Cluster Galaxy Evolution Science in the 2020s

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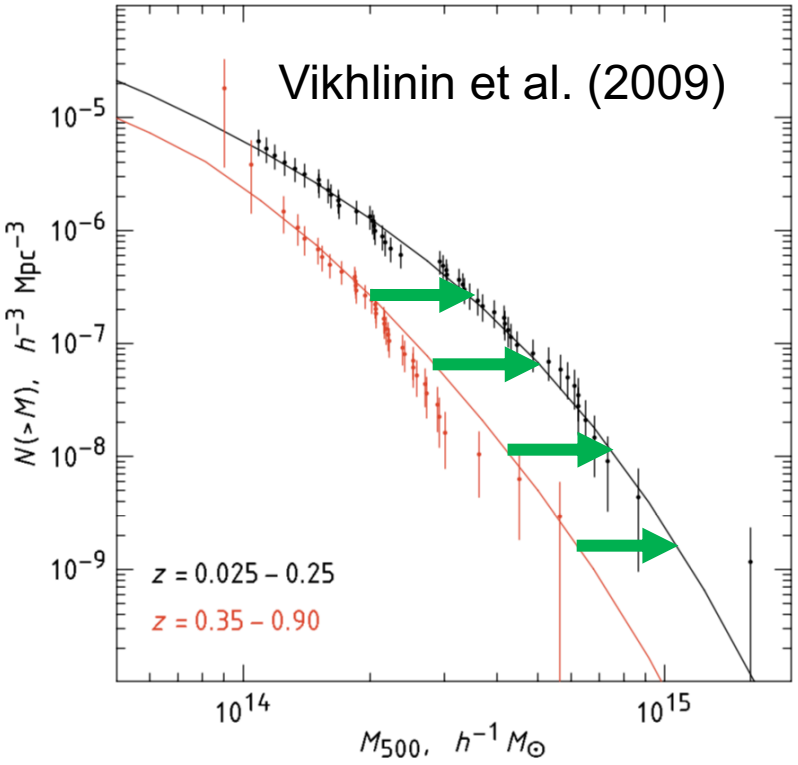
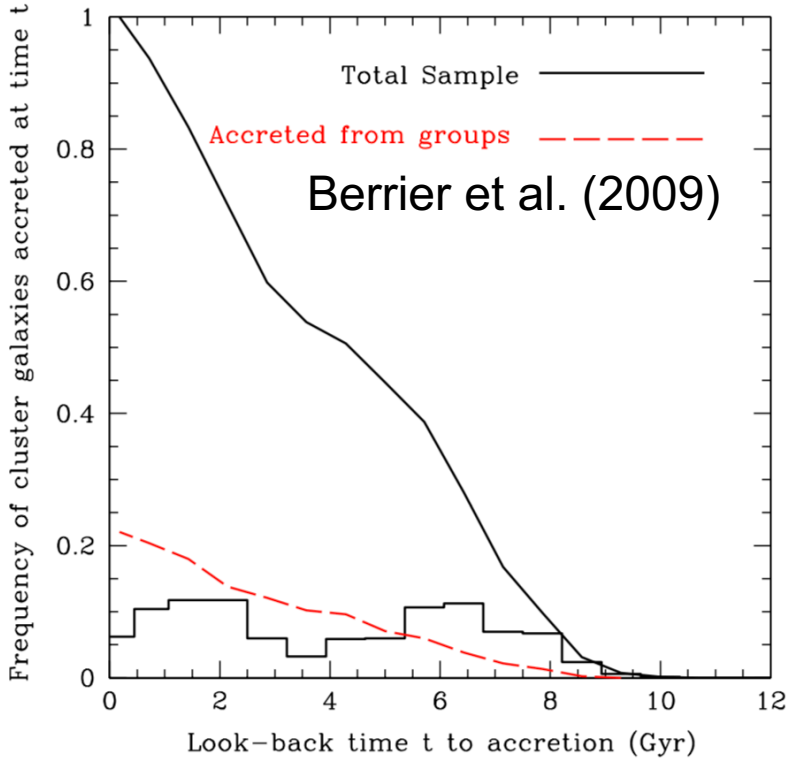
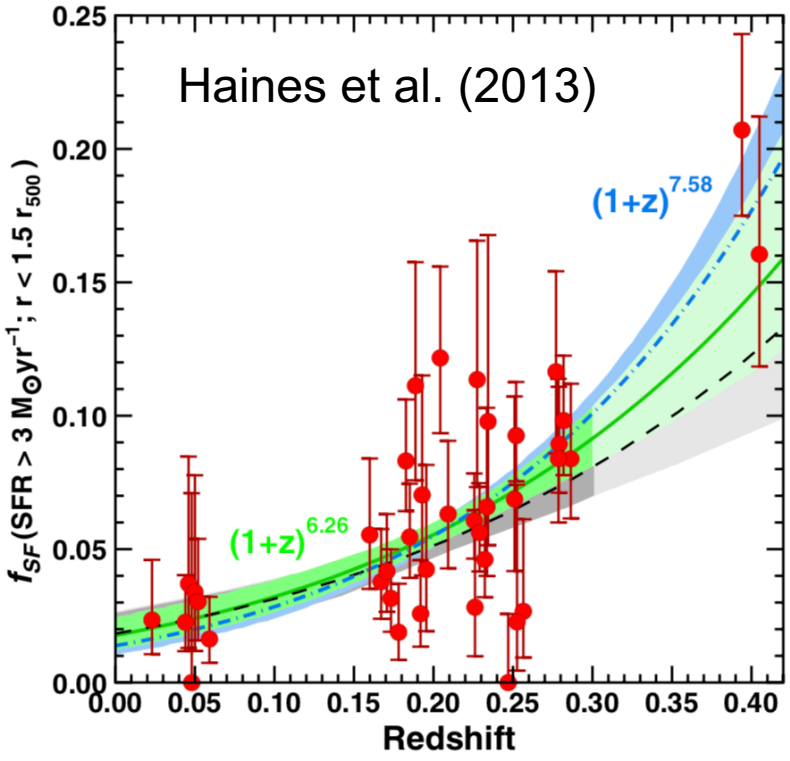
The rapid late evolution of clusters and their galaxies

- Galaxy clusters are assembled late, empirically doubling their masses on average since z~0.5 (Vikhlinin et al. 2009). Similarly, they accrete half of their present-day member galaxies at z<0.5 (Berrier et al. 2009)
- The fraction of star-forming cluster galaxies has evolved rapidly since z~0.4 (Butcher-Oemler effect), but this evolution has been mostly measured using heterogeneous data, with few clusters at z>0.3
- Motivates a single homogeneous survey that can track the rapid evolution of cluster galaxies over the last 4 billion years, and that extends well into the infall regions of z~0.4 clusters to track future member galaxies

