iStrings 2016 **GONG SHOW**

Emilia da Silva
Mario Herrero-Valea
Jesús Montero
Miguel Montero
Alessandro Pini
Ander Retolaza
Aurelio Romero-Bermúdez
Jesús A. Sierra-Garcia
Genís Torrents
Miquel Triana i Iglesias
Gianluca Zoccarato

Holographic Quantum Revivals, Entanglement and Quenches

Emilia da Silva

Dr. Esperanza Lopez , Dr. Javier Mas, Alexandre Serantes, Javier Abajo-Arrastia

arXiv:1412.6002 “Holographic Relaxation of Finite Size Isolated Quantum Systems” JHEP 1405 (2014) 126

arXiv:1403.2632 “Collapse and Revival in Holographic Quenches” JHEP 04 (2015) 038

In the CFT we study the out of equilibrium dynamics after a perturbation

Thermalization? Revivals?

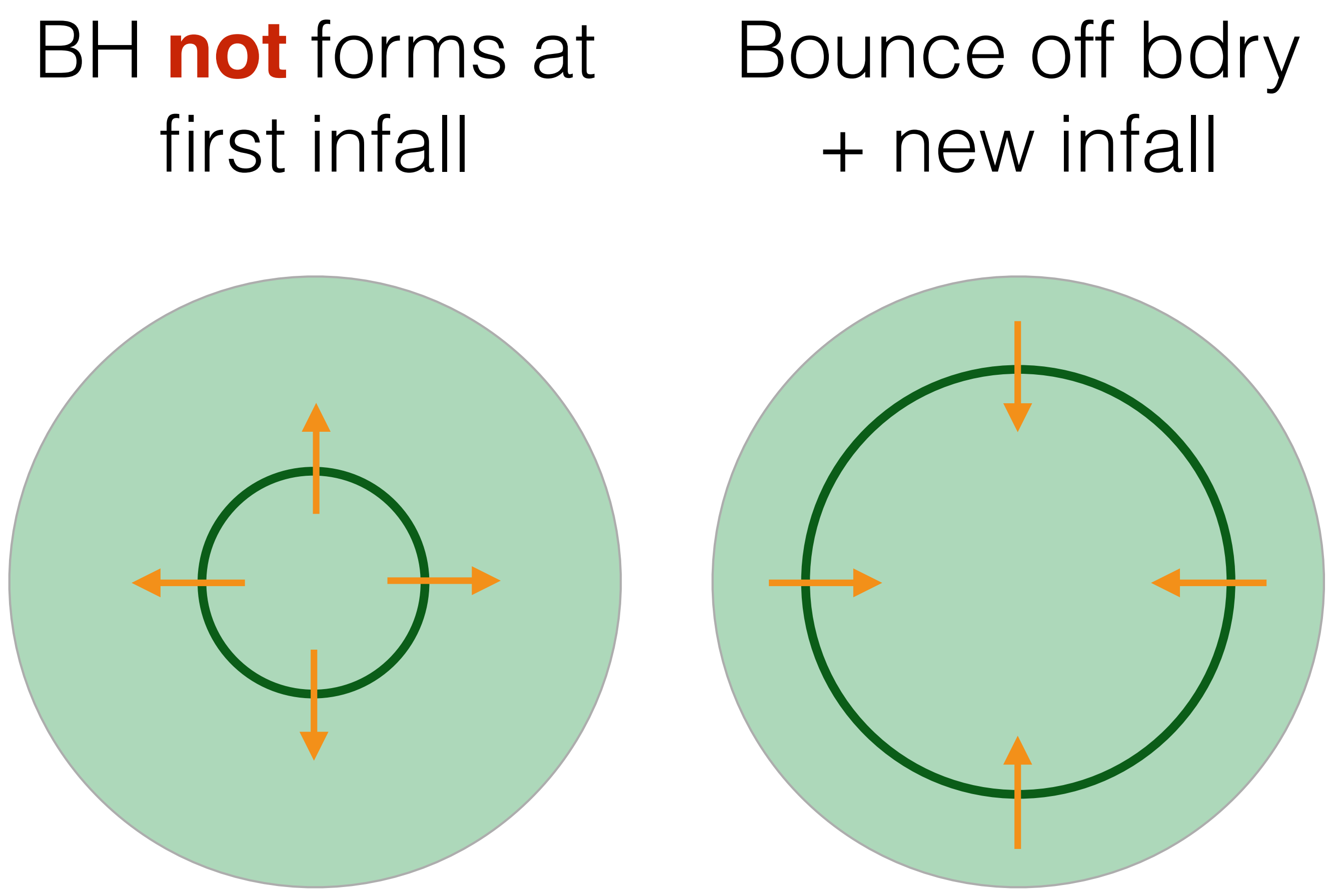
AdS/CFT

In AdS we study the formation of a black hole with some initial conditions

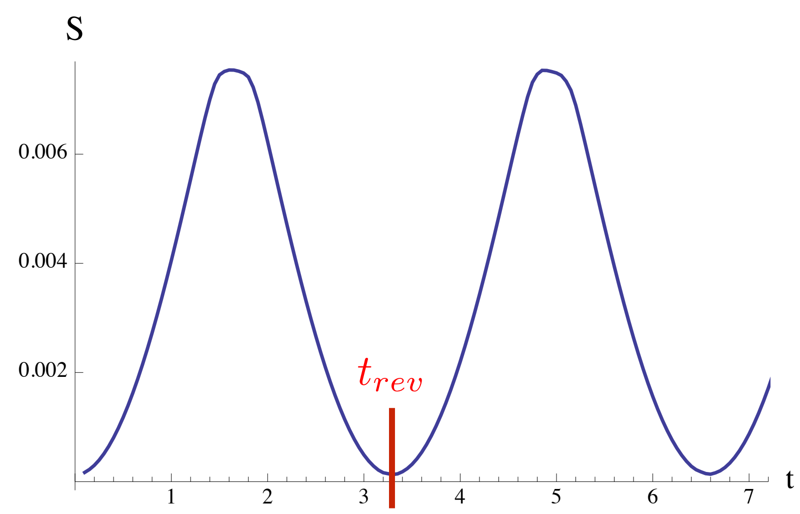
Bounces dual to revivals

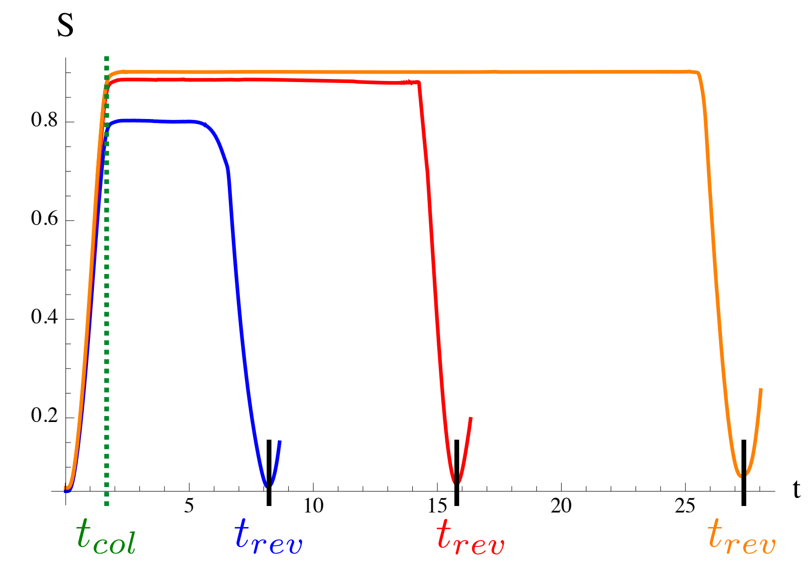
$$S = \int d^{d+1}x\sqrt{g}\left(\frac{1}{2\kappa^2}R - 2\Lambda - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi\right)$$

With some initial conditions bounces are observed:



With the time evolution of the Holographic Entanglement Entropy





- A series of Revivals and Collapse in CFT 2+1 and 1+1
- The role of the symmetries: CFT 2+1 vs CFT 1+1
- Simple model for entanglement propagation
- Comparison with the phenomenology of some simple QFT systems

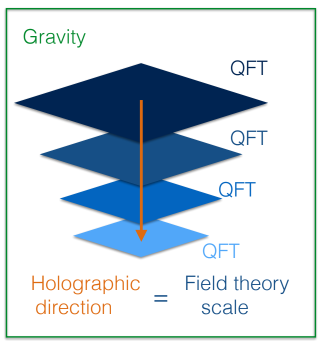
Collapse and Revival in Holographic Quenches

Emilia da Silva, Esperanza López, Javier Mas, Alexandre Serantes
IFT-UAM/CSIC, Universidad Santiago de Compostela

Aim

- Holographic model for quantum revivals in a CFT

Summary of AdS/CFT



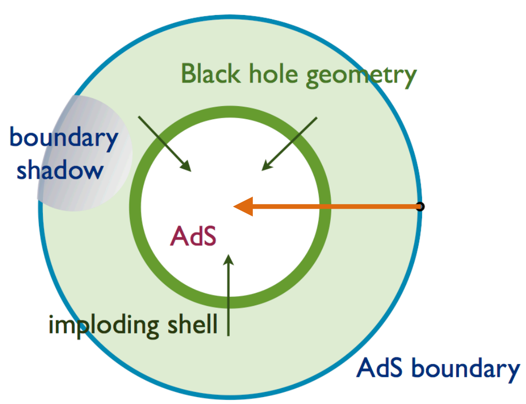
CFT	Gravity
d dimensions	d+1 dimensions
State ▸ Vacuum ▸ Thermal State ▸ Thermalization process	Geometry ▸ AdS ▸ Black Hole (BH) ▸ Gravitational collapse
Strong g and Large c	Classical Gravity

Holographic model for Thermalization of Finite Size Isolated Quantum System

Gravitational collapse of a matter shell

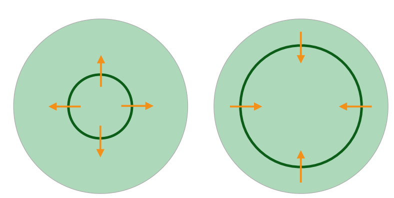
(shell mass)·(bdry volume) < 1

BH formation → CFT Thermalization



BH **not** forms at first infall

Bounce off bdry + new infall



BH can form after some bounces

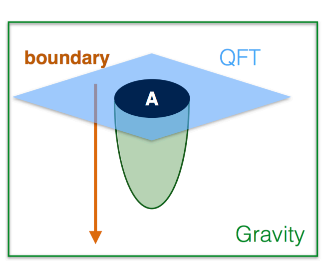
Dual to Quantum Revivals

Holographic Entanglement Entropy (HEE)

EE QFT

$S_A = -Tr_A(\rho_A \log \rho_A)$

$\rho_A = Tr_B \rho$



HEE

$S_A = \frac{Area(\gamma_A)}{4G_N}$

γ_A : extremal surface

arXiv:0905.0932[hep-th]

2+1 vs 1+1 : the role of the symmetries

CFT 2+1

- Revivals only for small energies

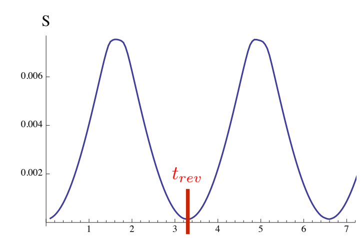
$t_{rev} \approx \pi$ ($R_{bdry}=1$)

free fly of entangled pairs

- As energy grows: no revivals

interaction leads to fast therm.

dual to grav. collapse at first infall



(S: EE of half the space)

CFT 1+1

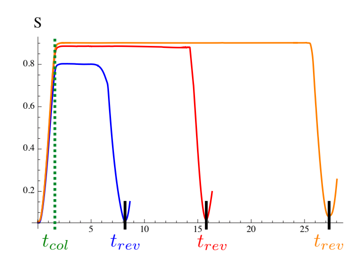
- Revivals also for higher energies

dual to: mass gap for AdS_3 BH

consistent with:

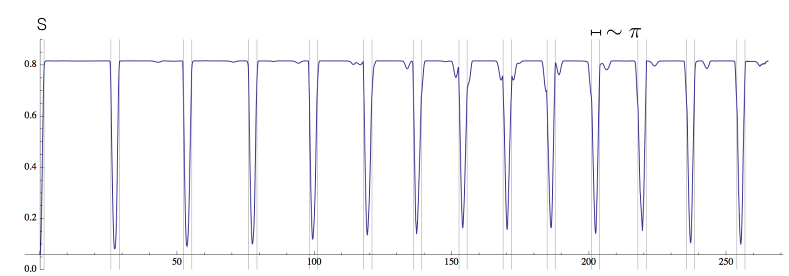
conformal group is infinite

- As energy grows: longer periods
- Two time scales emerge



$t_{col} \approx \pi/2$ $t_{rev} \geq \pi$

- Same pattern mantains along evolution:

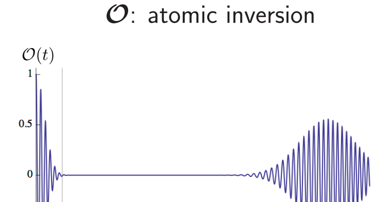


Collapse & revival

- CFT_{1+1} evoluion suggests a series of collapse and revivals
- Similar pattern found in experiments with coherent states

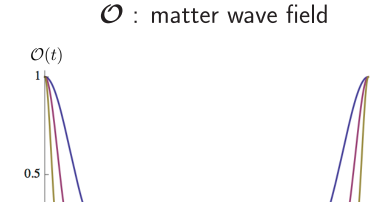
BE condensate of atoms in an optical trap

$\mathcal{O}$: atomic inversion



photons coupled to a 2-level atom in a cavity

$\mathcal{O}$: matter wave field



GONG

Horava-Lifshitz gravity in a nutshell

A. O. Barvinsky, D. Blas, M H-V, S. M. Sibiryakov and C. F. Steinwachs, arXiv[1512.02250]

Mario Herrero-Valea

Instituto de Física Teórica UAM/CSIC
Universidad Autónoma de Madrid

Iberian Strings 2016

Gong Show

The problem with (a canonical theory of) Quantum Gravity

Can Gravity be formulated as a Quantum Field Theory?

$$\mathcal{Z}[J] = \int [\mathcal{D}g_{\mu\nu}] e^{\frac{i}{\hbar} \frac{1}{16\pi G} \int d^4x \sqrt{|g|}\, R}$$

- It is not renormalizable, produces an infinite number of divergent diagrams and reduces the theory to an EFT
- A UV completion is required and normally assumed to be String/M Theory
- However, it should be possible to study gravitational phenomena in a self-contained way

- Adding higher derivatives (R^2) solves the problem but adding more **time** derivatives produces ghosts.
- Causality or unitarity violations
- Why not to add only **space** derivatives?

