DMMW - A Tool for Dark Matter Multi Wavelength studies

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Abstract: We present DMMW, a publicly available code, which computes the Dark Matter Multi-Wavelength emission spectrum for generic Dark Matter models. We concisely discuss a few applications to a variety of astrophysical systems within and beyond the Galaxy. In particular we constrain the averaged diffusion in the Cosmic Ray source regions of the Large Magellanic Cloud. DMMW calculates the secondary emission produced during the propagation of DM-induced leptons from the steady state distribution of these particles, as well as the prompt $\gamma$-ray emission produced directly during annihilation or decay. We believe it is extremely timely to introduce DMMW: a natural step needed to unveil the possibly exotic nature of some of Fermi unidentified sources will consist of follow-up multi-frequency observational campaigns. DMMW enables users to easily make theoretical predictions for the radio, UV, X-ray and soft $\gamma$-ray emissions associated with the relativistic electrons and positrons produced in Dark Matter annihilation or astrophysical sources. The DMMW code can be interfaced to spectral fitting packages relevant to various wave-lengths, e.g. XSPEC for X-rays, and the Fermi Science Tools. The code has been tested by comparison to numerical solutions obtained with the GALPROP code.

Keywords: multi messenger, indirekt dark matter searches, DMMW

1 Introduction

Secondary emission from relativistic $e^+ e^-$ pairs produced in DM annihilation can form an important constraint for indirect Dark Matter (DM) searches. Previous studies have shown that the amount of secondary emission can be comparable to the prompt $\gamma$-ray emission \cite{1}. In fact, for the Coma cluster the strongest limit on a possible DM annihilation signal is currently obtained from the radio data \cite{1}. Specifically, at radio frequencies the DM-induced emission is dominated by the synchrotron radiation of the relativistic electrons and positrons with a flux depending on environment (e.g. magnetic field and thermal electron plasma density). Inverse Compton (IC) scattering of the non-thermal $e^\pm$ on target CMB, starlight IR and possibly other photon background populations give rise to a spectrum of up-scattered photons stretching from below the extreme ultra-violet up to the soft gamma-ray band, peaking in the X-ray energy band. The last relevant contribution to the photon emission due to DM-induced relativistic electrons and positrons is the process of non-thermal bremsstrahlung, i.e. the emission of gamma-ray photons in the deflection of the charged particles by the electrostatic potential of ionized gas. Finally, a hard gamma-ray component arises from prompt emission in WIMP pair annihilations. Knowledge of the steady-state distribution of the DM-induced electron-positron population $n_{e}(E, r)$ allows one to compute the WIMP-induced secondary emission, provided the magnetic field structure and strength, as well as the gas and starlight densities are known. The steady-state distribution itself crucially depends on the diffusion coefficient. The right side of Fig. 1 illustrates the dependence of the secondary emission for the Draco dwarf galaxy on the diffusion coefficient and the magnetic field strength. In the following we will focus on the emission expected from extragalactic objects, such as galaxy clusters, dwarf galaxies and external galaxies. For these objects only very general arguments about the transport parameters can be made. In order to keep the number of free parameters small we neglect ill-constrained transport modes like diffusive reacceleration, convection and any spatial dependence of the transport parameters and describe the transport of Cosmic Rays (CRs) by the reduced transport equation:

$$Q_{e}(E, r) + \nabla \cdot \left( K(E, r) \nabla \frac{dn_{e}}{dE} \right) + \frac{\partial}{\partial E} \left( b(E, r) \frac{dn_{e}}{dE} \right) = 0,$$

(1)

where $dn_{e}/dE$ is the electron/positron density per unit of kinetic energy, $b(E) = \dot{\beta}(E) \beta$ is the momentum loss rate, which encodes the energy losses and $K(E, r) = \beta^n K_0 \left( \frac{E}{E_0} \right)^\delta$ is the spatial diffusion coefficient.

