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Gamma ray and antiparticles (e^+ and $\overline{p}$) as tools to study the propagation of cosmic rays in the Galaxy

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The spectra of cosmic rays observed at the Earth are determined by the properties of their sources and by the properties of their propagation in the Galaxy. Disentangling the source and propagation effects is a problem of central importance for cosmic ray astrophysics. To address this problem, the study of the fluxes of antiparticles (e^+ and $\overline{p}$) and of the diffuse Galactic flux of γ can be a very powerful tool, because it is expected that the dominant mechanism of production is identical for all three components, namely the creation of the particles as secondary products in the interactions of primary cosmic rays. In this case, the shape and relative size of the source spectra for the three particles is reasonably well known. Folding the inclusive hadronic cross section with the (power law) energy distribution of the primary particles one obtains secondary source spectra that for $E \gtrsim 20$ GeV, in good approximation, are also of power law form, with the same spectral index of the primary particles. The predicted ratios at production are $e^+/\overline{p} \simeq 2$ and $\gamma/e^+ \simeq 5$. The observed spectra of e^+, $\overline{p}$ and γ are power laws with spectral indices $\alpha_{e^+} \simeq \alpha_{\overline{p}} \simeq \alpha_\gamma \simeq 2.7$–$2.8$, with an observed ratio $e^+/\overline{p} \simeq 2$, equal to the ratio at production. These results suggests that the propagation effects for charged particles have only a weak energy dependence, and are approximately equal for e^+ and $\overline{p}$. This implies that the total energy losses for $e^\pm$ during propagation in the Galaxy is negligible, and therefore that the cosmic ray Galactic residence time is sufficiently short. An intriguing possibility is that a marked softening of the energy spectrum of the flux of $(e^+ + e^-)$ observed by the Cherenkov telescopes at $E \approx 0.9$ TeV is the manifestation of the critical energy where the energy losses of $e^\mp$ becomes important. This assumption determines the Galactic residence time as of order $T_{\rm age}(1~{\rm TeV}) \approx 1$ Myr. A comparison of the fluxes of antiparticles and the diffuse Galactic γ flux allows then to estimate the effective cosmic ray confinement volume as $V_{\rm CR} \simeq 300$ kpc^3. These tentative conclusions are in potential conflict with common interpretations of the fluxes of secondary nuclei (such as lithium, beryllium and boron) and require significant production of secondary nuclei inside or near the accelerators. Models where the cosmic ray confinement time is significantly longer than 1 Myr require a new hard source of positrons in the Galaxy, that must be fine tuned in spectral shape and absolute normalization. The implications of this puzzle are of profound importance for high energy astrophysics and the modeling of the cosmic ray accelerators.

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1. Introduction

The relation between the flux $\phi_j(E)$ of charged particles of type j and energy E observable in the vicinity of the solar system, and the total Galactic emission $Q_j(E)$ (that is the number of particles emitted per unit time and unit energy by the entire Milky Way), can be written as:

$$\phi_j(E) = \frac{\beta\, c}{4\,\pi}\, Q_j(E)\, P_j(E)\;. \tag{1.1}$$

In this equation the factor $\beta\, c/(4\pi)$ transforms a particle density into an (isotropic) flux, and $P_j(E)$ is what we define as the propagation function for particle type j. The propagation function $P_j(E)$ has the dimension of a time divided by a volume, and encode information about the residence time and confinement volume of CR of type j in the Galaxy. The decomposition of the CR spectra in the product of two factors that describe the source emission and the propagation effects can be seen as the first, fundamental task of CR astrophysics.

In contrast to cosmic rays (CR) that have trajectories bent by the Galactic magnetic field, gamma rays propagate along straight lines, therefore they have a non isotropic angular distribution that encodes the space distribution of their sources. The γ flux is formed by the sum of Galactic and extragalactic components, and the Galactic flux can also be decomposed into a contribution generated by an ensemble of point–like or quasi point–like sources, and a diffuse flux generated by the emission of CR particles in interstellar space. In this work we will be discussing only the diffuse Galactic γ emission, an compare this emission with the spectra of CR antiparticles.

