Search for the Unidentified 3.55 keV Line in Galaxy Clusters

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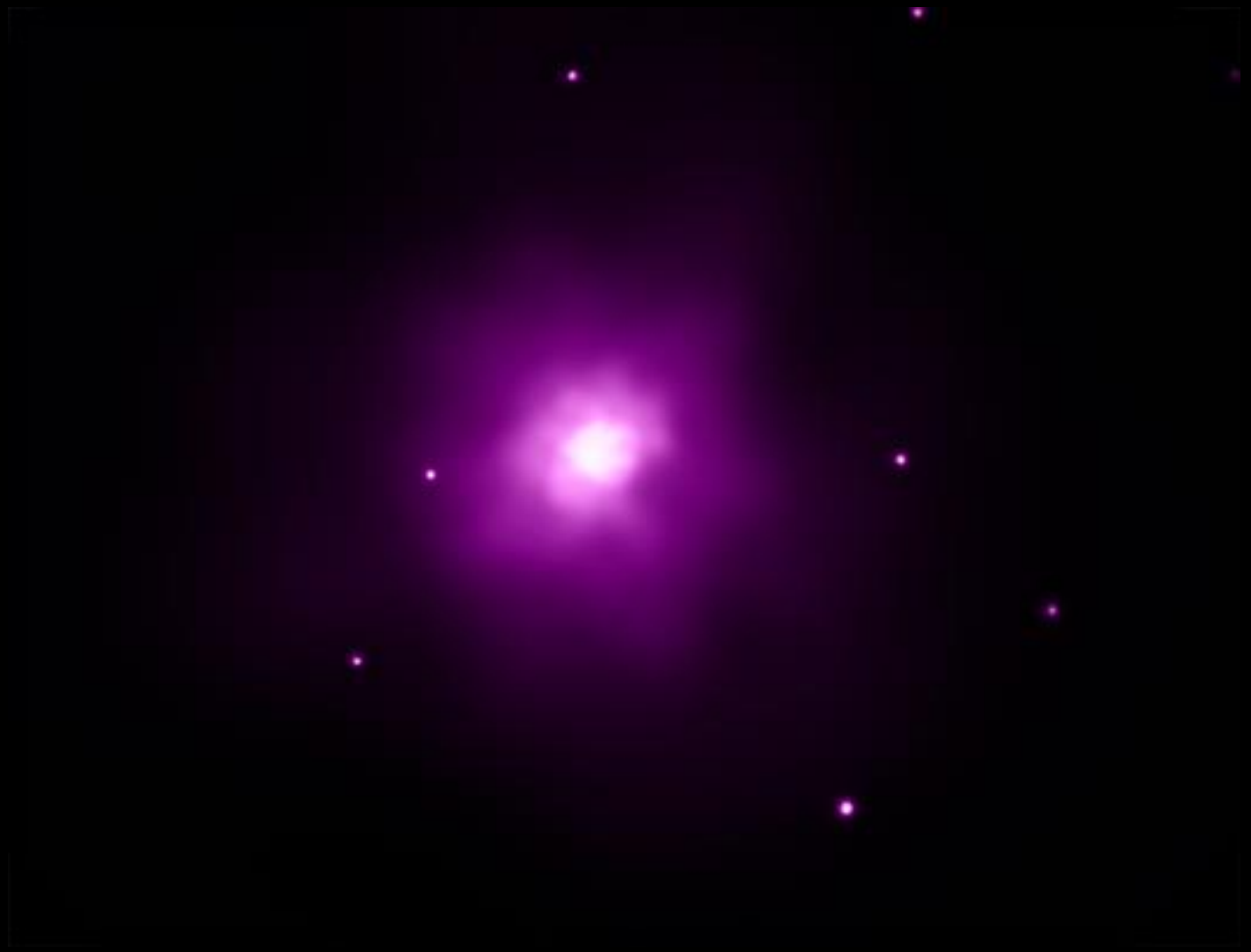
Special Thanks to Local Organizing Committee

ApJ, 789, 13B, published in June 2014

Galaxy Clusters in Visible Light (2%)

Galaxy Clusters in X-rays (13%)

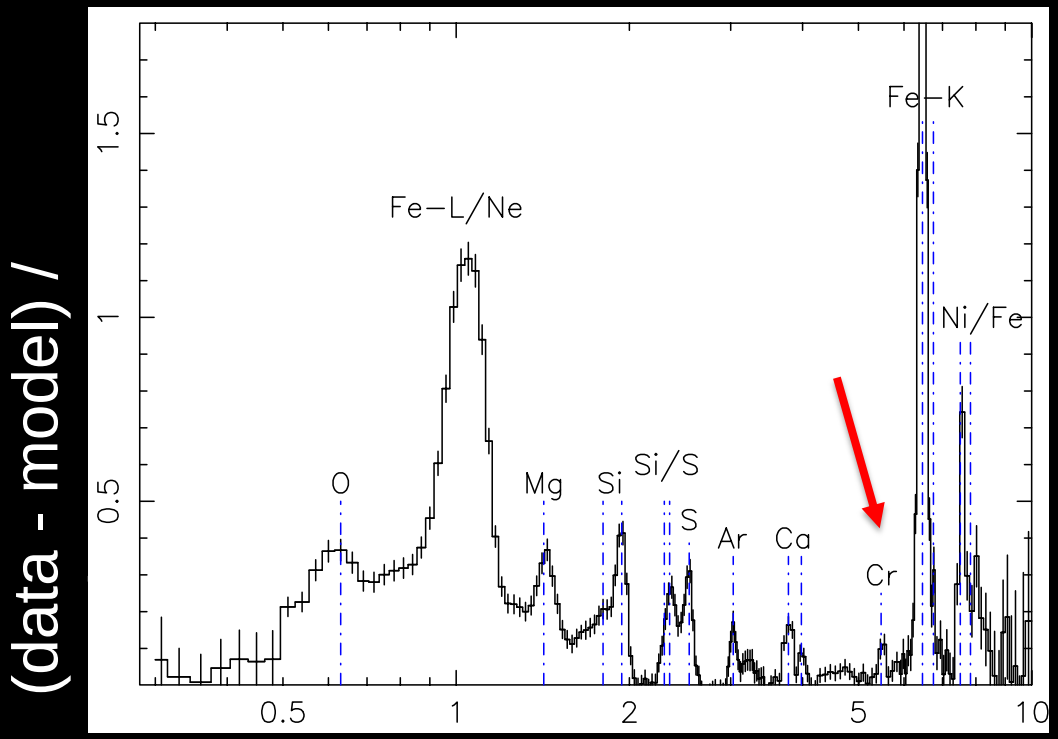


Galaxy Clusters Composite (%15)

Galaxy Clusters Rest (%85)

