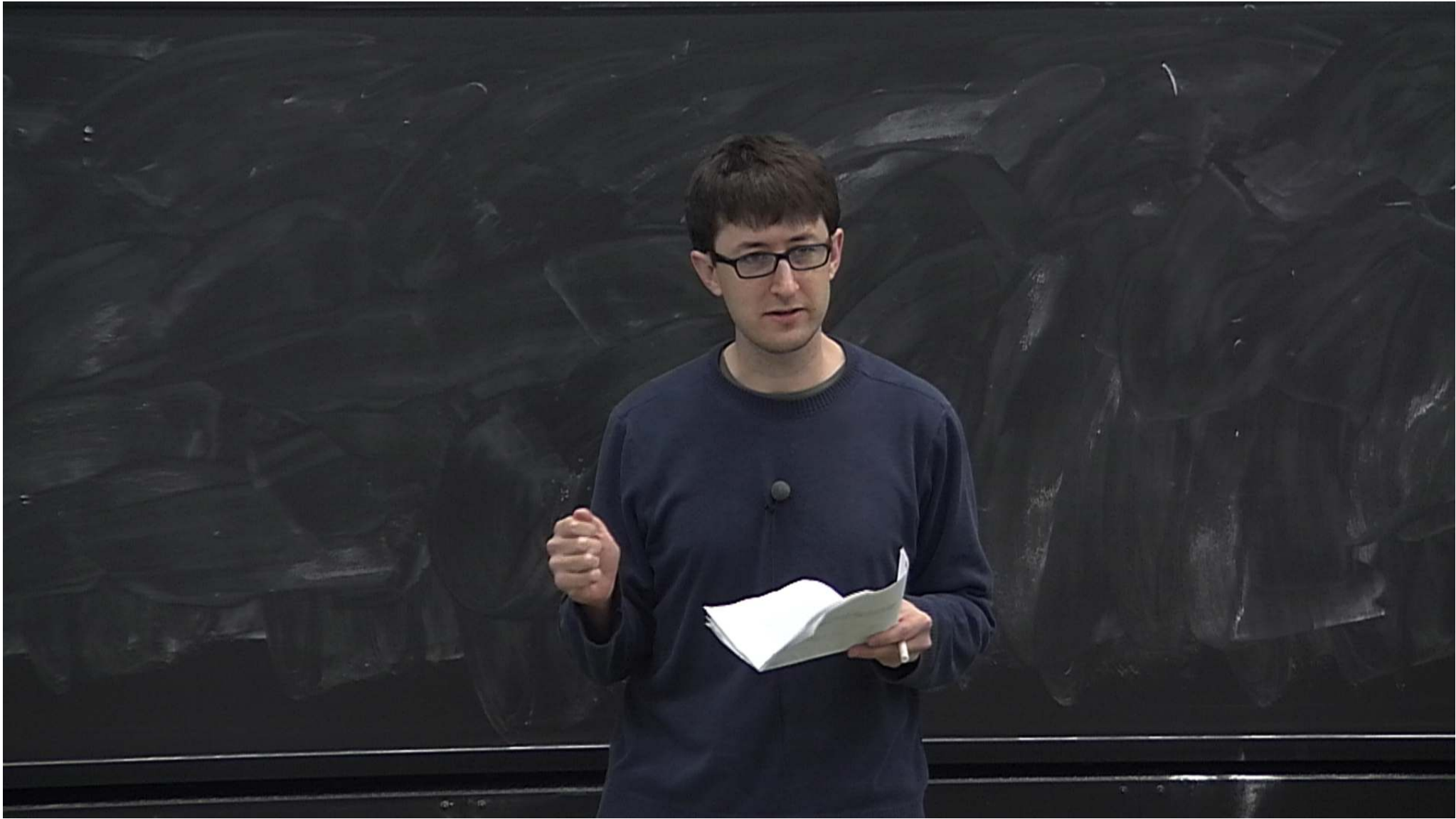


Title: Cosmology (Review) - Lecture 12

Date: Feb 08, 2012 11:30 AM

URL: <http://pirsa.org/12020028>

Abstract:



$$\text{DM. + D.E.}] \rightarrow \frac{\rho_{dm}}{\rho_{crit}} = 0.25 \quad (w = \frac{p}{\rho} = 0)$$

