Unveiling the Cosmic Dawn: looking for extended Lyman-alpha nebulae in an Universe younger than 600 Myr

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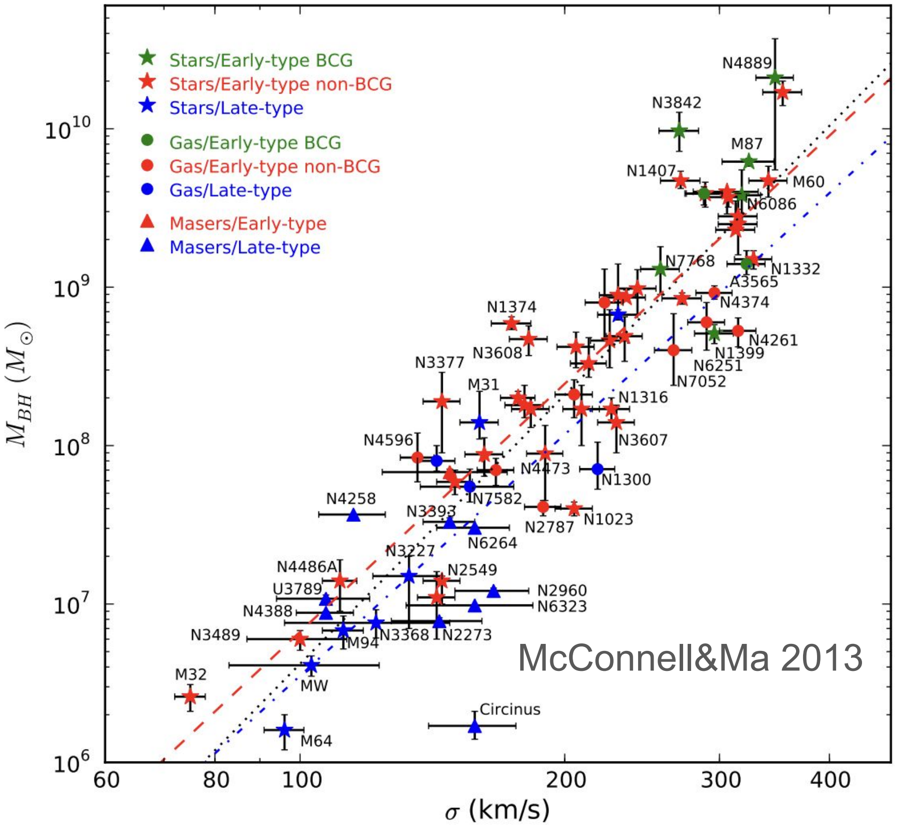
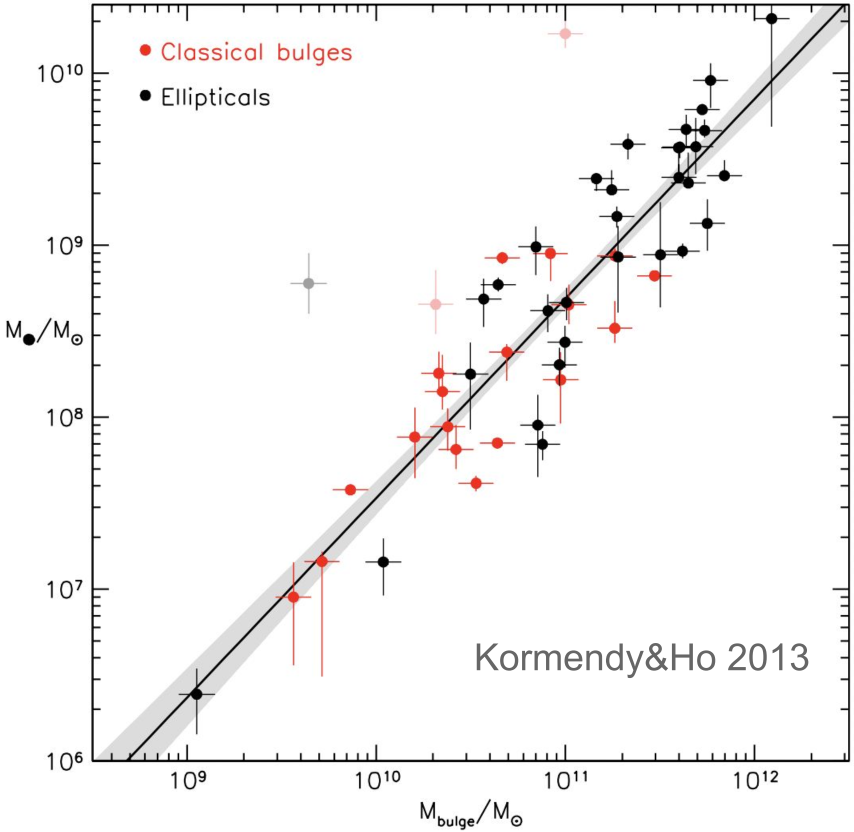
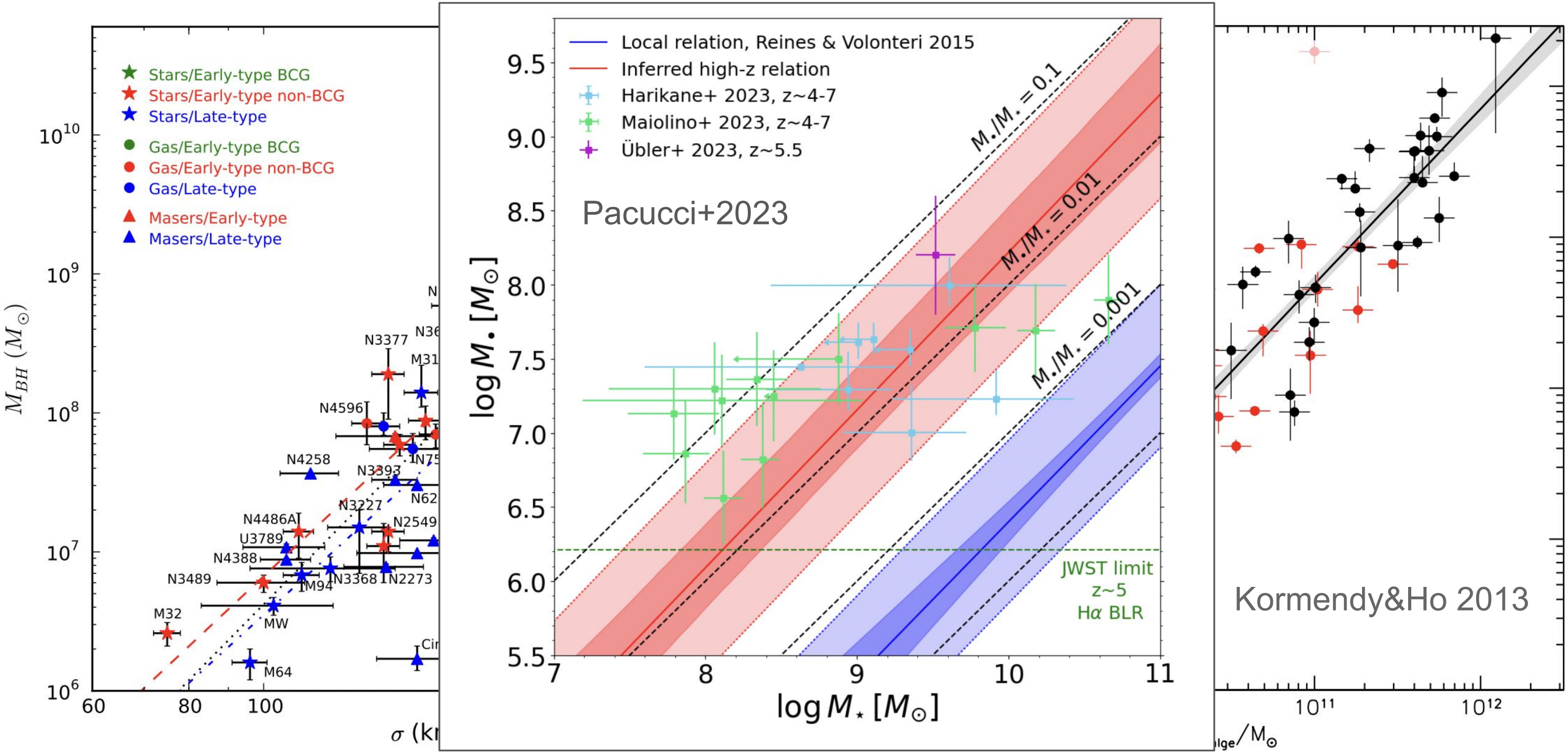
SMBH - Hosts coevolution



