

# Toward Unification of Gravity and Quantum Mechanics

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One of the most fundamental problems in modern physics is the unification of gravity and quantum mechanics.

Before discussing it, I would like to share how I became interested in this problem.

It begins with a story from my autobiographical notes: 探索观一个科学家的求知探索之旅



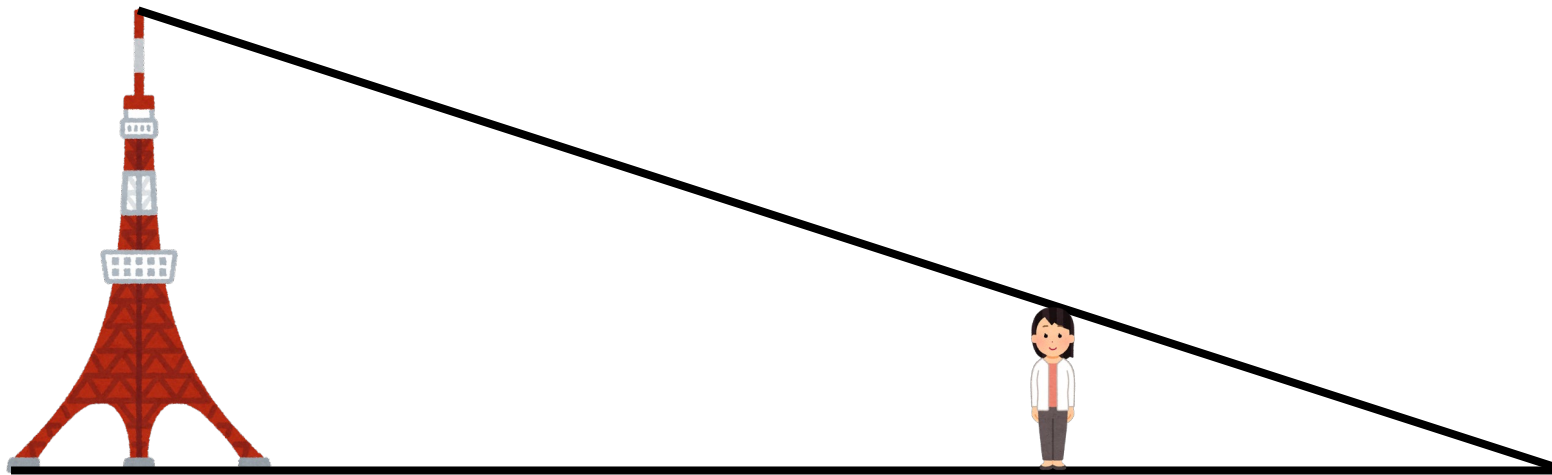
## “Spirit of Inquiry”

- published in 2021 in Japan.
- adopted as the textbook for liberal art courses at several universities in Japan.
- **published in China in 2022.**

# **Measuring the size of the Earth from a panoramic restaurant**



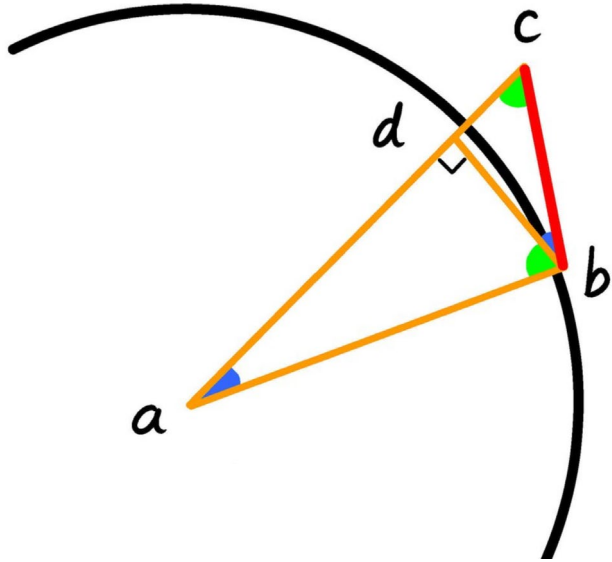
When I was in the 5<sup>th</sup> grade, we learned elementary geometry of triangles. Our teacher took us outside and we used the concept of **similarity** to measure the height of a nearby telephone tower.





While having lunch with my parents at a revolving restaurant, I wondered if I could use a similar idea to estimate the distance to the horizon.

By the time the restaurant had come full circle, I realized that the distance was equal to the square root of the product of the building's height and the radius of the Earth — **the geometric mean**.



Since the two triangles  $abd$  and  $bcd$  are similar,

$$\overline{bd}^2 = \overline{ad} \times \overline{cd}.$$

To be precise  $\overline{cd}$  is twice the height of the building.

$$\text{(Distance to Horizon)}^2 = 2 \times \text{(Building Height)} \times \text{(Earth Radius)}$$

I missed this factor 2 at the time.

$$\text{(Distance to Horizon)}^2 = 2 \times \text{(Building Height)} \times \text{(Earth Radius)}$$

However, I did not know the radius of the Earth.

$$(\text{Distance to Horizon})^2 = 2 \times (\text{Building Height}) \times (\text{Earth Radius})$$

However, I did not know the radius of the Earth.

Upon closer inspection, I noticed my father's hometown on the horizon. He told me it's about 20 kilometers away.



$$(\text{Earth Radius}) = \frac{(\text{Distance to Horizon})^2}{2 \times (\text{Building Height})}$$

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By simply observing the view from the window and doing some simple calculations, I was able to determine the size of the Earth.

