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A new component of cosmic rays?

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ABSTRACT

Recent direct measurements of the energy spectra of the major mass components of cosmic rays have indicated the presence of a 'kink' in the region of 200 GeV per nucleon. The kink, which varies in magnitude from one element to another, is much sharper than predicted by our cosmic ray origin model in which supernova remnants are responsible for cosmic ray acceleration and it appears as though a new, steeper component is responsible.

The component amounts to about 20 percent of the total at 30 GeV/nucleon for protons and helium nuclei and its magnitude varies with nuclear charge; the unweighted fraction for all cosmic rays being 36%.

The origin of the new component is subject to doubt but the contenders include O, B, A, supergiant and Wolf–Rayet stars, by way of their intense stellar winds. Another explanation is also in terms of these particles as the sources but then being trapped, and even further accelerated, in the Local Bubble.

1. Introduction

It is inevitable that, as the accuracy of measurements of the energy spectra of cosmic rays has increased, further structure should be resolved which, in turn, should throw light on the origin problem. Until recently, the only generally agreed 'structure' (i.e. departure from a very smooth spectrum) was the presence of a sharp 'knee' at several PeV and a sharp 'ankle' at several EeV. The latter is probably due to the transition from a rapidly falling Galactic component to a 'flatter' extragalactic component (e.g. [33] and references, therein). It must be remarked, however, that Berezinsky et al. [8] prefer that the ankle is intrinsic to a single extragalactic component, and is due to interactions of the primaries after acceleration. We shall see that this dichotomy – 'extrinsic' or 'intrinsic' – is relevant in the hundreds of GeV/nucleon region, too. To distinguish the 'ankle' of the spectra observed in this region from that at the EeV energy we coin for them the term 'kink'.

The new measurements comprise the results of satellite- and balloon-borne detectors of increasing size and complexity. Some of the most recent cover several decades of energy, with high statistical precision, and are thus of value for the analysis of structure. Previous measurements were for limited regions of energy, so that combinations of data from different detectors were necessary. This was, and is, a difficult procedure in view of the many biases, and can result in a remarkable disparity of estimates of the spectra over common energy ranges from one set of measurements to another. The situation is much better now where the latest experiments give intensities which are consistent with each other within the error bars, at least for the most abundent cosmic ray (CR) components, viz protons and helium nuclei.

The present work is preliminary, in the sense that only limited aspects of the results are considered, and the interpretation is 'broad brush'. If our contention for an extrinsic origin of the kinks is correct, and a new component is really present, the consequences for many CR processes could be considerable. The work is similar to that of Zatsepin and Sokolskaya [35], who invoked a 3-component model for CR spectra and attributed the component below about 250 GeV/nucleon to novae. However, there are important differences, as will be seen.

Here, we assess the evidence for a 'new component' in this energy region in the light of new data, firstly from the standpoint of its simply being due to a chance local supernova remnant. Secondly, having shown that the kink is too sharp for this hypothesis, we go onto consider alternative types of source. An examination is also made of the energy spectrum and mass composition of the new component as a way of endeavouring to determine its origin.

A further topic of relevance to the present work, although not 'structure' in the usual sense, is the possible dependence of the spectral exponent on nuclear charge. This is discussed here.

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2. Analysis of the energy spectra

2.1. Results for protons and helium nuclei

The data considered here are mainly from 3 detectors: ATIC Panov et al., [27], PAMELA [2] and CREAM [4,5,34]. In our analysis it was assumed that the measured intensities were equally valid within the errors (clearly, unknown systematic errors could not be included). A 5-parameter fit of the type introduced by Ter-Antonyan and Haroyan [31] (hereafter T–H) was adopted. This fit yields the normalization constant, two exponents (γ-values): one before the kink (γ_1) and one after ($\gamma_2 = \gamma_1 - \Delta\gamma$), together with the sharpness, S and energy E_k of the kink.

Fig. 1 shows the spectra of protons and helium nuclei with the values for the parameters: γ_1, γ_2 and the energy E_k at which the kink occurs. We assumed that the 'background spectrum' is that with slope γ_2 extrapolated back to lower energies with a minor correction for the rigidity dependent solar modulation. The subtraction of background spectra from the total intensity of protons or helium nuclei gives the spectra of these particles for the new component, 'NC'. The fraction f_{30} is the ratio of NC/total for the given mass at 30 GeV/nucleon.

2.2. Results for nuclei with Z > 2

Ahn et al. [5] have summarised the results from all the available experiments for all nuclei. At energies above 10 GeV/nucleon this summary included the data from the CREAM-1 and 2, BESS, HEAO-3, CRN, TRACER and ATIC-2 experiments. We have determined weighted mean spectra for each of the elements and performed similar analyses to those for P and He. As in the case of proton and helium spectra the unknown systematic errors were not used in the weighting. Examples of the spectra and the fits are given in Fig. 2 (for O, Mg and Fe). The quality of the fits is quite high: the probability to decribe them with two shoulders of the spectra is 0.94, 0.70 and 0.86 for O, Mg and Fe nuclei respectively. The fits with the single power law give substantially lower probability: 0.45, 0.10 and 0.54 for the same nuclei.

