Is Our Universe a Hologram?



Andy O'Bannon

SUNY OLD WESTBURY

COSMIC PATHWAYS

Adelphi University

November 7, 2026

My Research

I use a tool from STRING THEORY

called HOLOGRAPHY

to study STRONGLY-INTERACTING SYSTEMS.

Outline

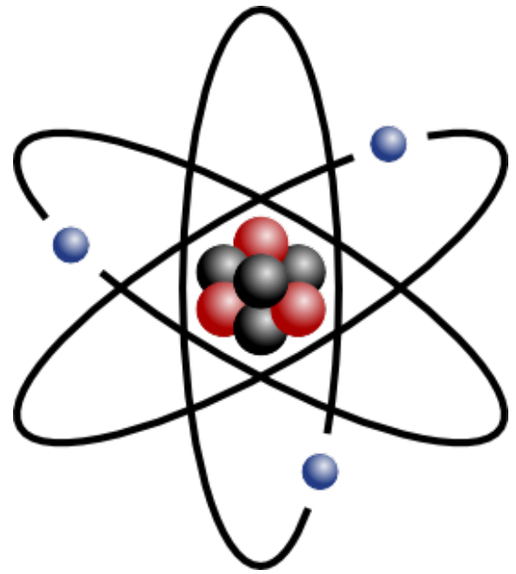
- String Theory
- Holography
- Strongly-Interacting Systems

Outline

- String Theory
- Holography
- Strongly-Interacting Systems

The Major Achievements of 20th Century Physics

Quantum Mechanics



Einstein's Relativity



Quantum Mechanics

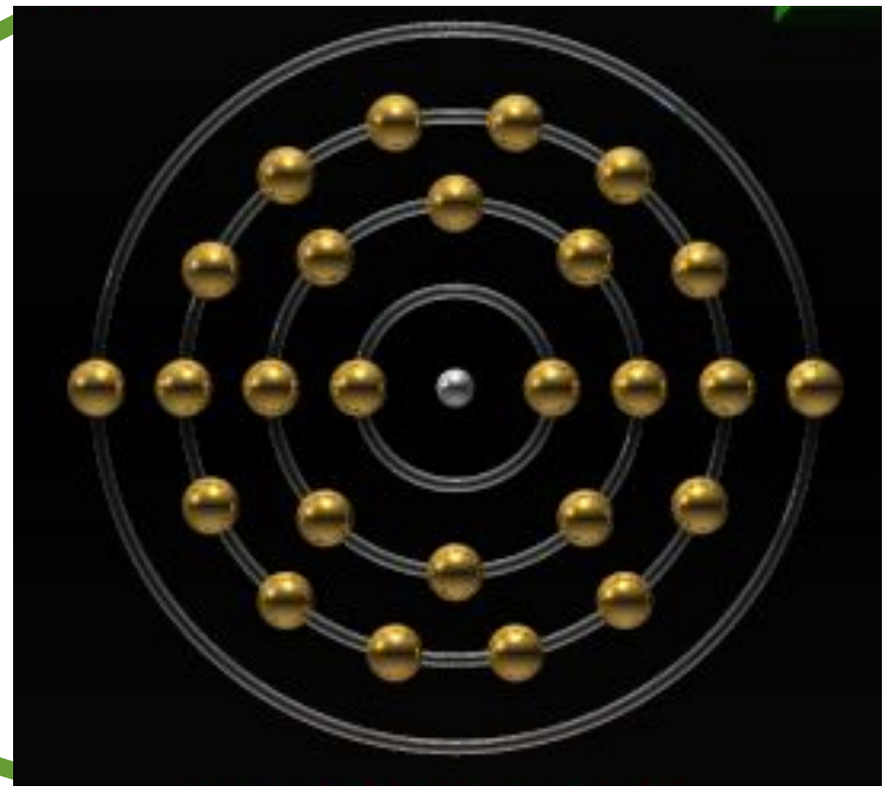
Describes the VERY SMALL

Iron skillet



about 30 cm

Iron atom



about 10^{-8} cm

Scientific Notation

Big Numbers

$10^2 = 10 \times 10 = 100$ hundred

$10^3 = 10 \times 10 \times 10 = 1{,}000$ thousand

$10^4 = 10{,}000$ ten thousand

$\vdots$ $\vdots$

$10^9 = 1{,}000{,}000{,}000$ billion

Scientific Notation

Small Numbers

$$10^{-2} = \frac{1}{100} = 0.01$$ one hundredth

$$10^{-3} = \frac{1}{1{,}000} = 0.001$$ one thousandth

$$10^{-4} = 0.0001$$ one ten thousandth

$$\vdots$$

$$10^{-9} = 0.000000001$$ one billionth

Quantum Mechanics

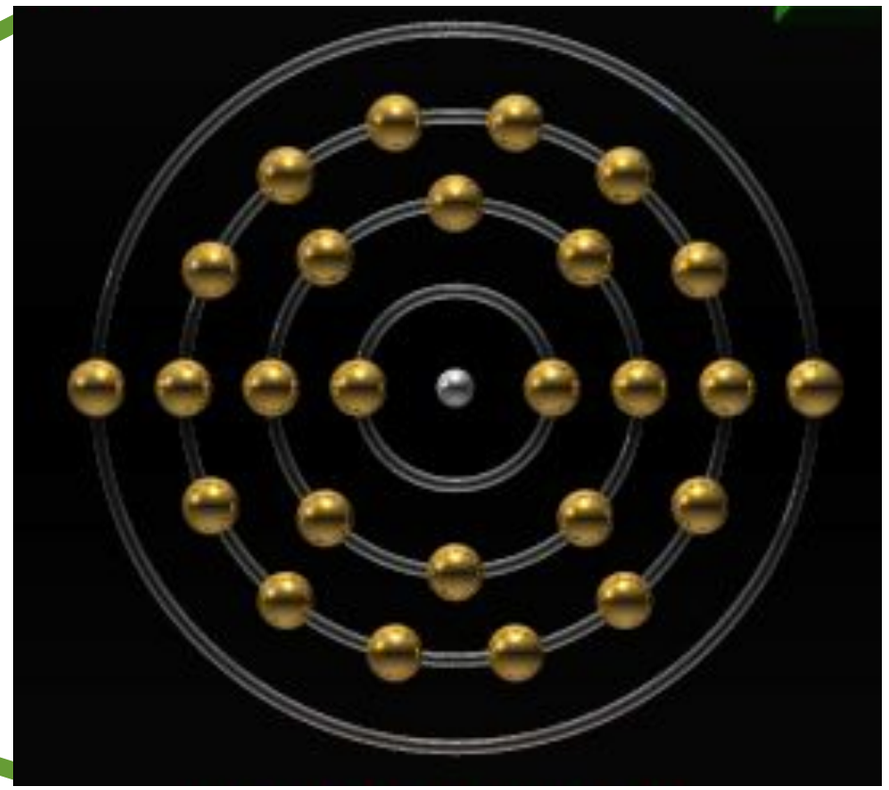
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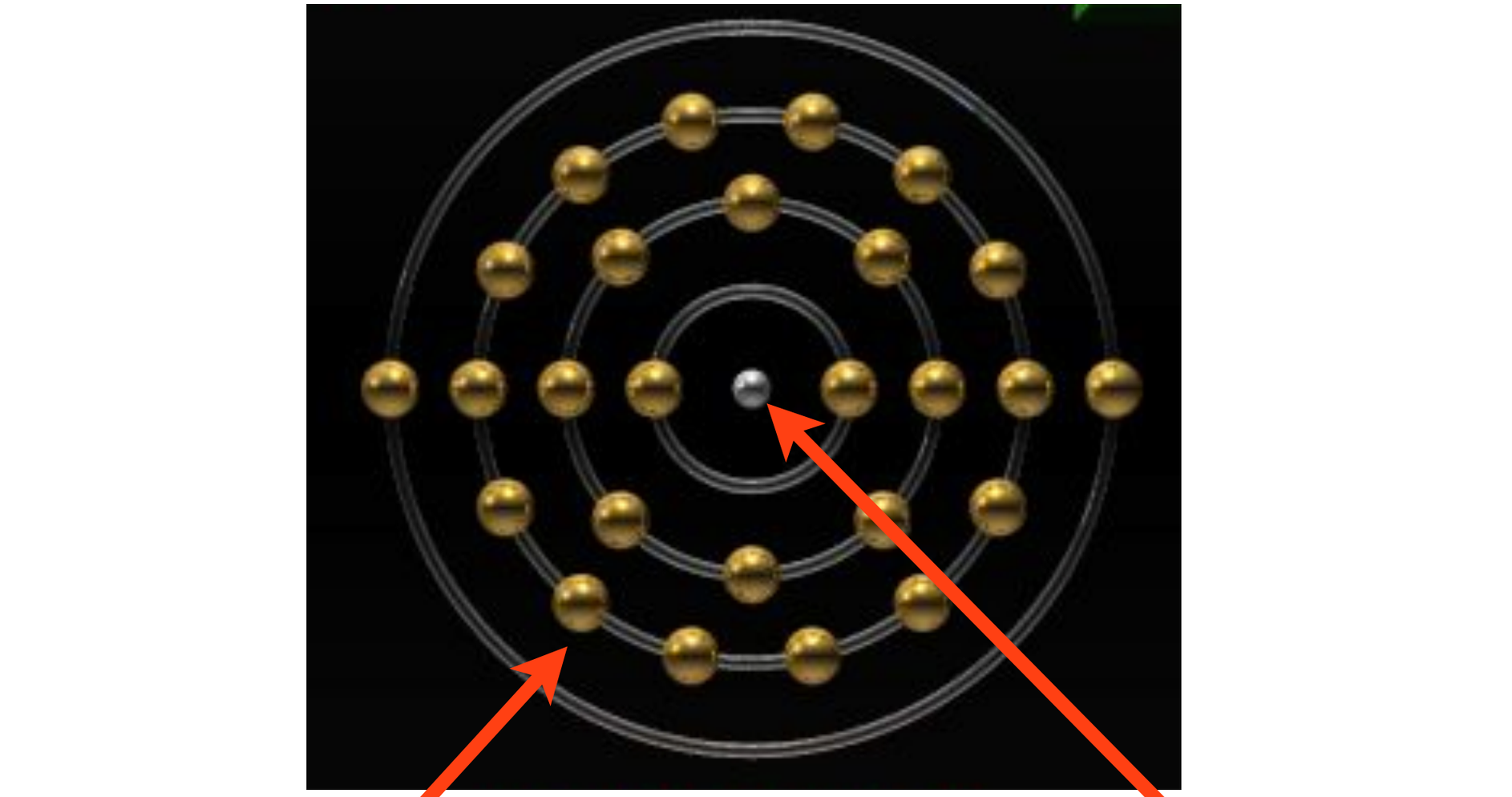


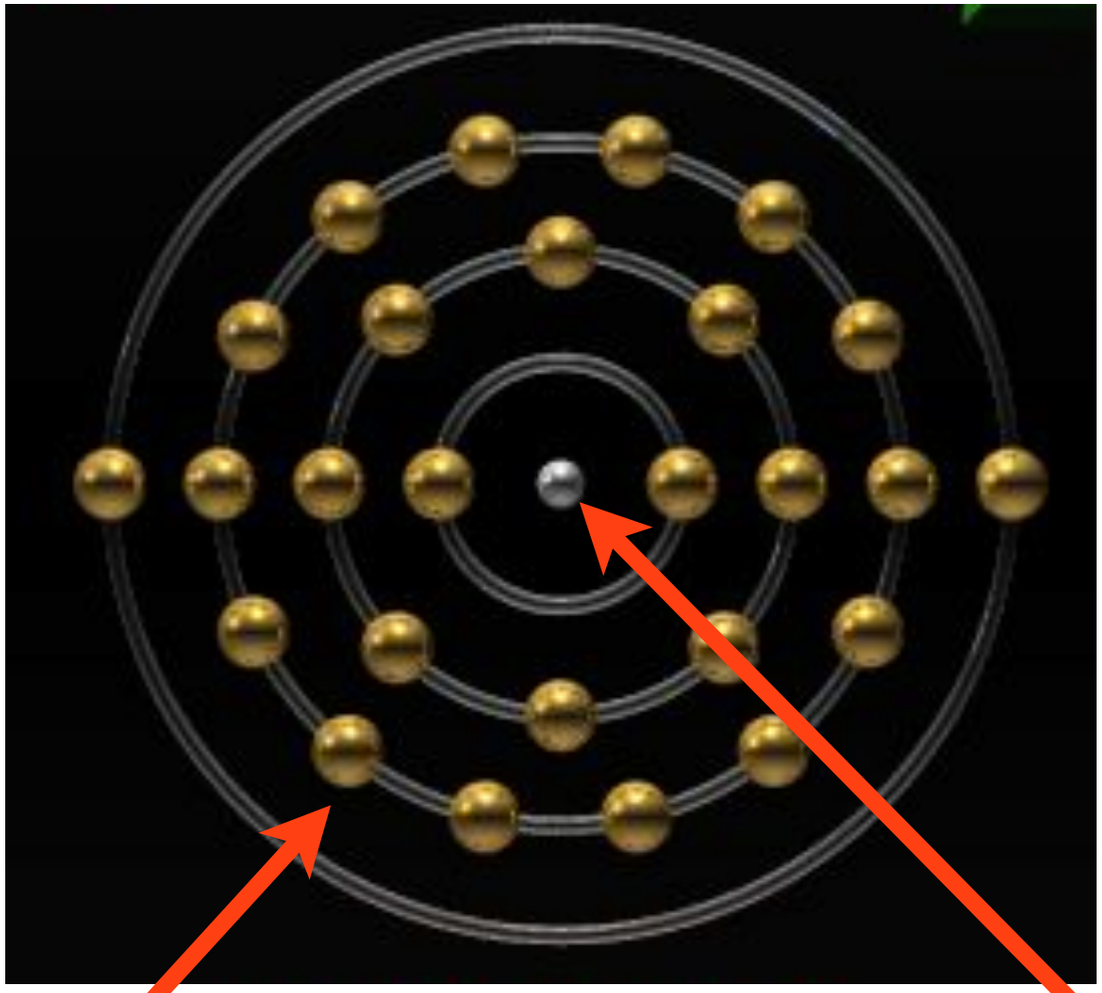
about 30 cm

Iron atom



about 10^{-8} cm


electrons
nucleus



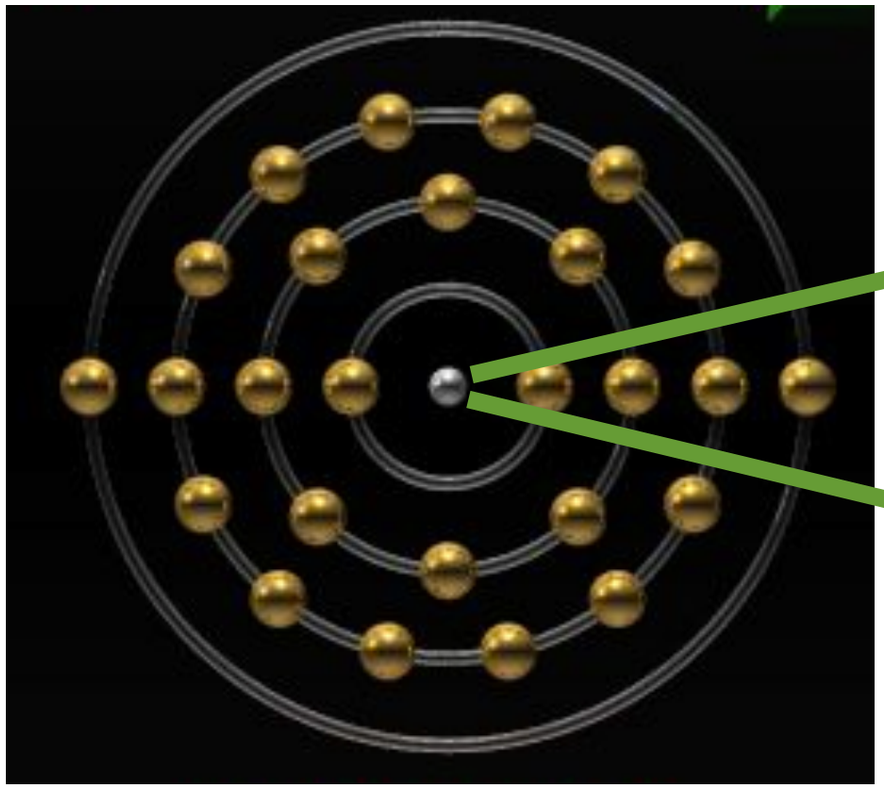
electrons

nucleus

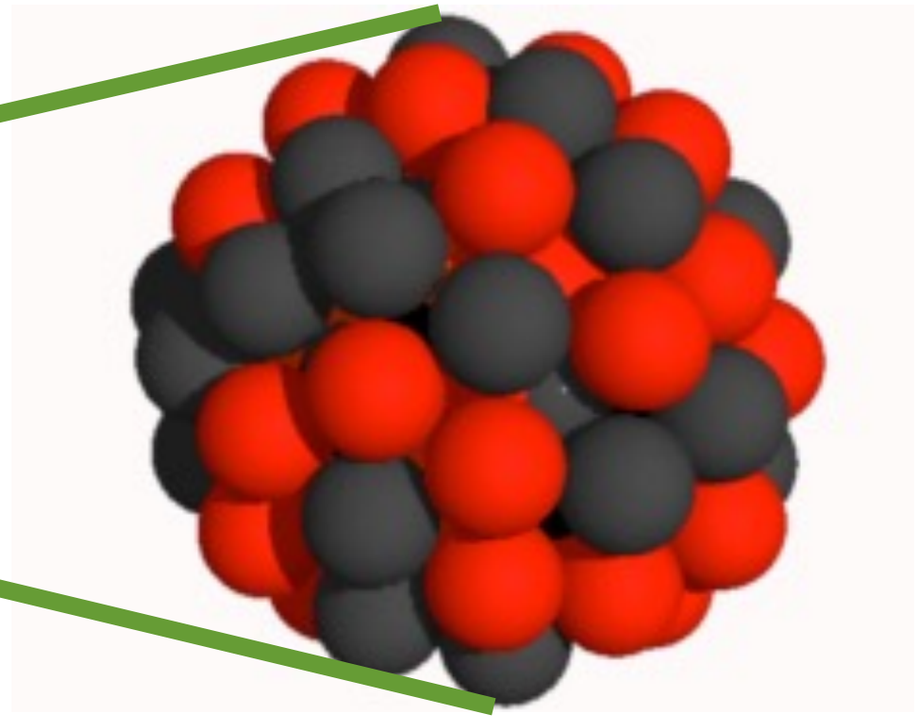
As far as we know, electrons are fundamental particles.

Atom

Nucleus





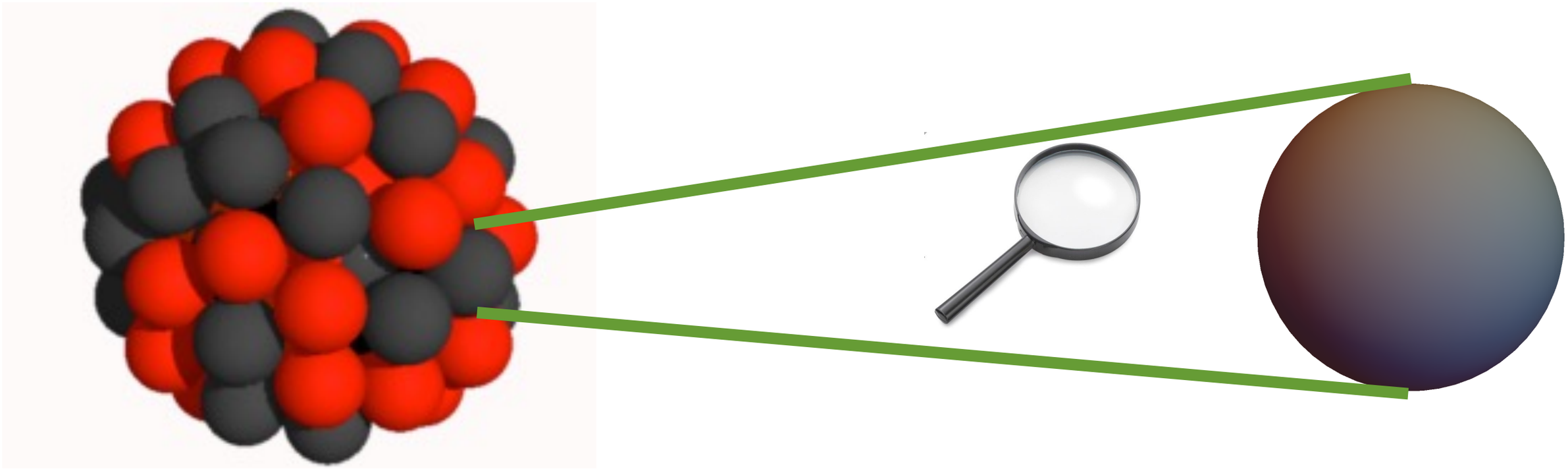


about 10^{-8} cm

about 10^{-12} cm

Nucleus

Protons and Neutrons



about $10^{-12}\,\mathrm{cm}$

about $10^{-13}\,\mathrm{cm}$

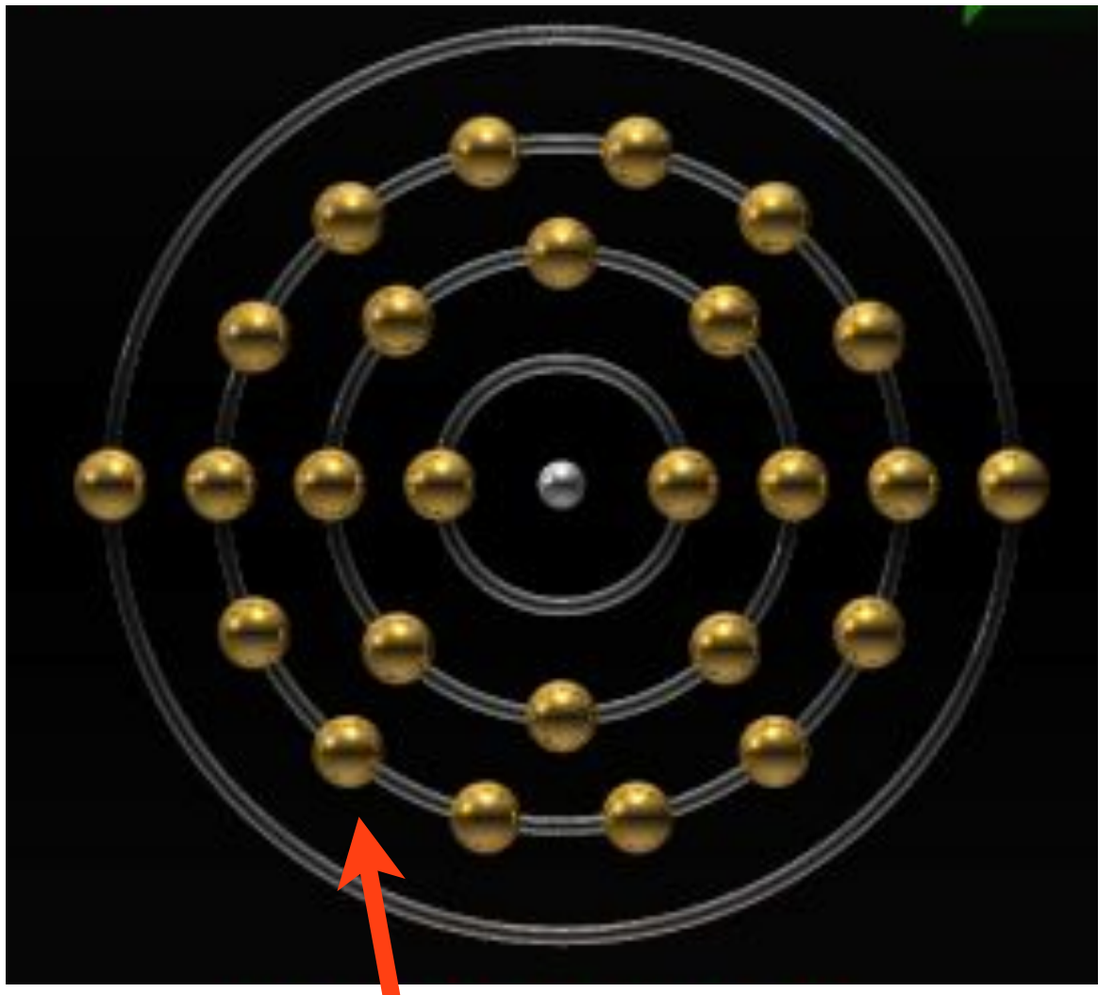
Protons and Neutrons

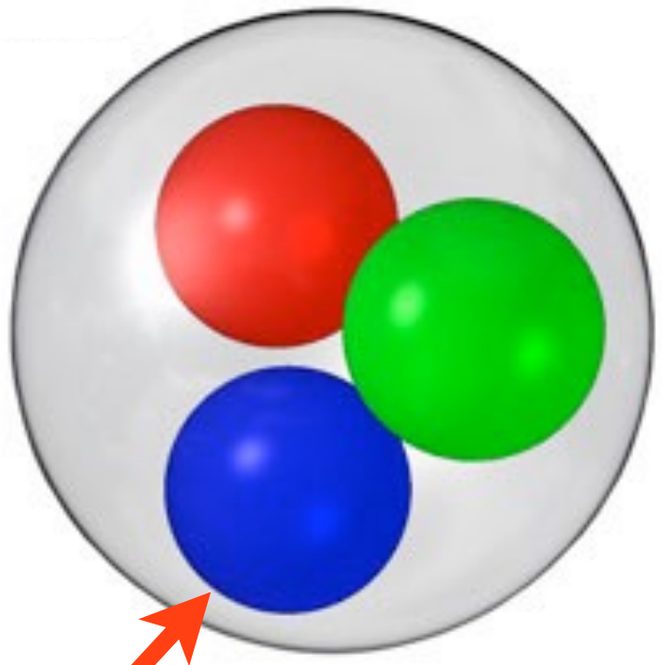
Quarks



about $10^{-13}\,\mathrm{cm}$

smaller than $10^{-13}\,\mathrm{cm}$





As far as we know,
electrons and quarks are fundamental particles.

