# The amazing world of String Theory

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**where $T$ is the tension of the string, $\sigma^\alpha$ are the world-sheet coordinates, $X^\mu$ are the space-time coordinates and $\eta_{\mu\nu}$ is the flat spacetime metric.**

**The more useful version is the so-called Polyakov action, that goes in the following way**

$$S = -T \int d^2\sigma \sqrt{h} h^{\alpha\beta} \partial_\alpha X^\mu \partial_\beta X^\nu \eta_{\mu\nu}$$

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**Lets start our talk now hopefully I'll manage to explain what on earth is string theory! Its also a good time to open your can of draft beer!**

# From very early on people have been thinking about this:

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# In this talk I'll try aim for this

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# In this talk I'll try aim for this hopefully!

**But before we start discussing String Theory, some of you might be wondering:**

# What is String Theory?

- **What is String Theory?**
- **How does this fit in with what we already know?**

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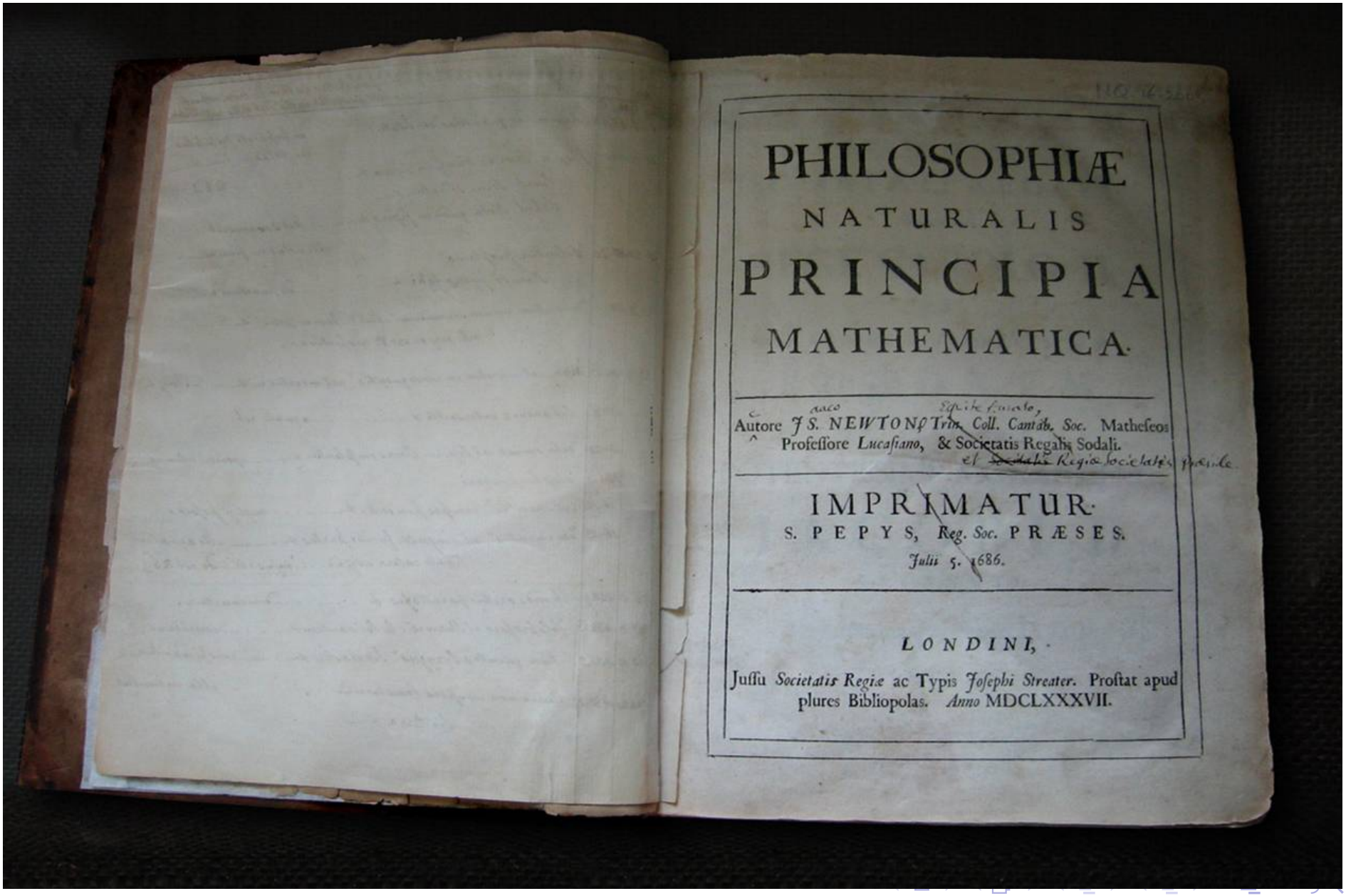
- How does this fit in with what we already know?
- Do we really need string theory to answer our fundamental questions?
- Where did those good old theories go wrong?

**Therefore let me start from the very beginning, way down in history, when Classical Mechanics ruled our ideas ...**

# It All Started With This Book



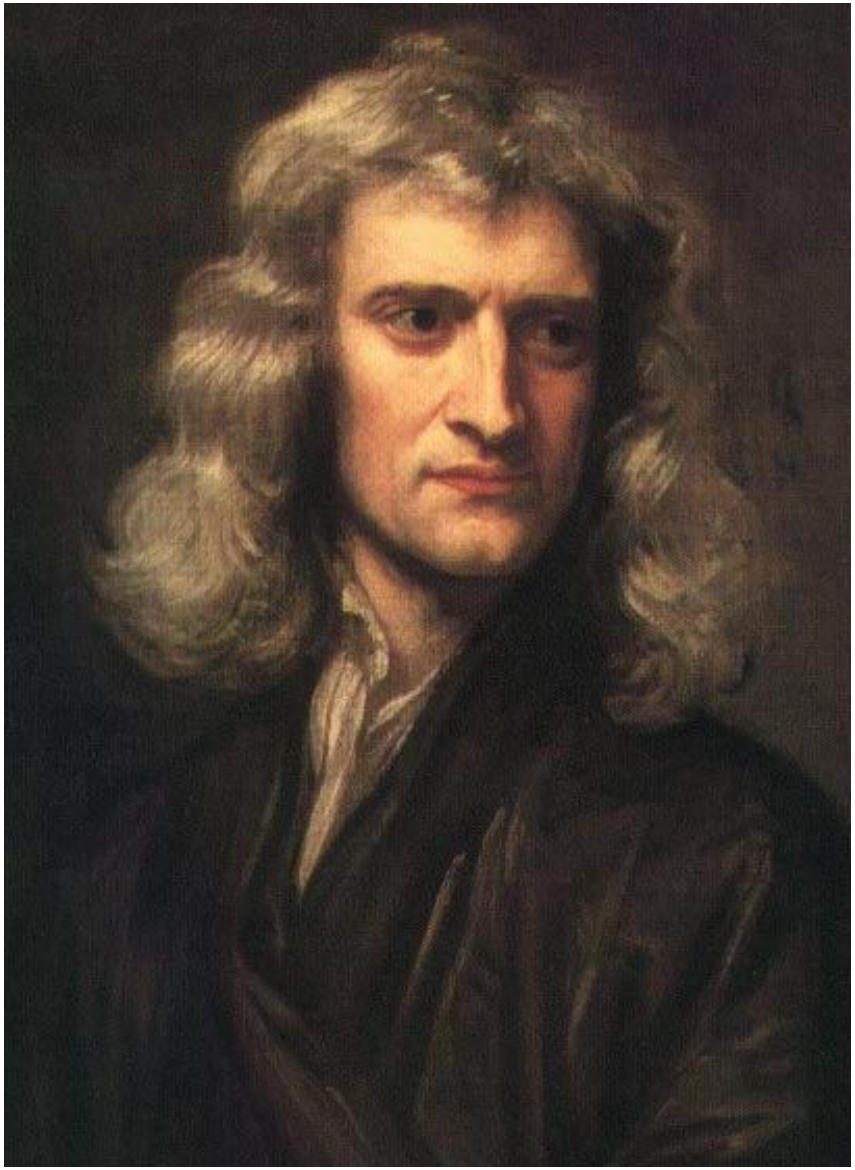
PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J. S. NEWTONO Trin. Coll. Cantab. Soc. Matheseos
Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

# And The Ideas Developed By Him



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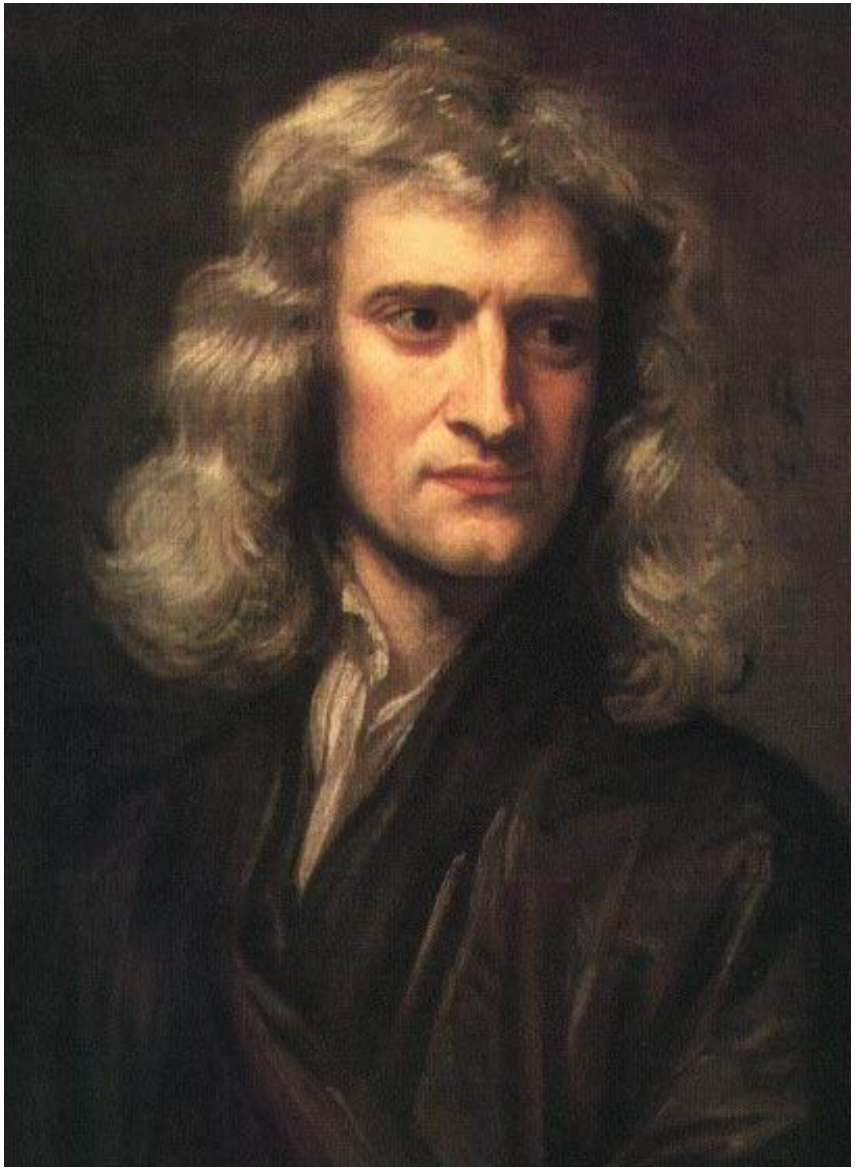

**The Year Was 1687**

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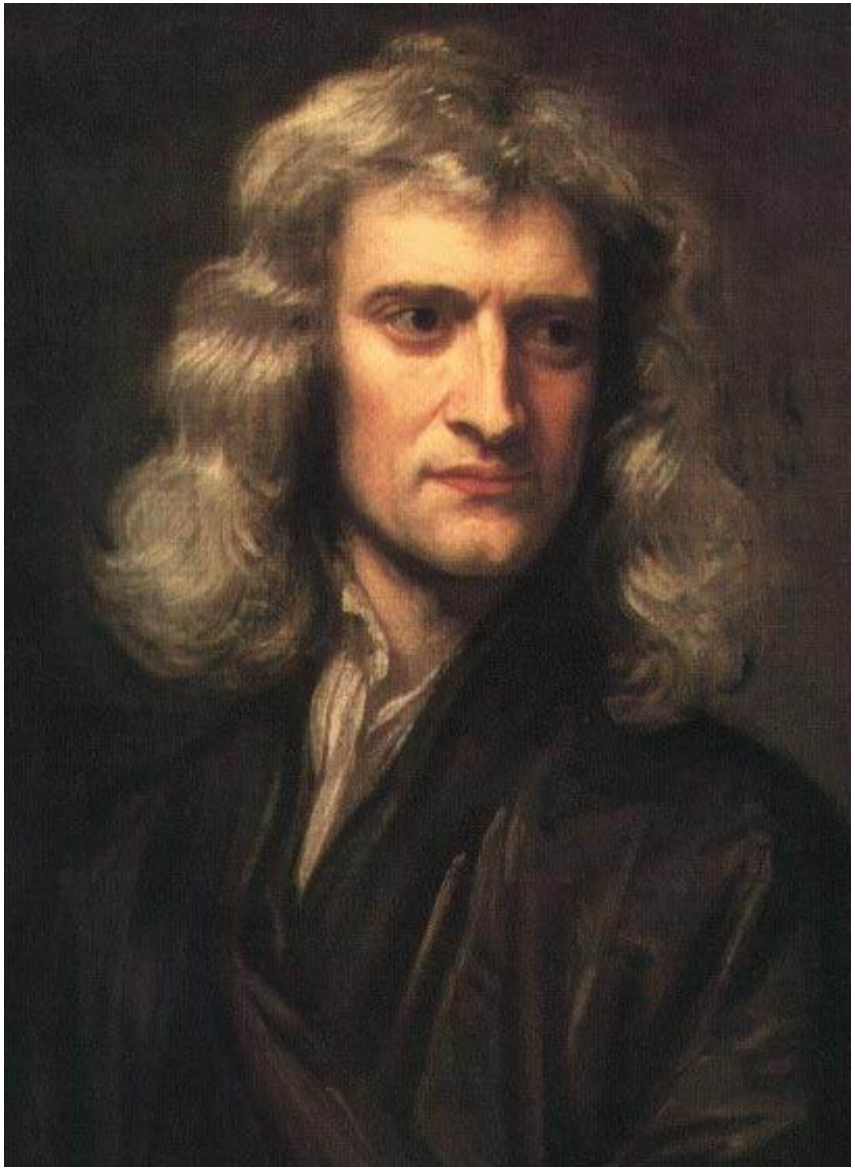

**The Year Was 1687**

**For almost two centuries the theory developed by Newton (and others) ruled supreme. However towards the beginning of the 20th century people started finding cracks in the edifice ...**

# These cracks came from two regions

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- **Exploring very high speeds**

# These cracks came from two regions

- **Exploring very high speeds**
- **Exploring very short distances**

# So First: What happens when we explore short distances?

**It is now known that the theory there should be Quantum Mechanics whose main result can be summarised by one line**

# Nature is probabilistic i.e Uncertainity rules supreme

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**or, more appropriately, just like coin toss! Before you toss the coin you'll never know the outcome!**

**The former idea was proposed by Erwin Schrodinger**

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**And the latter idea was presented by Werner Heisenberg**

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**Quantum mechanics is a strange theory which, fortunately, is visible only at very short distances! If it was visible at large distances, then we would see the following:**

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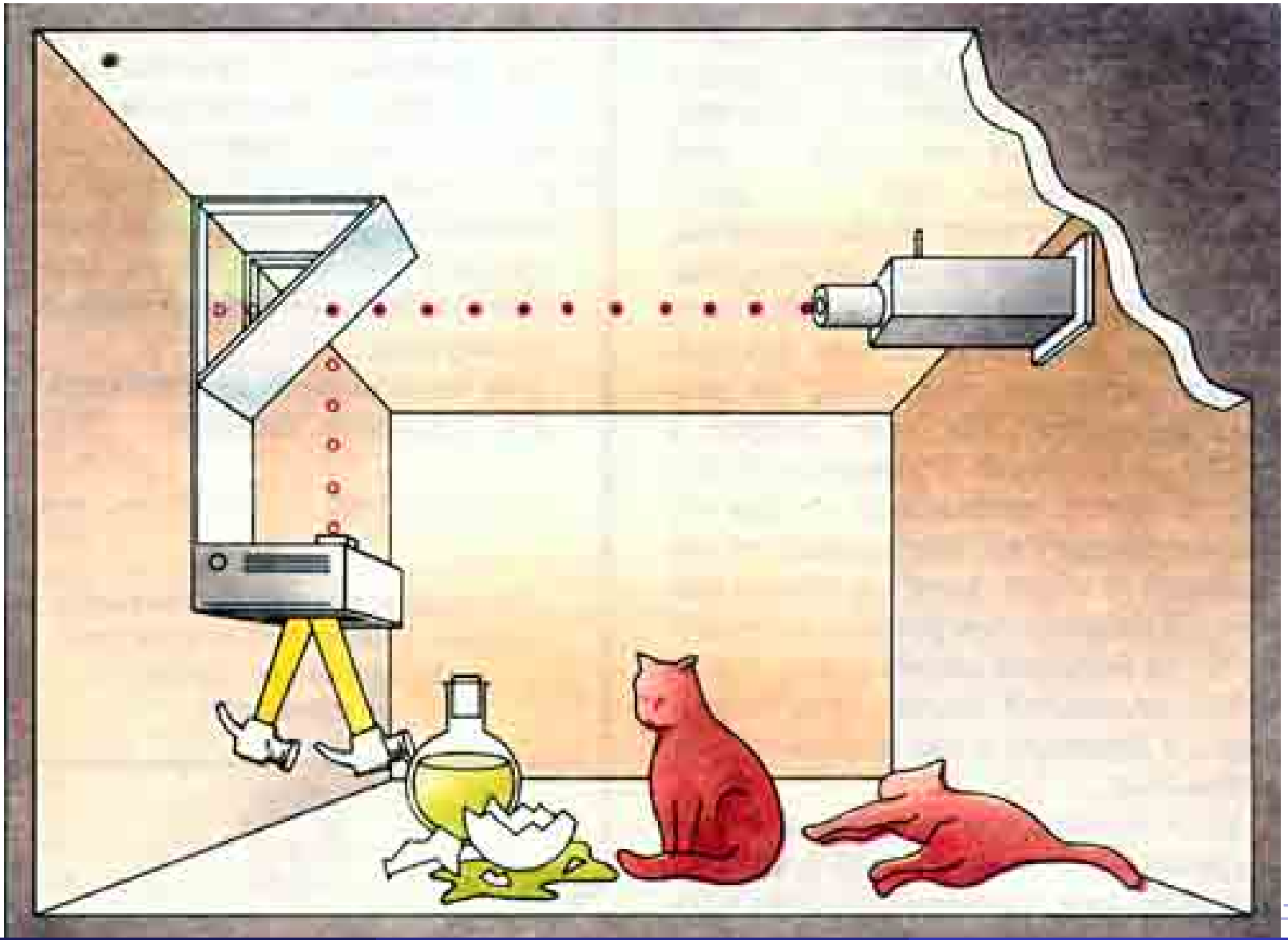

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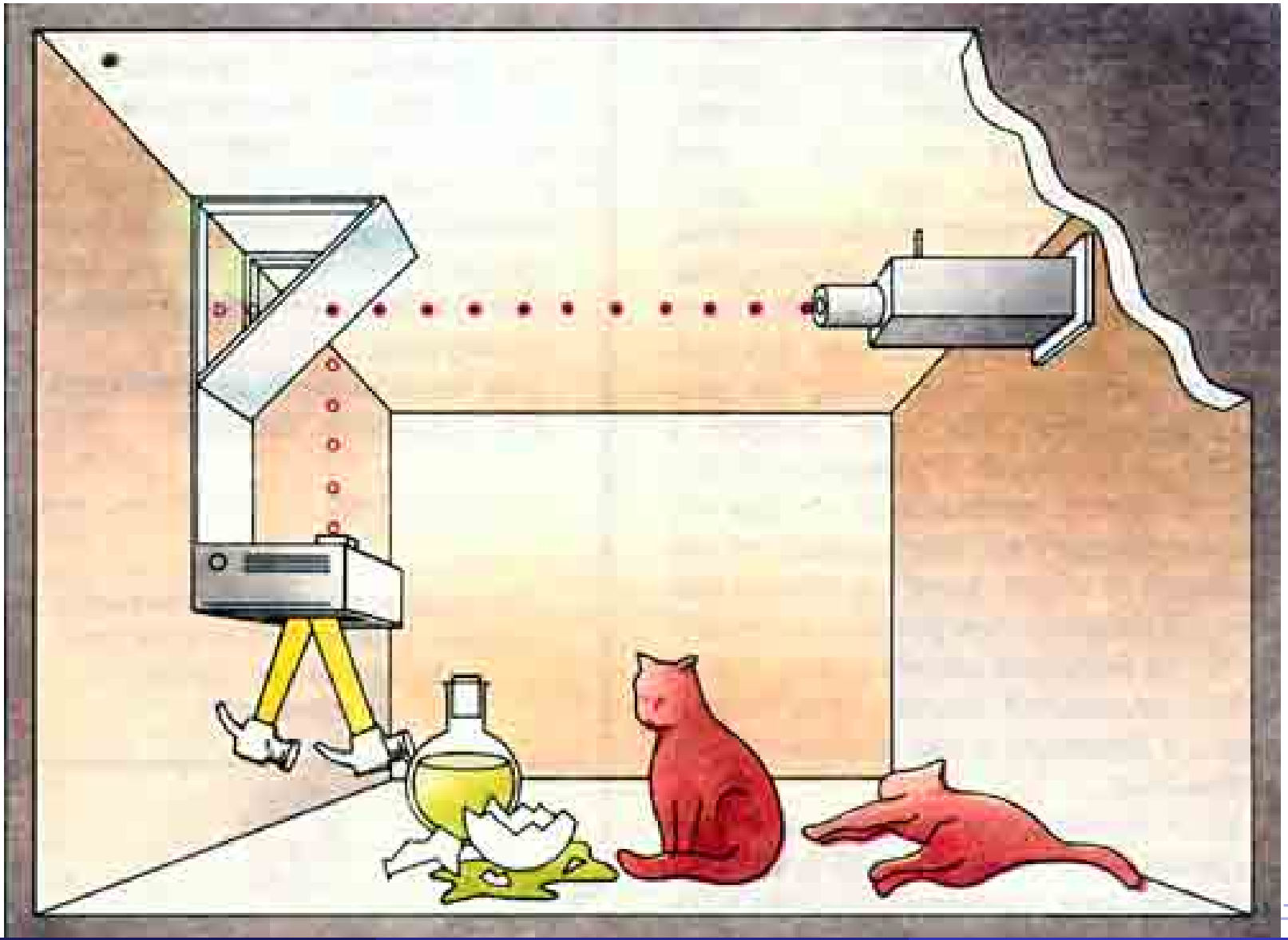

