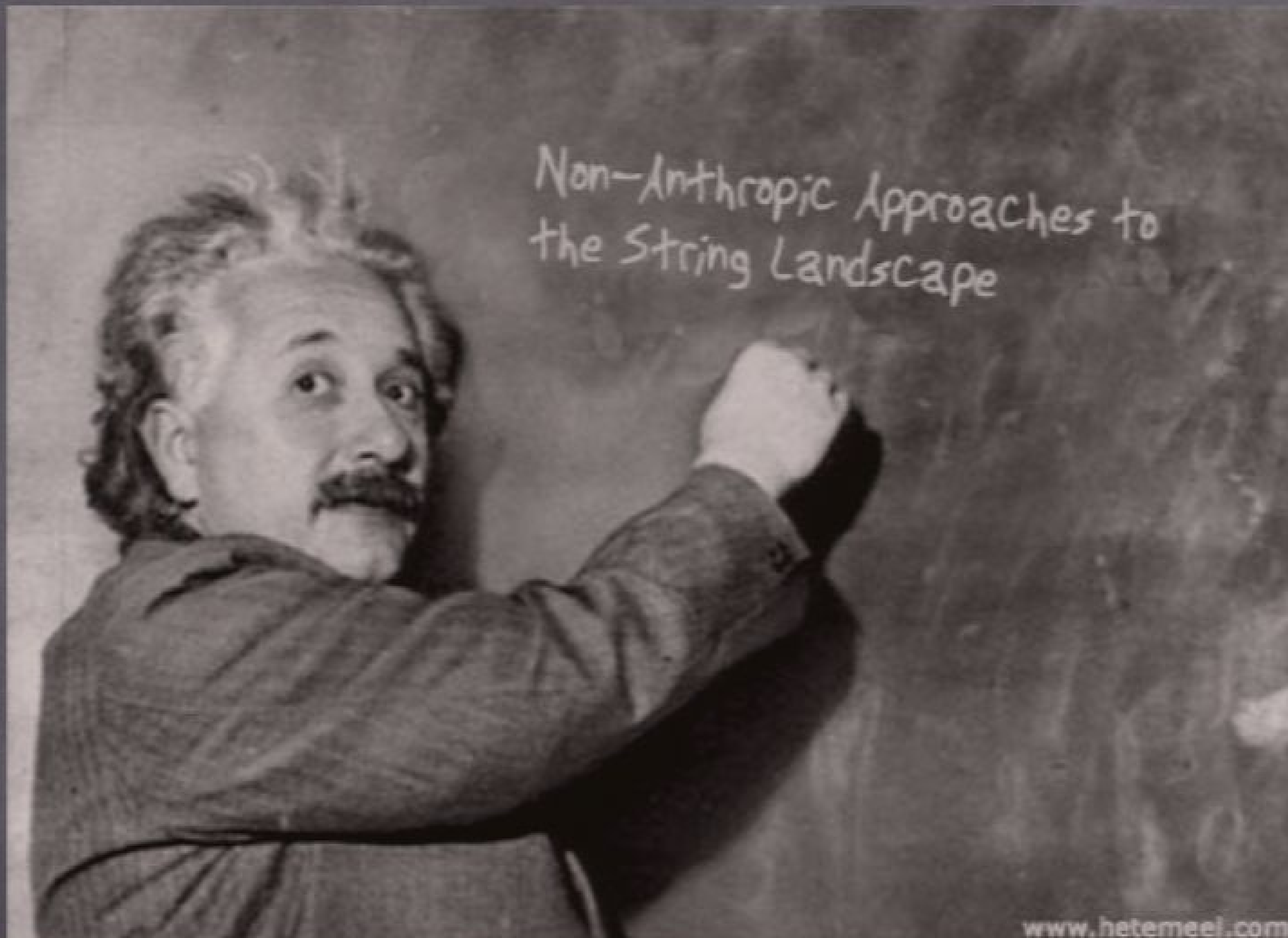
Title: Non-Anthropic Approaches to the String Landscape

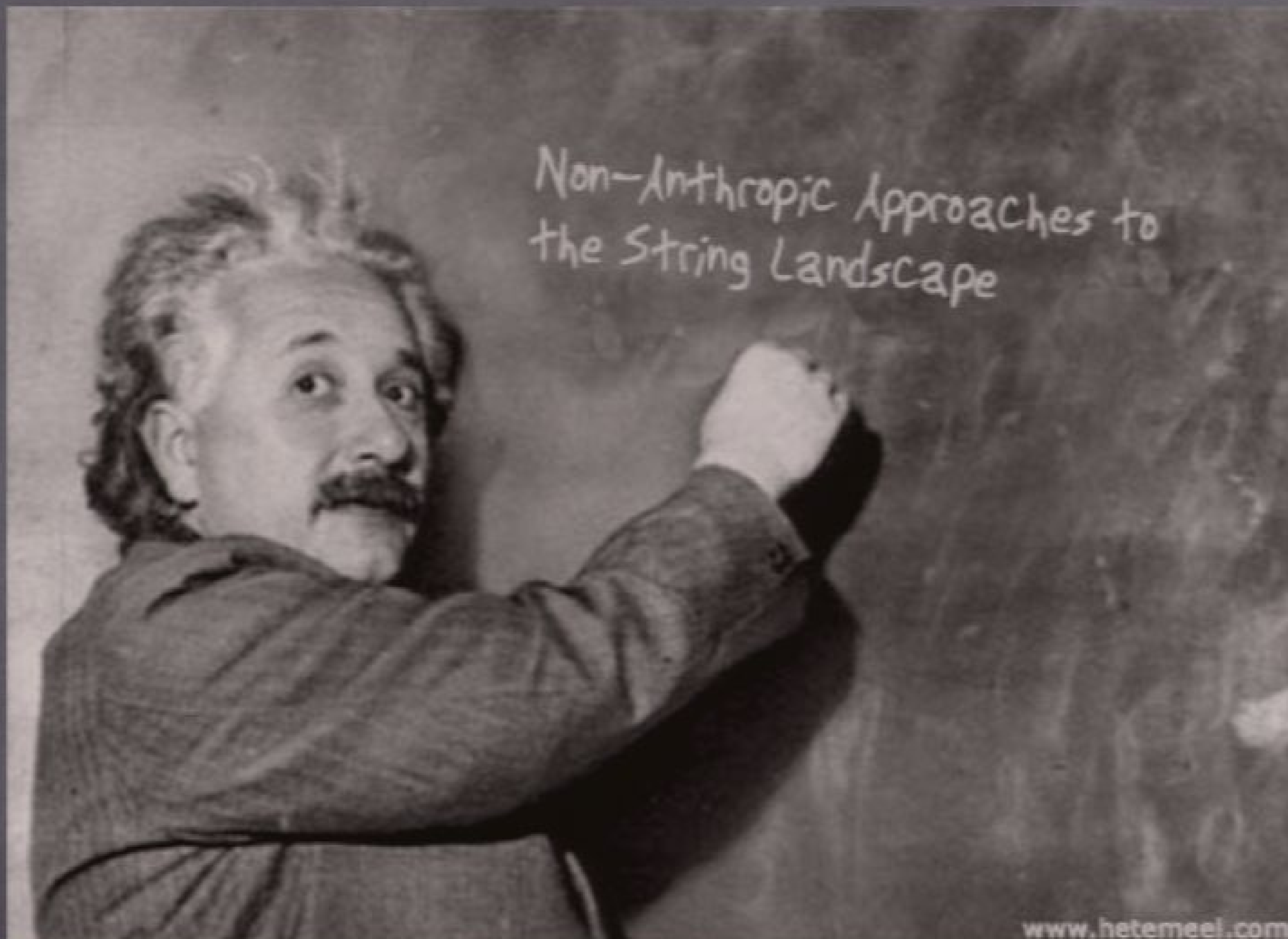
Date: May 19, 2007 04:00 PM

URL: http://pirsa.org/07050036

Abstract: We consider the effect that dynamical selection principles could have on the string landscape and for determining the value of the cosmological constant. The underlying symmetries of string theory, along with the dynamics of moduli in the low energy effective field theory, seem to suggest that not all vacua are created equal. However, in some simple models many vacua are alike and this degeneracy may suggest a *non-anthropic* approach to understanding the observed value of the cosmological constant. The approach may also lead to a viable model of inflation, without the need of fine-tuned potentials.



Scott Watson
Toronto / MCTP-Michigan



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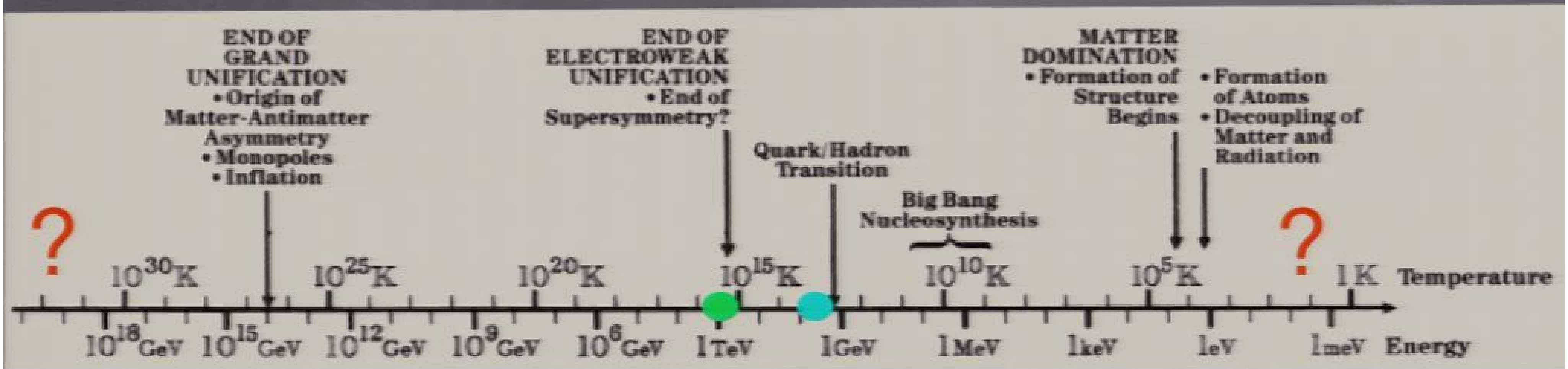
Phase Transitions and Cosmology



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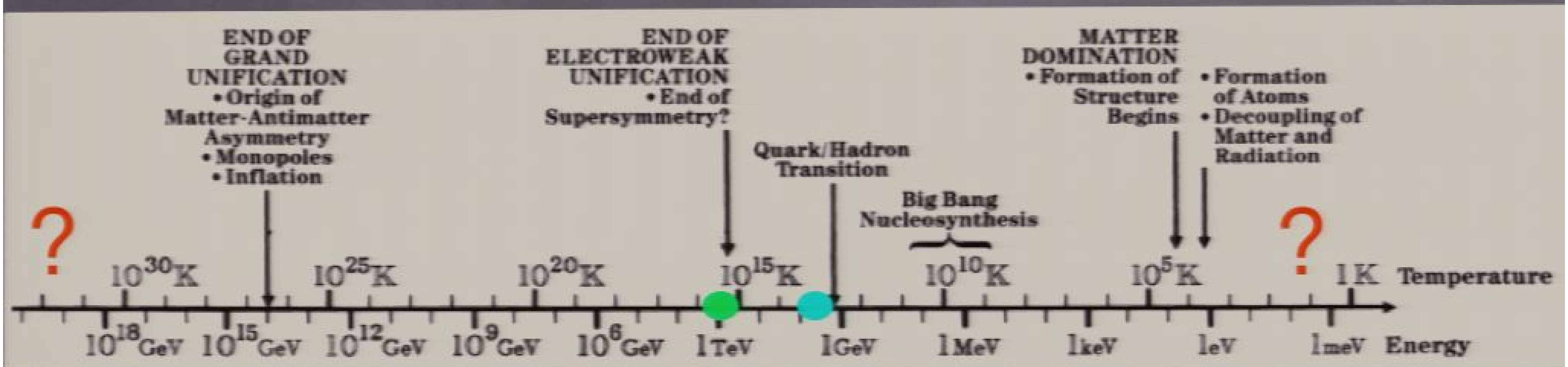

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$$\Lambda_{ew} \sim TeV \quad T \sim 10^{15}\ K$$

$$\rho_\Lambda \sim (TeV)^4$$ (or zero)