The Standard Model of Particle Physics

Developed in the 1950s-1970s



Feynman



Gell-Mann



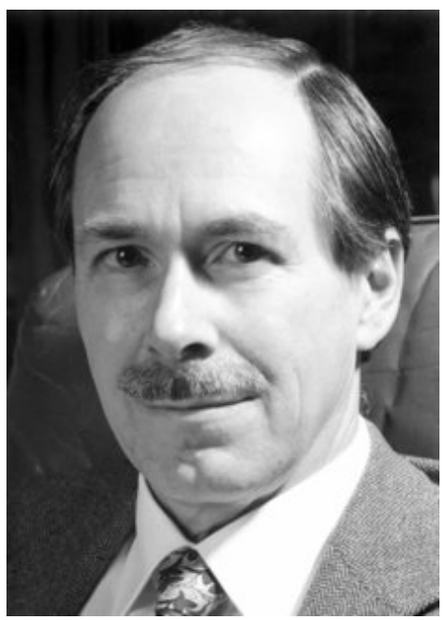
Glashow



Salam



Schwinger



't Hooft



Tomonaga



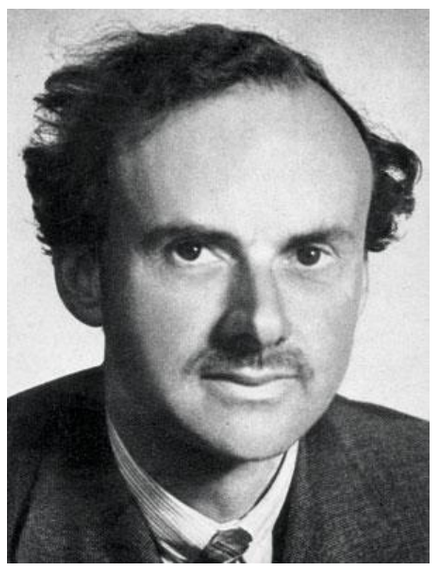
Weinberg

Quantum Mechanics

Developed in the 1920s-1930s



Bohr



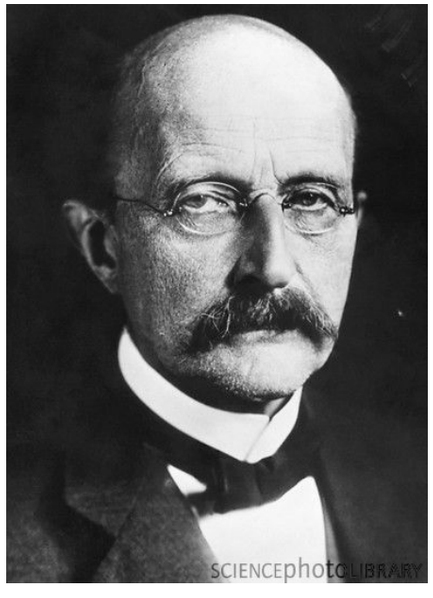
Dirac



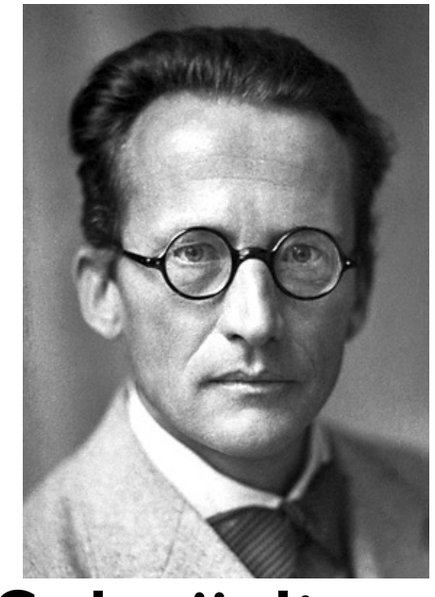
Heisenberg



Pauli

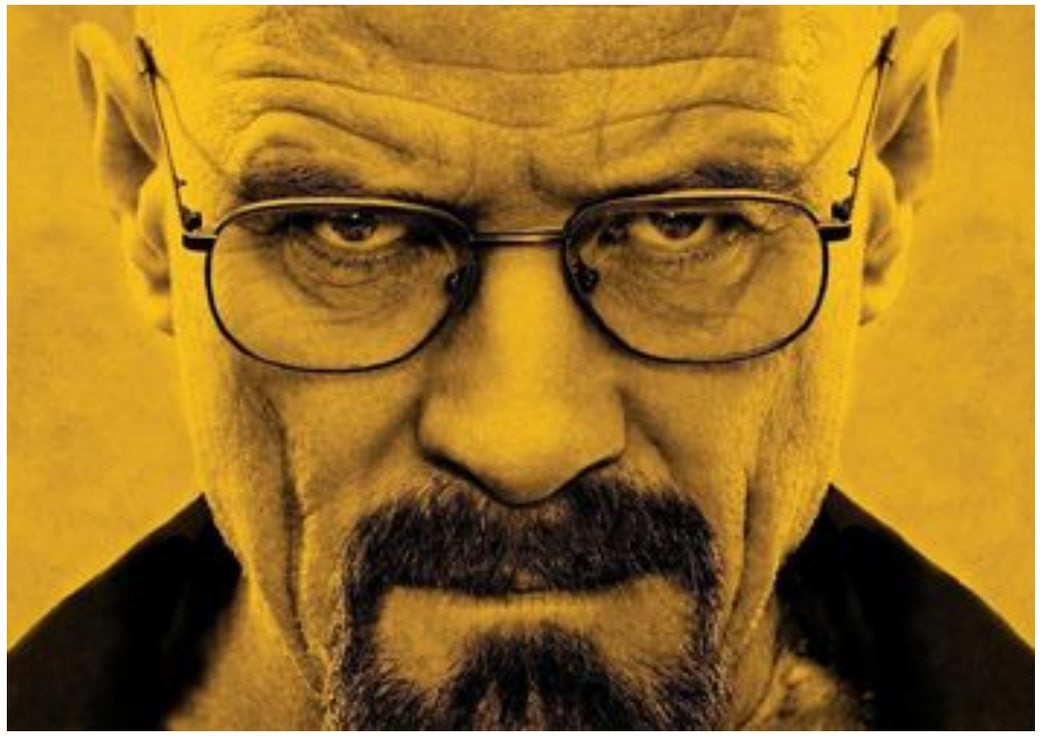


Planck



Schrödinger

Quantum Mechanics



Heisenberg



Heisenberg

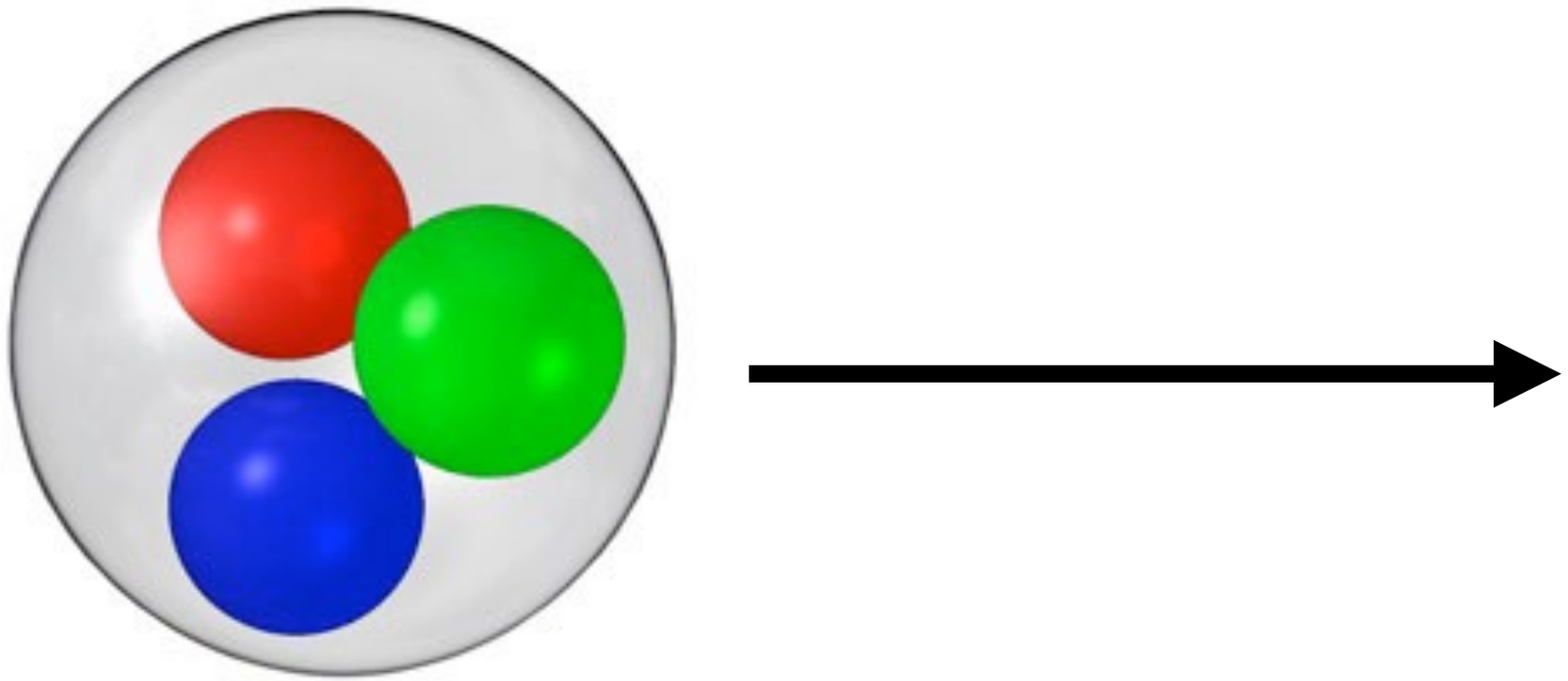
My 1st physics job

Werner Heisenberg Institute
Munich, Germany





Heisenberg Uncertainty Principle



The MORE precisely a particle's POSITION is determined,
the LESS precisely its MOMENTUM can be determined,
and vice versa

