Dark matter searches with radio observations

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Dark matter searches with radio observations

Marco Taoso

Department of Physics and Astronomy, University of British Columbia,
Vancouver, BC V6T 1Z1, Canada

E-mail: mtaoso@phas.ubc.ca

Abstract.   We compute the radio synchrotron emission induced by WIMP DM annihilations inside our galaxy and in extragalactic halos. Comparing DM fluxes with radio surveys from 22 MHz to 1420 MHz we derive bounds on the WIMP paramer space. Light WIMPs, $M_{DM} \leq 10$ GeV, with thermal annihilation cross-sections (i.e. $(\sigma v) = 3 \times 10^{-26}$ cm^3 s^{-1}) are strongly constrained, especially those candidates annihilating mainly into leptons. We then show that DM sources could account for a significant fraction of the extragalactic-radio emission inferred by the ARCADE-2 Collaboration. We argue that future telescopes with sensitives at μJy level will be particulary suitable to search for faint DM emissions. We show that future data on source counts and angular correlations could become relevant to distinguish DM signals from astrophysical sources, such as radio loud active galactic nuclei and star forming galaxies.

1. Introduction
Indirect searches of Dark Matter (DM) are particulary promising for Weakly Interacting Massive Particles (WIMPs), which currently are the most investigated class of DM candidates. Signatures of this scenario include a multiwavelength spectrum associated to radiative emissions involving electrons and positrons generated in WIMP annihilations or decays. Here we focus our attention on the synchrotron emission produced in the interactions of electrons and positrons with galactic magnetic fields. For electrons energies below about 10 GeV and typical values of galactic magnetic fields, i.e. $\mathcal{O}(\mu G)$, the synchrotron emission falls at frequencies around and below the GHz , i.e. in the radio band. Therefore, radio observations are appropriate tools for indirect WIMP searches.

In Sec. 2 we study the galactic synchrotron emission from DM annihilations. Using current radio surveys we derive constraints on the WIMP parameter space. For light WIMP candidates, $M_{DM} \leq 10$ GeV, annihilating into charged leptons the bounds are particulary strong and disfavour thermal annihilation cross-sections (i.e. $(\sigma v) = 3 \times 10^{-26}$ cm^3 s^{-1}) [1]. We briefly discuss the prospects for detection with future surveys.

In Sec. 3 we consider instead the extragalactic radio emission. We focus on three observables: intensity, differential number counts of sources and angular correlations. We present predictions for DM and compare with expectations for astrophysical sources and current data [1, 2].

2. Synchrotron emission from galactic DM annihilations
The goal of this section is to compare the synchrotron emission induced by DM annihilations inside our galaxy with observations (for other analysis on galactic DM radio signals see e.g. refs. [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]). As a benchmark case, in the following we focus on a
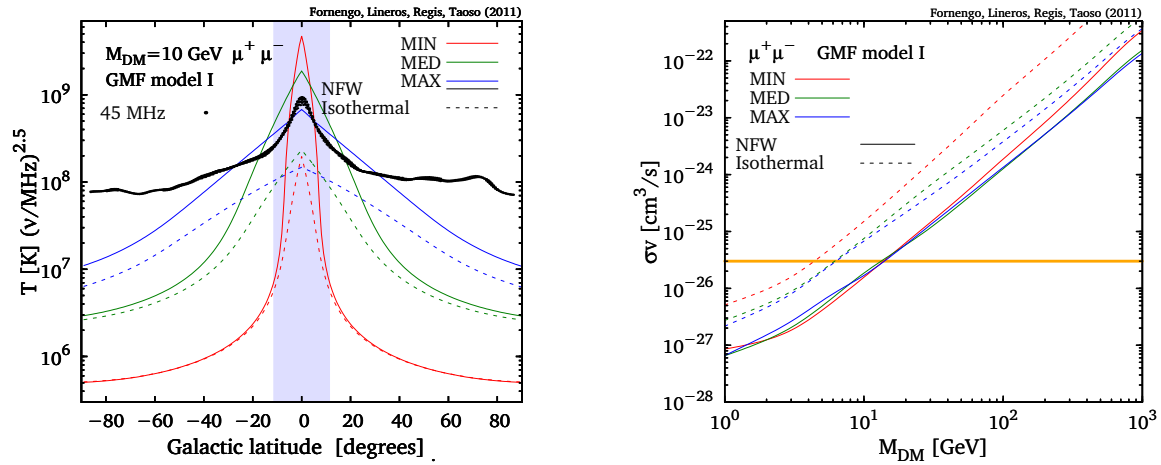
Figure 1. Left: Temperature versus galactic latitude at 45 MHz. The data corresponds to a thin strip $|l| < 3°$, with l the galactic longitude. Lines are predictions for DM models for $l = 0°$. Blue band corresponds to $|b| < 10°$ and it denotes the directions towards the galactic center region. Right: upper bounds on the annihilation cross section (σv) as a function of the DM mass for the muonic channel.

