Dark Matter and Cosmic Ray Observations

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Abstract

The inflationary model of the Universe predicts a density parameter Ω=1. Present dark matter observations do not support this assumption. It is shown that the study of cosmic rays might help to determine the role played by the major components of dark matter in the Universe. In particular, it is underscored that only positron-to-electron ratio observations above 10 GeV with errors smaller than 30% could give precious hints about supersymmetric particle annihilation in the galactic halo.

1 Introduction:

The prediction of the fate of our Universe is a longstanding, unresolved issue.

Depending from its actual density, ρ, the Universe will collapse on itself ($\rho > \rho_c$=1.9 10^{-29} $h_0{}^2$ g/cm^3 where h_0 is a parameter ranging between 0.4 and 1 because of the uncertainty on the Hubble constant), it will expand forever ($\rho < \rho_c$) or we belong to a flat Universe ($\rho = \rho_c$).

The density parameter due to visible matter is $\Omega_v = \rho_v / \rho_c$=0.007, while the inflationary model predicts $\Omega = \rho / \rho_c \sim 1$ (see for example, Pretzl, 1994). Observational facts let understand that unseen matter constitutes a major part of the Universe.

In this paper, galactic halo dark matter and neutrino oscillation searches are analized in order to determine the role that these different components of dark matter might play in the future of our Universe. It is also investigated if cosmic ray observations might help in explaining evidences and speculations about dark matter.

2 Dark Matter Candidates:

Galaxy motion inside clusters and spiral galaxy rotation curves suggest that a large amount of unseen matter might lie among visible material. The idea to use gravitational lensing to measure cluster masses was proposed by F. Zwicky in 1937 (Zwicky, 1937). In 1986 B. Paczynski (Paczynski, 1986) suggested that gravitational microlensing would have permitted to detect baryonic dark matter under the form of MACHOs (Massive Astrophysical Compact Halo Objects) in the Milky Way halo. Observations (Alcock et al., 1996) show that MACHOs can account for 20% of baryonic dark matter. However, because of statistical uncertainties, this measurement is consistent with the possibility that 100% of dark matter needed to explain the galactic rotation curves is made of MACHOs.

H_2 molecular clouds and supersymmetric particles in the galactic halo are other dark matter candidates that might contribute in explaining the Galaxy rotation curves.

Pfenniger & Combes (Pfenniger & Combes, 1994) have suggested that a large number of hydrogen molecular clouds might be present in the outer part of the galactic disks. This assumption is supported by the detection of CO lines from gas at about 12 kpc from the center of the Galaxy (Lequeux, Allen & Guilloteau, 1993).

Broken supersymmetry theories assume the existence in the galactic halo of relic particles produced at the Big Bang. The most light and stable of these supersymmetric particles such as neutralinos, sneutrinos and photinos are the principal candidates for dark matter.

Neutralinos and photinos are assumed to annihilate thus producing protons, antiprotons, electrons and positrons.

No experimental evidence has been ever found of supersymmetric particles in beam experiments suggesting that their mass, including neutralinos, cannot be smaller than about 40 GeV/c^2 (Abe et al., 1998). The indirect method to detect supersymmetric particles in the halo consists in observing their annihilation products in cosmic-ray measurements.

Massive neutrinos might be another source of dark matter.

Experiments for solar neutrino detection show that there is a disagreement of approximately a factor of two between expected and observed fluxes. This disagreement cannot be justified by uncertainties in solar models, neither by experimental detection inefficiencies (see for example Conforto et al., 1998 and references therein), therefore it is plausible that some neutrino families oscillate into others and that neutrinos have masses (Pontecorvo, 1946). This assumption is also supported by observations of the Super-Kamiokande experiment (Fukuda et al., 1998) on atmospheric ν_μ and ν_e that seem to indicate that (most likely) ν_μ oscillate into τ or sterile neutrinos and the recent results of the LSND experiment (White, 1998) where the evidence of ν_μ-ν_e oscillation has been claimed. The above experiments scan the region of L/E ranging from values larger than 10^3 m/MeV down to about 1. By taking into account simultaneously the results on solar, beam and reactor experiments (see Conforto, Barone & Grimani, 1998 and references therein) and by assuming the natural mass hierarchy in the three-flavour neutrino-mixing approximation, $m_1 \ll m_2 \ll m_3$ it results that the neutrino large mass ranges between 0.25 and 3.5 eV^2.

Even by assuming $m_3{}^2$-$m_2{}^2$=$m_3{}^2$-$m_1{}^2 \simeq$3.5 eV^2 and therefore m_3=1.8 eV, $\Omega_\nu h_0{}^2$ reaches a maximum value of about 2 10^{-2} (Conforto et al., 1996). Therefore a major amount of extra matter is still needed in order to have $\Omega \simeq 1$.

Large scale structures in the Universe indicate that by assuming Ω=1 dark matter should be a cocktail of hot (such as neutrinos), cold (for example, supersymmetric particles in the galactic halo) and baryonic matter in the following proportions: 30%, 69% and 1% respectively (Pretzl, 1994).

According to present observations there is no enough dark matter to support the predictions of the inflationary model of the Universe.

3 Dark Matter and Cosmic Rays:

Observations indicate that cosmic rays are confined both in the galactic disk and in the halo (Tang, 1984). It is desirable to investigate if cosmic ray measurements are consistent with dark matter present observations and assumptions.

