Kaluza–Klein Dark Matter from Deconstructed Universal Extra Dimensions

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Outline

- The dark matter puzzle
- Kaluza-Klein dark matter
- Radiative corrections
- Deconstructed extra dimensions
- A possible UV extension for KKDM
- Indirect detection
- Summary and outlook

In collaboration with: Tommy Ohlsson, KTH

The dark matter puzzle

Observations of e.g.

- Galaxy rotation curves
- Cosmic microwave background (CMB) radiation
- Gravitational lensing

$\rightarrow$ $22\,\%$ dark matter (DM), $74\,\%$ dark energy, $4\,\%$ ordinary matter

See for example: *WMAP 3-year results: implications for cosmology*, **D.N. Spergel et. al., astro-ph/0603449**

- In the standard model (SM), no particle candidates for DM
- New physics needed!

Kaluza-Klein dark matter

Popular new physics DM candidates

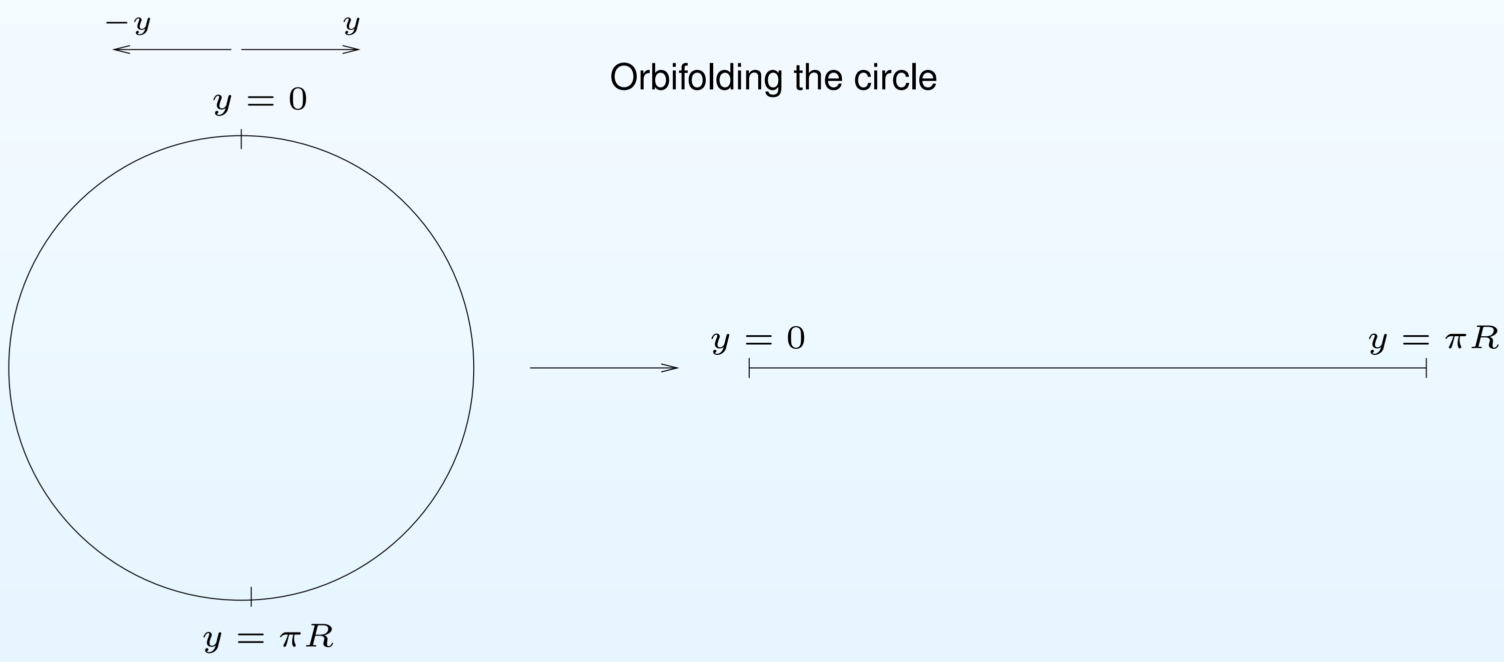
- Lightest supersymmetric particle (LSP)
- Kaluza–Klein dark matter (KKDM)

KKDM: cold bosonic DM candidate from universal extra dimensions (UED)

Kaluza–Klein dark matter

Universal extra dimensions: Accessible to all SM fields.

