אנטרופיקס - בעד ונגד

רוני הרניך

פרמילאב

Gilad asked me to talk about
"The Pros and Cons of Environmental Arguments".

However —

Gilad asked me to talk about
"The Pros and Cons of Environmental Arguments".

However –

Due to a **recent tunneling event**, my talk about anthropics will take place in another Universe. that way ↗.

Instead I'll talk about –
"Fermion Hierarchy from Sfermion Anarchy"
Altmannshofer, Frugiuele, RH – 1409.2522

Just kidding.

Lets end my vacation from anthropics.

* What I'll say will be a linear combination of

  o Trivial.

  o Provocative.

  o At times, subjective.

Outline

* Universe or Multiverse

  o Which one is radical? Which one is conservative?

  o Signals (from the birth of our Universe).

* Anthropics for the Weak scale.

  o The weakless Universe.   con

  o Anthropics for a little Hierarchy?

* Anthropics for the Cosmological Constant.

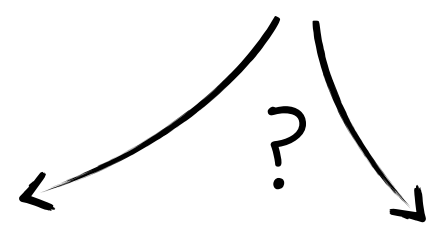 o The (Causal) Entropic Principle.   pro

Universe
or
Multiverse?

Universe or Multiverse?

* Look around.

- We're on one planet, out of many.

- Orbiting one star, out of many.

- In one galaxy, out of many.

- ....

- In one observable Universe,...

One Universe. period. ← ? → One out of many.

We don't know (so far).

A Historical Note

* At many of these steps, there was a temptation to stop.

Giordano Bruno,
burnt in rome in 1600 for
arguing there are other worlds.

Universe or Multiverse?

* My **subjective** opinion:

  A single Universe leaves us w/ huge questions—

  WHY? Why a big universe? Why is there anything inside it? Why light degrees of freedom? Why dynamics that allow for life? etc, etc...

* A multiverse addresses these elegantly – we are a random fluke. "Life Happens".

For me, a single Universe, the notion that we already have a good sample of everything, is more radical. The multiverse approach is more humble.

Tuning & Landscapes

* Discussions of naturalness implicitly assumes an ensemble of Lagrangians.

$$\text{Tuning} \sim \frac{d\,(\log m)}{d\,(\log g)}$$

"In many models it is natural that..."

* What does tuning mean for a unique Universe?

* A landscape gives the notion of naturalness a natural home.

But enough with this subjective mumbo-jumbo.

Signals of a Multiverse

* This question could be addressed by **data**!

* Assume only 60 e-foldings of inflation.

* Our birth, bubble nucleation, leaves a trace:

  o The Interior of a Coleman-DeLucia bubble is negatively curved. Potentially observable. (Frivogel et al)

  o If our parent vacuum is very different from our's there may be more spectacular signals.   (Graham, RH, Rajendran)
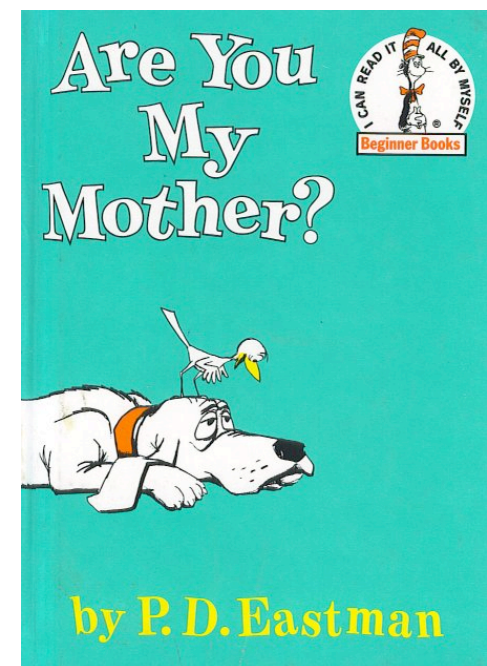
Signals of a Multiverse

* Example: Suppose our parent vacuum had 2 large + 1 compact dimensions.

* More compact dimensions → more vacua?

* The Colman-DeLucia Bubble in this case has anisotropic curvature.

standard rulers (CMB)

