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EDITED BY
Jia-Shu Niu,
Shanxi University, China

REVIEWED BY
Mattia Di Mauro,
National Institute of Nuclear Physics of Turin, Italy
Yi-qing Guo,
Institute of High Energy Physics (CAS), China

*CORRESPONDENCE
P. De la Torre Luque,
pedro.delatorreluque@fysik.su.se
D. Gaggero,
daniele.gaggero@ific.uv.es
D. Grasso,
dario.grasso@pi.infn.it
A. Marinelli,
antonio.marinelli@na.infn.it

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Prospects for detection of a galactic diffuse neutrino flux

P. De La Torre Luque[1]*, D. Gaggero[2]*, D. Grasso[3,4]* and A. Marinelli[5,6,7]*

[1]Stockholm University and the Oskar Klein Centre for Cosmoparticle Physics, Stockholm, Sweden, [2]Instituto de Física Corpuscular Universidad de Valencia and CSIC Edificio Institutos de Investigacíon, Paterna, Spain, [3]INFN Sezione di Pisa Polo Fibonacci, Pisa, Italy, [4]Dipartimento di Fisica Università di Pisa, Polo Fibonacci, Pisa, Pontecorvo, [5]Dipartimento di Fisica "Ettore Pancini" Università Degli Studi di Napoli "Federico II" Complesso Univ. Monte S. Angelo, Napoli, Italy, [6]INFN—Sezione di Napoli Complesso Univ. Monte S. Angelo, Napoli, Italy, [7]INAF Osservatorio Astronomico di Capodimonte, Napoli, Italy

A Galactic cosmic-ray transport model featuring non-homogeneous transport has been developed over the latest years. This setup is aimed at reproducing γ-ray observations in different regions of the Galaxy (with particular focus on the progressive hardening of the hadronic spectrum in the inner Galaxy) and was shown to be compatible with the very-high-energy γ-ray diffuse emission recently detected up to PeV energies. In this work, we extend the results previously presented to test the reliability of that model throughout the whole sky. To this aim, we compare our predictions with detailed longitude and latitude profiles of the diffuse γ-ray emission measured by Fermi-LAT for different energies and compute the expected Galactic ν diffuse emission, comparing it with current limits from the ANTARES collaboration. We emphasize that the possible detection of a Galactic ν component will allow us to break the degeneracy between our model and other scenarios featuring prominent contributions from unresolved sources and TeV halos.

KEYWORDS

galactic cosmic rays, cosmic-ray transport, diffuse gamma rays, high energy gamma rays, diffuse neutrinos, galactic plane

1 Introduction

The Tibet ASγ and LHAASO collaborations recently provided the first evidence of a diffuse γ-ray emission from the Galactic plane up to energies reaching the PeV (Amenomori et al., 2021; Zhao et al., 2021). Since this emission is expected to be originated by the interaction of cosmic ray (CR) particles with the interstellar medium (ISM) and interstellar radiation fields (ISRFs), the Tibet ASγ and LHAASO measurements offer a new valuable handle to study the origin and the propagation of Galactic CRs at energies never probed before ($\gg$ 100TeV).

The presence of a truly diffuse γ-ray at ~PeV is likely due to $\sim\mathcal{O}(10)$ PeV CRs injected by galactic PeV accelerators that were active in the past, the so-called *PeVatrons*. The ability to explore the *knee* region (E_{CR}~few PeV′s) of the CR spectrum is of outstanding importance for our understanding of CR physics. Indeed, if we assume the conventional scenario of Supernova Remnants (SNRs) as sources of the bulk of Galactic CRs, it is a theoretical challenge to even achieve particle acceleration at the level of $\sim\mathcal{O}(100)$ TeV (Lagage and Cesarsky, 1983). To overcome this problem, stellar clusters have recently come back as a viable explanation for such high-energy particle acceleration (Cesarsky and Montmerle, 1983), although it is not clear up to what extent in the locally observed CRs.

Whether the *knee* in the CR spectrum is due to a change in the CR acceleration mechanism or to a transport effect (see *e*.g. Thoudam, S. et al. (2016)) is also matter of debate. Moreover–since due to spallation losses at those energies CR reaching the Earth must be originated within few kpc's–it is not even clear if this feature is representative of the whole CR Galactic population or is shaped by local effects. The detection of γ-ray Galactic diffuse emissions above 100 TeV may offer a new valuable handle to clarify those conundrums.

