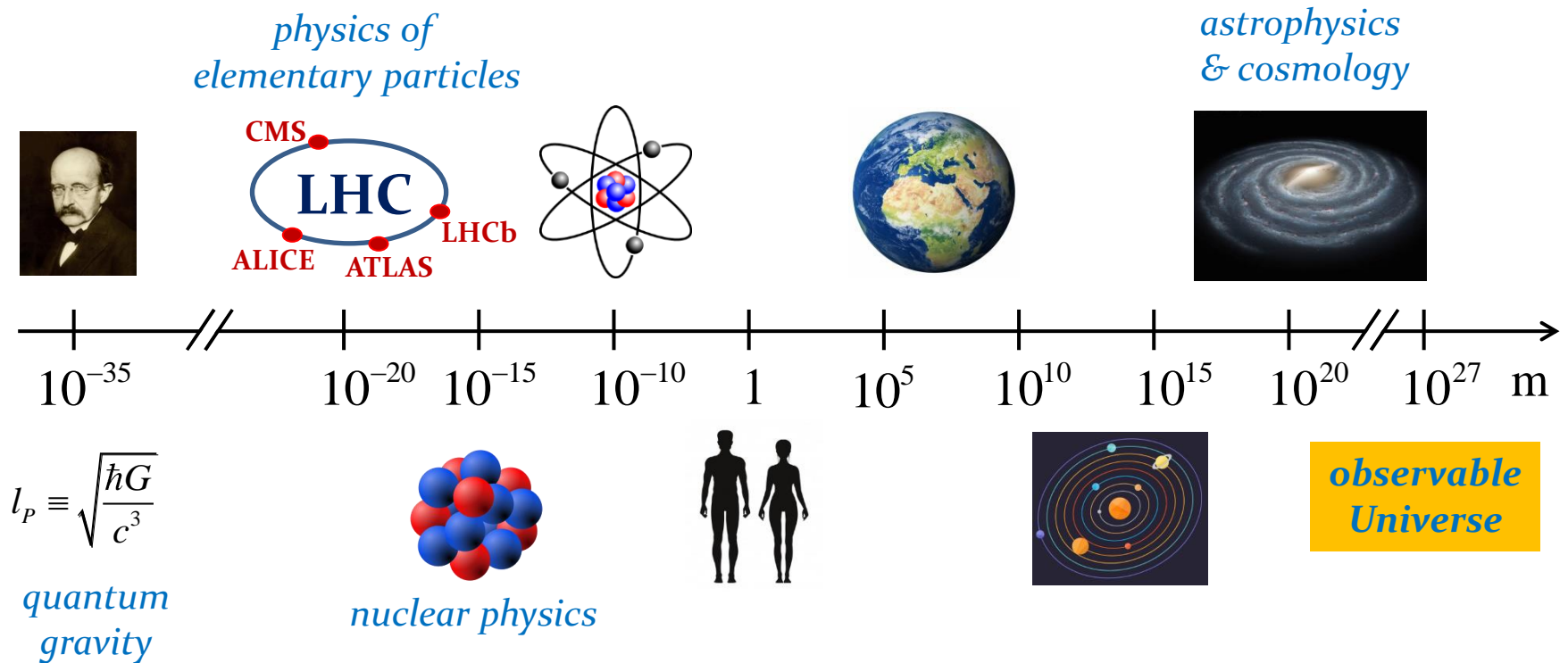


**Physics without experiment  
and  
cosmology with no observations?**

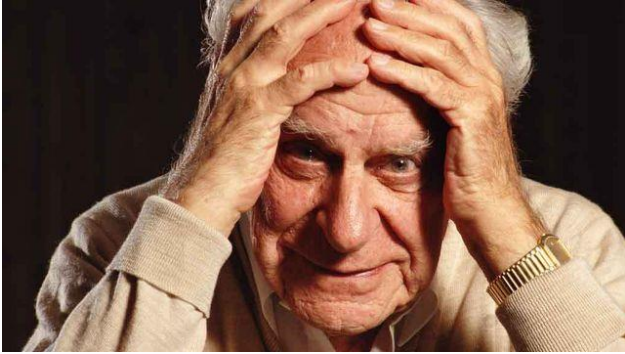
**Stanisław Mrówczyński**

*Institute of Physics, Jan Kochanowski University, Kielce, Poland  
and National Centre for Nuclear Research, Warsaw, Poland*

