

Title: PSI 2018/2019 - Cosmology Review - Lecture 5

Date: Jan 11, 2019 09:00 AM

URL: <http://pirsa.org/19010006>

Abstract:

Cosmological constant problem

C.C

Structure formation;

G.C.

$$\hbar=c=1 \quad [m]=[E]$$

$$\rho \sim \rho_{\text{crit}} \sim \frac{\text{a few } H}{m^3} \sim \frac{1 \text{ GeV}}{(10^{-27})^3} = [L]^{-1} = [T]^{-1}$$

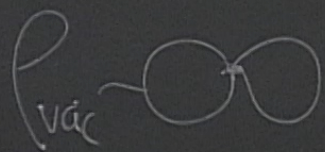
$$\sim (10^{-3} \text{ eV})^4$$

$$G=\hbar=c=1$$

$$M_{\text{Pl}} \sim 10^{19} \text{ GeV} \quad \frac{1}{m} \sim 10^{-7} \text{ eV}$$

$$l_p \sim 10^{-35} \text{ m} \quad \frac{1}{l_p} = m_{\text{Pl}}$$

QFT



$$\frac{\int d^4k d^4k'}{p^2(p')^2} \sim K_{cutoff}^4 \sim M_{pl}^4 \sim (10^{19} \text{ GeV})^4$$

$$\frac{1}{m} \sim 10^{-7} \text{ eV}$$

$$10^{19} \text{ GeV}$$

$$\frac{1}{L_p} = M_{pl}$$

QFT

$$\rho_{vac} \sim \text{bubble diagram}$$

$$\frac{\int d^4k d^4k'}{p^2 (p')^2} \sim K_{cutoff}^4 \sim M_{pl}^4 \sim (10^{19} \text{ GeV})^4$$

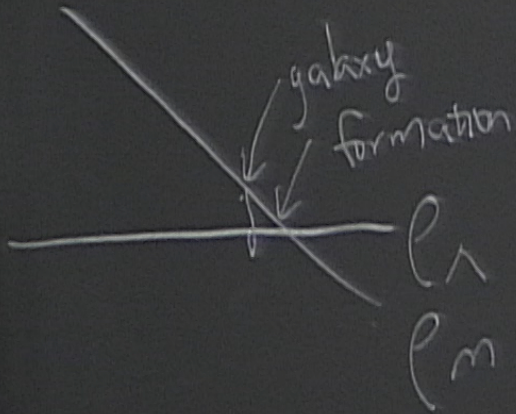
$$\frac{1}{m} \sim 10^{-7} \text{ eV}$$

$$\frac{\rho_{vac}}{\rho_{obs}} \sim 10^{120}$$

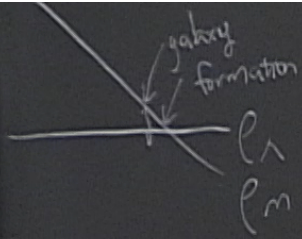
$$\rho_{susy} \sim (1 \text{ TeV})^4 \quad 10^{60}$$

$$\frac{1}{L_p} = M_{pl}$$

Cosmic coincident problem.



$\rho_n \sim \rho_m$
galaxy formation.



$$\rho_\Lambda \sim \rho_m$$

galaxy formation

Anthropic approach.

Λ take over after first galaxies: $\rho_\Lambda \leq 200 \rho_m$

would recollapse before life $\rho_\Lambda > -\rho_m$

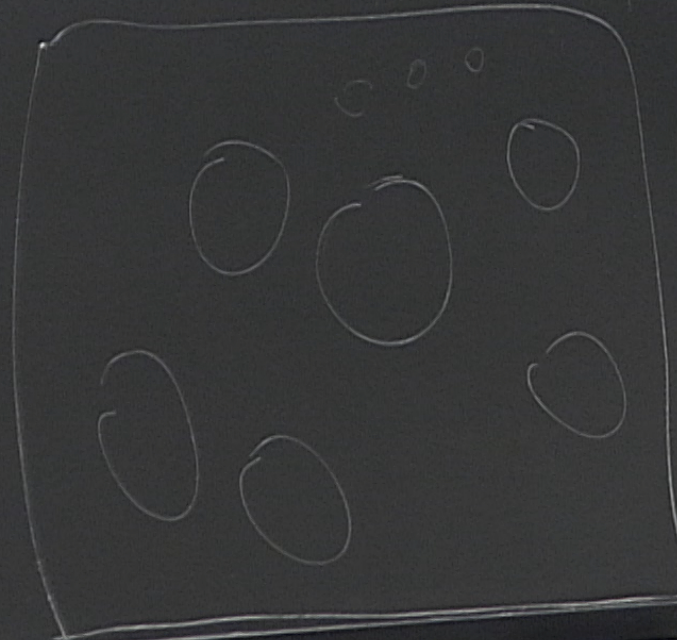
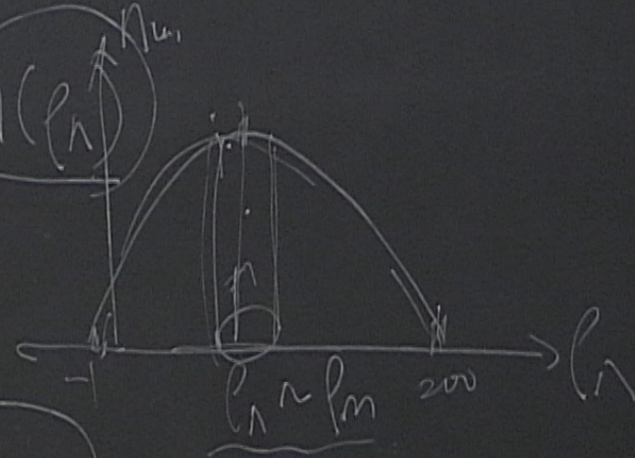
ρ_m galaxy formation

Anthropic approach.

