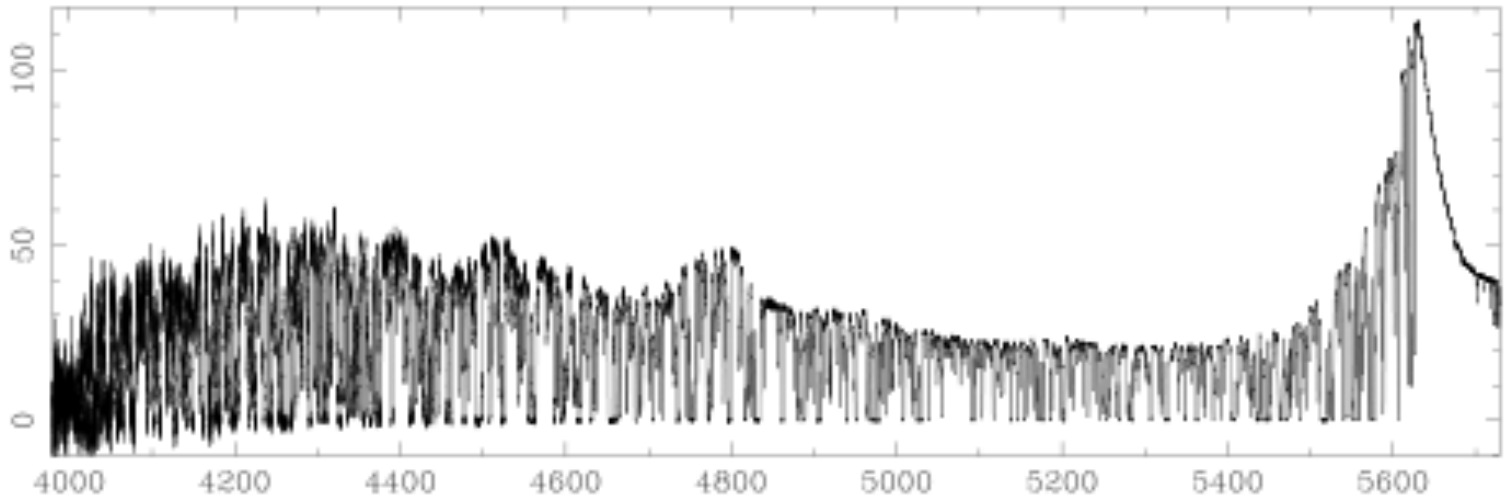
Mapping large-scale structure with the Lyα forest

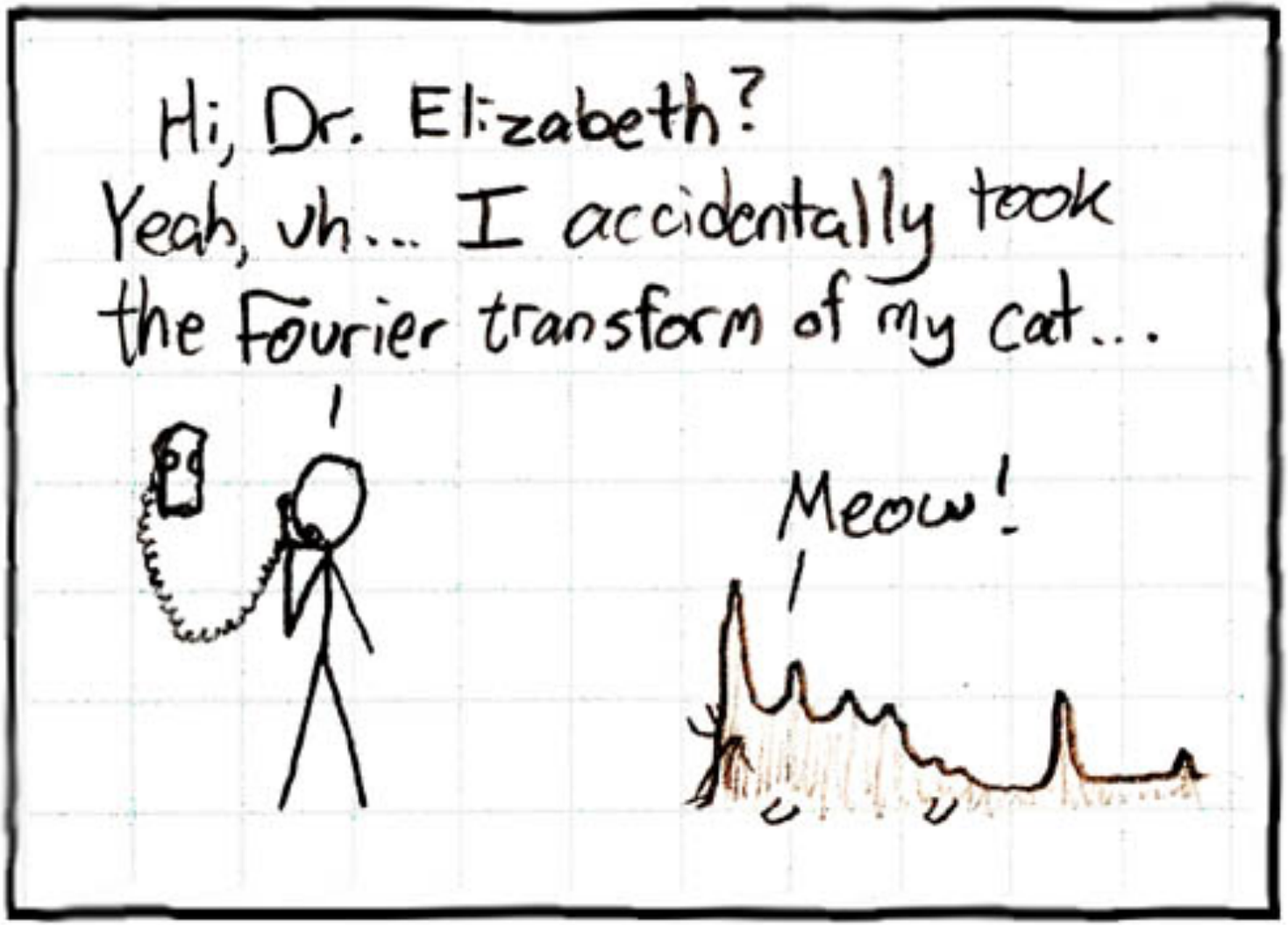
Martin White
with
K-G Lee, Joe Hennawi, Casey Stark & Ellie Kitanidis



QSO 1422+23

Beyond power spectra??