# Scales of physical objects



# Falsifiability – a pillar of physics

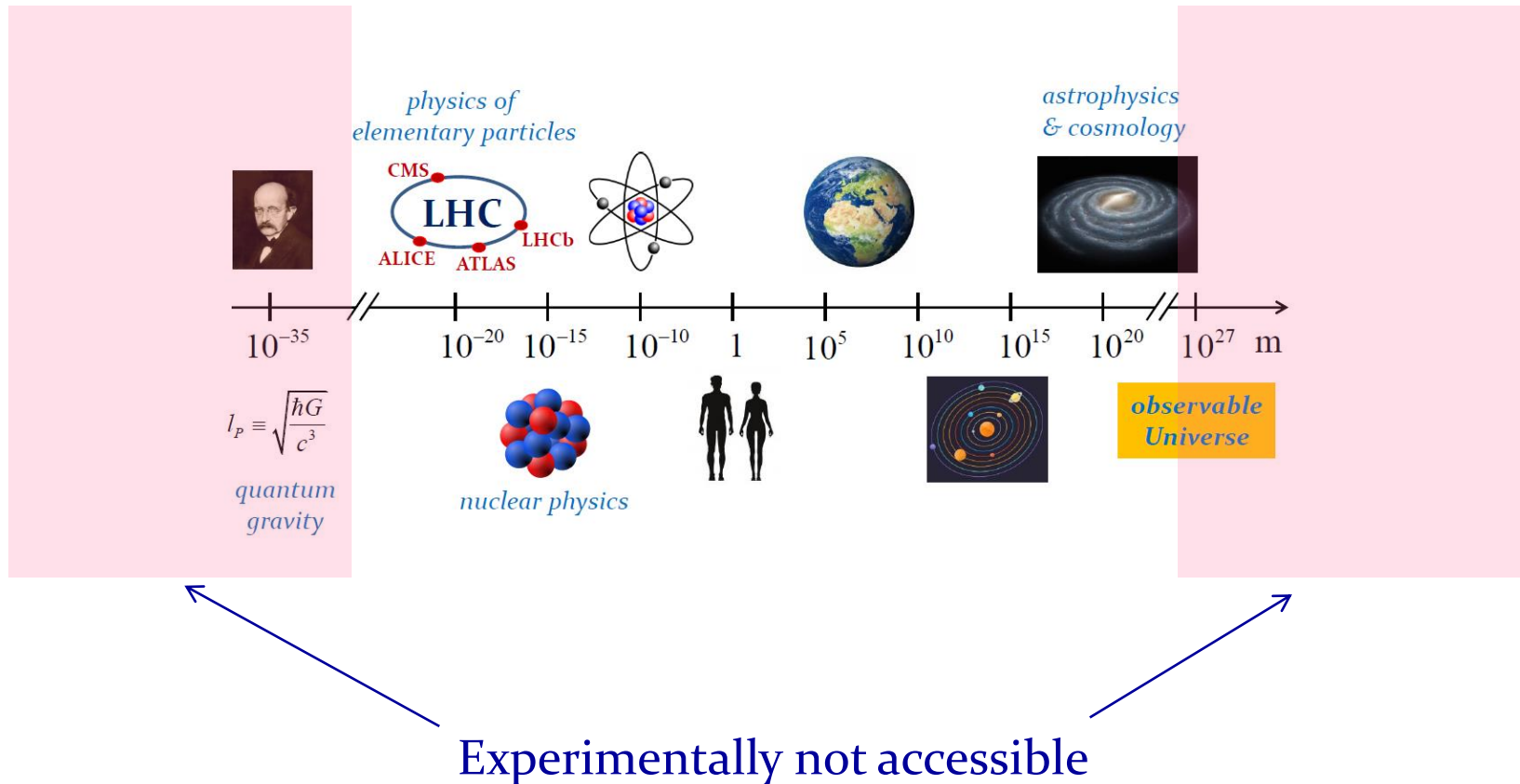


Karl Popper 1902-1994

A theory is scientific only if it is possible to establish that it is false!

