The Extragalactic Radio Background from Dark Matter Annihilation and the ARCADE-2 Excess

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TeVPA – Oct 27, 2015

KF & Linden PRD.91.083501, 1412.7545
KF & Linden submitted to PRD, 1506.05807
The ARCADE-2 Excess

Excess Antenna Temp (K)

22 MHz - 10 GHz
The ARCADE-2 Excess

$T_{\text{arcade}} = 1.26 \left( \frac{\nu}{\text{GHz}} \right)^{-2.6}$ K

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Exceeds the isotropic galactic diffuse emission & flux of extragalactic radio sources
Dark matter YES
Dark matter annihilation $\rightarrow$
electrons $\rightarrow$ diffusive
synchrotron emission

Fornengo et al, PRL, 107 (2011) 271302
Hooper et al, PRD, 86.103003, 2012
Dark matter YES
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Dark matter NO
Unusual smoothness of the
unresolved radio background $\rightarrow$
unlikely from large-scale structure

Fornengo et al, PRL, 107 (2011) 271302
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Anisotropy Constraints


- Planck
  857 GHz

\[ \frac{L(L+1)C_L}{2\pi^2} \frac{1}{T^2} \]

\[ \Delta T/T \]

- VLA 4.9 GHz
- VLA 8.4 GHz
- ATCA 8.7 GHz

- \( z=[0,1] \)
- \( z=[0,2] \)
- \( z=[5,10] \)

- 1 Mpc/h
- 2 Mpc/h

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\[ \frac{L(L+1)C_L}{2\pi^2} (\frac{\Delta T}{T}) \]

mass power spectrum

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Anisotropy Constraints

\[ C_\ell \propto \left( \frac{\delta T}{T_{\text{excess}}} \right)^2 = \left( \frac{\delta T}{T_{\text{CMB}}} \frac{T_{\text{CMB}}}{T_{\text{excess}}} \right)^2 \]
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[\text{CMB observation}]
Anisotropy Constraints

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mass power spectrum

uncertainties in excess temperature above 5 GHz -> requires a consistent computation of intensity & anisotropy
Intensity of the Extragalactic DM signals

\[ I(E_s) = \int d\chi \delta^2(z) W[(1 + z)E_s, \chi] \]
Intensity of the Extragalactic DM signals

\[ I(E_s) = \int d\chi \delta^2(z) W[(1 + z)E_s, \chi] \propto \langle \sigma v \rangle \frac{dN}{dE_s} \]

average flux from DM annihilation
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Average overdensity

\[ \propto \int dM \frac{dn(M, z)}{dM} \int dV \rho_{\text{DM}}(r, M, z)^2 \]
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Overdensity of individual dark matter halos

Halo mass function

Ando & Komatsu arXiv: 1301.5901, 0512217
KF & Linden PRD.91.083501, arXiv: 1412.7545
Anisotropy of the Extragalactic DM signals

\[ C_\ell(E_s) = \frac{1}{I(E_s)^2} \int \frac{d\chi}{\chi^2} W^2[(1 + z)E_s, \chi] P_{\delta^2}(k, z) \]
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Correlation between particles in the same halo & two distinct halos

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Power spectrum of DM halos

\[ P(k, z) = P_{1h}(k, z) + P_{2h}(k, z) \]

\[ P_{1h}(k, z) = \int dM \frac{dn}{dM} |\tilde{u}(k, M)|^2 \]
Substructure Contribution

Effective DM density that contributes to synchrotron

$$\rho_{\text{sync}}^2(r, M) = \rho_{\text{DM}}^2(r, M) \frac{\rho_B}{\rho_B + \rho_{\text{CMB}}}$$
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Dark matter substructure distribution

Normalized by volume fraction

\[ 1 - f_s(r) = 7 \times 10^{-3} \left( \frac{\rho_h(r)}{\rho_h(r = 100 \text{ kpc})} \right)^{-0.26} \]

Kamionkowski+ PRD 81 043532 (2010)
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Dark matter substructure distribution

Magnetic field structure

\[ B(M, r) = B_0 \left( \frac{M}{M_0} \right)^\alpha \left[ 1 + \left( \frac{r}{r_c} \right)^2 \right]^{-3\beta\eta/2} \]

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Kamionkowski+ PRD 81 043532 (2010)

\[ B_{\text{sub}} = 4 \mu G \text{ for } M = 10^{14} M_\odot \]
**Results with different DM models**

<table>
<thead>
<tr>
<th>Case</th>
<th>$m_{DM}$ (GeV)</th>
<th>annihilation channel</th>
<th>$\langle \sigma v \rangle$ (cm$^3$s$^{-1}$)</th>
<th>$r_{sub}$</th>
<th>$B^*_{sub}$ (μG)</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>50</td>
<td>$b\bar{b}$</td>
<td>$3 \times 10^{-26}$</td>
<td>8</td>
<td>8</td>
<td>72.64</td>
</tr>
<tr>
<td>II</td>
<td>8</td>
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![Graph showing $m_{DM} = 50$ GeV, $\chi^2 = 72.64$](https://example.com/graph1.png)

![Graph showing $C_l (l+1)/2\pi$ vs. $l$ for different frequencies](https://example.com/graph2.png)
# A Consistent Picture

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KF & Linden PRD.91.083501, 1412.7545
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![Graphs showing T vs \( \nu \) (GHz) and \( C_l (l(l+1)) / 2\pi \) vs \( l \)]

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A Consistent Picture - model III

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$T[K]$ vs $\nu[GHz]$

$C(l(l+1)/2\pi)$ vs $l$
Alternative to Substructure - Alfven Re-acceleration in Galaxy Clusters

Image credit: Bonafede et al. 2014
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Alternative to Substructure - Alfven Re-acceleration in Galaxy Clusters

\[
\frac{\partial W_k(t)}{\partial t} = -\Gamma(k)W_k(t) + I_A(k, t)
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\frac{\partial f}{\partial t} = \frac{1}{p} \frac{\partial}{\partial p} \left[ p^2 D_{pp} \frac{\partial f}{\partial p} + S p^4 f \right]
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Re-acceleration of electrons by Alfven waves that are excited by cluster mergers can substitute the substructure contribution.
Conclusion
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