A Minimal Dark Matter Model with Kinetic Mixing

Sophia Borowka

technische universität dortmund

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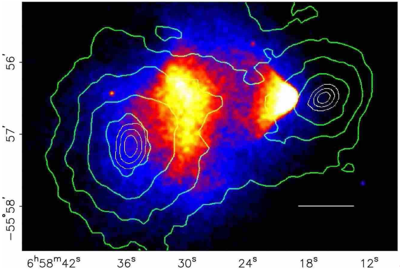
Hints for Dark Matter

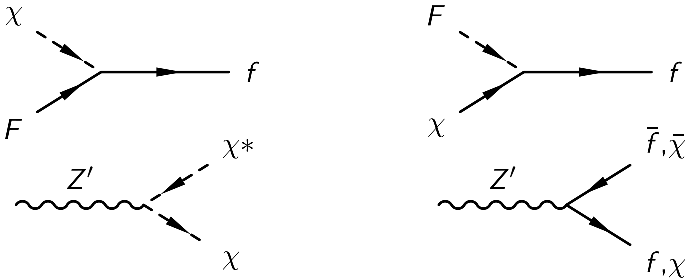
- Galaxy Rotation Curves
- Cosmic Microwave Background Observations
- Weak Gravitational Lensing Observations



arxiv:astro-ph/0608407

A Minimal Dark Matter Model

- First minimal dark matter models proposed by C.Boehm and P. Fayet '03



- Minimal extension of the Standard Model by an extra $\mathrm{U}(1)_X$:

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_X$$

Kinetic Mixing - Introducing a Link

B. Holdom '86

- The Lagrangian of the model

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4} C_{\mu\nu} C^{\mu\nu} - \frac{\delta}{2} C_{\mu\nu} B^{\mu\nu} - \frac{1}{2} m_X^2 C_\mu C^\mu + g_X J_X^\mu C_\mu + m_\chi \bar{\chi} \chi$$

with the kinetic mixing matrix κ and mass matrix M

$$\kappa = \begin{pmatrix} 1 & \delta & 0 \\ \delta & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \; M = \begin{pmatrix} m_X^2 & 0 & 0 \\ 0 & \frac{1}{4} v^2 g_1^2 & -\frac{1}{4} v^2 g_1 g_2 \\ 0 & -\frac{1}{4} v^2 g_1 g_2 & \frac{1}{4} v^2 g_2^2 \end{pmatrix}$$

Kinetic Mixing - Gauge Boson Masses

- Eigenvalues of the rotated mass matrix $\tilde{M}$

$$m_\gamma^2 = 0,\ m_Z^2 = \frac{(q-p)}{2},\ m_{Z'}^2 = \frac{(q+p)}{2}$$

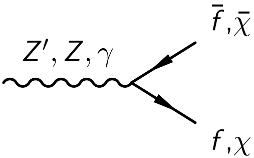
with

$$q = m_X^2 \beta + \frac{g_1^2 \beta + g_2^2}{4} v^2,\ p = \sqrt{q^2 - 4 m_X^2 (m_Z^{SM})^2 \beta}$$

and $\beta = \frac{1}{1-\delta^2}$. For small kinetic mixing we get

$$m_Z^2 = (m_Z^{SM})^2 + \mathcal{O}(\delta^2),\ m_{Z'}^2 = m_X^2 + \mathcal{O}(\delta^2)\ .$$

Kinetic Mixing - Neutral Current Couplings



- In canonical normalization

$$\mathcal{L}_{\mathcal{NC}} = \frac{g_2}{2\cos\theta_W} \bar{f}\gamma^\mu[(v_f' - \gamma_5 a_f')Z_\mu' + (v_f - \gamma_5 a_f)Z_\mu]f$$
$$+ e\bar{f}\gamma^\mu Q_f A_\mu f + \bar{\chi}\gamma^\mu[\epsilon_{Z'}^\chi Z_\mu' + \epsilon_Z^\chi Z_\mu + \epsilon_\gamma^\chi A_\mu^\gamma]\chi$$

- For small kinetic mixing and arbitrary $m_{Z'}$ the coupling factors to SM fermions f and dark fermions χ are

$$v_f, a_f = v_f^{SM}, a_f^{SM} + \mathcal{O}(\delta^2)$$
$$v_f' \propto \delta + \mathcal{O}(\delta^3)$$
$$a_f' \propto \delta + \mathcal{O}(\delta^3)$$

$$\epsilon_Z^\chi \propto \delta + \mathcal{O}(\delta^3)$$
$$\epsilon_{Z'}^\chi \propto g_X Q_X + \mathcal{O}(\delta^2)$$
$$\epsilon_\gamma^\chi = 0 \text{ (no millicharge).}$$