The profound nature of this world can be unraveled through observation and thought.

**There is truth in this world,  
and we can know it.**

I entered Kyoto University's graduate school  
in 1984 to study high-energy theory.

It turned out to be an important year.

The story goes back 20 years to the mid-1960s.

In the 1950s and 1960s, particle accelerators discovered a wide variety of new elementary particles.

Particle physics was in a state of chaos.



In 1970, Yoichiro Nambu suggested that mysterious properties of elementary particles could be explained if they were made of strings.

**However,**

String theory predicts the existence of particles that have not been found in particle experiments.

In 1974, Tamiaki Yonetani, a graduate student at Hokkaido University at the time, discovered that **one of these new particle mediates gravity.**

Scherck and Schwartz independently discovered this and proposed that string theory could be used to construct the **ultimate unified theory** of all the forces in nature, including gravity.

“When I made this discovery,  
I decided to devote my life  
to studying string theory.”

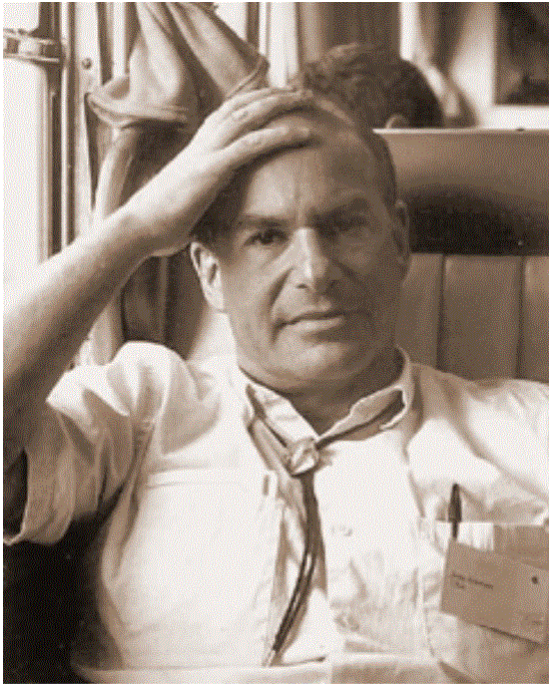
**However,**

String theory at the time was flawed  
as a model of elementary particles.

It could not explain some basic  
property of the electron.

Meanwhile, remarkable discoveries were made that led to the construction of the Standard Model of Particle Physics.

- Kobayashi-Maskawa Theory
- Asymptotic Freedom
- Discovery of the  $J/\psi$  meson

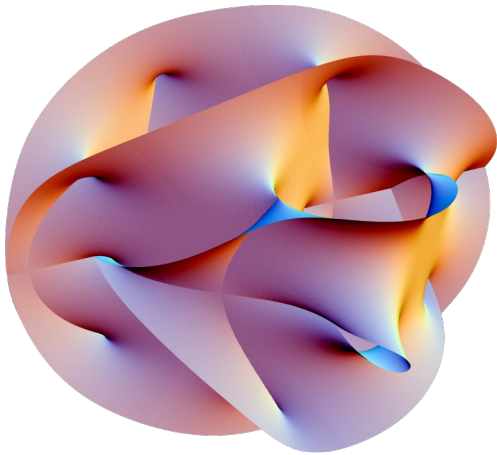


# Struggle for ten years



In 1984, Green and Schwarz found a way to use string theory to explain the properties of the electron.

# Superstring Revolution in 1984



I was particularly fascinated by the fact that the rich structure in the Standard Model of Particle Physics, such as 17 types of elementary particles, gauge forces, and Higgs boson, all emerges from the **Calabi-Yau geometry**.



It's been 41 years.  
Why haven't you been able  
to complete the theory?

Our goal is **quantum gravity**,  
which is the unification of  
general relativity and quantum mechanics.

