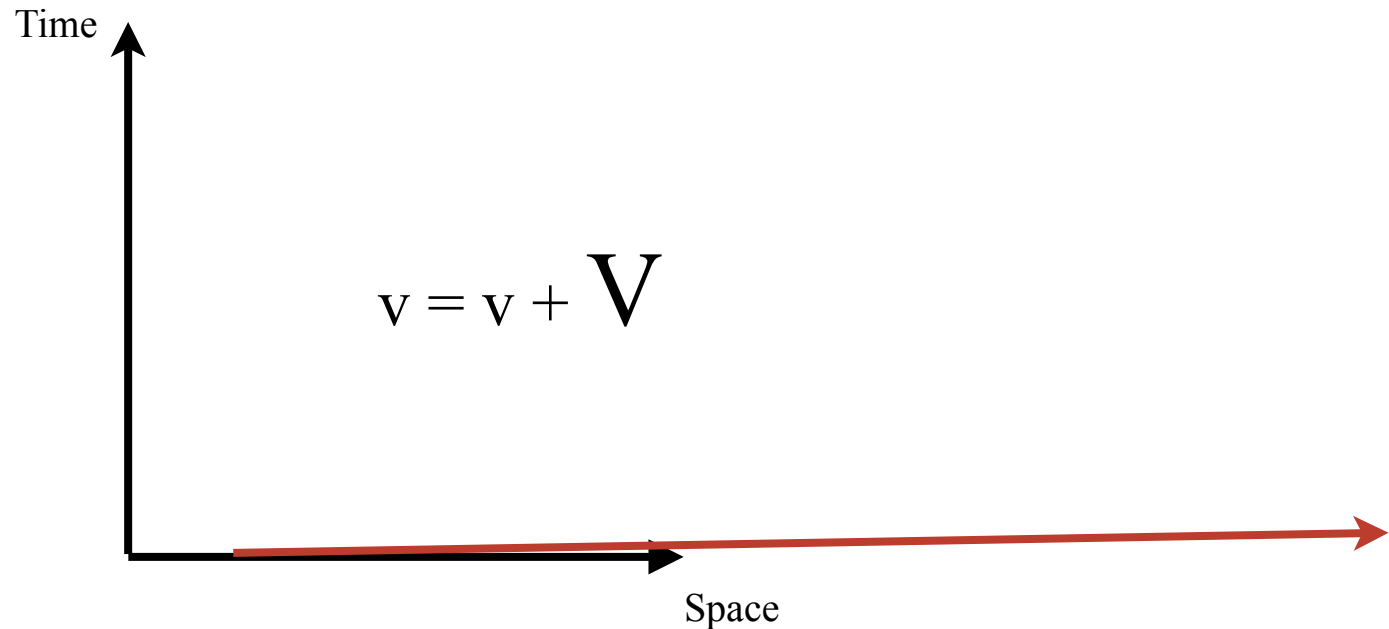
# Relativity before Einstein

Another example



*No limit to how fast we can make something*

# Relativity before Einstein



Can in principle send objects as fast as we want.

Regions arbitrarily far away can effect what is happening here and now.

## **Einstein's Big Idea:**

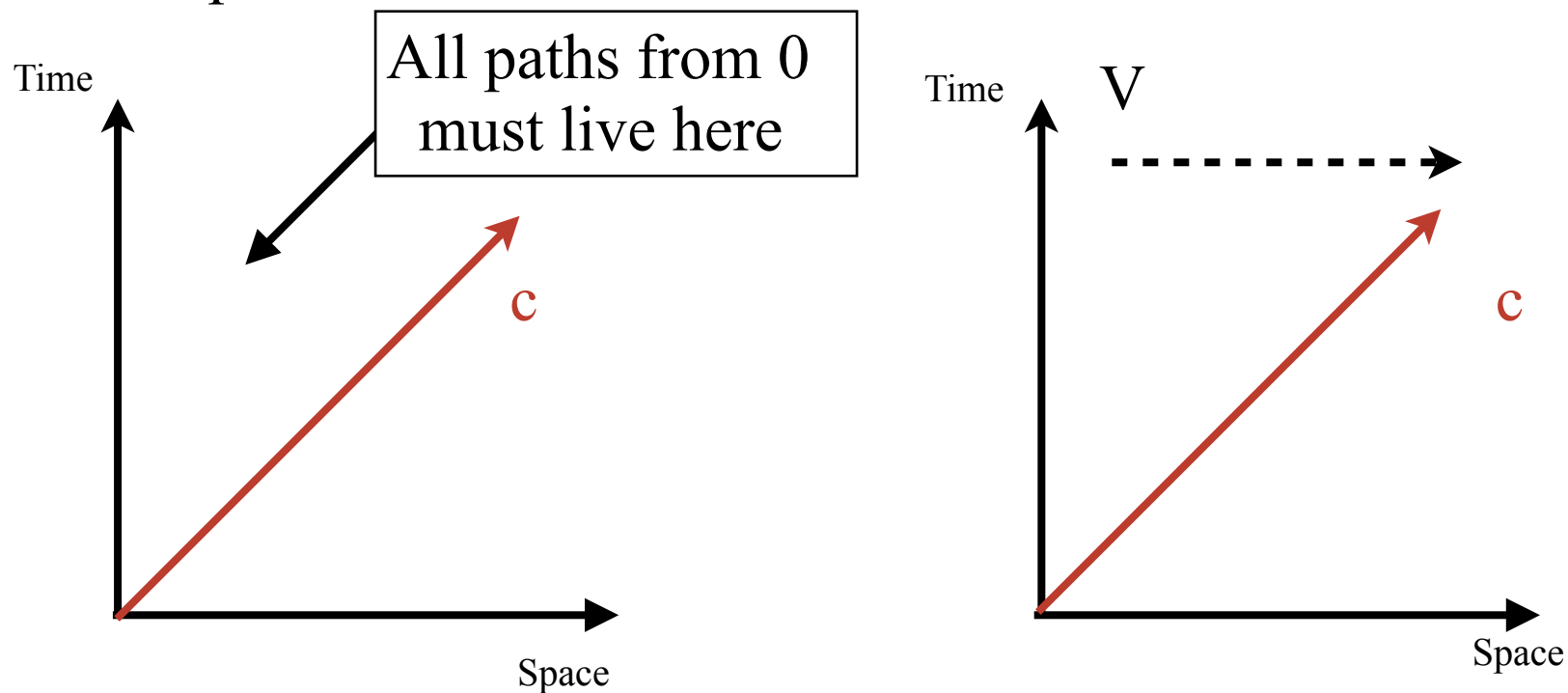
Limit the range over which things can have an affect