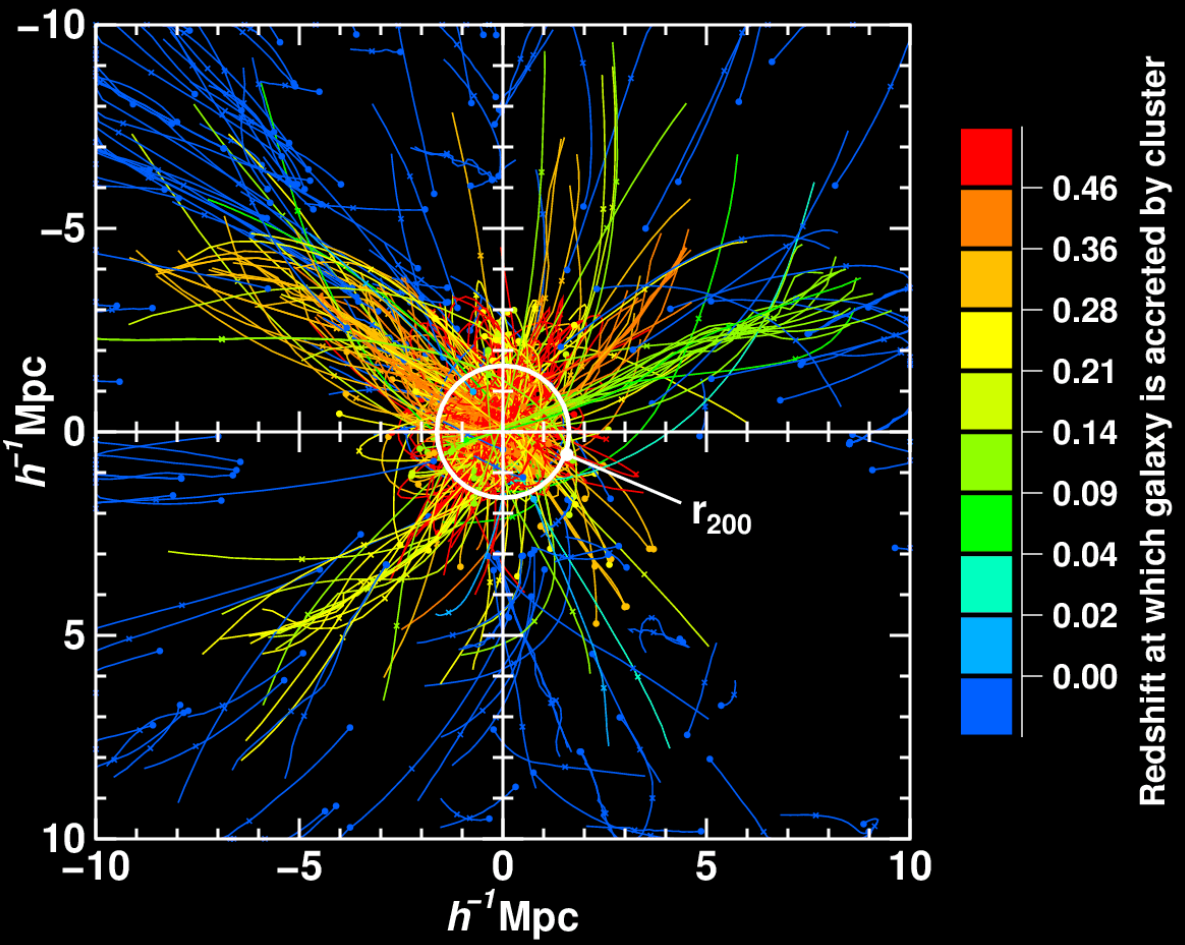


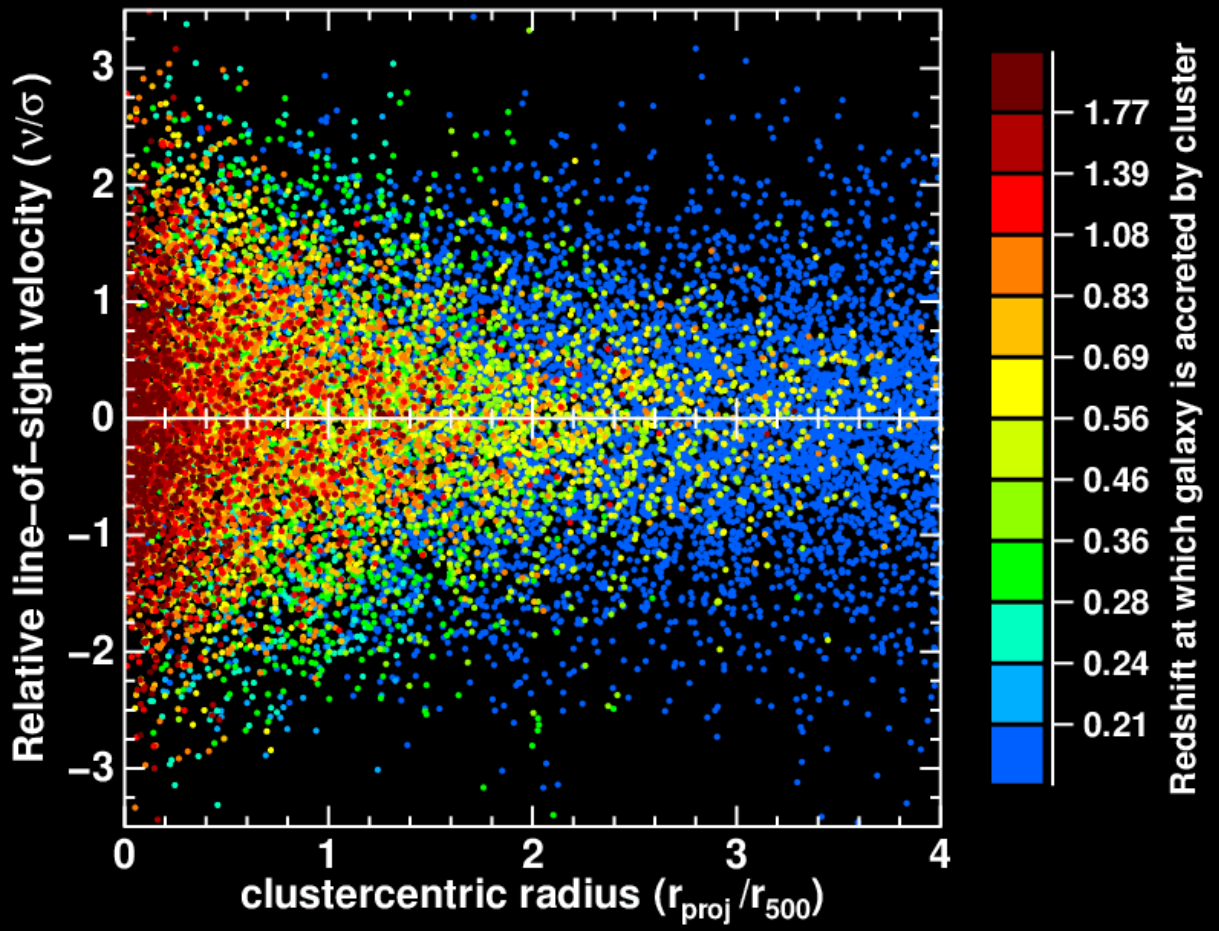




The continual infall and accretion of galaxies onto clusters

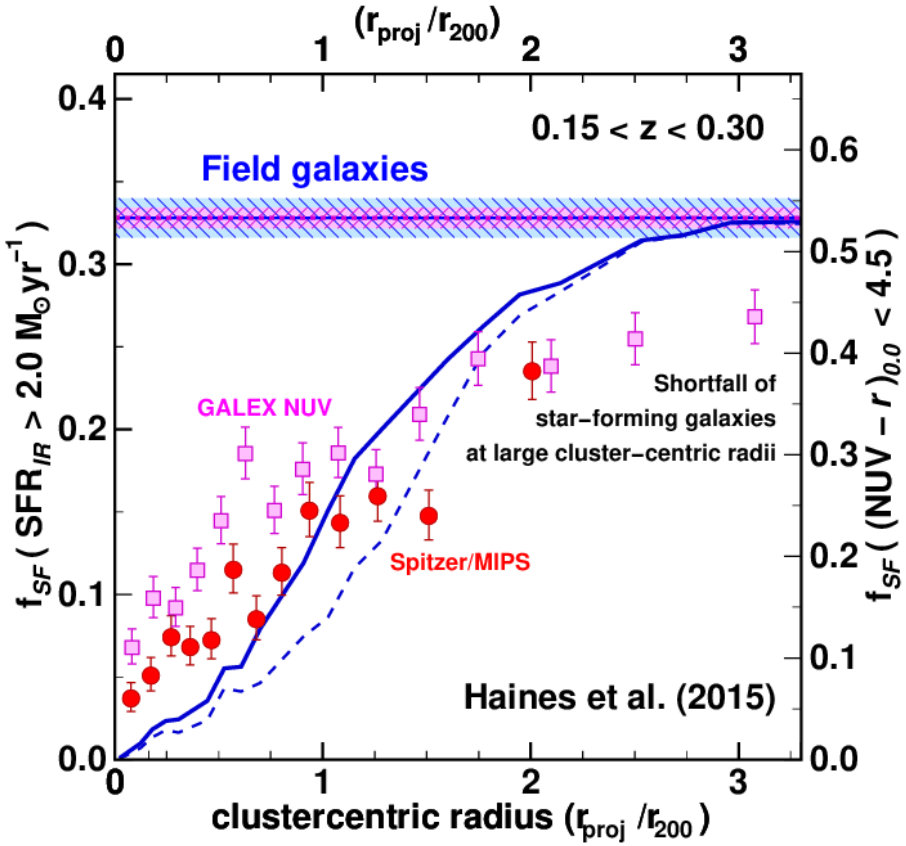
- To fully understand the evolution of cluster galaxies, we need to place clusters in the cosmological context of continually accreting galaxies and groups from the surrounding large-scale structure

