ANTIMATTER AND DARK MATTER SEARCH WITH AMS-02

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AMS-02 is a magnetic spectrometer that will operate on the International Space Station. The detector is designed to measure with very high accuracy the composition of Cosmic Rays near Earth. With a large acceptance (5000 cm^2), an intense magnetic field from a superconducting magnet (0.8 Tm^2) and a very efficient particle identification, AMS-02 will provide the highest precision in Cosmic Rays measurements up to the TeV region. In three years, AMS-02 will achieve a sensitivity to the existence of anti-Helium nuclei in the Cosmic Rays of one part in a billion, and provide important information on the nature of Dark Matter. The detector is now being integrated and will be ready for launch in 2010. We review the status and the discover capabilities.

1 Cosmic Rays measurements contribution to the Standard Cosmological Model

Recent precision measurements of cosmological quantities, such as the Cosmic Microwave Background temperature and polarization [1,2,3] and the Supernova luminosity-to-distance relationship, together with Large Scale Structure and structure formation studies [4,5], allowed to build a *standard cosmological model*, that describes a universe spatially flat, homogeneous and isotropic at large scales.

Our universe consists of ordinary matter and radiation only for a 4.5%: as shown in figure 1, a considerable fraction of the total matter (23%) is in the form of *cold* dark matter. The largest fraction (73%) consists of dark energy, acting like a cosmological constant, whose origin is unknown [6]. The antimatter content of the universe appears to be only 10^{-6} of the matter content [7].

The AMS-02 high-precision study of Cosmic Ray properties such as composition, production, acceleration and propagation mechanisms will help unveil the dark matter origin and the antimatter content puzzles, searching for primordial antimatter by direct detection of antinuclei, and for dark matter annihilation products independently in different charged and neutral particles spectra.

2 The AMS-02 detector

AMS-02 is designed for reliable operation in space as a single particle spectrometer with large acceptance, high momentum range and efficient particle identification, to provide high statistics spectra of charged particles with nuclei and isotope separation, as well as gamma-ray measurements. It will carry out a 3-years mission on board of the International Space Station, taking data above the Earth's atmosphere.

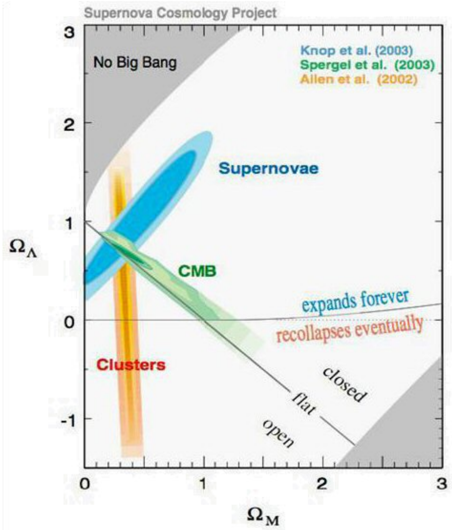

Figure 1: Independent measurements of several cosmological quantities all point in the direction of a universe composed mostly of dark matter and dark energy.

AMS-02 is shown in figure 2. It consists of a silicon tracker installed inside a superconducting magnet (the first ever to operate in space) providing a 0.8 Tm^2 magnetic field. Rigidity is measured up to 3 TeV and nuclei and isotopes are separated up to 12 GeV/n for $Z \leq 26$ or $A \leq 25$ with a Ring Imaging aerogel/sodium-flouride Cherenkov detector (Agl/NaF RICH), combined with Time of Flight (TOF) and dE/dX measurements. At 90% positron efficiency, a proton suppression by 3-4 orders of magnitude is achieved with a lead/scintillating fibre sandwich 3D sampling calorimeter (ECAL) based on shower shape information and the matching of shower energy with track momentum. Further proton suppression by 2-3 orders of magnitude up to 300 GeV/c is achieved with a 20 layer fibre fleece Xe/CO2 proportional wire straw tube Transition Radiation Detector (TRD). The overall 10^6 proton rejection factor is essential for dark matter search.

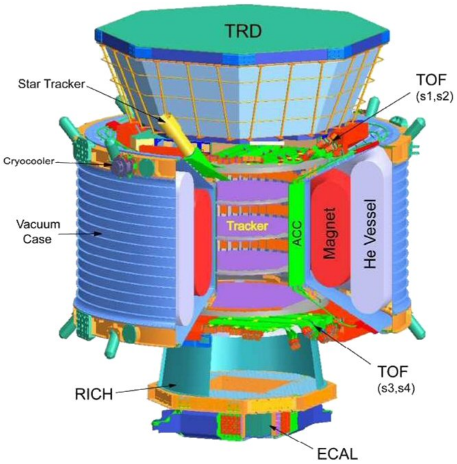

Figure 2: The AMS-02 detector.

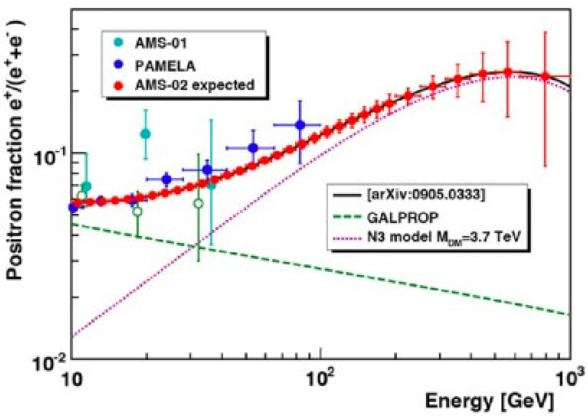

Figure 3: Expected positron flux in the energy region accessible to AMS-02 for a 3.7 TeV neutralino mass.