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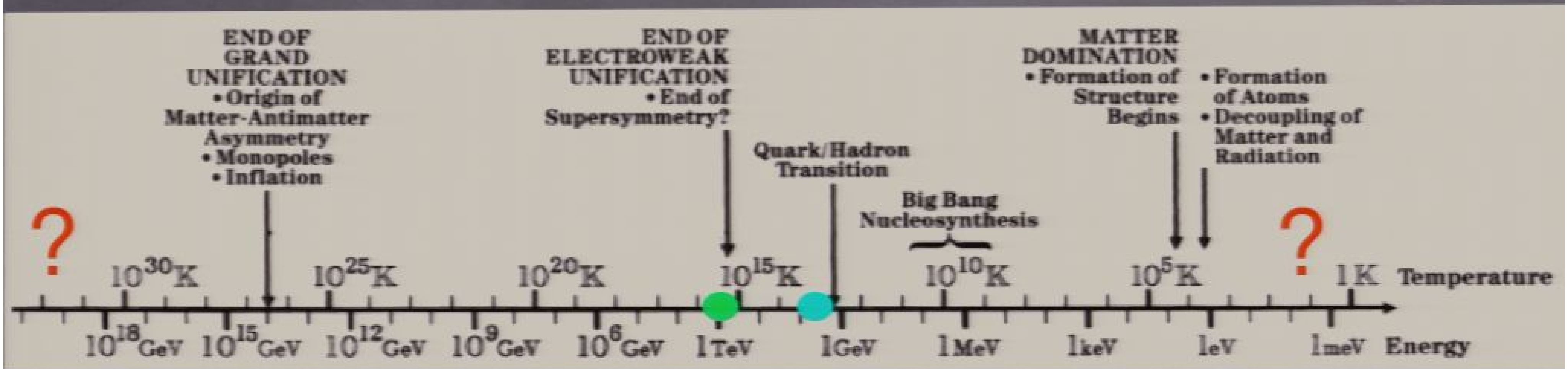

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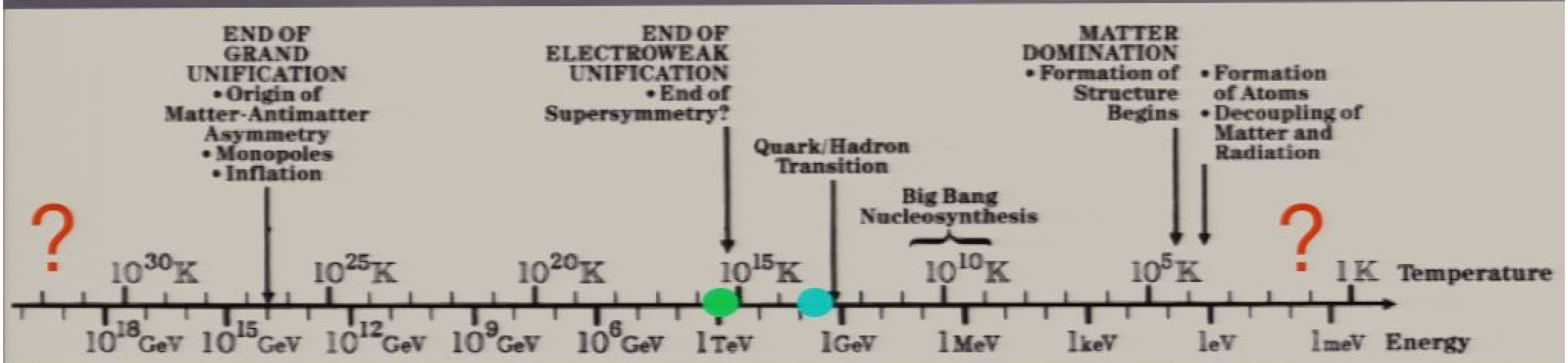

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$$\rho_\Lambda^{(obs)} \sim (10^{-3}\,eV)^4$$

Other Problems of Phase Transitions

- Higgs Mass
- Baryon asymmetry
  (How generated? -washed out by entropy prod. or Sphalerons)
- Confinement
- SUSY breaking
- Inflation
  - Realization in fundamental theory
  - Coupling to (MS) SM
- Problems w/ moduli and their stabilization

Cosmological Moduli Problem(s)

Moduli Potential

$$V_\Phi(T, H, \Phi) = 0$$

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Moduli oscillate in new minimum forming pressure-less condensate

$$\Delta\Phi \longrightarrow \Delta E \longrightarrow \rho_m$$

Fate of Moduli

Moduli are gravitationally coupled to other fields,

$$\Gamma_\Phi \sim \frac{m_\Phi^3}{M_p^2} \longrightarrow \tau_\Phi = \frac{\hbar}{\Gamma_\Phi} \approx \left(\frac{TeV}{m_\Phi}\right)^3 10^8 s$$

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Two possibilities:

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$$T_r > 1\, MeV\ (BBN) \longrightarrow \boxed{m_\Phi > 10\, TeV}$$

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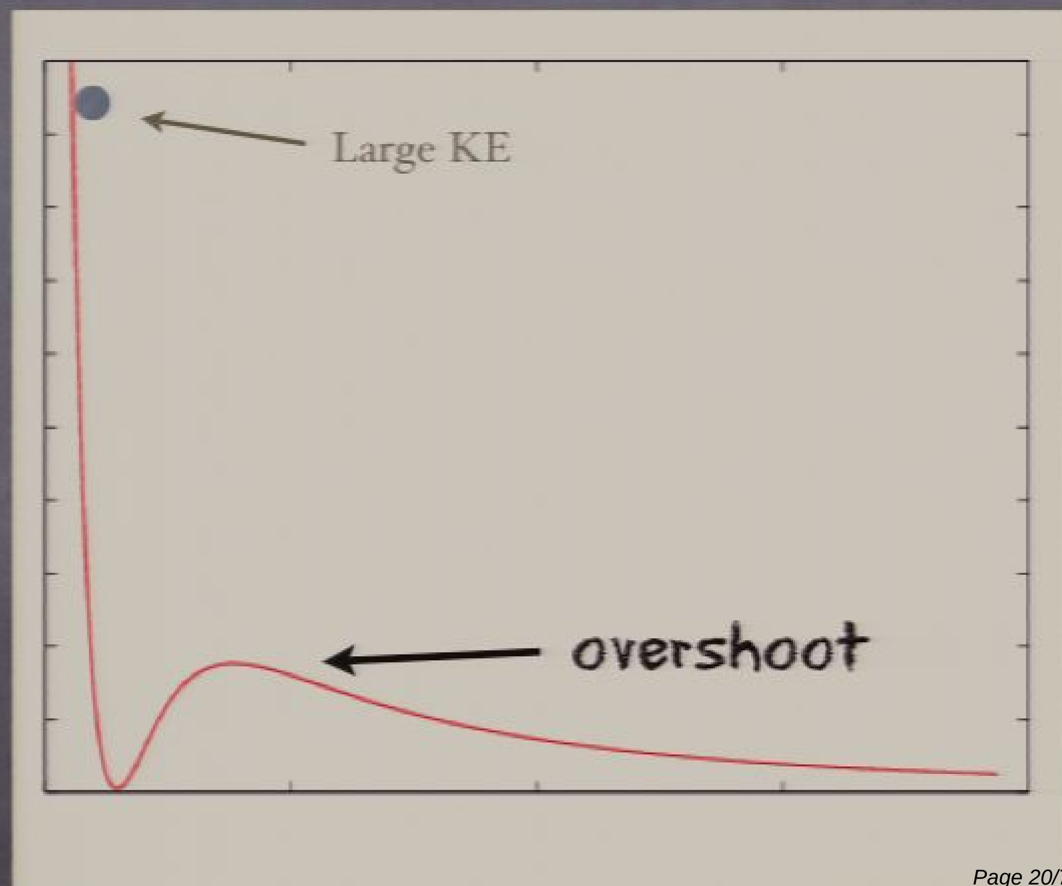
$$\boxed{m_\Phi < TeV} \qquad \rho_{mod} < \rho_c \longrightarrow \boxed{m_\Phi < 10^{-26}\ eV}$$

Non-perturbative Contributions

Brustein-Steinhardt: hep-th/9212049



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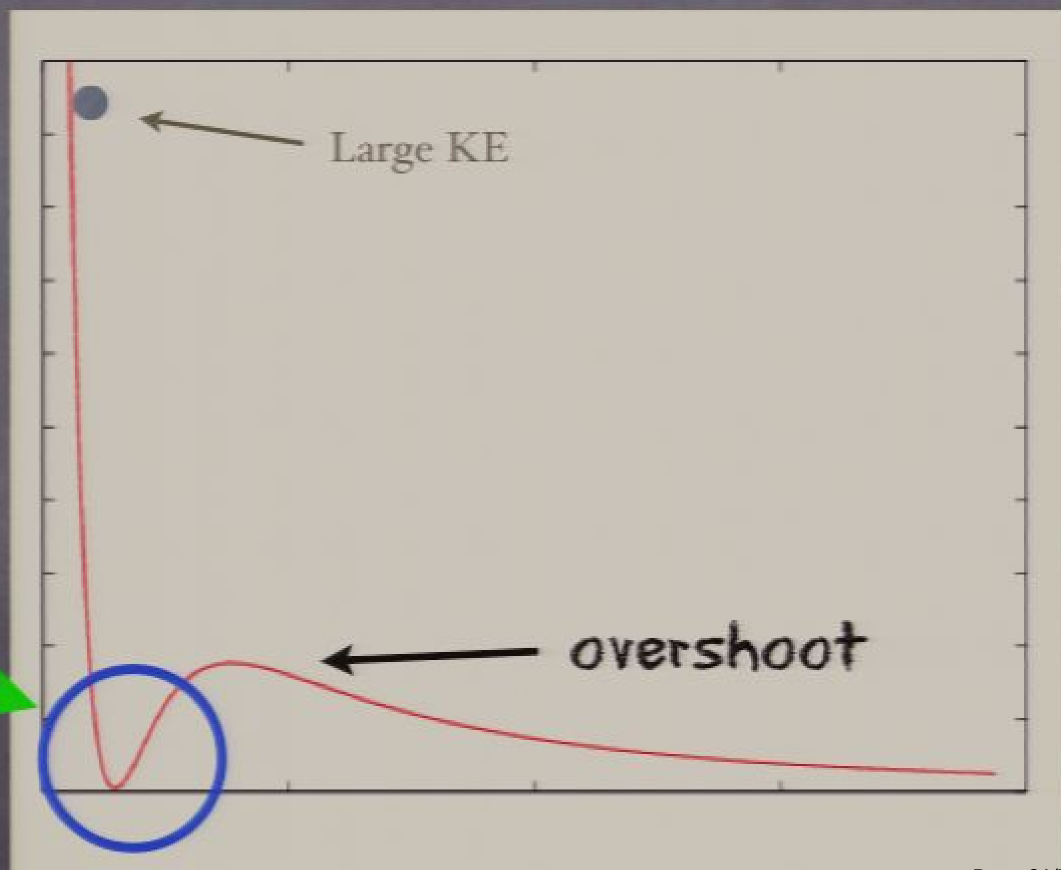
Dine-Seiberg: Phys.Rev.Lett.55:366,1985

Measure zero set



Summary thus far...

- Phase transitions generically displace moduli
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Solutions?

Cautionary remark on Warm inflation
- Wash pre-existing baryon asymmetry

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e.g. Banks, Dine, et. al.

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Moduli found at points of enhanced symmetry

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Why?

- Fixed pts of effective action
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Initial conditions?

- Why would you start there? – Question of probability?

Moduli Dynamics

What does one generically expect the motion to look like?

$$G_{ij}(\Phi)\partial_\mu\Phi^i\partial^\mu\Phi^j$$

Conifold:
- Mohaupts & Saueressig hep-th/0410272 & hep-th/0410273
- Greene, Judes, Levin, S. W., Weltman hep-th/0702220

Brane positions:
- Kofman, Linde, Liu, Maloney, McAllister, Silverstein hep-th/0403001
- Silverstein-Tong hep-th/0310221

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Classical Moduli Dynamics

- Horne & Moore hep-th/9403058

Axiodilaton in 4D

$$S_4 = \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\left(R - \frac{1}{2}\frac{\partial_\mu\tau\partial^\mu\bar{\tau}}{(Im\tau)^2} - \frac{\kappa^2}{4\pi}Tr\left[aF_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{1}{g_s}F_{\mu\nu}F^{\mu\nu}\right] + \dots\right)$$

