Forging AntiHelium in a Dark Matter Crucible

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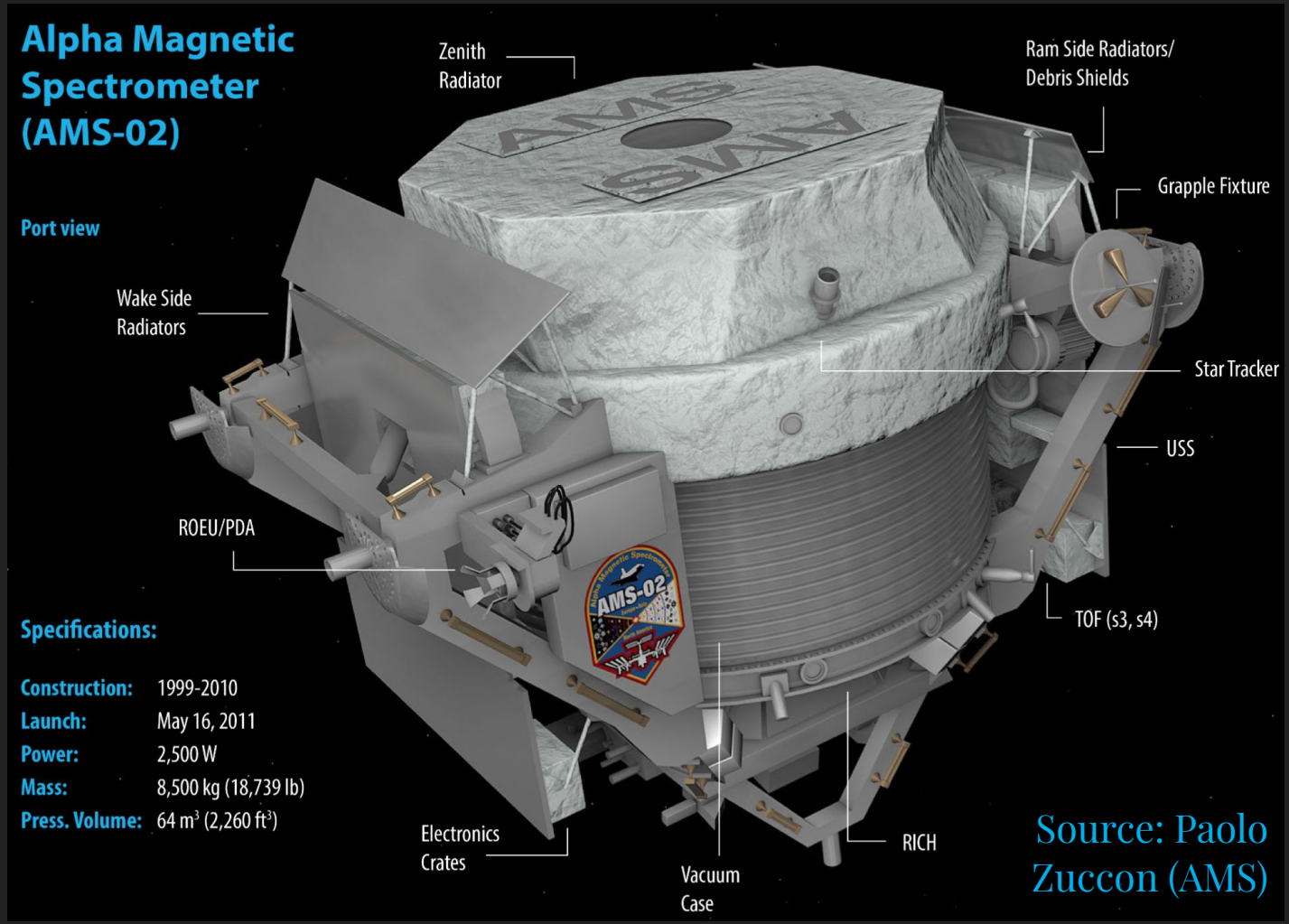
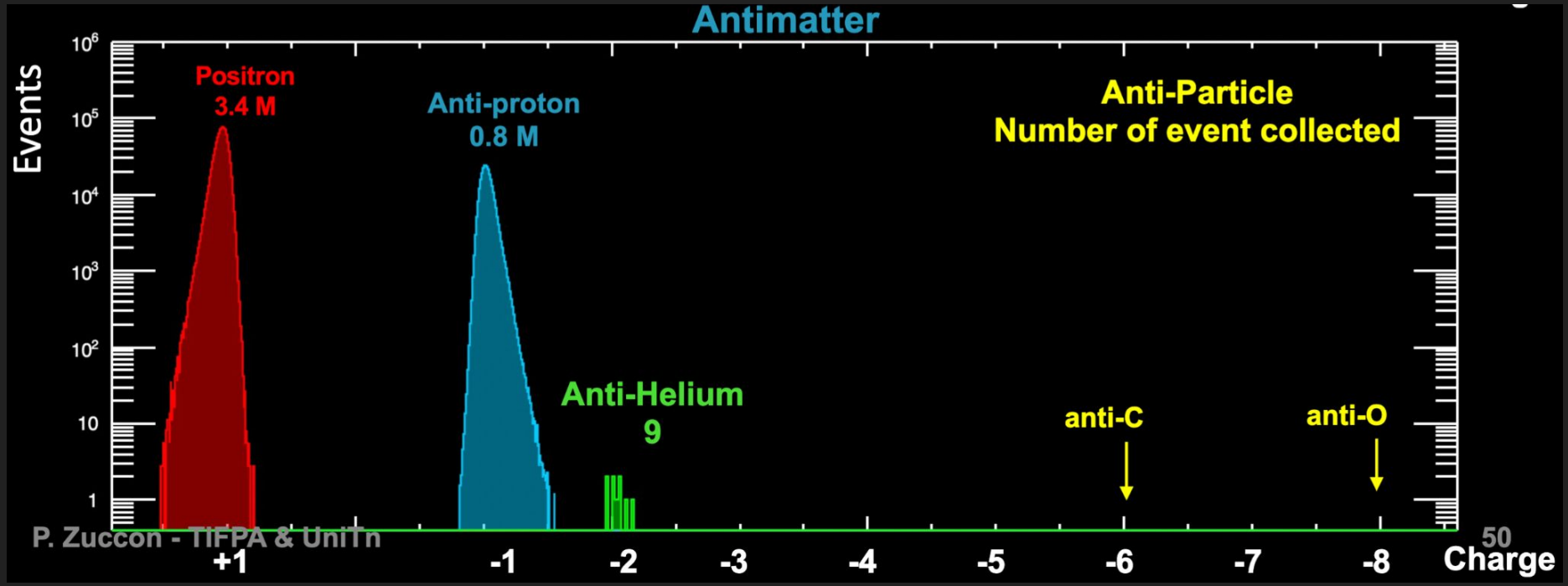
Johns Hopkins University