Moreover, since that emission is likely to be dominated by hadronic processes–this due both to the larger abundance of CR nuclei respect to leptons and the increasing IC and synchrotron losses which prevent very energetic leptons from getting far from the acceleration region–a corresponding diffuse Galactic ν emission is also expected (see *e.g.* Berezinsky et al., 1993; Evoli et al., 2007 and the more recent Ahlers et al., 2016; Gaggero et al., 2015a). Noticeably, after almost 10 years the birth of high energy ν astronomy (Aartsen et al., 2014), the experimental search of the Galactic ν diffuse emission has just started (Albert et al., 2017, 2018) and a detection hint (2σ) was recently reported by the IceCube collaboration (Aartsen et al., 2019). Forthcoming dedicated analysis of IceCube and ANTARES data as well as those of KM3NeT (Adrián-Martínez et al., 2016), presently under advanced construction, should soon provide stronger evidences. Interestingly, a recent analysis of the IceCube public track-like events above 200 TeV–performed externally to the collaboration–claimed a 4.1σ detection of a neutrino diffuse emission along the Galactic Plane (GP).

Neutrinos will offer a valuable complementary probe of the CR population of the Galaxy. In fact, they are not subject to absorption–which is significant for γ-rays above 100 TeV (see below)—and can allow to single out the CR hadron component. This may be especially helpful to quantify and subtract the contribution of unresolved sources to the observed γ-ray diffuse emission which is expected to be dominated by leptonic sources (see *e.g.* Casanova and Dingus (2008); Vecchiotti et al. (2021)).

The interpretation of those measurements needs to compare the observed γ-ray and ν emissions among themselves and against detailed simulated templates of the diffuse γ-ray and ν diffuse emissions of the Galaxy. Those simulations require advanced numerical packages to model CR transport and interactions for given source and interstellar gas and radiation distributions as inferred from astronomical observations of proper tracers. Well known examples of these packages are the GALPROP code (Strong and Moskalenko, 1998) which was extensively used by the Fermi-LAT collaboration or the more recently developed PICARD code (Kissmann, 2014). In this work we use the DRAGON2 code (Evoli et al., 2017, 2018)—to model CR transport–in combination with the recently released HERMES (Dundovic et al., 2021)—to produce simulated spectra and maps of the γ and ν diffuse emissions.

DRAGON2 is built to model CR transport under very general conditions. In particular, it allows to account for a dependence of the diffusion coefficient on rigidity and position which was invoked in order to explain the hardening of the γ-diffuse emission above 10 GeV observed by Fermi-LAT in the inner GP (Gaggero et al., 2015b; Guo and Yuan, 2018; Lipari and Vernetto, 2018) and motivated theoretically in Cerri et al. (2017).

Recently, we presented a model of inhomogeneous transport of CRs able to explain the current diffuse γ-ray data from the GeV to the PeV range throughout several regions of the sky Luque et al. (2022). In this work, we provide more details about that model, examine the predicted ν emission expected from such model and compare it with the model-independent limits posed by the ANTARES experiment.

2 The γ—Optimized models

Motivations: The transport of CR particles in the Galaxy is far from being well understood. Due to the complexity of the microphysics that describes the interactions of relativistic charged particles with the magneto-hydro-dynamic fluctuations, a fully satisfactory theoretical framework that describes how CRs are accelerated within astrophysical sources and subsequently propagate through the Galaxy is still far from being reached. Moreover, the measurements of CR spectra are limited to the vicinity of the Earth, preventing us from having information about the transport in other parts of the Galaxy. In addition, precision measurements of the CR spectra are limited to the energy region between a few hundreds of MeV to a few TeV, even though CRs have been detected up to energies of the order of 10^{11} GeV and Galactic CRs are thought to be produced up to, at least, 10^{6} GeV.

Conventional transport models are built to reproduce the local CR data and typically assume a very simplistic view of the Galaxy in which the propagation parameters characterizing the transport of CRs are isotropic and homogeneous. In particular, in these models the diffusion tensor is reduced to a spatially independent scalar function of the particle rigidity. Since the source spectrum (i.e. injection of CRs just depend on the sources accelerating them and not on where are the sources) is not expected to depend on the position, in this scenario the propagated CR spectrum–which is a convolution of those two quantities–is also expected to be

