Using Entropy to Discriminate Annihilation Channels in Neutralinos Making up Galactic Halos

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Applying the microcanonical definition of entropy to a weakly interacting and self-gravitating neutralino gas, we evaluate the change in the local entropy per particle of this gas between the freeze out era and present day virialized halo structures. An “entropy consistency” criterion emerges by comparing theoretical and empirical estimates of this entropy. We apply this criterion to the cases when neutralinos are mostly B-inos and mostly Higgsinos, in conjunction with the usual “abundance” criterion requiring that present neutralino relic density complies with \(0.2 < \Omega_{\tilde{\chi}_1^0} < 0.4\) for \(h \simeq 0.65\). The joint application of both criteria reveals that a much better fitting occurs for the B-ino than for the Higgsino channels, so that the former seems to be a favored channel along the mass range of \(155 \text{ GeV} < m_{\tilde{\chi}_1^0} < 230 \text{ GeV}\). These results are consistent with neutralino annihilation patterns that emerge from recent theoretical analysis on cosmic ray positron excess data reported by the HEAT collaboration. The suggested methodology can be applied to test other annihilation channels of the neutralino, as well as other particle candidates of thermal WIMP gas relics.

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I. INTRODUCTION

There are strong theoretical arguments favoring lightest supersymmetric particles (LSP) as making up the relic gas that forms the halos of actual galactic structures. Assuming that \(R\) parity is conserved and that the LSP is stable, it might be an ideal candidate for cold dark matter (CDM), provided it is neutral and has no strong interactions. The most favored scenario considers the LSP to be the lightest neutralino (\(\tilde{\chi}_1^0\)), a mixture of supersymmetric partners of the photon, \(Z\) boson and neutral Higgs boson. Since neutralinos must have decoupled once they were non-relativistic, it is reasonable to assume that they constituted originally a Maxwell-Boltzmann (MB) gas in thermal equilibrium with other components of the primordial cosmic plasma. In the present cosmic era, such a gas is practically collision–less and is either virialized in galactic and galactic cluster halos, in the process of virialization or still in the linear regime for superclusters and structures near the scale of homogeneity.

Besides the constraint due to their present abundance as main constituents of cosmic dark matter (\(\Omega_{\tilde{\chi}_1^0} \sim 0.3\)), it is still uncertain which type of annihilation cross section characterizes these neutralinos. In this paper we present a method that discriminates between different cross sections, based on demanding that (besides yielding the correct abundance) a theoretically estimated entropy per particle matches an empiric estimate of the same entropy, both constructed for actual galactic dark halo structures. The application of this “entropy consistency” criterion is straightforward because entropy is a state variable that can be evaluated at equilibrium states, irrespective of how enormously complicated the evolution between each such state might have been. In this context, the two fiducial equilibrium states of the neutralino gas are (to a good approximation) the decoupling (or “freeze out”) epoque and their present state as a virialized relic gas. Considering simplified forms of annihilation cross sections, the joint application of the abundance and entropy–consistency criteria favors the neutralinos as mainly “B–inos” over neutralinos as mainly “higgsinos”. These results are consistent with the theoretical analysis of the HEAT experiment which aims at relating the observed positron excess in cosmic rays with a possible weak interaction between neutralinos and nucleons in galactic halos.

The paper is organized as follows. In section 2 we describe the thermodynamics of the neutralino gas as it decouples. The microcanonical ensemble entropy is applied in section 3 to the post–decoupling neutralino gas to estimate the change in entropy between freeze out and present day conditions, leading to a suitable theoretical estimate of the entropy per particle. In section 4 we obtain an empirical estimate of this entropy based on actual halo variables, while in section 5 we examine the consequences of demanding that these two entropies coincide. We summarize our results in section 6.
II. THE NEUTRALINO GAS