looks like:
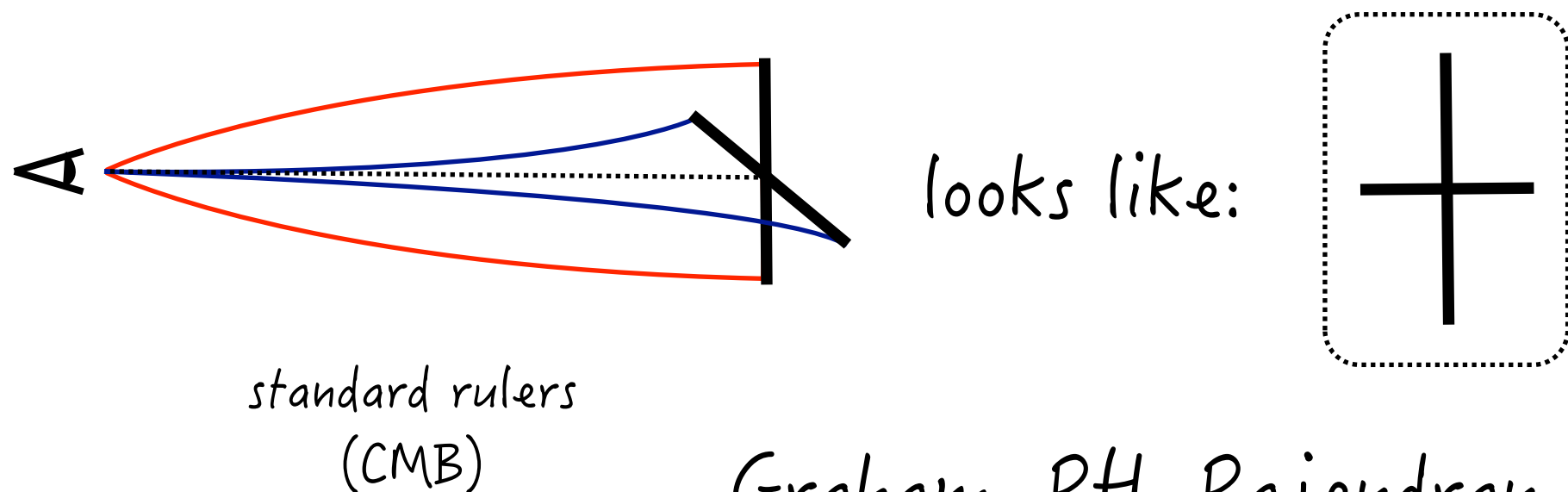
Graham, RH, Rajendran (2010)

Even if there is a Multiverse,
does it have anything to do with
the weak hierarchy problem?
Do we have a robust argument?

RH, Kribs, Perez (2006)

Atoms

* Agrawal, Barr, Donoghue, Seckel (97):
  raise $v \to m_{u,d}$ are higher $\to m_n - m_p$ goes up.

* Eventually neutrons in atoms decay:
  Raise v by a factor of a few $\to$ No Atoms.

* Interesting.
  But relies on keeping Yukawa couplings fixed.

* Of 10^{500} vacua, do we really think Yukawas
  are fixed??

The Weakless Universe

* Our approach: the Landscape is rich enough to include any Universe we can imagine.

* Can we imagine a Universe without a Hierarchy problem, which can support life?

* To avoid excessive calculations: Stick as closely as possible to our Universe.

The Weakless Universe

* The model: $SU(3)_{QCD} \times U(1)_{QED}$

    (equivalent to taking v to M_{pl})

* Particles: u, d, s, and e.

* Atomic physics is identical to ours.

* Nuclear physics is very similar, but richer.

Weakless Nuclear Physics

* A wider variety of stable isotopes:

What's Different?

Suppose we tunnel to the
Weakless universe now?
How would we know?

What's Different?

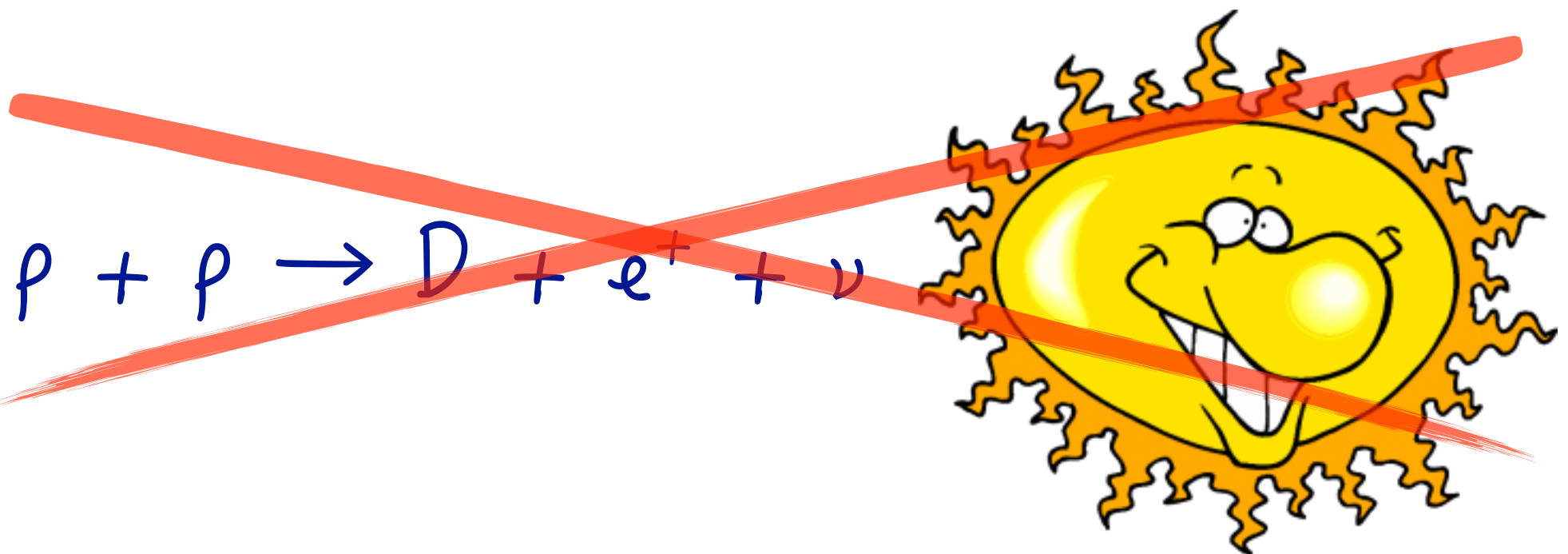Suppose we tunnel to the
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$$p + p \rightarrow D + e^+ + \nu$$

What's Different?

