

Some PPPs (particle physics puzzles)

- Are neutrinos their own anti-particles?
- What is dark matter?
- What is dark energy?
- Where does inflation come from?
- Why is there more matter than antimatter?
- Are there even more fundamental entities than quarks and leptons?
- Are there unknown forces?

Deficiencies of the Standard Model

The Standard Model is really successful, but...

- Does (fundamental particle rest) mass exist?
- Why are the masses so vastly different?
Lowest mass neutrino eigenstate $\rightarrow$ 170,000,000 times lighter than the heaviest
quark t (top quark) $\rightarrow$ 170,000,000 times heavier than the lightest
- Why are there so many “fundamental particles”?

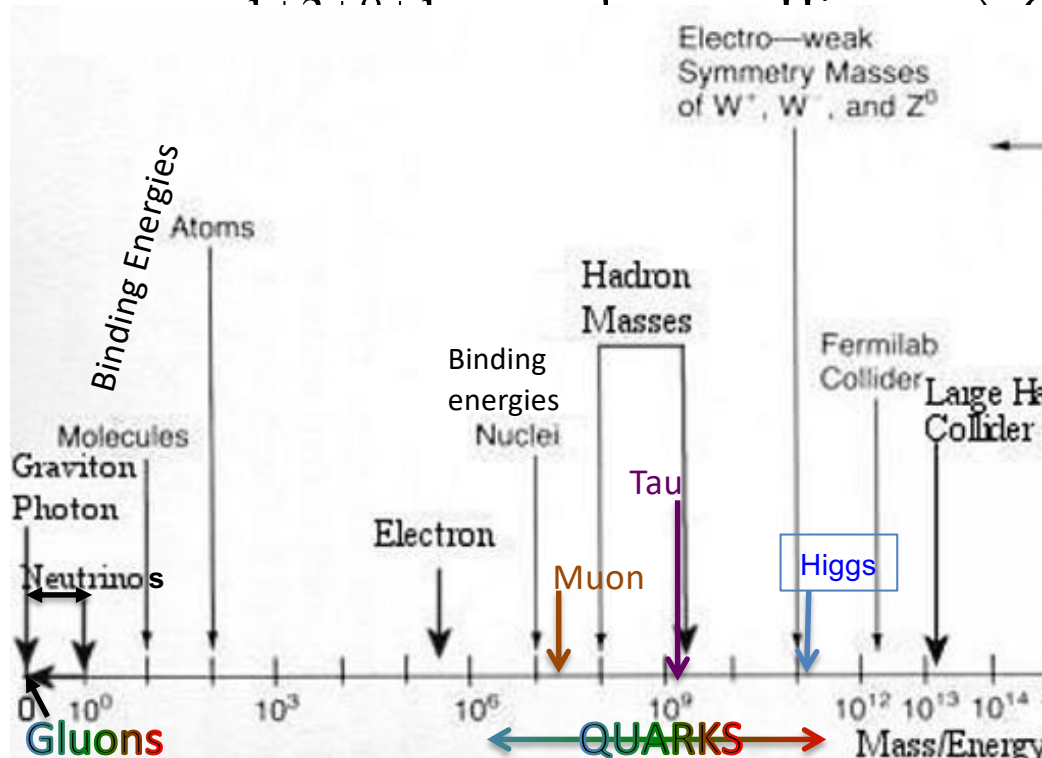
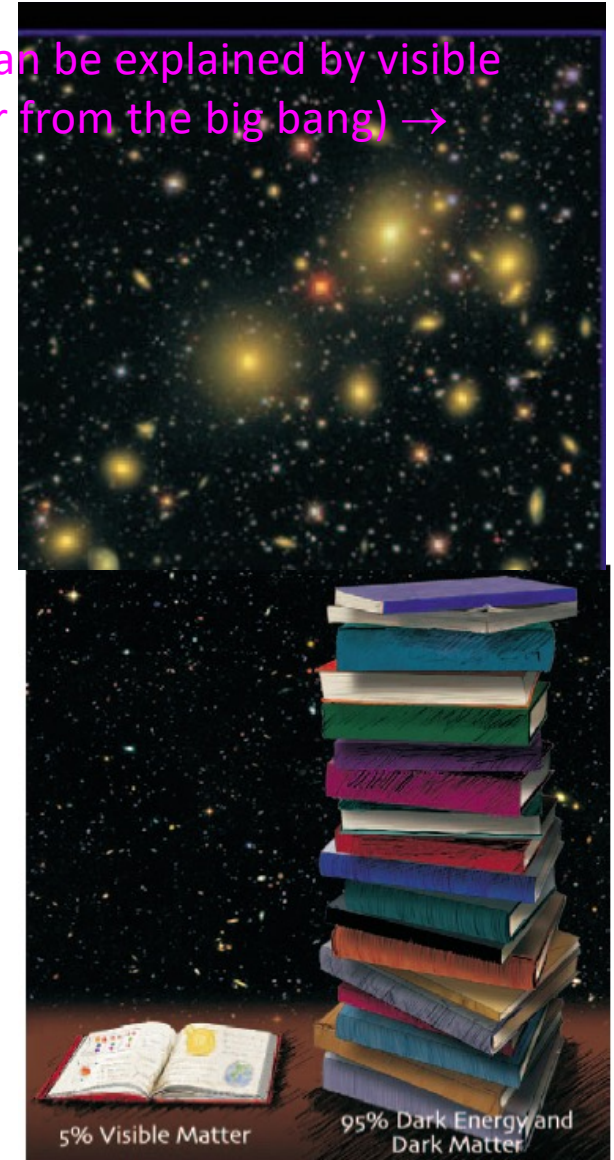
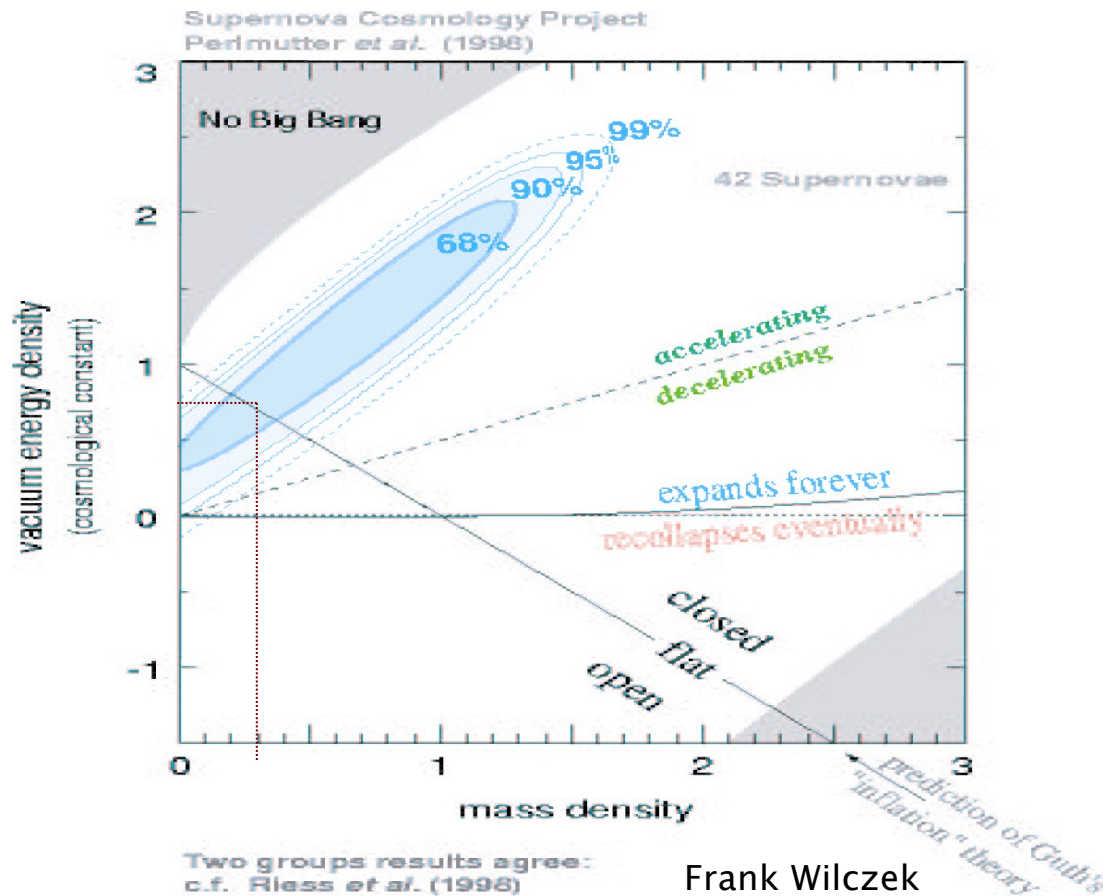


