GeV-Scale Messengers of Planck-Scale Dark Matter

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Various observations point to existence of Dark Matter in our Universe.

- **Galactic Rotational Velocities**
- **Gravitational Interactions**
- **X-ray gas**
- **Primordial Fluctuations**

+ Many more ....
The (Inconvenient) Truth about DM

If particle DM exists, we don’t know much about it

1. Mass = ???
2. Spin = ???
3. Decays = ???
4. Interactions = Gravity, ???
5. Elementary = ???
6. ...
We have no sense of the scale at which DM resides

DM models alone span many orders of magnitude in energy scales

The “space” of possible viable scenarios is too vast!

All guided by theoretical motivation
However DM at this scale is heavily constrained
Motivated Searches away from the weak scale, mainly toward sub-GeV scale

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Electron recoil allows for probing lower energy thresholds and accessing lower mass


Nothing stops us from searching above weak scale

How far above the weak scale?

- Planck Mass
- Scale of quantum gravity
- GUT scale

Masses of order $10^{15} - 10^{19}$ GeV

Let's call this Planck Scale DM (PSDM)
Outline

I will give motivation for PSDM

I will introduce a possible model for PSDM

Discuss the model constraints
Disadvantages

\[ n_{DM} \sim \frac{1}{M_{DM}} \] : Number density of larger particles is smaller

\[ M_{DM} > 100 \text{ TeV} \] : Leads to overclosure of Universe if produced thermally

Cannot produce such heavy particles at a collider unless collider is size of solar system

Advantages

Lower number density \( \Rightarrow \) experiments not very sensitive to PSDM

\( \Rightarrow \) PSDM may interact stronger with SM than weak scale DM

May scatter multiple times in detector
Multiple scattering signature would be a “smoking gun”

Multiple scattering can be searched for at current experiments

Cross-sections of order $10^{-36} - 10^{-30} \text{cm}^2$

DD limits extrapolated to include Multi-Scattering and Single Scattering
What kind of physics can give these kind of cross-sections?

- Simplest possibility is to consider very light mediators between these very large scales and the SM

- Vector bosons associated with gauge symmetries well motivated

- To keep vector light compared to Planck scale, need resilient gauge symmetry, not easily broken

Simplest gauge group $U(1)$ enjoys this property

Halverson & Langacker: arXiv:1801.03503

We propose a “dark” gauge group $U(1)_d$ which has vector $A_d$
We want to connect PSDM to nucleons via new vector

\[ U(1)_d \Rightarrow \text{gauged baryon number with} \]

\[ \mathcal{L} \supset g_d (Q^q_d q \bar{q} \gamma_\mu q + Q^\chi_d \bar{\chi} \gamma_\mu \chi) A^\mu_d + \epsilon e (q \gamma_\mu q + \bar{l} \gamma_\mu l) A^\mu_d \]

**Spin Independent PSDM-nucleon cross-section**

\[ \sigma_{\chi n} \sim \frac{16\pi \mu_{\chi n}^2 (Q_n^q Q_n^\chi)^2 \alpha_d^2}{m_{A_d}^4} \]
PSDM may show up through multiple scattering in detector

Messenger particle maybe searched for in complementary manner at low energy experiments

\[ \mathcal{L} \supset g_d (Q_d^q \bar{q} \gamma_\mu q + Q_d^X \bar{X} \gamma_\mu X) A_d^\mu + \epsilon e (\bar{q} \gamma_\mu q + \bar{l} \gamma_\mu l) A_d^\mu \]

\[ BR(A_d \to l^+ l^-) \text{ suppressed by } \left( \frac{\epsilon e}{g_d Q_d^q} \right)^2 \lesssim 10^{-2} \]

Experiments like BaBar searching for \( A' \to l^+ l^- \) less sensitive to \( A_d \)

Assume \( A_d \) has similar quantum numbers to \( \omega \)-meson

Above \( m_\pi \) threshold \( A_d \) goes to hadrons
We can recast the BaBar visible decay limit using

\[ N_{A_d} = \sigma_{A_d} \gamma BR(A_d \rightarrow l^+l^-) \mathcal{L} \]

Assuming \( N_{A_d} \approx N_{BaBar} \)

\[ \alpha_d = 10^{-3} \]

\[ \epsilon \]

\[ m_{A_d} [\text{GeV}] \]

Conclusions

- We need to look at many avenues in our search for Dark Matter

**PSDM is one possibility**

- We propose a model of gauged baryon number connecting low energy physics to Planck scale

- We can probe $10^{-38} - 10^{-33}\text{cm}^2$ cross-section & $m_\chi \lesssim 10^{16-17}\text{GeV}$

- We argue that baryon number maybe be the best way to connect PSDM to SM while maintaining potential for “smoking gun” signals

DM may be at Planck Scale, we just have to be open to the idea
Thanks
Back up Slides
$U(1)_B$ is anomalous, i.e. not a consistent gauge theory

Anomaly cancelation requires heavy fermions that are:
- Vector-like under SM
- Chiral under dark sector

Heavy fermions would get mass from $U(1)$ breaking by dark Higgs

Scale of spontaneous symmetry breaking $\gtrsim 100$ GeV

However….

Breaking $U(1)_B$ & preserving EWS results in non-zero Wess-Zumino terms

Giving non-decoupling longitudinal mode of vector showing up in low energy processes


Effects show up in:  
- B-meson decays  
- Z-boson decays

If $U(1)_B$ breaking is different i.e. not EWS preserving

No longitudinal mode effects
Including longitudinal mode enhancements

Were made assuming: \( \epsilon = \frac{e g_d}{(4\pi)^2} \)

\[ A_d \rightarrow l^+l^- \]

\[ A_d \rightarrow \mu^+\mu^- \]

\[ A_d \rightarrow \text{Hadrons} \]

\[ \sigma_{\chi n} \sim 10^{-33} - 10^{-38} \text{ cm}^2 \]
Consider other mediators?

How about gauged B-L?

\[ \sigma_{\chi n} \sim \frac{\mu_{\chi n} \alpha_{B-L}^2}{m_{A_{B-L}}^4} \]

\[ \sim 10^{-44} \text{cm} \]

Ilten, Soreq, Williams & Xue, JHEP 1806 (2018) 004
Other mediators

How about a low mass scalar?

- May lead to different, less constrained pheno

- May have to worry about stability of low mass against large quantum corrections

- Leading to question of “Naturalness”

However detection of scalar mediator in conjunction with PSDM could have implications for “Naturalness”
Further constraints

White Dwarf constraints on PSDM

\[ \sigma \chi \chi v \chi \sim \frac{4\pi\alpha_d^2}{m_{\chi}^2} \]
\[ \sim 10^{-54} \text{cm}^3/\text{s} \]

for \( m_{\chi} \sim 10^{17} \text{GeV} \)

& \( \alpha_D \sim 10^{-2} \)

Graham, Janish, Narayan, Rajendran & Riggins, arXiv:1805.07381
\[ m_{A_d} \sim g_d Q_{d}^{\Phi} < \Phi > \]
\[ m_F \sim y < \Phi > \]
\[ \mathcal{L} \supset y \bar{F}_L F_R \Phi \]

If \( < \Phi > \lesssim 100 \text{ GeV} \) Fermions F would have been seen at LEP/LHC

\[ \Rightarrow 100 \text{ GeV} \lesssim < \Phi > \]

For \( m_{A_d} \sim 1 \text{ GeV} \) \[ \Rightarrow Q_{d}^{\Phi} \ll 1 \]

\[ \Rightarrow Q_{d}^{F} \ll 1 \]

Many fermions at TeV scale to cancel anomalies