ORIGIN OF THE COSMIC RAY POSITRONS OBSERVED NEAR EARTH: MESON DECAY OR DARK MATTER DECAY?

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Received 2015 August 5; accepted 2015 September 1; published 2015 October 6

ABSTRACT

We show that the flux of the high-energy cosmic ray (CR) positrons observed near Earth is that expected from the decay of mesons produced by the primary CRs in the local interstellar medium.

Key words: astroparticle physics – dark matter

1. INTRODUCTION

A wide variety of evidence points to the existence of dark matter (DM) in the universe that cannot be seen directly, but that can be detected by its gravity. Precise measurements of the angular power spectrum of the cosmic microwave background (CMB) radiation analyzed with the standard model of cosmology indicate that nearly 27% of the total mass-energy density of the universe resides in this DM (Bennet et al. 2013; Ade et al. 2014), whose existence was first discovered in clusters of galaxies (Zwicky 1933, 1937) and later in galaxies (Rubin & Ford 1970). The nature and origin of this DM are still unknown.

If the DM is made of weakly interacting massive particles (WIMPs), relics from the Big Bang, their annihilation cross-section satisfies \( \langle \sigma v \rangle \approx 2 \times 10^{-26} \text{cm}^3 \text{s}^{-1} \) (Jungman et al. 1996), which is typical of weakly interacting ~TeV-mass particles. The annihilation/decay of such particles can produce stable particles such as electrons, positrons, protons, antiprotons, neutrinos, and gamma rays whose energy cannot exceed the mass of the DM particles. Hence, in recent years, bumps with a sharp cutoff due to the decay and/or annihilation of WIMPs were looked for in high-precision measurements of the energy spectrum of such cosmic ray (CR) particles. A bump around \( E = 620 \text{ GeV} \) with a sharp cutoff around \( E = 800 \text{ GeV} \) in the combined flux \( \Phi_p \) of \( e^\pm \) CRs was reported by the Advanced Thin Ionization Calorimeter (ATIC) balloon experiment (Chang et al. 2008). It was interpreted as a possible DM signal (e.g., Bergstrom et al. 2008; Arkani-Hamed et al. 2009; Cholis et al. 2009; Cirelli et al. 2009; Pohl 2009). However, such a peak was not confirmed by measurements with the ground-based Cherenkov telescopes of High Energy Stereoscopic System (H.E.S.S.; Aharonian et al. 2009b), or with more precise measurements with the Large Area Telescope (LAT) on board the Fermi satellite (Ackermann et al. 2010), or with the Alpha Magnetic Spectrometer (AMS) on board the International Space Station (Aguilar et al. 2014a). But at the same time, the energy spectrum of \( e^\pm \) CRs measured with H.E.S.S. (Aharonian et al. 2008) showed a sharp break near 1 TeV whose origin is still not clear.

Shortly after the ATIC report (Chang et al. 2008), an unexpected increase of the CR positron fraction \( \Phi(e^+)/\Phi(e^-) \) as a function of energy between \( \sim 10 \) and \( \sim 100 \text{ GeV} \), observed with the Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA) satellite was reported (Adriani et al. 2009, 2010, 2013). Unlike the ATIC bump, the rising positron fraction with increasing energy has been confirmed by measurements of the separate CR ray fluxes of \( e^- \) with Fermi-LAT (Ackermann et al. 2012), and with AMS (Aguilar et al. 2013, 2014b; Accardo et al. 2014) with much larger statistics and smaller systematic errors. In the high-precision AMS data, this rise continues beyond 100 GeV, but with a decreasing rate that appears to level off around 275 ± 32 GeV (Aguilar et al. 2014; Aguilar et al. 2014b; Pohl 2014).