Hořava-Lifshitz Gravity

$$S = \underbrace{\frac{1}{2\kappa^2}\int dt\, d^3x\, N\sqrt{|\gamma|}\left(K_{ij}K^{ij} - \lambda K^2 - \mathcal{V}\right)}_{\text{ADM variables}}$$

P. Hořava, (2009)

- It is a Quantum Field Theory of Gravity in four dimensions
- It is not Lorentz invariant
- It is expected to run to GR in the IR
- **It is power counting renormalizable**
- $\mathcal{V}$ contains powers of the curvature up to dimension d $\equiv$number of space dimensions

It is invariant not under *Diff* but under *FDiff*

$$t \to \tilde{t}(t), \qquad x \to \tilde{x}(t,x)$$

$$S = \underbrace{\frac{1}{2\kappa^2}\int dt\, d^2x\, N\sqrt{|\gamma|}\left(K_{ij}K^{ij} - \lambda K^2 - \mu R^2\right)}_{\text{ADM variables}}$$

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$$t \to \tilde{t}(t), \qquad x \to \tilde{x}(t,x)$$

The scale M_*

The Lorentz violating scale M_* is constrained in two ways

- From the UV by cosmological and astrophysical data

$$M_* \lesssim 10^{15}\, GeV$$

D. Blas, O. Pujolas, S. Sibiryakov (2010)

- From the IR by Lorentz tests on fermions and binary pulsar observations

$$M_* \gtrsim 10^{10}\, GeV$$

K. Yagi, D. Blas, E. Barausse and N. Yunes (2013)

Cosmology

- Dark energy can be accommodated (there is an extra degree of freedom in the IR).
- Dark matter is not required. We have a modified Newton's law

S. Mukohyama (2009)

- There is no initial singularity. Bouncing universe

R. Branderberger (2009)

Quantum??? Hořava-Lifshitz Gravity

- It is power counting renormalizable but it is a **gauge theory**
- We work in a reduced case where $N = 1$ (projectable theory)
- Naively fixing the gauge leads to non-local divergences

$$G(p_0, p_i) \sim \frac{1}{p_0^2} \to G(t, x) \sim \delta(x^i)$$

- Do they cancel order by order?

[1512.02250] Renormalization of Hořava Gravity

- We show that it is possible to take the non-localities to the ghost sector
- Then we prove that they are gauge artefacts
- When $N \neq 1$ non-localities persist and will require new techniques
- Work in progress suggest that it is **asymptotically free**

Projectable Hořava-Lifshitz Gravity is the first known example of a UV complete theory of gravity in four dimensions where we can compute.

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Challenging the AdS_3 version of LLM

Based on work done with:

Y. Lozano, N.T. Macpherson, E. Ó. Colgáin

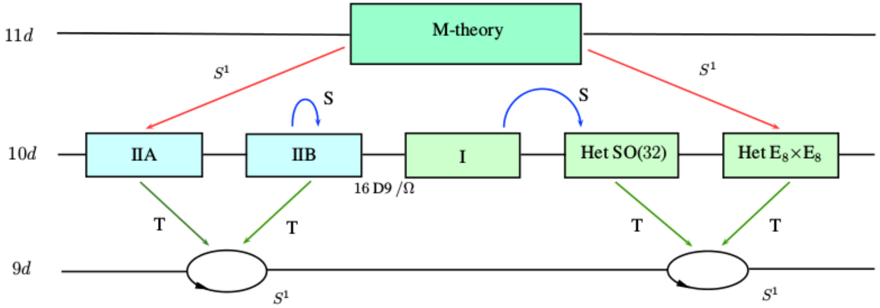
Universidad de Oviedo

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Jesús Montero

Iberian Strings 2016 (IFT, Madrid)

What is T-duality about?



Just need a compact direction with an

$U(1)$ isometry group

What is T-duality about?

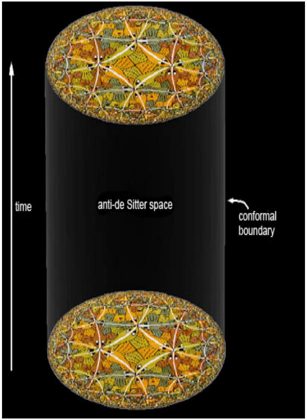
S^1 version of T-duality (Abelian)

- Invertible transformation (two T-dualities in a row give back original background). Duals keep the $U(1)$ isometry.
- T-duality is a symmetry of full (perturbative) string theory!

S^3 version of T-duality (non-Abelian)

- Non-invertible transformation: applying 2 NATDs in a row won't yield the original background. $SU(2)$ isometry partially destroyed for the dual.
- Only proven to be a symmetry at tree level.

Generating new SUGRA solutions



AdS/CFT

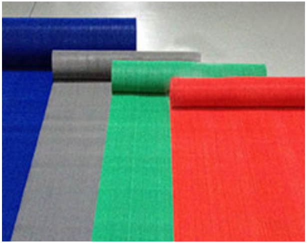
NATD-related backgrounds need not have equivalent CFTs.

⇓

We can find not only new SUGRA solutions, but also quite different dual CFTs.

Probing the generality of an M-theory classification

(Gauntlett, Mac Conamhna, Mateos, Waldram '06) classified *AdS* geometries coming from M5-branes wrapping supersymmetric cycles.



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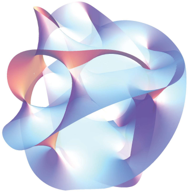

⇒ (Kim, Kim, Kim '07) gave an analogue of the AdS_5 Toda eq. (Lin, Lunin, Maldacena '04) for AdS_3 geometries with an $SU(2)$-structure for the internal manifold and dual to $\mathcal{N} = (0, 4)$ 2D SCFTs.

Probing the generality of an M-theory classification

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Some new AdS_3 solutions

- NATD-uplift of $AdS_3 \times S^3 \times T^4$: 1st explicit example.
- T-T-uplift of $AdS_3 \times S^3 \times S^3 \times S^1$: outside the (Kim, Kim, Kim '07) classification, possibly coming from a new M5 configuration (work in progress).
- NATD-T-T-uplift of $AdS_3 \times S^3 \times S^3 \times S^1$: even worse, also electric G_4 flux!

Your baggage from this talk:

T-duality techniques allow us to generate new AdS/CFT solutions which are hardly reachable by other means.

Wider classification needed for $\mathcal{N} = (0,4)$ $AdS_3 \times S^2$ geometries.

Thank you for your attention!

Hope you ask me around!

GONG

Relaxions, monodromy, and the weak gravity conjecture

M. Montero

Instituto de Física Teórica UAM-CSIC

iStrings
Jaunary 27 2016

European Research Council
SPLE Advanced Grant
UNIVERSIDAD AUTONOMA DE MADRID
Instituto de Física Teórica UAM-CSIC
CSIC Consejo Superior de Investigaciones Científicas

Motivation

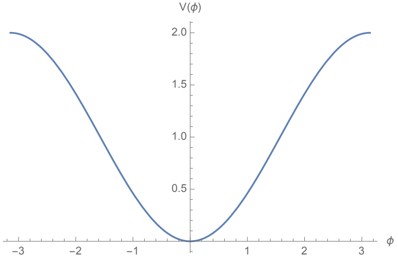
- Inflation: Transplanckian field range for sizeable r.
- Need to control Planck-suppressed terms in the potential

$$V(\phi) \sim \left(\frac{\phi}{M_P}\right)^n$$

- Good idea: Use **axions** with shift symmetry $\phi \to \phi + c$ broken to $\phi \to \phi + 2\pi f$ by nonperturbative effects.

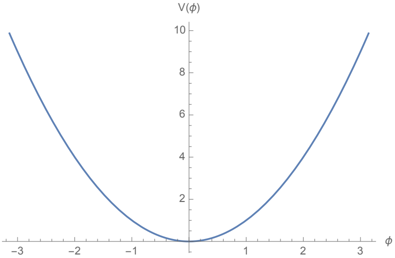
A tale of two models

Axion large-field inflation models fall in one of two categories:



Natural inflation

$$\Lambda^4(1-\cos(\phi/f))$$



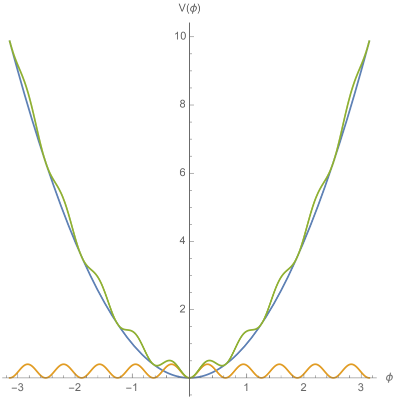
Monodromy

$$\frac{1}{2}m^2\phi^2$$

Monodromy

Monodromy looks better

- ϕ traverses several fundamental periods
- Instantons very suppressed
- Easy to obtain in string theory



Kaloper-Sorbo '08, McAllister-Silverstein-Westphal '08,'14, Marchesano-Shiu-Uranga '14, Ibañez-Valenzuela '14, Retolaza-Uranga-Westphal '15. . .

In monodromy, fundamental d.o.f are ϕ, C_3 such that

$$*F_4 \equiv dC_3 = m\phi + c$$

The potential is

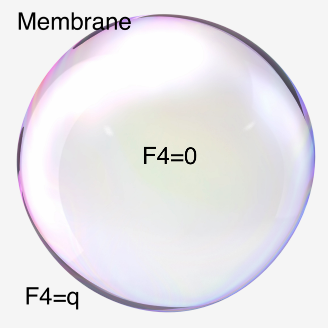
$$-\frac{1}{2}|F_4|^2 = \frac{1}{2}(m\phi + c)^2$$

Difference with natural inflation: there are **membranes**

$$2\pi mf \int_{\text{membrane}} C_3$$

which shift $\phi \to \phi + 2\pi f$

Bubble nucleation



- Bubbles nucleate with rate

$$P \sim \exp(-B), \quad B = \frac{27\pi^2}{2} \frac{T^4}{(\Delta V)^3}$$

[Coleman '78, Coleman-DeLuccia '80]

- T unknown
- Gravitational corrections can modify formula significantly

What is the value of T?

T can be estimated if the bubble is field-theoretical. Not our case. Two main avenues:

- Explicit stringy embedding available; bubble is usually a D-brane or other controlled object. Approach used e.g. [Brown-Cottrell-Shiu-Soler '15, Retolaza-Uranga-Westphal'15].
- Or from the Weak Gravity Conjecture [Arkani-Hamet et al. '06] for 3-forms, which implies

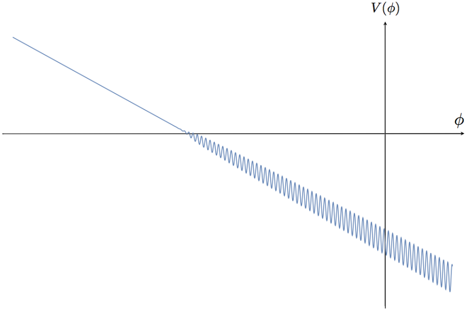
$$T \leq 2\pi m f M_P.$$

Relaxion: Solution to the hierarchy problem

We do not want too many bubbles!

- Using the WGC value $T = 2\pi m f M_P$, we find a constraint $m \leq \sqrt{f M_P}$ easily satisfied in monodromy.
- Apply to the relaxion[1512.00025, Relaxion Monodromy and the Weak Gravity Conjecture, Luis E. Ibáñez, MM, Ángel Uranga, Irene Valenzuela].

Relaxion: Solution to the hierarchy problem



- Axion with potential

$$V \supset \frac{1}{2}g^2\phi^2 + (-M^2 + g\phi)|h|^2 + \Lambda^4 \cos\left(\frac{\phi}{f}\right)$$

- At $\phi \sim M^2/g$ it triggers EW symmetry breaking, turning on nonperturbative effects which stabilize h.

Relaxion and monodromy

Only one known consistent way of breaking discrete symmetry of ϕ: Monodromy

$$m \leftrightarrow g$$

The relaxion potential can be rewritten in KS-fashion

$$V_{KS} = (g\phi \; - \eta|h|^2)F_4$$

But then the membranes are back. One caveat: Gravitational effects are very important, so this time

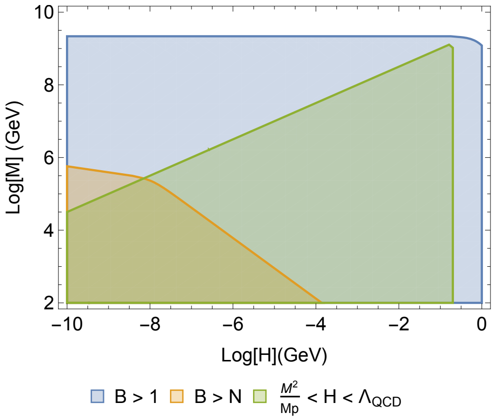
$$B \sim \frac{T}{H^3}$$

Relaxion constraints

- The constraint $B > N$ (not too many bubbles) translates to

$$M \lesssim \left(\frac{\Lambda_v^6 M_P^3}{f}\right)^{\frac{1}{8}} \simeq \text{ 300 TeV}$$

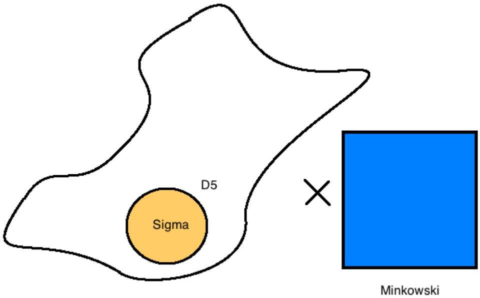
- If also QCD axion+inflaton coupling, $M \leq 500\ GeV$.



Stringy embedding

Now that we have killed relaxion. . . it's time to embed it in ST!

- Way to know if we can kill more generic models or if some survive
- No need of WGC
- Relaxion hierarchy difficult to obtain
- $B_2 = \phi\omega_\Sigma$ (original axion monodromy proposal)



- $D5$'s wrapping Σ provides monodromic potential and $SU(2) \times U(1)$ sector.