# The quest toward quantum gravity has a long history

1915

General Relativity

1924 – 1926

Quantum Mechanics

1974

Gravity in String Theory

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General Relativity

**1924 – 1926**

**Quantum Mechanics**

**1928 – 1929**

**Quantum Field Theory (QED)**

Unification of  
**Special** Relativity and  
Quantum Mechanics

Gravity in String Theory

# The quest toward quantum gravity has a long history

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General Relativity

**1924 – 1926**

**Quantum Mechanics**

**1928 – 1929**

**Quantum Field Theory (QED)**

**1947 – 1949**

**Renormalization of QED**

**1974**

**Standard Model**

1974

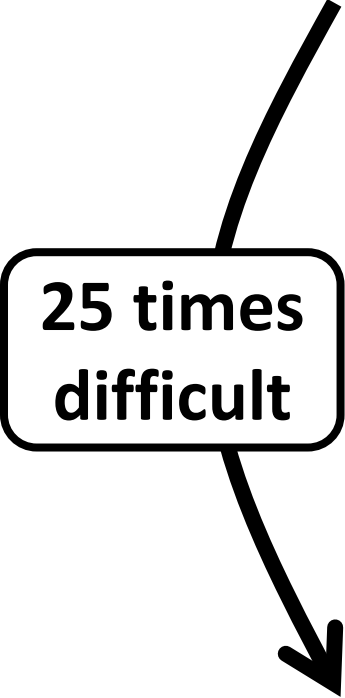
Gravity in String Theory

**2012**

**Higgs Discovery**

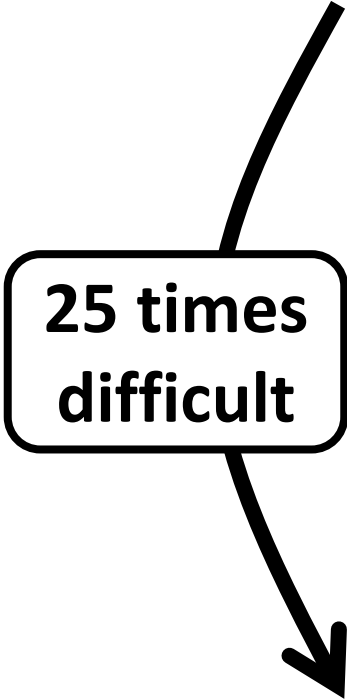
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- 50 years to construct the Standard Model of Particle Physics.
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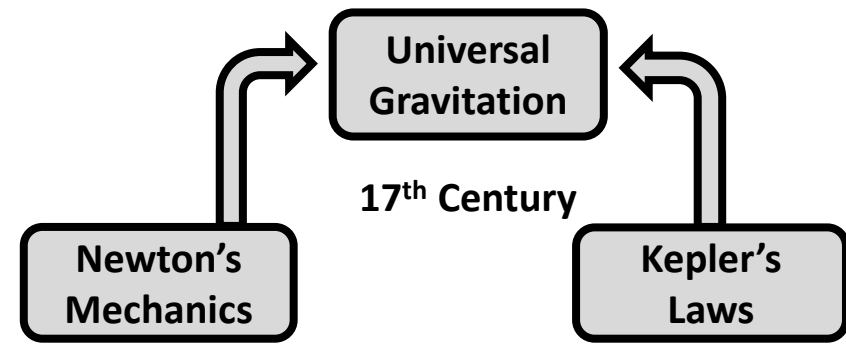
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- 50 years to propose the **unification of general relativity and quantum mechanics**, *i.e.*, superstring theory.
- 1,250 years to construct a realistic model?
- 1,000 more years to verify it experimentally?

**Why has quantum gravity  
been so difficult?**

Over the past four centuries, since Galileo and Newton, physicists have gained a deeper understanding of the universe by **unifying the laws of nature.**

**Newton's  
Mechanics**

**Kepler's  
Laws**



Electricity

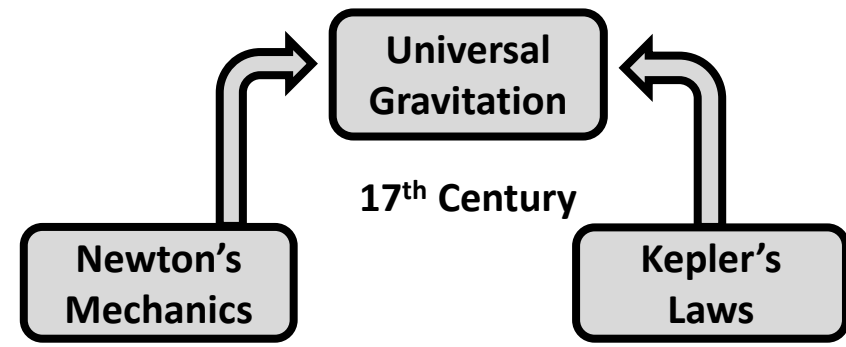
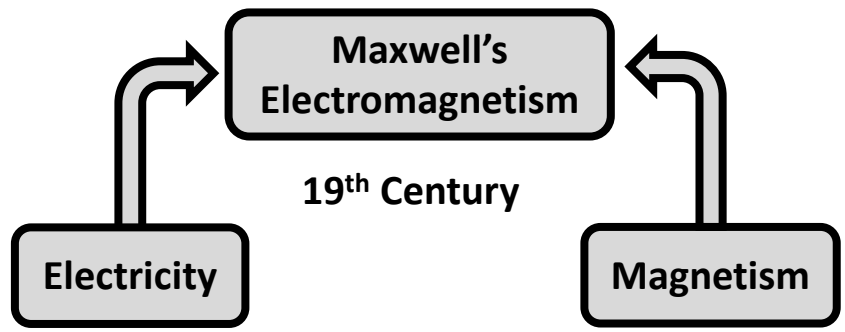
Magnetism

