Title: Reconstructing the evolution of dark energy with the variaton of fundamental parameters

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Abstract:

Reconstructing the evolution of dark energy with the variation of fundamental parameters

Nelson Nunes
DAMTP, University of Cambridge

Avelino, Martins, Nunes, Olive, PRD (2006)
Nunes and Lidsey, PRD (2004)

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1. Coupling quintessence to electromagnetism

1. The action

$$S = -\frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\,R + \int d^4x\sqrt{-g}\,(\mathcal{L}_\phi + \mathcal{L}_M + \mathcal{L}_{\phi F})$$

2. The coupling

$$\mathcal{L}_{\phi F} = -\frac{1}{4}B_F(\phi)F_{\mu\nu}F^{\mu\nu}$$

3. Gauge kinetic function

$$B_F(\phi) = 1 - \zeta\kappa(\phi - \phi_0)$$

4. Variation in α

$$\alpha = \frac{\alpha_0}{B_F(\phi)} \qquad \Rightarrow \qquad \frac{\Delta\alpha}{\alpha} \equiv \frac{\alpha - \alpha_0}{\alpha_0} = \zeta\kappa(\phi - \phi_0)$$

2. Proton to electron mass ratio, $\mu \equiv m_p/m_e$

From theories of gauge unification we expect $\frac{\Delta\mu}{\mu} = R\frac{\Delta\alpha}{\alpha}$ e.g.

$$\frac{\Delta\mu}{\mu} = [0.8A - 0.3(S+1)]\frac{\Delta\alpha}{\alpha}$$

(Coc et al. 2007) where

$$\frac{\Delta\Lambda}{\Lambda} = A\frac{\Delta\alpha}{\alpha} + \frac{6}{27}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right), \qquad \frac{\Delta v}{v} = S\frac{\Delta h}{h}$$

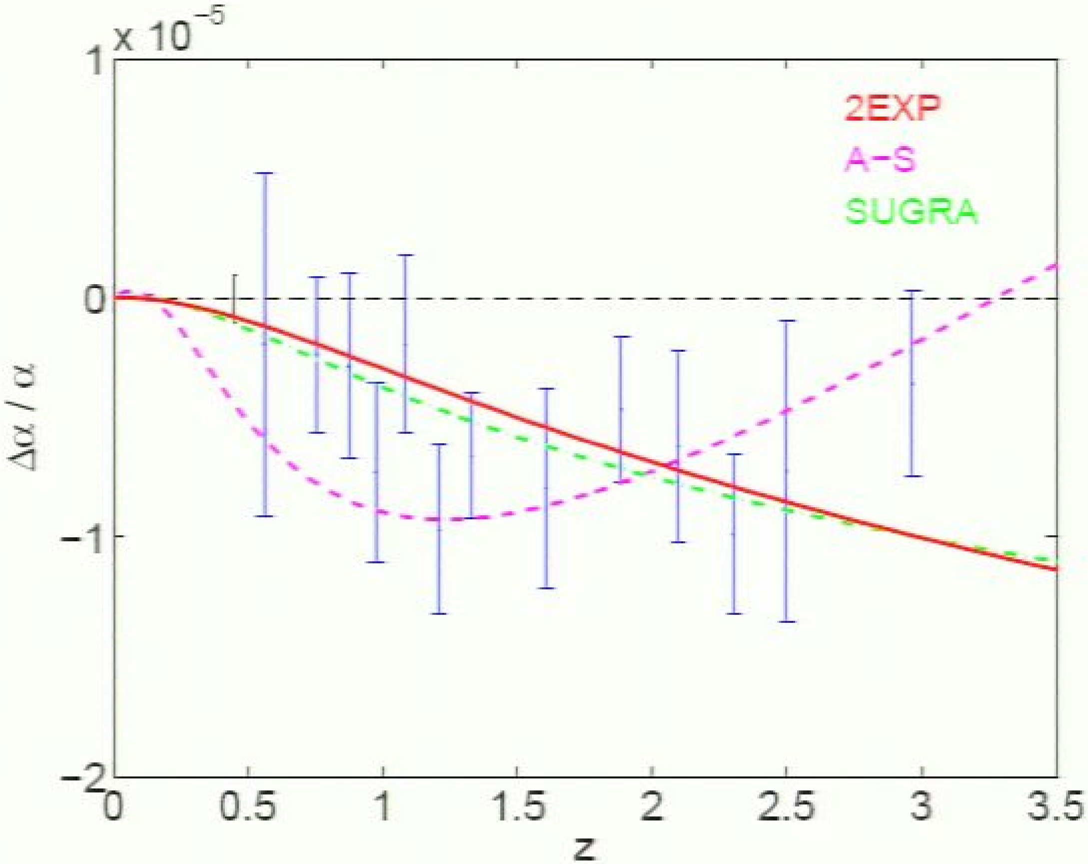
Under simple assumptions $A \approx 36$ and $S \approx 160$, and for a dilaton model with $\Delta\alpha/\alpha = 2\Delta h/h$, then

$$\frac{\Delta\mu}{\mu} \approx -19.5\frac{\Delta\alpha}{\alpha}$$

Observationally, using $\Delta\alpha/\alpha \approx -0.5\times 10^{-5}$ and $\Delta\mu/\mu \approx 3\times 10^{-5}$ at $z = 3$ we estimate

$$\frac{\Delta\mu}{\mu} \approx -6\frac{\Delta\alpha}{\alpha}$$

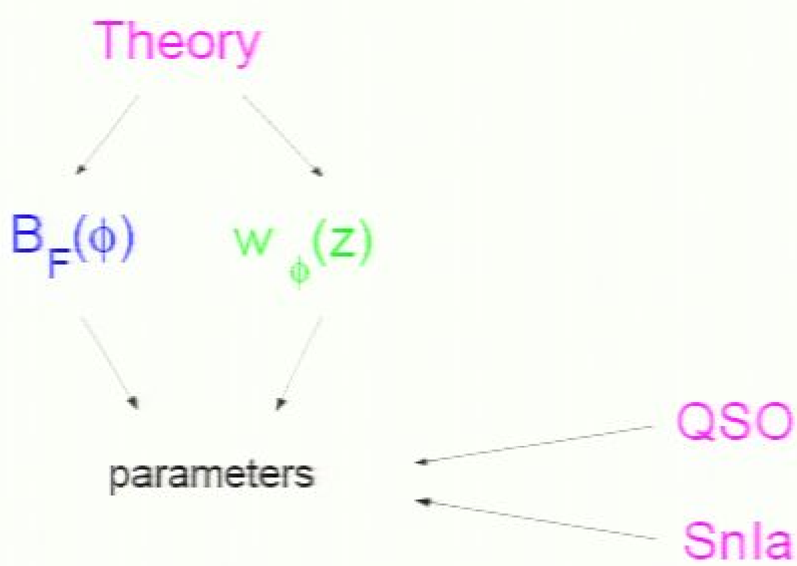
3. $\Delta\alpha/\alpha$ for some quintessence models

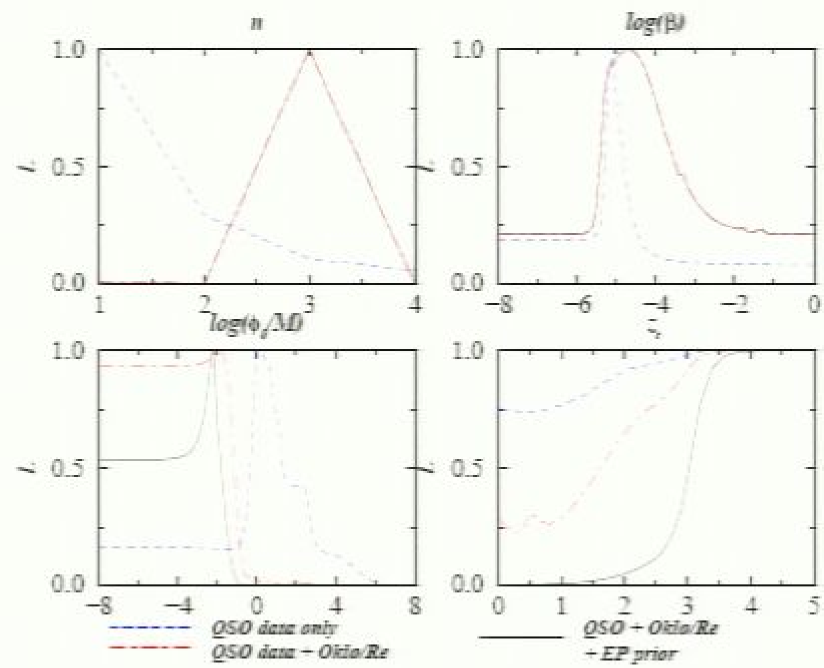


Anchordoqui, Goldberg (2003)
Copeland, NJN, Pospelov (2003)

4. Fitting the equation of state with variation of α

Parkinson, Bassett, Barrow (2003):



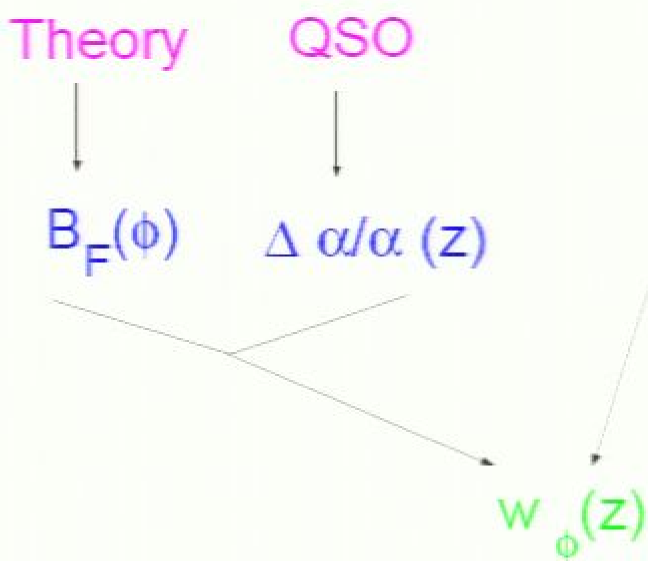


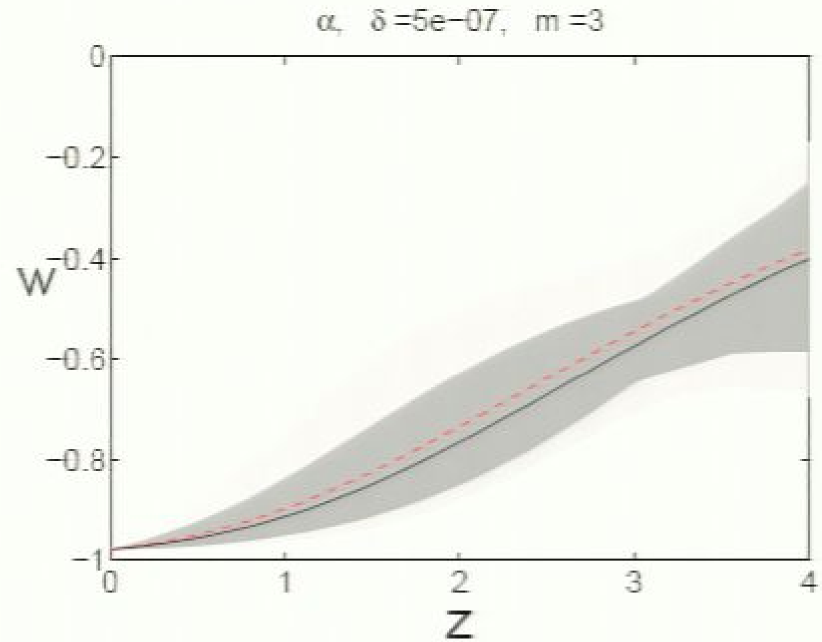
$$B_F(\phi) = \left[1 + \beta_n \left(\frac{\phi_0}{M}\right)^n \left(\frac{\phi}{\phi_0}\right)^n\right] \left[1 + \beta_n \left(\frac{\phi_0}{M}\right)^n\right]^{-1}$$