*Scientific theories are never finally confirmed, but incrementally corroborated through the absence of disconfirming evidence in a number of well-designed experiments.*

# Technological limits of empiricism



# Quantum gravity

$$l_P \equiv \sqrt{\frac{\hbar G}{c^3}} = 10^{-35} \text{ m}$$

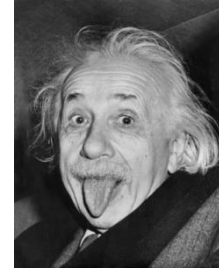
string  
theory?

loop  
gravity?

supergravity ?

$$m_P \equiv \sqrt{\frac{\hbar c}{G}} = 10^{19} \text{ GeV}/c^2$$

classical limit

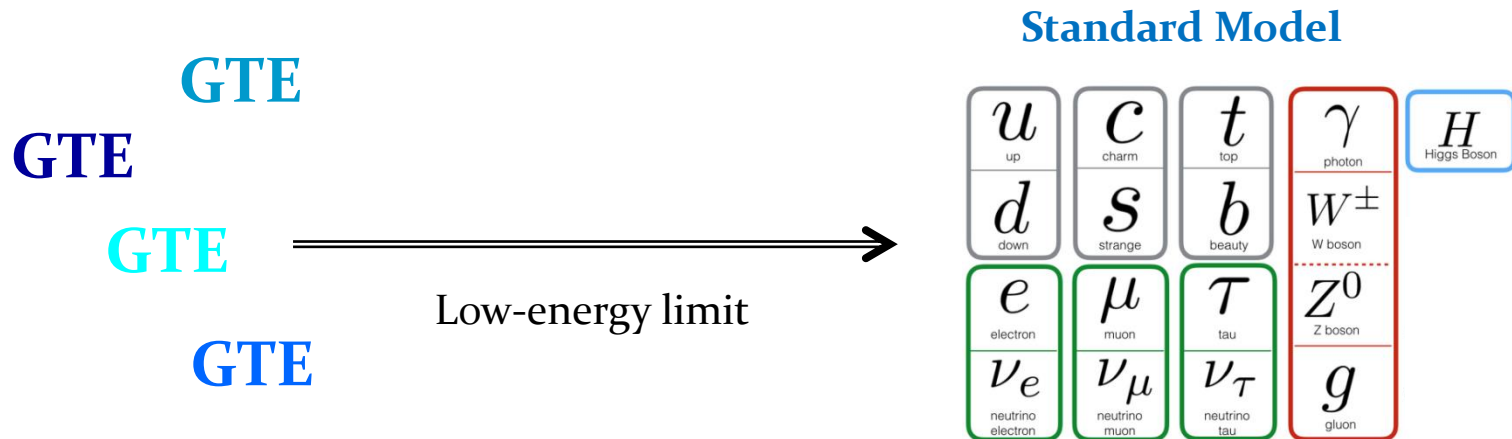


classical gravity

$$R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu} + \Lambda g^{\mu\nu} = \frac{8\pi G}{c^4} T^{\mu\nu}$$

# General Theories of Everything

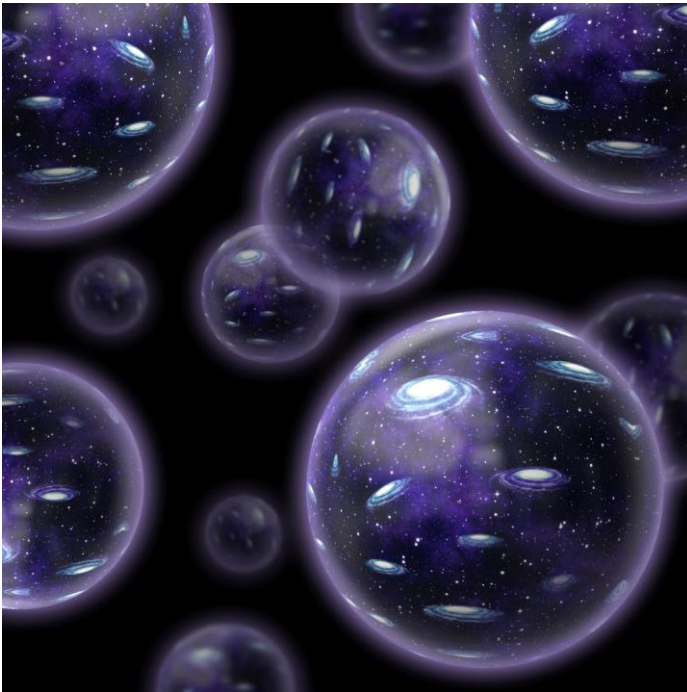
Standard Model summarizes our knowledge on microcosmos



