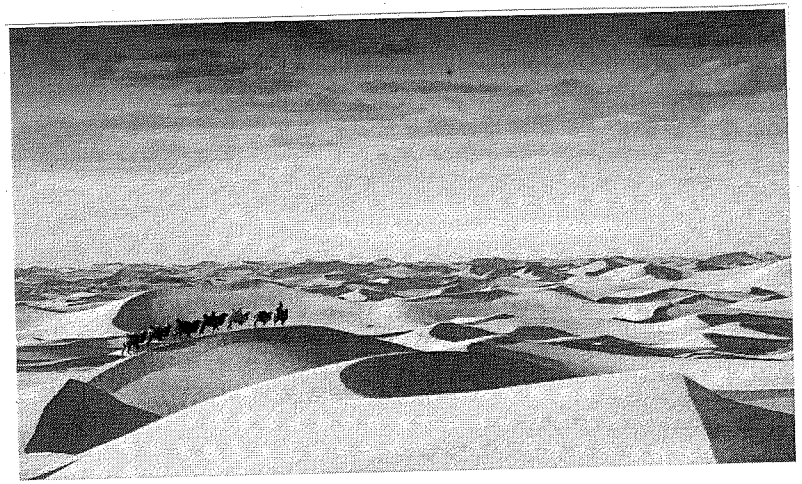
ANTHROPICS / WEAKLESS UNIVERSE (Henrique Rubira)

Beginning : Define anthropics
+ Different usages of anth
(CC, ..., ν)

Middle : Can we imagine a universe w/o EW? (a mental exercise)

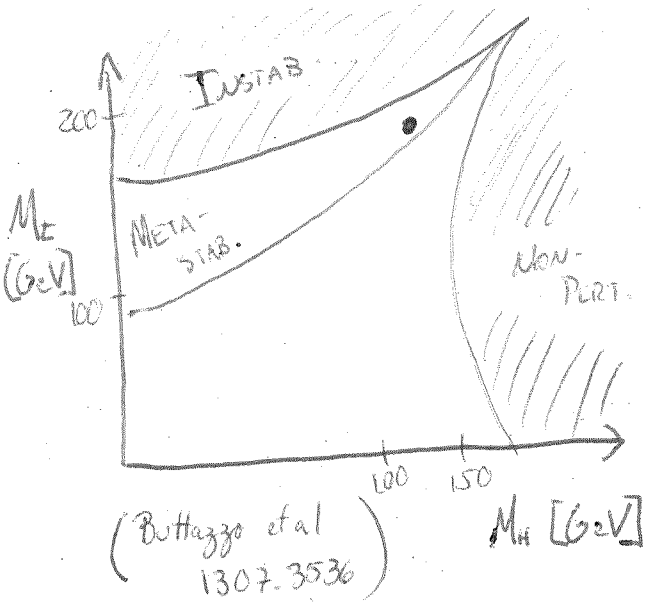
End : Does BBN sets EW scale?



Why all desert dunes have ~35° angle?

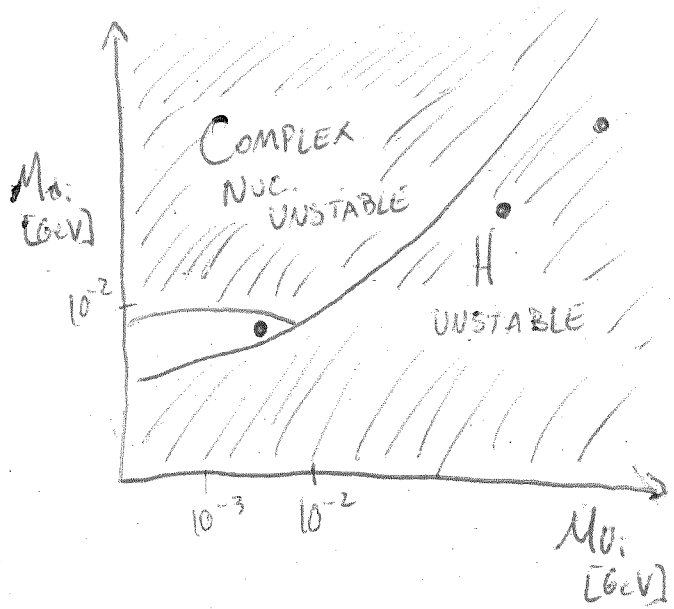
MULTIVERSE?

