The Prospects for IGM Cosmology in Future Surveys

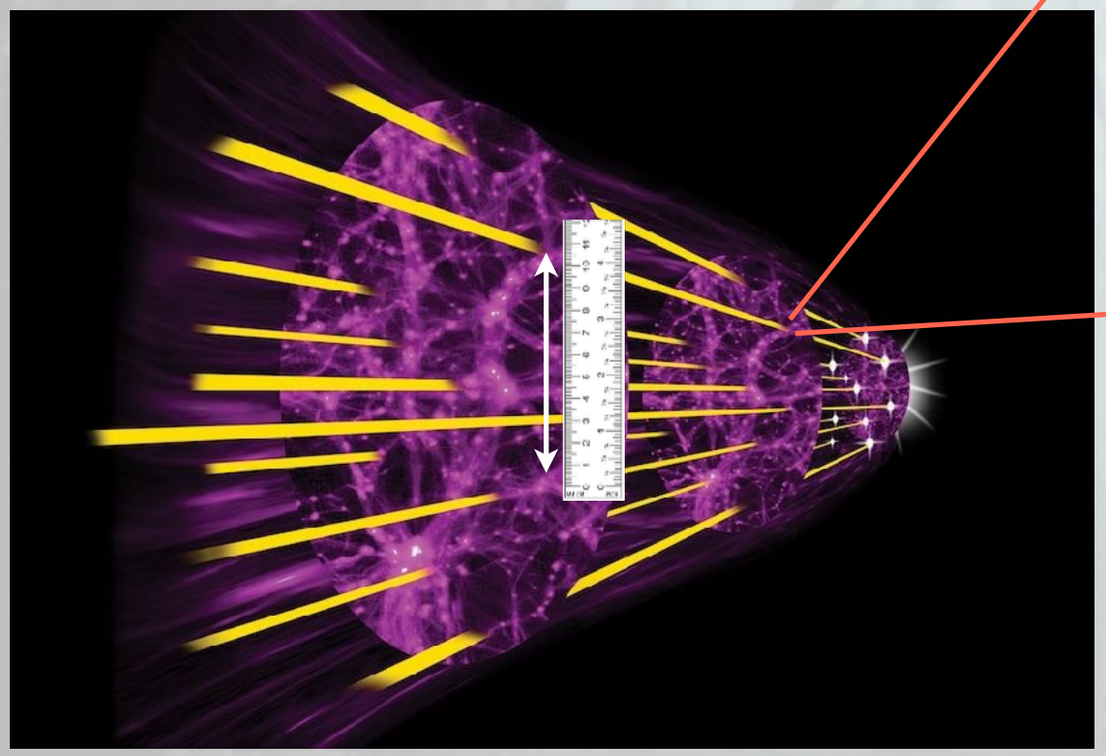
Mat Pieri
Laboratoire d'Astrophysique de Marseille

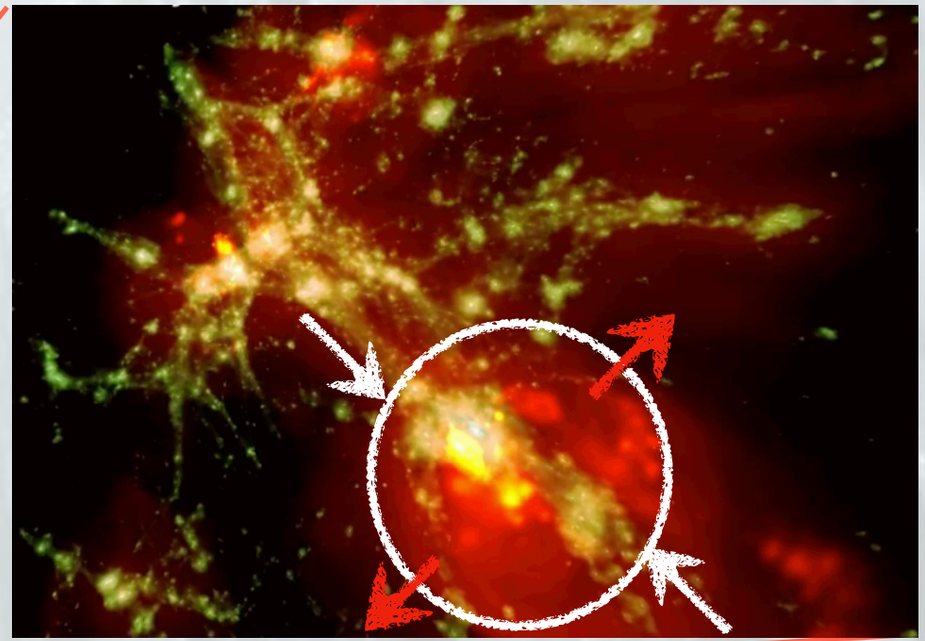
With Michael Blomqvist, Ignasi Perez Rafols,
Debopam Som, Sean Morrison
And the WEAVE-QSO and DESI-Lya teams

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

The Big Questions

Q1: How do galaxies form their stars from intergalactic gas?





Circumgalactic Medium (CGM)

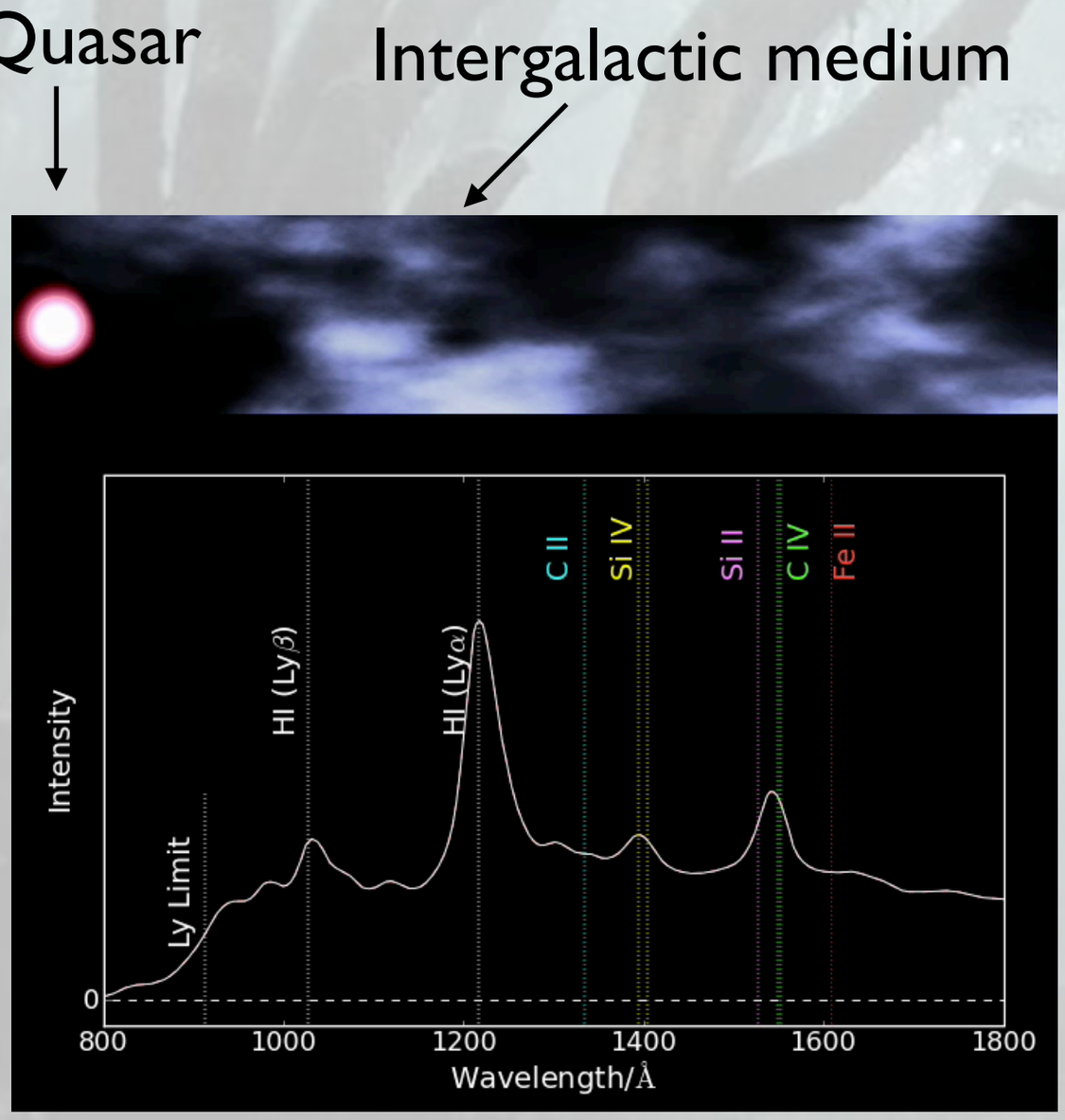
Q2: How does dark energy emerge to dominate the universe?

Q3: What is the nature of dark matter?

Q4: How does reionization occur?

