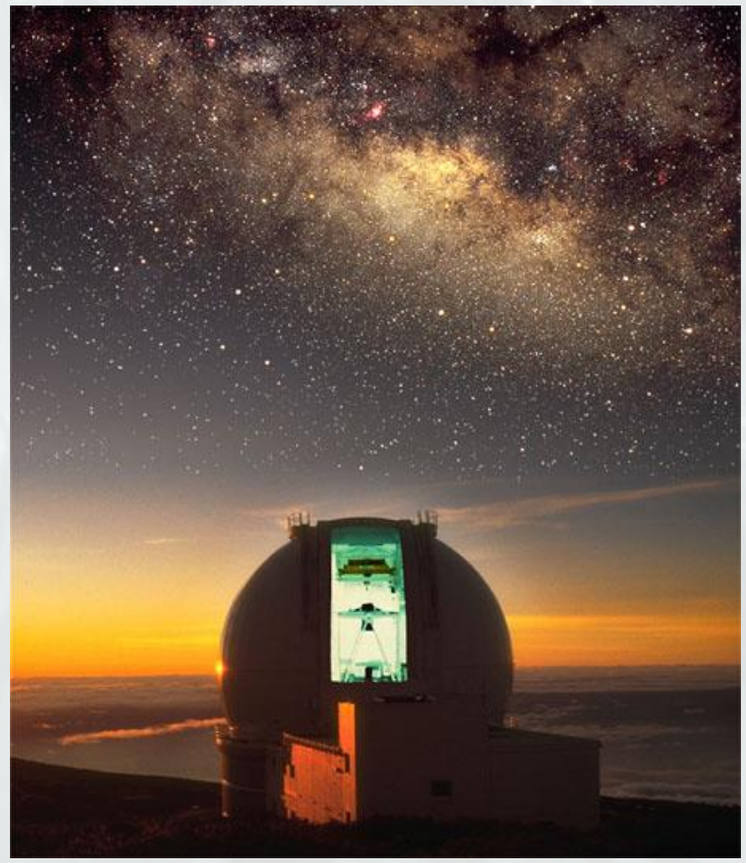
IPhU CLASS meeting 23rd Sept 2021

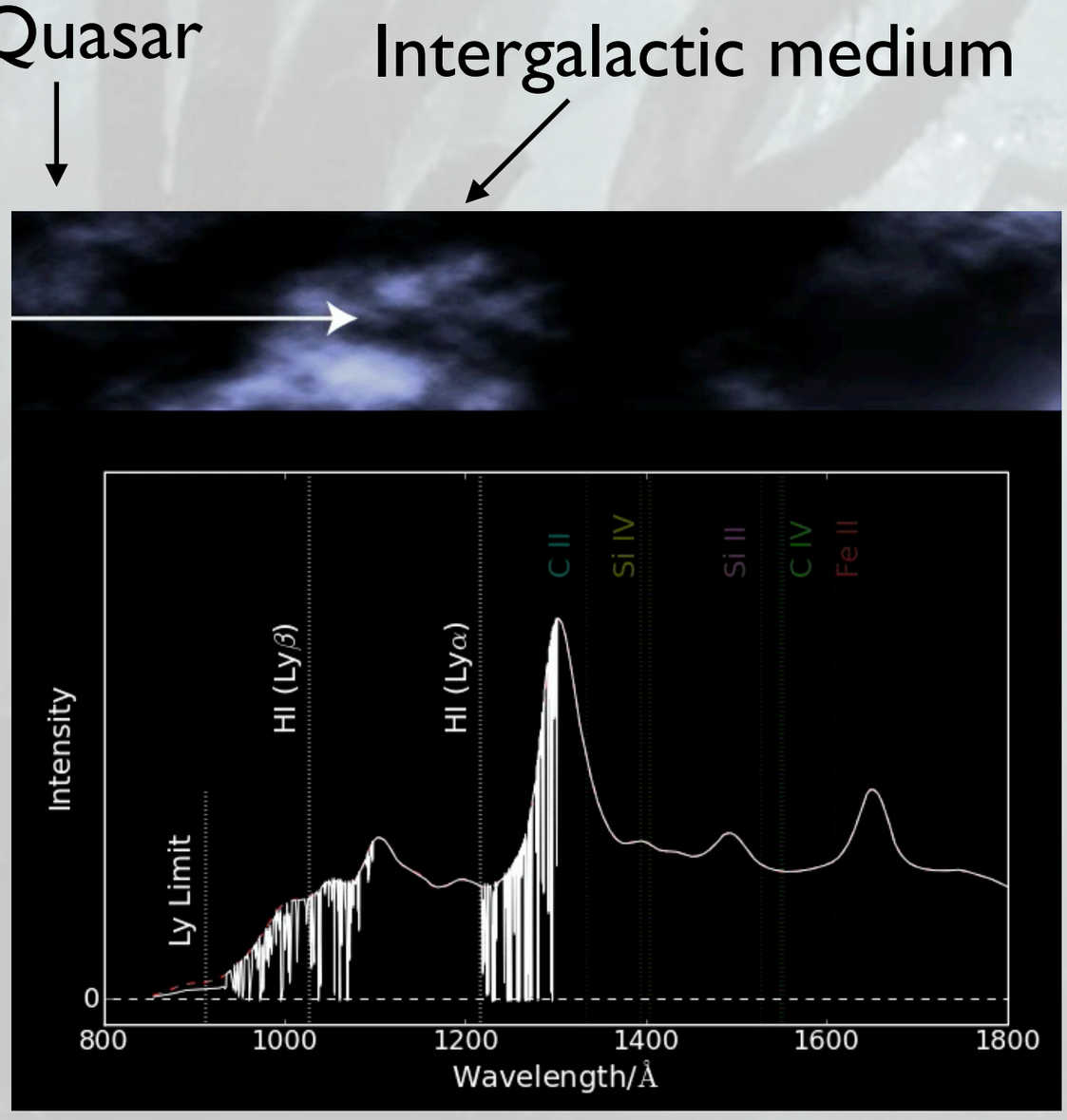
The WEAVE-QSO Survey

Mat Pieri

and the WEAVE Collaboration



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

The Intergalactic medium dominates the universe by mass and volume