# Which means we would never be sure if the cat is dead or alive, unless we make a measurement!

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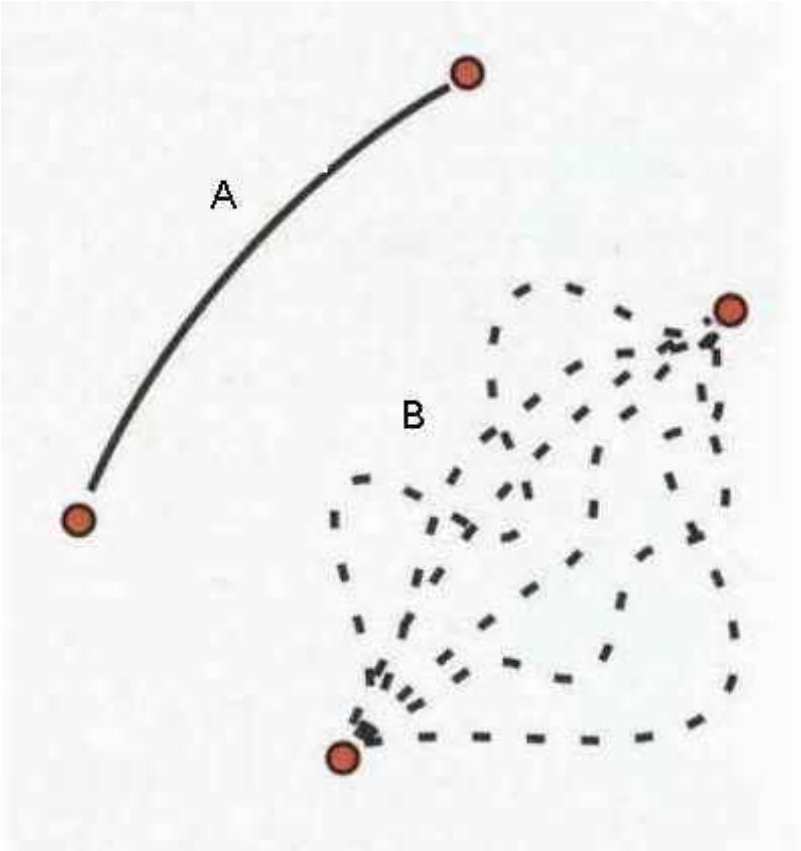

**These were all developed around 1927**

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**It was the best of times and it was the worst of times!**

**These ideas were very beautiful, and very very revolutionary. At that time the key person who really understood both these ideas was**

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# Neils Bohr

**In fact he understood the subject so well that he made the following comment**

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**"If Quantum Mechanics hasn't profoundly shocked you, you haven't understood it yet!"**

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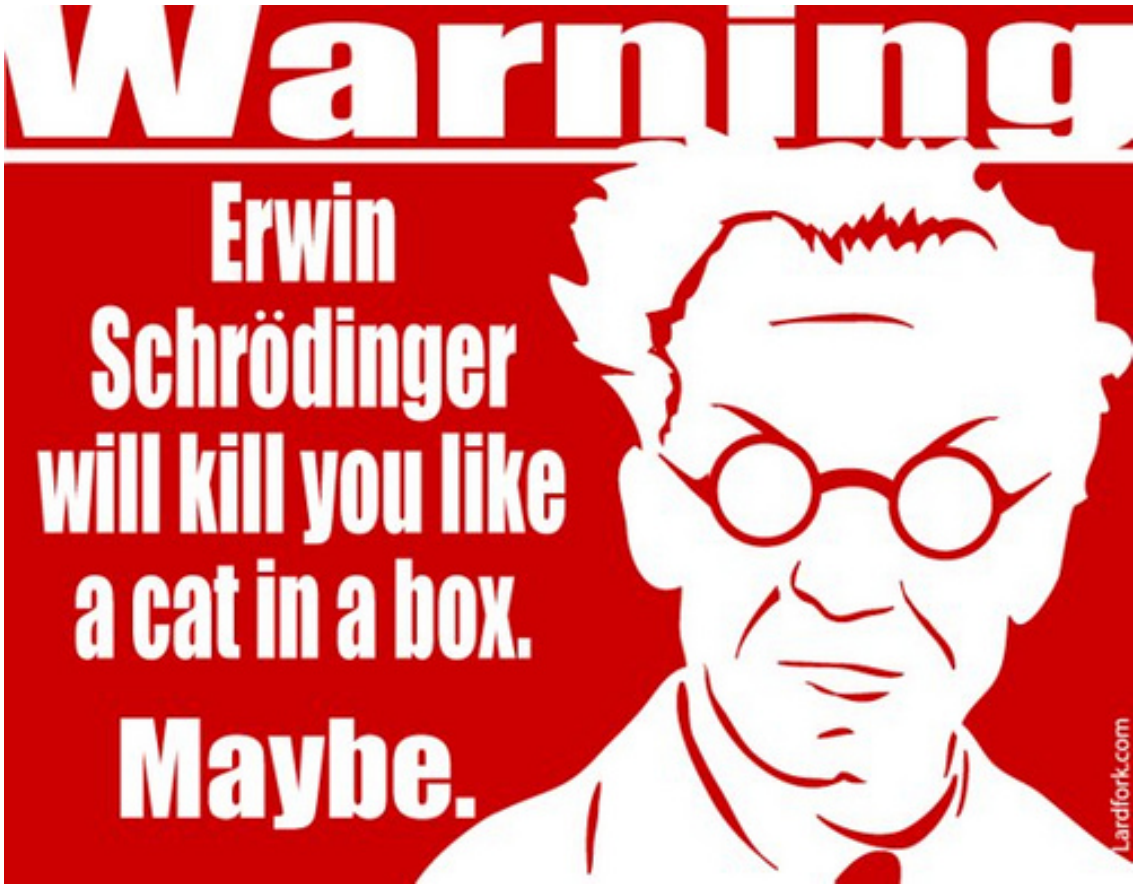

**But then there was one person who was really disturbed by Quantum Mechanics**

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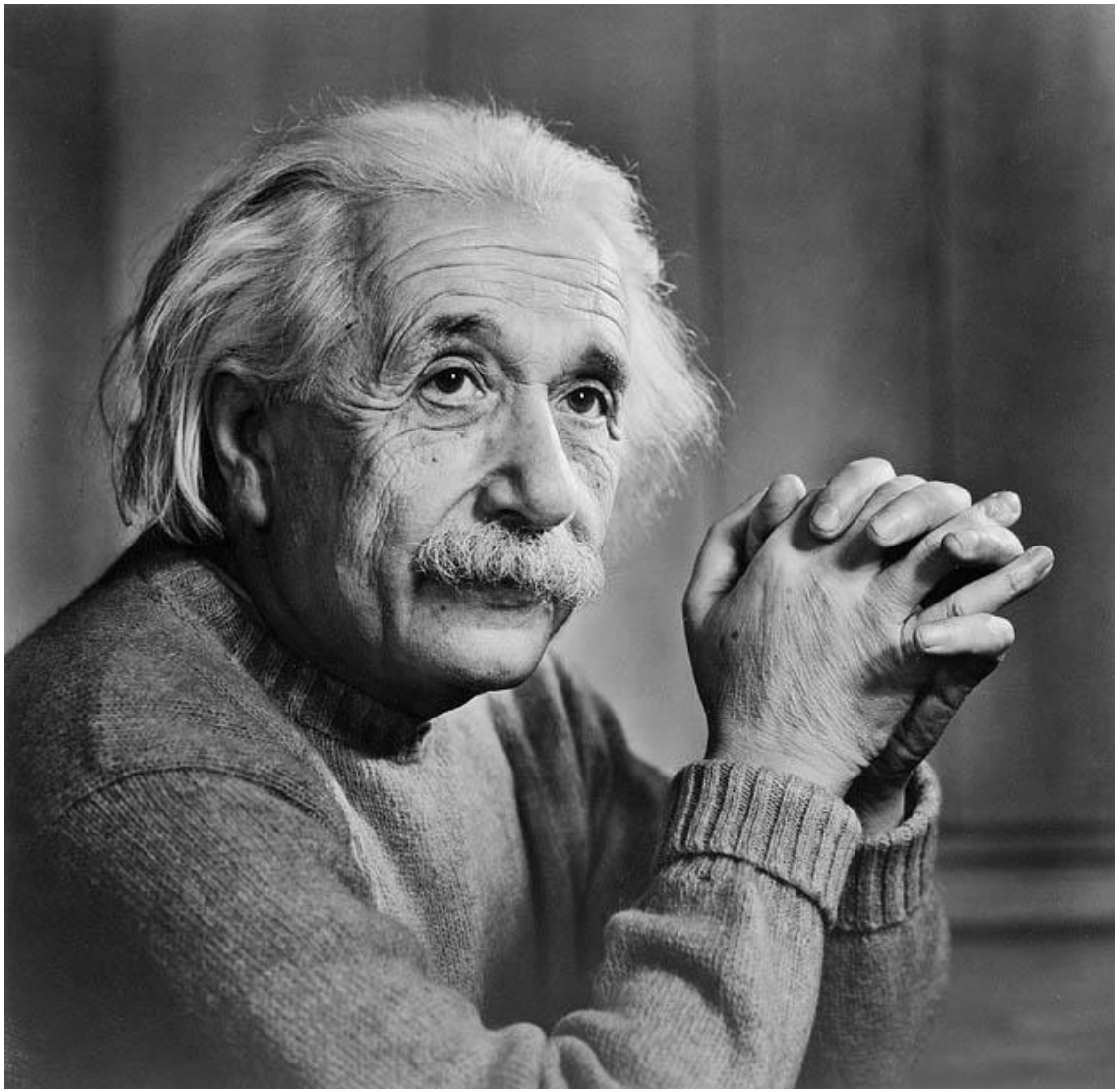

## Einstein said

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**Quantum Mechanics cannot be the right theory of nature, because it is hard to believe that God plays with dice!**

## To which Bohr replied

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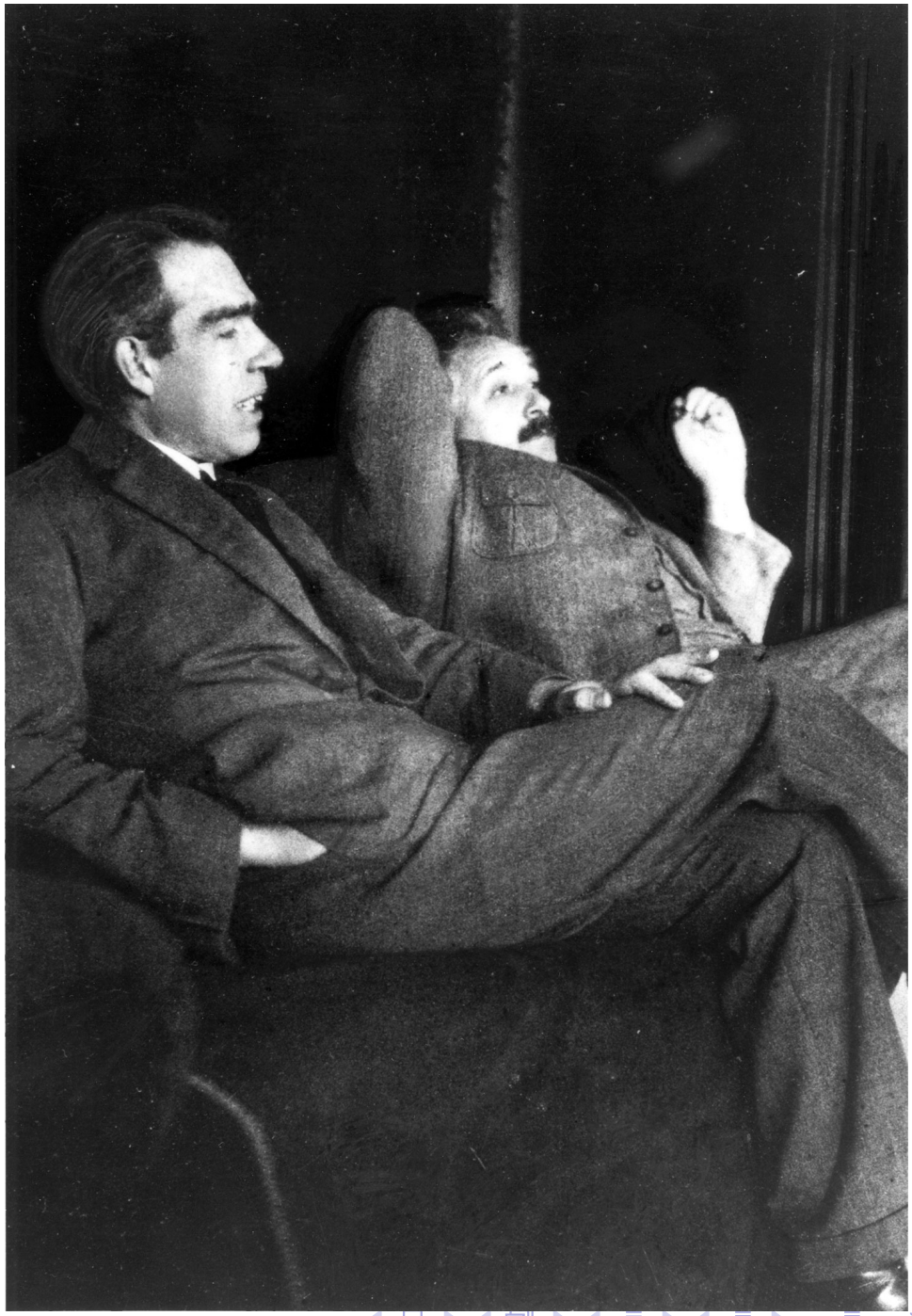
# Einstein, stop telling God what to do!



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# Special Theory of Relativity: at uniform speeds

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# Special Theory of Relativity: at uniform speeds

# General Theory of Relativity: at non-uniform speeds

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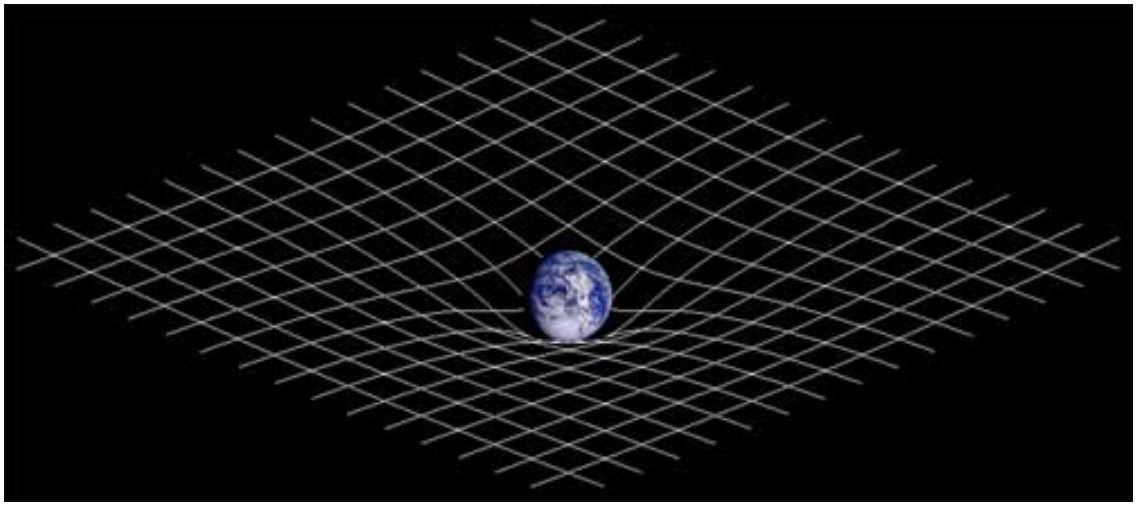

**So gravity is simply a distortion of geometry!**

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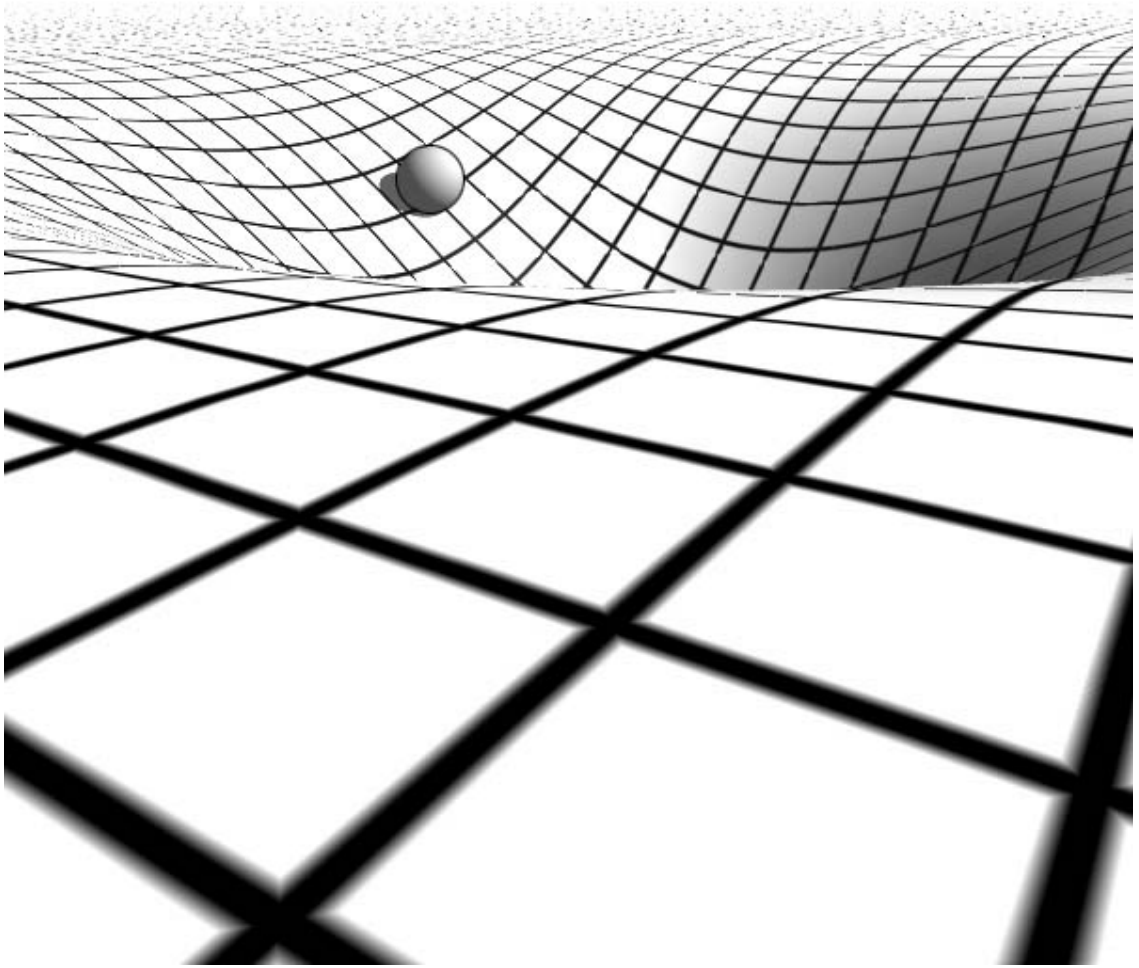

- **For Einstein this was nice and elegant because everything was precise and there was no ambiguity or uncertainity...**

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- **Yet Quantum Mechanics was right, so was General Theory of Relativity!**

**So whats going on? Does nature behave differently as we explore different limits?**

- **To investigate this first let us go to the limit where we can have**

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- **Short Distances**
  **+ High Speeds**

- **To investigate this first let us go to the limit where we can have**
- **Quantum Mechanics**
  **+ High Speeds**

- **To investigate this first let us go to the limit where we can have**
- **Quantum Mechanics + Special Theory of Relativity**

- **To investigate this first let us go to the limit where we can have**
- **Quantum Mechanics**
  **+ Special Theory of Relativity**
  **= QUANTUM FIELD THEORY**

