Galaxy Fueling and Quenching: A Science Case for Future UV MOS Capability

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The gas flows that drive galaxy accretion and feedback are critical, but still poorly understood, processes in their formation and evolution. One of Hubble's successes has been in characterizing the circumgalactic medium (CGM) that spans 30 times the radius and 10000 times the volume of the visible stellar disk. Thanks to Hubble and its ground-based optical collaborators, we know roughly how much matter the CGM contains, but the extremely low densities make it difficult to ascertain its exact role in galaxy evolution. The critical question is how this gas enters and leaves the galaxies: galactic star formation rates are limited by the rate at which they can acquire gas from their surroundings, and the rate at which they accumulate heavy elements is limited by how much they eject in outflows. Much of the still-unknown story of how galaxies formed comes down to how they acquire, process, and recycle their gas.

Hubble can make only crude statistical maps by sampling many halos with one absorption-line path through each. The future challenge is to "take a picture" of the CGM using wide-field UV spectroscopy that is > 50x more sensitive than Hubble. A moderate resolution (R~5000), wide-field (3-5 arcmin) multi-object UV spectrograph that can detect this CGM gas directly would revolutionize this subject. This is intrinsically a UV problem since most of the energy transferred by diffuse gas on its way in or out of galaxies is emitted or absorbed in rest-frame UV lines of H, C, O, Ne, and other metals, including rest-frame extreme-UV lines that redshift into the 1000-2000 Å band at $z > 0.5$ (Bertone et al. 2013; Fig. 1).

If sufficiently large (10-12 meters) and properly equipped, NASA's LUVOIR Surveyor will be able to map the density, temperature, and mass flow rates of the CGM, directly, using the UV radiation emitted by CGM gas as it cycles in and out of galaxies. Observing up to 50-100 sources at a time, LUVOIR could map the faint light ($S_B \sim 100$ photons cm^{-2} s^{-1} sr^{-1}) emitted by gas entering and leaving galaxies, to count up the heavy element content of this gas, to watch the flows as they are ejected and recycled, and to witness their fate when galaxies quench their star formation, all as a function of galaxy type and evolutionary state. LUVOIR could map hundreds of galaxies in fields where its deep imaging identifies filaments in the large-scale structure, and where ground-based ELTs have made deep redshift surveys to pinpoint the galactic structures and sources of metals to be seen in the CGM.

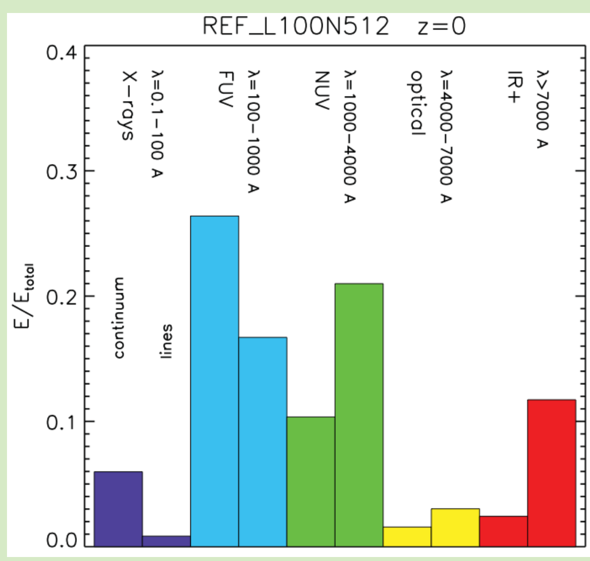

Figure 1: From "How the Diffuse Universe Cools", by Bertone, Aguirre, & Schaye (2013). The bars show the fraction of energy emitted in various rest-frame bands by gas cooling radiation in a hydrodynamical galaxy formation simulation. More than half of the radiation is emitted in the rest-frame FUV (100-1000 Å) and most of the remainder is in the NUV (1000-4000 Å).

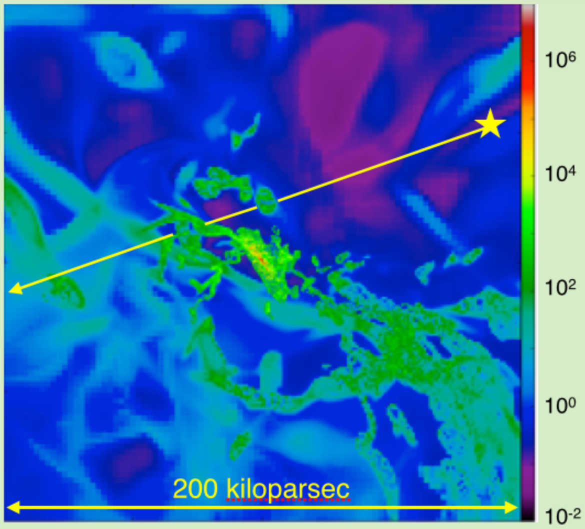

Figure 2: A visualization of the Circumgalactic Medium (CGM) gas fueling a Milky-Way like galaxy at z ~ 0.25. The color renders the strength of UV emission by C IV in the CGM gas in terms of photons cm^{-2} s^{-1} sr^{-1}. For real 2D characterization of the CGM, the LUVOIR Surveyor must reach CGM gas with $S_B \gtrsim 100$ units. The contrast between the 2D image of the CGM and the single hypothetical QSO sightline demonstrates the power of imaging the CGM over continuing to develop statistical maps from single sightlines. Image from Joung, Fernandez, Bryan, Putman and Corlies (2012, 2015).

Because this radiation is far weaker than local foreground radiation, ground-based telescopes seeking it at redshifts where it appears in the visible ($z > 2$) must perform exquisite sky foreground subtraction to reveal the faint underlying signal. These foregrounds will be considerably lower from space (by 10-100x), shortening required exposure times by an equivalent factor. Even apart from lower sky backgrounds, accessing the UV provides far better access to the relevant line diagnostics over most of cosmic time: the key lines HI Lyα, CIV 1550, and O VI 1032 are inaccessible from the ground over the last 10 billion years of cosmic time. This includes all cosmic star formation since its z ~ 2 peak, opening for view the complete co-evolution of galaxies and their gas supplies over the period when ~80% of the cosmic stellar mass density was formed (Madau & Dickinson 2015).

This unique UV capability will also address the mystery of how galaxies quench and remain so. The number density of passive galaxies has increased 10-fold over the 10 Gyr interval since $z \sim 2$ (Brammer et al. 2011). Galaxies undergoing quenching are the ideal laboratories to study the feedback that all galaxies experience: the galactic superwinds driven by supernovae and stellar radiation, the hot plasma ejected by black holes lurking in galactic centers, and the violent mergers that transform galaxy shapes while triggering the consumption or ejection of pre-existing gas. Only a 10-12 meter LUVOIR Surveyor would have the collecting area to support deep, wide-field UV MOS searches for CGM gas at the line emission fluxes that are expected, *and* the spatial resolution to observe the transformation of star forming disks to passive spheroids at 50-100 pc spatial resolution and closely examine the influence of AGN on this process. For galaxies identified as quenching, emission maps of the surrounding CGM will determine the fate of the gas that galaxies must consume or eject and powerfully elucidate the physical mechanisms that trigger and then maintain quenching. Only a 10-12 meter space telescope can achieve such spatial resolution in the optical and observe the rest-frame UV light necessary to witness the co-evolution of stars and gas in galaxies undergoing this transition. As most of the development of the present-day red sequence occurred since $z \sim 2$, and the key diagnostics are rest-frame UV lines, this critical problem is a unique and compelling driver for a 10-12 meter LUVOIR Surveyor mission in future decades.