Suppose we tunnel to the
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$p + p \rightarrow D + e^+ + \nu$

Weakless Stars

* In our Universe brown dwarves burn for a wee while via

$$D + p \rightarrow \,^3He$$

* Not enough Deuterium for steady-state star.
(D abundance from BBN is ~10^{-5})

* For D-mass-fraction of 10% such stars can burn for 7 billion years.
(Thanks to Adam Burrows for simulating this)

Weakless BBN

* If we form Deuterium colder it will not fuse.

* Lower η_B, by 2 orders of magnitude:

Enough fuel for stars
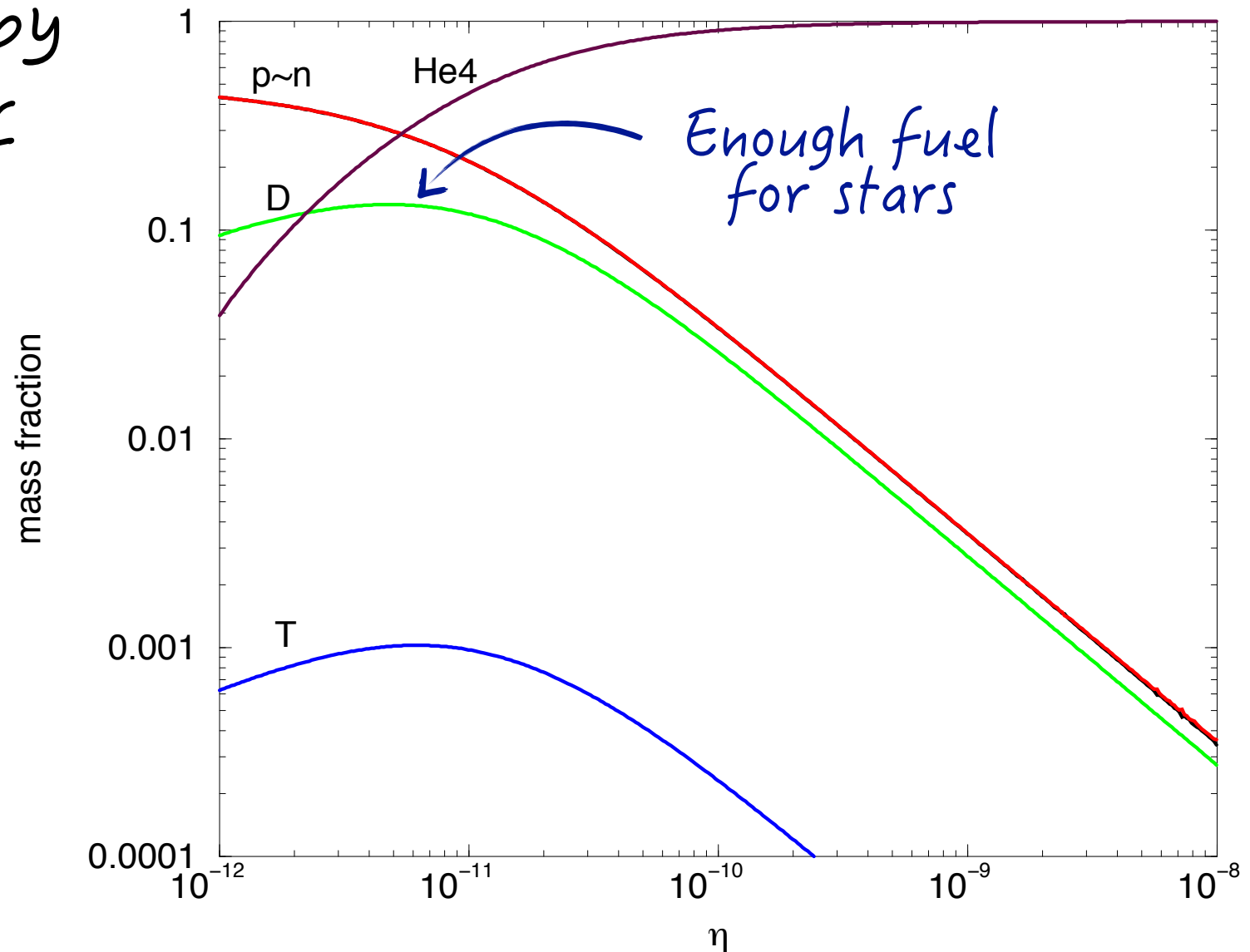
The Weakless Universe

* All-in-all, the weakless Universe has:

  o Chemistry

  o Nuclear Physics

  o Galaxies

  o Long lived stars

  o Heavy elements dispersed via type Ia SNe.