Before the freeze out, the neutralinos satisfy the thermal equation of state of a non-relativistic MB gas

\[ \rho = m_{\chi_0} n_{\chi_0} \left(1 + \frac{3}{2} \frac{x}{T}\right), \quad p = \frac{m_{\chi_0} n_{\chi_0}}{x}, \]

where \( m_{\chi_0} \) and \( n_{\chi_0} \) are the neutralino mass and number density. Since we will deal exclusively with the lightest neutralino, we will omit henceforth the subscript \( \chi_0 \), understanding that all usage of the term “neutralino” and all symbols of physical and observational variables (i.e. \( \Omega_0, m, \rho, n, \) etc.) will correspond to this specific particle. As long as the neutralino gas is in thermal equilibrium, we have

\[ n \approx n^{(eq)} = g \left(\frac{m}{\sqrt{2} \pi}\right)^3 x^{-3/2} \exp(-x), \]

where \( g = 2 \) is the degeneracy factor of the neutralino species. The number density \( n \) satisfies the Boltzmann equation

\[ \dot{n} + 3 H n = -\langle |v| \rangle \left[n^2 - (n^{(eq)})^2\right], \]

where \( H \) is the Hubble expansion factor and \( \langle |v| \rangle \) is the annihilation cross section. Since the neutralino is non-relativistic as annihilation reactions “freeze out” and it decouples from the radiation dominated cosmic plasma, we can assume for \( H \) and \( \langle |v| \rangle \) the following forms

\[ H = 1.66 g_*^{1/2} \frac{T^2}{m_p}, \]

\[ \langle |v| \rangle = a + b \langle v^2 \rangle, \]

where \( m_p = 1.22 \times 10^{19} \text{ GeV} \) is Planck’s mass, \( g_* \) is the sum of relativistic degrees of freedom, \( \langle v^2 \rangle \) is the thermal averaging of the center of mass velocity (roughly \( v^2 \propto 1/x \) in non-relativistic conditions) and the constants \( a \) and \( b \) are determined by the parameters characterizing specific annihilation processes of the neutralino (s-wave or p-wave) \( \mathbb{2} \). The decoupling of the neutralino gas follows from the condition

\[ \Gamma \equiv n \langle |v| \rangle = H, \]

leading to the freeze out temperature \( T_f \). Reasonable approximated solutions of \( \mathbb{2} \) follow by solving for \( x_f \) the implicit relation

\[ x_f = \ln \left[ \frac{0.0764 m_p c_0 (2 + c_0) \left(a + 6 b x_f\right) m}{g_* x_f^{1/2}} \right], \]

where \( g_* = g_* (T_f) \) and \( c_0 \approx 1/2 \) yields the best fit to the numerical solution of \( \mathbb{2} \) and \( \mathbb{7} \). From the asymptotic solution of \( \mathbb{2} \) we obtain the present abundance of the relic neutralino gas \( \mathbb{2} \)

\[ \Omega_0 h^2 = \frac{S_0 m}{\rho_{\text{crit}} h^2} \approx 2.82 \times 10^8 \frac{Y_\chi}{m_{\chi_0}}, \]

where

\[ Y_\chi = \frac{n_0}{S_0} = \left[0.264 g_s^{1/2} m_p m \left(a/x_f + 3(b - 1/4 a)/x_f^2\right)\right]^{-1}, \]

and \( S_0 \approx 4000 \text{ cm}^{-3} \) is the present radiation entropy density (CMB plus neutrinos), \( \rho_{\text{crit}} = 1.05 \times 10^{-5} \text{ GeV cm}^{-3} \).

Since neutralino masses are expected to be in the range of tens to hundreds of GeV’s and typically we have \( x_f \approx 20 \) so that \( T_f > \text{ GeV} \), we can use \( g_s \approx 80, 2 \) in equations \( \mathbb{S} - \mathbb{T} \). Equation \( \mathbb{S} \) shows how \( x_f \) has a logarithmic dependence on \( m \), while theoretical considerations \( \mathbb{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12} \) related to the minimal supersymmetric extensions of the Standard Model (MSSM) yield specific forms for \( a \) and \( b \) that also depend on \( m \). Inserting into \( \mathbb{9, 10, 11, 12} \) the specific forms of \( a \) and \( b \) for each annihilation channel leads to a specific range of \( m \) that satisfies the “abundance” criterion based on current observational constraints that require \( 0.2 < \Omega_0 < 0.4 \) and \( h \approx 0.65, \mathbb{1} \).

