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Heavy neutrinos : the heterodox strikes back

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Abstract

The properties of a fourth-generation doublet neutrino are severely constrained by the recent LEP results. This species is no longer a viable candidate for the dark matter which pervades the universe. Those who favour the heterodox will be relieved to notice that neutrinos embedded inside electroweak gauge triplets – a promising if unconventional possibility – may still solve the astronomical missing mass conundrum. High energy physics and cosmological relevance favour such a neutrino to have a mass in the range 30 – 80 GeV. Whilst elusively absent from the Z^0 boson peak width, these new dark matter candidates are associated by gauge symmetry to charged Dirac fermions whose discovery should not escape the LEP detectors once the beam energy reaches ~ 100 GeV.

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1 - Introduction.

Experiments at the Large Electron Positron storage ring, LEP, at CERN have recently measured the total decay rate of the Z^0 boson [1]. From its invisible width, the conventional assumption that there are only three light neutrino families turns out to be distressingly valid [2]. The LEP determination of the number of invisible species excludes [3] an appealing explanation of the astronomical “missing mass” conundrum in terms of a fourth generation heavy neutrino. The fossil abundance of such an exotic species would have accounted for the dark matter which pervades the universe if its mass were in the range 2-20 GeV and if it were stable. However, the LEP experiments have placed a lower bound of ~ 46 GeV on the mass of such a neutrino. Conventional Big-Bang calculations [4] show that for a mass above 46 GeV, neutrinos contribute too little to the overall density to account for the missing mass. This assumes cosmic symmetry between particles and antiparticles, which is always valid for Majorana species. A net cosmological lepton asymmetry may however be present for a Dirac neutrino which would enable it to be a viable dark matter candidate even above the LEP threshold. This is however excluded by direct searches using germanium detectors [5].

The LEP results also affect the lightest supersymmetric particle (LSP), a favoured dark matter candidate [6]. As shown by Gelmini *et al.* in their analysis of the minimal supersymmetric extension of the standard model [7], entire domains of the parameter space, which are cosmologically relevant (because the associated relic density $\Omega_\chi h^2$ being in the range 1/40 to 1) are now completely excluded by the LEP bound on the chargino mass and the UA2 and CDF limits on the gluino mass [8]. Those constraints are most stringent for large values of the Higgs vacuum expectation value ratio v_2/v_1 . If supersymmetry still provides a suitable framework for an explanation of the dark matter puzzle in terms of high energy physics species, accelerator bounds and constraints set by direct [5] and indirect [9] searches become so stringent that this appealing scenario appears more and more contrived and is now in jeopardy.

In this letter, a new scheme is proposed : if a heavy neutrino with gauge triplet interactions was stable, its cosmological relic abundance could fairly naturally reach closure density. Even if the reaction is kinematically allowed, this particle cannot be produced in Z^0 decay events and therefore evades direct detection. Whilst its gauge partner – the charged Dirac fermion $\bar{E}$ – is constrained by the LEP bound on the chargino mass, the neutrino N is nevertheless a viable dark matter candidate whenever its mass exceeds ~ 30 GeV. Section 2 is devoted to a presentation of our generic model.

The gauge couplings as well as the various reactions among the species N and E are discussed.

Previous analyses of the relic abundance of neutralino dark matter candidates [4,6] all rely on the same scheme. For vanishing cosmic asymmetry, the fossil density of the particles is primarily derived from consideration of their self-annihilations in the early universe. In our model, since N does not self-interact, its Big-Bang production is a delicate interplay between its annihilations upon its charged companion E and the fast reactions which constantly transmute both species. In section 3, the relic abundance $\Omega_N h^2$ is determined as a function of the masses M_N and M_E . The quite unconventional behaviour of our triplet system at early times is presented in some detail. The fossil density of N is shown to be cosmologically interesting for a fairly extended range of mass values.

In section 4, a simple yet plausible model is discussed. The mass splitting between neutral and charged particles is realized through the mixing of a triplet with a singlet, triggered by a Higgs triplet field whose neutral component acquires a vacuum expectation value. Finally, we discuss the main outcomes of our scenario and present some of its possible signatures.

