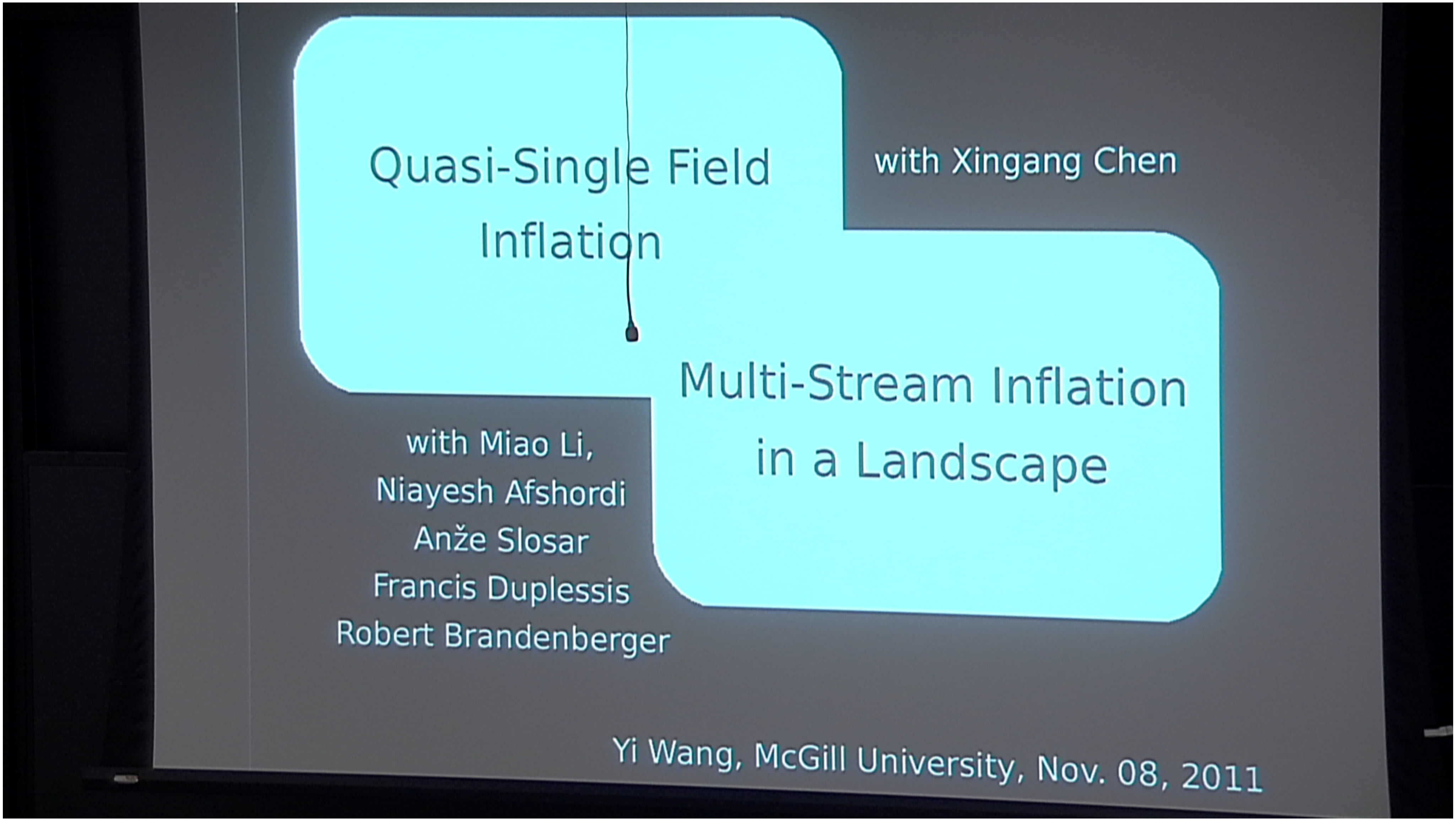
Title: Quasi-single and Multiple Field Inflation

Date: Nov 08, 2011 11:00 AM

URL: http://pirsa.org/11110002

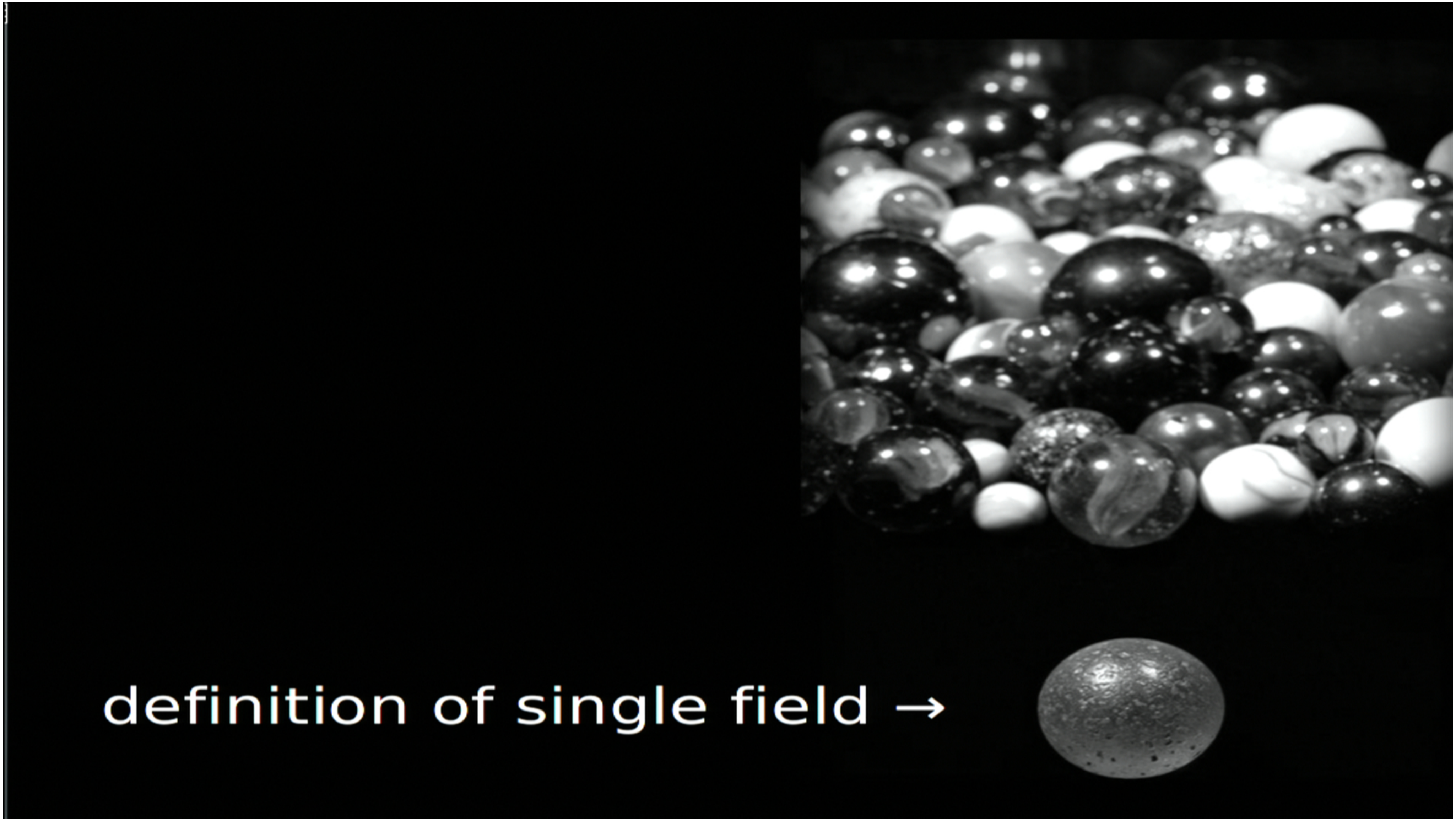
Abstract: The talk consists of two parts: (1) Quasi-single inflation, where the isocurvature direction has mass of order Hubble parameter. This part is based on 0911.3380 and new results about higher mass, and a sharp turn in trajectory. (2) Multi-stream inflation, where the inflationary trajectory bifurcates. This part is based on 0903.2123, 1006.5021 and a on-going project on calculating the bifurcation probability in a complicated landscape.

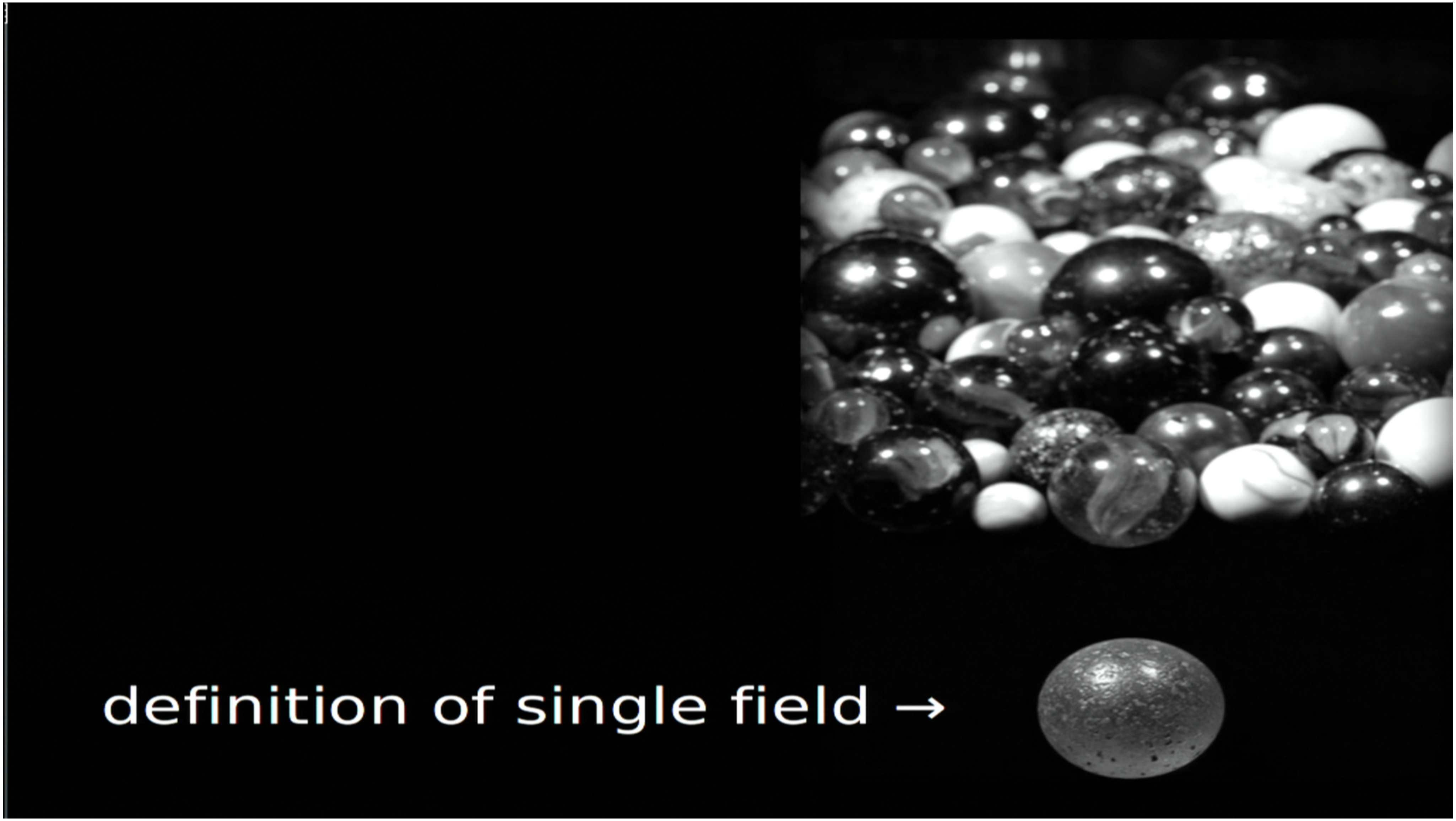

Quasi-Single Field Inflation
with Xingang Chen
Multi-Stream Inflation in a Landscape
with Miao Li,
Niayesh Afshordi
Anže Slosar
Francis Duplessis
Robert Brandenberger
Yi Wang, McGill University, Nov. 08, 2011

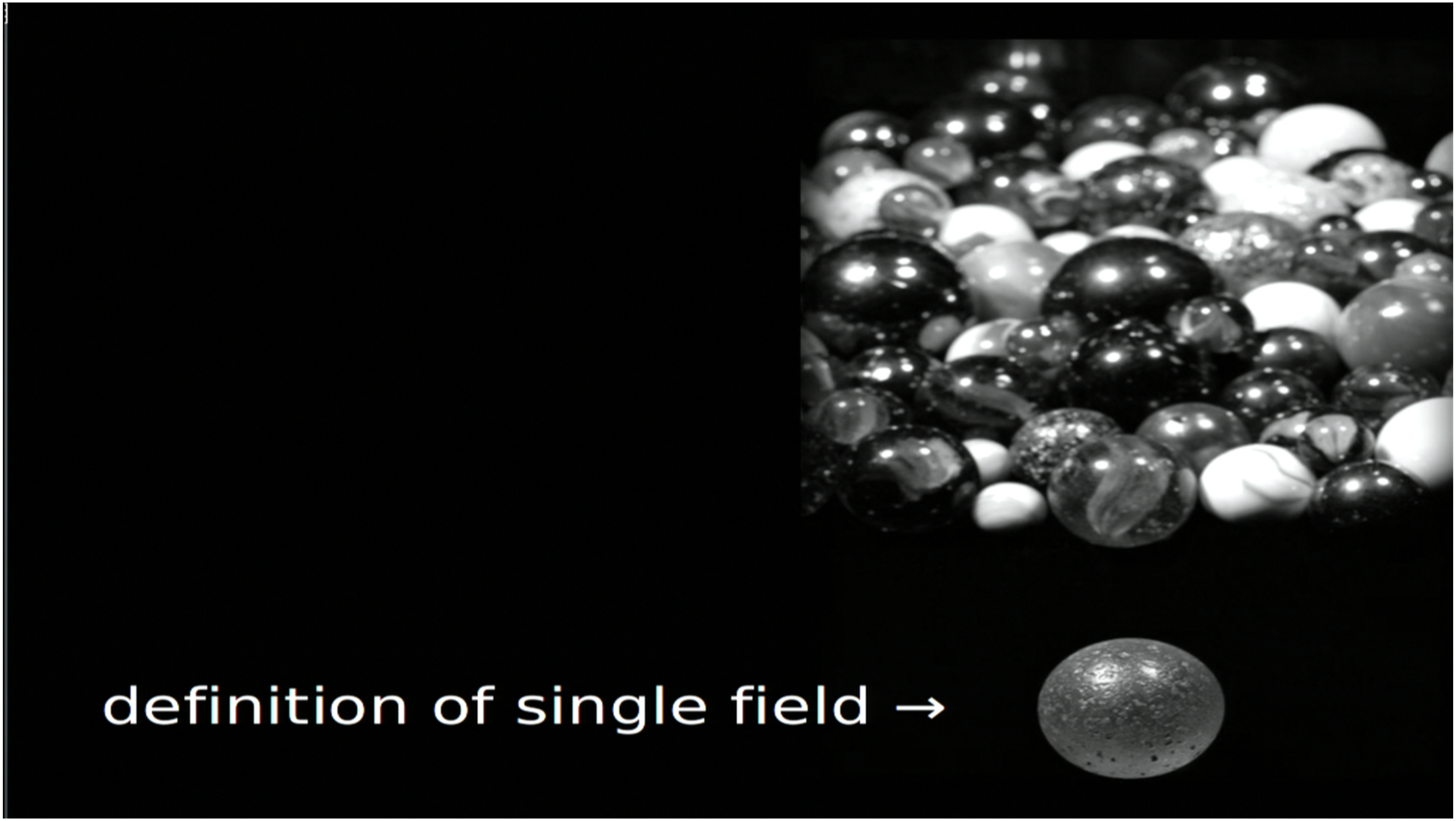
Quasi-Single Field Inflation

with Xingang Chen

Stream Inflation
in a Landscape


definition of single field →

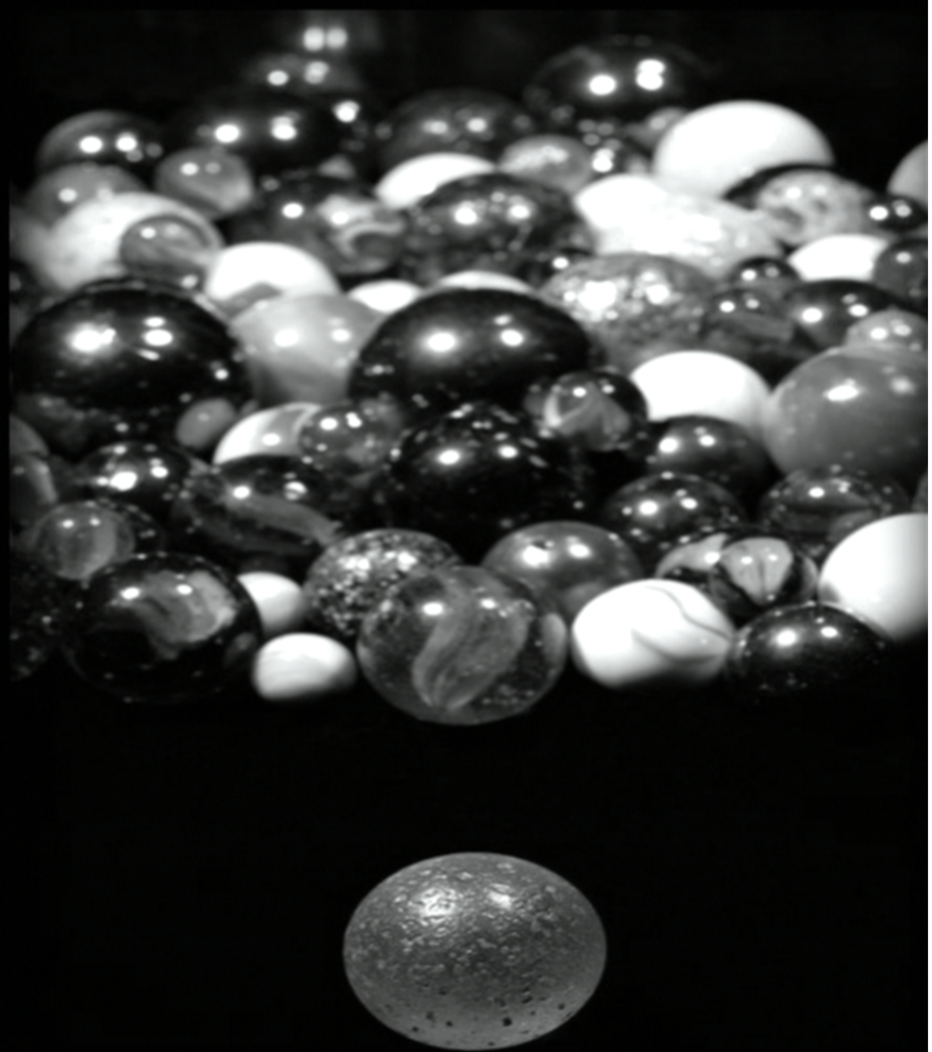

definition of single field →


definition of single field →

What is heavy?

