

Instituto de Física Teórica presents:

Six Lessons

on

Gravity Decoupling

by Fernando Marchesano

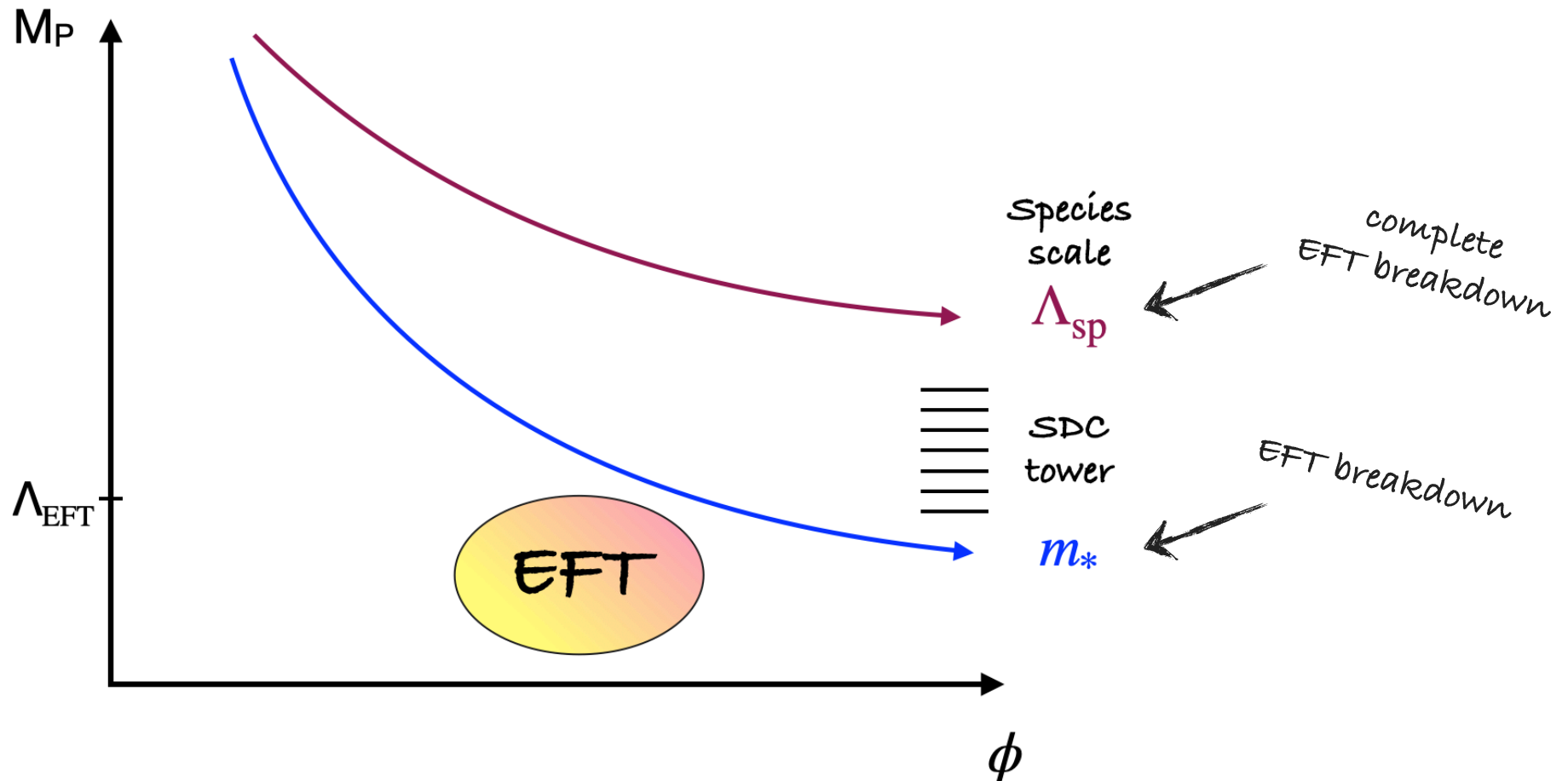
based on 2410.10966, 2602.04957 & WIP

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



Motivation: Distance Conjecture

Ooguri & Vafa '06



Interpretation #1:

$$\frac{M_P}{\Lambda_{\text{EFT}}} = \text{fixed} \quad \text{and} \quad \phi < \phi_{\text{max}}$$

Interpretation #2:

$$\phi \rightarrow \infty \quad \text{and} \quad \frac{M_P}{\Lambda_{\text{EFT}}} \rightarrow \infty \quad \rightarrow \quad \text{Gravity decoupling}$$

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).

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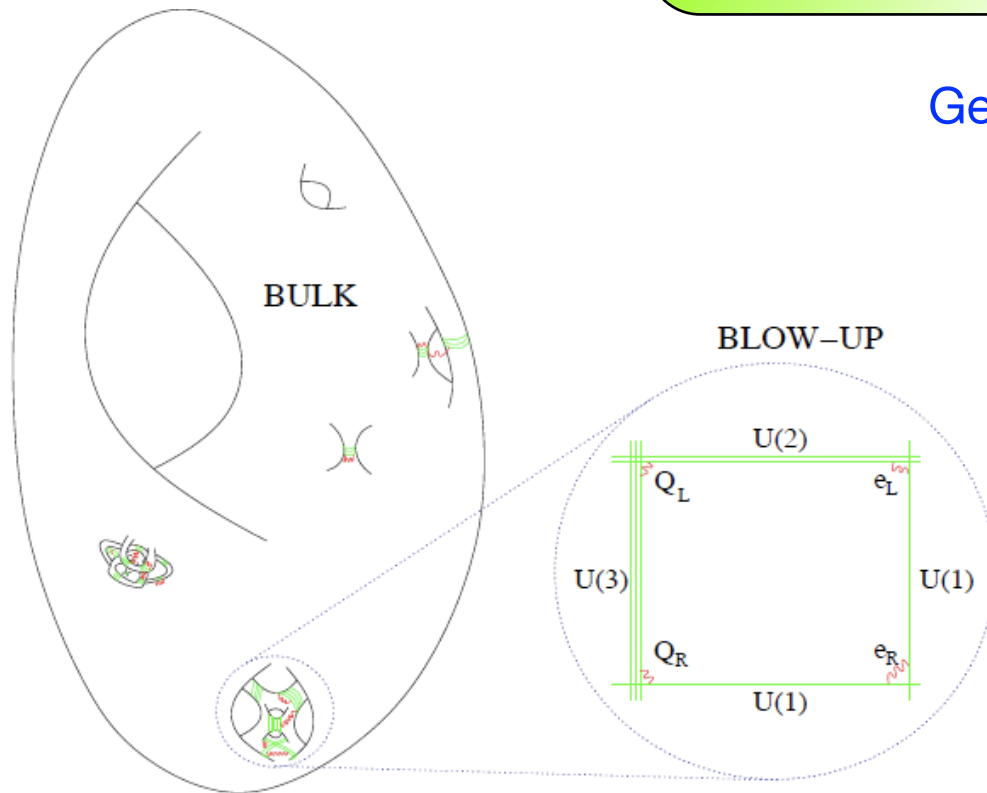
↙
*Mechanism involved
in gravity decoupling*

