Dark Matter Raining on DUNE (& other large detectors)

Javier F. Acevedo - TeVPA 2024

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SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

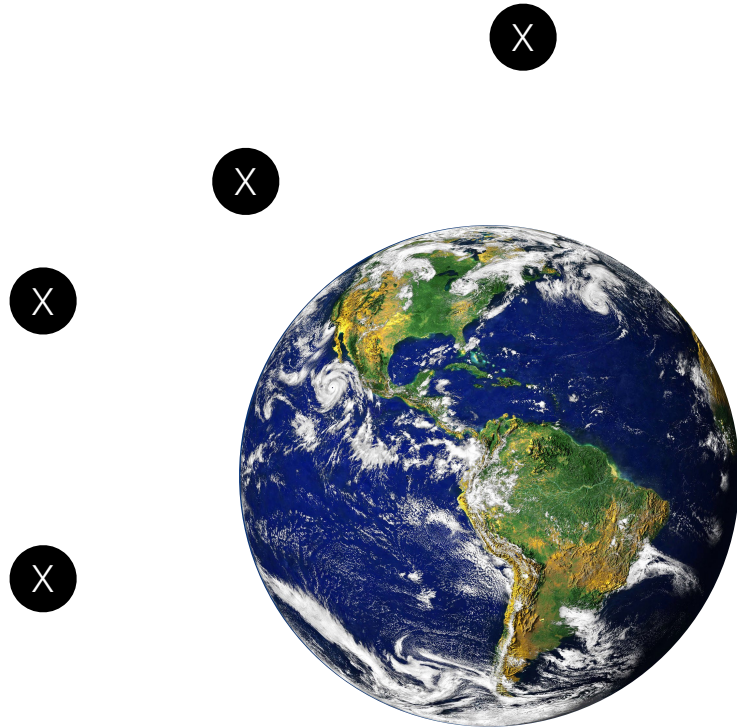# Direct Detection of Dark Matter

X

X

X

X
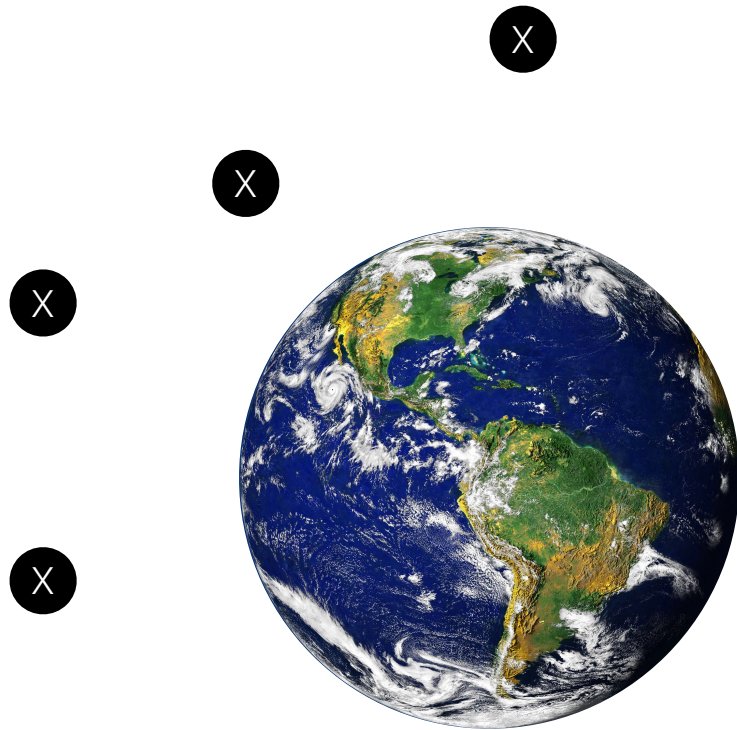
'usual' flux assumptions:

$$v_\chi \simeq 270 \text{ km/s}$$

$$\rho_\chi \simeq 0.4 \text{ GeV/cm}^3$$

Direct Detection of Dark Matter

Dark matter interactions could lead to a boosted component, through e.g.:
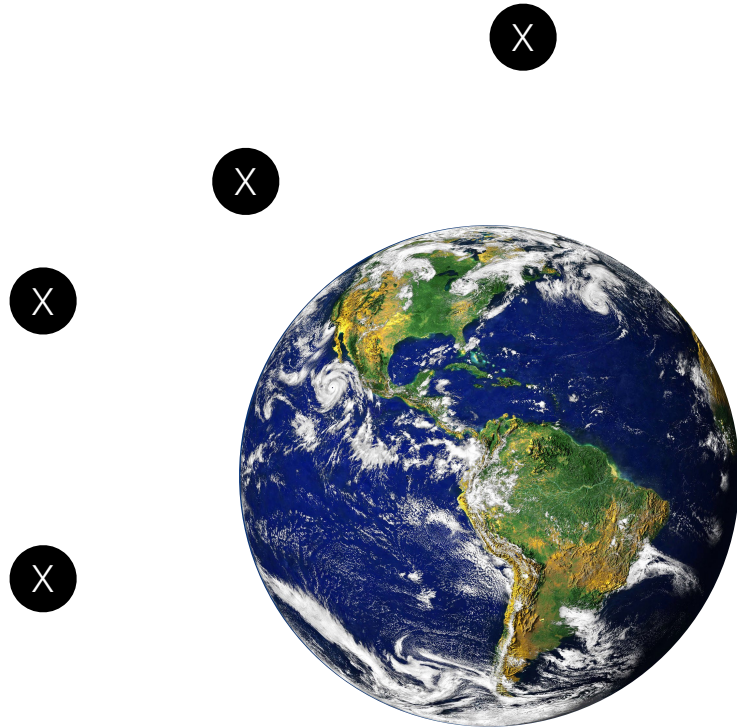
- Up-scattering with cosmic-rays, blazars, the Sun.

- Rich dark sectors including lighter states.

- Long-range DM-SM/DM-DM interactions.

