# GEOMETRIC ASPECTS OF THE SWAMPLAND

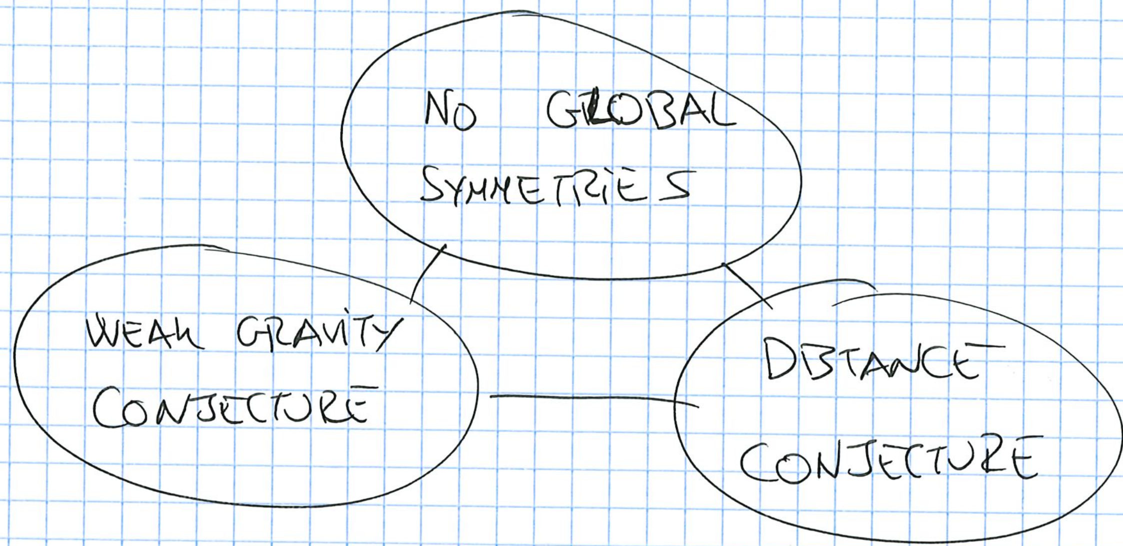
* SWAMPLAND OF EFTs ≡ EFTs INCONSISTENT WITH QUANTUM GRAVITY

  ↳ SWAMPLAND PROGRAMME (VAFA '05)

"THERE ARE INF. MANY MORE EFTs IN THE SWAMP. THAN IN THE LAND."

SWAMPLAND CONJECTURES:

PROPOSED CRITERIA TO DISTINGUISH EFTs CONSISTENT WITH Q.G.



## NO GLOBAL SYMMETRIES (BANKS & DIXON '88, BANKS & SEIBERG '10)

∄ GLOBAL SYMM. IN QG — BROKEN / GAUGED

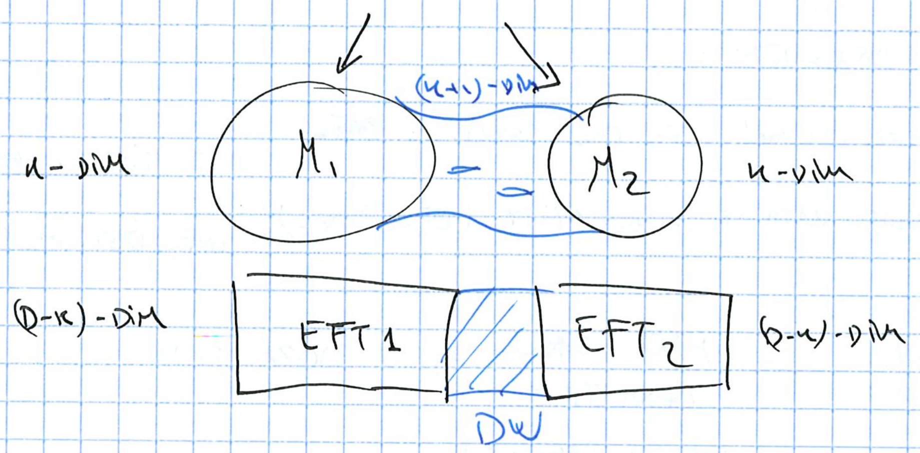
MOTIVATION: GS VIOLATE BEKENSTEIN-HAWKING BH ENTROPY FORMULA

→ FAMILIAR FROM STRING PERT. TH.

→ CONNECTED TO COMPLETENESS HYP. (∃ CH. MATTER STATES ∀ REP. GAUGE GR.)

