A Warped Model of Dark Matter

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Based on work
with Tony Gherghetta

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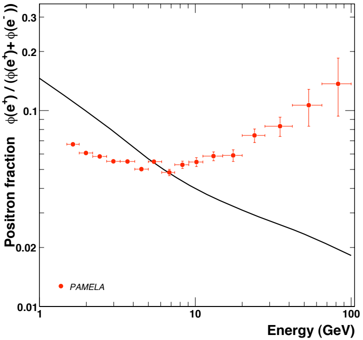
Introduction: Cosmic Ray Anomalies

- PAMELA found rising positron fraction $\frac{\phi(e^+)}{\phi(e^+)+\phi(e^-)}$ in energy range 10-100 GeV
- FERMI and HESS saw excess (over expected background) in $e^+ + e^-$ flux in range 100-$\sim$1000 GeV



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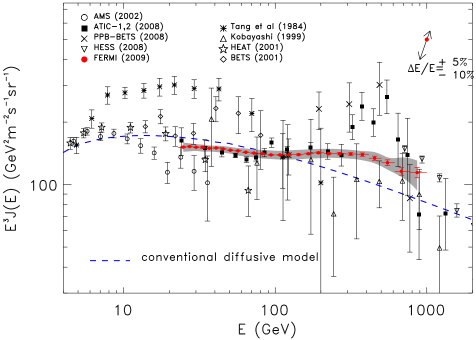

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Challenge for model builders:

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- Annihilation cross section to explain cosmic ray signals is $\mathcal{O}(100 - 1000)$ larger than cross section for right relic abundance

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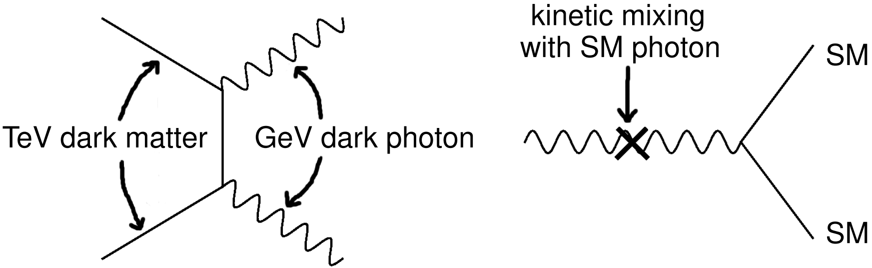

Outline of the talk

1. GeV gauge bosons from warped space
2. Mixing with Standard Model photon
3. Dark Matter
   - Dark matter on the IR brane
   - Dark Matter in the bulk
   - Gauge couplings
4. Conclusions

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GeV gauge bosons from warped space

Where does the GeV scale come from?

- SUSY (Katz & Sundrum; Morissey, Poland & Zurek; ...)
- We use: warped extra dimension (see also McDonald & Morissey)

Idea:

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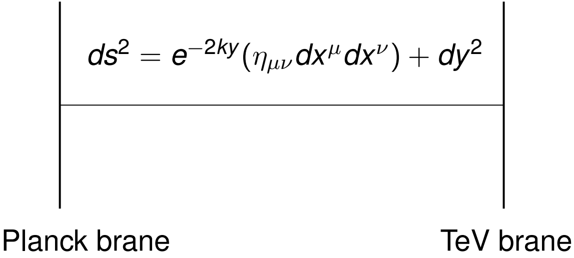

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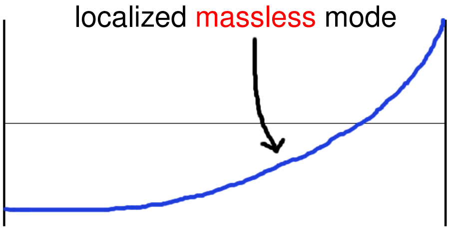

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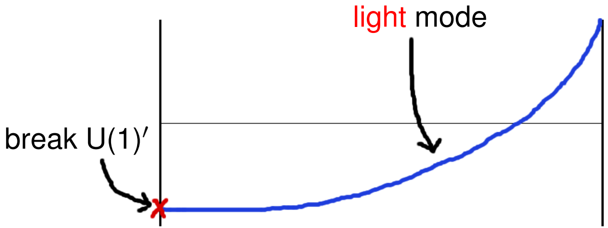

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$$S^{(A')} = \int d^5x \sqrt{-g} \left[-\frac{1}{4} e^{-2\phi} F'_{MN} F'^{MN} \right]$$

- Assume ϕ in coupling has y-dependent vev: $\langle\phi\rangle(y) \neq 0$.
- Massless KK mode has constant profile, $f^{(0)}(y) = N^{(0)}$:

$$\Rightarrow \quad S^{(A')} \supset \left((N^{(0)})^2 \int dy\, e^{-2\langle\phi\rangle} \right) \int d^4x \left[-\frac{1}{4} F'^{(0)}_{\mu\nu} F'^{(0)\mu\nu} \right]$$

- Normalization factor $\Rightarrow$ effective profile of massless mode is

$$\widehat{f}^{(0)}(y) \propto e^{-\langle\phi\rangle}$$

- Depending on $\langle\phi\rangle$(y) can be localized anywhere in 5th dim.

