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Cosmic Rays and Cosmology

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Three aspects of cosmic rays and cosmology are considered here. Firstly, the relevance of extragalactic cosmic rays to the radiation – and magnetic – fields in the Universe, secondly the contribution of Galactic cosmic rays (or other entities allied to them) to the 'foreground' in analysis of the cosmic microwave background (CMB)and finally, some comments about CR of the highest energies. Concerning the CMB, we present evidence strongly suggesting that the foreground is, indeed, important. Coupled with the demonstration of asymmetries, of Galactic form, in the CMB maps the case for changes to the presently-derived cosmological parameters is strong.

1. Introduction

For some years after the discovery of cosmic rays in 1912, it was thought that they were universal, i.e. filled the universe completely. Thus, the cosmological significance then was considered very important. However, it has been found that this is not the case, and the extragalactic (EG/CR) energy density is found to be only some 10^{-6} of that in the Galaxy. This result follows from measured Galactic anisotropies and a lack of sufficient EG gamma rays from the interactions of EGCR with gas. Nevertheless, even at the 10^{-6} level there is some significance, as will be demonstrated.

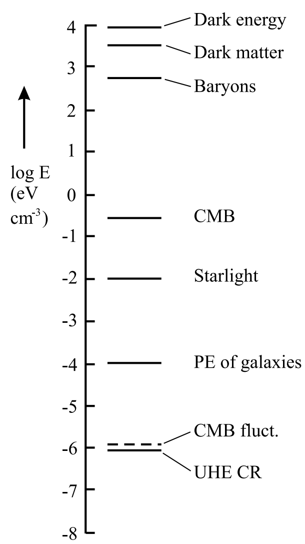

Figure 1. Energy densities in extragalactic space

2. Energy Densities

Locally, in the Galaxy, there is the well-known equality between the energy density of CR (most of which have energy below 10 GeV), of magnetic fields, of the motion of gas clouds and of starlight. These equalities have important astrophysical implications. A similar comparison can be made for EG space. (Fig. 1). Although much less than the other energy densities shown, that in ultra-high energy CR (UHECR) is seen to be of the same order as that in the fluctuations in the CMB (not the CMB itself), and it is of the order of 1% of that in the potential energy of galaxies i.e. the energy released when galaxies form. The latter provides a clue as to the origin of the UHECR.

It is the CMB aspect that concerns us more, here, however. The role of CR in the form of non-Maxwellian particle velocity distributions in the era of recombination (red shift $z \sim 1000$) appears not to have been considered but in view of the importance of the conclusions drawn from the details of the ensuing fluctuations in the CMB now detected, perhaps it should be.

Turning to the CMB fluctuations themselves it would be surprising if CR were not to provide some sort of foreground effect either in EG space (e.g. in galaxy clusters) or in the Galactic Halo. After all, other studies of rare cosmic effects (such as the search for neutrinos, dark matter particles, etc) need to take precautions to guard against CR effects. The method adopted there – operation underground – is not an option in studies of the CMB, nor is it relevant.