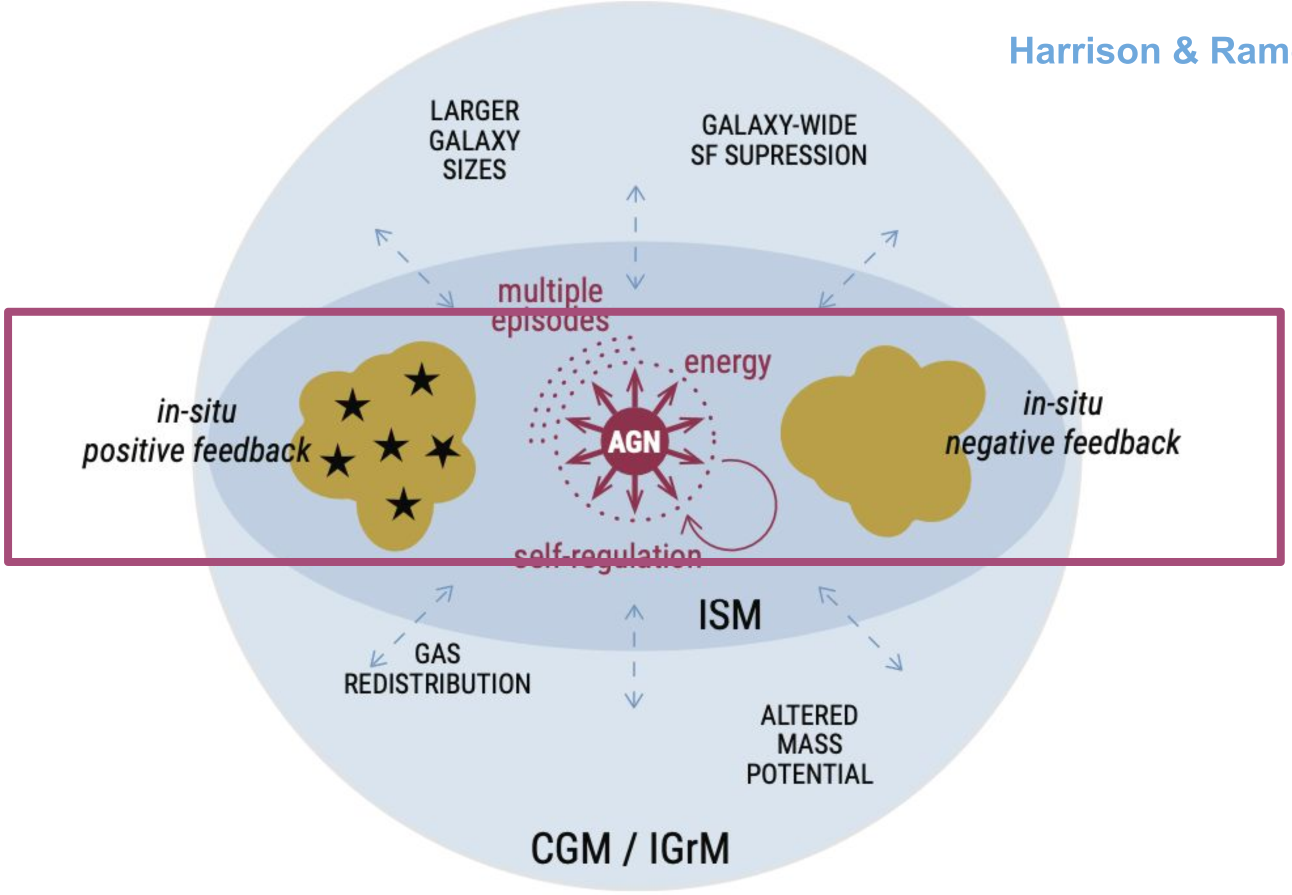


SMBH - Hosts coevolution