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$$\stackrel{\widehat{A}_M \equiv e^{-\langle\phi\rangle} A'_M}{\Longrightarrow} \quad S^{(A')} = \int d^5x \left[-\frac{1}{4}\widehat{F}^2_{\mu\nu} - \frac{1}{2} e^{-2ky} \left(\partial_y \widehat{A}_\mu\right)^2 - \frac{1}{2} e^{-2ky} \left(b^2 - 2b\right) k^2 \widehat{A}^2_\mu - e^{-2ky}\, bk \widehat{A}^2_\mu \left(\delta(y) - \delta(y-L)\right) \right]$$

$\Longrightarrow$ 'standard' gauge field in RS but with bulk and boundary masses
$\Longrightarrow$ KK decomposition straightforward (as usual using Bessel functs.)
$\Longrightarrow$ As expected, there is massless mode with wavefunction

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How to localize gauge bosons?

Now break U(1)′ at UV brane by imposing Dirichlet boundary condition.

From boundary conditions, we obtain mass quantization condition:

$$\frac{J_b\left(\frac{m_n}{\text{TeV}}\right)}{Y_b\left(\frac{m_n}{\text{TeV}}\right)} = \frac{J_{b-1}\left(\frac{m_n}{k}\right)}{Y_{b-1}\left(\frac{m_n}{k}\right)}$$

Expanding for $m_n \ll \text{TeV}$, we find exponentially light mode with mass

$$m_0 \approx \left(\frac{\text{TeV}}{k}\right)^{(b-1)} \text{TeV}$$

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Mixing with standard model photon

- Kinetic mixing due to heavy states charged under $U(1)_Y$ and $U(1)'$
- Prefactor of gauge kinetic term $\sim$ inverse gauge coupling-squared
  $\Rightarrow$ position-dependent gauge coupling $\propto e^{\langle\phi\rangle}$
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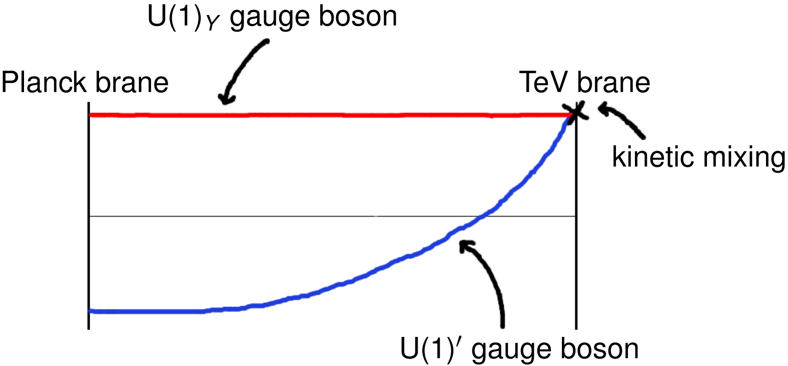

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- Mixing term mixes KK modes of A_M and A'_M. Diagonalize action via suitable KK ansatz, mixing term leads to particular boundary condition
- For $\langle\phi\rangle \propto y$, KK spectrum etc. straightforward to determine. For weak mixing $\zeta < 1$ find:
  - Spectrum contains mode with mass $\ll TeV$ (for suitable $\langle\phi\rangle$ and broken $U(1)'$ at UV brane) as well as massless mode
  - Light mode and corresponding KK mode tower couple suppressed by ζ to $U(1)_Y$ current but unsuppressed to $U(1)'$ current
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- Simplest: Fermion with TeV mass localized on TeV brane, charged under U(1)′ but neutral under SM gauge group
- Fermion stable by virtue of a global U(1)
- Annihilation cross section (to U(1)′ gauge bosons which then decay to SM) during freeze-out:

$$\langle \sigma V \rangle_{\text{freeze}} \sim \frac{\alpha_{\text{dark}}^2}{\text{TeV}^2}$$

  ⇒ Right relic abundance to be dark matter due to WIMP miracle
- Direct detection experiments: Kinetic mixing has to be suppressed by $\zeta \lesssim 10^{-6} - 10^{-8}$
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- Simplest: Fermion with TeV mass localized on TeV brane, charged under U(1)′ but neutral under SM gauge group
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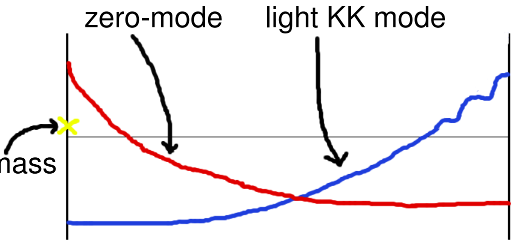

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- Case $\langle\phi\rangle \propto y$ easy to analyze. Checked also presence of light mode for case $\langle\phi\rangle \propto e^{-ay}$. Showed how to obtain such vev.
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