# String Theory as Quantum Gravity

by

Amanda Peet

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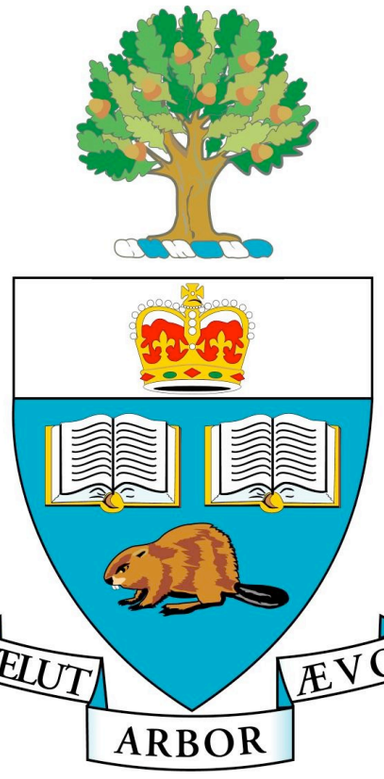
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PREMIER'S RESEARCH EXCELLENCE AWARDS
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## rough outline of talk

**basic ideas**

- powers of ten
- accountability: experiment
- incompatibility of GR and QFT ➠ string theory

**pesky puzzles**

- patterns in quark and lepton spectrum - why ?
- unification ?
- supersymmetry ?
- composition of universe - dark matter & energy = ?

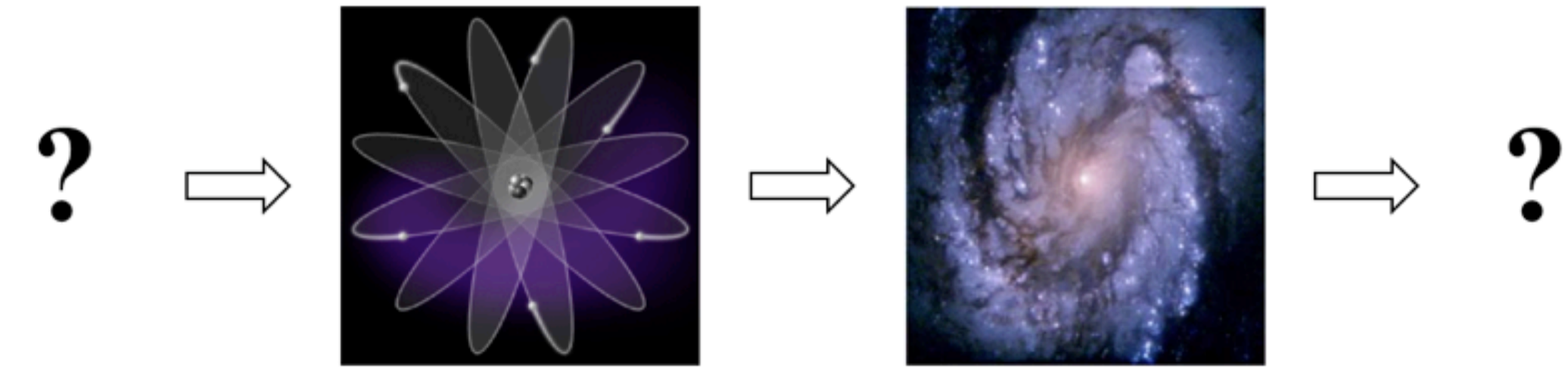
***modern* string theory**

- extra dimensions of space
- big bang or big crash?
- spacetime as *emergent*
- D-branes
- AdS/CFT

# basic idea

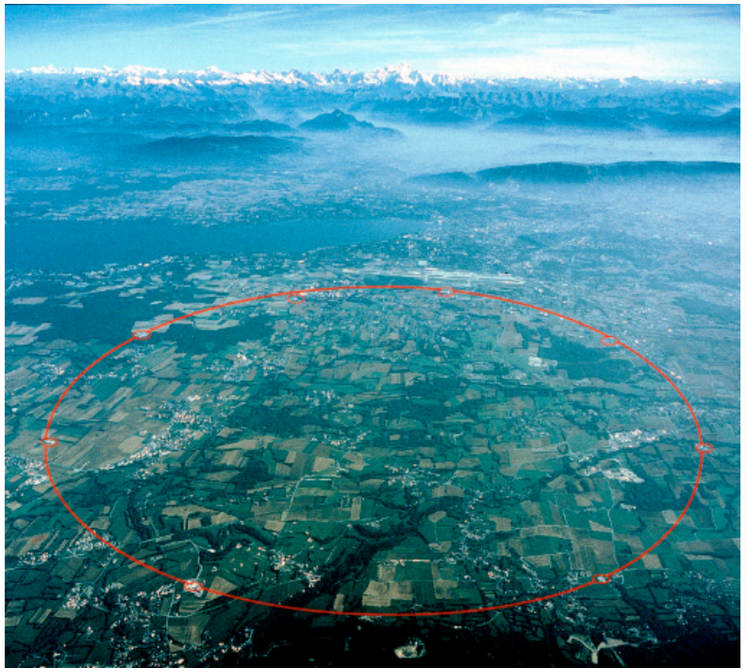
# Discerning Patterns

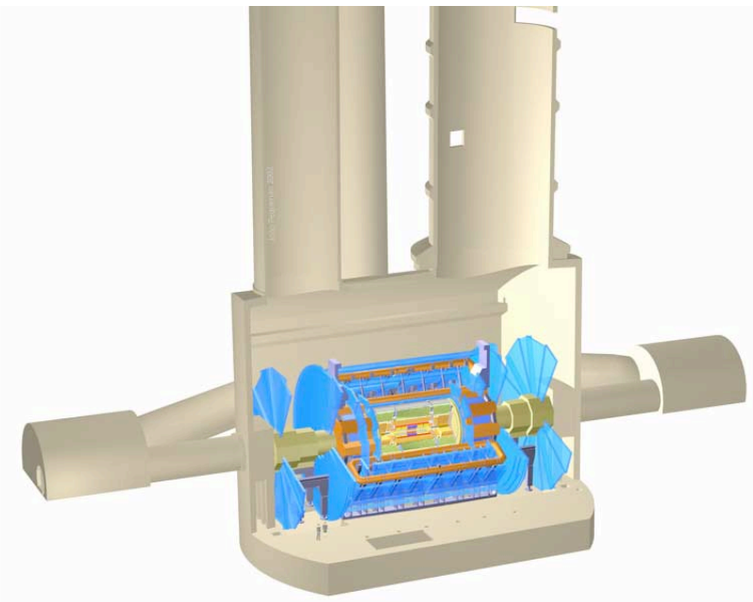
- Physicists want to cover a lot of ground, i.e. find principles that *always* work – in *heaps* of different situations.
- We want to explain origin and structure of fundamental matter + forces, from sub-atomic to cosmological scales.

