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

Ke Fang

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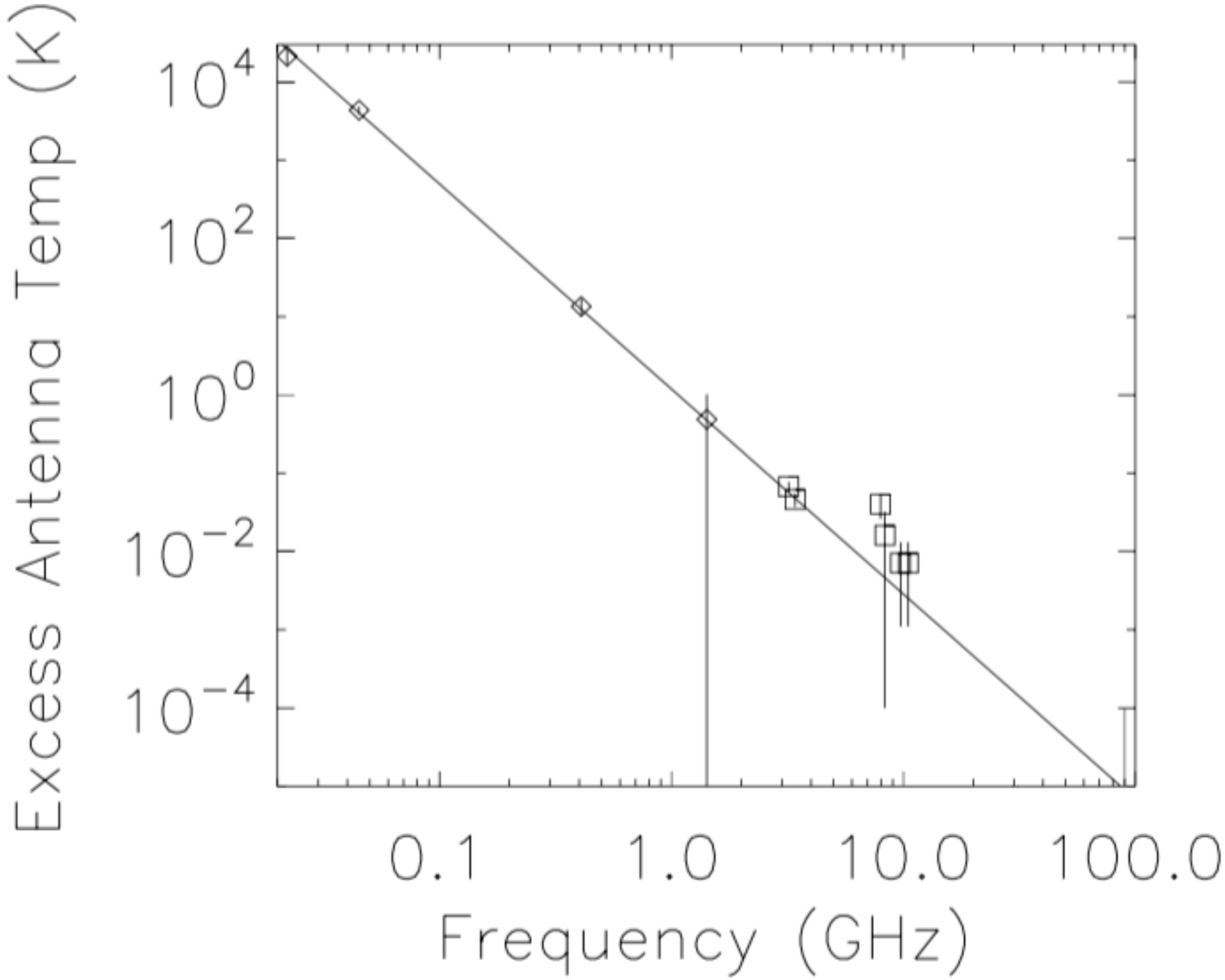
University of Maryland & NASA GSFC
TeVPA – Oct 27, 2015

KF & Linden PRD.91.083501, 1412.7545
KF & Linden submitted to PRD, 1506.05807

Fixsen et al, ApJ, 0901.0555
Kogut et al, ApJ, 734, 4, 2011
Singal et al, MNRAS, 409, 1172, 2010

The ARCADE-2 Excess

22 MHz - 10 GHz



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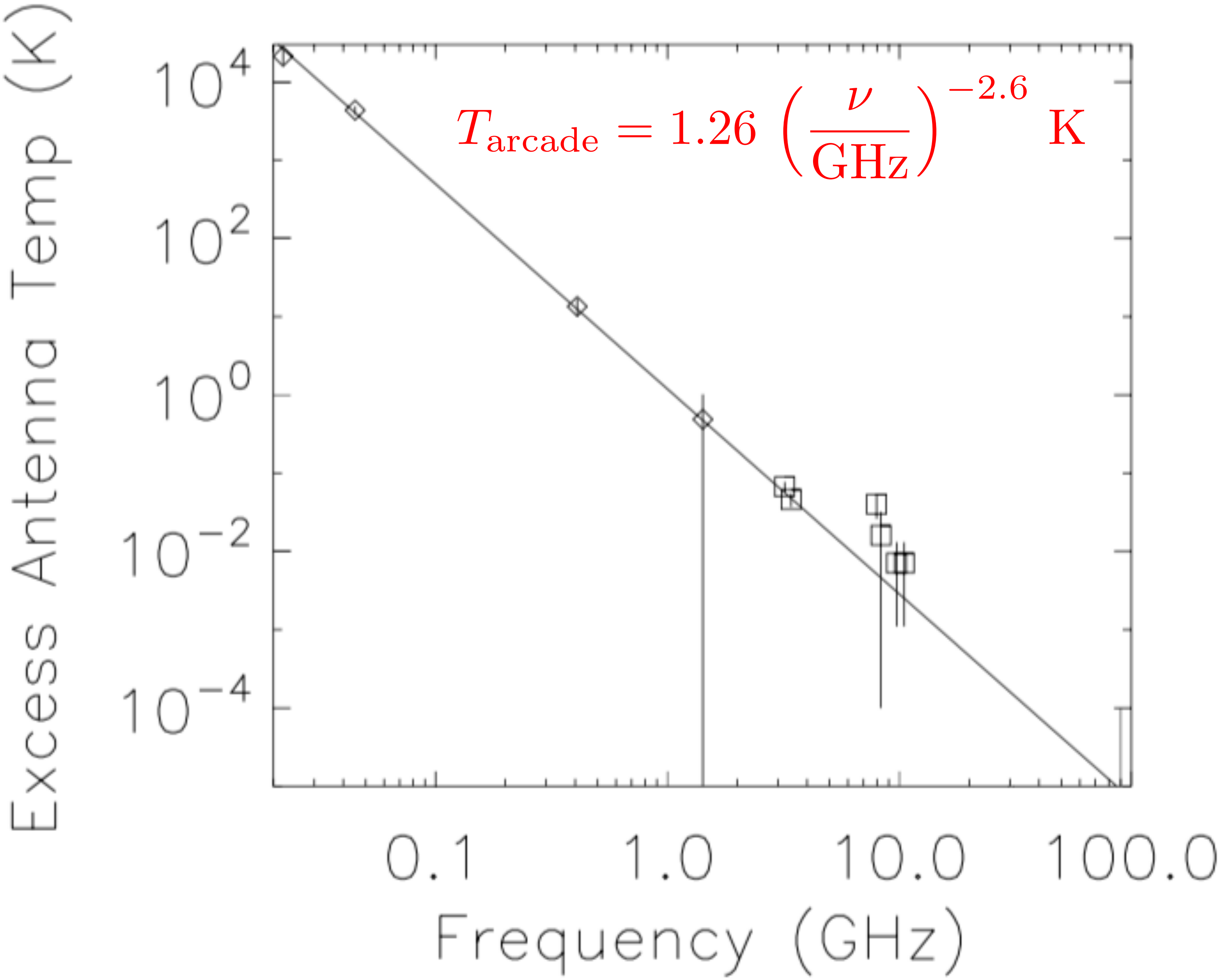

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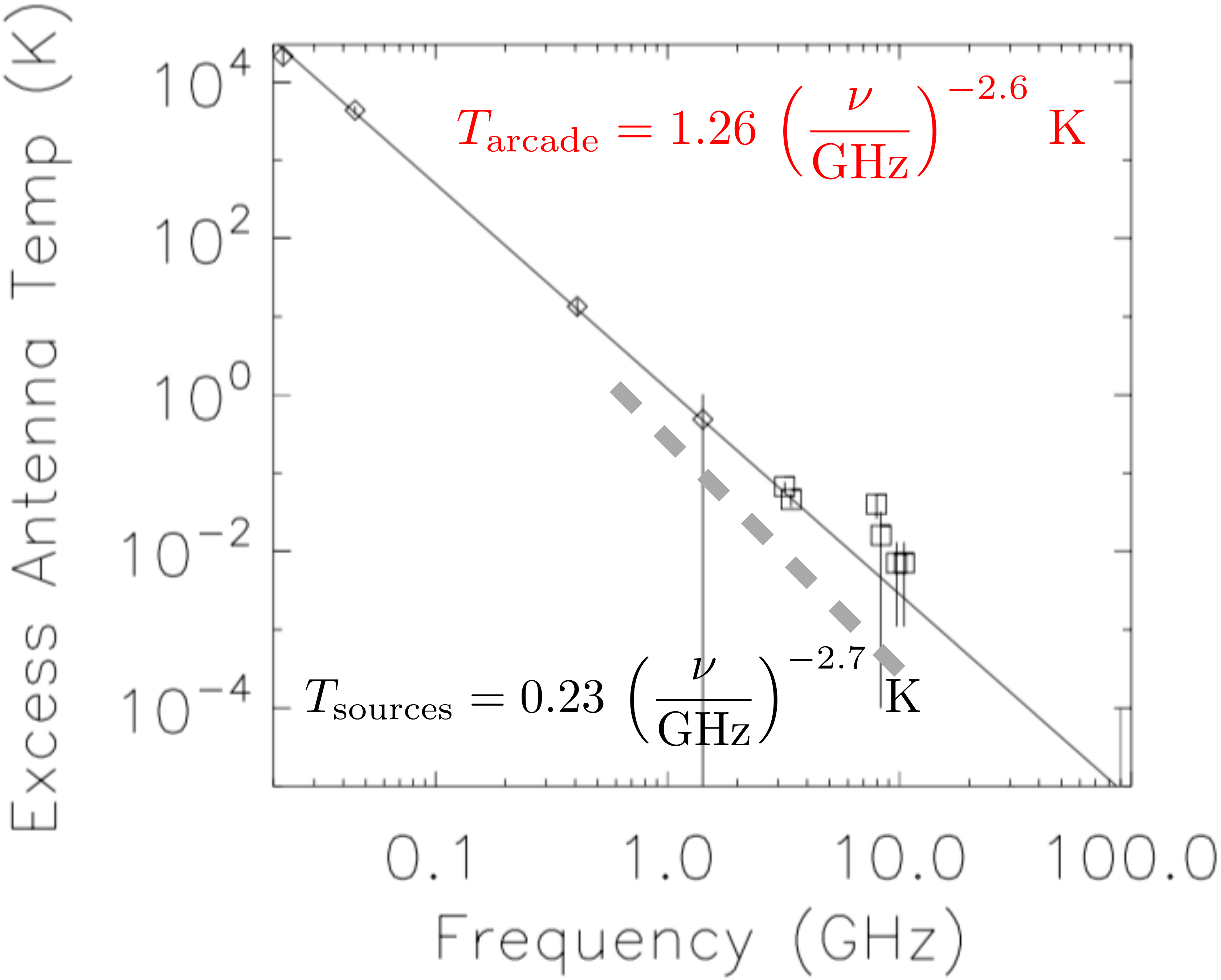

