Class 9: What is Dark Matter?

This class...
- General considerations
- MACHOs
- WIMPs
- The unknown...

I: General Considerations

To recap...
- Primordial Nucleosynthesis constrains the density of baryons to $\Omega_\text{b} = 0.040 \pm 0.008$
- This is roughly consistent with the visible mass that we see (stars + gas)
- But, there seems to be much more mass in galaxy and cluster halos ($\Omega \sim 0.1-0.3$)

Properties of dark matter...
- Has gravitational mass!
- Can “clump up” to form galaxy and cluster halos (cold dark matter)
- Emits no electromagnetic radiation
- Has very limited self-interaction
II: MACHOs

- Could dark matter correspond to a population of massive macroscopic objects (e.g. black holes, large “nuggets” of exotic matter)
- **MAssive Compact Halo Objects**
  - Best way to search for these is via **gravitational microlensing**
  
  - Suppose we look at a distant star in our Galaxy; then a MACHO passes in front of the star.
  - Light is focused by gravity of MACHO and star appears to temporally brighten

Really hard to do!

* MACHO Project
Microlensing surveys fail to find a large population of MACHOs...
- Can rule out MACHOs dominating the Galactic Halo if they are in the mass range $6 \times 10^{-8} \, M_{\odot} < M < 15 \, M_{\odot}$ (Tisserand et al., 2007, A&A, 469, 387)
- Can rule out MACHOs with mass $M > 40 \, M_{\odot}$ since they would disrupt binary star systems within the Galaxy
- So... its not looking good for the MACHO hypothesis

**Question:** Suppose an early generation of stars produced a large number of $25 \, M_{\odot}$ black holes... would these be allowable dark matter candidates?

**III : WIMPS**

- What about some “dark” sub-atomic particle?
- Let’s review the standard model of particle physics...
- Within standard model, only possibilities are neutrinos...
  - Advantage: They are real (we’ve detected them!) and they are part of standard model of particle physics
  - Problem: Each neutrino has a very small mass, and we just don’t think that there’s enough of them to make up the dark matter!
  - So, we need to look for some new kind of sub-atomic particle that is NOT in the standard model...
Weakly Interacting Massive Particles
- It’s dark - does not couple to electromagnetic force
- Very poor self-interaction – does not couple to strong force
- It gravitates - must couple to the gravitational force
- To exist (to have been formed in early Universe) – must couple to the weak force

Particle physicists have theorized various possibilities; leading option are supersymmetric particles
Many experiments currently on-going

IV : If not dark matter then...

- A radically different route is to assume that our understanding of gravity is wrong and that we don’t need dark matter to explain the observations...
- MODified Newtonian Dynamics (MOND)
  - Hypothesize that dynamics deviates away from standard picture in the “low acceleration” regime
  - Can explain galactic-scale dynamics rather well (e.g. galaxy rotation curves)
  - Doesn’t do well on galaxy cluster scales (but then maybe neutrinos can some into play there?)