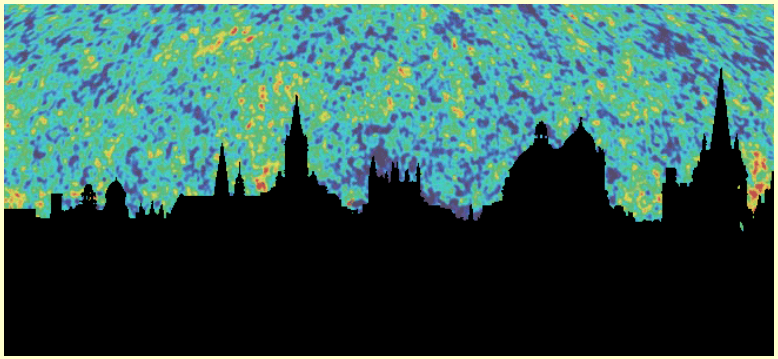

Why anthropic reasoning does not predict Λ

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Answering the big questions:

Is our Universe "special"?

Why is our Universe hospitable for life?

Is there an anthropic explanation to Λ?

Anthropic coincidences?

Are physical constants tuned for life?

(Aguirre 2001, 2005; Weinberg, 2000; Tegmark et al 2005; Rees 1998, ...)

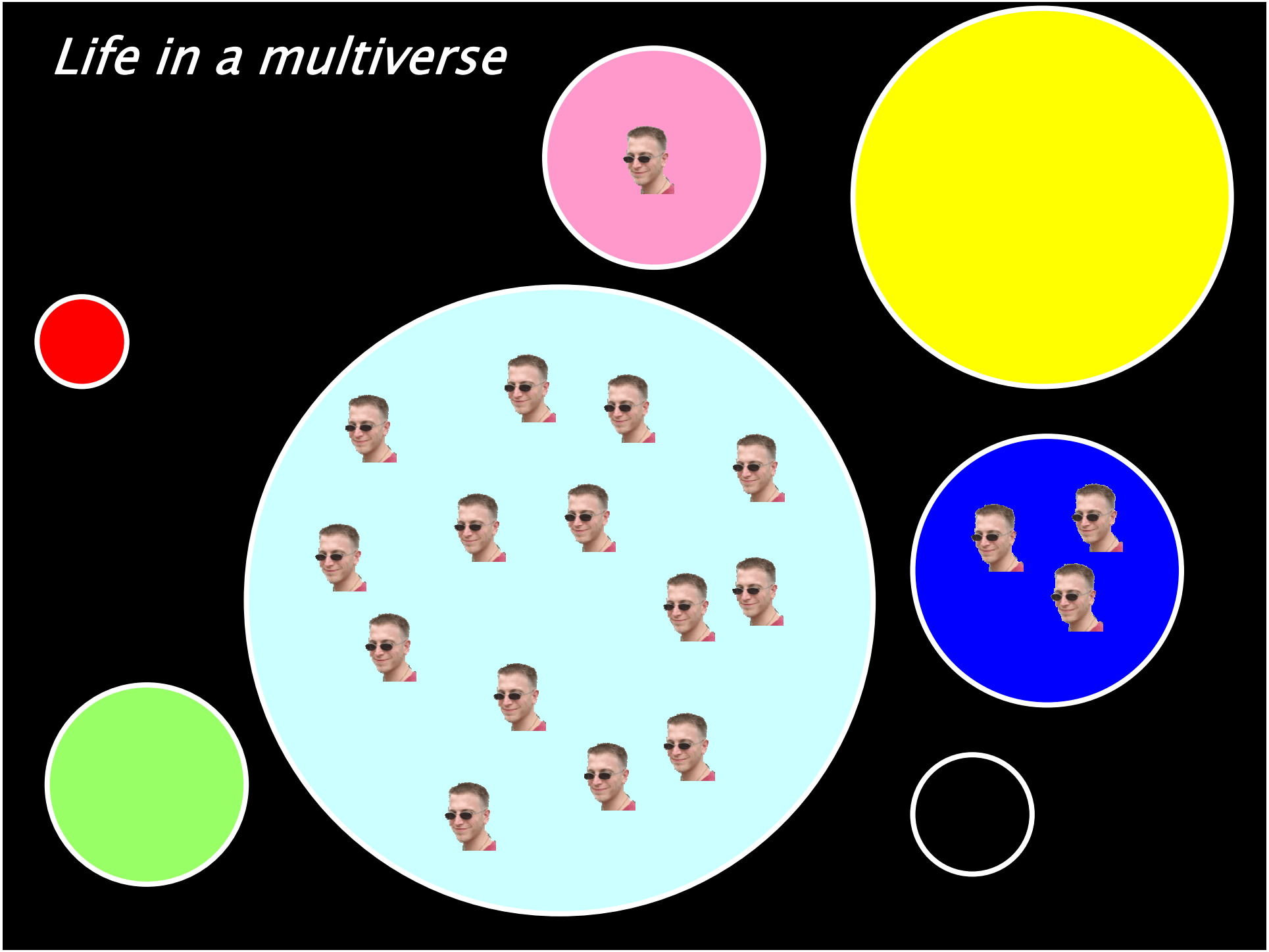
- *Primordial fluctuations amplitude Q*
- *α_{EM}/G and α_S*
- *Cosmological constant Λ, ...*