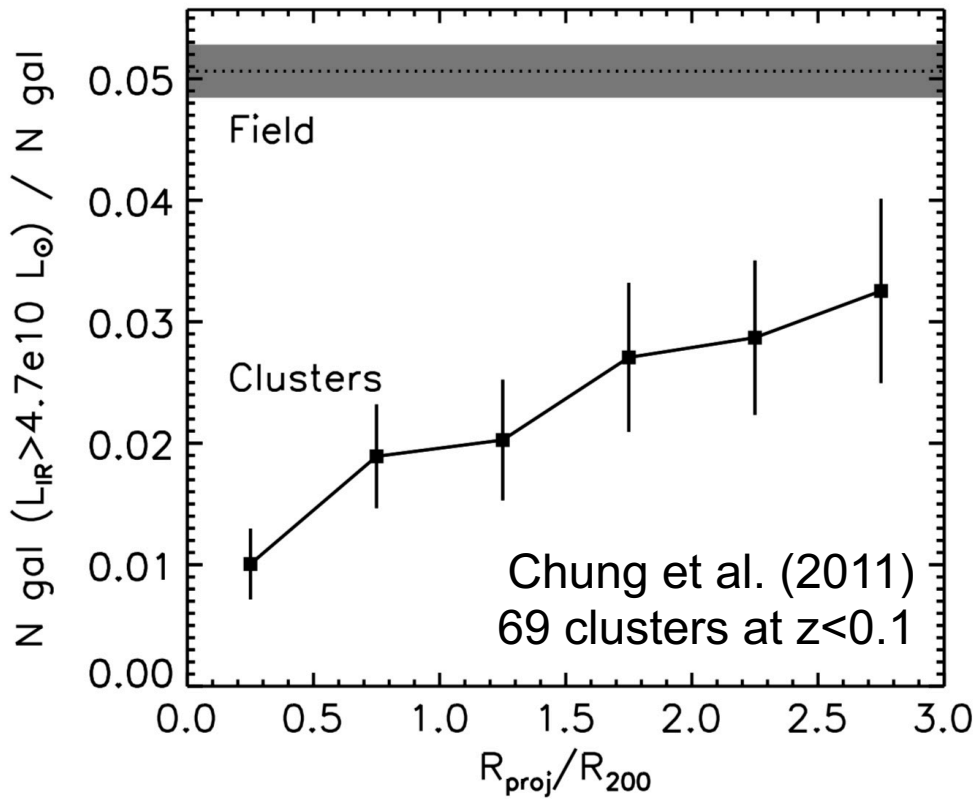




The need for pre-processing

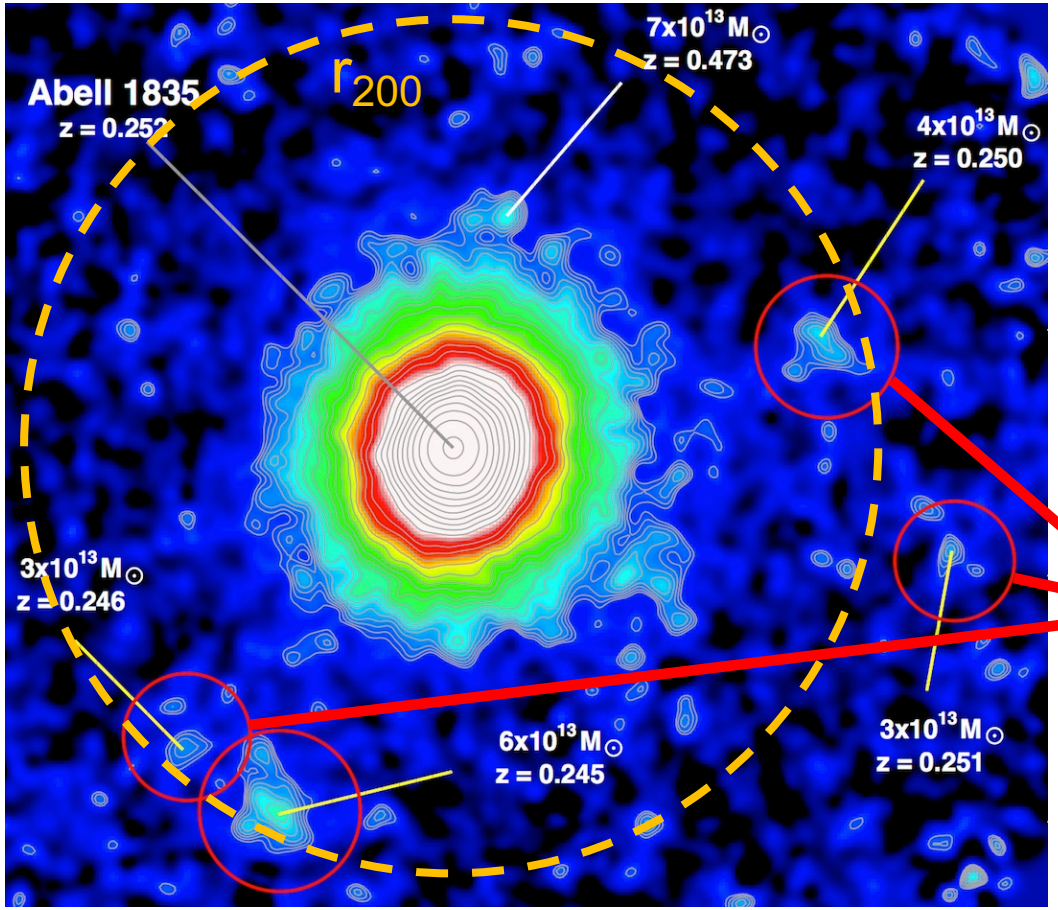
- Galaxies in the vicinity of clusters are more likely to be quiescent than counterparts in typical field regions, at fixed stellar mass and redshift, even at large distances from the cluster (~$3r_{200}$)
- Need a physical mechanism that can transform these galaxies prior to their arrival into the cluster.
- Galaxies may be pre-processed within galaxy groups that are later accreted onto the cluster





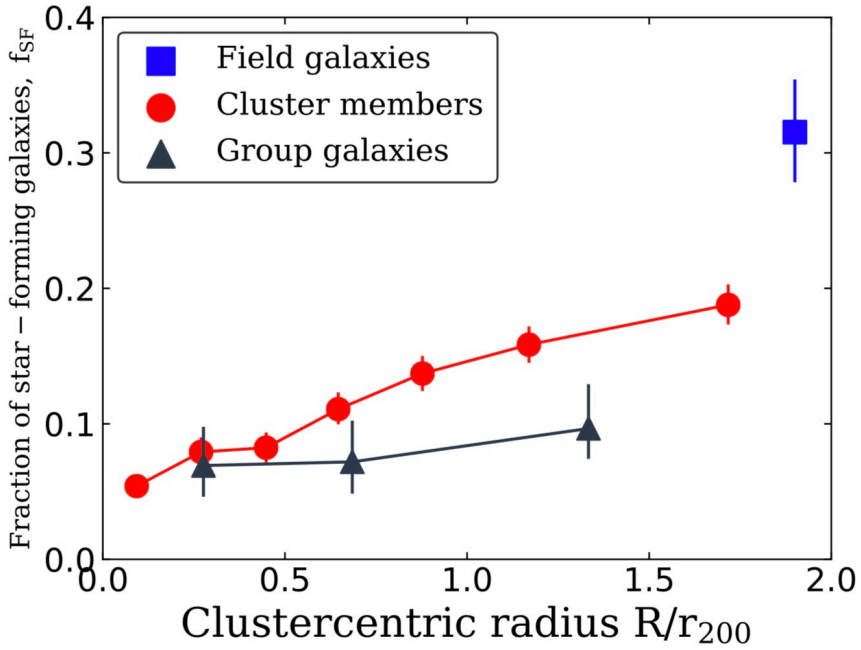
XMM survey of groups around massive clusters

Haines et al. (2018)

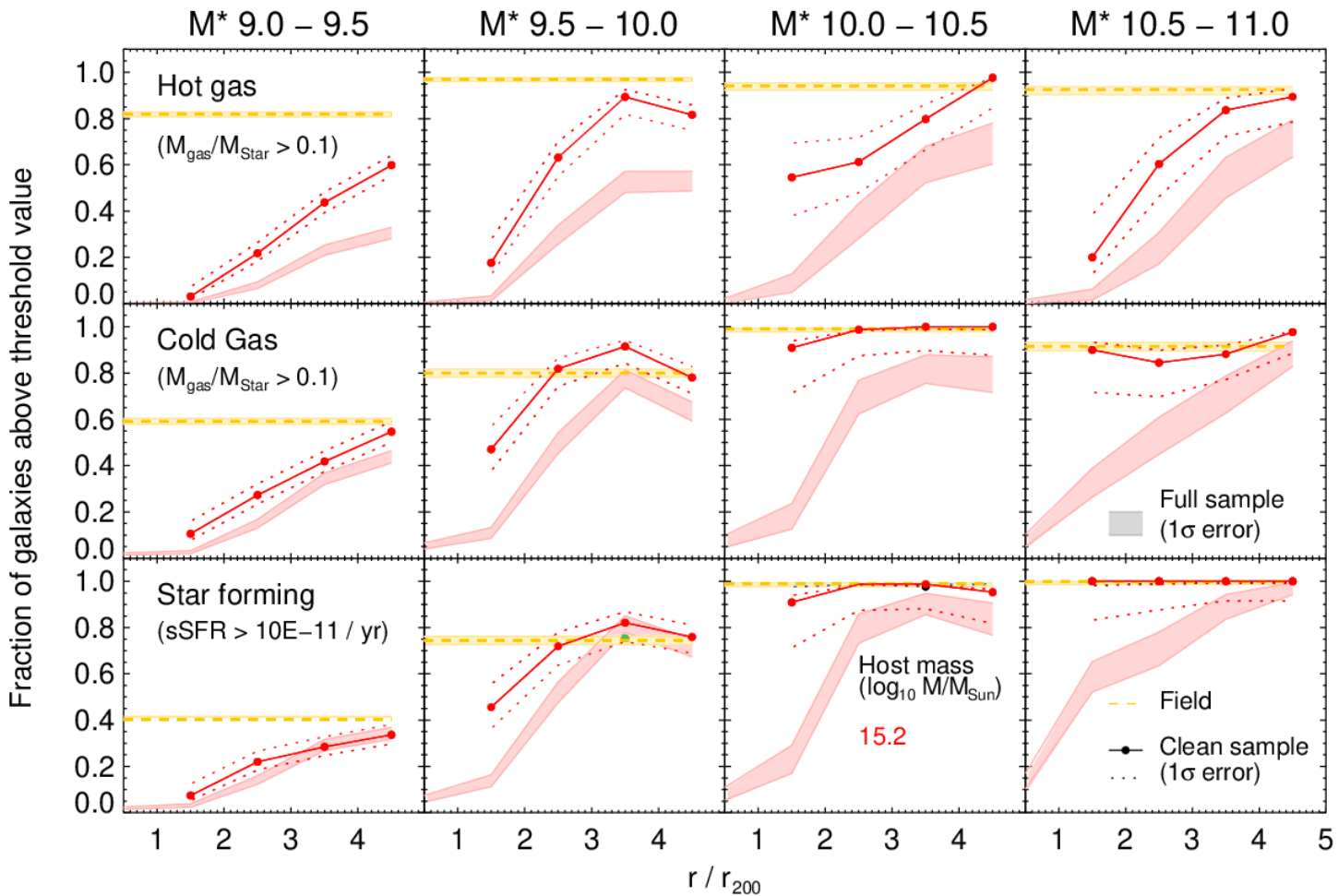


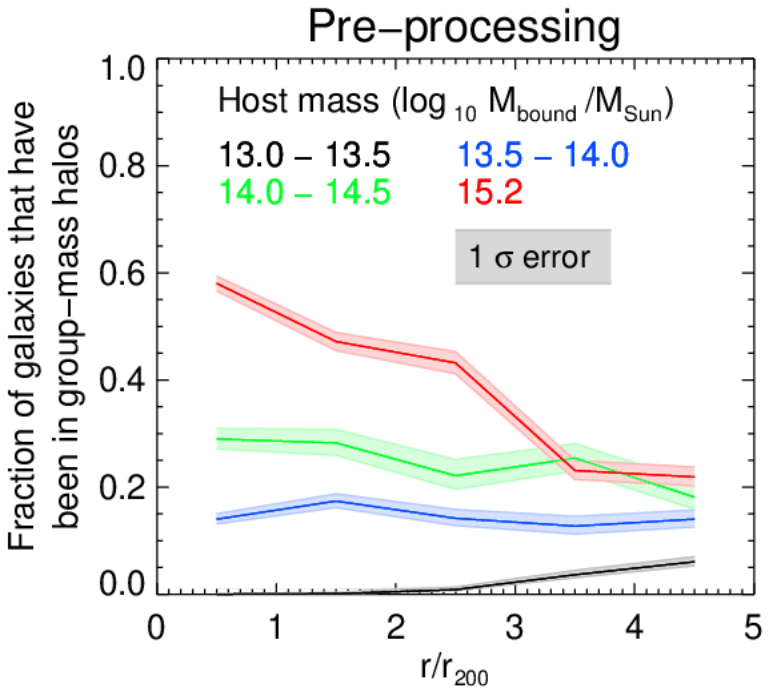
- Search XMM images of 23 massive clusters at z~0.2 for extended X-ray emission from groups falling into the clusters
- 39 infalling X-ray groups with spec-z at cluster redshift
- Typically 7+ confirmed group members, σ_v~300km/s
- Mass of infalling groups ~20% of cluster mass, contributing ~half of expected mass growth rate of clusters at late times.
- Limited XMM field-of-view means that can only find groups out to ~r_{200}. Can't map the whole cluster infall regions.
- Member galaxies of these infalling groups have same low f_{SF} as the host clusters. => pre-processing