↘
*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*



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

taken from Conlon, Cremades, Zuevedo '06

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

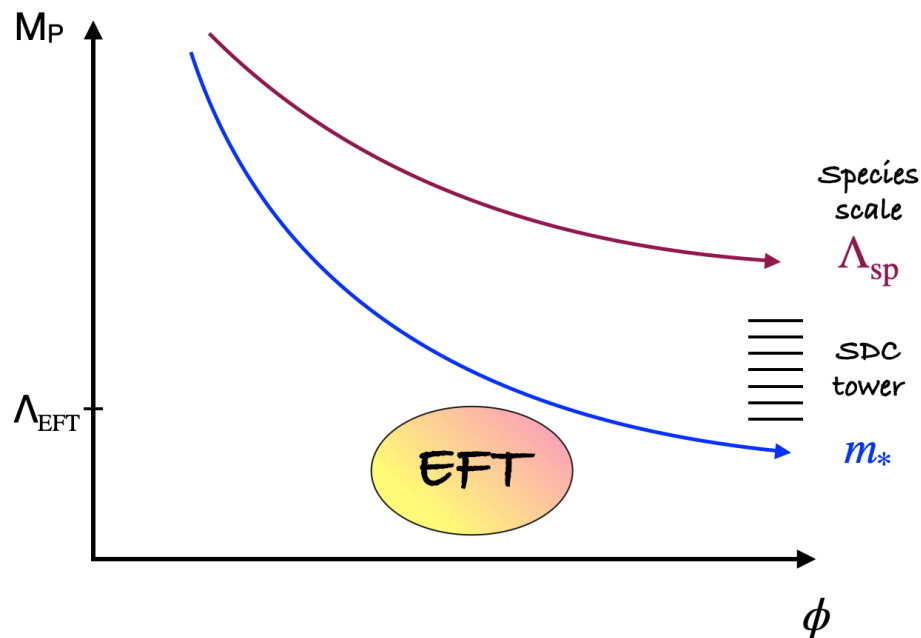
Gravity decoupling in string theory

Geometric engineering: exploits localisation properties of **Calabi-Yau manifolds** to decouple rigid theories from gravity.

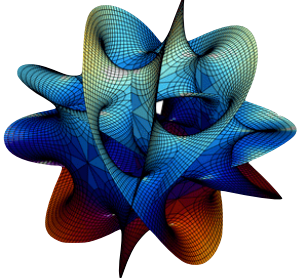
Katz, Klemm, Vafa '96

Type II on a CY: implemented via **infinite-distance vector multiplet limits**.

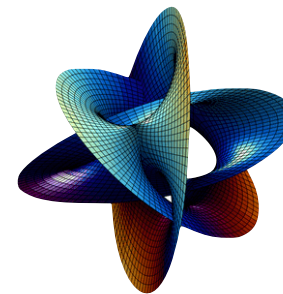
One recovers different classes of **4d N=2 rigid theories**:



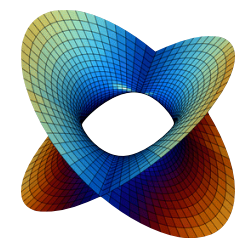

Seiberg-Witten theories



(dim. red.)
5d SCFTs



(dim. red.)
6d SCFTs



(dim. red.)
Little String Theories

Lee, Lerche, Weigand '19 Bastian, Grimm, van de Heisteeg '21

Castellano, F.M., Melotti, Paoloni, Wiesner '23-26

Combining two frameworks

Type II on a CY: implemented via infinite-distance vector multiplet limits.
One recovers different classes of 4d N=2 rigid theories:

Special Kähler geometry

Prepotential \mathcal{F}

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

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

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

Good notion of supergravity
vs. rigid couplings

Asymptotic Hodge theory

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

$$P_j \text{ nilpotent} \quad T^j = a^j + i s^j \rightarrow T^j + 1$$

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

Tailored to describe axionic
shift symmetries

Extends to 4d N=1

Schmid'73

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

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

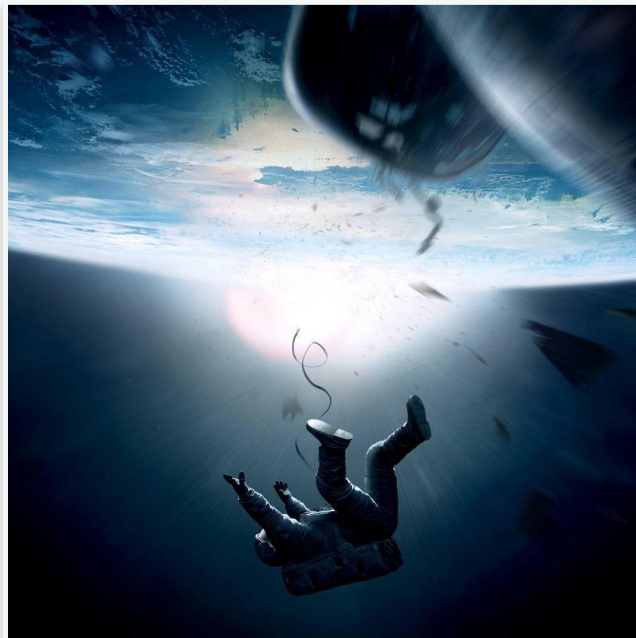
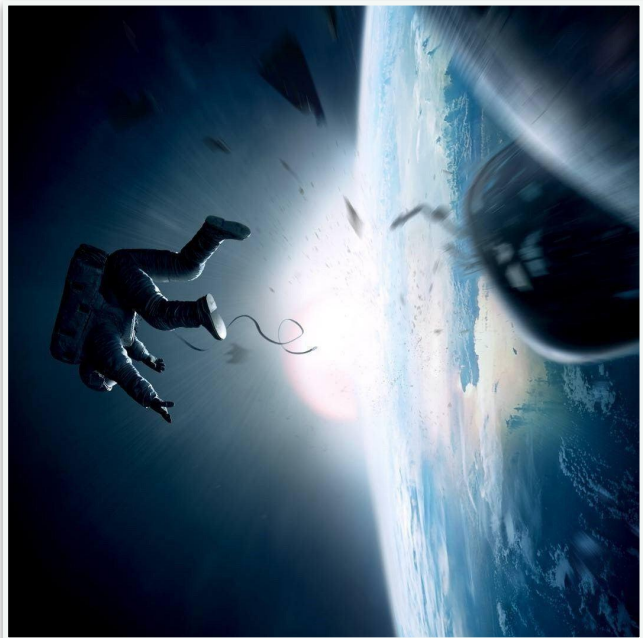
Corvilain, Grimm, Li, Palti, Valenzuela'18

Bastian, Grimm, van de Heisteeg'21

Hassfeld, Monnee, Weigand, Wiesner'25



SIX LESSONS





LESSON # 1

GRAVITY IS NOT ALONE

Extremal objects in asymptotic limits

Two kinds of BPS objects in terms of $\gamma \equiv Q/T$: ← *measures gravity relevance*

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

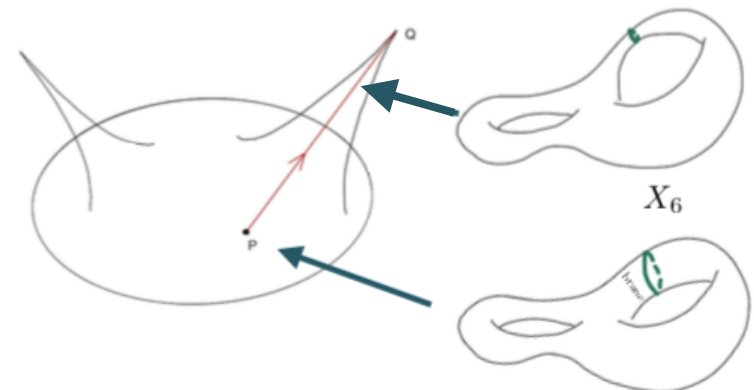
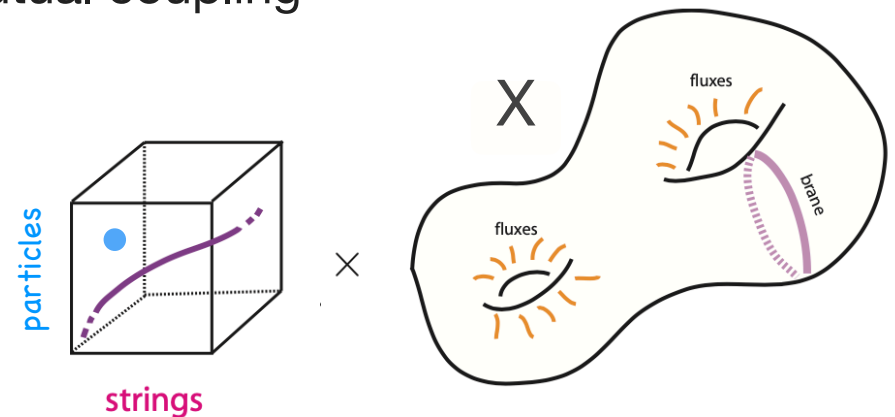
Axionic strings \rightarrow metric

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

Particles \rightarrow gauge couplings

$$Q_q^2 = 2|Z_q|^2 + Q_{q,\text{rigid}}^2$$

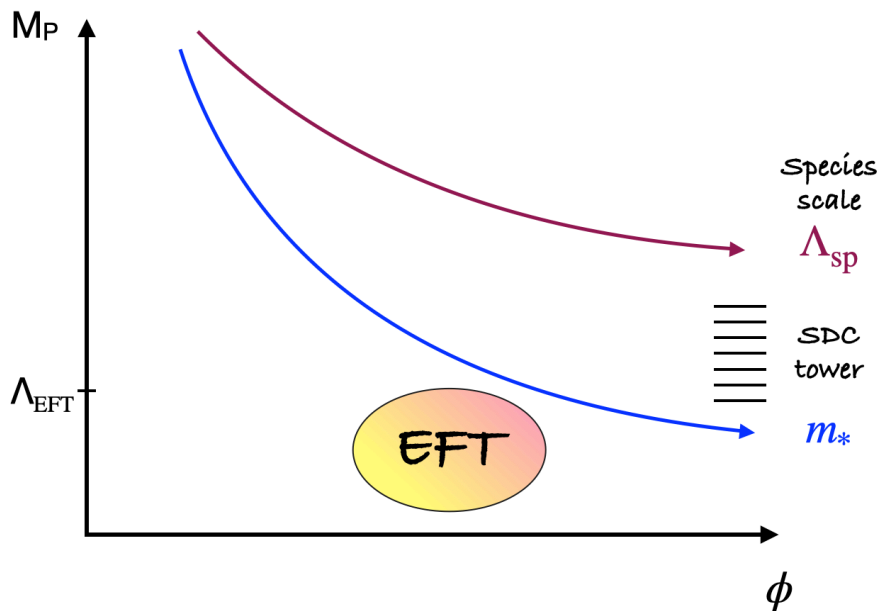
$$|Z_q| = e^{K/2} \left| q_I X^I - p^I \mathcal{F}_I \right| = m_q / M_{\text{P}}$$



