Punishing Environments at Low-z: Constraining Gaseous Conditions in the Modern Universe

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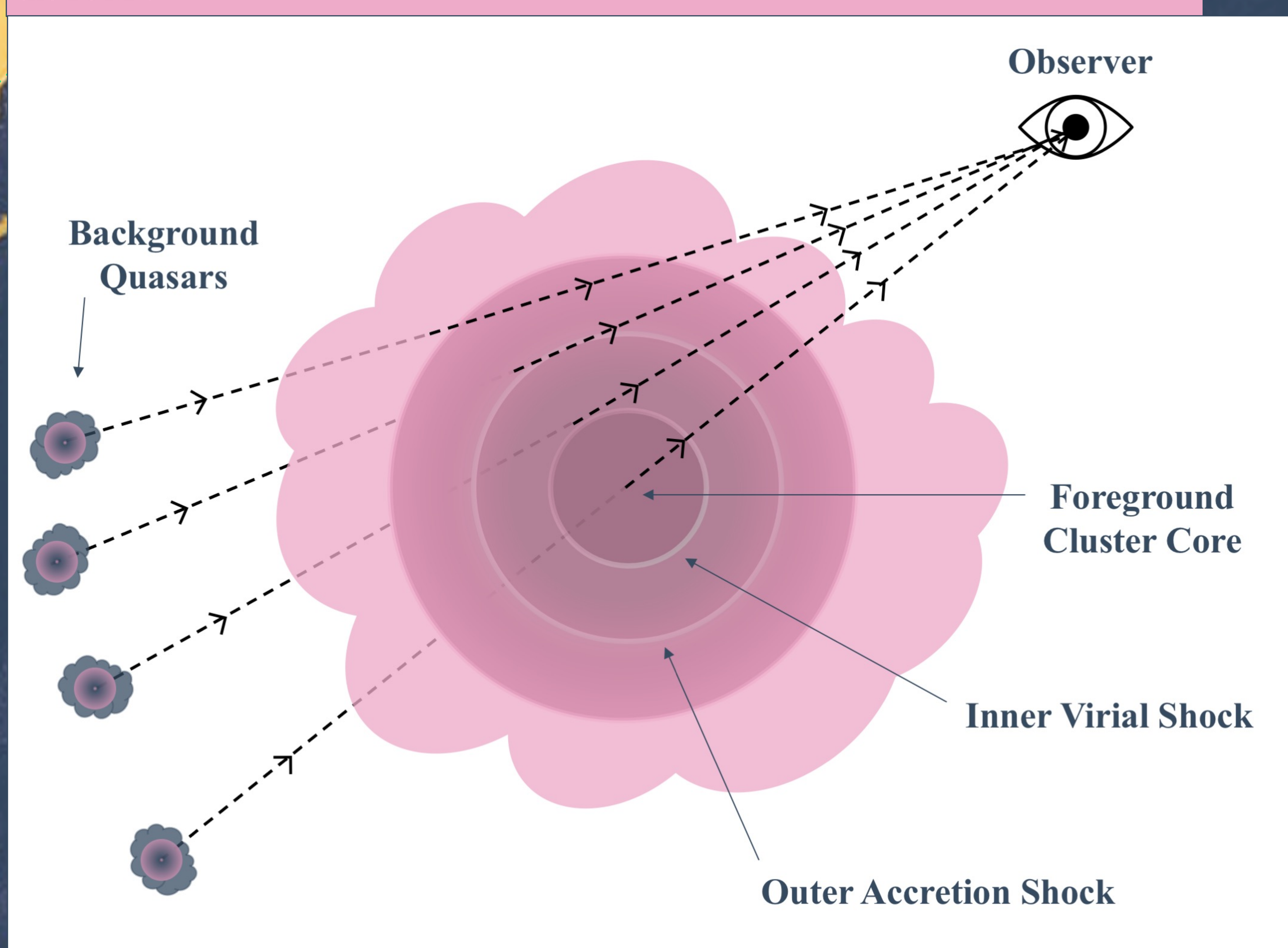
QUICK OVERVIEW