3.1 MACHOS: In order to explain the spiral galaxy rotation curves, the density parameter should be between 4 and 15 times larger than that determined by visible matter. As an example, in order to justify the rotation curves of the spiral galaxy NGC3198 (Palanque - De La Brouille, 1996) approximately 10^{44} g of dark matter are needed. A similar result can be obtained for the Milky Way (Merrifield, 1992). According to the virial theorem the mass of the halo at a distance D_s from the galactic center is M_{halo}=(v^2 D_s)/G, where v is the galactic rotation velocity, and G is the gravitational constant. The solar system is located about 8 kpc from the galactic center. It has been shown that only a small fraction of cosmic rays reaches the solar system from distances larger than 1 kpc (Ormes & Freier, 1978). By using the rotation curves of spiral galaxies, it is possible to estimate from the virial theorem the amount of dark matter between 7 and 9 Kpc from the galactic center which is 1.11 10^{43} g. The corresponding volume of the halo is 4.72 10^{67} cm^3. By supposing that 100% of the dark halo is made of MACHOs, a total of 10^{10} and 5 10^{11} white (wd) or brown dwarfs (bd) belong to this region of the halo. Cosmic rays with 8.4 million year lifetime (Wiedenbeck & Greiner, 1980) will hit 10^{-33} wd/cm^2 or 10^{-31} bd/cm^2 (to be compared with 5 g/cm^2 of regular matter which correspond to 10^{25} atoms/cm^2). The cosmic ray impacts on MACHOs would reduce their flux, but, because of the small chance they have to hit a MACHO, these celestial bodies have no effect in cosmic ray propagation.

3.2 Halo Hydrogen molecular clouds: Cosmic-ray interactions with halo hydrogen molecular clouds would produce secondary particles. Since dark clusters are located at distances greater than 10 Kpc from the galactic center, the only products of interactions observable at the Earth are gamma rays which present a mean free path of about 20 Mpc in the interstellar medium.

De Paolis et al. (De Paolis et al., 1995) have estimated the upper bound of the photon flux generated by high-energy protons penetrating the H_2 molecular clouds.

Their calculation is not in disagreement with observations.

3.3 Supersymmetric particle annihilation: About cosmic-ray measurements and supersymmetric particle annihilation in the galactic halo, it has been shown (Bottino et al, 1998) that at 95% CL exist supersymmetric configurations compatible with antiproton observations below 1 GeV leading to $0.03 \leq \Omega {h_0}^2 \geq 0.7$.

However it has to be pointed out that at these energies the solar modulation effect on opposite particle charge sign (Perko, 1987) and the uncertainty on the secondary antiproton calculation in the interstellar medium (Gaisser T. K. and Schaefer R. K., 1992) overcome for more than one order of magnitude the supersymmetric particle annihilation expected component. Therefore antiproton-to-proton ratio measurements below 1 GeV cannot lead to any final conclusion about supersymmetric particle annihilation in the galactic halo.

A different scenario might be presented by positrons.

The signature on positron fraction observations of annihilation of supersymmetric particles is expected above 10 GeV (Mc Kee, 1996 and references therein). At these energies the solar modulation effect is totally negligible and the contribution of supersymmetric particle annihilation causes a sudden increase of the positron-to-electron expected ratio which cannot be mistaken with the secondary positron component generated in the interstellar medium showing a decreasing trend. In particular, at 20 GeV the minimum value of the positron-to-electron relative ratio should be 5.8 10^{-2} with the minimum expected contribution of supersymmetric particle annilation products and 3.5 10^{-2} without. Therefore, measurements with errors smaller than 30% are needed in order to have the possibility to detect the halo supersymmetric particle annihilation process. Future experiments could help in understanding the contribution of photinos and neutralinos to dark matter.

3.4 Atmospheric neutrinos: Cosmic-ray observations might also give precious informations about atmospheric neutrino oscillations. The accurate determinations of proton and helium spectra reaching the top of the atmosphere as well as the measurements of secondary particles in the atmosphere, such as muons and pions, would help in reducing uncertainties in analytical and Monte Carlo calculations of atmospheric showers generated by cosmic rays. To reduce the indetermination on atmospheric neutrino flux estimates is a first priority goal in order to correctly interpret the neutrino flux meauserements in underground detectors. See for example Bellotti et al., 1998.

4 Conclusions

According to the predictions of the inflationary model of the Universe the density parameter is expected to be $\Omega \sim 1$.

Observations allow to identify a maximum of 10-20% of the total amount of the expected dark matter.

Present cosmic-ray measurements are compatible with galactic halo baryonic dark matter observations and assumptions. Positron-to-electron ratio measurements in cosmic rays with negligible statistical errors (less than 30%) above 10 GeV would permit to obtain final conclusions about the contribution of heavy supersymmetric particles to cold dark matter. Moreover, an accurate determination of proton and helium fluxes at the top of the atmosphere and of secondary particles at different atmospheric depths would contribute to solve the problem of the atmospheric neutrino oscillations by comparing these measurements to cascade simulations in the atmosphere and neutrino measurements in underground detectors.

Measurements carried out at different atmospheric depths and outside the atmosphere with the same instrument are therefore recommended in order to contain instrumental errors for different flux comparisons.

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