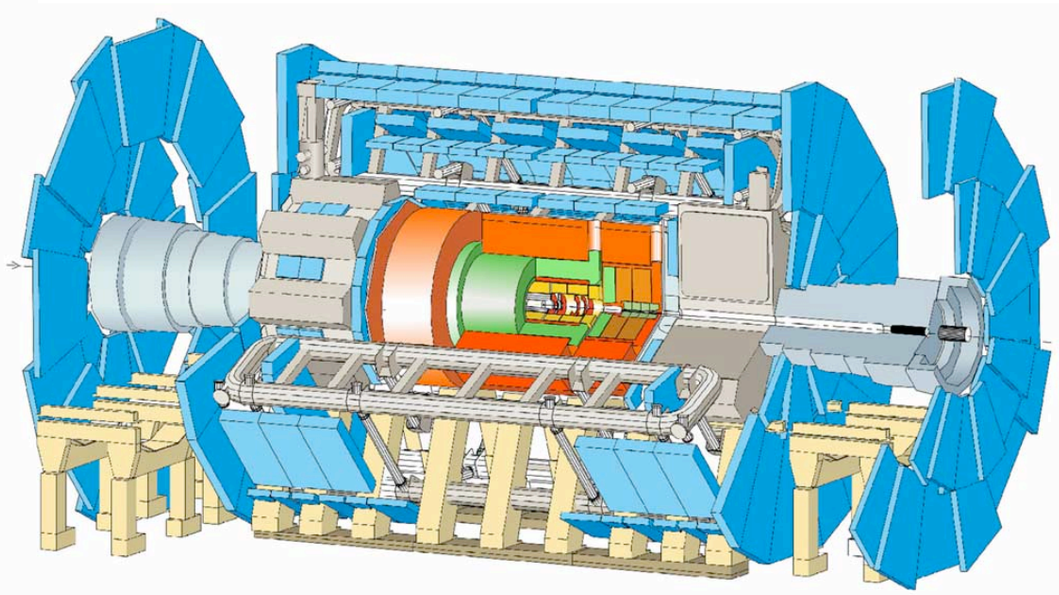


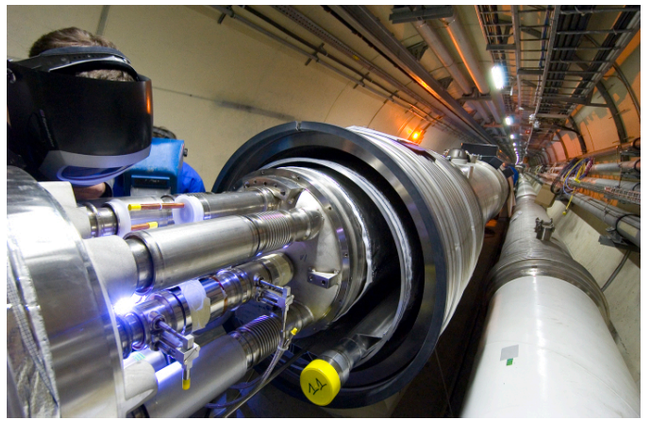

- Smallest distance imaginable: million-billion-billion-billion-th of a centimetre.
- Biggest distance imaginable: ten billion billion billion cm.

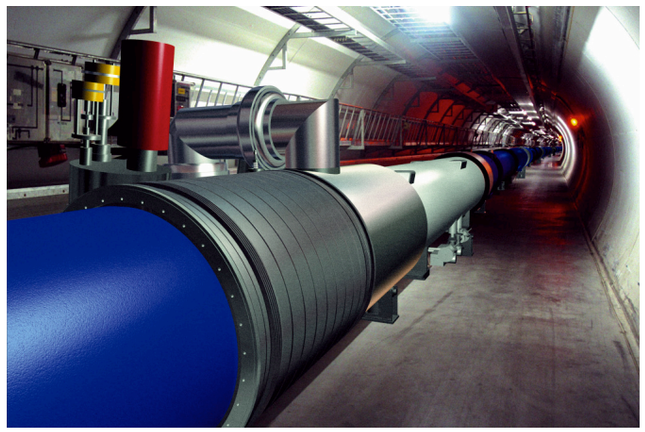
# Accountability: experiment, particle-style

