

Some open questions in physics

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Content

- Quantum Mechanics
- Standard Model
- dark matter and dark energy
- quantum gravity
- summary

The most incomprehensible fact about the
Universe is that it is comprehensible

A. Einstein

Introduction

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– physical laws
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- there are correlations among these numbers
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- with proper idealization these laws seem to be universal and rigorous
- we have no idea why these statements hold
the answer belongs to meta-physics rather than physics...

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- but mathematics gives us also a rigorous proof that cognition has its limits:

Gödel theorem + finite resources



“Theory of Everything” is impossible

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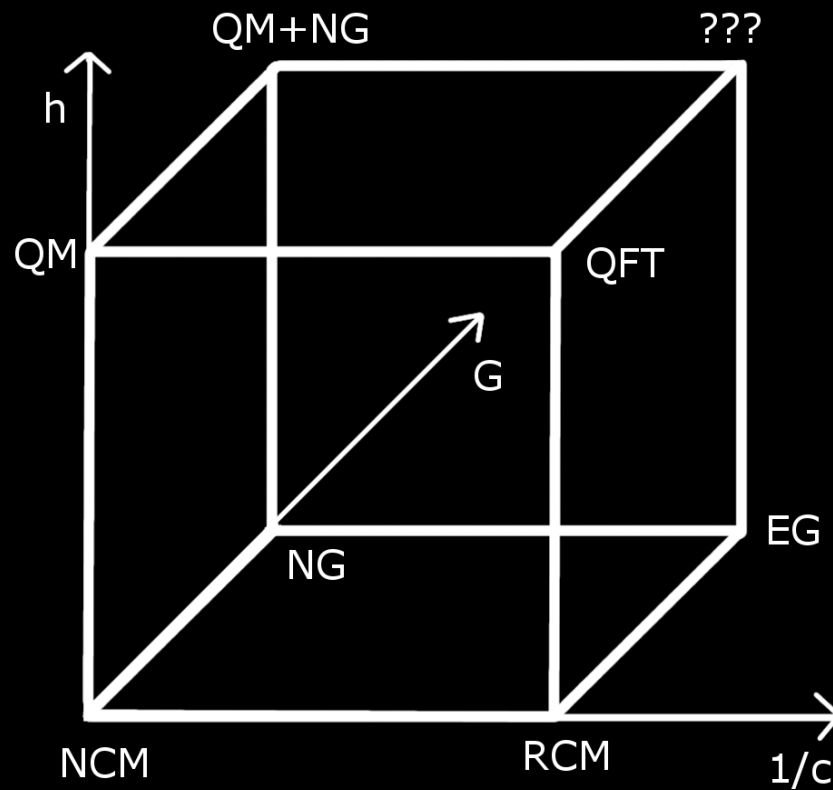
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- explanation in physics means converting “accidental” into “inevitable”
- how far can we go?

Cube of theories

Fundamental dimensionful constants: $1/c$, \hbar , G



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- problem of measurement (Copenhagen, Everett, Bohm, Penrose, ...) totally unclear...

Particles of the Standard Model

- Leptons (spin 1/2, $q_\nu = 0$, $q_e = -1$):

$$\begin{array}{ccc} \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L & \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L & \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L \\ e_R, \nu_{eR} & \mu_R, \nu_{\mu R} & \tau_R, \nu_{\tau R} \end{array}$$

- Quarks (3 colors, spin 1/2, $q_u = 2/3$, $q_d = -1/3$):

$$\begin{array}{ccc} \begin{pmatrix} u \\ d \end{pmatrix}_L & \begin{pmatrix} c \\ s \end{pmatrix}_L & \begin{pmatrix} t \\ b \end{pmatrix}_L \\ u_R, d_R & c_R, s_R & t_R, b_R \end{array}$$

- Spin 1: 8 gluons g ($SU(3)$),
 W^\pm and Z^0 , photon γ ($SU(2) \times U(1)$)
- Spin 0: Higgs H

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- why CP violation (and why not enough)???

