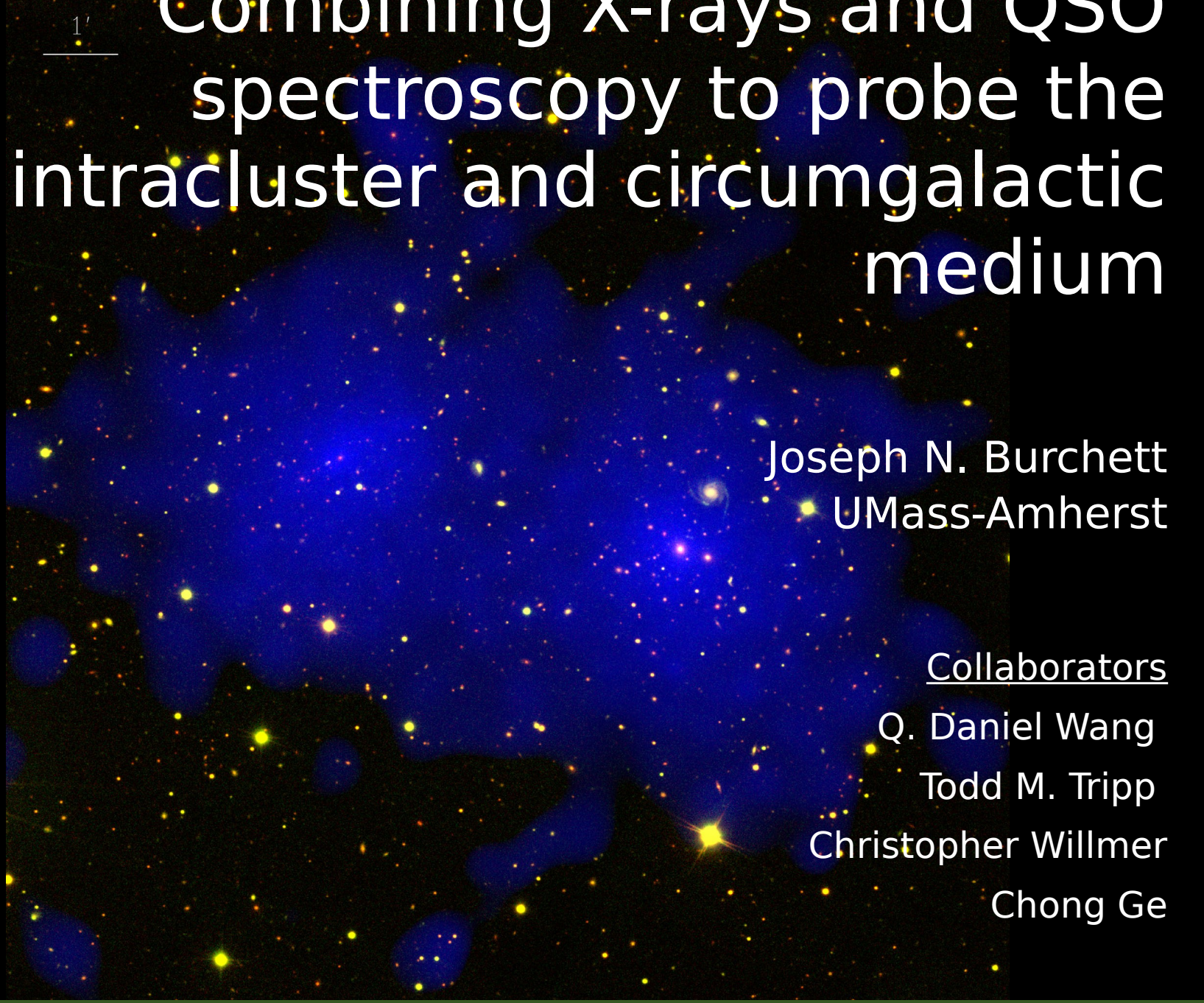


Combining X-rays and QSO spectroscopy to probe the intracluster and circumgalactic medium

Joseph N. Burchett
UMass-Amherst

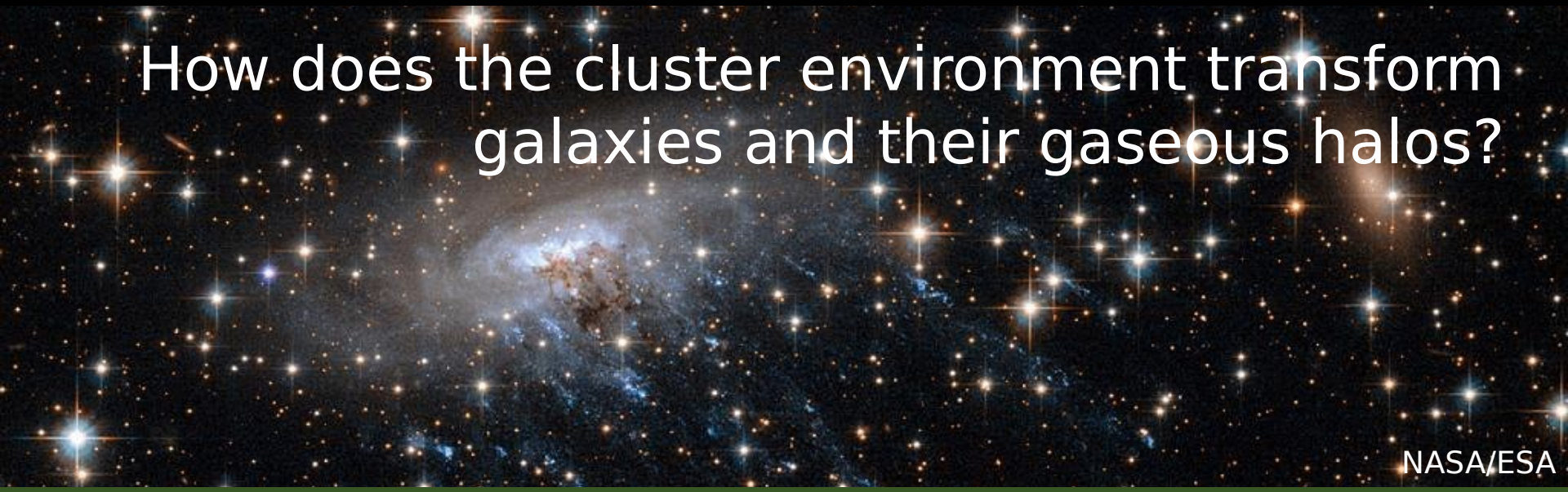
Collaborators
Q. Daniel Wang
Todd M. Tripp
Christopher Willmer
Chong Ge

Key Questions

Where are the ‘missing baryons’ in galaxy clusters?

NASA/ESA

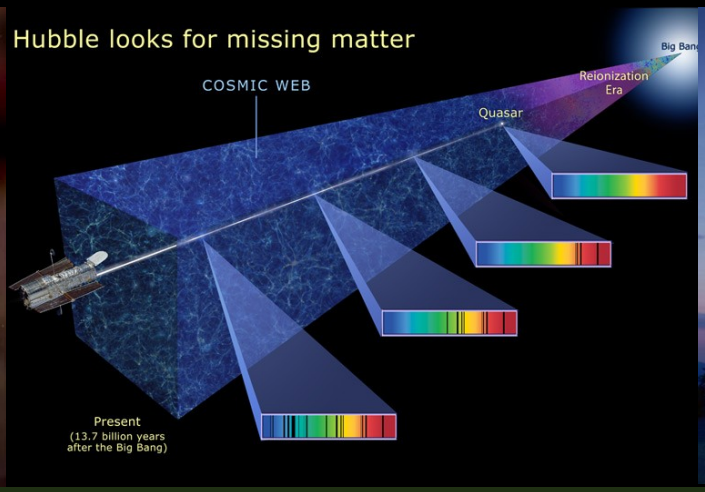
How does the cluster environment transform galaxies and their gaseous halos?