Image Credit: Fermilab

Deficiencies of the Standard Model

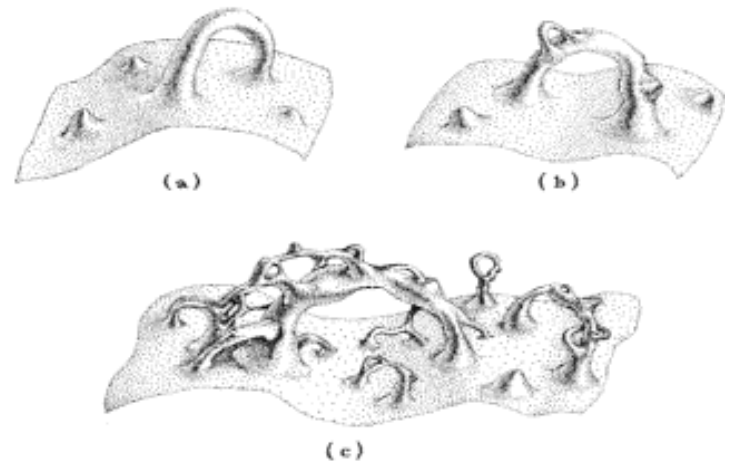
We observe much more gravitation in the Universe than can be explained by visible mass (and even by **all** hadronic and leptonic mass left over from the big bang) → WIMPs.



Deficiencies of the Standard Model

Gravitation - what happens at the Planck Scale?

- The Planck Scale - a universal size, time and energy scale
 - Einstein: $E^2 = m^2c^4 + p^2c^2 \Rightarrow E \geq pc$
 - Heisenberg: $\Delta p \cdot \Delta x \geq \hbar/2 \Rightarrow E \geq pc \geq \hbar c/2\Delta x$
 - Newton: $U_{\text{grav}} = m GM/r \Rightarrow$ Escape velocity $v_{\text{esc}} = (2GM/r)^{1/2} \leq c \Rightarrow$
Black hole: Schwarzschild radius $R = 2GM/c^2$
 - Einstein: $M \leftarrow E/c^2 \Rightarrow R = 2GE/c^4 \geq 2G\hbar/(2c^3 R)$
 - $\Rightarrow$ Planck length: $R = (G\hbar/c^3)^{1/2} = 1.6 \cdot 10^{-35} \text{ m}$;
Planck Mass $22\mu\text{g}$ (10^{19} GeV)
Planck Energy $2 \cdot 10^9 \text{ J}$
- What happens at the Planck Scale?
 - Space-Time becomes “frothy”
 - Pointlike interactions make no sense
 - Pointlike particles make no sense



