Title: Meeting the Challenges

Date: Jul 14, 2011 11:20 AM

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Abstract: This talk will be a heuristic discussion of the challenges for the big bang inflationary picture and possible approaches for addressing them.

Meeting the Challenge

Challenges for Early Universe Cosmology
Perimeter Institute
July 12-16, 2011

Two Principal Challenges for the Big Bang Inflationary Picture

Inflation makes no predictions

...without strong priors about initial conditions or measure

Inflation is highly unlikely

...or of indeterminate likelihood, based on conservative measures

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Why continue to think only about inflation?
Why not alternatives?

e.g., straw man theory: the original big bang model

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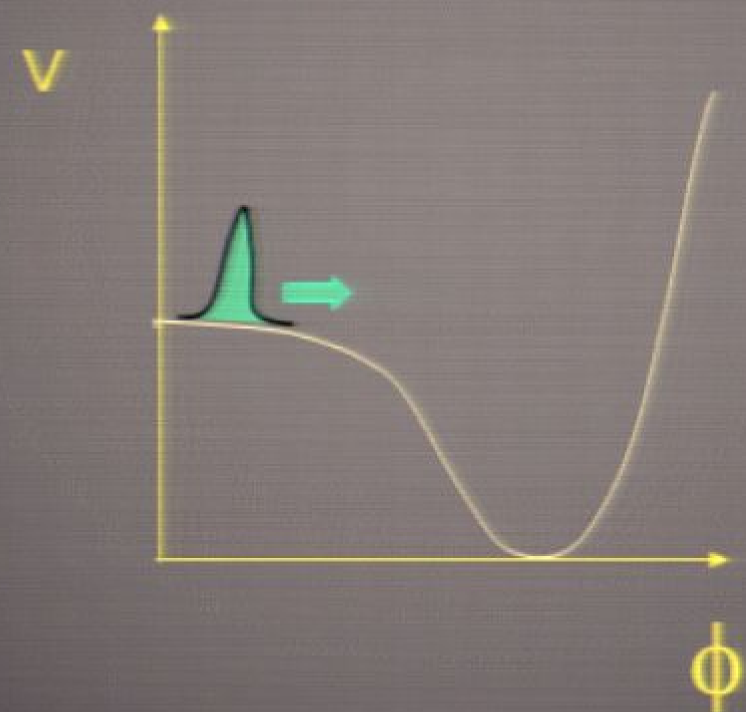

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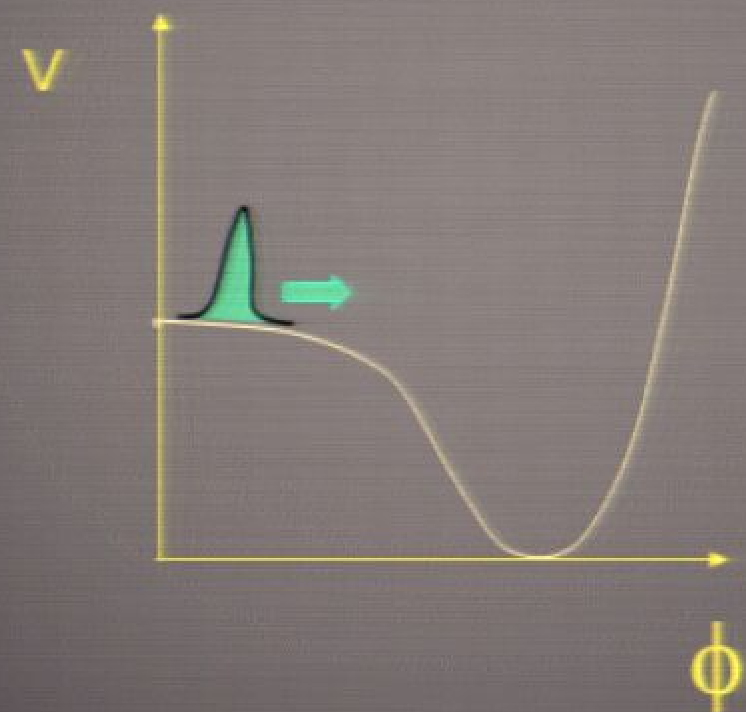

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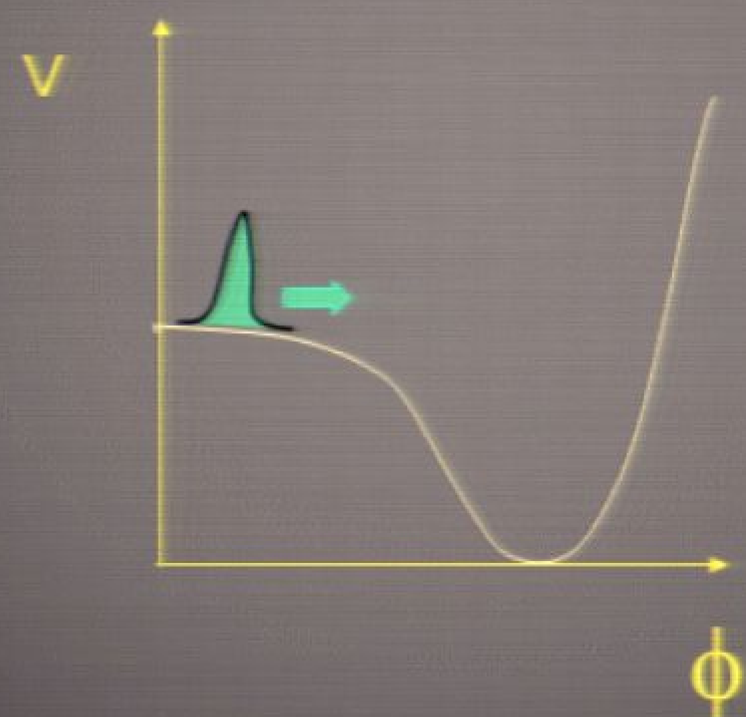
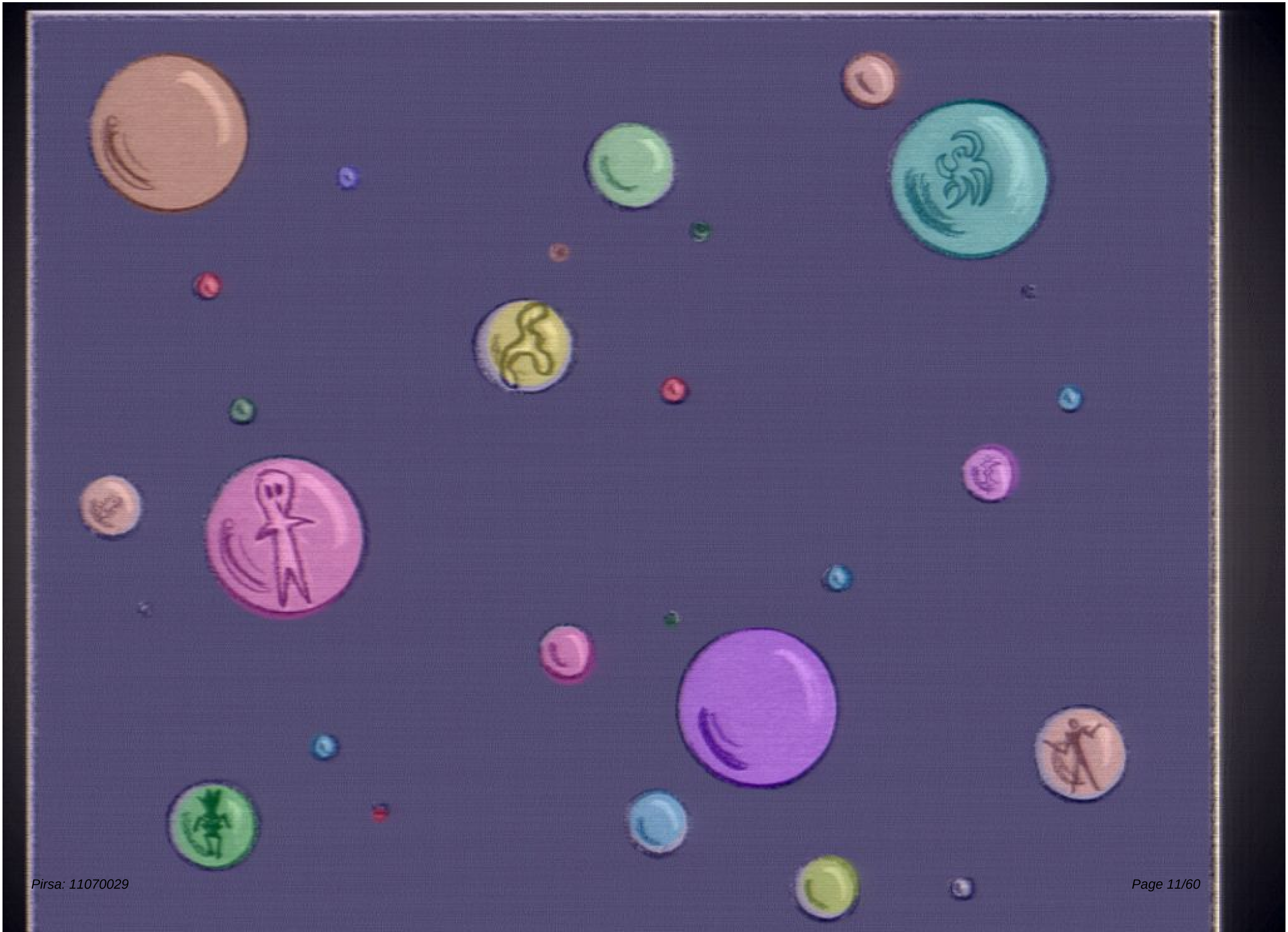


Inflation rewards "rogue" regions
(atypical regions normally, but here inflation makes them dominant)



"Anything that can happen will happen: and it will happen an infinite number of times."

Alan Guth, 2000

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Back where we started!

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Worse still: the volume measure fails

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So, if creative measures are going to save the day,
the cosmology will depend entirely on
the measure principle -- not inflation --
And then we have to consider how a similar
measure applied to the other theories compares in
predictive power

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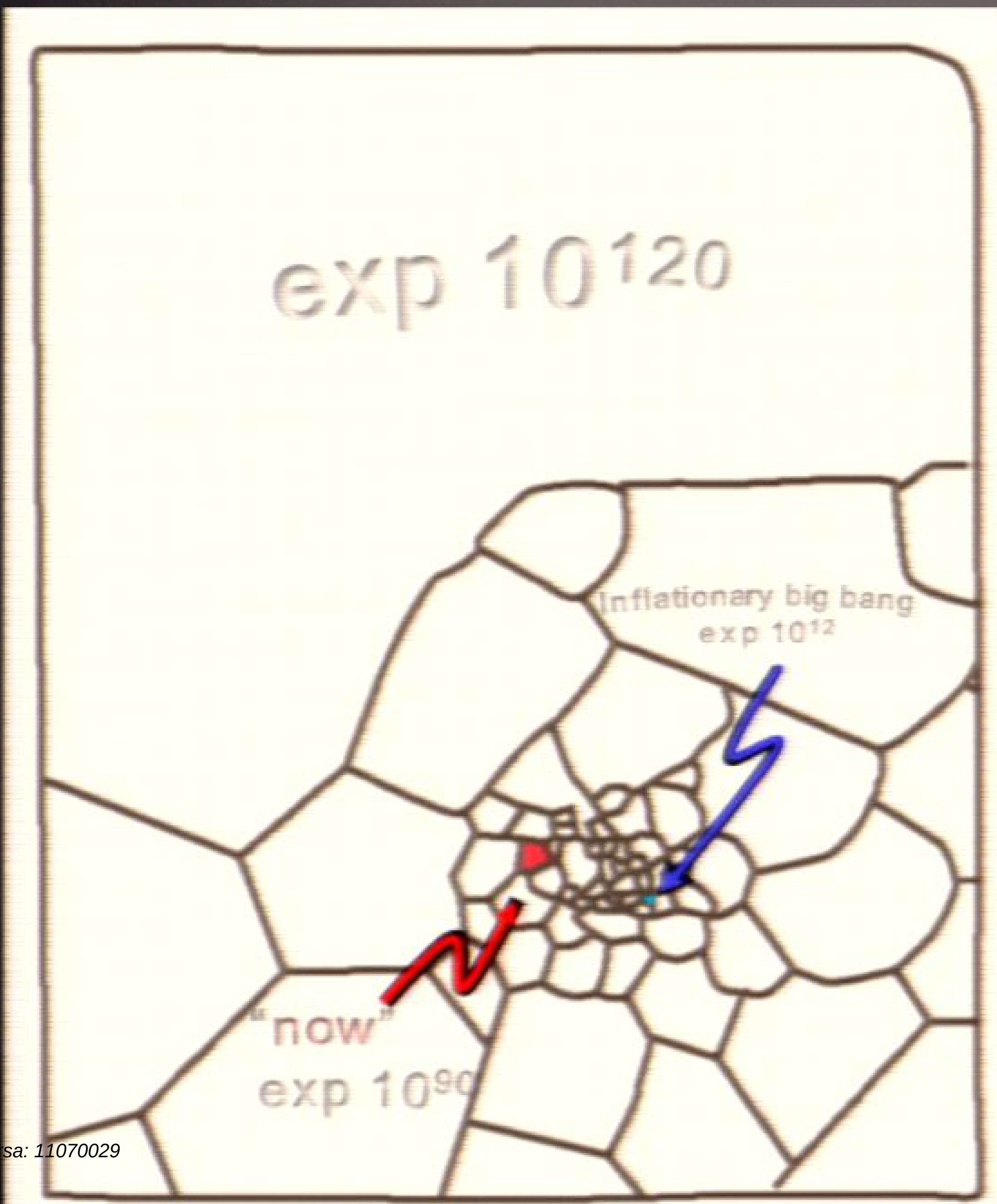
Naïve views about likely initial conditions

The Penrose (1989) argument...