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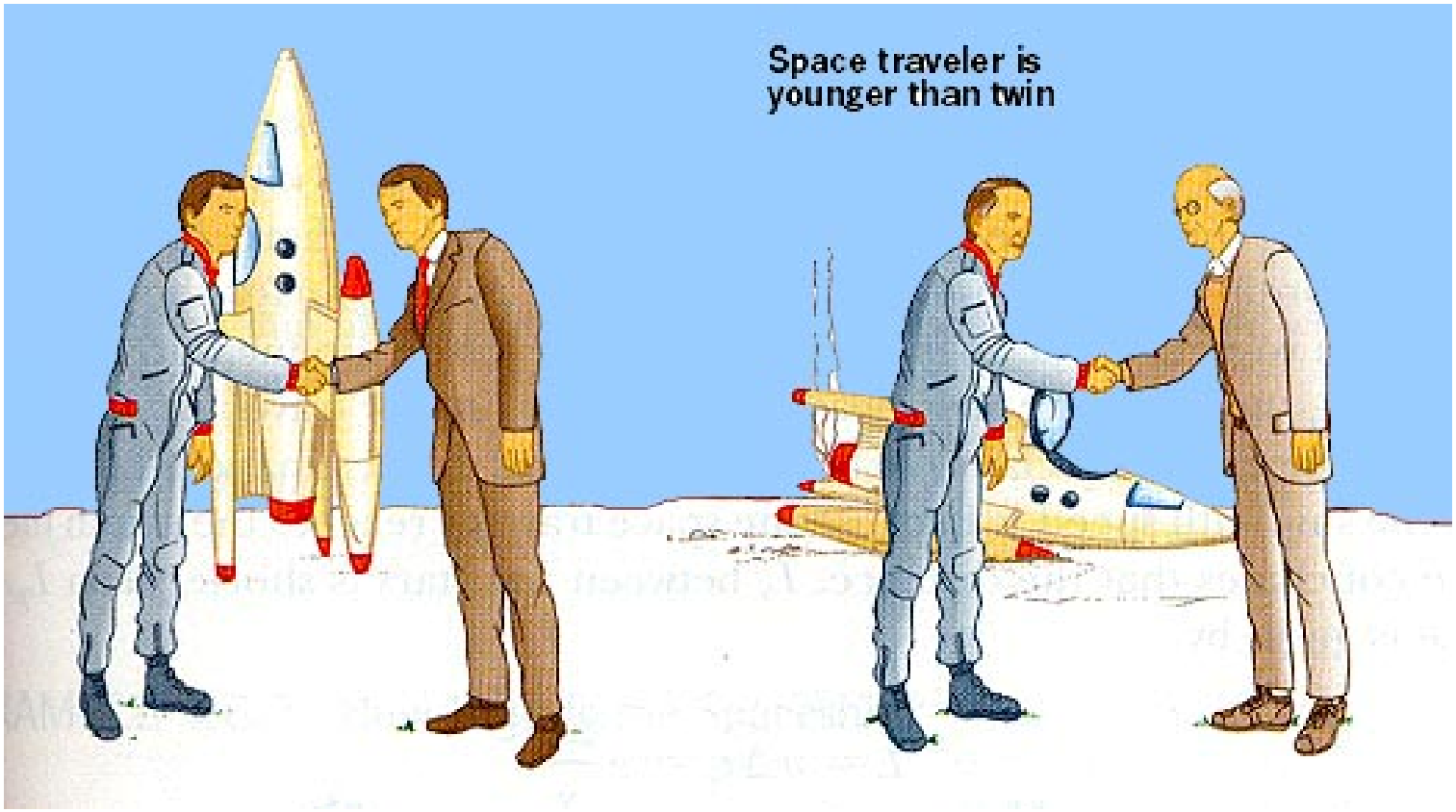

# And length contraction

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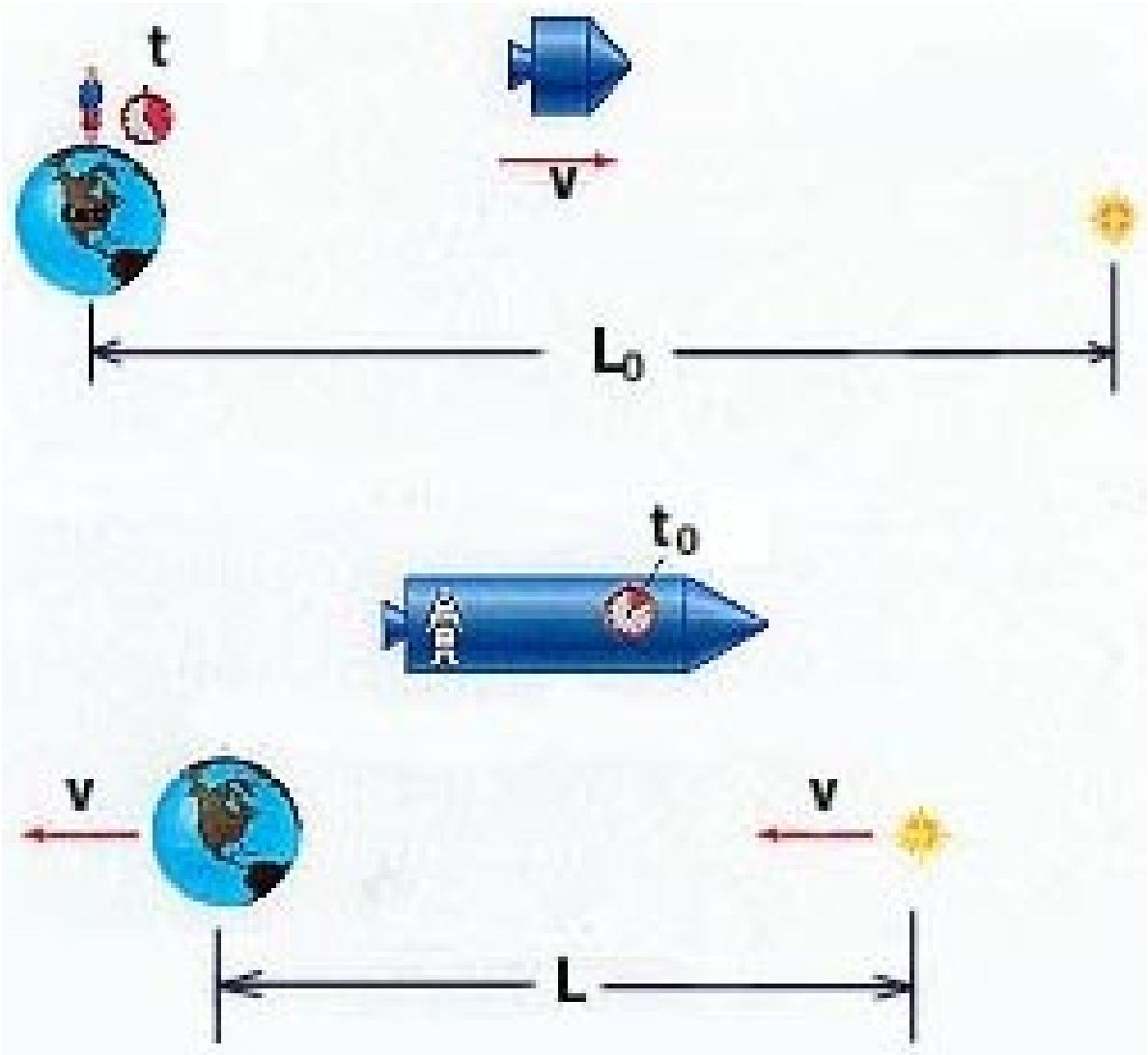

# Take 1: Lets mix QM with STR

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**What do we really get?**

# Well ...

# Well ...

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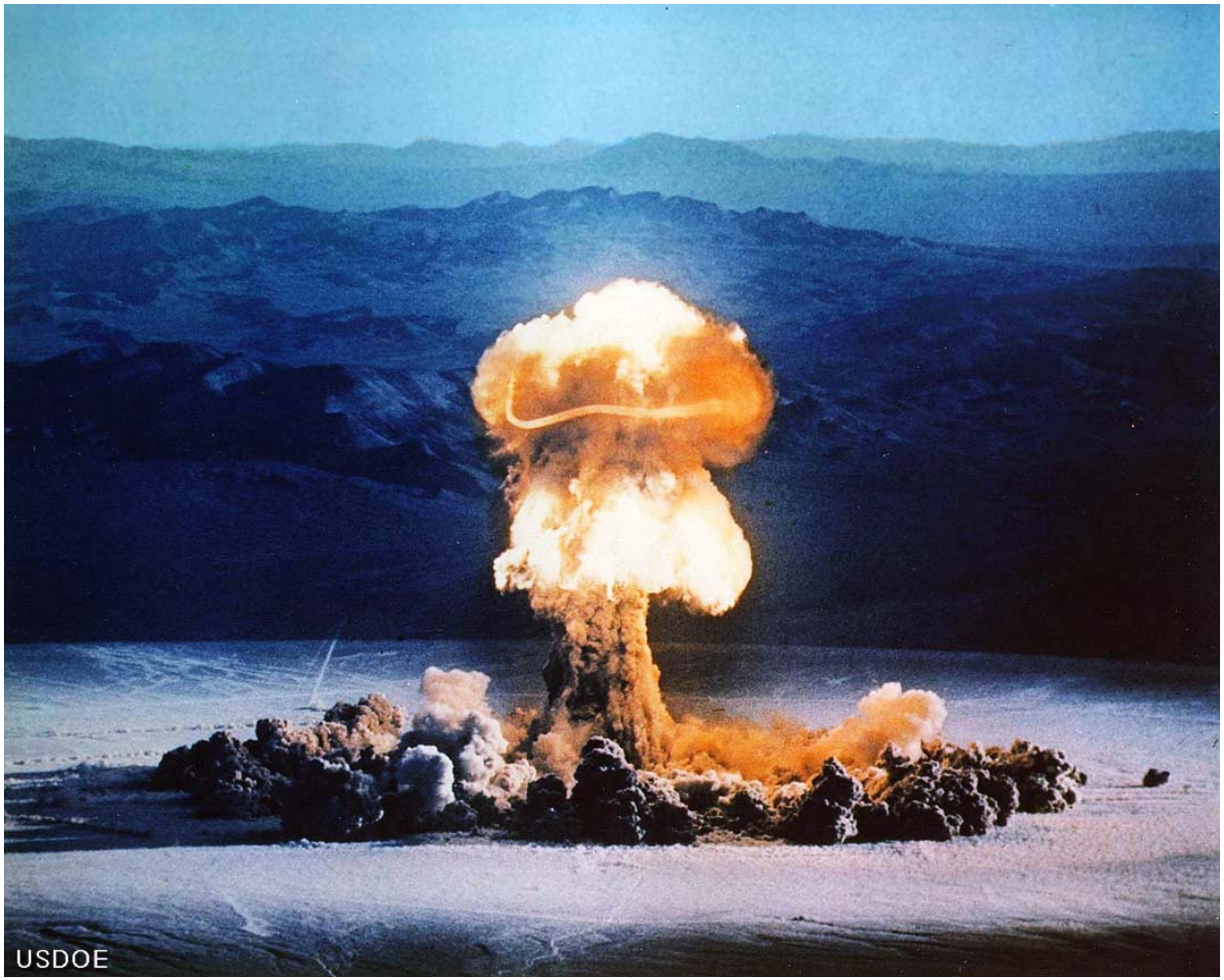


# More appropriately: disaster!

# What did we miss?

## What did we miss?
## After much confusion

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## After much confusion

## and anger..

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## After much confusion

## and anger..

**It was eventually suggested by Feynman**

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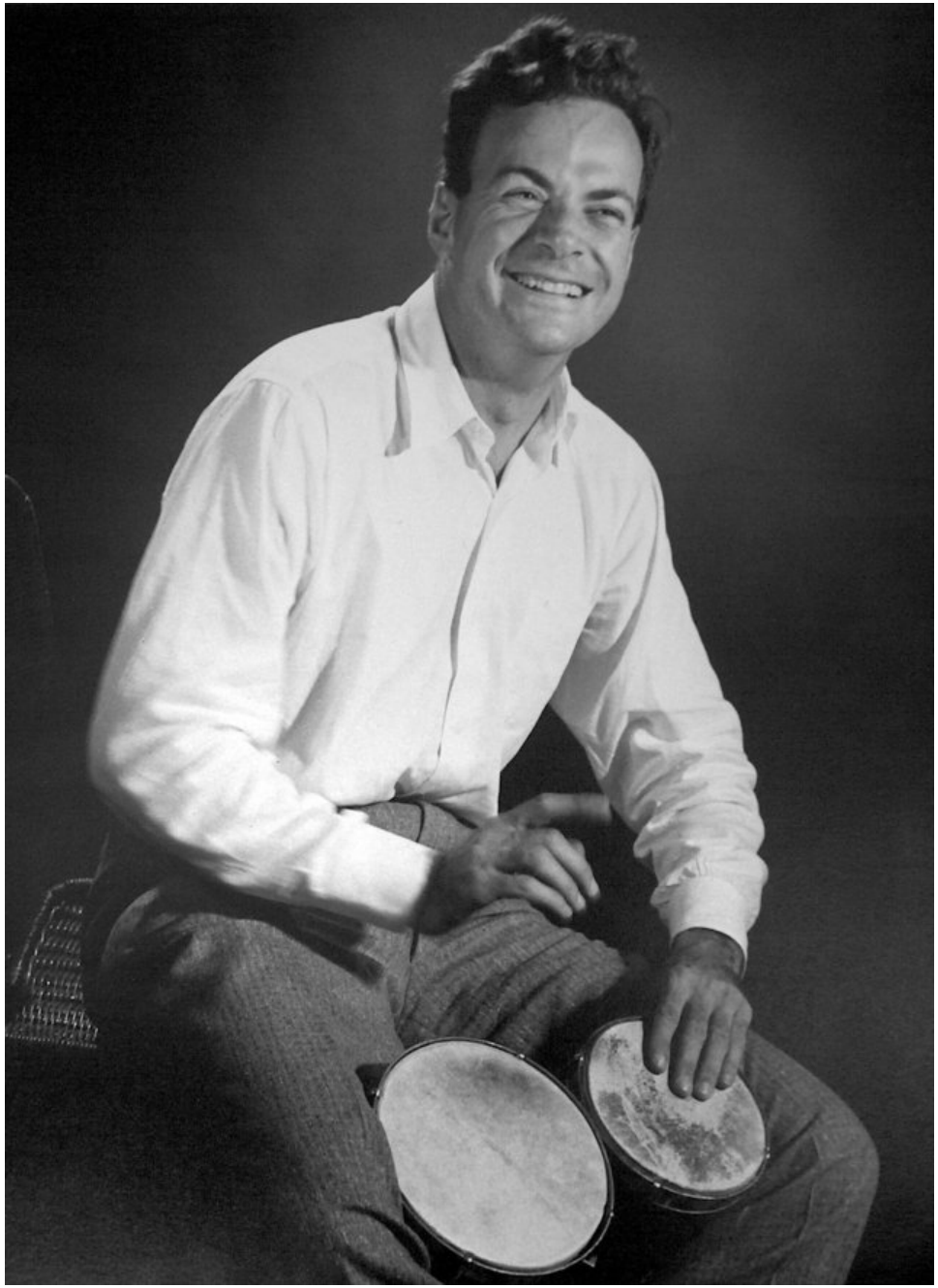
**and others...**



# Quantum Mechanics + STR + Renormalisation

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**= Something really nice and consistent**

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For example QED: Quantum Electrodynamics

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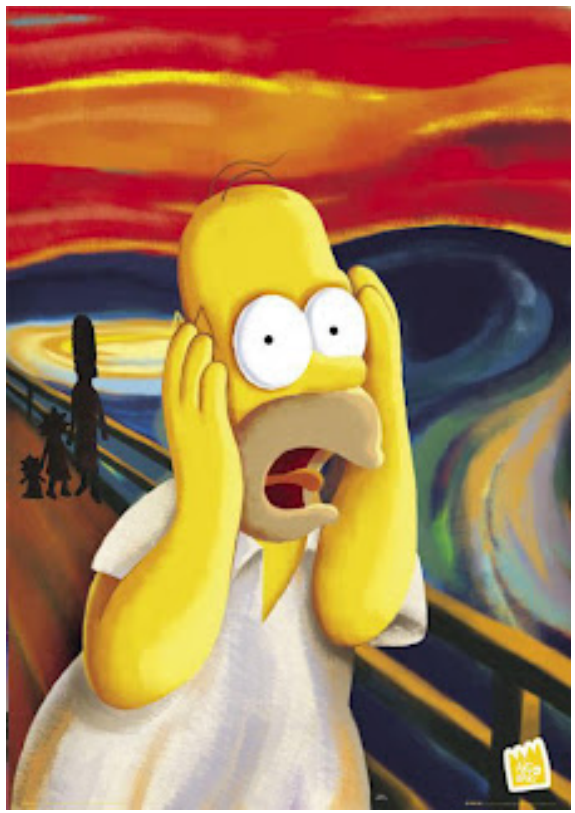

# Well it works, thats what matters, right?

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# This would make life very simple!

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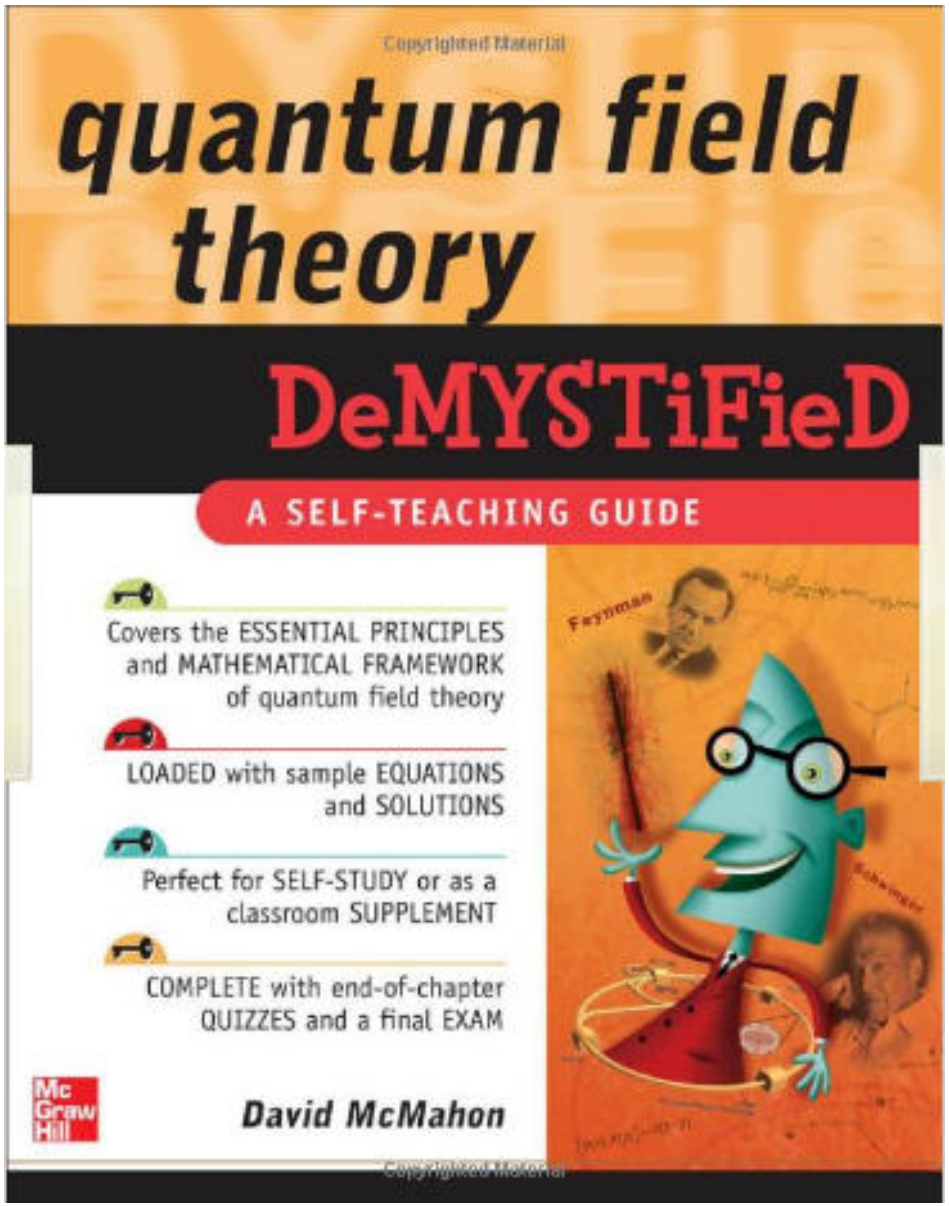

