# Generalized Global Symemtries and Quantum Gravity

(A Chern-Simons Pandemic)

M. Montero

ITF, Utrecht University

New Ideas in String Phenomenology
DESY, Feb 14th 2017

# A brief outline

- QG $\not\Rightarrow$ Global Symmetries
- Generalized Global Symmetries[Gaiotto et al. '14]: Also problematic
- Usually broken by charged objects (just like instantons for ordinary GS)

# A brief outline

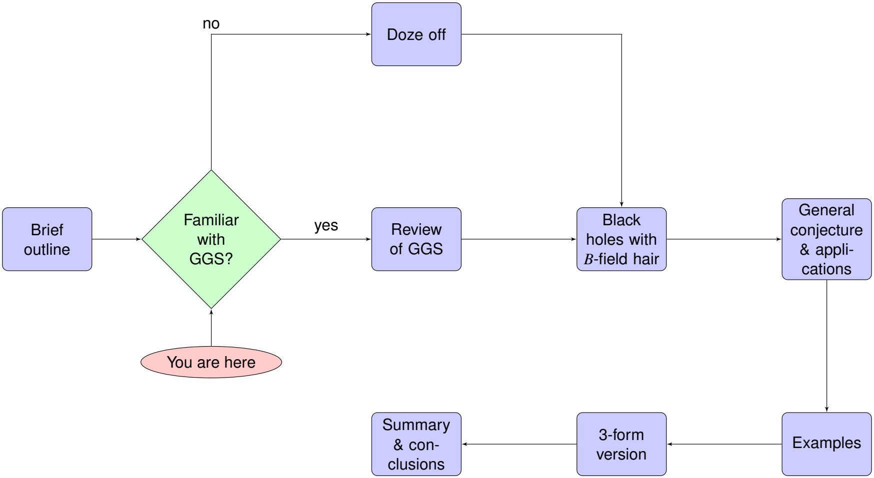
- QG $\not\Rightarrow$ Global Symmetries
- Generalized Global Symmetries[Gaiotto et al. '14]: Also problematic
- Usually broken by charged objects (just like instantons for ordinary GS)

We [ A. Uranga, I. Valenzuela, MM, arxiv: 1702.xxxxx] discuss examples where charged objects do **not** break the GGS.

In every case* we have found in ST, **Chern-Simons** terms break the GGS - this is a Swampland-like statement!*

* caveats to be discussed later :)

# Talk flowchart

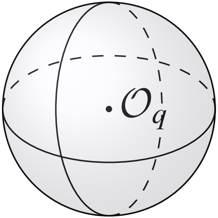


# A brief review of GGS

We will work in Euclidean picture, and focus on continuous syms.

- Global ($U(1)$) symmetry: Charged local operators $\mathcal{O}_q(x)$, such that
$$\mathcal{O}_q(x) \to e^{iq\lambda}\mathcal{O}_q(x).$$
is a symmetry – leaves correlators invariant.

- Noether's theorem: Associated conserved current $d * j = 0$.




$$\int *j = q$$

# A brief review of GGGS

- $p$-form global symemtry: **Nonlocal** Charged local operators $\mathcal{O}_q$, and $p$-form symmetry parameter $\lambda_p$, such that
$$\mathcal{O}_q \to \exp(iq \int_{C_p} \lambda_p)\mathcal{O}_q.$$
is a symmetry – leaves correlators invariant.
- Noether's theorem: Conserved current $d * j_{p+1} = 0$.
- Example: 4d $U(1)$ gauge theory w/o matter:
$$A \to A + \lambda_1,\ d\lambda_1 = 0, \quad \mathcal{O}_q = \exp(iq \int A), \quad j_e = F.$$
We will focus on this kind of GGS, arising from periods of gauge potentials. Often broken by charged objects.