Extremal objects in asymptotic limits

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

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



At infinite-distance limits:

- **Leading direction** \rightarrow axionic BPS extr. string
EFT strings: *Lanza, F.M., Martucci, Valenzuela '20-21*
- **SDC tower(s)** \rightarrow extremal BPS particles
Gendler & Valenzuela '20 *Bastian, Grimm, van de Heisteeg '20*

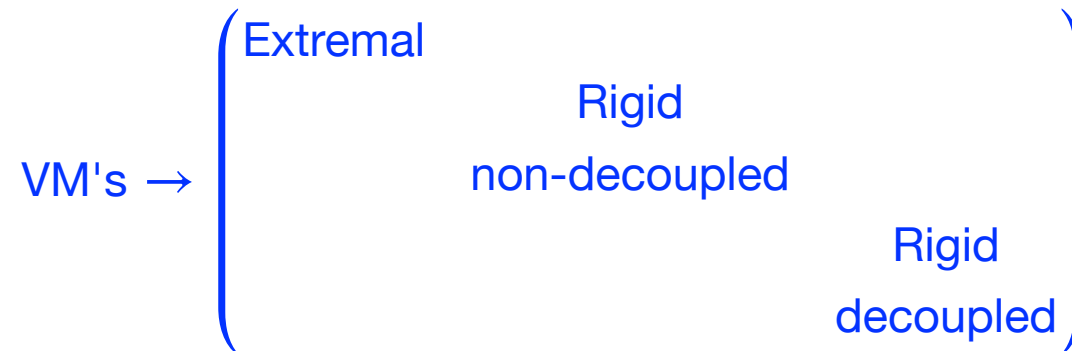
The graviphoton couples to more than one vector multiplet

The EFT structure of gravity decoupling

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

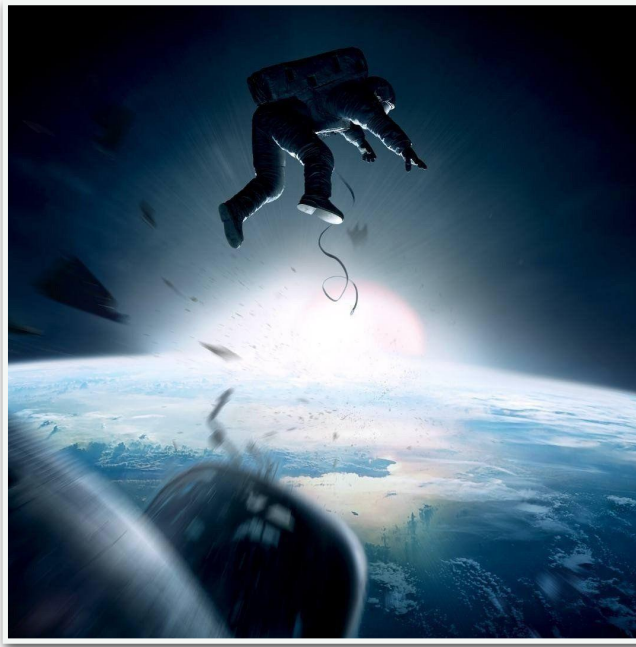
- ◆ BPS and extremal: $\gamma \sim \mathcal{O}(1) \rightarrow$ gravitational mutual coupling
- ◆ BPS and non-extremal $\gamma \rightarrow \infty \rightarrow$ rigid mutual coupling

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



Sectors: Gravitational Extended RFT Core RFT

10d picture (type IIA, LV): Nef divisor+pt. Non-effective growing divisors Shrinkable divisor