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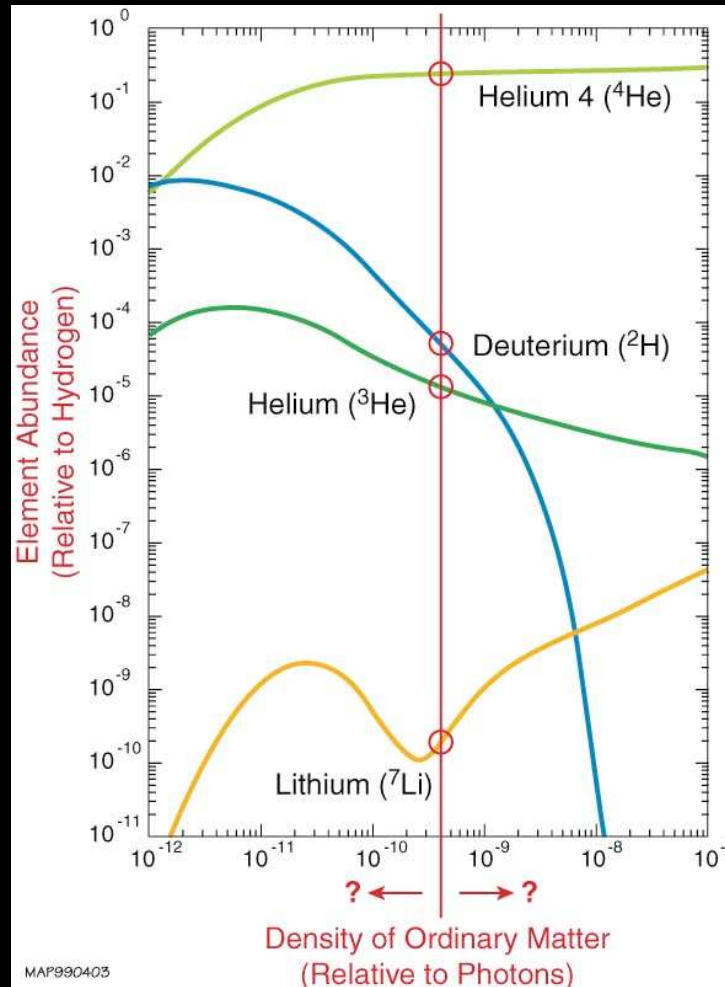
- hierarchy problem $\frac{v}{M_P} \approx 10^{-16}$

(supersymmetry, conformal symmetry)

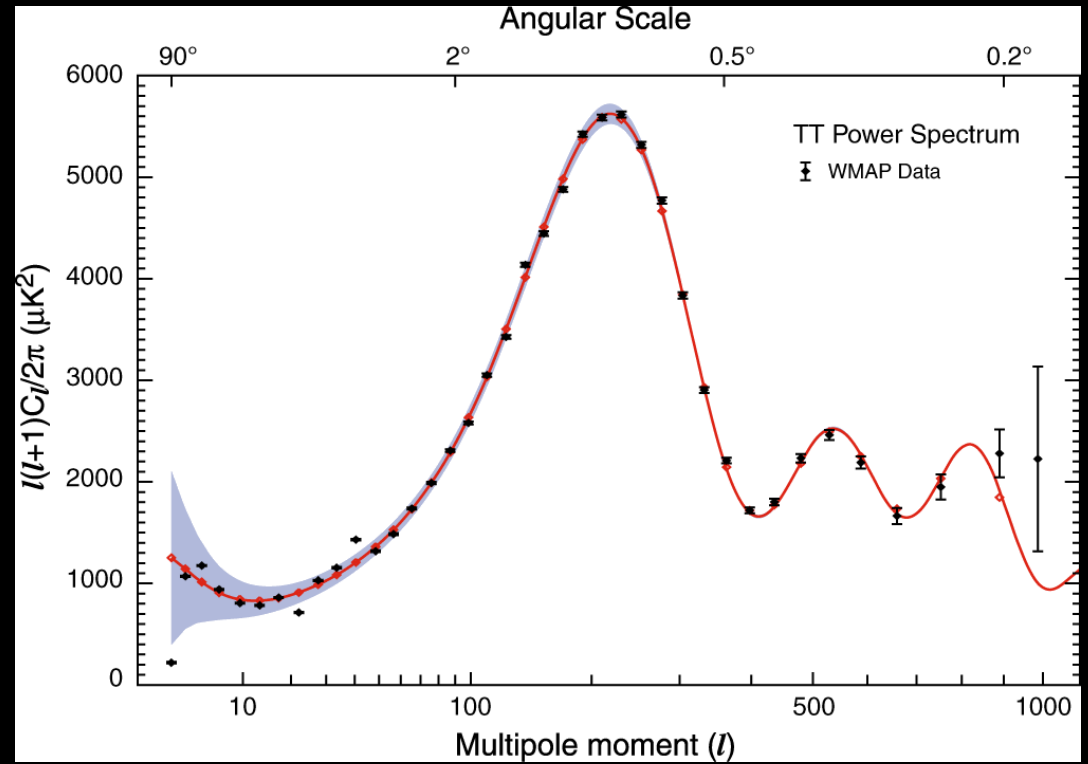
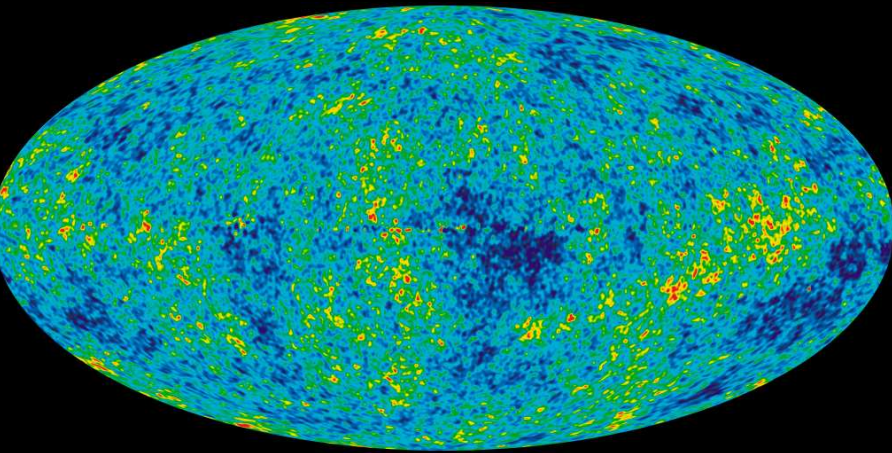
Present content of the Universe

