UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES
Département d'astronomie

Where are the baryons?

Dominique Eckert

Department of Astronomy, University of Geneva

Main collaborators:
S. Ettori, J. Coupon, M. Pierre, F. Pacaud, A. Le Brun, I. McCarthy (XXL);
M. Jauzac, J.-P. Kneib, H.Y. Shan, R. Massey, C. Tchernin (A2744)

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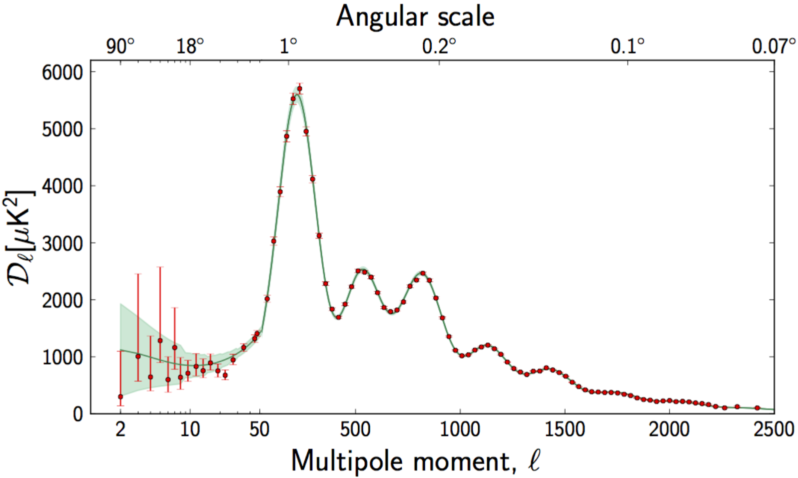
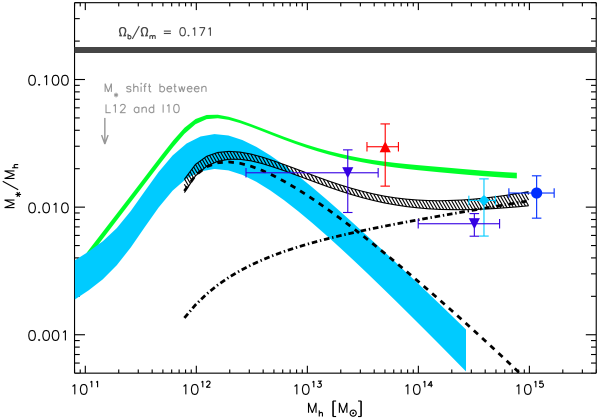
The cosmic baryon fraction



Planck 2015 release: $\Omega_b/\Omega_m = 0.156 \pm 0.003$; 2% uncertainty!

Where are the Universe's baryons?

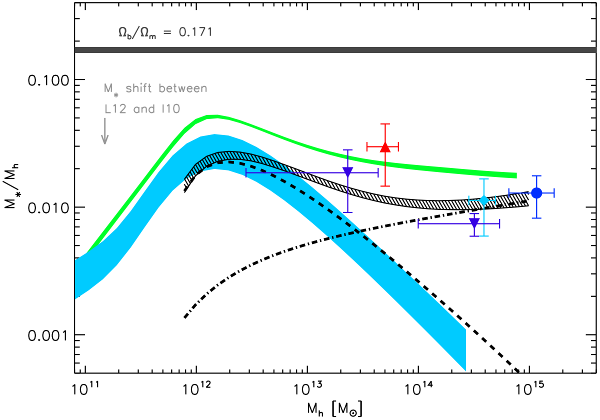
Star formation in the Universe is inefficient



Coupon et al. 2015

Where are the Universe's baryons?

