

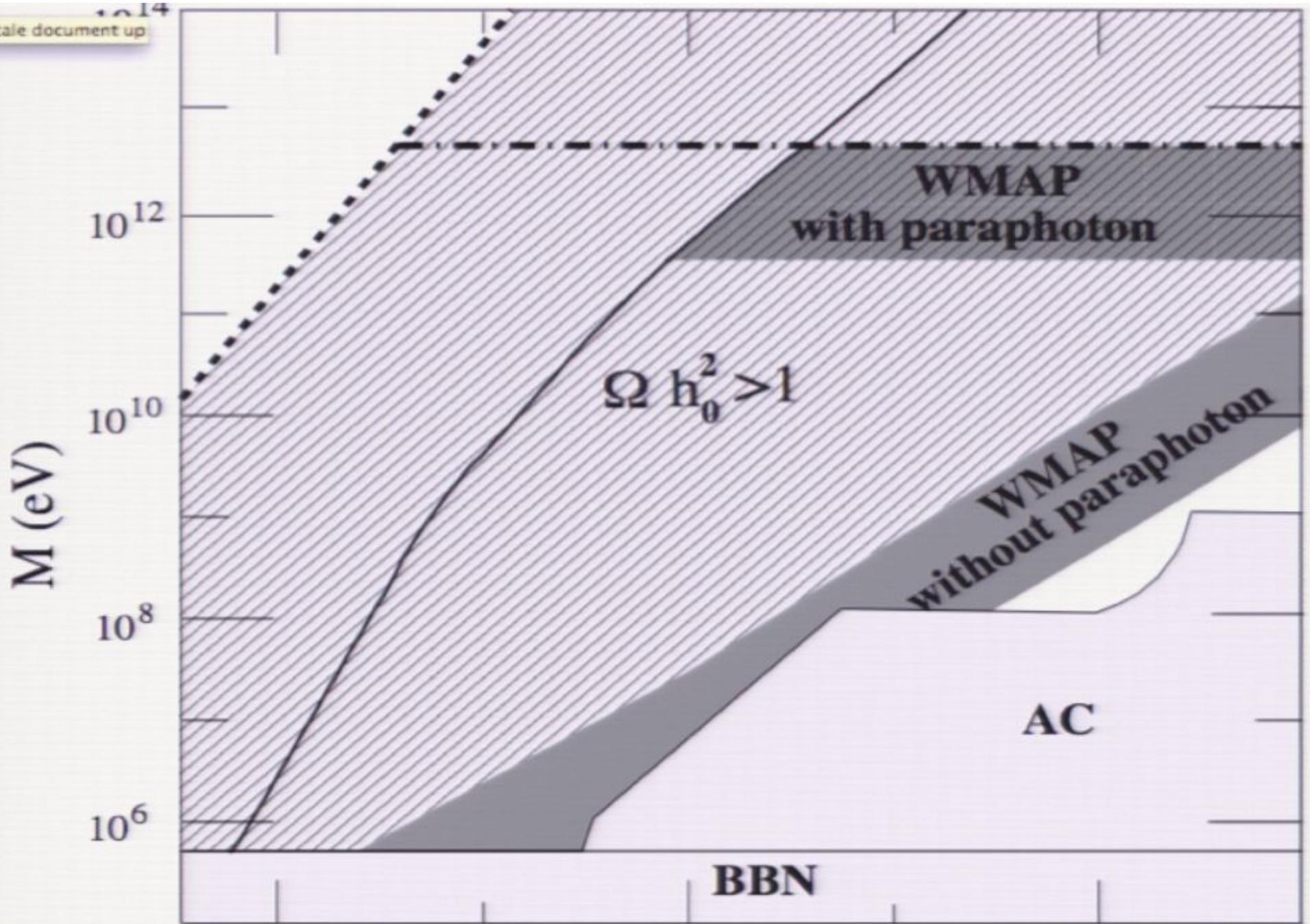
Title: Theories of Dark Matter- Lecture 1

Date: Jun 24, 2009 10:00 AM

URL: <http://pirsa.org/09060064>

Abstract:

Scale document up



① Summary of DM

② Models of DM

③ "DM anomalies" + new theories

No one knows anything about time†

† except some things

No one knows anything about DM†
Historically

† except some things

No one knows anything about Λ CDM

Historically

- ① None
- ② Missing gas, MACHOs
- ③ Neutrinos

← except some things

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Historically

- ① None
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- ④ Neutralinos
- ⑤ ?