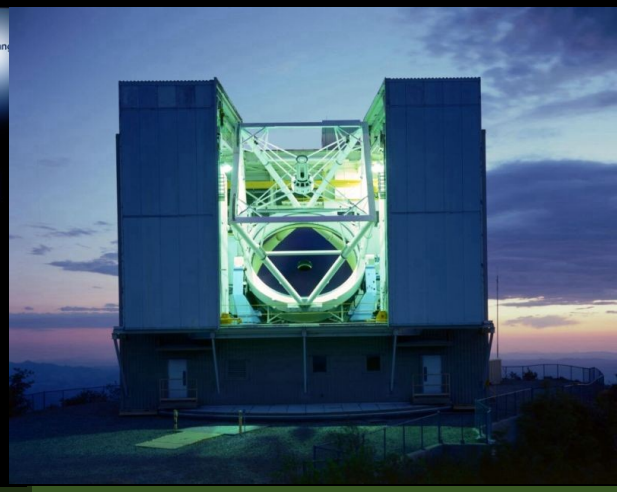


NASA/ESA

Data Sources

- X-ray imaging/spectroscopy from XMM-Newton and Chandra
- UV spectroscopy of background QSO from HST/COS
- Optical spectroscopy of galaxies from MMT/Hectospec



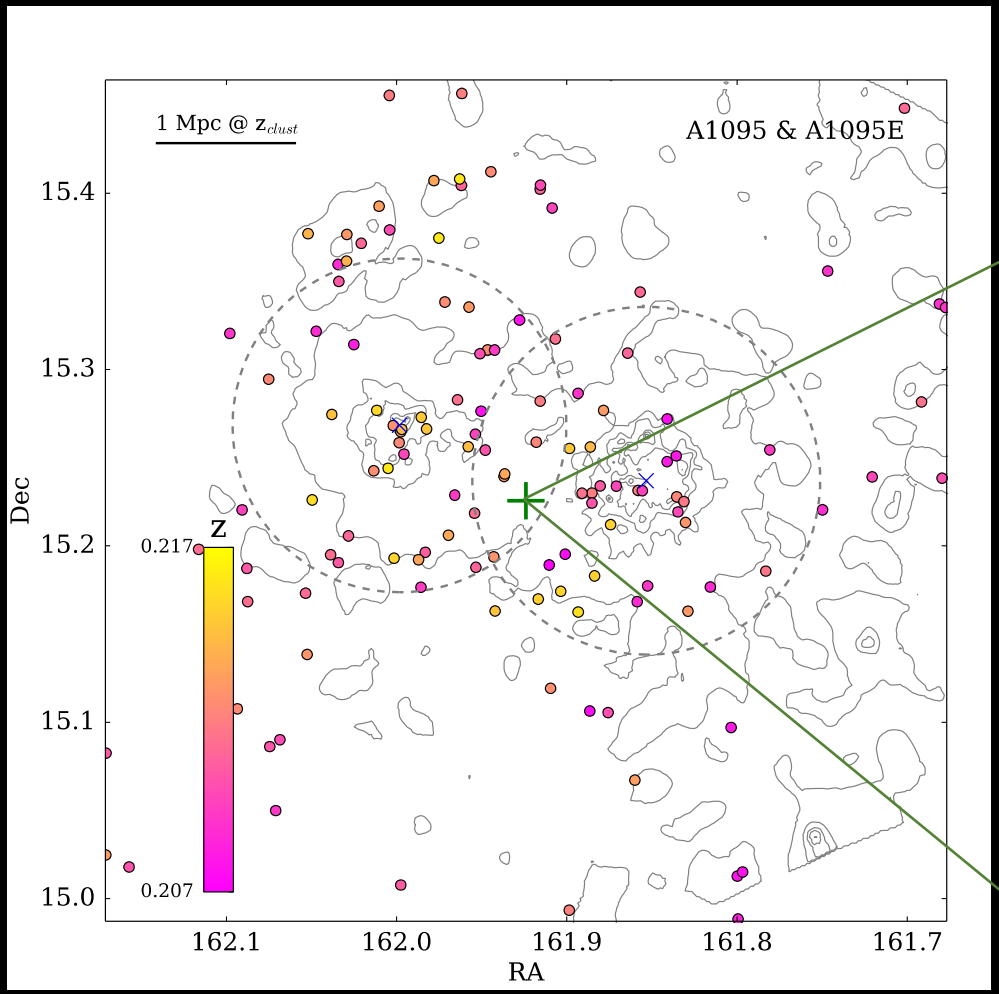


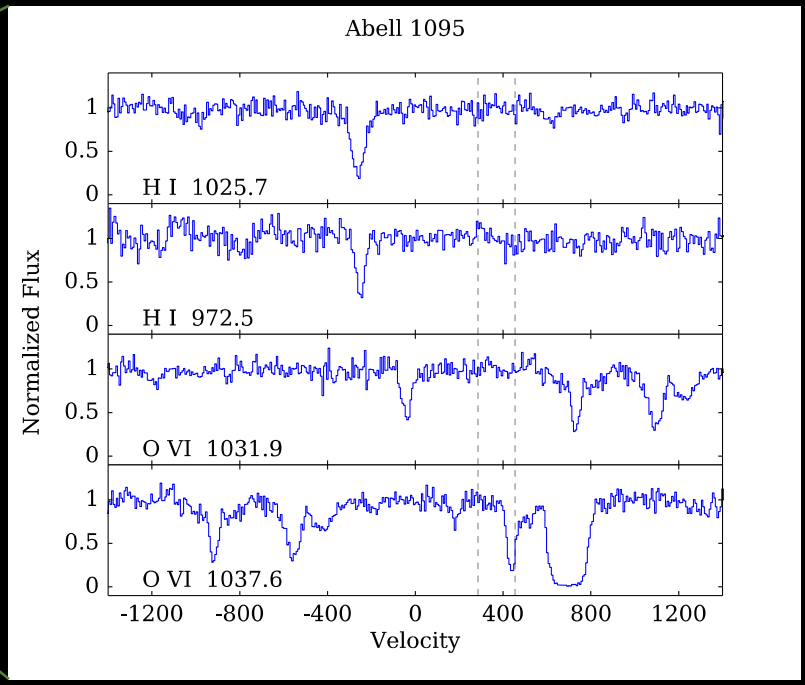
Putting it all together

7 clusters

3 sightlines

1000s of galaxies





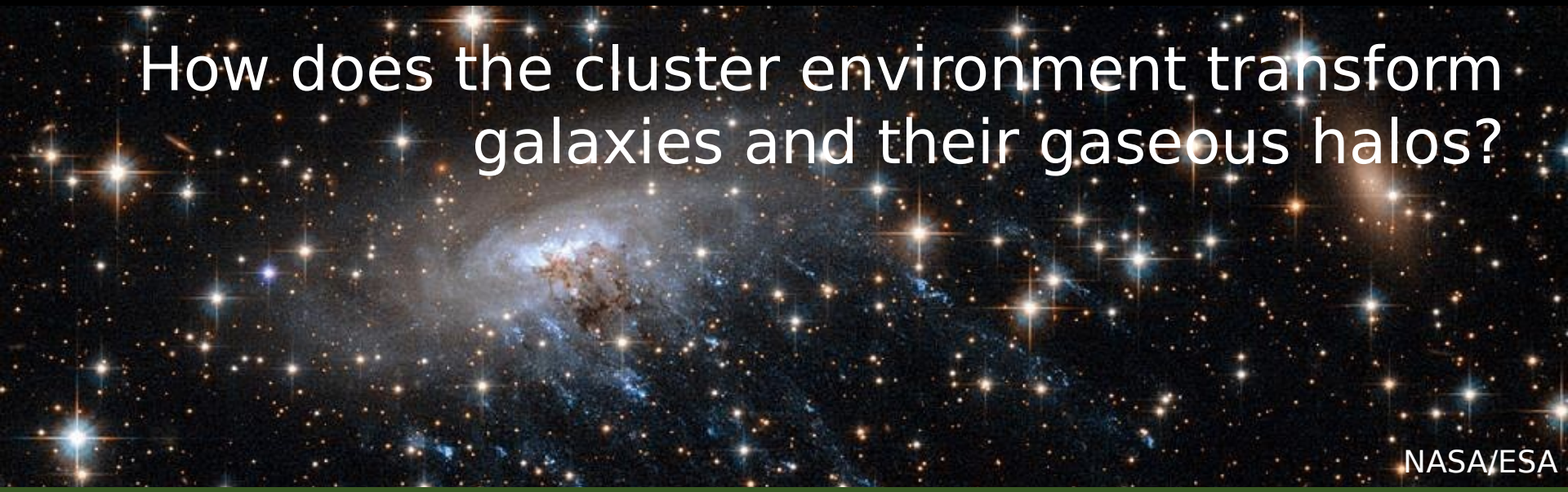
Burchett et al. 2016 (in prep)

Key Questions

Where are the ‘missing baryons’ in galaxy clusters?

