

**String Theory:**  
**Answering “Why?” Questions**  
**About Our Universe.**

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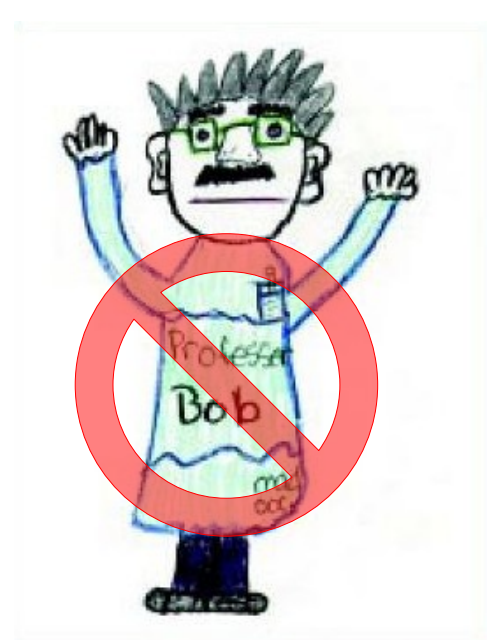
Matt’s String Theory Symposium;  
Terry Fox Elementary School, Barrie, Ontario;  
10-12h, Tuesday, June 8<sup>th</sup>, 2004.

Q1:

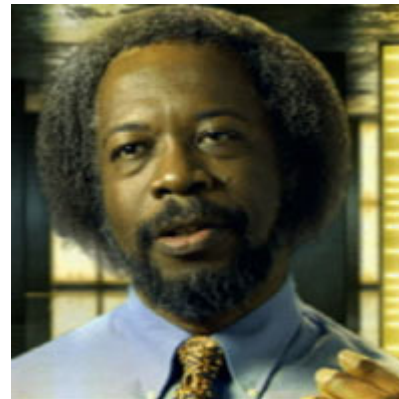
What do physicists do,  
and what tools do we use  
when we work?

## What Does a Physicist Look Like?

Physicist stereotype (male, white, loner, able-bodied yet un-sporty, unfashionable, with nerdy glasses, lab coat, plastic pocket protector, facial hair, and a “bad hair day”) is *wrong*.



*All* sorts of humans like physics and do physics! 😊



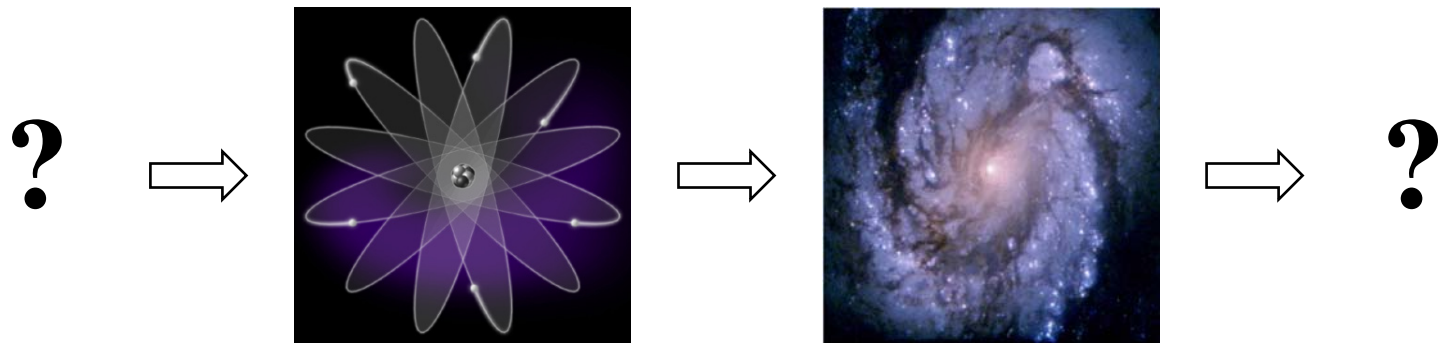
e.g. I am a woman, with a disability & I like hiking and skiing.