$$w(z) = \frac{w_0}{1 + e^{(z - z_t)/\Delta}}$$

5. Reconstructing the equation of state with variation of α

In this talk:





$$B_F(\phi) = 1 - \zeta\kappa(\phi - \phi_0)$$

$$w(z) = ???$$

6. Basic equations

1. Energy densities

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi)$$

$$\rho_M = \frac{\Omega_{M0}\rho_0}{a^3}$$

2. Equations of motion

$$\dot{H} = -\frac{\kappa^2}{2}(\rho_M + \dot{\phi}^2)$$

$$\dot{\rho}_\phi = -3H\dot{\phi}^2$$

3. Equation of state

$$w_\phi = -1 + \frac{\dot{\phi}^2}{\rho_\phi} = 1 - \frac{2V}{\rho_\phi}$$

4. Rewrite as:

$$\sigma' = -(\kappa\phi')^2(\sigma + a^{-3})$$

where

$$\sigma = \frac{\rho_\phi}{\rho_0\Omega_{M0}}, \qquad ' = \frac{d}{d\ln a}$$

and

$$w = -1 + \frac{(\kappa\phi')^2}{3}\left(1 + \frac{1}{\sigma a^3}\right)$$

$$w' = 2(1+w)\frac{\phi''}{\phi'} + w\left[3(1+w) - (\kappa\phi')^2\right.$$

$$w'' = \ldots$$

7. Reconstruction procedure

STEP 1: Obtaining the data sets

1. From observations or,
2. Simulations

– Simulate observational data by generating data points based on numerical evolution of the quintessence field ϕ for specific potential $V(\phi)$;

– Consider normal distribution with mean $\Delta\alpha/\alpha = \zeta\kappa(\phi - \phi_0)$;

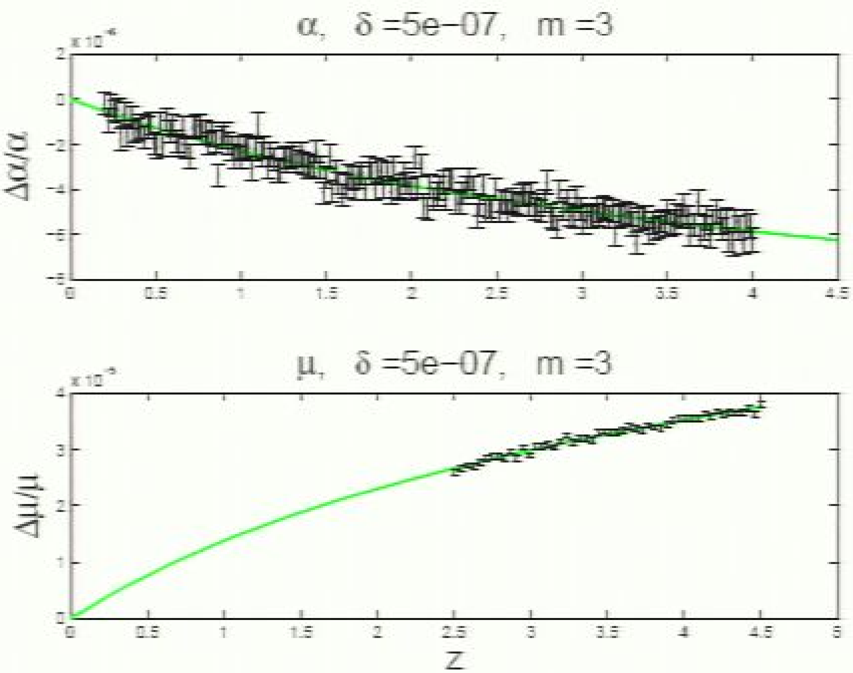
– Choose ζ and R such that

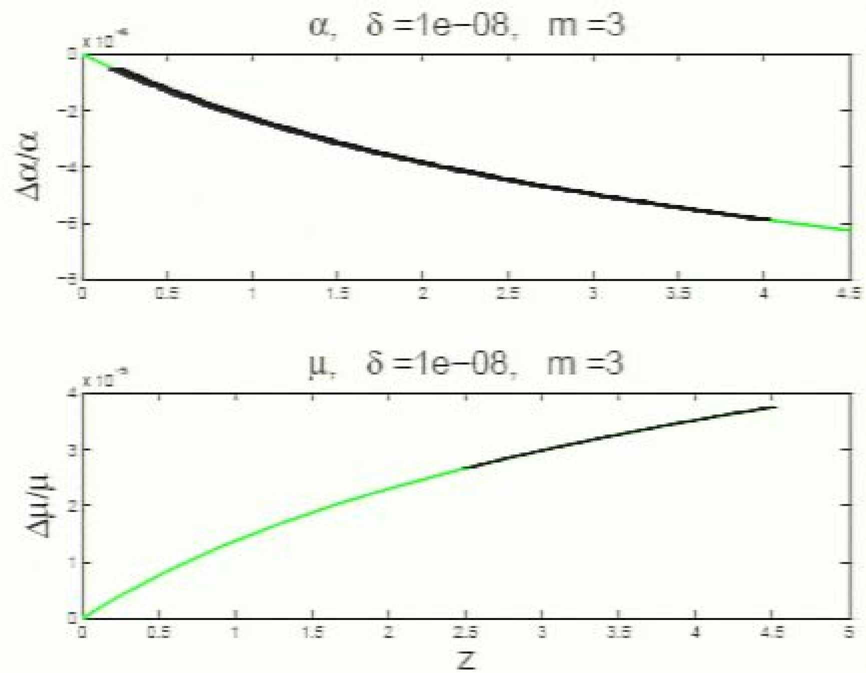
$$\left(\frac{\Delta\alpha}{\alpha}\right)_{z=3} = -0.5\times10^{-5}, \quad \left(\frac{\Delta\mu}{\mu}\right)_{z=3} = 3\times10^{-5} \quad \Rightarrow R = -6$$

8. Reconstruction procedure (*cont.*)

ESPRESSO
spectrograph for VLT:
200 objects in α
50 objects in μ

CODEX
spectrograph for ELT:
500 objects in α
100 objects in μ





9. Reconstruction procedure (*cont.*)

STEP 2: Fitting the data

$$g(N) \equiv \frac{\Delta\alpha}{\alpha} = g_1 N + g_2 N^2 + ... + g_m N^m$$

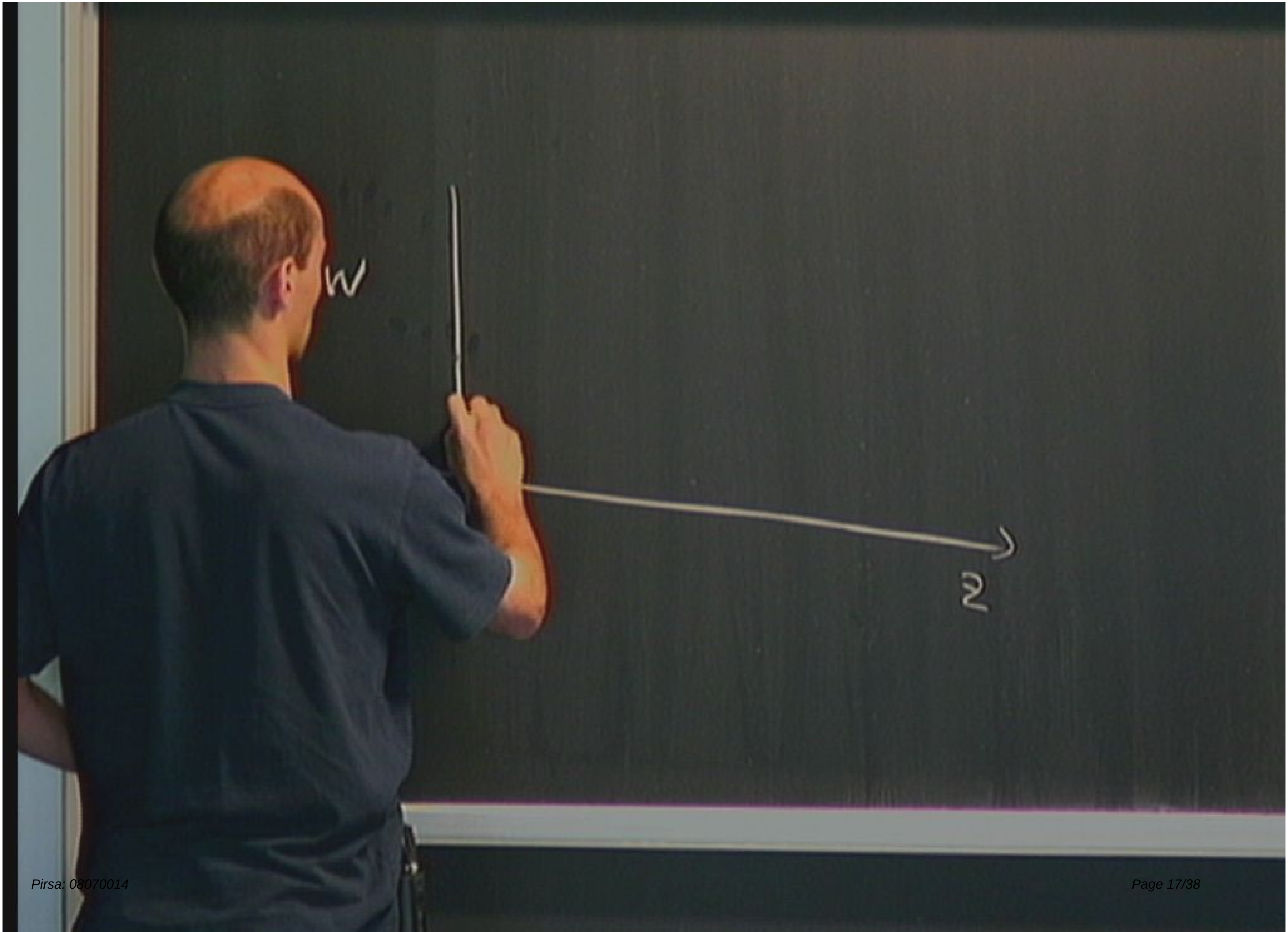
where $N = -\ln(1+z)$. But

$$\frac{\Delta\alpha}{\alpha} = \zeta\kappa(\phi - \phi_0) \quad \Rightarrow \quad \kappa\phi' = \frac{g'}{\zeta}$$