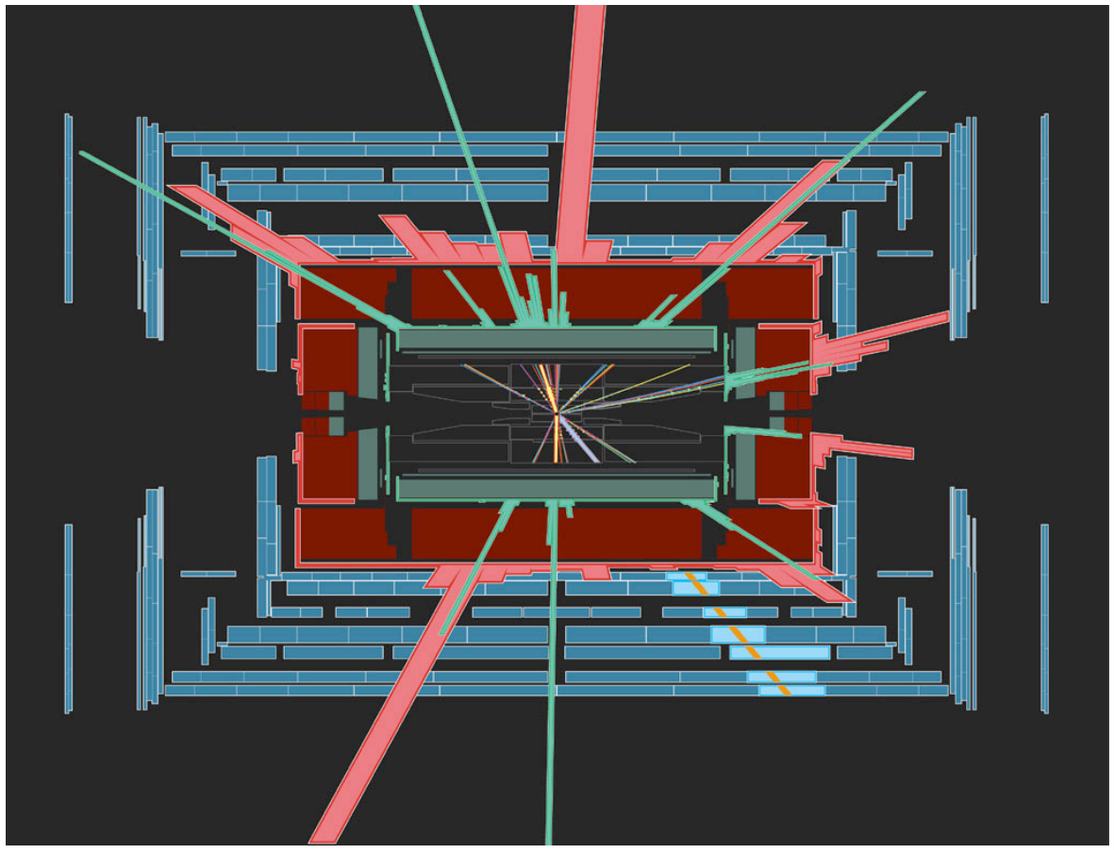


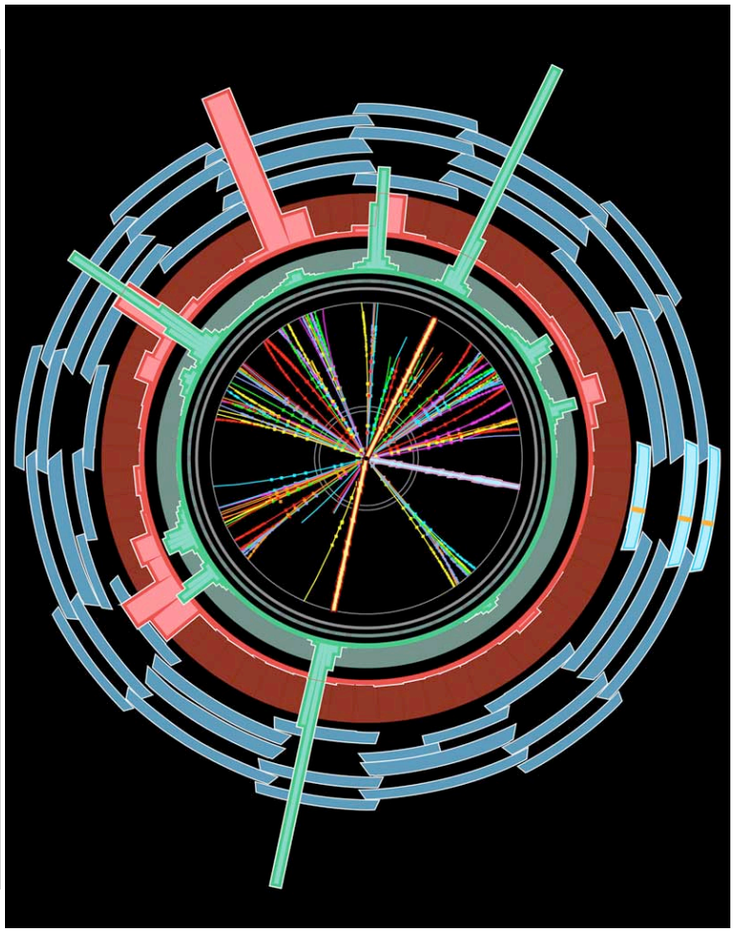




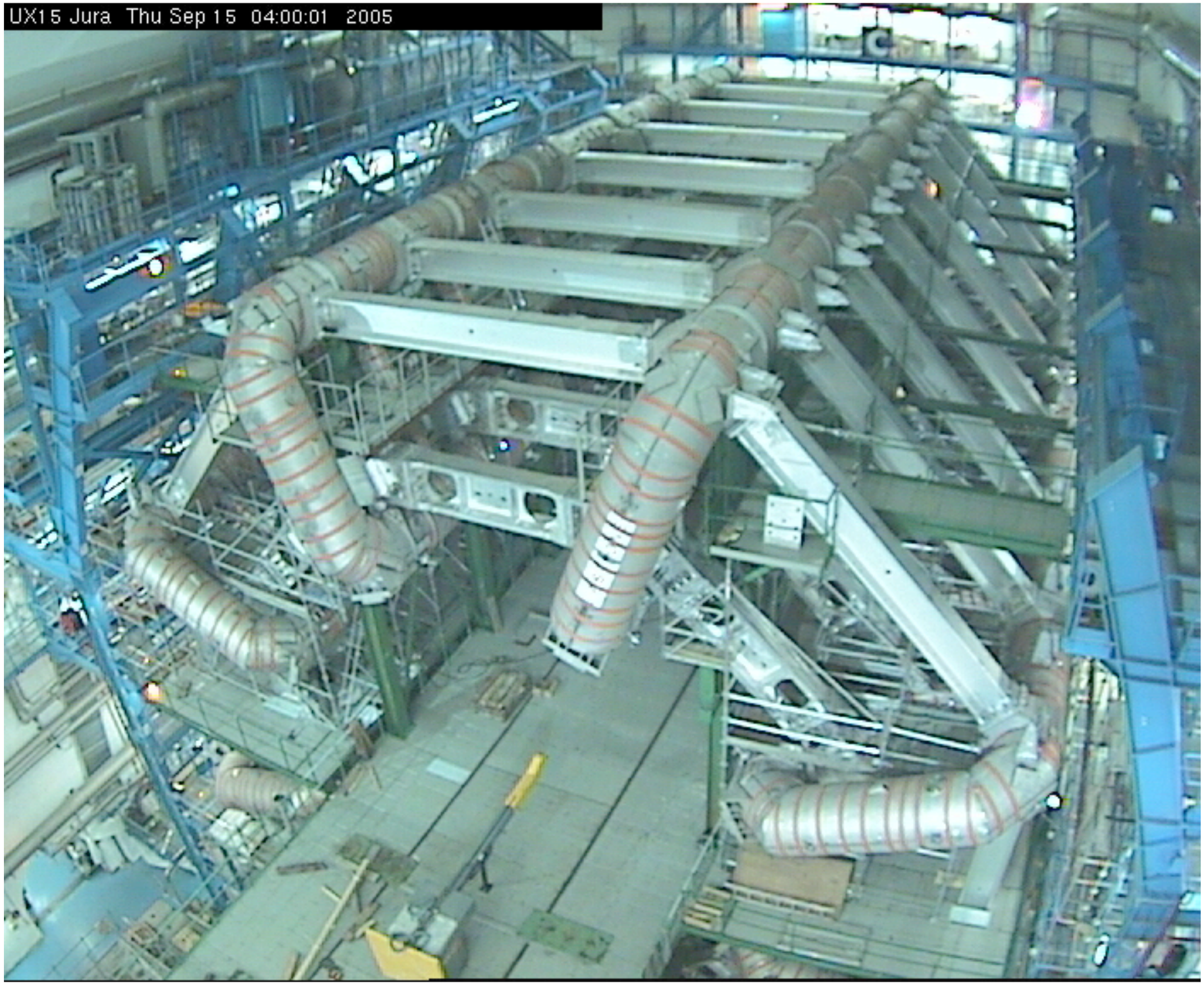




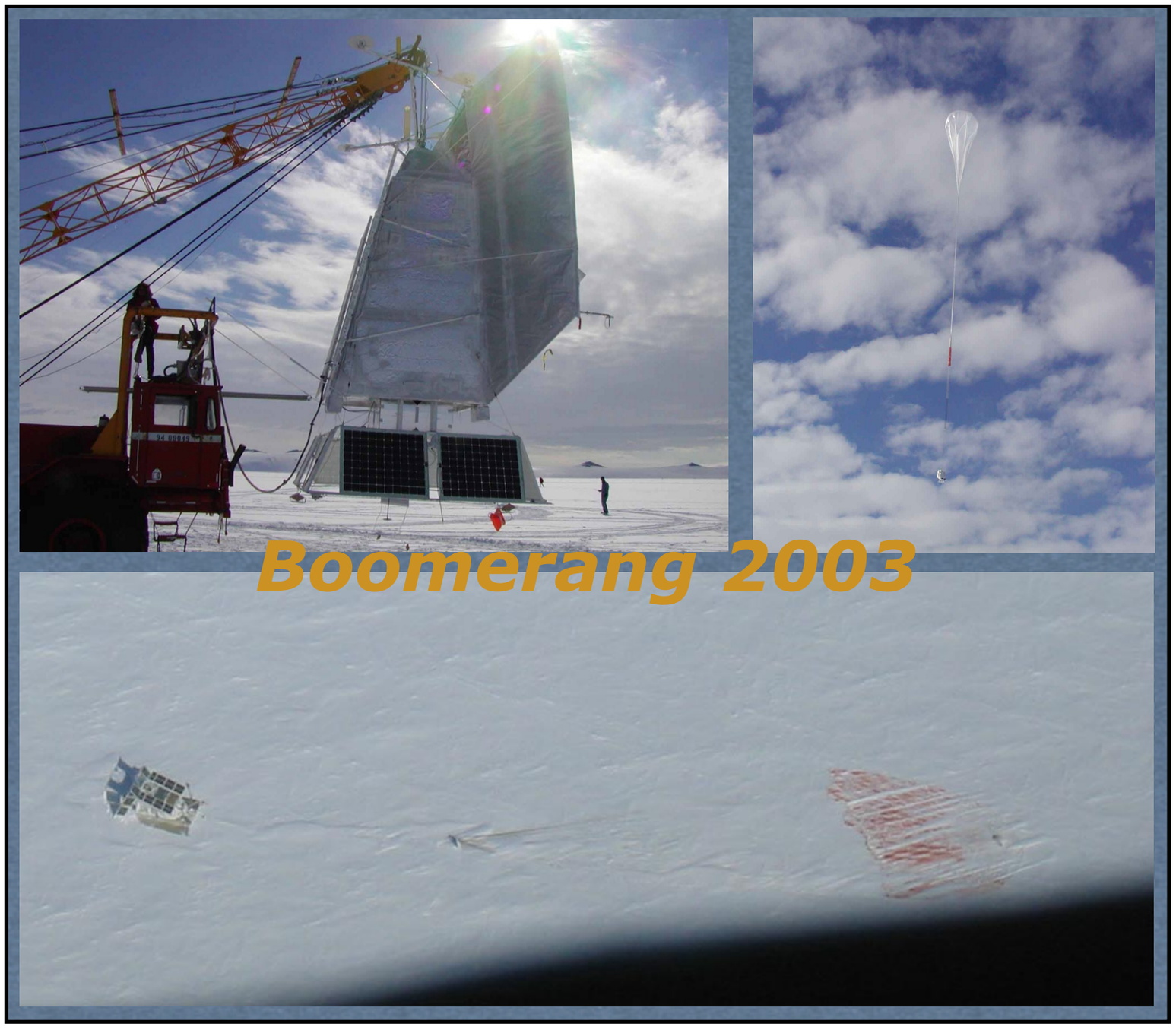




# Accountability: experiment, particle-style



# Accountability: experiment, cosmology-style



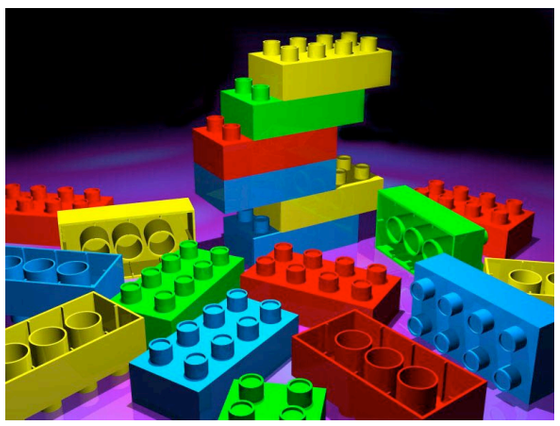

# A Theoretical Emergency

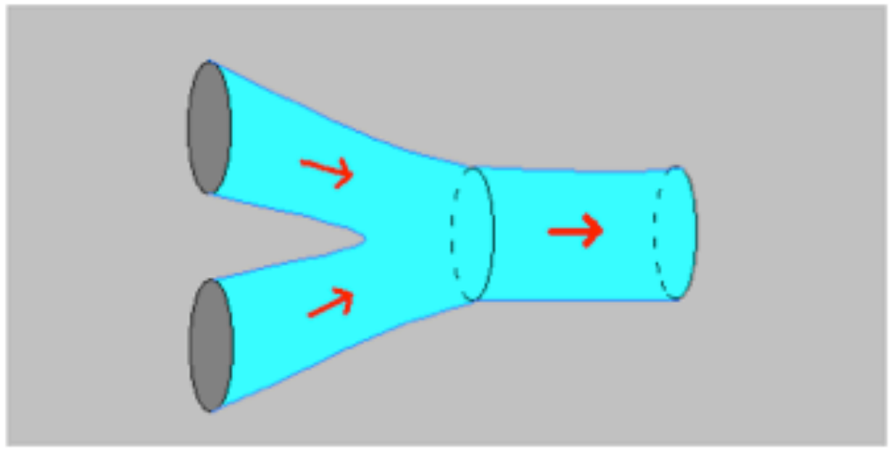
- Twin pillars of 20th century experimental physics: quantum and relativistic theory, fundamentally incompatible. Oops!!
