



Spectroscopic surveys @ SF2A 14th May 2019

# The Growth of Massive Spectroscopic Surveys of the Intergalactic Medium

Mat Pieri

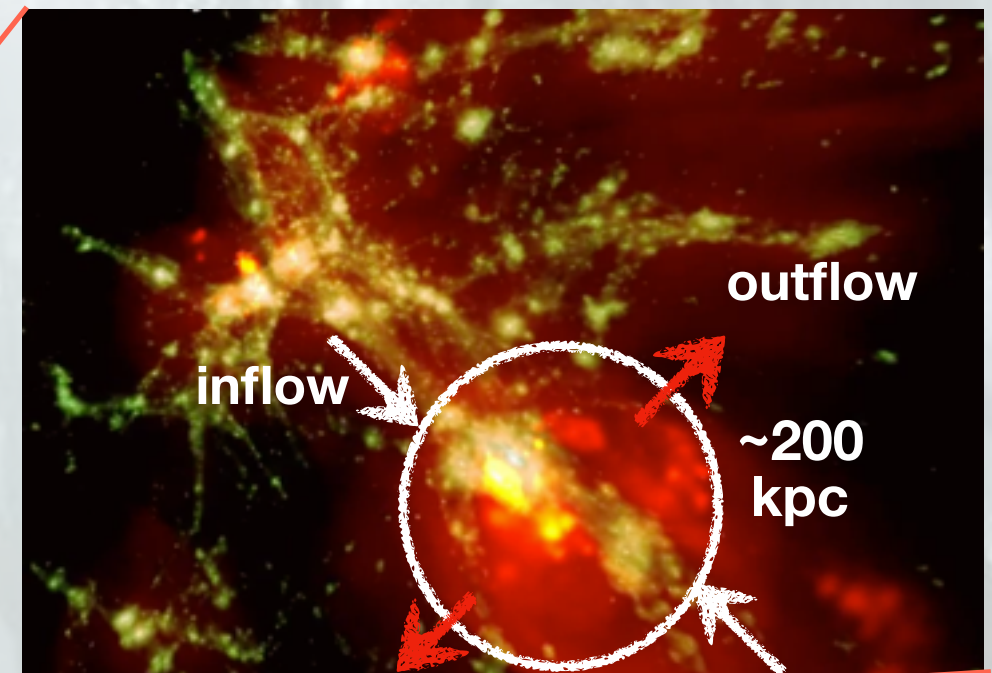
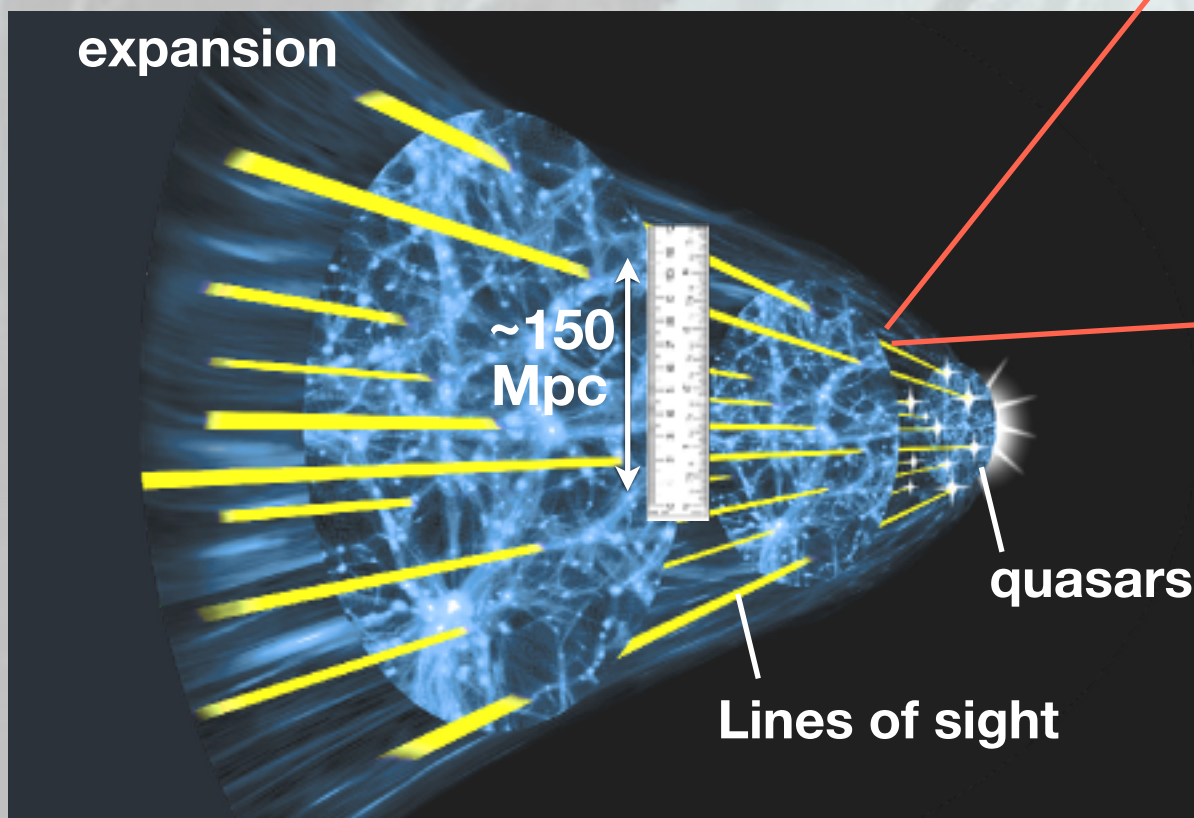
Laboratoire d'Astrophysique de Marseille





# The Big Questions

Q1: How does dark energy emerge to dominate the universe?



Circumgalactic Medium (CGM)

Q2: How do galaxies form their stars from intergalactic gas?