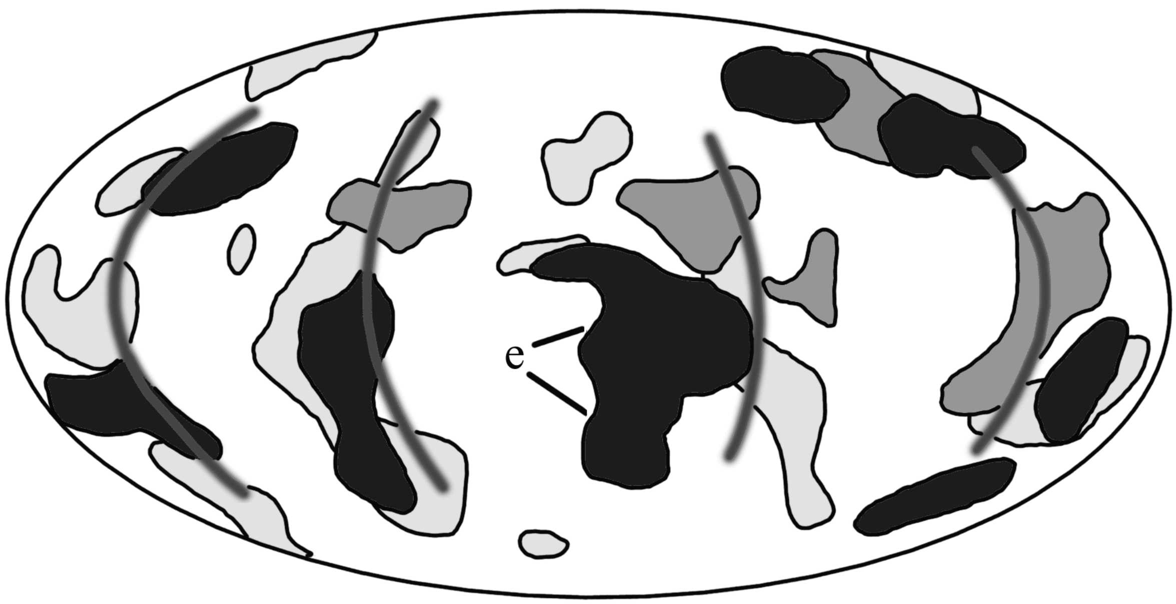

Figure 2. Map of the sky (Galactic Centre at the centre, longitude increasing to the left) showing regions of steep spectra of protons[4] (light grey) and electrons[5] (dark grey) and minima in the WMAP[3] (black). The thick lines represent low column densities of atomic hydrogen (chimneys) and interarm regions. 'e' represents two regions of steep electron spectra below the low CMB region.

That CR effects in the Galaxy might be important for the CMB came from our study[1] which showed a good correlation between the large low temperature regions in the so-called WMAP[2, 3] of the CMB fluctuations and regions having steep spectra for both protons and electrons as progenitors of the detected gamma rays. The situation is shown in Fig. 2. It cannot be claimed that CR themselves are responsible – some other mechanism could be invoked which correlates with both. However, it *could* possibly be a CR mechanism, for example very cold dust clouds in the Galactic halo could be mildly heated by Galactic CR. The low temperature CMB regions would then correlate with low CR intensities, i.e. steep spectra, insofar as the bulk of the CR heating would be in the tens of GeV energy region, intensities here being low for steep spectra.

Most of the rest of the paper is devoted to the CMB foreground problem, starting with a general, non-CR-related, examination of the WMAP[3].

