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Antihelium from Dark Matter

Antideuteron 2019
UCLA, March 28, 2019
Antideuterons and dark matter run deep in my academic family.
A NOVEL ANTIMATTER DETECTOR BASED ON X-RAY DEEXCITATION OF EXOTIC ATOMS

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ABSTRACT

We propose a novel antiparticle detector. The gaseous antiparticle spectrometer (GAPS) effects particle identification through the characteristic X-rays emitted by antiparticles when they form exotic atoms in gases. GAPS obtains particularly high grasp (effective area–solid angle product) at lower particle energies, where conventional schemes are most limited in their utility. The concept is simple and lightweight, so it can be readily employed on balloon- and space-based missions. An extremely powerful potential application of GAPS is a space-based search for the neutralino through the detection of a neutralino annihilation by-product—the antideuteron. Paradoxically, this space-based search for the neutralino is capable of achieving comparable sensitivity to as yet unrealized third-generation, underground dark matter experiments. And GAPS can obtain this performance in a very modest satellite experiment. GAPS can also provide superior performance in searches for primary antiprotons produced via neutralino annihilation and black hole evaporation and in probing subdominant contributions to the antiproton flux at low energies. In a deep space mission, GAPS will obtain higher sensitivity for a given weight and power than BGO calorimeters.

Subject headings: atomic processes — cosmic rays — dark matter — techniques: spectroscopic
...design (and acronym) has significantly evolved (see Sean Quinn's talk earlier today).

...but key science target of opportunity remains the same!

this curve also evolved quite a bit

Mori et al (2002)
The Mori+ 2002 GAPS proposal also mentions anti-Helium searches

**not so difficult anymore:** Alberto Oliva's talk, yesterday:

*Scooped Vivian Poulin 17 years ago!*

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**Anti-Helium Search Status**

Currently, AMS observed 8 anti-helium candidates (mass region from 0-10 GeV/c²) with rigidity <50 GV with respect to a sample of 700 million helium events selected.

*The rate of anti-helium is about 1 in 100 million helium.*

Six candidates are in the mass region of ³He and two in the mass region of ⁴He.

More events are necessary to augment the significance and ensure that there are no backgrounds.

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1.3. **Antihelium**

The discovery of a single antihelium atom is compelling evidence for the existence of an antimatter domain in the universe. Such searches are highly problematic and thus difficult to motivate. **In particular, observational con-
To anybody who has been working for almost two decades on indirect dark matter searches, a virtually "background-free" channel is a Holy Grail!
Low energy antideuterons: shedding light on dark matter

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Abstract. Low energy antideuterons suffer a very low secondary and tertiary astrophysical background, while they can be abundantly synthesized in dark matter pair annihilations, therefore providing a privileged indirect dark matter detection technique. The recent publication of the first upper limit on the low energy antideuteron flux by the BESS Collaboration, a new evaluation of the standard astrophysical background, and remarkable progress in the

Probably too pessimistic (Ng's talk)

Probably a bit pessimistic (Salati, Moskalenko)

Bottom line: there exist large overall uncertainties on predicting signals from DM models!
Antideuteron flux (m^{-2} s^{-1} sr^{-1} GeV^{-1})

- BESS limit
- GAPS balloon
- AMS-02
- GAPS

Kinetic energy per nucleon (GeV/n)

- b \bar{b}, m_\chi = 100 GeV
- W^+ W^-, m_\chi = 1000 GeV
- KK DM, m_{B^0} = 500 GeV
- LZP, m_{LZP} = 40 GeV

<σv>_0 = 3 \times 10^{-26} \text{ cm}^3/\text{s}

ϕ = 800 MV

Baer & Profumo, 2005
Old paper! (SUSY=DM)

soft nucleon spectrum = great at large masses!

Detecting antideuterons implies a feature in antiprotons!

hard nucleon spectrum = tougher!

Baer & Profumo, 2005
Broadly, these results on complementarity remain true (some of the points might have been killed by LHC)

Baer & Profumo, 2005
...the family tradition continues...
I. INTRODUCTION

Within the paradigm of weakly interacting massive particle (WIMP) dark matter, the pair-annihilation or decay of dark matter particles generically yields high-energy decay products which could be detectable by future experiments. Using a Monte Carlo event generator and an event-by-event phase space analysis, we compute, for the first time, the production spectrum of $^3\text{He}$ and $^3\text{H}$ for dark matter annihilating or decaying to $b\bar{b}$ and $W^+W^-$ final states. We then employ a semianalytic model of interstellar and heliospheric propagation to calculate the $^3\text{He}$ flux as well as to provide tools to relate the antihelium spectrum corresponding to an arbitrary antideuteron spectrum. Finally, we discuss prospects for current and future experiments, including GAPS and AMS-02.
It was critical to assess (1) systematics from coalescence picture (2) relative $D_{\text{bar}}$ and $^3\text{Hebar}$ ratio

