

OPENING THE ULTRA HIGH ENERGY COSMIC RAY WINDOW FROM THE TOP

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Abstract

While several arguments can be proposed against the existence of particles with energy in excess of $(3 - 5) \times 10^{19}$ eV in the cosmic ray spectrum, these particles are actually observed and their origin seeks for an explanation. After a description of the problems encountered in explaining these ultra-high energy cosmic rays (UHECRs) in the context of astrophysical sources, we will review the so-called *Top-Down* (TD) Models, in which UHECRs are the result of the decay of very massive unstable particles, possibly created in the Early Universe. Particular emphasis will be given to the signatures of the TD models, likely to be accessible to upcoming experiments like Auger.

1 Introduction

Cosmic ray particles with energy in excess of $\sim 10^{20}$ eV have been detected during the last thirty years by several independent experiments, such as AGASA (Takeda et al. 1998; Takeda et al. 1999; Hayashida et al. 1994), Fly's Eye (Bird et al. 1993, 1994, 1995), Haverah Park (Lawrence, Reid and Watson 1991), Yakutsk (Efimov 1991), Volcano Ranch (Linsley 1963) and more recently by the High Resolution Fly's Eye experiment (Kieda et al. 1999). These events represent now more than ever a big challenge for our understanding of particle physics and astrophysics.

While historically the first reactions to the detection of these particles were related to the already difficult problem of accelerating particles to the highest observed energies, it became soon clear that the existence of cosmic rays having energy larger than $\sim 4 \times 10^{19}$ eV [the so-called ultra-high energy cosmic rays (UHECR)] was more than that, and indeed represented a much more serious challenge to known Physics. Soon after the discovery of the cosmic microwave background radiation (CMBR), Zatsepin and Kuzmin (1966) and independently Greisen (1966) recognized that the propagation of a proton in the CMBR bath had to be limited to short distances due to photopion production. If the sources of UHECRs are distributed homogeneously in the sky, this immediately implies that the flux of UHECRs above $\sim 4 \times 10^{19}$ eV should be strongly suppressed. This is the so-called Greisen-Zatsepin-Kuzmin (GZK) cutoff. Similar arguments apply to nuclei.

This puzzling situation inspired on one side a proliferation of models of the generation of particles with sufficiently high energy, and on the other side it fueled interest in the study of the propagation of UHECRs [see for instance Lee, Olinto and Sigl 1995; Lemoine, Sigl, Olinto and Schramm 1997 and Bhattacharjee and Sigl 2000, and references therein] for different compositions and for realistic models for the distributions of the sources and for the intergalactic magnetic field, which still remains only constrained by upper limits, generally based on measurements of the Faraday rotation of light coming from distant quasars (Kronberg 1994; Blasi, Burles and Olinto 1998). These limits are at the level of $\sim 10^{-9}$ Gauss, although larger values are allowed in large scale structures. The angular deflection of ultra high energy protons in such fields would be comparable with or smaller than the angular resolution of current experiments, so that in principle it should be possible to do astronomy using UHECRs as probes. Several efforts have been put into the search for candidate nearby sources in the direction of arrival of UHECRs, but with no result (see for instance Elbert and Sommers 1995).

Recent analysis of the distribution of arrival directions of UHECRs (Takeda et al. 1999; Uchihori et al. 2000), in search for a possible large scale anisotropy also gave negative results: with the present statistics, the observed distribution appears to be consistent with isotropy, but indications have been found of small scales anisotropies, at a few degrees level. If confirmed, this finding will hopefully provide hints about the sources of UHECRs.

The paper is structured as follows: in section 2 we give a short outline of the observational situation; in section 3 we present a critical view of the GZK cutoff, its meaning and its potential power in limiting wide classes of models. In section 4 we introduce the astrophysics and particle physics inspired models; in section 5 we discuss topological defects variants of TD models, while in section 6 we discuss the models of relic quasistable massive particles. We conclude in section 7.

2 Observations

The cosmic ray spectrum is measured from fractions of GeV to a (current) maximum energy of 3×10^{20} eV. The spectrum above a few GeV and up to $\sim 10^{15}$ eV (the knee) is measured to be a power law with slope ~ 2.7 , while at higher energies and up to $\sim 10^{19}$ eV (the ankle) the spectrum has a different slope, of ~ 3.1 . At energy larger than 10^{19} eV a flattening seems to be present.