LESSON #2

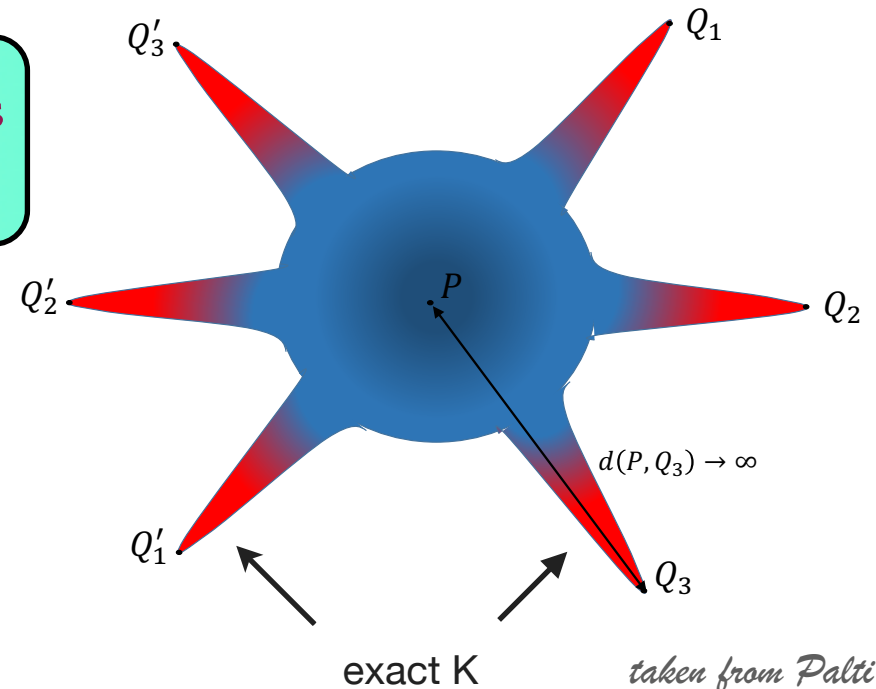
THERE IS A FAVOURITE K

The Kähler form and gravity decoupling

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

Komaragodski & Seiberg '10

Adams et al. '11



The Kähler form and gravity decoupling

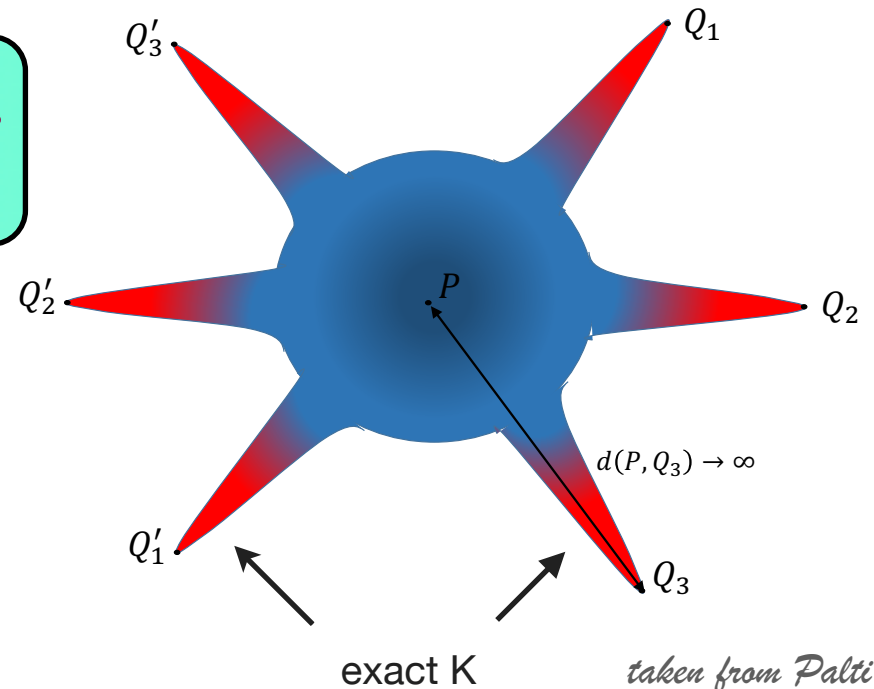
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Komaragodski & Seiberg '10

Adams et al. '11

How do we see this in asymptotic limits?

Period vector in the Nilpotent Orbit Theorem *Schmid '73*



$$\mathbf{\Pi} = e^{T^j P_j} \left(\mathbf{a}_0 + \sum_{r_j} \mathbf{a}_{r_1 \dots r_N} e^{2\pi i r_j T^j} \right) \quad P_j \text{ nilpotent}$$

$$\Omega = \Pi^A \sigma_A \quad \sigma_A \text{ basis of integer 3-forms}$$

Kähler transformation:

$$\Omega \rightarrow e^{-F} \Omega, \quad K \rightarrow K + F + \bar{F}$$

only compatible if F const.

$$\Rightarrow \vec{\nabla} K \text{ fixed!}$$

K and axionic shift symmetries

$$K_{\text{pol}} = -\log \left(i \Pi_{\text{pol}}^T \eta \bar{\Pi}_{\text{pol}} \right) \quad \Longleftarrow \quad \Pi = e^{T^j P_j} \left(\mathbf{a}_0 + \sum_{r_j} \mathbf{a}_{r_1 \dots r_N} e^{2\pi i r_j T^j} \right) = \Pi_{\text{pol}} + \Pi_{\text{exp}}$$

only depends on $t^j = \text{Im} T^j$ $\eta_{AB} = \int \sigma_A \wedge \sigma_B$

There is a number of **axionic shift symmetries** associated to K_{pol} , broken by Π_{exp}
 \implies extremal and rigid **BPS axionic strings** (If $\partial_i \partial_j K_{\text{pol}}$ is degenerate, further rigid axionic strings may arise or not, depending on essential instantons)

Their mass of these strings is computed as $\mathcal{T}_j / M_{\text{P}}^2 = \partial_j K \implies \vec{\nabla} K \text{ fixed}$

Lanza et al. '20-21

K and the Distance Conjecture

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

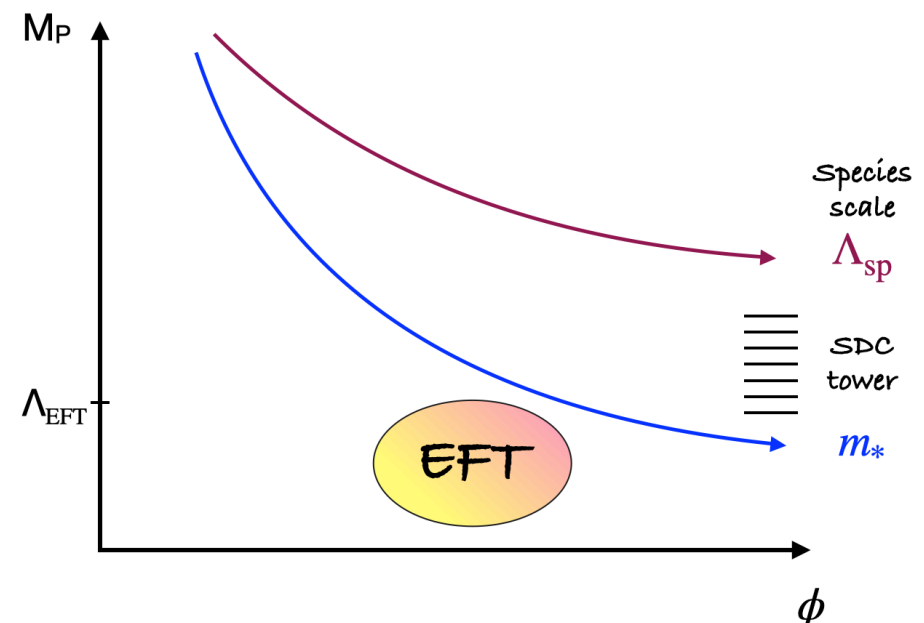
Another consequence is that the **lightest extremal particle** has a mass of the form