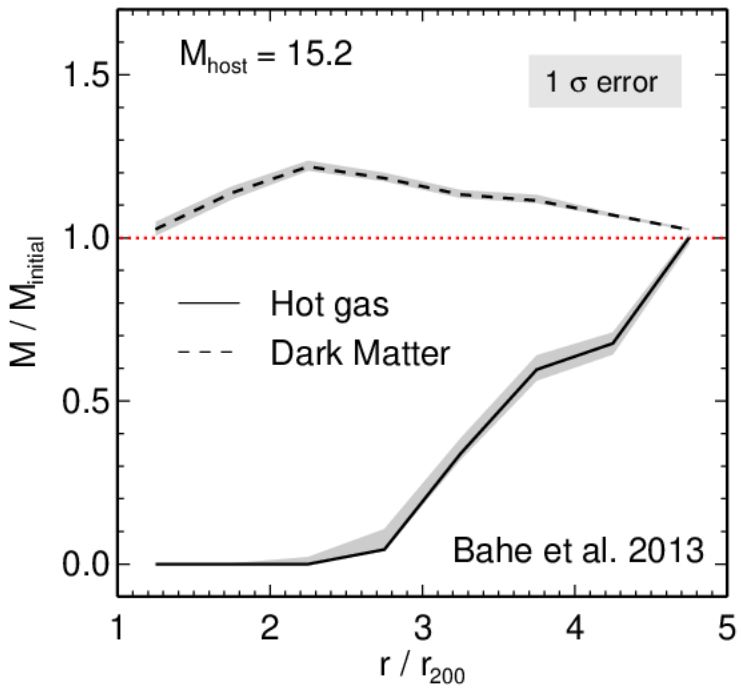
Sites for pre-processing galaxies in groups prior to their accretion into the clusters



Hydrodynamical simulations suggest that galaxies falling into massive clusters can start to be affected by ram-pressure stripping, starvation or pre-processing in groups as far out as $5r_{200}$, long before they are accreted into the cluster (Bahé et al. 2013)







Motivation for new low-z cluster galaxy survey

- A lot of the action is happening at $z<0.5$. Amenable to 4m-class survey telescopes and smaller.
- Need to go wide (out to $5r_{200}$) to understand where and how galaxies are being transformed prior to their accretion into clusters or if they have simply evolved more rapidly in these overdense parts of the Universe
- Launch of eROSITA X-ray telescope in 2019 will bring new impetus to field of cluster science, by carrying out all-sky X-ray survey over the next four years.
- It will detect all massive clusters in the Universe and all group-mass systems to $z<0.2$
- Upcoming ASKAP (HI) and LSST (lensing) surveys

The eROSITA all-sky X-ray survey

Bulk of eROSITA cluster detections will be at z<0.3

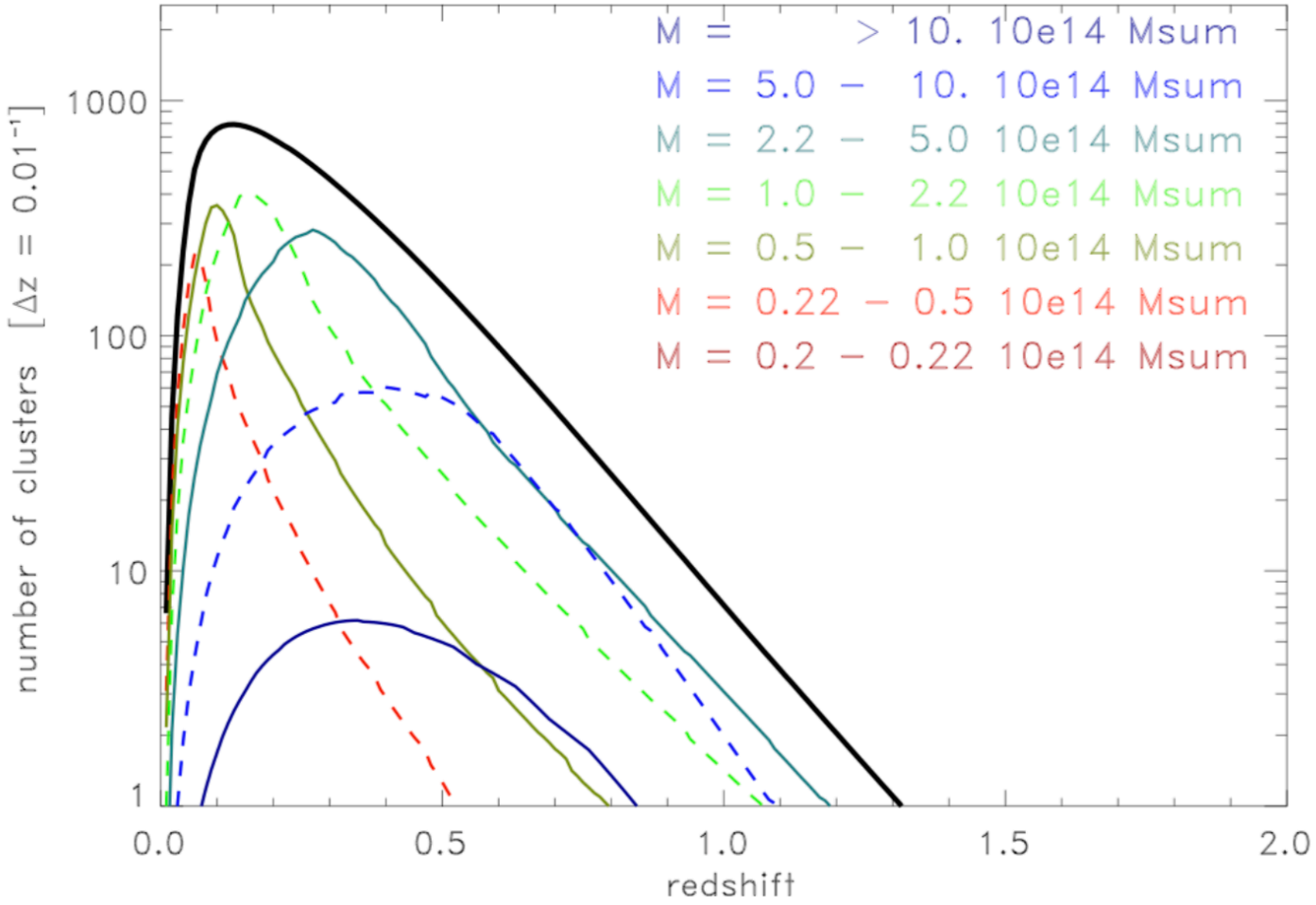
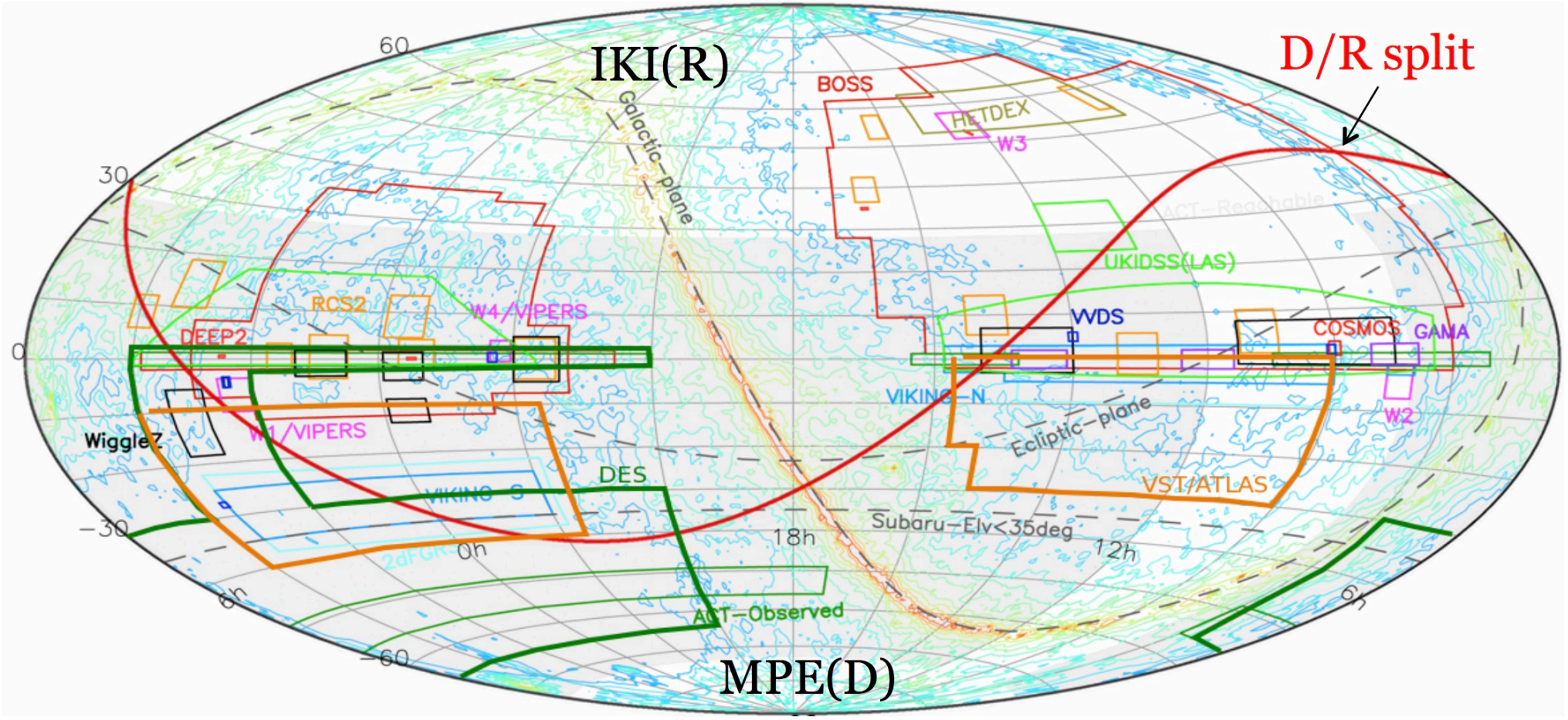


Figure 5.1.3: Mass - redshift distribution of the detected clusters in the full 4-years eROSITA all-sky survey, assuming 100 photons to secure a detection. Black solid line is for the total, with lines of different colors corresponding to different mass bins, as in the inset. The cluster numbers are given for redshift bins of $\Delta z = 0.01$