* But no hierarchy problem!
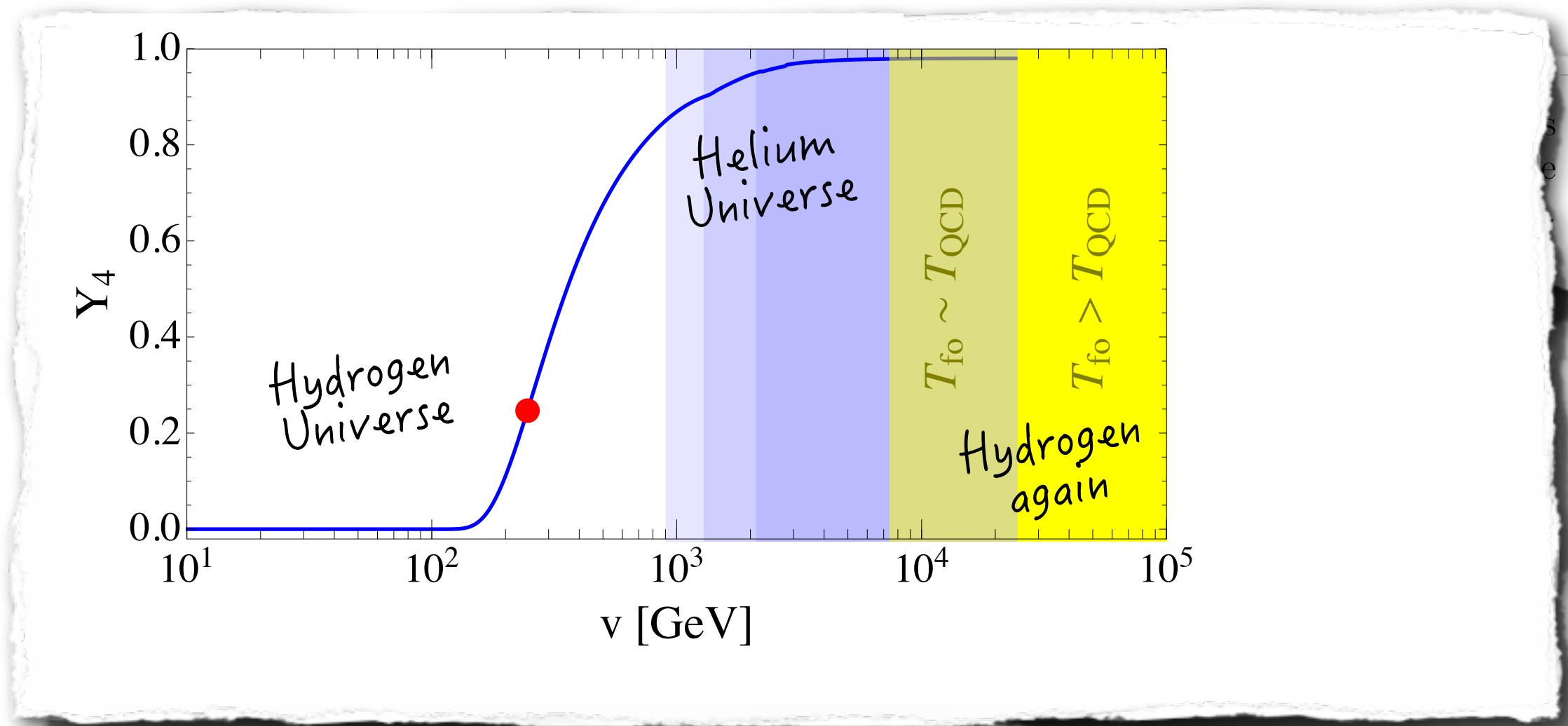 Why the hell are we not there?

RH, Kribs, Perez (2006)

Island or Runaway?

* Perhaps the weakless Universe is a "far away island" that is un-populated?

* A recent investigation - (Hall, Pinner, Ruderman)