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Discrete "stringy" symmetry

$$\frac{1}{g_s} \to g_s$$

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Moduli Space

Classical Moduli Dynamics

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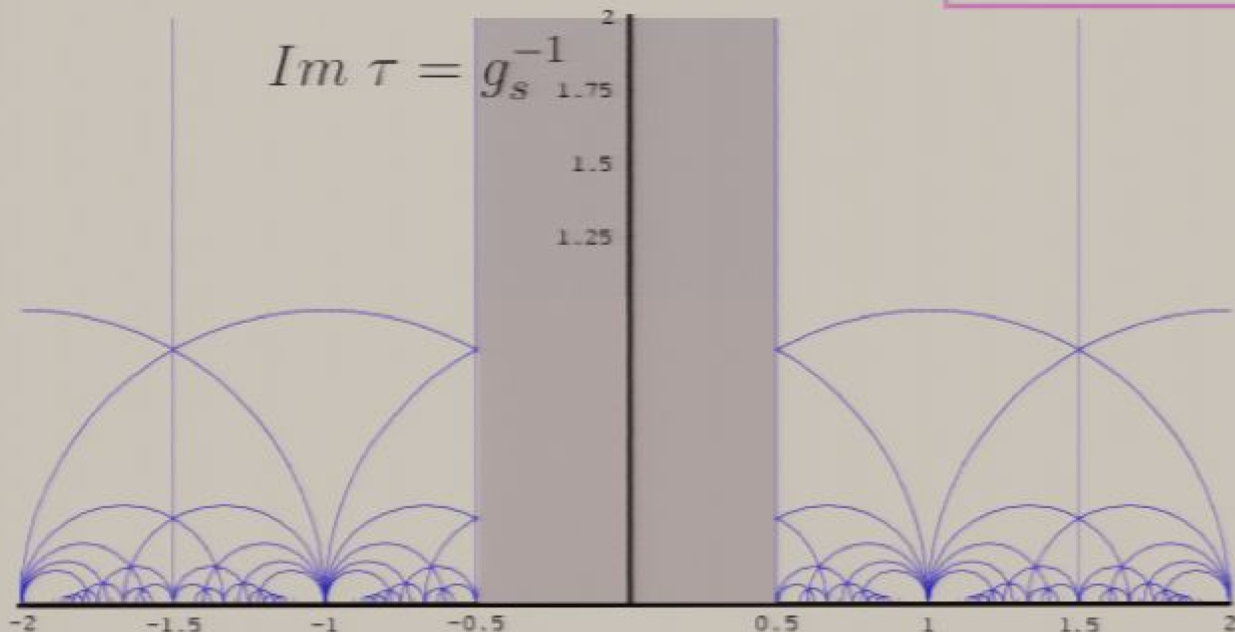
$$\int \frac{d^2\tau}{(Im\ \tau)^2} < \infty$$

$$Im\ \tau = g_s^{-1}$$



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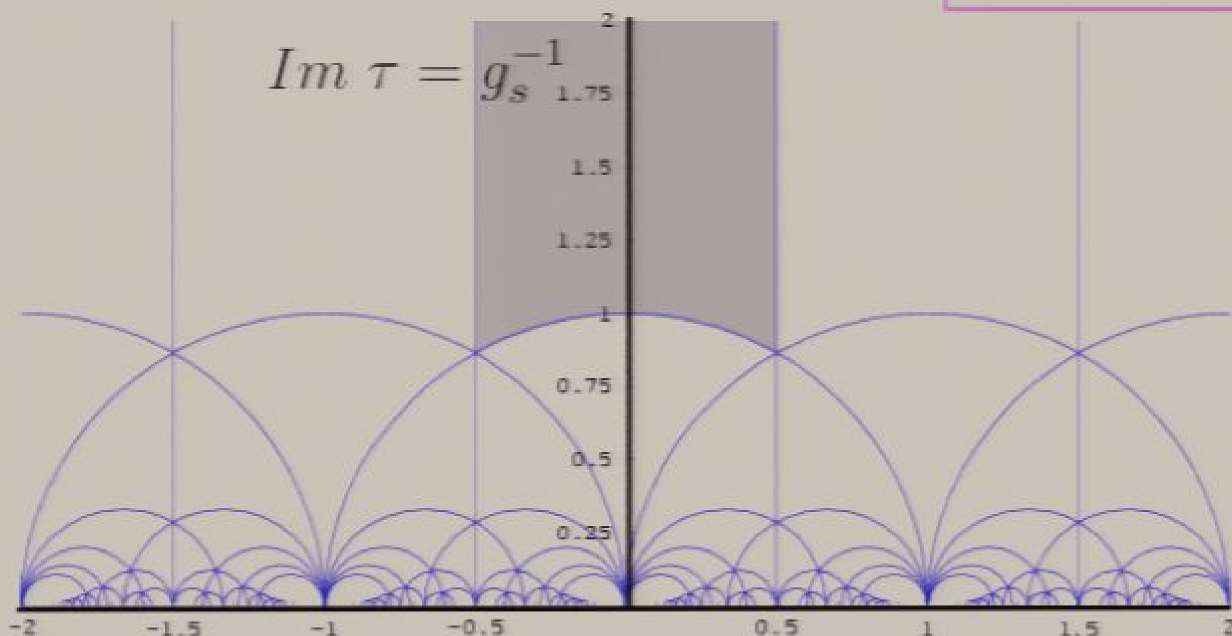

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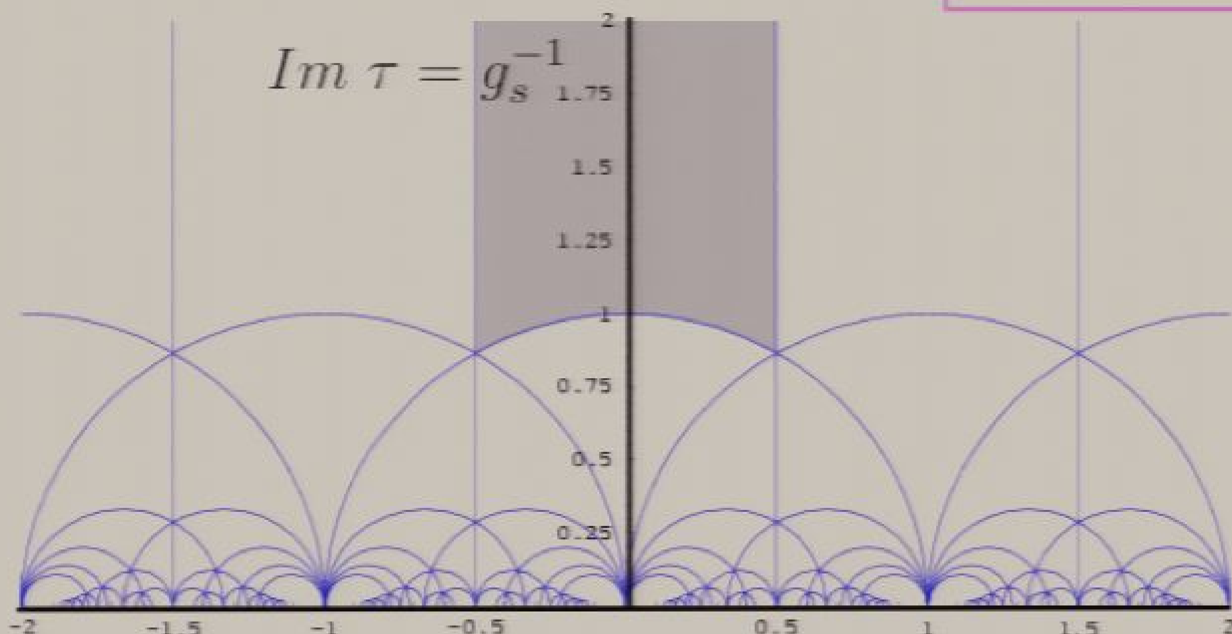

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Consequences:

- Probabilities ~ Moduli space volume (tree level)
- Decoupling gravity?

$$M_p^2 \sim \frac{M_s^8 V_6}{g_s^2} = M_s^8 V_6 (Im\,\tau)^2 \sim \ finite$$

If special points in moduli space exist, should encounter them in finite time

In particular, enhanced symmetry points suggested by Dine, et. al...

Enhanced symmetry

SUGRA Massless modes:

$R \equiv \sqrt{G_{55}} \rightarrow \phi$ $\quad A_\mu^{R/L} = G_{\mu 5} \pm B_{\mu 5}$ $\quad$ Chiral $U(1)$

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Enhanced gauge symmetry - ESP @ self-dual radius

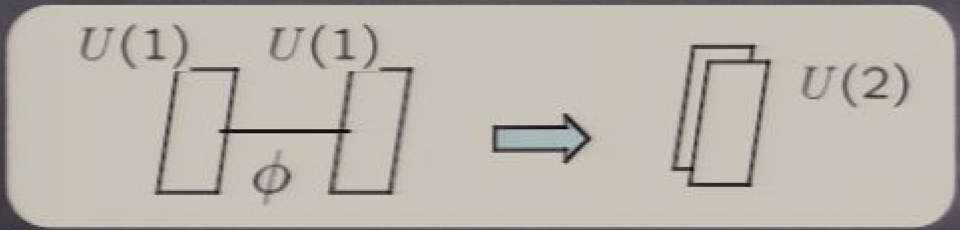
$R \to l_s \qquad m_w \to 0 \qquad U(1) \to SU(2)$

8 new scalars
4 new vectors

Enhanced Symmetry

Many examples of ESPs in string theory

- Heterotic strings on T^6 - Enhanced gauge symmetry
- Type II on K3 - ESPs at singularities
- Wrapped branes and strings on collapsing cycles (e.g. conifolds and flops)
- Coincident branes (open strings become light)



Moduli Trapping

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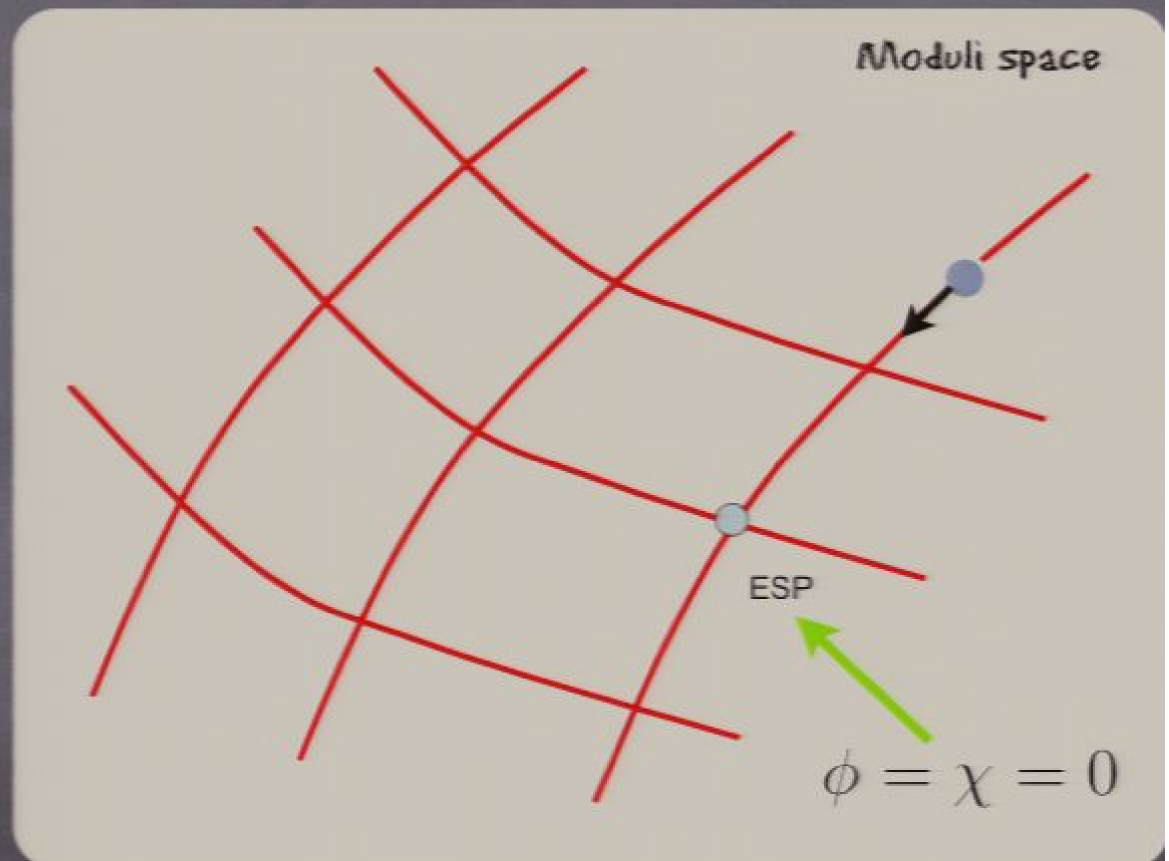