Give a cosmologist a map and they will reflexively take its Fourier transform …



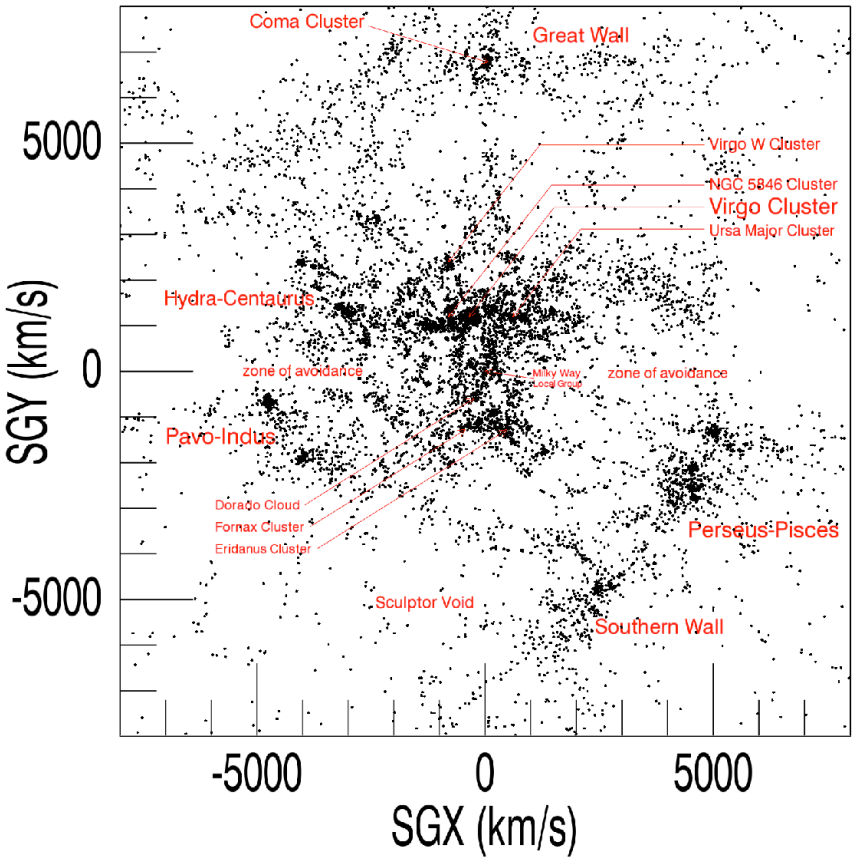
xkcd.com/26

Mapping large-scale structure?

- Sometimes you want to go beyond the 2-point function (gasp!).
- What are the observational requirements for making a map of the large-scale structure at high z?
  - Could we make a map of the large-scale structure with Mpc resolution over a representative volume of the Universe (e.g. $10^6\ h^{-3}\mathrm{Mpc}^3$) with existing telescopes?
- Could we survey massive volumes to find extreme objects (protoclusters, voids, …)?
  - This is really tough using the same "redshifts of galaxies" approach that was used to do this in the local Universe ~25 years ago … surface brightness scales as $(1+z)^4$!

Galaxy redshifts at z~0 and 2

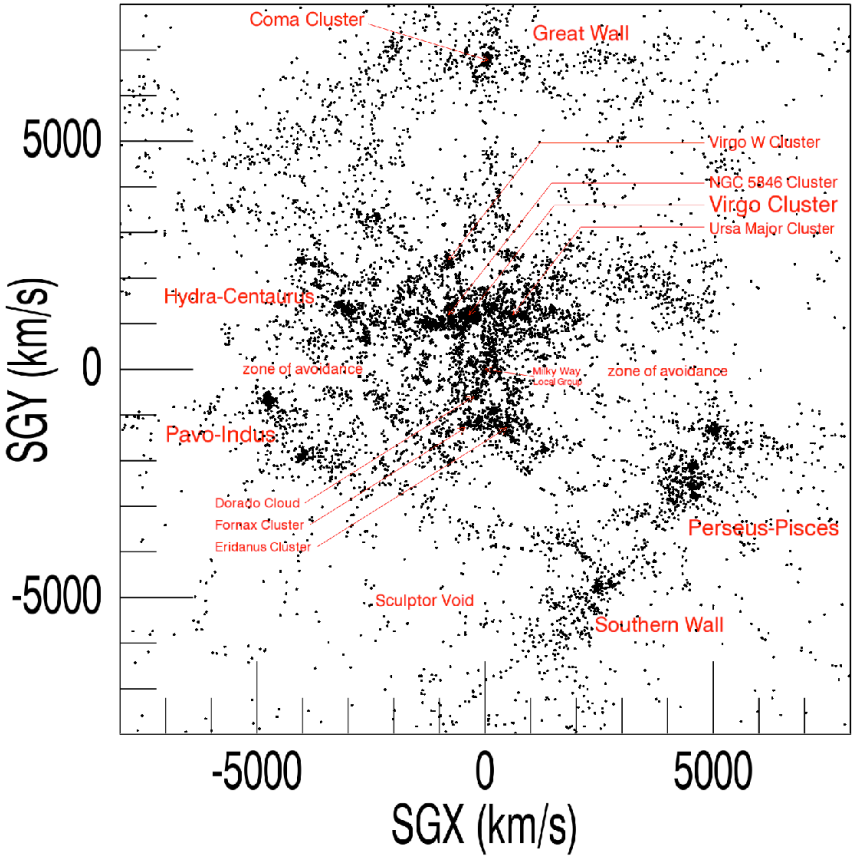
Locally we do cosmography with galaxy redshift surveys



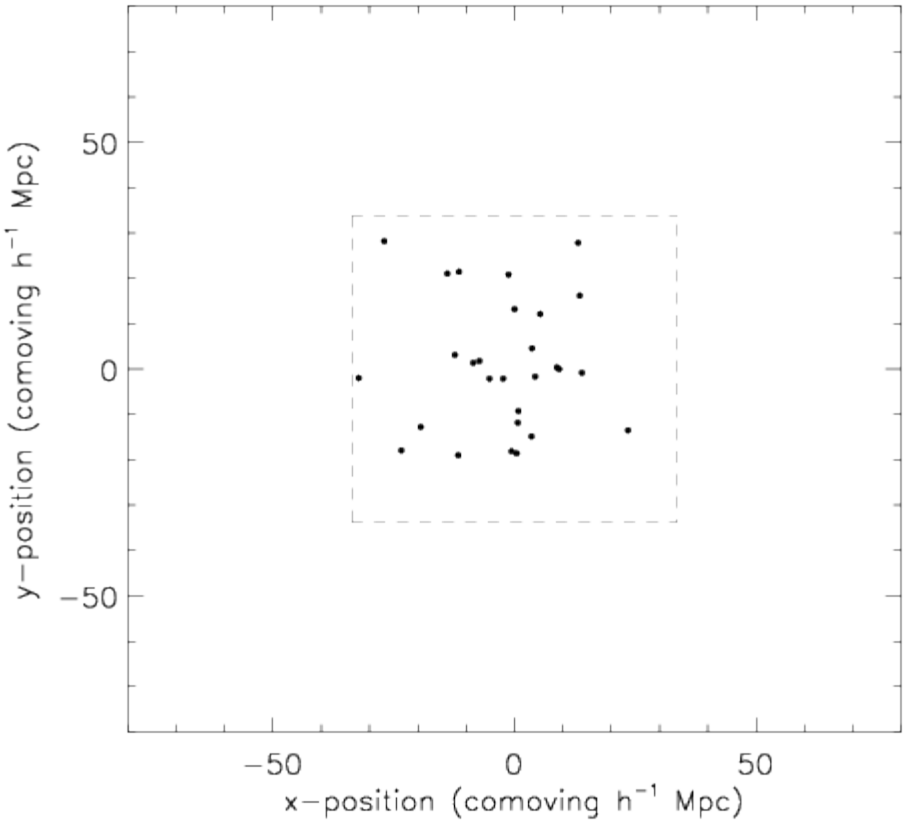
Courtois et al. (2013)

Galaxy redshifts at z~0 and 2

Locally we do cosmography with galaxy redshift surveys
… but redshifts get expensive at high z!