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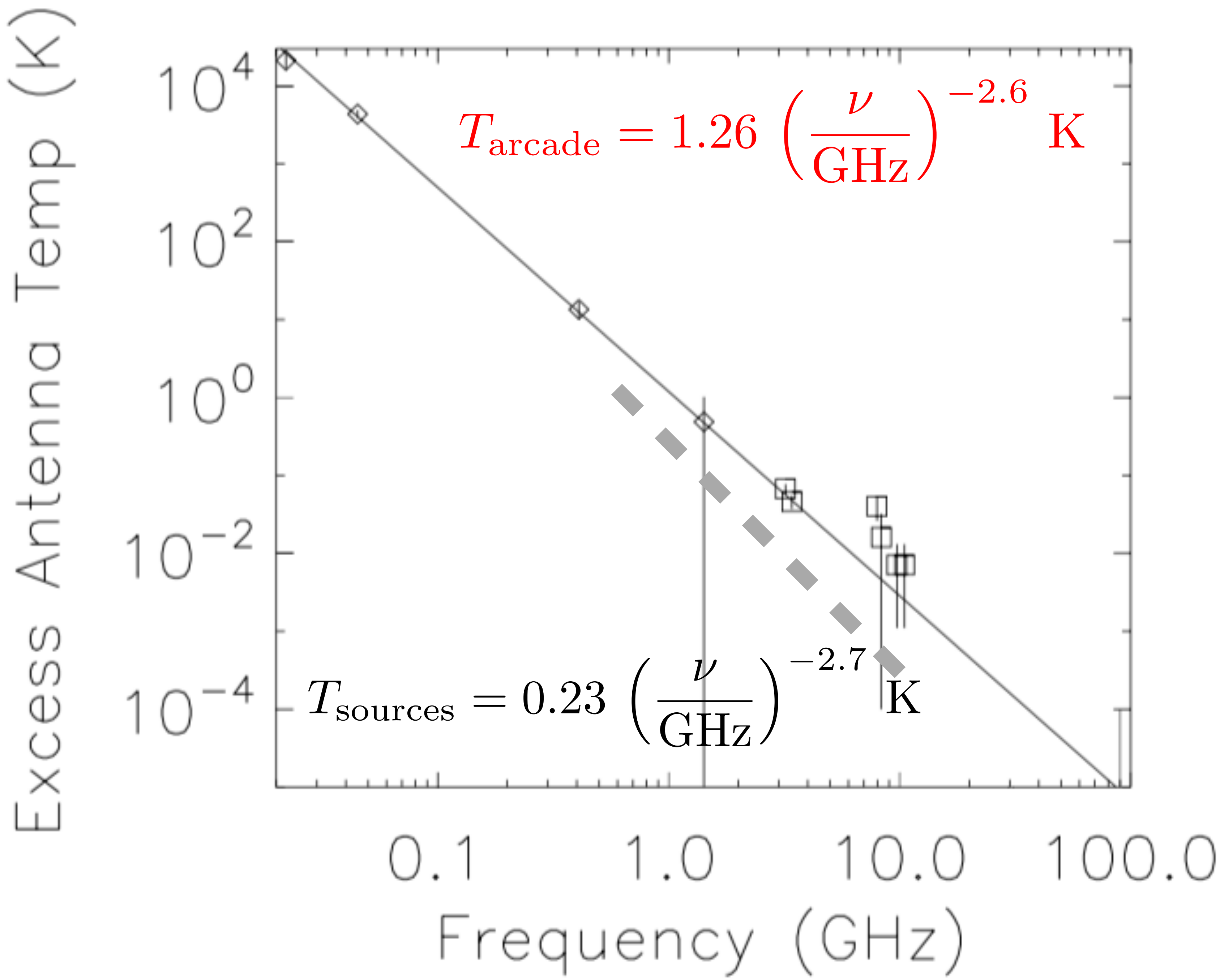
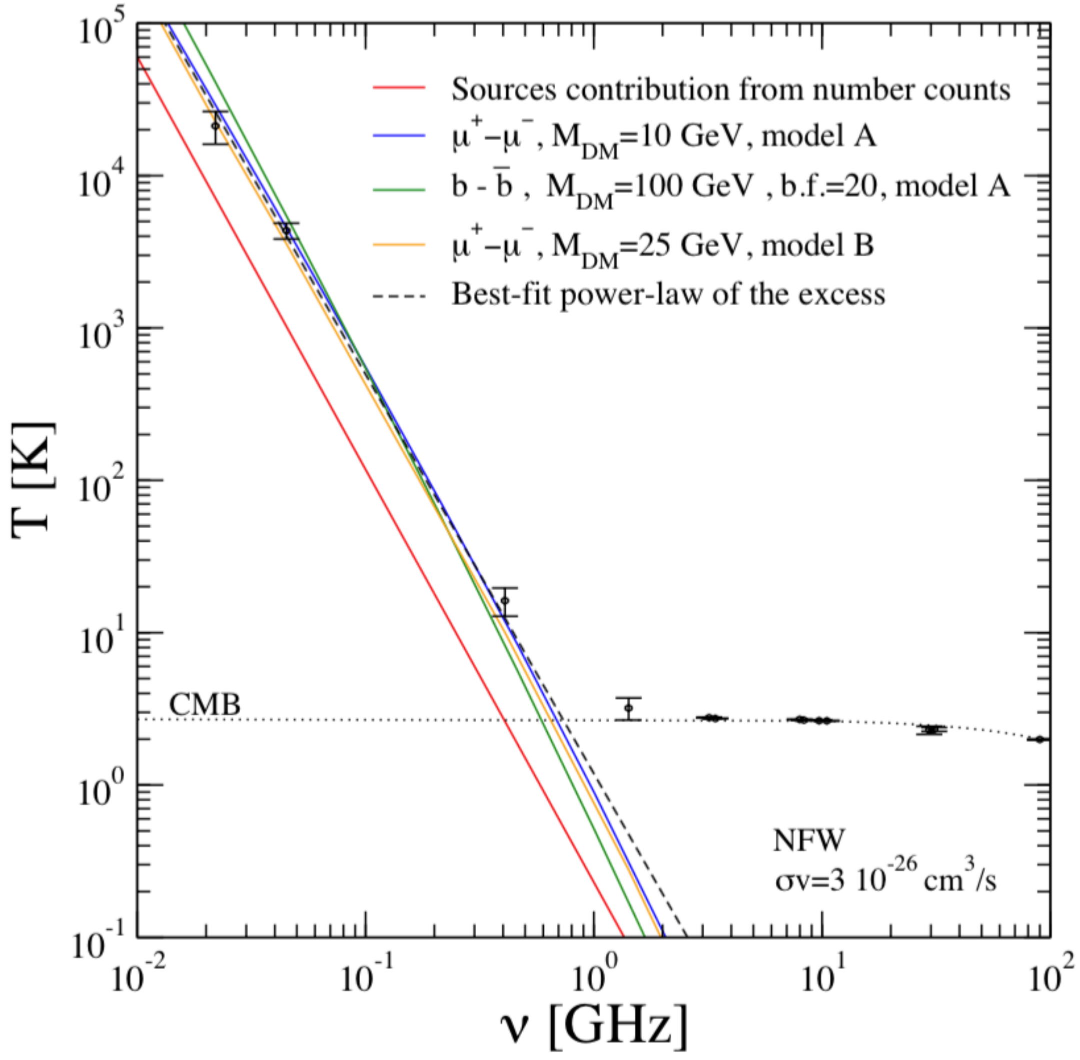


Exceeds the isotropic galactic diffuse emission & flux of extragalactic radio sources

Dark matter YES

Dark matter annihilation —> electrons —> diffusive synchrotron emission



Fornengo et al, PRL, 107 (2011) 271302
Hooper et al, PRD, 86.103003, 2012

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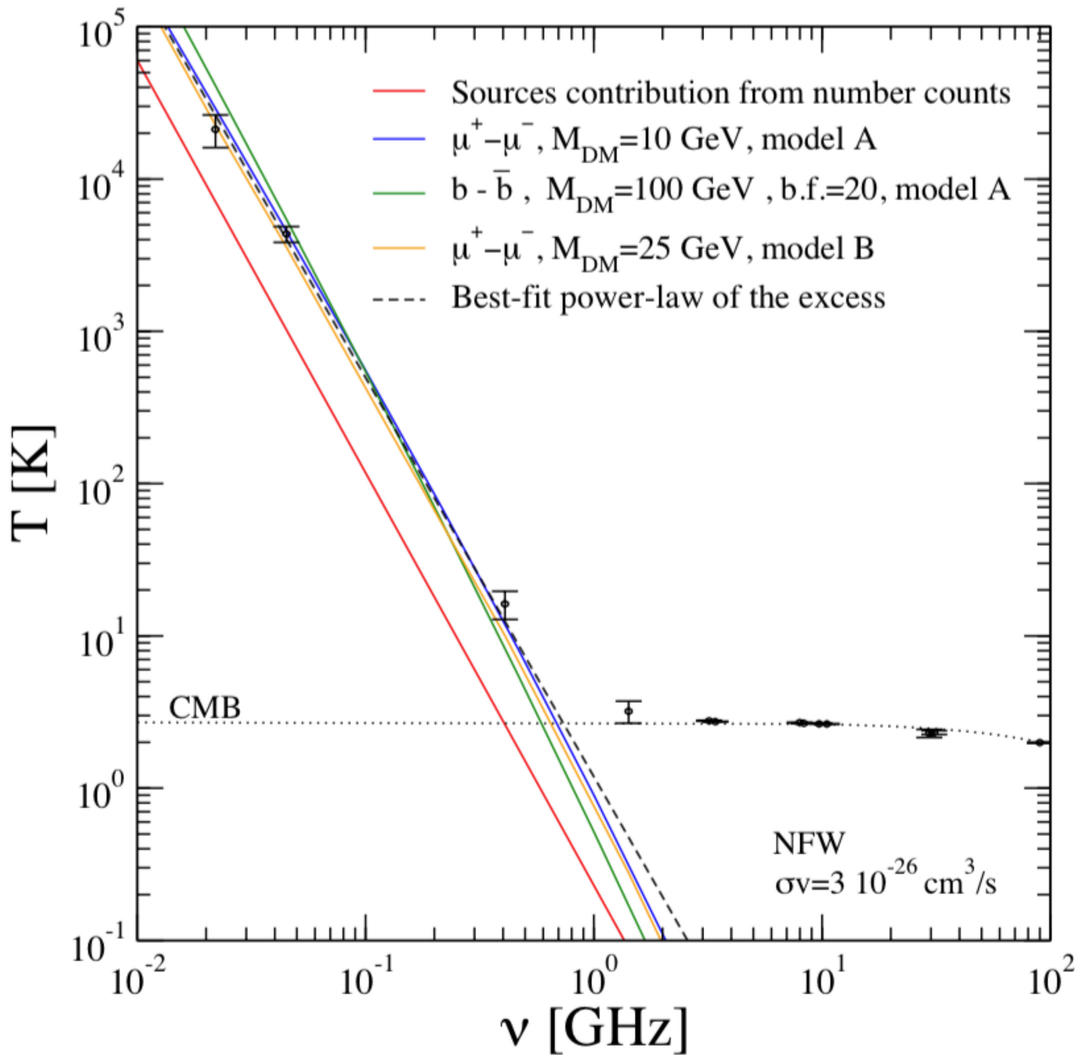

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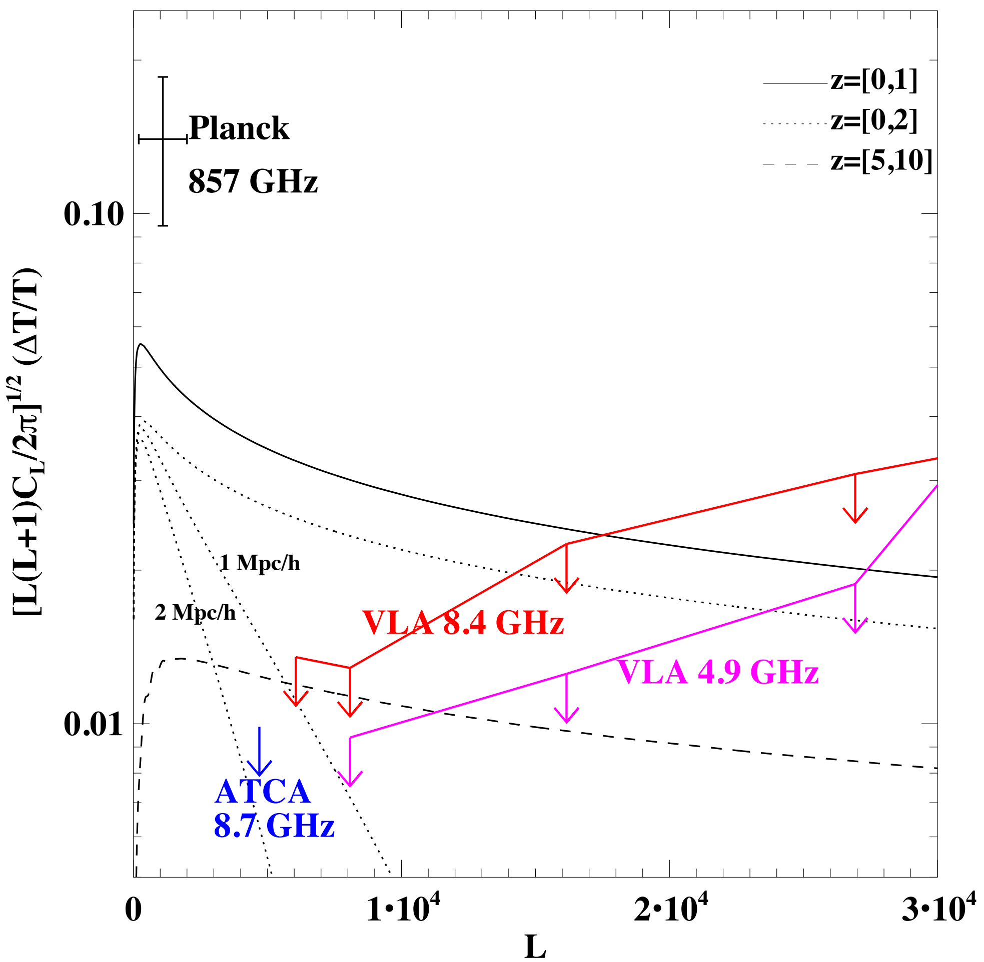
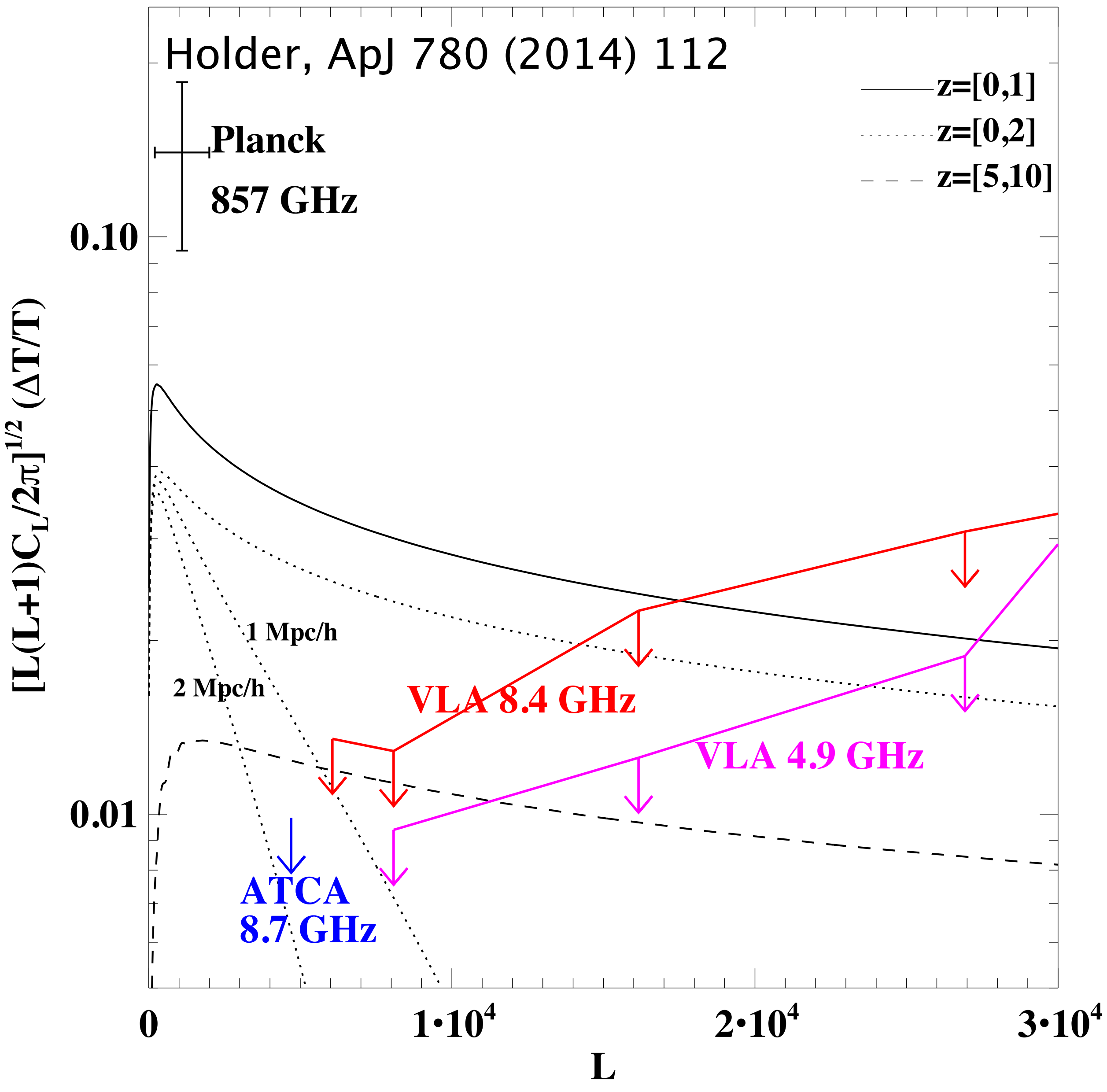
Dark matter NO

Unusual smoothness of the unresolved radio background —> unlikely from large-scale structure