Possible viewpoints:

- *Deeper symmetry / laws of Nature*

  (but what determined THAT particular symmetry in the first place?)
- *Design or necessity*

  (outside the scope of scientific investigation)
- *Any parameters will do (no explanatory power)*
- *Multiverse: we must live in one "realization" favourable for life*


Life in a multiverse

Anthropic reasoning and Λ

The cosmological constant problem:

$$\text{why is } \Lambda/M_{Pl} \approx 10^{-123} \text{ ?}$$

The anthropic "solution":

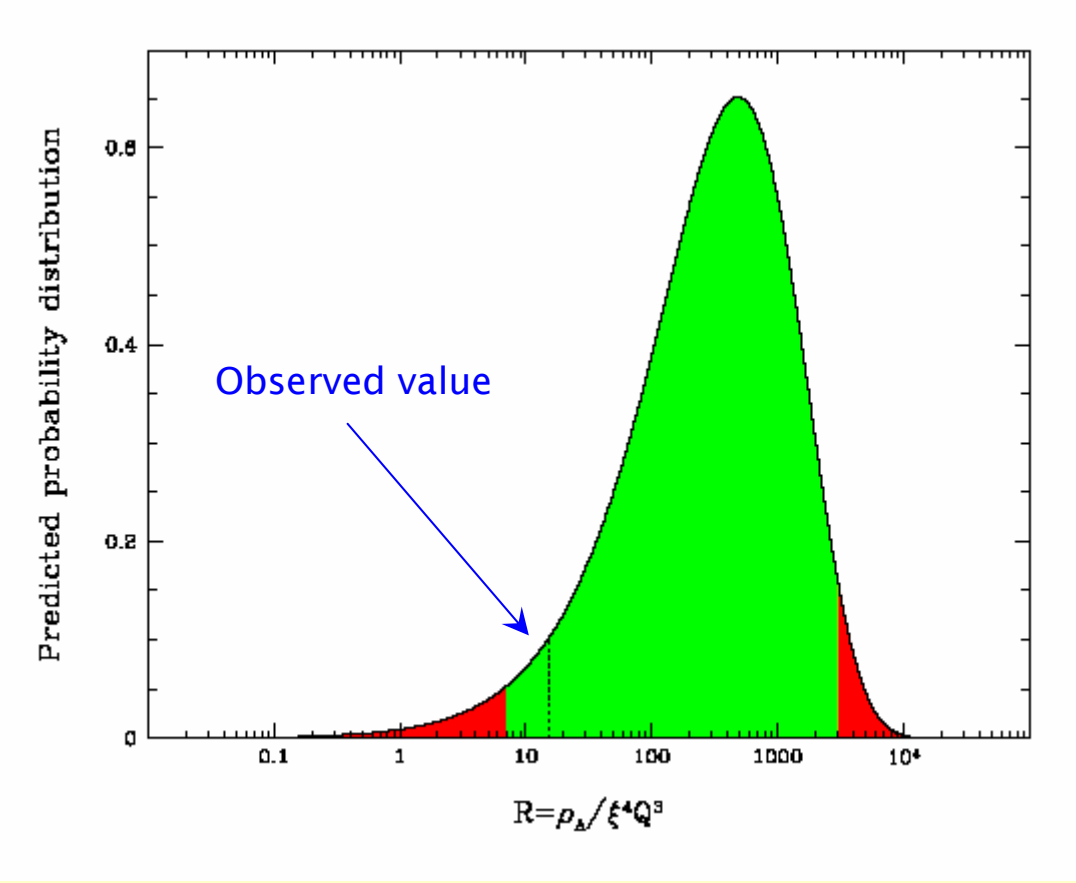
$$\text{if } \Lambda \gg 1 \text{ galaxies cannot form}$$
$$\text{hence no observers}$$