# The BGHHS black hole

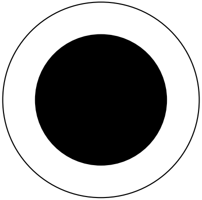
- GGS must be broken in QG: Otherwise rouble w. remnants.
- Example [Bowick et al. '88]: Schwarzschild BH with

$$b = \int_{S^2} B_2$$

- Degenerate charged states

$$|n\rangle \equiv \int db\, e^{inb} \, |b\rangle$$

See also Arthur's talk next!



Two options

- Gauging
- Breaking

# The BGHHS black hole

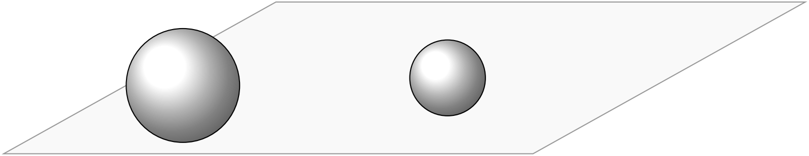
- Gauging: Coupling to $C_3$ lifts degeneracy of $|n\rangle$-states.

# The BGHHS black hole

- Gauging: Coupling to $C_3$ lifts degeneracy of $|n\rangle$-states.
- Breaking: Euclidean Schw. has $\mathbb{R}^2 \times S^2$ topology. Effective action for $b$ as a field on $\mathbb{R}^2$

$$\int \frac{4\pi}{(fr)^2} |db|^2$$

Instantons: Strings on $S^2$



# The BGHHS black hole

**Problem**

Due to backreaction, instanton action diverges as $R^3$ [Coleman, Preskill '92].

# The BGHHS black hole

**Problem**

Due to backreaction, instanton action diverges as $R^3$ [Coleman, Preskill '92].

This problem is generic to any compactification to 2d, related to Coleman-Mermin-Wagner theorem [ Mermin-Wagner '66, Coleman' 73]:
No SSB in 2d flat space.
CMW for GGS: $d - p < 3$ is always unbroken [Gaiotto et al. '14].

Rest of the talk: How to resolve

# A field theory solution

We need to break shift symmetry of $b$ w/o instantons.

- Add coupling

$$N \int bF_2$$

Uplifts to 4d BF.

# A field theory solution

We need to break shift symmetry of $b$ w/o instantons.

- Add coupling

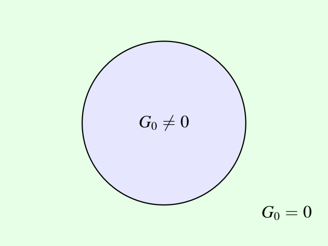
$$N \int bF_2$$

  Uplifts to 4d BF.

- Take $N$ to be dynamical: $N = \langle G_0 \rangle$.

$$\int G_0 b F_2$$

  Current divergence is nonvanishing: $d * d\phi = G_0 F_2$.




Even if $\langle G_0 \rangle = 0$, we can nucleate **bubbles** with $G_0 \neq 0$.

# CS pandemic

No need to break the shift symmetry within the EFT realm.

# CS pandemic

No need to break the shift symmetry within the EFT realm.

- In fact, precise holographic embedding of 5d BGHHS BH breaks sym. also via stringy/grav. effects

# CS pandemic

No need to break the shift symmetry within the EFT realm.

- In fact, precise holographic embedding of 5d BGHHS BH breaks sym. also via stringy/grav. effects

However

# CS pandemic

No need to break the shift symmetry within the EFT realm.

- In fact, precise holographic embedding of 5d BGHHS BH breaks sym. also via stringy/grav. effects

However

In every ST example we have found, symmetry-breaking CS-terms are present.

which motivates us to conjecture that there is a

# CS pandemic

No need to break the shift symmetry within the EFT realm.

