Fermi National Accelerator Laboratory

FERMILAB-Conf-91/061-A

February 1991

Indirect Detection Of Heavy Supersymmetric Dark Matter*

MARC KAMIONKOWSKI

Department of Physics and Enrico Fermi Institute, The University of Chicago, Chicago, IL 60637-1433
and
NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, IL 60510-0500

ABSTRACT

If neutralinos reside in the galactic halo they will be captured in the Sun and annihilate therein producing high-energy neutrinos. Present limits on the flux of such neutrinos from underground detectors such as IMB and Kamiokande II may be used to rule out certain supersymmetric dark-matter candidates, while in many other supersymmetric models the rates are large enough that if neutralinos *do* reside in the galactic halo, observation of a neutrino signal may be possible in the near future.

The idea that a heavy (meaning more massive than the $W^{\pm}$) neutralino[1,2] — a linear combination of the supersymmetric partners of the photon, Z^0, and Higgs bosons—makes up the bulk of the dark matter in the Universe and in the galactic halo has been the focus of much theoretical and experimental research recently.[2,3] Here we address the possibility of indirect detection of heavy neutralinos by observation of high-energy neutrinos from WIMP annihilation in the Sun.[4]

First let us briefly review the supersymmetric model. The neutralino field may be written

$$\tilde{\chi} = Z_{n1}\tilde{B} + Z_{n2}\widetilde{W}^3 + Z_{n3}\tilde{H}_1 + Z_{n4}\tilde{H}_2, \qquad (1)$$

where $(Z)_{ij}$ is a real orthogonal matrix that diagonalizes the neutralino mass matrix and depends only on the gaugino mass parameter M, Higgsino mass parameter μ, and the ratio of Higgs vaccuum expectation values $\tan\beta$. In Fig. 1 we plot neutralino mass contours (broken curves) and contours of $Z_{n1}^2 + Z_{n2}^2$ (solid curves), the gaugino fraction, for $\tan\beta = 2$ (plots for other values of $\tan\beta$ are similar). As noted originally by Olive and Srednicki[2] in much of parameter

* To appear in proceedings of the UCLA International Conference on Trends in Astroparticle Physics, Santa Monica, Nov. 1990

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

space where the neutralino is heavier than the W, the gaugino fraction is greater than 0.99 and the neutralino is almost pure B-ino, and in much of parameter space, the gaugino fraction is less than 0.01 and the neutralino is almost pure Higgsino.