Based on upcoming work with Michael Fedderke, Erwin Tanin, David E Kaplan & Surjeet Rajendran


Alpha Magnetic Spectrometer (AMS-02)
Port view
Zenith Radiator
Ram Side Radiators/ Debris Shields
Grapple Fixture
Wake Side Radiators
Star Tracker
USS
ROEU/PDA
TOF (s3, s4)
Specifications:
Construction: 1999-2010
Launch: May 16, 2011
Power: 2,500 W
Mass: 8,500 kg (18,739 lb)
Press. Volume: 64 m³ (2,260 ft³)
Electronics Crates
Vacuum Case
RICH
Source: Paolo Zuccon (AMS)



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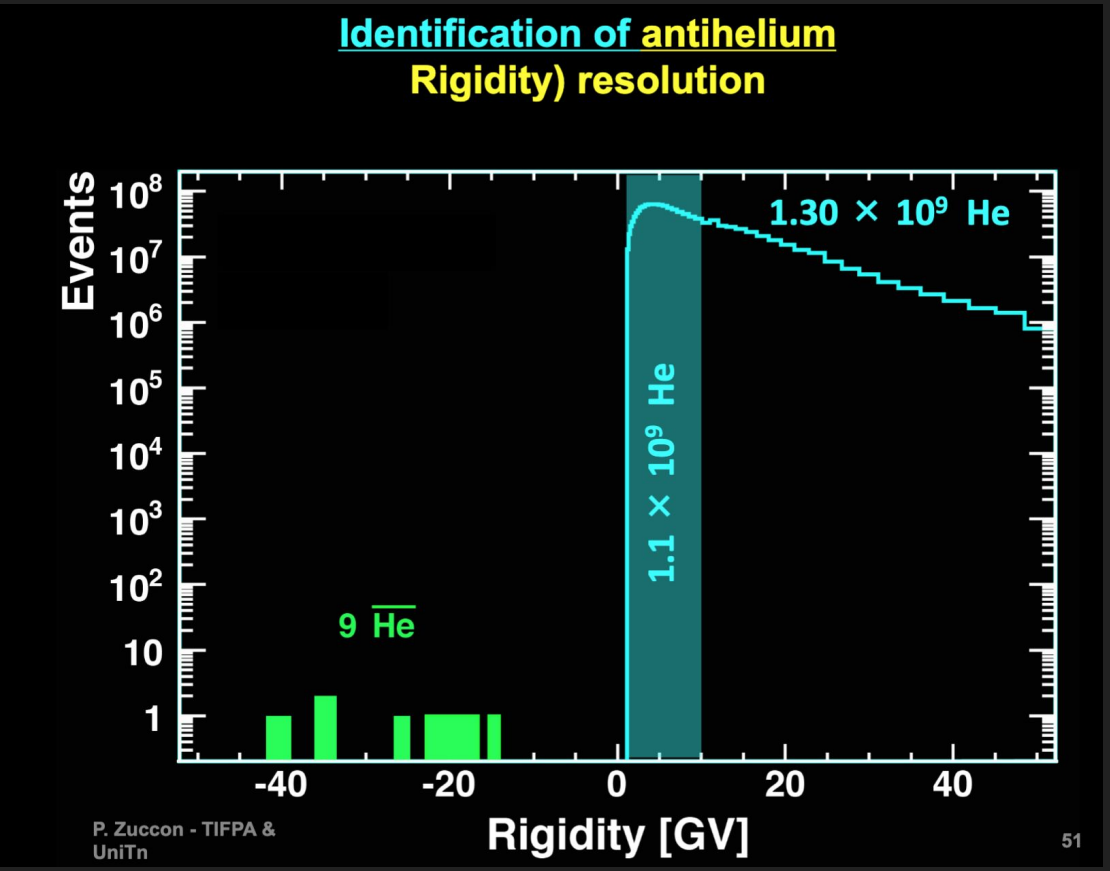

Key features

- 6 counts of $^3\overline{\text{He}}$
- 3 counts of $^4\overline{\text{He}}$
- 1 $\overline{\text{He}}$ / 100 million He
- Lorentz factor $\Gamma \sim 10$

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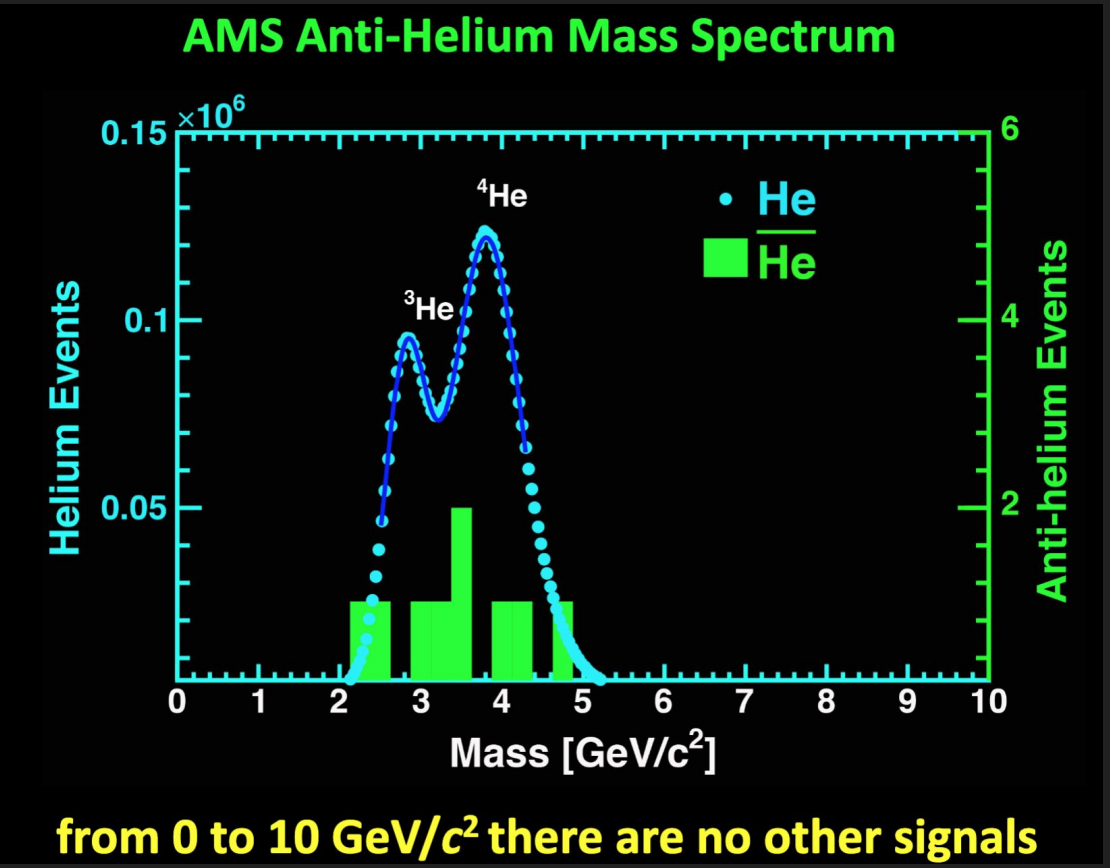

