Seeing the Landscape II: Living Dangerously with Catalyzed Vacuum Decay

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- Direct implication of existence of other vacua for physics in our own vacuum
- Positive verification is impossible
- Shocking anthropic “prediction” and possible constraints on vacuum structure **at all scales**.

Overview

1. Tangible or intangible?
2. Catalyzed vacuum decay
3. Formation of short-lived black holes (accretion of exotic matter in stars)
4. Implications
   - anthropic prediction
   - constraints on vacuum structure (at all scales)

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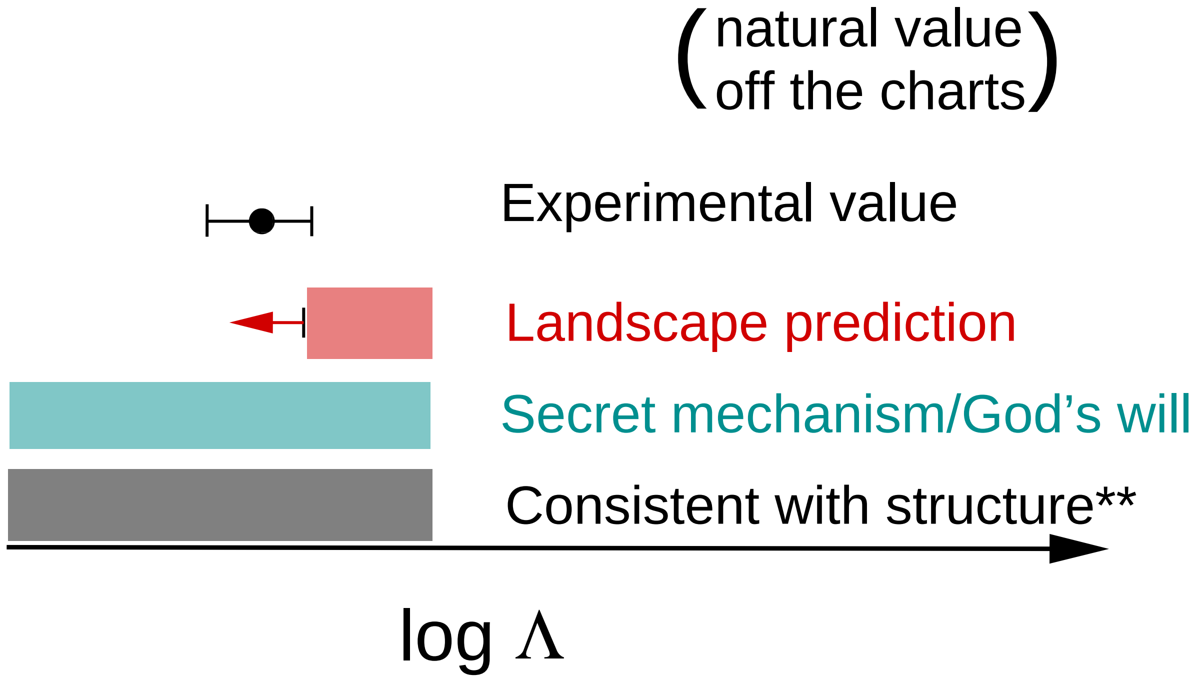
- Something in between? Fine-tuning would be gratuitous in mono-vacuum theory but *required* when there are other vacua

Anthropic predictions without landscape population statistics?