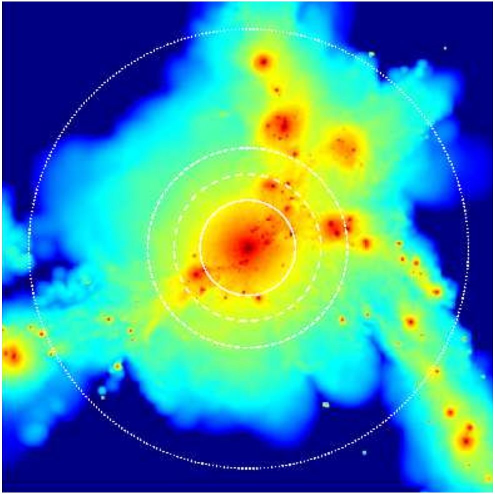
Star formation in the Universe is inefficient



Coupon et al. 2015

At all mass scales the stellar fraction only represents a small fraction ($< 20\%$) of the cosmic baryon fraction

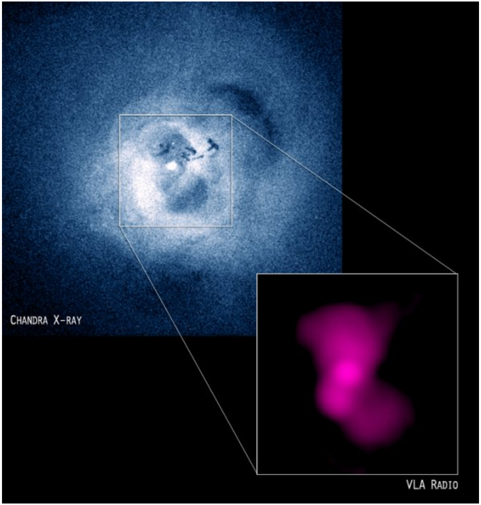
Hot gas in massive halos



Roncarelli et al. 2006

Most of the baryons are in the hot intracluster medium and shine in X-rays

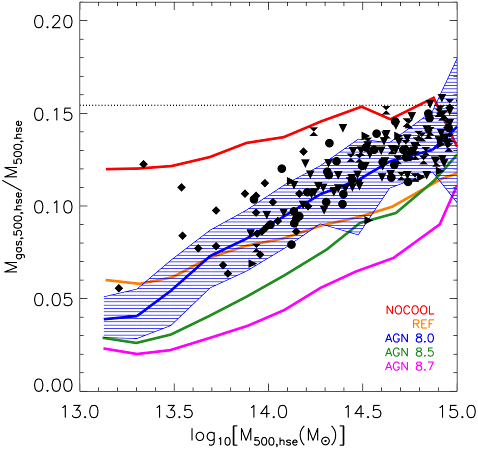
AGN feedback in massive halos



Perseus cluster, Fabian et al. 2000

Feedback from the central AGN reheats the surrounding medium

Adding baryonic physics and AGN feedback



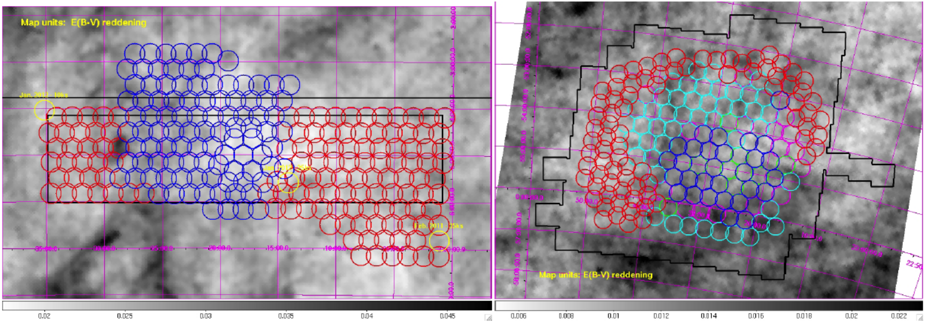
cosmo-OWLS, Le Brun et al. 2014

Cooling transforms some of the baryons into stars

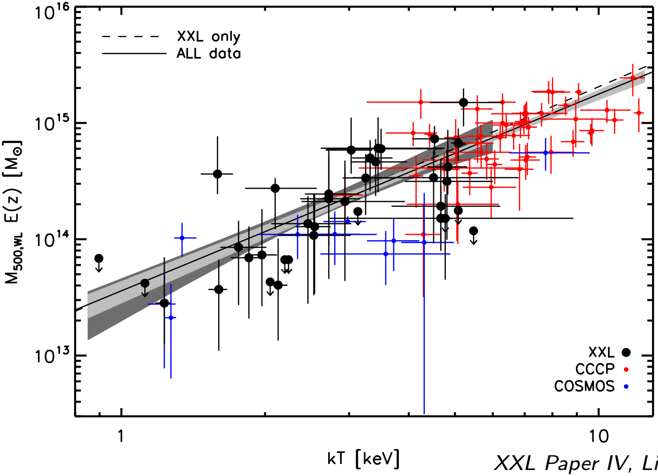
AGN feedback makes the gaseous atmosphere expand