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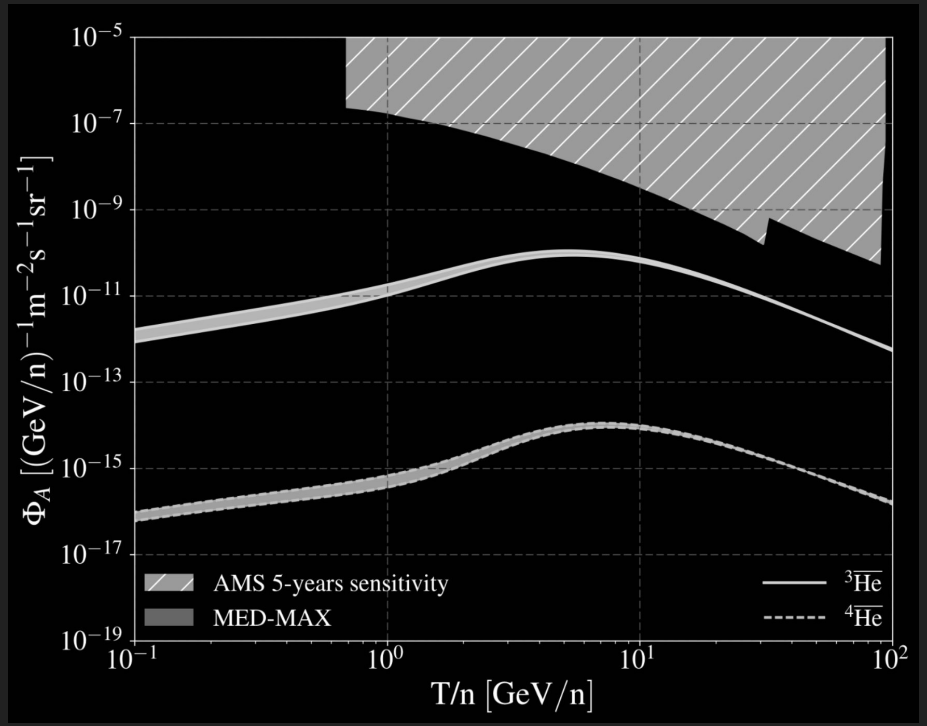
DISCLAIMER

- Results unpublished pending background studies / more data collection
- Still worth investigating possible origin stories

Possibilities

- Coalescence: SM processes can produce $^{3}\overline{\text{He}}$ but not $^{4}\overline{\text{He}}$



Source: V Poulin et al [1808.08961]

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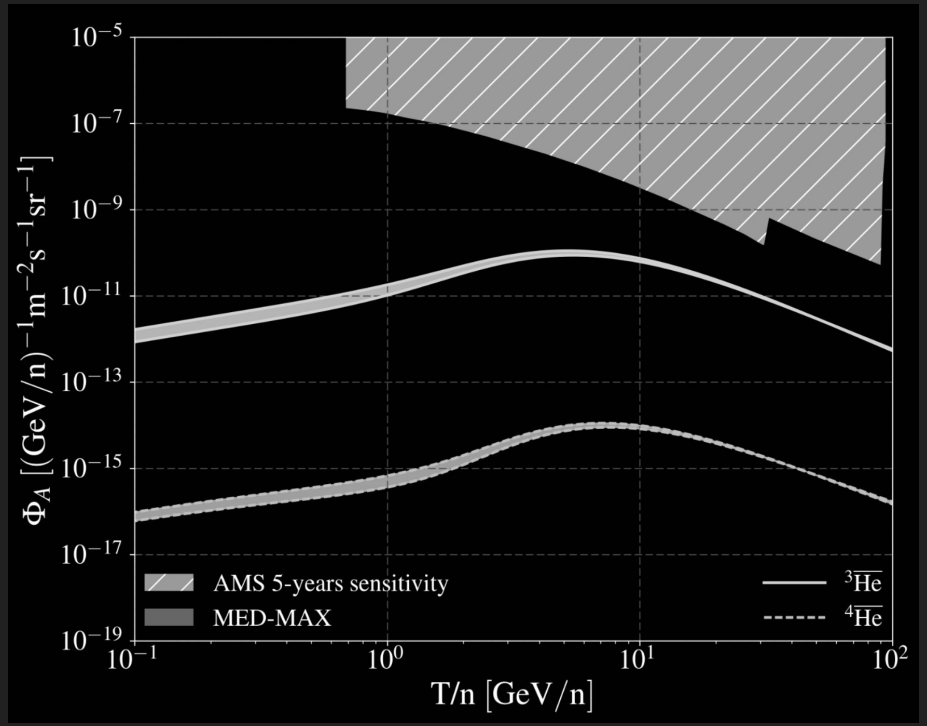

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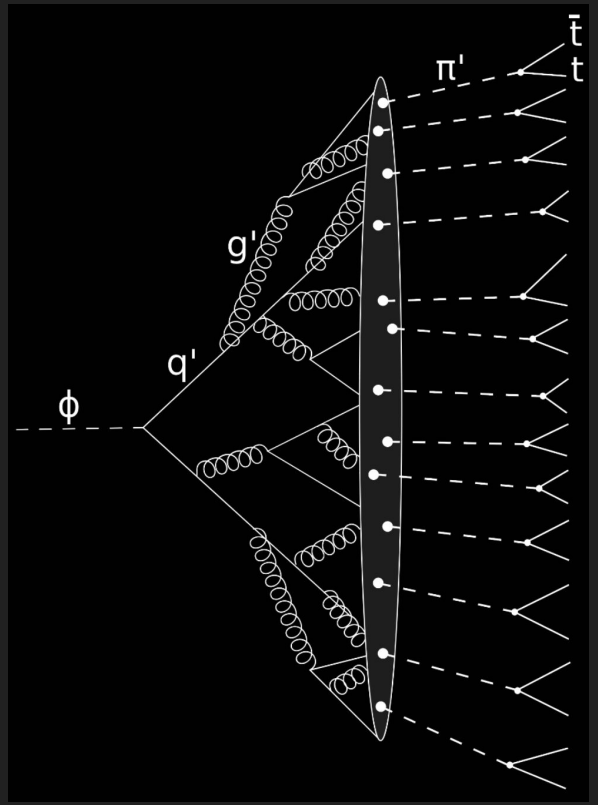
- Dark sector annihilations/decays: e.g. DM with strong coupling can “shower”