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Quasar Spectra and Lyman-α Forest

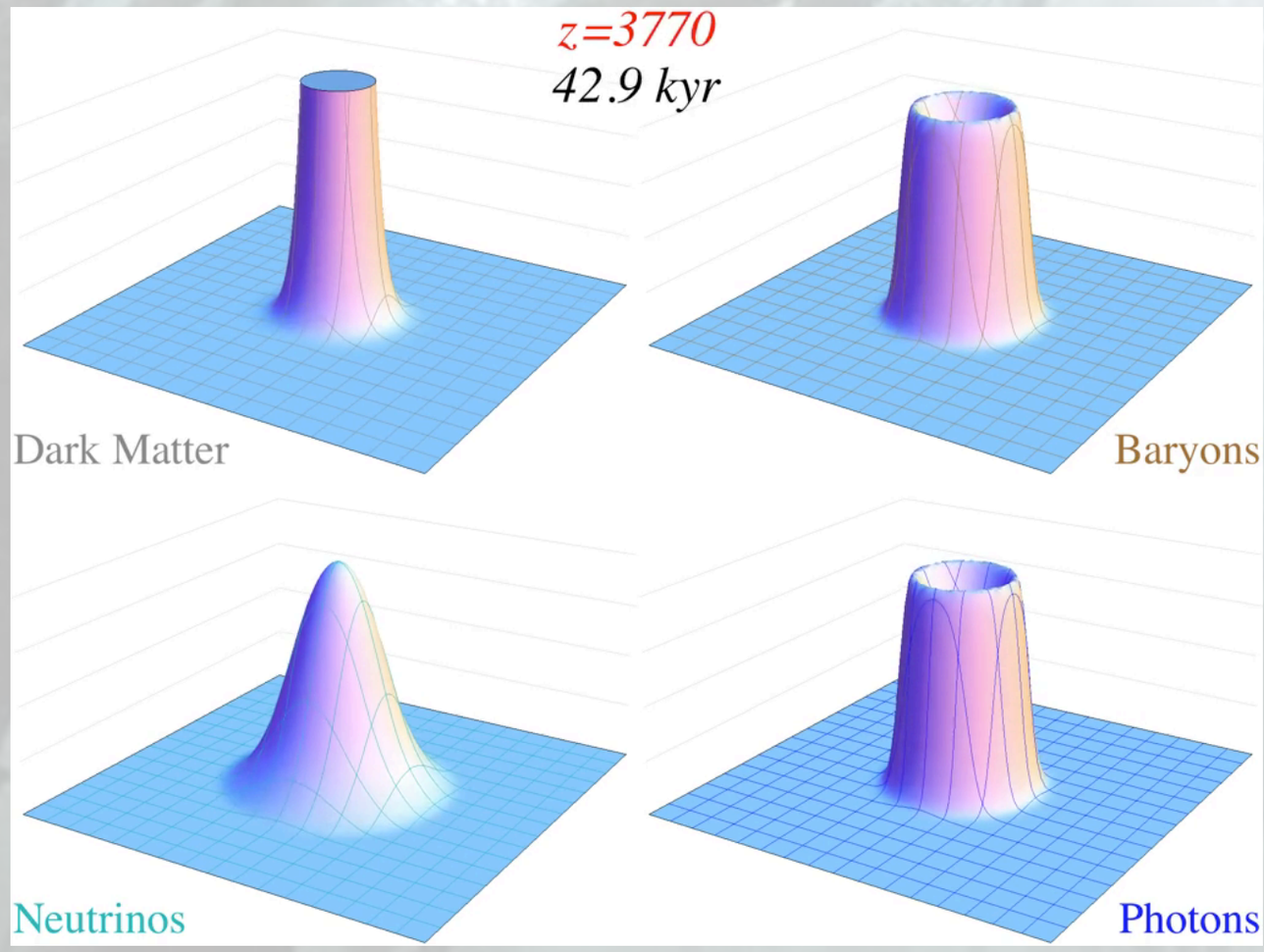


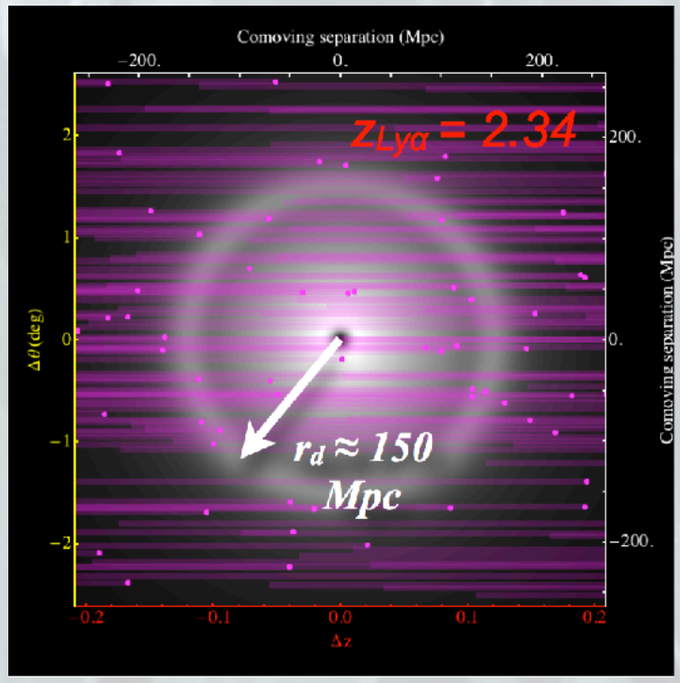
credit: Andrew Pontzen

- 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 $f = CF = Ce^{-\tau_{\rm HI}}$
- Departures from this
  - UV background modulation
  - Strong lines
  - Small scale physics
  - metal absorption

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

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 ~100 Mpc/h comoving
- Measurable in quasar absorption

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Q2: How does dark energy emerge?

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

SDSS-III/BOSS: 1st Probe of Dark Energy at High Redshift

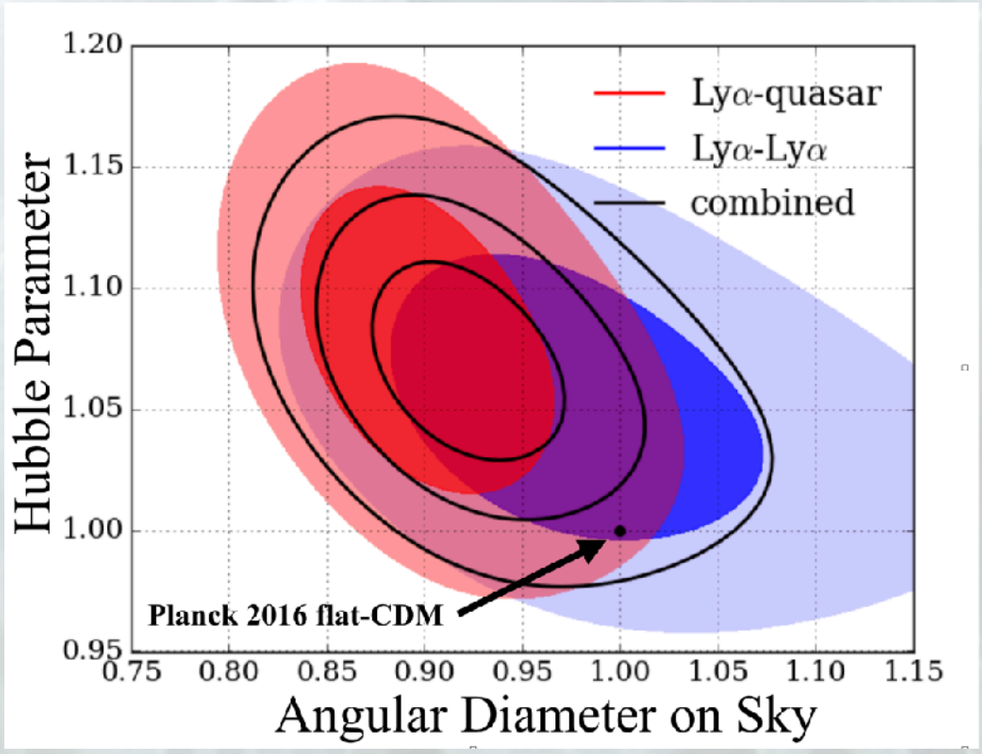
BOSS Survey

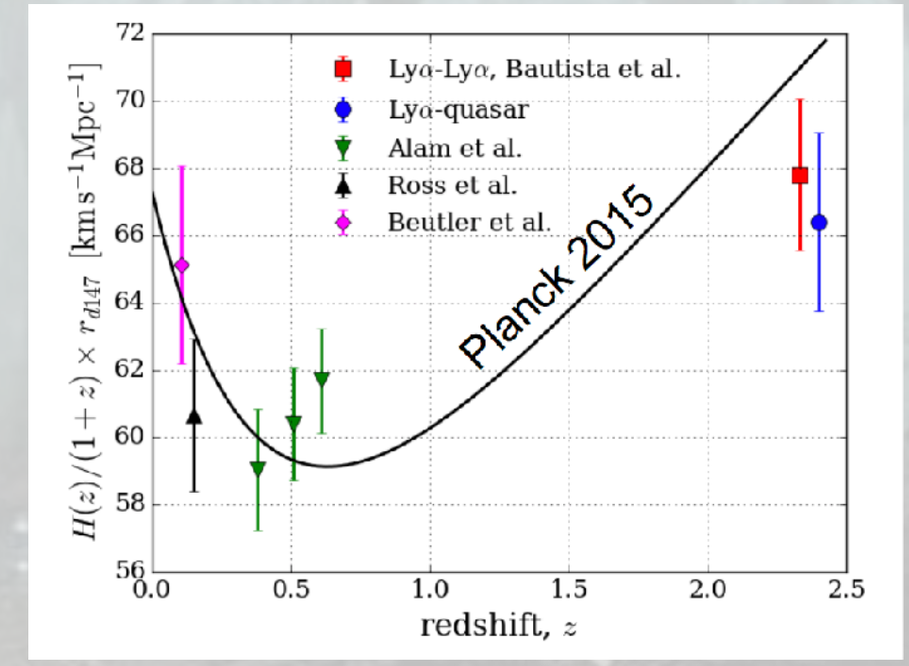
Early results

- 1st measurement of high-z expansion with `standard ruler'
- Most precise measurement of Hubble parameter

Latest results

- LSS from both absorption alone and ‘multi-tracer’ with quasars
- 2.3sigma tension with Planck assuming standard model
- Sign of dynamical dark energy?





