New evidence the '3.5 keV feature' in galaxy clusters is inconsistent with a dark matter origin

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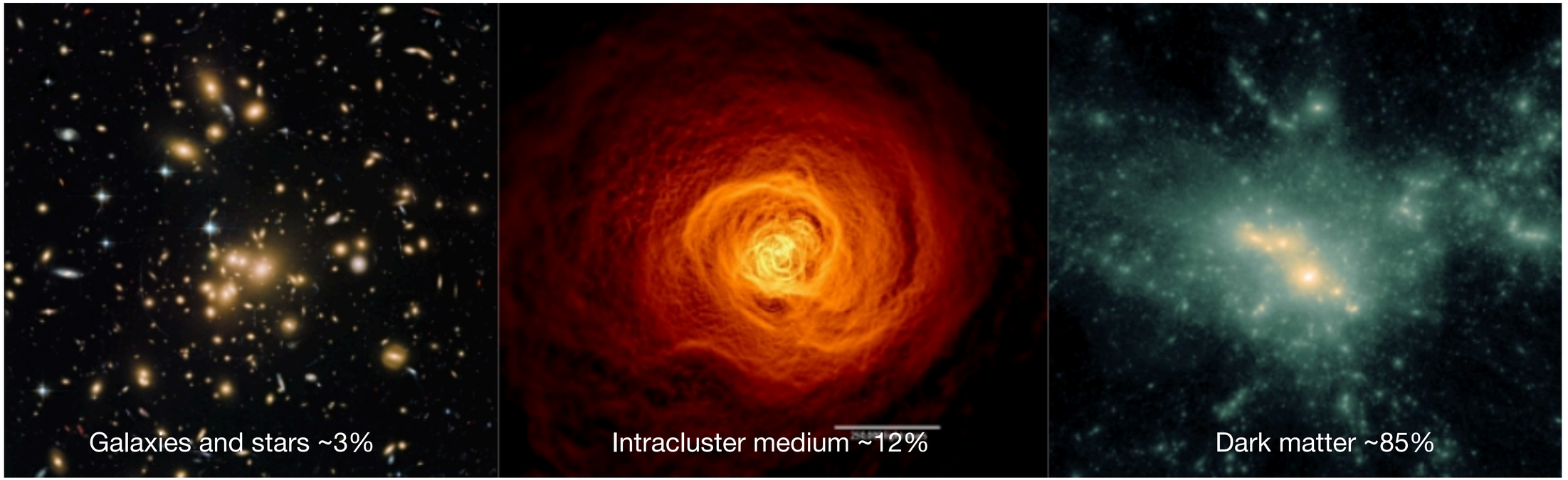
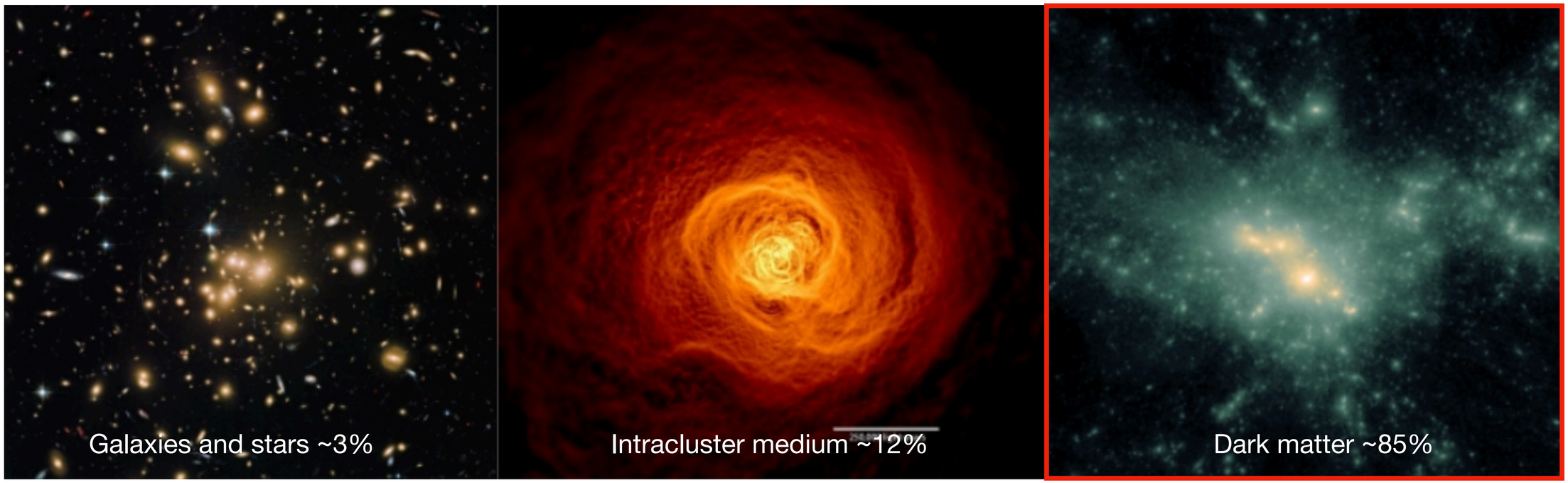
Galaxy clusters: novel probes of dark matter?