- In fact, precise holographic embedding of 5d BGHHS BH breaks sym. also via stringy/grav. effects

However

In every ST example we have found, symmetry-breaking CS-terms are present.

which motivates us to conjecture that there is a

**Chern-Simons pandemic**

**Every consistent theory w. gravity + $p$-form syms. with $d-p<3$ must have the appropriate Chern-Simons term when compactified to 2d.**

# Discussion

- It is an “almost Swampland” condition: Constraints the theory, but we do not know at which scale.
- Only expected to hold if gravity is weakly coupled.
- The CS terms can have various origins: parity anomaly, 10d CS terms, D-brane couplings.
- Recast in a more general way, independent of action: Symmetry-breaking phases must be present in the theory.
- Rationale: CS terms break the symmetry in a generic way.

# Applications

The CS pandemic puts in the Swampland:

- Pure gravity in $d \geq 4$; reduction on $T^2$ yields a 2d axion w/o CS term.
- Einstein-Maxwell+WGC-compliant matter in 4d: Again, 2d axion w/o CS.
- $\mathcal{N} = 8$ SUGRA in 4d.

These problems can be easily fixed e.g. with axions or chiral matter.

# Examples

- KK photons in ST: Reduction from T-dual

$$B \wedge F_q \wedge F_{8-q}$$

- RR axions: Sugra CS terms. IIA on CY w. dual 3-cycles $A, B$

$$\int_A H_3 = p, \quad \int_A C_5 = b_2', \quad \int_A C_3 = \phi,$$
$$\int_B H_3 = p', \quad \int_B C_5 = b_2, \quad \int_B C_3 = \phi'.$$

4d Lagrangian:

$$\mathcal{L} \sim (p\phi' - p'\phi)F_4 + (p'b_2 - pb_2')F_2$$

W. orientifold: $p', b_2 = 0$, and $D6$ for tadpole cancellation. For $p = 0$, they can have worldvolume $b_2' \mathrm{Tr} F_2$ in 4d.

# Examples

- IIA on $T^6$: BGHHS with $B_2$-hair which can be embedded in M-theory. Romans mass CS

$$\int B_2 F_0 F_8$$

- Nongeometric fluxes: IIB on $T^6$: BHGGS with $C_2' = \int_{T^6} C_8$ gets a CS term with $F_2$ and a R-type nongeometric flux. Same for $AdS_5 \times S^5$.
- Heterotic: From GS coupling $B_2 \wedge \mathrm{Tr} F^4$ we get

$$\int B_2 F_2 \mathrm{Tr}(F^3_{SU(3)}).$$

# (d-1)-form version

A version of the pandemic for $(d-1)$-form symmetries would demand e.g. 4d KS couplings for each 3-form:

$$\int G_0 C_3 \wedge d\phi$$

- More speculative, but some evidence [Bielleman, Ibañez, Valenzuela '15].
- Puts $d=3$ gravity in the (almost) Swampland. Aligns with recent $CFT_2$ results.
- Provides hints as to why Bousso-Polchinski is so hard to get: 3-forms always coupled to other stuff.

# Summary

- GGS must be broken in QG; Charged objects not enough when $d - p \leq 3$.
- A **pandemic of Chern-Simons** terms solves the problem generically.
- This is an almost-Swampland constraint for EFT's, killing $d \geq 4$ pure gravity, $d = 4$ EM+WGC, $\mathcal{N} = 8$ SUGRA.
- 3-form version relevant to Bousso Polchinski mechanism.

Outlook:

- Understand rationale better: AdS/CFT?
- Continue looking for (counter)examples.
- Explore 3-form version.

# Summary

- GGS must be broken in QG; Charged objects not enough when $d-p\leq 3$.
- A **pandemic of Chern-Simons** terms solves the problem generically.
- This is an almost-Swampland constraint for EFT's, killing $d\geq 4$ pure gravity, $d=4$ EM+WGC, $\mathcal{N}=8$ SUGRA.
- 3-form version relevant to Bousso Polchinski mechanism.

Outlook:

- Understand rationale better: AdS/CFT?
- Continue looking for (counter)examples.
- Explore 3-form version.

# Dankeschön!