$$S_{\max} \sim \frac{M_{Planck}^4}{\rho}$$

likelihood ~ e^S

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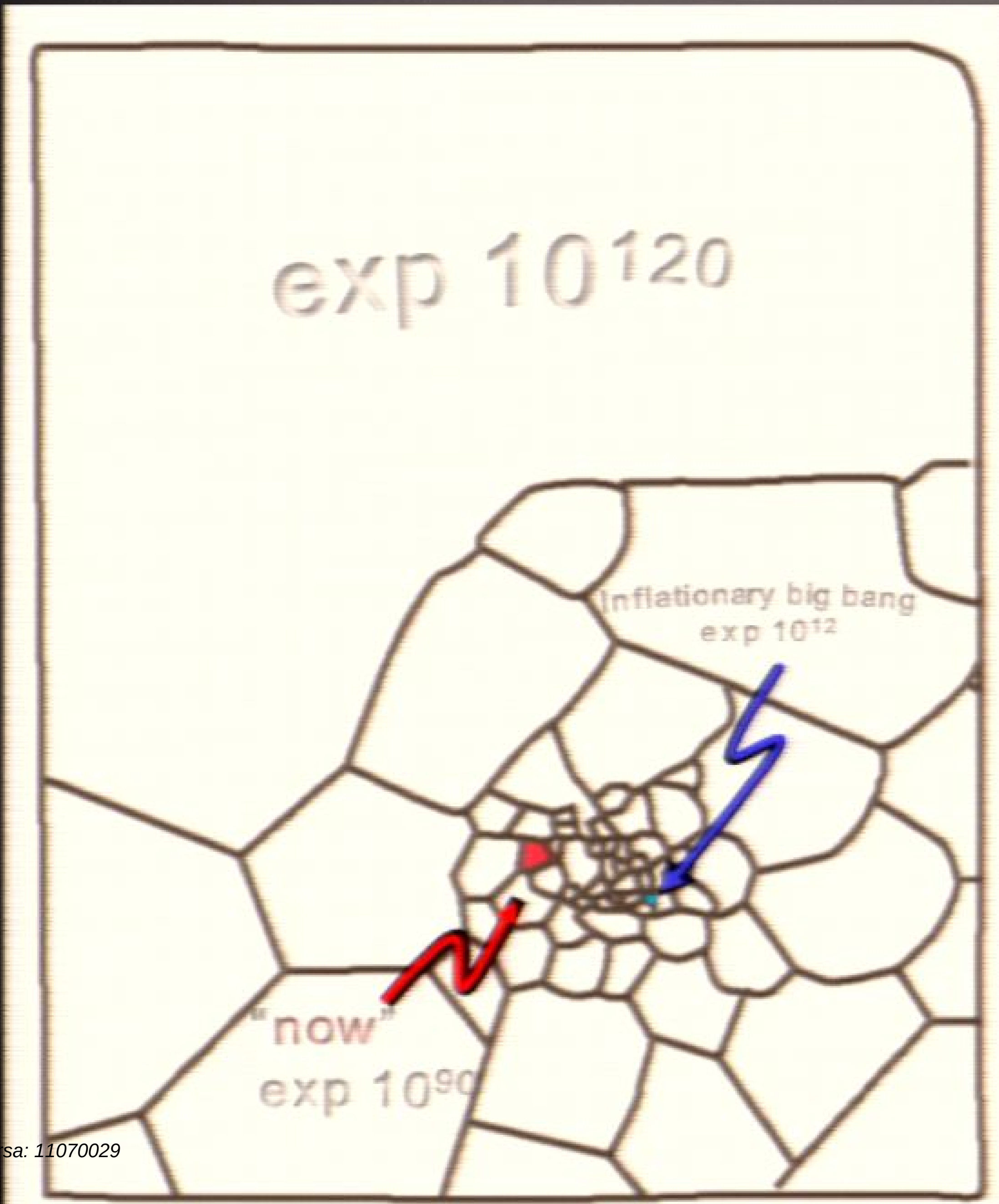
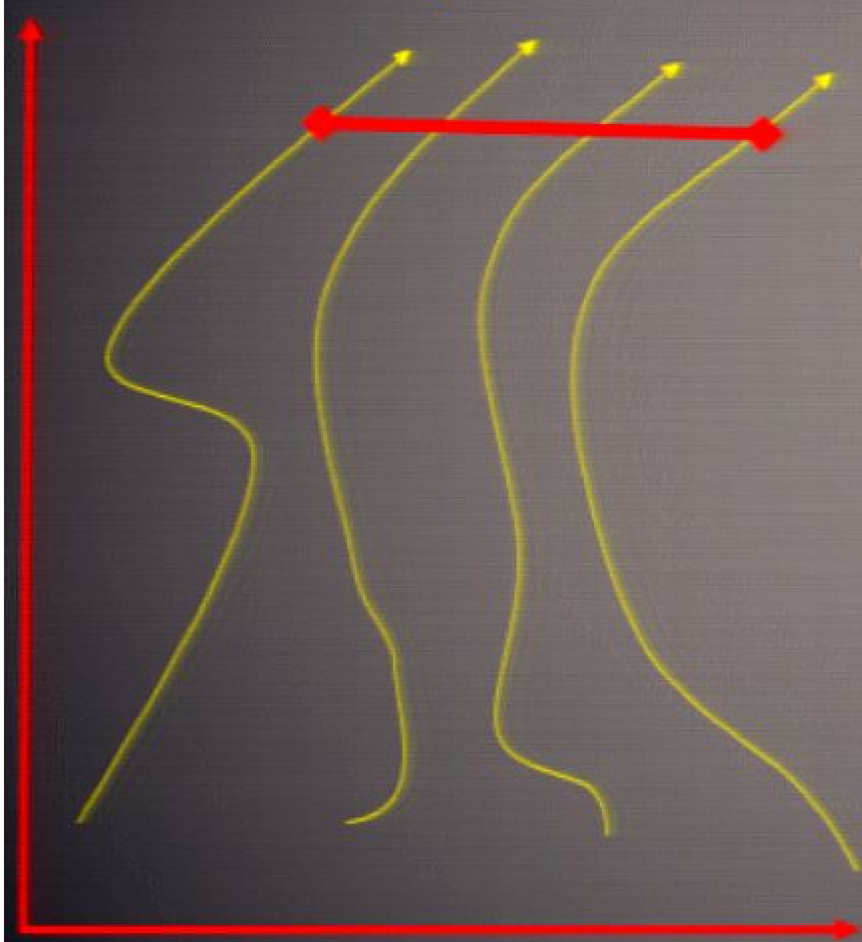


$$S_{\max} \sim \frac{M_{Planck}^4}{\rho}$$

$$\text{likelihood} \sim e^S$$

Many more ways to get to "now" by avoiding inflation than by going through it !

…and the Liouville argument



extrapolating backwards,

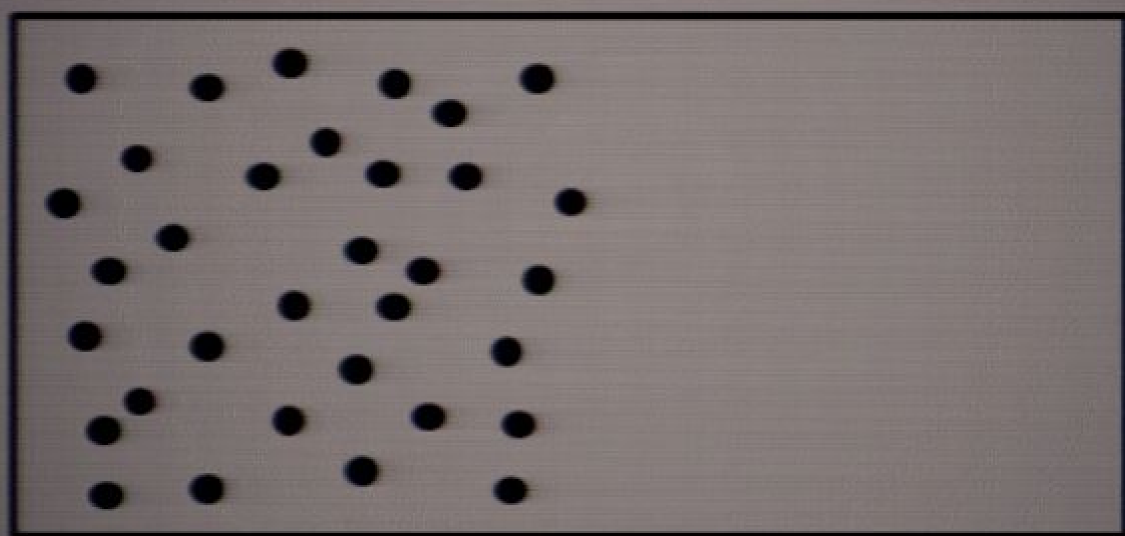
what fraction pass thru
> 60 e-folds of inflation?

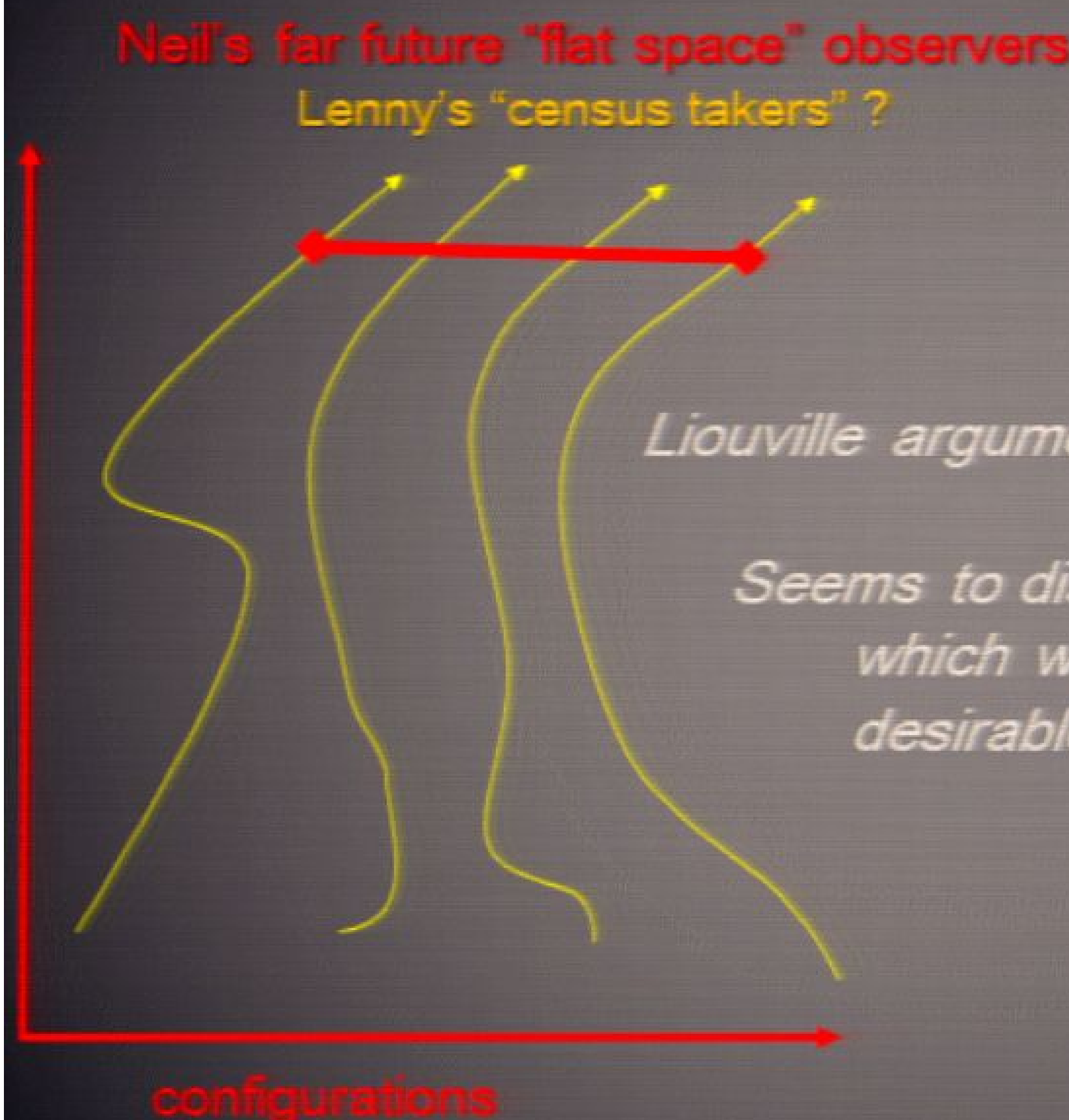
Answer: Almost none!

Gibbons & Turok (2006)

Turok (2011)

Lenny's Janitor



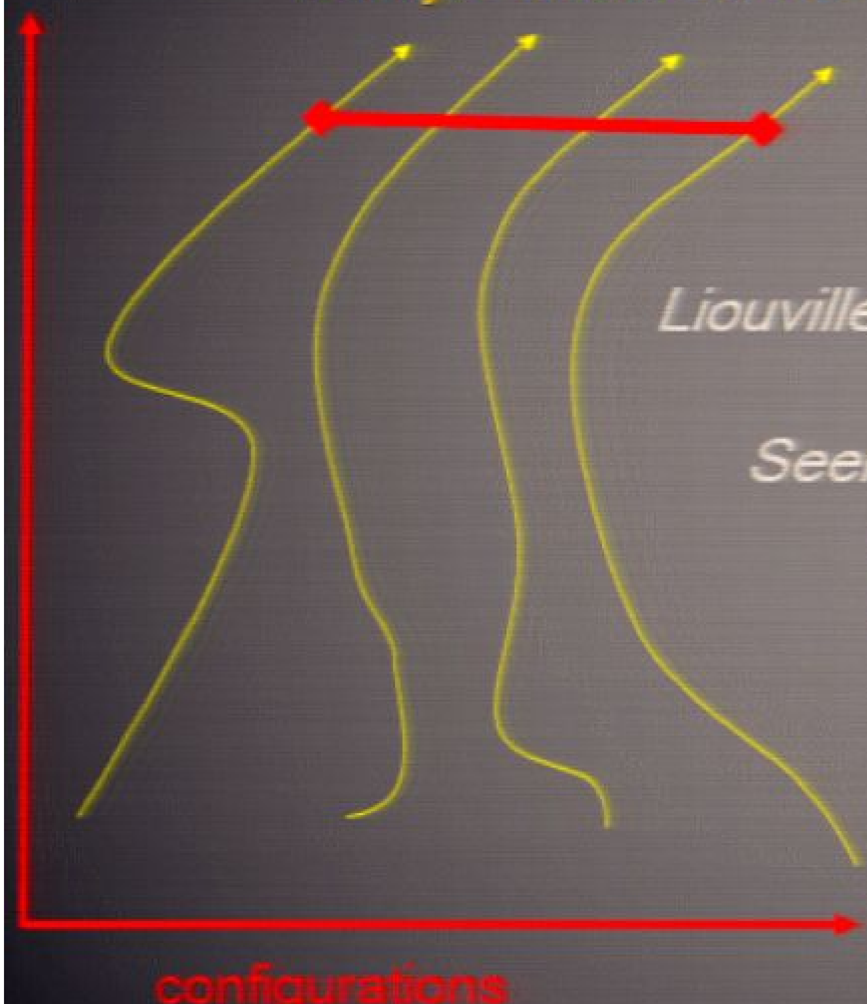


Liouville argument counterintuitive?

