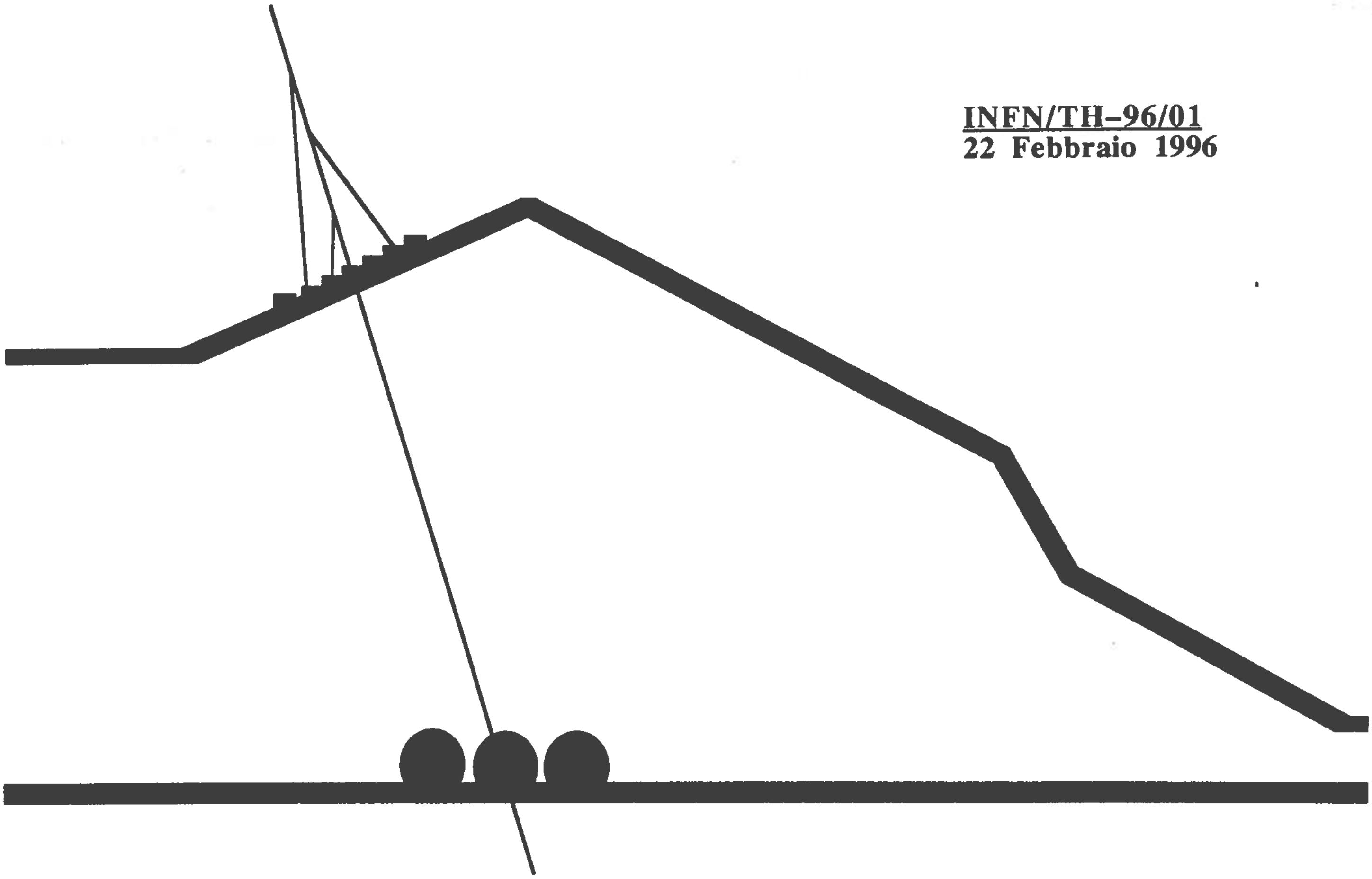
INFN/TH-96/01
22 Febbraio 1996



HIGHLIGHTS OF ASTROPARTICLE PHYSICS

V. Berezinsky

*(Plenary talk at the Europhysics Conference on High Energy Physics
July 27 - August 2, 1995, Brussels)*

INFN - Laboratori Nazionali del Gran Sasso

Published by **SIS–Pubblicazioni**
dei Laboratori Nazionali di Frascati

INFN - Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

INFN/TH-96/01
22 Febbraio 1996

HIGHLIGHTS OF ASTROPARTICLE PHYSICS

V.S. Berezinsky
INFN-Laboratori Nazionali del Gran Sasso, Statale 17bis, I-67010 Assergi (L'Aquila), Italy

Plenary talk at the Europhysics Conference on High Energy Physics
July 27 - August 2, 1995, Brussels

HIGHLIGHTS OF ASTROPARTICLE PHYSICS

V.BEREZINSKY

INFN, Laboratori Nazionali del Gran Sasso, 67010 Assergi (AQ), Italy

Three topics of astroparticle physics are reviewed in this paper: (i) the solar neutrino problem, (ii) the status of the neutralino as dark matter particle and (iii) a proposed connection between ultra-high energy cosmic rays ($E > 10^{19}$ eV) and gamma ray bursts. The solar neutrino problem can have in principle two solutions: one with a *standard neutrino* and the other with a *non-standard neutrino*, i.e. with properties beyond the SM. We demonstrate that the former case is strongly disfavored (or excluded) and thus it gives the strongest known evidence for physics beyond the SM.

1 SOLAR NEUTRINO PROBLEM

1.1 Introduction

The Solar Neutrino Problem (SNP) is a deficit of neutrino fluxes detected in all four solar-neutrino experiments: GALLEX [1], SAGE [2], KAMIOKANDE [3] and Homestake [4]. The data, as reported in 1995, are listed in Table 1 and compared with calculations of Bahcall and Pinnsoneault [5] for the Standard Solar Model (SSM).

Table 1: The solar-neutrino data of 1995 compared with the SSM prediction.

	DATA	SSM	DATA/SSM
GALLEX (SNU)	77.1 ± 9.8	137	0.563 ± 0.073
SAGE (SNU)	69 ± 12	137	0.504 ± 0.085
KAM. (10^6 cm^{-2}s^{-1})	2.89 ± 0.41	6.5	0.444 ± 0.062
HOM. (SNU)	2.55 ± 0.25	9.3	0.274 ± 0.027

The solar neutrino spectrum is characterized by three most important components.

(i) The most energetic part of the spectrum is presented by boron neutrinos from $^8B \to ^8Be + e^+ + \nu_e$ decay. The maximum energy of neutrinos in this spectrum is $E_{\nu,max} \approx 14$ MeV. Kamiokande, which has the highest threshold of neutrino detection ($E_\nu^{th} \approx 7$ MeV since 1991) detects only boron neutrinos.

(ii) Beryllium neutrinos ($^7Be + e^- \to ^7Li + \nu_e$) are monoenergetic ($E_\nu = 0.862$ MeV). The predicted flux of Be-neutrinos depends weakly on the solar model and is $(4.2 - 4.9) \cdot 10^9$ cm^{-2}s^{-1}. Homestake detects both boron and beryllium neutrinos: ^8B-neutrinos provide about 80% of the total signal and ^7Be-neutrinos - about 15%

(iii) The low-energy part of the solar-neutrino specrum is presented by *pp*- neutrinos ($p+p \to ^2H + e^+ + \nu_e$) with maximum energy $E_\nu^{max} = 0.42\ MeV$. These neutrinos greatly overnumber the flux of other neutrinos ($6.1 \cdot 10^{10}$ cm^{-2}s^{-1}). The flux is determined practically only by solar luminosity and therefore is very reliably predicted. GALLEX and SAGE measure mostly *pp*-neutrinos (about 60% of the total signal) with some contribution of ^7Be and ^8B neutrinos (about 25% and 10%, respectively).

From Table 1 one can see that the suppression factor, DATA/SSM, is ~ 0.5 within 1σ for the first three experiments, while for the Homestake detector it is ~ 0.3. It is easy to understand that this creates a problem for a nuclear/astrophysical solution to the SNP. Indeed, since the nuclear/astrophysical factors cannot change the shape of the ^8B-neutrino spectrum, the suppression factor for the boron neutrino signal in Homestake should be the same (~ 0.5) as in Kamiokande. Of course, ^7Be-neutrinos can be suppressed more strongly, but their contribution to the total signal in the Homestake detector is small ($\sim 15\%$). The incompatibility of the Homestake and Kamiokande results was first recognized Bahcall and Bethe [6].

Neutrino oscillations, e.g. $\nu_e \to \nu_\mu$, easily solve the Homestake/Kamiokande conflict. Each case of $\nu_e \to \nu_\mu$ conversion results in full disappearance of a signal in the Homestake detector, while in the Kamiokande detector it still exists due to $\nu_\mu + e \to \nu_\mu + e$ scattering. As a result the signal in Kamiokande should be stronger than in Homestake, as observed.

The discrepancy between predicted and observed neutrino fluxes, as given in Table 1, is a severe problem for an astrophysical solution. The SSM is the most elaborated stellar model. The modern status of the SSM is described in references [7,8].

There are at least 11 recently published calculations for the SSM as it is described above (see ref. [5] and ref. [9] till [19]. In all these works the physics included is the same. The slight difference in the results is caused by the different input parameters, most notably by the opacity of the

Sun. The calculated parameter which is most important for the solar neutrino fluxes is the central temperature. It varies by $\pm 1\%$ in the above cited calculations. The results are summarized [20] as $T_c = (15.55 \pm 0.15) \cdot 10^6 K$.

The numerial predictions of the SSM are hampered by uncertainties most notably in the rate of nuclear reactions [7,10] and in the opacity coefficients [7,8]. They can be also influenced by collective effects in the plasma [21].

There are actually three solar-neutrino problems.