The derived parameters are given in Figs. 3 and 4. Insofar as the nuclei with $Z > 2$ have intensities only as far as $\log E = 4$, new analyses have been made for P and He for the reduced energy range and it is the values of the parameters for this analysis (slightly different from those in Fig. 1) that are used in Figs. 3 and 4. The accuracy of the sharpness values obtained from the T–H fit is very poor. Instead our conventionally defined values [14] are preferred; they are given in Fig. 4. The caption gives the details.

Before continuing it can be remarked that a more direct and simpler analysis has been made in which straight line fits have been made to the data below and above the (obvious) kink positions, E_k. The values of f_{30} so derived are very close (to better than 10%) to those shown in Fig. 3. Thus, we regard the likely uncertainty in the f_{30}-values as being no more than ±10% in absolute units (further discussion is given in Section 2.3.1).

A further remark concerns the analysis for neon nuclei: Ne. Taken formally we have $\gamma_2 = 2.11 \pm 0.76$, the statistical error being large not only because it is influenced by uncertainties in the other 4 free parameters. It is also because with E_k being high ($\log E_k = 2.9$), there are only 5 intensities beyond the kink and these have high individual statistical errors. It is necessary to impose a lower limit on γ_2 because for its low value a linear extrapolation to higher energies would give intensities above those measured in the knee region. The boundary is at $\gamma_2 = 2.4$ and this value is taken for the fit.

2.3. Discussion of the results

2.3.1. Accuracy of the parameters

Starting with the accuracy of the f_{30} values, this is, formally, largely dependent on the values of γ_2, which give the background intensities to be subtracted from the observed intensities. The 'er-

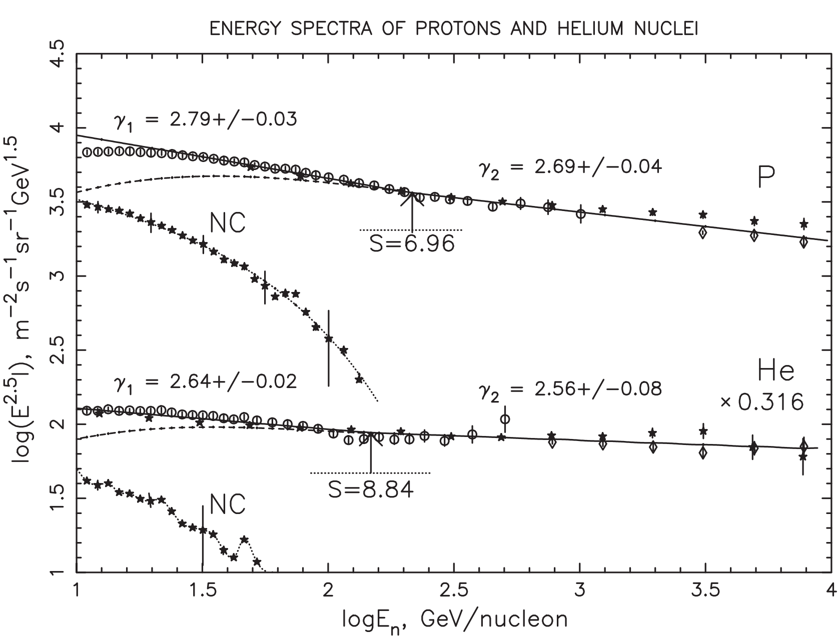

Fig. 1. Proton and Helium spectra and the derived 'new component', NC. Arrows indicate positions of the kinks, attached dotted lines show their uncertainties. 'S' is the sharpness of the kink given by the T–H formula. The S values are given for completeness; their uncertainties are difficult to estimate but the fact that the values are always large demonstrates that the kinks are sharp. Fig. 4 gives more conventional estimates. Protons. Key to symbols: circles-PAMELA, diamonds-CREAM, stars-ATIC (references in the text). Full lines-fit with the T–H formula. Dashed line- extrapolation of the fit obtained above the kink (power law with the exponent γ_2) to the low energy region below the kink. The curvature below $\log E_n = 2$ is due to allowance for solar modulation (using the analysis of Berezhko and Ksenofontov, 1999). Stars show the spectrum of the 'new component' (denoted as NC). Dotted line drawn through the stars-the fit of NC with an expression (1). Helium. As for protons. The correction for solar modulation, which is dependent on rigidity, is smaller for helium than for protons at the same energy/nucleon. The intensities have been multiplied by 0.316.