Slosar+ 2011, Busca+ 2013, Pieri 2014, Delubac+ 2015, Bautista+ 2017, dMd Bourboux 2017, Blomqvist 2018

Aubourg+ 2015, Zhao+ 2017

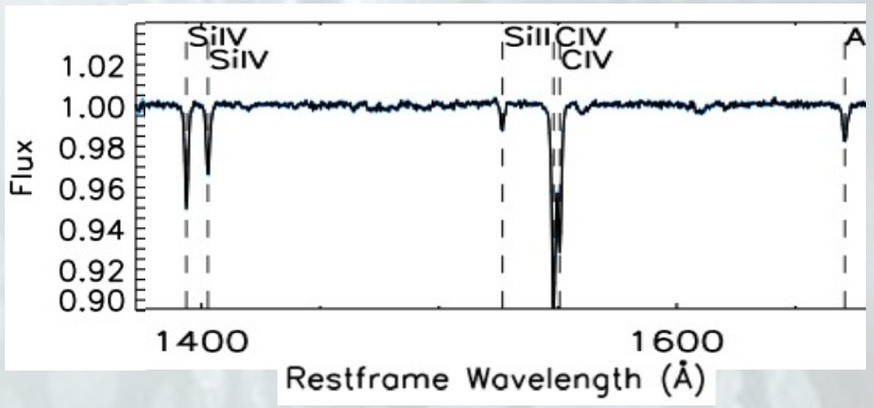
LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Q1: How do galaxies form from IGM?

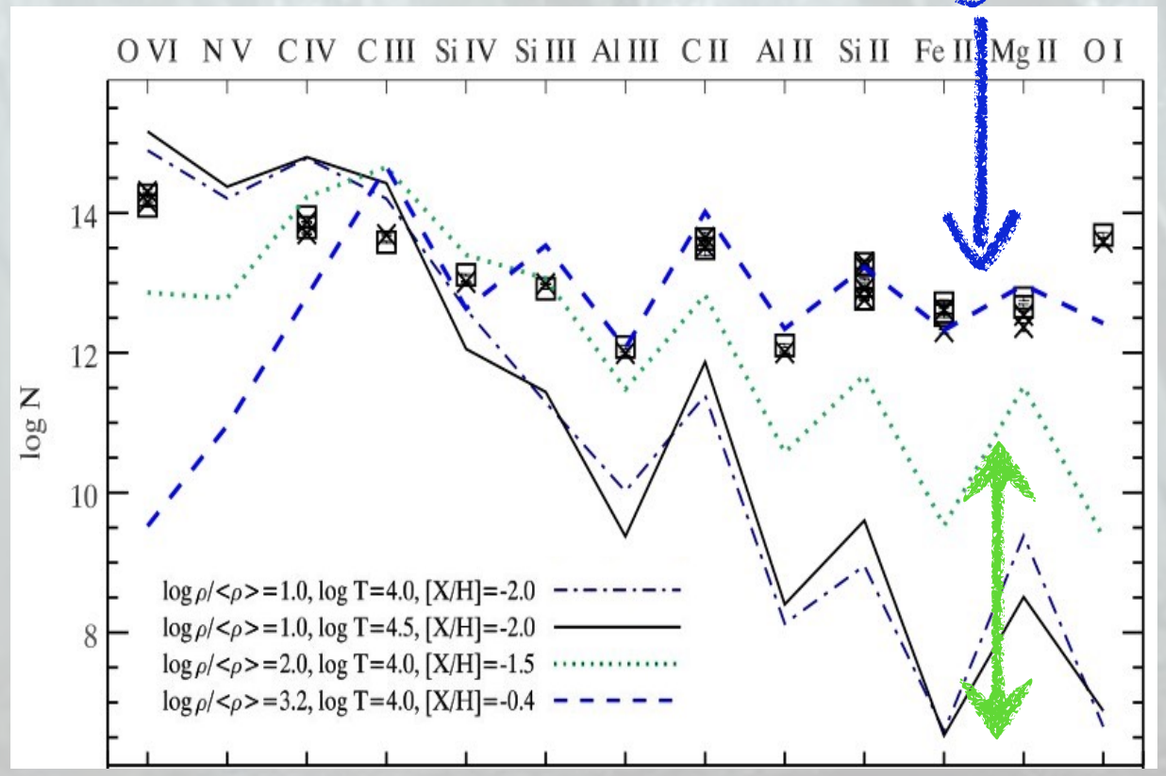
Mat Pieri, IGM-Inter, Marseille, 13th July 2018

Composite Spectra of the IGM in BOSS

- Stacking of strong Lyman-α (and damped Lyman-α)
- Metallicity, UV background, abundance pattern, physical conditions
- Absorption proxies for galaxies
  - ~500 000 CGM regions
  - Near-solar metallicities and ~30 pc clumping
- How do such small clumps occur?



Exotic circumgalactic



Standard IGM conditions

Pieri+ 2010, Pieri+ 2014, Som+ 2018

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

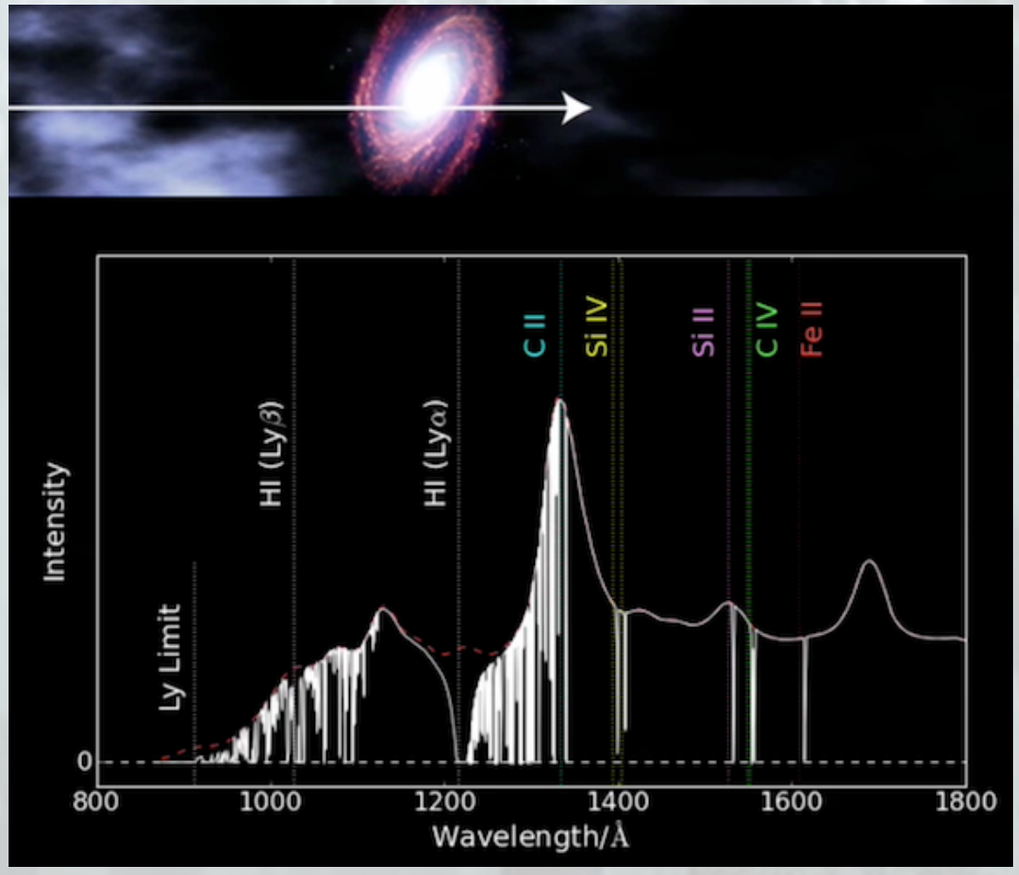
Combined Dark Energy and Galaxy Formation

