Instituto de Física Teórica presents:

New Lessons *on* Gravity Decoupling

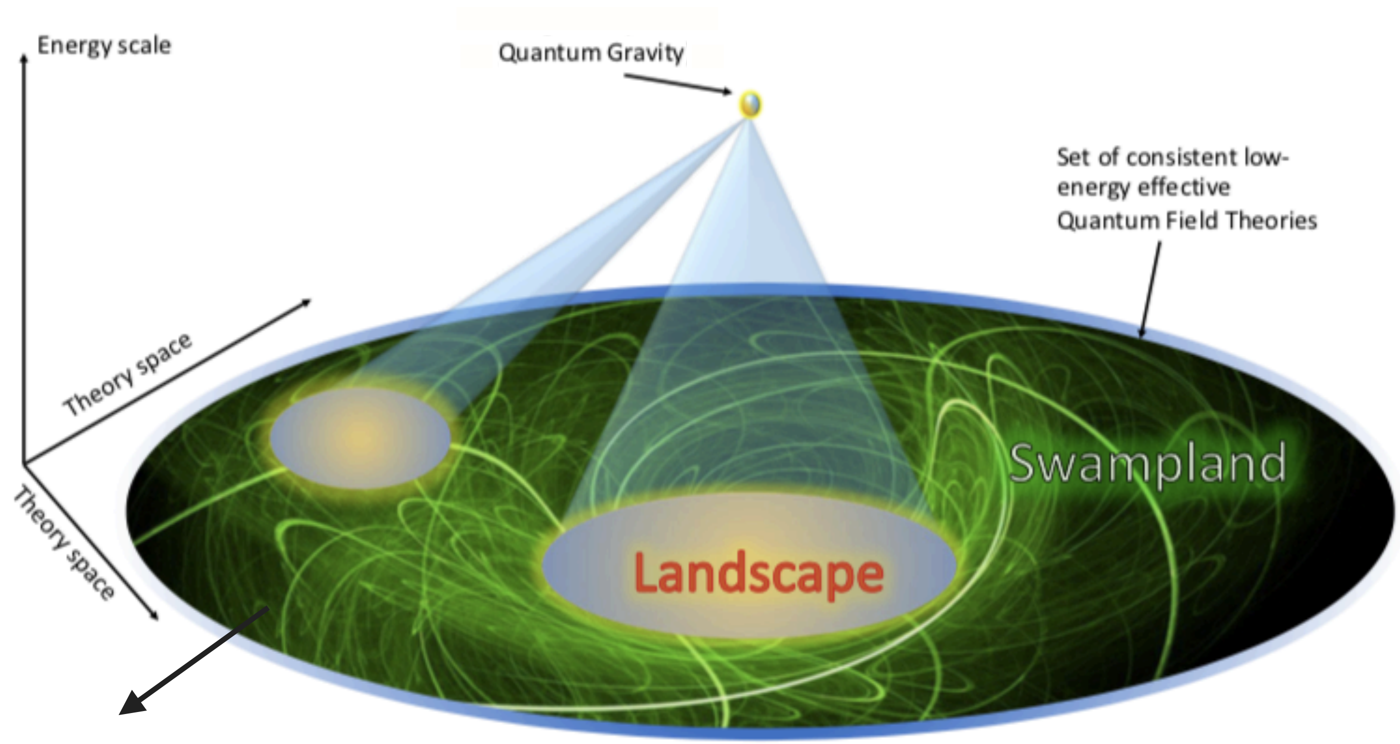
by Fernando Marchesano

based on 2602.04957 & 2605.28938

w/ Christian Aoufia, Gonzalo F. Casas, Alberto Castellano & Lorenzo Paoloni

Motivation: The Swampland Programme

Vafa '05



taken from Palti '19

Field theories inconsistent with quantum gravity

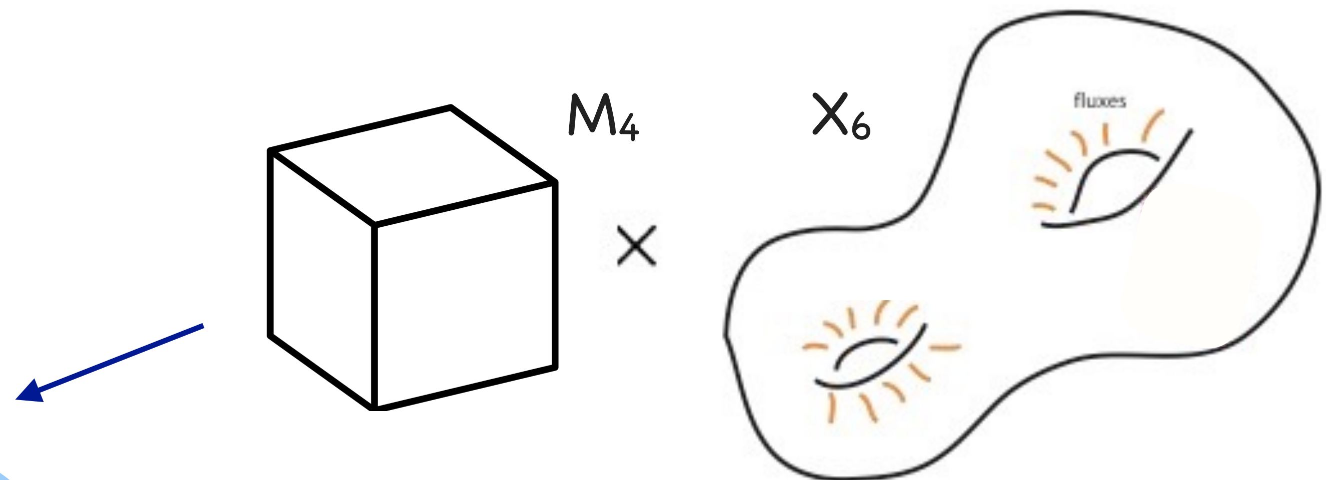
Swampland Conjectures:

Proposals for criteria to distinguish EFTs consistent with quantum gravity

Conjectures should become trivial when $M_{\mathrm{P}} \to \infty$

Reviews: Palti '19, van Beest et al '21, Herráez & Graña '21, ...

EFTs from string compactifications



No parameters: EFT moduli space $\mathscr{M}$ parametrised by massless scalar field vevs.

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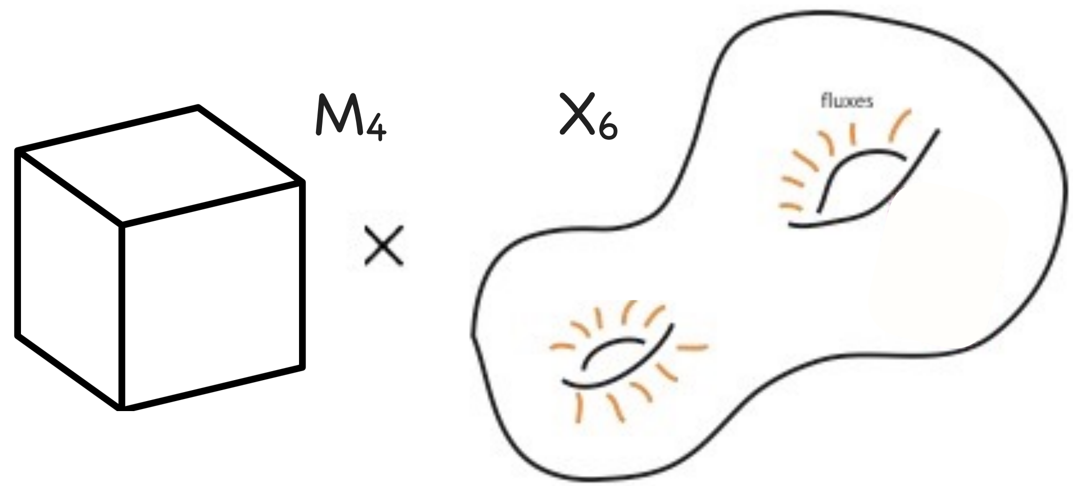