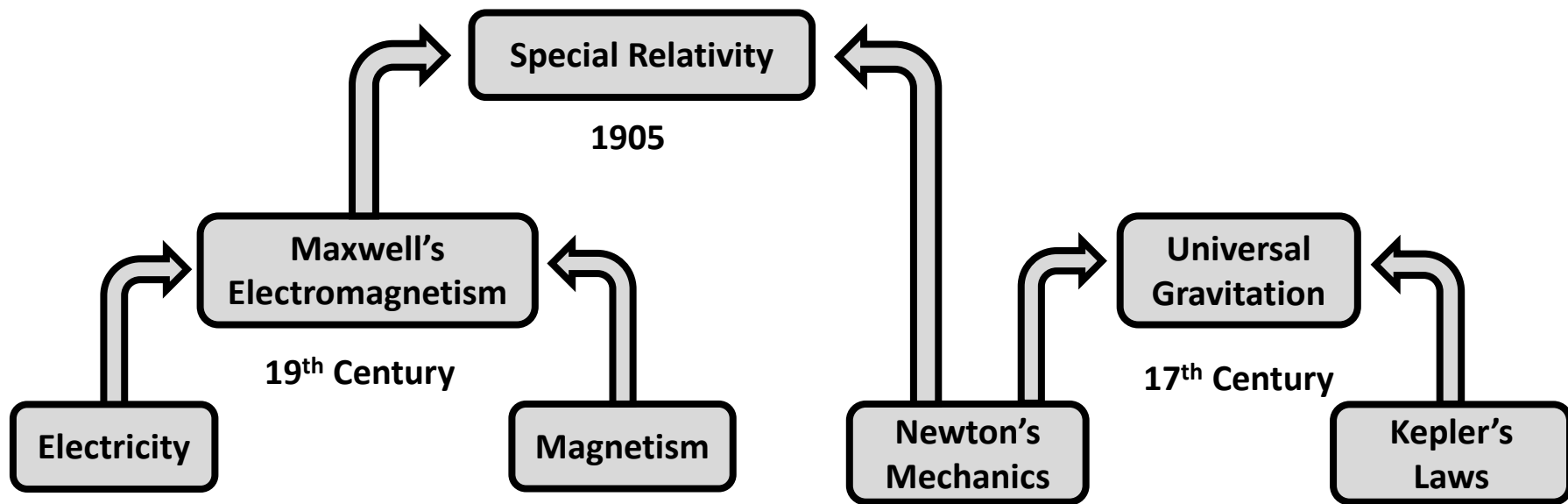
Newton's  
Mechanics

Universal  
Gravitation

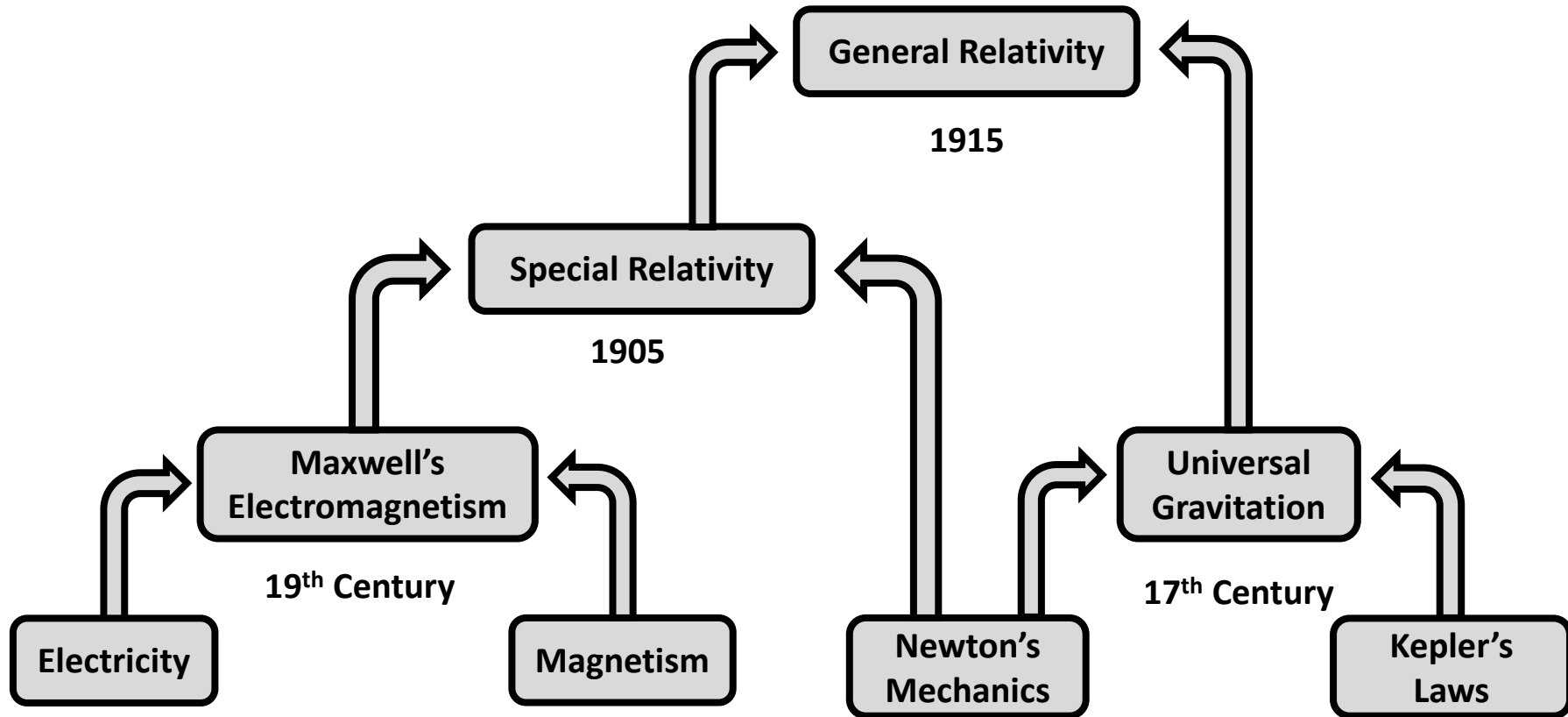
17<sup>th</sup> Century