# What I Look Like



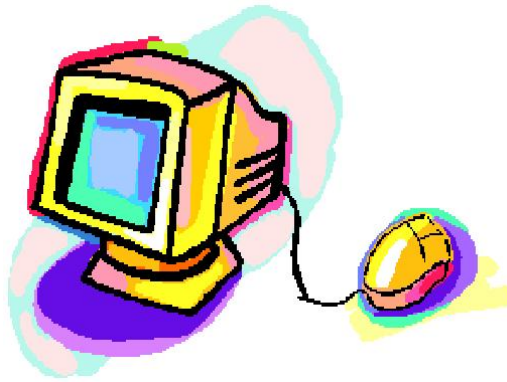
## Discerning Patterns

- Physicists want to cover a lot of ground, i.e. find principles that *always* work – in *heaps* of different situations.
- We want to explain origin and structure of fundamental matter + forces, from **sub-atomic to cosmological** scales.

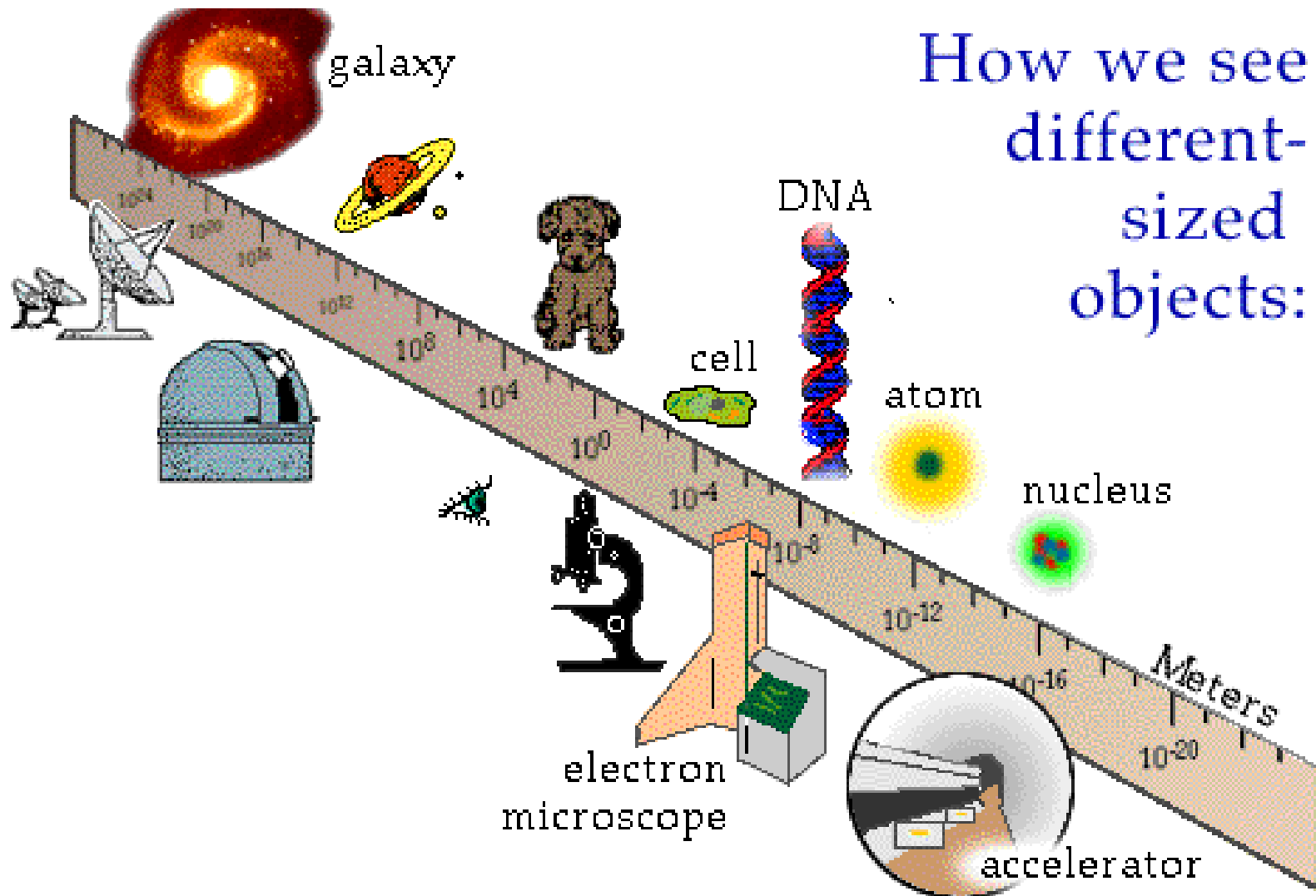


- Smallest distance imaginable: million-billion-billion-billion-th of a centimetre.
- Biggest distance imaginable: ten billion billion billion cm.