Landscape prediction comes from (and sensitively depends on) vacuum statistics

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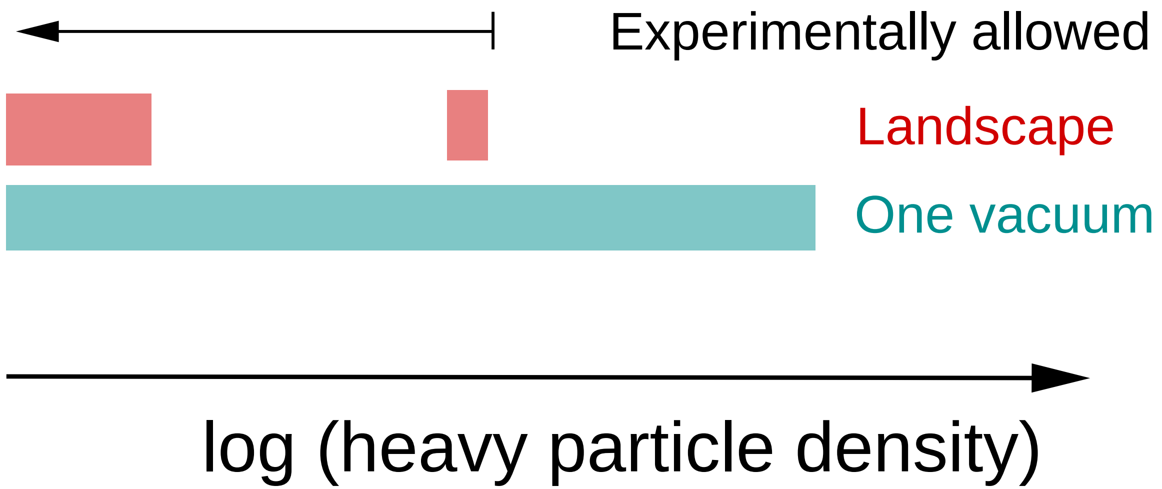


Still circumstantial, but insensitive to statistics; other vacua are more than just a mechanism for tuning.

2. Catalyzed Vacuum Decay

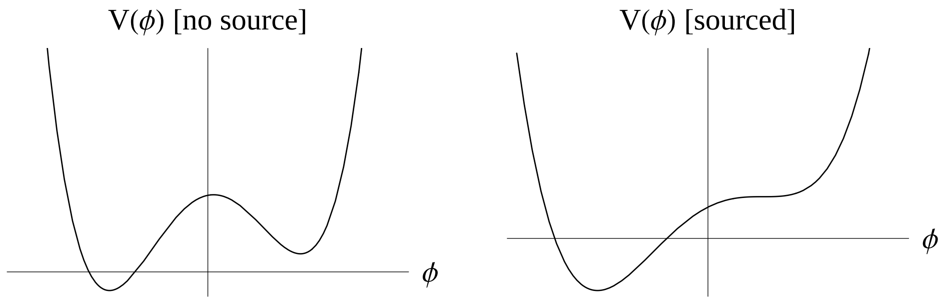
Review: Catalyzed Vacuum Decay

- A high density of particle ψ can change the potential for a “modulus” field ϕ, and even remove a potential barrier between minima
- If classical deformation is above critical bubble size, it leads to an expanding bubble of true vacuum
- Such classical sourcing can be accomplished by a high density of the source particle or by Hawking radiation from a black hole

Classical (Sourced) Bubble Nucleation

Let $V(\phi) = \frac{\lambda}{8}(\phi^2 - v^2)^2 + \frac{\epsilon}{2v}\phi + g\phi\bar{\psi}\psi$

Tunneling suppressed by $e^{-1/\alpha}$, where $\alpha \equiv \frac{\lambda\epsilon}{m_\phi^4}$.



...but if $\bar{\psi}\psi$ is large locally, ϕ rolls classically.

$\bar{\psi}\psi \gtrsim \frac{\lambda v^3}{g}$ to roll   Timescale: $\tau_{roll} \sim \frac{1}{\lambda v}$

Expanding classical bubbles

Classical deformation can produce an expanding bubble if it is above critical size, $R_c = \frac{1}{\alpha m_\phi}$

$\longrightarrow$ Vacuum decay without tunneling!

Catalyzed Decays via Hawking Radiation

Black holes are a democratic source of all fields ψ with $m_\psi \lesssim T_h$:

$$\langle \bar{\psi}\psi \rangle (r) \sim \frac{m_\psi}{r^2} \quad (r \gg r_s)$$

Catalysis is insensitive to detailed background—completely specified by the Lagrangian and T_h.