The measured flux of CR positrons and the increasing positron fraction were in stark contrast with those predicted for the secondary production of positrons in the interstellar medium (ISM) by primary CRs from detailed calculations with the elaborate GALPROP code (e.g., Moskalenko & Strong 1998a, 1998b). This sparked the publication of several alternative explanations of the origin of the excess of high-energy CR \( e^\pm \) flux, such as DM (e.g., Bergstrom 2009, 2013; Bergstrom 2009; for a recent review see, e.g., Ibarra et al. 2013 and the references therein), positron emission from a few nearby pulsars and/or supernova remnants (SNRs; e.g., Hooper et al. 2009; Shaviv et al. 2009), secondary production of positrons in collisions of primary CRs in/near their sources (Dado & Dar 2010) such as the highly relativistic jets launched mainly by supernovae Type Ic, and accreting stellar-mass and massive black holes (e.g., Dar & De Rújula 2004, 2008, and the references therein), and/or the spherical ejecta in SNRs (Blasi 2009; Stawarz et al. 2010). Other authors (e.g., Blum et al. 2013; Cowsik et al. 2014) maintained that the secondary production of positrons in the ISM by the primary CRs can explain the observed flux of CR positrons, although their calculations involved incorrect assumptions concerning the energy loss of positrons in the ISM.

The reported isotropy of the flux of high-energy CR positrons observed with AMS (Accardo et al. 2014), however, is in tension with the assumption that the observed flux of \( e^- \) CRs was produced by a few relatively nearby pulsars (e.g., Linden & Profumo 2013) or SNRs. At the same time, the high-precision data of AMS02 (Aguilar et al. 2014a) on the combined \( e^- \) flux up to 1 TeV and the separate \( e^- \) and \( e^+ \) fluxes, and the positron fraction (Accardo et al. 2014; Aguilar et al. 2014b) that appear to flatten above 200 GeV, do not yet show any convincing evidence for a cutoff/sharp decline, which begins below \( \sim 700 \text{ GeV} \), that could be associated with a decay/annihilation of DM particles.

In this paper, we reexamine the possibility that the main origin of the high-energy CR positrons observed near Earth is secondary production in hadronic collisions of the primary CR protons and nuclei in the ISM (Blum et al. 2013; Cowsik...
et al. 2014). We focus on the high-energy \((E > 10 \text{ GeV})\) behavior of the flux of CR \(e^+\)'s where it may be dominated by the decay/annihilation of DM particles. We consider the energy-loss of \(e^+\)’s above 10 GeV where it is dominated by synchrotron radiation, inverse Compton scattering, triple pair production, and escape from the Galaxy by diffusion in its turbulent magnetic fields. (Other energy loss mechanisms that are important only at energies well below 10 GeV, such as Coulomb scattering, ionization, and Bremsstrahlung, as well as threshold effects, geomagnetic shielding, and solar modulation, are not considered in detail, but are included for completeness through a best-fit phenomenological depletion factor \(D_{\text{cr}}(E) = 1 - \exp(-(E/V')^\alpha)\), which depends on the time of the measurements and on the electric charge \((\pm)\) but does not affect the behavior at \(E > 10 \text{ GeV}\).) Using only standard particle physics, the steady-state approximation for CR propagation, and the measured properties of the primary CRs and the local Galactic environment, we show that the spectrum of high-energy CR \(e^+\)’s measured by AMS (Aguilar et al. 2014b) with high statistics and small systematic errors is consistent with that expected from the secondary production of positrons in hadronic interactions of the primary CRs in the local ISM. In particular, the hardening of the positron spectrum with increasing energy between \(\sim 20\) and \(150 \text{ GeV}\) and its softening beyond \(250 \text{ GeV}\), as observed with AMS02 (Aguilar et al. 2014b), are expected from the transition of their inverse Compton scattering of diffuse Galactic light (DGL) from the Thomson regime to the Klein–Nishina regime (Schlickeiser & Ruppel 2010).

Moreover, the break near 1 TeV in the combined \(e^\pm\) flux, suggested by the data from H.E.S.S. (Aharonian et al. 2008), may be the maximum reacceleration energy of electrons in the ISM due to their radiative energy loss and escape from the Galaxy by diffusion. Indeed a break was reproduced in numerical calculations (e.g., Stawarz et al. 2010), which have used the elaborate GALPROP numerical code (Moskalenko & Strong 1998a, 1998b). Other standard astroparticle physics interpretations rather than a DM annihilation/decay signal are shortly discussed.

