Searching for Dark Photon Dark Matter with Cosmic-Ray Antideuterons

Weishuang Linda Xu, with Lisa Randall

Harvard University
AntiDeuteron 2019, UCLA

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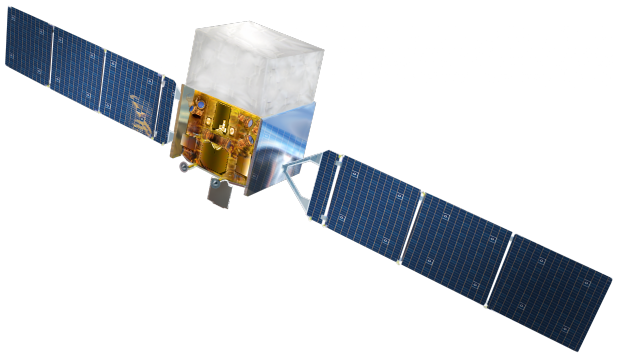
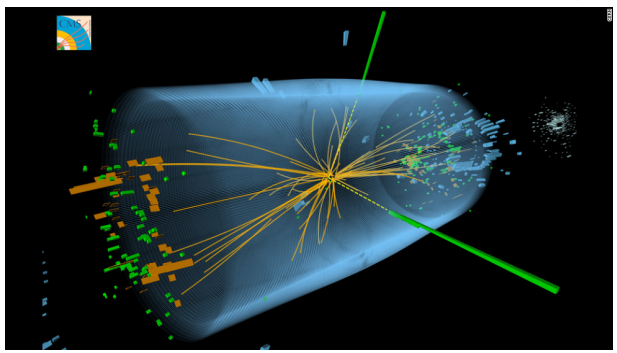
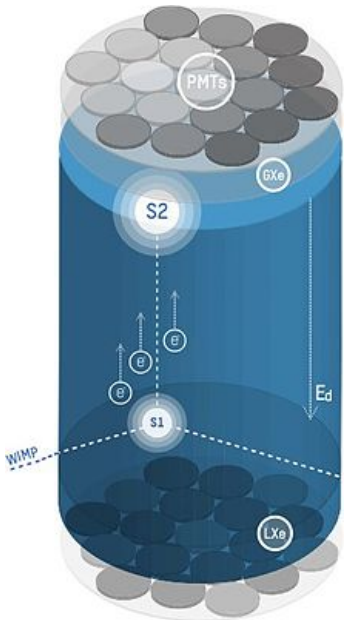
Agenda

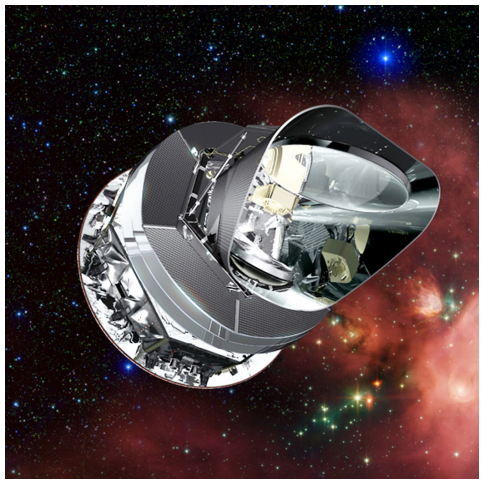
- Point out a class of dark matter models indirect detection is optimized to search for
- Present detection prospects of an example model with ongoing & future antideuteron experiments

