Through A Mini Halo, Darkly

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ABSTRACT
In this Letter we explore the effects of the scattering of photons incident on a dark matter halo through their interaction with either electrons or photons produced by dark matter annihilation. Particularly, we examine the effects of this scattering upon the observed spectrum of a distant AGN or of the Cosmic Microwave Background. Our results indicate that ultra-compact mini halos and other dense dark matter clumps can induce an observable Comptonisation of AGN spectra as well as a Sunyaev-Zel’dovich effect (SZE) with an optical depth similar to that attained by thermal electrons in the Coma cluster. The rate of encounters between a distant AGN and these dense mini-halos is also estimated using micro-lensing limits existing on the population of dark compact bodies.

Key words: dark matter – galaxies:nucleus – cosmic background radiation

1 INTRODUCTION
Previous work on the Comptonisation effects of the CMB resulting from electrons produced non-thermally by Dark Matter (DM) annihilation, in particular the DM-induced Sunyaev-Zel’dovich Effect (SZE), had concluded that it may be a promising approach to DM hunting, but, the expected signals would be fainter than local thermal electron Comptonisation in most cases (Colafrancesco 2004; Culverhouse et al. 2006; Colafrancesco et al. 2007b; Lavalle et al. 2010). It has been pointed out, however, that small compact structure like dwarf galaxies may be ideal targets for observation of DM-induced Comptonisation (Culverhouse et al. 2006) as they lack strong baryonic emission and are relatively compact objects; the amplitude of the effects is very sensitive however to assumptions about the DM halo profile (Lavalle et al. 2010).

In this letter we propose that Ultra-Compact Mini Halos (UCMHs) make even more attractive targets for hunting a DM-induced Comptonisation effect of the CMB as their extreme central density allows for a far greater optical depth. UCMHs are highly interesting structures, as they form very early in universe (Ricotti & Gould 2009; Bringmann et al. 2012) and have been shown to potentially provide constraints on the many different physical processes/phenomena that may give rise to them. These include cosmic strings and other topological defects (Silk & Stebbins 1993), as well as small-scale effects of inflation (Aslanyan et al. 2016), or even phase-transitions in the early universe (Josan & Green 2010). The large central density of UCMHs ensures that they can persist easily into the present epoch (Berezinsky et al. 2006, 2008; Bringmann et al. 2012). However, such objects are difficult to detect, as they have low mass, their DM-induced emissions are expected to be faint, and they are expected to contain very little baryonic matter (Ricotti & Gould 2009; Bertschinger 1985). Therefore, it is desirable to find additional methods for probing the nature of such objects due to their potential as probes of small-scale cosmology and inflation.

We demonstrate here that such compact structures would have potentially observable impacts on the CMB through the production of an SZE as well as Comptonize the spectrum of a distant AGN (out to z ∼ 1) if they were to impinge upon the line of sight to it. We also calculate a conservative rate of encounters between such AGNs and UCMHs. Furthermore, these effects potentially provide an additional avenue to put constraints on UCMHs which are otherwise so difficult to probe directly by limiting the number density of such objects according to SZE observations as well as potentially limiting the fraction of DM in UCMHs via null-observations of the form of AGN variation discussed.

This Letter is structured as follows: in section 2 we discuss the spectral models, the Comptonization processes, the UCMH characteristics, and DM annihilation process. In sections 3 and 4 we show the results of our computations, and we will present our conclusions in section 5.
2 METHODS AND SIMULATIONS

We simulate the passage of a beam of photons emitted from a distant source passing through an ultra-compact mini-halo. We will detail below the various aspects of these calculations.

2.1 AGN Spectra

The spectrum employed for the X-ray emission of an AGN is a power-law with a high-E cut-off:

\[ S(E) = \frac{AE^{-\Gamma}}{E_{c}} \exp \left( \frac{E}{E_{c}} \right). \]  

(1)

The relevant parameters are taken from Malizia et al. (2014) assuming \( \Gamma = 1.7 \), \( 80 \leq E_{c} \leq 160 \) keV and that the luminosity in the 17-60 keV range is \( 10^{41} \leq L_{X} \leq 10^{43} \) erg s\(^{-1}\) (which determines \( A \) based on the luminosity distance value at redshift \( z \)).

To consider more complete spectra, we make use of spectral shapes from Yan et al. (2013) and we normalise the flux appropriately for a given redshift of the source.