Heisenberg Uncertainty Principle

Quantum Mechanics

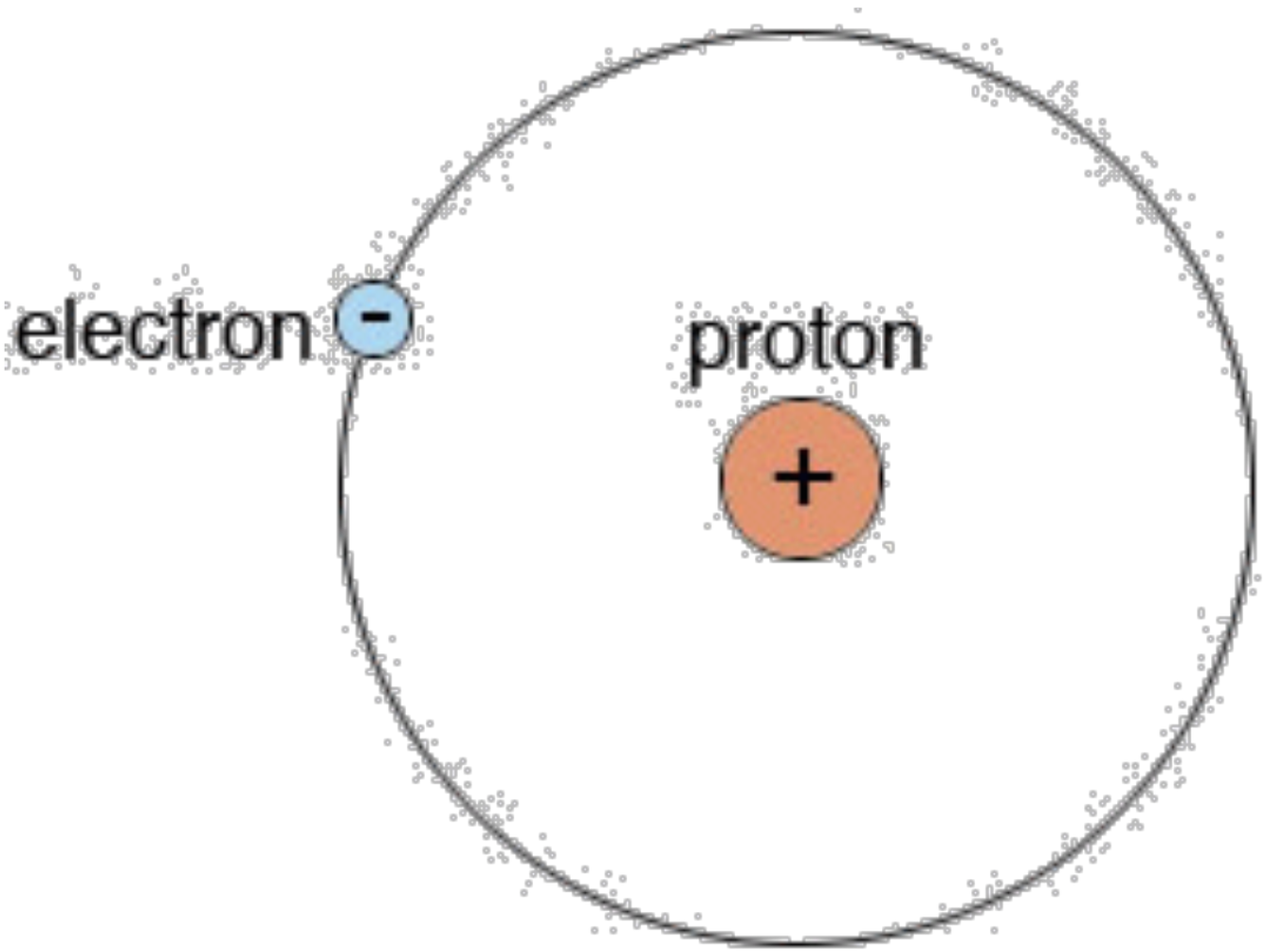
is

PROBABILISTIC

Outcome #1	20%
Outcome #2	15%
Outcome #3	10%
⋮	⋮

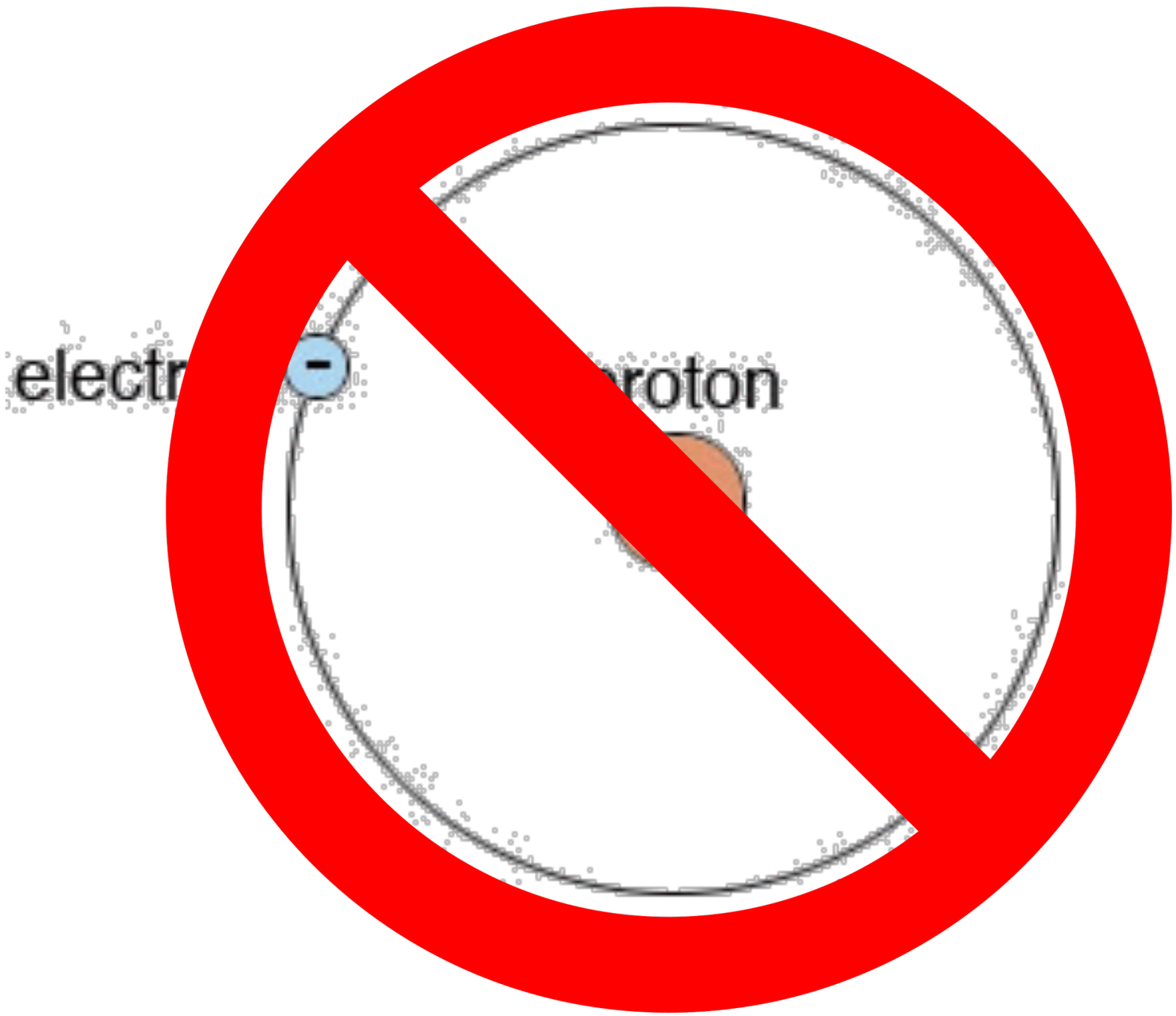
Heisenberg Uncertainty Principle

Hydrogen Atom



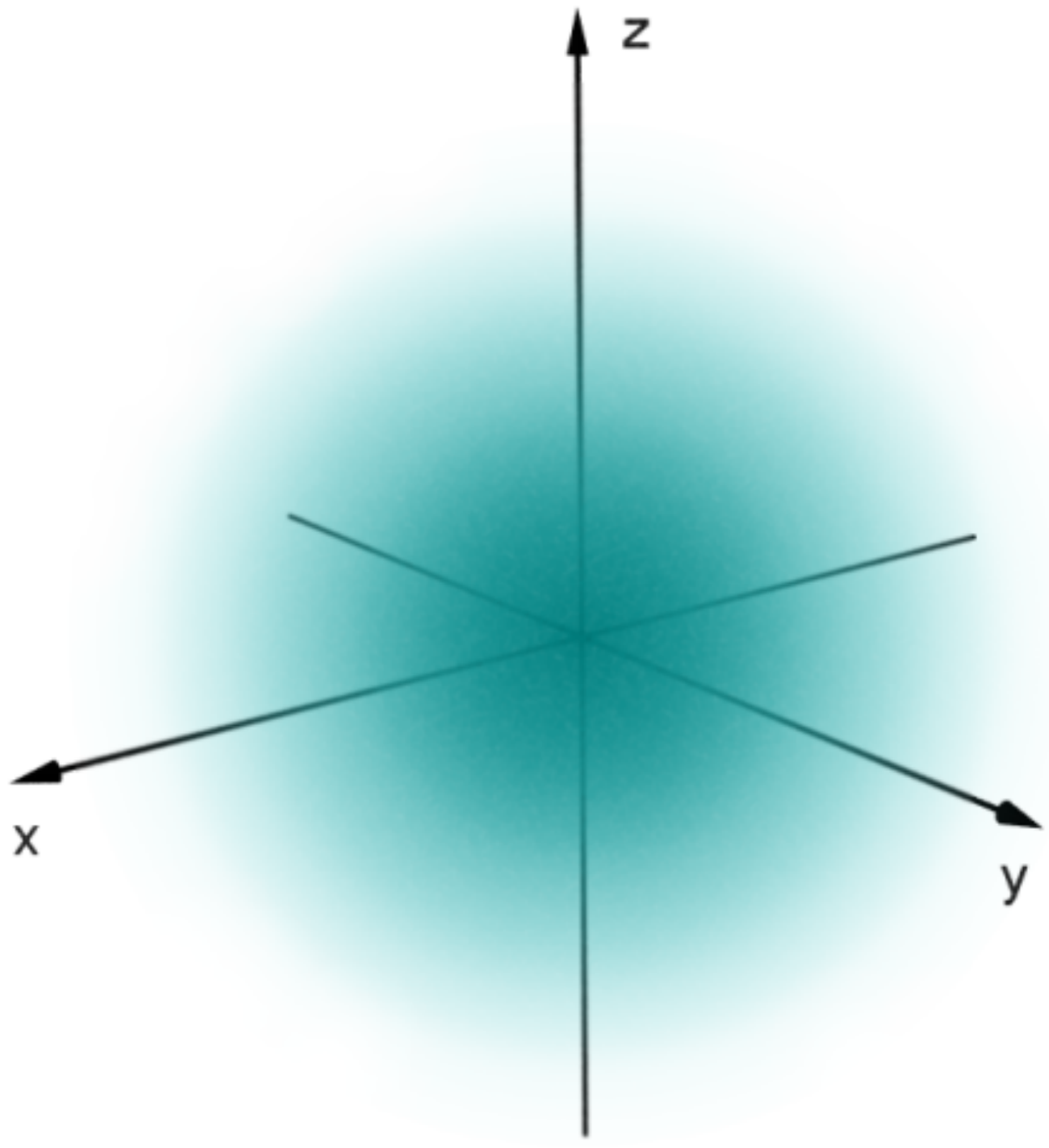
Heisenberg Uncertainty Principle

Hydrogen Atom



Heisenberg Uncertainty Principle

Hydrogen Atom



The Standard Model of Particle Physics

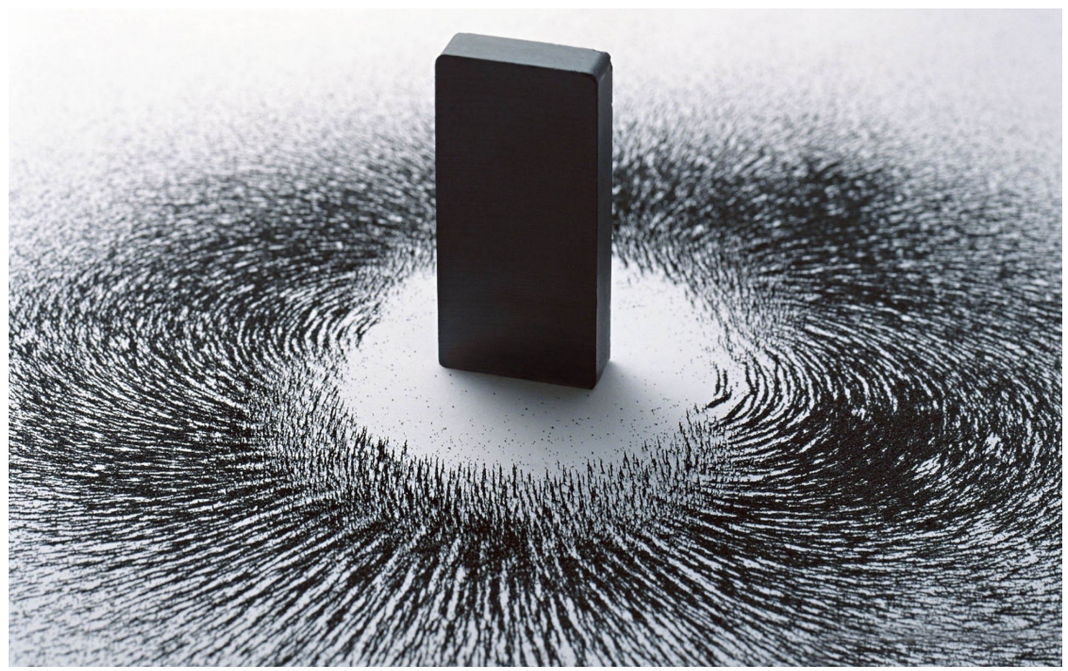
describes

Electricity and Magnetism









The Standard Model of Particle Physics

describes

Atomic Physics

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

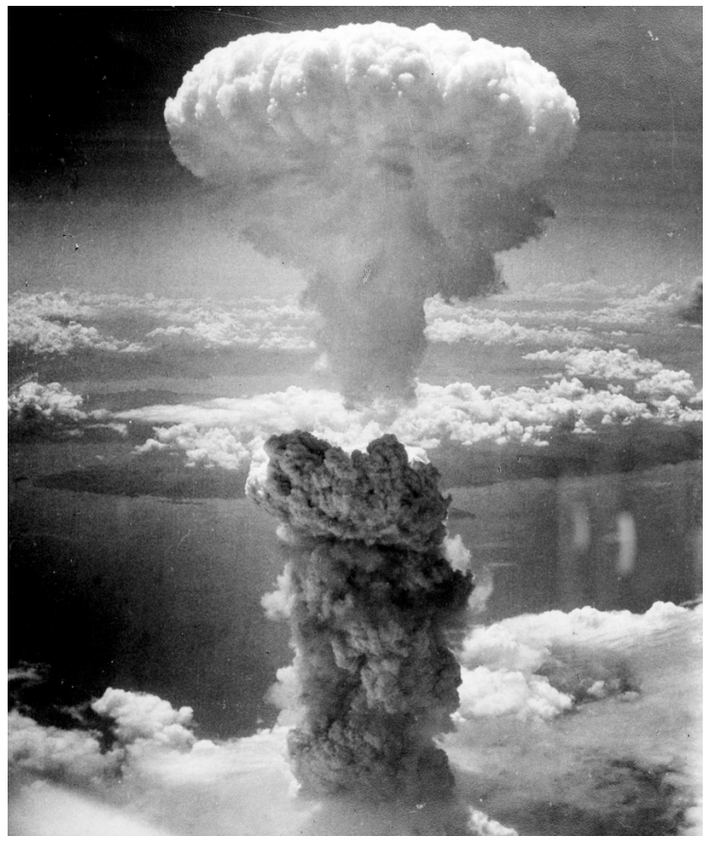
The Standard Model of Particle Physics

describes

Radioactivity and Nuclear Physics



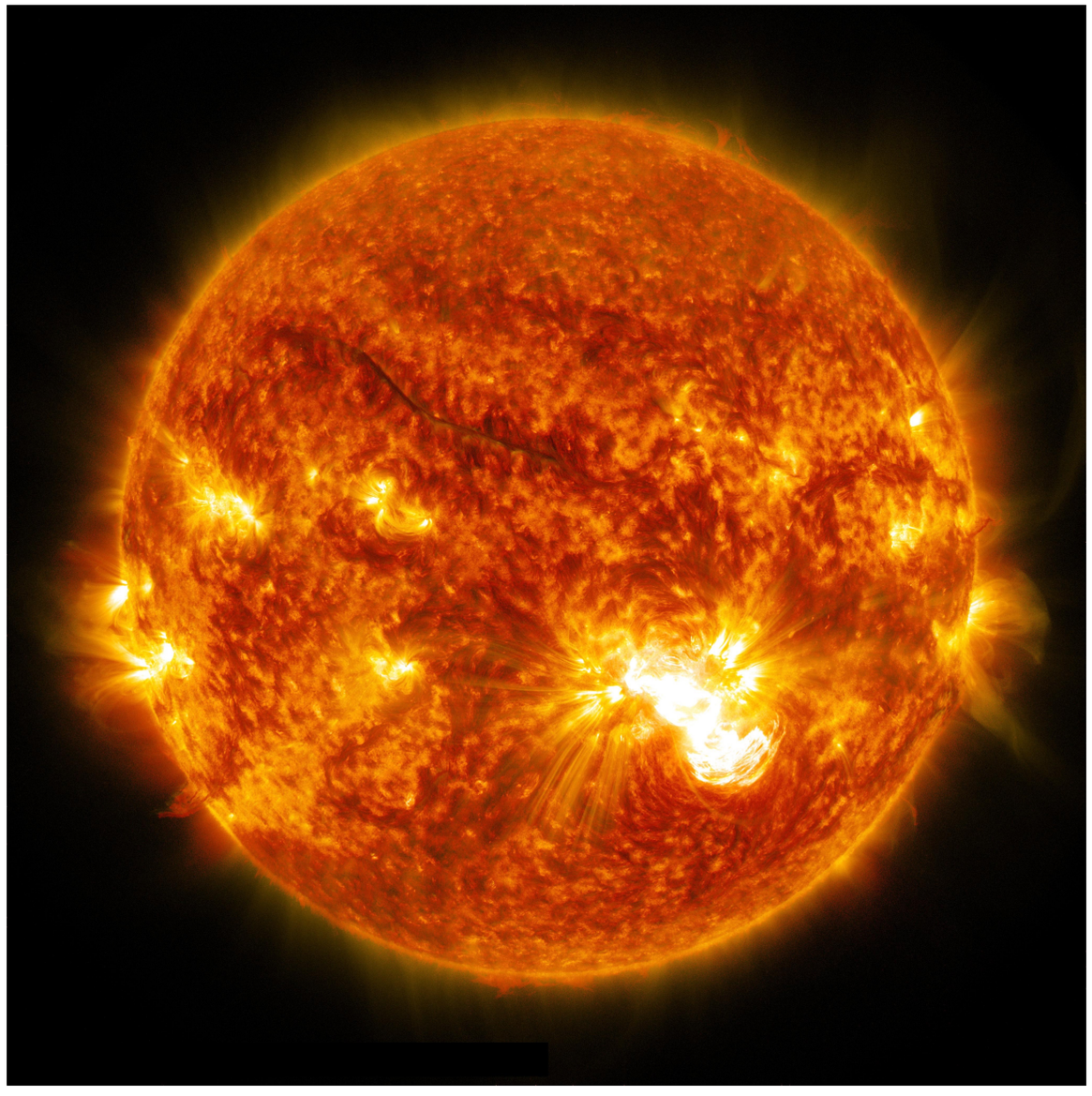




The Standard Model of Particle Physics

describes

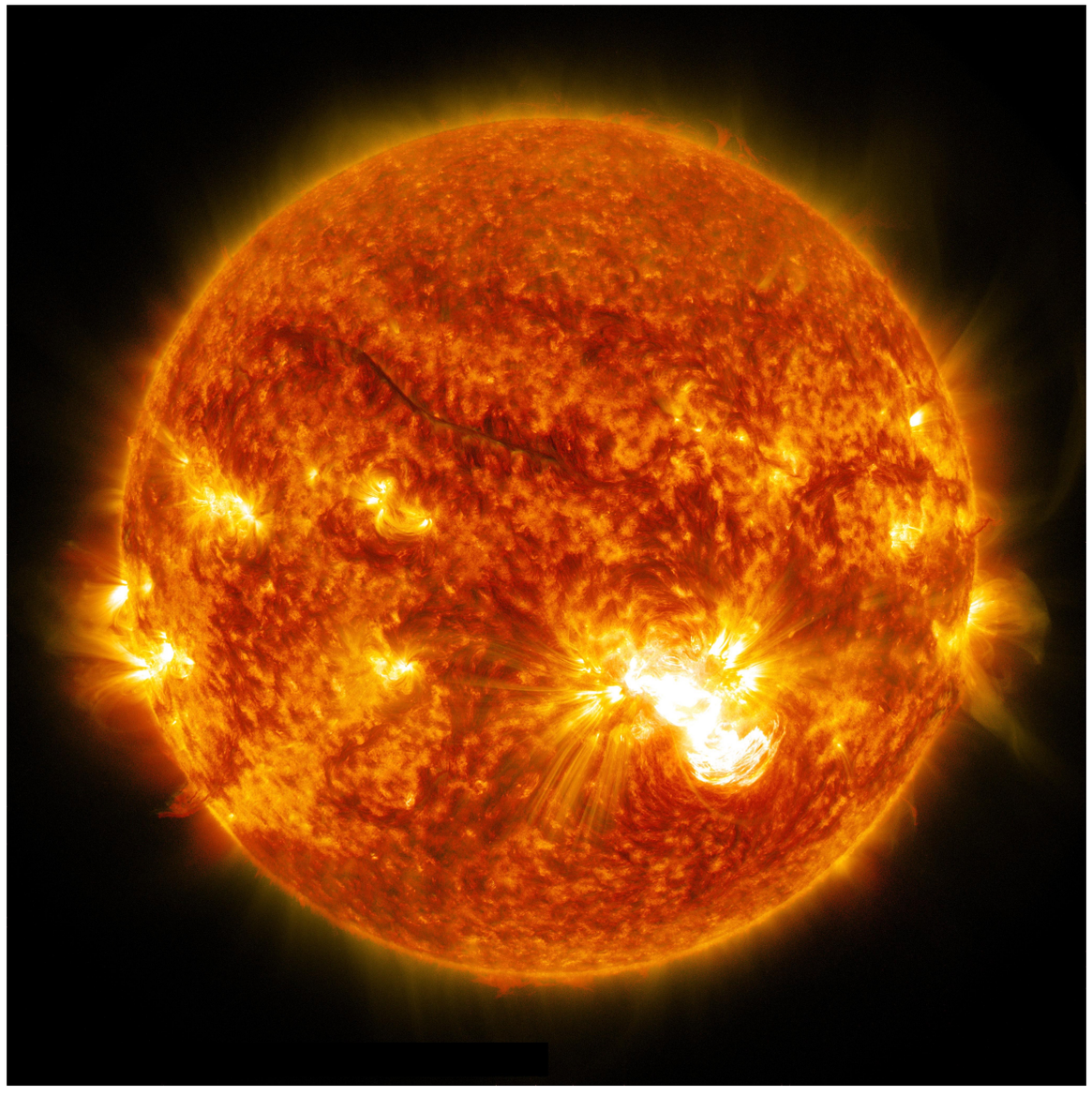
Radioactivity and Nuclear Physics



The Standard Model of Particle Physics

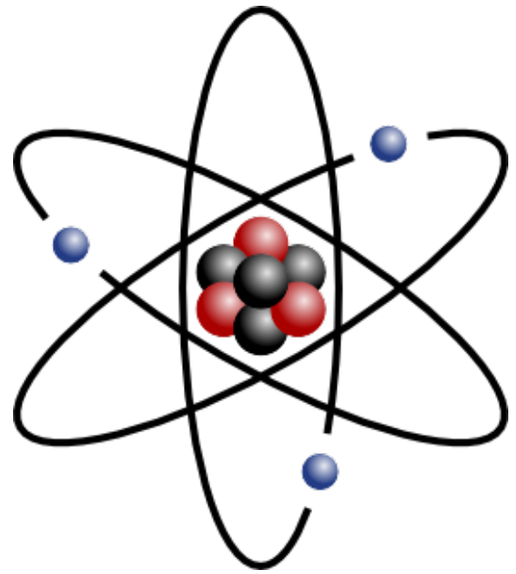
DOES NOT DESCRIBE

GRAVITY



The Major Achievements of 20th Century Physics

Quantum Mechanics

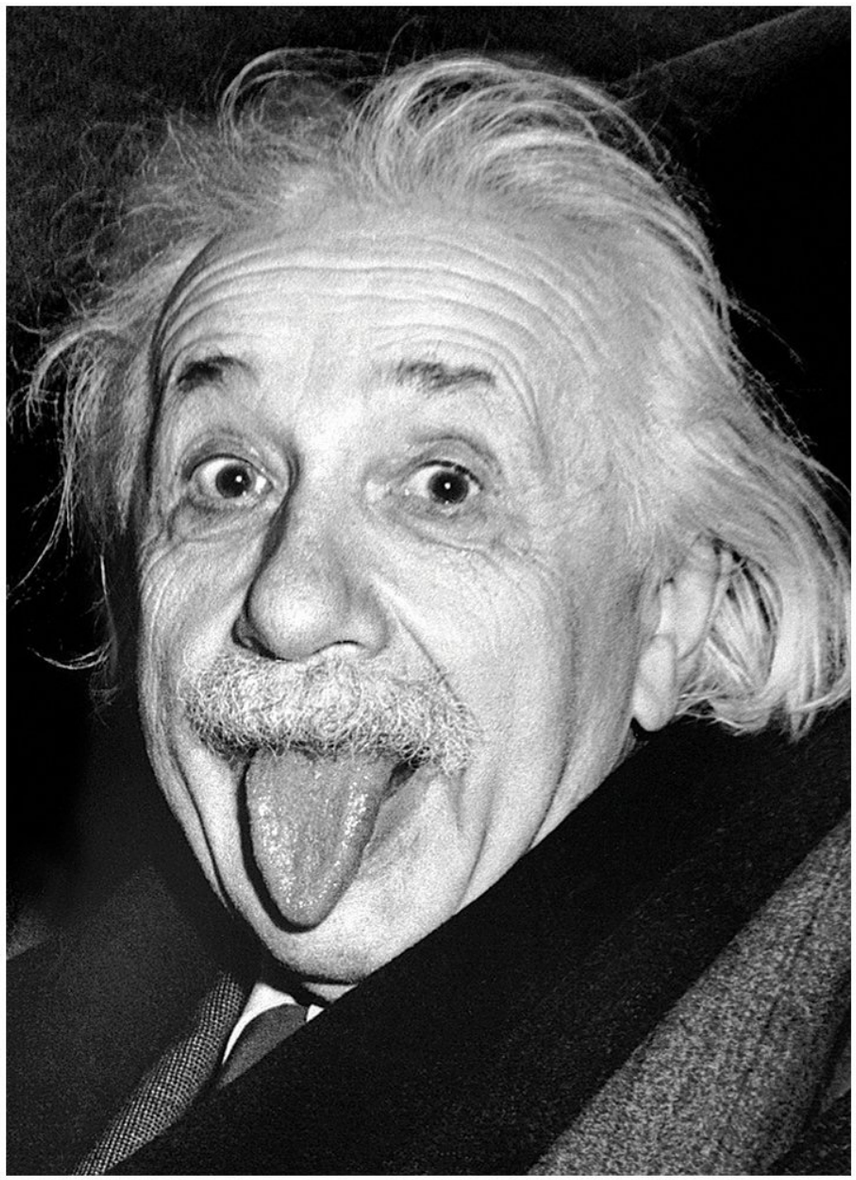


Einstein's Relativity



Einstein's Relativity

Developed in the 1910s-1920s



Einstein

Einstein's Relativity

Space and time are *malleable*

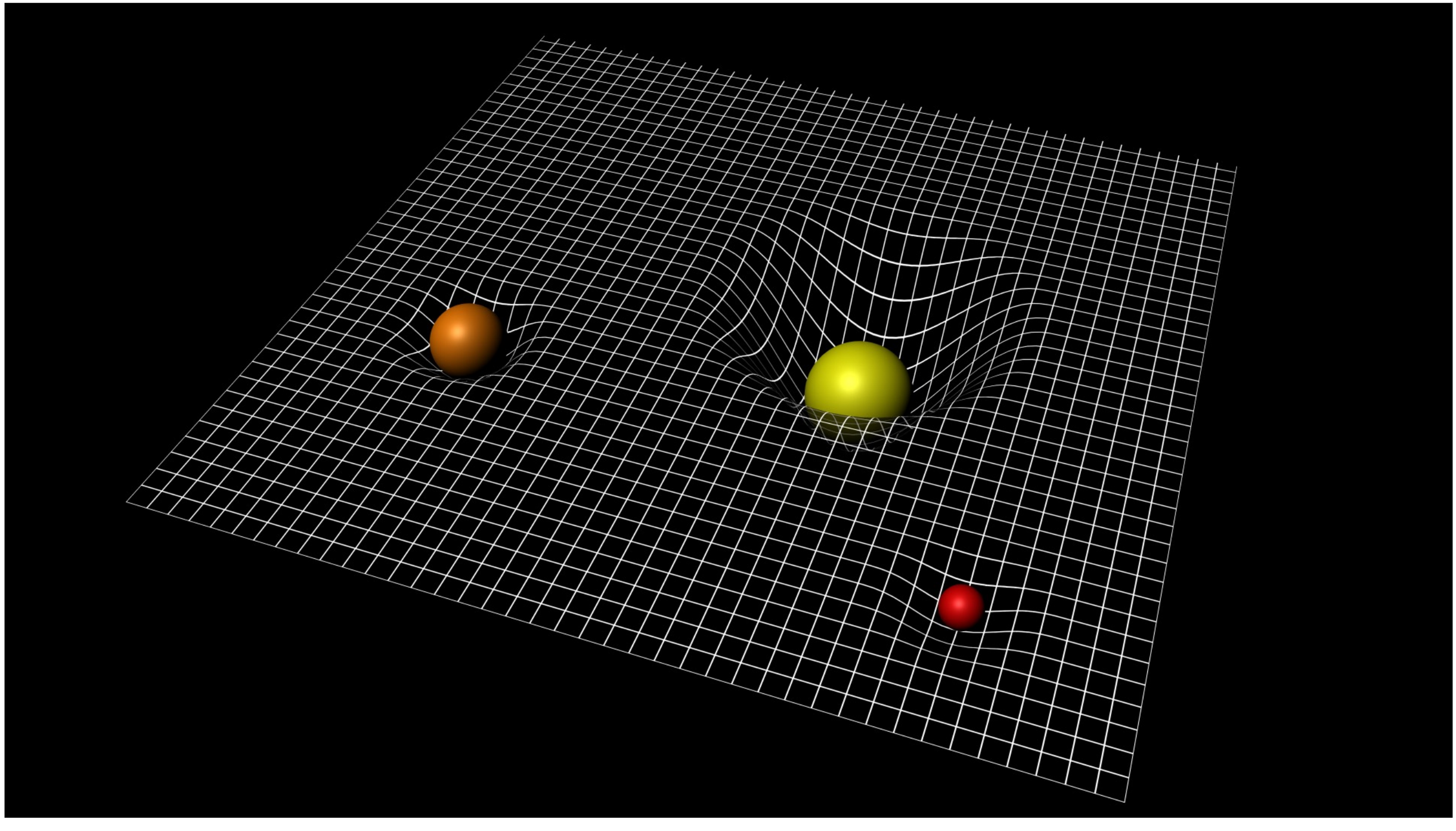






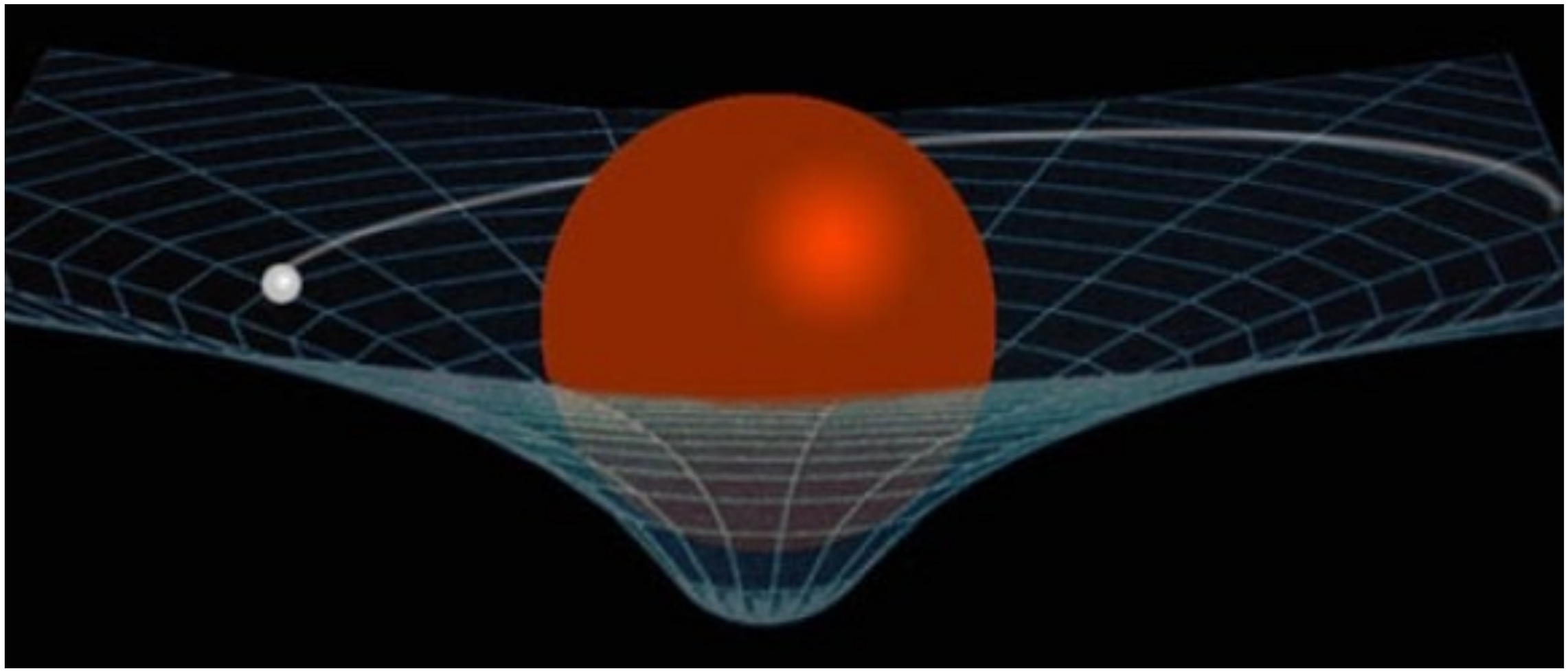
Einstein's Relativity

Space and time are *malleable*



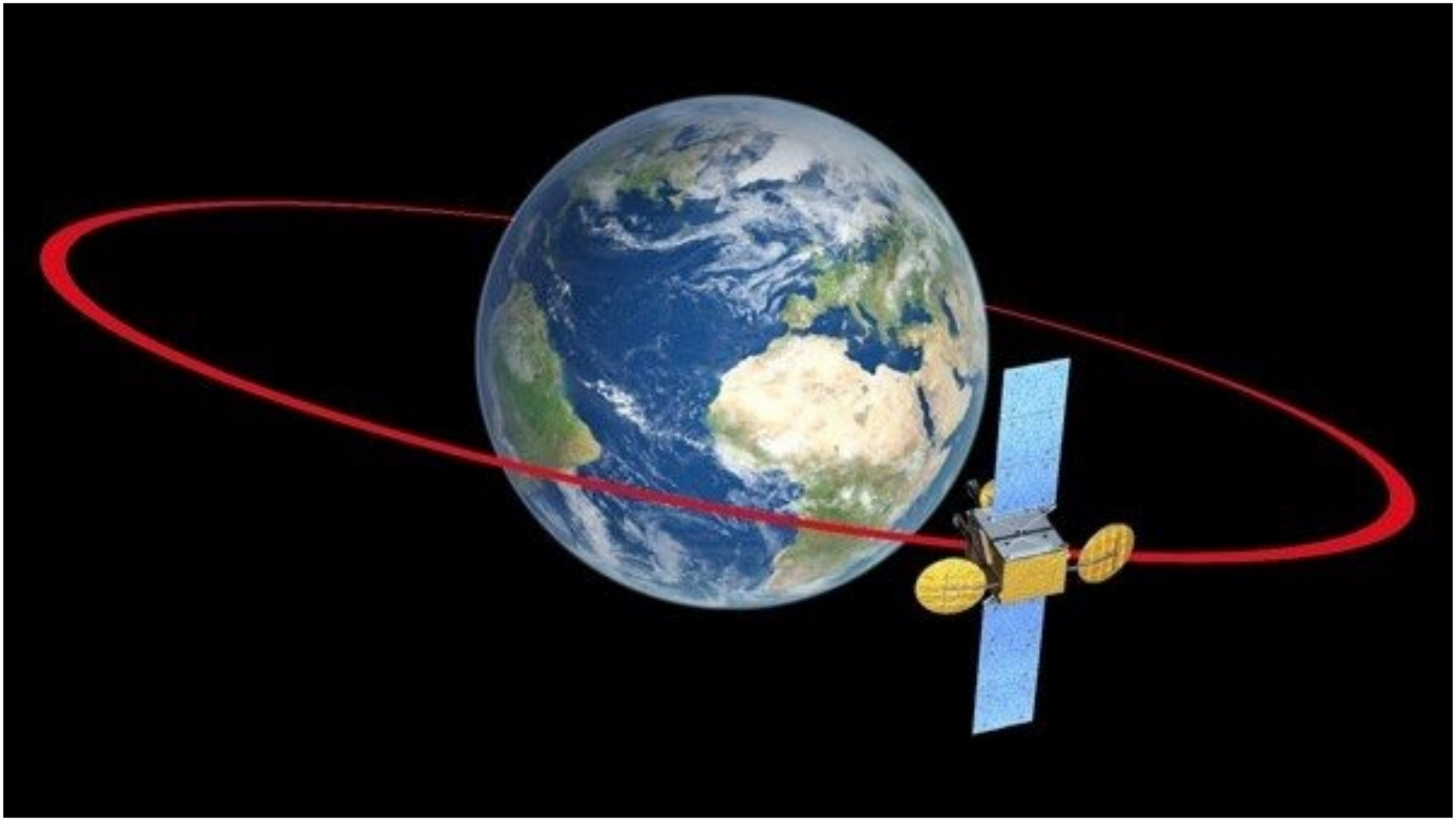
Einstein's Relativity

Space and time are *malleable*



Einstein's Relativity

Describes the VERY BIG



about 30,000 km

Einstein's Relativity

Describes the VERY BIG



about 10^9 km

Einstein's Relativity

Describes the VERY BIG



about 10^{18} km

Einstein's Relativity

