String Motivated Strongly Coupled Extra Sectors

Jonathan J. Heckman

University of Pennsylvania

Based On

hep-ph/xxxx.xxxxx w/ Adshead, Melcher, Watson

hep-th/xxxx.xxxxx w/ Balasubramanian, Lipeles

See also:

hep-th/1608.06635 w/ Del Zotto, Kumar, Malekian, Wecht

hep-th/1102.5346 w/ Rey

Outline

- Stringy Extra Sectors
- Pre / Reheating and Vis / Extra Mixing
- Entanglement and Random Couplings

Stringy Extra Sectors

Strings $\to$ 4D Physics

Common Features:

- Higher Dim $\to$ 4D ("compactification")
  ("moduli" remnants of $D > 4$ gravity)

- Standard Model Sector
  (many constructions in Heterotic, M-, F-theory)

- Extra Sectors
  (Required by Gauss' Law / Tadpole Constraints)

Strings $\rightarrow$ 4D Physics

Focus for today

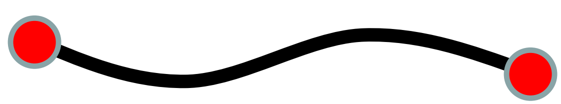
- Extra Sectors
  (Required by Gauss' Law / Tadpole Constraints)

Example: F-theory Models

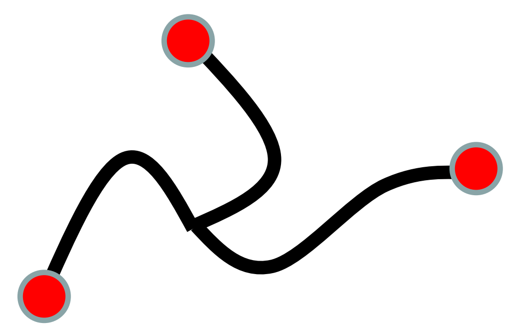
c.f. JJH et al. + many; 2008 - present

In F-theory, $g_{\text{string}} \sim O(1) \Rightarrow$ String Bound States

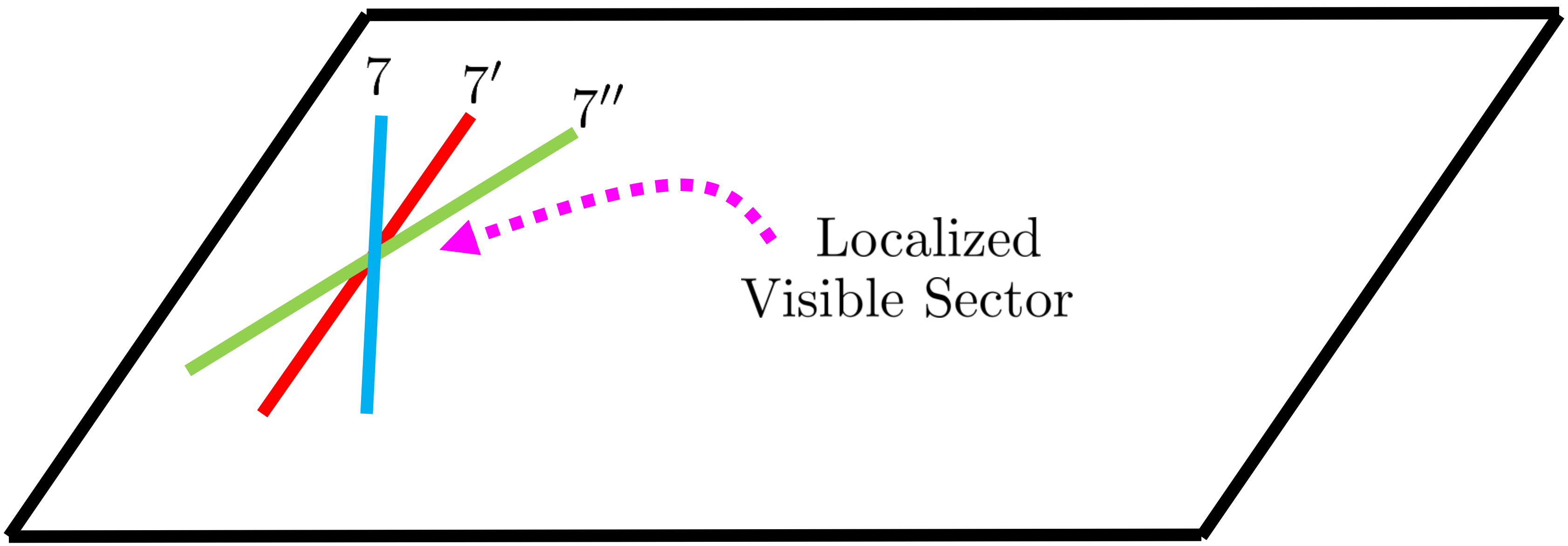
$g_{\text{string}} \ll 1$



$g_{\text{string}} \sim O(1)$



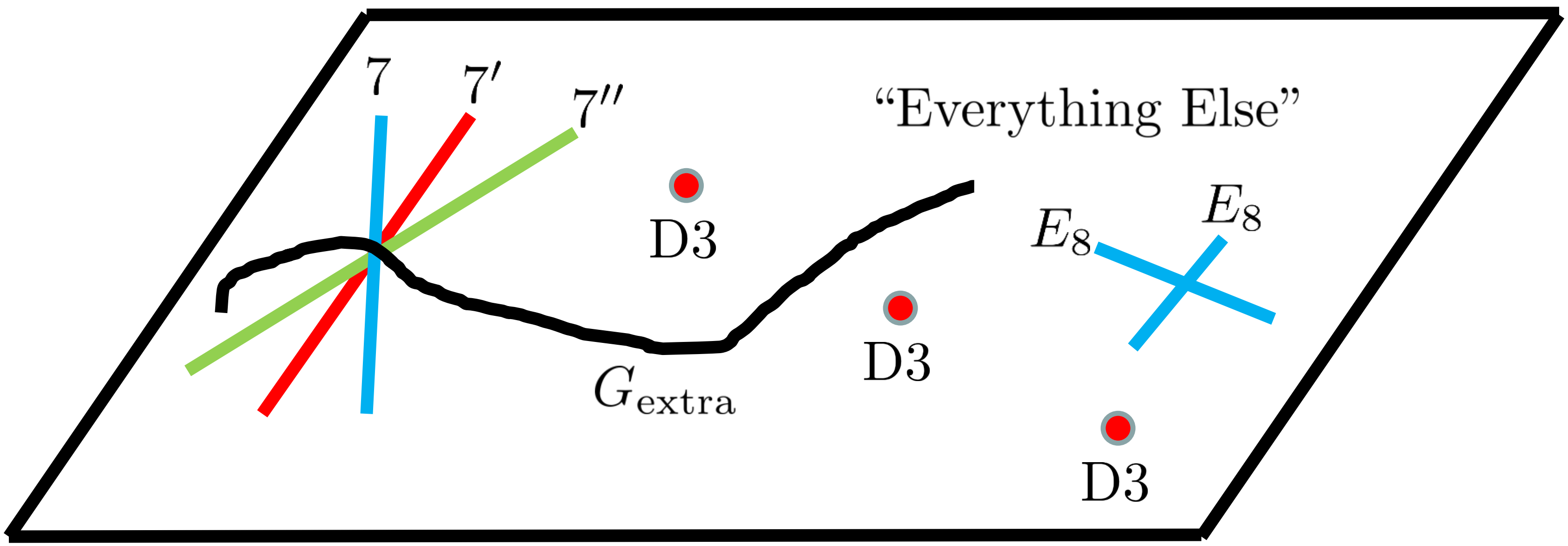
Example: F-theory Models



6 Extra Dimensions

+ Everything Else

(required by Gauss' law for brane charges)



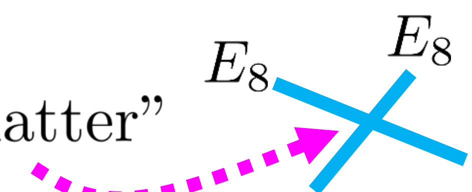
6 Extra Dimensions

Kinds of Extra Sectors

- D3-branes (fills 4D spacetime, point in 6_{extra})

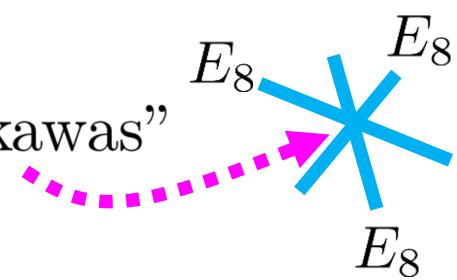
  JJH Vafa '10; JJH Rey '11; JJH '15;....