and we can now solve for σ

$$\sigma' = -\left(\frac{g'}{\zeta}\right)^2 (\sigma + a^{-3})$$

$$w = -1 + \frac{1}{3}\left(\frac{g'}{\zeta}\right)^2 \left(1 + \frac{1}{\sigma a^3}\right)$$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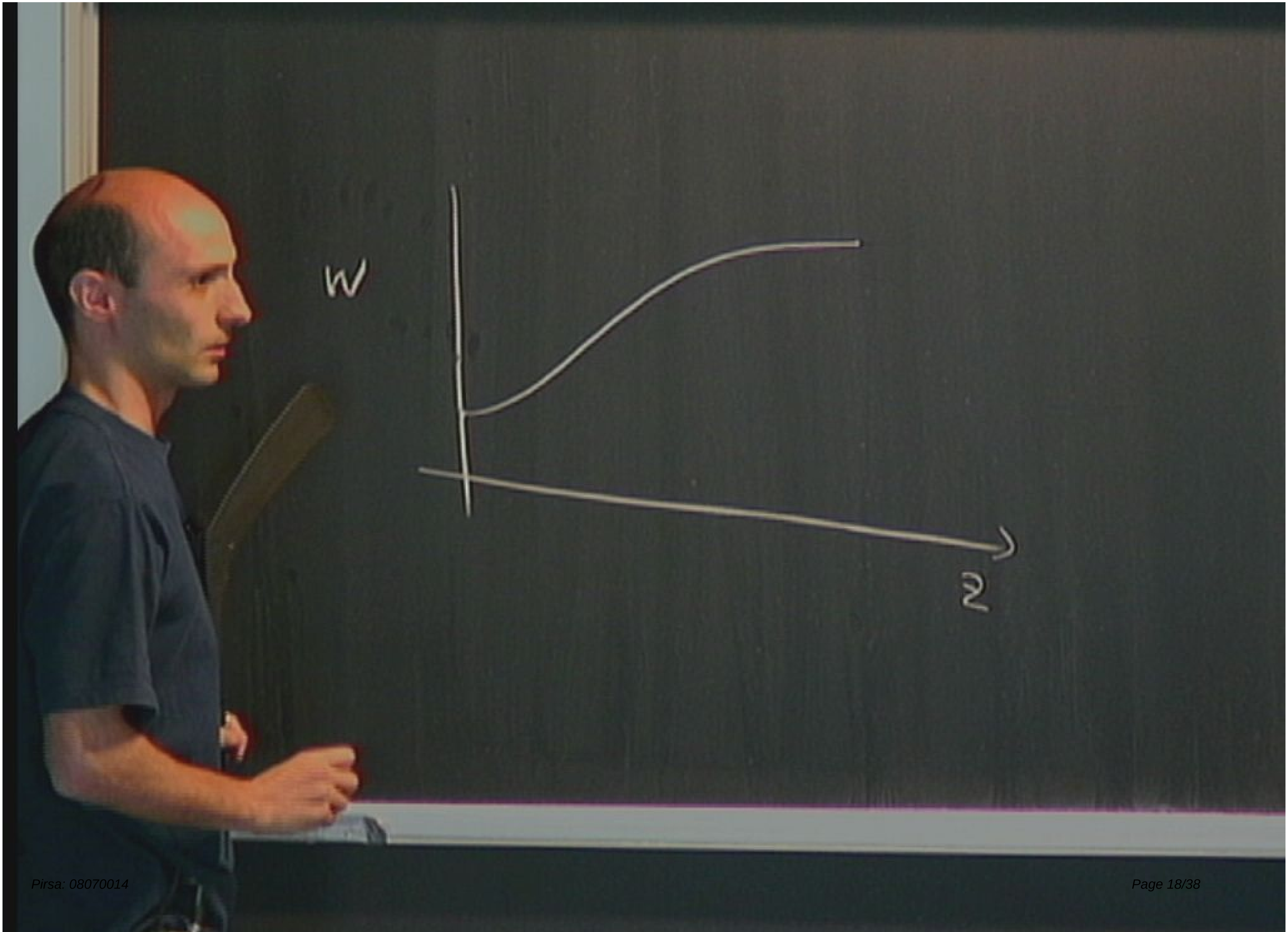
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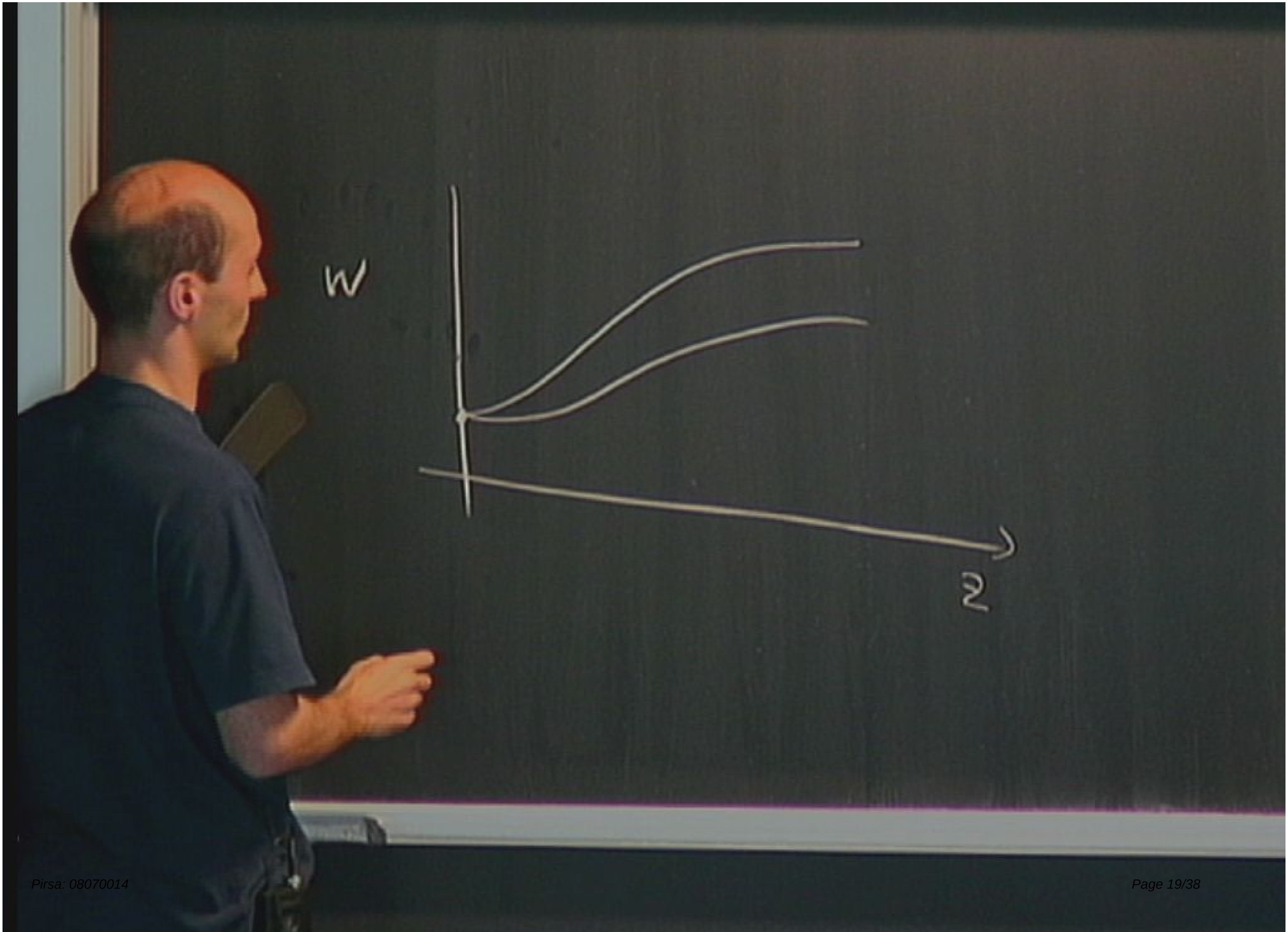
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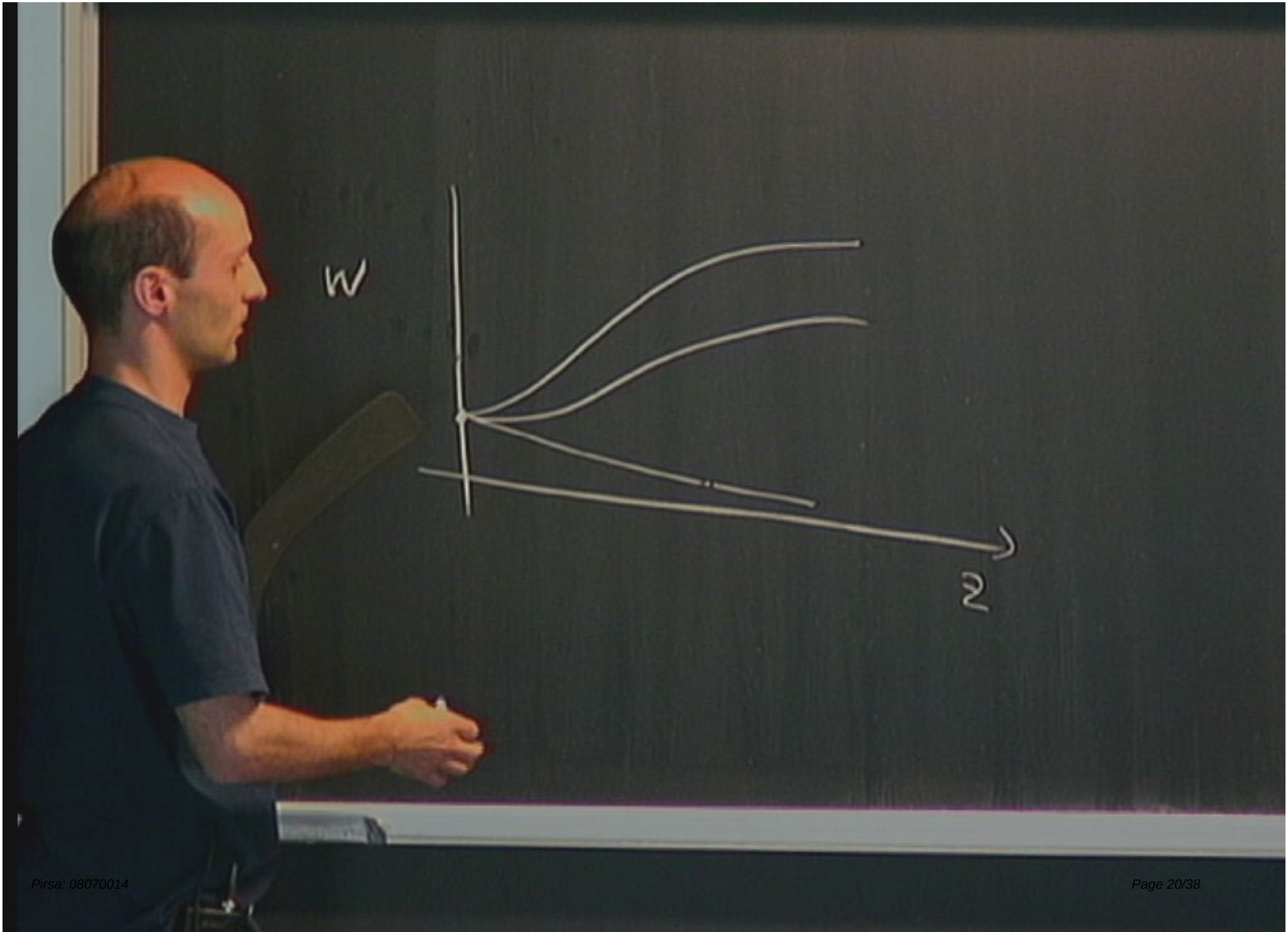
w
z