The Homestake/Kamiokande conflict, mentioned above, will be described in some detail in Section 1.2. This is the most serious problem for the case of the standard neutrino (the nuclear/astrophysical solution to the SNP). If both experiments are correct, the neutrino is not standard. The Homestake/Kamiokande problem is analyzed in refs.[6,10,22,23]. An interesting discussion of the adjacent problem, the ratio of beryllium and boron neutrino fluxes, is given in ref.[24].

The Boron-neutrino deficit is a second solar-neutrino problem. For the last 25 years the Homestake results were interpreted as a deficit of ^8B-neutrinos. As described in Section 1.3, it could be that the ^8B-neutrino problem will be solved by small correlated changes in the nuclear cross-sections combined with very small ($\sim 1-2\%$) reduction of the central temperature of the Sun. It must be emphasized that the boron-neutrino flux could be brought into agreement with the direct measurements by the *Kamiokande detector*, while the Homestake result remains unexplained.

The third solar-neutrino problem, the *deficit of* ^7Be-*neutrinos*, is discussed in Section 1.4. At present it looks like the essence of the solar-neutrino problem. A significant contribution to understanding this problem is given in ref.[25] till ref.[28]. The direct detection of ^7Be-neutrinos will be performed by BOREXINO [29] at Gran Sasso.

The three solar-neutrino problems, as discussed above, were recently reviewed in refs. [23,30].

It is worth to emphasize the role of gallium experiments in understanding the Be-neutrino problem. In fact, the gallium results alone limit the beryllium neutrino flux below the prediction of the SSM [31,32]: $\phi(Be)/\phi_{SSM}(Be) < 0.76$ at $95\% CL$. However, if one subtracts from the gallium counting rate the contribution due to ^8B- neutrinos (taken, for example, from the Kamiokande data) and the contribution due to *pp*-neutrinos (from the solar-luminosity sum rule) then no place is left for ^7Be-neutrino flux [33]. For more detailed analysis see ref.[27].

One can conclude therefore that the case of the standard neutrino (the astrophysical solution to the SNP) is strongly disfavored.

The other solution is given by the nonstandard neutrino: MSW conversion [34], vacuum oscillations [35] (for a state-of-the-art description see [36]), resonant spin-flavor precession [38], and matter enhanced transition induced by flavor-changing neutral currents [39]. The most accurate description of all solar-neutrino data is given by the small-mixing angle MSW conversion.

We shall not touch here the description of the experiments. The reader can find it in the recent review [40].

1.2 Homestake/Kamiokande conflict or a problem of Be/B neutrino ratio

It can be rigorously proved that the case of the standard neutrinos (a nuclear/astrophysical solution) is excluded or strongly disfavored if the Homestake and Kamiokande results are correct within the cited statistical and systematic errors.

The point is that the suppression of SSM flux for the Homestake detector (data/SSM = 0.27) is stronger than for Kamiokande (data/SSM = 0.44). However, Homestake detects the same boron neutrinos as Kamiokande, and additionally Be-neutrinos. This argument was first considered quantitatively by Bahcall and Bethe [6].

In refs.[10,22] the Homestake/Kamiokande problem was analyzed using the graph $\phi_\nu(^7Be) - \phi_\nu(^8B)$, where ϕ_ν is the neutrino flux at the Earth. It is demonstrated that two regions allowed by Kamiokande and Homestake, respectively, do not intersect each other. The separation of two regions is the smallest at zero ^7Be-neutrino flux. However, even here they do not intersect each other at $90\% CL$.

In ref.[23] the Homestake/Kamiokande problem is analyzed analytically in terms of two ratios: $R_{Be} \equiv \phi_\nu(Be)/\phi_\nu^{SSM}(Be)$ and $R_B \equiv \phi_\nu(B)/\phi_\nu^{SSM}(B)$. It is shown that independently of the choice of the SSM model

$$R_{Be}/R_B < -1.08 \pm 0.48$$

The uncertainties in nuclear cross-sections do not affect this proof. The temperature solution (low T_c) is strongly excluded.

The analysis described above implies that an astrophysical solution to the Homestake-Kamiokande conflict needs unphysically low Be-neutrino flux.

The only way to avoid the Homestake/Kamiokande contradiction is to assume that $\nu^{37}Cl$ cross-section is overestimated (however, according to ref.[7] it is clear that it is not the case) or that at least one of the two experiments (Homestake and Kamiokande) has unknown large systematic errors.

1.3 Boron neutrino problem

This problem is clearly seen from Table 1 as neutrino deficit in the Kamiokande detector, which measures only boron neutrinos. The neutrino deficit in the Homestake detector also shows the suppression of the boron neutrino flux, because about 80% of the total signal in this detector is provided by the boron neutrinos. The boron neutrino problem was recognized during the last 25 years due to the Homestake results.

Two recently discussed effects, if combined, can resolve this problem.

The first one is the new measurements of $p + {}^7Be \rightarrow {}^8B + e^+ + \nu_e$ cross-section. The boron neutrino flux is proportional to this cross-section or to the astrophysical S-factor, $S_{17}(0)$, which conventionally characterizes [7] this cross-section. Recently this factor was found from the inverse process, the dissociation of ${}^8B$-nuclei in the Coulomb field of ${}^{208}Pb$: ${}^8B + {}^{208}Pb \rightarrow {}^{208}Pb + {}^7Be + p$. These measurements [41] result in the value of S-factor $S_{17}(0) = 16.7 \pm 2\ eV \cdot b$ to be compared with $S_{17}(0) = 22.4 \pm 2.1\ eV \cdot b$ used by Bahcall and Pinsonneault [5]. This value of $S_{17}(0)$ coincides with the lowest value from the previous measurements and, if true, can lower the predicted flux by a factor 1.3, which alone is still insufficient to resolve the boron neutrino problem (see Table 1).

The second phenomenon is the presence of collective processes in the dense plasma [21], which can decrease T_c.

To bring the Kamiokande flux into agreement with theoretical prediction one needs, beyond the factor 1.3 due to the low value of $S_{17}(0)$, to diminish the central temperature T_c only by 2.5%. It can be achieved by lowering the opacity in the solar core due to e.g. the collective plasma effects or due to a slight increase of the heavy element abundancies. The increase of ${}^3He + {}^3He$ cross-section, S_{33}, or decrease of ${}^3He + {}^4He$ -cross-section, S_{34}, can also facilate this task.

We therefore conclude that the prediction for boron neutrino flux can be brought into agreement with the Kamiokande observations at the price of small correlated changes of the cross-sections and the central temperature. At present this possibility should be still considered as a speculative one.

1.4 Beryllium-neutrino problem

We have at least a realistic hope that the boron-neutrino problem can be solved within the nuclear/astrophysical solution.

In several works [25,26,27,28] it was recently realized that the essence of the solar neutrino problem is a deficit of beryllium neutrinos.

We saw already this problem in Section 1.2: the Homestake/Kamiokande conflict demands too low Be/B neutrino ratio.

The model-independent lower limit for the gallium experiment gives another insight into the problem [33]. To obtain this limit let us assume zero beryllium neutrino flux $\phi_\nu(Be) = 0$. The flux of *pp*-neutrinos can be found from the solar luminosity sum rule. We obtain $\phi(pp) = 6.48 \cdot 10^{10}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ or 76.5 SNU for a gallium detector. The flux of ${}^8B$- neutrino as given by the Kamiokande experiment is $(2.89 \pm 0.40) \cdot 10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. The 1σ lower limit (statistical error only) corresponds to $2.49 \cdot 10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ or 6.0 SNU for the gallium experiments. If we neglect all other neutrino sources we obtain in total 82.5 SNU. To compare this (unrealistically low) lower limit with observational data we use the latest data of GALLEX [1] ($77.1 \pm 8.5^{+4.4}_{-5.4}$ SNU) and SAGE [2] ($69 \pm 10 \pm {}^{5}_{7}$ SNU). If we take the average and sum the errors quadratically we obtain 73.1 ± 7.6 SNU, i.e. 1.2σ below the very stringent lower limit obtained above. We then conclude that the results of the gallium experiments combined with the lower limit of Kamiokande leaves no place for beryllium neutrinos.

The upper limits for beryllium neutrino fluxes were obtained in ref's [25] and [26] from gallium experiments and Kamiokande. In terms of the signal in the gallium detectors they are found to be 19 SNU at 95% CL [25] and 5.1 SNU at 68% CL [26]. These figures are to be compared with $31 - 36$ SNU predicted by most SSM's. If one takes the Homestake data instead of Kamiokande, almost the same contradiction arises [27].

1.5 Low neutrino-flux models.

Reducing the $S_{17}(0)$ and slightly changing the other cross-sections or the temperature, one can bring the prediction for the ${}^8B$- neutrino flux into agreement with observations (the Kamiokande data). Two models with low ${}^8B$-neutrino flux have been recently elaborated.

We start with the Shi and Schramm (SS) model [42]. This is the SSM model with two input parameters modified as $S_{17} = 20.2$ eV and heavy element abundance $Z = 0.015$. The low Z provides the lower central temperature T_c. Actually, this aim can be accomplished due to collective plasma effects. The ${}^8B$-neutrino flux is predicted to be $3 \cdot 10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, in a good agreement with the Kamiokande data $(2.75 \pm 0.45) \cdot 10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Dar and Shaviv [43] introduced in their model (DS) the following new elements: (i) they calculated $S_{17}(0)$ from the Filippone et al data and found this value as low as 17 eV$\cdot b$, (ii) they evaluated also $S_{34}(0)$ for ${}^3He(\alpha,\gamma){}^7Be$ reaction and found it to be 0.45 keV$\cdot b$, which is considerably lower than the Bahcall-Pinsonneault value 0.533 keV$\cdot b$, (iii) they used the updated value of the solar luminosity, $L_\odot = 3.826(8) \cdot 10^{33}$ erg/s, (iv) they reconsidered the screening effects for the nuclear reactions and (v) they included into the stellar evolution code the diffusion of *all* chemical elements and started the evolution calculations from the pre-main sequence stage. Actually, only items (i) - (iii) are relevant to neutrino fluxes. In fact, the item (v) was already included in the Kovetz-Shaviv[9] model and did not give much difference in comparison with the other SM calculations. The item (iv), as the authors mentioned, give a minor effect. The same is true for the item (iii),which was already taken into account in many other calculations. Therefore, the main impact on the neutrino fluxes is caused by diminishing S_{17} and S_{34}.

