Indirect Dark Matter Search with Antideuterons: Progress and Future Prospects for General Antiparticle Spectrometer (GAPS)

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How Does Cold Dark Matter Generate Antideuterons?

- Pair annihilating WIMPS produce: \( \gamma, \nu, e^+ \ldots \ p\ldots \)

- Donato et al. (2000) suggest antideuteron signal

Uncertainties in Primary Antideuteron Flux

(a) Nuclear Reactions
(b) Propagation
(c) Solar Modulation
(d) DM Halo

Baer & Profumo 2005
Low energy, neutralino-neutralino produced antideuterons are near background free

Antideuteron flux at the earth (with propagation and solar modulation)

- **Primary component:**
  - $\rightarrow$ neutralino annihilation
  - $X + X \rightarrow \bar{D}$

- **Secondary component:**
  - $\rightarrow$ spallation
  - $p + H \rightarrow p + H + D + \bar{D}$
  - $p + He \rightarrow p + He + D + \bar{D}$

- Clean signature @ low E, but see Baret et al. 2003

- However, sensitivity demand is daunting
GAPS is based on radiative emission of antiparticles captured into exotic atoms.

Anti-protonic atoms (in addition to Muonic, Pionic, Kaonic atoms) extensively studied and atomic transitions well understood.
Comparison of Direct & Indirect Antideuteron Detection Sensitivities for SUSY DM

There are ~20 current or planned direct detection experiments

- CDMS (Soudan) 2005 Si (7 keV threshold)
- CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
- CDMS Soudan 2004+2005 Ge/Si SD-neutron/proton
- CDMSII (Projected) Development ZBG
- SuperCDMS (Projected) Phase C
- CUORICINO projected exclusion limit
- COSMO 2001 Exclusion Limit, 72.7 kg-days
- CRESST-I projection limit, Al2O3
- CRESST-II projected limit, CaWO4
- CRESST I SD-neutron/proton
- CRESST II SD-neutron/proton
- DAMA 2000 58k kg-days NaI
- DAMA 2003 NaI SD-neutron/proton
- DAMA Xe129
- DMR projection for 100kg CsI, 1cpd
- ELEGANT V NaI Si/SD limit, OTO COSMO Observatory
- Edelweiss I final limit, 62 kg-days Ge 2000+2002+2003 limit
- Edelweiss SD-neutron/proton
- Edelweiss Ge, projected
- GEDEON projection
- Genius Test Facility projected limit, 2001, energy threshold 2 keV
- Genino projected exclusion limit, DM2000
- Heidelberg - Genius, projected
- IGEX projected exclusion limit (for 1kgyr)
- IGEX 2002 Nov limit
- NAIAID 2005 final result Si/SD
- PICASSO SD-neutron/proton (2005)
- SIMPLE SD-neutron/proton
- ZEPLIN I First Limit (2005)
- NAIAID spin indep. projected limit, 12 p.e./keV with 100 kg-yrs exposure
- XENON100 (100 kg) projected sensitivity
- XENON10 (10 kg) projected sensitivity
- XENON1T (1 tonne) projected sensitivity
- ZEPLIN I SD-neutron/proton (preliminary)
- ZEPLIN 2 projection
- SuperK indirect SD-proton

Indirect Antideuteron search offers a complementary method
Detector approach was dictated by trade between performance and shoe string budget

- 16 NaI(Tl) detector modules covering 40 cm long x 12 cm diameter target cell
- Each modular 4x2 arrays of 25mm diameter x of 5 mm thick crystals (128 total)
- Solid angle coverage ~ 0.3
KEK Accelerator Tests to Demonstrate Fast-timing, Multi-X-ray Spectroscopy Approach

TOF [ns] | E [keV]
---|---
-0.3 | 2.3
-0.2 | 2.7
0.1 | 3.3
-0.1 | 3.9
0.1 | 4.5
0.2 | 5.7

Atomic Transitions

Exotic Atom

TOF Trigger Counters

Degrader Shower Counters

Nuclear Annihilation Charged Veto

Charged Veto [MeV]

Nal Detector [keV]

π^*

π^*

π^*

92
50

E.

Jason Koglin – KAVLI Symposium – Dec 11, 2005
2004 KEK GAPS Results

We clearly get X-rays when we dump Antiprotons into our gas target.

More importantly, we see X-ray transitions in events with multiple signatures!!!

Hailey et al. 2005 (accepted by JCAP)
Solid and Liquid Targets Tested in 2005

Targets chosen based on known, high Kaonic yields

→ Goal to measure Antiprotonic atom yields

Al

CCl\textsubscript{4}

S

CBr\textsubscript{4}

(liquid)
CBr$_4$ – KEK 2005

Multi-X-ray Spectrum  4 X-ray Transition Event

Cut: $\geq 2$ X-ray & $\geq 4$ total signals

Hailey et al. 2005 (accepted by JCAP)
Sulfur – KEK 2005

Multi-X-ray Spectrum  2 X-ray + 3 $\pi^*$ Event

Cut: $\geq 2$ X-ray $&$ $\geq 4$ total signals

Hailey et al. 2005 (accepted by JCAP)
Preliminary results from KEK experiments

• Solid targets have been successfully utilized: simplification over initial gas concept is enormous

Gaseous Antiparticle Spectrometer

→ General Antiparticle Spectrometer

• Pion stars provide substantial additional antiparticle identification

• Preliminary results on X-ray yields per capture are consistent with those used in original sensitivity calculations

• Non-antiparticle background is cleanly identified and rejected

→ Conclusion: GAPS is probably more promising than originally anticipated
Goal is to conduct balloon-based GAPS antideuteron search by 2009-2010

- Investigate flight detectors (e.g., CZT, LaCl, NaI), readout geometries (PMT, APD, fiber-coupled scintillator bars) and low cost electronics. 2006-2007
- Detailed design and simulation of flight geometry, extending on original work. 2006-2007
- Design and construction of gondola and first flight module. 2007-2008
- Flight test of prototype GAPS – possibly from Sanriku in Iwate, Japan. 2008 (T Yoshida & H Fuke have recently joined GAPS collaboration)
- LDB flight from Antarctica or ULDB flight from Australia (if available). 2009-2010