In the absence of unexpected (or more accurately, not necessary) sources, the main mechanism for the production of e^+ and $\overline{p}$ and for γ emission at high energy is the same, namely the production (and decay) of secondary particles created in the inelastic hadronic interactions of primary CR (mostly protons and helium nuclei). The γ flux receives also contributions of photons radiated by relativistic $e^\mp$, however the leptonic emissions are subdominant for $E \gtrsim 10$ GeV.

The possibility that our Galaxy contains additional sources of γ's and relativistic e^+ and $\overline{p}$, such as the self–annihilation of dark matter particles, has received considerable attention in recent years, generating a large body of literature. The "Occam razor" principle, that gives priority to simplicity, suggests to start this study investigating the viability of the hypothesis that the standard mechanism of secondary production is the dominant source for all three (γ, e^+ and $\overline{p}$) fluxes.

2. Cosmic Ray and γ fluxes

Figure 1 shows measurements of the energy distribution of the (isotropic) flux for four CR particles: p, e^-, e^+ and $\overline{p}$, and also the Galactic diffuse flux of gamma rays, averaged over the entire sky. In the energy range $E_\gamma \gtrsim 10$ GeV, the γ angular distribution is consistent with being independent from energy, so that the flux has an approximately factorized form: $\phi_\gamma(E,\Omega) = \langle \phi_\gamma(E) \rangle\; F_\gamma(\Omega)$ where the function $F_\gamma(\Omega)$ is energy independent. Projections in Galactic latitude longitude of the function $F_\gamma(\Omega)$ are shown in Fig. 3 and Fig. 4.

Inspection of Fig. 1 shows some remarkable features, that cry out for an explanation. In the energy range $E \gtrsim 20$ GeV four of the spectra (for p, e^+, $\overline{p}$ and γ) have approximately the same shape, while the electron spectrum is much softer. In more detail, one can observe the following features:

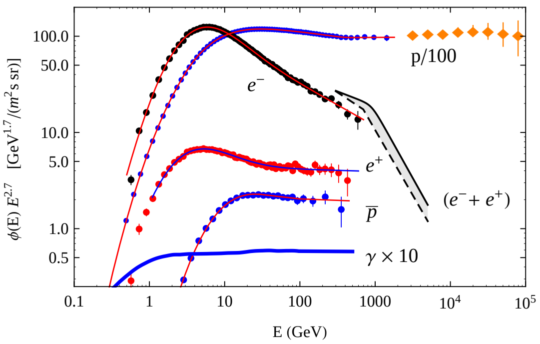

Figure 1: The points show the AMS [1] measurements of p, $e^{\pm}$ and $\overline{p}$, and the p flux measured by CREAM [2]. The thin lines show fits to the flux of $(e^- + e^+)$ obtained by HESS and VERITAS [3]. The thick line shows the diffuse γ flux measured by FERMI [4].

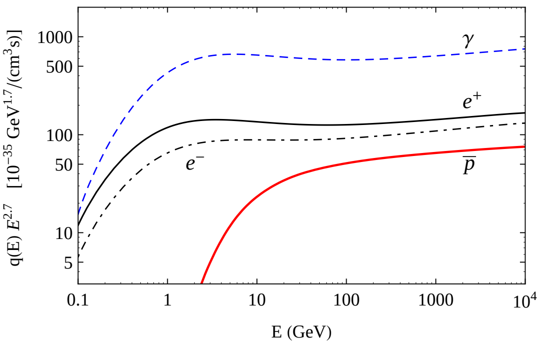

Figure 2: Local source spectra of gamma rays, positrons, electrons and antiprotons. The description of the cosmic ray spectra and the modeling of hadronic interactions is as in the work of [6].

• The proton flux is a power law with a spectral index $\alpha_p \simeq 2.7$–2.8. A moderate hardening (of order $\Delta\alpha \simeq 0.15$–0.25) is present at $E \simeq 230$–300 GeV [5, 1]

• The electron flux is much smaller than the proton flux (with a ratio $\phi_{e^-}(E)/\phi_p(E) \simeq 10^{-2}$ at $E \simeq 10$ GeV), and is also significantly softer, with a spectral index of order $\alpha_e \simeq 3.1$–3.2.

• The positron and antiproton spectra are power laws with spectral indices that are consistent with being equal to each other $\alpha_{e^+} \simeq \alpha_{\overline{p}} \simeq 2.75$–$2.80$. The antiparticles spectral indices are also very close to α_p, the spectral index of the proton flux.

