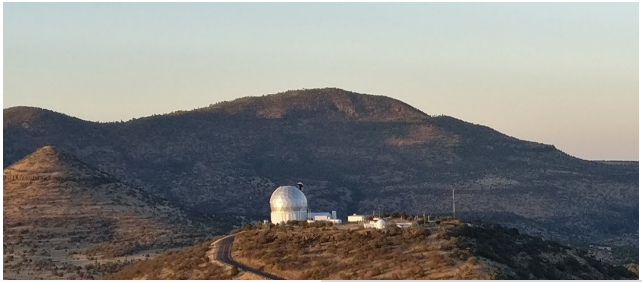
HETDEX: first galaxy bias measurements from our $z \sim 0.5$ and $z \sim 2.5$ samples

Daniel J. Farrow (USM/MPE) & the HETDEX team
USM: University Observatory, Ludwig-Maximillians University, Munich; MPE: Max-Planck Institute for Extraterresstrial Physics

Photograph of the Hobby-Eberly telescope, at the McDonald Observatory, West Texas

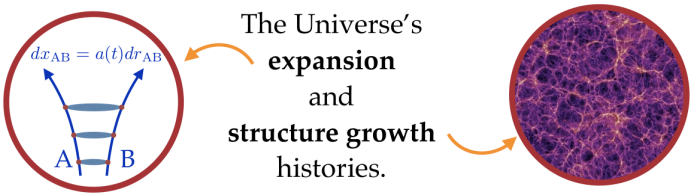


Introduction

- Cosmology and correlation functions
- Introduction to HETDEX
- Science highlights
- First clustering measurements from HETDEX
- Future prospects

The puzzle of the Dark Universe

- The ΛCDM model fits a wide range of cosmological probes
- It suggests the majority of the Universe is made up of "dark energy"
- We test these models with large-scale structure. This probes:



The correlation function - $\xi(s)$

- Correlation functions: the probability above random of finding a pair of galaxies at a given separation
- Fourier transform of the power spectrum, $P(k)$
- $\xi(s)$ and $P(k)$ are the main clustering statistics for constraining cosmology

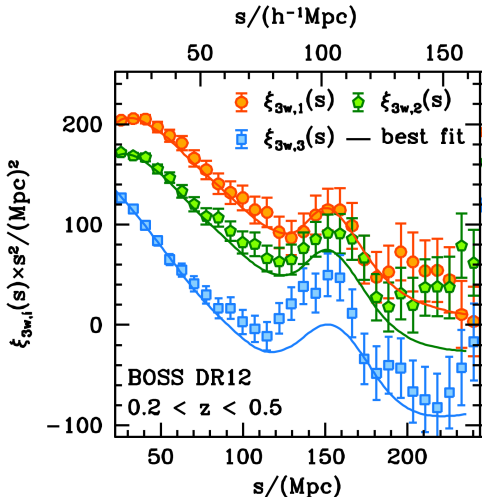
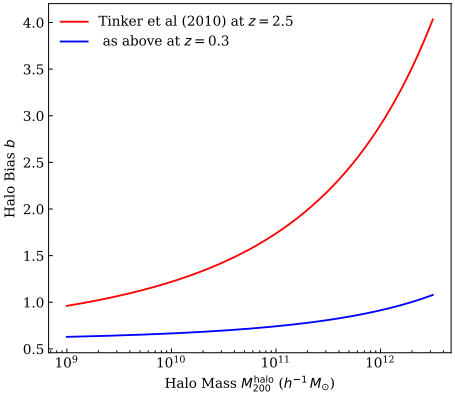


Figure credit: Sánchez, A. G. et al. 2017, MNRAS, 464, 1640

Galaxy bias

- Most models predict the clustering of the matter, $\xi_{\rm M}(s)$
- We measure the clustering of galaxies
- Galaxies are biased tracers, in the simplest model $\xi_{\rm gal}(s) = b^2 \xi_{\rm M}(s)$
- Galaxy bias depends on halo mass



Credit: Mass function evaluated using Diemer (2018)

Introducing HETDEX

- **H**obby **E**berly **T**elescope **D**ark **E**nergy e**X**periment
- Array of 74 'VIRUS' IFUs
- 18' diameter field of view
- R$\sim$ 800
- 3500 $< \lambda$ (A)$<$ 5500
- 10 m Hobby-Eberly telescope.
- 32,000 spectra at once.
- UT Austin lead, with heavy involvement by MPE, the USM & other partners