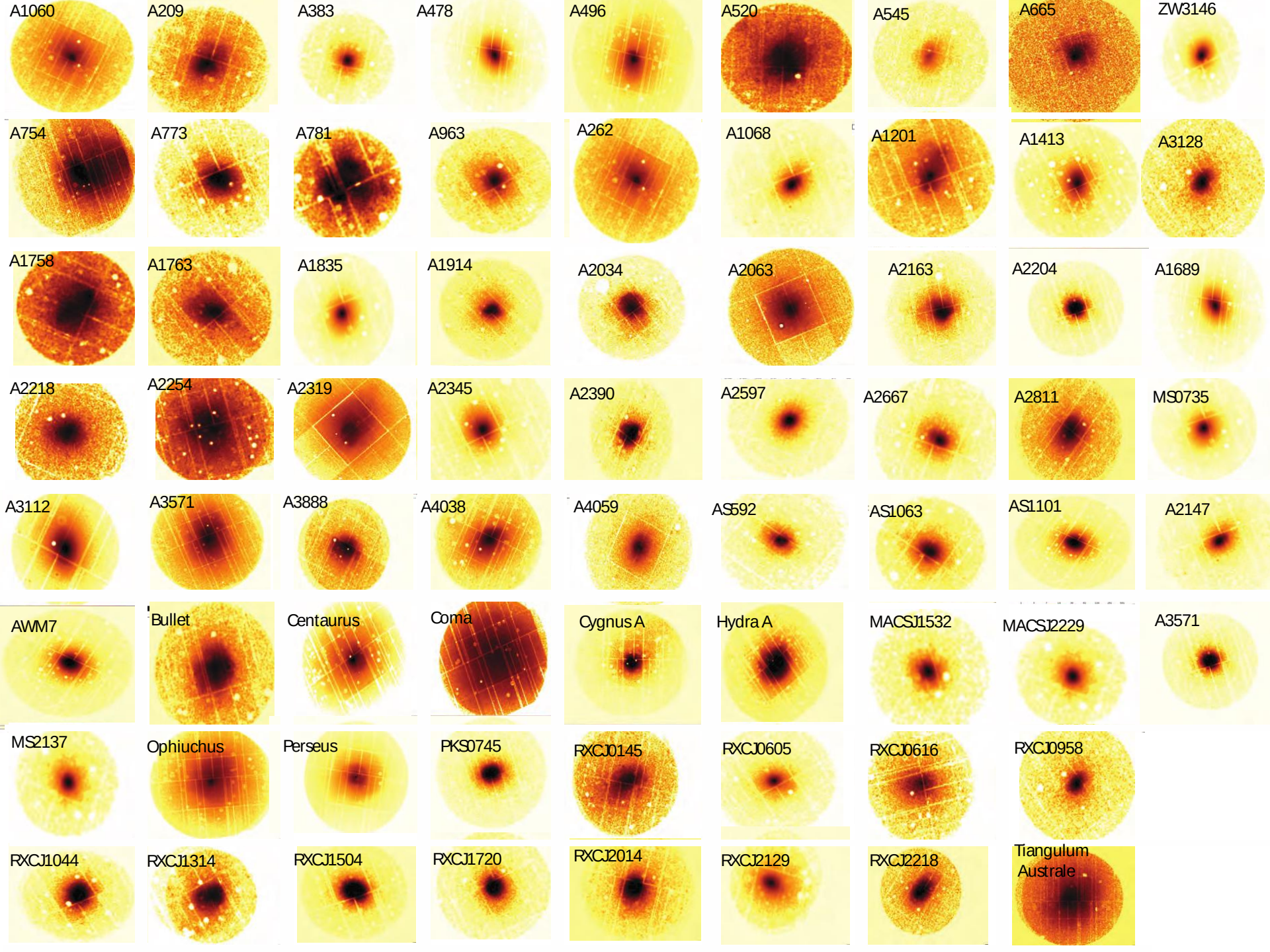
- Largest gravitationally bound aggregations of hot ICM and DM
- Emission lines are now being discovered through X-ray spectroscopy
- Not enough sensitivity for very weak emission lines due to short exposures, background and instrumental

2A 0335+096

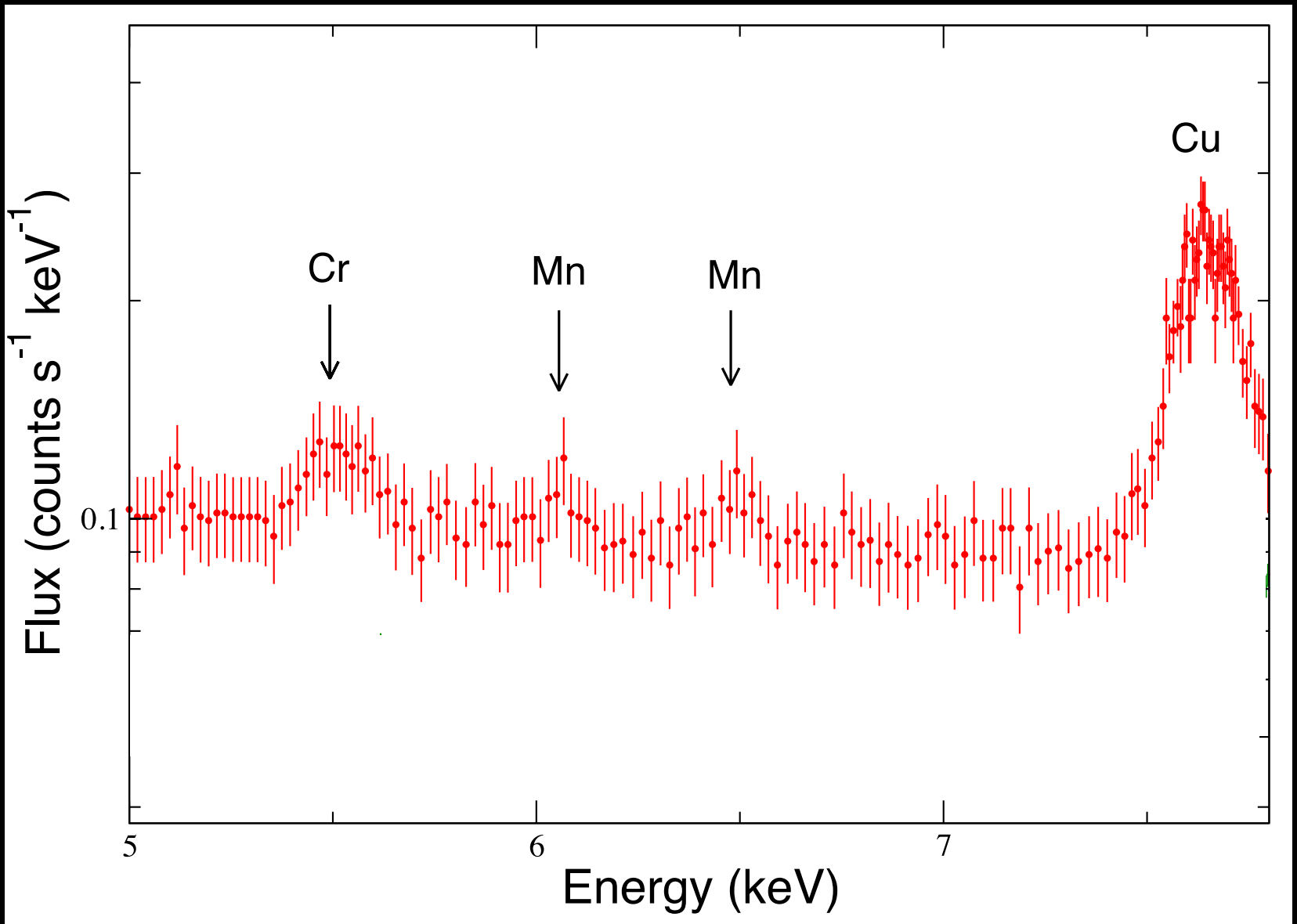


Werner et al. (2006)

