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中文摘要
PierreAuger 宣稱極高能宇宙射線源與活躍星系核之間有高度統計關聯，我們試圖檢驗此宣稱與極高能宇宙射線能譜是否存在矛盾。我們發現 PierreAuger 的能量標定為最重要決定因素。目前我們的研究重點為宇宙線化學成份及其導致的微中子流量

English Abstract
We have examined the consistency between the measured spectra of ultrahigh energy cosmic rays (UHECR) and the correlation of UHECR to the nearby Active Galactic Nuclei (AGN) claimed by the recent paper of Pierre Auger collaboration.
We pointed out that the energy calibration of Auger data plays an important role for the above consistency to hold. We are currently studying the composition of UHECR and its consequence to the cosmogenic neutrino flux. .

一、 前言

This is a mid-term report for a three-year project on the correlation research of ultra-high energy cosmic ray and corresponding neutrino. In Section II, we state the motivation for such an investigation. In Section III, we discuss existing works on this subject and our approach to the problem. In Section IV, we outline our research method. Our result and its implication are given in Section V.

二、研究目的

The origin of ultra high energy cosmic rays (UHECR) is a long-standing mystery in astrophysics. Active galactic nuclei (AGN) are one of the suggested sources. Recently, Pierre Auger observatory published results on correlation of the highest-energy cosmic rays with the positions of nearby active galactic nuclei (AGN) [1, 2]. In the Auger result, the correlation is maximal for the threshold energy of cosmic rays at 5.7×10^{19} eV, the maximal distance of AGN at 71 Mpc and the maximal angular separation of cosmic ray events at $\psi = 3.2^{\circ}$. With continuous energy loss approximation, the GZK horizon for protons with $E_{th} = 57$ EeV is about 200 Mpc by assuming a uniformly distributed UHECR sources with identical cosmic ray luminosity and spectral index [3]. The departure of theoretically calculated GZK horizon to the maximum valid distance of the V-C catalog [4] employed in Pierre Auger's analysis, which is around 100 Mpc, can be attributed to several factors. As mentioned in [2], such a deviation may arise from non-uniformities of spatial distribution, intrinsic luminosity and spectral index of local AGN. In addition, the energy calibration also plays a crucial role since the GZK horizon is highly sensitive to the threshold energy E_{th}. Our work focuses on examining the consistency of Auger's analysis and solutions to this departure.

三、文獻探討

GZK horizon of a uniform UHECR source distribution with identical cosmic ray luminosity and spectral index was calculated in [3]. The calculations based upon kinetic equation approach or stochastic energy loss also reach to similar conclusions [5, 6]. These calculations gave a GZK horizon of about 200 Mpc at $E_{th} = 57$ EeV. Here we try to introduce a local over density of UHECR sources and proposed energy calibration to resolve the deviation between GZK horizon and the valid distance of V-C catalog.

四、研究方法

We first consider the local over-density of UHECR sources as a possible resolution to the above discrepancy. It is motivated by the existence of Local Supercluster (LS) which has a diameter of the order 60 Mpc. In LS, the over-density of galaxies has been estimated to be ~ 2 . The local over-density of UHECR sources has been invoked to account for AGASA data. Such a density distribution naturally leads to a smaller GZK horizon. However, it also significantly affects the UHECR energy spectrum in $(5 \cdot 10^{19} - 10^{20})$ eV region. Hence fittings to the measured UHECR spectrum can provide information on the degree of local over-density. Subsequently, the magnitude of GZK horizon can be better estimated. We next study the energy calibration effect on the estimation of GZK horizon and the spectrum of UHECR. Certainly a 20% − 30% upward shift on UHECR energies reduces the departure of theoretically calculated GZK horizon to the maximum valid distance of V-C catalog [2].

We fit the UHECR spectrum for events with energies above 10^{19} eV. This is the energy range where the GZK attenuation exhibits its effect. It is also the energy range where the local over-density of UHECR sources shows significant effects. In our analysis, we take the UHECR as protons, which is hinted in the Auger events with energies ≥ 57 EeV although the composition study by the same group suggests a heavier composition for $E \leq 40$ EeV [7]. The HiRes experiment measures the composition up to 50 EeV [8] and obtains a composition lighter than that of Auger. For $E > 50$ EeV, the event number is still too small for the composition study. To fit the UHECR spectrum at the highest energy, it is more appropriate to treat the cosmic ray energy loss as a stochastic process. There are numerical packages available for treating stochastic energy loss of cosmic ray particles [9, 10]. We employ the latter package for our calculations. Although UHECR loses its energy mostly by scattering off CMB photons, it also loses some amount of energy by scattering off infrared background photons. Thus we include the infrared photon contribution to the UHECR energy attenuation. Source evolution $n(z) = n_0(1 + z)^3$ is adopted in the calculation of GZK horizon and spectrum, where n_0 is the source number density at the present epoch. It is from the generally-accepted soft evolution model which traces the star formation history and has been adopted in previous works.

