Light neutralino dark matter in gaugino non–universal models

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Abstract. We discuss the cosmology and the astrophysical signals produced by light–neutralino dark matter in the frame of an effective MSSM model without gaugino-mass unification at a grand unification scale.

1. Supersymmetry and gaugino non–universality

A typical assumption of supersymmetric models is the unification condition for the three gaugino mass parameters $M_{1,2,3}$ at the GUT scale: $M_{1} = M_{2} = M_{3}$. This hypothesis implies that at the electroweak scale $M_{1} \simeq 0.5 M_{2}$. Under this unification condition the lower bound on the neutralino mass is determined to be about 50 GeV, as a consequence of the experimental lower bound on the chargino mass (which theoretically depends on $M_{2}$ but not on $M_{1}$) determined at LEP2: $m_{\chi^{\pm}} > \sim 100$ GeV. In this paper we consider an extension of the Minimal Supersymmetric standard Model (MSSM) which allows for a deviation from gaugino–mass universality by the introduction of the parameter $R$, defined as: $M_{1} = R M_{2}$ and varied here in the interval: $(0.01 \div 0.5) \ [1, 2, 3, 4, 5, 6]$. This range for $R$ implies that neutralinos may be lighter than in the standard MSSM, down to few GeV for $R \sim 0.01$. The ensuing light neutralinos have a dominant bino component; a deviation from a pure bino composition is mainly due to a mixture of $\tilde{B}$ with $\tilde{H}_{1}^{0} [1, 2, 3]$. In this paper we will discuss the cosmological properties of these light neutralinos and analyze their relevant direct and indirect detection rates. For a more detailed discussion on all these topics, as well as for a more thorough list of relevant references, see Refs. [1, 2, 3, 4, 5, 6].

2. Cosmology of light neutralinos

In the class of models we are considering here, the relic abundance of the very light neutralinos is dominated by two competing annihilation channels [1, 2]: annihilation into $\bar{b}b$ through the exchange of the pseudoscalar higgs $A$, and annihilation into $\bar{\tau}\tau$ via stau exchange. The mixture of the dominant bino component with the subdominant, but not negligible, higgsino [1, 2, 3] provides sizable Yukawa–type interactions between neutralinos and higgses: when the $A$ boson is relatively light this makes the annihilation cross section into $\bar{b}b$ the dominant channel. The ensuing relic abundance is a decreasing function of the neutralino mass and largely exceeds the cosmological upper bound on the cold dark matter (CDM) content of the Universe [1, 2]. We can therefore set an absolute lower bound on the neutralino mass of 6 GeV [2]. When the $A$
3. Direct detection

The relevant quantity in direct detection is the neutralino–nucleon scattering cross section \( \sigma_{\text{scalar}}^{(\text{nucleon})} \), multiplied by the factor \( \xi \) which defines the fractional amount of neutralinos as CDM components of the galactic halo. As usual, we define the fraction \( \xi \) in terms of the calculated neutralino relic abundance as:

\[
\xi = \min[1, \Omega \chi h^2 / (\Omega \chi h^2)_{\text{min}}],
\]

where \( (\Omega \chi h^2)_{\text{min}} \) defines the minimal value of the neutralino relic abundance below which we cannot accept that all the galactic DM is made of neutralinos: we have set \( (\Omega \chi h^2)_{\text{min}} = 0.095 \) [1, 3].

