

DARK FORCES IN THE SKY

SIGNALS FROM Z' AND THE DARK HIGGS

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Dark Side of the Universe 2016

based on 1605.09382 with Nicole Bell and Rebecca Leane



THE UNIVERSITY OF
MELBOURNE



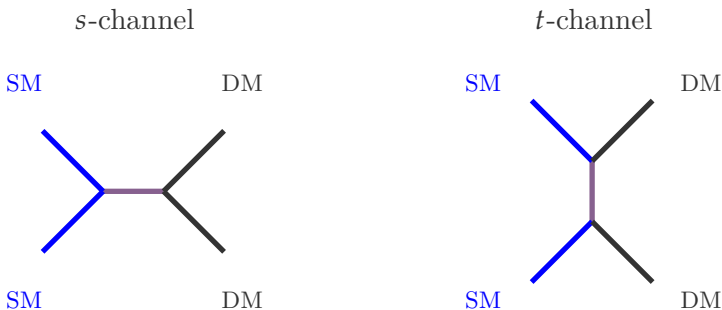
CoEPP

ARC Centre of Excellence for
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Simplified Model Study for DM

Simplified models suggested for the LHC Run 2 search 1507.00966

- a handful of new particles and interactions
- can be seen as a limit of various UV complete models

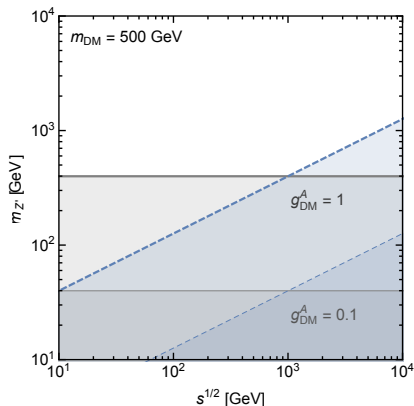


Each simplified model features **one** type of mediator.

Self-Consistency?

eg: a spin-1 mediator Kahlhoefer et. al. 1510.02110

$$\Delta\mathcal{L} \sim Z'^{\mu} \bar{f} \left[g_f^V \gamma_{\mu} + g_f^A \gamma_{\mu} \gamma^5 \right] f + Z'^{\mu} \bar{\chi} \left[g_{\chi}^V \gamma_{\mu} + g_{\chi}^A \gamma_{\mu} \gamma^5 \right] \chi$$

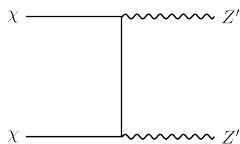
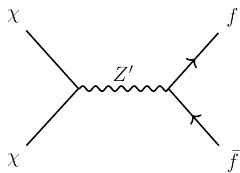


- Unitarity
 - DM self-scattering
 - DM annihilation
- Extra scalar needed for g_{χ}^A
 - solve the unitarity problem
 - can generate masses for DM and Z'
 - and **more?**

Talk on unitarity and DM this Thursday by Nicole Bell

A Second Look at Each Scenario in Indirect Detection

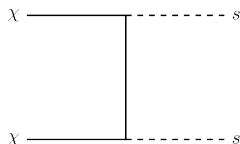
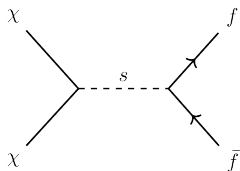
- vector mediator



$\chi\chi \rightarrow f\bar{f}$: s-wave if g_f^A

$\chi\chi \rightarrow Z'Z'$: always s-wave, can avoid LHC and DD bounds

- scalar mediator

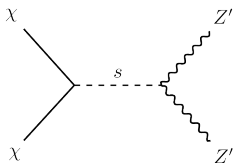


$\chi\chi \rightarrow f\bar{f}$: s-wave if s pseudoscalar

$\chi\chi \rightarrow ss$: always p-wave

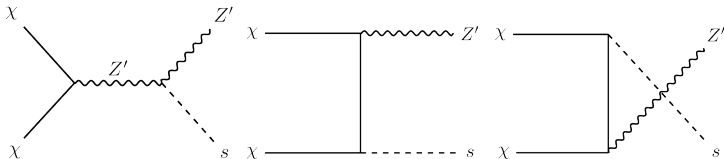
What is **More** for combing scalar and vector models?