# Einstein's Relativity

To limit the range over which things can have an affect:

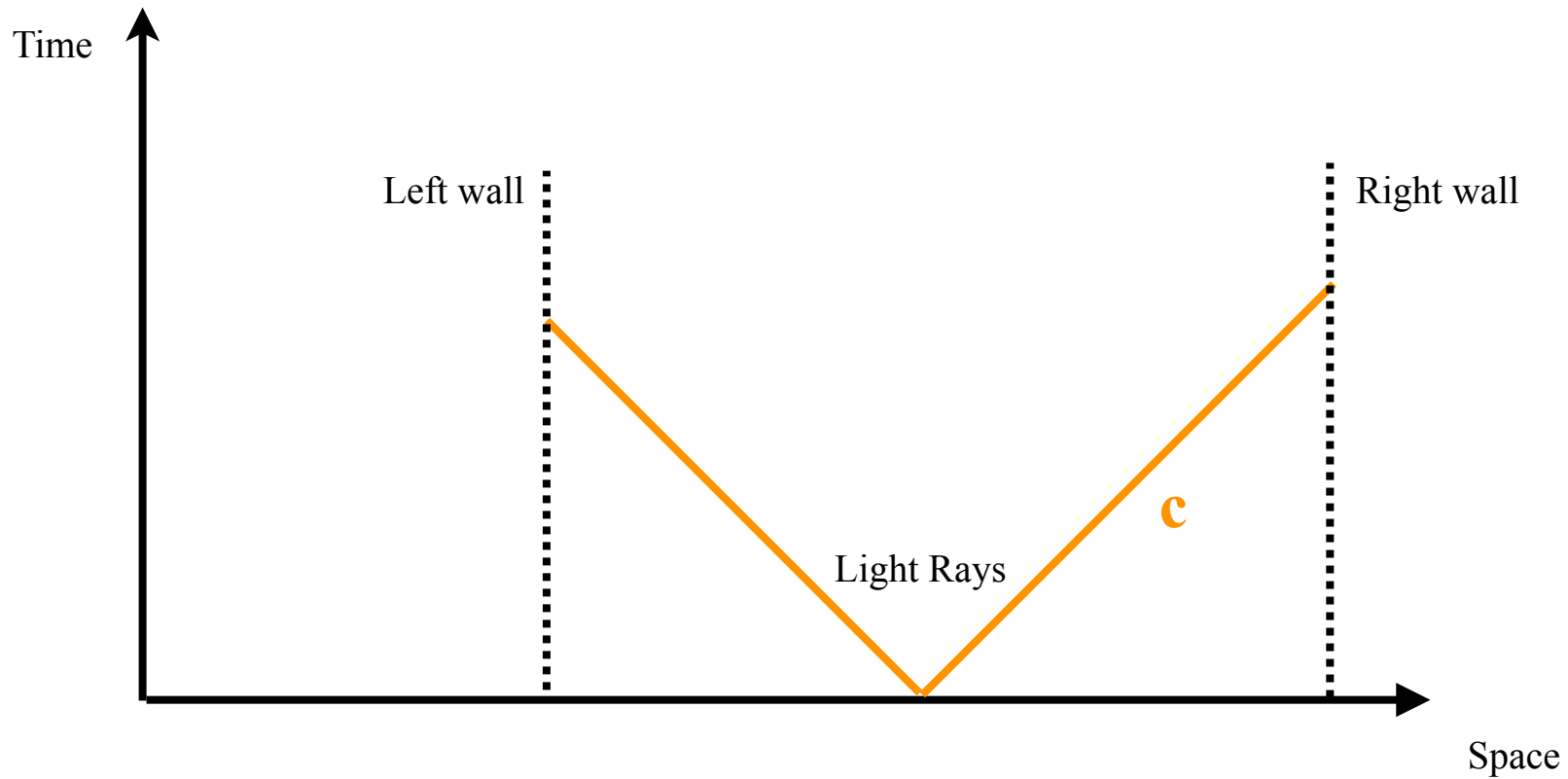
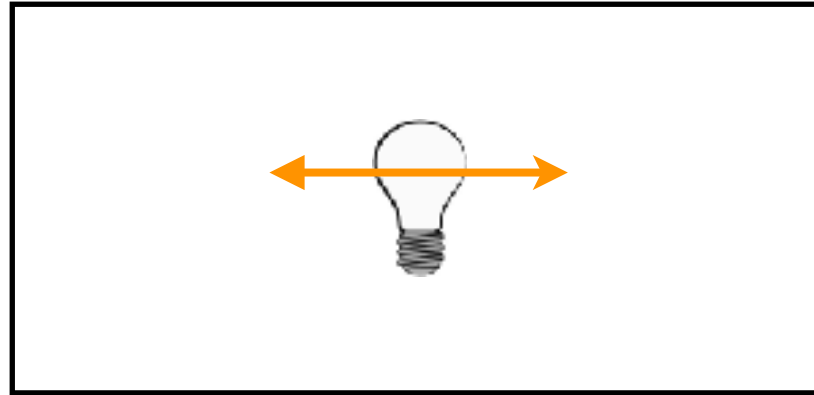
- 1) Must be a maximum speed.
- 2) Max speed must be same regardless of how fast you are moving.  
*(otherwise we are back where we started  $v + V$ )*