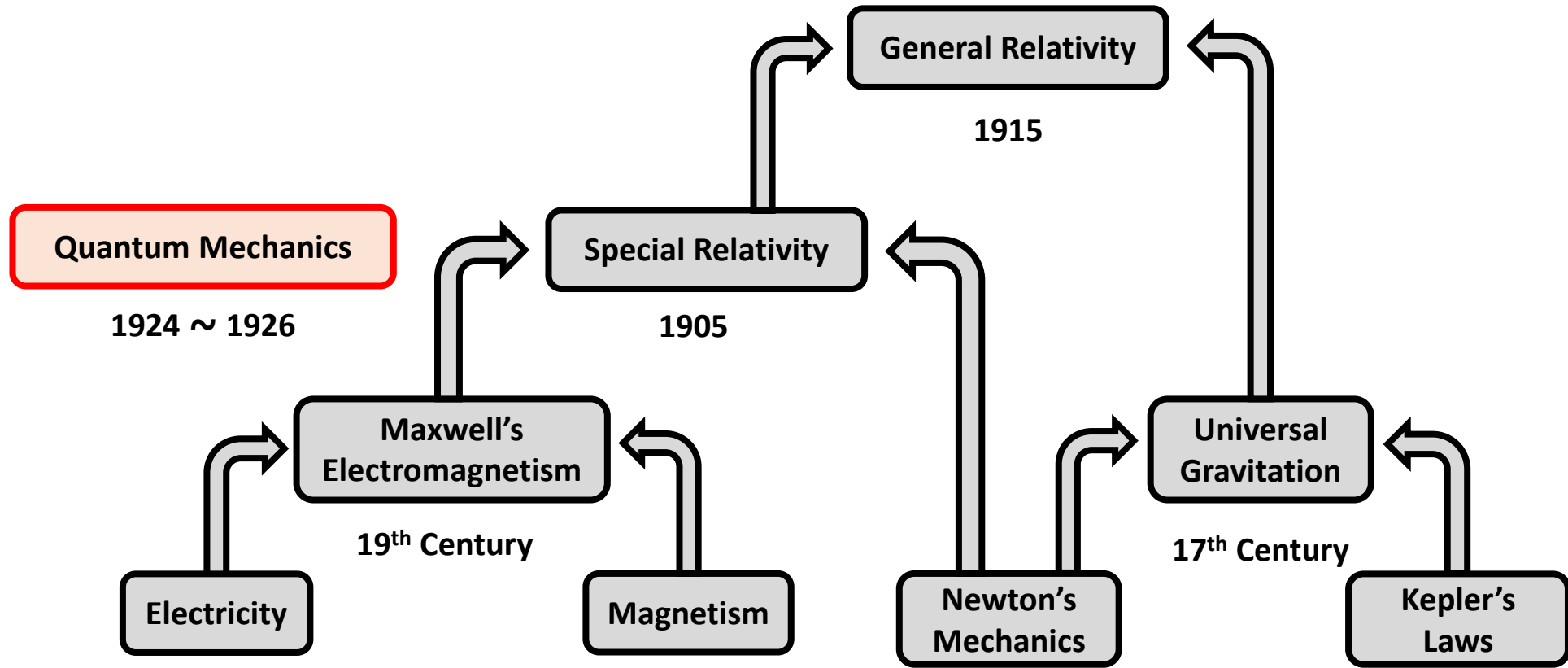
Kepler's  
Laws

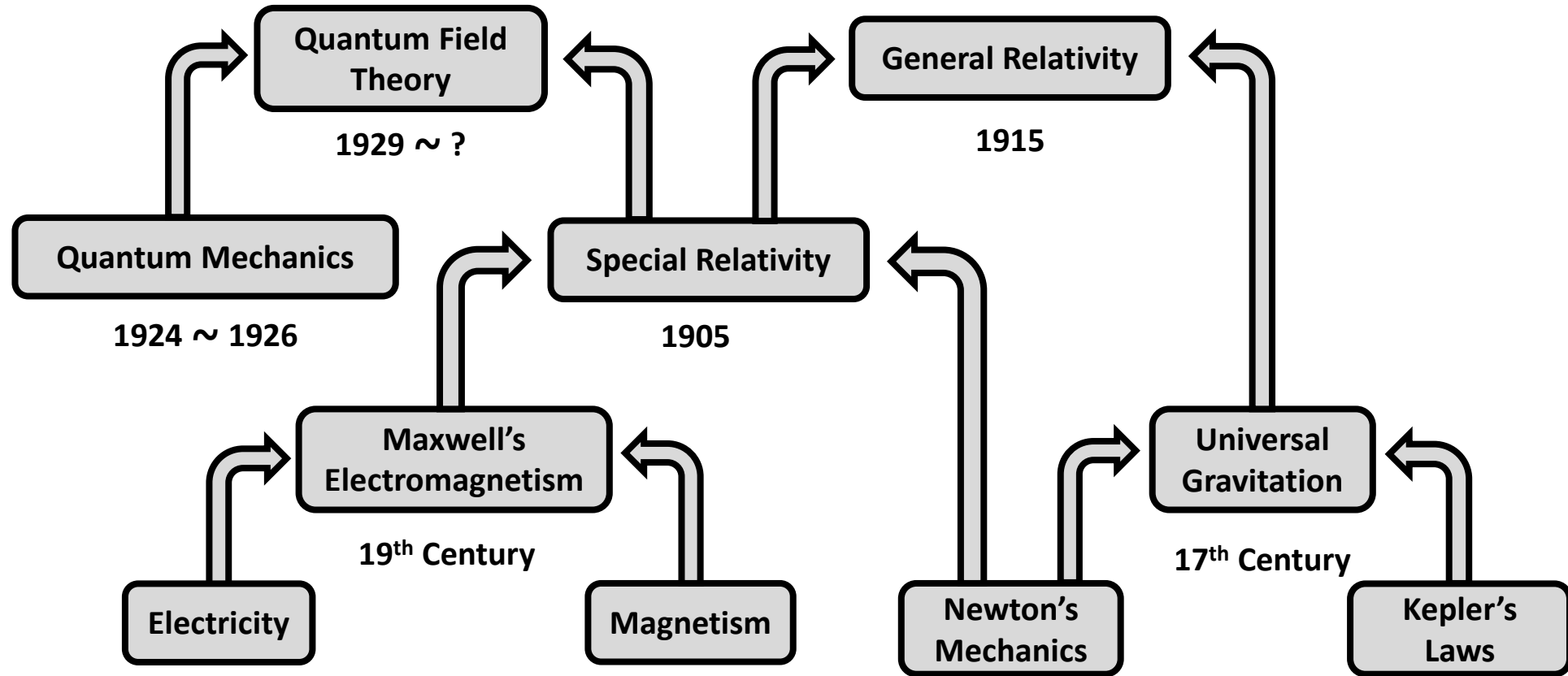


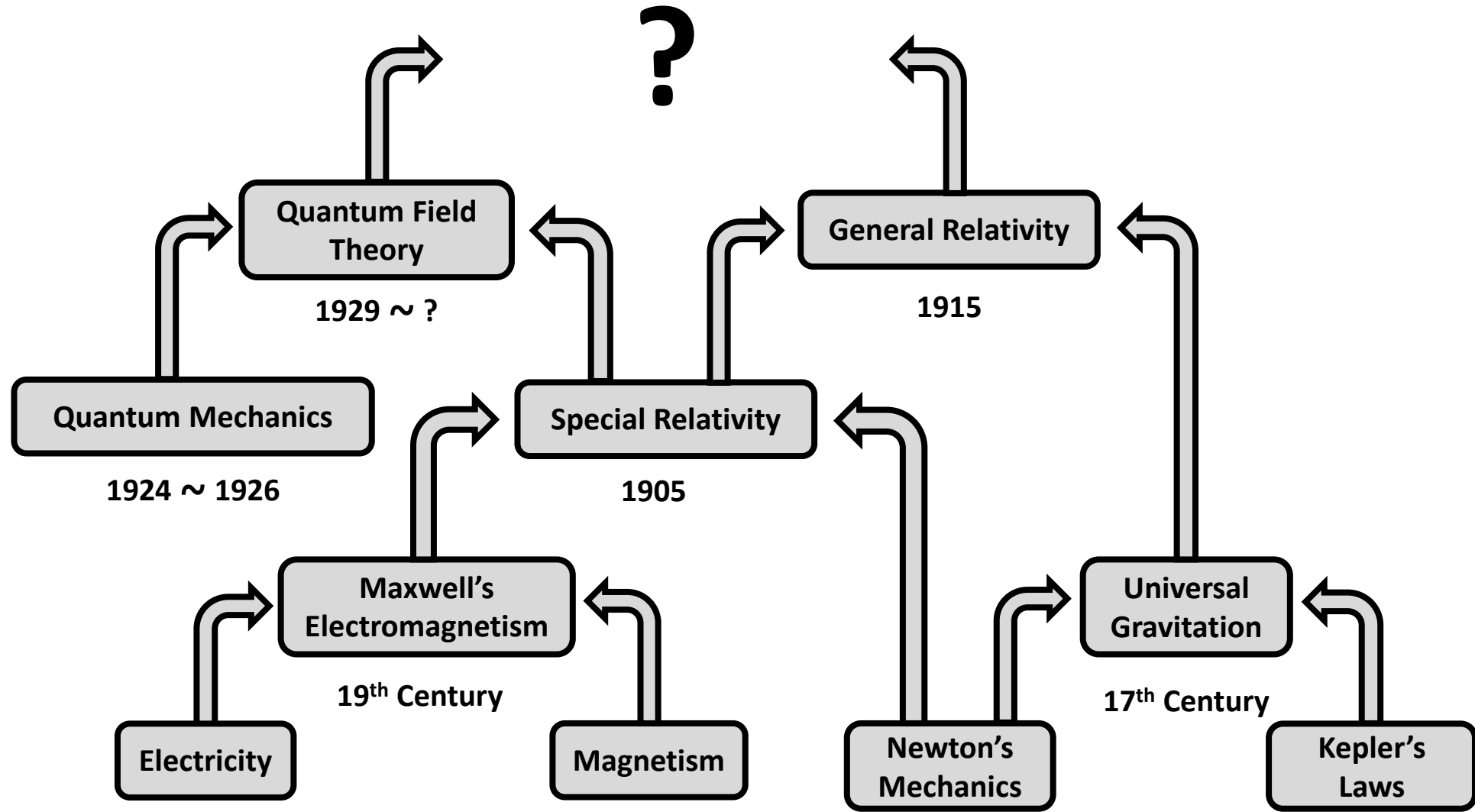


# Unification of Classical