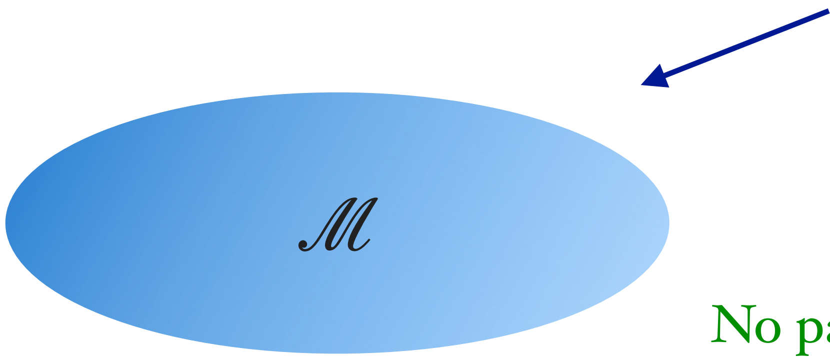

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parametrised by massless scalar field vevs.

EFT Lagrangian:

$$S = M_{\mathrm{P}}^{D-2}\int d^Dx\sqrt{-g}\left(\frac{1}{2}R - g_{ij}(\phi)\partial\phi^i\partial\phi^j + \dots\right)$$

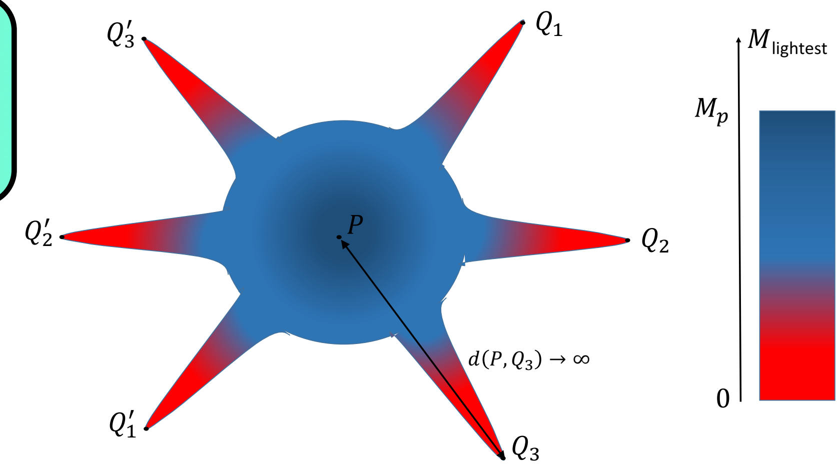
Ooguri & Vafa '06

there exist geodesic paths of infinite
distance starting at any point P

The Distance Conjecture (SDC)

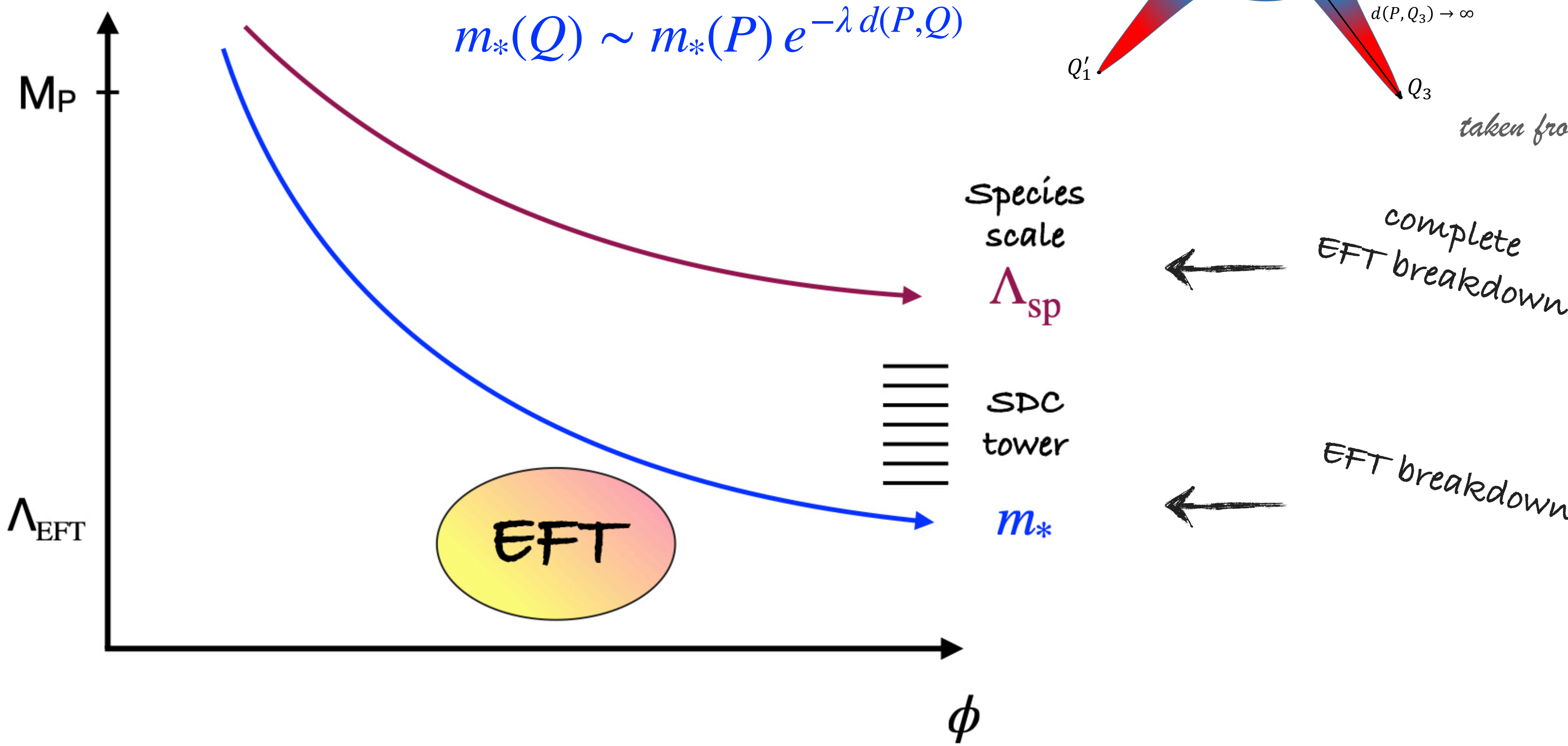
Ooguri & Vafa '06

Along such geodesics there is an infinite tower of exponentially light states in Planck units

