Lyman Alpha Emitting Galaxies at $2 < z < 3$: Towards a Calibrated Probe of Dark Energy

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The goal of this project was to establish the physical properties of Lyα emitting galaxies from redshifts of 2 to 3 in order to better calibrate the use of LAEs as probes of the large scale structure of the universe for upcoming dark energy experiments, such as the Hobby Eberly Telescope Dark Energy Experiment (HETDEX). This work was done in collaboration with Eric Gawiser (Rutgers) who had a separate DOE grant, co-I Robin Ciardullo (PSU) and an international team of collaborators including Ana Matkovic (postdoc PSU, now at Swarthmore), Nicholas Bond (postdoc Rutgers, now at NASA GSFC), Viviana Acquaviva (postdoc Rutgers, now at CUNY City Tech), Lucia Guaita (graduate student PU Catolica, now at Stockholm), Jean Walker-Soler (graduate student Rutgers), Alex Hagen (graduate student PSU), Harold Francke (postdoc PU Catolica), Michael Berry (graduate student Rutgers), John Feldmeier (faculty, Youngstown State), Nelson Padilla (faculty PU Catolica).

We have obtained narrow-band imaging of the Extended Chandra Deep Field South (ECDF-S) in two different narrow-band filters centered at Lyα at z=2.1 and 3.1. The resulting of samples of LAEs were used to determine the LAE luminosity function, equivalent width distribution and clustering properties (bias) of LAEs at these redshifts. These results were published in Guaita et al. (2010) and Ciardullo et al. (2012) and have been used extensively in the planned experimental design of the upcoming HETDEX survey of which Gronwall is a co-investigator. A more detailed 2-D and 3-D clustering analysis is underway being led by Francke which will be used to refine the HETDEX experimental design. Our research has created definitive samples of LAEs at redshifts 2 and 3, and we have explored the physical properties of these galaxies. We are also aggressively pursuing follow-up spectroscopy of these samples. In Guaita et al. (2010), we published our sample of 250 LAE galaxies at z=2.1, consistent with no change in number density versus z=3. This publication also reported the clustering strength, star formation rates, and emission-line equivalent width distribution of the z=2.1 LAEs. Most significantly, our clustering analysis found that the z=2.1 LAEs have a bias factor of 1.8+-0.3 and are hosted by dark matter halos with median mass $10^{11.5+-0.5}$ $M_{\odot}$. All of these are ground-breaking results, as this is the first large LAE sample published near z=2. Ciardullo et al. (2012) presents a detailed determination of the LAE luminosity functions at z=3.1 and z=2.1 and notes significant evidence for evolution with the LF fading with time by 0.4 mag, the number density of sources with $L_{Ly\alpha} > 1.5 \times 10^{42}$ ergs/sec declining by 50%, and the equivalent width scale-length contracting from 70 Angstroms to 50 Angstroms.

While the results from the ECDF-S appear robust, they are based on a single field. To explore the effects of cosmic variance and galaxy environment on the physical properties of LAEs, we have also obtained narrow-band data at both redshifts ($z = 2.1 and 3.1$) in three

additional fields (SDSS 1030+-05, the Extended Hubble Deep Field South, and CW 1255+01). These three fields already have deep broadband imaging available from the MUSYC survey (`http://physics.rutgers.edu/ gawiser/MUSYC` . The narrow-band imaging data has been reduced and LAE catalogs are being generated. We have calculated preliminary luminosity functions, equivalent width distributions, and clustering properties. These results are being prepared for publication by PI Gronwall and will be submitted by the end of January 2013. Our preliminary results show no change in the equivalent width distribution in the various fields, but do show that the LAE LF may be evolving less strongly than indicated by our previously published results in the ECDF-S alone which has implications for the HETDEX survey design.

We have also obtained follow-up spectroscopy in the optical (using VLT/FORS) and in the near-infrared (using Magellan/MMIRS). The results from the optical spectra, reporting absorption line properties of stacked LAE and Lyman Break Galaxy spectra from this and previous MUSYC spectroscopy runs have been published in Berry et al. (2012). A second paper in preparation will measure Lyα emission-line profiles and assess their implications for radiative transfer in these galaxies. The near-infrared spectroscopy of LAEs will be used to calibrate the mean and scatter of redshift offsets between those determined from Lyα emission and the true systemic velocity traced by rest-frame optical nebular emission lines which is a necessary input into the calculation of the Baryonic Acoustic Oscillation (BAO) signal by HETDEX. These spectra are included in a paper submitted to the Astrophysical Journal by Lucia Guaita (Guaita et al. 2012). We also have upcoming spectroscopy runs scheduled using the South African Large Telescope and Magellan in Spring 2013 to continue these observations.

Since individual LAEs have too little S/N to enable meaningful fits for stellar population parameters, our previous work has analyzed stacked Spectral Energy Distributions (SEDs). Guaita et al. (2011) performed SED fitting on several subsets of LAEs selected by their rest-UV luminosity, UV spectral slope, Ly alpha luminosity, Equivalent Width, or rest-optical (IRAC) luminosity. We found that the IRAC- bright, UV-bright and red LAEs have the largest stellar mass and dust reddening. The UV- faint, IRAC-faint, and high equivalent width LAE subsamples appear less massive ($< 10^9 M_\odot$) and less dusty, with E(B-V) consistent with zero. Overall, LAEs at z=2.1 are dustier and show higher instantaneous SFRs than those at z=3.1, while the observed stellar masses of the two samples are consistent. We are continuing our work with SED fitting using the additional data in the other three fields.

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