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

Fabio Zandanel

GRAPPA Institute – University of Amsterdam – f.zandanel@uva.nl

With C. Weniger & S. Ando (GRAPPA)

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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) – A. Palazzo (wed) + Sterile Neutrino Session (thu)
STERILE NEUTRINO DECAYS

$\nu_s \rightarrow \gamma \nu$

$\Gamma_{\nu_s} \simeq (7.2 \times 10^{29} \text{ s})^{-1} \left( \frac{\sin^2 2\theta}{10^{-8}} \right) \left( \frac{m_{\nu_s}}{1 \text{ keV}} \right)^5$

Claimed line feature in X-rays!

BULBUL ET AL. (2014A)

BOYARSKY ET AL. (2014A)
STERILE NEUTRINO DECAYS

3.5-keV line is debated...

**CONFIRM:** Boyarsky et al. (2014b,c); Bulbul et al. (2014b); Iakubovskii et al. (2015)
- Talk by J. Franse (wed)

**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)
ANGULAR POWER SPECTRUM

\[ C_\ell \equiv \langle |a_{\ell m}|^2 \rangle \]

Similarly to the CMB temperature \( \Delta T \) power spectrum

\[ a_{\ell m} = \int d\Omega_n I(n) Y_{\ell m}^*(n) \]

\[ D_l = C_\ell (\ell+1) / 2\pi \]

CXB INTENSITY ANGULAR POWER SPECTRUM AT MULTIPOLe L

\[ \theta = \pi / \ell \]

INTENSITY FLUCTUATIONS SPHERICAL HARMONICS

08/09/2015

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

Window function for $a = \text{AGNs, galaxies, clusters or sterile neutrinos}$

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

Power spectrum of source $a$ using halo model

$P^{1h}_\delta = \left(\frac{1}{\Omega_{dm}\rho_c}\right)^2 \int dM_{200} \frac{dn}{dM_{200}} \left[\int 4\pi r^2 dr \rho_{dm}(r) \frac{\sin(kr)}{kr}\right]^2$

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

See, e.g., Cooray & Seth (2002); Ando et al. (2007); Fornasa et al. (2012); Ando (2014); Fornengo & Regis (2014) – Talks by M. Fornasa (Mon) and S. Ando (Wed)
ANGULAR POWER SPECTRUM

3.4 – 3.6 keV

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

- $v_s$
- clusters
- galaxies
- AGNs
- poisson

NB: resolved & unresolved clusters

FZ, Weniger & Ando (2015)
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)

Talks by J.Q. Xia (mon), S. Camera (mon) and A. Cuoco (tue)
CROSS-CORRELATION WITH 2MASS – 2MRS

3.4 – 3.6 keV

FZ, Weniger & Ando (2015)

NB: resolved & unresolved clusters

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

3.4 – 3.6 keV

NB: resolved & unresolved clusters

FZ, WENIGER & ANDO (2015)
eROSITA is the primary instrument on the Russian Spektrum-Roentgen-Gamma (SRG) mission with launch in 2017

Merloni et al. (2012)
NB: 3 energy-bin side-band analysis

Project 95% CL upper limits

- 4yr eROSITA
- CC 2MRS
- 10yr data
- CC perfect DM map
- Bulbul + 2014, full sample
- Boyarsky + 2014, M31

FZ, Weniger & Ando (2015)
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 $e > 10$ keV limited by instrumental background + constraining power limited by shot-noise of galaxy catalogues
BACK-UP SLIDES
BIAS AND HALO MODEL

Allevato et al. (2011)

Cappelluti et al. (2012)

From CAMB

FZ, Weniger & Ando (2015)
CROSS POWER SPECTRUM

AT A GIVEN MULTIPOLe L = 50
FOR 2MRS AND 2MXSC

\[ C^X_{2MRS}(l = 50) \]

\[ C^X_{2MXSC}(l = 50) \]

FZ, Weniger & Ando (2015)
eROSITA should be able to detect all clusters of galaxies $>10^{14} \, M_\odot$
STERILE NEUTRINO IN MASS BINS

FZ, Weniger & Ando (2015)
NB: 3 energy-bin side-band analysis

4yr eROSITA, CC perfect DM map

- $\ell = 10^1 - 10^4$
- $\ell = 10^2 - 10^4$ (baseline)
- $\ell = 10^3 - 10^4$
- $\nu_s < 10^{13} M_\odot$

Too much DM
Too little DM
Excluded by X-ray

Dark matter mass, $m_s$ [keV]
Interaction strength, $\sin^2 2\theta$
CROSS-CORRELATION WITH 2MASS – 2MRS

0.9 – 1.1 keV

8.9 – 9.1 keV

FZ, Weniger & Ando (2015)