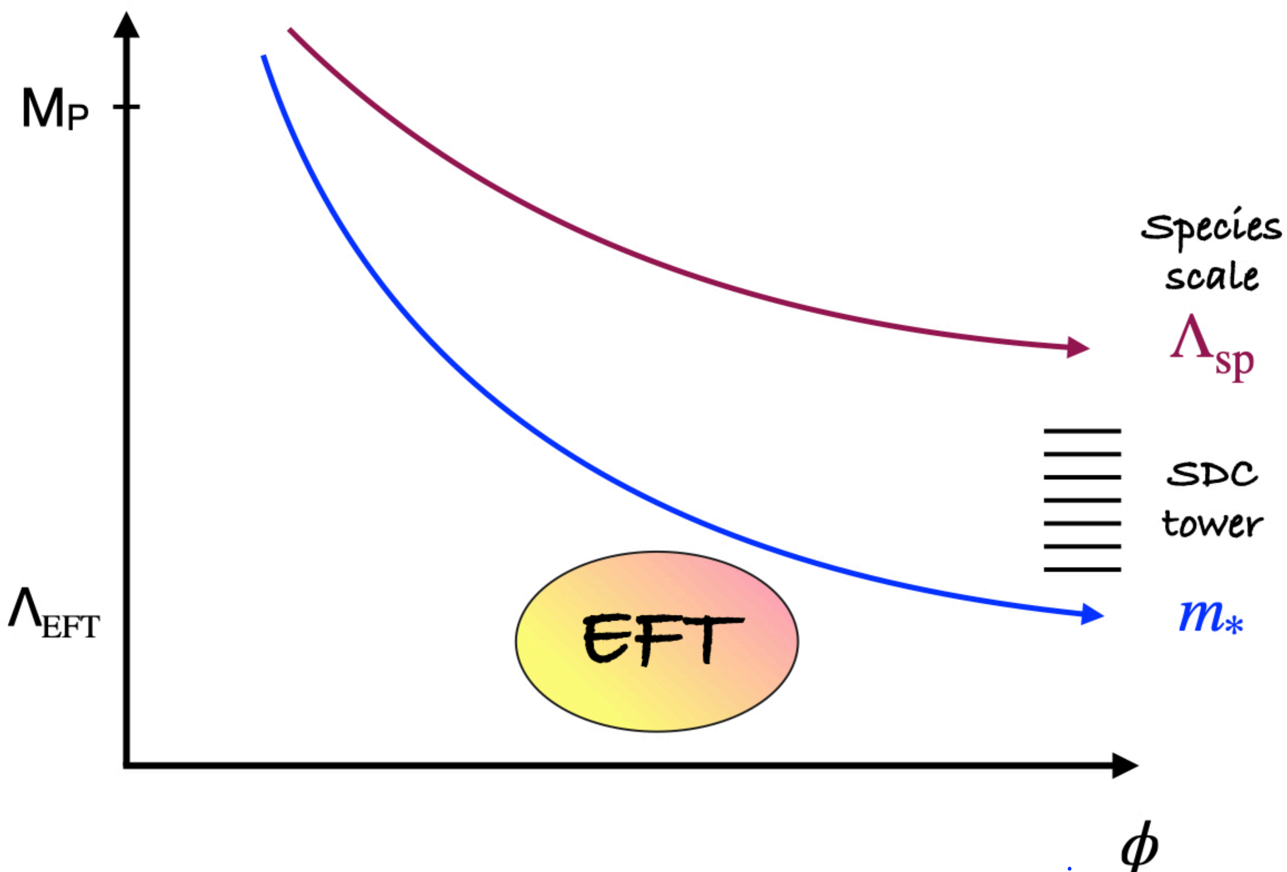


taken from Palti '19

$$m_*(Q) \sim m_*(P)\, e^{-\lambda\, d(P,Q)}$$



The SDC and gravity decoupling



There can be an EFT subsector $\{\phi^\mu\} \subset \{\phi^i\}$
whose couplings remain $\mathcal{O}(1)$ in m_* units

Gravity decoupling
RFT

Decoupling mechanisms in field theory

There are two main schemes to decouple two field subsectors A and B:

- Mass decoupling

  One generates a hierarchy of masses $m_A \gg m_B$, and sets m_A as a cut-off. The fields in A can be replaced by their vevs, which appear as parameters for the EFT(B). The larger the hierarchy m_A/m_B, the better the approximation.

- Interaction decoupling

  One suppresses all kind of mixing terms and interactions between A and B (kinetic mixing, mass mixing, Yukawas…), so that the equations of motion of the fields in A can be solved ignoring the fields in B. One then replaces them by their vevs and these again appear as parameters in EFT(B).

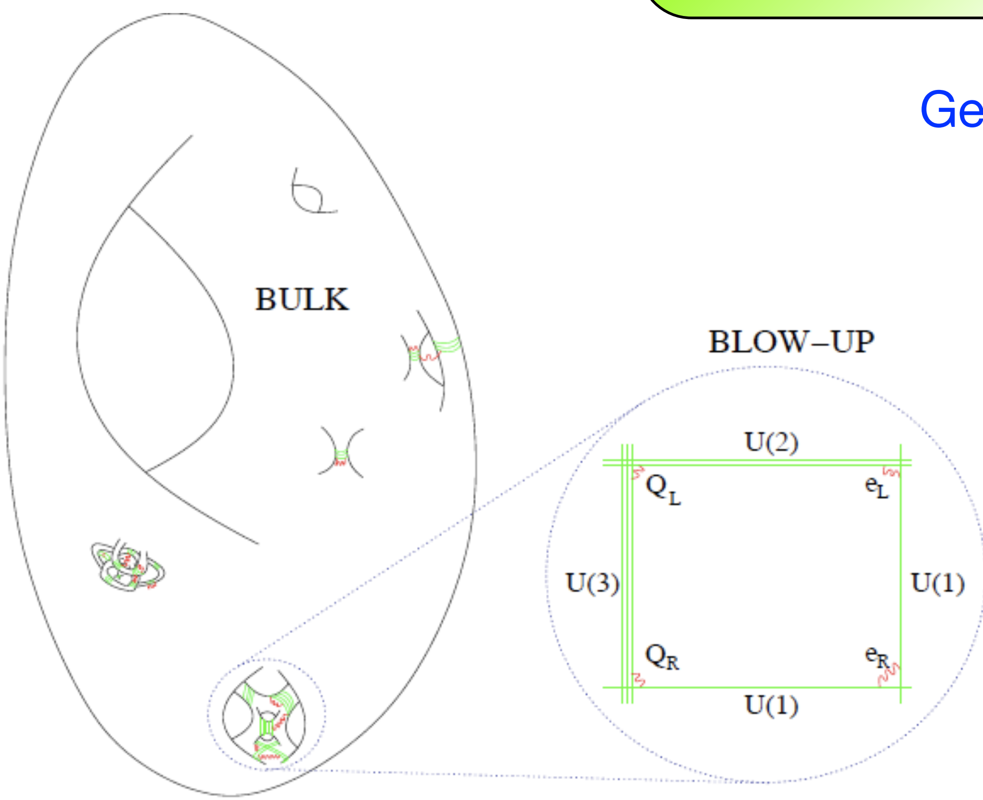
Mechanism involved in gravity decoupling

Works very similarly in 4d N=2 and N=1

Gravity decoupling in string theory

A standard mechanism to decouple gravity in string theory is to exploit the localisation properties associated to gauge d.o.f., as opposed to gravity