2.2 Ultra-compact Mini Halos

We will briefly review here the details of the UCMH model that is pertinent to our study.

UCMHs have been shown to plausibly collapse from over densities as small as \( \delta \sim 10^{-3} \) in the redshift range \( 200 \leq z \leq 1000 \) (Ricotti & Gould 2009), and this was expanded more rigorously in Bringmann et al. (2012). Their extreme central density allows them to survive any tidal stripping by larger structures (Bringmann et al. 2012) and persist into the present epoch for all the masses of UCMH that we will consider here.

Since, after kinetic decoupling of the WIMP from the Standard Model particles (which occurs after the WIMP abundance has frozen out (Bringmann 2009)), UCMHs form entirely via radial in-fall (Ricotti & Gould 2009; Ricotti et al. 2008; Bringmann 2009) (as their is no significant scattering between the WIMPs and other matter) this leads to a density profile of the form

\[ \rho_{UCMH}(r, z) = \frac{3f_{\chi} M_{UCMH}(z)}{16\pi R_{UCMH}(z)^{2}} r^{2}, \]  

(2)

where \( f_{\chi} \) is the fraction of matter in the form of DM, \( M_{UCMH}(z) \) is the UCMH mass, and \( R_{UCMH}(z) \) is the effective radius of the UCMH at redshift \( z \). This effective radius is given by the following expression derived from numerical simulations (Ricotti 2007; Ricotti et al. 2008)

\[ R_{UCMH}(z) = 0.019 \left( \frac{1000}{1 + z} \right) \left( \frac{M_{UCMH}(z)}{M_{\odot}} \right)^{\frac{1}{2}}. \]  

(3)

The extremely steep UCMH density profile \( \sim r^{-9/4} \) is a consequence of the spherically symmetric collapse, as derived in Fillmore & Goldreich (1984); Bertschinger (1985) and later demonstrated by numerical simulations (Vogelsberger et al. 2009; Ludlow et al. 2010). It must be noted that \( M_{UCMH} \) is assumed fixed for \( z \leq 10 \) following Bringmann et al. (2012), so for all the values of \( z \) we study here \( M_{UCMH}(z) = M_{UCMH}(0) \).

It is clear that such a profile cannot be valid all the way down to \( r = 0 \). Thus, some minimum radius must be established within which the density flattens and becomes constant. This is due to the fact that accretion at later times in the halo’s life will largely influence the outer regions of the UCMH (Ricotti & Gould 2009; Bertschinger 1985).

Thus, the DM density within the UCMH will be limited by

\[ \rho(r \leq r_{\text{min}}) = \rho(r_{\text{min}}). \]  

(4)

where \( r_{\text{min}} \) is defined by the expression from Bringmann et al. (2012) as

\[ r_{\text{min}} = 2.9 \times 10^{-7} \left( \frac{1000}{1 + z_{c}} \right)^{2.43} \left( \frac{M_{UCMH}(0)}{M_{\odot}} \right)^{-0.06} R_{UCMH}(0), \]  

(5)

where \( z_{c} \) is the redshift at which the UCMH collapsed. The effects of WIMP annihilation will also limit the cuspliness of the UCMH, with the maximum possible density being taken as

\[ \rho_{\text{max}} = \frac{m_{\chi}}{(\sigma V)(t_{i} - t_{f})}. \]  

(6)

This limit on the density defines a cut-off radius \( r_{\text{cut}} \) such that

\[ \rho(r \leq r_{\text{cut}}) = \rho_{\text{max}} \]  

(7)

where \( m_{\chi} \) is the mass of the WIMP with a thermally-averaged annihilation cross section of \( \sigma V \).

For UCMHs at the present epoch, \( t \) is 13.799 Gyr (Ade et al. 2016) and \( t_{i} \) is taken to be equal to \( t_{eq} \) following the arguments given in Scott & Sivertsson (2009); Wright (2006). Thus, if \( r_{\text{cut}} < r_{\text{min}} \) the cut-off radius and maximal density is determined by \( r_{\text{min}} \). But, if \( r_{\text{cut}} > r_{\text{min}} \), then the core density of the UCMH will be limited by Eq.(7), and will automatically satisfy the \( r_{\text{min}} \) requirement as well.