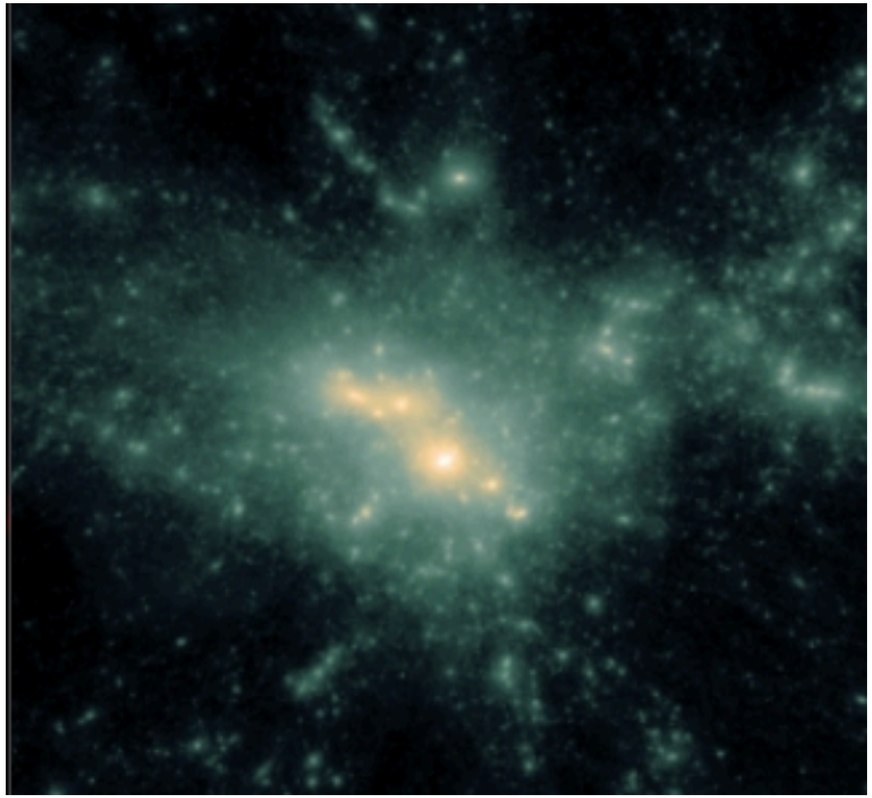


Galaxy clusters: novel probes of dark matter?



Galaxy clusters: novel probes of dark matter?

- Dark matter content typically measured indirectly using mass proxies
- More recently clusters have found a use in tracing *indirect dark matter signatures,* e.g. visible products from dark matter interactions
- The "3.5 keV line" arises from the decay of resonantly produced ~ 7 keV sterile neutrino dark matter (a WDM candidate)
- Sterile neutrino dark matter is stable on cosmological timescales and has a wide range of allowed masses ($m_s > 400$ eV)

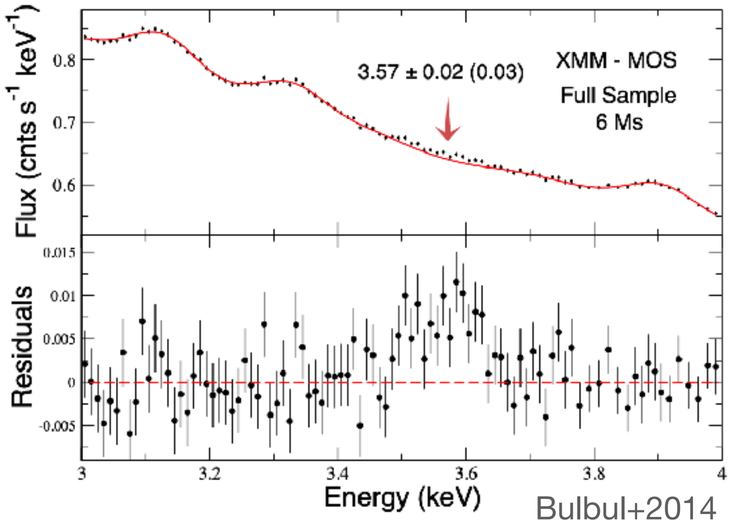


The status of 3.5 keV line searches in clusters

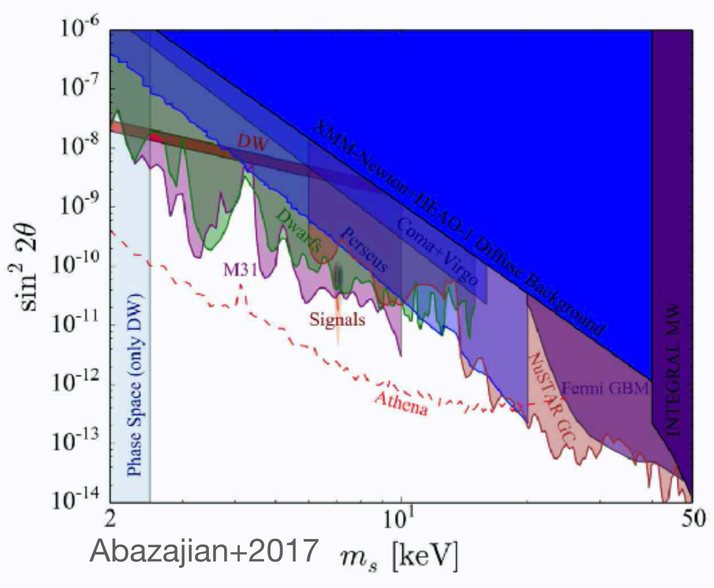
- Seminal work by Bulbul et al. 2014, finding a line with $> 3\sigma$ significance in the stacked spectra of 73 galaxy clusters using XMM-Newton (0.01 < z < 0.35)

- Follow-up observations of individual clusters such as Perseus (Urban et al. 2015, Hitomi Collaboration, 2017) find marginal and no evidence for a 3.5 keV line, respectively

792 citations!