NASA/ESA

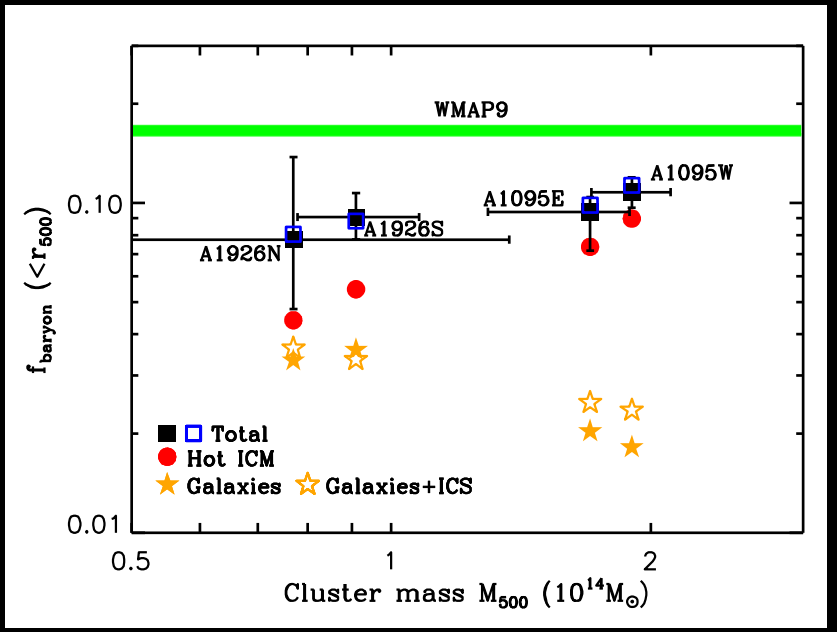
How does the cluster environment transform galaxies and their gaseous halos?



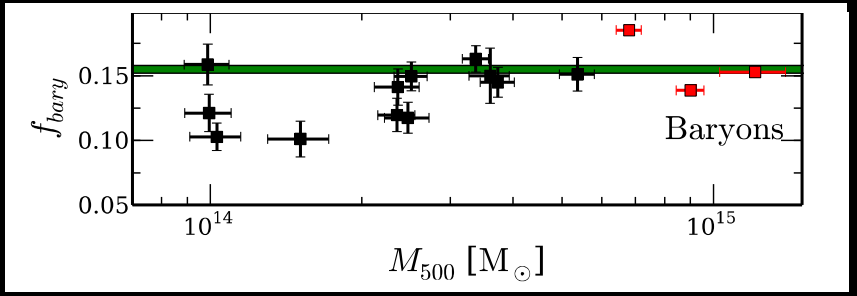
NASA/ESA

Missing Mass in Galaxy Clusters

- Universal Baryon Fraction: ~15-17 %
- Amount estimated from hot gas/intracluster light/stars: ~10 %
- Large fraction of baryons 'missing'
- Missing fraction dependent on total cluster mass



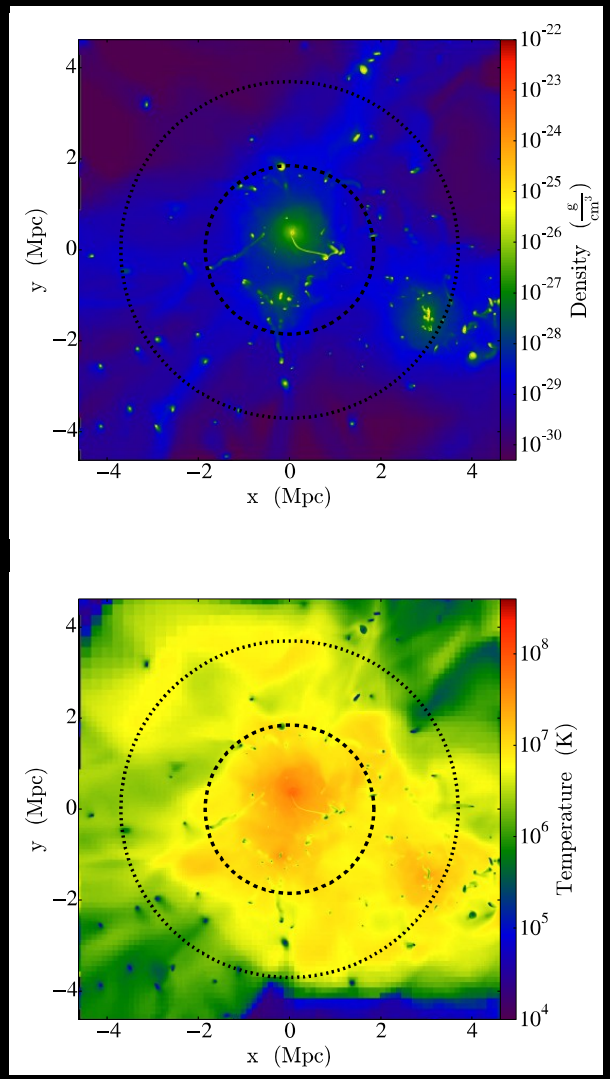
Ge & Wang 2016



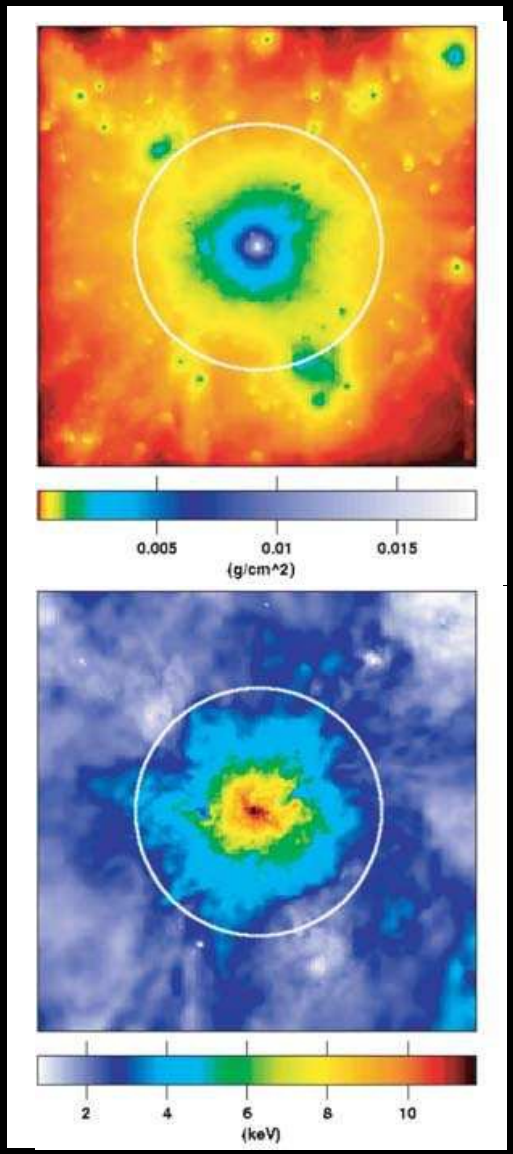
Gonzalez et al. 2013

Where could the baryons be hiding?

