“Non-Local” Effects from Boosted Dark Matter in Indirect Detection

Steven J. Clark

Brown Theoretical Physics Center
Department of Physics, Brown University

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In Collaboration with:
Kaustubh Agashe, Bhaskar Dutta, and Yuhsin Tsai

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Canonical Indirect Dark Matter Gamma-ray Searches

Detection of dark matter interactions coming from large dark matter densities is one indirect approach

The flux can be written as follows.

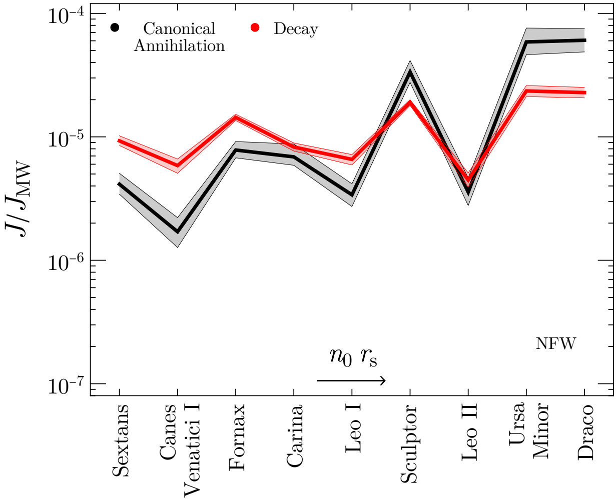
$$\frac{\mathrm{d}\Phi}{\mathrm{d}E_\gamma} = \frac{\mathrm{d}N}{\mathrm{d}E_\gamma} \begin{cases} \frac{\langle \sigma_{\mathrm{ann}} v \rangle_0}{8\pi\, m_\chi^2} \times J_{\mathrm{ann}} & \text{(annihilation)} \\ \frac{1}{4\pi\, m_\chi\, \tau_{\chi,0}} \times J_{\mathrm{decay}} & \text{(decay)} \end{cases} \tag{1}$$

The equations are separated into a particle physics portion and an astrophysical part, the J-factor.

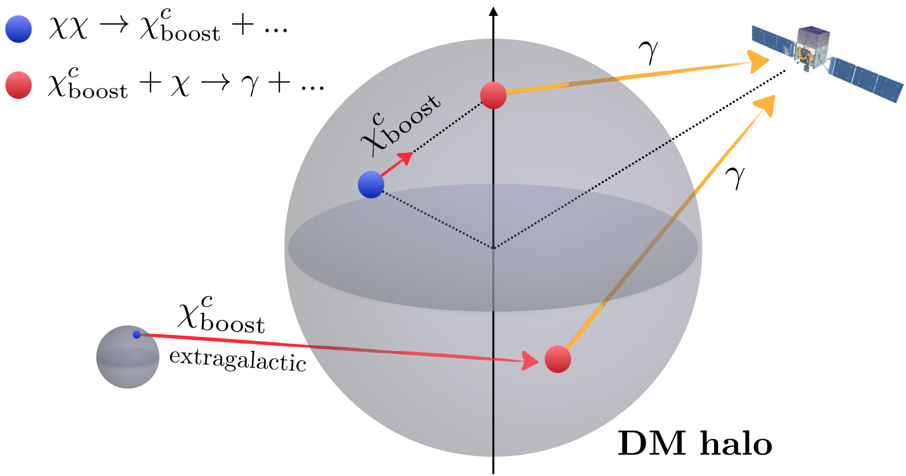
$$J_{\mathrm{ann}} = \int_{\mathrm{ROI}} \int_{\mathrm{los}} \rho^2(r)\, \mathrm{d}\ell \mathrm{d}\Omega \qquad J_{\mathrm{decay}} = \int_{\mathrm{ROI}} \int_{\mathrm{los}} \rho(r)\, \mathrm{d}\ell \mathrm{d}\Omega \tag{2}$$

Canonical J-Factor Ratio

The J-factor contains all astrophysical information.



