

Counting Pockets in Eternal Inflation : The World Line Method

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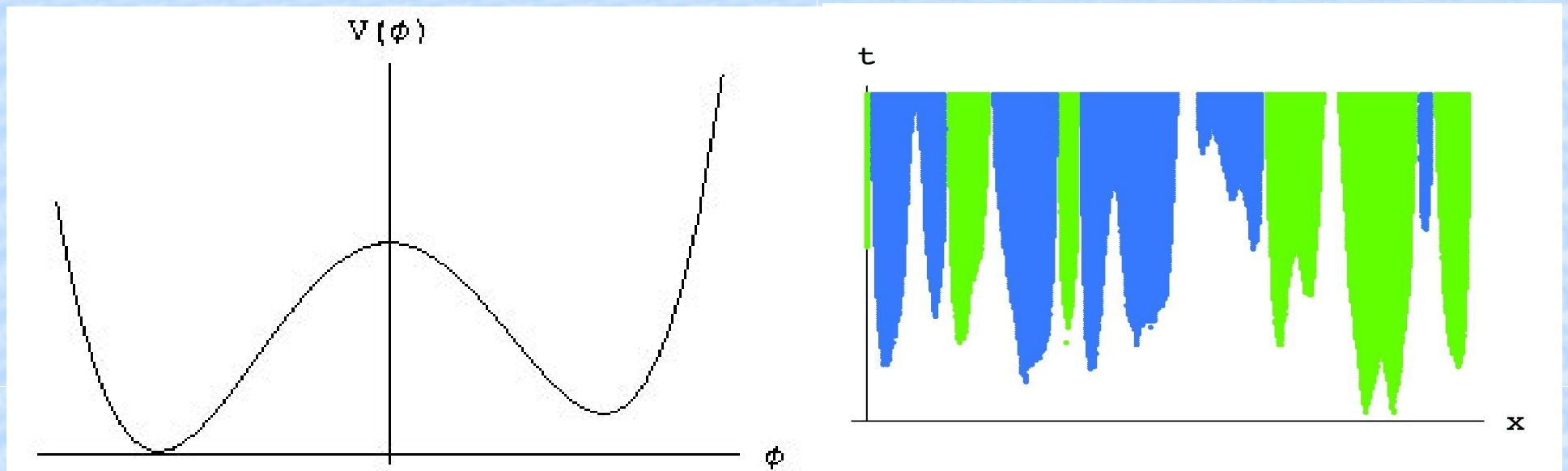
JCAP 0603 016 2006 (astro-ph/0511233)

see also : Garriga et. al. JCAP 0601 017 2006 (astro-ph/0509184)

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Eternal Inflation

- Vilenkin (1983), Linde (1986), Starobinsky (1986)
- Overview : Guth (astro-ph/0002156)
- We assume Eternal Inflation occurs: we want to compute probabilities given such as model.



Probabilities in an Eternally Inflating Universe

- Different vacua : different fundamental properties (e.g. String Landscape)
- Eternal inflation produces a *Probability Distribution* of “pocket” universes, each with fundamental properties dependent on its terminal vacuum.
- Different model of Eternal Inflation produces different distributions : which one is *more likely* to be right?

Challenges : Probabilities in an Infinite Universe

- There is an infinite number of spatially infinite pocket universes. Vanchurin, Vilenkin, Witnizki (1999)
- Naïve Calculation :
$$P(A) = \frac{Vol(A)}{Vol(total)}$$
- Time cut-off introduces gauge artifacts :
 - *Youngness Paradox* Guth (2000)
 - *Shrinking Volume Gauge* Witnizki (2005)

Splitting up the Problem

- Probability of finding an observer who sees fundamental properties α_i given eternally inflating potential $V(\psi_1, \psi_2, \dots)$ with vacua A, B, \dots

$$P(obs_{\alpha_i} | V(\psi)) = \sum_A P(A | V(\psi)) P(\alpha_i | A) P(obs | \alpha_i)$$

Our goal in this work
Probability Distribution of
Pockets

“Anthropic arguments”
See Aguirre (2005)

Future work (also see Vanchurin et. al. (2005))

Picking Pockets

- Still infinite number of pockets
- We want to find

$P(A|V(\psi)) = \# \text{ times a pocket } A \text{ drawn} / \text{ total } \# \text{ random drawings}$

- Use a manifestly covariant regulator : *World Lines*
- Using world lines, we *sample* the true probability distribution by drawing the pockets in a random way.

