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SUPERWIMPS IN SUPERGRAVITY

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In supergravity theories, a natural possibility is that neutralinos or sleptons freeze out at their thermal relic density, but then decay to gravitinos after about a year. The resulting gravitinos are then superWIMPs — superweakly-interacting massive particles that naturally inherit the desired relic density from late decays of conventional WIMPs. SuperWIMP dark matter escapes all conventional searches. However, the late decays that produce superWIMPs provide new and promising early universe signatures for cold dark matter.

1 Introduction

One of the many virtues of supergravity theories, such as minimal supergravity,¹ is that they naturally provide an excellent cold dark matter candidate — the neutralino.² Neutralinos emerge as the lightest supersymmetric particle (LSP) in simple models. Assuming R -parity conservation, they are stable. In addition, their thermal relic density is naturally in the range required for dark matter, and there are promising prospects for both direct and indirect detection.

Recently we have explored an alternative solution to the dark matter problem in supergravity theories.^{3,4} Neutralino dark matter is a possibility only if the gravitino mass $m_{\tilde{G}}$ is above the neutralino mass. In supergravity, this need not be the case — $m_{\tilde{G}}$ and the scalar and gaugino masses are all of the order of $M_{\text{weak}} \sim \langle F \rangle / M_{\text{Pl}}$, where $M_{\text{weak}} \sim 100 \text{ GeV} - 1 \text{ TeV}$, $M_{\text{Pl}} \simeq 1.2 \times 10^{19} \text{ GeV}$, and $\langle F \rangle$ are the weak, Planck, and supersymmetry-breaking scales, respectively. The specific ordering depends on unknown, presumably $\mathcal{O}(1)$, coefficients.

The gravitino is therefore the LSP in roughly “half” of parameter space, and it may be cold dark matter. Assuming that the universe inflates and then reheats to a temperature below $\sim 10^8 \text{ GeV} - 10^{10} \text{ GeV}$,⁵ the number of gravitinos is negligible after reheating. Then, because the gravitino couples only gravitationally with all interactions suppressed by M_{Pl} , it plays no role in the thermodynamics of the early universe. The next-to-lightest supersymmetric particle (NLSP) therefore freezes out as usual; if it is weakly-interacting, its relic density will be near the desired value. However, much later, after

$$\tau \sim \frac{M_{\text{Pl}}^2}{M_{\text{weak}}^3} \sim 10^5 \text{ s} - 10^8 \text{ s} , \quad (1)$$

the WIMP decays to the LSP, converting much of its energy density to gravitinos. Gravitino LSPs may therefore form a significant relic component of

our universe, with a relic abundance naturally near $\Omega_{\text{DM}} \simeq 0.23$.⁶ Models with weak-scale extra dimensions also provide a similar dark matter particle in the form of Kaluza-Klein gravitons,^{3,7} with Kaluza-Klein gauge bosons or leptons playing the role of the decaying WIMP.⁸ Because such dark matter candidates naturally preserve the WIMP relic abundance, but have interactions that are weaker than weak, we refer the whole class of such particles as “superWIMPs.”

The superWIMP possibility differs markedly from previous proposals for gravitino dark matter. In the original gravitino dark matter scenario, gravitinos have thermal equilibrium abundances and form warm dark matter.⁹ The required \sim keV mass for such gravitinos is taken as evidence for a new intermediate supersymmetry breaking scale $\langle F \rangle$. Alternatively, weak-scale gravitinos may be produced with the correct abundances during reheating, provided that the reheat temperature is tuned appropriately. In contrast to these scenarios, the properties of superWIMP dark matter are determined by the two known mass scales M_{weak} and M_{Pl} . SuperWIMP dark matter therefore preserves the main quantitative virtue of conventional WIMPs, naturally connecting the electroweak scale to the observed relic density. In addition, the mechanism of gravitino production through late decays implies that the superWIMP scenario is highly predictive, and, as we shall see, testable.