10. Reconstruction procedure (*cont.*)

STEP 3: Estimating ζ

Need to normalize the equation of state parameter at some value of redshift.

$$w = -1 + \frac{(\kappa\phi')^2}{3\Omega_\phi} \qquad \Rightarrow \qquad \zeta^2 = \frac{1}{3}\frac{g_1^2}{\Omega_{\phi 0}(1+w_0)}$$

Typical values:

$\Omega_{\phi_0} \approx 0.7; \quad w_0 \sim [-0.99, -0.6]; \quad g_1 \sim 10^{-5} \quad \Rightarrow$

$$\zeta \sim 10^{-7} - 10^{-4}$$

Equivalence principle tests $\Rightarrow$ $|\zeta| < 10^{-3}$ (Olive and Pospelov, 2002)

10. Reconstruction procedure (*cont.*)

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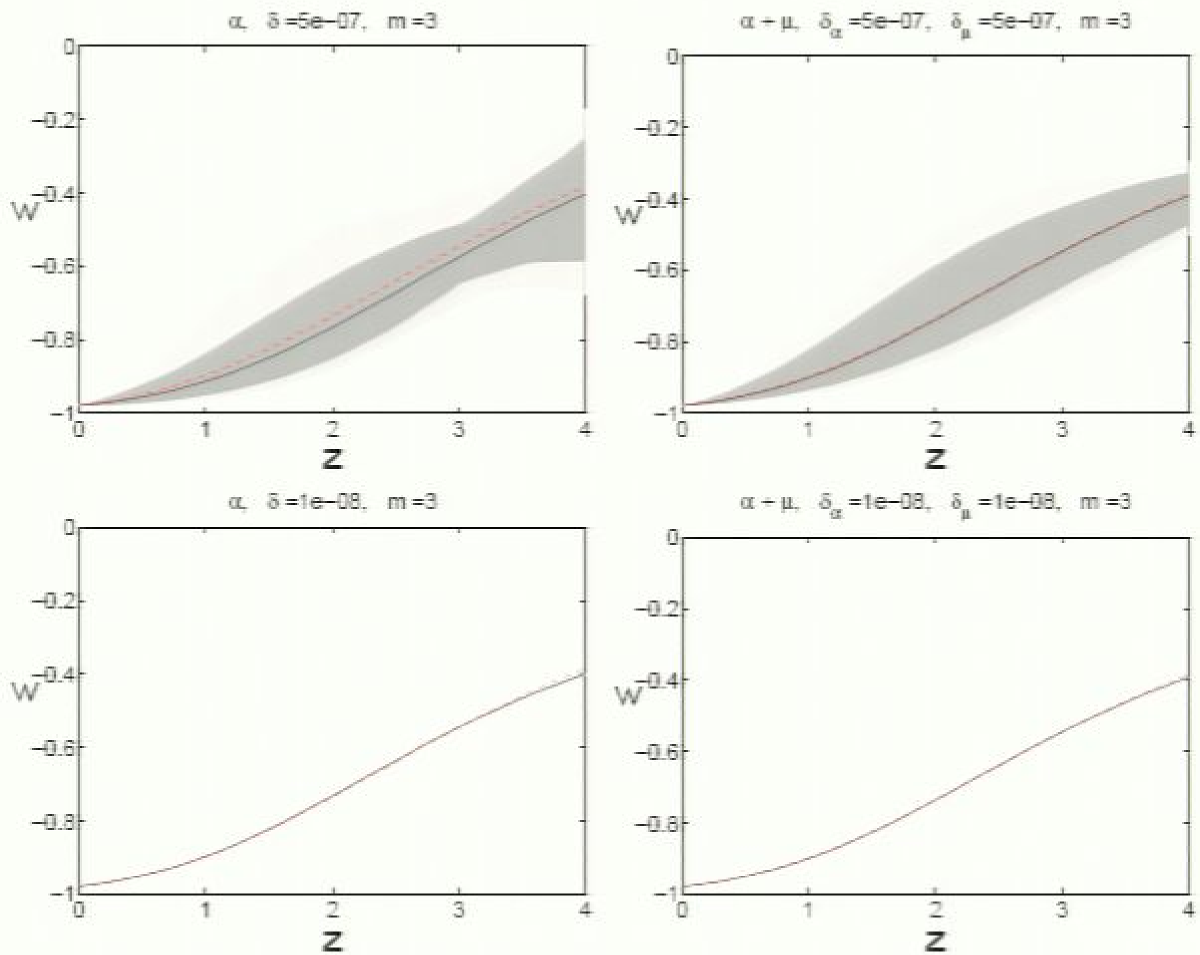
11. Reconstruction examples



$$V(\phi) = V_0(e^{10\kappa\phi} + e^{0.1\kappa\phi})$$

10. Reconstruction procedure (*cont.*)

STEP 3: Estimating ζ

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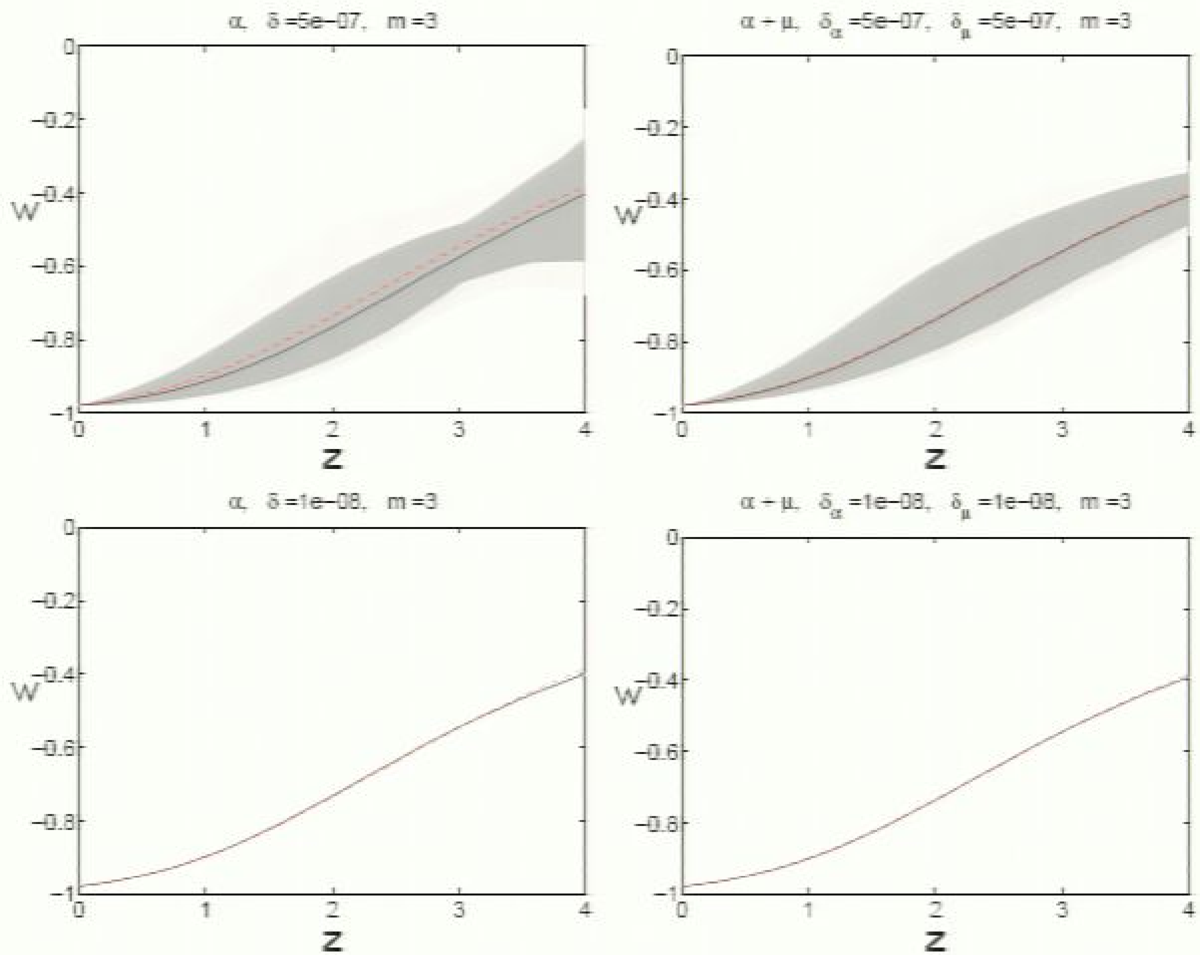
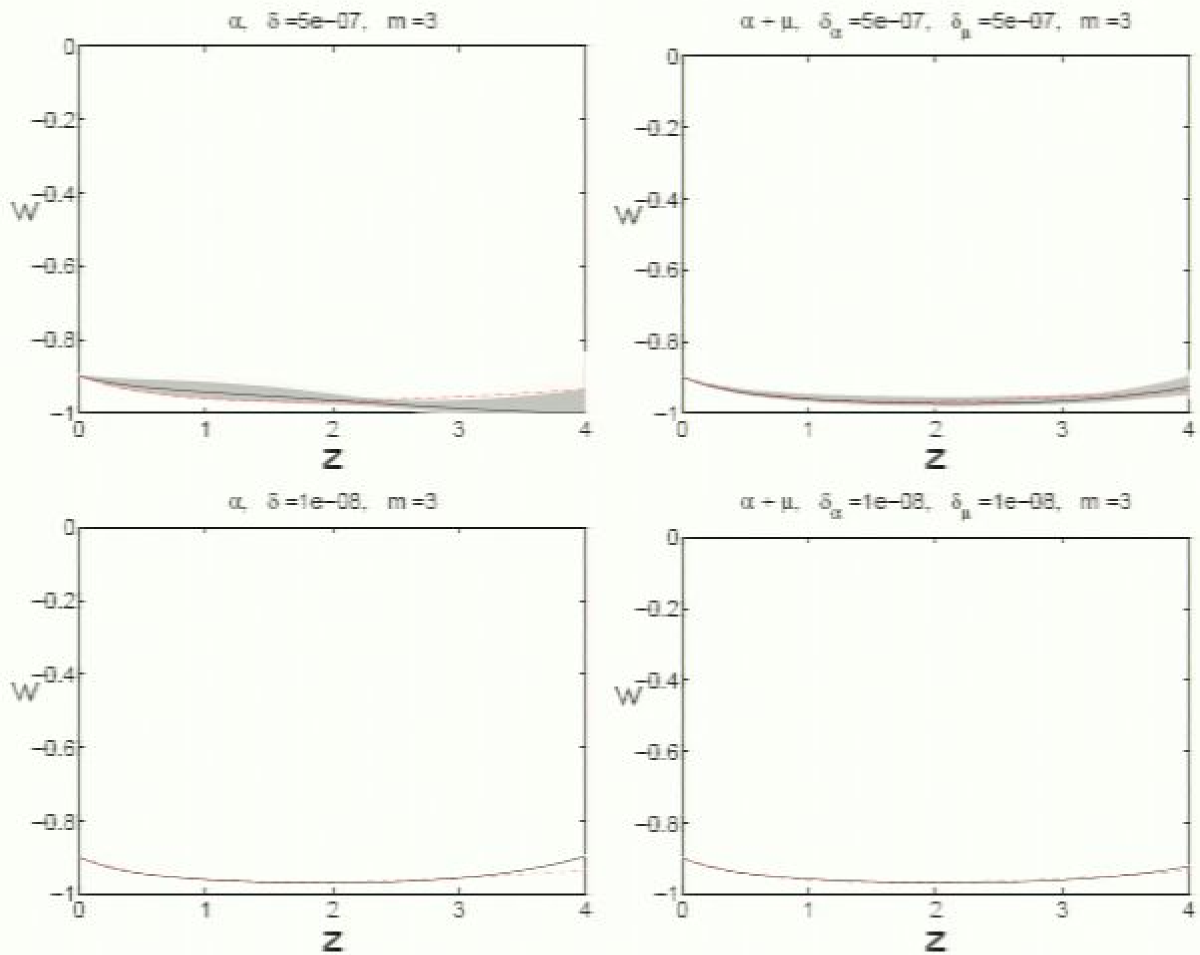