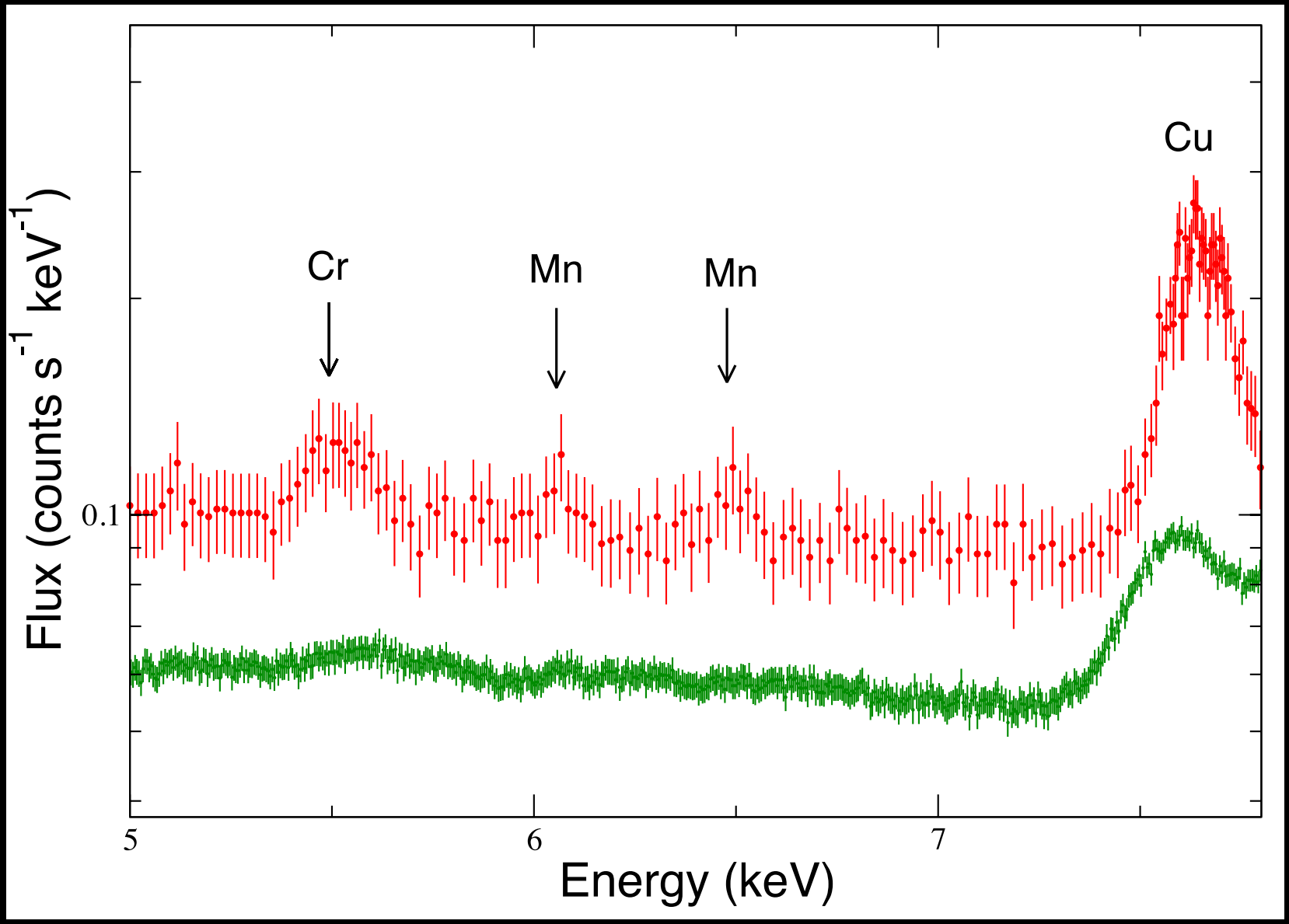
- Stacked 73 galaxy clusters at their rest frame
- Increased S/N
- Smeared non-source features, e.g. instrumental, background


A1060
A209
A383
A478
A496
A520
A545
A665
ZW3146
A754
A773
A781
A963
A262
A1068
A1201
A1413
A3128
A1758
A1763
A1835
A1914
A2034
A2063
A2163
A2204
A1689
A2218
A2254
A2319
A2345
A2390
A2597
A2667
A2811
MS0735
A3112
A3571
A3888
A4038
A4059
AS592
AS1063
AS1101
A2147
AWM7
Bullet
Centaurus
Coma
Cygnus A
Hydra A
MACSJ1532
MACSJ2229
A3571
MS2137
Ophiuchus
Perseus
PKS0745
RXCJ0145
RXCJ0605
RXCJ0616
RXCJ0958
RXCJ1044
RXCJ1314
RXCJ1504
RXCJ1720
RXCJ2014
RXCJ2129
RXCJ2218
Tiangulum Australe

