Weak Gravity Conjecture and Black Hole Puzzles

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Pascos - IFT Madrid, June 2017

Outline

- The Weak Gravity Conjecture (WGC)
- Axionic Black Holes and WGC
- Extremal Black Hole Entropy   Gary Shiu's talk
- Conclusions

The Weak Gravity Conjecture

The Weak Gravity Conjecture

- **Global** symmetries expected to be violated by gravity:

$Q \in \mathbb{Z}$

  - Infinite number of states (remnants) with $m \lesssim M_p$
  - Violation of entropy bounds.
  - In (perturbative) string theory, all symmetries are gauged.

Susskind '95

- **Global** symmetry = **Gauge** symmetry with g=0.
  - Naively expect problems as $g \to 0$. How/when precisely?

The Weak Gravity Conjecture

- The conjecture:

Arkani-Hamed et al. '06

"Gravity is the Weakest Force"

- For each gauge field there exists a (super)-extremal state:

$$q \geq \frac{m}{M_p}$$

  - Alternatively, there is a UV cutoff at $\Lambda \lesssim qM_p$
  - Original arguments for WGC are rather weak: infinite number of states in an **infinite mass range** are fine, e.g. BPS states.
  - Nevertheless, all examples in string theory satisfy WGC so far. Can we find *any other evidence* that supports the conjecture?

Gary Shiu's talk

WGC for 2-forms

- WGC for p-dimensional objects charged under p-form gauge fields:

Arkani-Hamed et al. '06

$$\frac{Q}{T_p} \geq \text{“1”}$$

  - Different p-WGC related by dualities and compactification

Brown, Cottrell, Shiu, PS '15
Heidenreich, Reece, Rudelius '15
Hebecker, Rompineve, Westphal '15

- We focus here in dual setup p=2: **strings** and **two-forms** (dual case to inflation).

See also Miguel Montero's talk

Axionic Black Holes and the WGC

WGC for 2-forms

- Consider a 2-form gauge theory:

$$S \sim \int \frac{1}{f^2}|dB_2|^2 + \sigma \int_\Sigma \sqrt{g} + \int_\Sigma B_2$$

- Dual to axion case. The WGC postulates

$$\sigma \lesssim f M_p \qquad \text{or} \qquad \Lambda^2 \lesssim f M_p$$

  - WGC predicts **light strings**, and constrains $f \ll M_P$ regime.

- Usual WGC arguments would involve (super)-extremal “black strings” or “gravitational instantons” and are problematic.

c.f. Henkenjohann's talk

  - Alternative (still speculative) arguments from **axionic BH.**

"Axionic Black Holes"

- Schwarzschild BH contains a topologically non-trivial 2-cycle. A "Wilson-line" b~b+1 can be turned on at **no energy cost**.

$$\int_{S^2} B_2 = b\,, \quad dB_2 = 0$$

Bowick, Giddings, Harvey, Horowitz, Strominger '88

- Locally 'b' is unobservable, but lassoing strings can measure 'b' a la Ahoronov-Bohm:

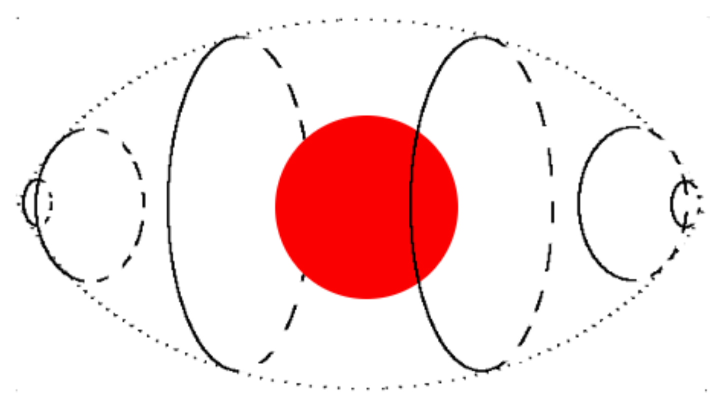
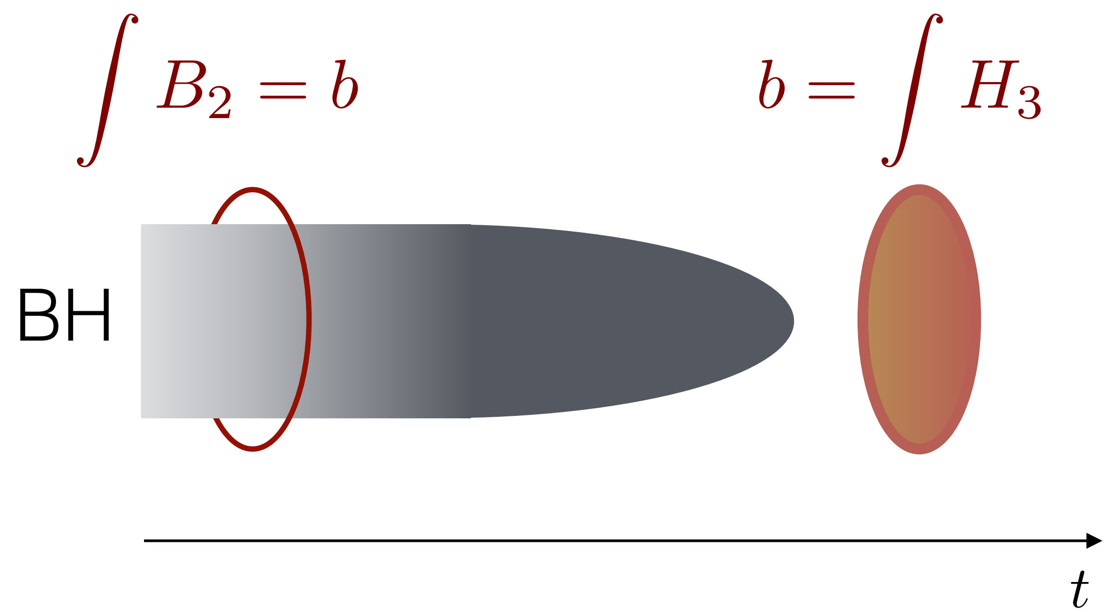


Figure from Dvali & Gußmann

- Caution: strings loops confine, albeit at an exponentially large radius $R_{max} \sim f^{-1} \exp\left(M_p^2/f^2\right)$. This is not a problem if $f \ll M_p$

"Axionic Black Holes"

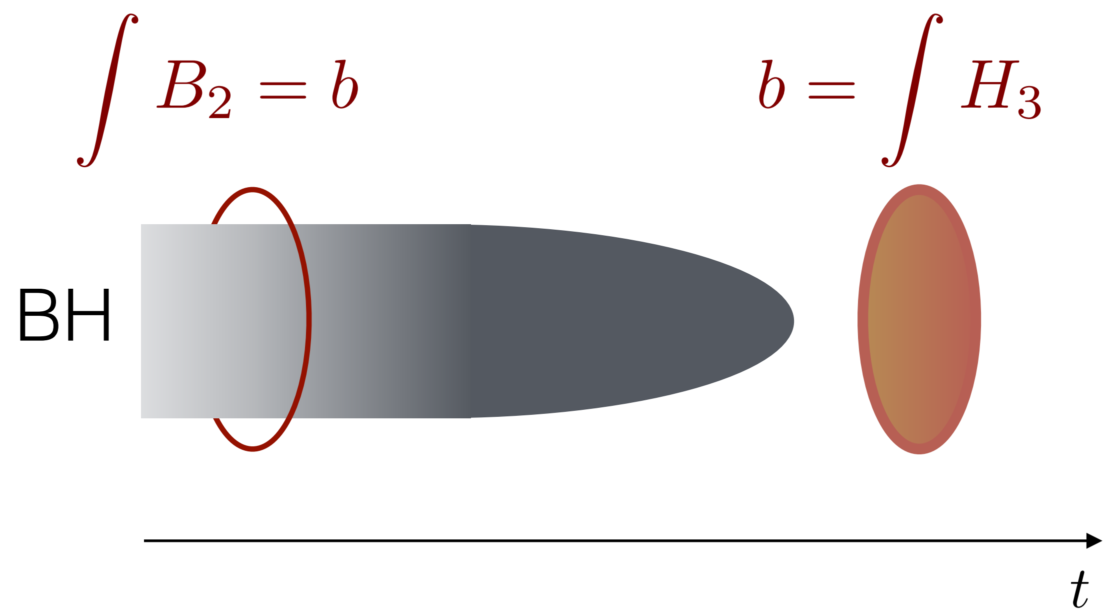
- Consider BH evaporation:



- If the BH 2-cycle disappears completely, the Wilson-line 'b' must be supported by an energetically costly flux.
  - Energetic balance requires: $M_{BH}(t_0) \geq \frac{1}{f^2}\int_{B^3} |H_3|^2$
  - By studying evaporation from the time t_0 at which the Wilson line is transferred into flux, we can put a lower bound on f

