Antideuterons as an Indirect Dark Matter Signature: Design and Preparation for a Balloon-born GAPS Experiment

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Abstract: The General Antiparticle Spectrometer (GAPS) exploits low energy antideuterons produced in neutralino-neutralino annihilations as an indirect dark matter (DM) signature that is effectively free from background. When an antiparticle is captured by a target material, it forms an exotic atom in an excited state which quickly decays by emitting X-rays of precisely defined energy and a correlated pion signature from nuclear annihilation. The GAPS method of using this combined X-ray and pion signature to uniquely identify antiparticles has been verified through accelerator testing of a prototype detector. We describe the design of a balloon-born GAPS experiment that complements existing and planned direct DM searches as well as other indirect techniques, probing a different, and often unique, region of parameter space in a variety of proposed DM models. We also outline the steps that we are taking to build a GAPS instrument and execute multiple long duration balloon flights.

Many extensions to the standard model predict weakly interacting, massive particles (‘WIMPS’) that are stable and thus ideal dark matter (DM) candidates. Underground direct detection experiments detect the nuclear recoil of WIMPS that scatter off target nuclei. WIMPS can also annihilate with other WIMPS in the galactic halo producing various debris such as gamma-rays, neutrinos, positrons, antiprotons and antideuterons. The General Antiparticle Spectrometer (GAPS) is specifically designed to uniquely identify low-energy, low-mass antiparticles which allows us to

- search for evaporating primordial black holes using antideuterons, setting the best limits on primordial black hole density, and
- perform low energy cosmic-ray antiproton spectroscopy with several orders of magnitude better statistics than current satellite and balloon experiments.

The detection rate for antideuterons yields direct information on the particle properties of the DM. When combined with observations from underground experiments, ground-based experiments such as VERITAS, space-based experiments such as GLAST and PAMELA, and accelerator-based experiments, an extremely comprehensive picture of the nature of DM can be obtained.
More than 80 recent papers discuss aspects of antideuteron DM searches. DM searches are highly model dependent, and there are lots of models! To illustrate the key features of a DM search with bGAPS, the antideuteron flux expected from three different benchmark models calculated by Baer and Profumo [1] are plotted in Figure 1. Here, the LSP is associated with SUSY models (mediated primarily by $\bar{b}b$), and the LKP (Kaluza-Klein) and the LZP (5D Warped GUT) are associated with UED models. These three models are representative of the most popular candidates for DM. GAPS is optimized for operation below 0.3 GeV/n, where the DM signal is largest. Also shown in the plot is the anticipated secondary and tertiary background of antideuterons [2]. Finally, Figure 1 shows the sensitivity to antideuterons for long-duration balloon (LDB) campaigns from Antarctica (60 days total over three flights) and the potential sensitivity from an ultra-long duration balloon (ULDB) flight (300 days total) that might be realized by our projected 2013 launch date. For comparison, the upper limit from the BESS experiment is also plotted. Figure 1 illustrates three important points:

1. GAPS is essentially a background free experiment,
2. GAPS has outstanding DM discovery potential for a wide variety of DM models, and
3. GAPS represents a major improvement over the state of the art.

Figure 1: LSP, LKP and LZP search with bGAPS along with the Secondary/Tertiary background and the reach of bGAPS and BESS.
GAPS is amenable to balloon-based experiments since the relevant science can be done with an instrument package of $\sim 1000$ kg. We have designed a complete balloon-based GAPS experiment (bGAPS), as well as a prototype balloon experiment (pGAPS) shown in Figure 3. The pGAPS contains all the important features of bGAPS that must be flight tested. The X-ray detectors are pixellated, high resolution Si(Li) detectors. Pixelated Si(Li) detectors for detecting X-rays in the relevant GAPS band ($\sim 10$-100 keV) have never previously been deployed in space. The Si(Li) detectors are produced from commercial 10 or 12.5 cm diameter wafers. The Si(Li) in bGAPS will be arrayed in a 13 layer tracking geometry, and each layer covers $\sim 2$ m$^2$. pGAPS will flight test a smaller, three layers array of Si(Li) detectors.

The Si(Li) must be cooled to $-40^\circ$C to provide low noise, high energy resolution performance. Groups of three Si(Li) will be mounted on the carriers and mechanically fixed to a central Al coupling (c.v., Figure 4). The carriers are made of 0.030" Al sheet metal with stiffening flanges on the six sides. The coupling acts as both the structural support for this module and a single pass heat exchanger. A coolant port for 3M Novec heat transfer fluid is machined into this coupling for maxi-
mum turbulent flow mixing. These base units are connected vertically via the thermal coupling with thin-walled, lightweight carbon-fiber tubes (0.5” diameter). PTFE tubing is routed inside of the vertical carbon tubes and connect the thermal couplings. The coolant risers transfer the heat generated by the detector and ambient heat load. A modular sub-assembly includes six risers in an independent closed-loop cooling system. The coolant temperature at the radiator is predicted to be -60°C and -40°C at the Si(Li) wafers.

A radiator panel system is required to remove the anticipated thermal load from the detector electronics and solar heat gain. One-time, deployable shades reduce the direct solar and albedo solar gain. These simple and lightweight shades are rolled thin aluminized Mylar sheet and thin coiled power springs that will unroll and support the mylar in the vacuum environment. A simple release mechanism deploys the shades at full altitude.

The goals of the pGAPS flight include: confirm proper operation of the Si(Li) detectors at float altitude; measure X-ray and particle backgrounds of relevance to determining the overall instrument sensitivity; confirm the thermal model for predicting Si(Li) operating temperature, and verify the concept for cooling the Si(Li) detectors. The first goal is particularly important since the Si(Li) detectors will be operated at float altitude without a pressure vessel. The Si(Li) utilizes a polymid coating to passivate it and permit non-vacuum operation. This is the approach taken for the SIXA arrays on the Spectrum X-Gamma mission [5], but it is crucial to ensure the validity of the approach in a flight test before applying it to the thousands of detectors of bGAPS. In-flight measurements of X-ray background will help bolster our confidence in model predictions of the confusion rate – the number of background particle events accidentally mistaken for antideuterons. The pGAPS experiment is anticipated to take place in late 2009 from Hokkaido, Japan.

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References