**So simple that we bring the cook again and mix**

**QM + General Theory of Relativity + Renormalisation**

**This should give us the ultimate nice theory that explains everything!**

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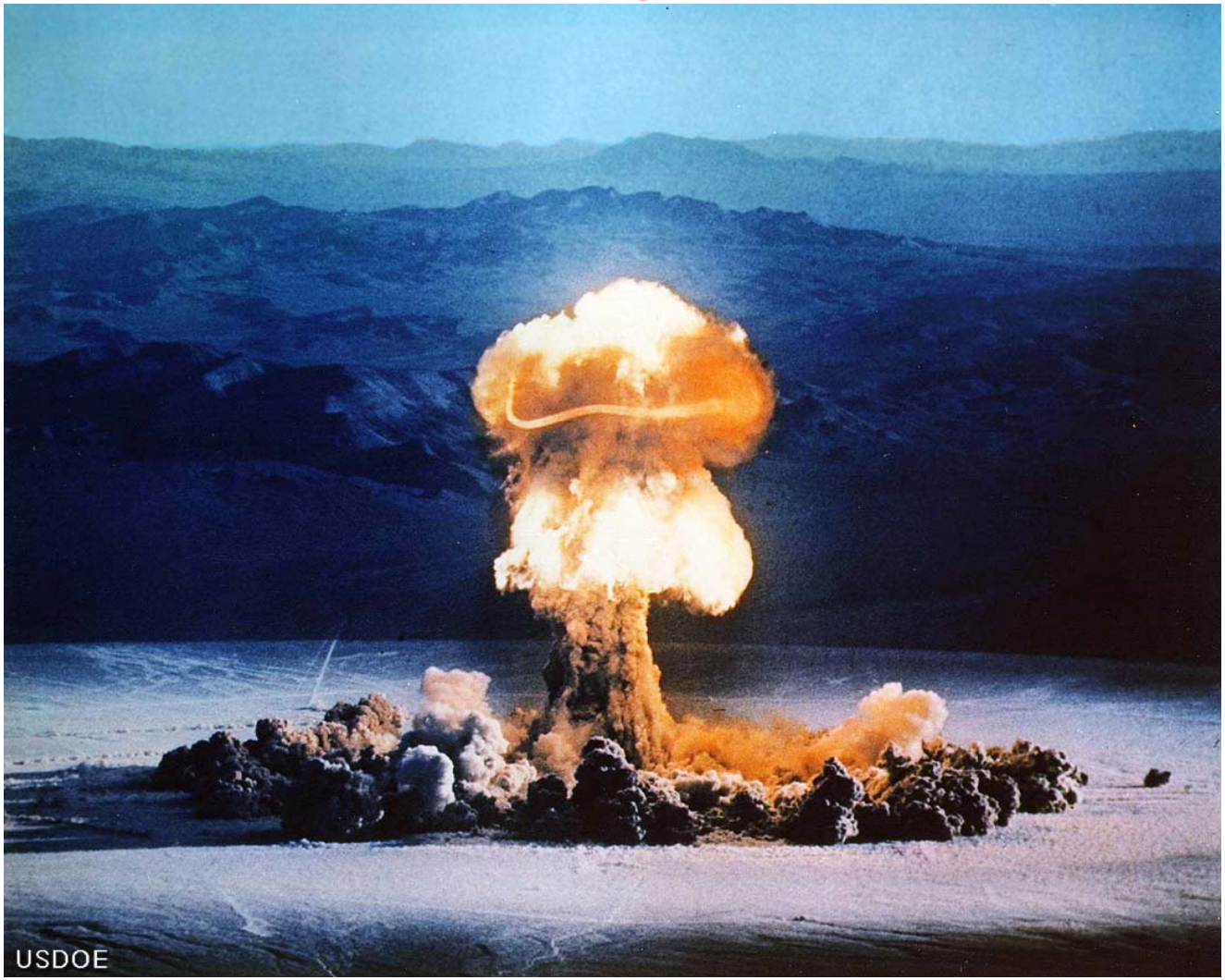
**So what do we get?**

# Unfortunately



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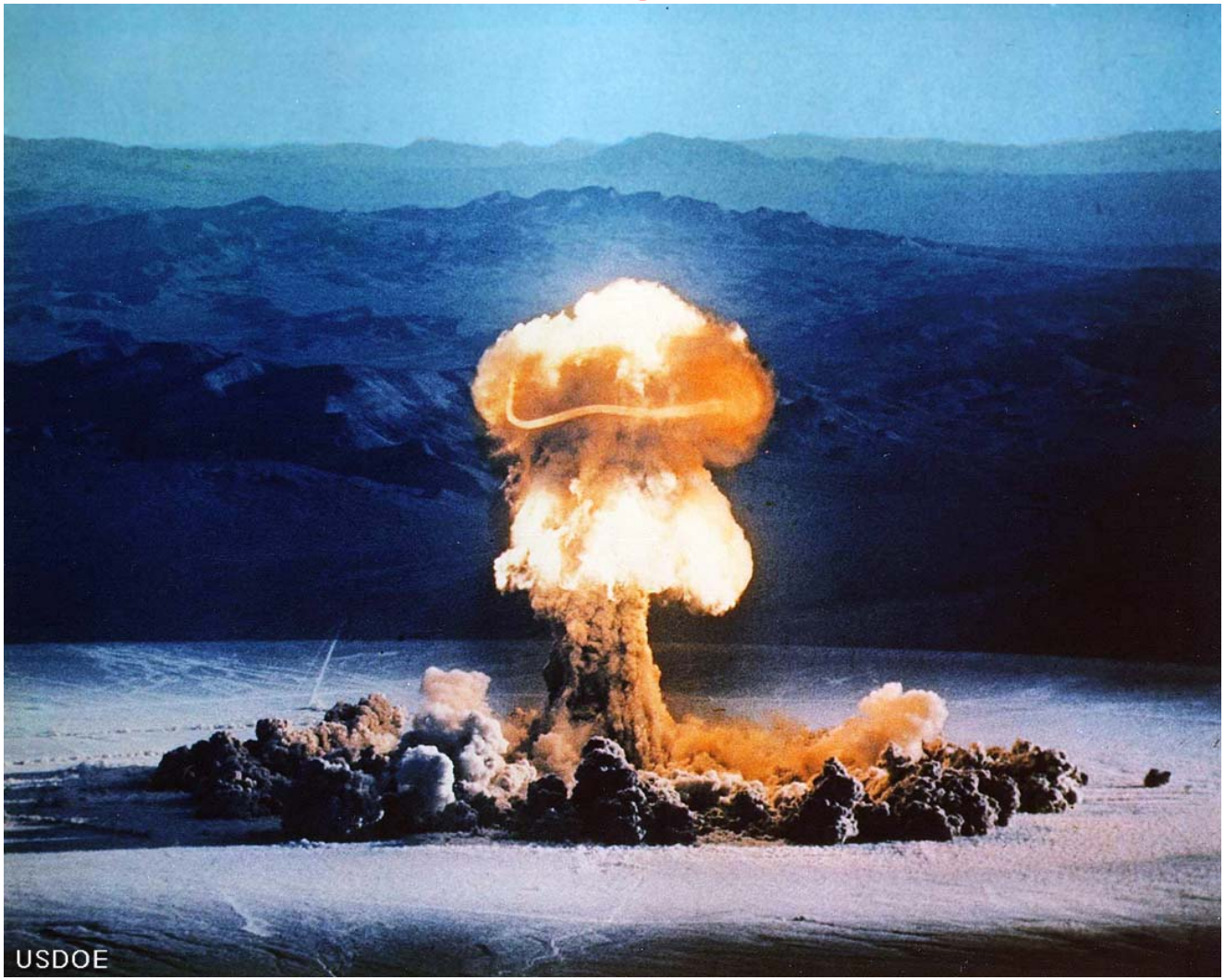


**What went wrong now??**

# After much thinking

**After much thinking**

**And this time it required a lot of thinking!**

**After much thinking**

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**It was realised that the problem was created by point particles**

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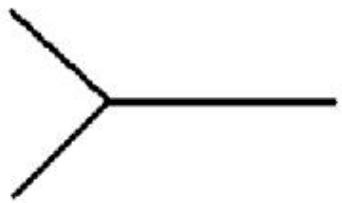
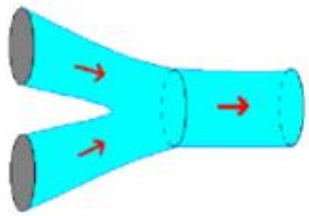
**Thus point particles have to be replaced by vibrating strings!**





# To understand how string theory changes the interaction “diagrams”, let us first draw a space-time picture

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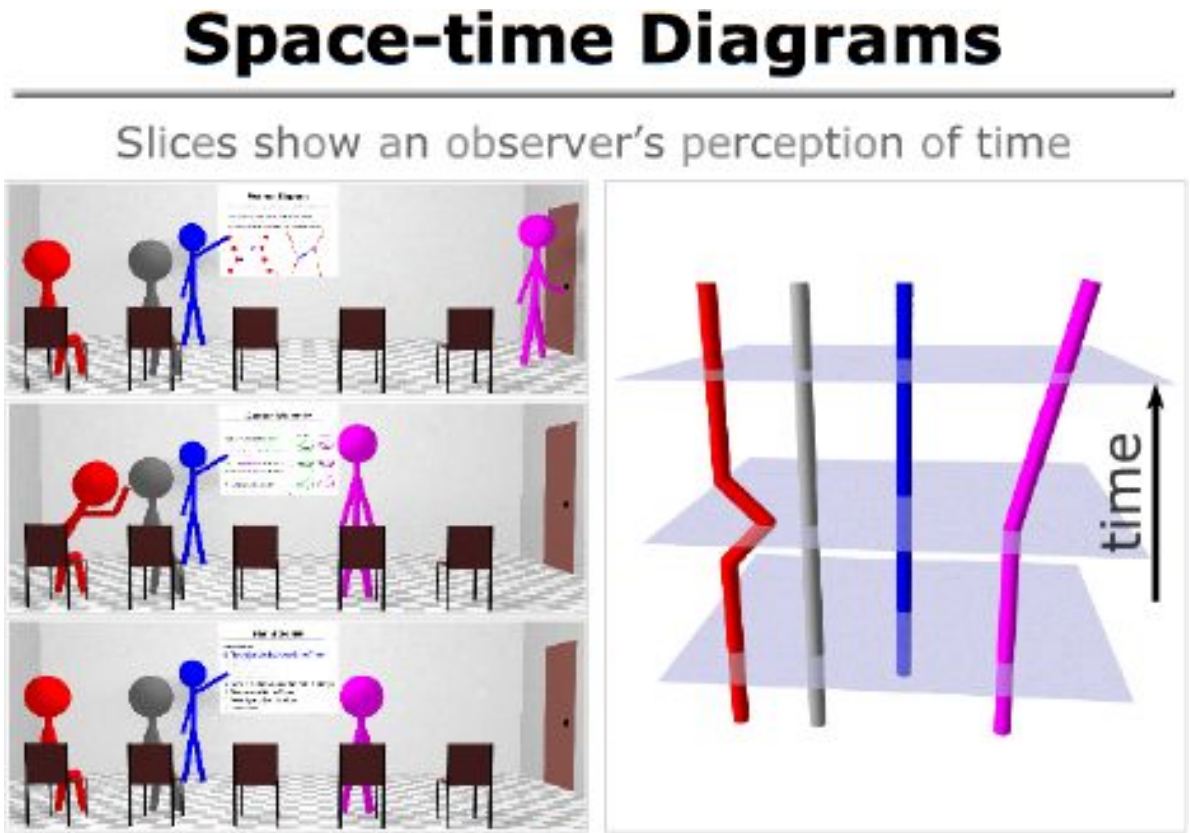

# This means that the “Feynman diagram” would be the following

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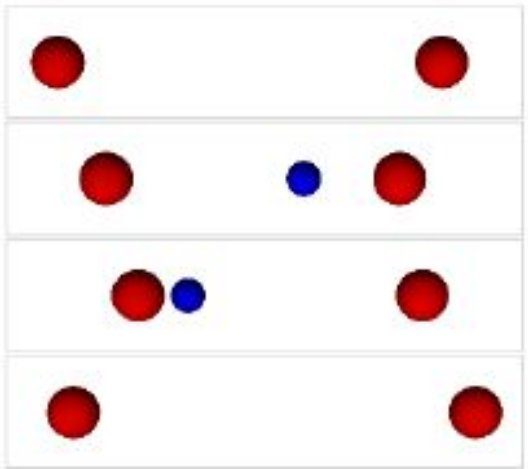
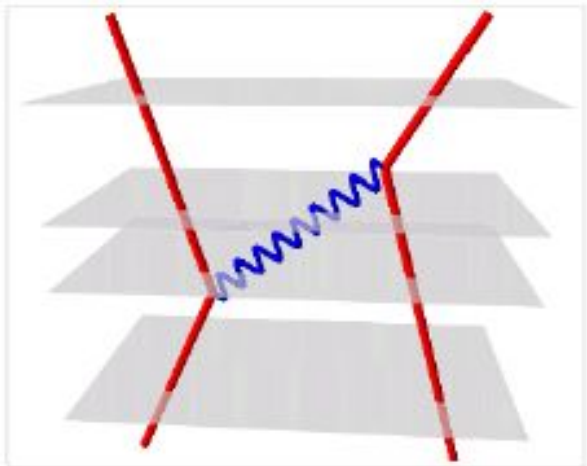
## Feynman Diagrams

Pictures of processes in Quantum Field Theory

- Interactions occur at specific points in space-time
  - Equations sometimes break down when there are special points!
- Each diagram can be associated with a complex number





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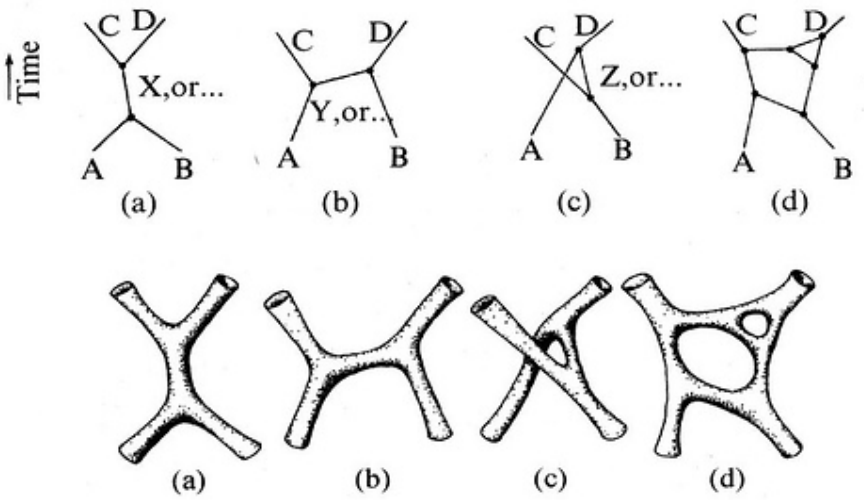

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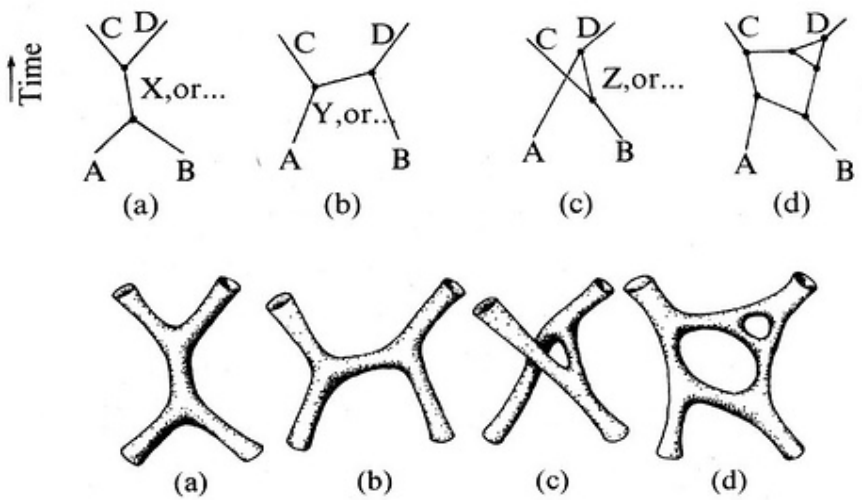


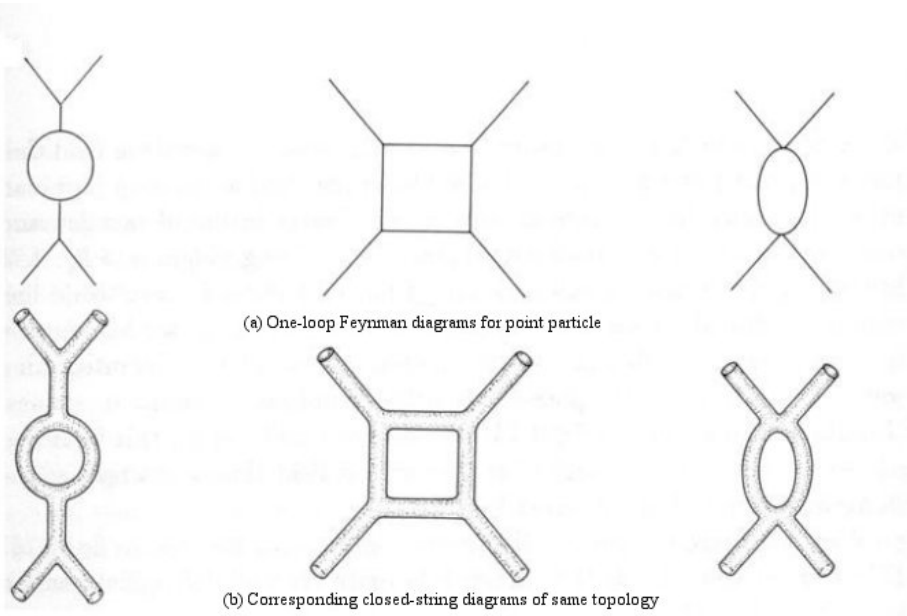

**Such a situation should get rid of all the problems and nothing should blow up again!**

**Such a situation should get rid of all the problems and nothing should blow up again!**

**Thus string theory was born.**

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**This was around 1970**

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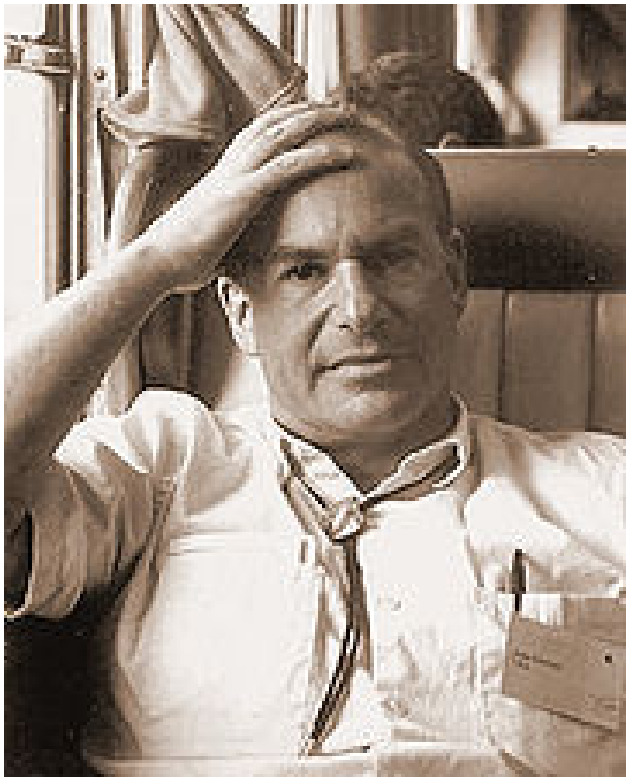

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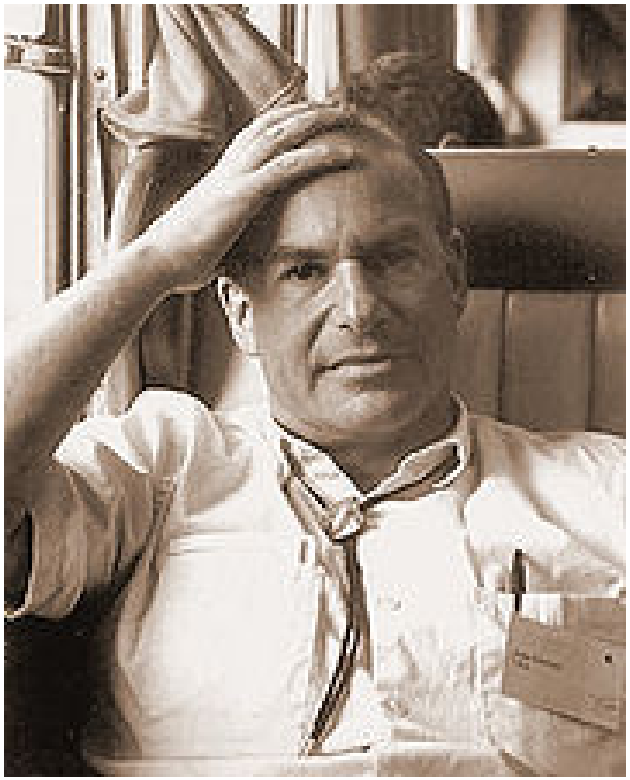

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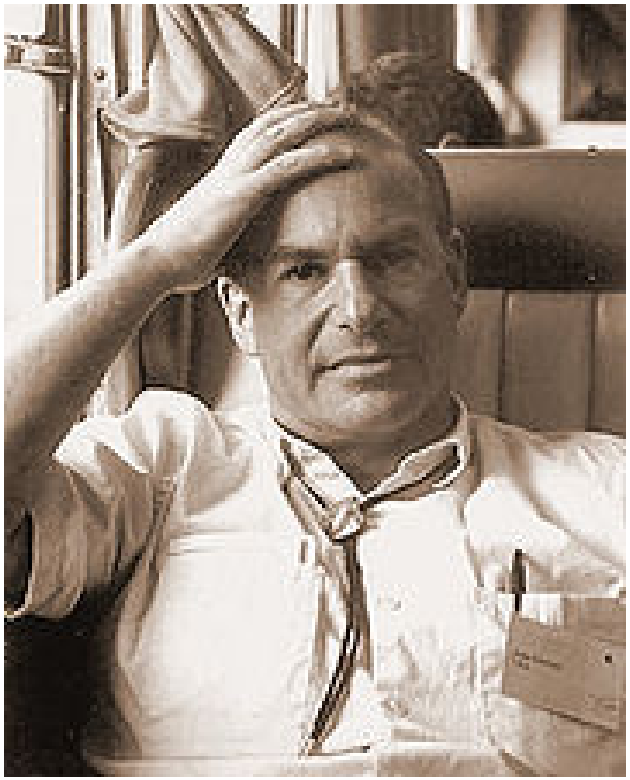