Suitable forms for \( \langle |v| \rangle \) can be obtained for all types of annihilation reactions \( \mathbb{2} \). If the neutralino is mainly pure B-ino, it will mostly annihilate into lepton pairs through t-channel exchange of right-handed sleptons. In this case the cross section is p-wave dominated and can be approximated by \( \mathbb{1} \) with \( \mathbb{6, 7, 13, 14} \)

\[ a \approx 0, \quad b \approx \frac{8 \pi \alpha_1^2}{m^2 \left(1 + m_l^2/m^2\right)^2}, \]

where \( m_l \) is the mass of the right-handed slepton \( (m_l \sim m, \mathbb{3}) \) and \( \alpha_1 = g_2^2/4\pi \approx 0.01 \) is the fine structure coupling constant for the \( U(1)_Y \) gauge interaction. If the neutralino is Higgsino-like, annihilating into W-boson pairs, then the cross section is s-wave dominated and can be approximated by \( \mathbb{5} \) with \( \mathbb{13, 14} \)

\[ b \approx 0, \quad a \approx \frac{\pi \alpha_2^2 (1 - m_W^2/m^2)^3/2}{2m^2 (2 - m_W^2/m^2)^2}, \]

where \( m_W = 80.44 \text{ GeV} \) is the mass of the W-boson and \( \alpha_2 = g_2^2/4\pi \approx 0.03 \) is the fine structure coupling constant for the \( SU(2)_L \) gauge interaction.

In the freeze out era the entropy per particle (in units of the Boltzmann constant \( k_B \) ) for the neutralino gas is given by \( \mathbb{T} \)

\[ \frac{S_f}{nT} = \frac{5}{2} + x_f, \]
where we have assumed that chemical potential is negligible and have used the equation of state \( \text{(14)} \). From \( \text{(8)} \) and \( \text{(13)} \), it is evident that the dependence of \( s_f \) on \( m \) will be determined by the specific details of the annihilation processes through the forms of \( a \) and \( b \). In particular, we will use \( \text{(11)} \) and \( \text{(12)} \) to compute \( s_f \) from \( \text{(8)} \) and \( \text{(13)} \).

III. THE MICROCANONICAL ENTROPY

After the freeze out era, particle numbers are conserved and the neutralinos constitute a weakly interacting and practically collision–less and self–gravitating gas. This gas is only gravitationally coupled to all other components of the cosmic fluid. As it expands, it experiences free streaming and eventually undergoes gravitational clustering forming stable bound virialized structures \( \text{(8)} \). The evolution between a spectrum of density perturbations at the freeze out and the final virialized structures is extremely complex, involving a variety of dissipative effects characterized by collisional and collision–less relaxation processes \( \text{(12)} \). However, the freeze out and present day virialized structures roughly correspond to “initial” and “final” equilibrium states of this gas. Therefore, instead of dealing with the enormous complexity of the details of the intermediary processes, we will deal only with quantities defined in these states with the help of simplifying but general physical assumptions.

While the assumption of an ideal (thermodynamical) gas complying with Maxwell-Boltzmann statistics is justified before the freeze out (because the collision–dominated interactions are short–ranged), this type of thermodynamical formalism, associated with extensive entropy and energy and with a well defined thermodynamical limit, cannot be applied to present day collision–less neutralinos subject to a long–range gravitational interaction \( \text{(15)} \). In these conditions, the appropriate approach follows from the microcanonical ensemble in the “mean field” approximation that yields an entropy definition that is well defined for a self–gravitating gas in an intermediate scale, between the short range and long range regimes of the gravitational potential. This intermediate scale can be associated with a region that is “sufficiently large as to contain a large number of particles but small enough for the gravitational potential to be treated as a constant” \( \text{(16)} \). Considering the neutralino gas in present day virialized halo structures as a diluted, non-relativistic (nearly) ideal gas of weakly interacting particles, its microcanonical entropy per particle under these conditions can be given in terms of the volume of phase space \( \text{(17)} \)