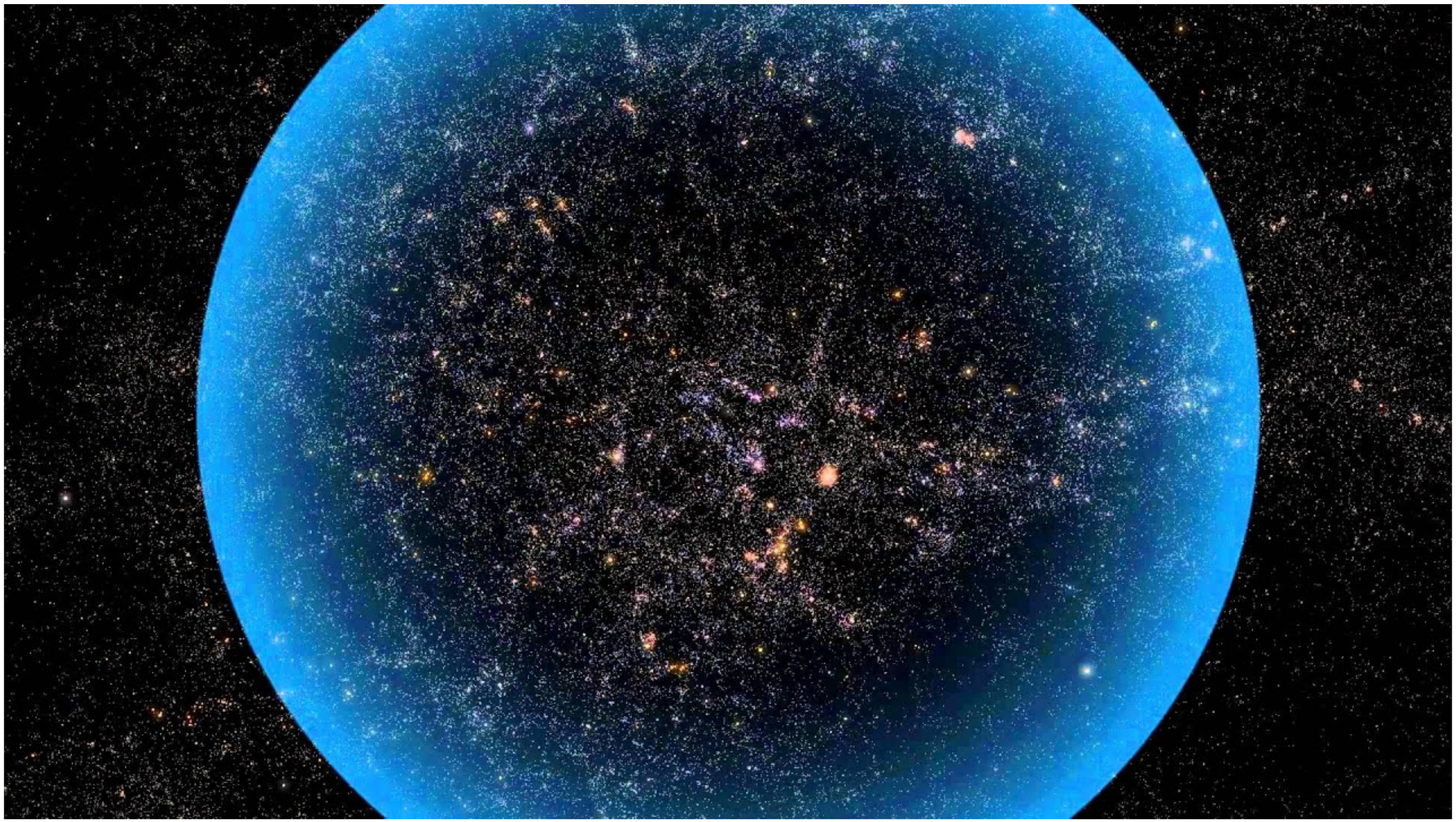
Describes the VERY BIG



about $10^{19} - 10^{23}$ km

Einstein's Relativity

Describes the VERY BIG



about 10^{23} km

Einstein's Relativity

NOT QUANTUM MECHANICAL!

Einstein's Relativity

NOT QUANTUM MECHANICAL!

THAT'S A PROBLEM.

Einstein's Relativity

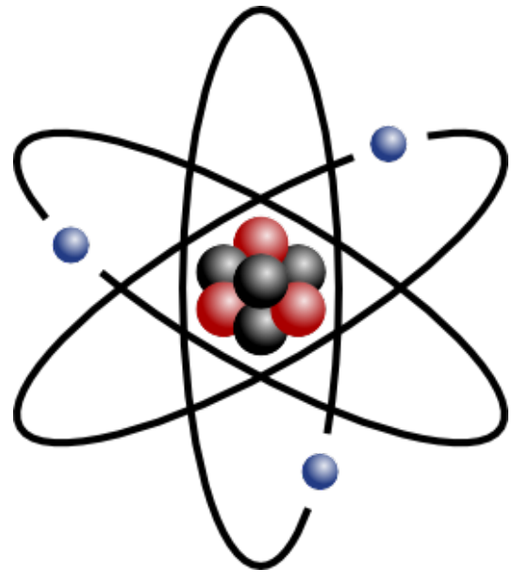
NOT QUANTUM MECHANICAL!

THAT'S A PROBLEM.

THE REAL WORLD HAS BOTH!

The Major Achievements of 20th Century Physics

Quantum Mechanics

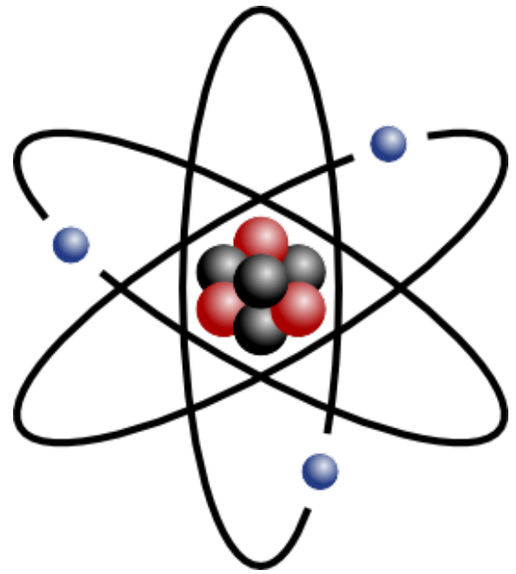


Einstein's Relativity



Usually we can ignore one or the other…

Quantum Mechanics

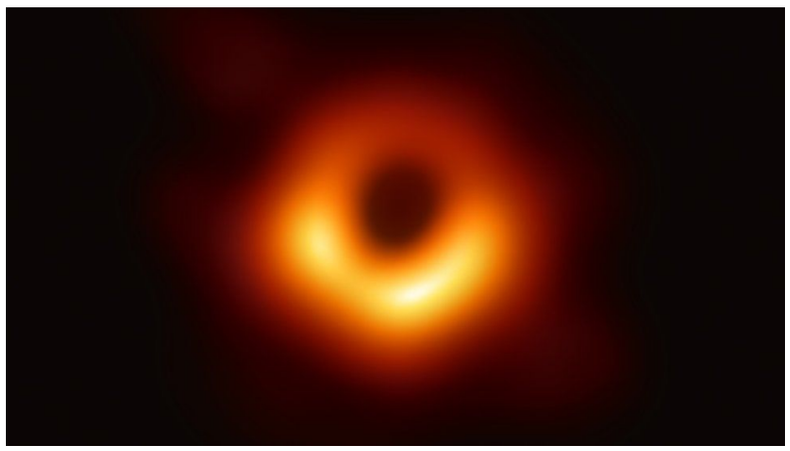


Einstein's Relativity

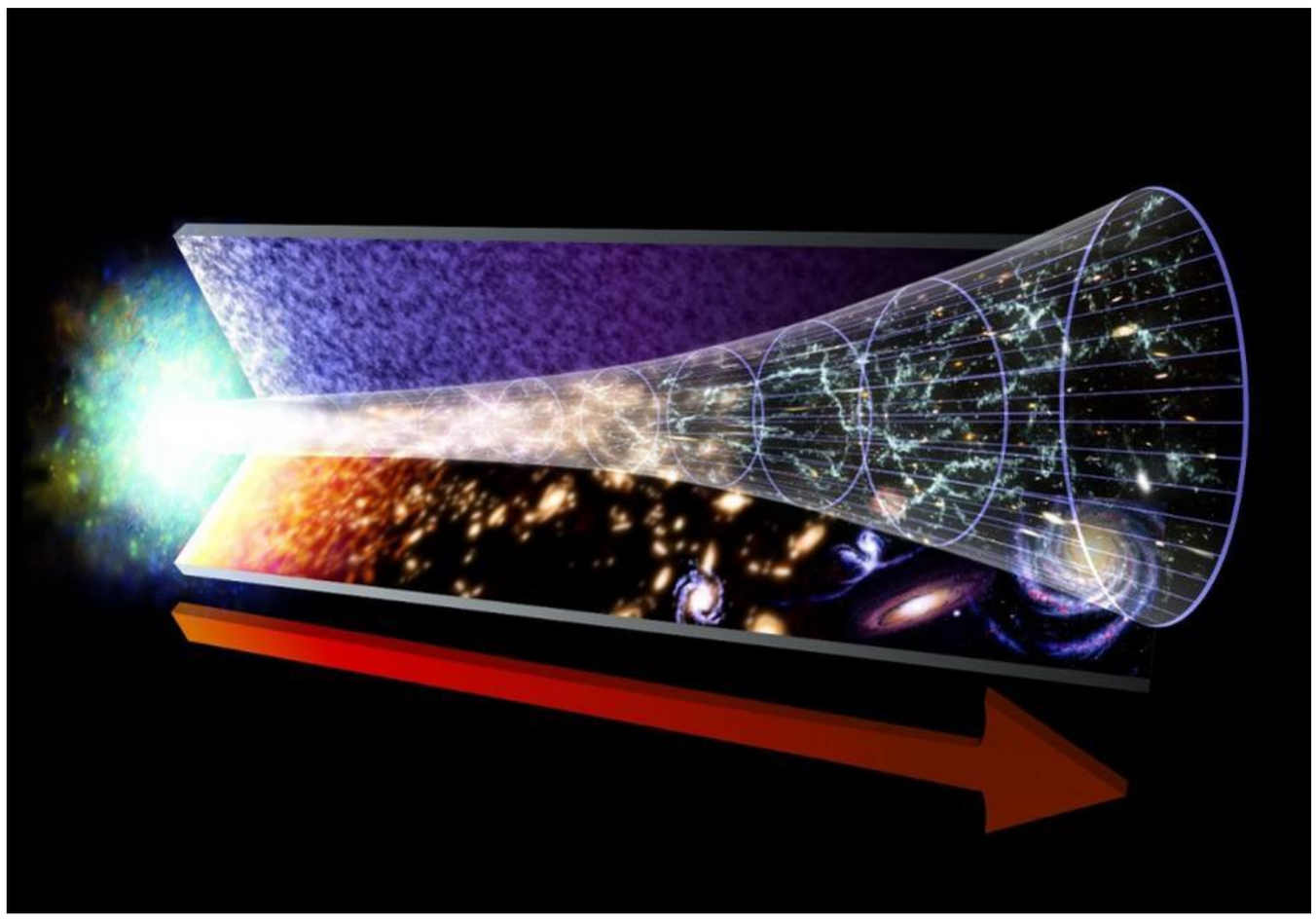


…but sometimes we can't!

Black Holes

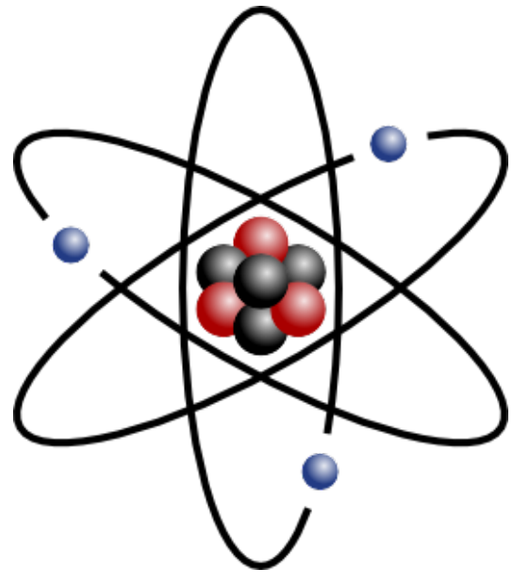


The Big Bang



The Major Achievements of 20th Century Physics

Quantum Mechanics

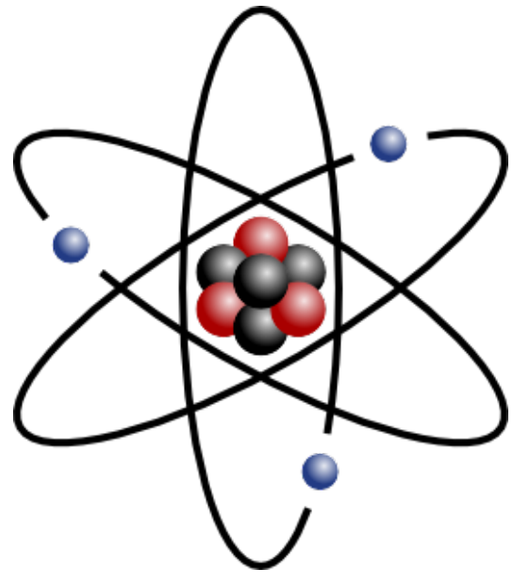


Einstein's Relativity



The Major PROBLEM of 21st Century Physics

Quantum Mechanics



Einstein's Relativity



The Major PROBLEM of 21st Century Physics

Qua

HOW TO

COMBINE

THE TWO?

Ein



The Major PROBLEM of 21st Century Physics

"Quantum Gravity"

or

"The Theory of Everything"

String Theory



String Theory

Developed in the 1970s-1980s



Green



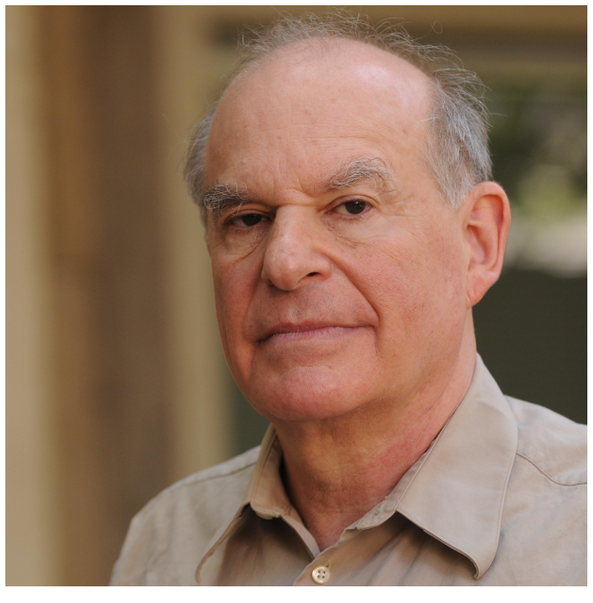
Polchinski



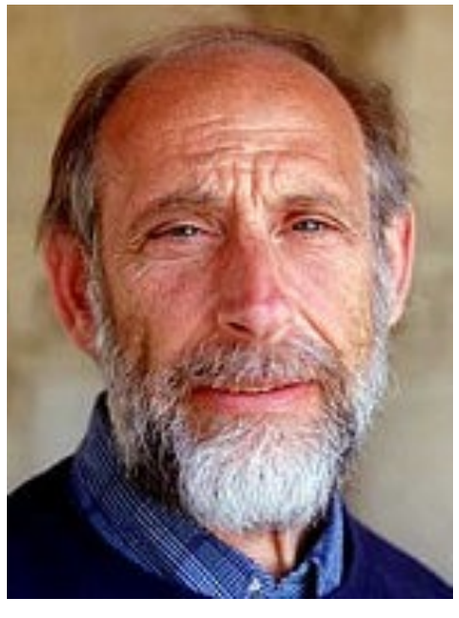
Polyakov



Ramond



Schwarz



Susskind



Veneziano



Witten

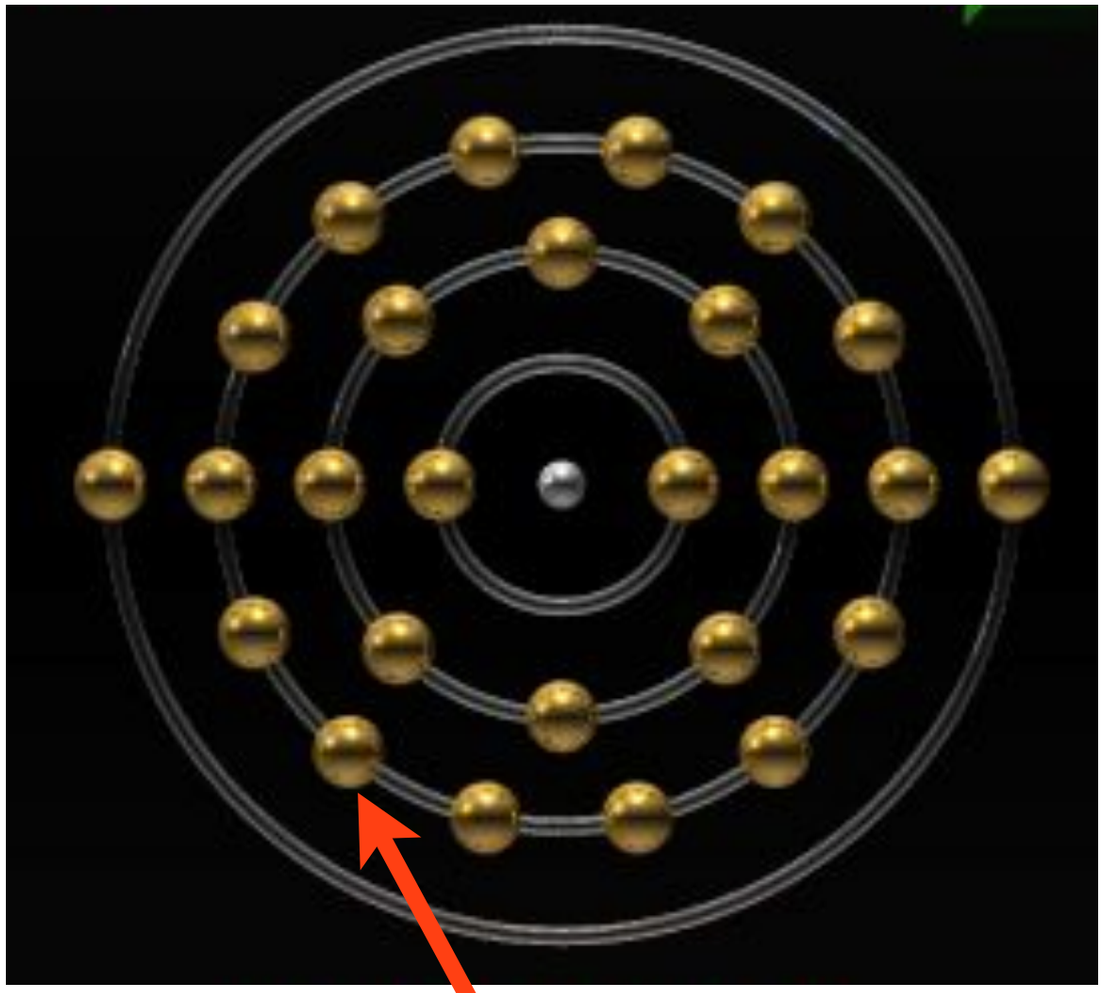
My 2nd physics job

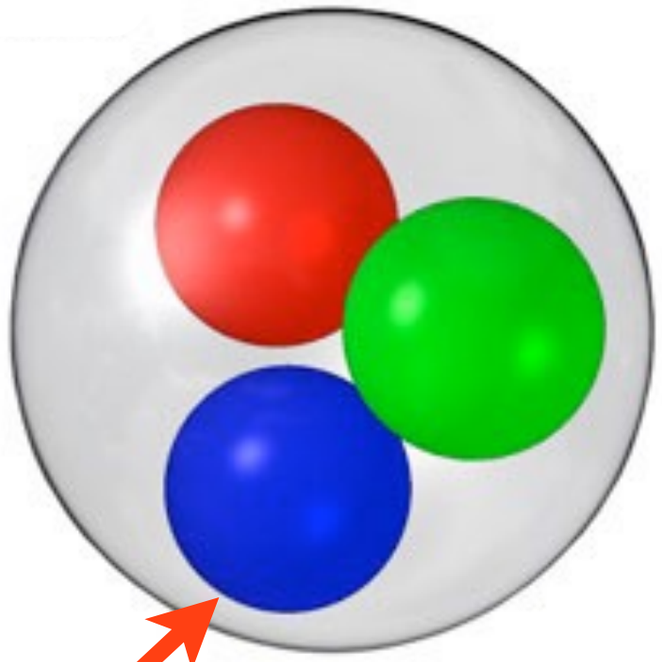
University of Cambridge





String Theory





What if the electrons and quarks ARE NOT fundamental?

What if they are made of something smaller?

String Theory

Quark

String



What are strings made of?





What are strings made of?