2 SuperWIMP Properties

As outlined above, superWIMP dark matter is produced in decays $\text{WIMP} \rightarrow \text{SWIMP} + S$, where S denotes one or more standard model particles. The superWIMP is essentially invisible, and so the observable consequences rely on finding signals of S production in the early universe. In principle, the strength of these signals depend on what S is and its initial energy distribution. For the parameters of greatest interest here, however, S quickly initiates electromagnetic or hadronic cascades. As a result, the observable consequences depend only on the WIMP’s lifetime τ and the average total electromagnetic or hadronic energy released in WIMP decay.^{10,11,12,13,14,15,16,17}

In many simple supergravity models, the lightest standard model superpartner is a Bino-like neutralino. For pure Binors,

$$\Gamma(\tilde{B} \rightarrow \gamma\tilde{G}) = \frac{\cos^2 \theta_W}{48\pi M_*^2} \frac{m_{\tilde{B}}^5}{m_{\tilde{G}}^2} \left[1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{B}}^2} \right]^3 \left[1 + 3 \frac{m_{\tilde{G}}^2}{m_{\tilde{B}}^2} \right]. \quad (2)$$

This decay width, and all results that follow, includes the contributions from couplings to both the spin $\pm 3/2$ and $\pm 1/2$ gravitino polarizations. These must all be included, as they are comparable in models with high-scale supersymmetry breaking. In the limit $\Delta m \equiv m_{\text{WIMP}} - m_{\text{SWIMP}} \ll m_{\text{SWIMP}}$,

$\Gamma(\tilde{B} \rightarrow \gamma\tilde{G}) \propto (\Delta m)^3$ and the decay lifetime is

$$\tau(\tilde{B} \rightarrow \gamma\tilde{G}) \approx 2.3 \times 10^7 \text{ s} \left[\frac{100 \text{ GeV}}{\Delta m} \right]^3, \quad (3)$$

independent of the overall m_{WIMP} , m_{SWIMP} mass scale.

If a slepton is the lightest standard model superpartner, its decay width is

$$\Gamma(\tilde{\ell} \rightarrow \ell\tilde{G}) = \frac{1}{48\pi M_*^2} \frac{m_{\tilde{\ell}}^5}{m_{\tilde{G}}^2} \left[1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{\ell}}^2} \right]^4. \quad (4)$$

This expression is valid for any scalar superpartner decaying to a nearly massless standard model partner. In particular, it holds for $\tilde{\ell} = \tilde{e}, \tilde{\mu}$, or $\tilde{\tau}$, and arbitrary mixtures of the $\tilde{\ell}_L$ and $\tilde{\ell}_R$ gauge eigenstates. In the limit $\Delta m \equiv m_{\text{WIMP}} - m_{\text{SWIMP}} \ll m_{\text{SWIMP}}$, the decay lifetime is

$$\tau(\tilde{\ell} \rightarrow \ell\tilde{G}) \approx 3.6 \times 10^8 \text{ s} \left[\frac{100 \text{ GeV}}{\Delta m} \right]^4 \frac{m_{\tilde{G}}}{1 \text{ TeV}}. \quad (5)$$

The electromagnetic energy release is conveniently written in terms of

$$\zeta_{\text{EM}} \equiv \varepsilon_{\text{EM}} Y_{\text{WIMP}}, \quad (6)$$

where ε_{EM} is the initial electromagnetic energy released in each WIMP decay, and $Y_{\text{WIMP}} \equiv n_{\text{WIMP}}/n_{\gamma}^{\text{BG}}$ is the number density of WIMPs before they decay, normalized to the number density of background photons $n_{\gamma}^{\text{BG}} = 2\zeta(3)T^3/\pi^2$. We define hadronic energy release similarly as $\zeta_{\text{had}} \equiv \varepsilon_{\text{had}} Y_{\text{WIMP}}$. In the superWIMP scenario, WIMP velocities are negligible when they decay. We will be concerned mainly with the case where S is a single nearly massless particle, and so we define

$$E_S \equiv \frac{m_{\text{WIMP}}^2 - m_{\text{SWIMP}}^2}{2m_{\text{WIMP}}}, \quad (7)$$

the potentially visible energy in such cases.