The comparison of the low neutrino-flux models (SS and DS) with the two standard models (BP [5] and TL [11]) and with the observational data is given in Table 2.

Table 2: Comparison of the low neutrino-flux models with the SM and experimental data.

	BP	SS(93)	DS(94)	experim.
pp (E10)	6.00	6.1	6.04	
$^7Be(E9)$	4.89	3.9	4.30	< 2.1 at $95\%CL$
$^8B(E6)$	5.69	3.0	2.77	2.75 ± 0.45 (Kamioka)
$^{13}N(E8)$	4.92	—	0.747	
$^{15}O(E8)$	4.26	—	0.217	
Homestake (SNU)	8.0 ± 3.0	4.5	4.2	2.55 ± 0.25
GALLEX (SNU)	132^{+21}_{-17}	114	109	77.1 ± 9.8
SAGE (SNU)	132^{+21}_{-17}	114	109	69 ± 12
S_{17} eV·b	24	20.2	17	
S_{34} keV·b	0.533	—	0.45	
S_{33} MeV·b	5.0	5.6	5.6	

The first column in Table 2 gives the list of physical quantities and of experiments, the second column gives the predictions of the Bahcall and Pinsonneault model[5], in the third and fourth columns the predictions of the low-flux models (Shi and Schramm [42] and Dar and Shaviv [43]) are listed and the last column gives the experimental data. The neutrino fluxes (pp, Be etc) are given in units cm^{-2}s^{-1} with the orders of magnitude indicated in the first column.

One can see that in both low neutrino-flux models the predicted ^8B-neutrino flux is in good agreement with the observations (Kamiokande). In accordance with the general demonstration given in Section 1.2, both models contradict the Homestake data. As we already know from Section 1.2, the only way to avoid this confict in the framework of an astrophysical solution is to assume that one of the two experiments (or both) has a large systematic error. This point is clearly recognized by Shi and Schramm [42]. Dar and Shaviv [43] claim that the discrepancy of their model with the Homestake data is not significant, if one takes the Homestake data after 1986. But actually even in this case their predicted flux (4.2 SNU) is 4.1σ higher than the the flux 2.78±0.35 SNU measured for the same period [4]. For the case of the flux, averaged over 1970 - 1993, it is 6.6σ higher.

We conclude therefore that both low neutrino-flux models are in contradiction with the Homestake observations as they must be according to the general demonstration given in Sections 1.2 and 1.4.

The second neutrino problem, i.e. the deficit of ^7Be-neutrinos, is also present in the low-flux models. It can be seen from the comparison of the predicted ^7Be-neutrino flux ($3.9 \cdot 10^9$ cm^{-2}s^{-1} and $4.30 \cdot 10^9$ cm^{-2}s^{-1} for the SS and DS models, respectively) with the model-independent upper limits $2.4 \cdot 10^9$ cm^{-2}s^{-1}($95\%CL$) and $2.1 \cdot 10^9$ cm^{-2}s^{-1}($95\%CL$) according to refs. [25] and [26], respectively). The deficit of ^7Be-neutrinos is also reflected by too high prediction for the counting rate in the gallium experiments (114 SNU and 109 SNU for the SS and DS models, respectively).

Thus the models confirm the model-independent conclusions of the Sections 1.2 - 1.4:
(i) The Boron-neutrino problem can be solved at the price of small correlated changes of the input parameters.
(ii) The Homestake/Kamiokande conflict and the deficit of ^7Be neutrinos are not solved by these models, in accordance with the model-independent analysis.

1.6 The last hope

One might hope to save an astrophysical solution in the following way.
First increase strongly S_{33} motivated by a hypothetical low-energy resonance in the $^3He + ^3He$ channel until $\phi_\nu(Be)$ decreases below the obtained upper limit. It results also in the undesired effect of equally strong suppression of the boron flux $\phi_\nu(B)$. To boost $\phi_\nu(B)$ back to the observed level one can either increase S_{17} (the boron flux is proportional to this factor) or increase the central temperature T_c ($\phi_\nu(B)$ grows with T_c much faster than $\phi_\nu(Be)$). The scheme of the pp-cycle of the nuclear reactions given below helps to understand this game.

$$p + p \rightarrow D + e^+ + \nu_e$$

$$p + D \rightarrow ^3He + \gamma$$

chain I		chain II
$^3He + ^3He \rightarrow ^4He + 2p$		$^3He + ^4He \rightarrow ^7Be + \gamma$
	$\phi_\nu(Be)$:	$^7Be + e^- \rightarrow ^7Li + \nu_e$
		$^7Be + p \rightarrow ^8B + \gamma$
	$\phi_\nu(B)$:	$^8B \rightarrow ^8Be + e^+ + \nu_e$

This possibility was recently studied numerically and found to be excluded (ref.[44]). The CNO neutrinos play an important role in the proof.

The best attempt is given by the case, when one arbitrarily neglects the CNO neutrinos and strongly increases S_{33} and S_{17}. However, the price for an agreement is unrealistically high: S_{33} should be increased by a factor ~ 200 and S_{17} by a factor of 3.

Thus the last hope turned out to be a no-hope case.

1.7 *MSW solution for the models with low ^8B-neutrino flux*

Assuming the SSM for neutrino production, the MSW conversion describes well all solar neutrino experiments. However, it seems plausible that the SSM will be modified as described above, with the boron neutrino flux reduced.

Does a MSW solution exist for such the models?

What are the parameters of this solution (Δm^2 and $sin^2 2\theta$) for the models with low ^8B-neutrino flux? The refs.[45] and [46] address these questions. Fig. 1 (from ref.[46]) illustrates how the allowed regions in $\Delta m^2 - \sin^2 2\theta$-plot transform with varying ^8B-neutrino flux.

The numbers in Fig. 1 give the ratio ζ of ^8B neutrino flux to that in the SSM [5].

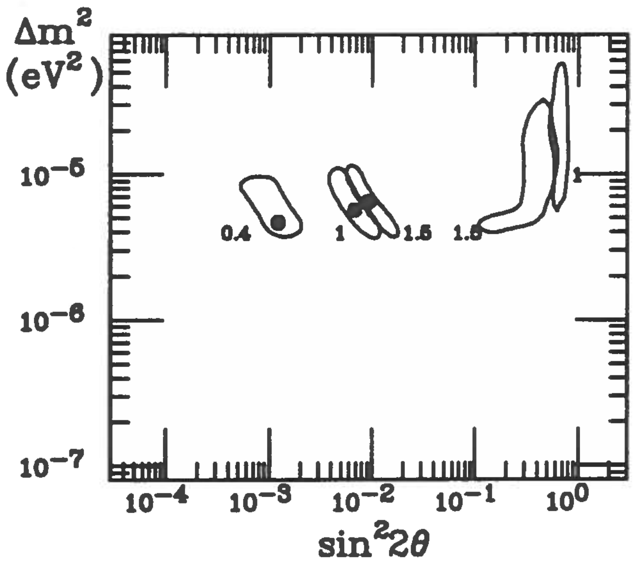


Fig. 1 The $\Delta m^2 - \sin^2 2\theta$ plot for SSM [5] with the boron neutrino flux varied (from [46]). The original boron neutrino flux in this model corresponds to the ratio $\zeta = 1$. The flux reduced by a factor $\zeta = 0.4$ is marked in Fig. 1 by a number 0.4. The region marked by number 1.5 corresponds to the boron flux increased by factor $\zeta = 1.5$. The confidence regions are defined as $\chi^2 = 7.82$.

The following conclusions can be derived from this picture.

(i) An MSW solution exists for a large range of ratios ζ.

(ii) The *small angle* MSW solution shifts to smaller mixing angles when the boron-neutrino flux becomes smaller (ζ decreases).

(iii) Increasing the boron neutrino flux results in appearance of a large allowed region for the *large-angle* MSW solution, while the decreasing results in disappearance of this solution.

(iv) Δm^2 remains practically unchanged with the variation of the boron neutrino flux.

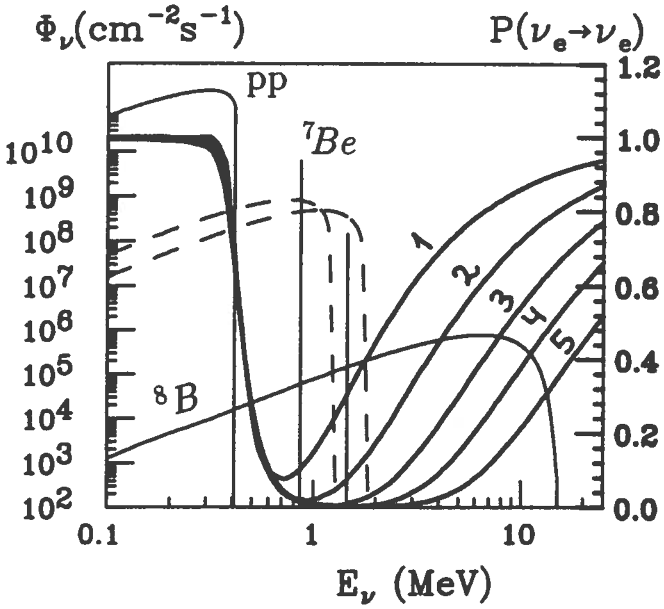


Fig. 2 Neutrino spectra and the MSW suppression factors for different mixing angles: the curves 1, 2, 3, 4 and 5 correspond to values of $sin^2 2\theta$ equal to 0.001, 0.0023, 0.0042 and 0.012, respectively. For large mixing angles, $sin^2 2\theta \sim 10^{-2}$, the suppression of boron neutrino flux at $E_\nu \geq 5$ MeV is strong and therefore both Kamiokande and SNO can observe the distortion of spectrum. For small mixing angles $sin^2 2\theta \sim 10^{-3}$ the suppression factors at $E_\nu \geq 5$ MeV are close to 1 and the effects in Kamiokande and SNO are weak.