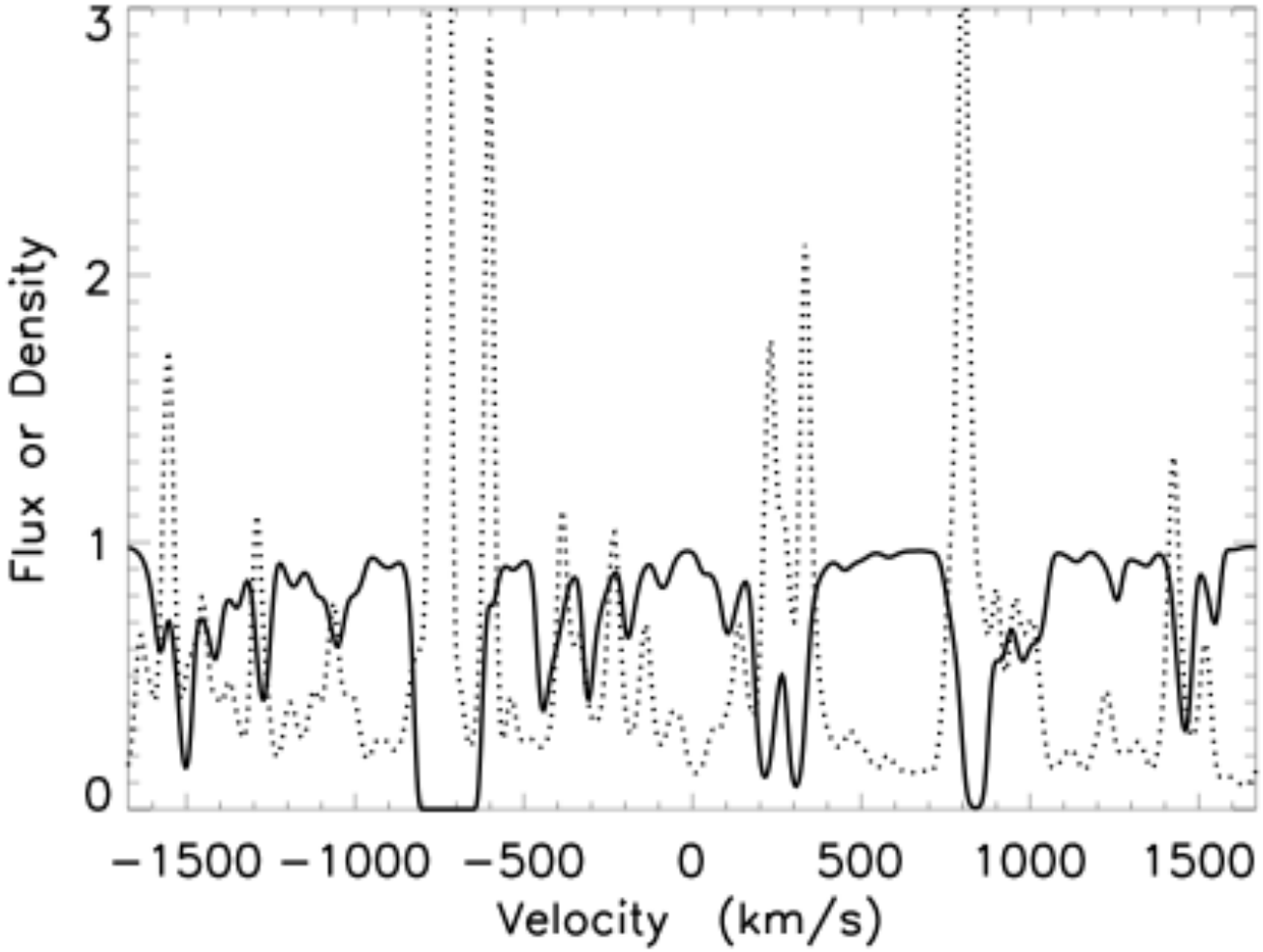


Courtois et al. (2013)



COSMOS collaboration

If we take a spectrum of a background source, neutral Hydrogen along the line of sight imprints features: the Lyα forest.



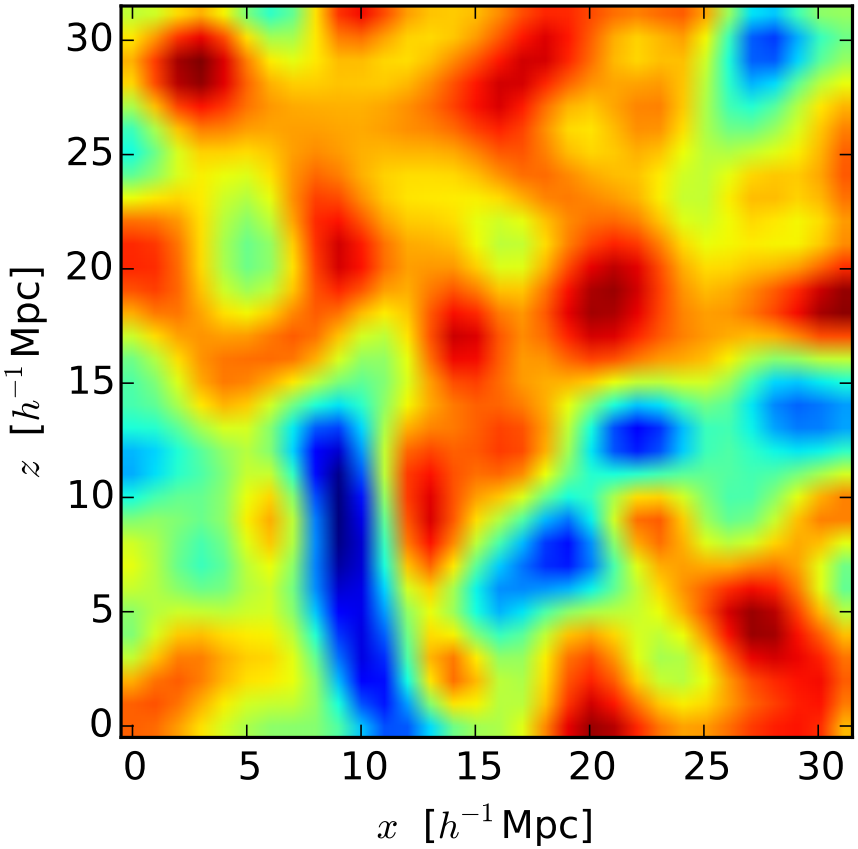
More H*I*, more absorption.

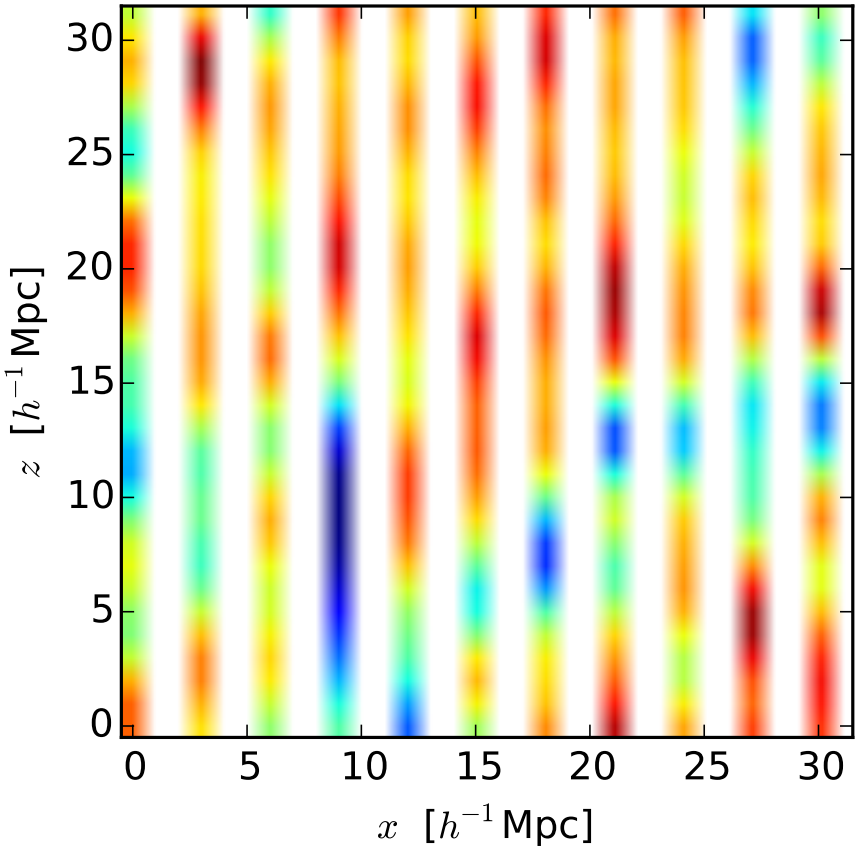
Spectrum "="