\[
s_f = \ln \left[ \frac{(2mE)^{3/2}}{v} \right],
\]

where \( V \) and \( E \) are local average values of volume and energy associated with the intermediate scale. For non-relativistic velocities \( v/c \ll 1 \), we have \( V \propto 1/n \propto m/\rho \) and \( E \propto m v^2/2 \propto m/x \). In fact, since the microcanonical description is more fundamental, definition \( \text{(14)} \), evaluated at the freeze out, is consistent with \( \text{(8)} \) and \( \text{(13)} \), and so it is also valid immediately after the freeze out era (once particle numbers are conserved). Since \( \text{(13)} \) is valid at both the initial and final states, respectively corresponding to the freeze out \( (s_f, x_f, n_f) \) and to the values associated with a suitable halo structure \( (s_f^{(b)}, x_f^{(b)}, n_f^{(b)}) \), the change in entropy per particle that follows from \( \text{(14)} \) between these two states is given by

\[
s_f^{(b)} - s_f = \ln \left[ \frac{n_f}{n_f^{(b)}} \left( \frac{x_f}{x_f^{(b)}} \right)^{3/2} \right],
\]

where \( \text{(13)} \) can be used to eliminate \( s_f \) in terms of \( x_f \). Considering present day halo structures as roughly spherical, inhomogeneous and self-gravitating gaseous systems, it is safe to assume that near the symmetry center the spacial gradients of all macroscopic quantities are negligible \( \text{(10)} \). Even if one assumes a “cuspy” density profile, as predicted by numerical simulations, the gravitational potential of the halo can be considered to be practically constant within any typical region of up to \( 10 \text{pc}^3 \) within the halo core (a scale that is smaller than the resolution scale of these simulations \( \text{(20)} \)). Since such a typical region fits reasonably well the conditions associated with the intermediate scale of the microcanonical description, we will consider current halo macroscopic variables as evaluated near the center of the halo: \( s_c^{(b)}, x_c^{(b)}, n_c^{(b)} \).

In order to obtain a convenient theoretical estimate of \( s_c^{(b)} \) from \( \text{(14)} \), we need to relate \( n_f \) with present day cosmological parameters like \( \Omega_0 \) and \( h \). Bearing in mind that density perturbations at the freeze out era were very small \( (\delta n_f/n_f < 10^{-4}, \text{(2)} \) \( \text{(3)} \) \( \text{(4)} \)), the density \( n_f \) is practically homogeneous and so we can estimate it from the conservation of particle numbers: \( n_f = n_0 (1 + z_f)^3 \), and of photon entropy: \( g_4 S_f = g_{*0} S_0 (1 + z_f)^3 \), valid from the freeze out era to the present for the unperturbed homogeneous background. Eliminating \( (1 + z_f)^3 \) from these conservation laws yields

\[
n_f = n_0 \frac{g_4}{g_{*0}} \left( \frac{T_f}{T_CMB} \right)^3 \sim 20.46 n_0 \left( \frac{x_c^{\text{CMB}}}{x_f} \right)^3,
\]

where \( x_c^{\text{CMB}} \equiv \frac{m_{\text{CMB}}}{t_0^{\text{CMB}}} = 4.29 \times 10^{12} \text{ GeV} \)

and \( g_{*0} = g_4 T_0^{\text{CMB}} \simeq 3.91 \) and \( T_0^{\text{CMB}} = 2.7 \text{ K} \). Since for present day conditions \( n_f/n_c^{(b)} = \rho_f/\rho_c^{(b)} \) and \( \rho_0 = \rho_{\text{crit}} \Omega_0 h^2 \), we collect the results from \( \text{(10)} \) and write \( \text{(13)} \) as

\[
s_c^{(b)} = x_f + 92.78 + \ln \left[ \left( \frac{m}{\text{GeV}} \right)^3 \frac{h^2 \Omega_0}{(x_f x_c^{(b)})^{3/2} \rho_{\text{crit}}^{(b)}} \right] = x_f + 81.31 + \ln \left[ \left( \frac{m}{\text{GeV}} \right)^3 \frac{h^2 \Omega_0}{(x_f x_c^{(b)})^{3/2} \rho_{\text{crit}}^{(b)}} \right]
\]