Holder, ApJ 780 (2014) 112

Anisotropy Constraints



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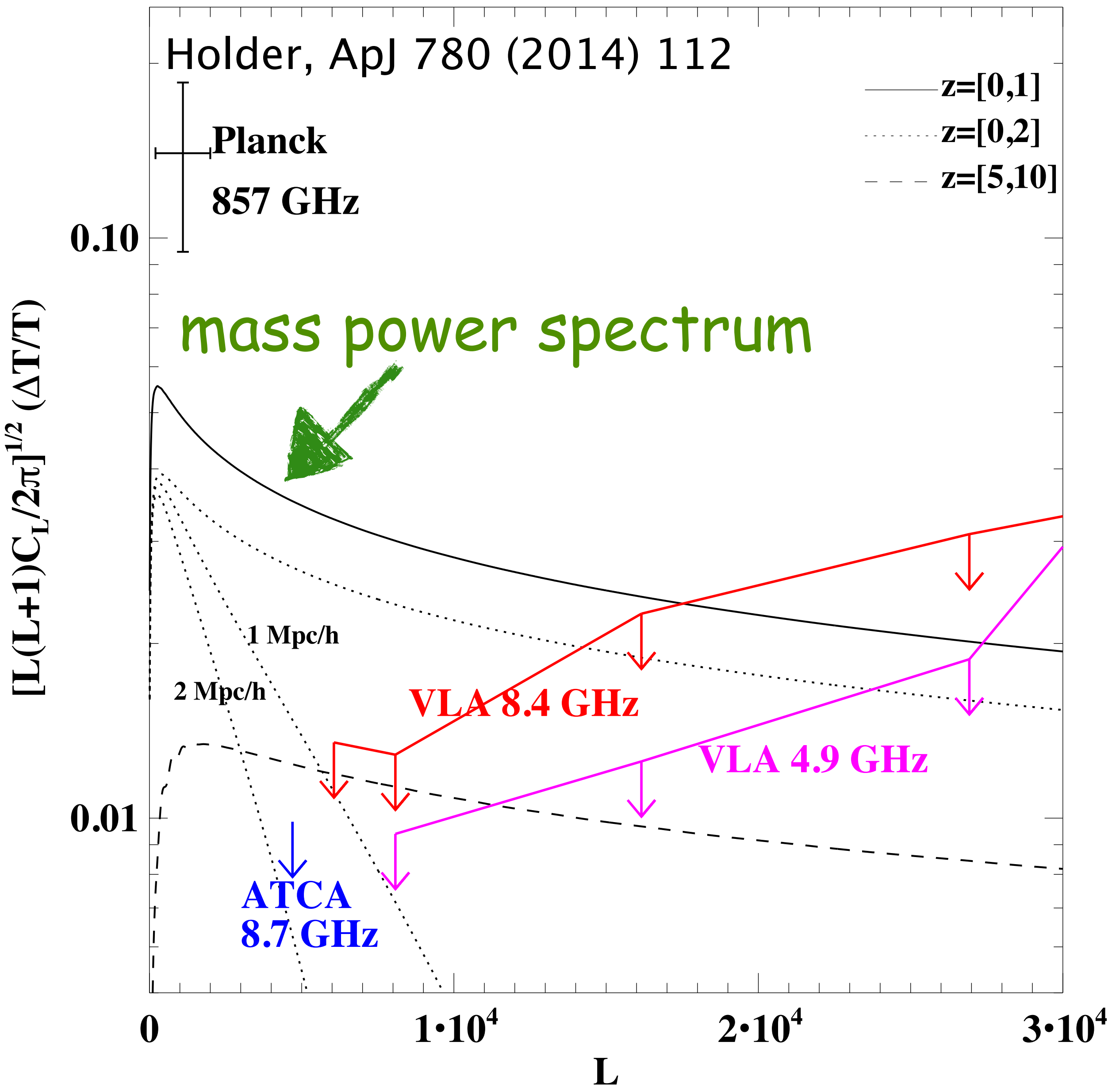

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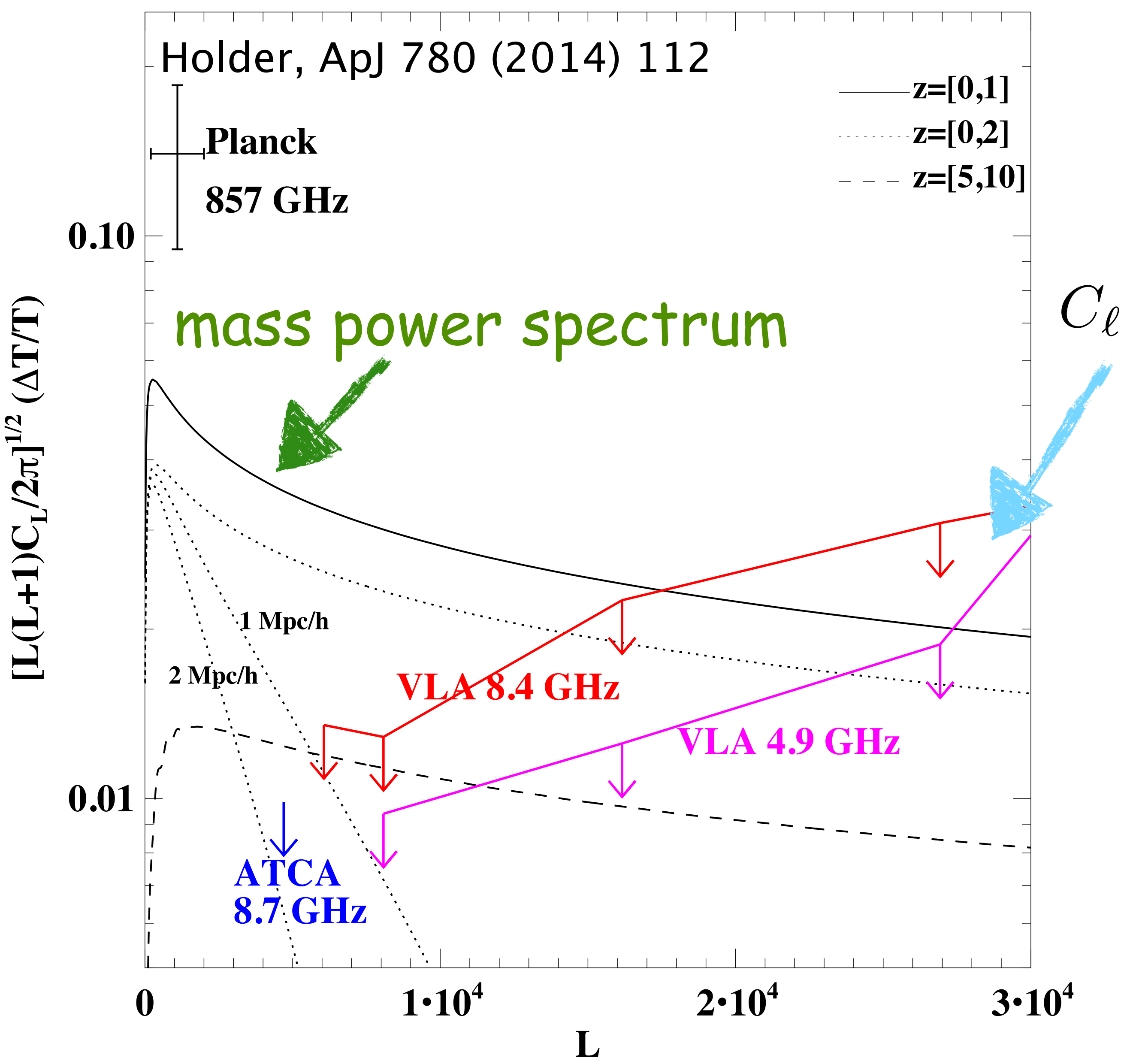

$$C_\ell \propto \left(\frac{\delta T}{T_{\rm excess}}\right)^2 = \left(\frac{\delta T}{T_{\rm CMB}}\frac{T_{\rm CMB}}{T_{\rm excess}}\right)^2$$

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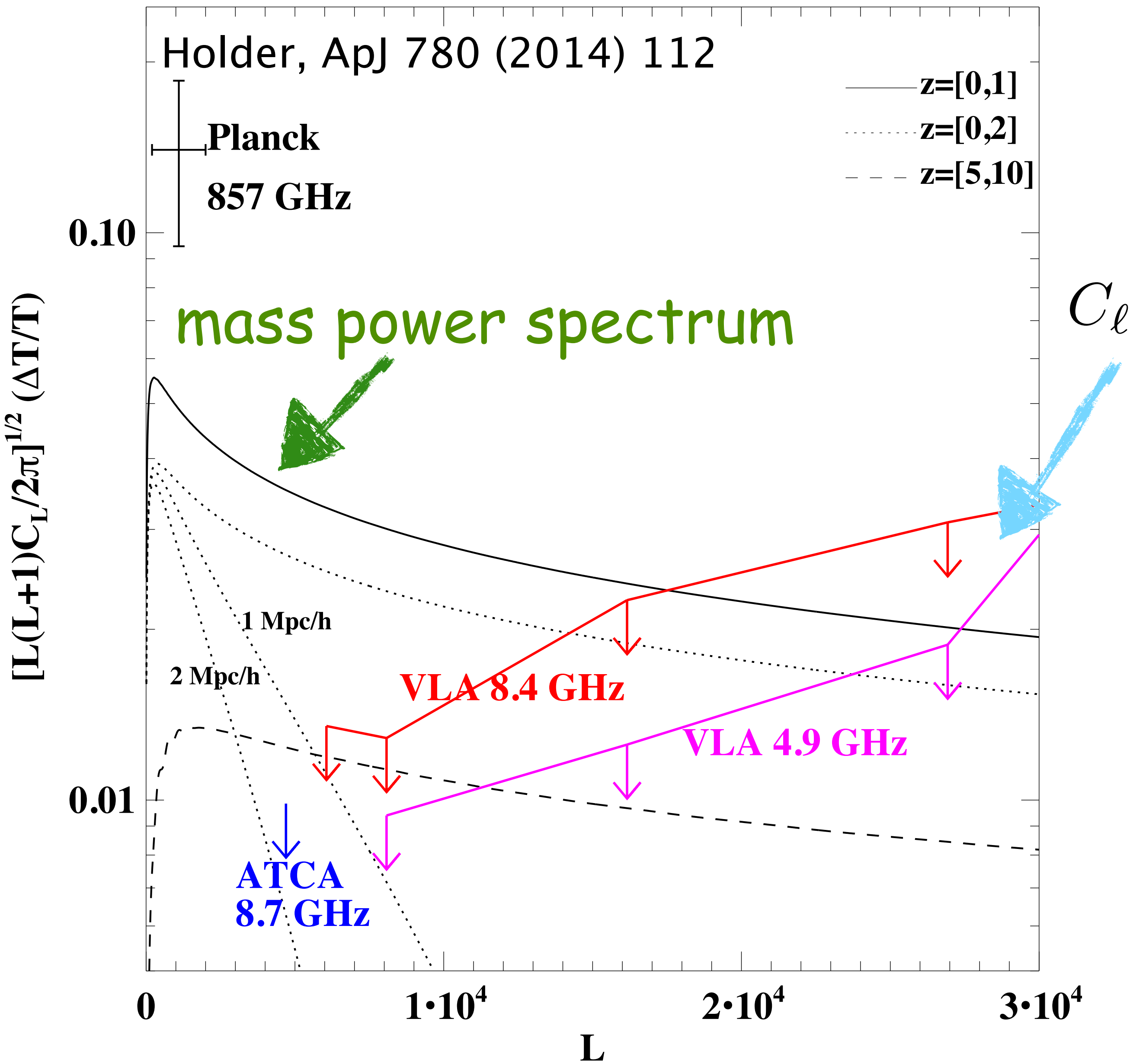

CMB observation

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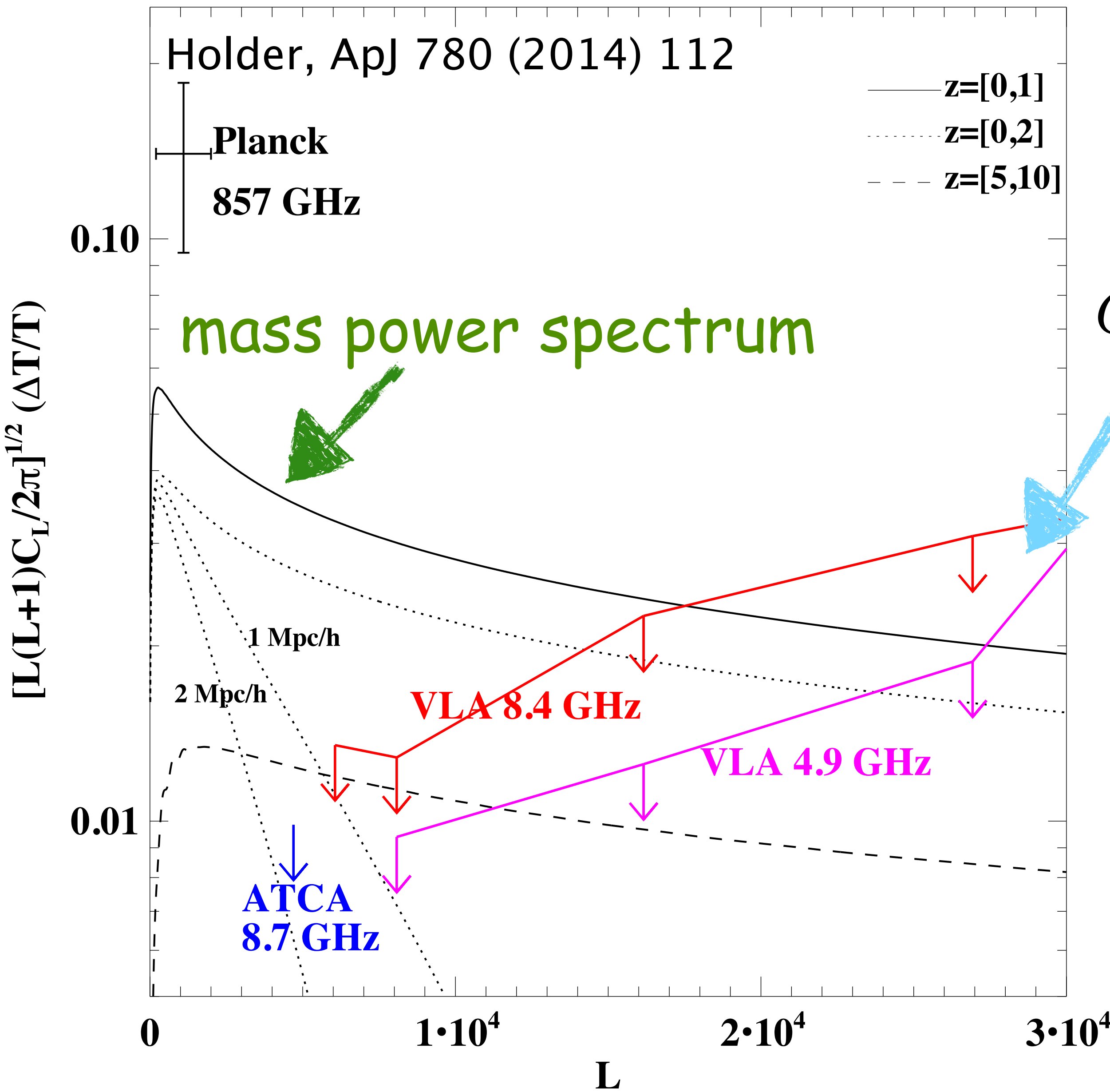