† except some things

"Era of Data"

PAMELA, Fermi, ACT, direct det
Planck (CDMS, XENON)

LHC, Fermilab

Theories of BSM



Theories of DM

Signals of DM



Theories

"Era of Data"

PAMELA, Fermi, ACT, direct det
Planck (CDMS, XENON)

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theories of BSM



theories of DM

Signals of DM



theories

Evidence for DM

Evidence for DM

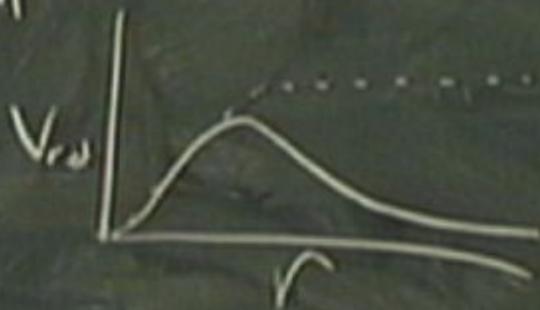
① Zwicky obs Coma Clusters

Evidence for DM

- ① Zwicky obs Coma Clusters
- ② Rubin rotation curves

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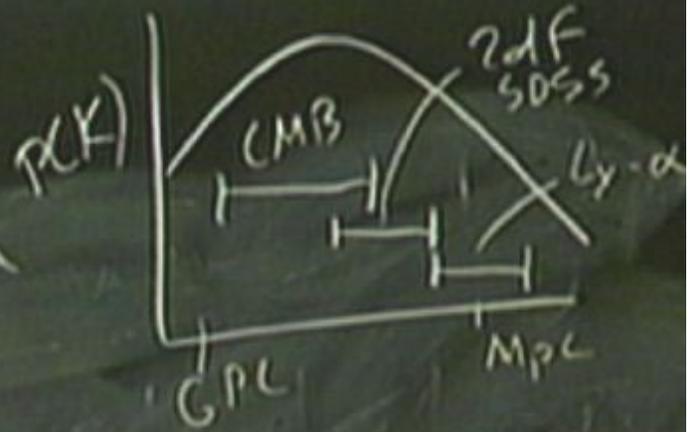
(4) Power



(4) Power Spectra

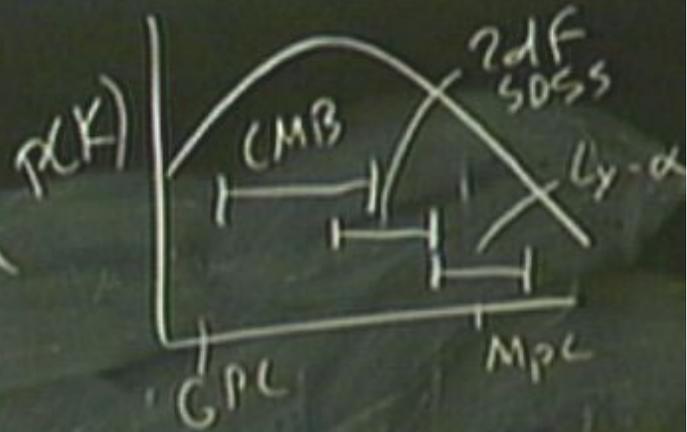


(4) Power Spectrum



(4) Power Spectra

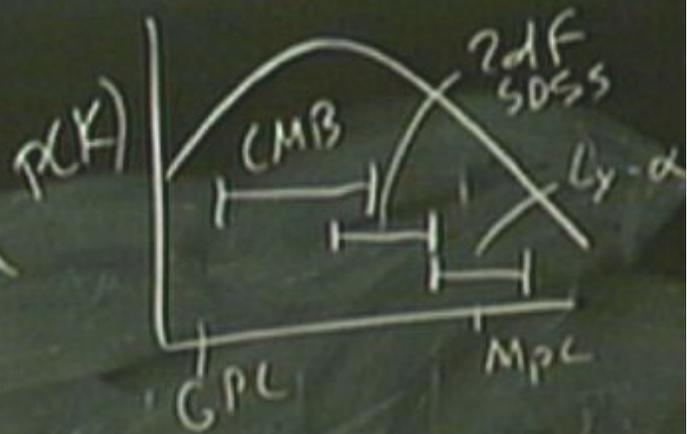
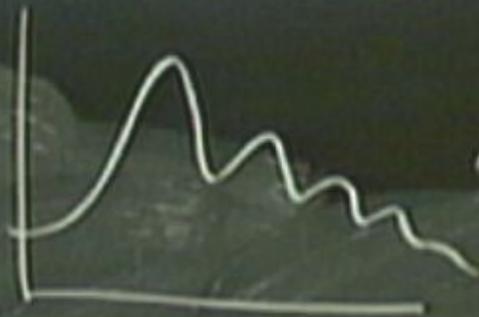
$$\frac{\delta P}{P}$$



(5) BBN \Rightarrow Li, He, D ...