- Warm-hot ionized gas
  - T = 10^5 – 10^6 K
- radii >R_{500}
- IGM: radii>>R_{200}



Emerick et al. 2015



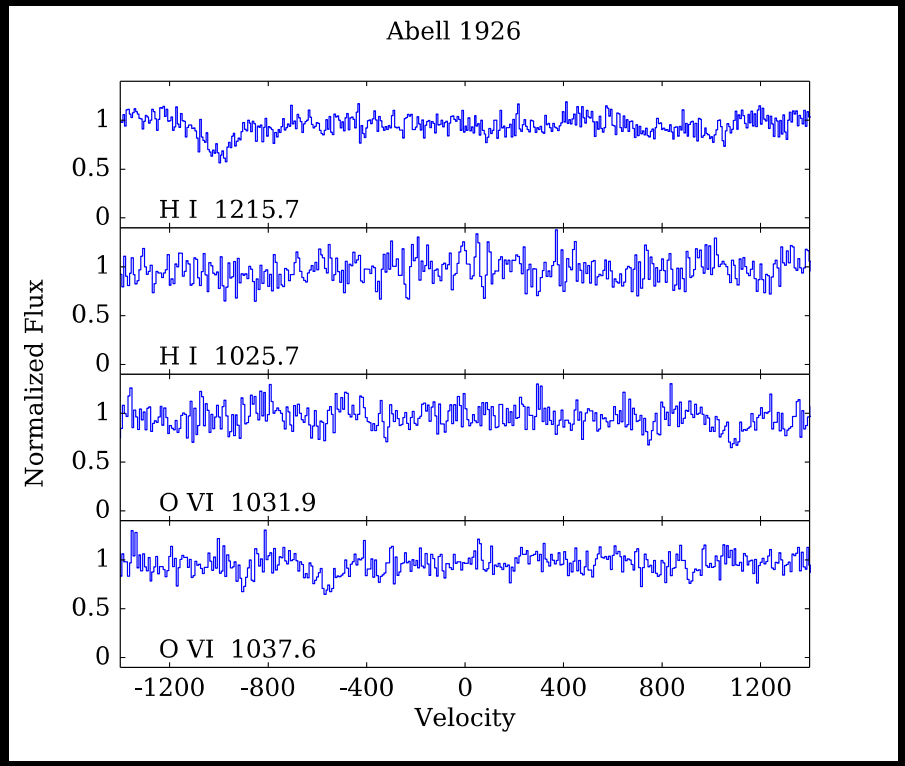
Roncarelli et al. 2006

QSO spectroscopy probing warm-hot gas

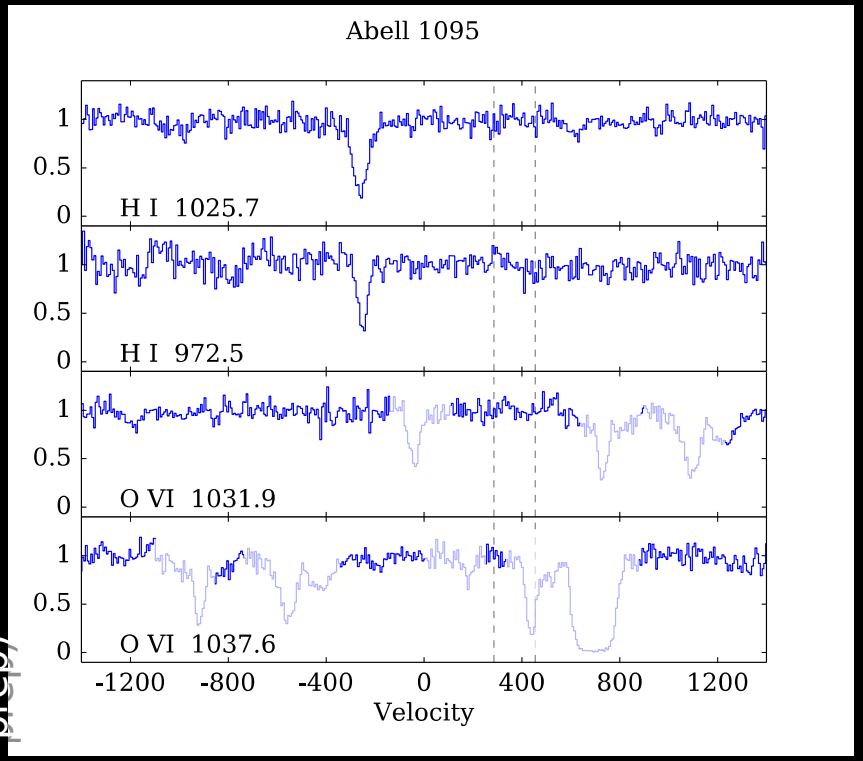
- O VI absorption
  - Strong doublet in the UV
  - Tracer of collisionally ionized gas

- Broad H I absorption
  - Extremely sensitive to H I gas
  - Line profile broadened by thermal and non-thermal motions

Absorption line results from HST/COS



Burchett et al. 2016 (in prep)



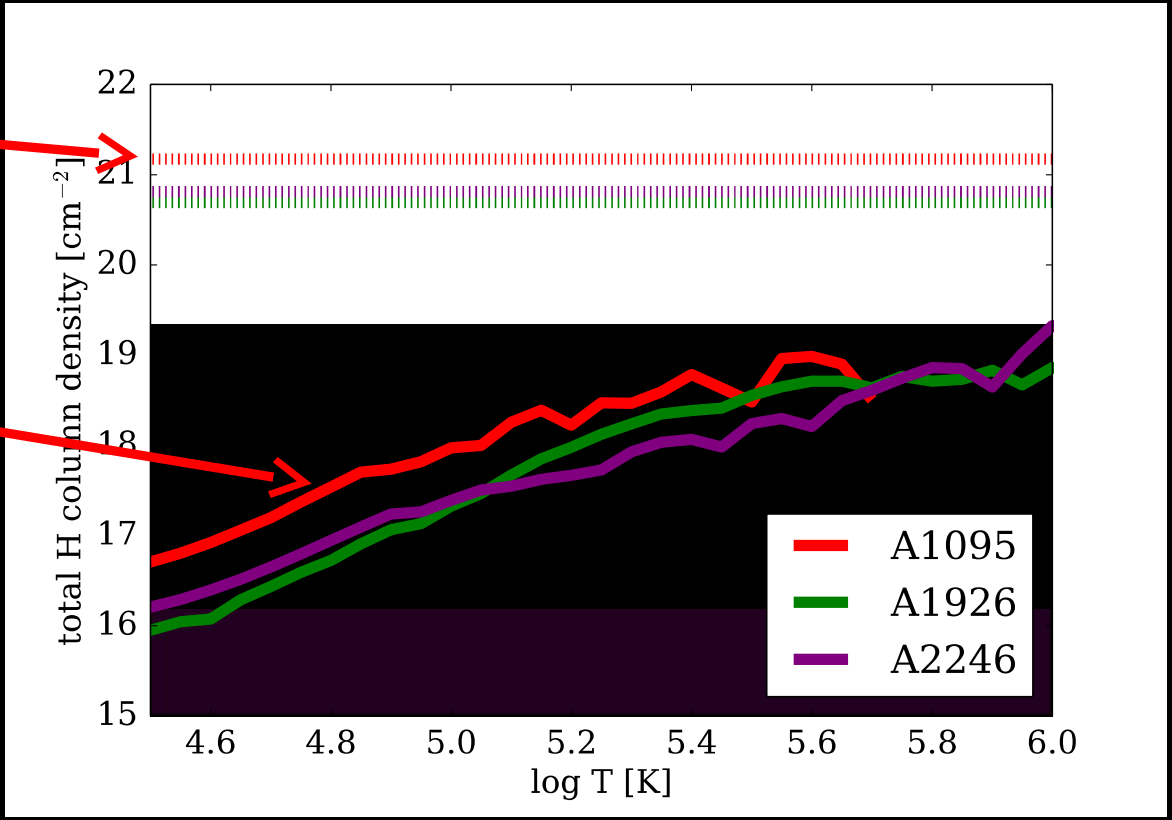
No O VI!

No broad HI!

Warm-hot contribution to baryon budget

Hot gas from X-rays

Limits on warm-hot gas from UV QSO spectra



Burchett et al. 2016 (in prep)

