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Roberto A. Lineros[1,0], **Torsten Bringmann**[2], **Fiorenza Donato**[3]

[1]IFIC, CSIC-Universidad de Valencia, Ed. Institutos,Apdo. Correos 22085, E–46071 Valencia, Spain & MultiDark fellow

[2] II. Institute for Theoretical Physics, University of Hamburg, Luruper Chausse 149, D–22761 Hamburg, Germany

[3] Dipartimento di Fisica Teorica, Università di Torino, Istituto Nazionale di Fisica Nucleare, via P. Giuria 1, I–10125 Torino, Italy

E-mail: rlineros@ific.uv.es

Abstract. The interaction between the galactic magnetic field and the non-thermal population of electrons is responsible for a large part of the radio sky from 10 MHz up to several GHz. This population is mostly composed of electrons with primary and secondary origin. Cosmic ray propagation models describe their evolution in space and energy, and allow to study the impact on the radio sky in intensity and morphology at different frequencies. We consider different propagation models and test their compatibility with available radio maps. We find models highly consistent both with B/C data, the local electron flux and synchrotron emission observations. The resulting constraints on propagation models could significantly improve prospects for indirect dark matter searches in these channels and, even more so, in antiprotons.

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1. Introduction

The emission of synchrotron radiation from a non-thermal population of electrons and positrons (from here simply refer to both as *electrons*) has given one of the first insights that Galactic cosmic rays (CR) propagate diffusively inside a magnetic halo which extends far beyond the distribution of gas and stars.

This evidence came from observations of extended radio haloes around edge-on galaxies. Current CR observations are nicely explained by semi–analytical propagation models which incorporate physical processes that typically happen in the Galactic environment. These models have been successfully tested and reproduce the observations with reasonible precision. Despite this precision, however, there is still a big degeneracy in the propagation parameters. These type of uncertainties highly affect possible dark matter searches based on CR observations. In this work, we study the possible effects of different propagation models on the radio sky. Further details can be found in Ref. [1].

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Model	L_z [kpc]	K_0 [kpc^2/Myr]	δ
min	1	0.0016	0.85
med	4	0.0112	0.70
max	15	0.0765	0.46

Table 1. Benchmark propagation models compatible with nuclear CR observations [6].

2. Electron propagation and synchrotron radiation

Electrons produced by Galactic sources travel across the Galaxy, interacting on their way with the radiation fields, the interstellar gas, and the Galactic Magnetic Field (GMF). The propagation of electrons is modeled consistently with the propagation of nuclear CR by using a successfully tested two–zone propagation model [**?**] in which electrons are confined by the GMF inhomogeneities to a cylinder, centered on the Galactic Center and oriented with the Galactic plane, with radius $R_g = 20$ kpc and vertical length L values between 1 and 15 kpc. Similar to nuclear CR, the propagation is described by a transport equation which for the case of electrons reads

$$-K_0(E/E_0)^\delta \nabla^2\psi - \frac{\partial}{\partial E}\big(b(E)\psi\big) = q(\mathbf{x}, E)\,. \quad (1)$$

Here, ψ is the number density of electrons per unit of energy, $b(E)$ is the energy loss term (for a further discussion of this term, see Sec. 3), $q(\mathbf{x}, E)$ is the *electron* source term, and E_0 is an energy scale with value of 1 GeV. We take into account that electrons have both a primary and a secondary origin [2] while positrons are only produced as secondaries [3]. The parameters K_0 and δ parameterize the diffusion constant; together with L they provide the most important parameters of the model. Different configurations produce different propagation models, each one with proper features in the predicted CR fluxes. The parameter space can be constrained by nuclear CR observations like boron over carbon ratio (B/C), radioactive isotopes (i.e. ^{10}Be/^{9}Be) and the antiproton to proton ratio ($\bar{p}/p$) [4, 5, 6]. More details may be found in Ref. [1] and references therein.

In our study, we consider three benchmark propagation models [6] *min*, *med*, and *max* (Tab. 1). The *min* and *max* models produce extreme behaviors (with respect to the *antiproton* signal expected from dark matter annihilation) which are still compatible with CR observations. The *med* model is very close to the best-fit point of the secondary/primary analysis. Let us comment that CR fluxes are measured with relatively small errors. The constrained space of parameters is still quite degenerate and allows, e.g., for rather big variations in the size L of the diffusion zone.