Bary genesis

$$\frac{\rho_{de}}{\rho_{crit}} = 0.70 \quad (w = -1)$$

$$\text{DM. + D.E.}] \rightarrow \left[\frac{\rho_{dm}}{\rho_{crit}} = 0.25 \quad (w = \frac{p}{\rho} = 0) \right] \rightarrow$$

Bary genesis

$$\left[\frac{\rho_{de}}{\rho_{crit}} = 0.70 \quad (w = -1) \right] \rightarrow$$

$$\rho = \rho_{crit}$$

$$a(t)$$

$$\rho = 30\% \rho_{crit}$$

$$\ddot{a} < 0$$

$$\ddot{a} > 0$$

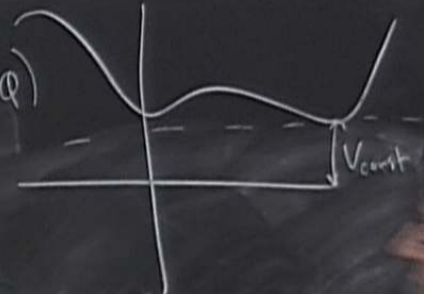
$$S = \int d^4x \sqrt{-g} \left\{ \frac{R - 2\Lambda}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \nabla_\mu \phi \nabla_\nu \phi - V(\phi) \right\}$$

$V(\phi)$

30% p.c.t

$$S = \int d^4x \sqrt{-g} \left\{ \frac{R - 2\Lambda}{16\pi G_N} + \frac{1}{2} g^{\mu\nu} \nabla_\mu \phi \nabla_\nu \phi - V(\phi) \right\}$$

$$V(\phi) = V_{\text{const}} + \tilde{V}(\phi)$$



$$DM + DE \rightarrow \left[\frac{p_{dm}}{p_{crit}} = 0.25 \quad (w = \frac{p}{p} = 0) \right] \rightarrow$$

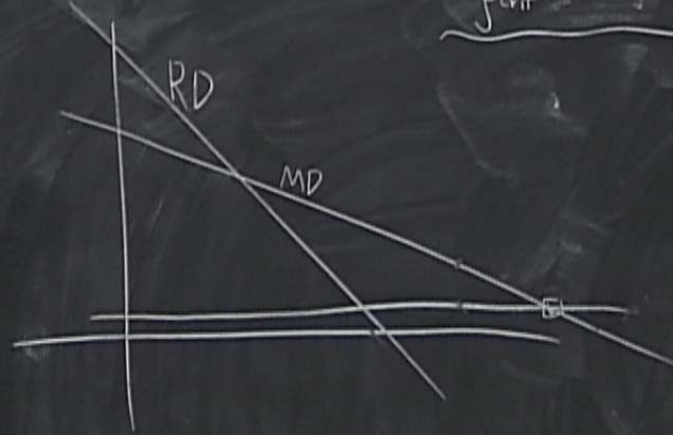
Bar/genesis

$$\left[\frac{p_{de}}{p_{crit}} = 0.70 \quad (w = -1) \right] \rightarrow p = p_{crit}$$

$$p = 30\%$$

$a(t)$

$$\begin{aligned} \dot{a} &< 0 \\ \dot{a} &> 0 \end{aligned}$$



$$S = \int d^4x \sqrt{-g} \left\{ \frac{R - 2\Lambda}{16\pi G_N} + \frac{1}{2} g^{\mu\nu} \nabla_\mu \varphi \nabla_\nu \varphi - V(\varphi) \right\}$$

$$V(\varphi) = V_{\text{const}} + \tilde{V}(\varphi)$$

$$\Lambda^4 = 10^{12} \text{GeV}^4$$

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

$$\Lambda = 0$$



$$\rho = 30\% \rho_{\text{crit}}$$

$$\ddot{a} < 0$$

$$\ddot{a} > 0$$

normal matter density

DM + DE] $\rightarrow \left[\frac{\rho_{dm}}{\rho_{crit}} = 0.25 \quad (w = \frac{p}{\rho} = 0) \right] \rightarrow$

Bar/genesis

$\left[\frac{\rho_{de}}{\rho_{crit}} = 0.70 \quad (w = -1) \right] \rightarrow$

$\rho = \rho_{crit}$
 $a(t)$

$\rho = 30\% \rho_{crit}$

$\ddot{a} < 0$
 $\ddot{a} > 0$

$S = \int d^4x$

MACHOs \rightarrow 1986 gravitational microlensing

$10^{-8} M_{\odot} < M_{BH} < 10^2 M_{\odot}$

$10^{15} g \rightarrow T_{evap} < H_0^{-1}$



$$DM + DE \rightarrow \left[\frac{\rho_{dm}}{\rho_{crit}} = 0.25 \quad (w = \frac{p}{\rho} = 0) \right] \rightarrow$$

