Connection between Flavor and Dark Matter

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Case of study WIMP DM:

SM states
Visible sector

Mediator

Dark Matter
Hidden sector
\[
\langle \sigma v \rangle \approx \frac{\lambda_{DM}^2 \lambda_{SM}^2 m_{DM}^2}{(4 m_{DM}^2 - m_{Portal}^2)^2} (a + \frac{b}{x}) \\
\approx \frac{\lambda_{DM}^2 \lambda_{SM}^2 m_{DM}^2}{(4 m_{DM}^2 - m_{Portal}^2)^2} (a + \frac{1}{2} b v^2)
\]
Connection between Portals and Flavour Physics

Only through the mediator

(Useful complementarity of flavor constraints especially for light dark sectors)

DM directly involved in flavour processes

DM stability related to flavor (flavored DM)
Singlet-doublet DM+ 2HDM


\[ - \mathcal{L}_{\text{yuk}}^{\text{SM}} = \sum_{f=u,d,l} \frac{m_f}{v} \left[ \xi^f_{h} \bar{f} f h + \xi^f_{H} \bar{f} f H - i \xi^f_{A} \bar{f} A \right] - \frac{\sqrt{2}}{v} \bar{u} \left( m_u \xi^u_{A} P_L + m_d \xi^d_{A} P_R \right) d H^+ + \frac{\sqrt{2}}{v} m_i \xi^l_{A} \bar{\nu} L l R H^+ + \text{h.c.} \]

\[ \mathcal{L} = \bar{\psi} \gamma^\mu \left( g_W^V \psi_i \delta_{ij}^W - g_W^A \gamma_5 \psi_j \right) \psi_i W^- + \text{h.c.} \]

\[ + \frac{1}{2} \sum_{i,j=1}^{3} \bar{\psi_i} \gamma^\mu \left( g_Z^V \psi_j \delta_{ij}^Z - g_Z^A \gamma_5 \psi_j \right) Z_{\mu} \psi_j \]

\[ + \frac{1}{2} \sum_{i,j=1}^{3} \bar{\psi_i} \left( y_h \psi_j \psi_j h + y_H \psi_j \psi_j H + y_A \psi_i \psi_j A \right) \psi_j + \text{h.c.} \]

\[ + \bar{\psi} \left( g_5^V \delta_{ij}^H - g_5^P \gamma_5 \psi_j \right) \psi_i H^- + \text{h.c.} \]

\[ - e A_{\mu} \bar{\psi} \gamma^\mu \psi - \frac{g}{2 \cos^2 \theta_W} (1 - 2 \sin^2 \theta_W) Z_{\mu} \bar{\psi} \gamma^\mu \psi + \text{h.c.} \]

<table>
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</table>
(Sample diagrams. For more complete references see e.g. in P. Arnan, D. Becirevic, F. Mescia, O. Sumensari Eur. Phys. J. C77 (2017) 11, 796
See also:
2HDM+Light Scalar/Pseudoscalar Mediator

Mass Mixing

2HDM

Dark Sector
$m_\chi=35 \text{ GeV}, \ t_\beta=2, \ M_A=600 \text{ GeV}, \ g_\chi=0.5$

$M_a[\text{GeV}]$ vs $\sin\theta$

$G.A., \ M. \ Lindner, F.S. \ Queiroz, \ W. \ Rodejohann, \ S. \ Vogl \ JCAP \ 03 \ (2018) \ 042$
Z’ models for B-anomalies

(JIncomplete list of possibilities)

$L_\mu - L_\tau$ model

LFV induced by DM

\[ \mathcal{L} \supset -\frac{g}{\sqrt{2}} \left[ \bar{N}_{aL} \gamma^\mu \ell_{aL} W^{\prime +}_\mu + \bar{\nu}_{aL} \gamma^\mu N_{aL} U^0 \right] - \frac{g}{\sqrt{2}} \left[ \bar{U}_{3L} \gamma^\mu d_{3L} W^{\prime +}_\mu + \bar{u}_{iL} \gamma^\mu D_{iL} W^{\prime +}_\mu \right] \]

\[ - \frac{g}{2 \cos \theta_W} \sum_f \left[ \bar{f} \gamma^\mu (g'_V + g'_A \gamma^5) f Z'_\mu \right] \]

\[ \text{Br}(\mu \to e\gamma) = 1.6 \times \left( \frac{1 \text{TeV}}{M_{W'}} \right)^4 \left| g^{N_1e\ast} g^{N_1\mu} \right|^2 \]

\[ g^{N_1e,\mu} = \frac{g}{2 \sqrt{2}} U^{N_1e,\mu} \]
G.A., C.P. Ferreira, F. Goertz, M.M. Guzzo, F.S. Queiroz
Flavored DM

P. Agrawal, M. Blanke, K. Gemmler JHEP 10 (2014) 072

<table>
<thead>
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</tbody>
</table>

$$\mathcal{L} = \mathcal{L}_{SM} + i \bar{\chi} \partial_i \phi - m_\chi \bar{\chi} \chi - (\lambda_{ij} \bar{d}_R i \chi_{j} \phi + h.c.)$$

$$+(D_\mu \phi) \dagger (D^{\mu} \phi) - m_\phi^2 \phi \dagger \phi + \lambda_H \phi \phi \dagger \phi H \dagger H + \lambda_{\phi \phi} \phi \dagger \phi \dagger \phi$$
\[ \lambda = U_\lambda D_\lambda \]

\[ U_\lambda = \begin{pmatrix}
-c_{12}c_{13} & c_{12} & s_{12}c_{13}e^{-i\delta_{12}} \\
-s_{12}c_{23}e^{i\delta_{12}} & c_{12}s_{23}s_{13}e^{i(\delta_{13}-\delta_{23})} & -c_{12}s_{23}s_{13}e^{i\delta_{13}} \\
s_{12}s_{23}e^{i(\delta_{12}+\delta_{23})} & s_{12}s_{23}s_{13}e^{i(\delta_{13}-\delta_{12}-\delta_{23})} & c_{12}s_{23}s_{13}e^{i(\delta_{13}-\delta_{12})} \\
-c_{12}c_{23}s_{13}e^{i\delta_{23}} & -s_{12}c_{23}s_{13}e^{i(\delta_{13}-\delta_{12})} & s_{13}c_{23}e^{-i\delta_{13}} \\
\end{pmatrix} \]

\[ D_\lambda \equiv \text{diag}(D_{\lambda,11}, D_{\lambda,22}, D_{\lambda,33}) = \lambda_0 \cdot 1 + \text{diag}(\lambda_1, \lambda_2, -(\lambda_1 + \lambda_2)) \]
Relic Density

Flavor

Collider

Direct Detection
M. Blancke, S. Kast, JHEP 05 (2017) 161
The DM and flavor are among the biggest puzzles in high energy physics.

We have presented a (non complete) list of scenarios in which these two puzzles can be correlated.