Centaurus A as a plausible source of ultra high energy cosmic rays registered by the Pierre Auger Observatory

O. B. Sushchov[1]*, O. O. Kobzar*[1], *B. I. Hnatyk*[2], *V. V. Marchenko*[1]

[1]Taras Shevchenko Chernihiv National Pedagogical University, Hetmana Polubotka Str., 53, 14013, Chernihiv, Ukraine
[2]Astronomical Observatory, Taras Shevchenko National University of Kyiv, Observatorna Str., 3, 04058, Kyiv, Ukraine

For ultra high energy cosmic rays events detected by the Pierre Auger Observatory which arrive from the region near Centaurus A the positions of the corresponding sources were calculated for the two chosen galactic magnetic field models. Also the influence of extragalactic magnetic field was taken into account for different energy and ultra high energy cosmic rays type to show the possibility of correlation with Centaurus A.

Key words: ISM: cosmic rays - galaxies: magnetic fields - galaxies: active

INTRODUCTION

Cosmic rays are high energy particles arriving to Earth which interact with the molecules of atmospheric gases and generating wide showers of secondary particles. There is no exact definition of what cosmic rays energies should be considered as ultra high, but generally this term is used to those ones which are supposed to be accelerated outside our galaxy. Due to interactions of ultra high energy cosmic rays (UHECR) with cosmic microwave background the spectrum is limited from above (the so-called GZK-cutoff) [1, 7]. Thus the number of registered UHE events is not substantial. The last data set published by the Pierre Auger Observatory [5] contains 69 events with the energy above 55 EeV. It is also stressed that there is some correlation of the registered events with the known positions of active galactic nuclei (AGN), which are considered to be possible UHECR sources. Among those 69 events 15 are located in the sky region surrounding Centaurus A (Fig. 1), the nearest active galaxy to the Milky Way.

MODELLING OF UHECR PROPAGATION

The trajectories of charged particle motion are deflected by magnetic fields via the Lorentz force. Generally cosmic magnetic fields have both regular and random components [6]. The studies of Faraday rotation show the evidences of the regular component presence in galactic magnetic field (GMF) only. The random component is present in intergalactic medium as well as in our galaxy. For the case of

UHECR the influence of the irregular GMF is negligible as against the regular component. We also do not take into account the influence of extragalactic magnetic field in the present paper.
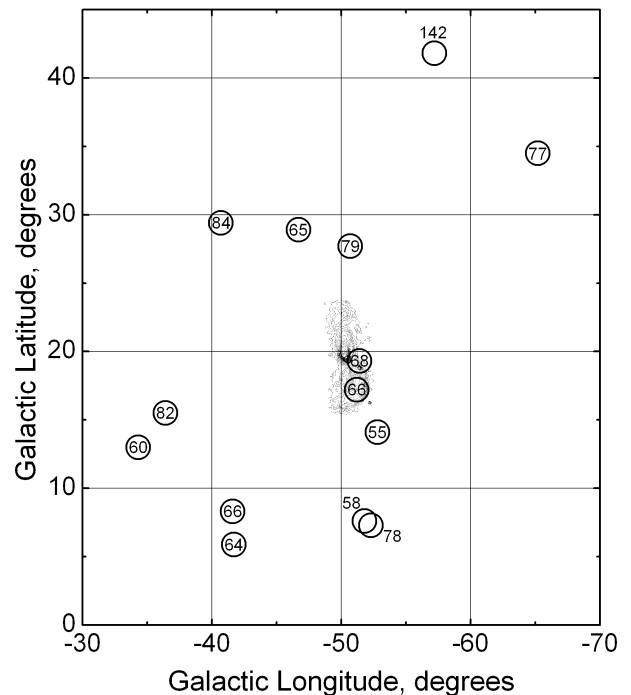

Fig. 1: UHECR events registered by the Pierre Auger Observatory near Centaurus A.

Among existing GMF models [4] we have chosen

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two models proposed in [3] and in [2]. Those models regard GMF consisting of two components, namely the field of the galactic disc and the halo field consisting of dipole and toroidal constituents. The field parameters for the two models differ as it is shown in Table 1.

For disk component, according to all used models the field has BSS-S configuration and its components in Galactocentric cylindrical coordinates are parametrise as

$$B_r = B(r, \theta, z) \sin(p),$$
$$B_\theta = B(r, \theta, z) \cos(p), \quad B_z = 0, \quad (1)$$

where p is the pitch angle.

The function $B(r, \theta, z)$ is the vector sum of magnitudes of B_r and B_θ at the disk plane ($z = 0$). It is usually modelled likewise the spiral structure of the matter distribution in the Galaxy:

$$B(r, \theta, z) = B_0 \frac{R}{r} \cos \left[\theta - \frac{1}{\tan p} \ln \left(\frac{r}{\xi_0} \right) \right] \times$$
$$\exp \left(-\frac{|z|}{z_0} \right). \quad (2)$$

For toroidal component the model of circles above and under the Galactic plane with a Lorentzian profile in z-axis is used. Cartesian components of the toroidal field are given by the following:

$$B_x = -B_T \frac{sign(z)}{1 + \left(\frac{|z|-h}{w} \right)^2} \cos \theta,$$
$$B_y = -B_T \frac{sign(z)}{1 + \left(\frac{|z|-h}{w} \right)^2} \sin \theta, \quad (3)$$

where $h = 1.5$ kpc is the height of the circle above the Galactic plane, w is the half-width of its Lorentzian distribution,

$$B_T = B_{Tmax} \left[\Theta(R_T - r) + \right.$$
$$\left. + \Theta(r - R_T) \exp \left(\frac{R_T - r}{R_T} \right) \right]. \quad (4)$$

Cartesian components of the dipole part of the GMF are:

$$B_x = -3\mu_G \cos \phi \sin \phi \sin \theta / \rho^3,$$
$$B_y = -3\mu_G \cos \phi \sin \phi \cos \theta / \rho^3,$$
$$B_z = \mu_G (1 - 3 \cos^2 \phi) / \rho^3,$$

where $\rho = \sqrt{r^2 + z^2}$, $\cos(\phi) = z/\rho$ and μ_G is the magnetic moment of the Galactic dipole.