- $G \cap G'$ 7-branes "6D conformal matter"



  JJH et al. + many '13 - present

- $G \cap G' \cap G''$ 7-branes "4D conformal Yukawas"



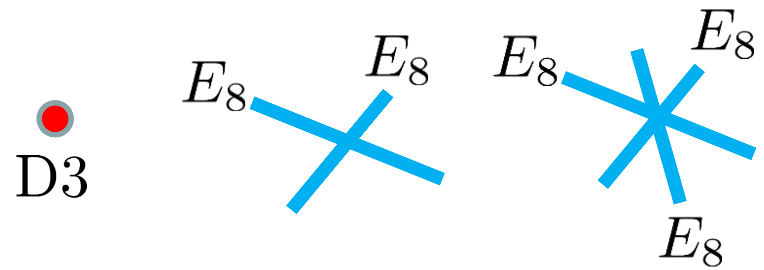
  Apruzzi JJH Morrison Tizzano '18

“Genericity”

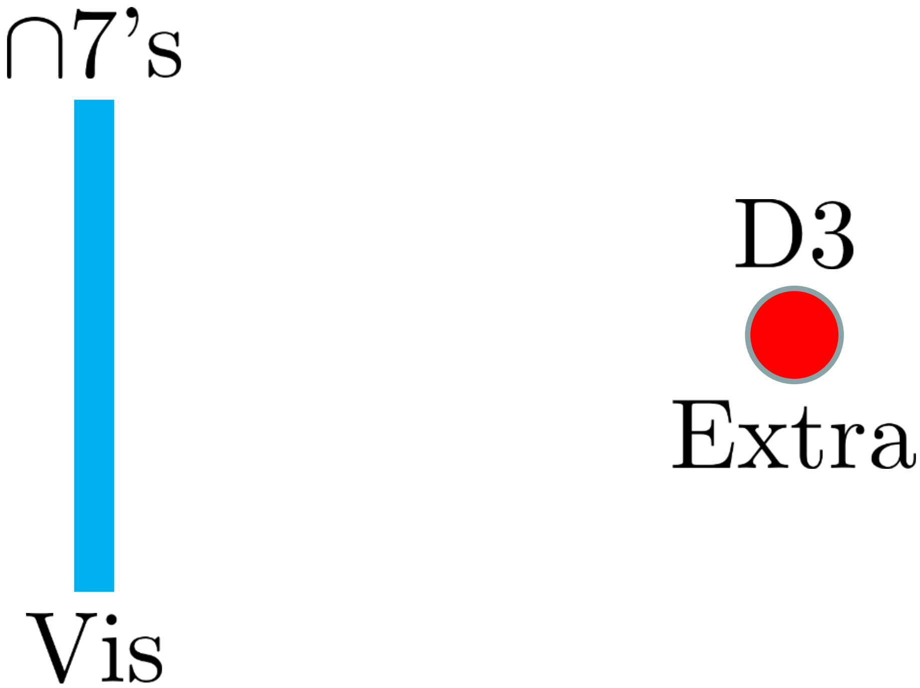
A Typical F-th Compactification has many such sectors...

(e.g. Taylor Wang ’17)

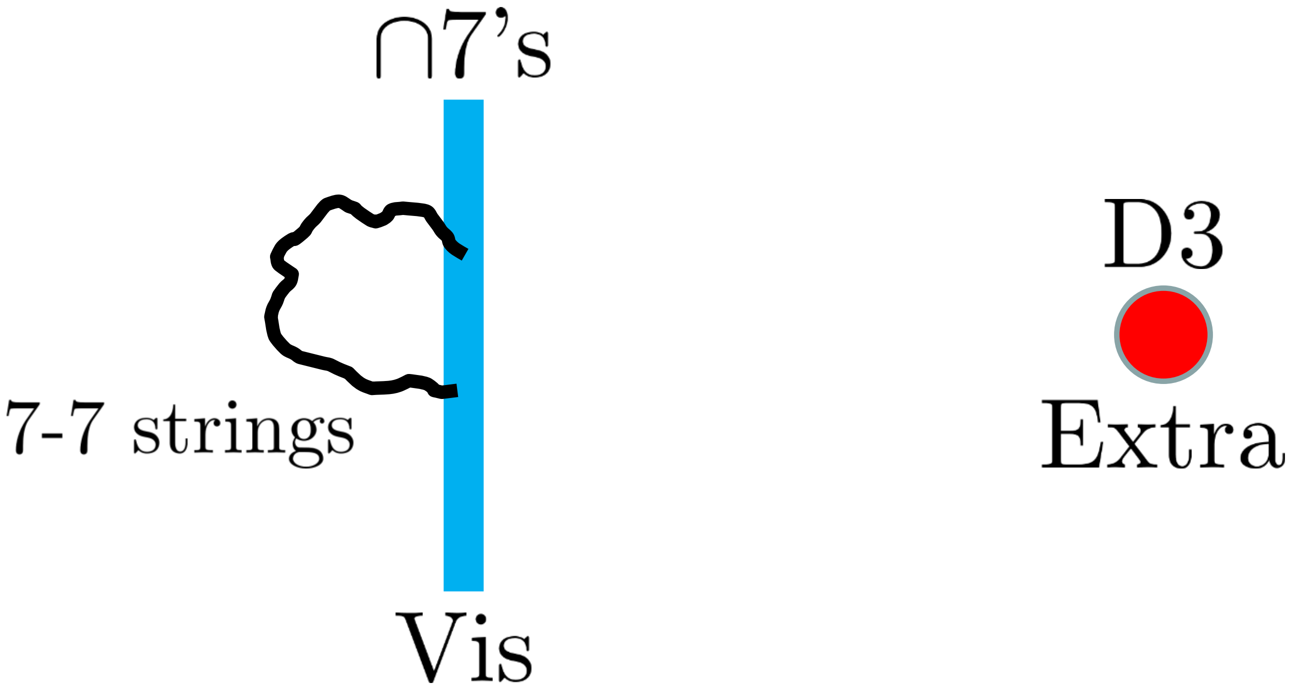
And usually, strongly coupled:



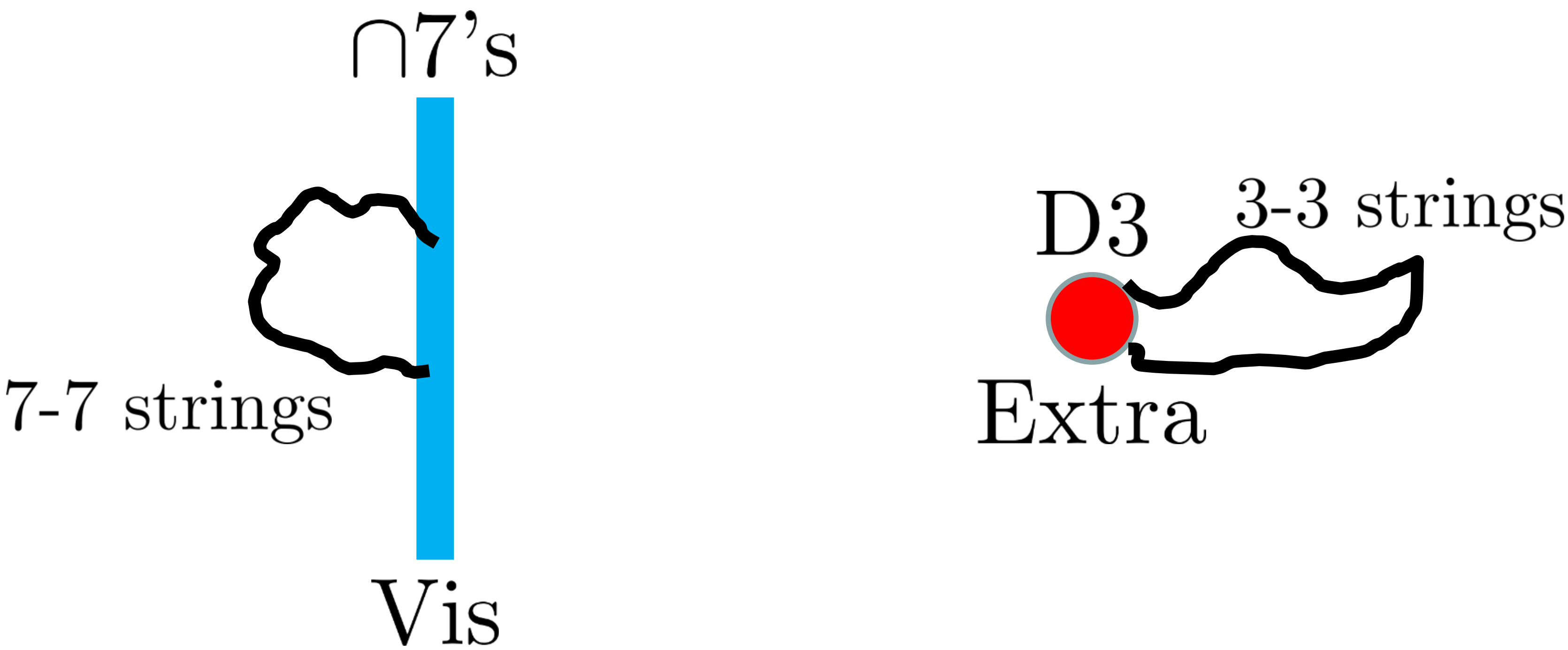
¿Mixing?



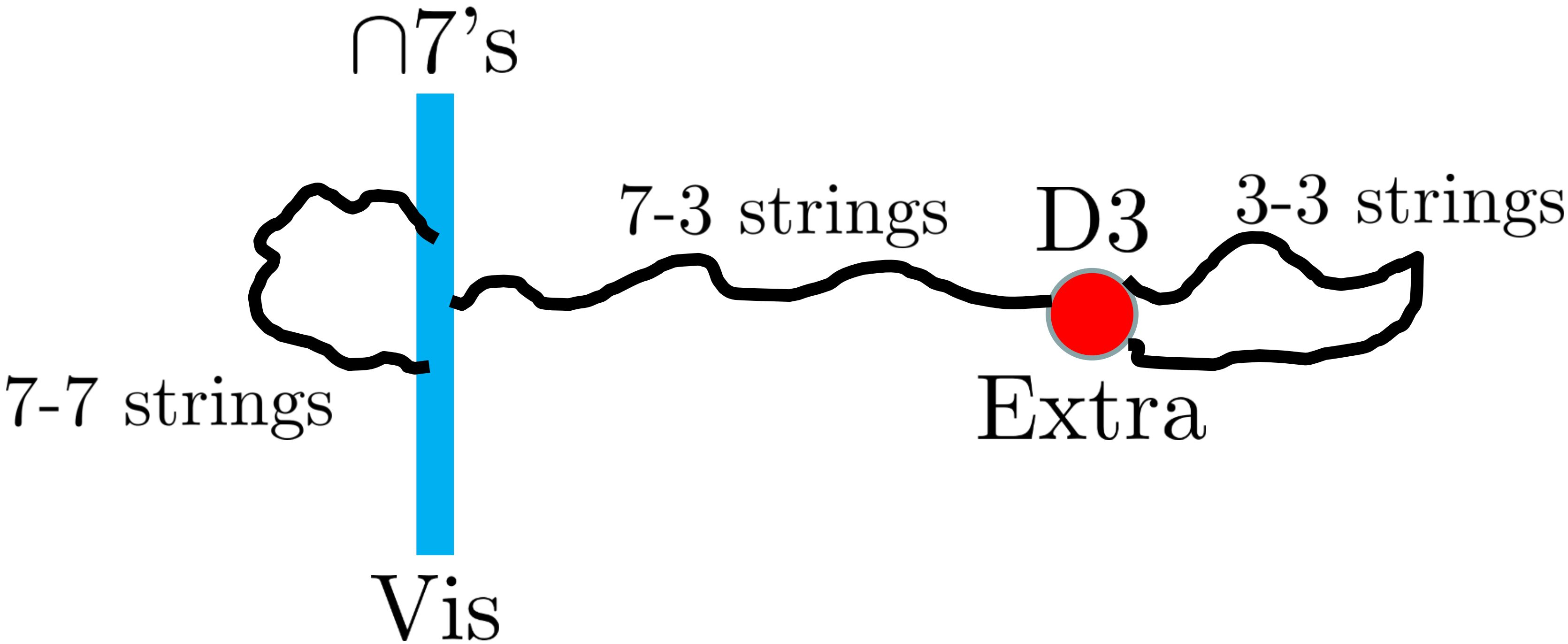
¿Mixing?



¿Mixing?



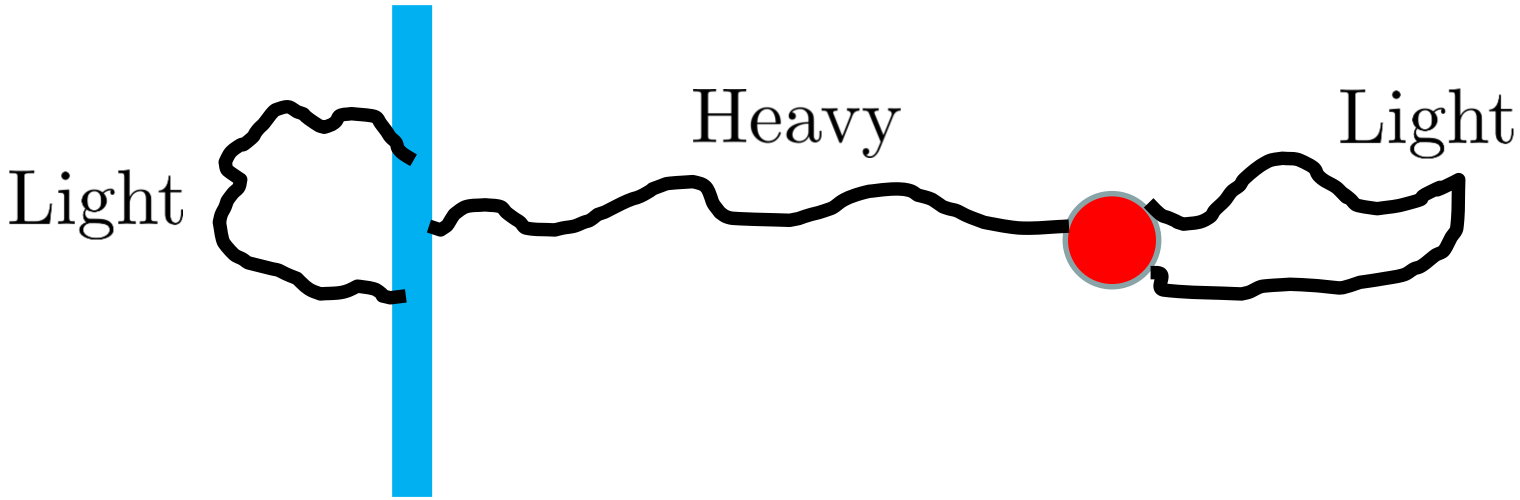
¿Mixing?