For the neutralino WIMP case, $S = \gamma$. (Possible contributions to hadronic decay products are discussed in the last section.) Clearly all of the initial photon energy is deposited in an electromagnetic shower, and so

$$\varepsilon_{\text{EM}} = E_{\gamma}, \quad \varepsilon_{\text{had}} \simeq 0. \quad (8)$$

For the slepton case, the energy release is flavor-dependent. For the case of staus,

$$\varepsilon_{\text{EM}} \approx \frac{1}{3} E_{\tau} - E_{\tau}, \quad \varepsilon_{\text{had}} = 0, \quad (9)$$

where the range in ε_{EM} results from the possible variation in electromagnetic energy from π^{\pm} and ν decay products. The precise value of ε_{EM} is in principle calculable once the stau's chirality and mass, and the superWIMP mass, are

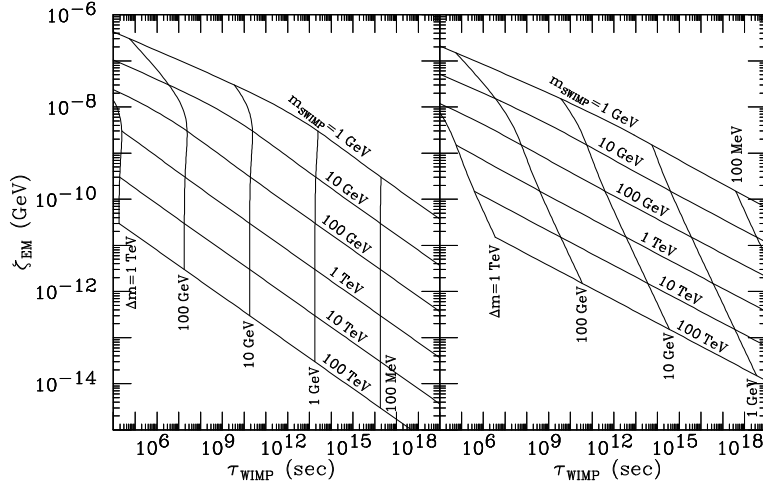


Figure 1. Predicted values of WIMP lifetime τ and electromagnetic energy release $\zeta_{\text{EM}} \equiv \varepsilon_{\text{EM}} Y_{\text{WIMP}}$ in the \tilde{B} (left) and $\tilde{\tau}$ (right) WIMP scenarios for $m_{\text{SWIMP}} = 1 \text{ GeV}, 10 \text{ GeV}, \dots, 100 \text{ TeV}$ (top to bottom) and $\Delta m \equiv m_{\text{WIMP}} - m_{\text{SWIMP}} = 1 \text{ TeV}, 100 \text{ GeV}, \dots, 100 \text{ MeV}$ (left to right). For the $\tilde{\tau}$ WIMP scenario, we assume $\varepsilon_{\text{EM}} = \frac{1}{2} E_{\tau}$.

specified. However, as the possible variation in ε_{EM} is not great relative to other effects, we will simply present results below for the representative value of $\varepsilon_{\text{EM}} = \frac{1}{2} E_{\tau}$.

The lifetimes and energy releases in the Bino and stau WIMP scenarios are given in Fig. 1 for a range of $(m_{\text{WIMP}}, \Delta m)$. For natural weak-scale values of these parameters, the lifetimes and energy releases in the neutralino and stau scenarios are similar, with lifetimes of about a year, in accord with the rough estimate of Eq. (1), and energy releases of

$$\zeta_{\text{EM}} \sim 10^{-9} \text{ GeV} . \quad (10)$$

Such values have testable implications, as we discuss in the following two sections.

3 Big Bang Nucleosynthesis

3.1 Standard BBN and CMB Baryometry

Big Bang nucleosynthesis predicts primordial light element abundances in terms of one free parameter, the baryon-to-photon ratio $\eta \equiv n_B/n_\gamma$. At present, the observed D, ^4He , ^3He , and ^7Li abundances may be accommodated for baryon-to-photon ratios in the range¹⁸

$$\eta_{10} \equiv \eta/10^{-10} = 2.6 - 6.2 . \quad (11)$$

In light of the difficulty of making precise theoretical predictions and reducing (or even estimating) systematic uncertainties in the observations, this consistency is a well-known triumph of standard Big Bang cosmology.

