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Mass Scales on Braneworlds

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Work with:

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- Jon Toebbe, Emory
- Sarah Scoles, Agnes Scott

Summary: Benson proceedings, hep-th/0510128

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MOTIVATIONS:

- Success, warped extra dimension
- Theoretical shortcomings

RECENT WORK:

- resolve shortcomings
- build sounder EFT formalism, calibrate braneworld EFTs
- Implications: hierarchy, particle, cosmology (Friedmann)

SUCCESSSES:

- Diversify warped extradimensional model
- Validate hierarchy solution, RS and others
- Clarify type of induced braneworld EFT
 - integrated bulk, unresolvably small r
 - (**holy grail**) localized on brane in extended extra dimension

FUTURE:

- **holy grail** colocalized EFTS
- Cosmology & Friedmann equations

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MOTIVATIONS:

Warped extra dimension promises

- Hierarchy $M_{\text{Pl}} \gg M_{\text{ew,GUT}}$
- particle hierarchies
- standard 4D gravity & cosmology, inflation
- interesting cosmology, quintessence/dark energy

SHORTCOMINGS:

Over-reliance on Randall-Sundrum Exact toy model, Horava-Witten vacuum in M-theory, but

- one in landscape
- single vacuum, vs thermodynamic ensemble:
updates 00,02 of Brandenberger-Vafa 89:
 - thermal ensemble, dimensions grow/some obstructed
 - Recent: 4 large, 2 intermediate, others Planck
motivates varied codimension (2)

RS asymmetric approach, matter/gravity EFT:

→ inconsistent conceptualization, 4D EFT ↔ bulk

See, review & critique RS model

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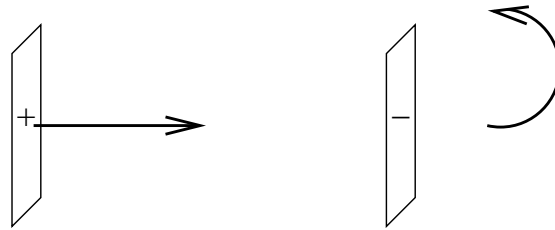
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WARPED EXTRA DIMENSIONS

Randall Sundrum 99

Setting

Horava-Witten vacuum

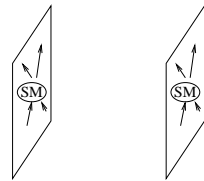


1 extra dimension

Branes at orbifold fixed points

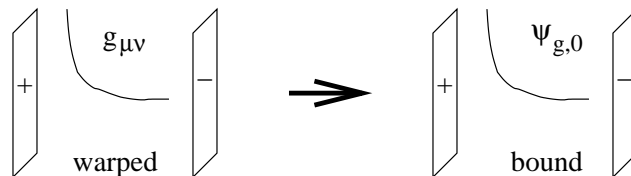
Separation large, infinite

Particles



bound, stringy

Gravity?



Bound \rightarrow 4D gravity $F_g \sim 1/r^2 +$ corrections on \square

Brane Location \rightarrow Hierarchy

$$|\psi_{g,0}|^2 \ll 1,$$

$$G_4 \ll G_5 \sim g \text{ on } \square$$

NOTE: WARP natural, NOT optional

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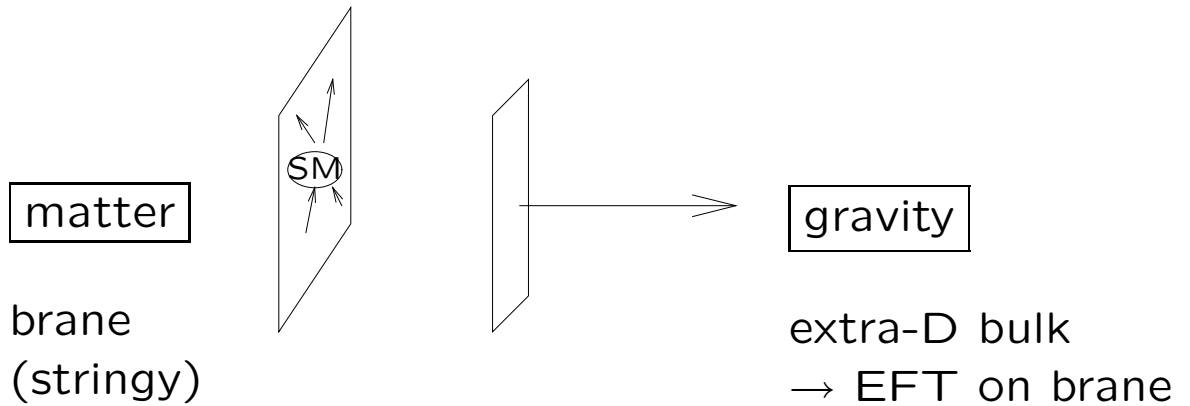
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THUS FAR