Then, given a fraction of DM found in the form of UCMHs \( f \), we can find the period of UCMH encounters with an object situated such that the local DM density is

\[ \rho_{\text{local}} = f \rho_{\text{UCMH}}(0) \sigma_{\chi}(0) \langle \sigma V \rangle^{-1} / \sigma_{A}, \]  

(8)

where \( \sigma_{\chi} \) is the DM velocity dispersion, and \( \sigma_{A} \) is the geometrical cross-section of the UCMH (we suppress this area by a factor of \( \sigma_{A} / \rho_{\text{max}}^{2/3} \) to reflect the steepness of the halo profile). In making use of Eqs. (3), we will assume a spherical halo profile for the UCMH, and determine \( \tau_{\text{UCMH}} \) values relative to approximate values for the conditions local to the solar system of \( \sigma_{\chi} \approx 300 \) km s\(^{-1}\) (Collar 1996) and \( \rho_{\text{local}} = 0.4 \) GeV cm\(^{-3}\).

2.3 Dark Matter Annihilation

The source function for particle \( i \) (electrons/positrons or photons) with energy \( E \) from a DM annihilation is taken to be

\[ Q_{i}(r, E) = \langle \sigma V \rangle \frac{dN_{i}}{dE} \int f \left( \frac{\rho_{\chi}(r)}{m_{\chi}} \right)^{2}, \]  

(9)

where \( r \) is distance from the halo centre, \( \langle \sigma V \rangle \) is the non-relativistic velocity-averaged annihilation cross-section, \( f \)
labels the annihilation channel intermediate state with a branching fraction $b_f$ and differential $i$-particle yield \( \frac{dN_f}{dE} \). $\rho_f(r)$ is the DM radial density profile, and $n_f$ is the WIMP mass. The $f$ channel used as a test case will be annihilation via quarks $q\bar{q}$.

The yield functions \( \frac{dN_f}{dE} \) are taken from Cirelli et al. (2011); Ciafaloni et al. (2011) (with electro-weak corrections).

This source function will be used to calculate photon distribution via

\[
N_{\gamma\lambda}(E) = \int_0^{R_{UCMH}} dr 4\pi r^2 Q_\lambda(r,E) t_{cross} ,
\]

with $R_{UCMH}$ being the UCMH radius and $t_{cross}$ being the halo crossing time. The electron distribution is defined as

\[
N_{e\lambda}(E) = \left( \frac{dne}{dE} + \frac{dne^+}{dE} \right) ,
\]

where $\frac{dne}{dE}$ are found via the stationary solution to the equation

\[
\frac{\partial}{\partial t} \frac{dn_e}{dE} = \nabla \cdot \left( D(E,r) \nabla \frac{dn_e}{dE} \right) + \frac{\partial}{\partial E} \left( b(E,r) \frac{dn_e}{dE} \right) + Q_e(E,r) ,
\]

where $D(E,r)$ is the diffusion coefficient, $b(E,r)$ is the energy loss function, and $Q_e(E,r)$ is the electron source function from DM annihilation/decay. In this case, we will work under the simplifying assumption that $D$ and $b$ lack a spatial dependence and thus we will include only average values for magnetic field and thermal electron densities. For details of the solution see Colafrancesco et al. (2007a).

We thus define the functions as follows (Colafrancesco & Blasi 1998)

\[
D(E) = \frac{1}{3} c r_L(E) \frac{\overline{B}^2}{k_L \int dk P(k)} ,
\]

where $\overline{B}$ is the average magnetic field, $r_L$ is the Larmour radius of a relativistic particle with energy $E$ and charge $e$ and $k_L = \frac{eB}{mc}$. This, combined with the requirement that

\[
\int_{k_0}^{\infty} dk P(k) = \overline{B}^2 ,
\]

where $k_0 = \frac{1}{\gamma}$, with $d_0$ being the smallest scale on which the magnetic field is homogeneous, yields the final form

\[
D(E) = D_0 d_0^2 \left( \frac{\overline{B}}{1 GeV} \right)^{-2} \left( \frac{E}{1 GeV} \right) ,
\]

where $D_0 = 3.1 \times 10^{28}$ cm$^2$ s$^{-1}$, and we assume that $d_0 = 1$ pc for the UCMHs we consider.