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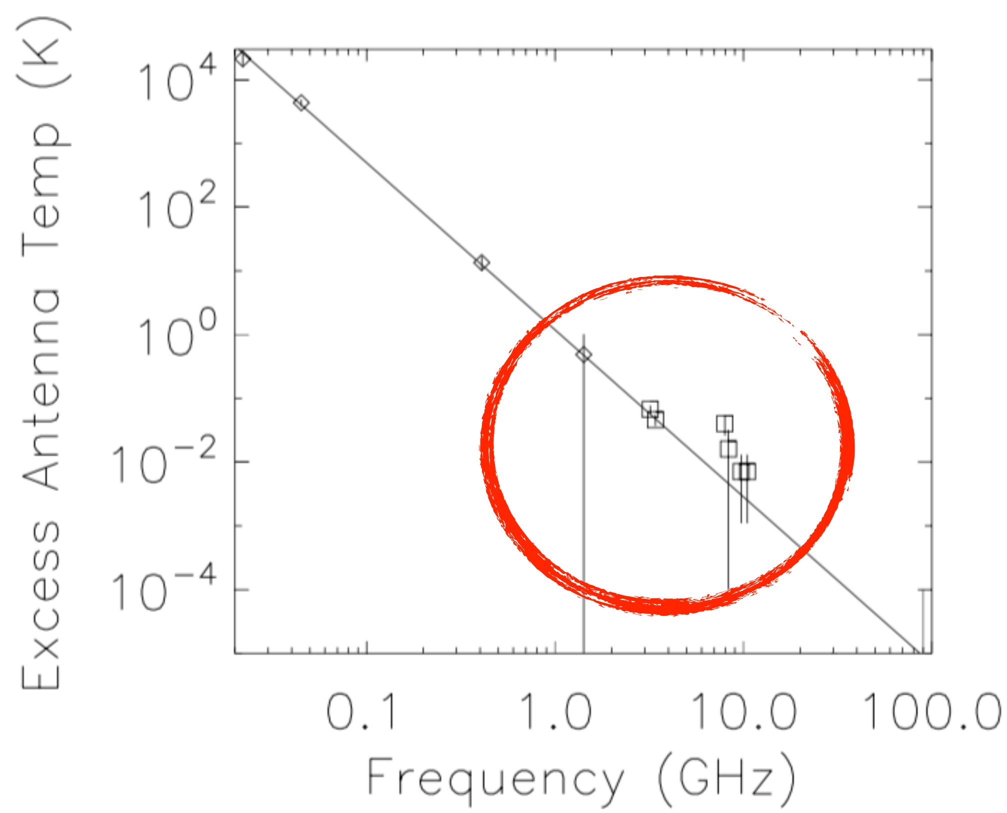

uncertainties in excess temperature above 5 GHz -> requires a consistent computation of intensity & anisotropy

Intensity of the Extragalactic DM signals

$$I(E_{\rm s}) = \int d\chi \delta^2(z)\, W[(1+z)E_s, \chi]$$

Ando & Komatsu arXiv: 1301.5901, 0512217
KF & Linden PRD.91.083501, arXiv: 1412.7545

Intensity of the Extragalactic DM signals

$$\propto \langle \sigma v \rangle \frac{dN}{dE_s}$$

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average flux from DM annihilation

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$$\propto \int dM \frac{dn(M,z)}{dM} \int dV \rho_{\rm DM}(r,M,z)^2$$

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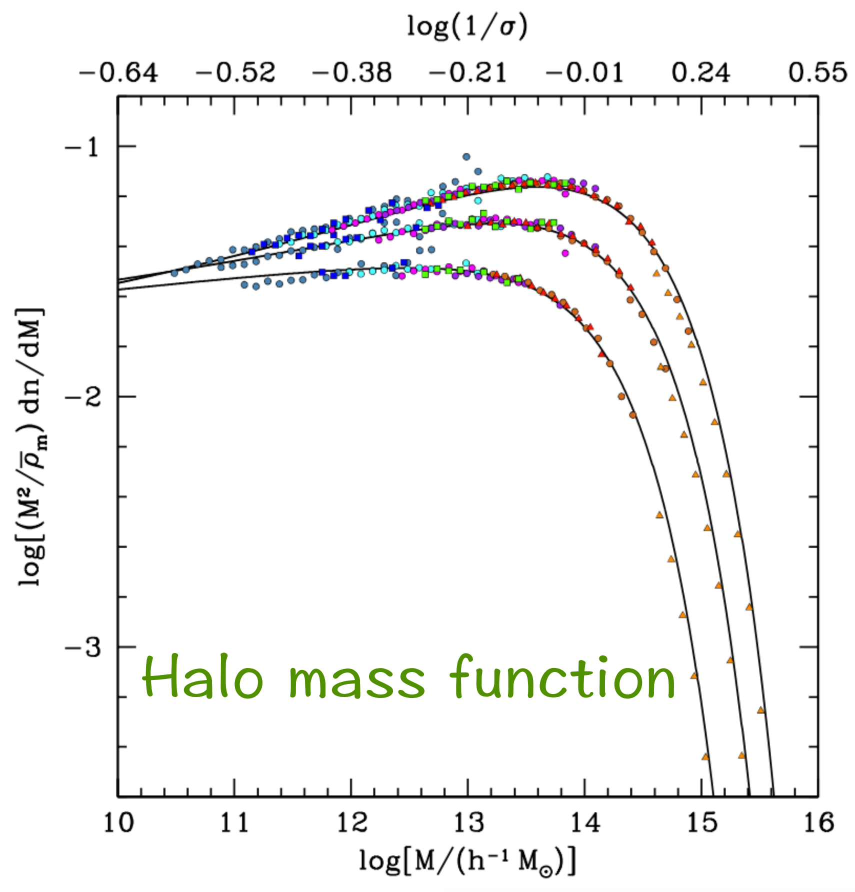

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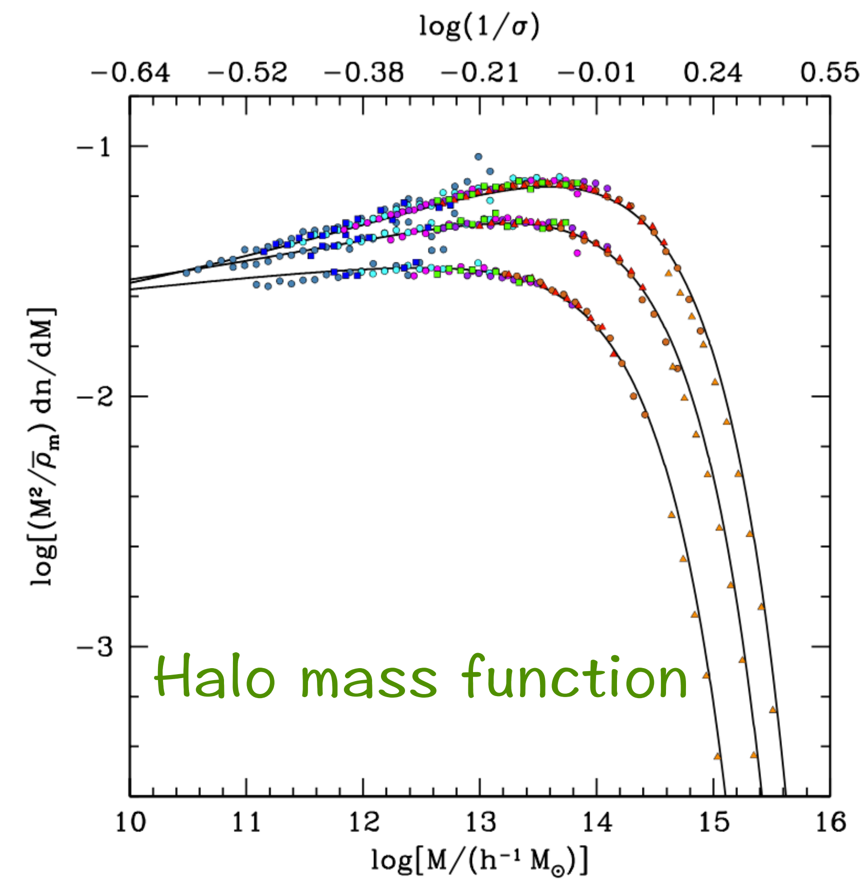
Overdensity of individual dark matter halos



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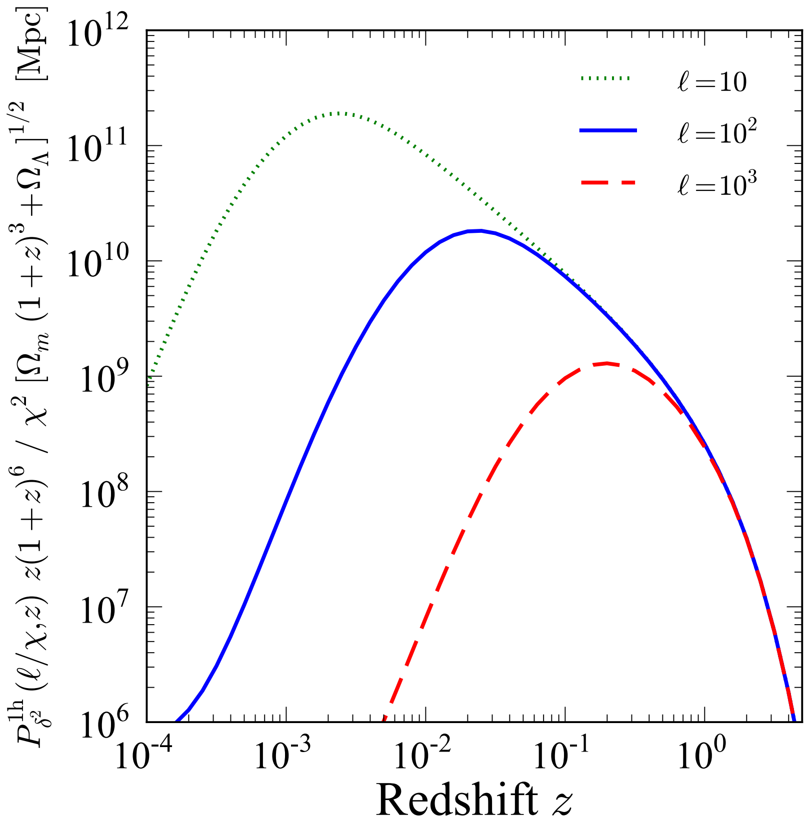
Anisotropy of the Extragalactic DM signals

$$C_\ell(E_s) = \frac{1}{I(E_s)^2} \int \frac{d\chi}{\chi^2} W^2[(1+z)E_s, \chi]\, P_{\delta^2}(k, z)$$



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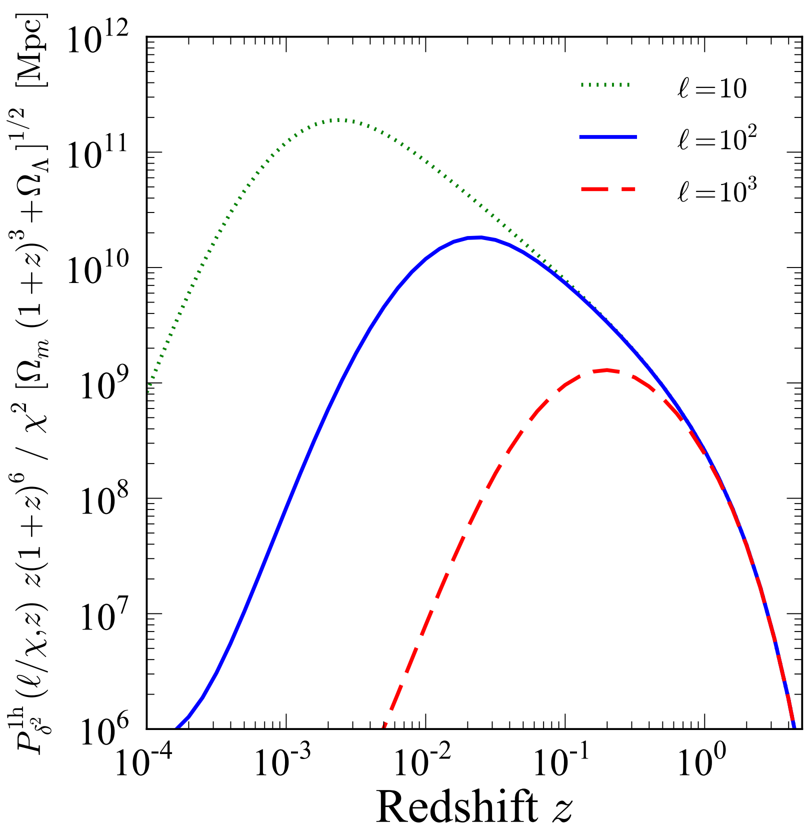
Correlation between particles in the same halo & two distinct halos



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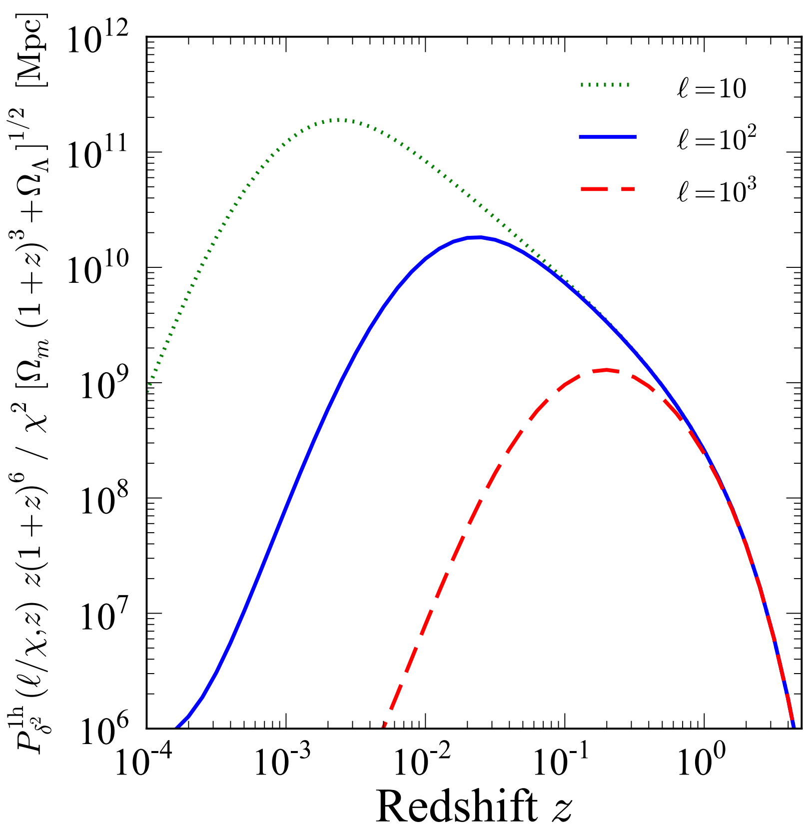

Power spectrum of DM halos

$$P(k,z) = P_{1h}(k,z) + P_{2h}(k,z)$$

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

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Substructure Contribution

Effective DM density that contributes to synchrotron

$$\rho^2_{\rm sync}(r, M) = \rho^2_{\rm DM}(r, M)\,\frac{\rho_B}{\rho_B + \rho_{\rm CMB}}$$