Flipped Density

Lyα forest tomography

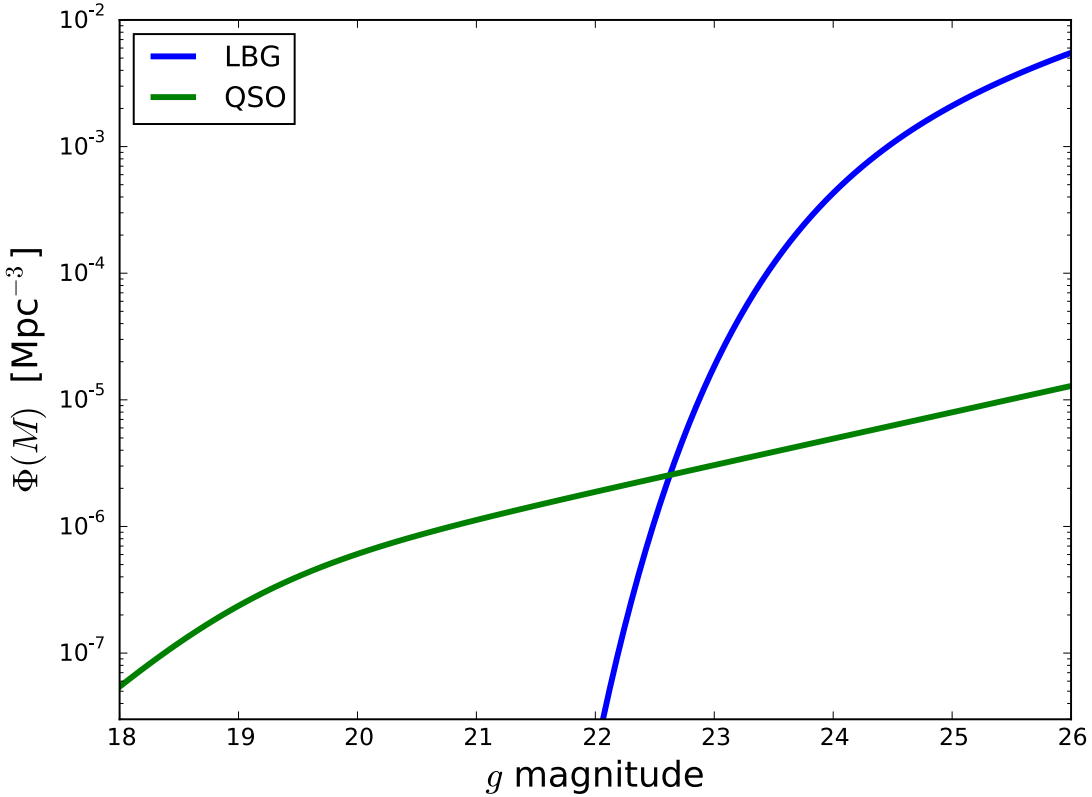
With the Lyα forest we get the line-of-sight sampling “for free”, so we just need to get the transverse sampling high enough.





Source luminosity functions

To increase the sightline density, we need to go beyond QSOs as backlights. Beyond g~22-23 LBGs dominate over QSOs …



Exponential increase in sightline density as probe below g~23!

Resolution requirements

- The standard in the field of IGM studies is to work with very high resolution spectra, of high S/N.
- BOSS taught us that you can get a lot of information from low resolution spectra with low S/N – if you have a lot of them!
  - Think of it as measuring local “mean absorption” rather than individual absorbers.
- Moderate resolution and S/N means what looks like 30m class science can actually be done with a 10m!

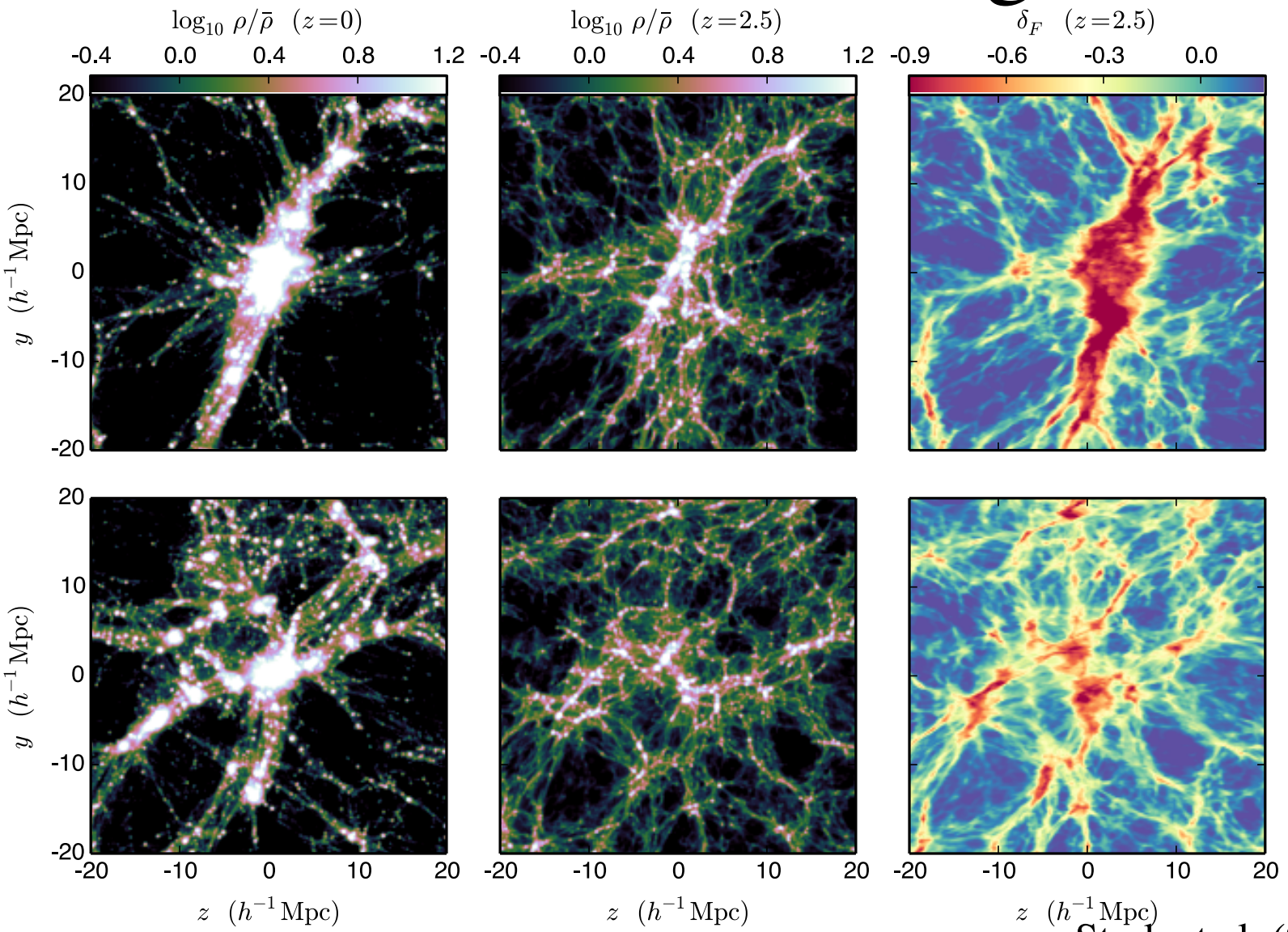
$$R > 1000 \left(\frac{1.4\, h^{-1}\mathrm{Mpc}}{\epsilon} \right) \left[\frac{3.25}{1+z} \right]$$

Lee et al. (2014)

What are we looking for?

