IL NUOVO CIMENTO Vol. 34 C, N. 3 Maggio-Giugno 2011
DOI 10.1393/ncc/i2011-10877-x

Colloquia: Scineghe2010

# A consistent interpretation of recent CR nuclei and lepton spectra

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(ricevuto il 25 Febbraio 2011; pubblicato online il 18 Maggio 2011)

**Summary.** — We show that a double component scenario computed in a Kraichnan-like diffusion setup (which is suggested by B/C and $\bar{p}$ data) gives a satisfactory fit of the recently updated measurement of the cosmic ray electron (CRE) spectrum observed by Fermi-LAT, together with PAMELA data on positron fraction. We confirm that nearby pulsars are good source candidates for the required $e^{\pm}$ extra-component and we show that the predicted CRE anisotropy in our scenario is compatible with Fermi-LAT recently published constraints.

PACS 96.50.S- – Cosmic rays.
PACS 98.70.Sa – Cosmic rays (including sources, origin, acceleration, and interactions).

## 1. – Introduction

Last year the Fermi-LAT Collaboration published the $e^+ + e^-$ spectrum in the energy range between 20 GeV and 1 TeV, measured during the first six months of the Fermi mission [1]. That result came in the middle of an interesting debate which arose after PAMELA Collaboration reported that the positron fraction increases with energy above 10 GeV; a feature which is not compatible with the standard scenario in which CR electrons are accelerated in supernova remnants (SNRs) and positrons are predominantly of secondary origin. The observed Fermi-LAT spectrum is compatible with a single power law with index $3.045 \pm 0.008$ and it is in agreement with the observations of the H.E.S.S. atmospheric Cherenkov telescope below 1 TeV. Recently, the Fermi-LAT Collaboration released a new measurement of the CRE spectrum based on one-year data. The observed spectrum extends down to 7 GeV [2] and is confirmed to be compatible with a single power law with a spectral index $3.08 \pm 0.05$. Hints of a deviation from a pure power law behavior, already found in the six-month data, are still present in the updated spectrum, whose low energy part is compatible with pre-Fermi measurement and not reproduced by the models proposed, *e.g.*, in [3]. Moreover, after the release of PAMELA antiproton data some of us used (see [4]) the recently developed `DRAGON`([1]) package [5] to perform a combined maximum-likelihood analysis on B/C and antiproton datasets and found that a model based on a Kraichnan-like turbulence is the most adequate to describe the nuclei CR measurements. Both these results gives a reason to revise the models described in [3] based on the conventional Kolmogorov setup.

## 2. – The propagation setups

The CR propagation in the Galaxy is described by a well-known diffusion-loss equation which can be solved analytically, under simplifying assumptions, or numerically, making use of `DRAGON` or `GALPROP` packages. This equation includes several free parameters which need to be tuned by comparison with data: $D_0$ and $\delta$, *i.e.* the normalization and energy dependence of the diffusion coefficient, the Alfvén velocity $v_A$ which parametrizes the level of reacceleration, the height of the Galactic diffusion region $z_h$, and the injection index of the CR species $\gamma_p$. Moreover, when considering data below a few GeV/n also the modulation due to solar activity plays a significant role and must be taken into account. We assume here a model of propagation obtained as the result of a combined maximum-likelihood analysis based on B/C and $\bar{p}/p$ measurements [4]. The model is grounded on a Kraichnan spectrum for the galactic turbulent magnetic field, hence $\delta = 1/2$ and a small reacceleration $v_A = 15\,\mathrm{km/s}$. See [6] for a discussion of other propagation models.