Seems to disfavor strong attractor behavior, which we normally considerable desirable in a theory???

Neil's far future "flat space" observers

Lenny's "census takers" ?



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In homogeneous case,
Inflation IS favored
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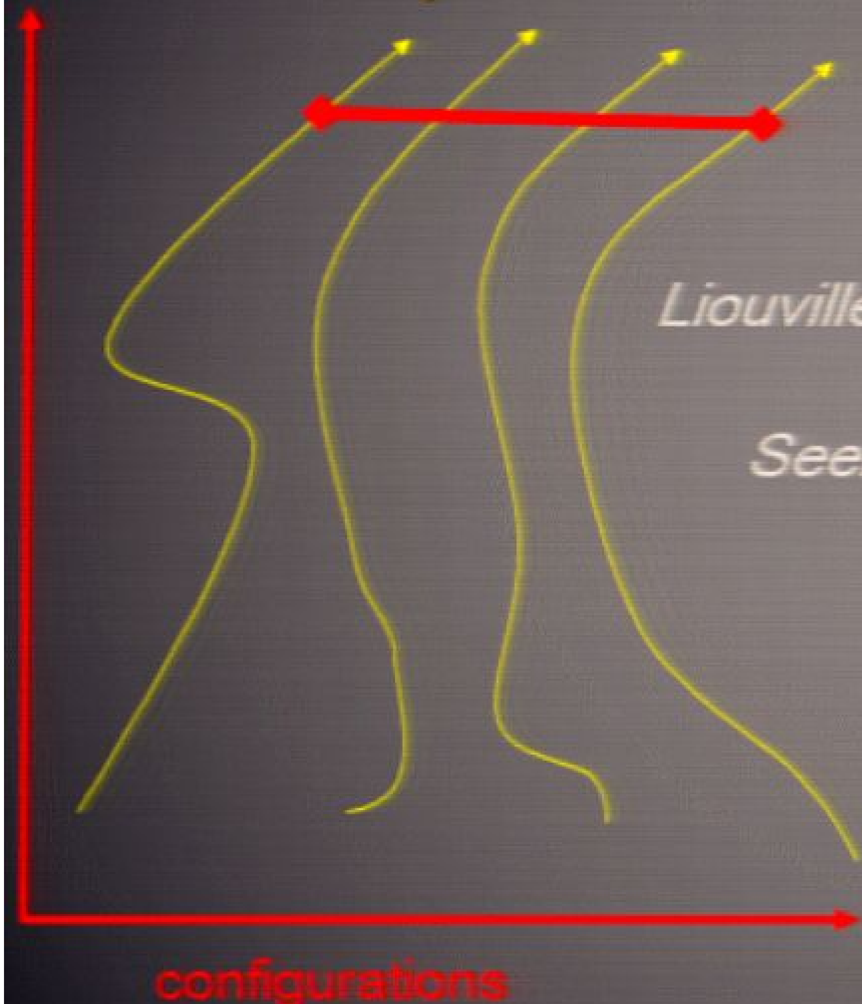

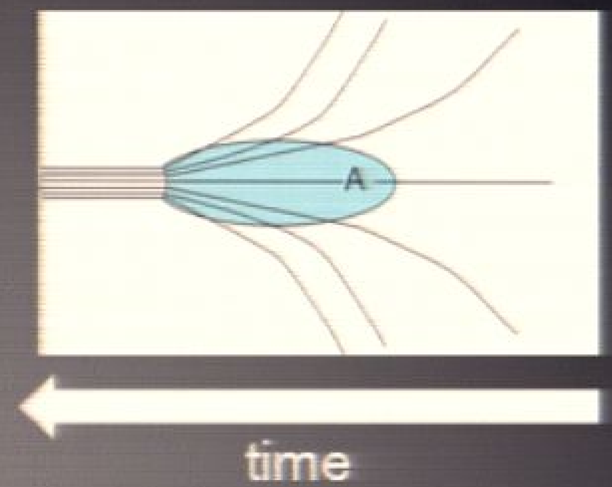

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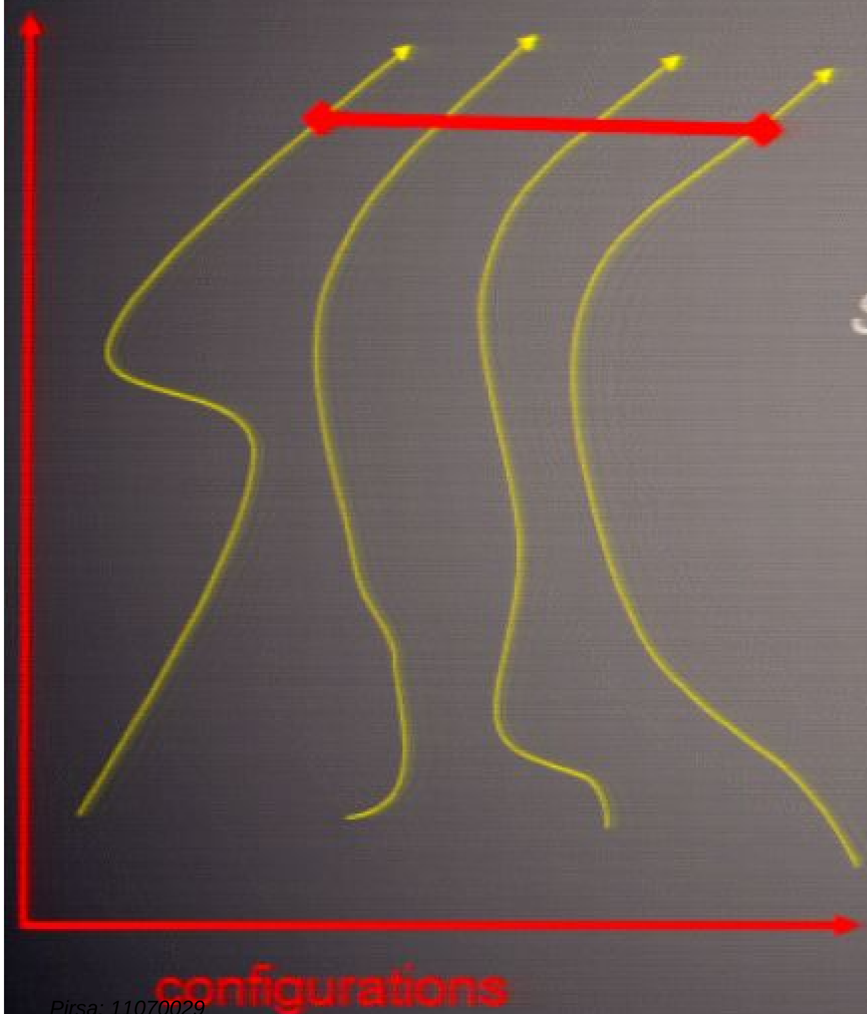
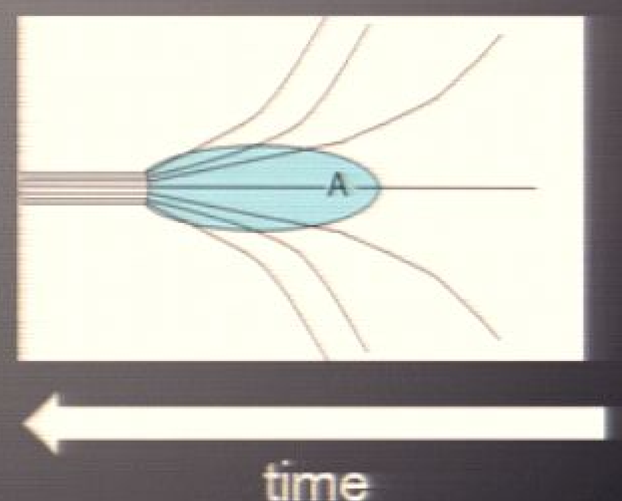


Stronger than the entropy argument ?



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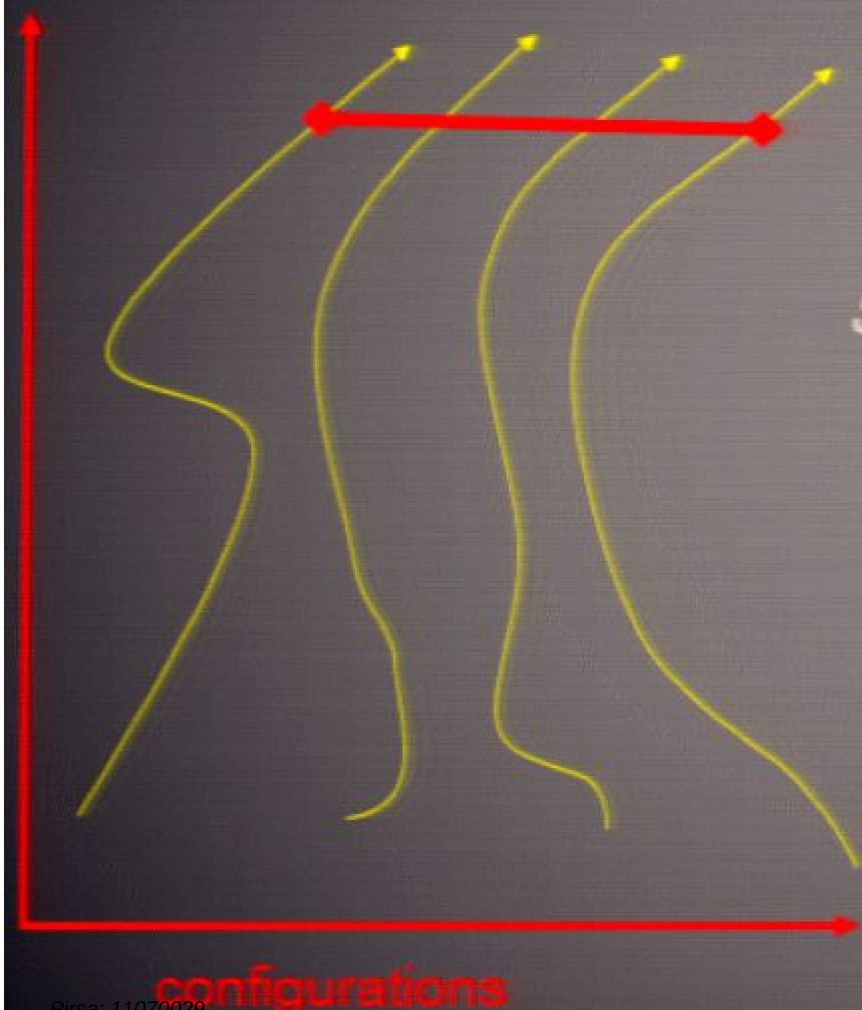

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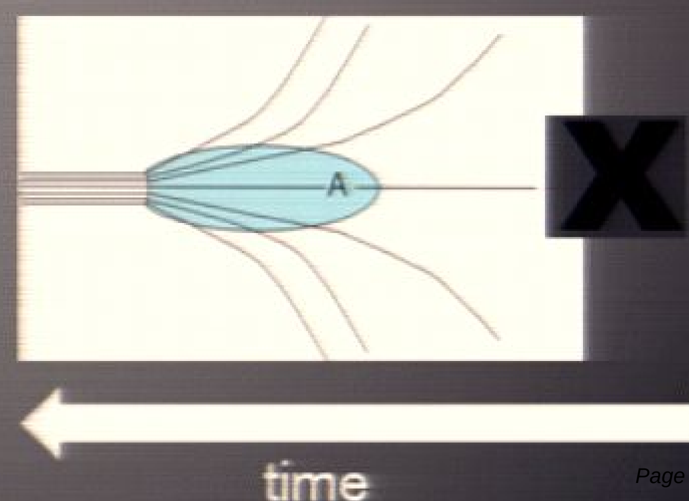