2 - Heavy neutrinos as gauge triplets.

Models of the weak interactions with neutrinos embedded inside gauge triplets were proposed [10] slightly before the discovery of neutral currents, in the early 70's. If the neutrino field is actually the neutral component of the $SU(2) \times U(1)$ gauge triplet

$$\mathcal{T}_\alpha = \begin{pmatrix} \psi_\alpha^+ \\ \psi_\alpha^0 \\ \psi_\alpha^- \end{pmatrix}, \quad (1)$$

then it does not couple directly to gauge bosons, provided its hypercharge vanishes. Note that since the ψ 's are Weyl spinors, two fermions may be built from $\mathcal{T}_\alpha$. By combining the upper and lower components, the Dirac fermion

$$\bar{E} = \begin{pmatrix} \psi_\alpha^+ \\ \bar{\psi}^{-\alpha} \end{pmatrix} \quad (2)$$

acquires the same electric charge as the proton. The remaining neutral spinor ψ^0 allows the existence of the Majorana field

$$N = \begin{pmatrix} \psi^0_\alpha \\ \bar{\psi}^0_{\dot{\alpha}} \end{pmatrix}, \quad (3)$$

whose hypercharge and T_3^U eigenvalue vanish. The neutrino N has no electric charge and does not couple to the Z^0 boson, so that it escapes detection at LEP. This elusive species nevertheless couples to its charged partner whose gauge interactions may be described by the Lagrangian

$$\mathcal{L}_{\text{int}} = \frac{e}{\sin\theta_W} W_\mu^- \bar{E} \gamma^\mu N + hc - e A^\mu \bar{E} \gamma_\mu E - e \cot\theta_W Z_\mu^0 \bar{E} \gamma^\mu E. \quad (4)$$

The two first terms describe the cross-interactions between E and its neutral partner N mediated by W exchange, whilst the last terms refer to the parity conserving couplings of E with the Z^0 boson and to the photon.

Annihilation processes between E 's and N 's are of paramount importance during the early stages of the universe. Since the charged species E directly couples to the neutral gauge bosons, its annihilation occurs through the exchange of both the photon and the Z^0 boson in the direct channel. The relevant cross-section for this reaction is a sum over all the possible annihilation channels of the typical expression

$$\sigma v(E^+ E^- \rightarrow f \bar{f}) = \frac{\pi \alpha^2}{M_E^2} \left\{ Q_f^2 + \left(\frac{Q_f v_f}{\sin^2 \theta_W} \right) X_1 + \left(\frac{a_f^2 + v_f^2}{4 \sin^2 \theta_W} \right) X_2 \right\}, \quad (5)$$

where Q_f is the electric charge – in units of the proton charge – of the final fermion f (whose mass is neglected for the sake of simplicity), and α is the electromagnetic fine structure constant. The parameters a_f and v_f are respectively the axial and vector couplings of f to the Z^0 boson

$$\begin{aligned} a_f &= T_3^U \\ v_f &= T_3^U - 2 Q_f \sin^2 \theta_W \end{aligned} \quad \text{whilst} \quad (6)$$

Since the annihilation of an E pair proceeds through both photon and Z^0 boson exchange, expression (5) contains a sum of three terms, the first of which refers to the pure electromagnetic mechanism. The quantity X_1 , in the second term, describes the interference process, whereas X_2 , in the last term, corresponds to the propagator of the

pure Z^0 exchange

$$X_1 = \frac{S(S - M_Z^2)}{(S - M_Z^2)^2 + \Gamma_Z^2 M_Z^2} \quad \text{and} \quad (7)$$

$$X_2 = \frac{S^2}{(S - M_Z^2)^2 + \Gamma_Z^2 M_Z^2}, \quad (8)$$

where $S = 4 M_E^2$. The mass (or decay width) of the intermediate Z^0 boson is denoted by M_Z (or Γ_Z).