Catalyzed Decays via Hawking Radiation

Require:

- Black hole lifetime exceeds rolling time
- $\bar{\psi}\psi$ at R_c exceeds critical value
- Sign of net sourcing effect at T_h destabilizes our vacuum

$$\rightarrow \frac{M_{Pl}^2}{m_\phi^2} \gtrsim \frac{m_\psi}{m_\phi} \gtrsim \frac{1}{\alpha^2 g \sqrt{\lambda}}$$

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- How generically is it a problem?
- Decays to AdS vacua: how does gravity change the story?

3. Production of Density Fluctuations and Small Black Holes

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- Accretion of massive, stable exotics in stars

  c.f. Gould, et al PRB 238 (1990)

- (Early universe formation)

Black Holes from Accreting Heavy Exotics

Suppose there's some small abundance of a stable, charged, massive exotic particle χ in the galactic halo ($m_\chi \sim 10^{10} - 10^{16}$ GeV)
These get trapped in stars, can collapse to black holes that

- eat the star $\longrightarrow$ observable
- evaporate $\longrightarrow$ may catalyze vacuum decay
- don't do much in 10^{10} yrs

Accumulation of exotics in stars

If:

- $\mathcal{O}(1)$ fraction of relics stop in stars
- $\mathcal{O}(1)$ asymmetry in stopping of χ and $\bar{\chi}$

$\rightarrow$ robust estimate of mass accumulated in star lifetime:

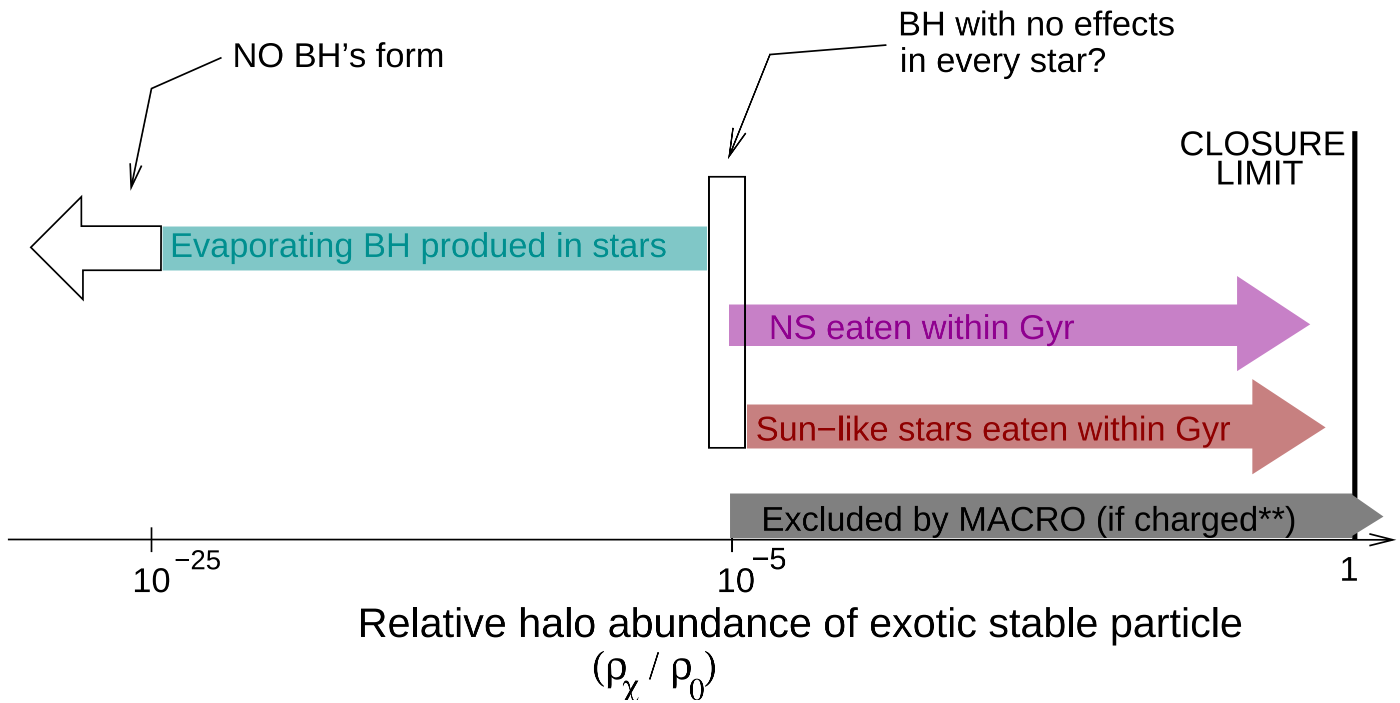
$$\left(\frac{\rho_\chi}{GeV/cm^3}\right)\left(\frac{v}{10^{-3}c}\right)\left(\frac{t}{Myr}\right)\left(\frac{R}{R_{sun}}\right)^2 \times 10^{42} GeV$$