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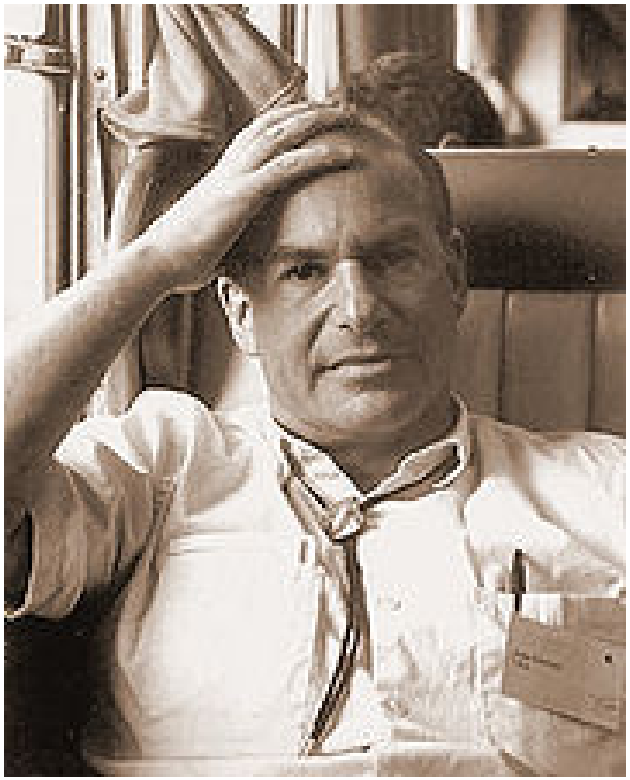

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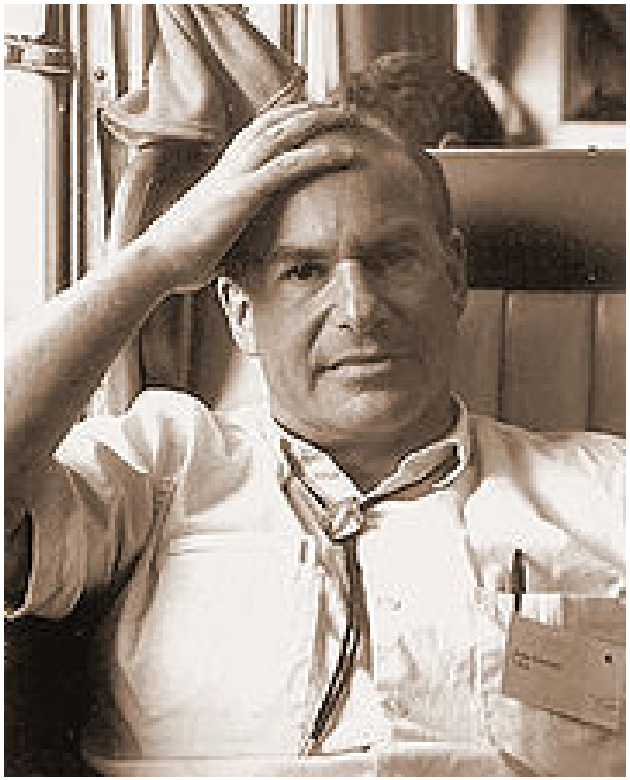

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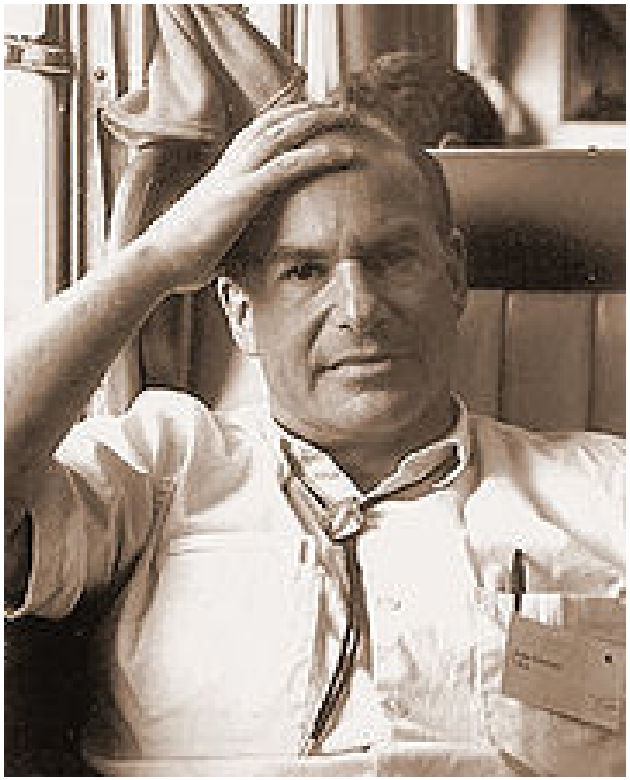

**John Schwarz**

**Michael Green**

**Edward Witten**

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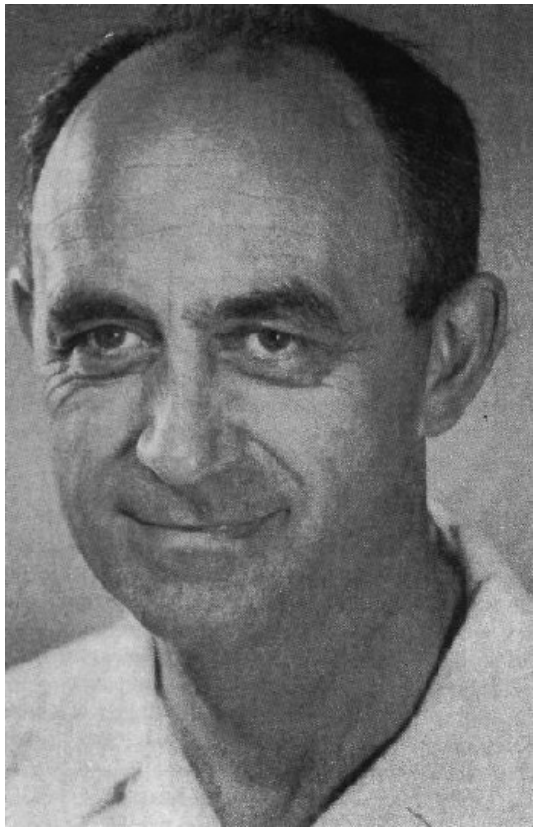

# The fermions also satisfy the Pauli Exclusion Principle, developed by Wolfgang Pauli

# The PEP says that no two fermions like each other!

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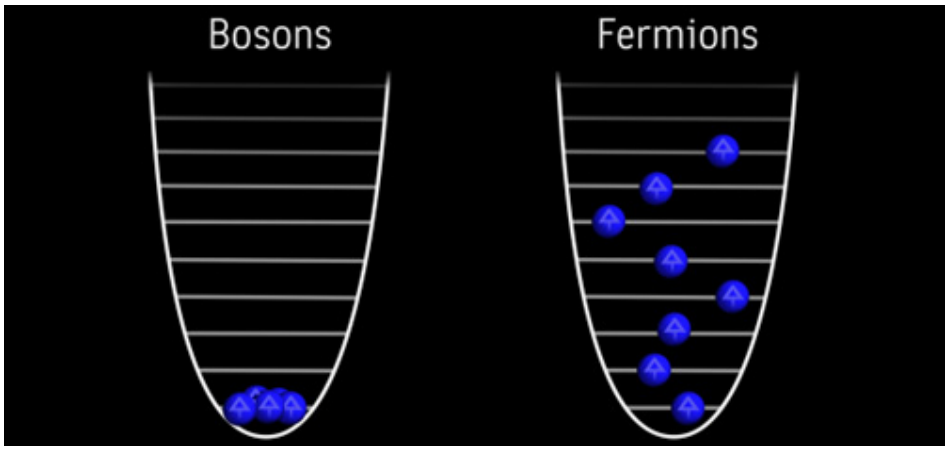

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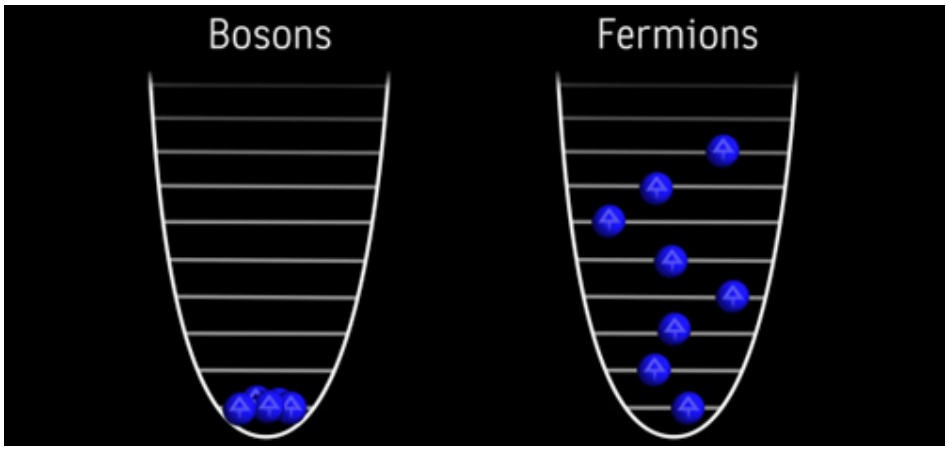


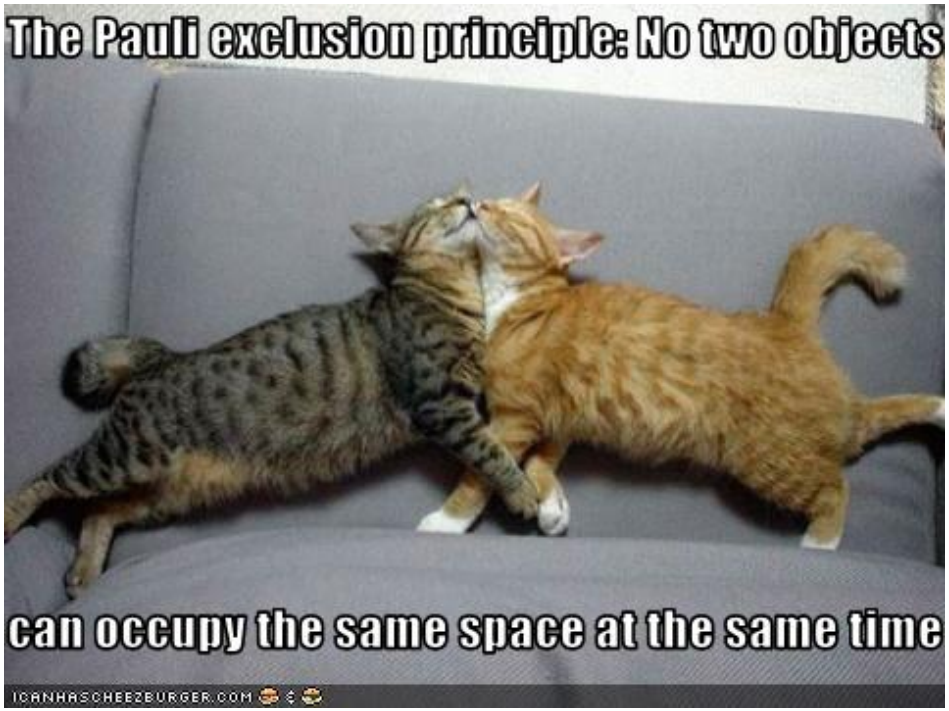

**However the string theory that we developed had three sides:**

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**The Good, The Bad and The Ugly!**

# The Good

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- **Theory reproduces Einsten General Theory of Relativity**

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- **Theory reproduces Einsten General Theory of Relativity**
- **Theory doesn't blow up**
- **Seemed perfectly consistent with Quantum Mechanics**
- **Predicts the existence of gravity particles called graviton, much like the bosons that we discussed**

# The Bad

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- **Any other lower/higher dimensions we face inconsistency**
- **Our observable universe is 3+1 dimensions, so we need to account for 22 extra dimensions**

# The Ugly

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- The theory has an imaginary mass particle, also known as the Tachyon that moves faster then light, violating STR
- So at best the theory is not well defined in the present form, but could be ok if certain modifications are made
- At worst, we have got the wrong theory

# What did we miss now?

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**Well, we haven't exploited one possible property of the particles**

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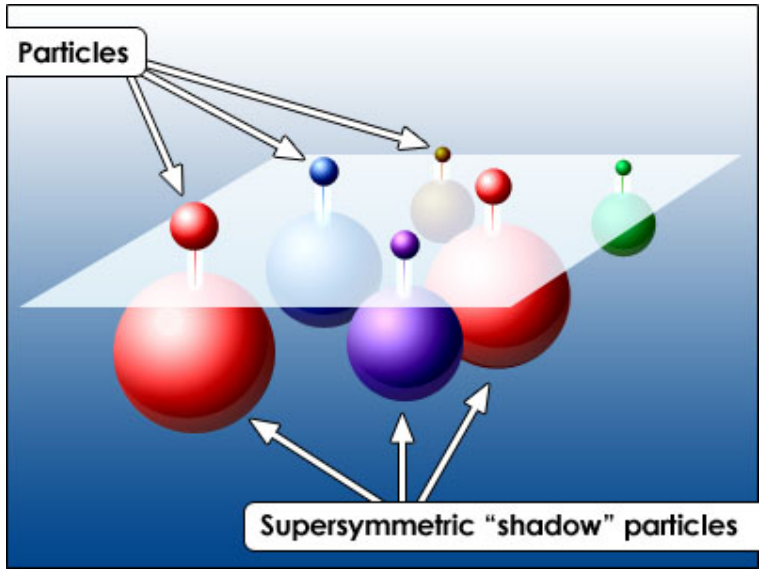
**Well, we haven't exploited one possible property of the particles**




**The existence of supersymmetry as a possible new symm!**

# Supersymmetry is based on the following idea

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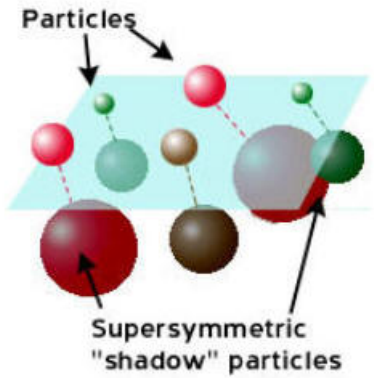


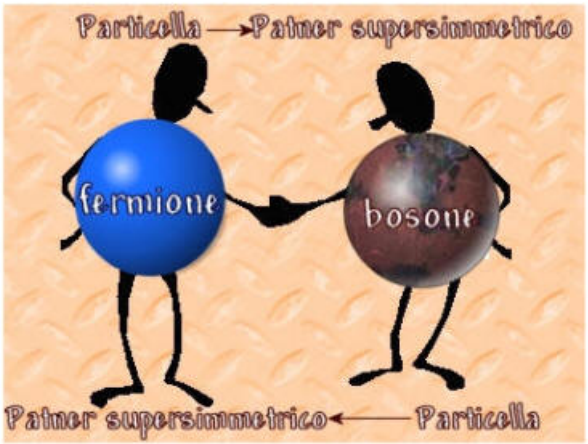


- **This is of course a conjecture and can only be proved experimentally**

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- **But let us assume that it is true...**

# So we bring our cook back and add all the ingredients

# So we bring our cook back and add all the ingredients

# Strings + Supersymmetry

# So we bring our cook back and add all the ingredients

# Strings + Supersymmetry

# What do we get now?

# We get this

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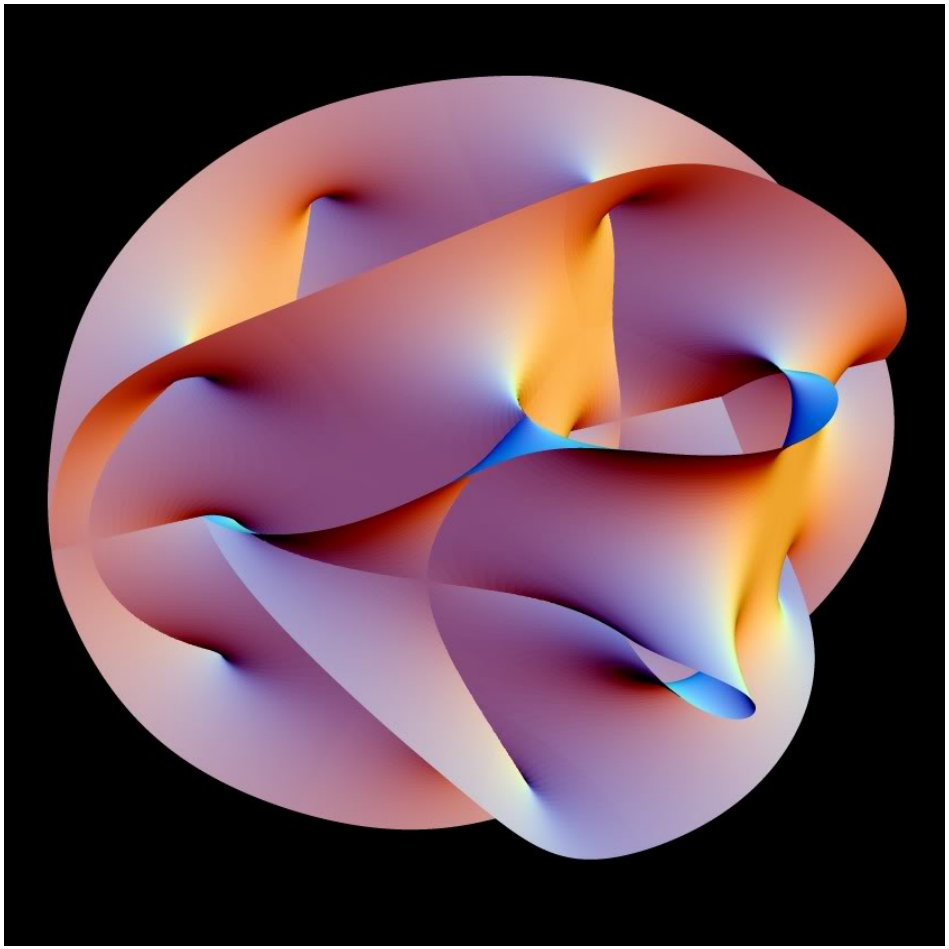

