Probing gas in the outskirts of galaxy clusters with CMB-S4

Eric Baxter
Institute for Astronomy, University of Hawaii

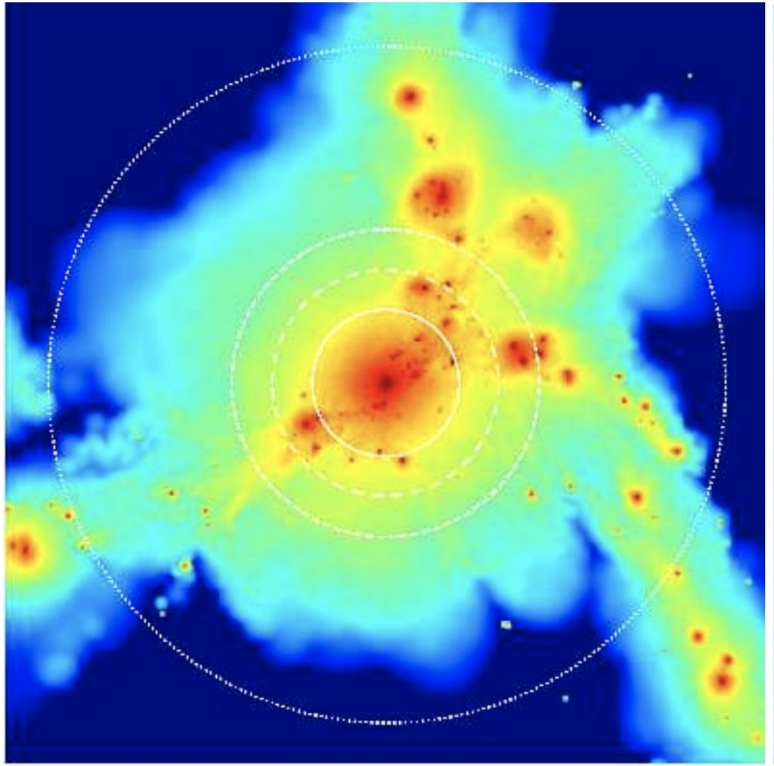
The outskirts of galaxy clusters

As the most massive, gravitationally bound objects in the Universe, clusters are the last to form

Clusters evolve through mergers and accretion

The outer profiles of clusters are sensitive to accretion

e.g. splashback



Reiprich et al. 2013

Dark matter vs. gas

Zhang et al. 2021

Merger of two initially self-similar clusters

Accreting collisionless dark matter leads to formation of caustics, i.e. splashback (see talk from Susmita)

Collisional gas experiences shocks:

Accretion shocks

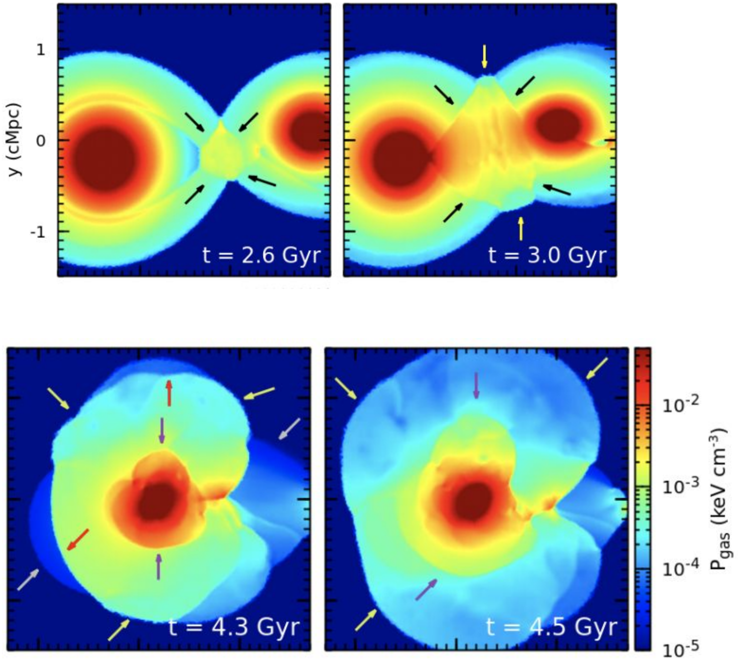
Infalling gas encounters one or more shocks on its way to becoming part of the intracluster medium (e.g. Bertschinger 1985)