radiation	$p \approx \frac{\rho}{3}$	negligible
luminous matter	$p \approx 0$	4 %
(stars		0.5%
interstellar gas		0.5%
intergalactic gas		3%)
dark matter	$p \approx 0$	23 %
dark energy	$p \approx -\rho$	73 %

Nucleosynthesis abundances



WMAP



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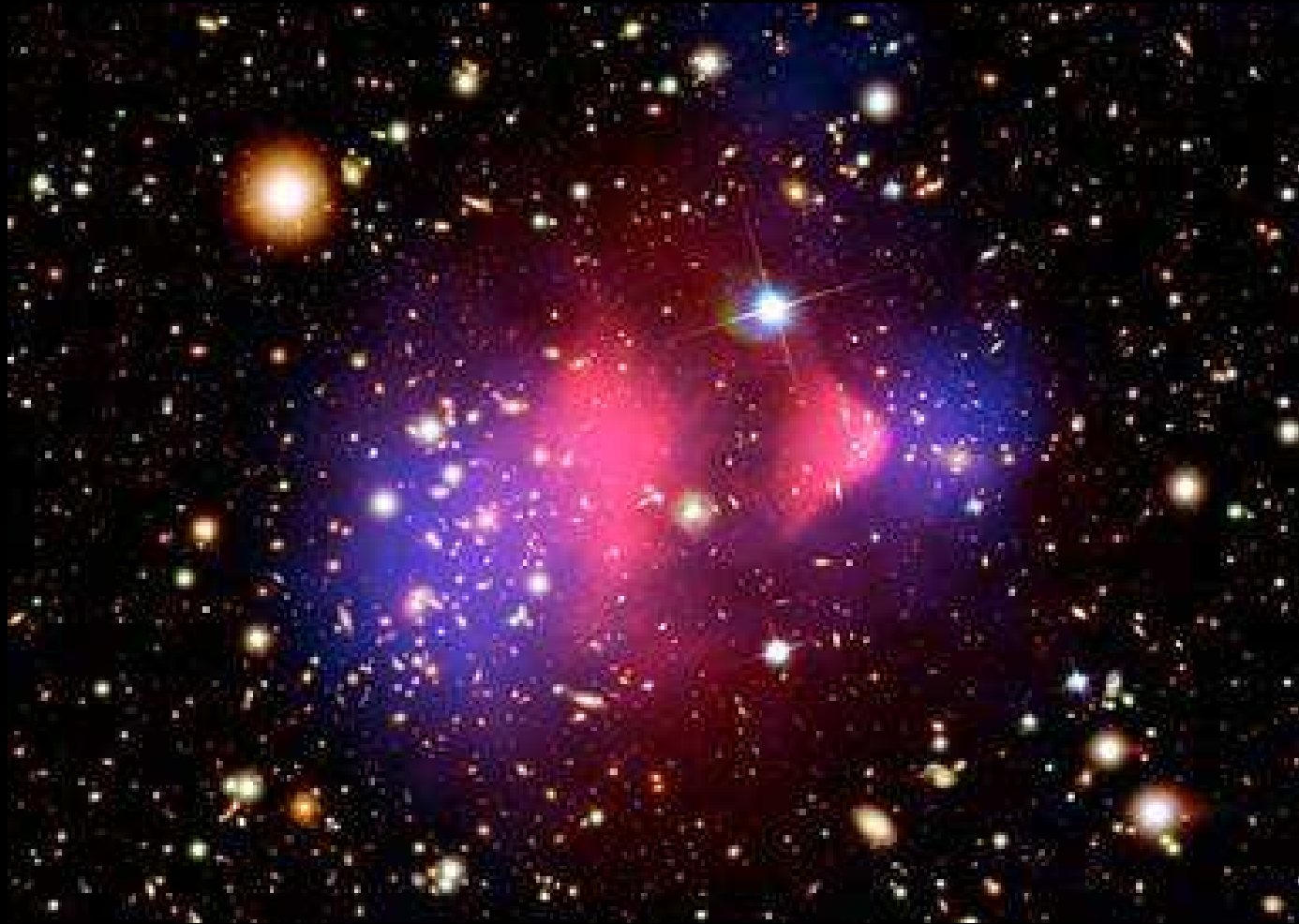
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$$\frac{\rho_{DM}}{M_P^4} \approx 10^{-120}, \quad \frac{\rho_{DM}}{M_W^4} \approx 10^{-54}$$