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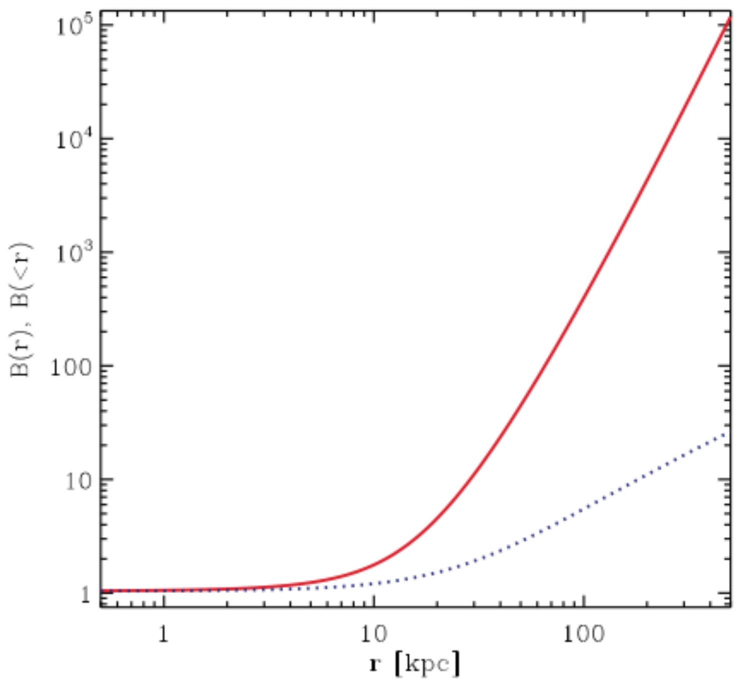
Dark matter substructure distribution



Normalized by volume fraction

$$1 - f_{\rm s}(r) = 7 \times 10^{-3} \left(\frac{\rho_{\rm h}(r)}{\rho_{\rm h}(r = 100\,{\rm kpc})}\right)^{-0.26}$$

Kamionkowski+ PRD 81 043532 (2010)

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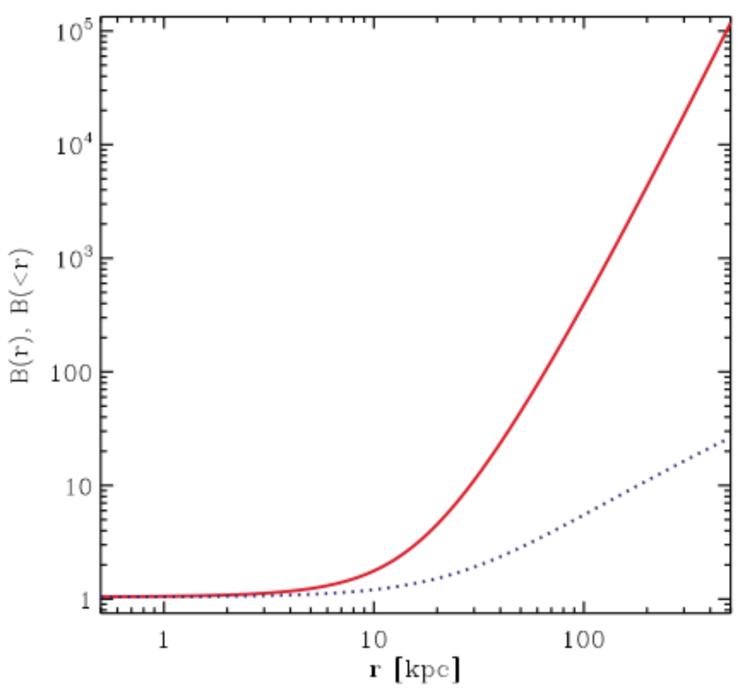

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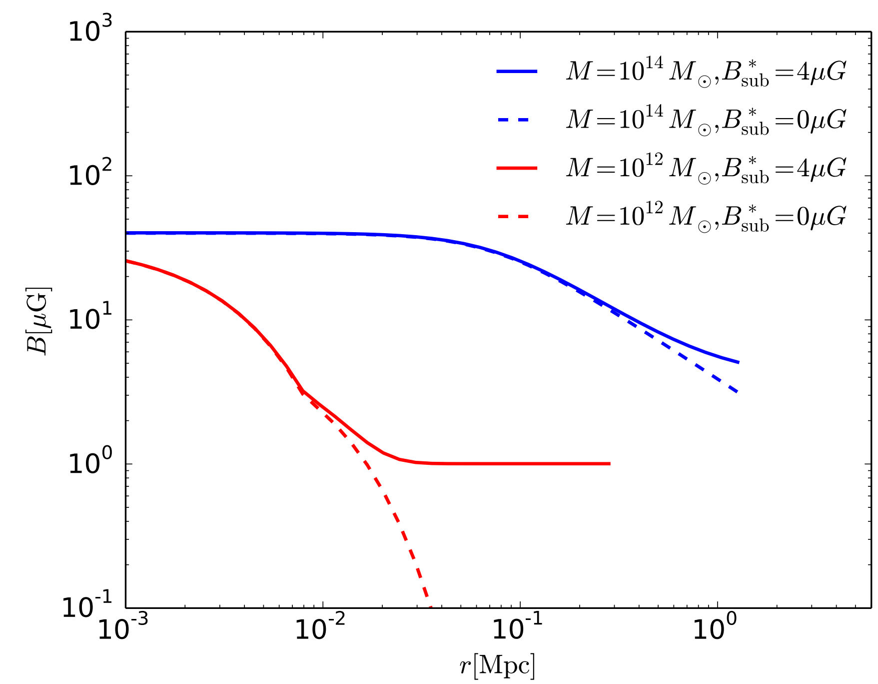
Magnetic field structure

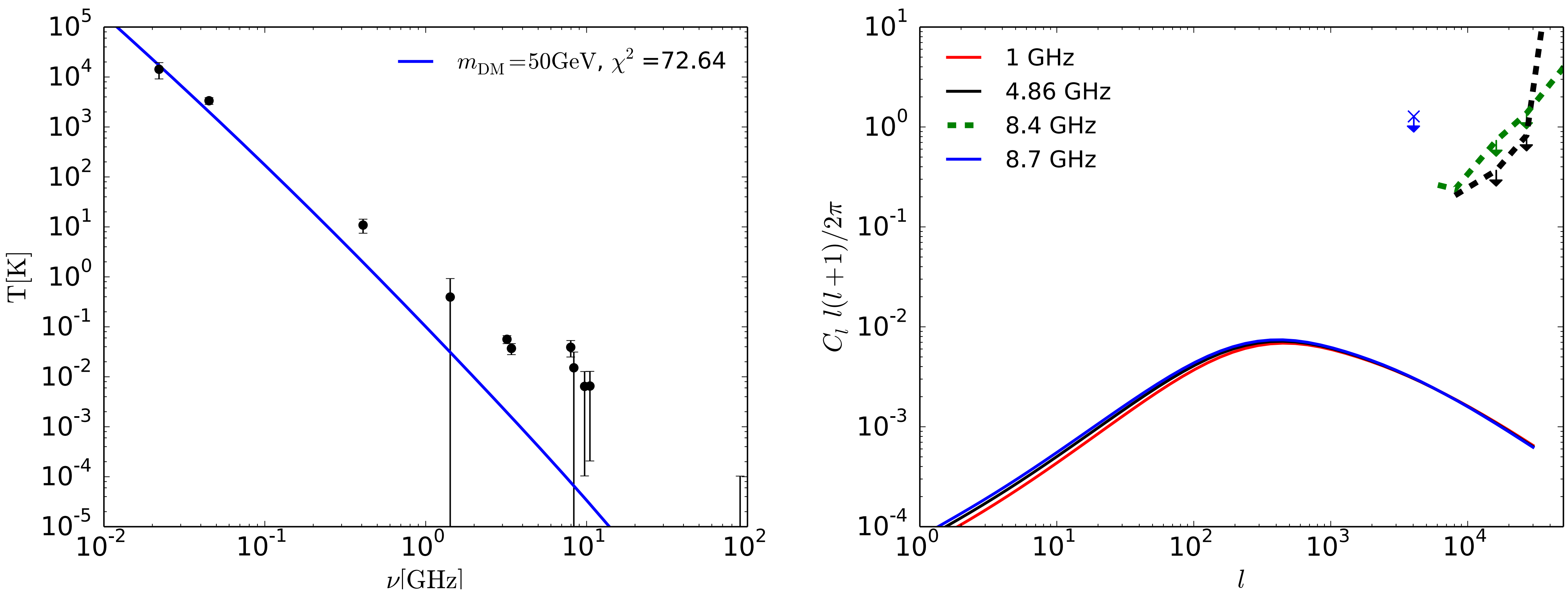
$$B(M,r) = B_0\left(\frac{M}{M_0}\right)^{\alpha}\left[1+\left(\frac{r}{r_{\rm c}}\right)^2\right]^{-3\beta\eta/2}$$



$$B_{\rm sub} = 4\mu G\ for\ M = 10^{14}M_\odot$$

Results with different DM models

Case	$m_{\rm DM}$ (GeV)	annihilation channel	$\langle\sigma v\rangle$ ($\rm cm^3 s^{-1}$)	$r_{\rm sub}$ ($r_{\rm vir}$)	$B^*_{\rm sub}$ (μG)	$\chi^{2\,a}$
I	50	$b\bar{b}$	3×10^{-26}	8	8	72.64
II	8	leptons	8.4×10^{-27}	4	4	44.58
III	23	charge coupled	7.2×10^{-27}	8	8	56.65



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A Consistent Picture

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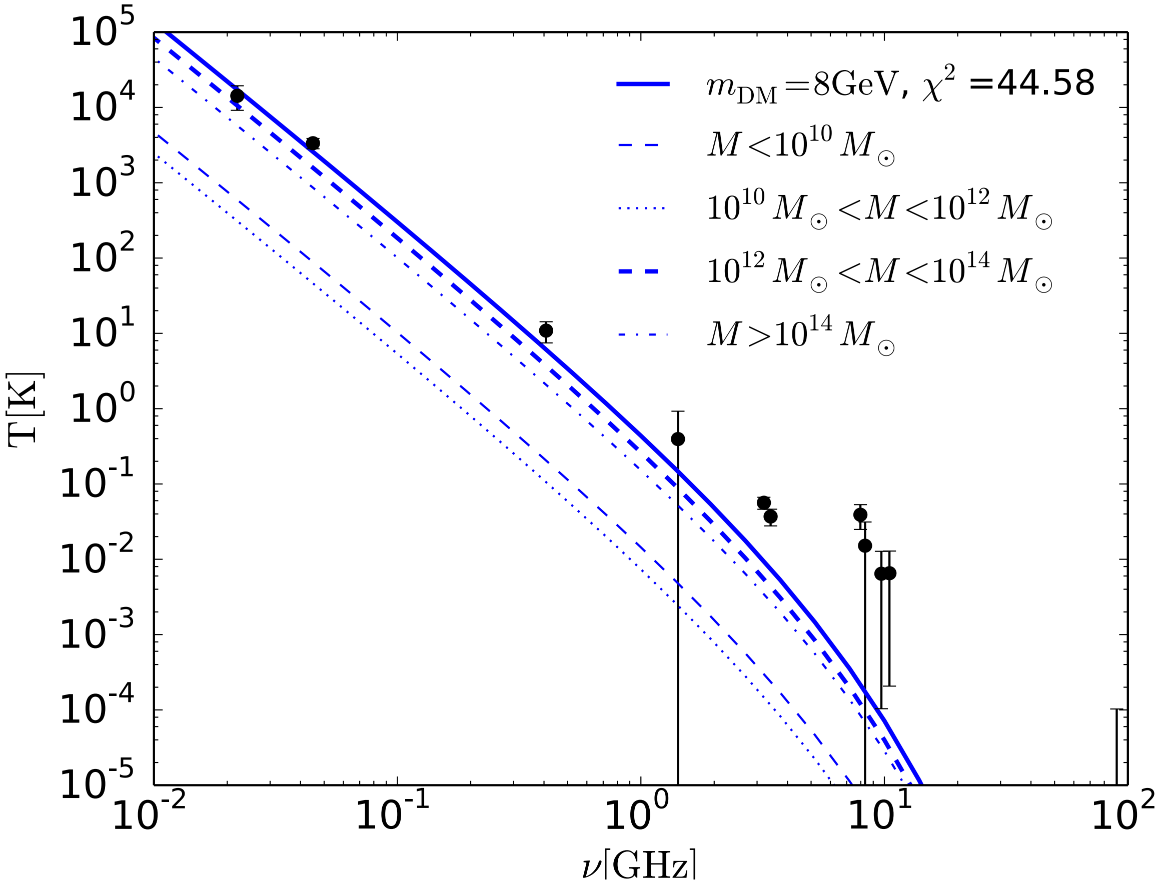