At the same time, given recent and expected advances in precision cosmology, the standard BBN picture merits close scrutiny. Recently, BBN baryometry has been supplemented by CMB data, which alone yields $\eta_{10} = 6.1 \pm 0.4$.⁶ Observations of deuterium absorption features in spectra from high redshift quasars imply a primordial D fraction of $D/H = 2.78_{-0.38}^{+0.44} \times 10^{-5}$.¹⁹ Combined with standard BBN calculations,²⁰ this yields $\eta_{10} = 5.9 \pm 0.5$. The remarkable agreement between CMB and D baryometers has two new implications for scenarios with late-decaying particles. First, assuming there is no fine-tuned cancellation of unrelated effects, it prohibits significant entropy production between the times of BBN and decoupling. Second, the CMB measurement supports determinations of η from D, already considered by many to be the most reliable BBN baryometer. It suggests that if D and another BBN baryometer disagree, the “problem” lies with the other light element abundance — either its systematic uncertainties have been underestimated, or its value is modified by new astrophysics or particle physics. Such disagreements may therefore provide specific evidence for late-decaying particles in general, and superWIMP dark matter in particular. We address this possibility here.

In standard BBN, the baryon-to-photon ratio $\eta_{10} = 6.0 \pm 0.5$ favored by D and CMB observations predicts²⁰

$$Y_p = 0.2478 \pm 0.0010 \quad (12)$$

$${}^3\text{He}/\text{H} = (1.03 \pm 0.06) \times 10^{-5} \quad (13)$$

$${}^7\text{Li}/\text{H} = 4.7_{-0.8}^{+0.9} \times 10^{-10} \quad (14)$$

at 95% CL, where Y_p is the ${}^4\text{He}$ mass fraction. At present the greatest discrepancy lies in ${}^7\text{Li}$, where all measurements are below the prediction of Eq. (14). The ${}^7\text{Li}$ fraction may be determined precisely in very low metallicity stars. Three independent studies^{21,22,23} find

$${}^7\text{Li}/\text{H} = 1.5_{-0.5}^{+0.9} \times 10^{-10} \quad (95\% \text{ CL}) \quad (15)$$

$${}^7\text{Li}/\text{H} = 1.72_{-0.22}^{+0.28} \times 10^{-10} \quad (1\sigma + \text{sys}) \quad (16)$$

$${}^7\text{Li}/\text{H} = 1.23_{-0.32}^{+0.68} \times 10^{-10} \quad (\text{stat} + \text{sys}, 95\% \text{ CL}) , \quad (17)$$

where depletion effects have been estimated and included in the last value. Within the published uncertainties, the observations are consistent with each other but inconsistent with Eq. (14), with central values lower than predicted by a factor of 3 – 4. ${}^7\text{Li}$ may be depleted from its primordial value by astrophysical effects, for example, by rotational mixing in stars that brings Lithium to the core where it may be burned,^{24,25} but it is controversial whether this effect is large enough to reconcile observations with the BBN prediction.²³

