

Title: 12/13 PSI - Cosmology Review Lecture 12

Date: Mar 06, 2013 11:30 AM

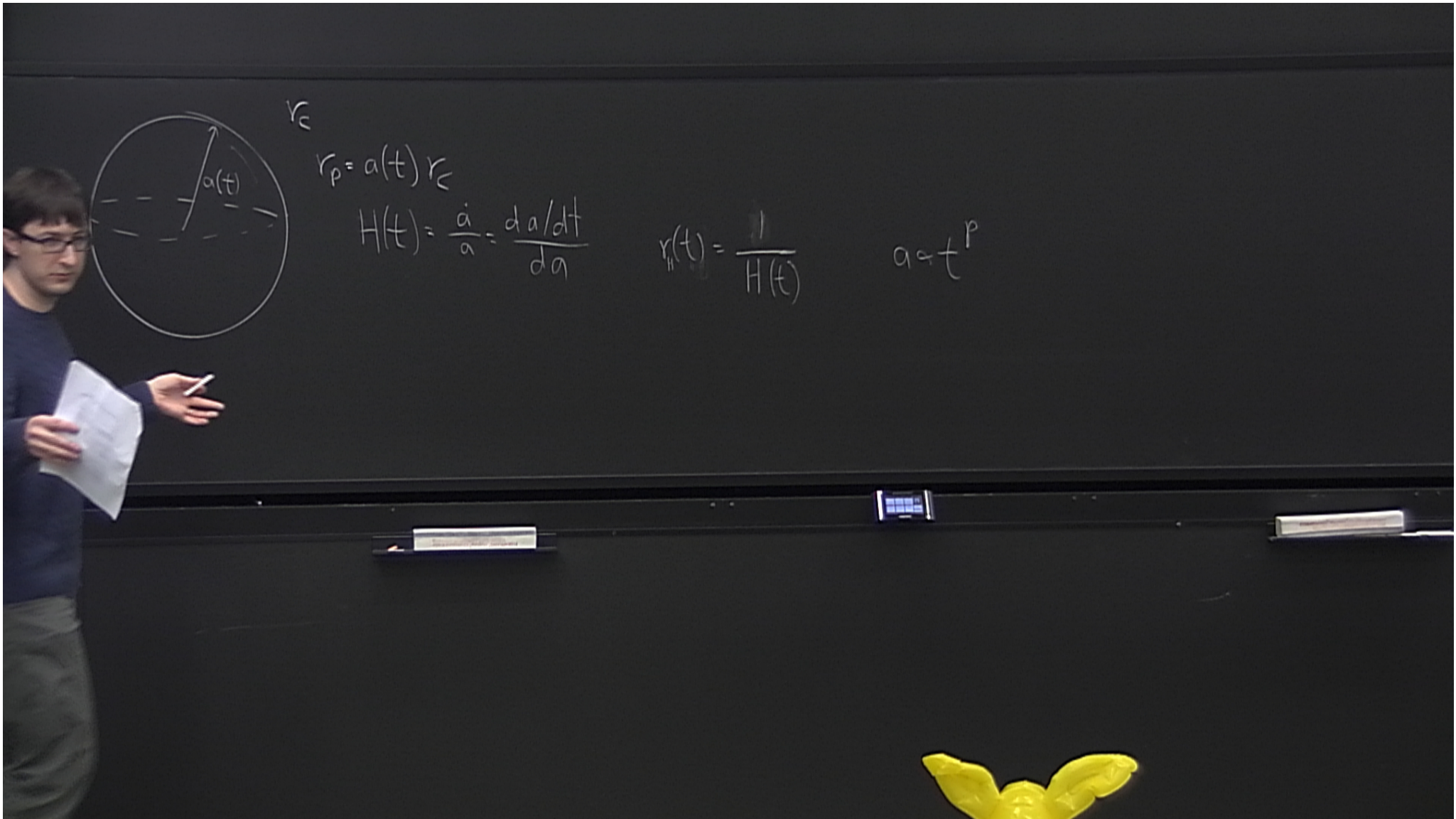
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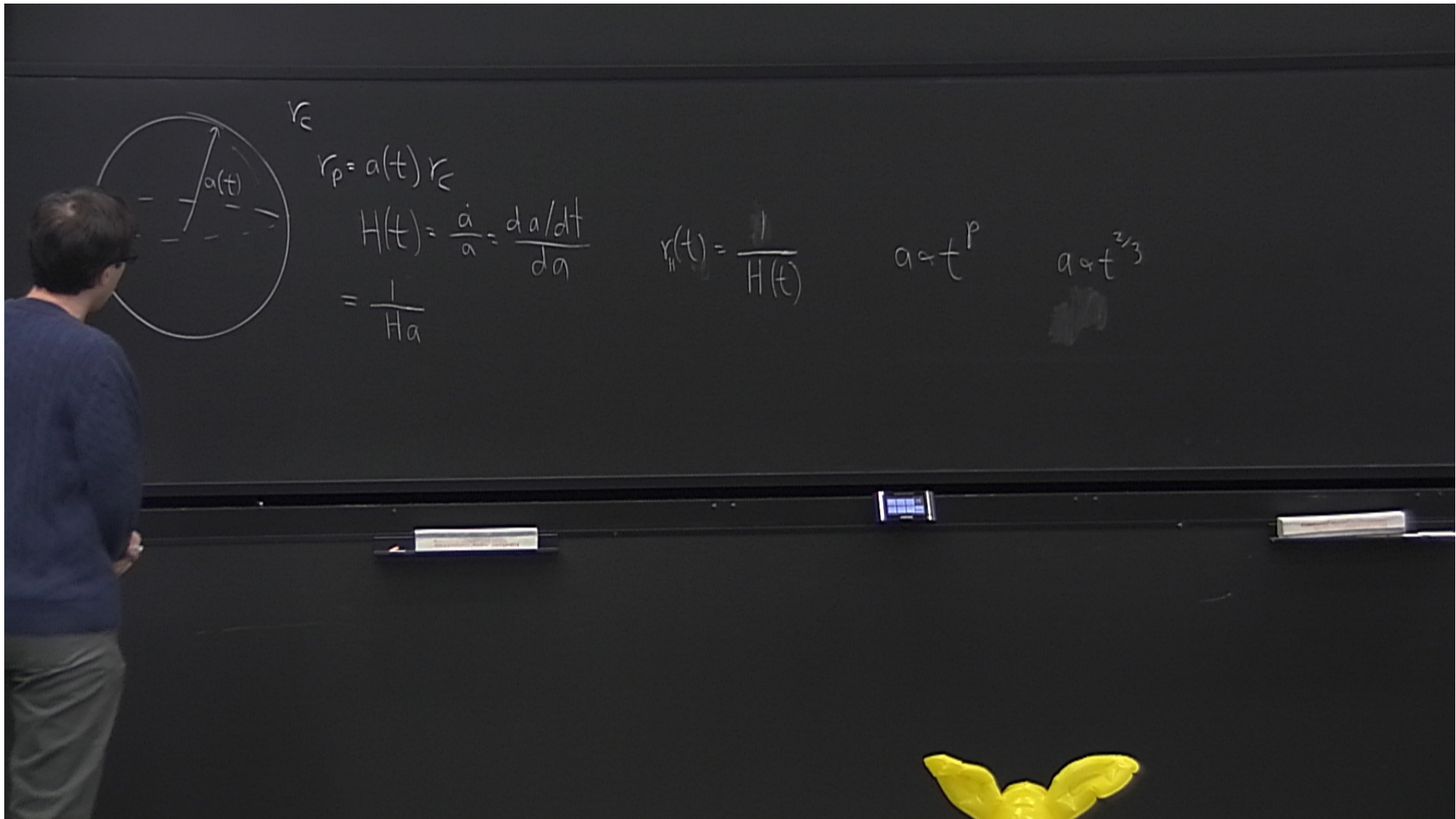
Abstract:

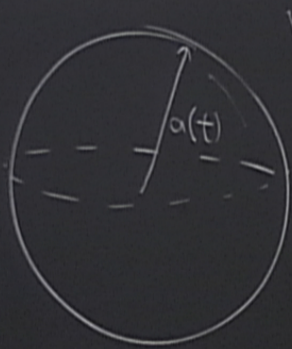
Inflationary Cosmology

→ Paul Steinhardt

homogeneous
2000







$$r_p = a(t) r_c$$

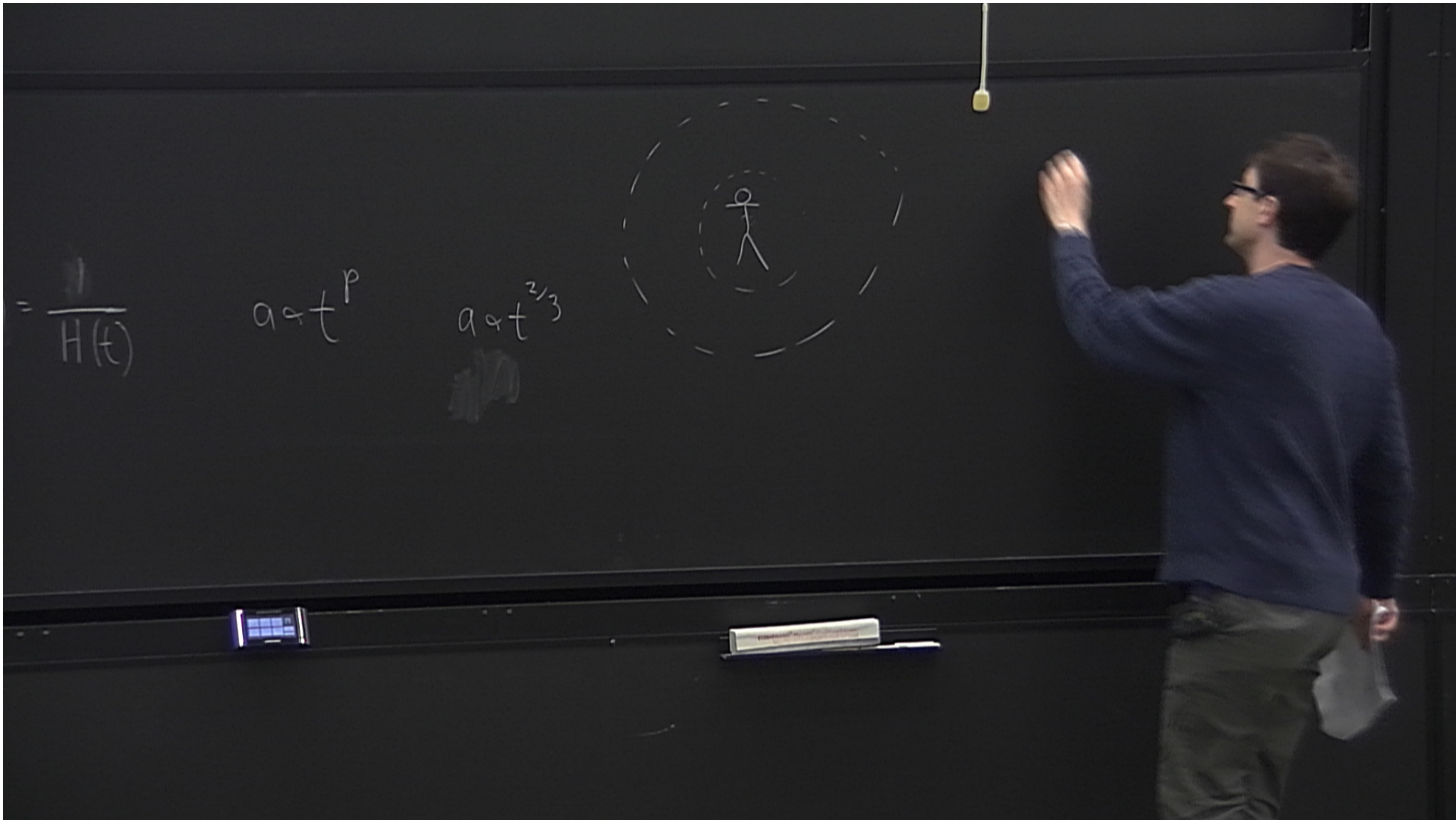
$$H(t) = \frac{\dot{a}}{a} = \frac{da/dt}{da}$$