2. CR PRODUCTION OF POSITRONS IN THE LOCAL ISM

The flux of primary CR nucleons (free protons and nucleons bound in atomic nuclei) in the energy range between several GeV and PeV per nucleon observed near Earth, is well-described by (e.g., Olive et al. 2014):

\[
\Phi_p(E) \approx 1.8 \left( \frac{E}{\text{GeV}} \right)^{-\beta} \text{fu},
\]

where \(\beta = 2.7\) and \(\text{fu} = 1/(\text{GeV cm}^2 \text{ s sr})\) is the flux unit. The contribution of nucleons bound in atomic nuclei (\(A, Z\) to the CR flux at the same energy per nucleon is less than 5% and comes mainly from light nuclei whose inelastic cross-section per nucleon is \(\sim \sigma_{\text{pp}}/A \sim \sigma_{\text{pp}}\), i.e., roughly that of free protons, while their effective rigidity \((R = AE/Z)\) is twice that of free protons. Hence, due to Feynman scaling (Feynman 1969), secondary production of high-energy positrons through the decay of \(\pi\) and \(K\) mesons, which are produced in hadronic collisions of CR nucleons with the baryons in the local ISM where the mean baryon density is \(n_{\text{baryon}} \approx 0.9 \text{ cm}^{-3}\) (Kalberla & Dedes 2008), inject a flux of \(e^+\)’s into the CR halo per unit volume roughly at a rate

\[
J_e \approx K_e \sigma_{\text{pp}} \text{fu} n_{\text{baryon}} \Phi_p(E), \quad (2)
\]

where \(K_e\) is a constant that depends only on the power-law index of the product \(\sigma_{\text{pp}} \Phi_p(E)\), but not on \(E\) itself. In a steady-state, the flux \(\Phi_e'(E)\) of secondary \(e^+\)’s produced in the ISM satisfies

\[
\frac{d}{dE} \left[ b(E) \Phi_e'(E) \right] = J_e'(E), \quad (3)
\]

where \(b(E) = dE/dt\) is the loss rate of \(e^+\) energy by radiation (rad) and by escape (esc) from the Galaxy by diffusion through its turbulent magnetic field. The solution of Equation (3) for \(\Phi_e \propto E^{-\beta}\) is

\[
\Phi_e'(E) \approx K_e \sigma_{\text{pp}} \text{fu} n_{\text{baryon}} \tau_e/\beta \Phi_p(\beta - 1), \quad (4)
\]

where \(\sigma_{\text{pp}} \approx 30 \left( \frac{E}{\text{GeV}} \right)^{0.06} \text{ mb},\) \(K_e \approx 7 \times 10^{-3}\) for \(\beta_1 \gtrsim \beta - 0.06 = 2.64\), and \(\tau_e = E/(dE/dt)\) is the mean lifetime of positrons in the ISM due to their escape (esc) from the Galaxy by diffusion and radiative (rad) energy losses (inverse Compton scattering of background photons and synchrotron radiation). Hence, the expected flux of high-energy CR \(e^+\)’s near Earth is simply

\[
\Phi_e'(E) \approx 6.22 \times 10^{-18} E^{-2.64} \tau_e(E) \text{ fu}, \quad (5)
\]

where the combined radiative losses and escape by diffusion yield

\[
1/\tau_e = 1/\tau_{\text{esc}} + 1/\tau_{\text{rad}}. \quad (6)
\]

At high energies, the rigidities of \(e^+\)’s and protons become practically equal. Consequently, their escape times by diffusion become practically equal. For random Galactic magnetic fields with a Kolmogorov spectrum (Kolmogorov 1941)

\[
\tau_{\text{esc}} \approx (7.5 \pm 1.5) \times 10^{14} \left( \frac{E}{\text{GeV}} \right)^{-1/3} \text{ s}, \quad (7)
\]

where the normalization has been adjusted to the value obtained by Lipari (2014) from a leaky box model analysis of the flux ratio \(^{18}\text{O}/^{16}\text{O}\) measured with the Cosmic Ray Isotope Spectrometer (CRIS) in the energy range of 70–145 MeV/nucleon (Yanasak et al. 2001). At the CR ankle near \(E \approx 4 \times 10^9 \text{ GeV}\), this normalization yields \(\tau_{\text{esc}} = (15 \pm 3)\) ky, consistent with an expected free escape time \(H/\epsilon = 5 \pm 1 \text{ kpc} \epsilon^{-1} = (16.3 \pm 3.2)\) ky, where \(H\) is the typical scale height of the Galactic CR halo perpendicular to the Galactic disk (e.g., Trotta et al. 2011).