Merger shocks

Shocks driven by mergers of halos

Merger accelerated accretion shocks

Mergers drive outwardly propagating shocks that overtake accretion shock (e.g. Zhang et al. 2020, 2021)

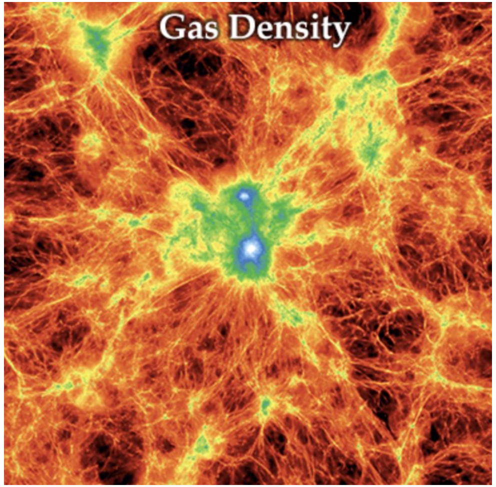


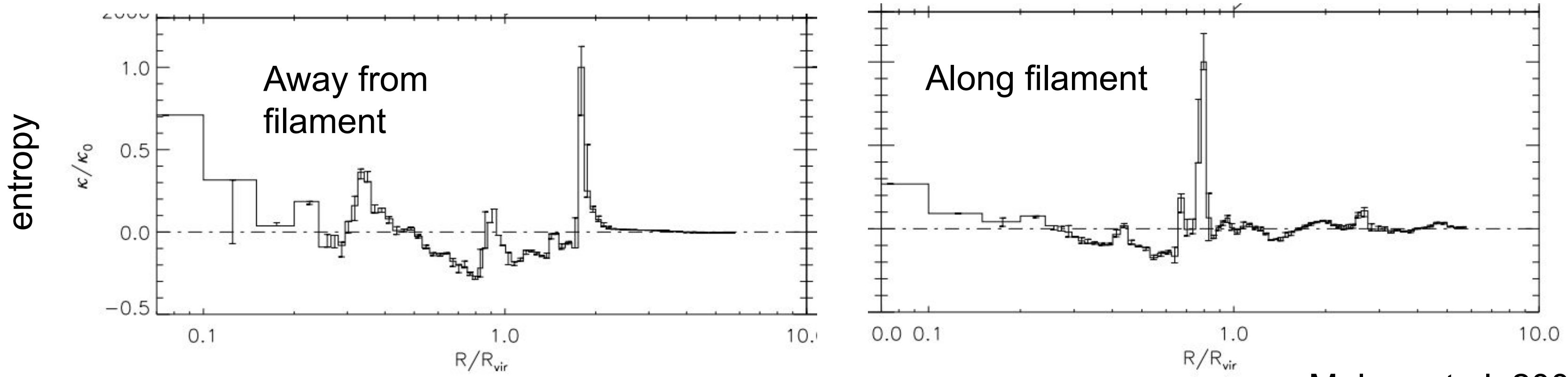
Shocks are impacted by filaments

Most gas accretion occurs along filaments

Along filaments, shocks occur deeper within clusters

Gas filaments in Illustris





Molnar et al. 2009

How do we observe the outer gas profile?