- Simplest UED: Compact extra dimension on S_1/Z_2 orbifold



Kaluza–Klein dark matter

Kaluza–Klein expansion:

$$\Psi_{\mathrm{odd}}(x,y) \sim \sum_n \sin(ny/R)\psi_n(x) \tag{1}$$

$$\Psi_{\mathrm{even}}(x,y) \sim \sum_n \cos(ny/R)\psi_n(x) \tag{2}$$

$\longrightarrow$

- Chiral zero mode fermions
- Removes unwanted scalars ($A_5^{(0)}$)
- LKP is stable from conservation of KK-parity $\rightarrow$ viable DM candidate

Radiative corrections

KK spectrum almost degenerate at tree-level $\longrightarrow$ radiative corrections crucial for:

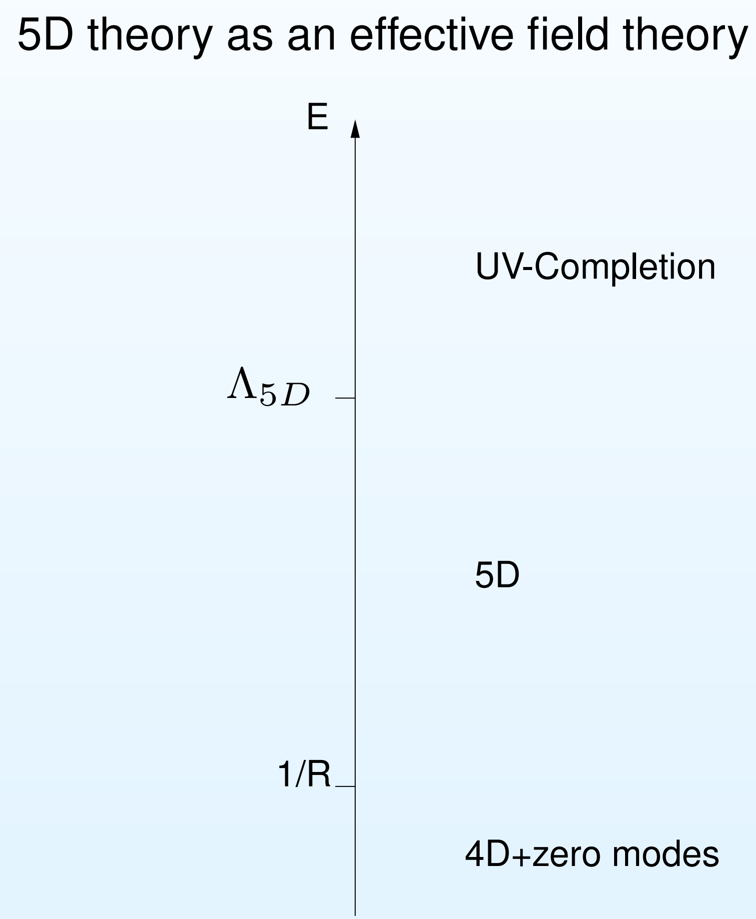
- Collider signals (decay channels)
- Nature of LKP

But: UEDs non-renormalizable field theories.

- Incalculable contributions from UV-physics
- UV-embedding relevant for phenomenology of KKDM!

Deconstructed extra dimensions

Higher dimensional gauge theories not renormalizable, considered as *effective field theories (EFT)*



Deconstructed extra dimensions

- If $\Lambda_{5D} \sim M_{Pl} \rightarrow$ String theory embedding possible.

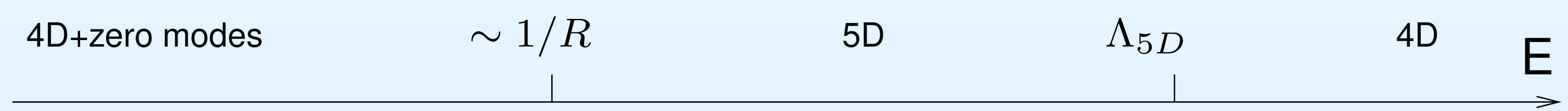
However, Λ_{5D} needs no be related to M_{Pl}.