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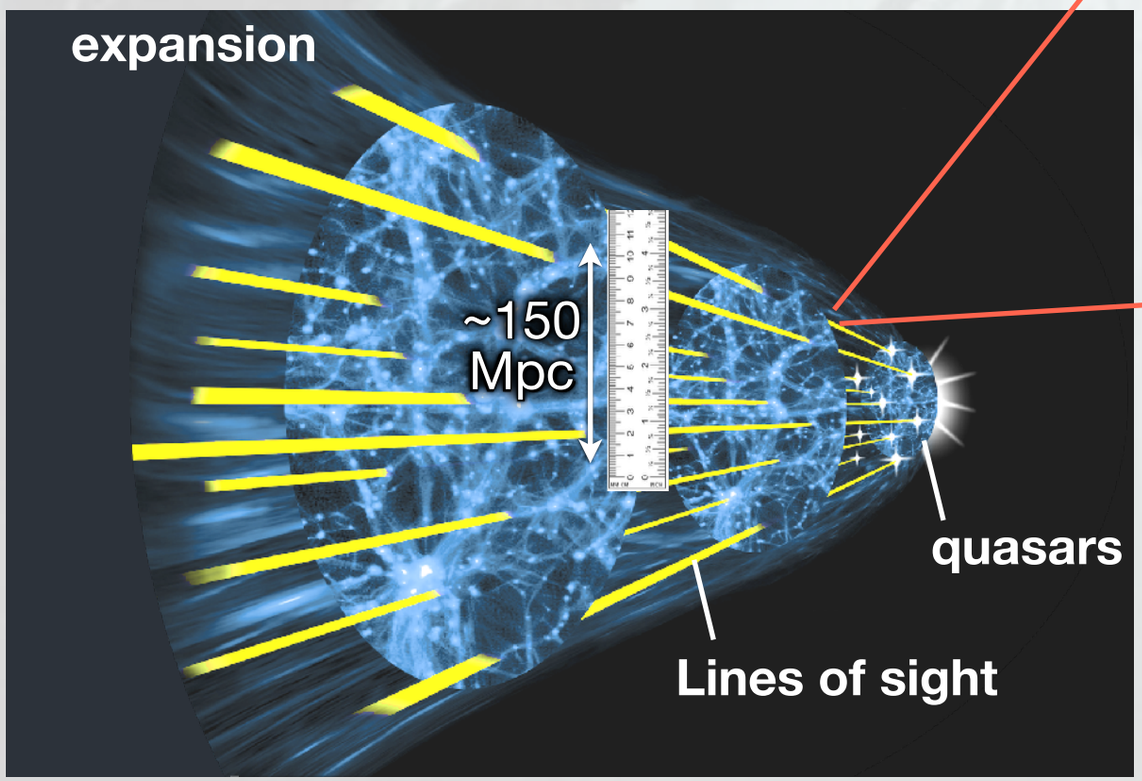
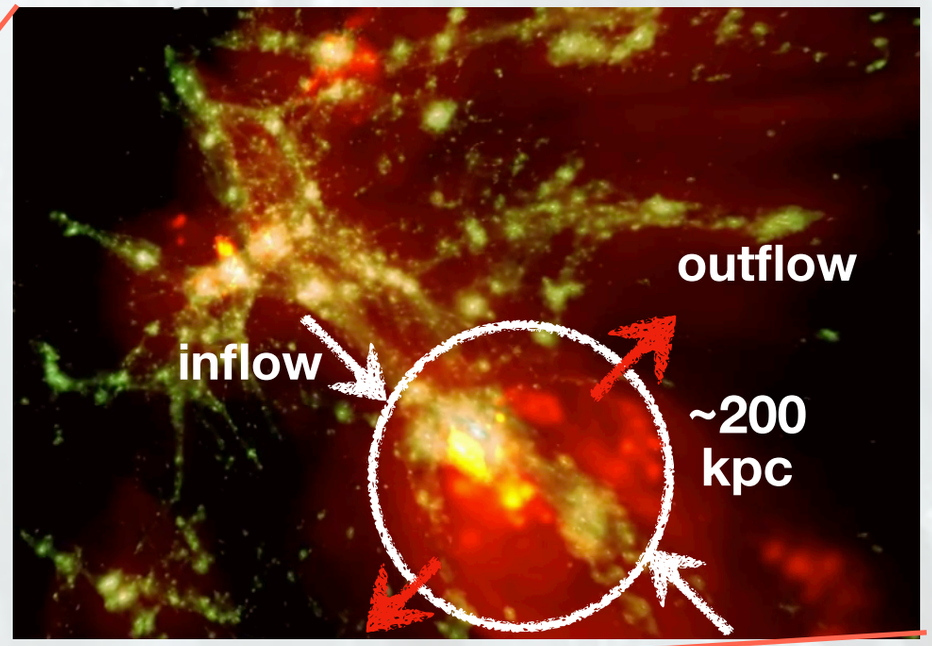
WEAVE-QSO: The Big Questions

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





Circumgalactic Medium (CGM)

Q2: How do galaxies form from IGM?

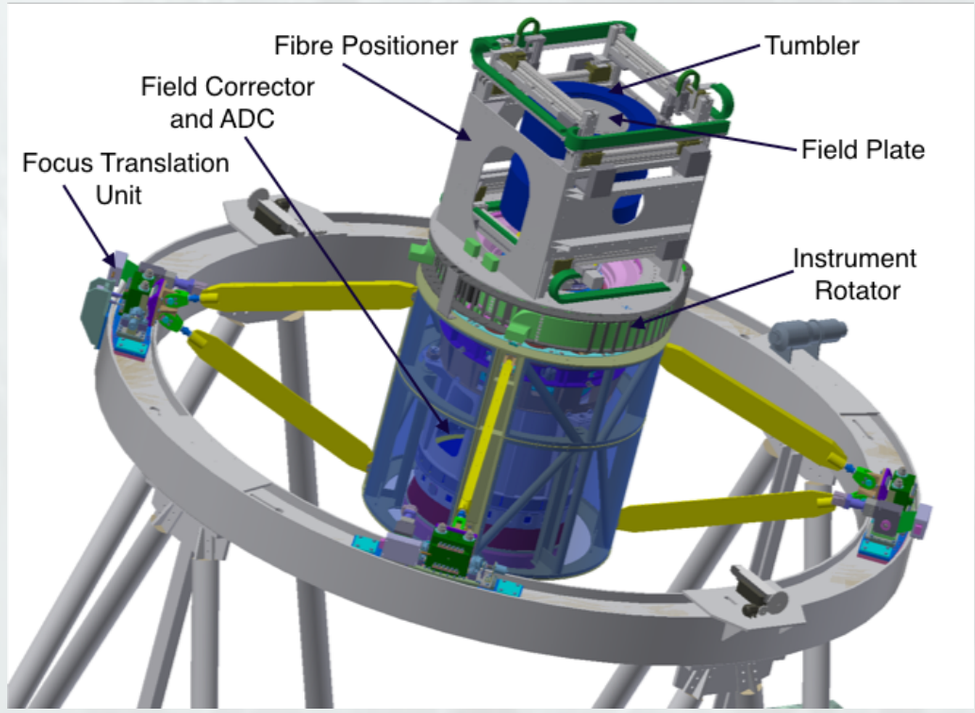
Q3: What is the nature of dark matter?

