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The mystery of the GZK cutoff in the light of the galaxy distribution

P. Chardonnet

Université de Savoie - LAPTH BP 110 74941 Annecy-le-Vieux Cedex France

Abstract. The Ultra High Energy Cosmic Rays are a long standing puzzle. Up to now, their origin remains unknown as well as the explanation of the absence of GZK cutoff observed in all the experiments. In this paper we analyze the possible absence of GZK cutoff in the light of galaxies surveys. We find that the overdensity in our neighbourhood deduced from the UZC survey couldn't reproduce the absence of cutoff in the cosmic rays spectra. The basic new element of this work is a detail treatment with the correct luminosity function. In addition we find an estimate of the density number of dwarf galaxies in order of 0.43 Mpc^{-3}.

1 Introduction

The past decade has seen tremendous progress in the search for the high energy cosmic rays (Nagano and Watson , 2000). Conclusive detections from different experiments present evidences indicating that the events above the GZK bound are statistically relevant. Let's first recall the observations that are the basic clue for all the models are :

1) The existence of events above 10^{20} eV. This fact require powerful acceleration mechanisms. As mentioned above this is not a hard task for astrophysicists.

2) The observed flux of $4.\ 10^{-30}\ GeV^{-1}.cm^{-2}.s^{-1}$ at 10^{20} eV. This is equivalent to a cosmic ray energy density of $2.\ 10^{-21}$ $ergs.cm^{-3}$. Again, such quite high density is not exceptional in astrophysical environment.

3) The absence of GZK cutoff. This fact is the most important constraint for all the models. The previous two regard mainly the energetic part. We are confident to find acceleration mechanism and sufficiently flux but the absence of this cutoff is very intriguing. We naturally interpret this fact saying that the sources are distributed inhomogenously. In other words it means that we live in an overdensity region. Analyzing this fact in the light of the distribution of galaxies is precisely the aim of this paper.

Correspondence to: P. Chardonnet (chardon@lapp.in2p3.fr)

In this paper we do not intend to propose a new model. But as a matter of fact a very stringent constraint is the normally presence of the GZK cutoff. Our aim is simply to analyze the presence of this cutoff in the light of the galaxy distribution.
It has long been hypothesized that the GZK cutoff could arise from a local overdensity in our neighborhood (Berezinsky and Grigorieva , 1988) . Our ignorance of the cosmic rays sources distribution is the principal obstacle for this mystery. Therefore, if we assume that these sources follow the distribution of matter in the universe we can examine the question more quantitatively. In order to trace the distribution of matter we will analyze how the galaxies are distributed. Such analyze was made in 1997 and the answer was that the absence of the GZK cutoff could be explained by the overdensity of order of 30 observed in the CfA survey (Medina-Tanco , 1999). Emphasis will be given here that there is no such local overdensity as claimed this paper . In this paper we put forward an interpretation that the error was an incorrect computation of the number of galaxies and the effect of the abundant dwarf galaxies that make a bias effect.
In literature we find a lot a reference regarding the computation of the local density of the universe (Saunders et al. , 1991). The previous works were all motivated by the study of the deviation to the Hubble law due to locally overdensity. It was claimed that the global overdensity in the Virgo supercluster is around 2 (Strauss et al. , 1992). It is important to notice that the IRAS survey is an infrared survey and as a consequence it is deeper than the optical one but as the inconvenient to be more sensitive to spiral galaxies. And it is clear from the redshift distribution that the IRAS survey present a more smooth picture of our local neighborhood (Strauss and Willick , 1995). We present here a study of the local density based on the optical survey UZC (Falco et al., 1999). This survey is magnitude limited up to 15.5. Previous analyses with optical survey have shown local overdensity in the Virgo cluster in agreement with the IRAS survey (Hudson , 1993; Davis et al. , 1981; Davis and Huchra , 1982). Both analyses reveal on overdensity in the Virgo cluster of order of 2. We want to compute the overdensity as a function of

redshift. Such a computation was done for the IRAS survey (Yahil and Huchra , 1991; Strauss and Willick , 1995). But this survey is very particular since it erase practically all the structure a part for the Virgo cluster where it confirmed an overdensity of order of two. So we address the question with the optical survey This parameter is crucial for the cosmic ray propagation.
There exist now a large number of redshift surveys (Strauss and Willick , 1995). One can classify briefly them into two categories: the deeper in redshift have the inconvenient to be very very narrow so there cover only a small fraction of the sky. Therefore in the study of the overdensity they certainly not constitute a faire sample of the universe. The other one are less deeper but cover a larger portion of the sky. In turn we may also ask if in this case the structure we observed are bound. According to Strauss (Strauss , 1993), the data of the redshift are consistent with the cosmological principal and we can say that above 60 Mpc the structure are bound inside the survey. This point is important in order to compute a mean value for the density of the universe and to make sense as regarding the cosmological principle.

