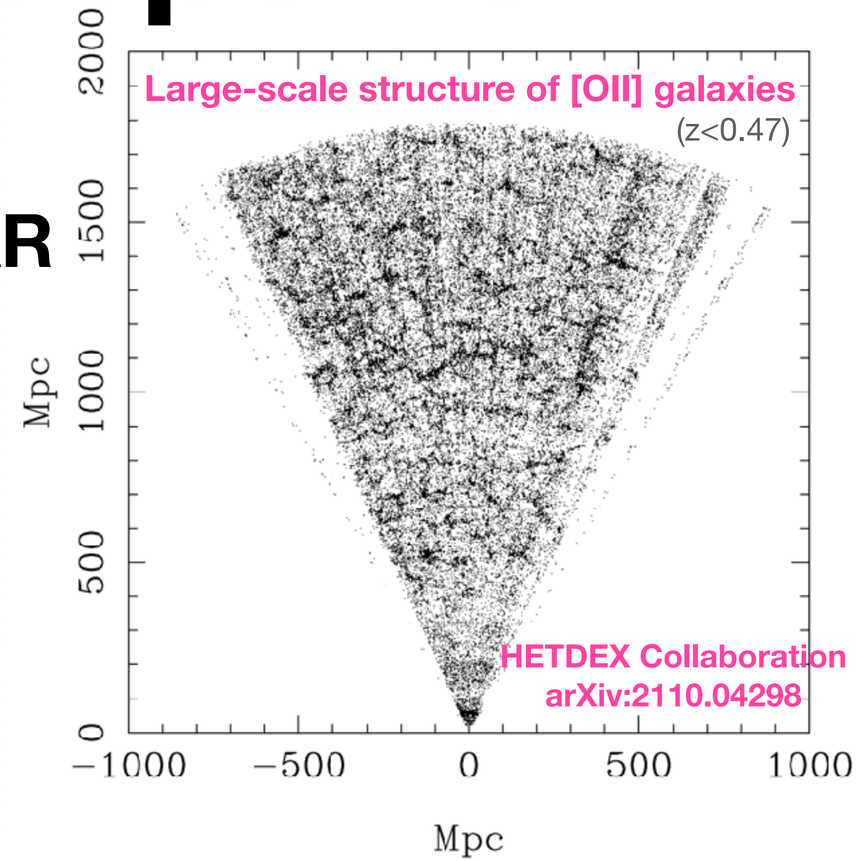
Hobby-Eberly Telescope Dark Energy Experiment

Science of HETDEX & Synergy with LOFAR



Eiichiro Komatsu (MPA)

Radio 2021 Symposium@MPA, November 23, 2021

HETDEX Collaboration, arXiv:2110.04298, 2110.03843

World's largest IFU on world's (almost) largest telescope

78 x 448 = 34944 fibers across 22' diameter field-of-view on 10-m telescope

HETDEX
Hobby-Eberly Telescope Dark Energy Experiment

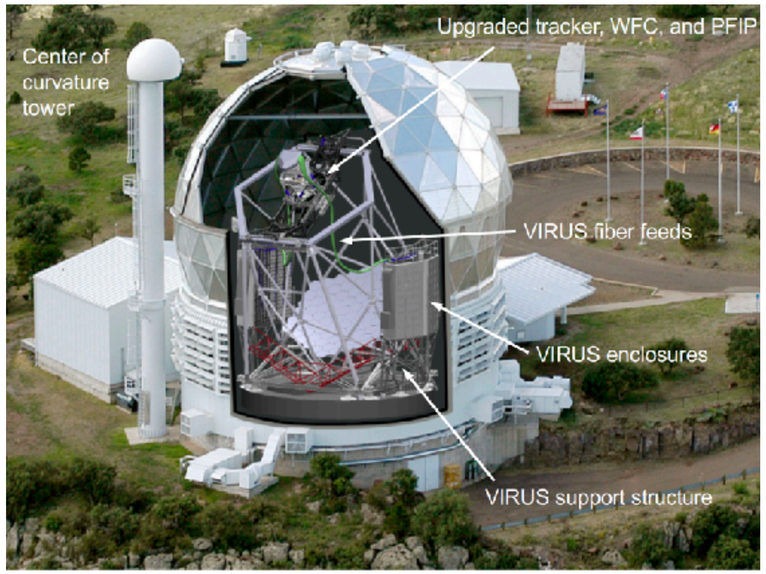
Location
McDonald Observatory
(West Texas)

Wavelength Coverage
350–550 nm (Δλ=5.6Å)

Spectrograph Type
Integral Field Unit (IFU)

Field of View
0.1 deg^2 (22' diam.)
~20 Mpc in one go!

Primary Mirror Size
10 m

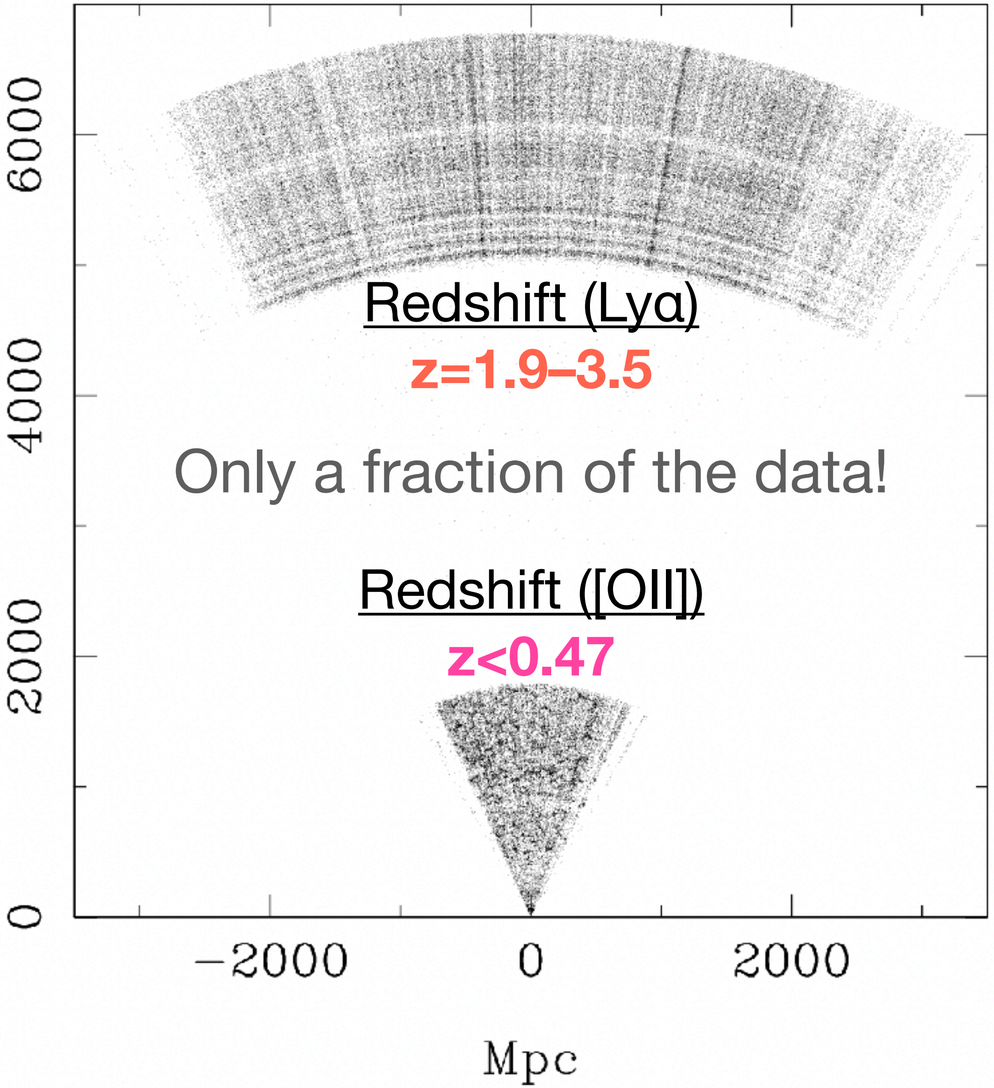


# of fibers
34,944

Fiber Diameter
1.5 arcsec

Survey Volume
10.9 Gpc^3

Survey Type
Blind



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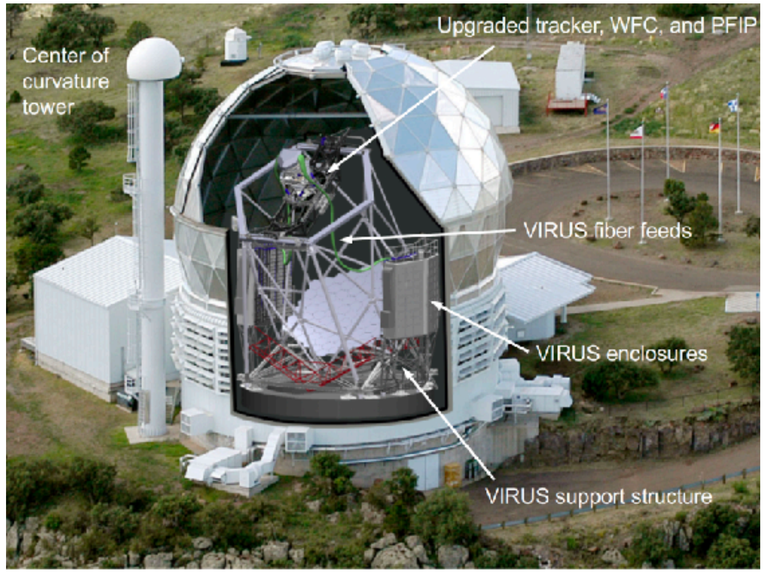