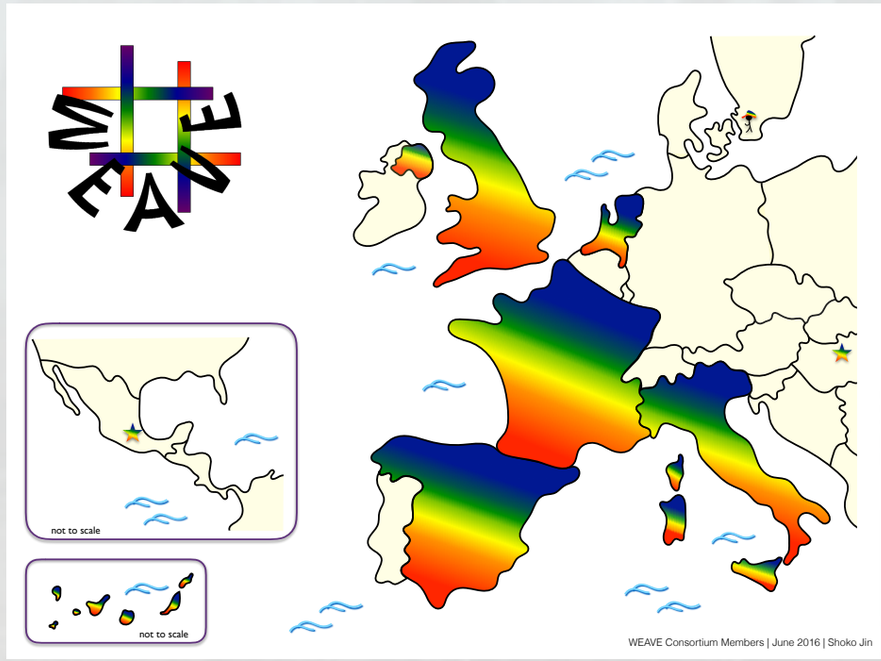
Q4: How does (re)ionization occur?

Addressed by WEAVE-QSO through high spatial and spectral resolution

WEAVE in a Nutshell

- New spectrographic survey facility for the 4.2m William Herschel Telescope
- Fide-field multi-object spectrograph with integral field units
- WEAVE survey 70% of WHT time
  - 1st light in Q1 2022
- Over 400 members over 11 countries
  - WEAVE-QSO around 50
- Open model membership based mostly on nations
  - But institutional and individual buy-in is possible
- More members and partners welcome





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Multi-Object Spectroscopy Mode

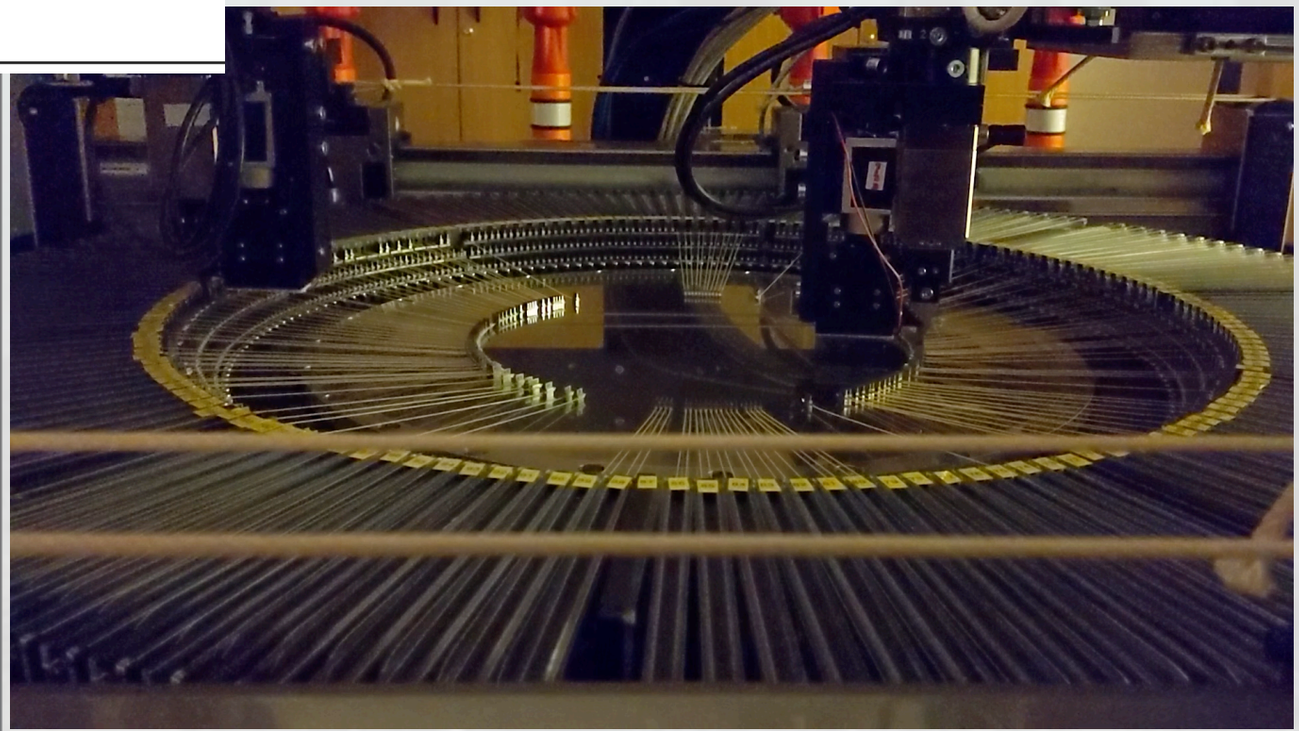
MOS: WEAVE-QSO's main survey mode in dark time

Focal-plane mode	MOS fibres (MOS-A)	MOS fibres (MOS-B)
Tumbler position	0°	180°
Diameter of individual fibres	1.3″ (85μm)	1.3″ (85μm)
Multiplex	960 fibres	940 fibres
Diameter of field over which deployable	2°	2°
Minimum separation on sky	~ 60″	~ 60″
Fibres per IFU	–	–
IFU field of view	–	–
IFU filling factor	–	–
Fibres for auto-guiding	8 × 3.″5 coherent bundles	8 × 3.″5 coherent bundles
Fibres for sky subtraction	~ 5 – 10% of science fibres	~ 5 – 10% of science fibres
Configuration time	~ 55 minutes	~ 55 minutes