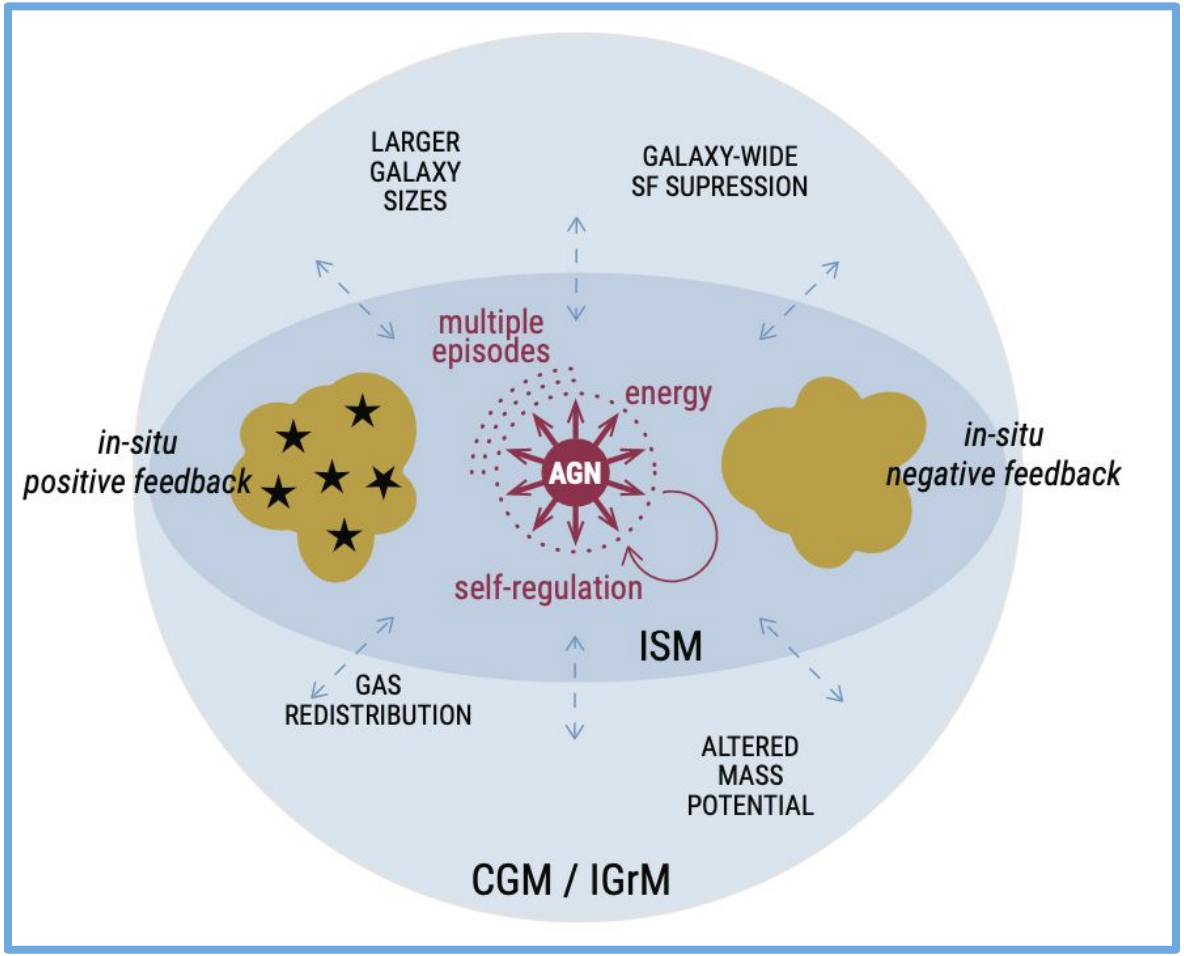
Feeding and Feedback: a multi-scale problem