- Need new theory that:-
  - predicts sensible physics in extreme regimes, like birth of universe and black holes (no "infinity" answers!);
  - is internally consistent (no mathematical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

# 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.

# pesky 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 | Gravi-tational | Electro-magnetic | 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!

## 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 ½ (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 |

# Evolution of Universe

- At beginning:

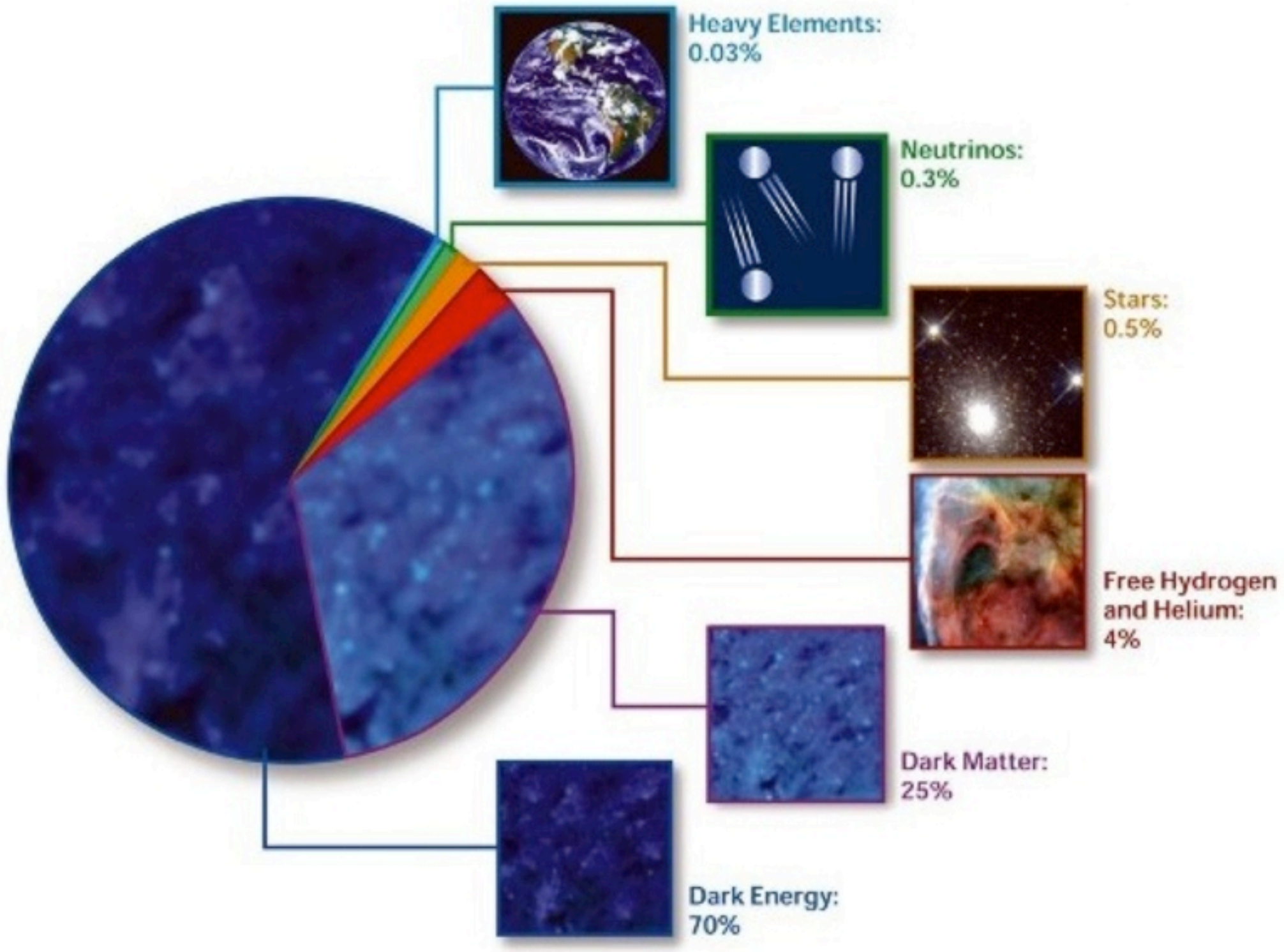


  - incredibly hot tiny universe;
  - no atoms, protons or neutrons: no binding possible;
  - quarks and leptons interchangeable;
  - all interactions same, and of same strength.