The eROSITA all-sky X-ray survey

- Only the Southern German half of the eROSITA will be publicly available in the next few years



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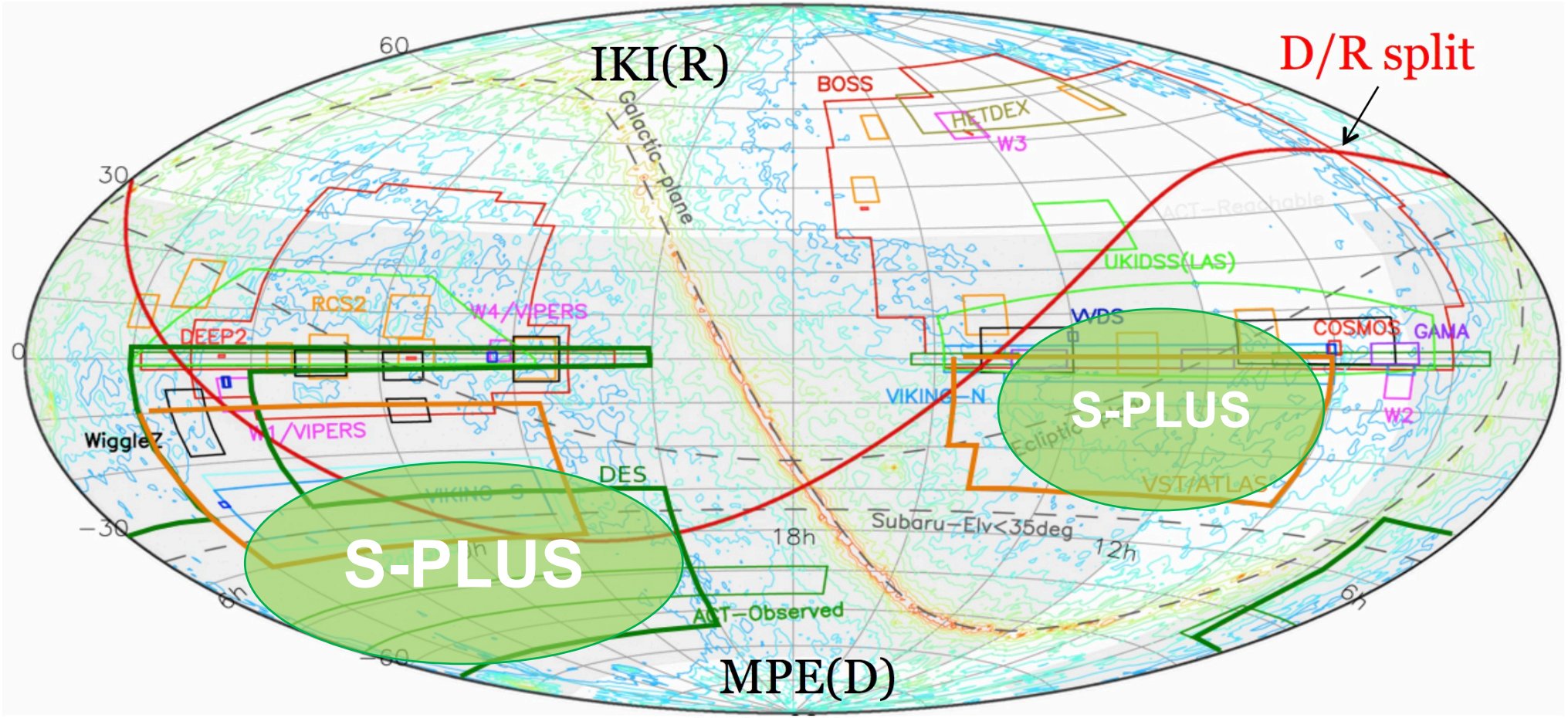

CHANCES

CHileAN Cluster galaxy Evolution Survey

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CHANCES CHileAN Cluster galaxy Evolution Survey

Summary

- Cluster galaxy evolution survey targeting ~300,000 galaxies around 150 of the most massive clusters over 0<z<0.4, extending out to $5r_{200}$ and down to r_{AB}~20.5 All using LRS (R=5000).

- Aims to provide legacy spectroscopic support for the eROSITA X-ray mission, complementing the 4MOST Consortium eROSITA Cluster Redshift Survey (S5). Target rare massive clusters across the ~10,000deg^2 4MOST-eROSITA footprint

- **Low-z CHANCES:** Survey 50 z<0.07 clusters (M>$10^{14}M_\odot$), two superclusters, and our nearest systems (20-40 Mpc) including the Fornax, Hydra and Centaurus clusters, targeting galaxies out to $5r_{200}$ and down to low stellar masses ($10^{8\text{-}9}M_\odot$). SNR>20/Å to get stellar population indices, σ_v.

- **CHANCES evolution:** Target the 50 most massive clusters over 0.07<z<0.4 to track evolution of cluster galaxies over last 4Gyr. High target density (4000deg^2), so aim is to simply get redshifts.

- **CHANGES CGM:** Observe 35K background QSOs within $3r_{200}$ of all z>0.35 eROSITA clusters, to search for MgII absorption systems within their spectra.

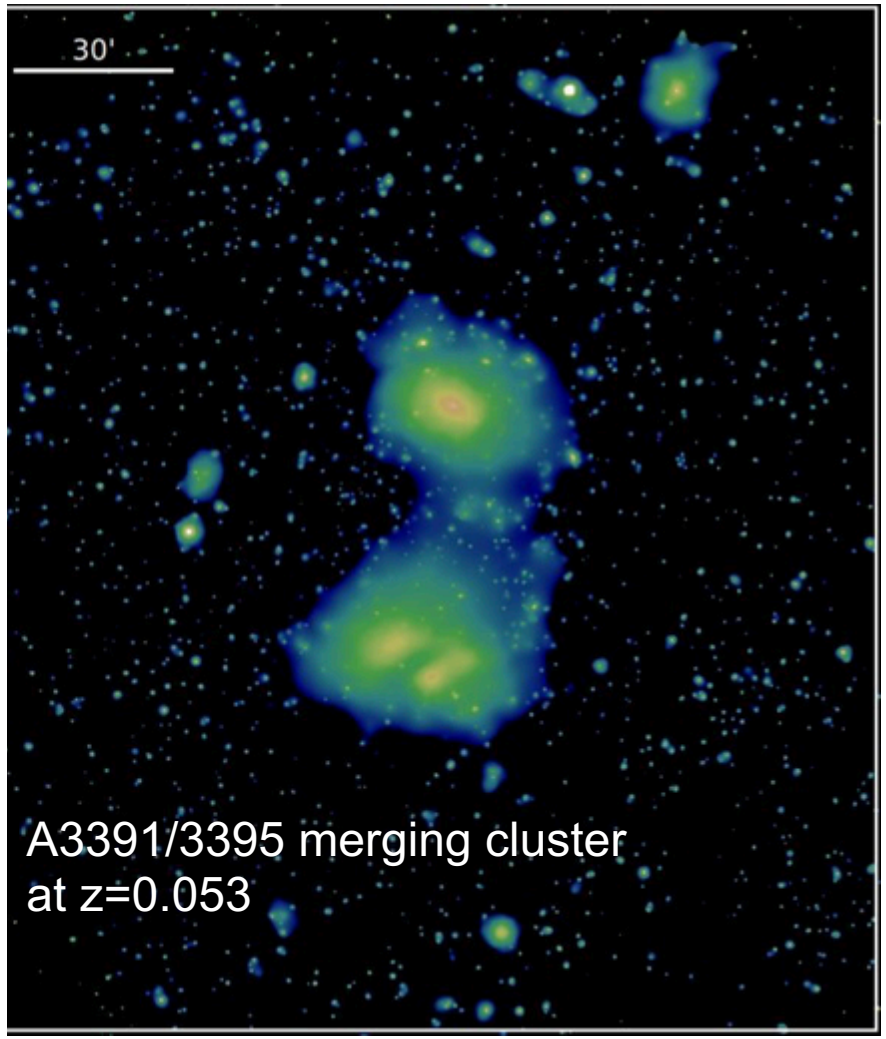
CHANCES CHileAN Cluster galaxy Evolution Survey

Key science goals

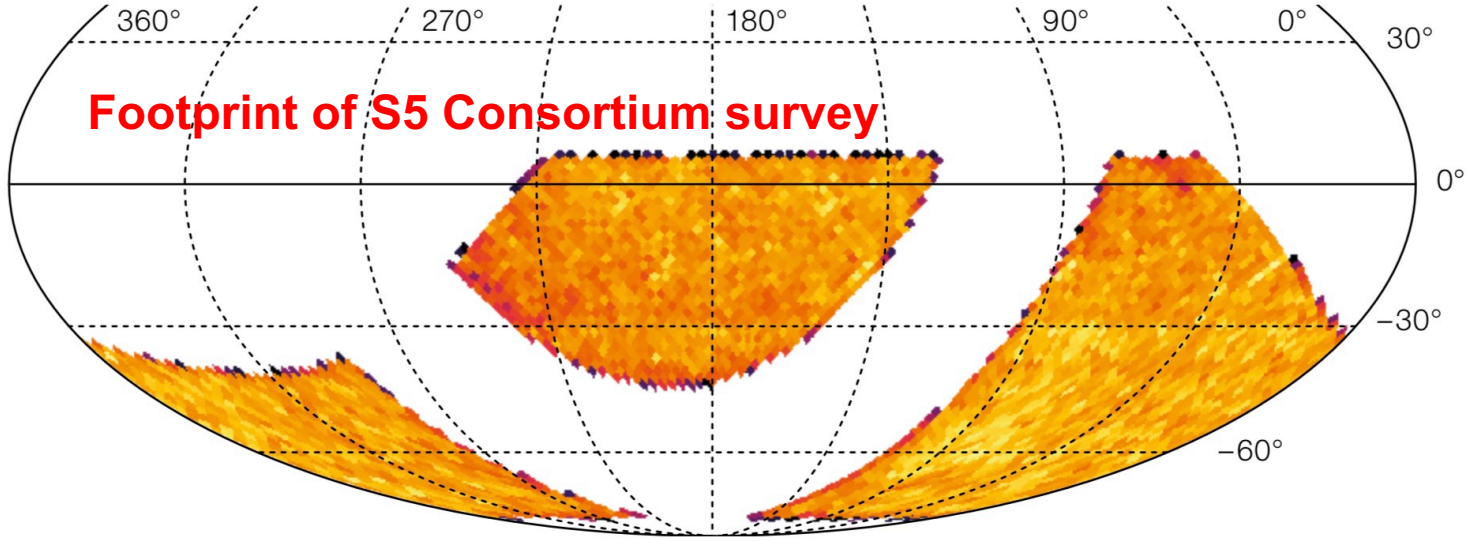
- Quantify **when,** **where** and **how** star-forming spirals are transformed in and around massive clusters to build up the present-day population of quiescent early-type cluster galaxies, as a function of M*
- Track the ongoing assembly of massive clusters at late-epochs, identifying the filaments and infalling galaxy groups through which each cluster accretes its mass and galaxy populations
- Quantify importance of pre-processing in groups for assembling the quiescent galaxy populations that dominate present-day clusters
- Probe the formation and evolution of the cluster dwarf galaxy population
- Track the continuous evolution of cluster galaxies over the last 4 billion years

