GRAVITY CONJECTURES AND BLACK HOLE EVAPORATION IN DE SITTER SPACE

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Navigating the Swampland, IFT Madrid, September 27th 2019
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But sometimes we also understand the underlying **principle**.

E.g. we don’t think (B-L) is an exact symmetry in the real world, even if we don’t know the right compactification.
EVIDENCE FOR WGC

- True in all **known examples**.

- Proof of mild form in worldsheet (proven stronger statement, a **lattice** version) 
  [Heidenreich-Reece-Rudelius '15, '16, MM-Shiu-Soler '16, Aalsma-Cole-Shiu '19].

- Arguments from holography [**MM'18**].

- Connection to Cosmic Censorship in AdS [**Crisford, Santos, Horowitz '17-'18-'19**]

- IR consistency/Unitarity [**Cheung-Remmen '18-19, Andriolo-Junghans-Noumi-Shiu '18, Hamada-Noumi-Shiu '18,Charles '19**]

- Strong enough breaking of global symmetries [**See Tom’s talk**, connections to SDC 
  [Heidenreich-Reece-Rudelius '18,Valenzuela-Palti-Grimm ‘18]]
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These support **principle**: It is bad if black holes are not (marginally) unstable
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Good review: [Anninos '12]

Static patch: What a local observer in dS can see

\[ ds^2 = -\left(1 - \frac{r^2}{\ell^2}\right) dt^2 + \frac{dr^2}{1 - \frac{r^2}{\ell^2}} + d\Omega^2 \]

There is a cosmological horizon

Radiates at a temperature \( T = \frac{H}{2\pi} \)
Observation/Principle [Gibbons-Hawking '83, Banks '00-'03-'05, Witten '07...]

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- Thermalization of long-wavelength modes with incoming radiation
- Finite horizon area suggests finite entropy
- Static patch is ``finite'': Maximum energy, charge…

**Black hole physics**: Horizon area backreaction, black hole evaporation, Schottky anomaly [Dinsmore-Draper-Kastor-Qiu-Traschen ’19, Johnson ’19]
Two principles:

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In this talk:

- Second implies (particular case of) the first
- Leads to a new constraint on the EFT.

To establish this, we will study charged black hole evaporation in dS
BH'S IN DE SITTER

- We have **RN-dS** black holes

\[ ds^2 = -U(r)dt^2 + U^{-1}(r)dr^2 + r^2d\Omega^2 \]

\[ U(r) = 1 - \frac{2M}{r} + \frac{Q^2}{r^2} - r^2 \]

\[ Q \equiv \frac{G(gQ_e)^2}{\ell^2}, \quad M \equiv \frac{GM_r}{\ell} \]

- First thing you do is to **draw extremality curve**.
- We have **two families** of extremal solutions
  - Usual extremal \((\text{AdS}_2 \times S^2)\)
  - Nariai solutions \((\text{dS}_2 \times S^2)\): **Biggest black hole that fits**
- **Problem**: How do they evaporate?
  - Exchange mass via **Hawking radiation**
  - Shed charge via **Schwinger effect** (particle of mass \(m\), ch. \(q\))
- **Difficulties**: Both horizons contribute, no asymptotic
  [see Hiscock-Weems ’90 for flat space case]
- Hawking radiation is always small (except for tiny BH’s).
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But Schwinger current is controlled by

\[ J \sim e^{-\pi \frac{m^2}{qE}} \]

So there are **two regimes**, depending on whether

\[ m^2 \gg qE \]

or

\[ m^2 \ll qE \]

We will analyze **both**.
- Suppose charge and mass flux is small, so solutions evolve **slowly**

- Einstein eqs. turn into **quasistatic** evolution equations on the $(M,Q)$ plane

\[
\dot{Q} = -4\pi r_g^2 \mathcal{J}, \quad \dot{M} = -4\pi r_g^2 \left( G \sqrt{U(r_g)} \mathcal{T} + \frac{Q}{r_g} \mathcal{J} \right)
\]

- Flow on **Nariai branch** stays there

- Very simple physics: $dS_2 \times S^2$ with constant electric field given by the charge of the black hole
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- The whole spacetime collapses to a **Big Crunch**.
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To recap:

- **Quasi-static** decay is OK with black hole sub-extremality and thermodynamic picture of dS

- **Adiabatic is not.**

- Perhaps the crunch magically thermalizes and goes back to dS.

- Perhaps one should not think about charged black holes in theories with very light charged particles.

- Perhaps the adiabatic regime is pathological, and avoiding it leads to a Swamp-like constraint.
Electric field on Nariai branch is $gM_P H$. If the crunch is pathological, we are forced to conclude that

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- **Flavor** of a Swampland constraint, but we cannot check against stringy examples.

- Becomes trivial in flat-space limit.

- Black holes satisfy the bound.

- Crunch is not avoided by slow-roll quintessence (so it applies to not-so-long-lived dS [Dvali-Gomez-Zell’17, Obied-Ooguri-Spodyenko-Vafa’18, Bedroya-Vafa ‘19])
- Taking the $U(1)$ to be electromagnetism, the constraint is satisfied by all charged fields in the SM.

- Since in SM masses are related to Higgs vev, it alleviates electroweak hierarchy problem [See Isabel’s talk]:

$$y v \gtrsim g \rho_{\text{vac.}}^{1/4}$$
Constraints on mili-charged dark matter, but uninteresting

Constrains inflationary models. Some ways out:

- Small field inflation ($\rho^{1/4} \sim 10^9$ GeV)
  
  [Similar bounds in Bedraya-Vafa ’19, Tom Banks’ talk]

- Higgs inflation with specific, flat potentials

- Coupling of gauge fields to inflaton (very small nongaussianities)
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- For g small enough, we go **adiabatic** again.
CONCLUSIONS

- Worked out the dynamics of evaporating RN-dS black holes
- Too fast evaporation of charged black holes leads to tension with thermal behavior of dS and superextremal-like crunches
- Avoiding this leads to a **constraint** on the EFT that is satisfied today and constrains inflation.
- It also leads to requiring **extremal BH’s to be unstable (WGC)**.
Thank you!