A PREAMBLE



(Buttazzo et al 1307.3536)

(Hall, Pinner, Ruderman 1409.0551)



Some Definitions ("The Anthropic Cosmo. Principle", Barrow & Tipler, sec 1.2)

The Weak Anthropic Principle (WAP): Values of all physical quantities are restricted by the existence of a carbon-based life

$\Rightarrow$ Relating w/ Bayes Th.: posterior is modified by life existence

Strong Anthropic Principle (SAP): The Uni. must have all properties which allow life to develop

$\Leftrightarrow$ Constants / laws of Nature must be such that life exists.

HR: During this talk, I will avoid talking about the (Strong!) bias that we only know one kind of life!

Some Examples of Anth. Usages

1) Whitrow, 1955 : only 3D space lead to observers like us

2) Time needed for stars production:

$$t_* \sim \left(\frac{G M_N}{hc}\right)^{-i} \frac{h}{M_N c} \sim 10^9 \text{ yrs}$$

3) Weinberg 1987 (also Vilenkin 1994)

Anthropics constraining CC

↳ Close 2 orders of mag from today's meas.

4) EW scale (Hall, Nomura; 0712.2454)

Using a flat prior in the multiverse parameters, they got

$$P_{\substack{NUC \\ STAB}} \leq 10^{-3(-2)}$$

$$P_{EWSB} \leq 10^{-2(-1)}$$

* For a very recent discussion, see 1911.01441

Before going on, String Vacua Landscape (+ Multiverse) and the Anthropics

- Vast # of low energy theories according to diff vacuas (to check some statistical attempts, see 0302219, 0303194, 0410286)
- Arkani-Hamed, Dimopoulos, Kachru; 0501082 — For some QFTs, they justify scanning only Super-Renorm. dimensionful parameters ($c.c$ & m_H for the SM)

The Weakless Universe (Harnik, Kribs, Perez; 0604027)

Mental Exercise: Universe w/o Weak interaction that matches our Uni ⇒ Counter-Argument for Anthropics

Adjusting other params have:
- BBN
- Matter Dom.
- Structure / star formation
- Similar Chemistry / Nuclear phys

Obs 1: changing v alone seems anth. Here, the opposite direction

Obs 2: Doing same exercise for c.c. doesn't change bounds (see 0511774)

The Weakless Set up

A) $SU(3)_c \times U(1)_{EM}$

B) $\tilde{\alpha}_{em} = \alpha_{em}$; $\tilde{\Lambda}_{QCD} = \Lambda_{QCD}$; $\tilde{M}_{Pl} = M_{Pl}$

C) $\tilde{m}_f = m_f$ ($f = u, d, (s), e$) ↓ more on s later

D) Global $U(1)_u \times U(1)_d \times U(1)_s \times U(1)_e$
↳ (individual quark/electron # cons.)

E) $\tilde{\Omega}_{TOTAL} = \Omega_{TOTAL} = 1$
$\tilde{\Omega}_{MATTER} = \Omega_{MATTER} \simeq 0.23$ (same M-R transition)

F) $\tilde{\eta}_b = 10^{-2} \eta_b$ (match H/He fraction. more later)

Important Comments

- no anomalies allow incomplete gen.
- Weakless universe is equivalent to set $\tilde{v} \to M_{Pl}$ and Yukawas $\lambda_{u,d,e,s} \sim 10^{-20}$, $\lambda_{orbitfirst} \sim 1$

1) QCD : ~ The same → confinement at Λ_{QCD}; same # of light fermions (u, d, s)
- m_π changes only due to radiative corrections
- m_N has ~10% contribution from m_s (that is why keeping s)

Differences: Hadrons are stable (no decay!)