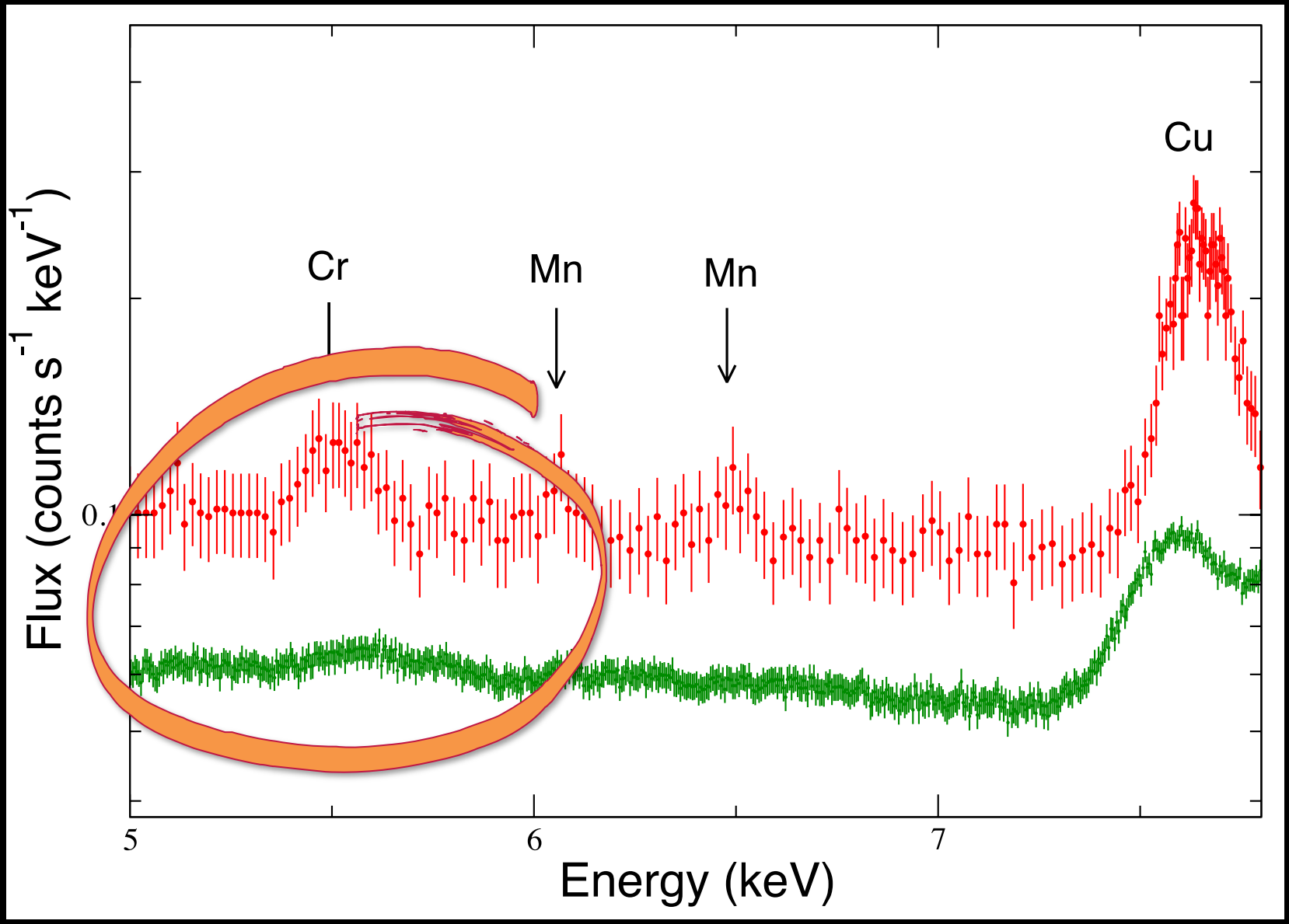
Background Before Stacking



Background After Stacking



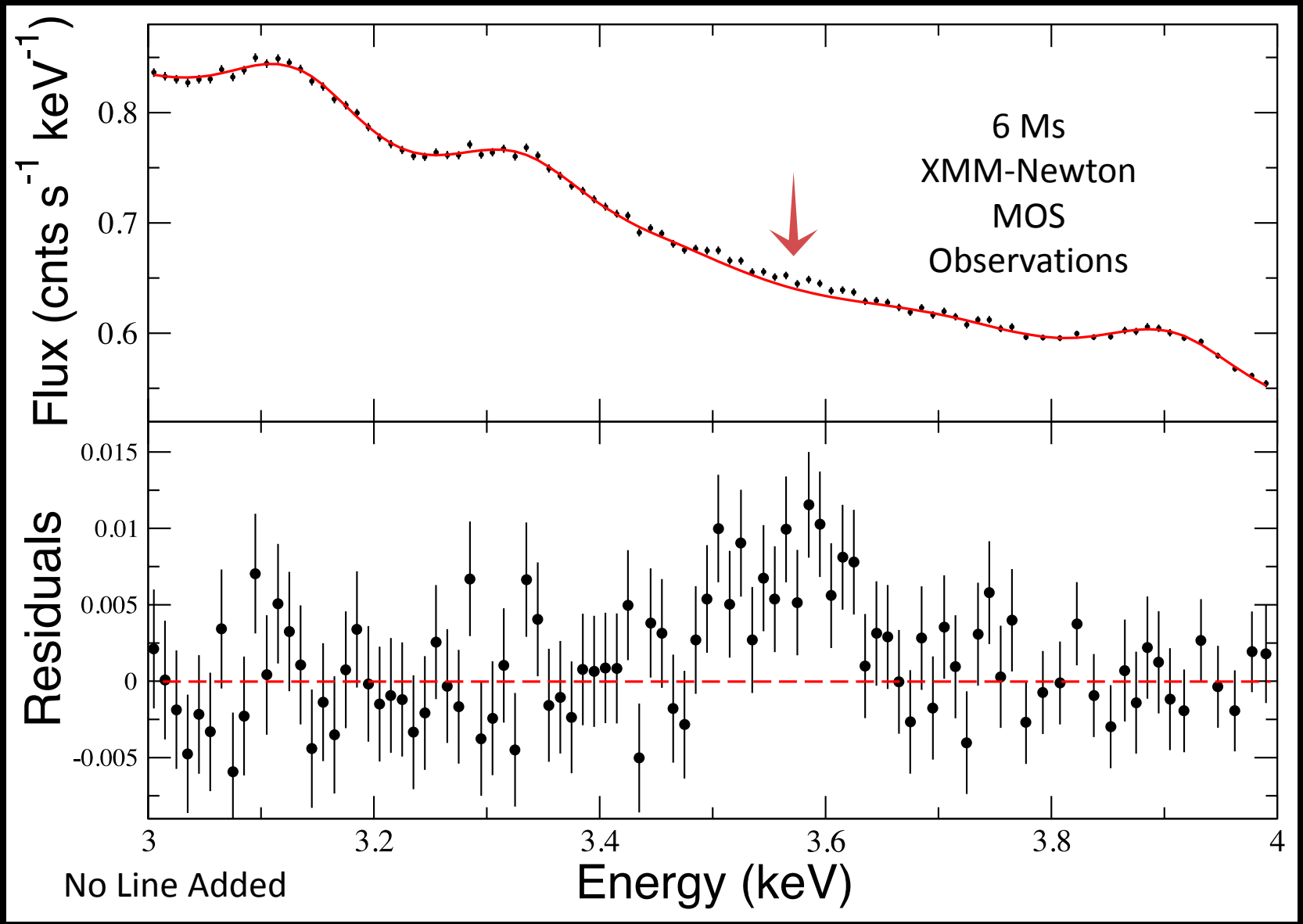
Background After Stacking



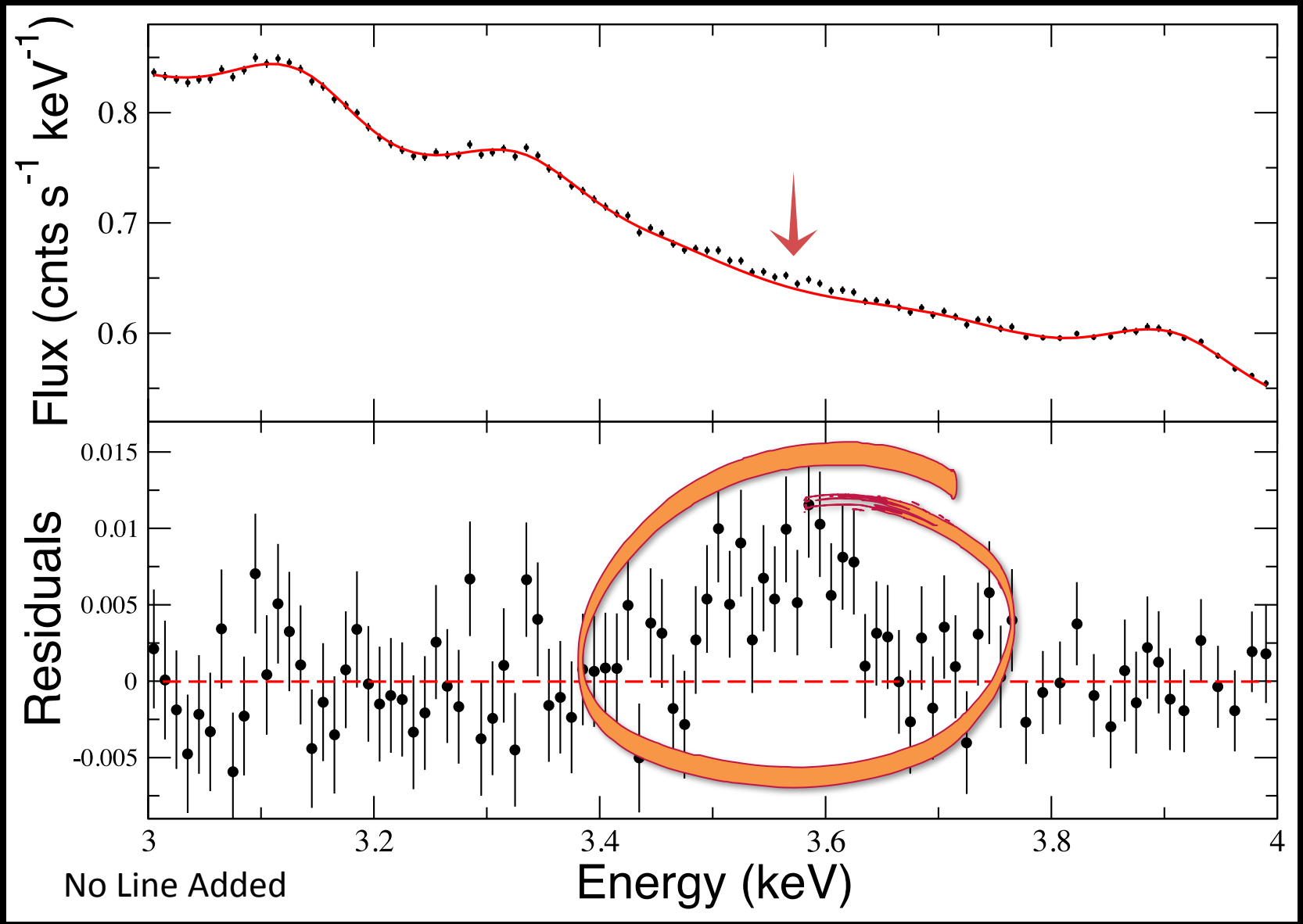
Modeled 2-10 keV band (Continuum and Atomic Lines)