“Axionic Black Holes”

- Consider BH evaporation:



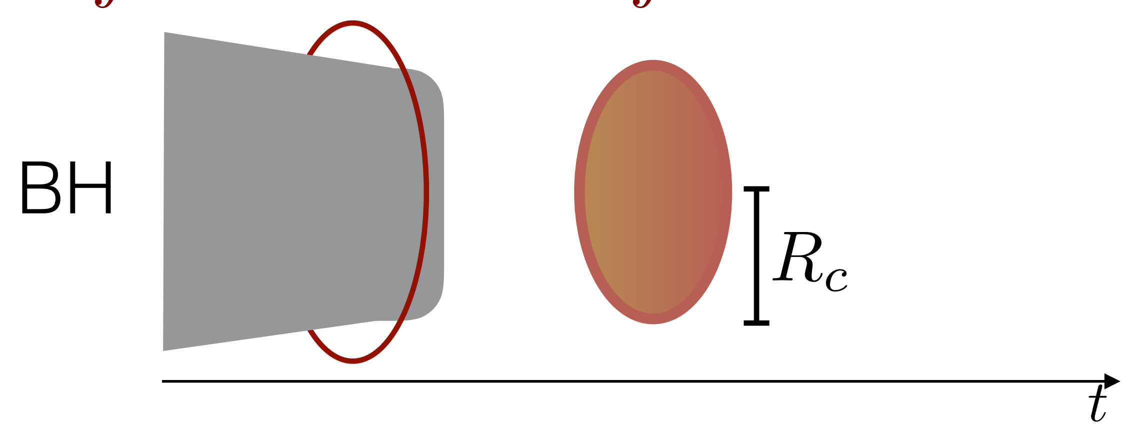
- ‘b’ insensitive to Hawking radiation. Initially remains constant.
- ‘b’ interacts with (virtual) strings lassoing the BH whose effects are exponentially suppressed $\sim e^{-4\pi R^2 \sigma}$
  - Effects on ‘b’ only relevant when BH has shrunk to a critical size

$$R_c \sim 1/\sqrt{\sigma} \qquad \text{or} \qquad T_c \sim \sqrt{\sigma} \equiv \Lambda$$

"Axionic Black Holes"

- **"Explosive" BH evaporation**: assume the BH evaporates in short time $\sim R_c$ when it reaches the critical size $R_c \sim 1/\sqrt{\sigma}$
  - E.g due to a (KK) tower of light states (strings).

$$\int B_2 = b \qquad b = \int H_3$$



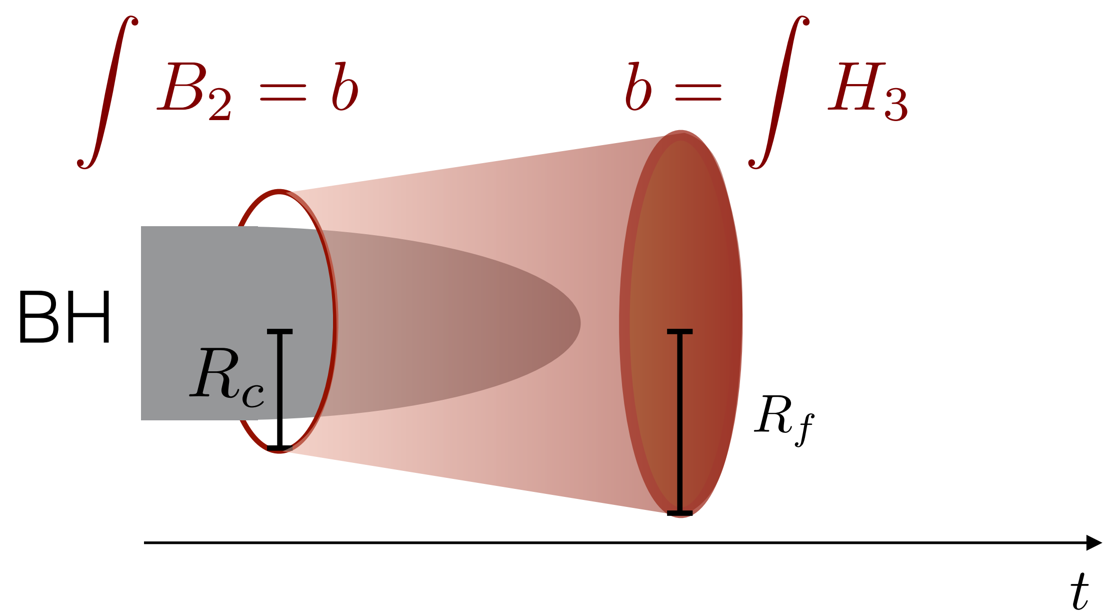
- Conservative assumption: whole energy transferred into flux.
  - Energy: $M_{BH}(R_c) \sim R_c M_p^2 \quad > \quad E_{flux} = \frac{1}{f^2}\int_{B(R_c)} |H_3|^2 \sim \frac{1}{f^2 R_c^3}$