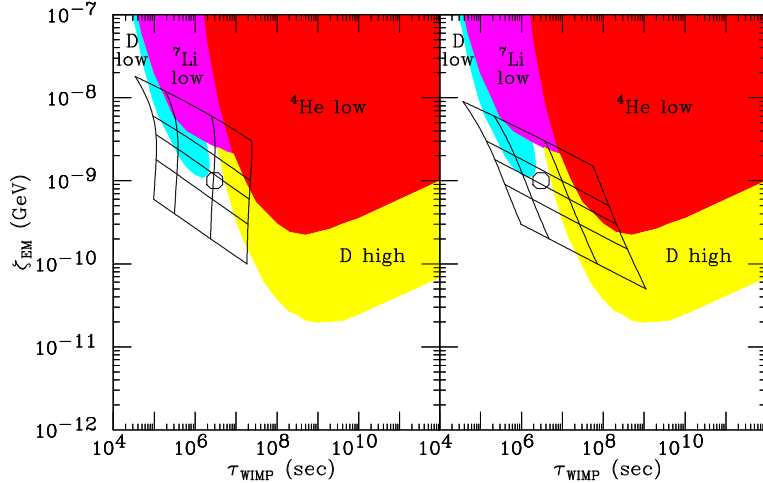


Figure 2. The grid gives predicted values of WIMP lifetime τ and electromagnetic energy release $\zeta_{\text{EM}} \equiv \varepsilon_{\text{EM}} Y_{\text{WIMP}}$ in the \tilde{B} (left) and $\tilde{\tau}$ (right) WIMP scenarios for $m_{\text{SWIMP}} = 100 \text{ GeV}, 300 \text{ GeV}, 500 \text{ GeV}, 1 \text{ TeV}, \text{ and } 3 \text{ TeV}$ (top to bottom) and $\Delta m \equiv m_{\text{WIMP}} - m_{\text{SWIMP}} = 600 \text{ GeV}, 400 \text{ GeV}, 200 \text{ GeV}, \text{ and } 100 \text{ GeV}$ (left to right). For the $\tilde{\tau}$ WIMP scenario, we assume $\varepsilon_{\text{EM}} = \frac{1}{2} E_{\tau}$. The analysis of BBN constraints by Cyburt, Ellis, Fields, and Olive¹⁶ excludes the shaded regions. The best fit region with $(\tau, \zeta_{\text{EM}}) \sim (3 \times 10^6 \text{ s}, 10^{-9} \text{ GeV})$, where ${}^7\text{Li}$ is reduced to observed levels by late decays of WIMPs to superWIMPs, is given by the circle.

The other light element abundances are in better agreement. For example, a global analysis,²⁰ using the “high” Y_p values of Izotov and Thuan,²⁶ finds $\chi^2 = 23.2$ for 3 degrees of freedom, where χ^2 is completely dominated by the ${}^7\text{Li}$ discrepancy.

3.2 SuperWIMPs and the ${}^7\text{Li}$ Underabundance

Given the overall success of BBN, the first implication for new physics is that it should not drastically alter any of the light element abundances. This requirement restricts the amount of energy released at various times in the history of the universe. A recent analysis by Cyburt, Ellis, Fields, and Olive of electromagnetic cascades finds that the shaded regions of Fig. 2 are excluded by such considerations.¹⁶ The various regions are disfavored by the following conservative criteria:

$$\text{D low} : \text{D}/\text{H} < 1.3 \times 10^{-5} \quad (18)$$

$$\text{D high} : \text{D}/\text{H} > 5.3 \times 10^{-5} \quad (19)$$

$${}^4\text{He low} : Y_p < 0.227 \quad (20)$$

$${}^7\text{Li low} : {}^7\text{Li}/\text{H} < 0.9 \times 10^{-10} . \quad (21)$$

A subset of superWIMP predictions from Fig. 1 is superimposed on this plot. The subset is for weak-scale m_{SWIMP} and Δm , the most natural values, given the independent motivations for new physics at the weak scale. The BBN constraint eliminates some of the region predicted by the superWIMP scenario, but regions with $m_{\text{WIMP}}, m_{\text{SWIMP}} \sim M_{\text{weak}}$ remain viable.

The ${}^7\text{Li}$ anomaly discussed above may be taken as evidence for new physics, however. To improve the agreement of observations and BBN predictions, it is necessary to destroy ${}^7\text{Li}$ without harming the concordance between CMB and other BBN determinations of η . This may be accomplished for $(\tau, \zeta_{\text{EM}}) \sim (3 \times 10^6 \text{ s}, 10^{-9} \text{ GeV})$.¹⁶ This “best fit” point is marked in Fig. 2. The amount of energy release is determined by the requirement that ${}^7\text{Li}$ be reduced to observed levels without being completely destroyed – one cannot therefore be too far from the “ ${}^7\text{Li}$ low” region. In addition, one cannot destroy or create too much of the other elements. ${}^4\text{He}$, with a binding threshold energy of 19.8 MeV, much higher than Lithium’s 2.5 MeV, is not significantly destroyed. On the other hand, D is loosely bound, with a binding energy of 2.2 MeV. The two primary reactions are D destruction through $\gamma\text{D} \rightarrow n\text{p}$ and D creation through $\gamma{}^4\text{He} \rightarrow \text{DD}$. These are balanced in the channel of Fig. 2 between the “low D” and “high D” regions, and the requirement that the electromagnetic energy that destroys ${}^7\text{Li}$ not disturb the D abundance specifies the preferred decay time $\tau \sim 3 \times 10^6 \text{ s}$.

