White and Dark smokes in cosmology

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>> decision made!

>> still thinking

White smokes: what we know about cosmology.

- Hot Big Bang
- Large-scale homogeneity
- Friedmann equation (early on)
- Perturbations are primordial
- Dark matter exists
- Universe is accelerating
- Baryon asymmetry is real

Dark smokes: what we don't know about cosmology.

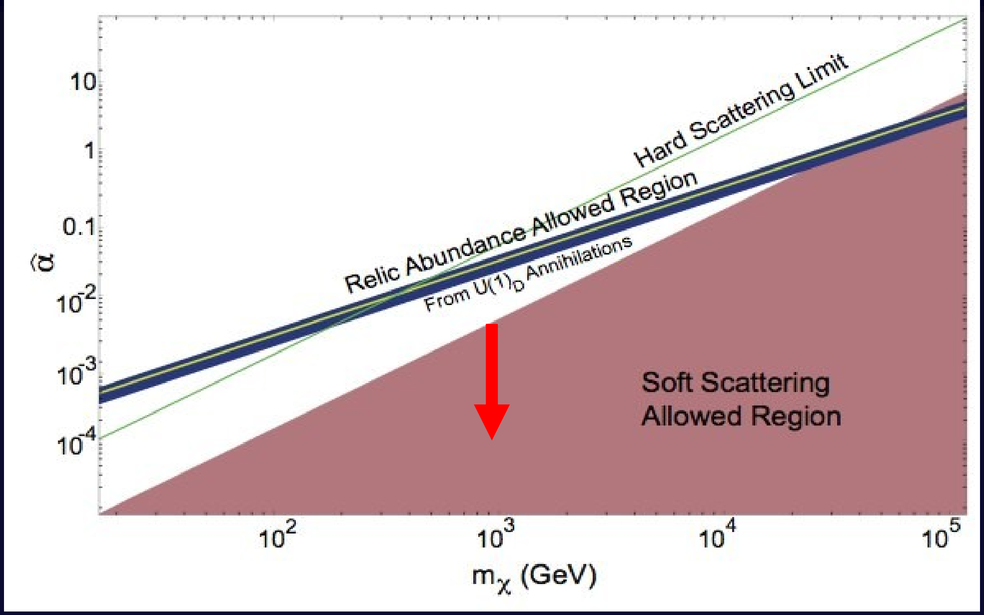
- What is the dark matter?
- Why is the universe accelerating?
- Why is there a baryon asymmetry?
- Did inflation happen?
- How did inflation happen?
- Galaxy formation, magnetic fields…

Really dark smokes:
questions we are reluctant to even ask.

Is there dark chemistry?

First, can there be dark electromagnetism?

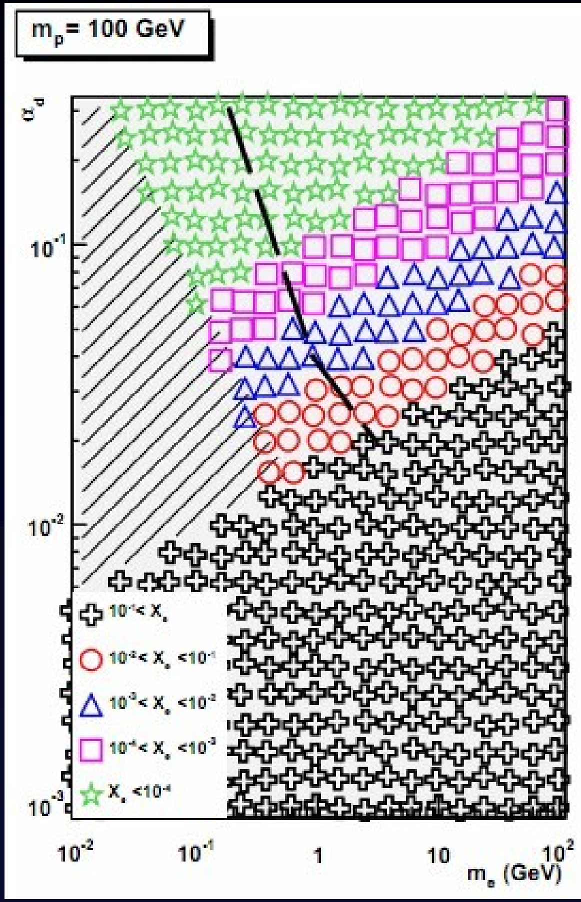
Remarkably, yes: unbroken $U(1)_{dark}$ is consistent with galaxy structure for reasonable parameters.



[Ackerman, Buckley, Carroll & Kamionkowski 2008]

However: probably doomed by magnetic instabilities.

Solution: dark atoms.



Posit an asymmetry in the dark sector (connected to baryons?), with dark protons and dark electrons.