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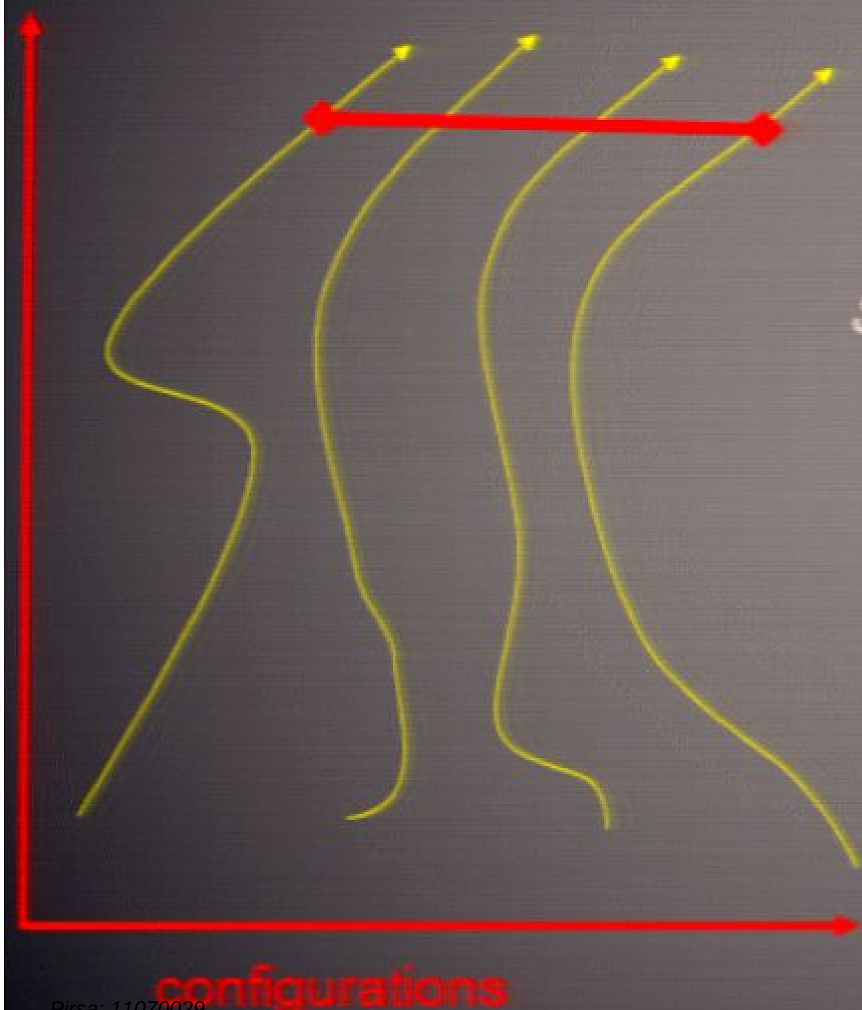

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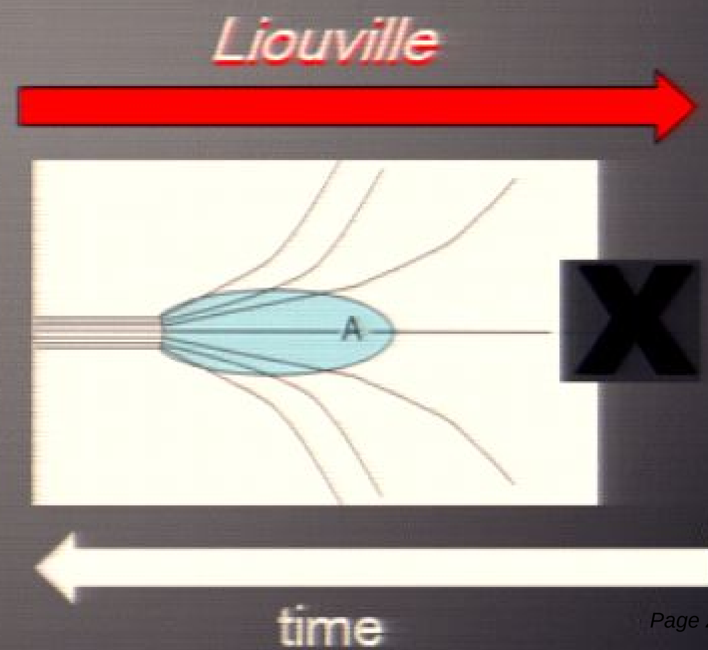

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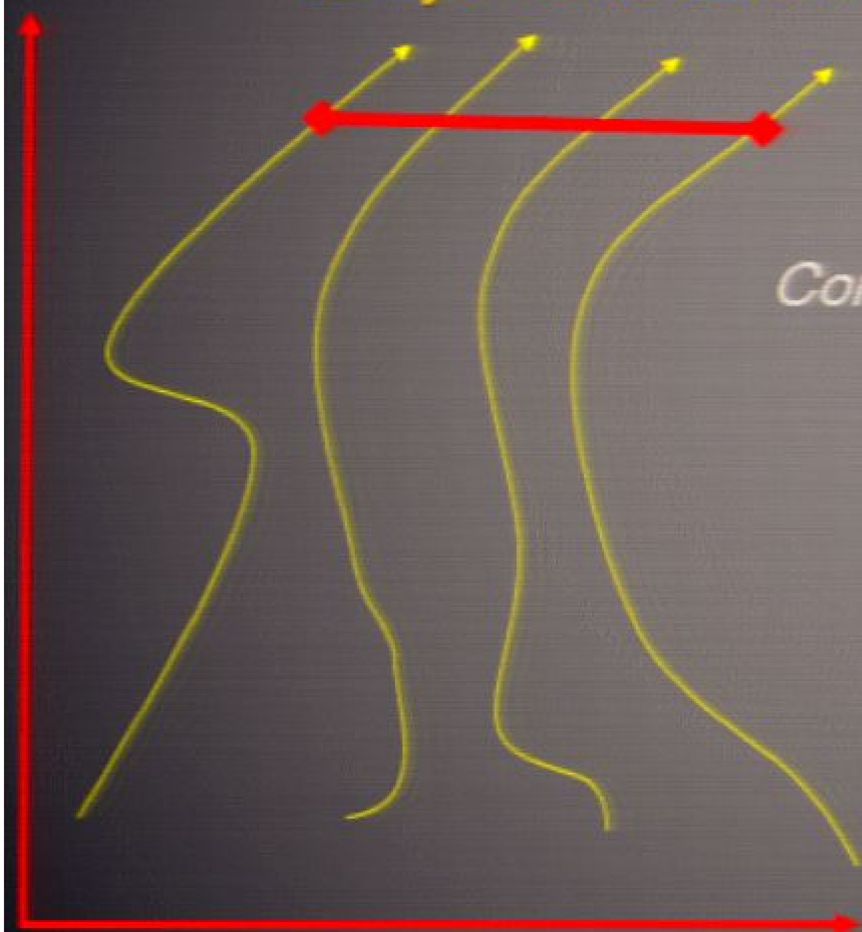
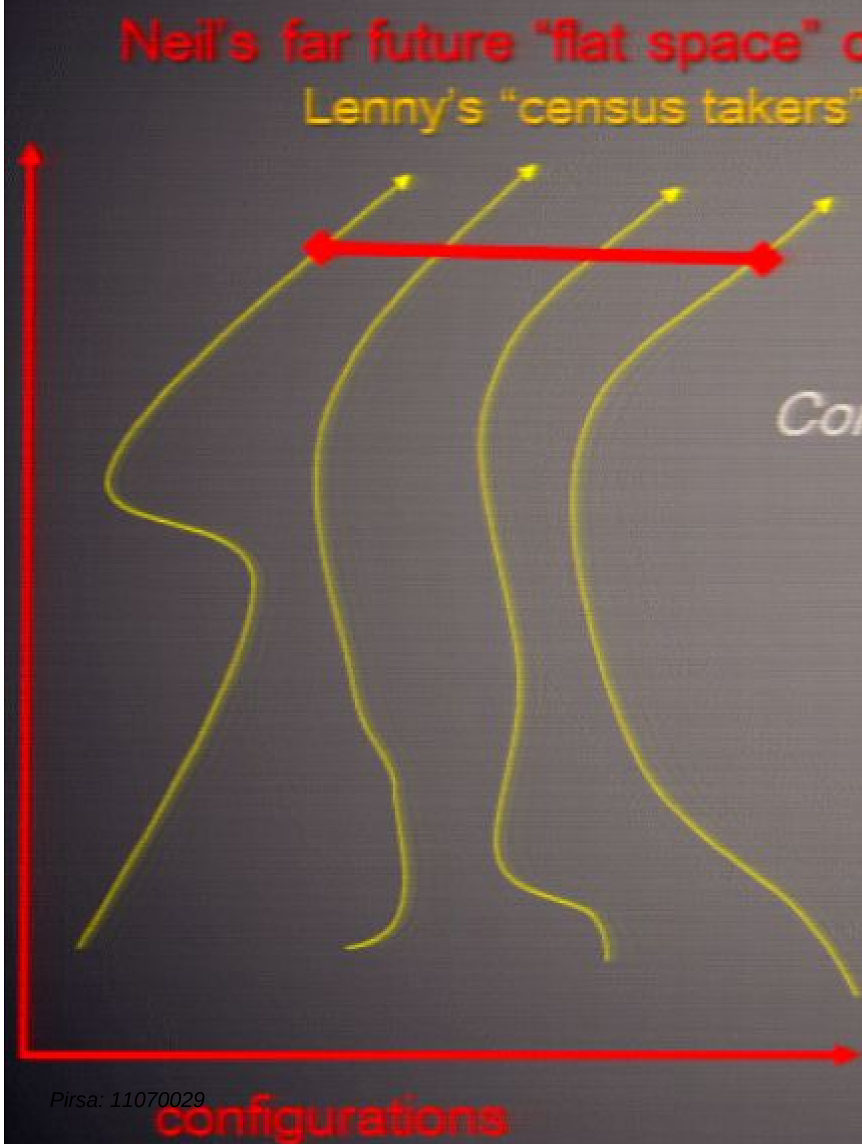


configurations

Corollary: makes clear that KE >>PE
as you extrapolate back in time

...and the Liouville argument



Corollary: makes clear that KE >>PE
as you extrapolate back in time

Except for special cases (oscillations),
only equal at one instant in time,
so equality is not likely

Therefore, KE >>> PE **much more likely** initial condition than KE ~ PE.

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Contrast with the standard lore (rough equipartition):

Since there is absolutely no *a priori* reason to expect that $\partial_\mu\varphi\,\partial^\mu\varphi \ll \mathrm{M}_\mathrm{P}^4$, $\mathrm{R}^2 \ll \mathrm{M}_\mathrm{P}^4$, or $\mathrm{V}(\varphi) \ll \mathrm{M}_\mathrm{P}^4$, it seems reasonable to suppose that the most natural initial conditions at the moment when the classical description of the universe first becomes feasible are

$$\partial_0\varphi\,\partial^0\varphi \sim \mathrm{M}_\mathrm{P}^4\,, \tag{1.7.7}$$

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Linde (2005)

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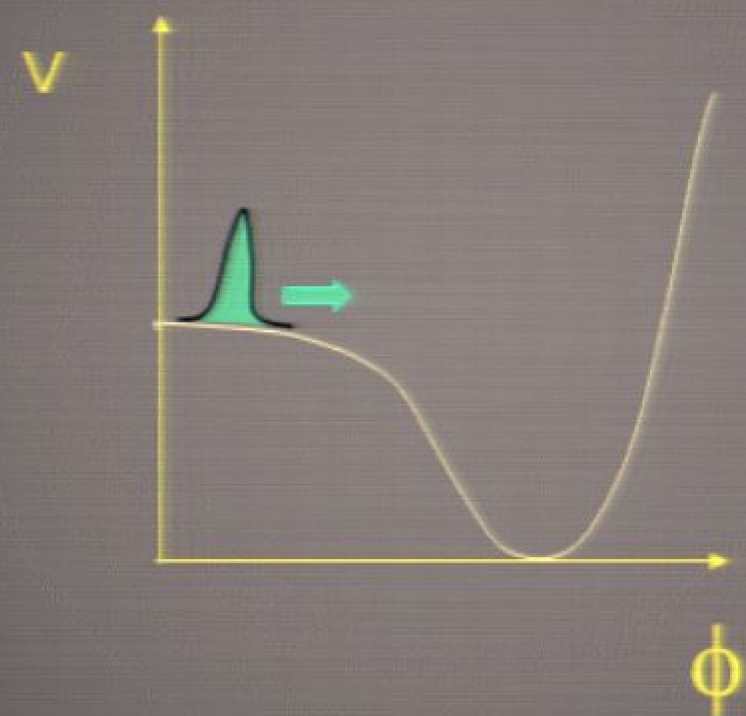
How much more likely?

Liouviille tells us exponentially more likely!
(which is why inflation is disfavored)

How to Fix the Problems?

Inflation makes no predictions



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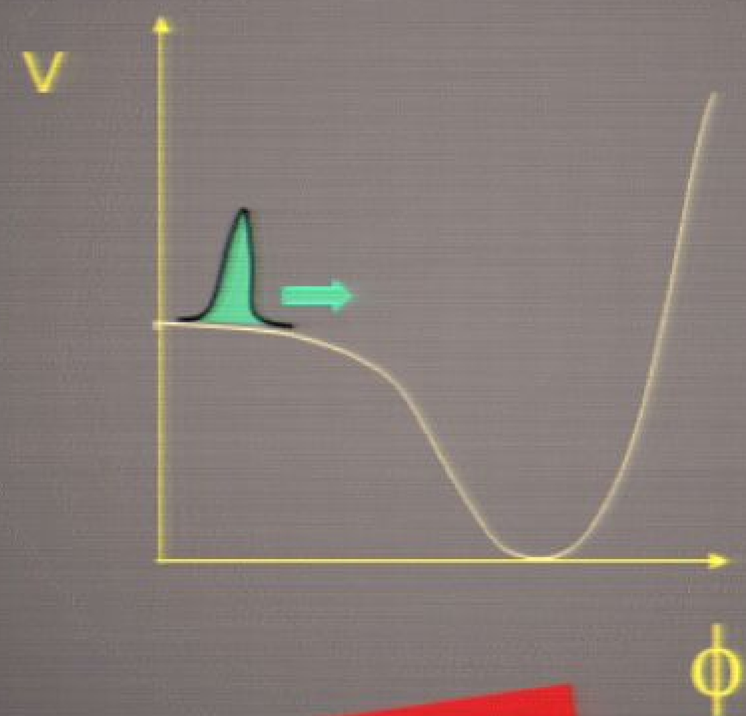

~~*Inflation rewards "rogue" regions*~~
~~*(atypical regions normally, but here*~~ *inflation makes them dominant)*

SMOOTH AND FLATTEN WHILE PENALIZING ROGUE REGIONS

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MUST VIOLATE NEC

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MUST VIOLATE NEC

wo logical possibilities:

smooth while expanding (.e.g., see Roger's talk)

smooth while contracting -- then need info preserving bounce

CONTRACTION HAS SOME IMMEDIATE ADVANTAGES:

NO CAUSALITY PROBLEM

NO FLATNESS PROBLEM

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$$+\frac{8\pi G}{3}\frac{\rho_\phi^0}{a^{3(1+w)}}$$