What is light?

not absolute,
comparison needed



Mass of isocurvature direction

-- Background:

compare with inflaton mass $m^2 \sim \eta H^2$

-- Perturbation:

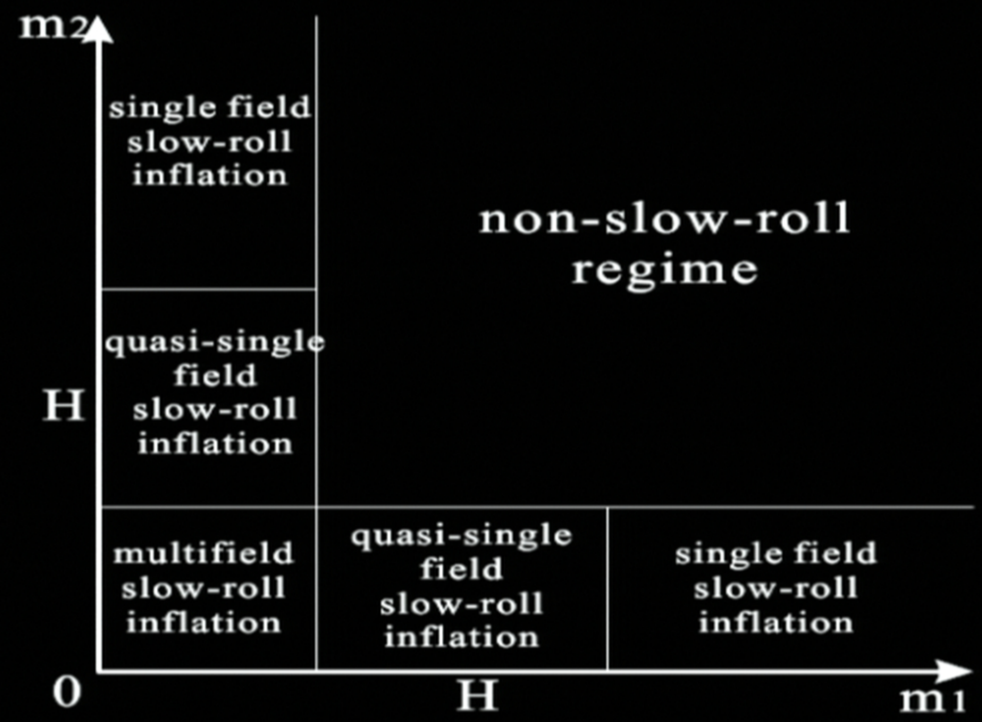
compare with Hubble parameter $m \sim H$

Isocurvaton with $m \sim H$

-- no effects at background level

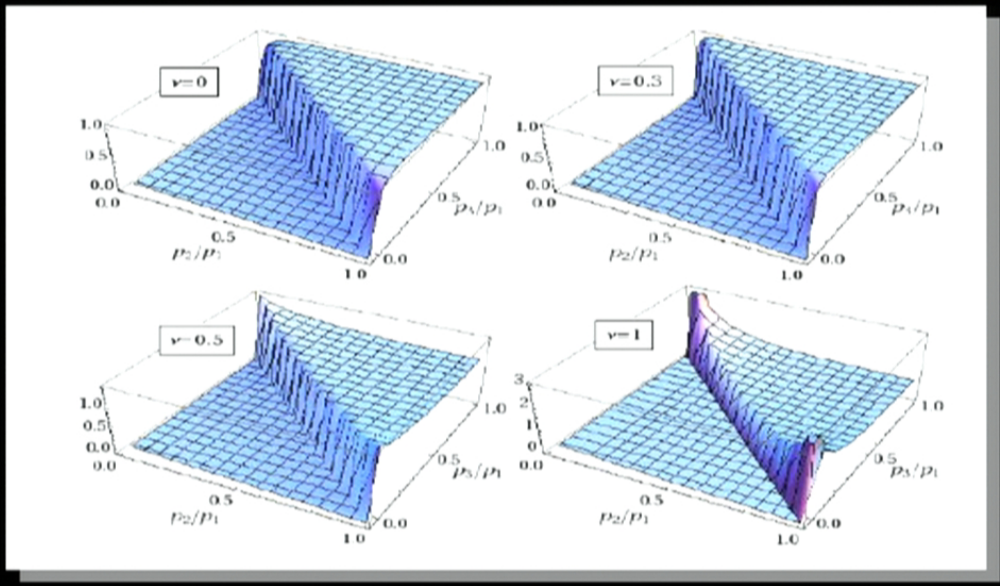
-- shows up in perturbations

Quasi-single field inflation

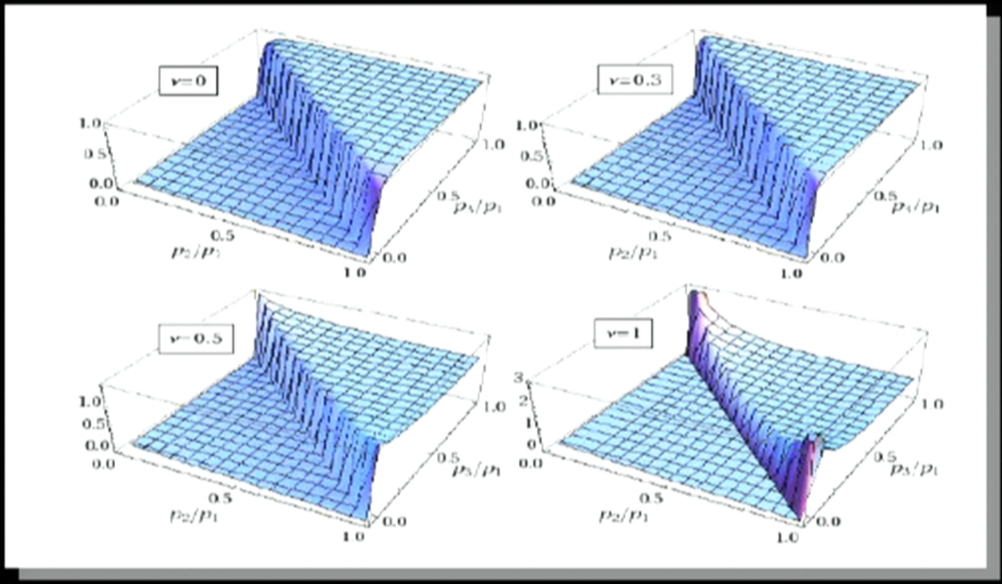

m2
single field slow-roll inflation
non-slow-roll regime
quasi-single field slow-roll inflation
H
multifield slow-roll inflation
quasi-single field slow-roll inflation
single field slow-roll inflation
0
H
m1

$m \sim H$:

- say, $H / 10 < m < 3H/2$
- -- a family of quasi-local shapes



ν=0
ν=0.3
ν=0.5
ν=1
p_2/p_1
p_3/p_1



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$m \sim H$:

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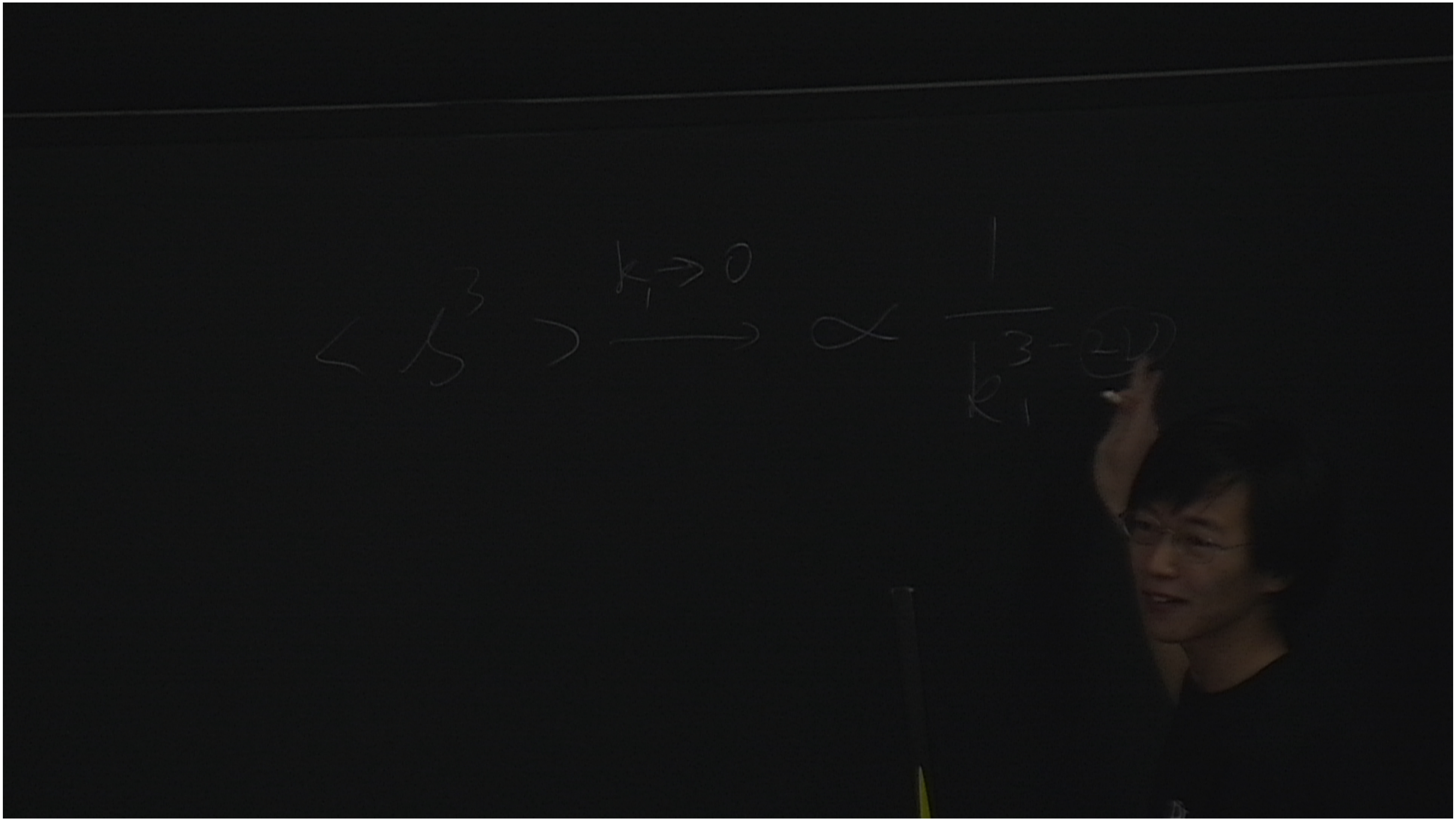
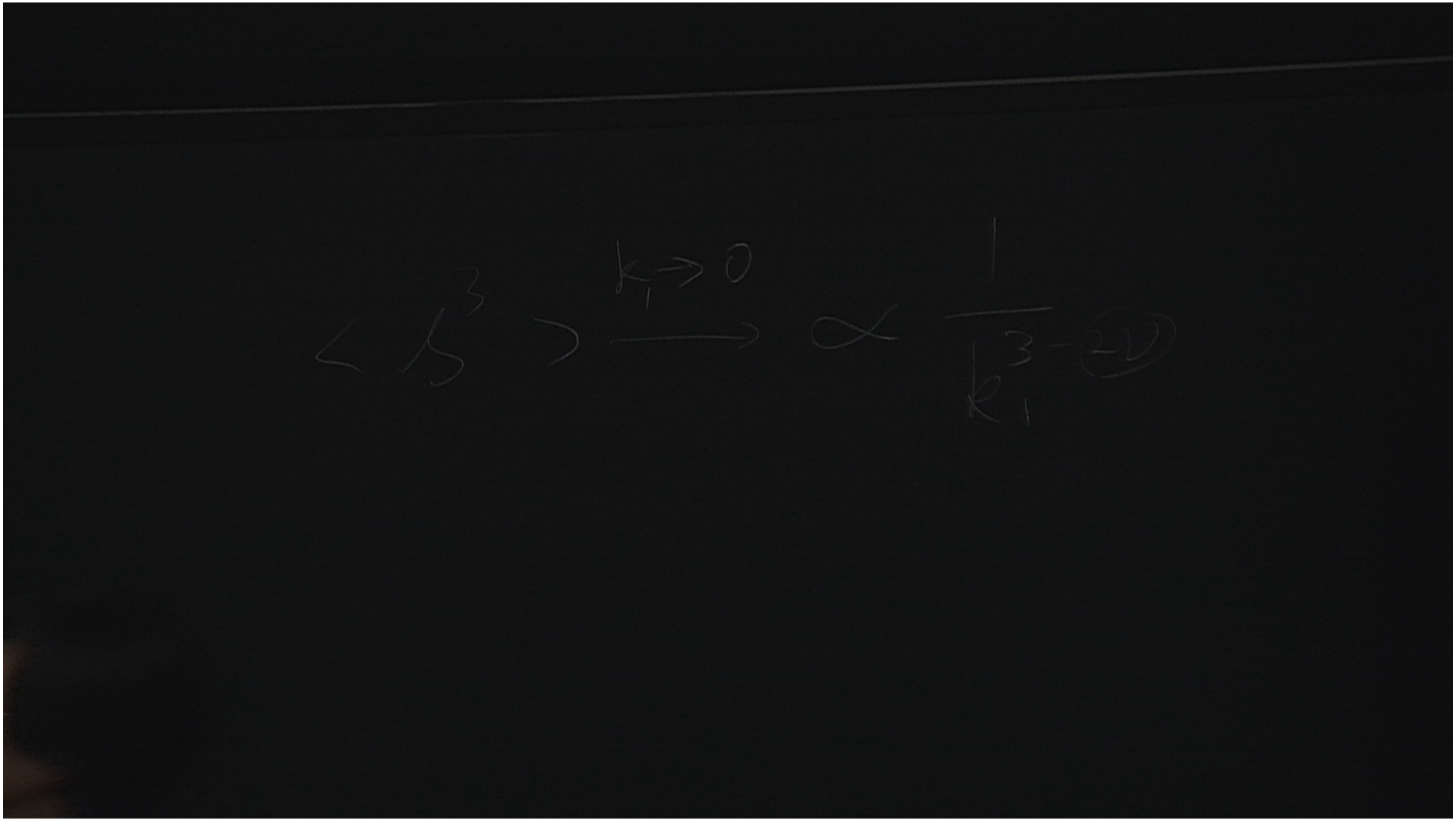
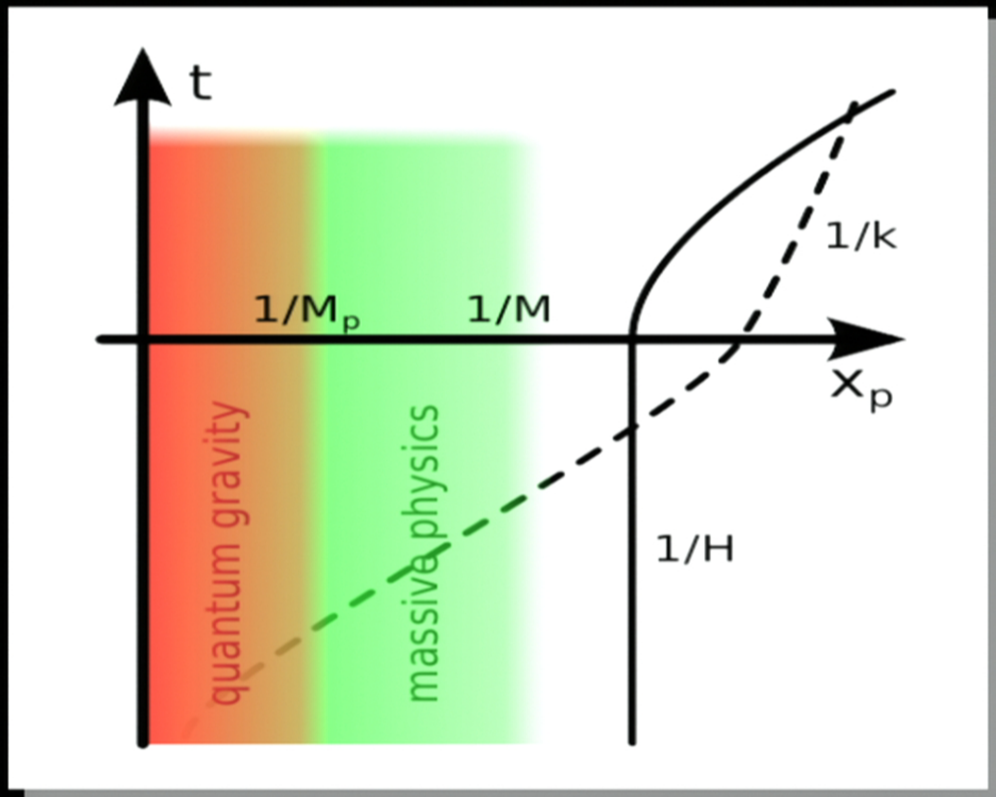
$m \sim H$:

- say, $H / 10 < m < 3H/2$
  -- a family of quasi-local shapes

- say, $3H/2 \leq M < 10\, H$
  -- a trans-M window of new physics




$\langle \zeta^3 \rangle \xrightarrow{k_1 \to 0} \propto \frac{1}{k_1^{3-2\nu}}$


t
1/k
1/M_p
1/M
x_p
quantum gravity
massive physics
1/H

m ~ H

Not only phenomenological, but also theoretical

The η problem: $m \ll H \;\rightarrow\; m \sim H$ (every field)

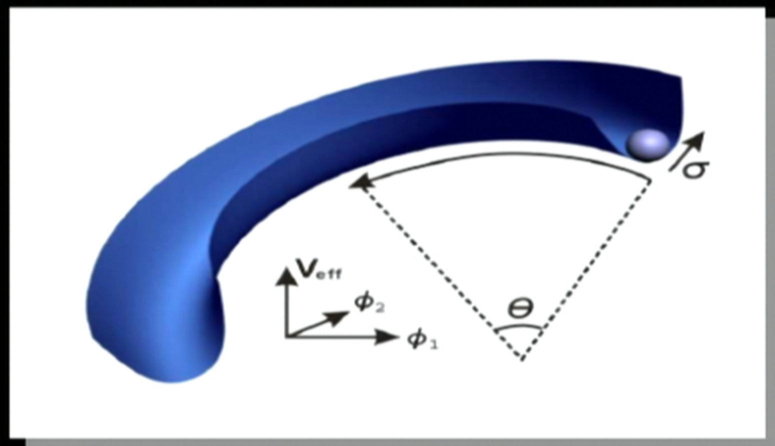
-- inflaton: probably fine tuned

-- isocurvaton: no need to tune again

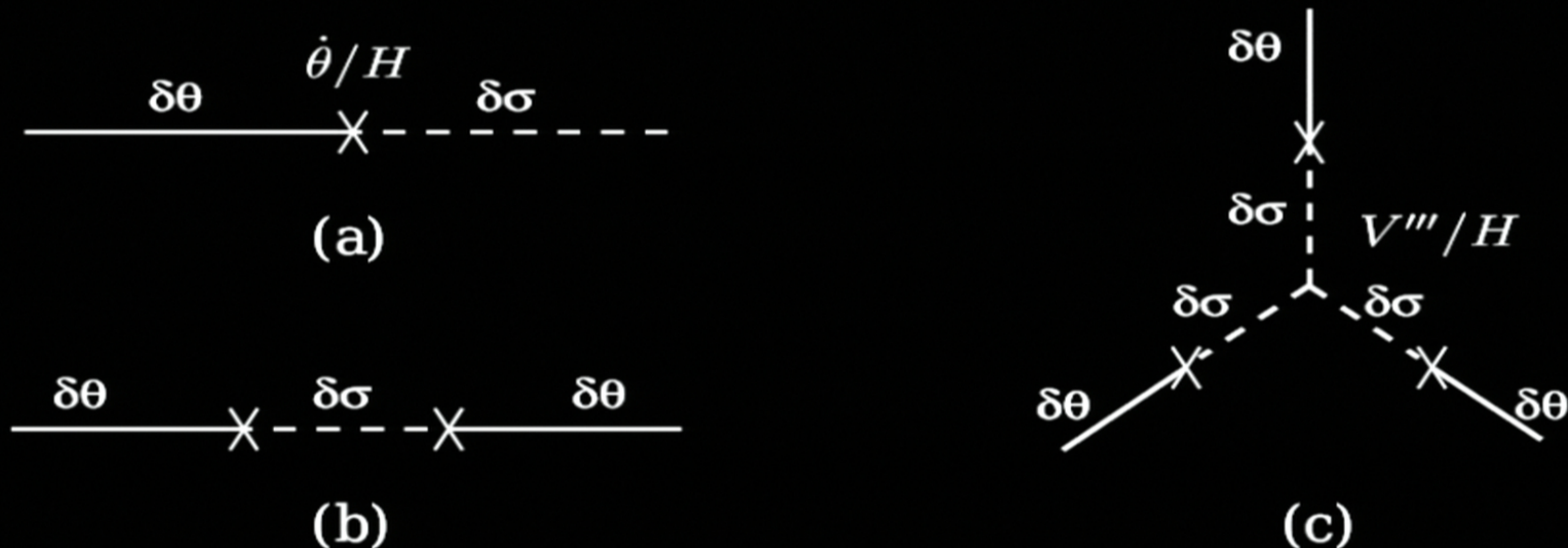
Also: Baumann, Green (2011):