Key Questions

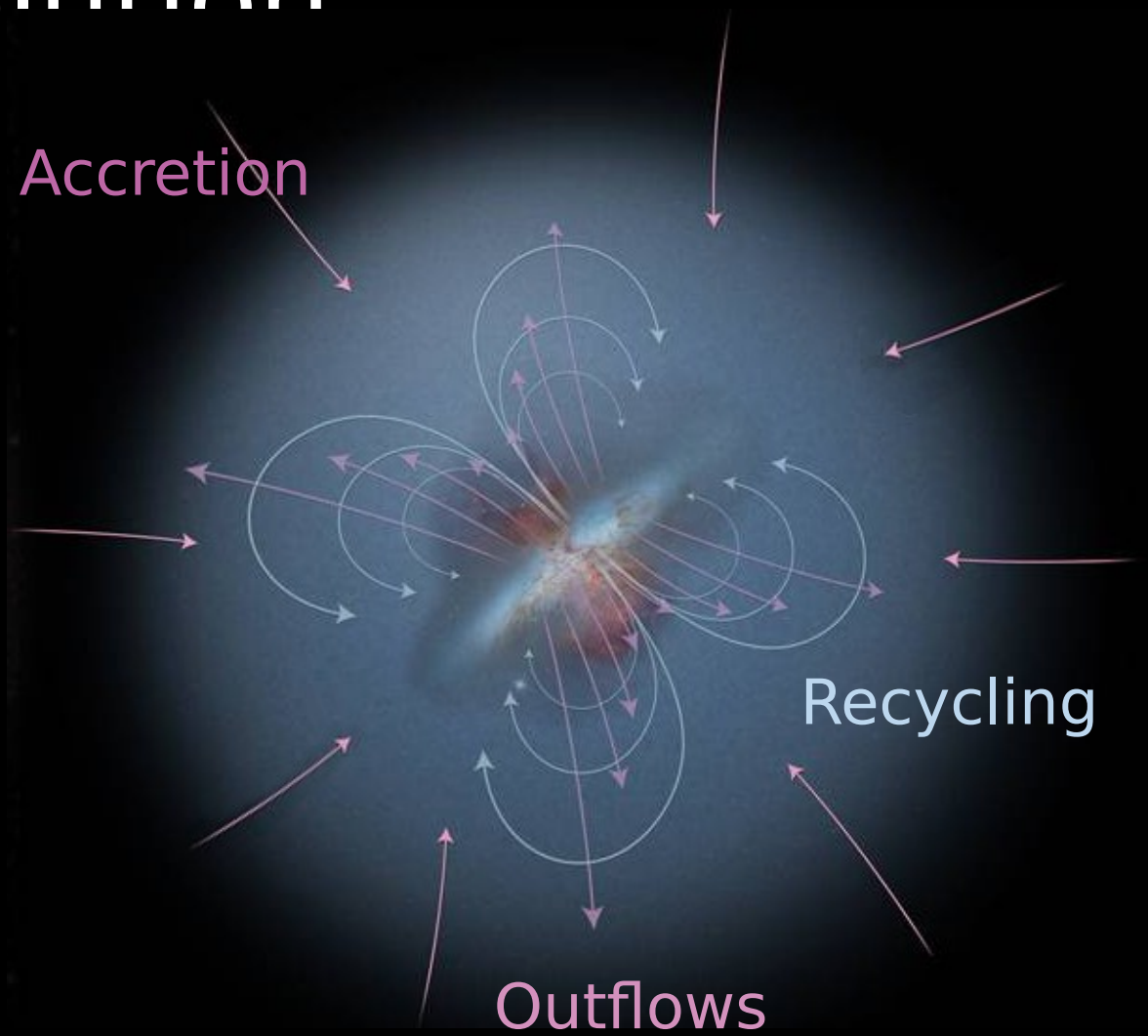
Where are the ‘missing baryons’ in galaxy clusters?

NASA/ESA

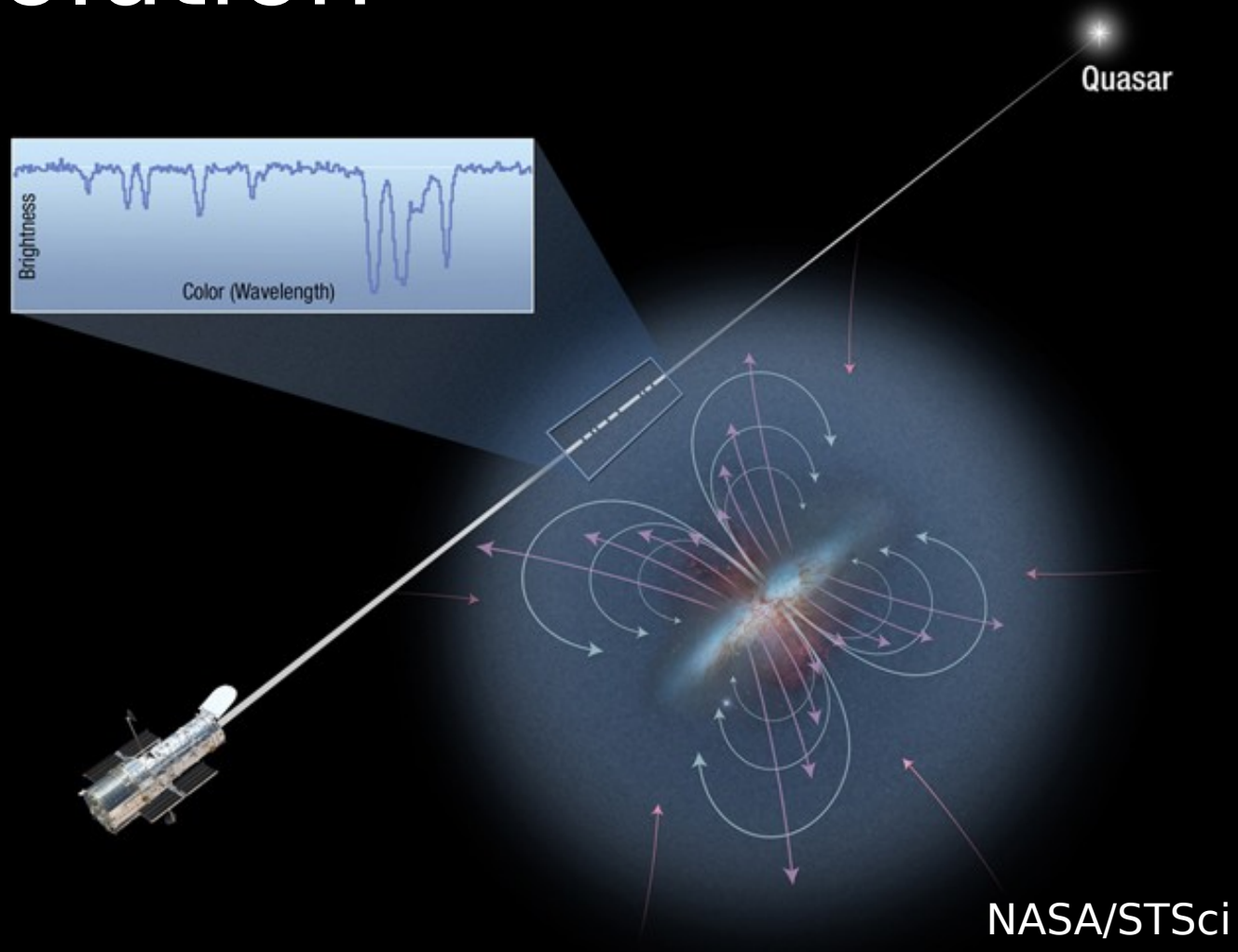
How does the cluster environment transform galaxies and their gaseous halos?