**No physics beyond SM observed @ LHC**

# Principal limits of empiricism - Multiverse

From inflationary cosmological model to multiverse



Andrei Linde

Causally disconnected  
Universes

**Is it still physics?**

# Fundamental limits of empiricism

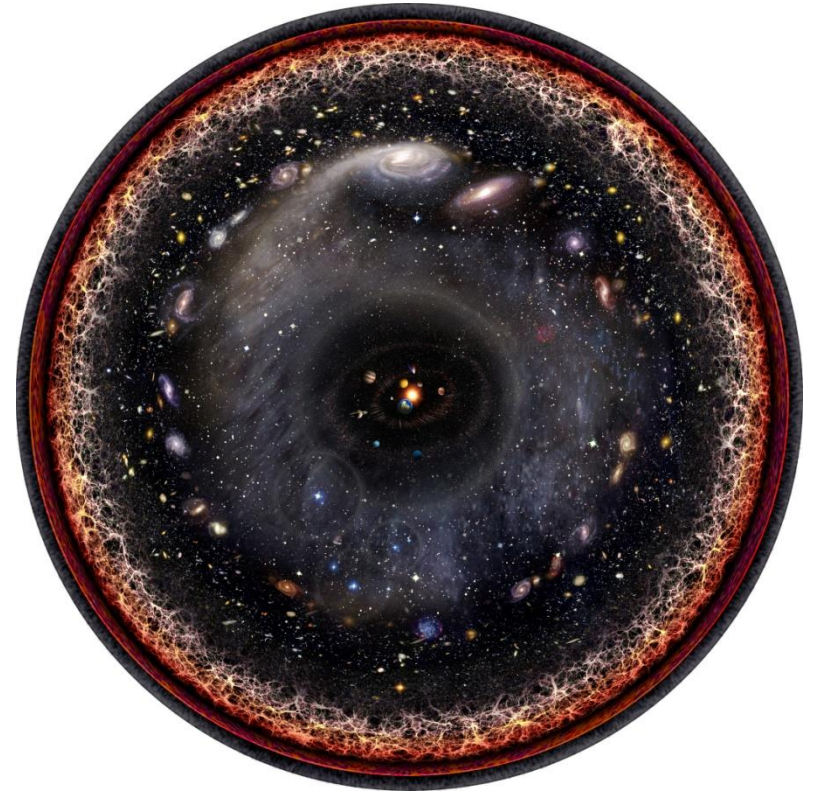
## Cosmology

### Cosmological principle

*The observable part of the Universe is typical, representative of the whole.*

### Cosmological hypothesis

*The laws of physics are the same, in any place and any time.*



Log-scale image by Pablo Carlos Budassi



# Deeper questions

## From how? to why?

### Example of the Coulomb law

The electrostatic force between two point charges is inversely proportional to the square of the distance between the charges.



Charles-Augustin de Coulomb (1736 – 1806)

Why inverse squares?

Because photons are massless?

Why photons are massless?

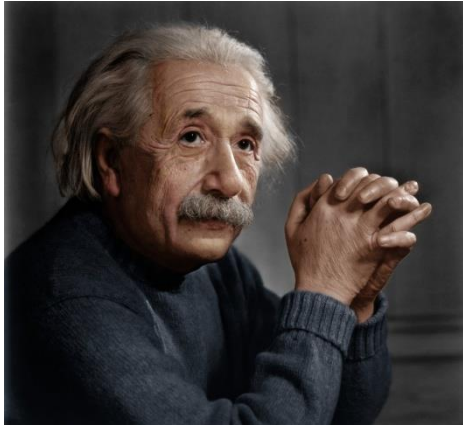
Because electrodynamics is gauge symmetric.

