A beam of ultrahigh energy particles of the same magnetic
rigidity

G. F. Krymsky,* I. Ye. Sleptsov,† M. I. Pravdin,‡ and A. D. Krasilnikov§

Yu. G. Shafer Institute of Cosmophysical Research and Aeronomy SB RAS
677980 Lenin Ave. 31, Yakutsk, Russia

Two EAS arrays during a day have recorded 3 particles with energies above 30 EeV arriving from the same sky region. Two events were registered by the Yakutsk array and one - by the Telescope Array. Two Yakutsk events were estimated to be same energy and the Telescope Array shower’s energy was almost 2 times higher. This indicates the same magnetic rigidity of all three particles, if the charge differs by a factor of 2. The relatively short sequence of all three events and their ”monochromaticity” in rigidity can be due to the magnetic separation of particles in the acceleration process and propagation of the beam.

Earlier it was reported that a short-lived cosmic rays (CRs) particle beam with energy above $3 \times 10^{19}$ eV was detected arriving from a compact sky region [1]. Two particles were detected at the Yakutsk EAS Array (YEASa) [2, 3], one — by the Telescope Array (TA) [4, 5]. Chance probability of random appearance of such triplet is $2.6 \times 10^{-6}$. Parameters of registered showers are listed in Table I. The probable mechanism for generation of such beams essentially is interaction of CRs with relativistic shock [6, 7]. If a shock carries a strong magnetic field it can trap particles of ultra-high energy CRs (UHECRs) and re-emit them. This process results in a rise of the particle flux intensity along the axis of generated beam by magnitude proportional to the shock’s Lorentz factor ($\gamma$) to the power of a value greater than 8 [1].

It’s worth noting that energies of two events recorded by YEASa are virtually identical and energy of TA’s shower is two times higher. The energy $E_0$ of Yakutsk events (given in Table I) was estimated according to a relation presented in 2003 which was obtained with the use of calorimetric method [8]:

* krymsky@ikfia.ysn.ru
† sleptsov@ikfia.ysn.ru
‡ m.i.pravdin@ikfia.ysn.ru
§ a.d.kras@ikfia.ysn.ru
TABLE I. Parameters of shower events constituting a beam. The $E_{2003}$ column cites energy estimation according to the formula (1). Zenith angle ($\theta$), right ascension ($\alpha$), declination ($\delta$), galactic latitude ($b_G$) and galactic longitude ($l_G$) are given in degrees.

| Array | Date       | Time       | $E_{2003}$ | $\theta$ | $\alpha$ | $\delta$ | $b_G$ | $l_G$ |
|-------|------------|------------|------------|----------|----------|----------|-------|-------|
| Yakutsk | Jan 21, 2009 | 23:40:35 | 36.3       | 35.5     | 356.3    | 65.8     | 4.0   | 116.5 |
| Yakutsk | Jan 22, 2009 | 10:51:52 | 35.5       | 42.7     | 333.3    | 62.3     | 4.9   | 105.9 |
| TA     | Jan 22, 2009 | 22:54:22 | 57.9       | 31.3     | 311.2    | 51.1     | 5.1   | 89.5  |

$E_{2003} = (4.6 \pm 1.2) \times 10^{17} \cdot S_{600}(0^\circ)^{0.98\pm0.03}$, \hspace{1cm} (1)

where $S_{600}(0^\circ)$ is experimentally determined parameter — particle density at 600 m from shower axis. Formula (1) was recently refined [9, 10] and the following relation was obtained:

$E_{2014} = (3.6 \pm 1.0) \times 10^{17} \cdot S_{600}(0^\circ)^{1.02\pm0.03}$.

(2)

Formula (2) does not significantly change the final $E_0$ value, since decrease of a constant is compensated by increased power-law dependency of $S_{600}$ parameter.

