Dark Matter Annihilation via Dark Bound State formation

Haipeng An
Caltech
In collaboration with Mark Wise and Yue Zhang
1604.01776
Bound state effects on dark matter indirect detection

- The Sommerfeld enhancement

Arkani-Hamed, Finkbeiner, Slatyer, Weiner 0810.0713
Pospelov, Ritz 0810.1502
Bound state effects on dark matter indirect detection

- The Sommerfeld enhancement

- If the dark photon is light enough, dark bound state can form by emitting a dark photon.

Arkani-Hamed, Finkbeiner, Slatyer, Weiner 0810.0713
Pospelov, Ritz 0810.1502
Bound state effects on dark matter indirect detection

- In the limit $m_V \rightarrow 0$
  - Sommerfeld enhancement
    \[\sigma v = \frac{\pi \alpha_D^2}{m_D^2} \frac{2\pi \alpha_D}{v}\]
  - Kramer’s formula
    \[\sigma v = \frac{128\pi \alpha_D^3}{3\sqrt{3}m_D^2 v} \log \left(\frac{\alpha_D}{v}\right)\]
Bound state effects on dark matter indirect detection

- In the limit $m_V \to 0$

$$\frac{\sigma v_{\text{Kramer}}}{\sigma v_{\text{Sommerfeld}}} \approx 4 \times \log \left( \frac{\alpha_D}{v} \right)$$
Bound state effects on dark matter indirect detection

- In the limit $m_V \rightarrow 0$

$$\frac{\sigma v_{\text{Kramer}}}{\sigma v_{\text{Sommerfeld}}} \approx 4 \times \log \left( \frac{\alpha D}{v} \right)$$

$$\int \frac{dE}{E} = \sum_n \frac{\alpha^2 \mu/n^3}{\left(\frac{1}{2} \frac{\alpha^2 \mu}{n^2} + \frac{1}{2} \mu v^2\right)} \sim 2 \log \left( \frac{\alpha}{v} \right)$$
Bound state effects on dark matter indirect detection

\[ \sigma \text{ (GeV}^{-2}) \]

\[ \alpha = 0.2, \quad m_D = 16.7 \text{ TeV}, \quad v = 10^{-3} \]

HA, Wise, Zhang 1604.01776
Bound state effects on dark matter indirect detection

Considering only the ground state in the Coulomb limit

\( \alpha = 0.2, \ m_D = 16.7 \ \text{TeV}, \ v = 10^{-3} \)

\[ \sigma \ (\text{GeV}^{-2}) \]

\( m_V \ (\text{GeV}) \)

\( m_H \) = 0.001, 0.01, 0.1

Kramer's formula

Pospelov, Ritz 0810.1502

HA, Wise, Zhang 1604.01776
Bound state effects on dark matter indirect detection

- Constraints from the Galactic center gamma rays

\[
\begin{align*}
\text{Fermi: direct annihilation} \\
\text{Fermi: annihilation via bound states}
\end{align*}
\]
In progress

- Constraint from dwarf galaxies
- Anti-protons
- Experiments sensitive to more energetic gamma rays
- ...

...