Benefits:

- atoms are neutral, no instabilities
- inelastic DM
- affects (helps?) small-scale structure

Let your imagination roam.

[Kaplan, Krnjaic, Rehermann & Wells 2009]

What is dark energy likely to be?

Bayes:

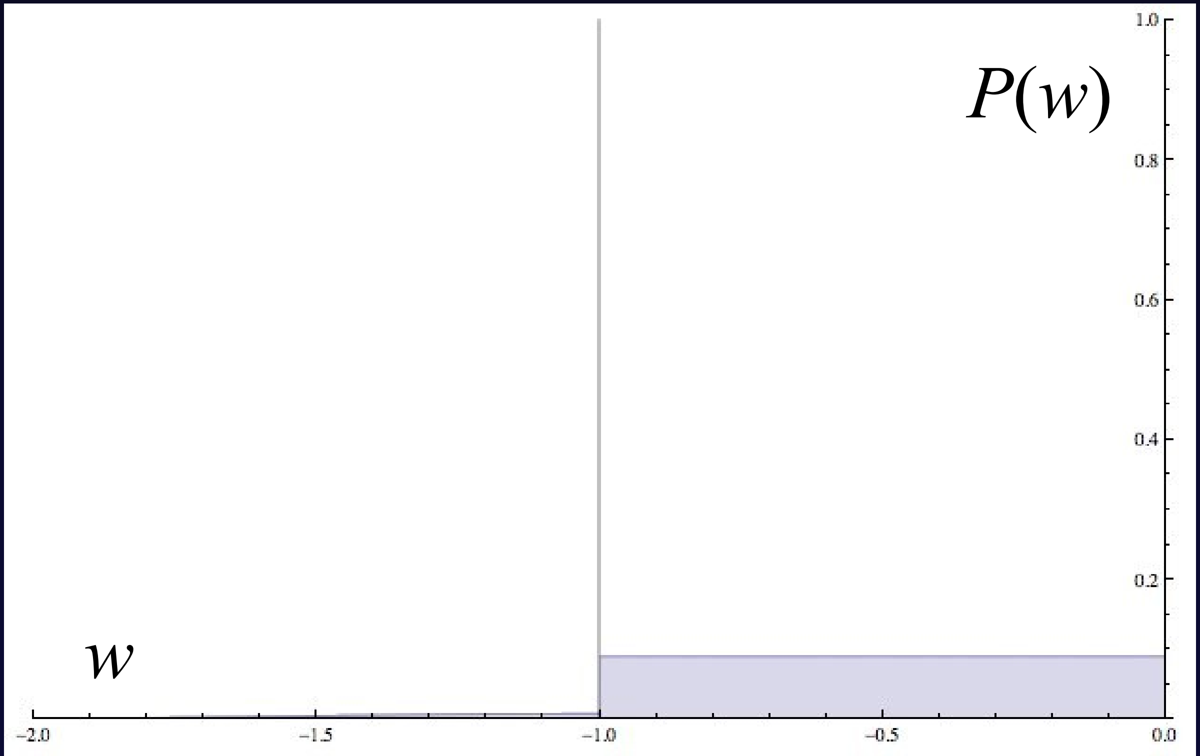
$$P(T_i|D) = \frac{P(D|T_i)P(T_i)}{\sum_j P(D|T_j)P(T_j)}$$

To be honest about whether the data favor a certain value of (for example) w, we need to specify the prior probability $P(w)$.

Also, to be honest about how much money we should spend measuring it.

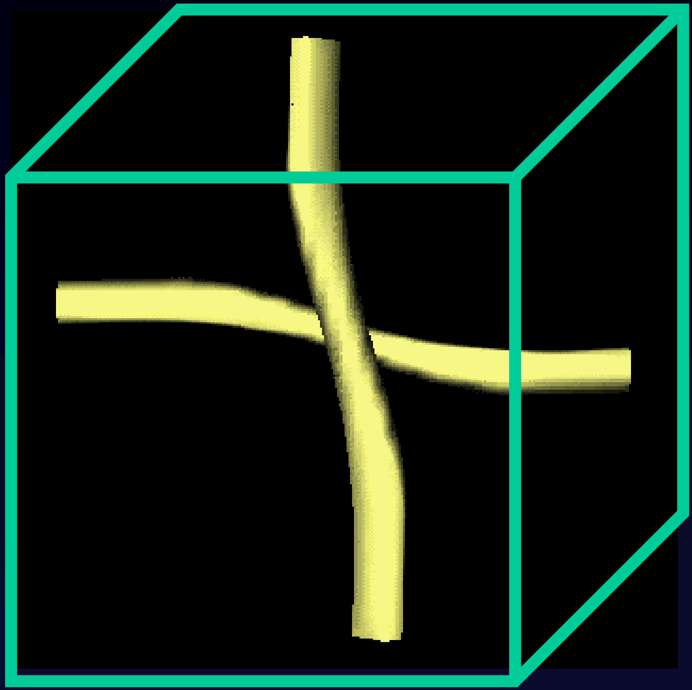
One person's guess:

$$P(w) = \begin{cases} 0, & w \geq 0 \\ 0.09, & -1 < w < 0 \\ 0.9\delta(w+1), & w = -1 \\ 0.01\frac{2\sqrt{2}}{\sqrt{\pi}}e^{-2(w+1)^2}, & w < -1 \end{cases}$$



Why four dimensions?