Introduction









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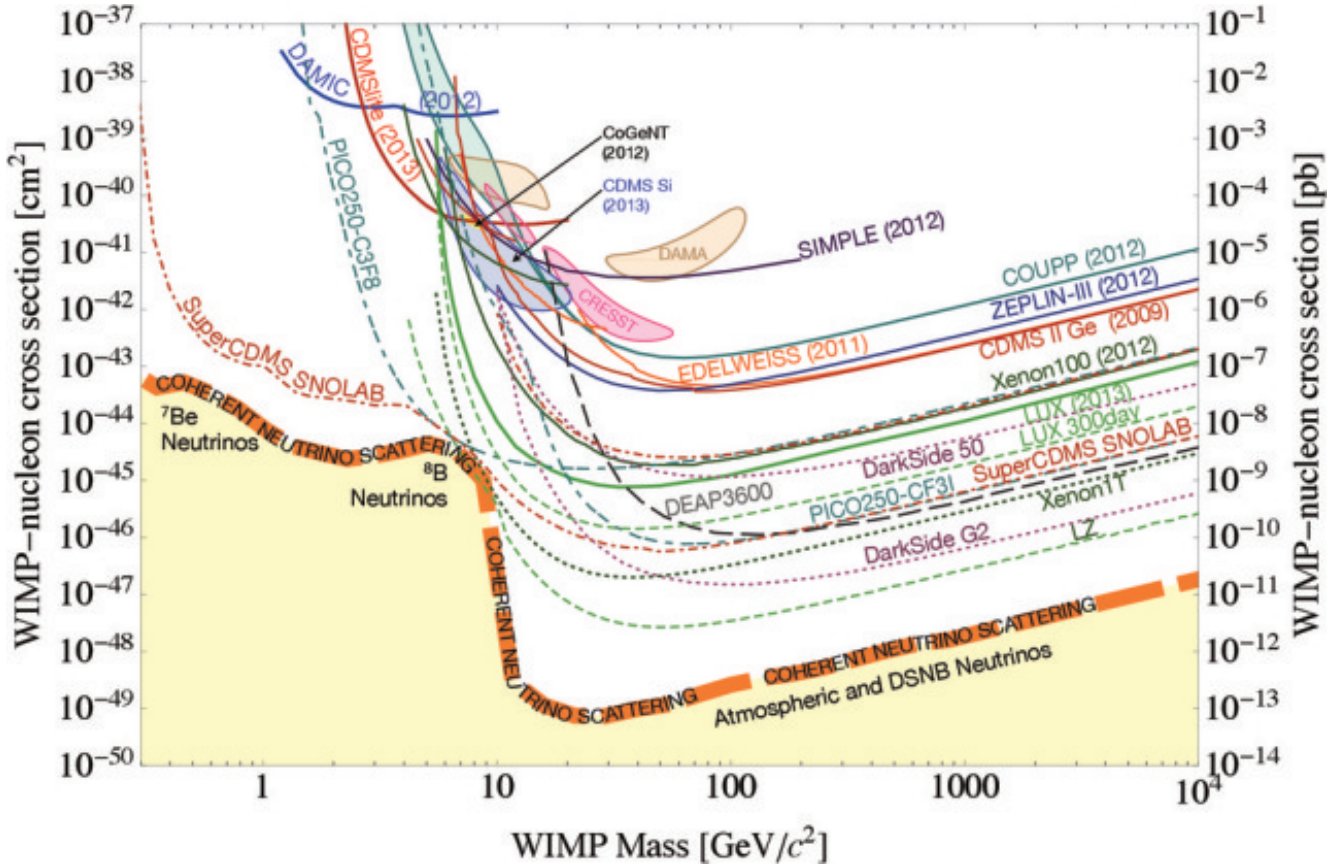