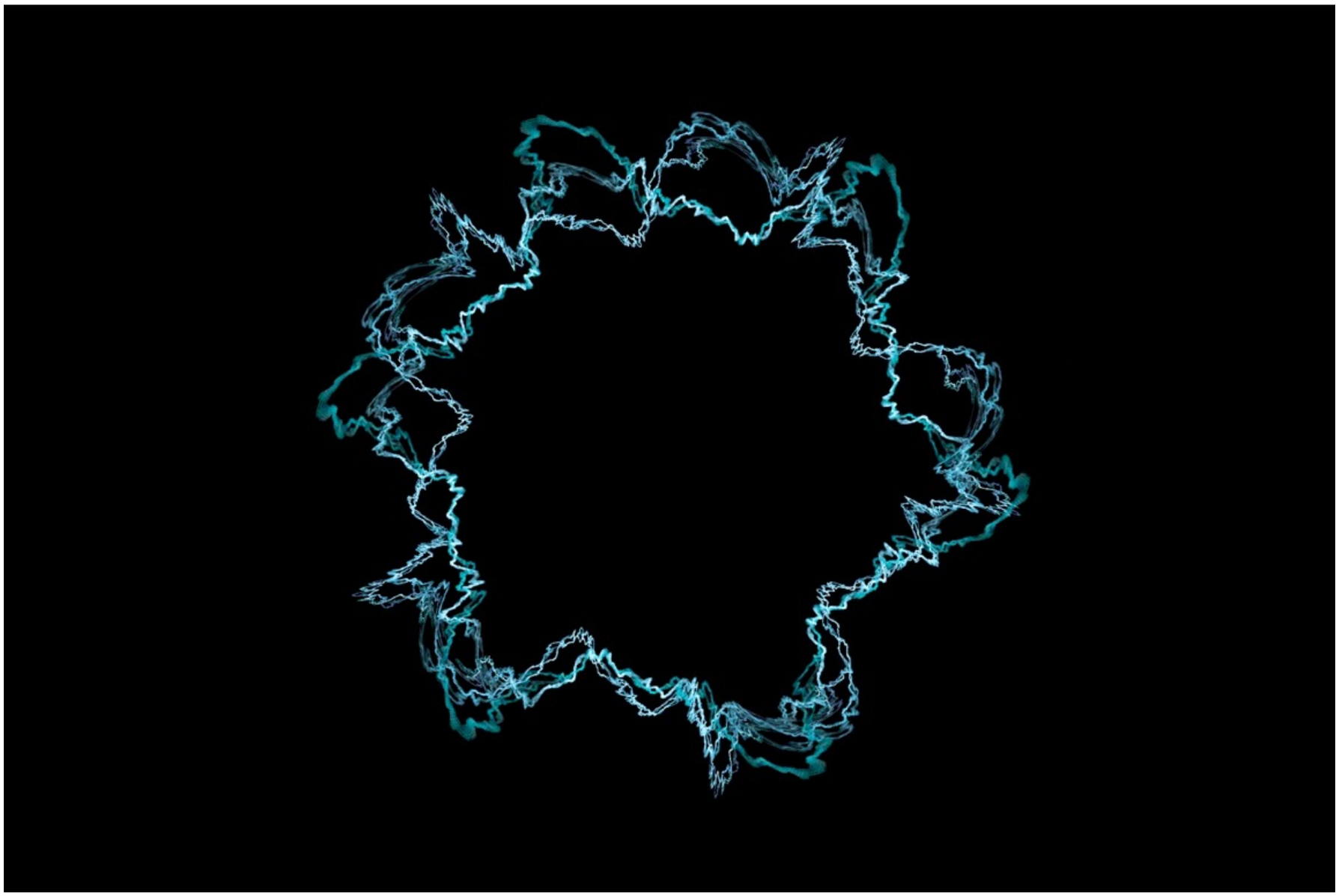
What are strings made of?

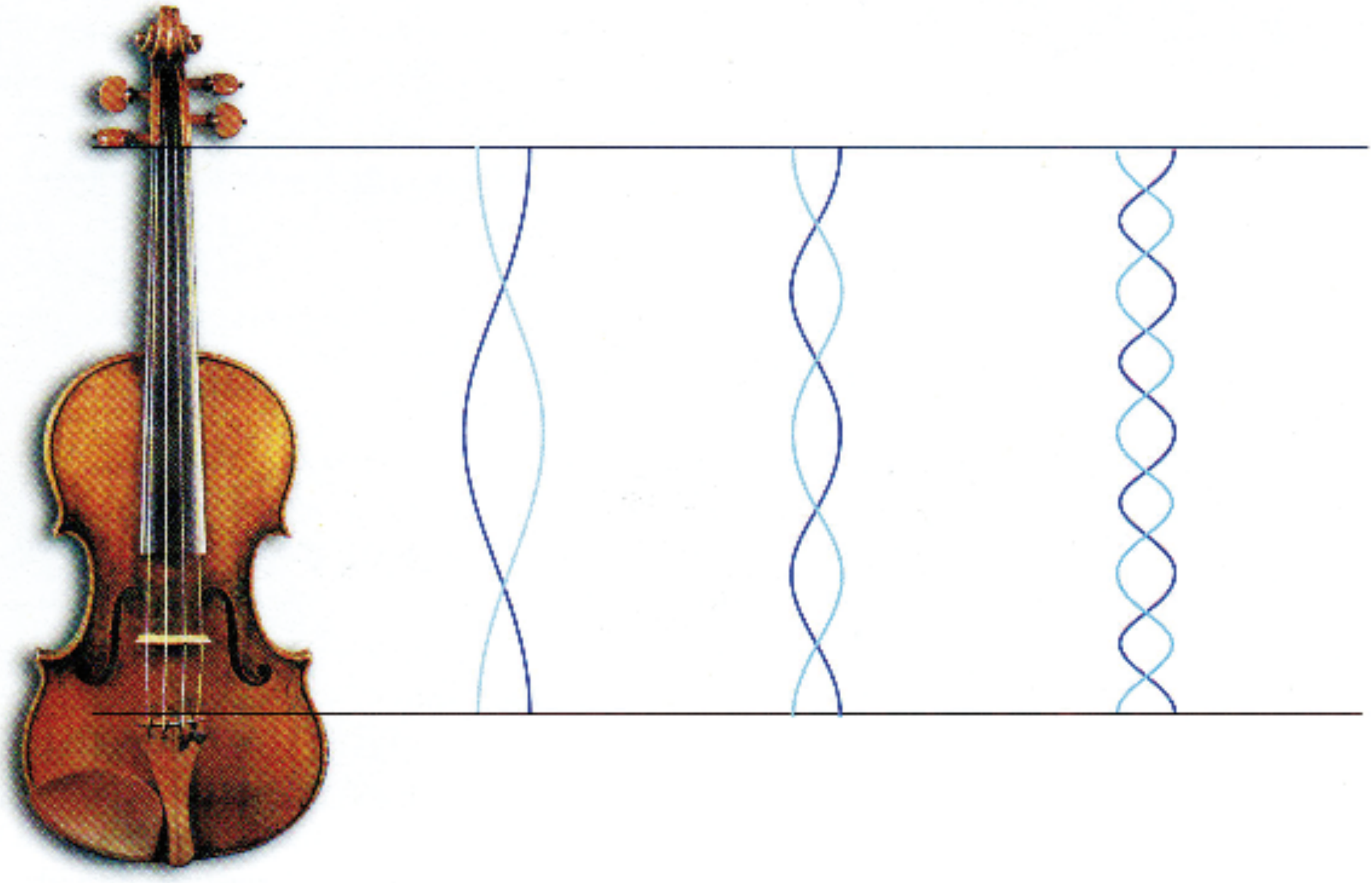
In string theory,
the strings are
THE fundamental objects.

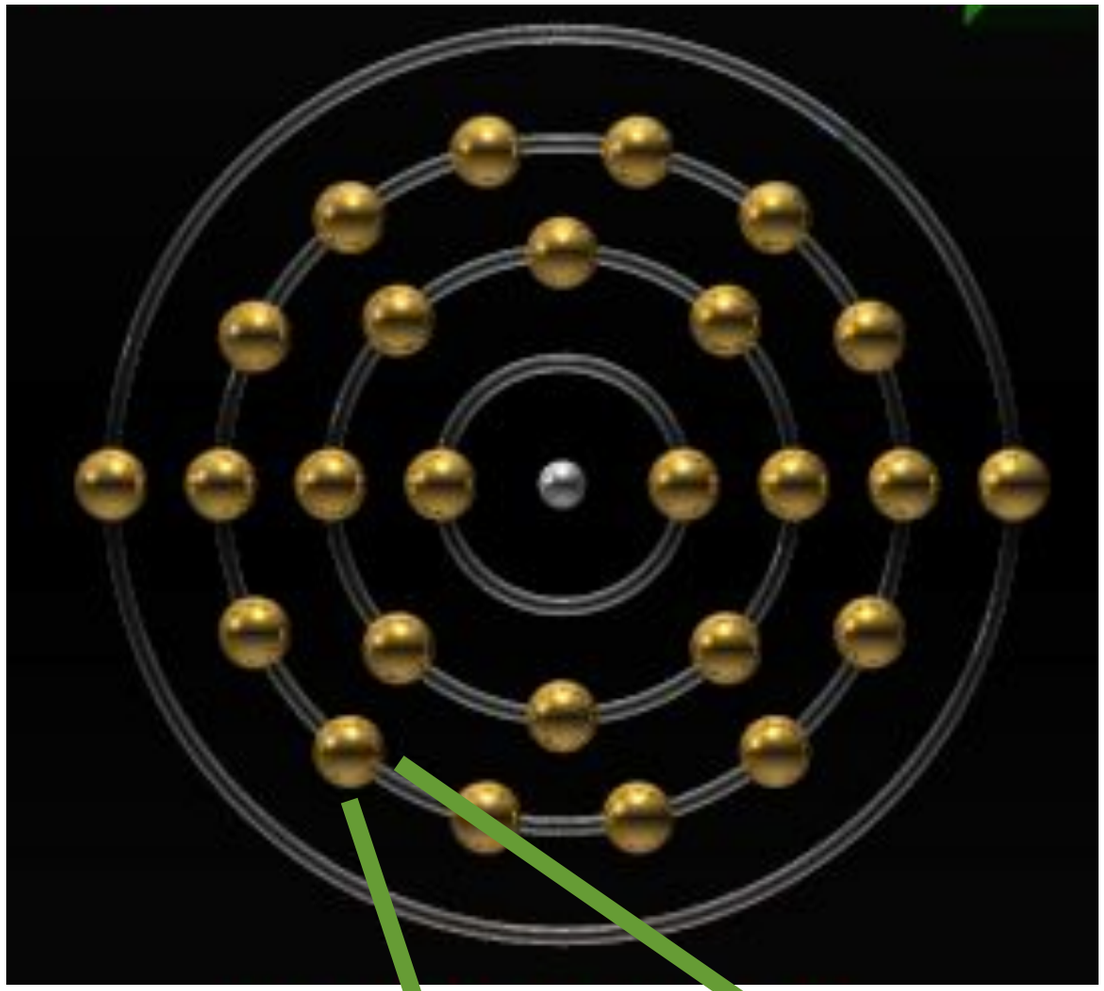
They're not made of anything smaller.

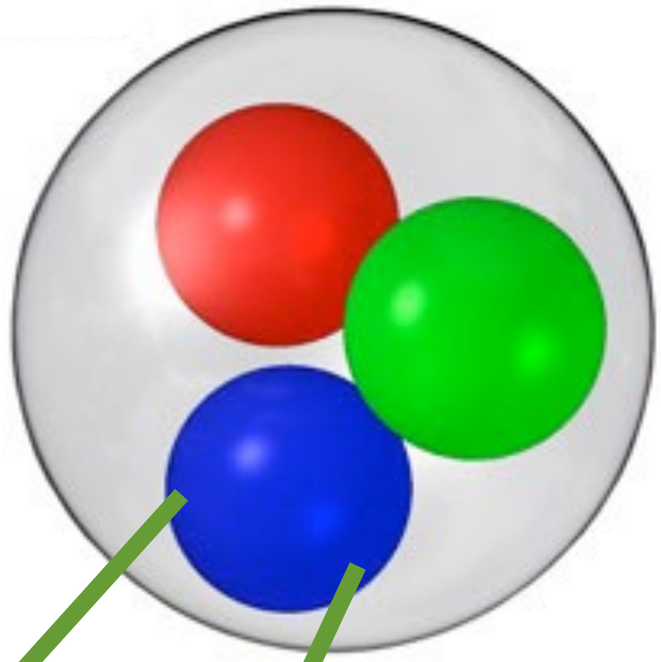
What are strings made of?

They are just “pure energy”



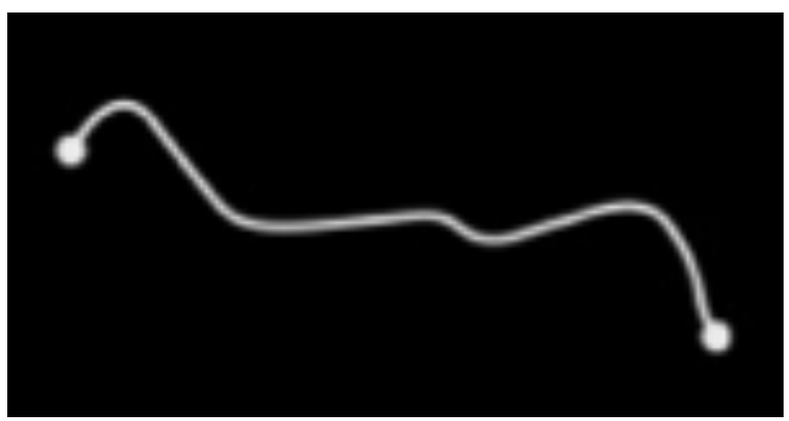


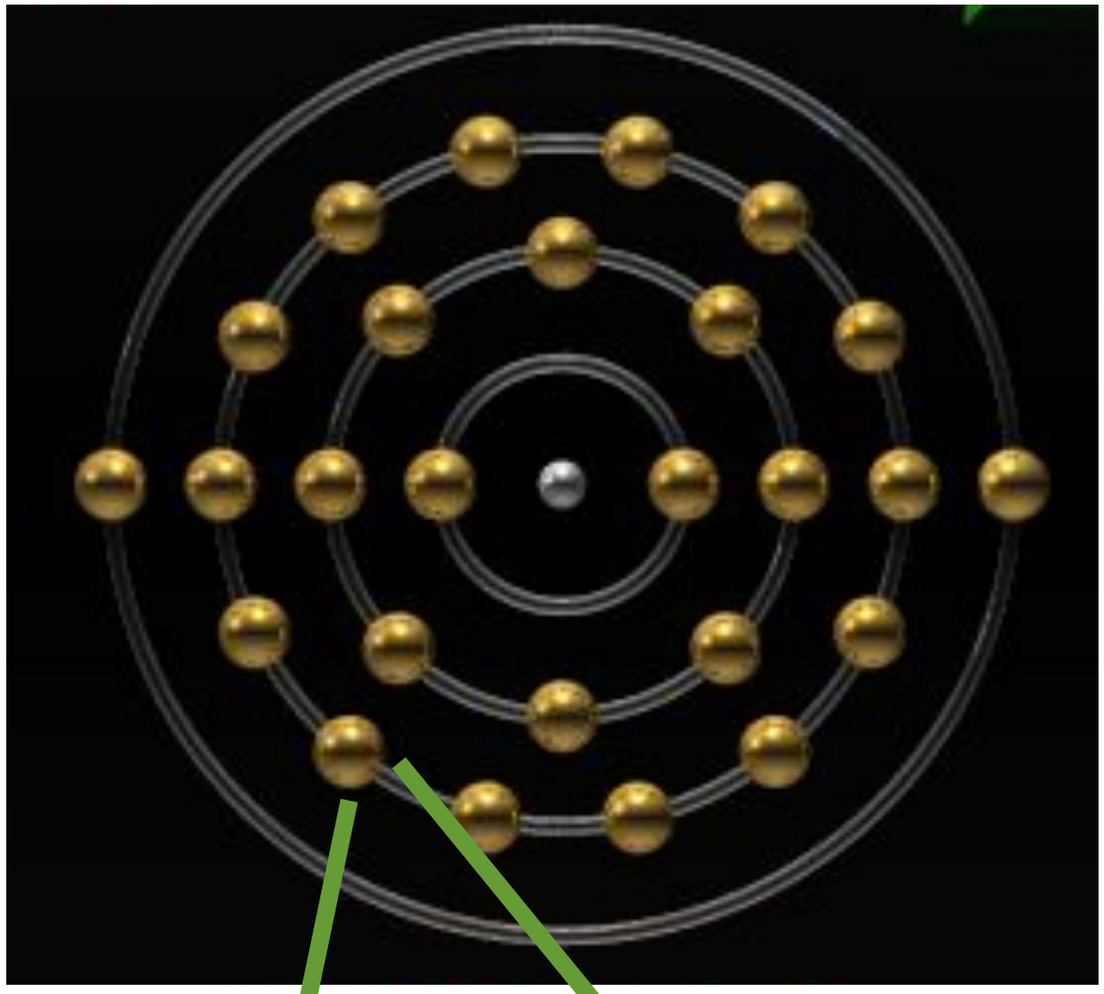




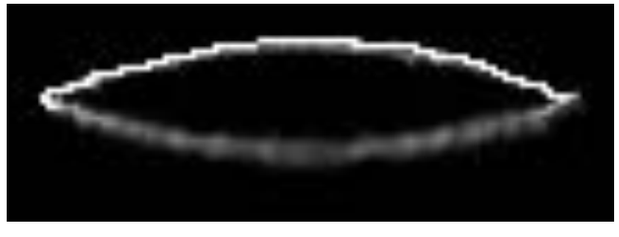


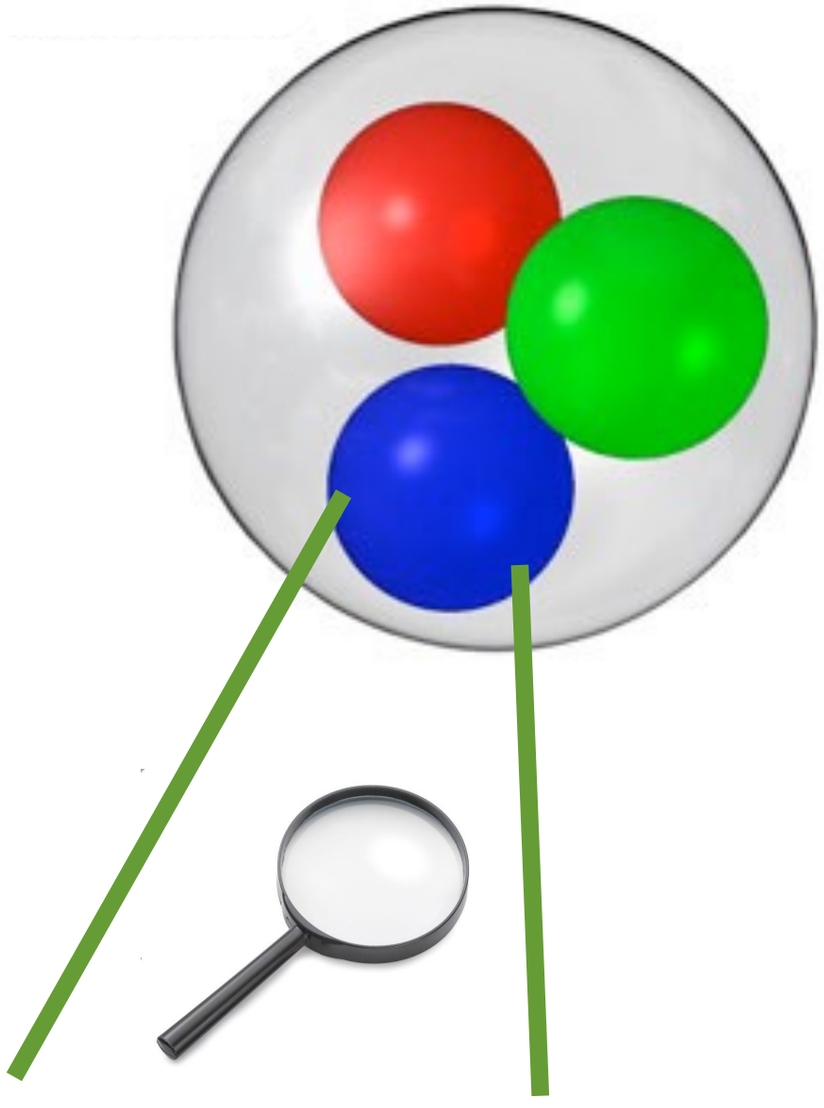


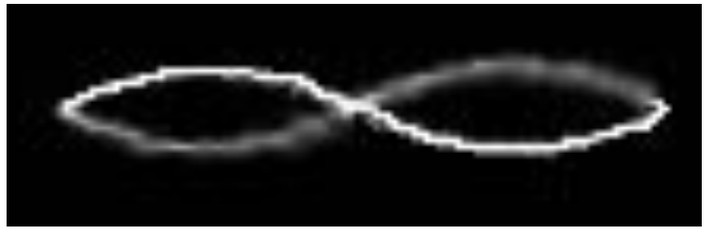










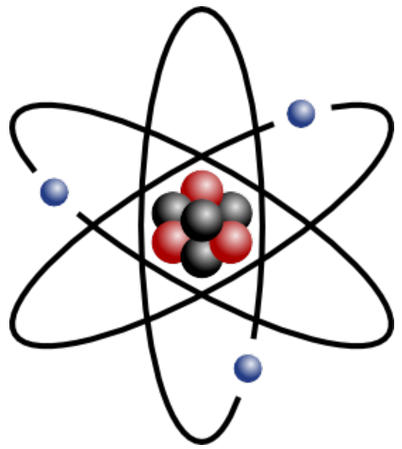


String Theory

is a theory of

Quantum Gravity

Quantum Mechanics



+

Einstein's Relativity



String Theory

Is string theory right?

Can we test string theory experimentally?

String Theory

Is string theory right?

Can we test string theory experimentally?

NO.

How big are strings?

Quarks

String



smaller than $10^{-13}\,\mathrm{cm}$

How big are strings?

Quarks

String



smaller than $10^{-13}\,\mathrm{cm}$

about $10^{-33}\,\mathrm{cm}$!

How big are strings?

Quarks

String



smaller than $10^{-13}\,\mathrm{cm}$

about $10^{-33}\,\mathrm{cm}$!

...which is why string theory has never been tested experimentally.

Outline

- String Theory
- Holography
- Strongly-Interacting Systems

Outline

- String Theory
- Holography
- Strongly-Interacting Systems

Holography

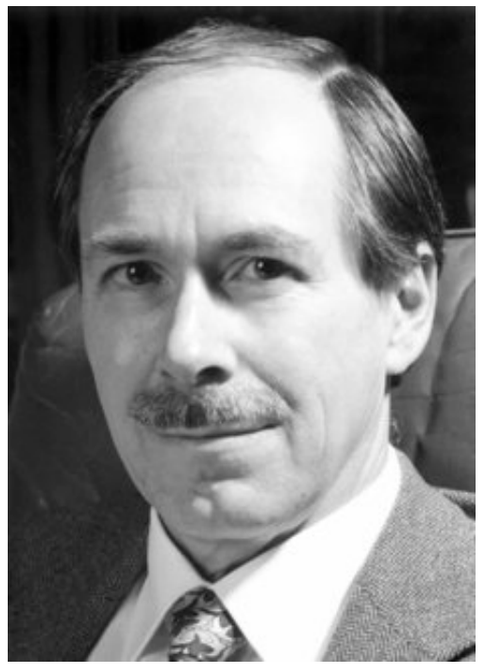
Developed in the 1990s to today



Maldacena



Susskind

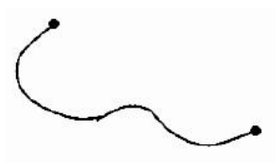


't Hooft



1997...

string theory



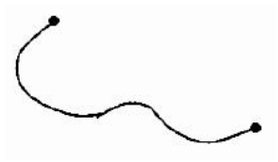






string theory

quantum particles





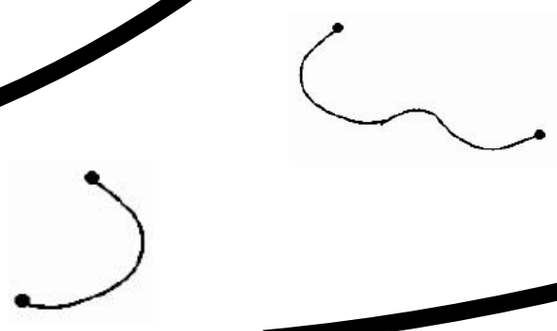




string theory

No gravity!

quantum particles







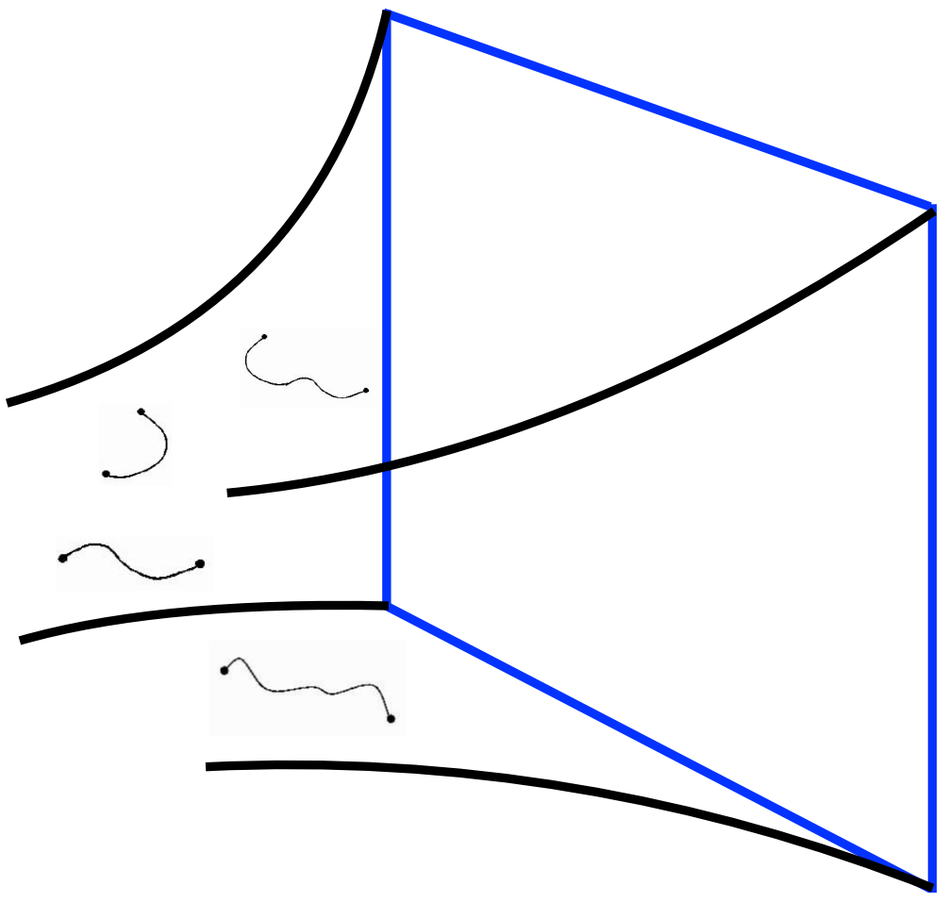
string theory

No gravity!

quantum particles

The two are EQUIVALENT!