There are currently 92 events above 4×10^{19} eV, 47 of which have been detected by the AGASA experiment.

The information available on the composition of cosmic rays at the highest energies is quite poor. A study of the shower development was possible only for the Fly's Eye event (Bird et al. 1995) and disfavors a photon primary (Halzen et al. 1995). A reliable analysis of the composition is however possible only on statistical basis, because of the large fluctuations between one shower and the other at fixed type of primary particle.

The Fly's Eye collaboration reports of a predominantly heavy composition at 3×10^{17} eV, with a smooth transition to light composition at $\sim 10^{19}$ eV (see talk by Alessandro, these proceedings). This trend was not confirmed by AGASA (Hayashida et al. 1994; Yoshida and Dai 1998).

In (Takeda et al. 1999) the directions of arrival of the AGASA events above 4×10^{19} eV were studied in detail: no appreciable departure from isotropy was found, with the exception of a few small scale anisotropies in the form of doublets and triplets of events within an angular scale comparable with the angular resolution of the experiments ($\sim 2.5^\circ$ for AGASA). This analysis was repeated in (Uchiyori et al. 2000) for the whole sample of events above 4×10^{19} eV, and a total of 12 doublets and 3 triplets were found within $\sim 3^\circ$ angular scales. The attempt to associate these multiplets with different types of astrophysical sources possibly clustered in the local supercluster did not give positive result (see Stanev, these proceedings).

3 The GZK cutoff: what is it telling us?

Although the existence of UHECRs is experimentally well established, it represents a big challenge from the theoretical point of view, because of a combination of puzzles related to the production and to the propagation of these particles. We will summarize the different parts of this puzzle in the following.

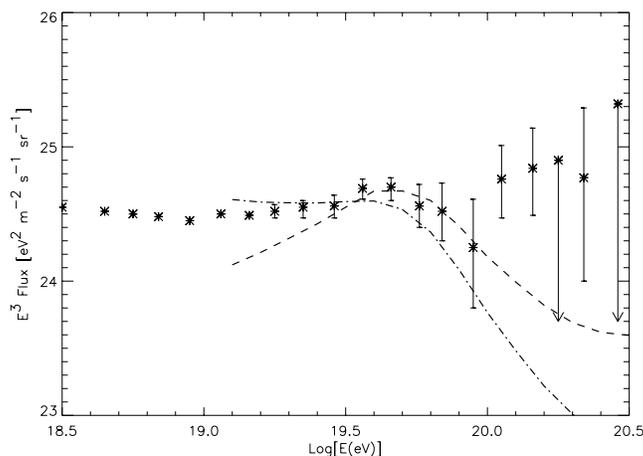


Figure 1: *Spectrum of UHECRs detected by AGASA. The lines are theoretical predictions for homogeneously distributed sources and injection spectra E^{-2} (dashed line) and E^{-3} (dash-dotted line).*

The first and most important part of the mystery is that the Universe should be dark at energies in excess of a few 10^{19} eV due to photopion production of UHECRs on the photons of the CMBR. This interaction has a typical pathlength $l_{int} < 50$ Mpc (corresponding to a travel time of $< 10^8$ years) at ultra high energies (see Stanev, these proceedings). If the sources of UHECRs are distributed nearly homogeneously in the universe, the photopion production results in an observed spectrum which has a pronounced cutoff that starts at $\sim 3 \times 10^{19}$ eV. This is the so-called GZK cutoff (Greisen 1966; Zatsepin and Kuzmin 1966). It is worth spending a few more words on the meaning of the cutoff, since it is so crucial in defining the problem of UHECRs. Particles generated at distances closer than $\sim l_{int}$ can reach the detector and be UHECR events. The pathlength l_{int} becomes gradually larger at lower energies, so that particles with these energies can come from correspondingly larger distances. It is clear that the problem of UHECRs exists because, for a homogeneous distribution of sources there are not enough nearby sources to provide the observed fluxes. In Fig. 1 we show the results of AGASA observations at energies $> 10^{18.5}$ eV and the theoretical prediction for a homogeneous distribution of sources and an injection spectrum E^{-2} (dashed line) and E^{-3} (dash-dotted line). Two comments are in order on this figure: 1) the predicted spectra may present a recovery above some energy, due to the flux contributed by the nearby sources; 2) the energy position of the cutoff increases for a locally overdense distribution of sources.