The energy loss function is defined by

\[
b(E) = \gamma b_{IC} E^2 (1 + z)^2 + b_{\text{sync}} E^2 (E - B)^2 + b_{\text{Coul}} \gamma (1 + z)^3 \left( 1 + \frac{1}{75} \log \left( \frac{\gamma}{(1 + z)^2} \right) - \frac{1}{3} \right) + b_{\text{Brem}} (1 + z)^3 \left( \log \left( \frac{\gamma}{(1 + z)^2} \right) + 0.36 \right) ,
\]

while $b_{IC}$, $b_{\text{sync}}$, $b_{\text{Coul}}$, and $b_{\text{Brem}}$ are the inverse Compton, synchrotron, Coulomb and bremsstrahlung energy loss factors, taken to be $0.25$, $0.0254$, $6.13$, and $1.51$ respectively in units of $10^{-16}$ GeV s$^{-1}$. Here $E$ is the energy in GeV and the B-field is in $\mu$G. We will assume $\overline{B} = 1$ $\mu$G, and $\pi = 10^{-6}$ cm$^{-3}$ for the UCMHs we consider. These values are chosen in keeping with the low electron density of dwarf galaxies, so this provides a conservative case where DM-electron energy-loss is increased.

All of the calculations in this work will feature diffusion, as it has a very significant impact in such small structures as UCMHs. Neglecting diffusion results in the optical depth from DM-produced electrons being over-estimated by a factor $\mathcal{O}(10^2)$.

2.4 Spectral effects

The two spectral modifications that we will examine will be produced by pair-production of AGN emitted photons with gamma-ray photons produced by DM annihilation and by Comptonization of the CMB background off DM-produced electrons/positrons.

For pair production the energy threshold for DM-produced photons is set by (Dwek & Krennich 2012)

\[
\epsilon_{th} = \frac{2 (m_e c^2)^2}{E_{\gamma}(1 - \mu)} ,
\]

where $\mu = \cos \theta$, $\theta$ is the angle between the interacting photons, and $E_{\gamma}$ is incoming photon energy.

The cross-section for pair production is given by (Dwek & Krennich 2012)

\[
\sigma_{\gamma \gamma}(E_{\gamma}, \epsilon, \mu) = \frac{3 \sigma_T}{16} (1 - \beta^2) \left( 2 \beta (\beta^2 - 2) + (3 - \beta^4) \ln \frac{1 + \beta}{1 - \beta} \right) ,
\]

where $\sigma_T$ is the Thomson cross-section, $\epsilon$ is energy of the DM-produced photon, and $\beta = \sqrt{1 - \epsilon_{th}}$.

The optical depth for incoming photons due to pair production is then (Dwek & Krennich 2012)

\[
\tau_{\gamma \gamma}(E_{\gamma}) = \int_{-1}^{1} d\mu \left( \frac{1 - \mu}{2} \int_{\epsilon_{th}}^{\infty} d\epsilon \frac{N_{e\lambda}(\epsilon)}{4\pi R_{UCMH}^2} \sigma_{\gamma \gamma}(E_{\gamma}, \epsilon, \mu) \right) .
\]

The resulting spectrum of a distant source modified by pair-production with DM-produced gamma-ray photons is then given by

\[
S_{\gamma\gamma}(E_{\gamma}) = S_0(E_{\gamma}) \exp(-\tau_{\gamma\gamma}) ,
\]

where $S_0$ is the intrinsic spectrum of the distant AGN.

For the case of the CMB Comptonisation off DM-produced electrons the optical depth is found via

\[
\tau_C(E_{\gamma}) = \sigma_T \int dl \int dE N_{e\lambda}(E) .
\]

Thus, to first-order in $\tau_C$ the shifted spectrum is given by

\[
S_C(E_{\gamma}) = (1 - \tau_C) S_0(E_{\gamma}) + \tau_C \int ds P_1(s) S_0(E_{\gamma} e^{-s}) ,
\]
where \( s = \ln \left( \frac{E}{E_0} \right) \) is the logarithmic energy shift of the incoming photon, and the single scattering redistribution function \( P_1(s) \) is given by

\[
P_1(s) = \int_0^\infty dp f_e(p)P_s(s, p),
\]

(24)

where \( p = \frac{E}{m_e c^2} \) is the dimensionless electron momentum, \( f_e(p) \) is the normalised electron momentum distribution with \( \int_0^\infty dp f_e(p) = 1 \), and \( P_s(s, p) \) is probability of an electron with momentum \( p \) inducing a logarithmic shift in the photon energy of \( s \) (see Enßlin & Kaiser (2000) for details).

