Phyx 320
Modern Physics

May 7, 2021

Suggested Reading: Introduction to Elementary Particles, Griffiths

Final Paper Due Next Friday (May 14)

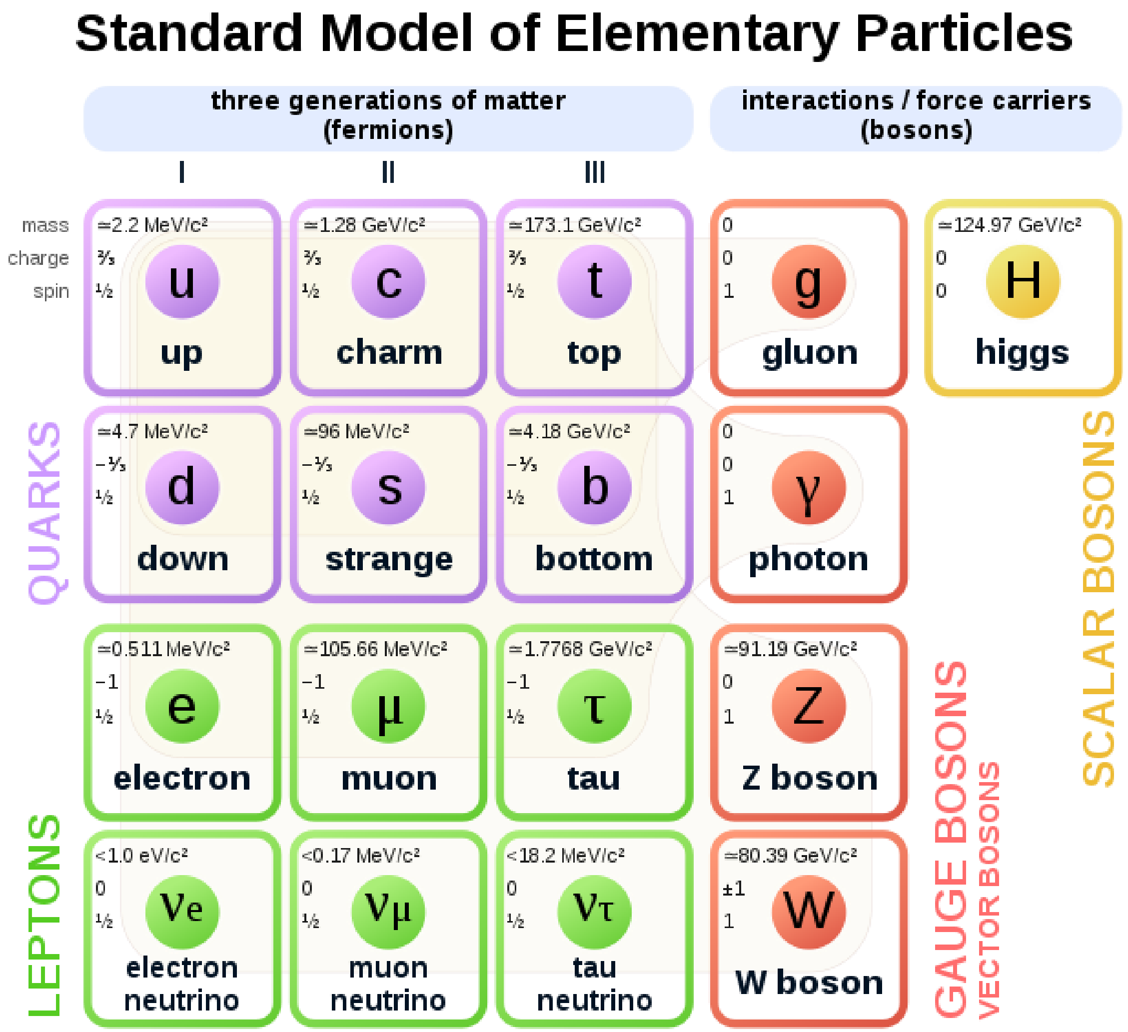
Fundamental Particles

We have two types of fundamental particles

- Fermions – spin 1/2, all matter is made of collections of fermions, follow Pauli exclusion principle
- Bosons – spin 1, forces are mediated by bosons, multiple can occupy same state

