Propagation of different components of cosmic rays from Centaurus A in the Galactic magnetic fields

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Propagation of different chemical composition ultrahigh energy cosmic rays in the galactic magnetic fields was simulated. The simulation for the ultra high energy events, registered by the AUGER observatory in the sky region near Centaurus A was performed. It is shown that some of these events could originate from Centaurus A.

Introduction

The problem of ultrahigh energy cosmic rays (UHECR) acceleration is one of the most relevant problems in the high energy astrophysics. Active galactic nuclei (AGN) are the most popular candidates to the sources and accelerators of UHECR. One of the possible places of particle acceleration and production of UHECR are the giant lobes of active galaxies [1]. In order to investigate the detection possibility of these cosmic rays one have to take into account the galactic and extragalactic magnetic fields between the source and detector [3].

E. g., the last data from the AUGER observatory demonstrate some correlation between arrival directions of cosmic rays and the radiogalaxy of FR I type Centaurus A (NGC 5128) [4]. Those events are shown in Fig. 1. The main purpose of the present work is to investigate the influence of Galactic magnetic fields on the UHECR trajectories and to define correlation of chosen events with Centaurus A depending on particle species.

The model of galactic magnetic field

For description of the regular Galactic magnetic field we use the model of Prouza and Smida [5] modified by Kachelries [2]. According to this model the field in the Galactic disk has bisymmetrical symmetry (BSS) with even parity (S type) (BSS-S) and its components in galactocentric cylindrical coordinates can be parameterized as

$$B_r = B(r,\theta)\sin(p), \quad B_\theta = B(r,\theta)\cos(2p),$$

where p is the pitch angle.

The function $B(r,\theta)$ is traditionally modeled likewise the spiral structure of the matter distribution in the Galaxy as:

$$B(r,\theta) = B_0 \frac{R_0}{r} \cos\left[\theta - \frac{1}{\tan(p)} \ln\left(\frac{r}{\xi_0}\right)\right] \exp\left(\frac{|z|}{h}\right),$$

where $R_0 = 8.5$ kpc is the galactocentric distance of the Sun, $p = -8^\circ$, $h = 0.2$ kpc, $\xi_0 = 9.98$ kpc. The local field is normalized to $2\,\mu$G.

The second constituent is a toroidal field

$$B_\theta = B_T(r) \frac{\text{sign}(z)}{1 + \left(\frac{|z|-H}{P}\right)^2},$$

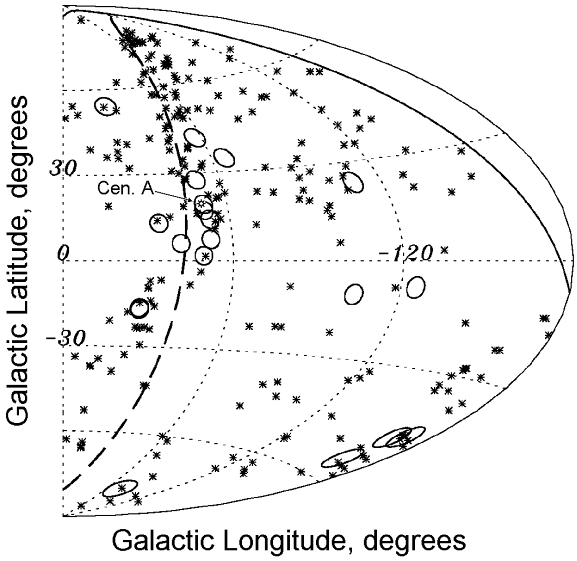

Figure 1: The map of UHECR events detected by the AUGER observatory (open circles). The AGN positions are indicated by simple asterisks. Centaurus A is indicated by asterisk with little circle.

where $H = 1.5$ kpc is the height of the maximum above the plane, $P = 0.3$ kpc is its lorentzian width and

$$B_T(r) = \left[\Theta(R_0 - r) + \Theta(r - R_0)\exp\left(\frac{R_0 - r}{R_0}\right)\right],$$

with Θ denoting the Heaviside step function.