Source: Winkler et al [2211.00025]

Wish List

1. Natural: correct isotopic ratio, energy, rate with simple dependence on model parameters

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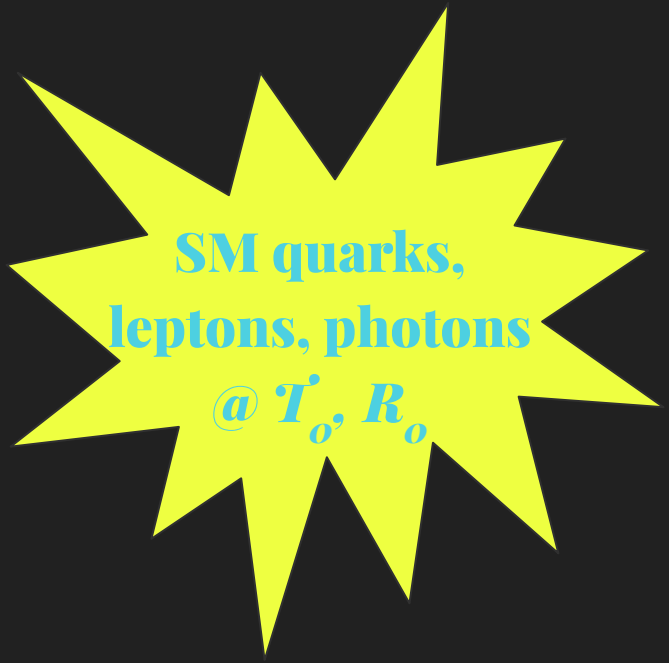
3. Flexible: can accommodate new observations from AMS, GAPS, …

Enter the Fireball

- Thermalized region of SM particles undergoing (anti)nucleosynthesis



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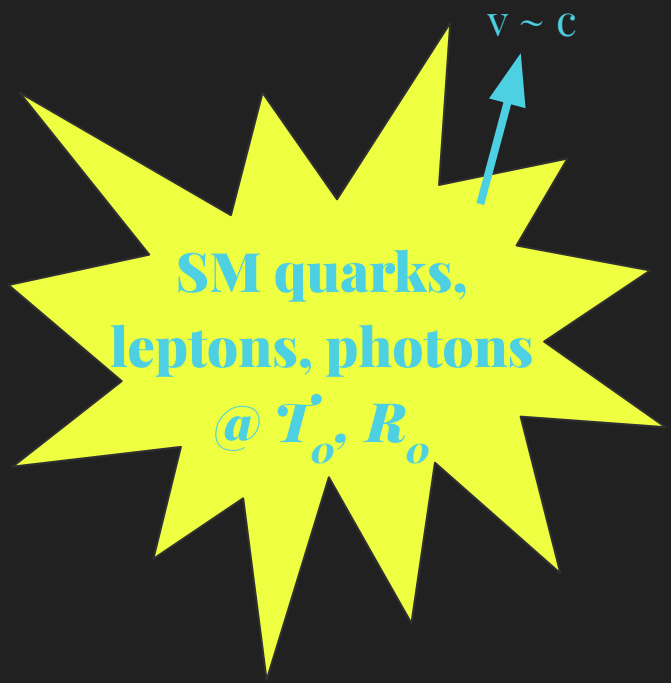

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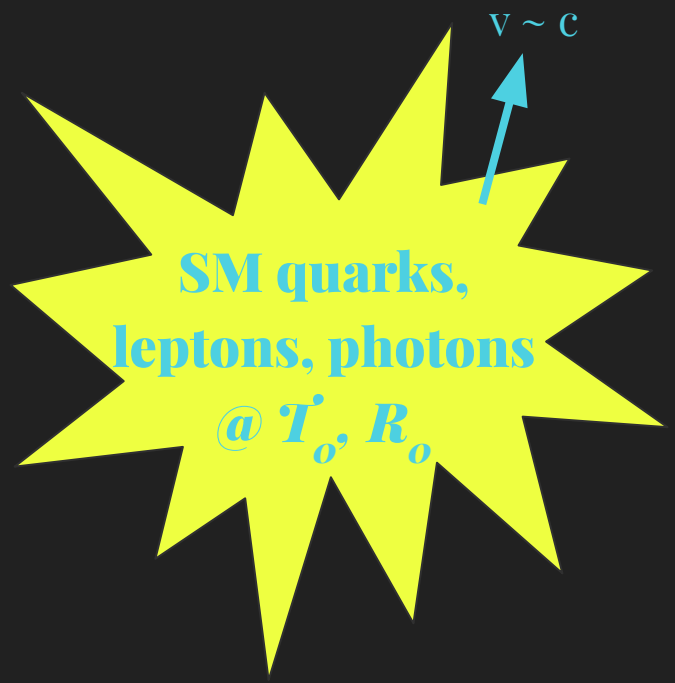
- Triggered by DM collisions whose details do not affect the evolution due to thermalization in SM sector



net antibaryon number B sets baryon-to-entropy ratio η

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- Finally becomes optically thin & releases burst of photons
- Unlike BBN, spatially finite and (very rapidly) expanding into vacuum

Nucleosynthesis

- Happens alongside expansion as fireball cools below binding energy
- As in BBN, burn to He through deuterium bottleneck

$$\bar{n} + \bar{p} \to \bar{D} + \gamma,$$

$$\bar{D} + \bar{D} \to {}^{3}\overline{\mathrm{He}} + \bar{n} \to \bar{T} + \bar{p},$$

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- $\overline{\mathrm{D}}$ decouples when photodissociation becomes weak
- $\overline{\mathrm{D}}$ fraction sets final isotope ratios of all species, with $\overline{\mathrm{He}}$ "freezing in" to the required abundance

$$X_{\bar{D},\,\mathrm{dec.}} \approx 4 \times 10^{-3} \left(\frac{T_0}{100\ \mathrm{MeV}}\right)^2 \left(\frac{R_0}{\mathrm{mm}}\right) \left(\frac{\Gamma}{10}\right)^{-5/3}$$

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$$X_{\bar{D},\,\mathrm{dec.}} \approx 4 \times 10^{-3} \left(\frac{T_0}{100\ \mathrm{MeV}} \right)^{2} \left(\frac{R_0}{\mathrm{mm}} \right) \left(\frac{\Gamma}{10} \right)^{-5/3}$$