Bonus questions:

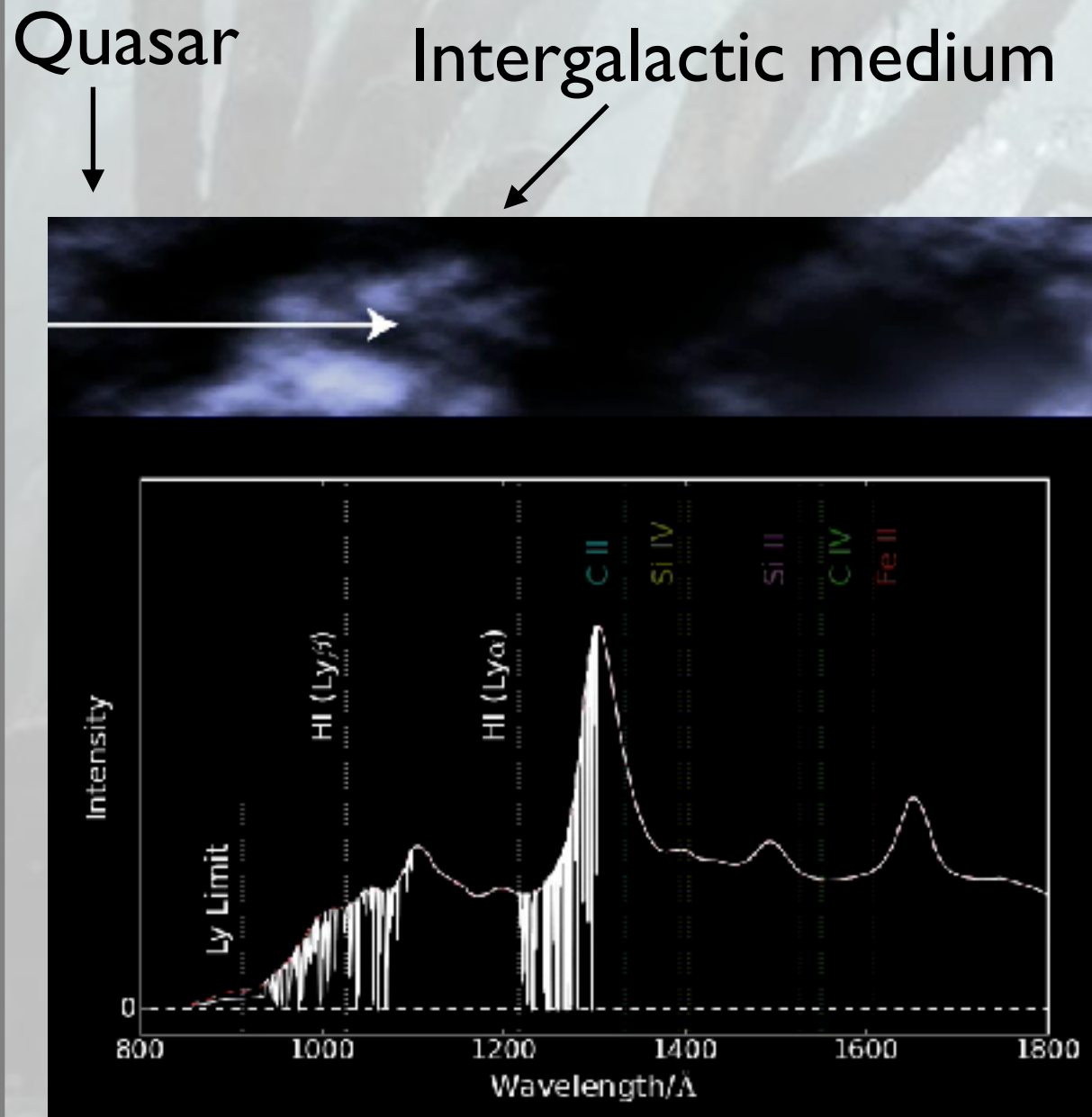
Q3: What is the nature of dark matter?

Q4: How does (re)ionization occur?