Three generations of matter, each generation is more massive than the last

Every charged particle has a corresponding antiparticle of opposite charge



Beta Decay

We can now understand the underlying process behind beta decay

Within a neutron inside the nucleus, a down quark turns into an up quark via the weak force

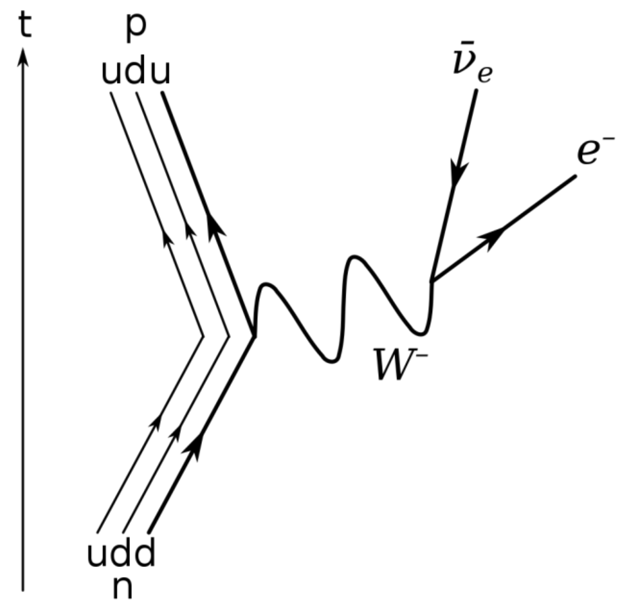
This emits a W^- (minus to preserve charge) that decays into an electron and an electron anti-neutrino

Beta-plus is the same but run backward (emitted particles become anti-particles)

$$^{A}X_{Z} \rightarrow {}^{A}Y_{Z+1} + e^{-} + \bar{\nu}_e$$ Atomic Picture

$$n \rightarrow p + e^{-} + \bar{\nu}_e$$ Nucleon Picture

$$d \rightarrow u + e^{-} + \bar{\nu}_e$$ Quark Picture



Quantum Vacuum

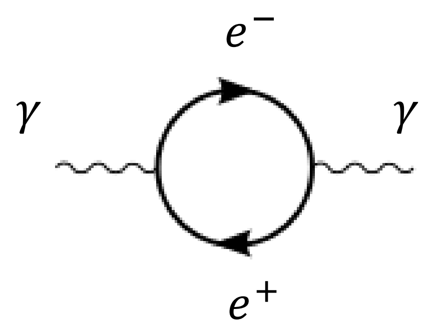
In most of physics, vacuum is the absence of anything, just empty space

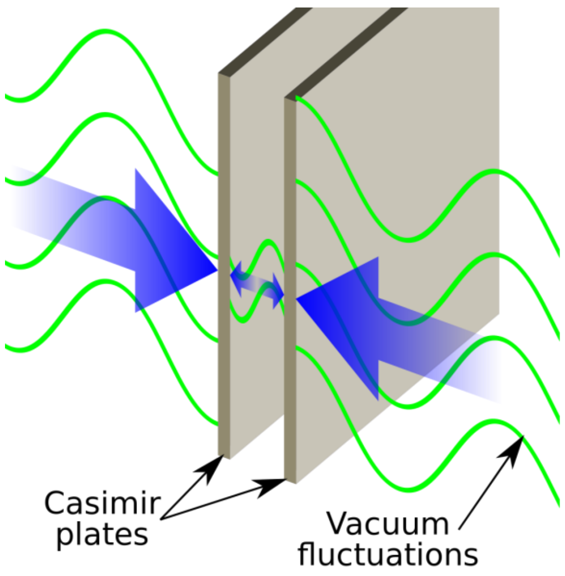
Particle physics shows that this can not happen, instead particle-antiparticle pairs are constantly popping into and out of existence