SUSY → broken by gravity → $m \sim H$

A simple model



$$S_m = \int d^4x\sqrt{-g}\left[-\frac{1}{2}(\tilde{R}+\sigma)^2 g^{\mu\nu}\partial_\mu\theta\partial_\nu\theta - \frac{1}{2}g^{\mu\nu}\partial_\mu\sigma\partial_\nu\sigma - V_{\rm sr}(\theta) - V(\sigma)\right]$$



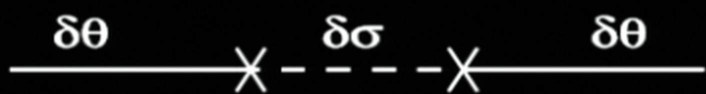
$$\delta P_\zeta \sim \left(\dot{\theta}/H\right)^2 P_\zeta$$

$$f_{NL} \sim P_\zeta^{-1/2} \left(\dot{\theta}/H\right)^3 (V'''/H)$$

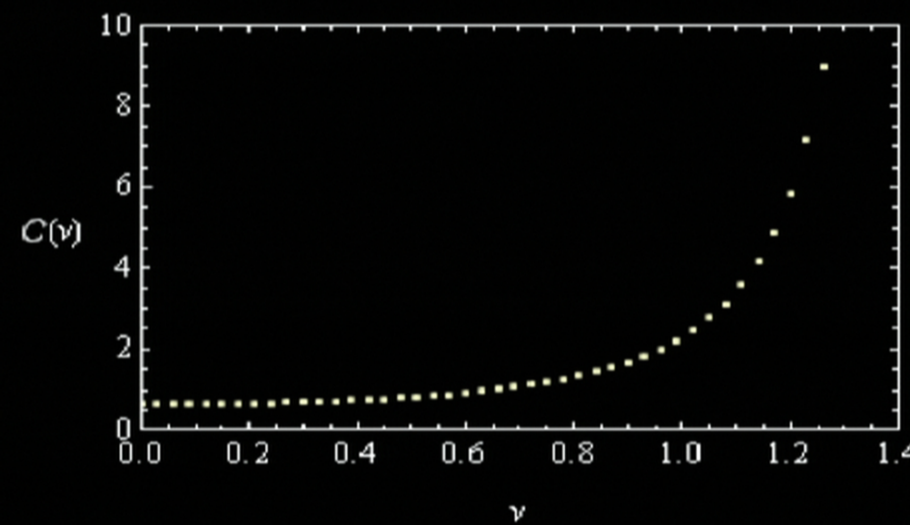
$$P_\zeta = \frac{H^4}{4\pi^2 R^2 \dot{\theta}_0^2} \left[1 + 8\mathcal{C} \left(\frac{\dot{\theta}_0}{H} \right)^2 \right]$$

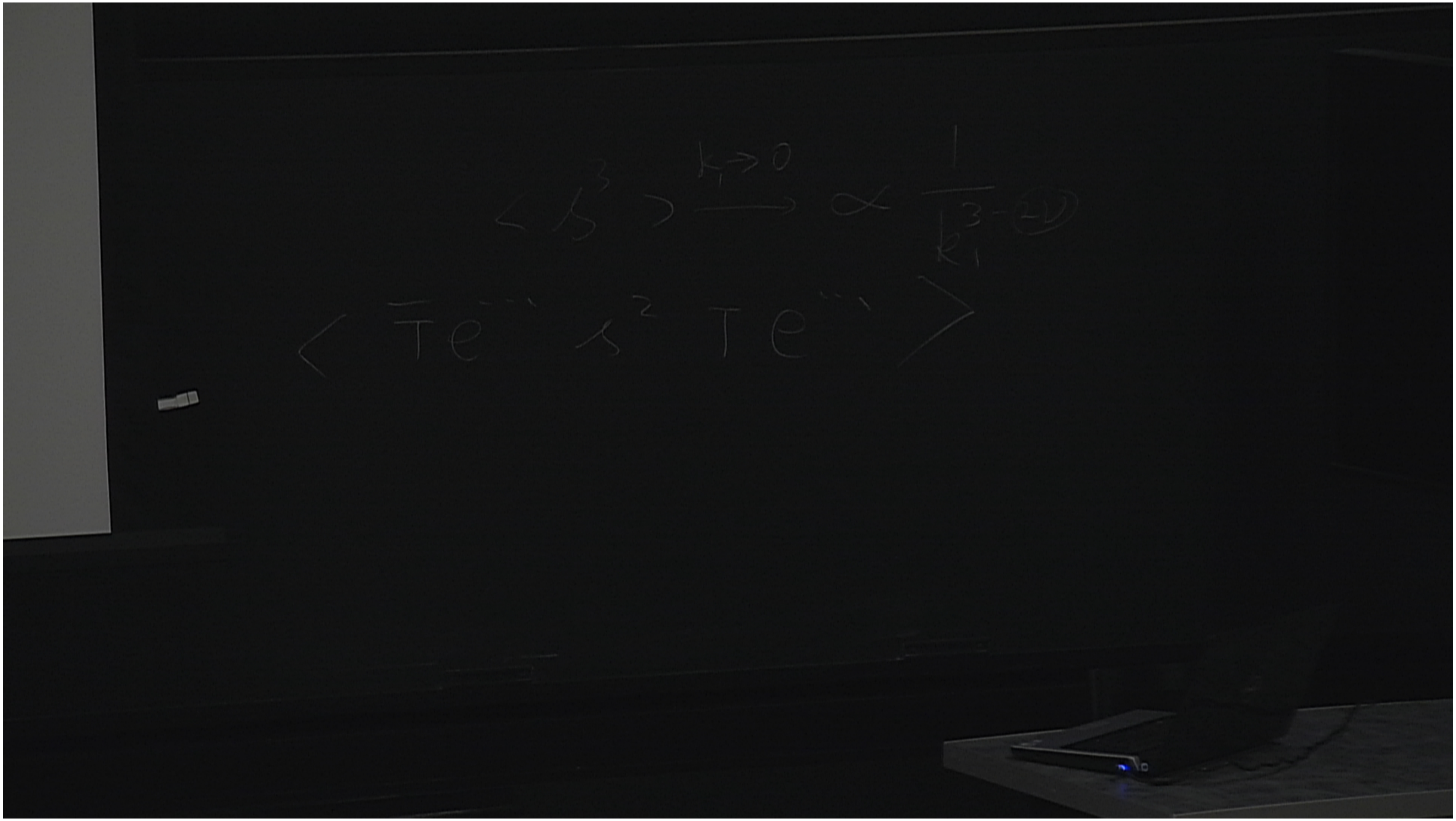
$$\mathcal{C}(\nu) \equiv \frac{\pi}{4} \mathrm{Re} \left[\int_0^\infty dx_1 \int_{x_1}^\infty dx_2 \left(x_1^{-1/2} H_\nu^{(1)}(x_1) e^{ix_1} x_2^{-1/2} H_\nu^{(2)}(x_2) e^{-ix_2} - x_1^{-1/2} H_\nu^{(1)}(x_1) e^{-ix_1} x_2^{-1/2} H_\nu^{(2)}(x_2) e^{-ix_2} \right) \right] .$$

$$\nu = \sqrt{9/4 - m^2/H^2}$$

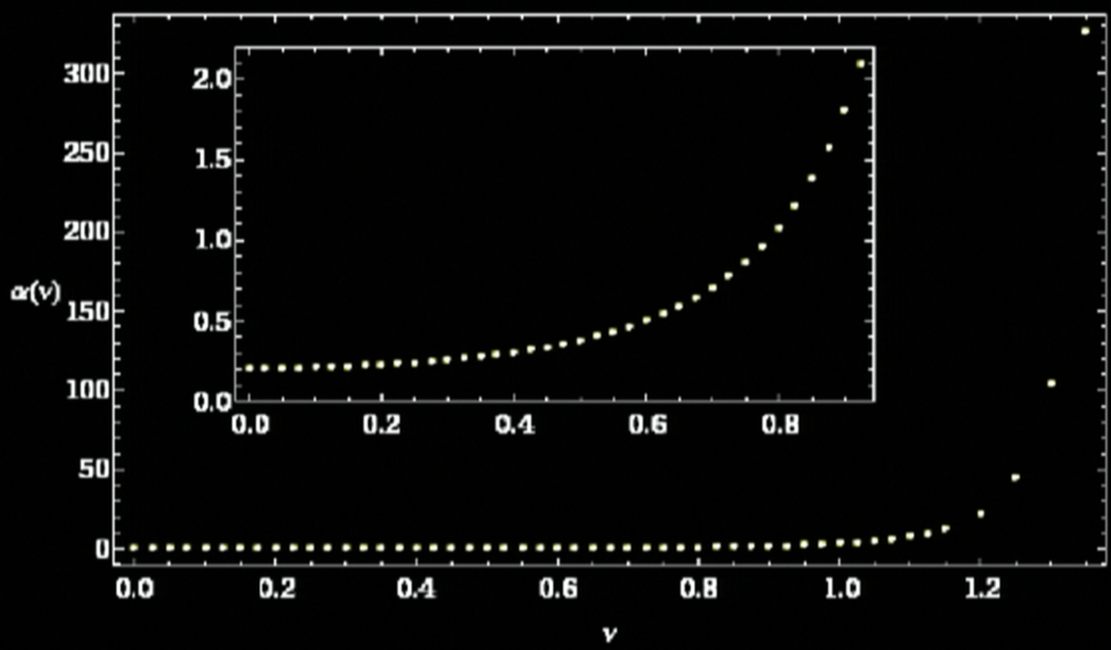


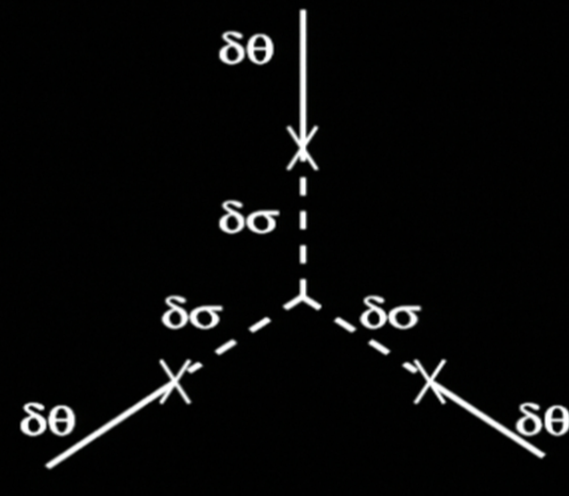
(b)





$$\langle \delta\theta^3 \rangle \equiv \langle 0| \left[\bar{T} \exp\left(i \int_{t_0}^{t} dt' H_I(t') \right) \right] \delta\theta_I^3(t) \left[T \exp\left(-i \int_{t_0}^{t} dt' H_I(t') \right) \right] |0\rangle$$

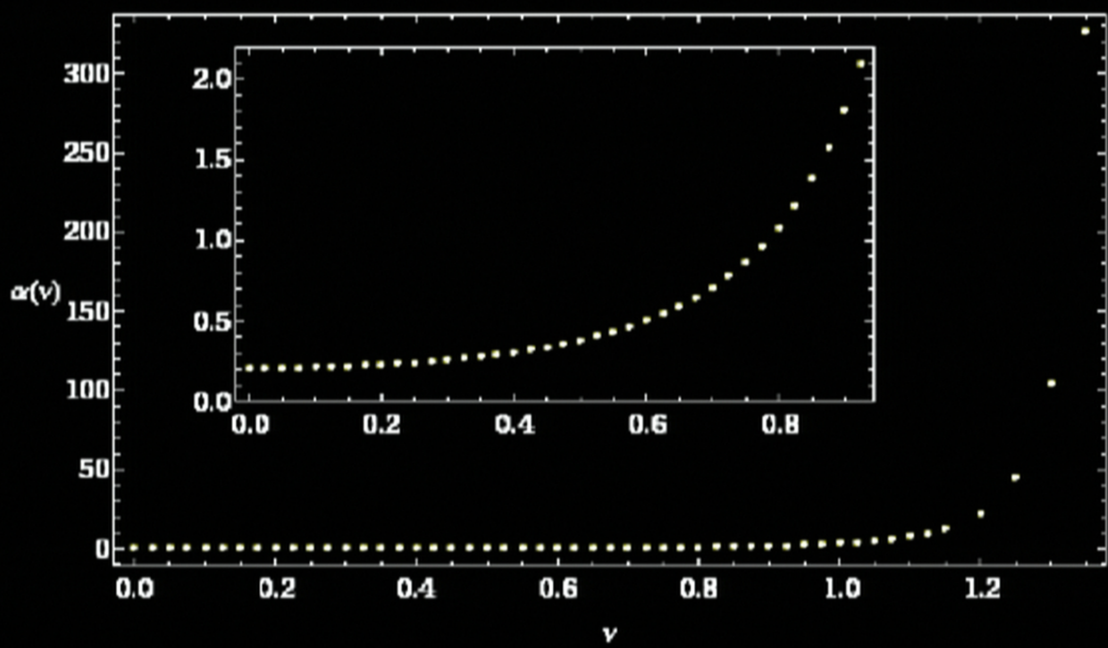


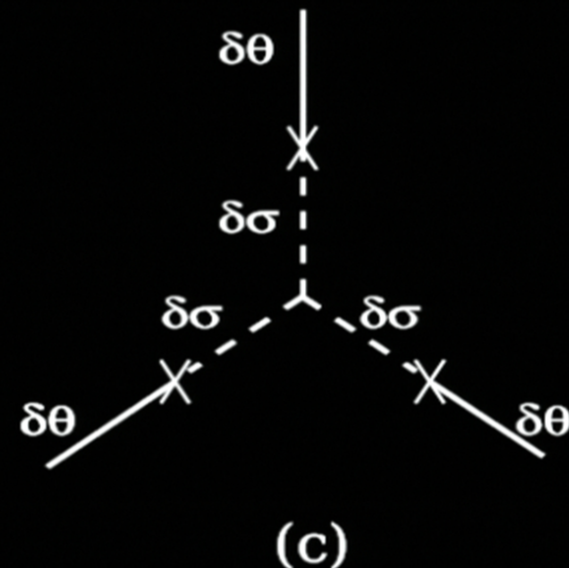


(c)

Perhaps they can be resummed, using the method by Burgess, Leblond, Holman and Shandera (2009)

$$\langle \delta\theta^3 \rangle \equiv \langle 0 | \left[\bar{T} \exp\left(i \int_{t_0}^{t} dt' H_I(t') \right) \right] \delta\theta_I^3(t) \left[T \exp\left(-i \int_{t_0}^{t} dt' H_I(t') \right) \right] | 0 \rangle$$





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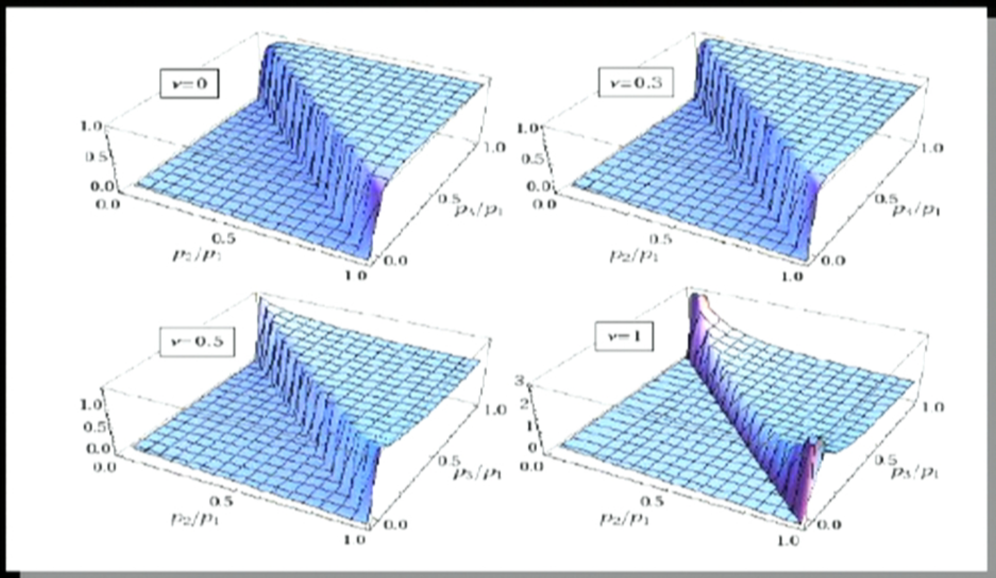
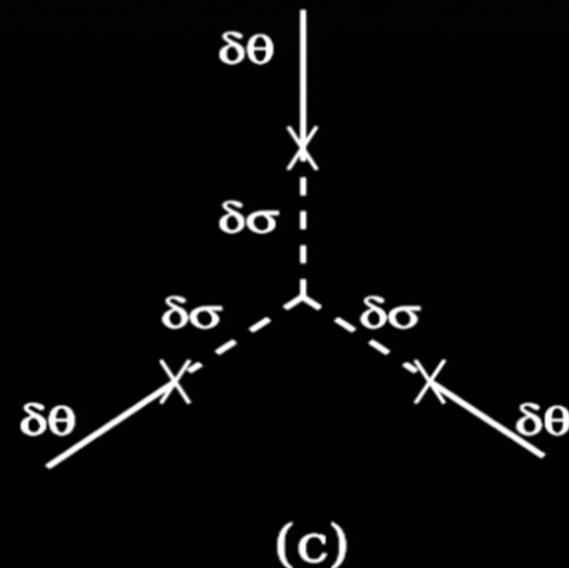
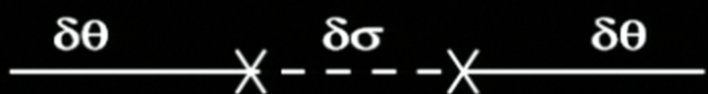




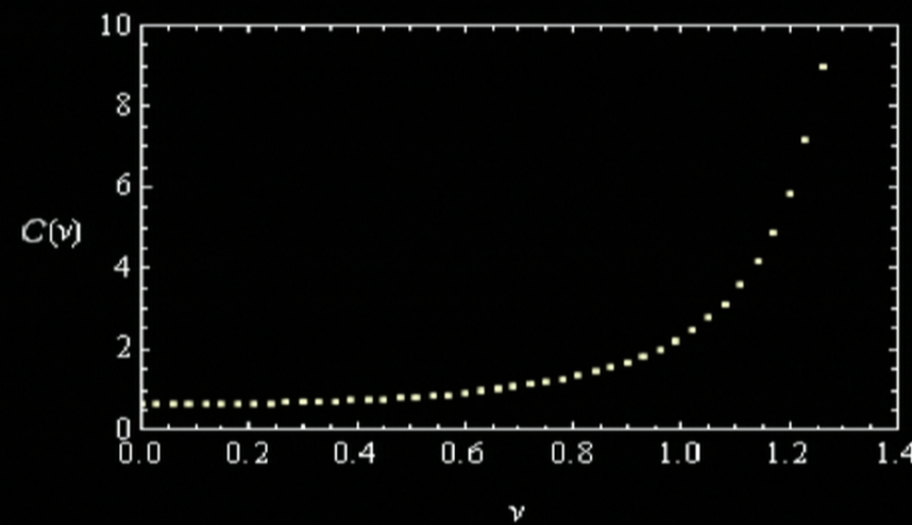
$$P_\zeta = \frac{H^4}{4\pi^2 R^2 \dot{\theta}_0^2}\left[1 + 8\mathcal{C}\left(\frac{\dot{\theta}_0}{H}\right)^2\right]$$