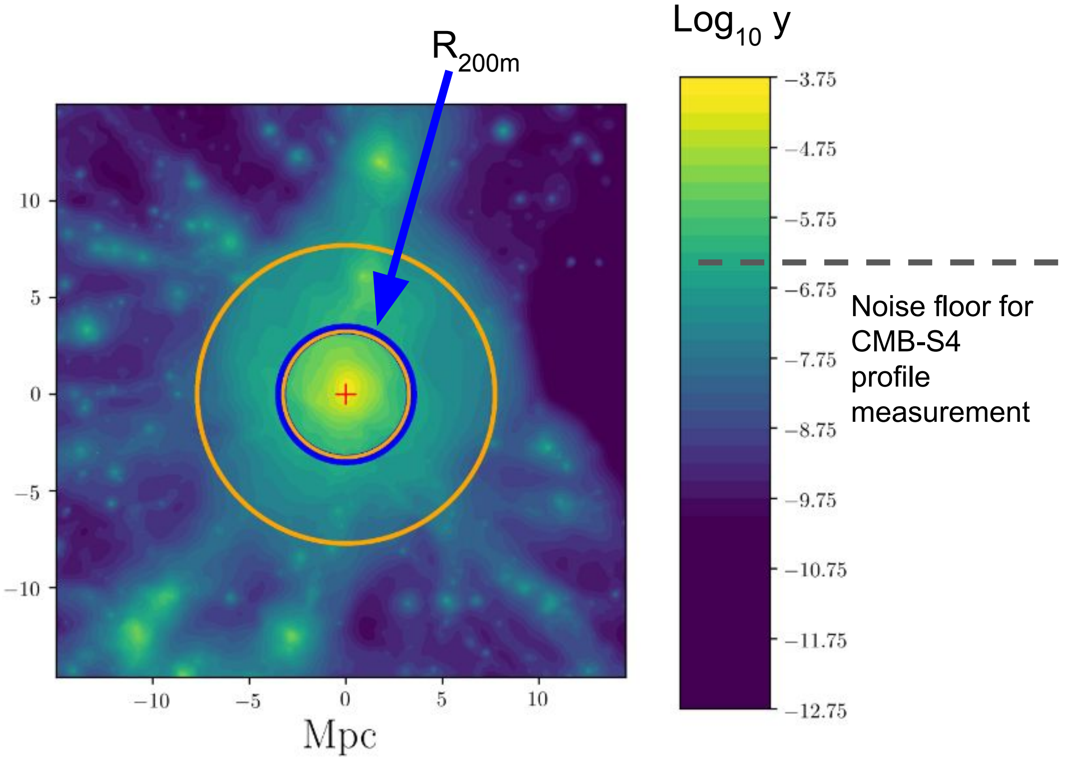
X-ray surface brightness ~ density^2

- Not well suited for cluster outskirts

Thermal Sunyaev-Zel'dovich effect ~ density x temperature

- better suited to cluster outskirts

However, for a single cluster, detection beyond a few virial radii will be challenging



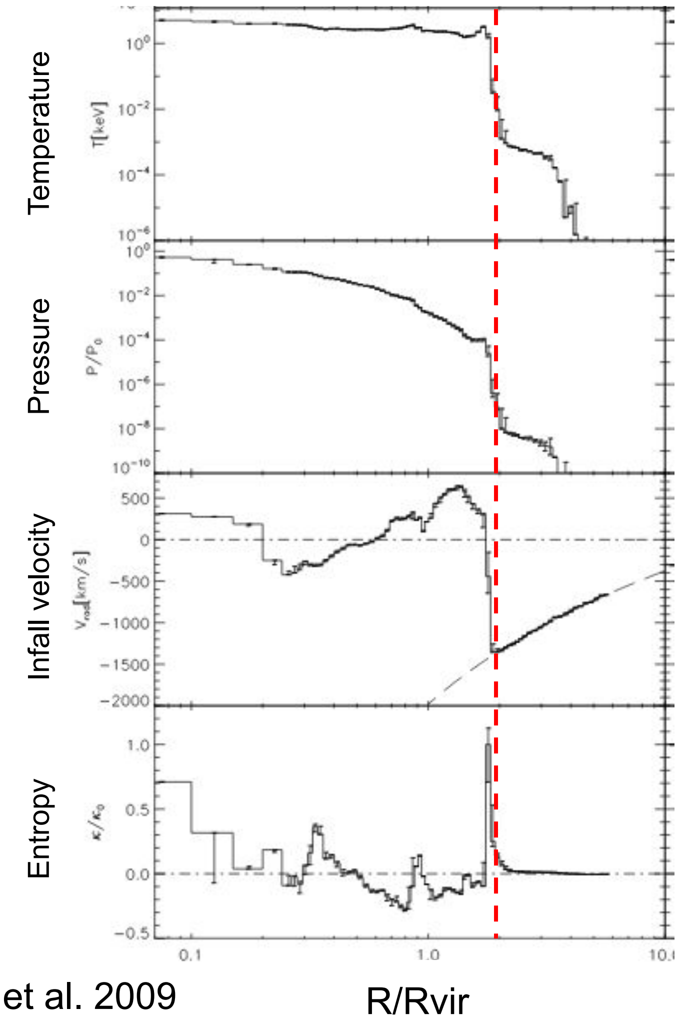
Shock features in the SZ profile

Can define “external shock” as first shock encountered by accreting gas (e.g. Ryu et al. 2003, Molnar et al. 2009)