(17)
Therefore, given \( m \) and a specific form of \( \langle \sigma | v \rangle \) associated with \( a \) and \( b \), equation (17) provides a theoretical estimate of the entropy per particle of the neutralino halo gas that depends on the initial state given by \( x_f \) in (8) and on observable cosmological parameters \( \Omega_0 \), \( h \) and on generic state variables associated to the halo structure.

IV. THEORETICAL VS. EMPIRICAL ENTROPIES

If the neutralino gas in present halo structures would strictly satisfy MB statistics, the entropy per particle, \( s_c^{(h)} \), in terms of \( \rho_c^{(h)} = m n_c^{(h)} \) and \( x_c^{(h)} = m c^2/(k_B T_c^{(h)}) \), would follow from the well known Sackur–Tetrode entropy formula (21)

\[
 s_c^{(h)}_{\text{MB}} = \frac{5}{2} + \ln \left( \frac{m^4 c^3}{h^3 (2\pi)^{3/2} \rho_c^{(h)}} \right) = 94.42 + \ln \left( \frac{m}{\text{GeV}} \right)^4 \left( \frac{1}{x_c^{(h)}} \right)^{3/2} \frac{\text{GeV/cm}^3}{\rho_c^{(h)}} .
\]

(18)

Such a MB gas in equilibrium is equivalent to an isothermal halo if we identify (22)

\[
 c^2 \langle \sigma_n \rangle = \frac{k_B T^{(h)}}{m} = \sigma_{(h)}^2 ,
\]

(19)

where \( \sigma_{(h)}^2 \) is the velocity dispersion (a constant for isothermal halos). However, as mentioned before, the assumption of MB statistics, in which entropy and energy are extensive quantities, does not apply for self–gravitating collisionless gases. Hence, an exactly isothermal halo is not a realistic model, not only because of these theoretical arguments, but also because its total mass diverges and its distribution function allows for infinite particle velocities (theoretically accessible in the velocity range of the MB distribution). Therefore, this case will not be considered any further.

More realistic halo models follow from “energy truncated” (ET) distribution functions (16, 22, 23, 24, 25) that assume a maximal “cut off” velocity (an escape velocity). Therefore, we can provide a convenient empirical estimate of the halo entropy, \( s_c^{(h)} \), from the microcanonical entropy definition (13) in terms of phase space volume, but restricting this volume to the actual range of velocities (i.e. momenta) accessible to the central particles, that is up to a maximal escape velocity \( v_e(0) \). It is reasonable to assume a relation of the form

\[
 v_e^2(0) = 2 |\Phi(0)| \approx \alpha \sigma_{(h)}^2(0) ,
\]

(20)

where \( \Phi(r) \) is the newtonian gravitational potential.

With the help of (20) we have then

\[
 s_c^{(h)}|_{\text{esc}} \approx \ln \left[ \frac{m^4 v_e^2}{(2\pi\hbar)^3 \rho_c^{(h)}} \right] = 89.17 + \ln \left[ \frac{m}{\text{GeV}} \right]^4 \left( \frac{\alpha}{x_c^{(h)}} \right)^{3/2} \frac{\text{GeV/cm}^3}{\rho_c^{(h)}} ,
\]

(21)

where we used \( x_c^{(h)} = \sigma^2/\rho_c^{(h)} \). As expected, the scalings of (21) are identical to those of (18).

