Multiple Extra Dimensions and Cosmic Sources of KK Particles

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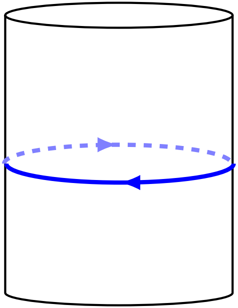
Plan

1. General introduction to extra dimensions
2. Warped extra dimensions
3. Multiple extra dimensions
4. Involving students in high energy theory
5. Cosmic sources (if time)

S^1: Wave function



Continuity requires:

$$\Psi(y) = \Psi(y + 2\pi R)$$

$$\Psi = \frac{1}{\sqrt{2\pi R}} \sum_{n=-\infty}^{+\infty} \psi^{(n)} e^{iny/R}$$

$$E^2 = (pc)^2 + \left(Mc^2\right)^2$$

S^1: Mass

$$E^2 = (pc)^2 + \left(Mc^2\right)^2 = (p_{3D}c)^2 + (p_y c)^2 + \left(Mc^2\right)^2$$

$$= (p_{3D}c)^2 + \underbrace{\left(\frac{n}{R}\hbar c\right)^2 + \left(Mc^2\right)^2}_{(m_n c^2)^2}$$

in particle physics, $\hbar = c = 1$:

$$m_n^2 = \frac{n^2}{R^2} + M^2 \qquad \text{Kaluza-Klein (KK) particles}$$

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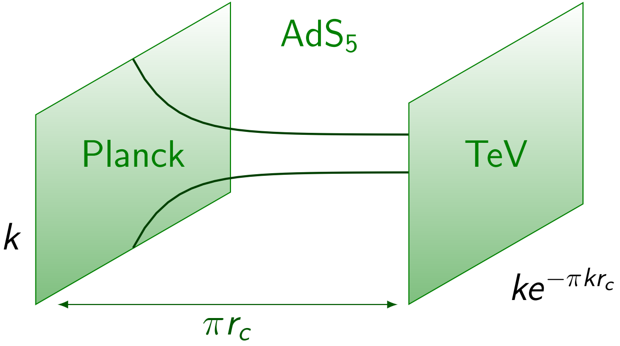
Randall-Sundrum Model

$$ds^2 = \underbrace{e^{-2kr_c|\phi|}}_{\text{warp factor}} \eta_{\mu\nu} dx^\mu dx^\nu - \underbrace{r_c^2 d\phi^2}_{\text{extra dimension}}$$



Multiple Extra Dimensions

Fermions in Randall-Sundrum models with two additional unwarped extra dimensions

Jeremy Perrin (2013 Apker Finalist)
and Erin De Pree
arXiv:1310.1928 [hep-ph]

6D Models

$$ds^2 = e^{-2kr_c|\phi|}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 d\phi^2 - \underbrace{R^2 d\theta^2}_{\text{new extra dim}}$$

Problem

No bulk mass terms that are also 6D-chiral and have four-components

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7D Warped Extra Dimensions

Instead we add two additional extra dimensions.

Choices

- Compactify on a torus (T_2) or a sphere (S_2)?
- Apply the warp factor to just the 4D dimensions or all other dimensions?

$\mathrm{AdS}_5 \times T_2$

$$ds^2 = e^{-2kr_c|\phi|}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 d\phi^2 - R^2\left(d\theta_1^2 + d\theta_2^2\right)$$

Set of coupled differential equations for the KK wavefuntions.

$\mathrm{AdS}_5 \times S_2$

$$ds^2 = e^{-2kr_c|\phi|}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 d\phi^2 - R^2\left(d\theta^2 + \sin^2\theta d\omega^2\right)$$

Problem

No zero-mode solutions without additional structure

General result for all manifolds of positive curvature.

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General result for all manifolds of positive curvature.

Research Group

1. Start early
2. Work in small groups
3. Not every project results in a publication

Questions and Discussion

Thank you

ekdepree@smcm.edu
arXiv:1505.00024 [astro-ph.HE]
arXiv:1310.1928 [hep-ph]