Synchrotron emission and inverse Compton scattering of background photons in the Thomson regime yield

\[
\tau_{\text{rad}} \approx 3 \left( \frac{m_e c^3}{4 \pi \epsilon c U E} \right)^{1/2} \approx 0.67 \times 10^{16} \left( \frac{E}{\text{GeV}} \right)^{-1} \text{ s}, \quad (8)
\]

where \(\sigma_T \approx 0.66 \text{ barn}\) is the Thomson cross-section and \(U \approx 1.47 \text{ eV cm}^3\) is the energy density of the background radiations plus the magnetic field in the local ISM. Roughly, the magnetic field \(B \approx 4 \mu \text{G}\) in the local ISM contributes \(B^2/8 \pi \approx 0.40 \text{ eV cm}^{-3}\) to \(U\), the DGL contributes \(0.39 \text{ eV cm}^{-3}\), the far-infrared (FIR) light contributes \(0.40 \text{ eV cm}^2\), and the CMB contributes \(0.26 \text{ eV cm}^{-3}\) (e.g., Porter et al. 2006; Schlickeiser & Ruppel 2010).
In the Klein–Nishina regime, \( w = 4 E_e \epsilon_e/(m_e c^2)^2 \gtrsim 1 \), the energy-loss rate by ICS is given by \( \epsilon_{\gamma} \approx 8 \sigma_{\gamma e} U_e \left( \frac{m_e c^2}{E} \right)^2 \ln\left[ \frac{E}{m_e c^2} \right] + 11/6 \). \( \tag{9} \)

Consequently, as can be seen from Equation (3), in a steady-state an injected power-law spectrum of electrons becomes softer in the Thomson regime, \( E^{-\beta} \rightarrow E^{-\beta-1} \), whereas in the Klein–Nishina regime it becomes harder, \( E^{-\beta} \rightarrow E^{-\beta-1} \).

In the case of a graybody radiation of temperature \( T \), the transition from the Thomson regime to the Klein–Nishina regime can be interpolated through replacing \( U(E) \) with \( U_{KN}(E) \approx U(E) E_{KN}^2/(E^2 + E_{KN}^2) \). \( \tag{10} \)

where \( E_{KN} \approx 0.27 \left( \frac{m_e c^2}{k T} \right) \). \( \tag{11} \)

with \( k \) being the Boltzmann constant. For the local DGL, \( T \approx 5700 \text{ K} \) and \( E_{KN} \approx 140 \text{ GeV} \). For the Galactic FIR radiation and the CMB, \( E_{KN} \) is well above 10 TeV.

Since the estimated values of the local energy densities of the DGL and FIR, as well as the local B suffer from uncertainties, we have best-fitted their values within the errors of their estimated values. At 100 GeV, they yield, for instance, \( \tau_{\text{rad}} \approx 7.2 \times 10^{13} \text{ s} \), and consequently \( \tau_{\text{esc}} \approx 0.50 \times 10^{14} \text{ s} \approx 1.6 \text{ MY} \).

The flux of high-energy \( e^+ \) CRs measured with AMS02 (Aguilar et al. 2014b), and the flux expected from CR production of \( e^+ \)’s in the ISM as given by Equation (5) multiplied by the low-energy best-fit phenomenological depletion factor \( D_e(E) = 1 - \exp(-E/V)^\alpha \), with \( V = 3.90 \text{ GeV} \) and \( \alpha = 1.78 \), are compared in Figure 1.

Figure 1. Comparison between the high-energy \( e^+ \) CR flux measured with AMS02 (Aguilar et al. 2014b) and the secondary \( e^+ \) flux expected from hadronic interactions of the primary CR nuclei in the local ISM.