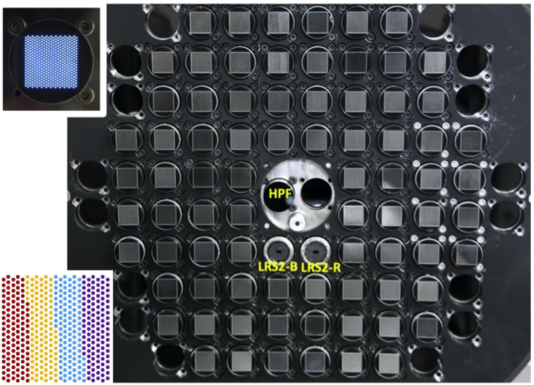


Figure credit: Hill, G. J. et al. 2021, AJ, 162, 298

Introducing HETDEX

- $\sim$ 1M Lyman α emitters (LAEs) at $1.9 < z < 3.5$
- $\sim$ 1M [OII] emitters at $z < 0.5$
- Two fields: Spring (390 deg^2) and Fall (150 deg^2)
- 60% of observations made, 43% processed
- Already 1M emission line detections
- Completetion expected 2024

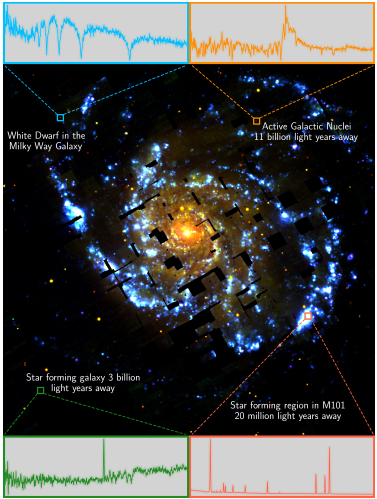
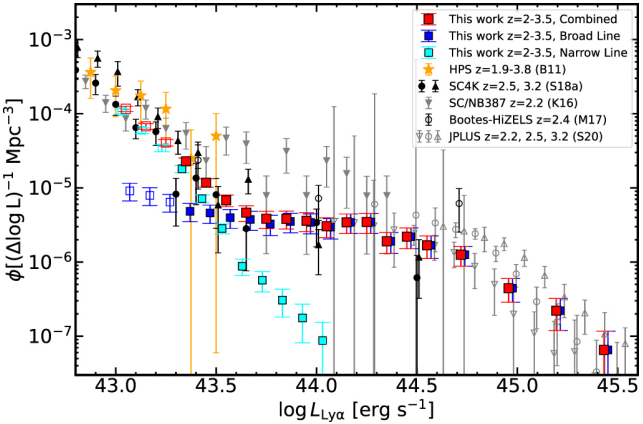


Figure credit: G. Zeimann /HETDEX collaboration

A couple of HETDEX science highlights



The bright end LAE luminosity function
Zhang Y. et al. (incl. Farrow), 2021, ApJ, 922, 167.

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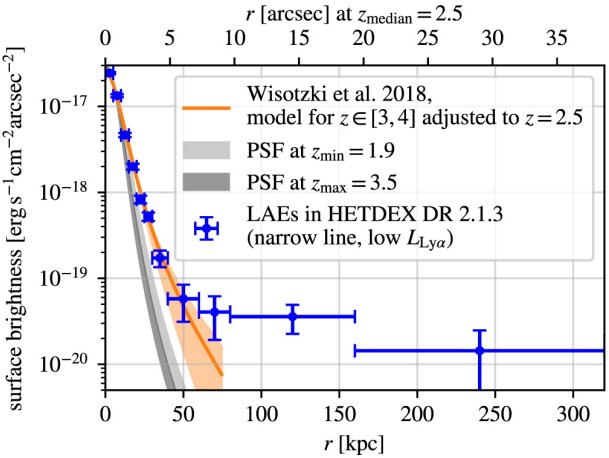
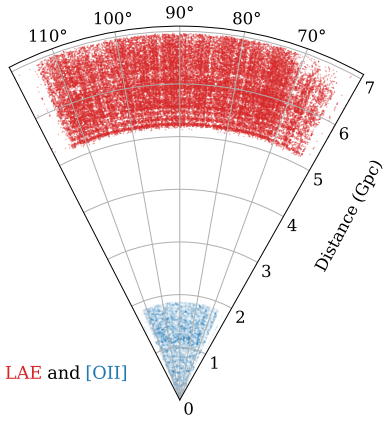
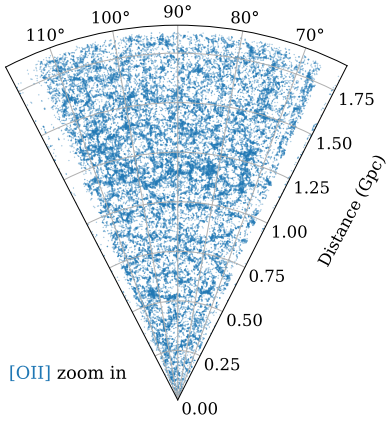