- Pure QFT alternative: dimensional deconstruction

  N. Arkani-Hamed, A.G. Cohen, H. Georgi, PRL 86, 4757-4761, 2001; C.T. Hill, S. Pokorski, J. Wang, PRD 64, 105005, 2001

- At high energies 4D renormalizable QFT. At low energies *extra dimension is generated/constructed dynamically*.

Dynamically generated dimension at $E \sim \Lambda_{5D}$



Deconstructed extra dimensions

Let us see how this is obtained.

- Start with 4D gauged linear σ model @ high energies.
- Product gauge group $G = G_1 \times G_2 \ldots \times G_N$
- Contains gauge fields and scalar "link" fields $\Phi_{j,j+1}$

Conveniently represented by moose or quiver diagram

- Circles: gauge groups
- Arrows: Scalars $\sim (\bar{f}, f)$.

$$S = \int d^4x \left(\sum_{j=1}^{N} \left(v^2 |D_\mu \Phi_{j,j+1}|^2 - \frac{1}{2} F_{j\mu\nu} F^{j\mu\nu} \right) + V(\Phi_{j,j+1}) \right)$$

Deconstructed extra dimensions

"Mexican hat" type of potential

$$V(\Phi_{j,j+1}) = \sum_j \left(m^2|\Phi_{j,j+1}|^2 + \lambda|\Phi_{j,j+1}|^4 + \ldots\right)$$

Where $m^2 < 0$ and $\lambda > 0$ to trigger spontaneous symmetry breaking (SSB)

For $m \to \infty$ linear sigma model $\to$ non-linear sigma model after SSB

For large m, link fields approximated by unitary "matrices"

$$\Phi_{j,j+1} = e^{iG_j/v}$$

where G_j are the Goldstone bosons and $v = \langle \Phi_{j,j+1} \rangle$.

Transverse lattice gauge theory

Identified with transverse lattice gauge theory

- $\Phi_{j,j+1} \rightarrow$ link variables of lattice gauge theory
- Identify $G_j/v = -agA_{5j}$
- $1/(gv) = a$ lattice spacing
- Size $Na = \pi R$, for N lattice sites

3+1 continuous dimensions, 5th latticized extra dimension

Gauge boson mass spectrum from $\sum_j |D_\mu \Phi_{j,j+1}|^2$ after SSB:

$$m_n^2 = 4g^2v^2 \sin^2\left(\frac{n\pi}{2N}\right)$$

For $n \ll N \rightarrow m_n \approx n/R$. Usual linear KK spectrum!

A possible UV extension for KKDM

Apply idea of deconstructed extra dimensions to UEDs (KKDM)

- 4D fundamental theory at high energies
- UED constructed @ low energies through SSB

H-C Cheng, C.T. Hill, S Pokorski, J Wang, Phys.Rev. D64, 065007, 2001

J.F. Oliver, J. Papavassiliou, A. Santamaria, Phys.Rev. D68, 096003, 2003

With application to KKDM:

T Hällgren, T Ohlsson, JCAP06(2006)014

Latticized UEDs

Fundamental UV-theory:

4D gauged linear σ model coupled to fermions, with gauge group

$$G = \Pi_{j=0}^{N} SU(3)_j \times SU(2)_j \times U(1)_j$$

and link fields $Q_{j,j+1}$, $\Phi_{j,j+1}$ and $\phi_{j,j+1}$.