Supersymmetry

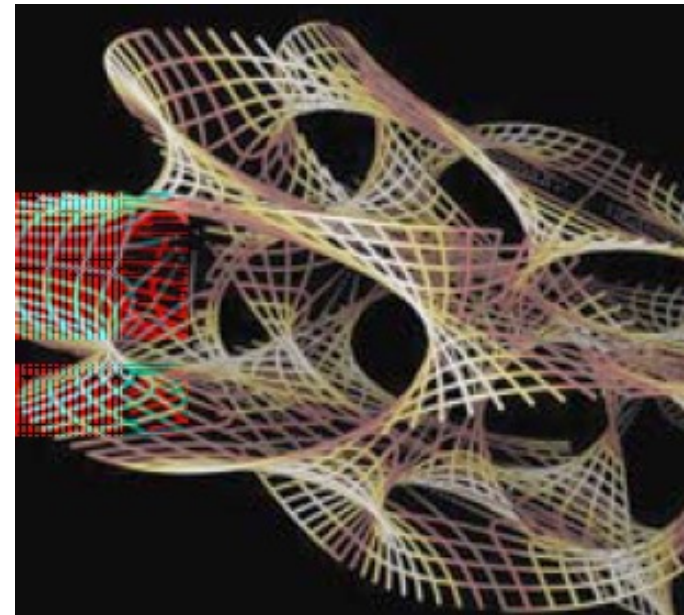
- Fundamental Space-Time-Spin symmetry
- Every Particle has a Super-Partner of different spin (different statistics!):
 - Fermions ($S = 1/2$) $\Leftrightarrow$ sFermions ($S = 0$)
 - sneutrinos, selectrons, smus, staus, squarks
 - Bosons ($S = 0,1,2$) $\Leftrightarrow$ Bosinos ($S = 1/2$)
 - winos, zino, photino, gluino, gravitino, higgsino
- May explain dark matter (WIMPs = lightest Super-partner)
- Supersymmetry is broken at high energy scale (1 TeV?) - should be accessible at LHC

Supersymmetry - some (minor?) problems

- Now we are supposed to **double** the number of particles (not a single one has been detected yet)? First LHC run came up empty!
- Add to that a whole bunch of other parameters and possibly new interactions (sfermion decays, quark decays $\rightarrow$ proton should be unstable, but so far only upper limits have been found)
- Why is supersymmetry broken, and why is it broken at yet another mass scale?

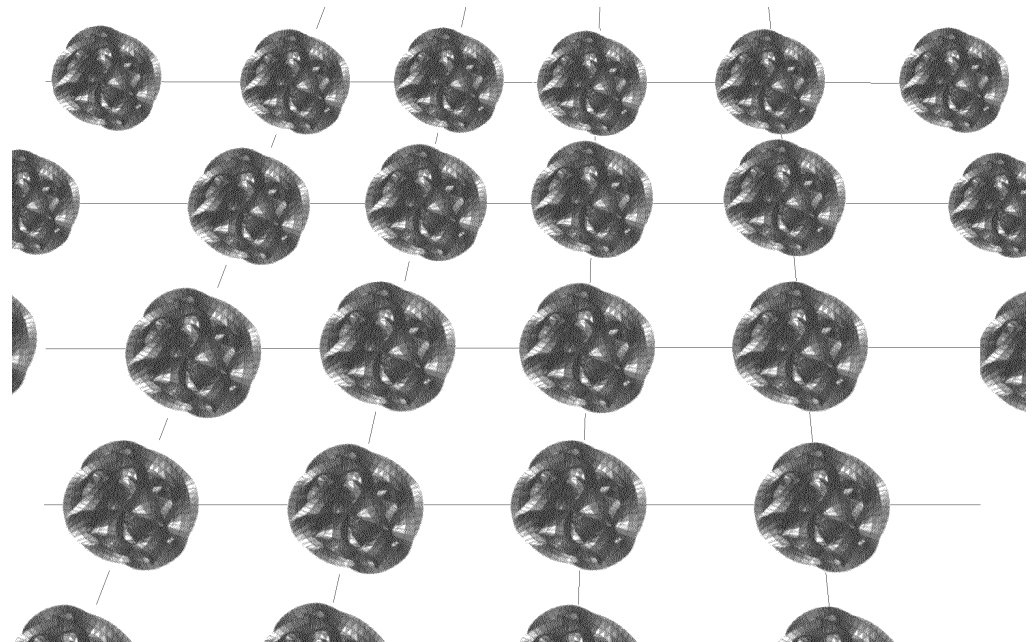
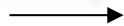
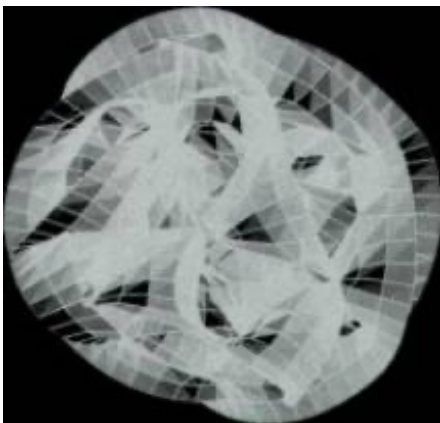
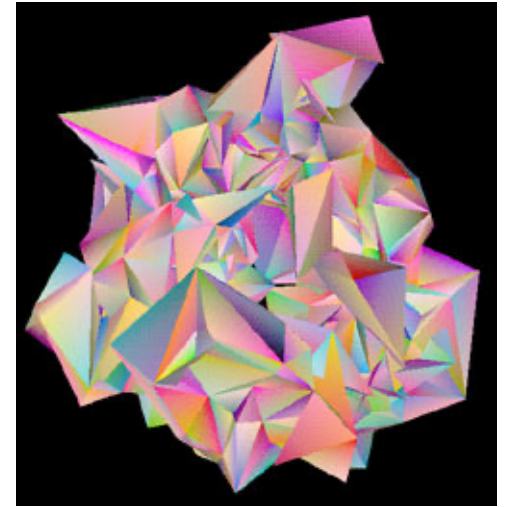
Super-Strings