• The $e^+/\overline{p}$ ratio is consistent with a constant $\phi_{e^+}(E)/\phi_{\overline{p}}(E) \simeq 2.0 \pm 0.04$.

• The measurements of the combined flux of $(e^- + e^+)$ performed by the Cherenkov telescopes indicate that the spectrum has a sharp softening at energy $E^*_{\rm Cherekov} \simeq 700$–$900$ GeV, indicating that both e^- and e^+ spectra do not extend as unbroken power laws in the multi–TeV energy range.

• The diffuse Galactic γ flux has also a power law spectrum, with a spectral index $\alpha_\gamma \simeq 2.65$–$2.75$, that (taking into account systematic uncertainties) is equal to the results for e^+ and $\overline{p}$.

The development of an understanding of the mechanisms that form the spectra of the five particles (p, $e^{\mp}$, $\overline{p}$ and γ), is obviously a task of central importance.

3. The proton and electron spectra

One the most important and interesting results of the CR observations is the large difference not only in normalization, but also in spectral shape between the electron and proton fluxes. The two limiting case explanation for the difference in spectral shape are:

(A) The CR sources generate e^- and p spectra that, in a broad energy range, have very similar shape, and the observed difference is entirely determined by propagation effects.

(B) The properties of Galactic propagation for e^- and p are approximately equal [$P_e(E) \simeq P_p(E)$], and The different shapes of the observed spectra are generated by the CR sources.

The main reason why one can expect that the properties of Galactic propagation for e^- and p to be different, is that the rate of energy loss for the two particles differ by many orders of magnitude.

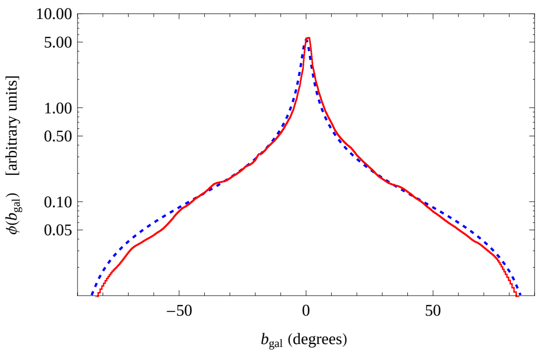

Figure 3: The (red) histogram shows the latitude distribution of the diffuse Galactic γ flux observed by FERMI [4] for energy $E_\gamma \gtrsim 12$ GeV. The dashed lines show the latitude distribution for the emission model of Eq. (4.2), with parameters $R = 5.2$ kpc and $Z = 0.22$ kpc.

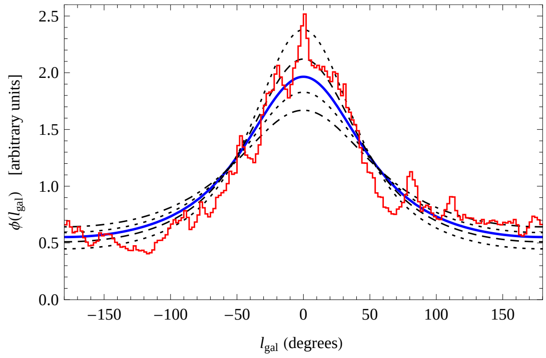

Figure 4: Longitude distribution of the γ flux. The lines show the distributions predicted for the emission of Eq. (4.2). The different curves are calculated for the choice of parameters that give $b^* = 5.2^\circ$ and $r_{\rm GC} = 1.80$ 2.0, 2.2, 2.4 and 2.6.

The average loss time for an $e^\mp$ (the time needed to lose one half of its energy) is:

$$T_{\rm loss}(E) = E/|dE/dt| \simeq 310.8\ [E/{\rm GeV}]^{-1}\ \left[(\rho_B + \rho_\gamma^*)/({\rm eV\ cm^{-3}})\right]^{-1}\ {\rm Myr} \tag{3.1}$$

where $\rho_B = B^2/(8\pi)$ is the energy density in magnetic field and $\rho_\gamma^*(E)$ the density of the radiation field, calculated including only photons with energy $\varepsilon \lesssim m_e^2/E$. It $T_{\rm loss}(E)$ is shorter than the residence time $T_{\rm age}(E)$, then the $e^\mp$ losses are significant for propagation.