The Intergalactic medium dominates the universe by mass and volume



# Quasar Spectra and Lyman- $\alpha$ Forest

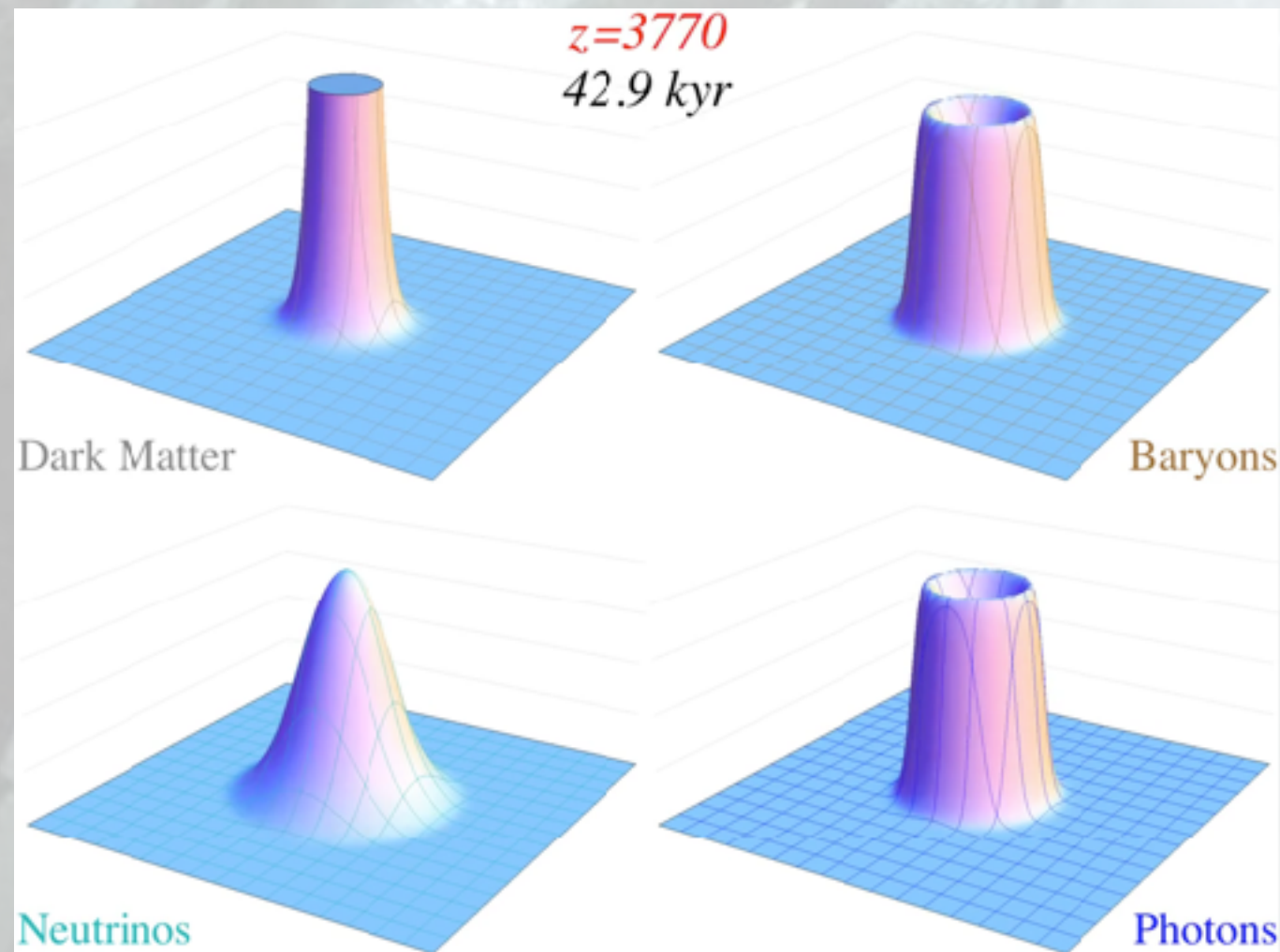


credit: Andrew Pontzen

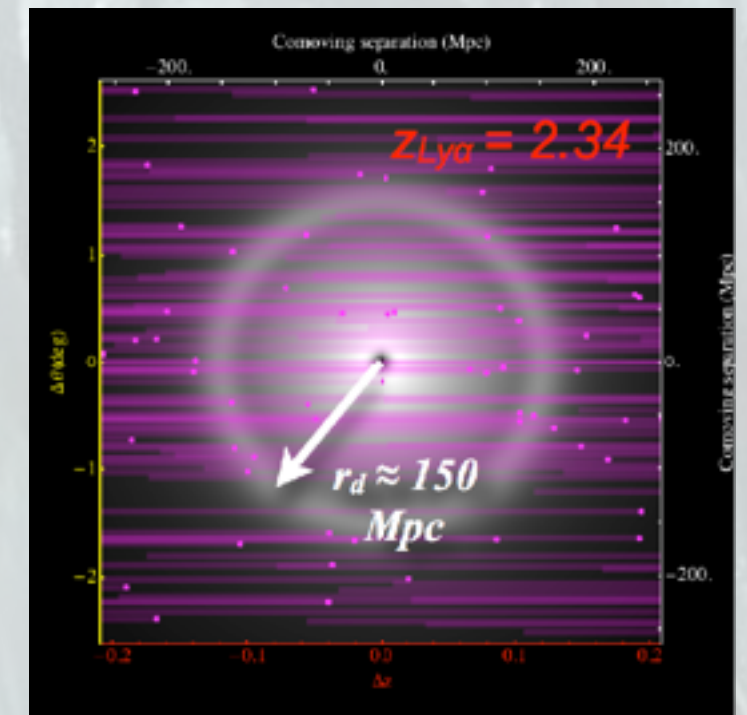
- Line-of-sight probe of the IGM
- Gas with  $1 \lesssim \frac{\rho}{\bar{\rho}} \lesssim 10$
- traces dark matter on large scales
- Largely photoionized
- $\tau_{HI} \propto \rho_H^{1.7}$  and  $f = CF = Ce^{-\tau_{HI}}$
- Departures from this
  - UV background modulation
  - Strong lines
  - Small scale physics
  - Metal absorption



# Baryon Acoustic Oscillations



credit:  
David  
Kirkby



- A useful ruler on the sky measured in the CMB (Eisenstein et al 2005, Cole et al. 2005)
- Trace expansion over time
- BIG  $\sim 100$  Mpc/h comoving
- Measurable in quasar absorption

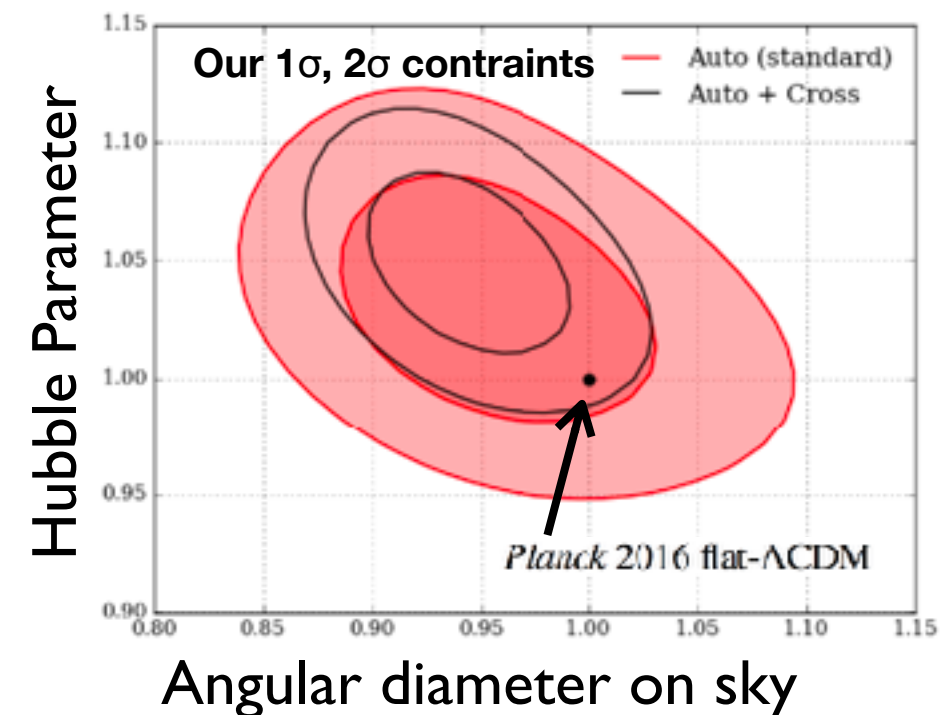
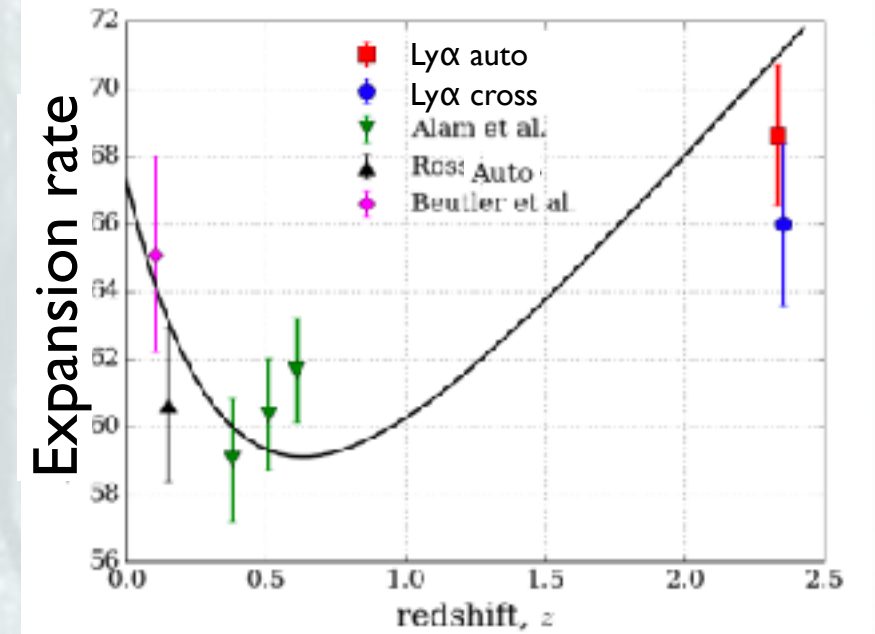