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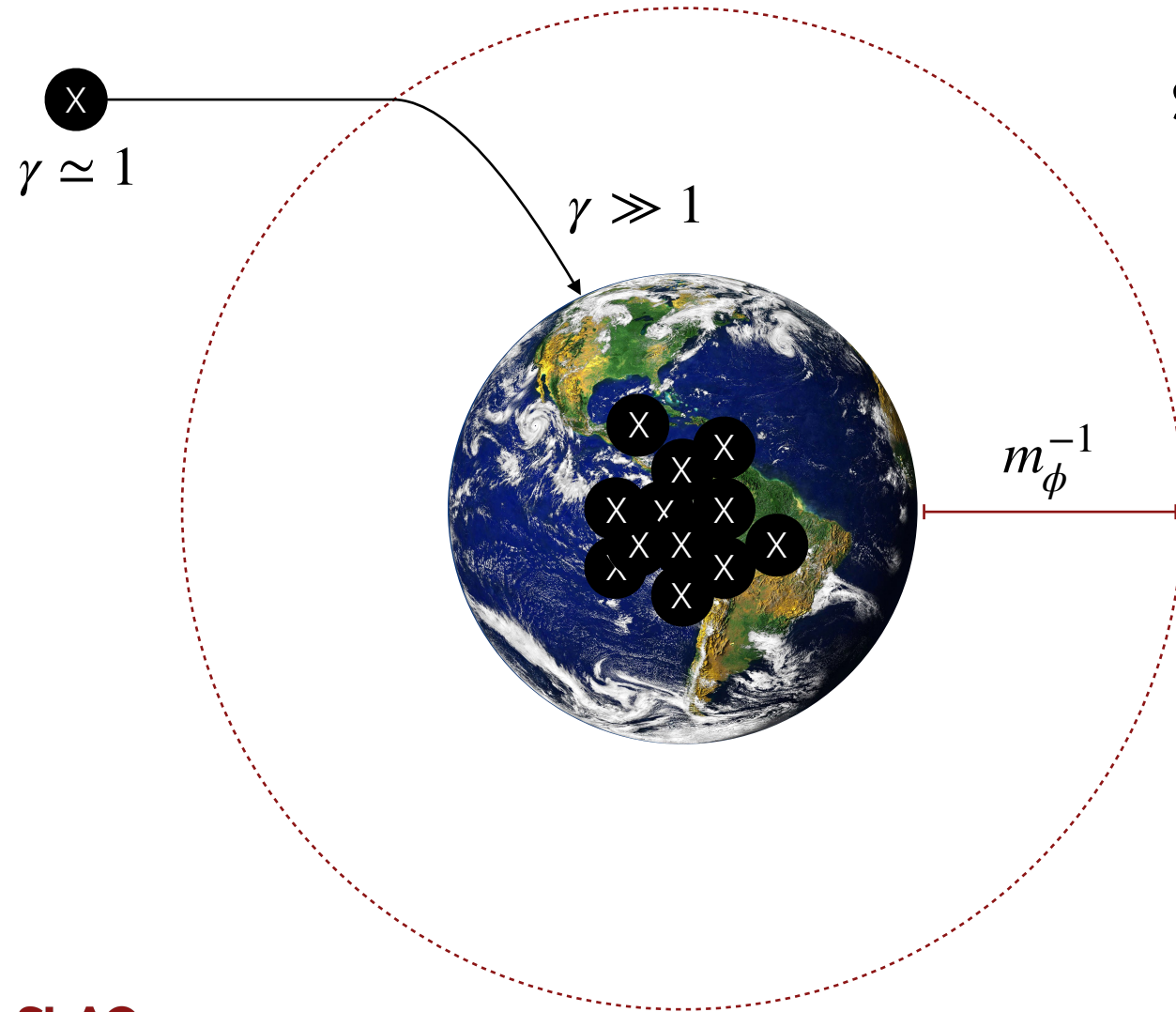Dark matter interactions could lead to a boosted component, through e.g.:

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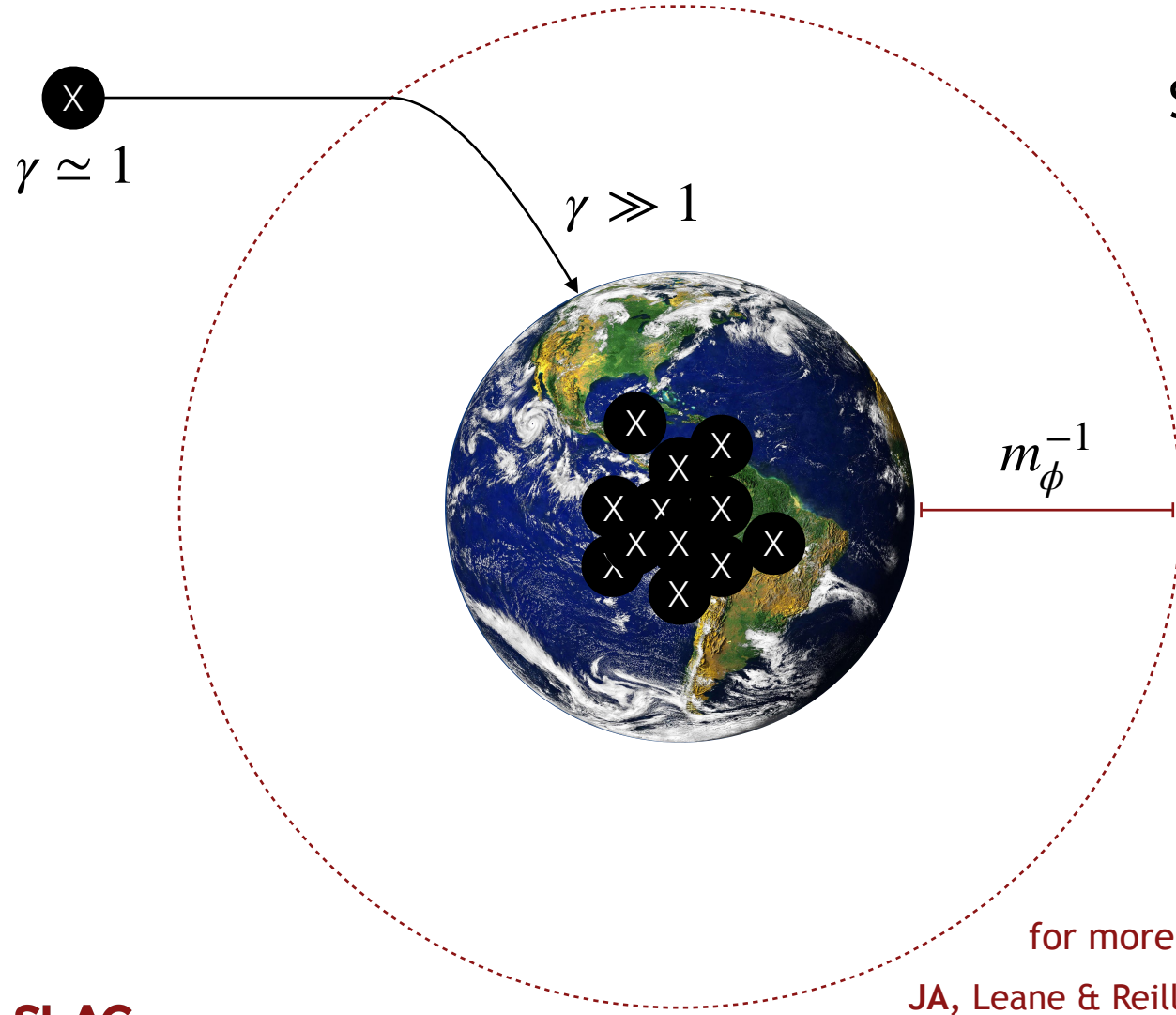$$\rho_\chi \simeq 0.4 \text{ GeV/cm}^3$$