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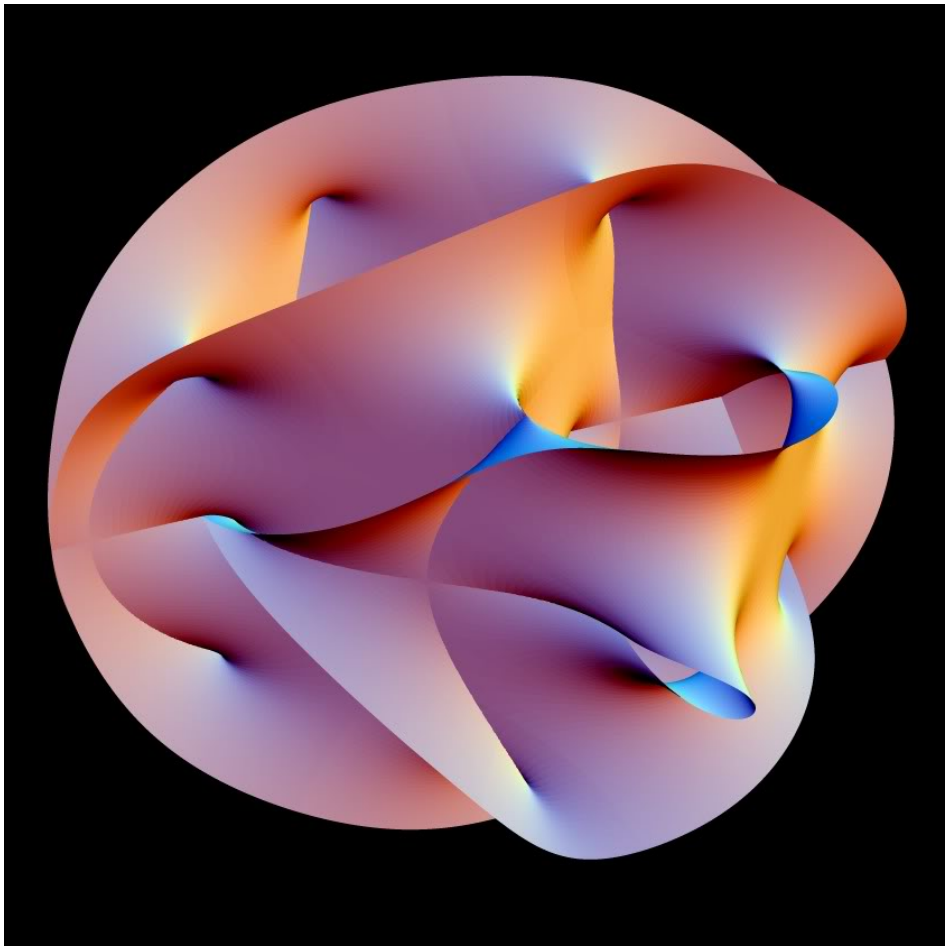
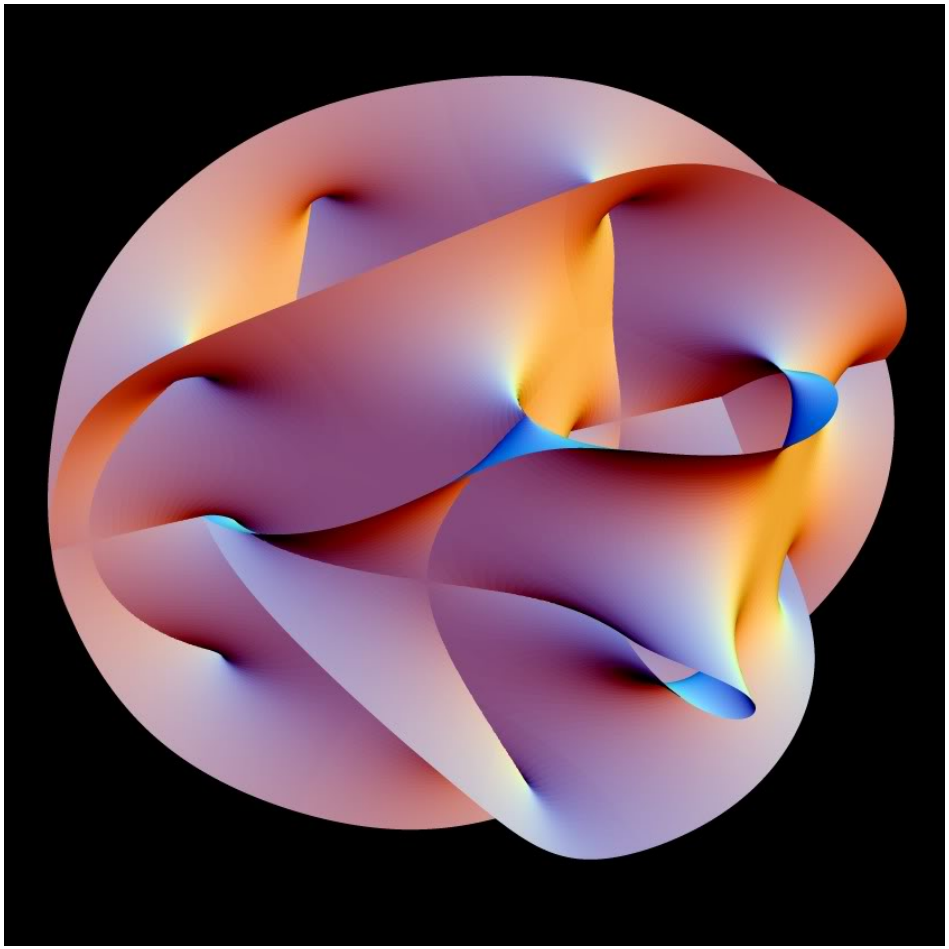


# or this ..

# We get this



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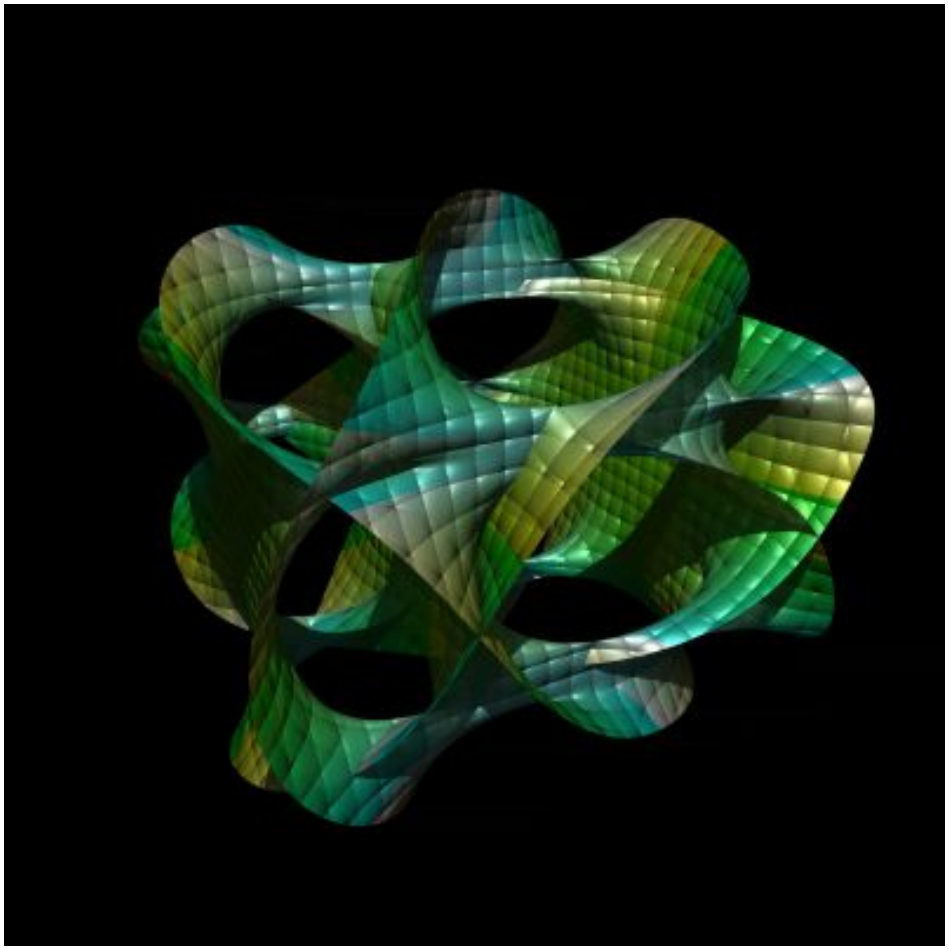

# .. Or more completely, this

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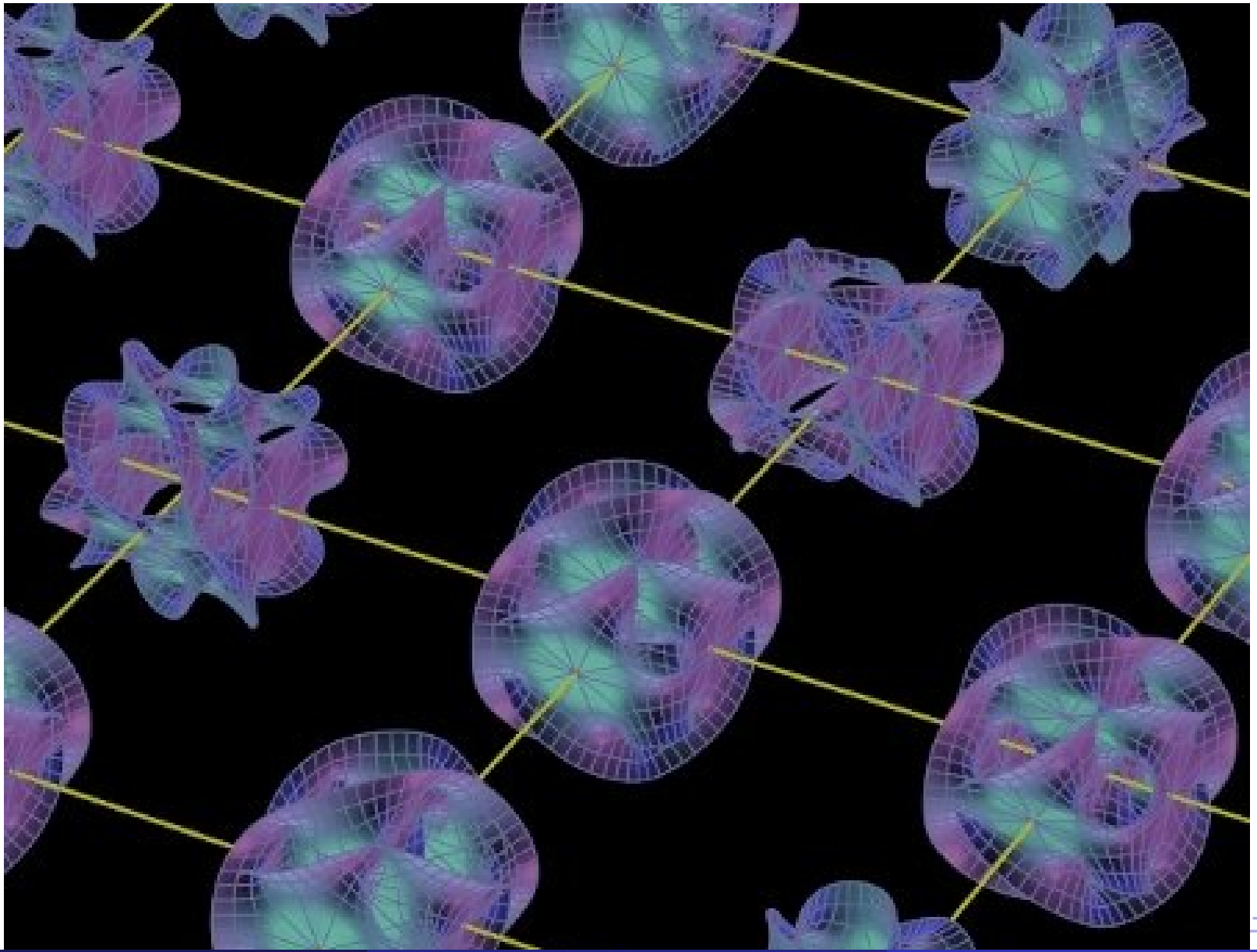

**Good thing is that nothing seems to blow up now**

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**But then, what is it?**

**To understand the last picture, let us take a simpler model:**

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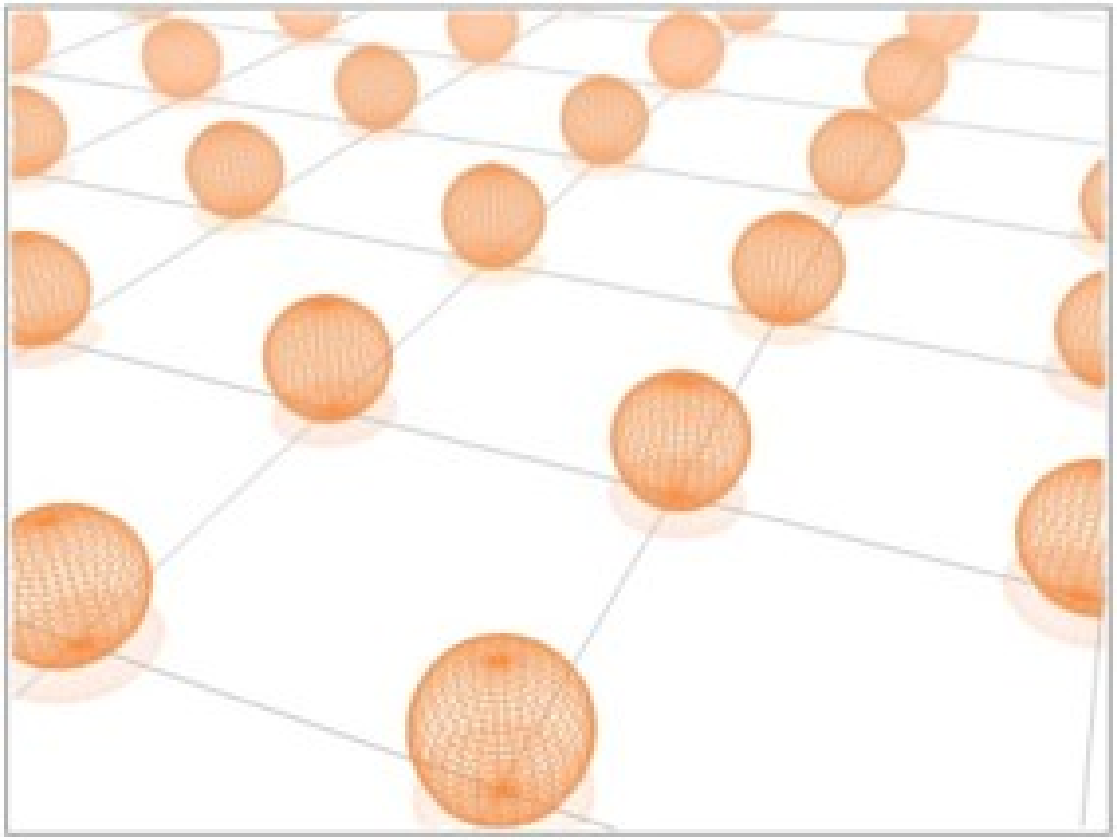

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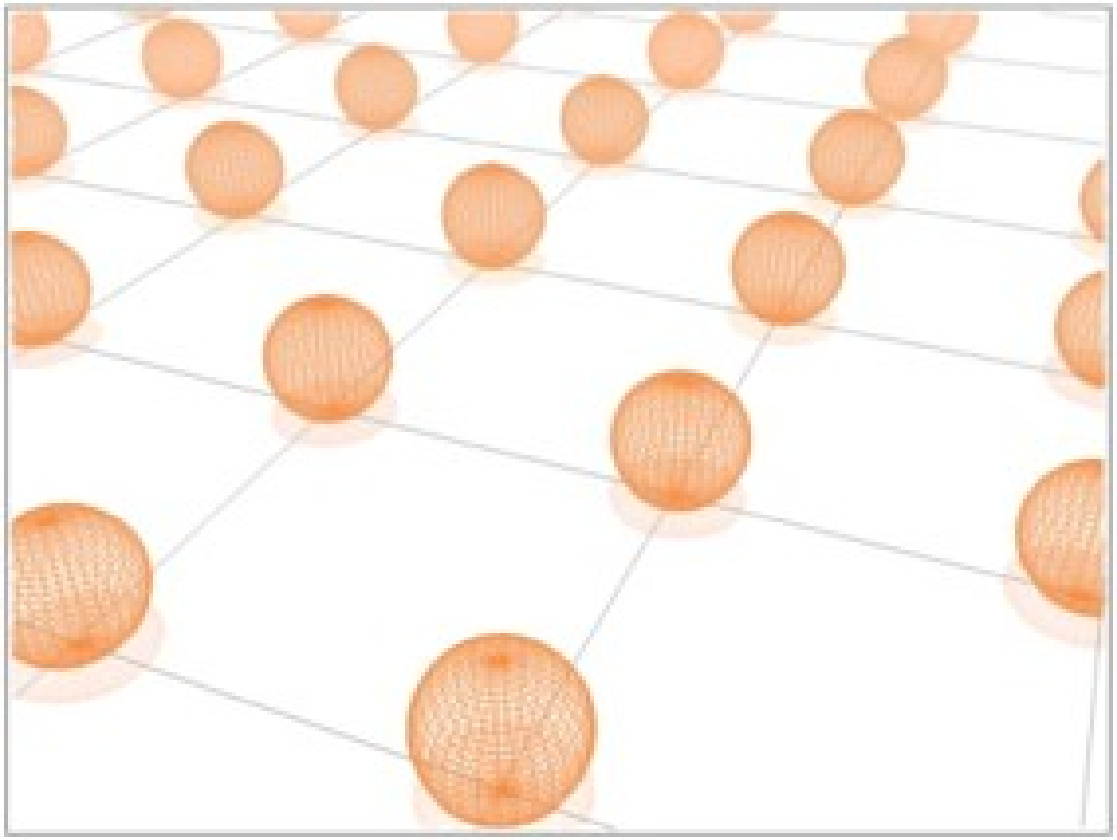

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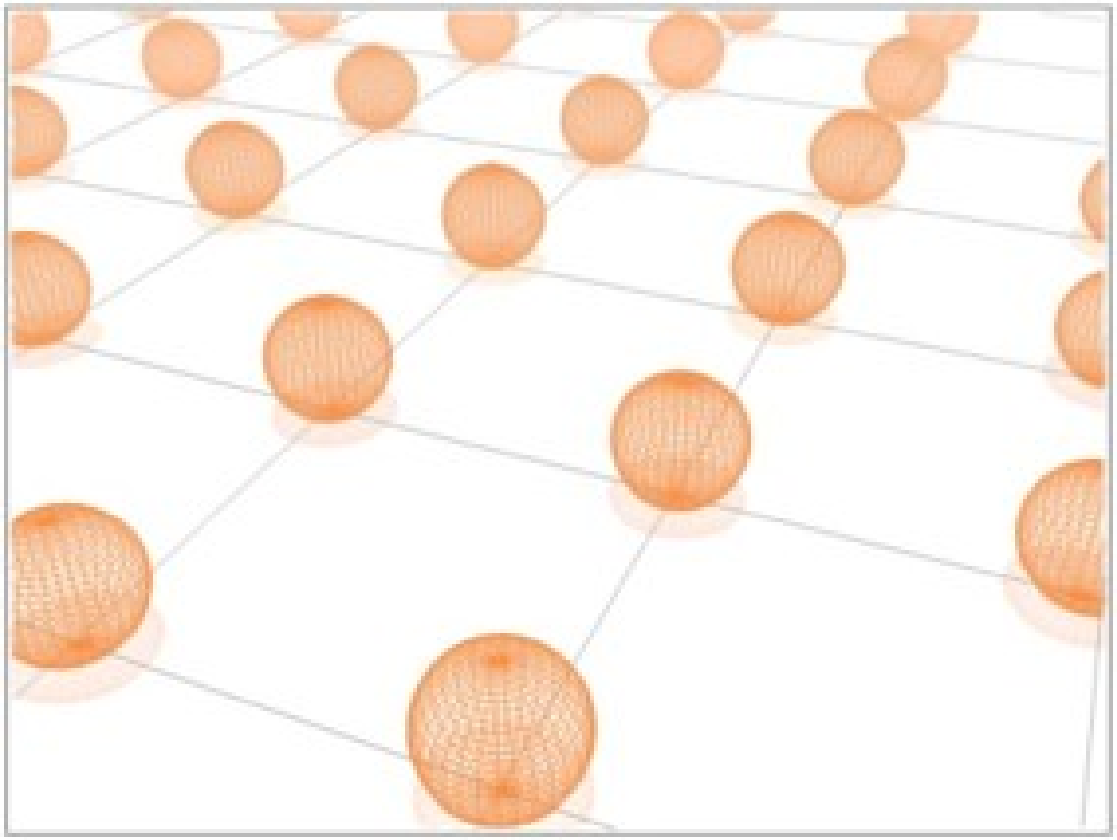

**The picture represents a sphere at every point on a base.**

**Now identify the base with our four dimensional universe**

# This is therefore a representation of a six-dimensional space

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**where the compact sphere is two-dimensional and the base is four dimensional. In other words:**

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$$6 = 4 + 2$$

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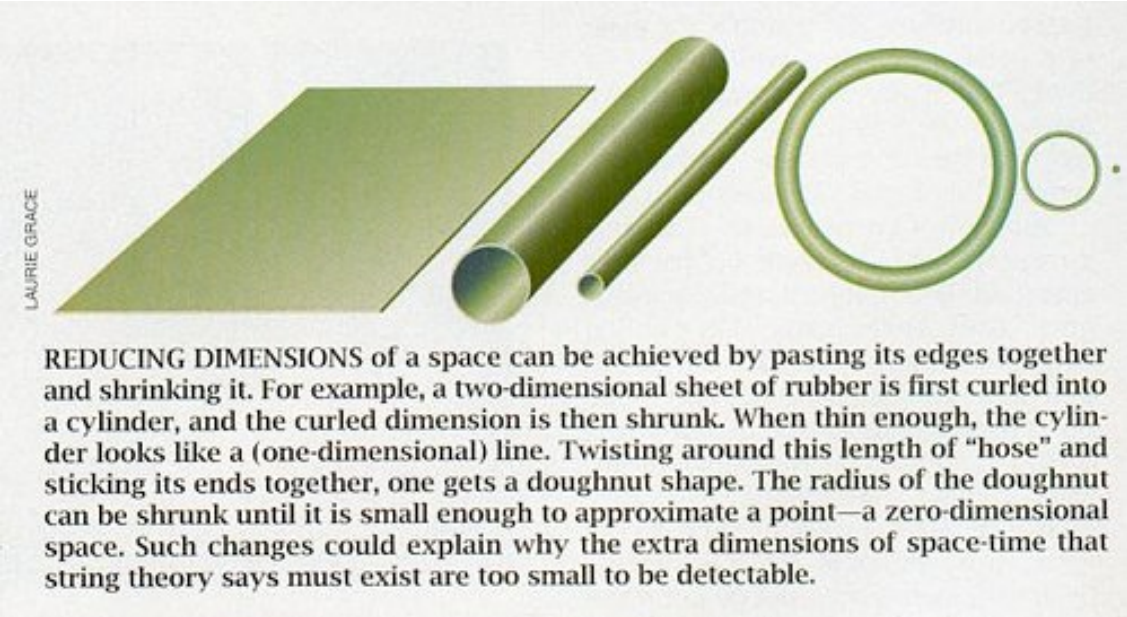


REDUCING DIMENSIONS of a space can be achieved by pasting its edges together and shrinking it. For example, a two-dimensional sheet of rubber is first curled into a cylinder, and the curled dimension is then shrunk. When thin enough, the cylinder looks like a (one-dimensional) line. Twisting around this length of "hose" and sticking its ends together, one gets a doughnut shape. The radius of the doughnut can be shrunk until it is small enough to approximate a point—a zero-dimensional space. Such changes could explain why the extra dimensions of space-time that string theory says must exist are too small to be detectable.