五、結果與討論

GZK horizons corresponding to different local over-densities and E_{th} are summarized inTable I. It is seen that local over-densities up to $n(l < 30\text{Mpc})/n_0 = 4$ do not alter GZK horizons significantly for a given E_{th}. One could consider possibilities for higher local over-densities. However, there are no evidences for such over-densities either from astronomical observations or from fittings to the measured UHECR spectrum. We note that GZK horizons are rather sensitive to E_{th}. Table I shows that GZK horizons are ~100 Mpc or less for Eth ≥ 80 EeV.

$n(l < 30\text{Mpc})/n_0$	$E_{th} = 57\,\text{EeV}$	$E_{th} = 70\,\text{EeV}$	$E_{th} = 80\,\text{EeV}$	$E_{th} = 90\,\text{EeV}$
1	220	150	115	90
2	210	140	105	75
4	195	120	85	60
10	155	85	50	30

TABLE I: GZK horizons of UHECR calculated with the local over-density $n(l< 30\text{Mpc})/n_0=1, 2, 4$, and 10, and arrival threshold energy E_{th} = 57 EeV, 70 EeV, 80 EeV and 90 EeV respectively. The listed numbers are in units of Mpc.

Table II and figure1 shows our fittings to the Auger measured UHECR spectrum with $\gamma = 2.5$ and 2.6 respectively. We note that, for both $\gamma = 2.5$ and $\gamma = 2.6$, the GZK horizon with $n(l < 30\text{Mpc})/n_0 = 10$, $E_{th} = 57$ EeV, $m = 3$ and $E_{cut} = 1000$ EeV is about 155 Mpc. Since $n(l < 30\text{Mpc})/n_0 = 10$ is clearly disfavored by the spectrum fitting, one expects a GZK horizon significantly larger than 155 Mpc for Eth = 57 EeV.

$n(l < 30\text{Mpc})/n_0$	1	2	4	10
$\gamma = 2.5$	14.12(9.34)	14.61(9.93)	17.09(10.50)	28.09(13.93)
$\gamma = 2.6$	16.64(12.28)	15.56(11.90)	16.01(11.83)	20.76(11.67)

TABLE II: The values of total χ^2 from fittings to the Auger measured UHECR spectrum. Numbers in the parenthesis are χ^2 values from fittings to the 8 data points in the energy range $19.05 \leq \log10(E/eV) \leq 19.75$. The last 4 data points record events with energy greater than 71 EeV.

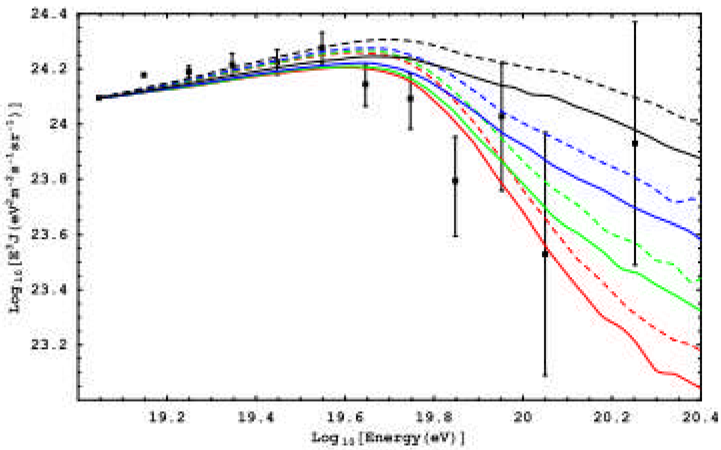

FIG. 1: Fittings to the Auger measured UHECR spectrum where the red, green, blue and black curves denote the model with the local over-density $n(l < 30\text{Mpc})/n_0 = 1, 2, 4$, and 10 respectively. Solid curves correspond to $\gamma = 2.6$ while dash curves correspond to $\gamma = 2.5$. We take the source evolution parameter m = 3 throughout the calculations.

We next perform fittings to the shifted Auger spectrum. The results are shown in Table III and Fig. 2 where the cosmic ray energy is shifted upward by 30%. We note that, with a 30% upward shift of energies, the cosmic ray events analyzed in Auger's correlation study would have energies higher than 74 EeV instead of 57 EeV. The GZK horizon corresponding to E_{th} = 74 EeV is 120 Mpc for $n(l < 30\text{Mpc})/n_0 = 2$ and 105 Mpc for $n(l < 30\text{Mpc})/n_0 = 4$. The smallest χ^2 value occurs approximately at γ = 2.4, $n(l < 30\text{Mpc})/n_0 = 2$ with χ^2/d.o.f = 0.82. It is seen that χ^2 values from current fittings are considerably smaller than those from fittings to the unshifted spectrum and the best fit imply a possibility for the local over-density of UHECR sources.