2 Observation and analyses with luminosity function

We will use the formalism of the luminosity function $\Phi(L)$ (Binggeli, Sandage and Tammann , 1988). If we look at a small volume dV placed at a redshift z and if we search galaxies with luminosity L in the range $(L, L + dL)$ then the number of observed galaxies is :

$$dN(z, L) \;=\; n(z)\, dV\, \Phi(L)\, dL \tag{1}$$

where $n(z)$ is the spatial density of galaxies at the redshift z. Here, the distance is express with a good approximation by: $r \;= r(z) \;\simeq\; \dfrac{c\,z}{H_o}$, where H_o is the Hubble constant and c the celerity of light. The standard form for the luminosity function is the Schechter form:

$$\Phi(L) \;=\; \Phi_\star\,(\frac{L}{L_\star})^{-\alpha}\, exp(-\frac{L}{L_\star}) \tag{2}$$

where α is a parameter, $L_\star$ a typical luminosity and $\Phi_\star$ is express in galaxies per Mpc^3. We have used the values taken from CfA2

From this expression we see immediately that the number of galaxies brighter than $L_\star$ falls exponentially. Since we will focus our analysis only at low redshift α is a pure constant independent of z.
To obtain the number of galaxies in a given volume for all possible luminosity we have to sum the all individual contribution in the luminosity range. But, since we have a magnitude limited catalog, it's imply that there is a typical luminosity below where we observe no galaxies. Finally, the expected number of galaxies in a given volume is :

$$dN(z) \;=\; n(r)\, dV \int_{L_{min(z)}}^{\infty} \Phi(L)\, dL \tag{3}$$

where $L_{min(z)}$ is a function of the distance r. So generally, people used to rewrite the last equation as : $dN(z) \;=\; n(r)\, dV\, \phi(r)$ where $\phi(r)$ is the selection function. It is important to notice that the luminosity function $\Phi(L)$ is a property of the galaxies while the selection function ϕ is a property of the survey by the magnitude limited. For a survey which cover the solid angle ω, the predicted number per interval of redshift is simply given by: $dN(z) \;=\; \omega\, n(z)\, r^2 dr\, \phi(r)$. At low redshift the behaviour of $dN(z)$ is proportional to z^2, while at a certain redshift the cut off in luminosity function break down this power law. The average density of galaxies can be compute using this formula. Following a definition proposed by Davis and Huchra in 1982, we have :

$$\overline{n_3} \;=\; \frac{N_T}{\int \phi(r) dV} \tag{4}$$

where N_T is the total number of galaxies in the survey. The integration is over the all volume of the survey. If we use the Schechter formalism for the luminosity function it means that the selection function depends only on α and $M_\star$. These two parameters are determined by fitting the data. The third parameter $\Phi_\star$ is obtained from the value of the mean galaxy density $\overline{n_3}$. In our case we find a density of galaxy $n_{field} \simeq 0.043\;\; Mpc^{-3}$. From this we can see that the determination of the selection function is fundamental to compute the number of galaxies per bin. At low redshift the behaviour is mainly due to the volume effect since all the galaxies present will be in the survey, but as we go father it is clear due the exponential cutoff of luminosity function that the theoretical prediction should goes down. This fact is of course well known from the astrophysical community (Strauss and Willick , 1995), but we want to stress that it was necessary to compute the overdensity from the point of view of the GZK cutoff.
We have used the Updated Zwicky Catalog for the survey (Falco et al., 1999) This survey is magnitude limited $m_B = 15.5$ and is complete for 87% We will as usual make the redshift correction toward the reference frame we used in this case the Local Group one so we add to the redshift the term $300 \times sin(l)cos(b)$. the full sample contain 19372 galaxies. The galaxies which have no redshift measurement have been excluded also those with negative redshift. It remains only 18667 galaxies. We have chosen bin in velocity of 300 km/s. We have used the luminosity function of CfA2 to compute the expected number of galaxies per bins. The result are display in fig. 1.