Q1: How  
does dark  
energy  
emerge?

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## SDSS-III/BOSS and SDSS-IV/eBOSS: 1st Probe of Dark Energy at High Redshift

- Autocorrelation Ly $\alpha$  forest + cross-correlation with quasars
- 1st measurement of expansion at high redshift in 2013
- Probe of early dark energy at  $z=2.3$
- In agreement with concordance cosmology in latest results
- More complete use of data
  - Far from the cosmic variance limit



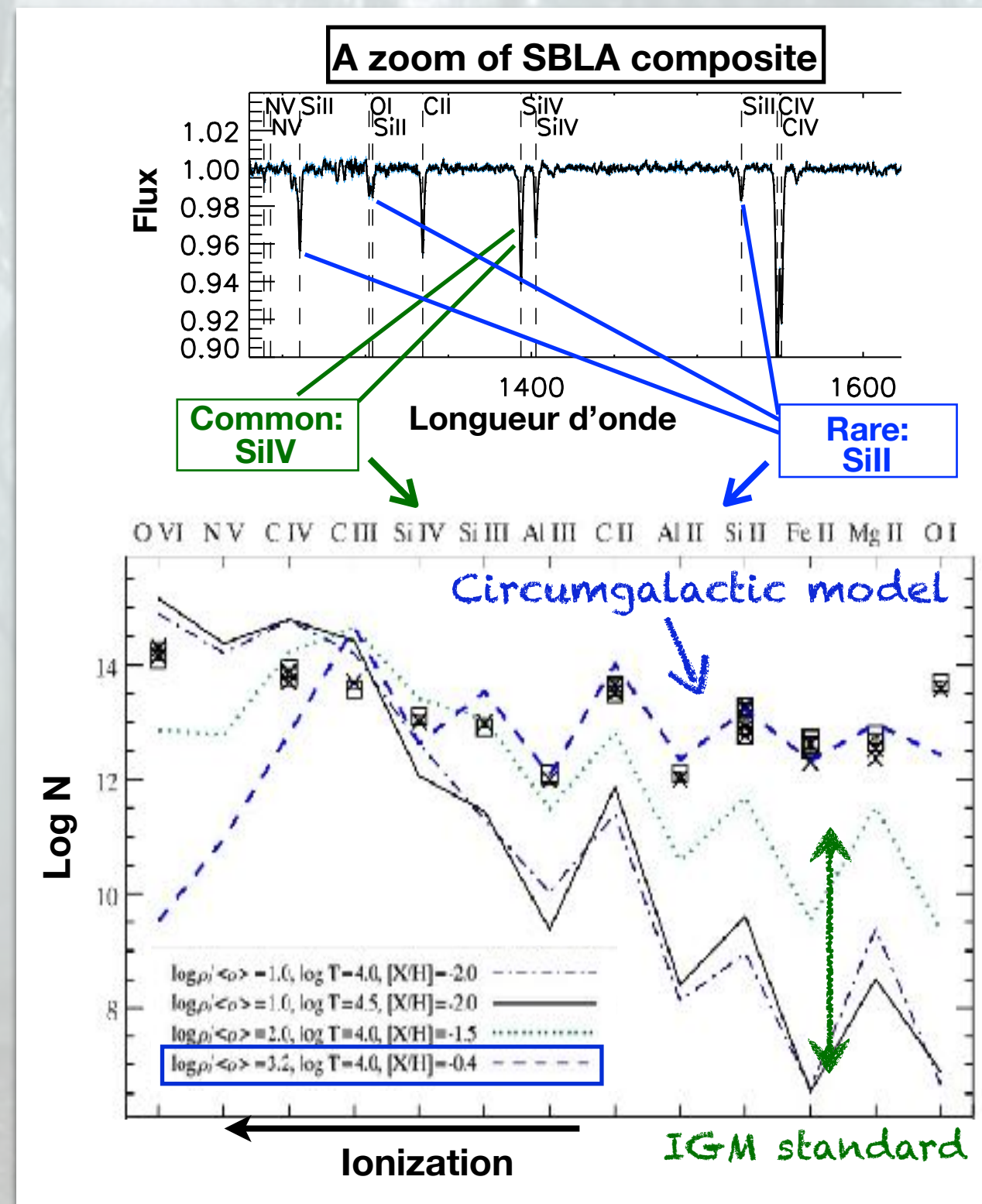
Slosar+ 2011, Busca+ 2013, Pieri 2014, Delubac+ 2015, Bautista+ 2017, dMd Bourboux+ 2017

Blomqvist+ 2018, Blomqvist+ 2019, Sainte Agathe+ 2019



# Studying IGM Properties in BOSS/eBOSS

- Stacking of Lyman- $\alpha$  absorption
  - Including SBLA and DLA galaxies
- Metallicity, UV background, abundance pattern, physical conditions
- Absorption proxies for galaxies
  - $\sim 0.5M$  CGM regions
  - Structures on  $\sim 30$  pc scales
- Brute force galaxy formation studied at star formation peak