WEAVE collaboration in prep

Low resolution: R=4000-7500

High resolution: R=16000-23000



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Integral Field Unit Modes

LIFU and mIFU: recent WEAVE-QSO addition as a filler program

Focal-plane mode	mini-IFUs (mIFU)	Large IFU (LIFU)
Tumbler position	180°	90°
Diameter of individual fibres	1.3″ (85μm)	2.6″ (170μm)
Multiplex	20 IFUs	1 IFU
Diameter of field over which deployable	2°	on axis
Minimum separation on sky	~ 60″	–
Fibres per IFU	37	547
IFU field of view	11″ × 12″	90″ × 78″
IFU filling factor	0.50	0.55
Fibres for auto-guiding	8 × 3.″5 coherent bundles	Separate camera (4′ × 3.′7 field)
Fibres for sky subtraction	one of the mIFUs	8 peripheral bundles of 7 fibres each
Configuration time	<20 minutes	~ 1 minute

WEAVE collaboration in prep

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The WEAVE Primary Science Surveys

The WEAVE Survey consists of 8 primary science surveys:

3 Galactic surveys:

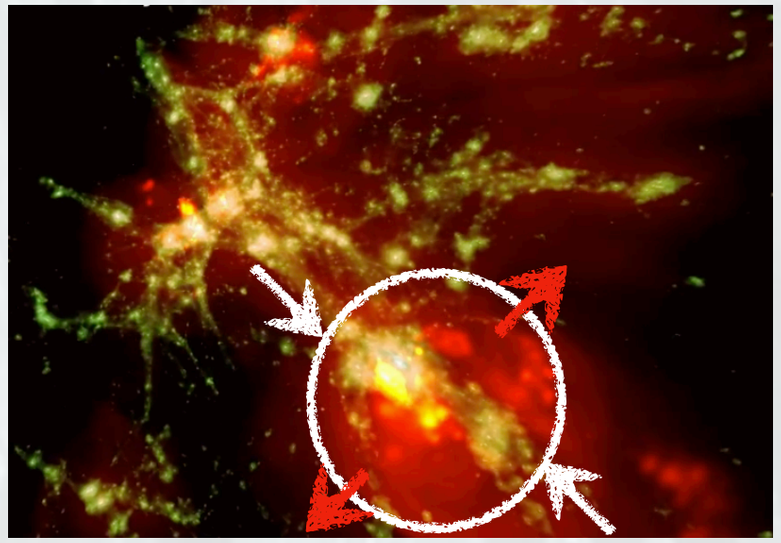
- Galactic Archaeology (STL: V. Hill, OCA)
- SCIP (Stellar, Circumstellar, and Interstellar Physics – STL: J. Drew, Herts)
- White Dwarfs (STL: B. Gänsicke, Warwick)

and **5 Extragalactic** surveys:

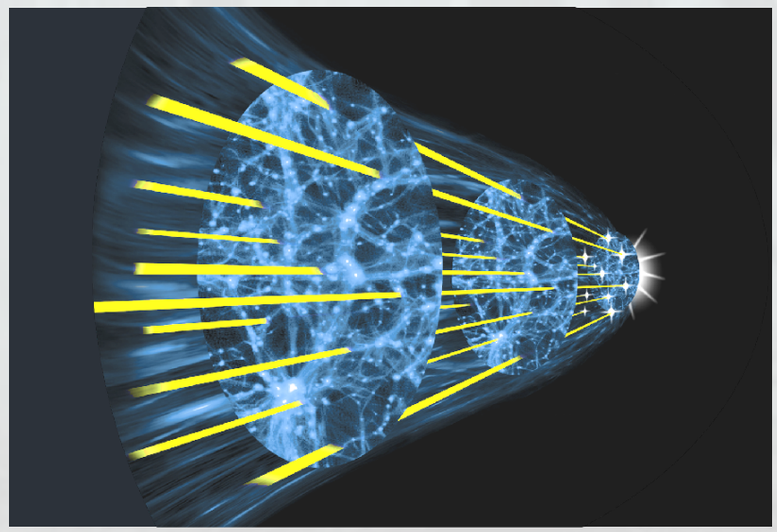
- WEAVE-Clusters (STL: J. A. Aguerri, IAC)
- WEAVE-Apertif (STL: J. Falcón Barroso, IAC)
- StePS (Stellar Population Survey at intermediate redshifts – STL: A. Iovino, Milano)
- WEAVE-LOFAR (STL: D. Smith, Herts)
- WEAVE-QSO (STL: M. Pieri, LAM)

WEAVE-QSO Transforms the Landscape

- High spectral resolution (R=6000 or 20000)
  - High fidelity recovery of galaxies in absorption (particularly metals)
  - Measure smaller line-of-sight structure for thermal history (reionisation), sum of neutrino masses and exotic dark matter



- High spatial resolution from dense sample of quasars
  - Measure BAO in large 3D structure
  - Map the cosmic web using IGM tomography
  - AGN environments, pressure support, detect galaxies in absorption, CW emission