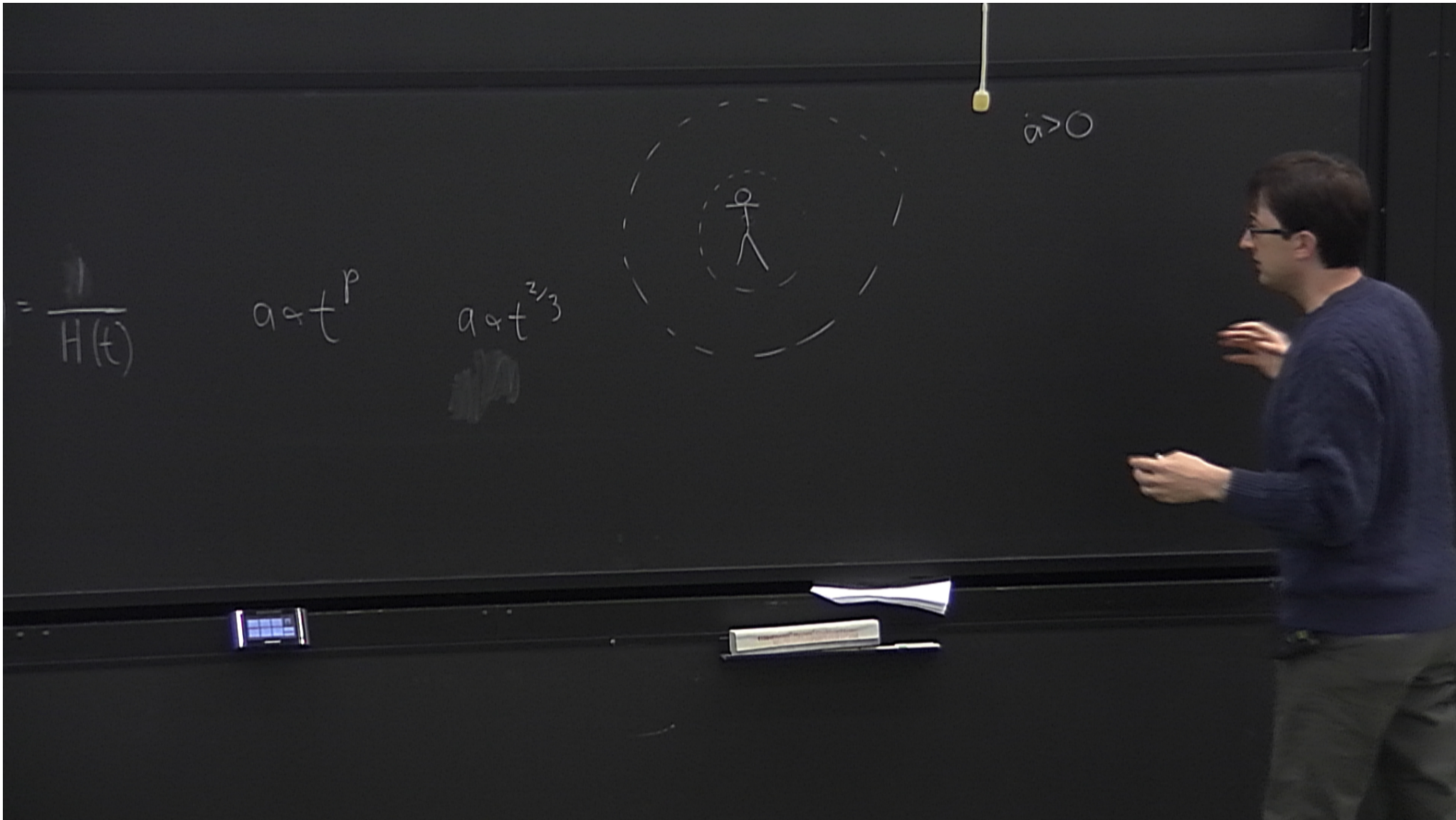
$$= \left(\frac{1}{Ha} \right)$$

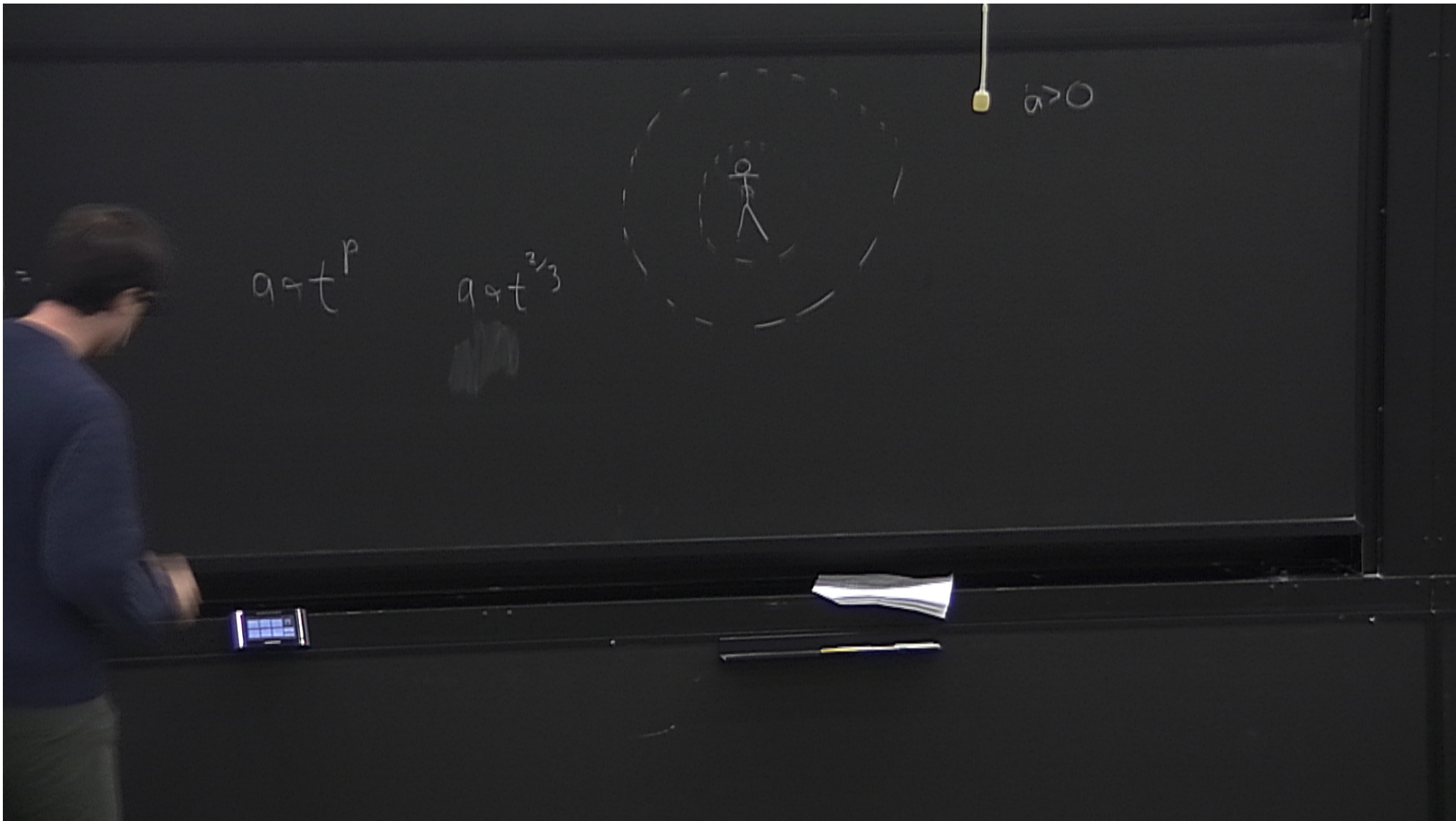
$$r_H(t) = \frac{1}{H(t)}$$

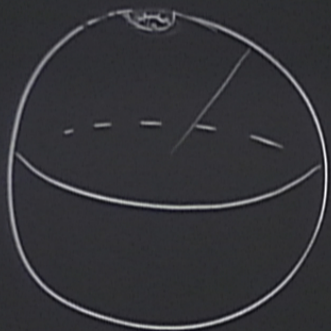
$$a \propto t^p$$

$$a \propto t^{2/3}$$







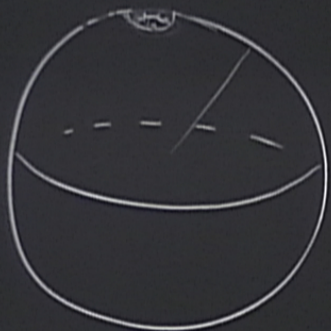


$$\frac{1}{Ha}$$

Flatness Puzzle

$$\left[\begin{aligned} H^2 &= \frac{8\pi G}{3} \rho - \frac{k}{a^2} \\ \dot{\rho} &= -3H(\rho + p) \end{aligned} \right]$$

$$1 = \frac{\rho}{\rho_{cr}} - \frac{k}{a^2}$$



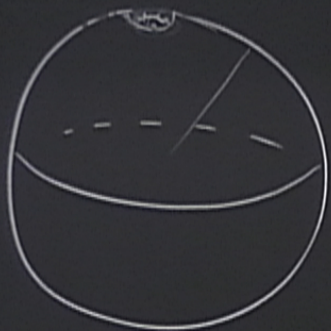
$$\frac{1}{Ha}$$

Flatness Puzzle

$$\left[\begin{aligned} H^2 &= \frac{8\pi G}{3} \rho - \frac{k}{a^2} \\ \dot{\rho} &= -3H(\rho + p) \end{aligned} \right]$$

$$1 = \frac{\dot{\rho}}{\rho H} - \frac{k}{(aH)^2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$



$$\frac{1}{Ha}$$

Flatness Puzzle

$$\left[\begin{aligned} H^2 &= \frac{8\pi G}{3} \rho - \frac{k}{a^2} \\ \dot{\rho} &= -3H(\rho + p) \end{aligned} \right]$$

$$1 = \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$p > -\frac{1}{3}\rho$$