NASA/ESA

The CGM and galaxy evolution

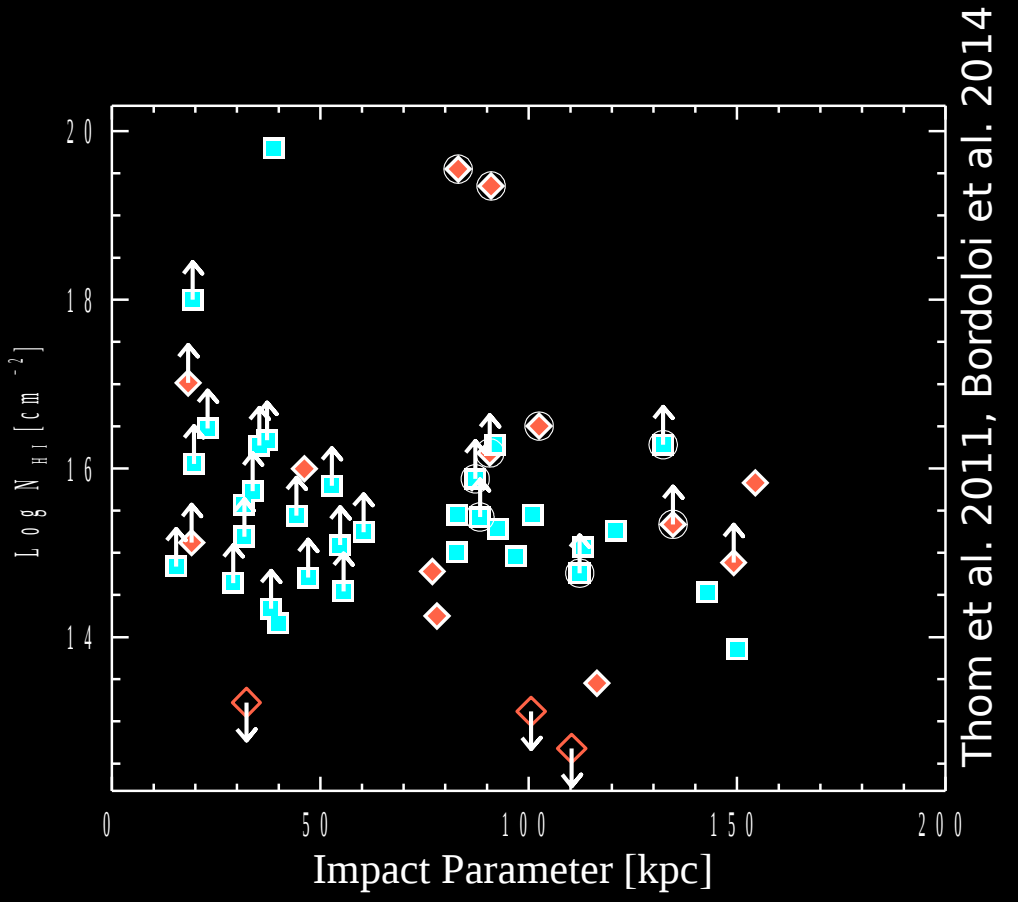


The CGM and galaxy evolution



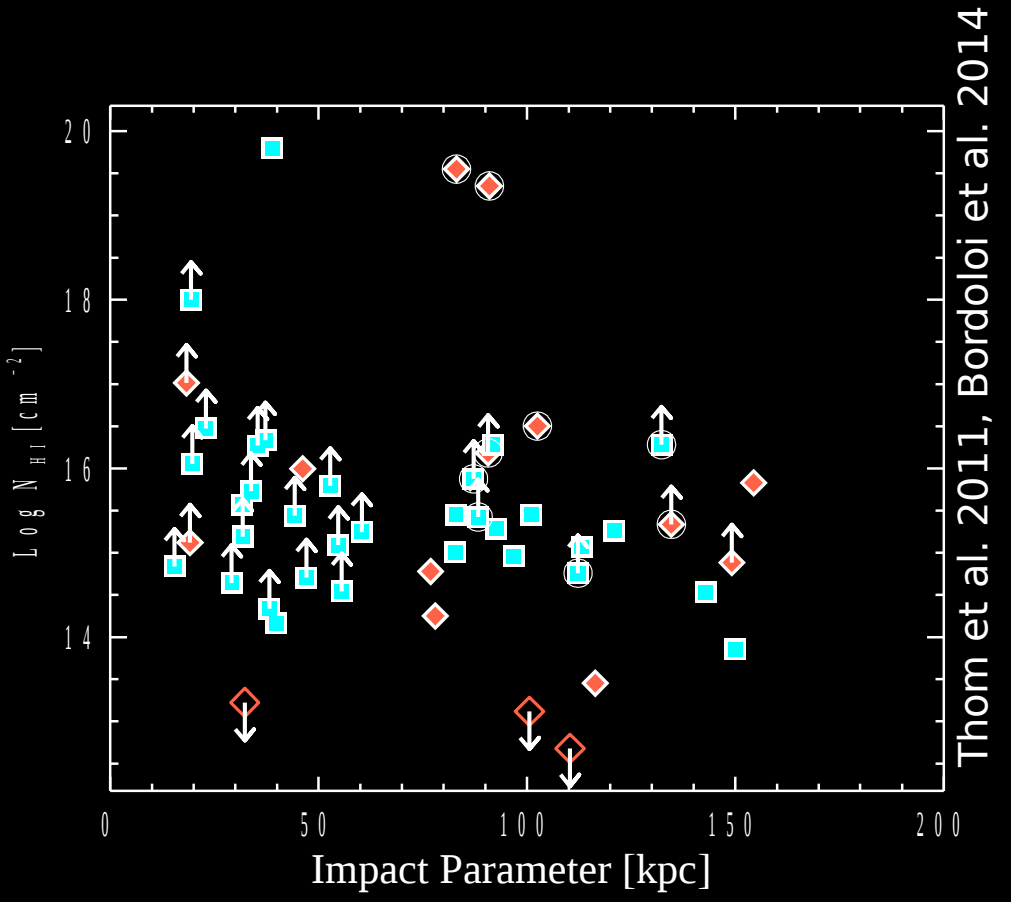
The CGM and host galaxies

- H I is prevalent in the CGM of galaxies in all masses*
- Presence of H I independent of star-forming/quiescent host galaxy*



The CGM and host galaxies

- H I is prevalent in the CGM of galaxies in all masses*
- Presence of H I independent of star-forming/quiescent host galaxy*

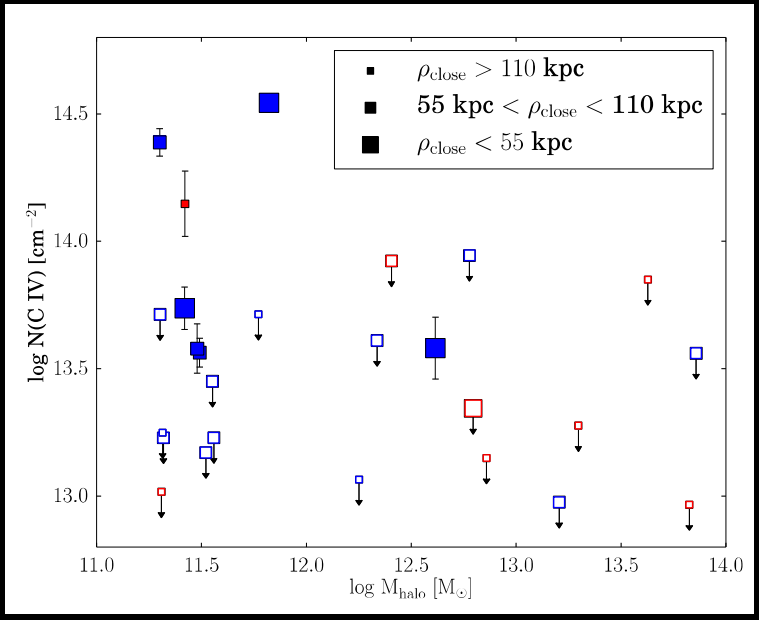


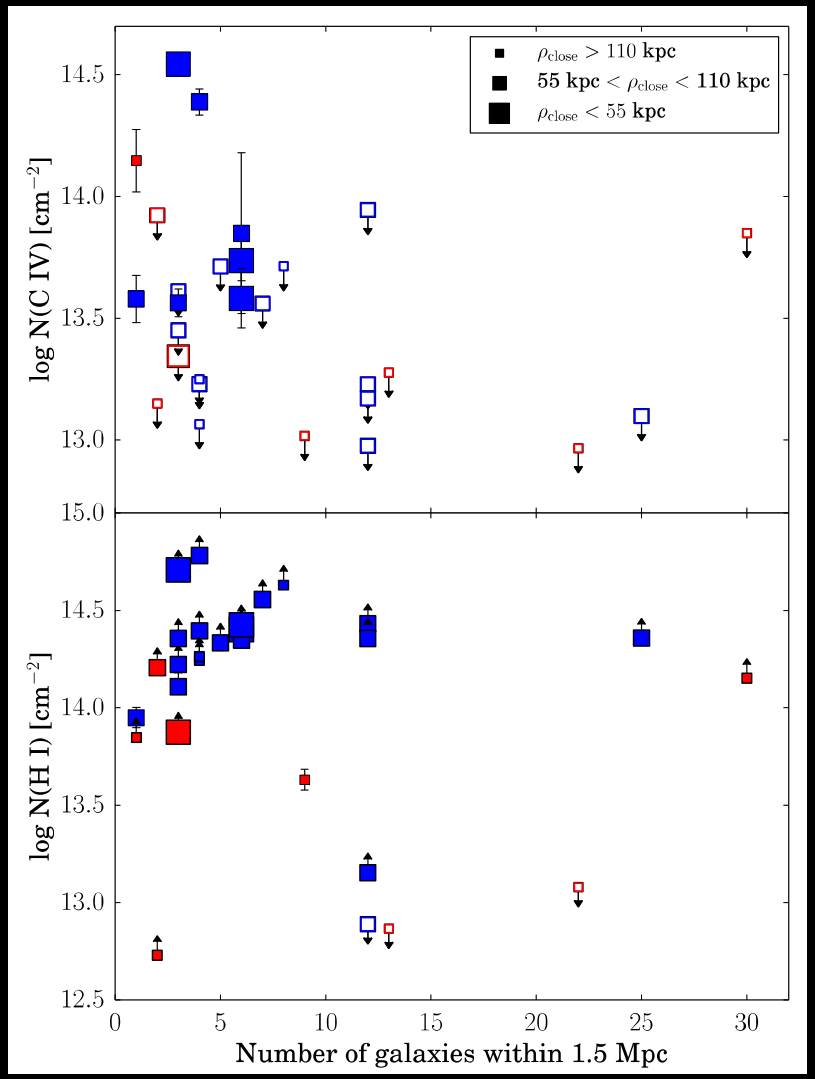
* For isolated galaxies

The CGM and environment

- Detection rate of CGM C IV plummets at high density ($M_{halo} \sim 10^{12.5}\ M_{sun}$)