Bar/genesis

$$\left[\frac{\rho_{de}}{\rho_{crit}} = 0.70 \quad (w = -1) \right] \rightarrow$$

$$\rho = \rho_{crit}$$

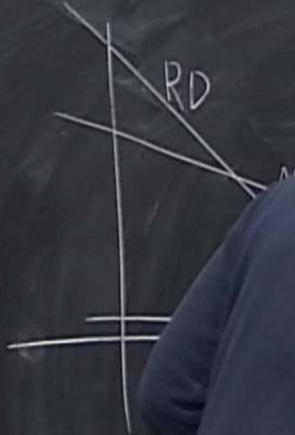
$$\rho = 30\% \rho_{crit}$$

$$a(t)$$

$$\ddot{a} < 0$$

$$\ddot{a} > 0$$

$$S = \int d^4x$$



MACHOs \rightarrow 1986 gravitational microlensing

$$10^{-8} M_{\odot} < M_{BH} < 10^2 M_{\odot}$$

$$10^{15} g \rightarrow T_{evap} < H_0^{-1} < 10^{10} \text{ yrs}$$



Dark Matter / Baryogenesis

$$E \sim 1 \text{ TeV}$$

Dark Matter / Baryogenesis

Thermal \rightarrow Hot Thermal
 \rightarrow Cold Thermal
Non-Thermal

$$E \sim 1 \text{ TeV}$$

Dark Matter / Baryogenesis

Thermal \rightarrow Hot Thermal $\rightarrow \frac{\rho_{rel}}{f_{rel}} \propto \left(\frac{m}{eV}\right)$
 \rightarrow Cold Thermal
Non-Thermal

$$E \sim 1 \text{ TeV}$$

Dark Matter / Baryogenesis

Thermal \rightarrow Hot Thermal $\rightarrow \frac{\rho_{rel}}{f_{rel}} \approx \left(\frac{m}{eV}\right)$

\rightarrow Cold Thermal \rightarrow

Non-Thermal

$$\frac{\rho_{X,0}}{f_{rel,0}} \approx \frac{10^{-10}}{\text{GeV}^2 \sigma_f}$$

$$E \sim 1 \text{ TeV}$$

Thermal \rightarrow Hot Thermal $\rightarrow \frac{p_{rel}}{p_{crit}} \propto \left(\frac{M}{eV}\right)$

\rightarrow Cold Thermal \rightarrow

Non-Thermal

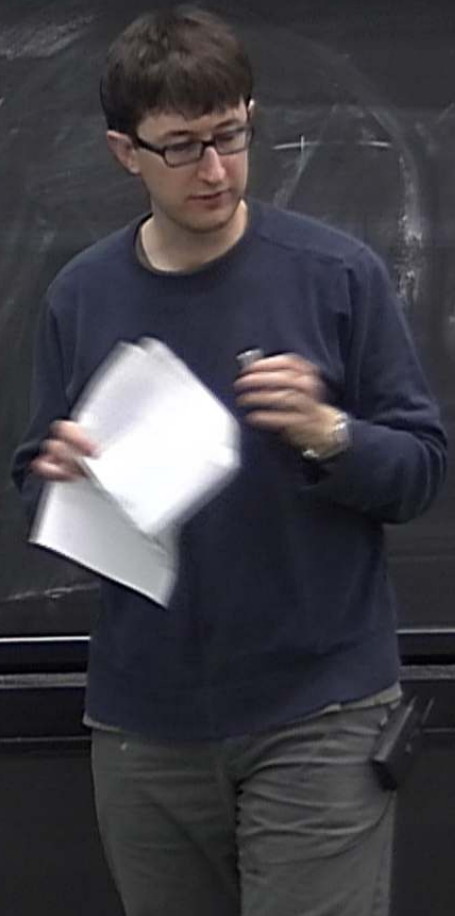
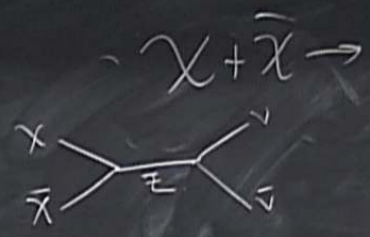
$$\frac{p_{\chi,0}}{p_{crit,0}} \approx \frac{10^{-10}}{\text{GeV}^2 (\sigma_f)}$$

