Today

- Announcements:
  - HW#8 is due Wednesday Nov. 2nd.
  - Exam #2 will be one week from today
- The exam review sheet will be available by 11:00pm tonight
- Today we will continue to discuss our current understanding of the forces and particles of nature

The Standard Model

The Standard Model is the name given to the current theory of fundamental particles and how they interact. This theory includes:

- Strong interactions due to the color charges of quarks and gluons.
- A combined theory of weak and electromagnetic interaction, known as electroweak theory.

The theory does not include the effects of gravity. Gravity is tiny compared to the other forces and can be neglected in describing atoms.

The particles of the standard model

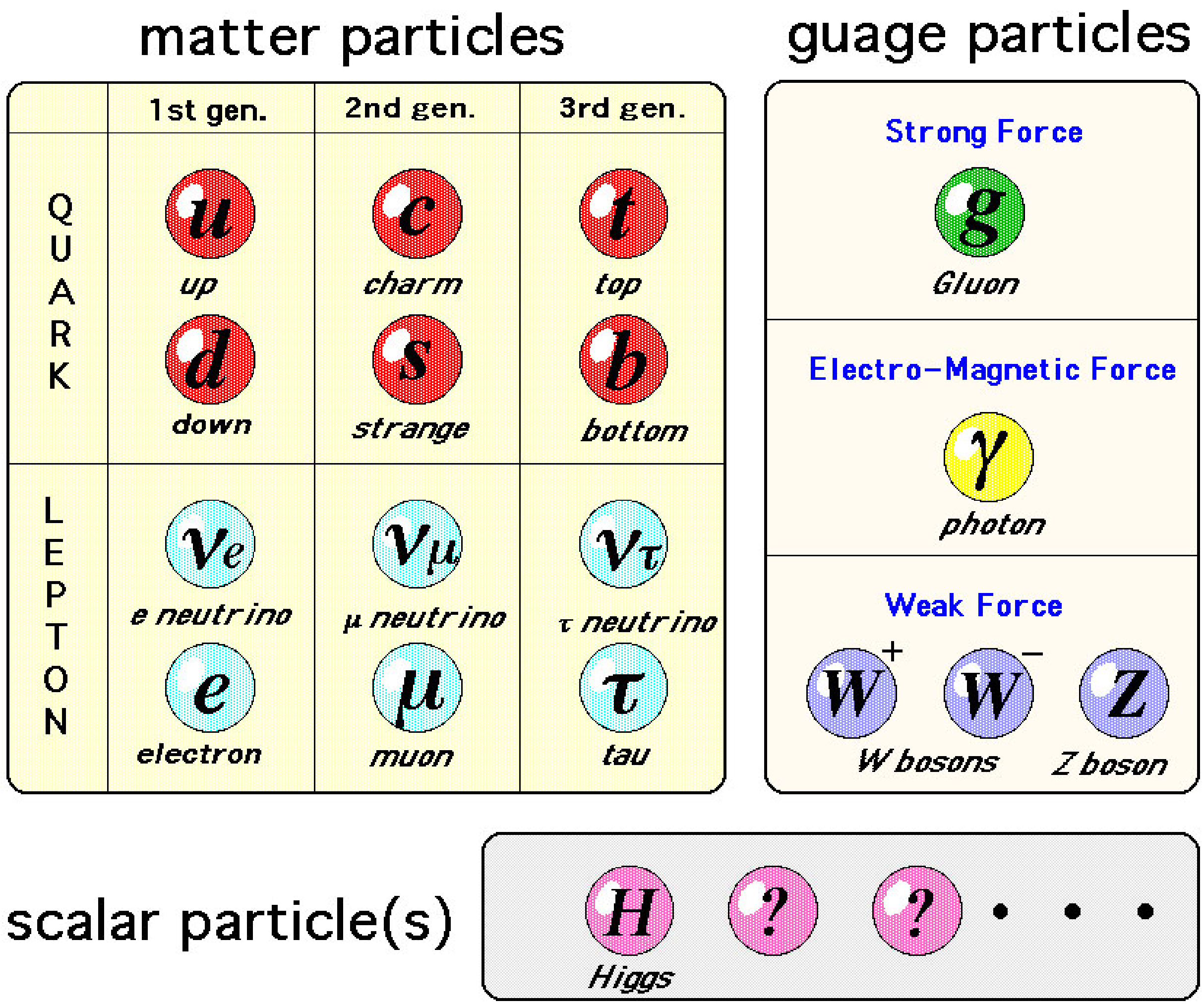
Charge

+2/3 →

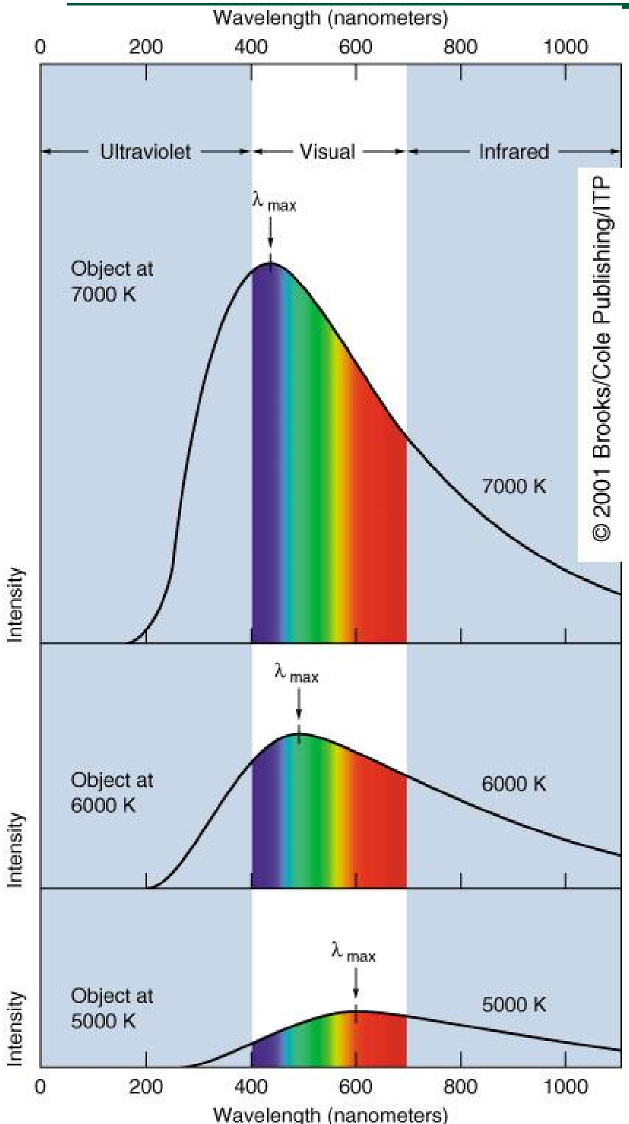
-1/3 →

$\bar{u}$ has a charge of –2/3

T. Kondo



Blackbody Radiation



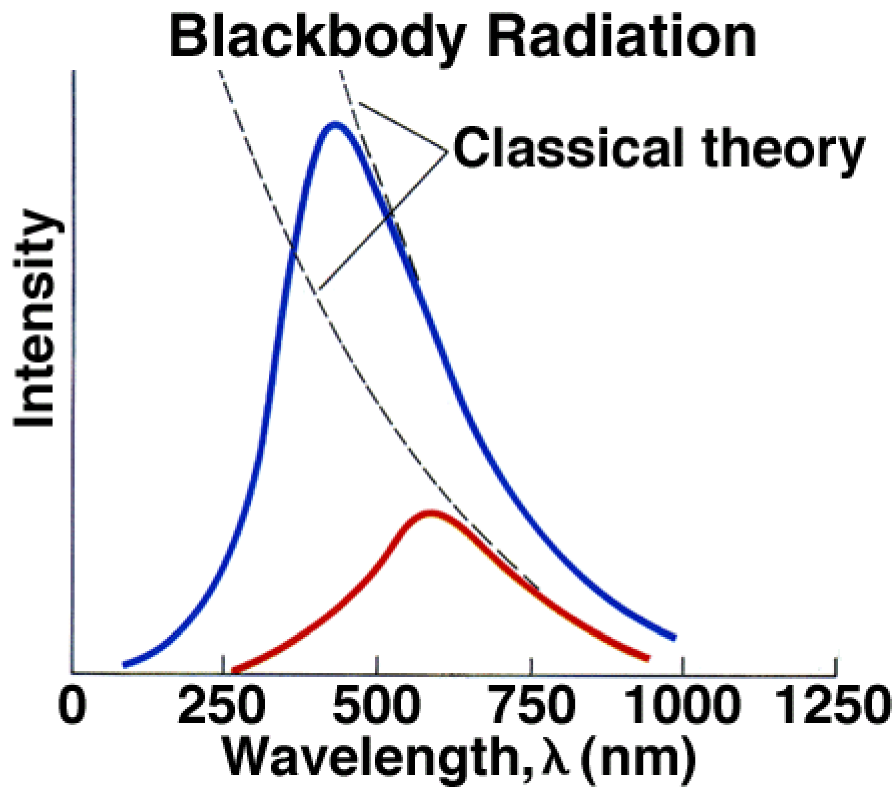
All objects emit a spectrum of photons. A perfect black body has the spectrum shown at the left.

The emission spectrum depends on temperature. The amount depends on size.