(Weinberg, 1987)

Shortcuts & difficulties:

- What counts as observers?
- Which parameters are allowed to vary?
- Is the multiverse a scientific (ie testable) theory?

Which parameters should we vary?



(Tegmark at al 2005)

if Λ, Q and ξ varied:

$\Lambda = 10^{17}\,\Lambda_0$
perfectly "viable" !

(Aguirre 2001)

"Prediction" only successfull
conditional on ξ, Q = fixed
(AND that T_{CMB} = 2.73 K)

Probability theory and Λ

$$f_{obs}(\Lambda) = f(\Lambda)\, f_{sel}(\Lambda)$$

*prob of observing = sampling distribution * selection function*

"random sample" "typical observer"

The sampling distribution $f(\Lambda)$

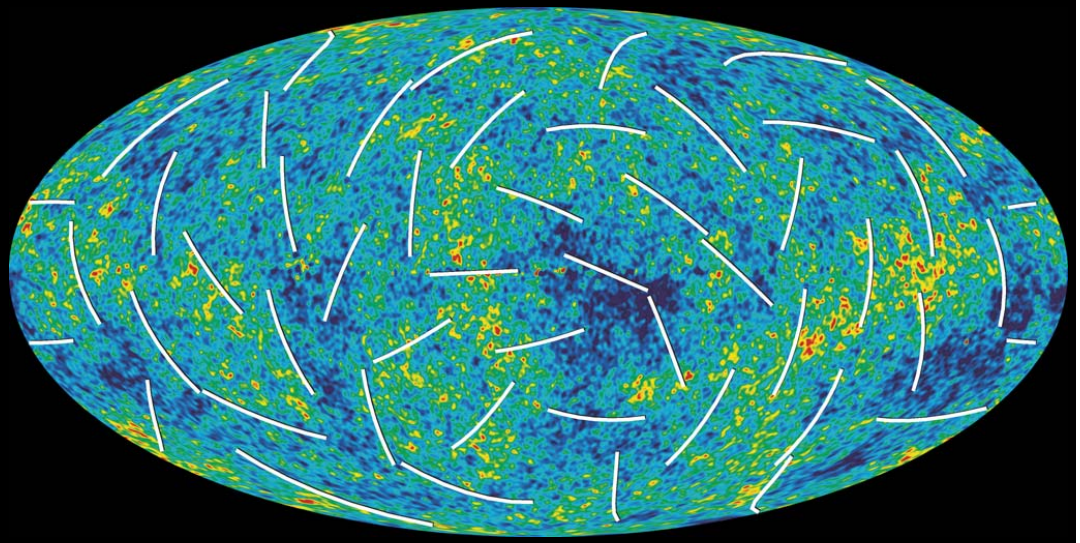
As a frequency of outcomes? (untestable in cosmology)

Flat distribution (the "Weinberg conjecture") ? (assumed)

Ergodic arguments? (unclear in an infinite Universe)

No operational def'on of "random" sample: probabilities are NOT physical properties!

Which probability theory for cosmology?



Probability as frequency

Repeatable sampling
Parent distribution
Asymptotically $N \to \infty$

Probability as state of knowledge

Only 1 sample
"Multiverse" approach ill-defined
N finite & limited

On the physical reality of probability

Coin tossing: is the coin fair?

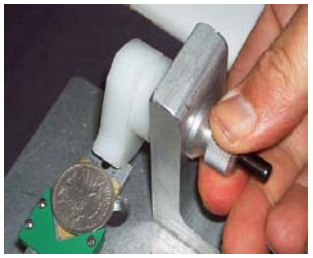
Test the null hypothesis H_0: $p = 0.5$

"The numbers p_r [the frequency with which a certain face comes up in die tossing] should, in fact, be regarded as physical constants of the particular die that we are using."