Maximum speed "c"



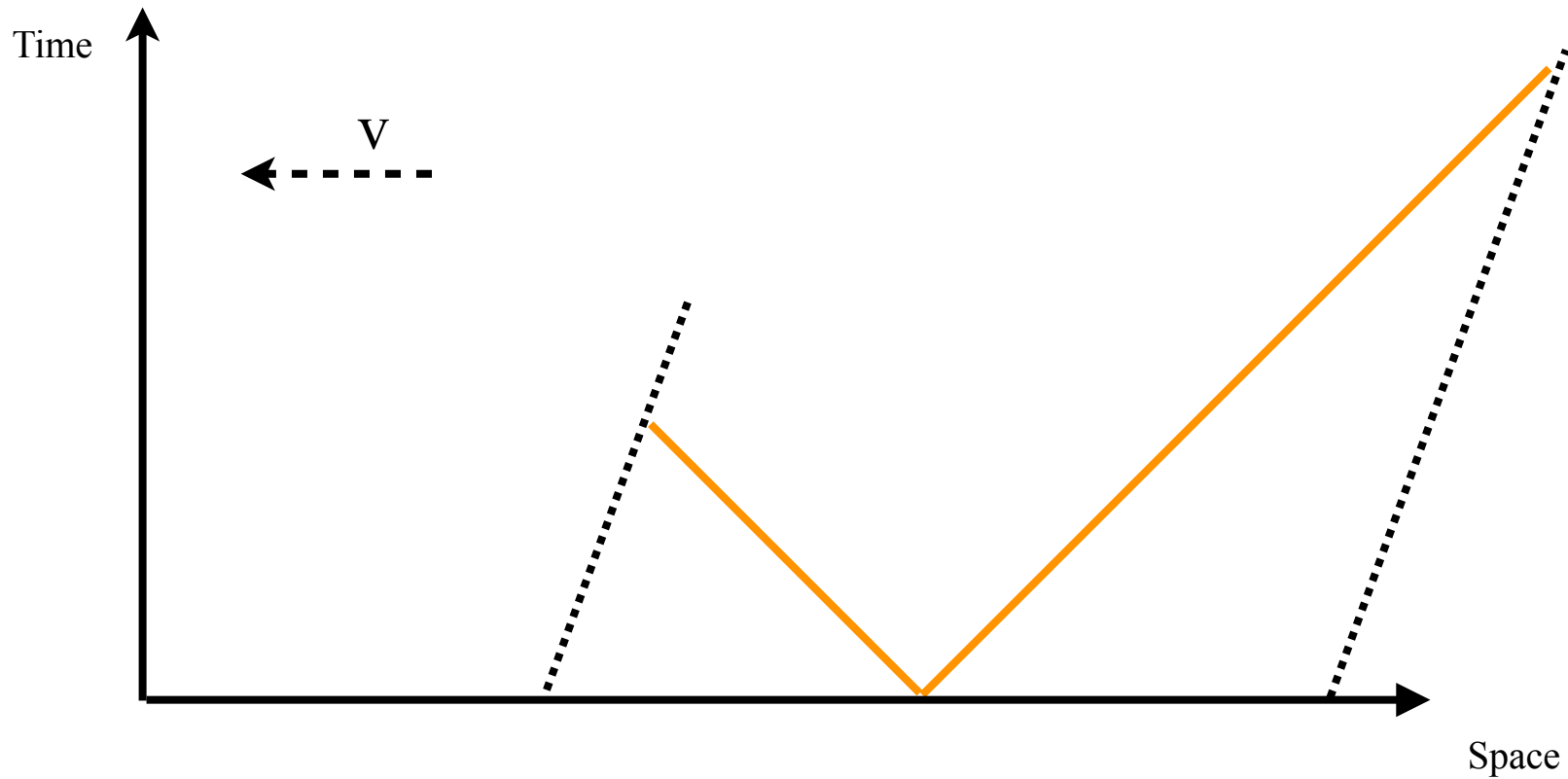
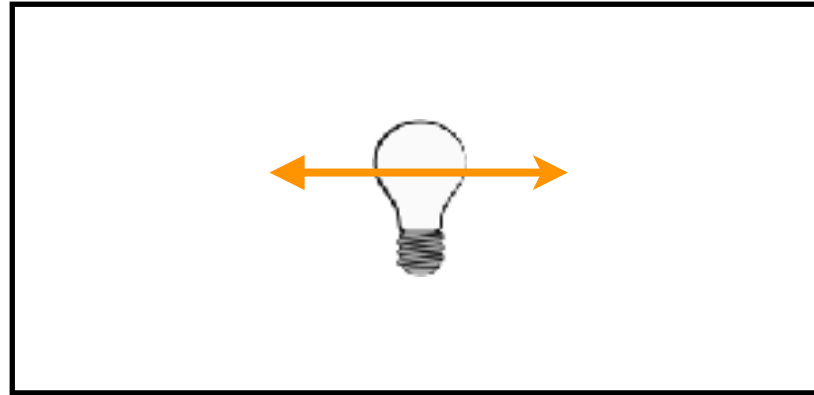
*Simple requirement has profound implications.*

