Physics Letters B 749 (2015) 267–271

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

‘Excess’ of primary cosmic ray electrons

Xiang Li[a,b], Zhao-Qiang Shen[a,b], Bo-Qiang Lu[a,c], Tie-Kuang Dong[a], Yi-Zhong Fan[a,d,*], Lei Feng[a,*], Si-Ming Liu[a], Jin Chang[a,d]

[a] *Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China*
[b] *University of Chinese Academy of Sciences, Beijing, 100012, China*
[c] *School of Physics, Nanjing University, Nanjing, 210092, China*
[d] *Collaborative Innovation Center of Modern Astronomy and Space Exploration, Nanjing University, Nanjing, 210046, China*

ARTICLE INFO

Article history:
Received 15 January 2015
Received in revised form 21 July 2015
Accepted 2 August 2015
Available online 6 August 2015
Editor: S. Dodelson

ABSTRACT

With the accurate cosmic ray (CR) electron and positron spectra (denoted as Φ_{e^-} and Φ_{e^+}, respectively) measured by AMS-02 Collaboration, the difference between the electron and positron fluxes (i.e., $\Delta\Phi = \Phi_{e^-} - \Phi_{e^+}$), dominated by the propagated primary electrons, can be reliably inferred. In the standard model, the spectrum of propagated primary CR electrons at energies ≥ 30 GeV softens with the increase of energy. The absence of any evidence for such a continuous spectral softening in $\Delta\Phi$ strongly suggests a significant ‘excess’ of primary CR electrons and at energies of 100–400 GeV the identified excess component has a flux comparable to that of the observed positron excess. Middle-age but ‘nearby’ supernova remnants (e.g., Monogem and Geminga) are favored sources for such an excess.

Thanks to the rapid progresses made in measuring the spectra of cosmic ray (CR) electrons and positrons, the presence of significant excesses in both the positron spectrum and the electron/positron total spectrum, with respect to the prediction of standard CR model [1], has been well established [2–6]. These excesses, attracting great attention, have been widely interpreted as a signal of dark matter annihilation/decay or alternatively the presence of new CR electron/positron sources [7]. In view of the spectral hardening displayed in the proton and heavier CR particle data of ATIC [8], CREAM [9] and PAMELA [10], it is quite natural to speculate that the primary CR electron spectrum also gets hardened at high energies (i.e., there is also an electron excess component, which just accounts for part of the total spectrum excess) and interesting observational signal is expected in AMS-02 data [11]. The joint fit of the positron-to-electron ratio ($\mathcal{R} = \Phi_{e^+}/(\Phi_{e^+} + \Phi_{e^-})$, where Φ is the flux) data and the positron/electron total flux data ($\Phi_{\rm tot} = \Phi_{e^+} + \Phi_{e^-}$) does favor such a possibility [11–13]. However, in the model of multiple pulsars for the positron excess [14] the primary-electron spectrum hardening/excess is found to be not needed. Such a “divergency” demonstrates that it is necessary to “identify” the excess as model-independent as possible, which is the main goal of this work.

For such a purpose we focus on the data of $\Delta\Phi = \Phi_{e^-} - \Phi_{e^+}$ (see the upper left panel of Fig. 1) that is dominated by the propagated primary CR electrons and can *“minimize” the possible uncertainties of the identified excess caused by the introduction of the “new” source(s) for the positron excess*. Such a treatment is only possible currently thanks to the release of the AMS-02 electron/positron spectra with unprecedented accuracy in a wide energy range [5,6]. The spectral index of $\Delta\Phi$ evolving with the energy of electrons is shown in the upper right panel of Fig. 1 (we slide the energy window covering the energy range of every 5 neighboring data bins, within which the power law spectral index and its error are obtained) and there is not any evidence for spectral softening at $\epsilon_e > 20$ GeV where the solar modulation of cosmic ray fluxes is negligible. It is in agreement with the empirical fit of the latest AMS-02 electron/positron data with the “minimal model” of [4], in which the so-called “diffuse” electron component dominating $\Delta\Phi$ can be well approximated by a signal power-law up to the energy of ~ 500 GeV [5,15]. Such a simple behavior, however, is actually unexpected in the standard/conventional CR propagation model, in which CRs are thought to originate in homogeneously-distributed supernova remnants and the primary electrons from different sources are assumed to take a single power-law energy distribution for $\epsilon_e >$ quite a few GeV [1,16]. The higher the ϵ_e, the quicker the cooling of the diffusing electrons. The cooling timescale of electrons/positrons is $\tau_c \sim 17$ Myr $(\epsilon_e/10~\mathrm{GeV})^{-1}$ while the proton CR age is estimated to be $\tau_a \sim 20$ Myr $(\epsilon_e/2.6~\mathrm{GeV})^{-0.53}$