$$V(\phi) = V_0(e^{10\kappa\phi} + e^{0.1\kappa\phi})$$

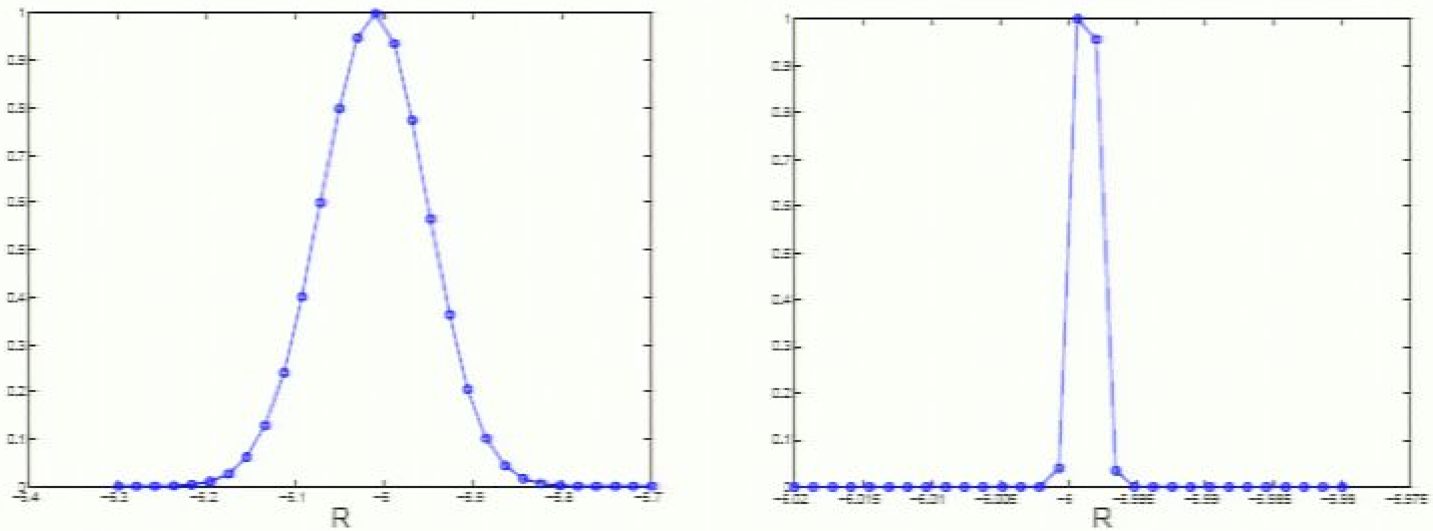
12. Reconstruction examples (*cont.*)



$$V(\phi) = V_0(e^{50\kappa\phi} + e^{0.8\kappa\phi})$$

13. Fitting R

$$\frac{\Delta\mu}{\mu} = R\,\frac{\Delta\alpha}{\alpha}$$

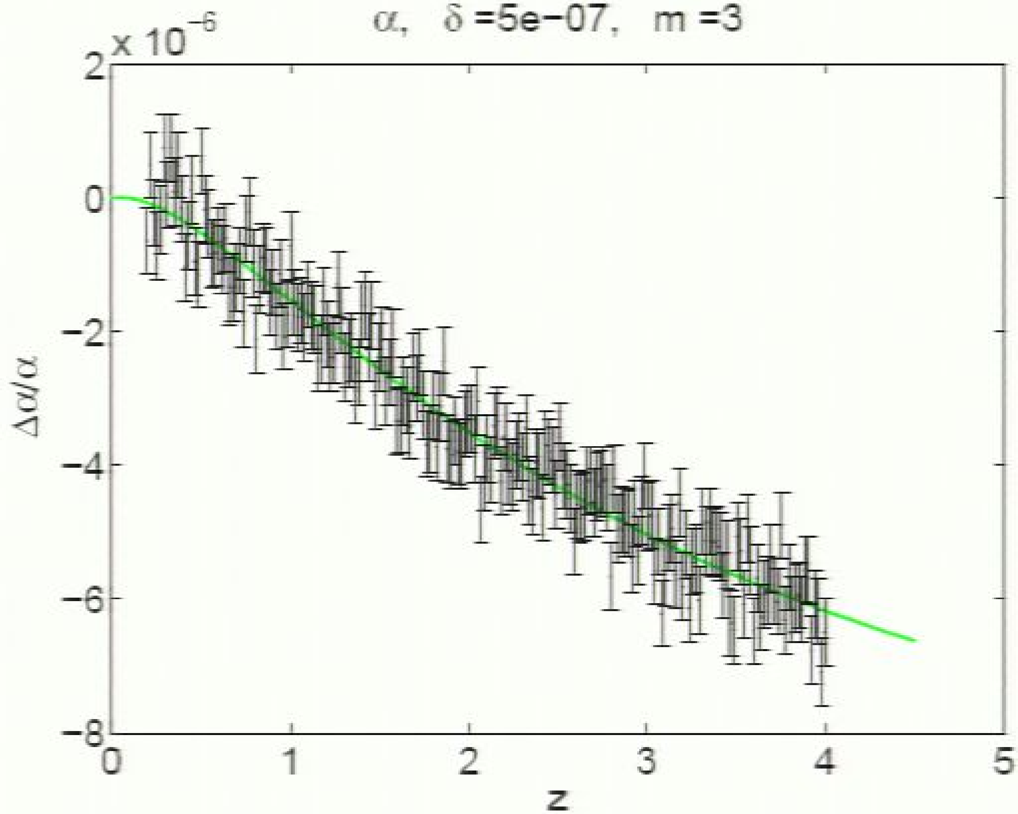


$$V(\phi) = V_0(e^{10\kappa\phi} + e^{0.1\kappa\phi})$$

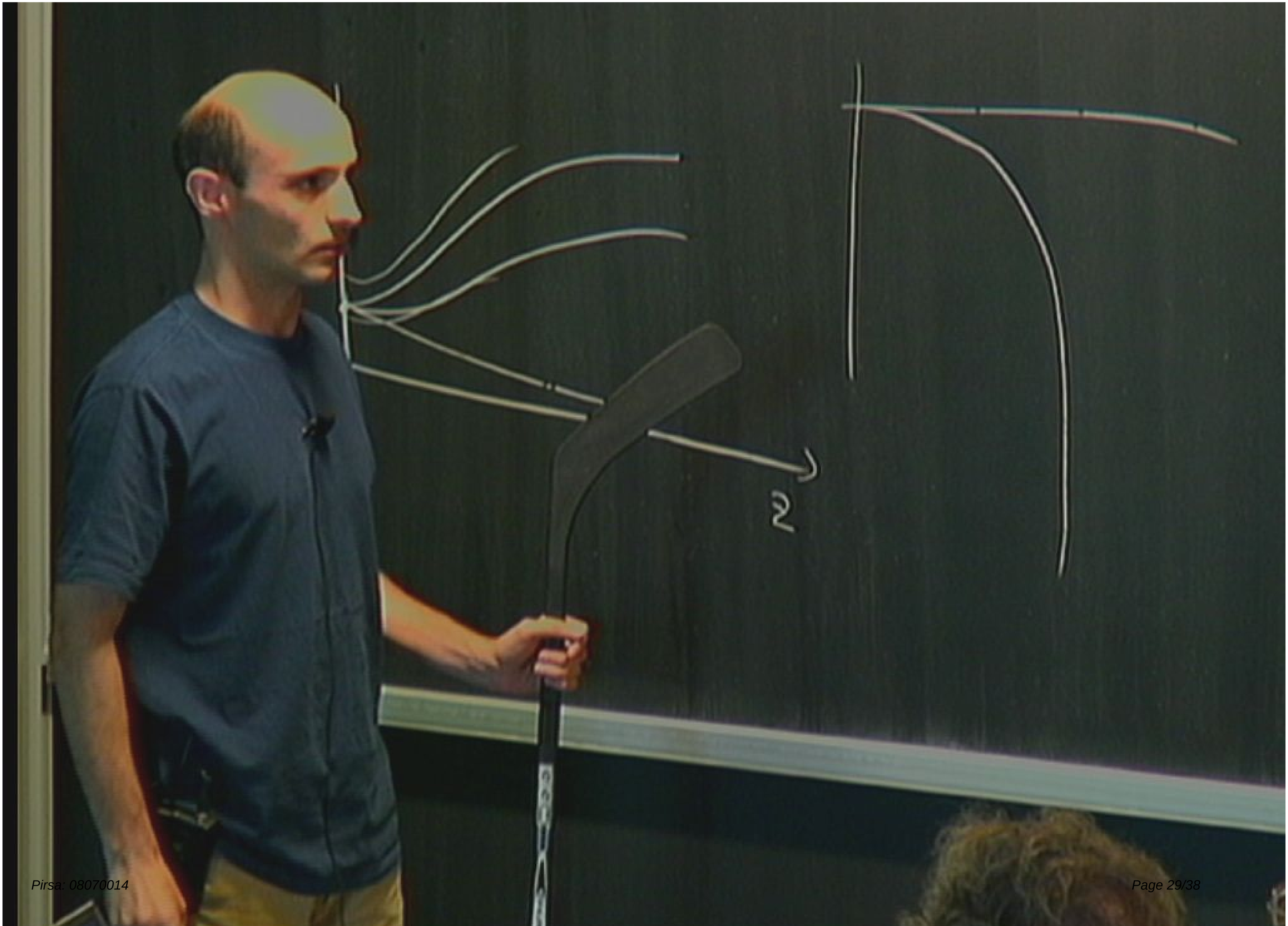
14. Reconstruction with oscillatory field