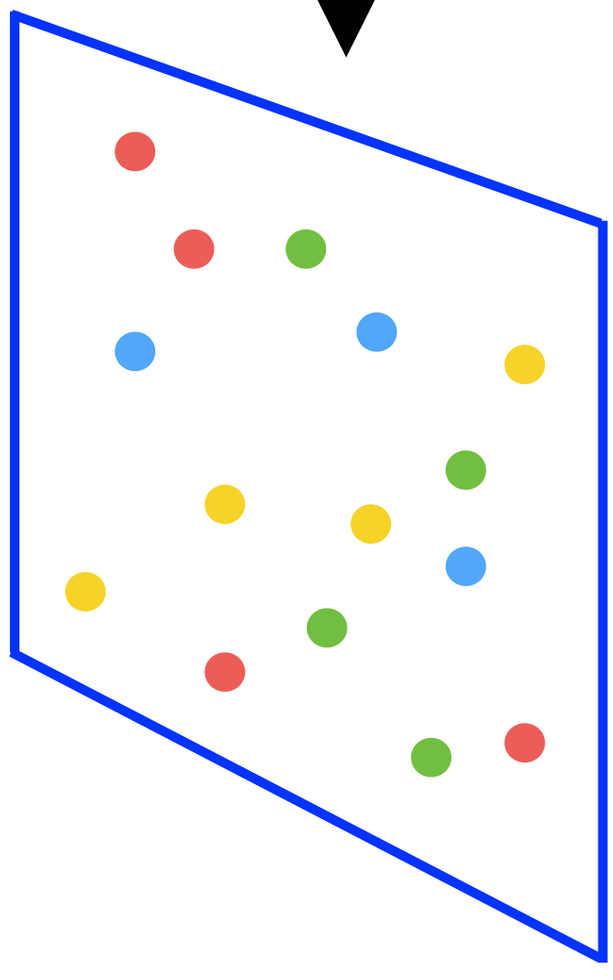
string theory

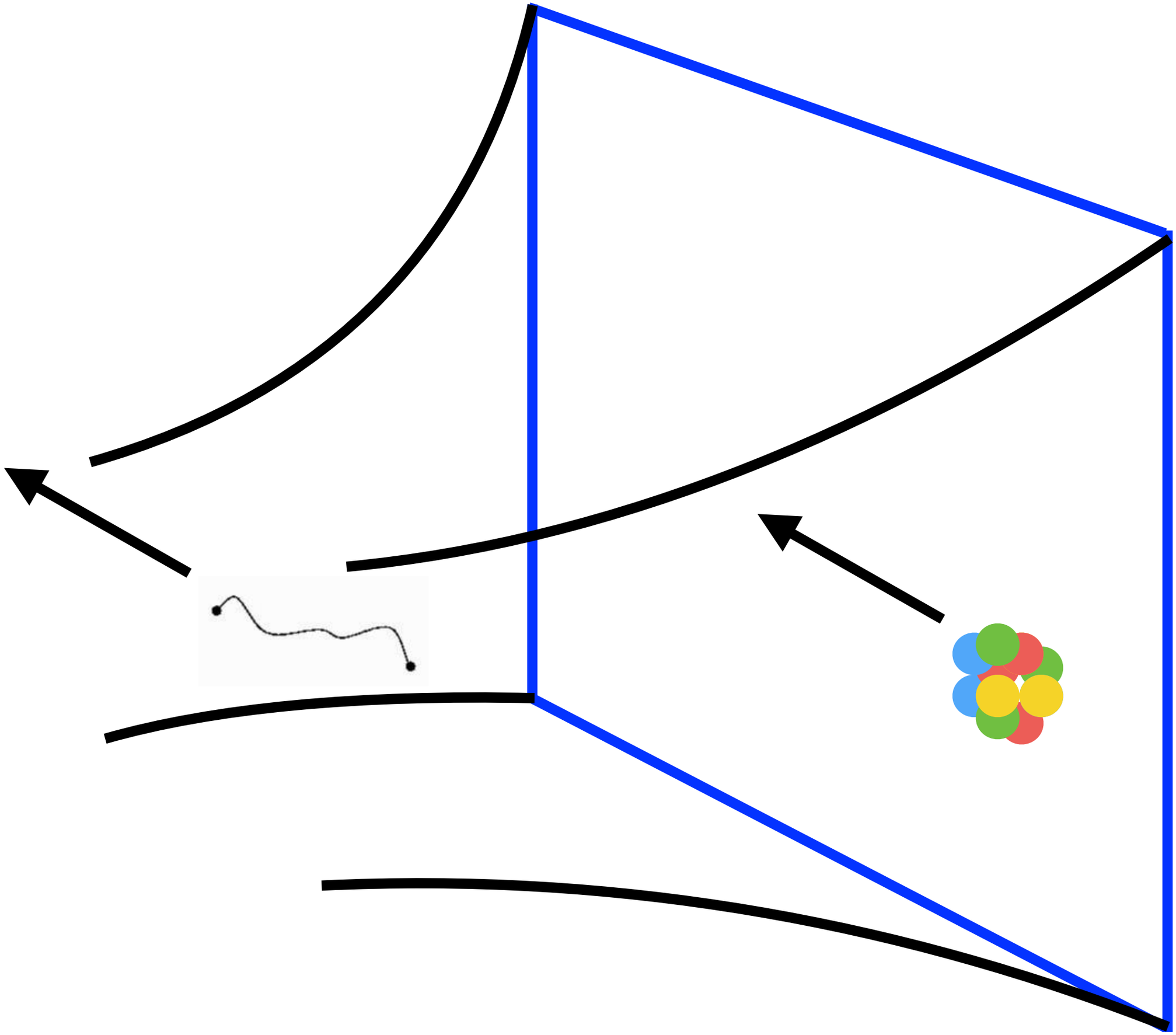


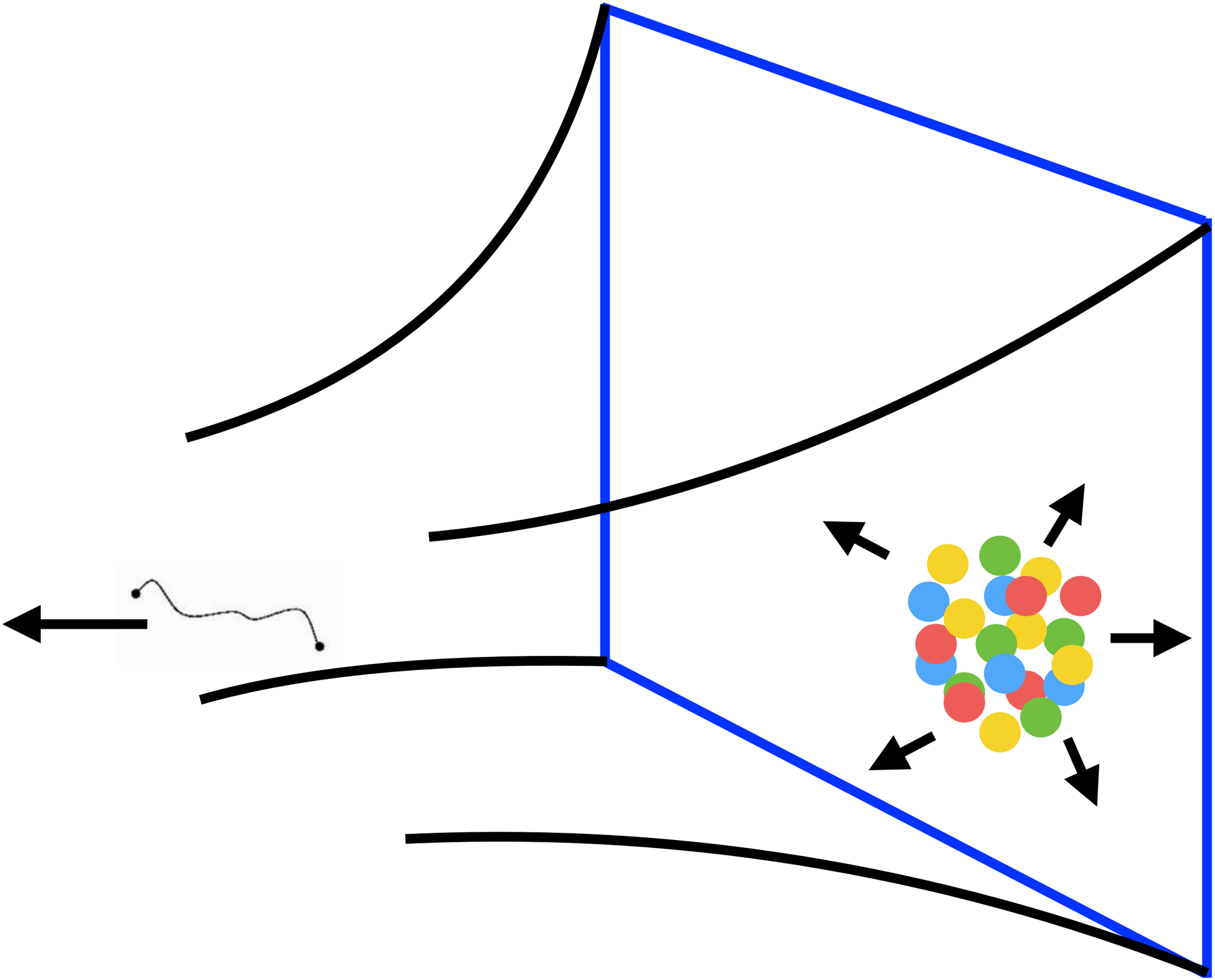
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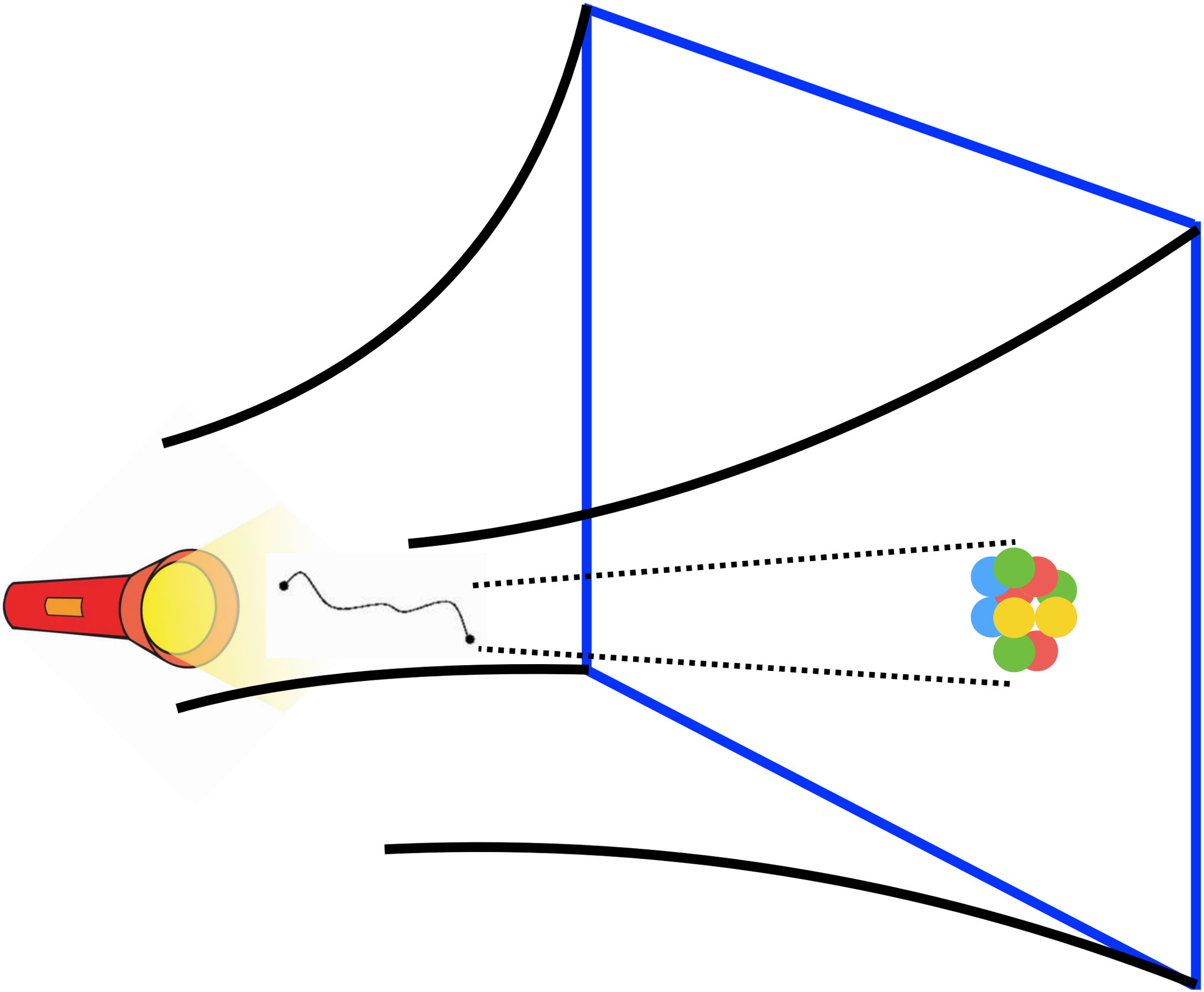
No gravity!

quantum particles

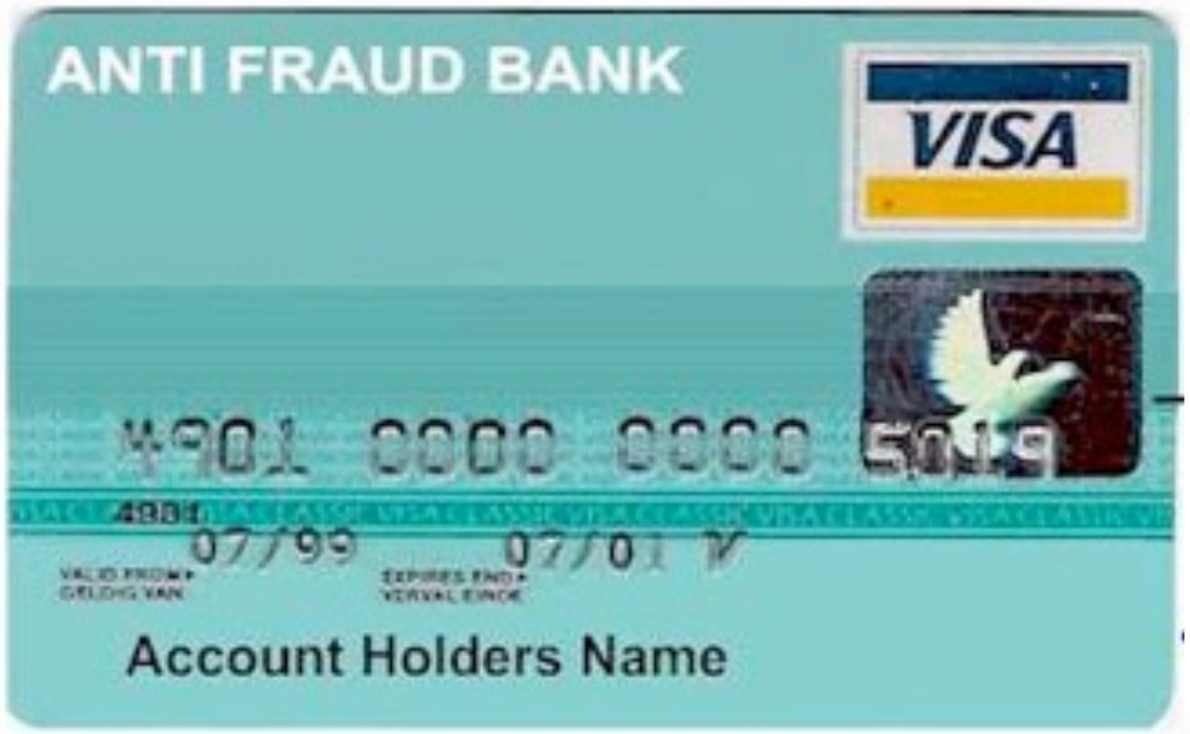








Holography





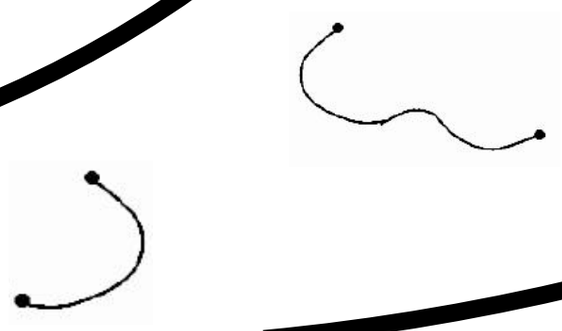
A two-dimensional (flat) image

that contains enough information to reconstruct

a three-dimensional (not flat) object

string theory

HOLOGRAM
of string theory



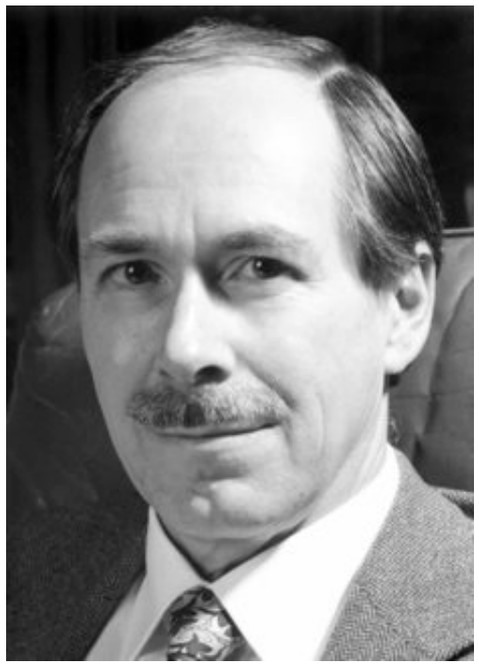




Holographic Principle



Susskind



't Hooft

ANY theory of Quantum Gravity is holographic.

Holography

How does it work?

What is the "dictionary"?

Does our universe have a hologram?

Is the Standard Model a hologram?

Can we test the holographic principle experimentally?