↳ Important to understand their abundance between QCD phase t. and BBN ⟹ Freeze-out (not mass suppressed)
- protons
- neutrons
- Λ^0_s hyperon

all s confined and interacts weak w/ n, p

2) Fermiogenesis: Individual quark # as free param

↳ Baryogenesis not enough (No EW to distribute B to light quarks) + No leptogenesis (No EW sphalerons) ⟹ Only mechanisms that don't rely in EW, like gravitational baryog.

3) BBN

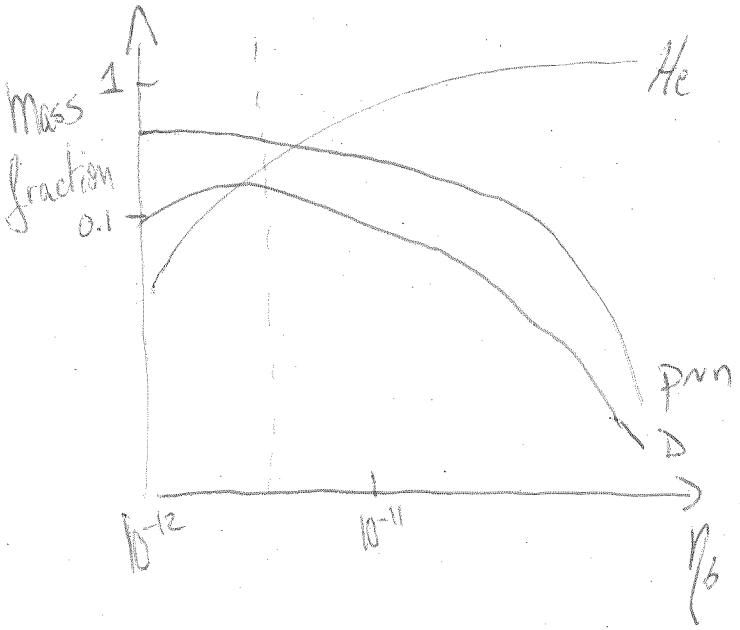
Since $n_n \sim n_p \Rightarrow n_p \sim n_p$

↳ Keeping η_b equal might overproduce He !

↳ Adustment needed

- (A) Set $n_n \neq n_p$ ($n_n \simeq \frac{5}{3} n_p$ lead to same He fraction)
- (B) **Change $\tilde{\eta}_b$**

↳ chosen to be $\tilde{\eta}_b \simeq 4 \cdot 10^{-12}$ such D is $\simeq 10\%$ of mass!



↳ We need D to ignite stars in the weakless un

Remembering BBN (also useful later)

~ 1 MeV → Relativistic species couplet (but neutrinos)

↳ Non-rel baryons w/ $\frac{n_b - \bar{n}_b}{s} \sim 10^{-10}$

↳ $\eta_b \equiv \frac{n_b}{n_\gamma} \sim 10^{-10}$

$$\sim \frac{n_p}{n_n} = e^{\frac{m_n - m_p}{T}} \quad (m_n - m_p \sim 1.3\,\text{MeV})$$

@ nucleo.

$$\Rightarrow X_n = \frac{n_n}{n_n + n_p} \overset{?}{=} 0.11$$

↳ $\frac{n_{He}}{n_H} = \frac{n_n/2}{n_p - n_n} \simeq 0.22$

4) Chemistry : same as our universe (only electrons form atoms, no μ, τ)

5) Matter Dom : $\tilde{\Omega}_{matter} = \Omega_{matter} \approx 0.23$, structures still form

+ Structures $\eta_n^{\nu} \approx 10^{-2} \eta_b \Rightarrow$ less stars, but they still

6) Dark Matter : Λ_s^0 hyperons behave as DM; but they are not enough

~~WIMP~~ ⇒ No freeze-out after EW decoupling

AXION

PBH

7) Isotopes Stability : No β^- decay ⇒ A lot of new stable elements/isotopes

⇒ but no very heavy elements (no pathway to them) ⇒ Geostructure affected (no volcanos, no tectonism)

8) STARS

→ FORMATION: dust needs to be cooled to virialize ⇒ same mechanism as normal one.