Detected a weak line at 3.55-3.57 keV (rest frame energy)

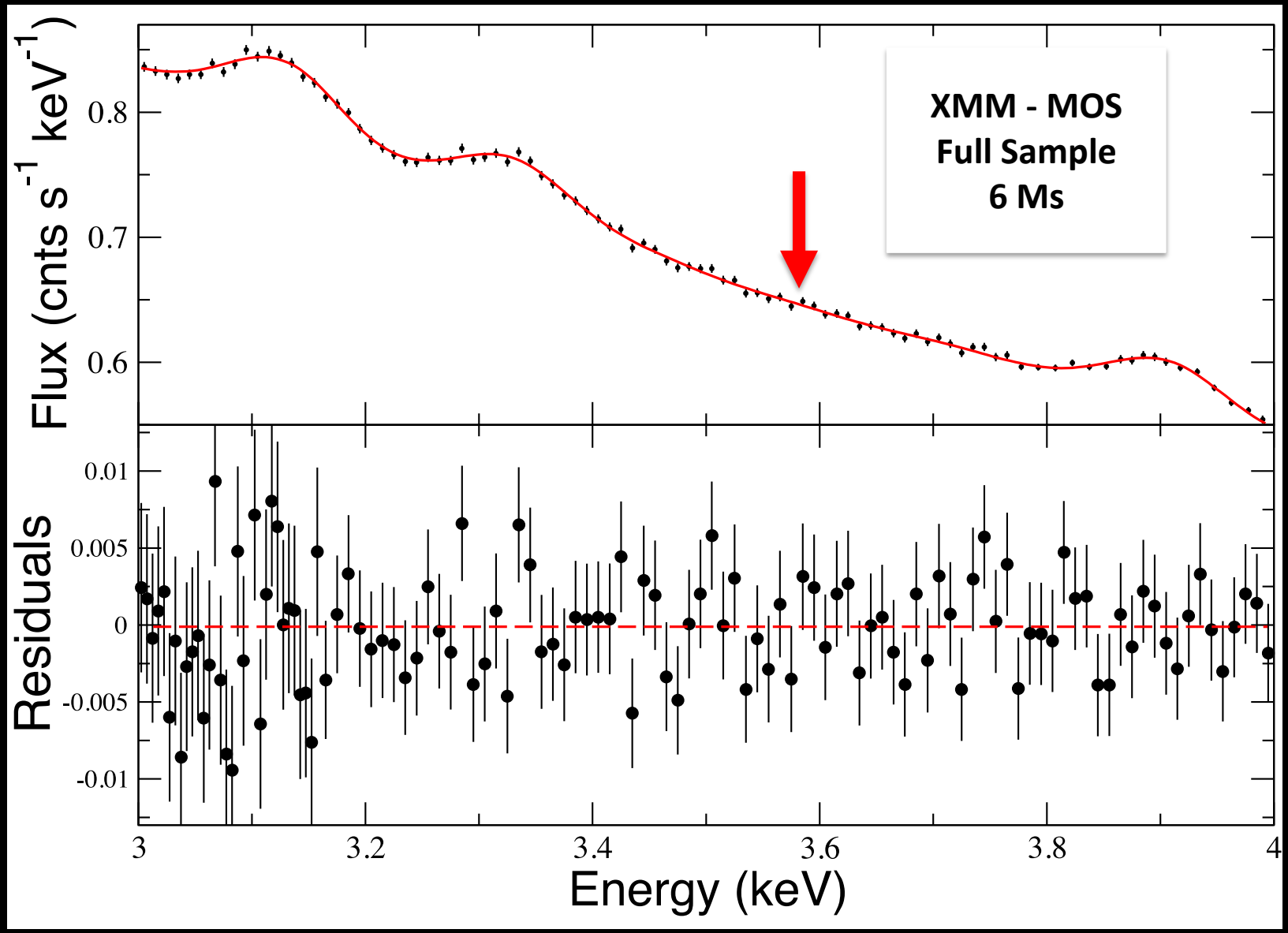
A Mysterious Line Detected!



A Mysterious Line Detected!



with a Gaussian Line Added…



“Mystery in the Perseus Cluster”