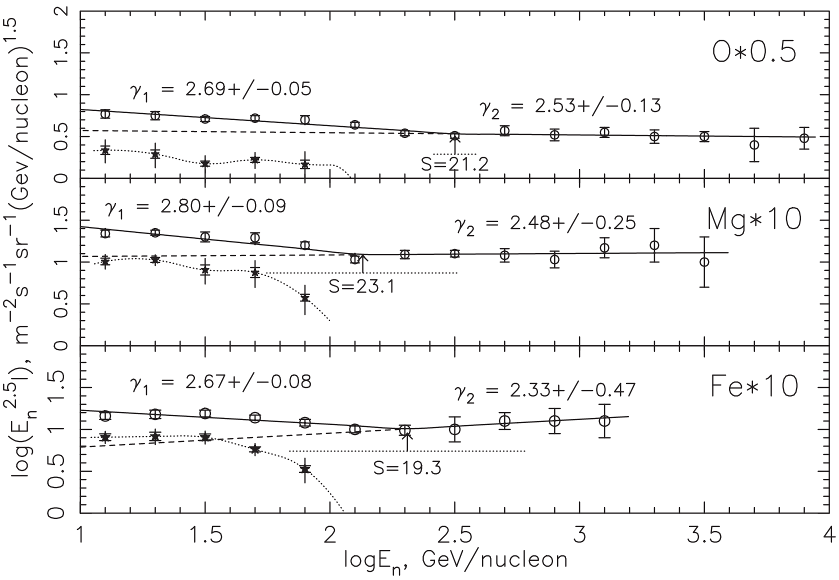

Fig. 2. Spectra for the elements indicated. The factors by which the intensities have been multiplied are also shown. The estimated NC is indicated by the stars and the dotted lines.

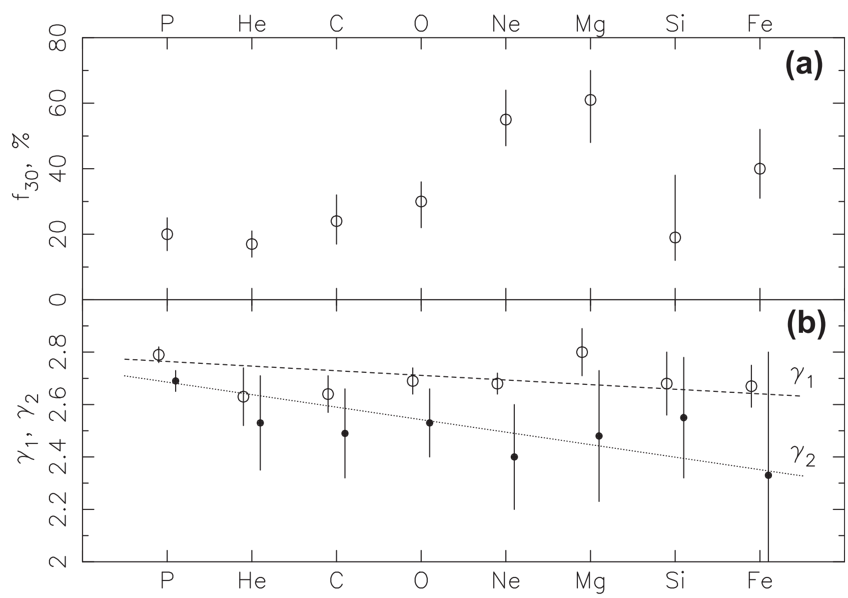

Fig. 3. (a) The values of f_{30}, the ratio of the NC intensity to the total at 30 GeV/nucleon, for the various elements. (b) The slopes before and after the kink are γ_1 and γ_2. The lines are drawn for illustration purposes only, as the values for the elements are spaced uniformly.

rors', taken as they are, would give unreasonably large errors in f_{30} but we note that the spread in γ_2 values, in Fig. 3, about a smoothly varying line is far smaller than would come from the indicated errors. It is the interdependence of the parameters that gives the large errors. Our 'internal' estimates give fractional errors in f_{30} varying from 20–60% and these values are the ones used in Fig. 3. It is evident that there is a significant increase of f_{30} with increasing Z, but not a smooth one.

Turning to the γ_1 values, these have smaller errors, due to there being more precise intensities at the lower energies of relevance. They are largely independent of Z for $Z > 2$ but smaller than for protons, i.e. nuclei have flatter spectra than protons (this topic is taken up again, later).

There is evidence for a discrepancy (again) for Ne in that E_k (and, correspondingly, R_k, the rigidity at the kink) is unusually high-specifically twice the average value for the rest of the data. Interestingly, Mg, which also has a high f_{30} value, does not have an unusually high E_k value; it is the high γ_1 value that causes the high value for f_{30} in this case.

The S-values for sharpness are crucial to the argument. Inspection of Fig. 4 shows that although the errors on S are large, there is no doubt that the mean is 'high'; approximately unity. In this connection they are bigger than expected from the values from the 'natural' curvature of the spectra expected from our random supernova model [17,18] from which S-values of less than 0.1 are expected. The probability distribution of the S-values from the random SN model is indicated. The values expected are very small because the predicted spectra are very smooth.

It is self-evident that the kink is sharper than those from the random SN model and its explanation is terms of a new component seems assured. Possible origins will be given later.