# of fibers
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10.9 Gpc³

Survey Type
Blind

Texas-led
$42M experiment

THE UNIVERSITY OF TEXAS AT AUSTIN

McDonald Observatory
THE UNIVERSITY OF TEXAS AT AUSTIN

NSF

PENNSTATE 1855

A&M

LMU USM

MPE

INSTITUT FÜR ASTROPHYSIK GÖTTINGEN

AIP

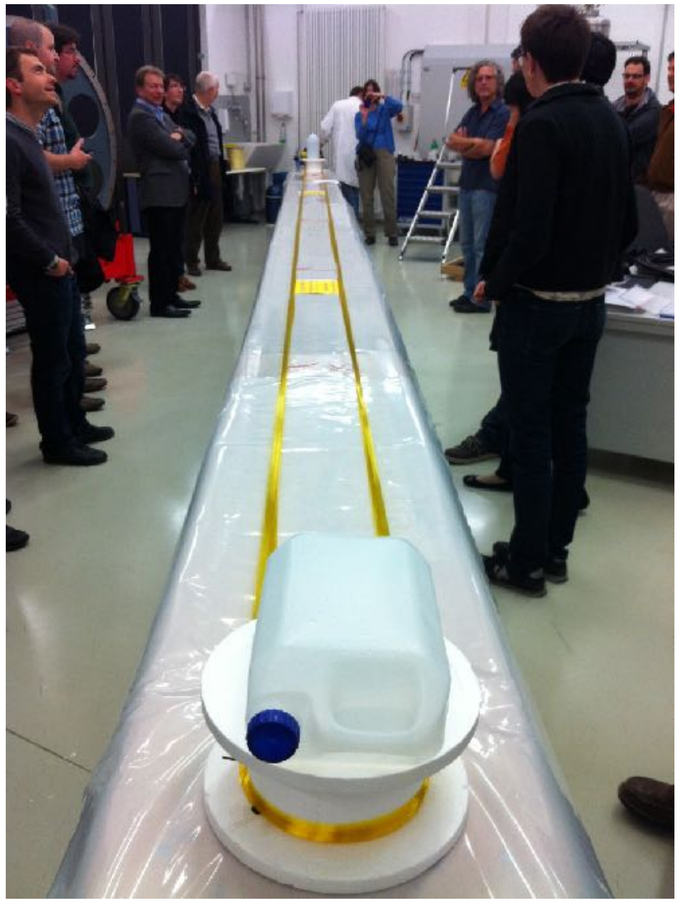
UNIVERSITY OF OXFORD

MISSOURI S&T
University of Science & Technology

東京大学 THE UNIVERSITY OF TOKYO

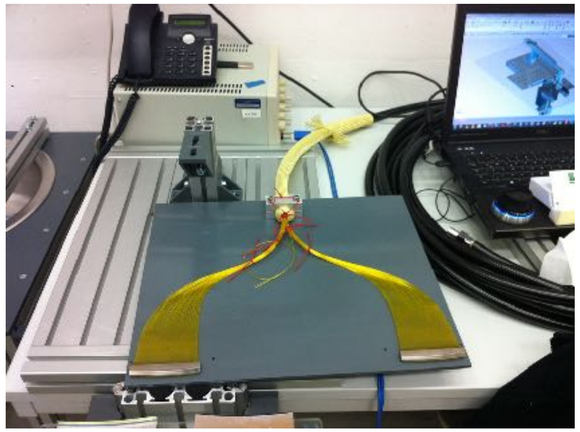
IFUs fabricated at AIP

It's a beauty!



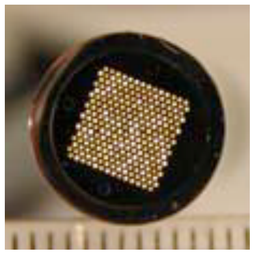
Long fibers!
(Each fiber sees 1.5")

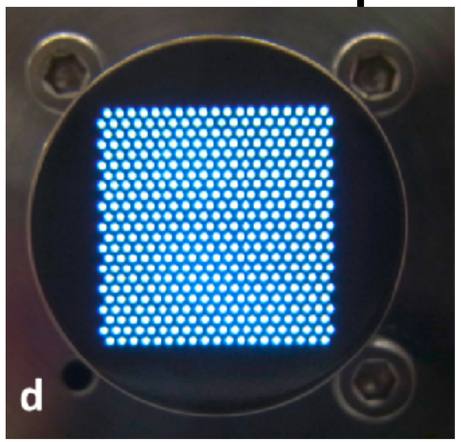
Put into cables...



One IFU feeds
two spectrographs

448 fibers per IFU





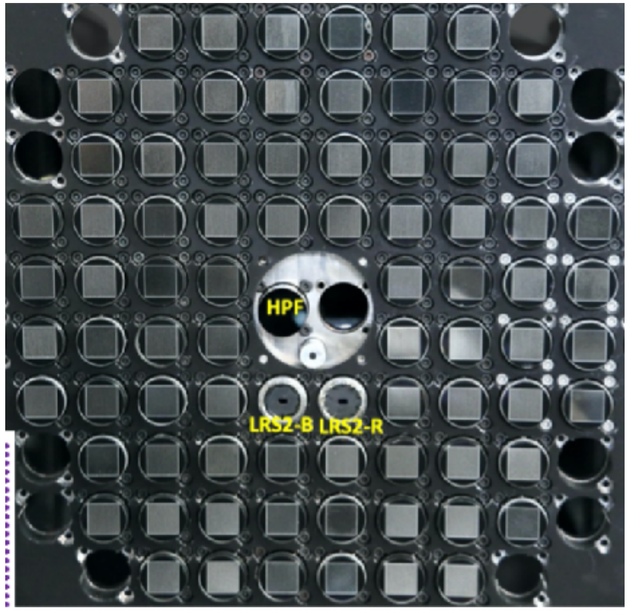
IFU being lit

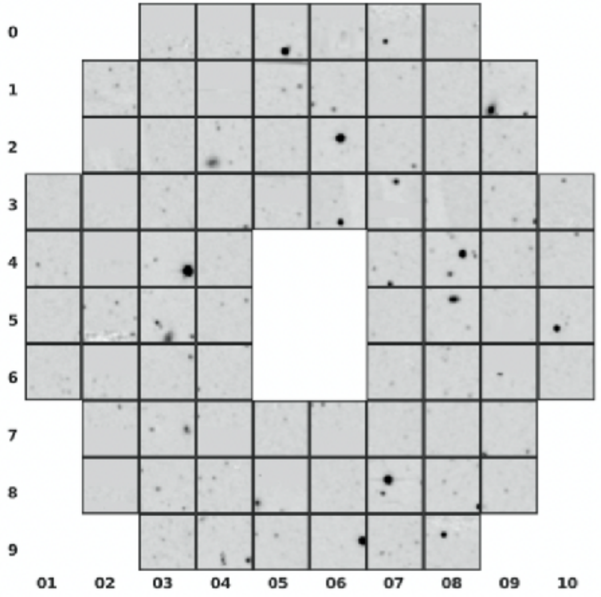
× 78

= "VIRUS"

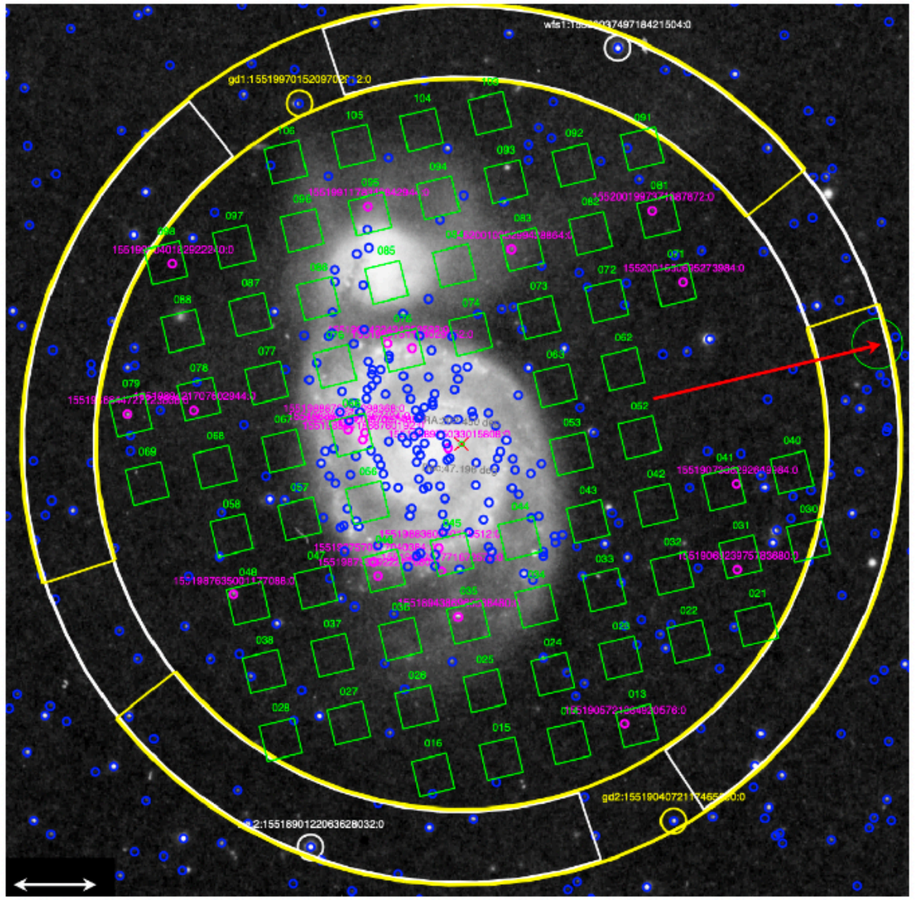
Visible Integral-field
Replicable
Unit Spectrograph