# Combined Dark Energy and Galaxy Formation

Simultaneously addressing both science goals

Multi-tracer:  
absorption +  
quasars

+

Galaxies in  
absorption

=

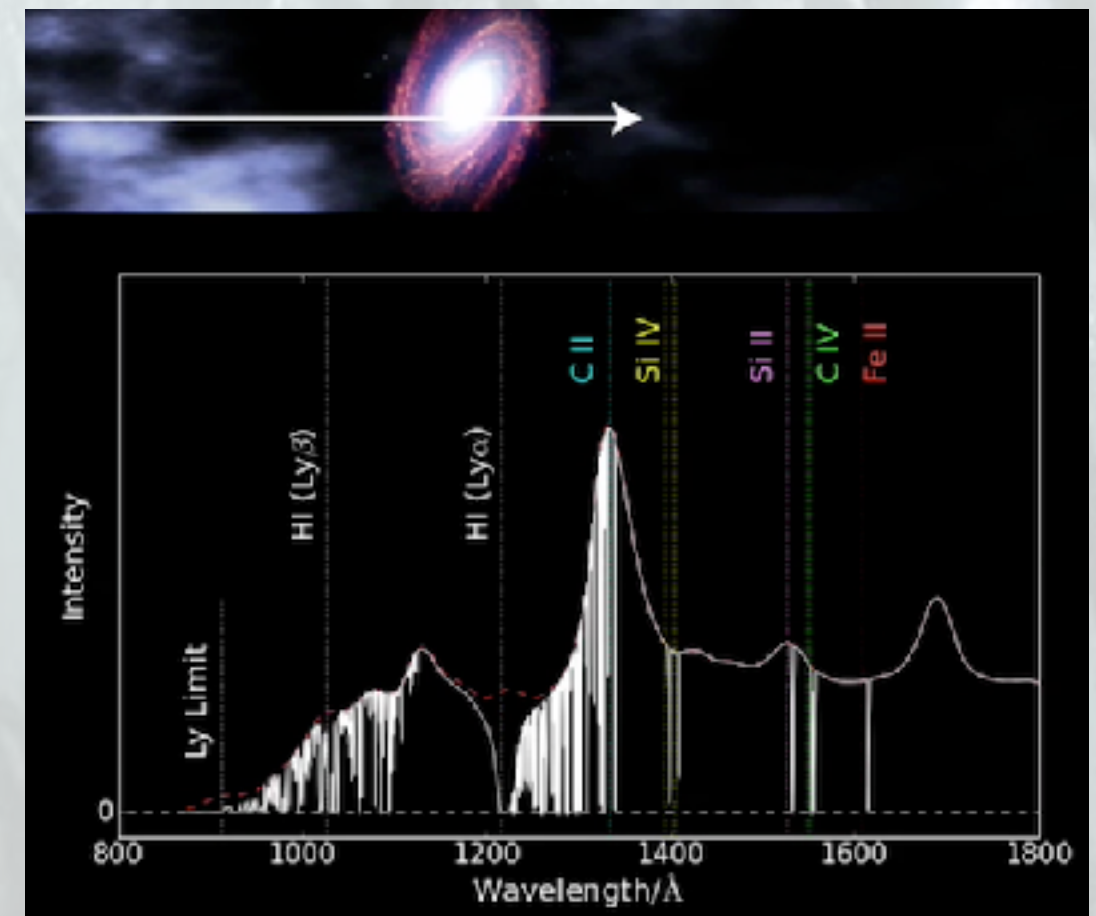
Dark Energy  
and expansion  
rate

+

Dark Matter  
Halo Masses of  
Galaxies

Q2

Q1



Perez-Rafols+ en prep, Som+ en prep

But this is all indirect. For further progress we need a data revolution...