$$10^{-10} \frac{1}{\text{GeV}^2}$$

$\chi + \bar{\chi} \rightarrow$

normal $\rightarrow \frac{p_{rel}}{f_{rel}} = \left(\frac{M}{eV} \right)$

normal $\rightarrow \frac{p_{rel}}{f_{rel,0}} = \frac{10^{-10}}{\text{GeV}^2 \sigma_F} = 10^{10} \frac{1}{\text{GeV}^2}$



Dark Matter / Baryogenesis

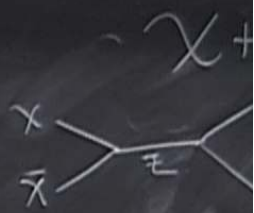
Thermal \rightarrow Hot Thermal $\rightarrow \frac{\rho_{rel}}{\rho_{crit}} \propto \left(\frac{M}{eV}\right)$
 \rightarrow Cold Thermal \rightarrow

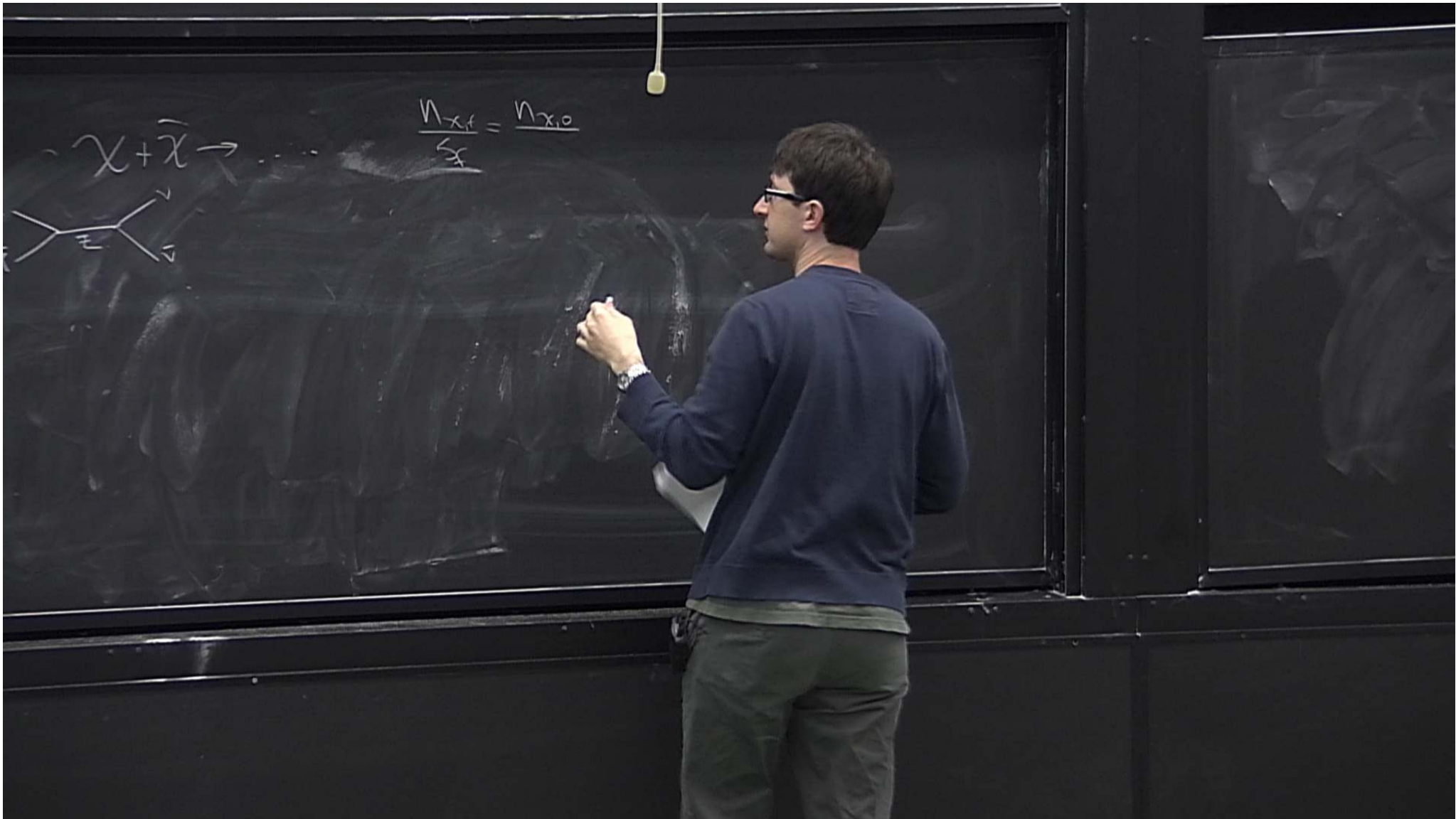
Non-Thermal

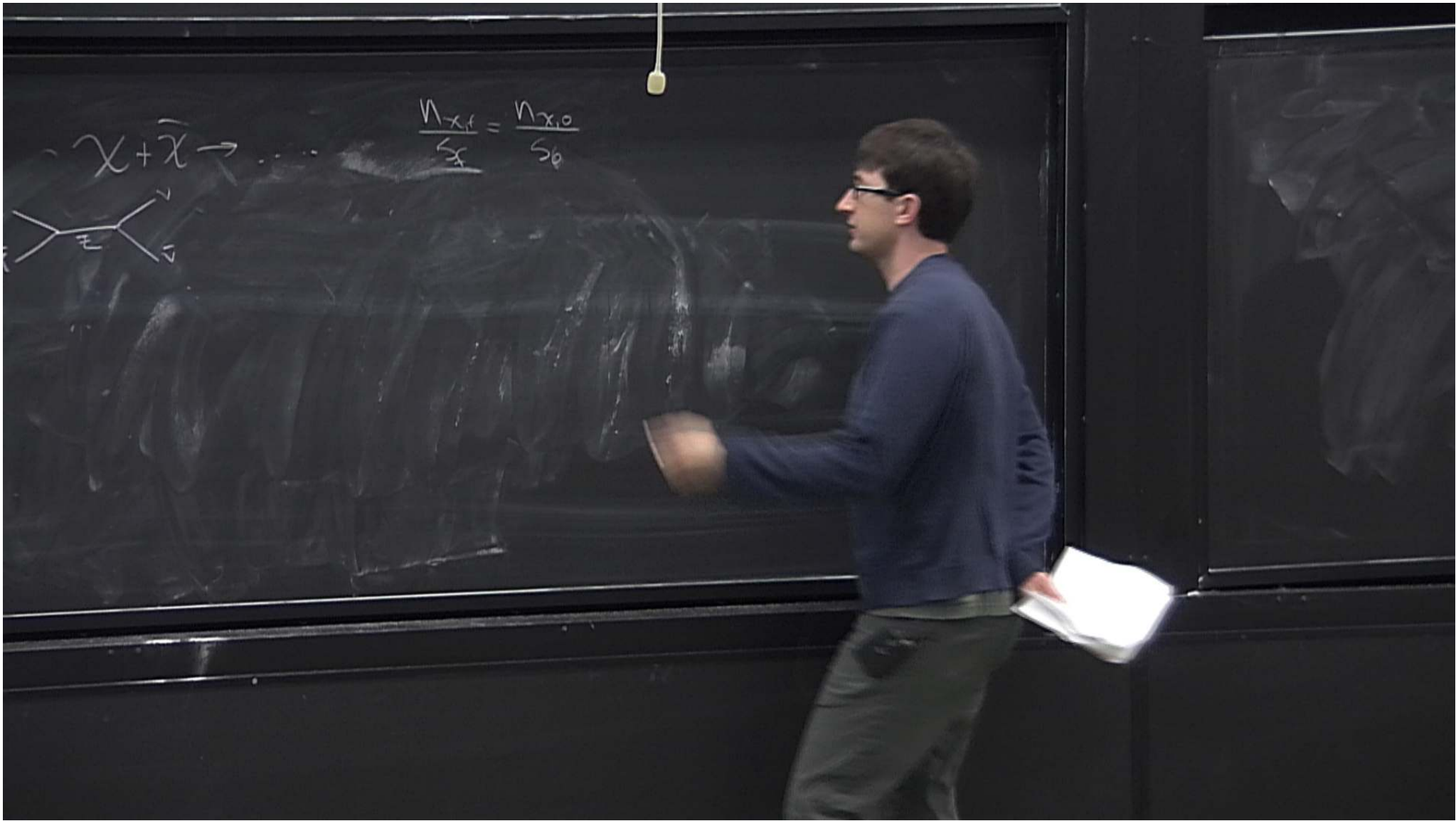
$$\frac{\rho_{X,0}}{\rho_{crit,0}} \approx \frac{10^{-10}}{\text{GeV}^2} \left(\frac{O_f}{O_f} \right) = 10^{10} \frac{1}{\text{GeV}^2}$$