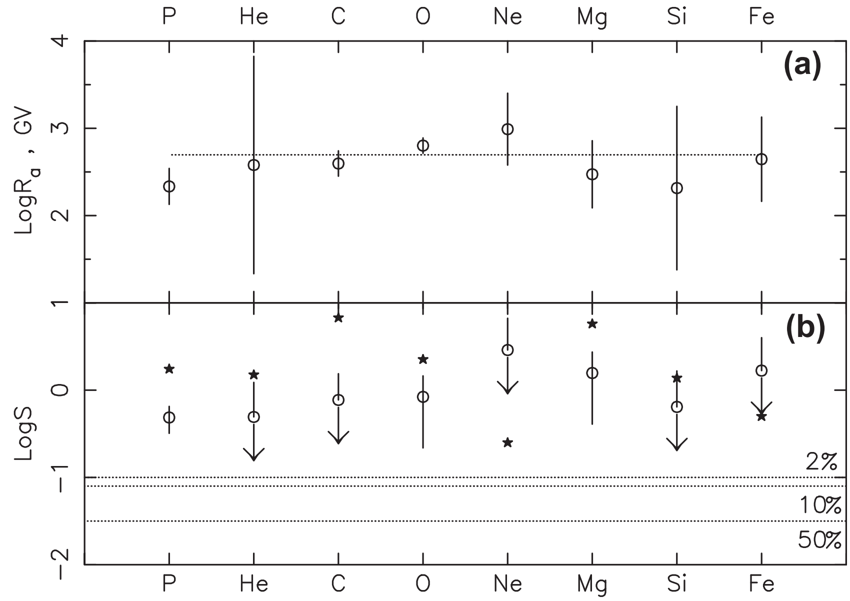

Fig. 4. (a) The rigidity at the kink (R_k) for the various elements. (b) Sharpness values for the elements. Circles: S from use of our standard technique of the second differential of the ordinate with respect to the abscissa, with an interval of $\delta(\log E) = 0.2$ [14]. Stars: S from an alternative method in which $S = (\gamma_2 - \gamma_1)/0.2$. The errors are given for this method. Those for the circles are similar. The horizontal lines with the percentages marked are from our random SN model (Erlykin et al., 2003). The model gives spectral profiles from which the S-values are derived.

2.3.2. The energy spectrum of the new component

The proton spectrum, at least, has intensities of sufficient precision to allow the determination of the energy spectrum of the new component (Fig. 1). A simple form which fits the spectrum is

$$I = AE^{-\gamma} \exp(-(E/E_1)^q) \quad (1)$$

Here the parameter q quantifies the steepness of the spectrum in the cut-off region, i.e. the speed of its deviation from the 'parent' power law spectrum with an exponent γ as the energy increases. Since we study the shape of the NC spectrum and particularly its steepness we fix the best fit values of the intensity normalisation constant A and the exponent γ of the 'parent' power law spectrum obtained by means of 4-free parameter χ^2-minimisation and determined the values of cut-off energy $E_1 = 74.4 \pm 1.3$ GeV/nucleon and the steepness parameter $q = 1.074 \pm 0.042$.

The results for the other nuclei are less clear cut, because of lower precision (see Fig. 2 for three representative nuclei) but a similar form with somewhat smaller values of E_1 will fit. Specifically, a value of 50 ± 15 GeV/nucleon, i.e. a rigidity of 100 GV, would be within a standard deviation of them all; such a value would be not inconsistent with the rigidity of 74 GV for the protons, i.e. there is some evidence that the NC has a common shape of the rigidity spectrum, but with a Z-dependent intensity.

The shape of the NC spectrum (Eq. (1)) should give guidance as to its mode of production. It is immediately apparent that it does not have the sharp cut-off which characterises the single SNR spectrum adopted by us, e.g. [14], nor that from Berezhko and Ksenofontov (1999) [7]. For example, the latter has a form near the cut-off which has a cut-off energy $E_1 = (1.25 \pm 0.02) \cdot 10^7$ GeV/nucleon and a steepness $q = 1.57 \pm 0.04$, which is higher than that for NC protons.

As we have shown [18], and as is obvious, in practice, when allowance is made for magnetic field variations from place to place within a single remnant and particularly when an averaging is made over a number of SNR of different characteristics (energy, magnetic field, etc.) a smoother cut-off results- more in accord with Eq. (1).

All that can be said at this stage is that the NC intensity falls more slowly with increasing energy than that for SNR in the PeV region transposed down to NC energies.

The conclusion is therefore that, for the NC, the spectral steepness is lower than expected from the simple SNR models. Taken together with the results for the mass composition of the NC, the spectral measurements, and our model, indicate that an explanation in terms of a single SNR is unlikely. Instead, the sum of previous multiple SNR (or O, B, etc. stars) within the Local Bubble appears to be favoured. Here, the spectral shape would be explained as the sum of several SNR of different 'strengths' and the mass composition, with its excess of high Z-nuclei, as due to the SN having exploded in a Z-rich environment due to the previous SN and other strong stellar activity. The excess of Ne, in terms of Wolf–Rayet stars is likely, e.g. [25], and other workers.

2.3.3. The exponent of the 'high energy spectra', γ_2, as a function of Z

The manner in which the spectral exponent varies with nuclear charge, Z, has been of interest for many years and, as the experimental precision increases, so does the interest. As an example of the earlier interest is our work: Erlykin and Wolfendale [15] demonstrated that 'γ' for protons and helium nuclei was higher than that for heavier nuclei. The trend for γ to fall smoothly with Z was used in the so called poly-gonato model of CR spectrum in a wide energy range by Hörandel [20]. With the contemporary increased accuracy of spectral measurements it would have been expected that the precision of $\gamma(Z)$ would have improved. However, due to our identification of a new component, extending to several hundred GeV/nucleon, part of previous changes of γ with Z is due to a varying NC.

