Equations written in the stars

Gabriel Bliard

$$G_{\mu\nu} = \frac{4\pi G}{c^4} T_{\mu\nu}$$

$$\vec{F} = \frac{d\vec{p}}{dt}$$

$$S_{BH} = \frac{\pi A k c^3}{2hG}$$

$$(i\gamma^\mu \partial_\mu - m)\psi = 0$$

$$Z = \int \mathscr{D} g_{\mu\nu} \mathscr{D} X e^{S_{string}}$$

What I'll talk about

- The origins of celestial mechanics and physics (Gravity v 1.0)
- Electromagnetism and astronomy
- Gravity v 2.0
- Quantum fields and the 'god particle'
- Gravity v 3.0

What I won’t talk about

- Most of the scientists
- Cosmology
- The standard model
- Very early science (Greeks, babylonian astronomy, for example)
- Gravitational waves

- However: I am always happy to answer questions, even slightly off topic

The early days

Galileo

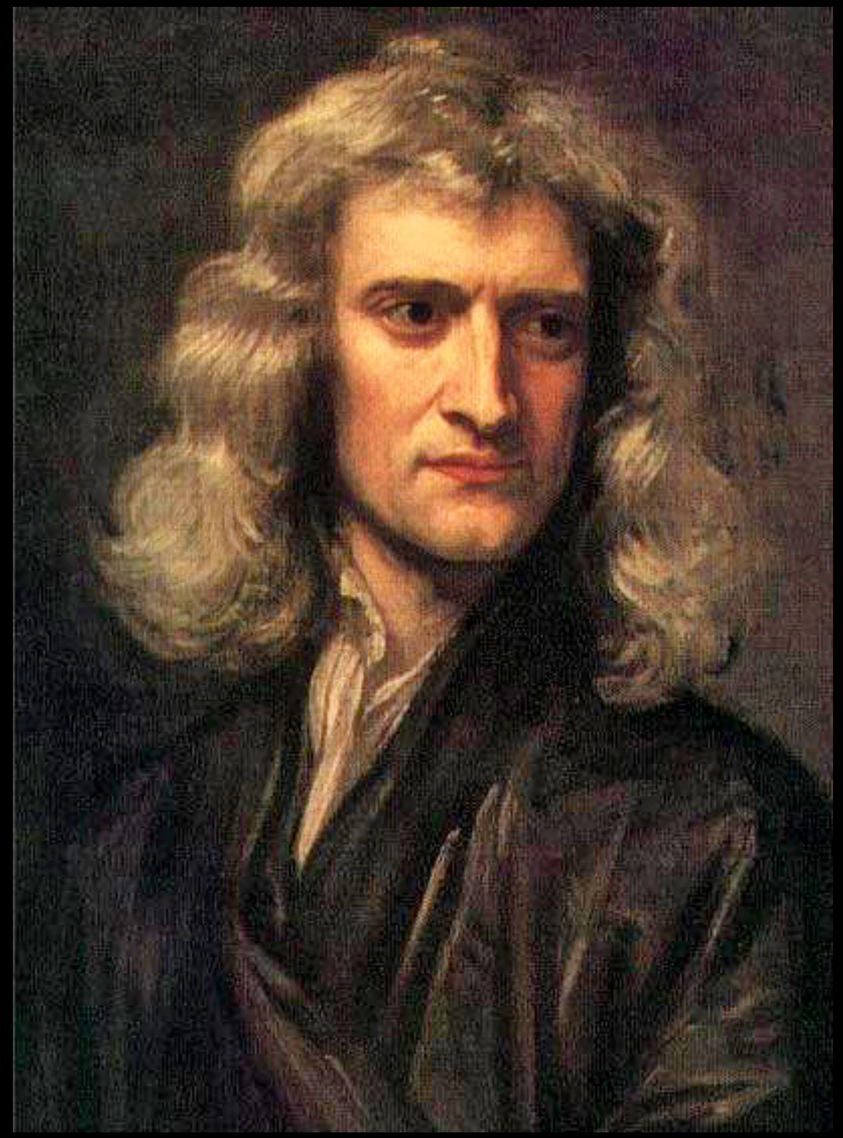
- Mostly geometric or qualitative
- Equation concerning the acceleration of bodies
- $d \propto t^2$

Sir Isaac Newton

Our first equation:

$$\overrightarrow{F} = \frac{d\overrightarrow{p}}{dt}$$

However, most analysis of orbits is still geometric



Pierre Simon Laplace

Did what Newton did, but better:
- Speed of sound in air
- Concept of potential
- Celestial dynamics
- Stability of the solar system
- ‘Lumipherous ether‘

$$\nabla^2 V = 0$$

Emilie du Chatelet

Made Newton and Leibniz's work accessible.

Mostly studied energy:

$$\frac{dE_{tot}}{dt} = 0$$

$$E_{kin} = mv^2$$

The advent of electricity

Edward Maxwell

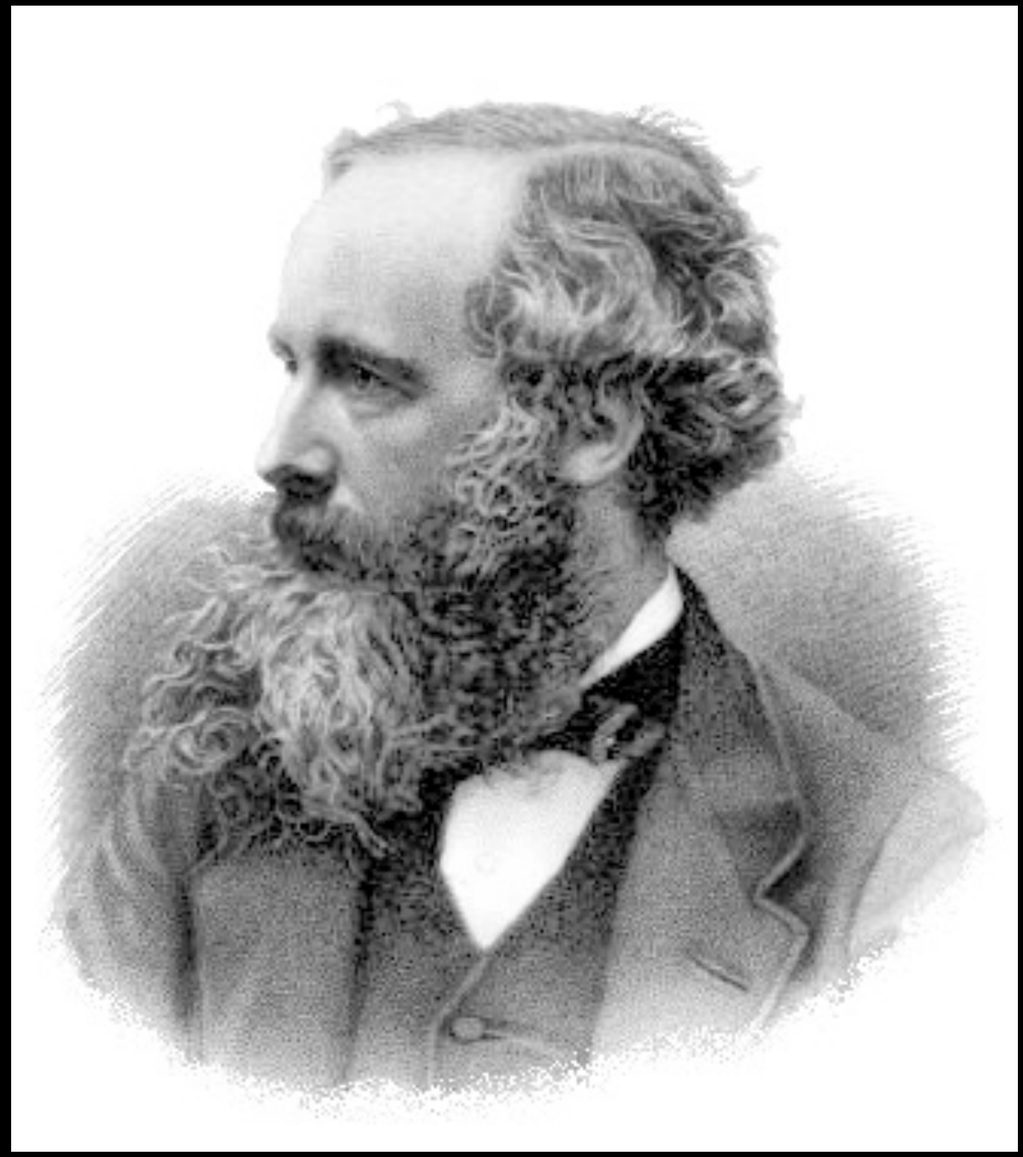
Saturn's rings
Theory of colour
Theory of Light:

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon}$$

$$\vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{dB}{dt}$$

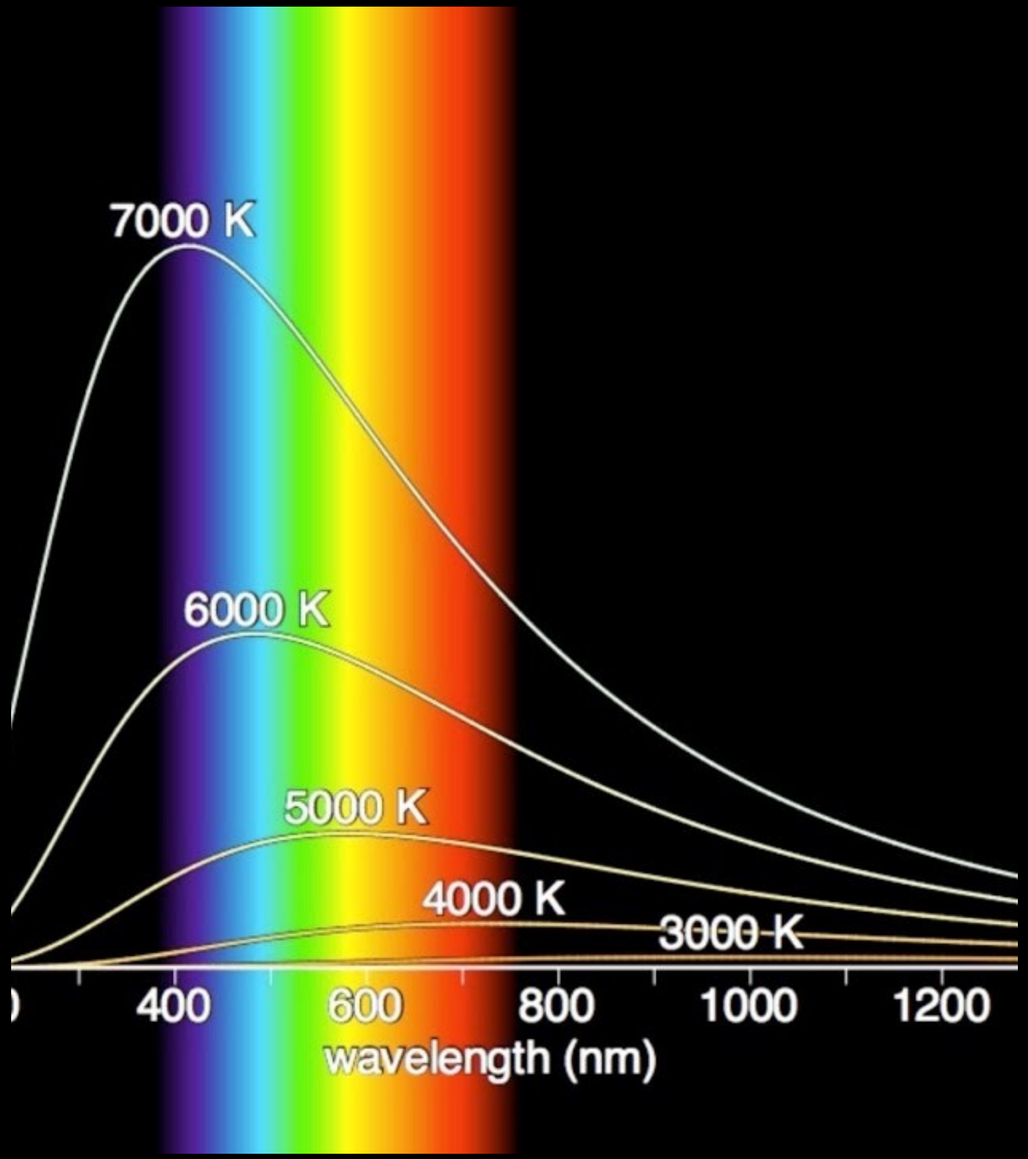
$$\vec{\nabla} \times \vec{B} = \frac{1}{c^2}\frac{d\vec{E}}{dt} + \frac{J}{\epsilon c^2}$$