$$\boxed{\Lambda^2 \equiv \sigma \lesssim f M_p}$$

WGC!!

"Axionic Black Holes"

- **Slow BH evaporation**: after critical radius $R_c \sim 1/\sqrt{\sigma}$ is reached, the BH takes time t_{ev} before complete decay.
  - H_3 flux has time to spread (diluting) into a region of size $R_f \sim t_{ev}$



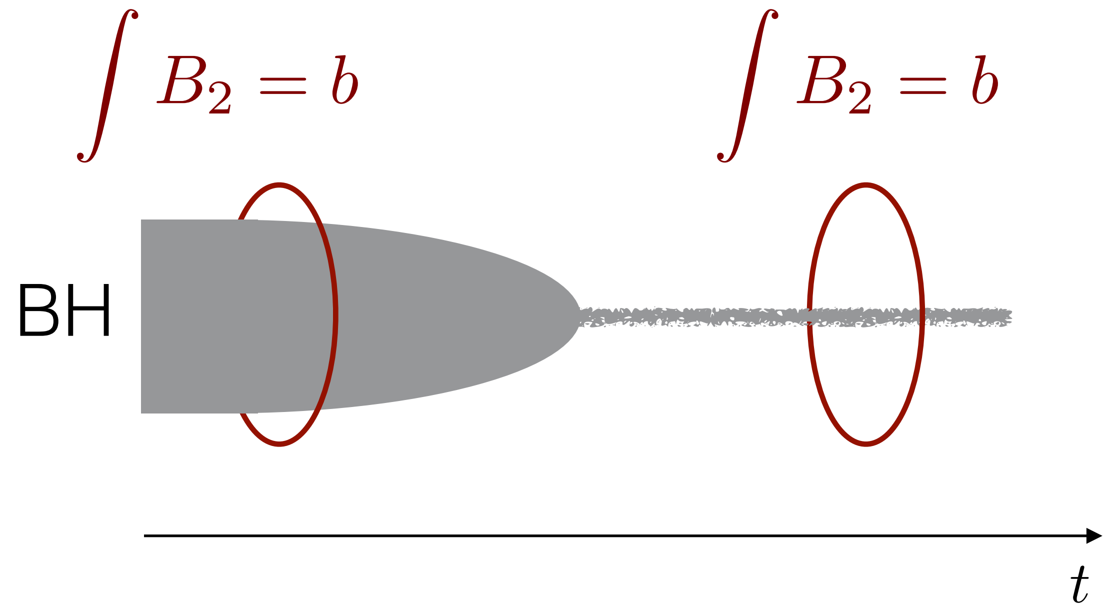
- Conservative estimate: evaporation 'Hawking rate' $t_{ev} \sim R_c^3 M_p^2$
  - Energy: $M_{BH}(R_c) \sim R_c M_p^2 \quad > \quad E_{flux} = \frac{1}{f^2} \int_{B(t_{ev})} |H_3|^2 \sim \frac{1}{f^2 t_{ev}^3}$

$$\Lambda^2 \equiv \sigma \lesssim f^{2/5} M_p^{8/5}$$

Conservative bound

"Axionic Black Holes"

- **Remnant hypothesis:** The BH never fully evaporates and leaves a remnant behind. The non-trivial topology of the remnant suffices to support the Wilson line.



- No bound on f at all.
- Same result as $t_{ev} \to \infty$

Conclusions

- Barring various simplifying assumptions (which may or may not be innocent) we provided a **new argument for the 2-form WGC**.
- Violation of WGC-like bounds leads either to **exotic remnants,** or serious dynamical problems in BH decay.
- A more careful analysis of the final moments of BH evaporation is desired to sharpen the constraints.
- Hopefully, one can generalize our arguments to different dimensions and form degrees.

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Thank you!