cost of excessive helium. In this paper we explore the possibility that the weak scale originates from environmental selection at BBN. We are interested in modest variations in v and assume that huge variations, as in the weakless universe [12], give universes less probable than our own.
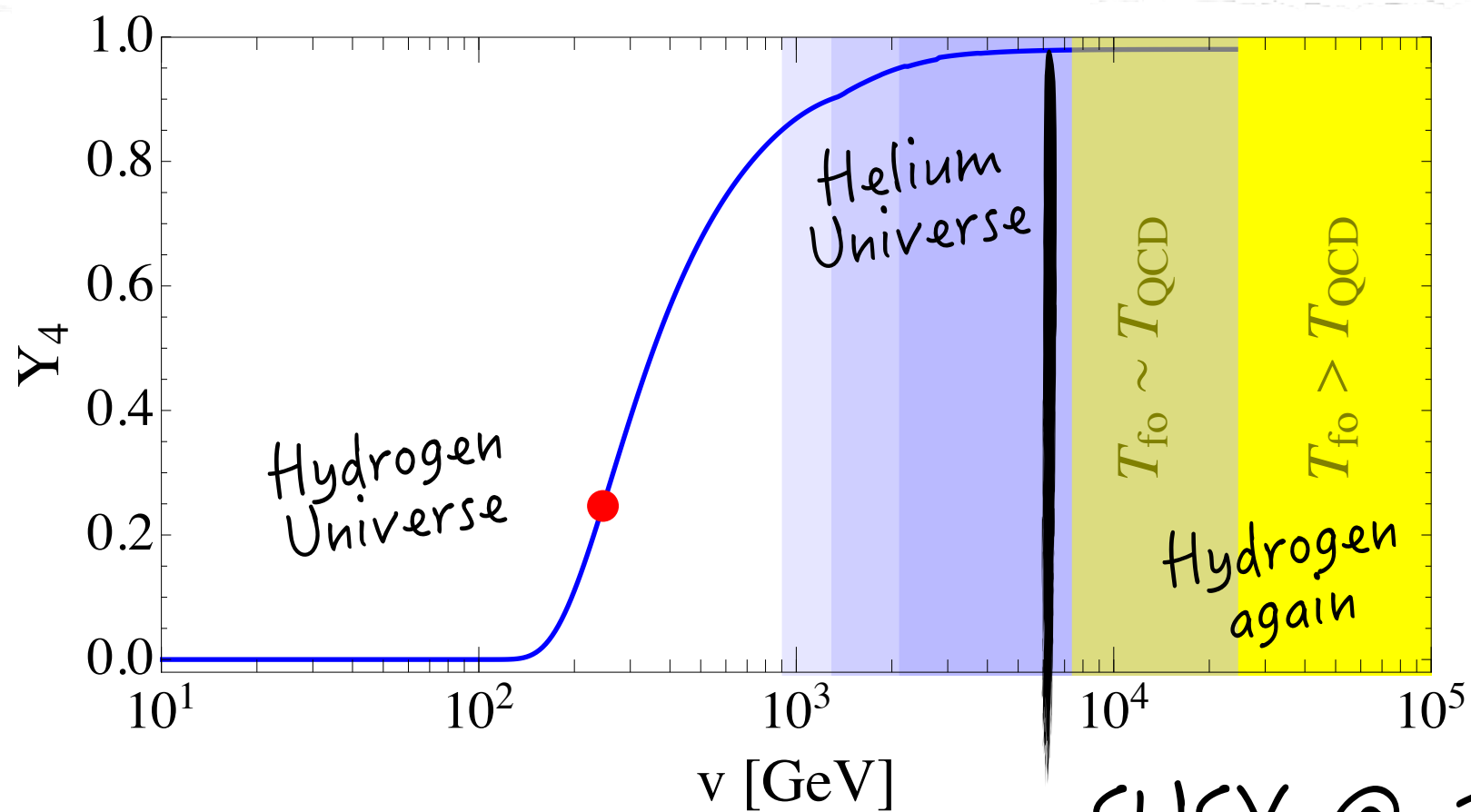
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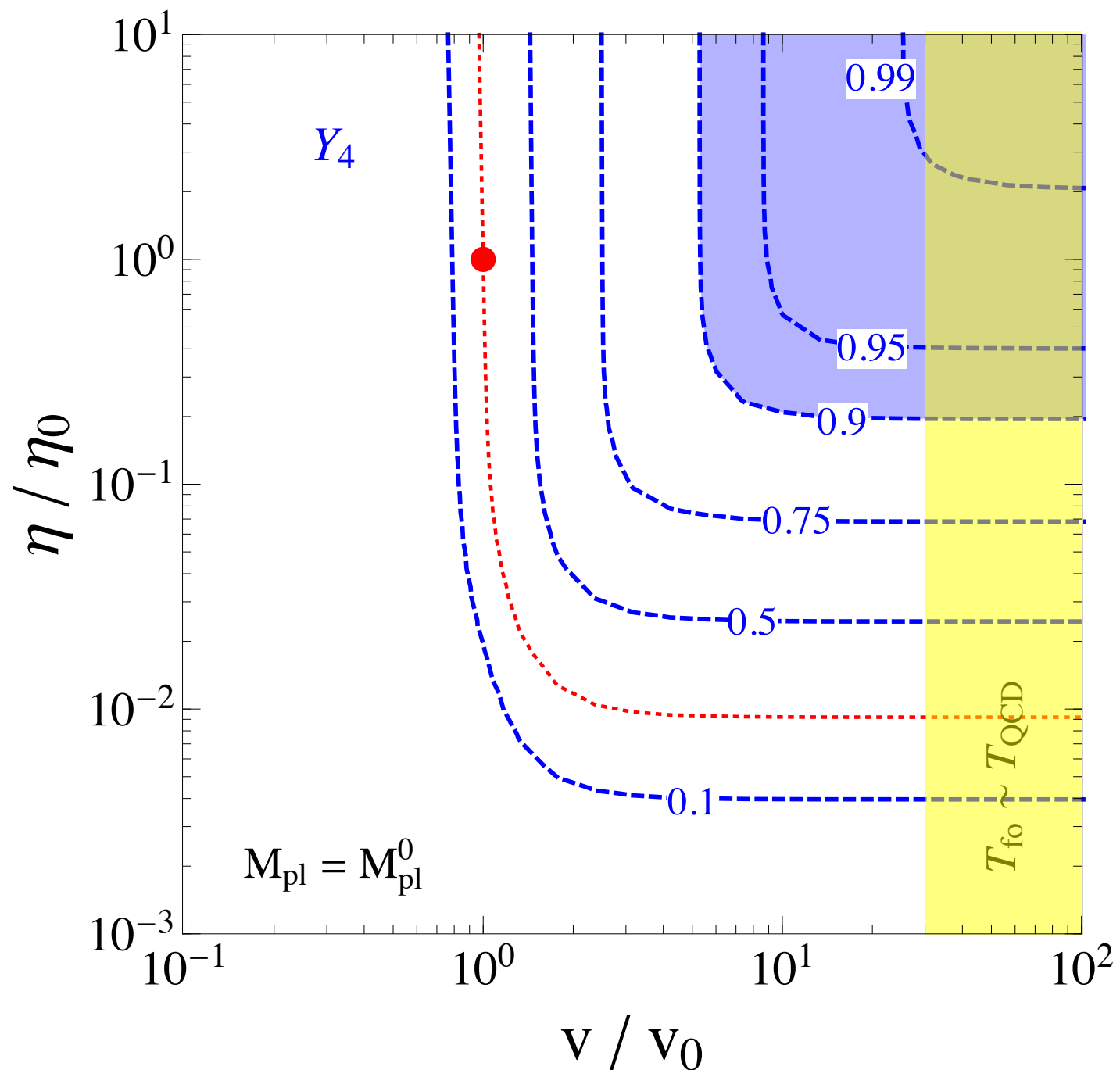
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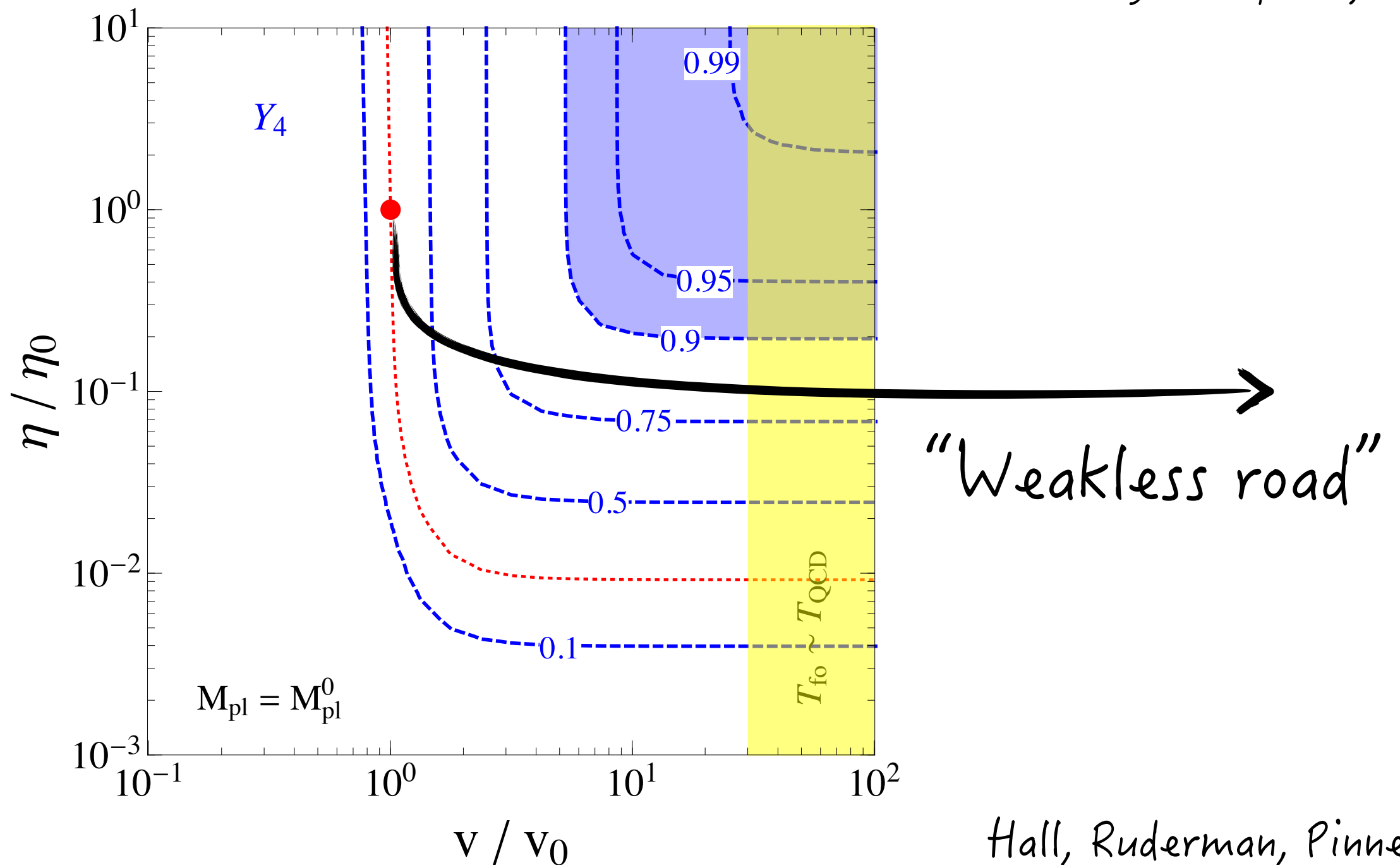SUSY @ 10 TeV?