$n(l < 30\text{Mpc})/n_0$	1	2	4	10
$\gamma = 2.4$	8.65(4.30)	7.39(4.67)	10.26(6.35)	27.31(13.34)
$\gamma = 2.5$	11.82(6.16)	8.67(5.49)	7.78(5.23)	16.18(7.39)

TABLE III: The total χ^2 values from fittings to the Auger measured UHECR spectrum with a 30% upward shift on UHECR energies. Numbers in the parenthesis are χ^2 values from fittings to the 8 data points in the energy range $19.16 \le \log10(E/\text{eV}) \le 19.86$. The last 4 data points record events with energy greater than 92 EeV.

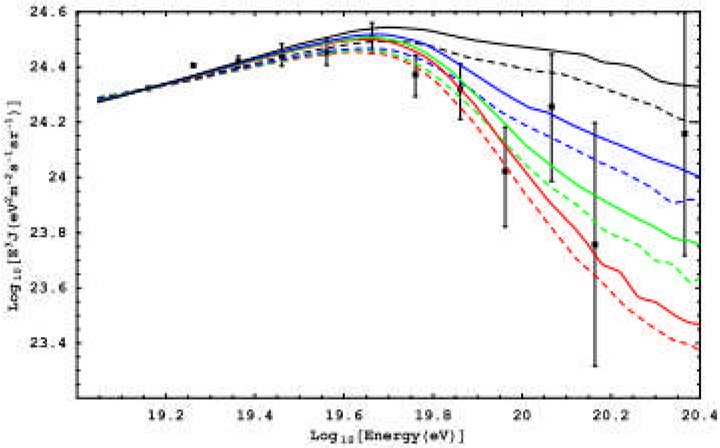

FIG. 2: Fittings to the Auger measured UHECR spectrum with a 30% upward shift on UHECR energies where the red, green, blue and black curves denote the model with the local over-density $n(l < 30\mathrm{Mpc})/n_0$ = 1, 2, 4, and 10 respectively. Solid curves correspond to $\gamma = 2.4$ while dash curves correspond to $\gamma = 2.5$. We take the source evolution parameter m = 3 throughout the calculations.

We conclude that degrees of local over density constrained by the spectrum can not resolve the deviation between the GZK horizon and the maximum valid distance of V-C catalog. Suitably adjusting the energies of UHECR events can resolve the above deviation, and fittings to the shifted spectrum imply n/n_0 =(2~4). It is testable in the future cosmic ray astronomy where directions and distances of UHECR sources can be determined.

六、計畫成果自評

We have achieved the goal of the project. A paper is posted in the archive and submitted to Astroparticle Physics [11]. These results were presented in the international conference, XXth RENCONTRES DE BLOIS-- Challenges in Particle Astrophysics(http://blois.in2p3.fr/2008/), and will be published in the coming proceeding.

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Travel Report

Feng-Yin Chang

December 27, 2007

The trip to Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) from Oct.16th to Dec.14 is for working with Dr. Pisin Chen on the extending study of plasma wakefield induced by the magnetowave oblique to the external magnetic field and astrophysical applications of snow plow acceleration mechanism. Both theoretical and simulation works were done for the study. During my staying, Dr. Robert Noble at Stanford Linear Accelerator Center(SLAC) also joined us and was interested in exciting magneto-shocks in plasma by particle in cell simulation. We weekly had a regular meeting on Friday discussing our progress on each work.

I used an one-dimensional particle-in-cell code written by R.Sydora to see the behavior of the magnetowave across the magnetic field. Several cases with different angles between the propagation and magnetic field were studied. The simulation results shows the absence of wakefield when the angle is over some threshold. The driving wave in plasma will have electromagnetic field parallel to the propagating direction, making the longitudinal electric field an extra component. We thought that may also give a chance to in phase accelerate particles.

Since the Auger Observatory published their newest results on the ultra high cosmic ray origins correlated to AGNs, I also spent some efforts reading AGNs literature to get some ideas of AGN properties and show the application of our acceleration mechanism.

Beyond the plasma wakefield work, the new project came to me was the astrophysical application of snow plow acceleration in plasma, which took place when the driving pulse is very intensive. I've done a simple theoretical derivation using ponderomotive force and phase slippage concept. Some interesting issues are yet to be addressed and many simulation studies are to be worked out.

It is excellent to work at KIPAC and have many discussions with many outstanding physicists there.