More important is the annihilation of N upon either E^+ or E^- , the cross section of which, for each annihilation channel, may be similarly expressed as

$$\sigma v(N E \rightarrow f \bar{f}) = \frac{2}{\pi} G_F^2 S \frac{M_W^4}{(S - M_W^2)^2 + \Gamma_W^2 M_W^2}, \quad (9)$$

where $S = (M_N + M_E)^2$. G_F is the weak Fermi constant whilst M_W and Γ_W denote the mass and decay width of the W boson.

A key process for the cosmological behaviour of the triplet species is, as we shall see in the next section, the very fast transmutation reactions

$$E^+ \rightleftharpoons N \rightleftharpoons E^-. \quad (10)$$

If embedded inside a gas of, say, electrons, positrons, and neutrinos, E^+ and N are kept in thermal equilibrium through the reactions

$$\begin{aligned} N \nu_e &\rightleftharpoons E^+ e^- \\ N e^+ &\rightleftharpoons E^+ \bar{\nu}_e \\ N e^+ \nu_e &\rightleftharpoons E^+, \end{aligned} \quad (11)$$

and behave as two different states of the same entity T_e . Reactions (11) are similar to those which maintain neutron-proton equilibrium before the onset of nucleosynthesis in the early universe. If N_D is the number of $SU(2)$ doublets – such as the leptonic (ν_e, e) or the hadronic (up, down) – which are involved in the equilibrium reactions (10), the rate of transmutation of E^+ into N may be expressed as

$$\Gamma(E^+ \rightarrow N) = \frac{4}{\pi^3} G_F^2 N_D Q_{EN}^5 \mathcal{I}(Q_{EN}/T), \quad (12)$$

where the thermal integral $\mathcal{I}(a)$ is given by

$$\mathcal{I}(a) = a^{-5} \int_{-\infty}^{+\infty} x^2 (x+a)^2 [1 + \exp(x)]^{-1} [1 + \exp(-x-a)]^{-1} dx. \quad (13)$$

The mass splitting between the neutrino N and its charged partner E is denoted by $Q_{EN} = M_E - M_N$ whilst T denotes the temperature of the medium. Note that the rate $\Gamma(N \rightarrow E^+)$ of the reverse reaction is similarly given by expression (12) where the relevant mass gap is now $Q_{NE} = -Q_{EN}$.

3 - Cosmological behaviour.

The particles, so far considered as dark matter candidates, have a common cosmological behaviour. In the early universe, the temperature decreases from a virtually infinite value so that the various species suffer from the combined action of spatial expansion and, eventually, loss of thermal equilibrium. At extreme temperatures, a doublet heavy neutrino – for instance – behaves as an ultra-relativistic gas. As soon as the temperature drops below its mass, the heavy neutrino self-annihilates (into light particles) so that its equilibrium number density decreases exponentially. This happens as long as the annihilation (and creation) reactions proceed faster than the expansion itself so that neutrinos are still kept in chemical equilibrium with the other particles. However, at some point, neutrinos are so depleted, and conversely the light species are so cold, that these reactions decouple and neutrinos go out of chemical equilibrium. The freeze-out occurs when the probability for neutrino annihilation during a typical expansion time drops below unity. Since then, provided they are stable, the ashes of the primordial neutrino gas have been pervading the universe. Their fossil density may be simply derived [4] from their self-annihilation cross-section.

Note that since N couples only to E , the analysis of the cosmological behaviour of our triplet neutrinos is more intricate. N is not allowed to self-annihilate so that the above scenario does not apply. The neutrino N needs its charged partner in order to disappear. As a consequence, we must follow the combined evolution of both species. Since a stable charged dark matter candidate suffers from insuperable constraints [11], we will thereafter consider the case $M_N < M_E$. The reverse option would correspond to an unstable heavy neutrino and is not relevant to our analysis. A true gauge triplet also implies the same mass for its components. We will discuss the lifting of this degeneracy in the next section and will focus here on the cosmological behaviour of the triplet particles as a function of their mass.

