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The single source model: An update

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Abstract. In a number of publications, we (Erlykin and Wolfendale) have proposed a 'Single Source Model' to explain the structure of the cosmic ray energy spectrum in the range (1–10) PeV. The paper presents an update, both by way of the inclusion of further data and further theoretical insight. We consider the Model to be alive and well.

1 Introduction

In a recent series of papers (e.g. Erlykin and Wolfendale — henceforth EW — 1998) we have proposed that the knee in the primary energy spectrum is due to particles, principally oxygen and iron nuclei, from a recent local supernova remnant (SNR). The evidence has come largely from EAS measurements and is such that our conclusion gathers weight only when data from different experiments are combined together. It is the combination that causes so much criticism of the result but our view is that the technique adopted — to take the knee position (defined in a certain way) as datum — is valid. Most of the evidence we have considered is, in our view, supportive of the model, the worst aspect relates to the dependence of mean primary mass on energy: we have a particular prediction but the experimental data have a remarkable spread. In fact, in our view, the spread is interesting in its own right because it strongly suggests that the models of nuclear interactions, particularly those relating to primary nuclei, are inconsistent. Interesting physics is waiting to be uncovered.

In what follows we add some very recent work to the earlier work to give an update of the conclusions.

2 Summary of EAS size spectra data

Table I gives a summary (see EW, 2001a for full details). S_0 represents the sharpness at the main knee — which we attribute to oxygen. We define sharpness as

$$S = \partial^2 \log I(N_e)/\partial \log N_e^2. \quad (1)$$

S_{Fe} represents the sharpness for our second knee, which we attribute to iron.

For the conventional Galactic modulation model we have shown that the maximum value of S_0 is $\simeq 0.3$; thus $S_0 > 1$, as in the Table, is completely unacceptable in the conventional model. A second peak is not expected at all in the conventional case.

We regard the results in Table 1 as very encouraging.

Table 1. Summary of EAS Size Spectra Data
A: total number of spectra; B: number of spectra with $S_0 > 1$; C: number of spectra with points at $\log N^{\rm knee} + 0.6$; D: number of spectra with $S_{\rm Fe} > 1$; N_e: Electron size spectra; N_μ: Muon size spectra; M_μ: Muon multiplicities; N_h: Hadron spectra; $\breve{C}$: Cherenkov spectra.

	A	B	C	D
N_e	40	29	34	33
N_μ	8	7	8	8
M_μ	3	3	3	3
N_h	2	2	2	2
$\breve{C}$	5	5	4	4

3 Knee position and sharpness versus atmospheric depth

Our survey yields the results shown in Figure 1. Although the dispersion is greater than expected from the quoted errors the general fit to expectation leads us to think that our analysis technique has merit.

Similarly, for sharpness (S_0) there is evidence (Figure 2) for the slow fall with increasing depth. The random error (σ, = error dispersion on a logarithmic scale) needed to achieve consistency ($\sigma \simeq 0.15$) for EAS measurements, is reason-

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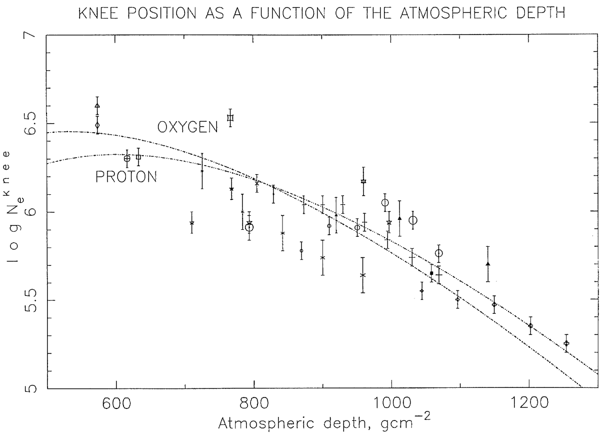

Fig. 1. Knee positions as defined by us from the published data on shower size spectra (see EW, 2001a). With a few exceptions the data cluster around the lines. The curves are calculated by us for particles of fixed primary energy (3 PeV); it is not claimed that the data enable a mass identification to be made.

able. That σ for Cherenkov measurements should be much smaller is also reasonable.