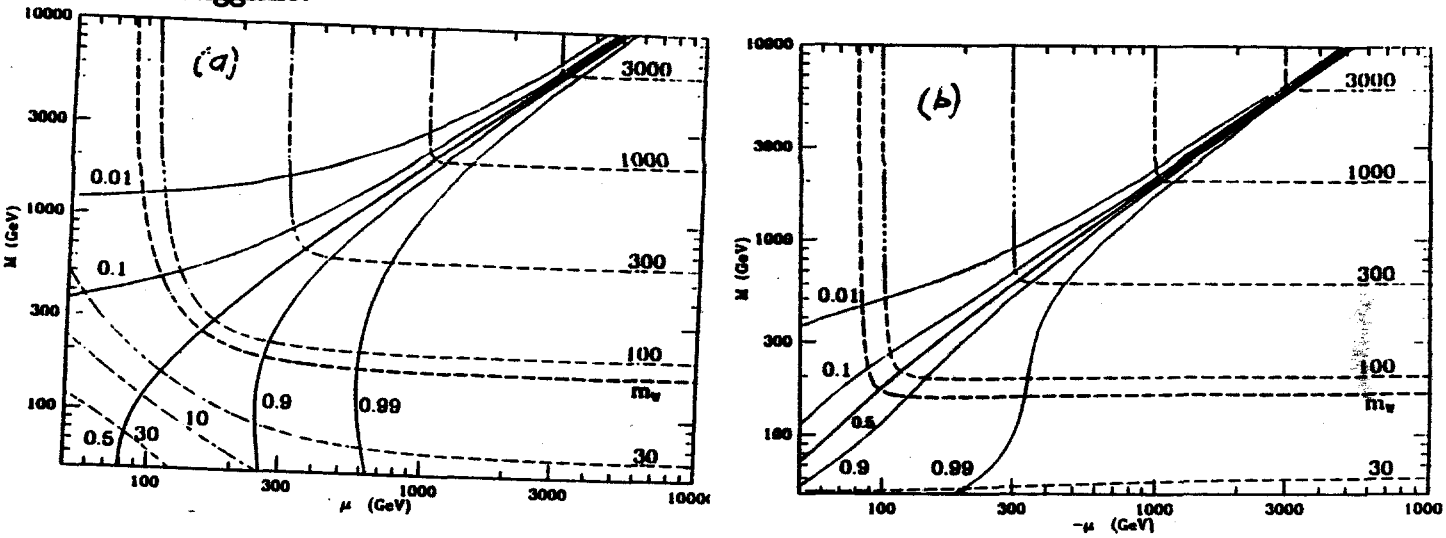


Fig. 1

There are also three neutral Higgs bosons and the lightest, H_2^0, is always less massive than the Z. The masses of the superpartners of the quarks and leptons, which we will collectively refer to as squarks, are all undetermined, but for simplicity we give them all the same mass $M_{\tilde{q}}$ which, assuming the neutralino is the LSP, is greater than $m_{\tilde{\chi}}$.

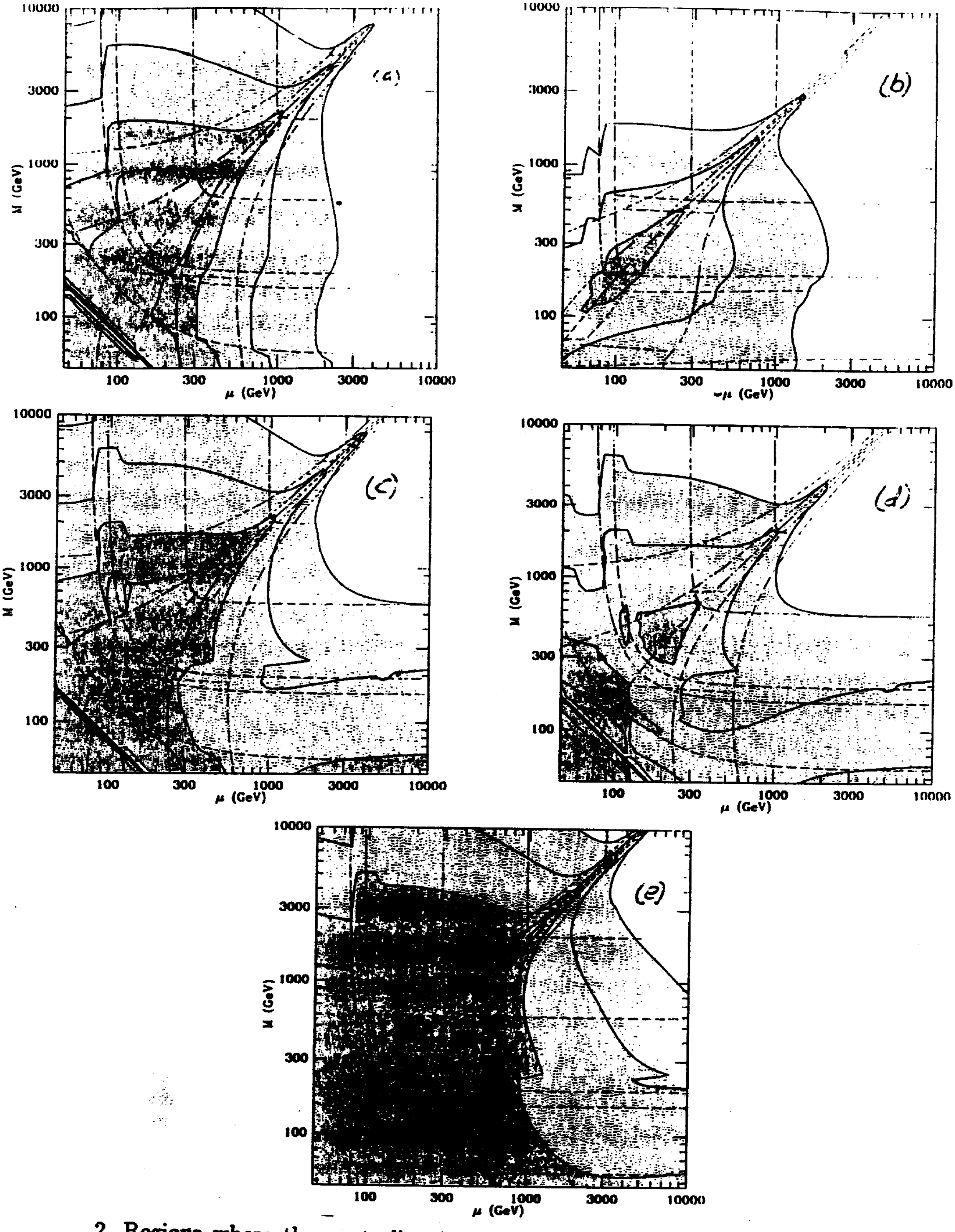
In most cases of interest accretion of neutralinos from the halo[5] onto the Sun and depletion from the Sun by annihilation come to equilibrium on a time scale much shorter than the solar age in which case the annihilation rate is given by the rate of capture. The capture rate for a specific model is determined by the elastic scattering cross section of the neutralino off of the nuclei in the Sun. Capture of neutralinos that are mixed gaugino/Higgsino states occurs by a coherent interaction with the heavier nuclei in the Sun in which the lightest Higgs boson is exchanged;[6] since the lightest Higgs boson is always lighter than the Z capture of such neutralinos is efficient even for heavier neutralinos. If the squark is not much heavier than a neutralino that is primarily gaugino, then such a gaugino is captured by a spin-dependent interaction in which a squark is exchanged[7] with the hydrogen in the Sun. Neutralinos that are primarily Higgsino (or, if the squark is much heavier than the neutralino, neutralinos that are primarily gaugino) are captured by coherent scattering off of heavy nuclei, but capture of such neutralinos rapidly becomes increasingly inefficient with increasing purity.