Together with the propagation, the interaction of CR *electrons* with the GMF will inevitably produce synchrotron radiation [7]. For an average magnetic field intensity of $\mathcal{O}(\mu\text{G})$ [8] and *electron* energies in the MeV–GeV range, the emission will be in the MHz–GHz range, i.e. at radio frequencies. This provides a link on how radio data and CR electrons are related. In order to compare the observations with predictions from propagation models, we calculate the synchrotron emissivity and integrate it along the line of sight (details in Ref. [1]). We consider 11 sky-maps at frequencies 0.010, 0.022, 0.045, 0.408, 1.42, 2.326, 23, 33, 41, 61 and 94 GHz. These were generated using a public software [9], which includes a compilation of several radio surveys in the frequency range between 10 MHz and 94 GHz.

3. Discussion and summary

We compare propagation model predictions with radio data using different approaches: frequency spectrum, *electron* CR flux at Earth, and morphology. Each of those reveals different

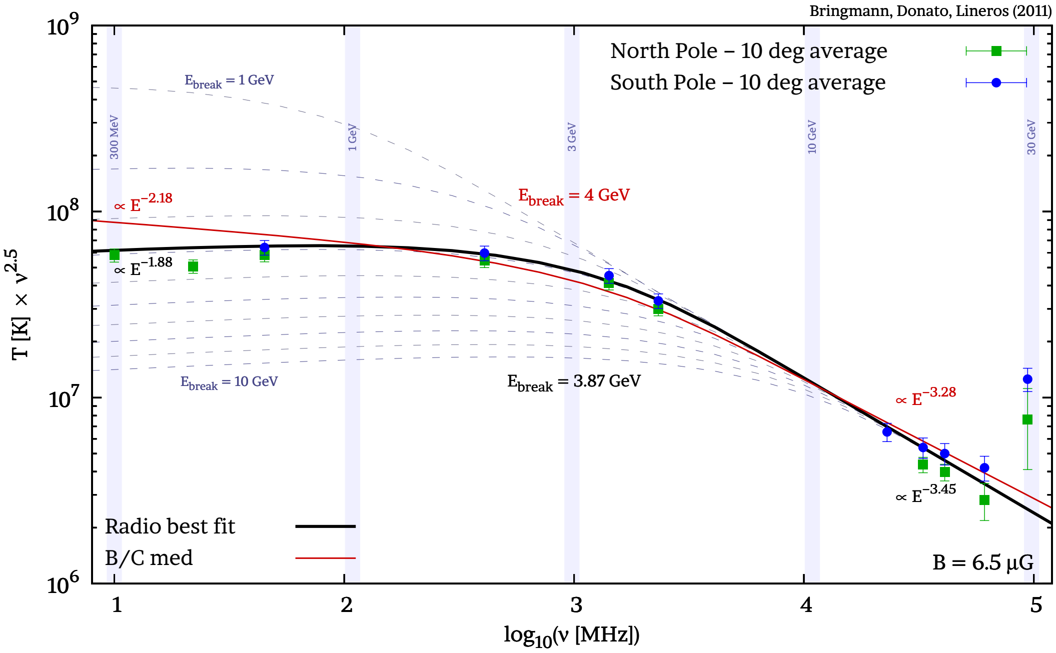

Figure 1. Temperature versus frequency (taken from Ref. [1]). The black line corresponds to the emission from an effective (propagated) electron distribution that follows a broken power-law with indices -1.88 and -3.45. The red line shows the emission from propagated electrons in the *med* model, with an energy loss term described by a broken power-law with indices 0.9 and 2 for low and high energies, respectively. The data points correspond to 10° angular averages in the direction of North and South poles and were calculated with the software described in Ref. [9].

features that help to understand the connection with the propagation model. In figure 1, we present the comparison in terms of the frequency spectrum. The observed frequency spectrum presents a shape resembling a broken power–law with indices ~ 2.5 below, and ~ 3.2 above, a break around 800 MHz. This shape in the frequency spectrum should be related to a similar behaviour in the (propagated) *electron* distribution. In fact, the frequency spectrum can be reproduced by a distribution of propagated *electrons* modeled by a broken power–law described by indices $(1.88, 3.45)$, with an energy break at 3.86 GeV (black line). Also, we calculate the prediction of the propagation model (red line). We find that a possible explanation of this frequency break could be that energy losses from bremsstrahlung and gas ionization start to dominate over inverse Compton scattering; these terms will induce a break in the energy loss term in eq. 1 that provides an alternative to the conjectured break in the injection spectrum of primary electrons [10]. A more thorough discussion is presented in [1] where the comparison with the *electrons* flux data is also addressed.

Another interesting prediction coming from different propagation models is the radio morphology. In figure 2, we calculate the emission at different latitudes (b), where the galactic anti-center is at $b = 0°$. We find that observations at 408 MHz and 1.42 GHz are in better agreement with a typical diffusive halo size of $L \sim 4$ kpc than with halo sizes as large as 15 kpc or as small as 1 kpc. This provides first indications that a complementary and/or independent analysis of the propagation model parameters can be done using radio data.