William Herschel
Max Planck
Albert Einstein

Blackbody radiation

$$\mathcal{Z}(\beta) = \sum_{E} \frac{e^{-\frac{\beta E}{2}}}{1 - e^{-\beta E}}$$



The birth of modern physics

The quantum revolution

Emmy Noether

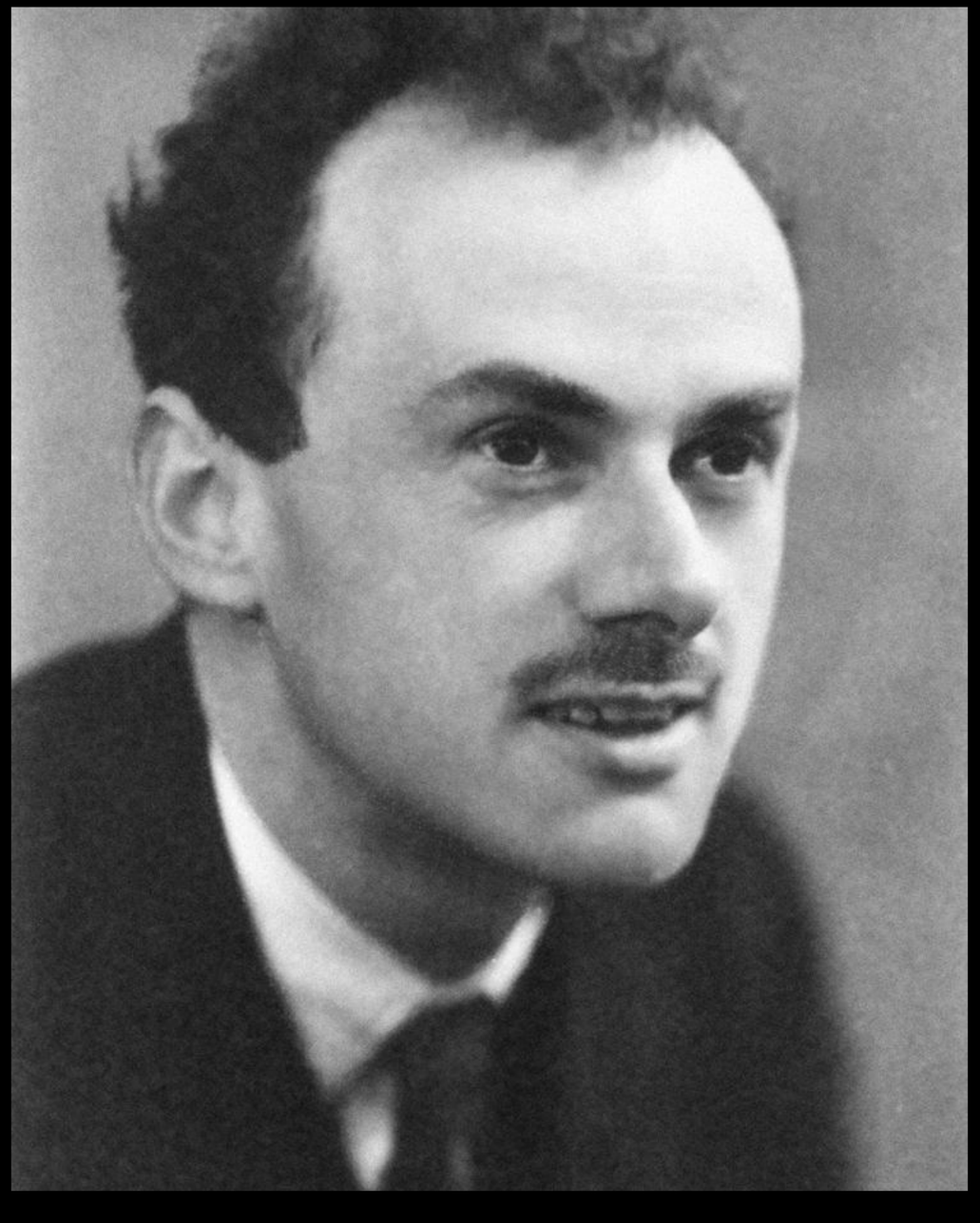
- Novel concept of using symmetries of a system.
- $Symmetry \leftrightarrow Conservation$
- One of the only physical theorems which we still use.

Paul Dirac

$$(i\gamma^{\mu}\partial_{\mu} - m)\psi = 0$$

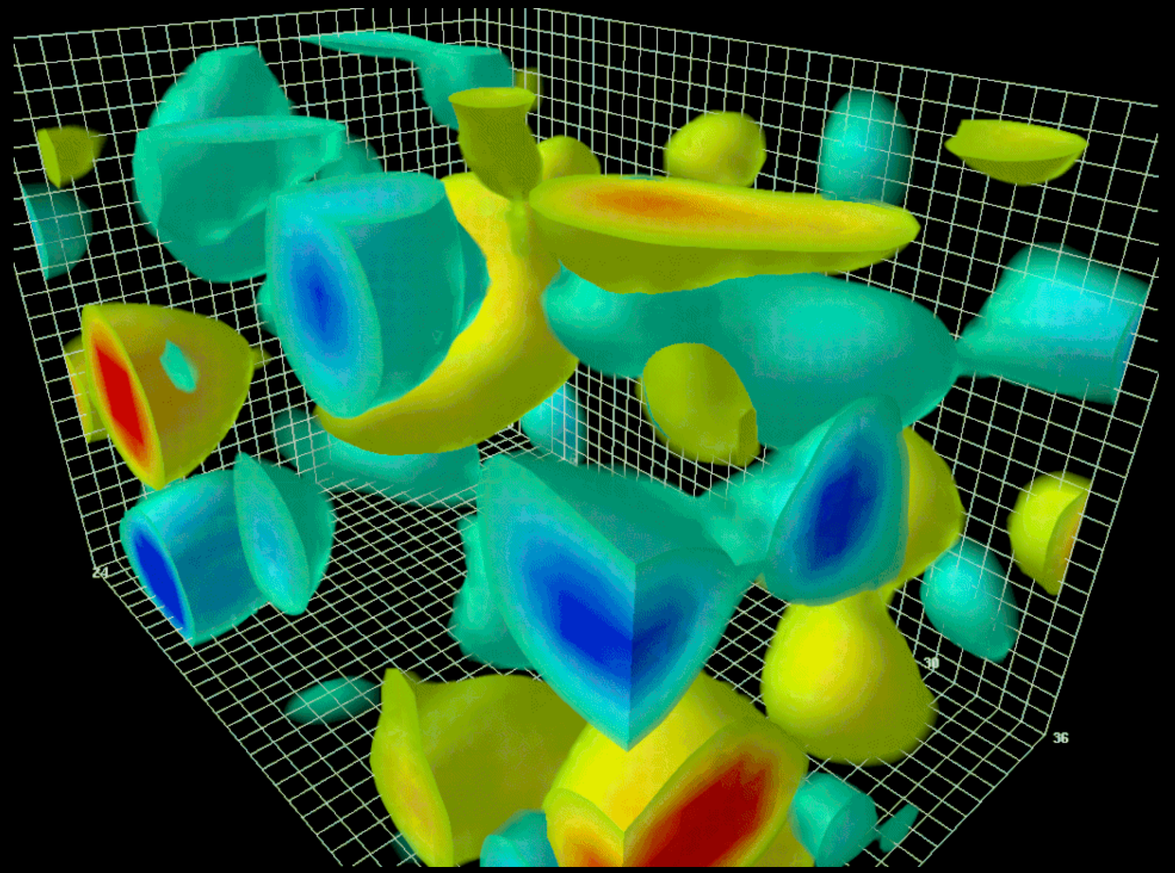
- Giant in the quantum revolution
- Linked heisenberg's uncertainty principle to the non commutativity of certain operators