$\dot{\alpha}/\alpha = (-1.6 \pm 2.3) \times 10^{-17} \mathrm{yr}^{-1}$ (Rosenband 2008)

Are models of monotonically varying field and linear $B_F(\phi)$ ruled out?



$$V(\phi) = V_0(e^{10\kappa\phi} + e^{-0.5\kappa\phi})$$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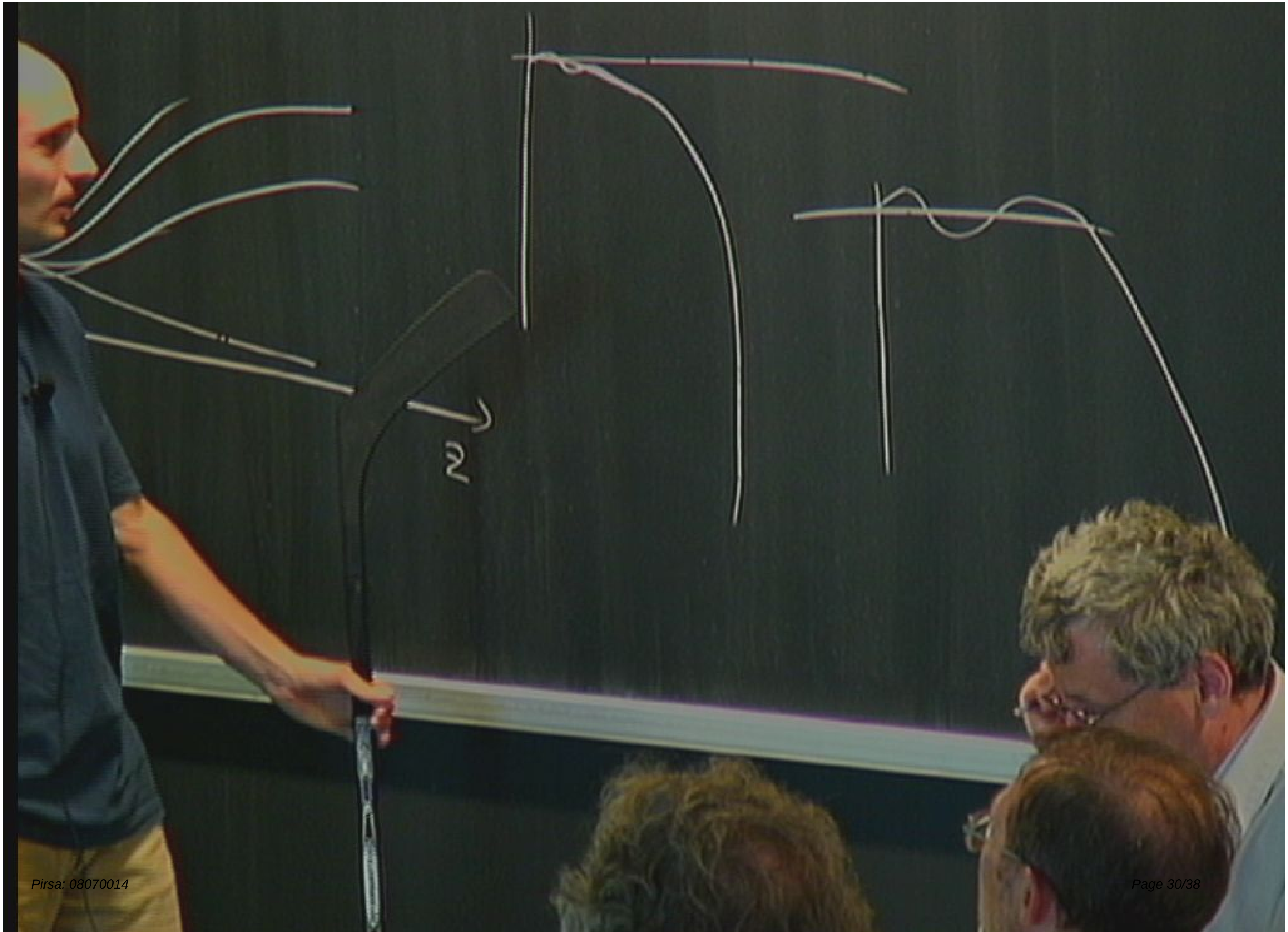

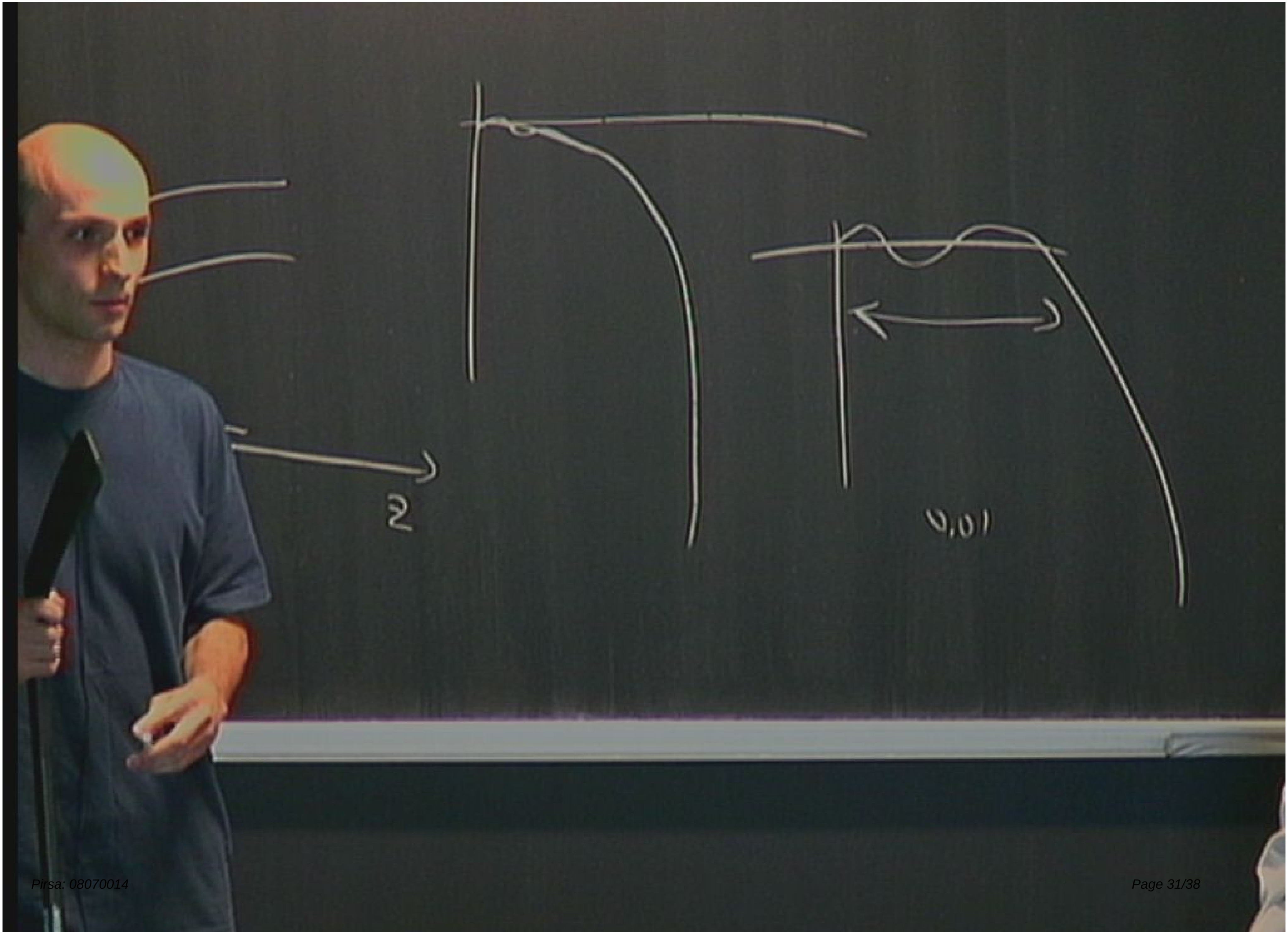
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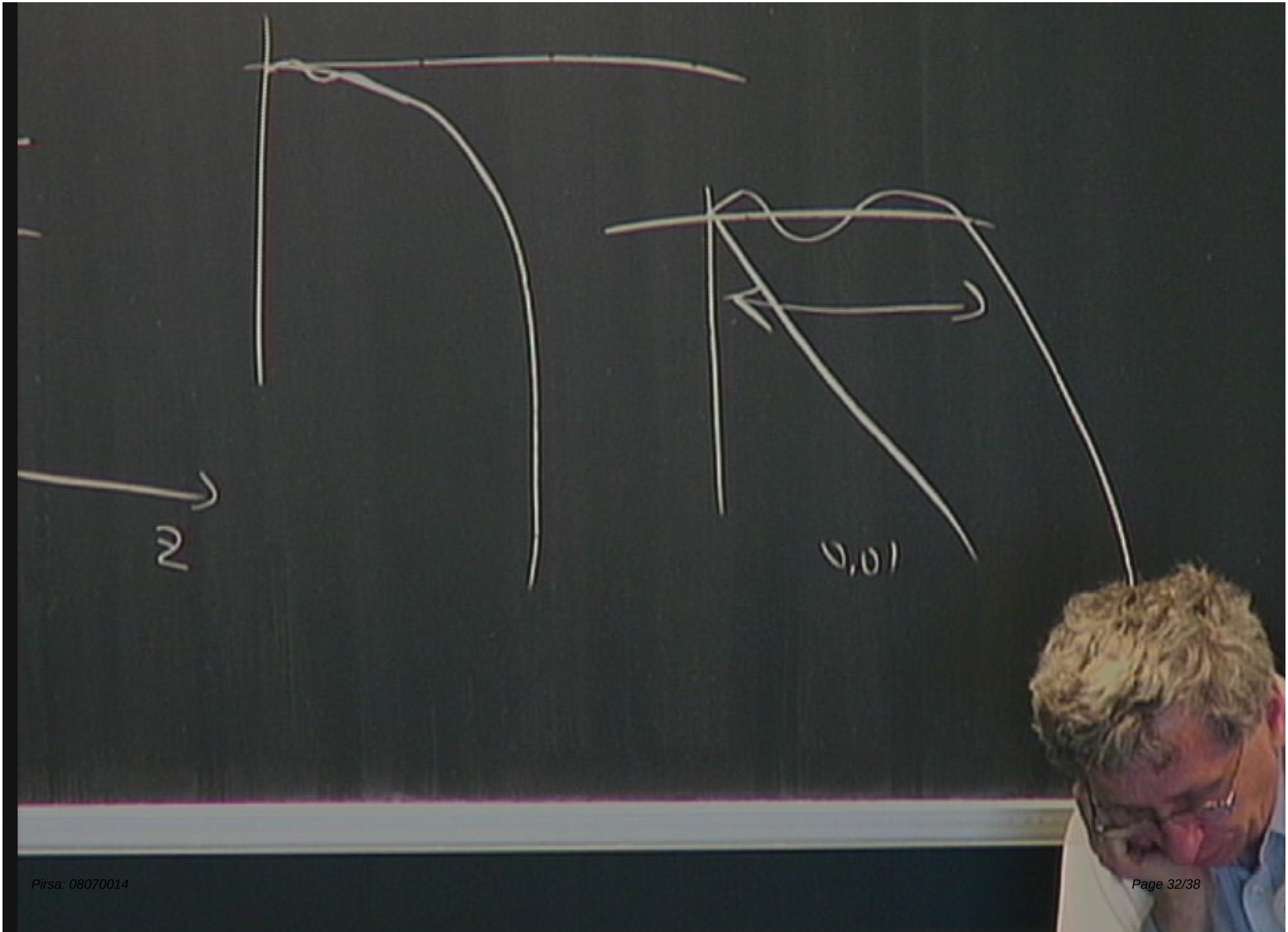
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14. Reconstruction with oscillatory field