# Effect on Time

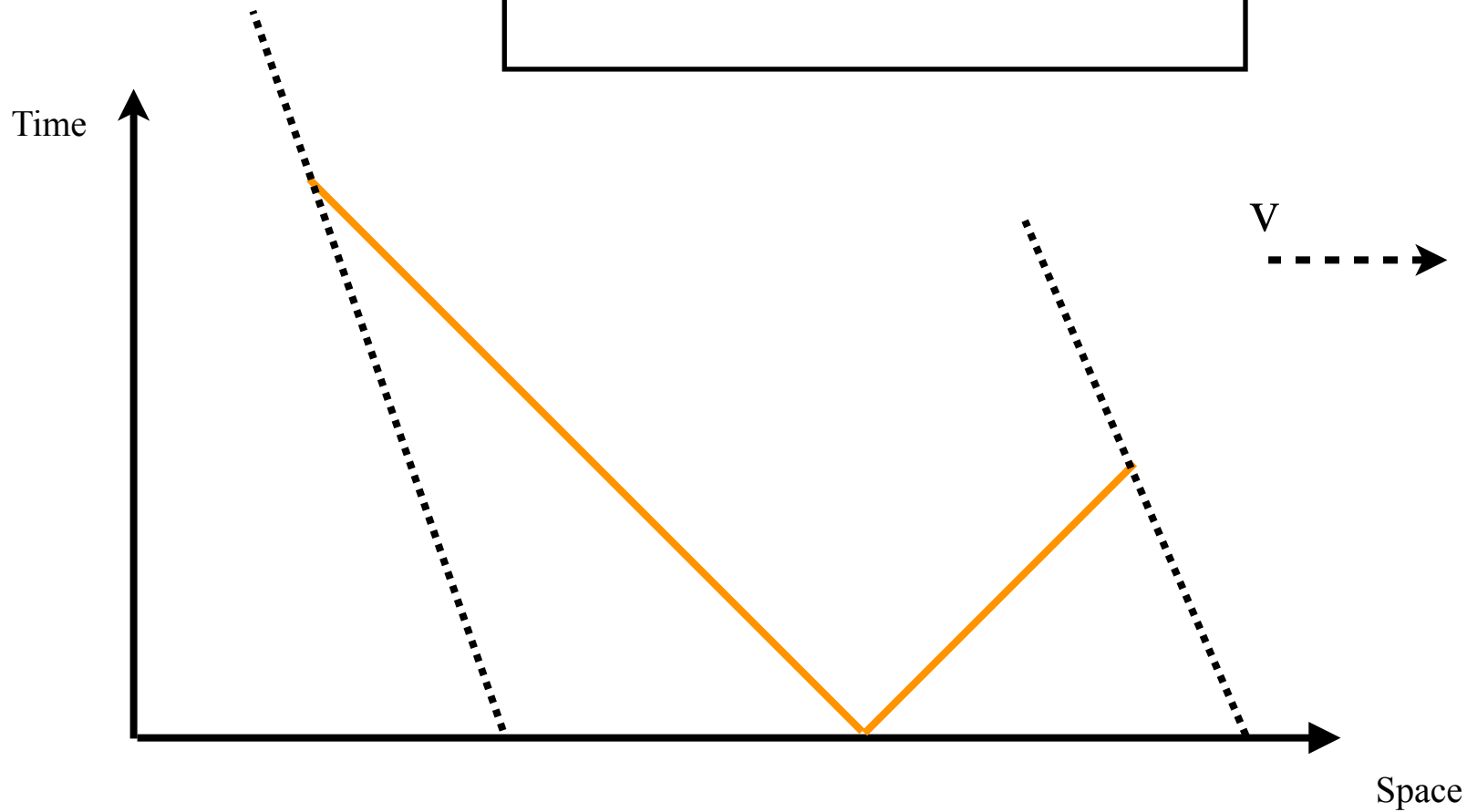
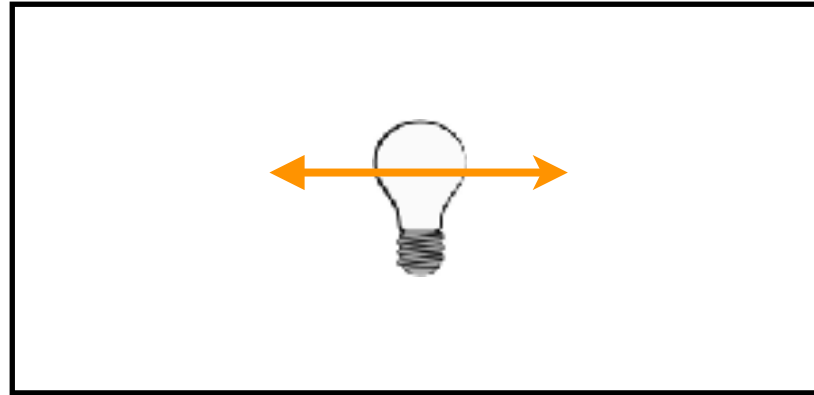




