Dark sources of cosmic ray spikes on Earth’s doorstep
[Background] Indirect detection and substructure
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DM + DM → e^+ e^−
[Motivation] The DAMPE excess

Adapted from Ambrosi et al. [2017] (1711.10981)
[Motivation] The DAMPE excess

$E^3 \phi_{e^\pm} \text{ (GeV}^2 \text{s}^{-1} \text{sr}^{-1} \text{cm}^{-2})$

- $R_b = 0.001 \text{ kpc}$
- $R_b = 0.02 \text{ kpc}$
- $R_b = 0.5 \text{ kpc}$
- $R_b = 2 \text{ kpc}$

Background
DAMPE

$E$ (GeV)

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[Problem] What kind of clump can source this spike?
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[Clump characteristics] Relevant quantities

Cosmic ray flux.
\[ \phi_{\text{clump}} \equiv \langle \sigma v \rangle_f \int d\text{Vol} \rho_{DM}^2 \exp \left[-\frac{r^2}{g(M_{DM},E)}\right] \]

Gamma ray flux.
\[ \phi_{\text{clump}}^\gamma(E,\theta) = \Delta \Omega \frac{\langle \sigma v \rangle^2 M_{DM}^2 dN_{\gamma} dE}{\Delta \Omega \int d\Omega \int_0^\infty d\ell \rho_{(\ell,\theta,\phi)}^2} \]

Line width.
\[ \int_{E_{i,\text{high}}}^{E_{i,\text{low}}} dE \left[ \phi_{\text{clump}}^{e \pm}(E) + \phi_{\text{bg}}^{e \pm}(E) \right] \leq \Phi_{\text{obs},i}^{e \pm} + 3\Delta \Phi_{\text{obs},i}^{e \pm} \]
[Clump characteristics] Relevant quantities

**Cosmic ray flux.**

\[
\phi_{e^\pm}^{\text{clump}}(E) \simeq \frac{\langle \sigma v \rangle}{f(m_{\text{DM}}, E)} \int \text{dVol} \, \rho^2 \exp \left[ -\frac{r^2}{g(m_{\text{DM}}, E)} \right]
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**Gamma ray flux.**

\[
\phi_{\gamma}^{\text{clump}}(E, \theta) = \frac{\Delta \Omega}{4\pi} \left[ \frac{\langle \sigma v \rangle}{2m_{\text{DM}}^2} \frac{dN_{\gamma}}{dE} \right] \left[ \frac{1}{\Delta \Omega} \int d\Omega \int_0^\infty d\ell \, \rho^2(\ell, \theta, \phi) \right]
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[Clump characteristics] Relevant quantities

**Cosmic ray flux.**

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**Line width.**

\[
\int_{E_{i,\text{low}}}^{E_{i,\text{high}}} dE \left[ \phi_{e^\pm}^{\text{clump}}(E) + \phi_{e^\pm}^{\text{bg}}(E) \right] \leq \Phi_{e^\pm}^{\text{obs},i} + 3\Delta \Phi_{e^\pm}^{\text{obs},i}
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1. Clump location — $d$ — free
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1. Clump location — \( d \) — free
2. Particle physics — \( \langle \sigma v \rangle, m \) — electrophilic, thermal
3. Clump properties — \( \rho(r) \) — not well known
[Clump characteristics] Clump profiles

\[ \rho(r) = \rho_0 \left( \frac{r}{r_s} \right)^{-2} \left( 1 + \frac{r}{r_s} \right)^{-1} \text{ (NFW)} \]
[Clump characteristics] Clump profiles

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[Clump characteristics] Clump profiles

Change to profile steepness

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\]
[Clump characteristics] Clump profiles

Change to profile steepness
Tidal stripping truncates profile

\[ \rho(r) = \rho_0 \left( \frac{r}{r_s} \right)^{-2} \left( 1 + \frac{r}{r_s} \right)^{-1} \] (NFW)
[Clump characteristics] Parametrizations

**Generalized NFW (GNFW).**

\[ \rho(r) = \rho_0 \left( \frac{r}{r_s} \right)^{-\gamma} \left( 1 + \frac{r}{r_s} \right)^{\gamma - 3} \]
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**Tidally-truncated (exp).**