The XMM-XXL survey

XXL (PI: M. Pierre) covers an area of 50 square degrees with uniform 10 ks XMM exposure



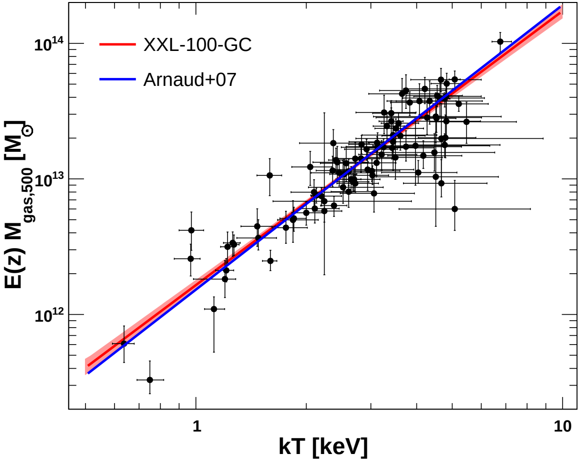
- Survey sensitivity: 5×10^{-15} ergs cm^{-2} s^{-1} (0.5-2.0 keV band)
- Observations completed in December 2013



XXL Paper IV, Lieu et al.

$M_{\rm WL} - T_X$ using 38 CFHTLenS systems. Low scatter $\sigma_{\rm int} \sim 20 - 30\%$

$M_{\text{gas}} - T$ relation

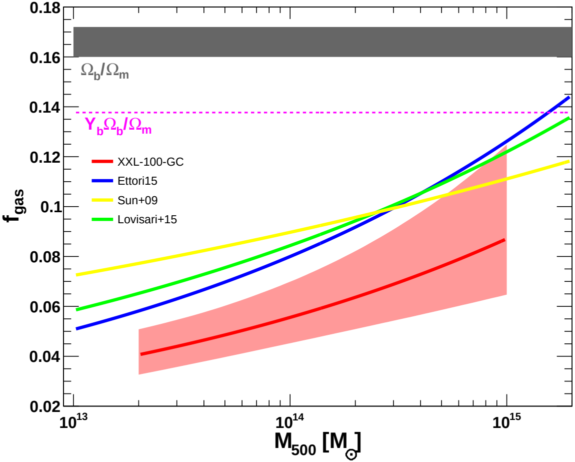


XXL Paper XIII, Eckert et al.