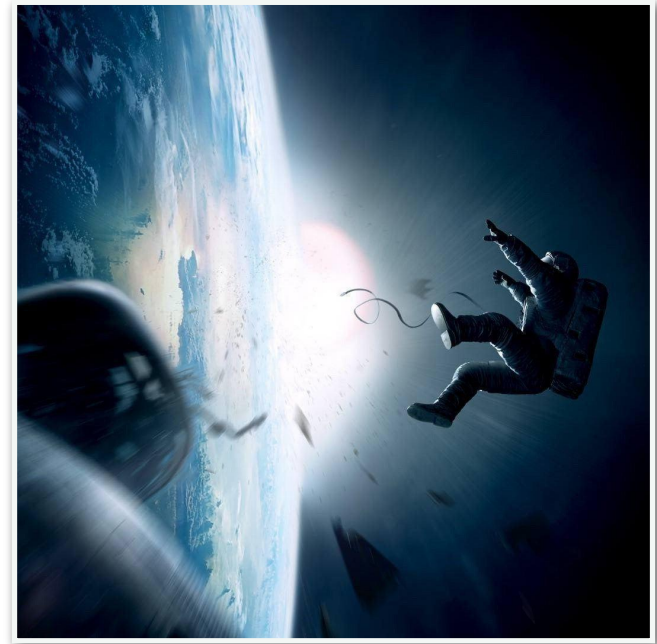
$$m_* = e^{K/2} a_* M_{\text{P}} \quad a_* \in \mathbb{R}_{>0} \implies \vec{\nabla} K \text{ fixed}$$

up to exponential corrections.

This is nothing but the **SDC scale**, and also coincides with the **RFT reference scale** m_{X^0}

*Castellano, F.M., Melotti,
Paoloni, Wiesner '23-26*





LESSON #3

KINETIC MIXING AS CHARGE VECTORS

Charge-to-mass vectors

No-force condition
between BPS particles

$$\frac{Q_q^2 M_{\text{P}}^2}{m_q^2} \equiv \gamma_q^2 = 1 + 2g^{ij} \partial_i \log \left(\frac{m_q}{M_{\text{P}}} \right) \partial_j \log \left(\frac{m_q}{M_{\text{P}}} \right)$$

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

Charge rep.

Gravity att.

Moduli exch. att.

$$\implies F_{\text{rep}} = F_{\text{att}}$$

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

$$\zeta_q^i \equiv -g^{ij} \partial_j \log \frac{m_q}{M_{\text{P}}}$$

Lee, Lerche, Weigand '19

Calderon-Infante, Uranga, Valenzuela '20

Etheredge et al. '22-24

Charge vectors and axionic shift symmetries

With the choice of Π , the charge vector for the SDC leading tower is

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

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

$$\vec{\xi}_e \equiv \frac{\vec{e}}{\mathcal{T}_e}$$

A straightforward computation gives

$$\vec{\zeta}_* \cdot \vec{\xi}_e = 1$$

In this setup, for the leading direction $\mathcal{T}_e^{1/2} \simeq \Lambda_{\text{sp}} \rightarrow$ species scale *F.M., Melotti '22*

$$\vec{\zeta}_* \cdot \vec{\xi}_e = 1 \implies \vec{\zeta}_{\text{SDC}} \cdot \vec{\zeta}_{\text{sp}} = \frac{1}{2} \text{ pattern observed in } \textit{Castellano, Ruiz, Valenzuela '23}$$

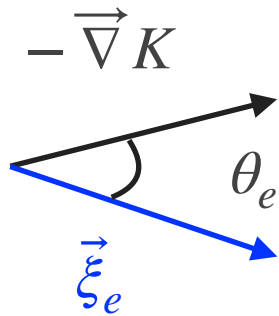
In this context, the pattern is a consequence of the axionic shift symmetry

Charge vectors and rigid limits

Another useful application of this result is the **relation with extremal and rigid strings**

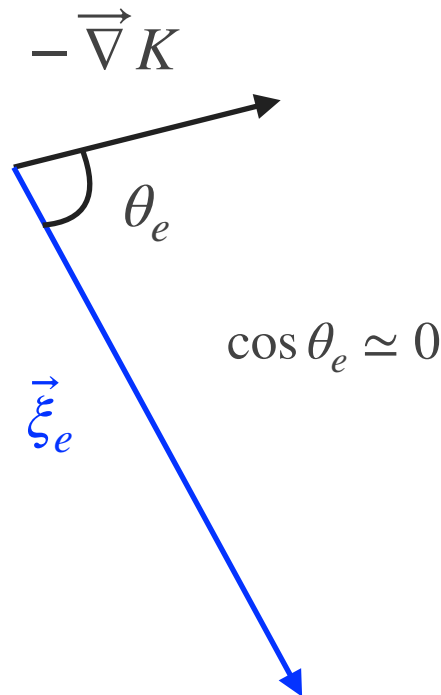
$$\vec{\zeta}_* \cdot \vec{\xi}_e = 1$$

Extremal string $\|\vec{\xi}_e\| = \mathcal{O}(1)$



$$\cos \theta_e = \frac{\vec{\zeta}_* \cdot \vec{\xi}_e}{\|\vec{\zeta}_*\| \|\vec{\xi}_e\|} = \mathcal{O}(1)$$

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



$$\cos \theta_e \simeq 0$$

This illustrates the **expansion of the Kähler potential** in rigid fields. Field directions that almost do not change K

$$\begin{aligned} K &= -M_{\text{P}}^2 \log \left(\mathcal{K}_{\text{ext}} - \mathcal{K}_{\text{rigid}} \right) \\ &= -M_{\text{P}}^2 \log \mathcal{K}_{\text{ext}} + m_*^2 \mathcal{K}_{\text{rigid}} + \dots \end{aligned}$$