Self-gravitation thresholds

- Gravitational collapse begins when self-gravity of a cloud of χ in hydrostatic equilibrium exceed's star's gravity.
- Main sequence star: $M_c \sim 10^{41}$ GeV
- Neutron star: $M_c \sim 10^{20}$ GeV $\rightarrow$ smallest possible black hole will form.

Black hole fate

- Balance between consumption rate $\propto R_S^2$ and evaporation rate $\propto 1/R_S^2$



Universality

- Capture occurs in all stars, though local fluxes vary by a few orders of magniture $\longrightarrow$ astrophysical constraints very applicable.
- The consistent flux window must be at least as big as the local flux variation. We'll see what can happen if it works.
- Must also constrain early universe physics so it doesn't form primordial black holes with $M < 10^{38}$ GeV

4. Implications for our Universe?

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Either small black holes don't form, or they don't lead to classical vacuum decay.

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They must never form!

(Similar constraints for dense clouds of a stable particle)

Accreting Heavy Exotics (Very) Dangerously

- We must live in a density window where evaporating black holes never form.
- The non-trivial anthropically allowed flux window is tiny (if it even exists!)
- Discovering a flux in this range would hint strongly at a selection effect.

A triple coincidence

The mass of black hole that...

- ...evaporates in $< 10^{10}$ yrs in vacuum
- ...eats a neutron star in $\sim 10^9$ yrs
- ...accretes in 10^6 yrs at current flux limits

...could be many orders of magnitude apart!