Multi-tracer: absorption + quasars + **Galaxies in absorption**

=

Dark Energy and expansion rate + **Dark Matter Halo Masses of Galaxies**

Q2 Q1



Beginning to address both science goals with a single measurement

Blomqvist, MP et al in prep

For further strong progress we need a data revolution…

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Wide Extragalactic Surveys

2009

Quasar absorption with Lyman-α at z > 2

Diffuse Baryons

BOSS, eBOSS, WEAVE/J-PAS, DESI, 4MOST

Emission sensitivity limited to z < 1

Galaxies

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

CGM at z > 2 Star Formation Rate Peak

Multi-tracer Large-scale Structure

Better sampling for a cosmic web map

2030

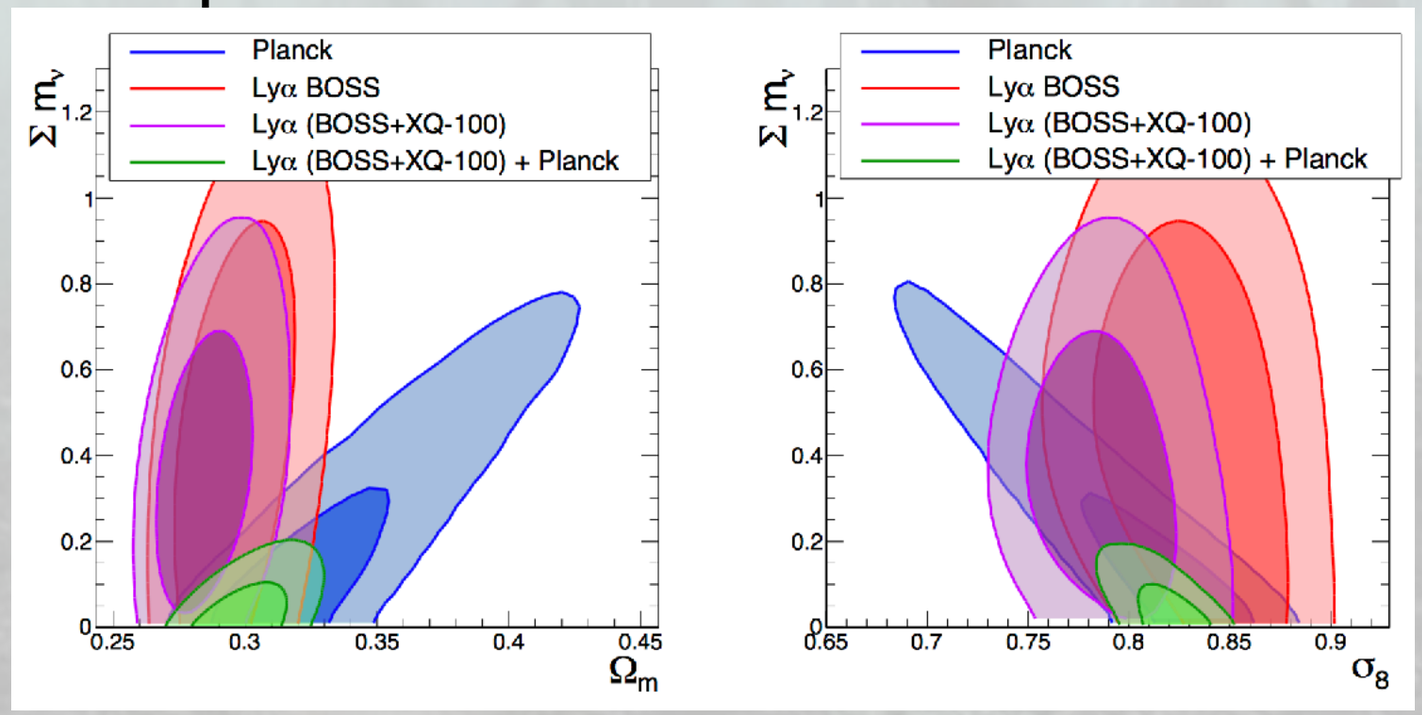
LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Q3 and Q4

Neutrinos, Dark Matter & Reionization

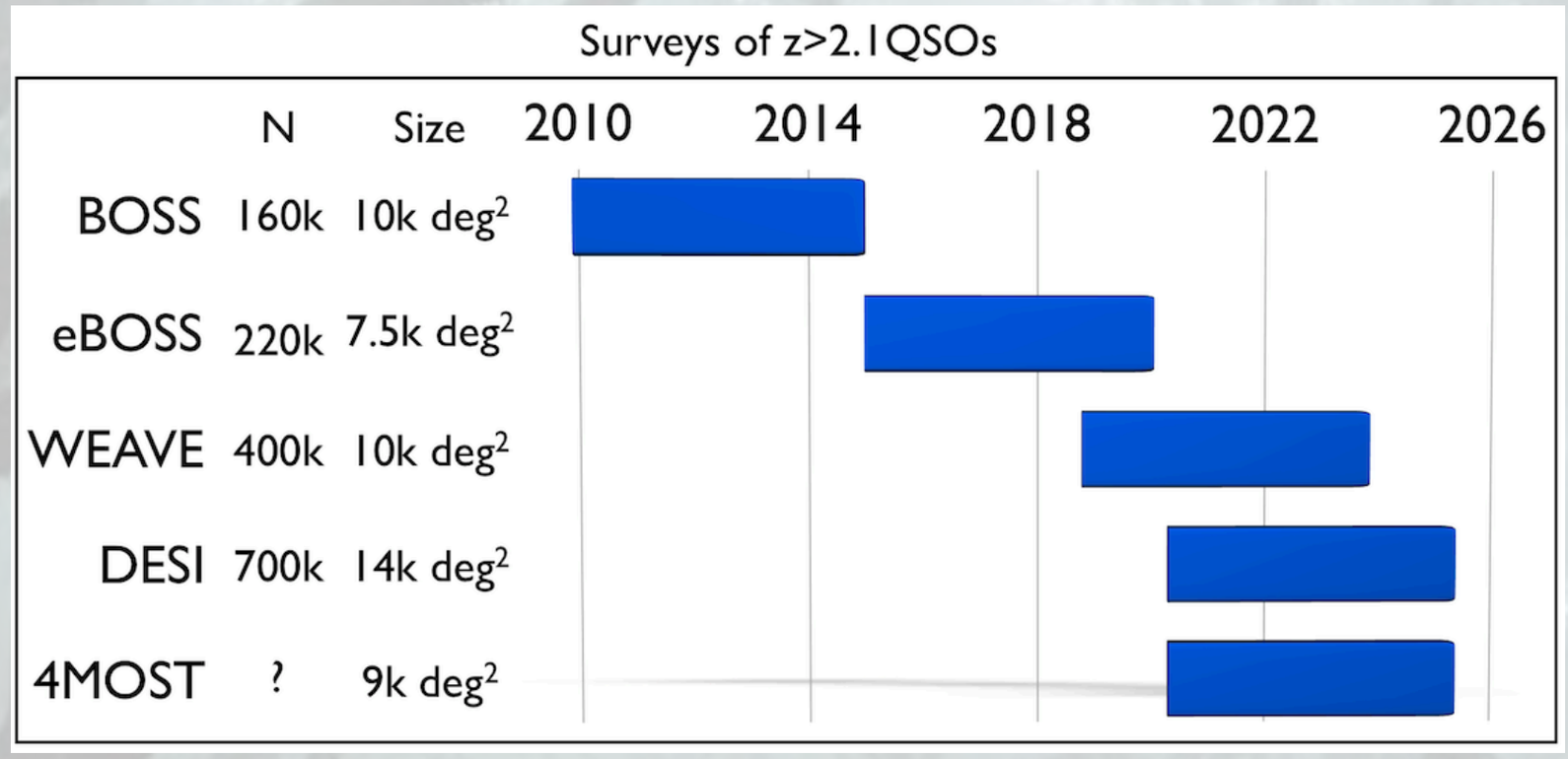
- Small scale structure in forest reflect various contributions from
  - Sum of neutrino masses
  - Nature of dark matter (warm/mixed/sterile neutrinos/ quantum)
  - Thermal imprint of reionization
  - IGM astrophysics e.g. outflows
- Spectral resolution is key and improvement reduces model

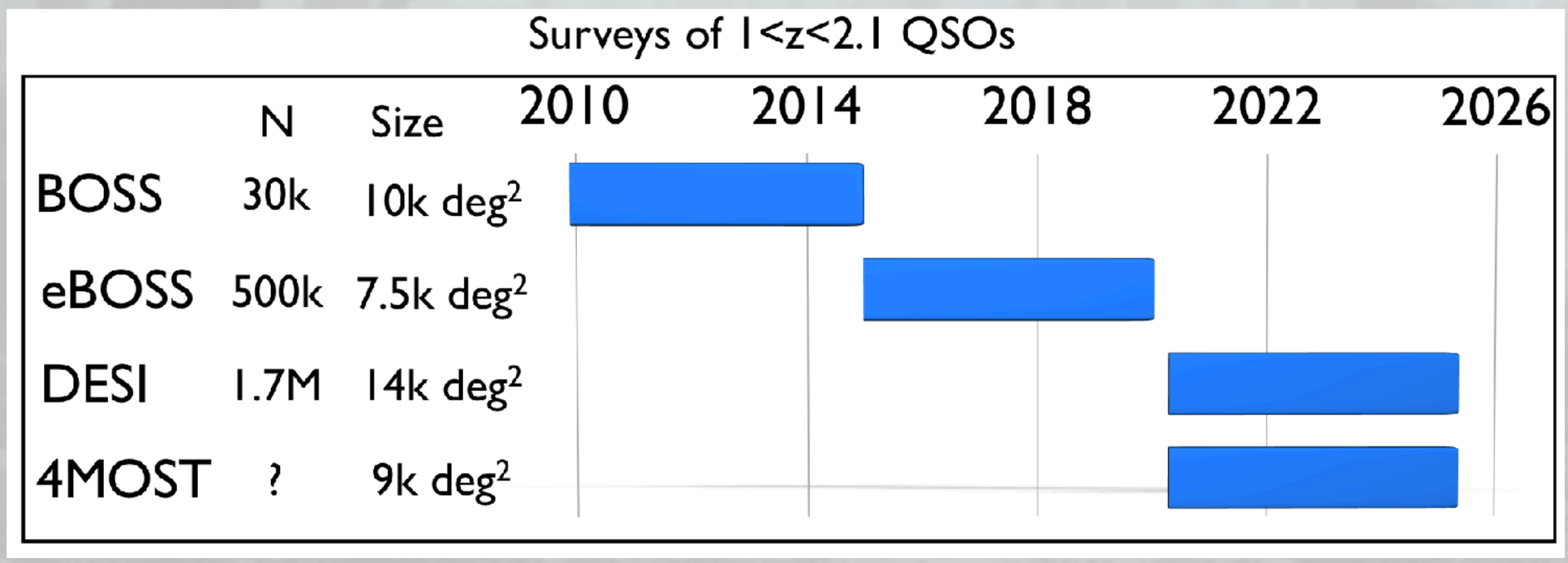
BOSS data used but spectral resolution marginal and dependent on hydro sims