2 DMMW: A brief Overview of the Code

DMMW allows the user to fit the DM particle properties for a variety of different objects and CR transport environments. The code solves the steady-state transport equation Eq. 1 for spherically symmetric boundary conditions for $e^\pm$ from DM annihilation or astrophysical sources, $p$ from astrophysical sources, as well as secondary $e^\pm$, $p$ and $\beta$ from interactions of primary $p$ with the gas. The secondary emission from synchrotron radiation, IC, bremsstrahlung and $\pi^0$-decay is calculated from the steady-state solution. The solution is obtained for a sphere with radius $R_0$, beyond $R_0$ free escape is assumed. Details on our boundary condition treatment can be found in an upcoming publication \cite{2}. The basic input for DMMW are the transport parameters, as defined by $K(E)$ and $b(E)$ (via the ISRF, the gas density and the magnetic field) in addition to the source distributions and initial energy spectra $\dot{Q}(r, E)$. The energy spectrum of the DM annihilation products is obtained from the DMFIT code \cite{3}, which calculates the differential $\gamma$-ray and $e^\pm_{DM}$ yields for a given DM mass; all parameters relevant to DMFIT (the decay channels, DM mass and interpolation options) are specified via the DMMW input file. The code out-
Way by a factor of 0.1.

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been scaled by a factor 0.1. The source distribution is taken as a Gaussian with a width of 3 kpc, the total magnetic field strength (0 = [12]). For the ISRF we use an averaged value of 10−15 cm−2 s−1.

−14 G, where we assumed a regular component of 1 G, ISRF is CMB only). The strongest limits have been used. The boundary has been set to R8 = 10 kpc in DMM and zmax = Rmax = 10 kpc in GALPROP. Right: Variations in the secondary emission of the Draco dwarf galaxy due to variations of the diffusion coefficient (1026 – 1030 cm2/s) and the magnetic field strength (0.5 – 5 μG). DM particle properties as on the left side of Fig. 1.

Figure 1: Left: The multi-wavelength emission of the Coma cluster for a 40 GeV particle annihilating into μ+μ− using the best-fit model from [11] (K = β · 2.1 · 1029(ρ/1 GV)0.33 cm2/s, B = 1.2 μG, ISRF is CMB only). The strongest limits are given by the radio observations of the extended halo. Data: radio [2], γ-ray upper limits [3]. Right: Variations in the secondary emission of the Draco dwarf galaxy due to variations of the diffusion coefficient (1026 – 1030 cm2/s) and the magnetic field strength (0.5 – 5 μG). DM particle properties as on the left side of Fig. 1.

Figure 2: Left: DMM prediction of the diffuse γ-ray emission from a region of 10° around the Galactic center compared to the GALPROP prediction. For this comparison a constant gas density of nHI = nHII = nH2 = 0.03/cm3, a constant magnetic field of 3 μG, only the CMB component of the ISRF and the transport parameters of the plain diffusion (PD) model[9] have been used. The boundary has been set to R8 = 10 kpc in DMM and zmax = Rmax = 10 kpc in GALPROP. Right: Diffuse γ-ray emission of the LMC for a diffusion coefficient of the form K(ρ) = β−2 · 3 · 1033(ρ/1 GV)cm2/s (as a function of particle rigidity ρ) and δ = 0.33/0.6 below/above 104 GV compared to the Fermi-LAT data [7]. We model the HI distribution within the LMC as a Gaussian with a width of 3.5 kpc and a total HI mass of 4.8 × 106M⊙[10], the H2 distribution as a Gaussian with a width of 3 kpc and a total mass of 5 × 103M⊙[11]. For the ionized hydrogen component we assume a total mass of 4 × 106M⊙and a Gaussian width of 2 kpc. Since the emission primarily originates from 30 Doradus, these values are not representative for the emission regions. To account for this the HI and H2 distributions have been scaled by a factor 0.1. The source distribution is taken as a Gaussian with a width of 3 kpc, the total magnetic field strength on large scales is 4.3μG, where we assumed a regular component of 1.1μG and a random component of 4.1 μG [12]. For the ISRF we use an averaged value of 10−7eVcm−3 between 0.2μm and 200μm for radii smaller than 4 kpc on top of the CMB component, which roughly corresponds to scaling the contribution from starlight and dust in the Milky Way by a factor of 0.1.
puts skymaps calculated from the steady state solution, as well as the CR fluxes. Figure 2 shows a comparison between the diffuse γ-ray emission in DMMW and GALPROP [1] for the Galactic center.