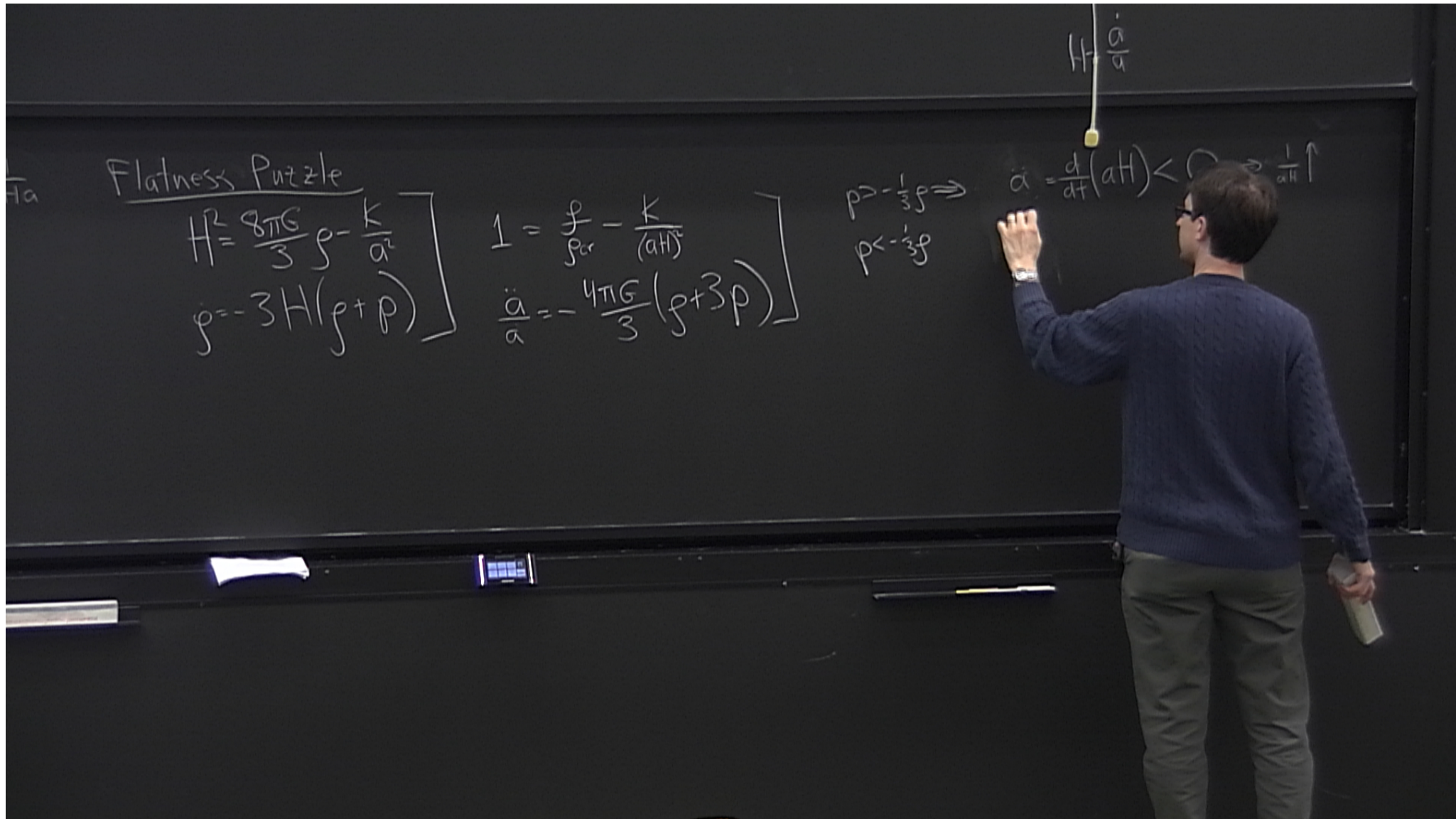
Flatness Puzzle

$$\left[\begin{aligned} H^2 &= \frac{8\pi G}{3} \rho - \frac{k}{a^2} \\ \dot{\rho} &= -3H(\rho + p) \end{aligned} \right]$$

$$\left[\begin{aligned} 1 &= \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2} \\ \frac{\ddot{a}}{a} &= -\frac{4\pi G}{3}(\rho + 3p) \end{aligned} \right]$$

$$p > -\frac{1}{3}\rho \Rightarrow \frac{d}{dt}(aH)$$

$$H \frac{\dot{a}}{a}$$



Flatness Puzzle

$$\left[\begin{aligned} H^2 &= \frac{8\pi G}{3} \rho - \frac{k}{a^2} \\ \dot{\rho} &= -3H(\rho + p) \end{aligned} \right]$$

$$\left[\begin{aligned} 1 &= \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2} \\ \frac{\ddot{a}}{a} &= -\frac{4\pi G}{3}(\rho + 3p) \end{aligned} \right]$$

$$\begin{aligned} p &> -\frac{1}{3}\rho \Rightarrow \\ p &< -\frac{1}{3}\rho \end{aligned}$$

$$\dot{q} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

$$H \frac{\dot{a}}{a}$$

Flatness Puzzle

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

$$\dot{\rho} = -3H(\rho + p)$$

$$1 = \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2}$$

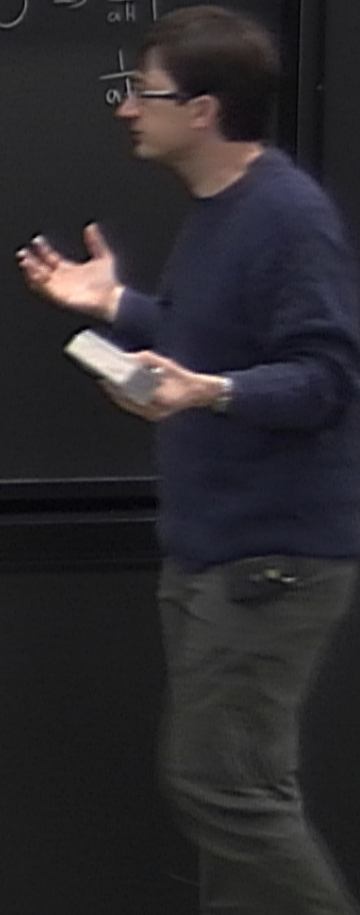
$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$p > -\frac{1}{3}\rho \Rightarrow$$

$$p < -\frac{1}{3}\rho$$

$$\dot{\alpha} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

$$\dot{\alpha} > 0$$



$$H \frac{\dot{a}}{a}$$

Flatness Puzzle

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

$$\dot{\rho} = -3H(\rho + p)$$

$$1 = \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$p > -\frac{1}{3}\rho \Rightarrow$$

$$p < -\frac{1}{3}\rho$$

$$\ddot{a} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

$$\ddot{a} > 0 \Rightarrow \frac{1}{aH} \downarrow$$

$$\frac{\rho}{\rho_{cr}} = 1 \pm 0.01$$

$$H \frac{\dot{a}}{a}$$

Flatness Puzzle

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

$$\dot{\rho} = -3H(\rho + p)$$

$$1 = \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$p > -\frac{1}{3}\rho \Rightarrow \ddot{a} < 0$$

$$p < -\frac{1}{3}\rho \Rightarrow \ddot{a} > 0$$

$$\frac{\rho}{\rho_{cr}} = 1 \pm 0.01$$

$$\ddot{a} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

t

$$H \frac{\dot{a}}{a}$$

Flatness Puzzle

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

$$\dot{\rho} = -3H(\rho + p)$$

$$1 = \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$p > -\frac{1}{3}\rho \Rightarrow$$

