Dark Matter 1.

What do we know about DM ?

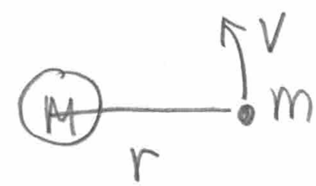
good source : Mariangela Lisanti TASI lectures on DM

only positive results are gravitational properties of DM.

1. Galaxy rotation curves

Mass of visible stuff in spiral galaxies is fairly central

⇒ star of gas cloud outside central region



$$G\frac{Mm}{r^2} = \frac{mv^2}{r}$$

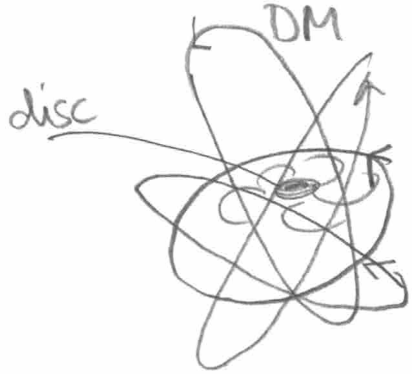
$$\Rightarrow \quad v = \sqrt{\frac{GM}{r}}$$

$\Rightarrow \quad v \propto \frac{1}{\sqrt{r}}$ for gas outside mass distribution

PLOT $\quad v_i = \sqrt{\frac{G}{r} M_i}$ for $i =$ disk, halo, d+h

bargons: dissipative due to scattering
⇒ loss of angular momentum, kinetic energy
⇒ collapse into disk.

DM : non-interacting ⇒ halo



flat rotation curve ⇒ $\frac{M(r)}{r} = \text{const}$ ⇒ $\rho(r)_{\text{halo}} \sim \frac{M(r)}{r^3} \sim \frac{1}{r^2}$

Milky way:

$M_{\text{halo}} \sim 10^{12}\, M_{\text{sun}}$

$r_{\text{sun}} \sim 8$ kpc

$r_{\text{galaxy}} \sim 500$ kpc

$\rho^{DM}_{\text{earth}} \sim 0.3 \frac{\text{GeV}}{\text{cm}^3} \sim 0.3 \frac{\text{TeV}}{\text{liter}} \sim \frac{300\ \text{TeV}}{\text{m}^3}$ $8.5\ 10^{-27} \frac{\text{kg}}{\text{m}^3}$

$\rho^{DM}_{\text{background}} \sim 20\%\ \rho_{\text{critical}} \sim \text{GeV}/\text{m}^3 \sim 3 \cdot 10^{-6} \rho^{DM}_{\text{earth}}$

virial theorem: $\overset{E_{kin}}{m\langle v^2\rangle} \sim \overset{E_{pot}}{\frac{m\,MG}{r}}$

$$\langle v\rangle \sim \sqrt{\frac{G M_{halo}}{R_{Halo}}} \sim 200\ \frac{km}{s} \sim 10^{-3} c$$ non-relativistic!

What could it be? "particles" of mass m

lightest possible boson: $\Delta p \Delta x \sim 1$

needs to fit inside galaxy $\Rightarrow \Delta x \gtrsim R_{sun}$

$\Delta p \gtrsim m v$

$$\Rightarrow m \gtrsim \frac{1}{v R_{sun}} \sim 10^{3} \frac{1}{8\cdot 3\, 10^{19} m} \sim \frac{10^{-17}}{2} \frac{1}{m} \cdot 2\, 10^{-7} eV m$$

$$\sim 10^{-24} eV$$

dwarf galaxy gives stronger bound because smaller $m_{boson} \gtrsim 10^{-22} eV$

fermion? Pauli exclusion

1 particle per phase space unit volume

$$(\Delta X)(\Delta P) = 1$$

$$\left(\frac{R_{halo}\, m_\psi V_{virial}}{\Delta X \Delta P}\right)^3 m_\psi \geq M_{halo}$$

→ should not have velocities dominated by Fermi motion but by gravity

$$V \sim \left(\frac{GM}{R}\right)^{1/2}$$

$$R^{3/2} G^{3/2} M^{3/2} m_\psi^4 \geq M \Rightarrow m_\psi \geq (MG^3R^3)^{-1/8}$$

$m_\psi \sim 10\,eV$ (Milky Way)

$m_\psi >$ keV dwarfs.

upper bound?

- smoothness of halos
- MACHOs Massive Compact Halo Objects

↘ gravitational lensing gives fluctuations in brightness of lensed stars

mass of sun $\sim 10^{57}$ GeV $\sim 10^{66}$ eV

$m \notin 10^{57} - 10^{67}$ eV

CMB, dwarfs m probably not $> 10^{67}$ eV

Cosmology

Cold Dark Matter collapses gravitationally to form overdensities which attract baryons to form galaxies, galaxy clusters, superclusters

$\Rightarrow \Omega_M \sim 20\%$ $\quad \rho_M \propto 1/V$

$\Omega_B \sim 5\%$ $\quad \rho_B \propto 1/V$

$\Omega_\Lambda \sim 75\%$ $\quad \rho_\Lambda \propto \text{const}$

$\rho_R \propto 1/V^{4/3}$