Yeche+17

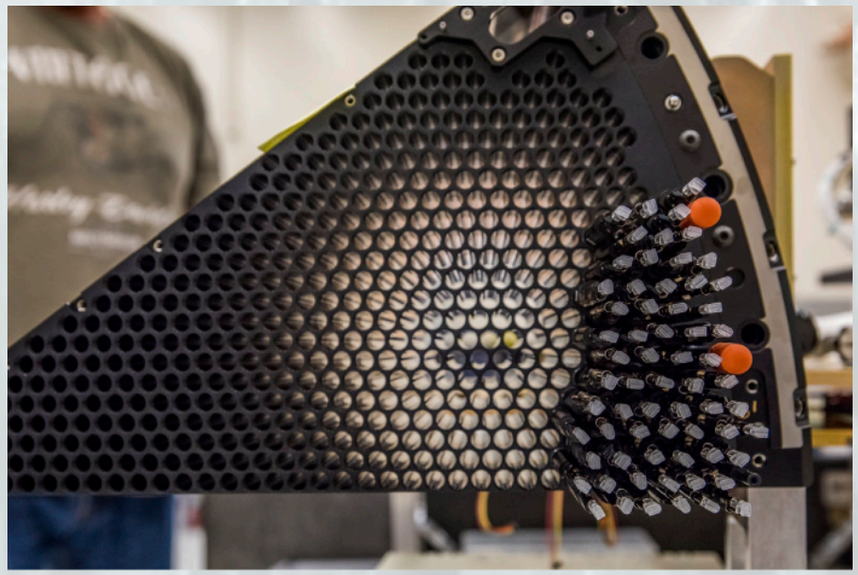
The Growth of Massive IGM Surveys





LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

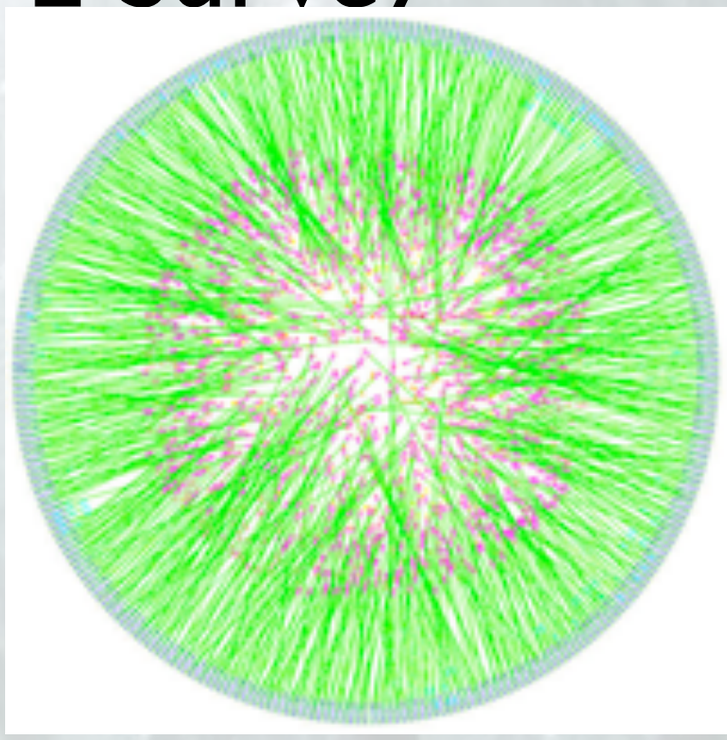
Growth of Massive IGM Surveys: DESI



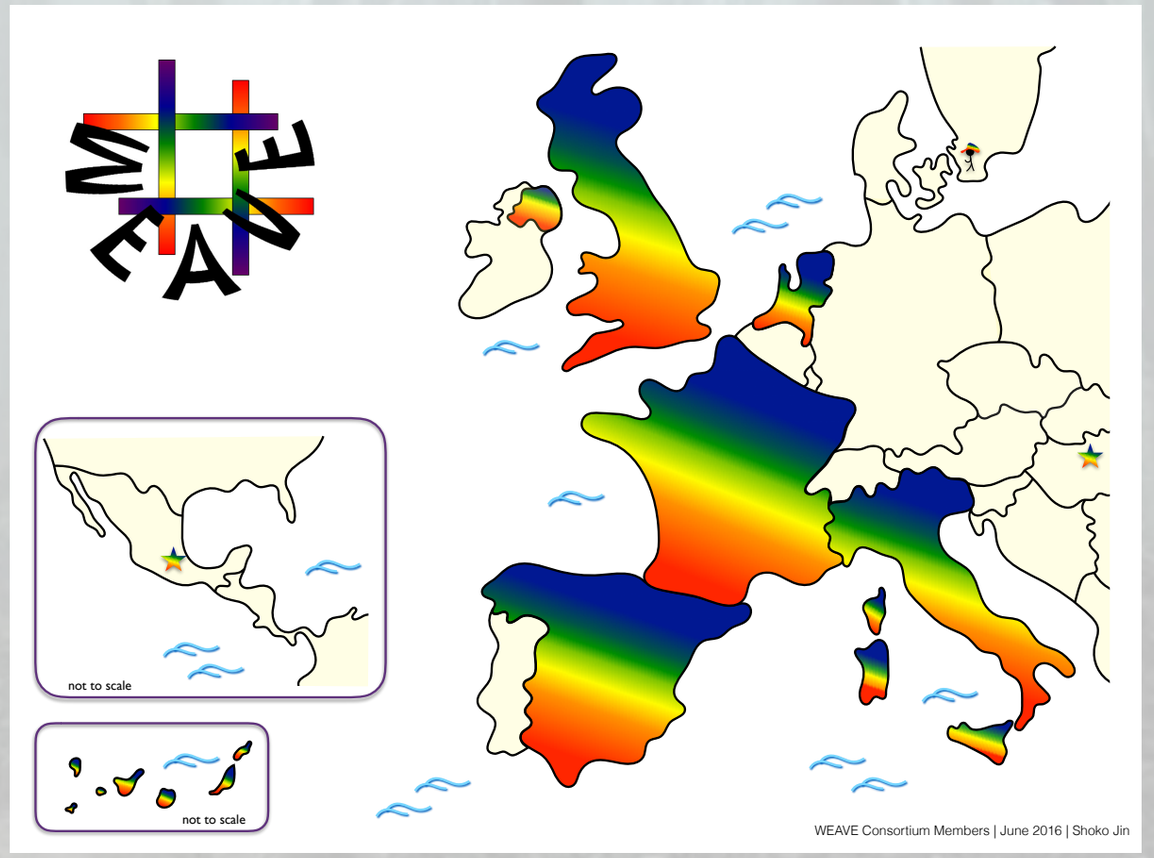
- Mayall (4m) - Kitt Peak Arizona, USA
- Resolution R=2000, 14k deg^2
- Photometric selection
- 5000 robotic fiber positioners
- 4 x 15 min. 1 pass for ID and 3 additional for S/N
- 700k high-z (Lyα forest) quasar spectra
- 1.4M intermediate-z quasar spectra
- 20M+ galaxies with z<1.6
- Potential to cross-correlate quasars, ELGs and carbon absorption at z~1.5
  - Effectively ~6 BAO measurements

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

The WEAVE Survey



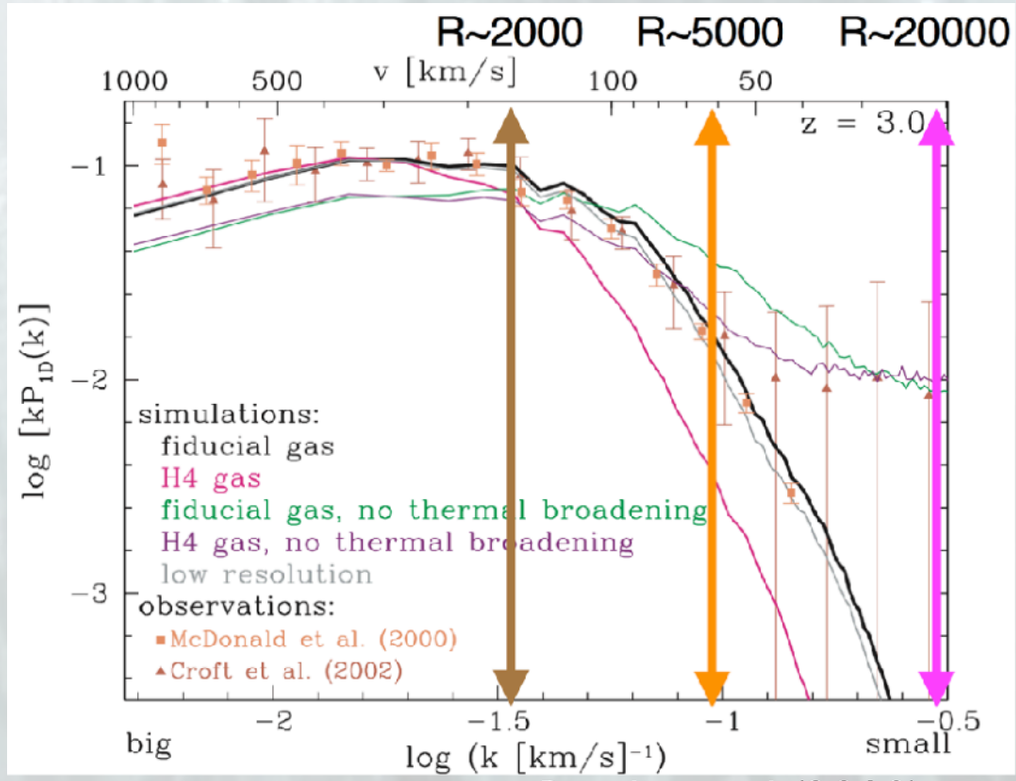
- William Herschel 4.2-m telescope
- 5 year survey starting in 2019
- Likely extension to 7-8 years
- Pick and place, drum roll system setting min observation time of ~1hr
- Buy-in free collaboration based on nation