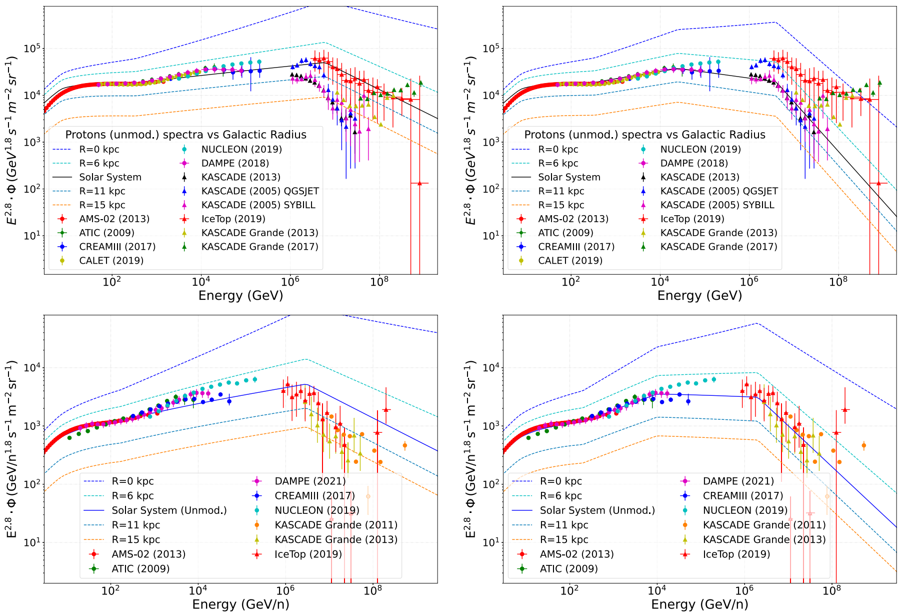

FIGURE 1
Spectra of protons (upper panels) and helium (lower panels) of the *γ-optimized* scenario for the Max (left panels) and Min (right panels) configurations, from 10 GeV to 10^9 GeV. Since in the *γ-optimized* scenario the propagation of CRs depends on the distance from the galactic center, we show the spectra at different galactocentric radii. Available local CR data from AMS-02, ATIC, CREAM, CALET, NUCLEON, DAMPE, KASCADE, KASCADE Grande and IceTop are included for comparison.

spatially invariant. The normalization and rigidity dependence of the diffusion coefficient $D(\rho)$ are generally fixed by reproducing the observations on secondary/primary ratios of CR species (mainly the boron-to-carbon ratio).

In fact, this simplified approach has been shaken when several independent analysis of the Fermi-LAT data found evidences of a hardening of the spectrum of the γ-ray diffuse emission at low Galactic longitudes (Gaggero et al., 2015b; Acero et al., 2016; Yang et al., 2016). Following Gaggero et al. (2015b,a); Luque et al. (2022), in this work we adopt a scenario that assumes a spatially dependent diffusion coefficient which reproduces that feature and matches Fermi-LAT data better than conventional models. For this reason we call it *γ-optimized*.

2.1 CR spectra in the galaxy from the *γ-optimized* model

In Luque et al. (2022), we model the transport of CRs with the DRAGON2 numerical code (Evoli et al., 2017, 2018) within two transport scenarios: the *γ-optimized* model, where the spectral index of the diffusion coefficient ($\delta(R)$) depends on the galactocentric distance (R), according to the trend hinted by Fermi-LAT diffuse data, and the *Base* model, where the diffusion coefficient is spatially constant and tuned on local CR data. Specifically, we assume $\delta = 0.5$ throughout the Galaxy for the *Base* scenario while it is parametrized as

$$\delta(R) = 0.04\,(\mathrm{kpc}^{-1}) \cdot R\,(\mathrm{kpc}) + 0.17 \quad (\text{for } R < 8.5\ \mathrm{kpc}),$$

for the *optimized* one. The latter behaviour allows to reasonably reproduce the dependence of the CR proton spectral index inferred from Fermi-LAT data (Gaggero et al., 2015b; Acero et al., 2016; Yang et al., 2016) for $R > 2$ kpc (below this radius the increasing errors do not allow to trace it any further and we just extrapolate to $R = 0$ kpc the behaviour inferred at larger radii). In both scenarios the normalization of the diffusion coefficient is tuned to reproduce the boron-over-carbon ratio as shown in **Figure 2** (the other main primary and secondary CR local spectra are reproduced as well). Moreover, in order to extend our predictions to the highest energies, we account for a wide set of CR data in the PeV domain. In this context, we emphasize the large discrepancies in the energy spectra observed by different collaborations at these energies (see **Figure 1**). In fact, these measurements suffer from large systematic errors, mostly associated with modelling hadronic interaction within the Earth atmosphere. Therefore, we consider two set-ups for the CR injection spectra (broken power-laws with spectral indexes and breaks reported in **Table 1**), which we call *Min* and *Max* configurations (see de la Torre Luque et al. (2022) for more details).