$$[p, x] = -i\hbar$$



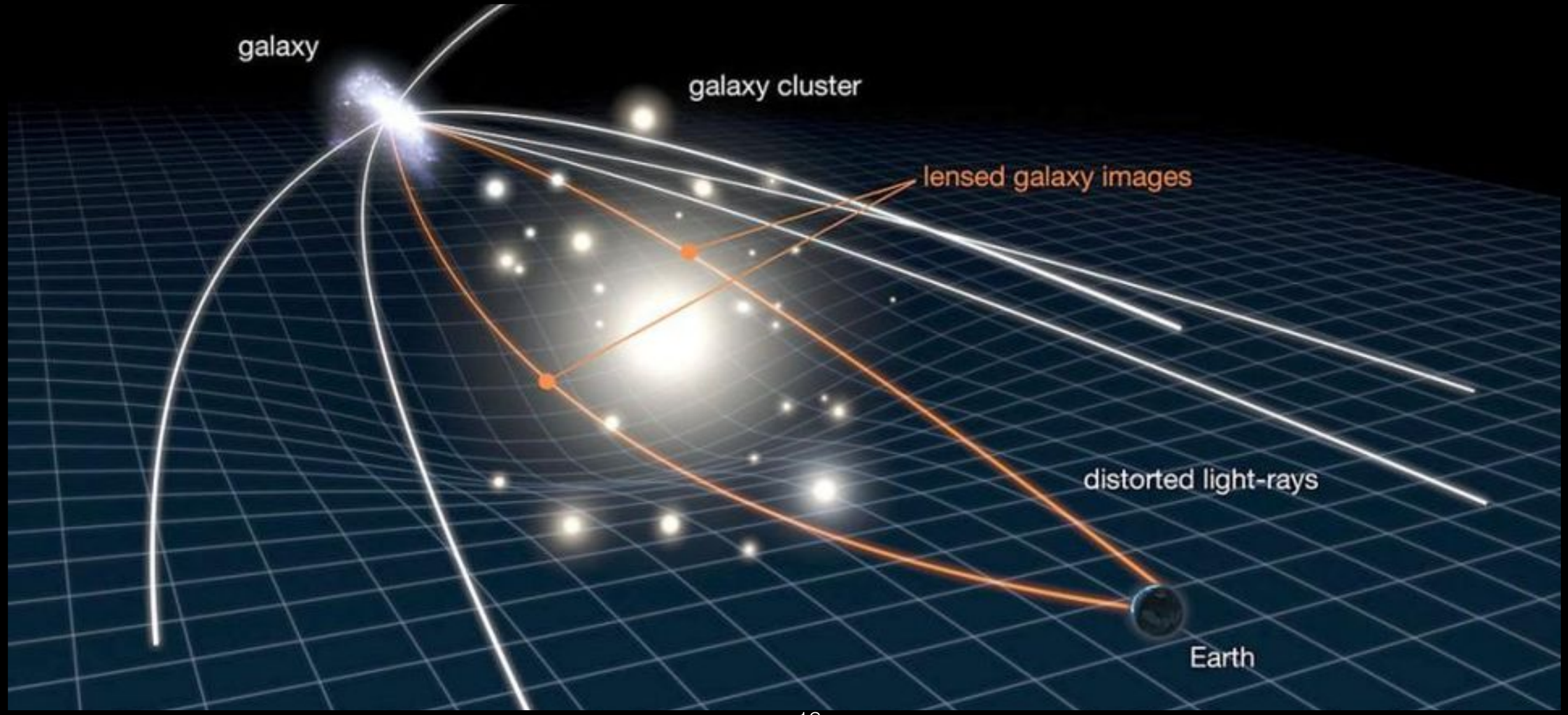
Quantum fields

- Particles are no longer the fundamental object
- Most tested theory in Human history
- Still is the best description we have to this day
- Explain why particles acquire mass
- Consequences for the Universe:



Gravity v 2.0

Einstein's Equation



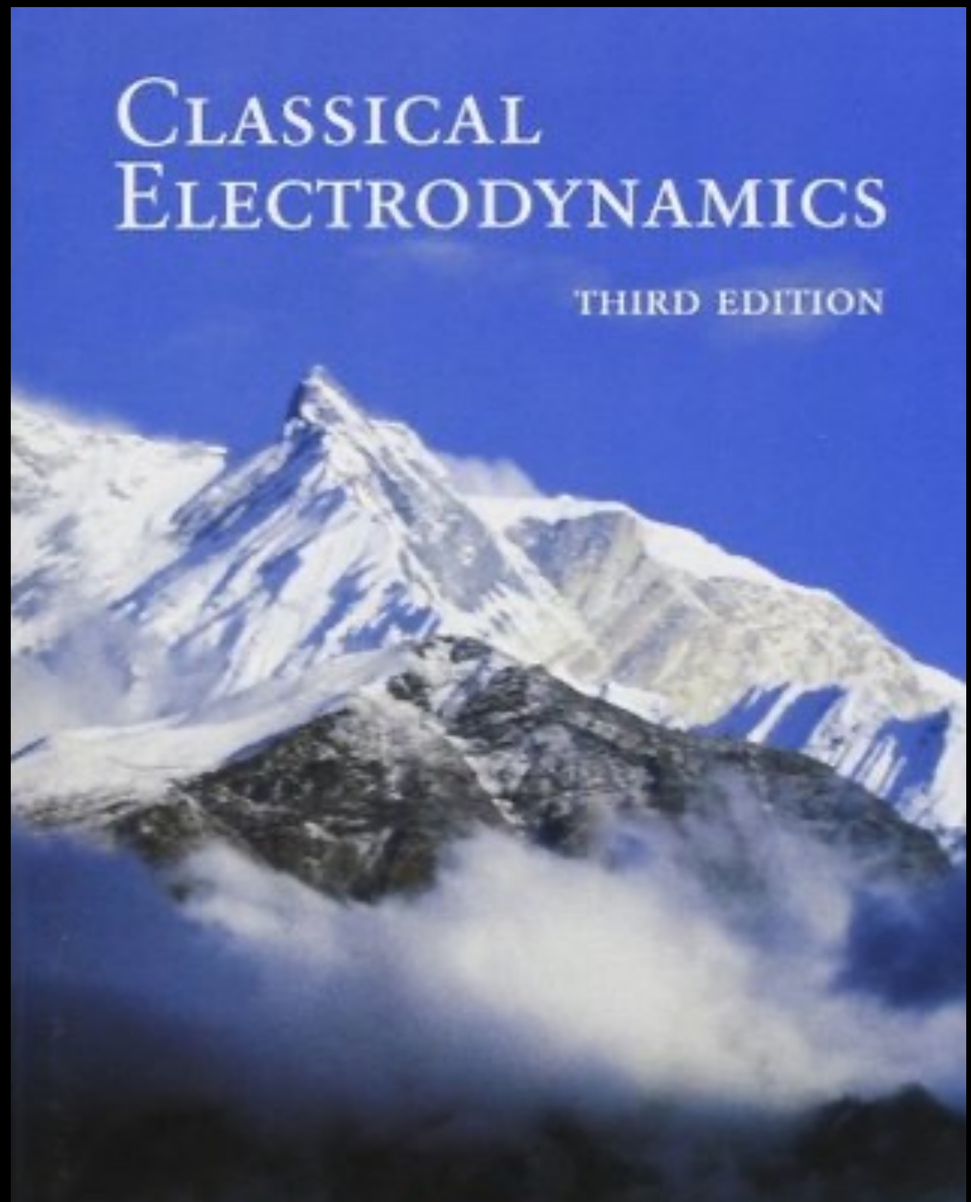
Einstein's Equation

$$G_{\mu\nu} = \frac{4\pi G}{c^4} T_{\mu\nu}$$

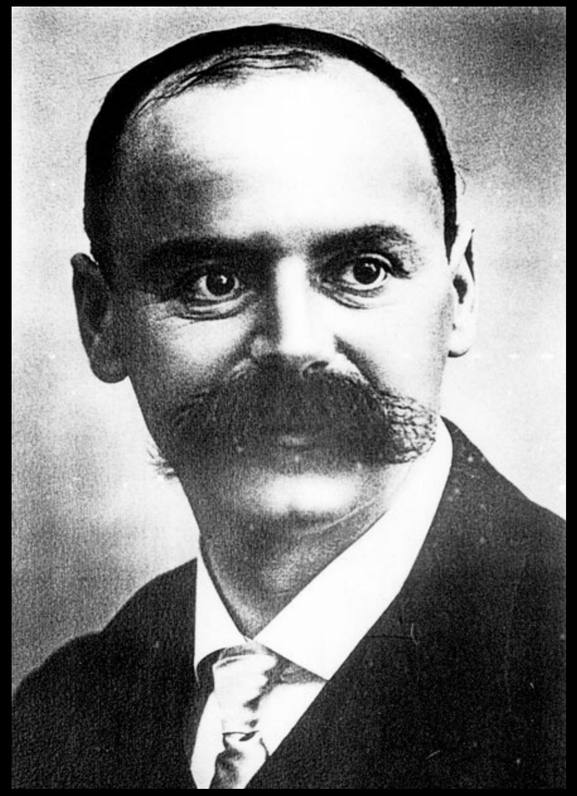
Compare to E-M

$$dF = 0 \quad d \star F = \mu_0 J$$

- Equations are solved exactly



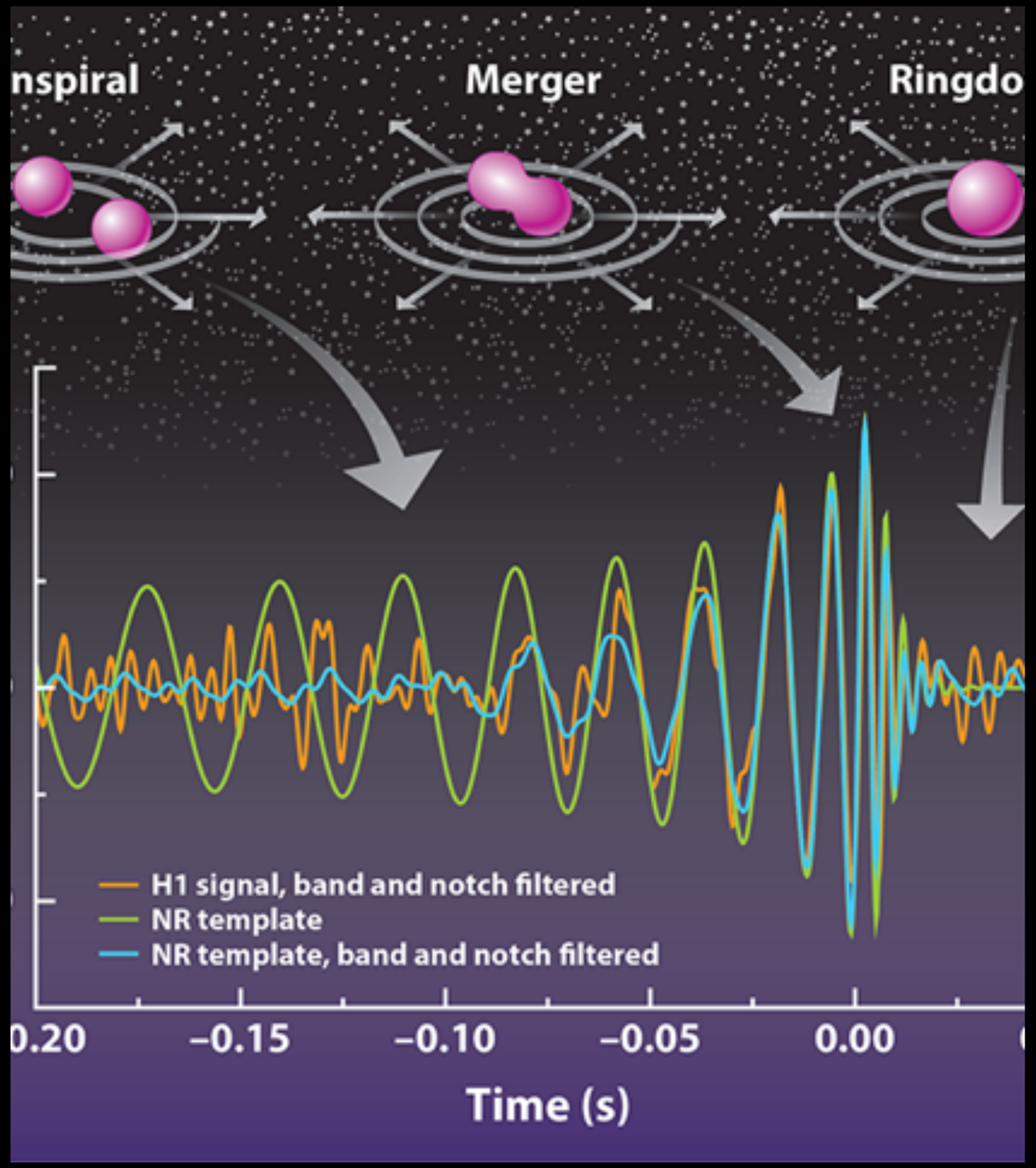
Schwarzschild