VIRUS on M51 and M101



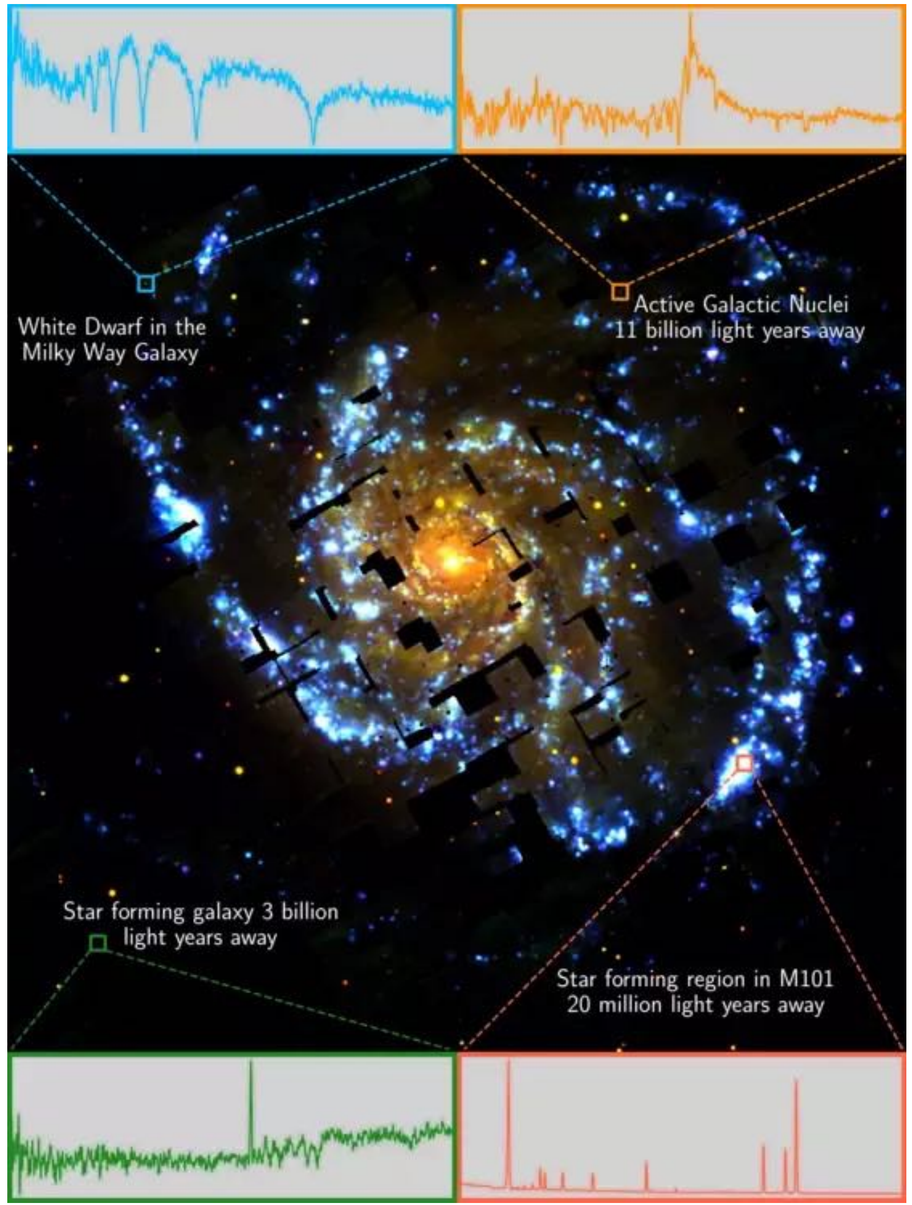


M51



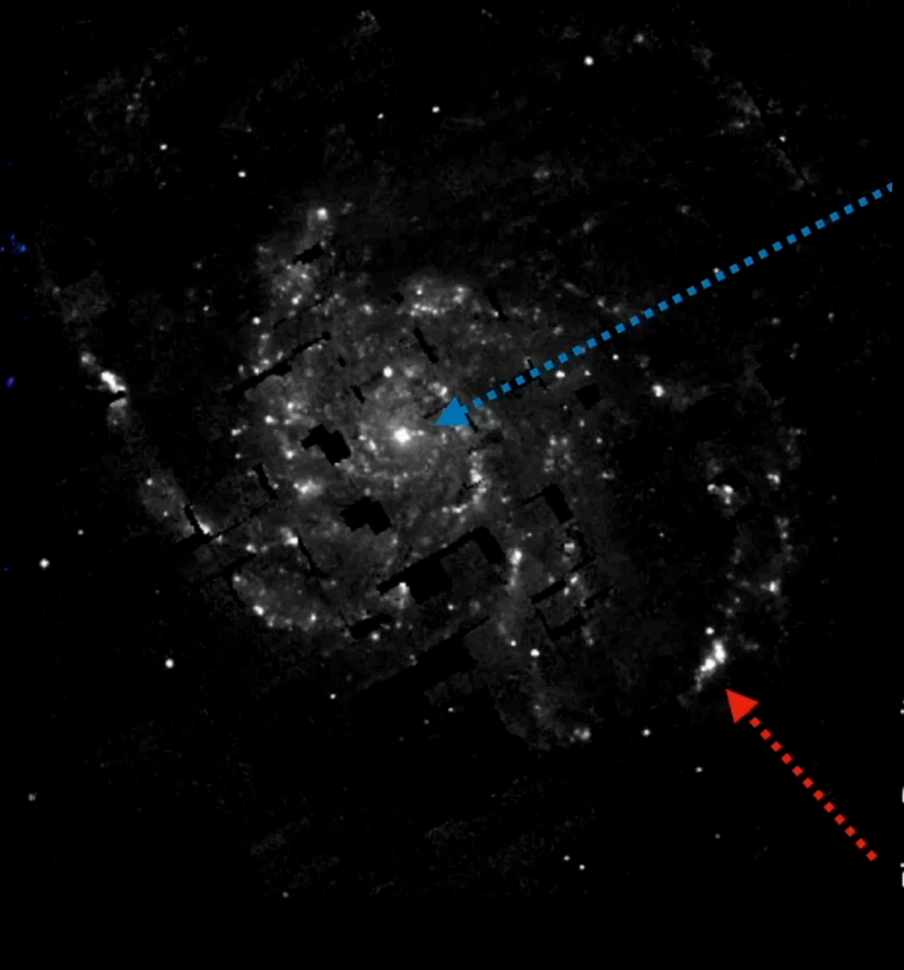
Fill factor ~ 1/4.6

M101

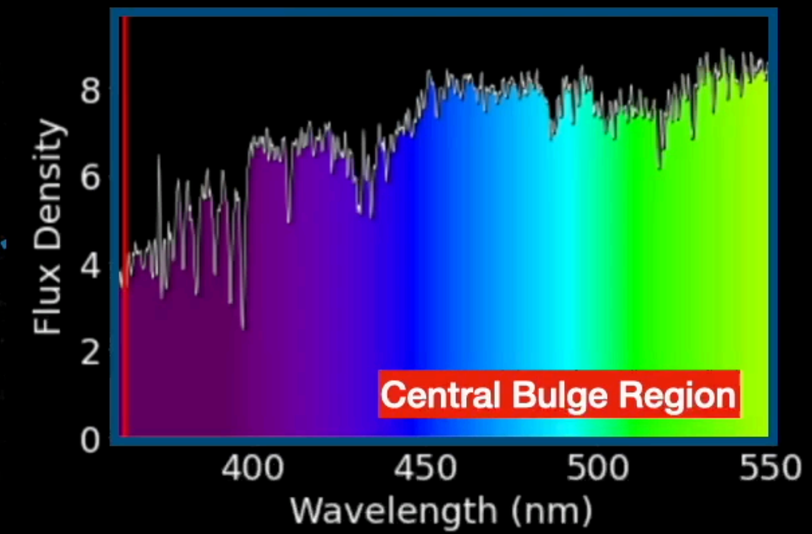


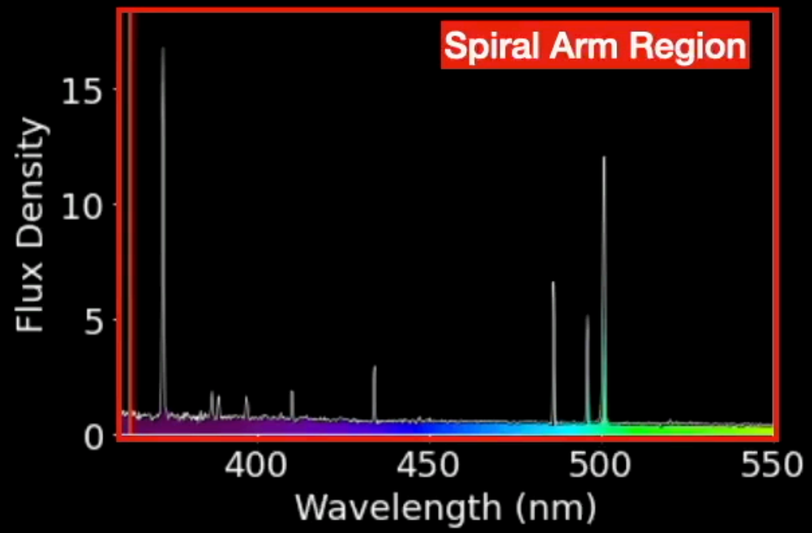
Pinwheel Galaxy from HETDEX

False color image constructed from the HETDEX data cube of the Pinwheel Galaxy



Full spectral scan through the Pinwheel Galaxy HETDEX/VIRUS data cube





Why should you care? We observe the same sky as LoTSS!

The LOFAR Two-metre Sky Survey*

II. First data release

T. W. Shimwell[1,2**], C. Tasse[3,4], M. J. Hardcastle[5], A. P. Mechev[2], W. L. Williams[5], P. N. Best[6], H. J. A. Röttgering[2], et al.