gravity is *diluted*



taken from Conlon, Cremades, Quevedo '06

Geometric engineering *Katz, Klemm, Vafa '96*

D-branes *Witten '96* *Lykken '96*

Arkani-Hamed, Dimopolous, Dvali '98

F-theory *Donagi & Wijnholt '08*

Beasley, Heckman, Vafa '08

Extensively used for particle physics model-building

recently reviewed in F.M., Shiu, Weigand '24

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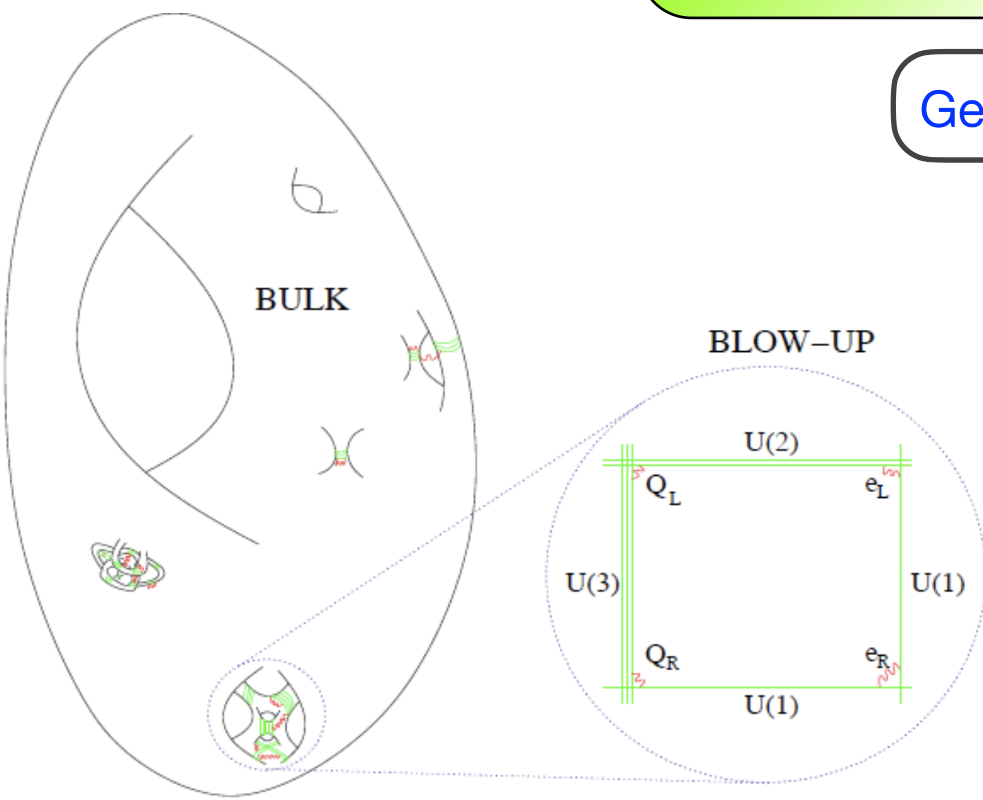

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Combining two 4d $\mathcal{N} = 2$ frameworks

$$\mathcal{M}_{\mathcal{N}=2} = \mathcal{M}_{\rm HM} \times \mathcal{M}_{\rm VM}$$

Setup: Type II on a CY_3

Special Kähler geometry

Prepotential $\mathcal{F}$

$$\Pi = \begin{pmatrix} X^A \\ \mathcal{F}_A \end{pmatrix}$$

$$K = -\log\left(-2\mathrm{Im}(\bar{X}^I \mathcal{F}_I)\right)$$

$$g_{i\bar{j}} = \partial_{z^i} K\, \partial_{\bar{z}^{\bar{j}}} K + |X^0|^2 e^K 2\mathrm{Im}\mathcal{F}_{ij}$$

Good notion of supergravity vs. rigid couplings

see e.g. Strominger'90 Andrianopoli et al'96

Freed'97 Billó et al'98 Gunara et al'13

Asymptotic Hodge theory

$$\Pi = e^{\phi^j P_j}\left(\mathbf{a}_0 + \sum_{r_j} \mathbf{a}_{r_1 \ldots r_N}\, e^{2\pi i r_j \phi^j}\right)$$

Schmid'73

P_j nilpotent $\quad \phi^j = a^j + i s^j \to \phi^j + 1$

$$K = -\log(\mathcal{G}_{\rm pol}(s^j) + \mathcal{G}_{\rm inst})$$

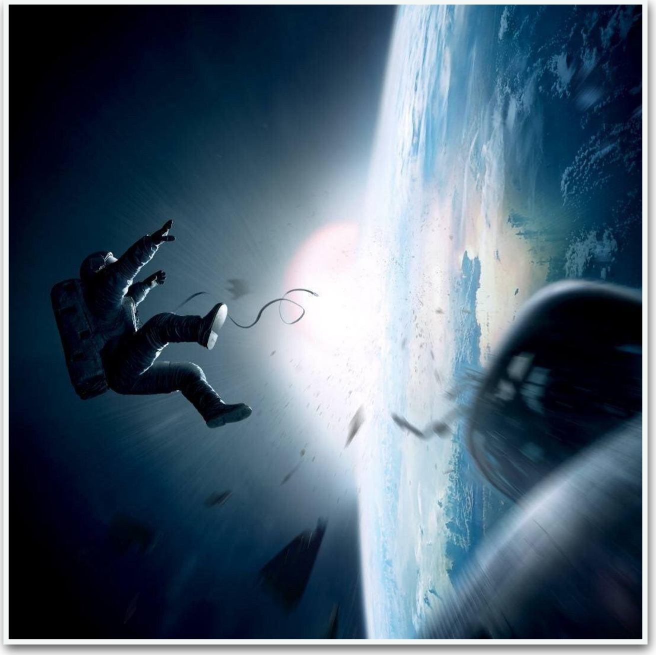
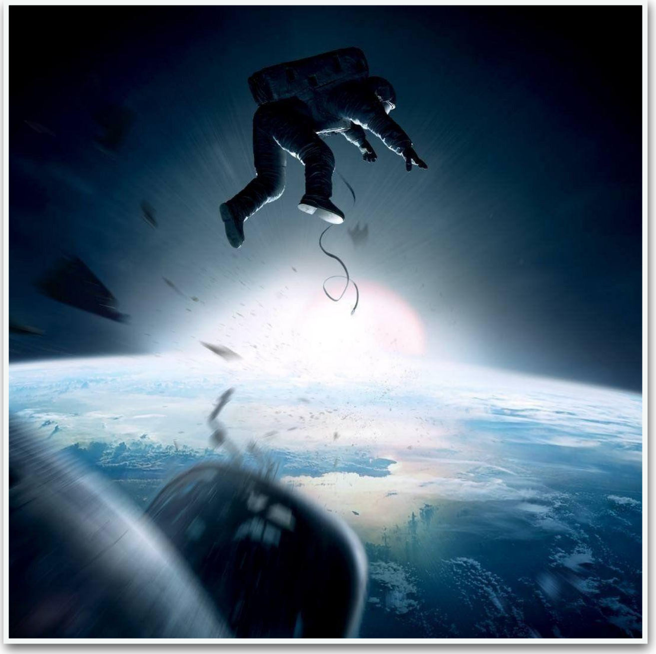
Tailored to describe axionic shift symmetries

Extends to 4d N=1

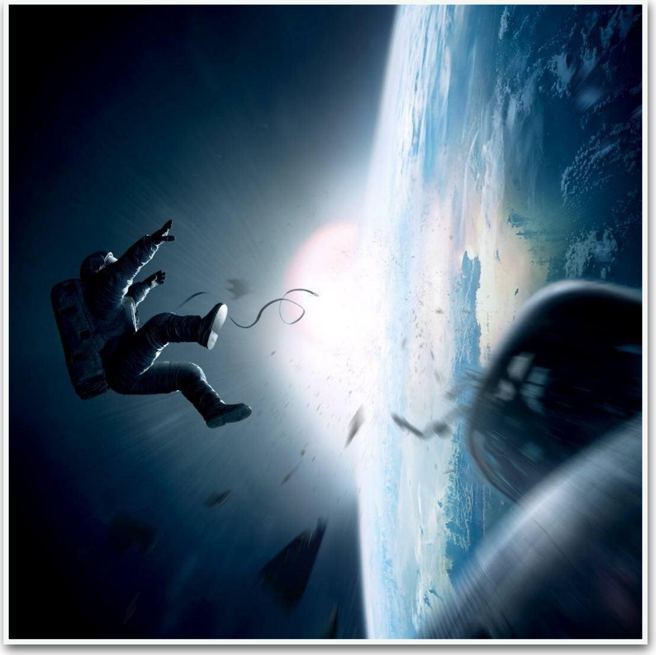
Corvilain, Grimm, Li, Palti, Valenzuela'18