Galaxy clusters serve as key laboratories for halo gas physics and galaxy evolution, hosting multiphase gas that contains clues as to how these environments have transformed over time. Accretion shocks are uniformly predicted in formation models of the intracluster medium (ICM), but their location (1-5 r_{200}) varies from model to model, with important implications for infalling galaxies and gas physics in cluster outskirts. I am conducting a novel experiment to detect these accretion shocks through UV absorption spectroscopy of background quasars probing foreground galaxy clusters. Using HST/COS spectra, we select a statistical sample of quasar sightlines that probe 20 foreground galaxy clusters from within r_{200} to 5 r_{200} to quantify the incidence of HI absorbers per unit redshift, dN/dz, as a function of projected clustocentric distance. My results reveal peaks around 1 r_{200} and 3 r_{200}, with an increase in the amount of absorption lines per sightline detected around the outermost accretion shock, indicating a buildup of infalling HI clouds just outside the outer accretion shock.

FIGURE 1. *(below)* The experimental setup depicting the use of background quasars to probe different regions within a cluster. Through employment of UV quasar absorption line spectroscopy, we can directly probe the extremely diffuse environments of galaxy clusters outskirts, out to radii up to 5 r_{200}. By studying the changes in HI absorption characteristics as a function of clustocentric radius, we can determine the location of the shocks and directly probe the interface between the outskirts of the galaxy cluster and the IGM[5].