M_{gas} correlates very well with temperature

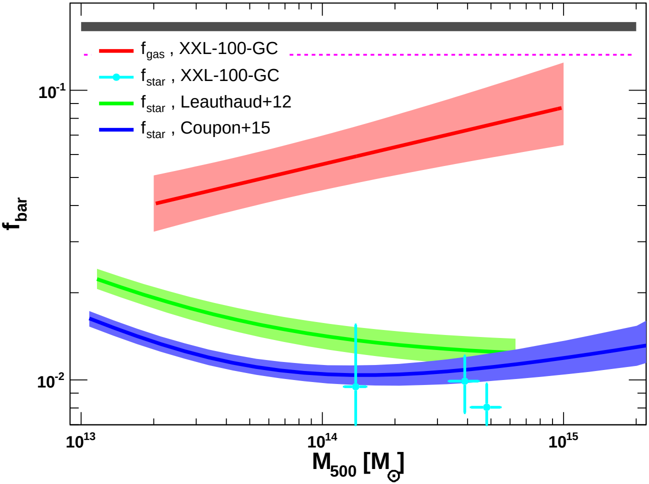
Gas fraction

We get $f_{\rm gas}$ by combining $M_{\rm WL} - T$ and $M_{\rm gas} - T$



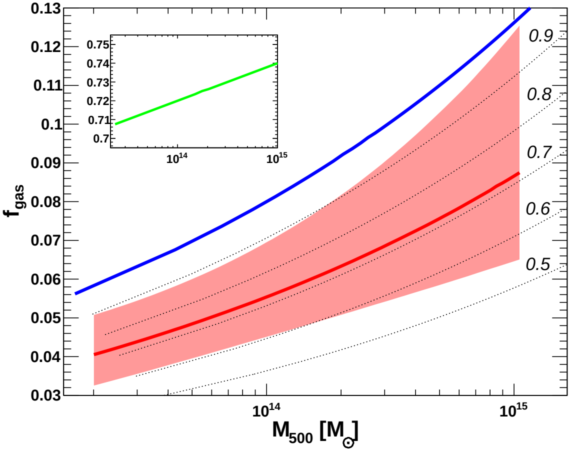
Our $f_{\rm gas}$ is significantly lower than HSE-based measurements

Baryon fraction (stars + gas)



$f_\star$ is largely insufficient to bridge the gap with the cosmic baryon fraction

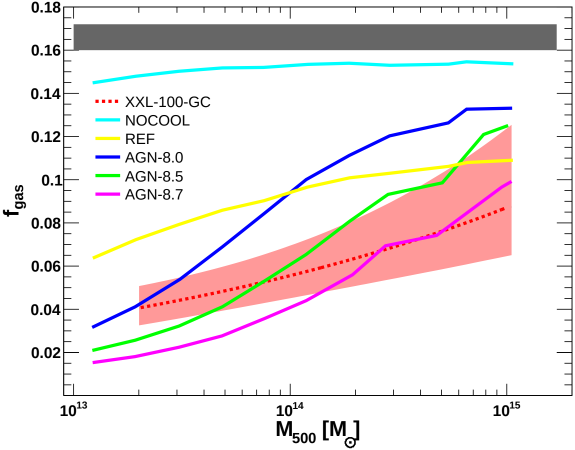
Hydrostatic bias?



Matching WL and hydrostatic relations would require a hydrostatic bias $1 - b = 0.72^{+0.08}_{-0.07}$

Comparison with numerical simulations

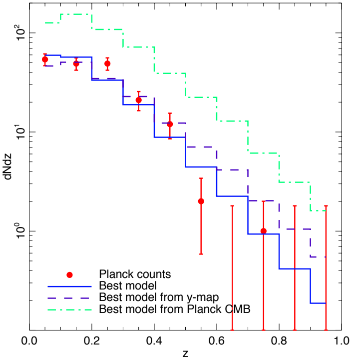
Comparison with hydrodynamical simulations (cosmo-OWLS, Le Brun et al. 2014)

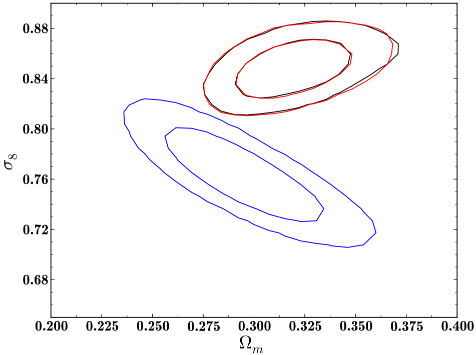


Puzzling result not easy to explain for simulations

Implications for cosmology

Planck: inconsistency between CMB and cluster counts



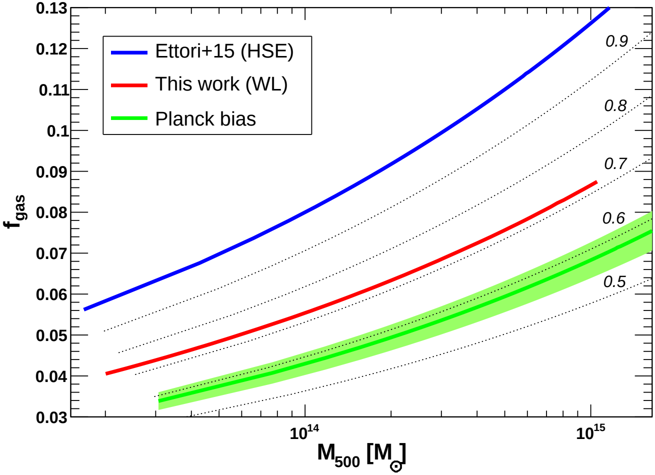


Planck Collaboration XX, 2013

The tension could be solved by invoking a very large HSE bias
$1 - b = 0.58 \pm 0.04$

