The 3.5 keV Candidate Dark Matter Decay Signal - Current Status and Near-Future Prospects

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With
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**Introduction**

**Decaying Dark Matter**

**WIMPs**
- Interaction strength at weak scale
- Correct $\Omega_{DM}$ for masses Gev – TeV
- Would have short lifetime
- Made stable with new physics

**SuperWIMPs**
- Interaction strength weaker-than-weak
- Correct $\Omega_{DM}$ for masses of order keV
- Lifetime longer than age of universe
- Allowed to be decaying DM
Decaying DM should decay into monochromatic X-rays
**Target Sources**

Good targets are dark matter dominated. Specifically, sources with high expected decay signal strength

\[
\text{signal } \propto \text{ DM mass in FoV / distance}^2
\]

- Milky Way
- Clusters
- Dwarf Galaxies
- Galaxies
Detections

Detection at $\sim 3.55$ keV in Andromeda (M31)

Boyarsky et al. 2014a [1402.4119]
# Detections of the Unidentified 3.5 keV Line

## Boyarsky et al. 2014a [1402.4119]

<table>
<thead>
<tr>
<th>Object</th>
<th>Instrument, Region</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>M31 galaxy</td>
<td>XMM-Newton, center &amp; outskirts</td>
<td>$4.4 \sigma$</td>
</tr>
<tr>
<td>Perseus cluster</td>
<td>XMM-Newton, outskirts only</td>
<td></td>
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## Bulbul et al. 2014 [1402.2301]

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<td>73 clusters</td>
<td>XMM-Newton (MOS &amp; PN), centers only, up to $z = 0.4$</td>
<td>$5 \sigma$ &amp; $4 \sigma$</td>
</tr>
<tr>
<td>Perseus cluster</td>
<td>Chandra, center only</td>
<td>$3.5 \sigma$</td>
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Estimated global significance $\sim 6.6 \sigma$
Instrumental origin unlikely

1. Detected in 5 different detectors
   - XMM-Newton MOS and PN detectors
   - Chandra ACIS-S, ACIS-I
   - Suzaku XIS

2. Line redshifts correctly with sources
   - Clusters stacked in object restframe (Bulbul et al. 2014)
   - Line in Perseus redshifted correctly at $\sim 2\sigma$

3. Not detected in blank sky dataset
   - 16 Msec with XMM
   - $\sim 8$ Msec with Suzaku (Sekiya et al. 2015 [1504.02826])
**ATOMIC LINE?**

**Unlikely**: can not explain consistently all observations

![Graph showing energy vs. line intensity](image)

*Unlikely* line ratios in M31 clusters need anomalous line ratios of a factor $\sim 10 - 20$

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*Line Origin*

M31 line is **stronger** than other atomic emission

CLUSTERS need **anomalous line ratios** of a factor $\sim 10 - 20$

Bulbul et al. 2014
The line flux should be proportional to mass / distance$^2$
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Expect large signal from GC → “easy” cross-check
Boyarsky et al. 2014b [1408.4388]
The Galactic Center (GC) is an extremely complicated environment. Line in GC might be potassium (Riemer-Sorensen [1405.7943]; Jeltema & Profumo [1408.1699]) but not necessarily (Boyarsky et al. 2014b,c [1408.2503, 1408.4388]). The important thing is the GC is not inconsistent and potassium cannot explain all observations.
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Line in GC *might* be Potassium

(Riemer-Sorensen [1405.7943]; Jeltema & Profumo [1408.1699])

but *not necessarily*

(Boyarsky et al. 2014b,c [1408.2503, 1408.4388])

The important thing is the *GC is not inconsistent* and potassium cannot explain all observations
POSSIBLE ALTERNATIVE: CHARGE-EXCHANGE

GU, KAASTRA, ET AL. 2015
[1511.06557]
Colliding cold gas and hot gas can emit lines through charge-exchange.

At 3.48 keV, possible S XVI CX-line.

Depends on amount of cold gas and velocity.
POSSIBLE ALTERNATIVE: CHARGE-EXCHANGE

**Gu, Kaastra, et al. 2015**
[1511.06557]

Difficult to predict, but may be plausible in Perseus.

Not expected in *dSph’s*.

**Astro-H** will be able to resolve line broadening.
Preliminary 1 Ms with Suzaku, $8\sigma$ detection in the center

Franse, Bulbul et al. (in prep)
MORE PERSEUS WITH SUZAKU (SOON)

Preliminary No detection in outskirts with Suzaku

Franse, Bulbul et al. (in prep)
We have been awarded 1.4 Ms of XMM observations of the Draco dwarf galaxy this year

- Highest expected signal of all dwarf galaxies (Geringer-Sameth+ 2014, Lovell+ 2014)
- Very gas-poor (do not expect any atomic lines)
- We will be able to confirm or deny the DM origin of the 3.5 keV line in early 2016.
Full 1.6 Ms analysed by Profumo & Jeltema [1512.01239]
**FUTURE: ASTRO-H MICRO-CALORIMETER**

Astro-H SXS
Perseus, 1 Msec
kT = 6.5 keV, 0.6 solar
z=0.0178
v(baryons) = 300 km/s
v(line) = 1300 km/s

**Graphical Content:**

- Flux (photons cm^{-2} s^{-1} keV^{-1})
- Energy (keV)
- Marked areas:
  - Ar XVII
  - Ar XVIII
  - 3.55 keV Line
  - 3.62 keV Ar XVII DR
  - Ca XIX

Bulbul et al. (2014)
Projected DM mass density, $M_{\text{Sun}}/\text{pc}^2$

Blank-sky

Bulbul et al. (2014) Stacked dSph bound

$\tau_{\text{DM}} = 2.1 \times 10^{27}$ sec

$\tau_{\text{DM}} = 15.6 \times 10^{27}$ sec

GC

Perseus

M31
PARAMETER SPACE

DM overproduction
Excluded by X-ray observations

Not enough DM