- Should coincide with location where gas infall velocity stops increasing
- Typically at few virial radii

Shock heating causes temperature and pressure of infalling gas to rapidly increase

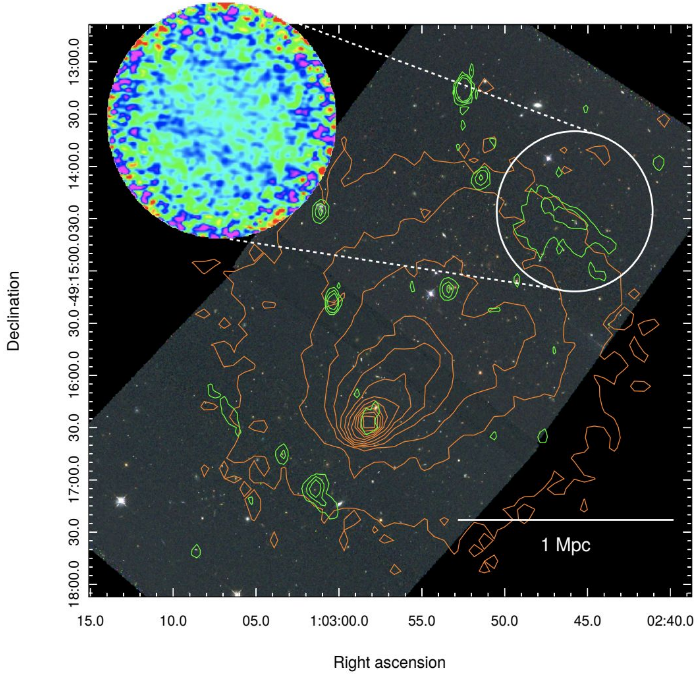
Increase in pressure should lead to signal in thermal SZ (e.g. Molnar et al. 2009)



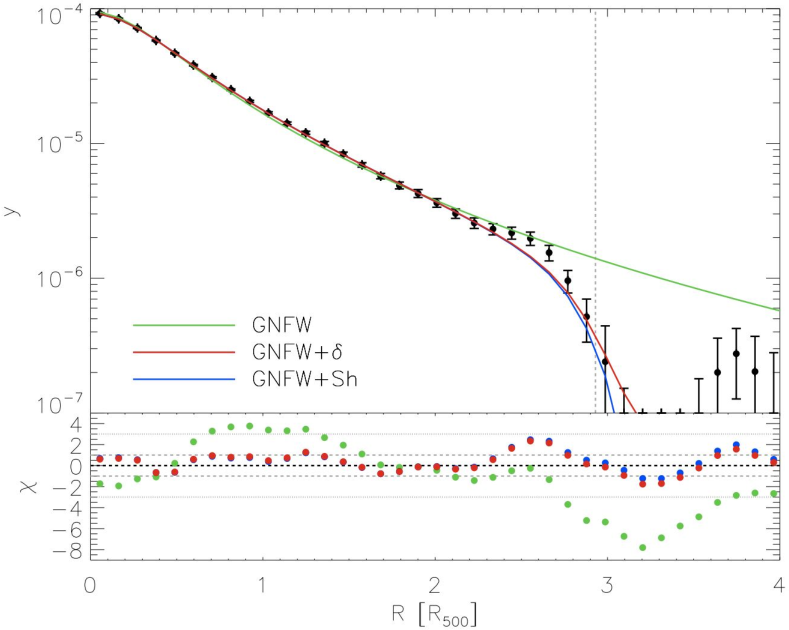
Molnar et al. 2009

Observing shocks in the SZ

Merger shock near El Gordo cluster with ALMA (Basu et al. 2016)



Accretion shock around Abell 2319 with Planck (Hurier et al. 2019)