The surface brightness profile of ∼1000 LAEs, from
Lujan Niemeyer M. et al. (incl. Farrow), 2022, ApJ, 929, 90

The Cosmic Web in HETDEX



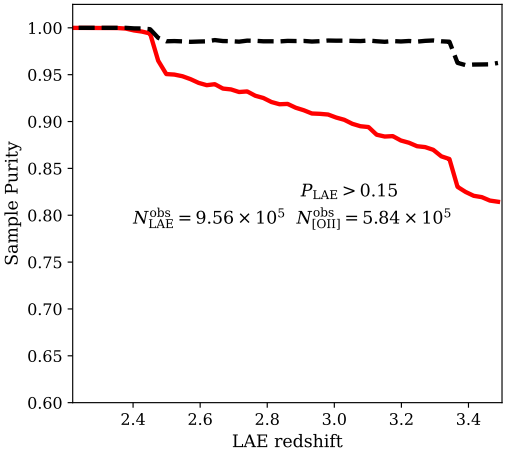


Using this data for cosmology faces two challenges: **catalogue contamination** and **understanding the selection function**. We are addressing both these issues.

Challenge I: [OII] Contamination

- Given the resolution of the spectrograph the [OII] doublet is not resolved
- This means [OII] can be mistaken for Lyman α (e.g. Leung et al. 2017).
- Adds a systematic bias to results
- Generated mock catalogues to explore this issue

Figure credit: Farrow, D. J., et al. 2021, MNRAS, 507, 3187

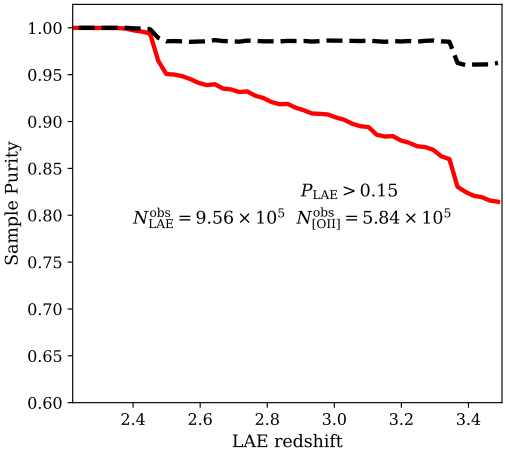


Results from mock catalogues

Challenge I: [OII] Contamination

- Decontamination and measurement of interloper fraction using auto- and cross-correlation functions (e.g. Grasshorn Gebhardt et al 2019, Awan & Gawiser 2020)
- Integrate over z-ranges via Yamamoto & Suto (1999), Suto et al (2000)
- Can correct for contamination from measurements in broad z-bins
- Can fit the z-dependent contamination fraction