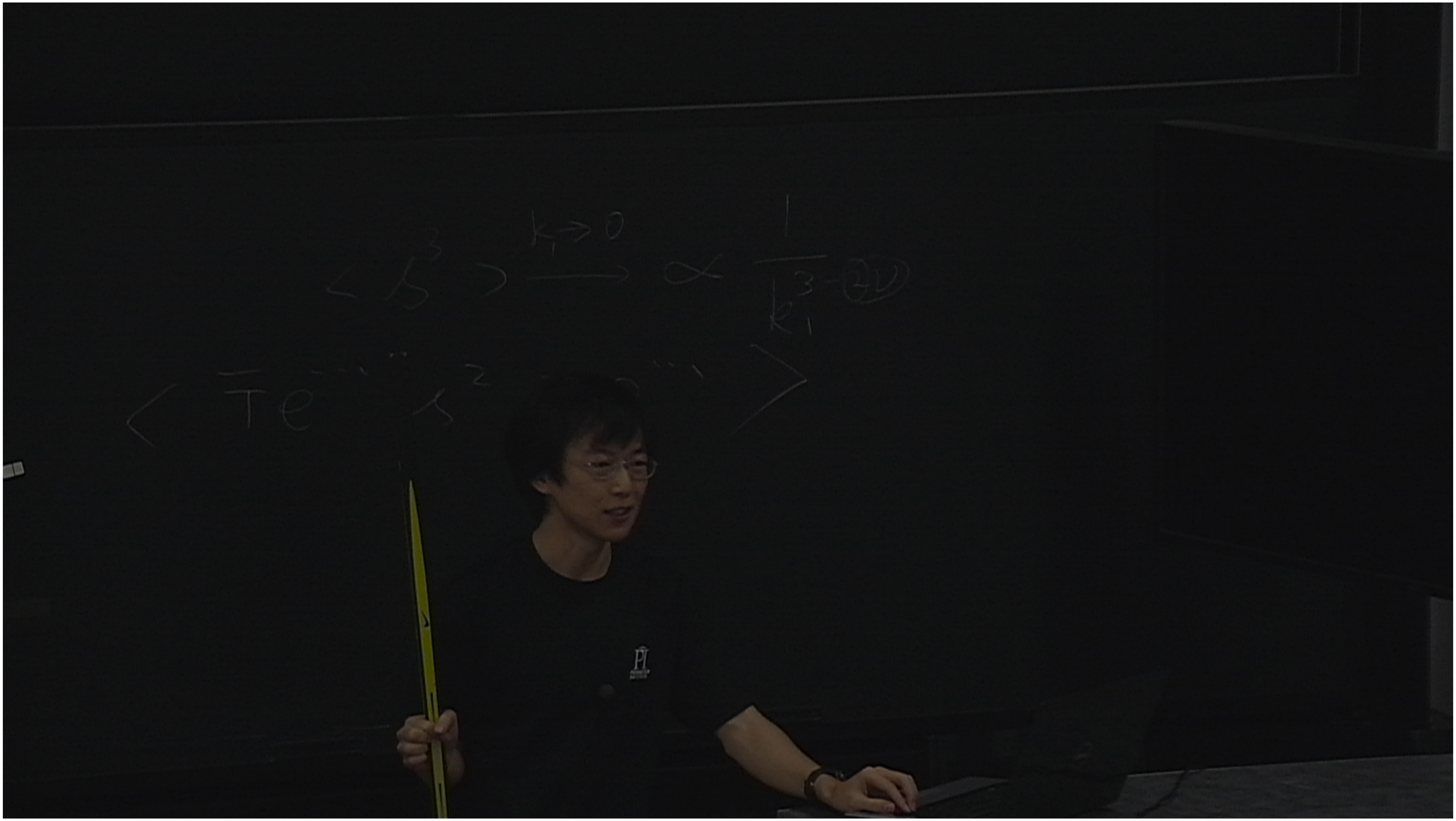
$$\mathcal{C}(\nu) \equiv \frac{\pi}{4}\mathrm{Re}\left[\int_0^\infty dx_1 \int_{x_1}^\infty dx_2 \left(x_1^{-1/2} H_\nu^{(1)}(x_1) e^{ix_1} x_2^{-1/2} H_\nu^{(2)}(x_2) e^{-ix_2} - x_1^{-1/2} H_\nu^{(1)}(x_1) e^{-ix_1} x_2^{-1/2} H_\nu^{(2)}(x_2) e^{-ix_2}\right)\right] .$$

$$\nu = \sqrt{9/4 - m^2/H^2}$$



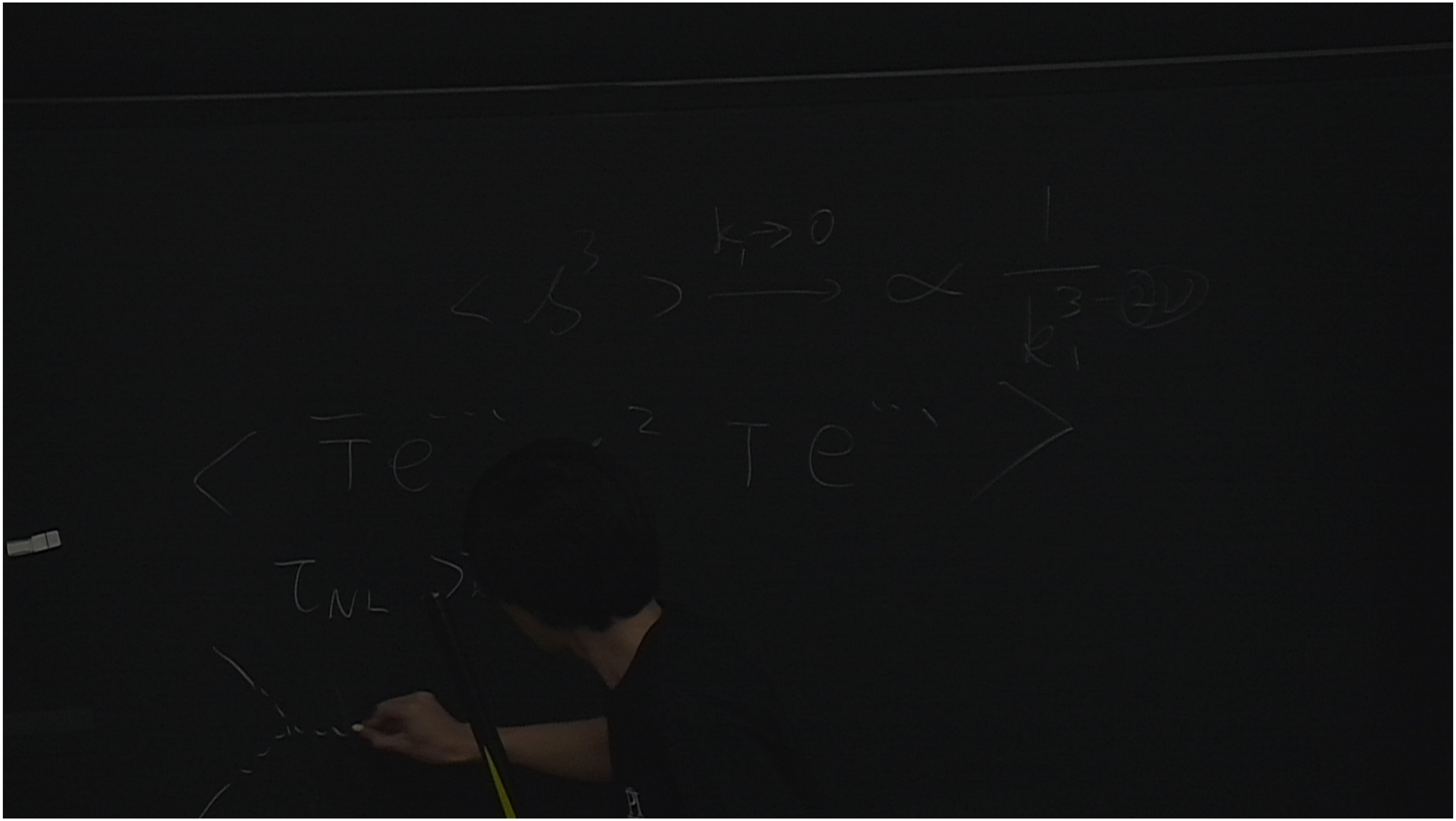
(b)

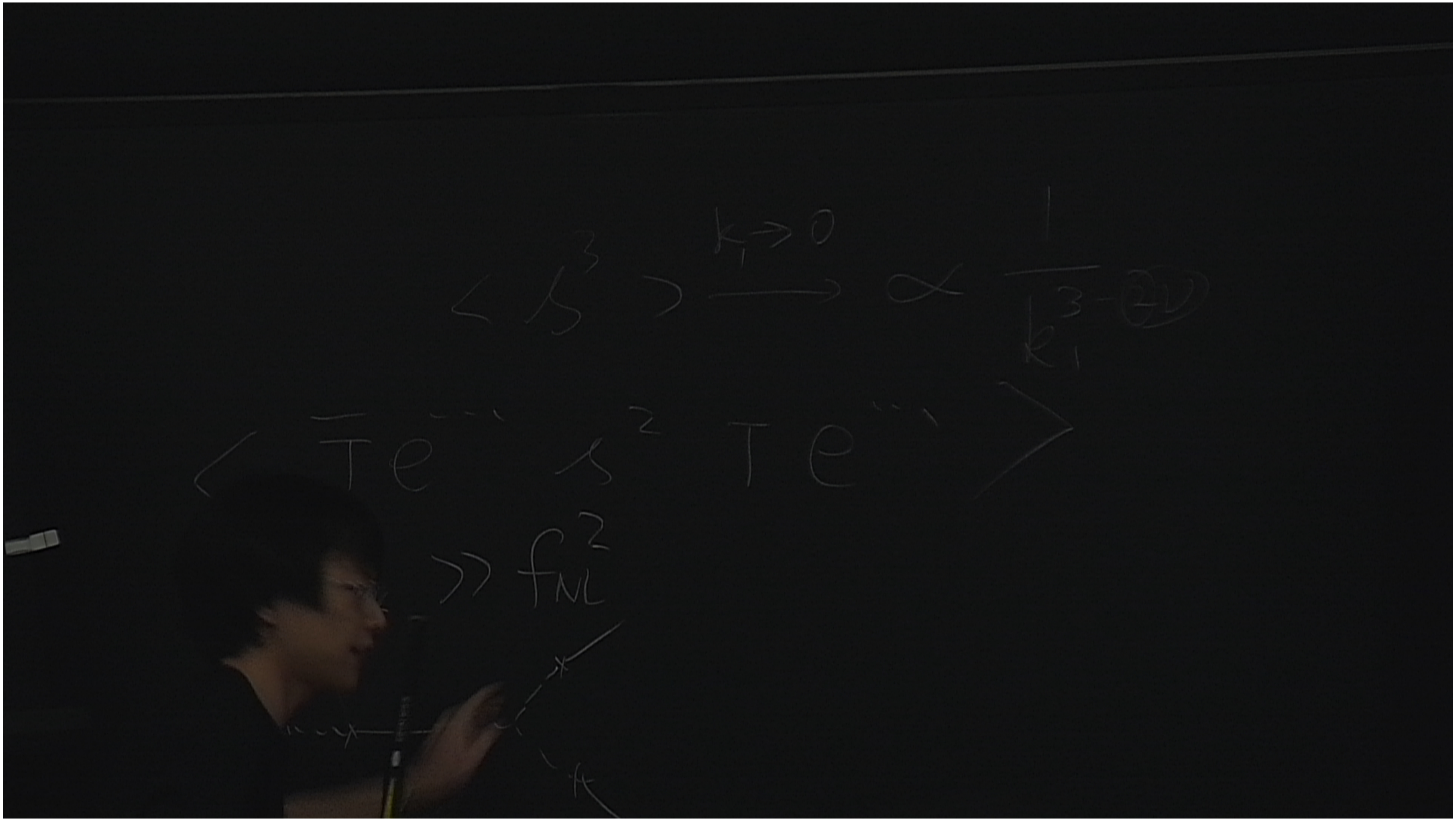




$$t_{NL} \sim \max\left\{ P_\zeta^{-1}\left(\dot{\theta}/H\right)^4 (V'''/H)^2 \ , \ P_\zeta^{-1}\left(\dot{\theta}/H\right)^4 V'''' \right\}$$

Connection to feeding mechanism (Barnaby & Shandera 2011)


$\langle \zeta^3 \rangle \xrightarrow{k_1 \to 0} \propto \frac{1}{k_1^{3-2\nu}}$
$\tau_{NL} >$



Now greater mass: say, $3H/2 \leq m < 10\ H$
-- a trans-M window of new physics

* Expect new physics to stabilize the scale of inflation
(analog to the story of Higgs hierarchy)

* Expect fields with mass (slightly) greater than H

As a first step:

the same model, extend the calculation:

$$P_\zeta = \frac{H^4}{4\pi^2 R^2 \dot{\theta}_0^2}\left[1 + 8\mathcal{C}\left(\frac{\dot{\theta}_0}{H}\right)^2\right]$$

$$\mathcal{C}_1 \equiv \frac{\pi}{8} e^{-\mu\pi} \left| \int_0^\infty dx_1\ x_1^{-1/2} H_{i\mu}^{(1)}(x_1) e^{ix_1} \right|^2 \qquad \mu \equiv i\sqrt{9/4 - m^2/H^2}$$

$$\mathcal{C}_2 \equiv -\frac{\pi}{4}\ e^{-\mu\pi}\ \mathrm{Re}\left\{ \int_0^\infty dx_1\ x_1^{-1/2} H_{i\mu}^{(1)}(x_1) e^{-ix_1} \int_{x_1}^\infty dx_2\ x_2^{-1/2} \left[H_{i\mu}^{(1)}(x_2)\right]^* e^{-ix_2} \right\}$$

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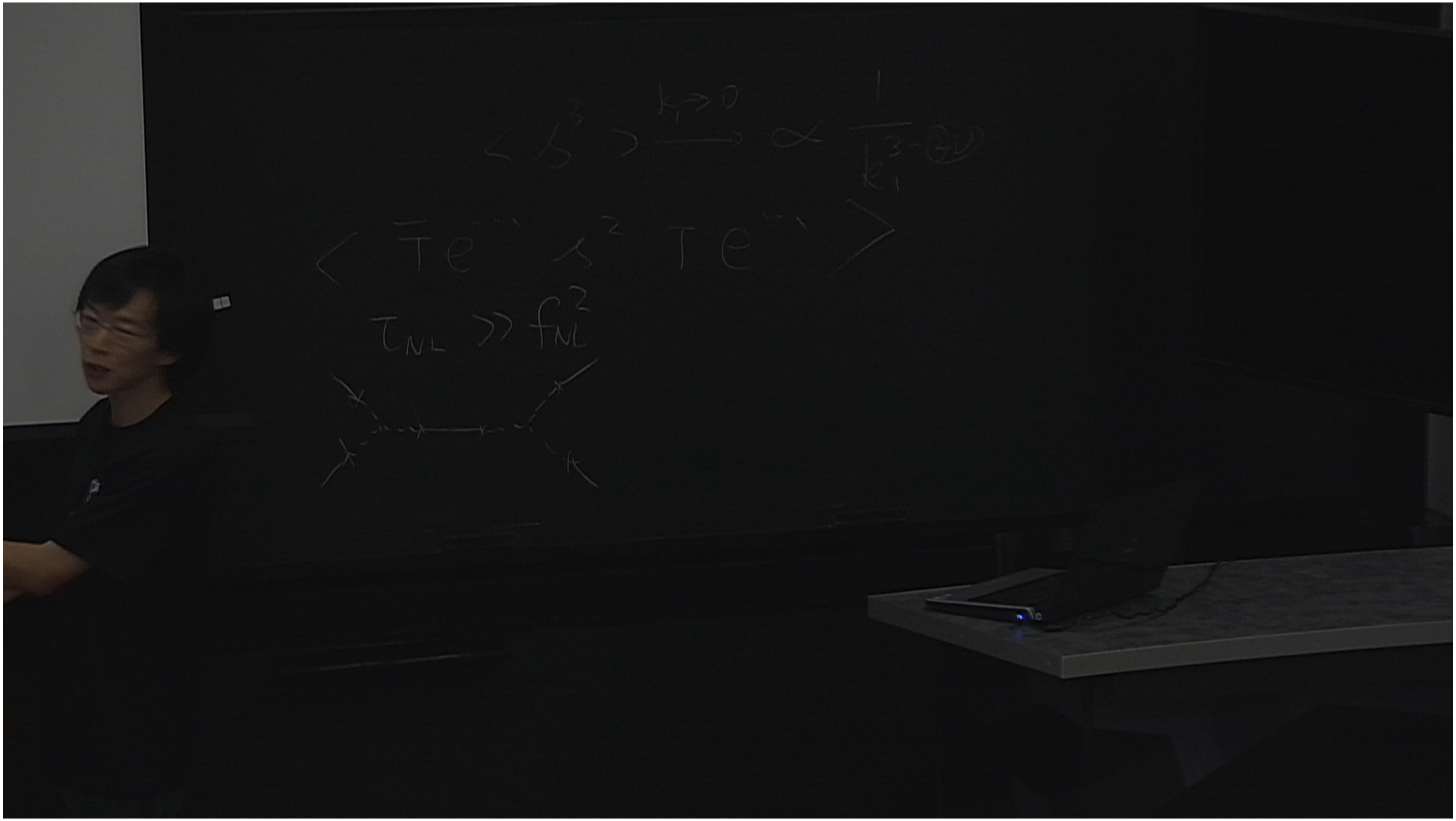
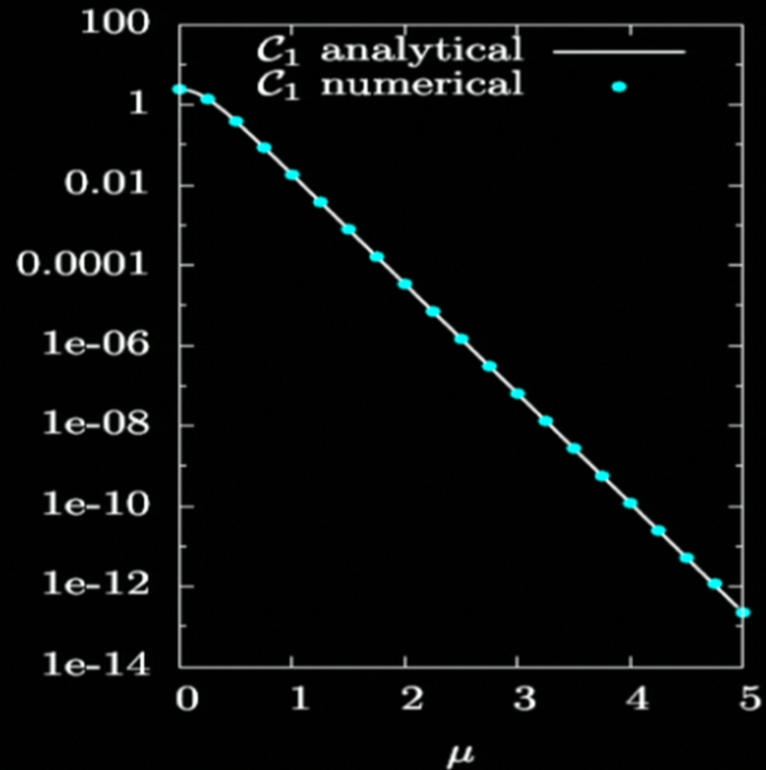
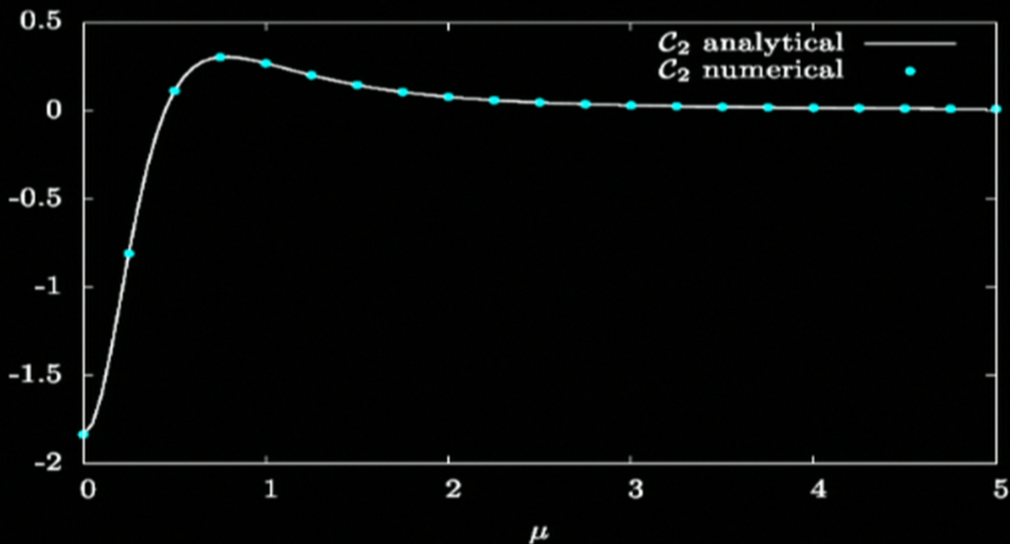