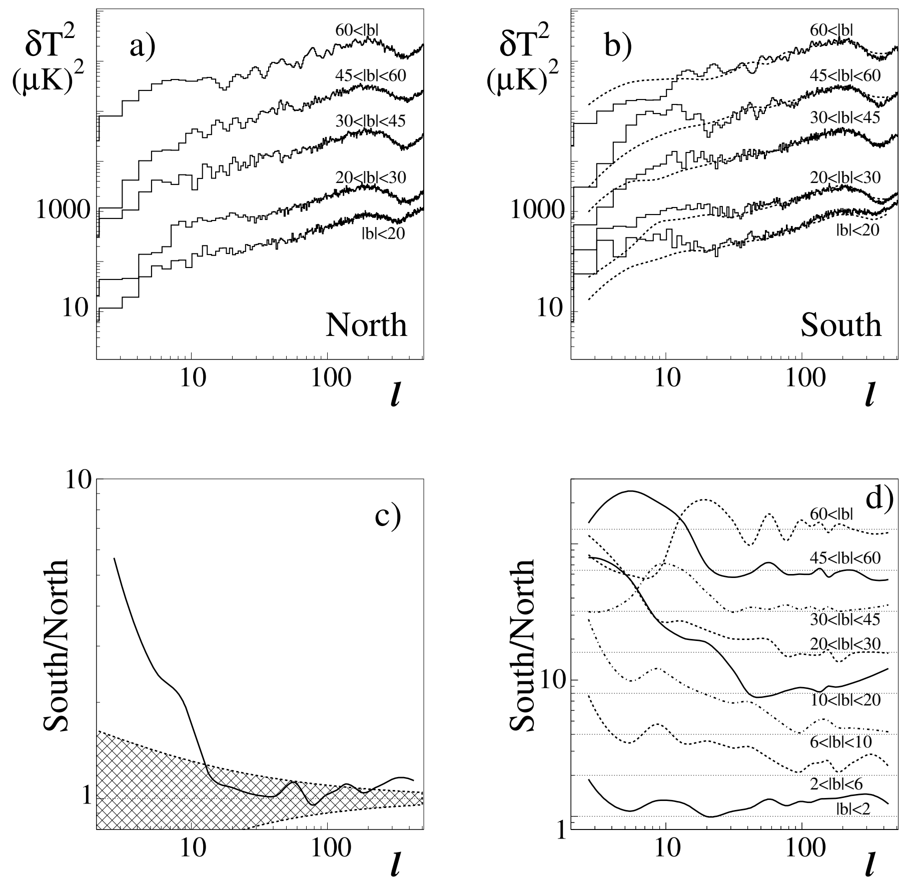

Figure 3. Power spectrum of the WMAP data[3] for the two Galactic hemispheres (a) North and (b) South. Moving upwards the latitude ranges are (plus or minus): $< 20°$, $20°/30°$, $30°/45°$, $45°/60°$ and $> 60°$. The data for positive latitudes (the North) have been smoothed and also plotted in (b) to allow observation of the fact that the 'Southern Excess' continues to 'high' latitudes. (c) Power Spectrum South/North ratio vs l.(d) Division by latitude band.

3. The Cosmic Microwave Background WMAP

3.1 Galactic anomalies

The CMB map[3], should 'know nothing of the existence of the Galaxy' insofar as it has been 'cleaned' of potential contributions from synchrotron radiation and dust. Thus, there should be no asymmetries associated with the Galactic Plane or Galactic Quadrants. However, this is not the case. Inspection of the power spectrum vs ℓ (the harmonic number) shows the results given in Figs. 3 and 4. Figure 3 shows the data divided into 'North' and 'South'. Clear differences are evident with a clear excess from the South. Figure 4 relates to the results Quadrant by Quadrant; very significant systematic differences are visible.

