ACTIVE GALACTIC NUCLEI WITH STARBURSTS: SOURCES FOR ULTRA HIGH ENERGY COSMIC RAYS

P.L. Biermann, J.K. Becker, L. Caramete, L. Á. Gergely, I.C. Mariș, A. Meli, V. de Souza, T. Stanev

1 MPI for Radioastronomy, D-53121 Bonn, Germany (www.mpifr-bonn.mpg.de/div/theory),
2 Institution für Fysik, Göteborgs Univ., Sweden,
3 Institute for Space Sciences, Bucharest, Romania,
4 Phys. Dept., Univ. of Szeged, Szeged, Hungary,
5 Inst. Nucl. Phys. FZ, Karlsruhe Inst. of Techn. (KIT), Germany,
6 Erlangen Center for Astroparticle Physics, Univ. Erlangen-Nürnberg, Germany,
7 Universidade de São Paulo, Instituto de Física de São Carlos, Brazil,
8 Bartol Research Inst., Univ. of Delaware, Newark, DE, USA

Ultra high energy cosmic ray events presently show a spectrum, which we interpret here as galactic cosmic rays due to a starburst in the radio galaxy Cen A pushed up in energy by the shock of a relativistic jet. The knee feature and the particles with energy immediately higher in galactic cosmic rays then turn into the bulk of ultra high energy cosmic rays. This entails that all ultra high energy cosmic rays are heavy nuclei. This picture is viable if the majority of the observed ultra high energy events come from the radio galaxy Cen A, and are scattered by intergalactic magnetic fields across most of the sky.

Keywords: Ultra high energy cosmic rays; Active Galactic Nuclei; Intergalactic magnetic fields.

1. Introduction

The origin of ultra high energy cosmic ray has been a riddle since their discovery 1963 by Linsley (Ref. [1]). After many experiments and measurements we are beginning to accumulate reasonable statistics with the Auger array, and have a very good spectrum, shown in our figure below (see Ref. [2]).

As there is a weak correlation with active galactic nuclei, various classes of such objects have come under consideration again. Radio galaxies have been argued to be sources for some time (see Ref. [3]), but none in our cosmic neighborhood readily accelerates protons to such high energy, as derived from the jet energetics (see Ref. [4]). Heavy nuclei seem to be required. Here we outline such a scenario (see Ref. [5]), and give a spectral fit in the figure below.

*Also at Univ. of Bonn, Univ. of Alabama, Tuscaloosa, AL, Univ. of Alabama at Huntsville, and at KIT Karlsruhe
†also at the University of Dortmund, and from June 2009 also at the University of Bochum
2. Starburst and relativistic jet

When two galaxies merge (see Ref. 6), we first have a starburst, and second a central activity that outshines the young stars, and also disperses much of the interstellar material. Usually such a merger is also accompanied by a spinflip of the more massive black hole, due to the dominant relative orbital spin, when two black holes merge. This implies that a new jet forms and bores a new channel through the environment, freshly filled with galactic cosmic rays. These new galactic cosmic rays have a relatively flat spectrum to the bend, commonly referred to as the knee, where the spectrum turns down. Gallant & Achterberg (Ref. 7) have shown that the shock in a single interaction pushes the particle energies up by $\Gamma_j^2$, where $\Gamma_j$ is the Lorentz factor of the shock. Studies of radio interferometry and other work has suggested that in the spine of the jet this Lorentz factor can reach 50. Therefore the spectral distribution near the knee (see Ref. 8) may be pushed up in energy by a factor up to 2500. This then clearly provides ultra high energy particles. The only source in our cosmic neighborhood capable of doing this is the radio galaxy Cen A.

Obviously, we do need scattering by magnetic fields (see Ref. 9, 10, 11) to explain a spectrum built from events all over the sky, but coming from a single source. In fact, since their MHD cosmological simulations already give some large angle scattering for protons, and we here argue for heavy nuclei, those models would produce an almost perfectly isotropic sky. However, as shown by inconsistencies in the magnetic field determinations in our Galaxy (see Ref. 12), the medium is probably highly filamentary, strongly reducing the angular scattering. This is reasonable for highly super-Alfvénic turbulence injected by super-nova explosions. In the intergalactic medium super-Alfvénic turbulence may be due to radio galaxies. Thus the scattering may be moderate even for heavy nuclei, explaining the large scale nearly isotropic sky distribution, but also allowing many events to come from directions close to Cen A.

3. The spectrum

We have taken the spectrum for galactic cosmic rays (Ref. 8), pushed it up to match the turnoff feature near 40 EeV and fitted it to the Auger data, as published (Ref. 2). We match the slope below the Fe-edge at 40 EeV, the step down, and the slope beyond 40 EeV. Obviously it is possible to improve the match, and so we tested modifying the abundances; we note that the abundances of the various chemical elements in the winds of Wolf-Rayet stars and Red Super Giant stars depend on the initial abundances, but most of all on the zero age masses of the stars, and so on their mass distribution: Therefore it cannot a priori be expected, that the abundances in cosmic rays in our Galaxy match those in another galaxy. A decrease by 20 percent the abundances of the two element groups Ne-S and Cl-Mn improves the match below 40 EeV to near perfect. Due to the small distance of the radio galaxy Cen A, we do not expect any strong effect from propagation; however, since some particles are required in our model to make detours, that clearly is
another simplification. We show the match without taking any of this into account (Ref. 2, 8):

Fig. 1. Testing the spectrum in paper CR-IV with Auger data, with all six element groups unmodified.

Taken literally, this interpretation of the data suggests that beyond 40 EeV the two dominant element groups are Ne - S and Iron, all coming from Cen A.

4. Discussion, conclusions and predictions

As interactions of photons with heavy nuclei give very much lower fluxes of high energy photons and neutrinos, we wonder, whether this argument would not reduce the high energy neutrino fluxes to below any possible detection limit (Ref. 13). On the other hand, we note that we expect high energy neutrinos from flat spectrum radio sources, which have their current relativistic jet pointed at the Observer on Earth. All such sources are highly variable, and so also the interactions may run right into saturation for many flares, producing very high neutrino fluxes, but for a very short time.

If there are any protons among the ultra high energy particles, they should point better towards their sources; very few events point to the radio galaxy Cen A (note, that Cen A extends 10 degrees on the sky: Ref. 14). Those that do appear to come
from inside the radio source extent cannot be protons and also be attributed to Cen A, since Cen A cannot give so high energies to protons, by the Poynting flux limit (see Ref. [4]) and using its jet power (Ref. [15]; this is also true, if protons initially accelerated get converted to neutrons that decay back to protons (Ref. [16]).

This model predicts: a) ultra high energy cosmic rays are mostly the elements Ne - S and Iron; b) most of events come from the radio galaxy Cen A; and c) we do need highly filamentary magnetic structures in the intergalactic medium which scatter to large angles without completely isotropizing the paths of the events. Further statistics should confirm spectrum, scattering distribution, and chemical composition.

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