NOT DIRECTLY CONNECTED TO GEOMETRY OF COMP., BUT...

## COBORDISM CONJECTURE (Mc & V '19) McNAMARA & VAFA




$M_1 \sim M_2$

$\Omega_k^{QG} = \{M_s\}/\sim$

QG VERSION OF A COBORDISM GROUP

COBORDISM: DW SEPARATING TWO EFTs

CONJECTURE: $\boxed{\Omega_k^{QG} = 0}$ ⟺


MOTIVATION:

$\Omega_k^{QG} \neq 0 \Rightarrow \exists$ (D-k-1)-GLOBAL SYMM.

REPRESENTED BY $[M] \in \Omega_k^{QG}$

A CLASS CAN BE TRIVIALIZED BY A DEFECT (ETW BRANE)

* SOME RESULTS :

- PREDICTION OF NEW DEFECTS

RECENT EX.: NON-SUSY HET. BRANES (KOYT'23) KAIDI, OHMORI, TACHIKAWA, YONEKURA

BLACK p-BRANES CANDIDATES (FKWY'24) FUKUDA, KOBAYASHI, WATANABE, YONEKURA

- CLASSIF. OF STRING VACUA W/ 16 SUPERCH. (MKV'20) MONTERO, VAFA

→ STRING UNIVERSALITY (SLP)

STRING LAMPPOST PRINCIPLE : ALL QG TH. ARE PART OF THE STRING LANDSCAPE

- CONSISTENCY CHECK FOR NON-SUSY STRING TH. (BDDM'23)

BASILE, DEBRAY, DELGADO, MONTERO

* DYNAMICAL COBORDISM :

→ DYNAMICAL REALISATION OF THE CONJ. :

EFT SOLUTIONS WITH A SINGULARITY (ETW BRANE) < FIN. DIST IN SPACETIME / INF. DIST. IN MOD. SPACE

APPROACH MERGES : COMP. TOP. ⟷ MOD. SPACE GEOMETRY (ASYMP. REGIONS) ⟷ SUGRA EOM.

- LOCAL DESCRIPTION NEAR ETW SIMPLIFIES DRAMATICALLY

PARAM BY CRITICAL EXP. $\delta$ (BCDU'21, ACDHU'22)

BURATTI, CALDERON-INFANTE, DELGADO, URANGA

ANGIUS, " , DELGADO, HUERTAS, URANGA

$$\Delta \sim e^{-\frac{1}{2}\delta D}, \quad |R| \sim e^{\delta D}$$

($D$: SPACETIME DIST.; $\Delta$: FIELD SP. DIST.; $|R|$: SPACETIME CURV.)

MORE RESULTS :

- CONNECTION TO COSMOLOGIES (MRS'21) MOURAD, SAGNOTTI
- " " HOLOGRAPHY (HHU'24) HUERTAS, URANGA
- " " TOP. CHANGE MORSE-BOTT TH. (RUIZ'24)

# WEAK GRAVITY CONJECTURE (AMNV'06) ARKANI-HAMED, MOTL, NICOLIS, VAFA

U(1) WEAK COUP. TO GRAVITY ⇒ ∃ SUPEREXTREMAL STATE

$m/M_p \lesssim \gamma Q$, $\gamma \equiv Q/M|_{\text{EXT BH}} = O(1)$, $Q \equiv g|q|$ PHYS. CHARGE

RELATED TO NGS VIA $g \to 0$   ORIGINAL MOT: ALLOW EXTREMAL BH DECAY

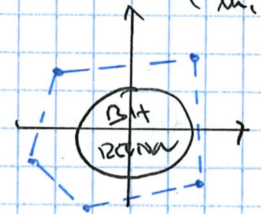
DOES NOT IMPOSE MUCH CONSTRAINTS ON EFTs NOR ON COMP. GEOM.

BUT GENERALISATIONS AND STRONGER VERIONS DO

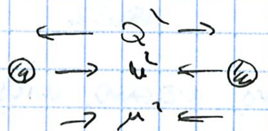
## GENERALISATIONS:

- MAGNETIC WGC: $\Lambda_{EFT} \lesssim g M_p^{\frac{d}{2}-1} \equiv \Lambda_{WGC}$
- P-FORM GAUGE FIELD ($m \to T$)
- SEVERAL U(1)'s → CH. LATTICE $\Gamma$ → CONVEX HULL COND.

