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On the possibility of AGN investigation using cosmic ray data

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It is substantiated that ultra high energy cosmic ray (CR) data provide information about AGNs which are CR sources: particle acceleration conditions, luminosity in CR, AGN variability. In addition, the possibility of AGN jet investigation using CR energy spectra and composition is discussed.

Keywords: Cosmic rays; Sources; AGN

1 Introduction

Cosmic rays discussed here have energies $E > 4 \cdot 10^{19}$ eV. Penetrating through the atmosphere CRs initiate electron-nuclear cascades called external air showers. Giant ground arrays detect showers determining primary particle energy through energies of secondaries. Accuracy of particle energy determination is 10–30%, and accuracy of arrival direction is not higher than 1° (for most of arrays it is 3° and more). The CR flux at ultra high energies is low: $J \approx 1$ particle/(100 km^2·year), making CR investigation difficult.

In spite of CR low intensity, indirect methods of particle energy determination and comparatively low energy resolution, CR investigation is of great interest. First, the problem is what are CR sources. In my opinion these are AGNs [1], namely Seyferts at distances $R < 50$ Mpc (near Seyferts) and Blue Lacertae objects (BL Lac's). At present the viewpoint on near Seyferts as CR sources is accepted by Pierre Auger collaboration [2]. Here I demonstrate that by analyzing ultra high energy CR data we can study some AGN characteristics.

2 Ultra high energy CR spectra measured and determination of CR spectra and CR maximal energy in AGNs

Charged particles can be accelerated either in electric fields or at shock fronts [3, 4]. I considered two simplest CR initial spectra in AGNs based on these acceleration

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mechanisms: monoenergetic and exponential. Propagating in extragalactic space CRs interact with microwave background photons (GZK-effect [5]) and lose energy. Therefore, the spectrum of CRs falling at an array differs from an initial CR spectrum in AGNs.

I calculated CR spectra at the Earth assuming that 1) the initial CR spectrum was monoenergetic or exponential, 2) red shift distributions of Seyferts and BL Lac's were nonuniform corresponding to AGN catalogues data [6], and 3) regarding CR energy losses in GZK-effect.

Calculated spectra were compared with those measured. It appears that some definite conclusions can be derived from the comparison in spite of large experimental errors. First, in sources the CR maximal energy is not higher than 10^{21} eV. Previously this result was obtained only theoretically analyzing conditions at which CR were accelerated in sources. Second, it is possible to choose between initial CR spectra in AGNs, whether they are monoenergetic or exponential. I found that CR initial spectra in Seyferts were exponential. As to BL Lac's initial spectra, they are monoenergetic to fit data of arrays AGASA, Fly's Eye, Haverah Park, and in Yakutsk. But BL Lac initial spectra are exponential to describe Pierre Auger and HiRes data (which are assumed to be the most significant at present). However in both cases of exponential spectra, in Seyferts or in BL Lac's, it is difficult to determine the spectral index if it is equal to 2.6 or 3, due to large experimental errors.

3 AGN luminosity in CRs

It is possible to estimate AGN luminosity in CRs using CR flux measured at the Earth. I got estimates of the luminosity in CRs in this way. Seyfert CR luminosity observed is $L_{\rm S} \approx 10^{40}$ erg/s, if the initial spectral index in the source is equal to 3. Observed CR luminosity of a BL Lac is $L_{\rm BL} \approx 2 \cdot 10^{42}$ erg/s if the initial spectrum is monoenergetic. However the power which is spent for CR acceleration in a source is higher, in Seyferts it is $3 \cdot 10^{42}$ erg/s and inside BL Lac's it is $2 \cdot 10^{48}$ erg/s as CRs emit the bulk of energy inside the source.

4 CR composition depending on parameters of CR acceleration in AGNs

In our model CRs are accelerated at shock fronts generated in jets, the field in the jet being parallel to jet axis. At present the value of magnetic fields is not known properly, being an undetermined parameter of the model. The next assumption is that the jet contains matter from the accretion disk, therefore CR composition indicates the composition of disk substance. Concurrently with acceleration in the magnetic field particles lose energy in synchrotron radiation. Assuming that particle energy losses are not higher than half of the energy gained during acceleration, the value of magnetic field in which the particle with charge Z is accelerated to the maximal energy is equal to $B_{\rm CR} \approx 50 \cdot Z^{-1/3}$. The nuclei maximal energy is $E_{\rm A} \approx 6.6 \cdot 10^{20} (Z/B)^{1/2}$ eV, and for protons the maximal energy is $E_{\rm p} \approx 1.65 \cdot 10^{20} B^{-1/2}$ eV.

So in our model only nuclei with $Z \geq 10$ are accelerated to energies $E \geq 2 \cdot 10^{20}$ eV, if the magnetic field ranges in the $\sim$(5–40) Gs. Lighter nuclei are accelerated to

$E \leq 10^{20}$ eV in this field. In fields of ∼1000 Gs only heavy nuclei with $Z \geq 23$ can be accelerated to $E \geq 10^{20}$ eV. Fe nuclei are the most energetic particles, their energy can reach $E \approx 8 \cdot 10^{20}$ eV in the field of $B_{\rm CR} \approx 40$ Gs. Protons are accelerated only to $E < 4 \cdot 10^{19}$ eV at any values of B. Light nuclei are accelerated at lengths of $(10-20)R_{\rm g}$ from the jet bottom, heavy nuclei are accelerated at lengths of $0.1R_{\rm g}$, $R_{\rm g}$ is the black hole radius. These results are valid for jet cross section in the range of $\sim 5 \cdot 10^{29}$–10^{33} cm^2. Recent measurements of jet magnetic fields show strong variations of the field value near the jet bottom (at lengths $r \lesssim 0.1$ pc), changing in the range 10^2-10^4 Gs. At lengths of ∼1 pc the field is about $10^{-2}-10^{-1}$ Gs, being uniform [7]. Our model assumptions are in accord with these data. I conclude that CR composition and energy spectra are additional tools for investigation of magnetic fields in AGN jets.

5 Clusters in CRs and AGN variability

CR clusters (groups of CRs with same arrival coordinates within error limits) were detected at AGASA during 10 years operating. The frequency of registration of CR in clusters is not less than ∼1 year. I conclude that analyzing CR clusters provides us with information about AGNs: AGN luminosity in CRs, CR energy spectra in sources, jet directivity, AGN variability, CR composition in jets.

Conclusion

CRs at ultra high energies, $E > 4 \cdot 10^{19}$ eV, can be used as an additional tool in AGN investigations.

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