

The Boltzmann Brain Problem

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The paradox requires few equations to state.

- ① A powerful consistency check for theories of ~~multiverse~~ measure on multiverse.
- ② A strong motivation to describe one causal patch in cosmology
- ③ May provide predictions about Landscape.

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Focus on finite piece of our reheating surface.

Follow this piece (comoving coords) into the future.

① At time $\sim H^{-1}$, see a finite # of ordinary observers.

② If our vacuum inflates eternally, the physical volume grows with time.

③ de Sitter is thermal \Rightarrow see thermal fluctuations.

$$V_4 = \infty$$

Conclusion: Count finite # of ordinary observers, ∞ Boltzmann Brains.

Page's conclusion: Our vacuum ③
is not eternally inflating:
lifetime $<$ Hubble time.
But lifetime is exponential!

Note: Could simply ask:
Given everything we observe,
are we more likely to be
ordinary observers or BB's?

Answers 100% BB's.
(Conflicts w/ observation: Dyson, Kleban, Susskind)

Our Comment: A given
comoving volume falls out
of causal contact in
de Sitter.

Who gave Page permission (4)
to count all of these
BB's?

- Answer seems crazy
- Answer is infinite
- Does not correspond to operational question.

Analogous to BH information
paradox.

Suggestion: Restrict to
one causal patch.

Back up:

Why count observers in just one vacuum if eternal inflation is occurring? (5)

Experimental evidence:

(a) Bousso, Harnik, Kribs, Perez:
Postdict Λ by counting #
of obs in causal patch \rightarrow
works beautifully

(b) Weinberg et al:
weight vacua by collapsed
baryon fraction.

Measures:

(6)

Vilenkin:

- ① Solve rate equations to determine bubble abundances
 - ② Count observers within each bubble (regulate by restricting to finite comoving volume).
- ① is finite; ② is infinite if any dS vacua which can fit BB's eternally inflate!

Bousso:

- ① Initial cond's
- ② Solve different rate eq'n's
- ③ Count observers in one causal patch.

Question: In one causal patch, are there more DO's or BB's?

Causal patch desc of dS is thermal

$$T = \frac{1}{R}$$

Typically, one photon per horizon volume. Time to make a BB: $t_{BB} = R e^{S_{BB}} = R e^{\frac{M}{T}}$

Lifetime: $e^{S_{\text{inst}}}$ (3)

Two regimes: Decay can be a field theory process, or our Λ may be important.

In latter case (above "Great Divide"),

lifetime $\sim e^{S_{\text{ds}}}$

In our vacuum, # of Earths: $t_{\text{BE}} = e^{\frac{M_{\text{e}}}{T}} = e^{M_{\text{e}} R}$

$$N_{\text{be}} = \frac{e^{10^{120}}}{e^{10^{92}}} \sim e^{10^{120}}$$
$$\sqrt{N_{\text{OE}}} \sim \frac{1}{\Lambda} \sim 10^{120}$$

BB's exist in $G_N \rightarrow 0$ limit. (9)

$$t_{BB} = \frac{R}{c} e^{S_{BB}}$$

$$\text{or } t_{BB} = \frac{R}{c} e^{\frac{ER}{c\hbar}}$$

$$t_{\text{decay}} \sim e^{\left(\frac{R}{l_p}\right)^2}$$

~~XXXXXXXXXXXX~~

If any BB's are made,
a doubly exponential #
are made. In Bousso

measure, no other exponentials.

Prediction: In landscape, $t_{\text{decay}} < e^{S_{\text{BH}}}$

Is this crazy?

Look at KKLT decay times. ~~SUSY~~ by $\overline{D3}$ in warped throat.

Long throat: Mild ~~SUSY~~, but brane-flux annihilation occurs near tip

In insensitive to warping.

Short throat: Strong ~~SUSY~~, destabilize fluxes in bulk of CY

$$t_{\text{decay}} \sim e^{\frac{m_{\text{pl}}^2}{M_{3/2}^2}} \quad (\text{EDGKL})$$

①①

Do there exist vacua
with small Λ where

decay time \sim recurrence time

Aside: \exists completely stable
~~SUSY~~ AdS vacua?

Basic Assumption: It

makes sense to ask:

"What are observers likely
to observe?"

- Necessary to Weinberg arg.
- Allows us to ask if we are likely to be BBs.

Conclusions:

(12)

- Computing decay times in landscape provides information about measures if we consider BB problem.

Vilenkin et al: $t < H^{-1}$

Bousso: $t < e^{S_{BB}}$

- BB problem encourages us to focus on one causal patch in cosmology
- If we assume counting obs in one causal patch makes sense (based on evidence), nontrivial prediction about Landscape