Only if the universe presents local overdensities by a factor > 10 it is possible to reconcile the expected spectra with the observed spectra and fluxes (Berezinsky et al. 1990), provided suitable sources are found in the local universe. These overdensities are not observed (Blanton, Blasi and Olinto 2000).

At this point the second part of the mystery enters: upper limits on the intergalactic magnetic field based on the Faraday rotation measurements are at the level of $10^{-9} - 10^{-10}$ Gauss (Kronberg 1994; Blasi et al. 1999), so that typical deflection angles of protons are forced to be within a few degrees. Searches for sources of UHECRs have been carried out, but no plausible candidate was found within $\sim 3^\circ$ of the direction of arrival of the events (Elbert and Sommers 1995). If the candidate particle is an iron nucleus then the deflection angles are likely to become larger and it becomes correspondingly harder to look for sources. However, if the deflection angle becomes too large, then the regime of propagation becomes closer to diffusive and this forces the distance to the source to be even smaller, making the situation more problematic. A possible exception to this is if the iron nuclei are accelerated locally in the Galaxy and deflected and isotropized in an extended halo. In this case no GZK cutoff is expected.

The problems mentioned above are all related to the propagation of UHECRs. However there is another problem, that historically was the first to be studied, and is related to the mechanism able to produce such particles. We dedicate the next section to this topic.

4 Astrophysics and Particle Physics Models

Astrophysical models for the production of UHECRs are generally based on an acceleration mechanism to be applied to a class of scenarios of astrophysical relevance. We do not discuss here any of the acceleration models, but we outline the general features

and problems they encounter. An exhaustive discussion of most of the models which are currently under investigation can be found in (Olinto 2000) and some of them are discussed by Stanev (these proceedings). A very broad classification of these models is that between galactic and extragalactic ones. In general, galactic models require heavy composition, in order to emulate the isotropic distribution of arrival directions.

In most of the extragalactic models that have been proposed so far, the highest energies are reached only for the extreme values of the parameters involved [see (Norman, Melrose and Achterberg 1995)]. Strong constraints on astrophysical models come from the spectrum they generate (after accounting for propagation). In fact, as long as the acceleration models are associated with sources with a homogeneous distribution in the sky, the problem of UHECRs remains, independently on the maximum energy. The case of a single source accidentally present in the nearby universe (for instance in the local supercluster) was investigated by Berezhinsky, Grigorieva and Dogiel 1990; Blasi and Olinto 1999; Sigl, Lemoine and Biermann 1999). Even with relatively strong fields of $10^{-8} - 10^{-7}$ Gauss, the anisotropy is too large compared with observations (see however (Ahn et al. 1999) for an alternative model involving M87).

The difficulty in acceleration to the highest energies (Norman, Melrose and Achterberg 1995), the presence of the GZK cutoff in most of the cases and the lack of counterparts in the arrival directions fueled the interest in a new class of models that could avoid these problems. These are *particle physics inspired models*, in which UHECRs are generated as a result of the decay of very massive particles (from here the name of Top-Down models). The problem of reaching the maximum energies is, in these models, solved *by construction*.

The spectra of the particles resulting from the decay are determined in principle by QCD, the channel of reactions being: $X \rightarrow q\bar{q}$, where q are quarks that hadronize, generating mainly pions and a small fraction of protons and neutrons. The spectra are generally very flat (roughly $E^{-3/2}$, although the realistic calculations do not give power law spectra), which represents one of the peculiar features of TD models. At the production, most of the ultra-high energy particles are gamma rays, but propagation effects can change the ratio of gamma rays to protons. The gamma rays generated at distances larger than the absorption length produce a cascade at low energies (MeV-GeV) which represents a powerful tool to constrain TD models.

There are basically two ways of generating the very massive particles and make them decay at the present time: 1) trapping them inside topological defects; 2) making them quasi-stable (lifetime larger than the present age of the universe) in the early universe. We discuss these two possibilities separately in the next two sections.

5 Topological Defects

Topological defects are naturally formed at phase transitions and their existence has been proven by direct observations in several experiments on liquid crystals and ferromagnetic materials. Similar symmetry breakings at particle physics level are responsible for the formation of cosmic topological defects [for a review see (Vilenkin and Shellard 1994)].