The World Line Method

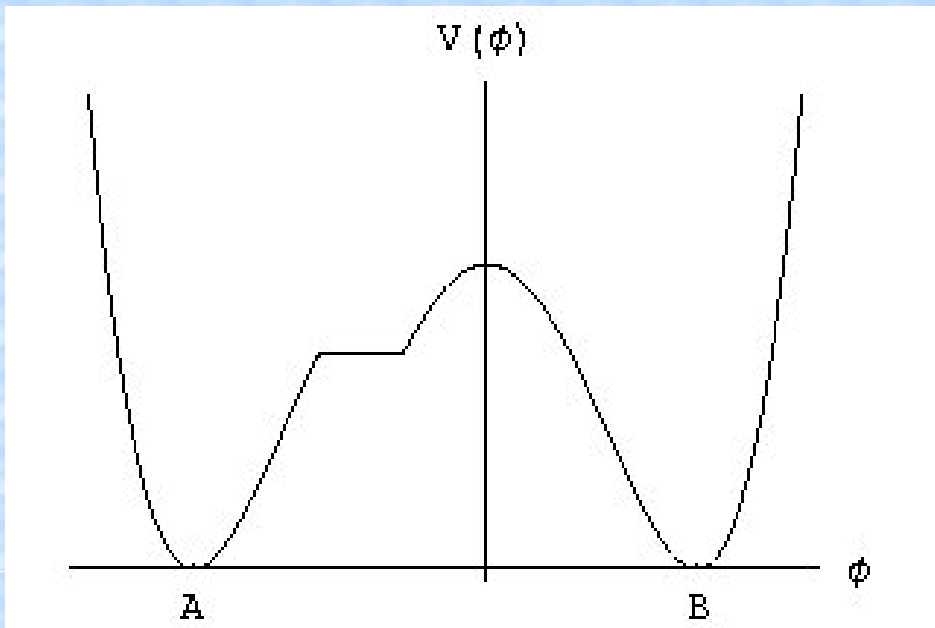
- Pick an eternally inflating region
- Lay down a distribution of N points in this region (method is insensitive to initial distribution)
- Follow each world line until it hits a thermalized region (e.g. pocket type A)
- Do not overcount : throw away all additional lines that enter the same pocket $N \rightarrow N'$

$$P(A) = \frac{N_A}{N'}$$

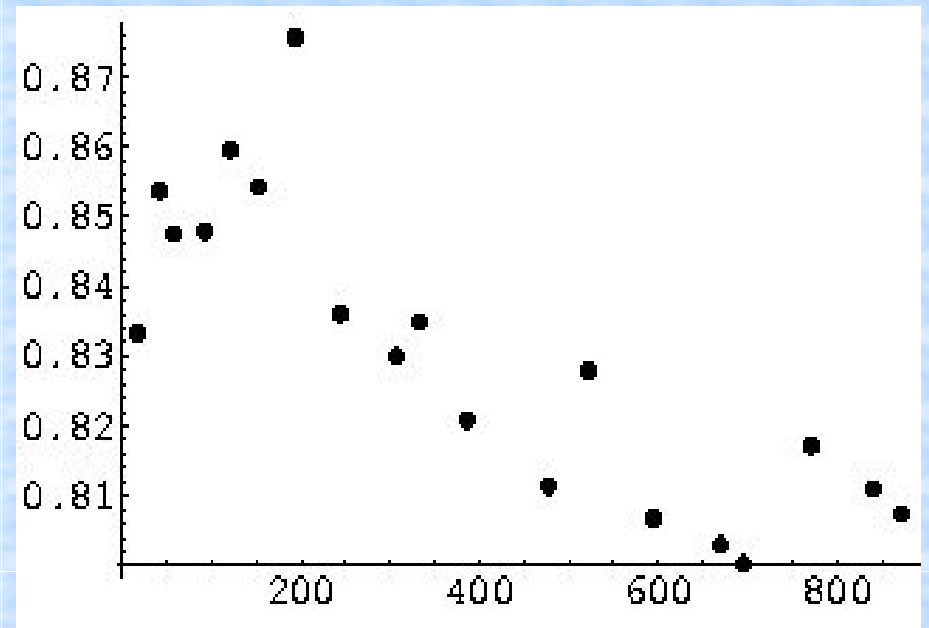
- Check for convergence as $N \rightarrow \infty$

Toy Model Example

- Eternal Inflation : use a simple model with discrete timestep and discrete Hubble volumes
- Assign probabilities to each tunneling or hopping event.



Asymmetric Potential with
2 Vacua A & B



$P(A)$ as $N' \rightarrow$ Large

Application : Testing models of eternal inflation

- Consider a 3-vacua model of eternal inflation with cosmological constants $\Lambda_{us}, \Lambda_0, \Lambda_{EW}$

$$P(\Lambda_0) \gg P(\Lambda_{EW}), P(\Lambda_{us})$$

We live in an *atypical* pocket of such a model

$$P(\Lambda_{us}) \gg P(\Lambda_0), P(\Lambda_{EW})$$

We live in a *typical* pocket of such a model

$$P(\Lambda_{EW}) \gg P(\Lambda_{us}), P(\Lambda_0)$$

Ignore EW pockets, and compare $P(\Lambda_{us}), P(\Lambda_0)$

- We did not use the *A* word to reject models.

Conclusions and Future Work

- We introduced an intuitively simple and gauge-invariant method of sampling pocket universes in eternal inflationary universes.
- Our results are equivalent to Garriga, Schwartz-Perlov, Vilenkin, Witnitzki (2005).
- Future work 1 : Extending the world line method to single pocket, to compute $P(\alpha_i|A)$
- Future work 2 : Extensions to topologically more challenging potential landscape (e.g. different evolution histories to the same vacuum)

Next Steps of Action

- Explain the steps that now need to be taken