$$\mathcal{C}_1 \equiv \frac{\pi}{8} e^{-\mu\pi} \left| \int_0^\infty dx_1 \; x_1^{-1/2} H^{(1)}_{i\mu}(x_1) e^{ix_1} \right|$$

$$\mathcal{C}_1 = \frac{\pi^2}{4\cosh^2(\pi\mu)}$$

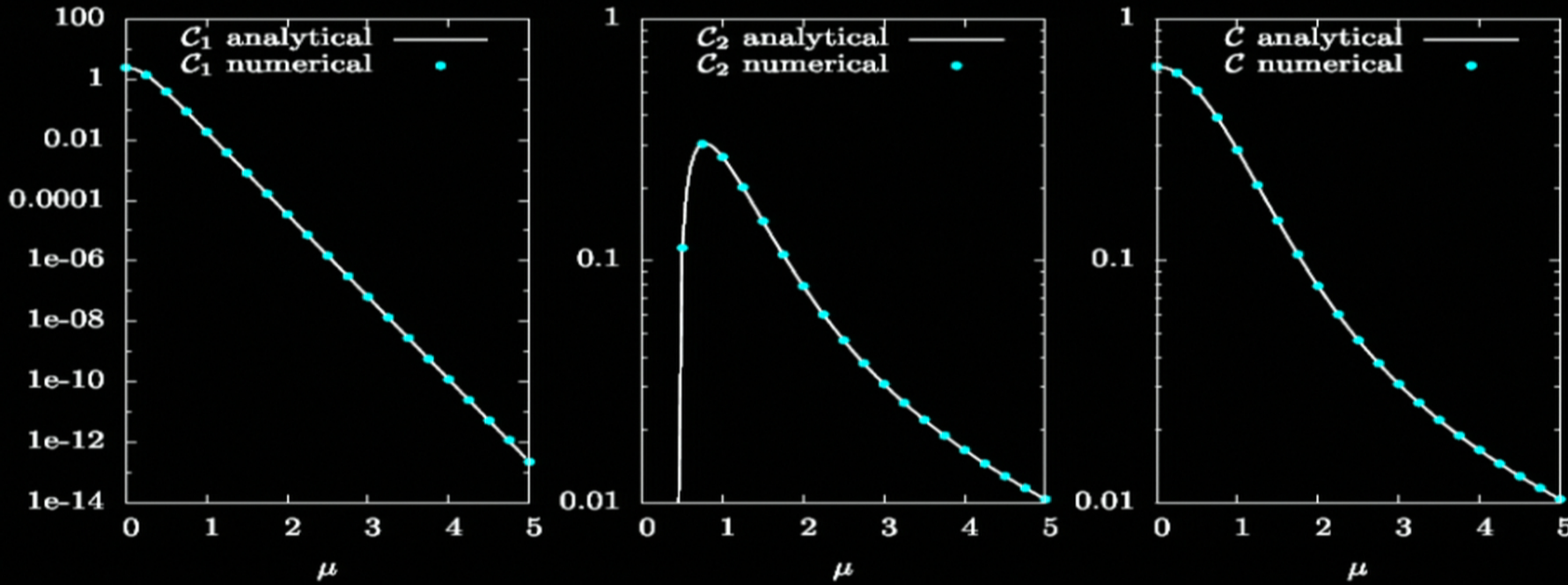


$$\mathcal{C}_2 \equiv -\frac{\pi}{4}\, e^{-\mu\pi}\ \mathrm{Re}\left\{\int_0^\infty dx_1\ x_1^{-1/2} H_{i\mu}^{(1)}(x_1) e^{-ix_1} \int_{x_1}^\infty dx_2\ x_2^{-1/2} \left[H_{i\mu}^{(1)}(x_2)\right]^* e^{-ix_2}\right\}$$



$$\psi^{(1)}(z) \equiv \frac{d}{dz}\left(\frac{d\Gamma(z)/dz}{\Gamma(z)}\right)$$

$$\mathcal{C}_2 = \frac{1+\coth(\pi\mu)}{16}\mathrm{Re}\left[\psi^{(1)}\left(\frac{3}{4}+\frac{i\mu}{2}\right) - \psi^{(1)}\left(\frac{1}{4}+\frac{i\mu}{2}\right)\right]$$
$$-\ \frac{e^{-\mu\pi}}{16\sinh\pi\mu}\mathrm{Re}\left[\psi^{(1)}\left(\frac{3}{4}-\frac{i\mu}{2}\right) - \psi^{(1)}\left(\frac{1}{4}-\frac{i\mu}{2}\right)\right]$$

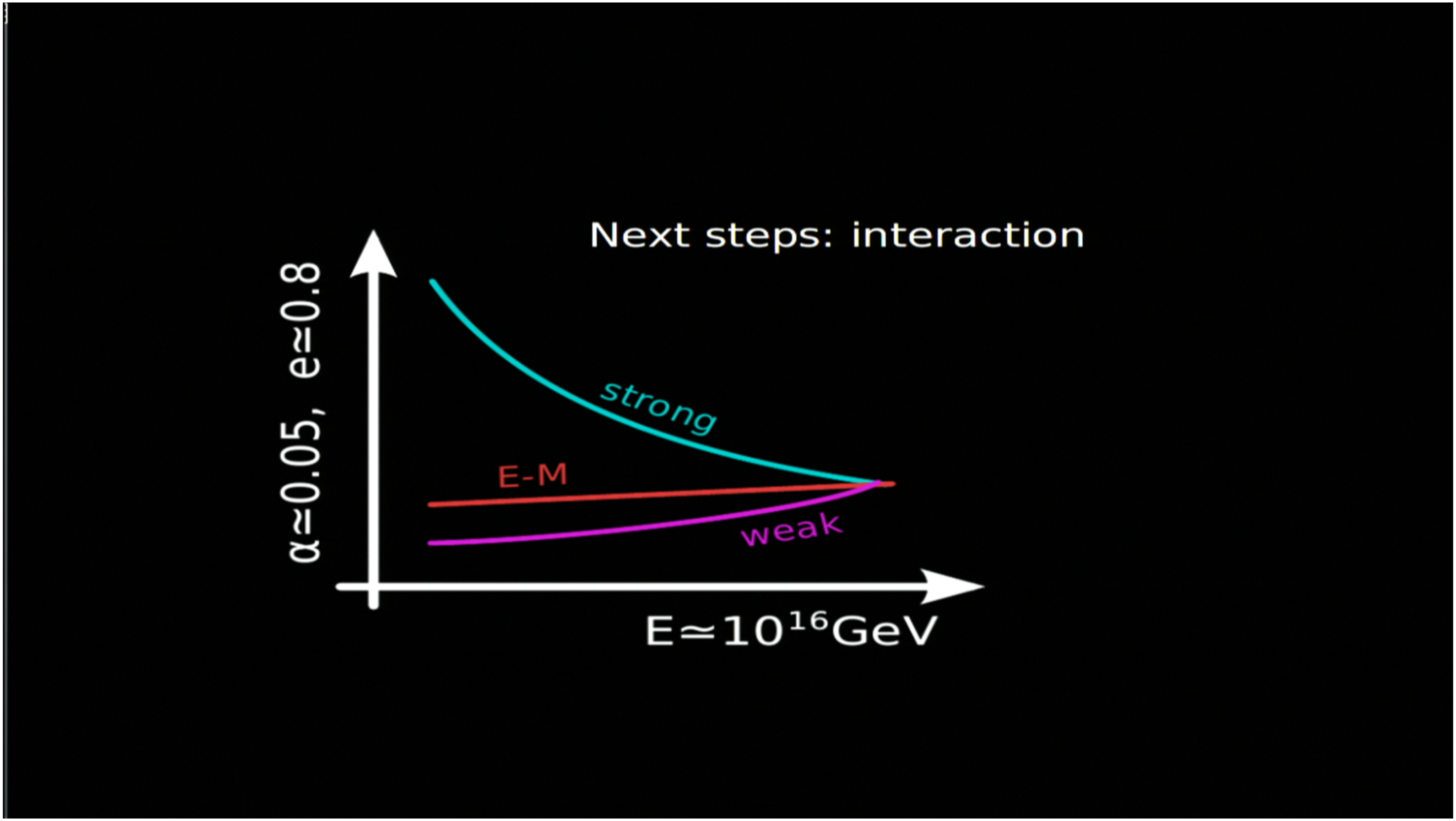


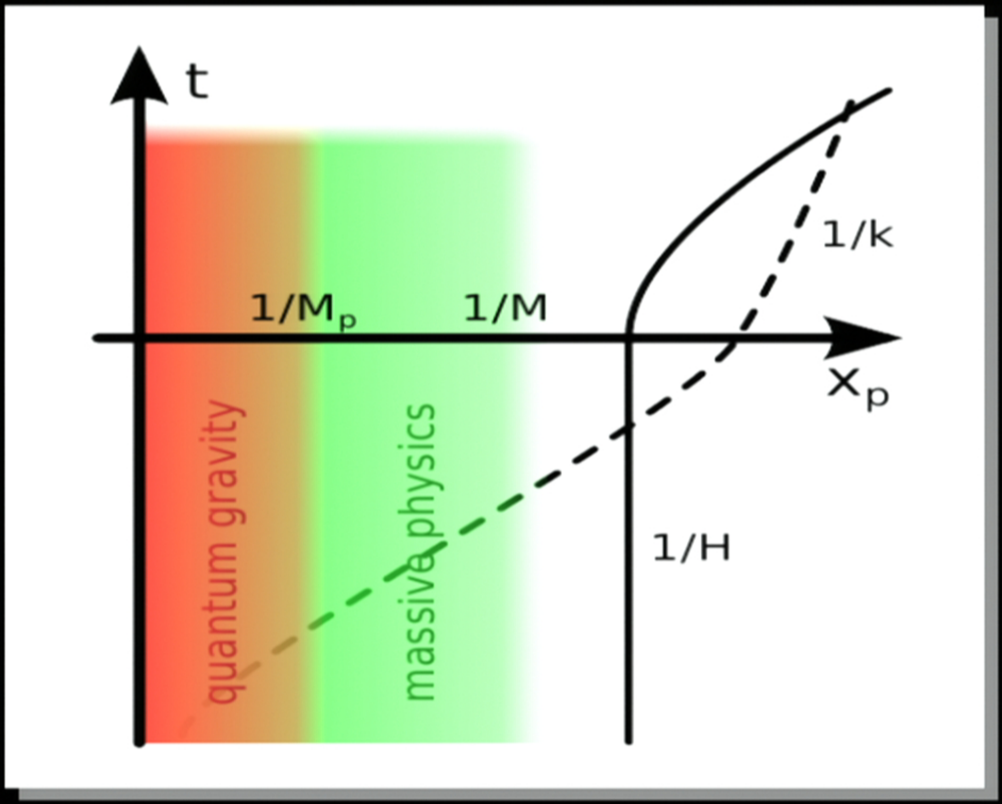
$\mathcal{C}_1$ analytical
$\mathcal{C}_1$ numerical
100
1
0.01
0.0001
1e-06
1e-08
1e-10
1e-12
1e-14
0 1 2 3 4 5
μ
$\mathcal{C}_2$ analytical
$\mathcal{C}_2$ numerical
1
0.1
0.01
0 1 2 3 4 5
μ
$\mathcal{C}$ analytical
$\mathcal{C}$ numerical
1
0.1
0.01
0 1 2 3 4 5
μ

In the large M / H limit:

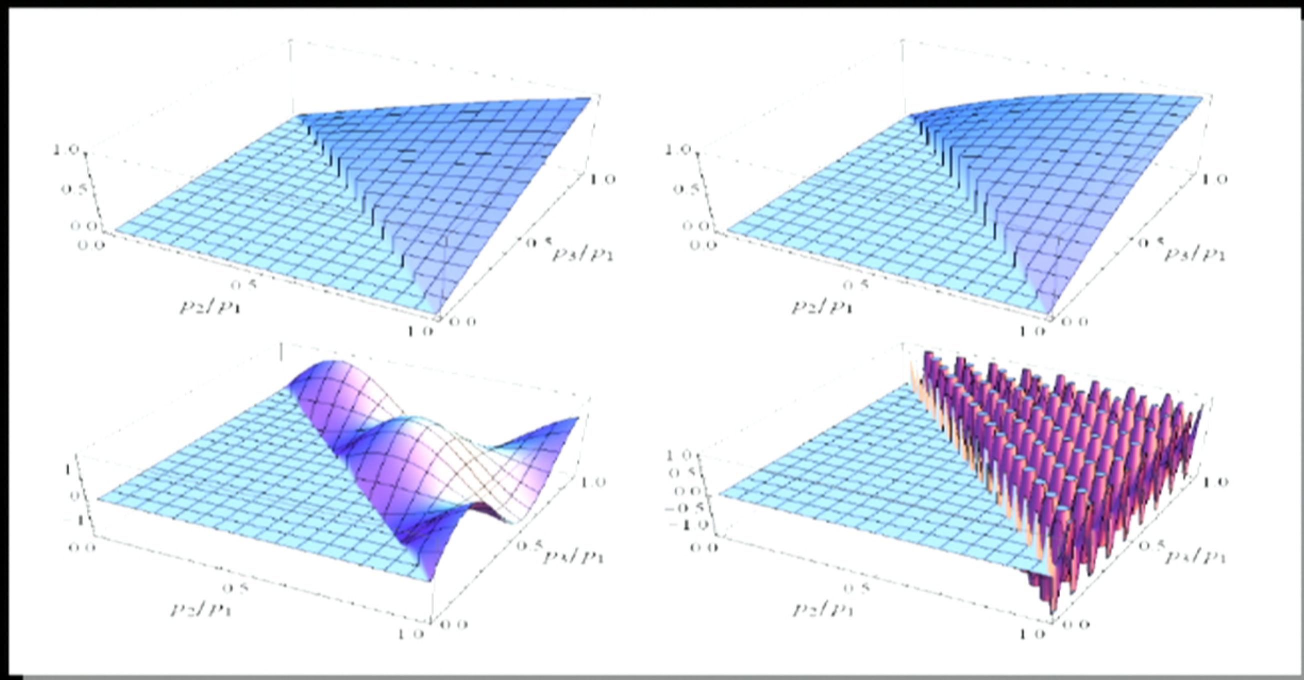
$$\lim_{\mu\to\infty} \mathcal{C}_1 = \pi^2 e^{-2\pi M/H} \qquad\qquad \lim_{\mu\to\infty} \mathcal{C}_2 = \frac{H^2}{4M^2}$$

Boltzmann v. s. effective field theory

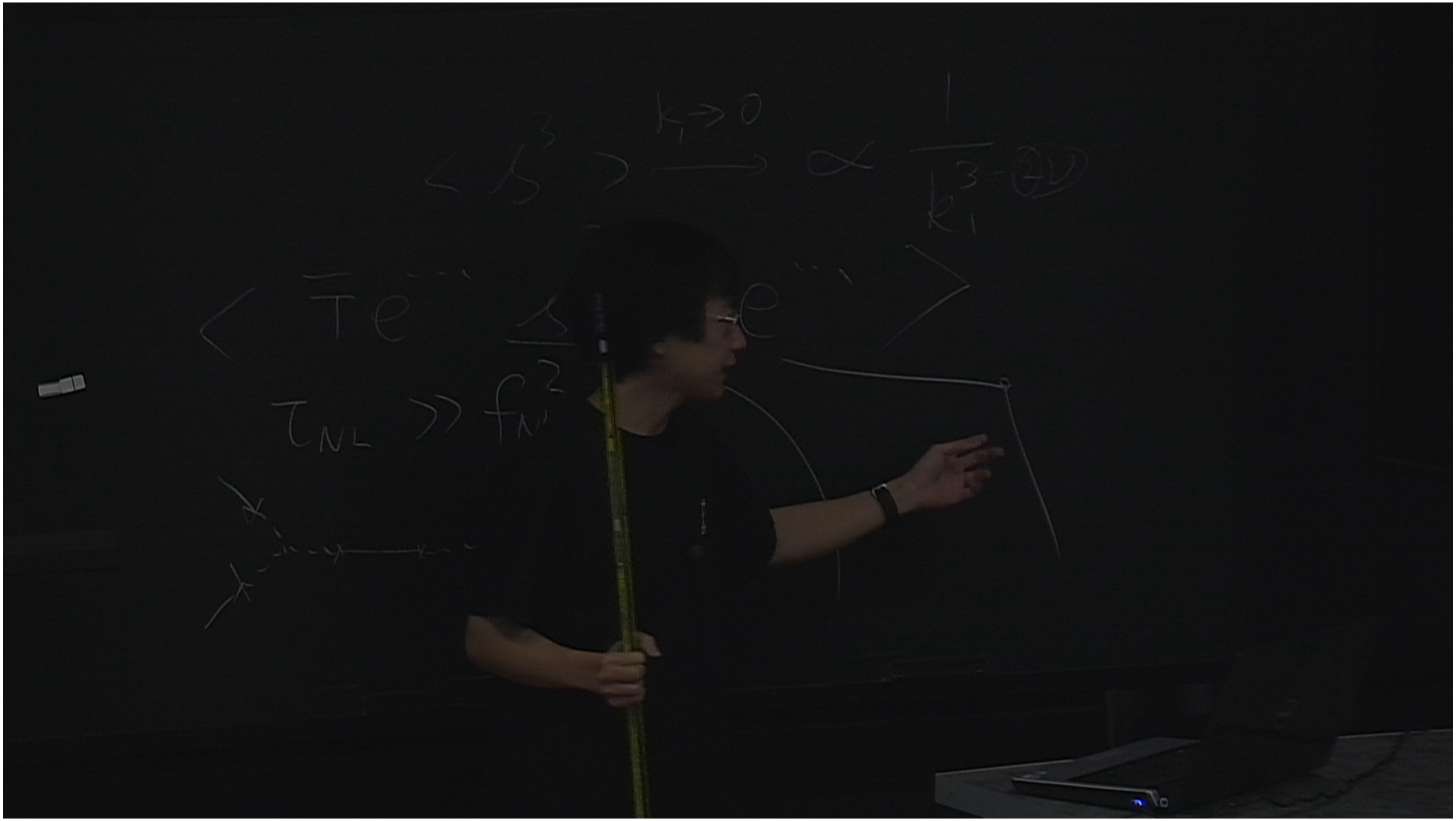

Next steps: interaction
α≃0.05, e≃0.8
strong
E-M
weak
E≃10^16GeV


t
1/Mp
1/M
1/k
xp
quantum gravity
massive physics
1/H

A sharp turn?