→ NUCLEOSYNTHESIS: $p + p \not\rightarrow D + e^+ + \nu_e$

but we have Deuterium!

$p + D \rightarrow {}^3He + \gamma$

${}^3He + {}^3He \rightarrow {}^4He + 2p$

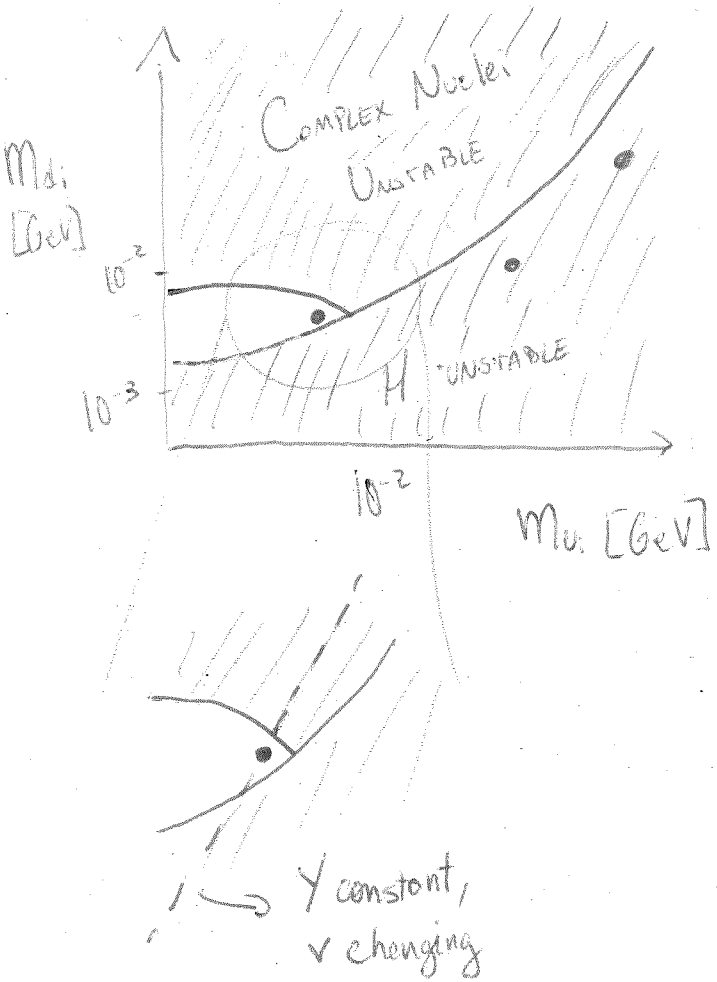
$D + {}^3He \rightarrow {}^4He + p$

→ Lifetime: $t_x = \frac{\text{Burnable Energy}}{\text{Luminosity @ steady state}}$ ⇒ $D + {}^3He$ burn (simulations $\sim 10^{10}$ yrs) ⇒ We have long lived stars

→ SN: Needed in order to disperse heavy elements ⇒ they still accreating matter, but no cooling mechanism

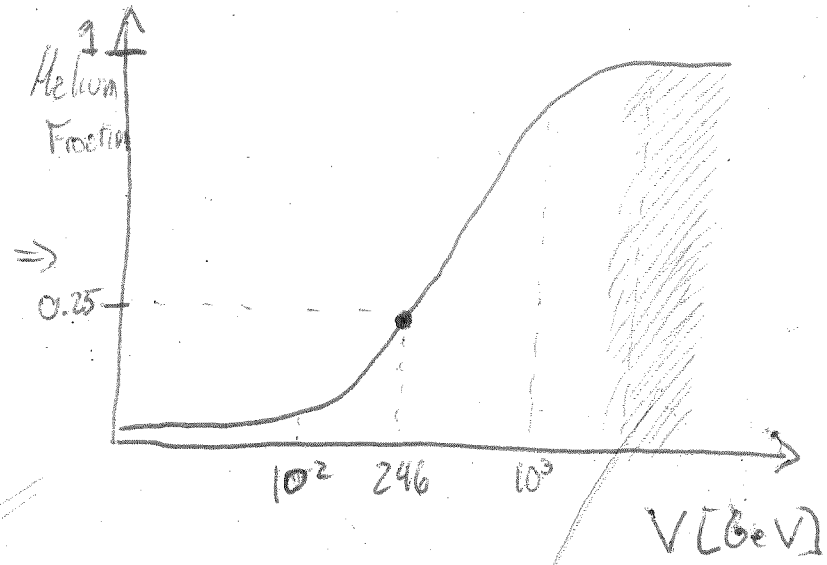
CONCLUSION: We have a similar universe! //