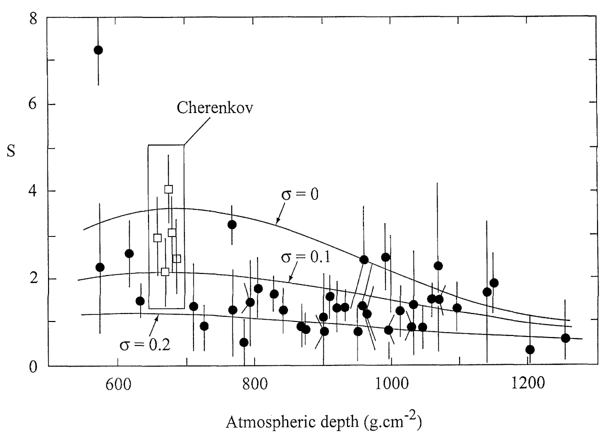

Fig. 2. Sharpness of the knee as a function of atmospheric depth (see EW, 2001a for the sources of the data). The curves relate to our predictions for various magnitudes of random error σ (in logarithmic units). The full circles refer to EAS particle measurements and the open squares to Cherenkov results. The latter are understandably higher because of the calorimetric nature of Cherenkov measurements.

4 Excess from the running mean

A good way to summarise the results is by way of an analysis of the excess of the intensity from the running mean, Δ. Figure 3 shows the results. The dashed lines represent the predictions from the early work; the full lines are fits to all the data. The excesses are smaller than before because much of the new data are from greater atmospheric depths than before where the sensitivity to structure in the primary spectrum is inevitably less.

We regard Figure 3 as giving strong support to the model.

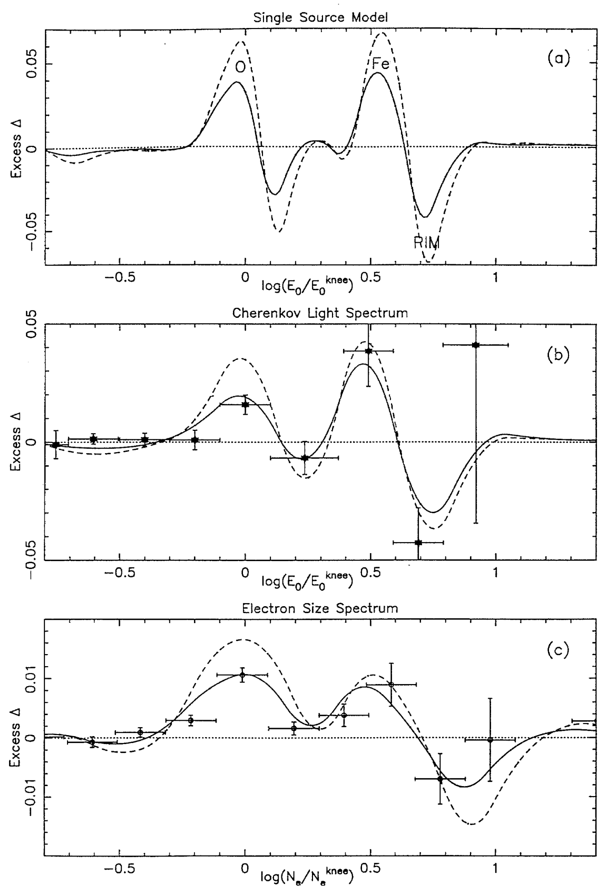

Fig. 3. Displacements from the running mean of the intensities. Δ is in logarithmic units. The dashed line is our earlier prediction and the full line is the update. The structure in the spectrum is seen to be still very significant.

5 Compendium of results for the Single Source Model

Figure 4 shows the primary spectrum, the abundance fraction and the 'mean mass' ($\langle \ln A \rangle$) versus energy predicted by the model. As remarked in the caption, the experimental situation with respect to the mean mass is very unclear, at present but we would argue that our plot is close to the mean of the world's data.

6 Extension of the Monte Carlo model to higher energies

Reference can also be made to contemporary work, using our Monte Carlo technique, above the knee. If most of the particles are of Galactic origin (to 10^{18} eV or so), and if the number of sources is fewer than about one hundred times the number of SNR, then the fluctuations of spectral shape will be significant at all energies. We are endeavouring to answer the question: do all sources of energetic CR (above the knee) have a spectral shape of the form $E^{-2.15}$ (as for SNR below the knee) with essentially no cut-off before 10^{20} eV? The observed spectral shape above the knee would then be due to a not-uncommon downward fluctuation. If so, then the EG sources need be no different from those in the Galaxy. Interestingly, if this were so, the observed EG flux might be accounted for by a model in which the average HE CR production rate is the same per unit mass of system (EG galaxies) as it is for our Galaxy.