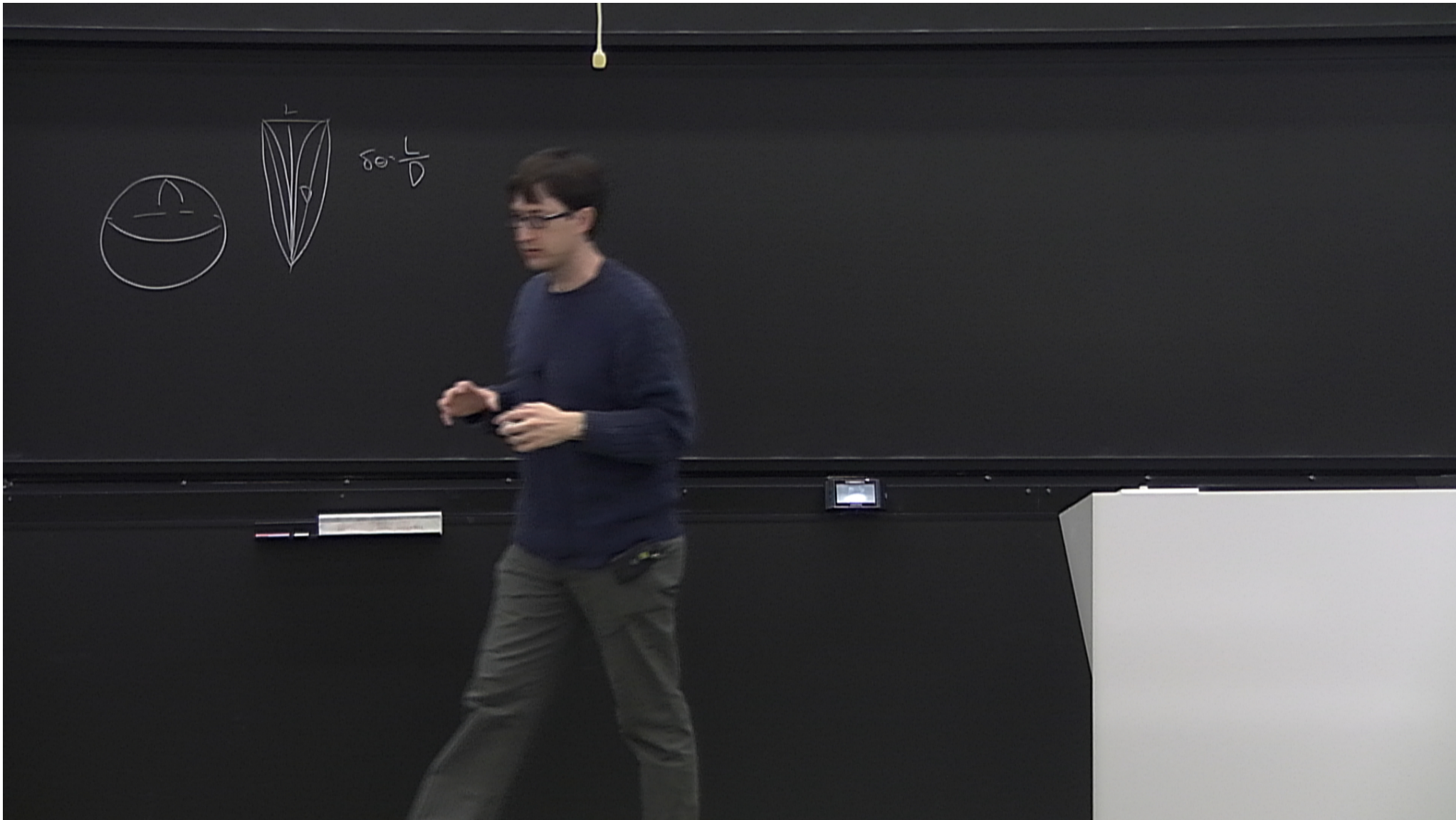
$$p < -\frac{1}{3}\rho$$

$$\dot{\alpha} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

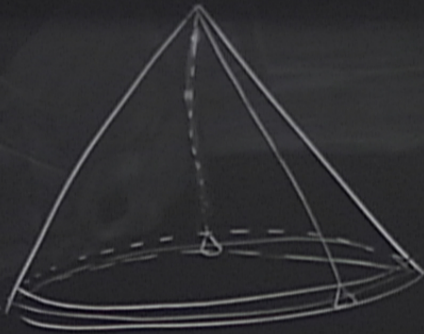
$$\dot{\alpha} > 0 \Rightarrow \frac{1}{aH} \downarrow$$