(Cramer, 1946)

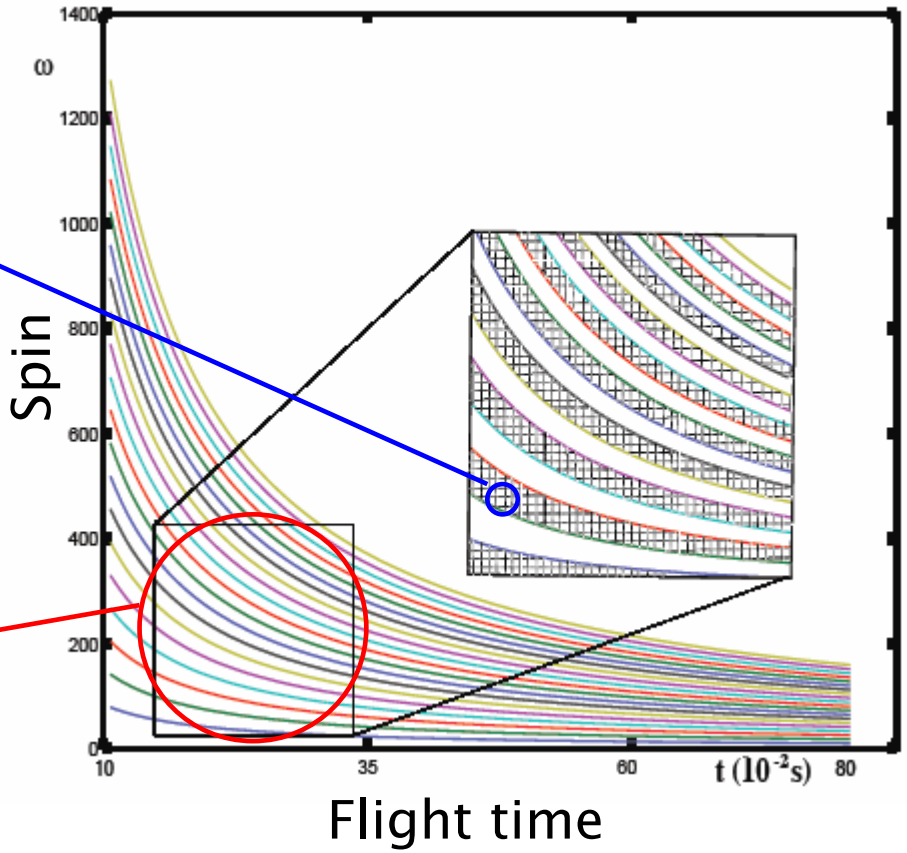
Are physical probabilities meaningful?
What does it mean "to throw at random"?

Initial conditions space



p irrelevant!

"Random" toss



With careful adjustment, the coin started heads up always lands heads up – 100% of the time. We conclude that coin-tossing is "physics" not "random".

(Diaconis et al 2004; Jaynes 1996)

Symmetric Lagrangian: $\Gamma_T = \Gamma_H$

$p \neq 0.5$: Γ_T/Γ_H is NOT independent on location!

The selection function

$$f_{obs}(\Lambda) = f(\Lambda)\, f_{sel}(\Lambda)$$

The selection function $f_{sel}(\Lambda)$

What counts as "observers"? (it's the total number that counts!)

What if the Universe is infinite? (number density/Hubble volume?)

Do observers outside your causal horizon count?

Certainly important to integrate over time: we might not be "typical" in that we are early arrivals...

An explicit counter-example: MANO weighting
Maximum Number of Allowed Observations

MANO weighting of Universes

- *Integrate over lifetime of the Universe to obtain the total number of observations that can POTENTIALLY be carried out*
- *Universes that allow for more observations should weight more*
- *Gauge invariant, time independent quantity*
- *Maximum number of thermodynamic processes in a $\Lambda > 0$ Universe:*