Since $T_{\rm loss}(E) \propto E^{-1}$, while it is likely that the CR age has a weaker energy dependence, one expects that the radiative energy losses of $e^\mp$ are important only for $E \gtrsim E^*$, where E^* is the critical energy defined by the condition $T_{\rm loss}(E^*) \simeq T_{\rm age}(E^*)$. For $E \simeq E^*$ one expects to observe softening features in the spectra of both e^- and e^+.

The two scenarios (A) and (B) outlined above imply very different values for the critical electron energy E^*. In fact, the smoothness of the e^- (and also e^+) spectrum between 10 and 500 GeV suggests that E^* is outside this range, and therefore that the energy losses are either always important, or always negligible for $e^\mp$ in this energy range.

4. Secondary particles production

The local spectra of secondary can be calculated folding the CR spectra present in the solar neighborhood (determined by direct bservations) with the inclusive cross sections for the production of different types of final state particles. Fig. 2 shows a calculation of the locally produced spectra of secondaries extending the study of [6] (for e^+ and $\overline{p}$) to e^- and γ.

The most important property of the results shown in Fig. 2 is that at high energy ($E \gtrsim 30$ GeV), the production spectra of the four particle types (γ, $e^\pm$, and $\overline{p}$) can be, in first approximation, described by power laws ($q_j(E) \propto E^{-\alpha}$) with approximately the same exponent (of order $\alpha \approx 2.7$) of the primary particles, so that the ratios of the production rates of different particles are approximately constant. This result is a consequence of the approximate scaling, in the forward fragmentation region, of the inclusive cross sections for the production of secondaries (see Fig. 5).

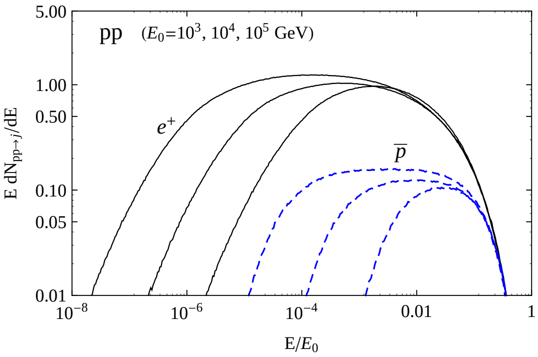

Figure 5: Inclusive spectra of e^+ and $\overline{p}$ in pp interactions at $E_0 = 10^3$, 10^4 and 10^5 GeV calculated with the Pythia Montecarlo code [11].

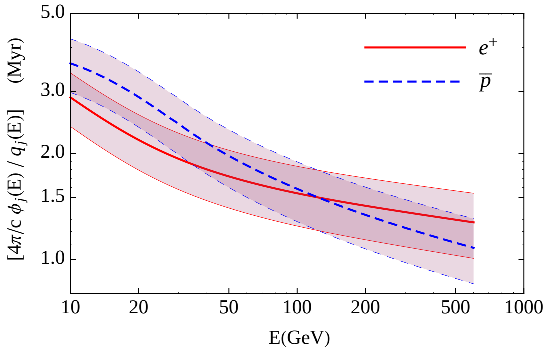

Figure 6: Ratios $(4\pi)/c\ \phi_{e^+(\overline{p})}(E)/q^{\rm loc}_{e^+(\overline{p})}(E)$ as a function of the kinetic energy E.

The production spectrum is then (in good approximation) proportional to the $(\alpha_p - 1)$ moment of the inclusive cross section. At $E \simeq 100$ GeV, the ratios between the spectra in the calculation shown in Fig. 2 are: $\gamma/e^+ \simeq 5.5$, $e^-/e^+ \simeq 0.80$, and $e^+/\overline{p} \simeq 2.0$.