$$ds^2 = -(1 - \frac{r_s}{r})dt^2 + \frac{1}{(1 - \frac{r_s}{r})}dr^2 + r^2 d\Omega^2$$

Numerical Relativity

Invented to solve the difficult problems
Only 5 known exact solutions to the EE



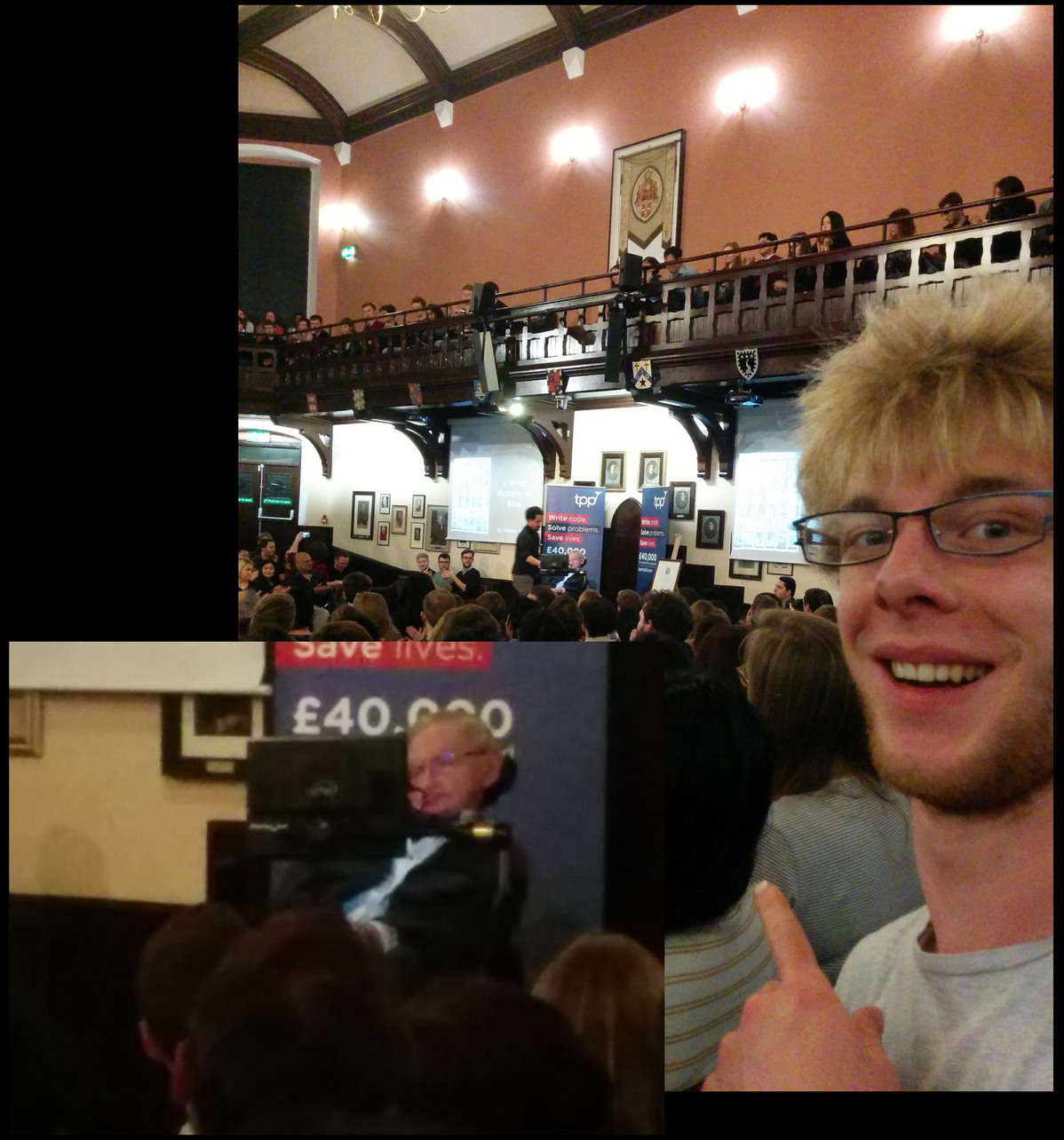
The clash of the titans

Stephen Hawking

First concrete calculation linking gravity to quantum field theory:

$$S_{BH} = \frac{\pi A k c^3}{2hG}$$

Black holes radiate!