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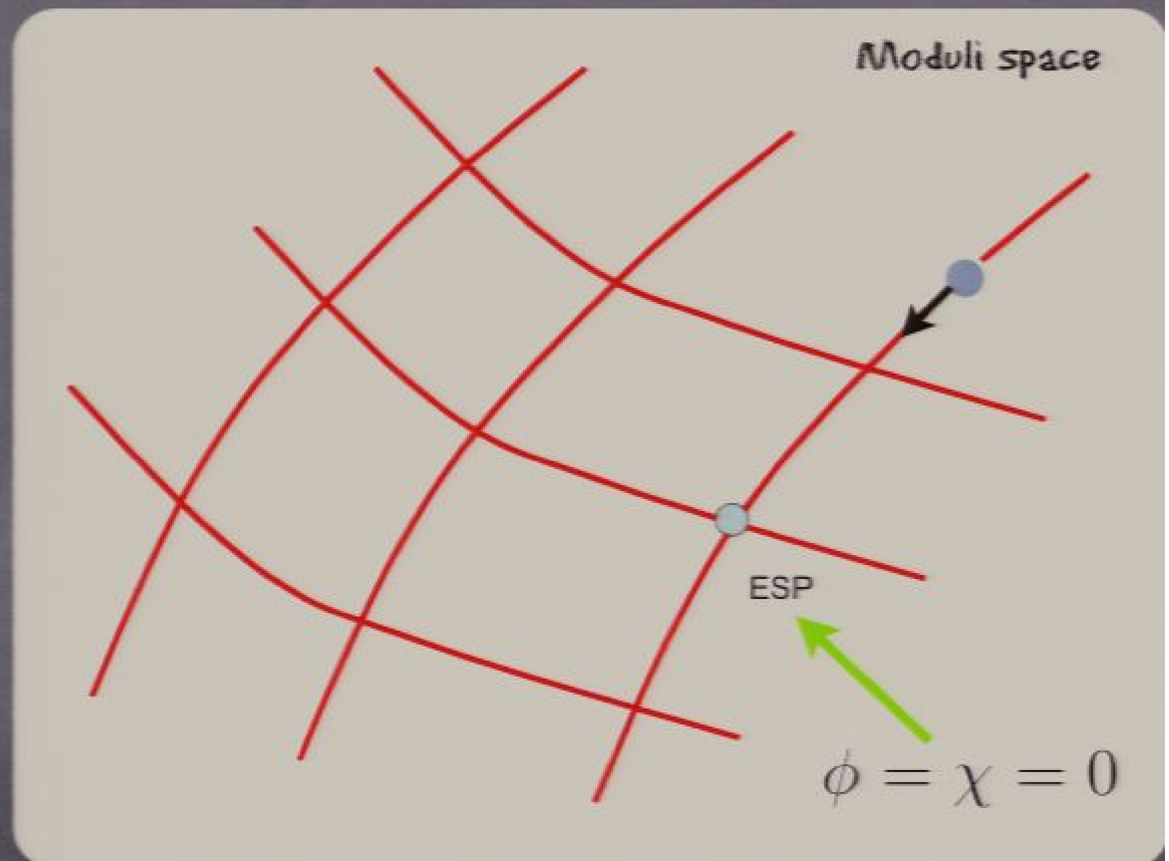

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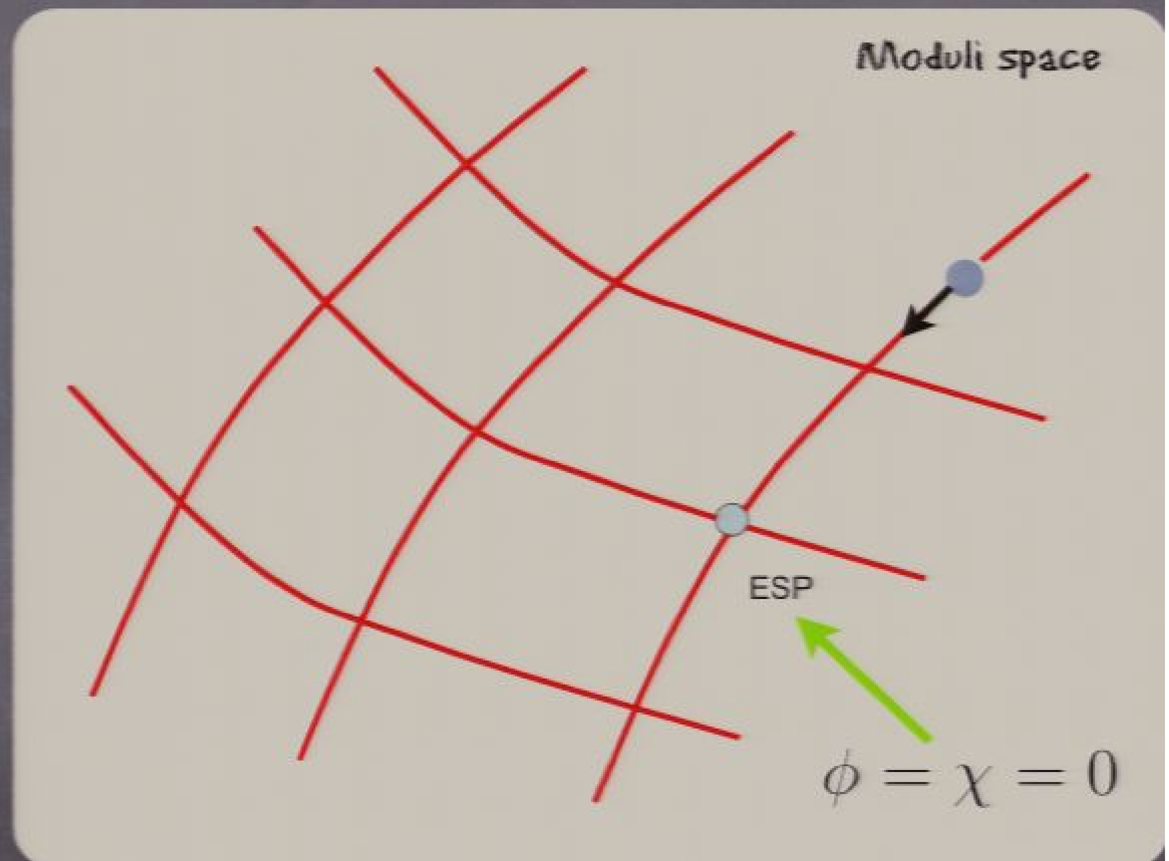
Near ESP modes become excited

-Particle production-



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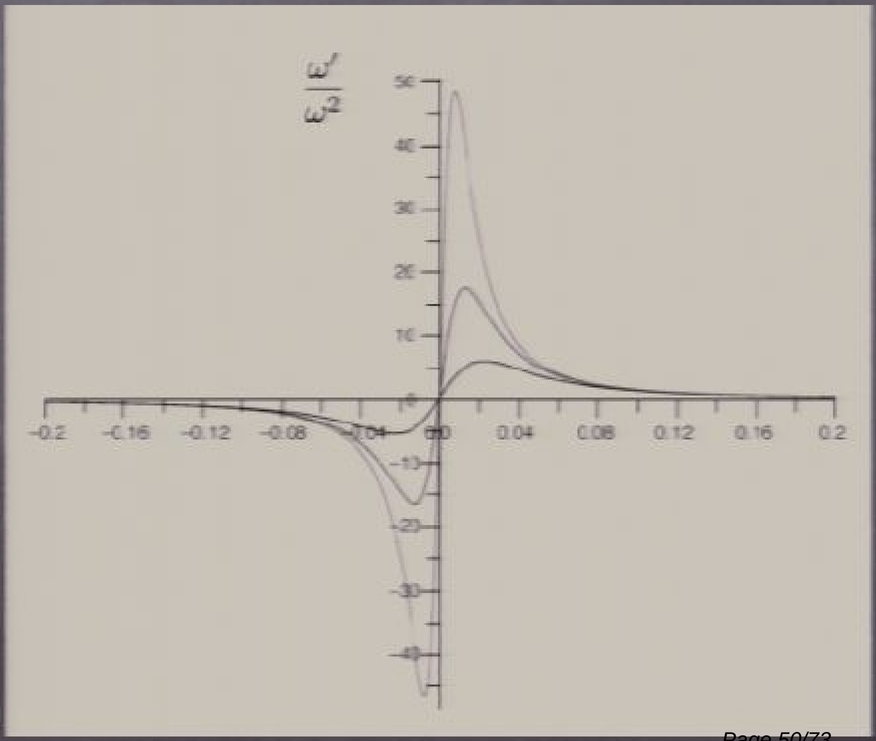
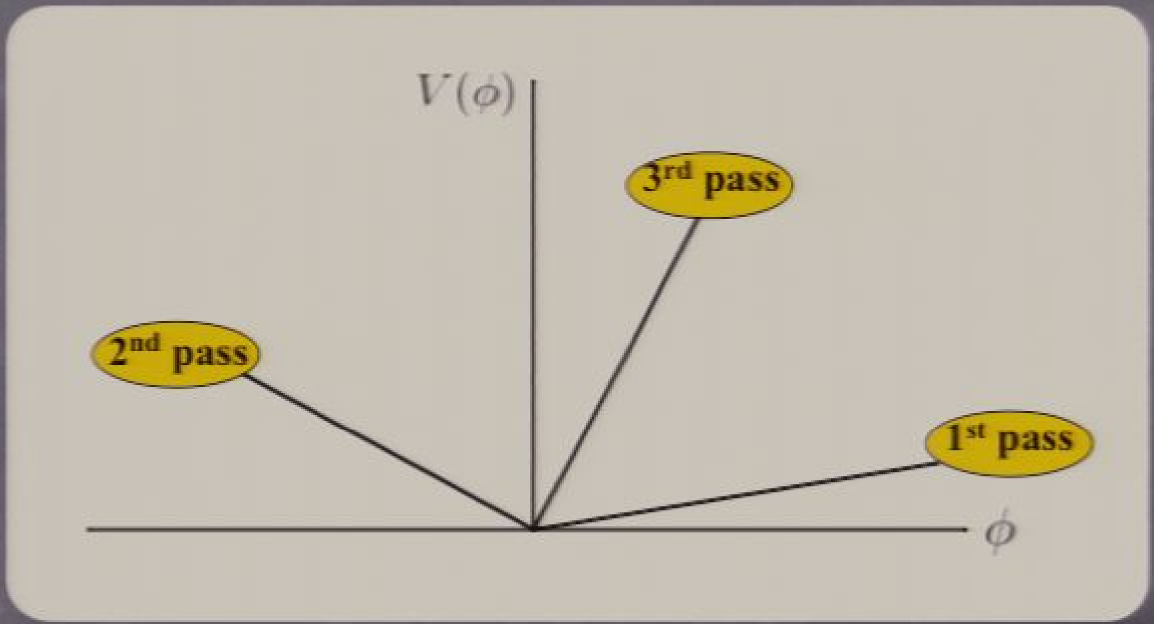
$$n_k \approx e^{-\frac{\pi k^2}{g v_0}}$$



$$\langle \chi^2 \rangle = \frac{n_\chi}{g|\phi|}$$

$$\ddot{\phi} + 3H\dot{\phi} = -g n_\chi \frac{\phi}{|\phi|}$$



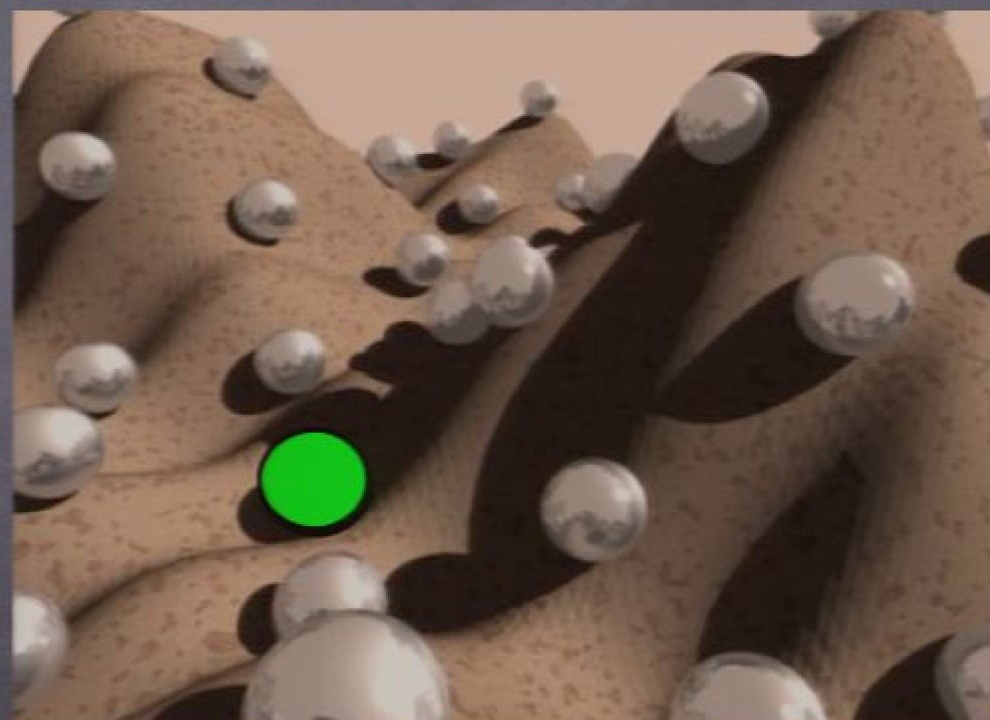
Summary of Quantum Dynamics:

- Moduli trapped in finite time (log w/ gravity)