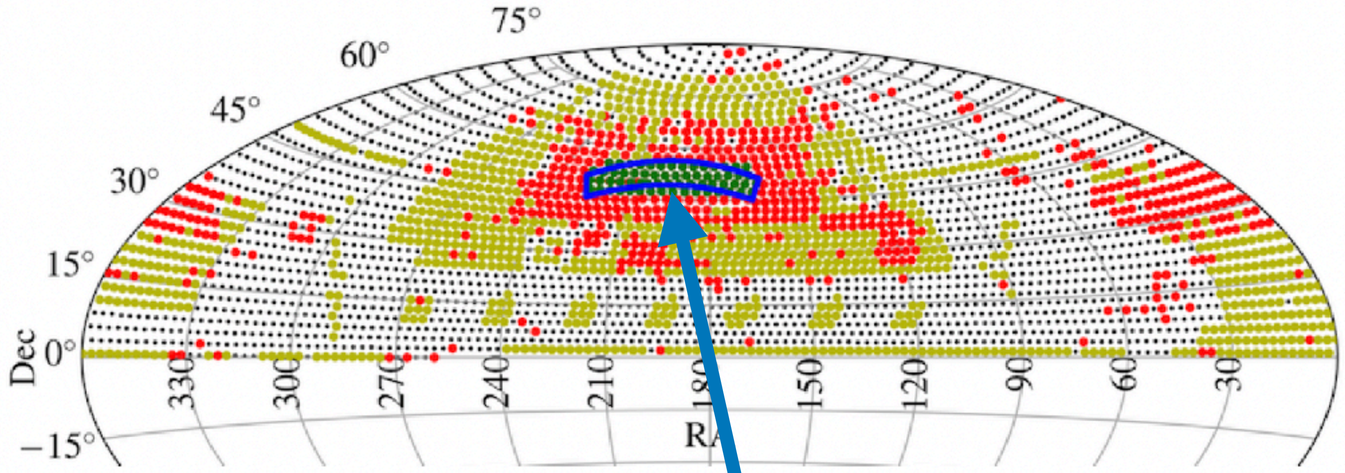
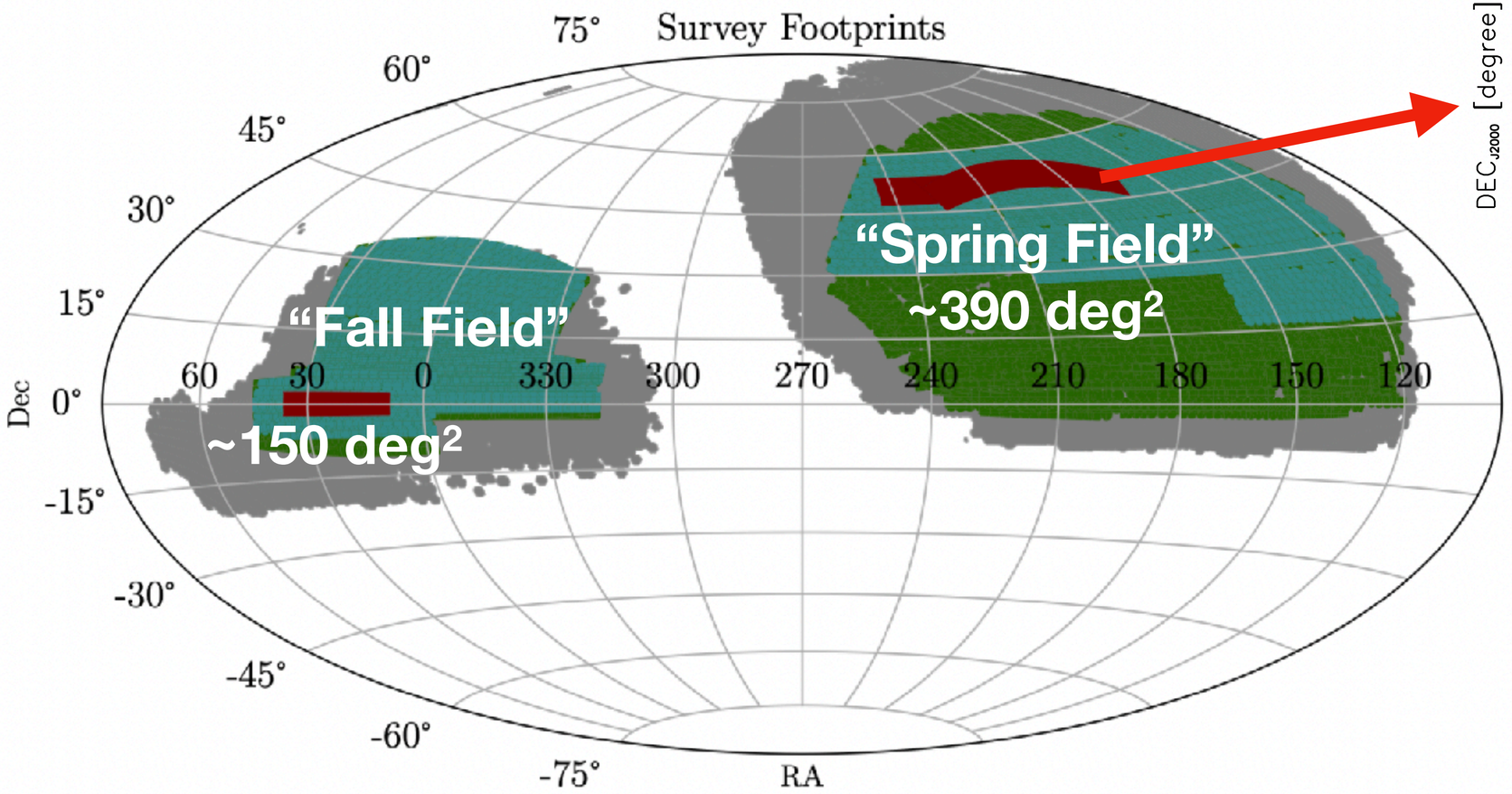


Fig. 2. Status of the LoTSS observations as of May 2018. The green dots show the images that are presented in this paper. The red, yellow, and black dots show the observed pointings (but yet unpublished), pointings presently scheduled for observation between May 2018 and May 2020, and unobserved pointings, respectively. The HETDEX Spring Field region is outlined in blue. The vast majority of the completed coverage (20% of the northern sky) and upcoming observations (an additional 30% of the northern sky) are regions with low Galactic extinction.

- We have a huge number of calibrated spectra in λ=3500–5500 angstroms.
- **On-going work with LoTSS members who are also in HETDEX**
  - Cross-matching objects based on “value-added catalog”: **45K objects** expected in 60 deg^2 covered by fibers

Large-scale structure survey with HETDEX

Simple: We tile the sky with lots of pointings with no-preselection



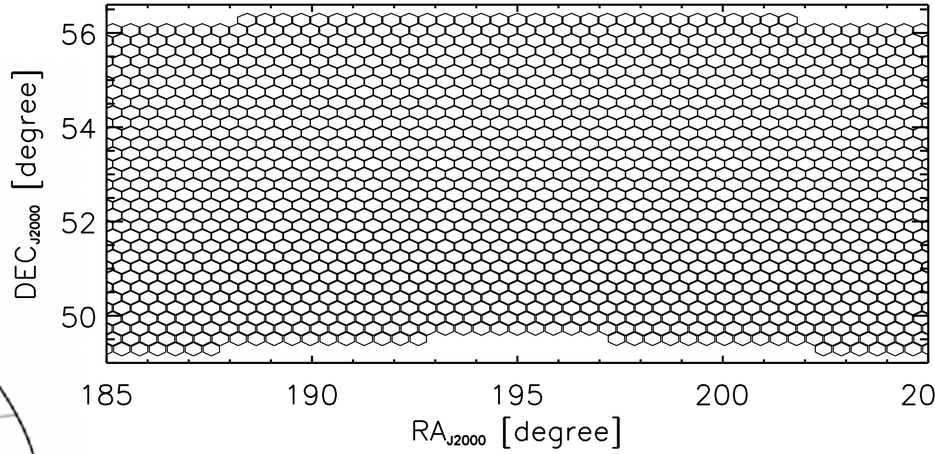
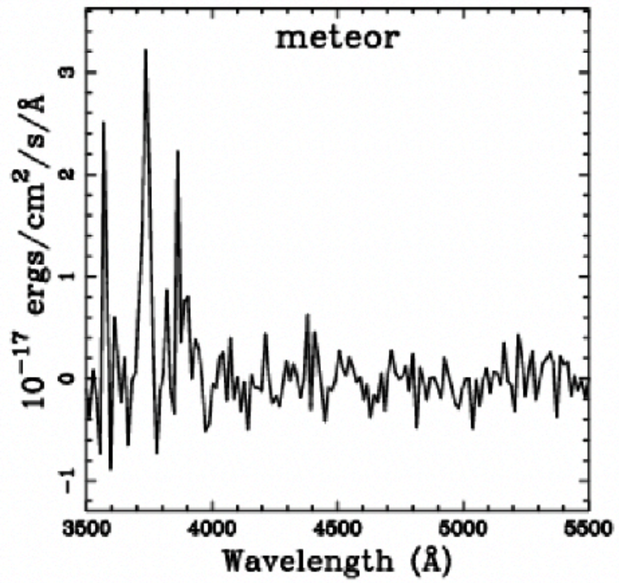
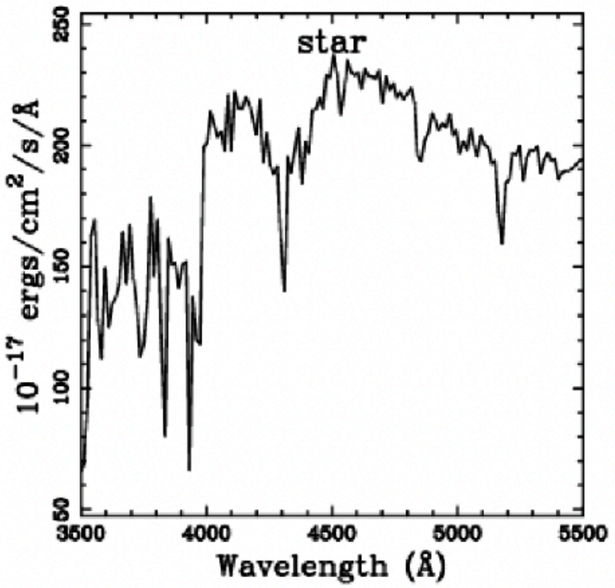


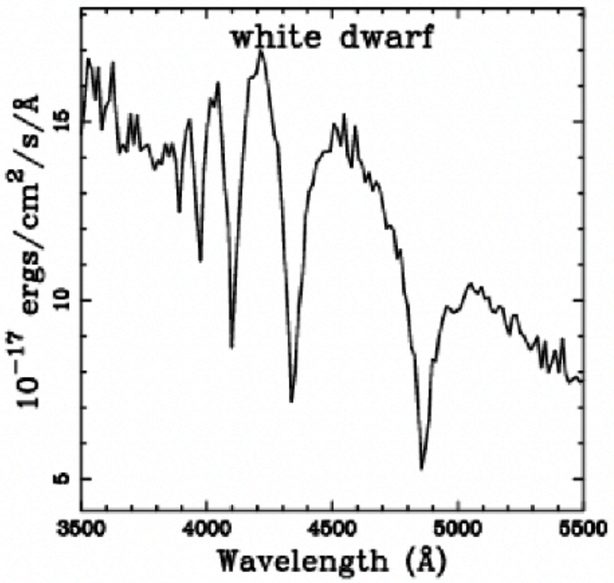
Figure 1. The HETDEX field compared to overlapping large-area surveys. The red regions display the 540 deg^2 baseline fields of HETDEX. The Green, Cyan and Gray areas show, respectively, the BOSS (Dawson et al. 2013), eBOSS (Dawson et al. 2016), and DESI (DESI Collaboration et al. 2016) footprints.

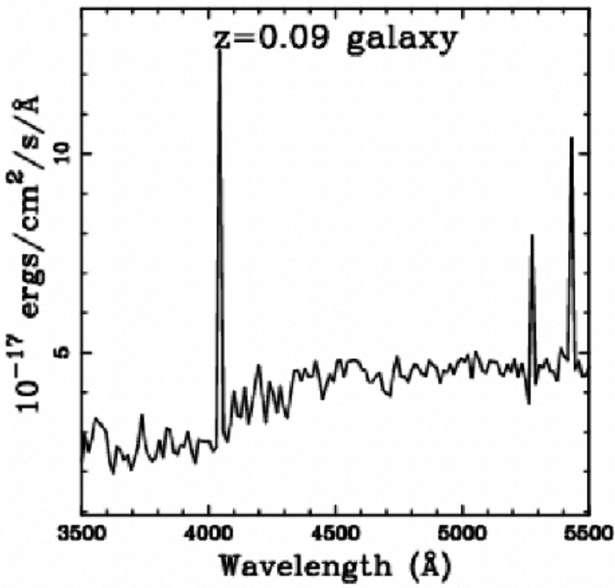
- *As of August 2020:*
  - 3100 pointings = 160K IFUs x 448 fibers/IFU x 3 dithers = **215M spectra**
- **Goal:** 468K IFUs = **629M spectra.** Big data!