# Tools of Theoretical Physics Research



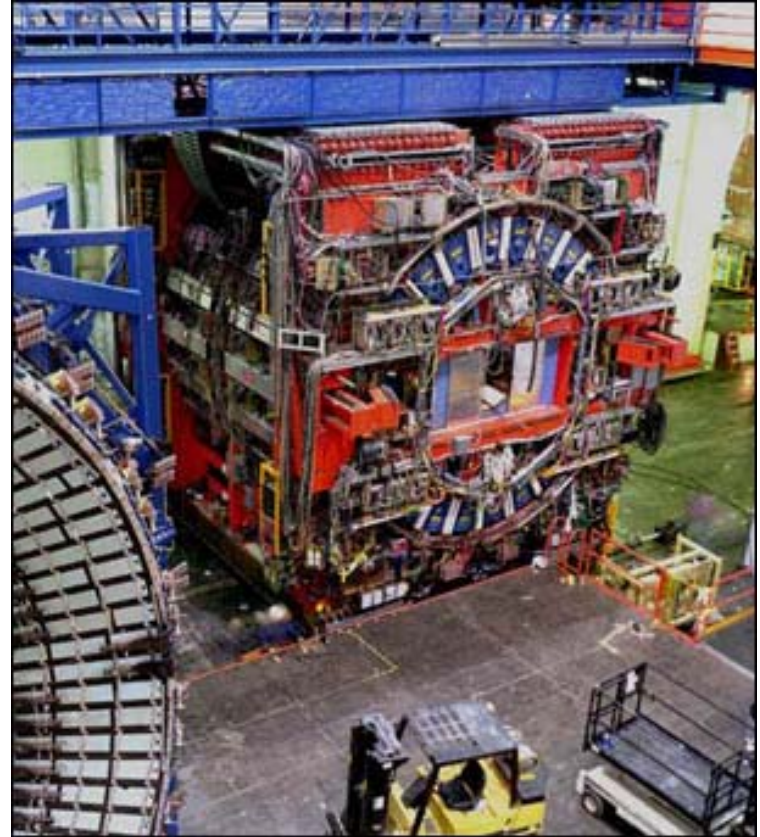
# Tools of Experimental Physics Research



# Particle Accelerators



ring kms across



detector several metres tall



# The Sky



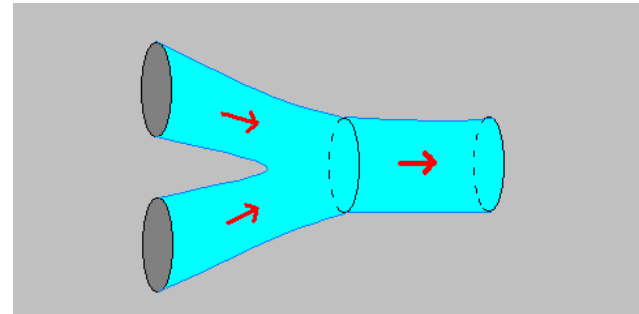
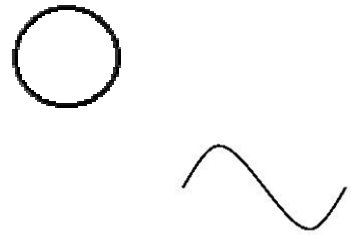
**BOOM launch by giant weather balloon**

Q2:

What is string theory,  
and why choose a string  
over some other thing?

## String Theory: Basic Idea

- All ‘particles’ – matter and force-carriers (e.g. electron, quark, photon) are really tiny vibrating *superstrings*, or “strings”.
- Forces described solely by **splitting and joining of strings**. Smooth process.



- If assume strings are basic stuff, gravity comes out automatically. (Particle theory can't do that!)
- String is simplest complication needed to solve puzzles.

