Confronting the Dark Matter explanation of the ARCADE excess with AMS data

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In this short note we show that positron data from AMS seems to rule out the explanation of the ARCADE isotropic radio background excess in terms of self-annihilating dark matter. In earlier works it was found that leptonic annihilation channels of light dark matter provide a good fit to the excess due to synchrotron emission of the final state particles. However, limits on the self-annihilation cross-section derived from the positron data of AMS now severely constrain light self-annihilating dark matter and cross-sections below that of a thermal relic are already tested for leptonic annihilation channels. Combining these two results, we conclude that an explanation of the excess in the radio background in terms of self-annihilating dark matter is excluded.

Introduction The density of thermal relic dark matter (including WIMP dark matter) is set by its ability to annihilate with itself in the early Universe. The cross sections required to obtain the correct density correspond to new physics at the electroweak scale and for this reason it is hoped that this annihilation can correspond to the energy regime currently being probed at the LHC and cross sections being searched for with the current and next generation of direct detection experiments. A third place to search for such dark matter is in space, as the standard model annihilation products can give rise to observable signals across many wavelengths.

The balloon experiment ARCADE 2 [1] has collected radio waves from the sky at frequencies between 3 and 90 GHz [2]. A detailed model of the background has to be created and subtracted from the data. Background radiation comes from Galactic emission or also from extra-galactic sources, such as the CMB or resolved point sources. Interestingly, after a careful background subtraction and including older maps at lower frequencies [3–5] in the analysis, an excess in terms of a power-law component remains, see e.g. [2] [7], but also [8] for a claim of no excess in the data. The possible excess is the so-called “ARCADE excess”.

A possible explanation in terms of annihilating dark matter seems promising [9] [10]. In earlier works it was found, that a good fit to the excess in isotropic radio waves can be achieved by light dark matter annihilating into lepton final states and subsequent synchrotron emission of the final state particles. Surprisingly, a self-annihilation cross-section close to that of the thermal WIMP paradigm is then needed [9] [11] making the dark matter explanation more feasible. In this short note, we confront this possible explanation further with limits derived from the AMS data [12] [13], and show that the dark matter explanation is under great pressure and seems to be excluded.

The ARCADE Excess and Annihilating Dark Matter

The observed spectrum from the ARCADE 2 collabora-
The injection spectrum of annihilating dark matter, solution of the electron spectrum is neglected (e.g. for electrons and positrons that lose energy due to synchrotron emission and mainly dominated by inverse Compton scattering and dark matter given by \( Q = \sigma v / (2m_{DM}^2) \rho_{DM}^2 dN_e/\text{d}E ) / \text{d}E_c \). This injection spectrum annihilating dark matter, \( dN_{e,\text{Inj}} / \text{d}E_c \), may be found in \[14\]. If diffusion can be neglected (e.g. for electrons and positrons that lose energy quickly in galactic magnetic fields), the steady-state solution of the electron spectrum is

\[
\frac{dN_e}{\text{d}E_c}(E_c) = \frac{\sigma v \rho_{DM}^2}{2m_{DM}^2 b(E_c)} \int_{E_c}^{\infty} dE' \frac{dN_{e,\text{Inj}}}{\text{d}E'}(E') .
\]

The synchrotron emission from dark matter annihilation is obtained by combining equations 2 and the steady state electron spectrum. For detailed information about the halo mass functions, treatment of halo substructures and magnetic fields, we refer the reader directly to reference \[11\].

It was found in earlier works that only annihilations into lepton final states can give a good fit to the radio excess \[9,11\]. Reference \[11\] confronted the annihilating dark matter explanation further with constraints from gamma ray data \[17,18\] and observations of dwarf spheroidals \[15,16\] and found that dark matter masses above 50 GeV are excluded as they would give a too large gamma ray flux, independent of the annihilation channel. Also, it was shown that a pure annihilation into tau/anti-tau pairs is excluded by the gamma-ray data already. This holds even when a marginalisation over different magnetic field models and dark matter density profiles is performed and when different models for the halo-substructures are considered.

Recently, AMS data has been re-investigated in terms of annihilating dark matter by performing a spectral analysis \[13\]. Strong constraints are derived on self-annihilating dark matter with lepton final states, especially for electron/positron pairs. For dark matter masses below 50 GeV the thermal annihilation cross-section of the WIMP paradigm \( \langle \sigma v \rangle = 3 \times 10^{-26}\text{cm}^3 \text{s}^{-1} \) is excluded by more than an order of magnitude for dark matter candidates which annihilate into electron/positron or muon/anti-muon final state particles. Annihilations into tau/anti-tau pairs are also under pressure, but within the quoted uncertainties the WIMP thermal cross-section is still compatible with observations. Uncertainties in this analysis are due to the unknown local dark matter density and arise also from the energy-loss of electrons/positrons in the magnetic fields. This has been accounted for by showing bands of the exclusion limits on the annihilation cross-section rather than a single limit. We respect these uncertainties and will show the exclusion bands in the final plots. Solar modulation may affect the diffusion of the low-energetic part of the positron flux and limits become less certain below a dark matter mass of 5 GeV and are not presented in \[13\].

Results In figures 1 and 2 we present the regions of parameter space that can give a fit the ARCADE excess as gray shaded regions and limits from dwarf spheroidal data as a black-dashed line, following reference \[11\]. Also, we show exclusion limits on the self-annihilation cross-section of dark matter coming from AMS positron data.
from reference [13] as a black-solid line and indicate the uncertainties quoted in this reference as black-dotted lines around the central exclusion value. The annihilation cross-section of a standard WIMP to produce the correct relic abundance is shown as a gray-dashed-dotted line.

For pure annihilation into electron/positron pairs or muon/anti-muon pairs, the good region for the ARCADE excess is clearly excluded by the positron data of AMS. Both regions are almost an order of magnitude above even the most conservative exclusion limit, see figure 1 and 2 respectively. For the case of electron/positron final states, a small window of less than a GeV is left open because limits from [13] do not apply in this small dark matter mass region.

The same conclusion can be drawn for the democratic case, see figure 3 in which annihilation proceeds into all three lepton flavors with equal probability. For this scenario we simply rescaled the limits on the annihilation into electron/positron pairs by a factor of three to account for the different branching ratio. We note again that a pure annihilation into tau/anti-tau pairs is already excluded by gamma ray data [11].

We see that all possible scenarios that can explain the excess observed in the radio wave background in terms of self-annihilating dark matter are inconsistent with positron data from AMS and other explanations are now necessary.

Conclusions In this note we assumed that the excess that is found in isotropic radio data is due to self-annihilating dark matter whose annihilation products emit synchrotron radiation and fit the observed power-law excess above the expected background. As was shown in earlier works [9] only leptonic annihilation channels can provide a good fit to the data and are already under pressure from cosmic ray data. We confronted this scenario further with limits on the dark matter self-annihilation cross-section derived from the positron data of AMS [13] that heavily constrain light dark matter with leptonic annihilation channels. We presented in figure 1, 2 and 3 that the explanation in terms of annihilating dark matter is ruled out by about an order of magnitude. Hence, other explanations have to be found.

Finally we note that it is possible that much stronger magnetic fields could increase the energy loss of annihilation products into synchrotron radiation and allow for smaller annihilation cross sections.

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