## 3. – Two components models

In the following we try to reproduce all data in the framework of a two-component scenario. The first component (standard) consists of electrons accelerated in SNRs. The second one (extra-component) is made of $e^-$ and $e^+$ injected in the ISM with a common spectrum of this kind: $Q_{e^\pm}(E) = Q_0(E/E_0)^{-\gamma_{e^\pm}} e^{-E/E_{\mathrm{cut}}^{e^\pm}}$, where the injection index is harder: $\gamma_{e^\pm} < 2$ and the same spatial distribution as the standard. We tune the standard component to reproduce both the $e^- + e^+$ spectrum measured by Fermi-LAT and the $e^+/(e^- + e^+)$ measured by PAMELA below 20 GeV, where the effect of the extra component is supposed to be negligible. Remarkably, this is possible only if we use propagation setups with low reacceleration. The required source spectral slopes for the electron standard component is $\gamma_{e^-} = 2.00/2.65$ below/above 4 GeV for this propagation model. Such index is quite steep if compared to theoretical predictions regarding Fermi acceleration mechanism, but we remind the reader that we modeled the standard component in the approximation of a cylindrically symmetric source distribution, which may be less realistic for high energy electrons where the local distribution is relevant. Accounting for the spiral arm distribution of SNRs may result in a different requirement for the injection index. Then we tune the extra-component to reproduce Fermi-LAT and H.E.S.S. high-energy CRE data. We find that this is possible by taking $\gamma_{e^\pm} = 1.5$ and $E_{\mathrm{cut}} = 1.0$–$1.5\,\mathrm{TeV}$ (see fig. 1). It is remarkable that such a relatively simple approach allows to reproduce such a large number of observations.

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([1]) Code available at `http://www.desy.de/~maccione/DRAGON/`

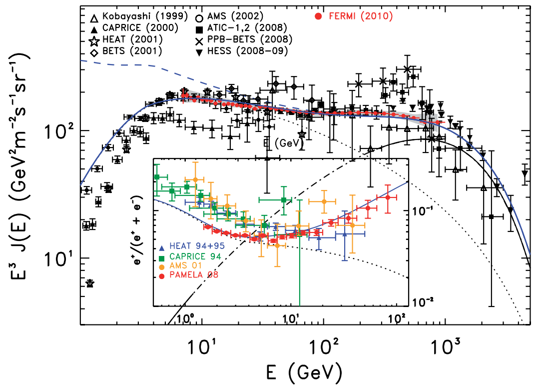
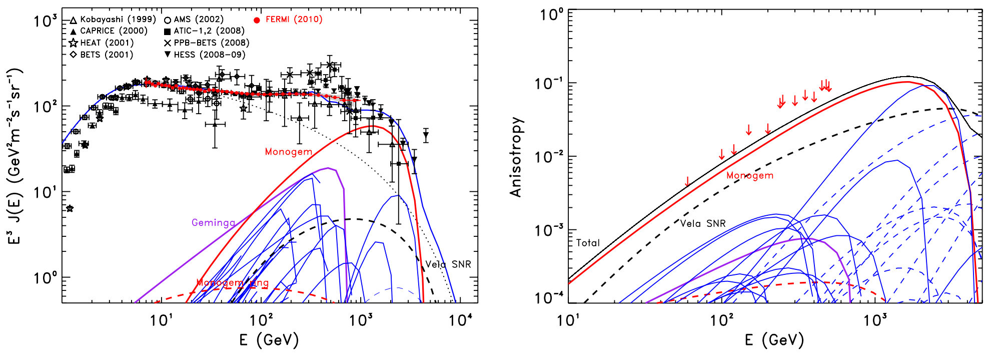



Fig. 1. – (Colour on-line) The $e^- + e^+$ total spectrum and positron fraction (in the box) for our two-component model. Dotted line: propagated standard component with injection slope $\gamma_{e^-} = 2.00/2.65$ above/below 4 GeV and $E_{\rm cut}^{e^-} = 3\,{\rm TeV}$; dot-dashed line: $e^\pm$ component with $\gamma_{e^\pm} = 1.5$ and $E_{\rm cut}^{e^\pm} = 1.4\,{\rm TeV}$. Blue solid line: modulated total spectrum ($\Phi = 550$ MV). Blue dashed: LIS total.