$$E \sim 1 \text{ TeV}$$

Axion





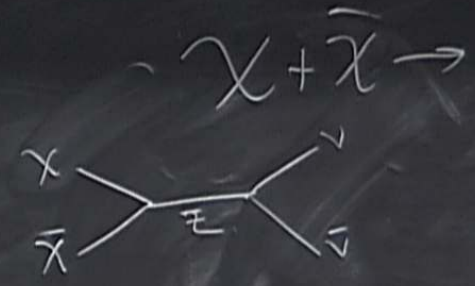


$$\frac{\sqrt{n}(\bar{x}_n - \mu_0)}{\sqrt{s_0}} = \frac{\sqrt{n}x_{i,0}}{\sqrt{s_0}}$$

Thermal \rightarrow Hot Thermal $\rightarrow \frac{p_{rel}}{f_{crit}} \approx \left(\frac{M}{eV}\right)$
 \rightarrow Cold Thermal \rightarrow

Non-Thermal

$$\frac{p_{X,0}}{f_{crit,0}} \approx \frac{10^{-10}}{\text{GeV}^2 \sigma_F} = 10^{10} \frac{1}{\text{GeV}^2}$$



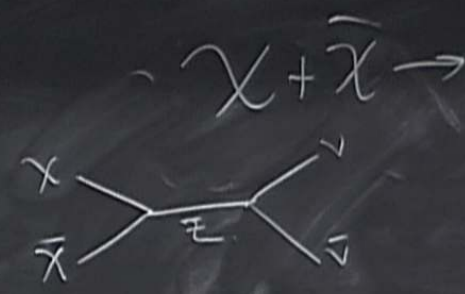
xion

Thermal \rightarrow Hot Thermal $\rightarrow \frac{f_{\text{rel}}}{f_{\text{crit}}} \approx \left(\frac{M}{eV}\right)$

\rightarrow Cold Thermal \rightarrow

Non-Ther

$$\frac{f_{\chi,0}}{f_{\text{crit},0}} \approx \frac{10^{-10}}{\text{GeV}^2 \sigma_F} = 10^{10} \frac{1}{\text{GeV}^2}$$



\Rightarrow

$$F = ma = m\ddot{x} \rightarrow \ddot{x} + 2\gamma\dot{x} + \omega^2 x = 0$$

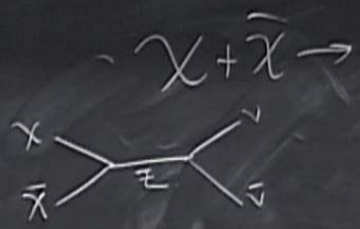
$-b\dot{x} - kx$

Thermal \rightarrow Hot Thermal $\rightarrow \frac{\rho_{rel}}{\rho_{crit}} \approx \left(\frac{M}{eV}\right)$

\rightarrow Cold Thermal \rightarrow

Non-Thermal

$$\frac{\rho_{x,0}}{\rho_{crit,0}} \approx \frac{10^{-10}}{\text{GeV}^2 \langle \sigma_f \rangle} = 10^{10} \frac{1}{\text{GeV}^2}$$



$$\frac{N_{x,0}}{S_0} = \frac{N_{x,0}}{S_0}$$

Axion

$F = ma = m\ddot{x} \rightarrow \ddot{x} + 2\gamma\dot{x} + \omega^2x = 0 \rightarrow x \propto e^{\Gamma t}$

$(\Gamma^2 + 2\gamma\Gamma + \omega^2) = 0$

$-b\dot{x} - kx$

$$\Gamma_{\pm} = \frac{1}{2} \left[-2\gamma \pm \sqrt{4\gamma^2 - 4\omega^2} \right] = -\gamma \pm \sqrt{\gamma^2 - \omega^2}$$