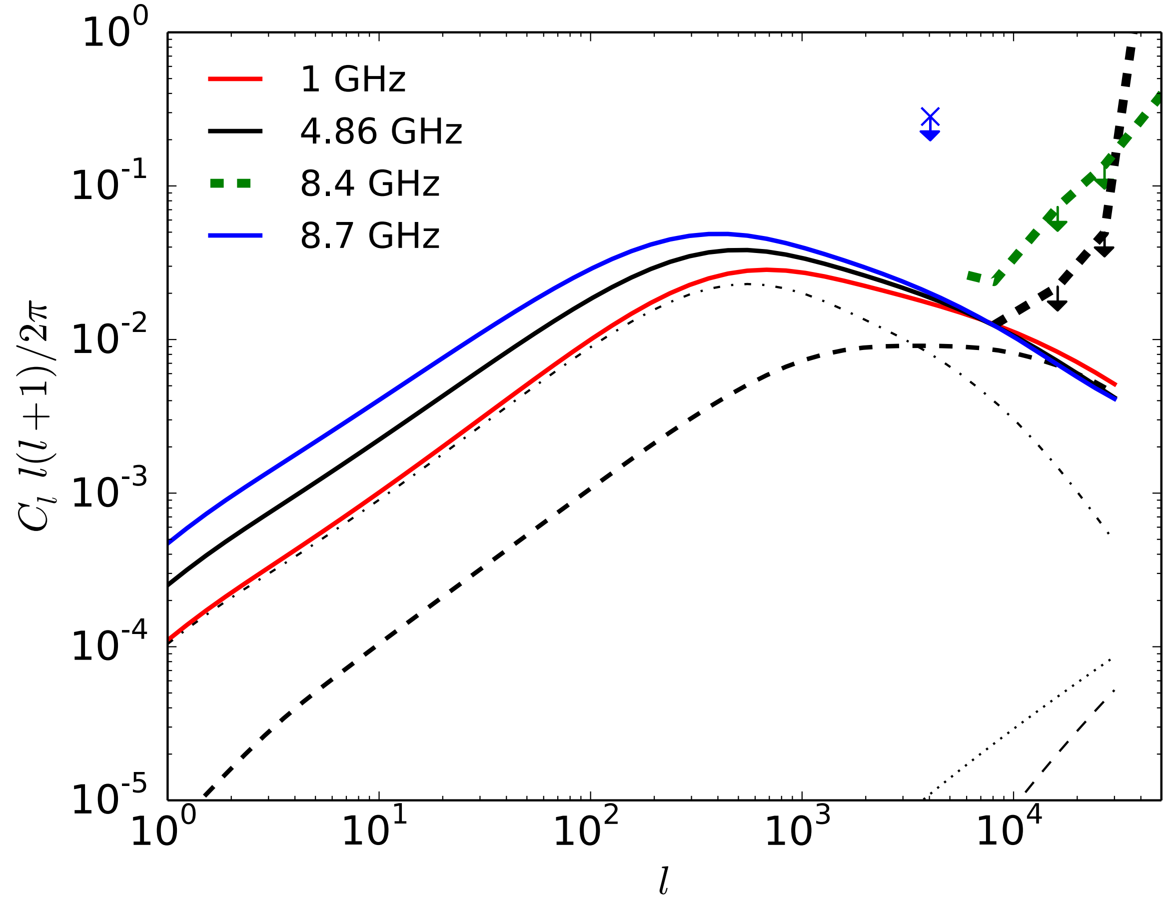

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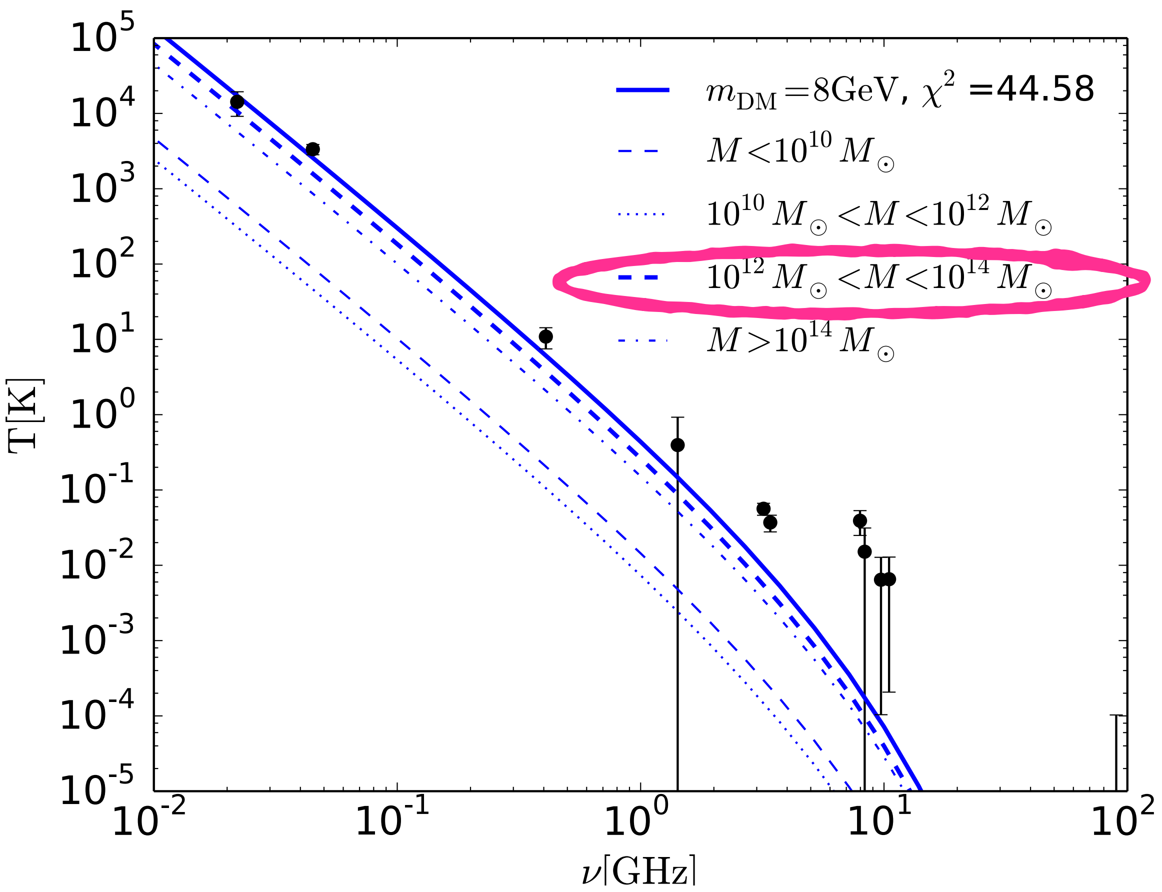

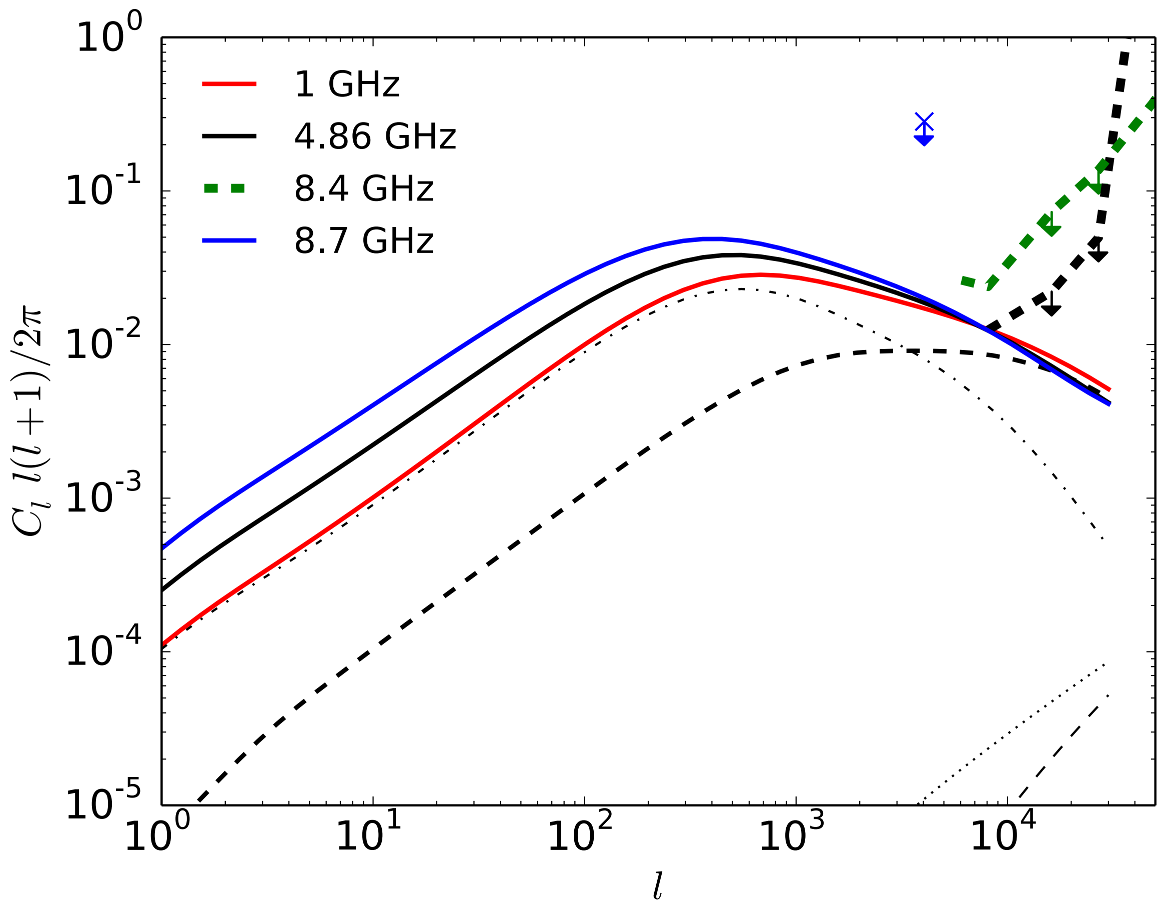

KF & Linden PRD.91.083501,
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A Consistent Picture - model III

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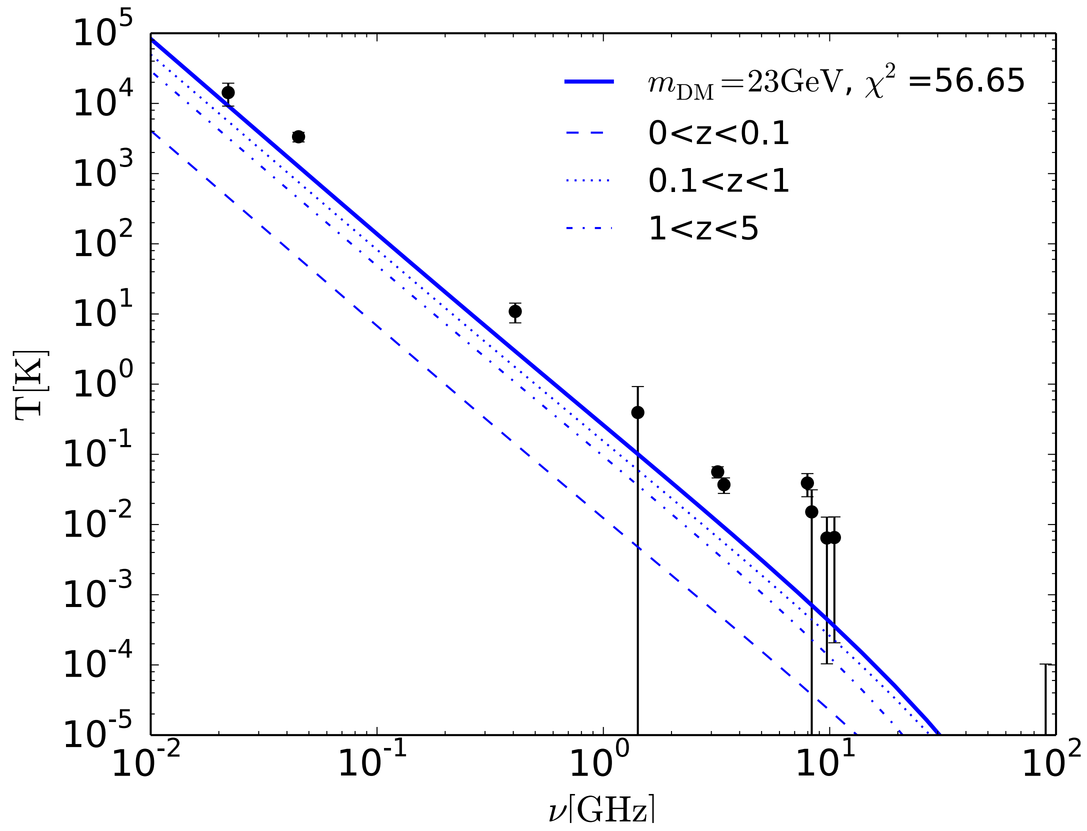

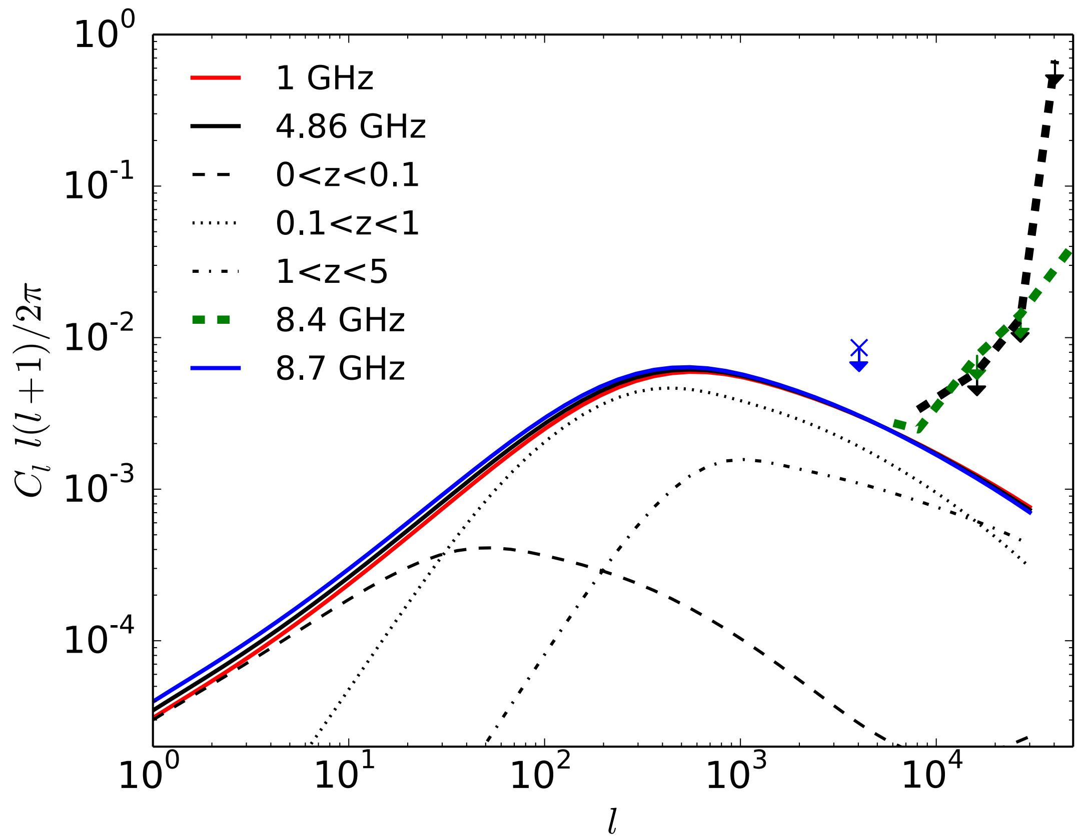

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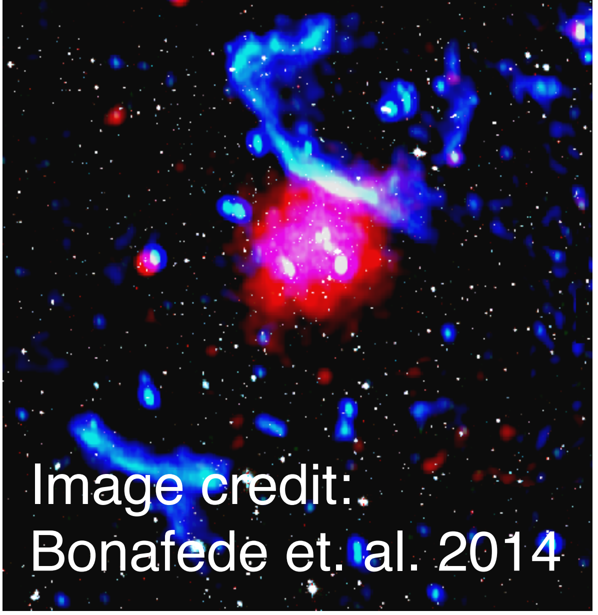

Alternative to Substructure - Alfven Re-acceleration in Galaxy Clusters

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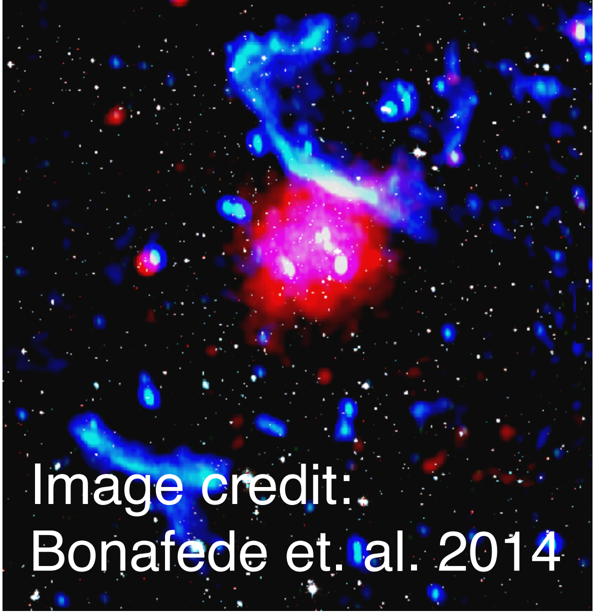