Changes how photons propagate, makes empty space have energy (vacuum energy), and causes the Casimir effect

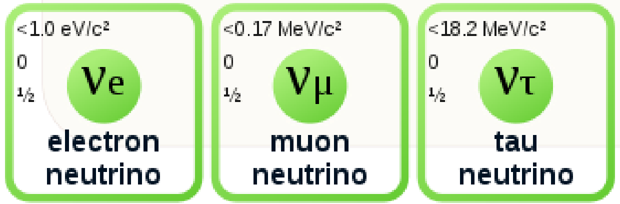
If you place two conducting plates near each other, they will feel a force inwards because the expel some of the vacuum energy

Hawking showed that this vacuum energy can evaporate black holes over time





Neutrinos



Neutrinos only interact via the weak force, so they can pass through matter with only minor interaction

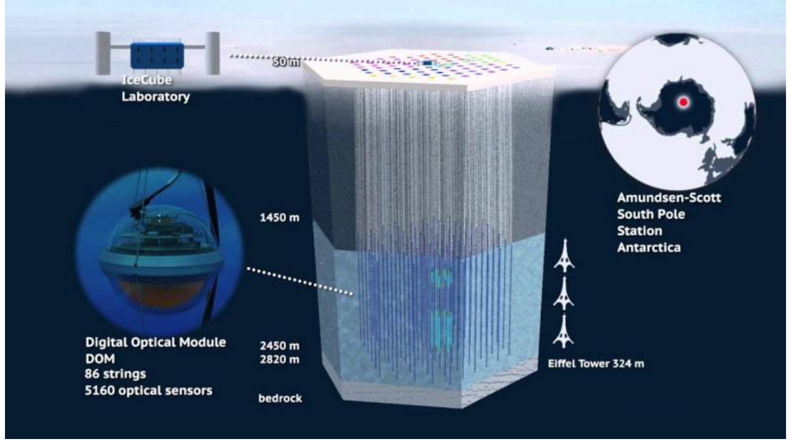
65 billion neutrinos hit the earth per second per square centimeter from the sun

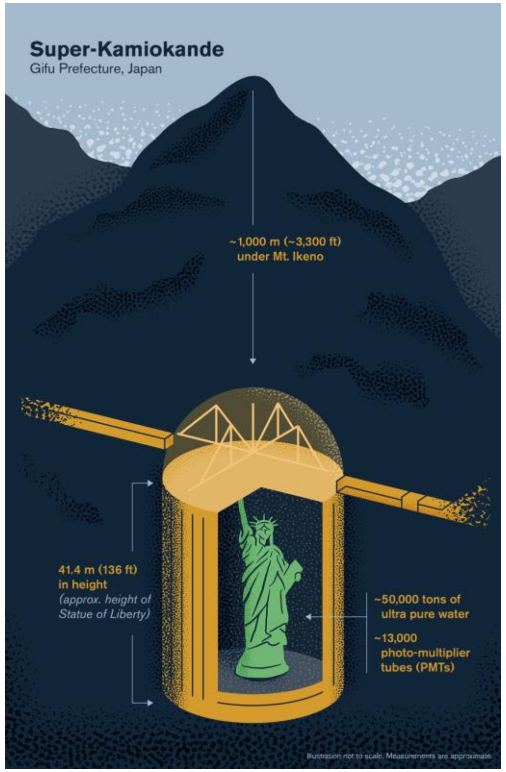
Detected by taking a large amount of transparent material (water) and watching for flashes

IceCube in Antartica and Super-Kamiokande in Japan are used to above neutrinos from the interior of the earth, the atmosphere, and astrophysical systems (supernovae, star mergers, etc.)

