Why Circumgalactic Matter Matters for Galaxy Evolution

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The circumgalactic medium (CGM; non-ISM gas within a galaxy virial radius) regulates the gas flows that shape the assembly and evolution of galaxies. It most likely contains enough material to harbor most of the metals lost in galaxy winds and to sustain star-formation for billions of years. Owing to the vastly improved capabilities in space-based UV spectroscopy with the installation of HST/COS, observations and simulations of the CGM have emerged as the new frontier of galaxy evolution studies. In this talk, I will describe observational constraints we have placed on the origin and fate of this material by studying the gas kinematics, metallicity and ionization state of gas 10 – 200 kpc from galaxies stars. I will conclude by discussing several unanswered questions about the CGM that should be addressed with future survey data and hydrodynamic simulations at high resolution.
Observational evidence is increasingly indicating that the ambient cooling time ($t_{\text{cool}}$) in the CGM of a massive galaxy never drops much below 10 times the freefall time ($t_{\text{ff}}$) at any radius. Phenomenological models suggest that ambient gas with a smaller $t_{\text{c}}/t_{\text{ff}}$ ratio cannot persist because it is too susceptible to multiphase condensation (i.e. precipitation) and chaotic cold accretion that strongly boosts AGN feedback which inflates bubbles in the CGM. Theoretical analyses of the condensation process show that feedback should couple both condensation and turbulence to the $t_{\text{c}}/t_{\text{ff}}$ ratio, providing some observational tests of precipitation-regulated feedback mechanisms. I will present the supporting evidence and discuss how the precipitation framework that emerges may apply to the CGM around lower-mass galaxies.
Gas in-flows and out-flows play a major role in galaxy formation and evolution. Inflows bring fresh material and play a crucial role in the angular momentum build-up of disks, while outflows are thought to expel 90 to 99% of baryons back into the intergalactic medium. I will begin by reviewing the impact of inflows/outflows on the global properties of galaxies and then review observational evidence of outflows at intermediate redshifts. I will review and compare the various techniques used to quantify outflow rates.
In quasar spectroscopy, we routinely observe cold photoionized gas in the circumgalactic medium of galaxies moving at high velocities close to the escape speed. The usual assumption is that this gas has been accelerated by ram pressure forces due to the hot outflowing wind. However, attempts to directly simulate this process have almost universally been unsuccessful, simply because the cloud-crushing and Kelvin-Helmholtz times are shorter than the acceleration time. I discuss some possible solutions to this vexing problem.
In this talk, I will present a simple model for gas infall in a dynamically growing dark matter halo and subsequent cooling and feedback heating based on a simple Bondi model, for a range of redshifts $z = 6 - 0$. We tune the feedback efficiency to match the existing stellar mass and halo mass relation, obtained from abundance matching, at low redshifts. We look at the “missing baryons” problem in this simple model. Additionally, we get reasonable radial profiles of the intracluster medium for density and temperature which are qualitatively similar to those observed in clusters. I will also talk about cold gas condensation in galaxy clusters, which are the largest halos in the universe. The hot intracluster medium shows multiphase gas if the ratio of the cooling time to the free-fall time is less than a threshold around 10. In lower mass halos, the density perturbations ($\delta \rho / \rho$) can be large. We show that condensation can occur at much higher $t_{\text{cool}} / t_{\text{ff}}$ if $\delta \rho / \rho \gtrsim 1$. This scenario may explain the ubiquitous multiphase gas observed by COS in galactic halos.
Using a large quantity of spectral and imaging data obtained with UVES & MUSE on the VLT and ACS & COS on-board HST, we have started a major campaign on the CGM of high-z \((z > 2.9)\) and low-z \((z < 0.9)\) galaxies. With nearly 350 low-z galaxies and 150 high-z Lyman alpha emitters detected in a total of 24 MUSE cubes (16 for low-z and 8 for high-z), we have built two statistically significant and by far the largest samples for which CGM absorption line (e.g. Lya, SiII, CIV, OVI) data are available. Preliminary results of our surveys (MUSE Quasar-field Blind Emitter Surveys; MUSEQuBES) will be presented in the talk.
The circumgalactic medium (CGM) of galaxies consists of a multiphase gas with components at very different temperatures, from $10^4$ to $10^7$ K. It constitutes the interface between the interstellar medium (ISM) and the intergalactic medium (IGM) and modelling its kinematics and dynamics is critical for our understanding of the role of feedback and gas accretion in galaxy evolution. The most puzzling component of this medium is the low-temperature ($T \sim 10^4$ K) material detected via UV-optical absorptions towards background QSOs. The ubiquitous presence of this material has recently been established both around star-forming and early-type galaxies. The origin, dynamics and fate of this medium are still unclear, in particular in early-type galaxies, where the presence of such a large amount of cold gas seems in contrast with the absence of star-formation. We have modelled this cold gas as an inflow of clouds from the IGM to the central galaxies and compared our model predictions with the observations of the COS-Halos collaboration, focusing on a sample of massive early-type galaxies. Our models successfully reproduce the observed kinematics of the cold gas as long as the infalling clouds are destroyed by the hydrodynamical interactions with the hot gas and therefore are not able to reach the central galaxy, explaining in this way the quenching of these passive galaxies. This scenario suggests that the fate of the cold CGM has a crucial role in the evolution of star formation in galaxies.
We present low frequency radio observations of the extended emission around an interacting galaxy pair in the Bootes void. Voids contain a sparse but significant population of galaxies that show signatures of ongoing star formation and AGN activity. They appear to be similar in nature to normal galaxies in denser environments but are evolving at a much slower rate. The sparse environment of voids allows us to study the evolution of the circum galactic medium (CGM) around AGN or starburst host galaxies in isolated environments. We have detected extended X-ray emission and radio emission around an interacting pair of galaxies CG693 and CG692 in the Bootes void. The AGN host galaxy CG693 has a hot X-ray halo whereas the companion galaxy CG692 has extended low frequency radio emission due to star formation. We present our results and its implications for understanding galaxy evolutions and AGN feedback in isolated environments.
It is well-known that most galaxies are missing most of their metals and their baryonic mass. I will present Chandra observations probing our Milky Way halo in absorption. Together with XMM and Suzaku data on emission, our results show that the Milky Way halo contains a huge reservoir of warm-hot gas that may account for a large fraction of missing baryons and metals. We also found evidence for the Galactic center cavity which is also traced by the Fermi bubbles. I’ll review current status of this field, discuss implications of our results to models of galaxy formation and evolution and outline paths for future progress.