## Similarities and Differences in Particle Zoo

- Two kinds of **fundamental matter** seen, so far:
  - **Leptons**:  $(e, \nu_e), (\mu, \nu_\mu), (\tau, \nu_\tau)$
  - **Quarks**:  $(u, d), (c, s), (t, b)$
- Four **fundamental forces** seen, so far:

Force name	Gravitational	Electromagnetic	Weak nuclear	Strong nuclear
Carrier particle?	graviton	photon	$W^+, W^-, Z$	gluon
Felt by leptons?	✓	✓ / ✗	✓	✗
Felt by quarks?	✓	✓	✓	✓
Range?	infinite	infinite	sub-nuclear	nuclear
Strength now?	weakest	weak	weaker	strong

# Unification

- Fundamental “constants” describing strengths of forces are *not* actually constant, but vary with energy:
  - Strong nuclear gets weaker at higher energy;
  - electromagnetic, weak nuclear, gravity all get stronger.
- Variation effect involves:-
  - relativity: **high-speed weirdness,**
  - quantum behaviour: **tiny-ness weirdness.**
- Extrapolating up suggests unification at ultra-high energy, maybe up near 100,000 billion billion billion degrees.
- ***Extreme Physics!***
  - Beginning of universe;
  - inside black holes.

## (Relativity)

- Einstein is famous. Not many people know why!
- In early 1900s, he published amazing theories of relativity. Basically, relativity is **high-speed weirdness**.
- Speed of light is fundamental speed limit. Nothing faster!
  
- When something gets up to a good fraction of the speed of light, ordinary rules no longer apply:-
  - velocities don't add simply;
  - pumping in more energy gives diminishing returns, and hit fundamental barrier at speed of light;
  - objects look shrunken in direction of motion;
  - moving clocks look to be running slow.

## (Quantum Behaviour)

- Everyday objects have definite properties, e.g. size, speed. Mathematical idealization! Only valid if object is heavy and slow. In real life, *quanta*, not particles.
- Sometimes behave like pointy things, sometimes like wavy things. **Tiny-ness weirdness.**
- Every quantum has fundamental jitter. Jitter frequency controlled by energy of quantum. Can never turn off quantum jitter - even at absolute zero temperature!
- Jitter causes tradeoffs: Heisenberg uncertainty principle. e.g. tradeoff in precision on weight *vs.* timing.
- Can have as many quanta as you like, but each costs huge energy price:  $Energy = (mass) \times (lightspeed)^2$ . Just 1 gram converts into explosive energy of ~21,468 tonnes of TNT!

# A Theoretical Emergency



- Twin pillars of 20<sup>th</sup> century experimental physics: quantum and relativistic theory, fundamentally incompatible. Oops!!
- Need new theory that:-
  - predicts sensible physics in extreme regimes, like birth of universe and black holes (no “infinity” answers!);
  - is internally consistent (no mathematical anomalies!);
  - unifies, explains patterns/differences.
- *Unique* theory which may do all this is **SUPERSTRING THEORY**.



# Evolution of Universe

- At beginning:



- incredibly hot tiny universe;
  - no atoms, protons or neutrons: no binding possible;
  - quarks and leptons interchangeable;
  - all interactions same, and of same strength.
- Soon afterwards – universe inflated very fast, particle creation. Leftover radiation: now stretched out, “CMB”.

Q3:  
Sci-fi *vs.* reality:  
how well do we know  
what we think we know?

## Where Will the Greeks' Quest End?



- If we keep looking deeper and deeper, will there be endless layers of the onion?
- For particle accelerators, more \$ gives better resolution.
- For string accelerators, it's different! Even theoretically, we already know: more money helps *only up to a point*.
  - At ultra-high energy, string resolution gets bad again!
  - Extra energy just pumps up size of string *probe*.
- Minimum sensible distance  $\sim$  “string scale”.
- So there may be no need to look for anything deeper.

## Matter vs. Forces

- How does a physicist tell particles apart?
  - By mass and [intrinsic] spin, which are *only* labels invariant under space-time symmetry.
- Two major types of particles:-
  - **matter**: spin  $\frac{1}{2}$  (**fermions**),
  - **interaction-transmitter**: spin 0,1,2 (**bosons**).
- **Supersymmetry**: theoretical boson-fermion pairing.
  - Logical extension of known symmetries of Nature.
  - Useful for helping explain unsolved puzzles!
- Supersymmetry **broken now**: no sparticles seen yet.