Λ take over after first galaxies: $\rho_\Lambda \leq 200 \rho_m$

would recollapse before life $\rho_\Lambda > \rho_m$

$$dP(l_n) = \underbrace{P(l_n)}_{\substack{\text{Prob: volume of universe} \\ \text{in interval } dl_n}} \cdot \underbrace{N(l_n)}_{\text{constant}}$$



big universe

$$l_n \leq 200 l_m$$

$$l_n > -l_m$$

constant problem

mation;

$$\rho_1 \sim \rho_{\text{crit}} \sim \frac{\text{a few } H}{m^3} \sim \frac{1 \text{ GeV}}{(10^{-3} \text{ eV})^3} = [L$$
$$\sim (10^{-3} \text{ eV})^4$$

phishists

$G = h$
 μ_{pl}
 ℓ_p
 t_p

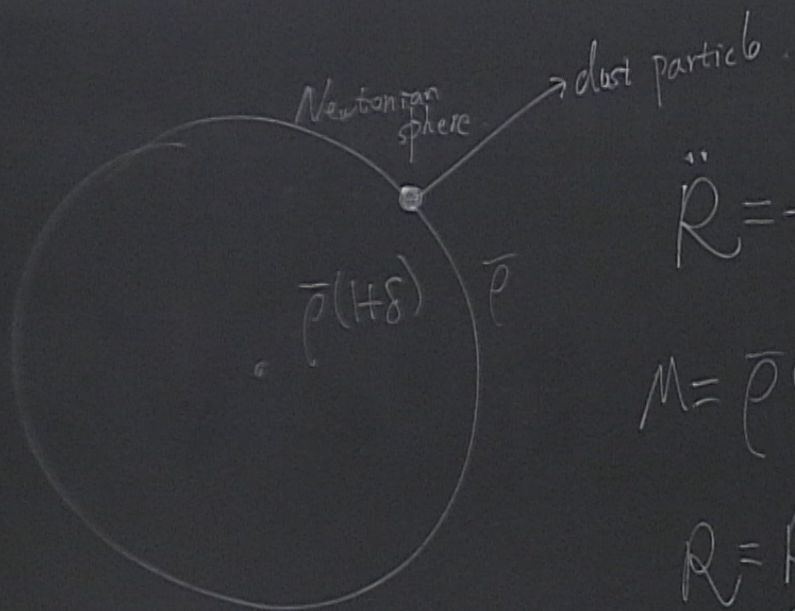
Structure formation
A blatantly wrong
assumption

static homogeneous matter universe

$$\bar{\rho}(t) = \frac{\int d^3x \rho(x,t)}{V}$$

$$\delta = \frac{\rho - \bar{\rho}}{\bar{\rho}} \quad -1 < \delta < 10^{-4}$$

$$\text{assume } |\delta| \ll 1$$



Newton's Second Law

$$\ddot{R} = -\frac{GM}{R^2} = -\frac{G\bar{\rho}\delta\frac{4\pi R^3}{3}}{R^2}$$

$$\boxed{-\frac{4\pi G}{3}\bar{\rho}\delta R = \ddot{R}}$$

$$M = \bar{\rho}(1+\delta)\frac{4\pi R^3}{3}$$

$$R = R_0(1+\delta)^{-\frac{1}{3}}$$

$$= R_0\left(1 - \frac{1}{3}\delta^{(1)}\right)$$

$$\boxed{4\pi G\bar{\rho}\delta = \delta^{(1)}(t)}$$

Mass conservation

$$\boxed{\ddot{R} = -\frac{R}{3}\delta^{(1)}(t)}$$

$$\ddot{\delta} = 4\pi G \bar{\rho} \delta$$

$$\delta = A_1 e^{\frac{t}{t_{\text{dyn}}}} + A_2 e^{-\frac{t}{t_{\text{dyn}}}}$$

$$t_{\text{dyn}} = \frac{1}{\sqrt{4\pi G \bar{\rho}}}$$

pressure:

$$P = nk_B T$$

$$\rho = n m$$

$\uparrow$ mass of particle

$$w = \frac{k_B T}{m}$$

pressure: $P = nk_B T$

$$\rho = n m$$

↑ mass of particle

$$w = \frac{k_B T}{m} \approx 0$$

$$t_{\text{pressure}} = \frac{R}{C_s}$$

✓ speed of sound

$$C_s = \sqrt{\frac{P}{\rho}} = \sqrt{W}$$

$$R_J = 2\pi C_s t_{dyn}$$

Jean Radius

$$t_{pressure} < t_{dyn}$$

$$\frac{R}{C_s} < t_{dyn}$$

$$R_J = 2\pi C_s t_{dyn}$$

Jean Radius if $R > R_J$

fluctuation wins
and grow and collapse

$$R < R_J$$

pressure gradient
builds up

we have sound wave

$$H^2 = \frac{8\pi G\rho}{3}$$

$$t_H = \frac{1}{H} = \sqrt{\frac{3}{8\pi G\rho}} = \sqrt{\frac{3}{2}} t_{\text{dyn}}$$

$$t_{\text{dyn}} = \frac{1}{\sqrt{4\pi G\rho}}$$

radiation domination

$$t_p = \sqrt{\frac{3}{2}} t_{yn}$$

matter domination

$c \propto$ domination

} different