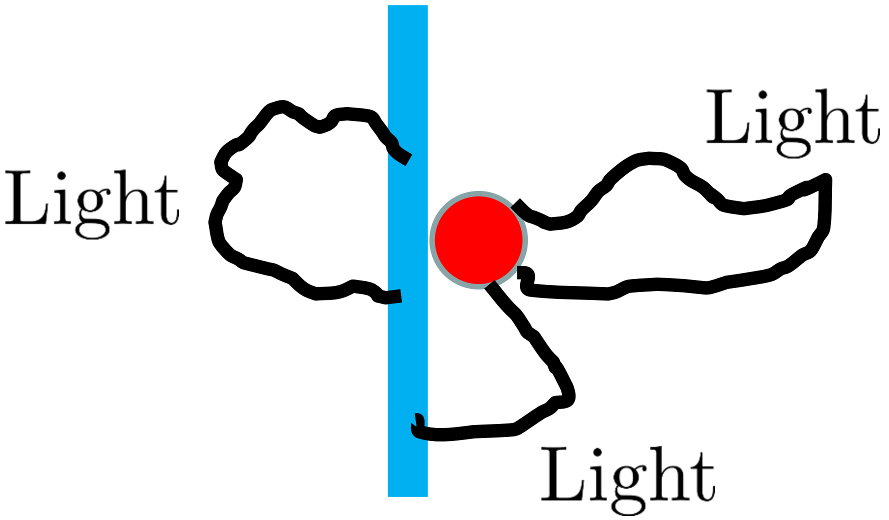
Mass Scales

$$\text{Mass} \sim \frac{\text{Length}}{\ell_{\text{string}}^2}$$

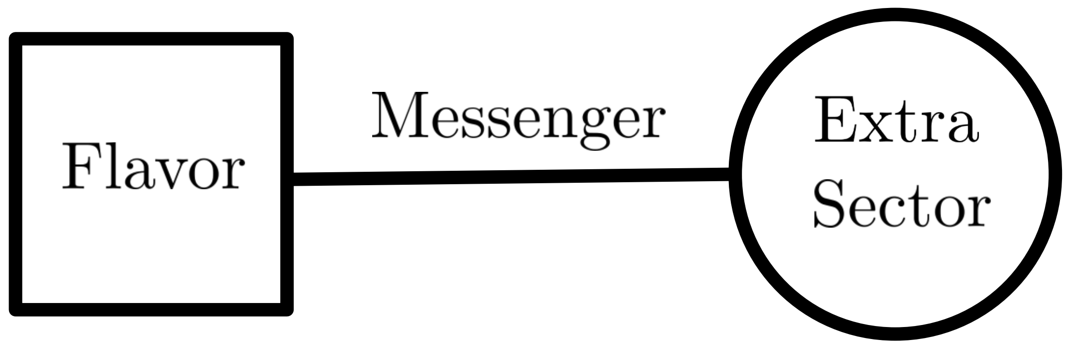
¿Mixing?



¿Mixing?



Field Theory Picture



$$G_{\text{Flavor}} \supset SU(3) \times SU(2) \times U(1)$$

EFT of Extra Sector

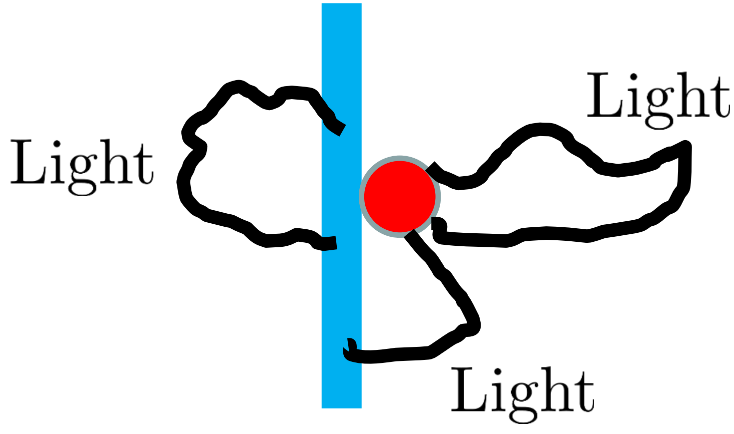
Two qualitative regimes:

- Messengers $\approx$ Massless
- Messengers $\approx$ Very Heavy (Integrate Out)

EFT of Extra Sector

Two qualitative regimes:

- Messengers $\approx$ Massless



¿Messengers $\approx$ Massless?

Can often approximate extra sector as

Deformation of a 4D $\mathcal{N} = 2$ SCFT

(much more calculable)

An Example

Minahan Nemeschansky '96

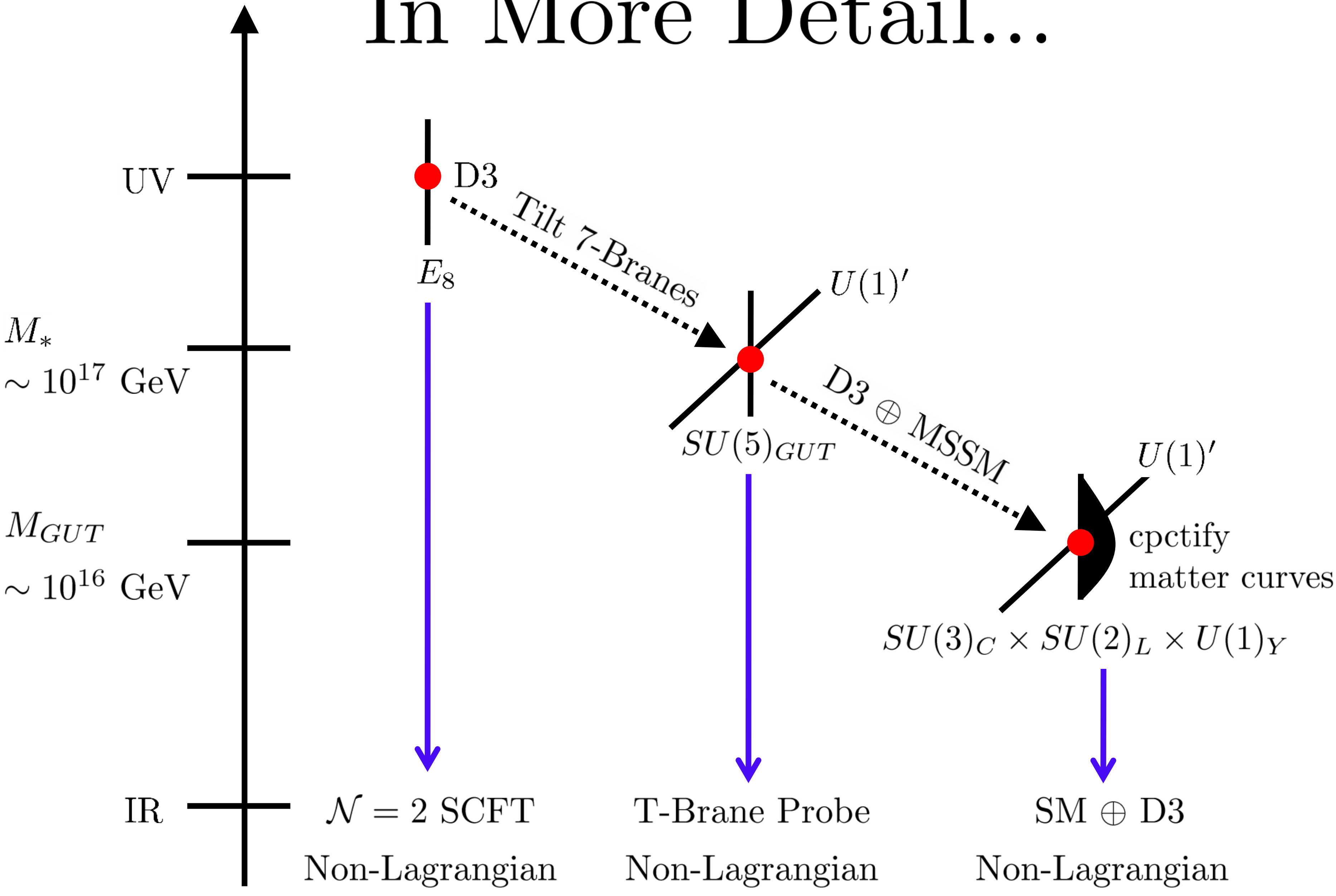
$\mathcal{N} = 2$ SCFT with E_8 flavor symmetry

$$\downarrow \quad \int d^2\theta \; \mathrm{Tr}_{E_8}(m_{248} \cdot \mathcal{O}_{248})$$

Huge class of $\mathcal{N} = 1$ SCFTs

JJH Tachikawa Vafa Wecht '10 ; Apruzzi Hassler JJH Rochais '18

In More Detail...