TABLE 1 Spectral indexes at injection for the Max and Min models. These spectral indexes are tuned to CR local data as described above and correspond to spectral breaks at the following energies: 335 and $6{\cdot}10^6$ GeV for the Max models and 335, $2{\cdot}10^4$ and $4{\cdot}10^6$ GeV for the Min models.

Injection parameters

	$^1H\ \gamma_1$	$^1H\ \gamma_2$	$^1H\ \gamma_3$	$^1H\ \gamma_4$	$^4He\ \gamma_1$	$^4He\ \gamma_2$	$^4He\ \gamma_3$	$^4He\ \gamma_4$
Max model	2.33	2.23	2.78	—	3.28	2.18	2.69	—
Min model	2.33	2.16	2.44	3.37	2.30	2.06	2.34	3.01

Figure 1 shows the spectra of protons (top panels) and Helium (bottom panels) on the Galactic plane at different distances from the centre for the *γ-optimized* scenario. As a consequence of the radially-dependent diffusion coefficient adopted in that scenario–we assume here the source spectra to be the same throughout the Galaxy–the propagated spectra are significantly harder towards the centre of the Galaxy, while for the *Base* scenario they have the same shape in every position although the normalization would vary depending on the density of sources at different regions of the Galaxy. In **Figure 1**, the left panels show our predictions for the Max injection spectra setup while the right panels show the predicted spectra for the Min one.

In addition, in **Figure 2** we show the boron-over-carbon spectrum obtained from the *γ-optimized* model at Earth position, compared to the existent data. This observable is directly related to the details of the propagation of CRs and the "grammage" associated to the production of secondary CRs de la Torre Luque et al. (2022); Luque (2021); Luque et al. (2021). The combination of this piece of information with the γ-ray diffuse emission in the Galaxy may allow us to test whether features in the CR spectra—such as the hardening at ~300 GeV/n found by CREAM (Ahn et al., 2010), PAMELA (Adriani et al., 2011), AMS (Aguilar et al., 2015) and the softening at ~10 TeV/n measured by DAMPE (An et al., 2019) and CREAM (Yoon et al., 2017) — are due to the injection or if they are representative of the whole Galaxy, namely due to transport effects (Blasi et al., 2012).

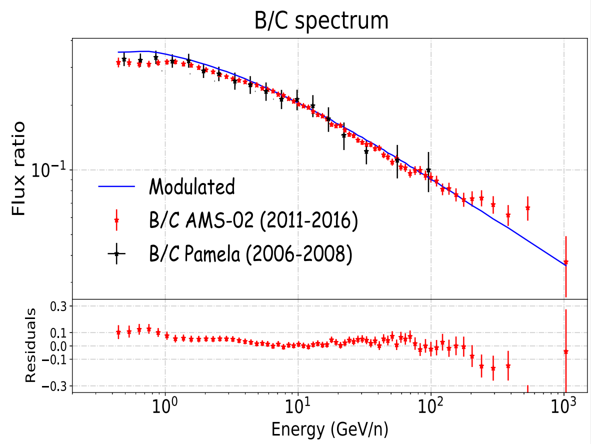

FIGURE 2
Boron-over-carbon spectrum predicted by the *γ-optimized* model at Earth position (~8.3 kpc from the galactic centre), compared to experimental data from Pamela and AMS-02.

2.2 γ-Ray profiles in the galaxy from the *γ-optimized* model

We use the recently released HERMES code (Dundovic et al., 2021) to convolve along the line of sight the CR spatial and energy distributions modeled with DRAGON2, updated gas (for the hadron emission) and ISRF (for the IC emission) models and the proper γ-ray cross-sections to get detailed full-sky maps of the expected diffuse emissions for each channel.

In our previous work (Luque et al., 2022), we tuned the CR propagation parameters to reproduce local CR data as well as the diffuse emission measured by *Fermi*-LAT for several GP quadrants. Then we used the same models to predict the emission at larger energies which we compared with ARGO-YBJ (Bartoli et al., 2015), Tibet ASγ data as well as with LHAASO preliminary results. We showed that those data in combination with *Fermi*-LAT favor a spatially dependent transport scenario.

Here we extend that analysis to other regions of the sky. First of all, in **Figure 3** we show latitudinal (top panels) and longitudinal (middle panels) profiles of the predicted γ-ray emission for the Min (right panels) and Max (left panels) setups compared to *Fermi*-LAT data. In this work, we make use of ~149 months of data (from 2008 to 08-04 to 2020-12-31), selecting CLEAN events from the PASS8 data. Their extraction and calculation of exposure maps is performed using *Fermi*-LAT ScienceTools[1] (2.0.8; released on 01/20/2021). We also account for the isotropic spectral template provided by the *Fermi*-LAT collaboration Ackermann et al. (2015) (iso_P8R3_CLEAN_V3_v1)[2].