$$L = \sigma A T^4 \,; \sigma = 5.67\times 10^{-8} \frac{W}{m^2 K^4}$$

$$E_{mean} = 2.705 \cdot kT; k = 8.617\times 10^{-5} \frac{eV}{K}$$

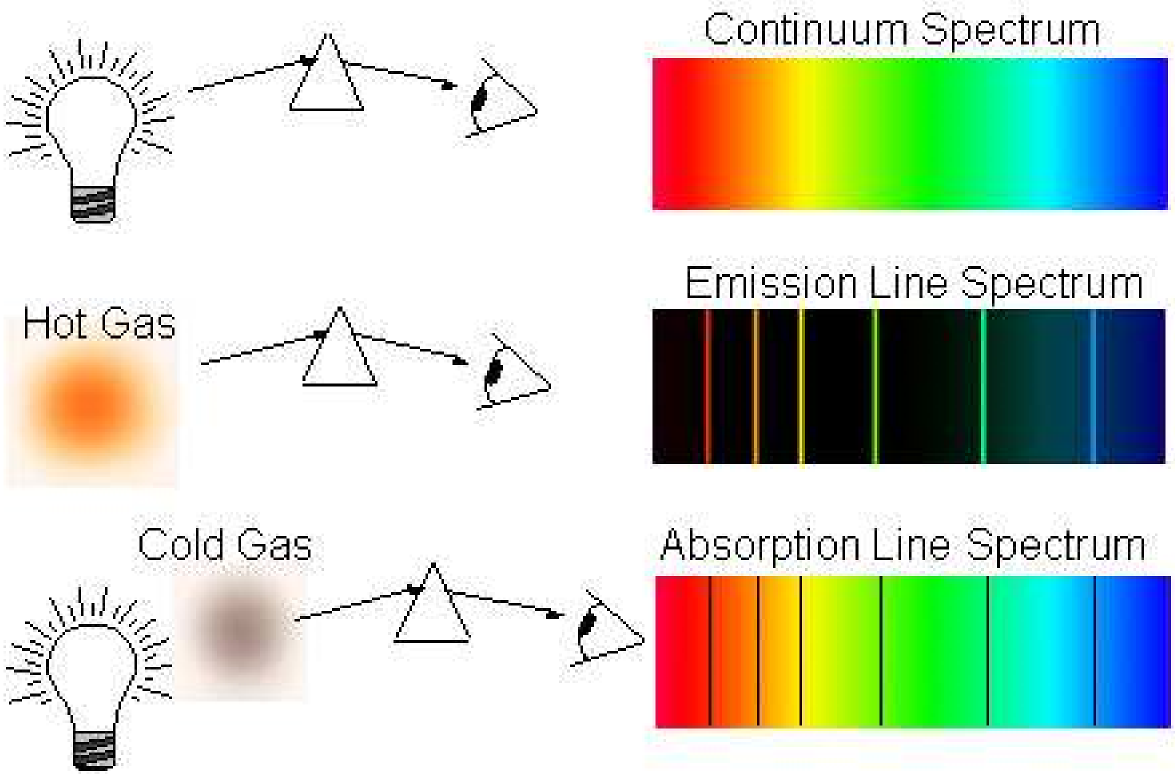
The Ultraviolet catastrophe



Quantum theory explains why the curves go back to 0 at zero wavelength.