Without theoretical guidance, this scenario for resolving the ${}^7\text{Li}$ abundance is rather fine-tuned: possible decay times and energy releases span tens of orders of magnitude, and there is no motivation for the specific range of parameters required to resolve BBN discrepancies. In the superWIMP scenario, however, both τ and ζ_{EM} are specified: the decay time is necessarily that of a gravitational decay of a weak-scale mass particle, leading to Eq. (1), and the energy release is determined by the requirement that superWIMPs be the dark matter, leading to Eq. (10). Remarkably, these values coincide with the best fit values for τ and ζ_{EM} . More quantitatively, we note that the grids of predictions for the \tilde{B} and $\tilde{\tau}$ scenarios given in Fig. 2 cover the best fit region. Current discrepancies in BBN light element abundances may therefore be naturally explained by superWIMP dark matter.

This tentative evidence may be reinforced or disfavored in a number of ways. Improvements in the BBN observations discussed above may show if the ${}^7\text{Li}$ abundance is truly below predictions. In addition, measurements of ${}^6\text{Li}/\text{H}$ and ${}^6\text{Li}/{}^7\text{Li}$ may constrain astrophysical depletion of ${}^7\text{Li}$ and may also provide additional evidence for late decaying particles in the best fit region.^{13,27,14,16} Finally, if the best fit region is indeed realized by $\text{WIMP} \rightarrow \text{SWIMP}$ decays, there are a number of other testable implications for cosmology and particle physics.^{3,4} We discuss one of these in the following section.

4 The Cosmic Microwave Background

The injection of electromagnetic energy may also distort the frequency dependence of the CMB black body radiation. For the decay times of interest, with redshifts $z \sim 10^5 - 10^7$, the resulting photons interact efficiently through $\gamma e^- \rightarrow \gamma e^-$, but photon number is conserved, since double Compton scattering $\gamma e^- \rightarrow \gamma \gamma e^-$ and thermal bremsstrahlung $eX \rightarrow eX\gamma$, where X is an ion, are inefficient. The spectrum therefore relaxes to statistical but not thermodynamic equilibrium, resulting in a Bose-Einstein distribution function

$$f_\gamma(E) = \frac{1}{e^{E/(kT)+\mu} - 1}, \quad (22)$$

with chemical potential $\mu \neq 0$.

For the low values of baryon density currently favored, the effects of double Compton scattering are more significant than those of thermal bremsstrahlung. The value of the chemical potential μ may therefore be approximated for small energy releases by the analytic expression²⁸

$$\mu = 8.0 \times 10^{-4} \left[\frac{\tau}{10^6 \text{ s}} \right]^{\frac{1}{2}} \left[\frac{\zeta_{\text{EM}}}{10^{-9} \text{ GeV}} \right] e^{-(\tau_{\text{dC}}/\tau)^{5/4}}, \quad (23)$$

where

$$\tau_{\text{dC}} = 6.1 \times 10^6 \text{ s} \left[\frac{T_0}{2.725 \text{ K}} \right]^{-\frac{12}{5}} \left[\frac{\Omega_B h^2}{0.022} \right]^{\frac{4}{5}} \left[\frac{1 - \frac{1}{2} Y_p}{0.88} \right]^{\frac{4}{5}}. \quad (24)$$

In Fig. 3 we show contours of chemical potential μ . The current bound is $\mu < 9 \times 10^{-5}$.^{29,18} We see that, although there are at present no indications of deviations from black body, current limits are already sensitive to the superWIMP scenario, and particularly to regions favored by the BBN considerations described in Sec. 3. In the future, the Diffuse Microwave Emission Survey (DIMES) may improve sensitivities to $\mu \approx 2 \times 10^{-6}$.³⁰ DIMES will therefore probe further into superWIMP parameter space, and will effectively probe all of the favored region where the ${}^7\text{Li}$ underabundance is explained by decays to superWIMPs.

5 Summary and Future Directions

SuperWIMP dark matter presents a qualitatively new dark matter possibility realized in some of the most promising frameworks for new physics. In supergravity, superWIMP dark matter is realized simply by assuming that the gravitino is the LSP. When the NLSP is a weakly-interacting superpartner, the gravitino superWIMP naturally inherits the desired dark matter relic density. The prime WIMP virtue connecting weak scale physics with the observed dark matter density is therefore preserved by superWIMP dark matter.