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\rho(r) = \rho_0 \left( \frac{r}{r_b} \right)^{-\gamma} \exp \left( -\frac{r}{r_b} \right)
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[Results] The clump parameter space

\[ L \text{ (Hz)} \]

\[
\begin{align*}
L & = 10^{35} \\
L & = 3 \times 10^{34} \\
L & = 7 \times 10^{33} \\
L & = 3 \times 10^{33} \\
L & = 10^{33} \\
L & = 10^{32} \\
L & = 3 \times 10^{31} \\
L & = 10^{31} \\
L & = 10^{1} \\
L & = 10^{0} \\
L & = 10^{-1} \\
L & = 10^{-2} \\
L & = 10^{-3} \\
\end{align*}
\]

\[
\begin{align*}
r_b \text{ (kpc)} & = 3 \times 10^{31} \\
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r_b \text{ (kpc)} & = 3 \times 10^{34} \\
r_b \text{ (kpc)} & = 10^{35} \\
\end{align*}
\]

\[
\begin{align*}
d \text{ (kpc)} & = 10^{-3} \\
d \text{ (kpc)} & = 10^{-2} \\
d \text{ (kpc)} & = 10^{-1} \\
d \text{ (kpc)} & = 10^{0} \\
\end{align*}
\]

- exponential,
  \[ \gamma = 0.52 \]

extended source

far away

Coogan, BVL, Profumo (1903.07177)
[Results] The clump parameter space

\[ L \text{ (Hz)} \]

\[ 10^{-3} \quad 10^{-2} \quad 10^{-1} \quad 10^{0} \]

\[ r_b \text{ (kpc)} \]

\[ 10^{31} \quad 10^{32} \quad 10^{33} \quad 10^{34} \quad 10^{35} \]

\[ d \text{ (kpc)} \]

\[ 10^{-3} \quad 10^{-2} \quad 10^{-1} \quad 10^{0} \]

exponential, \( \gamma = 0.52 \)

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[Results] The clump parameter space

$L$ (Hz)

extended source

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far away

Fermi

Line too broad

[Coogan, BVL, Profumo (1903.07177)]
[Life in a clump] A very local clump?
[Life in a clump] A very local clump?
[Results] Statistical considerations

exponential, \( \gamma = 0.52 \)
[Results] Statistical considerations

$p_N$-body [Z-score]

exponential, $\gamma = 0.52$

extended source

Line too broad

Improbable

Fermi

far away
[Results] Statistical considerations

$\gamma = 0.52$

Line too broad

Extended source

Fermi

$\rho_{N\text{-body}}$

[Z-score]

exponential,

Improbable
[Life in a clump] The view from within

\[ \frac{\rho_{\text{exp}}(d) + \rho_{\oplus}}{\rho_{\oplus}} \]

\begin{align*}
\gamma &= 0.52 \\
\text{exponential,} \\
\text{Line too broad}
\end{align*}

\begin{align*}
\rho_{\text{exp}}(d) + \rho_{\oplus} &\text{ extended source} \\
\rho_{\oplus} &\text{ far away}
\end{align*}
[Life in a clump] Direct detection
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Dark sources of cosmic ray spikes on Earth’s doorstep
Benjamin V. Lehmann

[Life in a clump] Direct detection

velocity distribution

log $v$
[Life in a clump] Direct detection

- Velocity distribution.
- Recoil spectrum.

Log \( \frac{dR}{dE_R} \) vs. Log \( E \)
[Life in a clump] Direct detection

velocity distribution

log v

recoil spectrum

log(\frac{dR}{dE_R})

log E

Coogan, BVL, Profumo in prep
[Life in a clump] Without indirect detection

[NFW] \( \Pr (\rho' > \rho \text{ and } v' < v) \)
Dark sources of cosmic ray spikes on Earth’s doorstep

Benjamin V. Lehmann
[Results] Summary

What does a narrow cosmic-ray spike say about dark matter?

▶ Clump parameters are tightly constrained
▶ DM interpretation is unlikely, but viable
▶ Cosmic-ray features imply connection to direct detection

Maybe we do live in a clump. . . and maybe we can find out.
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- Clump parameters are tightly constrained
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Maybe we do live in a clump... and maybe we can find out.
[Extra] Substructure abundance
[Extra] Gamma-ray constraints

\[
\Delta e^{\pm} (562 \text{ GeV}, 1998 \text{ GeV}) = \left(1.08, 10^{3} \text{kpc}\right)
\]

\[
d = 0.2 \text{kpc}, \gamma_{\text{exp}} = 0.74
\]
[Extra] Steeper profiles (UCMH)