(4) Power Spectra

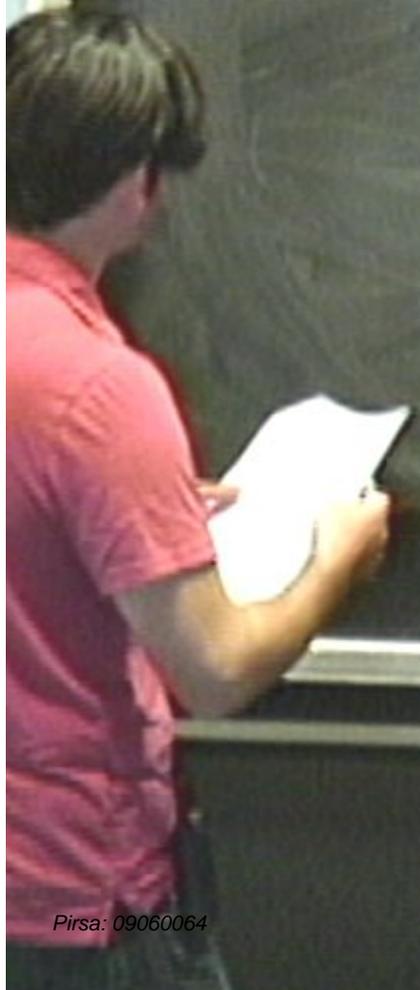
$$\frac{\delta\rho}{\rho}$$



(5) BBN \Rightarrow Li, He, D...

$$B_{\gamma} = 6 \cdot 10^{-7} \Rightarrow \Omega_b \approx 0.04$$

What do we know about DM?



What do we know about DM?

0) Massive, $w \approx 0$, $\rho = \rho_0 a^{-3}$

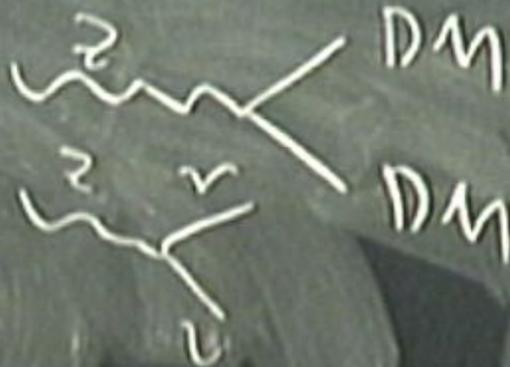
0b) Neutral

What do we know about DM?

0) Massive $w \approx 0$ $\rho = \rho_0 a^{-3}$

0b) Neutral

$$m < m_{\nu}$$



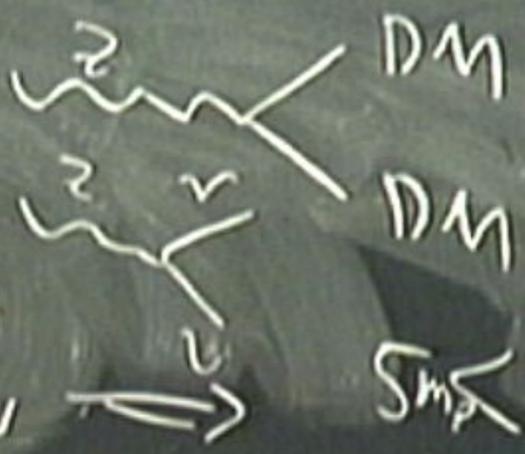
What do we know about DM?

0) Massive $w \approx 0$ $\rho = \rho_0 a^{-3}$

0b) Neutral

$$m < m_z$$

+1 → Heavy H
Searches



$$5m_p < m_X < 1600m_p$$

$$< 4 \times 10^{-17}$$

Milli-charged
tightly coupled
accelerating searches

Milli-charged
tightly coupled
accelerator searches

0c) not p/n/e

① Cold

↳ when DM was produced
it was NR

when $T \sim 10 \text{ keV}$

$T \sim 10^{-4} \text{ eV}$

$T_{\text{BBN}} \sim 1 \text{ MeV}$

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$T \sim 10^{-4} \text{ eV}$

$\Delta B N \sim 1 \text{ MeV}$

2) Non-interact²

2) Non-interacting

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DM should have scattered $\lesssim 1$
time in age of universe

0.36 yr

$$\sigma v \lesssim 1$$

↑ scattering rate

$14 \cdot 10^{17} \text{ yr}$

2) Non-interacting

DM should have scattered $\lesssim 1$
 time in age of universe

$$\frac{0.3 \text{ GeV}}{M_\chi}$$



$$\sigma < 10 \text{ cm}^2 \times \frac{\text{TeV}}{M_\chi}$$

Kesden + Kamionkowski

$$\beta < 0.2$$

↑
Strength

relative to gravity

Kesden + Kamionkowski

$$\beta < 0.2$$

↑
Strength
relative to gravity

Stable (on 14×10^9 yr scale)

non-int

neutral

$$\Omega_h^2 > 0.1$$

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Strength
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non-111t

neutral

$$\Omega_h^2 > 0.1$$

Cold

What models of DM

axion \rightarrow string

What models of NM

axion \rightarrow strong CP problem

$$\mathcal{L} \supset (\cancel{\theta} + \frac{a}{f}) G_{\mu\nu} \tilde{G}^{\mu\nu}$$

$$a \rightarrow -\theta + \tilde{a}$$

neutralino

motivated by Hierarchy P

$$a_1 \beta + a_2 W_3 + a_3 h_d$$

What models of NM

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 $a_1 B + a_2 W_3 + a_3 h_u + a_4 h_d \Rightarrow$ neutralinos