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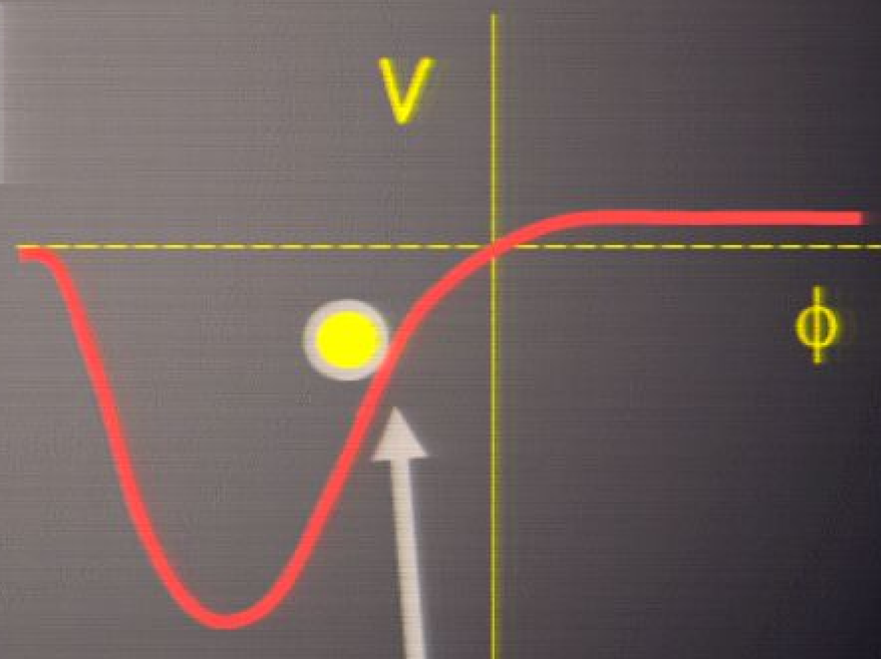
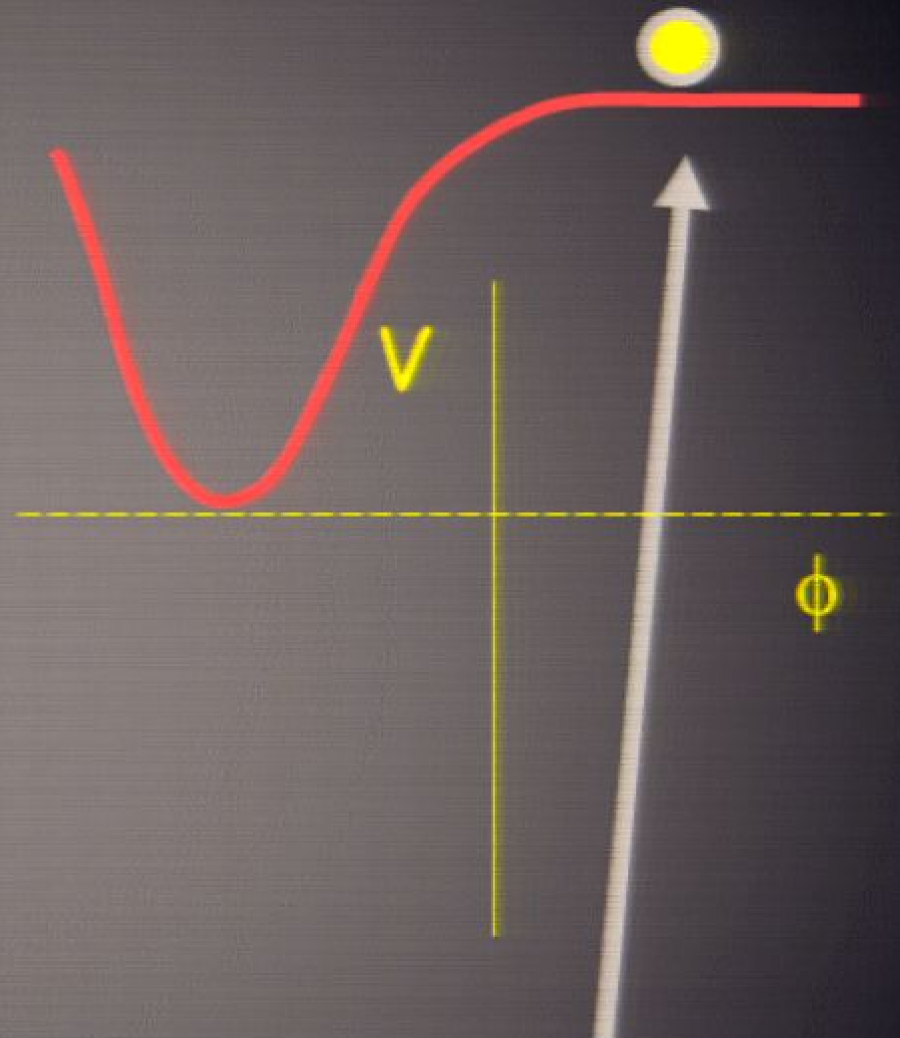


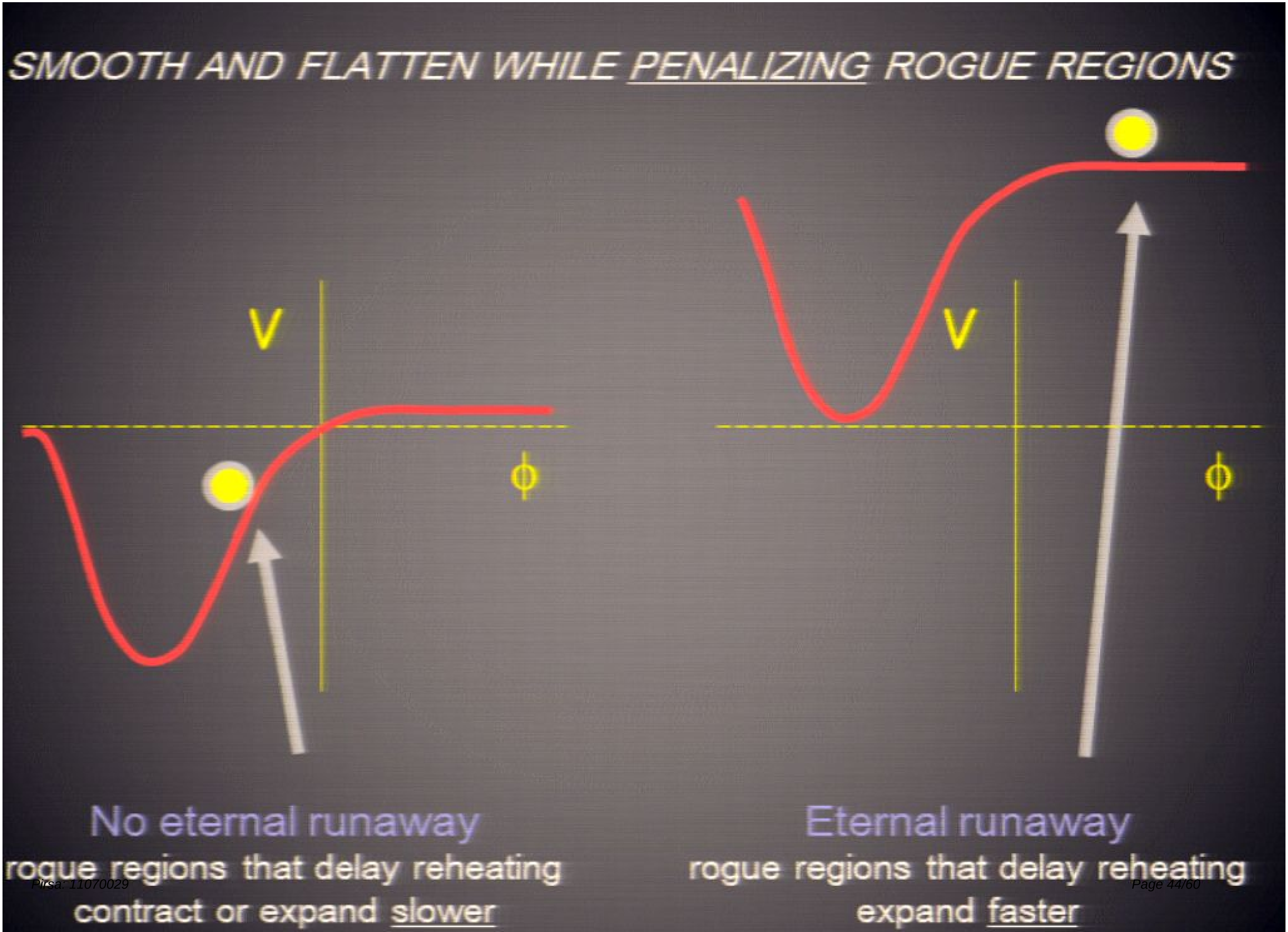
$$w = \frac{\frac{1}{2}\dot\phi^2 - V}{\frac{1}{2}\dot\phi^2 - V}$$

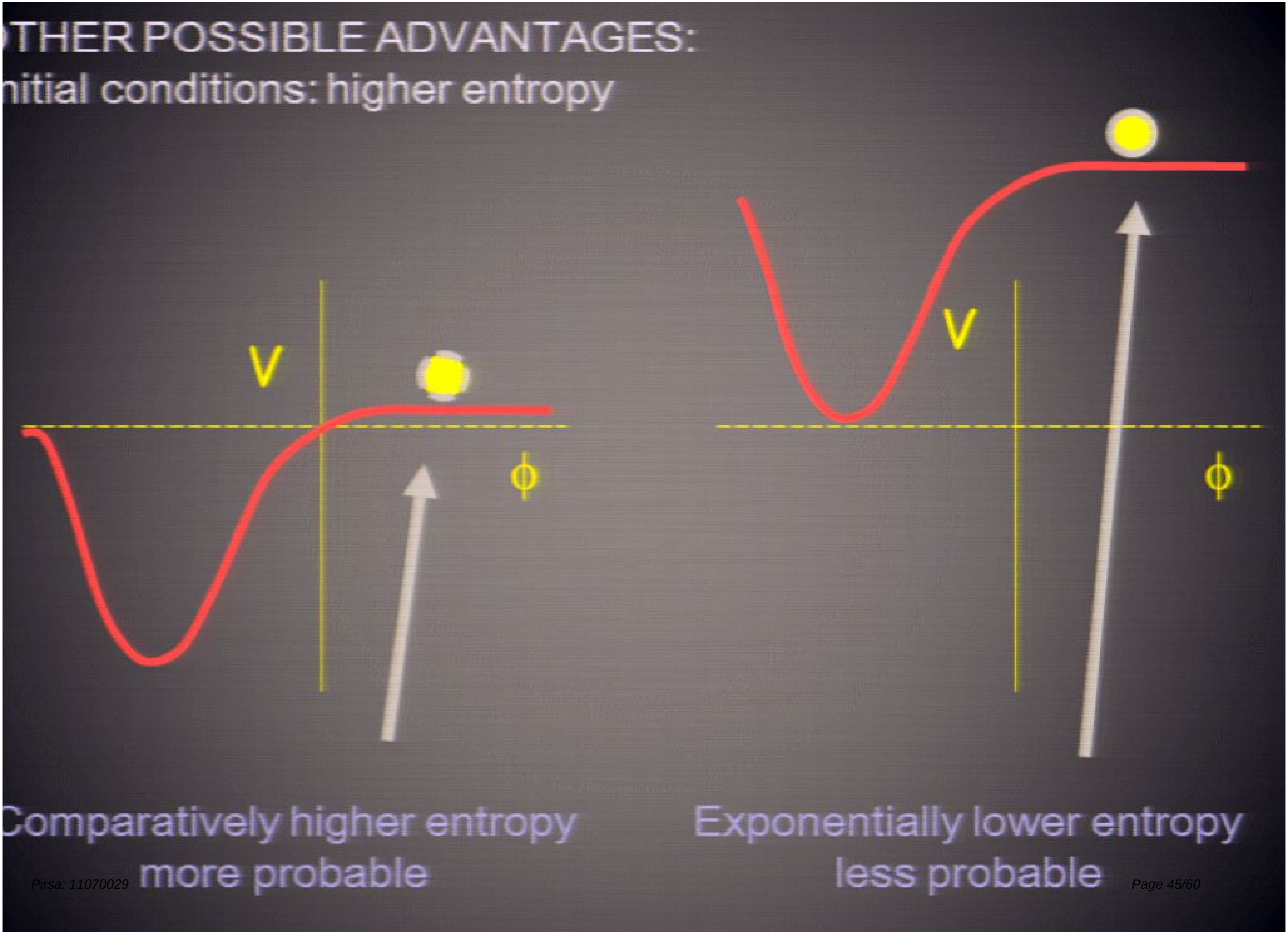
SMOOTH AND FLATTEN WHILE PENALIZING ROGUE REGIONS



Eternal runaway

rogue regions that delay reheating expand faster


SMOOTH AND FLATTEN WHILE PENALIZING ROGUE REGIONS
V
φ
V
φ
No eternal runaway
rogue regions that delay reheating
contract or expand slower
Eternal runaway
rogue regions that delay reheating
expand faster