We start with the proton component: our datum and a component with a rather accurate value of γ_2. As seen in Fig. 1, $\gamma_2 = 2.69 \pm 0.04$. This is less than the commonly quoted 2.75 because of the influence of the 'high' $\gamma_1 = 2.79 \pm 0.03$.

Turning to Helium, although Fig. 1 shows $\gamma_2 = 2.56 \pm 0.08$, utilising all the spectral data, which extend to $\log E = 4.7$ (with E in GeV/nucleon), yields $\gamma_2 = 2.56 \pm 0.04$, i.e. with a reduced error and now significantly less than that for protons. It is interesting to note that

$\gamma_2 = 2.56$ (assumed independent of energy) would yield a He spectrum at the knee in accord with our view [18], and other workers).

In the case of heavier nuclei, it would appear that γ_2 might be smaller still (Fig. 3b) but the undoubted errors on the γ_2 values make a conclusion premature.

The reason(s) for γ_2 being different for protons and nuclei are somewhat beyond the scope of the present work but some remarks can be made. The reasons could be due to injection differences or differences in acceleration efficiences. They may be associated with the abundances of the accelerated CR (as distinct from their exponents), the latter having been considered by Berezhko and Ksenofontov [7]. A possibility relates to the environment in which the particles are accelerated: near the 'accelerator' (SNR) the fraction of high Z nuclei in the ISM will be higher and it is here that the higher energy particles are accelerated, e.g. [36]. However, we had dismissed this idea in view of the fact that the radial gradient of 'high Z' material is too strong, only occupying a few pc [9] and the length of time too long, 10^4 years, for the acceleration of particles above 10^4 GeV or so [16]. Nevertheless, a possible scenario involves OB associations, regions where SN are in excess and the 'contaminated ISM' contains an excess of nuclei with $Z \geqslant 2$, and here the linear dimensions are greater.

The importance of OB associations as the site of CR acceleration was put forward by Bykov and Toptygin [10] and Rauch et al. [29] and, as remarked earlier, our NC may be accelerated preferentially in those in the Local Bubble, or nearby. Thus, the associations may be important for both NC and the 'background component' (characterised by γ_2) with the importance for the former being greater. Detailed observations of the composition of the ISM within OB associations appear not to have made but suffice to say that the linear dimensions are at least 100 pc [24] and thus quite adequate for the required radial gradient, in that SNR acceleration has finished by this distance.

2.3.4. The electron component

Insofar as acceleration mechanisms responsible for the acceleration of cosmic ray nuclei presumably accelerate electrons too, a similar feature (a kink) would be expected in the electron spectrum. Its presence could indicate the existence of a new component of electrons here, as well. Our analysis of electrons here is preliminary since there is no good agreement between different measurements of the electron spectrum, although this does not preclude our searching for a kink in each. Three experiments reported recently results of sufficient statistical accuracy, as follows:

PAMELA [3] although the statistical accuracy becomes increasingly poor above 100 GeV
ATIC (Panov et al., 2011)
FERMI LAT [1]

They are shown in Fig. 5. Since only PAMELA is able to distinguish electrons and positrons and ATIC and FERMI LAT measured an aggregate energy spectrum of both, we present the PAMELA's electron spectrum in Fig. 5 slightly uplifted by the fraction of positrons to give uniformity of presentation of all three experiments.