Why electrodynamics is gauge symmetric?

Because charges are conserved.



# The ultimate question



*Had God any choice in the creation of the World?*

Interesting question but experimentally inaccessible

# If not experiment then what?

## Cartesian rationalism

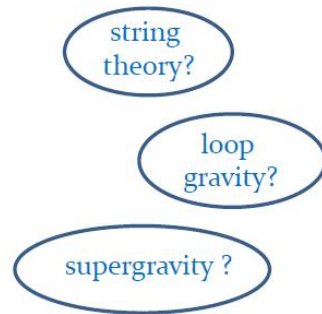
- *Logical consistency*
- *Agreement with experiments in limits*
- *No alternatives*
- *Minimum of assumptions and parameters*



René Descartes (1596-1650)

Example of quantum gravity

$$l_p \equiv \sqrt{\frac{\hbar G}{c^3}} = 10^{-35} \text{ m}$$



→  
classical limit



classical gravity

$$R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu} + \Lambda g^{\mu\nu} = \frac{8\pi G}{c^4} T^{\mu\nu}$$

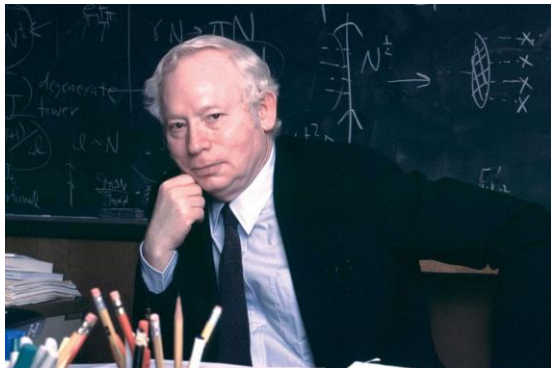
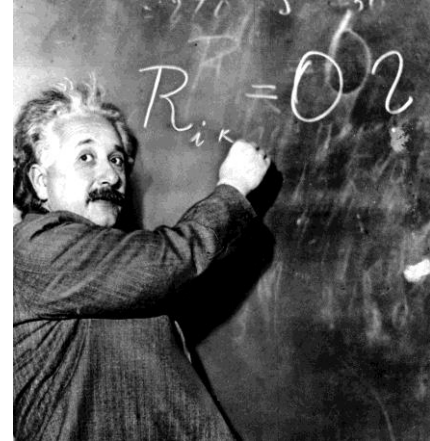
$$m_p \equiv \sqrt{\frac{\hbar c}{G}} = 10^{19} \text{ GeV}/c^2$$

# How it was with General Relativity

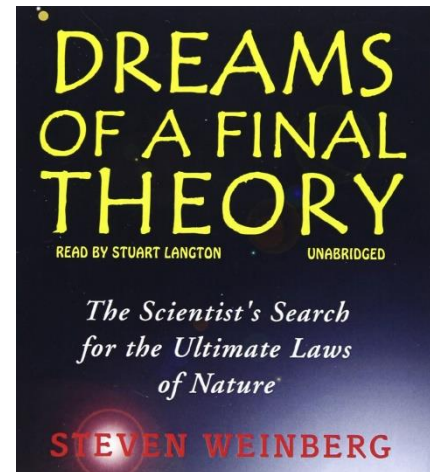
No experimental motivation to revise the newtonian gravity.

Why GR was commonly accepted soon after the discovery?