Computables

- $\frac{d}{d\log\mu}\left(\alpha_{\rm vis}^{-1}\right) \sim b_{\rm extra} \sim O(1) - O(10) \times b_{\rm fundamental}$

Computables

- $\frac{d}{d\log\mu}\left(\alpha_{\rm vis}^{-1}\right) \sim b_{\rm extra} \sim O(1) - O(10) \times b_{\rm fundamental}$

- $g_*(\text{extra}) \sim 200 \times a_{\rm CFT}$

  Recall $g_*(\text{MSSM}) \sim 228.75$

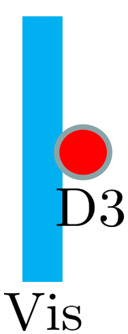
Computables

- $\frac{d}{d\log\mu}\left(\alpha_{\rm vis}^{-1}\right) \sim b_{\rm extra} \sim O(1) - O(10) \times b_{\rm fundamental}$

- $g_*(\text{extra}) \sim 200 \times a_{\rm CFT}$

  Recall $g_*(\text{MSSM}) \sim 228.75$

Example:



$g_*(\text{extra}) \sim 200 - 700$

Rey JJH '11; JJH Vafa Wecht '11

Apruzzi Hassler JJH Rochais '18

EFT of Extra Sector

Two qualitative regimes:

- Messengers $\approx$ Massless

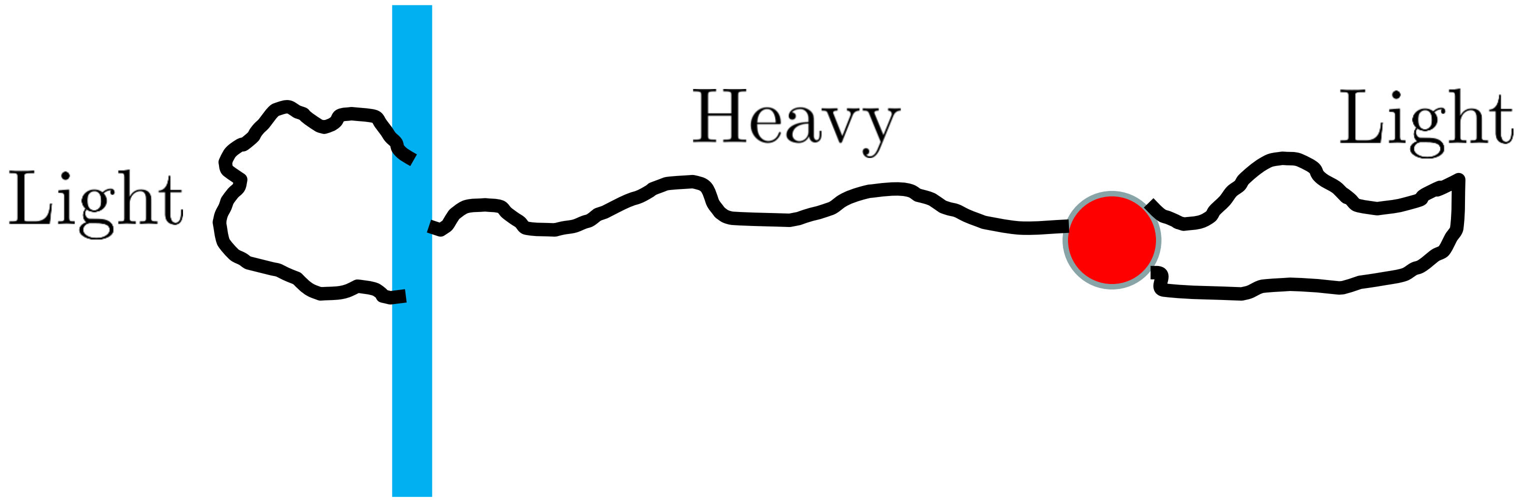
- Messengers $\approx$ Very Heavy (Integrate Out)

EFT of Extra Sector

Two qualitative regimes:

- Messengers $\approx$ Very Heavy (Integrate Out)

¿Mixing?



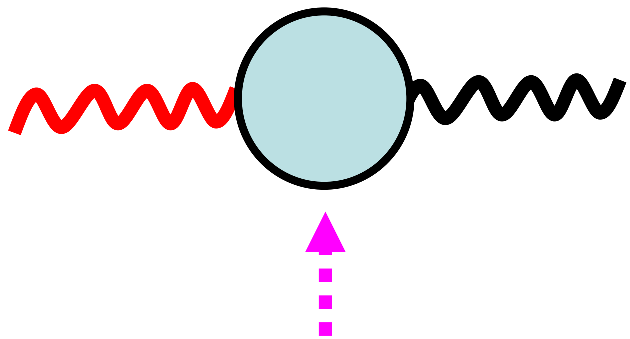
¿Messengers $\approx$ Heavy?

Can often approximate extra sector as

Deformation of a 4D $\mathcal{N} = 2$ $U(1)$ Gauge Theory

(calculable via Seiberg-Witten theory)

Computables: Kinetic Mixing



JJH Kumar Malekian Wecht '17, JJH Hassler Rochais (in progress)

Computables: Kinetic Mixing

$$L_{U(1)'s} = \sum_{i=1}^{2} \sum_{j=1}^{2} \left[-\frac{1}{4g_{i,j}^2} F_{\mu\nu}^{(i)} F_{\mu\nu}^{(j)} + \frac{\theta_{i,j}}{32\pi^2} F_{\mu\nu}^{(i)} \widetilde{F}_{\mu\nu}^{(j)} \right]$$

Electric Mixing

Magnetic Mixing

Outline

- Stringy Extra Sectors

- Pre / Reheating and Vis / Extra Mixing

- Entanglement and Random Couplings

A Scenario: D3 / D7 Inflation

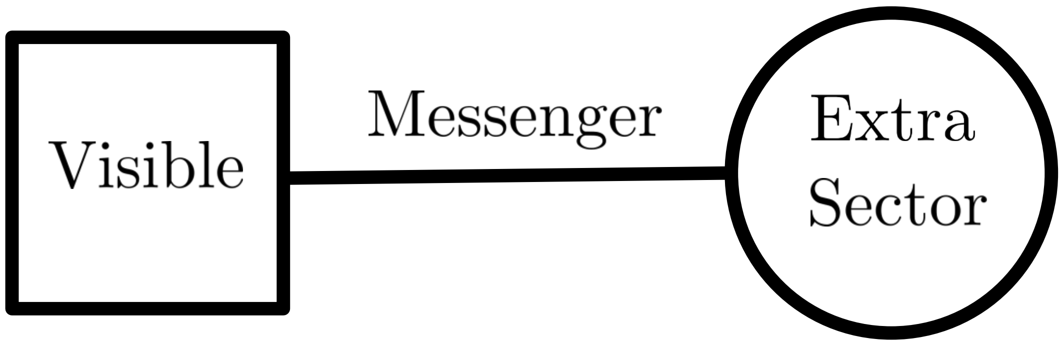
see e.g. Haack et al. '08; Burgess et al. '08

Consider position of D3 (it's a field):

In this talk: *Assume* Slow Roll Inflation (or a close cousin)