# Super-particles

- Massive hunt underway for super-particles.
- Discoverers would get Nobel Prizes! 😊
- Super-particles may be discovered in particle accelerator frontiers, and affect astrophysics & cosmology too.

Particle	Super-partner
leptons, quarks	sleptons, squarks
Higgs	Higgsino
photon, Ws, Z, gluons	photino, Wino, Zino, gluino
graviton	gravitino

## Extra Dimensions of Space

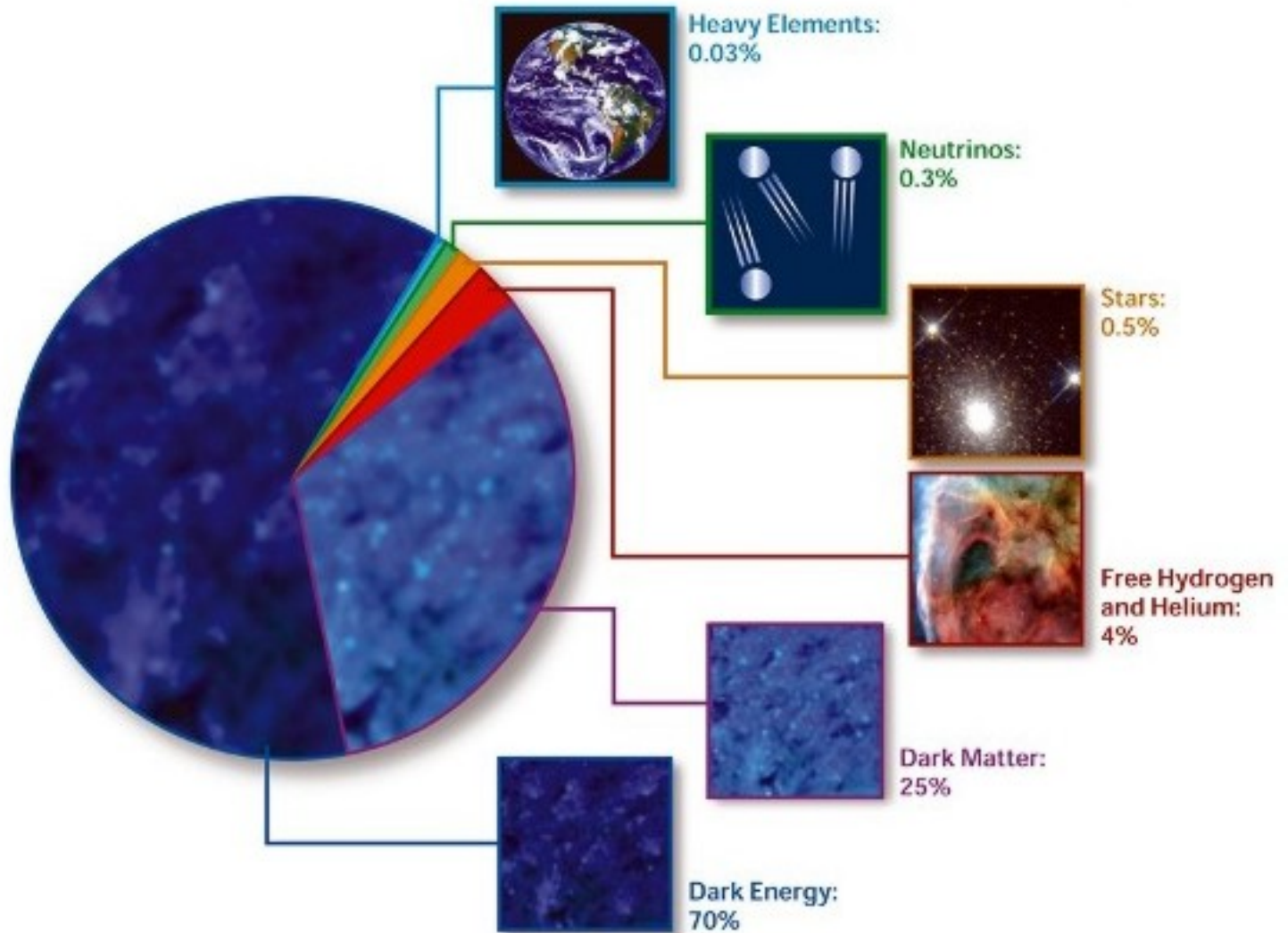
- Theories incorporating this idea go back over 80 years, but string theory is new in *requiring* more dimensions.