These plots show that the space-dependent γ-optimized scenario–especially its Min setup which better traces the CR local

1 https://fermi.gsfc.nasa.gov/ssc/data/analysis/software/; https://github.com/fermi-lat/Fermitools-conda/wiki/Installation-Instructions.

2 https://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html.

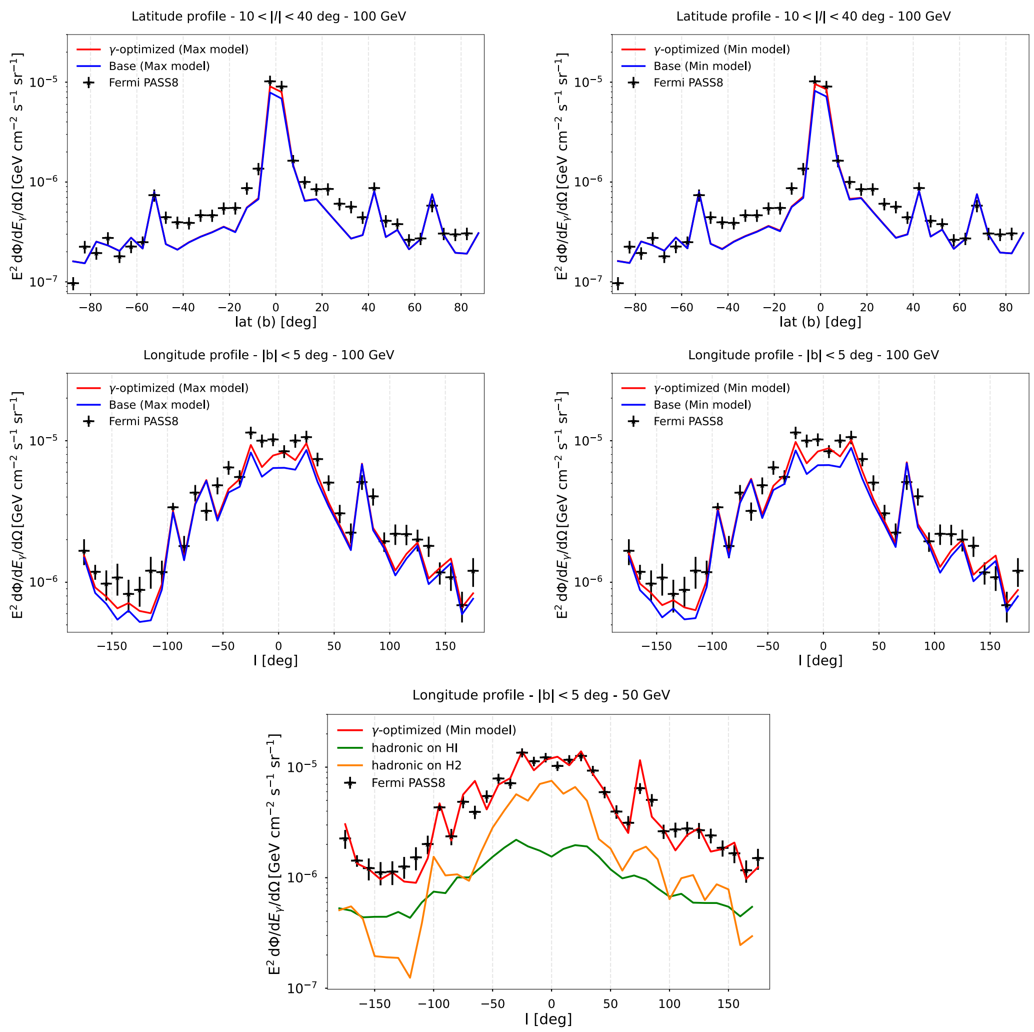

FIGURE 3
Upper panels show the latitude profiles for the total γ-ray emission (for longitudes of $10° < |l| < 40°$) at 100 GeV predicted by the *Base* and γ-*optimized* models for the Max (left) and Min (right) configurations. Likewise, middle panels show longitude profiles at 100 GeV predicted by the *Base* and γ-*optimized* models for the Max (left) and Min (right) configurations. The bottom panel reports the longitude γ-ray profile at 50 GeV predicted by the γ-*optimized* model (Min configuration), showing the emission that comes from the hadronic emission generated by HI (atomic) and H2 (molecular) gas. Fermi-LAT PASS8 data are added for comparison in every case.

spectra measured by CREAM and DAMPE–provides a very good description of *Fermi*-LAT results significantly better that the conventional Base one. In addition, in the bottom panel of the figure, we show the longitude profile of the emission at 50 GeV specifying the hadronic emission originated from collisions of CRs with molecular gas (H2) and atomic gas (HI), in order to illustrate the importance of both contributions in different parts of the Galaxy.