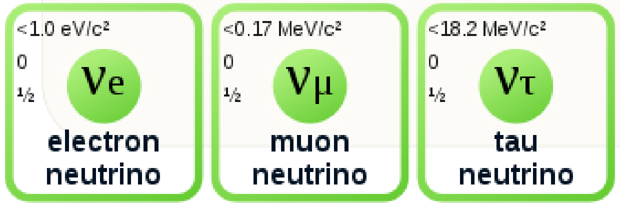
Neutrino Detection

$$\bar{\nu}_e + p^+ \rightarrow n + e^+ \longrightarrow e^+ + e^- \rightarrow \gamma + \gamma$$





Neutrinos



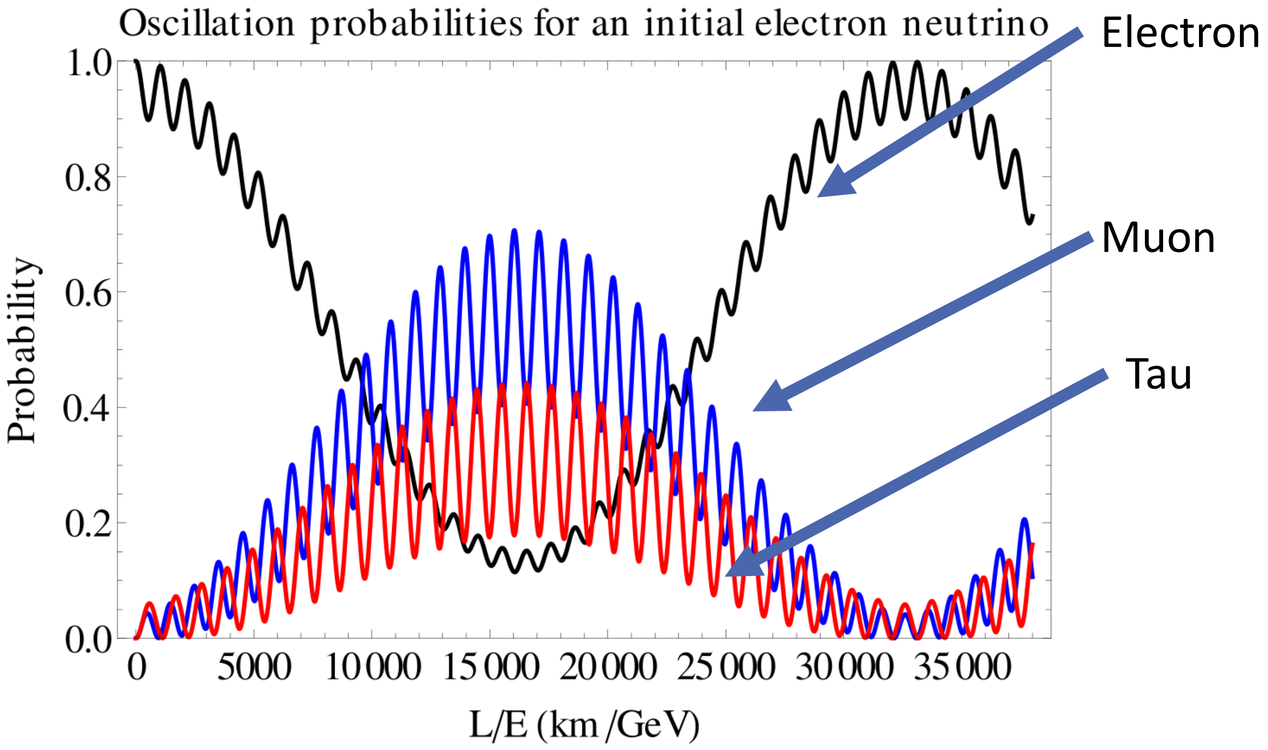
In late 1990s, we discovered that neutrinos can spontaneously change flavor

Causes oscillations between flavor as neutrino travels through space

Violates lepton flavor number conservation!