$$\frac{\rho}{\rho_{cr}} = 1 \pm 0.01$$

†



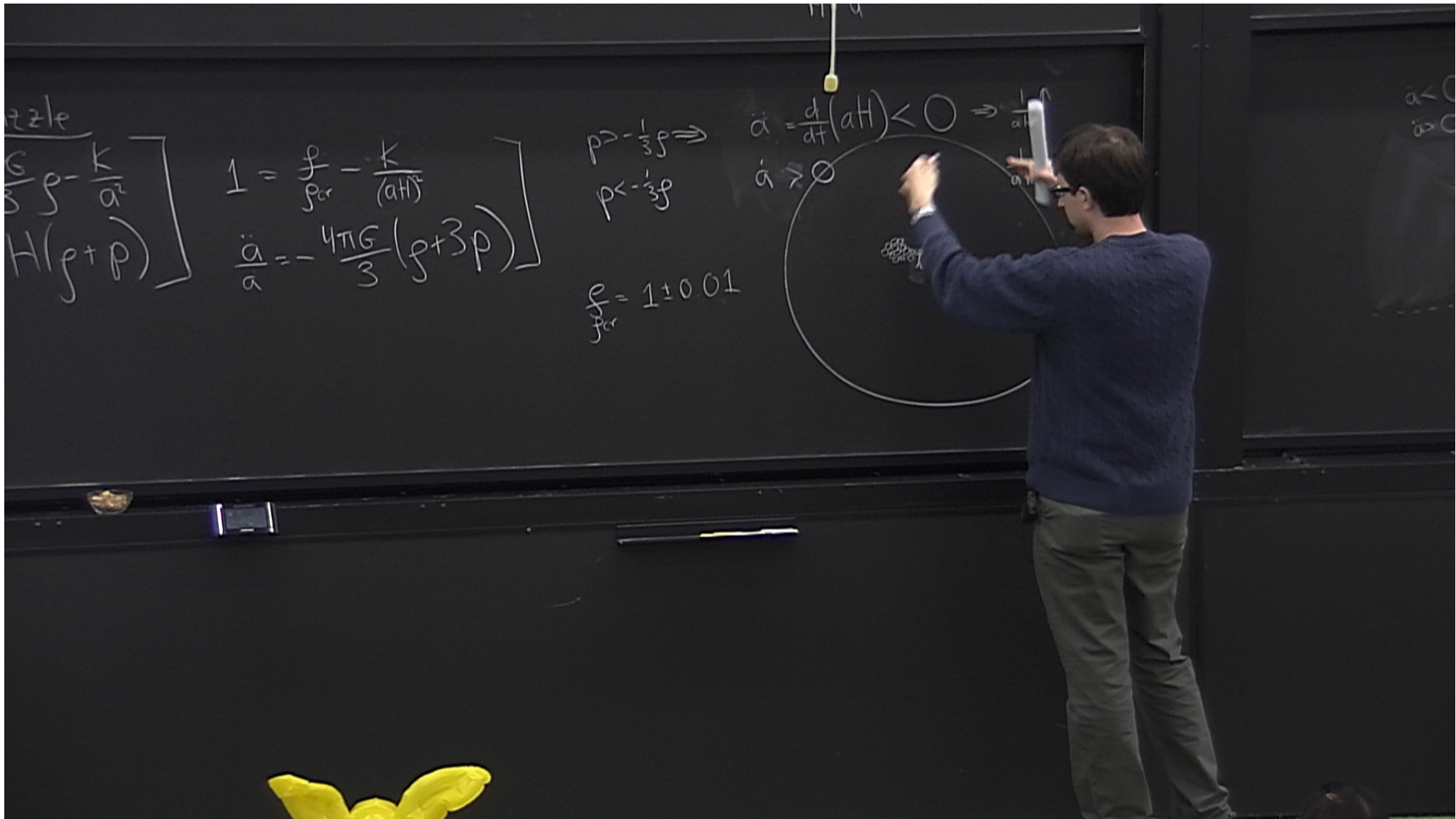
$a < 0$
 $a > 0$



Magnetic Monopole Problem

$$SU(3) \times SU(2) \times U(1) \subset SU(5), SO(10)$$

$a \rightarrow 0$ T_S



$$\left[\frac{G}{8\pi} \rho - \frac{k}{a^2} \right] H(\rho + p)$$

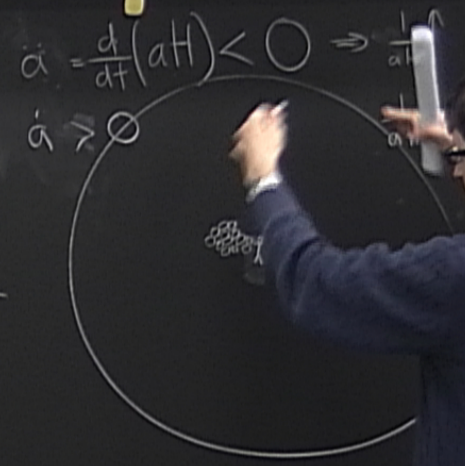
$$1 = \frac{\rho}{\rho_{\text{cr}}} - \frac{k}{(aH)^2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$\rho > -\frac{1}{3}\rho \Rightarrow$$

$$\rho < -\frac{1}{3}\rho$$

$$\frac{\rho}{\rho_{\text{cr}}} = 1 \pm 0.01$$



$$\ddot{a} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

$$\ddot{a} > 0$$

ss Puzzle

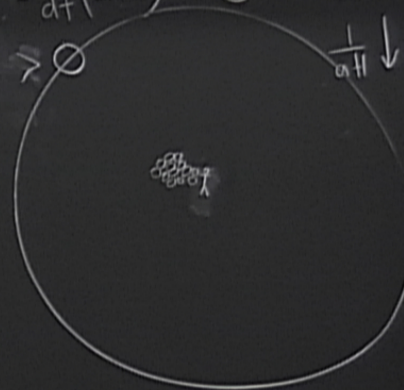
$$\left[\begin{aligned} H^2 &= \frac{8\pi G}{3} \rho - \frac{k}{a^2} \\ \dot{\rho} &= -3H(\rho + p) \end{aligned} \right]$$

$$\left[\begin{aligned} 1 &= \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2} \\ \frac{\ddot{a}}{a} &= -\frac{4\pi G}{3}(\rho + 3p) \end{aligned} \right]$$

$$\begin{aligned} p &> -\frac{1}{3}\rho \Rightarrow \\ p &< -\frac{1}{3}\rho \end{aligned}$$

$$\frac{\rho}{\rho_{cr}} = 1 \pm 0.01$$

$$\begin{aligned} \dot{a} &= \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow \\ \dot{a} &> 0 \Rightarrow \frac{1}{aH} \downarrow \end{aligned}$$



ss Puzzle

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

$$\rho = -3H(\rho + p)$$

$$1 = \frac{\rho}{\rho_{cr}} - \frac{k}{(aH)^2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