Summary

- Monodromy is a popular idea for large field inflation
- Membranes generically present (WGC)
- Monodromy inflation is OK with bubble nucleation
- Relaxion is not
- First steps towards stringy embedding of relaxion, to analyze in more detail.

Thank you very much!

GONG

Aspects of the moduli space of instantons on $\mathbb{C}P^2$

based on A. Pini and D. Rodríguez-Gómez, arXiv:1502.07876 [hep-th]

Alessandro Pini

27 January, 2016

Universidad de Oviedo

Introduction

- The study of gauge theories on curved background $\mapsto$ partition functions, index ... [V.Pestun (2012)]...
- Partition function (e.g. $4d$ on S^4 or $5d$ on $S^4 \times S^1$, S^5)

$$Z = Z_{pert} Z_{inst}$$

pure gauge theories with 8 supercharges.

$Z_{inst} \Leftrightarrow$ Hilbert Series of the instanton moduli space.

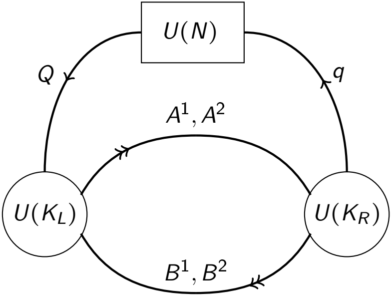
[D. Rodríguez-Gómez and G.Zafrir (2014)],[C.A.Keller,N. Mekareeya, J.Song and Y.Tachikawa (2012)]

- Instantons are very interesting objects in $4d$ and $5d$ gauge theories $\mapsto$ study of instanton moduli spaces.

$\Downarrow$

We analysed the ADHM construction for instantons on $\mathbb{C}P^2/Z_n$ and the corresponding moduli space using the Hilbert Series.

ADHM construction for $U(N)$ instantons on $\mathbb{C}P^2$ [A. King (1989)]



[F.Benini, C.Closset and S.Cremonesi (2010)]

- 3d $\mathcal{N} = 2$, $\quad U(1)_R \times SU(2) \times U(N)$
- Superpotential

$$W = \mathrm{Tr}[A^1 B^1 A^2 B^2 - A^1 B^2 A^2 B^1 + q A^1 Q],$$

- Instanton branch of the moduli space

[N. Mekareeya and D. Rodríguez-Gómez (2013)]

$$T = 0, \qquad \tilde{T} = 0, \qquad A_1 = 0,$$

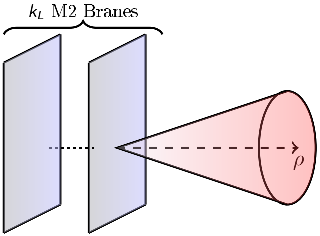
monopole operators

- $\partial_{A_1} W = 0$, $\qquad T\tilde{T} = A_1^N$

$$\mathrm{HS}[(k_L, k_R), SU(N), \mathbb{C}P^2](t, x, \vec{y}) = \mathrm{HS}[\min(k_L, k_R), SU(N), \mathbb{C}^2](t^3, x, \vec{y}),$$

[H.Nakajima and K.Yoshioka (2005)]

$k_L = k_R, \quad N = 1$



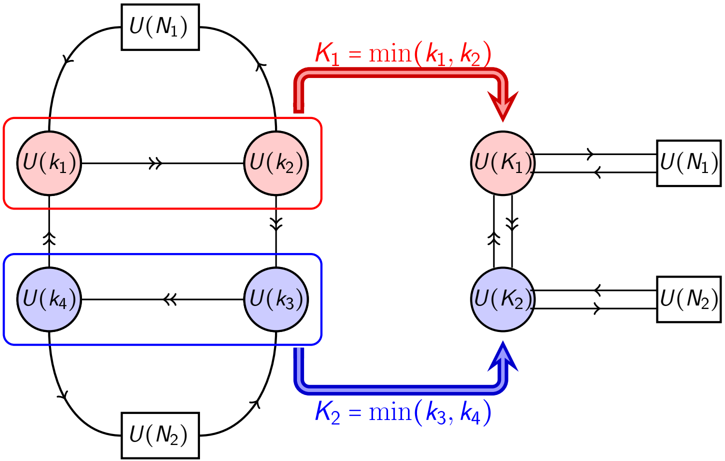
$$ds^2_{cone} = d\rho^2 + \rho^2 ds^2_{M}, \quad \mathcal{C} \times \mathbb{C}$$

Near horizon limit $\rho \to 0$

$$ds^2_{11} = L^2 (ds^2_{AdS_4} + ds^2_M)$$

Mesonic branch constructed from $\{B_i, A_2\}$ $\Longleftrightarrow$ dual geometry dual giant graviton

II aspect: $\mathbb{C}P^2/Z_2 \quad \Leftrightarrow \quad \mathbb{C}^2/Z_2$



$$\mathrm{HS}[(k_1, k_2, k_3, k_4), (N_1, N_2), \mathbb{C}P^2/Z_2] = \mathrm{HS}[(K_1, K_2, (N_1, N_2), \mathbb{C}^2/Z_2)]$$

Conclusions

We discussed several aspects of the moduli space of instantons on $\mathbb{C}P^2$:

- ADHM construction for the moduli space of the instantons on $\mathbb{C}P^2$.
- Dual giant graviton $\Leftrightarrow$ mesonic subranch of the moduli space.
- Hilbert Series for the moduli space of instantons on $\mathbb{C}P^2/Z_n$ with gauge group $G = U(N), O(N), Sp(N)$ $\Leftrightarrow$ Hilbert Series for the moduli space of instantons on $\mathbb{C}^2/Z_n$.

THANK YOU FOR THE ATTENTION

GONG

De Sitter uplift with Dynamical Susy Breaking

Ander Retolaza

Instituto de Física Teórica UAM/CSIC, Madrid

Based on 1512.06363 by A.R. & A. Uranga

Iberian Strings 2016,
IFT UAM-CSIC, 27th January 2016

European Research Council
SPLE Advanced Grant

UNIVERSIDAD AUTONOMA DE MADRID

Instituto de Física Teórica UAM-CSIC

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Consejo Superior de Investigaciones Científicas

De Sitter in String Theory

Problem: observations tell us that Universe is de Sitter, but in String Theory (ST) compactifications one usually finds $\Lambda \leq 0$.

General proposal: add a sector in the compactification to obtain $0 < \Lambda \ll$. Many proposals:

- Anti-branes in a throat (issues with EFT) KKLT
- Nilpotent goldstino Kallosh, Quevedo, Uranga '15
- T-branes Cicoli, Quevedo, Valandro '15
- ... Bergshoeff, Braun, Burgess, Dasgupta, Louis, Maharana, Rummel, Saltman, Silverstein, Sumitomo, Van Proeyen, Westphal, Wrase ...

De Sitter with Dynamical Susy Breaking

Our proposal: add a sector with Dynamical Susy Breaking (DSB)

$$0 < \Lambda$$

An example of DSB: "$\mathcal{N} = 1$" $SU(5)$ with $\bar{\mathbf{5}} + \mathbf{10}$ and $W = 0$.
Affleck, Dine, Seiberg '84

ST embedding: find a toric CY singularity whose holographic dual includes this gauge theory

De Sitter with Dynamical Susy Breaking

Our proposal: add a sector with Dynamical Susy Breaking (DSB) on the bottom of a *warped throat* in ST.
(generalization of the Randall, Sundrum idea in ST)
Klebanov, Strassler; H. Verlinde; Giddings, Kachru, Polchinski

$$0 < \Lambda \ll$$

An example of DSB: "$\mathcal{N} = 1$" $SU(5)$ with $\bar{\mathbf{5}} + \mathbf{10}$ and $W = 0$.
Affleck, Dine, Seiberg '84

ST embedding: find a toric CY singularity whose holographic dual includes this gauge theory and UV complete it as a complex deformation of a "more singular" toric CY.

De Sitter with Dynamical Susy Breaking

Theory with DSB: $"\mathcal{N} = 1"$ $SU(5)$ with $\bar{\mathbf{5}} + \mathbf{10}$ and $W = 0$

The toric CY singu where to embed this gauge theory is an orientifold of $\mathbb{C}^3/(\mathbb{Z}_2 \times \mathbb{Z}_3)$ Franco et al. '07

- Gauge group: $SO(n_1) \times SU(n_2) \times SU(n_3) \times Sp(n_4)$
- From anomaly cancellation: $n_1 + n_2 + 4 = n_3 + n_4$
- Matter content: many chiral superfields in *bifundamental* and *(anti)symmetric* representations
- In principle, it has a superpotential

De Sitter with Dynamical Susy Breaking

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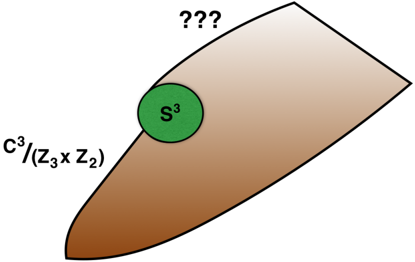
- In principle, it has a superpotential

$\Rightarrow$ Taking $n_2=n_4=0$, $n_1=1$ and $n_3=5$:

- $"SO(1)"\times SU(5)$ with $(\square\,,\bar{\square})+(1,\,\begin{smallmatrix}\square\\\square\end{smallmatrix})$ and $W=0$

De Sitter with Dynamical Susy Breaking

Small Λ: embed on a *warped* throat (generalization of Klebanov, Strassler)



"Worse singularity" can be found using toric geometry tools:

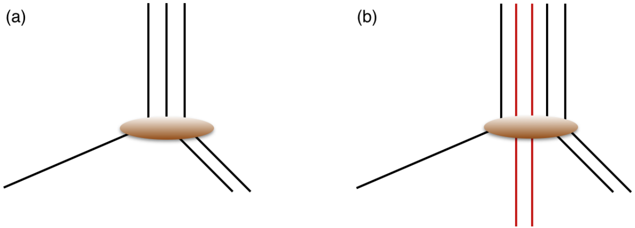
web diagrams

See e.g. Franco, Hanany, Uranga '10

De Sitter with Dynamical Susy Breaking

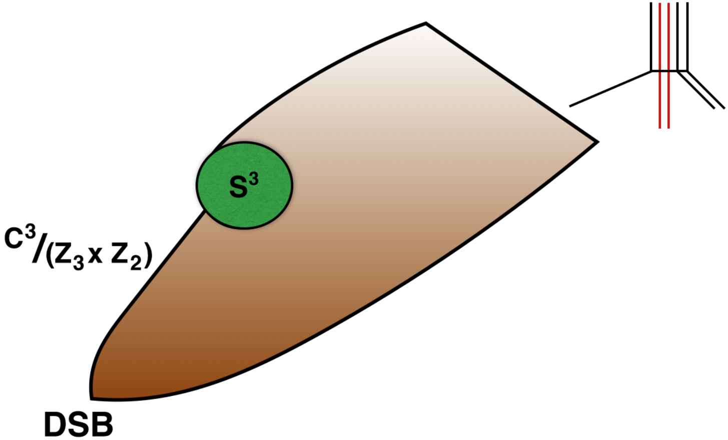
Small Λ: embed on a *warped* throat using web diagrams.

- The orientifold requires new technology
  A.R., Uranga (in progress)

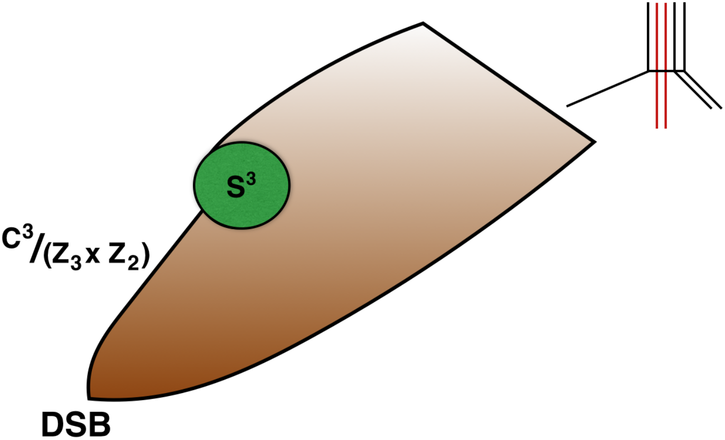


$\mathbb{C}^3/(\mathbb{Z}_3 \times \mathbb{Z}_2)$ UV completion

De Sitter with Dynamical Susy Breaking



De Sitter with Dynamical Susy Breaking



Thank You!

GONG

Mazur-Suzuki bounds in holography

arXiv:1512.04401

Aurelio Romero-Bermúdez.
abr31@cam.ac.uk
www.tcm.phy.cam.ac.uk/~abr31
In collaboration with Antonio M. García-García.

