

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*

How might we get out of this predicament ?

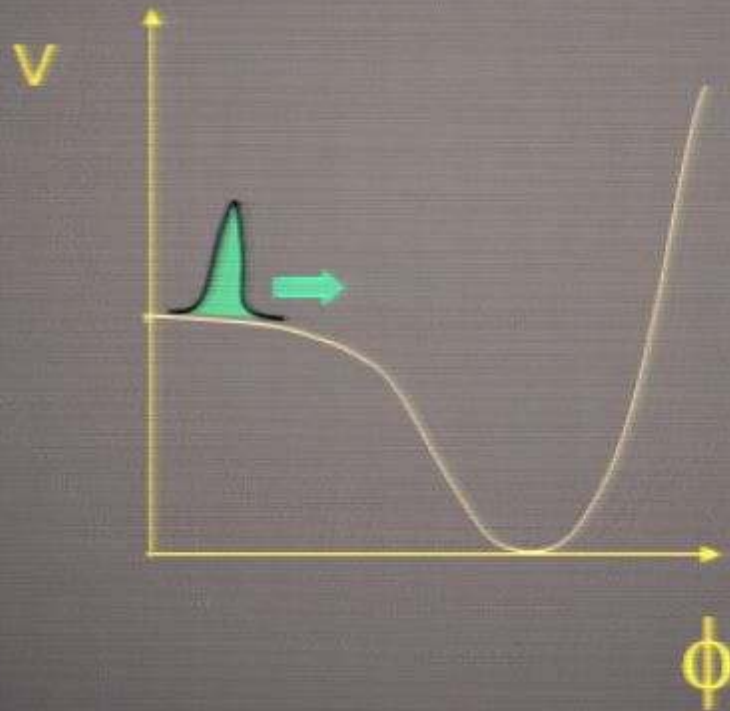
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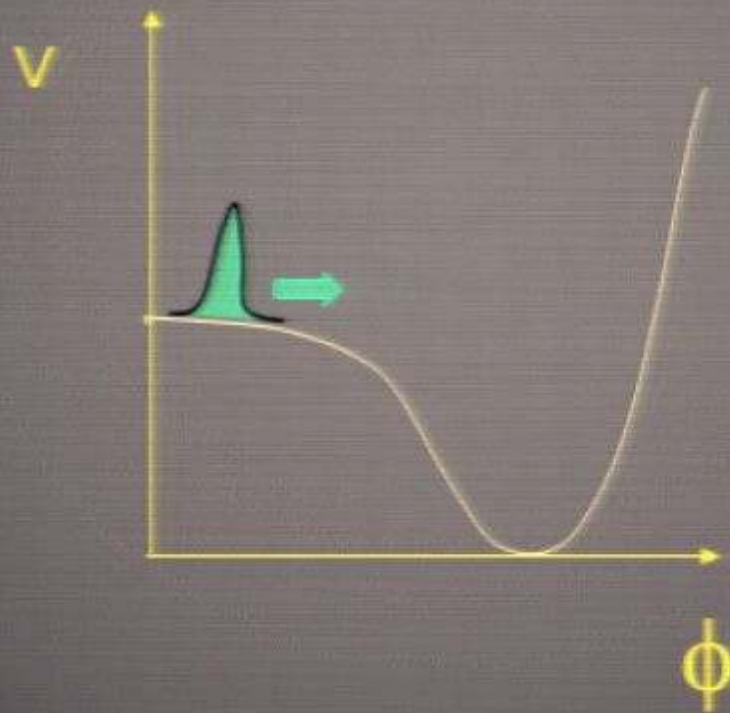
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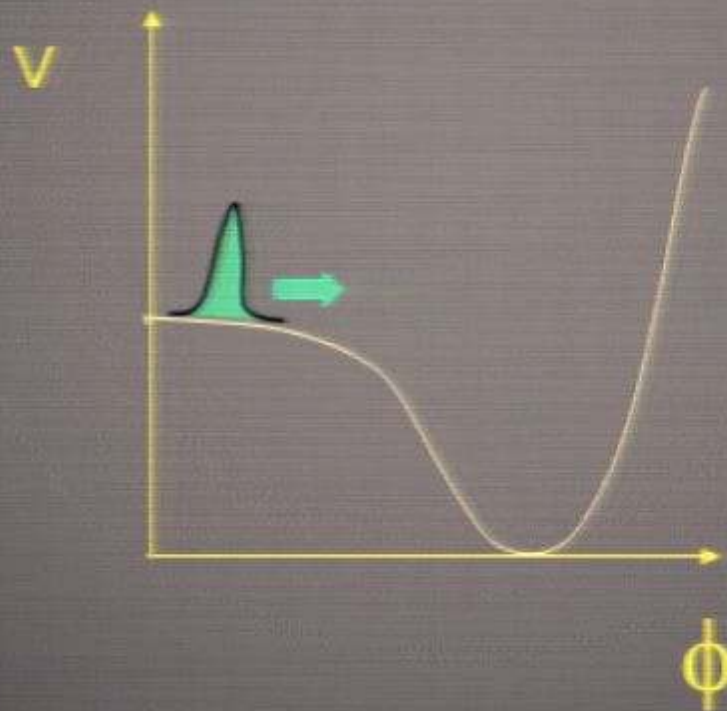
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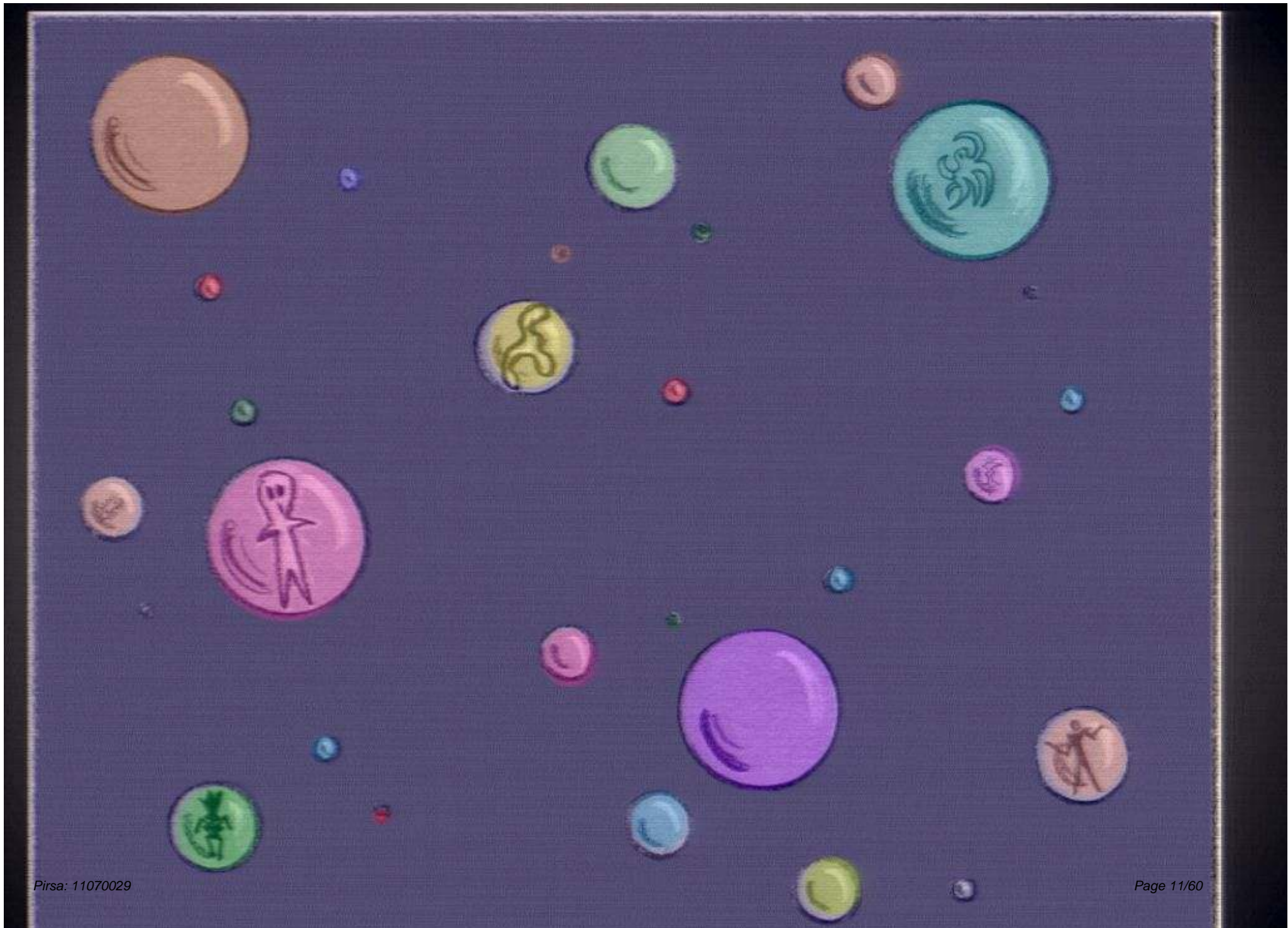
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and it will happen an infinite number of times.”

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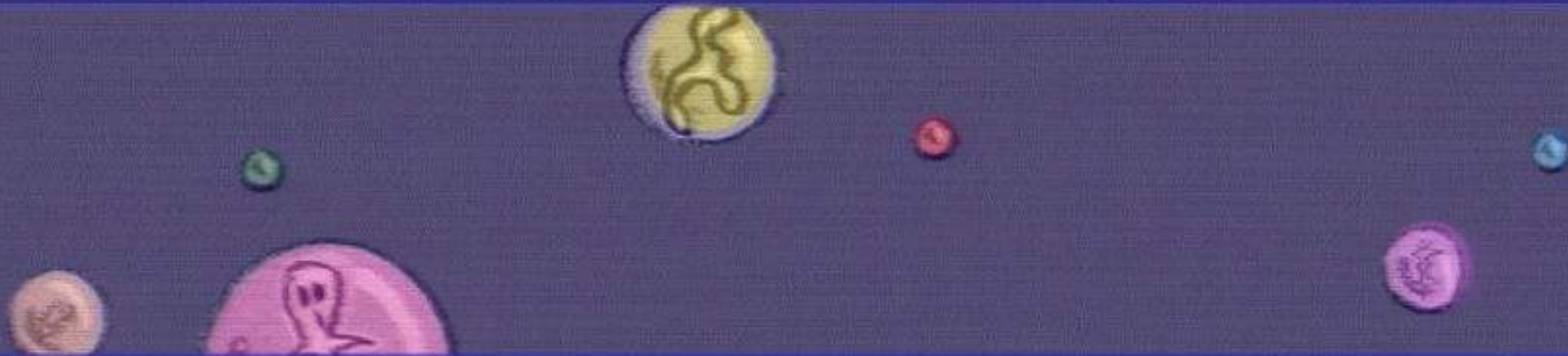
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So, if creative measures are going to save the day,  
the cosmology will depend entirely on  
the measure principle -- not inflation --  
And then we have to consider how a similar  
measure applied to the other theories compares in  
predictive power

# Two Principal Challenges for the Big Bang Inflationary Picture

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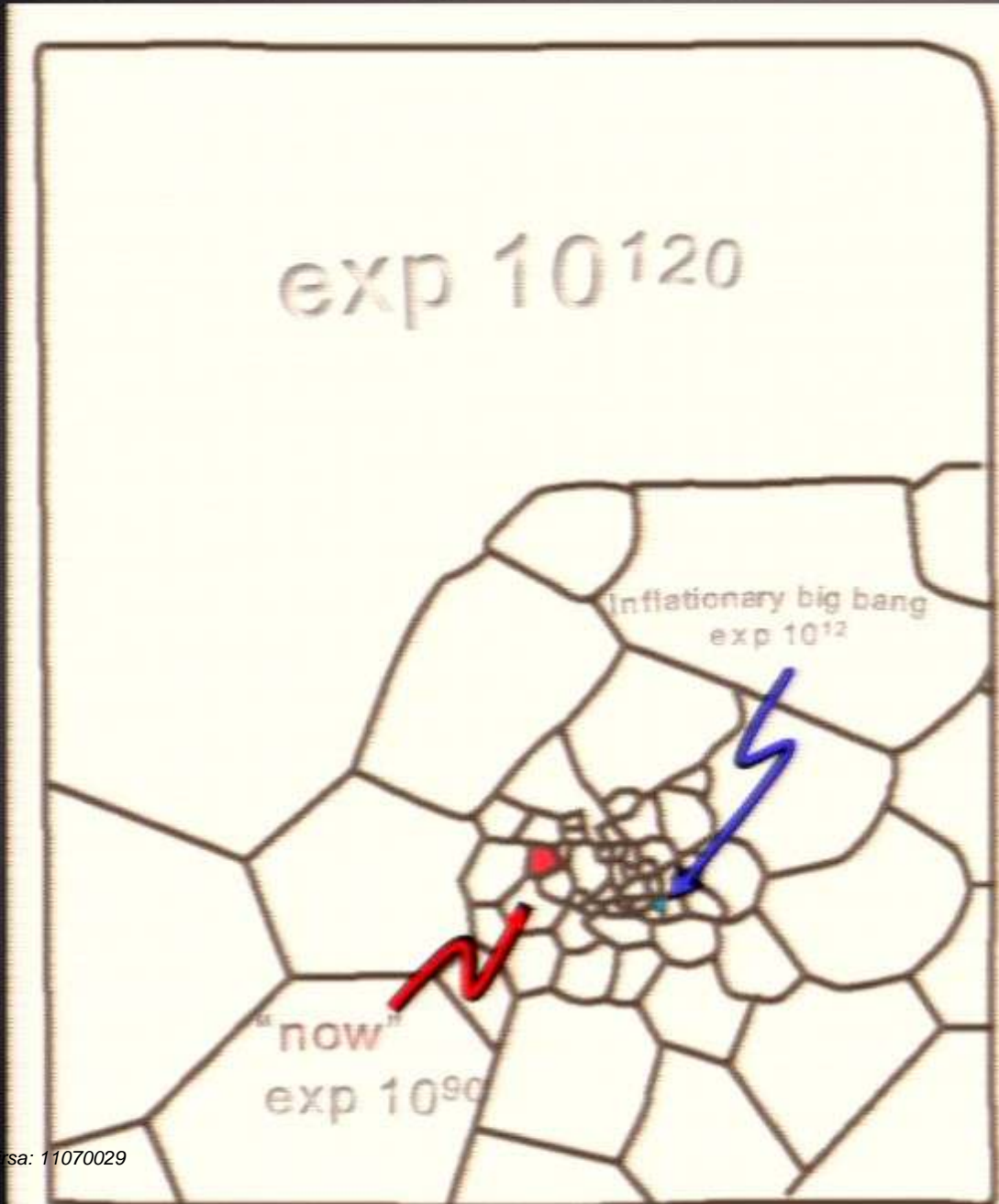
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## Inflation is highly unlikely