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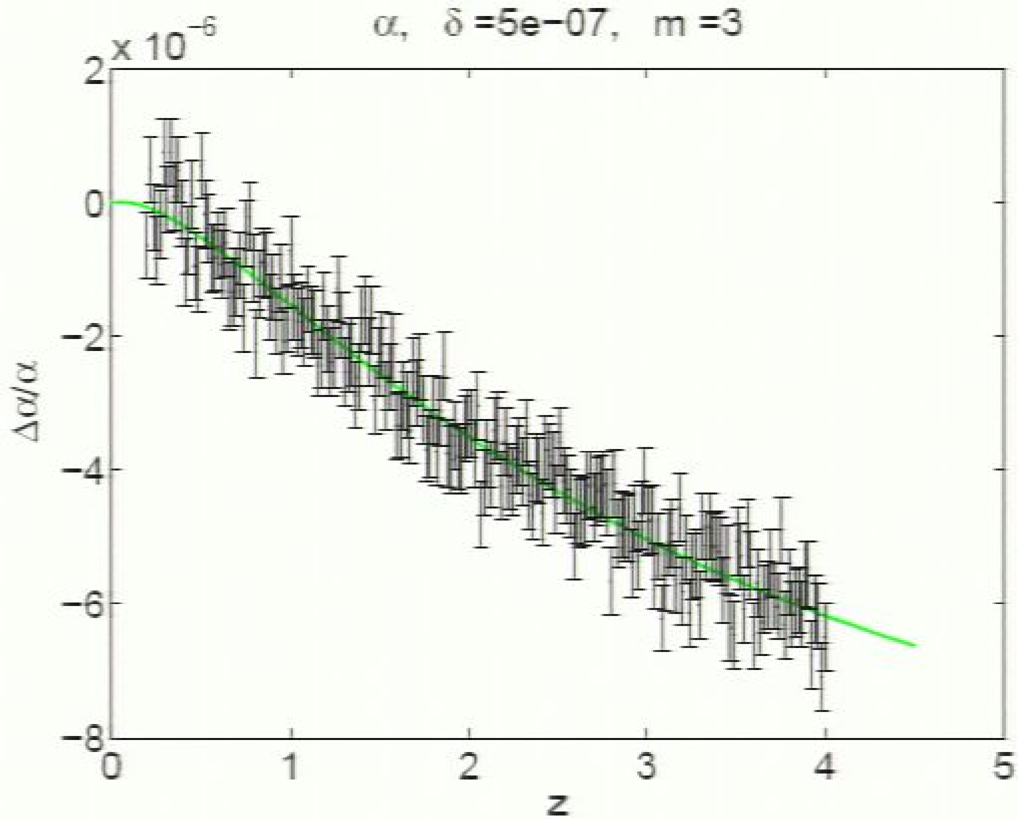
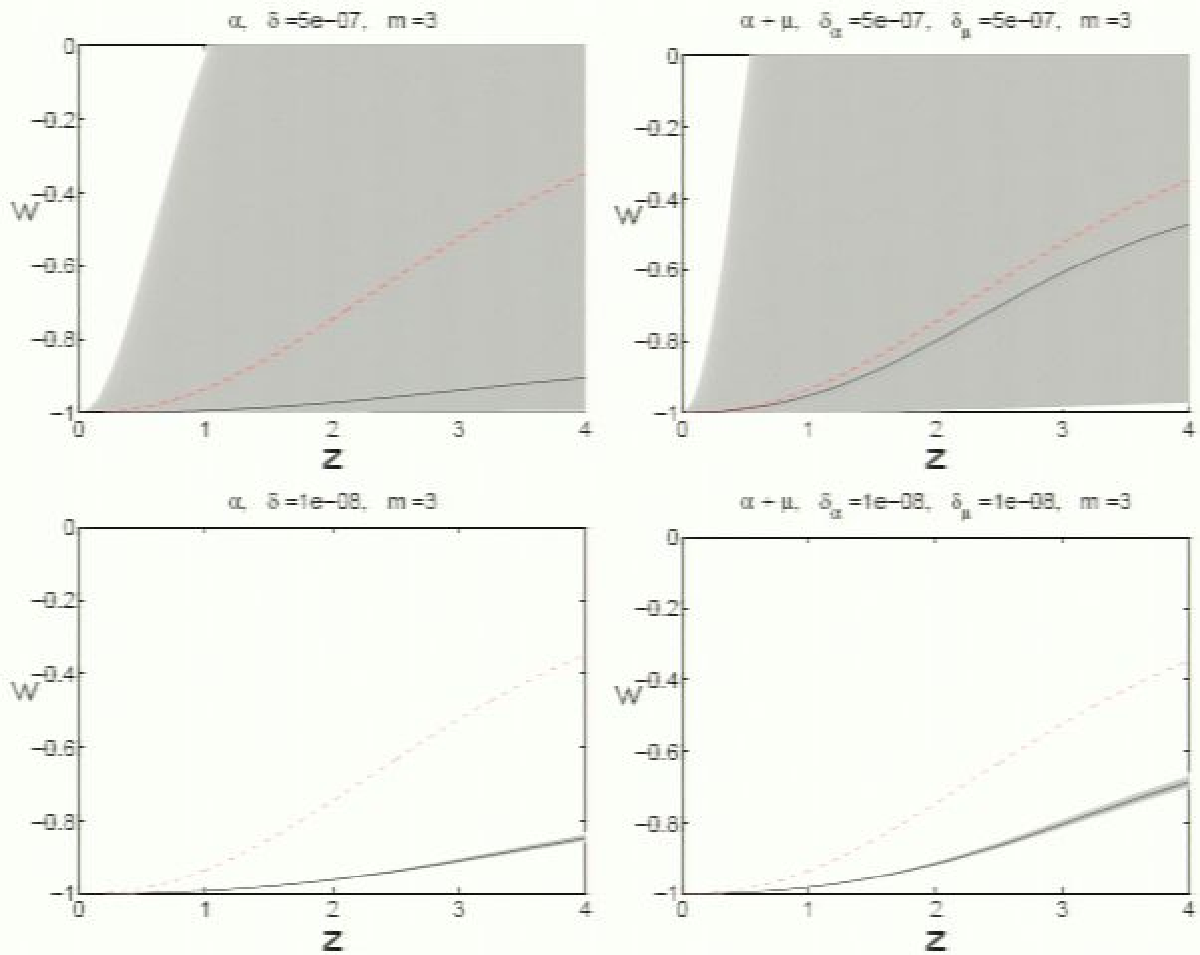