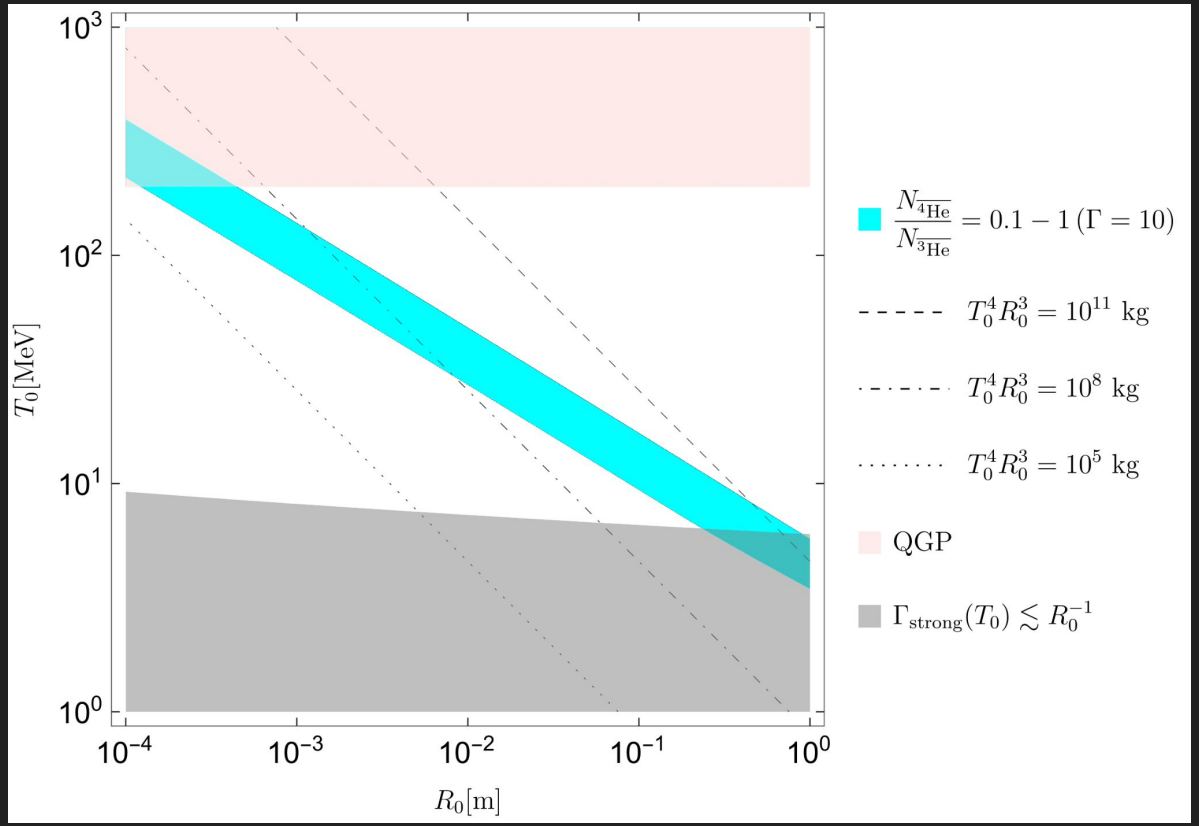
$$X_{{}^{3}\overline{\mathrm{He}}} \approx 4 \times 10^{-4} \left(\frac{X_{\bar{D},\,\mathrm{dec.}}}{5 \times 10^{-3}} \right)^{3}$$

$$X_{{}^{4}\overline{\mathrm{He}}} \approx 1 \times 10^{-4} \left(\frac{X_{\bar{D},\,\mathrm{dec.}}}{5 \times 10^{-3}} \right)^{5}$$