3. ORIGIN OF THE CR \( e^+ \) FLUX

Most of the Galactic accelerators of high-energy CRs (SNRs, pulsars, gamma-ray bursts, and the massive black hole near the Galactic center) are located in the Galactic disk within \( \sim 4 \text{ kpc} \) from its center (e.g., Case & Bhattacharya 1998; Yusifov & Kucuk 2004; Lorimer et al. 2006). Presumably, the Fermi acceleration (Fermi 1949) of high-energy electrons, protons, and nuclei is simultaneous and in particle energies of electrons becomes a fraction of the total energy density of high-energy CRs, protons, and helium. Consequently, without energy losses, they would have reached Earth from their common sources after the same mean diffusion time, and their fluxes in the local ISM then would have satisfied \( \phi_e(E) \propto \Phi_e(E) \). This relation can hold as long as their energy loss by radiation is quite small during their diffusion time from source to Earth.

The radiative energy loss of \( e^- \) CRs in the ISM satisfies \( dE/dt = -b E^2 \), whose solution is \( E = E_0 \left[ 1 - b E t_{\text{diff}} \right] \), where \( E \) is the energy of the \( e^- \) CR near Earth and \( E_0 \) is its injection energy. It implies that most of the sources that are located beyond \( \sim 4 \text{ kpc} \) cannot contribute much to the observed local CR \( e^- \)s unless their CRs are reaccelerated in the ISM or transported ballistically over long Galactic distances by highly relativistic jets, such as those emitted in supernova explosions of Type Ic, most of which do not point in our direction (e.g., Dar & Plaga 1999; Dar & Rújula 2008).

If the escape time of CR protons and electrons from their sources into the ISM is much shorter than their energy-loss rate there, then the Fermi-accelerated high-energy electrons are injected into the ISM at a rate of \( J_e \propto \Phi_e/\tau_{\text{esc}}(E) \). Hence, their steady-state flux near Earth satisfies \( \Phi_e = D_e(E) A_e E^{-\beta} \tau_e/\tau_{\text{esc}} + 0.74 \Phi_e \). \( \tag{12} \)

The first term on the right-hand side (rhs) of Equation (12) is due to primary CR \( e^- \)s, presumably reaccelerated in the ISM or transported ballistically by highly relativistic jets from all distant sources together with the CR protons (\( A_e \) is an unknown flux normalization constant, which is treated as a free parameter.) The second term on the rhs is the contribution from hadronic production of high-energy \( e^- \)s in pp collisions in the local ISM, assuming an inclusive production ratio identical to that of muons, \( \epsilon_e/\epsilon_{\mu^+} \approx \mu^-/\mu^+ = 0.74 \), which was measured for atmospheric muons and in accelerator experiments (Archard et al. 2004; Haino et al. 2004; Adamson et al. 2007; Agafonova et al. 2010; Khachatryan et al. 2010). Equation (12) can also be written as \( E^3 \Phi_e = D_e(E) A_e E^{-\beta} \left( 1 + \tau_{\text{esc}}/\tau_{\text{rad}} \right) + 0.74 E^3 \Phi_e \). \( \tag{13} \)

Assuming that the mean radiation field in the CR halo can be represented by that in the solar neighborhood, the predicted flux of CR \( e^- \)s as given by Equation (13) for the best-fit values \( A_e = 0.27 \text{ GeV}^3 \text{ fu} \), \( V = 2.25 \text{ GeV} \), and \( \alpha = 1.46 \) is
compared in Figure 2 to the CR e\(^-\) flux measured with AMS02 (Aguilar et al. 2014b). The agreement is quite satisfactory ($\chi^2/df = 0.85$).

4. THE e\(^+\) FRACTION AND THE COMBINED e\(^\pm\) FLUX

The positron fraction $\Phi_\text{e}^\pm/\Phi_\text{e}$ as a function of energy obtained from our predicted e\(^\pm\) fluxes, which are plotted in Figures 1 and 2, and the positron fraction measured with AMS02 (Accardo et al. 2014) near Earth, are compared in Figure 3 ($\chi^2/df = 0.35$). The combined e\(^\pm\) flux $\Phi_\text{e} = \Phi_\text{e}^+ + \Phi_\text{e}^-$ measured near Earth with AMS02 (Aguilar et al. 2014a) and the expected flux obtained from standard astroparticle physics are compared in Figure 4 ($\chi^2/df = 1.27$). As can be seen from Figures 1–4, the agreement between the near Earth e\(^\pm\) CR fluxes measured with AMS02 and those expected from standard astroparticle physics is quite good.