- Soon afterwards – universe inflated very fast, particle creation. Leftover radiation: now stretched out, “CMB”.

# Composition of Universe

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



# modern string theory

# Extra Dimensions of Space

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

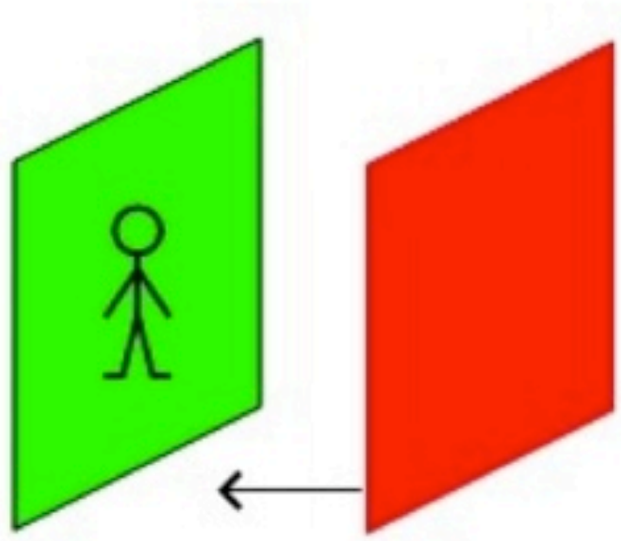

- Big ant can walk in only *one* direction - the circular dimension is just curled up so small it goes unnoticed.
- Tiny ant would think twig surface is *two*-dimensional.

- State-of-the-art experiment says:
  - if we're allowed in, extra dimensions must be $< 10^{-17}\,cm$
  - if only gravity is allowed in, they must be $< 0.15mm$

# 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?



# 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.

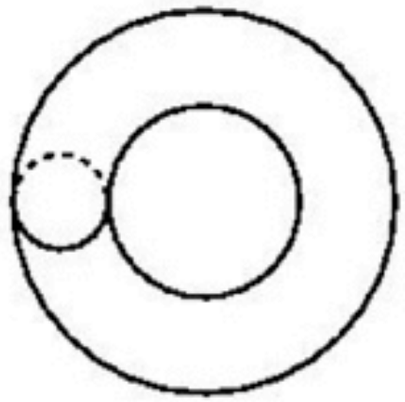
- For string acccelerators, it's different! Even theoretically, we already know: more money helps *only up to a point*.
  - At ultra-high energy, string resolution gets bad again!
  - Extra energy just pumps up size of string *probe*.

- Minimum sensible distance ~ "string scale".

- So there may be no need to look for anything deeper.

# Spacetime as Quantum and Dynamical

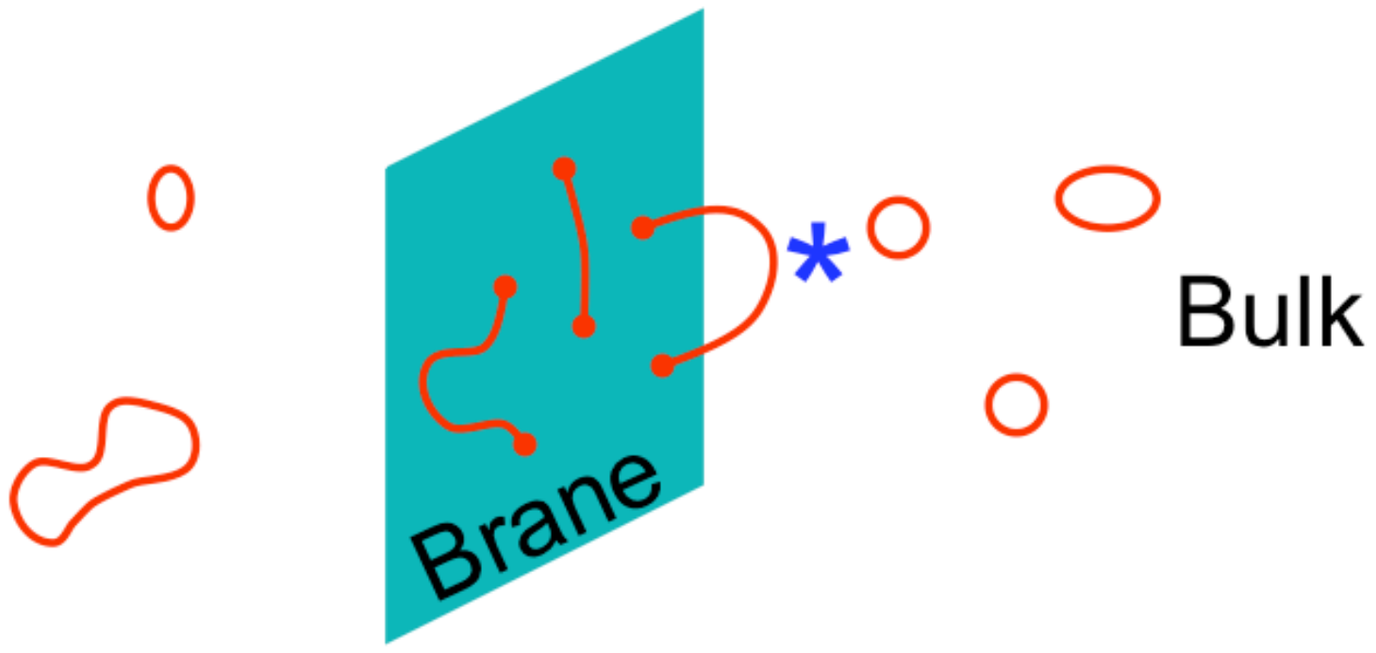
- Spacetime was thought of as merely the playing field of particles and forces.
- But in string theory, we can smoothly
  - tear the fabric of space, change its topology;
  - change the number of dimensions of space.