Iberian Strings – IFT, Madrid, January 2016

UNIVERSITY OF CAMBRIDGE

Drude weight, $\mathbf{K}$ and Mazur Suziki bound

$$\sigma_{\rm DC} = -{\rm Re} \lim_{\omega\to 0, q\to 0} \frac{G^R_{J^x J^x}(\omega, q) - G^R_{J^x J^x}(0, q)}{i(\omega + i\epsilon)}$$

$$\sigma_{\rm DC} = \sigma_{\rm Q} - {\rm Re}\frac{1}{i}\frac{K}{\omega + i\epsilon} = \sigma_{\rm Q} - {\rm Re}\left[\mathcal{P}\left(\frac{1}{\omega}\right)(-i)K - \pi K\delta(\omega)\right] =$$

$$= \sigma_{\rm Q} + \pi\mathbf{K}\delta(\omega)$$

'Universal' result $$K_{\rm U} = \frac{\rho^2}{\epsilon + P}$$

Given a Hamiltonian, H , consider all conserved quantities and define orthogonal ones:

$$\langle Q_i Q_j\rangle = Q_i^2 \delta_{ij}$$

$$K = \frac{\beta}{V}\lim_{t\to\infty}\langle J(t)J(0)\rangle = \lim_{N\to\infty}\frac{\beta}{V}\sum_i^N \frac{\langle JQ_i\rangle^2}{\langle Q_i Q_i\rangle}$$

$$K \geq K_{\rm MS} \equiv \frac{\beta}{V}\sum_i^k \frac{\langle JQ_i\rangle^2}{\langle Q_i Q_i\rangle}, \;\; k < \infty$$

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Klebanov-Witten CFT on Σ_2 and its Non-Abelian T-dual

J.A. Sierra-Garcia

Universidade de Santiago de Compostela, Spain

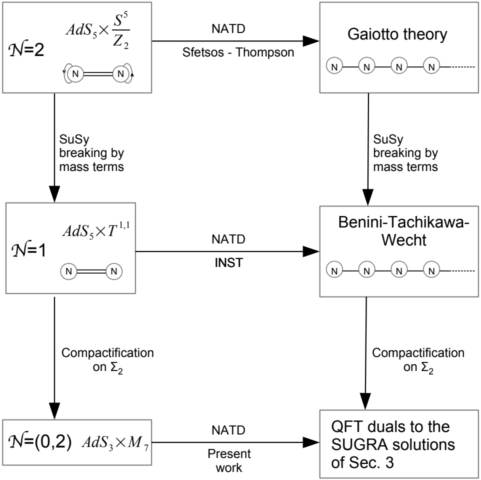
Iberian Strings 2016

January 27th, 2016

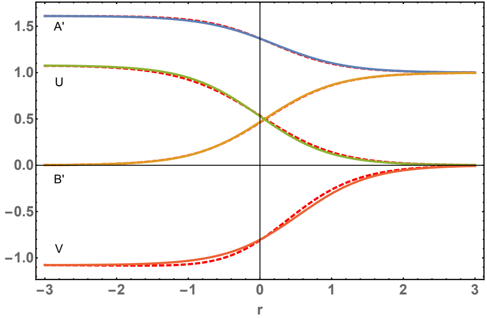
Based on 1503.07527 with:

Carlos Núñez (Swansea Univ., UK), *José Edelstein (Univ. Santiago de Compostela, Spain)* , *Georgios Itsios (Univ. Santiago de Compostela and Univ. Oviedo, Spain), Yago Bea (Univ. Santiago de Compostela, Spain), Daniel Schofield (Swansea Univ., UK) and Karta Kooner (Swansea Univ., UK)*

Introduction



$$\frac{ds^2}{L^2} = e^{2A}(-dy_0^2+dy_1^2)+e^{2B}(d\alpha^2+d\beta^2)+dr^2+e^{2U}ds_{KE}^2+e^{2V}\eta^2$$
$$B_2, F_3, F_5 \neq 0$$



IR to UV warp factors. Dimensionality flows.

1. BPS solution. (0,2) Poincare SUSY by construction
2. Regular everywhere
3. As $\frac{e^{2B}}{e^{2A}} \longrightarrow 0$ in the IR becomes effectively 2 dimensional.

Non-Abelian T-duality as generating technique. An example

Abelian T-duality: $U(1)$ **Non-Abelian T-duality:** $SU(2)$

$$
\begin{aligned}
ds^2 &= R^2 d\alpha^2 \\
e^{-2\Phi} &= 1 \\
B_2 &= 0
\end{aligned}
\qquad
\begin{aligned}
ds^2 &= d\theta^2 + d\phi^2 + 2\cos\theta\, d\phi\, d\psi + d\psi^2 \\
e^{-2\Phi} &= 1 \\
B_2 &= 0
\end{aligned}
$$

$$
\begin{aligned}
\widehat{R} &= \frac{1}{R} \\
e^{-2\widehat{\Phi}} &= R^2 \\
\widehat{B}_2 &= 0
\end{aligned}
\qquad
\begin{aligned}
d\widehat{s}^2 &= d\rho^2 + \frac{\rho^2}{1+\rho^2}(d\chi^2 + \sin^2\chi\, d\xi^2) \\
e^{-2\widehat{\Phi}} &= 1+\rho^2 \\
\widehat{B} &= \frac{\rho^3}{1+\rho^2} vol(S^2)
\end{aligned}
$$

- ρ range is unknown!

Non-Abelian T-dual of DG solution

$$
\begin{aligned}
\frac{d\hat{s}^2}{\hat{L}^2} &= e^{2A}(-dy_0^2+dy_1^2)+e^{2B}(d\alpha^2+d\beta^2)+dr^2+\frac{\alpha'^2}{\Delta}ds^2(M^5)\\
e^{-2\hat{\Phi}} &= \frac{\hat{L}^2}{324\alpha'^3}\Delta, \quad \Delta=\Delta(\rho,\chi,\xi)\\
B_2, F_2, F_4 &\neq 0
\end{aligned}
$$

1. $e^{2A}(-dy_0^2+dy_1^2)+e^{2B}(d\alpha^2+d\beta^2)+dr^2$ is preserved
2. (0,2) Poincare SUSY is preserved
3. Regular everywhere

Wilson Loop, Entanglement Entropy and c-function

$$
\begin{aligned}
\frac{\hat{E}(d)}{E(d)} &= \frac{\hat{L}^2}{L^2} && = const \\
\frac{\hat{S}_E(d)}{S_E(d)} &= \frac{\hat{L}^8}{L^8}\frac{vol(\rho,\chi,\xi)}{16\pi^2} && = const \\
\frac{\hat{c}(r)}{c(r)} &= \frac{\hat{L}^8}{L^8}\frac{vol(\rho,\chi,\xi)}{vol(T^{1,1})} && = const
\end{aligned}
$$

1. No phase transition
2. Area law for $dim = 4, 2$ for UV, IR.

Dual CFT guess. Page charges and ρ range

Perform large gauge transformation

$$B_2 \longrightarrow B_2 + \alpha' n\pi \sin\chi \, d\chi \wedge d\xi \quad \text{for } n\pi \le \rho < (n+1)\pi \qquad \Longrightarrow$$

$$\begin{aligned} Q_{NS5} &= n+1 \\ \Delta Q_{D4} &= n N_{D6} \\ \Delta Q_{D6} &= 0 \\ c \propto N_{NS5}^3 & N_{D6}^2 \end{aligned}$$

1. Q_{NS5} induced only by g.t.
2. $c \propto N_{NS5}^3 N_{D6}^2$ like $(1,0)$ Gaiotto-Tomasiello QFT.

Take away message

1. Start with KW CFT on deformed on T^2 (Donos-Gauntlett)

2. Generate AdS_3 solution with Non-Abelian T-duality!
   1. New and regular
   2. (0,2) SUSY is preserved

3. Compute its observables and guess CFT.
   1. Invariant WL, S_E and c
   2. $c \propto N_{D6}^2 N_{NS5}^3 \longrightarrow$ Gaiotto, Tomasiello QFT?

4. Similar results hold for $AdS_3 \times H_2 \times M_5$.

GONG

Madrid, January 27th, 2016

Probing $\mathcal{N}$=2 SCFT with localization

Genís Torrents

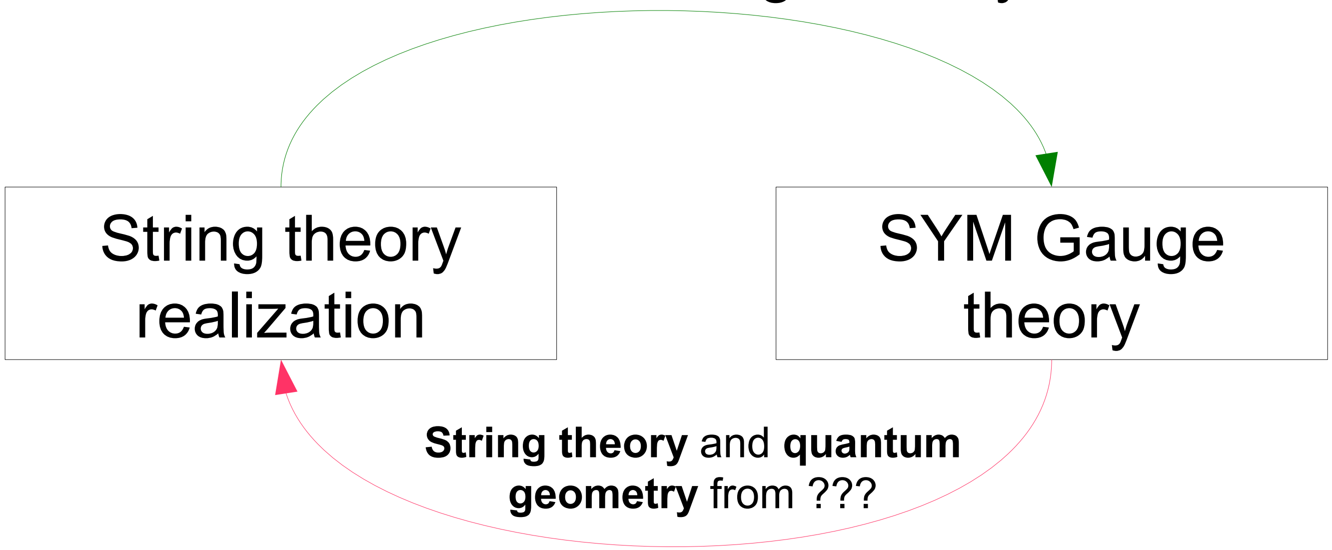
Universitat de Barcelona

In collaboration with **Bartomeu Fiol** (UB) and **Blai Garolera** (UCR)

Talk based on Fiol, Garolera, GT 1511.00616

AdS/CFT holographic conjecture

Large N, λ predictions from
semiclassical geometry



$$c \gg 1$$

How is geometry encoded
in the field theory?

Semiclassical $$\frac{|c-a|}{c} \ll 1$$

Q: What makes theories with
semiclassical duals special?

EH+ gradient exp. $$\lambda \gg N^{2/3}$$

Buchel, Myers, Sinha 0812.2521

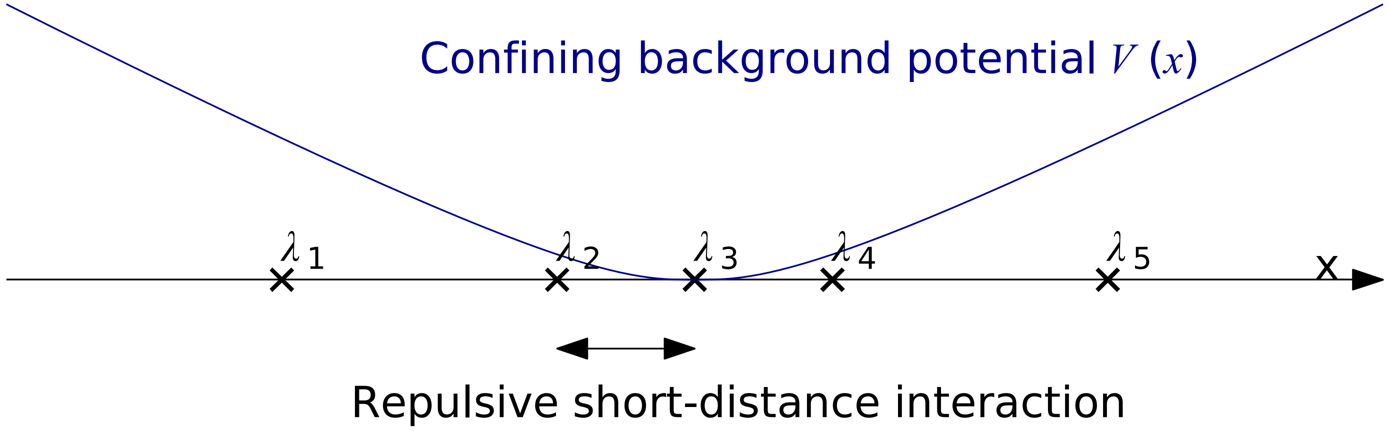
Set of **SCFTs** with examples of both $\frac{|c-a|}{c} \ll 1$ $\frac{|c-a|}{c} \sim 1$

Lagrangian 4D *N*=2 SYM with **classical Lie algebra (SU/SO/SP)**

Localization **Large N (c)**

After localization, theory of the **eigenvalues** of an NxN matrix

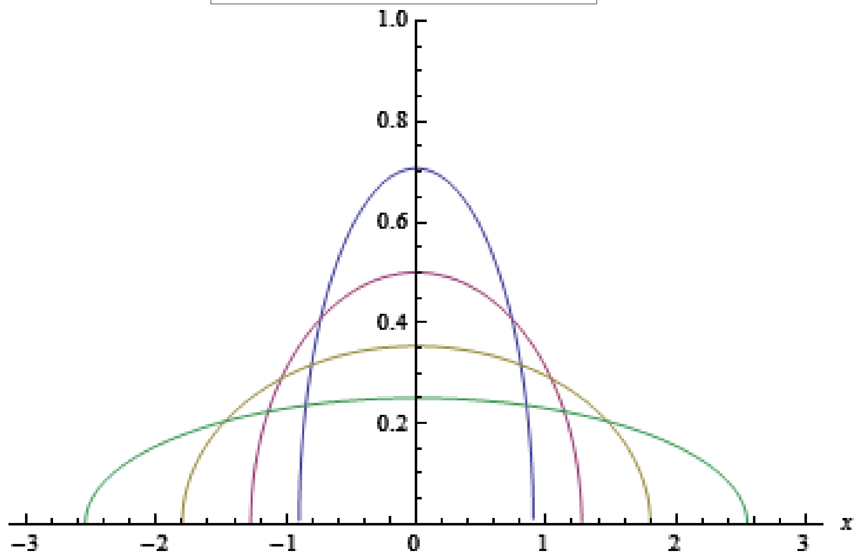
Equivalent to N interacting 1D particles



At large N, **eigenvalue density**

Results:

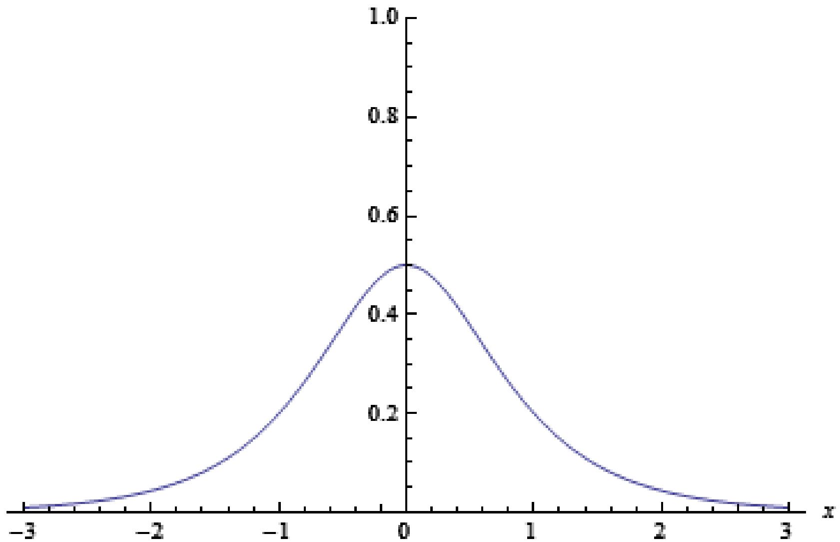
$$\frac{|c-a|}{c} \ll 1$$



Scaling distribution

$$\langle W \rangle \sim \lambda^{-\frac{3}{4}} e^{\sqrt{\lambda}}$$

$$\frac{|c-a|}{c} \sim 1$$



Limiting shape

$$\langle W \rangle \sim \left(\frac{\lambda}{\sqrt{\log \lambda}} \right)^{\frac{2\pi}{\theta} - 1}$$

$$\theta \equiv \arccos\left(1 - \nu\right)$$

Hints of geometry?

