Characterizing and Cataloguing Star-Forming Galaxies in Preparation for the LADUMA Survey

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Background

Looking At the Distant Universe with the MeerKAT Array (LADUMA) is a survey that will observe the Extended Chandra Deep Field South (ECDFS), collect data on neutral hydrogen gas (HI), and investigate a wide range of relationships between the HI content and the galaxies in which HI is found. The survey will use the MeerKAT radio telescope array, the precursor to the Square Kilometer Array (SKA), in South Africa. Some key research interests include studying how the HI mass function depends on environmental density and redshift, how the cosmic neutral gas density evolves to high redshift, how a galaxy's HI mass depends on stellar mass, dark matter halo mass, and other properties, and how the Tully-Fisher relation evolves over cosmic time. Due to the faint nature of the 21 centimeter HI line, there may be non-detections in some observations. The LADUMA team will overcome this obstacle using a technique known as stacking (see Fig. 1).

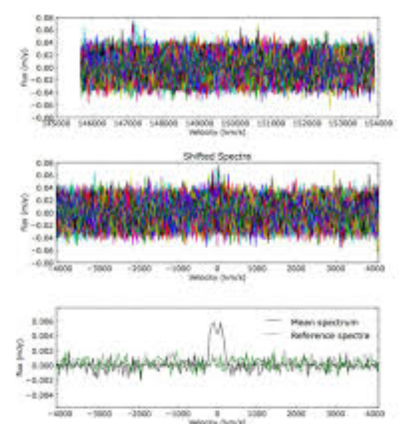


Figure 1. Simulated (top), shifted (middle), and coadded (bottom) HI spectra illustrating the power of stacking. Credit: B.W. Holwerda, ESA

Stacking experiments allow statistically insignificant non-detections to be averaged together and result in detections. This process allows us to characterize galaxies according to properties such as stellar mass, dust content, and star-formation rate (SFR). Many of these properties are calculated using an optical spectrum's nebular emission lines, so optical spectroscopy is essential for stacking science by the LADUMA team. This project deals with the processing of emission line profiles, the cataloguing of ~1,500 galaxies in the ECDFS by various properties, and visualization of the data to recognize relationships.

Figure 2. The MeerKAT array located in South Africa, displaying 13 of its anticipated 64 dish range. Credit: SKA South Africa

Observations

The optical spectra were collected with the Anglo-Australian Telescope's (AAT's) AAOmega spectrograph by J. Wu in late 2015. The AAOmega spectrograph guides each fiber located on the plate to an individual object inside the circular field of view (see Fig. 3), allowing the acquisition of ~400 galaxy spectra at once. Our observations consisted of seven plates in total.

Observed optical spectra of galaxies differ from their intrinsic spectra due to several astronomical effects. The first is redshift -- the increase of observed wavelength relative to rest (emitted) wavelength by a factor of 1+z, where z is the redshift value, primarily due to the expansion of the universe. Redshifts for our galaxies were calculated in automated fashion by the Marz software package (Hinton et al. 2016), using template galaxy spectra for comparison.

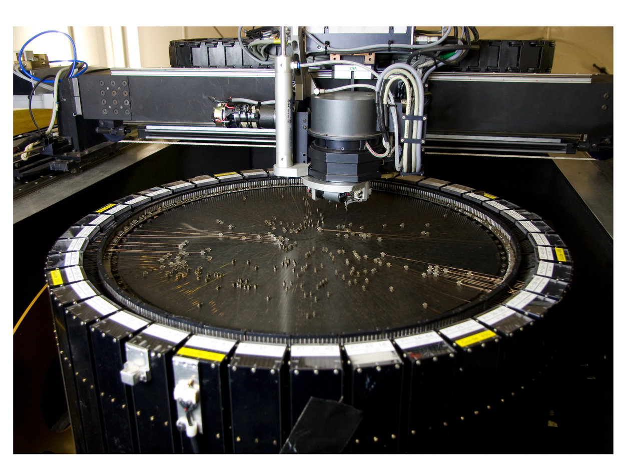


Figure 3. AAT's AAOmega spectrograph moving individual fibers during a run of observations through its two degree field. Credit: Barnaby Norris

In addition to redshift, extinction has a significant effect on observed optical spectra. Dust grains in the interstellar medium scatter and absorb light more efficiently at shorter, bluer wavelengths, leading to a wavelength-dependent suppression of emission. Interstellar reddening can be measured and corrected by combining an assumed extinction curve (e.g., Calzetti et al. 2000) with observed fluxes of Balmer lines, notably Hα and Hβ .