DM candidate annihilating into muon pairs. We consider two galactic DM density distributions, the popular NFW profile, which nicely fits the results of N-body simulations, and an isothermal profile which is instead used as a conservative case of a cored DM distribution.

The propagation of the electrons produced by DM annihilations is then modeled following a semi-analytical approach [14]. Electrons are assumed to be confined by the galactic magnetic field inside a propagation zone which is described by a cylinder centered at the galactic center with a radius $R_g = 20$ kpc. The number density of electrons per unit of energy $n_e(E, \mathbf{x})$ follows a transport equation which takes into account the spatial diffusion of the electrons and the energy losses due to the interactions with the galactic magnetic field and the interstellar radiation field. The parameters of the propagation model are constrained by cosmic-rays data, notably the Boron over Carbon ratio (B/C) and radioactive isotopes. In order to bracket the uncertainties on the electrons propagation we consider three propagation benchmarks, the so-called MIN, MED, and MAX models. These models are fully compatible with B/C and antiproton/proton ratio observations, describing the extreme behaviors (MIN and MAX) and best fit (MED) of these observables [15].

The structure of the Galactic Magnetic Field is still not well understood. Mainly, it is composed by a regular and a turbulent part, the last one responsible for the diffusive behaviour of the cosmic rays. Here, the total magnetic field is assumed to have a cylindrical symmetry with an exponential dependence on the distance on the galactic center and on the vertical height (more details in Ref. [1]). The normalization at the Sun position is set to 6μG, which is well consistent with the measurements.

In the left panel of Fig. 1 we compare observations and the DM emission at 45 MHz for a 10 GeV DM particle with a thermal annihilation cross section, $(\sigma v) = 3 \times 10^{-26}$ cm^3 s^{-1}. As expected the signal is enhanced at the center of the galaxy and its morphology is strongly affected by the choice of the DM density distribution and propagation model. Conservative bounds on the DM parameter space can be set comparing the DM signal with the data without attempting any astrophysical background subtraction. We employ data from five surveys from 22 MHz to 1420 MHz (see ref. [1] for more details about the method adopted to set the bounds.)
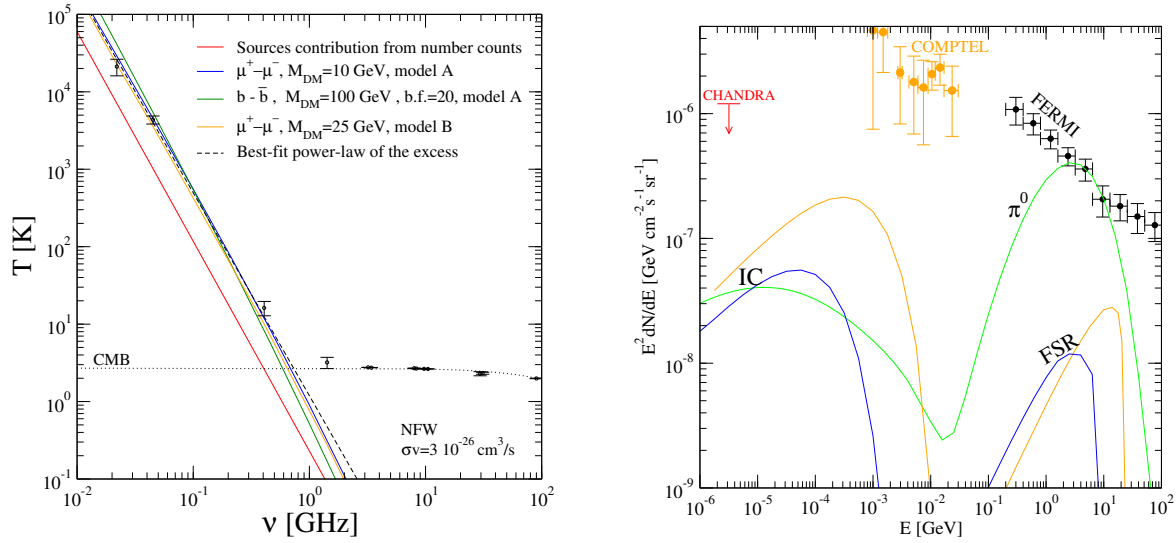
Figure 2. Left: extragalactic radio background as derived by ARCADE [16], together with three possible interpretations of the low–frequency ($<$ 10 GHz) excess in terms of WIMP annihilations. Right: X-ray and gamma-ray fluxes for the three benchmark WIMP cases shown in left panel. The CHANDRA [17] bound in the X–ray band and the COMPTEL [18] and FERMI [19] extragalactic gamma–ray fluxes are shown.