Focus: Particle Production

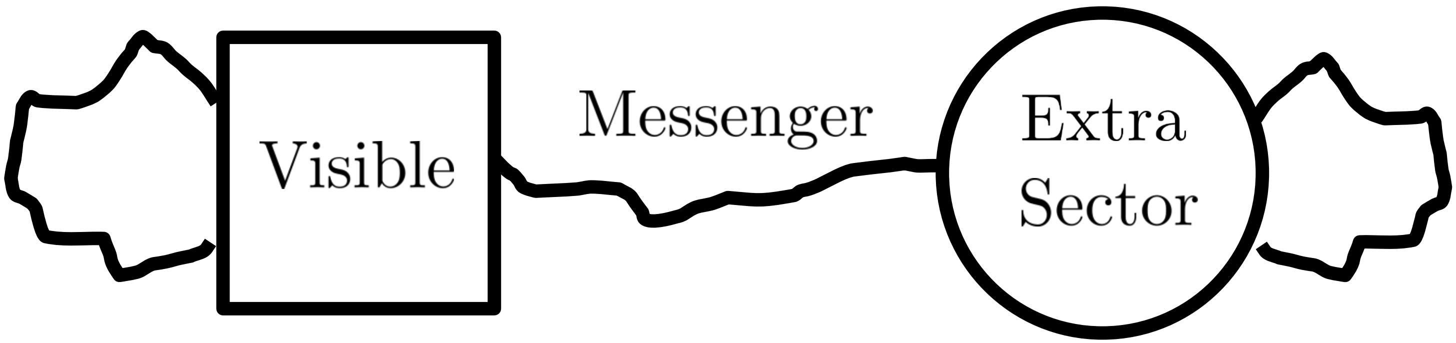
Particle Production

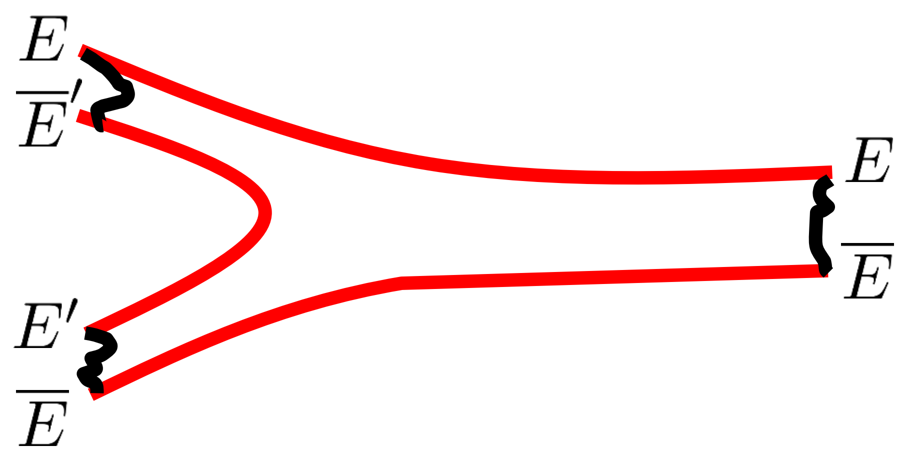


$$\text{Extras} \leftarrow \Phi_{\text{inf}}$$

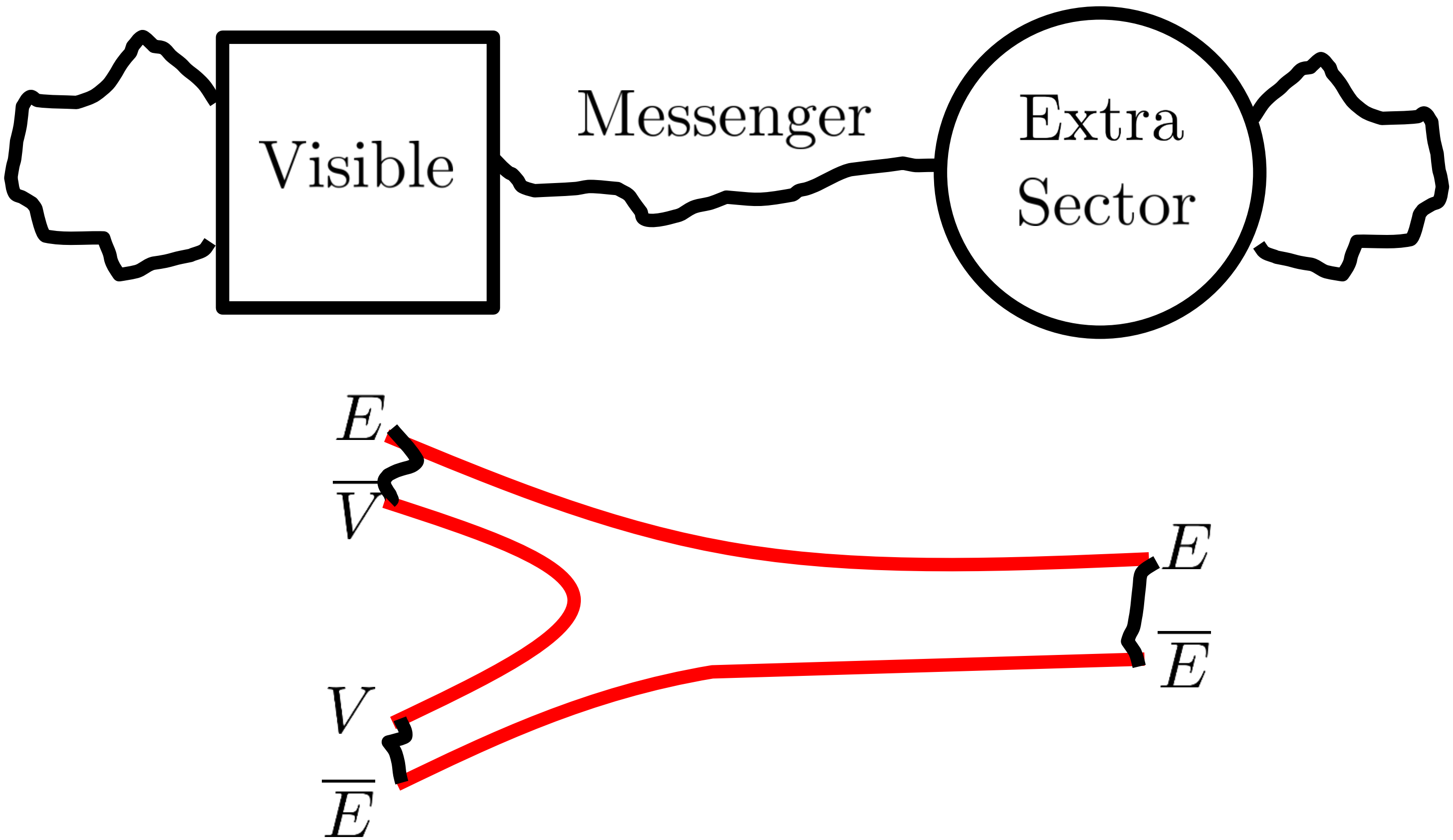
$$\text{Messengers} \leftarrow \Phi_{\text{inf}}$$