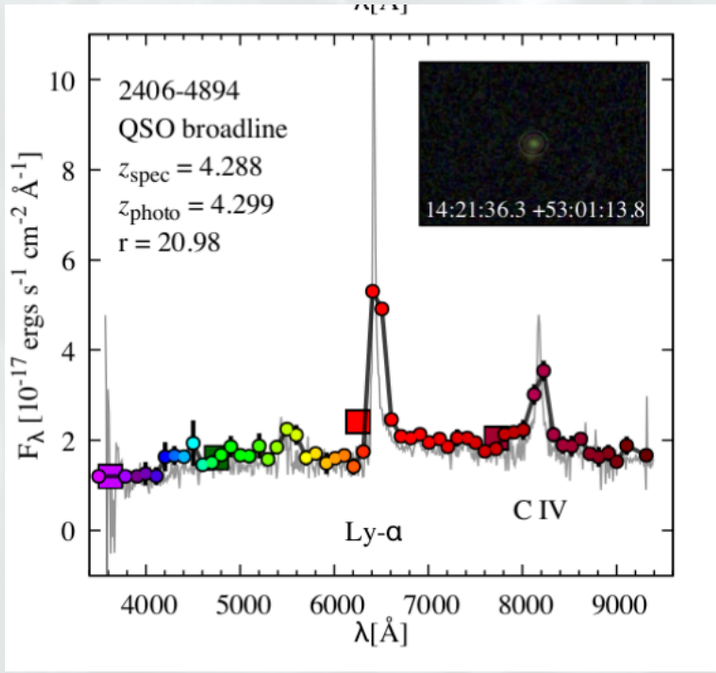


WEAVE-QSO Survey Plan Sketch

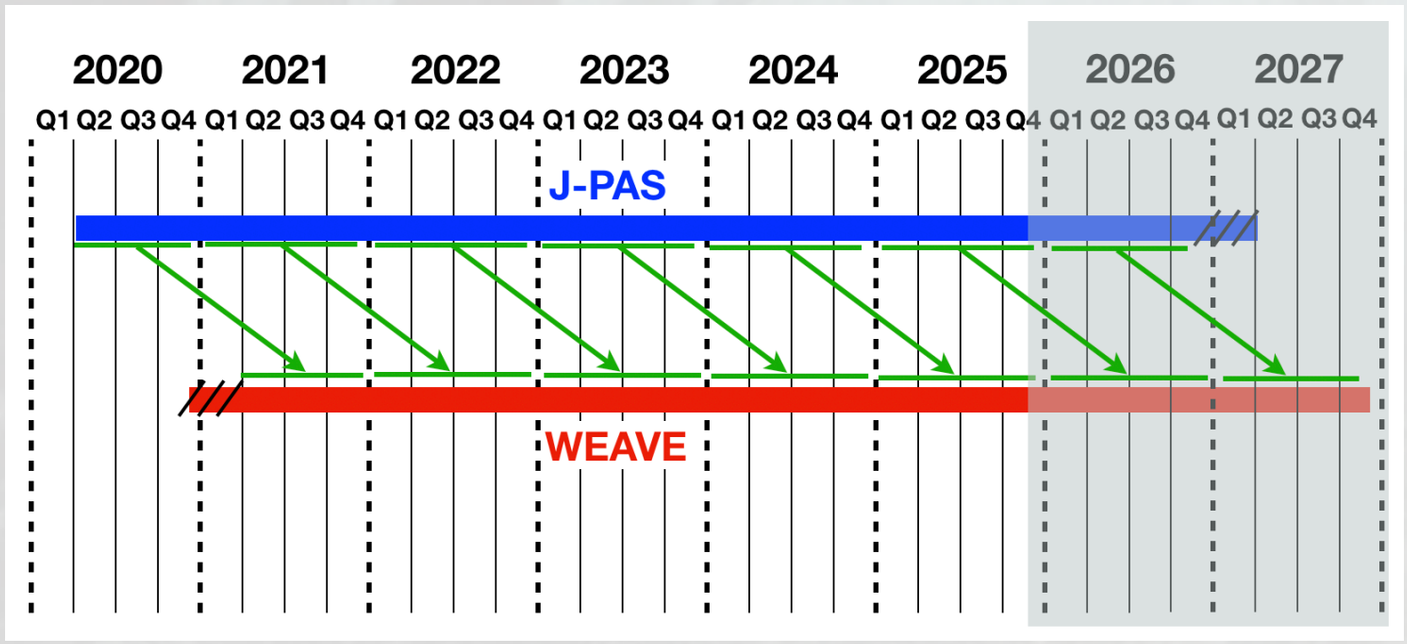
- "High resolution" massive IGM survey
  - Spectral res LR: 3xBOSS (2xDESI), or HR: 12xBOSS (9XDESI)
  - Spatial res - quasar number density: 4-5 x BOSS ~2 x DESI
  - + LIFU (quasars multiplexes) and mIFU (galaxies in absorption)
- MOS survey fields shared with Galactic Archeology and LOFAR
- Goal: 400,000 quasar spectra with $z>2.1$ and $m_r<23.2$ in MOS LR dark time
  - + small sample in HR grey time
- Target selection
  - 6000 deg^2 of $m_r<23.2$ quasars from J-PAS
  - 2500 deg^2 of quasars G=20.5 from Gaia and $m_r<21.5$ BOSS/eBOSS
- HETDEX: Special 400 deg^2 area in J-PAS footprint

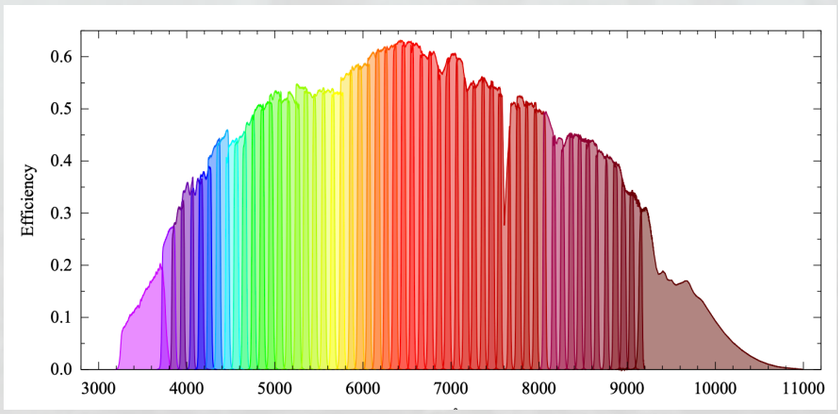
J-PAS and WEAVE-QSO

- J-PAS imaging with 54 narrow filters ideal for quasar identification
- Memorandum of understanding signed between the two surveys for
  - Sharing targets and spectra
  - 6000 WEAVE fibre hours awarded to J-PAS
  - Joint science (e.g. forest and image cross-correlation potential)