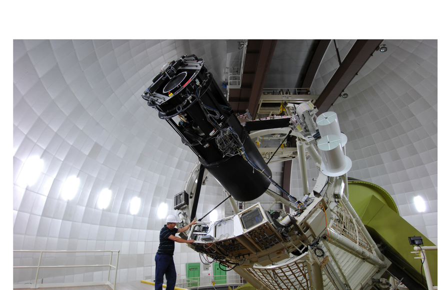


Figure 4. The 3.9-meter Anglo-Australian Telescope. Credit: Fred Kamphues

Analysis

In order to calculate the various nebular emission line features, each spectrum must undergo a process of redshift correction and extinction correction. Without these corrections, automated analysis of emission and absorption line features is not feasible due to a multitude of wavelength offsets (see Fig. 5).

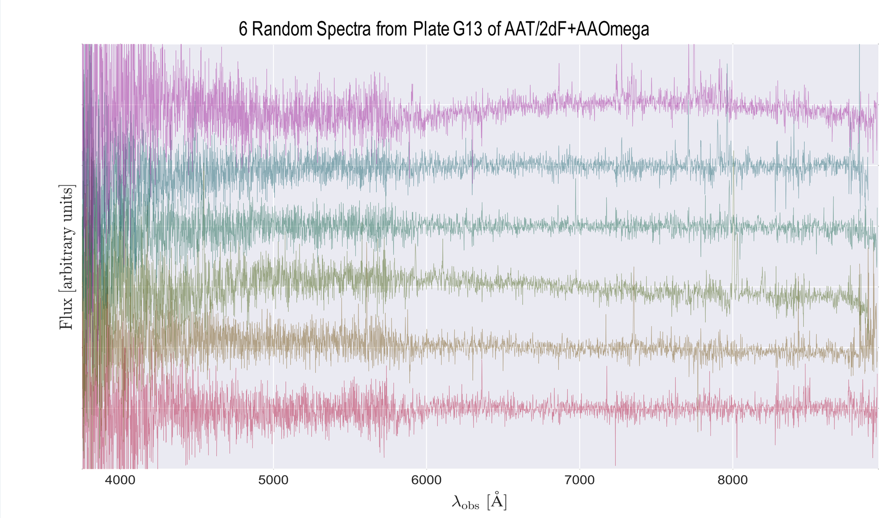
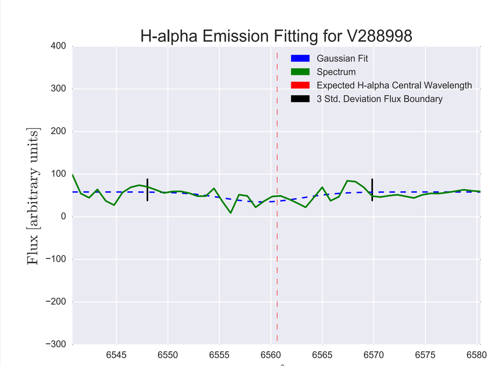


Figure 5. Six random spectra from Plate G13 are plotted with their observed wavelengths and flux densities. Many possible features are seen, but none can be confirmed until the intrinsic spectra are derived. Credit: J. Wu

These spectra were processed through an using a software pipeline we created to automate the process of de-redshifting, extinction correction, emission or absorption line fitting for flux calculation, and quality-flagging to categorize each galaxy by a variety of parameters. First, we used the Marz-calculated redshifts to shift the wavelengths back to the rest frame, followed by a fitting routine to calculate the total Hα and Hβ fluxes. This fitting finds the best fit Gaussian profile to the apparent line feature in a specified emission line region (see Fig. 6 & 7).