4.1 Gamma ray flux

Neglecting absorption during propagation (a good approximation in the energy range considered), the flux $\phi_\gamma(E,\Omega)$ of photons of energy E from the direction Ω can be calculated integrating the emission density $q_\gamma(E,\vec{x})$ over the line of sight. The total flux is then obtained integrating over all directions:

$$\Phi_\gamma(E) = \int_{4\pi} d\Omega \left[\int_0^\infty \frac{dt}{4\pi}\, q_\gamma[E,\vec{x}(t,\Omega)]\right] = \frac{1}{4\pi} \int d^3x\, \frac{q_\gamma(E,\vec{x})}{|\vec{x}-\vec{x}_\odot|^2} = \frac{Q_\gamma(E)}{4\pi\, L^2_{\rm eff}(E)}\,. \tag{4.1}$$

In the last equality $Q_\gamma(E)$ is total Galactic emission and $L_{\rm eff}$ has a transparent physical meaning as the average $\langle L^{-2}\rangle$, with L he distance traveled by the photons. The factorization of $\phi_\gamma(E,\Omega)$ into functions of only E and Ω implies that also the energy and space dependences of the emission $q_\gamma(E,\vec{x})$ are factorized, and therefore that $L_{\rm eff}$ is energy independent.

While it straightforward to obtain the flux angular dependence $\phi_\gamma(\Omega)$ from the space dependence of the emission $q_\gamma(\vec{x})$, inverting the relation is a non trivial problem, that does not have an exact or unique solution. For the purpose of building a simple, first order model of the space distribution of the emission sufficient to capture its main characteristics. we have taken the approach to describe it with a simple axially symmetric Gaussian form:

$$q_\gamma(E,\vec{x}) = \frac{Q_\gamma(E)}{(2\pi)^{3/2}\, R^2\, Z}\ \exp\left[-\frac{(x^2+y^2)}{2R^2} - \frac{z^2}{2Z^2}\right] \tag{4.2}$$

with two shape parameters R and Z that give the radial and height extension of the emission. Changing R and Z one obtains different values for b^* (the Galactic latitude that contains one half of the flux), and $r_{\rm GC}$ (the ratio of the fluxes in the hemispheres toward and opposite to the Galactic center). In the data one finds $b^* \simeq 5.2^\circ$ and $r_{\rm GC} \simeq 2.20$. These results are reproduced by the pair of shape parameters $Z \simeq 0.22$ kpc and $R \simeq 5.2$ kpc (see Figs. 3 and 4). The model then yields $L_{\rm eff} \simeq 4.7$ kpc. The knowledge of $L_{\rm eff}$ allows to compute the total Galactic γ emission and its associated power:

$$E^2\, Q_\gamma(E) = E^2\, (4\pi)^2\, \langle \phi_\gamma(E) \rangle\, L_{\rm eff}^2 \approx (4.0 \pm 0.6 \pm 1.0) \times 10^{37} \left[\frac{E}{30~{\rm GeV}}\right]^{-0.70\pm 0.05} {\rm erg~s}^{-1}. \quad (4.3)$$

The two errors in the absolute normalizations of the power at $E \simeq 30$ GeV are associated to the measurement of the angle averaged diffuse flux and to the estimate of $L_{\rm eff}$.

4.2 The antiparticle fluxes

A remarkable result (see discussion in [6]) is that for E in the range 1–400 GeV one finds:

$$\phi_{e^+}(E) \;/\; \phi_{\overline{p}}(E) \approx q_{e^+}^{\rm loc}(E) \;/\; q_{\overline{p}}^{\rm loc}(E)\;. \quad (4.4)$$

In the energy range $E \gtrsim 30$ GeV Eq. (4.4) corresponds to the statement that the ratio $e^+/\overline{p}$ is a constant with a value of order 2, but the results is also valid at lower energy. The simplest and most natural interpretation of Eq. (4.4) can be described as follows:
(i) The standard mechanism of secondary production is the dominant source of e^+ and $\overline{p}$.
(ii) The spectra of e^+ and $\overline{p}$ at production have approximately the same shape (equal to the local production) in all the Galaxy, so that: $Q_{e^+(\overline{p})}(E) \simeq q^{\rm loc}_{e^+(\overline{p})}(E) \times V_Q$, with V_Q a constant with the dimension of a volume.
(iii) The propagation functions for e^+ and $\overline{p}$ are approximately equal: $P_{e^+}(E) \simeq P_{\overline{p}}(E)$.