The fact that topological defects can generate UHECRs was first proposed in the pioneering work of Hill, Schramm and Walker (1987). The general idea is that the

stability of the defect can be locally broken by different types of processes (see below): this results in the false vacuum, trapped within the defect, to fall into the real vacuum (outside universe), so that the gauge bosons of the field trapped in the defect acquire a mass m_X . At this point, the very massive and unstable particles rapidly decay producing high energy particles.

Several topological defects have been studied in the literature: ordinary strings (Bhattacharjee and Rana 1990), superconducting strings (Hill, Schramm and Walker 1987), bound states of magnetic monopoles (Hill 1983; Bhattacharjee and Sigl 1995), networks of monopoles and strings (Berezinsky, Martin and Vilenkin 1997), necklaces (Berezinsky and Vilenkin 1997) and vortons (Masperi and Silva 1998).

Only strings, necklaces and monopolonia will be considered here, while a more extended discussion can be found in more detailed reviews (Bhattacharjee and Sigl 2000; Berezinsky, Blasi and Vilenkin 1998).

5.1 Ordinary strings

Strings can generate UHECRs if there are configurations in which microscopic or macroscopic portions of strings annihilate. In the contact regions the phase of the field trapped in the string becomes undetermined and the vacuum expectation value becomes non zero. If $\eta \sim m_X$ is the symmetry breaking scale at which the string formed, it is easy to see that during intercommutation of strings or self-intersection, only one (or a few) X-particles are generated. It was shown (Shellard 1987; Gill and Kibble 1994) that self-intersection events provide a flux of UHECRs which is much smaller than required. The same conclusion holds for intercommutation between strings.

The efficiency of the process can be enhanced by multiple loop fragmentation: as a nonintersecting closed loop oscillates and radiates its energy away, the loop configuration gradually changes. After the loop has lost a substantial part of its energy, it becomes likely to self-intersect and fragment into smaller and smaller loops, until the typical size of a loop becomes comparable with the string width η . At this point the energy is radiated in the form of X-particles. Although the process of loop fragmentation is not well known, some analytical approximations (Berezinsky, Blasi and Vilenkin 1998) show that appreciable UHECR fluxes imply utterly large gamma ray cascade fluxes. Bhattacharjee and Sigl (2000) argued however that there might be models of loop fragmentation in which this result is mitigated.

Another way of liberating X-particles is through cusp annihilation (Brandenberger 1987). Cusps can be produced along a string loop (Turok 1984) or due to kinks propagating in opposite directions on a long string (Mohazzab and Brandenberger 1993). Although during the cusp annihilation a macroscopic fraction of the string length can be transformed into X-particles, the corresponding UHECR flux is far too low (Bhattacharjee 1989; Gill and Kibble 1994).

The idea that long strings lose energy mainly through formation of closed loops was recently challenged by Vincent, Antunes and Hindmarsh (1998). Their simulations seem to show that the string can produce X-particles directly and that this process dominates over the generation of closed loops. This new picture was recently questioned by Moore and Shellard (1998).

Even if the results of Vincent et al. (1998) are correct however, they cannot solve the problem of UHECRs (Berezinsky, Blasi and Vilenkin 1998): in fact the typical

separation between two segments of a long string is comparable with the Hubble scale, so that UHECRs would be completely absorbed. If by accident a string is close to us (within a few tens Mpc) then the UHECR events would appear to come from a filamentary region of space, implying a large anisotropy which is not observed. Even if the UHECR particles do not reach us the gamma ray cascade due to absorption of UHE gamma rays produced at large distances imposes limits on the efficiency of direct production of X-particles by strings.

5.2 Monoponia and monopole-strings networks

The role of monoponia (bound states of monopoles and antimonopoles) for UHECRs was first pointed out by Hill (1983) and Schramm and Hill (1983). When the monoponium is produced it is in a very excited state, and later decays to the ground state, where the typical distance between the monopole and the antimonopole is smaller than the size of the inner (quantum) stable orbit. At this point the monopole and the antimonopole annihilate and generate X-particles. This process was studied in detail by Bhattacharjee and Sigl (1995). However, recently Blanco-Pillado and Olum (1999) have found that plasma friction on the monopoles result in a short lifetime for the monoponium, making it useless for UHECRs.