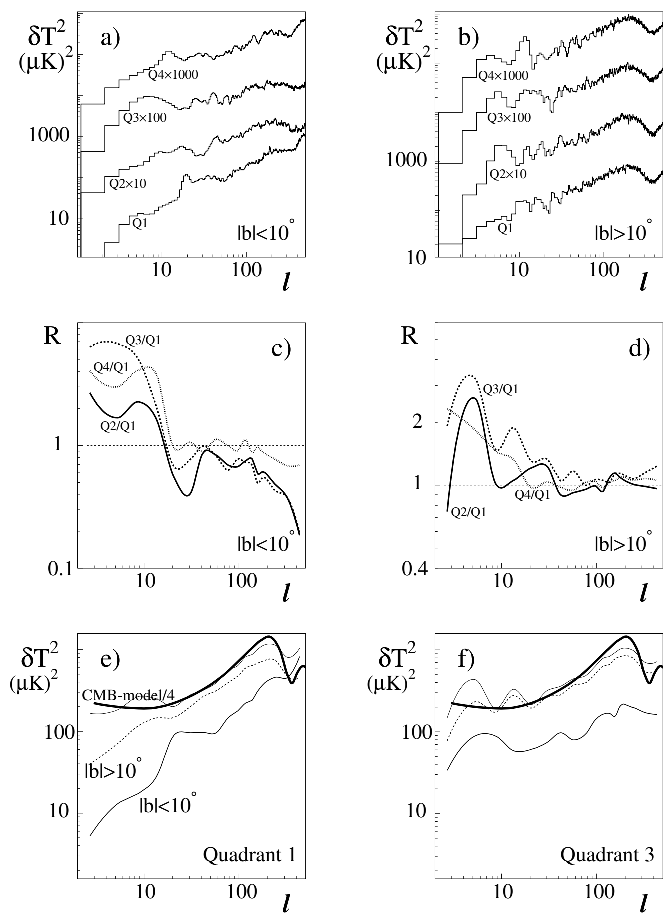

Figure 4. (a) Power spectra, for latitudes below 10°, for each Galactic Quadrant in turn. The lowest line refers to Quadrant 1, and so on. Successive lines are displaced upwards by a decade to help appreciation of their shapes. (b) As (a) but for latitudes above 10°. (c) The ratio of the power in the other Quadrants to that in Quadrant 1, for $|b| < 10°$. (d) As (c) but for $|b| > 10°$. Overall Power spectrum and spectra for the two latitude ranges for (e) Quadrant 1 and (f) for Quadrant 3. Also shown is the result from Ref. [3] for the whole sky.

Figure 5 shows a more subtle result. The data, which relate to the temperature of individual pixels, have been divided into positive and negative values and the power spectrum evaluated for each. The mean is zero and Monte Carlo studies of 'artificial universes' show that the two power spectra should be the same. They are not: Fig. 5 shows the results. It is evident that the positive-going pixels contain an extra source of noise, which manifests itself very largely in the ℓ-range $10 - 50$ $(18° - 3.6°)$ and above $\ell = 200$ $(< 1°)$.

The effect of the anomalies is to strongly suggest that the amplitude of the power spectrum is too high (and its shape 'wrong'), with consequently changes needed to the values of the hitherto derived cosmological parameters.

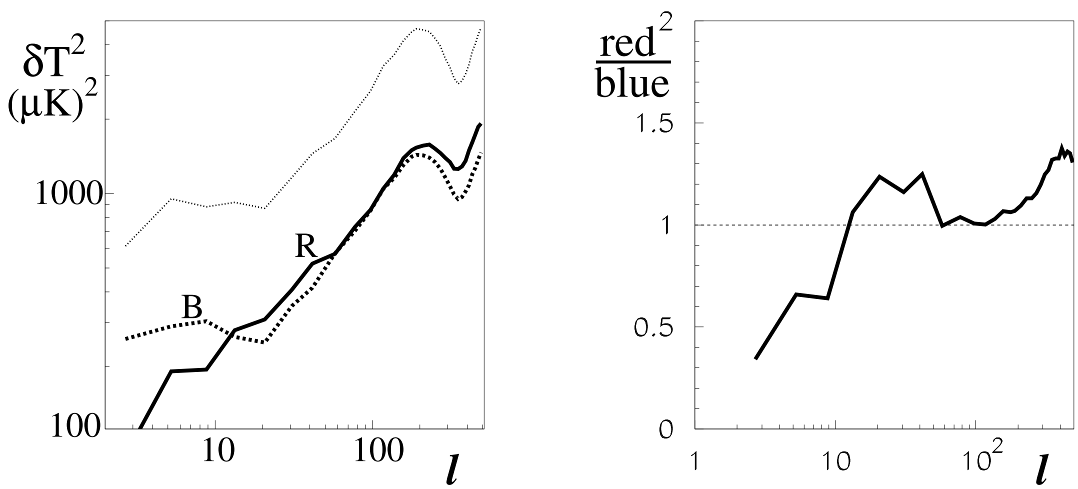

Figure 5. (a) The power spectra for the 'blue' regions (marked 'B') and the red regions (marked 'R'). (b) The ratio of the power for the red region to that for the blue region as a function of ℓ.

3.2 CMB – Cosmic Ray Correlations

The significance of Fig. 2 has already been mentioned. In a more detailed analysis we have identified 'special regions' of the sky where the CR spectra are steep[4, 5], where the HI column density is low (a possible indicator of low CMB foreground) and where the CR intensity is high (the Loop ISNR – specifically the 'shocked region' where we had previously[6] found evidence for CR acceleration). The cosmic ray intensities relate to gamma rays as measured by the EGRET detector on the Gamma Ray Observatory[7]. Figure 6 shows the results. There is no doubt that, for whatever reason, there is a correlation between the CMB and CR.