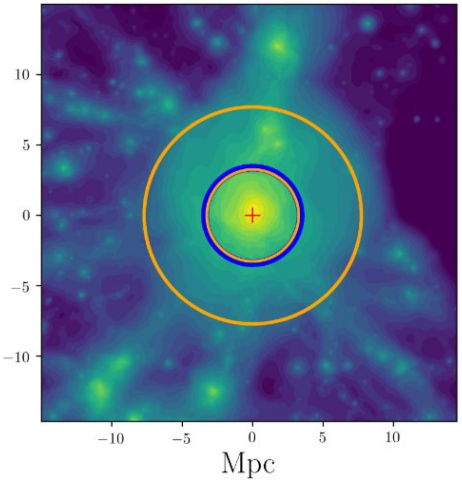


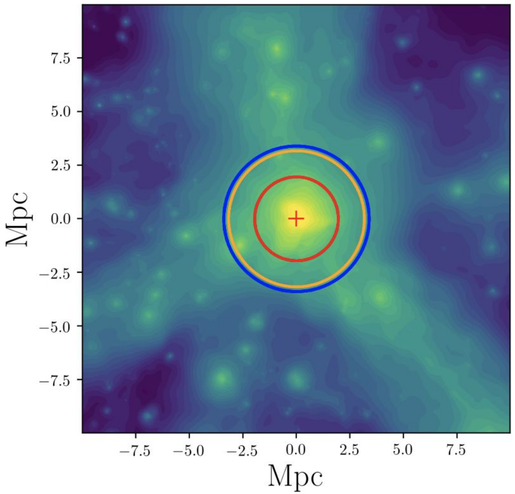
Stacking over many clusters to enhance detection prospects

CMB-S4 may not detect shocks around individual clusters, but it will detect many thousands of clusters (e.g. Raghunathan et al. 2021)

Custers have different merger histories, accretion rates, etc. ⇒ not obvious that stacked profile will contain information about shocks

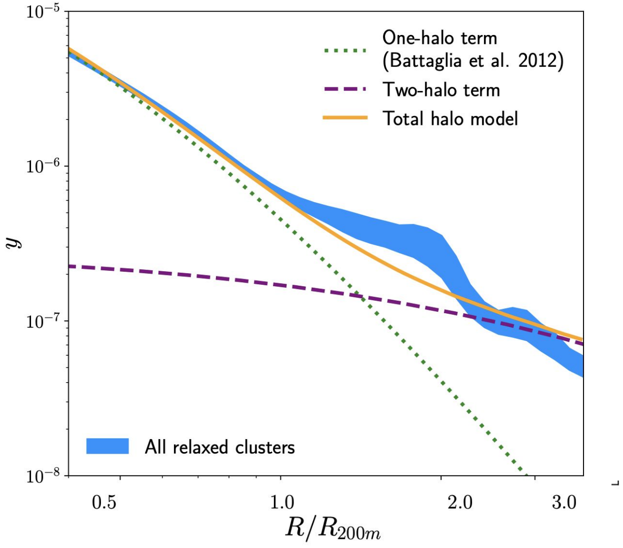
Can explore this possibility using simulations from the 300 project: hydrodynamical re-simulations of most massive ~300 clusters from the Multi-Dark Planck 2 simulation (https://weiguangcui.github.io/the300/)