As shown in the right panel of Fig. 1, models with DM masses $M_{DM} \leq 10$ GeV and a thermal value of the annihilation cross section are strongly constrained for a NFW profile and for for all the propagation models we have considered. We refer the reader to ref. [1] for a more complete discussion on the uncertainties affecting these bounds (see also ref.[20] for a similar work and a comparision with collider bounds).

While we have conservatively focused on the bounds which can be inferred from observations, it could be possible that the present data already contain a significant DM contribution. In Ref. [1] we have tried to single out this DM component using the 408 MHz map as a spatial template to model the galactic CR synchrotron emission in the low-frequency maps. With this method, a DM-induced component softer than the astrophysical galactic synchrotron emission would appear as an excess in the central galactic center region with an approximately spherical shape. We have concluded that present data does not support any evidence for the presence of this additional synchrotron component. However, we expect that future radio surveys, in particular with the LOFAR telescope [21], will improve coverage, angular resolution, and sensitivity in low-frequency radio maps, which may allow to disentangle a faint DM contribution.

3. DM extragalactic radio emission.

The ARCADE-2 collaboration has reported the measurement of an isotropic extragalactic radio background at frequencies below 10 GHz [16]. Surprisingly, the total contribution from the extragalactic radio sources detected in current surveys is a factor 5-6 smaller [22, 23]. Moreover, such level of cosmic radio background does not have an immediate explanation in standard astrophysical scenarios [22, 23, 24, 25]. For instance, radio supernovae, radio quiet quasars and diffuse emission from intergalactic medium and clusters have been considered, concluding that none of them can significantly contribute. Also an interpretation in terms of ordinary star-forming galaxies is strongly constrained by multi-wavelenght observations, in particular at far-infrared frequencies. The ARCADE-2 excess seems to point to the existence of a new population of numerous and faint synchrotron sources with no or faint correlated mechanisms
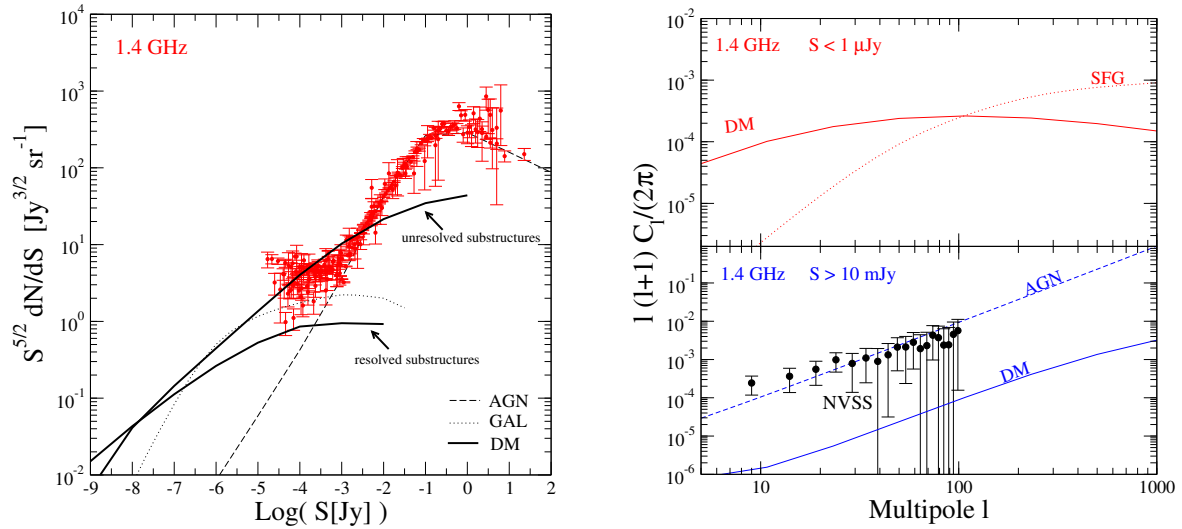
Figure 3. Left: differential number counts for AGNs (dashed line), star-forming galaxies (dotted line), and the same 10 GeV benchmark DM model (solid lines) shown in figs. 2. See ref. [2] for details. Right: angular power spectrum at 1.4 GHz of a bright ($S > 10$ mJy, lower) and a faint ($S < 1\,\mu$Jy, upper) samples for astrophysical (only dominant population is shown) and DM models. See ref. [26] for details.