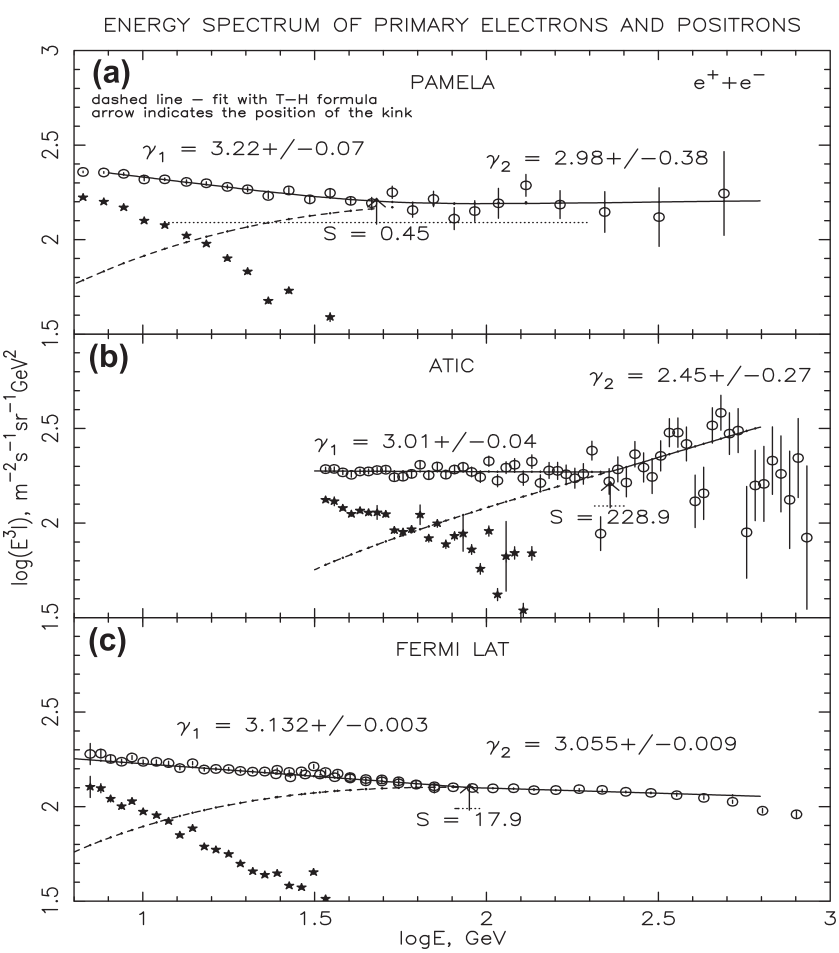

Fig. 5. The electron energy spectrum measured in the PAMELA (a) ATIC (b) and FERMI LAT (c) experiments. Notations are as in Fig. 1. The estimated NC is indicated by the stars.

Below we call the aggregate $e^+ + e^-$ spectrum as the 'electron' spectrum where it is not important to distinguish e^+ from e^-.

All three electron spectra were fitted by the T–H formula and by the linear fit as for protons and nuclei. Since we studied the gross features of the spectral shape the best fit parameters of the fit were obtained by minimising the χ^2 value using just the statistical errors. The upper end of the energy range for the fit was taken as 600 GeV, since at higher energies the electron spectra approach an increasing cut-off caused by rising energy losses (see for example, [16] for expectation for a non-uniform space–time distribution of the cosmic ray sources in our 'random' SN model). The statistical significance of the T–H fit is satisfactory for PAMELA: a probability of $P = 0.31$ and not good for the linear fit: $\sim$0.02. For ATIC and especially for FERMI LAT the significance of both fits are low: $1.4 \cdot 10^{-3}$ ($1.0 \cdot 10^{-5}$) for ATIC (with linear fit in brackets) and $\sim$0 for both fits of the FERMI LAT spectrum.

The bad confidence level of the fits is due to a number of points with a high statistical accuracy and a large deviation from the smooth line of the fit. In the case of FERMI LAT there are points differing from a smooth curve by as much as 40 standard deviations, with a catastrophic effect on the χ^2 value. If such a behavior of the intensities is true, it could mean that the shape of the electron spectrum is more complicated than that described by the 5 free parameter T–H fit. It could be another confirmation of the fine structure found by the ATIC collaboration [28].

It is more likely that the true random errors are much bigger than the statistical errors (but less than the systematic errors, which presumably, do not affect the spectral shape markedly). If true then inspection of Fig. 5 shows that ATIC and FERMI LAT both indicate a kink.

The situation seems to be that all three spectra show a flattening of the slope after some point ('the kink') and their kinks, although with a big uncertainty, are sharp. Positions of the kink in logarithmic coordinates ($\log E_k$, GeV) are 1.68 ± 0.61 (PAMELA), 2.36 ± 0.05 (ATIC) and 1.95 ± 0.03 (FERMI LAT)-they are shown by arrows in Fig. 5. Due to the errors it is impossible to tell whether they are different from the position of the kink for protons ($\log E_k = 2.33 \pm 0.20$). On the basis of these arguments we prefer to say that the behavior of the electron spectrum gives moderate support for the existence of the sharp kink in all cosmic ray components which can be interpreted as the existence of a new component at tens of GeV energies. Our estimates of the new electron component are shown by stars in Fig. 5.

Rather than a new electron component the kink could in fact be connected with the apparent non-uniform space–time distribution of the cosmic ray sources and the contribution of the single (or a few) nearby and young source(s) at the high energy part of the spectra. The correlation of the above mentioned fine structure of the electron spectra obtained in different and independent runs of the ATIC experiment could be the evidence of this non-uniformity [28]. The rising fraction of positrons (Adriani et al., 2011), reaching 20% at 100 GeV, may be related to the above. Both could come from a nearby supernova remnant, although the efficiency for creating the necessary e^+e^- pairs would need to be high. Whether the assumption about the contribution of a single source is valid or not it does not disprove the contribution of an assumed new component in electrons which is due to a soft energy spectrum giving the dominant contribution at tens of Gev energies.

3. Further fine structure

Before analysing the 'new component' in detail we search for other evidence of fine structure. Although we have not (yet) reached the stage of claiming 'hyperfine' structure in cosmic ray spectra there may be further fine structure on a somewhat smaller scale (i.e. smaller energy range).

Clearly, changes detected will be on a scale larger than the energy resolution of the detectors but with typical values for the new detectors of order 20%, structure at the tens of percent level in energy (and a few % in intensity) might be present-and sought.

A start was made with the analysis [13] of an apparent spike in the AMS spectrum [6] as detected by us from the published data. Such a spike could, in principle, arise from a delta function due to a discrete source such as a pulsar.

