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Universal Energy Spectrum from Point Sources

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ABSTRACT

The suggestion is made that the energy spectrum from point sources such as galactic black hole candidates (GBHC) and active galactic nuclei (AGN) is universal on the average, irrespective of the species of the emitted particles, photons, nucleons or others. The similarity between the observed energy spectra of cosmic rays, γ-rays and X-rays is discussed. In other words, the existing data for gamma-rays and X-rays seem to support the prediction. The expected data from GRO (Gamma Ray Observatory) will provide a further test.

The fundamental hypothesis for cosmic ray acceleration has been the Fermi mechanism by magnetic fields and its variations including shock wave acceleration in supernovae.[1–3] Although the latter constitutes the most frequently discussed source, it has been pointed out that supernova acceleration fails[4] to accelerate protons beyond 10^{13} eV. Then, one has to propose some other mechanism[5] to produce the high energy component of cosmic rays beyond the knee energy (10^{15-16} eV). The difficulty of having two independent mechanisms for cosmic rays below and above the knee energy is that one has to rely on an accidental coincidence that the respective mechanisms fall down at the same energy (the knee energy) and attain equal intensity at the knee energy. This is too much to ask for in explaining the observed data. [This would not be a problem if the slope index, λ of the energy spectrum $\sim E^{-\lambda}$, were smaller on the high energy side than on the low energy side. The observed spectrum is, in fact, just the opposite; $\lambda =\sim 2.6$ and 3 below and above the knee energy.] In other words, a unified mechanism for the entire energy region is required for cosmic ray acceleration. Jokipii and Morfill proposed that shock wave acceleration in supernovae continues by the galactic wind.[6] So far the evidence for the existence of galactic wind which would enable the necessary accelerations of charged particles up to $\sim 10^{20}$ eV with the required intensity is yet to be found.

As a consequence, one may ask whether there exist some other sources or mechanisms for cosmic ray acceleration. Possible candidates are obviously quasars and active galactic nuclei (AGN). The observed luminosity ($\lesssim 10^{46}$ erg/sec) is galactic ($\lesssim 10^{13}\, L_\odot$) and relatively short variability ($\lesssim 10^5$ sec) indicates that massive black holes might be the source of energy. The observation of jets from some of the AGN also enforces such an assumption. Although the mechanism of the energy output from AGN are not known (the central engine problem), it appears that gravitational forces are the main cause of energy outflow. This paradoxical characteristic of black holes requires an unusual scenario for energy outflow from black holes. It may be due to the Penrose mechanism for the Kerr metric or something else. [The present author proposed a mechanism.[8]] Whatever the details of the acceleration mechanism, one may discuss the outcome of the assumption,

"Cosmic rays are accelerated by gravitational forces".

One possible outcome of the assumption is that the gravitational acceleration does not discriminate particles by charge. Therefore, such acceleration produces essentially the same result for any particles, charged or not.

This argument motivates us to suggest the following:
"All particles emitted by point sources such as quasars, AGN and galactic black hole candidates (GBHC) have a universal energy spectrum. The shape of the universal spectrum should be identical to that of cosmic rays, except for some corrections due to the difference between the trajectories of neutral and charged particles."

The energy spectrum for γ-rays from quasar 3C273 was obtained by the CosB satellite and was reported to be[9]

$$\sim E^{-(2.5\pm0.6)} \tag{1}$$

around $100 \sim 400$ MeV. At this energy cosmic rays suffer solar modulation[3] but it is generally assumed that the original spectrum is an extension of the spectrum at higher energy (≥ 1 GeV), $\sim E^{-2.6}$. Therefore, the spectrum in Eq. (1) is remarkably close to that of cosmic rays, although an improvement of the accuracy in the measurement is needed. The expected data from GRO (Gamma Ray Observatory) will provide a further test of the prediction.