Also implies that neutrinos have mass

Their masses are still unknown, but many experiments are trying to find out



Higgs Boson

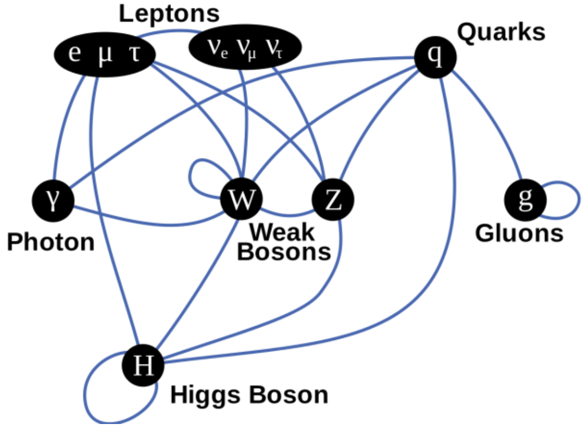
Last piece of the puzzle is the Higgs boson, discovered in 2012 at Large Hadron Collider (LHC) at CERN

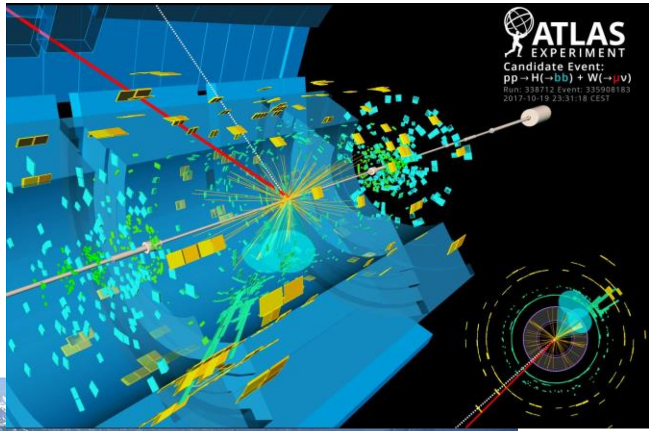
LHC collides high energy protons together which produce a whole slew of particles

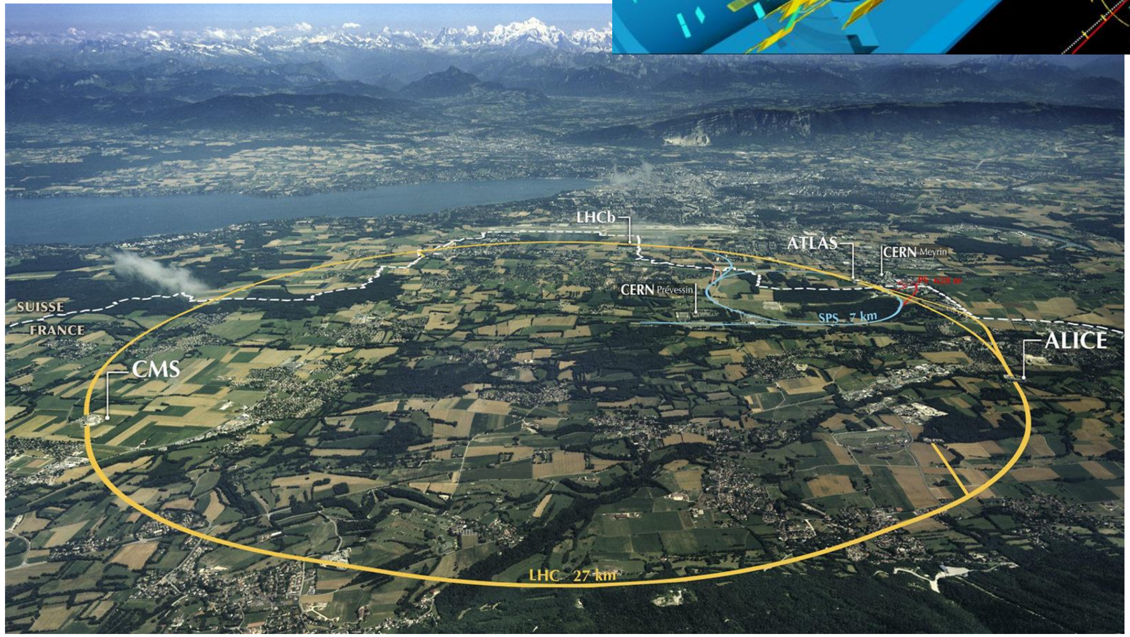
If an accelerator has enough energy to make the particle, then the particle will be made

