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Galaxy formation with HETDEX Correlation Functions

Supervisor: Daniel J Farrow
Contact email: d.j.farrow@hull.ac.uk

HETDEX is a spectroscopic survey containing both distant and nearby galaxies. It has the largest sample of high-redshift Lyman-alpha emitting galaxies in the world. Correlation functions measure the spatial distribution of galaxies. Marked correlation functions measure the probability of finding two galaxies with similar properties close to each other. Both probe the physics of how galaxies form within the “cosmic web” of dark matter. In this project you will measure luminosity dependent and marked correlation-functions and use them to probe how galaxies form, both in the nearby universe and at high redshifts.

Finding analogues to the Coma Cluster

Supervisor: Kevin Pimbblet
Contact email: k.pimbblet@hull.ac.uk

The Coma cluster of galaxies is the closest of its mass (2 x 10^{15} solar masses) to us. For decades it has been used as a redshift z=0 baseline to compare other, higher redshift, clusters against. It was once thought of as being “regular” and “relaxed”. It is anything but those qualities and its status as a comparator against which all other clusters should be baselined is questioned (Pimbblet et al., 2013). In this project, we will seek out analogues to the Coma cluster at slightly higher redshifts in order to expand on our previous works and determine not only how unusual (or not) Coma might be, but also to build a suite of galaxy clusters to act as a representative low redshift baseline. To do this, we will make use of large surveys such as SDSS and others to search across parameter space to find analogues and map their properties.

Galaxy kinematics in heterogeneous Shakhbazyan groups

Supervisor: Kevin Pimbblet
Contact email: k.pimbblet@hull.ac.uk

Shakhbazyan groups of galaxies (e.g. Shakhbazyan 1973) are an heterogeneous collection of various different stages of group formation and evolution that are sometimes missed in systematic surveys of the sky. They are environmentally and characteristically intermediate in measurable properties between loose and very compact groups and they are likely to contain a variety of physical conditions within them. Capozzi et al. (2009) performed a detailed investigation into such groups contained in the Sloan Digital Sky Survey and deduced there were two main sub-classes: compact, isolated groups and extended structures. In this project, you will extend these previous works by determining how galaxies of different spectroscopic types populate these two sub-classes in a manner similar to Pimbblet et al. (2006) and Pimbblet (2011) and thereby determine the effect of this "environment" on the evolution of their constituent galaxies.

X-Ray dark clusters and groups

Supervisor: Kevin Pimbblet
Contact email: k.pimbblet@hull.ac.uk

It is to be expected that most clusters of galaxies will shine brightly in the X-ray thanks to thermal bremsstrahlung of the hot intra-cluster gas that they contain. As we go down the cluster mass function, the amount of X-ray emitting gas may get lower, and the electron density will also be likely to drop. By the time we reach groups of galaxies, there may be little X-ray emission detectable with current instrumentation. On top of this, there is a variation in the amount of intra-cluster gas from cluster to cluster, and group to group, including possible X-ray dark clusters and groups whose emission might well be below the detection threshold of current instruments (cf. Gilbank et al. 2004). In this project, we will stack together clusters and groups of galaxies whose X-ray emission we cannot see on their own. By doing so, we can potentially make new estimates on the mass of these clusters and groups, depending on how we stack them together, and the electron densities that they contain within certain radii.

Far-Infrared Emission Line Diagnostics of the Interstellar Medium in Simulations of Galaxy Formation

Supervisor: Alex Richings
Contact email: a.j.richings@hull.ac.uk

Far-infrared emission lines from metal ions such as CII and OI are important coolants in the Interstellar Medium (ISM). Measuring these emission lines with space telescopes such as Spitzer and Herschel therefore gives us key insights into the physical properties of the interstellar medium (ISM) in other galaxies (e.g. Croxall et al. 2012). However, connecting the emission lines that we observe to the physical state of the gas that these lines are probing requires a detailed theoretical understanding of the thermo-chemical processes that produce these lines. In this project, we will use state-of-the-art hydrodynamic simulations of isolated disc galaxies (Richings et al. 2022) to create synthetic spectra of these far-infrared lines. We will use these predictions to explore the properties of the gas that produces these lines, and we will compare the simulation predictions to observational datasets to test our galaxy formation models. Finally, we will use the simulations to probe the origin of far-infrared line deficits, where far-infrared lines such as CII are observed to be weaker than expected in galaxies undergoing extreme star formation (e.g. Liang et al. 2024; see also Graciá-Carpio et al. 2011).