Non-Local Scheme



Non-Local Interaction

Features of the Non-Local Mechanism:

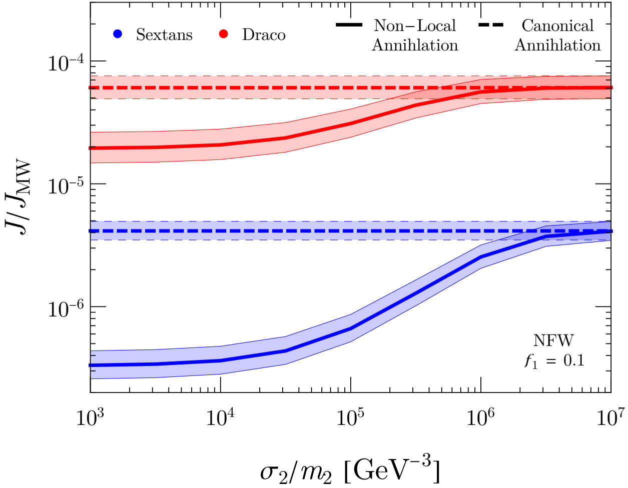
- Dark matter particles undergo an interaction event (just like the canonical scenario).
- The products are boosted and transported away from the original interaction sight.
- After traveling a non-negligible distance, the products interact with the local environment.

Some models that naturally incorporate these properties include:

- Semi-annihilation
- Asymmetric
- Forbidden

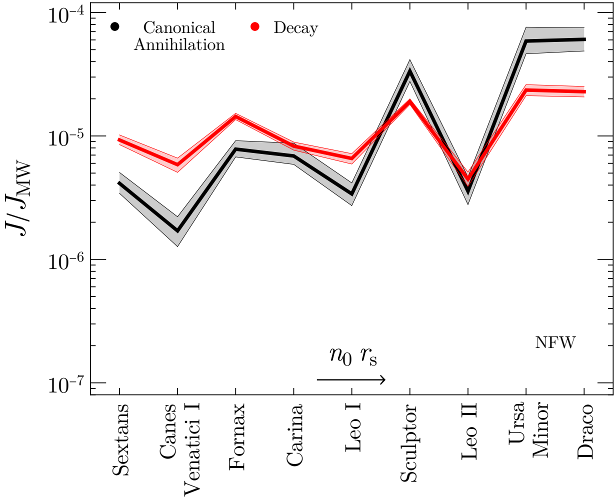
Non-Local J-Factor Ratio

At low secondary annihilation rates, smaller galaxies experience a larger reduction in their overall rate.



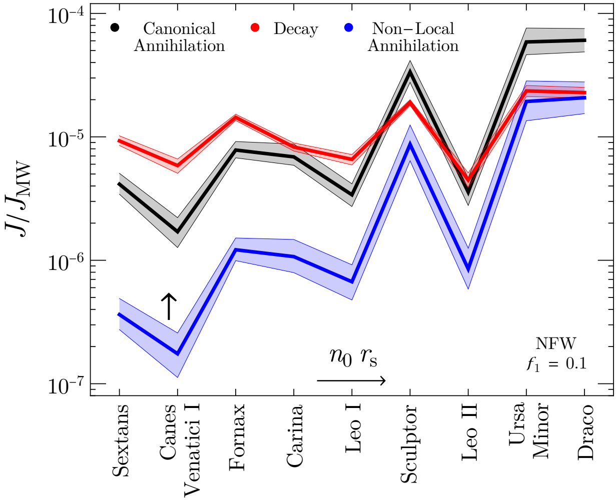
Non-Local J-Factor Ratio

Recall the canonical J-factor ratios.



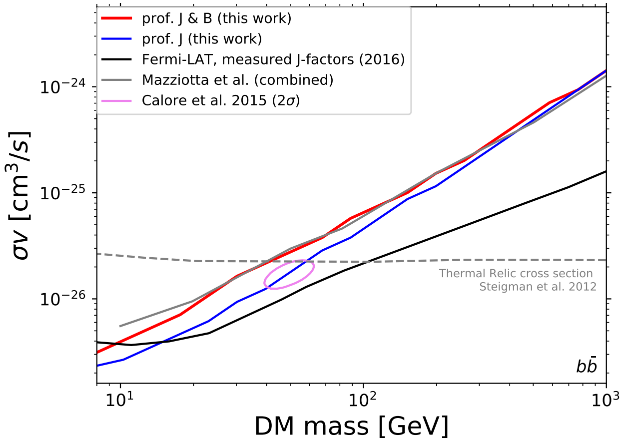
Non-Local J-Factor Ratio

Non-local J-factor is non-trivially dependent on the second interaction.