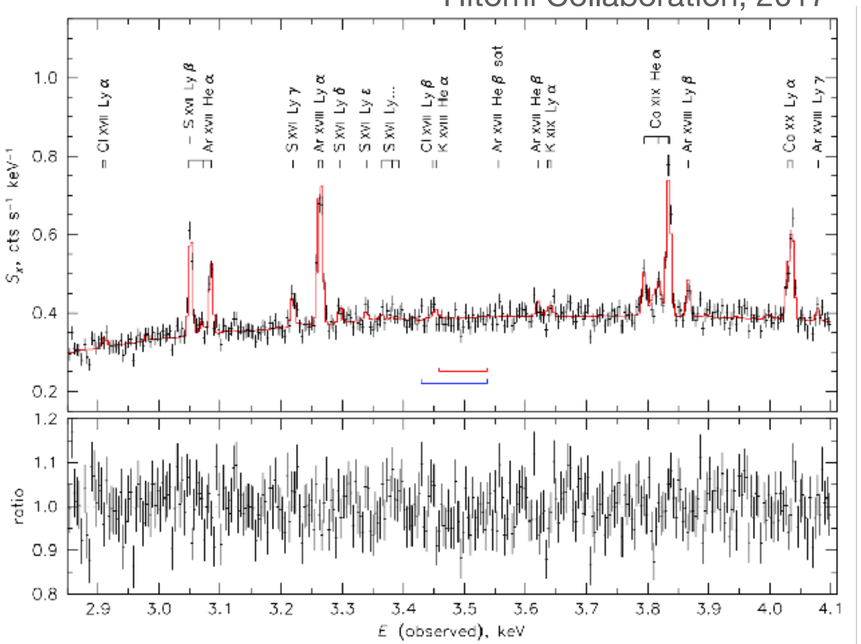


Bulbul+2014



Abazajian+2017

Hitomi Collaboration, 2017



Allowed sterile neutrino dark matter parameter space is compatible with gamma and X-ray excesses in astrophysical systems.

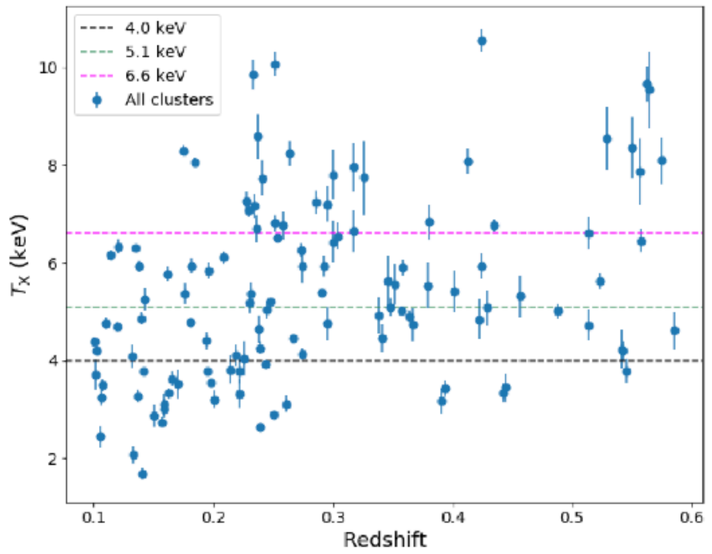
Testable scenarios for its existence - through cluster, individual galaxy and satellite searches.

Revisiting the search for the 3.5 keV line

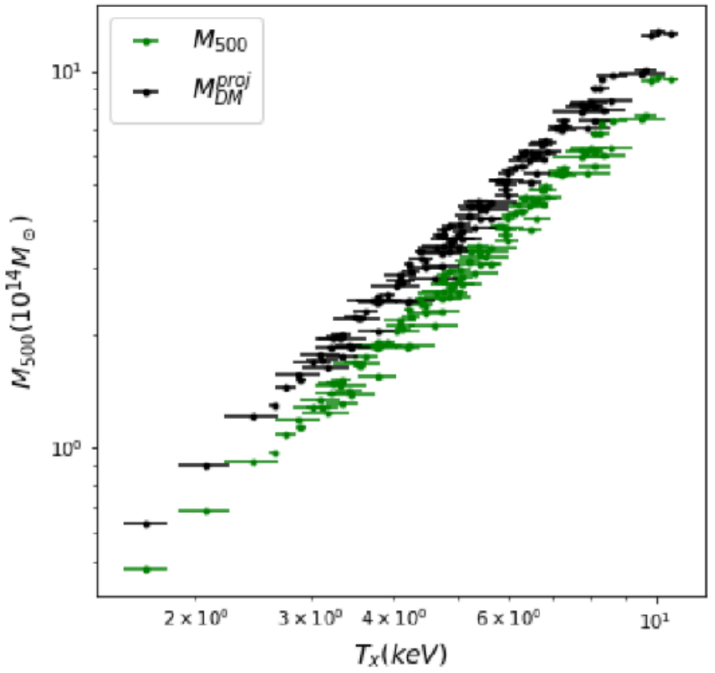
using 117 optically and X-ray confirmed clusters (0.1 < z < 0.6)

We use all subset of 117 redMaPPer confirmed clusters with photometric redshifts in the SDSS survey footprint with high quality X-ray data to search for the existence of an unidentified 3.5 keV feature as a function of X-ray temperature

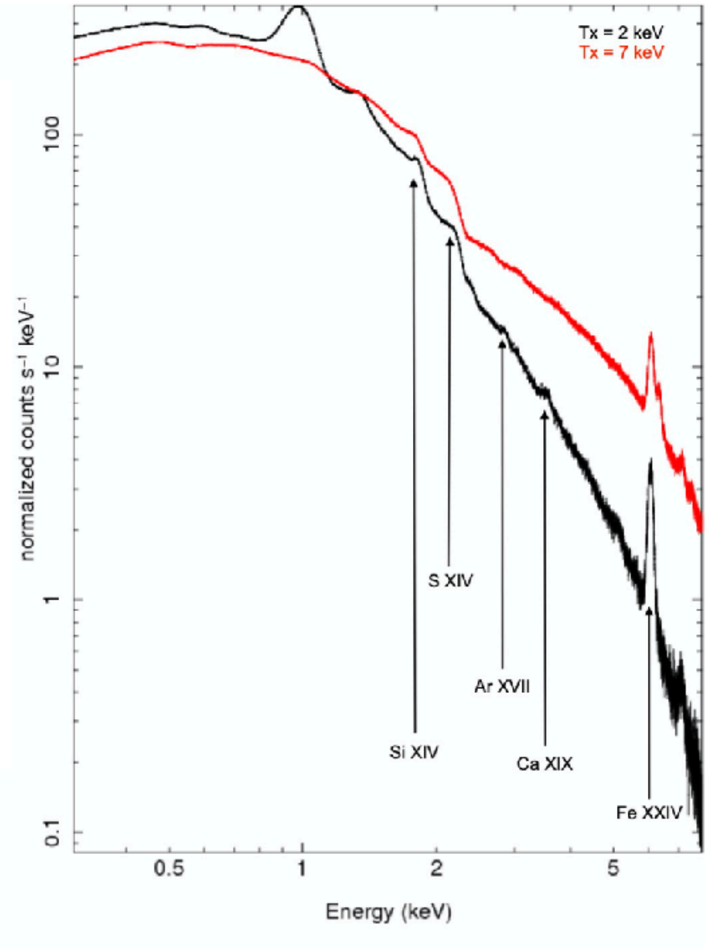
Temperature-redshift distribution of clusters