- 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?

# D-branes (new in 1995)

- Strings not the only extended objects in string theory!
- D-brane := hypersurface where open strings end.



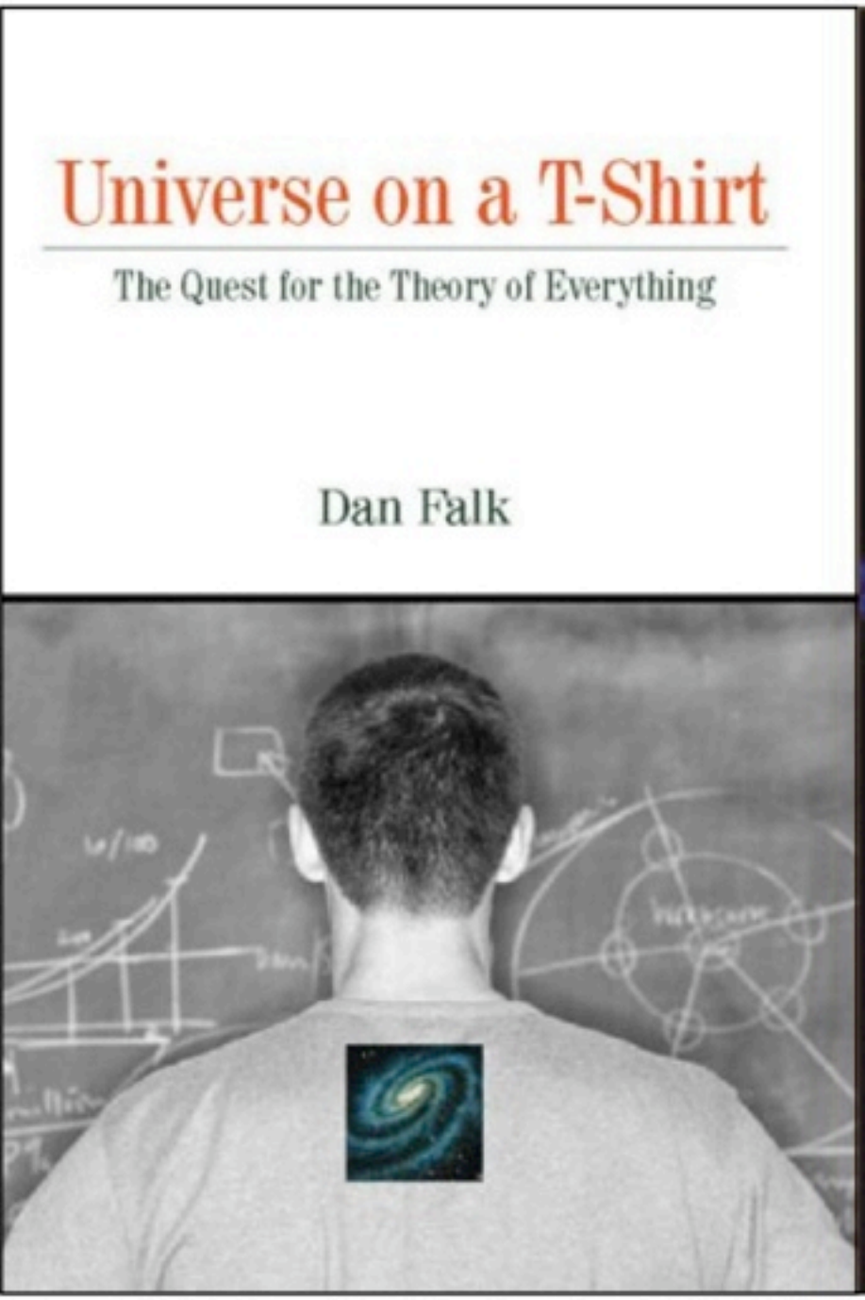

- Carries generalization of electric charge (“R-R”).
- Gravitational fields (+etc.!!) living in D=9+1 bulk.
- Gauge fields (+etc.!!) living in d=p+1 worldvolume.

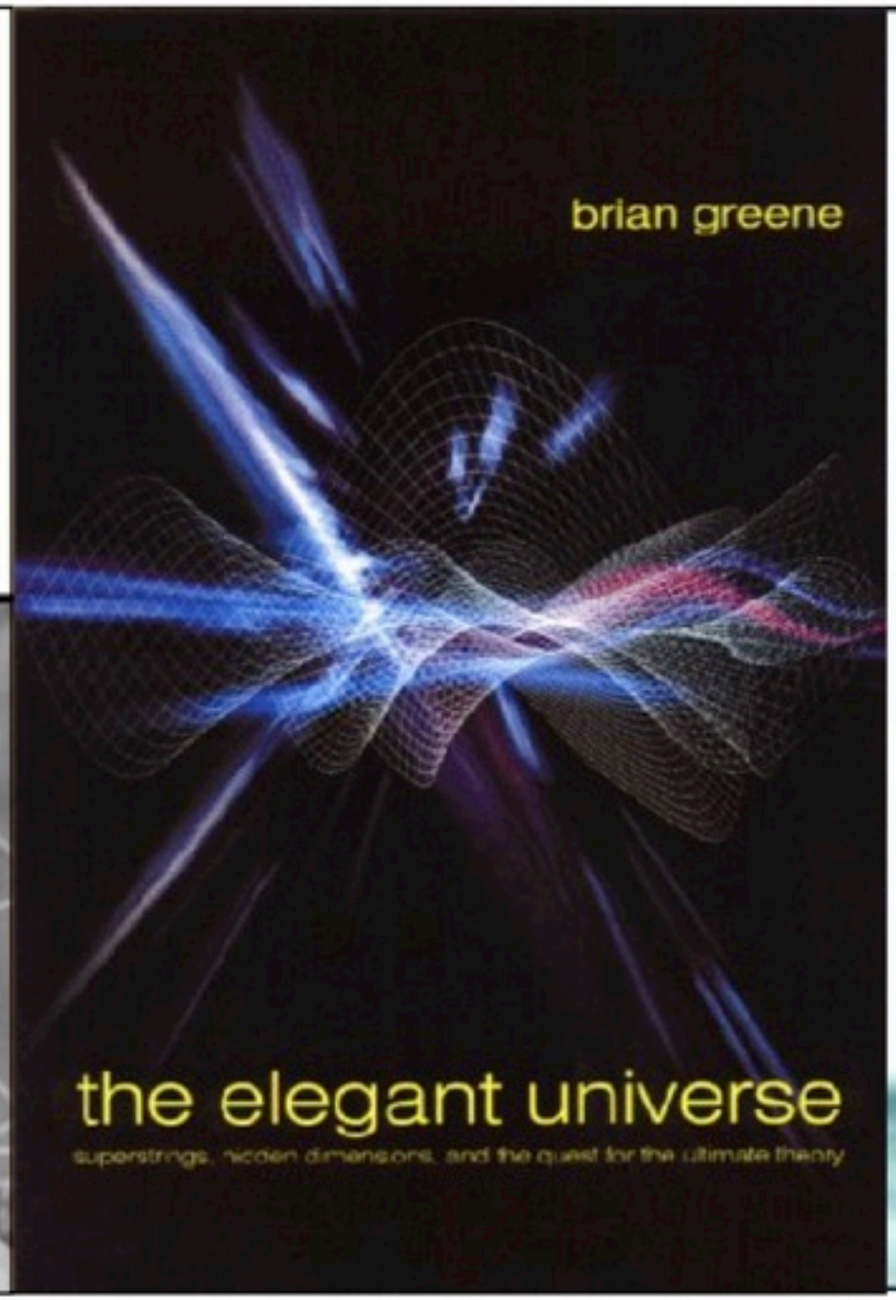
## AdS/CFT (new in Dec.1997)