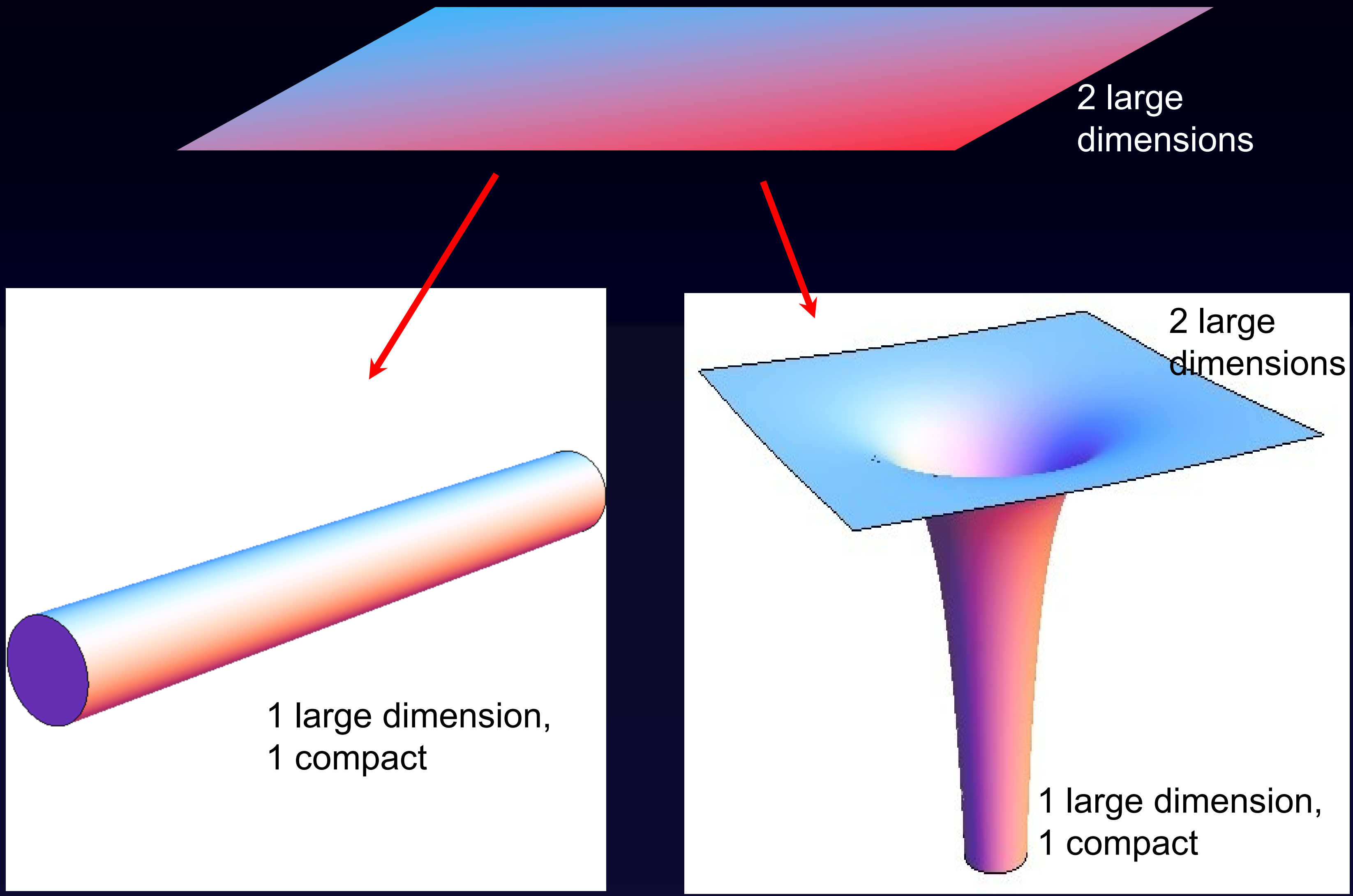
Brandenberger & Vafa, 1989:
decompacitify three spatial dimensions via string intersections



Issues:

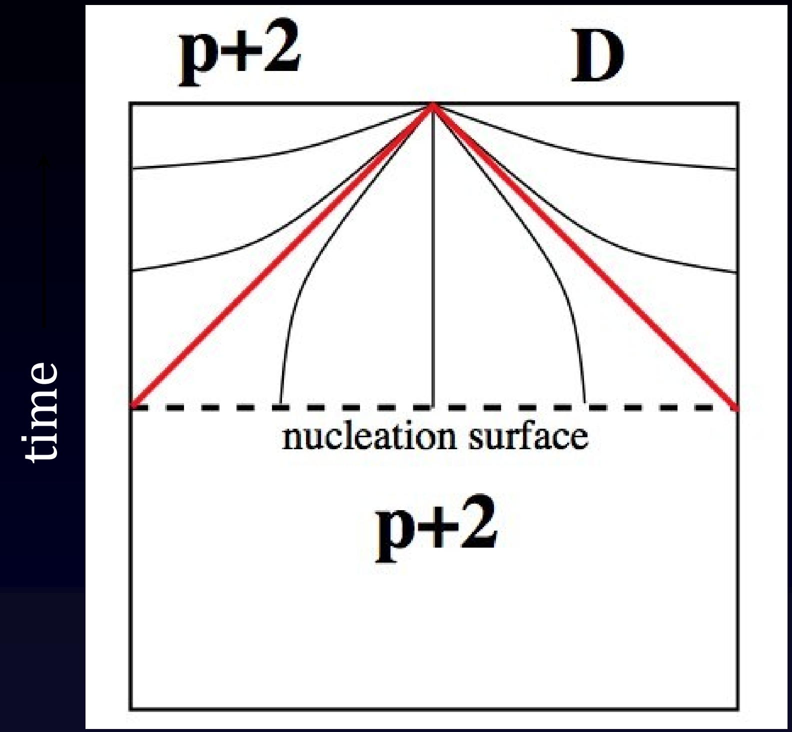
- branes
- non-torus geometries
- why did everything start compact?

Alternatively:
start with large dimensions, and spontaneously compactify.



Interesting result:
spontaneous compactification
happens automatically
via quantum transitions
as long as you have:

- de Sitter background
- an electromagnetic field
- at least 6 dimensions to start.



$$S = \int d^n x \left(R - \Lambda_n - \frac{1}{4} F_{ab} F^{ab} \right)$$

[Carroll, Johnson & Randall 2009]

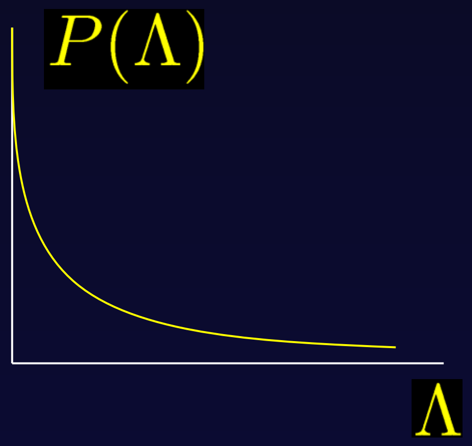
Can we calculate in a multiverse?

Weinberg: successful anthropic prediction for the cosmological constant, assuming a flat probability distribution near $\Lambda = 0$.

Reasonable alternative: weight different vacua by the number of states, $\sim e^S$.