Boosted Dark Matter from Long-Range Forces
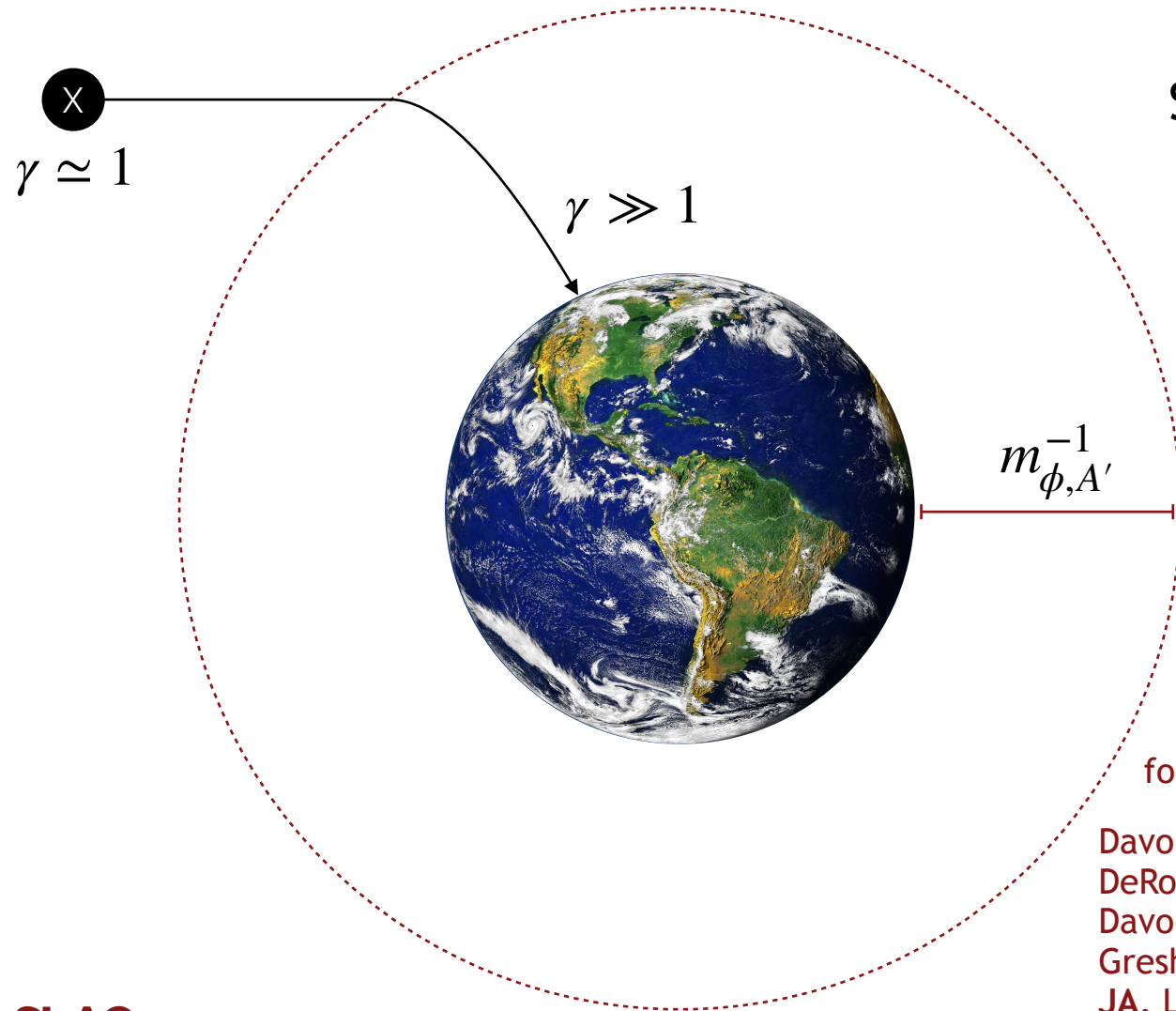

$\gamma \simeq 1$

$\gamma \gg 1$

m_ϕ^{-1}

Scenario #1: DM-DM long-range interaction

$$\mathcal{L} \supset g_\chi \bar{\chi} \phi \chi$$

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for more details:

JA, Leane & Reilly, 2405.02393

Boosted Dark Matter from Long-Range Forces

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$m_{\phi, A'}^{-1}$
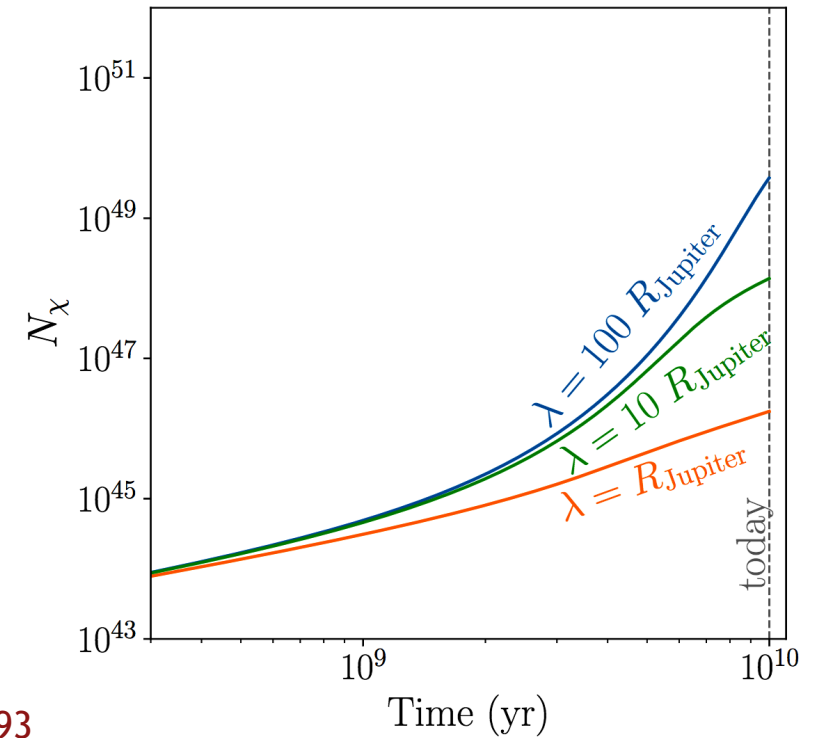
Scenario #2: DM-SM long-range interaction

(vector)

$$\mathcal{L} \supset g_\chi A'_\mu \bar{\chi} \gamma^\mu \chi + g_{\mathrm{SM}} A'_\mu \bar{\psi}_f \gamma_\mu \psi_f$$

(scalar)

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for related work:

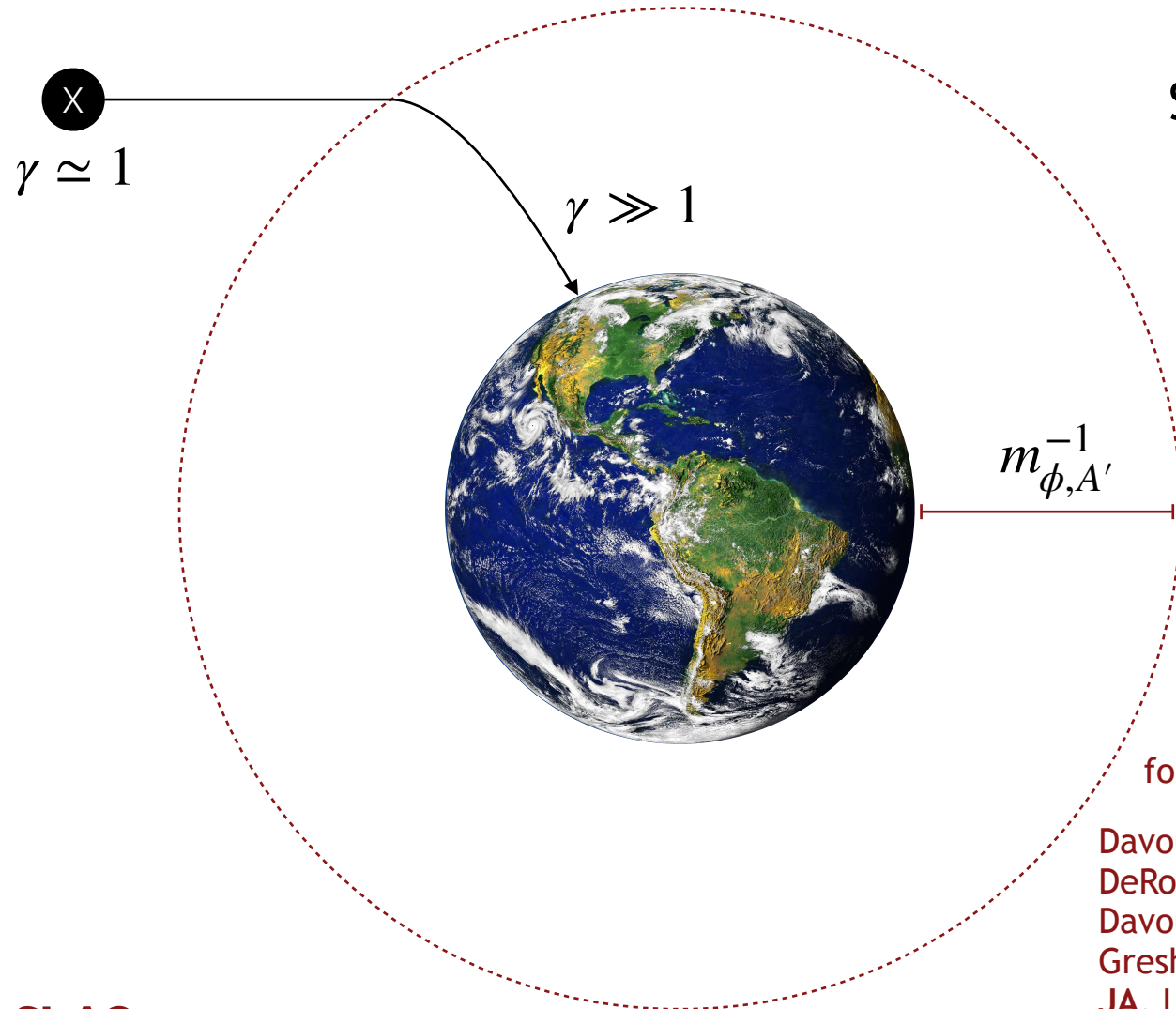Davoudiasl, 1705.00028
DeRocco, Graham & Rajendran, 2006.15112
Davoudiasl, Denton & Gehrlein, 2007.04989
Gresham, Lee & Zurek, 2209.03963
JA, Leane & Smirnov, 2303.01516
Raj, 2306.14981

