Angular Power Spectrum of Sterile Neutrino Decay Lines: the Role of eROSITA

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STERILE NEUTRINO DARK MATTER

Neutrino masses suggest the existence of right-handed degrees of freedom: THE STERILE NEUTRINOS

INTERESTING WARM(-ISH) DARK MATTER CANDIDATE

• NON-RELATIVISTIC SPEEDS IN THE RADIATION DOMINATED ERA

• Most CDM successes extended to WDM models

• Differences at small scales: suppression of small scale structures

See, e.g., Dodelson & Widrow (1994); Shi & Fuller (1999); Boyarsky, Ruchayskiy & Shaposhnikov (2009); Boyarsky et al. (2009); Kusenko (2009)
STERILE NEUTRINO
DARK MATTER

Neutrino masses suggest the existence of right-handed degrees of freedom: the sterile neutrinos

Interesting warm(-ish) dark matter candidate

Lovell et al. (2014)
STERILE NEUTRINO DECAYS

\[ \nu_s \rightarrow \gamma \nu \]\n
\[ \Gamma_{\nu_s} \simeq \left( 7.2 \times 10^{29} \text{ s} \right)^{-1} \left( \frac{\sin^2 2\theta}{10^{-8}} \right) \left( \frac{m_{\nu_s}}{1 \text{ keV}} \right)^5 \]

Claimed line feature in X-rays!

BULBUL ET AL. (2014A)

BOYARSKY ET AL. (2014A)
3.5-keV line is debated...

**Confirm:** Boyarsky et al. (2014b,c); Bulbul et al. (2014b); Iakubovski et al. (2015)

**Do Not Confirm:** Malyshev et al. (2014); Anderson et al. (2014); Urban et al. (2014); Jeltema & Profumo (2015); Carlson et al. (2015); Tamura et al. (2015)
A DIFFERENT APPROACH

Sterile neutrino decays should contribute to the observed Cosmic X-ray Background (CXB)

- Unresolved AGNs give the main contribution
  - [luminosity and density evolution model by Aird et al. (2010)]

- Unresolved galaxies powered by x-ray binaries
  - [luminosity function model by Ptak et al. (2007)]

- Thermal bremsstrahlung emission from resolved & unresolved clusters of galaxies
  - [mass function + phenomenological model by FZ, Pfrommer & Prada (2014)]

- Sterile neutrino decays from all structures in the Universe
  - [mass function + NFW DM profile + Bulbul et al./Boyarsky et al. sterile neutrino]

FZ, Weniger & Ando (2015)
Similarly to the CMB temperature $\Delta T$ power spectrum

$$a_{\ell m} = \int d\Omega_n \, \Delta T(n) \, Y_{\ell m}^*(n)$$

$$D_l = C_l \, (l+1) / 2\pi$$
\[ C^A_{\ell}(E) = \int_0^\infty \frac{d\chi}{\chi^2} \ W_A([1 + z]E, z)^2 \ P_A \left( k = \frac{\ell}{\chi}, z \right) \]

Window function for a = AGNs, galaxies, clusters or sterile neutrinos

\[ W_{\nu_s}(E, z) = \frac{\Omega_{dm}\rho_c \Gamma_{\nu_s}}{2(2\pi)^{3/2}m_{\nu_s}(1 + z)\sigma_E} \exp \left[ -\frac{(E - m_{\nu_s}/2)^2}{2(1 + z)^2\sigma_E^2} \right] \]

Power spectrum of source a using halo model

\[ P_{\delta}^{1h} = \left( \frac{1}{\Omega_{dm}\rho_c} \right)^2 \int dM_{200} \frac{dn}{dM_{200}} \left[ \int 4\pi r^2 dr \rho_{dm}(r) \frac{\sin(kr)}{kr} \right]^2 \]
\[ P_{\delta}^{2h} = \left( \frac{1}{\Omega_{dm}\rho_c} \right) \int dM_{200} \frac{dn}{dM_{200}} \ b(M_{200}, z) \int 4\pi r^2 dr \rho_{dm}(r) \frac{\sin(kr)}{kr} \right]^2 \ P_{\text{lin}}(k, \chi) \]