Figure credit: Farrow, D. J., et al. 2021, MNRAS, 507, 3187



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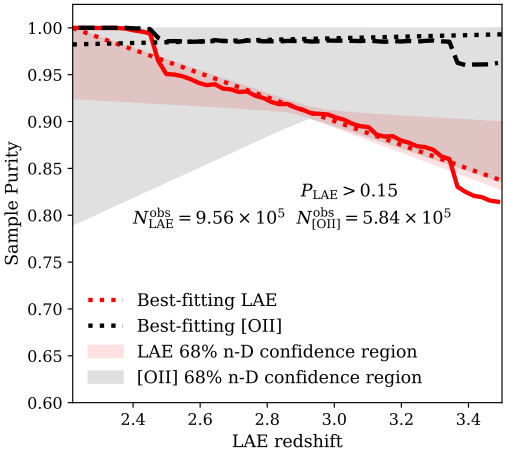
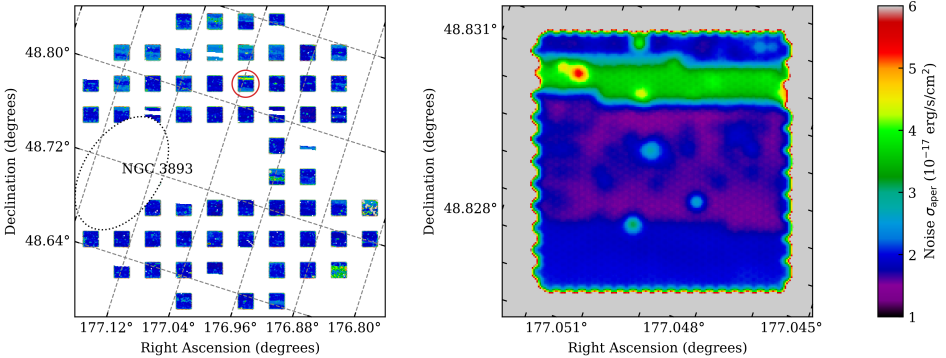


Results from mock catalogues

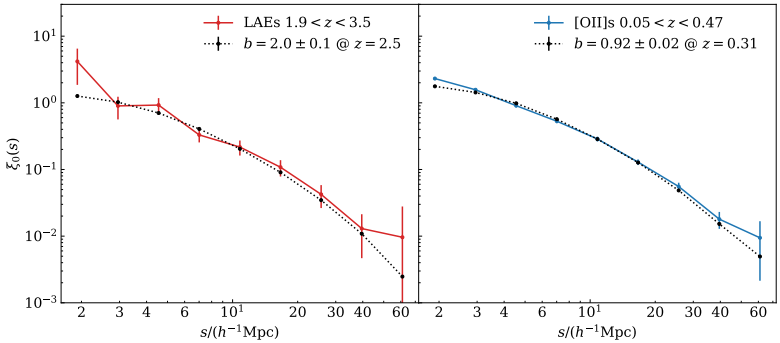
Challenge 2: Dealing with the selection function



A major requirement in measuring the correlation function is understanding how the completeness of the survey depends on position and redshift. This is a major area of research.

Figure credit: Farrow et al (in prep, 2022a)

First correlation function measurements



First measurements of the LAE and [OII] correlation function in HETDEX, with a simple linear theory model fit and a linear bias. Can be roughly translated via Tinker et al (2010) to DM halo masses of

$$\log_{10} M_{\mathrm{LAE}}(h^{-1}M_{\odot}) = 11.3 \pm 0.1 \quad \log_{10} M_{[\mathrm{OII}]}(h^{-1}M_{\odot}) = 12.0 \pm 0.1$$

Figure credit: Farrow et al (in prep, 2022a)

Cosmological Forecasts

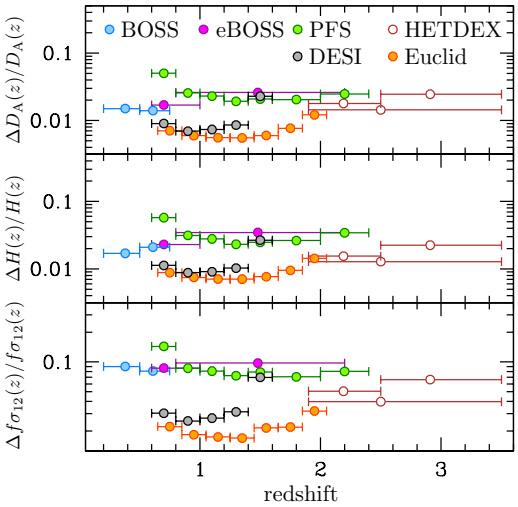


Figure credit: Farrow et al (in prep, 2022b)

Upcoming plans

Future exciting HETDEX projects with a cosmology focus

- **First LAE/[OII] clustering measurements** Farrow, Sánchez et al (in prep, 2022a)
- **Cosmological Forecasts** Farrow, Sánchez et al (in prep, 2022b)
- **Structure growth rate measurements from the [OII] sample**
- **Cosmological constraints from the LAE sample**

Other exciting projects

- **AGN luminosity function** Liu et al (submitted, 2022)
- **Catalogue description** Mentuch Cooper et al (in prep, 2022)
- **Faint end luminosity function** Jeong et al (in prep, 2022)

And many more excellent projects I didn't have space to list ...