de Sitter: $S_{dS} \sim 1/\Lambda \sim M_{Pl}^4/\rho_\Lambda$

Therefore: $P(\Lambda) \sim e^{1/\Lambda}$

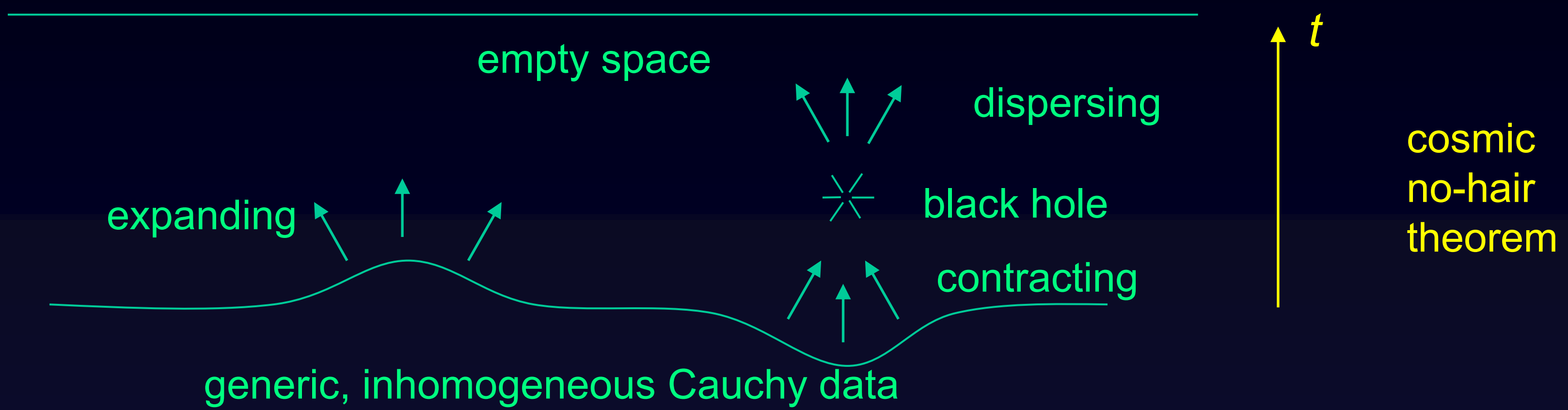


Prediction: $\Lambda = 0$ to incredible accuracy.

[Banks & Johnson 2005]

Why is there anything else in the universe?

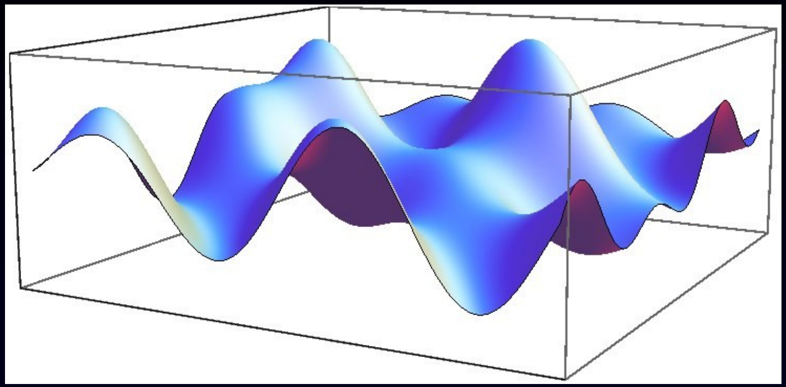
Ask yourself: what should the universe look like?



A “natural” (high entropy) state for the universe is empty space. de Sitter/Minkowski with a small cosmological constant.

Why don’t we live in empty space?

de Sitter space has a nonzero temperature, $T_{dS} = (E_{vac})^2/E_{Planck}$, about 10^{-30} K for our universe.



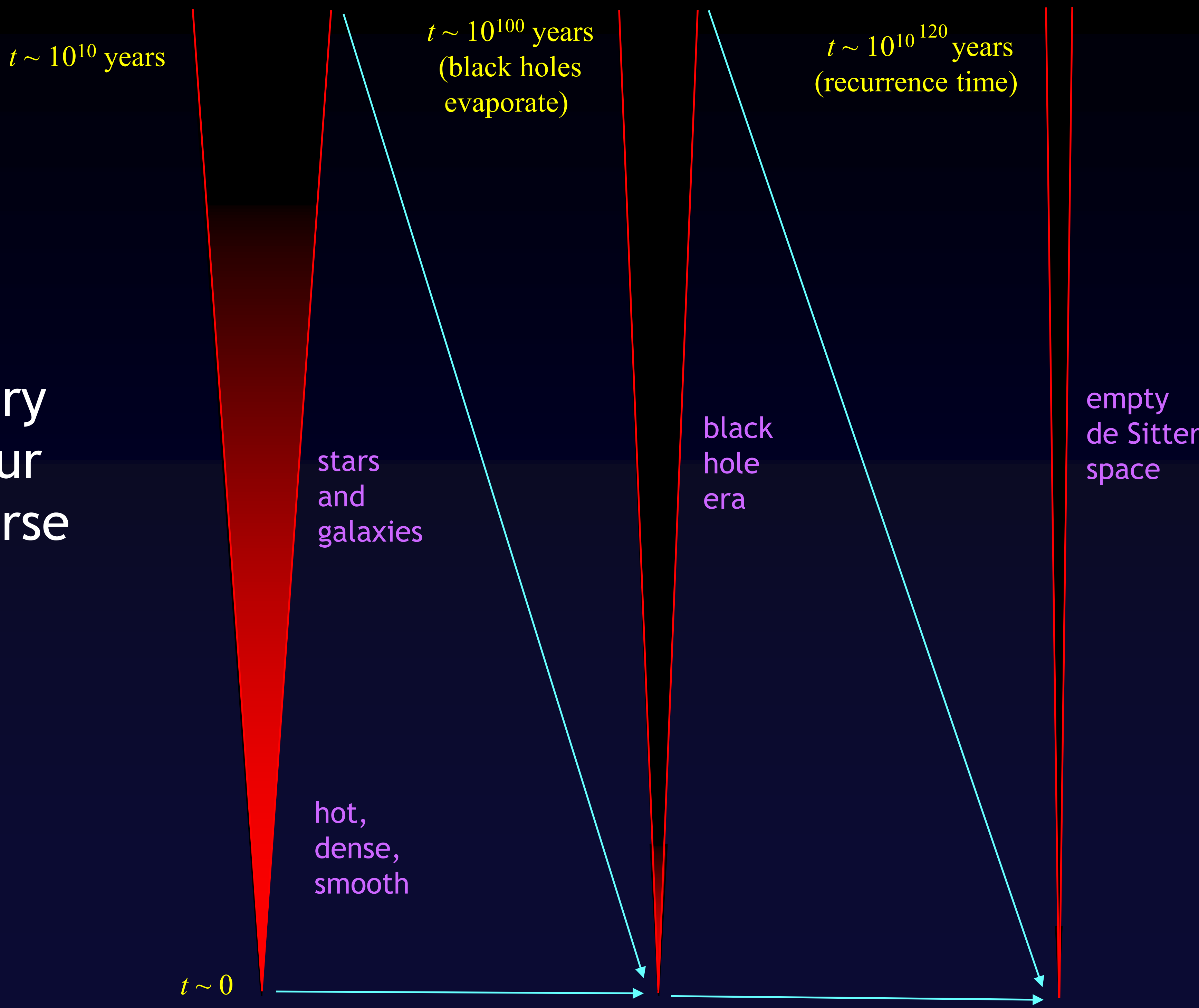
[Dyson, Kleban & Susskind; Albrecht & Sorbo]

