Observation of an Excess of Cosmic Ray Showers from the Direction of Centaurus A

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Abstract

An analysis of recent data from the Adelaide cosmic ray shower array suggests that an excess of events may have been observed to come from the general direction of Centaurus A. These data are presented and discussed together with directional data from other previous experiments.

1. Introduction

Cosmic rays which are detected through extensive air showers are generally believed to be high-energy nuclei. Our galaxy has a large-scale magnetic field which will deflect substantially all such charged cosmic rays (except perhaps those with energies above $\sim 10^{18}$ eV). It is not to be expected therefore that any distant source of cosmic rays would be detectable in a small region of sky which has an associated excess of events. Indeed, any deviations from isotropy which have generally been observed have been interpreted as a small excess of flux ($\leq 1\%$) from a very broad area of sky. This concept is built into the usual harmonic analysis of anisotropy.

It is usual, however, to check the data of an anisotropy experiment by using a chisquared test on maps of sky intensity (see e.g. Chitnis *et al.* 1960). These tests are normally negative. We usually have no *a priori* reason for expecting a specific preferred direction and it is not surprising when one bin out of several hundred shows quite a large excess. We have carried out such an analysis for data from the Buckland Park air shower array (latitude $35^{\circ}S$) and find that in our case this largest excess happens to coincide with the direction of Centaurus A, our nearest neighbour active galaxy. We find some corroborative evidence in the literature for this observation.

2. Adelaide Observations

Our experimental work was carried out with the air shower array situated at the Buckland Park field station of the University of Adelaide. This sea level array has been described in detail elsewhere (Crouch *et al.* 1981) but, briefly, it detects cosmic ray showers with primary particle energies typically between 10^{15} and 10^{17} eV. The directional accuracy is of the order of $3^{\circ} \sec \theta$, where θ is the zenith angle of the shower. There can be substantial fluctuations in this directional error, particularly for lower energy showers. The array has a low energy threshold of about 10^{15} eV. The collecting area rises above this energy to $\sim 3 \times 10^4$ m² for energies above $\sim 10^{16}$ eV.

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The array samples the electromagnetic component of the cosmic ray shower and no direct measure of the muon component is made. We obtain no information on the charge of the initiating particle or indeed whether it was a massive particle or a photon.

The data discussed in this paper were obtained in the period of three years up to December 1981. In this time $\sim 1.3 \times 10^5$ events were usefully recorded within a sensitive time of $\sim 7 \times 10^7$ s. The operation of the array and its results for conventional anisotropy work have been described elsewhere (Gerhardy and Clay 1983*a*). Whilst interesting, these results are non-controversial in the sense that they exhibit similar trends to other such experiments in the same energy range and at similar latitudes. There is no reason to suspect that such results are, in any way, strange or that there is any substantially non-uniform distribution of the system on-time when measured in sidereal time.

3. Small-scale Anisotropy Results

Having studied the overall anisotropy of our data by harmonic analysis, we wished to investigate any small-scale effects such as one might see from a local point source of primary particles (Gerhardy and Clay 1983b). We applied a chi-squared test to each of our declination bands (5° intervals) and found no band with an excessive chi-squared sum. The band exhibiting the largest chi-squared value when split into one-hour intervals of R.A. was the band 40°S to 45°S. The largest positive excess within this band is in the R.A. interval which also contains Cen A. This excess over the mean of the other 23 intervals is at a level of $2 \cdot 7$ standard deviations or $2 \cdot 7\sigma$. On its own, this result is not significant. This particular interval is also the most significant in our whole sky data, but there are many other bins in the survey and obtaining $2 \cdot 7\sigma$ is not at all surprising for one bin somewhere in the survey. The surprise at this stage is that the direction also coincides with Cen A, the *only* known Southern Hemisphere source of very high energy particles (Grindlay *et al.* 1975*a*, 1975*b*).

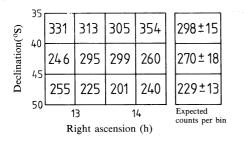


Fig. 1. Total accumulated counts in the general direction of Cen A (13 h 22 m, $-42 \cdot 8^{\circ}$) from the Buckland Park experiment.

Cen A is local by the standards of active galaxies and the angular size of the object itself, at least in the radio band, is very great with large lobes extending several degrees north and south (the northern lobe dominates). The axis of the system is in a NE–SW direction and there is an X-ray jet extending from the central galaxy in a north-easterly direction (Feigelson *et al.* 1981). We have therefore extended our investigation to other declination bands north and south of 40°S to 45°S and have extended the analysis by considering half-hour intervals of R.A. The basic cell, 5° in δ and 30 minutes in R.A., is roughly 5° square at these declinations. If we take all intervals which intersect a circle of 7° radius (roughly the radio size of Cen A convolved with

our directional uncertainty) about Cen A, a chi-squared test gives a confidence level of $\sim 0.2\%$ for a chance occurrence. Fig. 1 shows the distribution of counts in the general direction of Cen A. The bins contributing mainly to the excess are in a NE-SW line.

