Dark matter annihilation into right-handed neutrinos and the galactic center gamma-ray excess

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This slide is based on this paper, arxiv:1512.02899, by Yi-Lei Tang and Shou-hua Zhu
Introduction to the photon excess from the galactic center

- In Ref. arXiv:hep-ph/0508108, a $\gamma$-ray excess of 1-10 GeV from near the galactic center was studied in the EGRET era.
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Figure: Tansu Daylan, et al., arxiv:1402.6703.
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\chi^2 = \left[ \frac{dN}{dE} - \left( \frac{dN}{dE} \right)_{\text{obs}} \right] \cdot \Sigma^{-1} \cdot \left[ \frac{dN}{dE} - \left( \frac{dN}{dE} \right)_{\text{obs}} \right].
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Introduction to the photon excess from the galactic center

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- The data is actually on the homepage of one of the authors, http://christophweniger.com/?page_id=248.
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$X_f = \frac{m_{\text{DM}}}{T_{\text{dec}}} \approx 20$. 

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Guess... Rotate the Feynmann diagram by 90°, it is difficult to escape the direct detection experiments bounds.
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- Sub-dominant inverse Compton scattering to the CMB, bremsstrahlung, synchrotron radiation... (Usually omitted in the hadronic final states).
Explaining the Excess from the Galactic Center

$\chi^2$ p-val.

$hh$ 28.2 0.17

$WW$ 38.3 0.017

$t\bar{t}$ 43.5 0.0041

$b\bar{b}$ 24.2 0.34

$ZZ$ 35.6 0.033
Dwarf spheroidal (dSph) galaxy candidates offer constraints.
Explaining the Excess from the Galactic Center

- Dwarf spheroidal (dSph) galaxy candidates offer constraints.
- Take the $b\bar{b}$ as an example, the best-fitted point lies slightly outside the constraints. However, due to the uncertainty of the $\mathcal{J}$-factor, we can still say that the GCE’s photon originated from the dark matter has not been ruled out, yet.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{energy_distribution.png}
\caption{Energy distribution of photon flux in the Galactic Center.}
\end{figure}

\textbf{Yi-Lei Tang (汤亦蕾)}

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Explaining the Excess from the Galactic Center

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- It should be noted that recently, there seem to be some excesses from two dSphs, Reticulum II (See arxiv:1503.02320) and Tucana III (See arxiv:1511.09252).
See-saw Mechanisms

- Majorana mass among right-handed neutrinos.
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M = \begin{bmatrix}
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- & m_D & m_N
\end{bmatrix}
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- \( y_\nu \sim 10^{-7}-10^{-5} \), \( m_N < 1 \) TeV (Naive TeV Seesaw).
- For linear see-saw or inverse see-saw, \( y_\nu \) can be as large as \( 10^{-3} \).
Can dark matter mainly annihilate into light right-handed neutrinos?

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- Model examples,
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- Build model by ourselves?
If $m_N > m_W$, simple simulation by MicrOMEGAs shows that the spectrum induced by the $N$'s two-body decay are no better than the $W^{\pm}$ case.
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Solution: We have used MadGraph to calculate the three-body decay, and input the event file to Pythia8 to do showering, hadronization, and particle decay processes.
γ spectrum from the N’s decay

▶ One light right-handed neutrino for simplicity. In the multi-right-handed neutrino cases, we can only linearly sum over the spectrum by each single right-handed neutrino.
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\mathcal{L} \supset \frac{1}{2} \bar{N} \gamma^\mu \partial_\mu N - \frac{1}{2} m_N \bar{N}N - (y_i \bar{l}_L \cdot \tilde{H}N + \text{h.c.}),
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After EWSB,

\[ \mathcal{L} \supset c g_2 \sqrt{2} \theta_i (W^+_\mu \bar{N} \gamma^\mu P_L l_i^- + \text{h.c.}) + \frac{g_2}{\cos \theta_W} \theta_i Z_\mu (\bar{N} \gamma^\mu P_L \nu_i + \text{h.c.}), \quad (4) \]

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where \( \theta_i \approx \frac{y_i v}{m_N} \).

\( N \rightarrow \nu_i Z^* \), \( N \rightarrow \tilde{l}_i^\mp W^\mp \) dominate the decay width, and \( N \rightarrow h^* \nu_i \rightarrow \text{all} + \nu_i \) is negligible due to the small \( h\text{-SM-SM} \) vertices.
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- \( \frac{\sum_i \text{Br}(N \rightarrow \nu_i Z^*)}{\sum_i \text{Br}(N \rightarrow l_i^\pm W^{\mp*})} \) is independent on the specific value of \( y_i \)'s.
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$\tau_N \lesssim 10^{-3} \text{ sec} \ll 1 \text{ sec}$. It might fly for a distance of $10^5 \text{ m}$, which is far below the radius of the Milky Way.
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- $y_3 = 0$, $y_1^2 + y_2^2 \neq 0$. Since muons and electrons do not produce photons, and the ratios
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  are fixed at a given $m_N \gg m_\mu$, the gamma-ray spectrum should be independent on concrete values of $y_{1,2}$.
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The gamma-ray spectrum by general values of $y_{1,2,3}$ are just linear-combinations of the above two cases.
The best-fitted points are $m_N = 32.0$ GeV, $m_\chi = 44.2$ GeV, with $\chi^2 = 24.22$ and the best-fitted $\langle \sigma v \rangle = 2.63 \times 10^{-26}\text{cm}^3/\text{s}$ for the $y_1 = y_2 = 0, y_3 \neq 0$ case, and $m_N = 27.0$ GeV, $m_\chi = 45.4$ GeV, with $\chi^2 = 23.81$ and the best-fitted $\langle \sigma v \rangle = 3.37 \times 10^{-26}\text{cm}^3/\text{s}$ for the $y_3 = 0, y_1^2 + y_2^2 \neq 0$ case.
Numerical Results

Figure: The $\Delta \chi^2$ figures. The blue, green, yellow areas are corresponding to the 1, 2 and 3 $\sigma$ areas respectively. $\langle \sigma v \rangle$ is adjusted in order to acquire the best-fitted result. The left panel indicates the $y_1 = y_2 = 0$, $y_3 \neq 0$ case. The right-panel indicates the $y_3 = 0$, $y_1^2 + y_2^2 \neq 0$ case.
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Figure: The best-fitted $\langle \sigma v \rangle = \langle \sigma v \rangle_{\text{real}} J$, in the unit of cm$^3$/s. The left panel indicates the $y_1 = y_2 = 0, y_3 \neq 0$ case. The right-panel indicates the $y_3 = 0, y_1^2 + y_2^2 \neq 0$ case.
Figure: The best-fitted gamma-ray spectrum together with the observed central values and the errorbars. In the case of $y_1 = y_2 = 0, y_3 \neq 0$, $\chi^2 = 24.22$, with the p-value 0.336. In the case of $y_3 = 0, y_1^2 + y_2^2 \neq 0$, $\chi^2 = 23.81$, with p-value 0.357.
Future Plan

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- Build a well-motivated model including this scenario. I wish it would also contain the elements of the leptogenesis.
- Study the two existing model I have listed before.
Thank You!