Conservative Constraints on Dark Matter Self Annihilation Rate

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Indirect Detection

- Indirect detection often focuses on choosing a model, and comparing predicted flux to observed flux.
- Great for testing a model, not so great for finding the nature of DM.
Indirect Detection

- Indirect detection often focuses on choosing a model, and comparing predicted flux to observed flux
- Great for testing a model, not so great for finding the nature of DM

- So, what can we deduce about DM, in a model independent way, from its annihilation flux?
- Great progress in recent years; A number of bounds on annihilation cross section/decay width
- We expand and strengthen these limits, focusing on two final states, $\gamma\gamma$ and $e^+e^-$
- We can be confident that these upper limits are robust
 Photon line

‘Smoking Gun’

Common final state, even if small branching ratio

Don’t know branching ratio:
We constrain this channel only

Annihilation Flux

Annihilation flux from a nearby source:

\[
\frac{d\Phi_\gamma}{dE} = \frac{1}{2} \langle \sigma_A v \rangle Br(\gamma\gamma) \int_0^R \frac{\rho(s)^2}{4\pi m_\chi^2} d\ell \frac{dN_\gamma}{dE}
\]
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Flux in some direction depends on:
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\]

Flux in some direction depends on:
Cross section,
Annihilation Flux

Annihilation flux from a nearby source:

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Flux in some direction depends on:
- Cross section,
- Integral along the line of sight of the DM density squared,
Annihilation Flux

- Annihilation flux from a nearby source:

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\frac{d\Phi_\gamma}{dE} = \frac{1}{2} \langle \sigma_A v \rangle \text{Br}(\gamma\gamma) \int_0^R \frac{\rho(s)^2}{4\pi m^2_\chi} d\ell \frac{dN_\gamma}{dE}
\]

Flux in some direction depends on:
- Cross section,
- Integral along the line of sight of the DM density squared,
- The $\gamma$-ray spectrum per annihilation (Dirac delta)
Annihilation Flux

- Annihilation flux from a nearby source:

\[
\frac{d\Phi_{\gamma}}{dE} = \frac{\langle \sigma_A v \rangle_{\gamma\gamma} J_{\Delta\Omega}}{2 J_0} \frac{1}{4\pi m_{\chi}^2} \frac{dN_\gamma}{dE}
\]
Density profiles

- Minimize uncertainty by looking at large angular regions
- Focus on conservative Kravtsov profile, but show results for other profiles
Observation Regions

- Galactic Center
  - Our main flux source; lots of data
- M31 (Andromeda)
  - Relatively weak upper limits on $\langle \sigma_A V \rangle$
  - Analysis very similar to GC case
- Cosmic Annihilation
  - Diffuse photon flux from extragalactic DM annihilation
  - Analysis includes integral over redshift, photon attenuation, DM clumping factor
- Use data from INTEGRAL, COMPTEL, EGRET, HEGRA, CELESTE, HESS, SMM
- Cover broad range of energies: $\sim 10^{-5}$ to $\sim 10^4$ GeV

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Results

- Very conservative analysis

- Results more general than they appear: We integrate the signal over a large energy bin, so results are valid for an annihilation spectrum as wide as our analysis bin (0.4 in log$_{10}$ E)

- At worst, our limit would be increased by a factor of several for a broad annihilation spectrum (except for INTEGRAL/HEGRA)
Using $\text{Br}(\gamma\gamma) = 10^{-4}$, find a limit on the total cross section.
Positron Excess


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- Nearby Pulsars?
- Dark Matter Annihilation?
- No antiproton excess
- Large annihilation cross section


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- Look for associated gamma-ray emission


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Positron Excess

- Nearby Pulsars?
- Dark Matter Annihilation?
  - No antiproton excess
  - Large annihilation cross section
- Internal Bremsstrahlung
  - No dependence on Magnetic field, ISRF, Diffusion
  - Hard gamma rays near the endpoint, and background decreases with energy

Want to constrain annihilation to $e^+e^-$
Look for associated gamma-ray emission


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Internal Brem Spectrum

- Similar to analysis for gamma-gamma case
- Different spectrum

\[
\frac{d\Phi_\gamma}{dE} = \frac{\langle \sigma_A n \rangle}{2} \frac{J_\Delta \Omega}{J_0} \frac{1}{4\pi m^2_\chi} \frac{dN_\gamma}{dE}
\]

\[
\frac{dN_\gamma}{dE} = \frac{1}{\sigma_{tot}} \frac{d\sigma_{IB}}{dE_\gamma}
\]

\[
\frac{d\sigma_{IB}}{dE} = \sigma_{tot} \times \frac{\alpha}{E\pi} \left[ \ln \left( \frac{s'}{m^2_e} \right) - 1 \right] \left[ 1 + \left( \frac{s'}{s} \right)^2 \right]
\]

\[
s = 4m^2_\chi
\]

\[
s' = 4m_\chi(m_\chi - E)
\]

Constraints

\[ \sigma_{A v} \propto \frac{m}{m_{\chi}} \]

\[ \mathcal{B}(\bar{\nu} + \nu) > \text{total} \]

\[ \text{COMPTEL} \quad \text{EGRET} \quad \text{H.E.S.S.} \quad \text{KKT} \quad \text{Unitarity Bound} \]

\[ \text{Natural Scale} \]

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