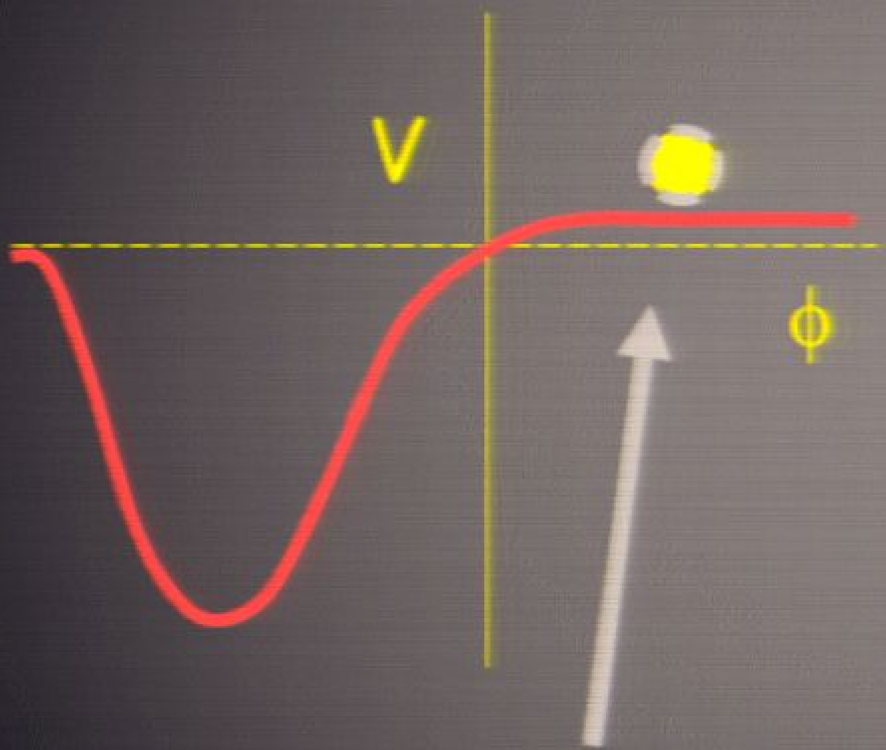
THER POSSIBLE ADVANTAGES:
nitial conditions: higher entropy
V
ϕ
V
ϕ
Comparatively higher entropy
more probable
Exponentially lower entropy
less probable

THER POSSIBLE ADVANTAGES:

nitial conditions: higher entropy

nore time": possible explanation for small Λ

cycling: efficient use of space



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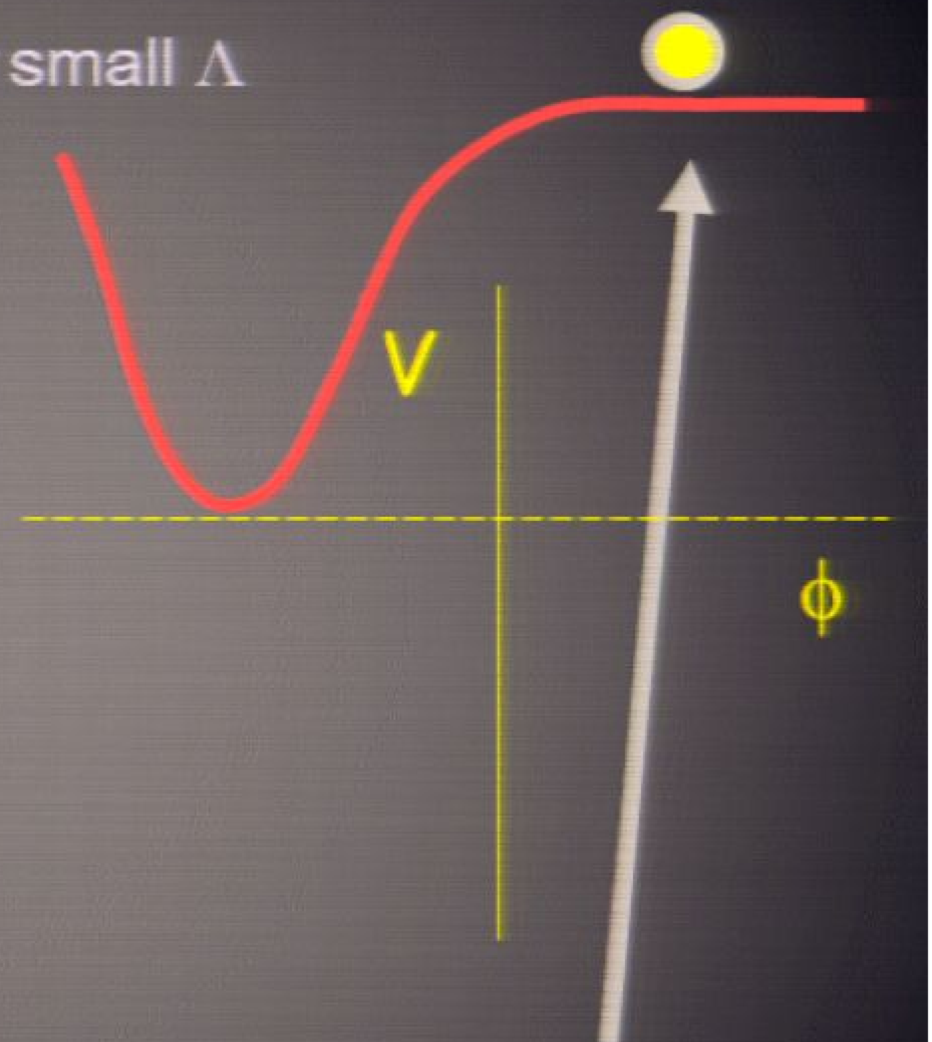

Exponentially lower entropy
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THE BOUNCE:

Required to have bounce that is unitary/analytic....

that smoothly matches conditions

from before to after

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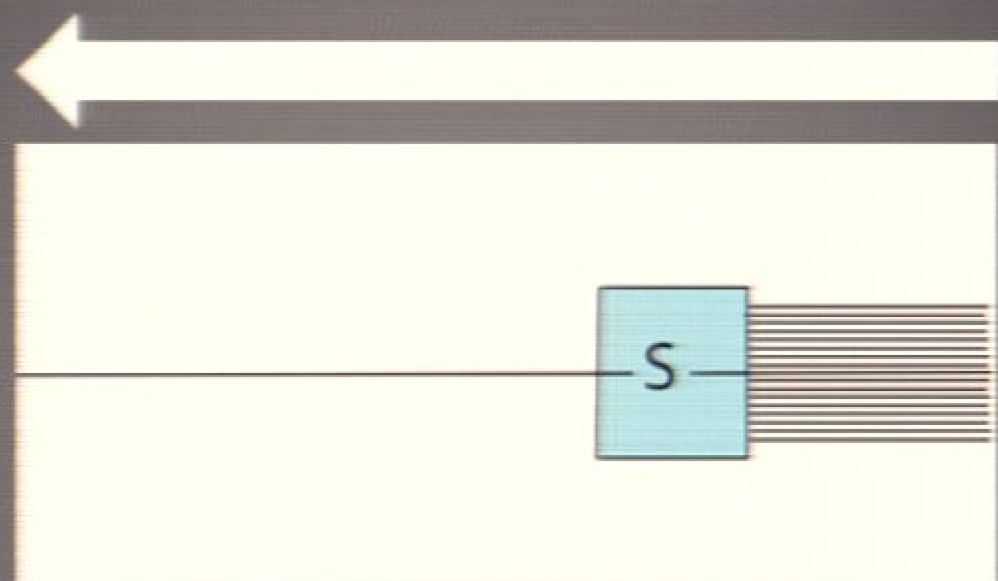
NEED NOT BE GENERIC !

THE IMPERFECT BOUNCE: AN IDEAL ENTROPY SIEVE?

TIME



Sieves out regions with large geometrical entropy (they form black holes)

Passes regions with tiny geometrical entropy and high matter entropy

A NON-HAMILTONIAN EVOLUTION

Generic predictions:

primordial g-waves: exponentially small and blue

H exponentially small and increasing in magnitude

non-gaussian perturbations

Koyama, Mizuno, Vernizzi, Wands
Buchbinder, Khoury, Ovrut
Lehners, PJS

Large w: $\zeta = \zeta_L + \frac{3}{5} f_{NL}\, \zeta_L^{\,2} + \frac{3}{5} g_{NL}\, \zeta_L^{\,3}$

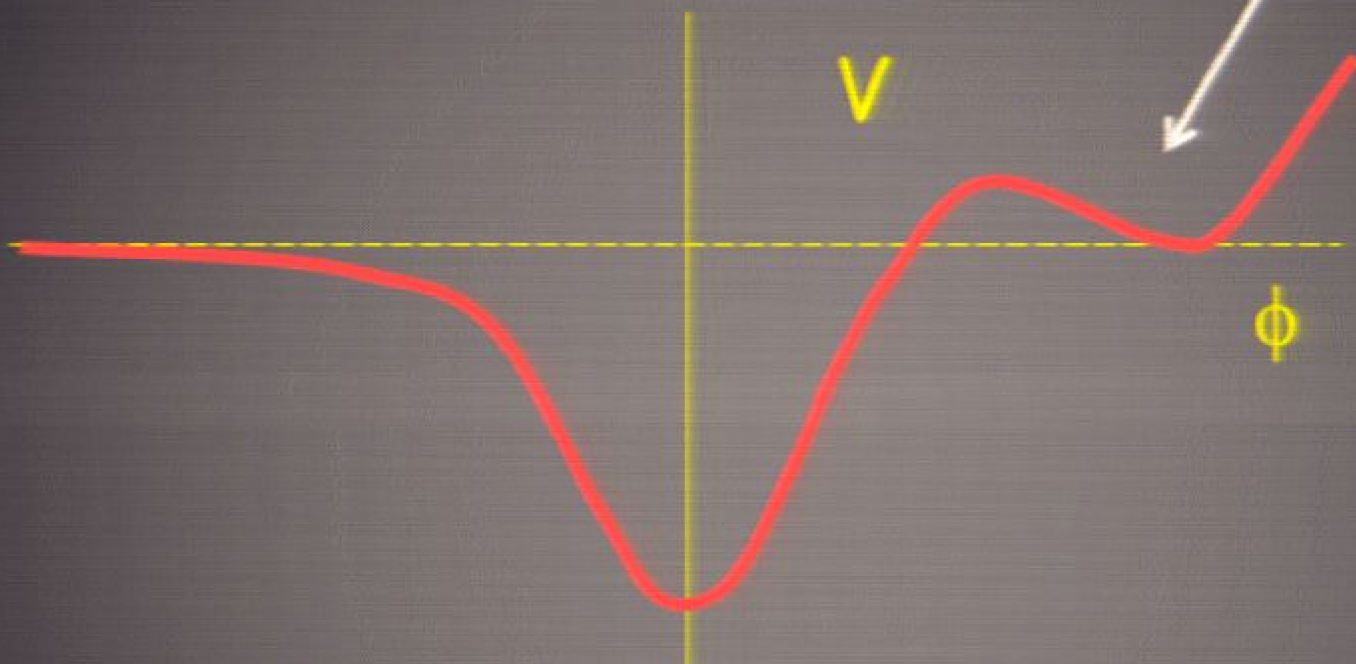
$$|f_{NL}|\,(\text{cyclic}) \sim \sqrt{w+1} = O(10)$$

$$g_{NL}\,(\text{cyclic}) \sim -40\,(w+1) = -O(1000)$$

LIOUVILLE REVISITED

w/ N. Turok

1) Begin asymptotically
in flat vacuum in
contracting phase
with small oscill.
(census takers)



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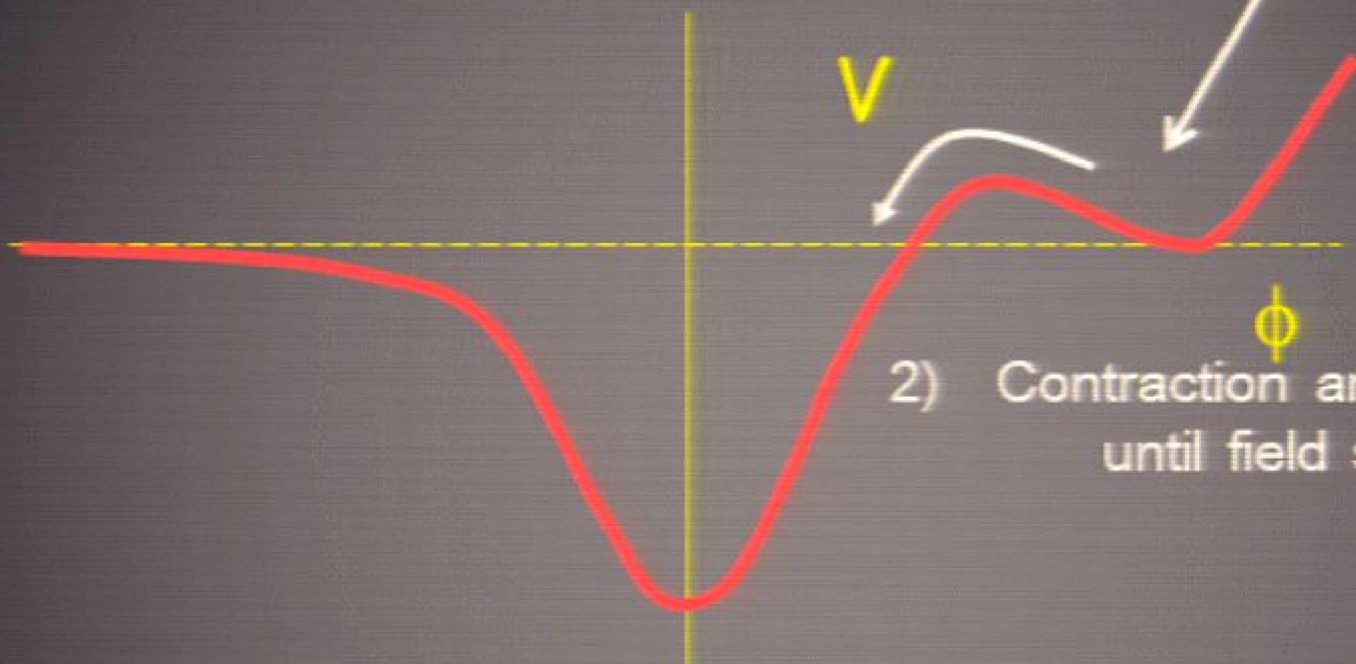