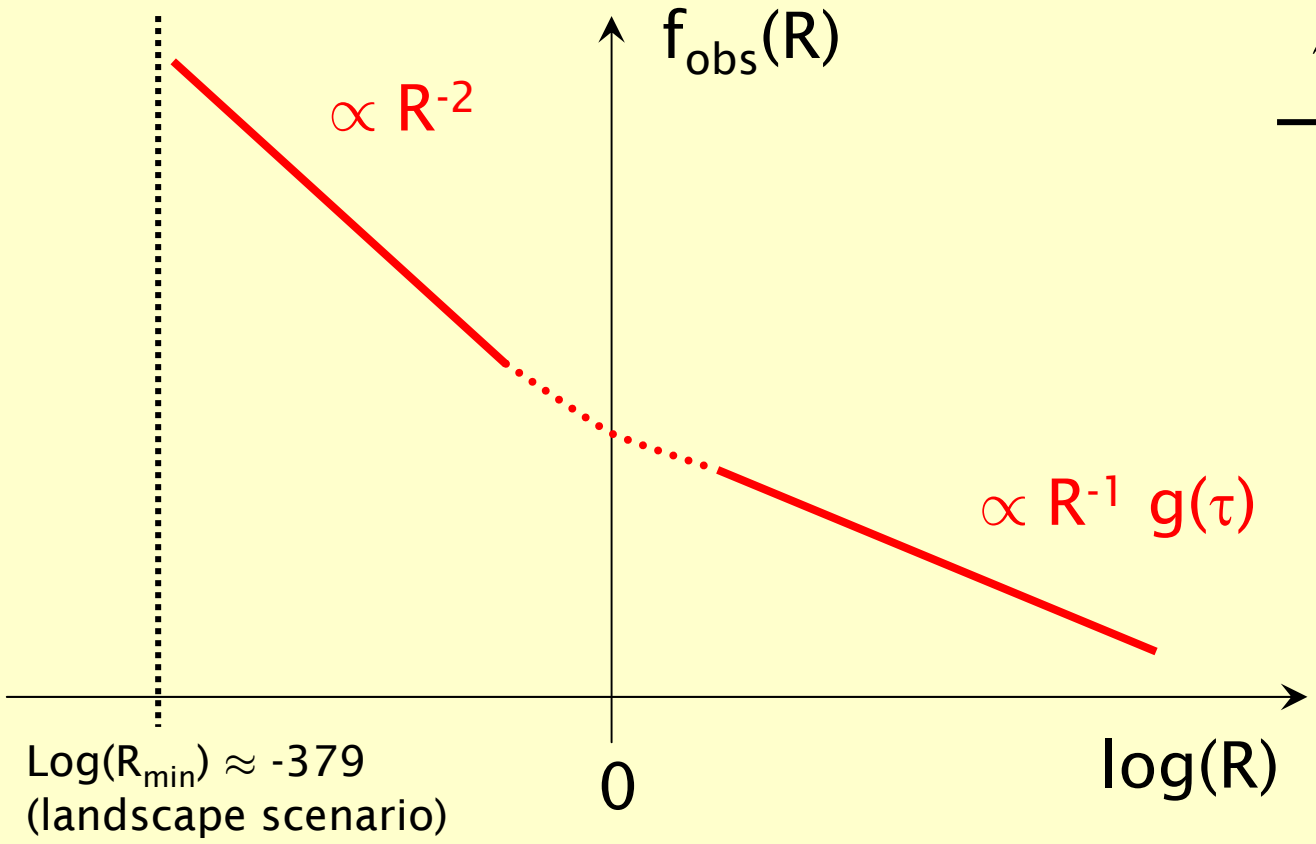
$$N_{max} < E_{coll}/k_B T_{ds}$$

- *This assumes "rare observers", otherwise density of observers sets the limit*
- *Still suffers from dependence of micro-physics + details of how civilizations arise & evolve*

Probability of observing Λ

- *2 parameters model:*

$$R = \Omega_\Lambda / \Omega_\Lambda{}^0 \qquad \tau = t_{obs}/t_0$$



τ	$f_{obs}(R>1)$
.1	8×10^{-3}
1	3×10^{-5}
3	5×10^{-8}
10	2×10^{-16}

Final remarks

PROBABILITY THEORY AND COSMOLOGY

- *Probabilities are not physical properties but **states of knowledge***
- *Uniqueness of the Universe calls for a fully Bayesian approach*

ANTHROPIC REASONING AND SELECTION EFFECTS

- *Outcome depends on selection function*
- *Probability theory as logic at odds with multiverse approach*
- *Within "traditional" anthropic arguments: you should at least integrate over time*
- *MANO counterexample: $P(\Lambda > 0.7) \sim 10^{-5}$*
- *Anthropic "predictions" completely dependent on (many) assumptions*