Physics









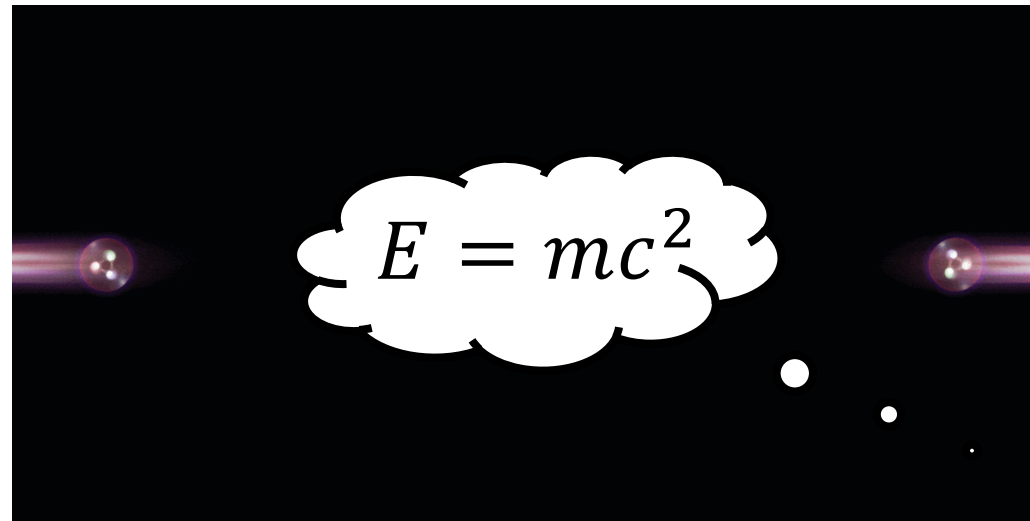
**Gravity is different**

The more powerful a particle accelerator,  
the shorter scale it can probe.