Parameter values of the two chosen models are presented in Table 1.

RESULTS AND DISCUSSION

We solved UHECR motion equation numerically using Runge-Kutta method. Varying the particle charge number we calculated the real sources positions for events with the corresponding energy. We present here some results of calculations for different GMF models. Events registered by the Pierre Auger Observatory are denoted by the circles with numbers corresponding to energy in EeV. Circles with the symbols of chemical elements denote the calculated positions of sources for the corresponding particle types. The circles radii are chosen to fit experimental errors of Auger detectors. Results for Prouza–Šmida model are presented in Fig. 2 and for Kacheleries model – in Fig. 3. Outline radio image of Centaurus A is also presented in Figs. 2 and 3. We have chosen the overlay of the circles with radii fitting the confidence interval of 3σ and Centaurus A radio map as the criterion of the corresponding events correlation with Centaurus A. The results are represented in Table 2. The numbers in the table denote the energy of corresponding events detected by Pierre Auger Observatory.
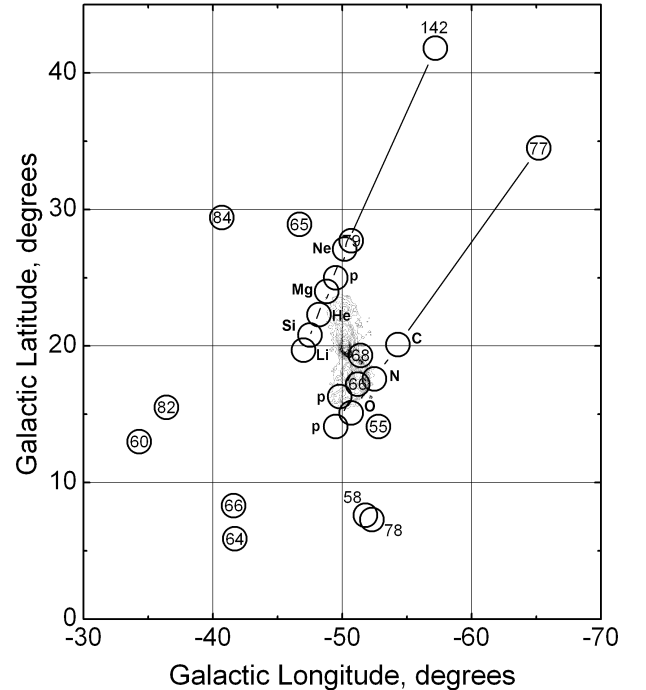

Fig. 2: UHECR sources positions calculated according to the model [3].

CONCLUSIONS

According to our simulations Centaurus A could be a plausible source of 4 or 5 UHECR events depending on the chosen GMF model. 3 events could originate from Centaurus A, if they were caused by

Table 1: The values of field parameters in the used GMF models.

GMF model	p, degrees	ξ_0, kpc	z_0, kpc	B_0, μG	R_T, kpc	W, kpc	B_{Tmax}, μG	μ_G, μG kpc^3
Prouza–Šmida	-10	9.0	1.0	3.0	15.0	0.3	1.0	100
Kachelrieß	-8	10.0	0.2	4.8	8.5	0.3	1.5	123

Table 2: UHECR types correlating with Centaurus A.

GMF model	UHECR Energy, EeV				
	142	77	79	68	66
Prouza–Šmida	Ne – Si	C – O	p – Li	p	p
Kachelrieß	Fe	–	p – Be	p – He	p

light nuclei for both used models. Another 2 events which trend to Centaurus A correspond to heavier nuclei and show worse correlation. The chemical composition of the events correlating with Centaurus A is model dependent.
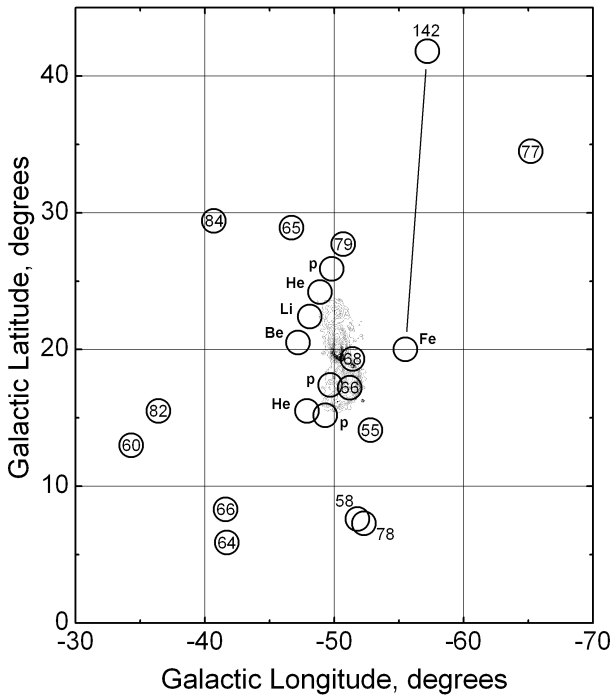

Fig. 3: UHECR sources positions calculated according to the model [2].

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