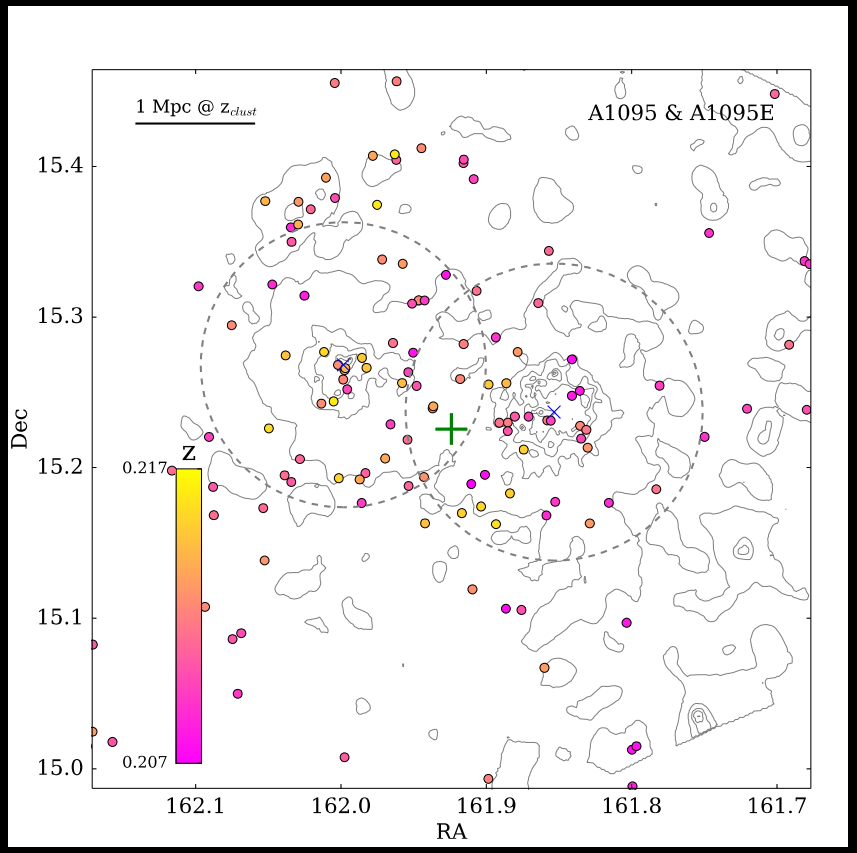
- H I is detected in CGM of galaxies at all densities

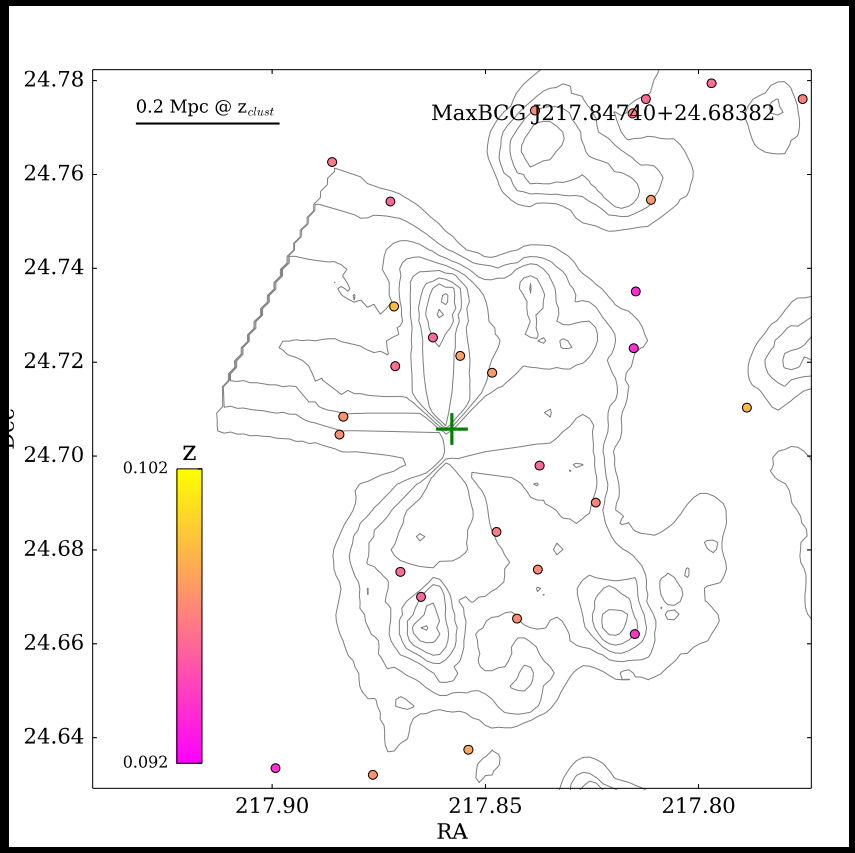




Burchett et al. 2016

CGM probed by our survey

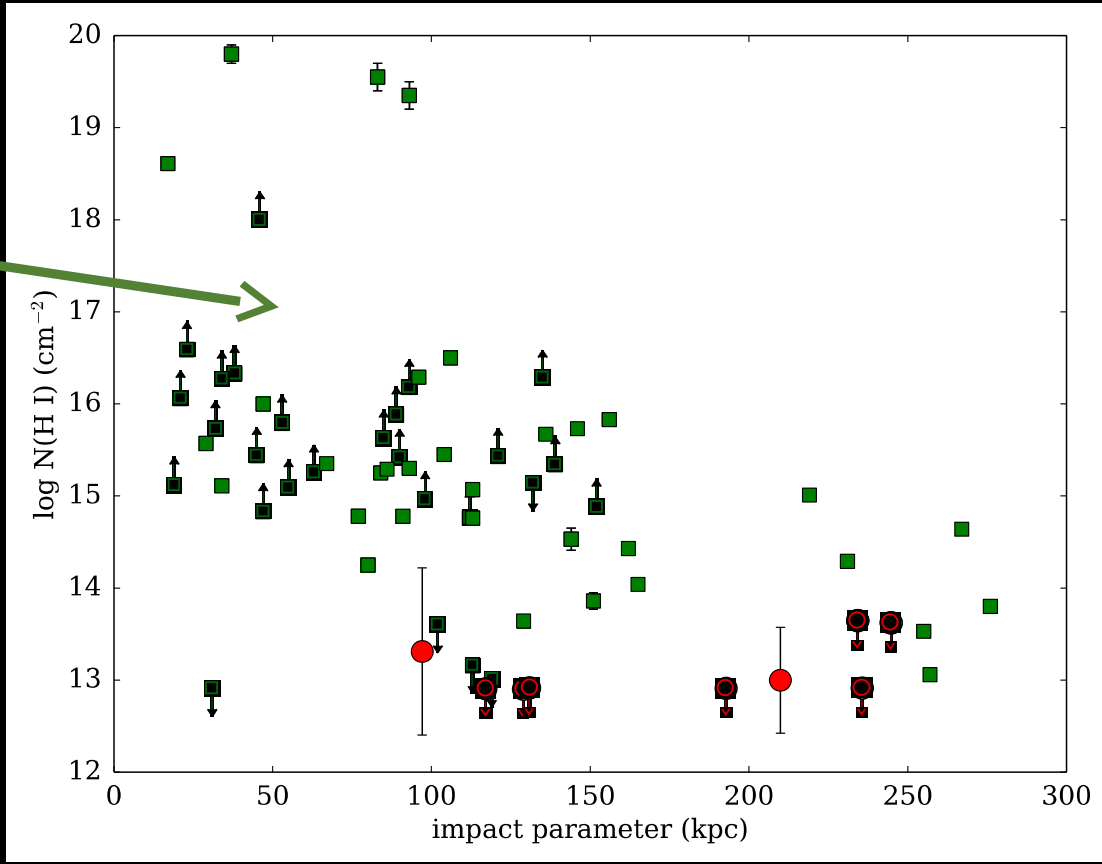




Burchett et al. 2016 (in prep)

A dearth of H I in cluster halos

H I is nearly ubiquitous in CGM even out to large impact parameters...