$\vec{z} = \left(\frac{Q_1 M_p}{m_1}, \frac{Q_2 M_p}{m_2}\right)$




- ∃ MODULI $\{\phi_i\}$ ⇒ $\gamma(\phi_i)$




REPULSIVE FORCE CONDITION (PALTI'17)

∃ SELF-REPULSIVE STATE $F_{ATT.} \lesssim F_{REP.}$

$m^2+\mu^2$ $\quad$ $Q^2$

⇕ IF $M_{PART} \neq M_{BH}$

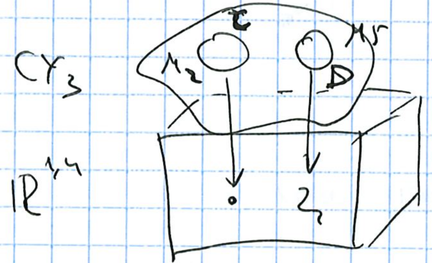
$m^2 \lesssim \gamma^2 Q^2$

* SIMPLEST CASE: BPS PART. IN SUSY TH.

NO-FORCE ⇒ $F_{ATT} = F_{REP}$

- SATURATES RFC
- SATISFIES WGC (BH SATISFIES BPS BOUND $m \geq |Z(q)|$) → CALIBRATED GEOM.

EX. M-TH ON $CY_3$




C EFF CURVE → BPS

C MOVABLE CURVE → BPS + EXTREMAL (SATURATES WGC)

EXTREMALITY ⇔ $Z(q) \neq 0$ IN MOD. SPACE

(AHR'21) ALIM, HEIDEREICH, RUDELIUS

# STRONGER VERSIONS

* TOWER WGC (HRR'16, MSS'16, AJNS'18) — HEIDENREICH, REECE, RUDELIUS; MONTERO, SOLER, SHIU; ANDRIOLO, JUNGHANS, NOUMI, SHIU

$\forall \vec{q} \in \Gamma$ (CH. LAT), $\exists\ m \in \mathbb{N}_{>0}$ S.T. $m\vec{q}$ HOSTS SUPEREXT. STATE

→ TOWER OF SUPEREXT. STATES — RECENT PROOF $D \geq 6$ PERT. BOS. STRING (HL'24) HEIDENREICH, LOTITO

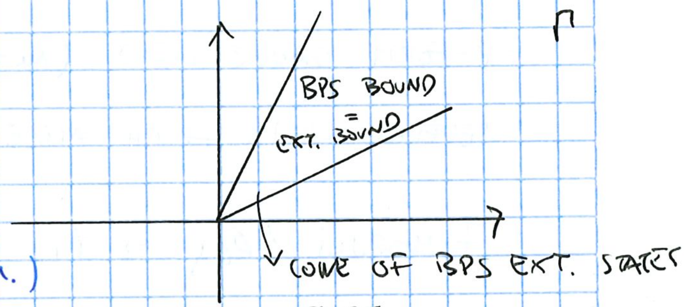
MOTIVATION: $D \xrightarrow[\text{DIM. RED.}]{S^1} D-1$ + CHC FOR $U(1)_{KK} \times U(1)_D$

- IF $\vec{q}$ HOSTS EXT. BPS STATE $\Rightarrow m_{\vec{q}} = \gamma_{\vec{q}} Q_{\vec{q}} = |Z_{\vec{q}}|$

BPS BOUND $\quad m_{m\vec{q}} \geq |Z_{\vec{q}}|$ (=)

TWGC $\quad m_{m\vec{q}} \leq \gamma_{\vec{q}} Q_{m\vec{q}}$

$\Rightarrow m_{m\vec{q}} = \gamma_{\vec{q}} Q_{m\vec{q}} = |Z_{m\vec{q}}|$




MORE GENERALLY:

M-TH EX. ⇒ CONE OF MOV. CURVES
(CONE STR. FAMILIAR IN ALG. GEOM.)

* MINIMAL WGC (CMWW'23) — COTA, MININNO, WEIGAND, WIESNER

$\exists$ SUPEREXT. TOWER ⟺ NEEDED BY DIM. RED.