Boosted Dark Matter from Long-Range Forces

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Scenario #2: DM-SM long-range interaction

(vector)

$$A'_\mu(r) = \delta_{\mu 0} \left(\frac{g_{\mathrm{SM}} N_\oplus}{4\pi r} \right) \exp\left(-m_{A'} r \right)$$

(scalar)

$$\phi(r) = \left(\frac{g_{\mathrm{SM}} N_\oplus}{4\pi r} \right) \exp\left(-m_\phi r \right)$$

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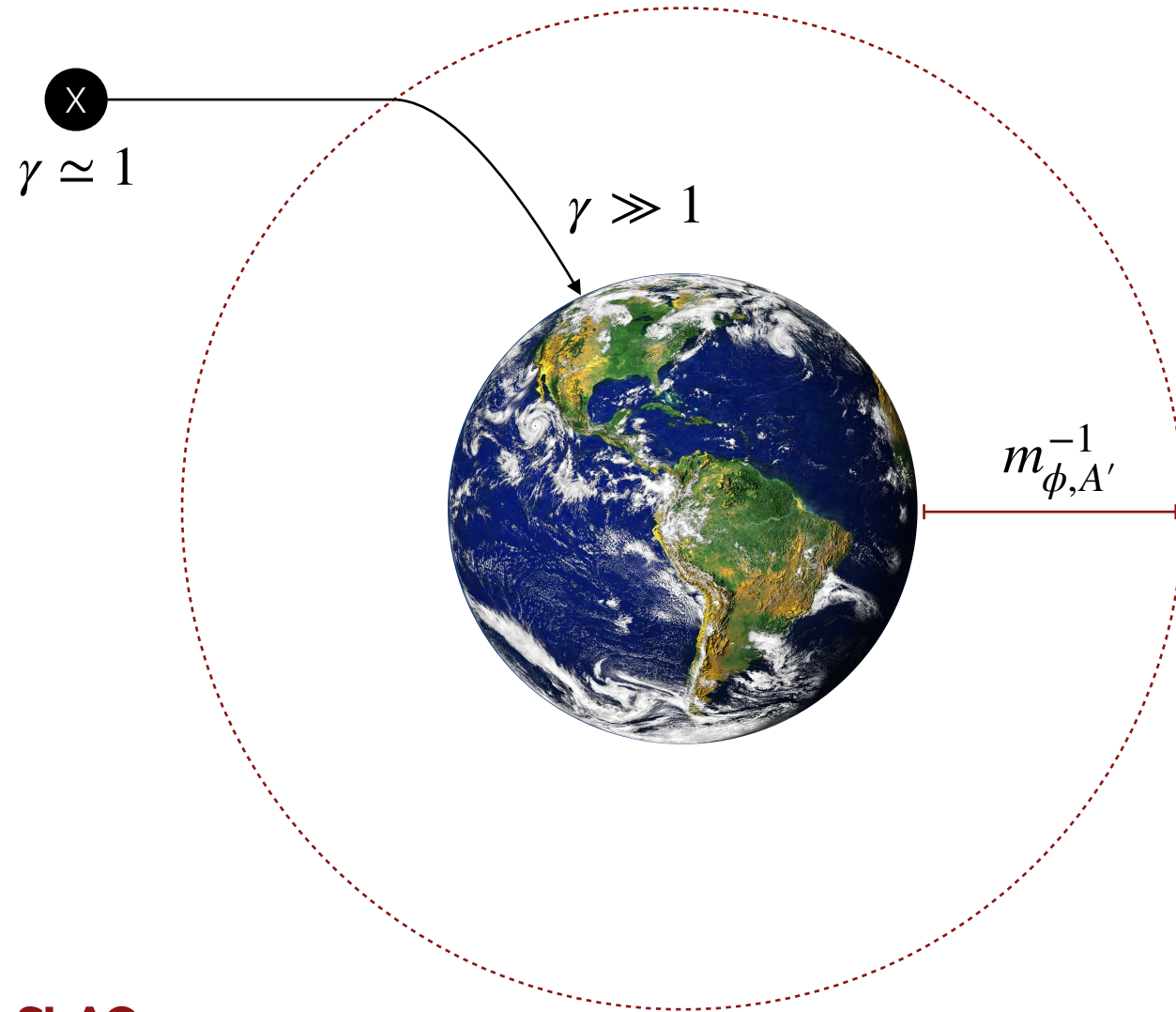Davoudiasl, 1705.00028
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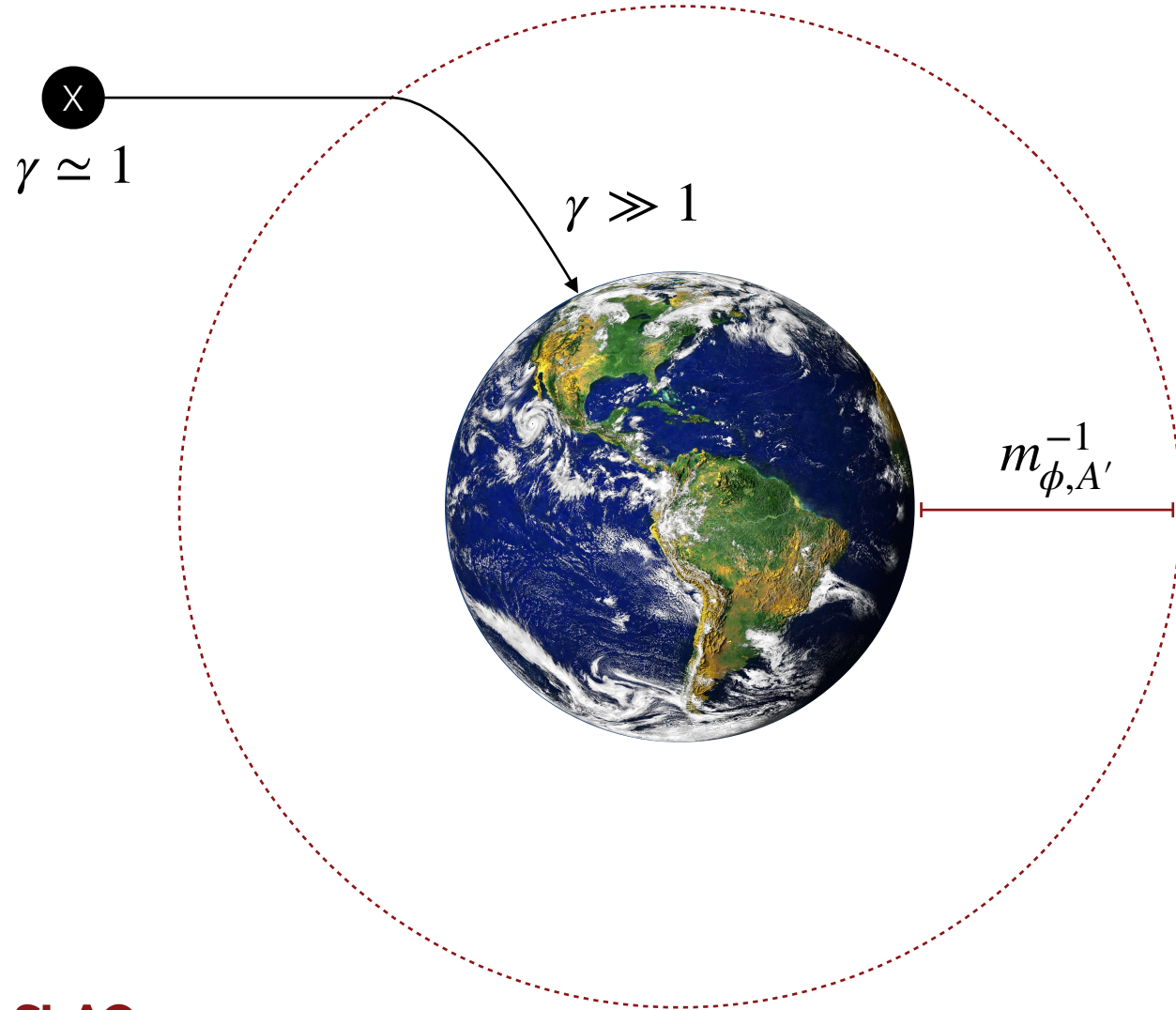**JA,** Leane & Smirnov, 2303.01516
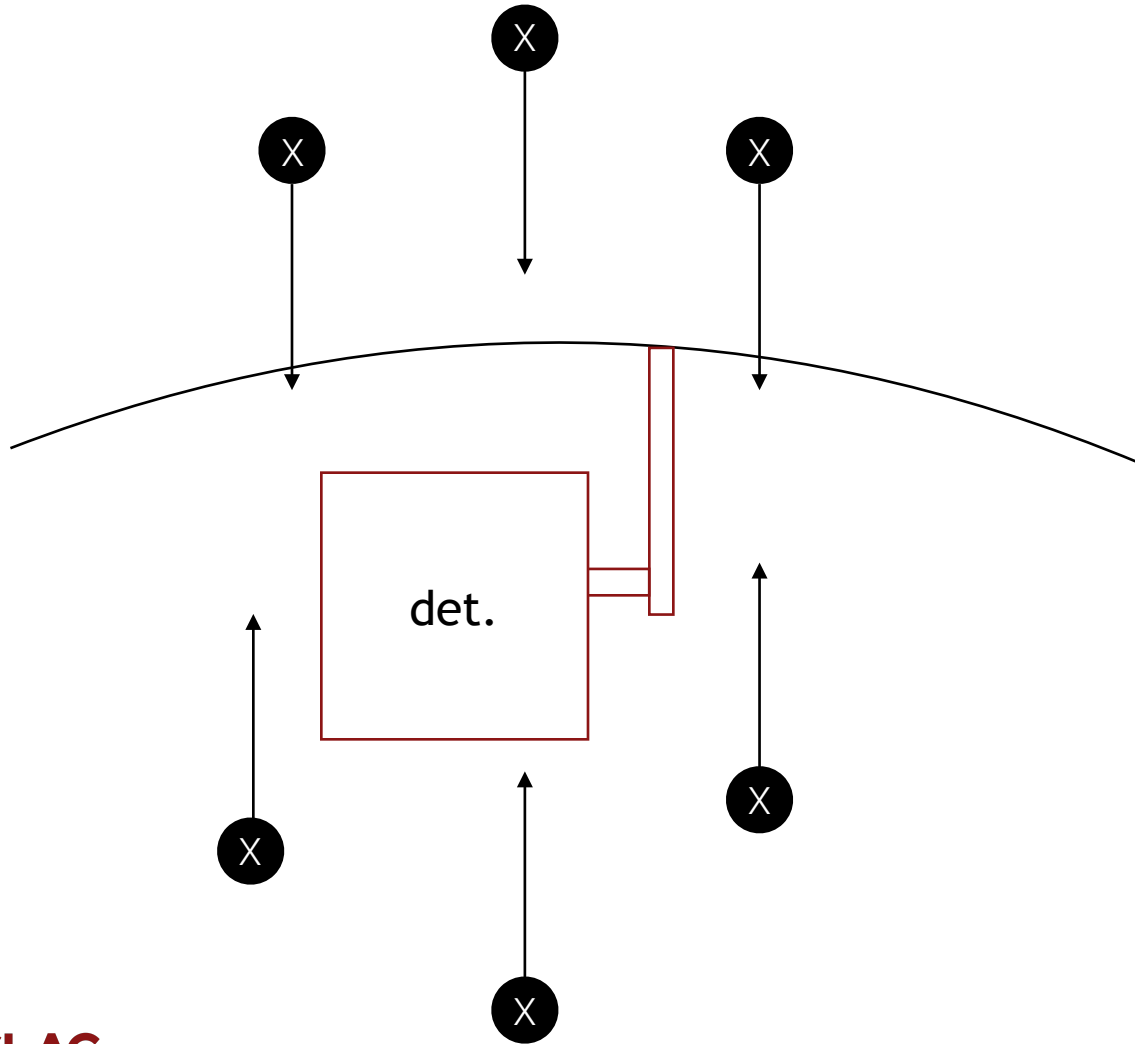Raj, 2306.14981