The last point implies that the much larger energy loss rate for positrons has no significant effect on propagation, and therefore that the residence time of antiparticles in the Galaxy is sufficiently short. In this scenario, the propagation functions for e^+ and $\overline{p}$ can be calculated as:

$$P_{e^+(\overline{p})}(E) = \frac{4\pi}{\beta c}\,\frac{\phi_{e^+(\overline{p})}(E)}{Q_{e^+(\overline{p})}(E)} \simeq \left[\frac{4\pi}{\beta c}\,\frac{\phi_{e^+(\overline{p})}(E)}{q^{\rm loc}_{e^+(\overline{p})}(E)}\right] \frac{1}{V_Q} = \frac{\tau_{e^+(\overline{p})}(E)}{V_Q}\;. \quad (4.5)$$

The functions $\tau_{e^+}(E)$ and $\tau_{\overline{p}}(E)$, defined in the last equality of Eq. (4.5)] as the ratio between the flux and the local source rate, are shown in Fig. 6 together with an estimate of their systematic uncertainty. These functions [that are consistent with being equal as implicit in Eq. (4.4)] have the dimension of a time, and are related to the residence time of the particles as $T_{\rm age}(E) \approx \tau(E)\, V_{\rm CR}/V_Q$ (with $V_{\rm CR}$ the effective confinement volume of the particles), so that $P \approx T_{\rm age}/V_{\rm CR}$.

4.3 Comparing the gamma ray and antiparticle fluxes

The result of Eq. (4.5) allows to estimate the energy dependence of the $\overline{p}$ and e^+ propagation functions, but not their absolute normalization. This normalization (and the value of V_Q) can be estimated comparing the observations of antiparticles ad gamma rays (and assuming that the production mechanism is the standard one). The effective volume for γ (or antiparticle) production can be estimated using Eq. (4.3):

$$V_Q = \frac{Q_{\overline{p}(e^+)}(E)}{q^{\rm loc}_{\overline{p}(e^+)}(E)} = \frac{Q_\gamma(E)}{q^{\rm loc}_\gamma(E)} \simeq \frac{(4\pi)^2\, \langle \phi_\gamma(E) \rangle\, L_{\rm eff}^2}{q^{\rm loc}_\gamma(E)} \simeq (160 \pm 40) \left(\frac{L_{\rm eff}}{4.7~{\rm kpc}}\right)^2 \left(\frac{{\rm cm}^{-3}}{n^{\odot}_{\rm ism}}\right) {\rm kpc}^3 \quad (4.6)$$

The propagation functions for e^+ and $\overline{p}$ are approximately equal and proportional to $1/(c\,L_{\rm eff}^2)$:

$$\frac{1}{P_{\overline{p}(e^+)}} \approx \frac{V_{\rm CR}}{T_{\rm age}} \approx (330 \pm 90) \left[\frac{E}{100 \text{ GeV}}\right]^{0.09\pm0.10} \left[\frac{L_{\rm eff}}{4.7 \text{ kpc}}\right]^2 \frac{\text{kpc}^3}{\text{Myr}} \tag{4.7}$$

(the uncertainties are associated to the measurements of the fluxes of γ, $\overline{p}$ and e^+, and to the calculation of the local source spectra). The propagation functions can be written as: $P \approx T_{\rm age}/V_{\rm CR}$, where $T_{\rm age}$ and $V_{\rm CR}$ are the average residence time and effective confinement volume for the particles. The value of $T_{\rm age}$ for $e^{\mp}$ can be estimated if one assumes that the softening feature observed by the Cherenkov telescopes at $E \simeq 700$–900 GeV is the critical energy E^*. This assumption implies [see Eq. (3.1)] that the age of CR is of order of 1 Myr, and therefore that the effective confinement volume is of order 300 kpc^3. If one accepts that positrons have a new non–standard source, and uses only the $\overline{p}$ result, the residence time can be much longer, and then the confinement volume can be much larger (scaling $V_{\rm CR} \propto T_{\rm age}$).