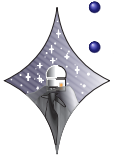
Summary

- HETDEX: cosmology with 1M $z > 2$ LAEs & similar number of $z < 0.5$ [OII] emitters
- Unique in that it covers a large area (540 deg^2) with untargeted IFU observations
- Over half way complete! First papers appearing
- Developed methods for dealing with misclassified sources
- Selection function a work in progress
- Made first clustering measurements
- On a $\sim$year timescale - first cosmology results

References/Recent HETDEX Publications I

Recent HETDEX science results

- **Survey paper:** Gebhardt, K., Mentuch Cooper, E., Ciardullo, R., et al. 2021, ApJ, 923, 217
- **Instrument paper:** Hill, G. J., Lee, H., MacQueen, P. J., et al. 2021, The Astronomical Journal, 162, 298.
- **[OII]/LAE misclassification:** Grasshorn Gebhardt H. S., Jeong D. et al., 2019, ApJ, 876, 32.
- **IGM-QSO/Galaxy connection:** Mukae S., Ouchi M. et al., 2020, ApJ, 903, 24.
- **Stars** Hawkins K., Zeimann G., Sneden C., Cooper E. M. et al., 2021, ApJ, 911, 108.
- **Lyα escape fraction** Weiss L. H., Bowman W. P. et al., 2021, ApJ, 912, 100.
- **z-dependent [OII]/LAE misclassification:** Farrow, D. J., Sánchez, A. G., Ciardullo, R., et al. 2021, MNRAS, 507, 3187



References/Recent HETDEX Publications II

Recent HETDEX science results

- **[OIII] emitting galaxies** Indahl B., Zeimann G., Hill G. J. et al., 2021, ApJ, 916, 11.
- **Lyman continuum** Davis D., Gebhardt K., Mentuch Cooper E. et al., 2021, ApJ, 920, 122.
- **Bright LAE Luminosity Functions** Zhang Y., Ouchi M., Gebhardt K. et al., 2021, ApJ, 922, 167.
- **LAE surface brightness profile** Lujan Niemeyer M., Komatsu E., Byrohl C. et al., 2022, ApJ, 929, 90.
- **AGN** Liu C., Gebhardt K., Mentuch Cooper E., Davis D., Schneider D. P., Ciardullo R., Farrow D. J., et al., 2022, arXiv, arXiv:2204.13658

References to Non-HETDEX papers

- Awan H., Gawiser E., 2020, ApJ, 890, 78
- Diemer, B. 2018, ApJS, 239, 35.
- Leung, A. S., Acquaviva, V., Gawiser, E., et al. 2017, ApJ, 843, 130
- Suto Y., Magira H., Yamamoto K., 2000, PASJ, 52, 249
- Yamamoto K., Suto Y., 1999, ApJ, 517, 1

Additional Image Credit Slide 3: Millenium Simulation/VIRGO consortium. **HETDEX Acknowledgement:** HETDEX is led by the University of Texas at Austin McDonald Observatory and Department of Astronomy with participation from the Ludwig-Maximilians- Universität München, Max-Planck-Institut für Extraterrestriche-Physik (MPE), Leibniz-Institut für Astrophysik Potsdam (AIP), Texas A&M University, Pennsylvania State University, Institut für Astrophysik Göttingen, The University of Oxford, Max-Planck-Institut für Astrophysik (MPA), The University of Tokyo, and Missouri University of Science and Technology. In addition to Institutional support, HETDEX is funded by the National Science Foundation (grant AST- 0926815), the State of Texas, the US Air Force (AFRL FA9451-04-2- 0355), and generous support from private individuals and foundations. The observations were obtained with the Hobby-Eberly Telescope (HET), which is a joint project of the University of Texas at Austin, the Pennsylvania State University, Ludwig-Maximilians- Universität München, and Georg-August-Universität Göttingen. The HET is named in honor of its principal benefactors, William P. Hobby and Robert E. Eberly. The authors acknowledge the Texas Advanced Computing Center (TACC) at The University of Texas at Austin for providing high performance computing, visualization, and storage resources that have contributed to the research results reported within this paper. URL: http://www.tacc.utexas.edu