Mass-temperature relation



Hence, we expect a 3.5 keV line with a dark matter origin to be strongest in our largest (hottest) clusters



Simulated X-ray spectrum in the 0.3-7.9 keV band

Methodology for the 3.5 keV line search in clusters

Blueshift all clusters to the rest-frame to smear out any redshift-dependent artefacts

Simultaneous fitting instead of stacking (not assuming any global properties for the sample), and three tests:

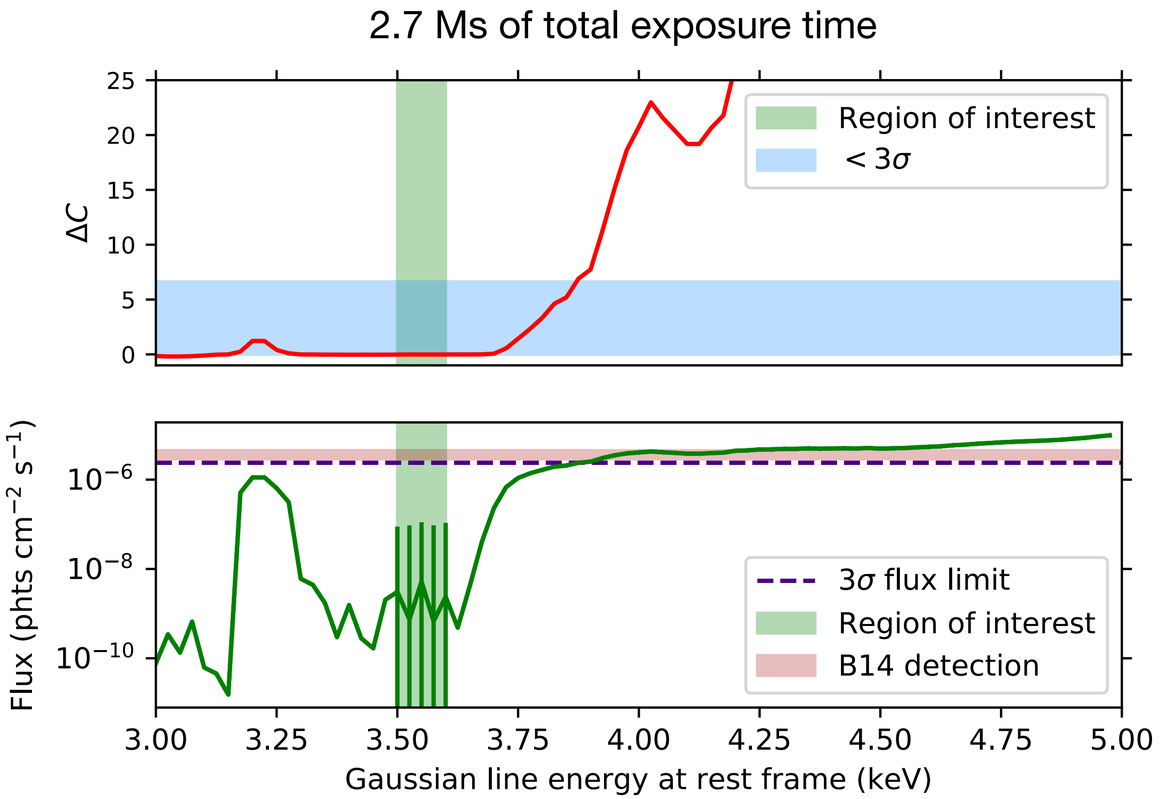
1. Individual clusters separately
2. Clusters binned into four temperature bins
3. All clusters in the sample jointly

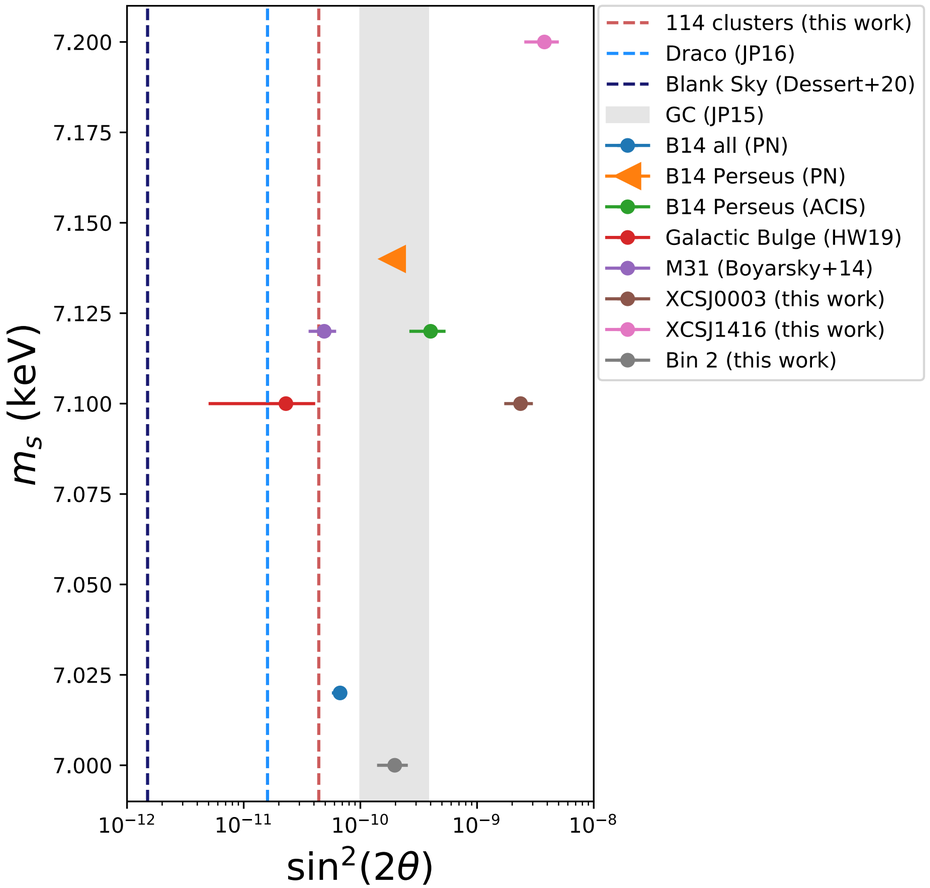
We use the XSPEC implementation of the APEC model to fit a baseline spectrum. We then iterate a Gaussian line between 3.5 and 3.6 keV, searching for a fit improvement (ΔC) relative to the baseline model