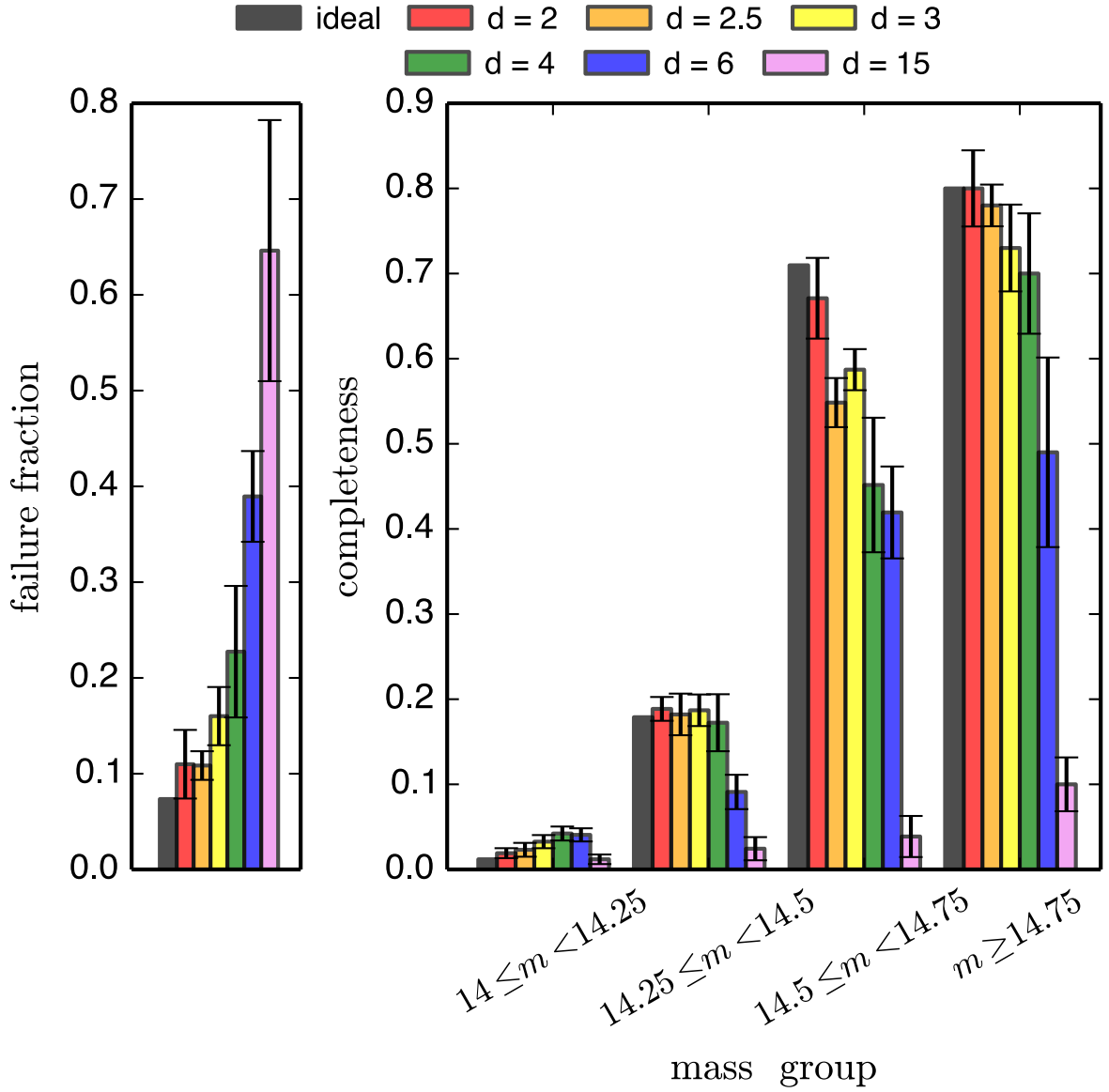
- IGM tomography is ideal for measuring large-scale environments of galaxies and QSOs.
- Map LSS and decompose into filaments, sheets and halos.
- Medium scale 3D Lyα clustering.
  - Possibly CGM studies
- Cross-correlations.
- Refining photo-z's with Lyα as prior.
- From such a map, ideally want to look for large, coherent objects spanning Mpc.
  - Protoclusters
  - Voids

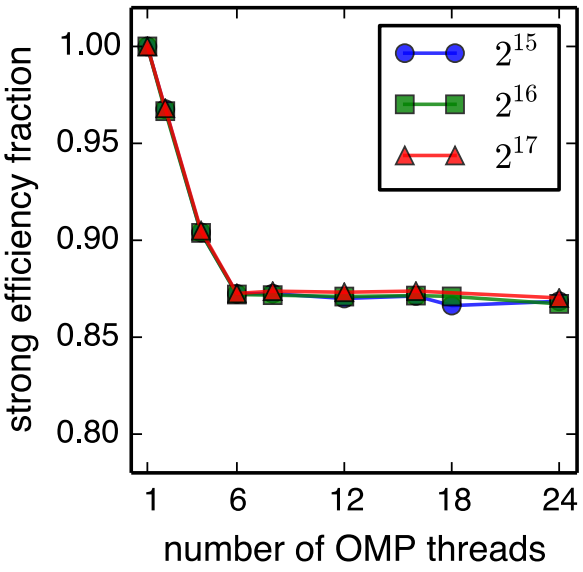
Protocluster finding



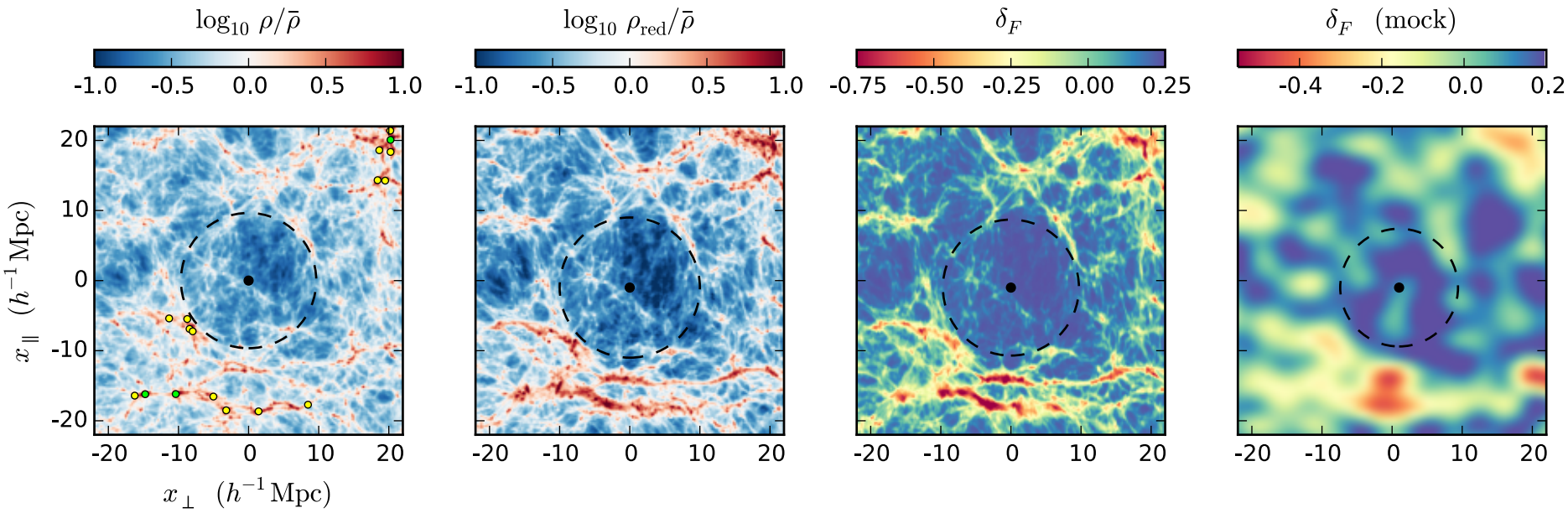
Stark et al. (2015)

Completeness and purity (and scaling!)