$\text{Extras} \leftarrow \Phi_{\text{inf}}$

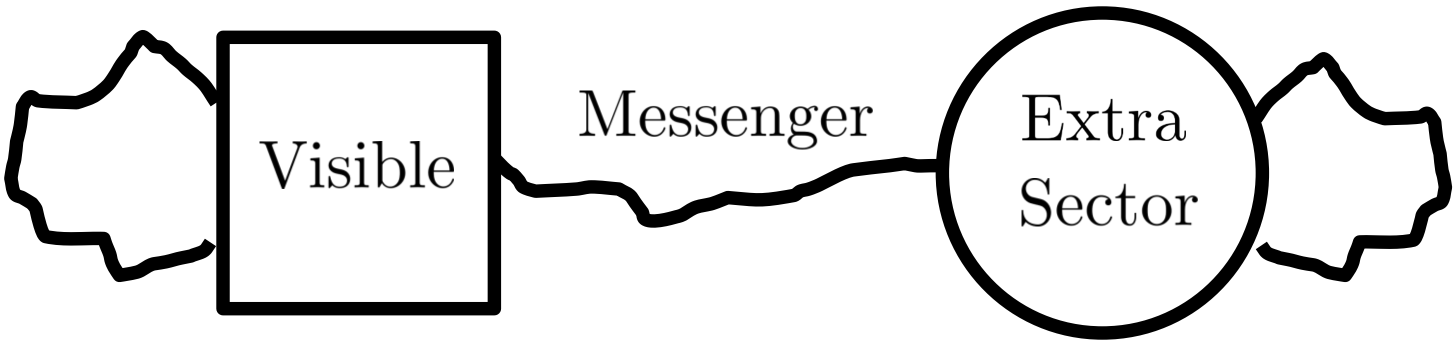


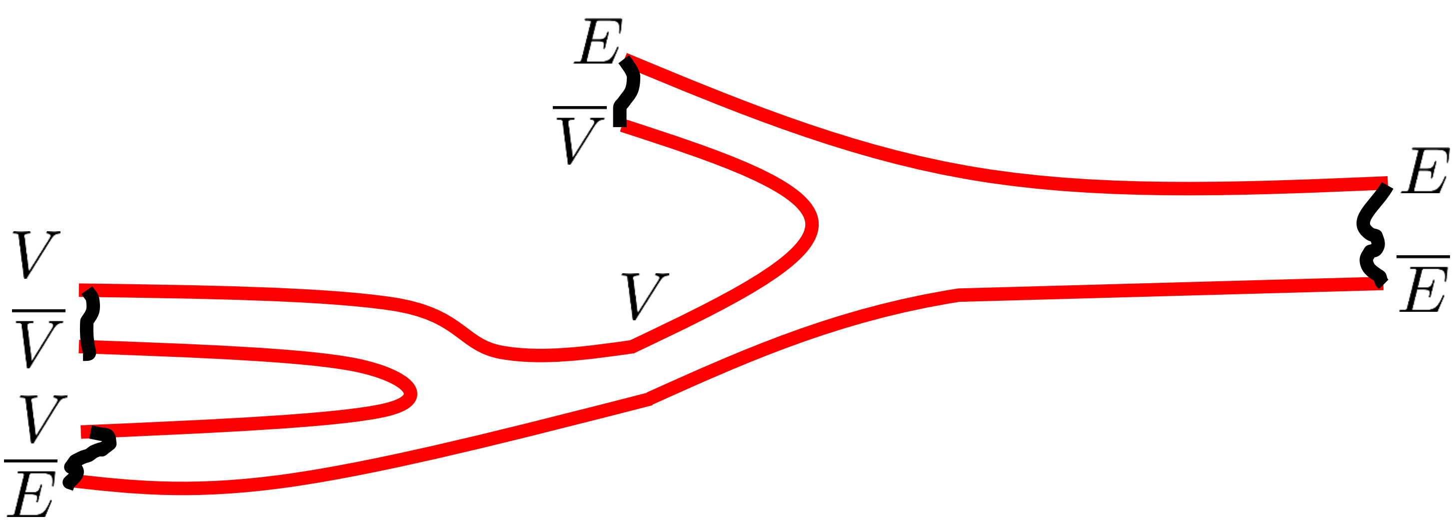


Messengers $\leftarrow \Phi_{\text{inf}}$



$$\text{Visibles} \leftarrow \text{Messengers} \leftarrow \Phi_{\text{inf}}$$





To Do a Calculation...

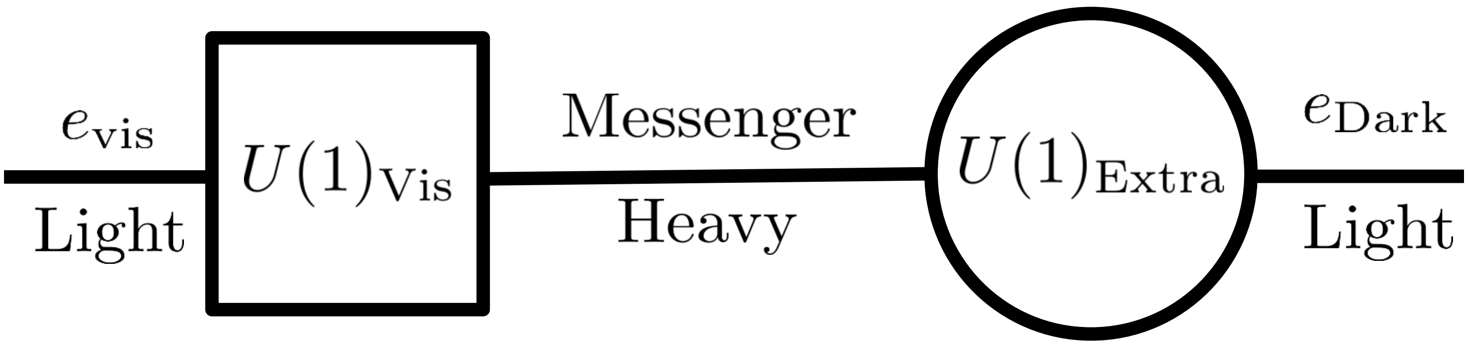
We'll assume Messengers heavy (integrate out)

$\Rightarrow$ Mixing Via:

$$L_{U(1)'s} = \sum_{i=1}^{2} \sum_{j=1}^{2} \left[-\frac{1}{4g_{i,j}^2} F_{\mu\nu}^{(i)} F_{\mu\nu}^{(j)} + \frac{\theta_{i,j}}{32\pi^2} F_{\mu\nu}^{(i)} \widetilde{F}_{\mu\nu}^{(j)} \right]$$

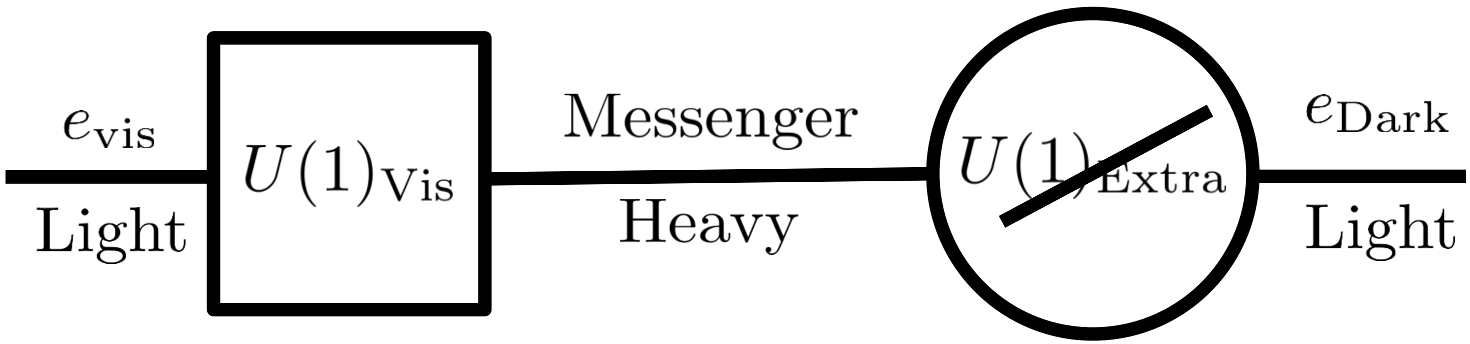
We'll also assume $U(1)_{\mathrm{Extra}}$ is broken
(decays to extra sector)

Toy Model



(see also Chu Mambrini Quevillon Zaldivar '14;
Adshead Ralegankar Shelton '19 + ...)