Systematic errors of energy reconstruction are presented in both experiments. In Yakutsk it amounts to 25%, at TA — it is 20% [11], hence there might be a systematic difference between energy scales of two arrays; possible hint to this is the difference in CR energy spectrum intensities in combination with close reproduction of the spectrum shape [9, 10]. On Fig. 1 are shown CR energy spectra of both experiments in energy range above $10^{19}$ — according to TA [11] and YEASa. Yakutsk points (red squares) lie higher than those of the TA (black circles). If one lowers the estimated energy of Yakutsk events by factor 0.8, then results of both experiments would agree with each other (green diamonds). This shows that this lessening might improve the agreement between energy scales of YEASa and TA. That said, such a correction wouldn’t exceed one sigma in expression (2).

Ratios between TA shower energy and different energy estimations of YEASa events are listed in Table II. In first two columns the energy is estimated according to expression (1), as in Table I; in next two columns a refined formula (2) was used. In next two columns energy
estimation according to (2) is multiplied by ratio 0.8. With respect to this correction it is more probable that the energy of shower registered by TA is approximately 2 times higher than energy of both YEASa’s events. For extreme energies such condition is satisfied when magnetic rigidity of all three particles is the same and if electric charge of the Telescope Array particle is 2 times higher than those registered by Yakutsk experiment. Hence we should have two protons and alpha particle.

TABLE II. Ratios between energy of the TA particle and energies of Yakutsk array events for different estimations.

| $E_{2003}$ (EeV) | $E_{TA}/E_{2003}$ | $E_{2014}$ (EeV) | $E_{TA}/E_{2014}$ | $E = E_{2014} \times 0.8$ (EeV) | $E_{TA}/E$ |
|-----------------|------------------|------------------|------------------|------------------------|-------------|
| 36.3            | 1.60             | 34.2             | 1.69             | 27.4                   | 2.12        |
| 35.5            | 1.63             | 33.4             | 1.73             | 26.7                   | 2.17        |

FIG. 1. A comparison of CR energy spectrum according to the data from TA (black circles) and YEASa (red squares). Green diamonds represent the Yakutsk spectrum with estimated energy reduced by 20%.
FIG. 2. Location of showers from assumed beam on celestial sphere in equatorial coordinates. Red circles denote Yakutsk events, purple — TA. Stars indicate X-ray sources with adjacent EAS arrival directions. Blue line represents Galaxy plane (GP), brown (SGP) — Super Galaxy plane. HotSpot-TA is the center of region with increased particle flux with energy above 57 EeV according to the Telescope Array [5], HotSpot-Yak — center of region with increased flux according to the Yakutsk array in energy range 10-30 EeV [12].

These three showers hint at existence of short-lived beams of UHECRs (with energy above $10^{19}$ eV) with virtually similar magnetic rigidity arriving from a small sky region. Such beams probably are generated during rapid explosive precesses with huge energy output. A relatively rapid succession of all three events near Earth and their “monochromaticism” in magnetic rigidity are most likely conditioned by magnetic separation of particles during propagation of a beam. If one limits the region of the sky sphere with 15° radius containing all three events and assumes that particle emission within this region is uniform; and if a burst lasts for exactly 1 day, then according to YEASa the UHECRs the luminosity of this region increases by factor $(0.8 + 1.0/ − 0.5) \times 10^4$ compared to the background value. The Telescope Array data published earlier [5] include events with energy above 57 EeV. It is
possible that this experiment have registered events of lower energy that could be related to the particle beam of our interest. Expansion of TA’s events selection towards lower energies and testing the set for presence of such additional events would be instrumental in obtaining a definitive evidence that assumed particle beam is real after all.

Locations of showers on celestial sphere in equatorial coordinate system are shown on Figure 2. Events recorded by Yakutsk experiment are represented with red circles, TA’s particle — with purple circle. Stars denote X-ray sources with adjacent EAS arrival directions. EAS events lie very tight to the 1E2259+586 X-ray pulsar. But also they are quite close to a more interesting source — Cygnus X-3 (Cyg X3); this source radiates in a wide range — from radio waves to ultra-high energy photons [13, 14]. In early 1980’s fluxes of gamma-photons with energy $10^{15} - 10^{16}$ eV were detected from Cyg X3 [15, 16] — an indication of UHECRs production.

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