- *Precession of Mercury's Perihelion*
- *Gravitational deflection of light*

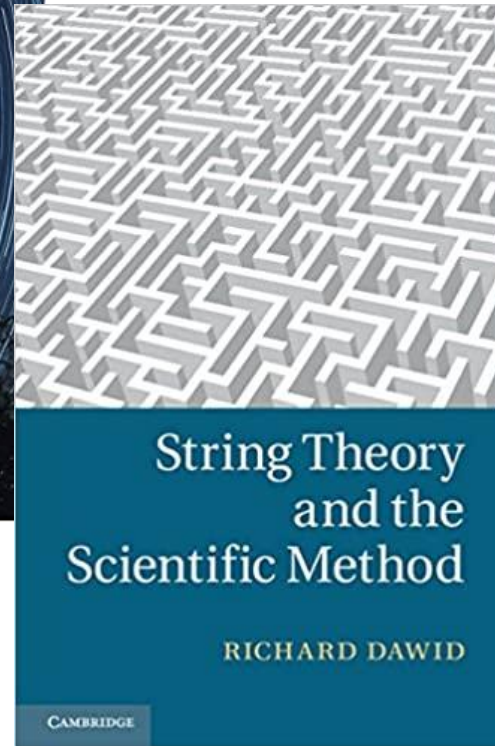
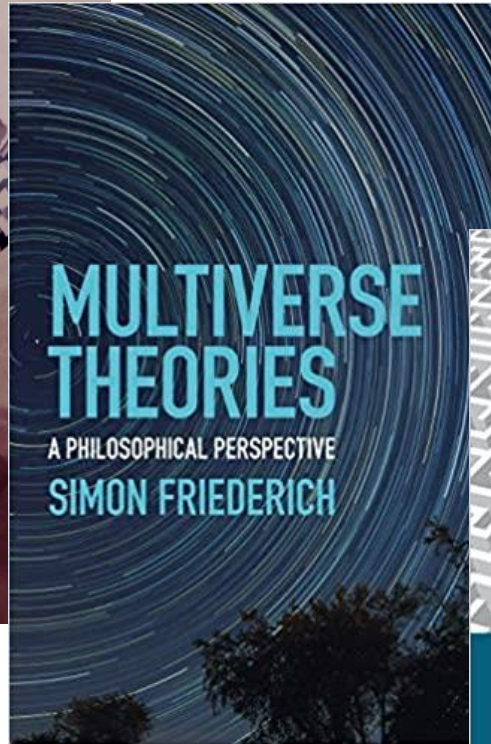
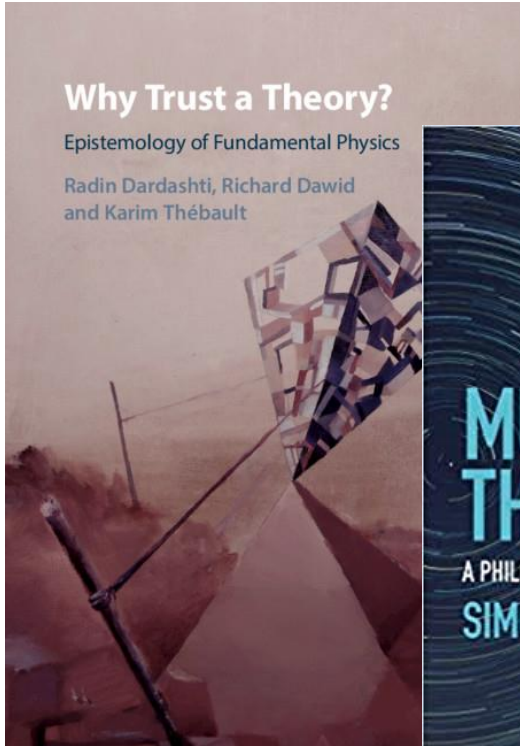


Steven Wienberg (1933-2021)

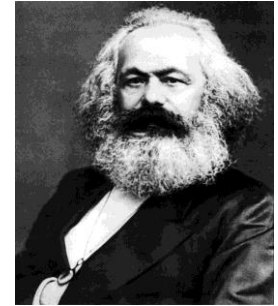


Chapter 5  
*Tales of Theory and Experiment*

# Physics, philosophy & scientific method



# Epilogue



*A spectre is haunting Physics*

*– the spectre of post-empiricism.*

*All the powers of old physics have entered into a holy alliance  
to exorcise this spectre.*

Breakthrough Prize in Fundamental Physics (\$3 milion) was awarded in 2019 to S. Ferrara, D. Freedman & P. van Nieuwenhuizen for supergravity.

APS Sakurai Prize was awarded in 2019 to Lisa Randall & Raman Sundrum for warped extra dimensions, and in 2020 to Pierre Sikivie for a method to detect axions.

# Outlook

## *Paradigm shift?*

*„The answers you get depend upon  
the questions you ask.”*



Thomas Kuhn (1922-1996)