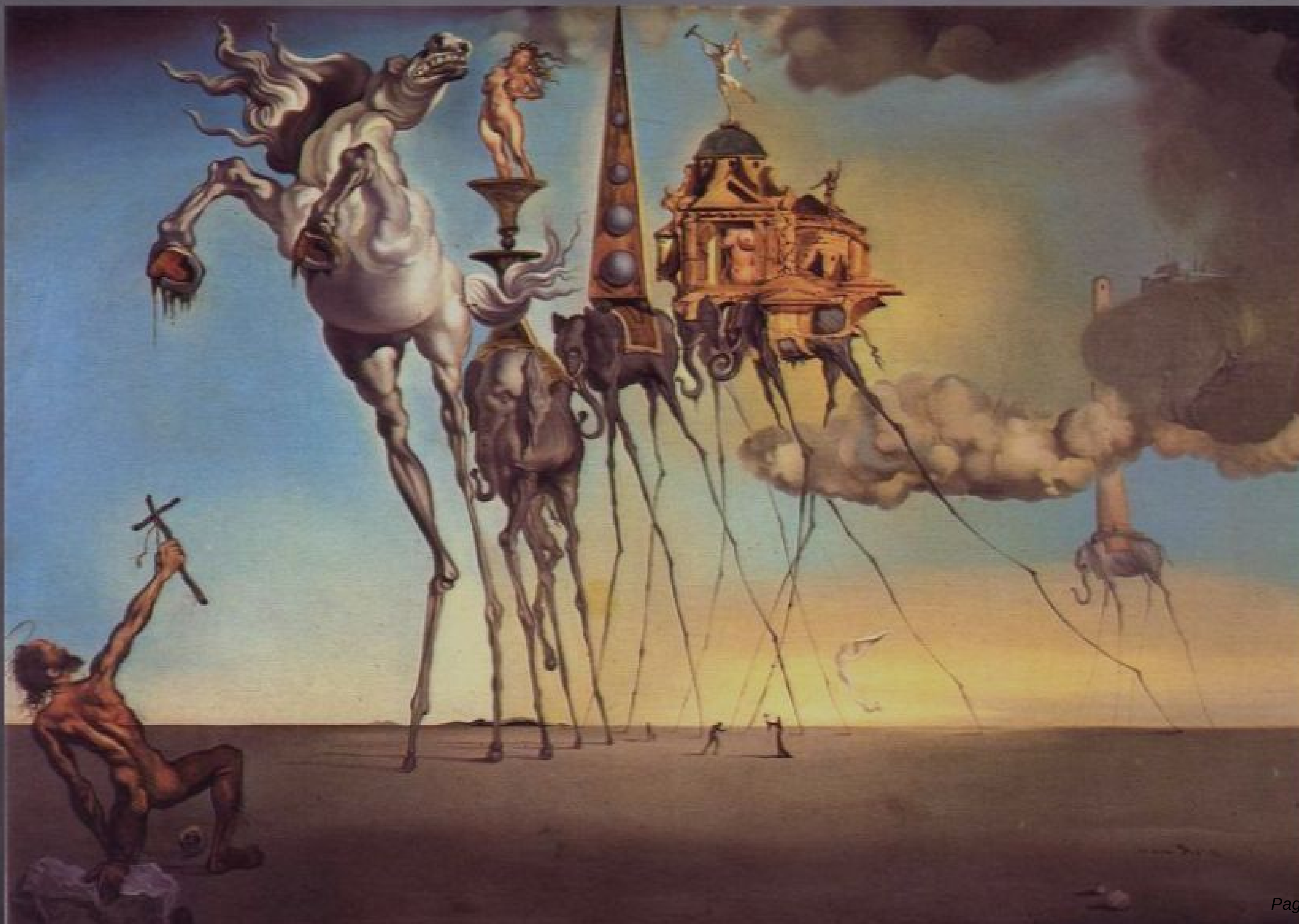
- ESPs are attractive channel (dynamic selection)

- At strong coupling corrections to motion (propagator) can be important (Silverstein-Tong)

- Lesson:
Dynamics can lead to "vacuum selection", at least in these simple models.

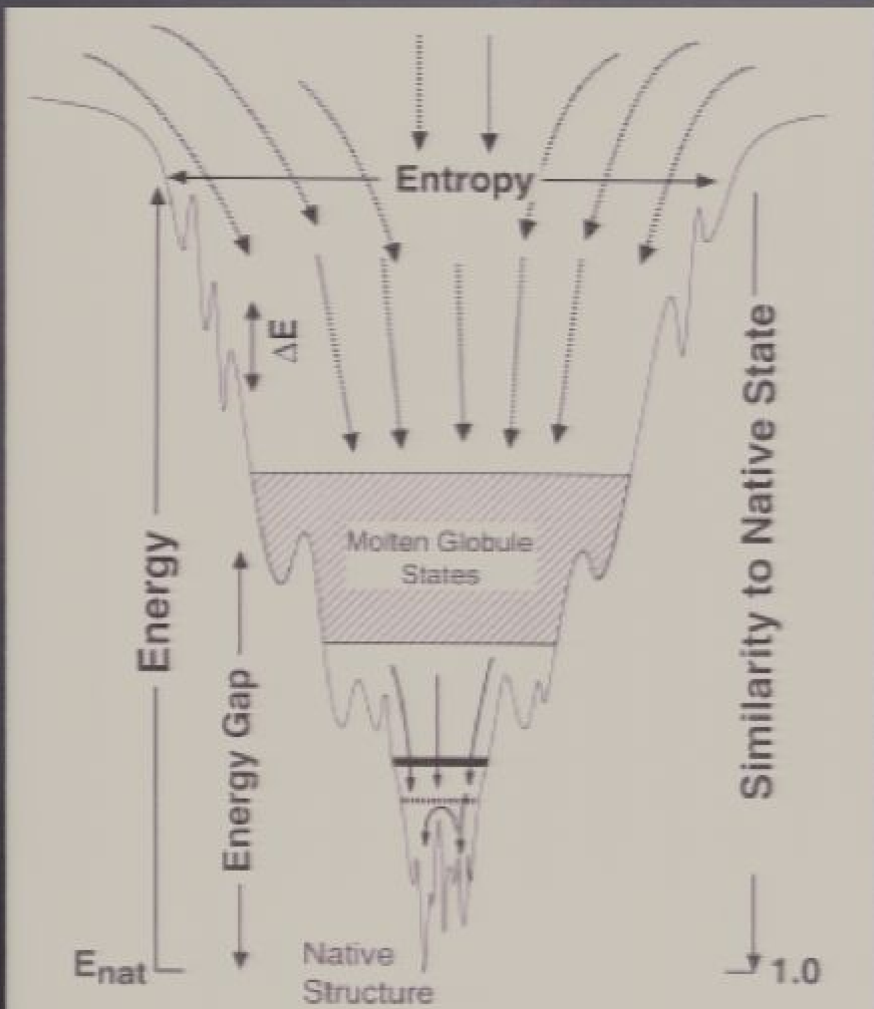


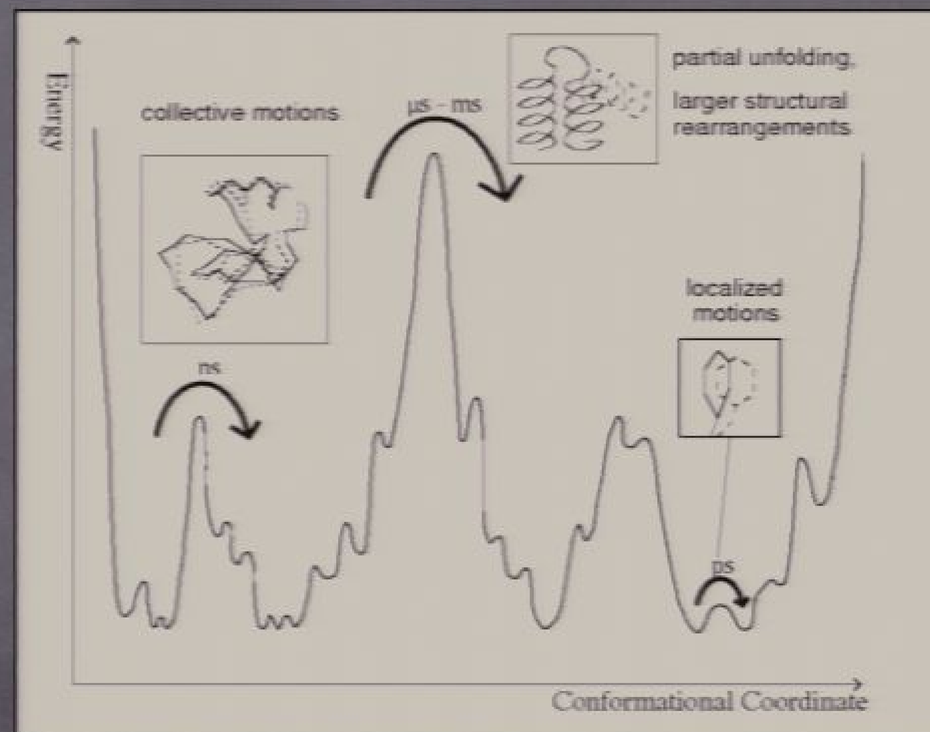
What about inflation and the CC?



Early Universe Phase Transitions?

"The Energy Landscape" of Protein Folding





Traveling through the landscape

Bousso-Polchinski (Scalar Free)

(extension of Brown-Teitelboim mechanism, also Feng, et. al.)

$$F^{(i)}_{\mu\nu\rho\sigma} = n_i q_i \epsilon_{\mu\nu\rho\sigma} \qquad n \in \mathbb{Z}$$

$$\Lambda = \Lambda_{bare} + \sum_{fluxes} \frac{1}{2} n_i^2 q_i^2$$

Make Λ dynamical: $\Lambda \rightarrow F_{(4)}$

Membrane nucleation (instantons)

$$n \rightarrow n - 1$$

Energy drop

$$\epsilon^4 = -\left(n - \frac{1}{2}\right) q^2$$

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Bousso-Polchinski (Scalar Free)

(extension of Brown-Teitelboim mechanism, also Feng, et. al.)

$$F^{(i)}_{\mu\nu\rho\sigma} = n_i q_i \epsilon_{\mu\nu\rho\sigma} \qquad n \in \mathbb{Z}$$

$$\Lambda = \Lambda_{bare} + \sum_{fluxes} \frac{1}{2} n_i^2 q_i^2$$

Make Λ dynamical: $\Lambda \rightarrow F_{(4)}$

Membrane nucleation (instantons)

$$n \rightarrow n - 1$$

Energy drop

$$\epsilon^4 = -\left(n - \frac{1}{2}\right) q^2$$

Traveling through the landscape

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Ex: M-theory compactification

$$\tau_4 = 2\pi M_{11}^3 (V_3 M_{11}^3)$$ M5 --> 4D

$$M_{11} \sim 10^{-3} M_p$$

$$V_3 M_{11}^3 \sim 10^3 \qquad n \sim 1000$$

$$\epsilon^4 \sim 10^{-7} M_p^4$$

Can we use degeneracy of vacua to address naturalness?

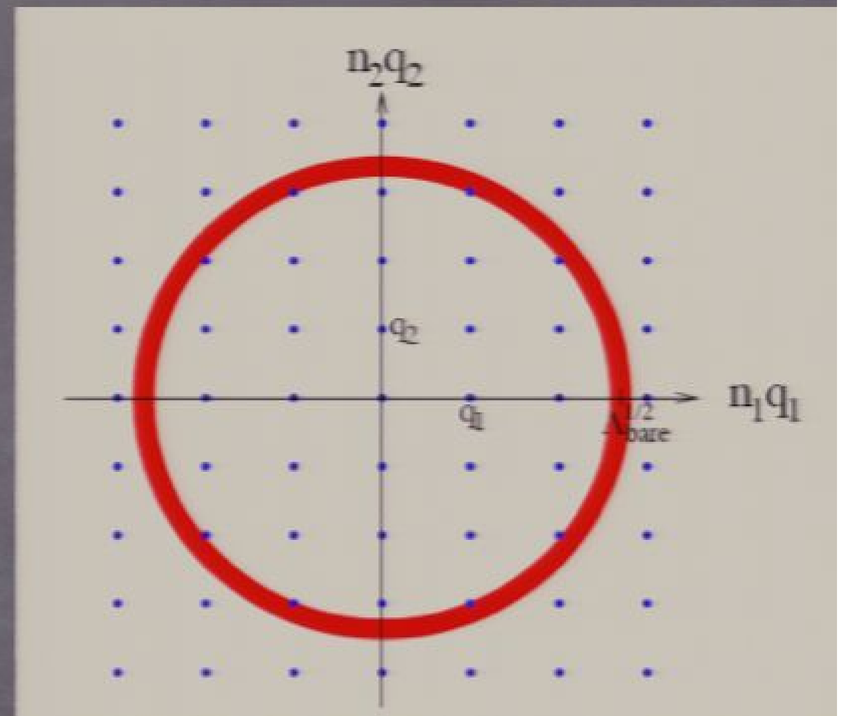
Kane, Perry, and Zytkow, hep-th/0311152

Near degeneracy

--> Superposition of vacua

Ground State Energy

$$\rho(\theta) \approx H^2 M_p^2 - 2\sum_{i=1}^{d} H^4 cos(\theta_i) e^{-S_E}$$



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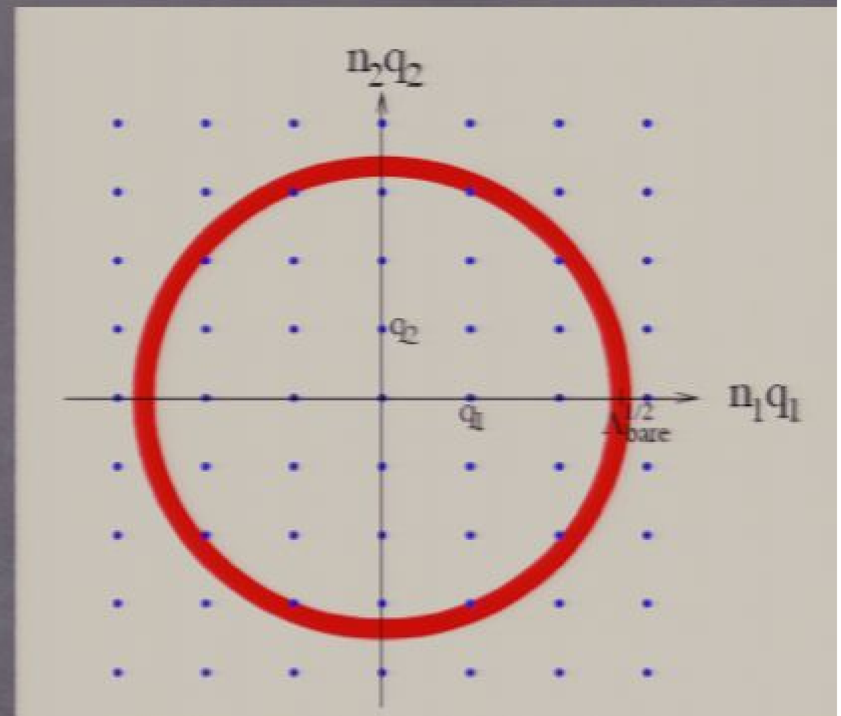