Bin number	T_X bin (keV)	No. of clusters	T_X average (keV)	M_{DM}^{proj} average (10^{14} $M_\odot$)	Fitted abundance $Z_\odot$	SNR average	
						0.3 – 7.9 keV	3.0 – 4.0 keV
1	≤ 4	30	3.24	1.88	0.24	89.6	14.7
2	4 – 5.1	29	4.60	3.26	0.34	118.9	22.8
3	5.1 – 6.6	28	5.82	4.92	0.20	179.0	37.1
4	≥ 6.6	30	7.89	8.07	0.29	163.8	36.5

Results

We jointly fit the spectra of 114 clusters (3 are removed, see next slide) to recover **an upper limit on the flux of an undetected line at 3.5 keV**; the most precise constraint on the allowed mixing angle from sterile neutrino dark matter from cluster studies so far.



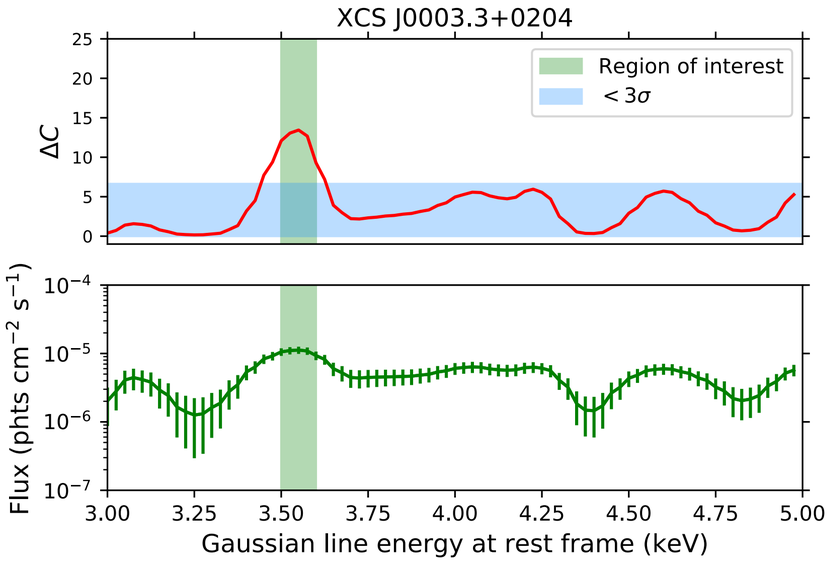


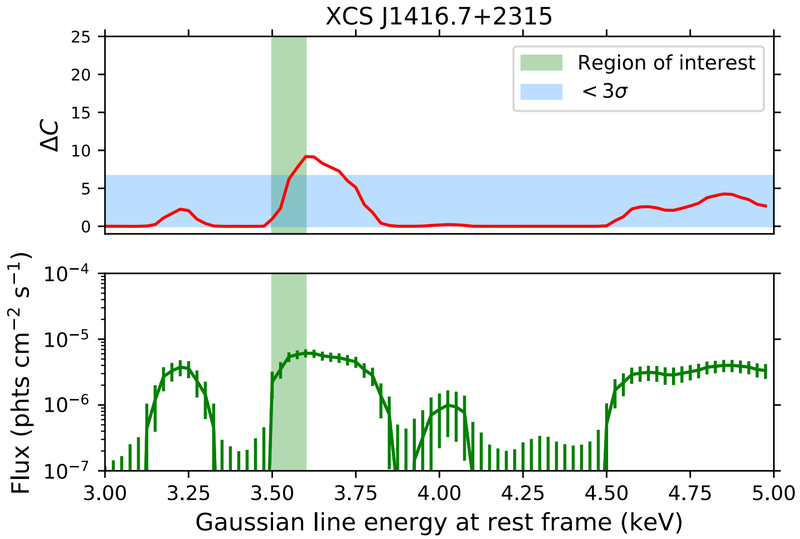
Individual clusters with 3.5 keV features

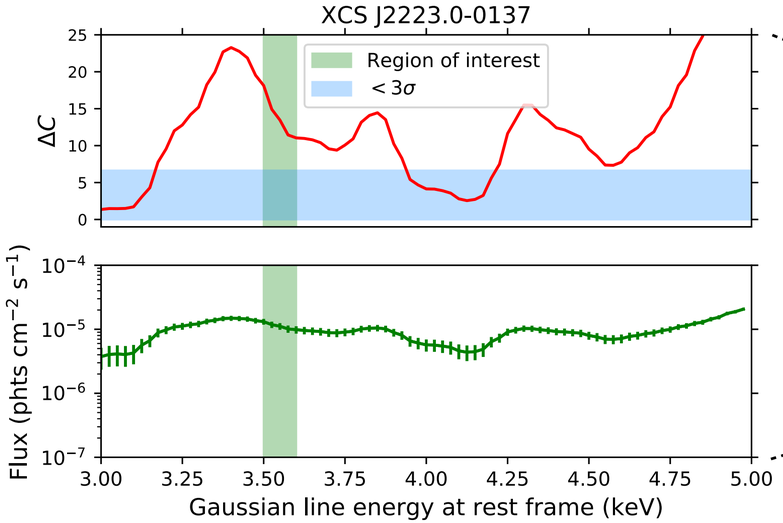
However, we find that three individual clusters in our sample **do** show $> 3\sigma$ fit improvements at ~3.5 keV