What models of NM

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neutralino

motivated by Hierarchy problem
 $\alpha_1 B + \alpha_2 W_3 + \alpha_3 h_d \rightarrow$ neutralinos

LTOP

KKDM

axino

4th

stino

Little Higgs model

Dim $R \sim (1/cv)^{-1}$

motiv HP + SCP

v motiv by 3 gens

HP + unpleasant childhood

Forming DM

Thermal
DM in early
universe in
equilibrium

Non-thermal

$SM \rightleftharpoons DM$

Cold

Forming DM

Thermal
DM in early
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SM \rightleftharpoons DM

Non-thermal

Decay
of
another
particle

LSP \rightarrow gravitino

phase
transition

Cold

Forming DM

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phase
transition

incomp
hGV

Cold

① Scalar field

$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

Scalar field

$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

$$\phi = \phi_0 e^{i\omega t}$$

$$\omega^2 + 3\omega H + m^2 = 0$$

$$\omega = \frac{-3H \pm \sqrt{9H^2 - 4m^2}}{2}$$

$$\phi = \phi_0 e^{-\frac{3H_0 t}{2}} e^{imt}$$

$$\psi = \psi_0 e^{-\frac{3Ht}{2}} e^{imt}$$

$$\rho_\psi = \frac{\psi^2}{2} + \frac{m^2}{2} \psi^2$$

$$= \frac{m^2 \psi_0^2}{2} e^{-3Ht} + \frac{m^2}{2} \psi_0^2 e^{-3Ht}$$

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Scalar field

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$$\omega = \frac{-3H \pm \sqrt{9H^2 - 4m^2}}{2}$$

$$m \gg H$$

$$\omega = -\frac{3H}{2} + im$$

$$H \gg m$$

$$\omega = -3H$$

$$\omega = -2m$$

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$$m^2 \phi^2 = m^2 b_0^2 e^{-\frac{4m^2}{3H} t}$$

$$m \ll H$$

"slow roll" $t \ll \frac{3H}{4m^2}$

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"coherently oscillating"

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$$m^2 \phi^2 = m^2 v_0^2 e^{-\frac{4m^2}{3H} t}$$

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Hum



$$m^2 \phi^2 = m^2 \phi_0^2 e^{-\frac{4m^2}{3H} t}$$

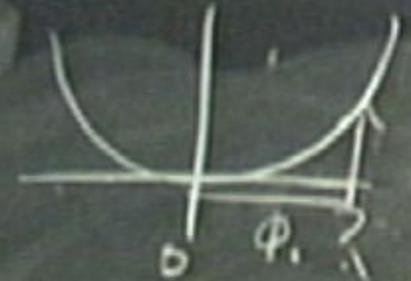
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"slow roll" $t \ll \frac{3H}{4m^2}$

Hum

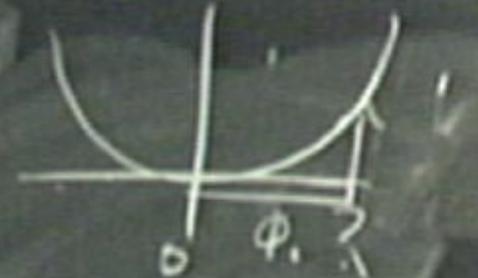


$$\phi_0 \sim M_{PI}$$



$$\phi_0 \sim M_{PI}$$

$$m = H ?$$

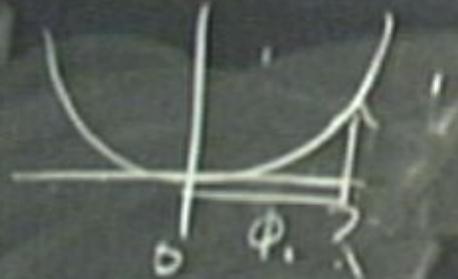


$$\phi_0 \sim M_{Pl}$$

$$m = H ?$$

$$\text{FRW } m^2 \sim H^2 \sim \frac{\rho}{M_{Pl}^2} \Rightarrow \rho \sim m^2 M_{Pl}^2$$

$$\rho_\phi \sim m^2 \phi_0^2 \sim m^2 M_{Pl}^2$$



$$\phi_0 \sim M_{Pl}$$

$$m = H ?$$

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