Correlation does not imply causality

Few fundamental matter multiplets is not sufficient

Large λ condition plays a major role

Relation between bubbling geometries and matrix models

Wilson loops dual to minimal area problems

Outlook

Extension to other theories (quivers, $d \neq 4$)

Alternative aproaches (integrability, resurgence, ...)

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Shock wave collisions in a family of non-conformal field theories

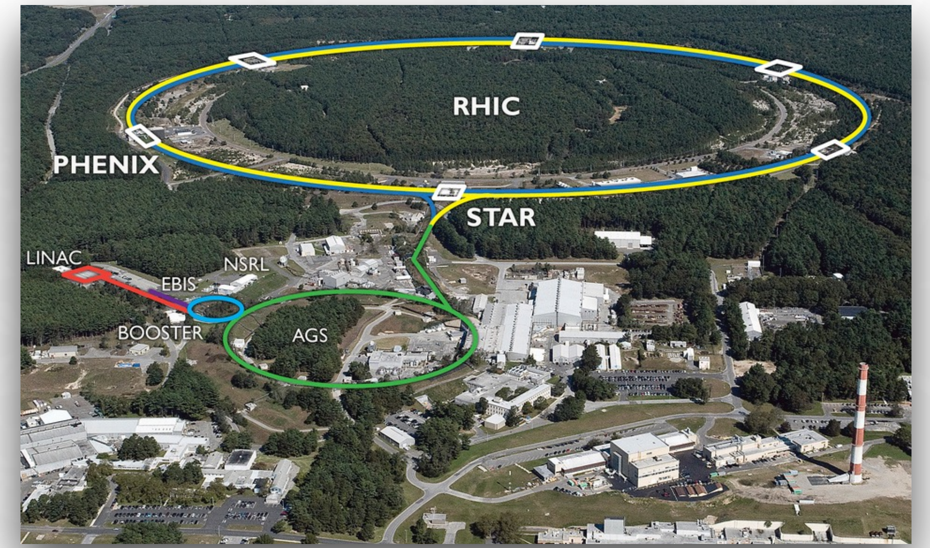
Miquel Triana i Iglesias - Universitat de Barcelona

Iberian Strings 2016 - Gong show

In collaboration with: Maximilian Attems, Jorge Casalderrey-Solana, David Mateos, Ioannis Papadimitriou, Daniel Santos, Carlos Sopuerta and Miguel Zilhao

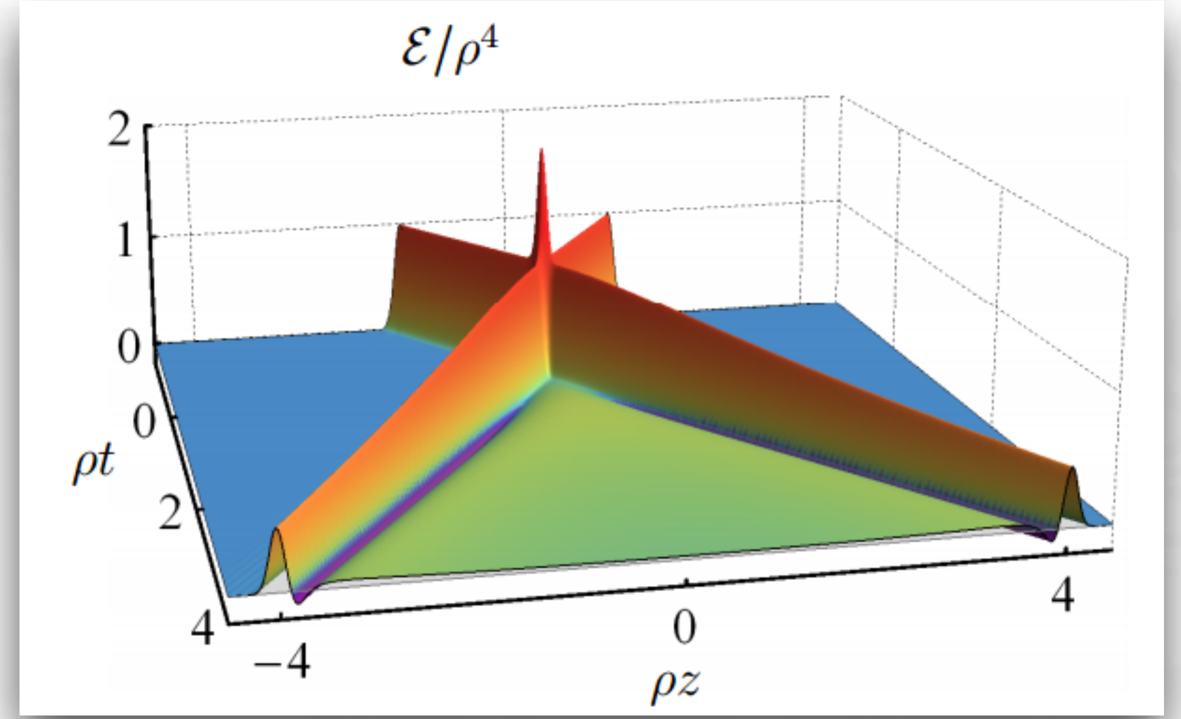
Holographic shock wave collisions in pure gravity

Heavy ion colliders



- **Quark-gluon plasma** is created after collision
- Plasma is quickly very well described by **hydrodynamics**

Holographic pure gravity setup



→ Captures **fast hydrodynamization**!

Non-conformal holographic models

However… quark gluon plasma in heavy ion colliders is non-conformal!

Minimalistic setup:
Gravity + scalar field with a potential

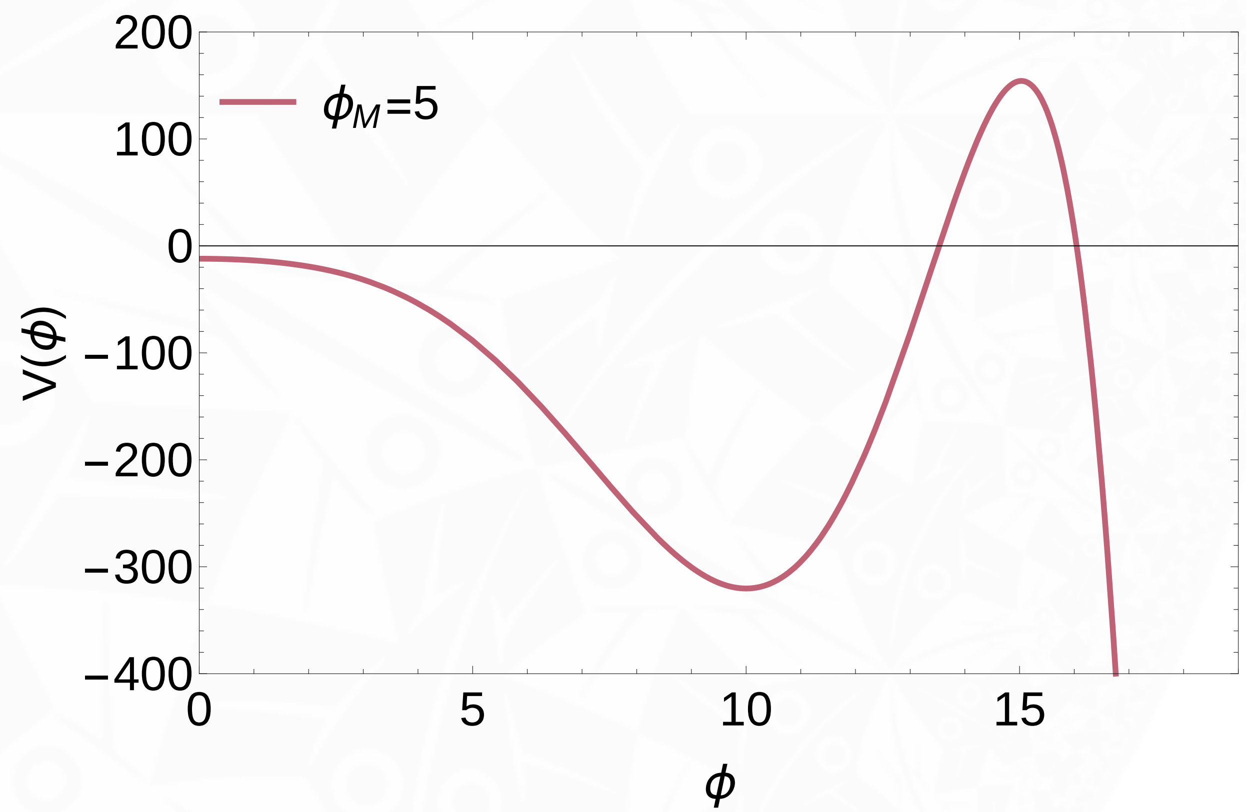
$$L = \frac{1}{2}R - (\partial\phi)^2 - 2V(\phi)$$

Lagrangian

The potential has a maximum and a minimum: interpolates two AdS regions

↓

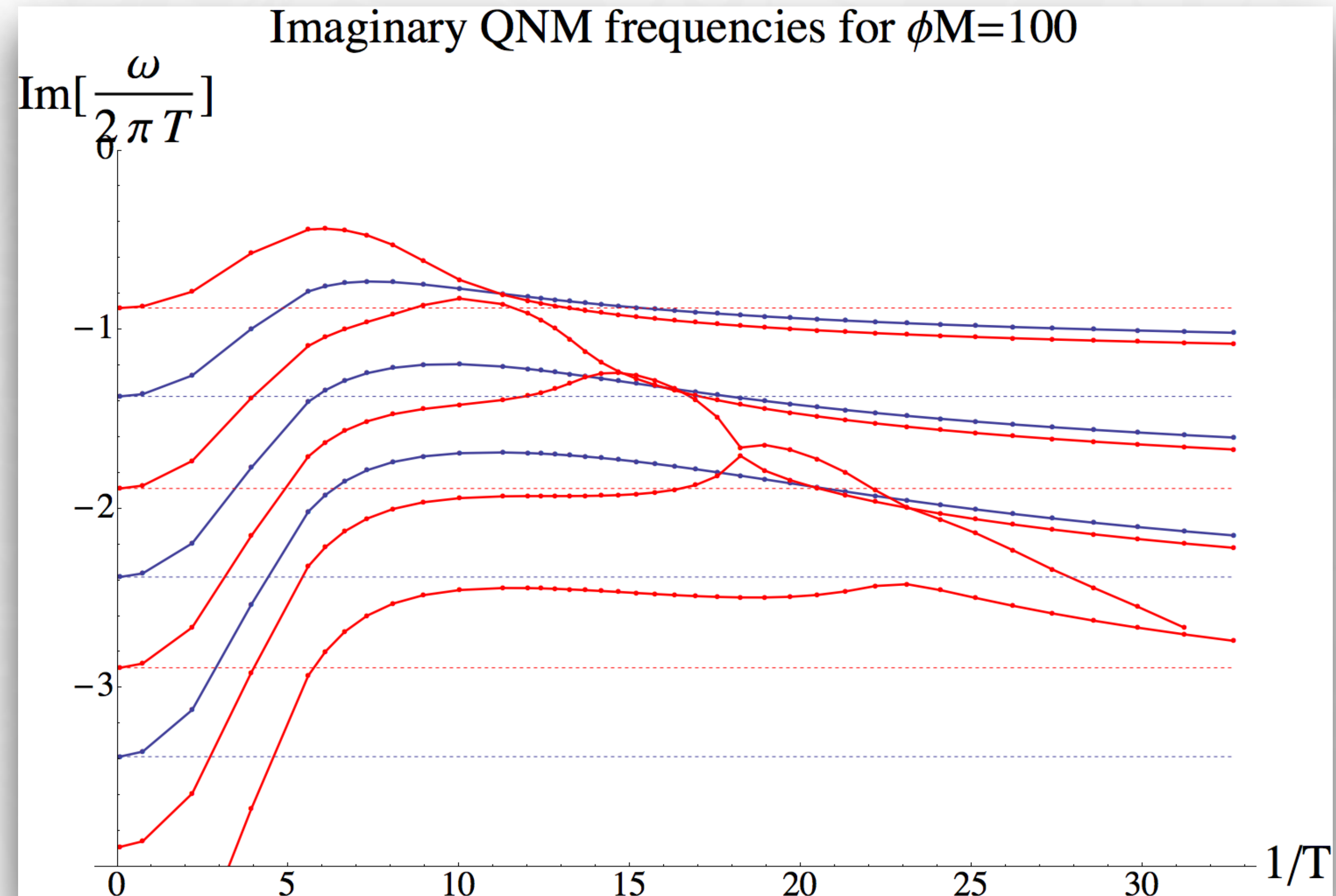
It is dual to an RG flow between two fixed points