IDEA: CHC LESS STRONG WHEN $S^1$ COMP. HAS MIN. RADIUS WHICH IS TYPICALLY THE CASE

EX. M-TH ON $CY_3 \times S^1 \Rightarrow r^2_{S^1} = e^{2\phi_{IIA}} = Vol_{IIA}(X_{IIA}) \to 0$ (QUANT. OBJ. ON VM)

MIRROR SYM: $= \int_{X_{IIB}} \Omega \wedge \bar{\Omega}$

- TOWERS NOT NEEDED IN CHARGED DIRECTIONS NOT WEAKLY COUPLED $\dfrac{\Lambda_{WGC}}{\Lambda_{sp}} \not\to 0$

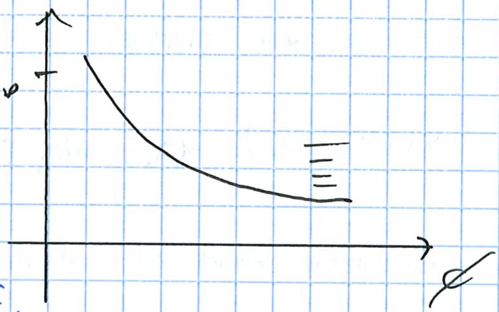
- NEEDED WHEN:
  - EXTREMAL STATES (E.G. CONE OF MOVABLE CURVES)
  - EMERGENT STRING LIMITS → SUPEREXT NON-BPS CRITICAL STRING STATES

# DISTANCE CONJECTURE (OOGURI & VAFA '06)

ALONG INF. DIST. GEODESICS AN INF. TOWER OF STATES BECOMES LIGHT

$$M(Q) \sim M(P)\, e^{-\lambda\, d(P,Q)}\,, \quad d = \text{GEODESIC DIST.}$$

MOTIVATION: STRING COMP.




- DIRECTLY CONNECTED TO MODULI SP AND PHYSICS OF WEAK COUP. LIMITS
- VALUE OF $\lambda$ CRUCIAL FOR LARGE FIELD INF.
- NON-TRIVIAL CHECK IN CY COMP. WITH 8 SUPERCH. (GPV'18, LLW'19)

CONNECTED TO POWERFUL MATH. CLASS. TH. — GRIMM, PALTI, VALENZUELA; LEE, LERCHE, WEIGAND

ETW REALISATION (ANGIUS '24)

## CONSEQUENCES:

1.- EMERGENCE PROPOSAL (HARLOW '15, GPV'18, HRR'18)

INF. DIST. ARE GENERATED BY INTEGRATING OUT THE INF. TOWER

2.- EMERGENT STRING CONJ. (LLW'19)

LIGHT TOWERS CAN EITHER BE { KK ; KK + UNIQUE CRIT. STRING }

3.- CONNECTION TO THE WGC

THE DC TOWER
- PROTECTS THE GS LIMIT $g \to 0$, LIKE THE MAGNETIC WGC
- IS IDENTIFIED WITH THE TWGC TOWER

EXTREMAL + BPS $\Rightarrow \lambda \sim \gamma \sim O(1)$

(G & V '20, BGvdH '20)

GENDLER, VALENZUELA

BASTIAN, GRIMM, VAN DE HEISTEEG

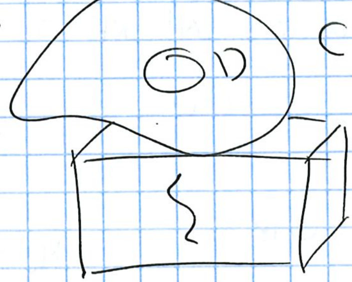
* SIMILAR CONNECTION FROM BPS EXTREMAL OBJECTS WHOSE BACKREACTION PROBES INF. DIST. LIMITS (LMMV'21)

"4d EFT STRINGS"

"5d SUPERGRAVITY STRINGS"

M-TH ON $CY_3$

M5 ON NEF DIVISOR




TYPE IIA ON $CY_3$

NS5 ON D

NEF DIVISOR

(KKTV'20) KATZ, KIM, TARAZI, VAFA

- REMOVED FROM EFT WHEN GRAV. IS DECOUPLED.
- UNITARITY OF WS TH. ⇒ CONSTRAINTS ON THE SUGRA COUPLINGS
  ↳ BOTTOM-UP RECONSTRUCTION OF KÄHLER CONE, INF. DIST. LIM.