The global behaviour is well represented by this luminosity function. The only disagreement is locally from our position to about 20 Mpc. As will see this apparent overdensity of order 10 is due to the faint dwarf galaxies. In order to compute the overdensity we assume that the luminosity function is a separate function of the position in space. It seems reasonable since we focus our analyze only for small redshift. The luminosity function formalism permit us to define a mean density associated with this survey using the galaxy counts from the survey we then be able to compute the devi-

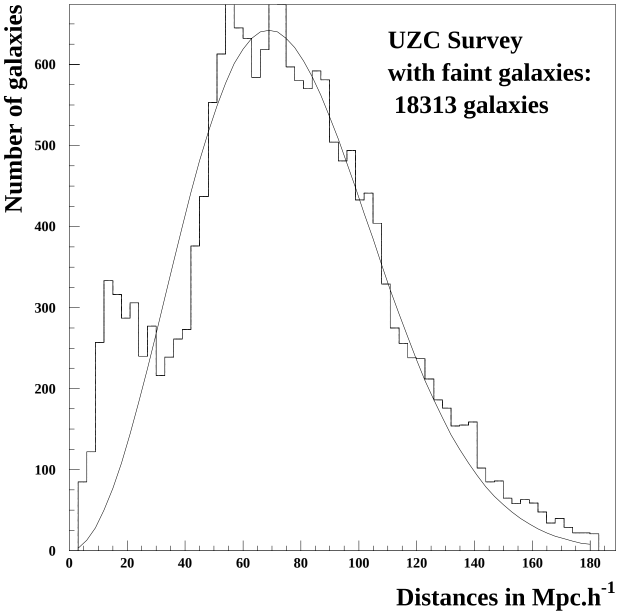

Fig. 1. The UZC Survey: counts versus prediction

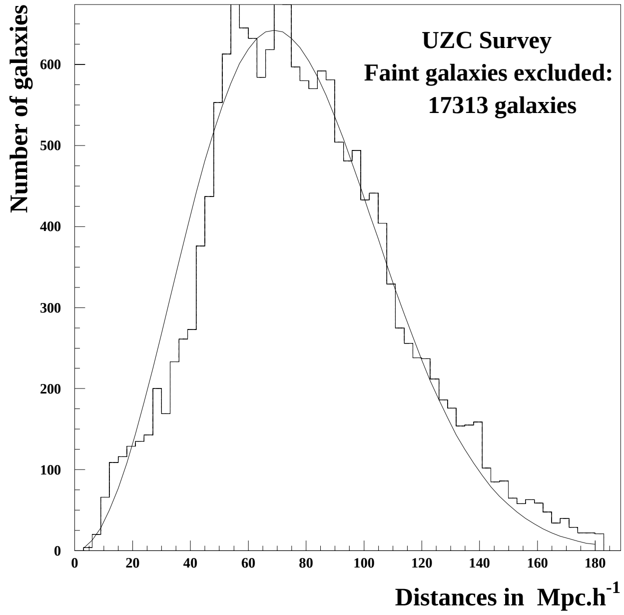

Fig. 2. The UZC Survey after exclusion of faint galaxies: counts versus prediction

ation to this local density as an overdensity $\frac{\delta\rho}{\rho}$ for each bin of the survey.

3 The abundant faint dwarf galaxies

Dwarf galaxies are certainly the most numerous type of galaxies in the universe. Their density is infered between 0.1 and 1 per Mpc^3. Most of the knowledge of their properties came from the studies of the local group. In fact since they are galaxies with very low surface brightness it is very hard to detect them. Since the survey we used is magnitude limit survey and according to the general acceptance that the dwarf galaxies are more or less uniformly distributed in the universe, we will see only those who are not so far from us. So in the distribution we excepted to have some kind of an overdensity locally due to both facts that they are presumably the most abundant galaxies type and that we miss the distant one. In fact we obtain the relative overdensity locally. In order to appreciate if this overdensity is due to faint galaxies we have made a cut in the distribution to reject the faint galaxies in absolute magnitude. In that way we will be sure to keep in the survey the galaxies with absolute magnitude greater than -17. The result represented in fig. 2 confirms the previous analyze.

The local overdensity disappear. If we assume the cosmological principle then we can estimate the density n_{dwarf} of these faint dwarf galaxies. The cosmological principle simply states that the n_{dwarf} inferred locally will be the same at greater distance (without the evolution effects). Locally we found that there are over abundant by a factor of ten to the field galaxies. And from the average number deduced from this survey we can conclude to a average density of dwarf as :

$$n_{dwarf} \simeq 10.0 \times n_{field} \simeq 0.43 \ Mpc^{-3} \tag{5}$$

where n_{field} is the density number of field galaxies given by the relation (5) for the present survey.