- A new contribution to $\chi\chi \rightarrow Z'Z'$



- A brand new channel of interests: dark Higgstrahlung

$$\chi\chi \rightarrow sZ'$$



The Self-Consistent Model

- Gauge symmetry: $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_\chi$
- Matter content:
 - Majorana fermion as dark matter χ
 - Z'
 - complex scalar S
- $U(1)_\chi$ charges
 - $Q'(S) = 1$ by rescaling g_χ
 - $Q'(\chi) = -\frac{1}{2}$ from Yukawa coupling $y_\chi \chi \chi S$
- After S gets vev $\langle S \rangle = \frac{w+s+ia}{\sqrt{2}}$
 - $m_{Z'} = g_\chi w$
 - $m_\chi = \frac{1}{\sqrt{2}} y_\chi w$
 - Relation: $\frac{y_\chi}{g_\chi} = \frac{\sqrt{2} m_\chi}{m_{Z'}}$

Relevant Interactions

- The dark sector

$$\begin{aligned} & -\frac{1}{4}g_\chi\bar{\chi}\gamma_\mu\gamma_5\chi Z'^\mu + g_\chi^2 w_s Z'_\mu Z'^\mu \\ & -\frac{y_\chi}{2\sqrt{2}}s\bar{\chi}\chi \end{aligned}$$

- Between SM and DM

- Higgs portal $\lambda_{HS}H^\dagger HS^*S$
- Kinetic mixing $\frac{\sin\epsilon}{2}Z'^{\mu\nu}B_{\mu\nu}$
- **Hidden sector setup** with λ_{HS} , $\sin\epsilon$ small

- When $m_s < 2m'_{Z'}$: $Z', s \Rightarrow \text{SM} + \text{SM}$

Annihilation: $\chi\chi \rightarrow Z'Z', ss, Z's \rightarrow \text{SM} + \text{SM}$

Four Parameters: $m_s, m_{Z'}, m_\chi, g_\chi$

Mediation parameters: ϵ, λ_{HS}

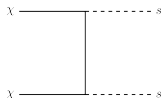
- ✓ small value consistent with non-observation of DD
- ✓ BBN requires $\tau < 1$ s, fairly easy to satisfy

COSMIC MICROWAVE BACKGROUND

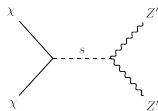
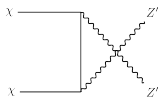
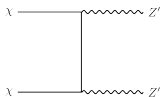
- ✓ constraints on annihilation cross section weaker than AMS-02 and dSphs

DM Annihilation

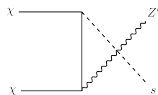
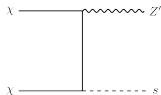
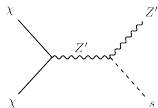
✗ $\chi\chi \rightarrow ss$: p -wave unless one s is a pseudo-scalar



✓ $\chi\chi \rightarrow Z'Z'$: s -wave contr. from t - and u -channels

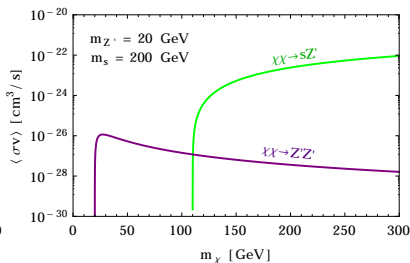
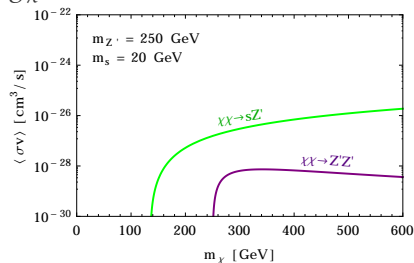


✓ $\chi\chi \rightarrow sZ'$: s -wave contr. from only s -channel



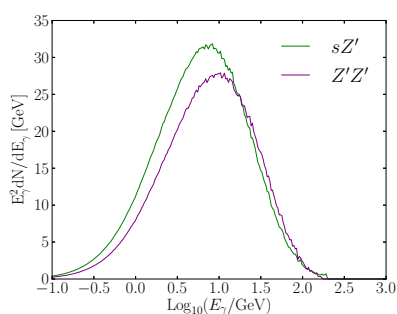
Comparison of Cross Sections

$$g_\chi = 0.1$$



- Both cross sections scale as g_χ^4
- Large cross section for $\chi\chi \rightarrow sZ'$
- With $m_s + m_{Z'} < 2m_\chi < 2m'_{Z'}$, sZ' is the only channel
- Inaccurate limits if only $Z'Z'$ considered

