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

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Key Questions

Where are the ‘missing baryons’ in galaxy clusters?

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

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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
Where could the baryons be hiding?

- Warm-hot ionized gas
  - $T = 10^5 - 10^6 \text{ K}$

- radii $> R_{500}$

- IGM: radii $>> R_{200}$
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

No O VI!  
No broad HI!

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Warm-hot contribution to baryon budget

Hot gas from X-rays

Limits on warm-hot gas from UV QSO spectra

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The CGM and galaxy evolution

Accretion

Recycling

Outflows

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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 ($M_{\text{halo}} \sim 10^{12.5} M_{\odot}$)

- H I is detected in CGM of galaxies at all densities
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 $10^{5-6}$ K gas at $<1.5 \ R_{200}$

Clusters show extreme examples of CGM dependence on environment