*Naïve views about likely initial conditions*

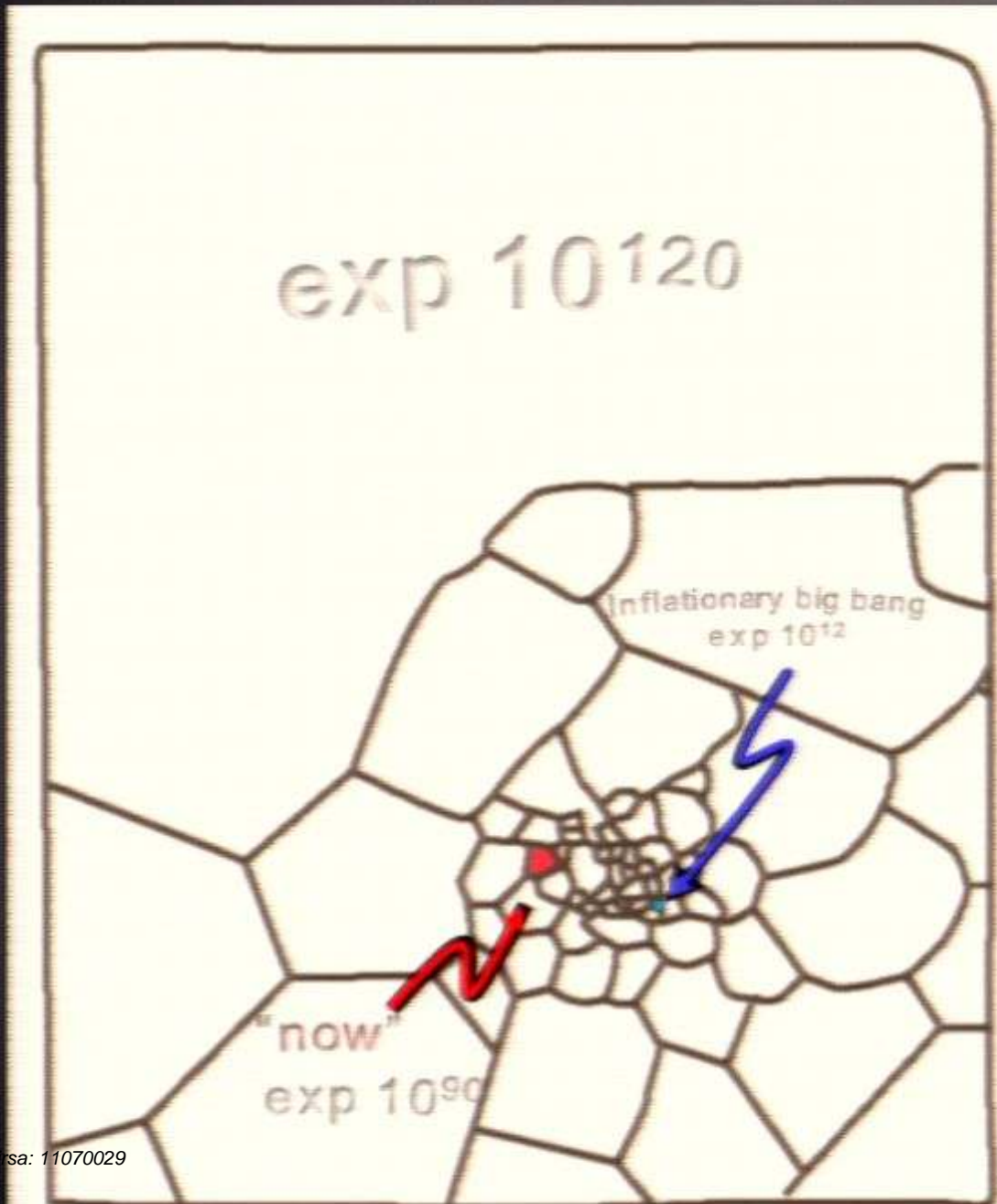
The Penrose (1989) argument...



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

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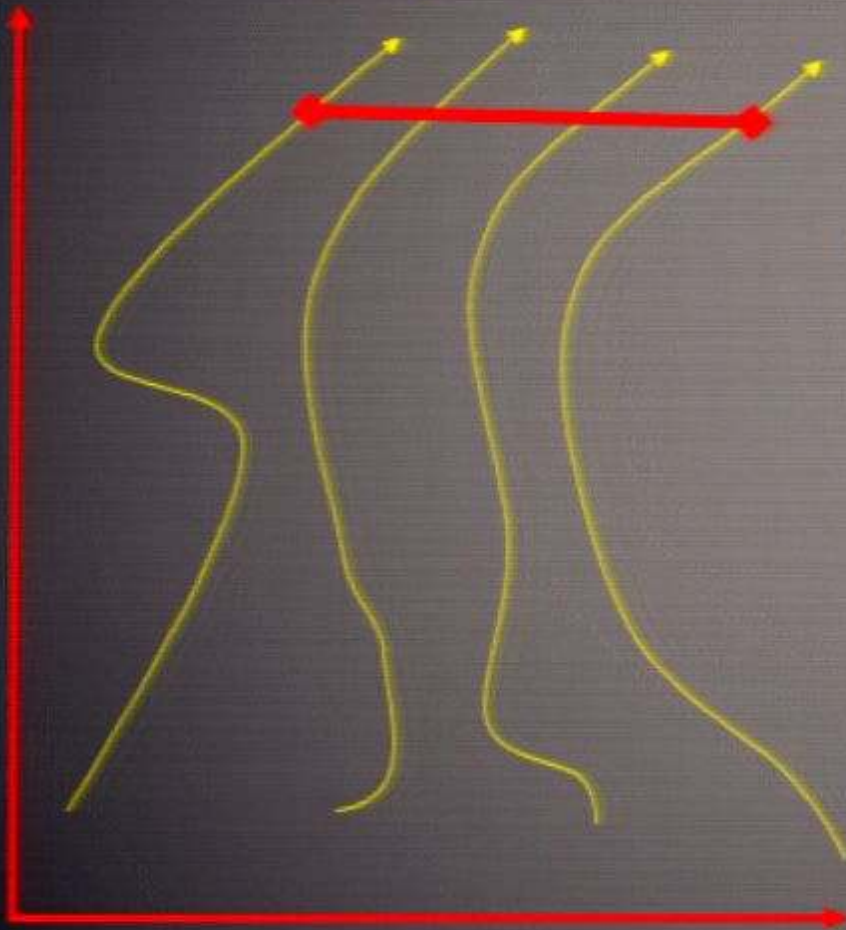
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Many more ways to get to "now" by avoiding inflation than by going through it!

*...and the Liouville argument*

Neil's far future "flat space" observers  
Lenny's "census takers" ?



*extrapolating backwards,*

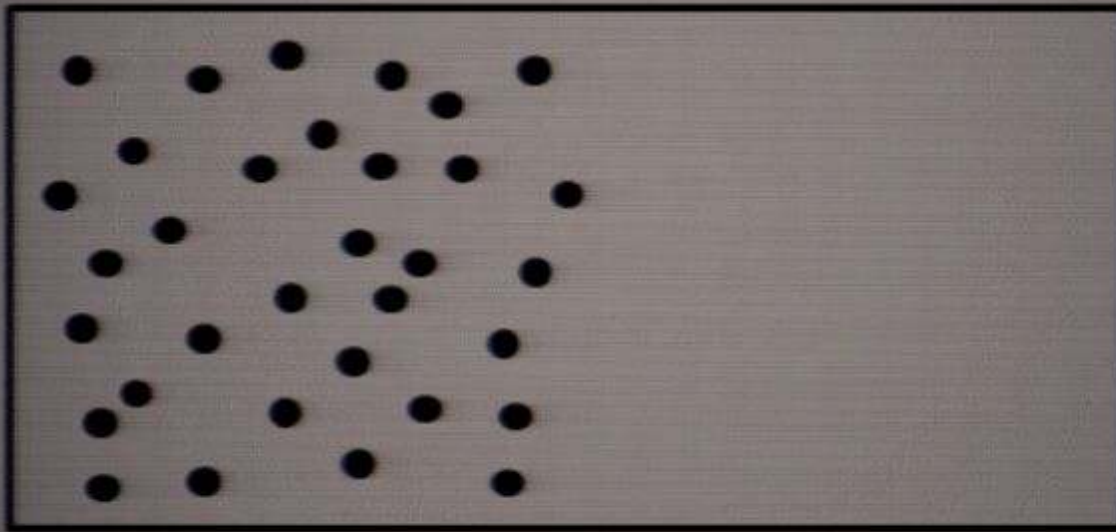
*what fraction pass thru  
> 60 e-folds of inflation?*

*Answer: Almost none!*

Gibbons & Turok (2006)

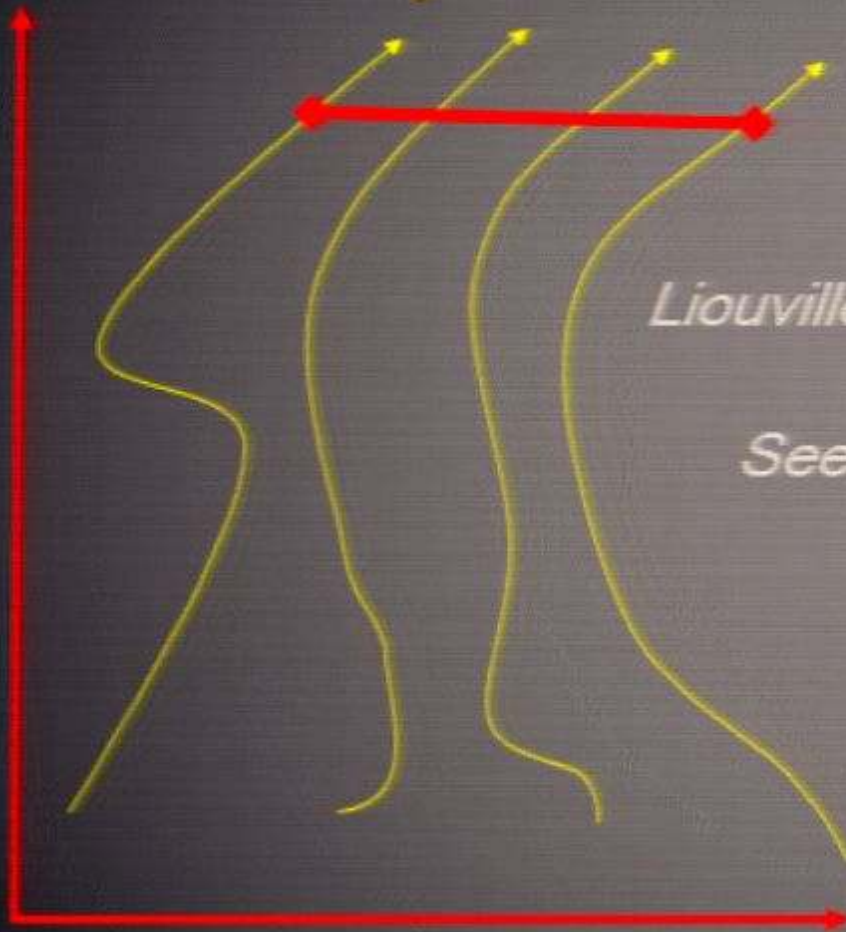
Turok (2011)