With this result at hand, we use the γ-optimized models to predict the γ-ray and ν spectra up to the PeV. For the γ-ray production cross-sections we used those by Kelner and Aharonian (2008) with the updated parameterization of the proton–proton total inelastic cross-section reported in Kafexhiu et al. (2014). At those energies we need to account for γ-ray opacity due to the scattering onto CMB photons–giving a ~10% depletion around the PeV–having checked that the effect of the interstellar radiation fields is negligible. The comparison of the γ-ray flux from the γ-optimized scenario is shown in **Figure 4** in comparison to Tibet ASγ (Amenomori et al., 2021), LHAASO (Zhao et al., 2021) (preliminary), Fermi-LAT Ackermann et al. (2012) and ARGO-YBJ (Bartoli et al., 2015) data in the window $|b| < 5°$, $25° < l < 100°$. The KRA$_\gamma^5$ model (cutoff energy of $E_c = 5$ PeV) (Gaggero et al., 2015a) is also included here for reference.

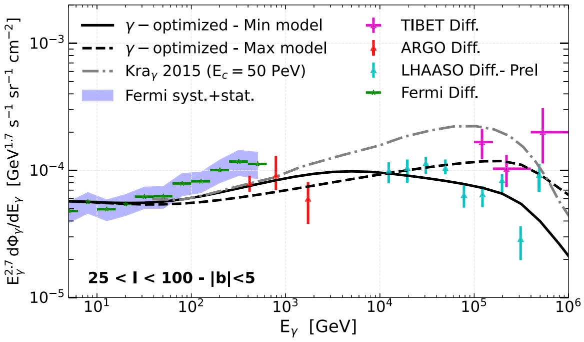

FIGURE 4
γ-ray diffuse spectra from the γ-optimized scenario compared to Tibet ASγ (Amenomori et al., 2021), LHAASO (Zhao et al., 2021) (preliminary), Fermi-LAT (Ackermann et al., 2012) (CLEAN events from PASS8 data with subtraction of flux from known sources and isotropic background) and ARGO-YBJ (Bartoli et al., 2015) data in the window $|b| < 5°$, $25° < l < 100°$. The KRA$_\gamma$ model (cutoff energy of $E_c = 5$ PeV) (Gaggero et al., 2015a) is also included. Here, we account for absorption of γ-rays into CMB photons (see Figure 7 of Ref. Luque et al. (2022)) and do not include the contribution of unresolved sources, which may be significant at the highest energies.Morphology of the hadronic emission.

3 Prospects for ν emission

As anticipated above, one of the main consequences of the γ-*optimized* model is that the hadronic γ-ray emission dominates over the leptonic one even at very high energies: in particular, it is expected to dominate in the innermost region of the GP. While the observation of related very-high-energy γ-ray emission ($E \gg 10$ TeV) from this region is very challenging for the currently operating wide-field γ-ray observatories, mostly located in the Northern hemisphere, the ν emission can be observed from both hemispheres taking into account different event topologies and reconstruction strategies.

The diffuse Galactic ν emission is expected to overcome possible point-like excess in the inner GP region with spectral features inherited from the accelerated CR populations. With the ν data recorded in the last decade by IceCube and ANTARES, it was possible to constrain this important diffuse signal that can account for ~10% of the total astrophysical events collected by IceCube.

Different studies from ANTARES and IceCube (Albert et al., 2017, 2018) placed upper limits on this diffuse ν emission taking advantage of the template fitting analysis method, with the model templates accurately reproducing the spatial distribution of the expected Galactic emission. This approach represented a step forward for the study of this diffuse signal considering that the angular resolution of different ν samples improved with time for both observatories thanks to new reconstruction quality techniques. Recently, an indication of a diffuse Galactic ν excess (2σ) tracing the KRA$_\gamma^5$ template was reported by the IceCube collaboration (Aartsen et al., 2019) using 7 years of collected cascade-type events.