Synergy with the eROSITA all-sky X-ray survey

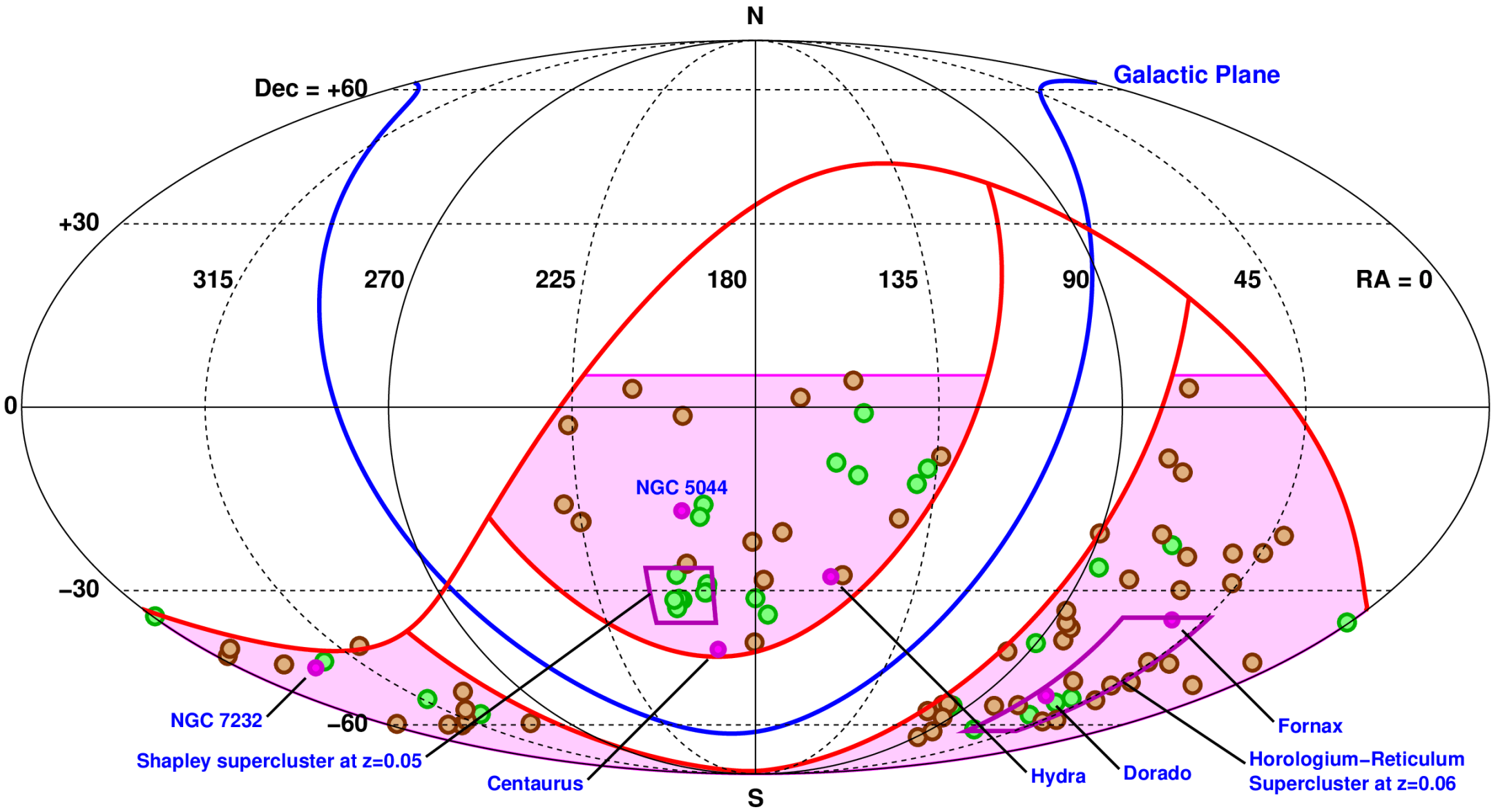
No field-of-view limitations!



- eROSITA will detect all massive clusters in the observable Universe
- For z<0.2 clusters, eROSITA will detect infalling groups ($M>10^{13}\,M_{\odot}$) over the entire cluster infall regions, and the connecting filaments
- Define environment using halos detected by their X-ray emission rather than clustering of member galaxies, permitting us to separate effects of ICM-halo processes from galaxy density (interactions)
- CHANCES will target clusters from the German half of eROSITA sky, that mostly lies in the Southern hemisphere => 4MOST
- Complementary to S5 eROSITA Galaxy Cluster Redshift Survey