It is because photons comes in packets (of energy hf) called photons

Spectra come in 3 kinds



Examples

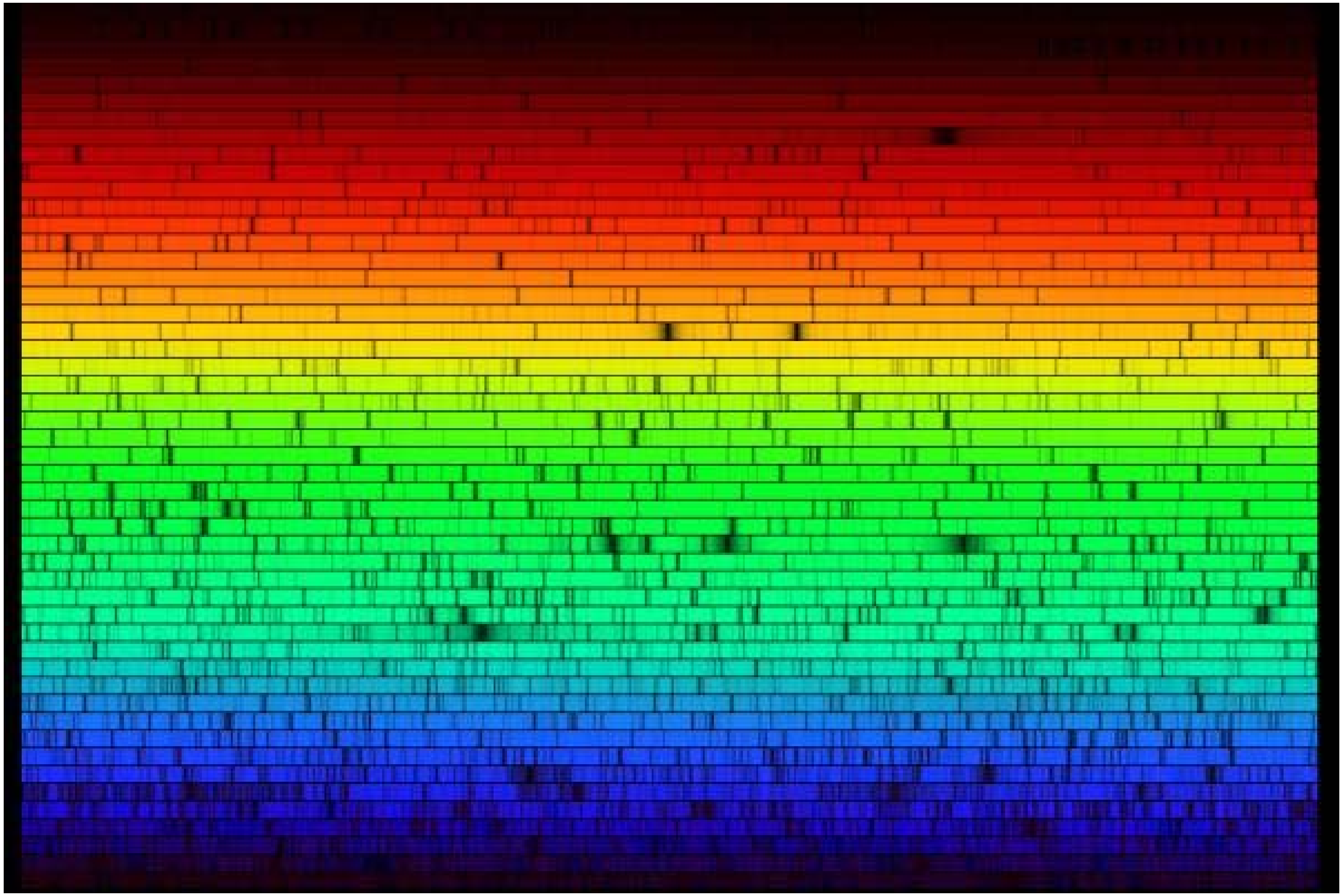
Heated rod or candle

Atoms in a gas excited by high temperature or high energy photons

Spectrum from the Sun

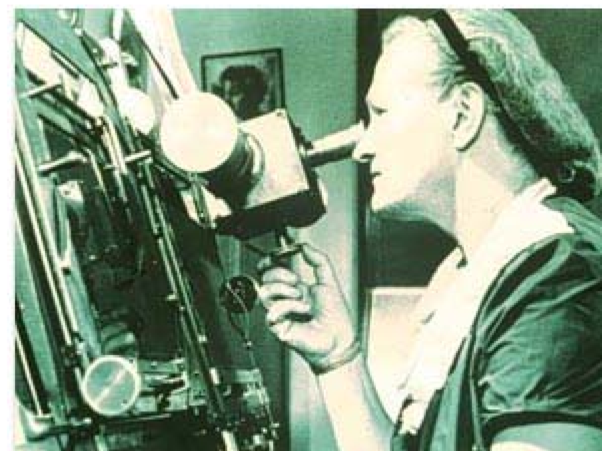
The pattern of lines tells what elements are present.

The spectrum from our Sun



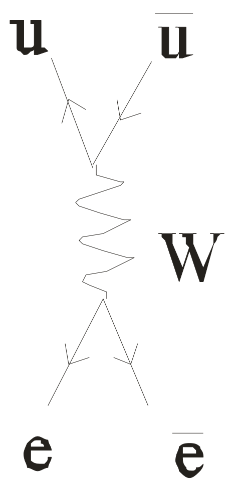
Cecilia Payne-Gaposchki Story

- Studied astronomy at Oxford
- Came to Harvard for graduate study because the only career for women in England in astronomy was teaching
- Was the first person to realize that the stars are mostly made of hydrogen and helium
- Here thesis is widely regarded as the best ever in astronomy.



Rules for particle interactions

Example: $e + \bar{e} \rightarrow u + \bar{u}$ ALLOWED



$n \rightarrow p + e$ NOTALLOWED (lepton number)

$n \rightarrow p + e + \bar{v}$ ALLOWED

Conserved: Electric charge, lepton number (e +1, $\bar{e}$ -1), color charge, baryon number (could also count quarks; quarks +1/3 antiquarks –1/3), energy, momentum, angular momentum

State whether or not the following are allowed (A) or not allowed (B):

$n + p \rightarrow \pi^+ + \pi^+ + \pi^-$ (Hint: pions are made of a quark and an antiquark)