# Lenny's Janitor



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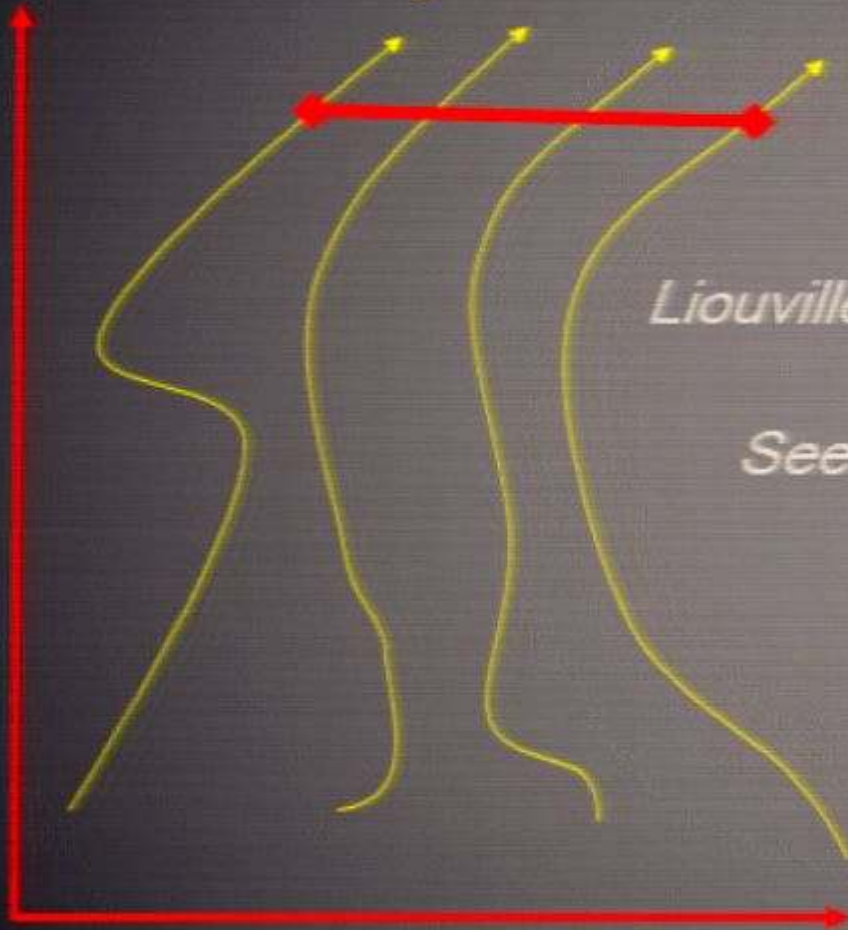
*Liouville argument counterintuitive?*

*Seems to disfavor strong attractor behavior,  
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configurations

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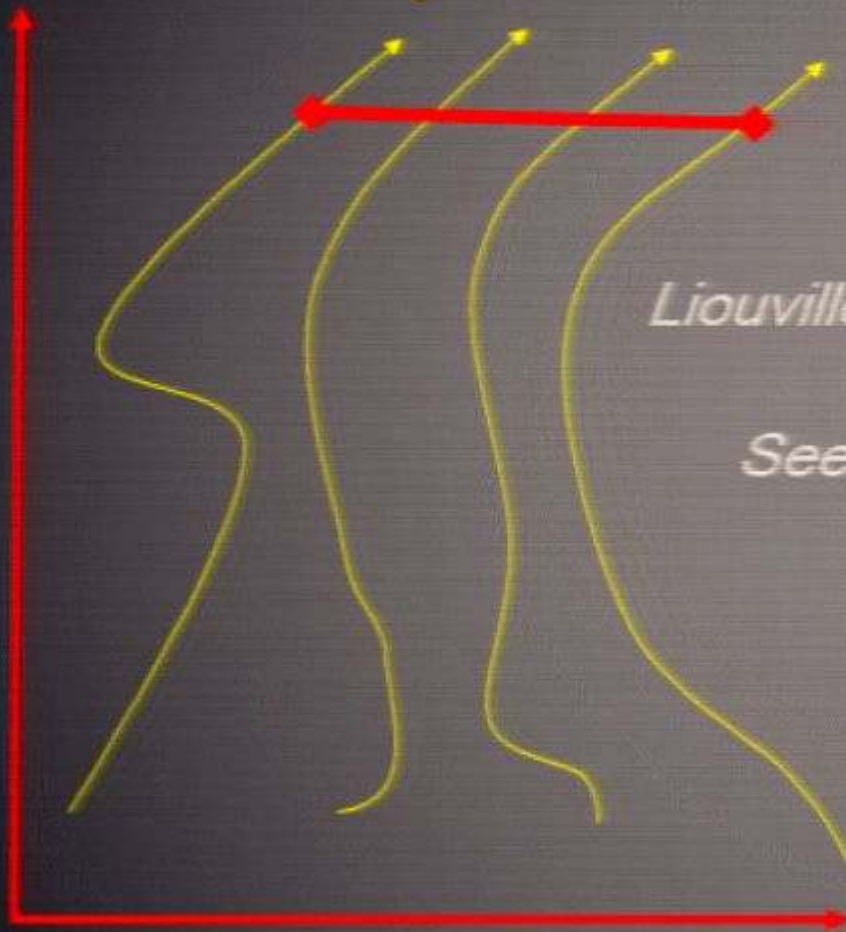
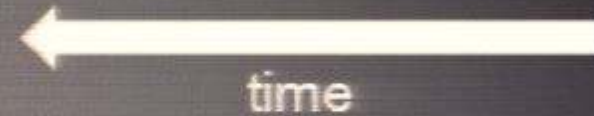
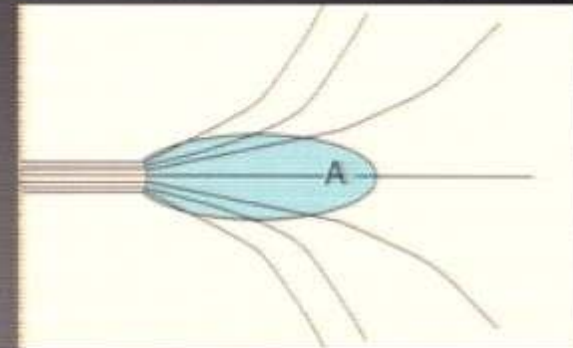
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Inflation IS favored  
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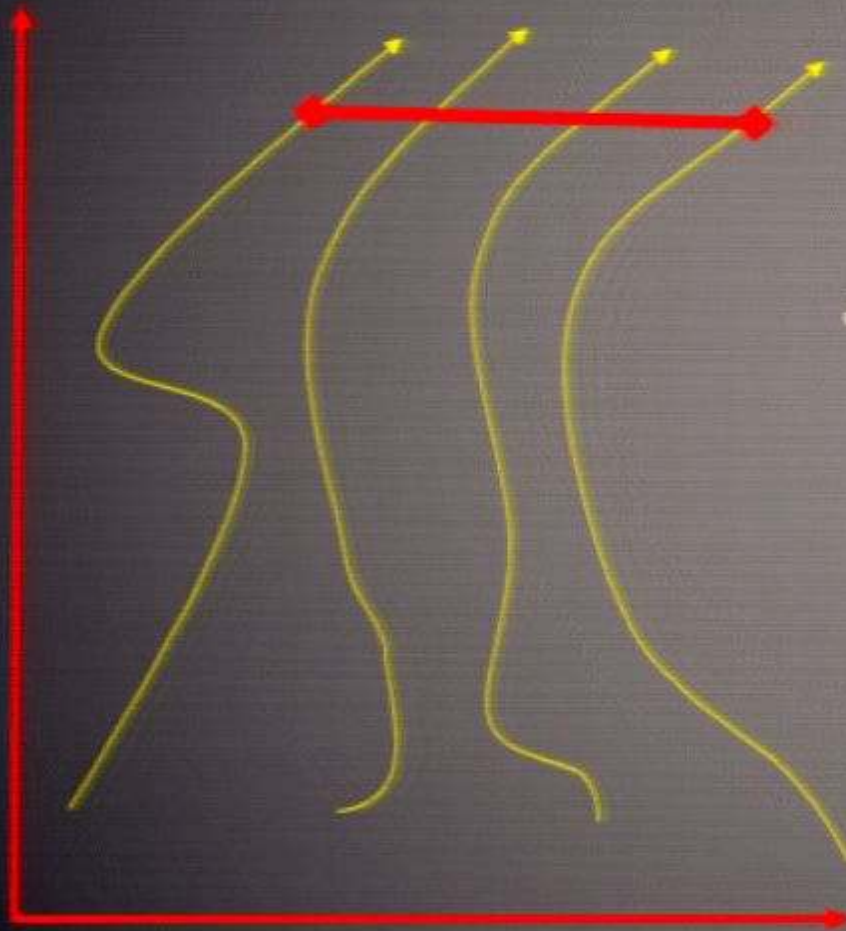
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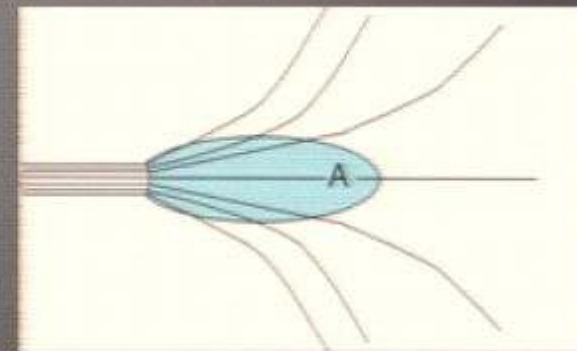
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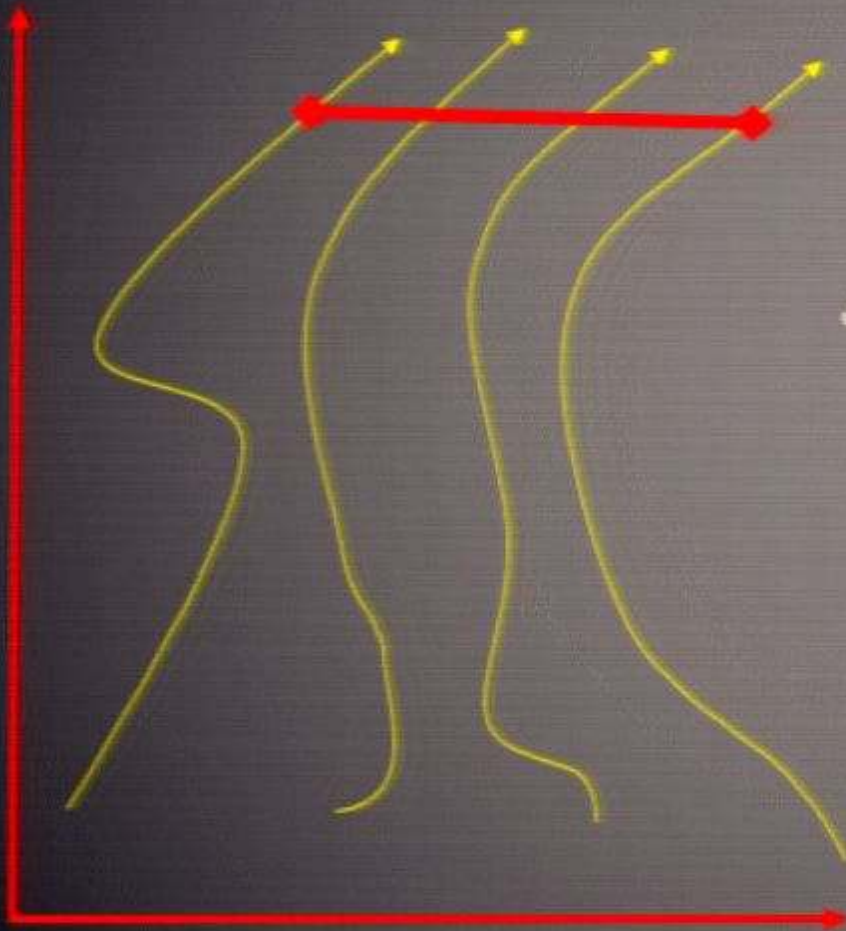
*Stronger than the entropy argument ?*