As an alternative, a similar system was proposed by Berezinsky, Martin and Vilenkin (1997), where the symmetry breakings $G \rightarrow H \times U(1) \rightarrow H \times Z_N$ ($N \geq 3$) results first in the formation of monopoles and then of strings connecting them and forming an infinite network. The shrinking of strings during their evolution causes the distance between monopoles to decrease. During this stage, monopoles accelerate and therefore radiate very high energy gluons, that generate hadrons through fragmentation. The fluxes of UHECRs that result from this process are negligible (Berezinsky, Blasi and Vilenkin 1998).

5.3 Necklaces

An interesting special case of monopole-string networks is realized when the following chain of symmetry breakings occurs: $G \rightarrow H \times U(1) \rightarrow H \times Z_2$. In this case each monopole gets attached to two strings, to form a necklace (Berezinsky and Vilenkin 1997). The critical parameter that defines the dynamics of this network is the ratio $r = m/\mu d$ where m is the monopole mass and d is the typical separation between monopoles (e.g. the length of a string segment). Berezinsky and Vilenkin (1997) proposed that there might be cases in which the system evolves toward a state where $r \gg 1$, although only numerical simulations can confirm this point. In this case, the distance between the monopoles decreases and in the end the monopoles annihilate, with the production of X-particles and their decay to UHECRs. The rate of generation of X-particles is easily found to be $\dot{n}_X \sim r^2 \mu / t^3 m_X$. The quantity $r^2 \mu$ is upper limited by the cascade radiation, given by $\omega_{cas} = \frac{1}{2} f_\pi r^2 \mu = \frac{3}{4} f_\pi r^2 \mu / t_0^2$ ($f_\pi \sim 0.5 - 1$). The typical distance from the Earth at which the monopole-antimonopole annihilations occur is comparable with the typical separation between necklaces, $D \sim \left(\frac{3 f_\pi \mu}{4 t_0^2 \omega_{cas}} \right)^{1/4} > 10 (\mu / 10^6 GeV^2)^{1/4}$ kpc.

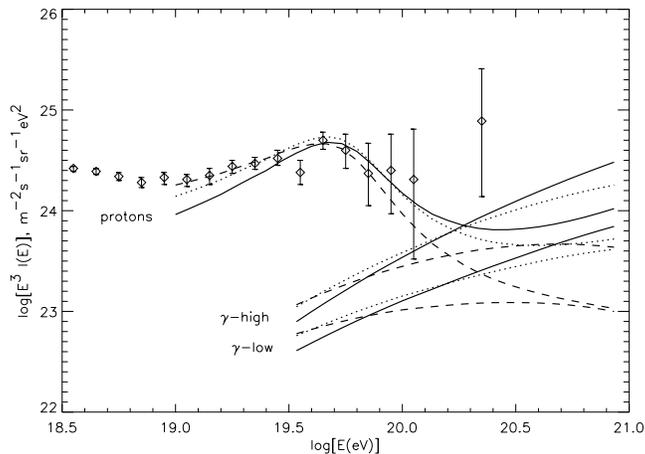


Figure 2: *Spectrum of UHECRs produced by necklaces.*

Clearly, necklaces provide an example in which the typical separation between defects is smaller than the pathlength of gamma rays and protons at ultra-high energies. Hence necklaces behave like a homogeneous distribution of sources, so that the proton component has the usual GZK cutoff. This component dominates the UHECR flux up to $\sim 10^{20}$ eV, while at higher energies gamma rays take over. The fluxes obtained in (Berezinsky, Blasi and Vilenkin 1998) are reported in Fig. 2, where the SUSY-QCD fragmentation functions (Berezinsky and Kachelriess 1998) were used. The dashed lines are for $m_X = 10^{14}$ GeV, the dotted lines for $m_X = 10^{15}$ GeV and the solid lines for $m_X = 10^{16}$ GeV. The two curves for gamma rays refer to two different assumptions about the radio background at low frequencies (Protheroe and Biermann 1996).

6 Cosmological relic particles

Super heavy particles with very long lifetime can be produced in the early universe and generate UHECRs at present. The existence of particles satisfying these requirements was studied recently by Berezinsky, Kachelriess and Vilenkin (1997); Kuzmin and Rubakov (1997), Chung, Kolb and Riotto (1998) and Kuzmin and Tkachev (1998) and reviewed by Kuzmin and Tkachev (1998a). In order to keep the same symbolism used in previous sections, we will call these particles X-particles.