Implications of Boost

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$m_{\phi, A'}^{-1}$

- Higher energy allows for detection in high-threshold experiments.

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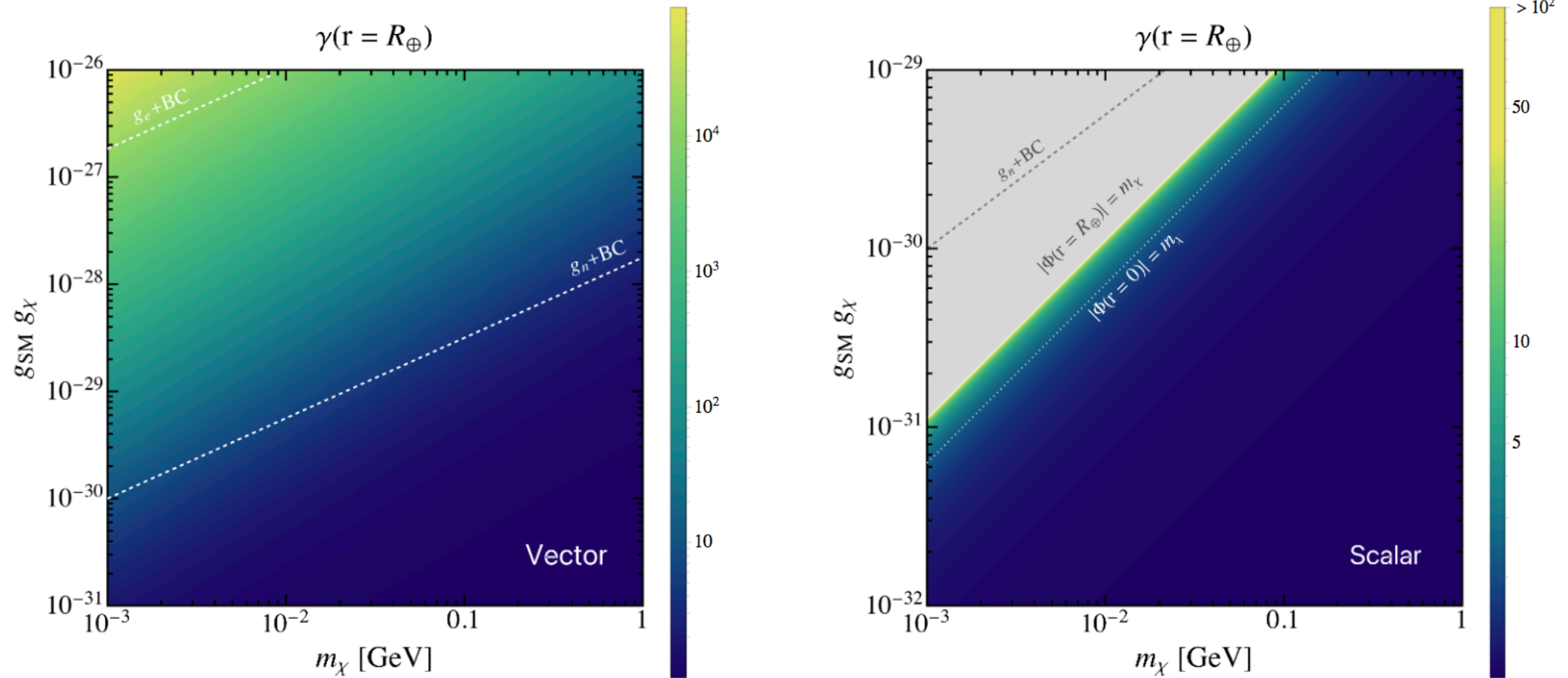- Flux passing through Earth is enhanced.