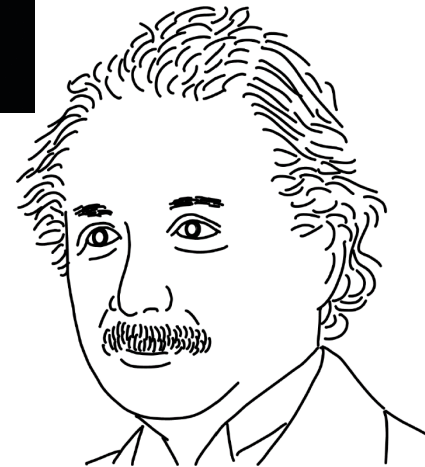


$$\Delta x \sim \hbar c / E$$

What happens if we build an accelerator that reaches the Planck length  $\Delta x \sim 10^{-35}$  m ?

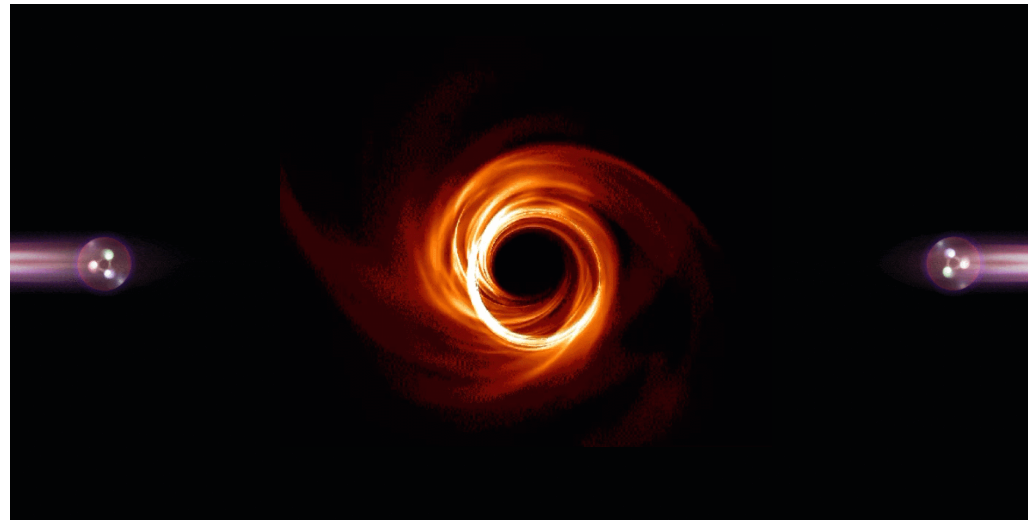


$$\Delta x \sim \hbar c / E$$



The Planck scale accelerator would create a black hole.

$$E = mc^2$$



Compton wavelength

$$\Delta x \sim \max \left( \frac{\hbar}{mc}, \frac{4G_N m}{c^2} \right)$$

Schwarzschild diameter

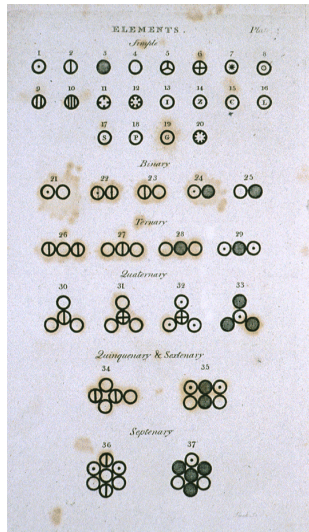
The Planck scale accelerator would  
create a black hole.

$$\Delta x \sim \max\left(\frac{\hbar}{mc}, \frac{4G_N m}{c^2}\right) \geq 2 \sqrt{\frac{G_N \hbar}{c^3}}$$

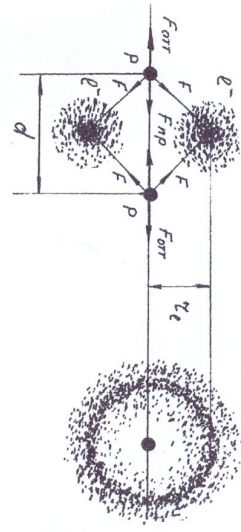
**We cannot probe phenomena shorter than**

$$\ell_p = \sqrt{\frac{G_N \hbar}{c^3}} \quad : \text{Planck length.}$$

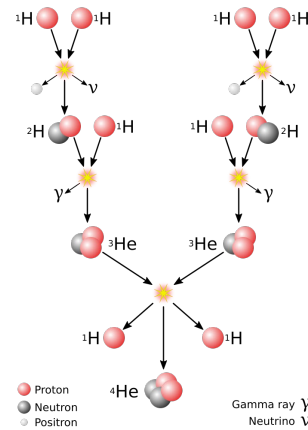
# Our historic march toward more fundamental laws of nature will terminate at the Planck scale.