Toy Model



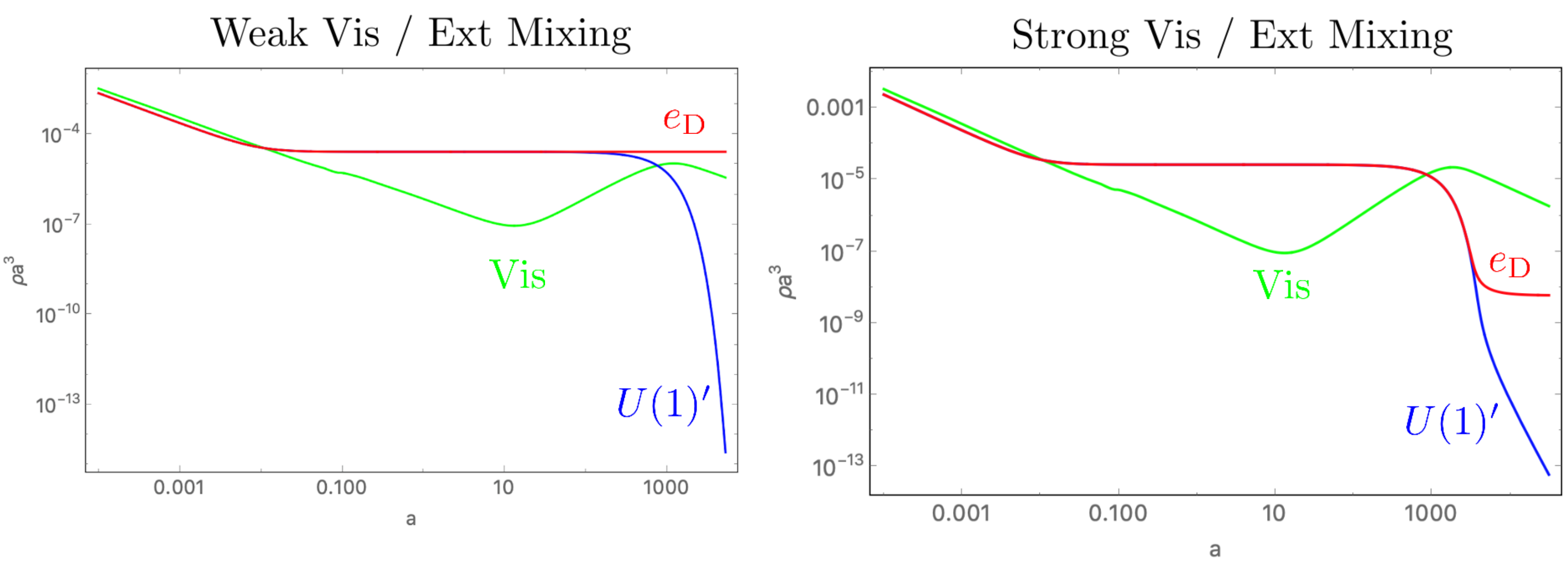
$e_{\rm vis}$
Light
$U(1)_{\rm Vis}$
Messenger
Heavy
$U(1)_{\rm Extra}$
$e_{\rm Dark}$
Light

Preliminary Plots

Preliminary Plots

Preliminary Plots

All Densities Initially Equal...



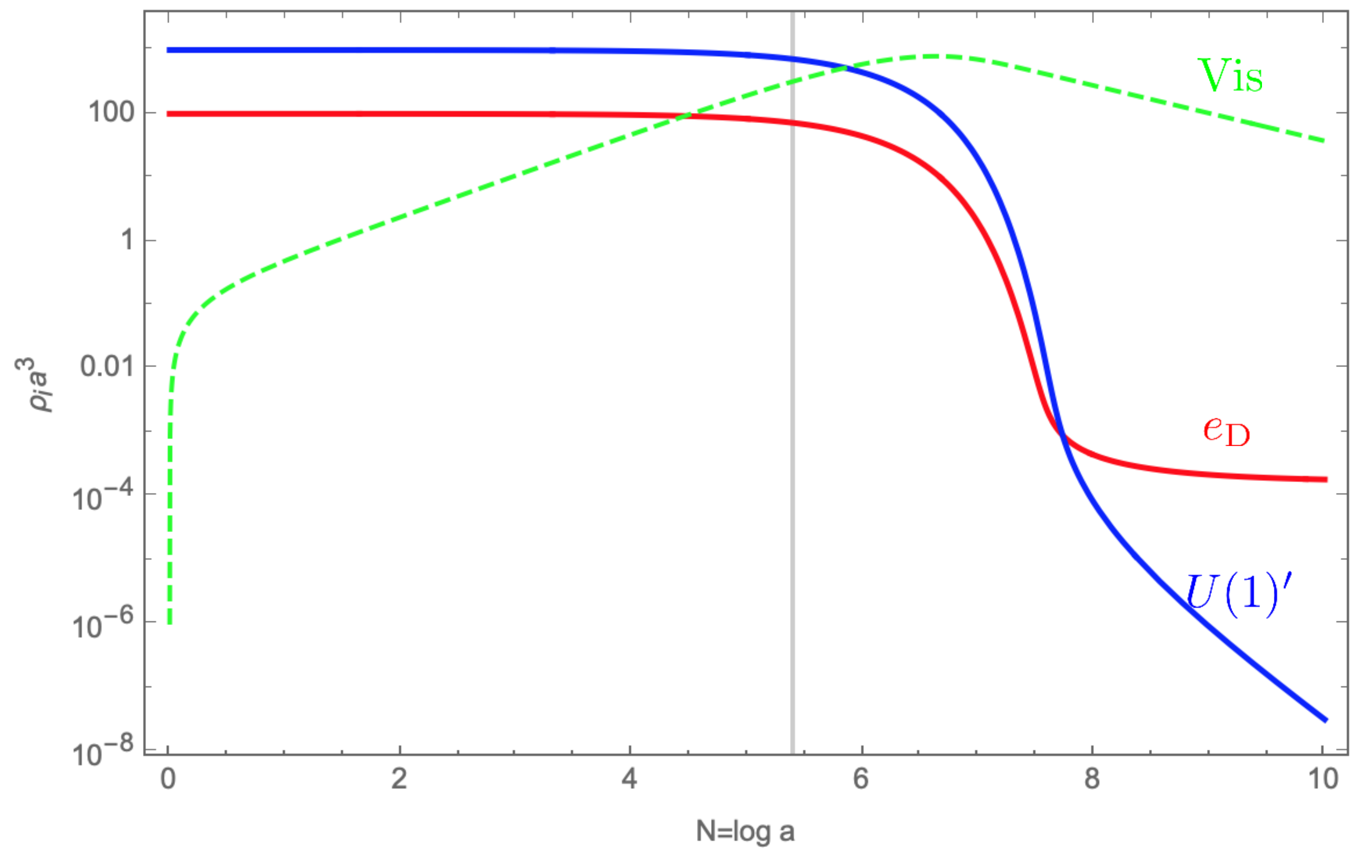
Initial energy densities all equal

Reference Mass Scales: $M_{\text{Ext}} \sim 100$ GeV, $\Gamma_{U(1)} \sim \frac{1}{16\pi} M$

(see also talk by Z. Weiner)

And with no ρ_{Vis} Initially?

Strong Vis / Ext Mixing



Outline

- Stringy Extra Sectors

- Pre / Reheating and Vis / Extra Mixing

- Entanglement and Random Couplings

Suppose...

Suppose we do not know much about other sectors

All we know is: $\mathcal{H}_{\mathrm{full}} = \mathcal{H}_{\mathrm{Vis}} \otimes \mathcal{H}_{\overline{\mathrm{Vis}}}$

Partial Trace: $\rho_{\mathrm{full}} \to \rho'_{\mathrm{Vis}}$

Observable Consequences?

Random Couplings

Consider Visible Coupling Constants $\{\lambda\}$

In strings, descend from "other sectors"

Partial Trace $\Rightarrow P(\text{coupling})$, probability distribution

$$\rho'_{\text{Vis}} = \sum_{\lambda} P(\lambda)|\lambda\rangle\langle\lambda|$$

Note: Higher Variance of $P(\lambda)$ at stronger coupling!

Precision vs. Energy

Assuming all distributions roughly Gaussian,

$$\Delta\lambda^2 \sim \left(\frac{Q_{\rm experiment}}{M_{\rm new\ physics\ limit}}\right)^4$$

$$M^{\rm atomic}_{\rm limit} \sim 1\ {\rm MeV} \times \left(\frac{\Delta\lambda_{\rm expt}}{10^{-10}}\right)^{-1/2} \times \left(\frac{Q_{\rm atomic}}{10\ {\rm eV}}\right),$$

$$M^{\rm collider}_{\rm limit} \sim 10\ {\rm TeV} \times \left(\frac{\Delta\lambda_{\rm expt}}{10^{-2}}\right)^{-1/2} \times \left(\frac{Q_{\rm collider}}{1\ {\rm TeV}}\right),$$

Summary

- Strongly coupled sectors generic in strings

- Can help with particle production

- Novel Observables $P(\lambda)$