See also Gary Shiu, Jiajun Xu (2011)



Conclusion for quasi-single field inflation:

* The mass range $m \sim H$ is interesting
  -- Not showing up in background, only in pert.
  -- Naturalness comes from unnaturalness
  -- The $m \leq H$ part opens up quasi-local shapes
  -- The $M \geq H$ part opens up a “trans-M” window

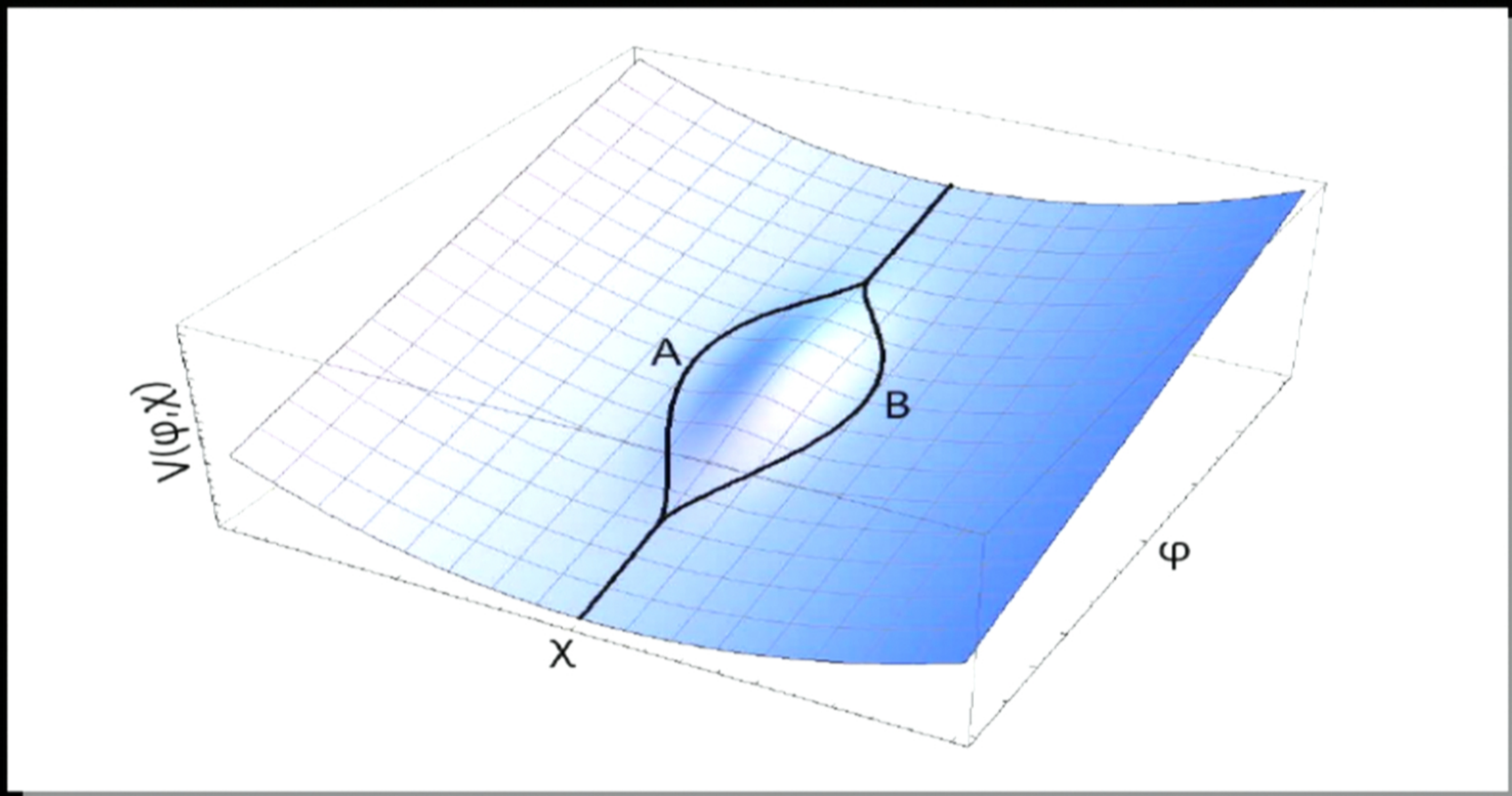
* On going / future directions:
  -- Interactions through the trans-M window
  -- Detailed study of quasi-local shapes

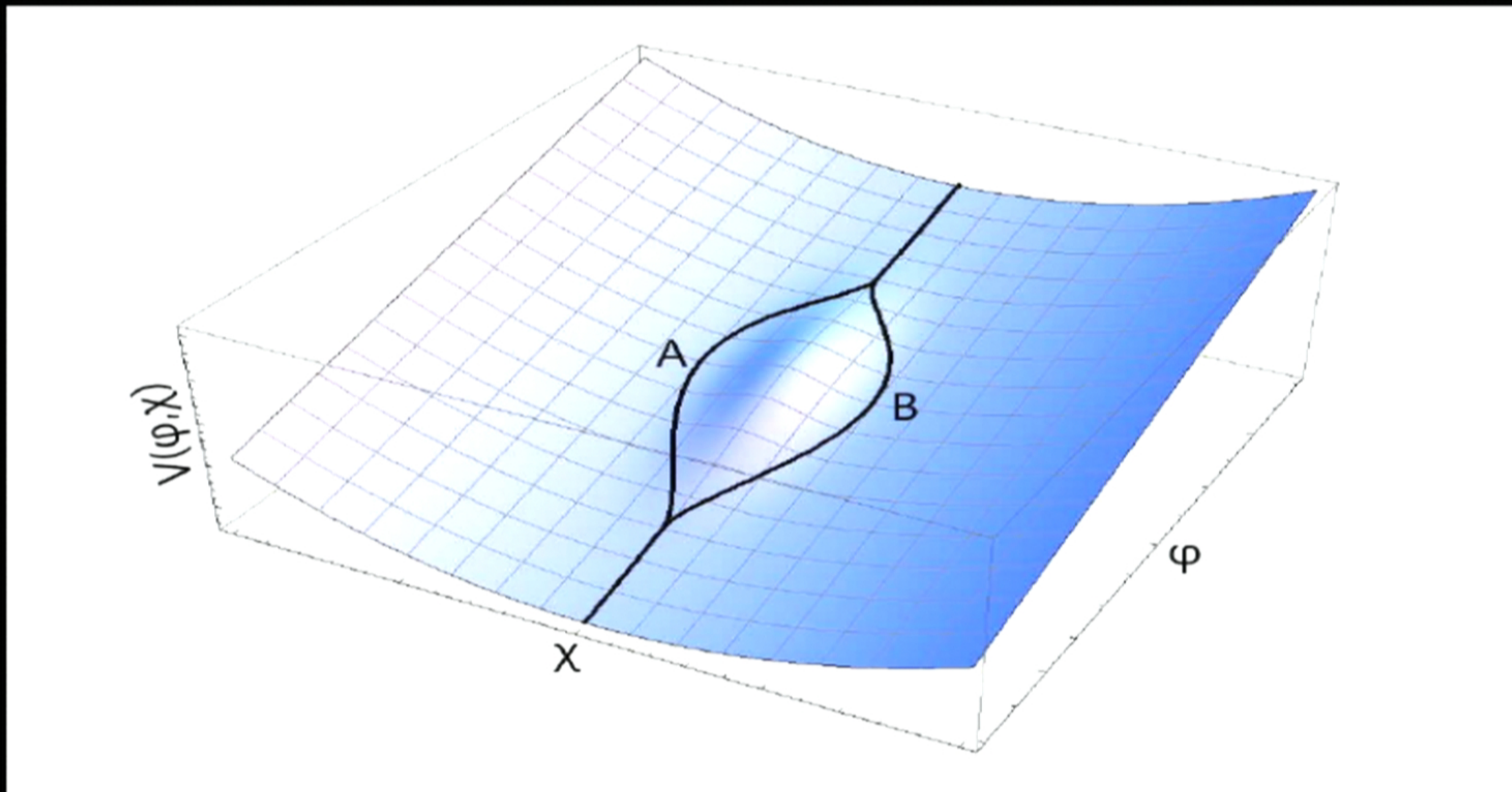
Quasi-Single Field Inflation

Multi-Stream Inflation in a Landscape

with Miao Li,
Niayesh Afshordi
Anže Slosar
Francis Duplessis
Robert Brandenberger

What are the observables for inflation?


A
B
V(φ,χ)
φ
χ

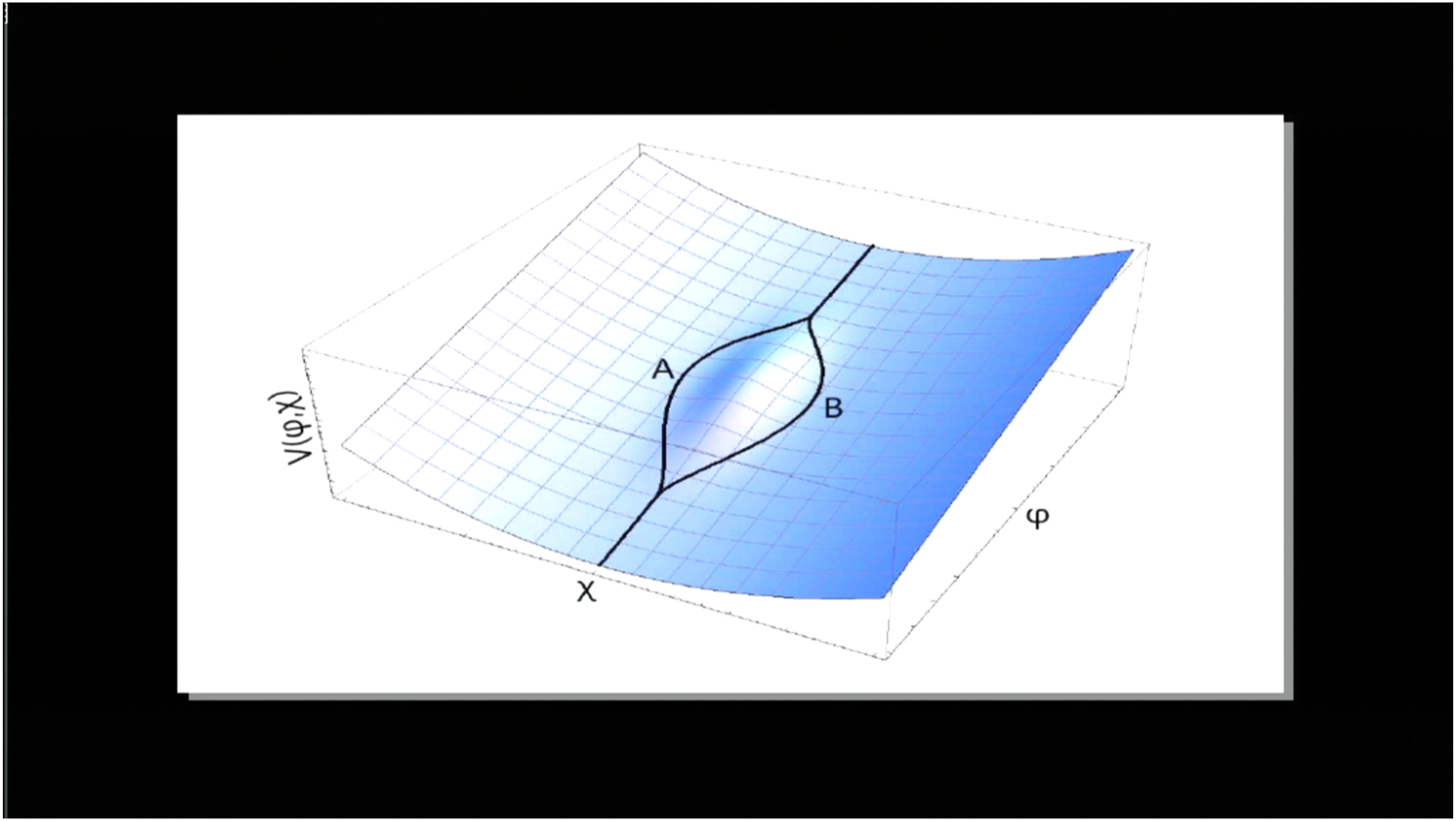


A
B
V(φ,χ)
φ
χ

Multi-stream inflation

Could be a realistic scenario,
where bifurcations are under control

Could be a constraint for landscape,
where bifurcations are not under control


A
B
V(φ,χ)
φ
χ

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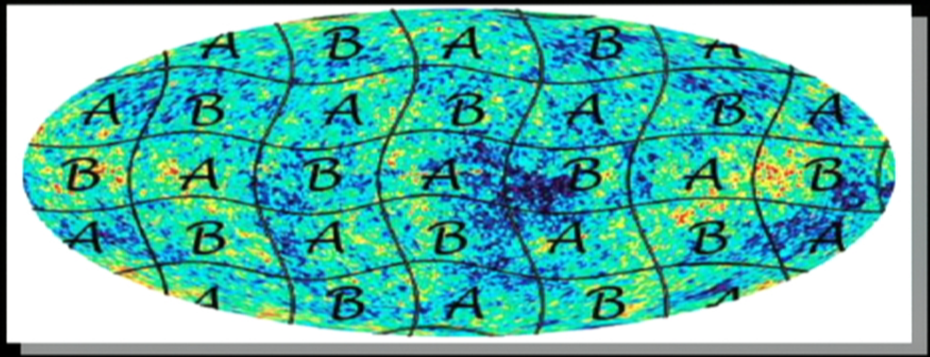


The symmetric case:

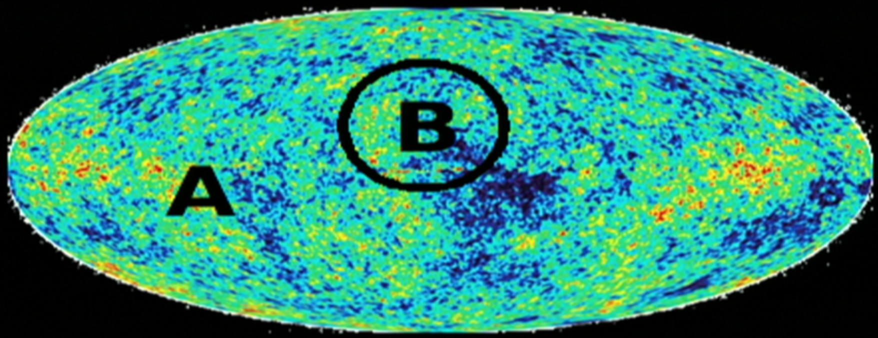
Bifurcation scale: $\zeta = \delta N$

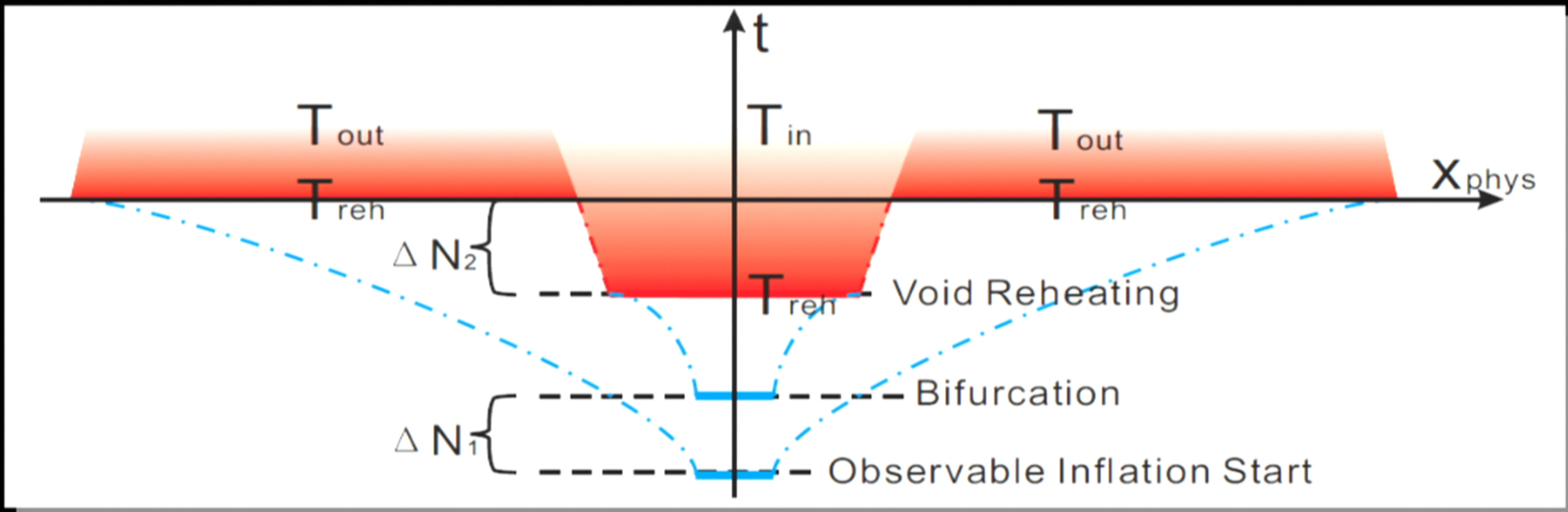
Smaller scales: different path, different power