# Large Surveys of the Intergalactic Medium and Galaxies and the Same Redshift

2009

## Diffuse Baryons

BOSS, eBOSS,  
WEAVE/J-PAS,  
DESI, MSE

## Galaxies

BOSS, DES, eBOSS,  
HETDEX, J-PAS,  
WEAVE, PFS, DESI,  
4MOST, Euclid, LSST,  
WFIRST, MSE

CGM at  $z > 2$  star  
formation rate peak

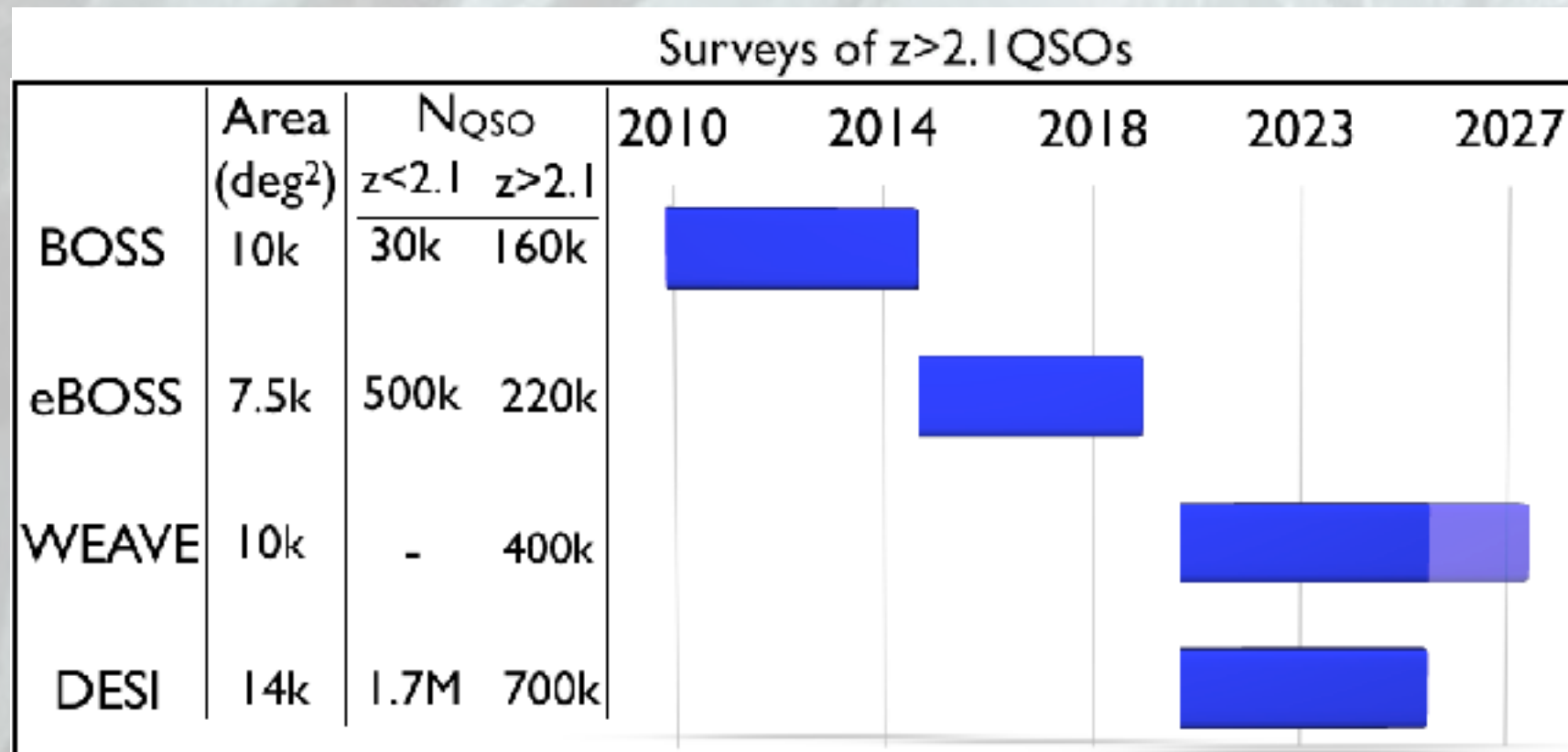
Multi-tracer large-scale  
structure

Dense sampling for a  
cosmic web map

2030



# The Growth of Massive IGM Surveys

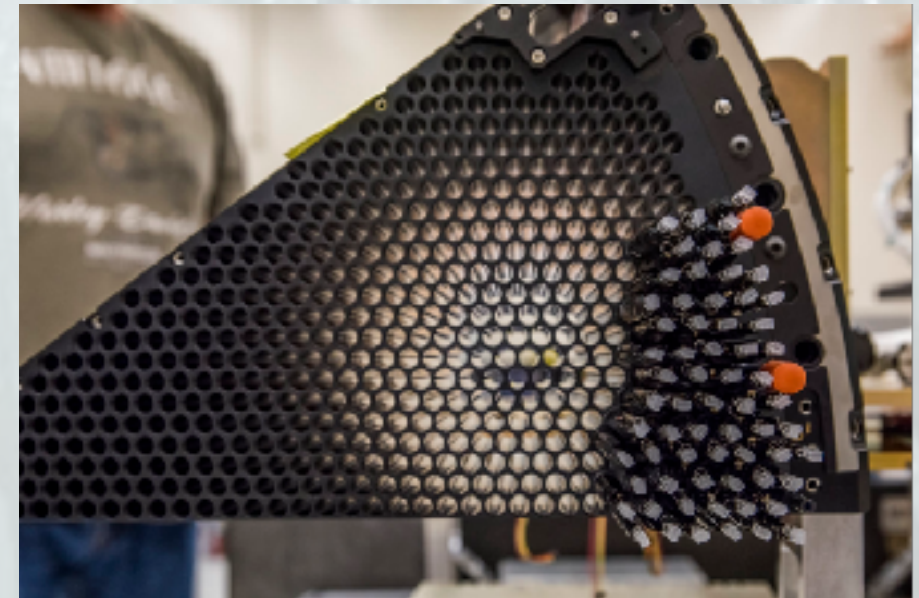






# The DESI Survey

- Mayall (4m) - Kitt Peak Arizona, USA
- Resolution  $R=2000$ ,  $14\text{k deg}^2$
- Photometric selection
- 5000 robotic fiber positioners
- 4 x 15 min. 1st confirms  $\text{Ly}\alpha$  quasars
- 700k high-z ( $\text{Ly}\alpha$  forest) quasar spectra
- 1.4M intermediate-z quasar spectra
- 20M+ galaxies with  $z < 1.6$ 
  - potential to cross-correlate quasars, ELGs and metal absorption
  - effectively  $\sim 6$  BAO measurements

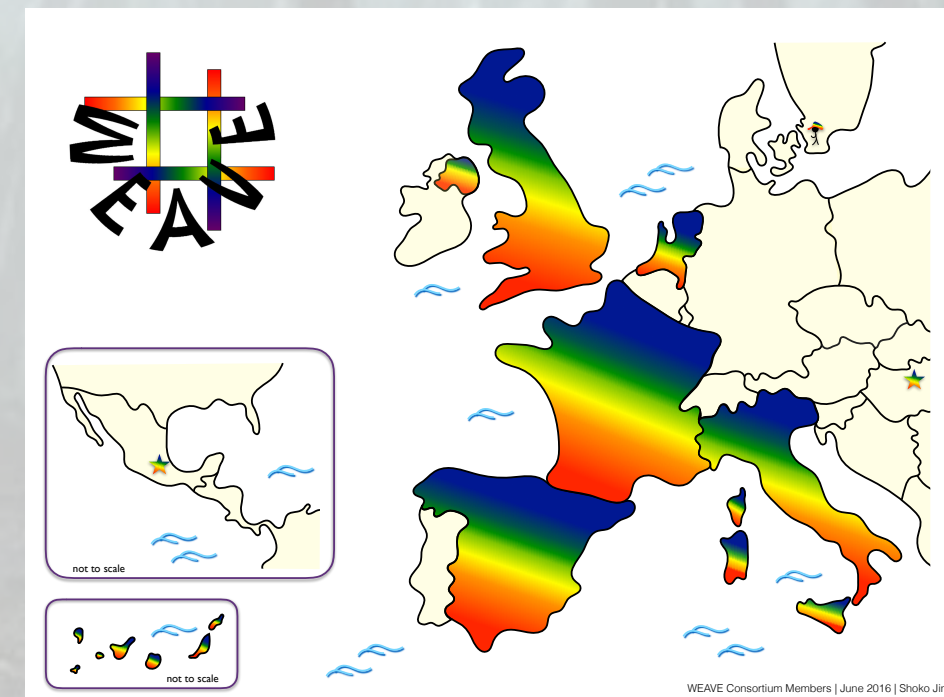
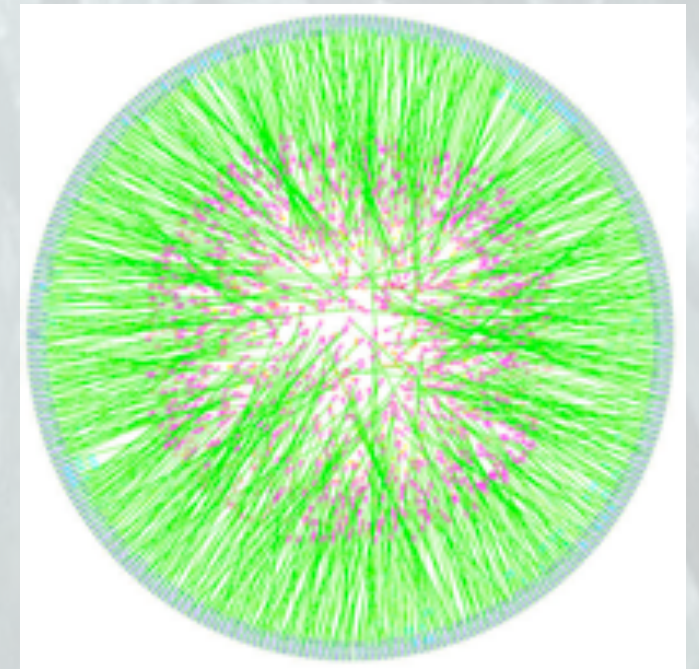