The main result of that calculation is a hint for a non-zero diffuse Galactic ν component, with a best-fit flux lying very close to the level of the γ-optimized model, with 29% p-value (see **Figure 6**). We remark that the γ-optimized model adopted in that work is based on Gaggero et al. (2015a), which did not feature the improved modeling of the knee region presented in this work.

In **Figure 5** we display the morphology of the hadronic emission for 100 TeV γ-rays for the *γ-optimized* model (Min configuration). This distribution will be also followed by the ν emission and it serves as a template to explore the zones where the ν emission will be more significant. As for the γ-ray production, we use the cross-sections described in Kelner and Aharonian (2008), with inelastic cross-section from in Kafexhiu et al. (2014), for the ν emission. We have tested that other common parameterizations (namely, Kamae et al. (2006) and AAFRAG Koldobskiy et al. (2021)) do not lead to important discrepancies at TeV energies, although a dedicated comparison of the effect of different cross sections in the predictions of the γ-ray and ν diffuse flux is left for a future work.

In **Figure 6** we show the predicted ν Galactic diffuse emission considering the Min and Max configurations of the *γ-optimized* scenario and the expected Galactic ν flux from the KRA$_\gamma$ model (cutoff energy of $E_c = 5$ PeV) (Gaggero et al., 2015a), compared to the model-independent limits obtained from the ANTARES collaboration Adrian-Martinez et al. (2016) considering 6 years of track-like events for the region $|l| < 40°$ and $|b| < 3°$. We notice that our scenario is compatible with the current upper limits set by the ANTARES and IceCube collaborations, and that the Max model is particularly close to that limit. Moreover, since the spectral energy distributions of the KRA$_\gamma^5$ and *γ-optimized* Max models are very close below 100 TeV, the hint of an excess tracing the former model found by the IceCube collaboration should hold also for the updated *γ-optimized* Max model. Remarkably, this is also the model which, for γ-rays, better matches the Tibet ASγ results (see **Figures 4**, **5** in Luque et al. (2022) and **Figure 3** of Eckner and Calore (2022)).

As also shown in **Figure 6** at energies larger than 10 TeV the *γ-optimized* Min and Max configurations predict significantly different ν spectral shapes. Forthcoming IceCube or KM3NeT measurements should have the sensitivity to single out the correct between those models. We also notice that these results are compatible with the non-detection of galactic ν emission from Super-Kamiokande Abe et al. (2006), since at the low energies at which Super-Kamiokande is able to perform the detection our model predicts a similar ν flux as the conventional models.

As already pointed out in Luque et al. (2022) we notice that a degeneracy holds between the choice of the transport

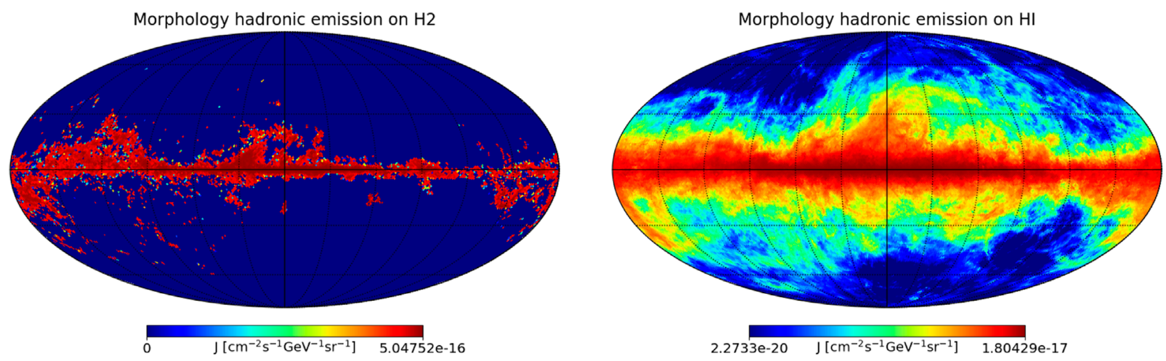

FIGURE 5
HEALPIX maps (NSIDE = 512) showing the morphology of the hadronic emission for 100 TeV γ-rays for the γ-*optimized* model (Min configuration). The left map shows the hadronic emission generated by the interactions of CRs with molecular (H2) gas, while the right map shows the hadronic emission generated by interactions of CRs with atomic (HI) gas. This distribution will be also followed by the ν emission.