A nonzero temperature implies thermal fluctuations. Every allowed configuration of matter eventually appears.

That includes planets, galaxies, and people.

Recurrence time: $10^{10^{120}}$ years.

History of our universe

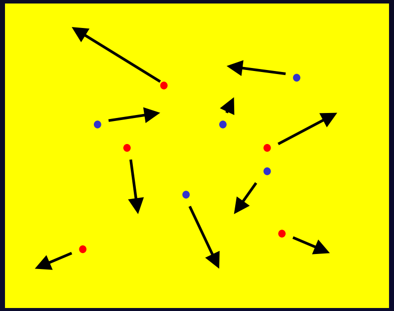


Why do we live in the aftermath of a low-entropy Big Bang?

We don't have a general formula for entropy, but we do understand some special cases.

Thermal gas (early universe):

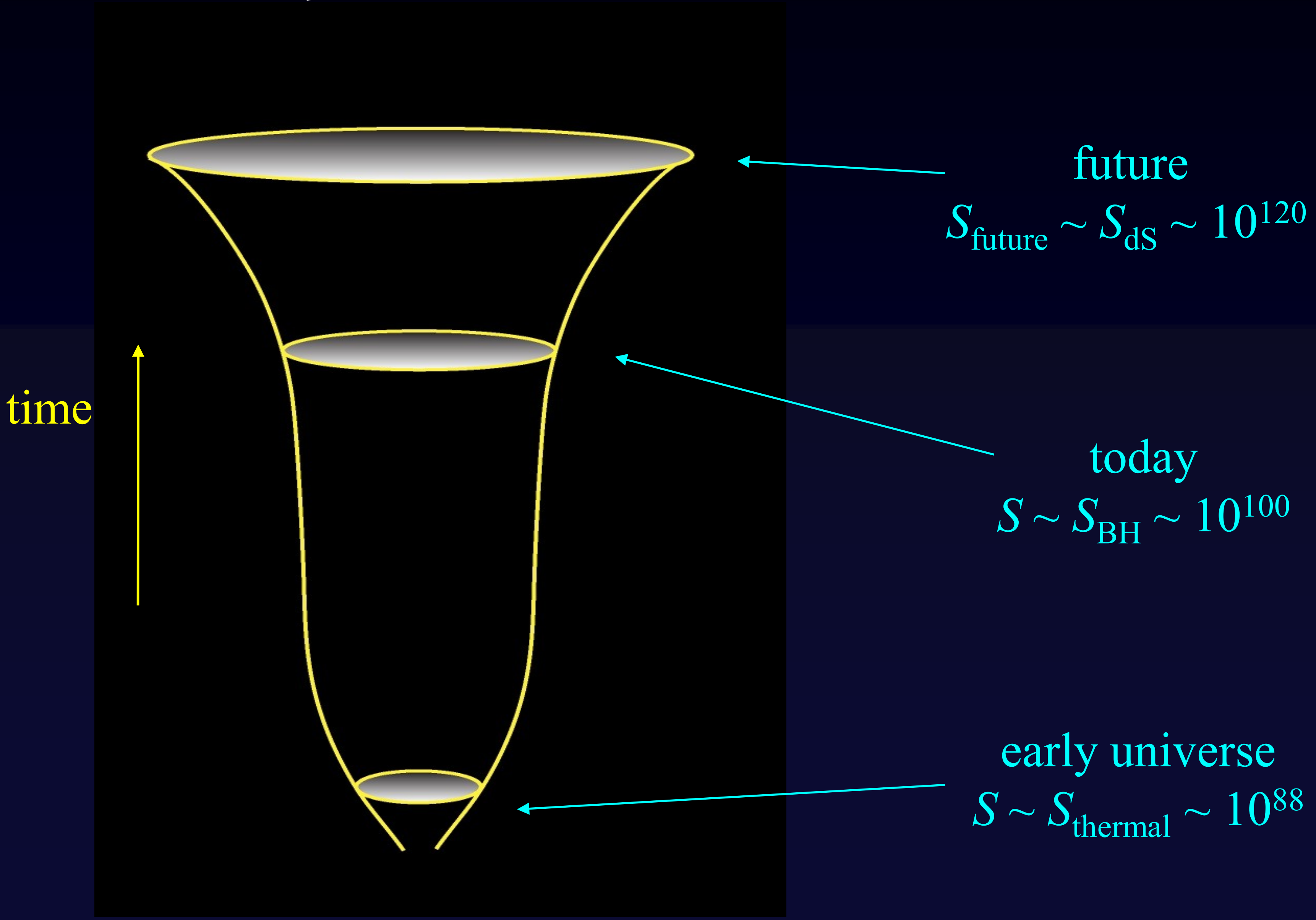
$$S_{\rm therm} = \left(\frac{\rho + p}{T}\right) V \sim N \sim 10^{88}$$