- the answer probably requires new (not QFT like) physics – quantum gravity?

Galaxy collision



Gravity

- gravitational interaction between elementary particles is extremely weak – why???

$$\alpha_G = \frac{Gm_p^2}{\hbar c} \approx 10^{-38}$$

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- α_G is so small \Rightarrow stars are so large

$$M_C \approx \frac{m_p}{\alpha_G^{3/2}} \approx 10^{30} \text{ kg}$$

(Chandrasekhar limit)

Quantum Gravity

- when gravity \approx EM? (G. Stoney, 1881)

$$\frac{Gm_S^2}{r^2} = \frac{e^2}{4\pi\epsilon_0 r^2} \Rightarrow m_S \approx 1.86 \cdot 10^{-9} \text{ kg}$$

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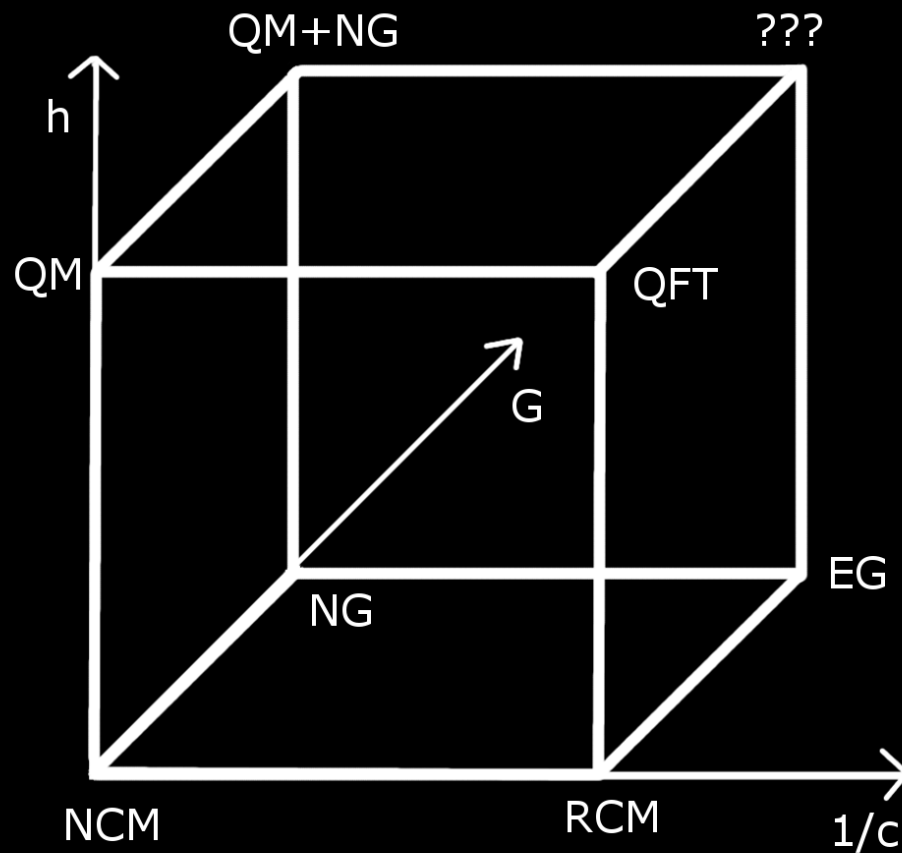
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- black hole entropy may be the key issue pointing to QG (as black body radiation did)

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- String Theory
- Loop Quantum Gravity
 - both claim solving BH entropy problem
 - neither solved the CC problem
 - nor the initial singularity and initial conditions problems ...

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- no single new result relevant for “low energy” particle physics or cosmology

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- we are still very far away from understanding quantum gravity

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 - cosmological constant and quantum gravity
- the biggest (meta-physical) mystery: why anything is subject to any law at all?
- Socrates' statement invariably true: "I neither know nor think that I know"