Taken from Cooley 1490.4960

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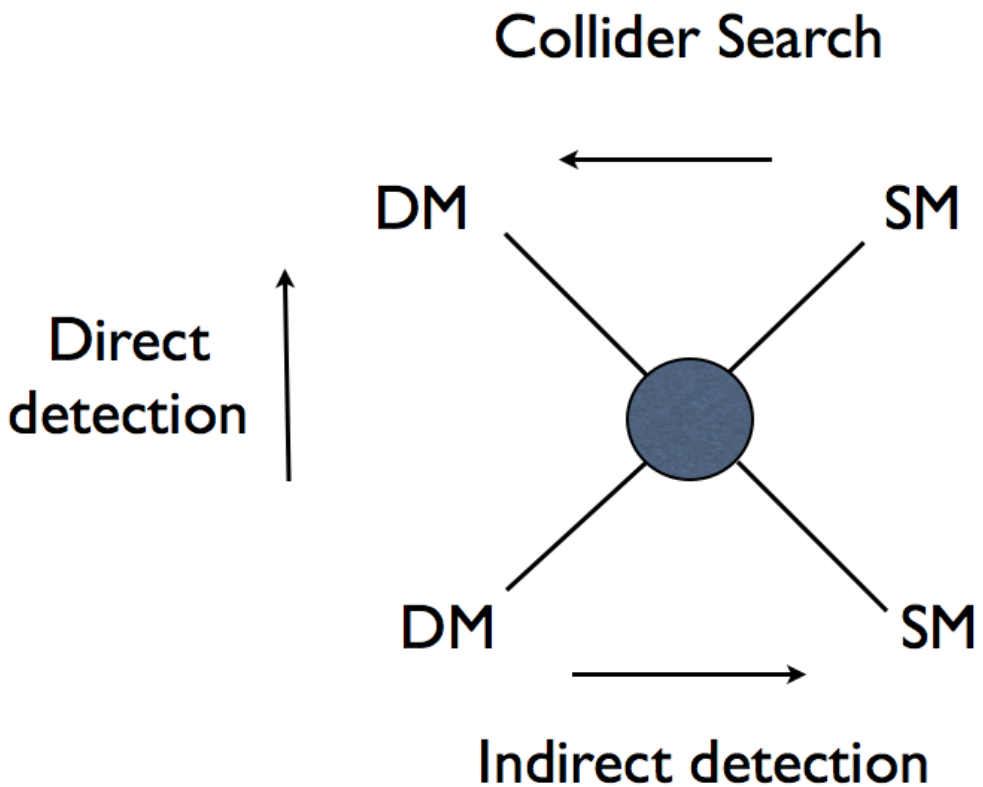
- Radiation $\rightarrow$ Neff (Cosmology)
- Matter $\rightarrow$ SM (Local detection)

Hidden Sector Dark Matter

If annihilated DM ends up in the SM, we should be able to find it!

- Direct detection, Indirect detection, Collider searches



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- Direct detection, Indirect detection, Collider searches
- Worst-case scenario:
  - dark matter is hidden sector
  - mixing between dark and light sectors is extremely small
- Indirect detection is uniquely poised for these searches

Dark Photon Dark Matter

- New players: Fermion dark matter χ, dark $U(1)$ with massive gauge boson A'

$$\mathcal{L} \ni -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu} - g\bar{\chi}\gamma^{\mu}A'_{\mu}\chi - e\bar{\psi}\gamma^{\mu}A_{\mu}\psi$$

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- Effective interaction

$$\mathcal{L} \ni -\epsilon e\bar{\psi}\gamma^{\mu}A'_{\mu}\psi$$

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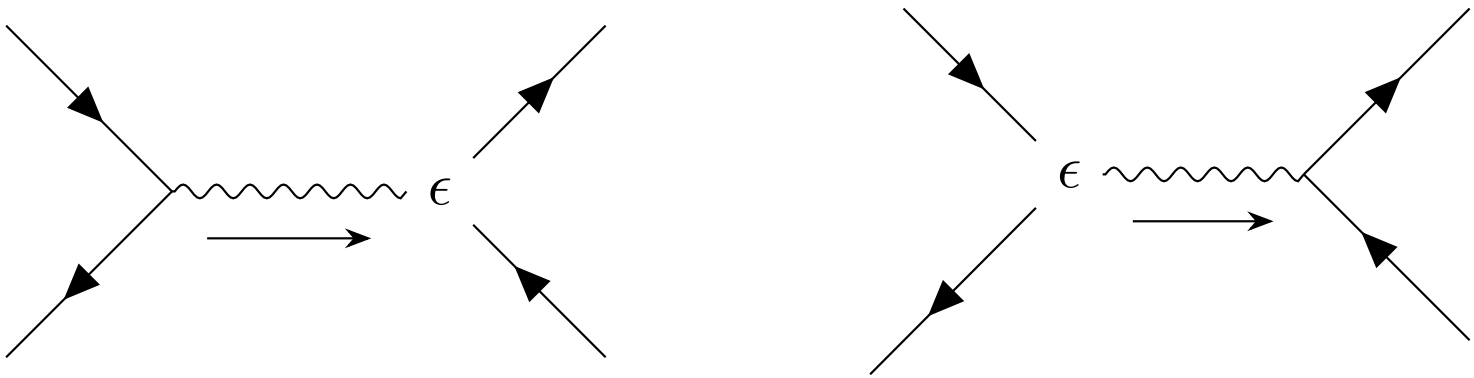
- Direct detection and collider signals are suppressed by ϵ^2