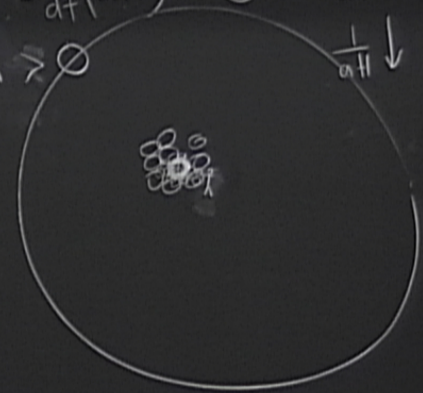
$$p > -\frac{1}{3}\rho \Rightarrow$$

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$$\frac{\rho}{\rho_{cr}} = 1 \pm 0.01$$

$$\dot{a} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

$$\dot{a} > 0 \Rightarrow \frac{1}{aH} \downarrow$$



ss Puzzle

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

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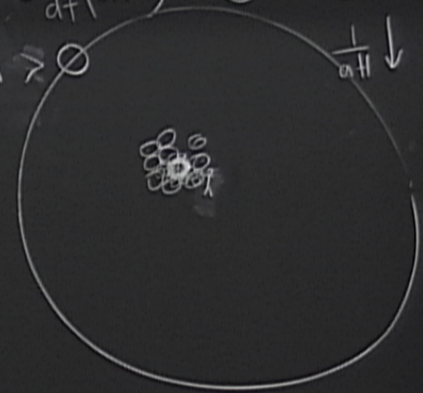
$$p > -\frac{1}{3}\rho \Rightarrow$$

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$$\dot{a} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

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ss Puzzle

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

$$\rho = -3H(\rho + p)$$

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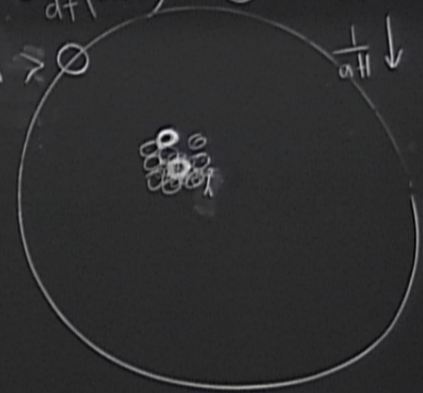
$$p > -\frac{1}{3}\rho \Rightarrow$$

$$p < -\frac{1}{3}\rho$$

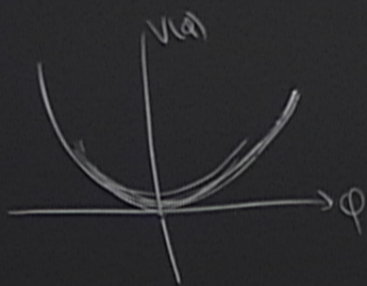
$$\frac{\rho}{\rho_{cr}} = 1 \pm 0.01$$

$$\dot{a} = \frac{d}{dt}(aH) < 0 \Rightarrow \frac{1}{aH} \uparrow$$

$$\dot{a} > 0 \Rightarrow \frac{1}{aH} \downarrow$$



$$S = \int \sqrt{g} d^4x \left\{ \mathcal{L} - \frac{1}{2}(\partial\phi)^2 - V(\phi) \right\}$$

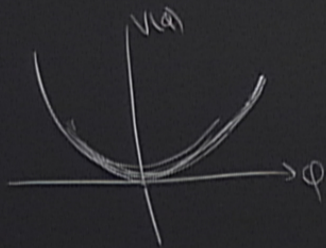


$$V(\phi) = \frac{1}{2} m_\phi^2 \phi^2$$

$$T_{\mu\nu} \rightarrow \begin{aligned} \rho &= \frac{1}{2} \dot{\phi}^2 + V(\phi) \\ p &= \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{aligned}$$

$$\dot{\rho} = -3H(\rho + p) \Rightarrow \ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

$$S = \int \sqrt{g} d^4x \left\{ \mathcal{L} - \frac{1}{2}(\partial\phi)^2 - V(\phi) \right\}$$



$$V(\phi) = \frac{1}{2} m_\phi^2 \phi^2$$

$$T_{\mu\nu} \rightarrow \begin{aligned} p &= \frac{1}{2} \dot{\phi}^2 + V(\phi) \\ p &= \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{aligned}$$

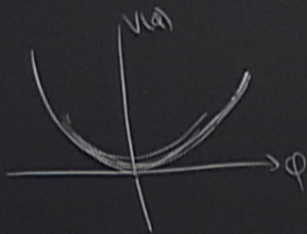
$$\dot{\phi} = -3H(p+p) \Rightarrow \ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$



$$H^2 = \rho$$

$$\phi = C + C \frac{1}{a^3}$$

$$S = \int \sqrt{g} d^4x \left\{ \mathcal{L} - \frac{1}{2}(\partial\phi)^2 - V(\phi) \right\}$$



$$V(\phi) = \frac{1}{2} m_\phi^2 \phi^2$$

$$T_{\mu\nu} \rightarrow \begin{aligned} p &= \frac{1}{2} \dot{\phi}^2 + V(\phi) \\ p &= \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{aligned}$$

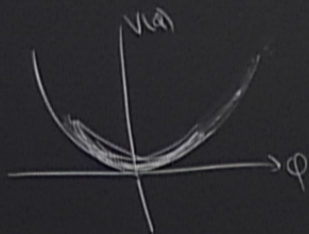
$$\dot{\phi} = -3H(p+p) \Rightarrow \ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$



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

$$\dot{\phi} = -\frac{m^2 \phi}{3H}$$

$$S = \int \sqrt{g} d^4x \left\{ \mathcal{L} - \frac{1}{2}(\partial\phi)^2 - V(\phi) \right\}$$



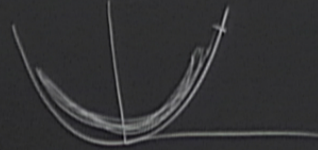
$$V(\phi) = \frac{1}{2} m_\phi^2 \phi^2$$

$$T_{\mu\nu} \rightarrow \begin{aligned} p &= \frac{1}{2} \dot{\phi}^2 + V(\phi) \\ p &= \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{aligned}$$

$$p \approx -p \quad w = -\frac{1}{3}$$

$$p = (0)p$$

$$\dot{p} = -3H(p+p) \Rightarrow \ddot{\phi} + 3H\dot{\phi} + \frac{V'(\phi)}{m^2} \phi = 0$$



$$H^2 = p \quad \boxed{\dot{\phi} \approx -\frac{m^2 \phi}{3H}}$$

$$\phi = C + C \frac{1}{a^3}$$

$$\boxed{\phi \propto \frac{1}{a^2} \cos(mt)}$$

$$\phi = w = 0$$