Ground State Energy

$$\rho(\theta) \approx H^2 M_p^2 - 2\sum_{i=1}^{d} H^4 cos(\theta_i) e^{-S_E}$$

$$H \sim 10^{15} GeV$$

$$d \sim 10^{12} \quad N \sim 10^{100}$$

$$\longrightarrow \quad \rho_0 \sim \left(10^{-3} eV\right)^4$$

Early Universe would have band structure --> interesting cosmology

S.W., Kane, Perry, and Adams, hep-th/0601005

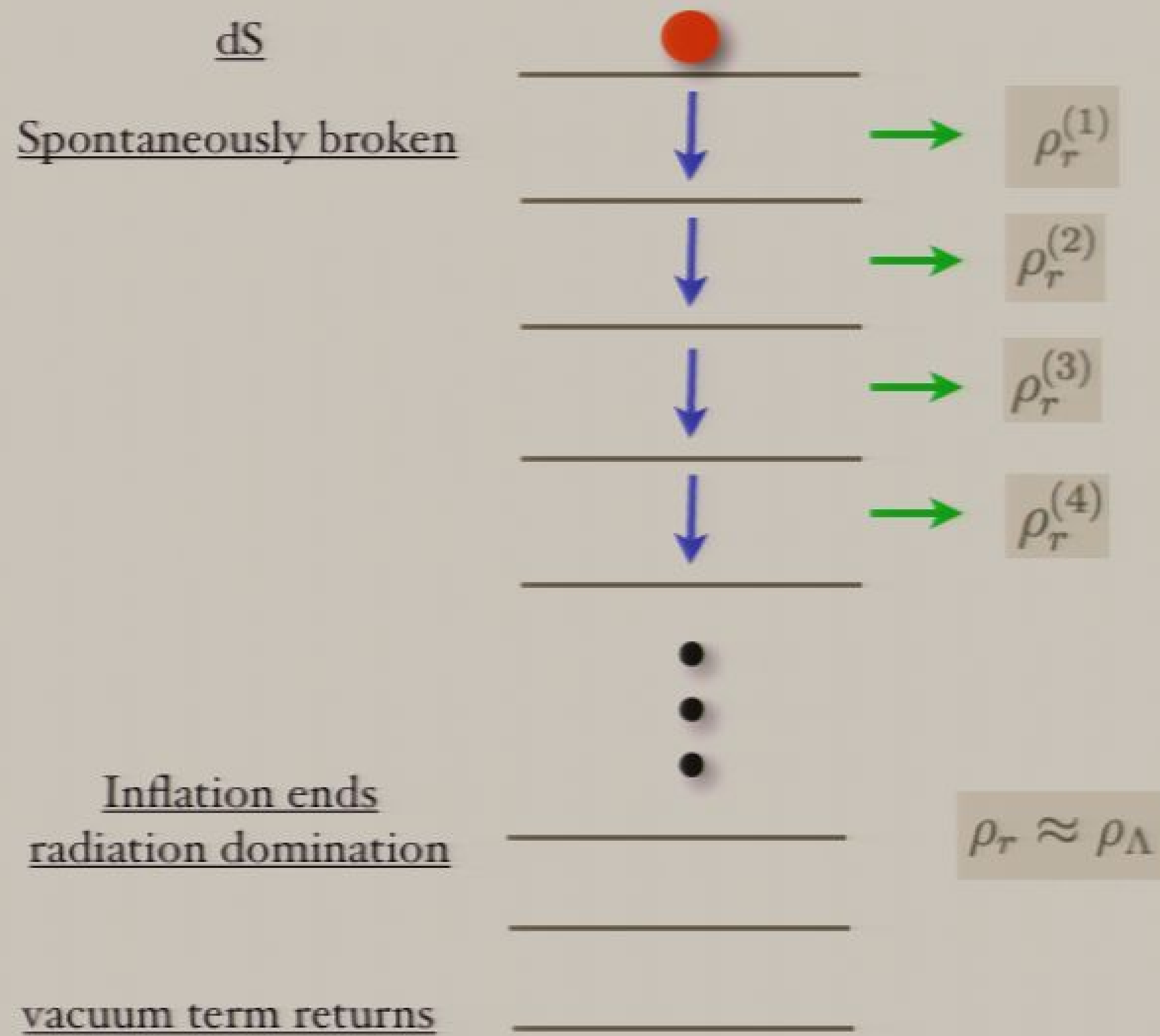
A Cascading Universe

$$H^2 = \frac{8\pi}{3M_p^2}(\rho_\Lambda + \rho_r)$$

$$\frac{\ddot{a}}{a} = \frac{8\pi}{3M_p^2}(\rho_\Lambda - \rho_r)$$

$$\dot{\rho}_\Lambda = -\Gamma\rho_\Lambda$$

$$\dot{\rho}_r = -4H\rho_r + \Gamma\rho_\Lambda$$



Deformation parameter

$$\hat{\epsilon} = -\frac{\dot{H}}{H^2} = 2\frac{\rho_r}{\rho}$$

Assume: Decay continuous and Gamma constant

Cascading Model

$$\dot{\rho}_\Lambda = -\Gamma \rho_\Lambda$$

$$\dot{\rho}_r = -4H\rho_r + \Gamma \rho_\Lambda$$

Standard inflation (cold)

$$\Gamma \to 0 \qquad \rho_\Lambda \approx \; const \qquad \rho_r \to 0$$

"Warm" inflation (Berera)

$$\Gamma \gg H$$

New regime?

$$\Gamma \approx H \qquad \rho_r \approx \; const$$

Thoughts on transitions:

- Must be near 2nd order (but some tunneling can occur --> gravity waves!!!)
- Thermal effects can play crucial role (e.g. over barrier transitions)
- Models seem feasible in early universe at high temperature
- Problematic in late universe (transitions proceed slowly, usually exp suppression)
- Hard to calculate decay rate from fundamental theory (e.g. Feng, et. al.)

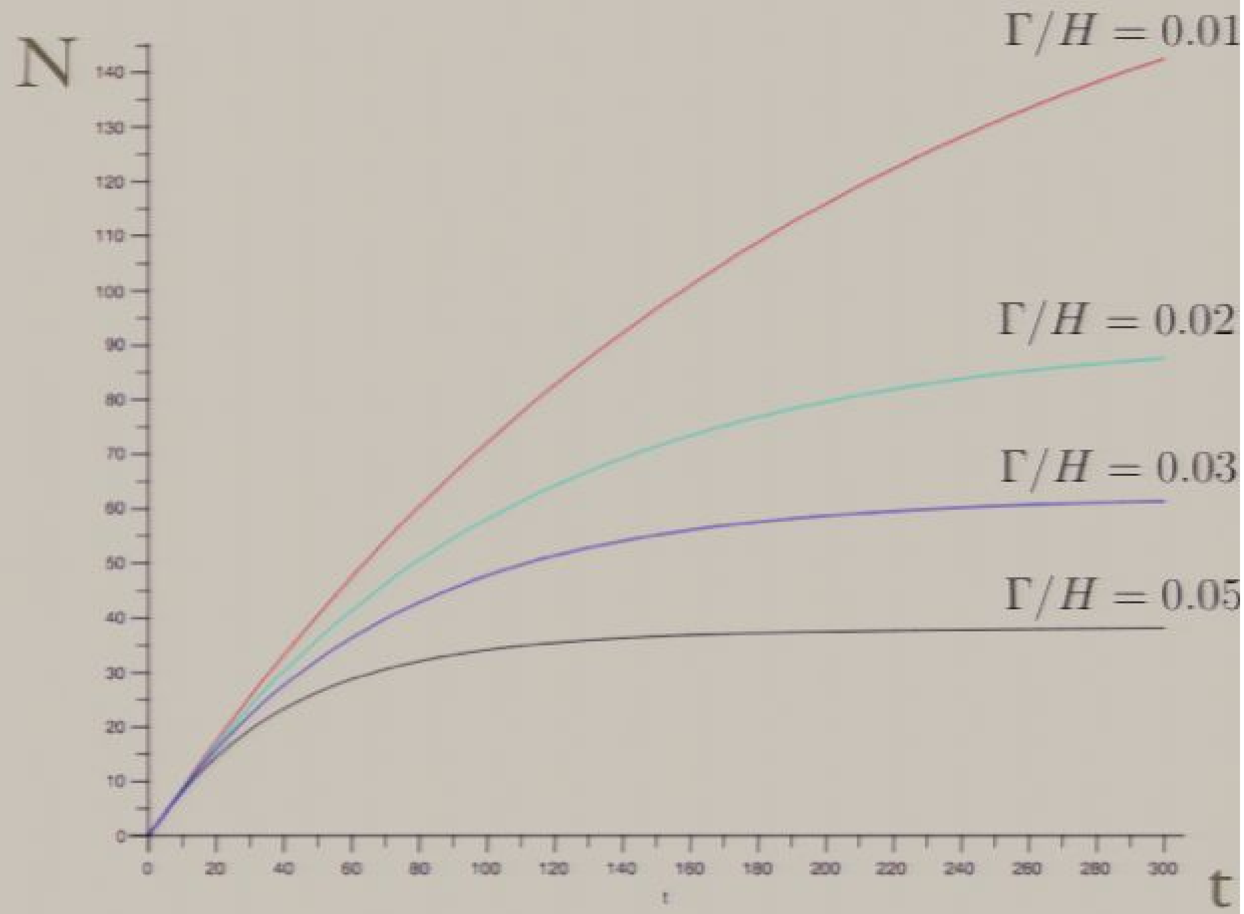
Do we get enough inflation?

$$N = \ln\left(\frac{a_e}{a_0}\right)$$

$$N = \left(\frac{16\pi\rho_{\Lambda_0}}{3M_p^2}\right)^{1/2} \int_{t_e}^{t_0} \frac{e^{-\Gamma t/2}}{\sqrt{2-\hat{\epsilon}}}\, dt,$$