These models can have rather pessimistic predictions for the nearest-future solar neutrino experiments, SNO and Superkamiokande. In the models with small mixing angles, $sin^2 2\theta \leq 1 \cdot 10^{-3}$, the MSW conversion of ν_e-neutrinos occurs most effectively at energy $E_\nu < 5$ MeV, (see Fig. 2) i.e. below the threshold energy for SNO and Superkamiokande. Therefore, the distortion of the boron-neutrino spectrum, as well as anomalous NC/CC-ratio, are small effects for these detectors.

1.8 *Time variation of solar neutrino flux*

The data of the Homestake detector show the time variation of neutrino flux in anticorrelation with solar activity (e.g. sunspot number) during a period from 1970 to 1990. Most notably this effect was established in ref.[47], where the pronounced anticorrelation of the ^{37}Ar production with the product $s \mid z \mid$ (where s is sunspot number and

z is the latitude of the line of sight) was found at the confidence level 0.9993 (for the other results see ref's [48,49,50] and references therein).

This anticorrelation was explained in terms of neutrino spin precession [37] or spin-flavor precession [38] in the toroidal magnetic field in the convective zone of the sun.

For these models the large magnetic magnetic moment of neutrino ($\mu \sim 10^{-11}\mu_B$) and strong magnetic field in the convective and radiation zones of the sun are needed.

A recent analysis of Stanev [52] has demonstrated that runs 106 - 126 in the Homestake experiment reveal no correlation with the sunspot number at all. Inclusion of the last 16 runs after 1990 in the analysis of ref.[47] has decreased the confidence level of the correlation from 0.9993 to 0.99. Simultaneously the data of the Kamiokande detector for 1987 - 1994 reveals no correlation, being consistent with time-independent flux. The GALLEX data are also consistent with constant flux.

A natural question arises, whether the time variation of the spot number reflects well the variation of perpendicular component of the toroidal magnetic field which is responsible for neutrino spin precession.

Recently there were the attempts to find the correlation between variations of neutrino flux and magnetic field on the surface of the sun, measured by the Zeeman effect. Obridko and Rivin [53] have searched for correlation of neutrino flux with different components of magnetic field on the surface of the sun. The strongest correlation was found with the perpendicular component of the surface magnetic field along a neutrino trajectory. The authors analyzed the data (Homestake and Kamiokande) up to 1992. The statistical significance of the correlation is not presented.

A more accurate analysis was performed by Oakley et al [54]. These authors also found a statistically significant correlation between the Homestake counting rate and the surface magnetic field along the line of neutrino propagation. The significance level decreases with increasing the latitude band, over which the magnetic field was averaged. It gives an additional signature for neutrino propagation effect.

One can observe that the Kamiokande data contradict the results of both analyses. In ref.[53] the Kamionkande data are displayed in a way different from the original presentation of the Kamiokande group (e.g. [55,56]). The authors of ref.[54] hope that the absence of time variation in the Kamiokande data are connected with the limited time of reported observations (January 1987 - April 1990) which coincides with the beginning of the solar cycle. Now the Kamiokande data [55,56] are available up to 1994 and they are consistent with time-independent neutrino flux.

Interesting attempts to reconcile the variability of the Homestake data and the apparent constancy of the Kamiokande flux are made in ref's [52,51].

My personal opinion is that at present we do not have neither convincing proof of neutrino flux variability, nor strong evidences for correlation with the solar activity. The data we have can be considered just as an indication for the existence of these phenomena and only future experiments can shed light on this problem, exciting but controversial at present.

1.9 Conclusions

The low p^7Be- cross-section and reduced core opacity (due to collective plasma effects) can diminish the flux of ^8B- neutrinos to the level of the Kamiokande observations. Thus, the 25 year-old problem of the ^8B- neutrino deficit can disappear. Instead we face now the problem of low $\phi_\nu(Be)/\phi_\nu(B)$- ratio or Be- neutrino deficit. This problem is mainly created by the ratio of the Homestake to Kamiokande counting rates and is supported by the deficit of the ^7Be- neutrinos in the gallium experiments. If the Homestake and Kamiokande data are correct within the given statistical and systematic errors and if the $\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e$- cross-section is not overestimated, a nuclear/astrophysical solution to the $\phi_\nu(Be)/\phi_\nu(B)$ problem is excluded. It means the existence of the *nonstandard* neutrino, i.e. with properties outside the SM of electroweak interactions.

If one belives that one of these experiments is wrong, we are still left with the conflict (though statistically less significant) between the gallium experiments and the remaining experiment. This comparison results in very small lower limit for ^7Be-neutrinos: $\phi_\nu(Be) < 2.6 \cdot 10^9$ cm^{-2}s^{-1}($95\%CL$) [25] and $\phi_\nu(Be) < 2.1 \cdot 10^9$ cm^{-2}s^{-1}($95\%CL$) [26]. These limits are to be compared with the SSM prediction $4.89 \cdot 10^9$ cm^{-2}s^{-1}.

The deficit of the beryllium neutrinos looks now as the essence of the solar neutrino problem. SNO and Superkamiokande have too high energy threshold (5 MeV) for detection of beryllium neutrinos. BOREXINO [29], recently approved at Gran Sasso, will detect the beryllium neutrinos even in the case of the full conversion of electron neutrinos into muon or tau neutrinos. This is possible due to NC scattering of these neutrinos off the electrons. Among the future projects, HELLAZ [57] is an extremely efficient detector of ^7Be neutrinos. Like BOREXINO it will exploit νe-scattering. The signature of ^7Be-neutrinos in this project is their energy, which is supposed to be known due to precise measurements of the energy of the recoil electron and its scattering angle.

In conclusion, a nuclear/astrophysical solution to the Solar Neutrino Problem is strongly disfavored, while the MSW solution can explain the results of all four neutrino experiments, even if the prediction for ^8B neutrino flux is considerably changed. This solution needs a neutrino with properties beyond the SM of EW interactions (massive neutrinos with mixing of different flavors).

2 NEUTRALINO AS DM PARTICLE

2.1 Cosmological environment

Inspired mostly by theoretical motivation (horizon problem, flatness problem and the beauty of the inflationary scenarios) the $\Omega_0 = 1$ cosmological model is widely accepted. No observational data significantly contradict this model and some data (IRAS, POTENT) confirm it. We shall use here this model too.

From cosmological point of view the critical density ($\Omega_0 = 1$) is generically provided by four component: baryonic matter, cold dark matter (CDM), hot dark matter (HDM) and the vacuum energy described by the cosmological constant Λ ($\Omega_\Lambda = \Lambda/(3H_0^2)$), where H_0 is the Hubble constant. Further on we shall use the dimensionless Hubble constant $h = H_0/(100\ kms^{-1}Mpc^{-1})$.

These components play different role in formation of the density fluctuation spectrum which is observed by COBE, IRAS, CfA etc. They also produce different effects for cluster-cluster correlations, velocity dispersion etc. The simplest model for a correct description of all these phenomena is the so-called mixed model or cold-hot dark matter model (CHDM). This model is characterized by following parameters:

$$\Omega_\Lambda = 0, \Omega_0 = \Omega_b + \Omega_{CDM} + \Omega_{HDM} = 1,$$
$$H_0 \approx 50\ kms^{-1}Mpc^{-1}(h \approx 0.5),$$
$$\Omega_{CDM} : \Omega_{HDM} : \Omega_b \approx 0.75 : 0.20 : 0.05, \tag{1}$$

where $\Omega_{HDM} \approx 0.2$ is obtained in ref.[58] from damped $Ly\alpha$ data. Thus in the CHDM model the central value for the CDM density is given by

$$\Omega_{CDM} h^2 = 0.19 \tag{2}$$

with uncertaities within 0.1.

The best candidate for the HDM particle is τ-neutrino with mass $m_{\nu_\tau} \approx 4.7$ eV, if $\Omega_\nu = 0.2$.

The most plausible candidate for the CDM particle is the neutralino (χ): it is massive, stable (when the neutralino is the lightest supersymmeric particle and if R-parity is conserved) and the $\chi\chi$-annihilation cross-section results in $\Omega_\chi h^2 \sim 0.2$ for a large area of the neutralino parameter space.

In the light of recent measurements of the Hubble constant the CHDM model faces the *time problem.*

The lower limit on the age of Universe $t_0 >$ 13 Gyr (age of globular clusters) imposes the upper limit on the Hubble constant in the CHDM model $H_0 <$ 50 $kms^{-1}Mpc^{-1}$. This value is in slight contradiction with the recent observations of extragalactic Cepheids, which can be summarized as $H_0 > 60\ kms^{-1}Mpc^{-1}$. However, it is too early to speak about a serious conflict taking into account the many uncertainties and the physical possibilities (e.g. the Universe can be locally overdense - see the discussion in ref.[59]).

2.2 Different theoretical approaches describing the neutralino as DM particle

The neutralino is a superposition of four spin 1/2 neutral fields: the wino $\tilde{W}_3$, bino $\tilde{B}$ and two Higgsinos $\tilde{H}_1$ and $\tilde{H}_2$:

$$\chi = C_1\tilde{W}_3 + C_2\tilde{B} + C_3\tilde{H}_1 + C_4\tilde{H}_2 \tag{3}$$

The neutralino is a Majorana particle. With a unitary relation between the coefficients C_i the parameter space of neutralino states is described by three independent parameters, e.g. mass of wino M_2, mixing parameter of two Higgsinos μ, and the ratio of two vacuum expectation values $\tan\beta = v_2/v_1$.