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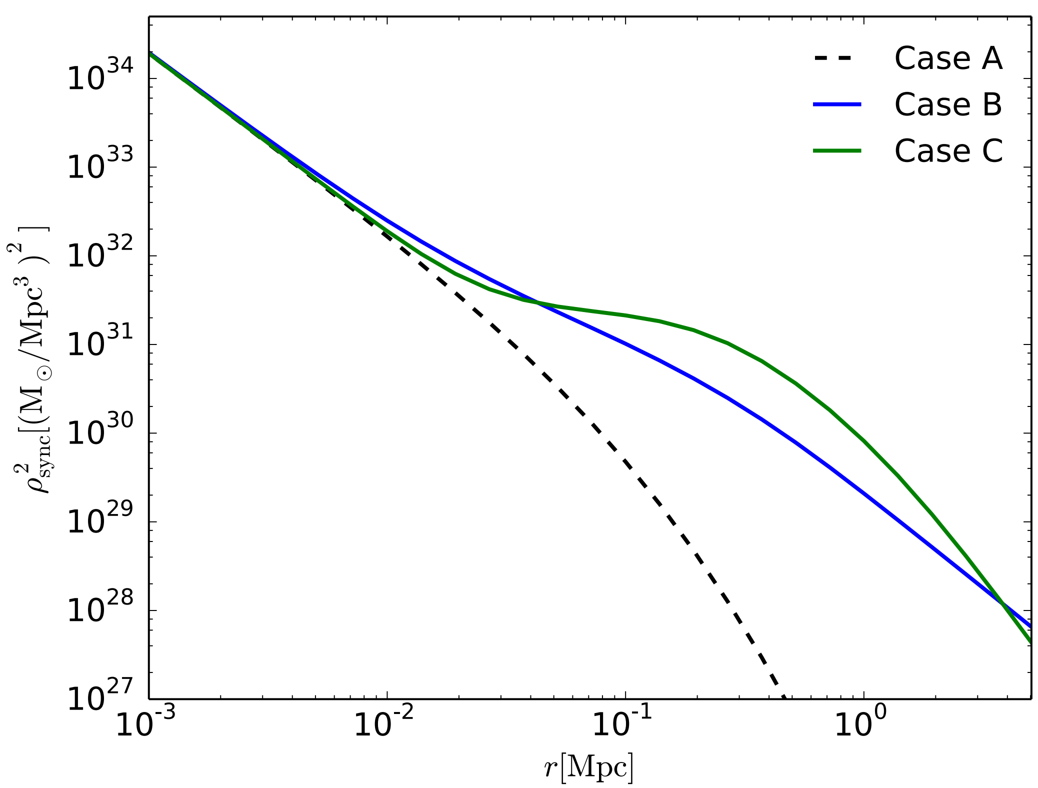

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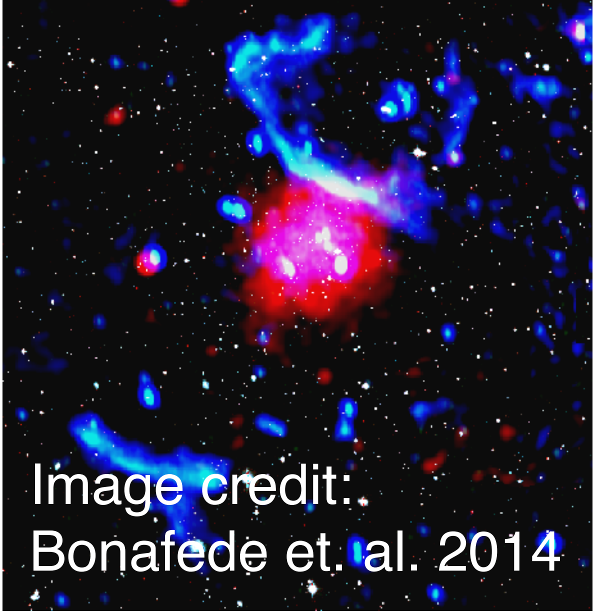

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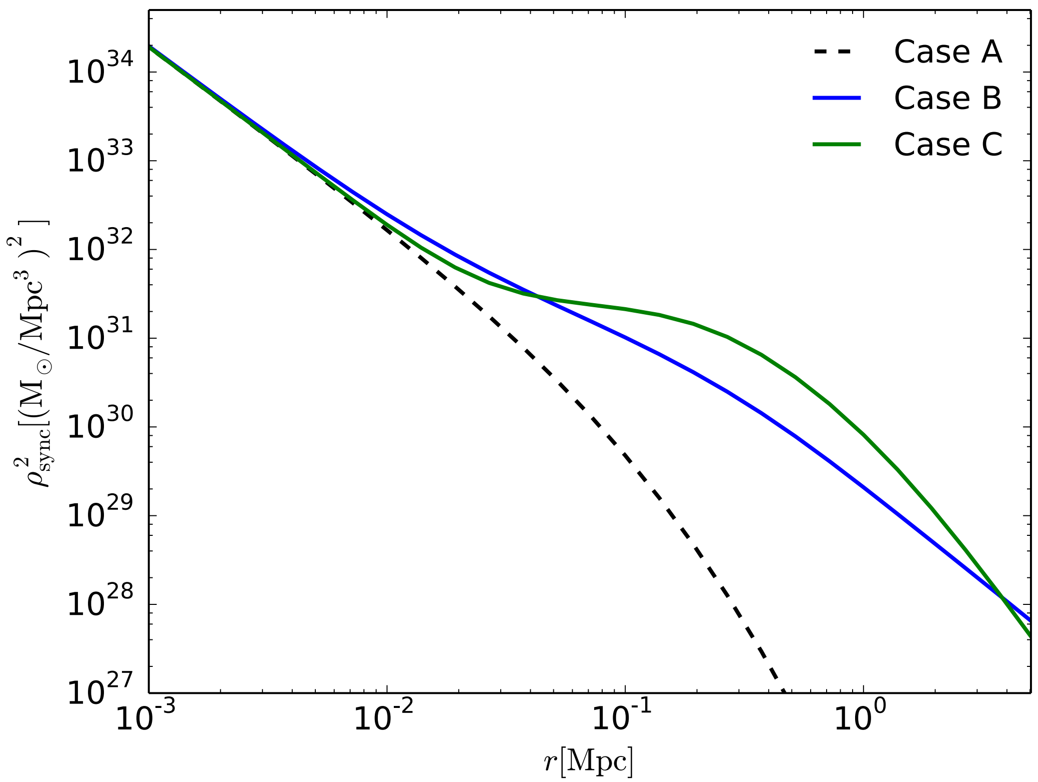
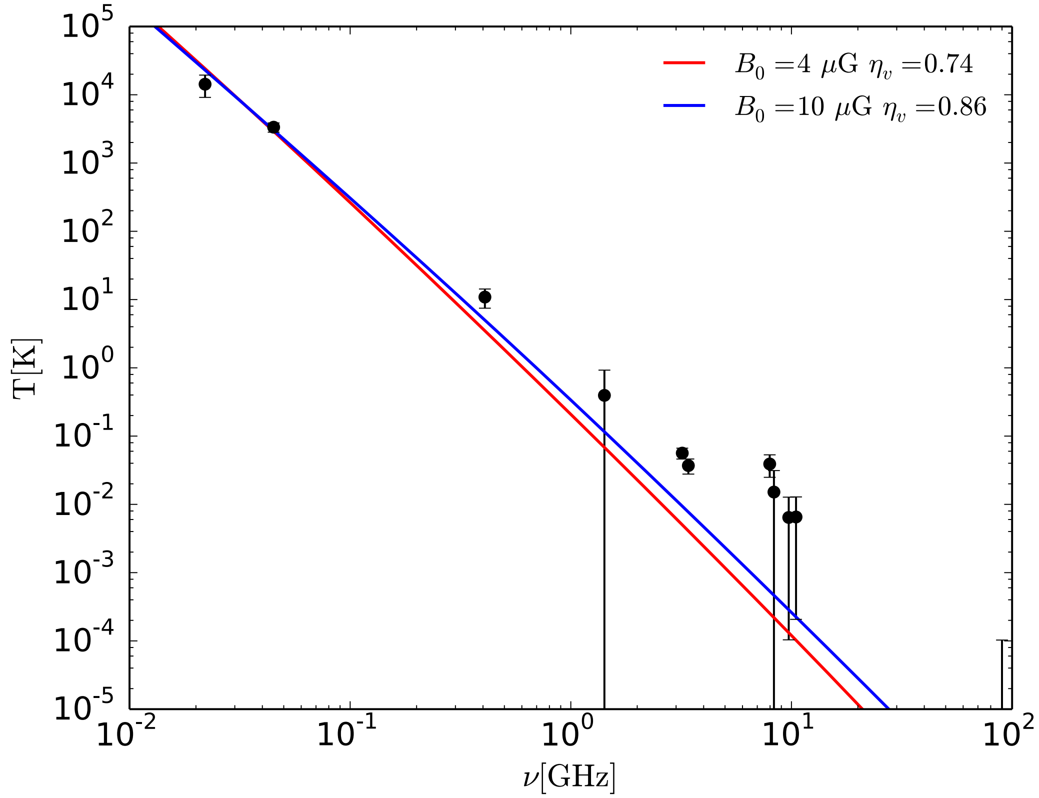
$$\frac{\partial W_k(t)}{\partial t} = -\Gamma(k) W_k(t) + I_A(k,t)$$

$$\frac{\partial f}{\partial t} = \frac{1}{p}\frac{\partial}{\partial p}\left[p^2 D_{pp}\frac{\partial f}{\partial p} + S p^4 f\right]$$





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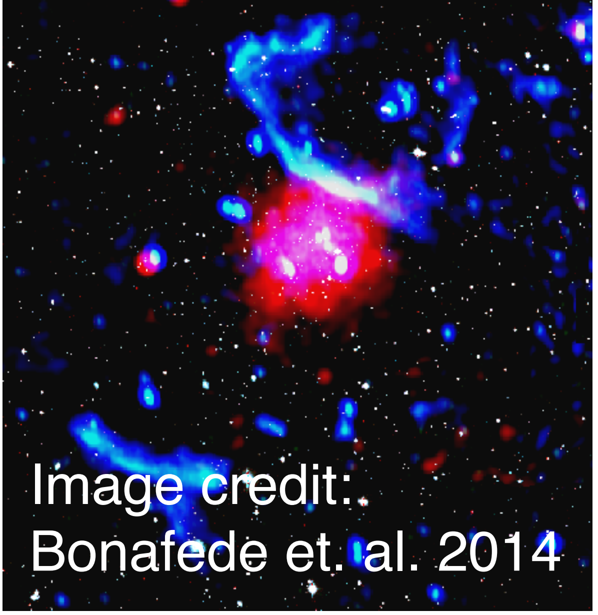

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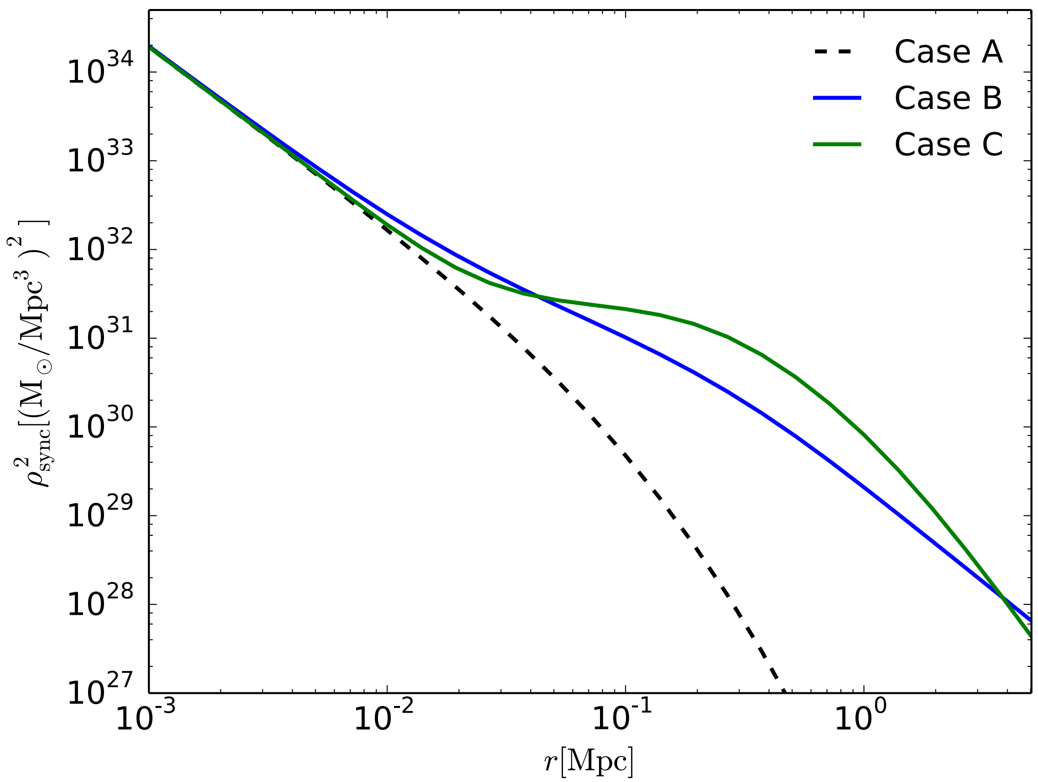

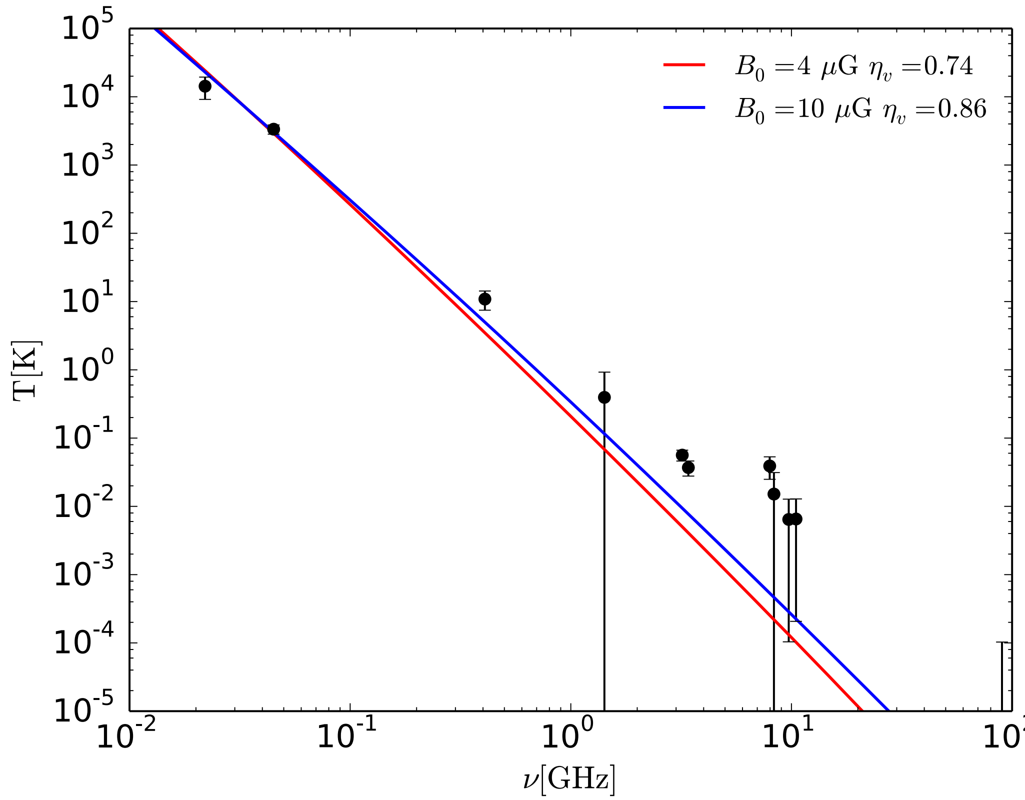

Re-acceleration of electrons by Alfven waves that are excited by cluster mergers can substitute the substructure contribution.