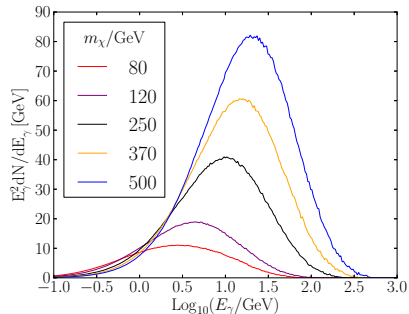
Per annihilation including all final states



$$m_{Z'} = 60 \text{ GeV}$$

$$m_s = 100 \text{ GeV}$$

$$m_\chi = 200 \text{ GeV}$$



$$\chi\chi \rightarrow sZ'$$

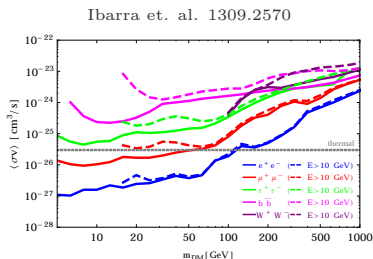
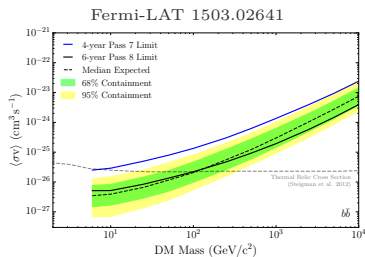
$$m_{Z'} = 120 \text{ GeV}$$

$$m_s = 30 \text{ GeV}$$

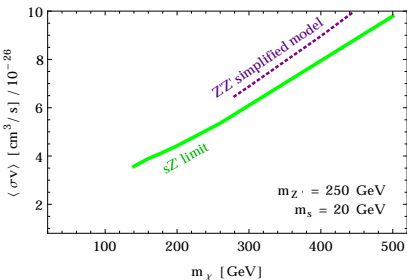
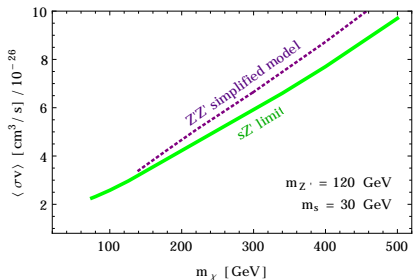
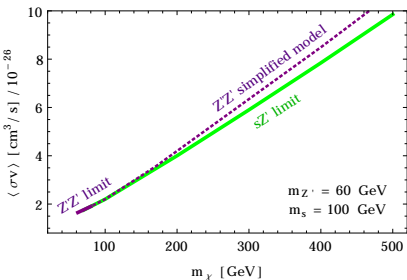
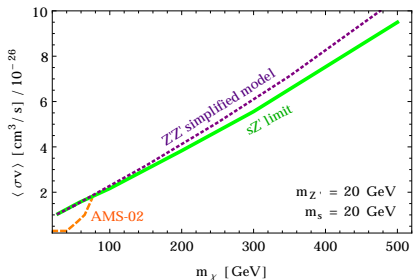
Limits from Indirect Detection

- From Fermi-LAT dwarf spheroidal results
 - No results for s and Z'
 - s and Z' with different masses
 - Likelihood functions of 15 dSphs used to derive limits
 - J -factor as nuisance parameter
 - Limits reproduced within 10%

- From AMS-02
 - Consider e^\pm final states as they are the strongest
 - Cascade decay via s negligible
 - Only competitive for low m_χ
 - Crude estimate with cross section of Z' rescaled with Br_{e^\pm}



Results for ID



Summary

- A Majorana DM model with vector mediator is examined for self-consistency.
- Perturbative unitarity requires extra degrees of freedom, a dark Higgs.
- Dark Higgs provides mass generation mechanisms for both Z' and DM.
- A novel channel $\chi\chi \rightarrow sZ'$ appears and can dominate in a hidden sector setup.
- sZ' channel also gives more stringent limits for indirect detection.