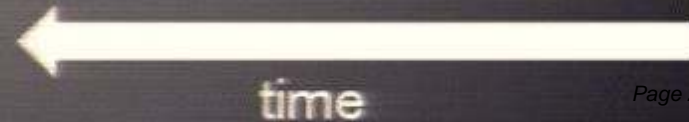
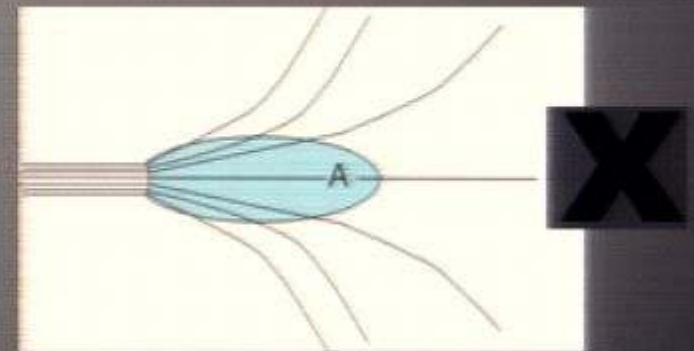
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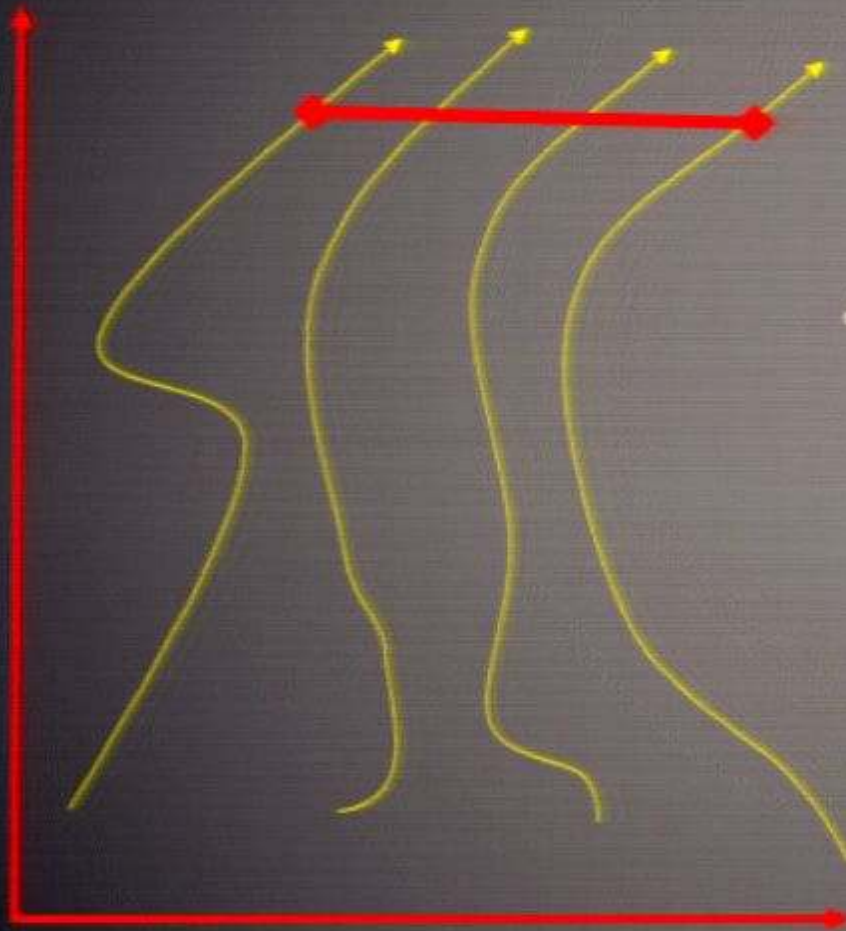
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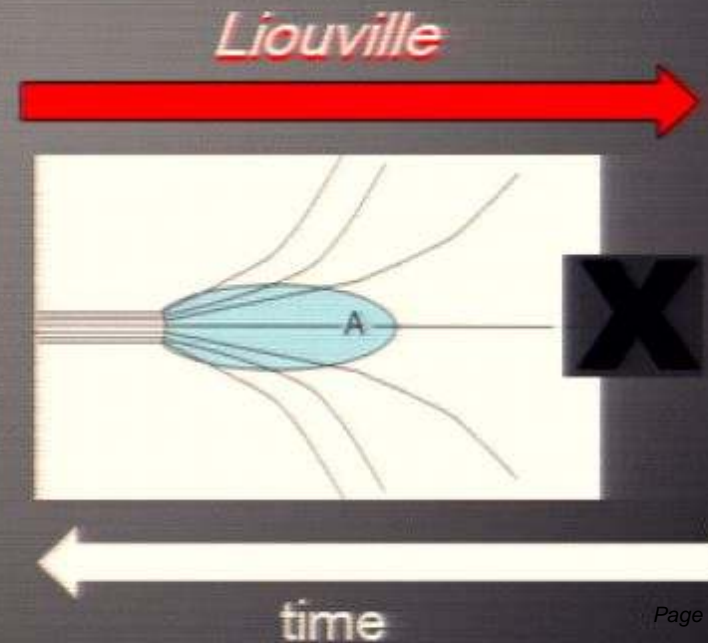
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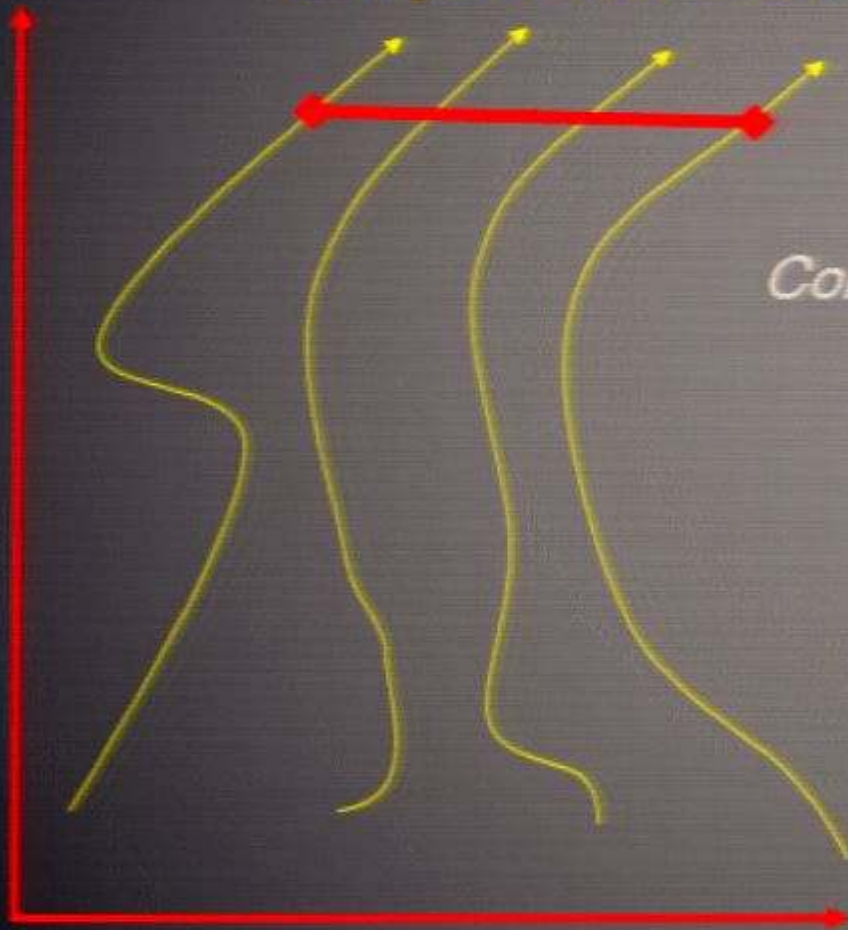
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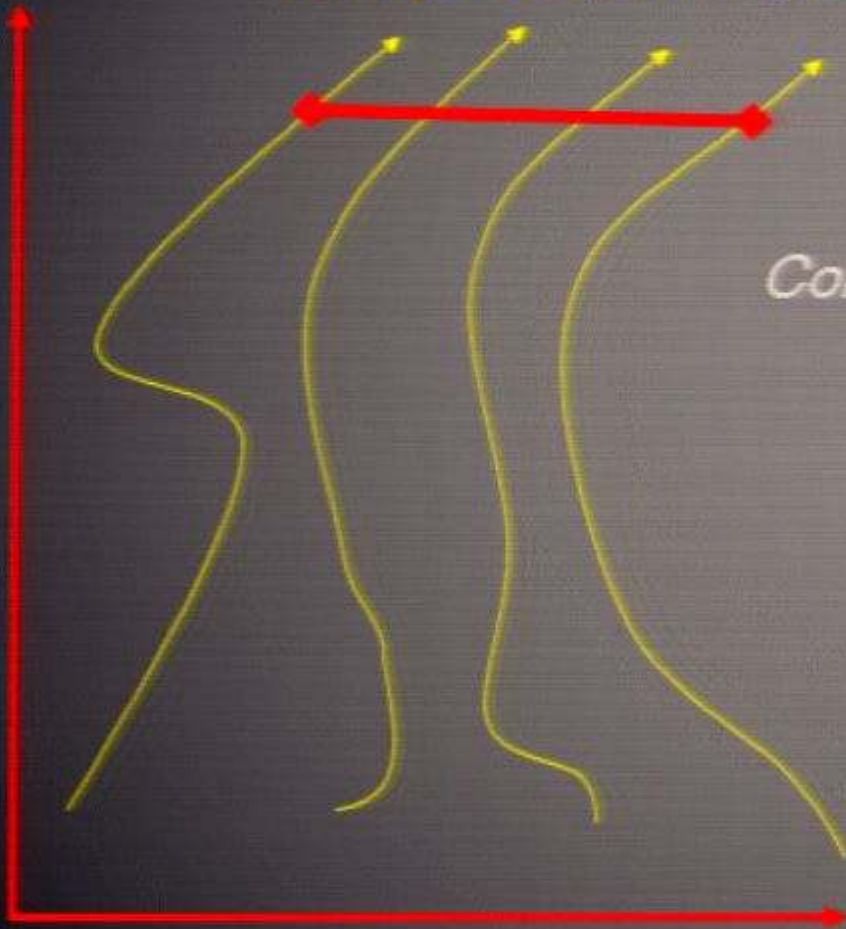


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*...and the Liouville argument*

**Neil's far future "flat space" observers**

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*Corollary: makes clear that  $KE \gg PE$   
as you extrapolate back in time*

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

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*Contrast with the standard lore (rough equipartition):*

Since there is absolutely no *a priori* reason to expect that  $\partial_\mu \varphi \partial^\mu \varphi \ll M_{\text{p}}^4$ ,  $R^2 \ll M_{\text{p}}^4$ , or  $V(\varphi) \ll M_{\text{p}}^4$ , 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

$$\partial_0 \varphi \partial^0 \varphi \sim M_{\text{p}}^4, \quad (1.7.7)$$

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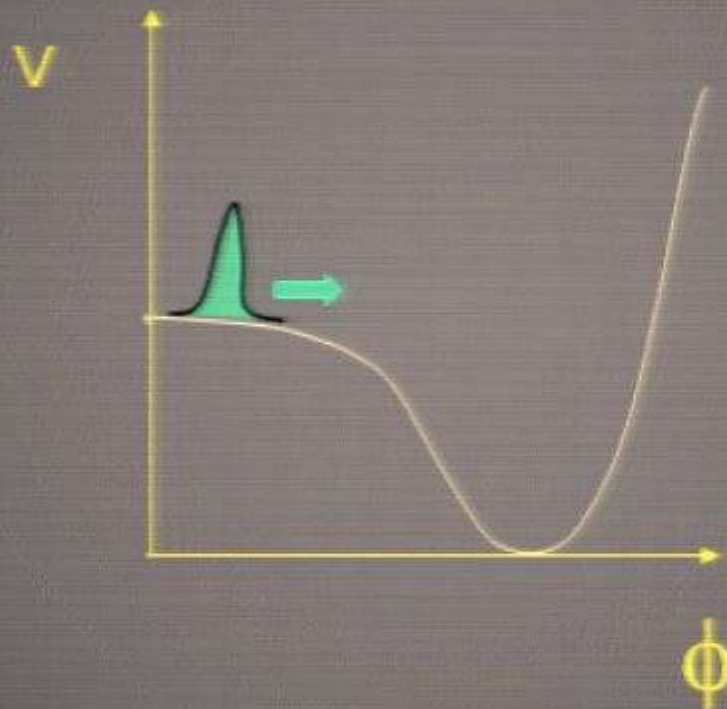
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*How much more likely?*

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

# How to Fix the Problems?

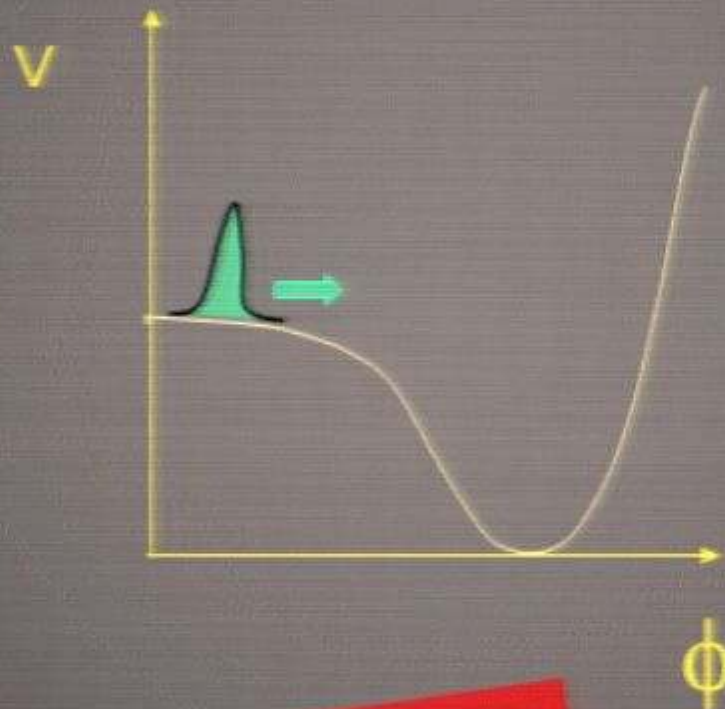
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*MUST VIOLATE NEC*

two logical possibilities:

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

smooth while contracting -- then need info preserving bounce

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*NO CAUSALITY PROBLEM*

*NO FLATNESS PROBLEM*

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*w > 1*

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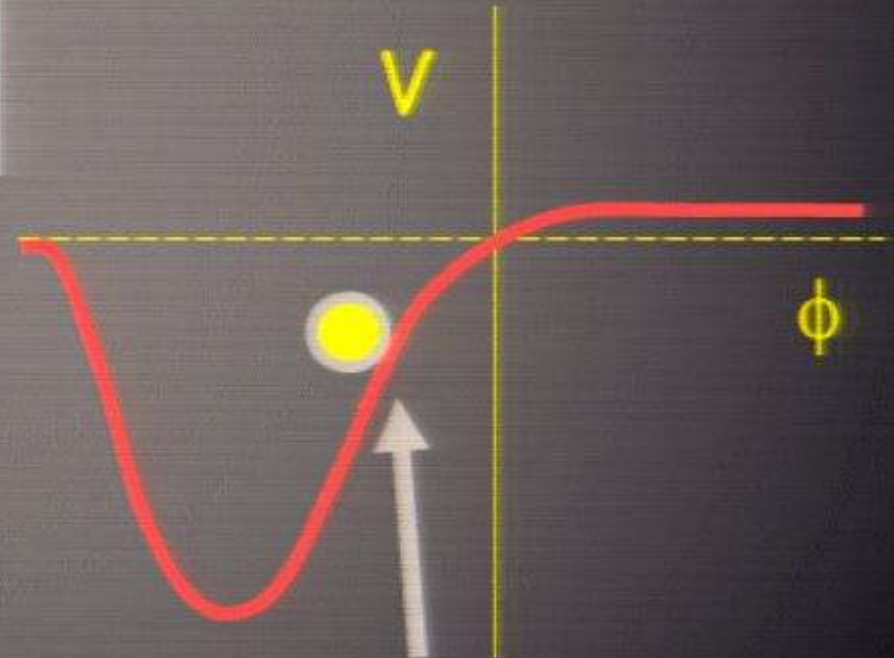
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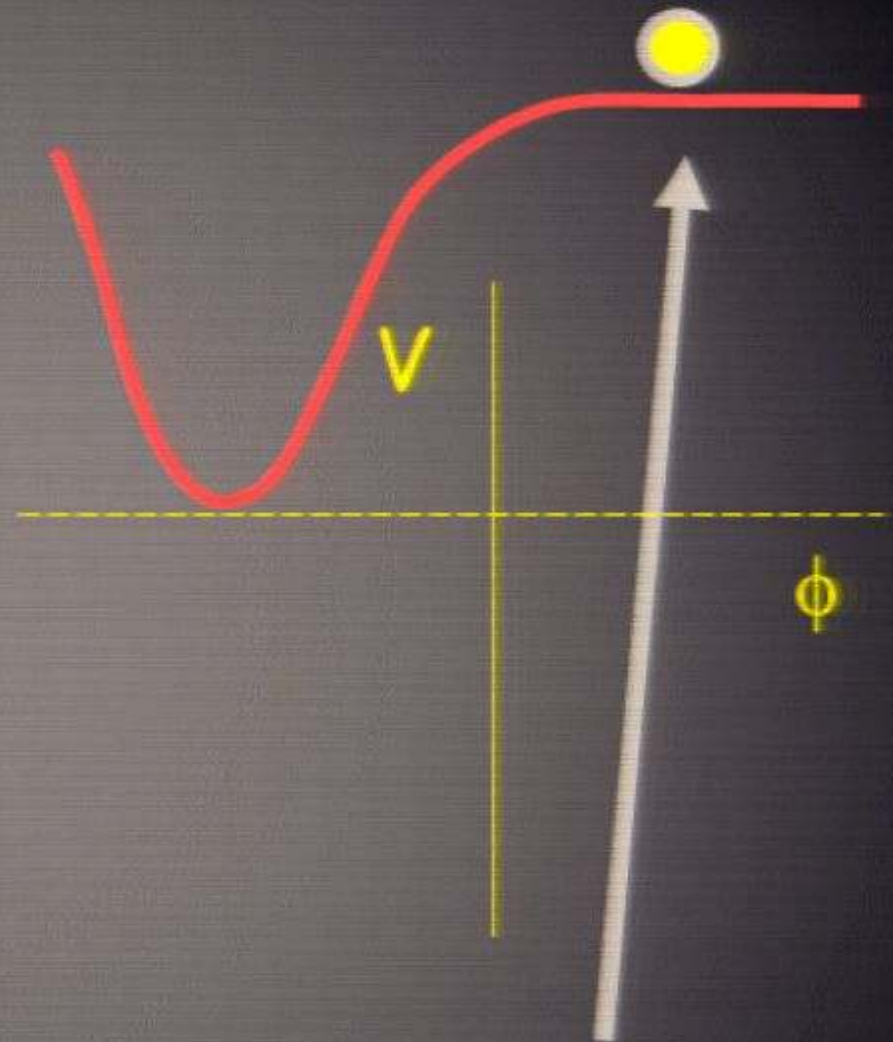
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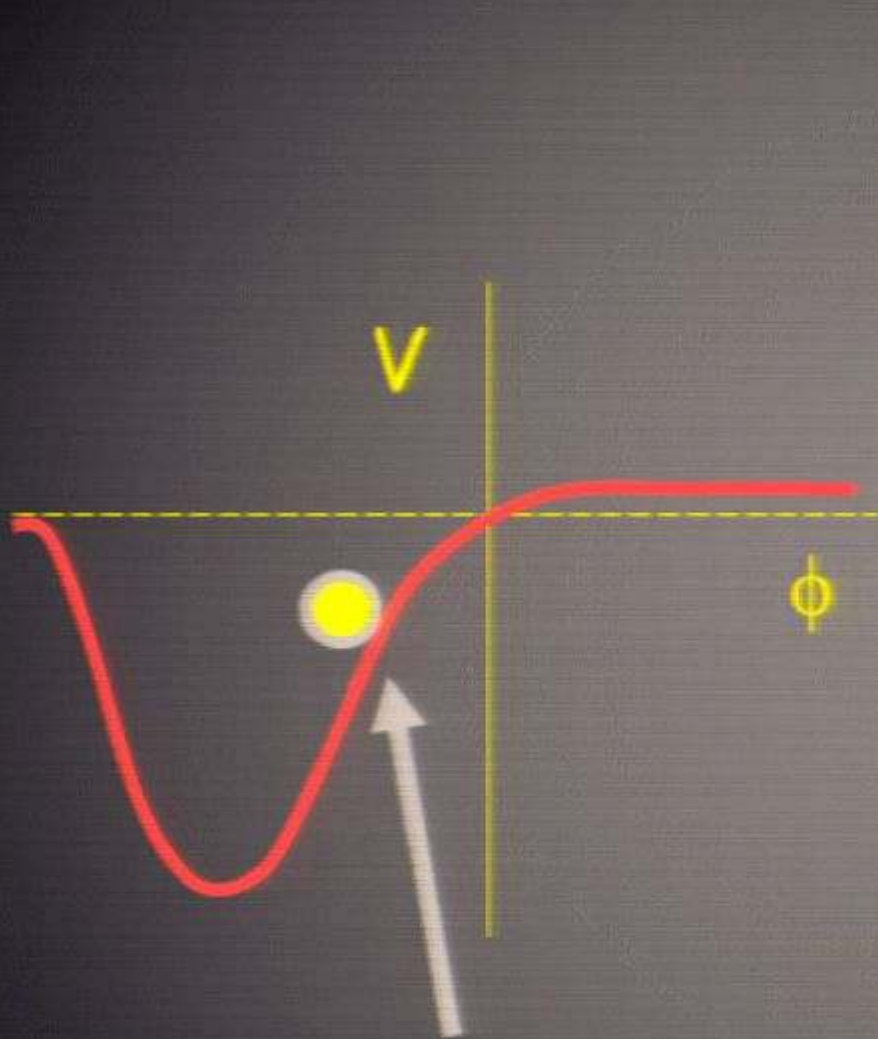
$$w = \frac{\frac{1}{2}\dot{\phi}^2 - V}{\frac{1}{2}\dot{\phi}^2 + V}$$

*SMOOTH AND FLATTEN WHILE PENALIZING ROGUE REGIONS*

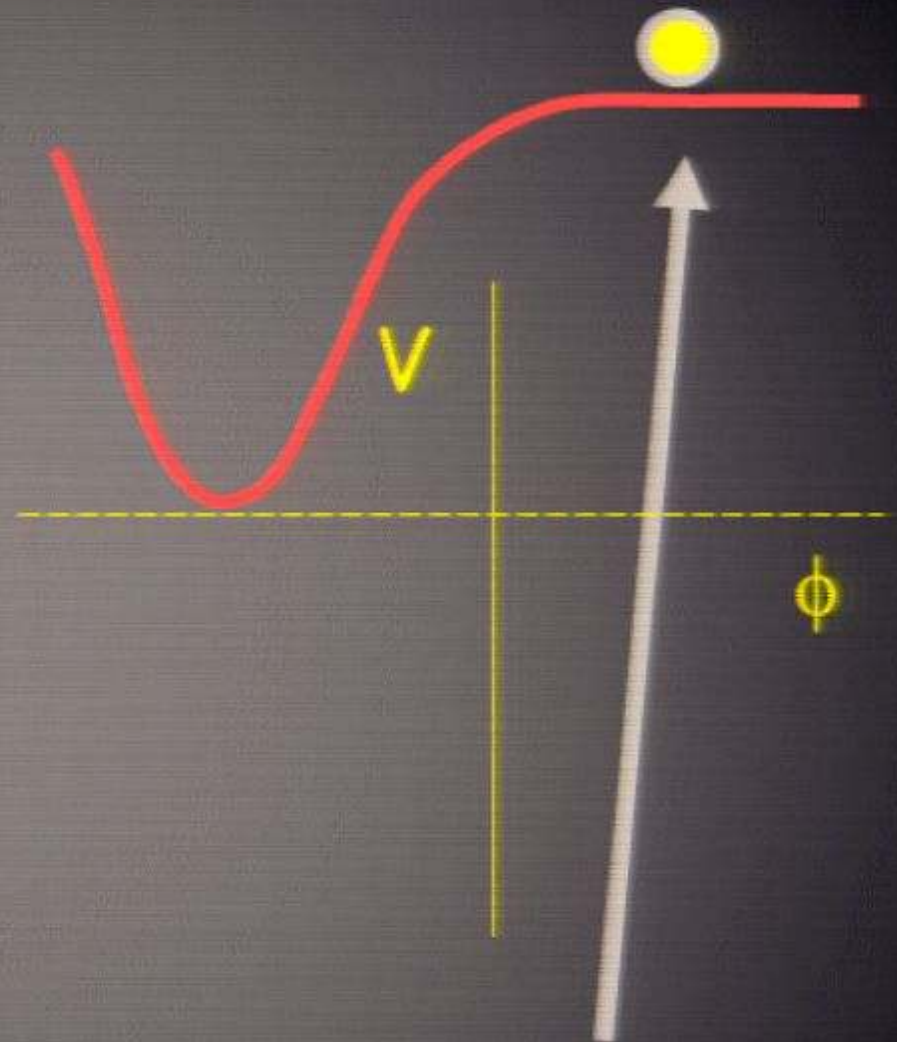


Eternal runaway  
rogue regions that delay reheating  
expand faster

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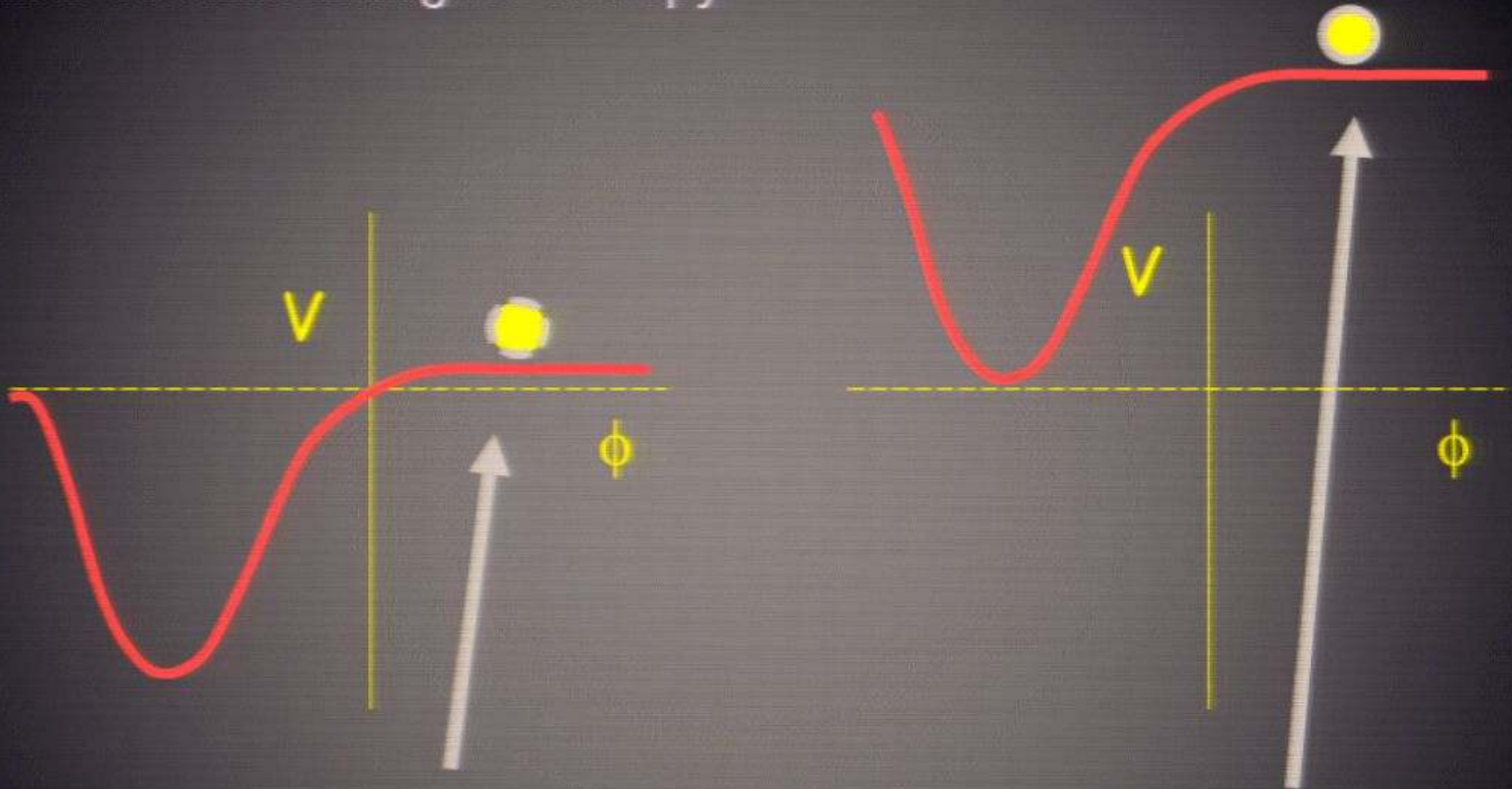
No eternal runaway  
rogue regions that delay reheating  
contract or expand slower