The connection between radio data and CR physics relates two rather different research fields. Making use of this connection would increase the possibilities to obtain a better global picture of Galactic diffusion processes. The reduction of the uncertainties in CR physics will affect

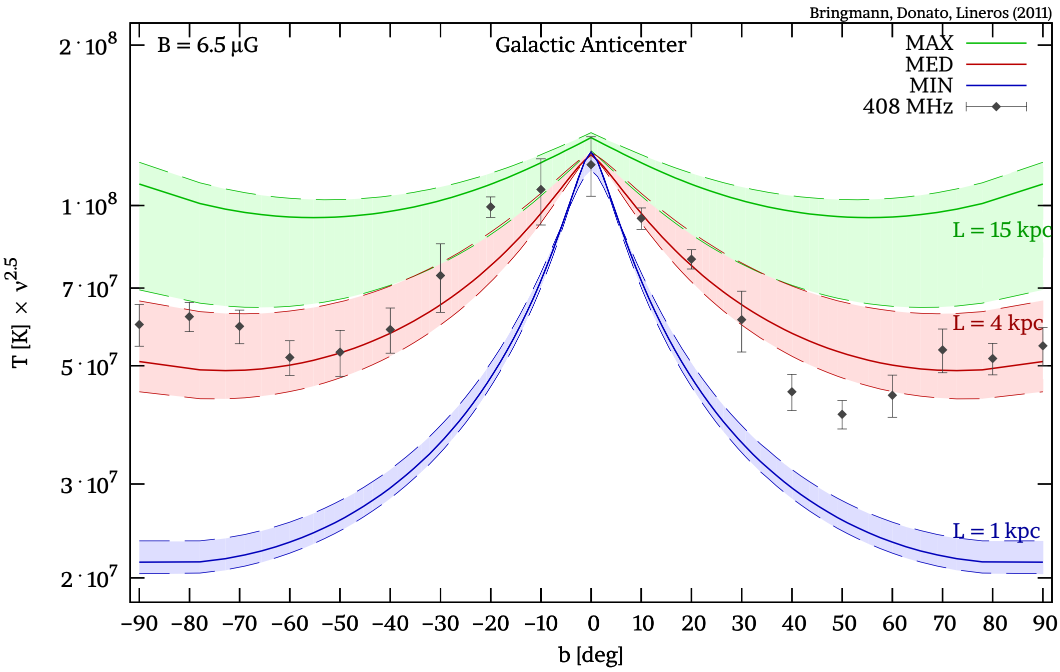

Figure 2. Temperature at 408 MHz versus galactic latitude (taken from Ref. [1]). The emission produced by the three propagation models of Tab. 1 (solid lines) and uncertainty bands for fixed L are shown (resulting from the variation of all other propagation parameters within the bounds allowed by B/C). Models with $L \lesssim 1$ kpc and $L \gtrsim 15$ kpc are clearly disfavoured by observations. Data points correspond to 10° averages.

tremendously Dark Matter searches due to a better control of the background and, for the case of antiprotons even more important, greatly reduced uncertainties in the predicted flux from dark matter annihilation.

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[1] Bringmann T, Donato F and Lineros R A 2012 *JCAP* **2012** 049 (*Preprint* `1106.4821`)
[2] Delahaye T, Lavalle J, Lineros R, Donato F and Fornengo N 2010 *A & A* **524** A51 (*Preprint* `1002.1910`)
[3] Delahaye T, Lineros R, Donato F, Fornengo N, Lavalle J, Salati P and Taillet R 2009 *A & A* **501** 821–833 (*Preprint* `0809.5268`)
[4] Maurin D, Donato F, Taillet R and Salati P 2001 *APJ* **555** 585–596 (*Preprint* `astro-ph/0101231`)
[5] Maurin D, Taillet R and Donato F 2002 *A & A* **394** 1039–1056 (*Preprint* `astro-ph/0206286`)
[6] Donato F, Fornengo N, Maurin D, Salati P and Taillet R 2004 *PRD* **69** 063501 (*Preprint* `astro-ph/0306207`)
[7] Berezinskii V, Bulanov S, Dogiel V, Ginzburg V and Ptuskin V 1990 *Astrophysics of Cosmic Rays* (North Holland)
[8] Han J L 2009 *IAU Symp.* **259** 455 (*Preprint* `0901.1165`)
[9] de Oliveira-Costa A, Tegmark M, Gaensler B M, Jonas J, Landecker T L and Reich P 2008 *MNRAS* **388** 247–260 ISSN 1365-2966
[10] Strong A W, Orlando E and Jaffe T R 2011 *A & A* **534** A54+ ISSN 1432-0746 (*Preprint* `1108.4822`)