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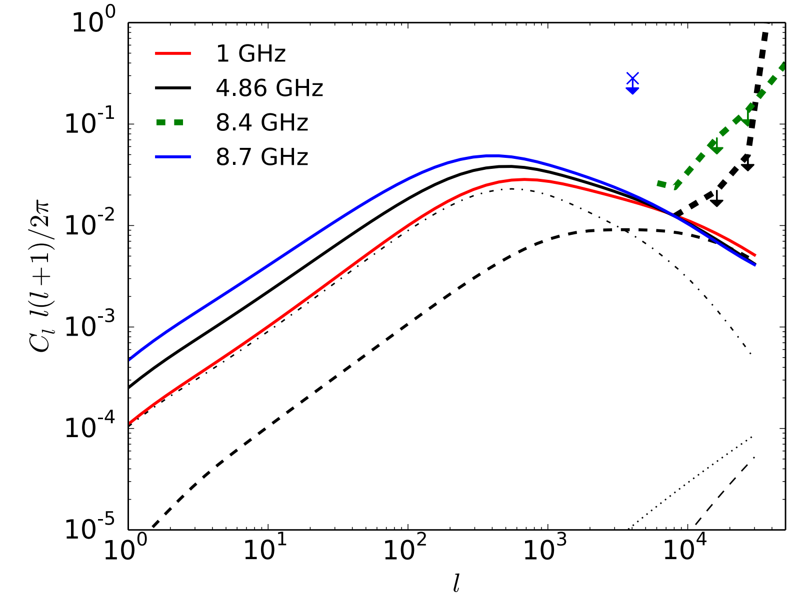
Conclusion


1 GHz
4.86 GHz
8.4 GHz
8.7 GHz
$C_l\ l(l+1)/2\pi$
l
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

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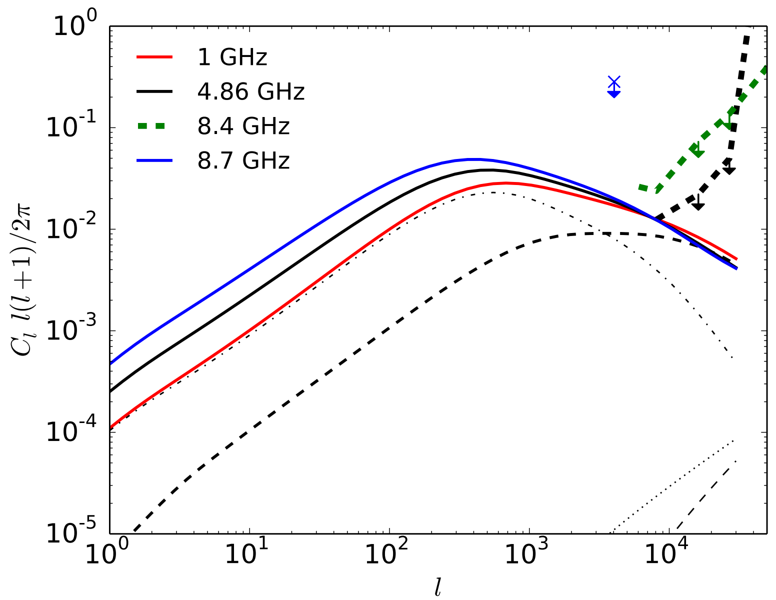

- Synchrotron emission from dark matter annihilations could explain the ARCADE-2 excess while being consistent with anisotropy limits

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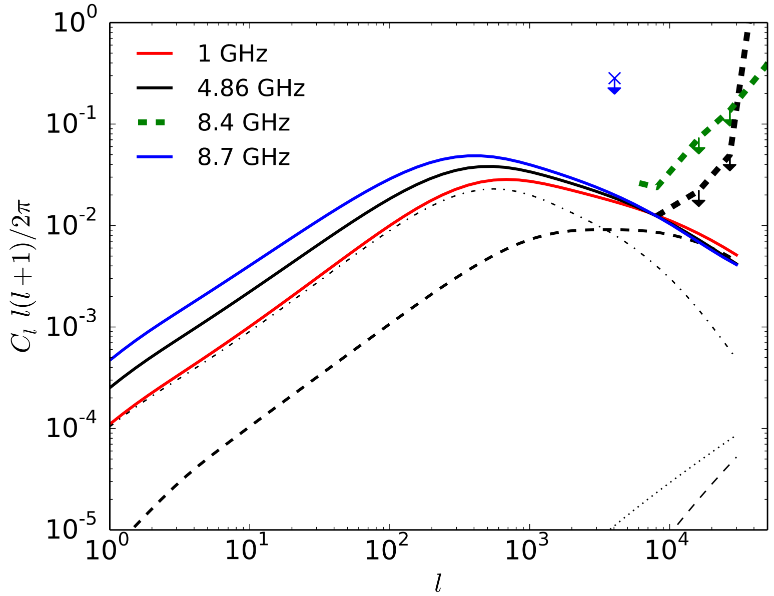

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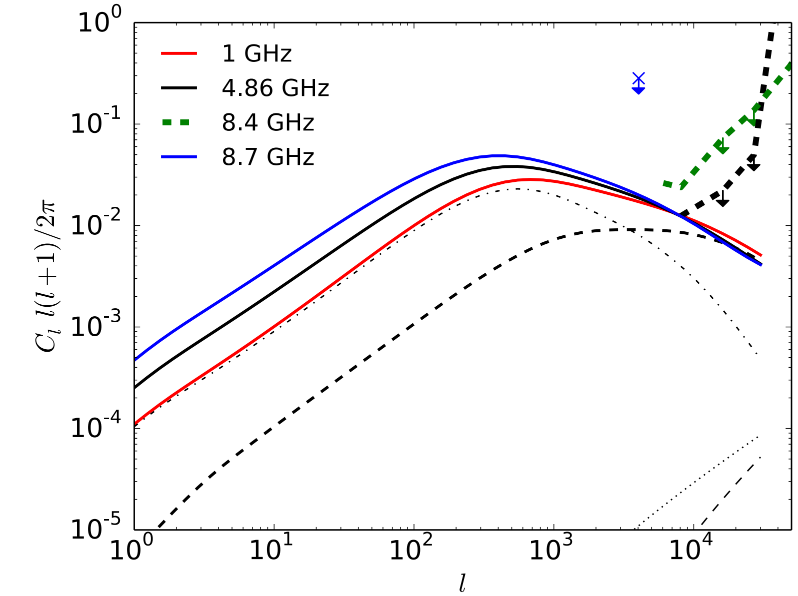

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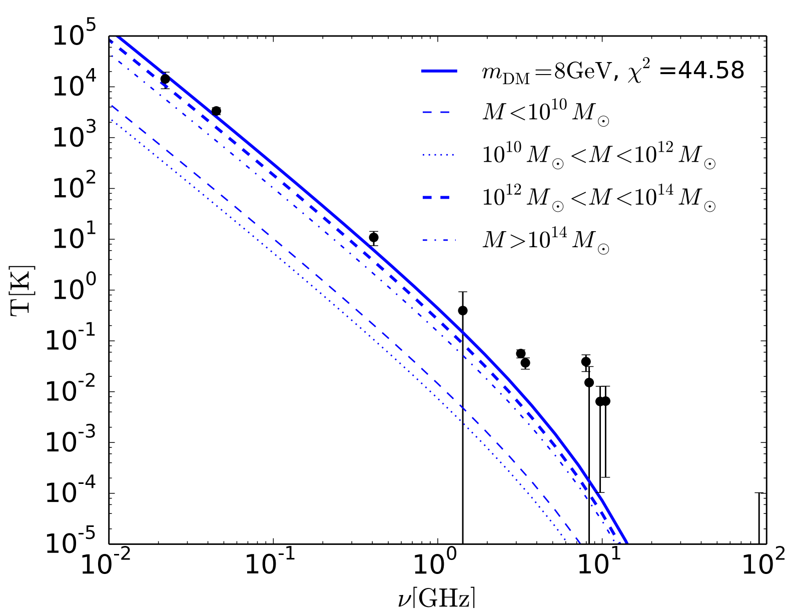

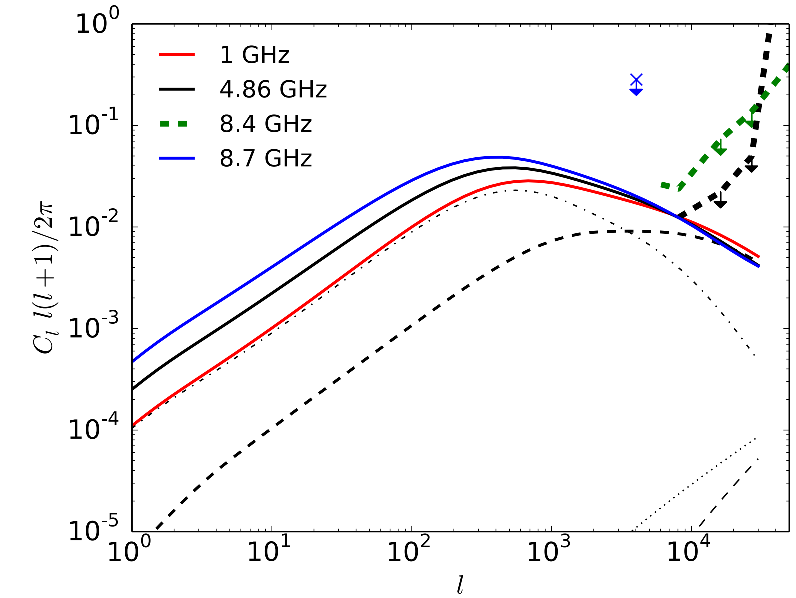

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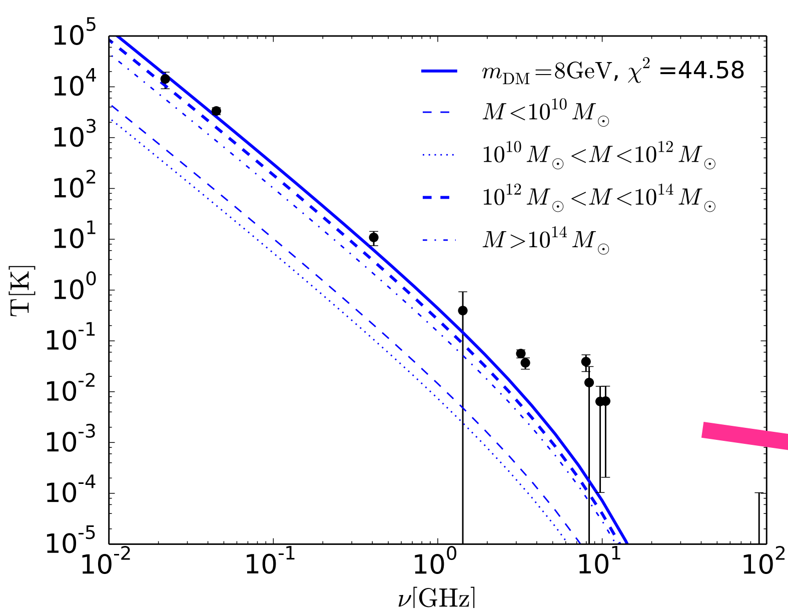
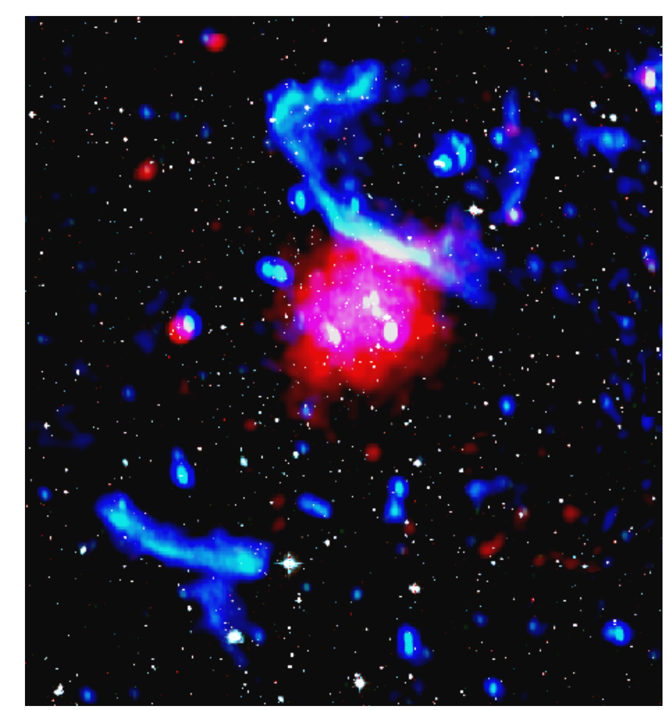
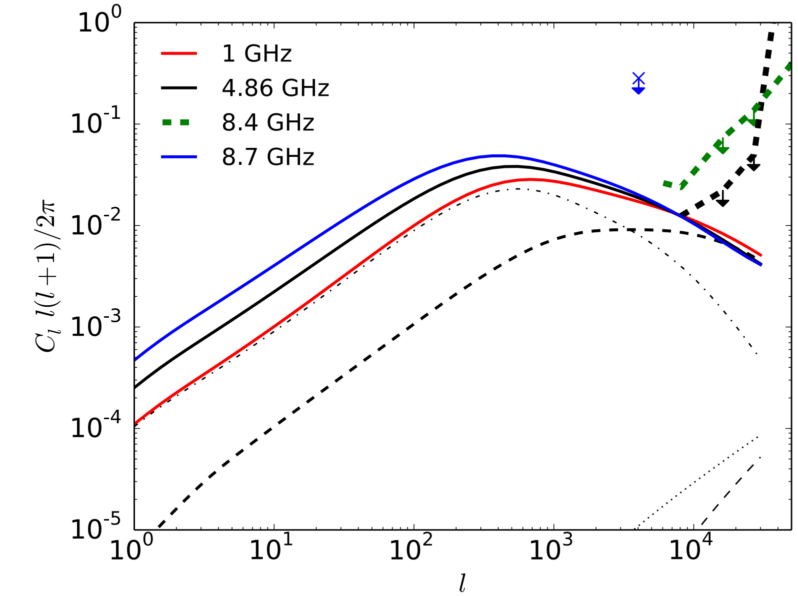




Conclusion



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