THE WEAK SCALE FROM BBN (Hall, Pinner, Ruderman; 1409.0551)



CAN WE SCAN v WITH YUKAWA COMPENSATING?

(remember that $\frac{n_p}{n_N} = e^{\frac{m_N - m_p}{T}}$)



CAN v COME FROM BBN SELECTION?

freeze-out of $u \leftrightarrow d$ before QCD phase transition

(we don't scan v more than 10^2 factor)

$$T_{fo} \approx (0.9\,\mathrm{MeV}) \left(\frac{v}{v_0}\right)^{4/3} \left(\frac{m_{p,0}}{m_p}\right)^{1/3}$$

Scanning Parameters

Multiverse PDF $dP = f(X_i)\, W(X_i)\, d\ln(X_i)$ → set of params

$f(X_i)$: prior multiv. distribution; $W(X_i)$: weight ∝ # obs

$$\Rightarrow dP = f\left(\frac{m_a}{v}, v\right) n_{WC}(m_a)\, n_{BBN}(Y_4)\, n_{OTHER}(m_a, v)\, d\ln m_a\, d\ln v$$

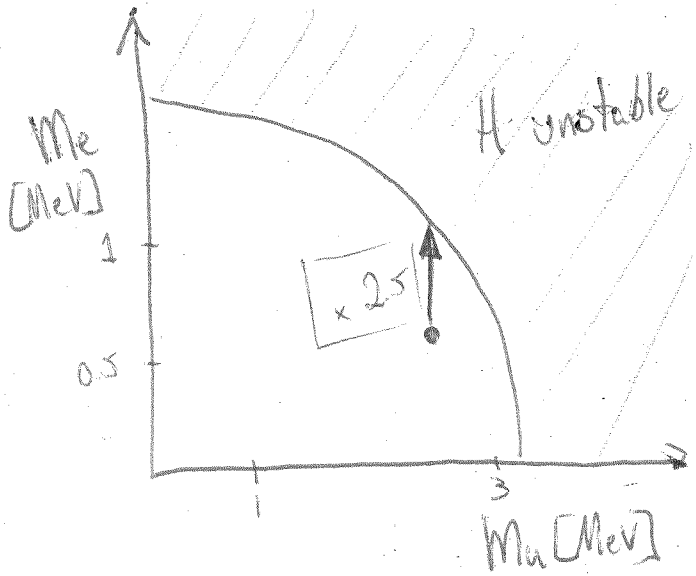
n_{OTHER}: 1

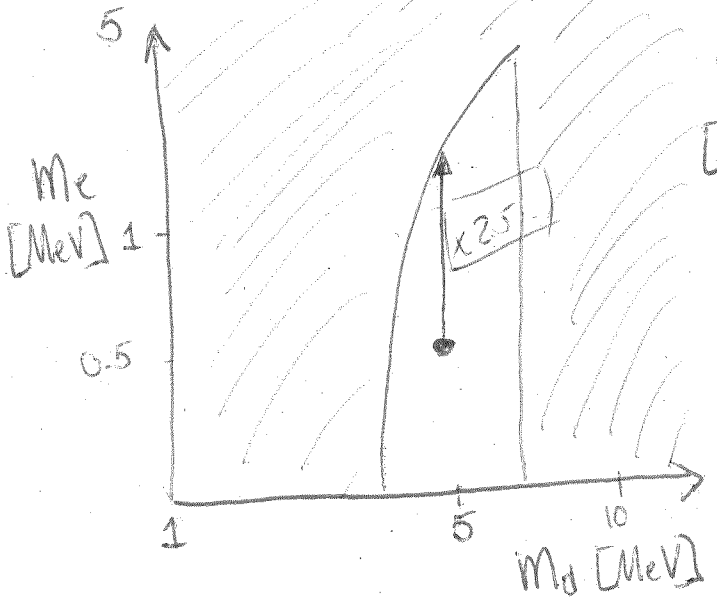
$n = \begin{cases} 1 & \text{in observ. region} \\ 0 & \text{outside} \end{cases}$