Gas stripping in turbulent galaxy clusters

Supervisor: Dr Elke Roediger
Contact email: e.roediger@hull.ac.uk

Galaxies that fall into galaxy clusters move at transonic speeds through the cluster's hot atmosphere, the intra-cluster medium (ICM). The ICM head wind experienced by a cluster galaxy can remove its own gas. This process is known as gas stripping or ram pressure stripping (Gunn & Gott 1972). The stripped galactic gas is expected to eventually mix with the ICM. The degree of mixing along the stripped gas tail has been used to measure the ICM viscosity (Roediger et al. 2015ab, Kraft et al. 2017). However, pre-existing turbulence in the ICM could impact the mixing efficiency. In this project, we investigate how gas stripping of cluster galaxies depends on ICM turbulence properties using hydrodynamical simulations and comparisons to well-observed examples.

Sloshing in a turbulent cluster

Supervisor: Dr Elke Roediger
Contact email: e.roediger@hull.ac.uk

Galaxy clusters are the largest collapsed structures in the Universe. A cluster's hot atmosphere, i.e., its intra-cluster medium (ICM), is settled approximately in hydrostatic equilibrium in the cluster's gravitational potential. However, minor mergers, i.e., the collision with a significantly smaller cluster, triggers slow sloshing motions of the ICM in the cluster potential. Such sloshing leads to the well-known sloshing cold fronts, which are discontinuities in ICM density, wrapped around the cluster in a spiral pattern (e.g., Ascasibar & Markevitch 2006). Shear flows along those discontinuities are expected to lead to Kelvin-Helmholtz instabilities (KHIs). Hydrodynamical simulations found that sloshing cold fronts are generally not destroyed by KHIs but only distorted (e.g., Roediger et al., ZuHone et al.). However, the net effect of the KHIs could depend on the seeds they grow from, i.e., on the properties of perturbations existing in the ICM. In this project, we investigate how the evolution of sloshing cold fronts depends on pre-existing turbulence in the ICM. We use hydrodynamical simulations and compare to well-observed sloshing clusters.

AGN activity in the minor merger cluster Hydra A

Supervisor: Dr Elke Roediger
Contact email: e.roediger@hull.ac.uk

The nearby cluster Hydra A contains a strong outburst from its central active galactic nucleus (AGN) that has inflated radio bubbles in its intra-cluster medium (ICM) and driven a 500 kpc large shock surrounding the pair of bubbles (Simionescu, Roediger, et al. 2009). Additionally, this cluster appears to be undergoing a minor merger, indicated by a galaxy group with a slingshot gas tail in its southern outskirts (De Grandi et al. 2016, Sheardown et al. 2019). This ongoing minor merger could also have caused the north-south asymmetry in the AGN bubble-shock structure. The young turbulent wake left by the southern group throughout the main cluster could now be interacting with the large-scale AGN shock. The goal of this project is to perform numerical hydrodynamical simulations of the combined AGN and merger activity and test whether this scenario can reproduce features observed in Hydra A quantitatively.

Alien fingerprints – building the next database of molecular signatures

Supervisor: David Benoit
Contact email: d.benoit@hull.ac.uk

Are we alone in the Universe? This question has been driving remarkable scientific achievements in astronomy and astrobiology over decades (see for example Des Marais et al. 2008). A fundamental step to answer this question is the observation of biologically-relevant molecules in the Universe. However, apart from well-known molecules like water, ammonia, methane and methanol, we lack basic data to detect most biomolecules. For instance, data on halogenated compounds is under-represented despite those molecules being important tracers for oceanic life (Seager et al., 2016). Most of the ways to detect those chemical signatures ultimately rely on looking for spectroscopic evidence of molecules that could support (or be direct evidence of) life. Seager et al. (2016) provided a set of over 16,000 molecules that could be considered as viable biosignatures. Yet, we know less than five percent of these much-needed spectral fingerprints (Seager et al., 2016). Therefore, expanding our knowledge is key to mapping out the diversity of our molecular environment.

In this project, we will use a new computational method (the Prometheus software) developed in our group to simulate the infrared spectral signature of diatomic molecules. We will compare our simulated results with the available data from the CDMS database and determine how accurately our approach reproduces known molecular signals, before extending the approach to model lesser-known ones. These new molecular signatures will form the basis of a new database for future biosignature detection.