The X-ray data from point sources do not show the energy spectrum of Eq. (1). Analysis of the X-ray data by the Ginga group suggests that there are two components[10] in X-rays from point sources, GBHC: One from black body radiation at a temperature T and the other constituting a power law energy spectrum, which photon index $\lambda_0 = 1.5 \sim 2.0$ with an average of 1.7. The former component would come from black body radiation from a disk surrounding the hole, while the latter would originate from somewhere else and is Compton-scattered by the disk. The energy spectrum of the original X-rays before being Compton-scattered can be computed by[11]

$$\lambda \;=\; 2(\lambda_0 - 1) + 1. \tag{2}$$

It follows from Eq. (2) that the photon index of the original X-rays is

$$\lambda \;=\; 2.0 \sim 3.0 \tag{3}$$

with the average

$$\lambda_{\text{av}} \;=\; 2.4. \tag{4}$$

For the case of AGN, the observed photon index is[11] $(\lambda_0)_{\text{AGN}} = 1.3 \sim 2.3$ with the average 1.7. This corresponds to the photon index of the original X-rays to be

$$\lambda_{\text{AGN}} = 1.6 \sim 3.6 \tag{5}$$

with the average

$$(\lambda_{\text{av}})_{\text{AGN}} = 2.4 \tag{6}$$

Again, the value in Eq. (4) and Eq. (6) is close to that for the power spectrum of cosmic rays ($2.5 \sim 2.6$). An improvement in statistics as well as data from many more sources is required from the future X-ray satellites.

Finally, some comments are in order concerning the knee energy in the cosmic ray energy spectrum. The reason for the existence of the knee energy is not known. It could be due to either

[A] galactic magnetic fields ($\sim 3\mu G$).

or

[B] some unknown but intrinsic reason for gravitational acceleration.

Case [A] implies that the galactic magnetic fields in the Milky Way provide the depletion of high energy cosmic rays exiting from the galaxy and/or of low energy cosmic rays entering into the galaxy [assuming a single power energy spectrum]. Case [B] suggests that the existence of the knee energy has something to do with the gravitational acceleration mechanism with an intrinsic energy scale (of a few hundred TeV). [The example in ref. 8 is of this kind.] Again, without going into a discussion of the details of the acceleration mechanism, these two cases can be decided indirectly by observing the energy spectrum of γ-rays from point sources at higher energies. If the γ-ray energy spectrum from point sources exhibits the knee energy spectrum (not necessarily at the same energy since the gravitational redshift and the Doppler blueshift might be relevant to the final outcome) one may conclude that Case [B] is true. The γ-ray data from point sources at higher energies (by the Fly's Eye, the Whipple Observatory and other high energy γ-ray observatories) can decide which of Case [A] or [B] is the correct answer.

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REFERENCES

1. e.g., A.M. Hillas, Ann Rev. Astron. Astrophys. 22 , 425 (1984).
2. A.R. Bell, M.N.R.S. 182 , 147, 443 (1978); R.D. Blandford and J. P. Ostriker, Ap. J. 221 , L29 (1978).
3. e.g., M.S. Longair, *High Energy Astrophysics*, (Cambridge University Press, 1981); S. Hayakawa, *Cosmic Ray Physics*, (Wiley-Interscience, NY, 1969).
4. P.O. Lagage and C.J. Cesarsky, Astron. Astrophys.118 , 223; 125 , 249 (1983).
5. e.g., J.E. Gunn and J.P. Ostriker, Phys. Rev. Lett. 22 , 728 (1969).
6. J.P. Jokipii and G.E. Morfill, Ap. J. 290 , L1 (1985).
7. M.J. Rees, Ann. Rev. Astron. Astrophys. 22 , 471 (1984).
8. Y. Tomozawa, Lectures in the Proc. of the 2nd Workshop on Fundamental Physics (ed. E. Esteban, 1986), p. 144; in *Quantum Field Theory* (ed. F. Mancini, 1985), p. 241; in *Active Galactic Nuclei* (ed. R. Miller and P. Wiita, Springer Verlag, 1988), p. 236; in *Symmetry in Nature* (Scuola Normale Superiore, 1989), p. 779; Quasars, Galaxy Distribution and Cosmic Background Radiation, UM-TH-91-15, 1991.
9. G.F. Bignami et al., Astr. Ap. 93 , 71 (1981).
10. H. Inoue, X-Rays from Galactic Black Hole Candidates and Active Galactic Nuclei, an invited talk presented at the Texas/CERN Symposium, Dec. 17-21, 1990, Brighton, United Kingdom.
11. G.B. Rybicki and A.P. Lightman, *Radiative Processes in Astrophysics*, (Wiley-Interscience Pub.), 1979.