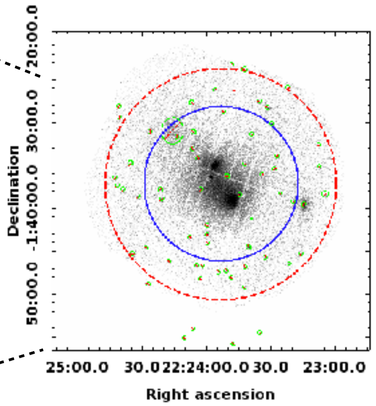
None of these clusters are the most dark-matter dominated in our sample

Of these three, two (J0003.3+0204 and J1416.7+2315) are most likely to indicate a genuine feature







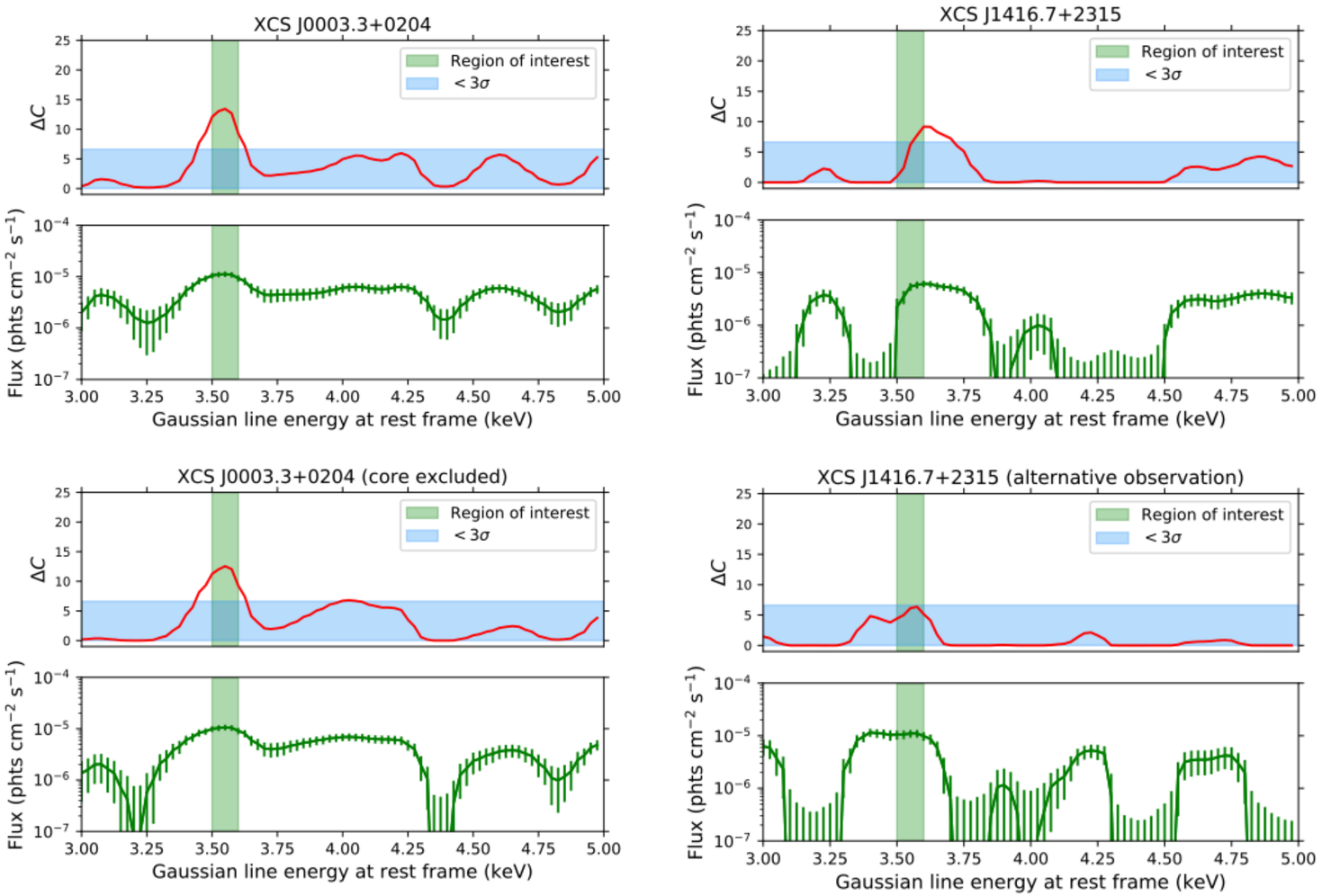


(Merging cluster Abell 2440)