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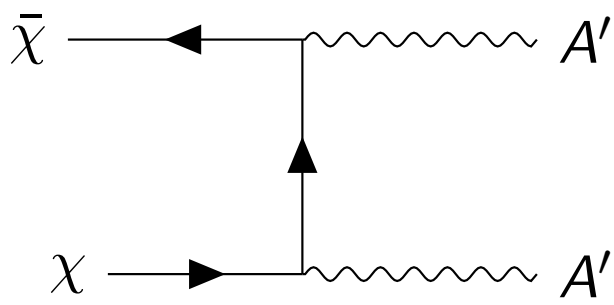
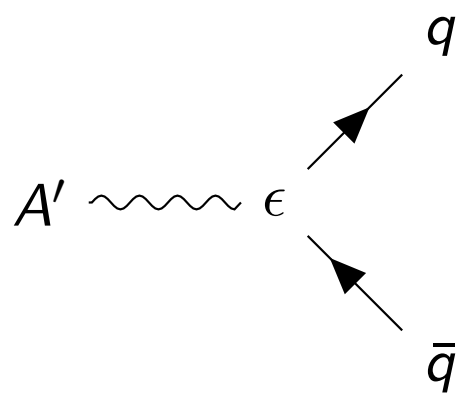
- A' propagates and decays to $q\bar{q}$ with $\tau \sim (\epsilon^2 e^2 m_{A'})^{-1}$





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If DPDM is thermal relic but ϵ is small, direct detection/colliders* will not be able to find it. Indirect detection will.

Anti-Deuteron Prospects

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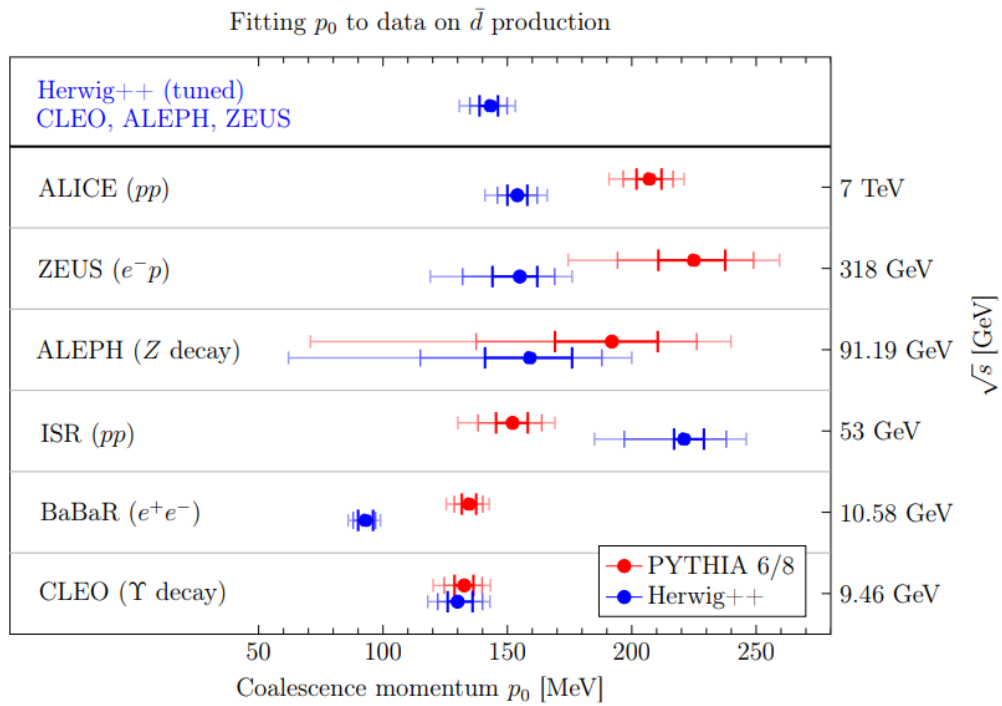
- MC with Pythia 8. Coalescence model

$$C(\vec{\Delta}) = \Theta(p_0^2 - \vec{\Delta}^2) \qquad p_0 = 200 \text{ MeV}$$