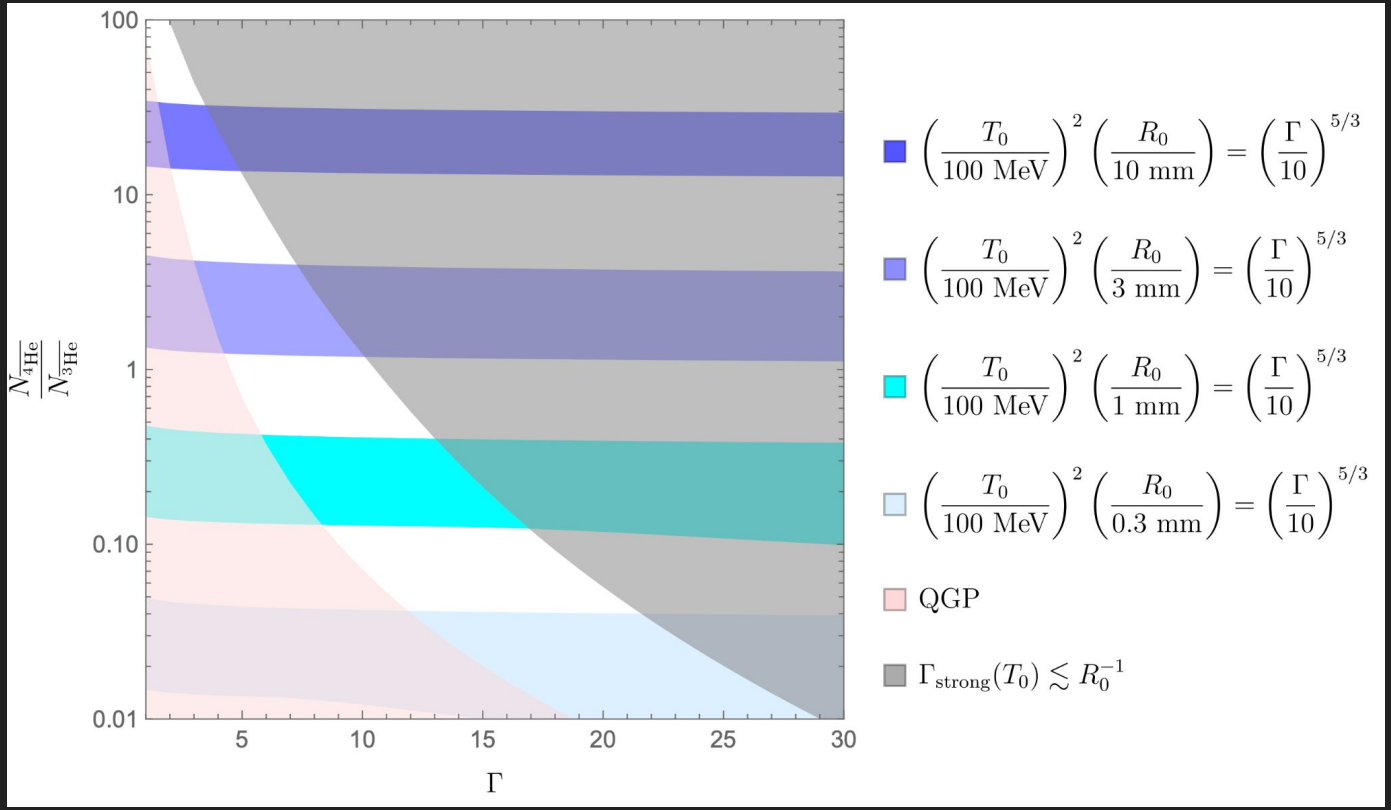
Fireball Parameter Space

Solve Boltzmann equations for nuclear reaction network numerically

$$\frac{N_{\overline{^4\mathrm{He}}}}{N_{\overline{^3\mathrm{He}}}} \approx \frac{1}{4}\left(\frac{X_{\bar{D},\,\mathrm{dec.}}}{5\times 10^{-3}}\right)^2$$



Fireball Output Space



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Antinuclei produced in fireball propagate thru Milky Way before reaching AMS

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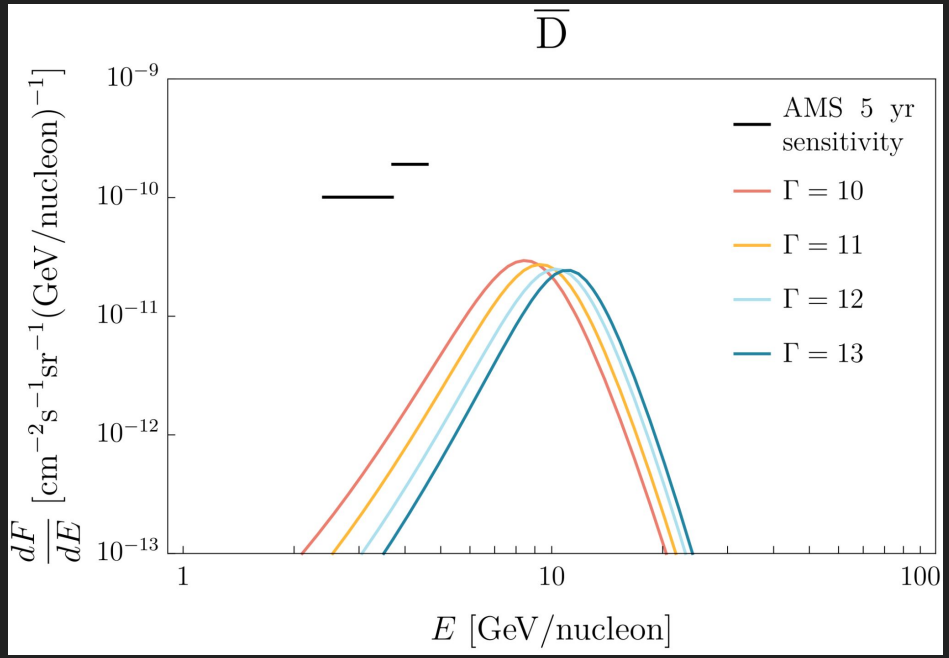

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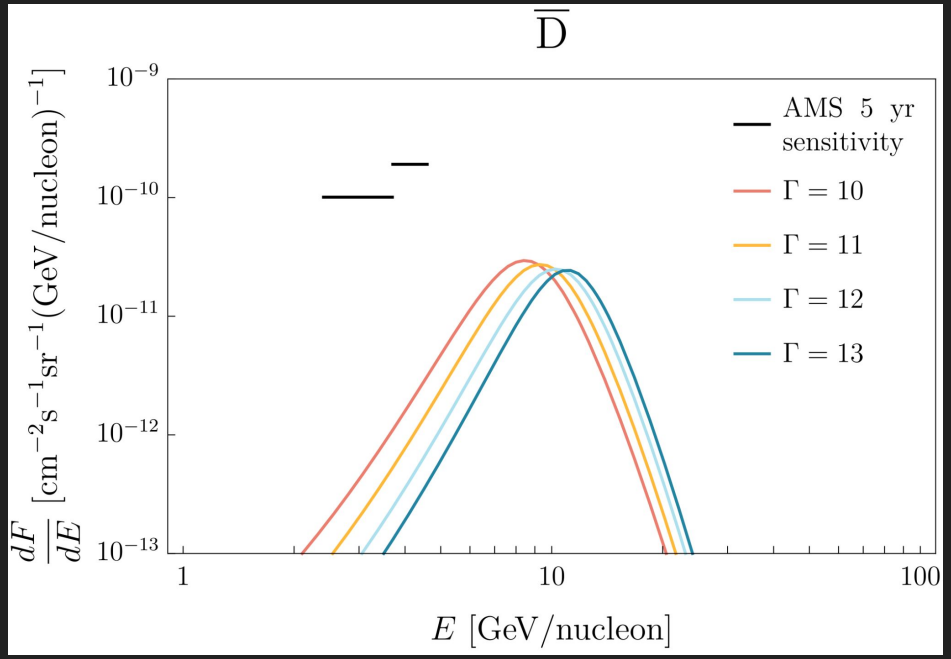