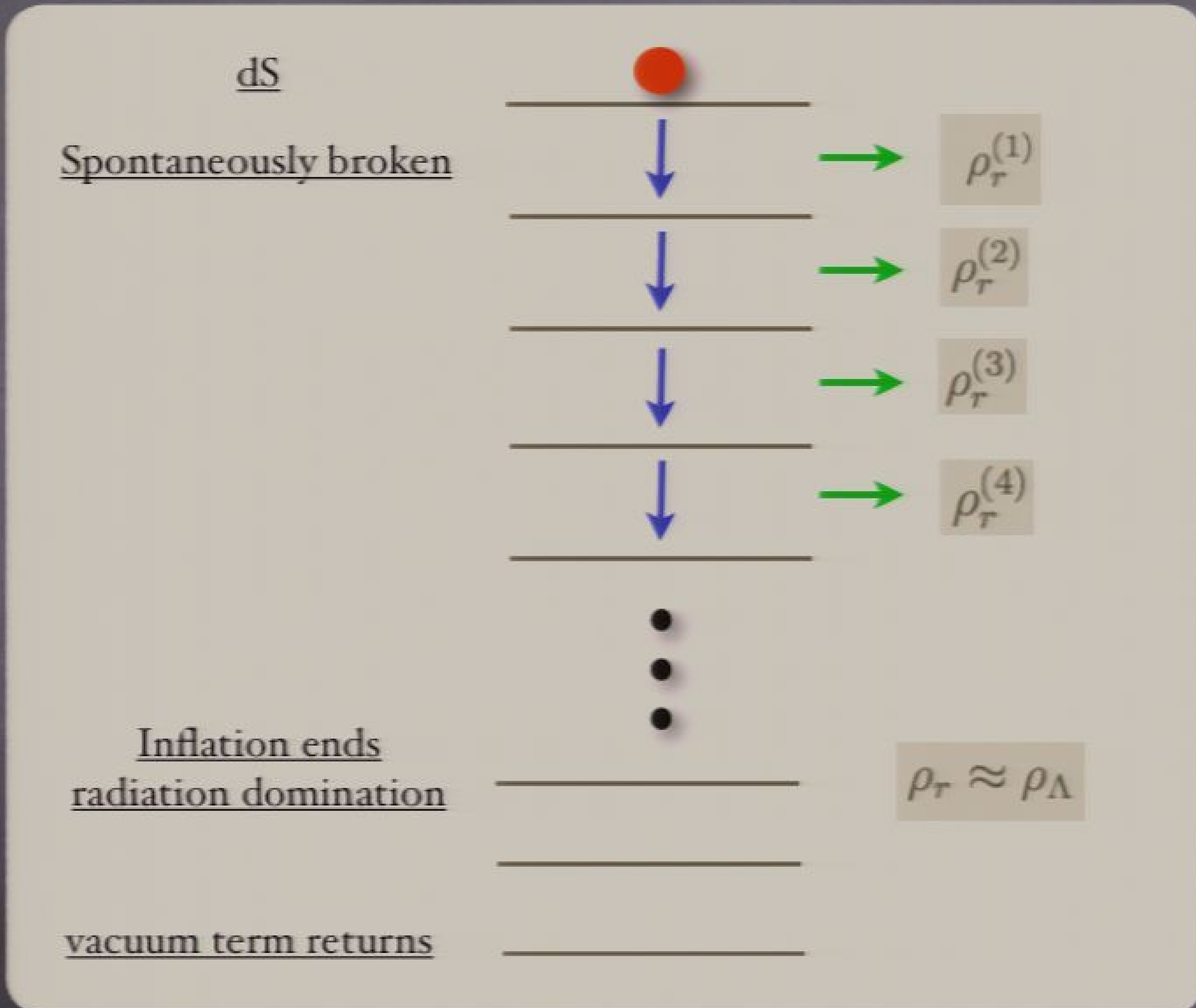
$$\approx \frac{2}{\Gamma}\left(\frac{16\pi\rho_{\Lambda_0}}{3M_p^2}\right)^{1/2} \sim \frac{8\rho_{\Lambda_0}^{1/2}}{\Gamma M_p} \sim 8\frac{H_b}{\Gamma}$$

$$\Gamma/H \lesssim 0.02$$



Compare to flatness of inflaton potential

CC problem?



Biggest Challenge: Understanding relaxation as decoherence sets in

Issues:

What's "New":

- No need for reheating
- Multi fluid approach, no need for *fundamental* scalars
- Band Structure Idea?
- CC result of degeneracy near TeV

What's not:

- Difficult to realize in string theory (we are working)
- KEY: must find decay rate (compare to inflationary potential)
- Simple examples like B-P promising, but technically difficult

Biggest Challenge: Understanding relaxation as decoherence sets in

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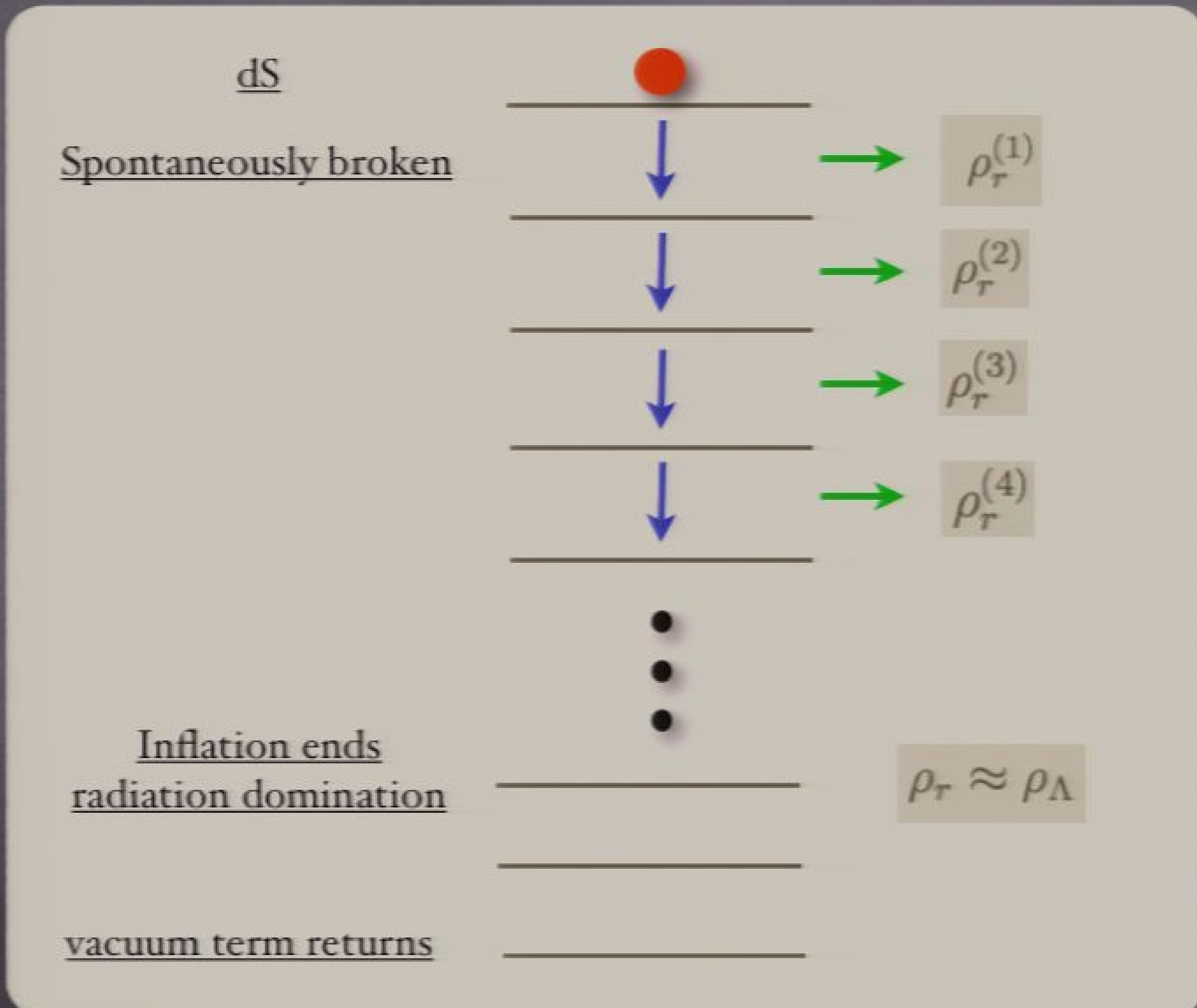