Bastian, Grimm, van de Heisteeg'21

Hassfeld, Monnee, Weigand, Wiesner'25


Three Lessons



Lesson #1

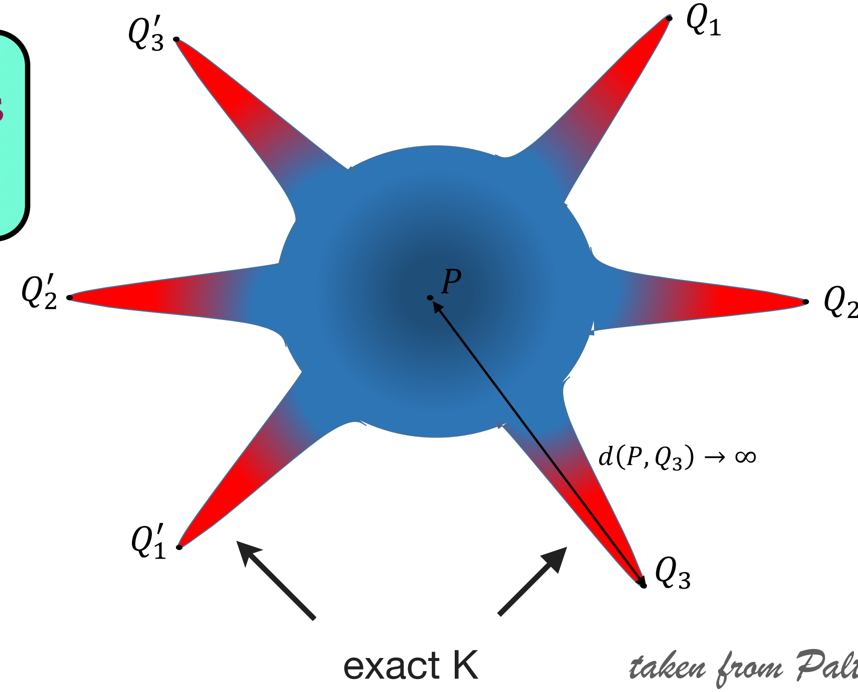
There is a favourite K

The Kähler form and gravity decoupling

To (weakly) couple gravity to an RFT, one needs an exact Kähler form in field space

Komargodski & Seiberg '10

Adams et al. '11



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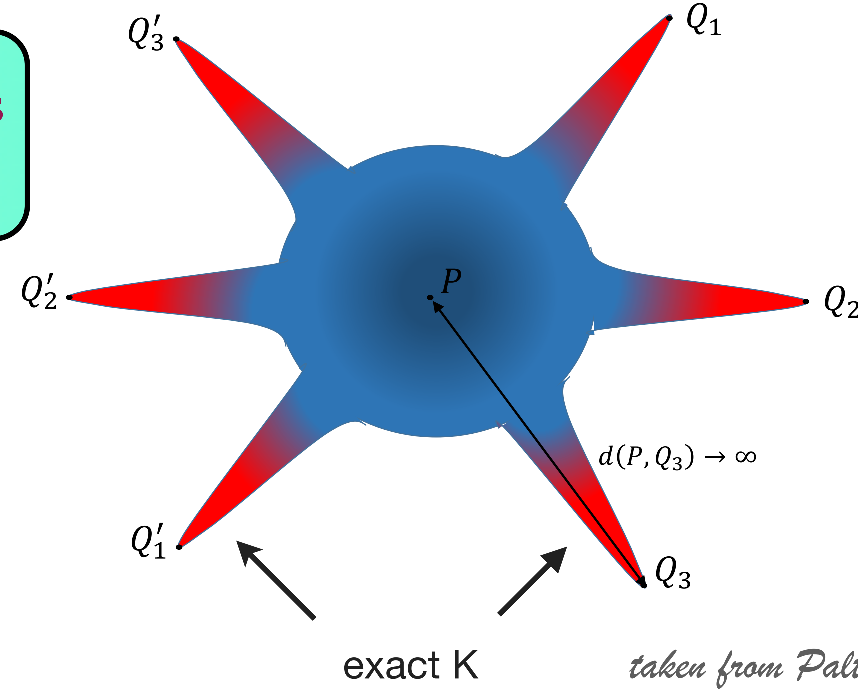

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How do we see this in asymptotic limits?

Via the Nilpotent Orbit Theorem one can show that:

$$m_*^2 = e^K |X^0|^2 M_P^2 \qquad X^0 \simeq \text{const.}$$

preserved by a Kähler transformation

$K \to K + F + \bar{F}$ only if F const.

$\Longrightarrow \vec{\nabla} K$ fixed!

K and axionic shift symmetries

$$\Pi = e^{\phi^j P_j} \left(\mathbf{a}_0 + \sum_{r_j \in \mathbb{N}} \mathbf{a}_{r_1 \ldots r_N} e^{2\pi i r_j \phi^j} \right) = \Pi_{\text{pol}} + \Pi_{\text{exp}}$$

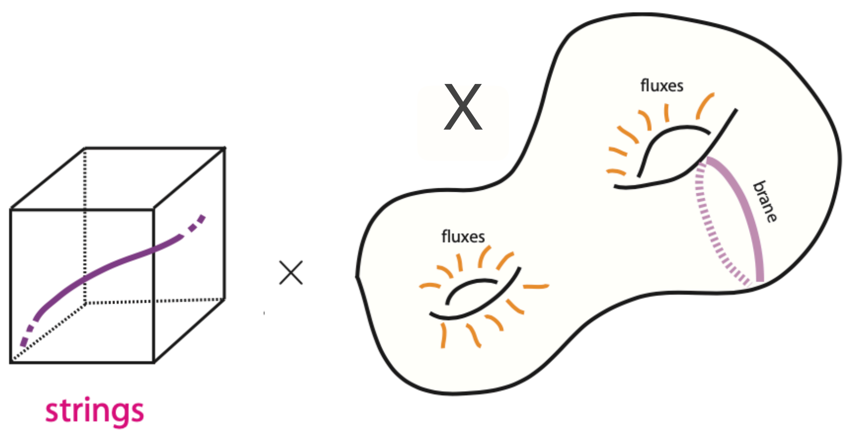
$$K_{\text{pol}} = -\log \left(i \mathbf{\Pi}_{\text{pol}}^T \eta \overline{\mathbf{\Pi}}_{\text{pol}} \right)$$ only depends on $s^i = \text{Im}\phi^i$

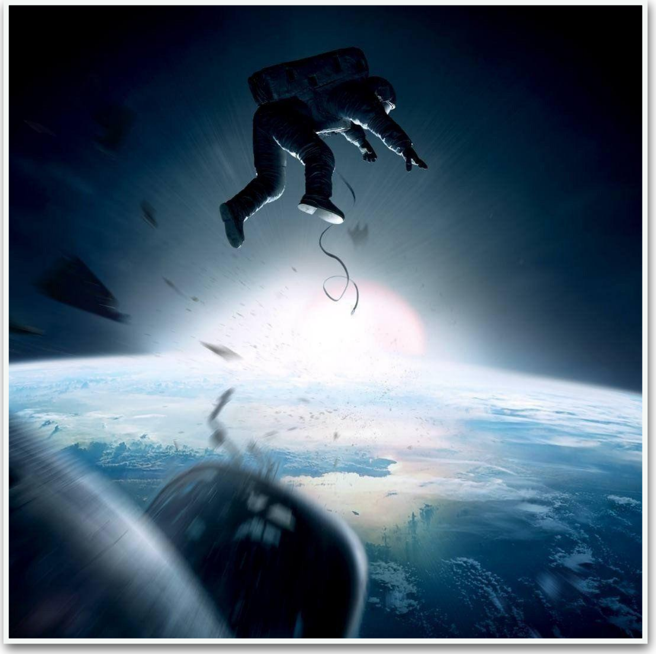
There is a number of axionic shift symmetries associated to K_{pol}, broken by Π_{exp}