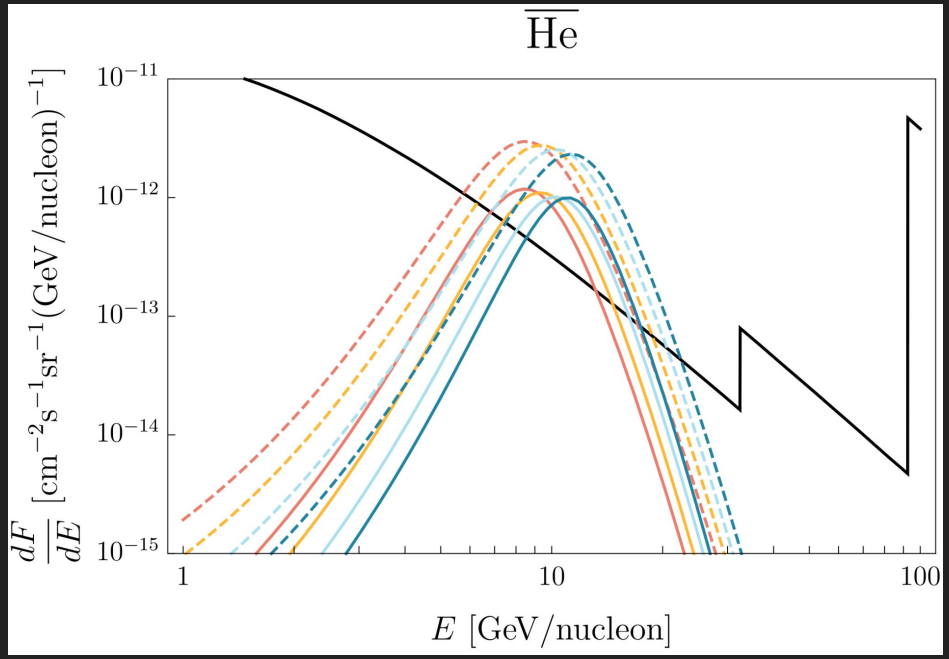

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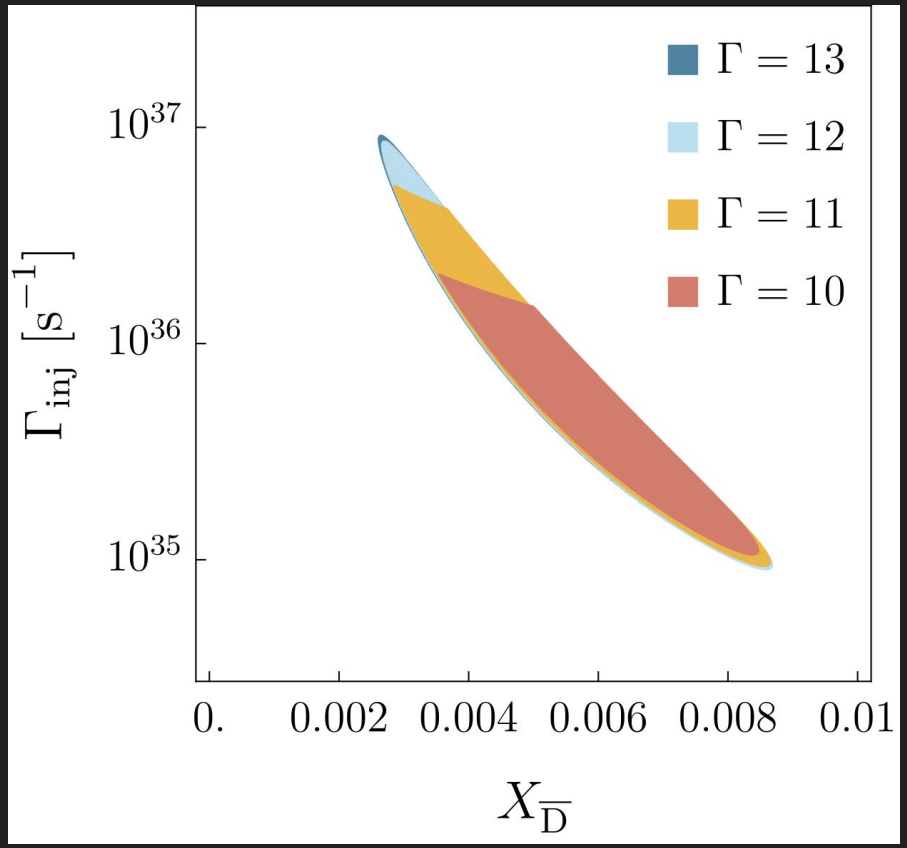
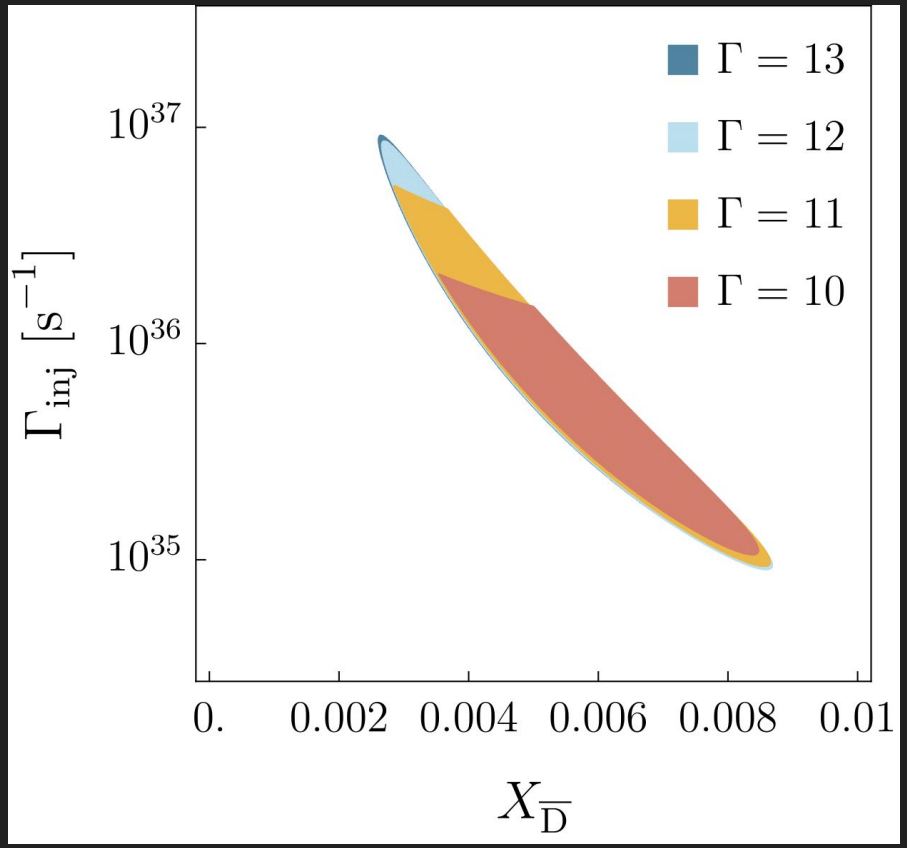
- Requirement on fireballs in order to explain the observed* AMS events



