Dark Matter:
How well do we know our universe?
1. Brief explanation of Dark Matter's properties.

   - Mass-to-light ratios
   - Rotational curves
   - Gravitational lensing

3. Estimation of the density of baryonic matter in the universe.

Dark matter

- Doesn't interact electromagnetically
- Infer it's existence through gravitational effects.
Mass to Light Ratios

- Measure of rotational mass to luminosity mass
- Luminous mass is calculated using the Mass-Luminosity relation.
- Finding the absolute luminosity gives the mass

Rotational mass is found using the Doppler Shift to determine orbital velocities.

\[
\frac{L}{L_{\odot}} = \left(\frac{M}{M_{\odot}}\right)^{3.5}
\]

Fritz Zwicky, in 1933, was the first to discover the large discrepancy in the rotational mass to luminosity mass of galaxies.
Rotational Curves

- Measurement of orbital velocity as a function of radius.
- We expect orbital velocity to decrease as a function of radius.
- “Keplerian drop-off”
Gravitational lensing

- The bending of approaching light from a luminous object by the gravity of intervening matter, creating a shifted image of the background object.

  Gathering the measurements of many of these shifts we can determine the distribution of the intervening matter.
How do we know that ordinary matter contributes such a low percent of the total mass of the universe.

- How do we know the distribution and quantity of dark matter in our universe?
Big Bang Nucleosynthesis

- Occurred 1 second to 3 minutes after the big bang.
- Created most of the Deuterium, He-3, He-4, and Li-7.

- Uses the established physics of the standard model.

- The Baryon density of the early universe, as a lone parameter determines the quantities of these different elements created during the Nucleosynthesis period.

Can we find a way to observe the primordial quantities of these isotopes to put bounds on the baryonic matter density of the universe?
BBN cont.....

Deuterium
- No stellar source for creation of Deuterium.
- Any value obtained would present a lower bound for the baryonic density of the universe.
- Generally we study spectra of distant quasars to determine the relative abundance of D.
- Observations give a D/H value of $3.4 \times 10^{-5}$, corresponding to a baryon density of 4.6% closure density.

Conclusion: We know that dark matter isn't composed of baryons because this would drastically change the deuterium abundance in the universe.
- Bad news for MACHOs.
Cold Dark Matter vs. Hot Dark Matter

- HDM - Nearly Massless particles moving with relativistic speed
- Support a top-down model of large scale structure development
- Ex. Neutrinos
Cold Dark Matter

- Massive slow moving particles
- Support the bottom-up development of large scale structure in the universe
- Ex.s: Weakly Interacting Massive Particles, Axions

N-body simulations with cold dark matter tend to agree with large scale structures we see in the universe today.
Future of dark matter study

- N-body simulations
- Ex. Via Lactea Two
- Uses a billion particle simulation to replicate the formation of large scale structure in the universe.
- Halo structure we see in the universe today agrees with a bottom-up cold dark matter model of the universe.