Void finding

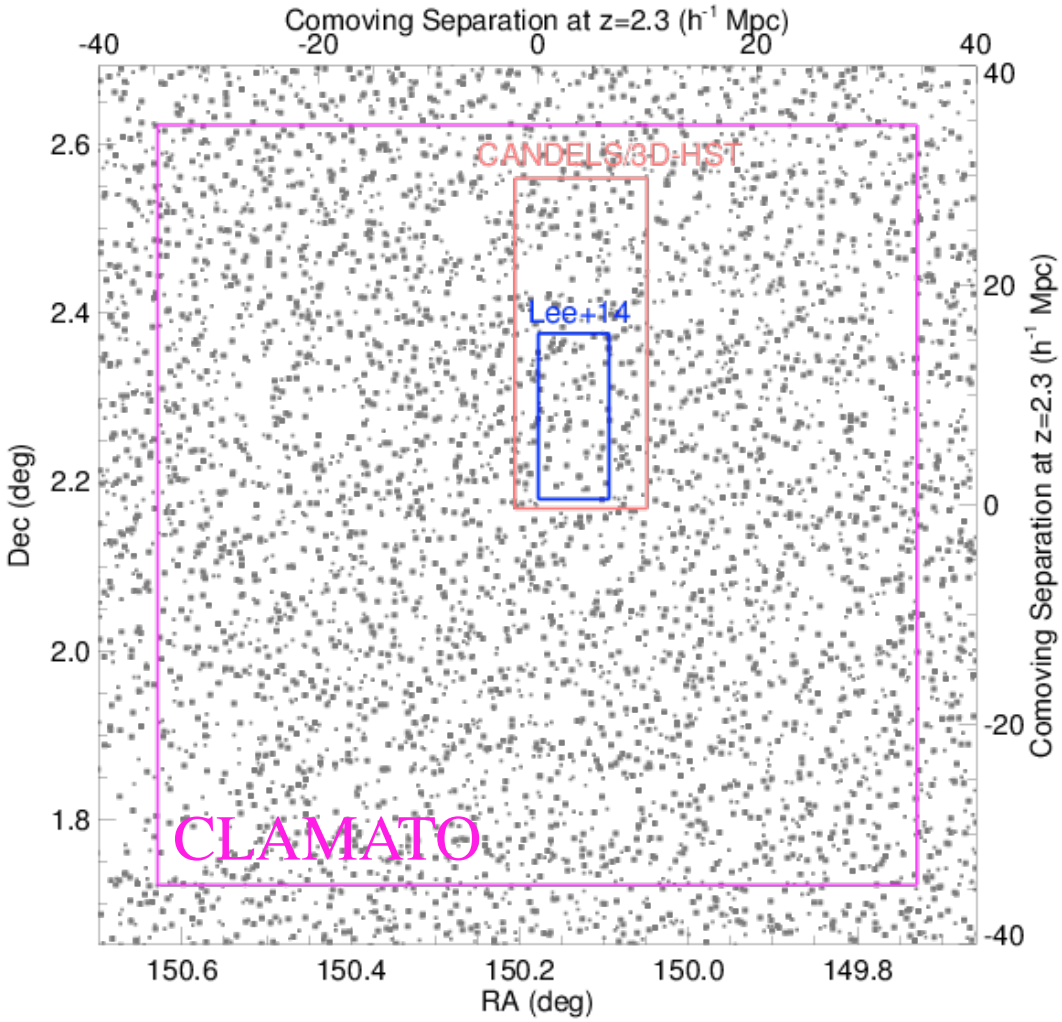


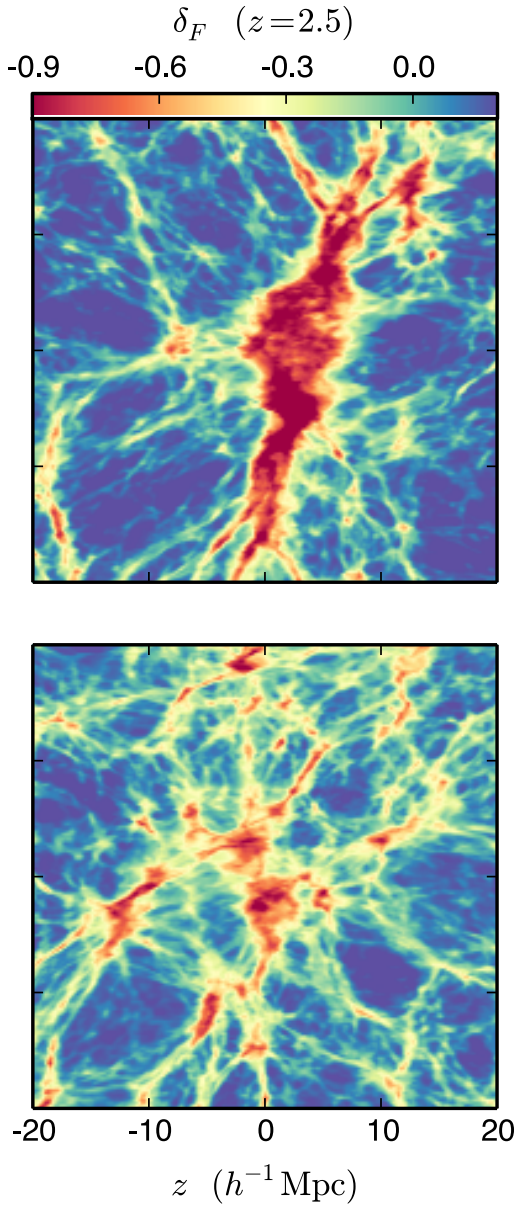
It is also possible to find large underdensities – in fact this is in some ways easier since voids aren't really empty, just underdense in galaxies (see dots in left panel).