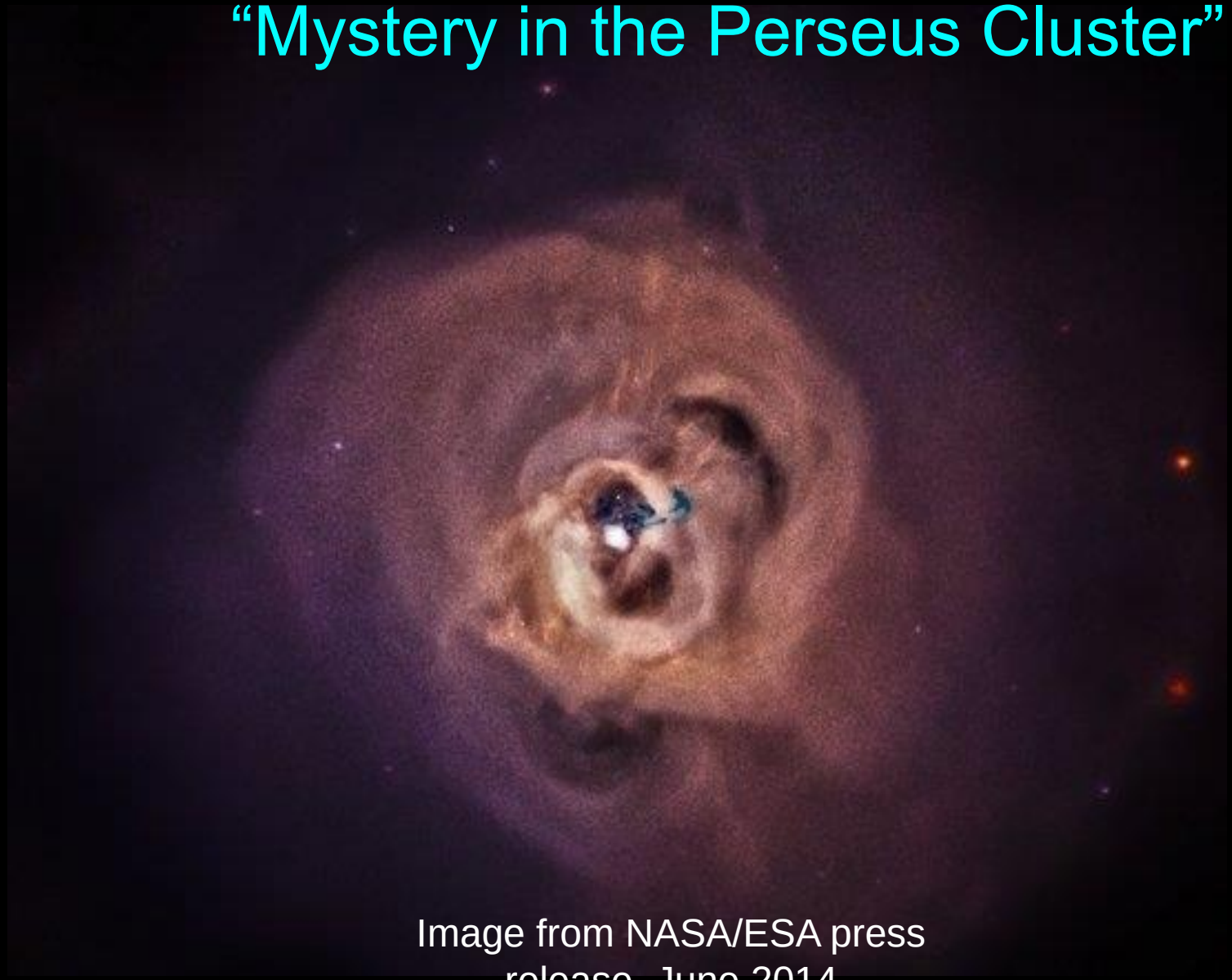
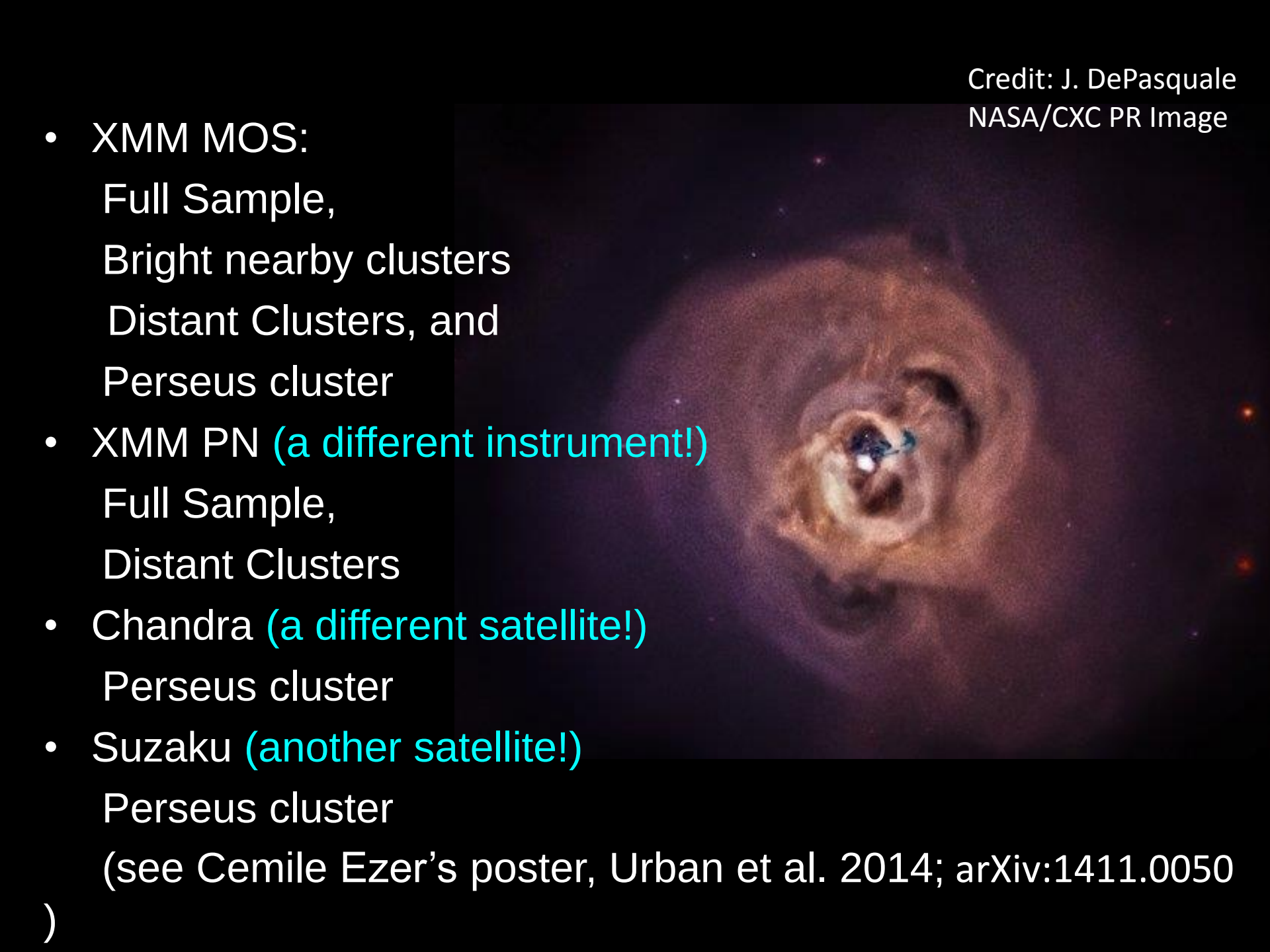


Image from NASA/ESA press release, June 2014

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



Credit: J. DePasquale
NASA/CXC PR Image

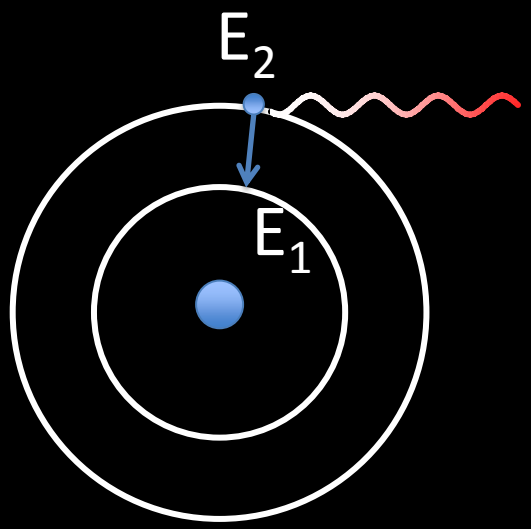
- XMM MOS:
  Full Sample,
  Bright nearby clusters
  Distant Clusters, and
  Perseus cluster
- XMM PN (a different instrument!)
  Full Sample,
  Distant Clusters
- Chandra (a different satellite!)
  Perseus cluster
- Suzaku (another satellite!)
  Perseus cluster
  (see Cemile Ezer's poster, Urban et al. 2014; arXiv:1411.0050
)

What is the origin of this line?