5. DM ANNIHILATION SIGNAL IN AMS02?

The AMS collaboration presented an impressive “minimal model” fit ($\chi^2/df = 0.63$) to their updated data (Accardo et al. 2014) on the CR positron fraction, which is shown in Figure 5. In this model the e\(^\pm\) CR fluxes were parameterized as the sum of a power-law spectrum and a common source term with an exponential cutoff, which may represent a dark matter decay/annihilation contribution,

$$\Phi_\text{e}^+ = C_\text{e}^+ E^{-\gamma_\text{e}^+} + C_\text{e} e^{-E/E_\text{e}^+},$$
$$\Phi_\text{e}^- = C_\text{e}^- E^{-\gamma_\text{e}^-} + C_\text{e} e^{-E/E_\text{e}^-},$$

with $E$ in GeV. However, the positron fraction $\Phi_\text{e}^+/\Phi_\text{e}^+ + \Phi_\text{e}^-$ is invariant under division of both fluxes by an arbitrary $E$-dependent term. In particular, by dividing the minimal model fluxes by $C_\text{e} E^{-\gamma_\text{e}^+}$, a very good best fit ($\chi^2/df = 36.4/58$) to the positron fraction in the energy range 1–500 GeV yielded (Accardo et al. 2014) $C_\text{e}^+/C_\text{e}^- = 0.091 \pm 0.001$.

A major feature of the minimal model is the sharp decline of the positron fraction above $\sim 500$ GeV. In order to test the AMS minimal model, we have best-fitted $\Phi_\text{e}^+$ and $\Phi_\text{e}^-$ as given by Equations (13) and (14), respectively, to the separate e\(^+\) and e\(^-\) fluxes measured with AMS02 (Aguilar et al. 2014b).
The best-fit parameters were constrained to reproduce the above relations between the parameters of the minimal model. Unlike the minimal model impressive fit to the positron fraction published by the AMS collaboration, (Accardo et al. 2014) as shown in Figure 5, the best fits to the separate \( \text{e}^+ \) and \( \text{e}^- \) fluxes, and to their sum, are rather poor, as shown in Figures 6–8. That is particularly true for \( E < 10 \text{ GeV} \) and \( E > 300 \text{ GeV} \).

One may argue, however, that the minimal model represents the source spectra of \( \text{e}^\pm \) CRs, which are later modified by propagation effects in/near the source, in the ISM, and in the heliosphere. But because solar modulation, escape by diffusion in the turbulent Galactic magnetic fields, and energy loss through ionization, Bremsstrahlung, synchrotron radiation, inverse Compton scattering, and pair production, which strongly affect the observed spectra of \( \text{e}^\pm \) CRs near Earth, are independent of the sign of charge, they modify the injection spectra of \( \text{e}^\pm \) CRs by the same energy-loss factor \( E/(dE/dt) = b(E) \). However, the spatial distribution of Galactic DM is quite different from that of the more conventional sources of primary \( \text{e}^- \) and secondary \( \text{e}^\pm \) CRs. This makes the possibility that the strong modifications of the source spectra of both high-energy \( \text{e}^+ \) and \( \text{e}^- \) CRs observed near Earth are nearly identical rather unlikely.

6. CR \( \text{e}^\pm \) KNEE NEAR TEV?

The energy spectrum of high-energy \( \text{e}^\pm \) CRs measured with AMS02 (Aguilar et al. 2014a) does not show any sign of sub-TeV break (see Figure 9). However, the energy spectrum of high-energy \( \text{e}^\pm \) CRs measured with H.E.S.S. (Aharonian et al. 2008, 2009) suggests a sharp break in the combined \( \text{e}^\pm \) spectrum below \( E \sim \text{ TeV} \). This is shown in Figure 10 where we plotted a smooth cutoff power-law fit to the combined \( \text{e}^\pm \) flux measured with AMS02 (Aguilar et al. 2014a) and with H.E.S.S (Aharonian et al. 2008, 2009) after normalizing the H.E.S.S data within their reported systematic errors to match the more precise AMS02 sub-TeV data. This fit yielded a break energy around 1 TeV.