Only spin-0 particle discovered so far

Interactions with the Higgs field is what gives fundamental particles mass, more interaction means more mass







Dark Matter

In 1970s, Vera Rubin showed that stars in galaxies rotate faster than we'd expect given the amount of visible matter

Implied the existence of matter that did not emit light (dark matter)

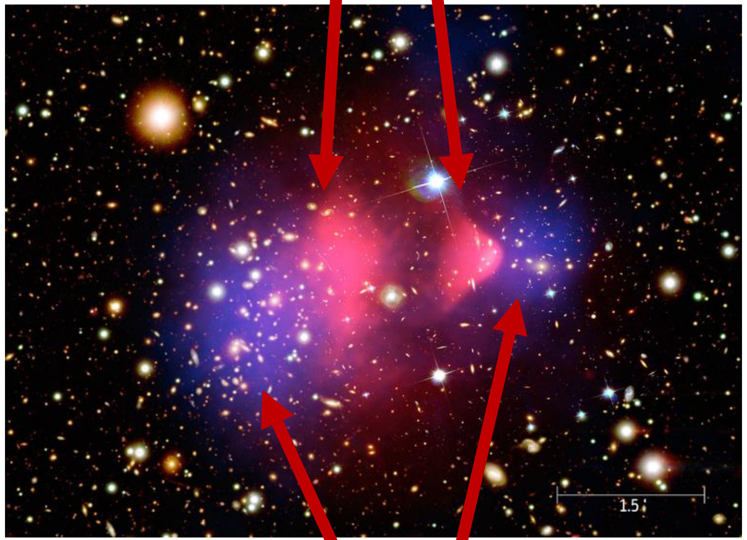
Bullet cluster showed that dark matter is actually matter and does not interact strongly with normal matter

Dark matter makes up ~85% of all matter of the universe and 23% of energy of the universe

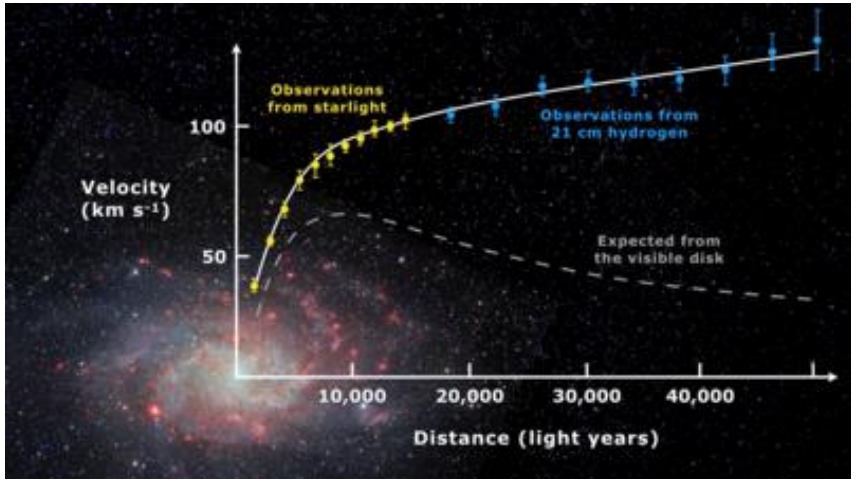
Many ideas of what it could be and many experiments trying to observe its non-gravitational interactions

Bullet Cluster: two clusters of galaxies colliding

Matter



Mass



Dark Energy

By looking at the shifts in the emission spectra of distant stars, we found that the universe is expanding