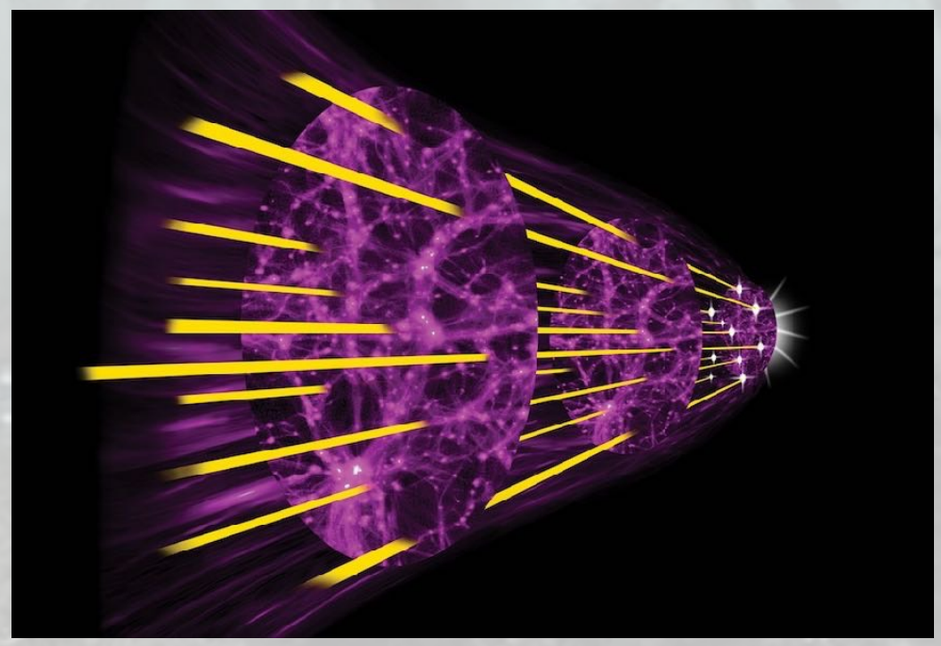
LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

WEAVE-QSO

- High resolution massive IGM survey (MP et al 2016)
  - Spectral res 2x or 10x BOSS and DESI
  - Spatial res - quasar number density: 4-5 x BOSS ~2 x DESI
- Total area in 5 years ~6000 sq deg
  - High spectral resolution small Gaia targeted sample (to r=21)
  - High spatial resolution coming from J-PAS target selection efficiency (to r=23.2)
- J-PAS key to WEAVE-QSOs science



Peebles et al (2010)

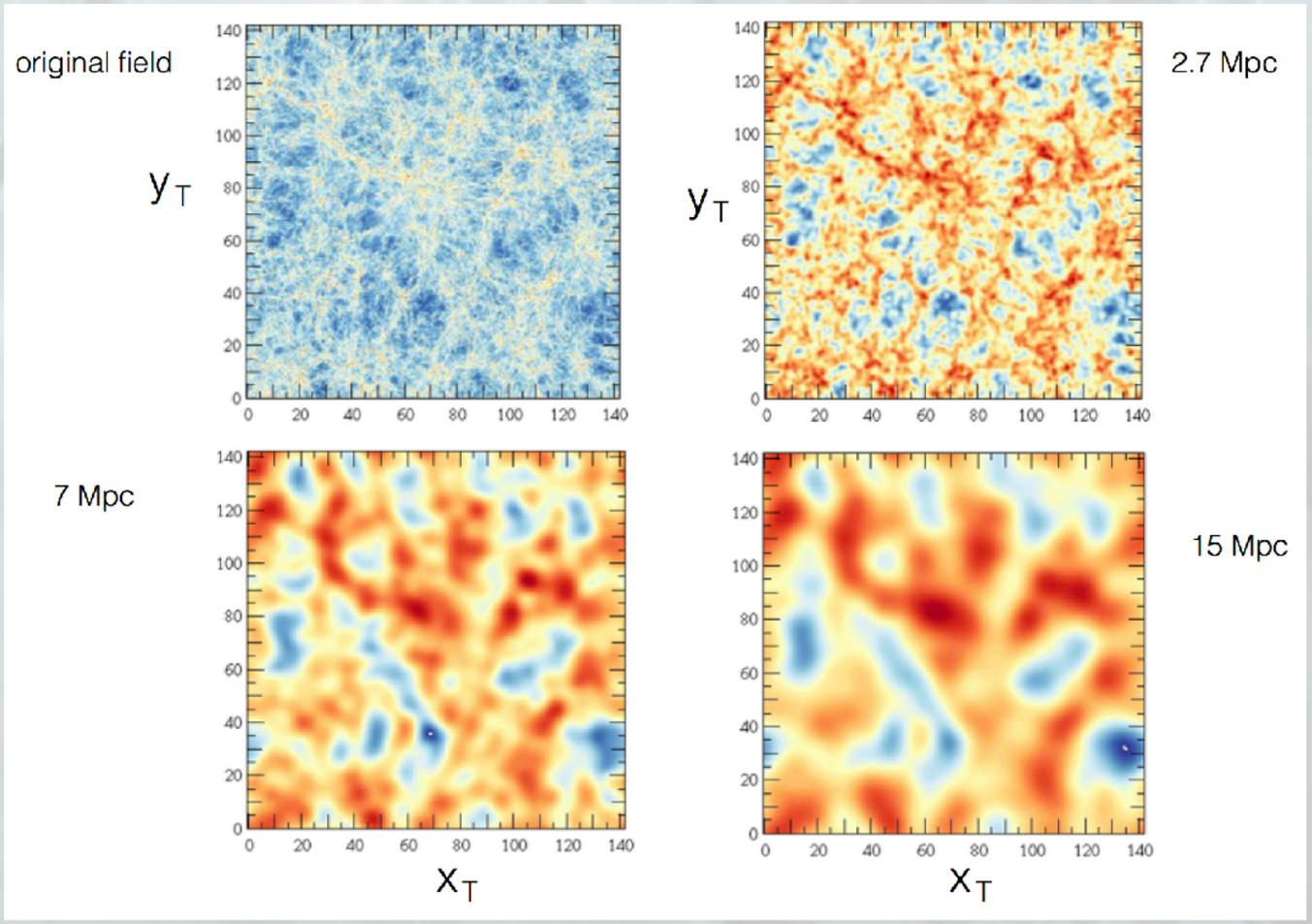


LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

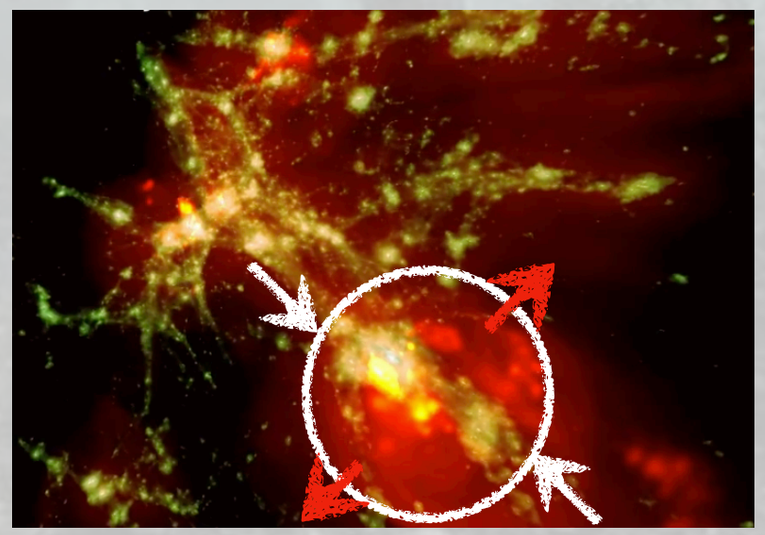
Mat Pieri, IGM-Inter, Marseille, 13th July 2018

IGM Tomography in WEAVE

- WEAVE alone reaches
  - ~10 Mpc resolution on average
  - ~1 Mpc when QSOs clustered
- Combination with HETDEX (+ J-PAS)
  - potential to measure 1Mpc
  - Lyman-α emitter galaxy CGM regions