If the number density of the species E^+ , E^- and N are respectively denoted by n_{E^+} , n_{E^-} and n_N , the evolution of the relevant populations during the first stages of the Big-Bang obeys a system of differential equations

$$\begin{aligned} \frac{dn_{E^+}}{dt} + \{3Hn_{E^+}\} &= \left\{ \Gamma(N \rightarrow E^+)n_N - \Gamma(E^+ \rightarrow N)n_{E^+} \right\} + \\ &+ \left\{ \sigma v(NE^+ \rightarrow f\bar{f})[n_N^0 n_{E^+}^0 - n_N n_{E^+}] + \right. \\ &\quad \left. + \sigma v(E^+ E^- \rightarrow f\bar{f})[n_{E^+}^0 n_{E^-}^0 - n_{E^+} n_{E^-}] \right\} \\ \frac{dn_N}{dt} + \{3Hn_N\} &= \left\{ \Gamma(E^+ \rightarrow N)n_{E^+} + \Gamma(E^- \rightarrow N)n_{E^-} \right\} + \\ &\quad - \left\{ \Gamma(N \rightarrow E^+) + \Gamma(N \rightarrow E^-) \right\} n_N \\ &+ \left\{ \sigma v(NE^+ \rightarrow f\bar{f})[n_N^0 n_{E^+}^0 - n_N n_{E^+}] + \right. \\ &\quad \left. + \sigma v(NE^- \rightarrow f\bar{f})[n_N^0 n_{E^-}^0 - n_N n_{E^-}] \right\} \\ \frac{dn_{E^-}}{dt} + \{3Hn_{E^-}\} &= \left\{ \Gamma(N \rightarrow E^-)n_N - \Gamma(E^- \rightarrow N)n_{E^-} \right\} + \\ &+ \left\{ \sigma v(NE^- \rightarrow f\bar{f})[n_N^0 n_{E^-}^0 - n_N n_{E^-}] + \right. \\ &\quad \left. + \sigma v(E^+ E^- \rightarrow f\bar{f})[n_{E^+}^0 n_{E^-}^0 - n_{E^+} n_{E^-}] \right\}. \end{aligned} \quad (14)$$

The time evolution of the particle densities may be derived from the combined action of three mechanisms.

(i) The dilution resulting from the expansion of the universe involves the Hubble parameter $H = \dot{R}/R = -\dot{T}/T$ in the first bracketed term of each equation.

(ii) The various species may be transmuted into each other as discussed above. Those reactions preserve the total number of E^+ , E^- and N . The rates (12) appear in the second bracketed term.

(iii) Finally, particles are constantly created and destroyed. Densities evolve according to the adjustment between the direct annihilations and their reverse reactions for which detailed balance has been assumed. Production from light fermions is determined by the values n_i^0 of the corresponding densities (in thermodynamical equilibrium).

The evolution equations (14) do not look conspicuously simple. Three a priori independent non-linear differential equations need to be solved in order to understand the cosmological behaviour of both the neutrino N and its gauge partner E . However the problem is simplified by noting the efficiency of the transmutation reactions. At very high temperature – $T \gg Q_{EN}$ – the mass gap is negligible so that the direct and reverse reactions occur at the same rate

$$\Gamma(E^+ \rightarrow N) \simeq \Gamma(N \rightarrow E^+) \simeq \frac{28\pi}{15} G_F^2 N_D T^5. \quad (15)$$

In the reverse regime $-T \ll Q_{EN}$ – the heavier particle E merely decays into N

$$\Gamma_{dec}(E^+ \rightarrow N) \simeq \frac{4}{30} \frac{G_F^2}{\pi^3} N_D Q_{EN}^5, \quad (16)$$

whilst light fermions are too cold to allow the opposite reaction. Since we are mostly concerned with particles in the mass range 10 - 100 GeV, cosmological relevance implies a mass gap $Q_{EN} > 1$ GeV (see fig. 1) so that the transmutation rates (15) and (16) always exceed the expansion rate H by several orders of magnitude. Species E and N should not be pictured as distinct particles whose populations evolve independently according to relations (14). Transmutation occurs so rapidly with regard to spatial expansion and general cooling that they behave like the components – maintained in relative thermodynamical equilibrium – of the same entity, namely the gauge triplet $\mathcal{T}_a$. The fraction of neutrals $X_N = n_N/n_{tot}$ is therefore given by the Boltzmann equilibrium formula

