**What is the Coma Cluster?**

The Coma Cluster contains of 1,000 galaxies, located about 321 million light years away.

**How are rotational velocity curves measured?**

The rotational velocity of stars in the galaxy is measured by using Doppler shifts of their absorption line spectra.

**What is gravitational lensing?**

Gravitational lensing occurs when the light from a distant cosmological object is bent around a massive object which is distorting space-time. There are three catergories of gravitational lensing:

1. Strong Lensing: Distortion of light is visible to the eye
2. Weak Lensing: Distortion of light can only be detected by statistical analysis of the image
3. Microlensing: No distortion in light can be seen, but the amount of light received changes in time due to magnification of the lens for a brief amount of time

**Why does dark matter form halos?**

When we refer to “dark matter halos,” what we really mean is a sphere made of dark matter clouds. The density of this dark matter sphere does decrease with the distance from the galactic center, but since the dark matter halos have a radius ~4 times larger than the luminous matter disk, M/r remains more or less constant within the luminous matter disk itself.

**What is the density of Dark Matter like in the halos**?

We know V(r)=Constant -> M=V^2\*r/G… differentiate with respect to r to get dM/dr

Since M(r)=Integral of 4\*Pi\*r^2\*rho(r) dr, we can find dM/dr=4\*Pi\*r^2\*rho(r)… solve for rho(r) to get the density of dark matter as a function of r.

**Why is the density parameter defined using the critical density?**

The density parameter is defined such that it is equal to one if the density of the universe is equal to the critical density at which the universe is spatial flat. If the density parameter is less than 1, the universe will expand forever. If the density parameter is greater than 1, the universe will collapse on itself.

**What are MACHO searches?**

MACHO searches look for object on the solar mass scale within the Milky Way. These MACHOs will cause microlensing events when they pass in front of a light source (as opposed to DM halos causing larger scale lensing of distant galaxies outside of the Milky Way). The number of lensing events allows us to set a limit on how many MACHOs exist within the Milky Way DM halo.

**What are x-ray emission temperature studies?**

Most of the normal, baryonic matter in the Universe is in gaseous form. Within a galaxy cluster, the gas is squeezed by gravitational forces, heating it until it emits light at X-ray wavelengths. Analysis of the X-ray emissions from these sources can determine how much matter exists within the cluster gas.

**What is Big Bang Nucleosynthesis**?

Big Bang nucleosynthesis models the production of heavier nuclei from hydrogen during the first moments of the universe. The time window in which this occurred ranges from a few tenths of a second up to 1000 seconds. During this time the temperature of the universe was as hot as 116 gigkelvin. Theorists can model these conditions to put a limit on the total baryonic matter component of the universe.

**What is the strong-CP problem?**

In QCD it is thought that the laws of physics should be the same if a particle can is switched with its antiparticle, and has its parity reversed. This is referred to as CP-symmetry. It is thought that CP-symmetry can be violated in strong interactions. However, when the coefficient of the CP-violation term is the QCD lagrangian is measured, it is found to be nearly zero. This is known as the Strong-CP problem.

**What are neutrino oscillation measurements?**

It has been experimentally determined that neutrinos oscillated between the three flavor states. Since massless particles travel at the speed of light, they experience no time, and therefore could not evolve from a pure flavor state to a mixed state (since the evolution operator goes like Uexp(-iEt)U\*). Thus, since the neutrinos oscillate to different states, they must have a nonzero mass. Studying the oscillations gives insight into the mass difference between each state.

**How is the neutrino density parameter derived?**

The neutrino density parameter is derived from big bang nucleosynthesis models which put a constraint on relic density of neutrinos. See the cited source for more info.

**How is the upper limit on neutrino density parameter determined?**

Big Bang nucleosynthesis models the production of heavier nuclei from hydrogen during the first moments of the universe. The time window in which this occurred ranges from a few tenths of a second up to 1000 seconds. During this time the temperature of the universe was as hot as 116 gigkelvin. CMB observations give us insight into these early moments of the universe. Lyman-alpha observations study the neutral transition line in the hydrogen emission spectrum known as the Lyman-alpha line. The vast number of cosmological sources with differing redshifts produces a “lyman-alpha forest.” Studying this lyman-alpha forest provides constaints on the amount of hydrogen present at the early stages of the universe.

**How is the CDM density parameter derived?**

The best I can do is to explain the process in words, as I just did. For a more quantitative analysis which start with Maxwell-Boltzmann statistics, please see the cited source.

**How is the neutralino density parameter derived?**

The neutralino density parameter is derived using SUSY models. Explaining them in detail is beyond the scope of this presentation… and for that matter beyond the scope of my abilities… so please see the cited source.

**Where does the theorized WIMP mass come from?**

Weak vector bosons have mass of 100 GeV… so 10GeV-a few TeV is a factor of 10 on either side of that. Stronger constraints on this mass have been placed using direct detection data.

**How is the energy recoil spectrum derived?**

This is derived from theoretical calculations of WIMP-nuclei ineteractions. It is a complicated calculation. It takes into account the number of WIMPs incident per unit cross sectional area per second, as well as the probability that a collision will occur that results in a recoil of a particular kinetic energy. For more information see the cited source.

**How are the cross sections derived?**

This calculation is too detailed for me to describe here. I’ll refer you to the cited source if you are interested in the details that lead to this result.

**What is form factor suppression?**

When we say “form factor” suppression, we mean that the function which describes the scattering amplitude, F(q), will have a sharper spectrum at higher values of q. This leads to a sharper recoil energy spectrum.

**What does time projection chamber mean?**

A time projection chamber is a type of detector which uses the timing difference between two signals to reconstruct the z-coordinate of an event in the detector. In our case, the time between S1 and S2 signals provides the z-coordinate of an event.

Why do we want the source to be a single beta emitter?

**What does q-value mean?**

Q-value is the mass difference between the mother and daughter in a decay process. In our case, tritium decays into helium-3, with a mass difference of 18.6 keV

**Why is tritium a broad spectrum?**

Tritium is a beta decay. Bet decays share their q-value with a neutrino. The energy can be split in different ways, resulting in a continuous spectrum.