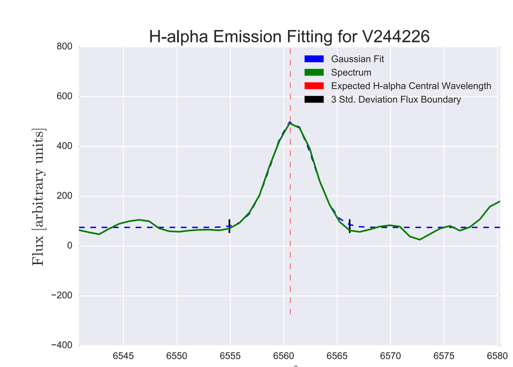


Figure 6 (left). An example of the fitting process where there is no significant Hα detection.

Figure 7 (right). An example of the fitting process where there is a significant Hα detection.

This same pipeline was used to classify each galaxy based on various qualities such as goodness-of-fit, Balmer decrement, stellar color excess (a measure of dust), signal-to-noise ratio, and other important properties. All values were then processed into catalogs for future reference. After the cataloguing was completed, the Hα and Hβ flux values were then used in a separate pipeline we created to correct for extinction and derive the intrinsic spectra of the galaxies (see Fig. 8).

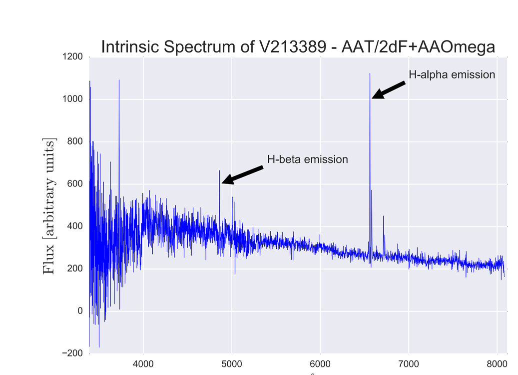


Figure 8. An example of an AAT spectrum that has been corrected for redshift and extinction with Hα and Hβ indicated. In contrast to the spectra in Figure 4, the shorter wavelengths have much higher flux values than the longer wavelengths, thanks to our applied extinction correction.

Acknowledgements

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References

1. Calzetti et al. 2000, ApJ, 533, 682
2. Hinton et al. 2016, Astronomy and Computing, 15, 61
3. Holwerda, B.W. 2011 , Kloster Seeon *Gas in Galaxies* Seminar. http://wwwmpa.mpa-garching.mpg.de/gas2011/talks/Holwerda.pdf

Visualizations

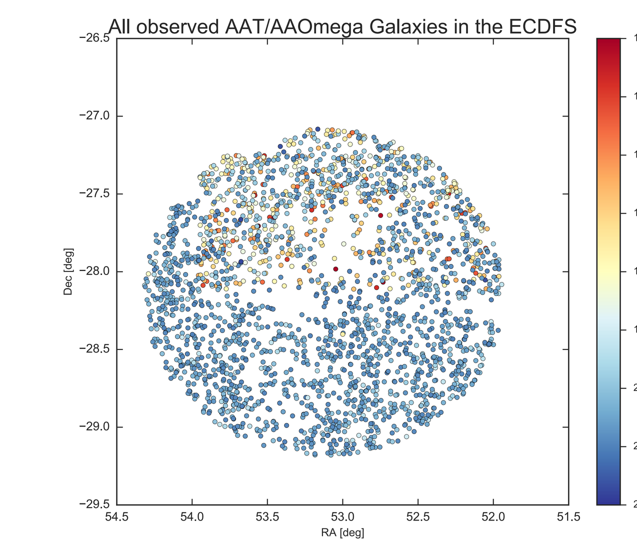

Figure 9. Observed galaxies in the ECDFS that we processed. The color gradient reflects R-band magnitudes observed (blue = fainter, red = brighter). Objects in the upper half of the field tend to be brighter than those in the lower half, due to an effort to clean up previously uneven depth of sampling.