Galactic Center Excess and dSph Reconciliation*

Naturally predicts a variation between GCE and dSph signals



*Calore, Serpico, and Zaldivar – arXiv:1803.05508

Summary

- Canonical J-factors are solely astrophysical
- The non-local mechanism introduces non-trivial scale dependencies
- The non-local mechanism includes multiple scales and reduces to the canonical framework for limiting cases
- One possible consequence of the non-local mechanism is to alleviate GCE/dSph discrepancies

Thank You!

Non-Local Annihilation J-Factor

The J-factor of the gamma-ray signal from a galaxy is derived as

$$J_{\mathrm{NL}} = \int_{\mathrm{ROI}} \int_{\mathrm{los}} \mathrm{d}\ell \, \mathrm{d}\Omega_\ell \, \rho_{1,0}^2 \times \mathcal{P}_{\chi_2^c \chi_2}(|\vec{r}|) \times \frac{\mathrm{d}N}{\mathrm{d}\Omega}(\vec{r}, \Omega_\ell). \quad (3)$$

$\mathcal{P}_{\chi_2^c \chi_2}$ is the probability of $\chi_2^{\mathbf{b}}$ annihilating after traveling a displacement $\vec{s}$ from the χ_1 annihilation point

$$\mathcal{P}_{\chi_2^c \chi_2}(r) = \frac{\Lambda \, \eta_2(r)}{4\pi} \int \mathrm{d}q \, \mathrm{d}\Omega_q \, [\eta_1(q)]^2 \left(\frac{q}{s}\right)^2 \exp\left[-\Lambda \int_0^s \mathrm{d}s' \, \eta_2(s')\right] \quad (4)$$

$\frac{\mathrm{d}N}{\mathrm{d}\Omega}(\vec{r}, \Omega_\ell)$ accounts for the directional dependence in the signal, a result of the boosted reference frame.

Non-Local Annihilation J-Factor: Limiting $d \gg r_s$ Behavior

In the far away approximation with distance d, the J-factor becomes

$$J_{\rm NL} \approx d^{-2} \int {\rm d}V \, \rho_{1,0}^2 \times \mathcal{P}_{\chi_2^c \chi_2}(\vec{r}) \, . \qquad (5)$$

$\frac{{\rm d}N}{{\rm d}\Omega}(\vec{r}, \Omega_\ell)$ no longer appears in the large d approximation as interior annihilation angles are averaged out over the entire galaxy resulting in spherical symmetry.

In the limit $d \gg r_s$, the canonical J-factors can also be reduced.

$$J_{\rm ann} \approx d^{-2} \int {\rm d}V \rho^2(r) \qquad J_{\rm decay} \approx d^{-2} \int {\rm d}V \rho(r) \qquad (6)$$

Non-Local Annihilation J-Factor: Limiting Λ Behavior

Recall Eq. (4),

$$\mathcal{P}_{\chi_2^c \chi_2}(r) = \frac{\Lambda\, \eta_2(r)}{4\pi} \int \mathrm{d}q\, \mathrm{d}\Omega_q\, [\eta_1(q)]^2 \left(\frac{q}{s}\right)^2 \exp\left[-\Lambda \int_0^s \mathrm{d}s'\, \eta_2(s')\right]$$

At $\Lambda \gg 1$, we recover canonical annihilation as χ_2^c is unable to travel far.

$$\mathcal{P}_{\chi_2^c \chi_2}(r) \approx [\eta_1(r)]^2 \qquad\qquad J_{\mathrm{NL}} \approx d^{-2} \int \mathrm{d}V\, [\rho_1(r)]^2 \tag{7}$$

At $\Lambda \ll 1$, χ_2^c have a very low chance of annihilation within the galaxy.

$$\mathcal{P}_{\chi_2^c \chi_2}(r) \approx \frac{\Lambda\, \eta_2(r)}{4\pi} \int \mathrm{d}q\, \mathrm{d}\Omega_q\, [\eta_1(q)]^2 \left(\frac{q}{s}\right)^2 \tag{8}$$

Furthermore, if most χ_1 annihilation occurs in a central core, then $q \ll r$ for relevant regions, and $s \to r$

$$J_{\mathrm{NL}} = c_1\, d^{-2} \Lambda \int \mathrm{d}r\, \eta_2(r) \int q^2 \mathrm{d}q\, \mathrm{d}\Omega\, \rho_1^2(q) = c_2\, \Lambda\, d^{-2} \int \mathrm{d}V\, \rho_1^2(q) \tag{9}$$