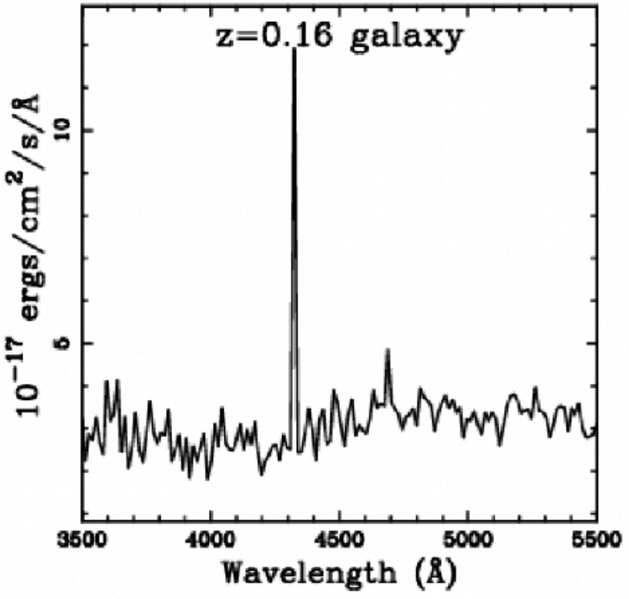
We take spectra of a lot of objects without pre-selection