3 The Large Magellanic Cloud

In this section we apply DMMW to CR transport in the Large Magellanic Cloud (LMC). Diffuse γ-ray emission from the LMC has been observed by the EGRET telescope aboard the Compton Gamma-Ray Observatory (CGRO, 1991-2000) [6] and most recently with much higher angular resolution by the Fermi-LAT telescope [7]. The integrated flux above 100 MeV amounts to $1.6 \pm 0.1 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$, while the spectrum of the γ-ray emissivity is very similar to the diffuse γ-ray emissivity of the Milky Way. It was demonstrated, that the emission can be described by scaling the GALPROP predictions for the Milky Way to the LMC data [7].

Here we build a model for CR transport within the LMC, by estimating the diffusion coefficients and source luminosities which are compatible with the Fermi-LAT observations of the LMC, assuming realistic gas densities. The γ-ray emission from the LMC shows only little correlation to the gas and is rather correlated to the massive star forming region 30 Doradus. In particular, Fermi does not observe any significant enhancement in the γ-ray emission from the gas ridge, which runs over ∼ 3° along $\alpha_{2000} \sim 05h40m$. This region is expected to contain about 20% of the total gas mass in the LMC [8] and mainly consists of giant molecular clouds. Since these $H_2$ clouds are not prominent in γ-rays, the GeV protons from 30 Doradus have to be efficiently confined to the source region and hence their average propagation length is expected to be significantly smaller than in the Milky Way. From here we estimate that an initial 5 GeV proton may not travel further than ∼ 2.5 kpc before it drops below 0.5 GeV. This limits the diffusion coefficient in the GV range to values below $(2.8 - 4.7) \cdot 10^{25}$ cm$^2$/s, which in turn means that the source luminosity has to be $\sim 10^{39}$ erg/s. This value is considerably lower than the upper limits from the SN rate estimate, but it is consistent with the assumption that the sources in 30 Doradus dominate the observed γ-ray emission. The supernova rate in the LMC and SMC is approximately 1 SN/300 yrs, about a factor 6 smaller than the SN rate in the Milky Way [13]. Assuming that the averaged source luminosity obtained from the GALPROP models is representative for the CR sources in the LMC, an upper limit for the expected source luminosity of CR electrons and protons is given by $L_e = 4.2 \cdot 10^{39}$ erg/s and $L_p = 1.8 \cdot 10^{40}$ erg/s.

The right panel of Fig. 2 shows the γ-ray spectrum between 100 MeV and 20 GeV. The required source luminosities are $L_p = 1.5 \cdot 10^{39}$ erg/s and $L_e = 2.3 \cdot 10^{38}$ erg/s.

4 Conclusion

We briefly presented DMMW, a novel tool for the calculation of secondary γ-ray emission from both, CRs and DM annihilation/decay products in extragalactic objects, DMMW can be used for a wide range of different applications in the context of indirect DM searches or generic studies of transport parameters. Here we have demonstrated the exemplatory application to the Milky Way, the Draco dwarf galaxy, the Coma cluster and the LMC. The code uses semi-analytical solutions to the simplified CR transport equation [1, 4], which makes the simultaneous fit of the unknown transport parameters and DM properties feasible. DMMW is available from the author upon request.

References