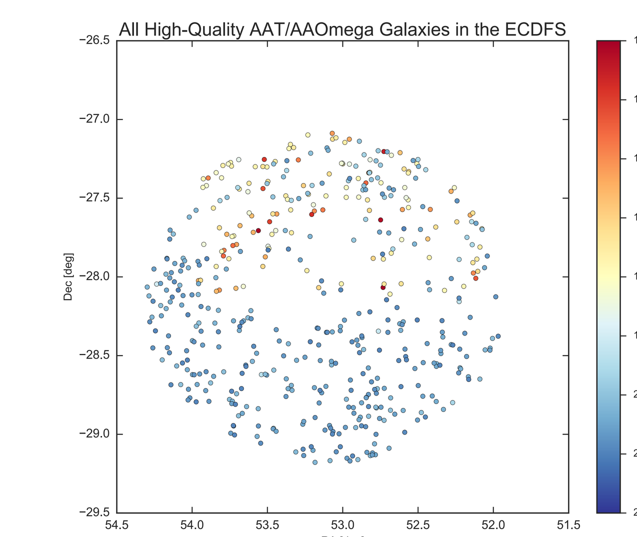

Figure 10. Galaxies with >3 sigma detections in both Hα and Hβ (i.e., high data quality) in the ECDFS. Object selection was decided upon by their associated flags as previously described. (blue = fainter, red = brighter)

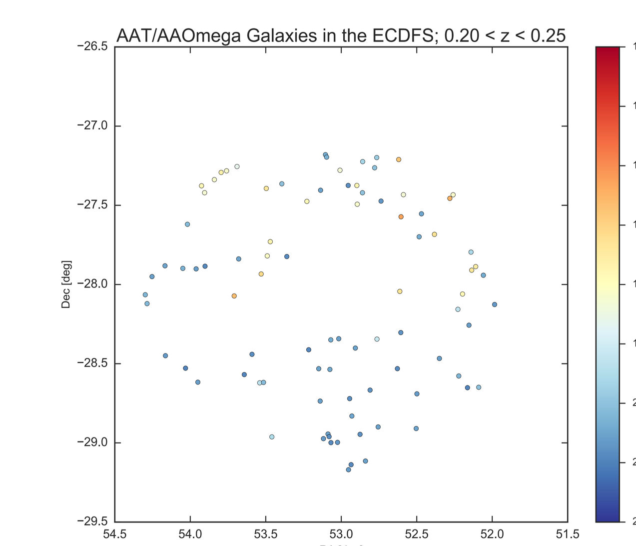

Figure 11. High-quality, usable galaxies in the ECDFS between redshifts of z = 0.20 to z = 0.25. Note the potential cluster at RA = ~53°, Dec = ~29°. (blue = fainter, red = brighter)

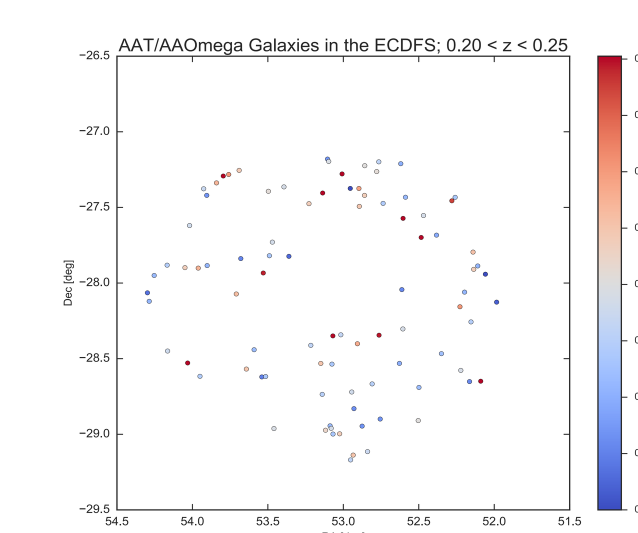

Figure 12. High-quality, usable galaxies in the ECDFS between redshifts of z = 0.20 to z = 0.25. The color gradient now reflects the stellar color excess (blue = less dusty, red = more dusty). The potential cluster is even more intriguing now due to the objects sharing both a tight redshift range and similar stellar color excess values.

Conclusions

- Created software that automates the processing and fitting of any optical spectrum (which can be extended to additional datasets) to an emission/absorption line while storing the intrinsic spectrum of the galaxy
- Processed ~1,500 AAT spectra and catalogued 493 high-quality, usable spectra
- Developed sky visualizations useful for trend recognition in follow-up science