In order to provide a numerical estimate for \( \alpha \), we remark that by a suitable choice of a core radius and a total radius, \( R_{\text{core}} \) and \( R_{\text{tot}} \), any realistic halo model can be accommodated to a generic galactic halo density profile consisting of a region of constant density \( 0 < r < R_{\text{core}} \), joined continuously to an outer region \( R_{\text{core}} < r < R_{\text{tot}} \). If we further assume a velocity dispersion \( \sigma_{(h)}^2(0) \approx 2 v_e^2 \), where \( v_{\text{tot}} \) is the maximal observed rotation velocity, the parameter \( \alpha \) defined in (20) will be given by:

\[
 \alpha \approx 2 + 4 \ln \left( \frac{R_{\text{tot}}}{R_{\text{core}}} \right) .
\]

(22)

From this estimation, the minimum value of \( \alpha \) occurs for the combination of large \( R_{\text{core}} \) and small \( R_{\text{tot}} \), with extreme values given (for a large spiral galaxy) by 10 kpc and 100 kpc, respectively. Conversely, the maximum value of \( \alpha \) corresponds to small \( R_{\text{core}} \) and large \( R_{\text{tot}} \), with extreme values safely estimated as 1 kpc and 300 kpc, respectively. Considering these extreme values, we obtain the uncertainty range

\[
 11.2 \lesssim \alpha \lesssim 24.8 .
\]

(23)

Values of \( \alpha \) outside these bounds are unrealistic (21, 27, 28), an assertion that can be also based on theoretical studies of dynamical and thermodynamical stability associated with ET distribution functions (21, 24, 25, 31, 32) and on observational data for normal spiral and LSB galaxies as well as galaxy clusters (18, 33, 34, 35, 36). In any case, it must be noted that \( \alpha \) is an integral feature of the halo, highly insensitive to the differential details of the density profile.

V. TESTING THE ENTROPY CONSISTENT CRITERION

The expressions for \( s_c^{(h)} \) obtained from (17) and (21) are not very useful, since they depend on dynamic halo variables, such as \( \rho_c^{(h)} \) and \( x_c^{(h)} \), whose values depend on specific galactic systems and are subject to possibly large uncertainties. However, since both entropy estimates (17) and (21) must correspond to the same quantity, \( s_c^{(h)} \), the comparison of these independent estimates leads to the
that can be tested on suitable desired values of trivial but leads to an “entropy consistency” criterion between the two sets of variables: equation (25).

Two expressions for the same quantity yields a constraint on the halo parameters in the latter. In this way, equating the calculation of (16) and (17), and containing only (14) twice, both in estimating the change in entropy in going from the freeze out condition to the present virialized halo, and in obtaining the actual empirical entropy integral feature of the dark halos, the central escape velocity (hence, it is also insensitive to the structure formation scenario that might be assumed). Further, the details of this criterion is its direct dependence on the physical details (i.e., annihilation channels and mass) of the neutralino gas at freeze out, \(x_f\). This last quantity depends explicitly not only on \(m\), but also on its interaction cross section, and hence on the details of its phenomenological physics through \(\Omega_0\). Notice that in reaching (25) we have used twice, both in estimating the change in entropy in going from the freeze out condition to the present virialized halo, and in obtaining the actual empirical entropy in present day halos. However, in these two instances, was expressed in terms of two different sets of variables, involving \(\Omega_0\) and \(h\) in the former case (through the calculation of (16) and (14)), and containing only halo parameters in the latter. In this way, equating the two expressions for the same quantity yields a constraint between the two sets of variables: equation (25).

At this point we consider values for the constants \(a\) and \(b\) that define the interaction cross section of the neutralino, and use (24) to plot \(\Omega_0\) as a function of \(m\) in GeV's. Using \(h = 0.65\) and given the uncertainty range of \(\alpha\) in (24), we will obtain not a curve, but a region in the \(\Omega_0 - m\) plane. Considering first condition (24), corresponding to Higgsino-like neutralinos, leads to the shaded region in figure 1a. On this figure we have also plotted the relation which the abundance criterion (9) yields on this same plane. It is evident that within the observationally determined range of \(\Omega_0\) (the horizontal dashed lines 0.2-0.4), there is no intersection between the shaded region and the abundance criterion curve. This implies that both criteria are mutually inconsistent, thus the possibility that Higgsino-like neutralinos make up both the cosmological dark matter and galactic dark matter can be ruled out.