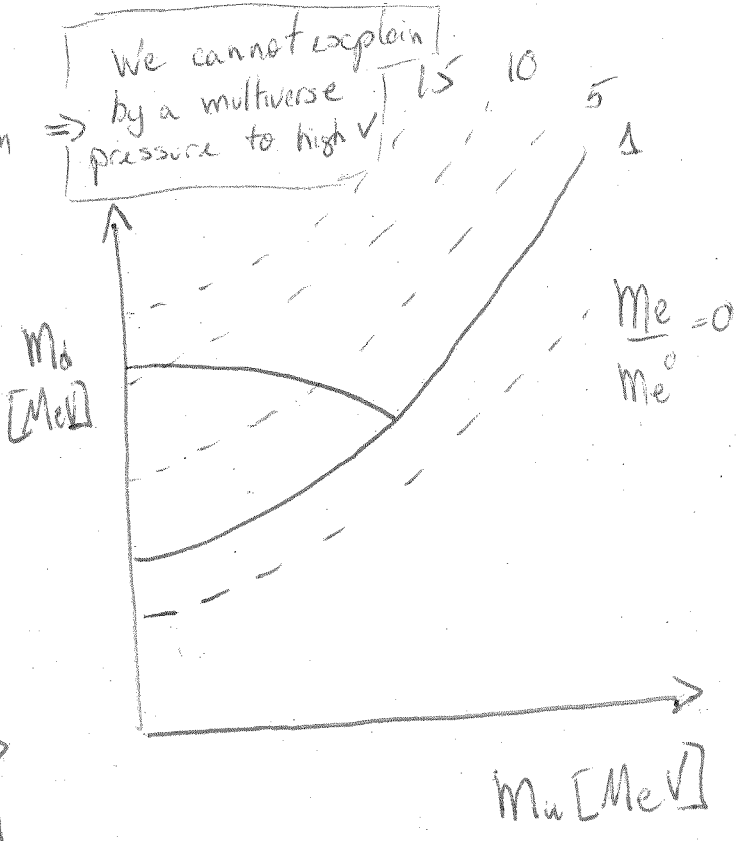
⇒ We can marginalize in each param

Scanning only $m_{u,d,e}$:

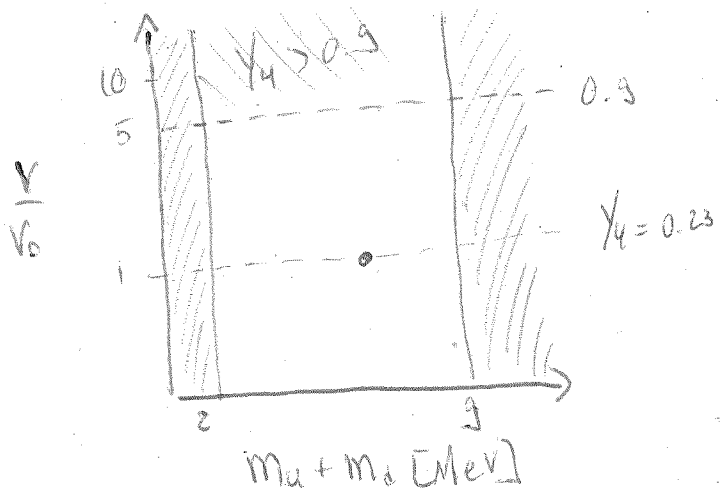
Not so close in the m_e direction ⇒ We cannot explain by a multiverse pressure to high v