# Effect on Time

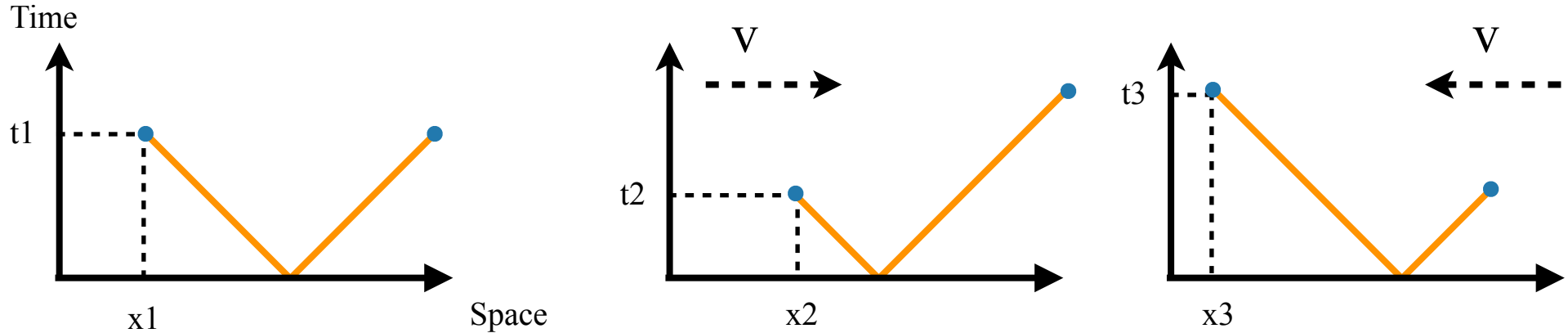


# Effect on Time



# Effect on Time

Time is not absolute !



Which order of what came first depends on how you are moving.

Observers do agree on the speed:  $x = c \times t$

$$x_1^2 - (ct_1)^2 = 0$$

$$x_2^2 - (ct_2)^2 = 0$$

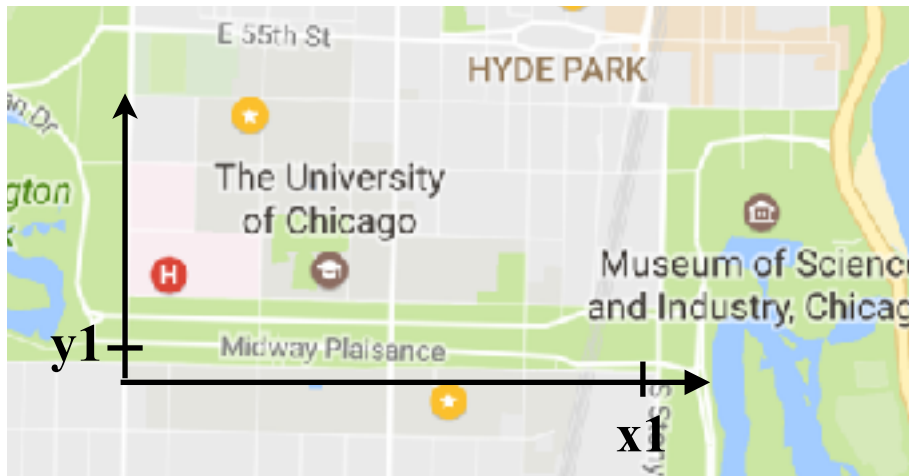
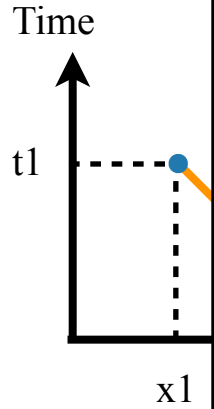
$$x_3^2 - (ct_3)^2 = 0$$

$x^2 - (ct)^2 = 0$  is “invariant”, independent of how you are moving.