- Big ant can walk in only *one* direction - the circular dimension is just **curled up so small it goes unnoticed**.
- Tiny ant would think twig surface is *two*-dimensional.
- State-of-the-art experiment says:
  - if we're allowed in, extra dimensions must be  $< 10^{-17} \text{ cm}$
  - if only gravity is allowed in, they must be  $< 0.15 \text{ mm}$

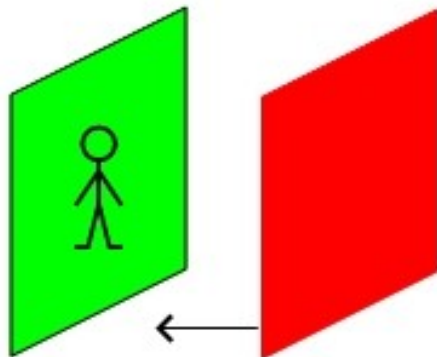
# Composition of Universe

Survey  
stuff of  
universe  
through  
gravity  
effects.  
CMB,  
super-  
novae  
sense  
different  
effects.



## What Caused the Big Bang?

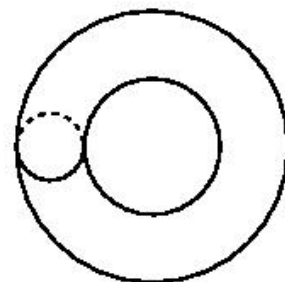
- (Children are smart! When an adult says, “God made the universe.”, the child asks, “Then who made God?!”.)
- String theory gives new options for creating the initial tiny fireball that expanded to eventually create Earth+us.
- Imagine car crash  
(with eyes, ears shut) →
- Brane crash?





## Spacetime as Quantum and Dynamical

- Spacetime was thought of as merely the playing field of particles and forces.
- But in string theory, we can smoothly
  - tear the fabric of space, change its topology;
  - change the number of dimensions of space.
- So spacetime as a fundamental idea is probably doomed!
- Big fat space-time must be emergent, *dynamically* – how?
- Some of the remaining, intriguing questions:
  - Why does time run forwards?
  - Was there anything before the Big Bang?
  - Should quantum theory be applied to the whole universe?
  - Is our universe a lucky cosmological accident or unique?