Fermi acceleration of electrons is cutoff by synchrotron emission when the energy-loss rate by synchrotron radiation exceeds the energy gain by magnetic deflections. This synchrotron cutoff energy is given roughly by \( E \approx \sqrt{6/\sigma_T} B m_e c^2 \). However, the typical magnetic field \( B \) in SNRs, which are widely accepted as the main source of high-energy Galactic CR electrons, is well below 100 \( \mu \text{G} \). The corresponding synchrotron cutoff in the energy spectrum of CR \( \text{e}^+ \)'s accelerated in SNRs is expected to be at \( \gtrsim 1 \text{ PeV} \), well above that suggested by the H.E.S.S. data.
The observed flux of primary $e^-$ CRs is also cutoff when their radiative life becomes shorter than their travel time by diffusion from the source to Earth as discussed in Section 3. However, for the main Galactic sources, this cutoff is below the H.E.S.S. break. The H.E.S.S. cutoff could be a DM signal. However, the data of Fermi-LAT (Ackermann et al. 2010) and AMS02 (Aguilar et al. 2014a, 2014b) that have been published so far do not show any hint for such a break below TeV. Moreover, such a break, if real, still could be explained by standard astroparticle physics rather than as a DM signal. The origin of a break could be, for example:

(A) A reacceleration cutoff when the reacceleration time in the Galactic ISM exceeds the electrons’ lifetimes due to their radiative energy losses and escape from the Galaxy by diffusion.

(B) A CR $e^-$ “knee” at $E_{\text{knee}}(e^-) = (m_e/m_p)E_{\text{knee}}(p) \approx 1$ TeV in the spectrum of $e^-$ CRs, which are Fermi-accelerated together with protons and nuclei by the highly relativistic jets launched in SNe Ic to the same Lorentz factor distribution (e.g., Dar & De Rújula 2008). ($E_{\text{knee}}(p) \approx 2$ PeV is the CR “knee” in the flux per nucleon of CR nuclei.)

(C) A cutoff when the energy deposition rate of high-energy electrons in the ISM by highly relativistic jets can no longer compensate their energy loss by radiation and escape from the Galaxy by diffusion.

For other possible standard astroparticle physics origins of the H.E.S.S break see, e.g., Stawarz et al. (2010) and Cowsik et al. (2014).

7. CONCLUSIONS

Figures 1–4 demonstrate that standard astroparticle physics, such as positron production in the ISM in hadronic collisions of the primary CRs with gas in the local ISM and electron acceleration in a variety of Galactic sources, can explain the observed fluxes of CR electrons and positrons near Earth, which were measured with AMS02 (Accardo et al. 2014; Aguilar et al. 2014a, 2014b) without invoking a contribution from the annihilation/decay of DM particles. In particular, the hardening of the positron flux between 20 and 200 GeV can be due to the Klein–Nishina suppression of the energy loss of positrons by inverse Compton scattering from the DGL in the local ISM.

Neither the current published data on the spectra of the separate and combined $e^\pm$ CRs near Earth, nor the minimal
model fit by the AMS collaboration to their measured positron fraction (Accardo et al. 2014) provide compelling evidence or hints for a contribution from decay or annihilation of DM particles.

If the hadronic production of mesons in the local ISM at energies well above TeV becomes the main source of high-energy $e^\pm$ CRs near Earth, then the positron fraction should reach the asymptotic value $\approx 0.57$ (Cowsik & Burch 2010; Dado & Dar 2010), which is expected from the observed charge ratio $\mu^-/\mu^+ \approx 1.35$ of high-energy atmospheric and accelerator muons.

The existence of a break near TeV in the combined $e^\pm$ flux measured with H.E.S.S. still needs confirmation from independent and more precise measurements with instruments such as Fermi-LAT and the AMS. If verified, standard astroparticle physics may still explain it, as shortly discussed in Section 6. Moreover, any alternative interpretation of its origin, including DM decay/annihilation, must provide falsifiable predictions to establish its validity.

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