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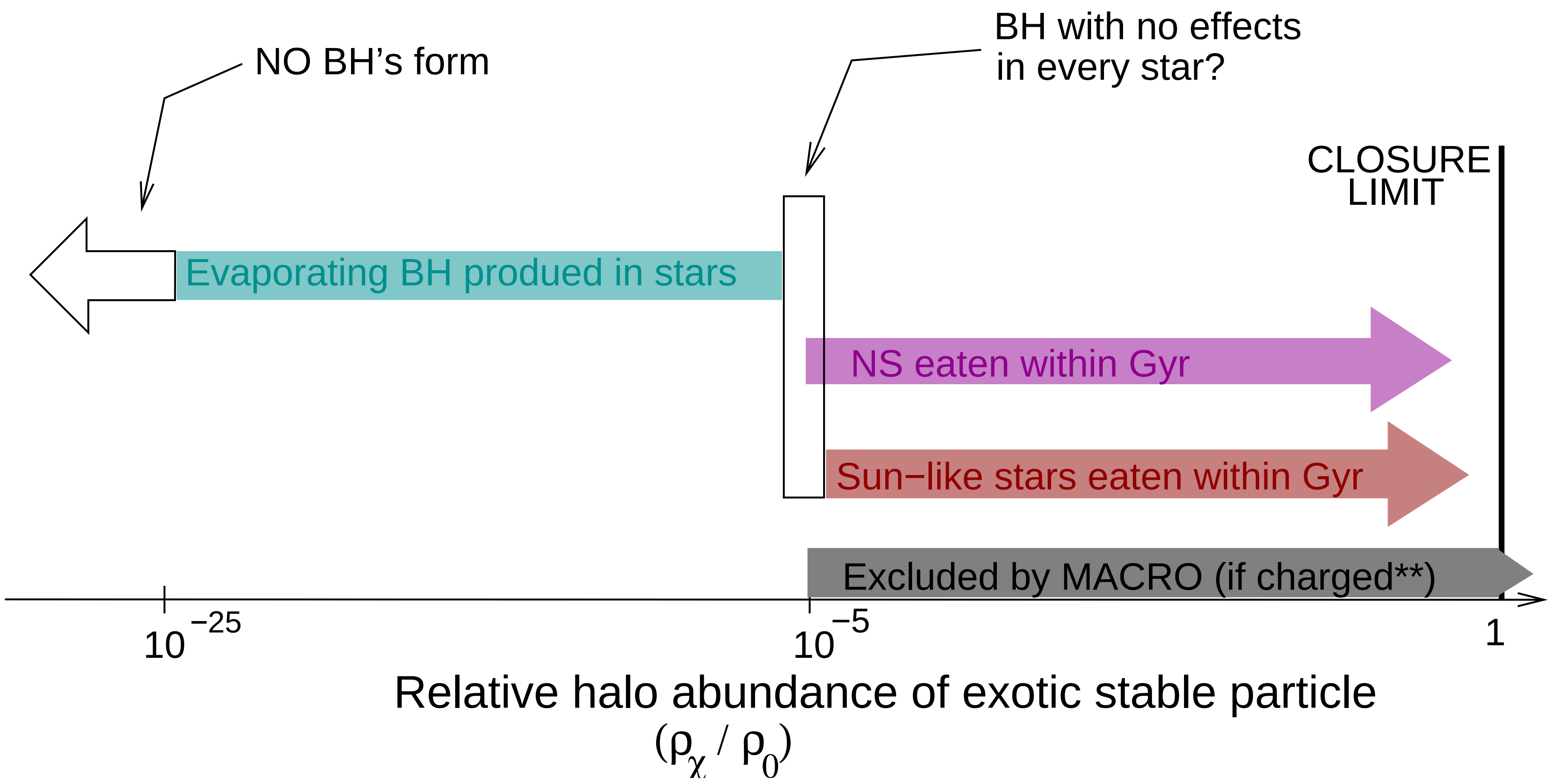

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Instead, they're on top of each other...
and **close to flux at which suns get eaten by accreted black holes**.

Conclusion is more interesting than it had to be!

Is there a flux?

- There exists (?) a window of exotic particle flux whose explanation requires both an anthropic tuning and the existence of many vacua
- It is readily within reach of a next-generation successor to MACRO (none is being planned)
- Motivation for a renewed search and for more detailed astrophysical modeling to study the window.

Constraining vacuum structure?

On the other hand, if we found independent evidence for formation of small black holes (say, a stable relic and a careful astrophysics calculation),
$\longrightarrow$ constraint on vacuum structure at all scales.

Any theory that predicts vacuum is destabilized by Hawking decay would then be excluded.

That was easy!

We've seen two proposed new tests of landscape-y physics that go beyond the fine-tuning+statistics formula for predictions:

- Q-Balls: Bubbles of other vacua in the spectrum of our theory, and possibly produced in the early universe. (Direct search)
- Catalyzed vacuum decay: Anthropic exclusion of universes where $M < 10^{38}$ GeV black holes are produced and they catalyze vacuum decay. (Anthropic argument with a twist)

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- This is just the beginning. . . why not more?

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- Try to realize ideas like this in the string Landscape.
  - Limits of validity of toy landscapes?
  - Interesting new variants on Q-balls?