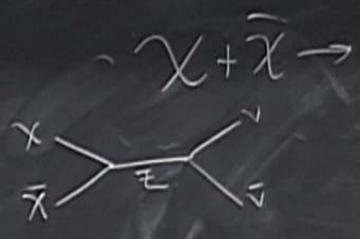


Thermal \rightarrow Hot Thermal $\rightarrow \frac{f_{rel}}{f_{rel,0}} \approx \left(\frac{m}{T}\right)$

\rightarrow Cold Thermal \rightarrow

Non-Thermal \rightarrow

$$\frac{p_{x,0}}{f_{rel,0}} \approx \frac{10^{-10}}{\text{GeV}^2} \left(\frac{0_f}{\text{GeV}^2} \right) = 10^{10} \frac{1}{\text{GeV}^2}$$



$$\frac{N_{x,0}}{S_0} = \frac{N_{x,0}}{S_0}$$

Axion

$$F = ma = m\ddot{x} \rightarrow \ddot{x} + 2\gamma\dot{x} + \omega^2x = 0 \rightarrow x \propto e^{\Gamma t}$$

$$-b\dot{x} - kx$$

$$(\Gamma^2 + 2\gamma\Gamma + \omega^2) = 0$$

$$\Gamma_{\pm} = \frac{1}{2} \left[-2\gamma \pm \sqrt{4\gamma^2 - 4\omega^2} \right] = -\gamma \pm \sqrt{\gamma^2 - \omega^2}$$

$$x + \bar{x} \rightarrow$$

$$\frac{N_{x,f}}{5x} = \frac{N_{x,0}}{50}$$

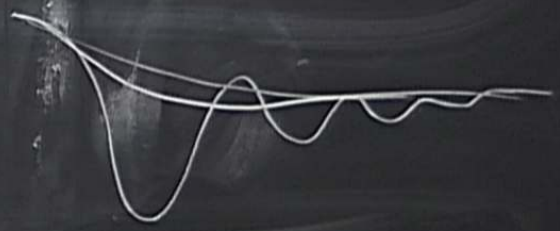


$$-\omega^2 x = 0 \rightarrow x \propto e^{\Gamma t}$$

$$(\Gamma + \omega^2) = 0$$

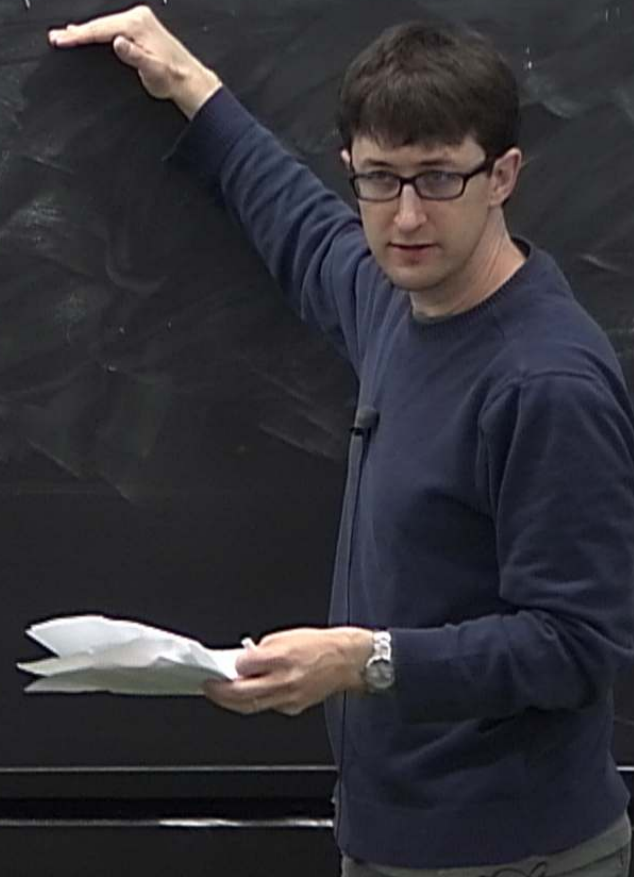
$$\Gamma = \frac{-2\gamma \pm \sqrt{4\gamma^2 - 4\omega^2}}{2} = -\gamma \pm \sqrt{\gamma^2 - \omega^2}$$