X-particles can be produced in the early universe through different mechanisms. The simplest of them is the *gravitational production*: particles are produced naturally in a time variable gravitational field or indeed in a generic time variable classical field. In the gravitational case no additional coupling is required (all particles interact gravitationally). If the time variable field is the inflaton field ϕ , a direct coupling of the X-particles to ϕ is needed.

The gravitational production of particles was first proposed by Zeldovich and Starobinsky (1972). It does not require any additional assumption neither on the X-particles nor on cosmology. In particular inflation is not required a priori, and indeed it reduces

the effect. It can be shown that at time t , gravitational production can only generate X-particles with mass $m_X \leq H(t) \leq m_\phi$, where $H(t)$ is the Hubble constant and m_ϕ is the inflaton mass. Chung, Kolb and Riotto (1998) and Kuzmin and Tkachev (1998) demonstrated the impressive result that the fraction of the critical mass contributed by X-particles with $m_X \sim 10^{13}$ GeV produced gravitationally is $\Omega_X \sim 1$, with no additional assumption! In other words, cold dark matter can naturally be explained in terms of X-particles in this range of masses.

If the X-particles are directly coupled to the inflaton field, they can be effectively generated during preheating (Kofman, Linde and Starobinsky 1994; Felder, Kofman and Linde 1998). Alternative mechanisms for the production of X-particles are based on non-equilibrium thermal generation during the preheating stage (Berezinsky, Kachelriess and Vilenkin 1997).

As mentioned in the beginning of this section, in order for X-particles to be useful dark matter candidates and generate UHECRs they need to be long lived. The gravitational coupling by itself induces a lifetime much shorter than the age of the universe for the range of masses which we are interested in. Therefore, in order to have long lifetimes, additional symmetries must be postulated: for instance discrete gauge symmetries can protect X-particles from decay, while being very weakly broken, perhaps by instanton effects (Kuzmin and Rubakov 1998). These effects can allow decay times larger than the age of the universe, as shown by Hamaguchi, Nomura and Yanagida (1998).

The slow decay of X-particles produces UHECRs. The interesting feature of this model is that X-particles cluster in the galactic halo, as cold dark matter (Berezinsky, Blasi and Vilenkin 1998). [If monopolonia survived they would also cluster in the halo]. Hence UHECRs are expected to be produced locally, with no absorption, and as a consequence the observed spectra are nearly identical to the emission spectra, and therefore gamma rays dominate. The very flat spectra and the gamma ray composition are two of the signatures. The calculations of the expected fluxes have been performed by Berezinsky, Blasi and Vilenkin (1998), Birkel and Sarkar (1998) and Blasi (1999). In figure 3 we report the results found in (Blasi 1999). The two solid lines are obtained for SUSY-QCD fragmentation functions and the dashed lines are for the QCD fragmentation function in the MLLA approximation, with $m_X = 10^{14}$ GeV (solid lines) and $m_X = 10^{13}$ GeV (thin lines).

The strongest signature of the model is a slight anisotropy due to the asymmetric position of the sun in the Galaxy (Dubovsky and Tinyakov 1998; Berezinsky, Blasi and Vilenkin 1998). More recently a detailed evaluation of the amplitude and phase of the first harmonic has been carried out by Berezinsky and Mikhailov (1999) and Medina Tanco and Watson (1999). The two papers agree that the present data is consistent with the anisotropy expected in the model of X-particles in the halo. In fact, as discussed in section 2, observations at present do not suggest any appreciable deviation from isotropy, with the exception of a few degree scale anisotropies showing up in the form of doublets and triplets of events within an angular scale comparable to the resolution of the experiments. Uchihori et al. (2000) investigated the total of 92 events above 4×10^{19} eV collected by Volcano Ranch, Haverah Park, Yakutsk and Akeno and found 12 doublets and 3 triplets within 3° .