$\Longrightarrow$ BPS axionic strings whose tension is computed as $\mathcal{T}_j / M_{\text{P}}^2 = \partial_j K$

Lanza et al. '20-21

$\Longrightarrow$ $\vec{\nabla} K$ fixed





Lesson #2

EFT subsector splitting

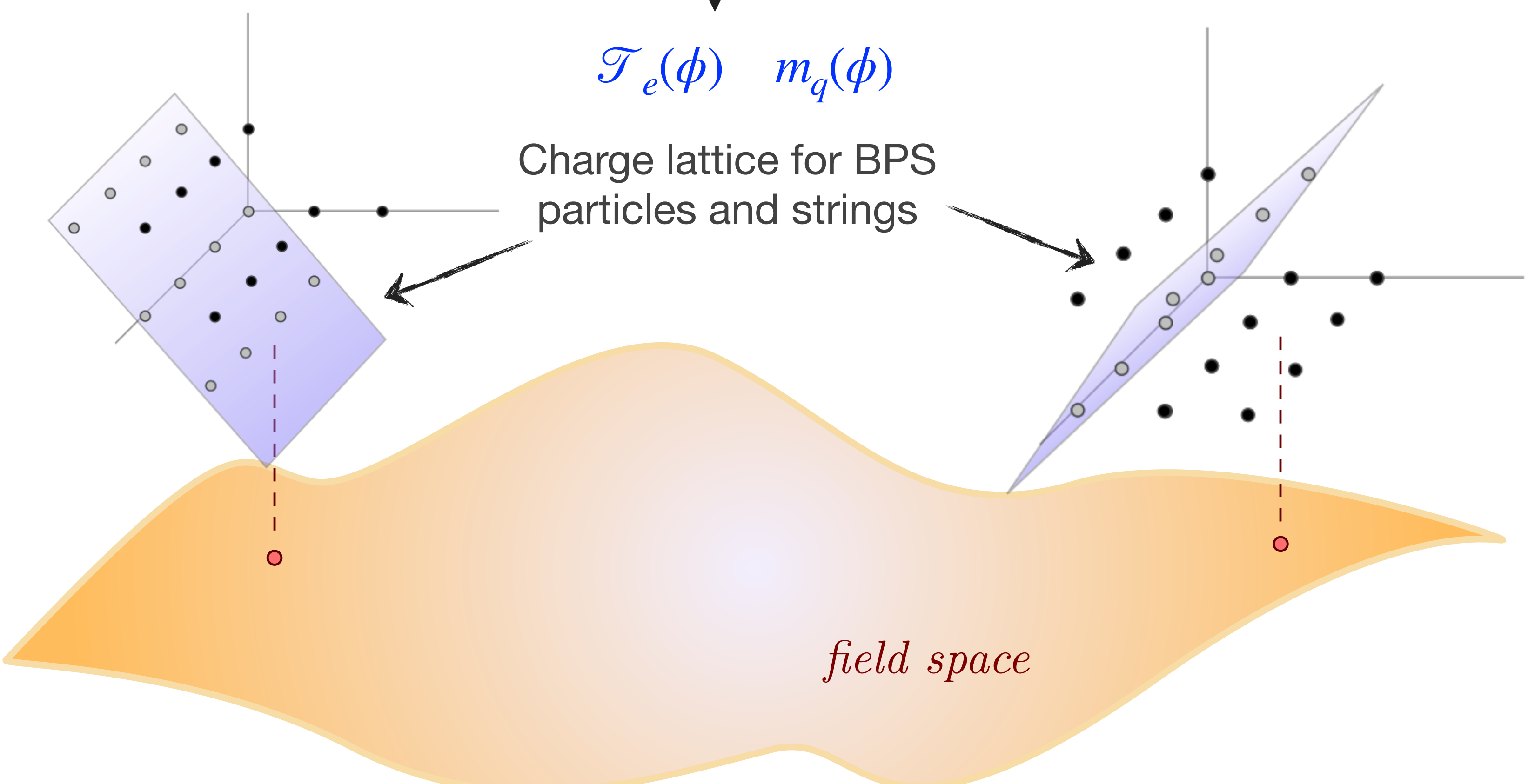
The EFT along moduli space

$$S^{\mathrm{VM}}_{4\mathrm{d}} = \frac{1}{2\kappa_4^2}\int_{\mathbb{R}^{1,3}} R\star\mathbf{1} - 2g_{i\bar{j}}d\phi^i\wedge\star d\bar{\phi}^{\bar{j}} + \frac{1}{2}\int_{\mathbb{R}^{1,3}}\mathcal{I}_{IJ}F^I\wedge\star F^J + \mathcal{R}_{IJ}F^I\wedge F^J$$

$\updownarrow$ same information

$\mathcal{T}_e(\phi) \quad m_q(\phi)$

Charge lattice for BPS particles and strings



Charge-to-mass vectors

BPS particles satisfy
no-force relations

$$\boxed{Q_q^2 = \frac{m_q^2}{M_{\rm P}^2} + 2g^{ij}\partial_i\left(\frac{m_q}{M_{\rm P}}\right)\partial_j\left(\frac{m_q}{M_{\rm P}}\right)}$$

Ceresole, D'Auria, Ferrara '95 *Palti '17*

Charge rep. Gravity att. Moduli exch. att. $\Longrightarrow F_{\rm rep} = F_{\rm att}$

$\mathcal{I}_{IJ}, \mathcal{R}_{IJ}$

charge-to-mass vectors → tool
to analyse asymptotic limits

$$\vec{\zeta}_q \equiv -\vec{\nabla}\log(m_q/M_{\rm P})$$

Lee, Lerche, Weigand '19

Calderon-Infante, Uranga, Valenzuela '20

Etheredge et al. '22-24

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Etheredge et al. '22-24

$$\frac{Q_q^2 M_P^2}{m_q^2} \equiv \gamma_q^2 = 1 + 2\|\vec{\zeta}_q\|^2 \Longrightarrow$$

$\|\vec{\zeta}_q\| \sim \mathcal{O}(1)$ *extremal* BPS part. → gravity is relevant

$\|\vec{\zeta}_q\| \gg 1$ *non-extremal* BPS part. → gravity is negligible

Example: vector for the SDC tower m_*

$$\vec{\zeta}_* \equiv -\frac{1}{2}\vec{\nabla}K \qquad \|\vec{\zeta}_*\| = \mathcal{O}(1)$$

Charge vectors and axionic shift symmetries

For a BPS axionic string with charge $\mathcal{T}_e = e^i \mathcal{T}_i$ we have

$$\vec{\xi}_e \equiv -\vec{\nabla}\log(\mathcal{T}_e/M_{\rm P}^2) = \frac{\vec{e}}{\mathcal{T}_e}M_{\rm P}^2$$

$$g_{i\bar{j}} \longrightarrow \frac{Q_e^2 M_{\rm P}^2}{\mathcal{T}_e^2} \equiv \gamma_e^2 = \|\vec{\xi}_e\|^2$$

$$\|\vec{\xi}_e\|^2 \gg 1 \iff \begin{aligned} g_{i\bar{j}} &= \partial_{z^i}K\,\partial_{\bar{z}^{\bar{j}}}K + |X^0|^2 e^K 2\mathrm{Im}\mathcal{F}_{ij} \\ &\simeq |X^0|^2 e^K 2\mathrm{Im}\mathcal{F}_{ij} \end{aligned}$$

$$\iff G_{\mu\bar{\nu}} \equiv \frac{M_{\rm P}^2}{m_*^2} g_{\mu\bar{\nu}} \simeq 2\mathrm{Im}\mathcal{F}_{\mu\nu}$$