The third constituent is a dipole field

$$B_r = -3\mu_G \cos(\varphi)\sin(\varphi)/\rho^3,$$

$$B_z = \mu_G(1 - 3\cos^2(\varphi))/\rho^3,$$

where $\rho = \sqrt{(r^2 + z^2)}$, $\cos(\varphi) = z/\rho$, $\sin(\varphi) = r/\rho$ and $\mu_G = 123\,\mu$G kpc^3 is the magnetic moment of the Galactic dipole.

Finally, to avoid a singularity in the central regions, it was assigned $B_z = -100$ μG inside a sphere of 500 pc radius centered in the Galactic center.

The influence of the galactic magnetic fields on the UHECR trajectories

It is well known, that in magnetic fields the Lorenz force influences the moving charged particles. To obtain the trajectories of certain UHECR we carried out the numerical solutions of the motion equations

$$\frac{d\mathbf{v}}{dt} = \frac{qc^2}{E}[\mathbf{v} \times \mathbf{B}], \quad \frac{d\mathbf{r}}{dt} = \mathbf{v},$$

using the Runge–Kutta method.

The positions of UHECR events, detected by the AUGER observatory in the Centaurus A region are shown in Fig. 2 (bold open circles of 1°). Numbers denote the events energy in EeV (10^{18} eV). Calculated positions of corresponding sources are shown with the circles with symbols of particle inside. The filled circles correspond to the particles which are probably connected with Centaurus A or at least have trend to this, and open circles correspond to the particles which hardly could originate from Centaurus A.

The influence of the the random component of the Galactic magnetic field was not considered because for the particles with energy $E > 10^{19}$ eV it is negligible in comparison with the influence of the regular

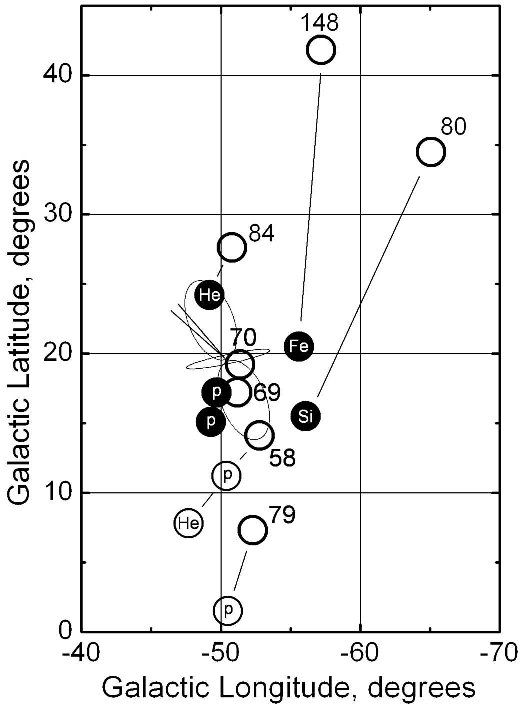

Figure 2: The positions of UHECR events detected by the AUGER observatory and calculated positions of the corresponding sources given in the galactocentric coordinates. Schematic image of Centaurus A with the radio-lobes and the jet is also presented.

component. Indeed, the spatial scale of the random magnetic field is essentially less then a regular one. Hence, the averaged deflection of UHECR with considered energies caused by the random component of the magnetic field is inessential in the scale of Galaxy.

Extragalactic magnetic field has similar random character. Therefore taking into account this field does not change the calculated source positions, but leads to the expansion of its possible localization. In detail the influence of extragalactic magnetic field on the propagation of UHECR is a subject of the next study.

Conclusions

According to the used model of Galactic magnetic field the radiogalaxy Centaurus A can be the source of at least five UHECR events detected by the AUGER observatory. Two of those events could originate from the bottom radio-lobe of Centaurus A, if they were caused by protons. One event could originate from the upper radio-lobe of Centaurus A, if it was caused by Helium (He). Also two events trend to Centaurus A, if they are caused by heavy particles such as Silicium (Si) and Ferrum (Fe).

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