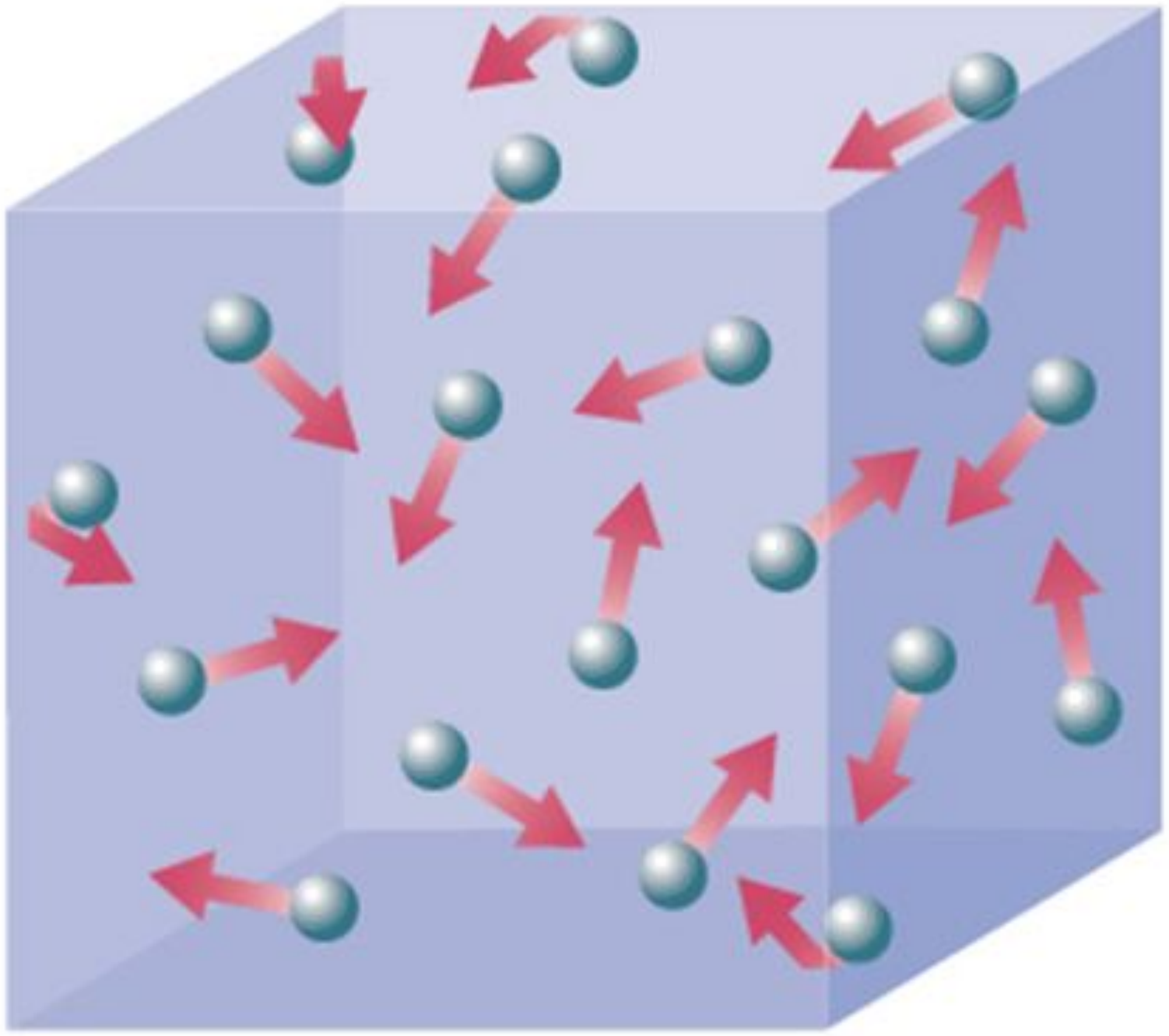
Outline

- String Theory
- Holography
- Strongly-Interacting Systems

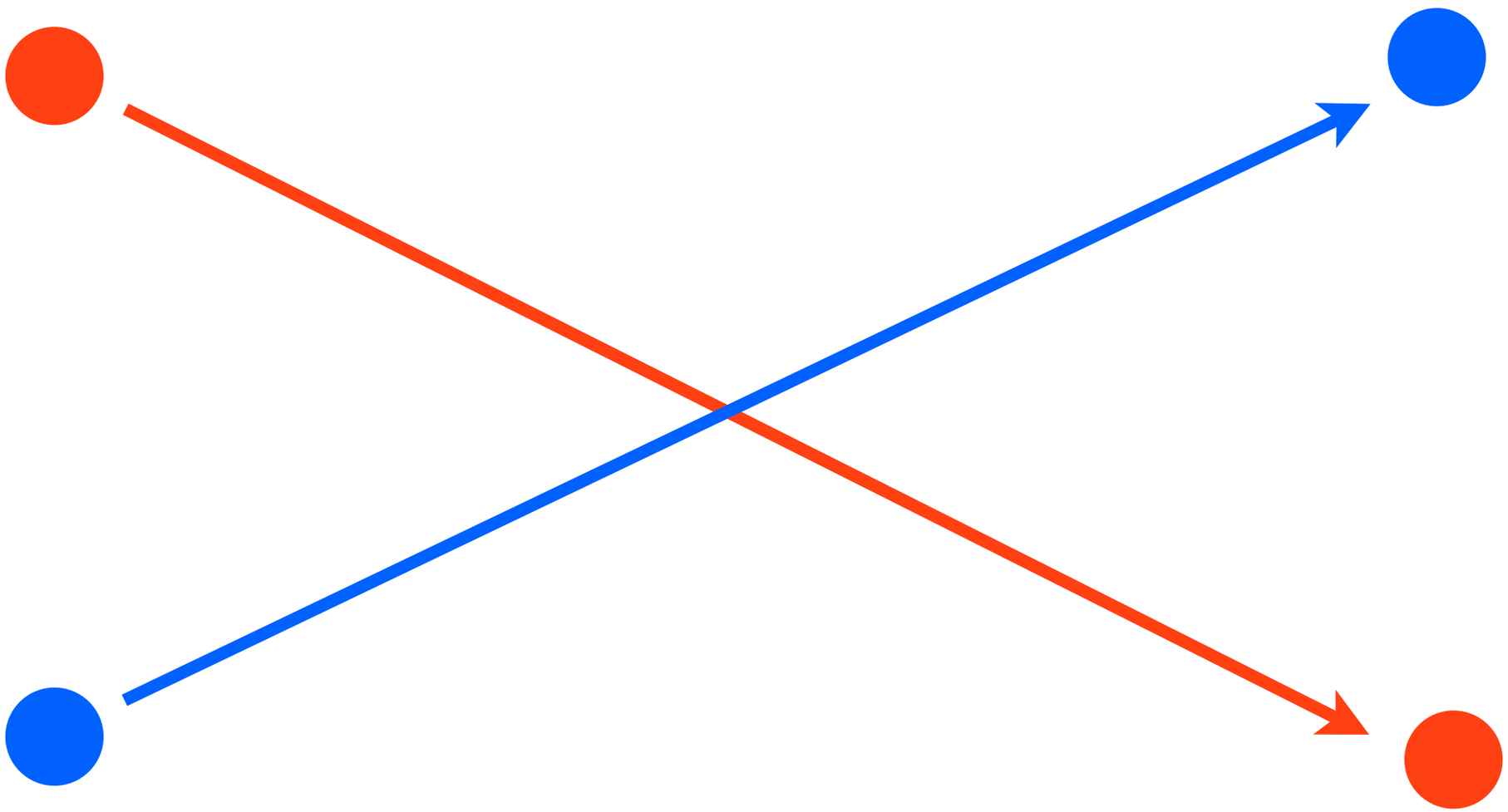
Outline

- String Theory
- Holography
- Strongly-Interacting Systems

Particles in a Box



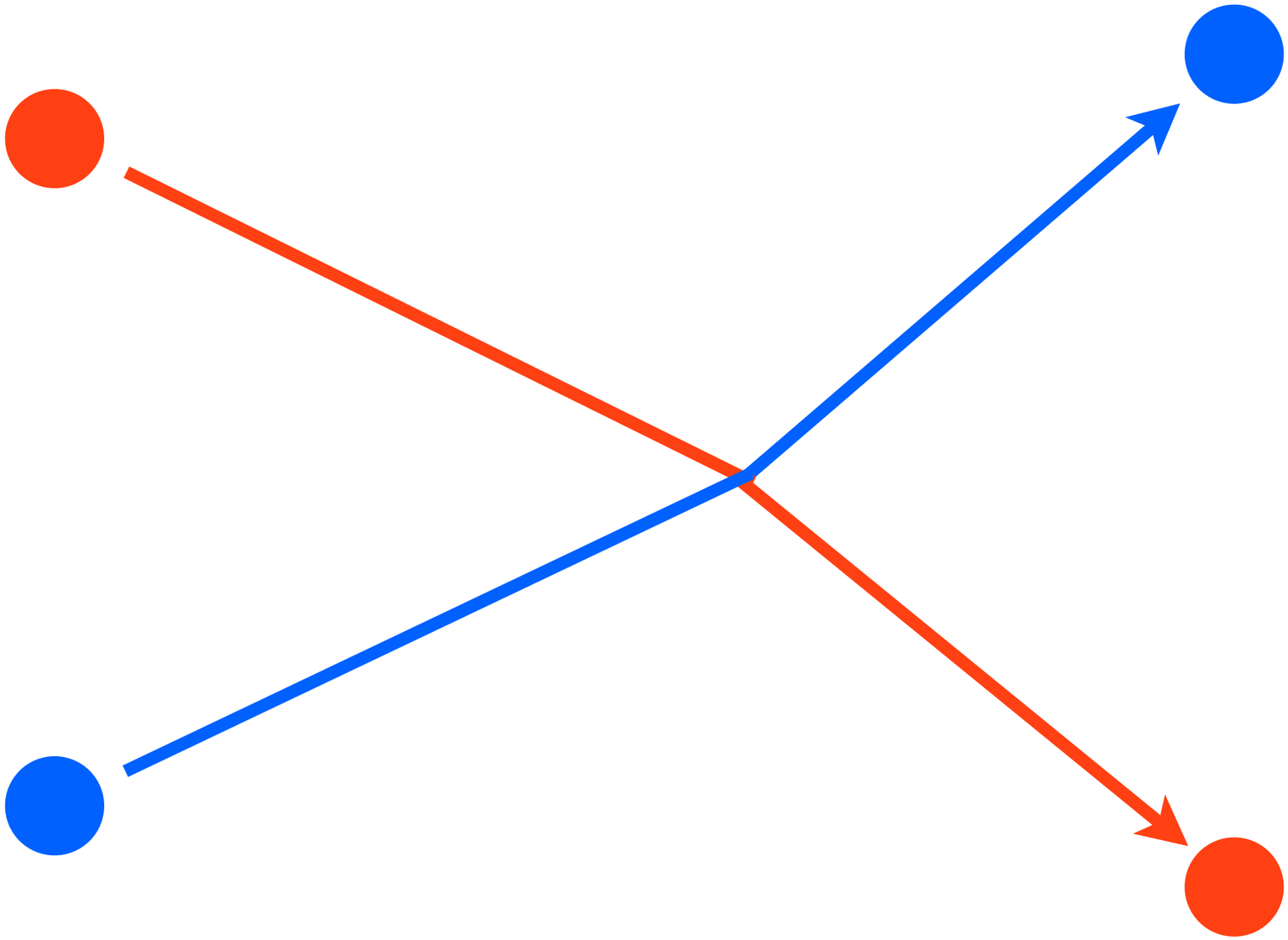
Non-Interacting Systems



Particles pass through each other

Completely under control

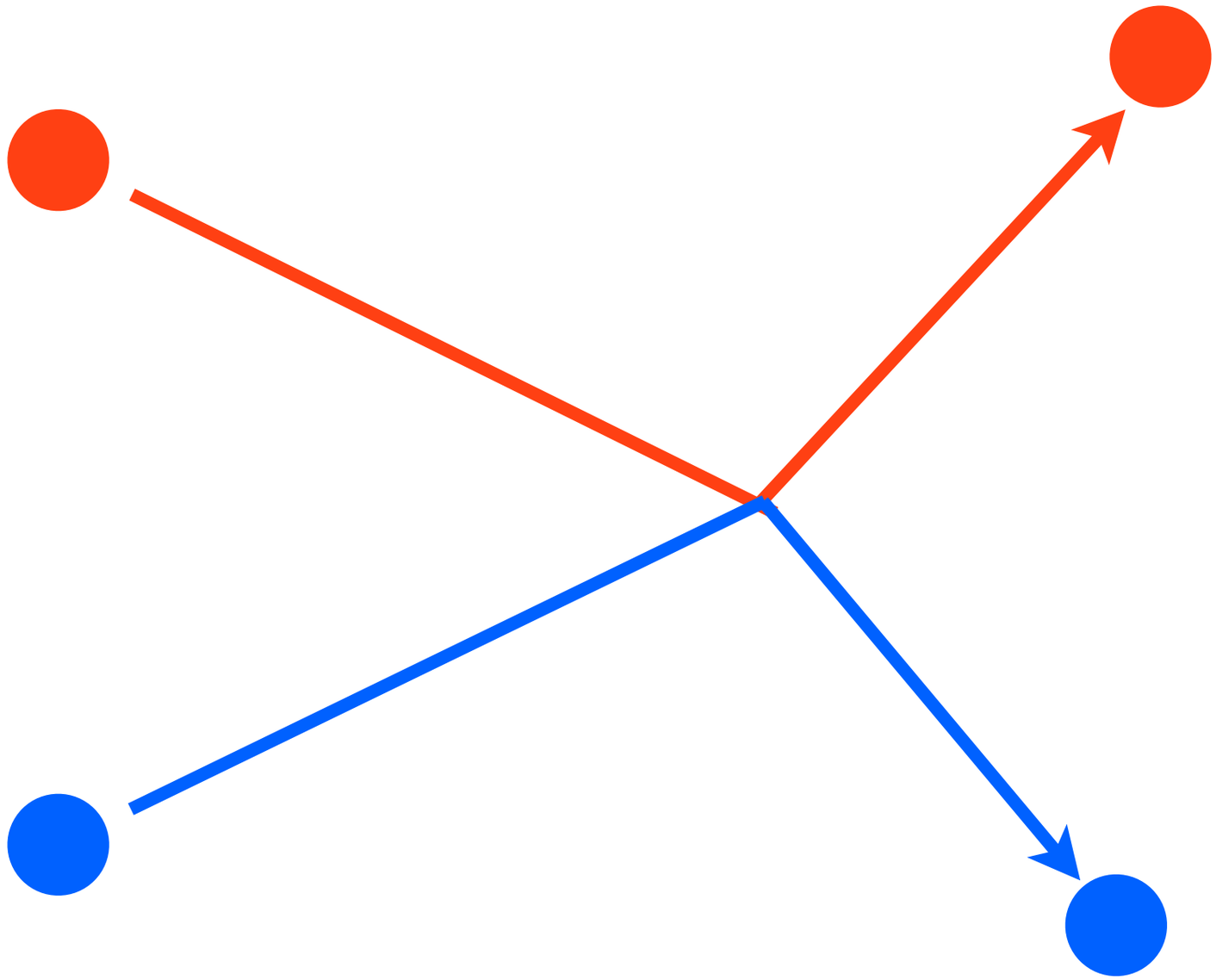
Weakly-Interacting Systems



Each experiences a slight deflection

Mostly under control

Strongly-Interacting Systems



Each may experience an enormous deflection

NOT UNDER CONTROL

Strongly-Interacting Systems

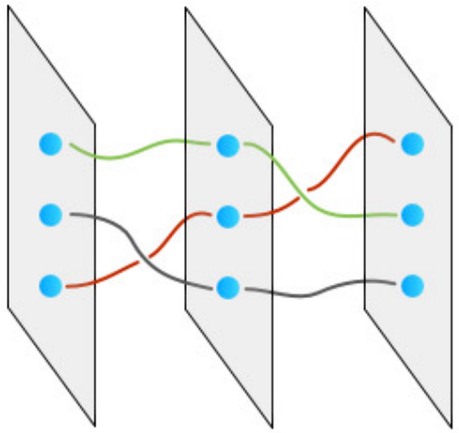


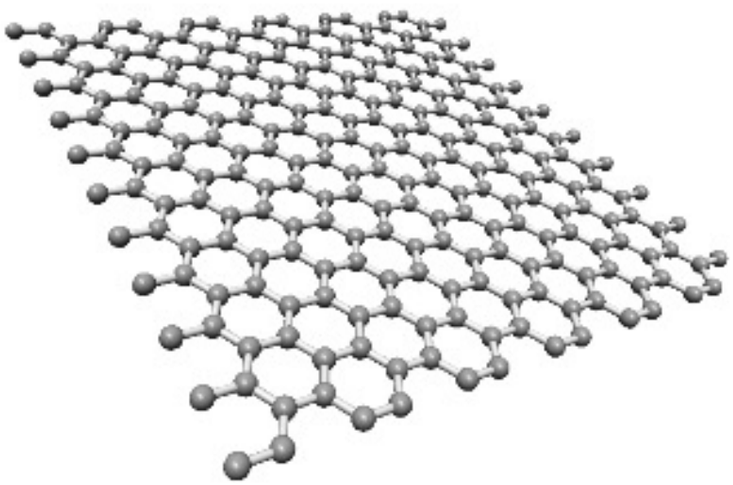
High-temperature superconductors





Topological Insulators

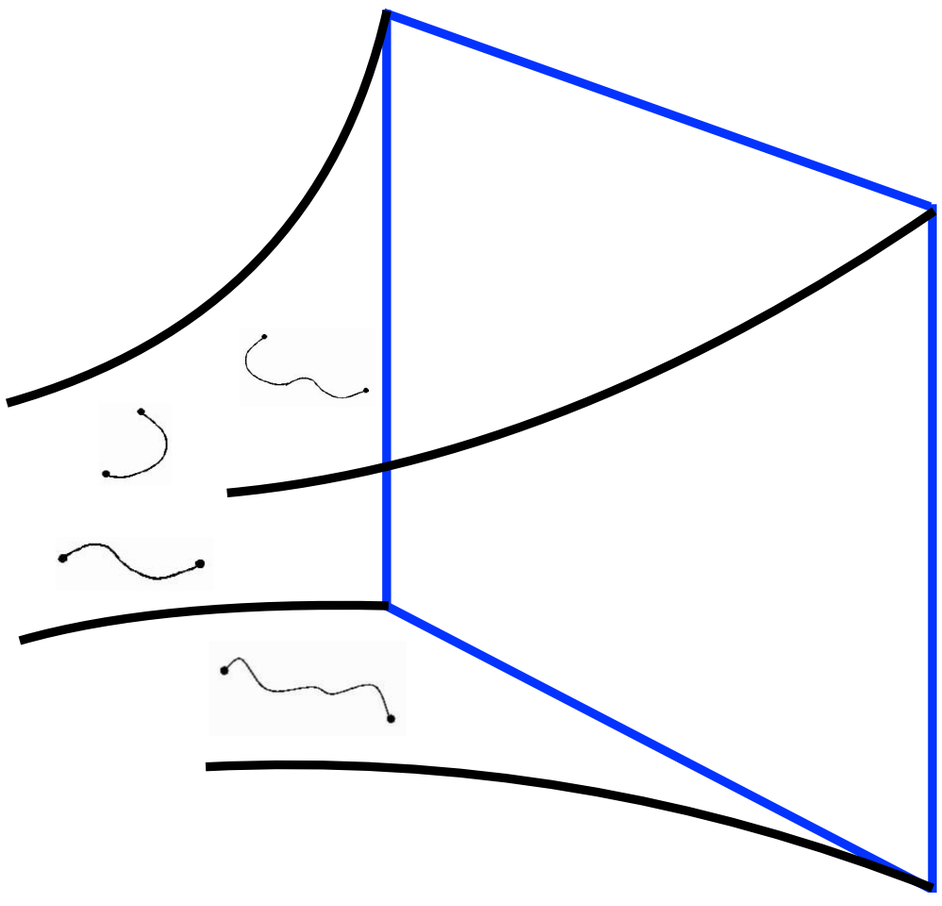




Graphene



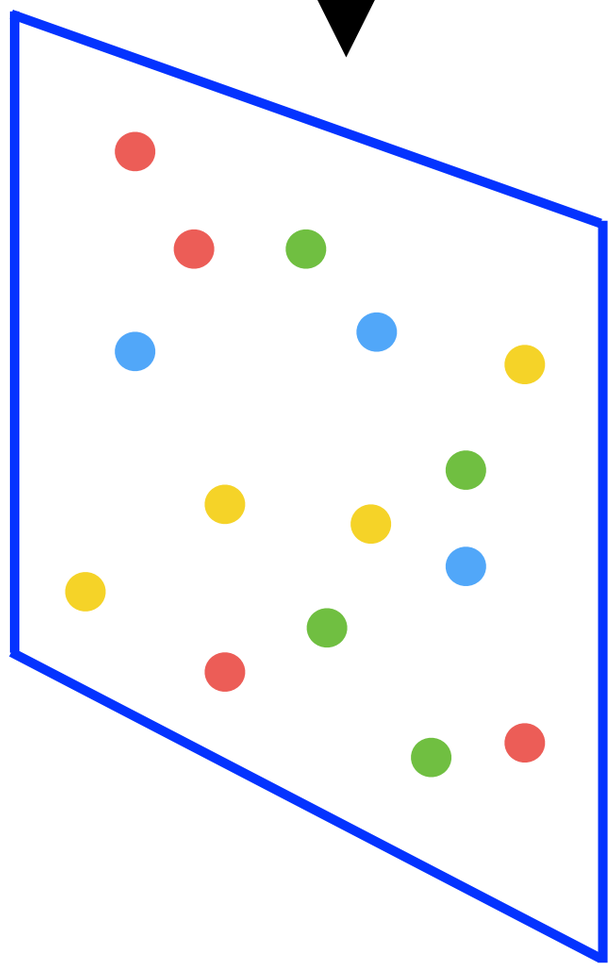
string theory



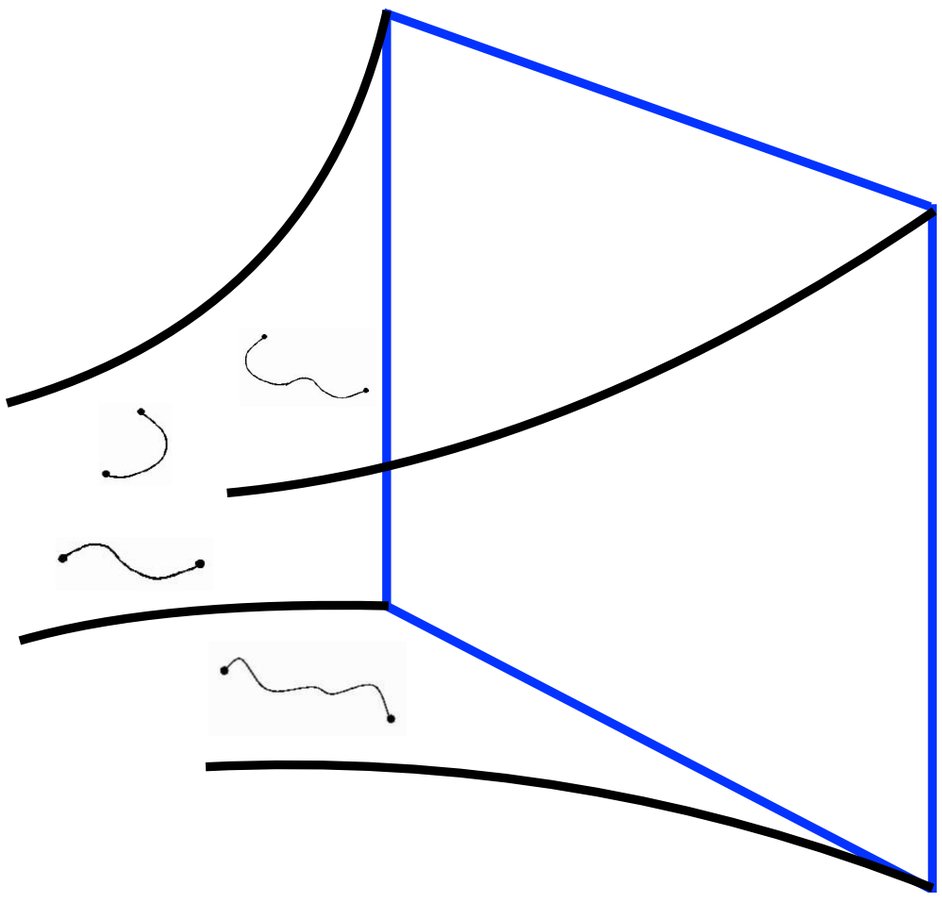
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No gravity!

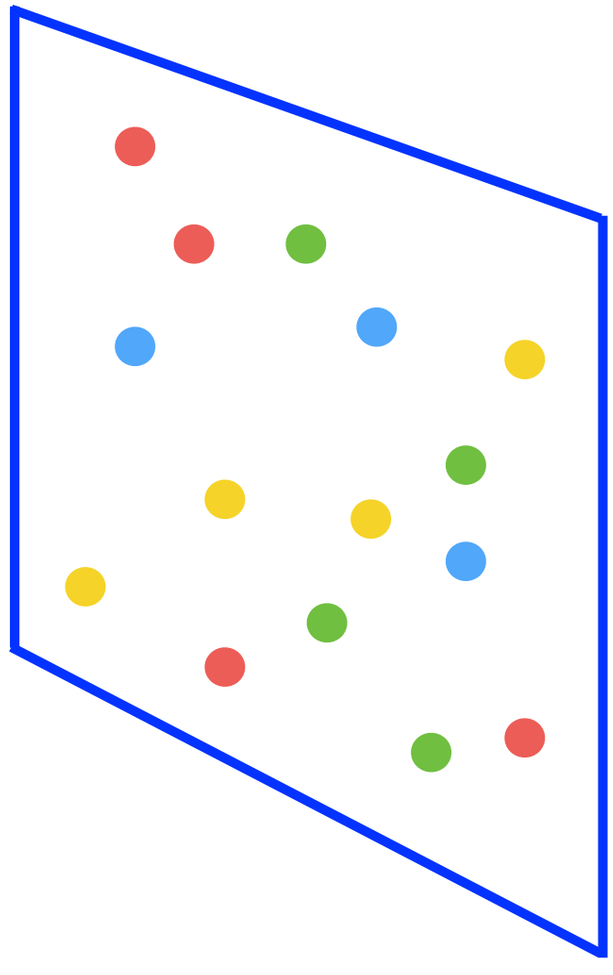
quantum particles



weakly-interacting



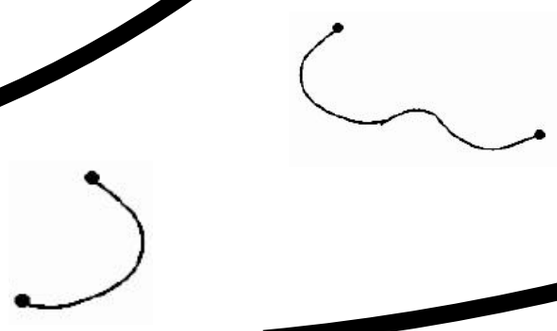
strongly-interacting



string theory

No gravity!