STANDARD PATH → braneworld cosmology



VARIANT:

- Also ϕ , A_a explore bulk
- detune $\Lambda_4 \neq 0$, cosmology

DIVERGE: Critique 4D EFT, Hierarchy in RS
Construct Dimensional Reduction

{ matter }
 { gravity } symmetrically, quantitatively

BOTH in extra-D bulk

⇒ bound to brane forms, warps → 4D EFT

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CRITIQUE

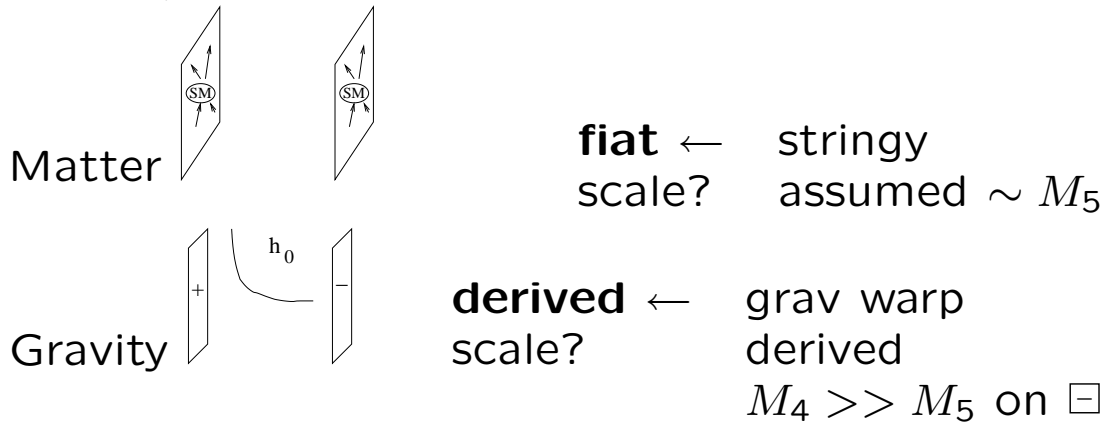
RS → huge literature
phenomenological/cosmological success

FOCUS

4D EFTs for matter, gravity

Hierarchy solution

- Matter/gravity asymmetry



ASYMMETRIC!

ASYMMETRY from long HISTORY:

warped confinement of matter, **holy grail**

- colocalize all matter on brane
- assure charge universality

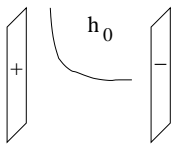
STRINGS stringy mechanism for this
NEW RS grav localization of 4D gravitons

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but **INCONSISTENT**:

Brane forms **once**, $\left\{ \begin{array}{l} \text{warps } g_{\mu\nu} \\ \text{binds matter/gravity} \\ \text{shifts **both** } M_5 \rightarrow M_4 \end{array} \right\}$
MUST TRACK **both** scales through brane formation

- Local versus Integrated EFT for Gravity
integrated 4D S_g (valid on \boxplus)



→

RS: valid also on \boxminus

resolved:

$$S_g (g_{\mu\nu} \text{ on } \boxminus) \Rightarrow M_4 \gg M_5$$

ODD HYBRID

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GOAL Lift brane formation veil