The claim for the AMS spike, at 50 GeV, in the proton spectrum, although not substantiated by others at the time, gives a datum energy at which to use the current more precise measurements to search for fine structure there. We have examined the data from PAMELA, CREAM-2, AMS, CAPRICE and BESS, as given in Ahn et al. [5] for P and He and found either small positive signals or no signal. The detected signal, averaged over P and He is (2.9 ± 0.6)%.

It is evident that the signal is of a smaller magnitude than that found by us in the initial AMS experiment, which was 11 ± 1.5%, but that does not invalidate the conclusion that the more recent measurements appear to give a measure of confirmation for the existence of fine structure at the level of a few % in the region of 50 GeV.

The other rigidity region to be examined relates to the range 200–300 GV. The reason for such a study is that the PAMELA instrument [2] has found a sharp dip (or kink) at $\sim$220 GV in the proton and helium rigidity spectra, as evident from Fig. 1. This could be classified as an 'absorption line' although it may be associated with the postulated 'new component' referred to above.

The rapidly falling rigidity spectra cause the statistical accuracy of most measurements to be too poor above 100 GV for an adequate search. Nevertheless, some progress can be made. A study has been made of both the nuclear data, referred to above, and the results of ATIC-2 and ATIC-4 [28] for electrons with the following conclusions.

(i) There is evidence for a coherent dip in most studies, for the range 200–300 GV.
(ii) The degree of sharpness is greatest for electrons.
(iii) The exception to coherence concerns the patterns for the heavier nuclei.
(iv) There is a spread, by a factor 5, in the magnitudes of the intensity of the dips.

An explanation for the feature for nuclei is straightforward in terms of the presence of the new component having a steeper spectrum than that of the main component. The two spectra will 'cross' and produce a kink at an energy dependent on their relevant magnitudes so that the energy for the kink will vary from element to element and 'fine structure' is not involved.

The relevance of this analysis to the search for further fine structure is therefore that, apart from the electron results, it has none; a straightforward explanation is forthcoming. The electron results are different in the sense that the dip is very sharp and an explanation is not obvious.

The question of the statistical reliability of the electron dip is paramount: it is one point only with a displacement from the mean significant at the 2.8σ level. It's main attractions, however is that its energy (210–220 GeV) is in the region occupied by the P and He dips.

4. Discussion of the results on the new component

4.1. Intrinsic or extrinsic

Following the remarks in the Introduction it is necessary to decide whether, or not, the spectral shapes are intrinsic or extrinsic.

The former would involve 'natural' slope changes for a simple acceleration model, such as that involving near homogenous SNR and we have ruled that out. Furthermore, the kinks for the various nuclei would need to be at the same rigidity, whereas, in fact, there is some dispersion (see Fig. 4a, where the R_k values are given).

Some sort of threshold for a change in CR diffusion properties by a considerable amount is possible, but seems to us to be very unlikely.

Thus, we prefer an extrinsic explanation, that is that we are dealing with an extra CR component.

4.2. The origin of the new component

4.2.1. Evidence from the abundances

A clue as to the origin of the NC should come from its mass composition (and to a lesser extent from its energy spectrum) and, here, Figs. 3 and 4 have relevance. It is evident that Neon and Magnesium and, to a lesser extent, Iron are in excess in comparison with the overall abundances. These excesses should feature in the search.

The first possibility is novae, and this is considered next.

4.2.2. Novae as the source of the New Component?

Zatsepin and Sokolskaya [35], in their 'three component model of cosmic ray spectra from 10 GeV to 100 PeV', attributed some of the particles below 300 GeV/nucleon to the 3rd component and proposed novae as candidates, as we have already remarked. In comparison with supernovae, novae have, presumably, a much reduced CR yield, but in principle this could be compensated by their much enhanced frequency.

Our own analysis of nova properties leads to a different conclusion, however. The problems can be listed, as follows.

1. Energetics.
   An analysis of the literature yields a mean Galactic rate of $\sim$30 year^{-1} and a mass loss of $\sim 3.10^{-5}$ M_0 per nova, e.g. [32]. The total energy lost per nova (the equivalent of the 10^{51} erg for SN) is not easy to calculate because of the jet-like emission, but progress is possible. The average spherically-smoothed velocity is $\sim$1000 km s^{-1}, e.g. Kato and Hachisu [21], leading to an average energy loss rate of about $3 \cdot 10^{38}$ erg s^{-1} for the Galaxy as a whole. This is $\sim 10^{-3}$ of the equivalent in SN and, therefore, small. The new component carries about 40% of the total CR energy so that if, indeed, most CR are generated by SNR, novae fall short by a factor 400 in explaining NC.
2. Mass composition.
   The mechanism of novae-fusion caused by gas from a companion impinging on the surface of a white dwarf-is such that the nova ejecta contain an excess of He and CNO with, occasionally, Ne. This does not match the abundances needed for the NC.

Thus, the arguments involving energies and mass composition are against novae being responsible for the NC.

4.2.3. O, B, A supergiant and Wolf–Rayet stars

These stars have very intense stellar winds (velocities of order 1000 km^{-1}) and contribute one fifth as much kinetic energy to the Galaxy as given by SN. The energetics, at least, are reasonable. The excess Neon (Fig. 3a) would favour this explanation insofar as they have excess Ne in their vicinity, e.g. [11]. Concerning Wolf–Rayet stars it is interesting to note that there is one such star (Gamma Velorum) only 258 pc distant. It must be said, however, that the commonly quoted factor of 5 increase in Ne in Wolf–Rayet winds is dependent on Wolf–Rayet type and is uncertain [11].

