Galaxy Evolution in Groups & Clusters at 'low' Redshift: Theory & Observations

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Open Questions

AGN and their feedback:

- How many people think that the central AGN can affect the gas reservoir/ISM of satellite galaxies?
- Is there **concrete evidence for AGN feedback affecting** star formation rate in **galaxies**?
- Is AGN feedback sufficient to quench BCGs?

- What does conformity tells us about the **link between AGN feedback and environmental quenching**?
- Simulations of ram pressure with AGN, and comparison with observational evidence for a link between the two

- How are SMBHs fed and how is their output power dissipated?
- How do AGN transform from high to low Eddington rate accretion states?
- What determines the onset (when an AGN outburst begins) and the total energy output of an AGN outburst?
- **How are massive black holes fueled?**

BCG formation and cluster cores:

- How is the structure of BCGs established and how does it evolve over time?
- How do BCGs assemble and what processes control the evolution of the structure?
- **Formation mechanism of BCGs?**
- What are the effects of mergers on cluster cores?

- Can a satellite ever retain its ISM gas reservoir through infall and deliver it all the way to the central galaxy, if so, what conditions/regimes are necessary?

- Do we need to review computational models of BCGs?

ICM/IGM:

- How diverse are the properties of the intragroup medium across different groups (i.e. baryon budget, entropy profile)? What explains this diversity / lack of diversity?

- **What drives thermal instability** in galaxies and clusters?
- Is our picture of the physics of the cooling and heating cycle in cluster cores robust?
- What is the **microphysics of the ICM** (viscosity, magnetic field properties)?

- What is the relation between star formation in clusters and the properties of the ICM?

ICL:

- Is there an actual **physical boundary between central galaxy and ICL**? Can we revise the observational methods and subtleties for the determination of the amount of diffuse stellar mass in groups and clusters?
- Where do galaxies end and where does ICL start - what is their relation?
- Can one separate BCGs from the surrounding ICL?
- Is there a (physically motivated) boundary between the BCG and the ICL?

- Progenitors of the ICL
- What is the ICL fraction coming from surviving galaxies?
- **ICL: how much is tidal stripping and how much is extragalactic star formation?** Theoretical predictions and observational hints for the ICL origin

- Exact amount of ICL in the context of cluster baryon budget?

Star cluster populations: formation and environment:

- Can we trace back the cluster history from its star cluster population?
- Why does globular cluster system mass correlates so well with its host halo mass?

- How can we **model the formation of globular clusters** in low-mass galaxies at high redshift?

- Do we trace the same star formation and galaxy assembly epochs with different observations (different tracers: stellar light, globular clusters, planetary nebulae, gas)?

Angular momentum of galaxies and environment:

- **What is the role of environment on galaxy spin?**
- Can a cluster environment really change the stellar angular momentum distribution of many galaxies?

- How can we kinematically and dynamically connect late-type galaxies to dwarfs?
- What is the angular momentum of dwarfs and other low surface brightness galaxies?

Ultra Diffuse Galaxies:

- How might the properties/number densities of Ultra Diffuse Galaxies in clusters help us understand efficiency of environmental processing?
- What are the SFHs and mass content of faint, diffuse cluster dwarfs?
- **What are the M/L ratios of large Ultra Diffuse Galaxies?**

Galaxy build-up and resulting characteristics:

- How to determine the ex situ stellar mass fraction observationally?

- How are various **scaling relations built up** and why most of them seem invariant in time? (eg total galaxy stellar mass vs cluster mass)
- What sets the metallicity of cluster satellites?
- How tight is the color-magnitude relation?

- What are the reasonable parameters for a classification of dwarfs and how has each population evolved?

Large-scale environment:

- How important is the connection between a cluster and its surrounding cosmological environment for the cluster population?
- What type of observational signatures do cosmic web stripping simulations predict?
- Is the **cosmic web stripping** efficient? What could be some observational evidence? Do "undisturbed" galaxies really exist?

Simulation challenges:

- Can we trust "2nd-order" predictions (environment) from simulations that are still struggling with "1st-order" issues (e.g. GSMF, assembly of centrals, ...)?
- Which **fundamental predictions from simulations** of galaxy formation and evolution can be **tested observationally** and what are the most important diagnostics?

- How can we improve the treatement of environmental effects in numerical simulations?

- In the light of astronomical surveys, many new faint dwarf-size galaxies and stellar streams covering wide range in luminosity, morphology and stellar contents have been detected. Nearly one decade of investigation on low-mass galaxies in groups, clusters and field, aiming to study their formation history, have shown the significance of environmental effects in their evolutionary path. However, the efficiency of individual mechanisms in different environments and their role in formation of galaxies, notably dEs, UDGs and UFDs are not clear. It demands more observations and precise astrophysical simulations in future. This knowledge is crucial to understand non-linear regime structure formation in more details to answer main questions regarding to “to-big-to-fail” and “missing-satellites-problem”.

Other:

- How should we prepare for Hitomi's recovery mission?