### 3 RESULTS - SZE

We start showing the results for the test case of DM particles with mass 100 GeV annihilating via quarks with \( \langle \sigma v \rangle = 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1} \) producing an SZE through the DM-electrons produced by annihilations in a mini-halo situated along the line of sight to the observer.

In Figure 1 we see that the Compton optical depth of DM-produced electrons in a UCMH scales as \( \tau_C \propto M_{\text{UCMH}}^{1/3} \). This means that \( \tau_C \) reaches a value similar to the thermal electron optical depth in the Coma cluster for \( M_{\text{UCMH}} \approx 10^{-2} M_\odot \), and begins to exceed this value for \( M_{\text{UCMH}} \geq 10^{-1} M_\odot \). Despite the tiny size of the UCMH, such structure is capable of generating a similar depth from DM annihilations as found in a galaxy cluster \( \sim 10^{14} \) times heavier. This is due to the extreme value of the UCMH central density which can be illustrated as follows for \( M_{\text{UCMH}} = 10^4 M_\odot \); the core radius \( r_{\text{cut}} \approx 4 \times 10^7 \text{ R}_\text{Earth} \) with \( \rho_{\text{max}} \approx 2 \times 10^{10} \text{ GeV cm}^{-3} \). For smaller mass UCMHs \( \rho_{\text{max}} \) is constant but \( r_{\text{cut}} \propto M_{\text{UCMH}}^{1/3} \) so that the minimum size for \( r_{\text{cut}} \) to obtain values of \( \tau_C \) similar to the Coma cluster is \( \sim 4.1 \times 10^3 \text{ R}_\text{Earth} \) (for \( M_{\text{UCMH}} = 10^{-2} M_\odot \)). It must be noted that, unlike in previously studied halos (Culverhouse et al. 2006; Colafrancesco et al. 2007b; Lavalle et al. 2010), the form of Eq. (6) means that \( \tau_C \) will be amplified for heavier WIMPs. This means that there is the potential for a significant Comptonization from UCMH objects for a range of halo and WIMP masses.

In order to detect an SZE signal in UCMHs we need to resolve such DM halos adequately. At \( z \sim 1 \) this requires milli-arcsecond resolution; however, within \( \sim 10 \) Mpc of Earth we can resolve halos above \( 1M_\odot \) at arcsecond levels (the angular size scales as \( M_{\text{UCMH}}^{1/3} \)) which should be achievable for a large range of masses with both ALMA 1 and Millimeterron (Wild et al. 2009), with the potential to reach milli-arcsecond resolution via sub-millimeter VLBI Wild et al. (2009).

The flux amplitude of the SZE negative peak, integrated over the angular area of the UCMH, at \( \sim 150 \) GHz is \( 3 \times 10^{-4} \) of the CMB peak amplitude if \( M_{\text{UCMH}} = 10^{-4} M_\odot \), with the positive part of the SZE at \( \sim 500 \) GHz being an order of magnitude smaller. On the other end of our mass scale, for a UCMH with \( 10^5 M_\odot \) mass, the negative SZE peak reaches 0.1 of the CMB maximum amplitude. This implies that the major limiting factor to observation is resolving the effect spatially, as the magnitude of the effect can be substantial. If we employ the lensing upper-limit (Henderson et al. 2014) on dark compact bodies and assume a mono-chromatic mass-distribution of UCMHs, then an order of magnitude estimate suggests there could be as many as \( 10^{13} 10^{-4} M_\odot \) halos or \( 10^7 \) \( 10^4 M_\odot \) halos within just the Milky-Way, providing a potential abundance of observational opportunities. Of course, an important factor limiting observation would be the problem of source confusion and cosmological backgrounds. However, investigating this would require a detailed analysis that is currently beyond the scope of this work.

### 4 RESULTS - AGN

Here we show the results for the test case of DM particles with mass 100 GeV annihilating via quarks with \( \langle \sigma v \rangle = 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1} \) producing a spectral distortion of an AGN spectrum via a mini-halo situated along the line of sight to the observer.

We consider two effects: Comptonization of the AGN spectrum produced by DM-produced electrons in the UCMH, and pair production produced by AGN emitted photons interacting with the gamma-ray photons produced in the DM annihilation. In contrast to the Compton optical depth from DM annihilation discussed previously, that for pair-production between incoming photons from an AGN spectrum studied here and DM-produced gamma-rays is negligible, meaning that no halo can provide a spectral absorption effect (even for photons experiencing Compton scattering prior to interaction with DM photons). Therefore, only the Comptonization results will be shown for the AGN spectrum.