A possible problem concerns the steepness of the spectrum at the cut-off in the NC energy spectrum; it is this feature that causes the sharp kink. Its implication is that we are dealing with perhaps only one source. However, as pointed out in Section 2.3.2, several sources could, in fact, contribute and this is where the local bubble has relevance.

4.2.4. The local bubble

The 'local bubble', a rather neglected phenomenon in CR physics, seems to have resulted from perhaps 10 SN exploding in a period 1–10 My before the present and is an example of the Superbubbles which are now known to permeate galaxies in general, e.g. [23], although it is not as strong as some. In it the density of ionized gas is of order 10^{-3} cm^{-3}, its linear dimension is $\approx$300 pc and mean temperature $\sim 10^6$ K. A simple calculation shows that the energy density of the gas in the Bubble is at least of the order of that in CR, so that if equipartition of energy between CR and gas energy holds it could be relevant.

CR could have been trapped in the bubble if the 'walls' are sufficiently reflective and, indeed, the ubiquitous shocks could be accelerating low energy CR even now.

It can be added that, some time ago, Streitmatter and Jones [30] put forward a model for CR origin in which the local bubble plays an important role. However, their particle energies involved are very different from those considered by us. Specifically, an 'interior' (to the LB) proton spectrum with exponent -2.7 crosses an 'exterior' proton spectrum at an energy of $\sim 5.10^{14}$ eV, i.e. a factor 2000 times that suggested here. We consider that the problems manifest in such a model with a kink at $5 \cdot 10^{14}$ eV would be very great.

In fact, the situation considered in Section 4.2.3 above could be considered inside the local bubble, e.g. [19], and this is a preferred option; the increase in flux of heavier nuclei with increasing energy could be due to those grains nearest the stronger shocks being accelerated to higher energies before fragmenting; the presence of extended OB associations would allow the necessary tens of pc extent of the region of excess of heavier nuclei for the SNR-shock.

The information in Fig. 4 is relevant. The somewhat higher f_{30} values for the refractory elements (Mg and Fe) suggest a similar origin for the new component to CR in general, where the well-known excess for the refractories suggests that grains play an important role in the acceleration process (e.g. [7]; Meyer and Ellison, 1999; [25]). It must be said, however, that Si is a disappointment.

Concerning the form of spectra needed, i.e. with a rather sharp cut-off (e.g. Fig. 1), this is of the standard form associated with shock acceleration (e.g. [7]. More particularly, Niemiec et al. [26] give spectra expected for 'short-wave turbulence' which are, for appropriate choice of parameters, similar to those in Fig. 1. The, as yet, inadequately determined properties of the ISM in the Local Bubble make it impossible, so far, to specify the exact form of spectrum of the new component that would be expected although weak shocks can be quite sufficient, e.g. [22].

4.2.5. The 'silicon problem'

As remarked earlier, there is evidence from elsewhere favouring refractory elements amongst low energy CR leading to a model in which there is a sputtering of accelerated grains. Our high f_{30} values for Mg and Fe fit in with this model for the NC but the low value of f_{30} for Si is a problem. At the risk of over-interpreting the data we address this problem.

A study has been made of the variability of the relevant abundances in the local region of the Galaxy (within 1 kpc of the Sun) to find the extent to which the low value could have occurred by chance. Useful data on the abundances in local stars, OB associations and clusters have been given by Daflon and Cunha [12] and these show: (a) a spread in abundances of (logarithmic) standard deviation 0.13 (i.e. ±35%), and (b) the mean abundance for each element to be less than that of the Sun. Unfortunately, only a limited number of elements were studied but these included: C, O, Mg and Si. It is found that the discrepancy between the solar abundance (A_{sun}) and the mean for 'stars', $\langle A_{stars} \rangle$, was biggest in the case of Si and smallest for Mg. Plotting f_{30} vs $\langle A_{stars} \rangle / A_{sun}$ shows near linearity, e.g. for Si, there is a low f_{30} and low $\langle A_{stars} \rangle / \langle A_{sun} \rangle$ and for Mg the reverse. The low Si value is thus probably explained as a real effect rather than it being due to chance.

The above is not definitive but it indicates how the analysis can proceed once further data (both CR and spectroscopic) are available. The search for a Z-dependent f_{30} value is clearly important in the search for the origin of the New Component.

5. Conclusions

Although there are variations in spectra from one measurement to another, the presence of kinks in the hundreds of GeV/nucleon region seems well founded; the electron component seems to show this feature, too.

The explanation in terms of an extra component (the 'New Component') with an eventually steeply-falling energy spectrum is an attractive one.

The mass composition of this new component hints at an origin in OB associations in the local bubble, with a small number of SN and Wolf–Rayet stars having been active.

If substantiated (and new data from AMS should help considerably), many new studies are indicated, including aspects of the local electron spectrum, radio astronomical phenomena, gamma rays, secondary to primary ratio and isotopic compositions.

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