Runaway

* **Once η is varied there is a runaway.** (unless you make strong assumptions)

Hall, Ruderman, Pinner

Runaway

* Once η is varied there is a runaway. *(unless you make strong assumptions)*

Hall, Ruderman, Pinner

By contrast, could we have
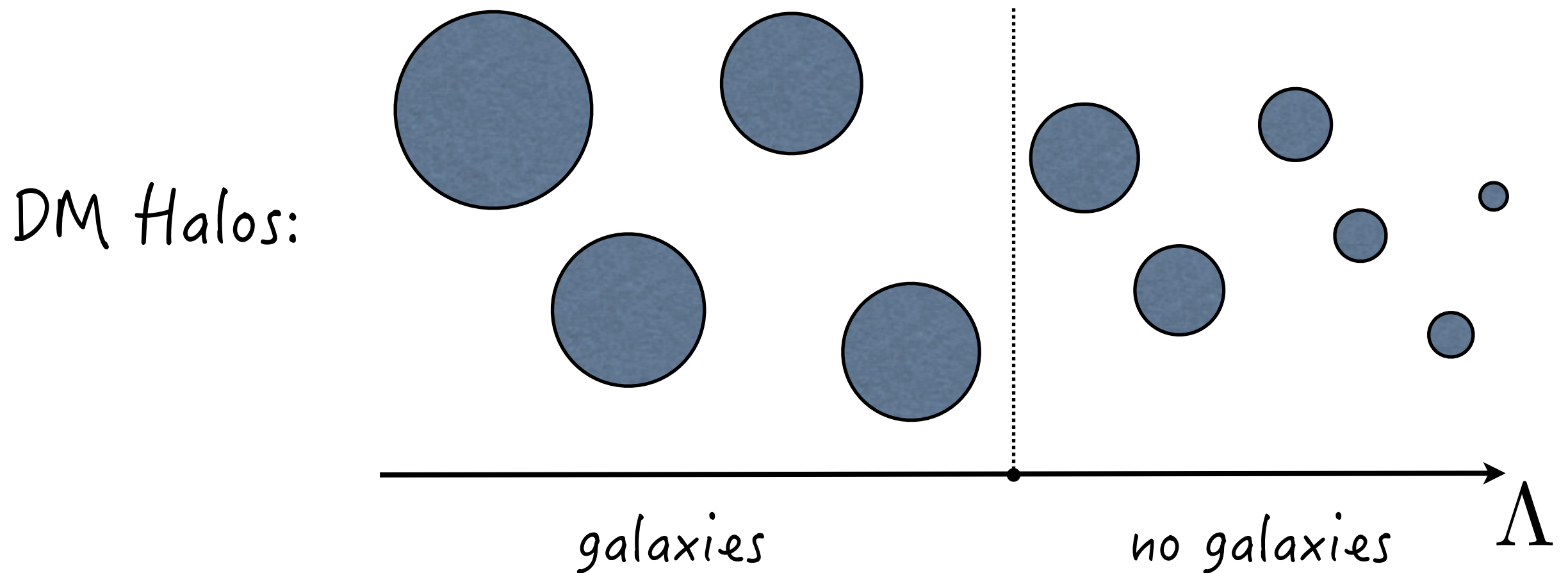done this for the cosmological constant?

Absolutely not!
The horizon is too small for complexity
or CC takes over too quickly.

Anthropics and the CC

Weinberg

* Weinberg **predicted** the CC will be close to the critical value above which no bound structures exist.
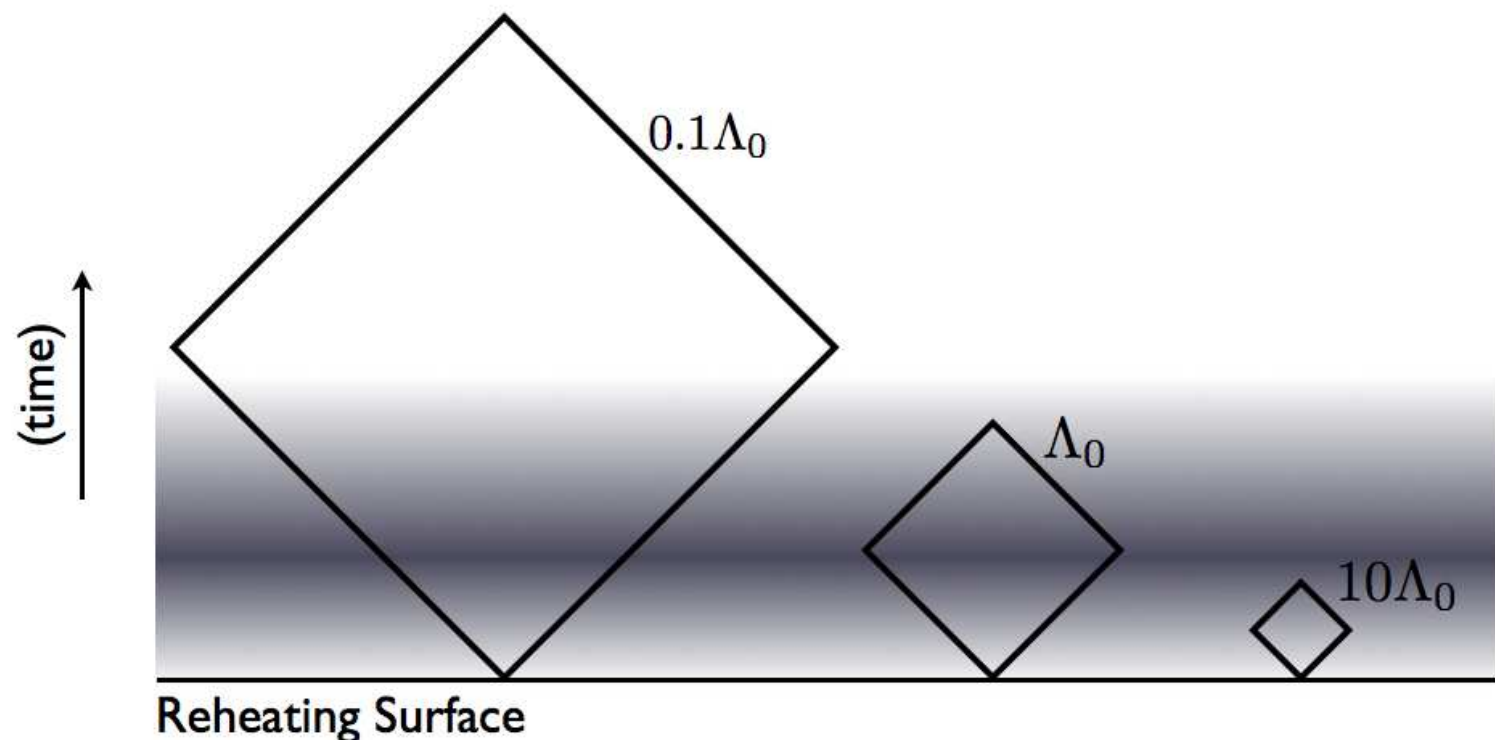
DM Halos:

galaxies | no galaxies

Λ

Runaway?