In TD models the presence of these multiplets of events is usually not well accommodated because of the homogeneous distribution of the topological defects or of the

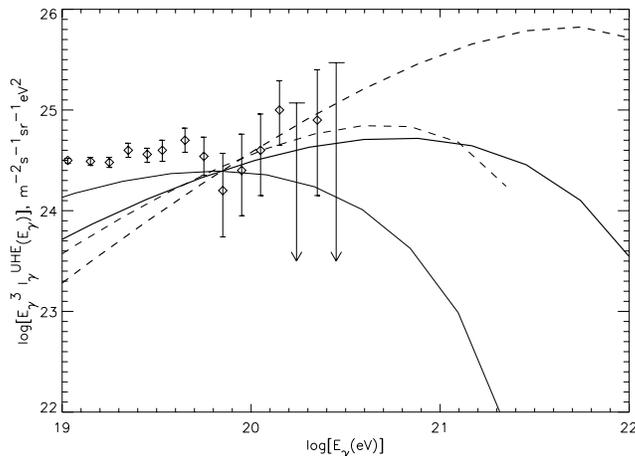


Figure 3: *Spectrum of UHECRs produced by SH particles in the halo.*

superheavy particles. However, it was shown by Blasi and Sheth (2000) that in the latter the presence of the multiplets is actually naturally explained, taking into account the dark matter distribution in the galactic halo.

The spatial distribution of cold dark matter has been studied in detail in N-body simulations (Ghigna et al. 1999; Moore et al. 1999; Tormen, Diaferio and Syer 1998) and a few elements seem to be well established: 1) the density of dark matter has a behaviour $r^{-\gamma}$ with $\gamma \sim 1 - 1.5$ in the central part of galaxies; 2) at large radii the radial profile is r^{-3} ; 3) in addition to the smooth component, simulations show very clearly the existence of a clumped component. Berezhinsky (2000) suggested that the multiplets might be correlated with the clumps of dark matter. Blasi and Sheth (2000) carried out a numerical simulation of the arrival directions of UHECR events from a realistic distribution of dark matter in the halo (including the clumps) and derived the probabilities to detect the observed numbers of doublets and triplets (or more). They adopted a Navarro-Frenk-White (NFW: Navarro, Frenk and White 1996) smooth distribution of dark matter and used the results of the N-body simulations for the small scale structure, assuming each clump being represented by an isothermal sphere. The numbers of doublets and triplets found by generating a large number of halo configurations and the corresponding pattern of arrival directions of UHECRs are comparable with the observed ones and in excess of the number expected from an isotropic distribution of arrival directions. Surprisingly, the main reason for the increase in the predicted number of doublets and triplets with respect to isotropy is that the smooth component has an NFW profile. The effect of the clumps, apart from increasing slightly the numbers of multiplets, is to enhance the probability of having more than the average number of doublets and triplets. This result can be understood by accounting for the shape of the dark matter profile, increasing toward the central part of the galaxy. Predictions for future full sky experiments were proposed.

7 Conclusions

The problem of the existence of UHECRs is all but solved. Astrophysical models are being narrowed down by several constraints: most of the extragalactic sources would suffer a GZK cutoff, since the large overdensities needed locally to avoid it do not seem to be present. Moreover it is difficult to reach the highest energies (Norman, Melrose and Achterberg 1995). Galactic accelerators usually require an iron dominated composition in order to account for the isotropy of arrival directions. Further studies are needed to quantify the expected and observed anisotropies in these models, since the magnetic field strength and extension in the halo are poorly known.

Top-Down models naturally provide the highest energies, and at least some of them can describe quite well the observed spectral shape above $\sim 4 \times 10^{19}$ eV. As positive examples we considered in some detail the cases of necklaces and relic super massive particles in the halo of the Galaxy. In the former model, the composition of UHECRs should be dominated by protons up to $\sim 10^{20}$ eV, and by photons at higher energies. In the latter, UHECRs are gamma rays and a peculiar pattern of large and small scale anisotropies should be visible in future observations. In all Top-Down models there is at least an appreciable fraction of UHECRs in the form of gamma rays.

Experiments like HiRes (Corbato' et al. 1992), currently operating, the Auger project (Cronin 1992), the proposed Telescope Array (Teshima et al. 1992) and the OWL-Airwatch satellite (Streitmatter 1997) will nail down the answers to the dark points. An unambiguous determination of the composition will be fundamental: heavy composition would rule out all Top-Down models and open a window of opportunity for galactic scenarios. A Gamma ray dominated composition would instead be a smoking gun for Top-Down models. The measurement of the anisotropy on different scales will also be a crucial step: galactic models all predict some degree of anisotropy toward the galactic disk or center. A peculiar pattern of anisotropy is also predicted by super heavy particles clustered as dark matter in the galactic halo.

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