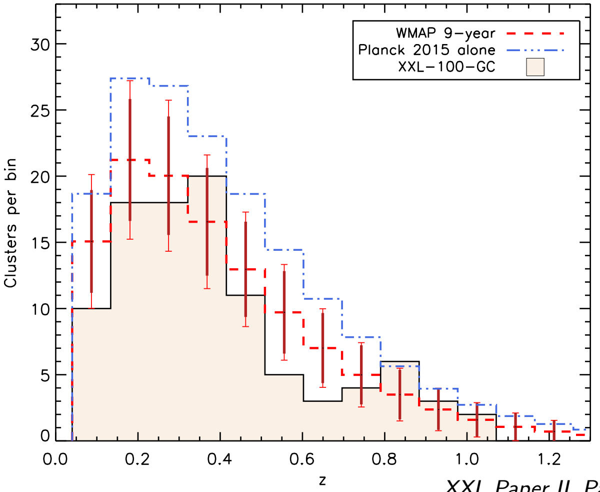
Implications for cosmology

Expected f_{gas} for $1 - b = 0.58$



Large HSE bias strongly disfavored by f_{gas} data

XXL vs Planck cosmology

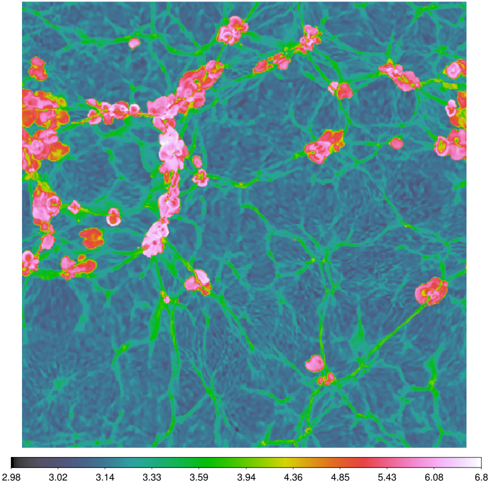


XXL Paper II, Pacaud et al.

XXL prefers lower σ_8 compared to *Planck* CMB, agreement with clusters and WL shear

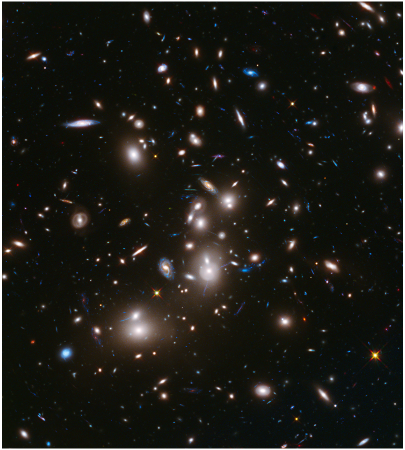
The Warm-Hot Intergalactic Medium (WHIM)

- Numerical simulations predict that $\sim 50\%$ of the baryons should be located in intergalactic filaments
- Temperatures in the range $10^{5.5} - 10^{7}$ K
- Density, temperature, gas mass scale with filament mass



Gheller et al. 2015

Abell 2744 is one of the HST "Frontier Fields" clusters

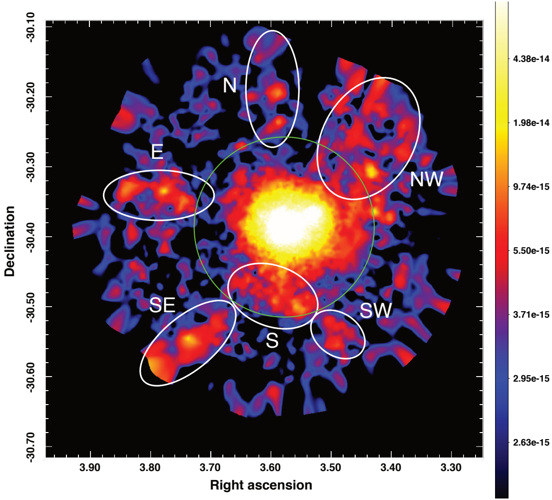


Jauzac et al. 2015

Jauzac et al. 2015: We detected ~ 50 lensed galaxies in this cluster, corresponding mass model known at 1% precision