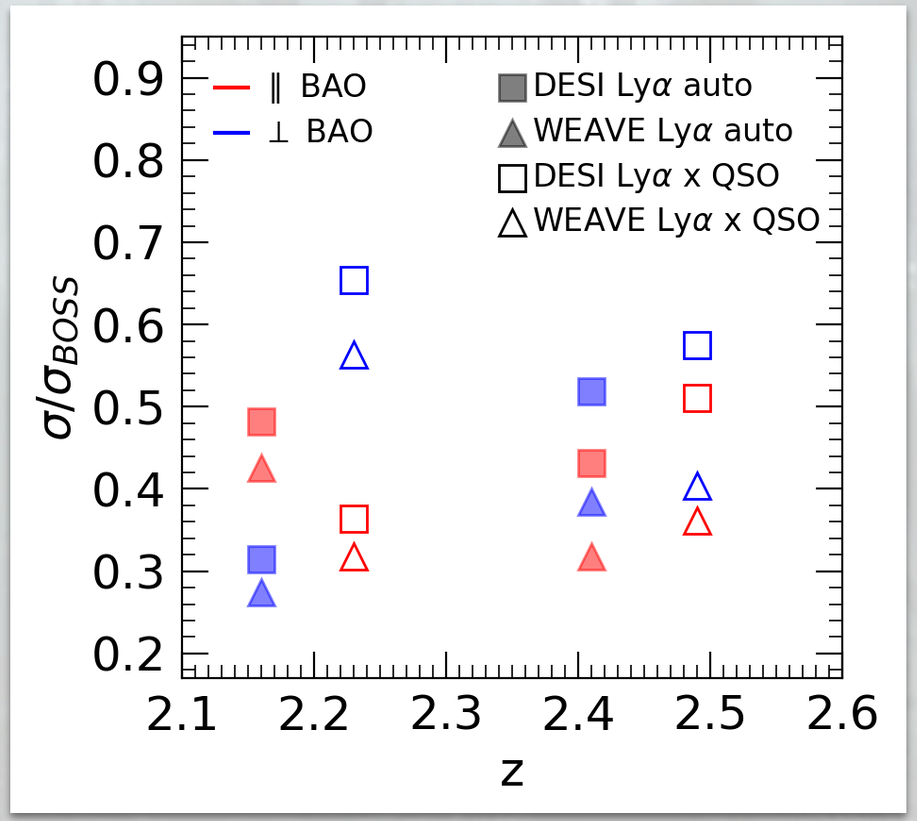
Bonoli+ 2021





Projected BAO constraints

- WEAVE-QSO BAO ~6000 deg^2 J-PAS targeted footprint
- DESI: more Lyα quasars but lower density
  - $\sigma \propto$ 1/Density and $\propto 1/\sqrt{\text{Area}}$
  - WEAVE-QSO fibre hour constrained - choose between z<2.45 or z>2.45
    - 25% smaller errors at z>2.45 ✓
    - 12% smaller errors at z<2.45
- Prospects for novel BAO
  - Galaxies in absorption (paper in prep)
  - Using J-PAS as a Lyα intensity map and x-corr with Lyα forest



credit: Michael Blomqvist

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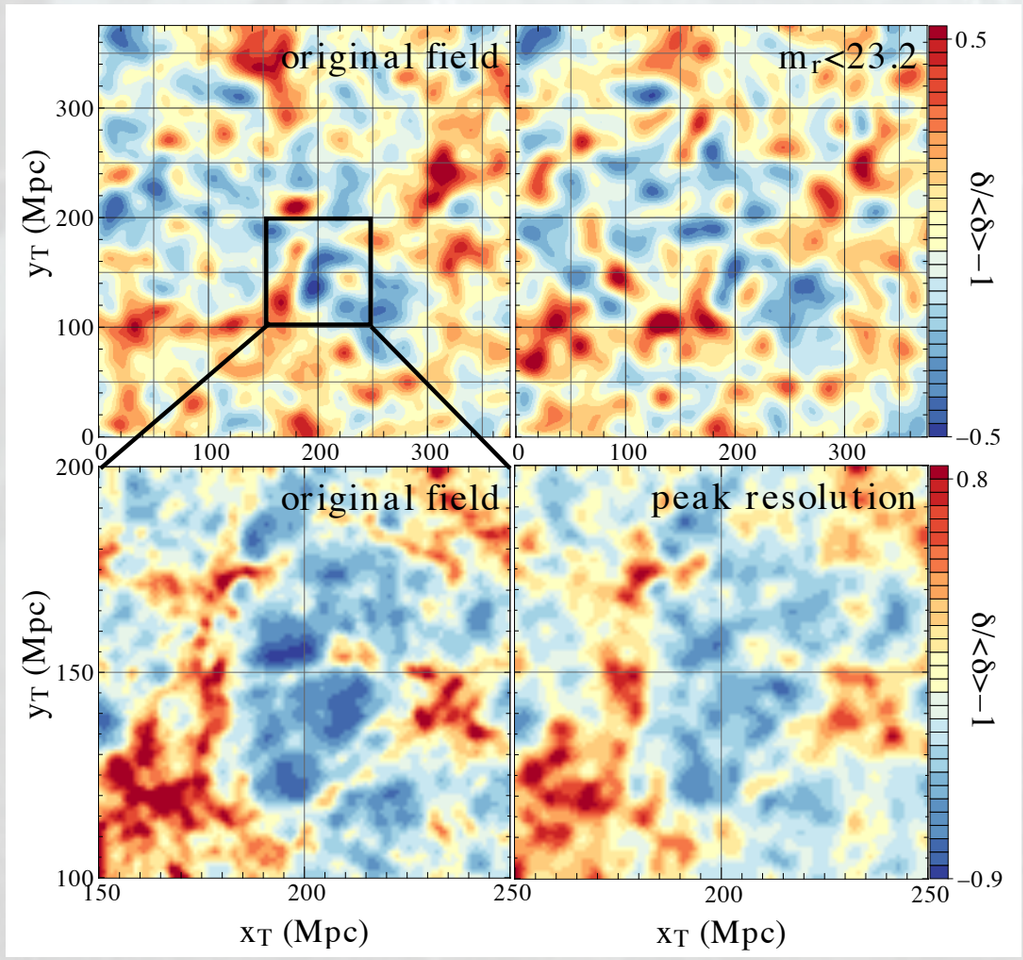
WEAVE

IGM Tomography in WEAVE-QSO

- The next frontier of galaxy formation and cosmology: mapping at z>2
- Large-scales allow novel cosmology (e.g. void counts, critical points etc)
- Small-scales allow big picture on galaxy formation at cosmic noon
- See Katarina's talk



HETDEX footprint

Close groups of quasars

credit: Clotilde Laigle

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WEAVE-QSO as a Tomography Pilot

Survey/Facility	When	Area	m_r	$\langle L_T \rangle$	z	References
CLAMATO	2014-	0.8 deg^2	24.7	2.5 Mpc	[2, 2.5]	Lee et al. 2018 [82]
PFS (Subaru)	2022-	∼15 deg^2	24.7	∼3 Mpc	[2.5, 3.]	Takada et al. 2014 [159] and private comm.
MOSAIC (ELT)	2024-	1-2 deg^2 (TBC)	25.5	∼2 Mpc	[3, 3.5]	Japelj et al. 2019
WQ wide (J-PAS)	2020-	6000 deg^2	23.2	∼20 Mpc	[2, 3.5]	this work
WQmid (HETDEX-N)	2020-	418 deg^2	23.5	∼14 Mpc	[2, 3.5]	this work
WQ high density	2020-	-	23.2	∼2 Mpc	[2, 3.5]	this work
MSE	-	∼80 deg^2	-	-	[2, 3]	"The Detailed Science Case for the MSE, 2019"[1] (p182)
GMT	-	-	-	-	-	"the GMT Science Book 2018"[2] (p136)

DESI also (plan under discussion)