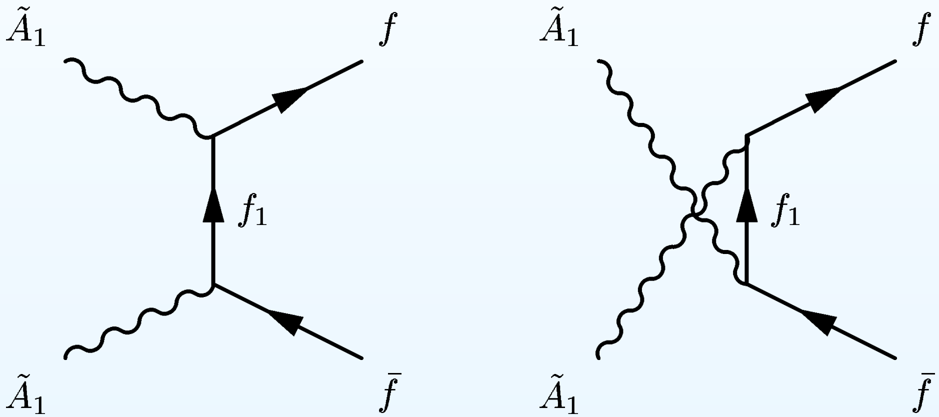
$$Q_{j,j+1} = (\bar{3}, 3),\ \Phi_{j,j+1} = (\bar{2}, 2),\ \phi_{j,j+1} = (-Y_\phi, Y_\phi)$$

Suitably chosen scalar potential $\longrightarrow$ latticized universal dimension appears @ low energies.

Analogue of KK-parity conserved, even for a few-site model$\longrightarrow$ $A^{(1)}$ potential DM candidate.

Indirect detection

Indirect detection of $A^{(1)}$: Positrons (e^+) from $A^{(1)} + A^{(1)} \to e^+ + e^-$ annihilation in the galactic halo.



Annihilation of KK gauge bosons to SM fermions. Shown are t- and u- channel diagrams

For indirect detection of KKDM via positrons in continuum UEDs, see:

H-C. Cheng, J.L. Feng, and K.T. Matchev, PRL 89:211301,2002

Positrons from dark matter annihilation

Propagation of e^+ through galaxy by diffusion.

Differential positron flux (at Earth):

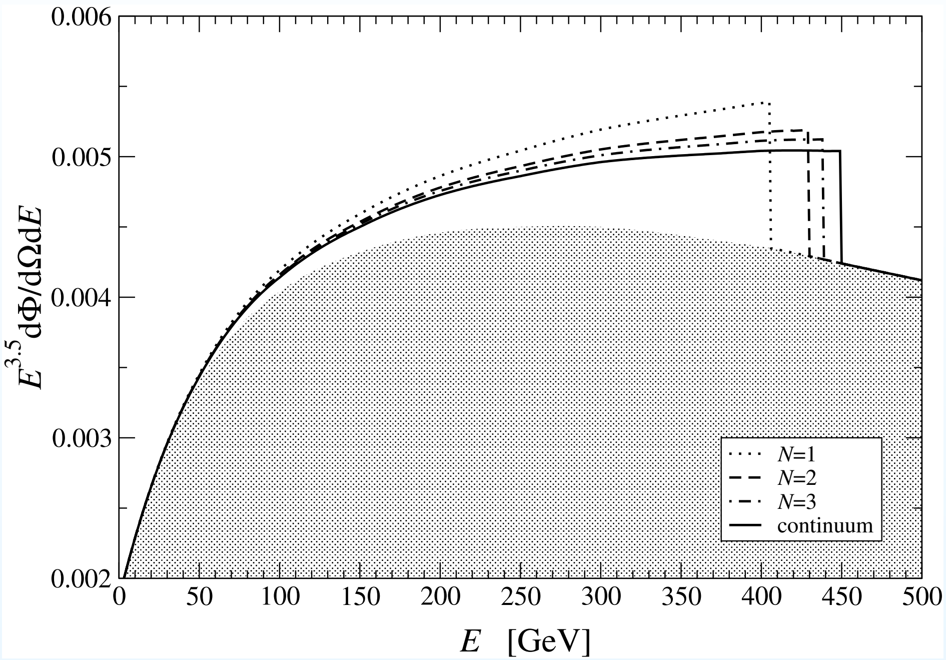
$$\frac{\mathrm{d}\Phi_{e+}}{\mathrm{d}\Omega \mathrm{d}E} = \frac{\rho_0^2}{m_{\tilde{A}_1}^2} \sum_i \sigma_i v B_{e+}^i \int \mathrm{d}\epsilon f_i(\epsilon) G(\epsilon, E)$$

ρ_0 local DM density, $G(\epsilon, E)$ propagation Green function

I.V. Moskalenko, A.W. Strong, PRD 60; J.L. Feng, K. T. Matchev, and F. Wilczek, Phys. Rev. D63, 045024