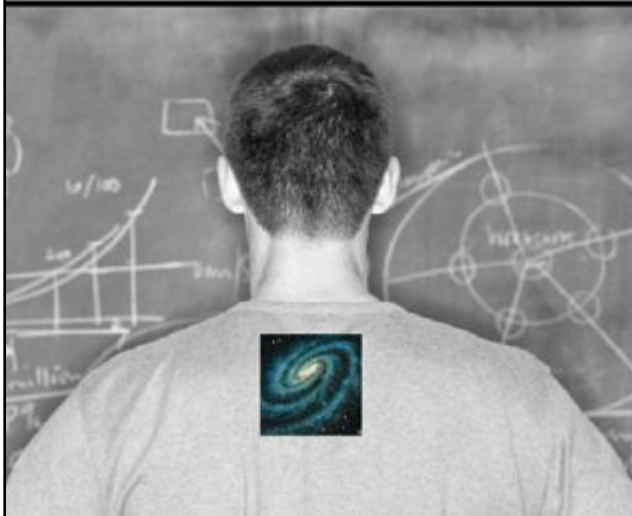
**The End ...**

# Where to Learn More

## Universe on a T-Shirt

The Quest for the Theory of Everything

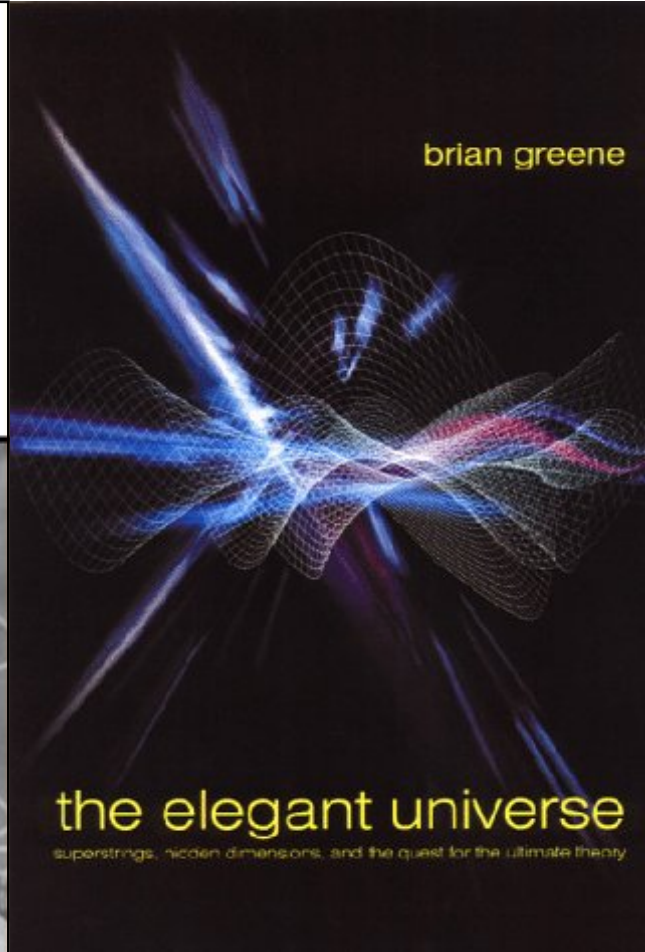
Dan Falk



brian greene

## the elegant universe

superstrings, hidden dimensions, and the quest for the ultimate theory

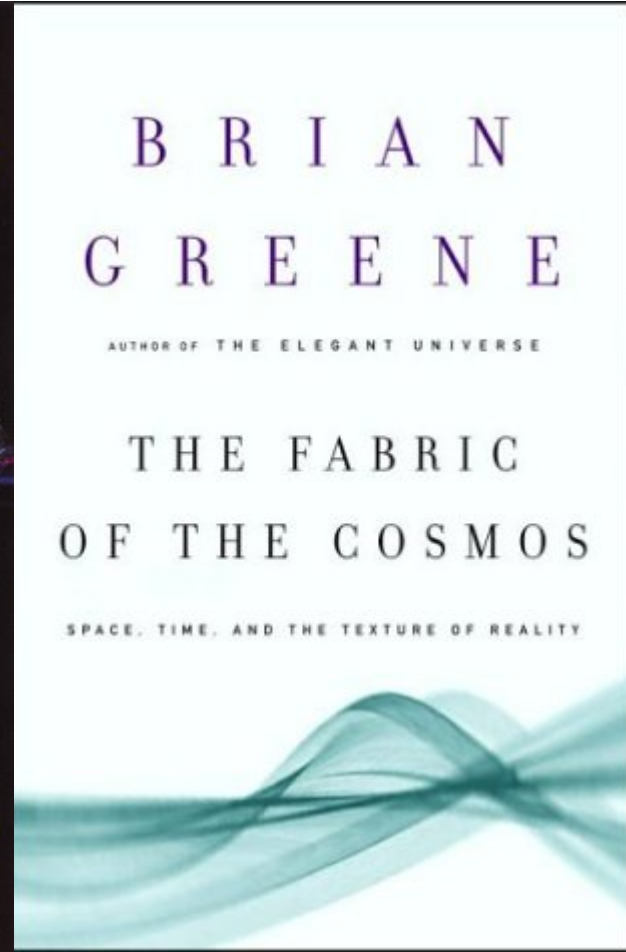


B R I A N  
G R E E N E

AUTHOR OF THE ELEGANT UNIVERSE

## THE FABRIC OF THE COSMOS

SPACE, TIME, AND THE TEXTURE OF REALITY



## Where to Learn More



**The Official  
STRING THEORY  
Web Site**

[www.superstringtheory.com](http://www.superstringtheory.com)



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