To obtain the neutrino spectrum from neutralino annihilation in the Sun one must determine the differential energy flux of neutrinos at the surface of the Sun resulting from the injection of the particles (*e.g.*, pairs of gauge or Higgs bosons or fermion-antifermion pairs) into which the neutralino annihilates in the core of the Sun.[4,8]

The experimental signature on which we focus is the number of upward-moving muons induced by high-energy neutrinos from the Sun that are observed in underground detectors. The IMB collaboration has found an upper limit on the flux of upward-moving muons induced by neutrinos from the Sun with energy larger than 2 GeV of 2.65×10^{-2} m^{-2} yr^{-1},[9] (and similar, though slightly weaker limits have been found by Kamiokande II[10]). Supersymmetric models which result in larger fluxes are inconsistent candidates for the primary component of the galactic halo. In Fig. 2 the dark shading denotes the regions of parameter space excluded by this constraint. The light shaded regions are those that would be excluded if the observational flux limits were to be improved by a factor of 100. The curve inside the light shaded areas encloses regions of parameter space that would be excluded if current observational limits were improved by a factor of 10. To indicate the sensitivity of these results to uncertainties in the calculation, the dashed curve inside the excluded region indicates the region excluded if the true neutrino rate is only 1/5 as large as our calculations indicate. In (a) $\tan\beta = 2$, $m_{H_2^0} = 20$ GeV, the squark mass is taken to be infinite and $\mu > 0$, and (b) is similar except that $\mu < 0$. In (c) $\tan\beta = 2$ and $m_{H_2^0} = 20$ GeV, in (d) $\tan\beta = 2$ and $m_{H_2^0} = 35$ GeV, and in (e) $\tan\beta = 25$ and $m_{H_2^0} = 35$ GeV. In (c), (d), and (e), the squark mass is assumed to be 20 GeV greater than the neutralino mass and only regions of positive μ are shown.