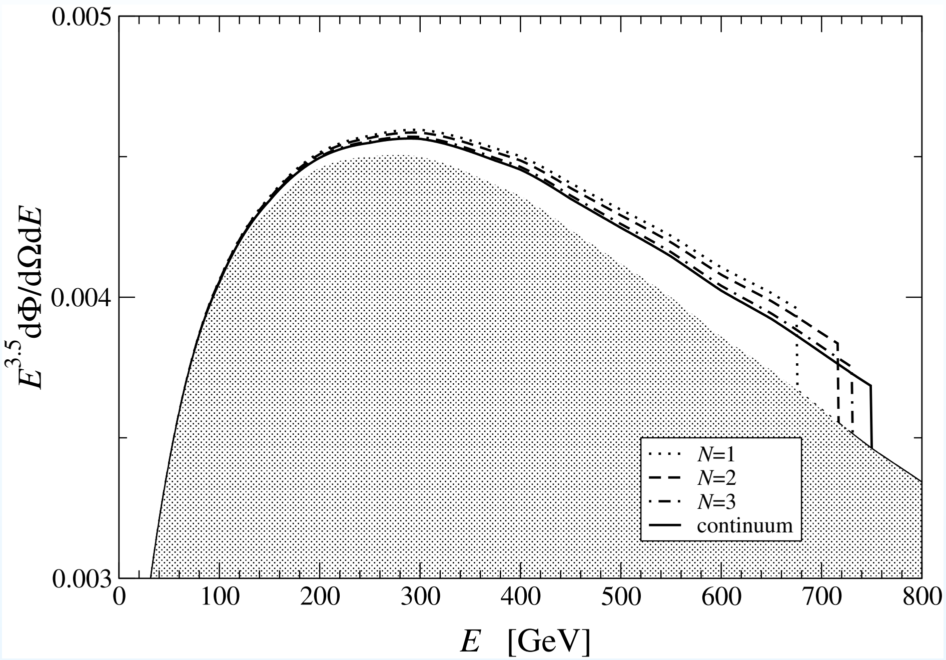
Positron flux calculated with DarkSUSY. Uses diffusion model with cylindrical symmetry. **P. Gondolo et. al., JCAP07(2004)008**

Positron flux



Differential positron flux. Given is the continuum model as well as $N = 1$ (two lattice sites), $N = 2$ and $N = 3$. Here $R^{-1} = 450$ GeV. Adopted from T. Hällgren and T. Ohlsson, JCAP06(2006)014

Positron flux



Differential positron flux. Given is the continuum model as well as $N = 1$ (two lattice sites), $N = 2$ and $N = 3$. Here $R^{-1} = 750$ GeV. Adopted from, T. Hällgren and T. Ohlsson, JCAP06(2006)014

- Characteristic peak from monoenergetic source.
- In principle observable by upcoming PAMELA or AMS-02 experiments.

PAMELA is expected to be launched today, June 15!

Phenomenological bounds

- Accelerator bounds: $1/R \gtrsim 700$ GeV $(99\%$ C.L.) (from LEP2 data and 2-loop effects) **T.Flacke, D. Hooper, J. March-Russell, Phys.Rev. D73,095002,2006**
- Also bounds from e.g. direct detection. Less severe.

Softened accelerator bounds for few-site lattice model.

J.F. Oliver, J. Papavassiliou, A. Santamaria, Phys.Rev. D68,096003, 2003

- Accelerator bounds reduced by 25 $\%$! (LEP2 data and 2-loop effects not included)
- Important feature for detection prospects

Summary and outlook

- Latticized UEDs from fundamental linear sigma model
- Analogue of KK-parity conserved, even for few-site model
- Detection prospects better than for continuum KK theory

Outlook:

- Radiative corrections to KK masses from deconstructed UEDs.
- Calculate improved accelerator bounds (LEP2 etc) for lattice model
- Upcoming PAMELA and AMS-02 experiments

References

This talk was in part based on:

Indirect detection of Kaluza–Klein dark matter from latticizied universal dimension,

Tomas Hällgren and Tommy Ohlsson, **JCAP06(2006)014**.