

First class T 1-12-16

(2nd time taught)

- Youtube clip of Monty Python's Holy Grail "She's a witch" scene that inspired course poster and illustrates the search for solutions
- Discuss syllabus, course work - homeworks, exams course website
333 vs 433 - extra work for 433; also a project

- Overview lecture Keynote/class 1

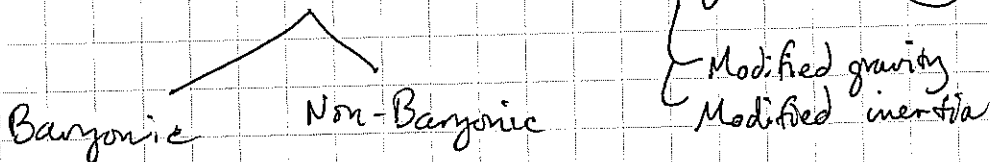
- Evidence for mass discrepancies
- DM candidates
- Modified gravity if time permits

Emphasize the distinction between the problem "Mass discrepancy" or "Acceleration discrepancy" vs. the solution Dark matter or Modified dynamics

Evidence on DM tree

- Oort discrepancy - local ~~the~~ dynamical mass > stars ($\approx 2x$ - not much) from vertical motions (1932)
- Flat rotation curves (1970s, 1980s)
- Cluster velocity dispersions - also X-ray Temps & hydrostatic Eq. (1930s) - Gravitational lensing (more modern)
- Large Scale Structure (70s, 80s) needs time to grow
- $\Omega_m \neq 1$ coincidence problem; $\Omega_m > \Omega_b$ from BBN

Possible solutions: ^{unseen} Extra (dark) mass OR Equations wrong



Baryonic dark matter candidates

conventional

Brown dwarfs $< 0.08 M_{\odot}$
 Jupiters $\approx 12 M_J$
 Cold ($\sim 3K$) molecular gas
 warm-hot ($\sim 10^5 K$) gas

exotic

strange nuggets
 white dwarfs
 neutron stars
 black holes

Non-Baryonic dark matter candidates

neutrinos ν

• originally thought to have zero rest mass ("had" to be zero)

If there are 3 ν flavors (electron, muon, ~~tau~~ ^{tau})
 need each to weigh $\sim 10 eV$ to add up to $\Omega_m \approx 0.3$

$$\sum_i m_{\nu,i} = 94 \Omega_m h^2 eV \quad \Omega_m = \rho / \rho_{crit}$$

known from equilibrium in early universe $h = H_0 / 100 \text{ km s}^{-1} \text{ Mpc}^{-1}$

But

• neutrinos free-stream, erasing structure $< 3 \times 10^{15} \left(\frac{m_{\nu}}{30 eV}\right) M_{\odot}$
 (destroy galaxies before they can form)

• neutrinos obey Pauli exclusion principle
 (can't pack them too closely)

Don't get up to observed DM density in dwarf galaxies
 unless $m_{\nu} > 30 eV$

neutrinos now known to have mass, but too small

to be solution: $m_{\nu} < 1 eV$ (experimental)

probably $\ll 1 eV$ (cosmology, assuming structure formation)