In another analysis we have studied the whole sky Quadrant by Quadrant in 15 discrete latitude bands. Taking the correlation coefficients to be of equal weight the following results appear:

- There is an overall positive correlation.
- There is approximate symmetry about the Galactic Plane.

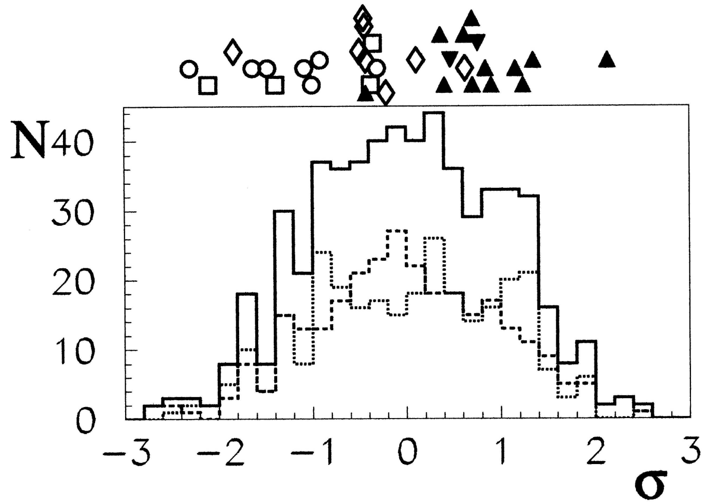

Figure 6. Excesses and Deficits. Values for the C–R associated excesses and deficits of CMB temperature in comparison with the frequency distribution of mean temperatures for similar spatial regions are shown by the solid histogram (dashed and dotted histograms are for the Northern and Southern hemispheres, respectively). The filled–in symbols relate to the SNR shell excesses and the open symbols are for hydrogen poor regions and regions having steep electron or proton spectra where we expect deficits. The histogram is for similar areas distributed at random all over the sky. 'N' is the number of 'areas'.

- There is a marked disparity between the Inner and Outer Galaxy.

Referring to the last mentioned result, the overall correlation in the Outer Galaxy is strongly positive whereas that in the Inner Galaxy is mildly negative. This may be due to the fact that the overall gamma ray intensity in the Inner Galaxy is higher than in the Outer and much is not likely to be related to the CMB; another factor is the presence of a large Inverse Compton contribution in the Inner Galaxy – again, it is unlikely that this has any connection with the CMB.

3.3 The Resulting power spectrum

The power spectrum after correction for CR-effects is the objective of this work; it is from the details of this function that the cosmological parameters are derived: the degree of flatness of the universe, the baryon fraction, the dark matter and dark energy fractions, the degree of re-ionization, the form of the primordial spectrum, etc. Demonstration of CR-related effects, is one thing, correction for them is another, however. At this stage we can only choose the region of the sky for which the CR-related effects are a minimum. Analysis of the N-S and Quadrant asymmetries indicate that Quadrant 3, North is probably the best region to take, and Fig. 7 shows the corresponding power spectrum.

Several features are apparent from a comparison of the spectrum from the present work (PW) and the standard form, as follows:

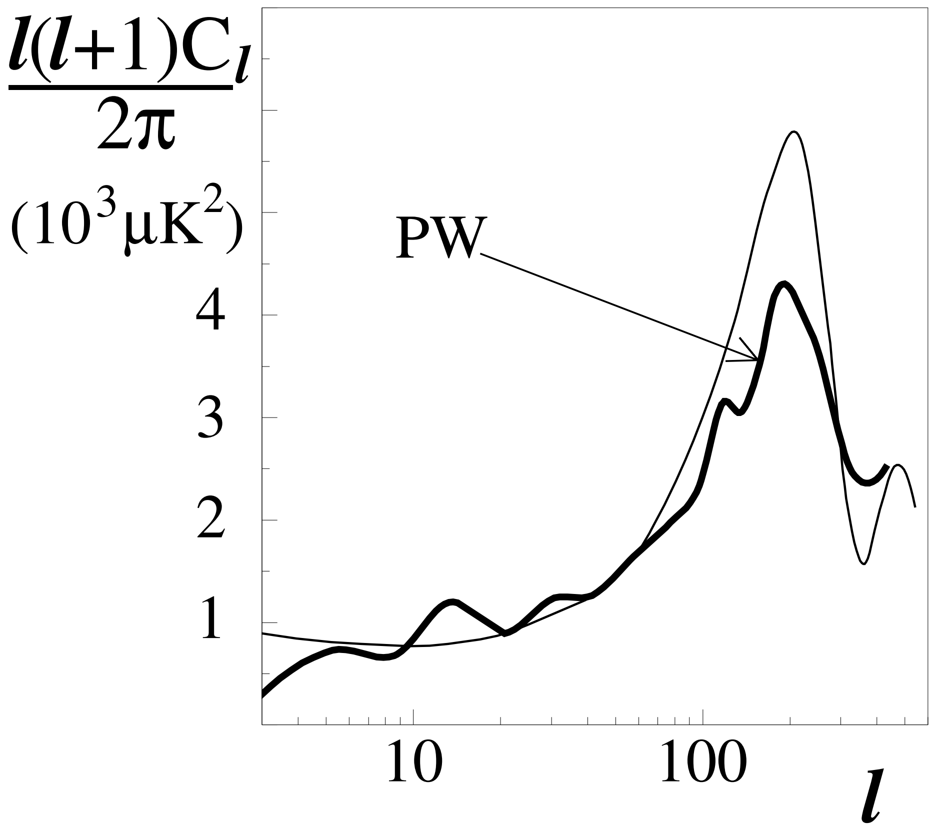

Figure 7. The power spectrum for the 'low CR-contribution' region (Quadrant 3, North), marked 'PW' in comparison with the standard spectrum, from Ref. [3].

- The peak is lower and displaced slightly to a lower ℓ-value.
- There is a structure at all ℓ.
- There is a deficit at low ℓ.

The significance of the differences will be considered in the next section.

3.4 Preliminary conclusions from the 'new' power spectrum

It is appreciated that the 'new' spectrum is only tentative, but it is likely that the finally-corrected version will be lower still and it is thus useful to examine possible implications.

The lowness of the peak and its small displacement is in the spirit of there being a higher mass content in the universe[8]; a value of $\Omega_m h^2 = 0.3$ instead of the canonical 0.15 would suffice.

The structure may be due to 'cosmic variance' and not significant; however, their presence means that the values of the cosmological parameters derived from the WMAP data have bigger errors than reported. Indeed, this conclusion follows in any event because of the contribution of CR-related effects.

Turning to the lowest ℓ-values, the lack of power noted by others is confirmed. One possibility[9] is an increase in the values for both Ω_c (cold matter) and Ω_b (baryonic matter) together with a reduced value for Ω_Λ (dark energy).

Clearly there is scope for much further analysis.

4. Cosmic Rays of the Highest Energies

4.1 The Energy Spectrum

In that particles above about 10^{19}eV are extragalactic and that they interact with the CMB in their transit through the Universe, some remarks about them are relevant.