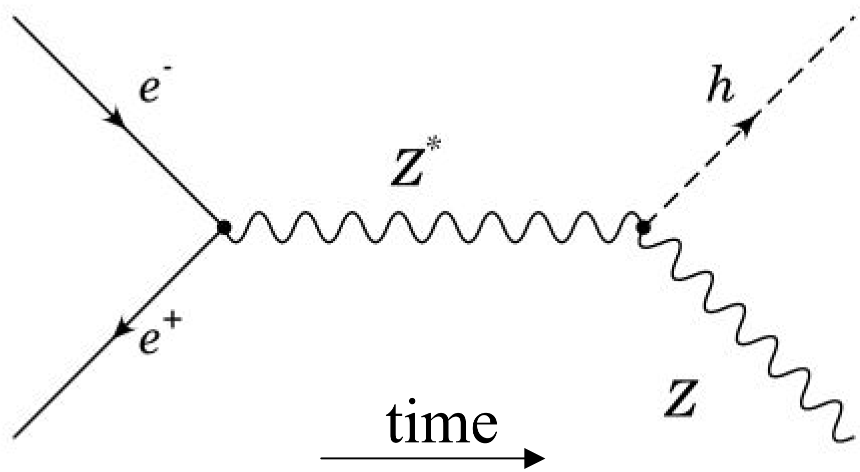
$\pi^- \rightarrow e + \bar{\nu}$

Where does mass come from?

- Space is filled with a (scalar) particle called the Higgs boson. The more a particle interacts with the Higgs field, the greater its mass is.

CERN

Here is how to produce one:



Problems with the standard model

- Why so many particles?
- Are there more particles we don't know about yet?
- What is charge? Why does it come in fixed units?
- Why is the standard model so complicated? Why 4 forces?
- How is gravity related to the other forces?
- In general the standard model does not answer the WHY question. Everyone agrees it is not a complete theory.

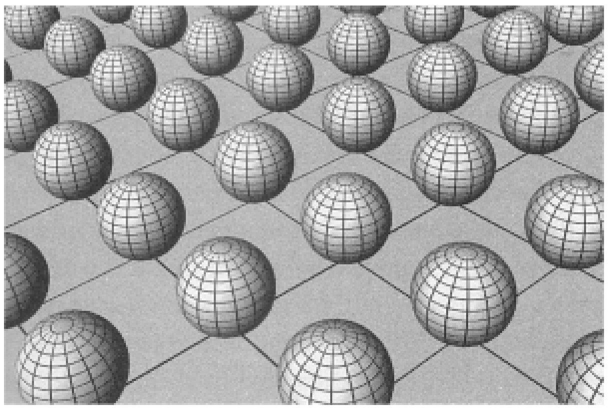
What comes next?

- There are attempts to extend the standard model to include gravity; these are called supersymmetric theories.
- These say that all fermions (which make up matter) and bosons (that transmit forces) have a corresponding partner boson (to go with our standard fermions) and fermion (to go with our standard bosons).
- Supersymmetric theories predict a whole set of new particles called s-particles, e.g. selectron, sneutrino, photino, Wino, and so on
- A new accelerator (Large Hadron Collider at CERN-Europe) may be able to produce some of these particles in the next two years.

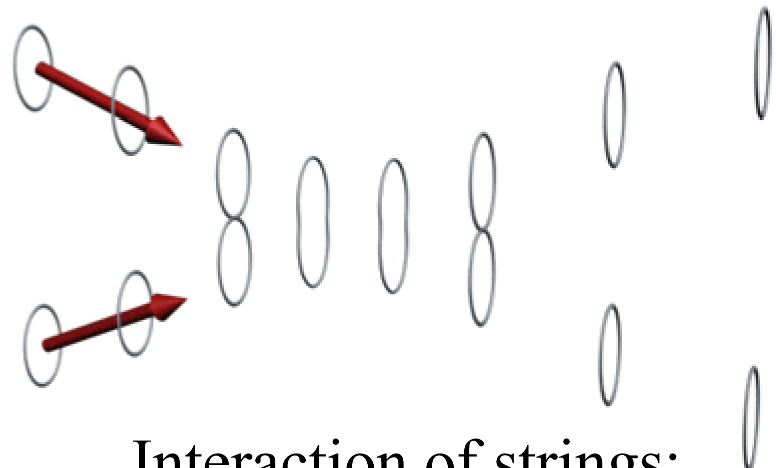
Superstring Theory

- One of the most promising new theories is string theory. It says that the fundamental building blocks of nature are tiny (10^{-35} m) strings.
- The particles we observe in nature are difference ways for strings to vibrate.
- String theory of not accepted because so far it only looks like solutions are possible.
- String theories require at least 10 dimensions.
- Gravity is weak because the graviton exists mostly in another dimension, but there is a slight overlap with us.
- String theory may be a theory of everything where all phenomena can be described by one equation.