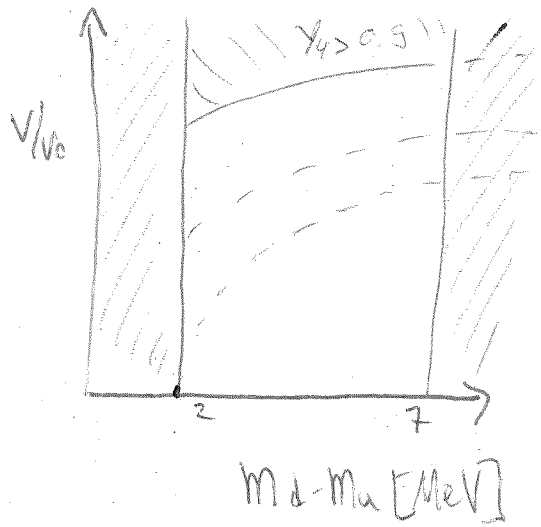






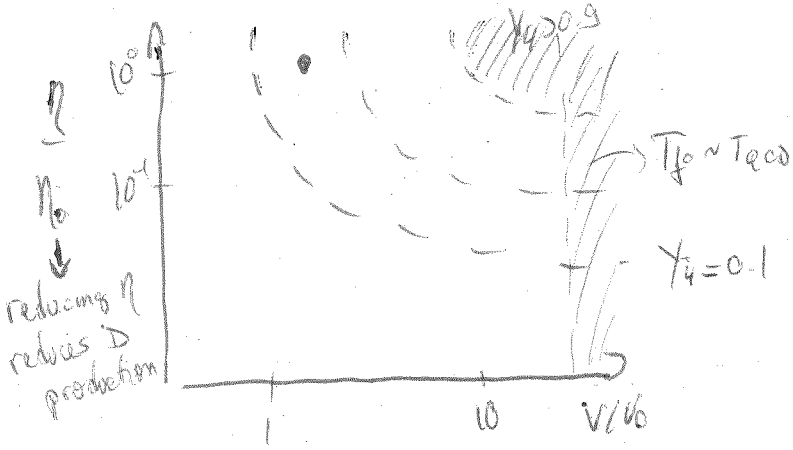
How scanning $m_{u,d,e}$, V plane affects Helium Fraction (Y_4)?

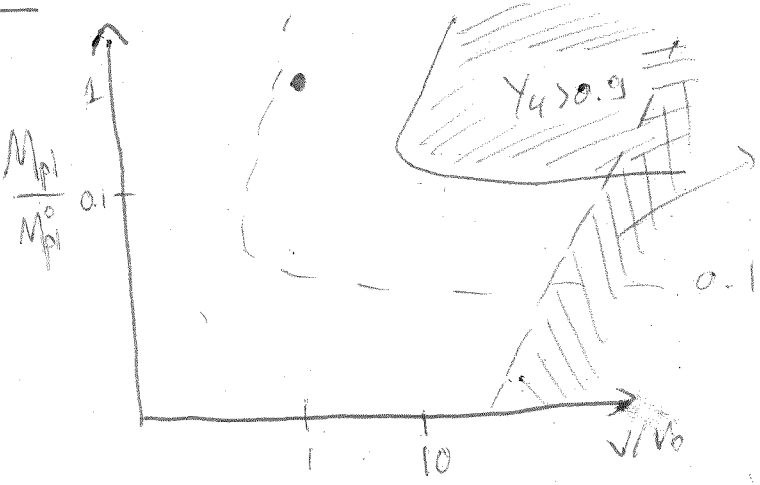




⇒ Scanning masses params allow us to increase $\frac{V}{V_0}$ ~ 10 times

What about scanning η or M_{Pl}?





⇒ Scanning M_{Pl} 2 orders of mag. larger or smaller allow us to scan V

Conclusions (what they claim...)

- evidences that m_u, m_d, m_e are anthropically determined