3 Indirect search for dark matter

A weakly interacting massive particle (WIMP) is a suitable dark matter canditate, and supersymmetric extensions of the standard model such as mSUGRA predict a *neutralino* which is stable when R-parity is conserved. WIMPs can be observed indirectly by detecting decay products of particles produced in annihilations, as an extra source for positrons, antiprotons, antideuterons and gammas on top of standard model predictions from galactic propagation models. With annihilation cross sections proportional to the square of the neutralino density, these measurements are also sensitive to dark matter density fluctuations.

Existing measurements of gamma-ray fluxes [8,9] and positron fraction [10] have in some cases shown deviations from standard model expectations which are consistent with supersymmetric dark matter, but controversial within the available statistics and without standard model explanation for the positron excess [11,12].

AMS-02 will measure the positron spectrum with substantially improved precision for background and signal, in the energy region where an excess has been claimed. Moreover, the simultaneous measurement in other independent channels will increase the sensitivity to dark matter detection. The positron spectrum expected in the AMS-02 sensitivity region is shown in figure 3.

4 Direct search for antimatter

In the Big Bang theory, matter and antimatter are created with equal abundances, and the disappearance of antimatter requires barion number violation and another source of CP violation. Antiparticles are indeed produced in collisions between high energy particles, and are observed in the Cosmic Rays. For example, $\phi(e^+)/\phi(e^-) \sim 10^{-1}$ at 10 GeV and $\phi(p)/\phi(\bar{p}) \sim 10^{-5}$ at 10 GeV. However, an anti-Helium nucleus has very low probability of being produced in collisions: $\phi(\bar{H}e)/\phi(He) \sim 10^{-6} - 10^{-8}$. Anti-Helium detection in the Cosmic Rays would be a clear indication of the existence of an antimatter area somewhere in the universe.

AMS-02 will collect in three years 2×10^9 nuclei with energies up to 2 TeV, with sensitivity up to anti-Iron, thus improving of a factor 10^3 the limit put by the precursor flight AMS-01. The limit on antimatter presence that can be set by AMS-02 is shown in figure 4.

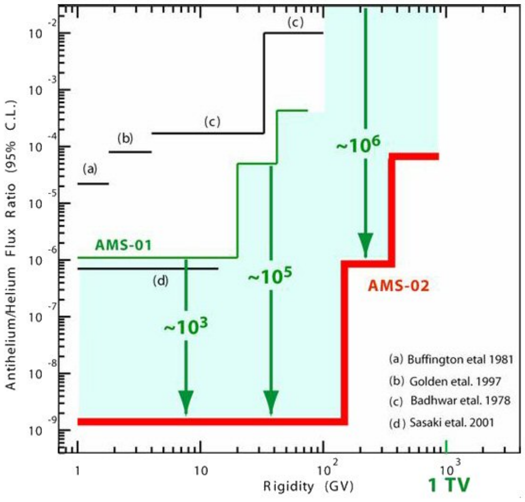

Figure 4: AMS-02 sensitivity to the anti-Helium flux.

5 Status and outlook

AMS-02 will provide a coherent dataset of unprecedented precision for charged Cosmic Rays and gamma rays up to the TeV region, confirming or disproving with high accuracy the excess in the PAMELA positron data in the few GeV region. The multichannel analysis will allow combined fits to the parameters of standard model extensions to establish the nature of dark matter. Several models can be constrained and eventually ruled out.

AMS-02 will put a stringent limit on the presence of antimatter: if no antinucleus is observed, the hypothesis of barion asymmetry will be strongly favoured.

In general, our knowledge of the Cosmic Rays physics will be improved. AMS-02 will perform an accurate study of composition (H, He, B/C, ^{9}Be/^{10}Be) and energy spectra, put significant constraints on galactic propagation model parameters, and search in Cosmic Rays for new types of matter (e.g. strangelets).

The detector integration will be completed in 2009, on schedule to be ready for launch with the Space Shuttle in 2010.

References

1. D. N. Spergel *et al.* [WMAP Collaboration], Astrophys. J. Suppl. **170** (2007) 377
2. L. Page *et al.* [WMAP Collaboration], Astrophys. J. Suppl. **170** (2007) 335
3. C. B. Netterfield *et al.* [Boomerang Collaboration], Astrophys. J. **571** (2002) 604
4. A. G. Riess *et al.* [Supernova Search Team], Astrophys. J. **607** (2004) 665
5. S. Perlmutter, M. S. Turner and M. J. White, Phys. Rev. Lett. **83** (1999) 670
6. R. A. Knop *et al.* [Supernova Cosmology Project], Astrophys. J. **598** (2003) 102
7. J. Alcaraz *et al.* [AMS Collaboration], Phys. Lett. B **461** (1999) 387
8. S. D. Hunter *et al.*, Astrophys. J. **481** (1997) 205.
9. T. A. Porter *et al.* [FERMI Collaboration], arXiv:0907.0294 [astro-ph.HE].
10. O. Adriani *et al.* [PAMELA Collaboration], Nature **458** (2009) 607
11. A. W. Strong, I. V. Moskalenko and O. Reimer, Astrophys. J. **613** (2004) 962
12. W. de Boer, C. Sander, V. Zhukov, A. V. Gladyshev and D. I. Kazakov, Phys. Rev. Lett. **95** (2005) 209001
13. A. Jacholkowska *et al.*, Phys. Rev. D **74** (2006) 023518