XMM-Newton observation of Abell 2744

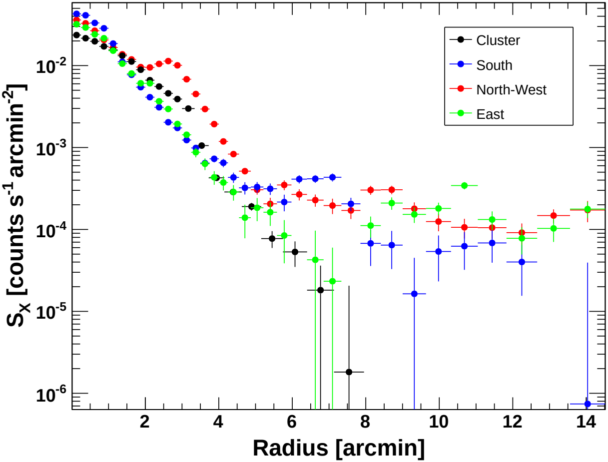
We discovered 5 regions of extended X-ray emission radially connected to the cluster



Eckert et al. 2015

Hot gas filaments in Abell 2744

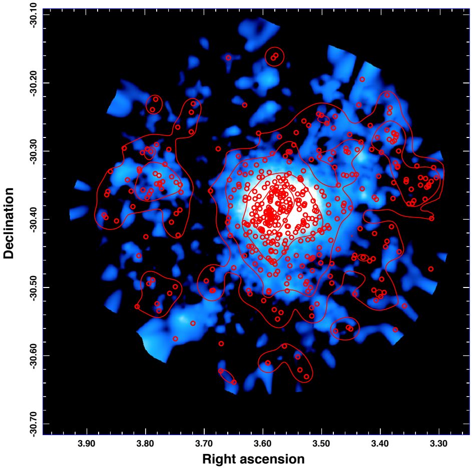
Significant extended emission detected in the direction of the filaments out to ~ 4 Mpc



Eckert et al. 2015

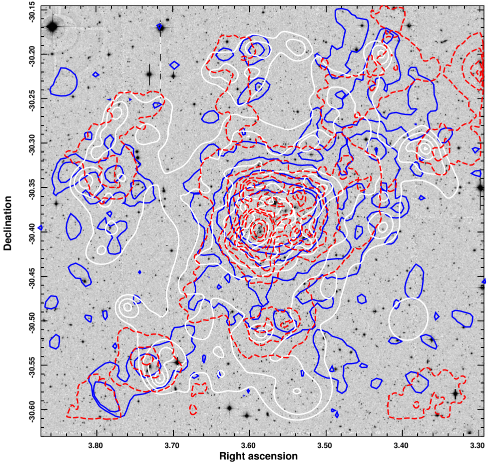
Hot gas filaments in Abell 2744

The filamentary structures correspond with overdensities of cluster galaxies (spectroscopically confirmed)...



Eckert et al. 2015

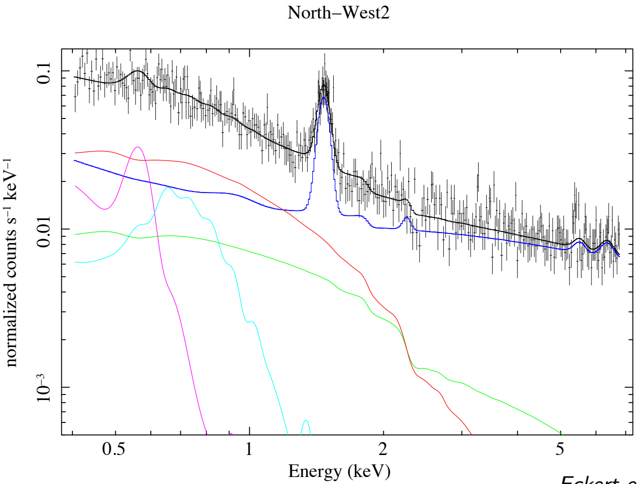
The filamentary structures correspond with overdensities of cluster galaxies ... and DM (CFHT weak lensing)!