String Theory Pictures

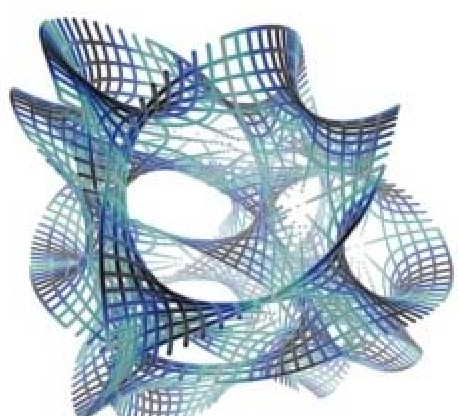


Extra dimensions



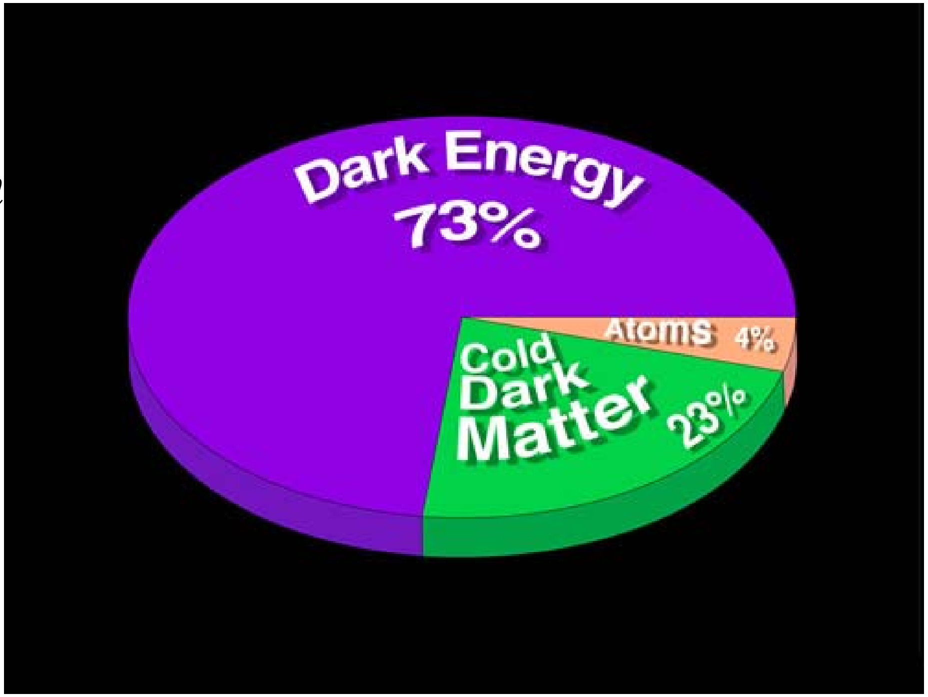
<u>Interaction of strings:</u>
The finite size (10^{-35}m) overcomes many of the problems with the interaction of point particles.

What one of the dimensions might look like. Calabi-Yau space



The Ultimate Copernican Revolution

- In 1543 Nicolas Copernicus published his treatise *De Revolutionibus Orbium Coelestium* (The Revolution of Celestial Spheres)
- We are at the brink of a new revolution. What is the Universe made of?
- All of the things we have been talking about amount to only about 4% of the mass of the universe.
- What is dark matter and dark energy? We don’t know.



We will discuss how we know this in a few weeks. Basically there is a lot more gravity than we can account for