# The WEAVE Survey



- William Herschel 4.2-m telescope
- Pick and place, drum roll system setting min observation time of  $\sim 1$  hr
- Buy-in free collaboration based on nation (inc France)
- Targets in narrow band imaging (J-PAS)
- SO4-WEAVE: target selection, catalogue making, survey modelling, pipeline tests, fibre allocation

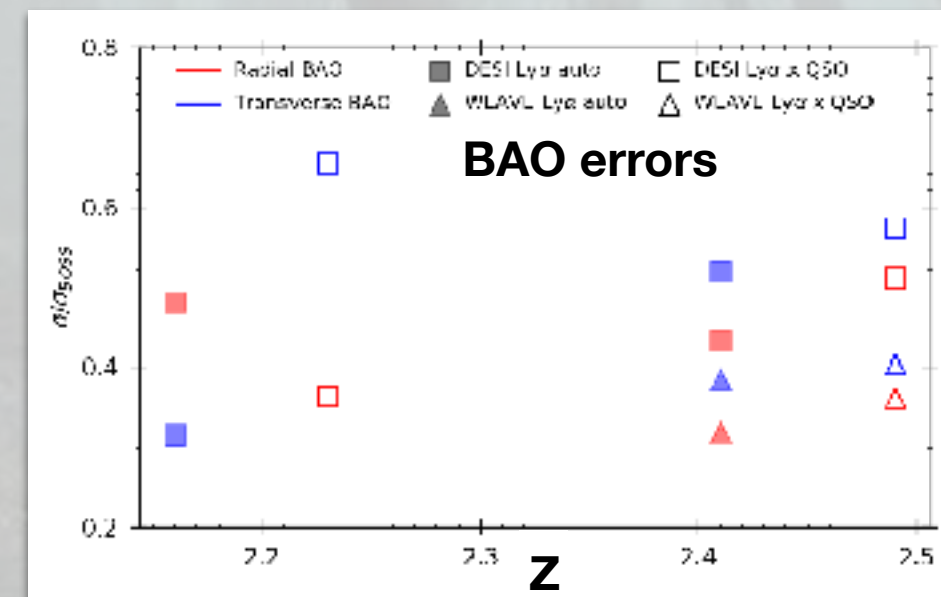
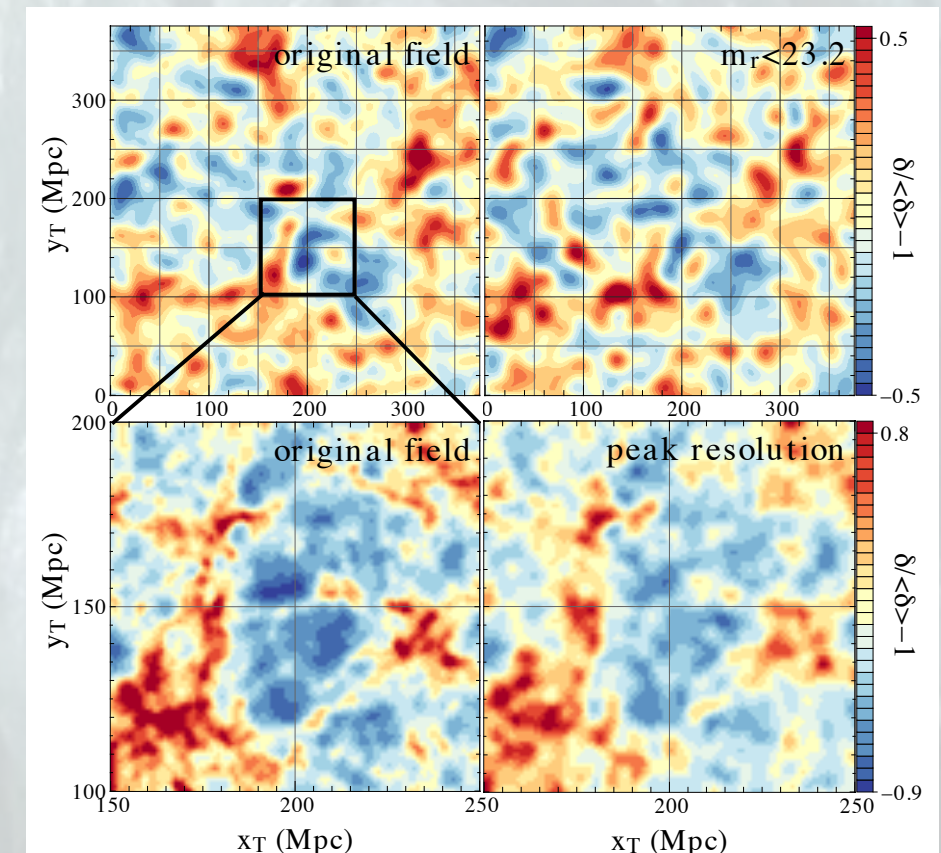




# WEAVE-QSO

- **High resolution massive IGM survey**
  - Spectral: 2x BOSS and DESI (+10x ?)
  - Spatial (source density): 4-5 x BOSS ~2 x DESI
- One of 8 WEAVE surveys
- J-PAS Survey key to WEAVE-QSOs plan
- Targets ~100% complete for  $\sim 6000 \text{ deg}^2$  ( $r < 23.2$ )
- Cross-correlations with faint quasars and LAEs
- Boosted in  $450 \text{ deg}^2$  HETDEX field
- Also possible high spectral resolution Gaia targeted sample ( $r < 21$ )