$p_0 \sim \sqrt{B}$

$p_0^{A=3} = \sqrt{\frac{B_{\pi^0}}{B_D}} p_0^{A=2} = 0.357 \pm 0.059 \text{ GeV/c}$

$p_0^{A=3} = 1.28 p_0^{A=2} = 0.246 \pm 0.038 \text{ GeV/c}$

- Ratio depends on annihilation mode and DM mass
- Can be anywhere from $\mathcal{O}(0.1)$ to $\mathcal{O}(10^{-4})$
Comparatively, the uncertainty from propagation is small (~20%)
- Thermal cross section; only propagation uncertainties shown (not coalescence)

- WW final state, and large masses, are a long shot! (x100!)

- $^3$He detection not unreasonable for canonical DM density and annihilation cross sections, and low masses, at GAPS (SAT)
Sam Ting’s Alpha Magnetic Spectrometer was delivered to space in 2011 on the last-to-last space shuttle flight.

SAM TING’S LAST TEASE

How the physicist’s aging space magnet, in a final flourish, may have trapped heavy antimatter

By Joshua Sokol

Sam Ting speaks softly and deliberately as he gets ready to deliver some juicy news to his audience. Finally delivering on the promise of its original name, when “AMS” stood for “antimatter,” So far, the AMS has measured the masses that the AMS may have trapped a bigger and weirder form of antimatter. The AMS, he says, has seen a handful of candidate

Science, April 2017
See Alberto's presentation today!

Momentum = 40.3 ± 2.9 GeV/c
Charge = -2
Mass = 2.96 ± 0.33 GeV/c²
Velocity = 0.9973 ± 0.0005 c
I. INTRODUCTION

Background-free processes are the Holy Grail of astrophysical searches for dark matter (DM); in numerous recent examples, ranging from the Galactic center excess to the positron fraction excess to the 3.5 keV line, possible DM signals have well-known, plausible astrophysical counterparts. Conclusively discriminating between a DM origin cautiously states that “it will take a few more years of detector verification and to collect more data to ascertain the origin of these events” [5].

Event misidentification notwithstanding, in this study we consider the possibility that one or all of the tentatively detected antihelium events stem from DM annihilation or decay (for definiteness, we will hereafter focus on annihilation, but our results would apply directly to decaying...
One event with **40 GeV** momentum in 5 years

Coogan and Profumo (2017)
One event with **40 GeV** momentum in 5 years

Coogan and Profumo (2017)
No bueno

\( \chi \chi \rightarrow W^+ W^- \)

one \(^3\text{He}\) per year

Coogan and Profumo (2017)
FIG. 2. As in Fig. 1, but for the predicted antiproton and antideuteron fluxes for 100 GeV (yellow lines) and 1 TeV (blue lines) dark matter particles pair-annihilating into $W^+W^-$ (left panel) and $b\bar{b}$ (right panel), normalized to yield one $^3$He per year overall. Spectra are computed using $\phi_F = 500$ MV, MethodAnn and MAX propagation.

one $^3$He per year

Coogan and Profumo (2017)
4) A word on dark matter

Could anti-helium ($^3\text{He}$) events be produced by DM?

![Graphs showing dark matter annihilation]

- If AMS-02 $^3\text{He}$ events are from DM, beware of $\bar{p}$ flux.
- To evade the $\bar{p}$ constraint, $p_{\text{total}}$ exceedingly large.

Salati (yesterday)

MIN is excluded by positrons

FIG. 2. As in Fig. 1, but for the predicted antiproton and antideuteron fluxes for 100 GeV (yellow lines) and 1 TeV (blue lines) dark matter particles pair-annihilating into $W^+W^-$ (left panel) and $b\bar{b}$ (right panel), normalized to yield one $^3\text{He}$ per year overall. Spectra are computed using $\phi_F = 500$ MV, MethodAnn and MAX propagation.

one $^3\text{He}$ per year

Coogan and Profumo (2017)
3He from DM: a potentially self-consistent picture

Can be tested with better constraints on coalescence momentum

Predicts features in pbar and Dbar – better statistics and control over misidentified events will allow sharper predictions

To do: GeV (<10) DM!

Coogan and Profumo (2017)
...more antimatter warriors to come!