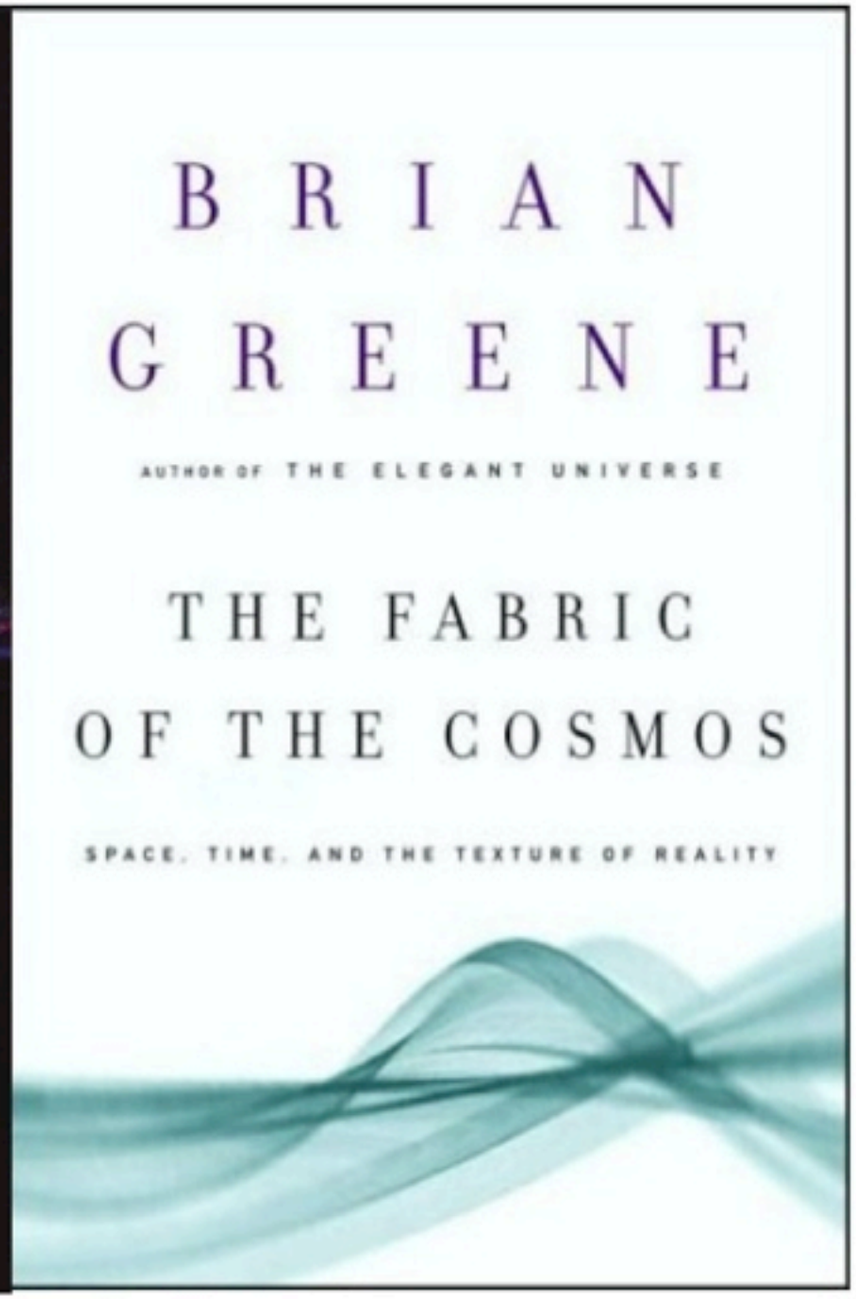
- Taking "decoupling limit", i.e. special low-energy limit, of system of N Dp-branes ⇛ massive simplifications.
- Open string theory on branes ⇛ simple gauge *field theory*, specifically n=4 supersymmetric Yang-Mills.
- Closed string theory in bulk ⇛ *near-core region* of bulk supergravity spacetime, plus stringy corrections in [interior of] near-core bulk SUGRA spacetime.
- Stunning new duality, i.e. equivalence, between gravitational stringy system and SYM field theory. *Explicit, computable* example of emergent gravity. Spacetime classical only as $N \to \infty$ and $g \to 0$.
- p=3 is "AdS/CFT", p≠3 cases more tricky. ☺

more?

# Where to Learn More



# Where to Learn More


The Official STRING THEORY Web Site

www.superstringtheory.com

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# Where to learn more

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Thanks for watching!

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