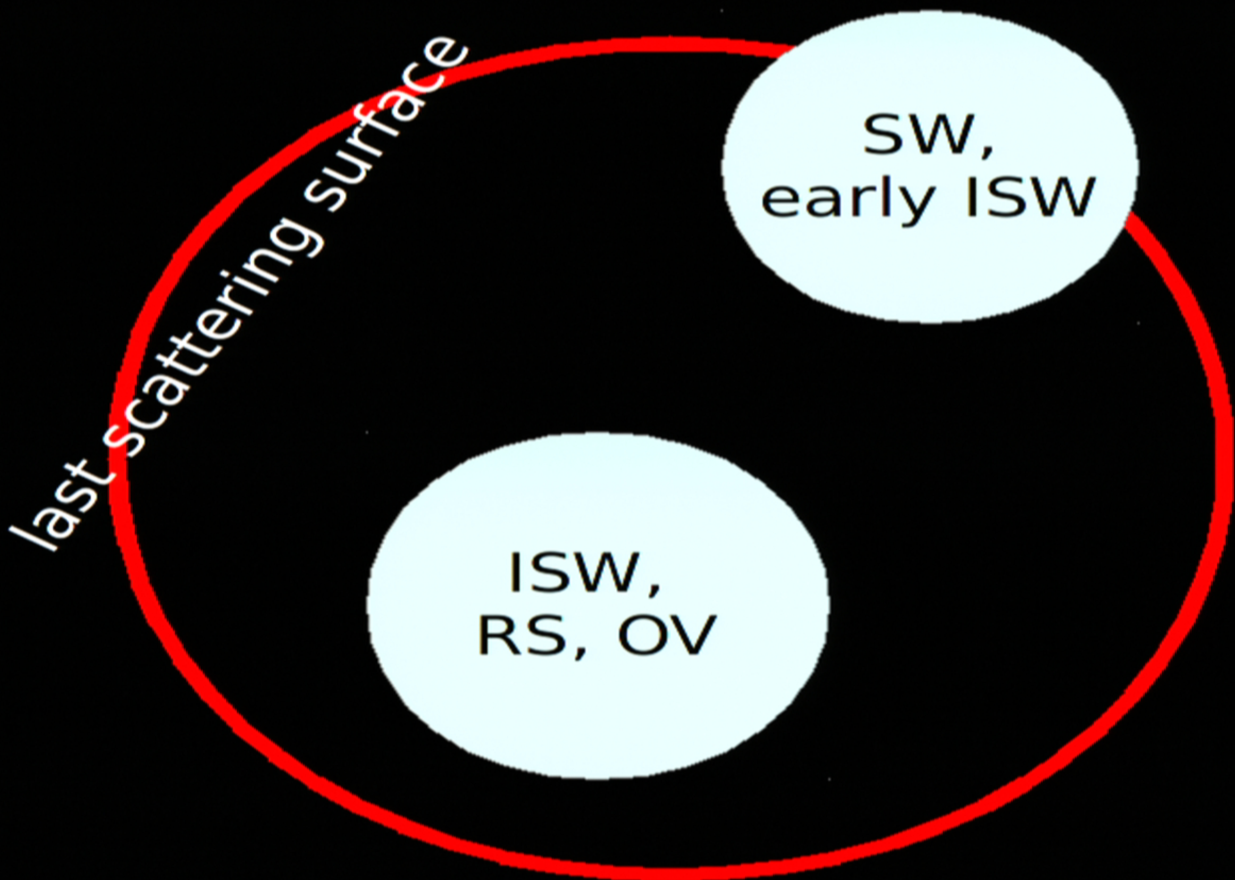
Their correlation: non-Gaussianity

The asymmetric case:

a spot on the CMB / LSS

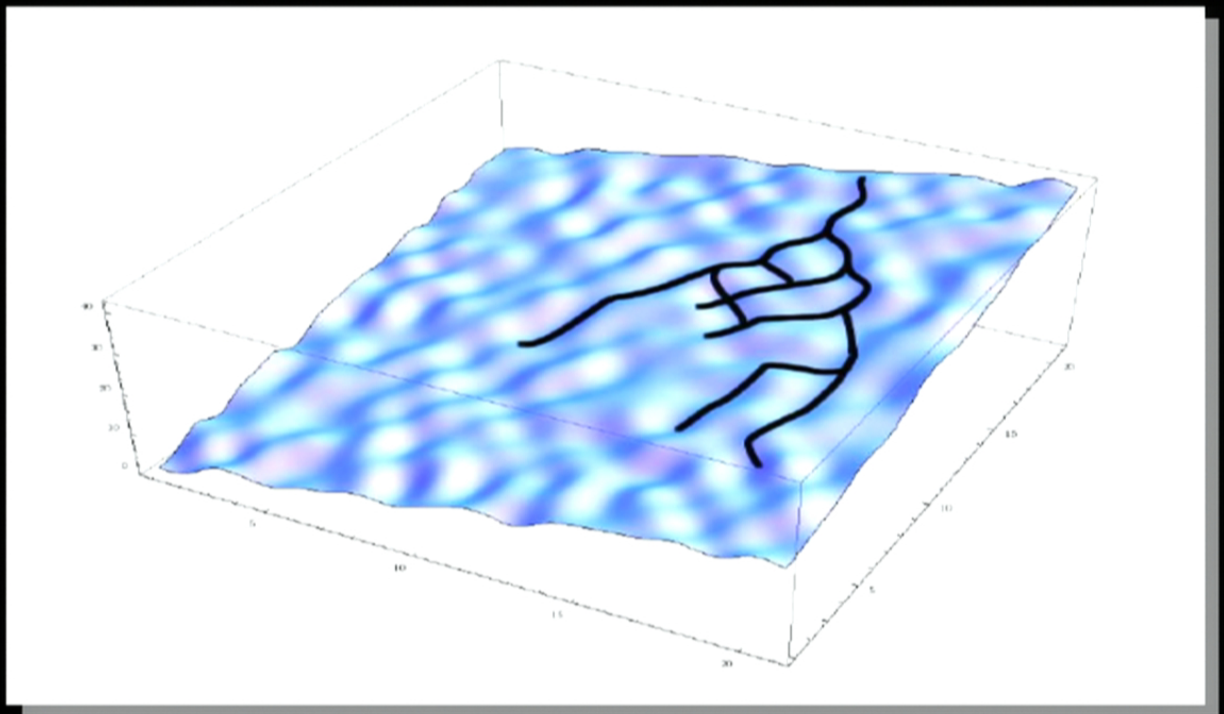



t
T out
T in
T out
x phys
T reh
T reh
Δ N2
T reh
Void Reheating
Bifurcation
Δ N1
Observable Inflation Start

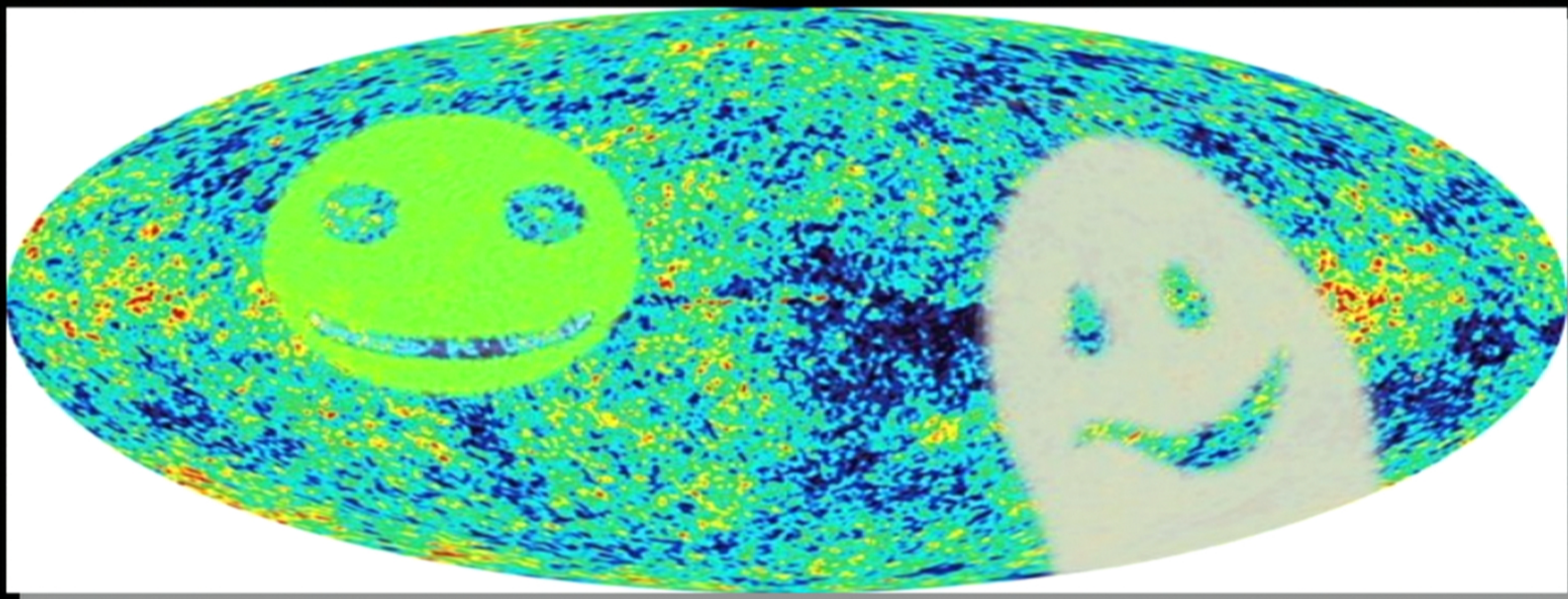


For earlier work on cold spot, see, e. g.
Cruz, Turok, Vielva, Martinez-Gonzalez
and Hobson (Science, 2007)

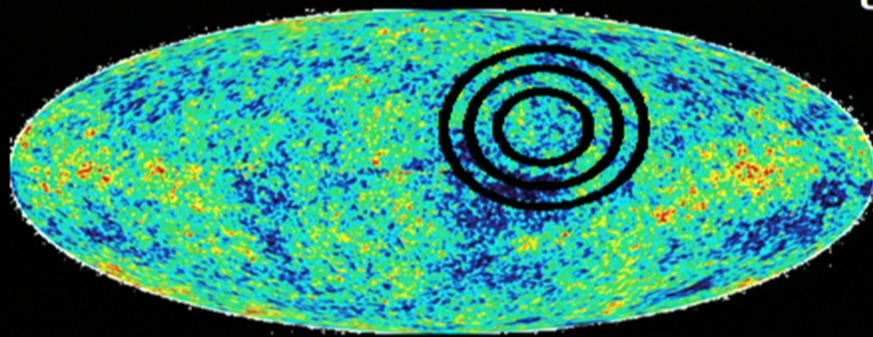
MSI as a constraint on landscape:



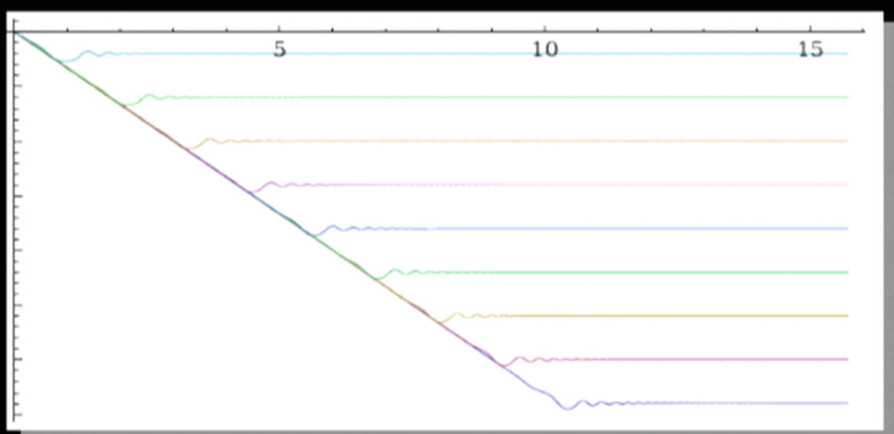
A feature in position space?
Reminder: multi-stream inflation

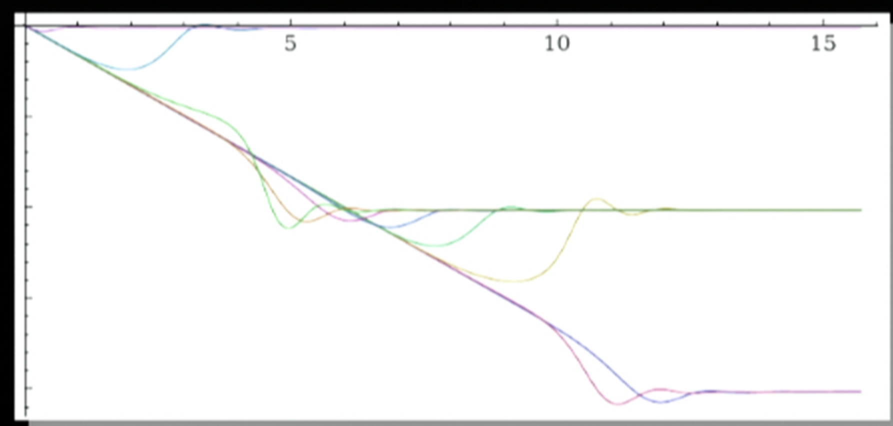


topological defect induced MSI

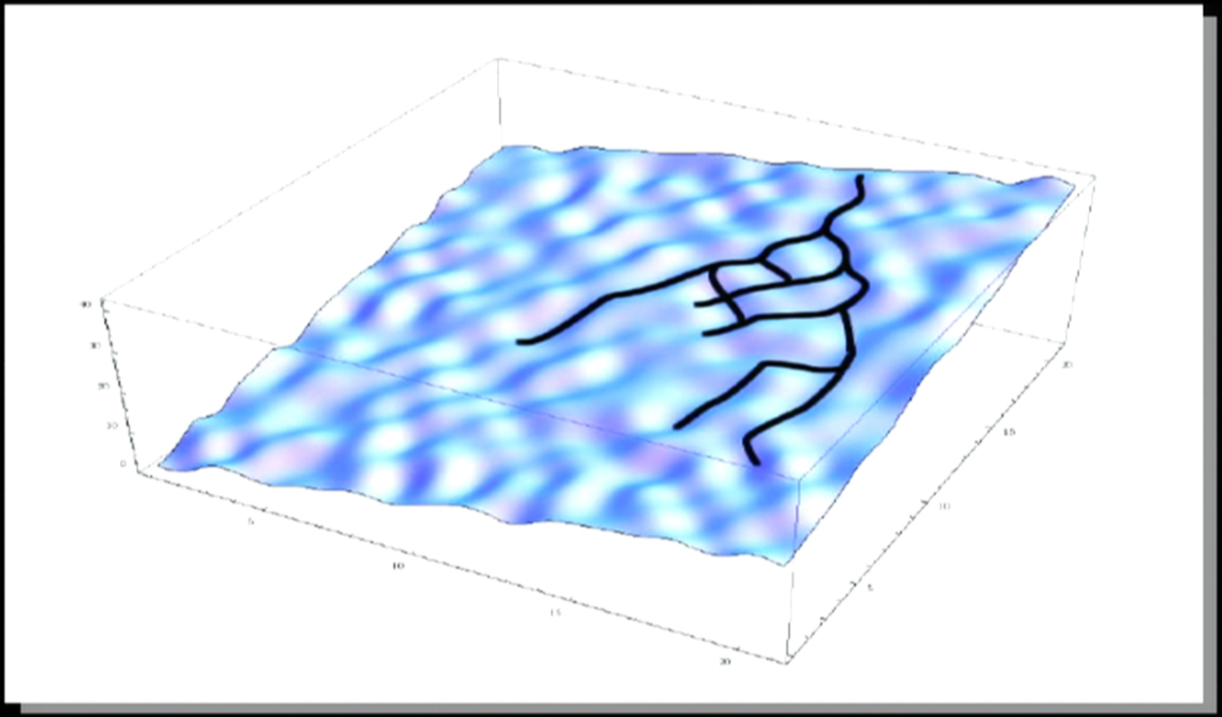


$$V = V_{sr}(\varphi) + s\chi + m^2 \Psi^a \Psi^a \cos(\chi/\chi_0)$$

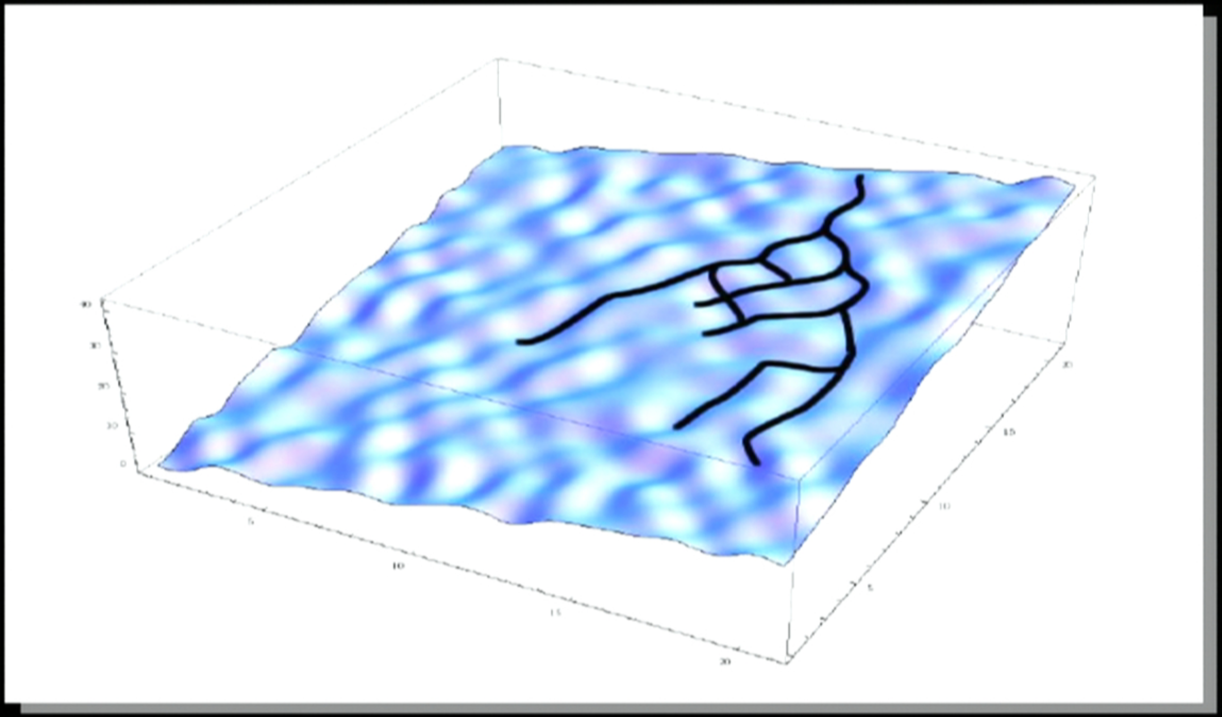


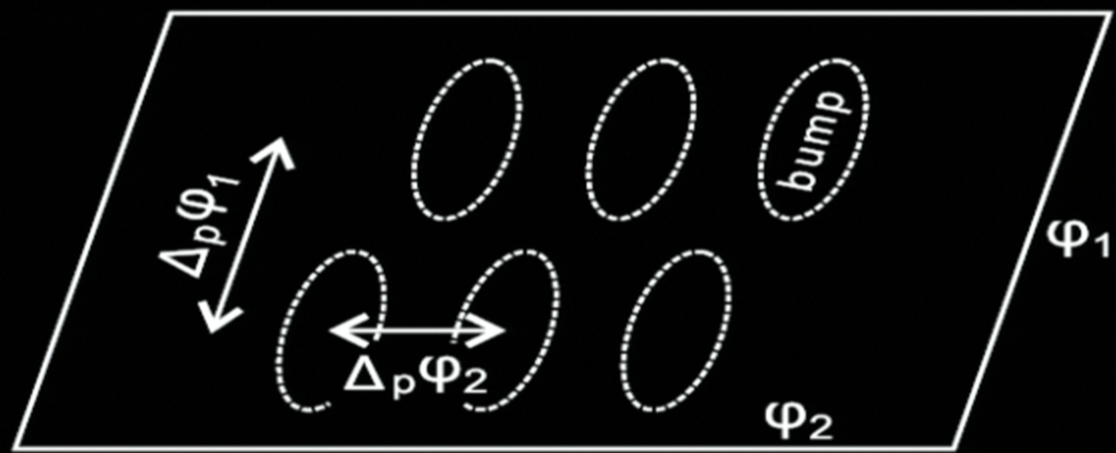


MSI as a constraint on landscape:



MSI as a constraint on landscape:





$$\xi = \Delta_p\varphi_1 \,/\, \Delta_p\varphi_2$$

$$\ddot{\varphi}_1 + 3H\dot{\varphi}_1 + \partial_1 V(\varphi_1) + \partial_1 U(\varphi_1, \varphi_2) = 0 \ ,$$

$$\ddot{\varphi}_2 + 3H\dot{\varphi}_2 + \partial_2 U(\varphi_1, \varphi_2) = 0 \ ,$$

$$\lambda \equiv \sqrt{\langle(\partial_1 U)^2\rangle}/|\partial_1 V|.$$

$$\delta \equiv \varphi_2^{(A)} - \varphi_2^{(B)}$$

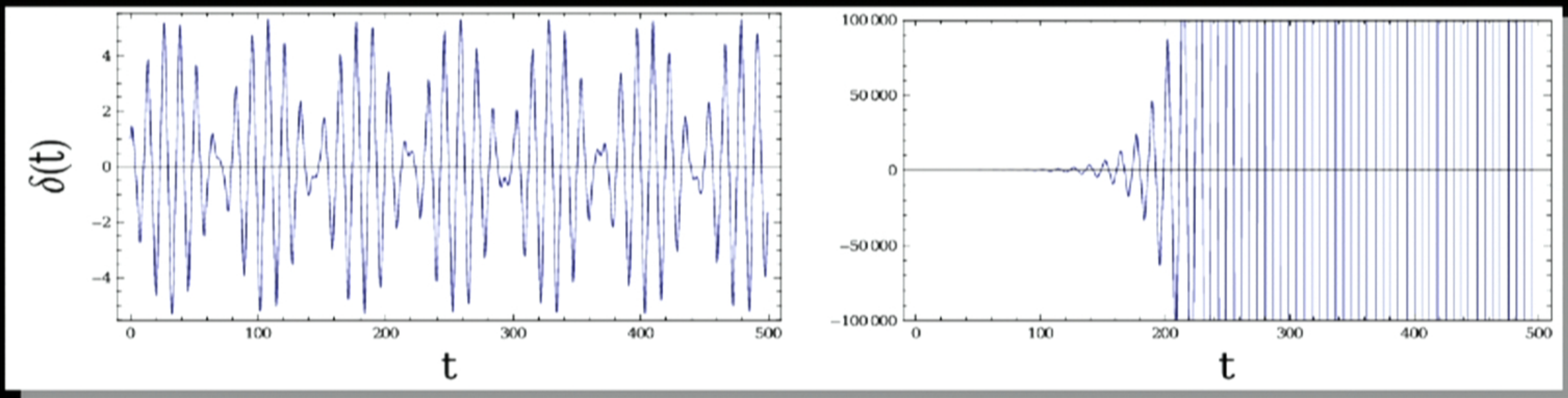
$$\ddot{\delta} + 3H\dot{\delta} + (\partial_2^2 U)\delta = 0$$

$$\partial_2^2 U \simeq \frac{\lambda\xi\partial_1 V}{\Delta_p\varphi_2} \sin\left(\frac{2\pi\dot{\varphi}_1 t}{\Delta_p\varphi_1}\right)$$

oscillate?

or grow?