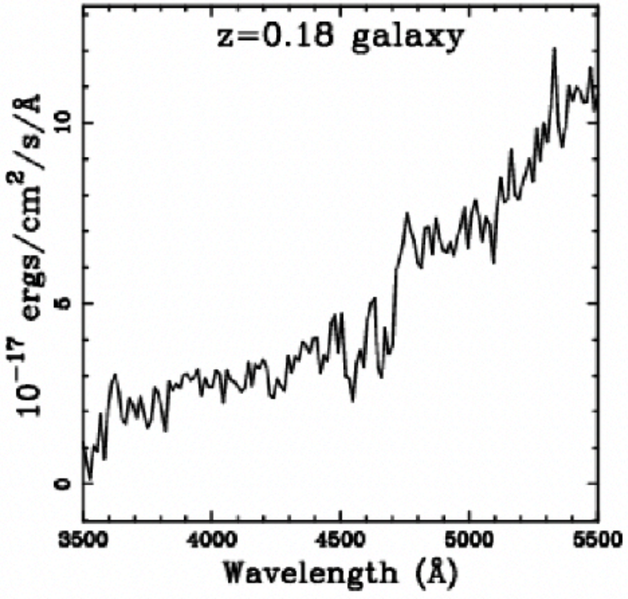


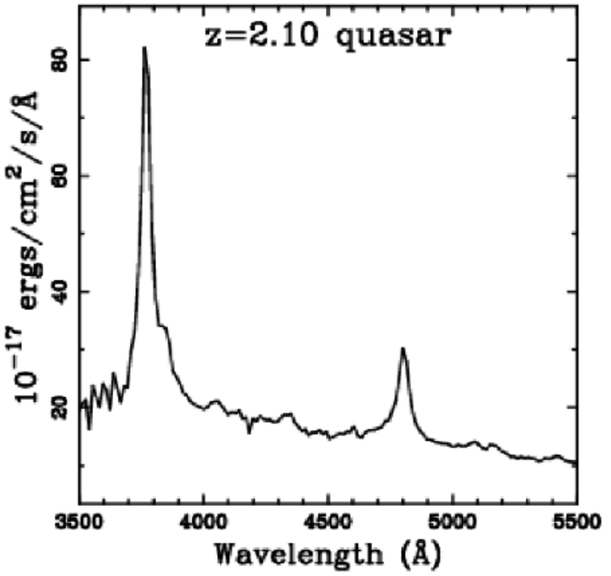


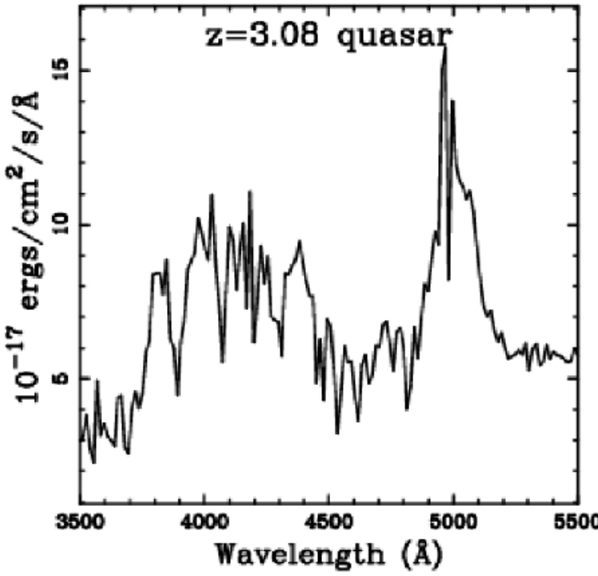






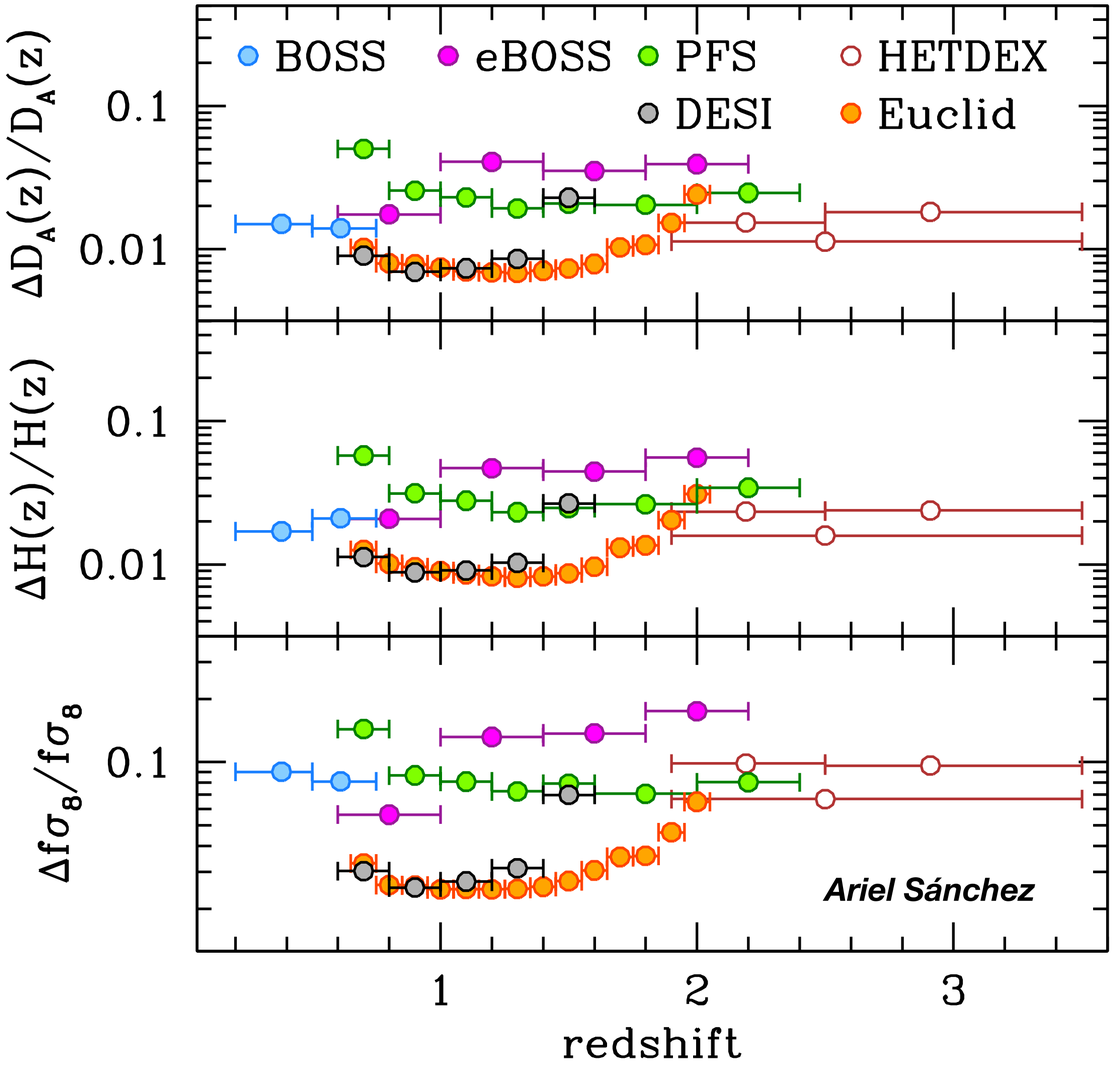






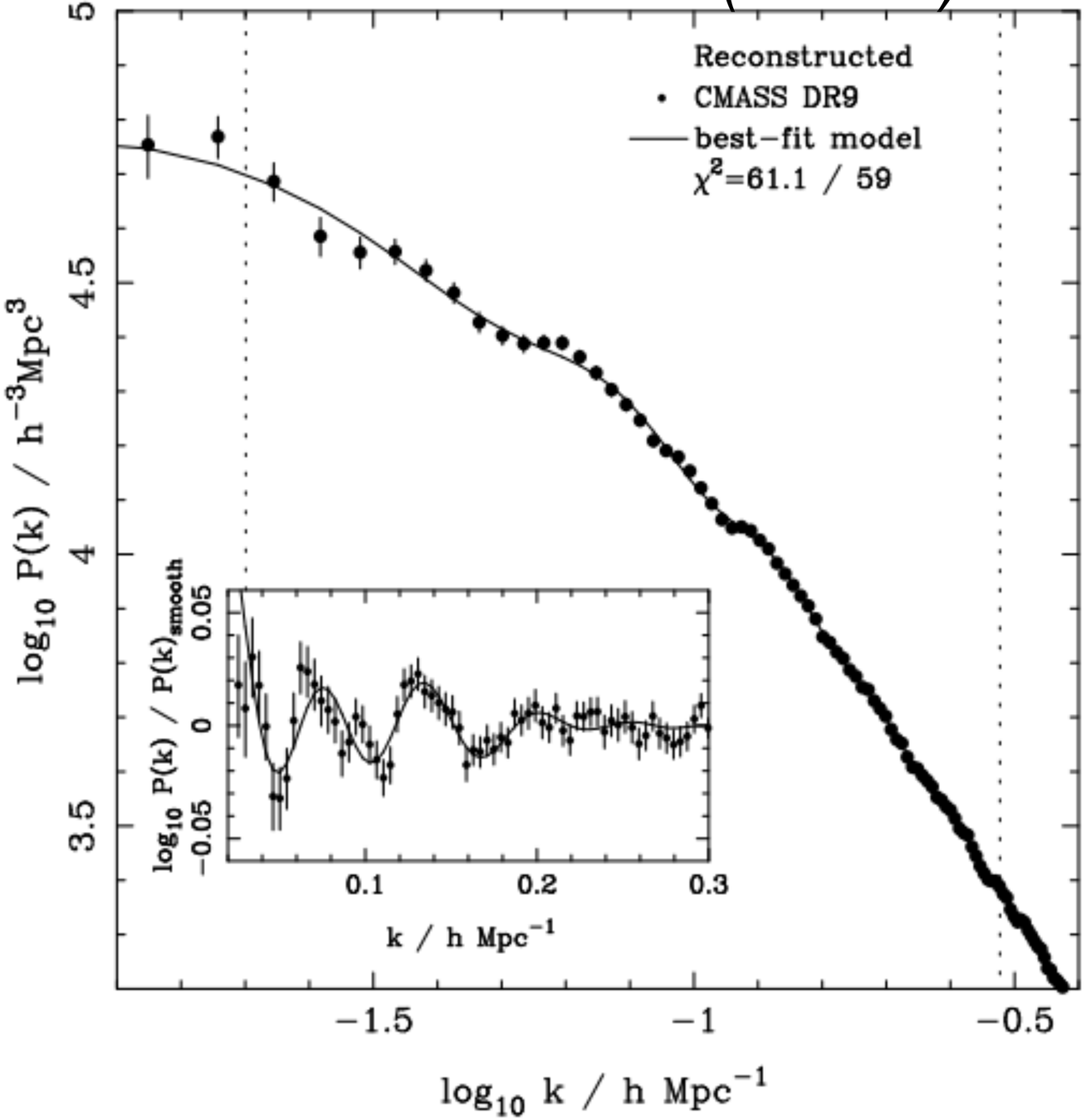
Scientific Goal

This is “Dark Energy Experiment”

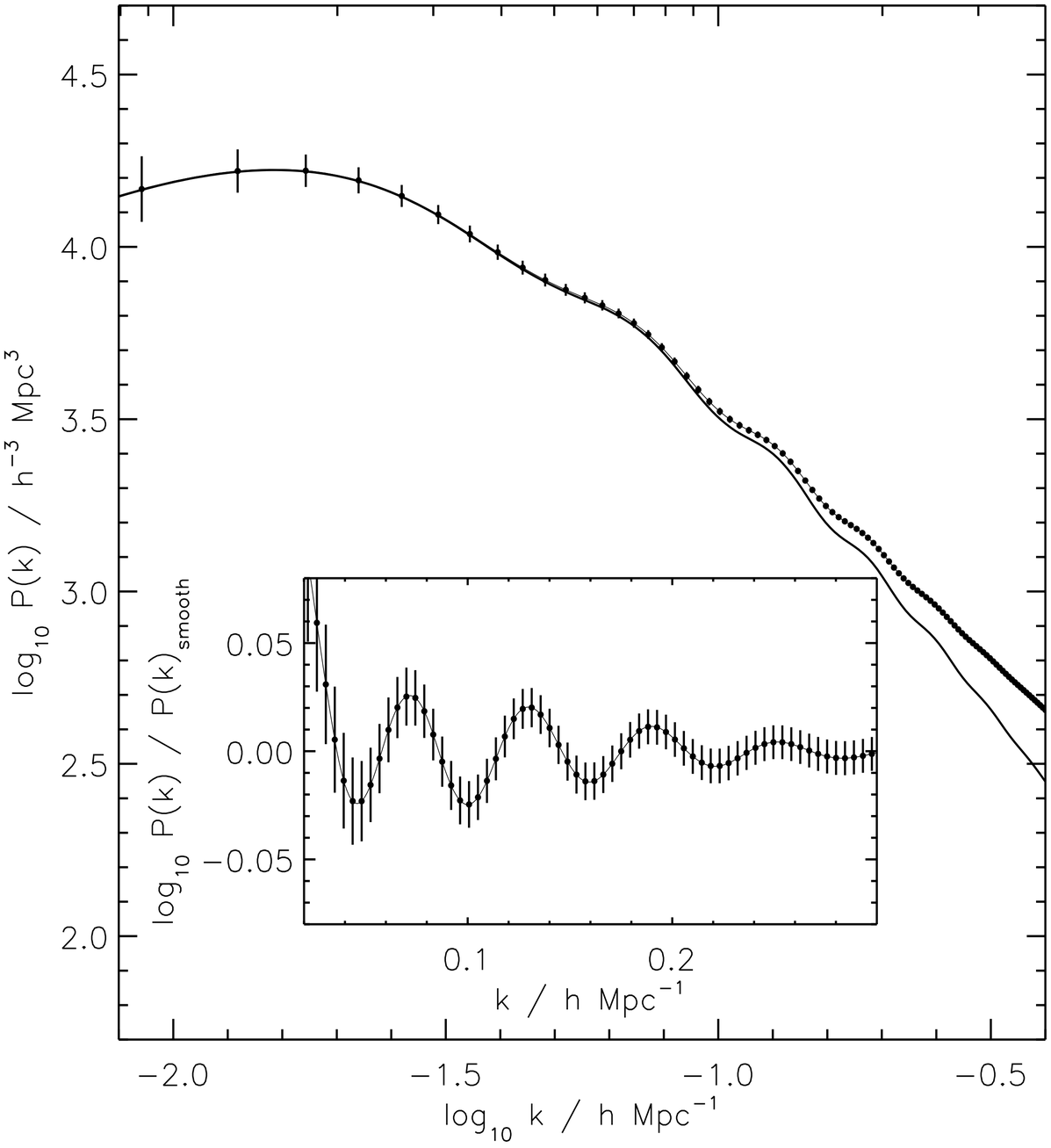


- We have *designed* HETDEX to determine the angular diameter distance $D_A(z)$ and the Hubble expansion rate H(z) to a percent-level precision.
  - We can detect dark energy at z>2, **probing time evolution of dark energy density**.
  - We can also measure the linear growth rate of density fluctuations $f\sigma_8$.
- We are the only players at z>2.4 Lasting impacts well beyond Euclid.

SDSS-III/BOSS (z=0.6)



HETDEX (z=2.5) (Forecast)



Beyond DE: Breadth of Science with HETDEX

Stars, galaxies, AGNs, …

1 2021ApJ...921...58S 2021/11 cited: 6

The NEWFIRM HETDEX Survey: Photometric Catalog and a Conservative Sample of Massive Quiescent Galaxies at z = 3-5 o 17.5 deg^2 in the SHELA Field

Stevans, Matthew L.; Finkelstein, Steven L.; Kawinwanichakij, Lalitwadee *and 10 more*

2 2021ApJ...920..122D 2021/10 cited: 1

Detection of Lyman Continuum from 3.0 < z < 3.5 Galaxies in the HETDEX Survey

Davis, Dustin; Gebhardt, Karl; Mentuch Cooper, Erin *and 15 more*

3 2021ApJ...916...11I 2021/07 cited: 1

HETDEX [O III] Emitters. I. A Spectroscopically Selected Low-redshift Population of Low-mass, Low-metallicity Galaxies

Indahl, Briana; Zeimann, Greg; Hill, Gary J. *and 16 more*

4 2021arXiv210511497Z 2021/05 cited: 4

First HETDEX Spectroscopic Determinations of Lyα and UV Luminosity Functions at $z = 2 - 3$: Bridging a Gap Between Fair AGN and Bright Galaxies

Zhang, Yechi; Ouchi, Masami; Gebhardt, Karl *and 21 more*

5 2021arXiv210502892I 2021/05

HETDEX [OIII] Emitters I: A spectroscopically selected low-redshift population of low-mass, low-metallicity galaxies

Indahl, Briana; Zeimann, Greg; Hill, Gary J. *and 16 more*

6 2021ApJ...912..100W 2021/05 cited: 3

The HETDEX Survey: The Lyα Escape Fraction from 3D-HST Emission-Line Galaxies at z ~ 2

Weiss, Laurel H.; Bowman, William P.; Ciardullo, Robin *and 13 more*

7 2021ApJ...911..108H 2021/04 cited: 3

The Stars of the HETDEX Survey. I. Radial Velocities and Metal-poor Stars from Low-resolution Stellar Spectra

Hawkins, Keith; Zeimann, Greg; Sneden, Chris *and 19 more*

8 2020ApJ...903...24M 2020/11 cited: 4

Cosmological 3D H I Gas Map with HETDEX Lyα Emitters and eBOSS QSOs at z = 2: IGM-Galaxy/QSO Connection and a ~40 Mpc Scale Giant H II Bubble Candidate

Mukae, Shiro; Ouchi, Masami; Hill, Gary J. *and 20 more*

Maja Lujan Niemeyer, EK, et al. (to be submitted this week)