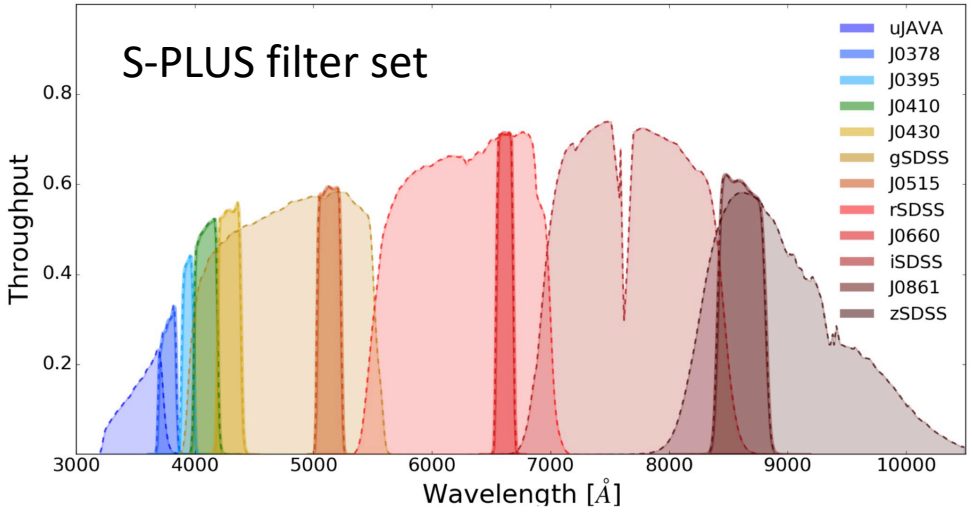
Distribution of CHANCES target clusters

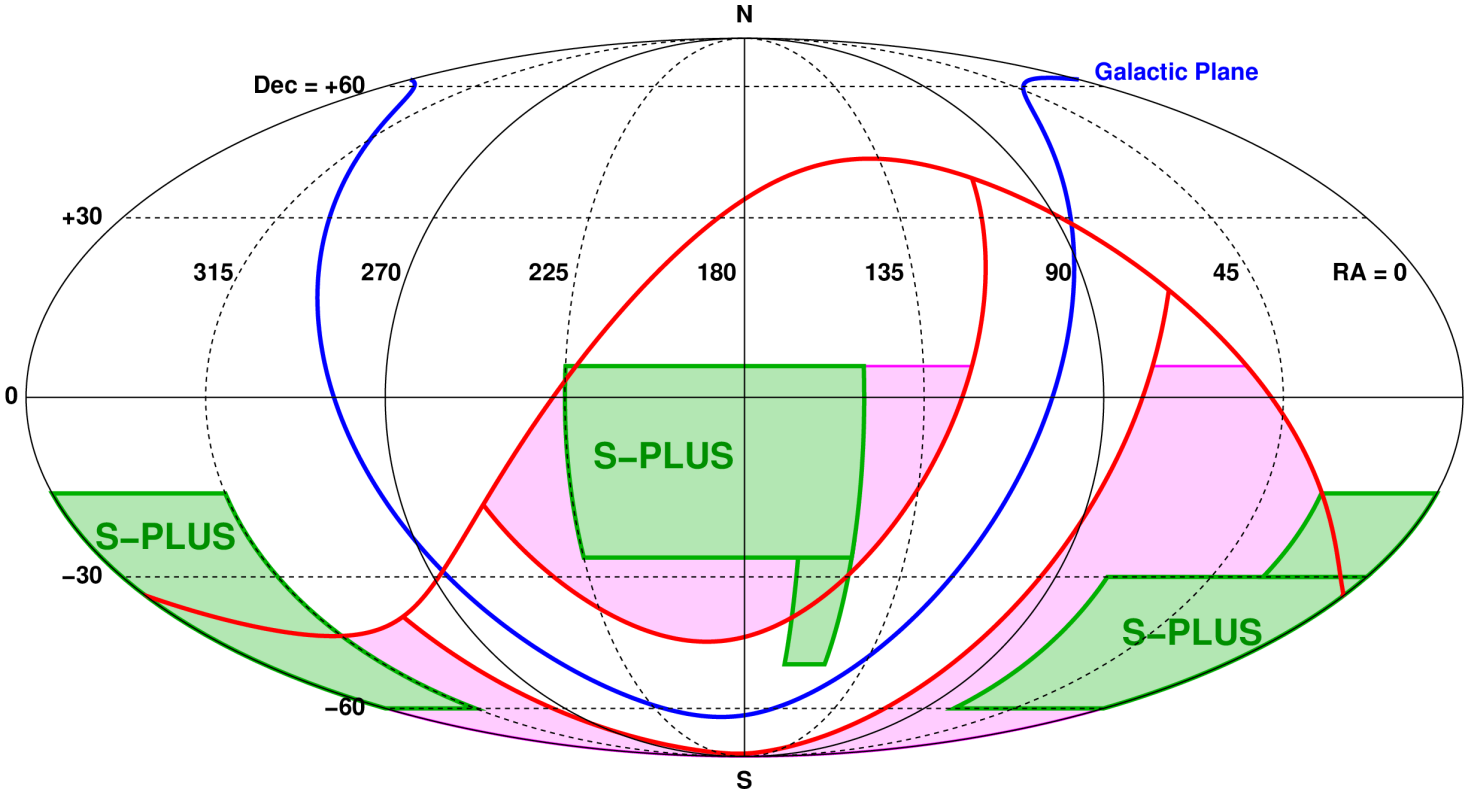


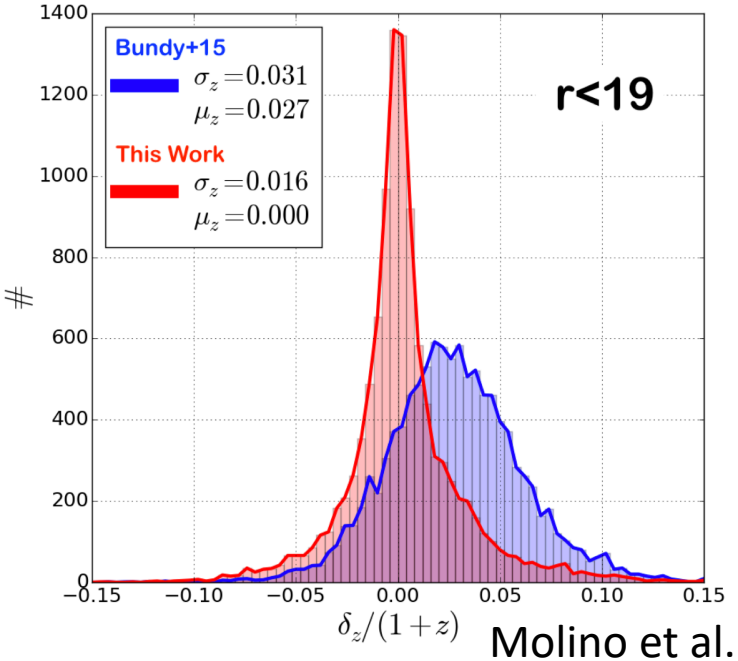
Southern Photometric Local Universe Survey

PI: Claudia Mendes de Oliveira (São Paolo)

- SDSS *ugriz* filters plus 7 narrow-band filters, to r=21
- Greatly improved photometric redshift estimates relative to SDSS
- Use S-PLUS survey to select 4MOST targets as having photometric redshifts consistent with being cluster members
- Expand S-PLUS to cover our other target low-redshift clusters







Molino et al. 2019

Southern Photometric Local Universe Survey

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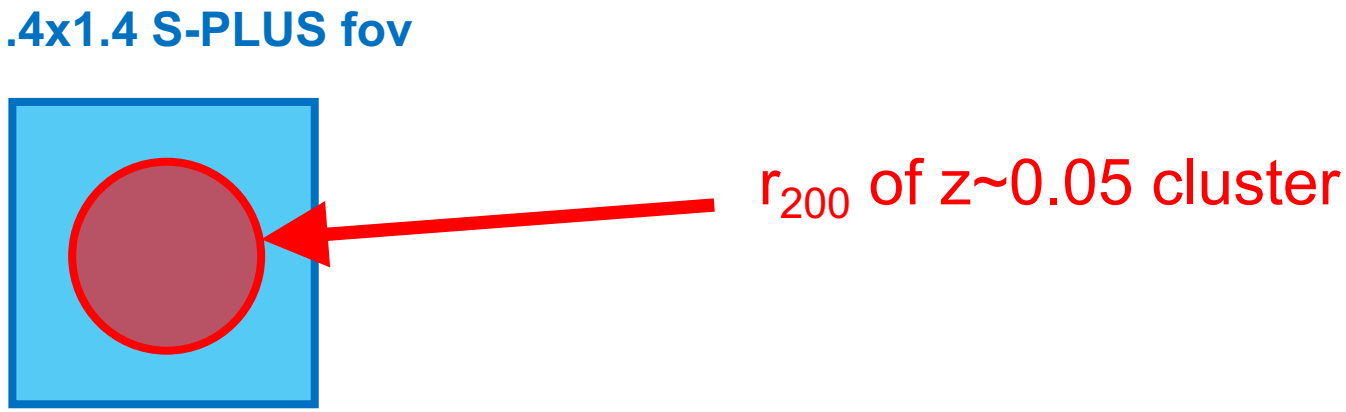
- Chilean proposal (PI: Yara Jaffé to expand S-PLUS to cover our other target low-redshift clusters



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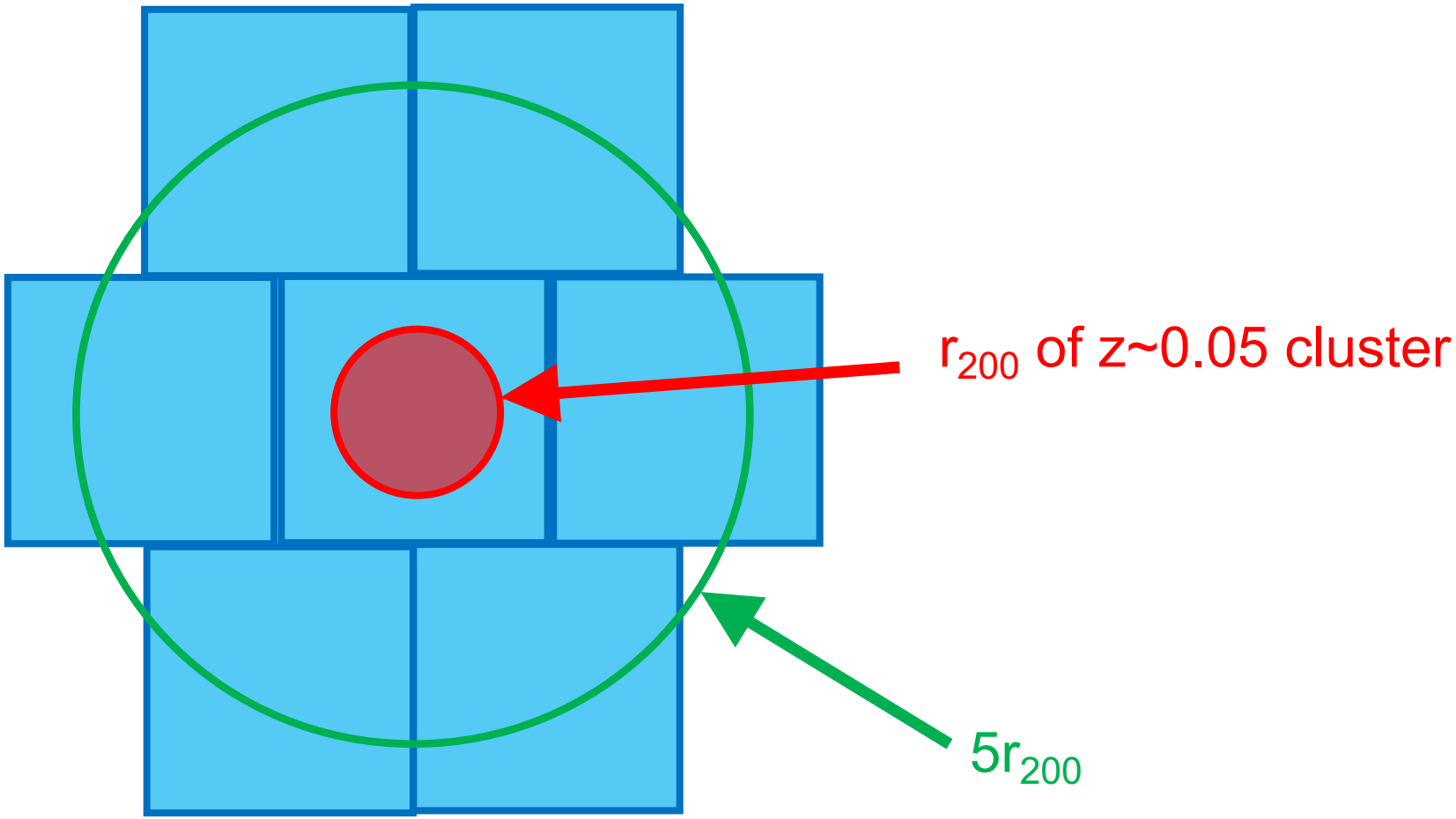
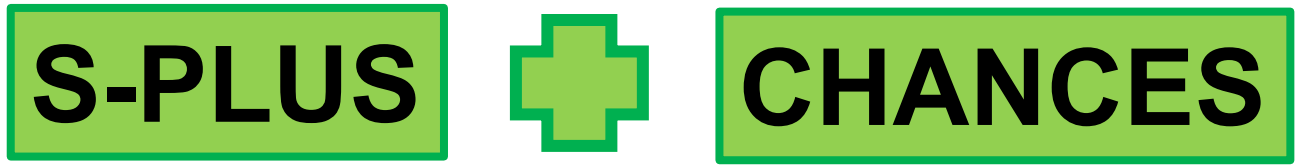