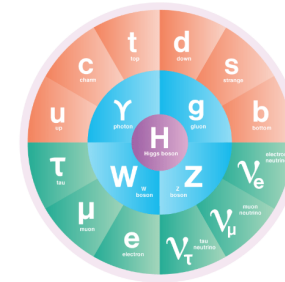
1808



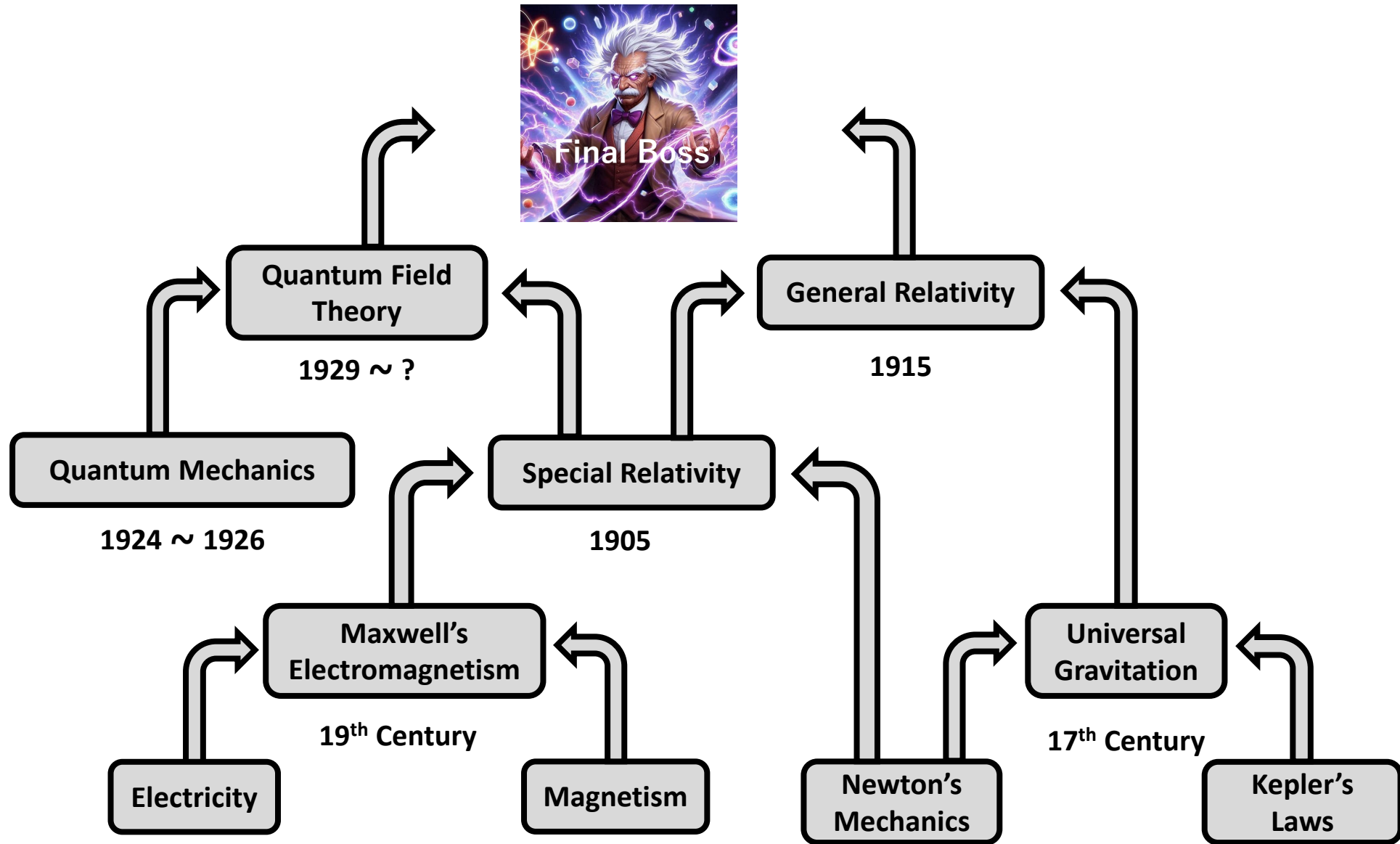
1913



1937



$l_P$



Q: Why is quantum gravity so difficult?

A: Because it is the **Final Boss** in our quest to unify the laws of nature.



**Why is Basic Science  
important for the Society?**



Max Weber (1864 – 1920) classified social actions into four types:

- Instrumental Rational Action
- Value Rational Action
- Traditional Action
- Affectual Action

**Instrumental Rational Action** aims to work out the most efficient way to achieve a particular goal.

**Value Rational Action** works towards a goal that seen as desirable for its own sake.

# Basic Science is **Value Rational Action**

Henri Poincaré (1854 – 1912)

From “Science and Method”

In response to the question, “What are valuable basic sciences?”

“Some discoveries teach us nothing beyond particular facts.”

“On the other hand, there are discoveries that teach us new principles and provide new insights. Researchers, who must make choices, should pursue the latter kind of discovery.”



Valuable basic science emerges from  
the curious minds of researchers.



森 重文

Recipient of the 2025 ICBS Basic Science Lifetime Award

In response to the question, “Is pure mathematics  
useful for the society?”

“It may not be right now, but it will be useful in 50 or 100 years.  
In the meantime, the curiosity of mathematicians is the best  
compass for guiding research.”