Implications of Boost

- Higher energy allows for detection in high-threshold experiments.

- Flux passing through Earth is enhanced.

- Majority of DM flows almost vertically through the surface: *the 'rain'*

Scalar vs. Vector Force: Boost

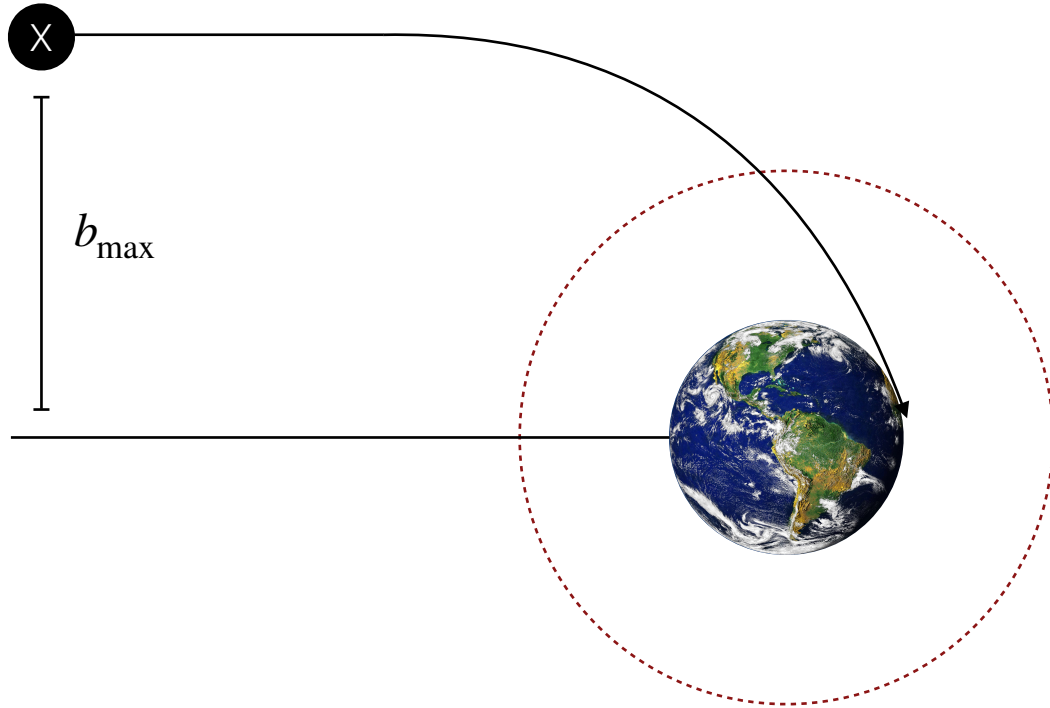Under the effect of the long-range force, the DM is boosted as:

$$\gamma(R_\oplus) = \begin{cases} 1 - \dfrac{g_\chi A_0'}{m_\chi} & \text{(vector)} \\[2em] \dfrac{1}{1 + \dfrac{g_\chi \phi}{m_\chi}} & \text{(scalar)} \end{cases}$$

Scalar vs. Vector Force: Boost

JA, Berger & Denton, 2407.01670

Scalar vs. Vector Force: Flux

X

b_{max}

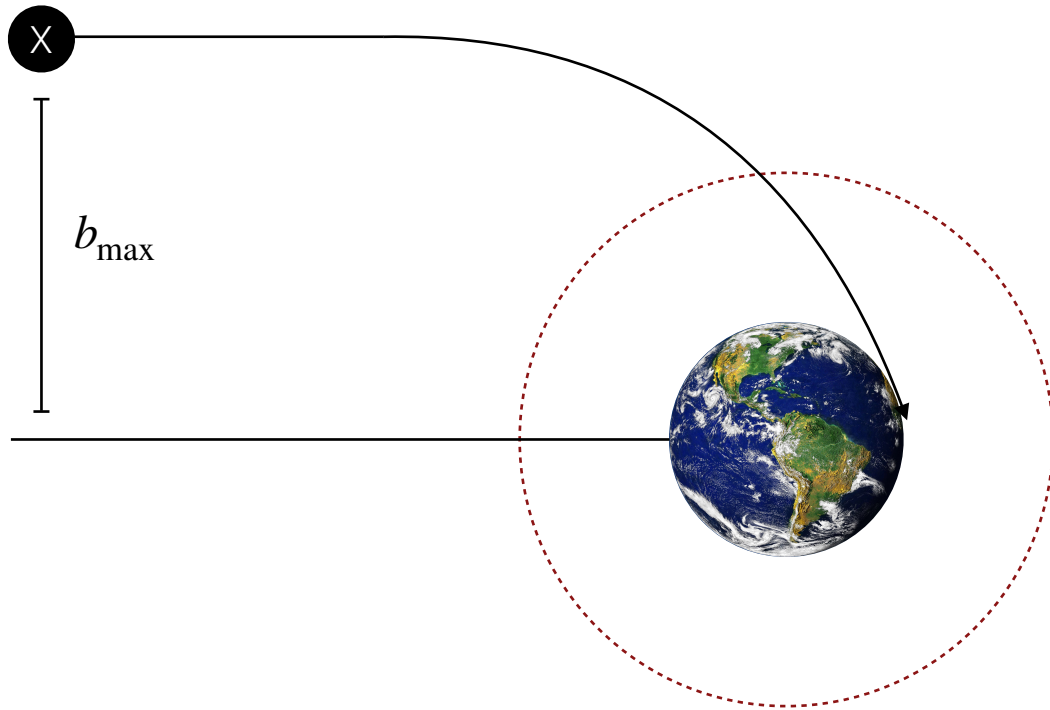Flux passing through detector has a simple scaling:

$$\frac{d\mathscr{F}}{dA} \propto b_{\text{max}}^2$$

In the purely gravitational case: $b_{\text{max}} \sim R_{\oplus}$

Scalar vs. Vector Force: Flux
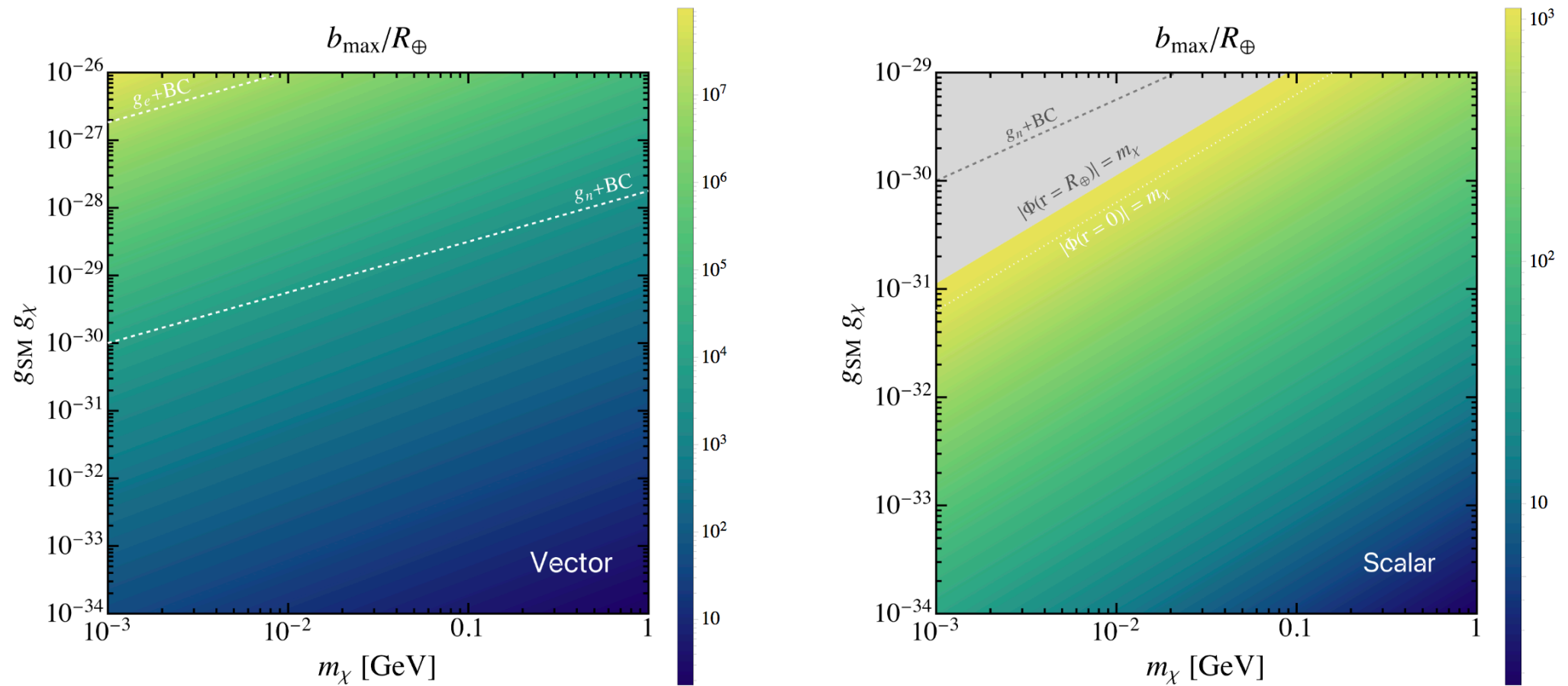

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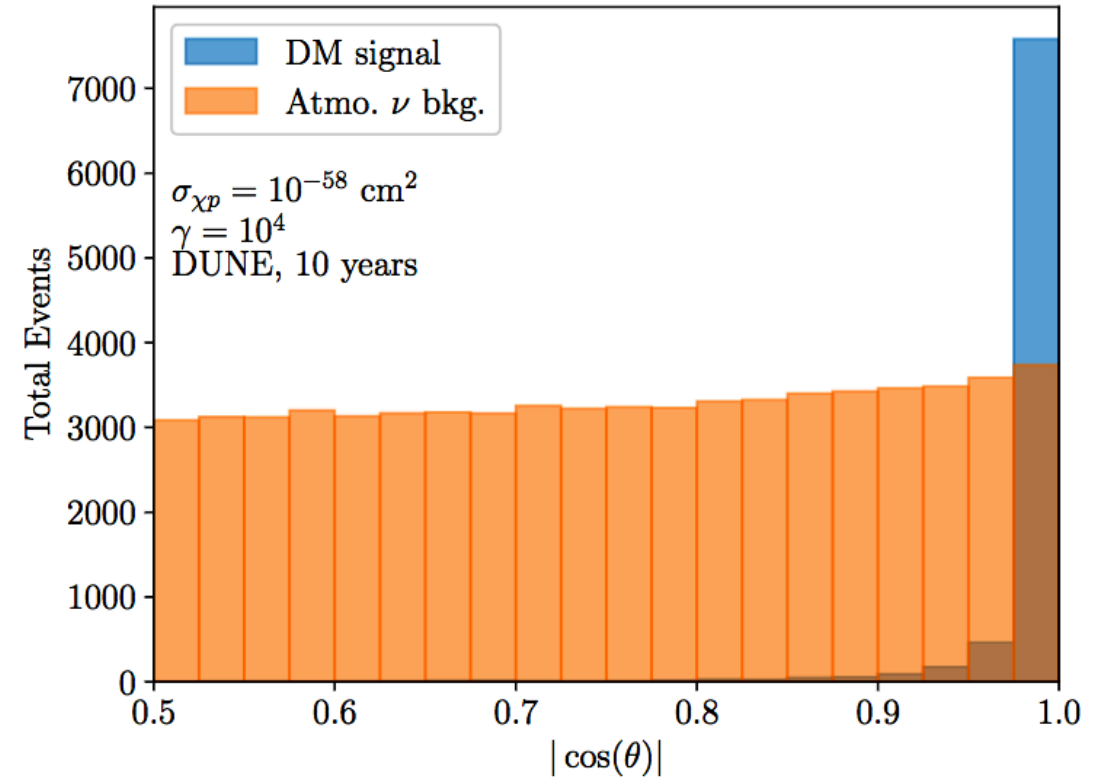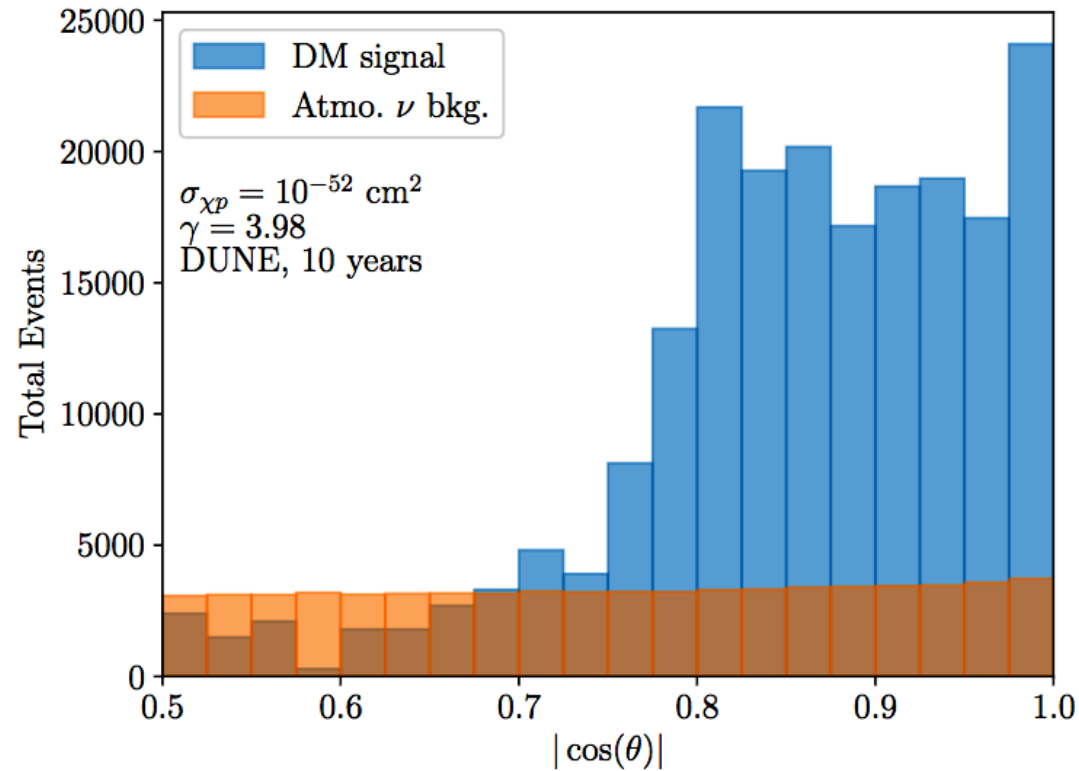
$$\frac{d\mathcal{F}}{dA} \propto b_{\text{max}}^2$$