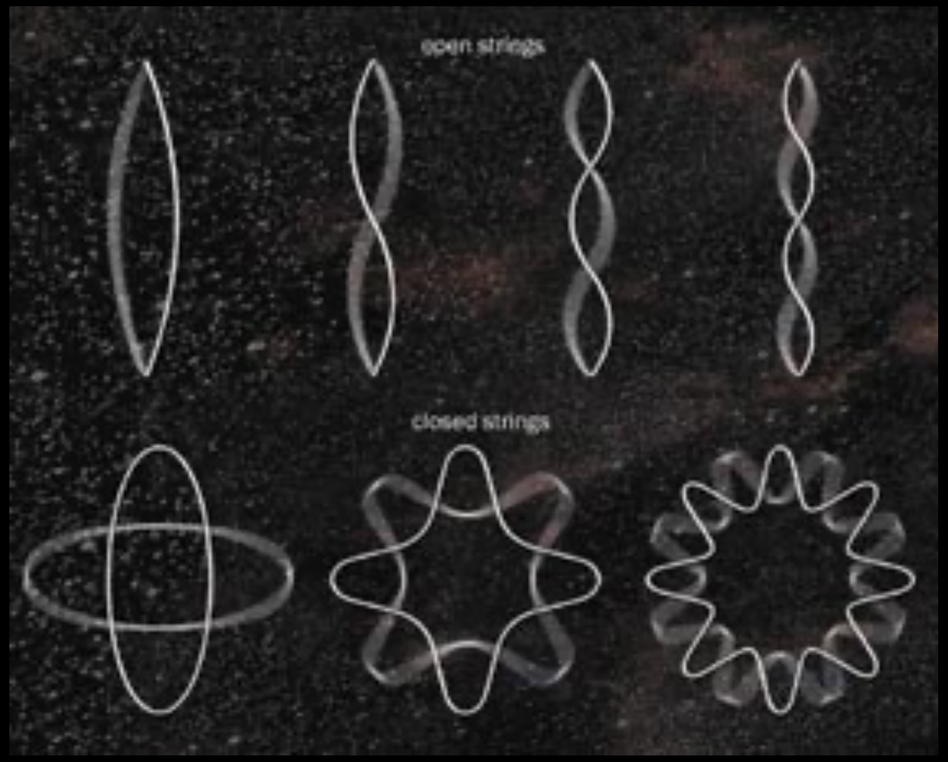
Gunnar Nordstrom & Albert Einstein

In search for a ‘Unified theory’

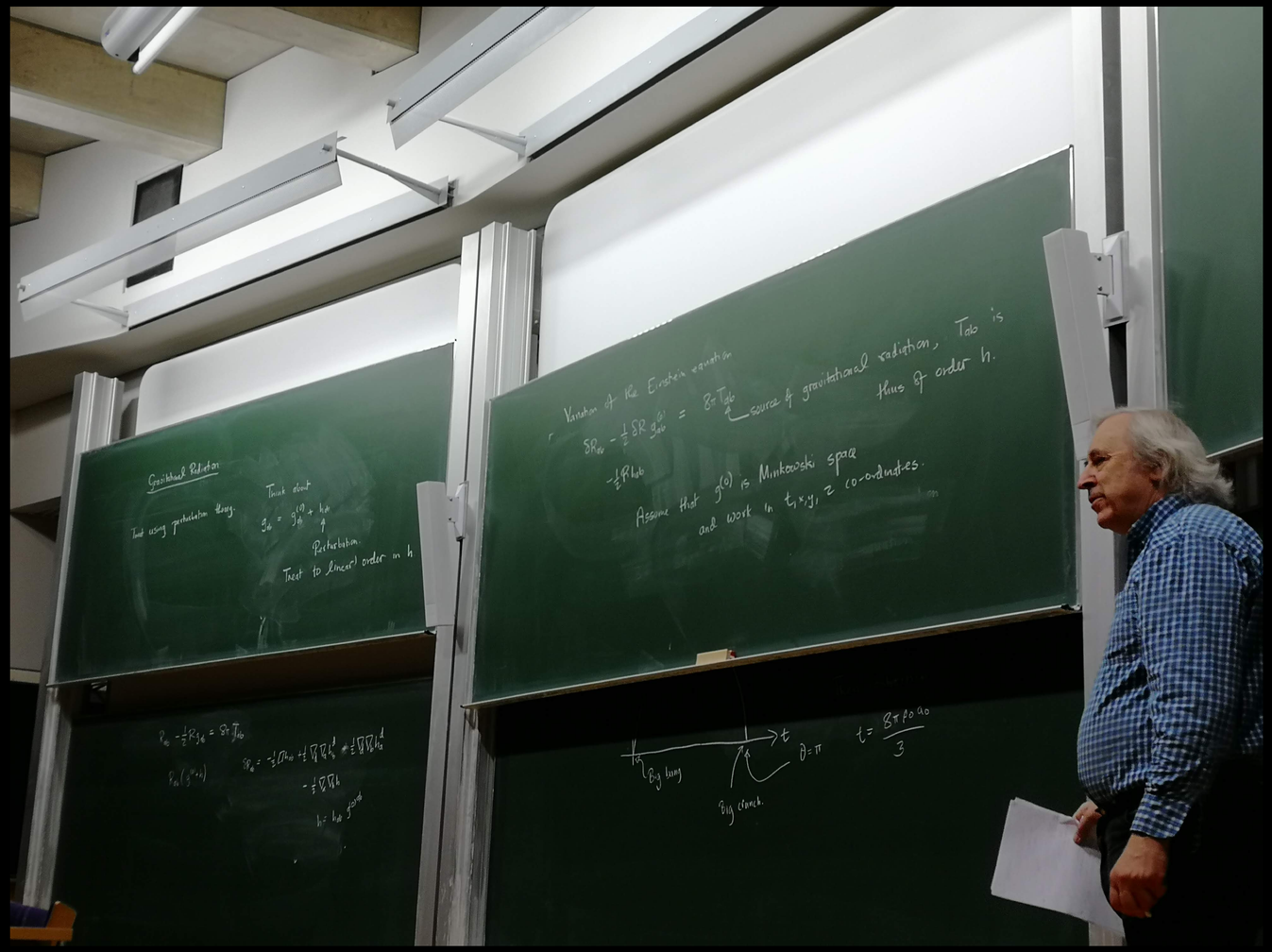
5d Gravity -> 4d Gravity + E-M

Gravity v 3.0 ?