Repeating the same procedure for mainly B-ino neutralinos, (11) yields figure 1b. In this case, we can see that the abundance criterion curve falls well within the shaded region defined by the entropy criterion. Although we can not improve on the mass estimate provided by the abundance criterion alone, the consistency of both criteria reveals the B-ino neutralino as a viable option for both the cosmological and the galactic dark matter.

As noted above, the results of figures 1a and 1b are totally insensitive to the values of halo variables, \(x_f\) and \(\rho_h\), used in evaluating (24) and (17). Different values of these variables (say, for different halo structures) would only result in larger or smaller actual values of \(s_c^{(h)}\) for each halo structure (subject to potentially large uncertainties). Therefore, our results are not only insensitive to these uncertainties, but are also scale–invariant.

VI. CONCLUSIONS

We have presented a robust consistency criterion that can be verified for any annihilation channel of a given dark matter candidate proposed as the constituent particle of the present galactic dark matter halos. Since we require that the empirical estimate \(s_c^{(h)}\) of present dark matter halos must match the theoretical value \(s_c^{(h)}\), derived from the microcanonical definition and from freeze out conditions for the candidate particle, the criterion is of a very general applicability, as it is largely insensitive to the details of the extremely complicated evolution of the neutralino gas from its freeze out era (hence, it is also insensitive to the structure formation scenario that might be assumed). Further, the details of the present day halo structure enter only through an integral feature of the dark halos, the central escape velocity, thus our results are also insensitive to the fine details concerning the central density and the various models describing the structure of dark matter halos. A crucial feature of this criterion is its direct dependence on the physical details (i.e. annihilation channels and mass) of any particle candidate.
Recent theoretical work by E. A. Baltz et al. [10] confirmed that neutralino annihilation in the galactic halo can produce enough positrons to make up for the excess of cosmic ray positrons experimentally detected by the HEAT collaboration [11] [12]. Baltz et al. concluded that for a boost factor \( B_s \sim 30 \) the neutralinos must be primarily B-inos with mass around 160 GeV. For a boost factor \( 30 < B_s < 100 \), the gaugino-dominated SUSY models complying with all constraints yield neutralino masses in the range of \( 150 \text{ GeV} < m_{\tilde{\chi}^0_1} < 400 \text{ GeV} \). On the other hand, Higgsino dominated neutralinos are possible but only for \( B_s \sim 1000 \) with masses larger than 2 TeV. However, our results show this second option to be unlikely and are in agreement with the predictions that follow from [10], as we obtain roughly the same mass range for the B-ino dominated case (see figure 1b) and the Higgsino channel is shown to be less favored in the mass range lower than TeV’s.

We have examined the specific case of the lightest neutralino for the mostly B-ino and mostly Higgsino channels. The joint application of the “entropy consistency” and the usual abundance criteria clearly shows that the B-ino channel is favored over the Higgsino. This result can be helpful in enhancing the study of the parameter space of annihilation channels of LSP’s in MSSM models, as the latter only use equations (8) and (9)–(10) in order to find out which parameters yield relic gas abundances that are compatible with observational constraints. However, equations (8) and (9)–(10) by themselves are insufficient to discriminate between annihilation channels. A more efficient study of the parameter space of MSSM can be achieved by the joint usage of the two criteria, for example, by considering more general cross section terms (see for example [2]) than the simplified approximated forms (11) and (12). This work is currently in progress.

**FIG. 1:** Figures (a) and (b) respectively correspond to the Higgsino and B-ino channels. The shaded regions display \( \Omega_0 \) vs m from our entropy criterion with the solid curve giving \( \Omega_0 \) from the cosmological abundance criterion (9), in all cases for \( h = 0.65 \). The horizontal dashed lines give current estimates of \( \Omega_0 = 0.3 \pm 0.1 \). It is evident that only the B-ino channels allow for a simultaneous fitting of both the abundance and the entropy criteria.

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