CLAMATO

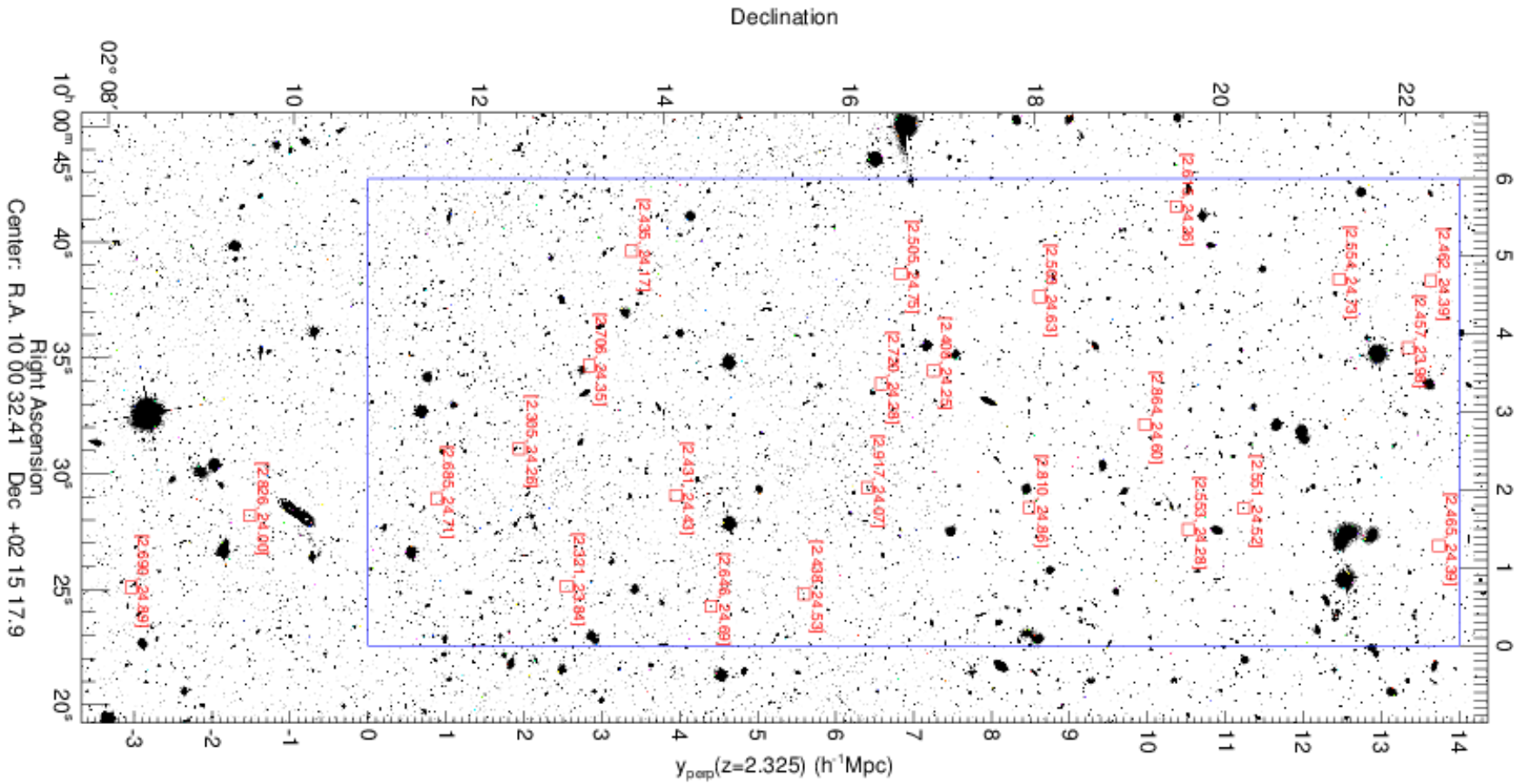
- Survey to do Lyα forest tomography in the central sq. deg. of the COSMOS field.
  - Overlaps CANDELS/3D-HST. Allows study of colors, morphology, SF rate, AGN activity, etc. as a function of large-scale environment.
  - Survey for protoclusters and voids.
- $(60h^{-1}\mathrm{Mpc})^2 \times 300h^{-1}\mathrm{Mpc} \sim 10^6\ h^{-3}\mathrm{Mpc}^3$
- Observing has begun…
  - 1st run was largely "rained out" (70% weather loss), but we got 4hrs on-sky giving spectra of 24 galaxies for ~2hr each (on LRIS).
  - 2nd run was good, data being reduced …

