Search for the Unidentified 3.55 keV Line in Galaxy Clusters

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Special Thanks to Local Organizing Committee

Galaxy Clusters in Visible Light (2%)
Galaxy Clusters in X-rays (13%)
Galaxy Clusters Composite (%15)
Galaxy Clusters Rest (%85)
• Largest gravitationally bound aggregations of hot ICM and DM

• Emission lines are now being discovered through X-ray spectroscopy

• Not enough sensitivity for very weak emission lines due to short exposures, background and instrumental artifacts.
• Stacked 73 galaxy clusters at their rest frame
• Increased S/N
• Smeared non-source features, e.g. instrumental, background
Background Before Stacking

![Graph showing flux vs. energy with peaks labeled Cr, Mn, and Cu.](image)
Background After Stacking

![Graph showing the flux (counts s⁻¹ keV⁻¹) versus energy (keV). Peaks for Cr, Mn, and Cu are indicated.]
Background After Stacking
Modeled 2-10 keV band (Continuum and Atomic Lines)

Detected a weak line at 3.55-3.57 keV (rest frame energy)
A Mysterious Line Detected!

6 Ms XMM-Newton MOS Observations
A Mysterious Line Detected!
with a Gaussian Line Added…

XMM - MOS Full Sample 6 Ms
“Mystery in the Perseus Cluster”

Image from NASA/ESA press release, June 2014

Credit: J. de Pasquale
146 citations since June, most of which propose various dark matter explanations ...

- An X-Ray Line from eXciting Dark Matter
- SIMPle Dark Matter: Self-Interactions and keV Lines
- The 7 keV axion dark matter and the X-ray line signal
- X-ray line signal from decaying axino warm dark matter
- 3.5 keV x-ray line from decaying gravitino dark matter
- 7 keV scalar dark matter and the anomalous extragalactic x-ray spectrum
- Decaying Vector Dark Matter as an Explanation for the 3.5 keV Line
- The 3.5 keV X-ray line signal from decaying moduli with low cutoff scale
- Nonabelian dark matter models for 3.5 keV X-rays
- 3.5-keV X-ray line from nearly-degenerate WIMP dark matter decays X-ray
- Line from the Dark Transition Electric Dipole
- 3.5 keV X-rays as the “21 cm line” of dark atoms
• XMM MOS: Full Sample, Bright nearby clusters, Distant Clusters, and Perseus cluster
• XMM PN (a different instrument!) Full Sample, Distant Clusters
• Chandra (a different satellite!) Perseus cluster
• Suzaku (another satellite!) Perseus cluster
(see Cemile Ezer’s poster, Urban et al. 2014; arXiv:1411.0050)
What is the origin of this line?
Astrophysical Line?

- K XVIII at 3.51keV $\rightarrow$ 10$A_\odot$
- Ar XVII DR at 3.62 keV $\rightarrow$ 30$A_\odot$
- Cl XVII Lyβ at 3.51keV $\rightarrow$ >30$A_\odot$

• Radiative Recombination Feature
• Charge Exchange
• Any other astrophysical explanations?

More exotic than sterile neutrinos!
Dark Matter?

Sterile neutrinos can decay into an X-ray photon and an active neutrino (Dodelson & Widrow 94)
Comparison with Earlier Limits

Mixing angle vs. Mass (keV)

Limits are taken from Abazajian et al. (2009)

Previous Upper Limits from Clusters
Decaying Sterile Neutrinos?

- Boyarsky et al. (2014, PhRL, 113, 251301)
- Urban et al. (2014, arXiv:1411.0050)

Graph showing the flux in units of $10^5 \text{ cm}^{-2} \text{s}^{-1}$ as a function of angle in degrees. The graph compares data from Bulbul et al., Boyarsky et al., and Urban et al. with measurements from XMM with core and Perseus.
Current Status

Detections
- Perseus Cluster (core and outskirts) ✓
- Stacked clusters ✓
- Nearby Clusters ✓
- Distant clusters ✓
- M31 (Boyarsky et al., arXiv:1402.4119) ✓
- Galactic Center (Boyarsky et al., arXiv:1408.2503) ✓

Non-Detections
- Virgo Cluster (Bulbul et al., ApJ,789,13B); consistent ✓
- Dwarf Spheroidals (Malyshev et al., arXiv:1408.3531); inconsistent at 2.5σ?
- Stacked galaxies (Anderson et al., arXiv:1408.4115); inconsistent 12σ?
Exciting Dark Matter Particle?

- Velocity dependence in the scattering cross section
- Fluxes from all samples and objects are consistent!

Cline et al. (2014, PhysRevD, 89, 121302)
Dark Matter vs Astrophysical Line?

Astro-H
Spectrometer
Observations of the Perseus cluster
1 Ms

3.55 keV Line

Flux (ph cm$^{-2}$s$^{-1}$keV$^{-1}$)

Energy (keV)

Ar XVII
Ar XVIII
Ca XIX

3.62 keV Ar XVII DR
Tesekkurler
Thank you
Merci beaucoup