In literature one can find two extreme approaches describing the neutralino as DM particle.

(i)*Phenomenological approach.* The allowed neutralino parameter space is restricted by the LEP and CDF data. In particular these data put a lower limit to the neutralino mass, $m_\chi > 20$ GeV. In this approach the usual GUT relations between gaugino masses $M_1 : M_2 : M_3 = \alpha_1 : \alpha_2 : \alpha_3$ are are used as an additional assumption: where α_i are coupling constants. All other SUSY masses which are needed for the calculations are treated as free parameters, limited from below by accelerator data.

One can find the relevant calculations within this approach in refs.[60,61] and in the review[62] (see the also the references therein). There are large areas in neutralino parameter space where the neutralino relic density satisfies the relation (2). This is especially true for heavy neutralinos with $m_\chi > 100 - 1000$ GeV, ref.[63]. In these areas there are good prospects for *indirect* detection of neutralinos, due to high energy neutrino radiation from Earth and Sun (see [64,65] and references therein) as well as due to production of antiprotons and positrons in our Galaxy. The *direct* detection of neutralinos is possible too though in rather restricted parameter space areas of light neutralinos (see review [62]).

This model-independent approach is very interesting as an extreme case: in the absence of an experimentally confirmed SUSY model it gives the results obtained within most general framework of supersymmetric theory.

(ii) *The rigid model approach.* This approach is based on the remarkable observation that in the minimal SUSY SU(5) model with fixed particle content, the three running coupling constants intersect at one point corresponding to the GUT mass M_{GUT}. Because of the fixed particle content of the model, its predictions are rigid and they strongly restrict the neutralino parameter space. This is especially true for the limits due to proton decay $p \to K^+\nu$. As a result very little space is left for neutralino as DM particle. Normally neutralinos overclose the Universe ($\Omega_\chi > 1$). The relic density decreases to the allowed values in those areas where $\chi\chi$-annihilation is large (e.g.due to the Z^0 exchange term - see e.g. ref.[66,67]).

Thus, this approach looks rather pessimistic for neutralino as DM particle. However, most serious restriction - proton decay - can easy be eliminated by a number of modifications.

(iii) *Constrained models.* In several recent works[68] till [72] the less restricted SUSY models were considered. In particular the limits due to proton decay were lifted. Although, the neutralino can be heavy in these models, the prospects for indirect detection, including the detection of high energy neutrinos from the Sun and Earth, is rather pessimistic [70]. The *direct* detection is possible in many cases [71,72,70].

In section 2.5, following ref.[73], we shall analyze the restrictions to neutralino as DM particle, imposed by *basic* properties of SUSY theory. Like in ref.[68,69,70] we consider as the fundamental element the radiatively induced EW symmetry breaking (EWSB). The EWSB constraint will be weakened by an assumption of mass splitting in Eq.(4) (see ref.[74]). The powerful restriction from the no-fine-tuning condition will be added to those previously considered.

2.3 SUSY theoretical framework

The basic element which should be involved in the analysis is a scheme of supersymmetry breaking and induced by it (through radiative corrections) electroweak symmetry breaking [75]. We shall refer to this restriction as to the EWSB restriction.

One starts with unbroken supersymmetric model described by some superpotential. It is assumed that local supersymmetry is broken by supergravity in the hidden sector, which communicates with the visible sector only gravitationally. This symmetry breaking penetrates into the visible sector in the form of global supersymmetry breaking. More specifically it is assumed that the symmetry breaking terms in the visible sector are the *soft breaking terms* given at the GUT scale $Q^2 \sim M^2_{GUT}$ by the following expression:

$$L_{sb} = m_0^2 \sum_a |\phi_a|^2 + m_{1/2} \sum_a \lambda_a \lambda_a + A m_0 f_Y + B m_0 \mu H_1 H_2 \quad (4)$$

where ϕ_a are scalar fields of the model (sfermions and two Higgses H_1 and H_2), λ_a are gaugino fields, f_Y are trilinear Yukawa couplings of fermions and Higgses and the last term is an additional (relative to the superpotential term $\mu H_1 H_2$) soft breaking mixing of two Higgses.

The soft breaking terms (4) are described by 5 free parameters only: $m_0, m_{1/2}, A, B$ and μ. This is a strong assumption which we shall call after ref.[70] *superunification.* Superunification implies that all scalars ϕ_a and all gauginos λ_a at the GUT scale have the common masses m_0 and $m_{1/2}$, respectively. The assumption of superunification can be relaxed, as we shall discuss later.

The soft breaking terms (4) together with supersymmetric mixing give the following potential defined at the EW scale at the tree level:

$$\begin{aligned} V &= m_1^2|H_1|^2 + m_2^2|H_1|^2 - B\mu m_0(H_1H_2 + hc) + \\ & (1/8)(g_1^2 + g_2^2)(|H_1|^2 - |H_2|^2)^2. \end{aligned} \quad (5)$$

The mass parameters m_1 and m_2 at the GUT scale are equal to

$$m_1^2(GUT) = m_2^2(GUT) = \mu^2 + m_0^2, \quad (6)$$

and the term μ^2 in Eqs.(5),(6) appears due to the mixing term $\mu H_1 H_2$ in the superpotential of unbroken SUSY.

The radiative EWSB occurs due to evolution of m_{H_2}, the mass of the Higgs field H_2, which is connected with the upper components of the doublets and in particular with t-quark. Because of the large mass of t-quark and consequently the large Yukawa coupling Y_{ttH_2}, $m^2_{H_2}$ evolves from m_0^2 at the GUT scale to the negative value $m^2_{H_2} < 0$ at the EW scale. At this value the potential (5) aquires its minimum and the system undergoes the EW phase transition coming to the minimum of the potential. In the tree approximation the conditions of the potential minimum (vanishing of the derivatives) give:

$$\begin{aligned} \mu^2 &= \frac{m^2_{H_1} - m^2_{H_2}\tan^2\beta}{\tan^2\beta - 1} - \frac{M_Z^2}{2} \\ \sin 2\beta &= \frac{-2B\mu}{m^2_{H_1} + m^2_{H_2} + 2\mu^2} \end{aligned} \quad (7)$$

With these equations we obtain one connection between five free parameters describing the soft-breaking terms (4). Thus the number of independent parameters is reduced to four, e.g.$m_0, m_{1/2}, A, \mu$ (or $\tan\beta$).

Using the renormalization group equations (RQE) one can follow the evolution of the scalar particles (Higgses and sfermions) and spin 1/2 particles (gauginos) from the masses m_0 and $m_{1/2}$ at the GUT scale to the masses at interest at the EW scale. Analogously the evolution of the coupling constants can be calculated. In particlular the masses of Higgses are given by

$$m^2_{H_i}(EW) = a_i m_0^2 + b_i m^2_{1/2} + c_i A^2 m_0^2 + d_i A m_0 m_{1/2} \quad (8)$$

where a_i, b_i, c_i and d_i are numerical coefficients.

Equivalently, using Eqs.(7) one finds

$$M_Z^2 = J_1 m^2_{1/2} + J_2 m_0^2 + J_3 A^2 m_0^2 + J_4 A m_0 m_{1/2} - \mu^2, \quad (9)$$

where J_i are also numerical coefficients.

Eq.(9) allows to impose the no-fine-tuning restriction in the neutralino parameter space. Indeed, one can keep large values of masses in the rhs of Eq(9) only by the price of accidental compensation between the different terms. It is unnatural to expect an accidental compensation to a value less than 1% from the initial uncompensated values. This is the no-fine-tuning condition.

Naturally the described condition is just the same as the one due to the radiative corrections to the Higgs mass.

2.4 *Restrictions: the price list*

Within the theoretical framework outlined above one can choose the restrictions from the following price list:

- Soft breaking terms (4) and EWSB conditions (7),
- No-fine-tuning condition,
- Particle phenomenology (masses of particles and a condition that the neutralino is the LSP),
- Restrictions due to $b \to s\gamma$ decay,
- Crossing of coupling constants at M_{GUT},
- $b-\tau$ and $b-\tau-t$ unification,
- Restrictions due to $p \to K\nu$ decay.

Taking into account some (or all) restrictions listed above one can start calculations for the neutralino as DM particle. The regions where the neutralinos are overproduced ($\Omega_\chi > 1$) must be excluded from consideration and the allowed region should be determined according to the chosen cosmological model (e.g. $\Omega_\chi h^2 = 0.2 \pm 0.1$ for the CHDM model). For the allowed regions the signal for direct and indirect detection can be calculated.

2.5 *SUSY models with basic restrictions*

Accepting all restrictions listed above one arrives at the fixed SUSY model, with the neutralino parameter space being too strongly constrained. In ref.[73] the SUSY models with basic restrictions were considered. These restrictions are as follows:
(i)Radiative EWSB, (ii) No fine tuning stronger than 1%, (iii) RGE and particle phenomenology (accelerator limits on the calculated masses and the condition that neutralino is LSP), (iv) Limits from $b \to s\gamma$ decay taken with the uncertainties in the calculations of the decay rate and (v) $0.01 < \Omega_\chi h^2 < 1$ as the allowed relic density for neutralinos. Rather strong restrictions are imposed by the condition (ii); in particular it limits the mass of neutralino as $m_\chi < 200$ GeV.

At the same time some restrictions are lifted as being too model-dependent: (i) No restrictions are imposed due to $p \to K\nu$ decay, (ii) Unification of coupling constants at the GUT point is allowed to be not exact (it is assumed that the new very heavy particles can restore the unification), (iii) Superunification in the soft breaking terms (4) is relaxed. Following ref.[74] it is assumed that masses of Higgses at the GUT scale can deviate from the universal value m_0 as

$$m_{H_i}^2(GUT) = m_0^2(1+\delta_i), \qquad (10)$$

where i runs throuh values 1 and 2. This non-universality affects rather strongly the properties of neutralino as DM particle: the allowed parameter space regions become larger and neutralino is allowed to be Higgsino-dominated, which is favorable for detection.