$$X_N^0 = \left(1 + 2e^{Q_{EN}/T}\right)^{-1}, \quad (17)$$

where $n_{tot} = n_N + n_{E^+} + n_{E^-}$ is the total number of triplet particles. Since reactions (10) are in chemical equilibrium, no cosmic asymmetry is allowed between E^+ and E^- and the identity $X_{E^+} = X_{E^-} = (1 - X_N)/2$ obtains. The only cosmologically relevant parameter, n_{tot} , obeys the simplified relation

$$\frac{df_{tot}^0}{dt} + \Gamma_{relax} f_{tot}^0 = \Gamma_{relax}^0 f_{tot}^0, \quad (18)$$

where $f_{tot} = n_{tot}/T^3$ is the total codensity. If perturbed, f_{tot} relaxes towards its equilibrium value f_{tot}^0 with typical rate

$$\Gamma_{relax} = 2(\sigma v)_{EE} n_{E^+} X_{E^+} + 4(\sigma v)_{NE} n_{E^+} X_N. \quad (19)$$

The evolution of the rate Γ_{relax} determines entirely the cosmological behaviour of the heavy neutrinos.

- (i) For extreme temperatures $-T \gg M_N$ – particles are ultra-relativistic and in thermal equilibrium. Due to spin degeneracy, there are twice as many E 's as N 's.
- (ii) The densities n_E and n_N fall rapidly as soon as the temperature drops below the particles mass. This stage is characterized by a significantly large relaxation rate Γ_{relax} relative to the expansion rate H so that thermal equilibrium obtains. The density n_{tot} may relax towards its equilibrium value n_{tot}^0 much faster than the latter varies itself. Since the density n_{E^+} exponentially decreases, so does the rate Γ_{relax} .
- (iii) The freeze-out occurs when annihilations have depleted the various species so much that Γ_{relax} drops below H . If on the one hand equilibrium is achieved among the

components of the triplet system, on the other hand, the total number n_{tot} is no longer able to follow the equilibrium value n_{tot}^0 .

- (iv) Since decoupling, decays of E 's into N 's have been dominant. The final comoving density remains fixed at the freeze-out value f_F . The stable relic neutrinos today contribute a fraction

$$\Omega_N h^2 = f_F T_N^3 \frac{M_N}{\rho_c} \quad (20)$$

to the closure density ρ_c . The present Hubble constant h is expressed in units of 100 km/s/Mpc whilst T_N denotes the present value of the neutrino gas temperature.

Fig. 1 presents the domain of the (M_N, Q_{EN}) diagram where the fossil abundance $\Omega_N h^2$ lies between 1/40 and 1. For fixed neutrino mass and temperature, the larger the value of M_E is, the lower the charged species abundance n_E and annihilation rate Γ_{relax} are and, consequently, the earlier the decoupling. An increase of the mass gap Q_{EN} implies a larger abundance of the relic neutrinos. The closure density bound, $\Omega_N h^2 = 1$, therefore lies above the $\Omega_N h^2 = 1/40$ curve. The kinks which both lines exhibit around $M_N \sim 30$ GeV correspond to the W resonance enhancement of the annihilation cross section $(\sigma v)_{NE}$ which dominates the behaviour of the rate Γ_{relax} .

LEP excludes any unconventional charged particle below ~ 46 GeV. In the region of the plot (M_N, Q_{EN}) where the heavy neutrino N is a plausible dark matter candidate, this translates into a lower bound of ~ 30 GeV on M_N . Conversely, above the W boson threshold, a new annihilation channel opens up $-N + N \rightarrow W^+ W^-$ – and our analysis does not apply. Finally, as is obvious from fig. 1, a heavy triplet neutrino achieves interesting cosmological abundances for quite a wide range of values of the mass gap Q_{EN} . Triplet species may actually be an interesting option for cold dark matter since supersymmetry is becoming unbearably contrived.