The potential has a **free parameter** to control **non-conformality**

Non-conformal holographic near equilibrium dynamics

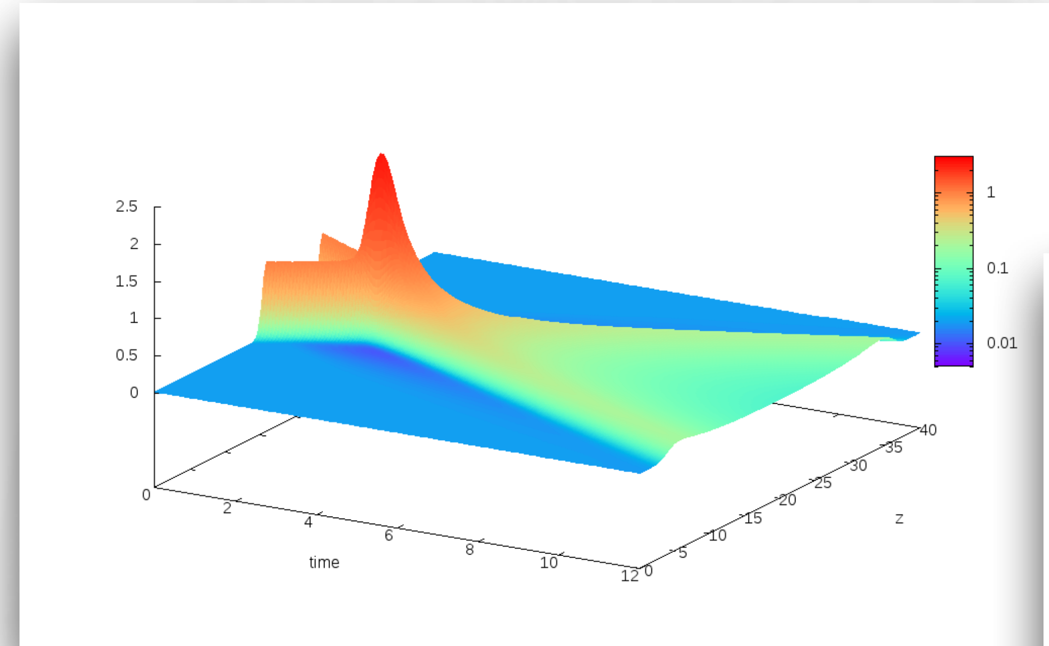
Quasi-normal modes: perturbations on a black brane dual to modes being thermalized

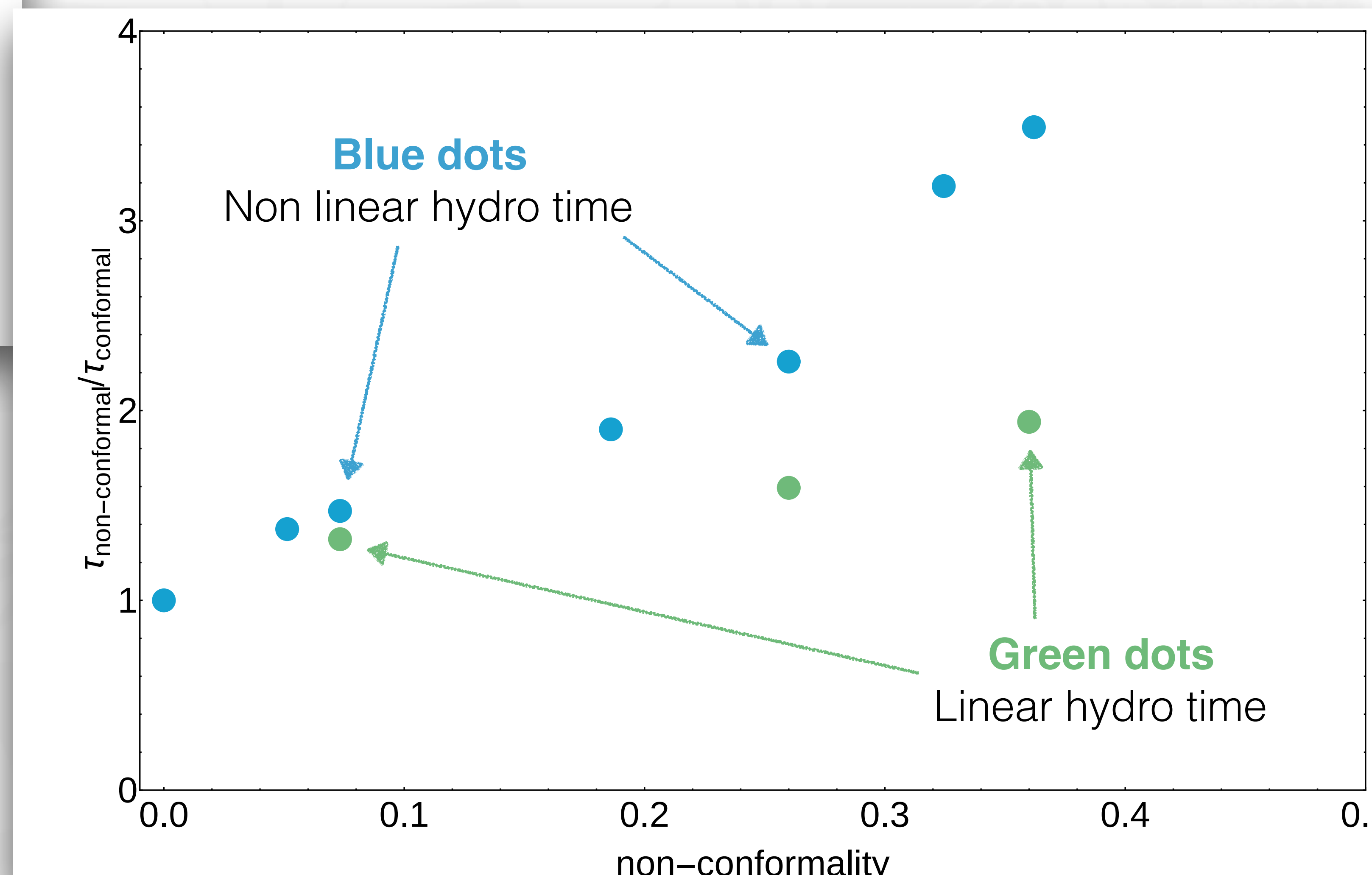


$$t_{hydro} \approx \frac{1}{Im(\omega_1)}$$

Main result: hydrodynamization time at a linear level increased by factor 2 at most when non-conformality is increased

Non-conformal holographic shock wave collisions





Main result: non-linear hydrodynamization times get *notably* increased by non-linearities. More studies required.

Shock wave collisions in a family of non-conformal field theories

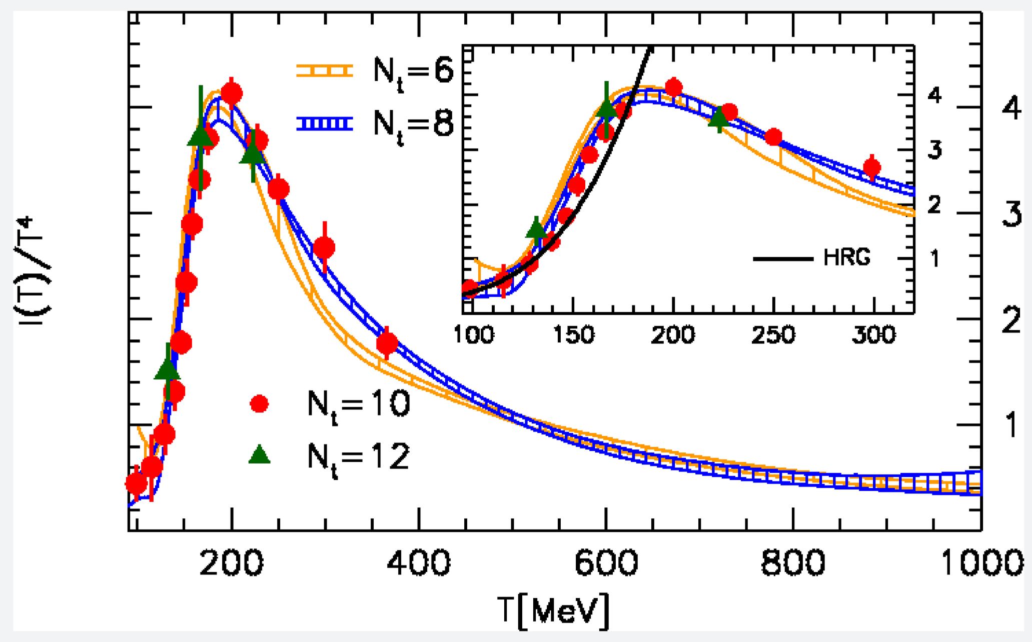
Maximilian Attems, Jorge Casalderrey-Solana, David Mateos, Ioannis Papadimitriou, Daniel Santos, Carlos Sopuerta, Miquel Triana and Miguel Zilhao
Departament de Física Fonamental, Universitat de Barcelona
E-mail: mtriana@ffn.ub.edu

UNIVERSITAT DE BARCELONA

Introduction

Holographic shock wave collisions provide a compelling toy model for the quark-gluon plasma (QGP) created in heavy ion colliders. Despite the simplicity of the set-up and the differences in the theories, shock wave collisions have been able to reproduce some of the key features of the QGP present in the colliders: the existence of a hydrodynamic regime and the fast hydrodynamization.

So far, most holographic far from equilibrium dynamics computations have been performed for conformal models. However, the QGP created in colliders still has a significant amount of non-conformality as lattice QCD calculations show (see plot), making a good case for non-conformal holographic set-ups.



[S. Borsanyi et alii arXiv:1007.2580 [hep-lat]]

A family of non-conformal models

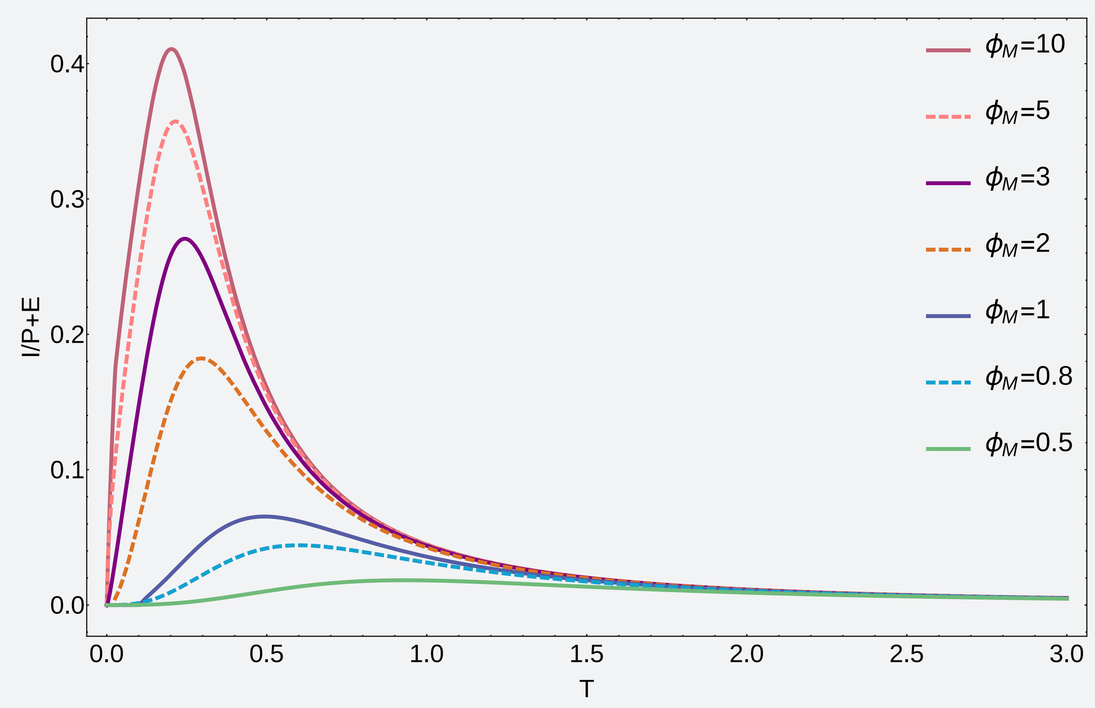
•Gravity + scalar field with a potential

$$L = \frac{1}{2}R - (\partial\phi)^2 - 2V(\phi)$$
$$V = -3 - \frac{3}{2}\phi^2 - \frac{1}{3}\phi^4 + \frac{\phi^6}{3\phi_M^2} + \frac{\phi^6}{2\phi_M^4} - \frac{1}{12\phi_M^4}\phi^8$$

where ϕ_M controls the non-conformality.

•The potential selected has a maximum and a minimum, which provides a vacuum geometry interpolating between two AdS spaces. This is dual to an RG flow between two fixed points.

•The interaction measure given by $I = \epsilon - 3p$ gives a meaningful parameter to characterize the degree of non-conformality (see plot).