2) Contraction amplifies oscillations until field spills across barrier

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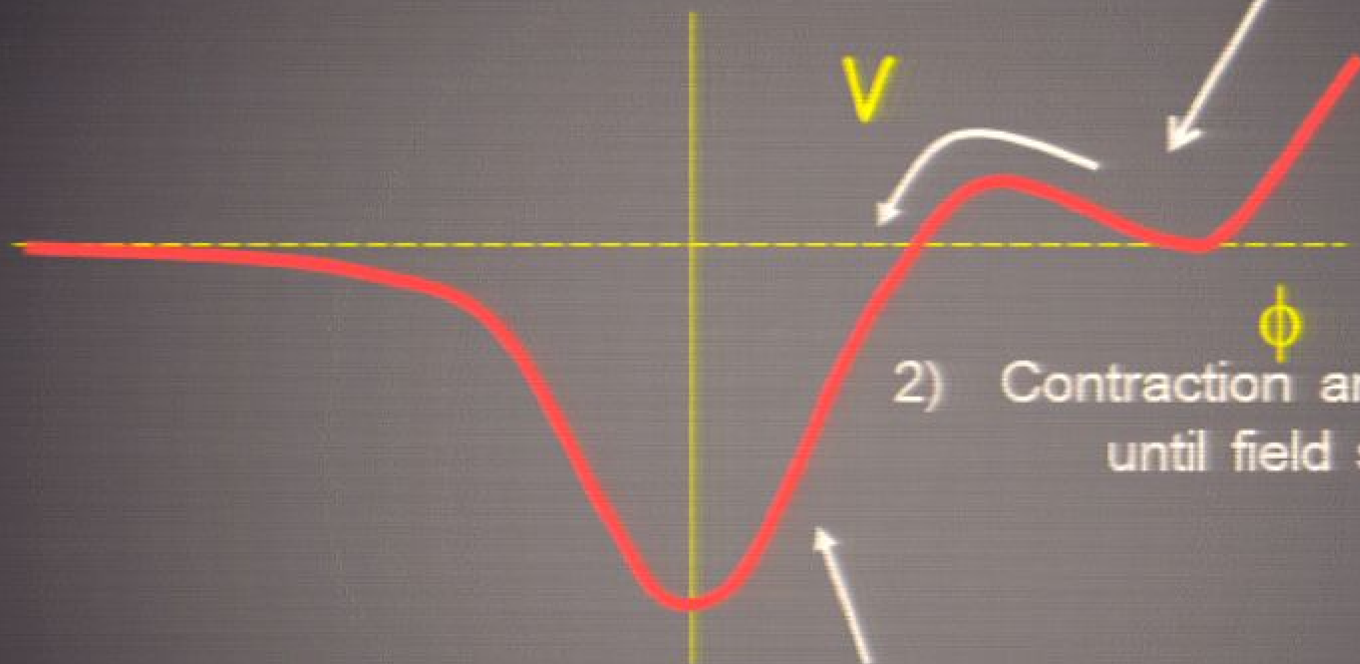

2) Contraction amplifies oscillations until field spills across barrier

3) Almost all initial conditions lead to nearly full ekpyrotic phase (N >> 60)

"fat attractor"

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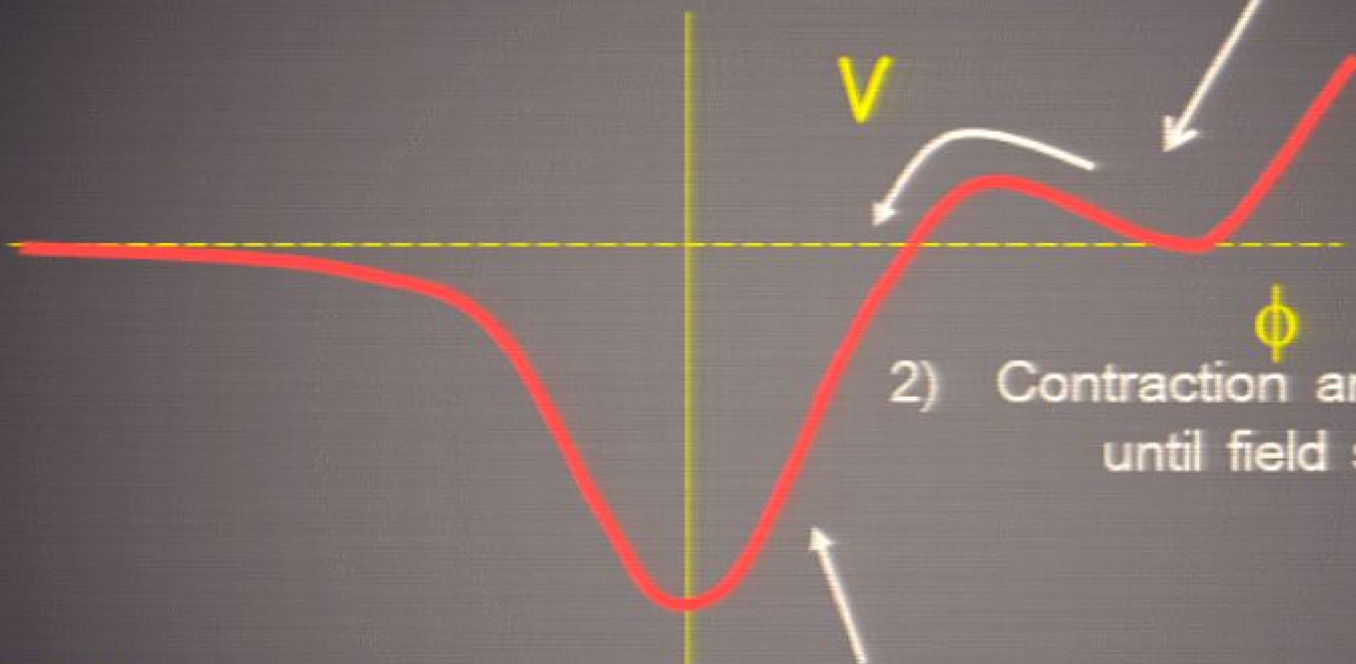

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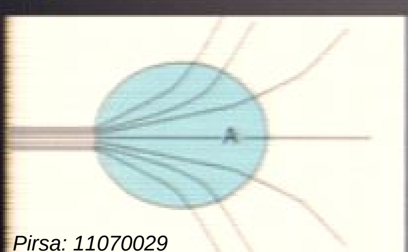

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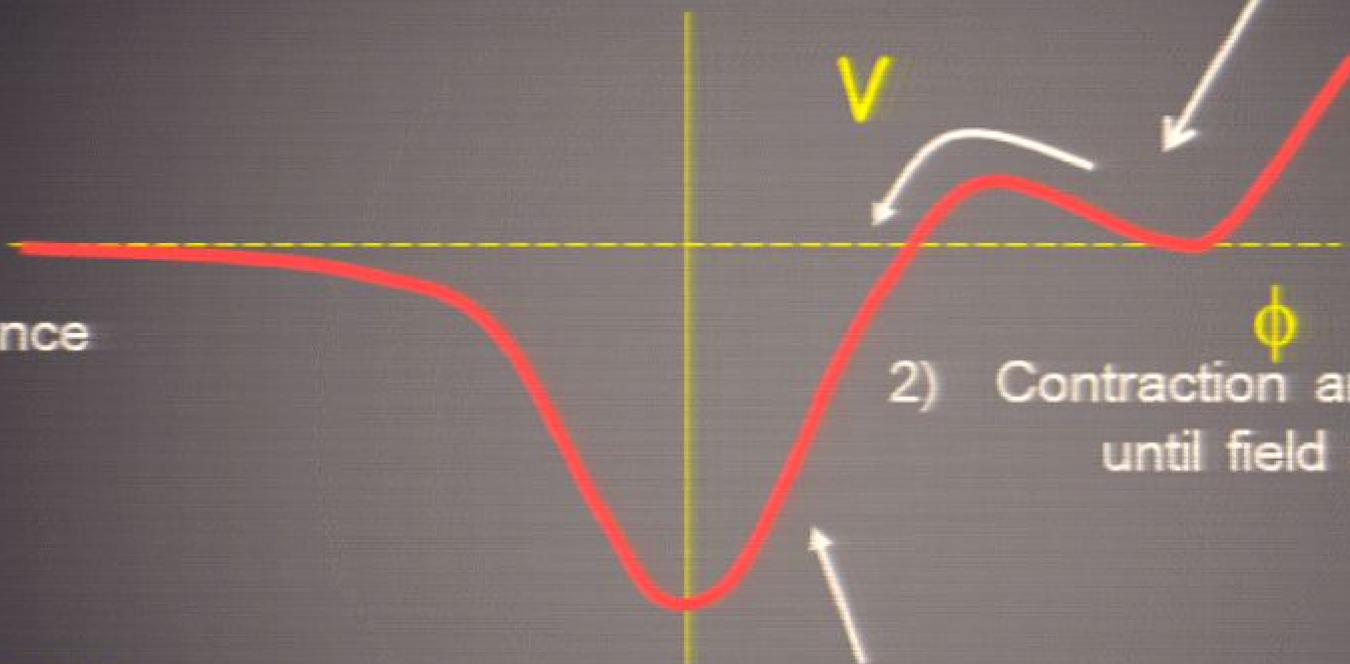

4) Bounce

2) Contraction amplifies oscillations until field spills across barrier

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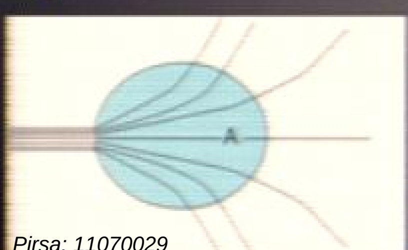
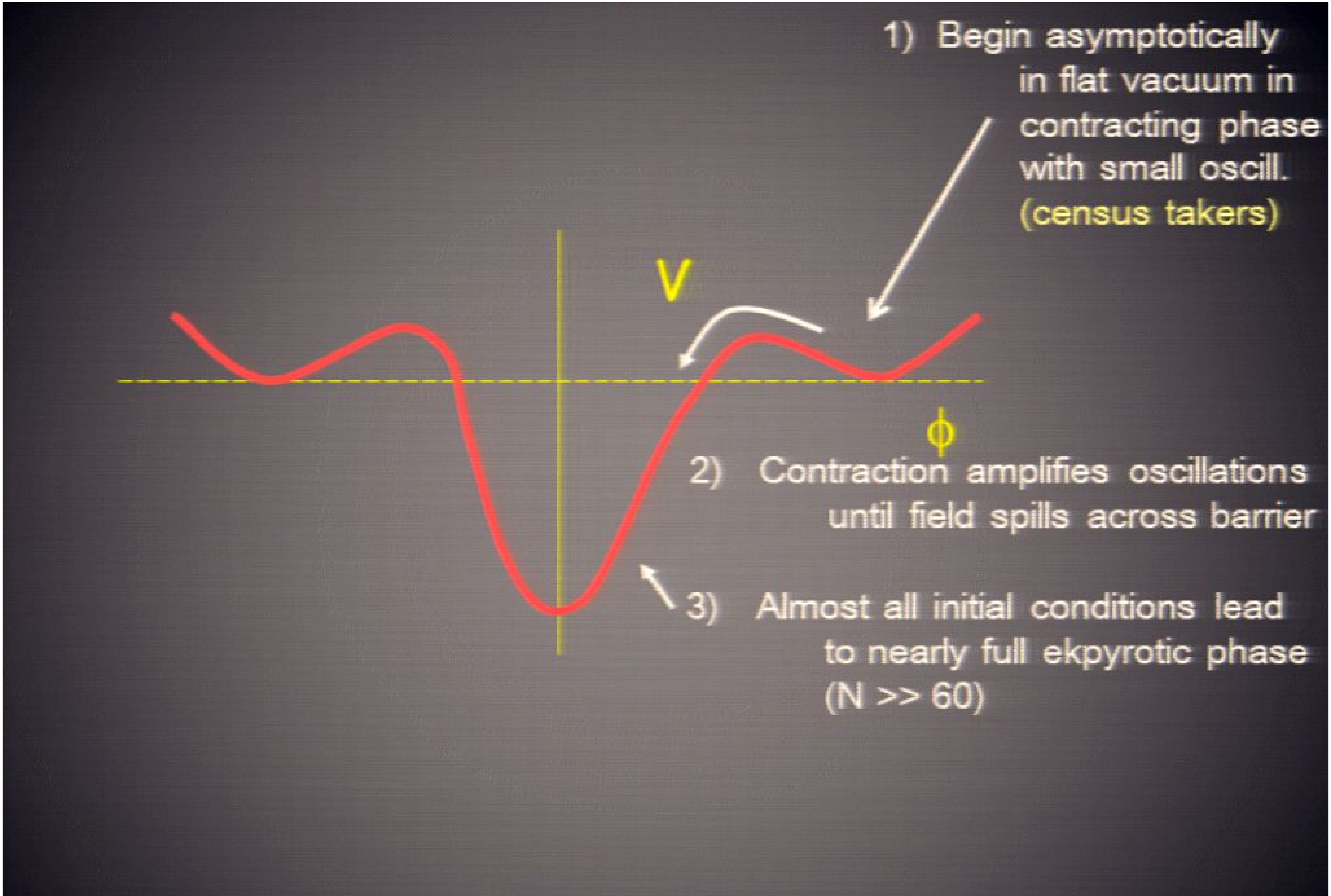
"fat attractor"