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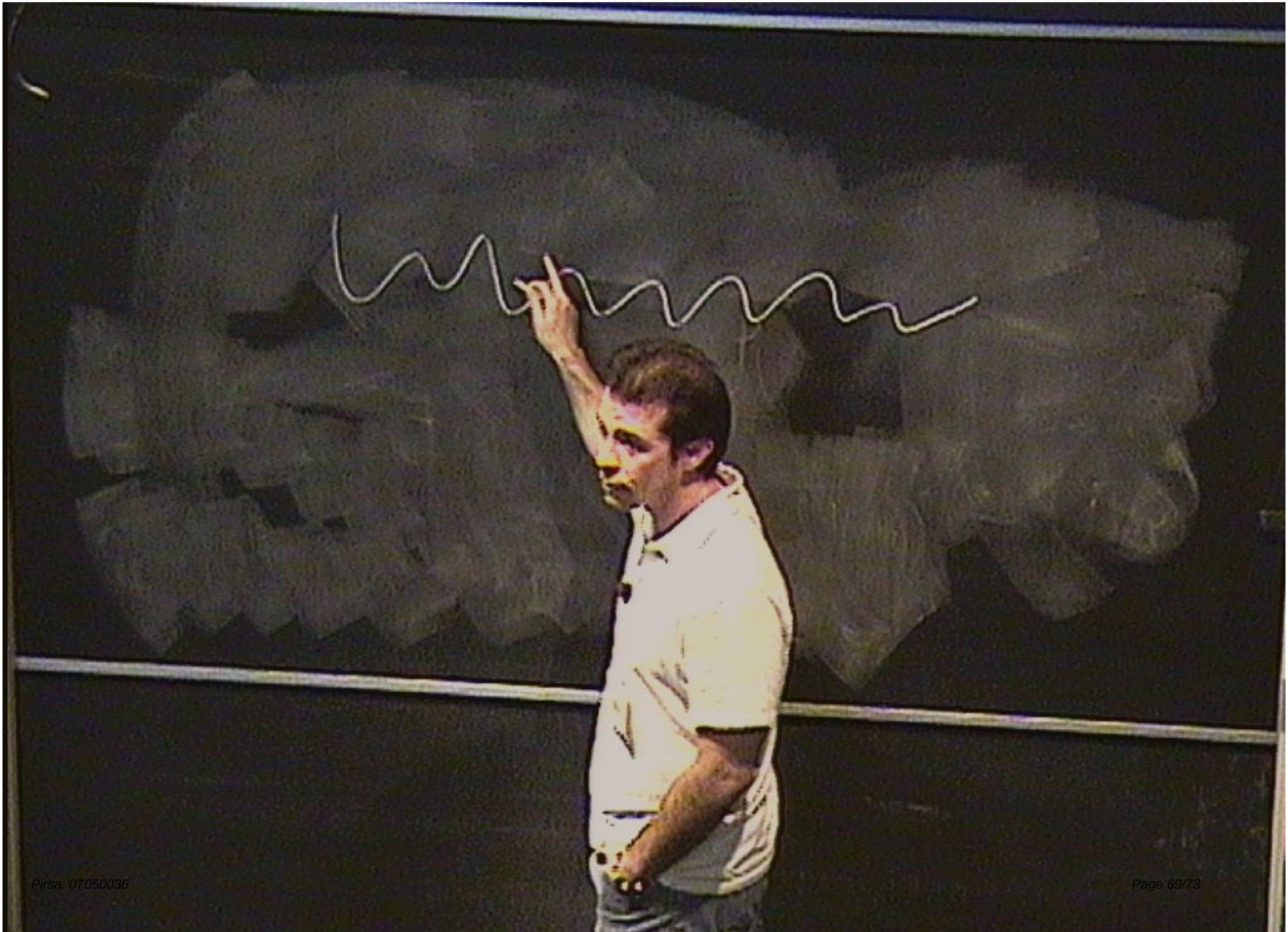
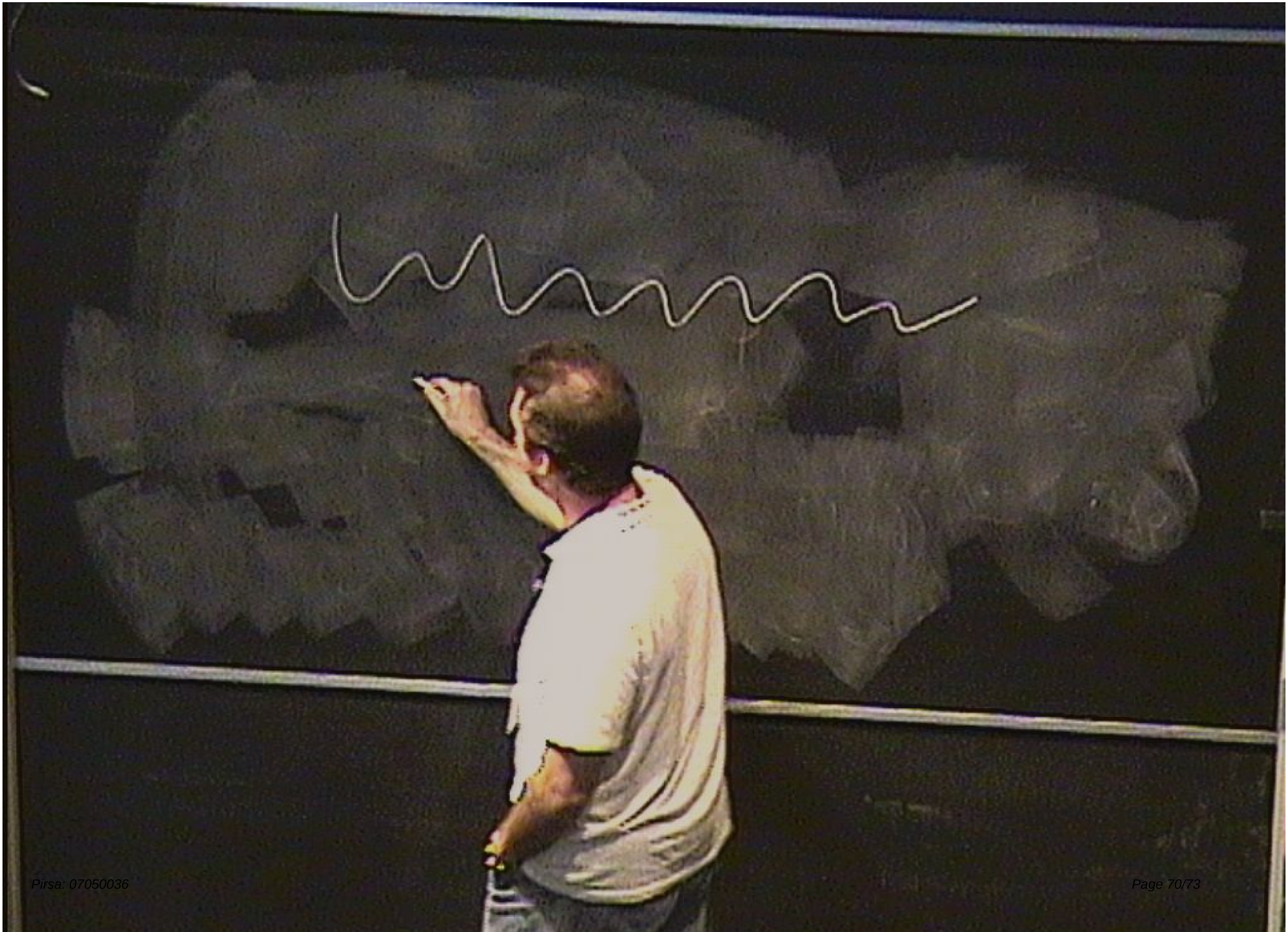
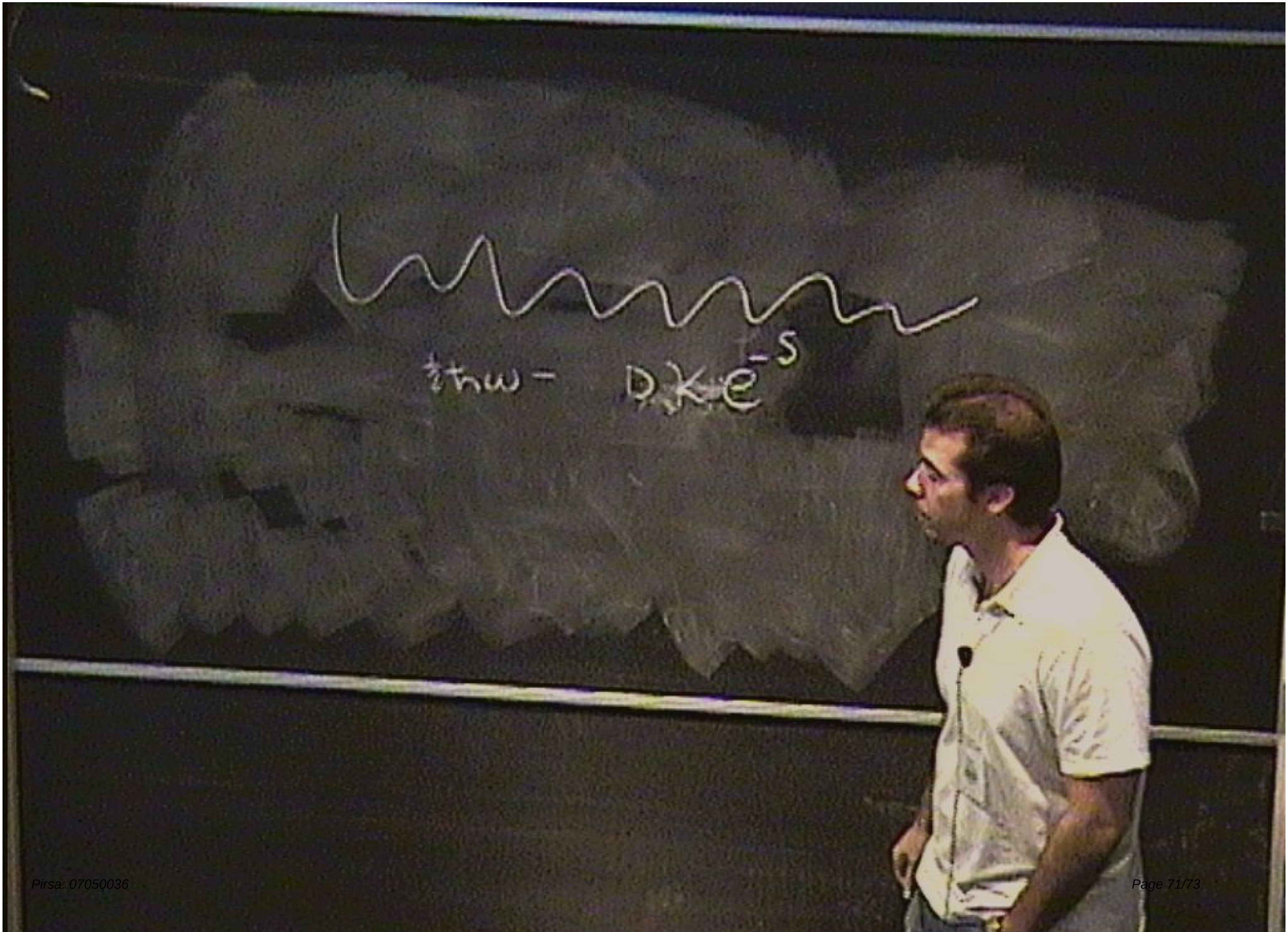
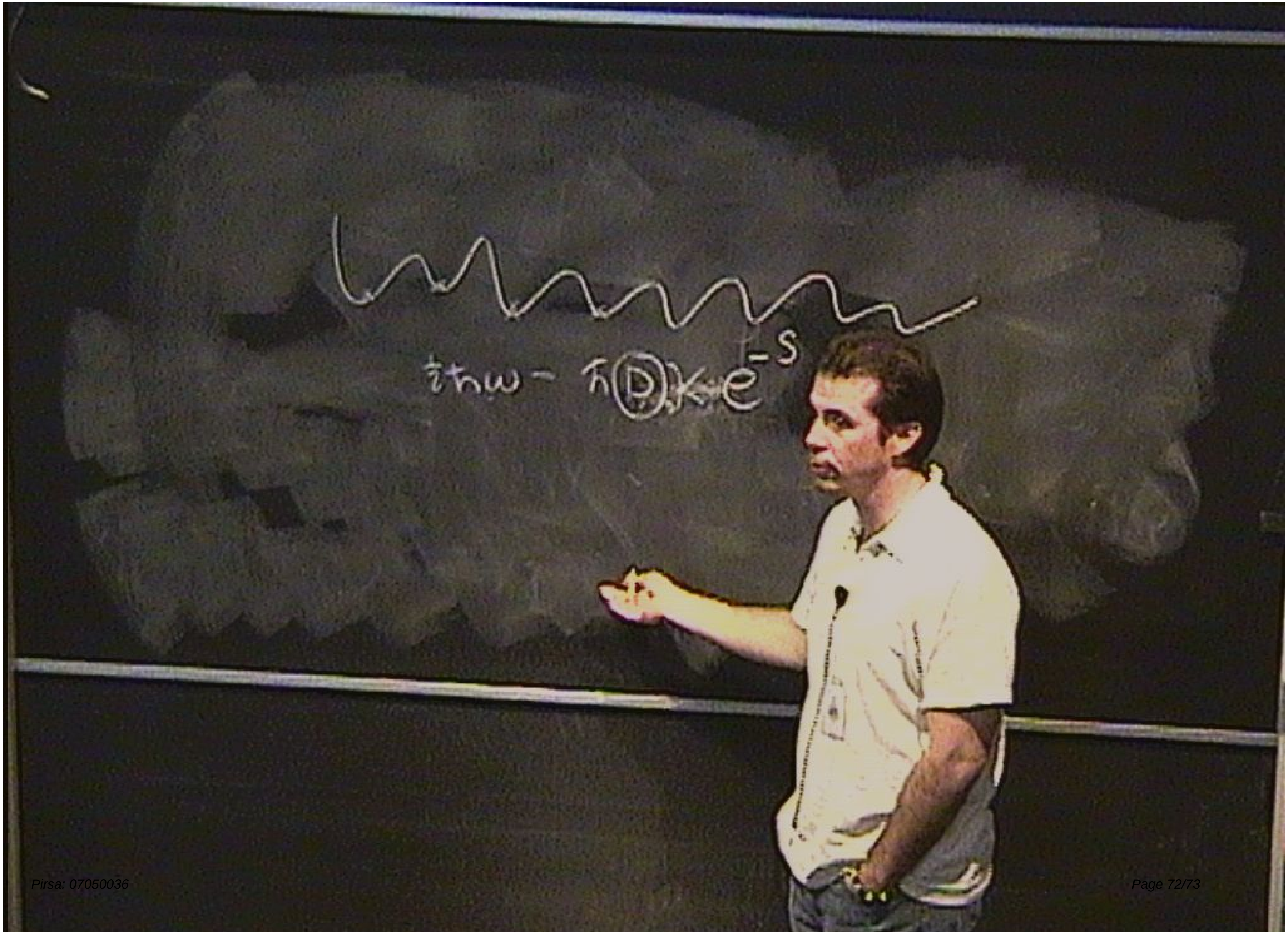
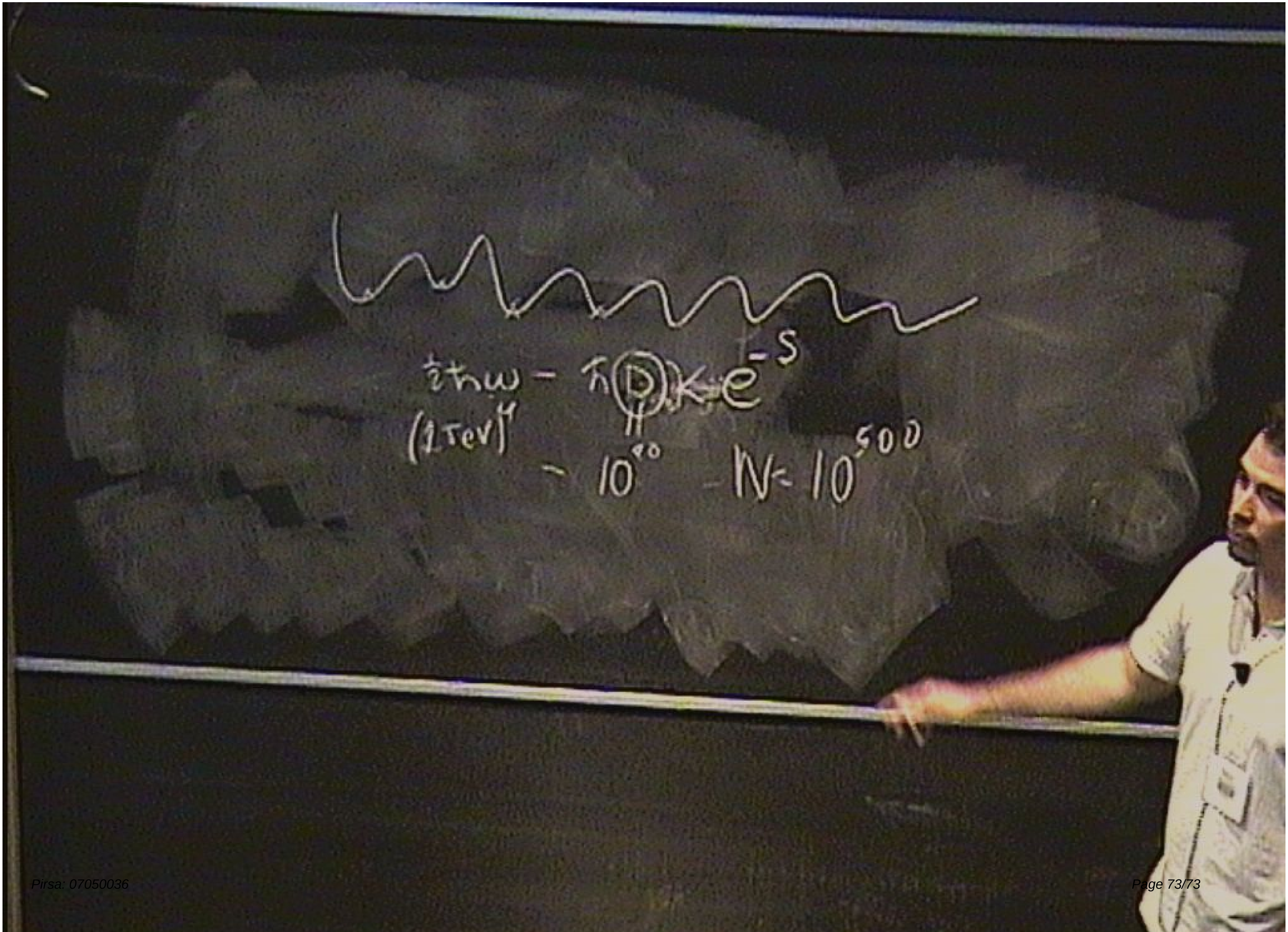





½ħω − D_s K e^{-s}




½ħω ~ ħ D K e^-s
(1 TeV)^4
~ 10^40
N ~ 10^500