5. Secondary Nuclei

The data on the fluxes of stable and unstable secondary nuclei (created in the fragmentation of higher mass primary nuclei) can give information on the propagation of Galactic cosmic rays. The ratio secondary/primary allows to estimate the average column density crossed by the nuclei. For example, the recent data on the boron/carbon (B/C) ratio by AMS02 [7] can be interpreted to obtain the estimate: $\langle X \rangle \simeq 4.7\ [|p/Z|/(30 \text{ GV})]^{-0.33}$ g/cm^2. The crucial question is if this column density is integrated during propagation of the nuclei in interstellar space, or inside or in the vicinity of the the sources where the primary particles are accelerated [8]). In the first case $\langle X \rangle$ is proportional to the residence time of the particles, and one obtains:

$$T_{\rm age} \simeq 3.0\ \left[\langle n_{\rm ism}\rangle/\text{cm}^{-3}\right]^{-1}\ \left[|p/Z|/30 \text{ GV}\right]^{-0.33} \text{ Myr}\,. \tag{5.1}$$

This estimate is inversely proportional to the average density of interstellar gas along the particle trajectory and therefore depends on the size and shape of the CR confinement volume. If this result is assumed to be valid also for $e^{\mp}$, it can be used to estimate the critical energy E^*. Combining Eqs. (5.1) and (3.1) one obtains:

$$E^* \simeq 193\ \left[\langle n_{\rm ism}\rangle/\text{cm}^{-3}\right]^{1.5}\ \left[\langle \rho_B + \rho_\gamma^*\rangle/(\text{eV cm}^{-3})\right]^{-1.5} \text{ GeV}\,. \tag{5.2}$$

The result scales as $E^* \propto [\langle n_{\rm ism}\rangle/\langle \rho_B + \rho_\gamma^*\rangle]^{1/(1-\delta)}$ where $\langle n_{\rm ism}\rangle$ is the average number density of the interstellar gas and $\langle \rho_B + \rho_\gamma^*\rangle$ is the average energy density in magnetic field and radiation along the particle trajectory, and $\delta \simeq 0.33$ is the exponent of the (power law) rigidity dependence of the B/C ratio. This interpretation of the B/C data is therefore in conflict with the hypothesis that the energy losses are negligible up to 400 GeV.

Unstable secondary nuclei are the most reliable method to estimate directly the CR age. The idea is to measure the suppression of the flux of an unstable nuclear isotope such as beryllium–10 ($T_{1/2} \simeq 1.51 \pm 0.04$ Myr) relative to the flux of a stable isotope such as beryllium–9. For example, the CRIS collaboration aboard the ACE spacecraft [9] has measured a isotopic ratio ^{10}Be/^{9}Be of order 0.11–0.12 for nuclei with $E_{\rm kin} \simeq 70$–150 MeV per nucleon, and interpreted the measurement, on the basis of a steady state leaky–box model, to obtain a residence time $T_{\rm age} = 15.0 \pm 1.6$ Myr. At higher energy the dependence on the Galactic propagation model becomes less important [12]. A recent work of of Kruskal, Ahlen and Tarlé [10] discusses observations of the beryllium isotopic composition at a $E_{\rm kin} \simeq 2$ GeV/nucleon (a rigidity of order 7.0 GV), setting an upper limit $T_{\rm age} \lesssim 2$ Myr. This result is in conflict [see Eq. (5.1)] with the hypothesis that boron is mostly created during propagation in the interstellar medium, giving support to models where the secondary nuclei are created inside or near the accelerators [8]). The result also in conflict with models where the difference in spectral shape between e^- and p is entirely determined by propagation effects.

6. Summary and outlook

We find that the hypothesis that the spectra of e^+ and $\overline{p}$ and the diffuse Galactic γ flux are all generated by the standard mechanism of secondary production is viable. This conclusion requires that the $e^\pm$ energy losses remain negligible for $E \lesssim 400$ GeV, and therefore imply a short residence time of CR in the Galaxy. It is then natural to interpret the softening of the $(e^- + e^+)$ flux observed by Cherenkov telescopes at $E \approx 900$ GeV as the manifestation of the critical energy for $e^\pm$ Galactic propagation. This conclusion is conflict with commonly accepted interpretations of the data on secondary nuclei, and challenges generally accepted ideas on cosmic ray acceleration and propagation. The alternative requires a new hard source of relativistic positrons that is sufficiently "fine tuned" in spectral shape and normalization.

The solution to this problem has profound implications for our understanding of the Galactic sources of cosmic rays, because the hypothesis that both the e^+ and $\overline{p}$ fluxes are of secondary origin implies that the CR sources release in interstellar space spectra of e^- and p with different shape.

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