Eckert et al. 2015

Nature of the filaments

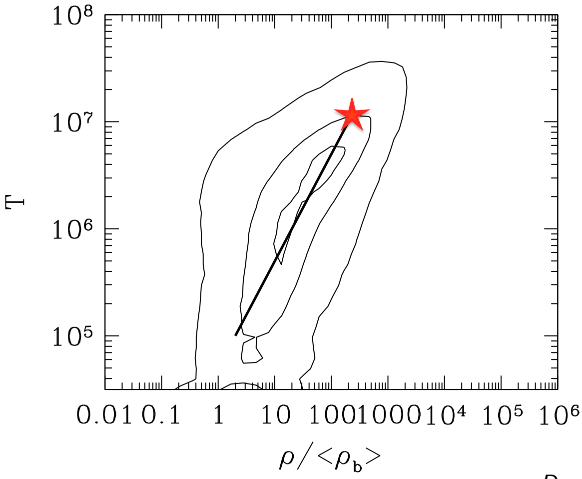
Spectral analysis reveals thermal gas with $T \sim 1$ keV



Eckert et al. 2015

We are observing diffuse hot gas originating from the LSS and heated up by the gravitational pull of A2744

Is it the WHIM?

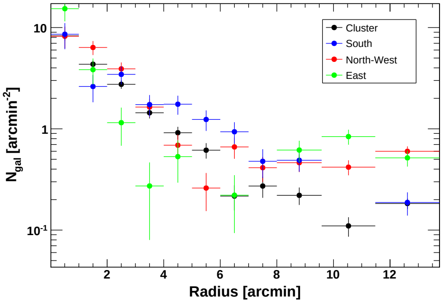


Davé et al. 2001

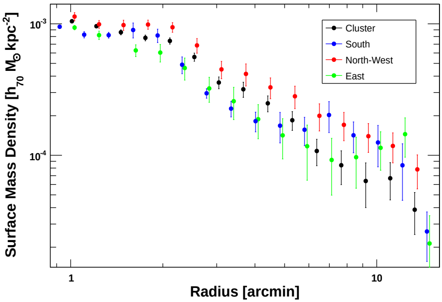
We are observing gas with overdensity ~ 200 and $T \sim 10^7$ K: consistent with predictions for the high-T part of the WHIM.

Galaxies and DM overdensity in the filaments

Galaxy density



Lensing signal

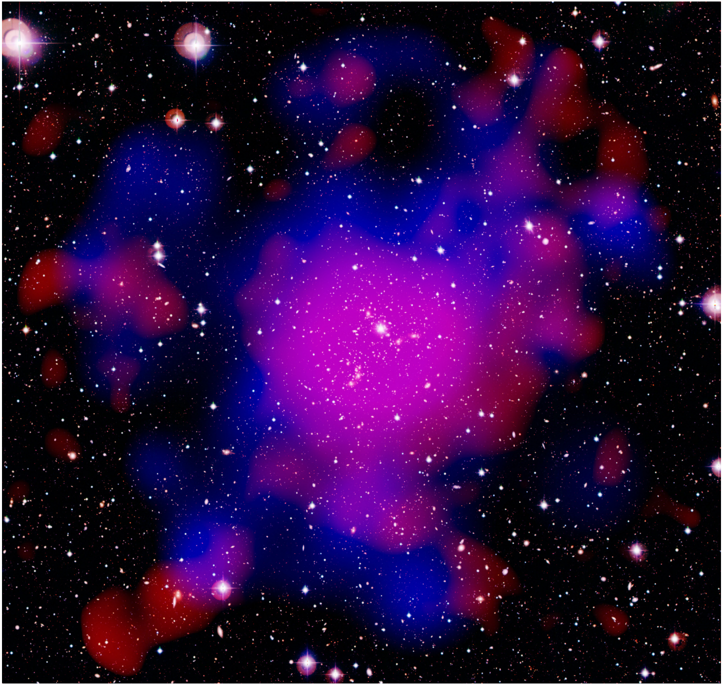


Eckert et al. 2015

Excess galaxy and DM density is observed in the regions encompassing the filaments. The gas fraction in the filaments is 5-10%