Charge vectors and kinetic mixing

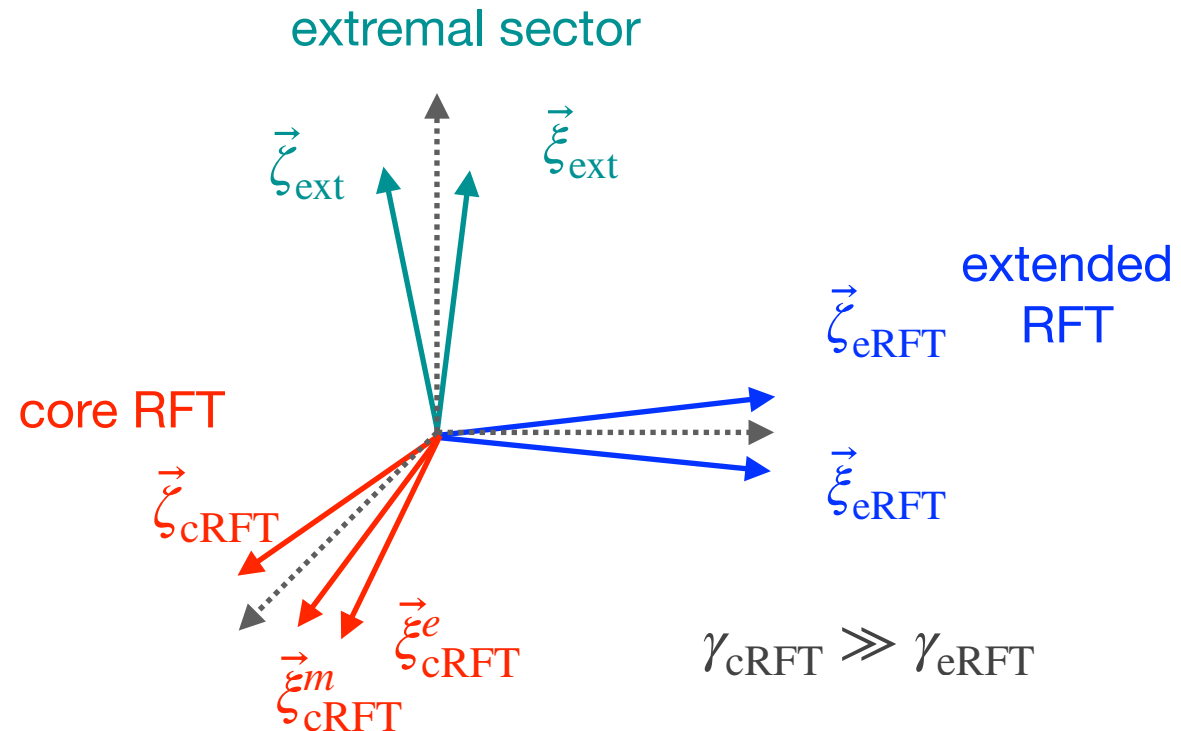
Together with **further bounds** one arrives at the following picture:

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

kinetic mixing

$$\frac{\vec{\xi}_p \cdot \vec{\xi}_q}{\|\vec{\xi}_p\| \|\vec{\xi}_q\|} \stackrel{\text{RFT}}{\simeq} \frac{Q_{pq}^2}{Q_{pp} Q_{qq}}$$

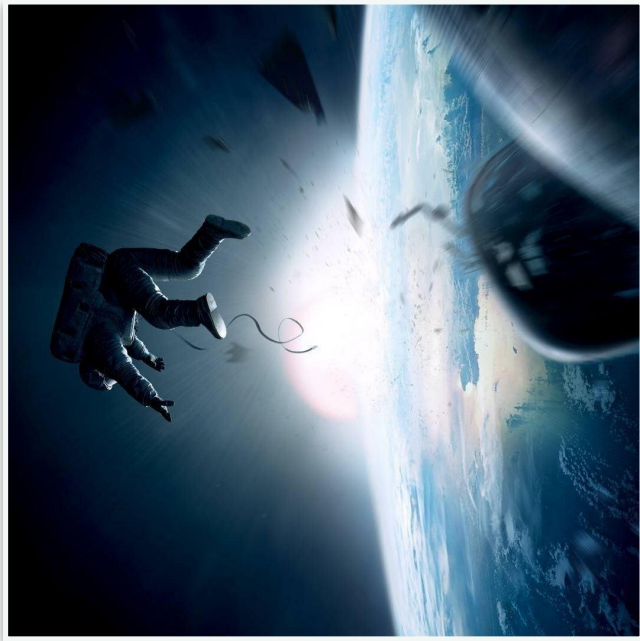
gauge kinetic mixing



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

LESSON #4

FULL DECOUPLING AND THE MODULI SPACE CURVATURE



Mixing at the level of interactions

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.



In our setup,* such interactions are Pauli couplings:

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

↑
gauge kinetic term

* Exception: 4d
N=4 rigid sectors

The Moduli Space Curvature

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

$$R = -n_V(n_V + 1) + \|P\|_{\text{Ext}}^2 + \|P\|_{\text{RFT}_1}^2 + \|P\|_{\text{RFT}_2}^2 + \|P\|_{\text{mixed}}^2$$

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

Geometric intuition:

$$R_{\mu\bar{\mu}\mu\bar{\mu}} \simeq \frac{1}{2} P_{M\mu\mu} \bar{P}_{N\bar{\mu}\bar{\mu}} \mathcal{F}^{MN} = \frac{m_*^2}{M_{\text{P}}^2} R_{\mu\bar{\mu}\mu\bar{\mu}}^{\text{rigid}} + \|P\|_{\text{mixed}}^2$$

Either negligible or we cannot integrate out fields with $M \neq \mu$

In all cases, this leads to a **curvature divergence**:

$$R_{\text{div}} \simeq \frac{M_{\text{P}}^2}{m_*^2} R_{\text{rigid}} \lesssim \max \gamma_{\text{RFT}_i}^2$$

$$R_{\text{rigid}} = G^{\mu\bar{\nu}} G^{\rho\bar{\sigma}} G^{\tau\bar{\eta}} \mathcal{F}_{\mu\rho\tau} \bar{\mathcal{F}}_{\bar{\nu}\bar{\sigma}\bar{\eta}}$$

$$R \rightarrow \infty \implies \text{RFT limit}$$

Curvature Criterion

LESSON #5

DECOUPLING AT THE LEVEL OF MONODROMIES



The Core RFT

Not all RFT sectors can achieve full decoupling. To source a curvature divergence, **a necessary condition** must be satisfied by the **monodromy group**
→ **core RFT** definition

$$e^{k^i P_i} = \begin{pmatrix} M_{\text{Ext+RFT}_i} & 0 \\ 0 & M_{\text{cRFT}} \end{pmatrix} \quad \swarrow \begin{array}{l} \text{Block diagonal} \\ \text{structure, involving} \\ \text{electro-magnetic pairs} \end{array}$$

Consequences:

- The decoupling also occurs at the level of the theta angles.
- All core RFT interactions with **Planckian vevs are exponentially suppressed**
- The core RFT hosts the largest γ divergences.