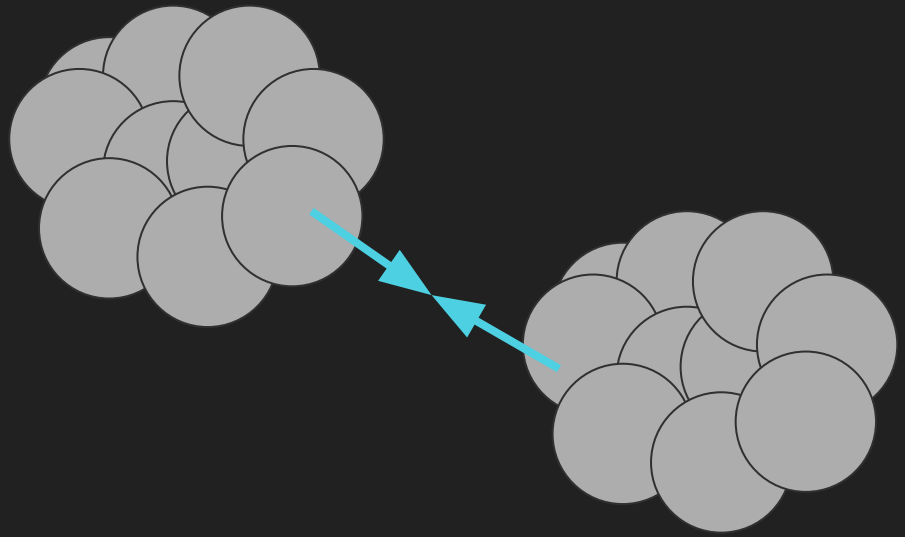
Propagation

- Diffusion, spallation, energy loss, etc. modelled numerically using Galprop
- Requirement on fireballs in order to explain the observed* AMS events
- Broadly independent of the choice of transport model



Rates

Collisions of composite DM “blobs” happening all the time, dominantly in MW



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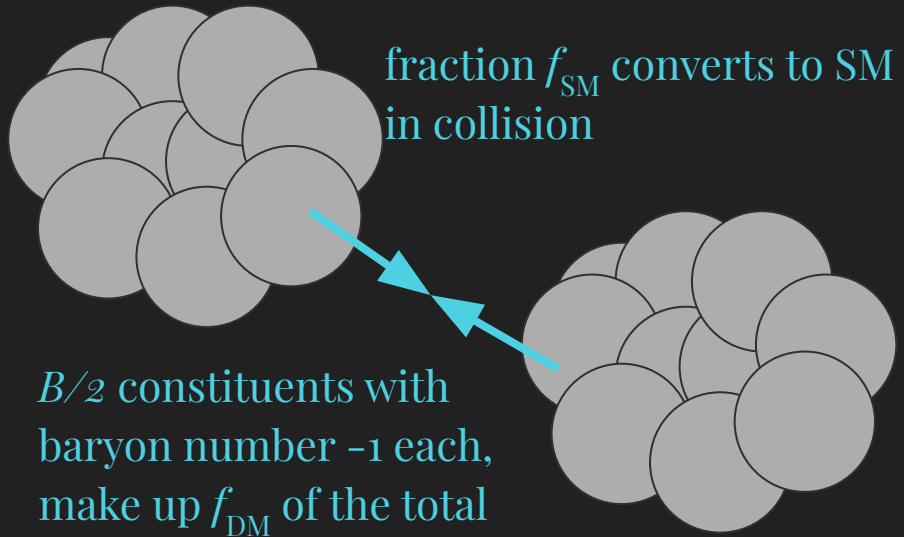

fraction f_{SM} converts to SM in collision

$$\Gamma_{\mathrm{inj}} \sim \int_{\mathrm{MW}} (n_{\mathrm{blob}}^2 \sigma v_{\mathrm{blob}})(f_{\mathrm{SM}} B) dV$$

B/2 constituents with baryon number -1 each, make up f_{DM} of the total DM energy density

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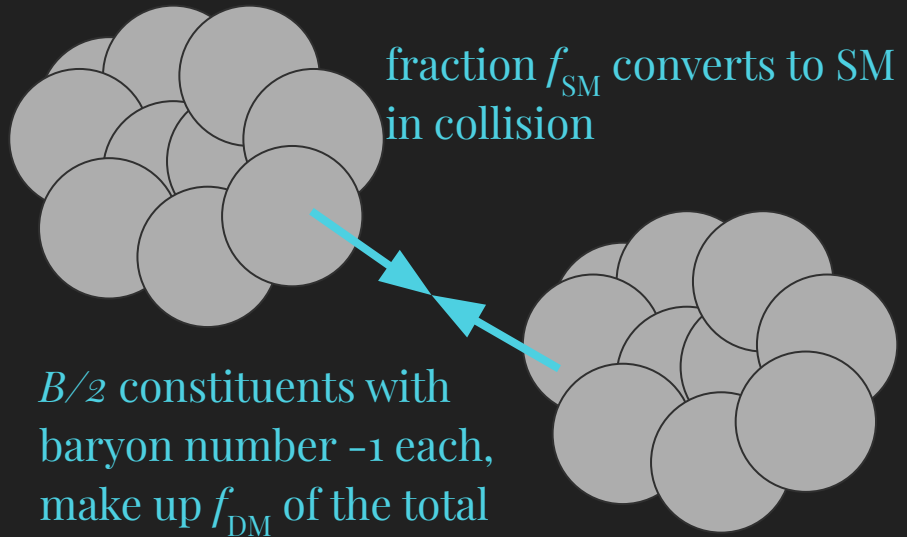

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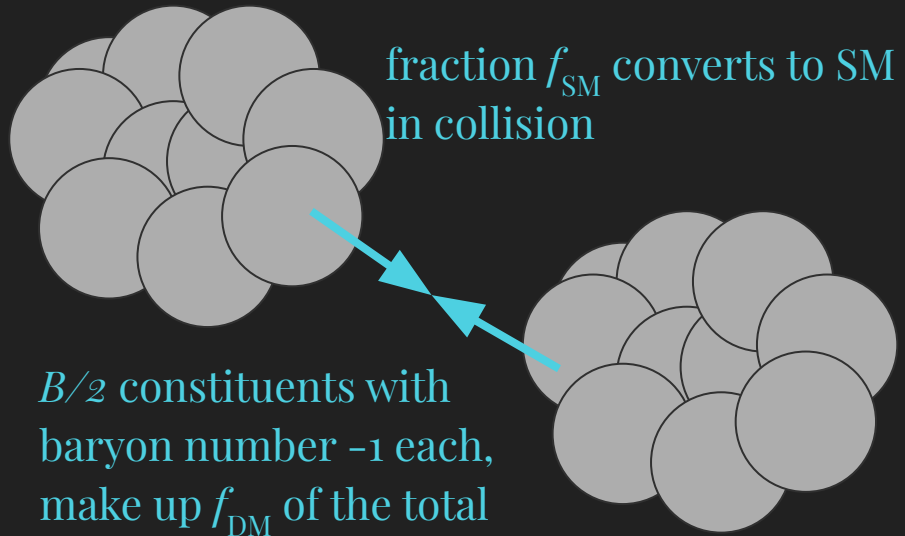

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Example model exists, but talk too short!

Outlook

- $\overline{\text{He}}$ events* can be explained with nucleosynthesis in SM fireballs
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- Published results from AMS would be monumental
- GAPS online later this year, may shed further light

Thank you!