Note: I am a new coordinator of MOSIAC SWG2

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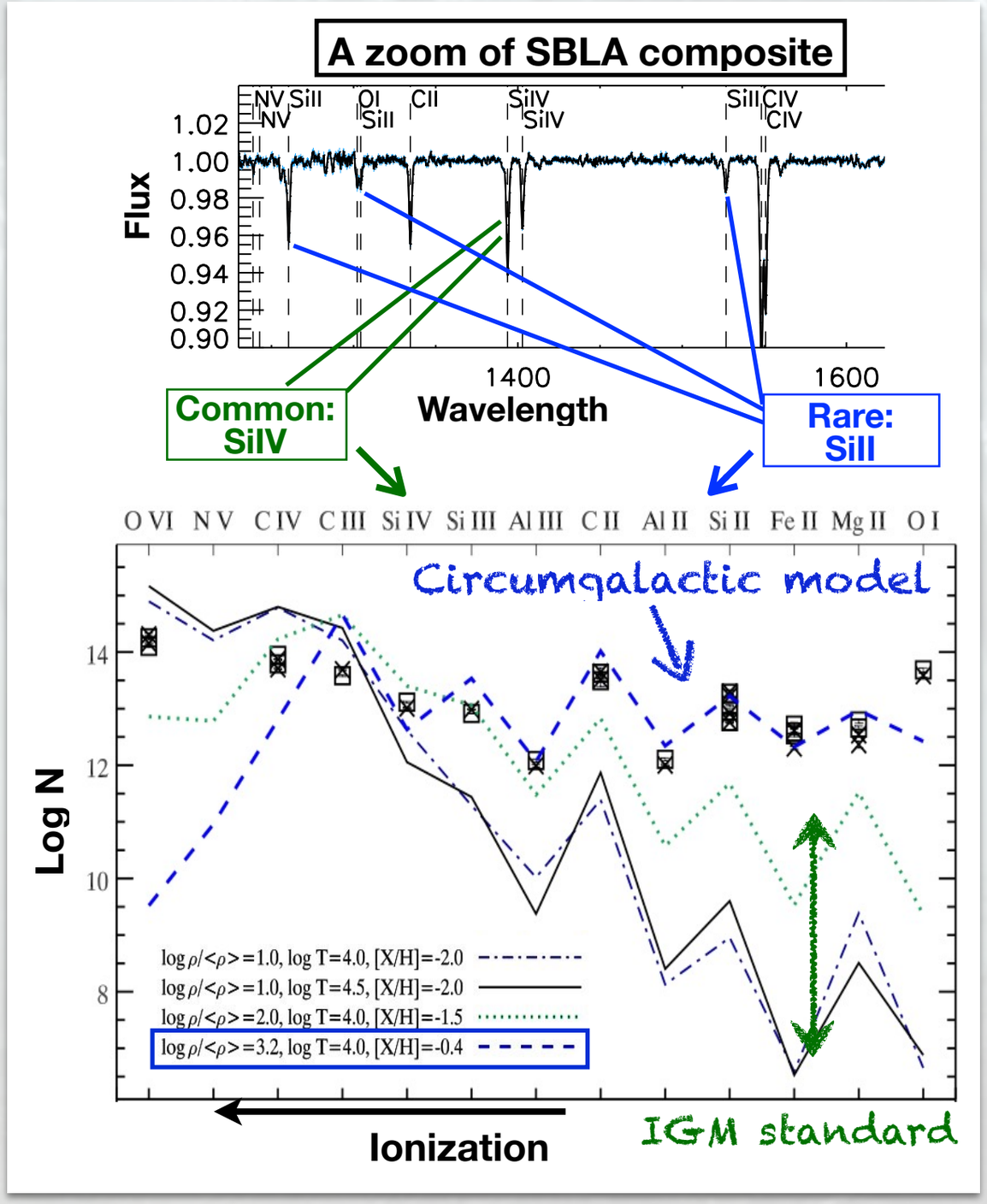
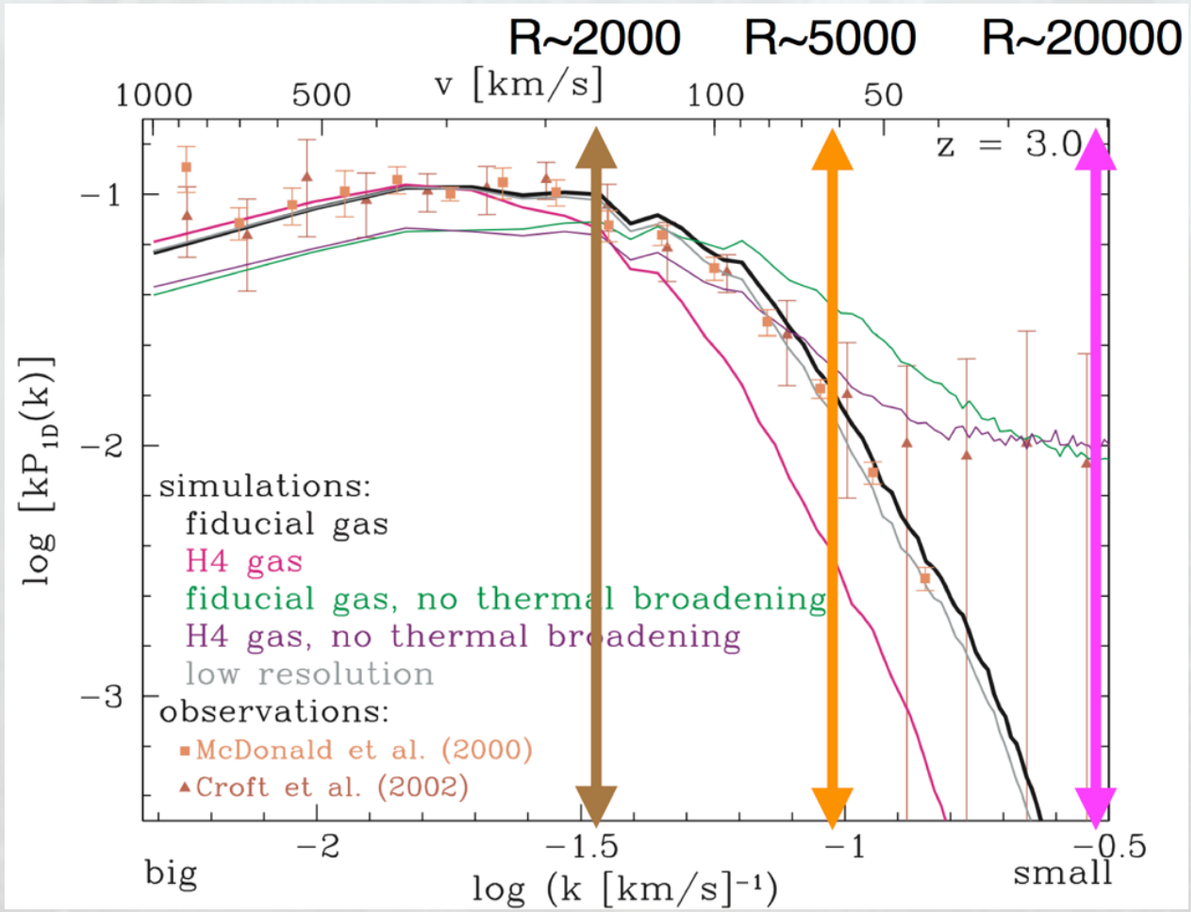
Absorber Science in WEAVE-QSO

