Dark Matter Through the Neutrino Portal

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work in progress with Adam Falkowski and José Juknevich

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Models with nontrivial dark sectors have recently received a lot of attention

Unusual or unexpected signals $\Rightarrow$ nontrivial structure in the dark sector
  - (DAMA and inelastic dark matter; PAMELA+ATIC and Sommerfeld)

Nontrivial structure in the dark sector $\Rightarrow$ unusual or unexpected signals
  - (Inelastic dark matter and XENON)

Today: a simple, strongly coupled dark sector which leads to striking and unusual signals for neutrino telescopes
A Confining Dark Sector

- Dark sector consists of $SU(N) + \lambda^a$, with $m_\lambda \gg \Lambda$.
  - UV: $(N^2 - 1)$ gluons + $\lambda^a$
  - IR: glueballs + heavy fermion $\Psi$
  - For $N = 3$, stable glueball spectrum is known from the lattice (Morningstar and Peardon):

![Graph showing the spectrum of glueballs and heavy fermions](Plot from JMS 09)
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```
0^+ -- 0^+ -- 0^+ -- 2^{++} 2^{++} 2^{++} 3^{++} 3^{++} 3^{++} 1^{--} 1^{--}
```

Plot from JMS 09
Cosmic Eightballs

- **Freezeout is governed by three parameters:** $N$, $m_\lambda$, $m_\lambda/\Lambda$
  - Proper relic density is achieved for $m_\lambda \sim \text{TeV}$, $\Lambda \sim \text{few GeV}$, depending on $N$

- **Eightballs can decay via the neutrino portal:**
  \[
  O_\nu = \frac{c}{M^2} \lambda^a \sigma^{\mu\nu} G^a_{\mu\nu} H L L
  \]

- **Dominant decay process:**
  - $\Psi = (\lambda + g) \xrightarrow{O_\nu} g + g\nu \langle h \rangle$
  - decay products: hard monoenergetic neutrino and hidden glueballs
Constraints from SuperK

- Most stringent constraints come from SuperKamiokande (Desai et al., 2004)

- Negligible capture rates in earth and sun, so bounds come from observations of the Galactic Center
  - upward through-going $\mu$ flux $\Phi_{\mu} < 1.5 \times 10^{-14} \text{(cm}^2\text{s})^{-1}$ in a cone of half-angle $30^\circ$ around Galactic Center

- Limit on $\Psi$ lifetime $\frac{\Gamma}{m_\Psi} \lesssim 10^{-52}$, indicating scales $M \gtrsim 10^{14} - 10^{15}$ GeV for $\mathcal{O}_\nu$

- Neutrino masses $m_\nu \sim \frac{v^2}{M}$ point to new physics at scales $M \gtrsim 10^{12}$ GeV
  - beginning to probe the region where we might naturally expect new physics entering through the neutrino portal
Signals for IceCube

- **IceCube can observe this signal despite poor exposure to galactic center**
  - *large signal*: atmospheric neutrino background falls like $E^{-3}$ at high energies
  - *good angular resolution*: $0.5^\circ$ resolution enables directional analysis

- **Look at downward-going muons:**
  - accept only showers initiating in instrumented volume to reject cosmic ray backgrounds
  - order of magnitude reduction in effective detector area

- **IceCube should be able to see above backgrounds with sufficient livetime.**
  - Northern Hemisphere telescopes like ANTARES can see this signal with usual techniques.
A sticky situation with glueballs

- **Glueballs cannot be cosmologically stable:**
  - Overclosure $\Rightarrow m_g \sim \Lambda \sim \frac{eV}{N^2-1}$
  - Astrophysical observations bound dark matter self-interactions:
    \[ \sigma/m \lesssim 1 \text{ cm}^2/\text{g} \simeq 5000/(\text{GeV})^3 \]
    (Bullet Cluster observations: Markevitch et al. (2002), Randall et al. (2007))
  - Glueball masses are intrinsically tied to interaction strengths: cannot evade

- **Three possibilities for decay:**
  - Within the dark sector
  - To the Standard Model
  - To Yet Another sector
A sticky situation with glueballs

- **Decay within the dark sector:** add new light states to dark sector to destabilize the glueball(s).
  - a model building game:
  - light pions: (technically) natural, but possibly disfavored due to DM scattering properties
  - light neutral scalar: works, but looks contrived

- **Decay to the Standard Model:** add additional interaction coupling dark sector to SM
  - Can easily avoid destabilizing $\Psi$: accidental $\mathbb{Z}_2$ preserved by large class of interactions
  - Can get glueballs to decay before BBN to avoid cosmological constraints
  - May lead to observable LHC signals if additional interaction(s) at TeV scales
• With glueballs decaying to SM, in order to understand all visible signals of dark matter decay we need to know $dN_i/dE$ and $BR(G_i \rightarrow X_j)$ for all species.
  
  ◦ $BR(G_i \rightarrow X_j)$: computable, with input from lattice (and extrapolation for $N \neq 3$) (Juknevich, Melnikov, Strassler, 2009). Sensitive to operator(s) used to mediate decay: model dependence.
  
  ◦ $dN_i/dE$: depends on fragmentation of dark color string in final state. Not computable from first principles; worse, cannot use well-tested principles from QCD as lack of fundamentals changes the game.

• By contrast, since $m_\lambda \gg \Lambda$, relic abundance is comparatively insensitive to uncertainties from strong dynamics.

• (This is on top of the usual astrophysical uncertainties.)
Conclusions

- A model of dark matter which decays to the standard model through the neutrino portal
  - observable signal for IceCube requiring analysis of downward-going neutrino events

- Non-trivial dark dynamics are key to dominance of hard neutrino signal
  - Available two-body decay suppresses production of hard $h$, $W$, $Z$, and charged leptons
  - Fragmentation into multiple glueballs softens visible SM decay products