Black holes (today):

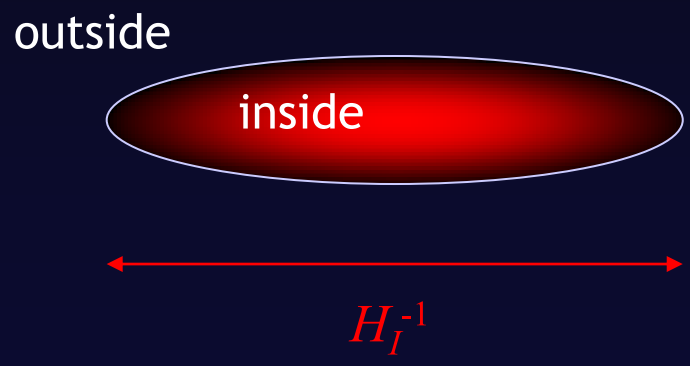
$$S_{\rm BH} = \frac{A}{4G} \sim 10^{90} \left(\frac{M_{\rm BH}}{10^6 M_\odot}\right)^2 \sim 10^{100}$$

The current universe is very low entropy; the early universe was even lower.



Inflation does not explain why entropy was originally low.

Inflation tries to make the state of the early universe seem natural, by invoking a tiny proto-inflationary patch dominated by false vacuum energy at a very high scale. Almost all modes were exactly in their ground states.



But that's a <u>lower-entropy</u> (more finely-tuned) initial condition than conventional Big-Bang cosmology. Assumes the answer, doesn't provide it.

$$S_{\text{inflation}} \sim (M_P/E_I)^3 \sim 10^{12} \ll 10^{88}\ !$$

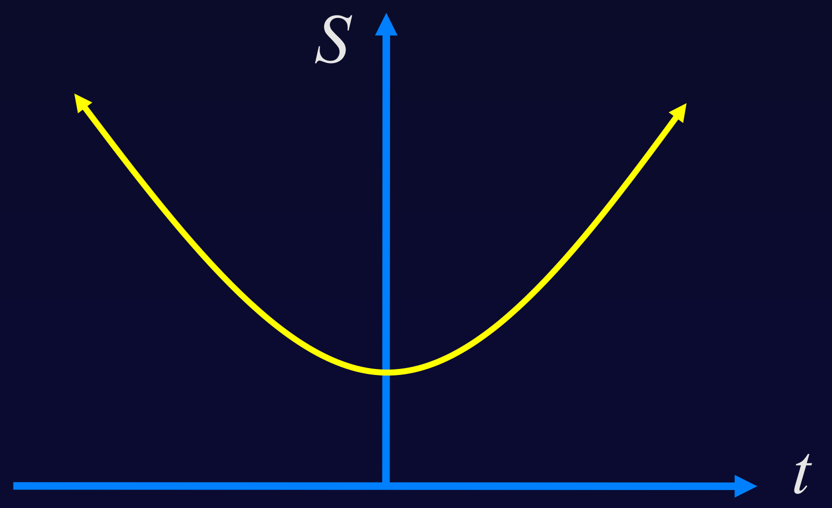
The goal is to construct "Sagan-like" cosmology:

if $S_n(t + \Delta t) > S_n(t)$,

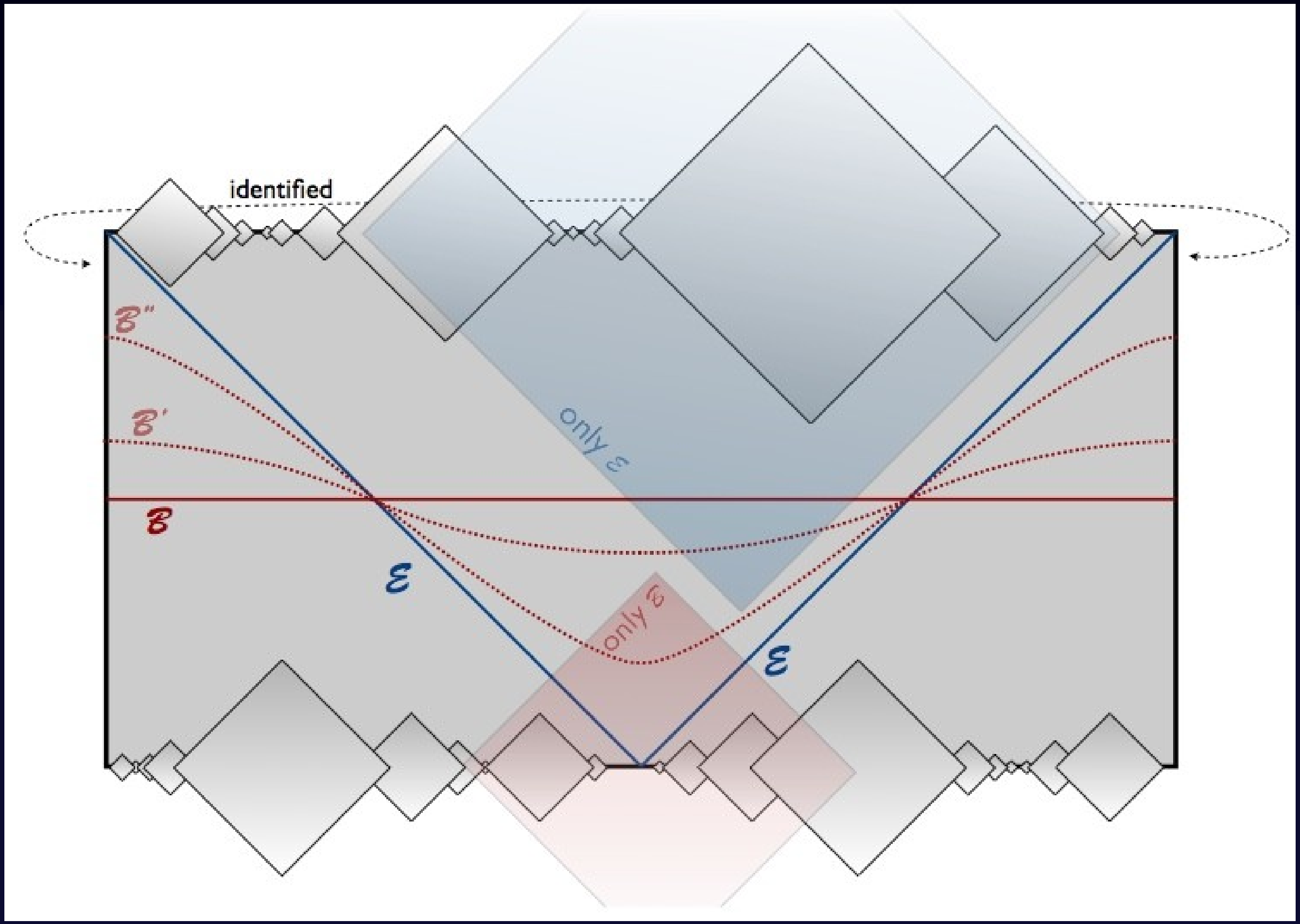
then $S_n(t) > S_n(t - \Delta t)$ with high probability.

That is: if entropy is increasing, it's probably been increasing for a while.

Trick to avoiding Boltzmann-brain fluctuations: unbounded entropy toward past and future.



The multiverse might be time-symmetric on the largest scales: entropy increasing toward both the past and the future.



[Carroll & Chen;
Aguirre & Gratton; Page;
Hartle and Hertog]

I Don't know if you Exist

But I Do! I bo not Agree with your Articl and I Do not Beleave that "MOMBO — JOMBO" if you Do... Well! its DisturBing Thought But I know How to Deal with it! I will Not let the wolb. Disiper Unber My Nose But if you Do I can't say I'm sorry!

Sincerely

a Ten year olD who knows alittle More than SOME PePeol!

George. Wing

PS. some pepl Have a libt in th Marn time

Always some skeptics.