Individual clusters with 3.5 keV features

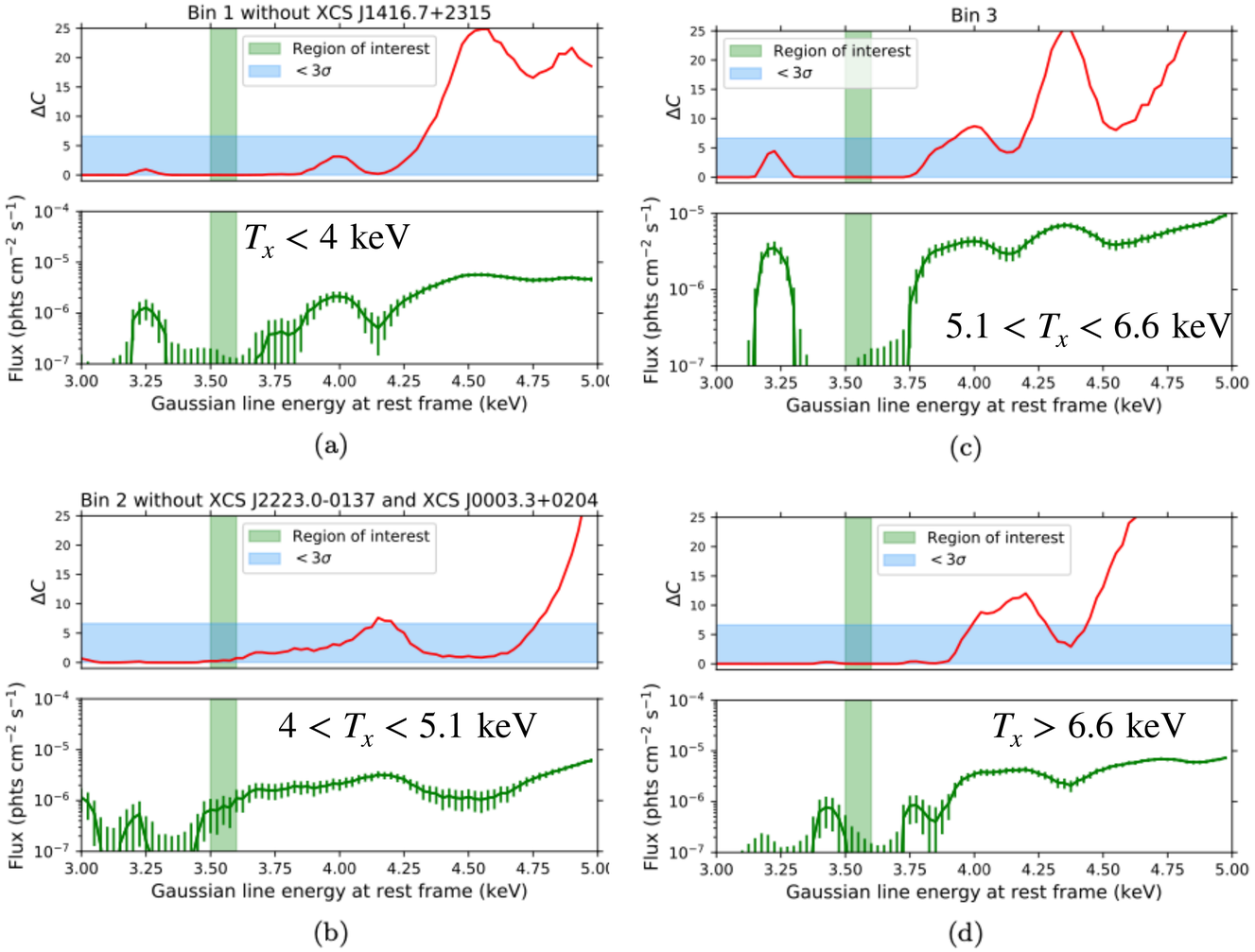
We find that in the two cases of genuine line-like features, the excess shown is broadly insensitive to:

1. photometric vs spectroscopic redshifts (X-ray gas offset from galaxy positions)
2. Core-excluded vs core-included spectra (if the line is the result of core-physics)
3. Alternative observations where available (variability)
4. Different cluster abundance tables (plasma origin)



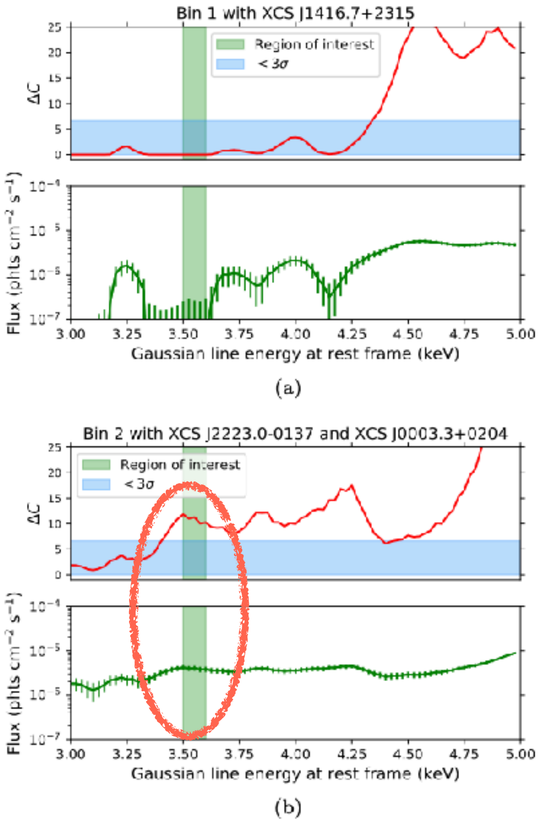
No temperature dependence of the 3.5 keV line

But individual clusters can "contaminate" results!



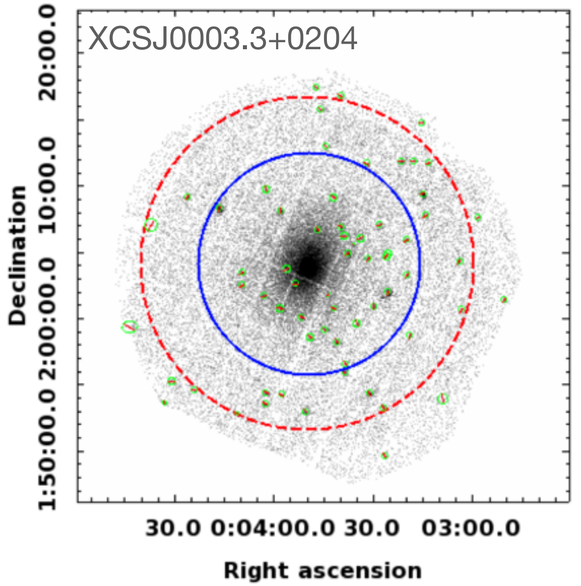
No evidence for any fit improvement at 3.5 keV in any temperature range

But individual clusters can contribute more strongly than others in a joint fit, mimicking the appearance of an overall line-like feature