LESSON #6

DECOUPLING AND EFFECTIVE CYCLES



Effective cycles and RFT towers

In all examples where the core RFT decouples, there is some **effective cycle in the local geometry** that describes it.

At some scale Λ_{ch} there is some **tower of states with unbound charges** under the core RFT

F.M. Melotti, Wiesner '24

\implies **rigid UV completion scale**

Examples: SW dyon tower, 5d SCFT tower, LST tower, hyper + 6d KK bound states, ...

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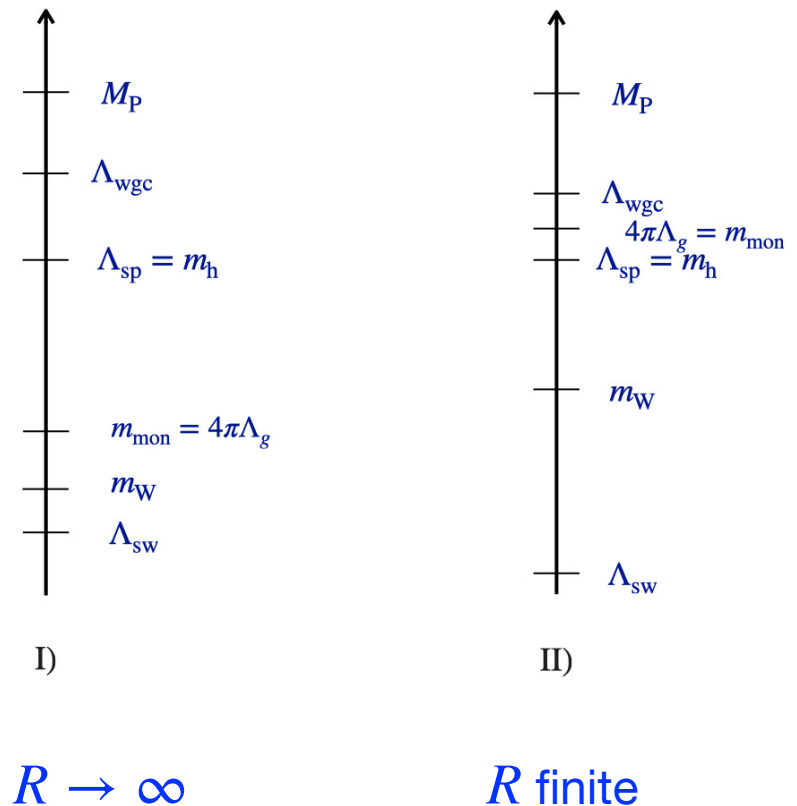
Examples: SW dyon tower, 5d SCFT tower, LST tower, hyper + 6d KK bound states, ...

SW case

full decoupling \iff **dyon SW tower decouples from species scale**

Rigid UV scale \ll gravity UV scale

F.M. Melotti, Wiesner '24



Quotients of scales

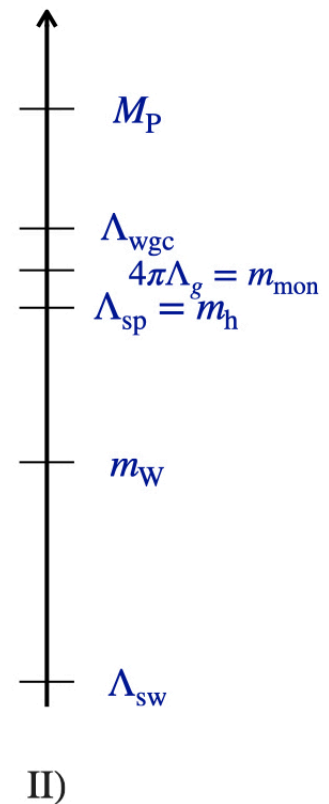
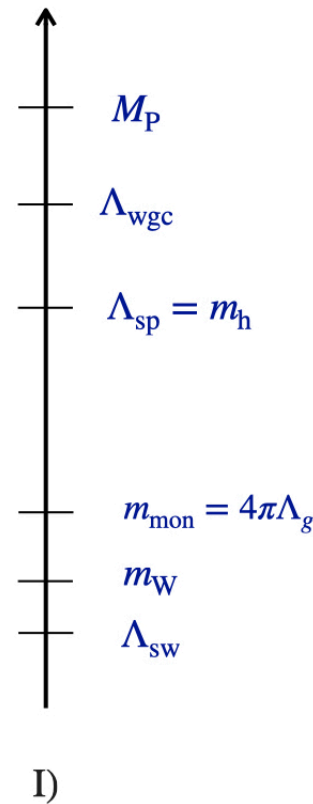
Is this a **general lesson**? Yes and No



$$R \rightarrow \infty \iff \Lambda_{\text{ch}}/\Lambda_{\text{sp}} \rightarrow 0 ??$$

Exception: emergent string limits whose **core RFT** is the dimensional reduction of an **LST**. In this case, the standard field theory mechanism of decoupling do not need to be at play.

Using quotients of scales to measure gravity decoupling is only partially successful. The only **general criterion** seems to be the **curvature divergence**.



Conclusions

- **Swampland criteria** have proven to be particularly powerful in **asymptotic regions** of field space. Here we have focused on **gravity-decoupling rigid 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 extremal/gravitational and rigid sectors.
- A key ingredient of this analysis is the presence of **axionic shift symmetries**, related to **monodromies**, which provide a particular frame for the Kähler potential, as well as several 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.

An astronaut in a white space suit is floating upside down in the dark void of space. The Earth's blue and white clouds are visible in the upper half of the frame. A bright light source, likely the sun, is positioned behind the text, creating a lens flare effect. The overall scene is dynamic and celebratory.

Thank you!