From Ibarra & Wild 1209.5539, Dal & Raklev 1402.6259

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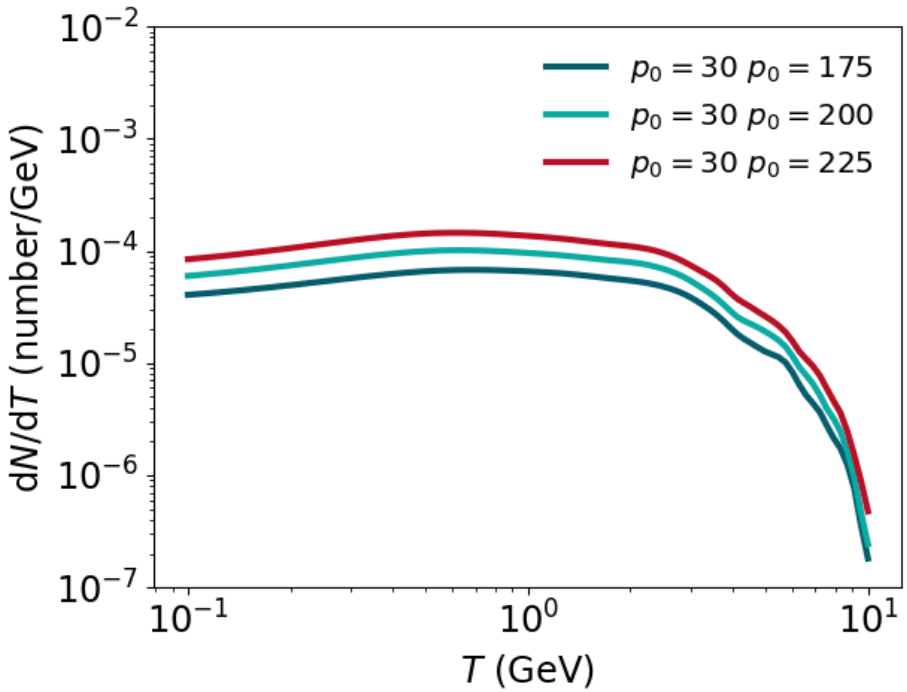

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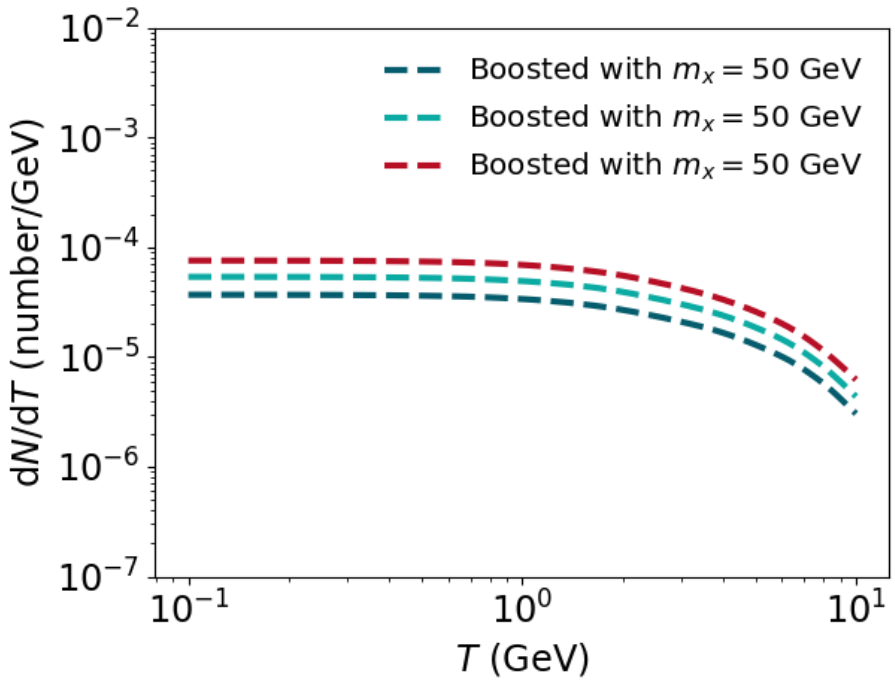
- Boost antideuteron to rest frame of χ (isotropically)