Not only is it expanding but the rate of expansion is accelerating

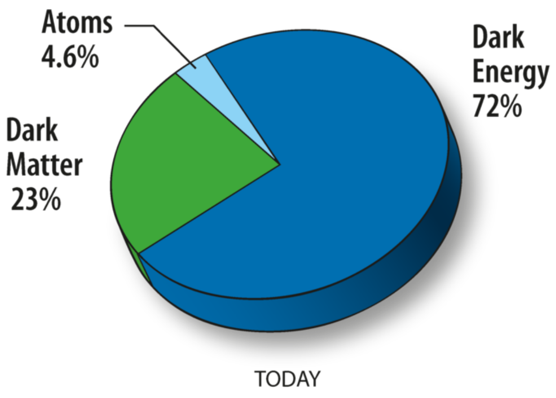
This requires some sort of energy to cause the acceleration (dark energy)

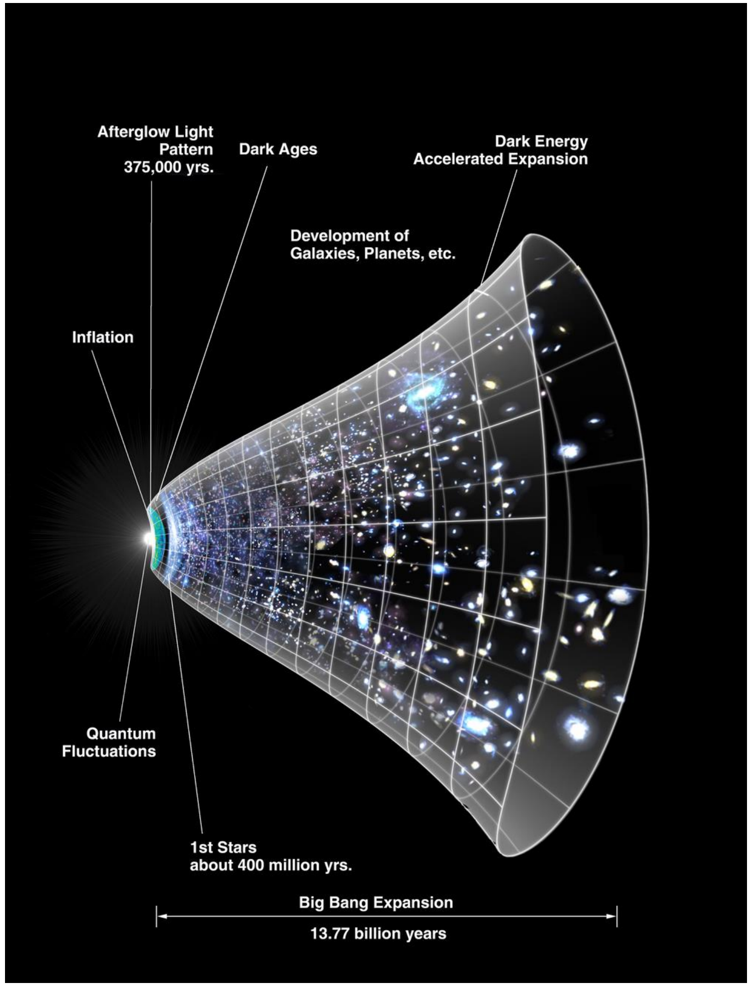
Makes up ~72% of all energy in the universe

General relativity allows a constant energy density of space called the cosmological constant (Λ)

The prediction from the Standard Model for this value is 120 orders of magnitude larger than what we observe ("the worst theoretical prediction in the history of physics")

Energy breakdown of the universe





Modern Physics

Some of the problems that physicists are trying to answer right now:

- What is dark matter?
- What is dark energy?
- Can we combine quantum mechanics with gravity?
- What is the mass of neutrinos?
- Are there more fundamental particles out there?
- Are there other universes?
- How does time work?
- Are there only four dimensions (3 space, 1 time)?
- What’s up with black holes?
- What was the early universe like?
- Why did the big bang happen?

Homework Questions

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