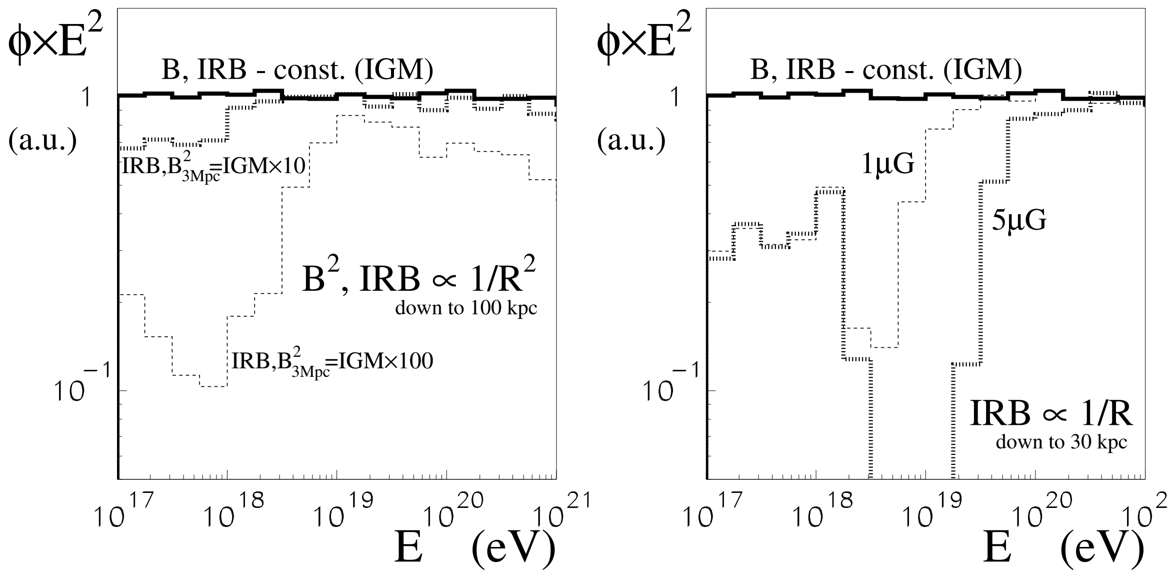

Figure 8. (a) UHECR spectra expected on emergence from a sphere of radius 3 Mpc round a very strong source. Various dependencies of the magnetic field, B, and infrared intensity, IRB, on distance from the source have been assumed. Details are given on the graph. Injection spectrum of the form E^{-2}. The actual spectra depend on the form of the cosmic ray diffusion; here we adopt the Kolmogorov formalism. In calculations for models assuming injection from strong sources the assumed injection spectrum should be multiplied by an appropriate function of the type shown, before propagation calculations commence. (b) As (a) but for the case where the magnetic field is constant over the cluster, of radius 3 Mpc. This field comes from emission from all the galaxies in the cluster. A value of 5μG is representative of a rich cluster.

Many workers have evaluated the effect on the energy spectrum of ultrahigh energy cosmic rays (UHECR) and derived the shape of the spectrum expected at earth for a variety of production and propagation scenarios (see, e.g., Ref. [1]). Our own very recent contribution has been to draw attention to extra losses incurred by particles interacting with the infrared radiation near their sources. Two situations have been examined: production in quasars and in active galactic nuclei (AGN) within galaxy clusters. The basic idea is that due to local (to the source) magnetic fields the particles will spend a significant time escaping from the source and if the infrared radiation level is high, significant losses will occur. In the quasar case, the magnetic field is associated with the low energy cosmic rays that stream from the object and in the galaxy cluster case the magnetic field is intrinsic to the system.

It will be appreciated that there are many uncertainties in the values of the relevant parameters but some estimates have been made. Figure 8 gives preliminary results for what are probably upper limits to some of the parameters. Evidently, the 'damaging effect' of the infrared radiation can lead to serious changes to the spectral shape.

Interestingly, when accurate spectral measurements of UHECR are available it might be possible to use the shape as a diagnostic in efforts to determine 'cosmic ray origin'.

5. Anisotropies

The low upper limits to the anisotropy at the highest energies reported at this Conference by the Auger group has important cosmological implications. Elsewhere [10] we gave upper limits to the fraction of UHECR that could have come from dark matter (DM) decays in the Galactic Halo. These limits were already low: less than $\sim 10\%$ of the EG flux could have come from DM particles in a conventionally shaped Halo. With the smaller anisotropy the limit will be lower still (probably by a factor of ~ 3). It seems very unlikely that DM decays can be invoked to explain the origin of the UHECR; conventional acceleration mechanisms (colliding galaxies accelerating heavy nuclei?) seem more likely.

References

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