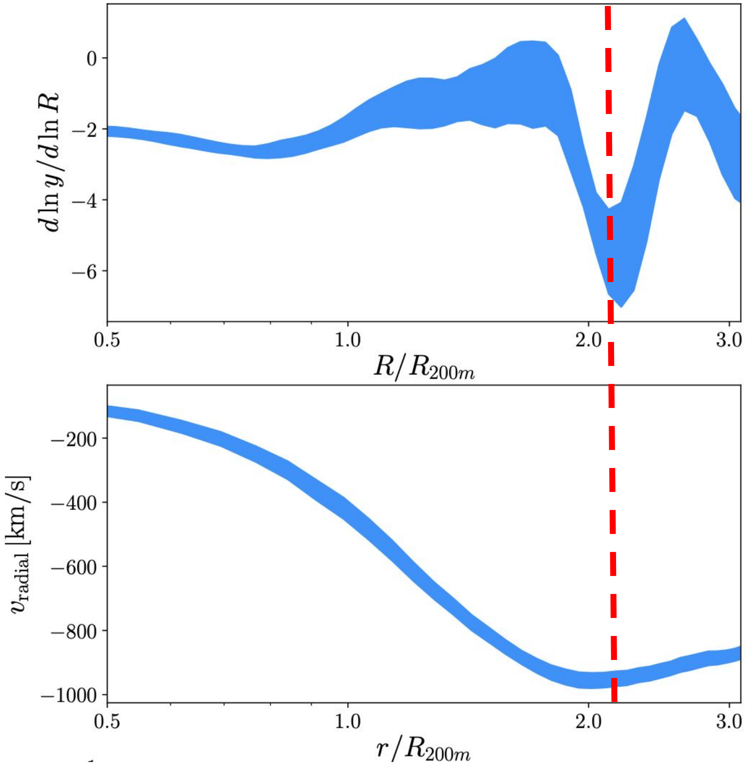




The imprint of shocks on the stacked y profile

If profiles are stacked as function of R_{200m}, there is evidence of shocks in outer profile (in simulated clusters)

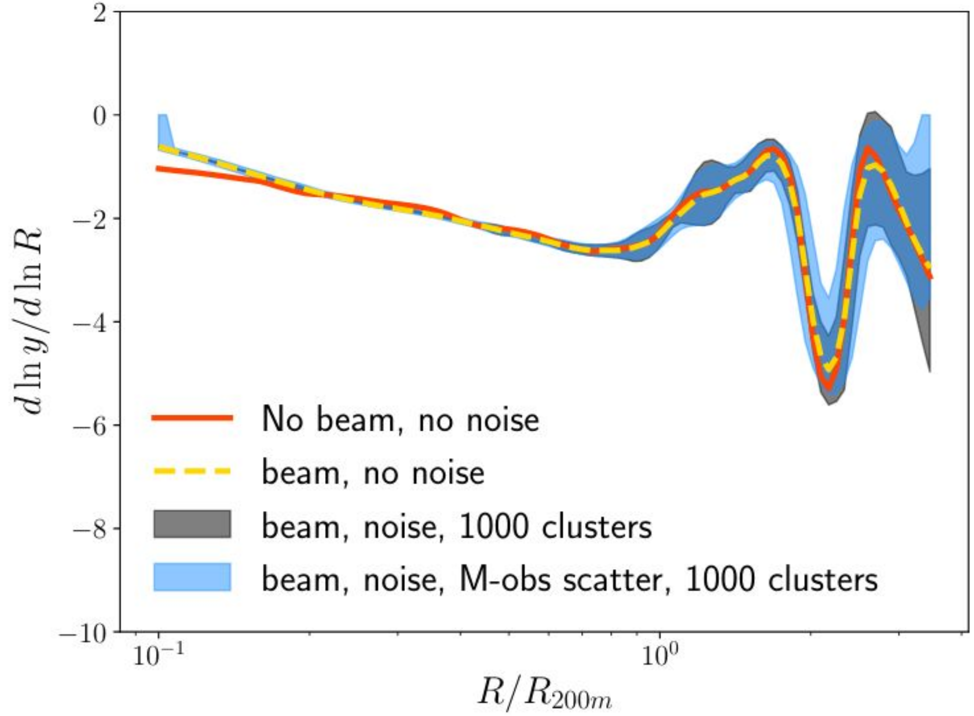




EB et al. 2021

Is it detectable possible with CMB-S4?

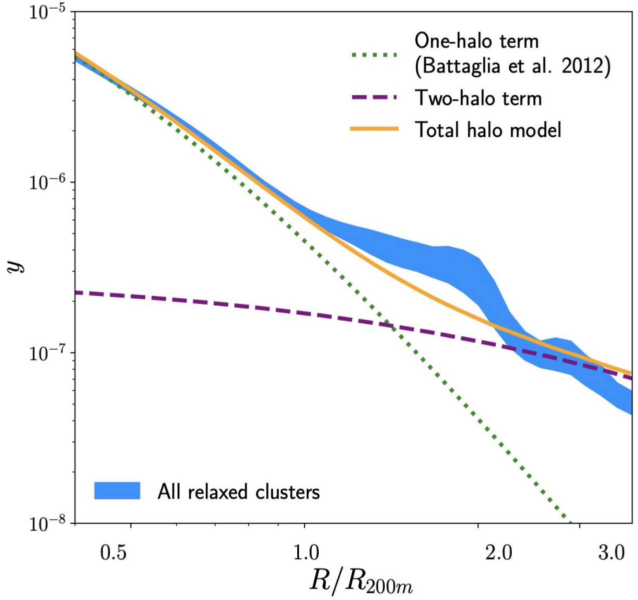
Possible to obtain high significance detection of stacked shock features with CMB S4-like observations

