Particle Physics & Cosmology

Lecture 11

Another Scale of Structure

- We accept the statement : Atoms are the building blocks of matter; they are the smallest whole units of matter. Here we speak of the elements and how molecules and crystals exist.
- However, there is structure at a smaller scale which makes up the Atoms and transfers force between all matter.
- The subatomic particles which make up atoms: protons, neutrons and electrons are not alone, there are many other types of particles in the universe.

Two Major Types of Particles

- Those involved in **structure (families)**
  - leptons
  - hadrons
- Those involved in **force**
  - gauge particles (messenger mesons)
  - one particular to each of the 4 major forces

Particle Families

- **Hadrons**
  - the name refers to their thick, bulky nature
  - they are the strongly interacting particles found inside the nucleus of atoms
  - examples are protons and neutrons, but many others exist as well
- **Leptons**
  - they are the weakly interacting particles
  - they are found external to the nucleus
  - examples are electrons and neutrinos

Force/ Field	**Particle Family**	**Interactive particles**	**Messenger mesons (gauge particles)**
Gravity	All matter	All particles	Graviton?
Electro-magnetism	Charged particles	Electrons, protons, ions, alpha particles…	Photon
Weak Force	Leptons	Electrons, neutrinos, muons...	W and Z bosons
Strong Force	Hadrons	Quarks, nucleons: protons & neutrons, …	Mesons & gluons

Force

- Interaction among structural particles is seen as **rebound or recoil** as they absorb or emit carrier particles of force.
- The forces differ and involve the exchange of a different gauge particle.
- Example: if a photon is exchanged electromagnetism is the force acting. If it is a gluon then it is the strong force, and if it is a W or Z boson exchanged then the weak force is involved.
- A graviton has yet to be observed, but is thought to be the carrier particle of gravity.

- **Hadrons** are made of smaller particles called quarks, and there are six kinds of quarks.
- Ultimately **quarks** and **leptons** make up all particles and at its smallest scale all matter; though atoms remain the basic unit of matter. That is the scale of most common materials.
- Hundreds of particles have been observed in particle accelerators. Why smash them into each other? What is the purpose here?

Unification Theories

- The thought that there must be a unifying dynamic to all of the forces and the production of particles is linked to the cosmos and to relativity.
- What seems like two different situations could end up looking the same if the environment were changed enough to reveal how energy, particles and forces are related. (example p.131 of your text)

- The conditions at the formation of the universe or in star formation are very different from the current conditions at the surface of the earth.
- Perhaps the link to how the forces and matter are all interrelated would be clear if viewed through those conditions.
- As energy and temperature increase things should merge in stages, at least this is the theory.

Particles are everywhere

- Particles rain down on us from outer space as well as exist within atoms, and are emitted from atoms.
- It is logical to also look to stars and extreme conditions to study elemental particle physics as well as elemental matter and atoms.
- All elements are thought to be able to be produced and spread out in supernovae.

A look at the life of a star:

- **Star** : a luminous celestial mass of hot gas held together by its own gravity
  - Stars are born, have a life-span and death. All of which varies from star to star.
  - The life of a star is a balance between the pull of its own gravity and expanding pressure from the heat of nuclear fusion inside the core of collapsing burning gases.
  - Energy from the fusion reactions are emitted as electromagnetic radiation. (the star shines)

- Stars come into existence as dust clouds:
    - a heavy cluster of material draws more material to itself by the attractive force of gravity, drawing in more & more.
    - it becomes massive over time, collapsing in on itself.
    - This collapse creates a hot, pressurized core. Plasma is created as electrons are stripped away from nuclei.
    - The heat increases & primarily hydrogen nuclei move faster and eventually fuse creating fusion reactions.

      (4 protons $\longrightarrow$ helium + energy + leftover particles)
    - Immense energy and heat pours outward, creating a pressurized gas layer in the outer portion of the star, and illumination starts, as electromagnetic radiation leaves.
    - The outward pressure from the gas balances the inward gravitational pull to collapse.