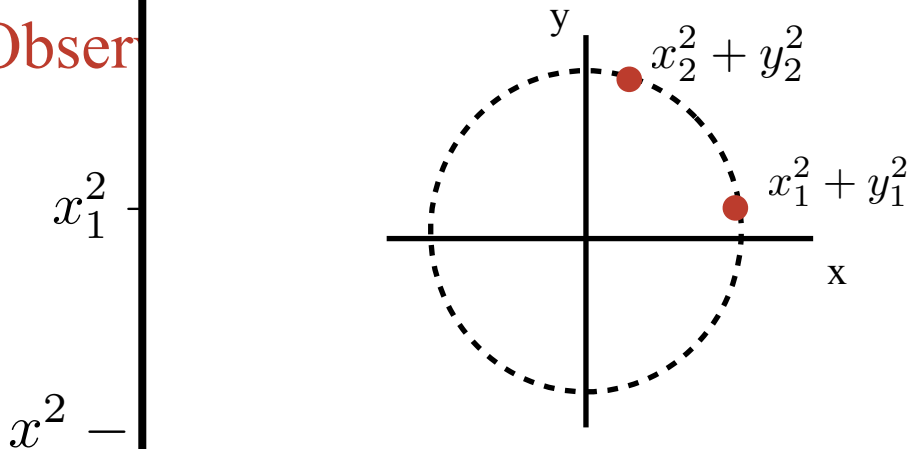
# Effect on Time

Time is not absolute !