$$V(\phi) = V_0(e^{10\kappa\phi} + e^{-0.5\kappa\phi})$$

15. Reconstruction with oscillatory field (*cont.*)



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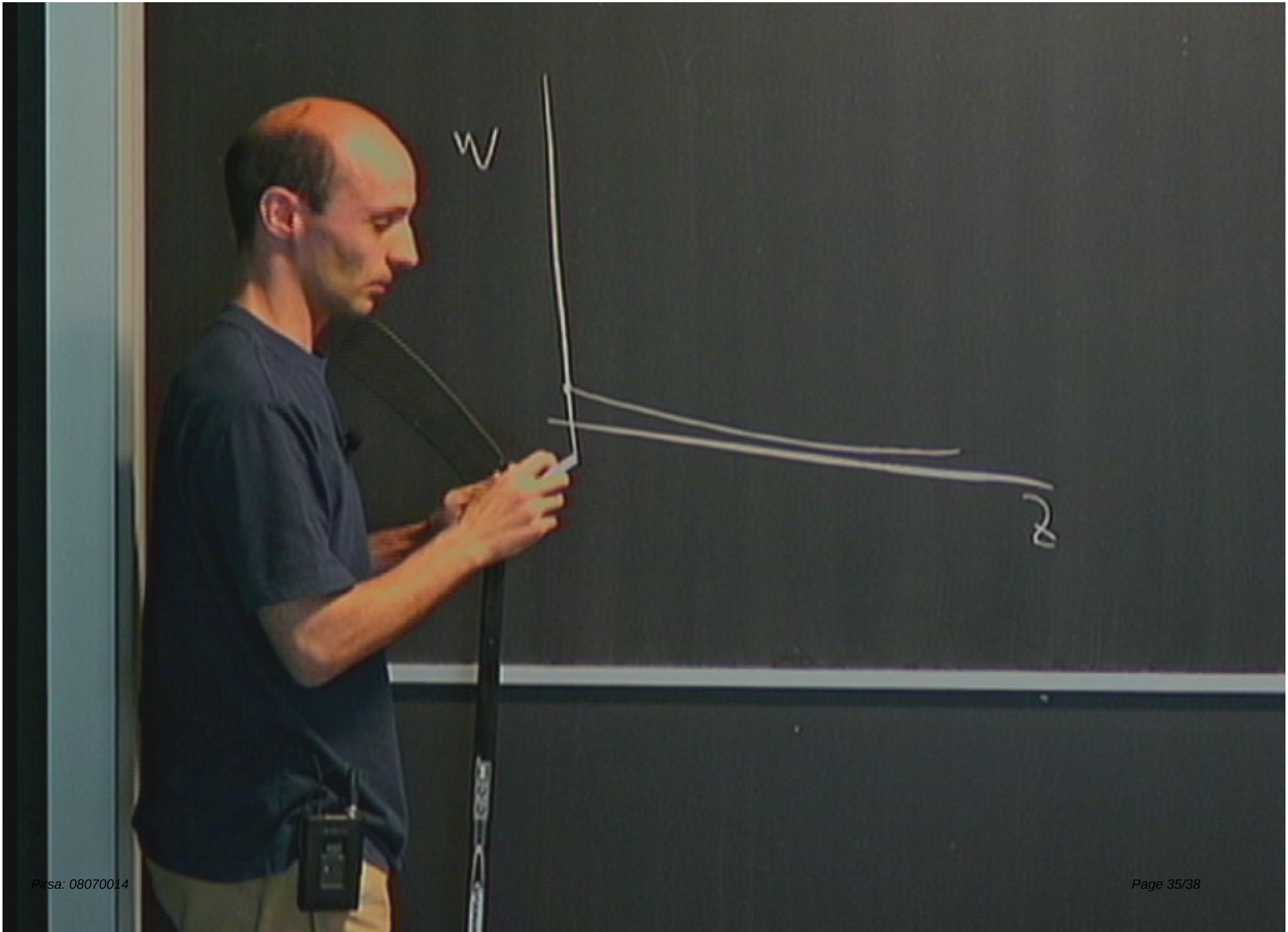
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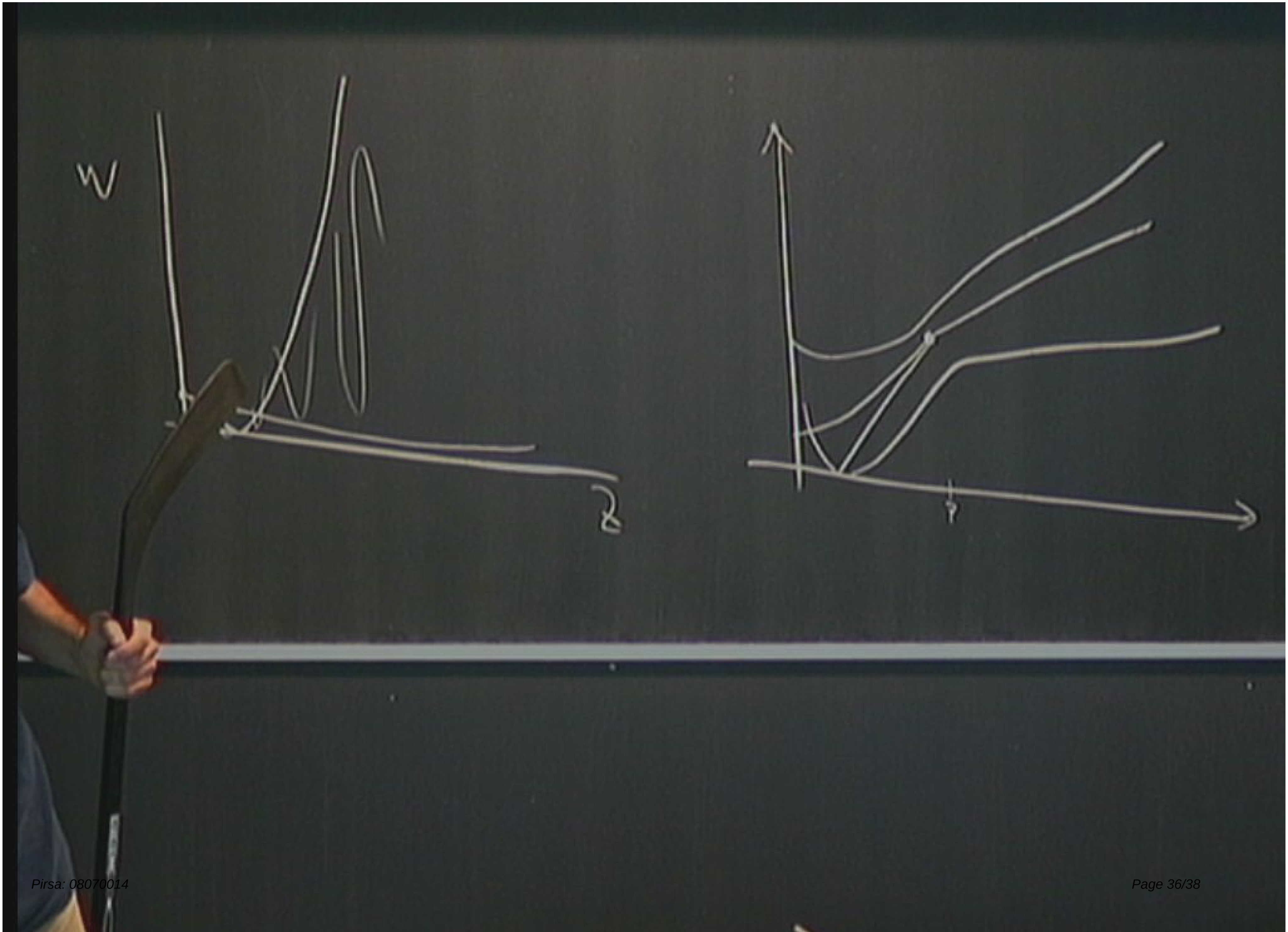
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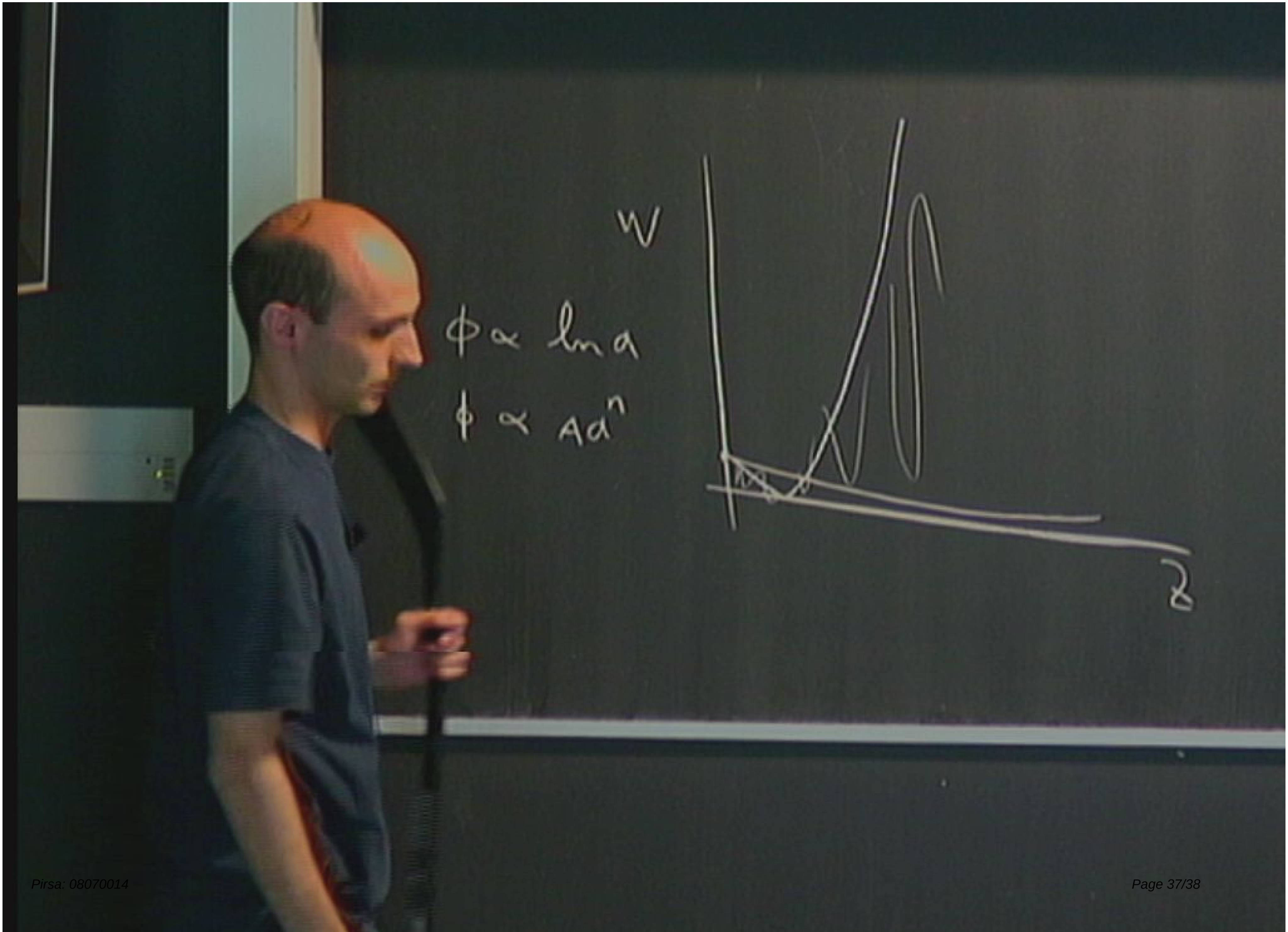
W
φ ∝ ln a
φ ∝ Aa^n
z

16. Consider general $B_F(\phi)$

$$B_F(\phi) = \left(\frac{\phi}{\phi_0}\right)^{\epsilon} [1 - \zeta(\phi - \phi_0)^q] \; e^{\tau(\phi - \phi_0)}$$

(Marra and Rosati 2005)

Assume $V(\phi) = M^{4+n}\,\phi^{-n}$

1. $B_F = 1 - \zeta(\phi - \phi_0)$ $\Rightarrow$ $\zeta < 0.6 \times 10^{-6}$
2. $B_F = 1 - \zeta(\phi - \phi_0)^q$ $\Rightarrow$ $q = 17$, experimental constraints are satisfied even for $\zeta = 1$.
3. $B_F = (\phi/\phi_0)^{\epsilon}$ $\Rightarrow$ $|\epsilon| < 4 \times 10^{-7}$
4. $B_F = (\phi/\phi_0)^{\epsilon}(1 - \zeta(\phi - \phi_0))$ $\Rightarrow$ oscillations in $\Delta\alpha/\alpha$
5. $B_F = (1 - \zeta(\phi - \phi_0))e^{-\tau(\phi - \phi_0)}$ $\Rightarrow$ oscillations in $\Delta\alpha/\alpha$