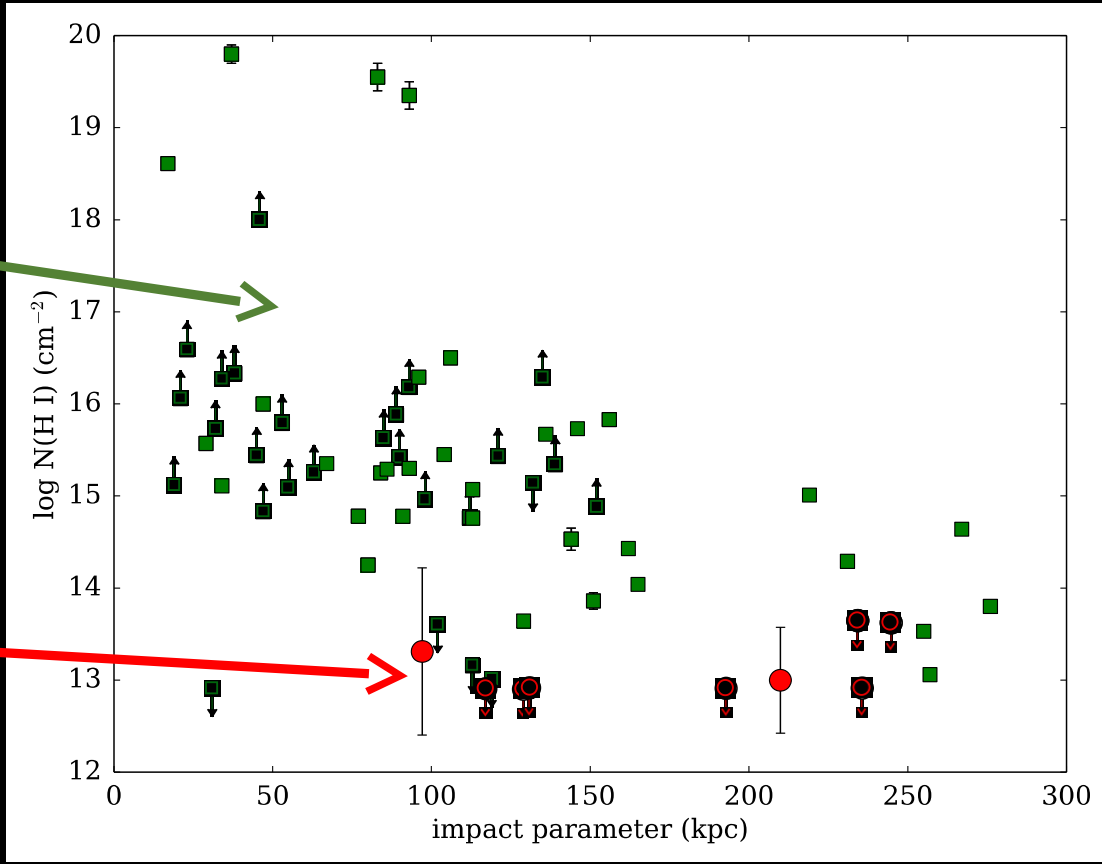


Burchett et al. 2016 (in prep)

A dearth of H I in cluster halos

H I is nearly ubiquitous in CGM even out to large impact parameters...

...but not in our cluster galaxies



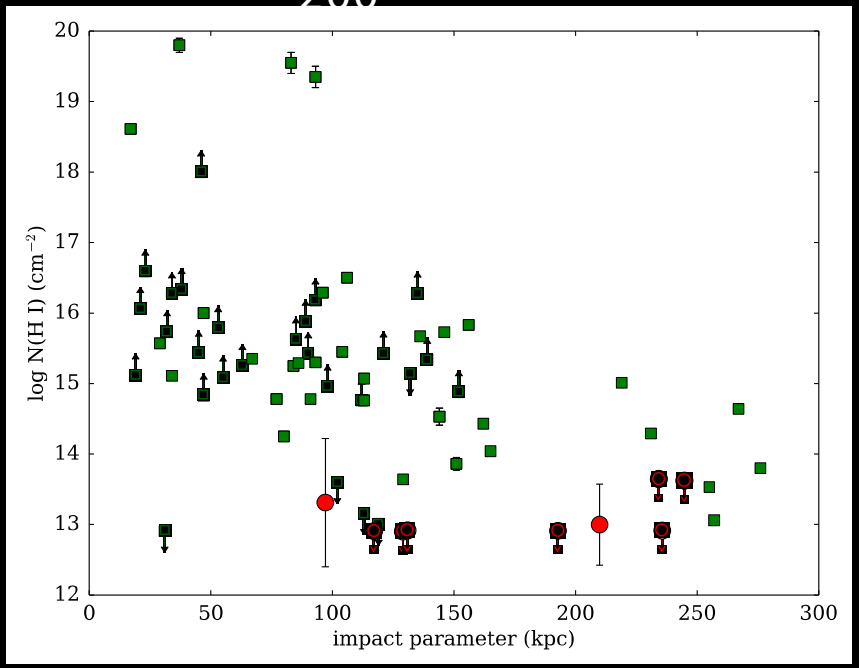
Burchett et al. 2016 (in prep)

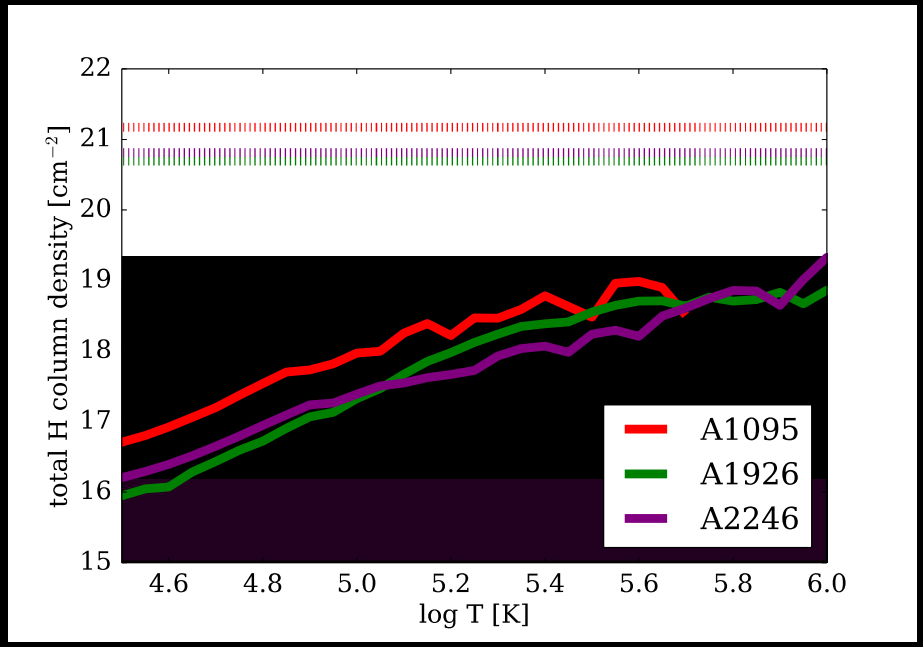
Toward the future

- Science drivers: parameter space
  - Cluster mass and richness
  - Dynamical states of clusters
  - Redshifts to cover different UV diagnostics
- Getting the data
  - UV
    - HST/COS observations of new QSOs
    - Growing COS archive
  - X-ray
    - Chandra
      - Characterizing higher redshift clusters
      - Resolving local substructure around individual galaxies

Conclusions

No evidence for significant reservoir in $10^{5\text{-}6}$ K gas at $<1.5\ R_{200}$





Clusters show extreme examples of CGM dependence on environment