Charge vectors and axionic shift symmetries

For a BPS axionic string with charge $\mathscr{T}_e = e^i \mathscr{T}_i$ we have

$$\vec{\xi}_e \equiv -\vec{\nabla} \log(\mathscr{T}_e / M_{\rm P}^2) = \frac{\vec{e}}{\mathscr{T}_e} M_{\rm P}^2$$

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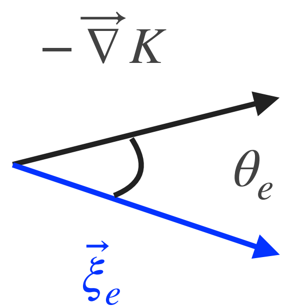
$$\|\vec{\xi}_e\|^2 \gg 1 \iff \begin{aligned} g_{i\bar{j}} &= \partial_{z^i} K \, \partial_{\bar{z}^{\bar{j}}} K + |X^0|^2 e^K 2\mathrm{Im}\mathscr{F}_{ij} \\ &\simeq |X^0|^2 e^K 2\mathrm{Im}\mathscr{F}_{ij} \end{aligned}$$

A straightforward computation gives $\boxed{\vec{\zeta}_* \cdot \vec{\xi}_e = 1}$

Extremal string

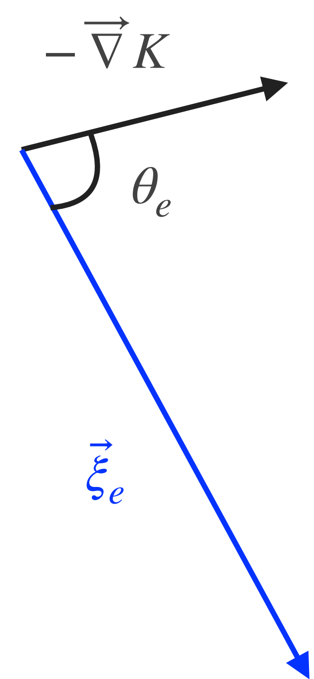
$\|\vec{\xi}_e\| = \mathscr{O}(1)$



Rigid string

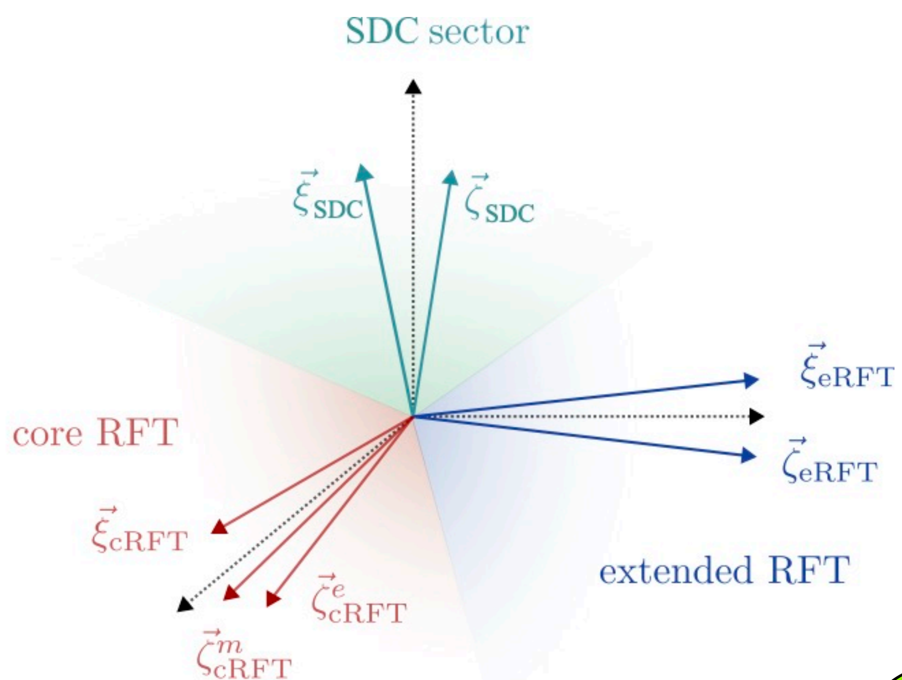
$\|\vec{\xi}_e\| \gg 1$

$\cos\theta_e \simeq 0$



Charge vectors and kinetic mixing

Together with further bounds one arrives at the following picture:



$\mathcal{O}(1)$ couplings in m_* units

$\gamma_{\mathrm{cRFT}} \gg \gamma_{\mathrm{eRFT}}$

$$\frac{\vec{\xi}_i \cdot \vec{\xi}_j}{\|\vec{\xi}_i\|\,\|\vec{\xi}_j\|} = \frac{|K_{ij}|}{K_{ii}^{1/2} K_{jj}^{1/2}}$$

kinetic mixing

$$\frac{\vec{\zeta}_p \cdot \vec{\zeta}_q}{\|\vec{\zeta}_p\|\,\|\vec{\zeta}_q\|} \overset{\mathrm{RFT}}{\simeq} \frac{Q_{pq}^2}{Q_{pp} Q_{qq}}$$

gauge kinetic mixing

Orthogonal sectors in tangent moduli space decouple from each other at the kinetic level