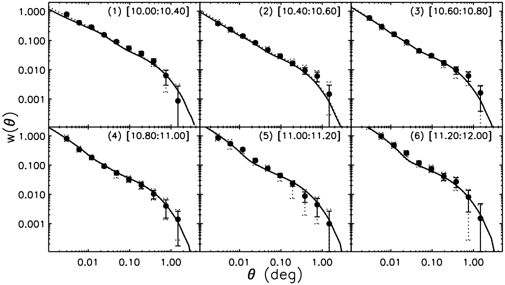
Summary

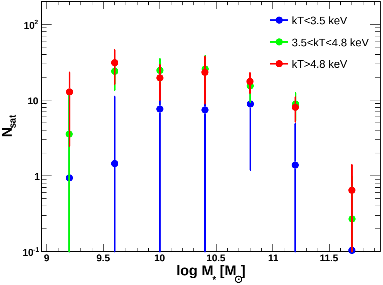
- WL-calibrated baryon fraction of XXL-100 clusters lower than expected
- Trouble to explain this result using cosmological simulations
- XXL prefers low σ_8, similar to other cluster and WL shear measurements
- A large HSE bias as needed to reconcile Planck CMB and cluster counts would require an even lower $f_{\rm gas}$, this is challenging for our understanding of structure formation
- We discovered 3 filaments of hot gas radially connected to A2744
- The position of the filaments coincides with excesses in the distribution of galaxies and WL signal
- Properties consistent with WHIM, gas fraction 5-10%



Stellar fraction

We compute the 2-point correlation function of cluster galaxies in bins of galaxy stellar mass



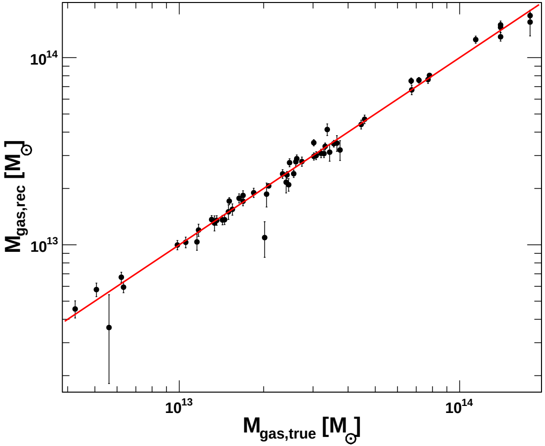


Coupon et al. 2015

Then $M_{\star} \propto \int_0^{R_{500}} w(R) R \, dR$

Validation using cosmological simulations

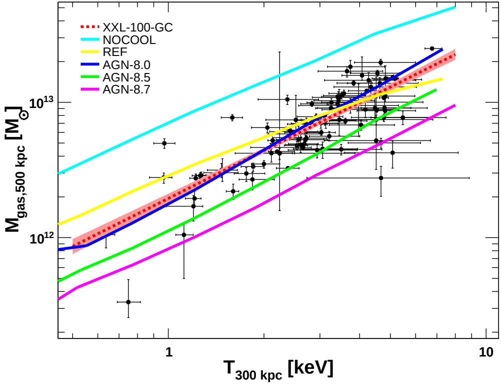
We used mock X-ray observations from numerical simulations to test the method

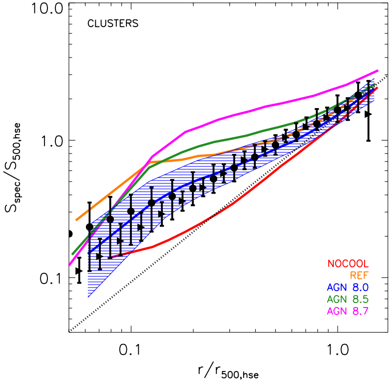


$M_{\rm gas}$ reconstructed with no bias and $\sigma_{\rm int} < 6\%$

Comparison with numerical simulations

Strong AGN feedback is inconsistent with X-ray-only observations





Puzzling result not easy to explain for simulations