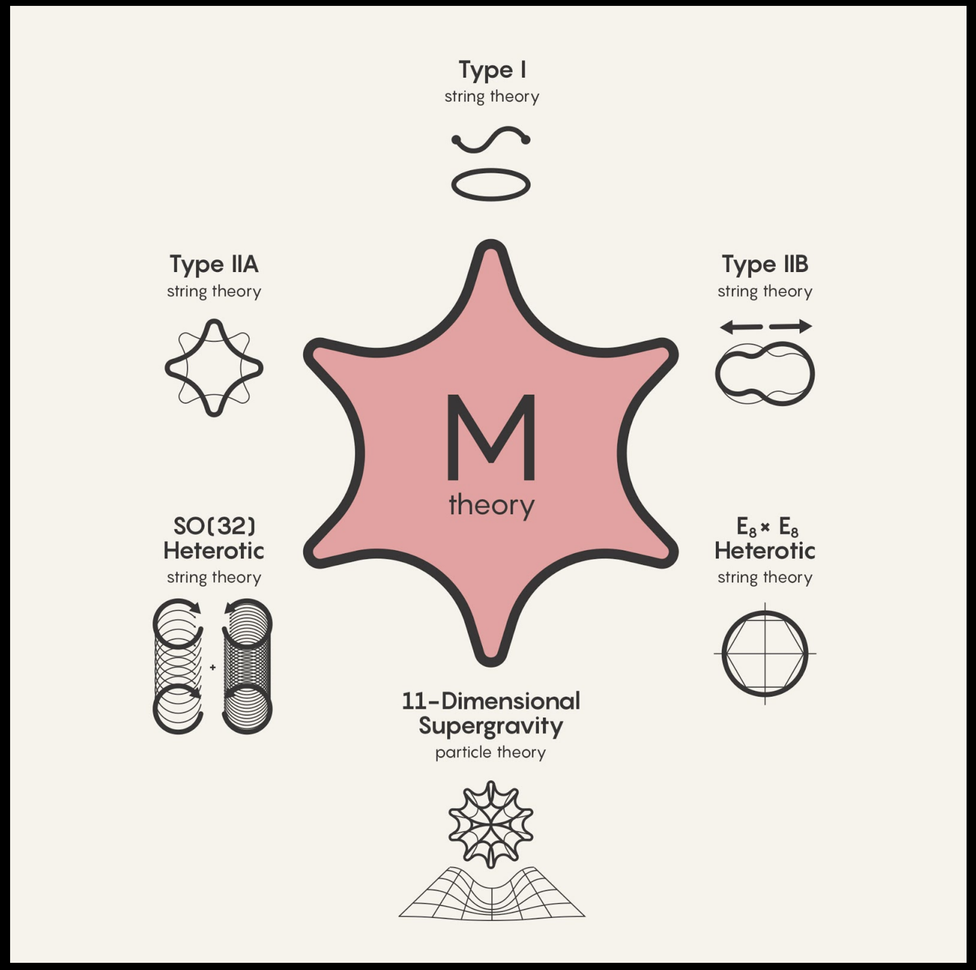
String theory and geometry



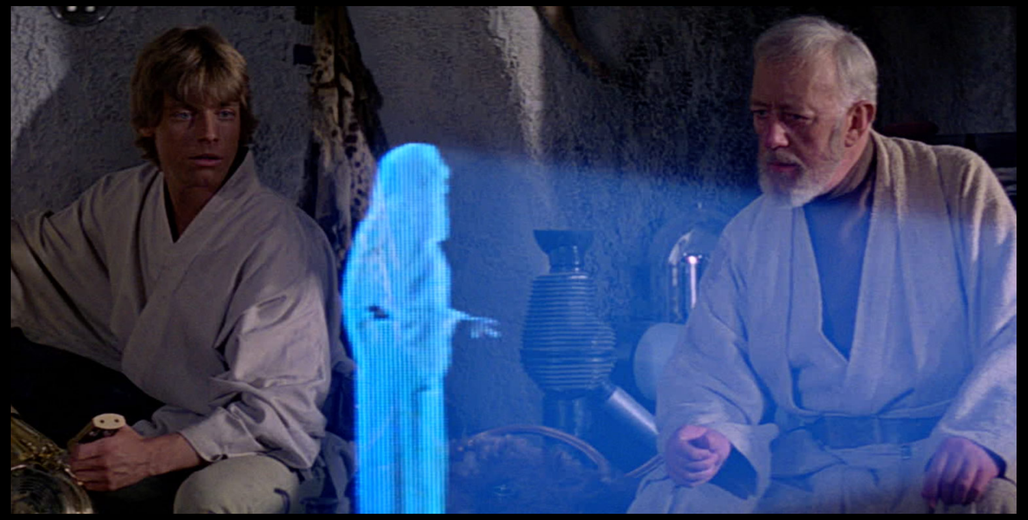
Malcom Perry



Edward Witten



Juan Maldacena



The Universe as a Hologram

What now?

The Equations

$$\overrightarrow{F} = \frac{d\overrightarrow{p}}{dt} \qquad G_{\mu\nu} = \frac{4\pi G}{c^4} T_{\mu\nu} \qquad S_{BH} = \frac{\pi A k c^3}{2hG}$$

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Open Problems

- String theory is the ‘Problem of the 21st century’
- Does another quantum gravity describe our universe
- Are there giant strings in our universe
- How does string theory work?

Possible experimental revolution

2. arXiv:2004.14192 [pdf, ps, other] astro-ph.EP hep-ph hep-th

Searching for a Black Hole in the Outer Solar System

Authors: Edward Witten

Abstract: There are hints of a novel object ("Planet 9") with a mass $5 - 10\ M_{\oplus}$ in the outer Solar System, at a distance of order 500 AU. If it is a relatively conventional planet, it can be found in telescopic searches. Alternatively, it has been suggested that this body might be a primordial black hole (PBH). In that case, conventional searches will fail. A possible alternative is to probe the grav... ▽ More

Submitted 29 April, 2020; **originally announced** April 2020.

Comments: 4 pp

- Experimental black holes: ‘9th planet’
- Experimental black holes at cern
- New particles revealing Supersymmetry