---

* Corresponding authors at: Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China.
E-mail addresses: yzfan@pmo.ac.cn (Y.-Z. Fan), fenglei@pmo.ac.cn (L. Feng).

http://dx.doi.org/10.1016/j.physletb.2015.08.001

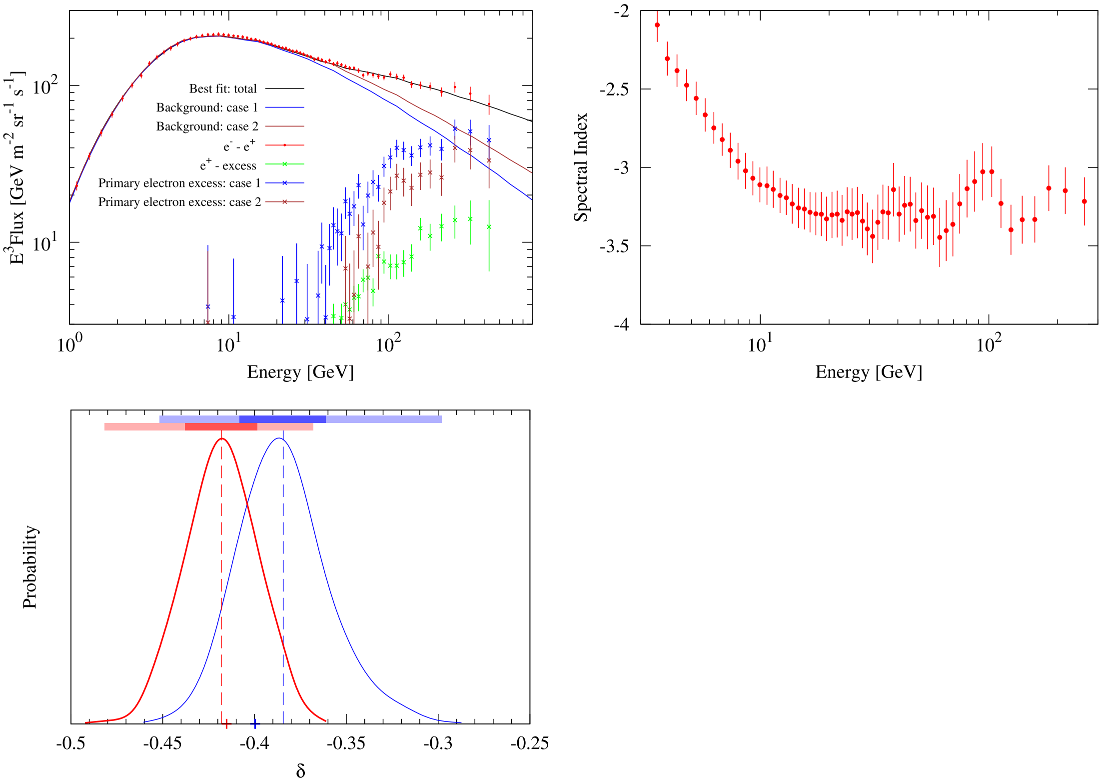

Fig. 1. Upper left panel: E^3Flux as a function of energy of the electrons/positrons. The Φ_{e^+} and Φ_{e^-} data are taken from [5,6]. Upper right panel: the spectral index of $\Delta\Phi$ evolving with the energy of the electrons. Lower panel: The probability distribution of δ found in numerical simulations with our own code [11] based on the COSMOMC (http://cosmologist.info/cosmomc/). The horizontal bar indicates the 1σ and 3σ standard deviations, and the vertical dashed line (cross) represents the statistic-mean (best-fit) value. The color blue (red) represents the result of DR (DC) propagation model. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