- All particles are vibrations of incredibly tiny strings (of size of the Planck scale, 10^{17} times smaller than resolution of present accelerators).
Tension = $10^9\text{J}/10^{-35}\text{m} = 10^{40}$ tons
- They are “wrapped” around extra dimensions
- Their vibrational energies determine their masses.
- Vibration patterns determine charges and spin (determined by geometry of extra dimensions).
- Original idea: Kaluza-Klein.



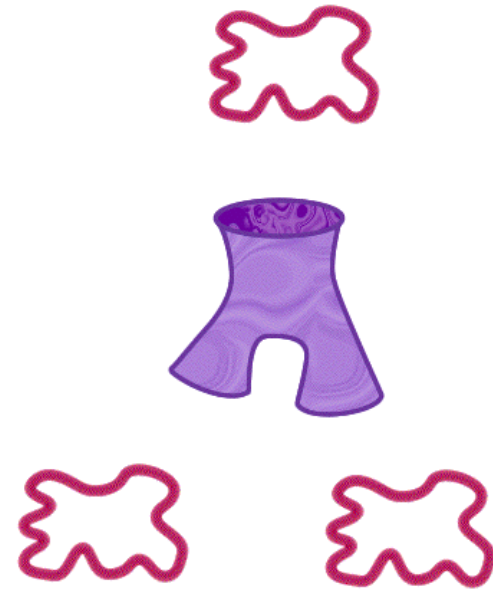
Super-Strings

- Require 9+1 dimensions to avoid negative probabilities
- Extra dimensions “curled up”
- “Calabi Yau Spaces”
- Compare to ants on a hose



Super-String Theory

- Unified picture of all four interactions
- Avoids singularities in particle interactions - you can't make them smaller than the Planck Length
- Includes Supersymmetry "automatically"
- Could be compatible with all 4 forces uniting in strength at the Planck scale
- Might explain beginning of Universe



Super-Strings - some (minor?) Problems

- Nobody can write down the exact theory (equations aren't fully known)
- Only approximate solutions known
- Many competing versions (Brane theory...) -> too many solutions
- Presently hard to see how we can test them experimentally

Nobel Laureate 2004



The New York Times
nytimes.com

September 2, 2003

One Cosmic Question, Too Many Answers

By DENNIS OVERBYE

Call it the theory of anything.

But the same calculations confirmed that string theory could have a vast number of solutions, each representing a different universe with slightly different laws of physics. The detailed characteristics of any particular one of these universes — the laws that describe the basic forces and particles — might be decided by chance.

As a result, string theorists and cosmologists are confronted with what Dr. Leonard Susskind of Stanford has called "the cosmic landscape," a sort of metarealm of space-times. Contrary to Einstein's hopes, it may be that neither God nor physics chooses among these possibilities, Dr. Susskind contends. Rather it could be life.