In Figure 2 we show the modifications to the high-E tail of an AGN spectrum caused by the passage through UCMHs of various mass where we assume that both the halo and the AGN are at \( z \sim 1 \), the AGN has a 17-60 keV luminosity of \( 10^{43} \text{ erg s}^{-1} \), and a cut-off energy at 80 keV. The DM annihilation-produced population of electrons was determined assuming \( \langle \sigma v \rangle = 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1} \). As long as

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1. http://almascience.nrao.edu/documents-and-tools/cycle5/alma-technical-handbook/view
2. http://astro-h.isas.jaxa.jp/researchers/sim/sensitivity.html
the UCMH mass remains above $1 \, M_\odot$, then there is an extension of the power-law spectrum beyond the intrinsic cut-off, visible within the ASTRO-H band of a project like ASTRO-H or THESEUS. Notably, for the smaller halos, the extension is in the fashion of a broken power-law, whereas larger halo masses simply continue the power-law spectrum unbroken.

Using a complete spectrum similar to that from Yan et al. (2013) we also studied the modification of the rest of the AGN spectrum as a consistency check. Unlike the above case, the low energy cut-off becomes more severe (i.e. moves to higher energies) as low energy photons are lost to Comptonisation. As expected, however, this is at least an order of magnitude less apparent than the modification to the high-energy cut-off shown in Fig. 2. At the inflection point between synchrotron and the synchrotron-self-Compton spectra the flux is boosted by a factor that varies between 1.004 and 1.4 over the mass range $10^{-2}$ to $10^4 \, M_\odot$. Thus, the most prominent effect is to be found in the high-energy cut-off, due to the large difference in photon energies between the extremities of the spectrum.

A necessary question is how common the occlusion of an AGN by UCMHs actually is. The rate of UCMH encounters per AGN and per year is estimated using Eq (8) yielding a rate of $2 \times 10^{-8} M_{UCMH}^{1/6}$ encounters per AGN per year when the DM density and velocity dispersion match those of the local environment of our Solar system. Note that this only accounts for the AGN and UCMH being close to each other rather than anywhere along the line of sight to the AGN. Thus, this may present a very conservative estimate of the rate of encounters. These results suggest that such events are very rare, being three or four orders of magnitude less common than estimates for binary neutron star mergers per galaxy (Chruslinska et al. 2017) for environments similar to the local one. However, AGNs themselves tend to reside in far denser regions of DM halos and, since the effect of the UCMH will remain within observable windows for $z \lesssim 1$, our observational window covers a very large co-moving volume $\sim 150$ Gpc$^3$.

5 CONCLUSIONS

We have shown that there are potentially observable consequences both of an UCMH impinging upon the line of sight to a distant source, like an AGN, as well as an induced SZE upon the CMB spectrum that is resolvable at the $\sim$ arcsecond level within $\sim 10$ Mpc of Earth. Notably, neither of these effects are as significant in conventional DM halos, because the resulting optical depth is far too small. A further important point is that the probable lack of baryonic matter in a UCMH (due to tidal stripping) means that these effects will not be significantly obscured by purely baryonic emissions within the UCMH structure. The SZE in particular can be used to limit UCMH abundances in the local environment, as an expected number density resolvable at arcsecond levels, an achievable resolution for sub-millimetre observatories such as ALMA or Millimetron, can be determined for a given UCMH fraction $f$. This is of course subject to a caveat regarding the effects of source and background confusion that are not studied here.

Unlike these Comptonization effects, no significant pair-production process can be induced by photons from DM annihilation.

The occlusion of the line of sight to a distant AGN by such a compact body is shown to have potentially dramatic consequences across the AGN spectrum, producing large modifications to spectral cut-offs and a boost to the flux at the inflection point. These events were shown to be comparatively rare. However, because this effect is potentially accessible out to redshifts $z \sim O(1)$, a large volume can be studied for the characteristic Comptonisation of the AGN spectrum. Null results for this variation of AGN spectra could also be used to limit the UCMH fraction $f$ which is presently only weakly constrained (Henderson et al. 2014; Wyrzykowski et al. 2015; Brown et al. 2016).

Finally, these effects yield a promising new approach to the search for such compact DM halos, which is usually complicated by their small size, lack of baryonic matter, and faint fluxes from potential annihilation/decay.

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