TIME



Liouville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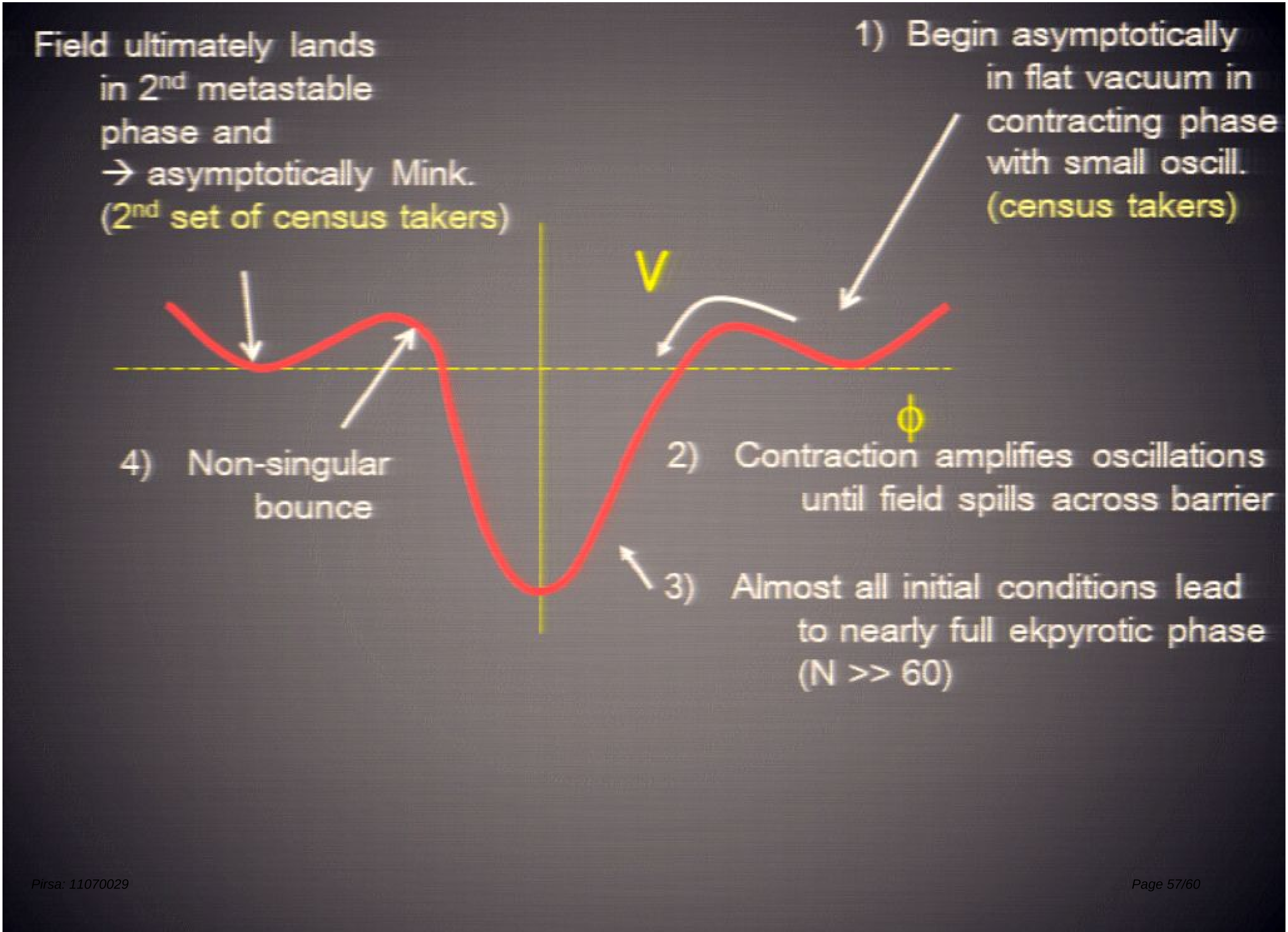

Field ultimately lands in 2nd metastable phase and
→ asymptotically Mink.
(2nd set of census takers)
1) Begin asymptotically in flat vacuum in contracting phase with small oscill.
(census takers)
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ϕ
4) Non-singular bounce
2) Contraction amplifies oscillations until field spills across barrier
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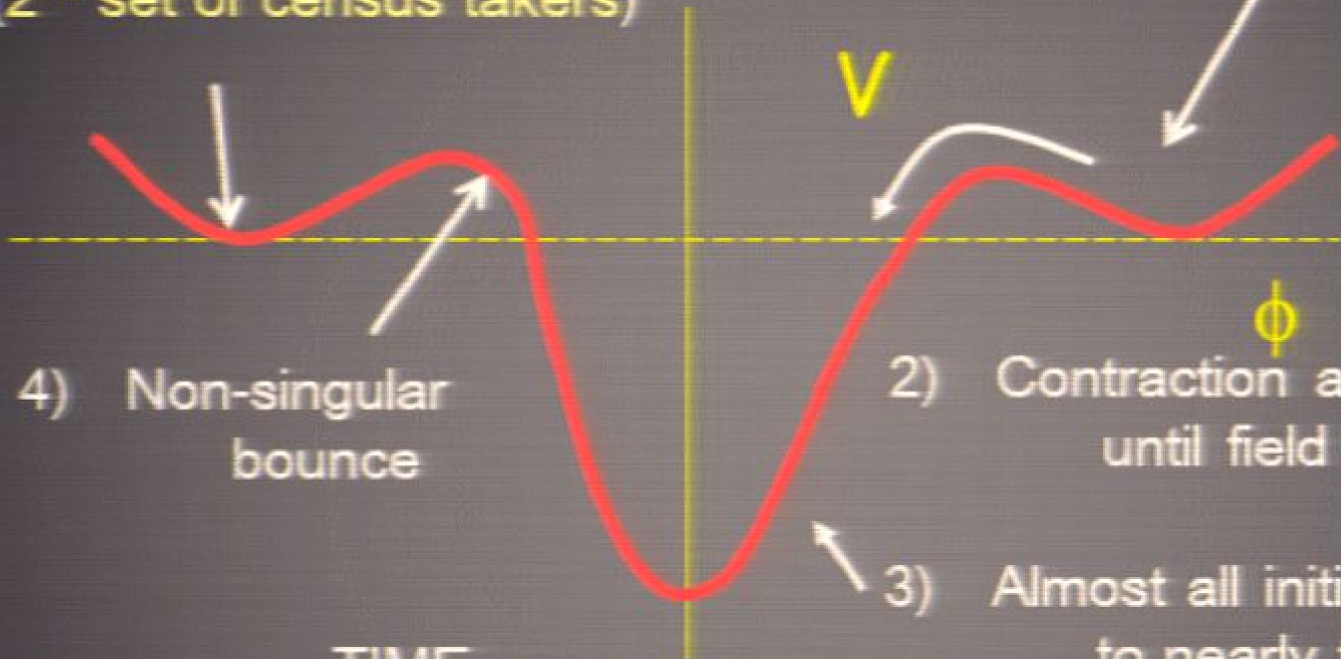
Field ultimately lands in 2nd metastable phase and → asymptotically Mink. (2nd set of census takers)

1) Begin asymptotically in flat vacuum in contracting phase with small oscill. (census takers)

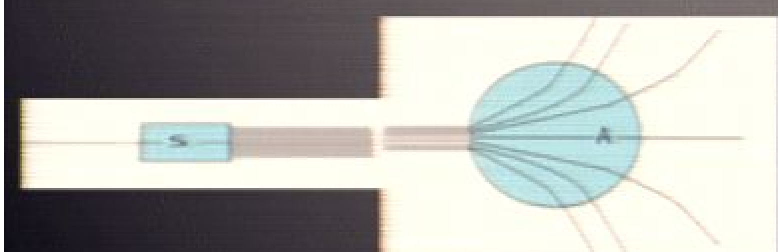


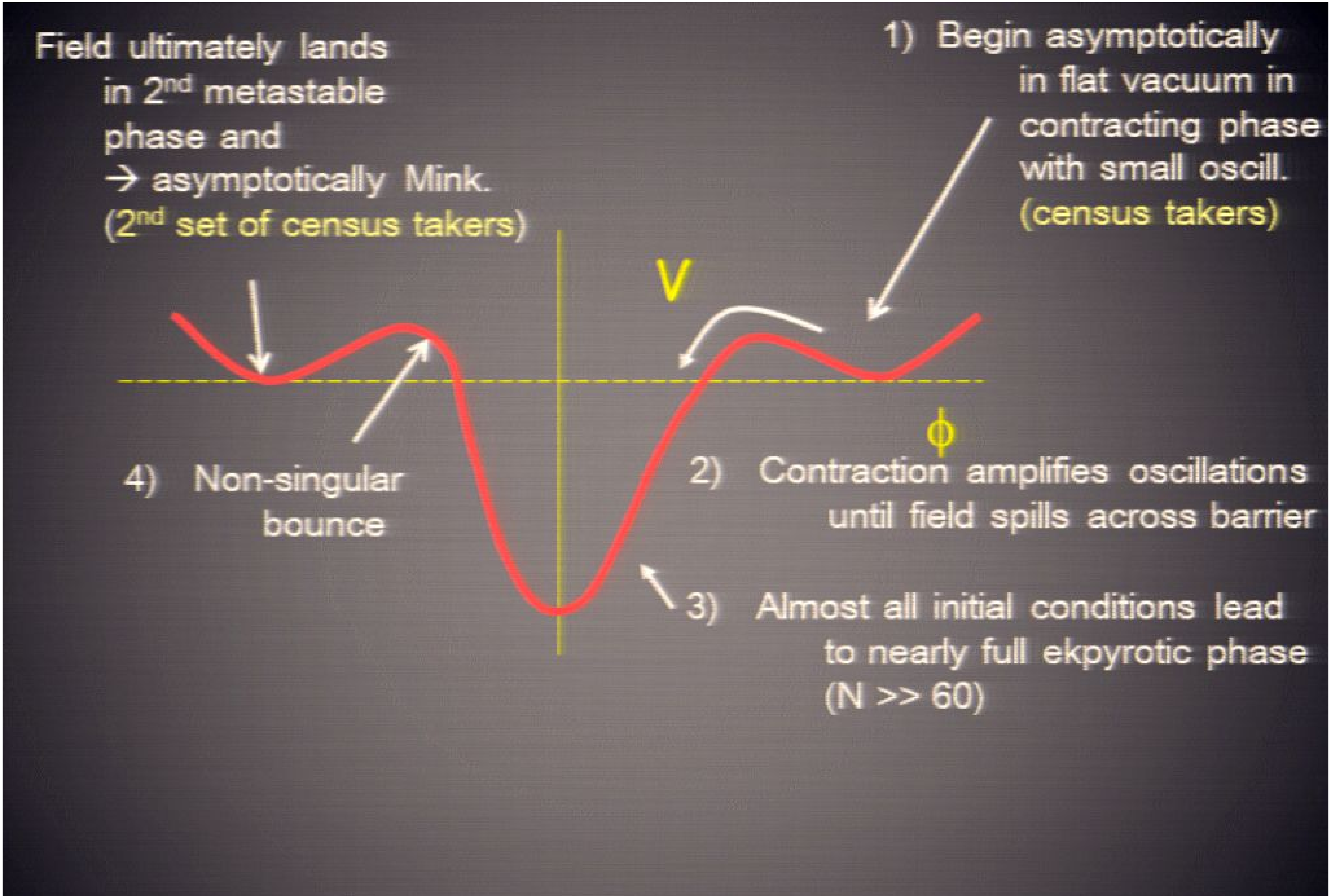
4) Non-singular bounce

2) Contraction amplifies oscillations until field spills across barrier

3) Almost all initial conditions lead to nearly full ekpyrotic phase (N >> 60)

TIME





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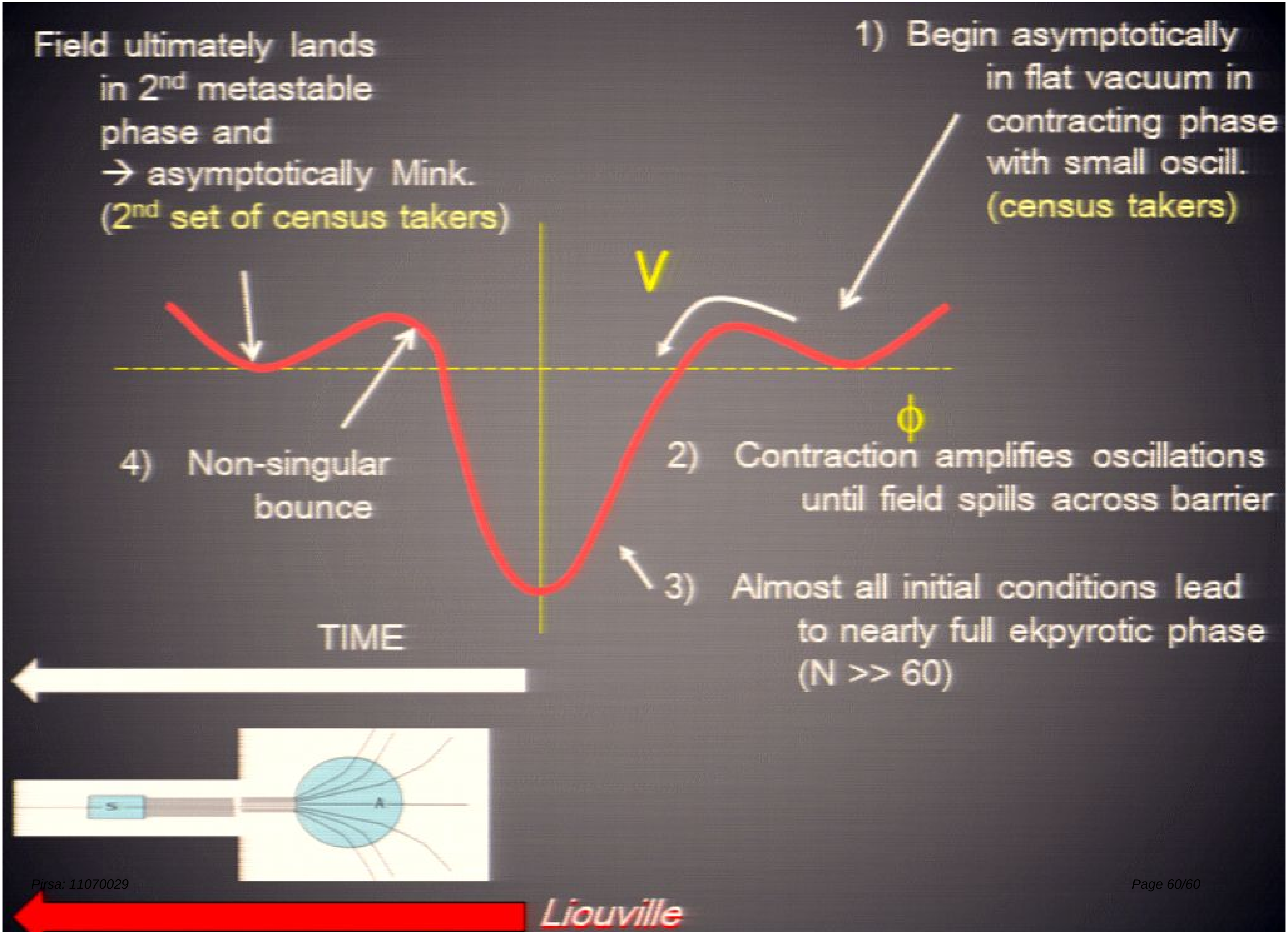
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