Astrophysical Line?

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

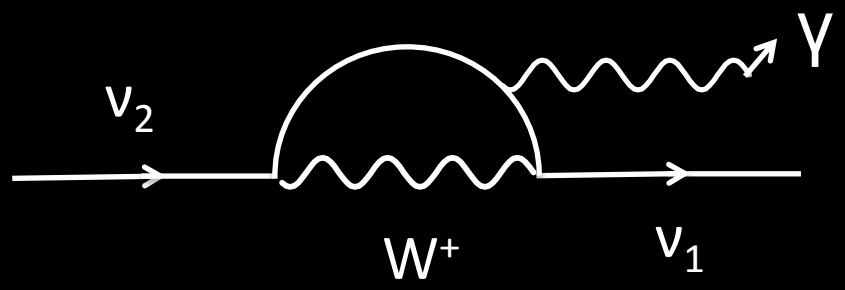
More exotic than sterile neutrinos!



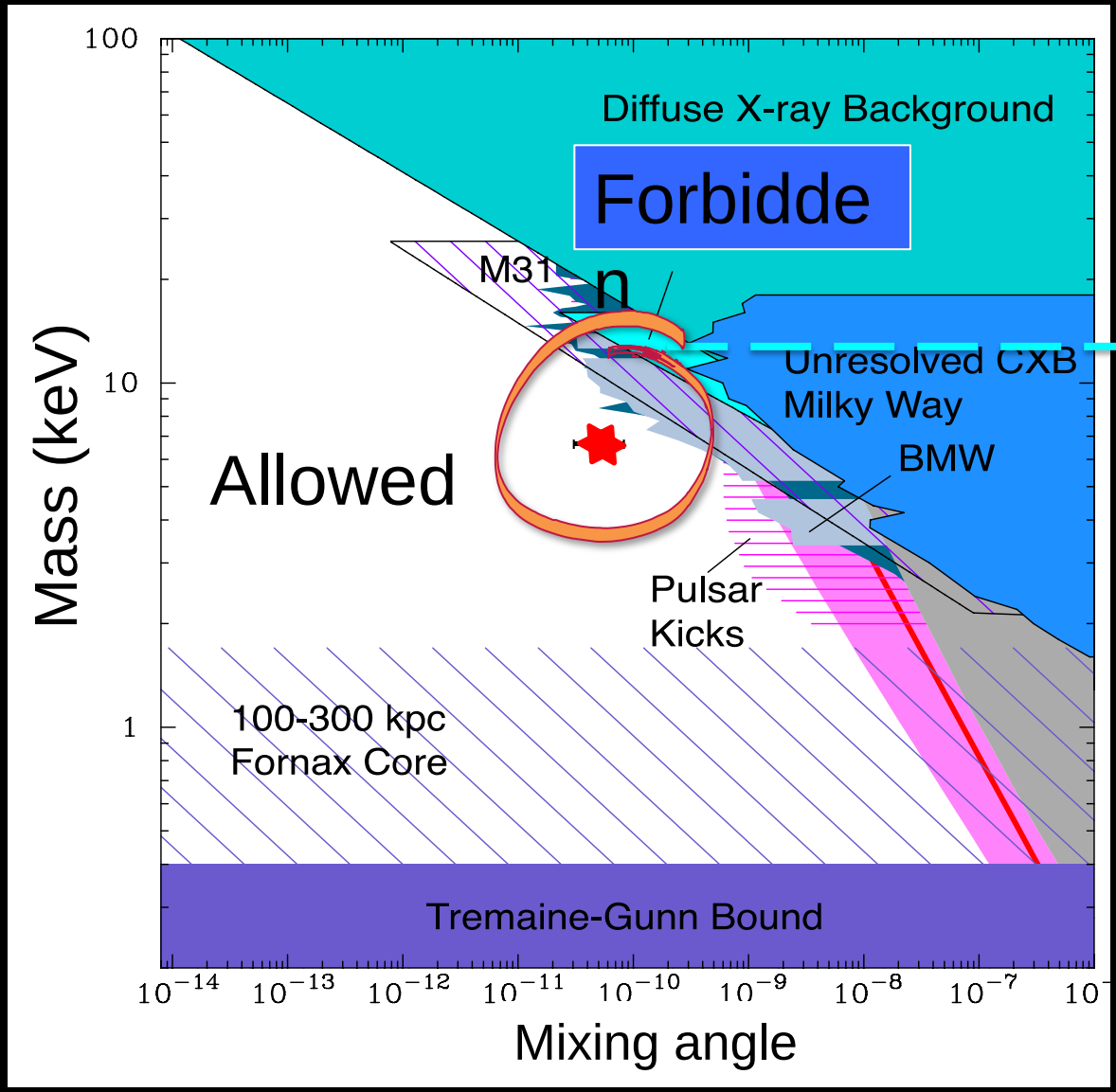
- Radiative Recombination Feature
- Charge Exchange
- Any other astrophysical explanations?

Dark Matter?