for $\epsilon_e \geq 2.6$ GeV [1,17]. It is reasonable to assume that the primary CR electrons and protons were from the same sources and thus at the same ages, we can then define a "cooling" energy ($\epsilon_{e,c} \sim 30$ GeV given by $\tau_c = \tau_a$) of the electrons above which the cooling softens the spectrum effectively. As a result of the superposition of the particles from different sites, the spectrum of propagated primary electrons would be continually softened. Indeed a general behavior found in the numerical calculations is that at $\epsilon_e > 10$ s GeV the spectrum of the propagated primary CR electrons gets softer and softer and the softening between the energy ranges of 100–400 GeV and 10–50 GeV is $\sim \epsilon_e^{-0.2}$ (see for example the "background" component of Fig. 1 and Fig. 2 of [18]). The inconsistence between the data and the prediction of the conventional CR model likely suggests a significant spectral excess at high energies, which could arise from for example a group of nearby supernova remnants [19,20,11,21–23].

Please bear in mind that the puzzling non-softening spectral behavior of propagated primary electrons could be just an illusion if in deriving $\Delta\Phi$ either "(a) too much electron flux has been subtracted at lower energies" or "(b) too little electrons have been removed at high energies". If scenario (a) is correct (i.e., Φ_{e^+} overestimates the corresponding electron flux at low energies significantly and the 'intrinsic' $\Delta\Phi$ is as large as the standard CR model prediction), we need $\Phi_{e^+} \sim 0.4\Phi_{e^-}$ at $\epsilon_e \sim 10$ GeV, which has already been convincingly ruled out by the $\mathcal{R}$ data of AMS-02. As for scenario (b), we have assumed that the sources giving rise to the positron excess component do not generate more abundant electrons at given energies, which is the case for the most widely discussed new CR-electron/positron sources include pulsars [24] and dark matter annihilation/decay [25,26], for which the electrons/positrons were born in pairs. (One exception is the so-called asymmetric dark matter model, in which the possibility of decaying into electrons and positrons does not equal with each other [27].) Moreover, for the collision of high energy CRs with other particles/photons taking place in both the interstellar medium and the CR sources, it is well known that among the resulting secondary particles the positrons are more (rather than less) than electrons [1,7,28]. For instance, the most-widely discussed proton–proton and proton–Helium collisions in the interstellar medium (these processes have also been properly taken into account in our numerical fit of $\Delta\Phi$, see below) yield charged pions and kaons, which further decay as $K^\pm \to \pi^\pm + \pi^0$, $K^\pm \to \mu^\pm + \nu_\mu$, $\pi^\pm \to \mu^\pm + \nu_\mu$ and $\mu^\pm \to e^\pm + \bar{\nu}_\mu + \nu_e$. At $\epsilon_e \gg 1$ GeV, the secondary electrons have a flux about half of the corresponding positrons [1,7]. Hence the hypothesis described in scenario (b) does not apply, either. So far we have shown that the non-softening spectral behavior of propagated primary electrons is reliable.

The propagation of CR can be described by a *transport equation* including diffusion, convention, re-acceleration, radioactive and so on [1]. As usual we adopt the GALPROP [16] package to calculate the propagation of the CR particles numerically. The diffusion–reacceleration (DR) and diffusion–convection (DC) models are introduced to discuss the systematic uncertainty of CR propagation. The CR propagation parameters are fixed in our discussion, which can reasonably fit the observational B/C, ^{10}Be/^{9}Be and proton data. To be precise, we use parameters in [30,31] when discussing DR model, while we fix the propagation parameters [13,29] and fit the latest AMS-02 proton data [32] to get proton injection parameters in DC model. The main parameters we used are summarized in Table 1. To account for the possible spectrum "hardening" of the injected primary electrons, three spectral indexes (Γ_1, Γ_2, Γ_3)