- The new star will contract and expand and begin to rotate.
  - If it contracts it will spin faster and frequently pulls the new star apart
  - either totally
  - or into 2 stars
  - or creates planets
  - the spin is transferred from the star to the second star or planets created creating orbits
  - two thirds of the stars we see in the sky are multiple star systems

- Stars maintain this state until they run out of hydrogen to burn.
  - It is approximated that our sun is so large that it has another 4.6 billion years to burn.
  - The larger a star is the more hydrogen it must burn to keep from collapsing in on itself. Our star is average in size. One 30x larger would burn out in a few million years.
  - As the hydrogen runs out, the helium filled core contracts from the gravitational collapse and starts to heat up. The heat pushes the outer layers to expand. This expanding dying star is called a red giant.

- A White Dwarf is
  - what you call a star with a contracting core that heats until its helium core is so hot that those nuclei fuse into carbon nuclei. Once this happens the star collapses but only to a point, and counters gravity with its electron pressure. It has no energy left to burn up, but will glow and slowly cool off.
- Neutron Stars
  - are the end of massive stars, so hot that as they burn up,nuclei fuse progressively in stages, until the end result is iron. Iron doesn’t undergo fusion. Electrons and protons fuse creating neutrons in the core. Eventually a cool shrunken sphere of neutrons exists.

- Supernovae :
  - a spectacular end to the star. The outer layers of a star collapse inward and collide with the expanding neutron core and reaction products (neutrinos).
  - This rips the star apart, within a half hour temperature ranges produce and push most elements including plutonium and uranium out into space. The concentration of heavy elements increases throughout space over time, incorporated into other stars.
  - Elements heavier than helium are all made in stars.
  - A neutron core remains but spins faster, creating radiowaves in pulses from its poles due to a condensed magnetic field.
  - If massive enough the neutron core will collapse beneath the force of gravity into a **black hole**.

- Solar system formation:
  - the nine planets of our solar system are portions of the initial sun cloud debris.
  - Along with asteroids and moons, all orbiting the sun, this is our solar system.
  - The inner, hot planets are rocky, as you move out and it cools, gases and liquids are found. In the coldest furthest areas are frozen planets of light gases like helium, hydrogen and methane.
  - The solar wind of the sun’s particles sweep across all of the planets.

- **Terrestrial planets (earth like) : first four**
  - Mercury, Venus, Earth (with moon), and Mars are small and rocky all but mercury and our moon are large enough to have an atmosphere. Venus is clouded but close to earth in size, ~500 C (850F)
  - Mars is half the size of earth, has a thin CO_2 atmosphere and a lot of iron in its rocks.
- **Jovian Planets: Jupiter, Saturn, Uranus & Neptune** (Pioneer and Voyager space craft missions)
  - Jupiter, the mass is 300x larger than earth. All have a rocky center about the earth's size but under layers of liquid and frozen helium, hydrogen, methane, water and ammonia.
  - They all have multiple moons and ring systems.
- **Pluto, the dwarf planet:**
  - Not as large as the others, and rocky, orbits the sun, is spherical from mass and gravity, but has not cleared the area of its orbit

Galaxies

- Stars exist in groups or clusters of about 100 billion solar masses collectively called a galaxy; 1,500 to 300,000 light years across.
- We are in the Milky Way Galaxy. Others can be seen and are called nebulae, they are fuzzy patches of light in the sky at night.
- Most galaxies are quiet, but some have violent activity, maybe they are just forming.

Big Bang

  - the universe came into being and was once a single condensed point
  - space has been ever expanding (Doppler effect, red shift, lower frequency) All galaxies are moving away from eachother but selves not expanding.
- Initial stages: at the very start forces unified?
  - condensed means the temperature and energy was high (thought that 6 times the universe underwent major changes called freezes, ever cooling)
  - the very beginning was a mass of leptons and quarks, soon there after elementary particles formed the four major forces should have been at action.

Evidence for Big Bang

- Cosmic microwaves rains down from deep space
  - Radiation emitted from a body at 3 C above absolute zero are microwaves. That is the temperature you would expect the universe to be if you calculated the cooling over time.
  - The abundance of elements expected to be produced in the initial stages of the universe (H, He, Li) and that observed match up.

This is all linked to Relativity.

- Define it :
  - special relativity
  - general relativity
  - time space dilation
  - predictions of relativity