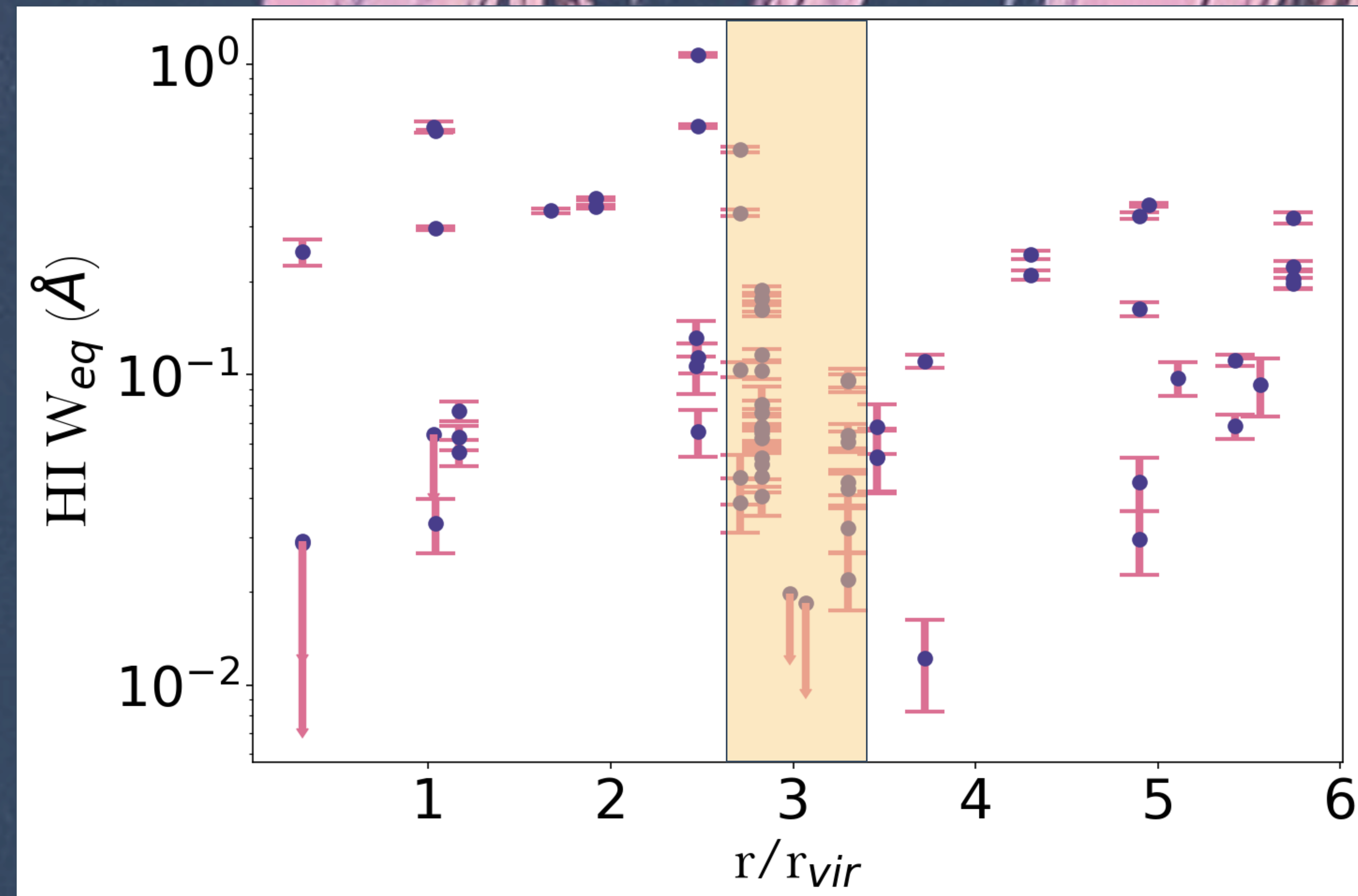


FIGURE 2. *(above)* The equivalent width measurements for detected HI Lyman-α (Lyα) absorption and upper limits (denoted by downward arrows). We see an increase in the frequency of absorbers around 3 r_{vir}, highlighted by the yellow bar, indicating there may be a buildup of HI occurring here. This is a potential marker of hydrodynamic processes contributing to the creation of the clumpy, multiphase gas that marks the interface between the cluster and the IGM.

FINDINGS + FUTURE WORK

Analysis of HI absorber equivalent widths (W_{ew}) reveals an increase in the amount of absorption lines per sightline detected around the 3 r_{vir} accretion shock, shown in **Figure 2.**. This indicates there may be a buildup of infalling HI clouds just outside the outer accretion shock. **Figure 3.** corroborates this finding, with a peak in the amount of HI absorbers per unit redshift, dN/dz, occurring between 2 – 3 r_{vir}. This increase in the incidence of absorbers right around the outer accretion shock highlights the need for observational constraints on the hydrodynamics occurring in these interface regions. Future work will entail comparison between results from our observational data and the results from an identical analysis done with simulated data. We can use this comparison to work towards further refinement of the current gas physics modeling we have for the outer regions of galaxy clusters where interaction with the IGM is thought to occur.

REFERENCES + ACKNOWLEDGEMENTS

[1]Nagai & Lau 2011; [2]Walker et al. 2019; [3]Nelson et al. 2014; [4]Molnar et al. 2009; [5]Burchett et al. 2019; I would like to acknowledge the NM Higher Education Grant as a source of funding, as well as Prof. Joe Burchett, Profe. Nicolas Tejos, Prof. Daisuke Nagai, Prof. X Prochaska, and Prof. Todd Tripp for the insightful discussions and guidance with this project.

A NOVEL EXPERIMENT

Hydrodynamical simulations of the gaseous outskirts in galaxy clusters reveal two key features that work to create a non-homogeneous ICM: two accretion shocks, at 1 and 3 r_{vir} respectively,[4] that heat gas as a result of infalling material, and density enhancements (i.e., clumping).[1,2,3] The cool, densest regions of this intracluster gas can be observed through the absorption profiles of gas tracers like neutral hydrogen (HI) and metal ions like OVI. QSO absorption line spectroscopy, depicted in **Figure 1.**, provides extremely sensitive line-of-sight observations through these gaseous regions, down to column densities N(HI) ≥ 10^{13} cm^{-2}. The accretion shock front heats infalling gas, which ionizes these gas clouds to a greater degree than photoionization in the intergalactic medium (IGM), and once the gas is exceedingly shock-heated, the neutral fraction should plummet, causing mappable depressions in the presence of HI. Virtually no such observational constraints currently exist for models of cluster formation and multiphase gas physics of ICM outskirts.

FIGURE 3. *(below)* The number of HI absorbers, dN, per unit redshift, dz, is shown as a function of binned virial radii. The blue dots denote the dN/dz values for each r_{vir} bin, while the pink bars and shaded area depict the 1σ confidence interval for the data. These dN/dz values are calculated using a W_{lim} of 50 mÅ, meaning all HI detections used to compute dN are stronger than this. We can see there is an increase in the number of absorbers detected in the 2 – 3 r_{vir} bin. This is the outskirts region that corresponds with the outer accretion shock, revealing the buildup and plummet following 3 r_{vir} that we expected as gas is ionized by the outer shock-front, causing a mappable depression in HI.