Eternal runaway  
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OTHER POSSIBLE ADVANTAGES:

initial conditions: higher entropy



Comparatively higher entropy  
more probable

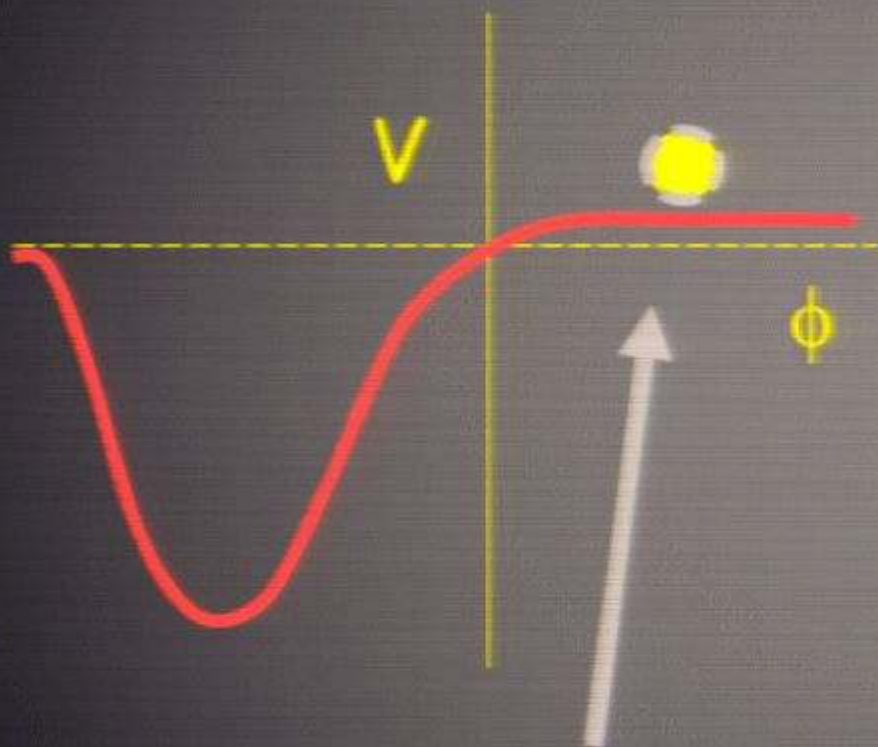
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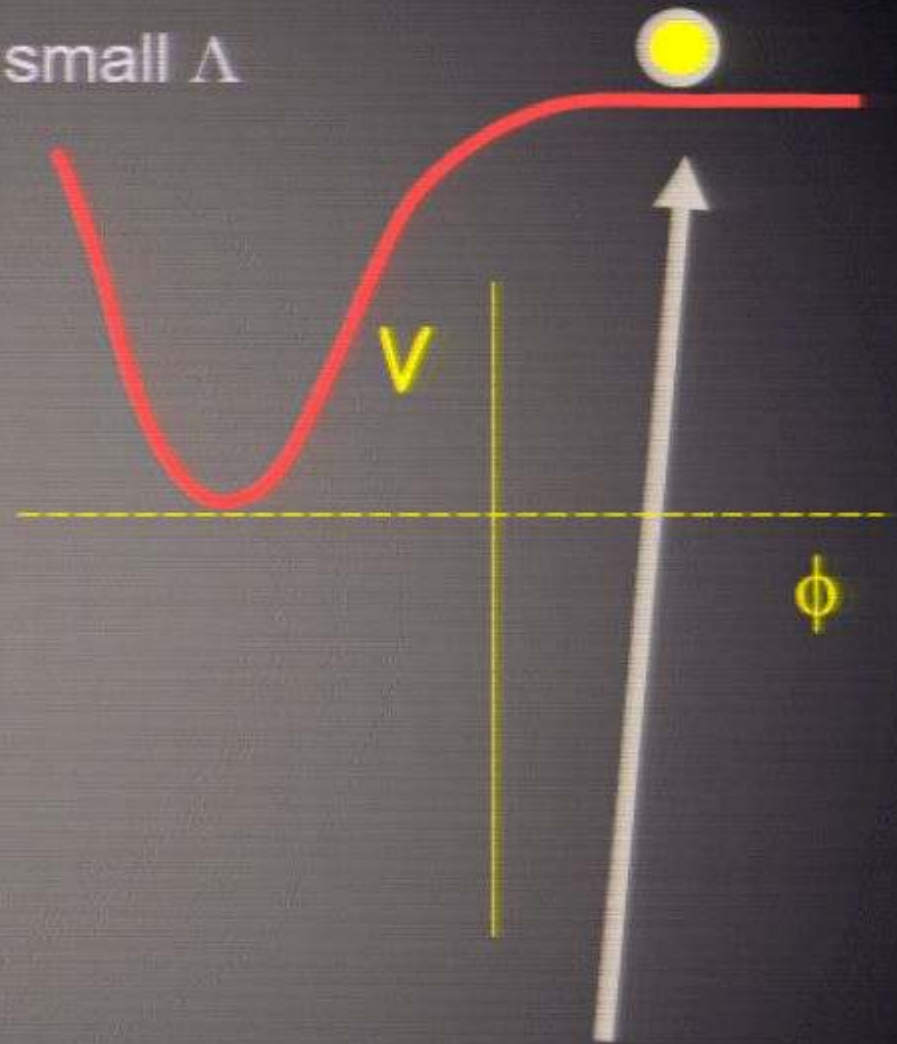
initial conditions: higher entropy

"more time": possible explanation for small  $\Delta$

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*

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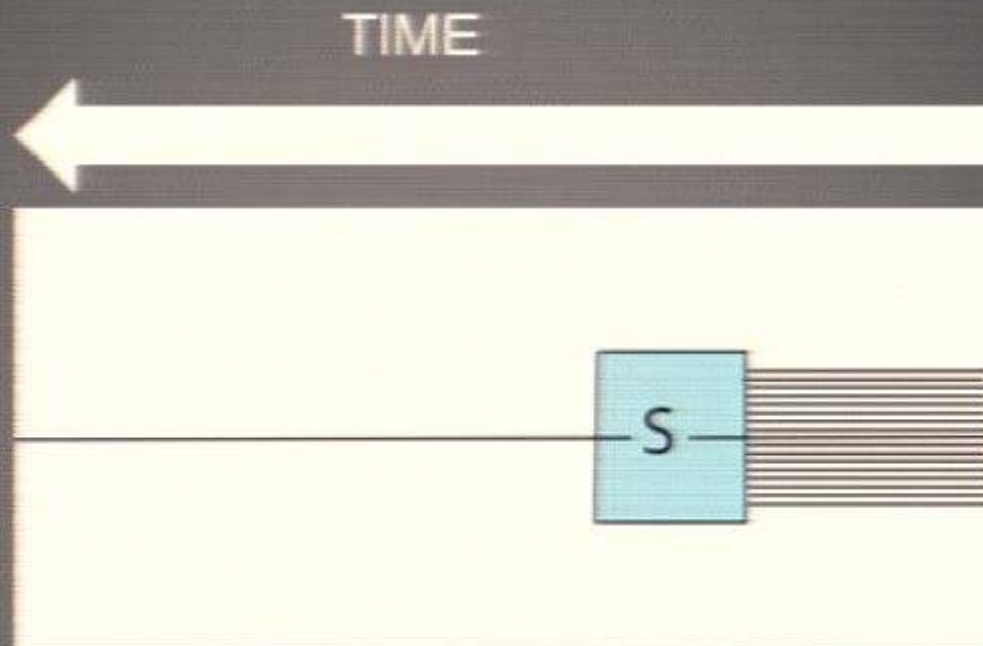
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**NEED NOT BE GENERIC !**

# *THE IMPERFECT BOUNCE: AN IDEAL ENTROPY SIEVE?*



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

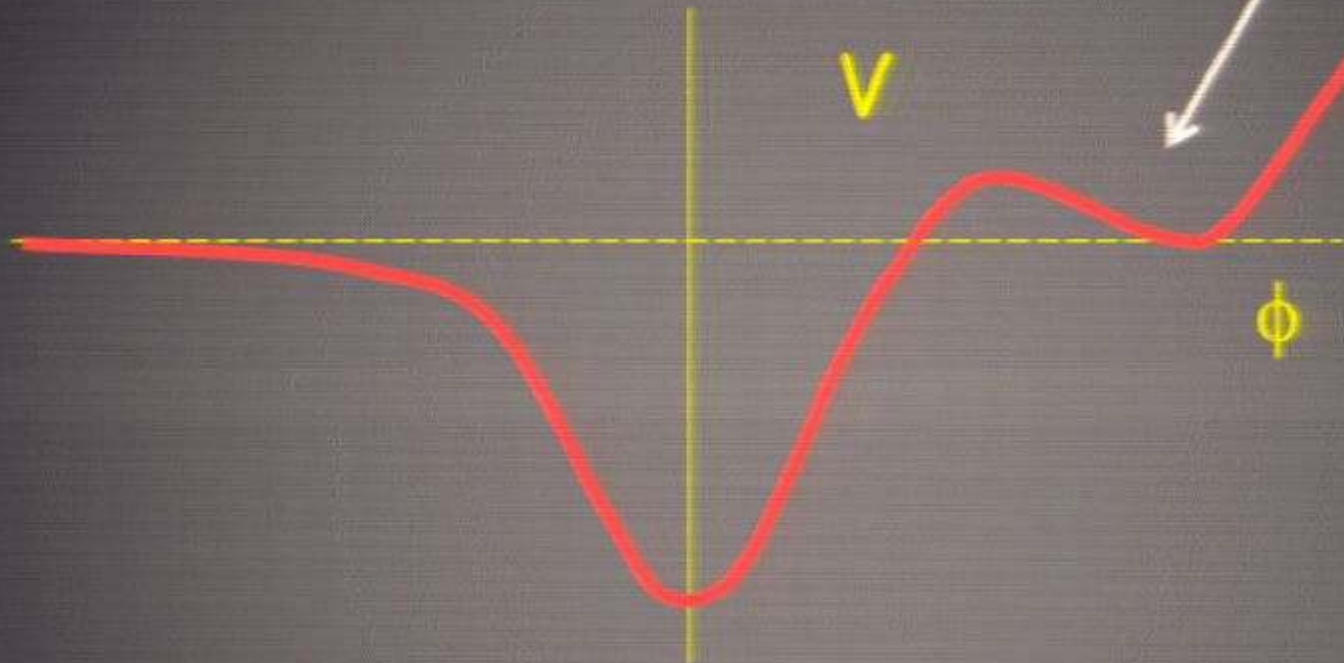
$$|f_{NL}| \text{ (cyclic)} \sim \sqrt{w+1} = O(10)$$