Direct analog: Length - Independent of angle that your looking



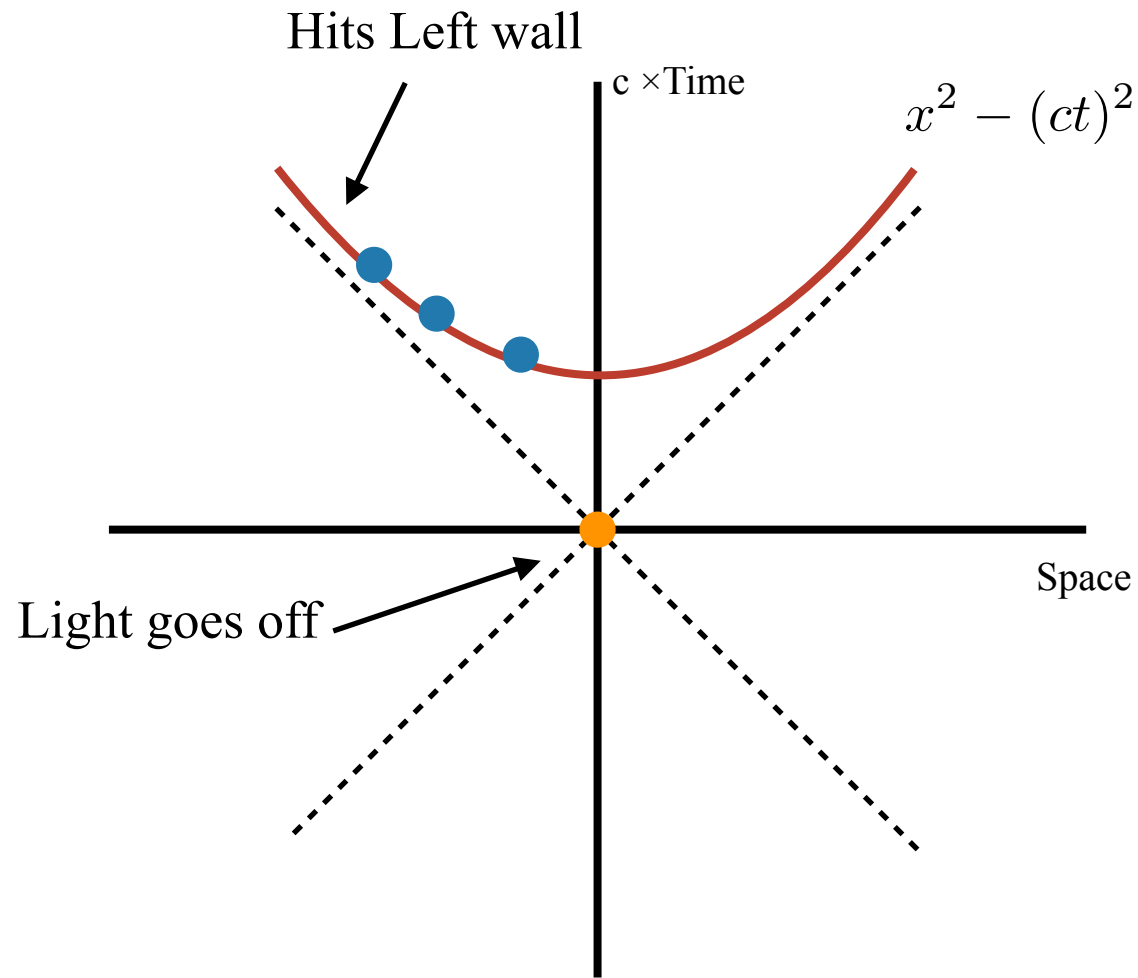
Observer



60

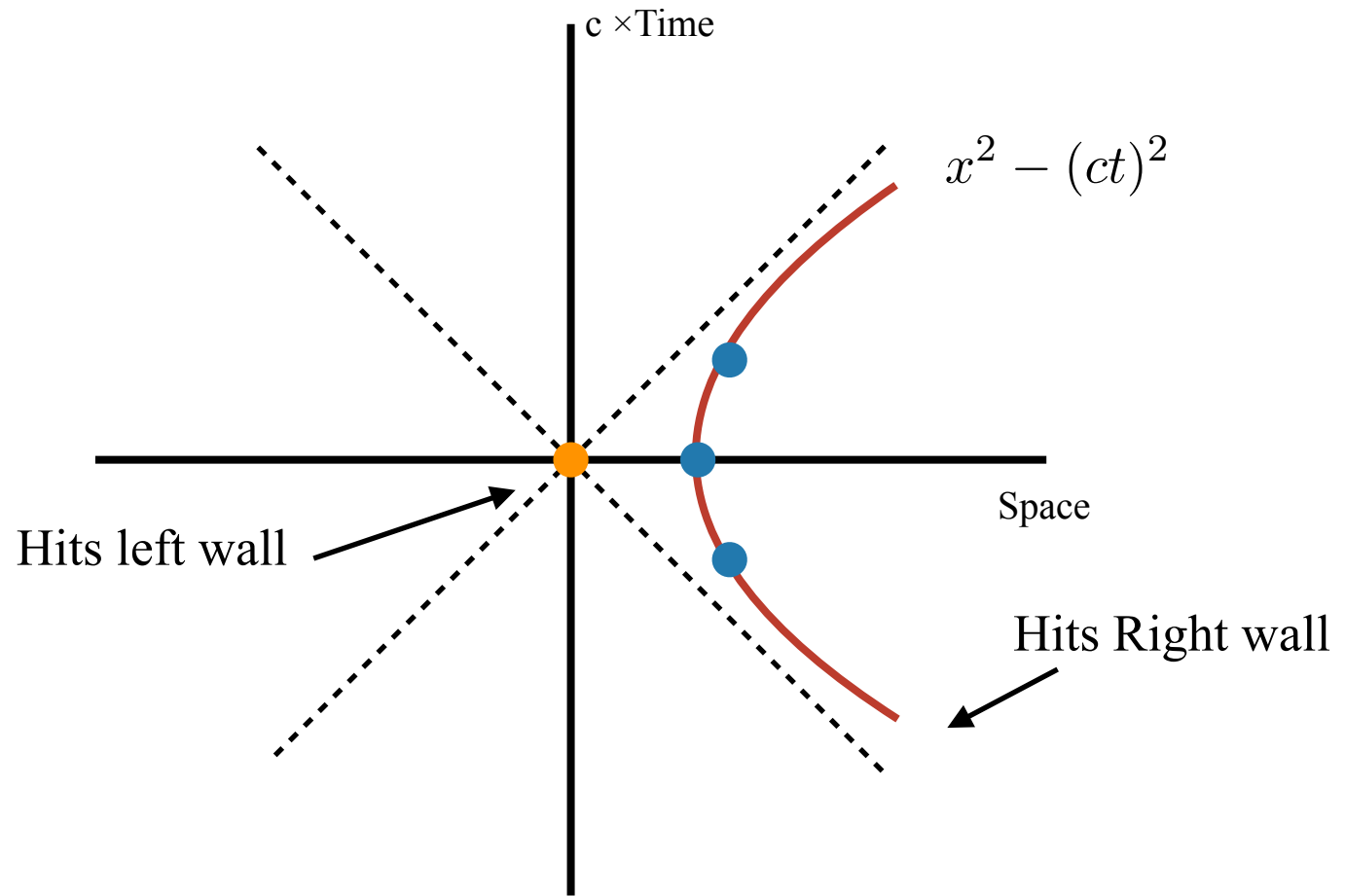
# Space-Time

Mixing of space and time



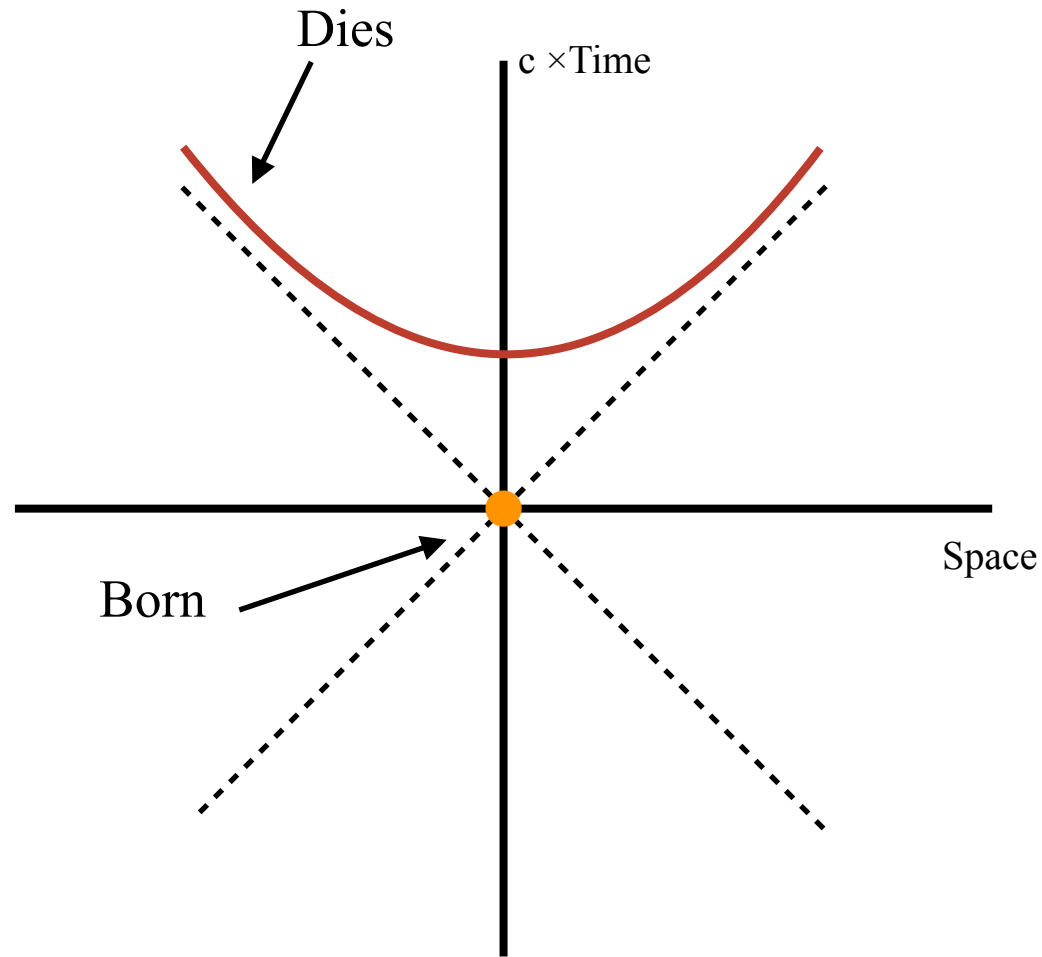
# Space-Time

Mixing of space and time