quantum particles







weakly-interacting

strongly-interacting

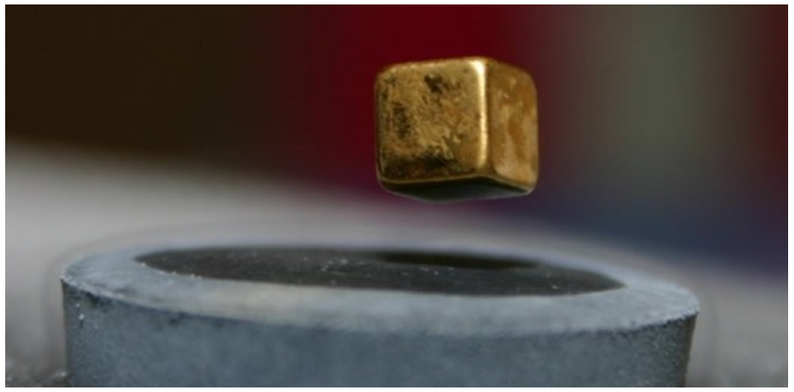








Strongly-Interacting Systems

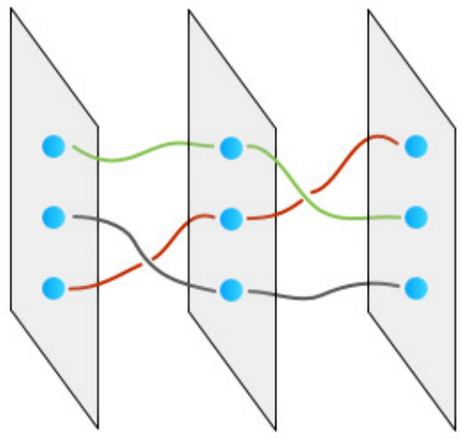


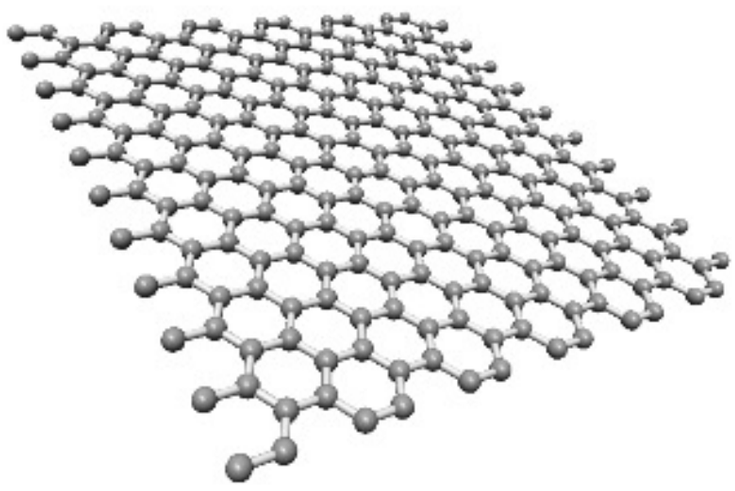
High-temperature superconductors





Topological Insulators





Graphene



Outline

- String Theory
- Holography
- Strongly-Interacting Systems

My Research

I use a tool from STRING THEORY

called HOLOGRAPHY

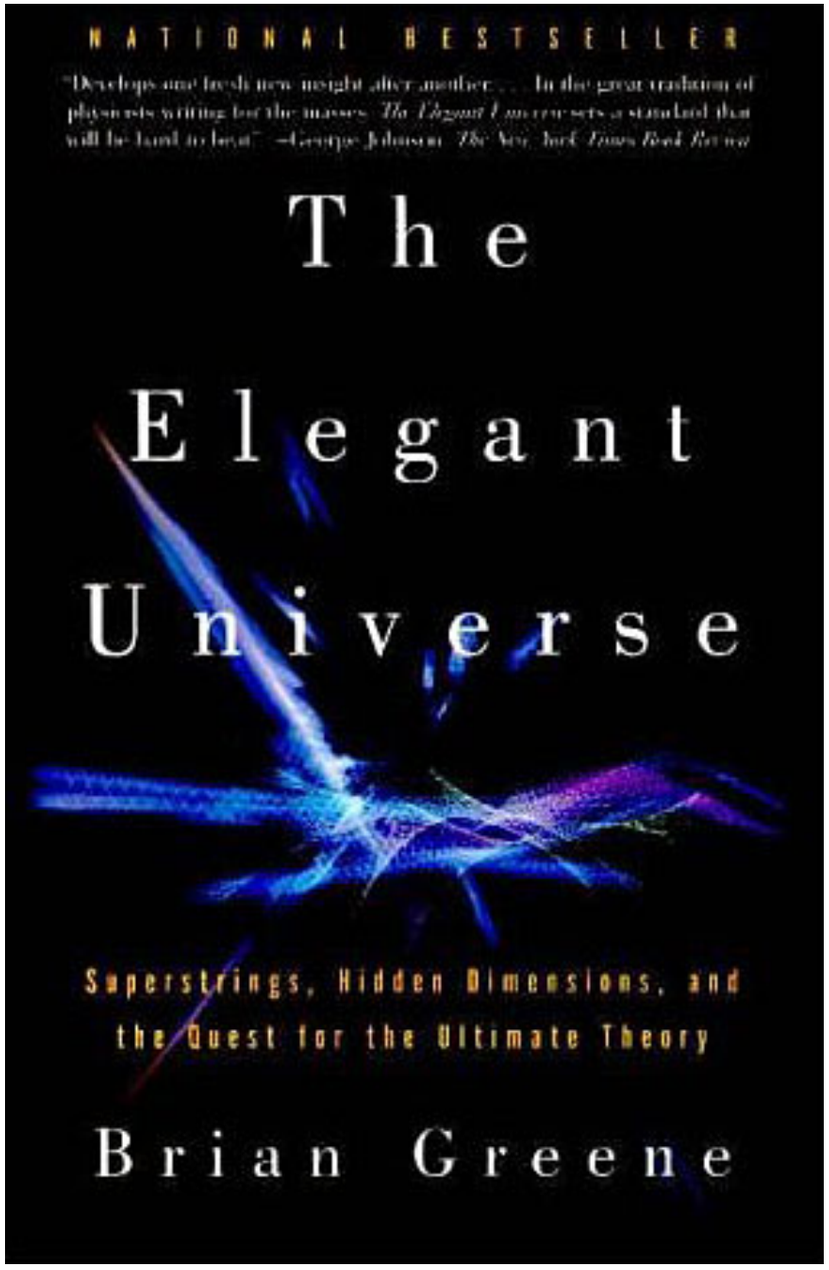
to study STRONGLY-INTERACTING SYSTEMS.

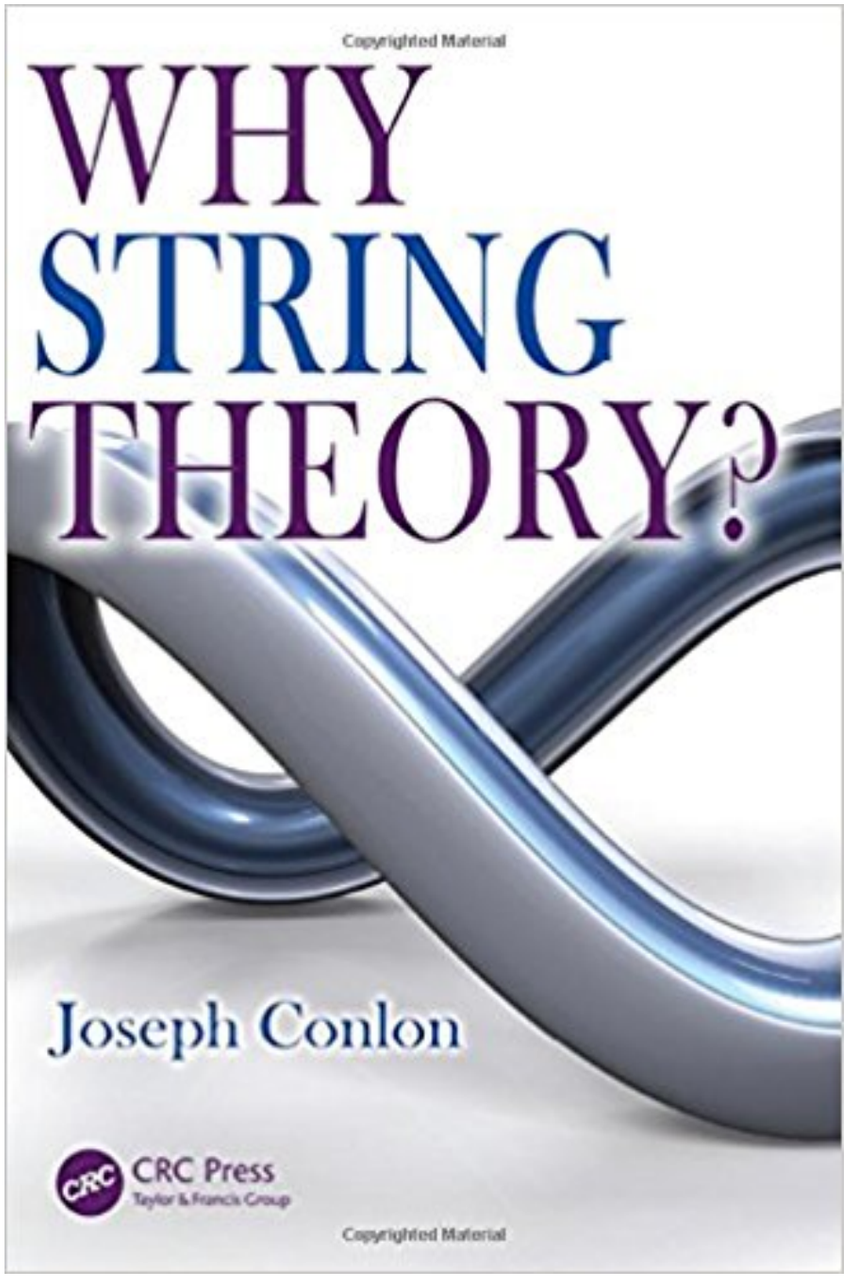
What is string theory good for?

Leading candidate for Quantum Gravity.

Useful tool for studying strongly-interacting systems!

Want to Know More?





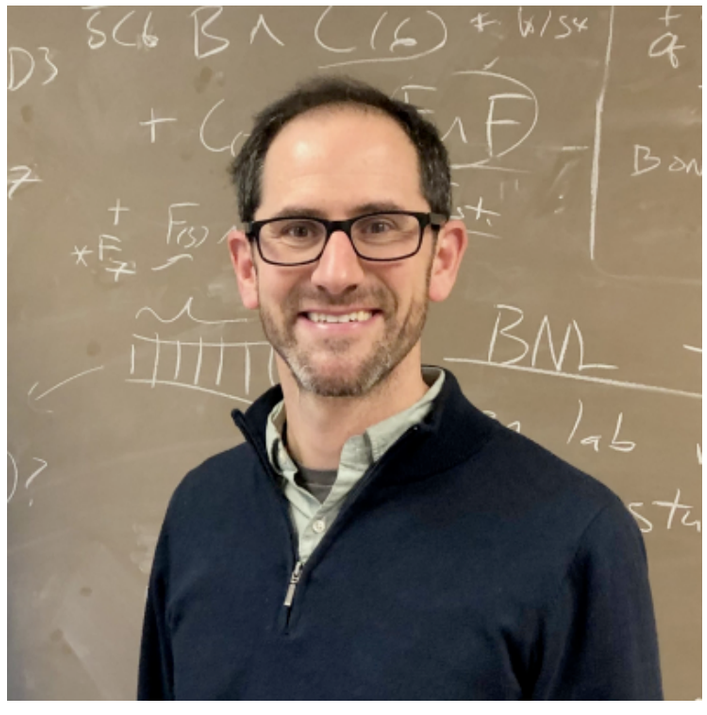
obannona@oldwestbury.edu

SUNY OLD WESTBURY

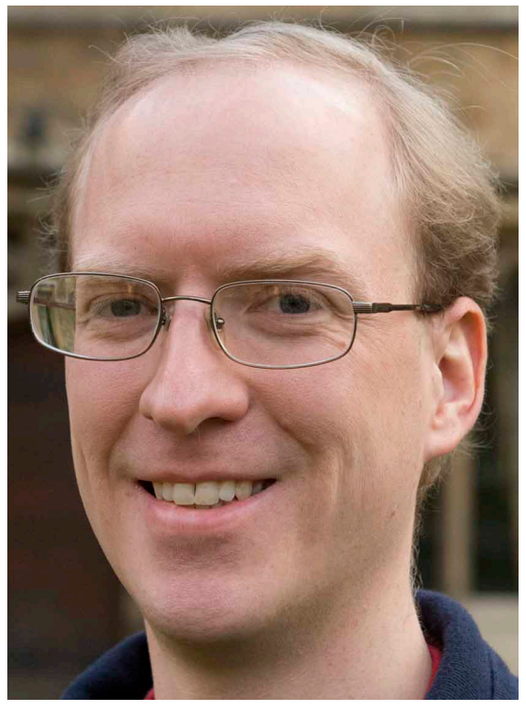
Astronomy, Strings, and Holography Lab (ASHLab)



John Estes



Matt Lippert



Andy O'Bannon

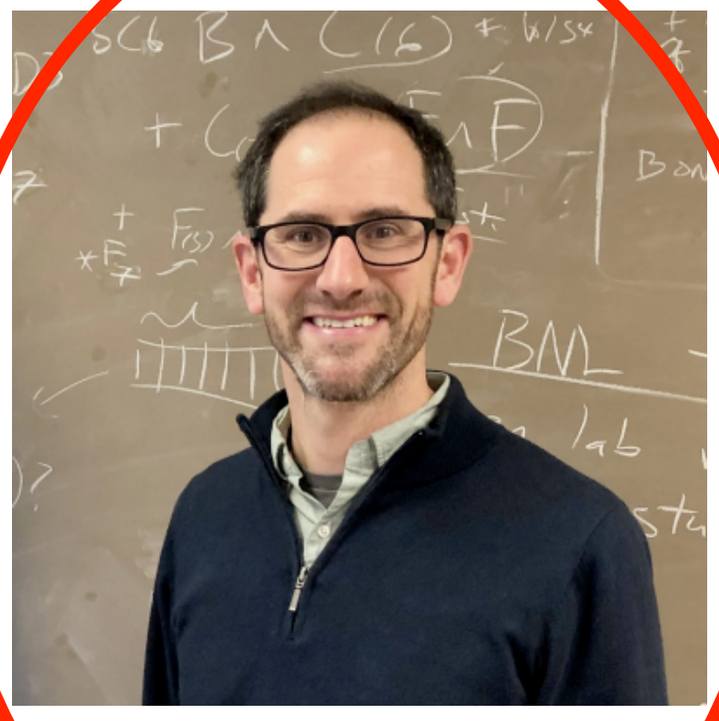
https://sites.google.com/view/ashlab-ow/home

SUNY OLD WESTBURY

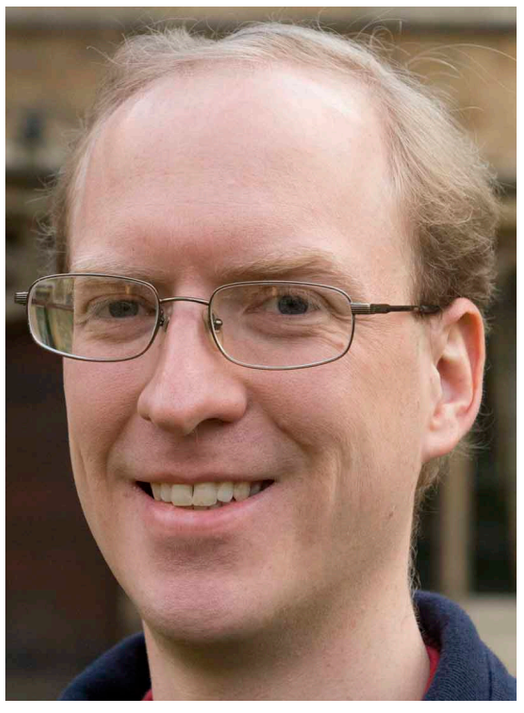
Astronomy, Strings, and Holography Lab (ASHLab)



John Estes



Matt Lippert



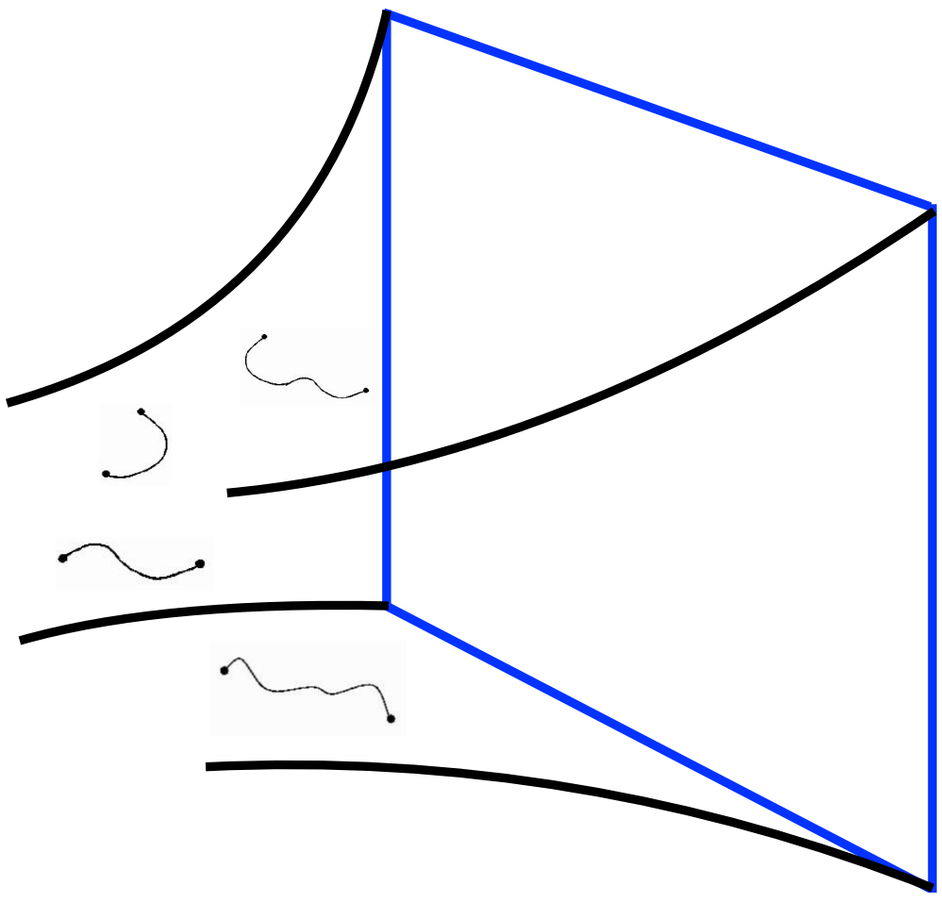
Andy O'Bannon

See Matt Lippert's talk!

Thank You.

Backup Slides

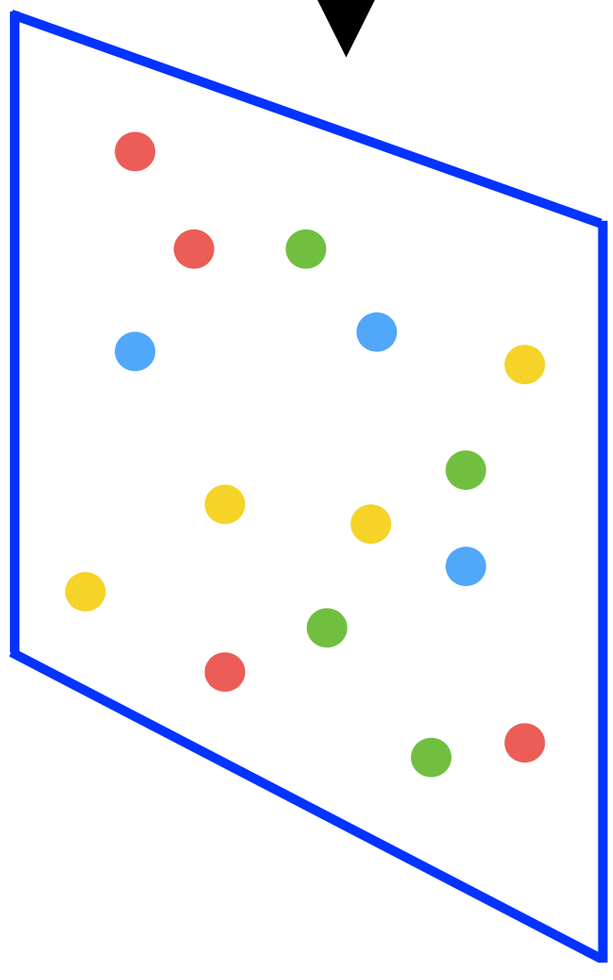
string theory



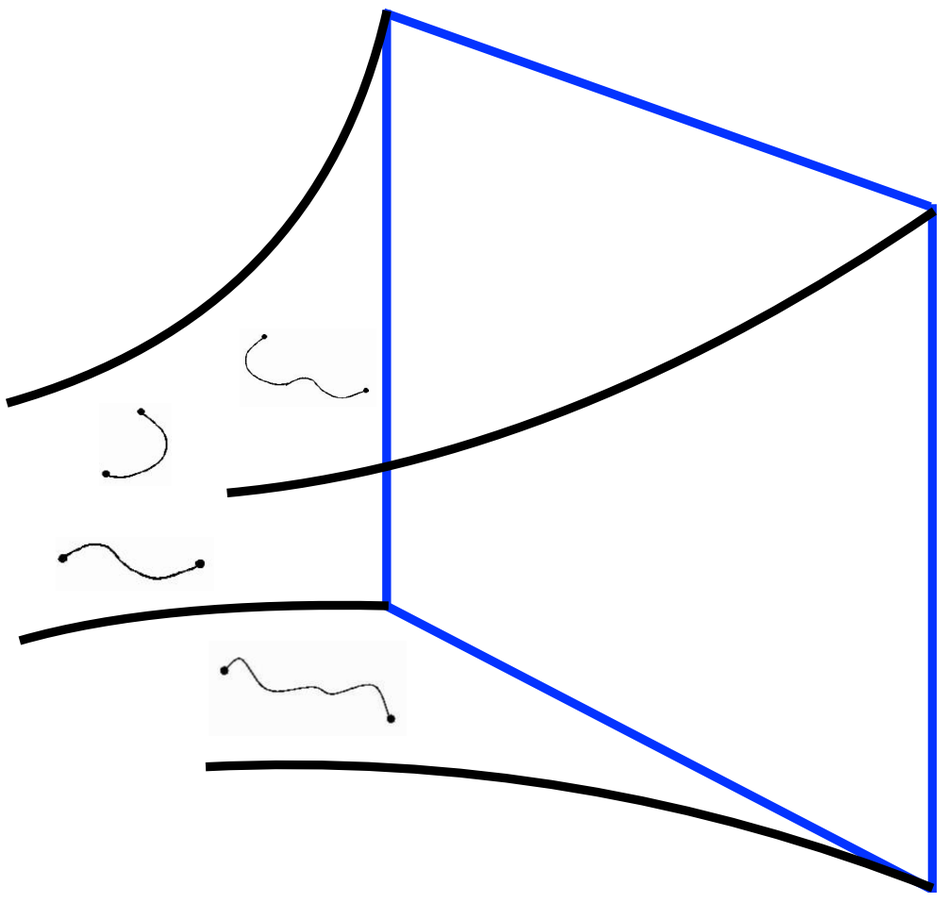
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No gravity!

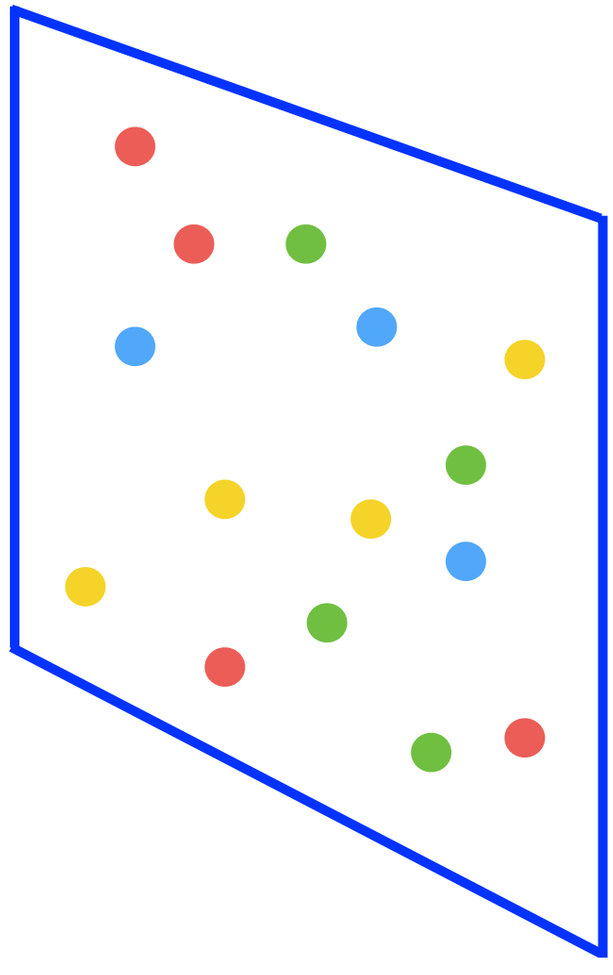
quantum particles



weakly-interacting



strongly-interacting



weakly-interacting

weakly-interacting



weakly-interacting

weakly-interacting