See, e.g., Cooray & Seth (2002); Ando et al. (2007); Fornasa et al. (2012); Ando (2014); Fornengo & Regis (2014)
ANGLULAR POWER SPECTRUM

3.4 – 3.6 keV

$C_{\ell}(l+1)/2\pi \left[\text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}\right]^2$

$v_s$
clusters
galaxies
AGNs
poisson

NB: resolved & unresolved clusters

FZ, Weniger & Ando (2015)
**Angular Power Spectrum**

**Auto-correlation power spectrum:**

\[
C^A_\ell(E) = \int_0^\infty \frac{d\chi}{\chi^2} W_A([1 + z]E, z)^2 P_A \left( k = \frac{\ell}{\chi}, z \right)
\]

**Cross-correlation power spectrum:**

\[
C^{A,B}_\ell(E) = \int \frac{d\chi}{\chi^2} W_A([1 + z]E, z) W_B(\chi) P_{A,B} \left( k = \frac{\ell}{\chi}, \chi \right)
\]

**Idea is to correlate with a tracer (B) of the dark matter distribution to highlight the possible sterile neutrino decays**

See, e.g., Camera et al. (2013, 2014); Fornengo & Regis (2014); Ando et al. (2014); Ando (2014); Shirasaki et al. (2014); Fornengo et al. (2015); XIA et al. (2015); Cuoco et al. (2015); Fornasa & Sanchez-Conde (2015)
CROSS-CORRELATION WITH 2MASS – 2MRS

3.4 – 3.6 KEV

\[ C_{\chi}^{X-2MRS} (l + 1) / l / 2 \pi \] [cm^{-2} s^{-1} sr^{-1}]

- **clusters**
- **galaxies**
- **AGNs**

\[ v_s < 10^{13} M_\odot \]

NB: RESOLVED & UNRESOLVED CLUSTERS

FZ, WENIGER & ANDO (2015)
CROSS-CORRELATION WITH 2MASS – 2MXSC

3.4 – 3.6 keV

\[ C_{l}^{X-2MXSC} (l+1) / 2 \pi \text{ [cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}] \]

- clusters
- galaxies
- AGNs

\[ \nu_s < 10^{13} M_\odot \]

NB: resolved & unresolved clusters

FZ, Weniger & Ando (2015)
WINDOW FUNCTIONS

$Z \times W_{3.4-3.6 \text{keV}}^{\nu_s}(z)/W_{\text{max}}$

- $\nu_s$ clusters
- galaxies
- AGNs

$Z$ vs $\log_{10}(Z)$

2MRS
2MXSC

FZ, WENIGER & ANDO (2015)
STERILE NEUTRINO IN MASS BINS

\[ C_{\nu\nu} \left( l + 1 \right) \frac{1}{2 \pi} \left( \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \right)^2 \]

\[ \log_{10}(M_{200} \times h) = [6,16] \]

1-halo

2-halo

FZ, Weniger & Ando (2015)

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eROSITA is the primary instrument on the Russian Spektrum-Roentgen-Gamma (SRG) mission with launch in 2017

Merloni et al. (2012)
PROJECTED LIMITS FOR eROSITA

NB: 3 energy-bin side-band analysis

[Graph showing projected 95% CL upper limits for Dark matter mass, $m_s$ [keV] vs. Interaction strength, $\sin^2 2\theta$. The graph includes lines for 4yr eROSITA, CC 2MRS, CC perfect DM map, Bulbul + 2014, full sample, and Boyarsky + 2014, M31. The graph illustrates the regions excluded by X-ray and areas with too much and too little DM.]
SUMMARY AND PROSPECTS

3.5-keV line could be due to sterile neutrino decays, but interpretation is debated

Alternative approach: look at anisotropy power spectrum of Cosmic X-ray Background

Sterile neutrino decays are subdominant in auto-correlation but can be highlighted cross-correlating with DM tracers

eROSITA can test this scenario, but $m_\nu > 10$ keV limited by instrumental background + uncertainties in modeling potentially important + constraining power limited by shot-noise of galaxy catalogues