* Weinberg argument has a potential runaway if you let $\delta\rho/\rho$ grow.

* The world record in raising the CC for a "habitable Universe" is by a mere 10^{17} (Agguire).

* Whether this is a runaway depends on the "measure problem" of eternal inflation.

* By contrast, the EW runaway is independent of the measure.

Causal Entropic Principle

* A Regulator for eternal inflation that was motivated by black hole complimentarity: Weigh vacua by

  o The number of observers in a "causal diamond".

  o Approximate observers by **Entropy Production**.

Bousso, RH,
Kribs, Perez (2007)

(time)

$0.1\Lambda_0$

Λ_0

$10\Lambda_0$

Reheating Surface

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Kribs, Perez (2007)

This removes the $(\delta\rho/\rho)$ runaway.

(time)

$10\Lambda_0$

Reheating Surface
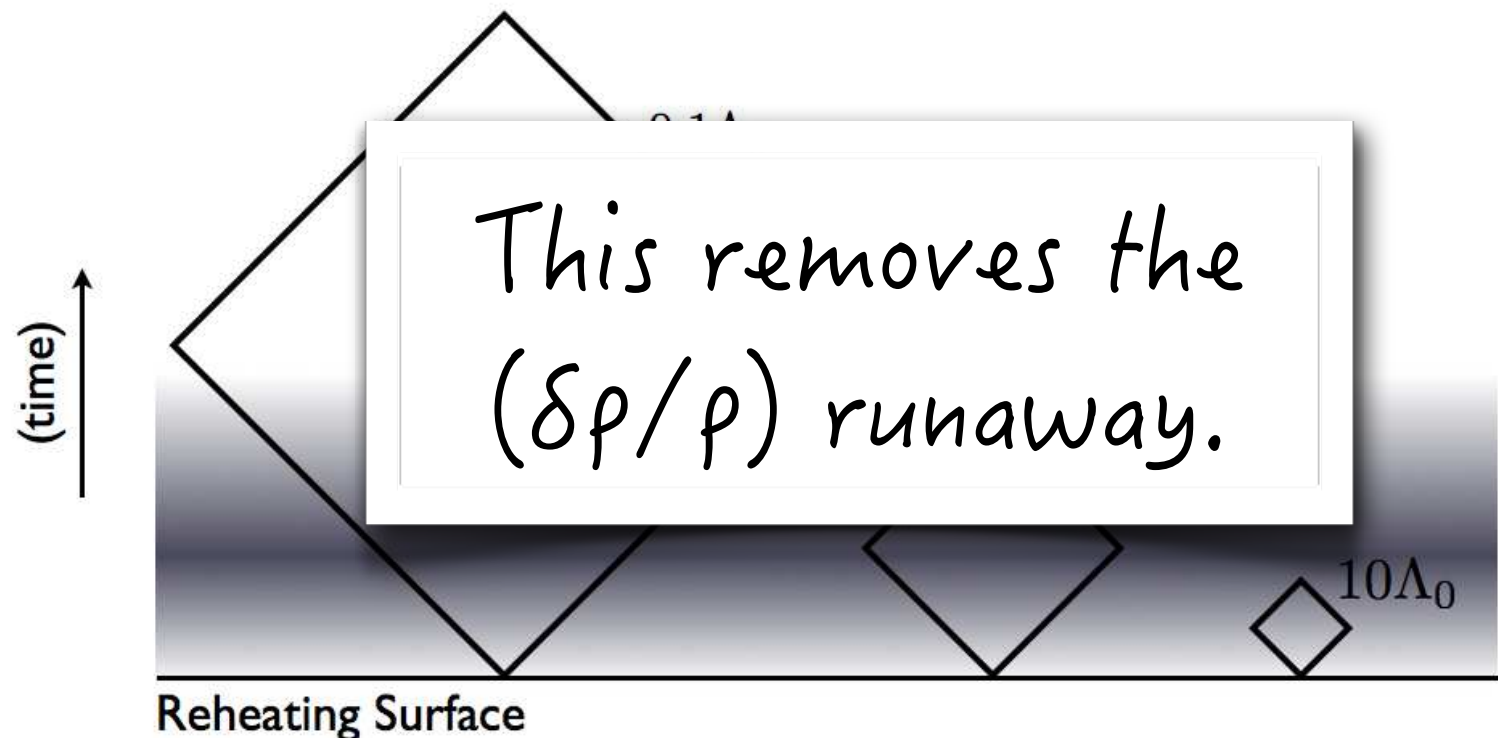
Summary

* A multiverse is a beautiful extension of our picture of the Universe.

* It is not clear if it is relevant for solving our hierarchy problems.

* We do not have a water tight anthropic argument for the weak scale.

* Perhaps we do for a "meso-tuned" theory?

* By contrast: have better arguments for the CC.

Deleted Scenes

Entropy Production

* Using entropy production as a proxy for life is an old idea:

"...forgetting at the moment all that is known about chromosomes, inheritance, and so on...

How would we express in terms of the statistical theory the marvelous faculty of a living organism, by which it delays the decay into thermodynamical equilibrium (death)?...
It feeds upon negative entropy."

E. Schroedinger 1944 in "What is Life".