Under the effect of the long-range force, this is:

$$b_{\text{max}} = \begin{bmatrix} R_{\oplus} \gamma \left(\dfrac{v_{\chi}}{v_{\text{halo}}} \right) & \text{(vector)} \\[2em] R_{\oplus} \left(\dfrac{v_{\chi}}{v_{\text{halo}}} \right) & \text{(scalar)} \end{bmatrix}$$
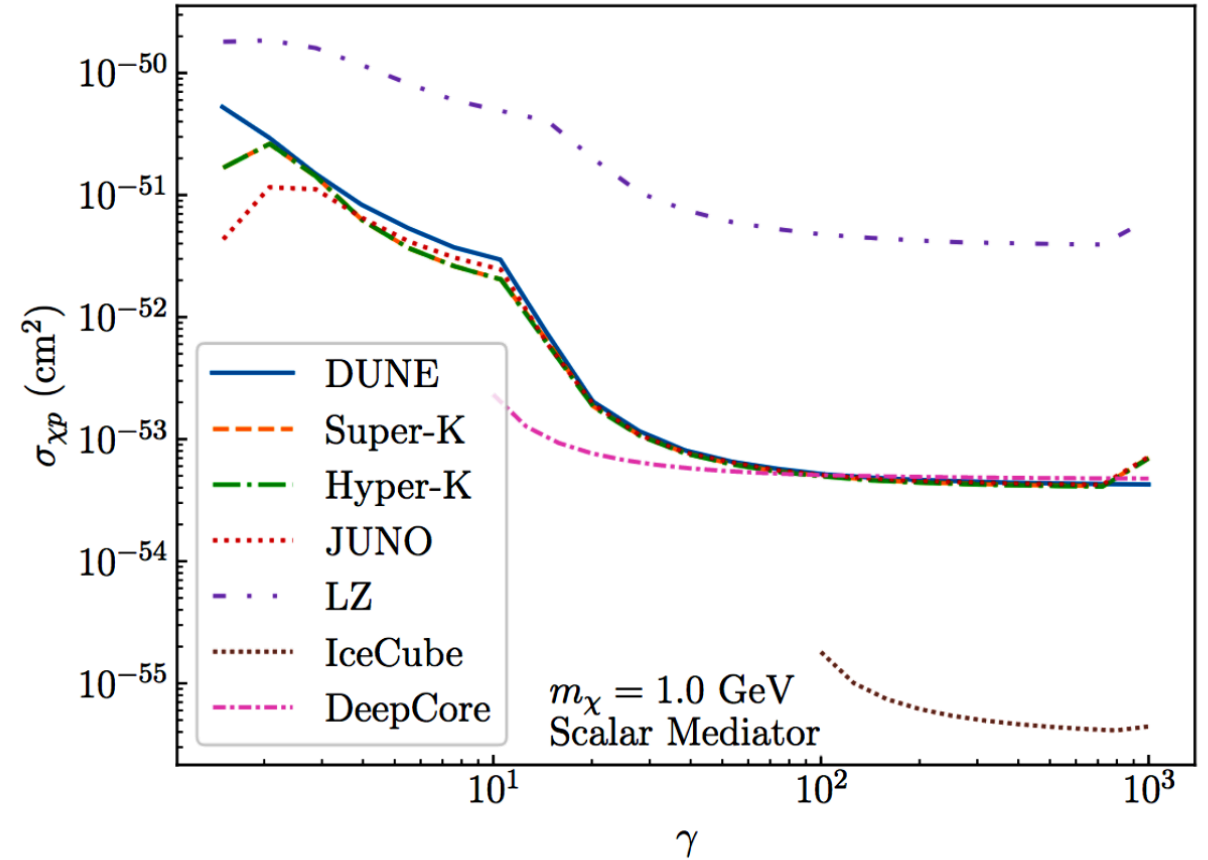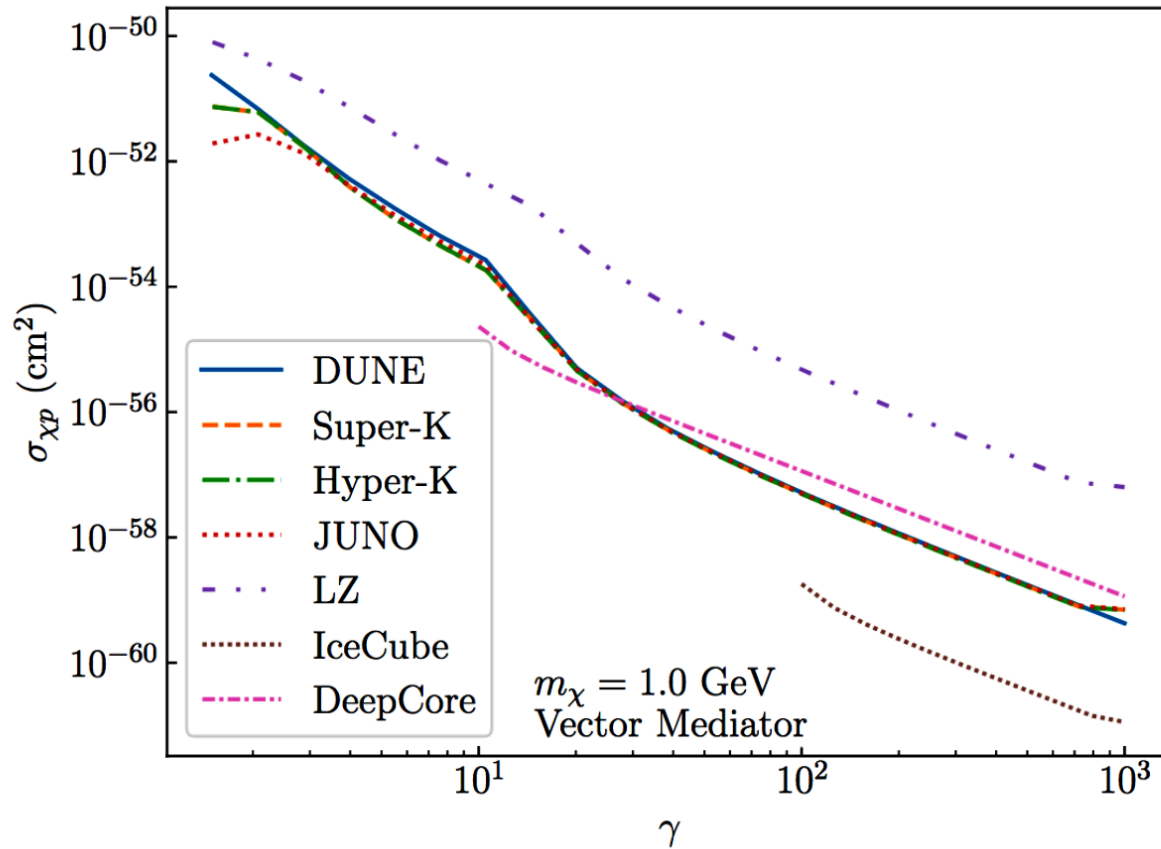
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JA, Berger & Denton, 2407.01670

The Dark Matter 'Rain'

JA, Berger & Denton, 2407.01670

Sensitivity of Large Volume Detectors

JA, Berger & Denton, 2407.01670

Summary

- It is possible that dark matter interacts through long-range forces: even for tiny couplings, these could lead to striking new phenomena in experiments and astrophysical searches.

- Large-volume detectors offer an interesting avenue to explore and test some of these scenarios.

- The nature of the long-range interaction results in unique detection signatures and qualitatively different parameter space.