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



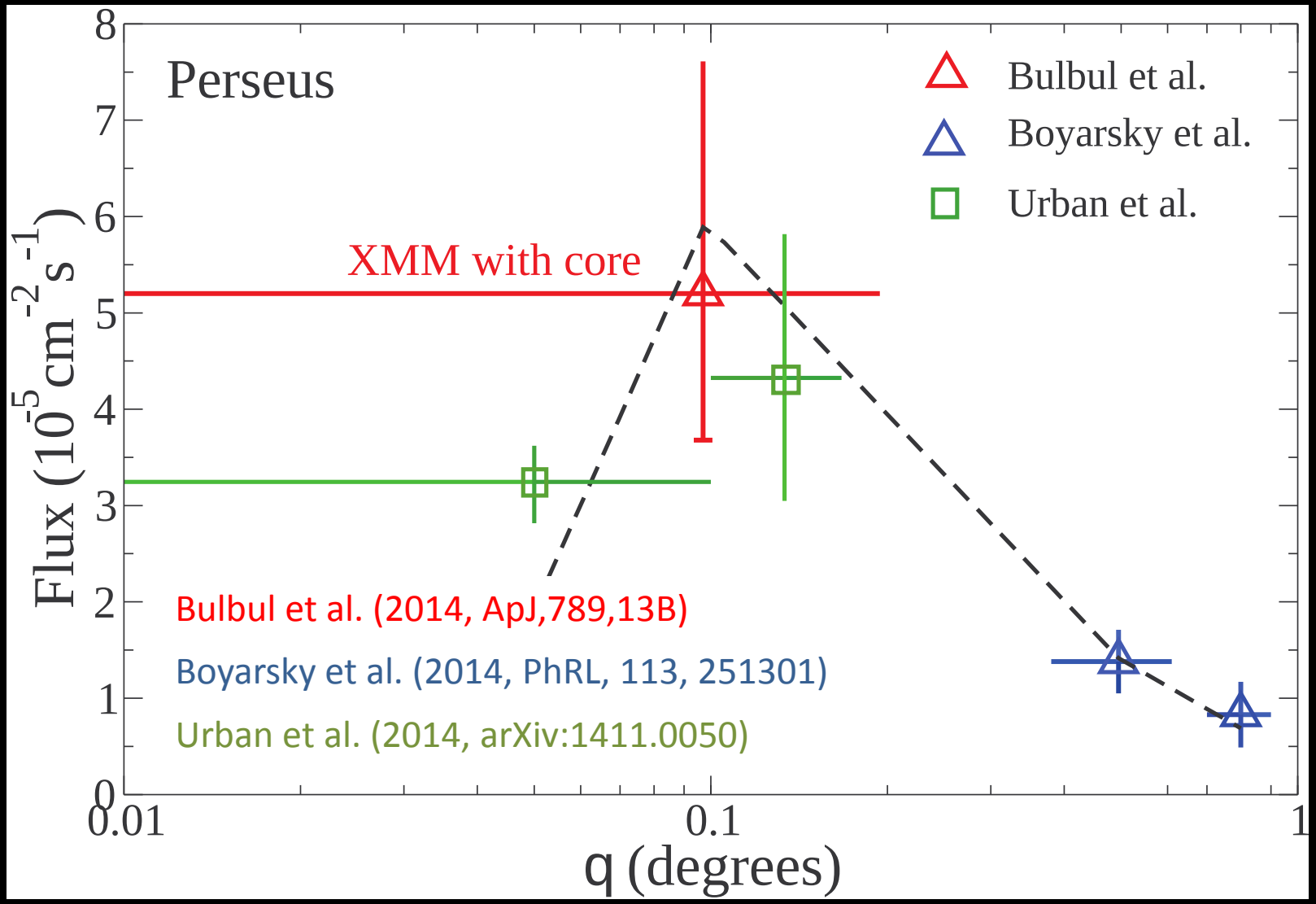
Comparison with Earlier Limits



Previous Upper Limits from Clusters

Limits are taken from Abazajian et al. (2009)

Decaying Sterile Neutrinos?



Cline & Frey (2014, JCAP, 10, 013)

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) ✓

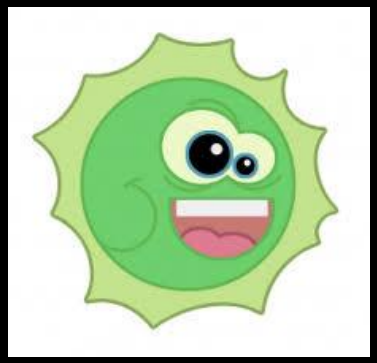
Follow scaling for simplest DM decay model

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

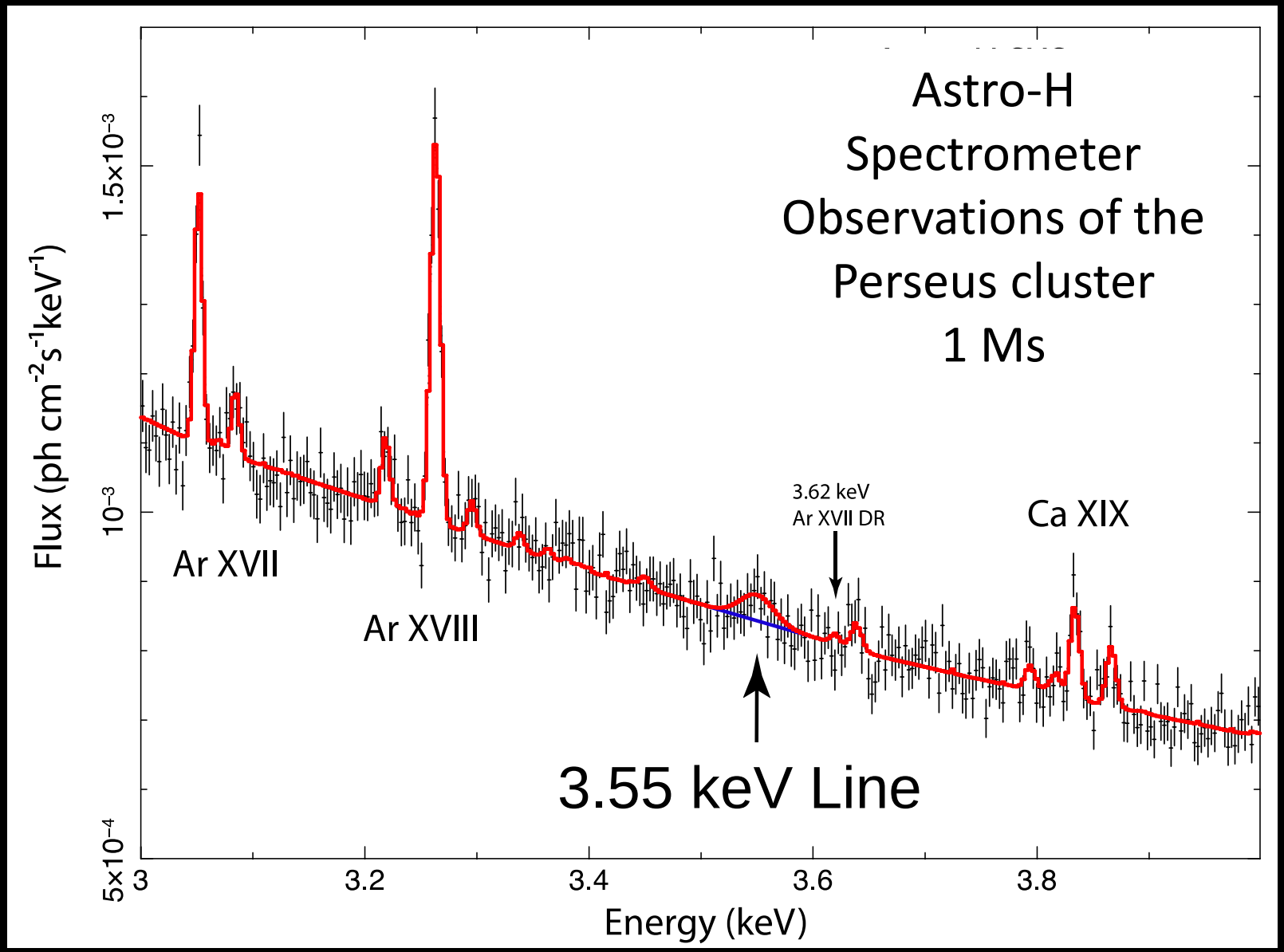


Exciting Dark Matter Particle?

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

Finkbeiner & Weiner (2014, arXiv:1402.6671)
Cline et al. (2014, PhysRevD, 89, 121302)

Dark Matter vs Astrophysical Line?



Tesekkurler

Thank you

Merci beaucoup