There is a transition:



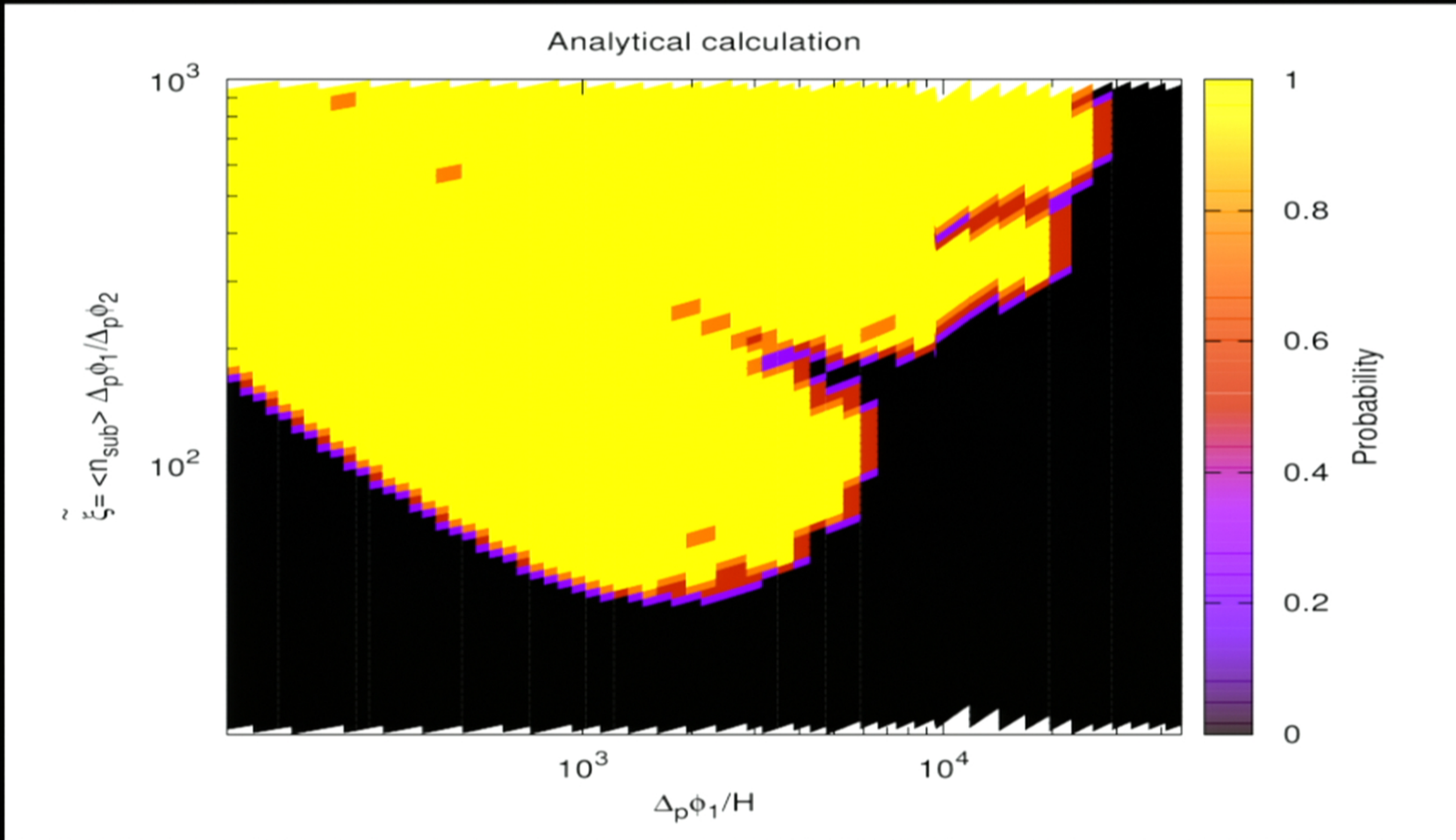
$$\delta \equiv \varphi_2^{(A)} - \varphi_2^{(B)}$$

$$\ddot{\delta} + 3H\dot{\delta} + (\partial_2^2 U)\delta = 0$$

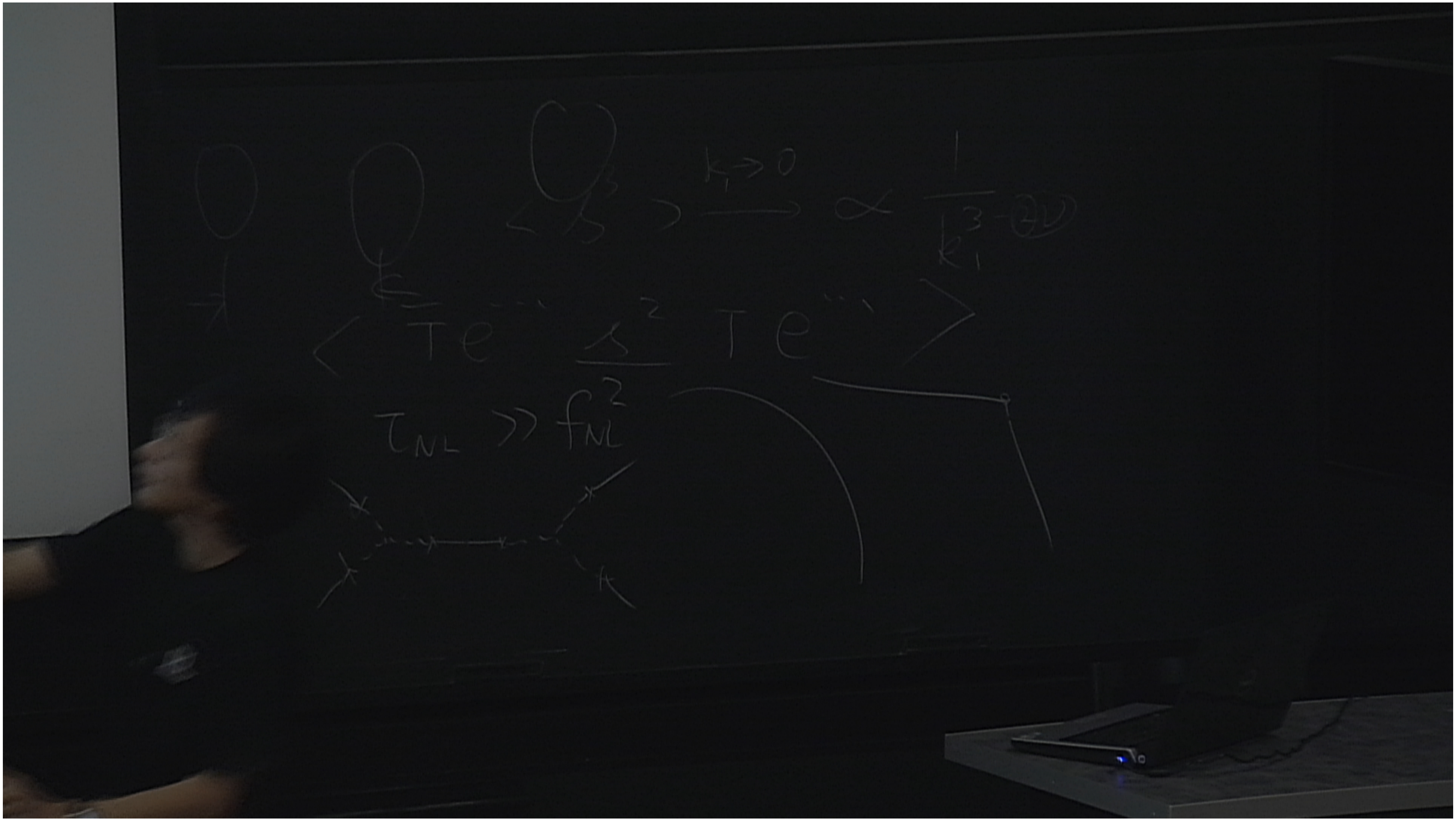
$$\partial_2^2 U \simeq \frac{\lambda \xi \partial_1 V}{\Delta_p \varphi_2} \sin\left(\frac{2\pi \dot{\varphi}_1 t}{\Delta_p \varphi_1}\right)$$

oscillate?

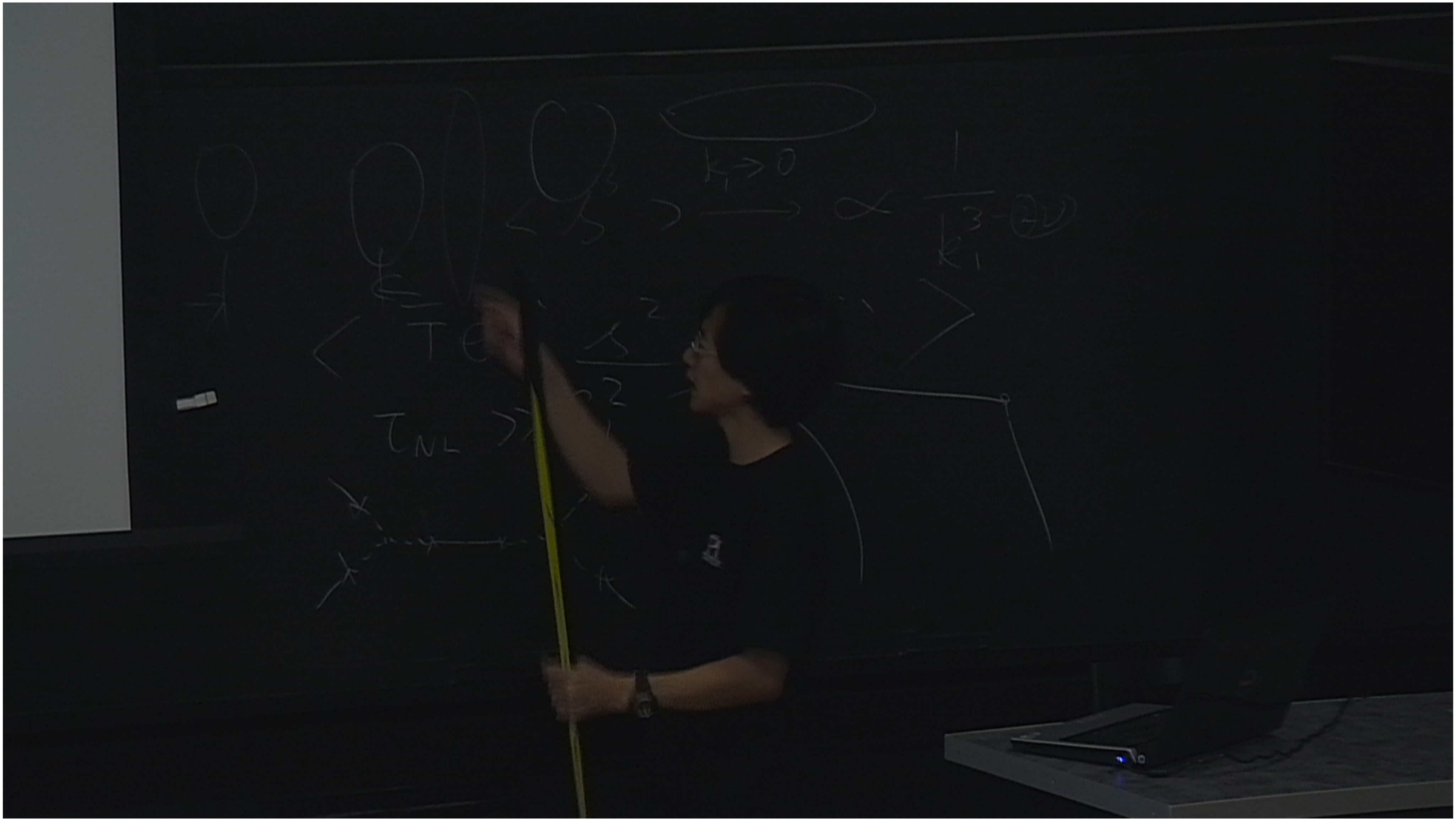
or grow?

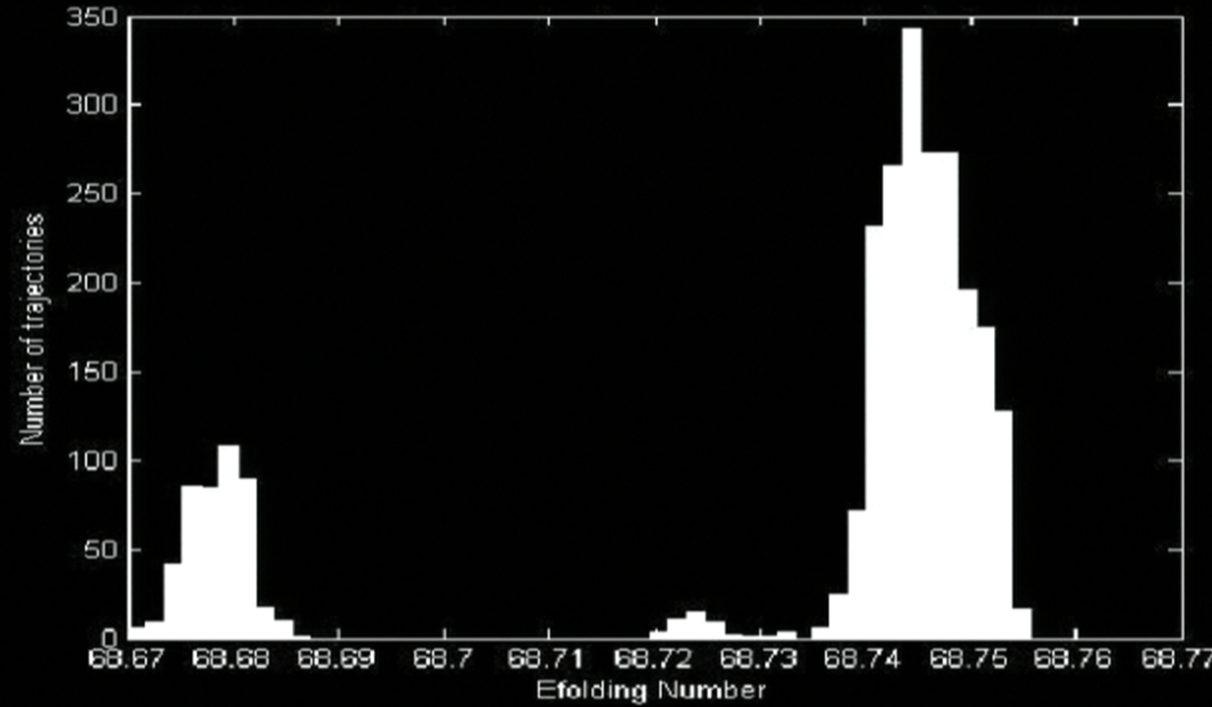


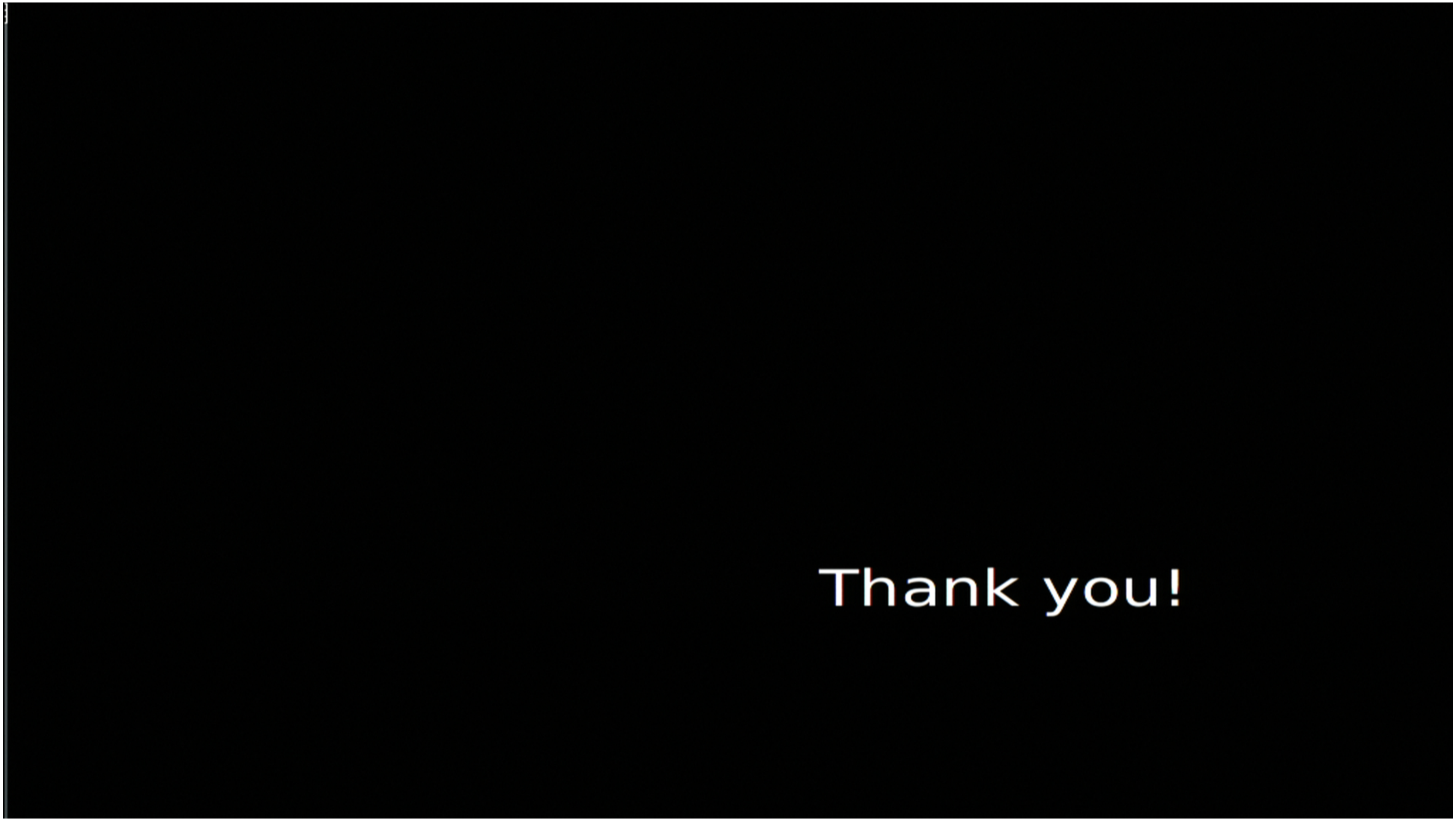
Analytical calculation
10^3
10^2
$\tilde{\xi} = \langle n_{sub} \rangle \Delta_p\phi_1/\Delta_p\phi_2$
10^3
10^4
$\Delta_p\phi_1/H$
1
0.8
0.6
0.4
0.2
0
Probability



τ_NL >> f_NL²




350
300
250
200
150
100
50
0
Number of trajectories
68.67
68.68
68.69
68.7
68.71
68.72
68.73
68.74
68.75
68.76
68.77
Efolding Number


Thank you!