4 Results and discussion Toward a local overdensity ?

From the last section it is now clear that there is no local overdensity in average with the direction. Therefore it is important to compute the local overdensity in each direction for a given solid angle. It is related to the question if the local overdensity some clouds could the rosetta stone for the GZK cutoff. This analyze was done using the same parameter for the luminosity function changing only the normalization for each solid angle. The results are display in figure 4 for the direction of Virgo Cluster. The overdensity obtained are greater than the corresponding in figure 3. It is not surprizing since we didn't average over the solid angle of all the survey.

Our principal conclusion is represented in figure 3 where the overdensity is plotted as a function of distance without the faint galaxies. From this figure it is clear that we live in an relatively homogeneous universe. In fact if we average the local overdensity with angle only the Virgo Supercluster present a remnant overdensity which is obviously known from the IRAS survey and from previous study. This fact is well known. The computation of the local over-density as a function of the angular position in the sky gave simply the concentration of galaxies inside structure like cluster. The definitive answer of this question is of course related to the magnetic field distribution. If we have some indication

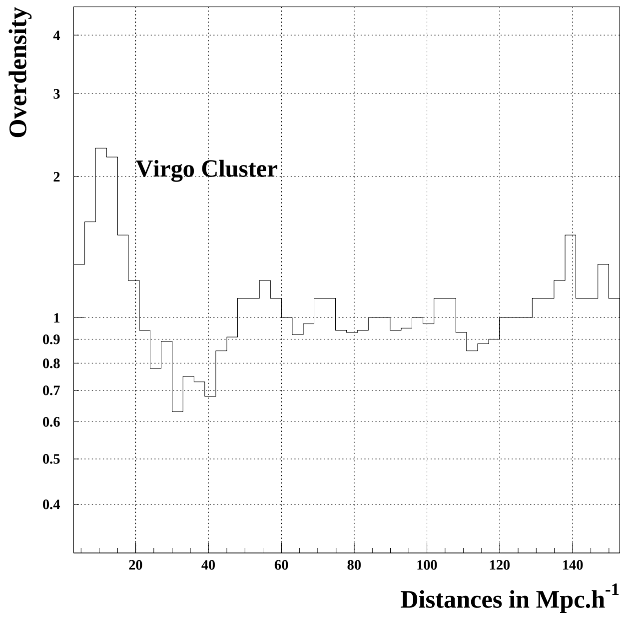

Fig. 3. The overdensity in the UZC Survey after average on angle

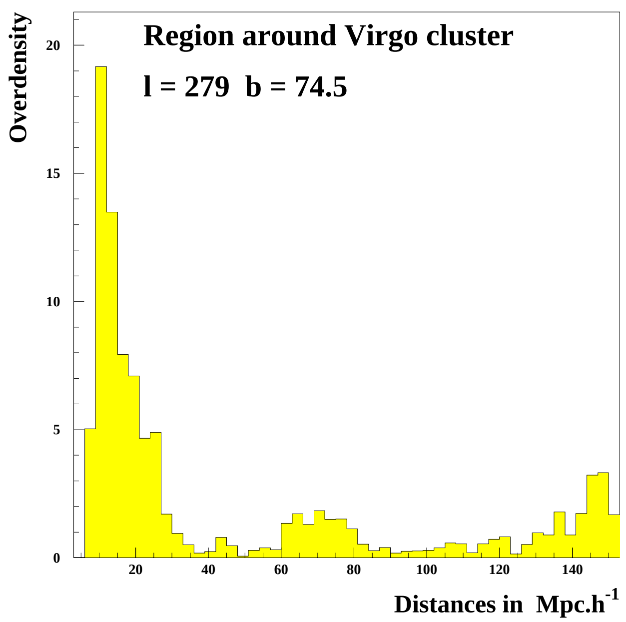

Fig. 4. The overdensity computed toward Virgo cluster: the LSC is clearly visible

of large magnetic field inside cluster (Vallée , 1991). It remains less probable that such field pervade all the intergactic medium. Therefore we can conclude that the structure we observed cannot be responsible for the absence of GZK cutoff.

In this paper we have compute the overdensity as a function of the redshift for the UZC survey. We find that there is no room left for an explanation of the absence of the GZK cutoff arising from a local overdensity. This allows us to derive a density of dwarf galaxies based on the assumption that they are uniformly distributed.

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