Stacking analysis of (a subset of) LAEs

HETDEX is ideal for this type of analysis

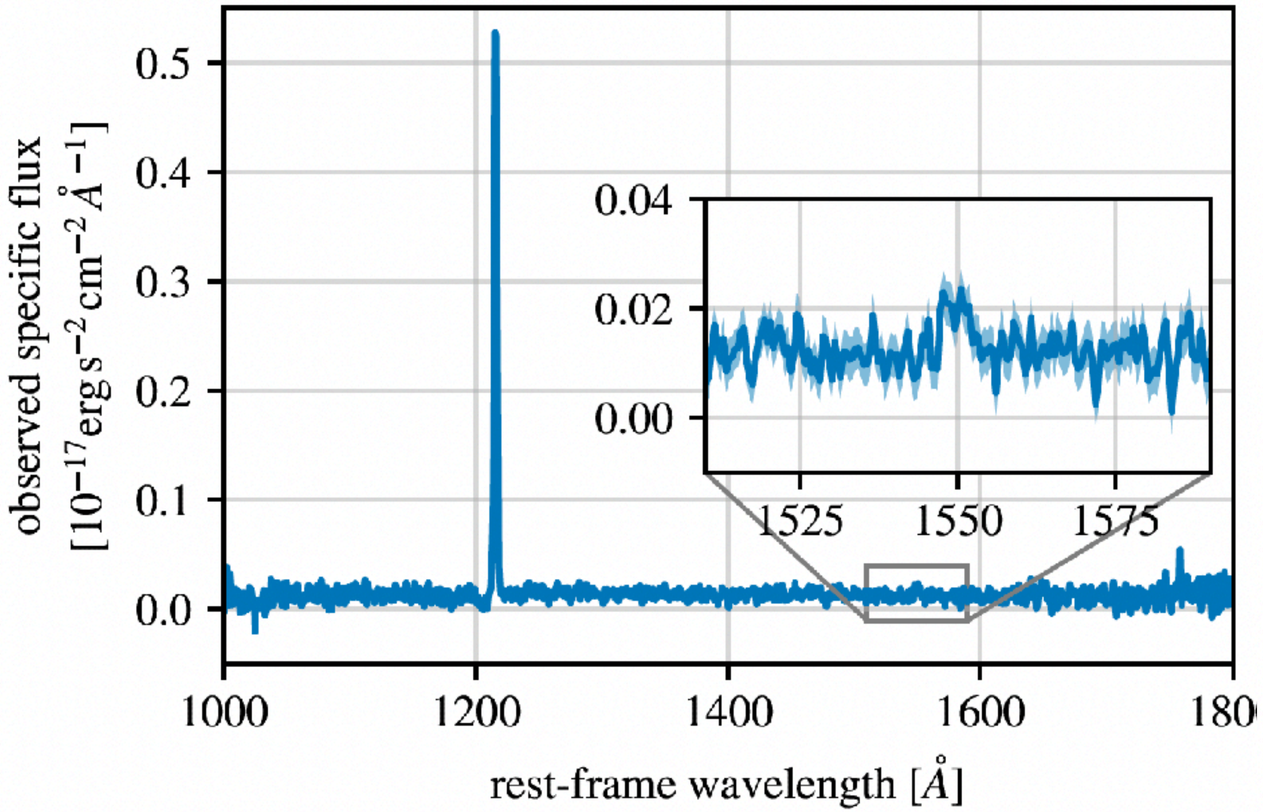


Figure 2. Median spectrum of the 968 LAEs

In the end we expect to detect one million LAEs!

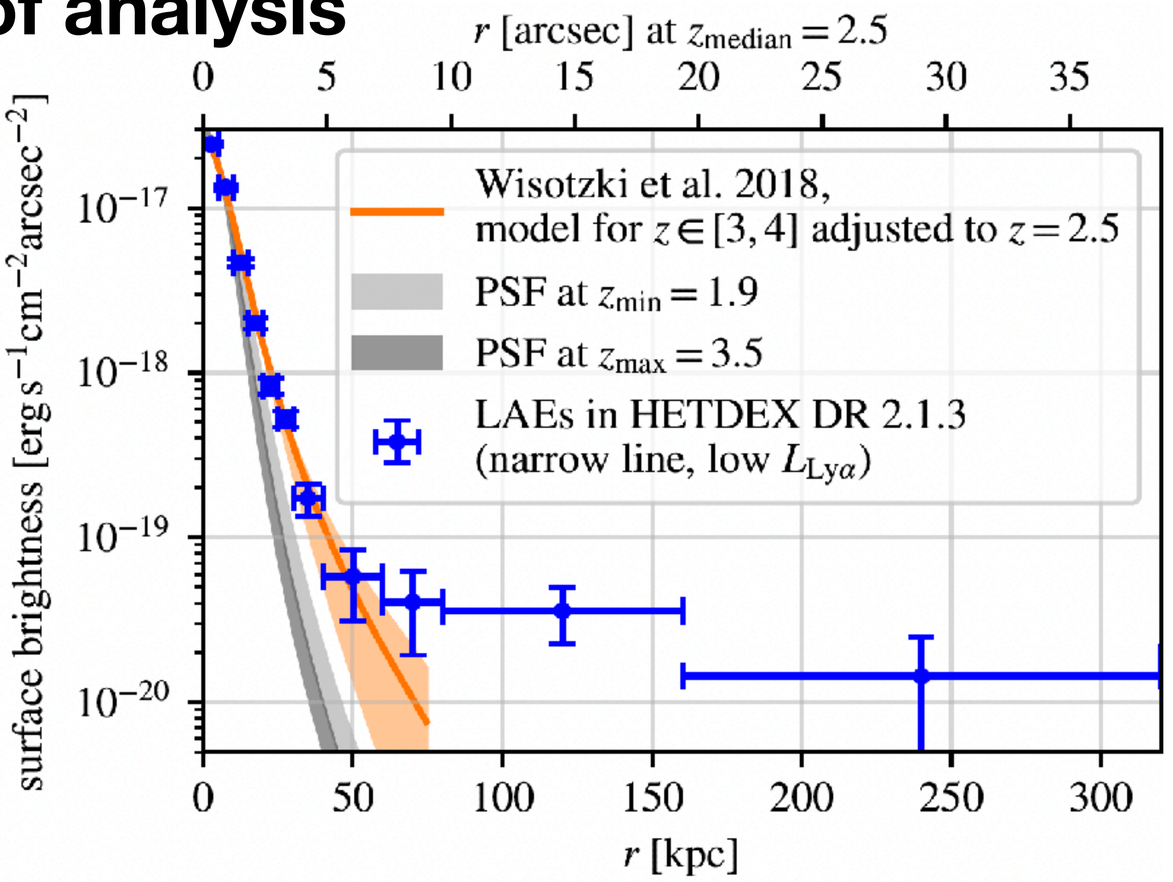


Figure 4. Left: Average Lyman-α surface brightness profile

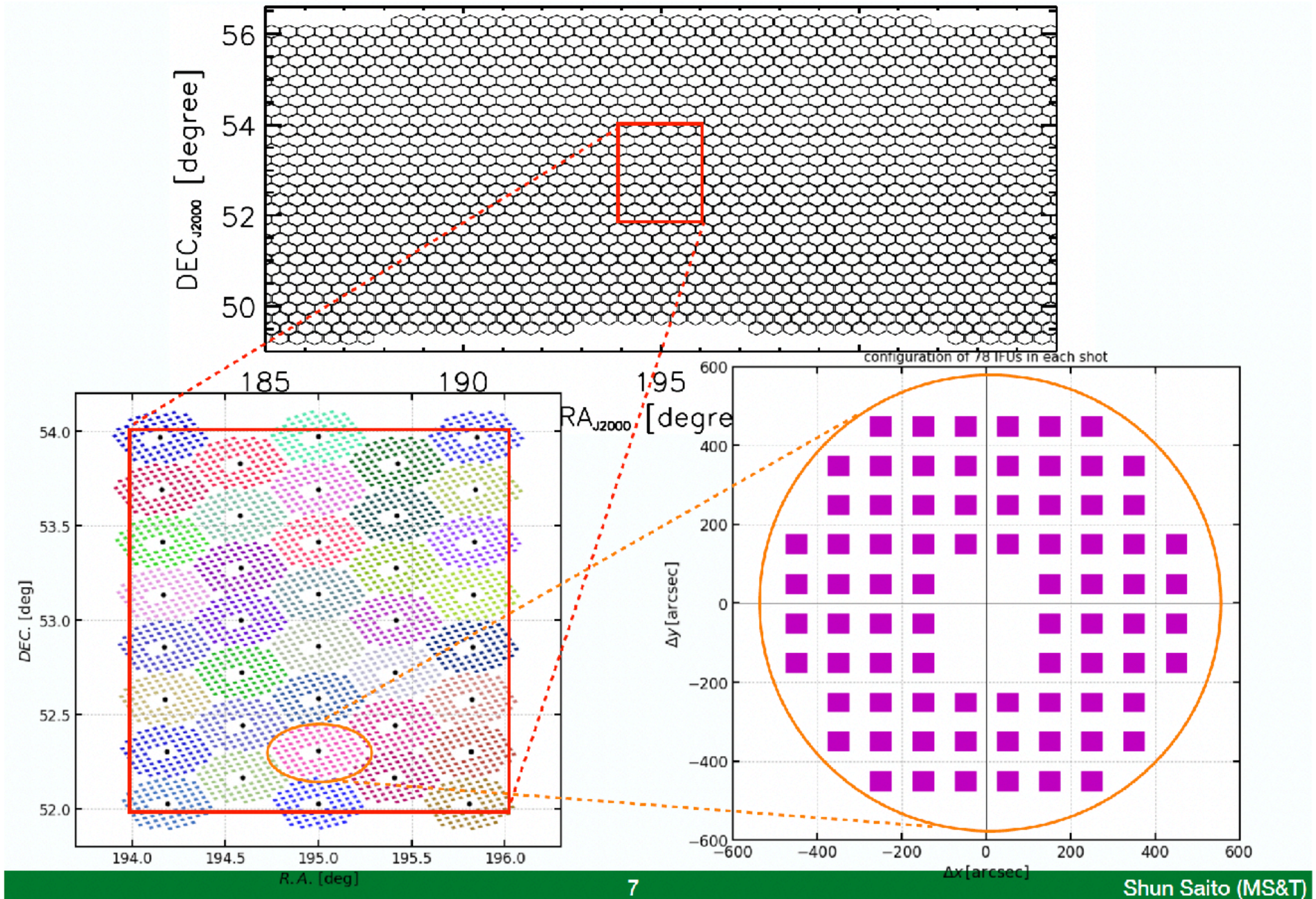
Clear detection of very extended Lyman-alpha emission out to 160 kpc!

Lyman-alpha intensity mapping

No photons left behind

- One million LAEs over 468K IFUs is **only a couple of LAEs per IFU**.
  - Each IFU contains 448 fibers. Are we wasting fibers?
- LAEs are detected over a certain signal-to-noise threshold. But, there are a lot of Lyman-alpha photons below the threshold.
- We can retrieve all photons by **cross-correlating the locations of detected LAEs with intensities in the rest of fibers.**
  - Purely internal to HETDEX, but cross-correlation with other data sets is an obvious next step.
- No photons are left behind!