4 - A simple model.

In order to lift the degeneracy between the neutral and charged components of the $SU(2) \times U(1)$ gauge triplet $\mathcal{T}_a$, we introduce an additional field, the singlet S_a^0 , with zero hypercharge. The mass of the triplet (or singlet) is denoted by M_1 (or M_2). Mixing between the neutral states ψ_a^0 and S_a^0 occurs through their couplings to the Higgs triplet field $\vec{H}$

$$\mathcal{L}_{mixing} = \lambda \vec{H} \cdot \vec{\psi}^c S_a + h.c., \quad (21)$$

whose neutral component acquires a vacuum expectation value $< H_z >$. The mass matrix may be expressed as

$$L_{mass} = -\frac{1}{2} (\bar{\psi}^0, \bar{S}^0) \begin{pmatrix} M_1 & \epsilon \\ \epsilon & M_2 \end{pmatrix} \begin{pmatrix} \psi^0 \\ S^0 \end{pmatrix}, \quad (22)$$

where the mixing term $\epsilon = \lambda < H_z >$. This section is intended to present a naive yet generic example [12] where the mass gap Q_{EN} lies naturally in the interesting domain of fig. 1. We set $M_1 = M_2$ for the sake of simplicity. Mixing between the neutral Majoranas ψ^0 and S^0 is complete and, after a $\pi/4$ rotation, the new mass eigenstates N and N' correspond to the eigenvalues

$$\begin{aligned} M_N &= M_E - \epsilon \\ \text{and} \\ M_{N'} &= M_E + \epsilon, \end{aligned} \quad (23)$$

whilst the mass of their charged partner, $M_E = M_1 = M_2$, does not change. The degeneracy is lifted with a mass difference Q_{EN} precisely equal to the off-diagonal term ϵ of the mass matrix (22). The rotation from the original (ψ^0, S^0) to the eigenstates (N, N') introduces an additional factor of $1/2$ in expressions (9) and (12) where couplings between N and E are involved. Note that the charged species E is not affected by the mixing.

The vacuum expectation value of an exotic yet possible additional Higgs triplet is severely constrained by measurements of the so-called ρ parameter. This ratio $\rho = M_N^2 / (M_Z^2 \cos^2 \theta_W)$ quantifies the deviations from the conventional wisdom according to which the gauge symmetry breaking is triggered only by pure Higgs doublets. The upper limit on $< H_z >$ is ~ 9 GeV at the 90% confidence level [13] whilst slightly larger values, say 15 GeV, are not inconceivable. In fig. 2, where the cosmic abundance of the neutrino remnants is plotted as a function of their mass, the mass shift $Q_{EN} = \epsilon$ has been varied from 5 to 15 GeV. Note that the only relevant parameters are the mass M_N and the mixing term ϵ . As discussed above, the mass gap ϵ lies naturally in the relevant area of diagram 1 where only the fairly moderate values of Q_{EN} allow plausible dark matter densities. The three cases of fig. 2 respectively correspond to $\epsilon = 5$ GeV (solid), 10 GeV (long dash) and 15 GeV (short dash). As already discussed, the larger the mass gap ϵ , the larger the fossil density $\Omega_N h^2$, while the dips which every curve exhibits occur precisely for $M_N + M_E = M_W$ where the W boson resonance implies a much more efficient primordial annihilation of the heavy neutrinos upon their charged partners. Note that the remnant density $\Omega_N h^2$ is close to unity so that the neutral

species N of our model could well account for the astronomical missing mass without any fine-tuning of either the mass M_N or the mixing parameter ϵ .

Suppose, for instance, that $\epsilon = 10$ GeV and that the present value of the Hubble constant is $H = 50$ km/s/Mpc; N then contributes $\sim 40\%$ of the bulk matter in the universe provided its mass lies in the range between 50 and 80 GeV. If $\epsilon = 15$ GeV, a fairly large value with regard to the ρ measurements, a 30 GeV neutrino nevertheless reaches closure density whilst its gauge partner is on the verge of being produced at LEP.