The cosmic web

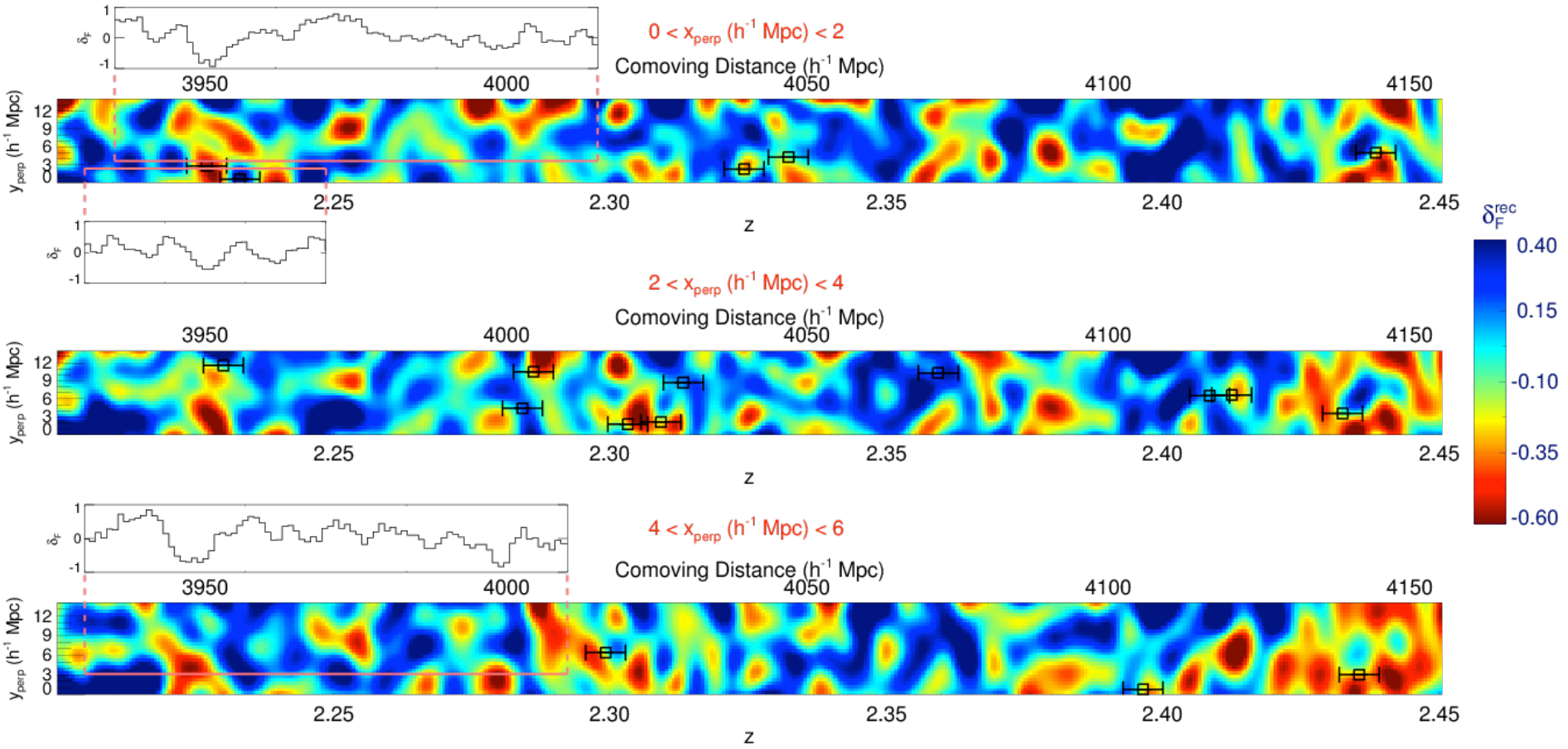




The field

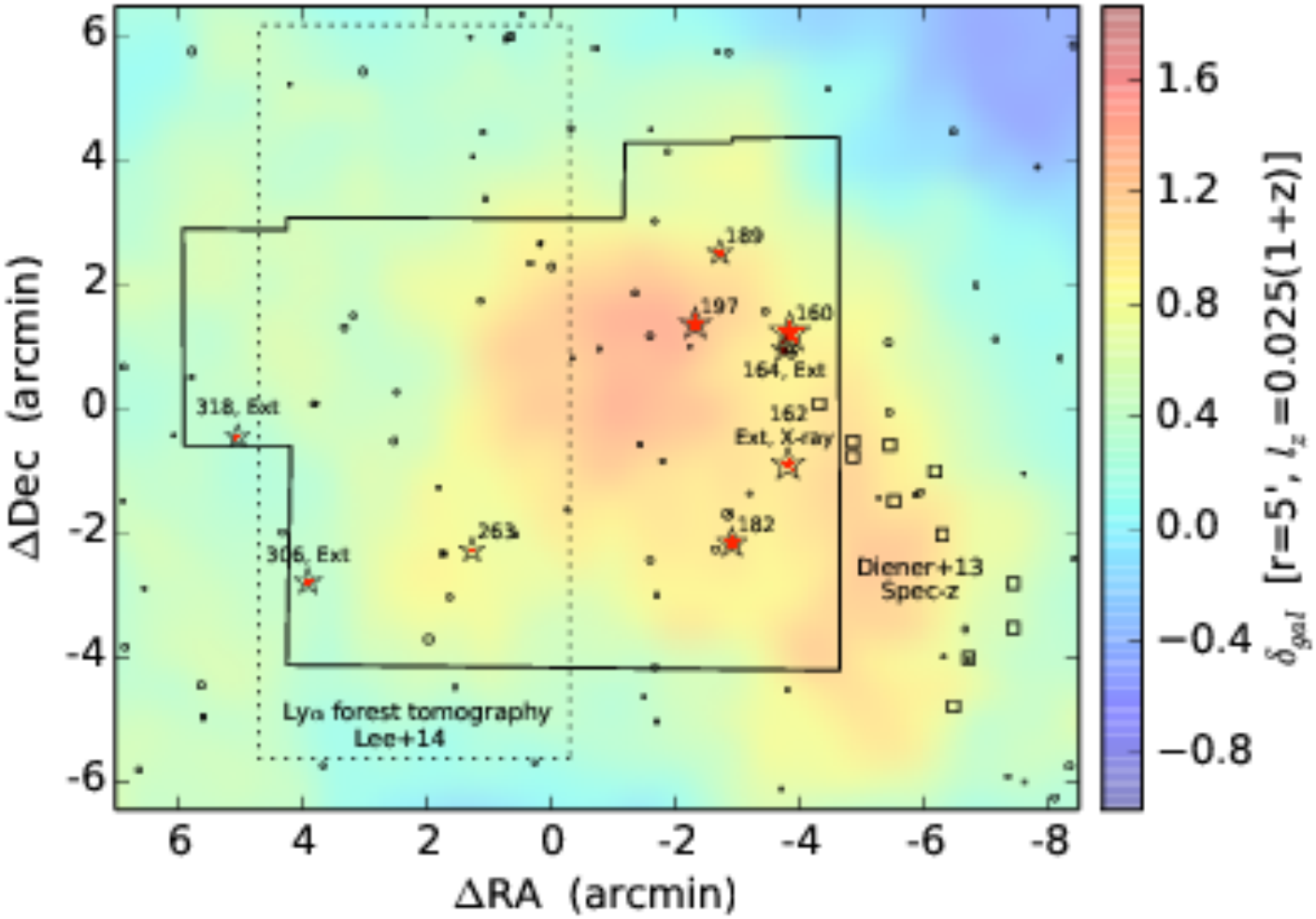

Declination
x_{perp}(z=2.325) (h^{-1}Mpc)
y_{perp}(z=2.325) (h^{-1}Mpc)
Right Ascension
Center: R.A. 10 00 32.41 Dec +02 15 17.9

Preliminary maps: 24 spectra



Protocluster at z=2.43?

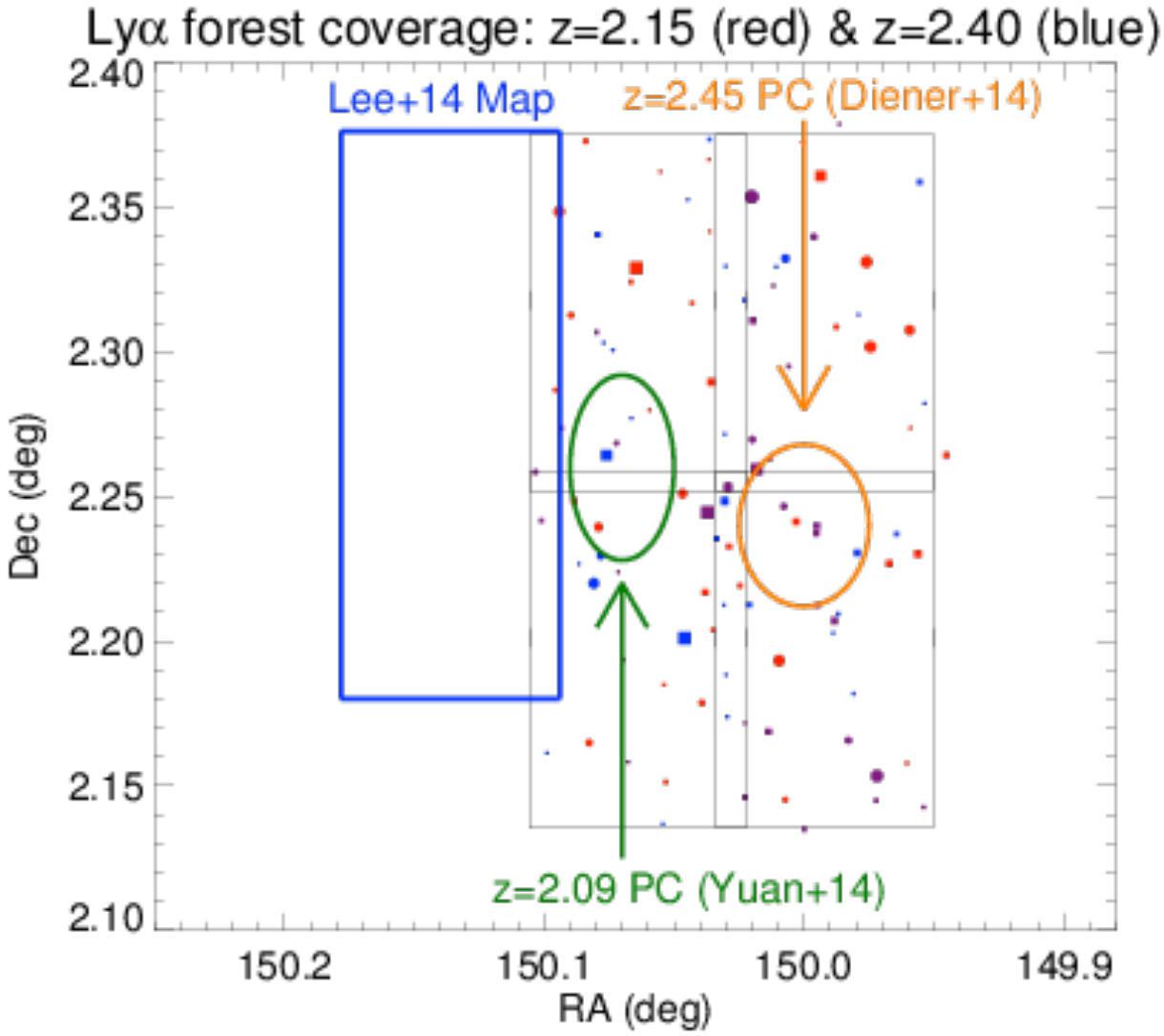
Chiang et al. (submitted)



Color: photo-z galaxy density
Stars: HETDEX pilot.
Squares: zCOSMOS.

Where to next …

- We have reobserved the COSMOS field …



Detailed IGM Mapping through Protocluster Lines-of-Sight (DIMPLS)

- Use known protocluster galaxies as sources for high-resolution foreground tomography.
- Reduce <d> from 3-4Mpc/h to 1.5Mpc/h (reconstructions at 400kpc proper).
- Have upcoming time on VLT and Keck.

Conclusions

- With BOSS, and now Clamato, studies of the IGM have entered the “3D era”.
- Can (sort of) do 30m science with an 8-10m telescope.
- Surveys of huge volumes at z~2-3 are possible with modest investments in telescope time.
  - Search for “large” (Mpc scale) objects at hi z.
  - Make higher resolution maps in special locations (e.g. in the foreground of proto-clusters).

http://tinyurl.com/lya-tomography-sim-data

The End