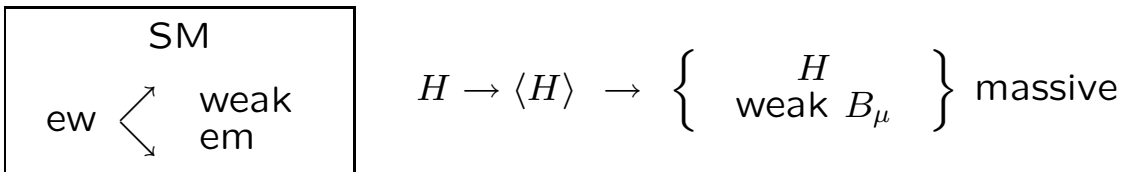
Derive sensible 4D EFTs for matter and gravity
Calibrate **both** induced 4D mass scales

Definite, rigorous framework

PROGRAM Dimensional SSB, Extradimensional QFT

Start QFT matter, gravity extradimensional

2 SSB's: BULK condensates



Here: $H \rightarrow \langle H \rangle$ constant, in BULK

H, B_μ massive extradimensional fields

Dimensional Branes form

GR: brane $T_{\mu\nu} \Rightarrow$ warped $g_{\mu\nu}$

Warped $g_{\mu\nu} \rightarrow$ BULK eom for gravitons \bar{h} H, B_μ matter

integrated \rightarrow EFT: $S_D(\phi_D, m) = \sum_{KK} S_4(\phi_4, m_{KK})$

BULK eom:

- Allowed 4D m_{KK}^2 , values SL
- Extra-dim profile: Confinement (?)
Effective 4D $q: \int () \psi^* \mathcal{A} \psi$

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Examine 2 contexts:

Field Theoretic Extradimensional RS

Generic Warped Extra Dimension

- Varying Codimension
- Brane formation = Defect formation
Dimensional SSB, scalar $\phi \rightarrow \langle \phi \rangle$ winds,
DEFECT, 3-brane at core
Defect $T_{\mu\nu}$ warps $g_{\mu\nu}$, binds $h_o \rightarrow$ 4D gravity
- Precedents: Cohen-Kaplan, Shaposhnikov et al, KB + Cho
gauged/global strings, monopoles
bind gravity, solve hierarchy
matter: ad hoc RS approach

GOAL Start with extradimensional EFTs

Warp \rightarrow Sensible matter + gravity 4D EFTS

ASSESS $\left\{ \begin{array}{l} \text{hierarchy} \\ \text{localization}(A^\mu) * \\ \text{charge universality}^* \end{array} \right.$

* field theoretic conundra

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Generic Findings

Matter & Gravity EFTs from Warped Extra Dimensions

Warped Metric: $ds^2 = B(r) \bar{g}_{\mu\nu} dx^\mu dx^\nu + A(r) dr^2 + r^2 d\Omega^2$

flat $\bar{g}_{\mu\nu} = \eta_{\mu\nu}$; defect core at $r = 0$, $B(0) = 1$
 $\Lambda_4 = 0$, often from $\Lambda_D < 0$ (AdS)

Gravity: $\bar{g}_{\mu\nu} = \eta_{\mu\nu} + \bar{h}_{\mu\nu}$

massless mode: $m_{KK}^2 = 0 \rightarrow 1/r^2$ 4D gravity

$$\bar{h} = 1/\sqrt{N}$$

$$\int_D : S_D \rightarrow S_4 \quad m_{Pl,4}^2 = M_{Pl,D}^{D-2} N$$

Matter:

lowest $m_{KK}^2 \rightarrow$ 4D Higgs, gauge masses

Confinement? Model-dependent

Usual $\left\{ \begin{array}{l} \text{massless } h_o, A^\mu, \psi \\ \text{massive } \phi, B^\mu, \psi \end{array} \right\}$ different bulk regions

Elusive: confine **all** to single brane

BUT: for small warped extra dimension (UNRESOLVED)

Diverse localization OK

Smearred 4D EFT for matter, gravity sensible

Charge Universality:

q to A^μ universal

q to B^μ model-dependent (possibly universal)

RS: universal, all ψ to massive B_n^μ (few zms)