$\omega = \gamma$ "critically damped"



$$\mathcal{L} = -\frac{1}{2}(\partial_n \varphi)^2 - \frac{1}{2}m^2 \varphi^2$$

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

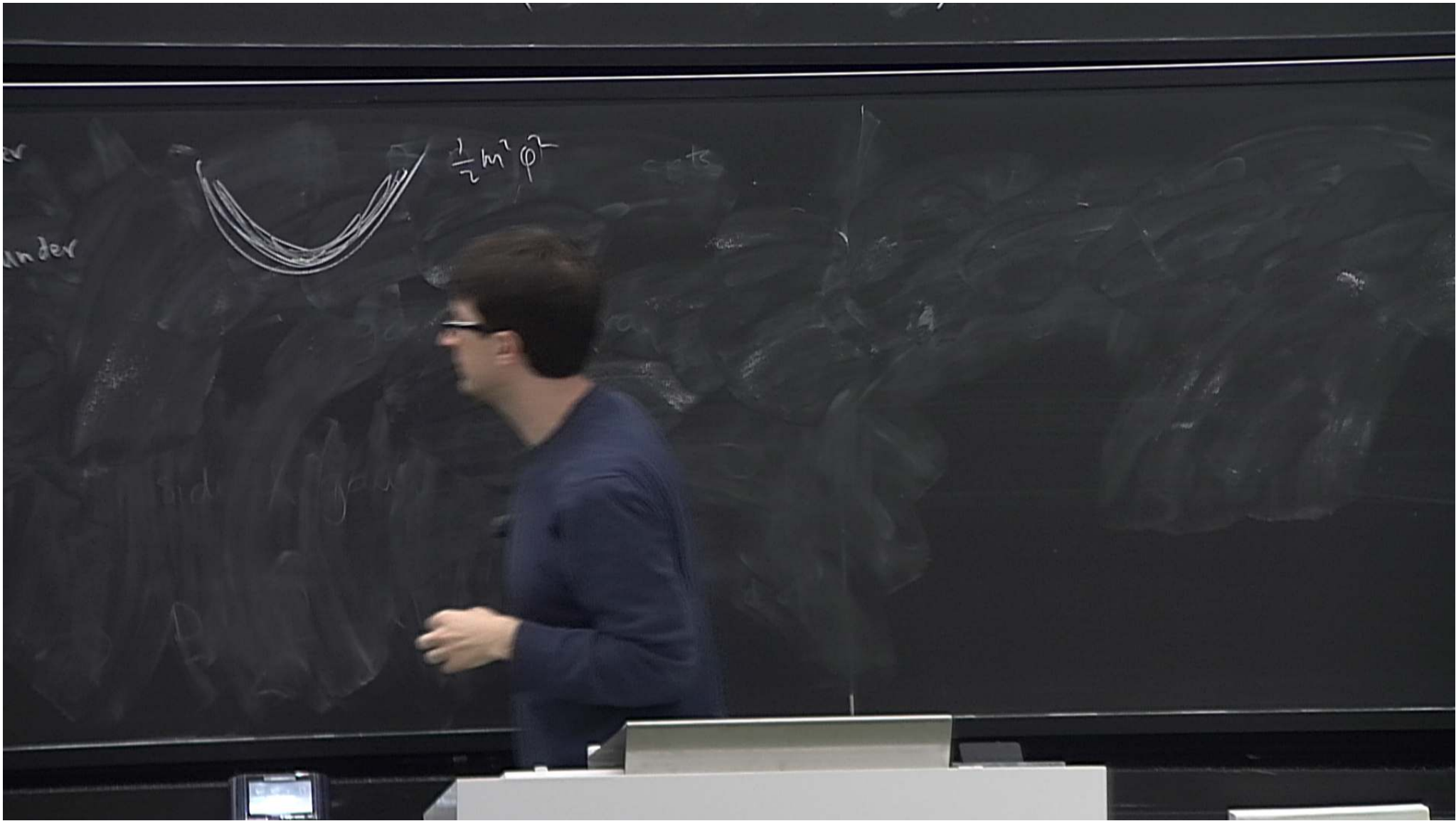


$$\ddot{\varphi} + \underbrace{3H}_{\uparrow} \dot{\varphi} + m^2 \varphi = 0$$

$H \gg m \rightarrow \text{over}$

$H = m$

$H \ll m \rightarrow$



$$\frac{1}{2}(\dot{\varphi})^2 - \frac{1}{2}m^2\varphi^2$$

$$\ddot{\varphi} + \underset{\uparrow}{3H} \dot{\varphi} + m^2\varphi = 0$$

$H \gg m \rightarrow$ over

$H = m$

$H \ll m \rightarrow$ under