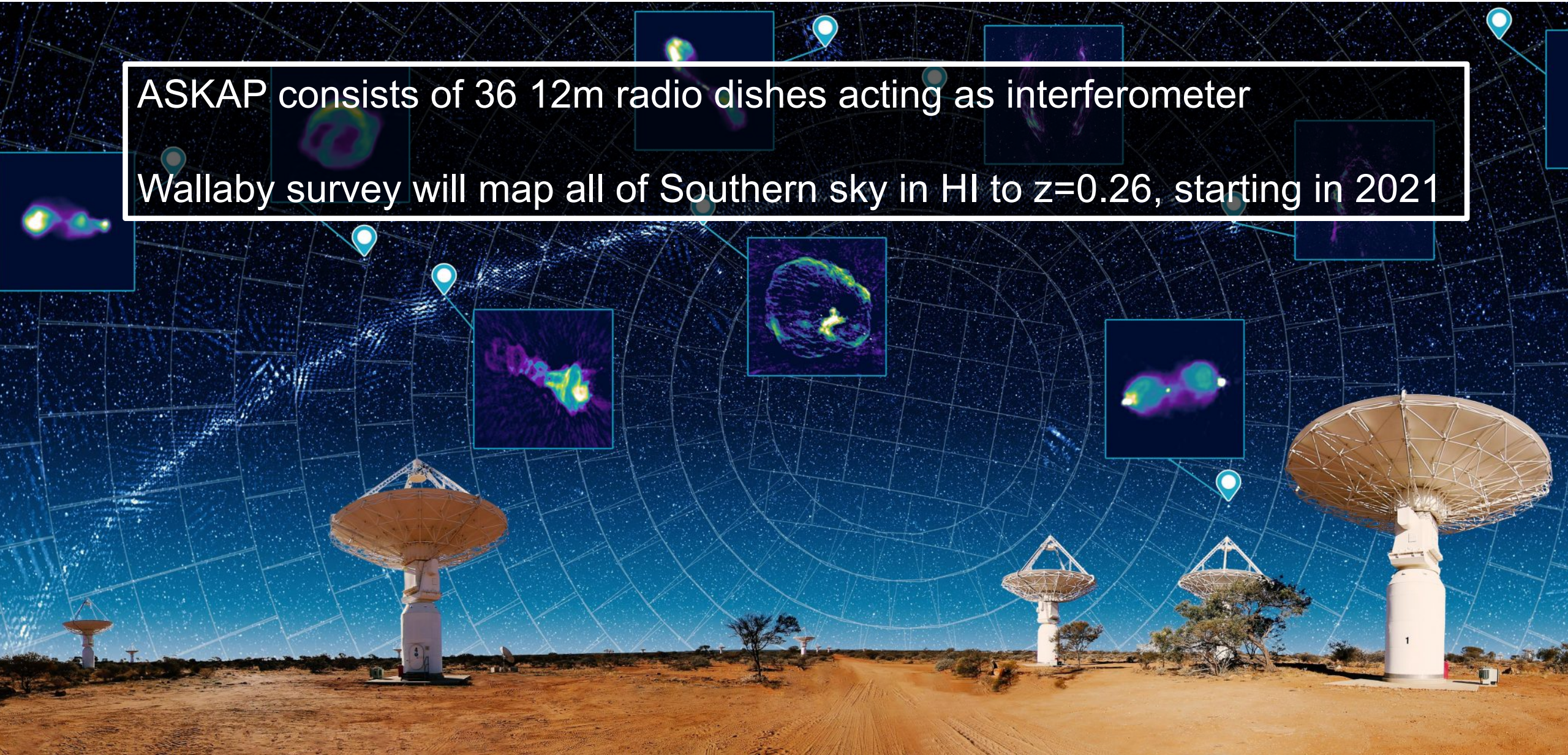
Synergies between CHANCES and S-PLUS



Stellar masses
Morphologies
Resolved galaxy colours, SFHs

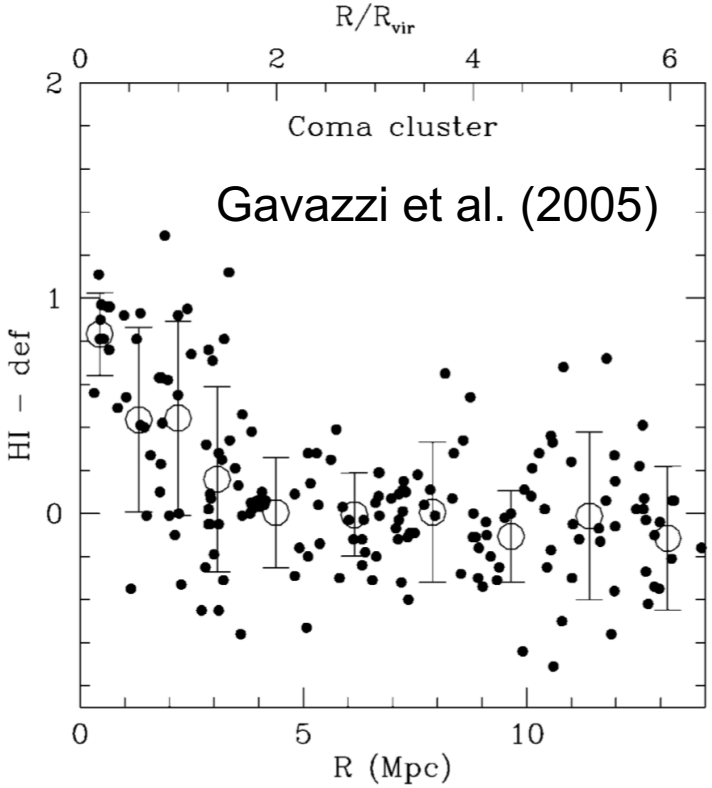
Redshift
Location in cluster phase-space

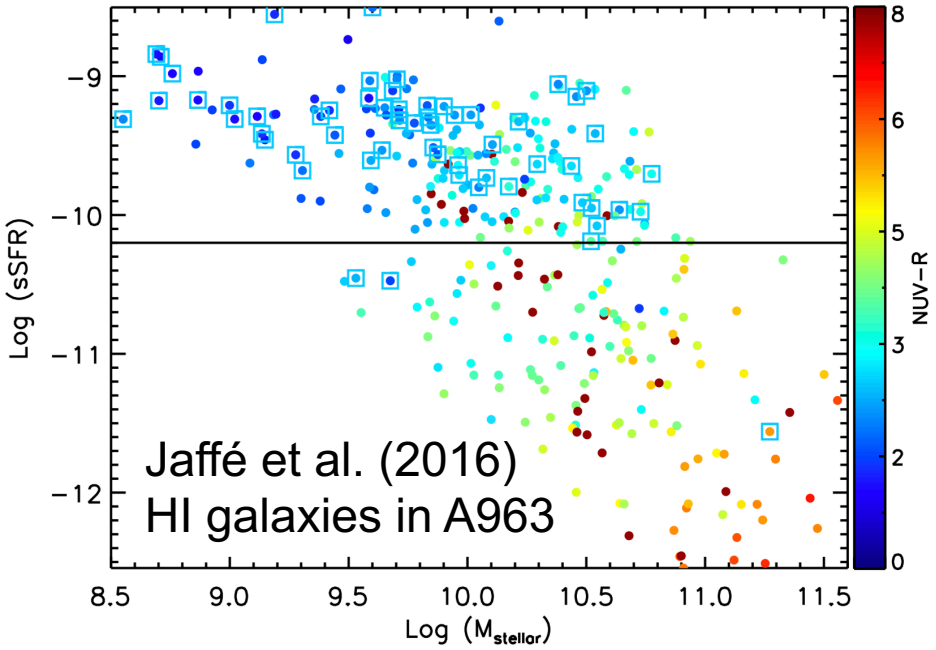
The Wallaby HI Survey with ASKAP



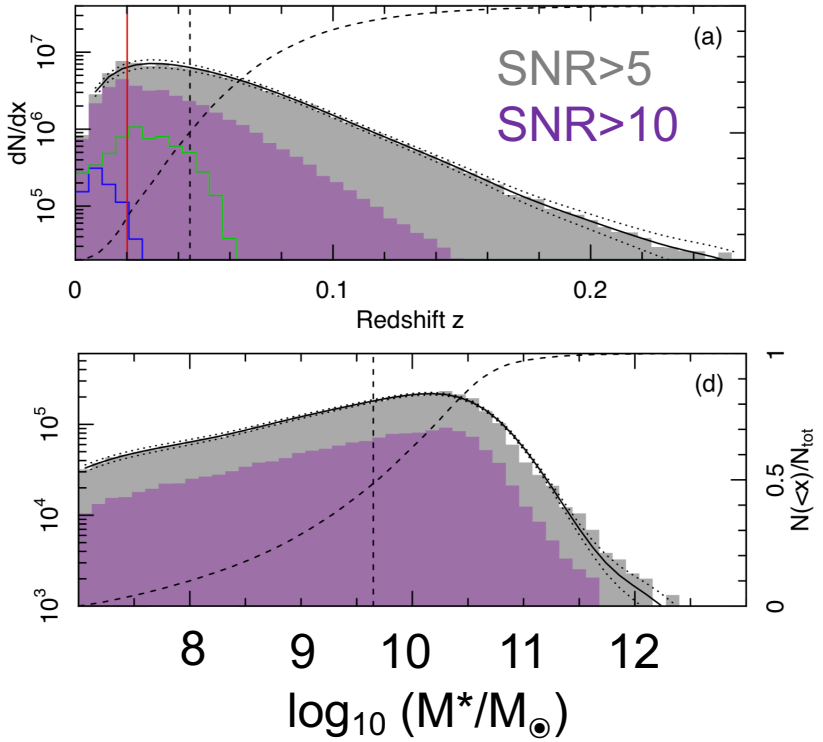
Synergy with Wallaby/ASKAP Survey

- The large HI gas disks of galaxies are very susceptible to ram-pressure stripping in clusters, making HI a sensitive tracer of environmental effects
- Most HI-detections are in low-mass galaxies, due to their high gas fractions
- CHANCES-Wallaby synergy to track impacts of cluster environment on the HI gas contents of dwarf galaxy population in nearby (z<0.07) clusters, and how this feeds through to their ability to continue forming stars





Expected mass and redshift distribution of galaxies detected by the Wallaby HI survey



Koribalski et al. (2020)

CHANCES CHileAN Cluster galaxy Evolution Survey

Summary

Sub-survey	Redshift range	No. of clusters	Area (deg^2)	LRS/ HRS	Target density (deg^{-2})	T_{exp} (min)	SNR	Number of targets
Low-z	0<z<0.07	100	~900	LRS	100-1000	20-120	>15	200K
Evolution	0.07<z<0.4	50	~100	LRS	800-5000	20	2-3	100K
QSO	Z>0.35	10^4	10^4	LRS	3	10	10	35K

The anticipated X-ray data returns from eROSITA motives a cluster galaxy evolution legacy survey across the Southern hemisphere matched to the German half of the eROSITA sky, tracking the late assembly of massive clusters, and the continual accretion and transformation of cluster galaxies since z~0.4.

Impending arrival of Wallaby/ASKAP and LSST will provide further impetus for studying galaxy evolution in low-redshift clusters across the Southern Sky with S-PLUS and CHANCES