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

# LIIOUVILLE REVISITED

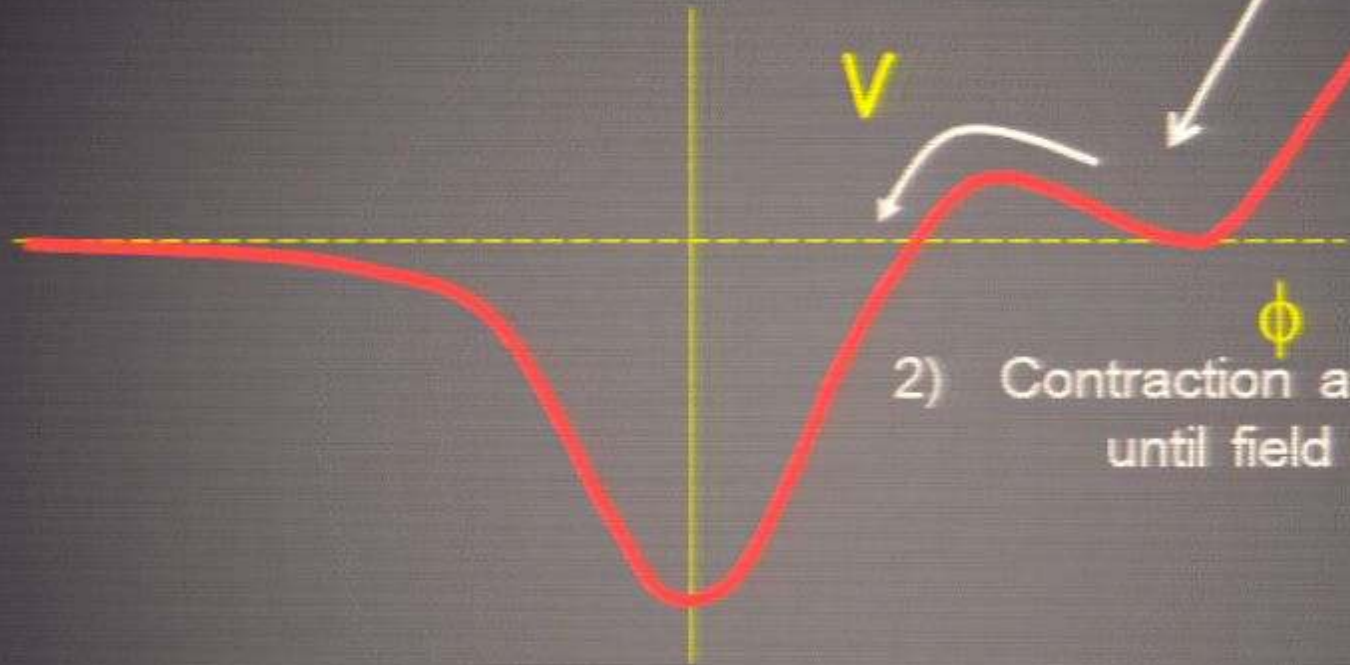
w/ N. Turok

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



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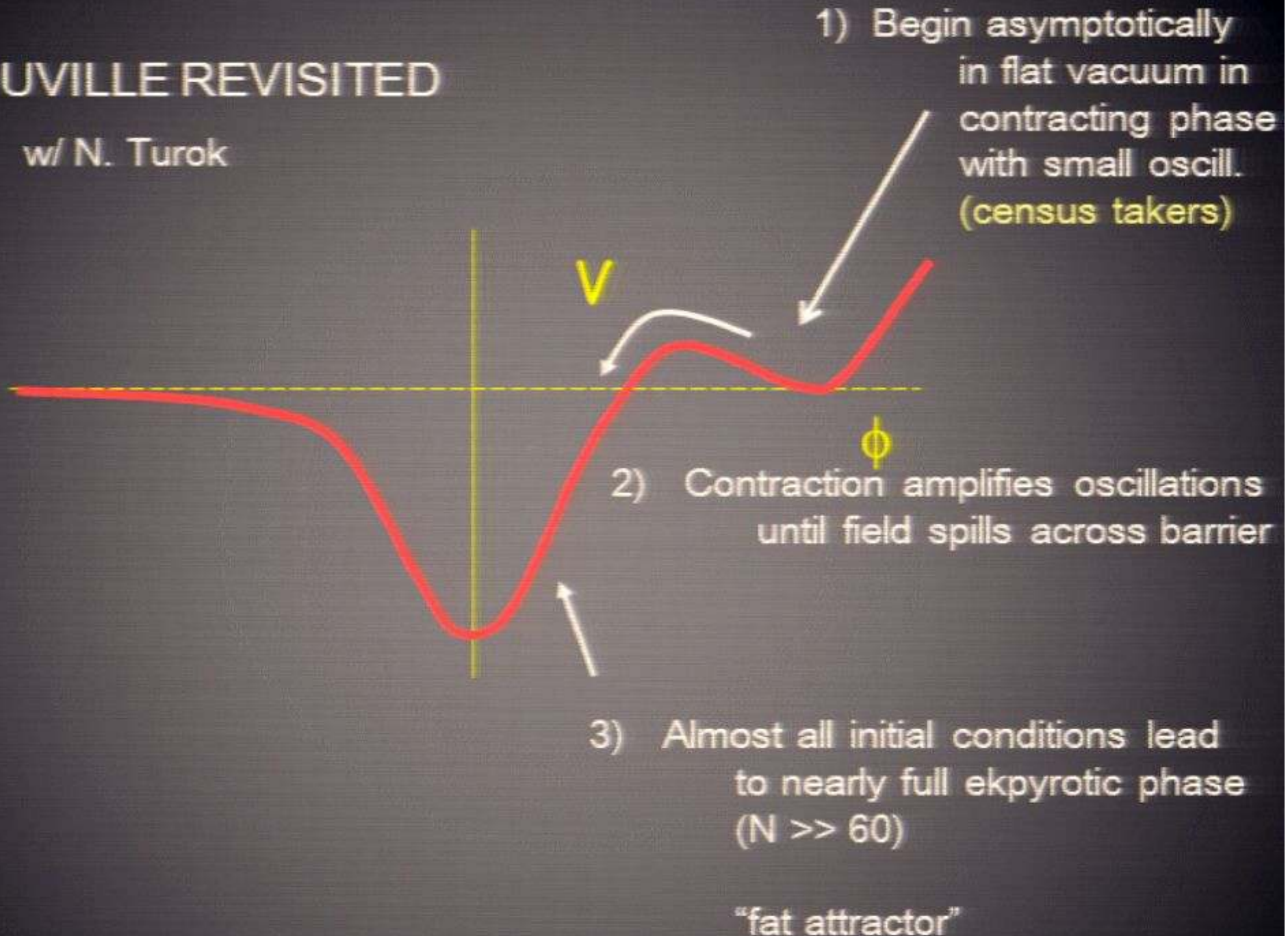


1) Begin asymptotically in flat vacuum in contracting phase with small oscill. (census takers)

2) Contraction amplifies oscillations until field spills across barrier

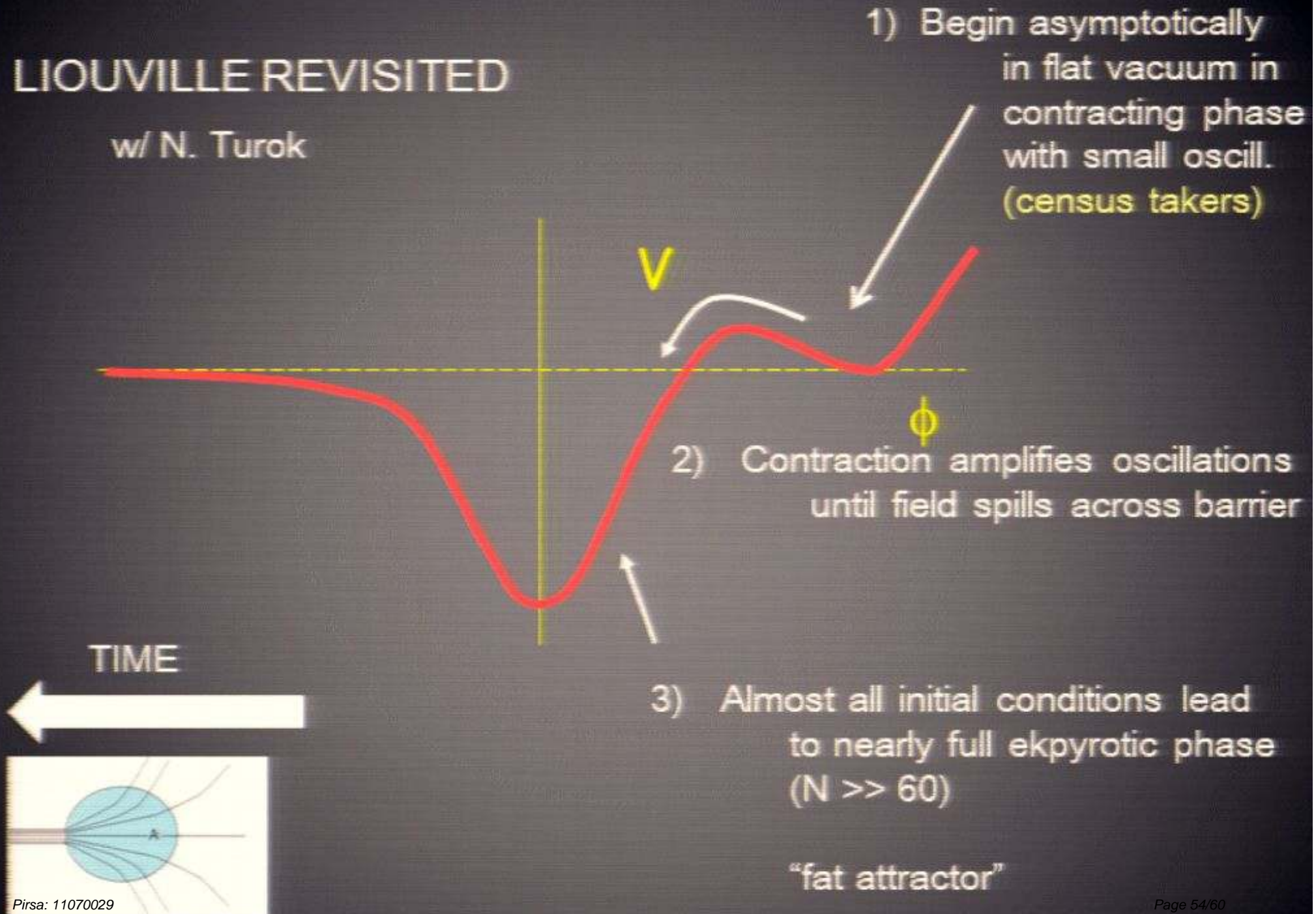
# LIOUVILLE REVISITED

w/ N. Turok



# LIOUVILLE REVISITED

w/ N. Turok



# LIUVILLE REVISITED

w/ N. Turok

4) Bounce

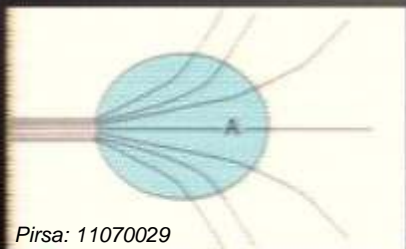
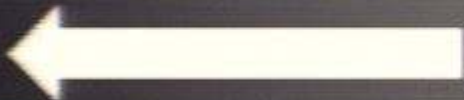
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3) Almost all initial conditions lead to nearly full ekpyrotic phase ( $N \gg 60$ )

"fat attractor"