Some results obtained in ref.[73] are illustrated by Figs. 3 - 7.

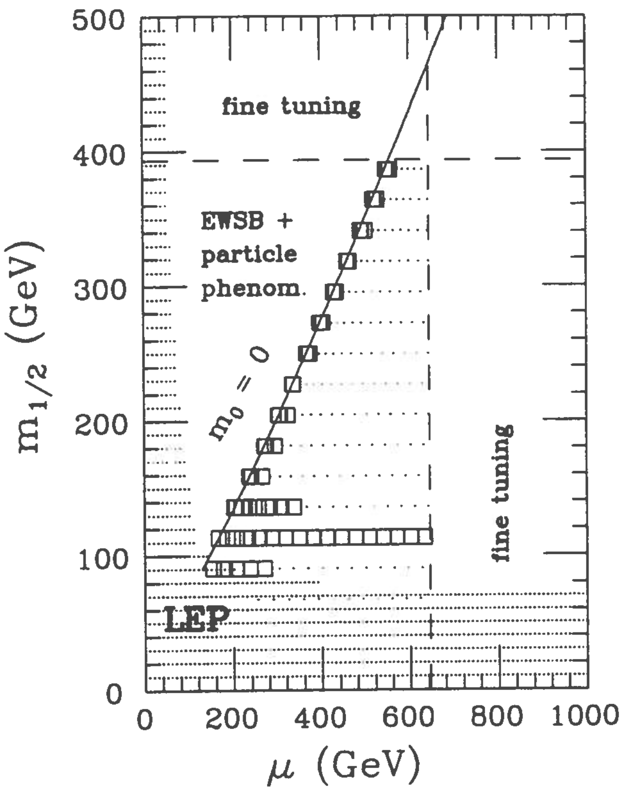


Fig. 3 The neutralino parameter space for superunification case $\delta_1 = \delta_2 = 0$ and $\tan\beta = 8$. The regions excluded by the LEP and CDF data are shown by dots and labelled as LEP. The regions labelled "fine tuning" have the accidental compensation to less than 1% of the initial mass and thus are excluded. No-fine-tuning region inside the broken-line box corresponds to the neutralino mass $m_\chi \leq 200$ GeV. The region "EWSB+particle phenom." is excluded by the EWSB condition combined with particle phenomenology (neutralino as LSP, limits on the masses of SUSY particles etc). In the region marked by rarefied dotted lines neutralinos overclose the Universe ($\Omega_\chi h^2 > 1$). The solid line corresponds to $m_0 = 0$. The regions allowed for neutralino as CDM particle ($0.01 < \Omega_\chi h^2 < 1$) are shown by small boxes. As one can see in most regions the neutralinos are overproduced. The allowed regions correspond to large $\chi\chi$ annihilation cross-section (e.g. due to Z^0-pole).

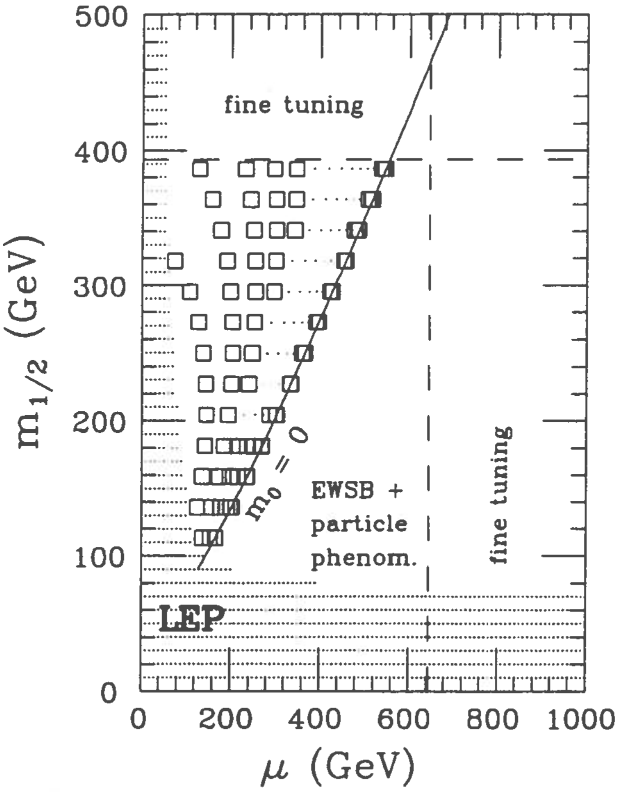


Fig. 4 Case $\delta_1 = -0.2$, $\delta_2 = 0.4$ and $\tan\beta = 8$.

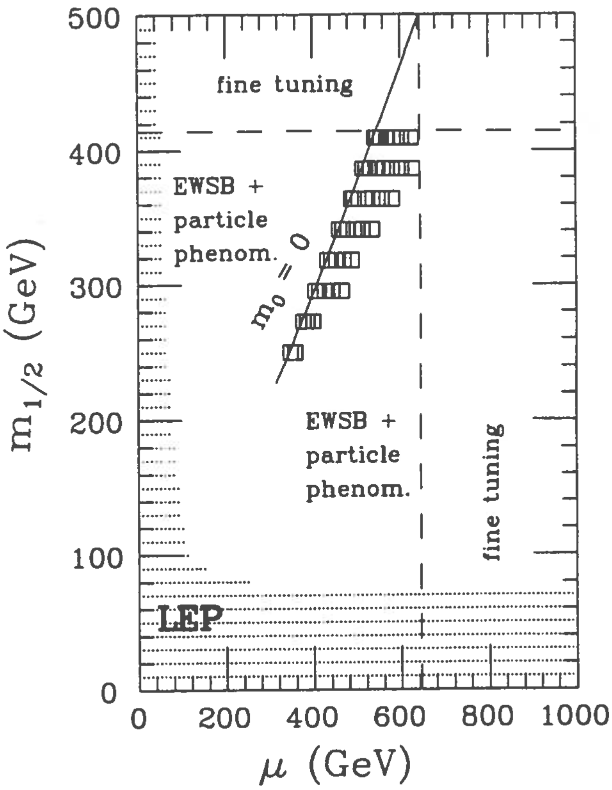


Fig. 6 Case $\delta_1 = 0$, $\delta_2 = -0.2$ and $\tan\beta = 53$.

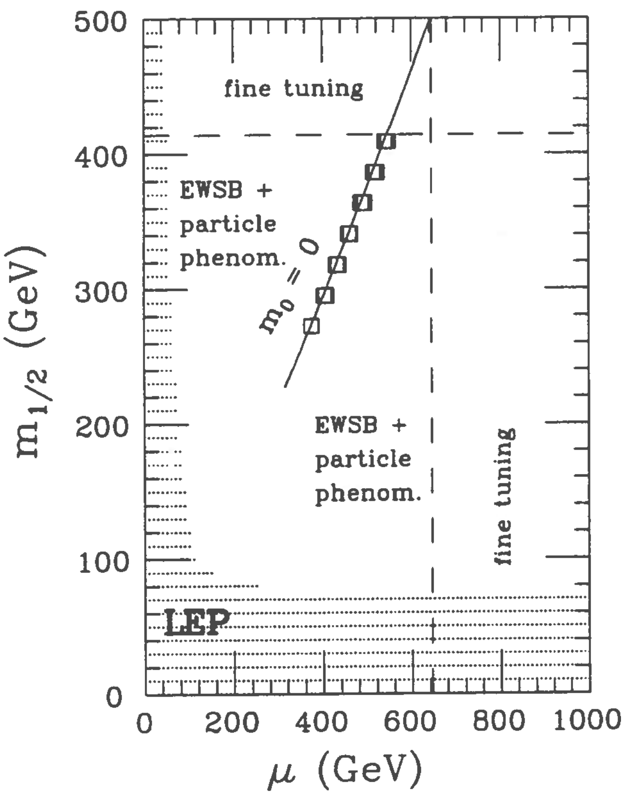


Fig. 5 Superunification case and $\tan\beta = 53$.

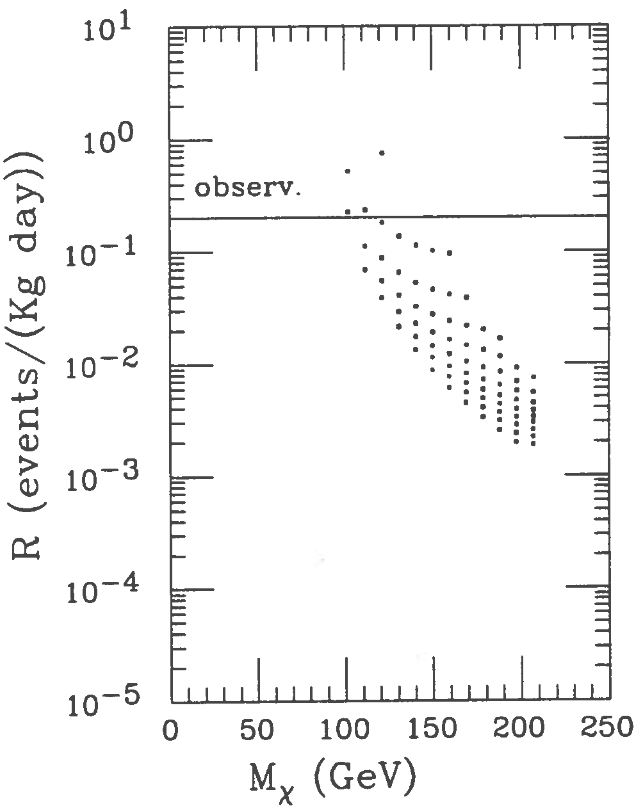


Fig.7 Rate for direct detection ($\delta_1 = 0, \delta_2 = -0.2$ and $\tan\beta = 53$) .