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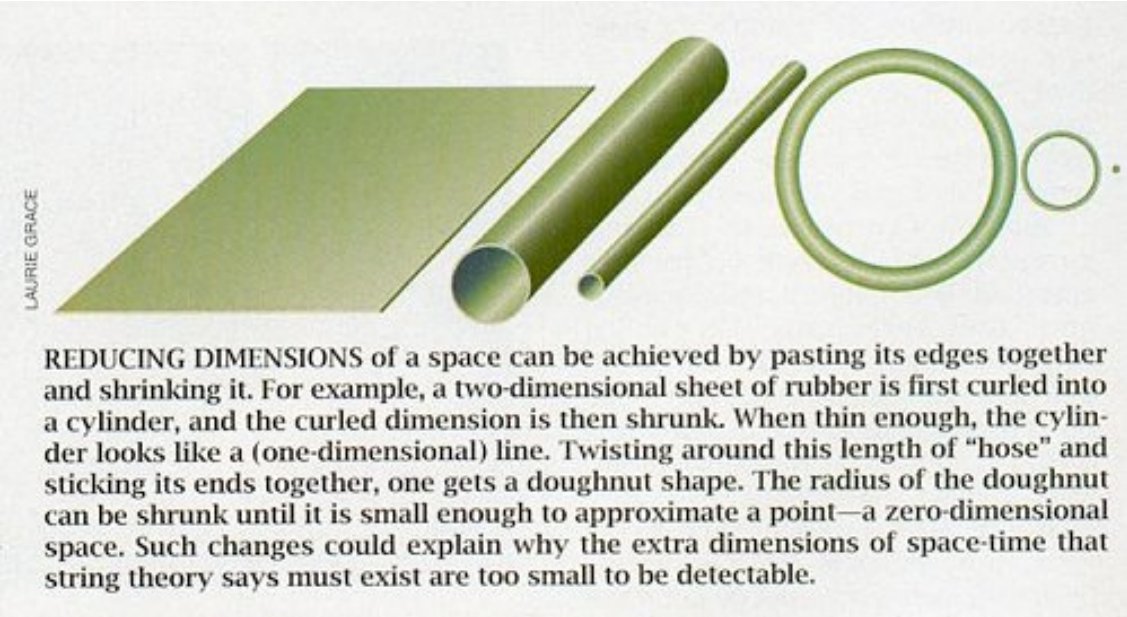


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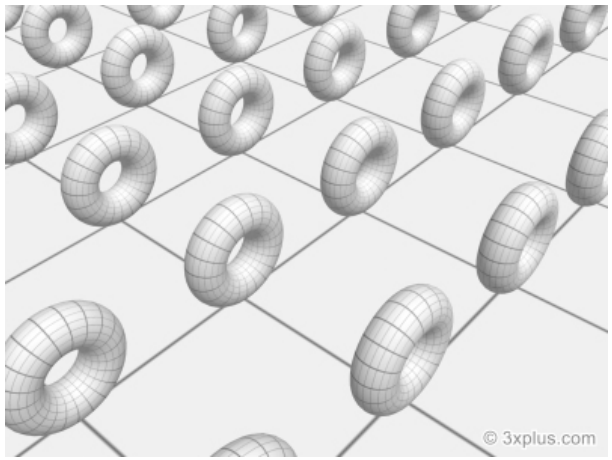

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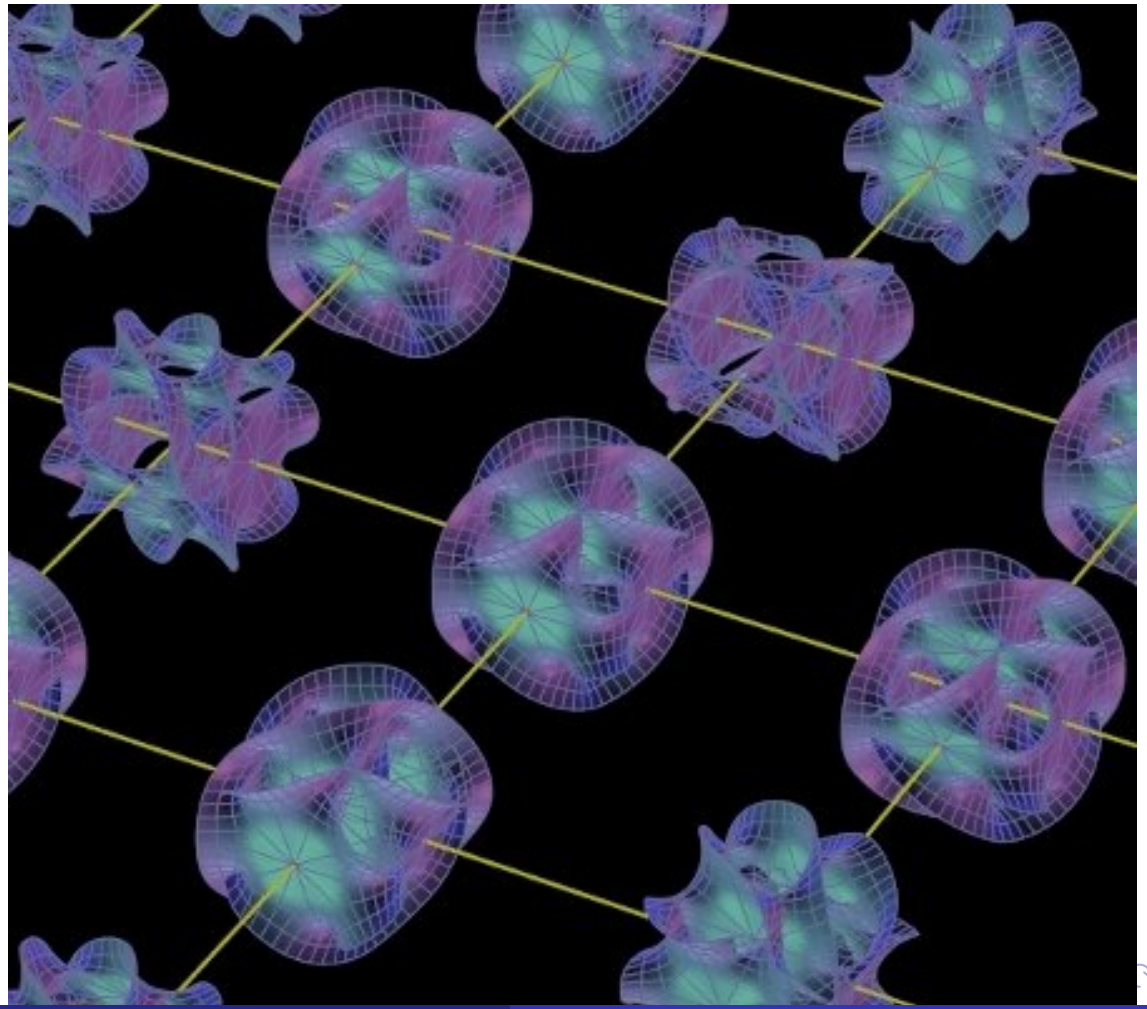

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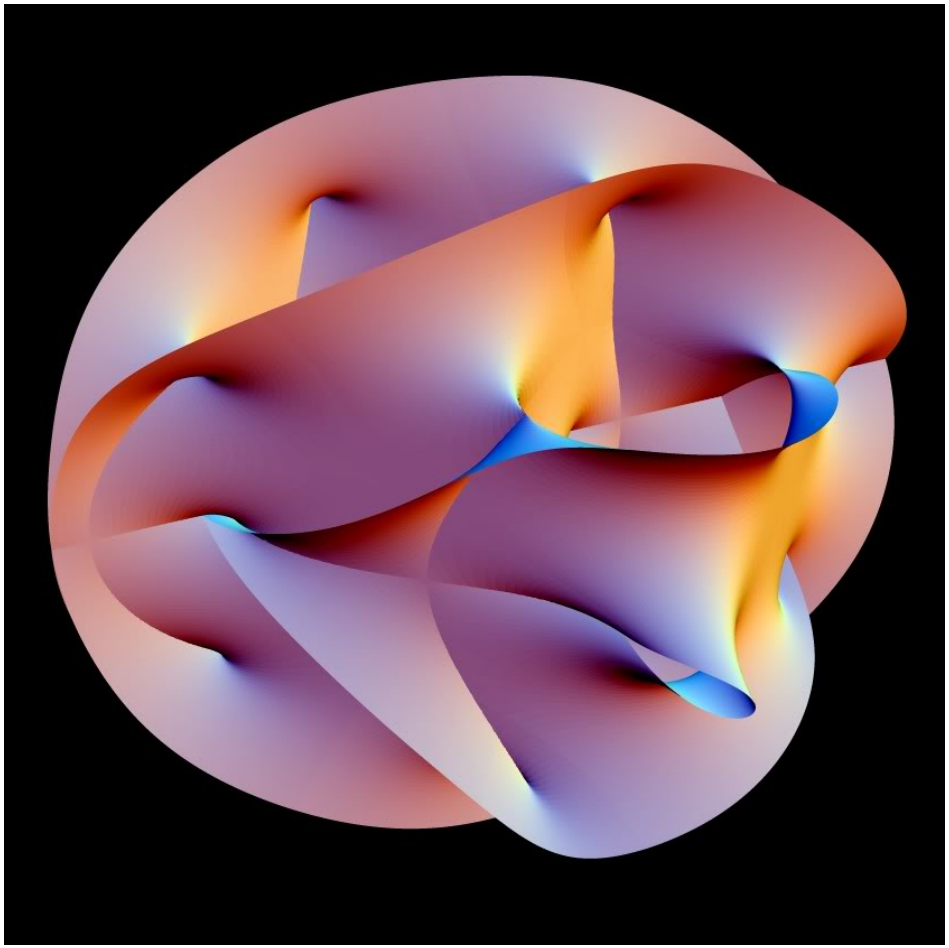

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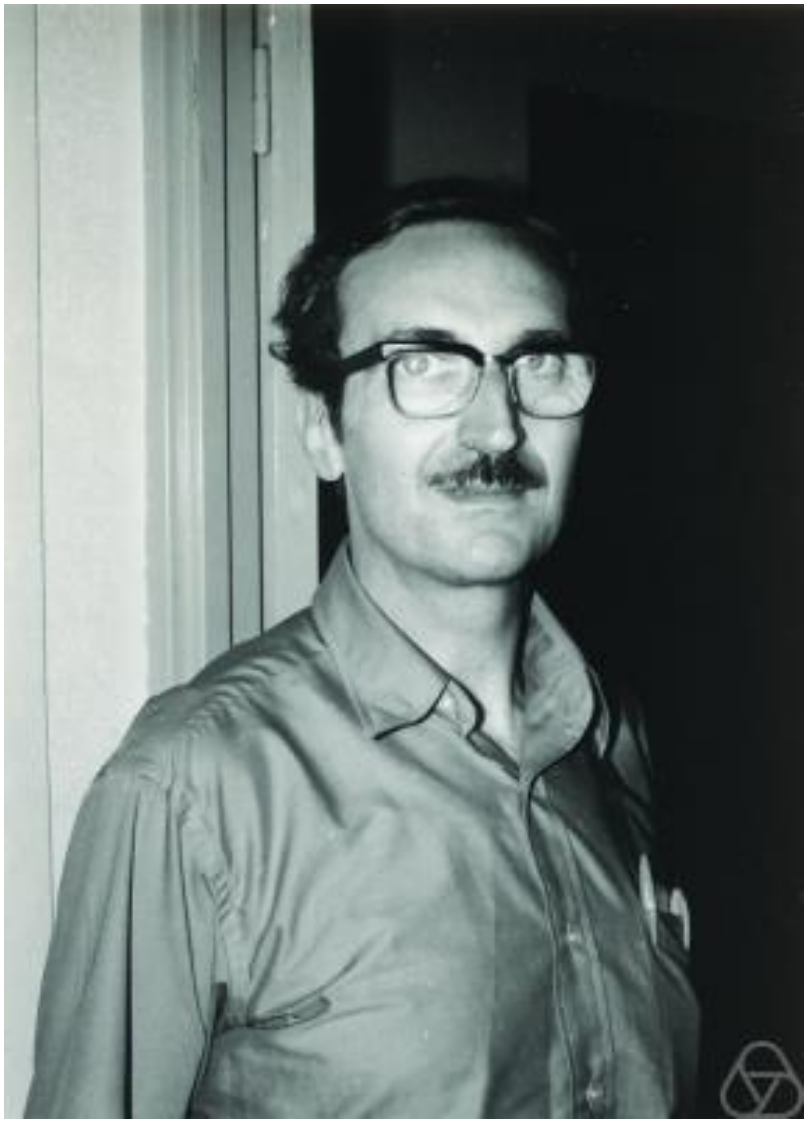

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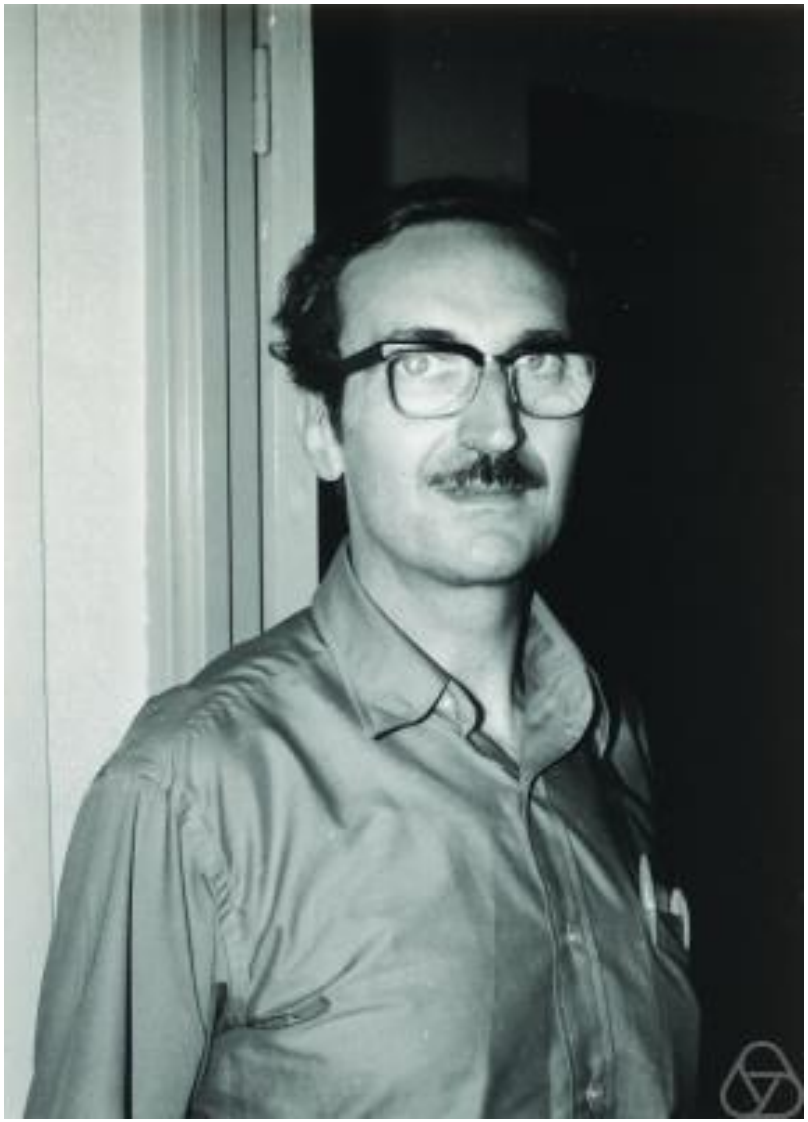

**Eugenio Calabi**

# The mathematical structures of these manifolds are developed by

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**Shing-Tung Yau**

**However with all the heavy mathematical machinery one might be feeling a bit**

**However with all the heavy mathematical machinery one might be feeling a bit confused**

**However with all the heavy mathematical machinery one might be feeling a bit confused**

## and depressed

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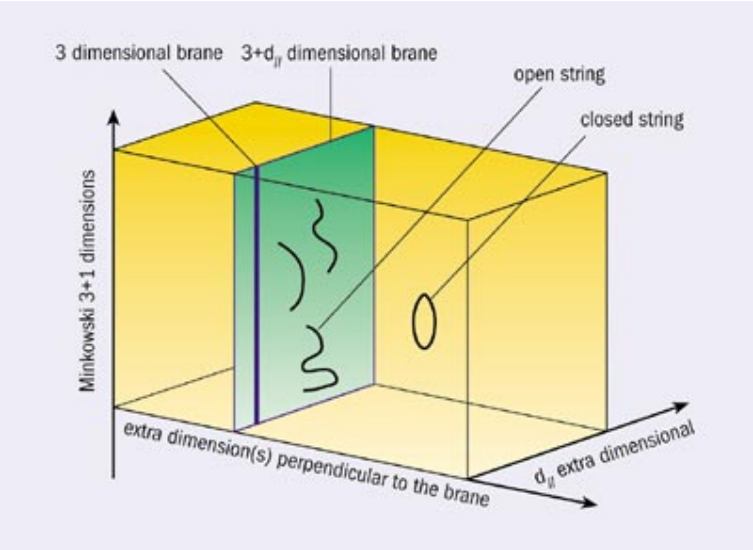

**These slices could move and could have any dimensions**

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**These slices were called D-Branes**

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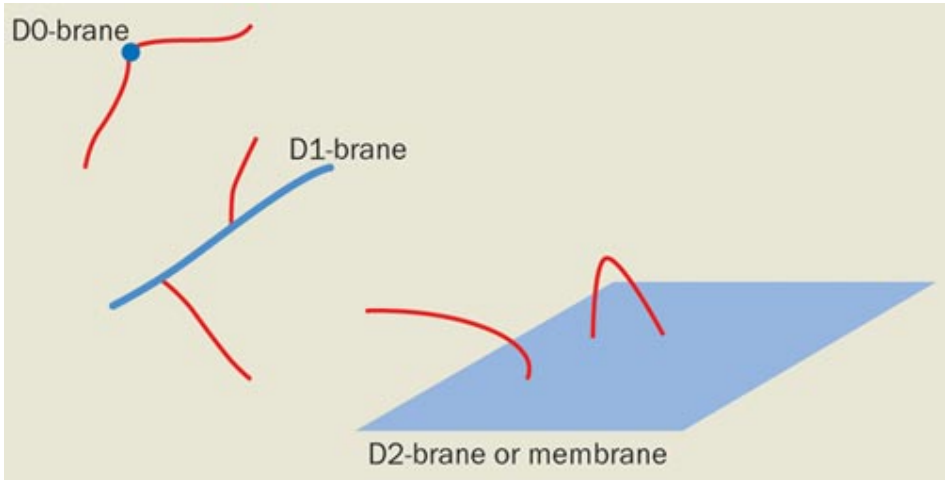


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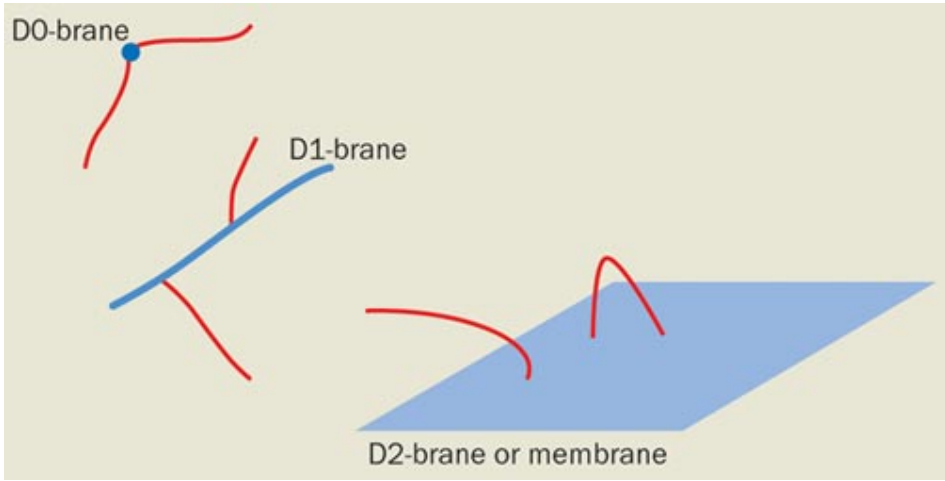


**In this language, we could be living on a three brane!**

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**Raman Sundrum**

**They toyed with the idea that maybe we don't need any Calabi-Yau manifolds to understand our universe. A simple three-brane would be enough because we would live on this surface!**