Cosmic Ray Propagation: Galactic

Two zone diffusion model (Donato, Maurin, Taillet, 2002):

- Propagation in a cylinder of radius R =20 kpc, half-height L
- Annihilation in disk of half-height $h = 100$ pc.

$$-\nabla[K(r,z,T)\nabla n_{\bar{d}}(r,z,T)] + \frac{\partial}{\partial z}[\mathrm{sgn}(z)V_c n_{\bar{d}}(r,z,T)]$$
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$$\rho(r,z) = \exp(-2[(\sqrt{r^2+z^2}/r_s)^\alpha - (r_\odot/r_s)^\alpha/\alpha])$$

$$r_s = 20 \text{ kpc},\ \alpha = 0.17$$

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Annihilation:

$$\Gamma^{\bar{d}}_{ann} = (n_H + 4^{2/3} n_{He})\sigma^{\bar{d}p} v_{\bar{d}}$$

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$$\Phi_\odot(r, z, T) = \frac{v_{\bar{d}}}{4\pi} n_{\bar{d}}(r, z, T)$$

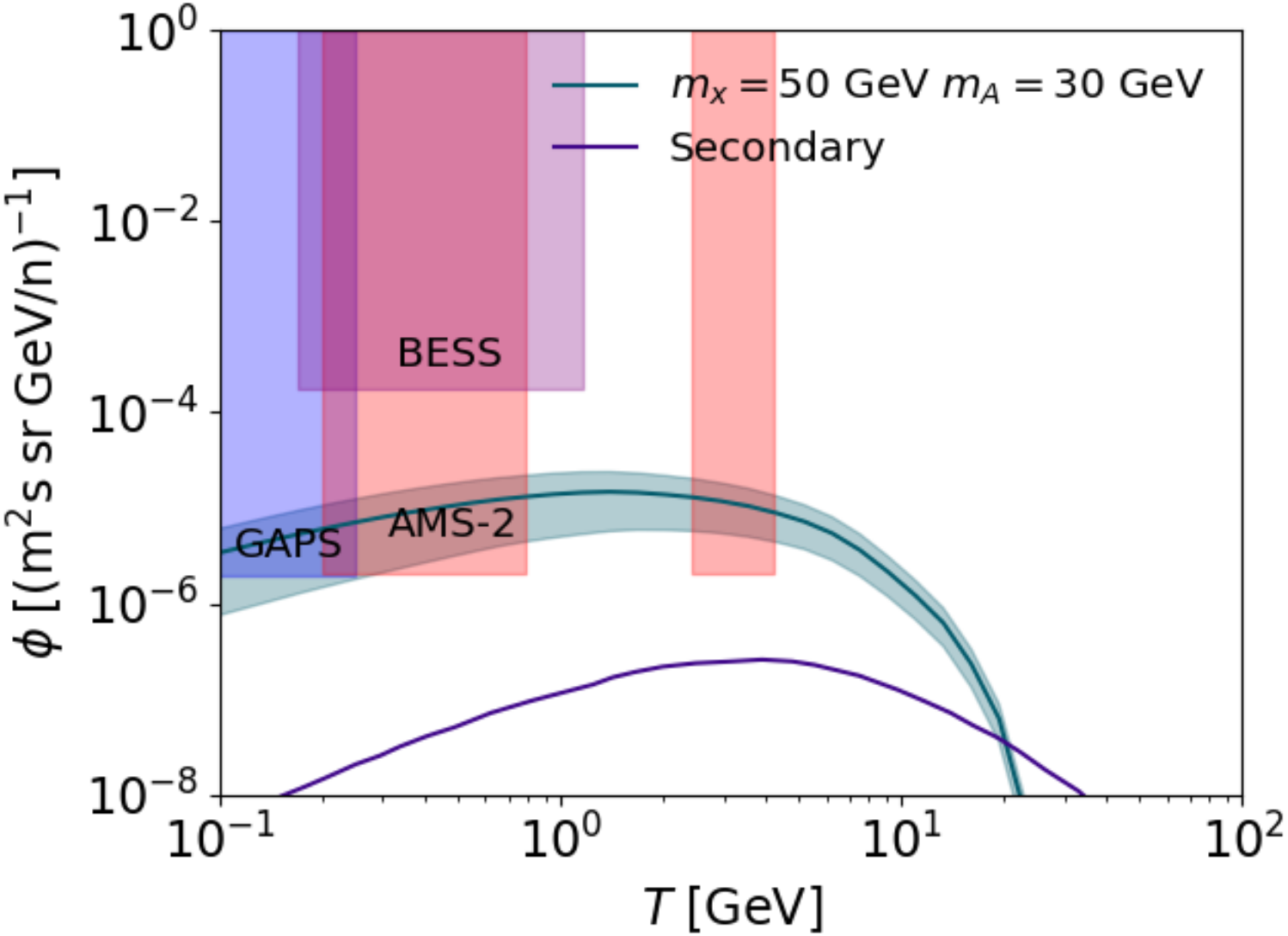
	K_0 [kpc^2/Myr]	δ	L [kpc]	V_c [km/s]
MED	0.0112	0.70	4	12
MAX	0.0765	0.46	15	5