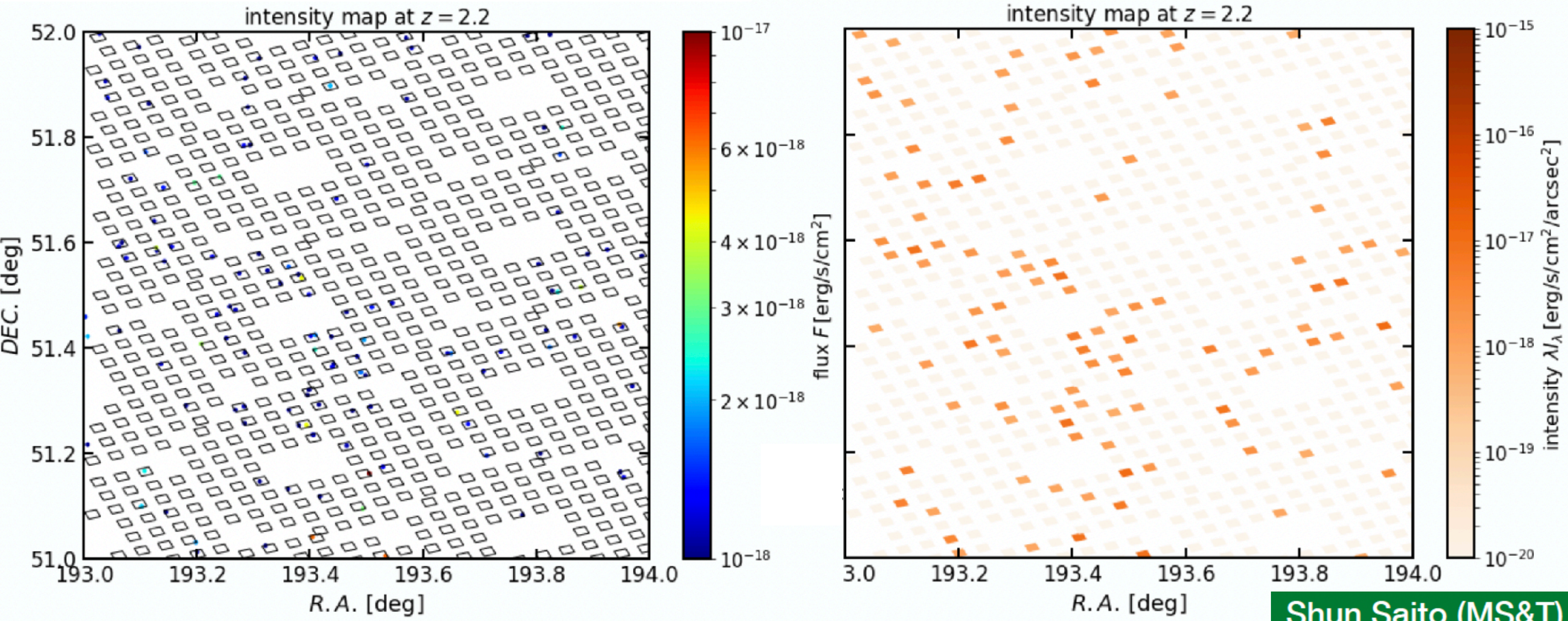
Simulation study of Lyman-alpha IM with HETDEX



Shun Saito

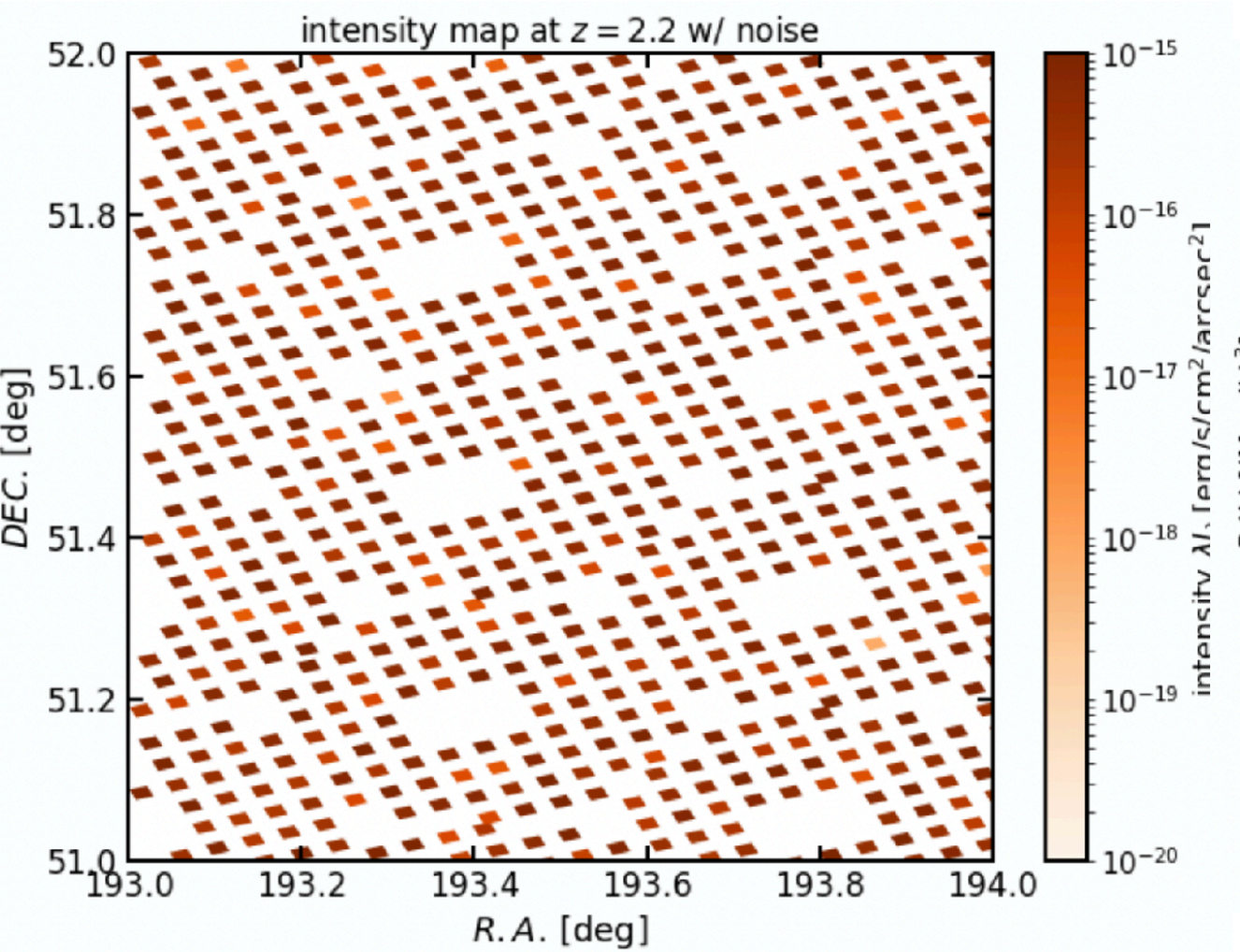
LAEs below a signal-to-noise threshold

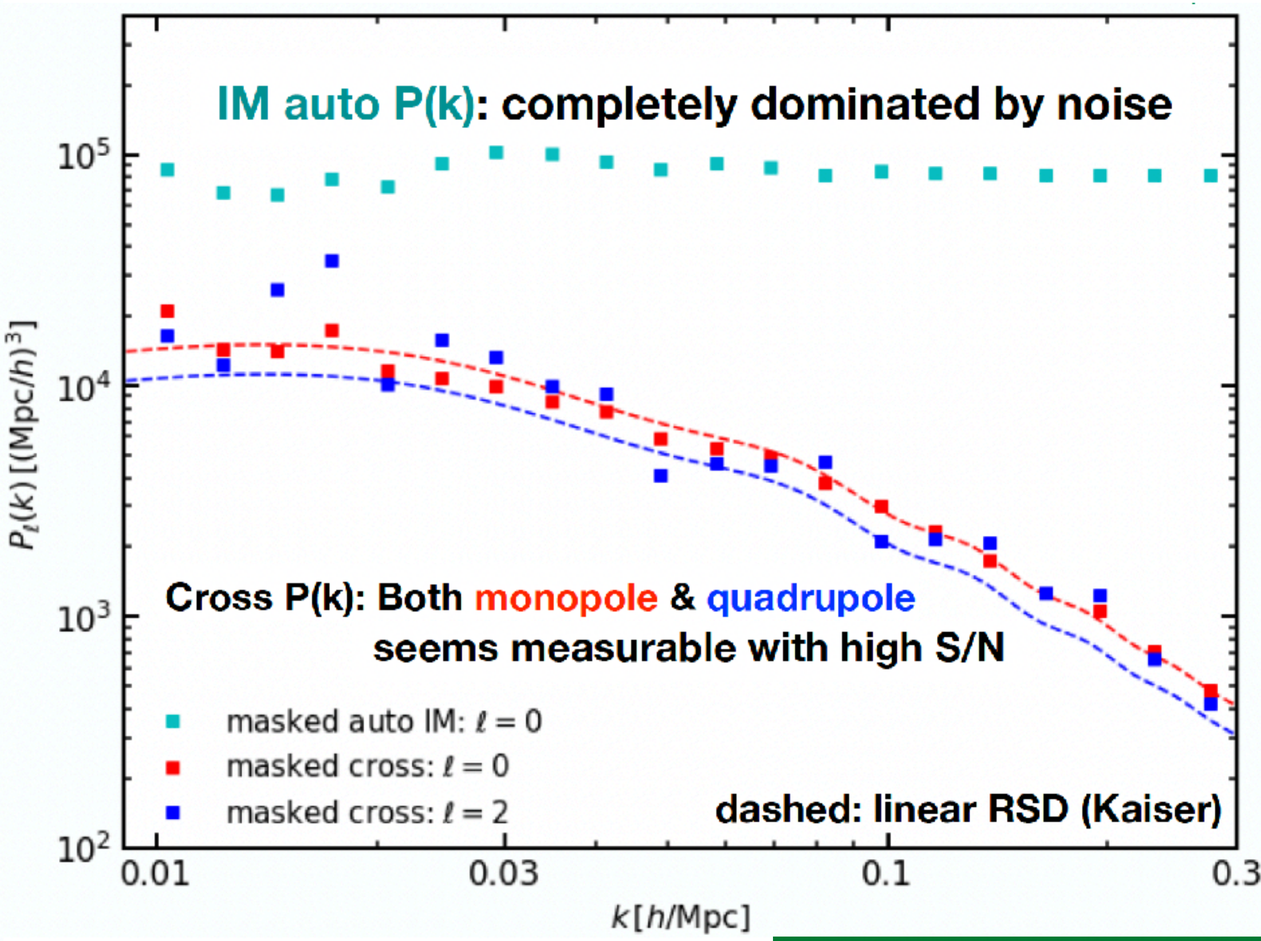
Intensity map!



Shun Saito (MS&T)

Extracting intensity from a noisy map via cross-correlation





Shun Saito (MS&T)

Holy grail: Mapping the cosmic web in Lyman-alpha. This requires (much) deeper observations than HETDEX.

Figure 1: Simulated Lyα surface brightness map at z=2.0 for a slice depth of 5.7Å in the observed frame with the footprints of VIRUS,

HETDEX Collaboration, arXiv:2110.04298, 2110.03843

Conclusion

The HETDEX has arrived.

- The HETDEX data are a gold mine. We take spectra of the Universe without pre-selection. Stars, galaxies, AGNs, meteors, …, and intensity mapping!
  - HETDEX (Internal) Data Release 2 (HDR2): 215 million spectra (100TB!)
  - We will have 629 million spectra in the end.
- The survey is expected to be complete in 2024.
- We are planning staged public data releases.
- On-going collaboration with LOFAR Two-metre Sky Survey. We will likely have many other collaborations with other surveys.