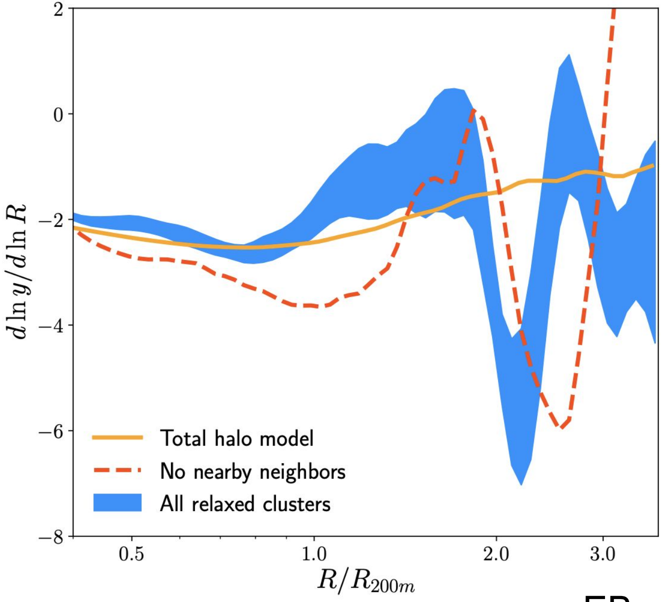


EB et al. 2021

Fitting the cluster-y correlation

Shock features may impact fits to the cluster-y correlation





EB et al. 2021

Summary

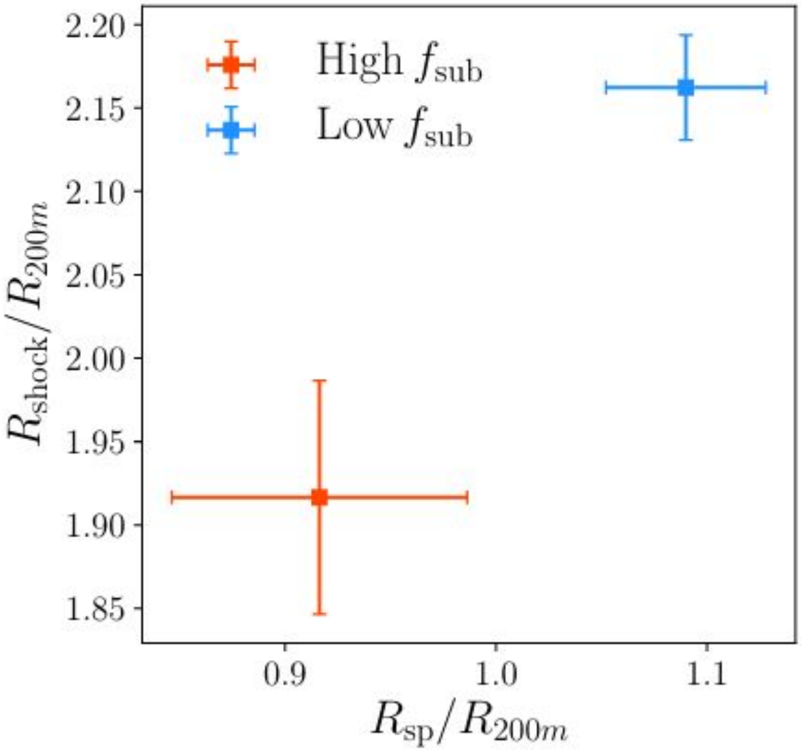
The outer gas profiles of clusters contain information about their accretion and merger histories via shocks

Shocks can be probed with thermal SZ, but detecting individual shocks with CMB-S4 will likely be challenging

Detection seems possible with stacked SZ measurements across many clusters

Connection to splashback

Higher accretion rate means smaller splashback radius and smaller shock radius



EB et al. 2021