Possible sources of KK particles

Colliders

- Control the source (luminosity, E_{CM}, etc)
- Expensive

Cosmic sources

- Free
- No control over the source

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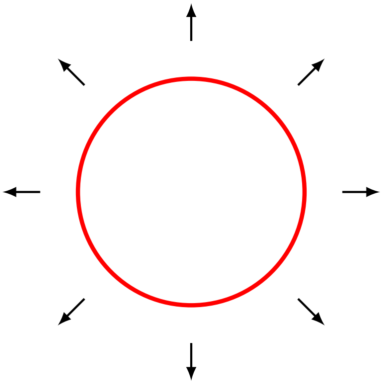
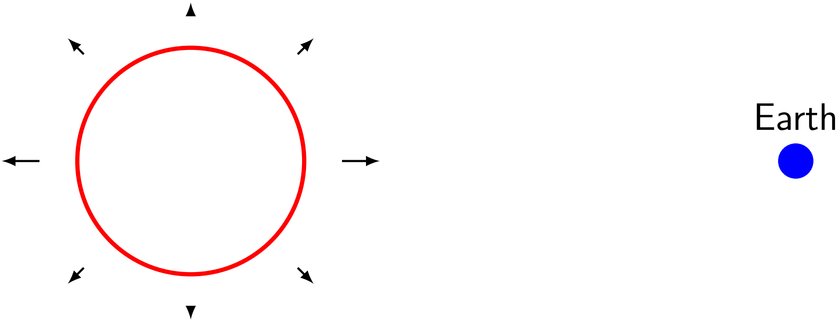
Gamma Ray Bursts (GRBs)

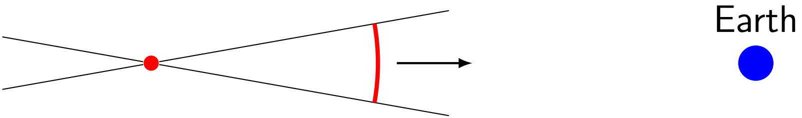


Ian Morgan, Ted Tao, De Pree, Kevin Tennyson
arXiv:1505.00024 [astro-ph.HE]

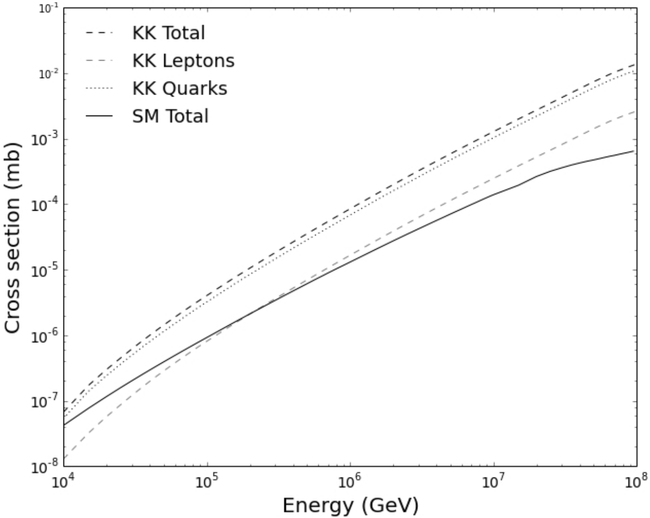
Observer's frame



Beaming



Results


KK Total
KK Leptons
KK Quarks
SM Total
Cross section (mb)
Energy (GeV)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}

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Thank you

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S^1: Momentum

$$p^2 = \mathbf{p}\cdot\mathbf{p} = p_{x_1}^2 + p_{x_2}^2 + p_{x_3}^2 + p_y^2 = p_{3D}^2 + p_y^2$$

$$\hat{p} = -i\hbar\nabla, \qquad \hat{p}_y = -i\hbar\frac{\partial}{\partial y}$$

$$\hat{p}_y\Psi = \frac{-i\hbar}{\sqrt{2\pi R}}\psi^{(n)}e^{iny/R}\left(\frac{in}{R}\right) = \frac{n\hbar}{R}\Psi$$

Eigenvalue for $\hat{p}_y$: $n\hbar/R$

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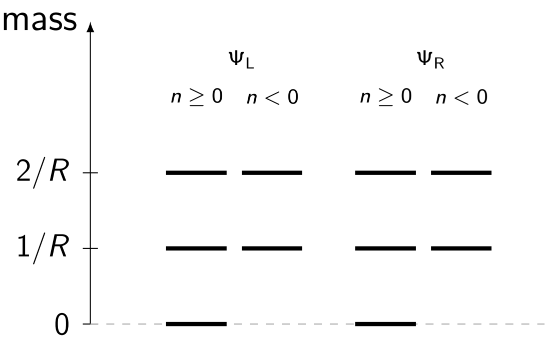
S^1: Fermion KK Spectrum



For $M = 0$

AdS_7 Model

$$ds^2 = e^{-2kr_c|\phi|}\left[\eta_{\mu\nu}dx^\mu dx^\nu - R^2\left(d\theta_1^2 + d\theta_2^2\right)\right] - r_c^2 d\phi^2$$