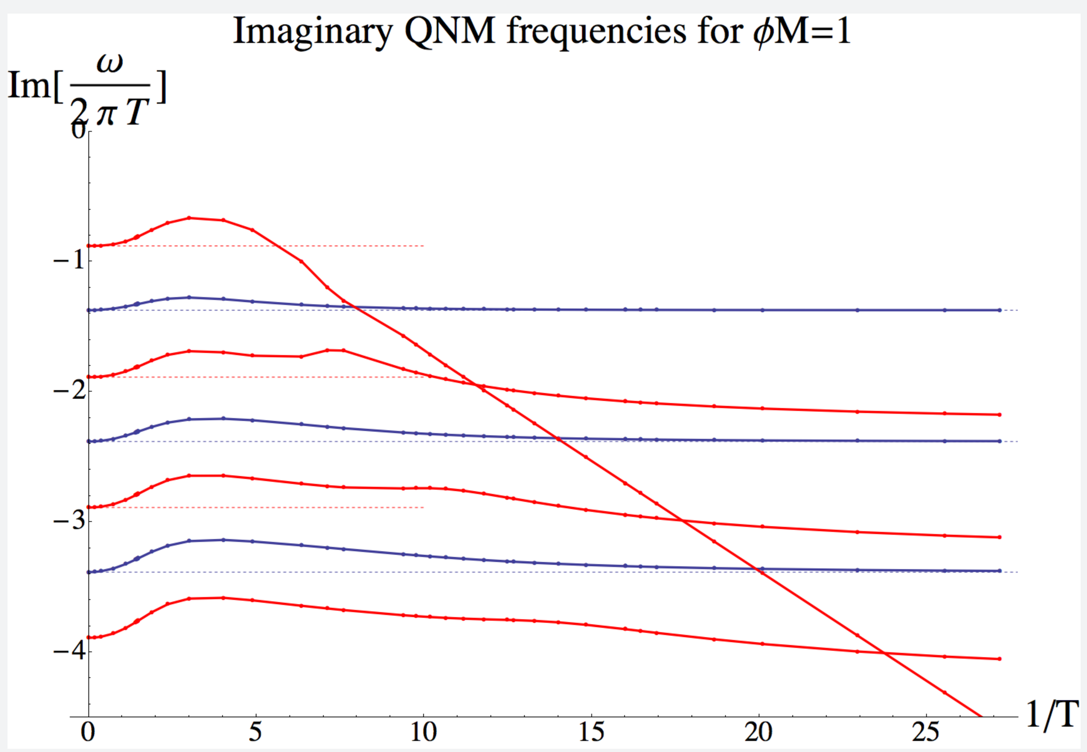


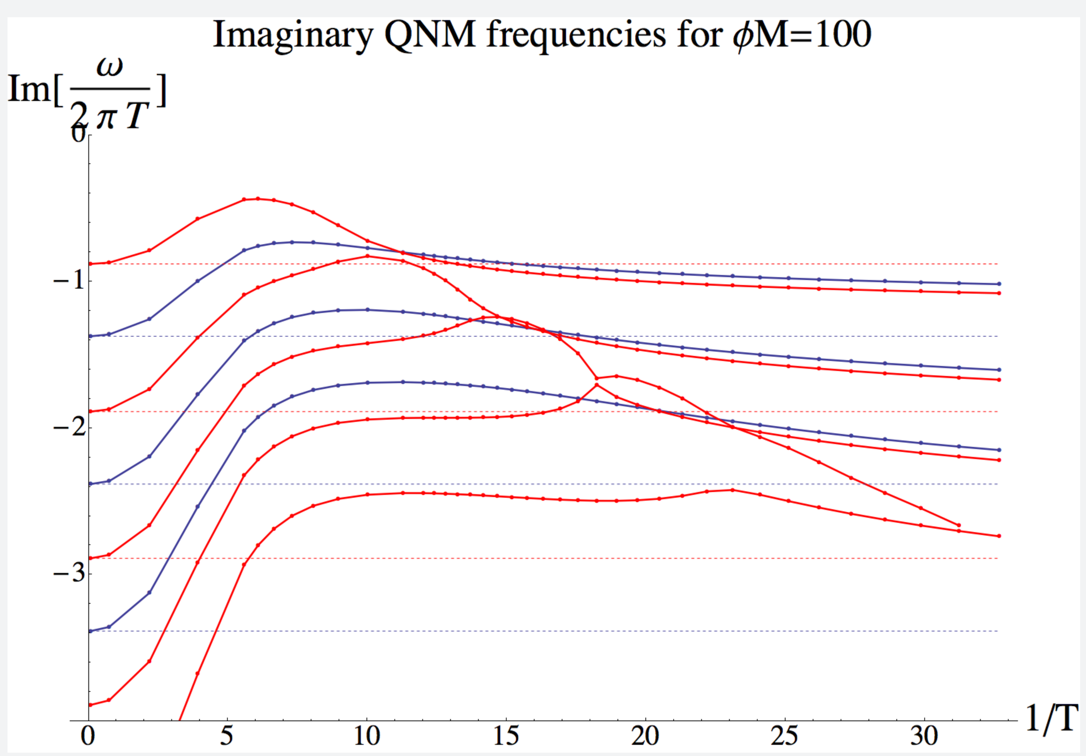
Near-equilibrium dynamics

The near-equilibrium perturbations are described on the gravity side of the duality by quasi-normal modes (QNMs) on top of a static black brane.

$$g_{\mu\nu} = g_{thermal} + \epsilon h_{\mu\nu}(r)e^{iqx_1 - it\omega}$$
$$\phi = \phi_{thermal} + \epsilon\delta f(r)e^{iqx_1 - it\omega}$$

The imaginary part of the frequency of the lowest QNM gives an estimation for the hydrodynamization time at a linear level.





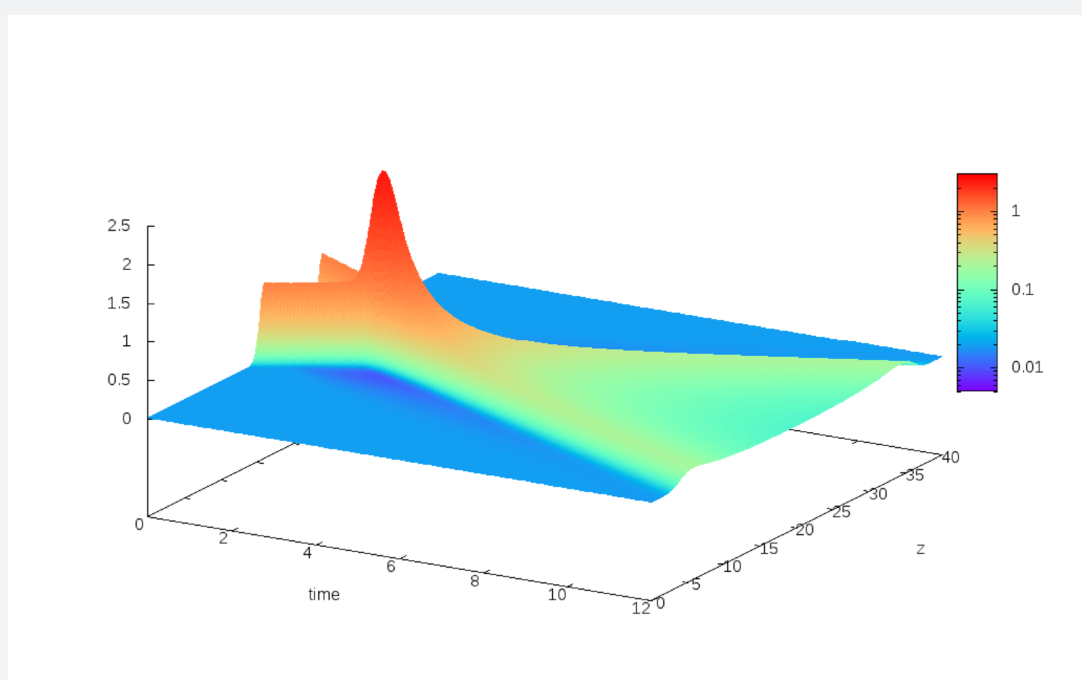
Main result: hydrodynamization time at a linear level increased by factor 2 at most when non-conformality is increased.

Far from equilibrium dynamics: shock wave collisions

The initial state for the evolution is given by two infinite sheets of energy travelling at the speed of light, the shock waves. The evolution is computed numerically in a set-up with 2+1 dynamic directions.

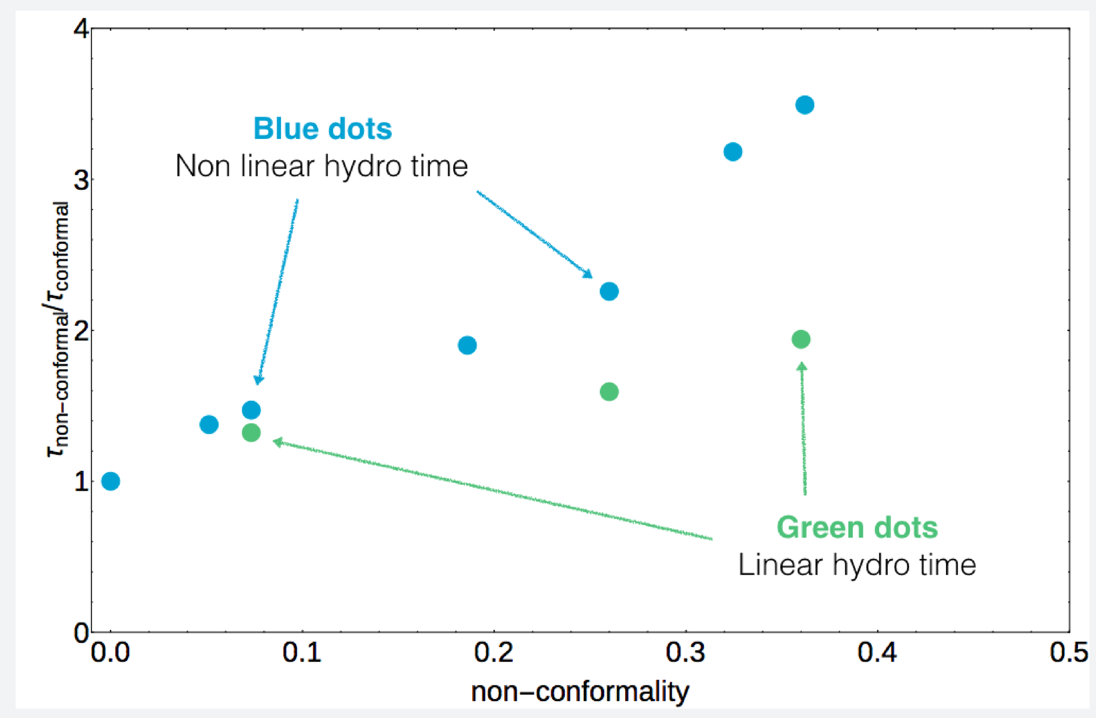
$$ds^2 = \frac{1}{u^2}du^2 + e^{2A[u]}(d\mathbf{x}_T^2 - dx_+dx_-) + f[u]h[x_\pm]dx_\pm^2$$

The outcome from the computation are magnitudes such as the energy density, the pressure or the fluid velocity for the dual plasma.



Energy density in terms of time and the longitudinal direction of the collision.

The plasma created also shows a hydrodynamic regime and hydrodynamization times of order $\frac{1}{T}$, although they increase with the non-conformality of the model.



Main result: non-linear hydrodynamization times get notably increased by non-linearities. More studies are required to assess if the hydro times can be made parametrically big.

Summary

•First simulation of a holographic non-conformal model for heavy ion collisions

•Hydrodynamics works early
  Despite non-trivial equation of state
  Despite non-zero bulk viscosity

•Hydrodynamization time slowed by > 3

•Hydrodynamics applies while non-conformal modes are still fully out of equilibrium

•More studies are on the way
  Systematic exploration of the parameter space
  Asymmetric collisons
  Different potentials are possible

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Fermion hierarchies in F-theory GUTs

Gianluca Zoccarato   Instituto de Física Teórica, UAM/CSIC

iStrings 2016, IFT Madrid, January 27th 2016

European Research Council
SPLE Advanced Grant
UNIVERSIDAD AUTONOMA DE MADRID
Instituto de Física Teórica UAM-CSIC
CSIC Consejo Superior de Investigaciones Científicas

Fermion hierarchies in F-theory GUTs

Gianluca Zoccarato Instituto de Física Teórica, UAM/CSIC

iStrings 2016, IFT Madrid, January 27th 2016

Based on: Marchesano, Regalado, G.Z. '15

Carta, Marchesano, G.Z. '15

Related work: Font, Ibañez, Marchesano, Regalado '12

Font, Marchesano, Regalado, G.Z. '13

Yukawa couplings MSSM

In the MSSM the Yukawa couplings are

$$W_{MSSM} \supset y^{\mathbf{u}}_{ij}\, H_u Q^i u^j + y^{\mathbf{d}}_{ij}\, H_d Q^i d^j + y^{\mathbf{e}}_{ij}\, H_d L^i e^j$$

$$W_{SU(5)} \supset Y^{\mathbf{u}}_{ij}\, \mathbf{10}_M \cdot \mathbf{10}_M \cdot \mathbf{5}_U + Y^{\mathbf{d}/\mathbf{e}}_{ij}\, \mathbf{10}_M \cdot \bar{\mathbf{5}}_M \cdot \bar{\mathbf{5}}_D$$

Need a local enhancement to generate couplings in F-theory

- E_6 enhancement for $\mathbf{10}_M \cdot \mathbf{10}_M \cdot \mathbf{5}_U$ ← Not possible in type IIB
- SO(12) enhancement for $\mathbf{10}_M \cdot \bar{\mathbf{5}}_M \cdot \bar{\mathbf{5}}_D$

$E_6 + SO(12) \rightarrow \ldots$

Heckman, Tavanfar, Vafa '09

Idea: generate both couplings at a single point

- Possible to compute all couplings using the same local model

  I. Compute CKM matrix elements

  II. Find preferred value for some MSSM parameters ($\tan\beta$)

- Large separation induces large mixing angles

A group containing both E_6 and $SO(12)$ → E_7, E_8

Local E_7/E_8 models

Defining data of the local model

1. Vev of the adjoint Higgs

   - Describes the configuration of 7-branes
   - Breaks E_n down to $SU(5)$
   - If reconstructible defines the local spectral cover

2. Open string fluxes

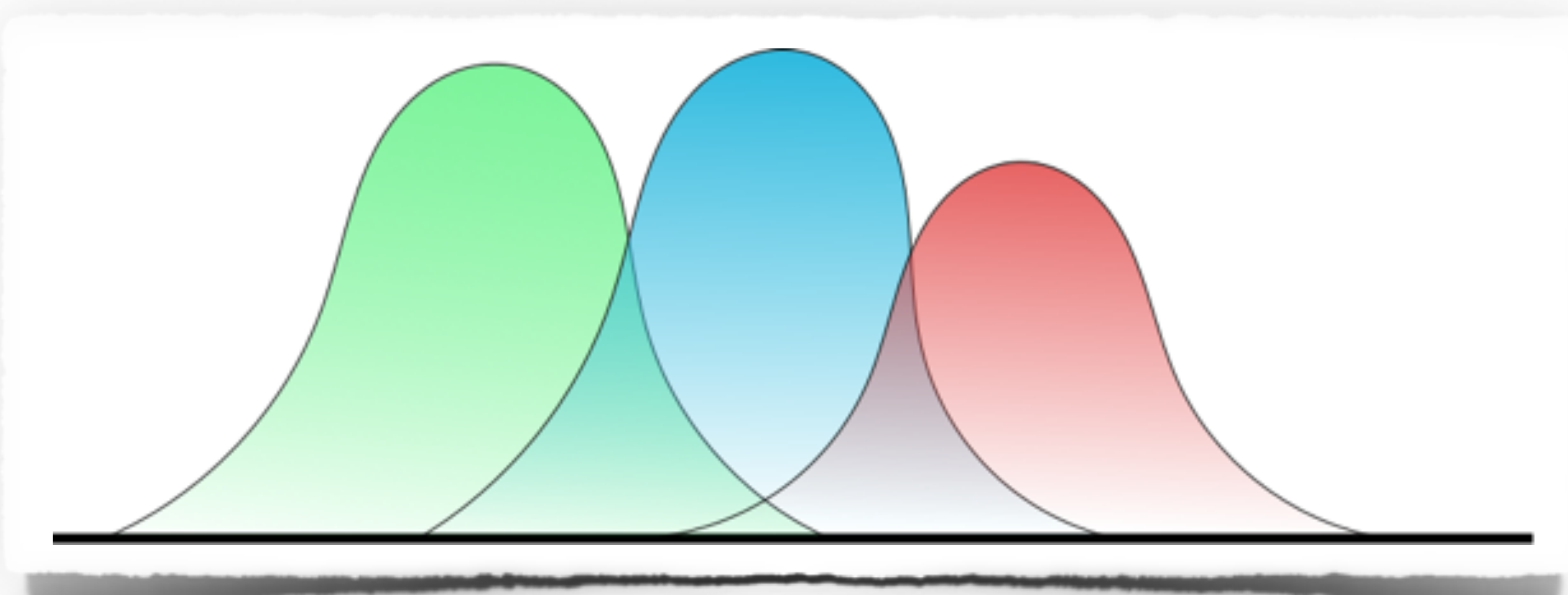
   - Generate chirality in 4d
   - Break $SU(5)$ down to $SU(3) \times SU(2) \times U(1)_Y$