5 - Discussion and prospects.

Whereas prospects have faded for doublet neutrinos in cosmology [3], an interesting new possibility is a heavy neutral species embedded inside a gauge triplet. A triplet neutrino may solve the astronomical "missing mass" conundrum provided its mass lies in the range $\sim 30 - 80$ GeV, in a domain presently accessible to accelerators. The primordial behaviour of the species N is intermediate between that of a pure gauge singlet for which, due to the lack of interactions with gauge bosons, annihilation as well as thermalization are absent from the early universe, and that of a charged particle whose relic present density is severely constrained [11], and too low to account for the dark matter. The neutral component N is a natural mixture of those typical particles so that its fossil abundance may actually reach closure density.

Though N is not directly detectable since it does not couple to the Z^0 and is electrically neutral, its charged companion E must nevertheless weigh less than ~ 100 GeV in order for the entire scheme to be cosmologically relevant. Whilst still undetectable at the Z^0 peak, the charged species E should be spotted by LEP detectors as soon as the beam energy is cranked up during the second phase of LEP. Such a charged particle has similar interactions to the so-called "chargino", a supersymmetric mixture between charged Higgsinos and the W boson. We therefore urge experimentalists to consider our triplet option for dark matter as a plausible alternative to the supersymmetric extensions of the electroweak Standard Model.

Note that simple non-supersymmetric extensions of the Standard Model, which may solve the dark matter puzzle and lead to an $\Omega = 1$ universe, have recently been considered [14]. A generic gauge multiplet is added to the existing particles. These authors have actually focused on the neutral component N of a gauge triplet. However, the

lifting of the mass degeneracy between N and E is only induced by pure radiative corrections so that Q_{EN} is always very small (this mass gap actually does not exceed ~ 500 MeV in the asymptotic regime where $M_N \sim$ a few TeV). For vanishing mass gap, the relic triplet neutrinos reach closure density provided their mass is large, i.e., for a value of $M_N \sim 6.6 \sqrt{\Omega_N h^2}$ TeV.

Our approach is quite different. In section 3, we delineate the region of the (M_N, Q_{EN}) diagram where the triplet neutrino N is a plausible dark matter candidate. The mass gap Q_{EN} is the relevant free parameter of our analysis and triggers a quite unconventional primordial behaviour of the triplet species. In section 4, we show that mixing between triplet and singlet fields naturally leads to the relevant values of the mass difference Q_{EN} so that triplet neutrinos may indeed be plausible dark matter candidates already in the low mass regime $\sim 30 - 80$ GeV.

Direct detection of the heavy neutrinos from the galactic halo by shielded silicon or germanium detectors does not seem promising. Elastic scattering of the N upon a nucleus involves a second order diagram where two W bosons are exchanged. The cross-section for that process is desperately low and does not allow much hope. However, if the N 's pervade the galaxy, they may be detectable through their direct annihilations into two photons. Naively scaling from the doublet case [15], we infer a two-gamma ray line signal of ~ 1 to 10 photons per year for a $1 \text{ m}^2 \text{ sr}$ effective area gamma ray detector of the ASTROGAM calibre, with a 1% energy resolution. Such a signal compares with the background noise (provided the latter is well understood). Further work is in progress to determine whether the LEP signature or the two-gamma ray line signal is most promising for future tests of this model.

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Figure captions

Figure 1 : The region of the (M_N, Q_{EN}) diagram with border lines $\Omega_N h^2 = 1/40$ and $\Omega_N h^2 = 1$ is of cosmological relevance. Inside this fairly extended domain, the neutral species N may naturally provide a significant fraction of the astronomical missing mass.

Figure 2 : For three different values of the mixing term, $\epsilon = 5$ GeV (solid), 10 GeV (long dash) and 15 GeV (short dash), the dependence of the fossil abundance $\Omega_N h^2$ is presented as a function of the neutral mass M_N . In spite of the naivety of the model discussed in section 4 where a triplet is mixed with a singlet, values of the remnant density close to unity are fairly naturally achieved.

Figure 1

Figure 2