Cosmic Ray Propagation: Solar

Model transport in the solar environment by the force-field approximation (Gleeson, Axford, 1968):

$$\Phi_{\oplus}(T) = \Phi_{\odot}(T + e\phi_F)\frac{E^2(T) - m_{\bar{d}}^2}{E^2(T + e\phi_F) - m_{\bar{d}}^2} \qquad \phi_F = 500 \text{ MV}$$

Detection Prospects



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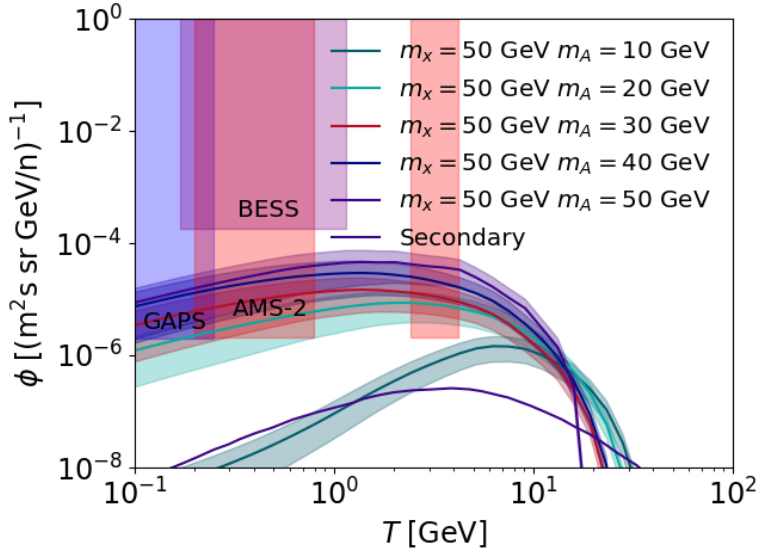