Constraining the Model

- The Z' and Z decay width $\Gamma_{Z'}$ and $\Gamma_{Z'}$
- Direct dark matter detection cross sections $\sigma_{N\chi}$
- Thermal relic abundance of dark matter $\Omega_\chi h^2$
- Anomalous magnetic moment of the muon $a_\mu = (g-2)_\mu/2$

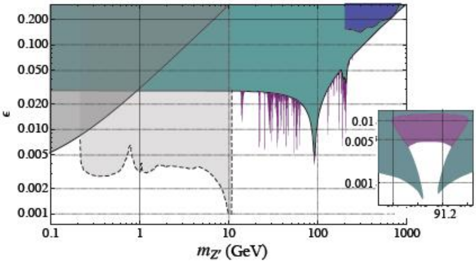
Constraining the Model - Z' Decay Width

- For $m_\chi \geq \frac{m_{Z'}}{2}$

$$\Gamma_{Z',tot} = \sum_f \Gamma_{Z' \to f\bar{f}} \leq \frac{\delta^2 m_{Z'}}{4\pi} 10^{-2} \qquad \text{“narrow“}$$

- For $m_\chi < \frac{m_{Z'}}{2}$

$$\Gamma_{Z',tot} = \Gamma_{Z' \to \chi\bar{\chi}} + \sum_f \Gamma_{Z' \to f\bar{f}} \leq \frac{m_{Z'}}{4\pi} 10^{-2} \qquad \text{“wide“}$$

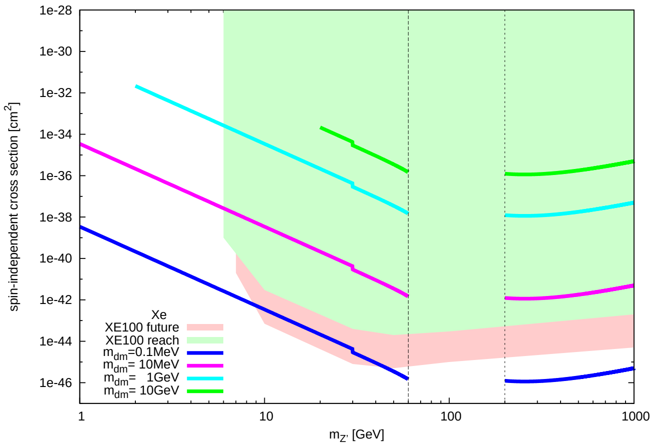


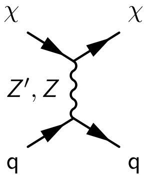
A. Hook, E. Izaguirre, J. G. Wacker '10

$\Rightarrow$ rough bound on kinetic mixing parameter: $\delta \lesssim 0.03$

Constraining the Model - Direct Detection

- Dark matter-nucleon cross section $\sigma_{\mathrm{Xe},\chi}$ (for ${}^{129}_{54}\mathrm{Xe}$) vs $m_{Z'}$ for different m_χ for the XENON experiment arxiv:0902.4253, 1005.0380





(very preliminary)

Summary and Outlook

Summary

- Proposal of a minimal model to explain dark matter
- Provide a link by using kinetic mixing
- Interesting reach in direct detection experiments

Outlook

- Maybe interesting signals at LHC?

References

Literature

- Scalar Dark Matter candidates (C. Boehm, P. Fayet '03): arxiv:hep-ph/0305261
- Two U(1)'s and ϵ charge shifts (B. Holdom '86): Phys. Lett. B, 166, 196
- Model Independent Bounds on Kinetic Mixing (A. Hook, E. Izaguirre, J. G. Wacker '10): arxiv:1006.0973 [hep-ph]
- First Dark Matter Results from the XENON100 Experiment (XENON100 Collaboration '10): arxiv:1005.0380 [astro-ph]
- Status and Sensitivity Projections for the XENON100 Dark Matter Experiment (E. Aprile, L. Baudis '09): arxiv:0902.4253 [astro-ph.IM]

Picture

- A direct empirical proof of the existence of dark matter (D. Clowe, M. Bradac, A. H. Gonzalez, M. Markevitch, S. W. Randall, C. Jones, D. Zaritsky): arxiv:astro-ph/0608407