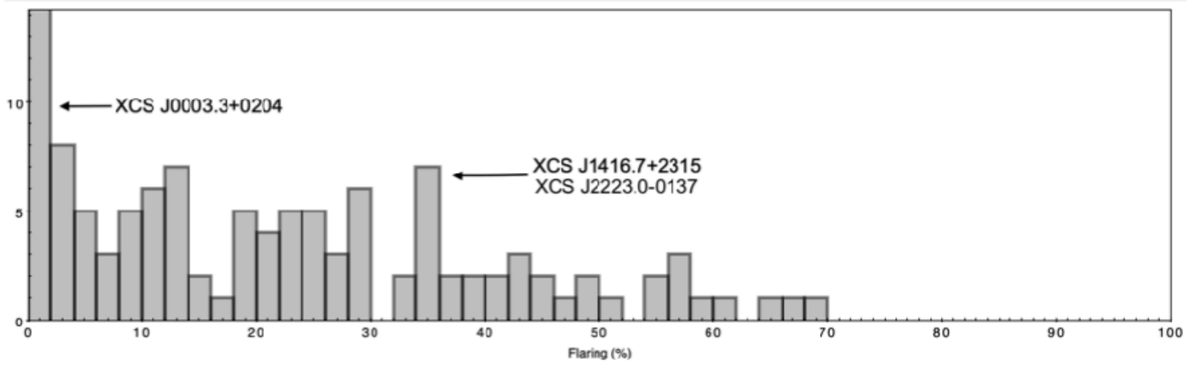
What is responsible for the anomalous 3.5 keV feature in individual clusters?

- The fact that the 3.5 keV excess is not a ubiquitous feature within the cluster sample **disfavours a dark matter origin**
- However, an alternative origin is not yet clear as an e.g. plasma/charge exchange line should not be present in only two systems
- The rate of flaring in the cluster observations is not likely to be the cause
- Furthermore, the presence of these detections is above the expected threshold of producing a 3.5 keV line from a statistical fluctuation (e.g. false positive rates)



Possible explanations:

- Point source contamination
- Variable sources e.g. AGN within clusters (which could produce 3.5 keV photons from axion-like particles)
- Incompleteness in the plasma modelling producing residuals at ~3.5 keV
- A statistical artefact



Read the full paper here!

Summary

Probing the Milky Way's Dark Matter Halo for the 3.5 keV Line

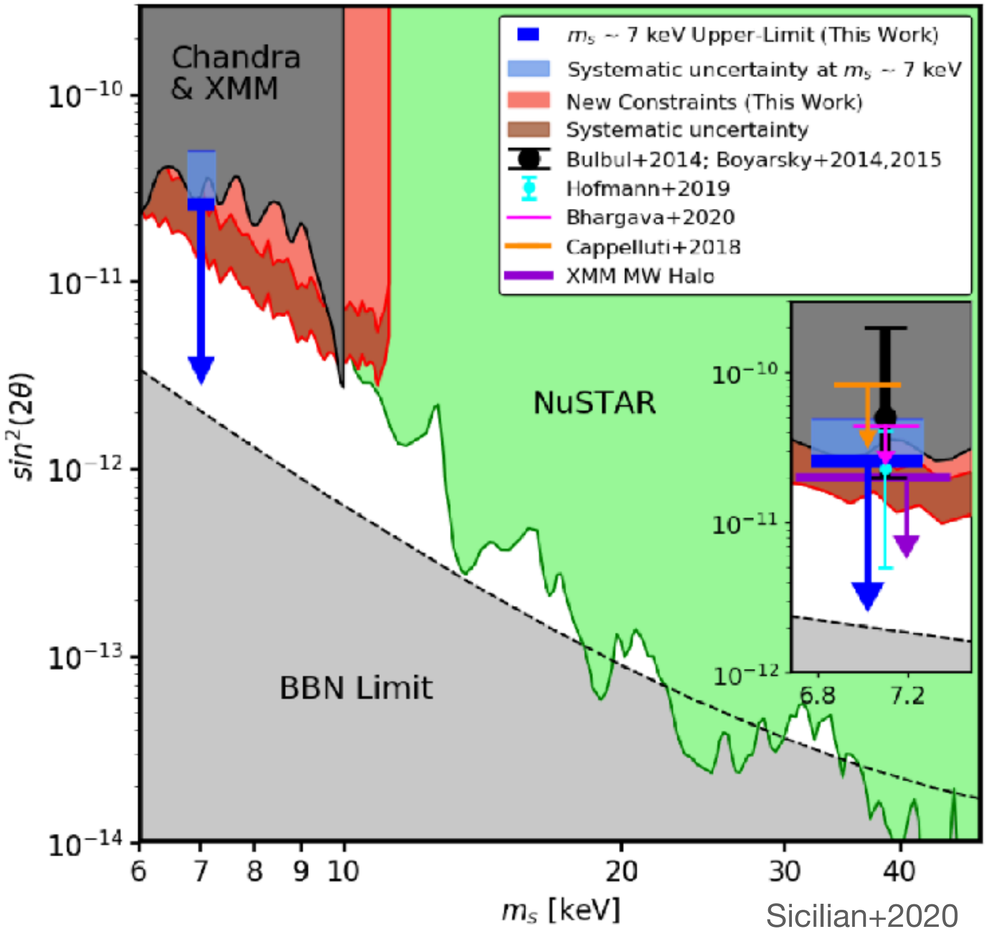
Dominic Sicilian,[1,2] Nico Cappelluti,[1] Esra Bulbul,[2,3] Francesca Civano,[2] Massimo Moscetti,[1,4] a
Christopher S. Reynolds[5]

Where are 3.5 keV studies so far?

We have used the largest sample of confirmed clusters (117) to investigate the potential dark matter origin of the '3.5 keV line,' placing the most stringent constraint on its flux and mixing angle from cluster studies so far.

We find **no evidence of a X-ray temperature dependence** in the 3.5 keV feature in clusters

Combining all cluster observations with new satellites such as *XRISM* will minimise susceptibility to systematic/calibration uncertainties will offer a chance to detect this possible astrophysical dark matter signal in X-ray systems



Sicilian+2020

Spectral resolution ~ 20-40 times better than the CCD instruments on *XMM* and *Chandra*