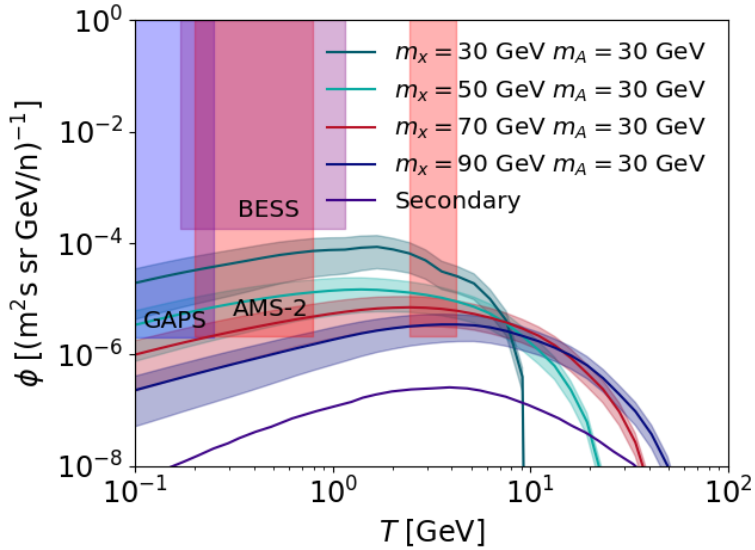

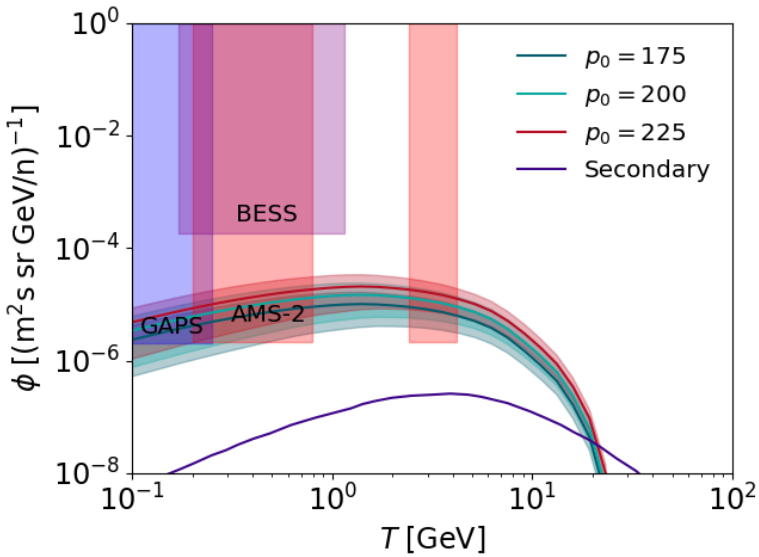

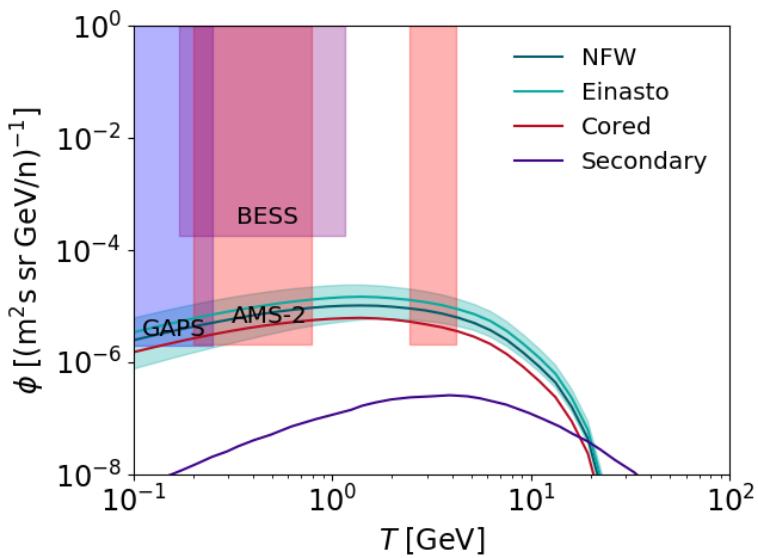

Summary

- Given current detection results, it is likely that DM is hidden sector
- If so, indirect detection may be the only way to look for it
- Dark photon dark matter is a very general type of HSDM
- Antideuterons are promising probes of $m_\chi \gtrsim m_{A'} \sim \mathcal{O}(10\text{GeV})$ DPDM
- Very few other methods can access this space

Thank you!

Constraints on ϵ

Upper:

- Collider searches
- Direct detection:

  $\sigma_{\chi p} \sim \frac{1}{4\pi} \frac{g^2 \epsilon^2 e^2}{m_{A'}^4} \frac{m_\chi^2 m_p^2}{(m_\chi + m_p)^2}$

Lower:

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  $\tau \lesssim$ kpc
- BBN: $\tau \lesssim$ s

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