From Fig. 2, we see that limits on energetic neutrino fluxes from the Sun already exclude many supersymmetric models with heavy mixed-state neutralinos lighter than about a TeV when the lightest Higgs is light and $\tan\beta$ is small [Fig. 2(a), (b), and (c)], or when $\tan\beta$ is large [Fig. 2(e)], independent of the squark mass. Current neutrino-flux bounds are ineffective in ruling out neutralinos that are almost pure Higgsino or B-ino; however, if the observational bounds are improved by a factor of ten, far more supersymmetric dark-matter candidates would be observable. The rates from heavy B-inos are sensitive to the squark mass while the rates from heavy B-inos are relatively insensitive to the squark mass as may be seen by comparing Fig. 2(a) and Fig. 2(c).

To conclude, we note that the properties of the heavy neutralino in many



2. Regions where the neutralino is excluded as the primary component of the galactic halo by limits on the flux of upward-moving neutrino-induced muons from the Sun. The dark shaded regions are those excluded by current IMB limits. The light shaded regions are those that would be excluded if current observational limits were improved by a factor of 100. See text.

models are such that their capture and annihilation in the Sun yields an observable flux of energetic neutrinos. We also point out that in many models, a heavy neutralino may easily make up the primary component of the galactic halo while remaining invisible to neutrino detectors, so null results from energetic neutrino searches are not likely to rule out supersymmetric dark matter. Nevertheless, given the present uncertainty as to the nature of the dark matter, the popularity of supersymmetry in particle physics, and the interesting "coincidence" that the relic abundance of the LSP in most supersymmetric models falls near the dark-matter window, it is clear that the search for energetic neutrinos from the Sun holds considerable promise for discovery, should neutralinos reside in the galactic halo.

I wish to thank David Seckel, Kim Griest, and Michael Turner for valuable discussions, comments, and suggestions. This research was supported in part by the DoE (at Chicago and at Fermilab), by NASA (grant NGW-1340 at Fermilab), and by the NASA Graduate Student Researchers Program.

REFERENCES

1. H. E. Haber and G. L. Kane, *Phys. Rep.* **117**, 75 (1985).
2. K. A. Olive and M. Srednicki, *Phys. Lett. B* **230**, 78 (1989); K. Griest, M. Kamionkowski, and M. S. Turner, *Phys. Rev. D* **41**, 3565 (1990).
3. For recent reviews of dark matter and its detection, see V. Trimble, *Ann. Rev. Astron. Astrophys.* **25**, 425 (1989); J. R. Primack, B. Sadoulet, and D. Seckel, *Ann. Rev. Nucl. Part. Sci.* **B38**, 751 (1988); *Dark Matter in the Universe*, eds. J. Kormendy and G. Knapp (Reidel, Dordrecht, 1989).
4. M. Kamionkowski, Fermilab Report No. FERMILAB-Pub-90/181-A.
5. A. Gould, *Astrophys. J.* **321**, 571 (1987).
6. R. Barbieri, M. Frigeni, and G. F. Giudice, *Nucl. Phys.* **B313**, 725 (1989); T. P. Cheng, *Phys. Rev. D* **38**, 2869 (1988); H.-Y. Cheng, *Phys. Lett. B* **219**, 347 (1989).
7. K. Griest, *Phys. Rev.* **D38**, 2357 (1988).
8. S. Ritz and D. Seckel, *Nucl. Phys.* **B304**, 877 (1988).
9. IMB Collaboration: J. M. LoSecco *et al.*, *Phys. Lett. B* **188**, 388 (1987).
10. Totsuka, Y., Institute for Cosmic Ray Research Report No. ICR-Report-192-89-9.