## 4. – The role of astrophysical nearby sources

The nature of the extra-component of primary electrons and positrons that we invoked in the previous section is an intriguing matter of debate, and the possible scenarios include both an exotic explanation (involving annihilation or decay of Particle Dark Matter) or a purely astrophysical interpretation. Here we concentrate on the second possibility. Differently from the previous section, we treat the extra component as originating from a discrete collection of sources; we then treat electron and positron propagation from those sources to the Solar System by solving analytically the diffusion-loss equation. There are basically two classes of objects we consider: SNRs (as sources of *electrons only*) and pulsars (as sources of *electron+positron pairs*). The possibility that electrons and positrons from nearby pulsars can dominate the high energy tail of the CRE spectrum and explain the rising behavior of the positron fraction was already proposed in [8] and studied in more recent papers (see *e.g.* [9, 10]). We model the emission from SNRs and pulsars as a point-like burst; for pulsars we also introduce a time delay with respect to the birth of the object: such a delay is motivated by the fact that electrons and positrons are expected to be trapped in the PWN until it merges with the ISM. We assume that for both SNRs and pulsars particles are injected with a power law spectrum up to an exponential cutoff; the injection index is however set in a different way for the two classes of objects. We considered all observed SNRs within 2 kpc as taken from the Green catalogue [11] and the pulsars within 2 kpc from Earth taken from the ATNF catalogue [12]. We verified that more distant objects give a negligible contribution. In fig. 2(a) we represent the CRE spectrum obtained for a reasonable combination of parameters, namely: for SNRs: spectral index $\gamma_{e^-{\rm SNR}} = 2.2$, cutoff energy $E_{\rm cut}^{\rm SNR} = 2\,{\rm TeV}$, electron energy release per SN $E^{\rm SNR} = 2 \times 10^{47}$ erg; for pulsars: $\gamma_{e^\pm} = 1.5$, cutoff energy $E_{\rm cut} = 1\,{\rm TeV}$, efficiency $\eta_{e^\pm} \simeq 30\%$. We see from fig. 2(a) that the main contribution comes from Monogem pulsar; this is due to the proximity of this source and to the introduction of the delay. It is important to check if these results are compatible with recently published upper limits on the anisotropy in $e^-+e^+$ flux [7]. Our prediction is plotted in fig. 2(b). The important




(a) (b)

Fig. 2. – (Colour on-line) The computed CRE flux from both nearby (within 2 kpc) SNRs and pulsars is added to the standard component. Panel a): $e^+ + e^-$ spectrum. Panel b): the integrated expected anisotropy, as a function of minimum energy, is compared to Fermi-LAT upper limits [7].

result is that our scenario is not excluded by anisotropy measurements; the reader may notice that the Monogem pulsar (red solid line) and the Vela SNR (black dashed line) contribute most to the total anisotropy (the black solid line). However, the total expected anisotropy is very close to the measured upper limit, so that a future detection at level $\sim 1\%$ at $\sim 1$ TeV towards the portion of the sky where Vela and Monogem are located is to be expected in the next years.

## 5. – Conclusions

The spectacular data on CR electrons and positrons, together with measurements on light nuclei and antiprotons, suggest that a double-component approach to the leptonic part of CRs computed in the framework of a Kraichnan-like turbulence provides a good self-consistent scenario which satisfactorily reproduces all existing observations. In this picture, in addition to the conventional component accelerated in SNRs, a contribution from pulsars, as emitters of electron+positron pairs, permits to correctly fit both the features revealed by Fermi-LAT in the CRE spectrum and the $e^+/(e^+ + e^-)$ measured by PAMELA. The expected anisotropy in the direction of the most prominent CRE candidate source, Monogem pulsar, is compatible with the present upper limit just released by Fermi-LAT Collaboration and may be detectable in a few years.

REFERENCES


[1] Abdo A. A. *et al.*, *Phys. Rev. Lett.*, **102** (2009) 181101.
[2] Ackermann M. *et al.*, *Phys. Rev. D*, **82** (2010) 092004.
[3] Grasso D. *et al.*, *Astropart. Phys.*, **32** (2009) 140.
[4] di Bernardo G., Evoli C., Gaggero D., Grasso D. and Maccione L., *Astropart. Phys.*, **34** (2010) 274.
[5] Evoli C., Gaggero D., Grasso D. and Maccione L., *J. Cosmol. Astropart. Phys.*, **10** (2008) 18.
[6] Di Bernardo G., Evoli C., Gaggero D., Grasso D., Maccione L. and Mazziotta M. N., arXiv:1010.0174 [astro-ph.HE] (2010).

[7] Ackermann M. *et al.*, *Phys. Rev. D*, **82** (2010) 092003.
[8] Aharonian F. A., Atoyan A. M. and Voelk H. J., *Astron. Astrophys.*, **294** (1995) L41.
[9] Hooper D., Blasi P. and Dario Serpico P., *J. Cosmol. Astropart. Phys.*, **1** (2009) 25.
[10] Profumo S., arXiv:0812.4457 [astro-ph] (2008).
[11] Green D. A., *Bull. Astron. Soc. India*, **37** (2009) 45.
[12] Manchester R. N., Hobbs G. B., Teoh A. and Hobbs M., *Astrophys. J.*, **129** (2005) 1993.