Understanding the connection between an environment and its galaxies:

- What do we need to trace back the cluster history from its galaxy population? What is the relative importance of groups vs clusters for galaxy evolution?
- How do we connect the observations of low-mass galaxies in groups and clusters to the satellite halos in cosmological simulations?
- To what extent did the early environment of a low-mass subhalo determine the baryonic galaxy's properties that got shaped inside it?
- Is there any difference between the properties of quiescent galaxies formed mainly through hydrodynamical effects (e.g., in big clusters) and those of quiescent galaxies formed mainly through gravitational effects (e.g., in groups)?
- Do we trace the same star formation and galaxy assembly epochs with different observations (different tracers: stellar light, globular clusters, planetary nebulae, gas)?
- What galaxy properties depend on the post-infall orbital history vs their earlier growth as centrals?
- What sets the metallicity of cluster satellites?
- Do field and cluster low-mass galaxies share a common origin?
- What galaxy properties are influenced the strongest by pre-processing in groups/subclusters? Do these properties reflect the cluster's assembly history?
- Can the cluster environment enhance the star formation activity of galaxies?
- Is pre-processing in groups more important than the subsequent evolution within a cluster for a cluster galaxy?
- **Do "undisturbed" galaxies really exist?**
- Which galaxies care about being "in a cluster"?
- What is environment?
- **What is a protocluster?**
- How are various scaling relations (eg total galaxy stellar mass vs cluster mass) built up and why most of them seem invariant in time?

Quenching and starvation:

- What is the quenching route of satellites? How do we reconcile the observational claims for slow quenching, rapid quenching or delayed-then-rapid quenching? What are the physical mechanisms which dominate satellite quenching?
- Transformation: morphology first, then quenching or quenching first then morphology?
- When do galaxies in clusters stop forming stars?
- What are the dominant quenching mechanisms in each environment.
- **How are we going to settle the issue as to the MAJOR satellite quenching mechanism?**
- How much of the quenching in cluster galaxies takes place in-situ or through preprocessing. What clues does the gas kinematics hold related to quenching mechanisms.
- How fast is star formation shut off in satellites which become red and what observational signatures therefore exist?
- Timescales for quenching
- How many different kinds of starvation are important in the universe? How can we distinguish between different types of starvation? (halo gas removed by tidal interactions or ram pressure, or driven out by feedback, or kept hot by feedback or accretion energy)
- Dominance of different quenching mechanisms, quenching timescales, evolution of environmental quenching with cosmic time

- What physical process(es) cause environmental quenching? Does the dominant mechanism vary with redshift?
- What is the main mechanism for star formation quenching in groups and clusters?
- Which mechanisms are important for quenching star formation in group/cluster galaxies under which circumstances?
- How does quenching work?
- What stopped the star formaion in infalling galaxies onto a cluster and how long was the time scale?
- Are `quenching' time-scales estimated observationally for large statistical samples the best tool to unveil the physical processes affecting galaxies?
- What are the physical mechanisms responsible for the star formation quenching in dense environments?
- What's more important for SF quenching between mass and environment?

Environmental processes and their relative importance:

- Transformation: morphology first, then quenching or quenching first then morphology?
- How do galaxy morphologies transform in groups and clusters.
- Do we understand the relative balance of gravitational and hydrodynamical mechanisms as a function of group/cluster mass?
- How do galaxies interplay with environments and what are consequences(quenching star formation, morphological transient and gaseous structure deformation) of interactions?
- How do we distinguish different environmental effects observationally?
- Identification of the dominant perturbing mechanisms in different environments
- What environmental processes dominate the transformation of satellite galaxies at different host masses?
- Is there a hard boundary (e.g. virial/splashback radius) only within which satellites start to experience strong environmental effects?
- What is the average fraction of stellar mass a satellite galaxy has lost due to tidal effects?
- Are destructive environmental mechanisms important for building up the population of dwarf galaxies in clusters today?
- How important were gravitational interactions in the past evolution of today's cluster low-mass galaxies?
- What is the timescale of morphological versus color evolution and do they vary with galaxy mass? Where--at what local density--does the environment begin to drive galaxy evolution, and again, how does it vary with galaxy mass and morphology? Does feedback have a strong role in driving satellite galaxy evolution?
- How can we improve the treatement of environmental effects in numerical simulations?
- **How to properly define/and quantify pre-processing?**
- What is the role of environment in shaping galaxy morphology?

Ram Pressure Stripping:

- Have we found any direct evidence of ram pressure stripping in groups and small clusters? And more in general, do we understand the r**elative balance of gravitational and hydrodynamical mechanisms** as a function of group/cluster mass?
- **How does ram pressure really work on a multi-phase, clumpy ISM?** Can the best, high-res simulations make predictions that we can test with observations?

- How exactly does the cold galactic gas and the hot ICM interact, in particular given that both are actually plasmas?
- What is the difference is the evolution of GMCs in disks and in ram pressure stripped tails?
- Why star formation efficiency is low in stripped gas?
- Fate of the stripped gas
- What is/are the fate(s) of the stripped gas from galaxies?
- Can a satellite ever retain its ISM gas reservoir through infall and deliver it all the way to the central galaxy, if so, what conditions/regimes are necessary?
- Isn't starvation (loss of the gaseous halo) of low-mass galaxies more relevant than ram pressure stripping of disk gas, simply because it set in many gigayears earlier?
- Observations and theory of ram pressure stripping in groups
- Simulations of ram pressure with AGN, and comparison with observational evidence for a link between the two