The Goal: Complete picture of galaxy and gas properties in environment



LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

Future BAO Projections with High/Low z-Split

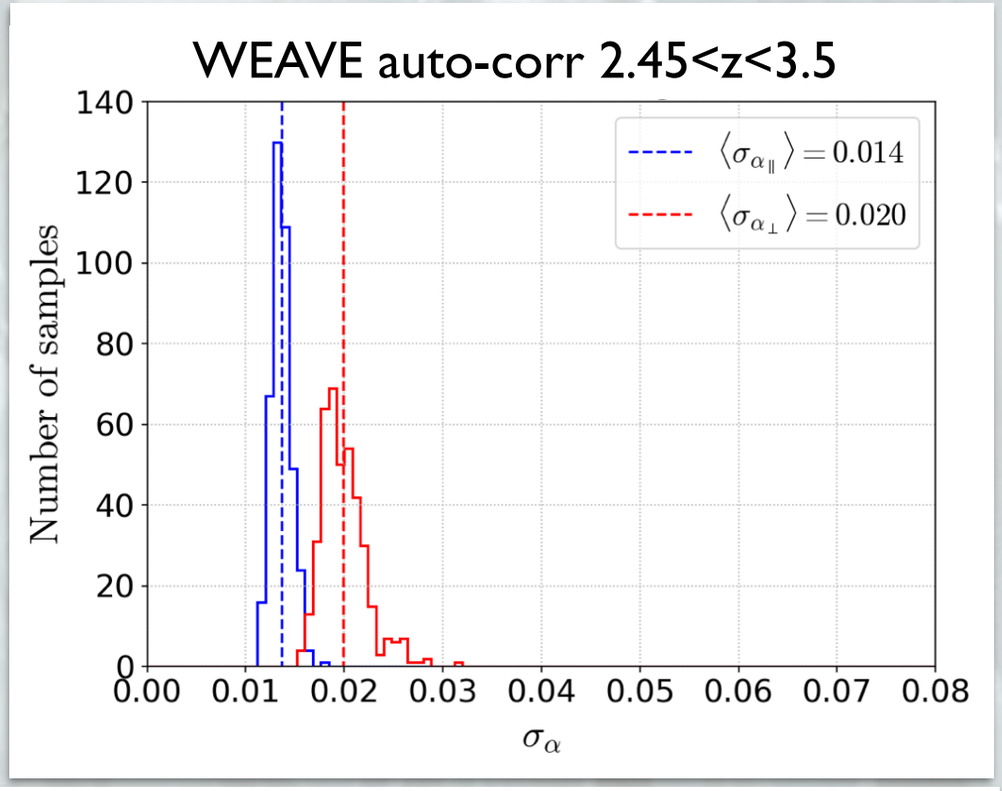
Projections from data-based mocks:

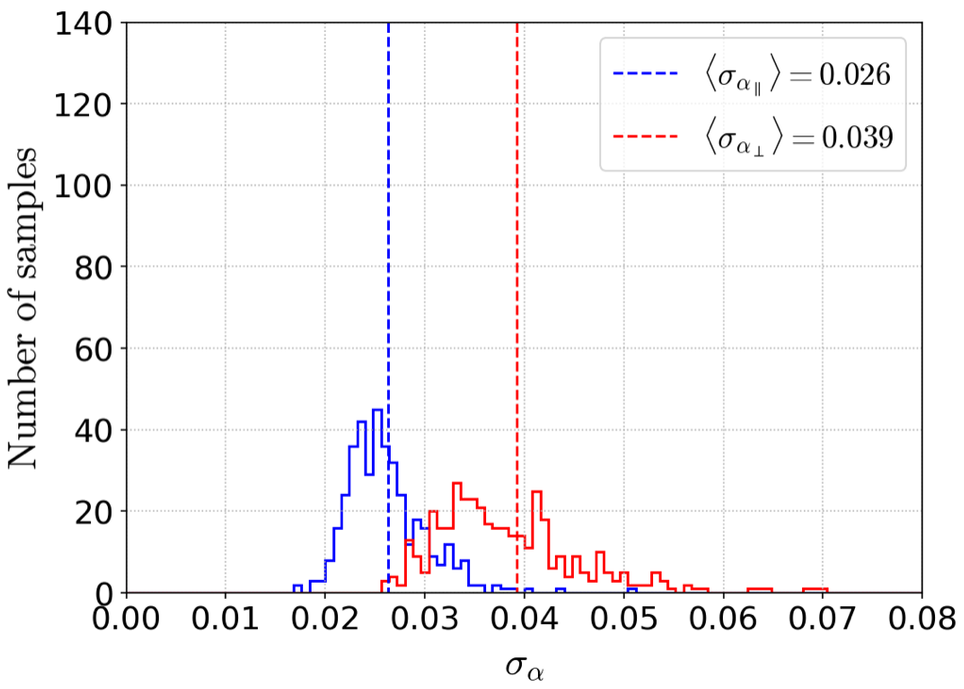
WEAVE focus on highest z with 25% smaller errors compared to DESI

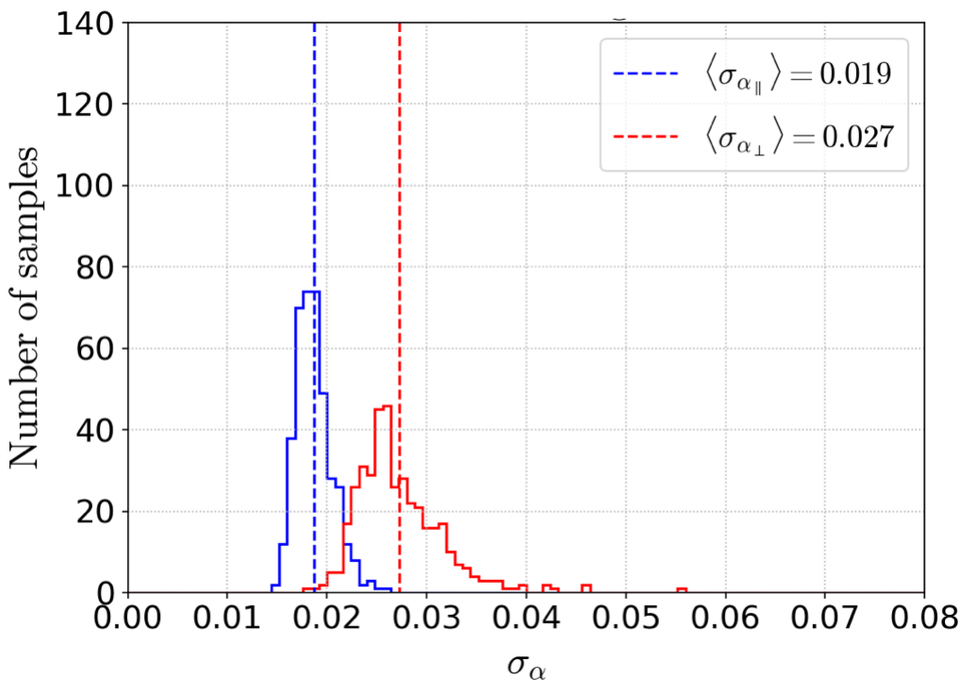
Compare to BOSS DR12:

Low-z: 4% &12%

High-z: 4% & 5%



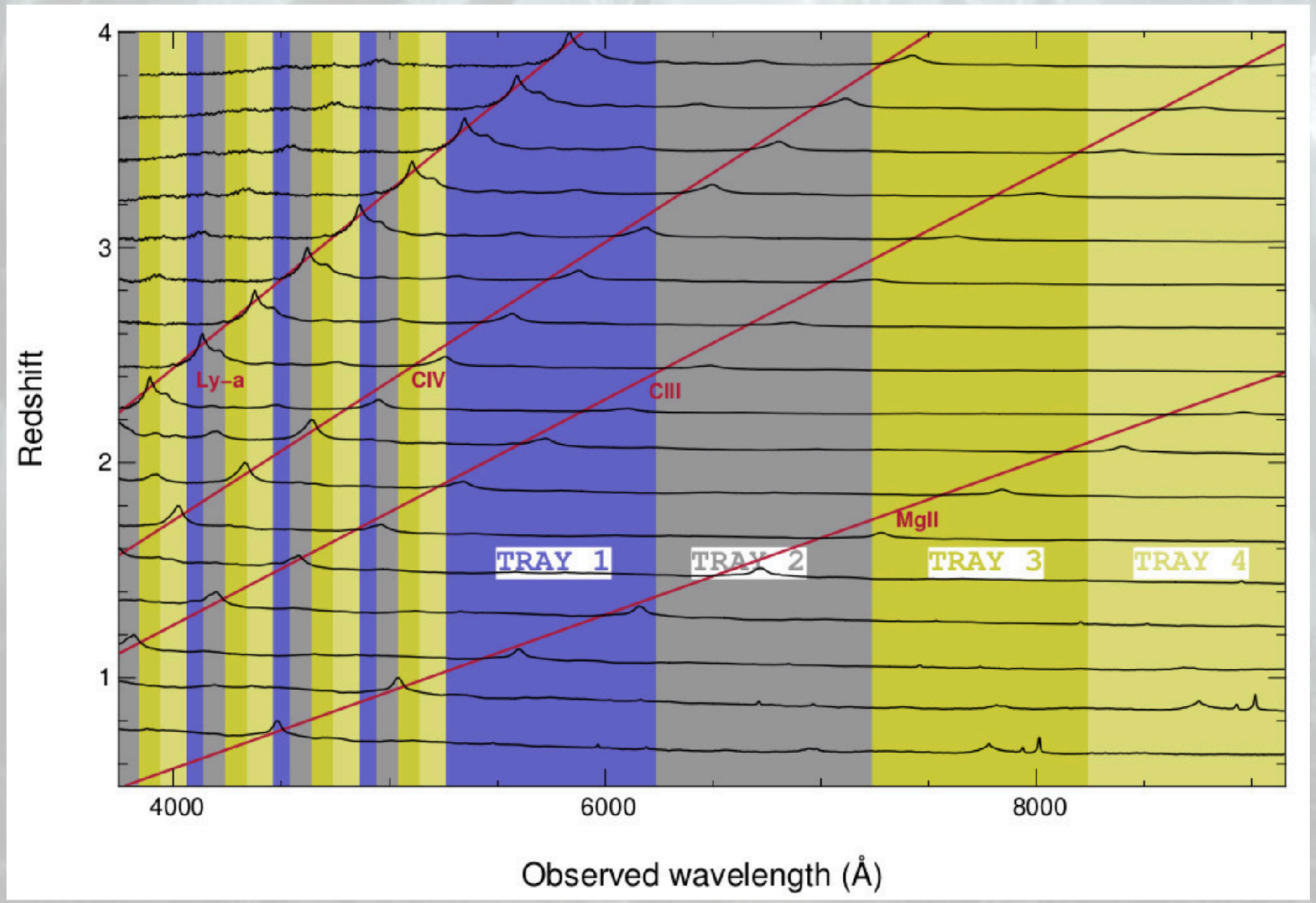




LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

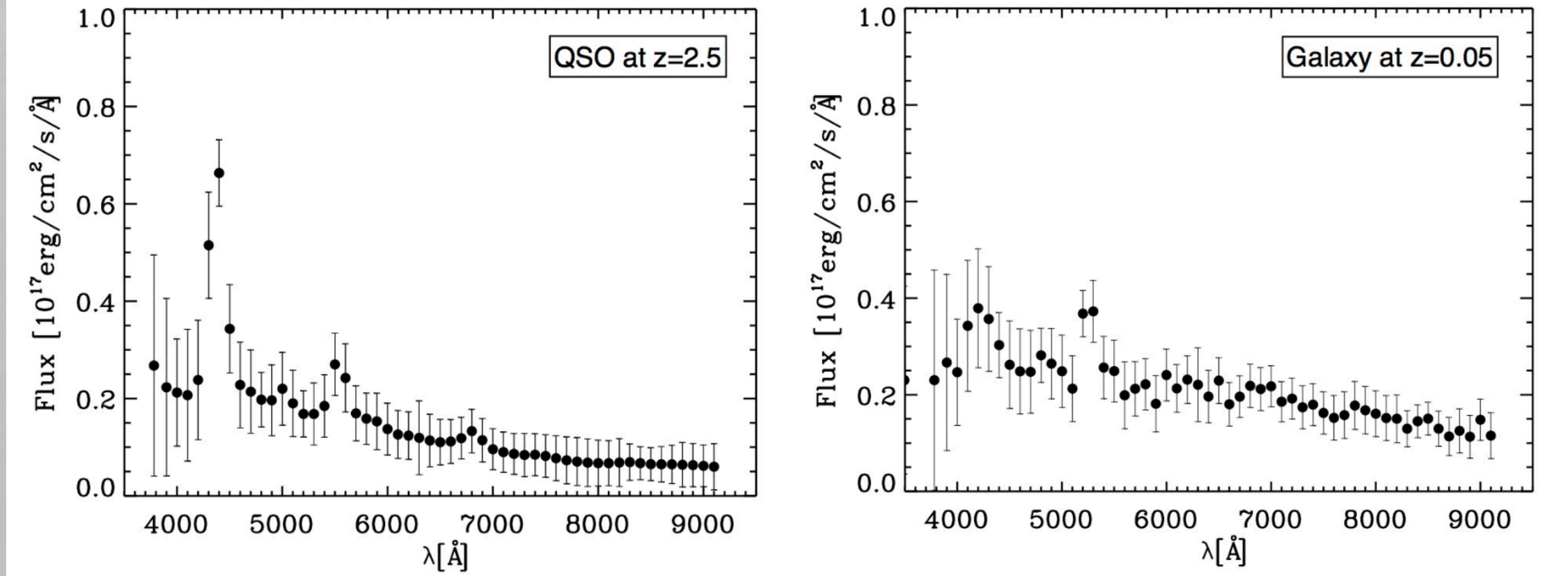
Quasar Target Selection with J-PAS



LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

Quasar Target Selection with J-PAS



- Unbiased samples quasars of through J-PAS pseudo-spectroscopy
  - Address quasar contribution to (re)ionization epochs
- Expected near 100% completeness and efficiency to r=23.2 for Lyman-α Forest QSOs
- Various automated codes under development including …

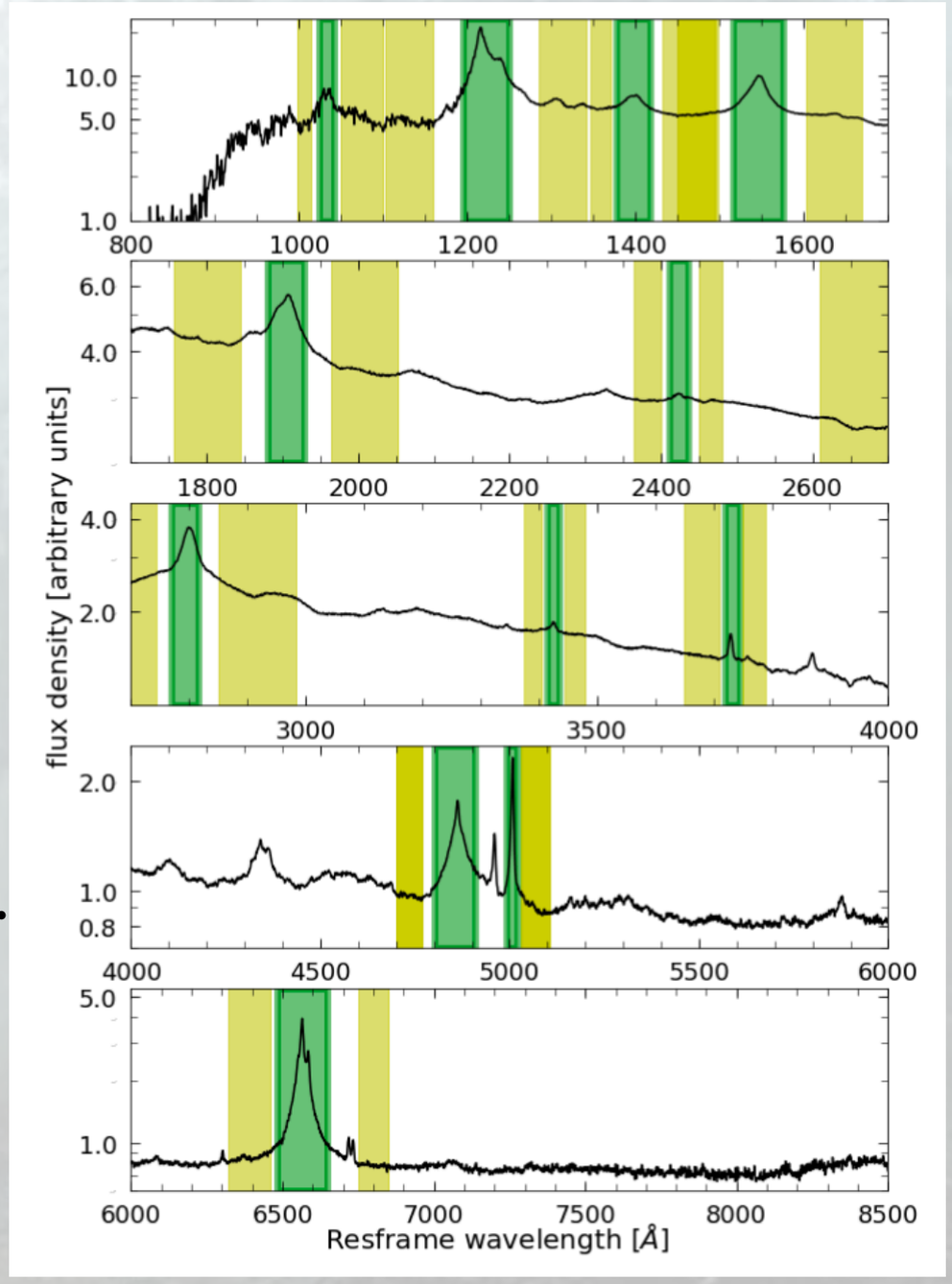
LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

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 vector machine learning
- Demonstration on BOSS data:
  - Perez-Rafols, MP et al in prep
  - >95% complete and pure
- Public code for eBOSS, WEAVE, J-PAS, DESI …



LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Summary

- Lots of exciting science to do with WEAVE and DESI
  - Two complementary BAO measurements
  - Address whether the Lyman-α Forest really does force a rethink on emergence of dark energy
  - Gas properties in a small and large scale context at the epoch of the star formation rate peak
  - Mostly unbiased quasar samples down to r=23.2
- Large samples require automated target selection and catalogue building

Mat Pieri, IGM-Inter, Marseille, 13th July 2018

LAM
LABORATOIRE D'ASTROPHYSIQUE
DE MARSEILLE