In our class of models, neutralinos with a mass close to the lower limit established in the previous Section are accompanied by light higgses [1, 3]: in this case not only the relic abundance, but also the scattering cross section is dominated by higgs exchange and \( \sigma_{\text{scalar}}^{(\text{nucleon})} \) is sizable, with peculiar properties [1, 3] which constrain the values of \( \sigma_{\text{scalar}}^{(\text{nucleon})} \) to lie in a very narrow range [1, 3]: the upper bound on \( \sigma_{\text{scalar}}^{(\text{ nucleon})} \) is set by the experimental lower limit on the higgs mass; the lower limit is a consequence of the upper bound on the neutralino relic abundance, which is strongly correlated to \( \sigma_{\text{scalar}}^{(\text{nucleon})} \) in this class on gaugino non–universal models [1, 3]. The values of \( \xi \sigma_{\text{scalar}}^{(\text{nucleon})} \), obtained by a wide scan of the supersymmetric parameter space, are shown in Fig. 1, where we also show the upper bounds we calculated [6] for the CDMS experiment [7], for different galactic halo models. We see that limits for neutralino masses above 25–30 GeV can be set for a standard isothermal halo, while in the case of axisymmetric halos neutralinos as light as 7 GeV can be probed. On the contrary, for the spherical but anisotropic models B1, no limit on light neutralinos are currently set. As we showed in Refs. [2, 3], the predicted rates are also largely compatible with the annual–modulation data of the DAMA Collaboration [8]. We conclude that direct detection is a very sensitive probe for the light neutralinos of gaugino non–universal supersymmetric models, the most sensitive together with antiprotons and antideuterons searches discussed in the next Section.

Figure 1. The colored region shows the values of \( \xi \sigma_{\text{scalar}}^{(\text{nucleon})} \) obtained in a wide scan of the supersymmetric parameter space. The funnel at low neutralino masses corresponds to gaugino non–universal models. The solid lines show the summary of our analysis on the upper limit from CDMS data [7]. The standard isothermal model with local rotational velocity 220 km sec\(^{-1}\) and local mass density 0.3 GeV cm\(^{-3}\) (A0) is the central solid line. The upper an lower curves show the two extremes obtained in our analysis and refer to a spherical model with anisotropic velocity dispersion (B1) and to an axisymmetric model (C3). For details, see [6].
4. Indirect detection at neutrino telescopes
Indirect evidence for WIMPs in our halo may be obtained at neutrino telescopes by measurements of the upgoing muons, which would be generated by neutrinos produced by pair annihilation of neutralinos captured and accumulated inside the Earth and the Sun [4]. For \( m_\chi \lesssim 40 \) GeV the signal from the Earth presents several peaks due to neutralino resonant capture on Oxygen, Silicon and Magnesium. Apart from the resonances, the predicted flux of light neutralinos is always very small and difficult to be accessed by experimentally [4]. Also the signal from the Sun is suppressed for masses below 50 GeV [4] and hard to detect. We conclude that investigations of light neutralinos by up-going muons from the Sun do not provide favorable prospects.

5. Gamma rays in space
The flux of gamma–rays produced by neutralino self–annihilation inside the galactic halo is potentially a promising tool of investigation. By comparing the predicted fluxes for a NFW DM profile with EGRET data we obtain that the small mass range is the most favorable sector of the supersymmetric model for this kind of signal (as is for all the signals which come from neutralino annihilation in the Galaxy). Nevertheless, the predicted signal is at least one order of magnitude smaller than the detected flux [4]. In the case of steeper DM density profiles, like in the case of the Moore et al. shape, gamma–ray studies could access the signal produced by neutralinos in the mass range below 10–20 GeV [4]. For cored isothermal halos, the predicted fluxes are one order of magnitude smaller than the NFW ones.

6. Antimatter in space: antiprotons and antideuterons
Annihilation of neutralinos in the galactic halo may lead also to the production of antiprotons and antideuterons [10], as well as positrons. Once antiprotons or antideuterons are produced, they undergo diffusion and energy losses inside the galactic halo before reaching the Earth. For this reason, this kind of signals are less sensitive to the actual DM density profile, since they do not significantly probe the central parts of the galactic halo, where the various halo shapes mostly differ. However, uncertainties in the modeling of propagation and diffusion introduce large variability in the predicted fluxes. These uncertainties somehow limit the capabilities of the antiproton signal. Nevertheless, especially for neutralinos lighter than 20 GeV, antiprotons represent a potentially relevant probe [4, 5]. Very promising is the antideuteron signal [10]. The full neutralino mass range below 40 GeV could be probed by antideutrons searches in space by foreseeable experiments is space like GAPS or AMS.

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