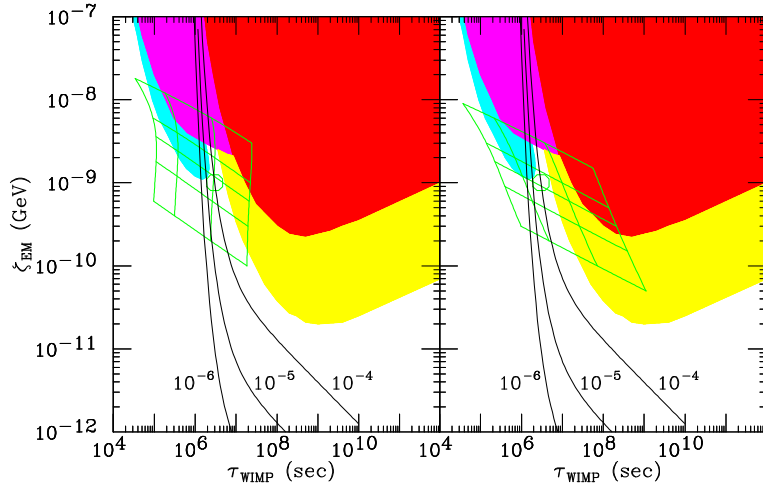


Figure 3. Contours of μ , parameterizing the distortion of the CMB from a Planckian spectrum, in the $(\tau, \zeta_{\text{EM}})$ plane. Regions predicted by the superWIMP dark matter scenario, and BBN excluded and best fit regions are given as in Fig. 2.

Because superWIMP dark matter interacts only gravitationally, searches for its effects in standard dark matter experiments are hopeless. At the same time, this superweak interaction implies that WIMPs decaying to it do so after BBN. BBN observations and later observations, such as of the CMB, therefore bracket the era of WIMP decays, and provide new signals. SuperWIMP and conventional WIMP dark matter therefore have disjoint sets of signatures; we have explored the new opportunities for dark matter detection presented by superWIMPs. We find that precision cosmology excludes some of the natural parameter space, and future improvements in BBN baryometry and probes of CMB μ distortions will extend this sensitivity.

We have also found that the decay times and energy releases generic in the superWIMP scenario may naturally reduce ${}^7\text{Li}$ abundances to the observed levels without sacrificing the agreement between D and CMB baryometry. The currently observed ${}^7\text{Li}$ underabundance therefore provides evidence for the superWIMP hypothesis. This scenario predicts that more precise BBN observations will expose a truly physical underabundance of ${}^7\text{Li}$. In addition, probes of CMB μ distortions at the level of $\mu \sim 2 \times 10^{-6}$ will be sensitive to the entire preferred region. An absence of such effects will exclude this explanation.

We have considered here the cases where neutralinos and sleptons decay to gravitinos and electromagnetic energy. In the case of sleptons, BBN constraints on electromagnetic cascades provide the dominant bound. For neutralinos, however, the case is less clear. Neutralinos may produce hadronic en-

ergy through two-body decays $\chi \rightarrow Z\tilde{G}, h\tilde{G}$, and three-body decays $\chi \rightarrow q\bar{q}\tilde{G}$. Detailed BBN studies constraining hadronic energy release may exclude such two-body decays, thereby limiting possible neutralino WIMP candidates to photinos, or even exclude three-body decays, thereby eliminating the neutralino WIMP scenario altogether. At present, detailed BBN studies of hadronic energy release incorporating the latest data are limited to decay times $\tau \lesssim 10^4$ s.¹⁷ We strongly encourage detailed studies for later times $\tau \sim 10^6$ s, as these may have a great impact on what superWIMP scenarios are viable.

Finally, the gravitino superWIMP scenario has strong implications for the supersymmetric spectrum and collider searches for supersymmetry. In particular, the possibility that the lightest observable superpartner is charged, long thought to be excluded in supergravity by the problems associated with charged dark matter, is in fact viable. Searches at hadron colliders for “exotic” long-lived heavy charged particles³¹ are therefore probes of supergravity, the most conventional of supersymmetric theories.

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