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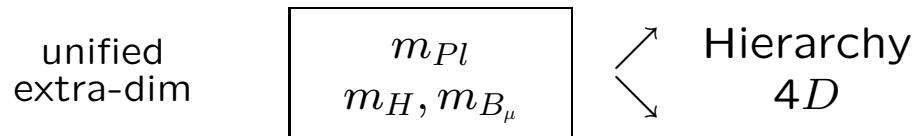
BLUEPRINT for HIERARCHY

$$m_{Pl,4}^2 \text{ fixed by } N = \int dr \rho \bar{h}_{m=0}^2$$

$$m_{H,4}^2, m_{B_\mu,4}^2 \text{ fixed by lowest values of SL eqns}$$

Distinct scale flows: different physics

DIVERGENT FLOW \Rightarrow Mechanism for Hierarchy!



SPECIFIC RESULTS

Matter & Gravity EFTs from Warped Extra Dimensions

Global Monopole
KB & Domokos
Global String
KB & Toebbe

hierarch. enhanced m_F

$$m_{Pl,7} \nearrow$$

$$m_H, m_{B_\mu} \rightarrow \sim \text{unchanged}$$

Field theoretic RS
KB

$$m_{Pl,5} \rightarrow \sim \text{unchanged } m_{Pl,4}$$

$$m_H, m_{B_\mu} \searrow$$

hierarch. suppressed

Both cases: hierarchy solution robust!

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SPECIFICS: Adapted Randall-Sundrum

$$ds^2 = e^{-2kR|\phi|} \bar{g}_{\mu\nu} dx^\mu dx^\nu + R^2 d\phi^2, \quad k \sim M_{\text{Pl},5}$$

Mass Scales

Gravity

$$h_o = 1/\sqrt{N}, \quad N = \int_{-\pi}^{\pi} \rho d\phi = \frac{1}{k} (1 - e^{-2kR\pi})$$

$$M_{\text{Pl},4}^2 = (1 - e^{-2kR\pi}) M_{\text{Pl},5}^3/k$$

Massive Higgs Goldberger-Wise 99, bulk ϕ

Ghergetta & Pomarol; Grossman & Neubert;
Chang *et al.* 00, bulk ψ

$$m_n = kx_{n\nu} e^{-kR\pi} \quad \text{exponentially suppressed}$$

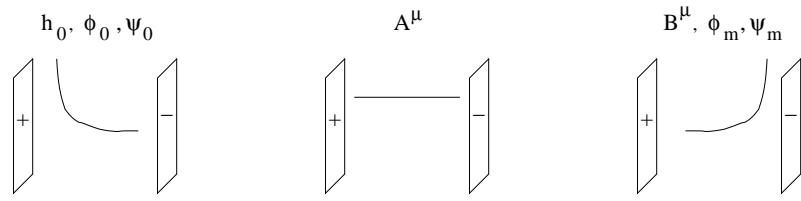
Massive Gauge Fields Pomarol 99, bulk A^μ

$$m_{a,n} = kx_{an\nu'} e^{-kR\pi} \quad \text{exponentially suppressed}$$

Hierarchy $kR = 12$, 4D, 5D gravity at Planck scale
4D matter at TeV scale

Localization Mixed

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BUT hierarchy $\Rightarrow R \sim 12M_{\text{PL}}^{-1}$ **unresolved**
 smeared integrated EFT viable

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Charge Universality photon: $e_4 = \frac{e_5}{\sqrt{2\pi R}}$, universal

massive B_n^μ : g_{4B_n}

Universal for ψ , depend on B^μ bulk and KK mass

UPSHOT

Recast Randall-Sundrum model as brane-warped background

For extradimensional field theoretic matter and gravity

- Sensible 4D EFTs for matter and gravity
- Solve hierarchy and charge universality
- **Small** warped extradimension $\sim 12M_{\text{Pl}}^{-1}$
- 4D EFT integrated, unresolved

Generic warped extra dimension:
model dependence, but promise

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Future Directions

- EFT holy grail: specific theories with bulk ew symmetry (zero modes)
promise colocalization (Oda 03)
- detuned Λ_4 ; dynamical bulk moduli; induced Friedmann eqns and cosmology

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