Fig. 3 and Fig. 4 differ only by universality: in Fig. 3 $\delta_1 = \delta_2 = 0$ (superunification), while in Fig. 4 $\delta_1 = -0.2$ and $\delta_2 = 0.4$. The cosmologically allowed region in Fig. 4, shown by small boxes, becomes much larger and is shifted into the Higgsino dominated region. Figs. 5 and 6 are given for $tan\beta = 53$. This large value of $\tan\beta$ correspond to $b - \tau - t$ unification of the Yukawa coupling constants. Again one can notice that in the superunification case ($\delta_1 = \delta_2 = 0$) only a small area is allowed for neutralino as CDM particle, while in non-universal case ($\delta_1 = 0, \delta_2 = -0.2$) the allowed area becomes larger and shifts towards the gaugino dominated region.

In Fig. 7 the scatter plot for the rate of direct detection with the *Ge* detector [76] is given for the non-universal case ($\delta_1 = 0, \delta_2 = -0.2$) and $\tan\beta = 53$. One can see that part of the allowed region is already excluded by existing data [76].

2.6 Conclusions

There are the different approaches to study the neutralino as DM particle in SUSY models with R-parity conservation.

In the *phenomenological approach* apart from the LEP-CDF data and accelerator limits on the masses of supersymmetric particles very few other constraints are imposed. The Minimal Supersymmetric Model is used in the way that only two Higgsinos exist and that there is one GUT relation $M_1 : M_2 : M_3 = \alpha_1 : \alpha_2 : \alpha_3$ between gaugino masses. While the coupling constants are known, the mass parameters needed for calculations are taken as the free parameters. Many allowed configurations in the parameter space give the neutralino as DM particle with observable signals for direct and indirect detection (antiprotons and positrons in our Galaxy and high energy neutrinos from the Sun and Earth).

The other extreme case, the complete SUSY SU(5) model with fixed particle content, with crossing of coupling constants at the GUT point and with the constraints due to proton decay, leaves very little space for the neutralino as DM particle.

In the third option the SUSY soft breaking terms (4) and induced EW symmetry breaking are used as the general theoretical framework. Combined with a no-fine-tuning condition this framework already gives essential restrictions. In particular, fine tuning allowed at the level weaker than 1% results in the neutralino being lighter than 200 GeV. Here the neutralino is gaugino dominated, which is unfavorable for direct detection. If we employ further other restrictions, such as exact crossing of coupling constants at the GUT point, $b \to s\gamma$ limit and $b - \tau$ unification, the model becomes as rigid as the one considered above.

If, on the other hand, we relax the constraints, assuming non-universality of the scalar mass term in Eq.(4), then even in the case of 1% no-fine-tuning condition the neutralino can be the DM particle in a large area of the parameter space and can be detected in some parts of this area in direct and indirect experiments.

3 GAMMA RAY BURSTS AND HIGHEST ENERGY COSMIC RAYS

Recently these two phenomena attracted much attention. With the data as presented now, both of them require rather extraordinary explanations.

Can these two phenomena be connected with each other?

3.1 Gamma Ray Bursts (GRB)

We shall list here the basic properties of GRB as observed by BATSE, COMPTEL, YGRET, ULYSSIS and other detectors. The total number of observed events exceeds now (1995) 1000.

- The typical energies of photons are confined between 10 keV and 100 MeV, with maximum energy 18 GeV observed for one of the bursts.
- The fluencies are in the range $10^{-7} - 10^{-3}$ erg/cm^2 with the typical value $\sim 10^{-6}$ erg/cm^2.
- Duration of the bursts is typically in the interval $0.01 - 1000$ s, though very short bursts (a few ms) and very long ones (~ 100 min) were observed. Probably there are two classes of the bursts, the short ($\delta t < 1$ s) and the long ($\delta t > 1$ s) ones.
- Two types of the time profiles are observed. The *complex* bursts have a rich structure with short ($\sim$ ms) spikes; the smooth bursts have no structure at all. About 40% of the bursts have a precursor.
- The angular distribution reveals no anisotropy.
  The homogeneity tests ($\log N/\log S$ ratio and V/V_{max} as function S/S_{min}, where N is the number of bursts with fluency S and V is the volume from which a source with the fluency S can be seen) exclude the radius of homogeneity less than 50 kpc and thus imply the extragalactic origin of the bursts. The time dilation of the weak bursts also evidences in favor of the cosmological origin of the bursts.
- No radio, optical or X-ray counterparts of the bursts are found.
- At least three repeaters are reliably observed.

Two possibilities for the origin of GRB are widely discussed.

If the bursters have the galactic origin they should occupy the large halo with size larger than 50 kpc. This is unusually broad distribution: most of the stellar populations of our Galaxy are confined within the disc with radius $\sim$ 10 *kpc* and width $\sim$ 0.4 *kpc*. The total energy release in case of galactic bursters is rather modest ($10^{41} - 10^{42}$ *erg*), while in case of cosmological distances it should reach $10^{50} - 10^{52}$ *erg*.

In case of the cosmological origin the most plausible model is given by a fireball scenario, which was put forward by P.Meszaros and M.Rees in 1992. The powerful energy release (e.g. due to neutron stars merging in a binary) results in the production of an expanding fireball. The dense optically thick γ, e^+, e^- plasma expands relativistically. Due to internal pressure the Lorentz factor Γ grows with the fireball radius until it saturates at some value Γ_s, which can reach $10^2 - 10^3$. The superrelativistic shock might accompany the expansion of the fireball. This model explains in principle most properties of the observed GRB.

However, the repeaters as well as the bursts with the complex, *ms* time structure are in contradiction with this model and more generally with any cosmological model. It could be that two different types of GRB are actually observed.

3.2 Ultra High Energy Cosmic Rays (UHECR)

The particles observed with energies between 10^{17} eV and $3 \cdot 10^{20}$ eV are called UHECR. Since particles of these energies cannot be confined by galactic magnetic fields, they are assumed to be extragalactic. In fact, the arguments which support the extragalactic origin of UHECR are the absence of noticeable anisotropy and the absence of reliable mechanisms for acceleration to these tremendous energies in our Galaxy. The observed energy spectrum is proportional to $E^{-3.1}$ up to $(1-2) \cdot 10^{19}$ eV and then it becomes somewhat *flatter*.

The signature of extragalactic UHECR is given by the so-called black-body cutoff (bb-cutoff), predicted in 1966 by K.Greisen and independely by G.T.Zatsepin and V.A.Kuzmin. It can be rigorously formulated in the following way. If sources of UHECR protons fill homogeneously the Universe the observed spectrum has a sharp steepening which starts at $E_{bb} \approx 3 \cdot 10^{19}$ eV. This steepening (bb-cutoff) is caused by pion production in collisions of protons with microwave (2.7 K) photons. The UHECR nuclei suffer a similar cutoff due to pair($e^{\pm}$)-production energy losses.

Experimentally this cutoff is not found. Recently two very clear events with the highest energies were obesrved: a shower with $3 \cdot 10^{20}$ eV was detected by the Fly's Eye detector and with energy $2 \cdot 10^{20}$ eV - by the Akeno detector. Actually these two events question most seriously the existence of the bb-cutoff.

A very exciting observation was recently made by M.Milgrom and V.Usov [77]. They found the coincidence between arrival directions of these two highest energy CR events with the two powerful GRB. The UHECR events are delayed by 5.5 months and 11 months relative to the GRB arrival. Realizing all scepticism about statistical significance of this coincidence, one can address the question, whether the GRB sources can provide acceleration to energies above 10^{20} eV.

3.3 Acceleration in GRB sources

Considering GRB sources as the sources of UHECR one should answer two questions: how particles are accelerated and whether they can propagate not suffering the bb-cutoff.

The acceleration was studied in ref.[78] in the framework of the fireball model. The basic effect is that a particle reflected from ultrarelativistic wall increases its energy by factor Γ^2, where Γ is the Lorentz factor of the wall. The expansion of the fireball is accompanied by propagation of the direct and reversed shocks. The direct shock propagates through unshocked matter, while the reversed one moves downward in the ejecta and has a reversed direction in the laboratory system due to motion of the ejecta (the fireball). Particles are accelerated in the region between the shock fronts (shocked shell), reflecting from each front. Inspired by equiparition, a tremendous magnetic field is assumed at the shock fronts, with the initial field being as high as 10^{17} G. After n reflectios the energy of a particle increases by a factor Γ^{2n} and for $\Gamma \sim 10^2$ it can reach 10^{29} eV after 5 reflections.

If the GRB sources are distributed homogeneously in the Universe the resulting spectrum at the Earth has a bb-cutoff. The exceptional case is given by very flat generation spectrum dE/E. This spectrum is invariant relative to the energy losses, if the energy needed at production is less than maximum energy at acceleration. Therefore, realistically this model belongs to the category of the models with the spectrum cutoff.

Acknowledgements

I am much indebted to my collaborators, A.Bottino, J.Ellis, G.Fiorentini, N.Fornengo, M.Lissia, G.Mignola and S.Scopel for many useful discussions.

References

1. P.Anselman et al (GALLEX collaboration), preprint LNGS 95/37, to be published in Phys.Lett. 1995.
2. V.N.Gavrin (SAGE collaboration), Talk at Int. Workshop TAUP-95 (Toledo) 1995.
3. K.Inoue, Talk at XXX Rencontres de Moriond, March 12-18, 1995.
4. B.T.Cleveland et al (Homestake), *Nuclear Phys. B (Proc.Suppl.)* **39** (1995) 47.
5. J.N. Bahcall and M. Pinsonneault, preprint IASSNS-AST 95/ 24 to be published in Rev. Mod. Phys.1995.