6D (KSV'19) KIM, SHIU, VAFA

4D (MRW'23) MARTUCCI, RISSO, WEIGAND

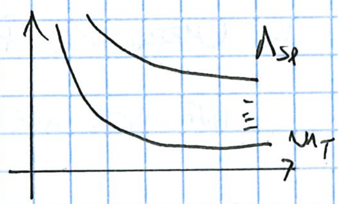
5D (KLW'24) KAUFMANN, LANZA, WEIGAND

4. ROLE OF THE SPECIES SCALE $\Lambda_{sp}$ (1/2 AUDIENCE)

$$\Lambda_{sp} \equiv \frac{M_P}{N^{\frac{1}{d-2}}}$$

\# SPECIES

FUNDAMENTAL QG SCALE AT WHICH GRAVITY BECOMES STRONGLY COUPLED




- NICE GEOM. DESC. IN CY COMP.: $\Lambda_{sp}/M_p \sim \int_X c_2(X) \wedge J$ (VdHVWW'23) VAN DE HEISTEEG, VAFA, WIESNER, WU
- WEAK COUP. LIM ⇒ $\frac{\Lambda_{WGC}}{\Lambda_{sp}} \to 0$ (FOR SOME g)
- $\vec{\nabla} \log \Lambda_{sp}/M_p$ vs. $\vec{\nabla} \log m_T/M_p$ DESCRIBE INF. DIST. LIM. (CRV'23) (EHRRV'24) ETHERIDGE, HEIDENREICH, RUDELIUS, RUIZ, VALENZUELA
- DETERMINED BY EFT STRING TENSION (MRVV'24) MARTUCCI, RISSO, VALENTI, VECCHI

* EMERGING PICTURE

∃ SET OF EFT "BRANES" ABOVE $\Lambda_{EFT}$ THAT ARE CENTRAL TO THE PROGRAMME

- THEY PROBE THE INT. BULK GEOM, AND DECOUPLE WHEN GRAV. DOES
- $T, Q \to 0$ IN ASYMP. LIMITS, BUT $\gamma = Q/T \sim O(1)$ GRAVITATIONAL OBJECT
- THEIR EFT BACKREACTION PROBES INF. DIST. LIMITS → BOUNDS ON $\lambda$
- THEIR CONSISTENCY ⟹ BOTTOM-UP DESCRIPTION OF ASYMP. LIMITS
- GEOMETRICALLY THEY REPRODUCE CONE STRUCTURES OF SUBMANIFOLDS → NEEDED FOR WGC CONSISTENCY (E.G. GV INVARIANTS)

5.- MODULI SPACE CURVATURE

* RIGID BRANES > OPPOSITE TO SUPERGRAVITY BRANES
  - F-TH ON $CY_3$ : D3 ON CONTRACT. $C \subset B_2$ → 6d SCFT, → 6d LST
  - M-TH ON $CY_3$ : M5 ON " $D \subset X_3$ → 5d SCFT

ALONG A GRAV. DECOUP. LIMIT

- THEY REMAIN IN (NON-GRAV) EFT · - $\gamma \to \infty$ - $\Lambda_{WGC}^{RIGID}/\Lambda_{SP} \to \infty$

* MODULI SP. CURVATURE SENSITIVE TO THE DECOUP. (MMP'23, MMW'24, CMMP'24)

TYPE II ON $CY_3$, VM SECTOR

$$R \simeq -2n_V(n_V+1) + e^{-K} R_{RIGID} \quad ; \quad e^{-K} = \left(\frac{M_P}{M_{IR}}\right)^2 \to \infty \text{ AT INF. DIST.}$$

$R_{RIGID} > 0$ MEASURES GAUGE WC STRENGTH

WHEN $\frac{M_P}{M_{IR}} \to \infty$, $R_{RIG} = $ CT. (INF. DIST.)

$\frac{M_P}{M_{IR}} = $ CT., $R_{RIG} \to \infty$ (FIN. DIST.) $\Big)$ $R \to \infty$

GAUGE SUBSECTOR PARAM. STRONGER THAN GRAVITY

## CURVATURE CRITERION

$R \to \infty \Rightarrow$ GRAV. DEC. LIMIT.

WITH INTERACTING RIGID TH.

## LV / LCS CY LIMITS

$$R_{div} \simeq \left( \frac{\Lambda^{QZ}_{WGC}}{\Lambda_{sp}} \right)^{2\nu}$$

$\nu = 3$ 5d SCFT

$\nu = 2$ 6d SCFT

$\nu = 1$ LST

## MORE ON MODULI SPACES

AMPLITUDE FINITENESS → COMPACTIFIABILITY

- SEMI-SIMP REP. OF DUALITY GROUP

van de Heisteeg's TALK

- RELATION TO TAMENESS

GRIMM's TALK

## NON-GEOMETRIC VACUA

VAFA's TALK