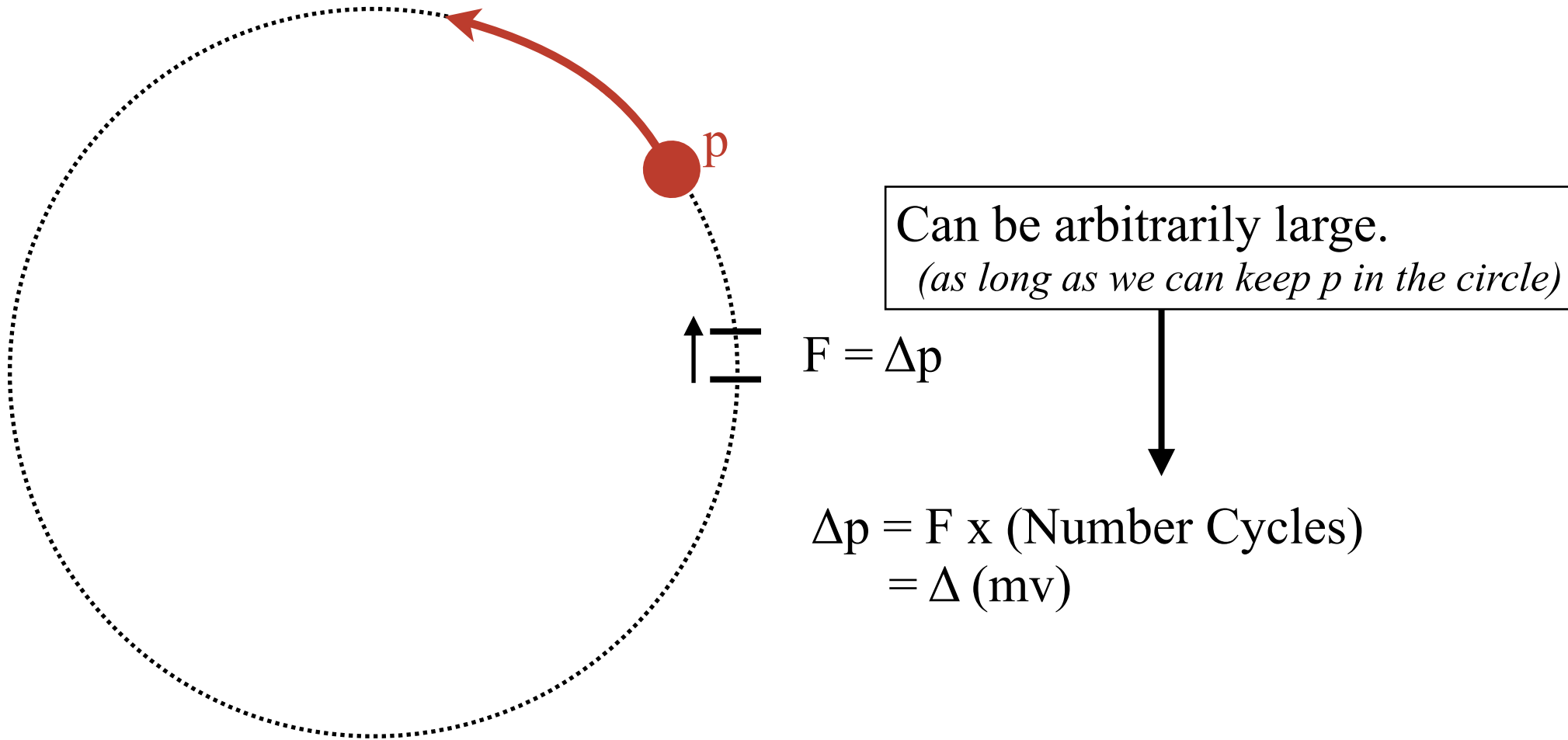
# Space-Time

Mixing of space and time



- Time dilation
- Crazy but true !  $\mu$  are hitting us now

# Effect on Mass



When  $v \sim c$ ,  $\Delta p$  must come from  $\Delta m$

*Mass increases with speed!*



# *Next Time:* Quantum Mechanics