6. J.N. Bahcall and H.A. Bethe, *Phys. Rev. Lett.* **65** (1990) 2233.
7. J.N. Bahcall, *Neutrino Astrophysics*, Cambridge Univ. Press, Cambridge, 1989.
8. S. Turck-Chieze, W. Däppen, E. Fossat, J. Provost, E. Schatzmann and D. Vignaud, *Phys. Rep.* **230** (1993) 57.
9. A.Kovetz and G.Shaviv, *Ap.J.* **426** (1994) 787.
10. V.Castellani, S.Degl'Innocenti, F.Fiorentini, *Astron. Astrophys.* **271** (1993) 601.
11. S.Turck-Chiese and I.Lopes, *Ap.J.* **408** (1993) 347.
12. G.Berthomieu et al, *Astron. Astroph.* **268** (1993) 775.
13. D.B.Günter et al, *Ap.J.* **387** (1992) 372.
14. J.Christiansen-Dalsgaard, *Geophys. Astrophys. Fluid.Dyn.* **62** (1992) 123.
15. B.Ahrens, M.Stix and M.Thorn, *Astron. Astroph.* **264** (1992) 673.
16. J.A.Guzik and A.N.Cox, *Ap.J.Lett.* **381** (1991) 331.
17. C.R.Proffitt and A.N.Cox, *Ap.J.* **380** (1991) 238.
18. I.J.Sackman, A.I.Boothroyd and W.A.Fowler, *Ap.J.* **360** (1990) 727.
19. Y.Lebreton and W.Däppen, in *Seismology of the Sun and the Sun-like Stars*, (ed. V.Domingo and E.J.Rolfe), European Space Agency, Noordwijk, 1988.
20. J.N.Bahcall, *Phys. Rev. Lett.* **71** (1993) .2369
21. V. Tsytovich, in *"Solar Neutrino Problem"*, eds V.Berezinsky and E.Fiorini, vol.1, p.238, (1994).
22. N.Hata, S.Bludman and P.Langacker, *Phys. Rev.* **D 49** (1994) 3622.
23. V.Berezinsky, *Comm.Nucl.Part.Phys.* **21** (1994) 249.
24. R.S.Raghavan, *Science* **267** (1995) 45
25. J.Bahcall, *Phys. Lett.* **338 B** (1994) 276.
26. S.Degl'Innocenti, G.Fiorentini and M.Lissia, Preprint INFNFE-10-94,(1994)
27. V.Castellani, S.Degl'Innocenti, G.Fiorentini, M.Lissia, B.Ricci, *Phys. Rev.* **D50** (1994) 4749.
28. W.Kwong and S.P.Rosen, *Phys. Rev. Lett.* **73** (1994) 369.
29. C.Arpesella et al, *"Borezino at Gran Sasso"* (Proposal),ed. by G.Bellini and R.Raghavan, INFN, Univ.of Milan, 1991, E.Bellotti, *Nucl.Phys.B (Proc.Suppl)* **38** (1995) 90.
30. T.Kirsten, Invited talk at 17th TEXAS Symposium on Relativistic Astrophysics, Munich, 1994, to be published in Ann. N.Y. Academy of Sciences (1995),
31. T.Kirsten, Invited talk at Int. Conf. "Neutrino-95", *Nucl.Phys.B (Proc.Suppl)* **38** (1995) 68.
32. W.Hampel, Talk at the Topical Session *"Berrylium Neutrinos: Problem and Detection"*, Gran Sasso, 1995.
33. V.Berezinsky, Int. Workshop *"Neutrino Telescopes"* ed. M.Baldo Ceolin, Venice, Febr. 22-24 1994, p.239, (1994).
34. S.P.Mikheyev and A.Yu.Smirnov, *Yadern. Fiz.* **42** (1985) 1441, L.Wolfenstein, *Phys. Rev.* **D 17** (1978) 2369.
35. B.Pontecorvo, *Zh.Eksp.Theor.Fiz.* **33** (1953) 549.
36. P.I.Krastev and S.T.Petcov, Preprint SISSA 4/94/EP, S.T.Petcov, Talk at *Recontres de Physique de la Vallee d'Aoste, 1995.*
37. M.B.Voloshin, M.I.Vysotsky, L.B.Okun, *Sov. Phys. JETP* **64** (1988) 446.
38. E.Kh.Akhmedov, *Phys. Lett.* **213B** (1988) 64. C.S.Lim and W.Marciano, *Phys. Rev.* **D37** (1988) 1368.
39. S.P.Mikheyev and A.Yu.Smirnov, *Proc. of Weak and Electromagnetic Interactions in Nuclei* (Heidelberg 1986), ed. H.V.Klapdor, 710, (1987), M.Guzzo, A.Masiero and S.T.Petcov, *Phys.Lett* **B 260** (1991) 154; E.Roulet, *Phys. Rev.* **D 44** (1991) R935.
40. T.J.Bowles and V.N.Gavrin, *Ann. Rev. Nucl. Part. Sci.* **43** (1993) 117.
41. T.Motobayashi et al, *Phys. Rev. Lett.* **73** (1994) 2680.
42. X.Shi and D.N.Schramm, *Part World* **3** (1993) 149 D.N.Schramm and X.Shi,*Nucl.Phys.B (Proc.Suppl.)* **35** (1994) 321 X.Shi, D.N.Schramm and D.S.Dearborn, *Phys. Rev.* **D50** (1994) 2414.
43. A.Dar and G.Shaviv, Preprint Technion, (1994) G.Shaviv *Nucl.Phys.B(Proc.Suppl.)***38** (1995) 81.
44. V.Berezinsky, G.Fiorentini, M.Lissia, preprint LNGS 95/56, to be published in Phys.Lett.B.
45. P.I.Krastev and A.Yu.Smirnov, *Phys. Lett.* **338 B** (1994) 282.
46. V.Berezinsky, G.Fiorentini, M.Lissia, *Phys. Lett.* **341 B** (1994) 38.
47. J.W.Bieber, D.Seckel, T.Stanev, G.Steigman, *Nature (London)* **348** (1990) 407.
48. B.W.Filippone and P.Vogel, *Phys. Lett.* **246 B** (1990) 546.
49. J.N.Bahcall and W.H.Press, *Astrophys. J.* **370** (1991) 730.
50. V.Gavryusev and E.Gavryuseva, Proc. of 6th Int. Workshop *"Neutrino Telescopes"*(ed. M. Baldo Ceolin), p.319 (1994).
51. E.Akhmedov, Proc. of 6th Workshop *"Neutrino Telescopes"* (ed. M.Baldo Ceolin) p.285 (1994).
52. T.Stanev, Proc. Int. Workshop *"Solar-Neutrino Problem: Astrophysics or Oscillations?"* (ed's V.Berezinsky and E.Fiorini), v.2, p.51, (1994).
53. V.N.Obridko and Yu.R.Rivin, to be published in Izvestia of Russian Academy of Sciences, Seria Fizica **9**, (1995).
54. D.S.Oakley et al., *Astrophys. J. Lett.* **63** (1994) 437.
55. Y.Suzuki, Proc. of 6th Int. Workshop *"Neutrino Telescopes"* (ed. M. Baldo Ceolin), 191, (1994).

56. Y.Totsuka, Talk at Workshop TAUP-95, (1995).
57. T.Ypsilantis et al Preprint LPC-92-31; G.Bonvicini, *Nucl.Phys. B (Proc.Suppl.)* **35** (1994) 438.
58. A.Klypin, S.Borgani, J.Holtzman and J.Primack, *Astrophys. J.* **444** (1995) 1.
59. J.R.Primack, to be published in Proc. *Snowmass* (eds E.W.Kolb and R.Peccei) (1995).
60. A.Bottino, V.De Alfaro, N.Fornengo, G.Mignola and S.Scopel, *Astroparticle Physics***2** (1994) 77.
61. A.Bottino, C.Favero, N.Fornengo and G.Mignola, *Astroparticle Physics* **3** (1995) 77.
62. G.Jungman, M.Kamionkowski and K.Griest, to be published in *Phys. Rep.*(1995).
63. K.Griest, M.Kamionkowski and M.S.Turner,*Phys.Rev.* **D41** (1990) 3565; M.Kamionkowski and M.S.Turner, *Phys. Rev.* **D43** (1991) 1774.
64. M.Kamionkowski, *Phys. Rev.* **D44** (1991) 3021.
65. A.Bottino, N.Fornengo, G.Mignola and L.Moscoso, *Astroparticle Physics* **3** (1995) (65).
66. J.Lopez, D.Nanopoulos and A.Zichichi, *Phys. Lett.* **B291** (1992) 255.
67. J.Lopez, D.Nanopoulos and H.Pois,*Phys. Rev.* **D47** (1993) 2468.
68. R.Rattazzi and U.Sarid, Stanford Univ.preprint (1995).
69. G.L.Kane, C.Kolda, L.Roszkowski and J.D.Wells, *Phys. Rev.* **D49** (1994) 6173.
70. E.Diel, G.L.Kane, C.Kolda and J.D.Wells, Michigan Univ. Preprint, hep-ph/9502399 (1995).
71. P.Nath and R.Arnowitt, *Phys. Rev. Lett.* **70** (1993) 3696.
72. R.Arnowitt and P.Nath, this conference (1995).
73. V.Berezinsky, A.Bottino, J.Ellis, N.Fornengo, G.Mignola and S.Scopel, *Astroparticle Physics* to be published (1995).
74. M.Olechowski and S.Pokorski, *Phys. Lett.* **B344** (1995) 201.
75. L.E.Ibanez and G.G.Ross, *Phys.Lett* **B110** (1982) 215; J.Ellis, D.Nanoupos and K.Tamvakis, *Phys. Lett.* **B121** (1983) 123.
76. M.Beck (Heidelberg-Moscow collaboration) *Nucl. Phys. B (Proc.Suppl.)***35** (1994) 150.
77. M.Milgrom and V.Usov *Astrophys. J. Lett.* **449** (1995) L37.
78. M.Vietri, preprint astro-ph/9506081 (1995)