7 Conclusions

The updated results on shower size spectra and the Cherenkov- (and hadron-) inferred energy spectra strongly support our contention of structure in the region of knee. The results on muons (EW, 1999) give further support.

Most recently, we have embarked on a series of Monte Carlo calculations involving SNR distributed randomly in the Galaxy in time and space and providing cosmic rays which then have opportunity to diffuse to the earth (EW, 2001b,c,d and these Proceedings). In no case is there a prediction at variance with observations.

A final remark can be made; if, as seems likely, CR of energy below 10 PeV are largely produced in 'discrete sources' — of which SNR are an example, there *must* be structure in the spectral shape at some level. It is therefore necessary for experimenters to give upper limits to such structure (if they find no actual evidence). Without such limits it is difficult to see how the subject will advance.

References

Erlykin, A.D. and Wolfendale, A.W., 1998, *Astropart. Phys.*, **8**, 265; 1999, *Proc. 26th Int. Cosmic Ray Conf., Salt Lake City*, **3**, 140; 2001a, *J. Phys. G: Nucl. Part. Phys.*, **27** 1005; 2001b, *ibid*, p.941; 2001c, *ibid*, p.959; 2001d, *J. Phys. G: Nucl. Part. Phys.*, (to be publ.).

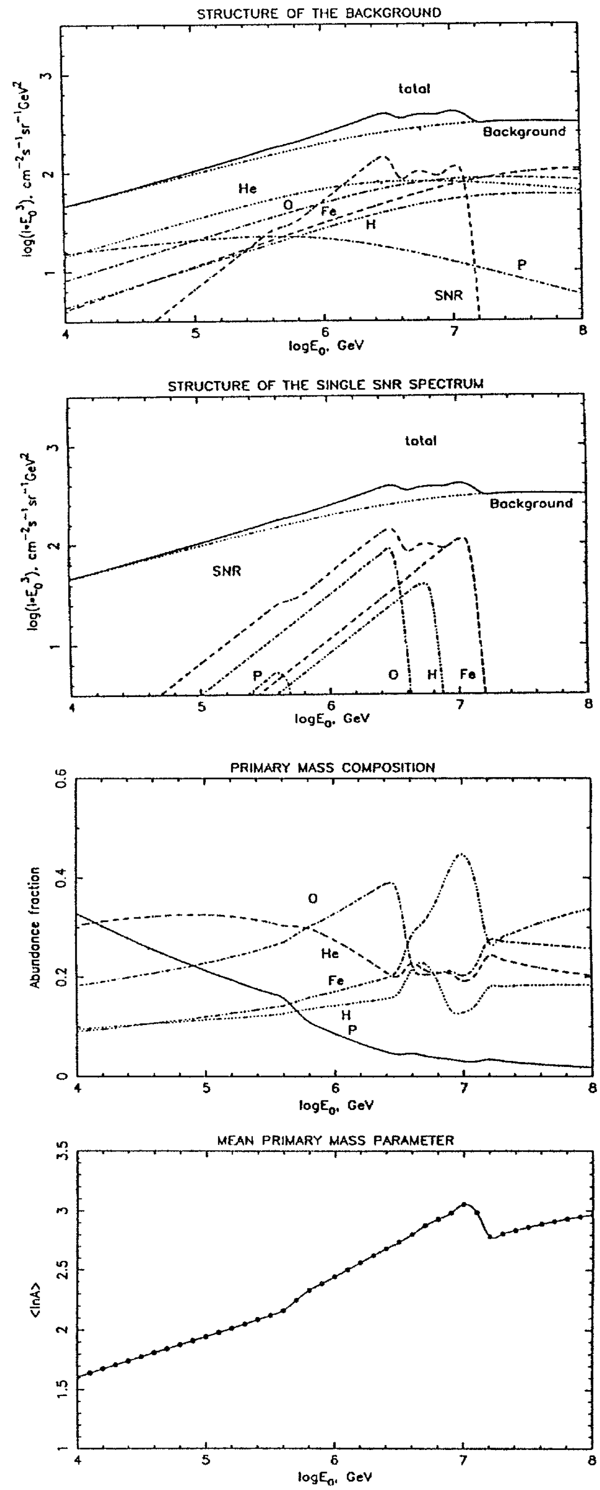

Fig. 4. A summary of the main features of the Single Source Model. As remarked in the text, the experimental results for $\langle \ln A \rangle$ are disparate, from one experiment to another. Specifically, at $\log E = 6.5$, where we predict $\langle \ln A \rangle = 2.7$, the experimental results range from 1.7 to 3.2. At higher energies the spread is even bigger.