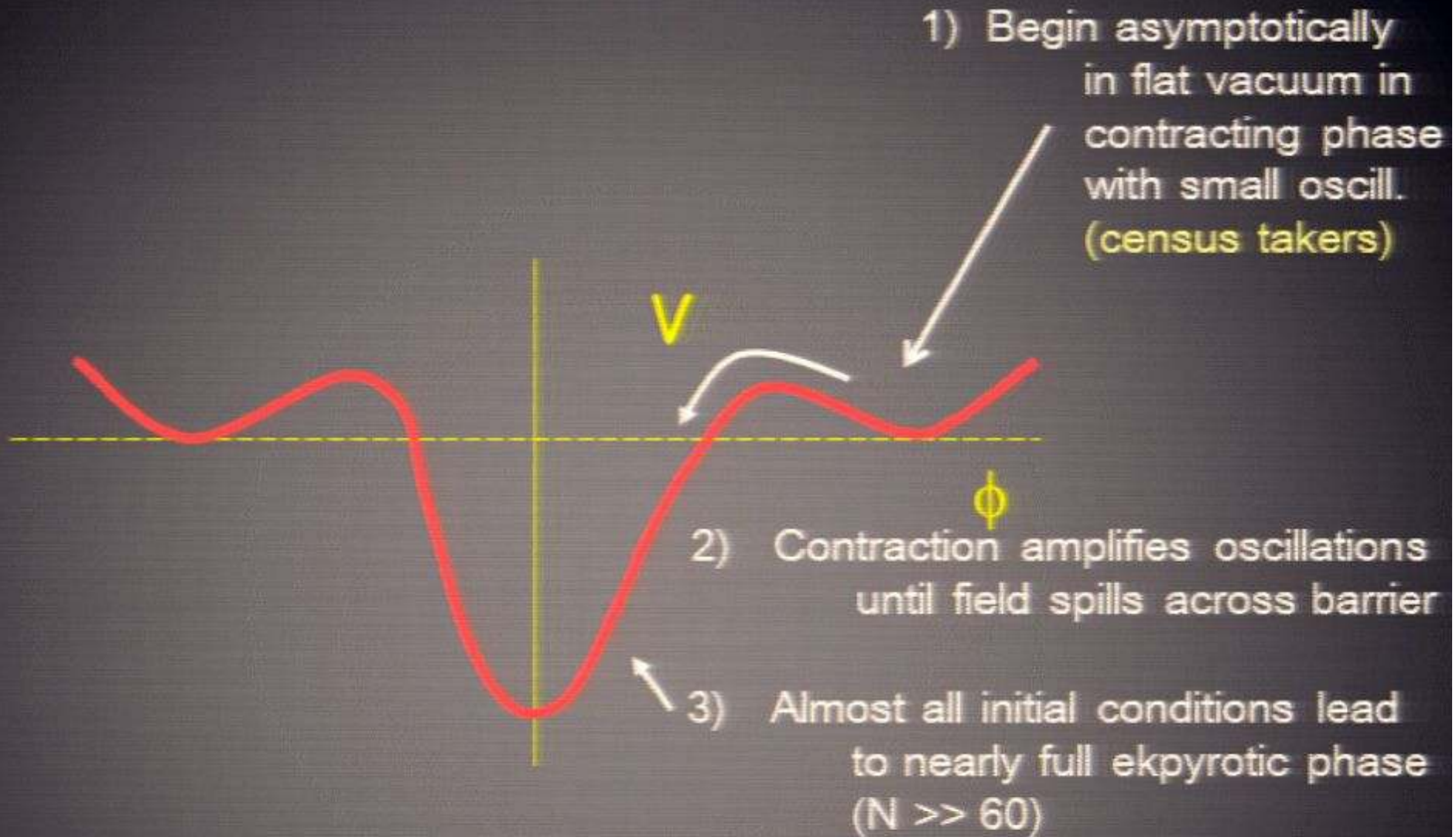
TIME



Pirsa: 11070029

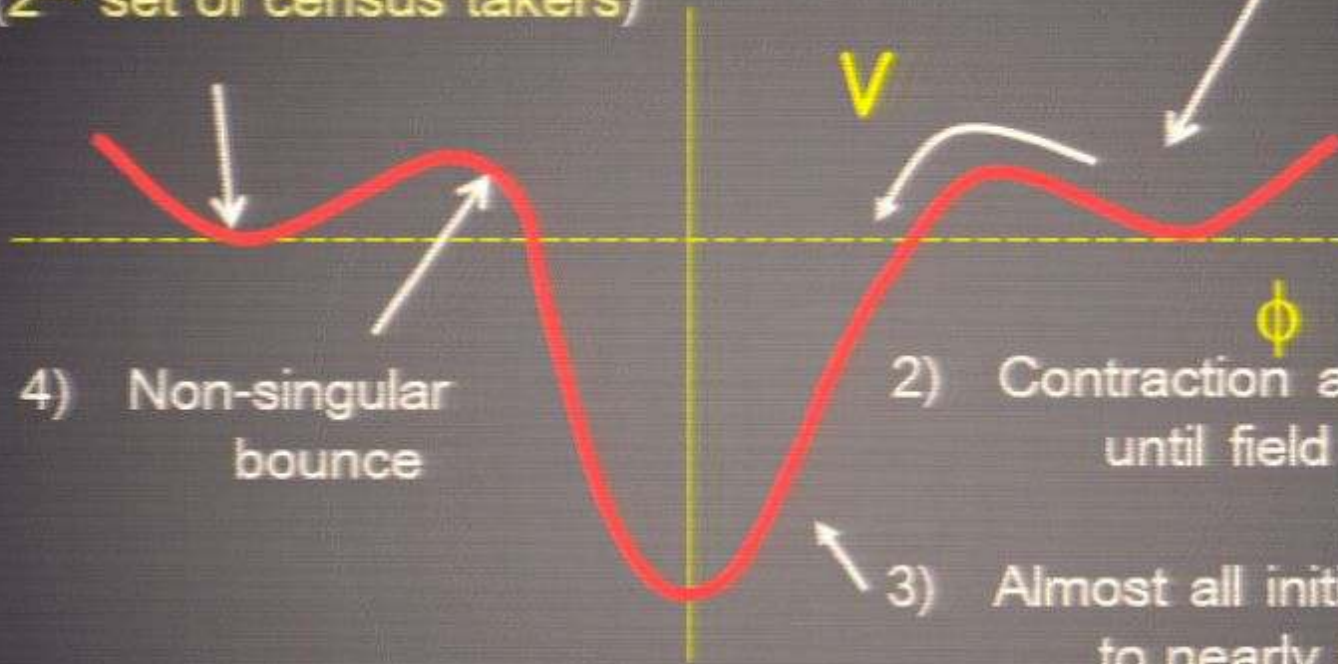
Page 55/60

Liouville



Field ultimately lands  
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phase and  
→ asymptotically Mink.  
(2<sup>nd</sup> set of census takers)

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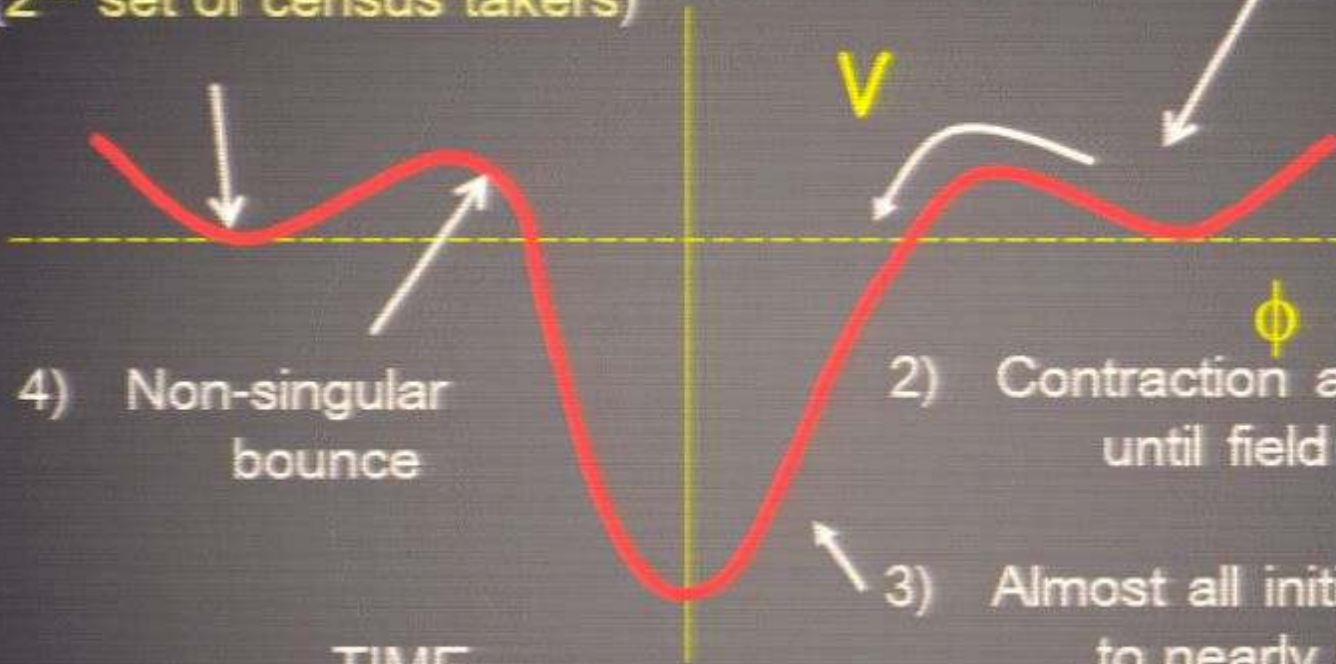
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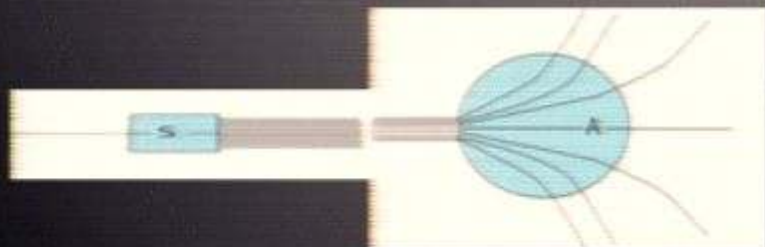


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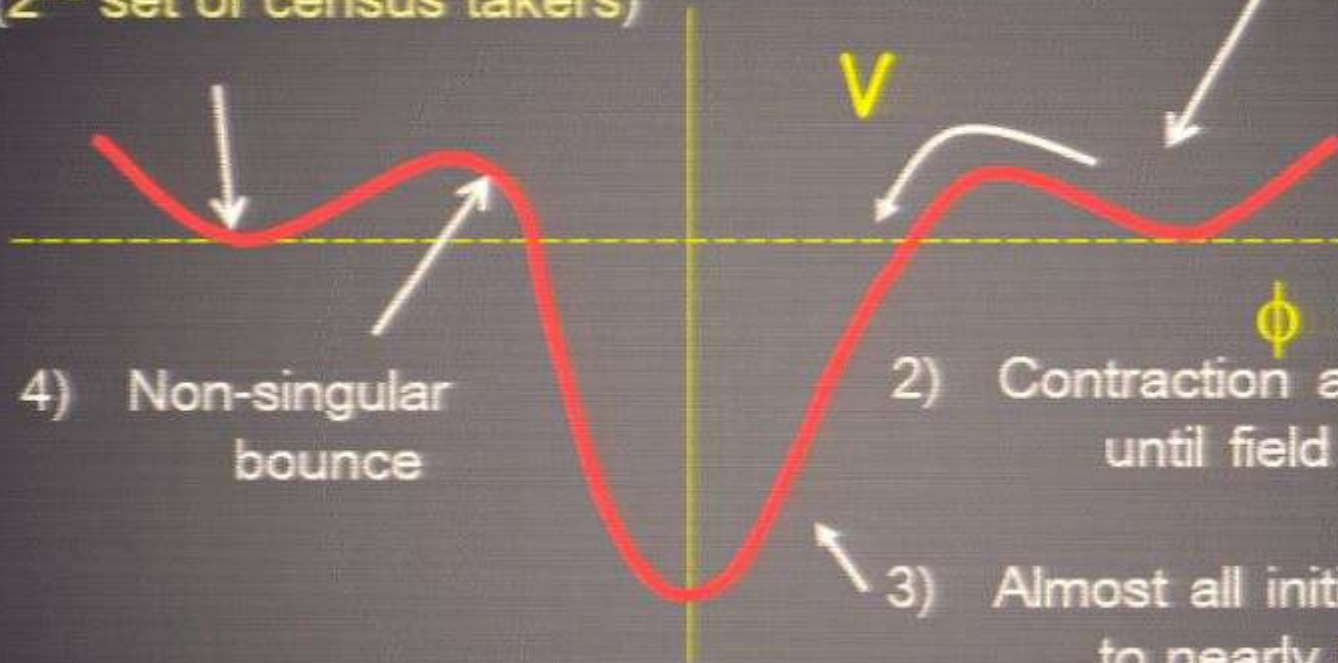
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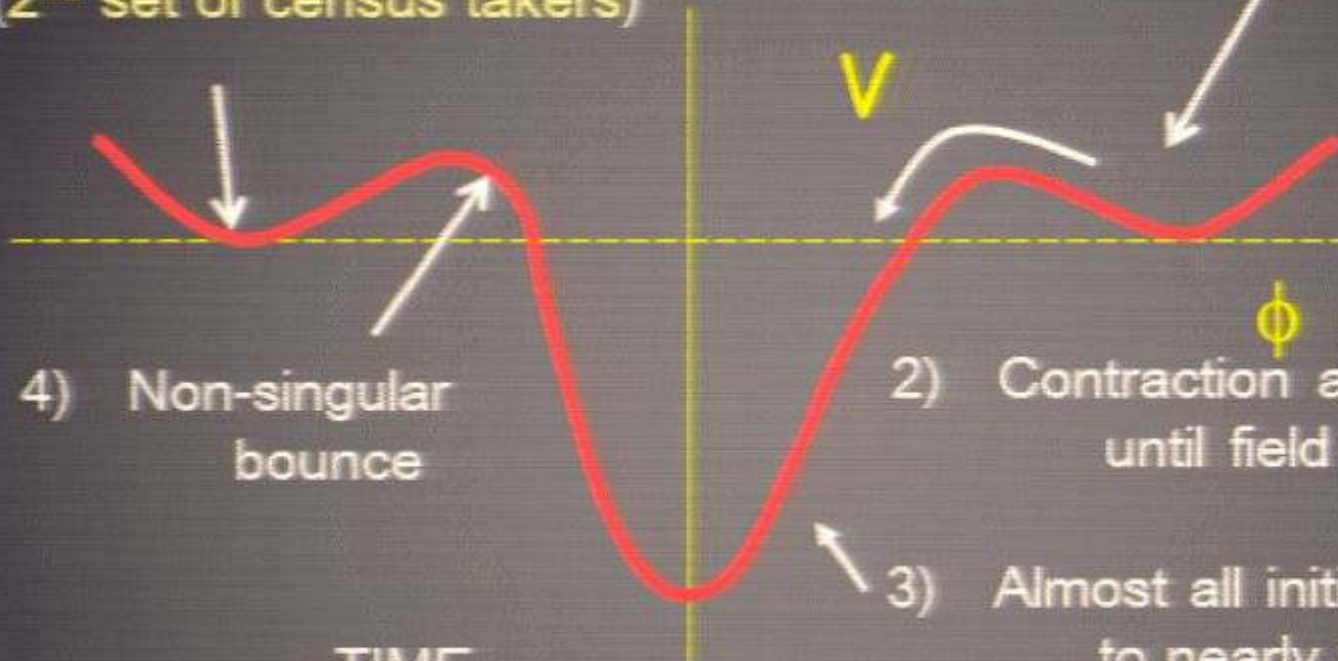
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TIME