Lesson #3

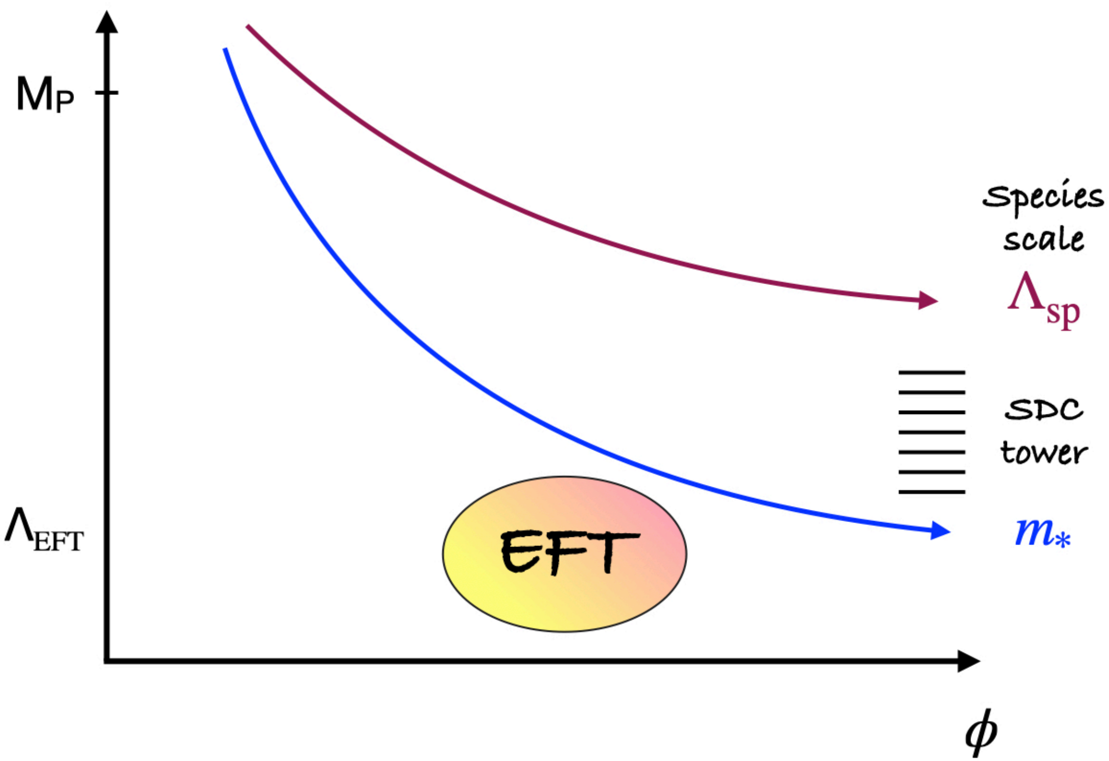
The Curvature Criterion

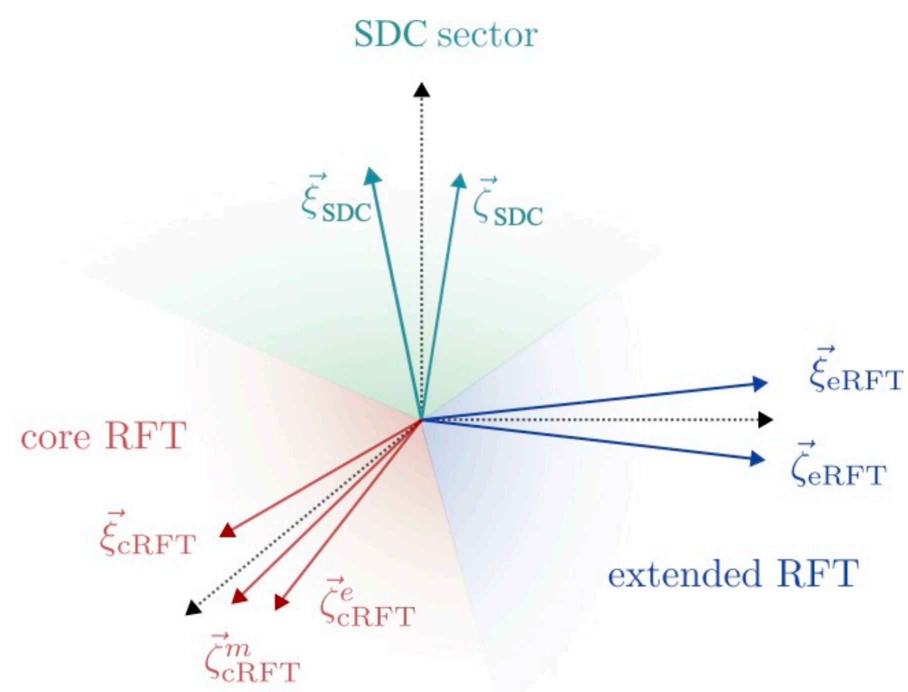
Rigid fields and Curvature

For infinite distance VM limits, along certain field directions one finds

$$G_{\mu\bar{\nu}} \equiv \frac{M_{\rm P}^2}{m_*^2} g_{\mu\bar{\nu}} \simeq 2{\rm Im}\mathscr{F}_{\mu\nu}$$

recovering the 4d $\mathcal{N} = 2$ rigid relation $\Longrightarrow$ $\{\mu, \nu\}$ rigid field directions.





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$$G_{\mu\bar{\nu}} \equiv \frac{M_{\rm P}^2}{m_*^2} g_{\mu\bar{\nu}} \simeq 2{\rm Im}\mathcal{F}_{\mu\nu}$$

recovering the 4d $\mathcal{N}=2$ rigid relation $\Longrightarrow$ $\{\mu,\nu\}$ rigid field directions.

This fixes how this sector contributes to the curvature of the supergravity EFT

$$R = -n_V(n_V+1) + \frac{M_{\rm P}^2}{m_*^2} R_{\rm rigid} + \ldots \to +\infty$$

where in m_* units $R_{\rm rigid} = G^{\mu\bar{\nu}}G^{\rho\bar{\sigma}}G^{\tau\bar{\eta}}\mathcal{F}_{\mu\rho\tau}\bar{\mathcal{F}}_{\bar{\nu}\bar{\sigma}\bar{\eta}} \geq 0\,.$

$R_{\rm rigid} \simeq \mathcal{O}(1)$

Curvature criterion: all curvature divergences are of this form

$$\boxed{R \to \infty \quad \Longrightarrow \quad \text{gravity decoupling limit}}$$

diagnostic for gravity decoupling

Curvature and decoupling

Two conditions must be met for interaction decoupling:

- No significant kinetic mixing

  In our case involves plain kinetic mixing and gauge kinetic mixing.

- No mixing at the level of interactions

  The interactions that mix different sectors must be suppressed compared to the sector that one wants to decouple.

Pauli couplings and divergences

In our setup,* the relevant interactions are Pauli couplings: $P_{Ijk}(F_-^I)_{\mu\nu}\bar{\lambda}^{\bar{j}A}\gamma^{\mu\nu}\lambda^{kB}\epsilon_{AB}$

$$\|P\|^2_\Lambda \equiv -\mathcal{I}^{IJ}g^{j\bar{m}}g^{k\bar{n}}P_{Ijk}\bar{P}_{J\bar{m}\bar{n}} \simeq |X^0|^6 e^{2K}g^{i\bar{j}}g^{k\bar{l}}g^{m\bar{n}}\mathcal{F}_{ikm}\bar{\mathcal{F}}_{\bar{j}\bar{l}\bar{n}}$$

* Exception: 4d N=4 rigid sectors

Using *Strominger '90* one can write the curvature as a sum of Pauli couplings:

$$R = -n_V(n_V+1) + \|P\|^2_{\text{SDC}} + \|P\|^2_{\text{eRFT}} + \|P\|^2_{\text{cRFT}} + \|P\|^2_{\text{mixed}}$$

In general $\|P\|^2_{\text{SDC}} \sim \mathcal{O}(1)$ and one needs to require that $\|P\|^2_{\text{RFT}} \gg \|P\|^2_{\text{mixed}}$

In all cases, this leads to a curvature divergence:

$$R_{\text{div}} \simeq \frac{M_{\text{P}}^2}{m_*^2}R_{\text{rigid}} \lesssim \max \gamma^2_{\text{cRFT}}$$

The EFT structure of gravity decoupling

Two kinds of BPS objects in terms of $\gamma \equiv Q/T$:

- BPS and extremal: $\gamma \sim \mathcal{O}(1)$ → gravitational mutual coupling
- BPS and non-extremal $\gamma \to \infty$ → rigid mutual coupling

To achieve gravity decoupling one must decouple a rigid VM sector from the whole set of SDC U(1)’s, not only the graviphoton.

$$
\begin{array}{cc}
\text{VM's} \rightarrow & \begin{pmatrix} \text{Extremal} & & \\ & \begin{array}{c}\text{Rigid}\\ \text{non-decoupled}\end{array} & \\ & & \begin{array}{c}\text{Rigid}\\ \text{decoupled}\end{array} \end{pmatrix} \\
\text{Sectors:} & \begin{array}{ccc} \text{SDC} \qquad & \qquad \text{Extended RFT} & \quad \text{Core RFT} \end{array}
\end{array}
$$

Conclusions and Outlook

- Swampland criteria have proven to be particularly powerful in asymptotic regions of field space. We have used the SDC scale to formulate gravity-decoupling limits. These must be understood as a decoupling at the level of interactions.

- An important ingredient for such a decoupling is the lack of kinetic mixing. We have encoded this information at the level of charge vectors for particles and strings, which have a very different behaviour when their charge to mass ratio diverges. This allows to distinguish between SDC and two rigid sectors.

- A key ingredient is the presence of axionic shift symmetries, which provide a specific frame for the Kähler potential, as well as relations between charge vectors.

- Besides lack of mixing, one needs to impose decoupling at the level of Pauli interactions. This results in a divergence in the moduli space scalar curvature.

- We have mostly analysed the 4d N=2 CY VM moduli spaces, which have been recently classified in light of the SDC. However, the lessons extend to 4d N=1 settings. One simply needs to replace particles by membranes.


Thank you!