## Cosmic Web reconstruction →

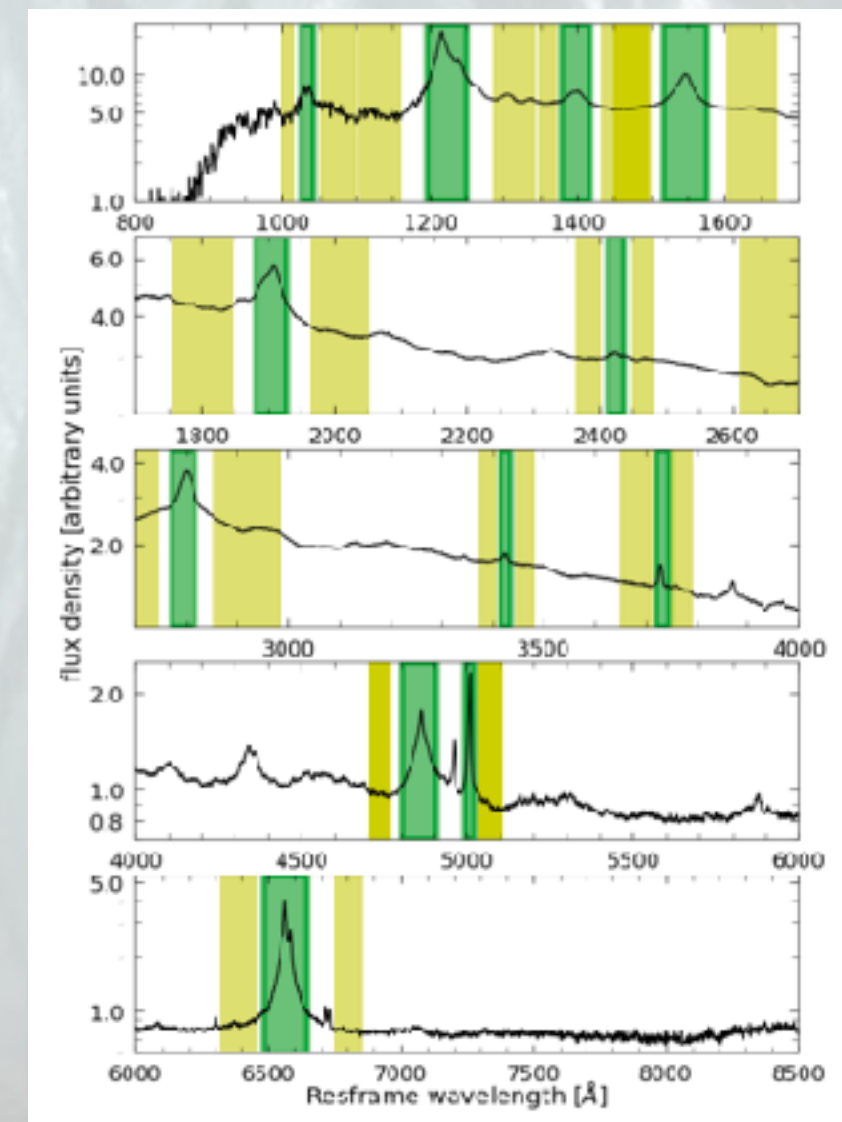
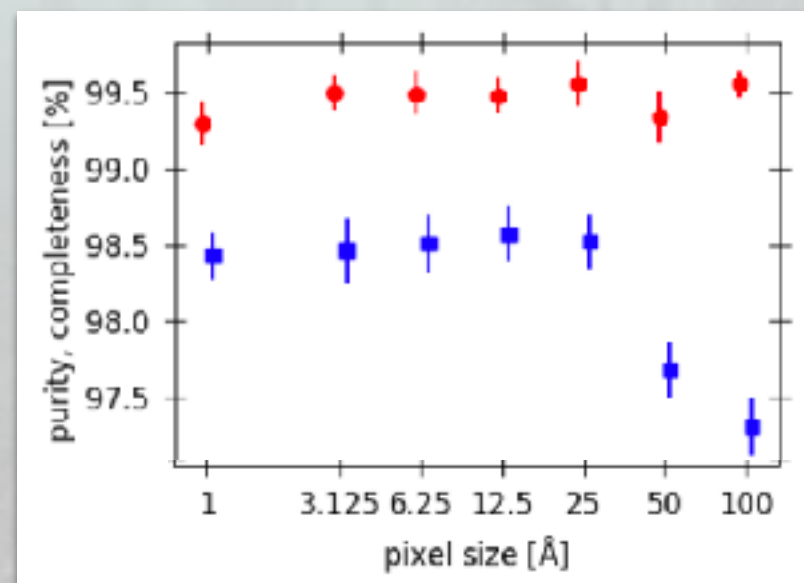
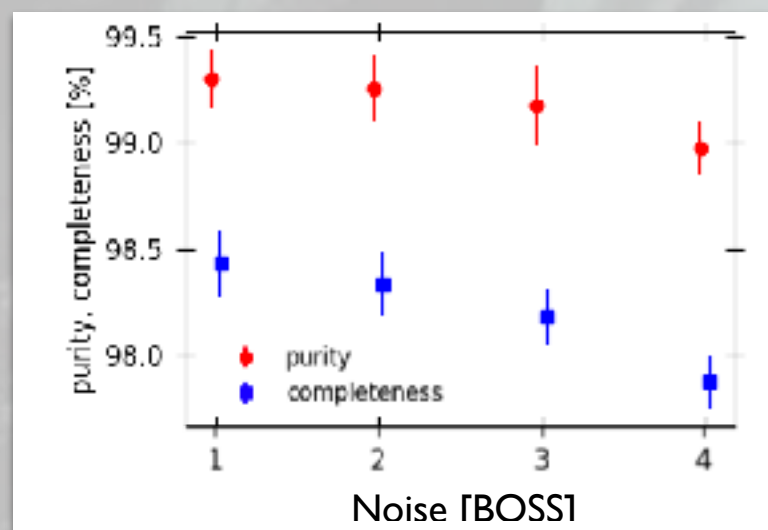




# SQUEzEing all the Quasars out of a spectroscopic data

Get ready for the flood with Spectroscopic QUasar Extractor and redshift Estimator

- Emission line strength metrics plus support random forest classifier
- Resistant to changes in
  - Noise - DESI Ly $\alpha$  quasar confirmation)
  - Resolution - WEAVE target selection with J-PAS (SO4-WEAVE)
- Potential for use on galaxies





# Summary

- Strong IGM growth with WEAVE and DESI with strong French contribution
- Two complementary BAO surveys
- Galaxies and IGM at  $z > 2$  important for
  - BAO cross-correlations
  - Cosmic web mapping
  - CGM regions
  - Small and large scale environment at key galaxy formation epoch
- Galaxies found in absorption now
- Galaxy surveys beginning to reach  $z > 2$
- Diverse science motivations for a  $z > 2$  MSE survey



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For discussion:

Can we use galaxies as well as quasars for a  $\times 10$  boost in background sources?