Only a fraction of the universes in this metarealm would have the lucky blend of properties suitable for life, Dr. Susskind explained. It should be no surprise that we find ourselves in one of these. "We live where we can live," he said.

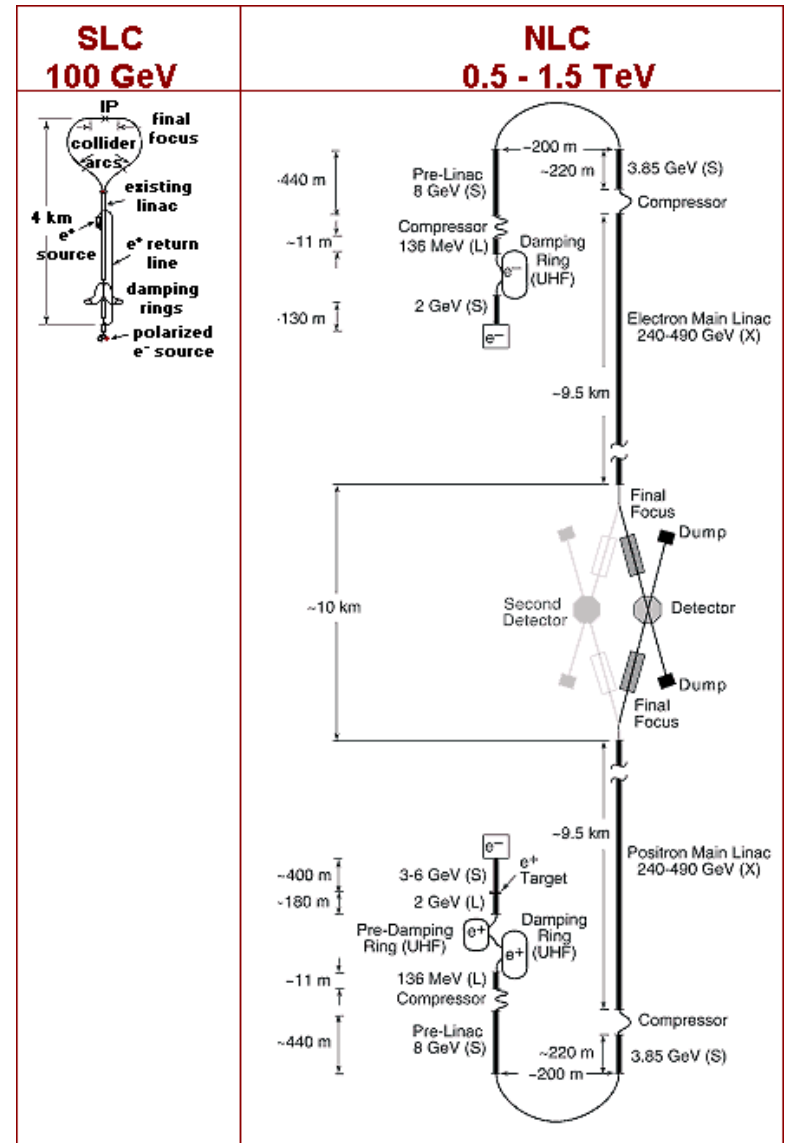
Dr. Susskind conceded that many colleagues who harbor the Einsteinian dream of predicting everything are appalled by that notion that God plays dice with the laws of physics.

Among them is **Dr. David Gross**, director of the Kavli Institute of Theoretical Physics in Santa Barbara, Calif., who said, "I'm a total Einsteinian with respect to the ultimate goal of science." Physicists should be able to predict all the parameters of nature, Dr. Gross said, adding, "They're not adjustable."

The Future ?



- LHC (CERN)



- NLC ?

...back to nuclei

Question

- What keeps nuclei from falling apart? Gluons?
 - Not likely (need at least 2 $\rightarrow$ short range)
 - How do water molecules stick together? Residual (van der Waals) forces (e.g., dipole-dipole interaction)
- First need to study how protons and neutrons interact with each other
 - E&M (Coulomb repulsion, magnetic interaction through spins)
 - Strong Force
- HOW do we figure this out?

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- HOW do we figure this out?
- OF COURSE: Through scattering experiments