- Recovery of DLAs and LLS
- New sample: Strong-blended Lya
- Public absorber catalogue with high legacy value
- Galaxy formation at SFR peak: Combination with cosmic web and galaxy surveys



Line-of-sight Forest Power Spectrum

- WEAVE resolution for small-scale structure suppression
  - Reionization/thermal history
  - Neutrino masses
  - Cold DM, Warm DM, Fuzzy DM

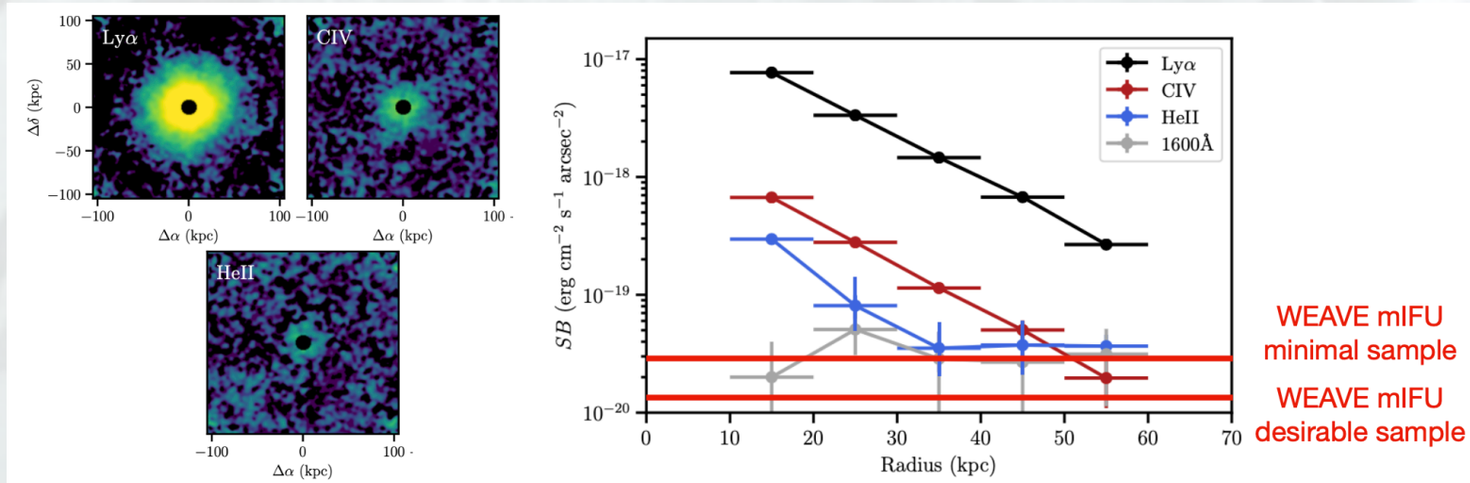


Peeples+2010

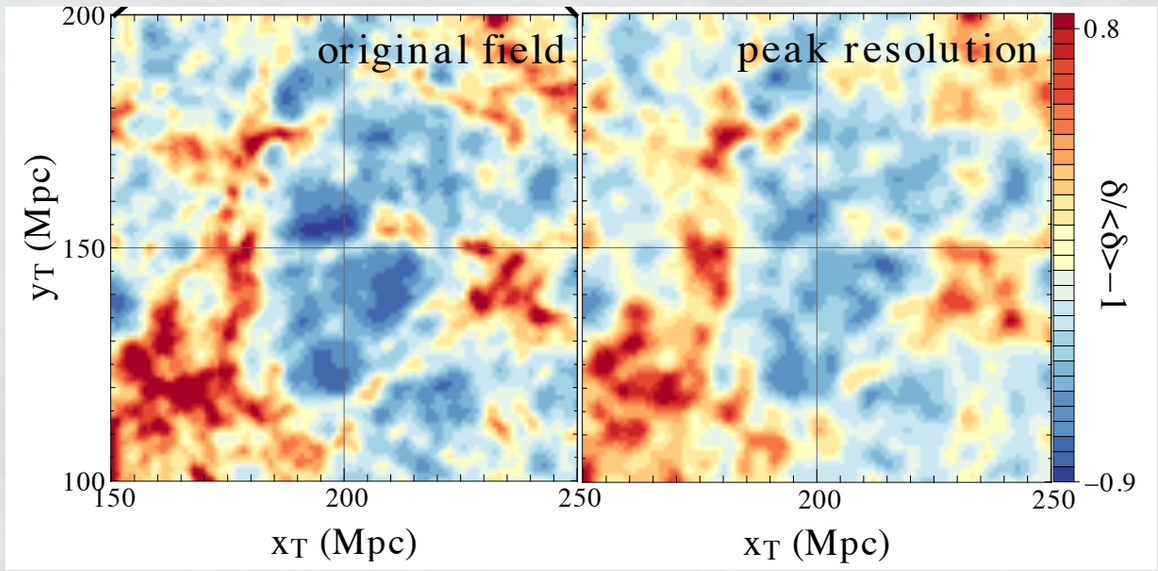
Whats new? IFU as filler program

- Moderate seeing and grey time: MiniIFU
  - Galaxy and quasar environments in emission

Comparison to MUSE (Fossati et al 2021)



- Worst seeing: LargeIFU for quasar multiplets within 1Mpc
  - AGN environments in absorption
  - Small scales: DM, pressure, line broadening
  - Cosmic web small scale extension



Whats new? Reviewing Survey Plan

- WEAVE delays with respect to DESI
- J-PAS delays to give targets to WEAVE-QSO
- CW given greater priority
  - More large-scale multiplets
- BAO get boost by going fainter to $m_r<23.5$ but over narrow redshift
  - What redshift?

Summary

- WEAVE will span the full range of astrophysics on stellar scales to the largest structures measured
- From our region of the Milky Way to beyond reionization
- WEAVE-QSO is diverse
  - From small-scales (in the CGM) to the CW filaments to the largest scales
  - Measuring galaxy formation and early dark energy
- Entering an exciting and busy period

  science pay off is coming soon!