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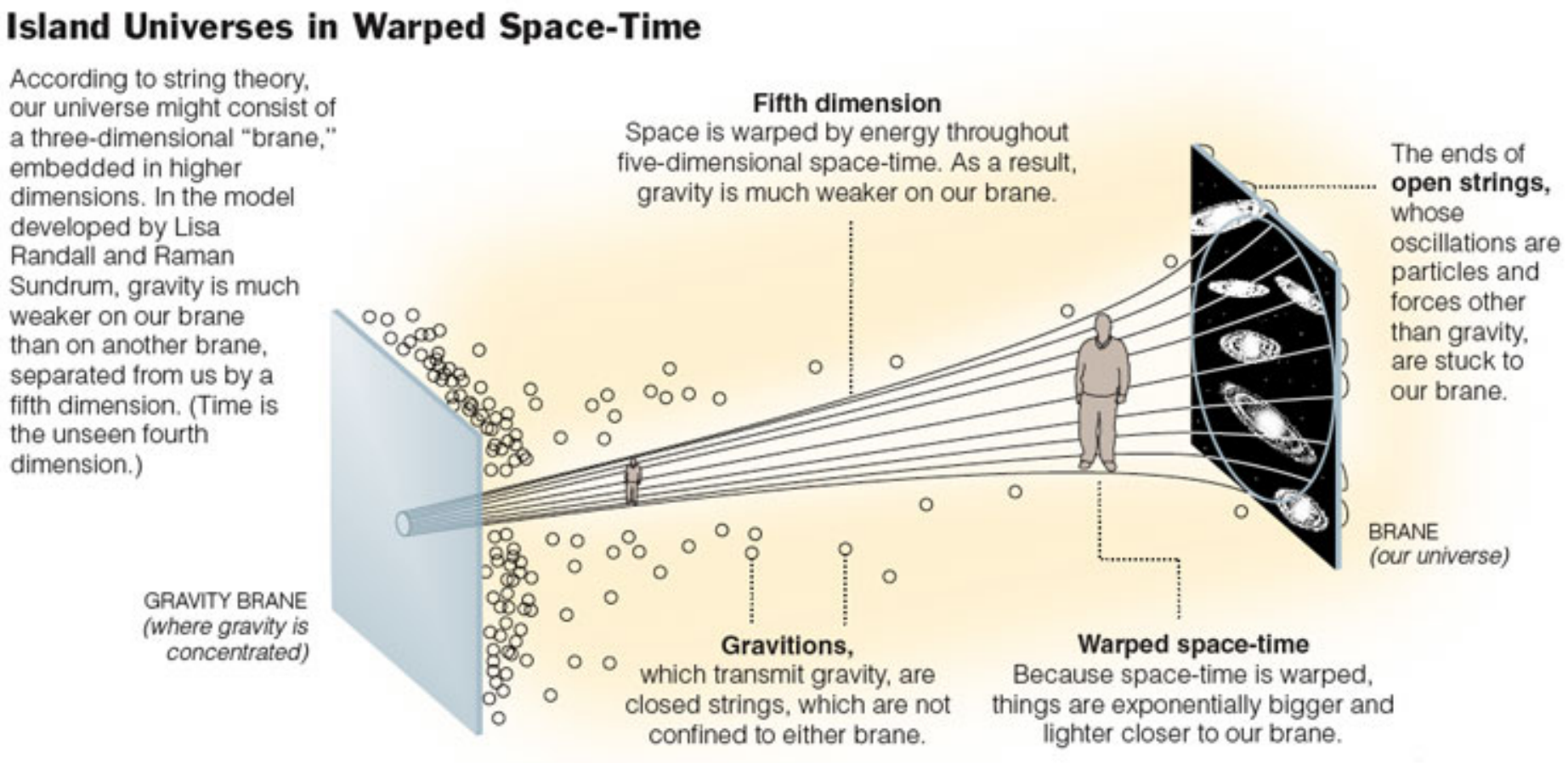

# This picture led to numerous works in our field

**This picture led to numerous works in our field but**

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**Unfortunately (or fortunately) such a simple idea doesn't quite work ...**

**What seems to work well is when D-branes are mixed with Calabi-Yau manifolds**

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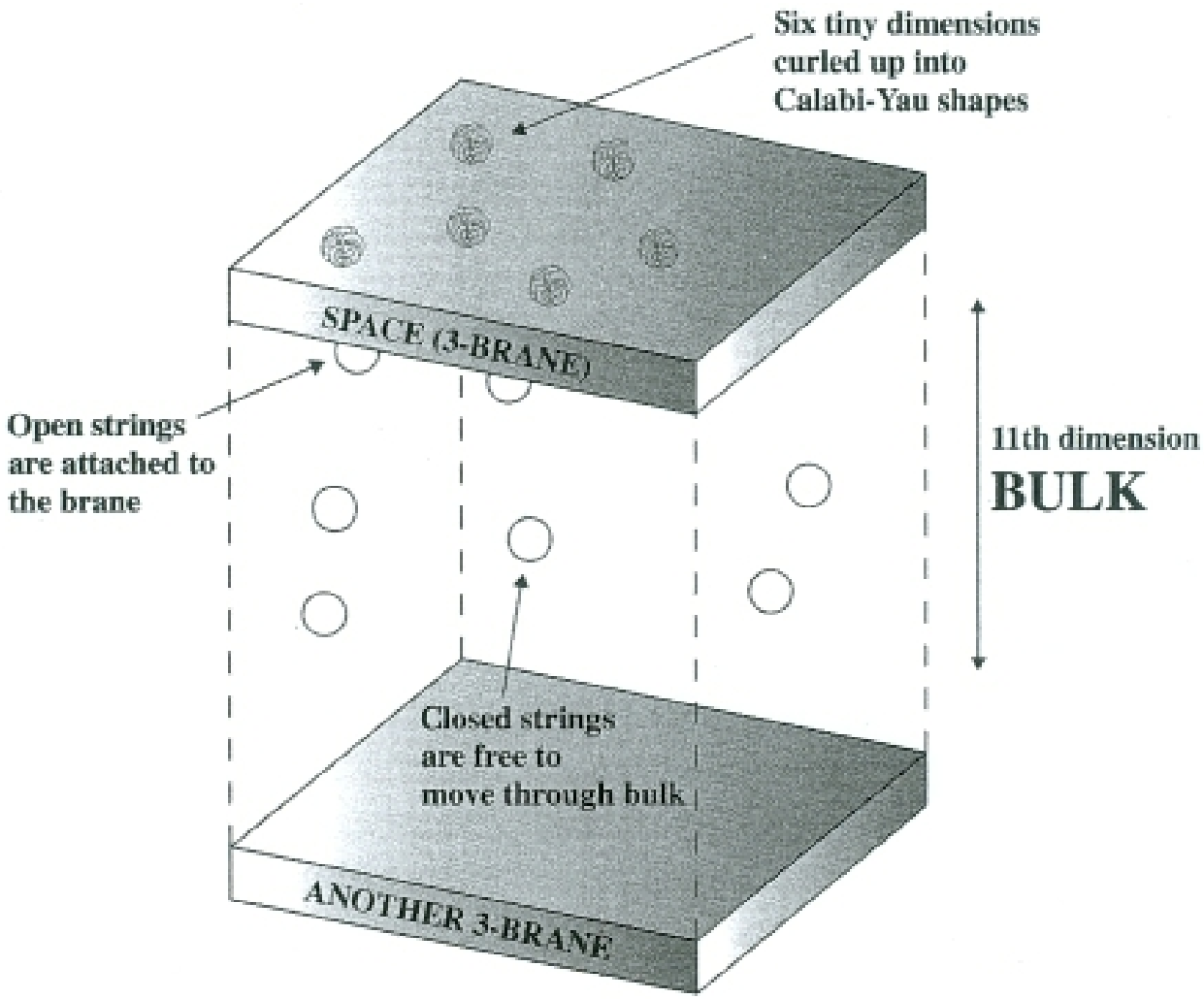

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# Conclusion

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**It all started with this book**

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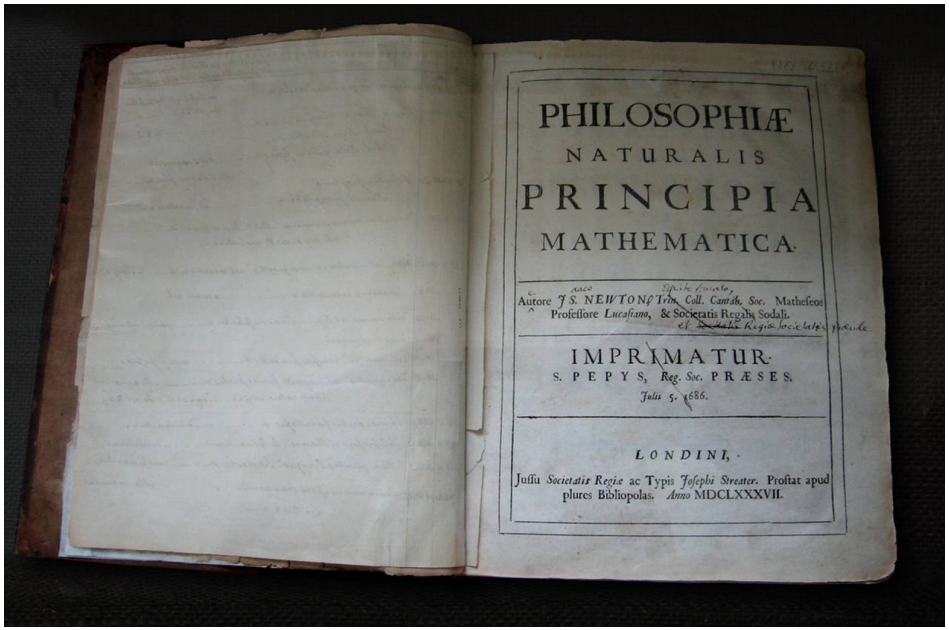
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S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

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**which eventually led to**

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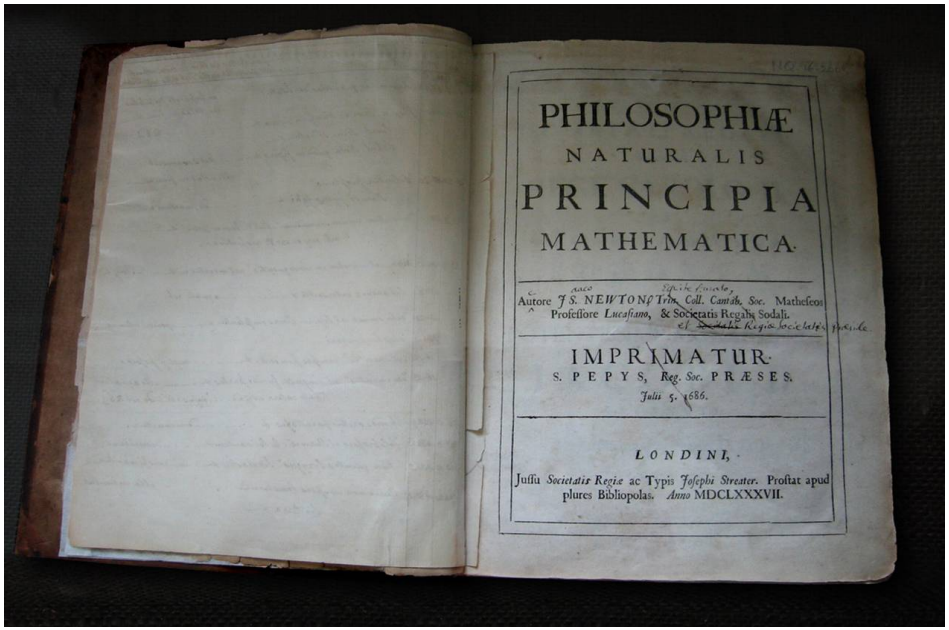
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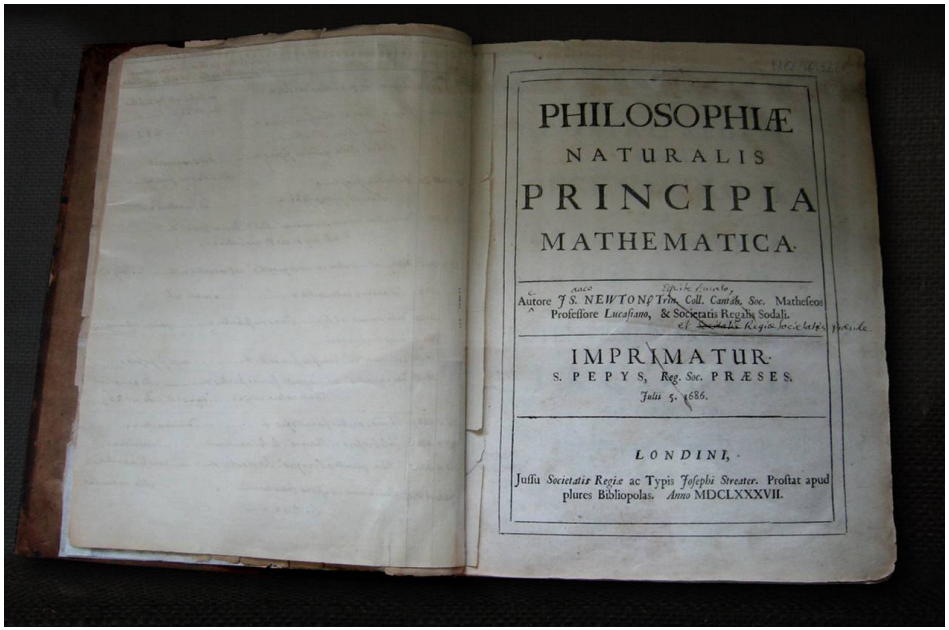
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**Therefore in the second phase it all started with the following books**

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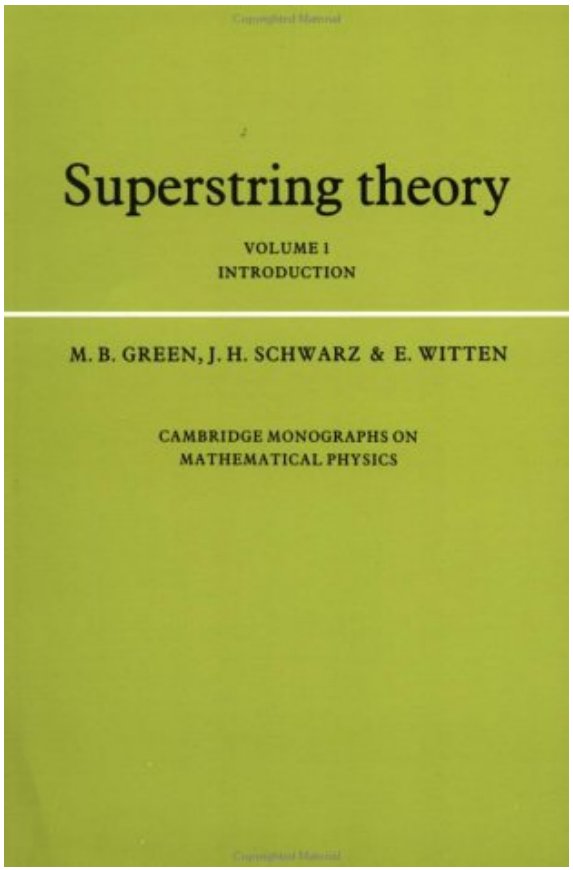

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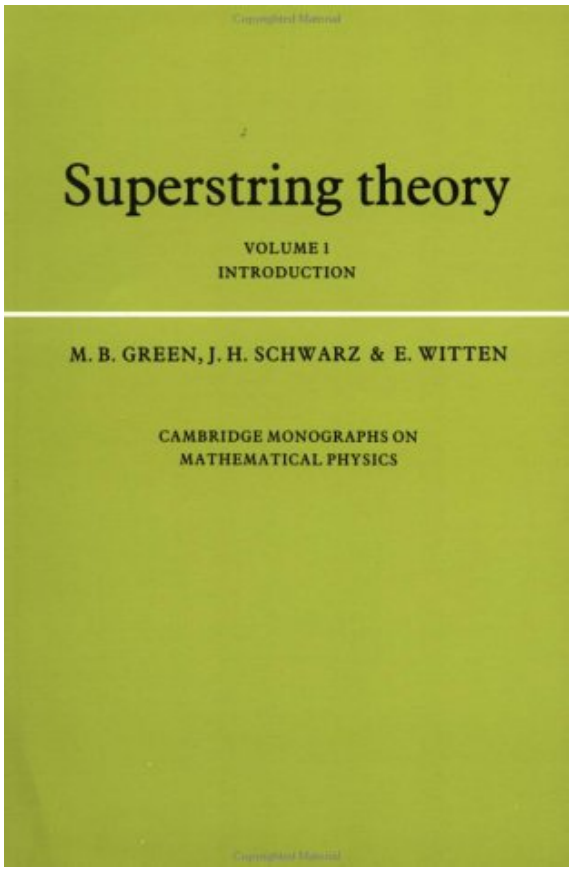


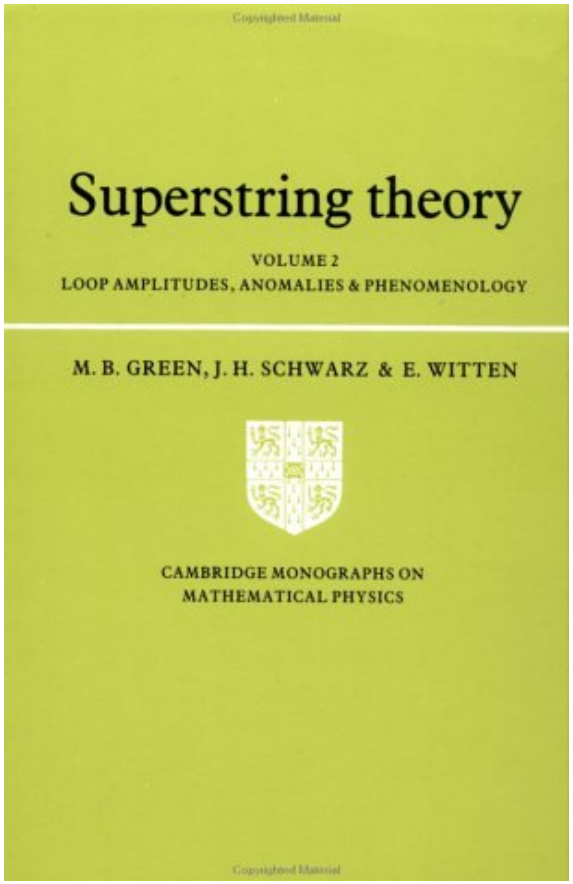

# Which eventually led us to this

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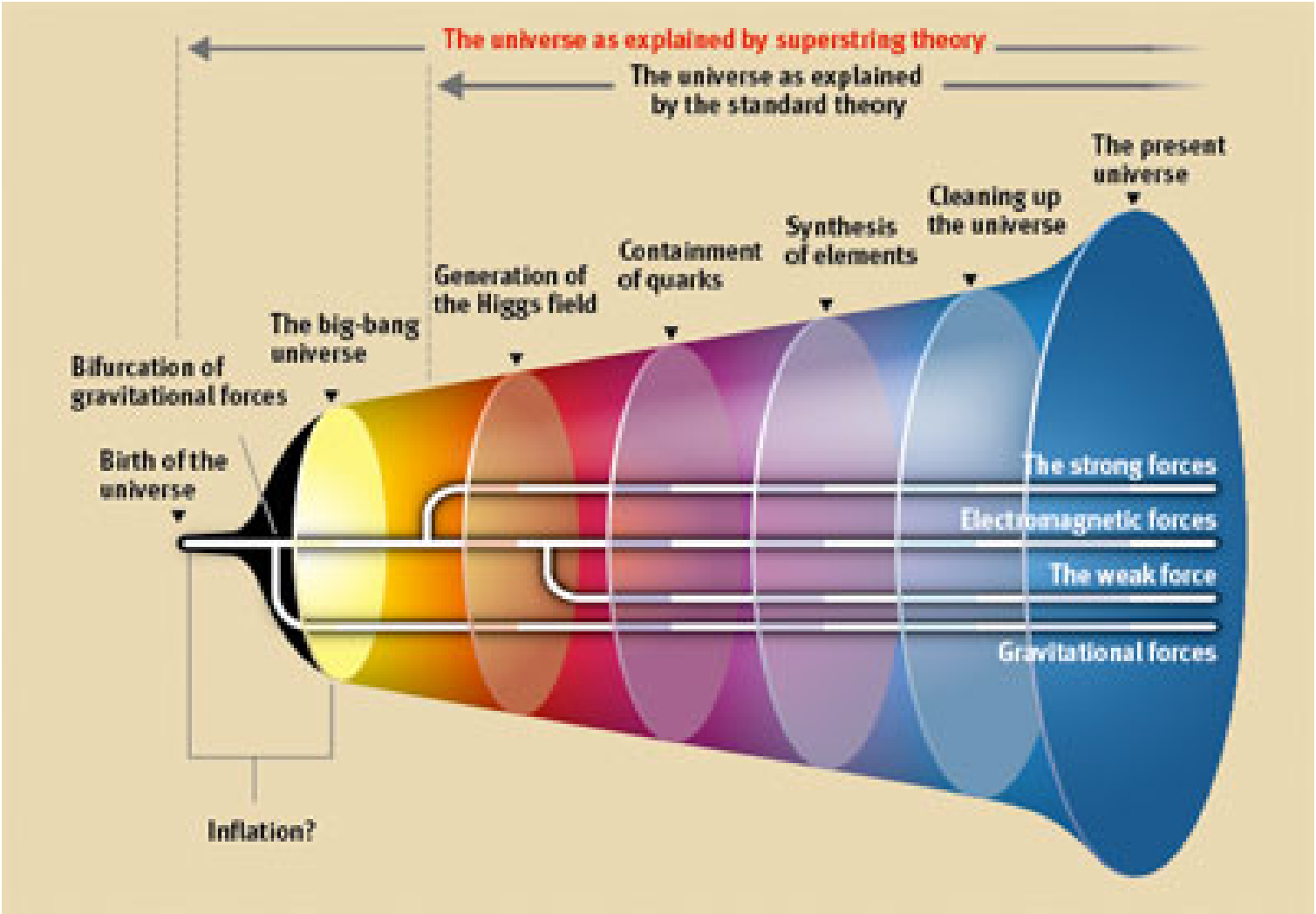

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**But recently some subtle hints of supersymmetry has emerged..!**

# Thank You!

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# And hopefully it wasn't too confusing!

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# FIN!