at other frequencies. Here we show that WIMP annihilations in extra-galactic halos provide a possible candidate.

In the left panel of Fig. 2 we show the extragalactic radio background derived by ARCADE-2 as well as the radio signals for different DM masses, annihilation channels and assumptions on the astrophysical inputs, i.e. DM clustering and magnetic fields (see ref. [2] for more details). Leptonic channels provide an hard synchrotron spectrum which can nicely match the data. In addition, for light WIMPs ($\sim$ few tens of GeV) the correct normalization of the excess can be obtained for fairly realistic assumptions on the astrophysical parameters, without the need of large DM overdensities. For these DM candidates, the X-rays and gamma-rays constraints can be satisfied, as shown in the right panel of Fig. 2. In conclusion, a viable dark matter interpretation of the radio excess requires light WIMPs annihilating mostly into electrons and muons. These results have been confirmed by the analysis in Ref.[27].

If dark matter annihilations contribute substantially to the extragalactic radio background, a population of DM halos could appear in the catalogue of sources detected by radio telescopes. In Fig. 3 we show the differential number counts of sources at 1.4 GHz as well as predictions for DM halos and two populations of astrophysical sources. While at large fluxes the counts are dominated by radio-loud AGN, DM sources dominates over astrophysical contributions at the sub μJy level. These sensitivies will be reached by the Square Kilometer Array (SKA) [28] and possibly also by its precursors, ASKAP [29] and MeerKAT [30]. In order to distinguish DM and astrophysical emissions one can also employ informations on the the angular distribution of sources. Present data on the angular power spectrum are not very relevant for DM since they refer to levels of brightness at which the number of DM sources is very low. This is shown in the lower right panel of Fig. 3. However, as discussed above, with flux thresholds at μJy level it will be possible to probe realistic WIMP scenarios and angular correlations will become important, especially at low multipoles, as shown in the upper right panel of Fig. 3.

4. Conclusions

We have argued that radio observations are particularly suitable to search for WIMPs annihilations. Present low-frequency surveys do not support any clear evidence for a galactic DM signal. However, the data can be used to set strong constraints on the WIMP parameter space which are complementary to those obtained with other indirect DM searches, like gamma-ray observations.

The isotropic extragalactic background inferred by ARCADE-2 is larger than expectations from astrophysical sources. This excess can potentially be explained by WIMPs annihilations in extragalactic halos. This scenario could be tested by the next-generation radio telescopes, in particular employing data on differential source counts and angular correlations.

Acknowledgments

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