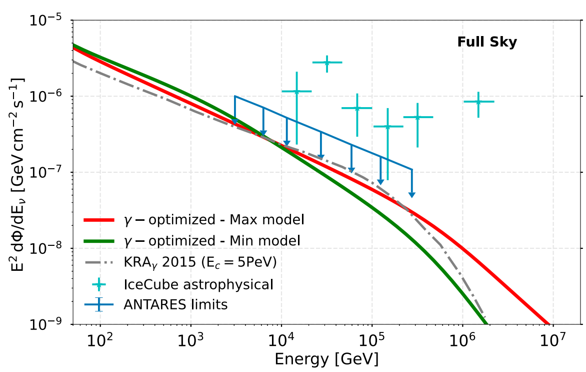

FIGURE 6
Full sky ν diffuse emission predicted from the γ-*optimized* model (Min and Max configurations) compared to the model-independent upper limits obtained from the ANTARES collaboration. The predicted galactic ν flux from the KRA_{γ} model (cutoff energy of E_c = 5 PeV) (Gaggero et al., 2015a) is also included. In addition, the IceCube astrophysical ν flux as measured from IceCube using 7.5 years of track events (Abbasi et al., 2021) are added for completeness.

model and the shape of the source spectrum above 10 TeV. Indeed the spectrum predicted for Min configuration of the γ-*optimized* scenario is quite close to the *Base* Max model at those high energies. This degeneracy, however, can be broken using γ-ray data at lower energy showing, again, the importance of synergistically using ν and γ-ray channels to get to fully understanding of the underlying physics.

4 Conclusion

More than 100 years after the discovery of CRs, our current knowledge about the sources of these particles and the way they propagate through the Galaxy is still very limited. This is especially true at very high energies ($E \gg 100$ TeV) at which many interesting and enlightening phenomena are expected to take place. This situation is swiftly improving thanks to the use of new γ-ray and ν measurements which are providing complementary information besides that given by CR data alone. The consistent interpretation of those multi-messenger results requires accurate modeling of CR propagation and interaction with the ISM under more general conditions than those generally assumed to describe local CR data.

In this paper, we have revisited a recently released CR transport model implemented to allow a consistent description of local CR data up to energies of several PeVs and the diffuse emission γ-ray spectrum measured by *Fermi*-LAT, ARGO and Tibet ASγ in different regions of the Galaxy.

In particular, we have reported new details on the predicted CR spectra in different regions of the Galactic plane obtained from the γ-*optimized* (spatial dependent transport) scenario and shown that they are totally compatible with the local measurements of the boron-over-carbon ratio (B/C) from the GeV region. In addition, we have compared the predicted γ-ray diffuse emission latitude and longitude profiles with the *Fermi*-LAT PASS8 data. We also showed the contributions of the hadronic emission coming from the different phases of the gas, namely atomic and molecular gas. A good agreement is found throughout the full plane of the Galaxy thanks to the CR density enhancement predicted by this scenario in the innermost region of the Galactic plane around 100 GeV.

At larger energies the predictions of our scenario depend on the assumed source spectral shape. Due to the large experimental uncertainties above 10 TeV we considered two configurations (Min and Max) roughly bracketing the available proton and Helium experimental data.

For those models we computed here for the first time–though similarly to what already done for γ-rays–the diffuse ν emission of the Galaxy over a wide energy range which we compared with available ANTARES and IceCube upper limits and provide as templates for the forthcoming experimental campaigns.

We showed that the predicted full-sky spectrum for the Max configuration is very close to that obtained with the KRA_{γ}^{5} model presented in Gaggero et al. (2015a). Since this model has recently received a positive–though not yet conclusive–evidence by the likelyhood analysis of the cascade events collected by IceCube (Aartsen et al., 2019) our results provide a very intriguing science case for future analyses, which may have the unique opportunity to confirm this prediction.

We argued that complementary analysis of γ-ray add ν emissions are required both to lift the degeneracy between the choice of the transport scenario and the shape of the source spectra at very high energies and to constrain the contribution of unresolved sources to the γ-ray diffuse emission of the Galaxy.

We, finally, show here the all-sky predicted ν emission from this model, compared to upper limits from the ANTARES collaboration, showing that a possible measurement of this emission can be really around the corner. We also emphasize that the different observations coming from high-energy CRs, γ-rays and ν seem to be compatible with a maximal energy reached by the Galactic CR accelerators below tens of PeV. The diffuse ν emission throughout the Galaxy and its possible experimental detection will be extensively explored in a follow-up paper.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://fermi.gsfc.nasa.gov/.

Author contributions

PD has been in charge of the technical calculations. DGa, DGr, and AM has been critically revising the ideas involved and discussing ways to improve the presentation of the materials shown here. All the authors have made a substantial contribution to the concept and design of the article and drafted the article with important intellectual content.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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