Yukawa couplings in 8d SYM

Yukawa couplings can be computed by dimensional reduction of the 8d superpotential

$$W = \int_S F^{(0,2)} \wedge \Phi = \int_S \bar{\partial} A \wedge \Phi + \boxed{\int_S A \wedge A \wedge \Phi}$$

Beasley, Heckman, Vafa '08



Yukawa couplings in 8d SYM

Yukawa couplings can be computed by dimensional reduction of the 8d superpotential

$$W = \int_S F^{(0,2)} \wedge \Phi = \int_S \bar{\partial} A \wedge \Phi + \boxed{\int_S A \wedge A \wedge \Phi}$$

Beasley, Heckman, Vafa '08

- Yukawa matrix has rank 1

→ Non perturbative corrections deform the superpotential

Marchesano, Martucci '09

$$W = \int_S F^{(0,2)} \wedge \Phi + \frac{\epsilon}{2} \sum_{n \in \mathbb{N}} \int_S \theta_n \mathrm{STr}\left(\Phi^n F \wedge F\right)$$

Yukawa matrix has rank 3 and possibly a hierarchy in the eigenvalues

$$\boxed{(\mathcal{O}(\epsilon^2), \mathcal{O}(\epsilon), \mathcal{O}(1))}$$

Fermion masses at GUT scale

Ross, Serna '07

Possible to accommodate GUT scale masses for tanβ ~ 10 - 20

$\tan\beta$	10	38	50
m_u/m_c	$2.7 \pm 0.6 \times 10^{-3}$	$2.7 \pm 0.6 \times 10^{-3}$	$2.7 \pm 0.6 \times 10^{-3}$
m_c/m_t	$2.5 \pm 0.2 \times 10^{-3}$	$2.4 \pm 0.2 \times 10^{-3}$	$2.3 \pm 0.2 \times 10^{-3}$
m_d/m_s	$5.1 \pm 0.7 \times 10^{-2}$	$5.1 \pm 0.7 \times 10^{-2}$	$5.1 \pm 0.7 \times 10^{-2}$
m_s/m_b	$1.9 \pm 0.2 \times 10^{-2}$	$1.7 \pm 0.2 \times 10^{-2}$	$1.6 \pm 0.2 \times 10^{-2}$
m_e/m_μ	$4.8 \pm 0.2 \times 10^{-3}$	$4.8 \pm 0.2 \times 10^{-3}$	$4.8 \pm 0.2 \times 10^{-3}$
m_μ/m_τ	$5.9 \pm 0.2 \times 10^{-2}$	$5.4 \pm 0.2 \times 10^{-2}$	$5.0 \pm 0.2 \times 10^{-2}$
Y_τ	0.070 ± 0.003	0.32 ± 0.02	0.51 ± 0.04
Y_b	0.051 ± 0.002	0.23 ± 0.01	0.37 ± 0.02
Y_t	0.48 ± 0.02	0.49 ± 0.02	0.51 ± 0.04

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Conclusions

- In F-theory models Yukawa matrix has rank 1

- Inclusion of non-perturbative effects increases the rank and may generate favourable hierarchies

- Not all E_7/E_8 models accommodate a good hierarchy

- Computation of physical coupling shows that GUT scale masses can be accommodated

Conclusions

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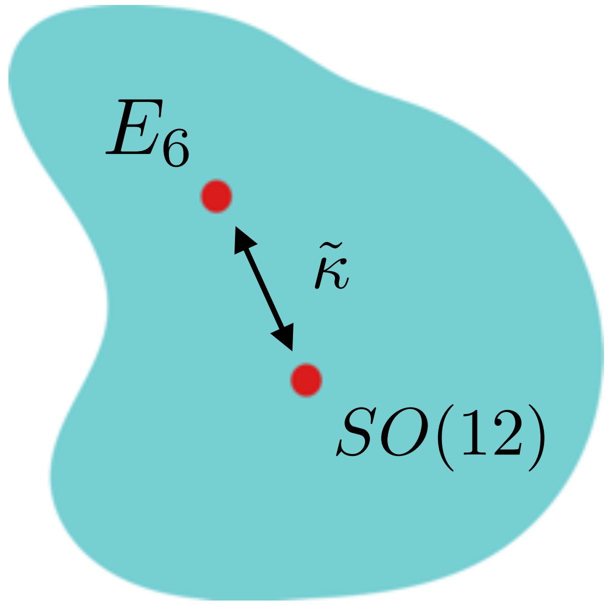
Thank you!

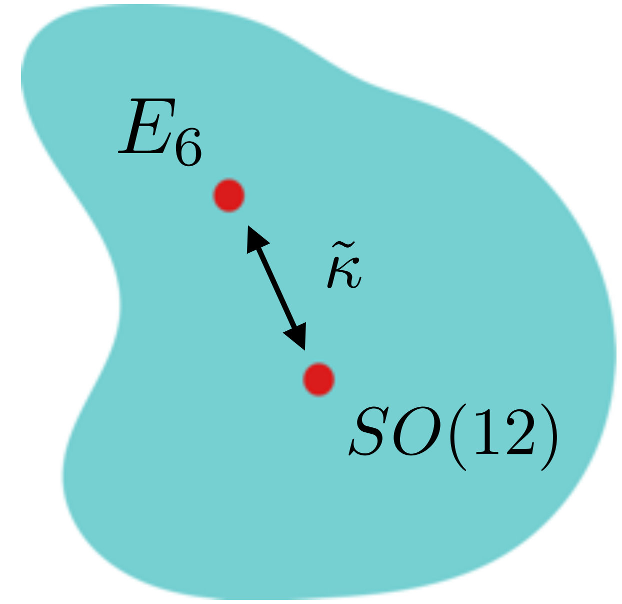
Back up slides

Separating the points

Small separation between Yukawa points



Separating the points



Small separation between Yukawa points

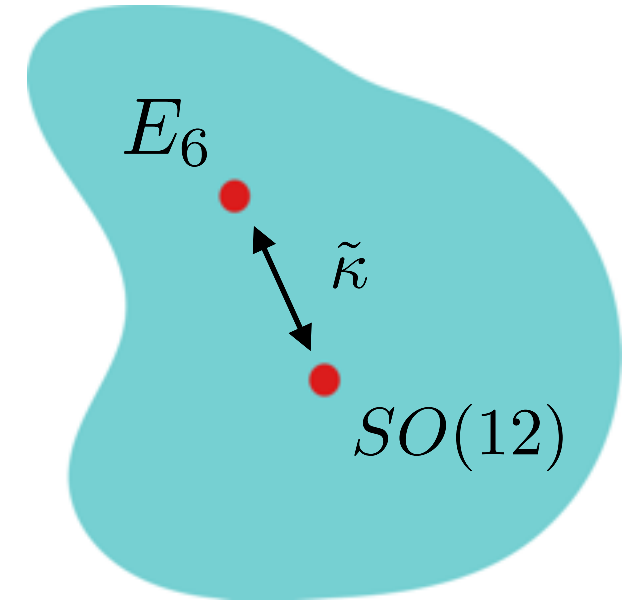
Change of wavefunction basis $\longrightarrow$ Effect on CKM matrix

Randall, Simmons-Duffin '09

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$|V_{tb}| \simeq 1 \quad \longrightarrow \quad |\tilde{\kappa}| \sim 10^{-2} - 10^{-3}$$

Separating the points



Small separation between Yukawa points

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$$|V_{tb}| \simeq 1 \longrightarrow |\tilde{\kappa}| \sim 10^{-2} - 10^{-3}$$

Only very small separation of points is possible in this scheme

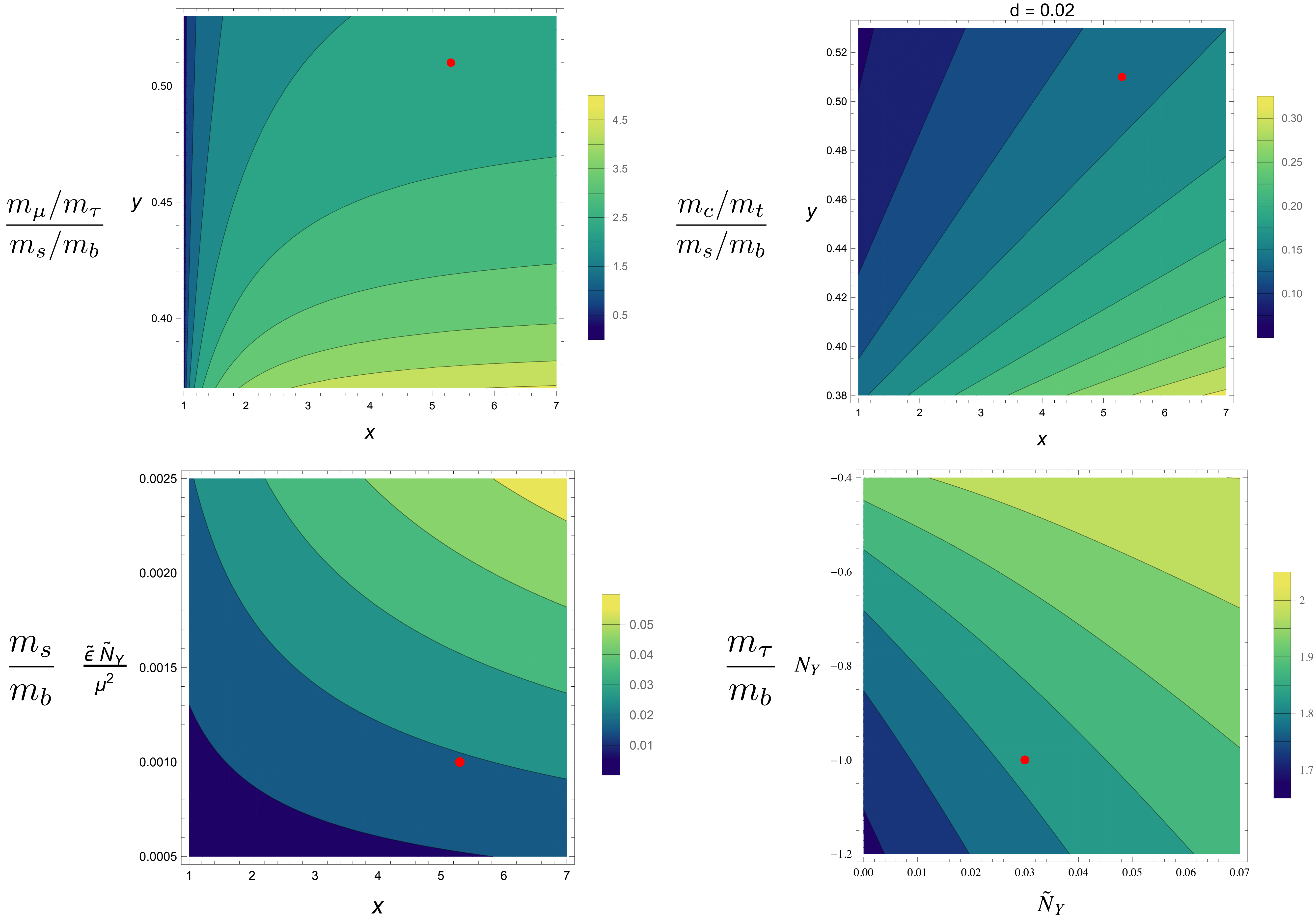
Yukawa matrices

Up Yukawa matrix:

$$Y_U = \frac{\pi^2\,\gamma_U\,\gamma^Q_{10,3}\gamma^U_{10,3}}{2\rho_m\rho_\mu}\begin{pmatrix} 0 & 0 & \tilde{\epsilon}\frac{\gamma^Q_{10,1}}{2\rho_\mu\gamma^Q_{10,3}} \\ 0 & \tilde{\epsilon}\frac{\gamma^Q_{10,2}\gamma^U_{10,2}}{2\rho_\mu\gamma^Q_{10,3}\gamma^U_{10,3}} & 0 \\ \tilde{\epsilon}\frac{\gamma^U_{10,1}}{2\rho_\mu\gamma^U_{10,3}} & 0 & 1 \end{pmatrix} + \mathcal{O}(\tilde{\epsilon}^2)$$

Down Yukawa matrix:

$$Y_D = -\frac{\pi^2\,\gamma_D\,\gamma^Q_{10,3}\,\gamma^D_{5,3}}{2d\,\rho_m\rho_\mu}\begin{pmatrix} 0 & \tilde{\epsilon}\tilde{\kappa}\frac{\gamma^Q_{10,1}\gamma^D_{5,2}}{d\rho_\mu^2\gamma^Q_{10,3}\gamma^D_{5,3}} & \left(\frac{2\tilde{\kappa}^2}{\rho_\mu} - \frac{\tilde{\epsilon}}{d}\right)\frac{\gamma^Q_{10,1}}{2\rho_\mu\gamma^Q_{10,3}} \\ \tilde{\epsilon}\tilde{\kappa}\frac{\gamma^Q_{10,2}\gamma^D_{5,1}}{2d\rho_\mu^2\gamma^Q_{10,3}\gamma^D_{5,3}} & -\tilde{\epsilon}\frac{\gamma^Q_{10,2}\gamma^D_{5,2}}{2d\rho_\mu\gamma^Q_{10,3}\gamma^D_{5,3}} & -\tilde{\kappa}\frac{\gamma^Q_{10,2}}{\rho_\mu\gamma^Q_{10,3}} \\ -\tilde{\epsilon}\frac{\gamma^D_{5,1}}{2d\rho_\mu\gamma^D_{5,3}} & 0 & 1 \end{pmatrix} + \mathcal{O}(\tilde{\epsilon}^2)$$



mμ/mτ / ms/mb
y
x
mc/mt / ms/mb
d = 0.02
y
x
ms/mb
ε̃ ÑY / μ²
x
mτ/mb
NY
ÑY

GONG