We note also that if the data are split on the basis of shower size (a rough split in terms of primary particle energy), the NE-SW general feature persists but with poorer statistics.

We conclude that there is interesting evidence to associate Cen A with the arrival direction of an excess of cosmic rays of ~100 particles (of energy $\geq 10^{15}$ eV) in 10⁴ m² over a period of ~7×10⁷ s. This is more usefully expressed as about 3% of the cosmic ray background from the direction of the radio source Cen A. The confidence level of these data is not compelling. We have therefore examined the literature for other anisotropy studies at these declinations.

4. Other Anisotropy Studies

There are only two other studies which cover our declination range at about our energy and with reasonable statistics. These are the very early counting experiment at Auckland of Farley and Storey (1954), and a mu-poor experiment at Mt Chacaltaya in the 1960s (Kamata *et al.* 1968).

The most significant data of Farley and Storey (1954) correspond to energies of about 10^{15} eV. They relied on atmospheric collimation to give them a beamwidth of $\sim \pm 20^{\circ}$. The latitude of Auckland is such that Cen A passes through this beam. The results of this counting experiment show their most significant peak ($\sim 3\sigma$) at 14 h sidereal time, close to the direction of Cen A.

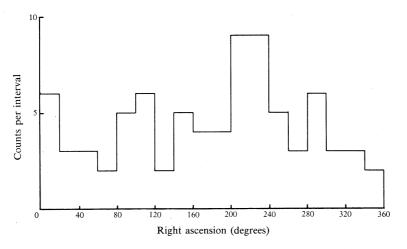


Fig. 2. Distribution of mu-poor showers detected at Mt Chacaltaya (Kamata *et al.* 1968) for declinations south of 30° S. The mean count per interval is $4 \cdot 4 \pm 2 \cdot 1$.

The experiment at Mt Chacaltaya (Kamata *et al.* 1968) studied the arrival directions of a subset of all showers (with typical energies of $10^{15}-10^{16}$ eV) which were apparently deficient in muons (mu-poor showers). This criterion was thought to be characteristic of photon initiated showers. The experiment accumulated a total of only 213 mu-poor showers, but summing all declinations showed a large peak (27 events) in the

R.A. range $200^{\circ}-220^{\circ}$ ($13\cdot 3-14\cdot 71$ h) compared with an expected number of $13\cdot 8$ events. Kamata *et al.* presented an arrival direction map of the sky; if we pick out the distribution of all events south of 30° S, we obtain the distribution in Fig. 2. There is a clear and significant excess in the direction $13\cdot 5-16$ h. It may be worth pointing out that the zenith angles of these showers would have been quite large ($\geq 30^{\circ}$) and the directional accuracy probably poor.

The excess of events from each of the anisotropy experiments appears to be of the order of 1%-10% of the cosmic ray background in the appropriate direction. The Mt Chacaltaya data are difficult to interpret in this sense since extra selection criteria were employed based on an apparent deficiency of muons from the accepted showers.

It would seem that all three experiments which cover the area of the sky including Cen A suggest an excess of events from that general direction.

5. Discussion

Only three objects have been observed with reasonable statistical confidence at high γ -ray energies: these are Cen A (Grindlay *et al.* 1975*a*, 1975*b*), the Crab Nebula (Dzikowski *et al.* 1980; Boone *et al.* 1983) and Cygnus X-3 (Samorski and Stamm 1983), all of which in many ways are quite different objects. The Crab Nebula has been detected at $\sim 10^{15}$ eV using air shower techniques, particularly by looking for mu-poor showers. Cen A has been detected at energies lower by a factor of 10^3 using air Cerenkov techniques. There are good reasons for believing that the Crab Nebula would be at the limit of observable distances with 10^{15} eV γ rays since the microwave 3 K background photons are expected to have catastrophic collisions with such γ rays. These collisions are expected to have an interaction mean free path of only a few kiloparsecs (see e.g. Wdowczyk *et al.* 1971). The Crab Nebula is ~ 2 kpc from us, whilst Cen A is ~ 5 Mpc distant, and it would appear that if the present observations are causally related to Cen A, then their interpretation will not be straightforward. It may be necessary to invoke high-energy neutrinos or secondary γ rays from undeviated high-energy protons from Cen A which interact in the vicinity of our own galaxy.

In conclusion, there seems to be accumulated evidence from a number of experiments for an excess of cosmic ray showers from the general direction of Cen A with a directional distribution apparently related to the source structure. An interpretation of these data in terms of a high-energy photon flux from Cen A appears to be unacceptable due to the interaction of such photons with the microwave background.

Note added in proof: Preliminary results from a new air shower array at the University of Sydney (Luorui 1983) indicate a small peak for the declination band -30° to -40° at a direction close to that of Cen A discussed in the present paper.

Acknowledgments

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