Harrison & Ramos Almeida 2024



Few parsecs up to 10s of kpc

Feeding and Feedback: a multi-scale problem

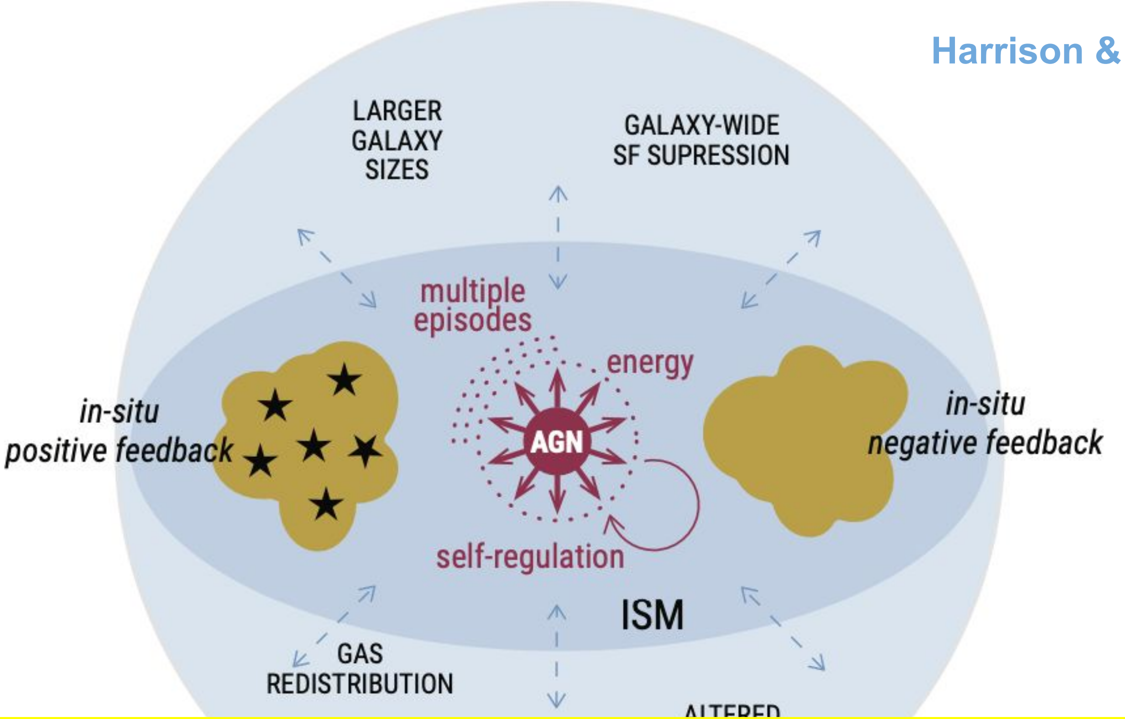


mos Almeida 2024

10 kpc up to 100s of kpc

Feeding and Feedback: a multi-scale problem

Harrison & Ramos Almeida 2024



Integrated/cumulative history of energy injection form AGN most important in shaping hosts' properties (e.g. Piotrowska+2022, Bluck+2023, Terrazas+2016)

Challenge: extreme growth and star formations at high z

hundreds of quasars at z>6 → Fan et al. 2023

current redshift frontier:
- z = 7.54 → Bañados et al. 2018
- z = 7.52 → Yang et al. 2020
- z = 7.64 → Wang et al. 2021

SMBH

$10^9 - 10^{10} M_\odot$ SMBH, using up gas, are able to form in ~ 700 Myr (Fan+2023), by efficiently growing mass onto smaller BH seeds (Volonteri et al. 2021, Inayoshi et al. 2020)

HOSTS

host galaxies of quasars at z~6 with SFR >> 100 $M_\odot$/yr consuming gas of the environment.

e.g. Decarli+2018, Kim&Im2019, Shao+2019)

Challenge: extreme growth and star formations at high z

hundreds of quasars at z>6 → Fan et al. 2023

z = 7.54 → Bañados et al. 2018

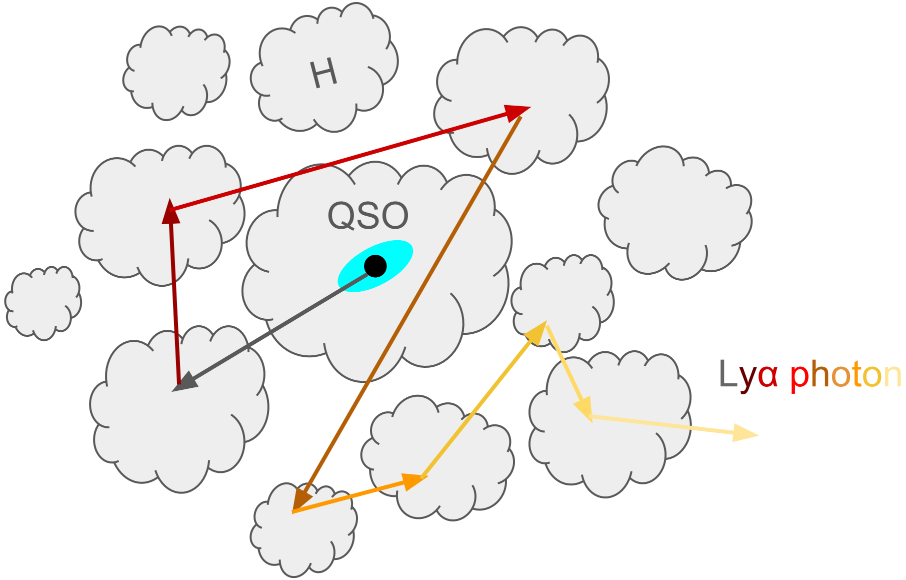
Where do these structures live and are these environments sustainable for hosting such extreme objects?

Hints: high-z quasars hosted only by >$10^{12} M_\odot$ dark matter halos (e.g. Costa+2014, Volonteri&Rees2006) **and hosts fueled by cold streams from the IGM or mergers with gas rich halos** (e.g. Fumagalli+2011, DiMatteo+2012, Mayer&Bonoli 2019)

by efficiently growing mass onto smaller BH seeds (Volonteri et al. 2021, Inayoshi et al. 2020)

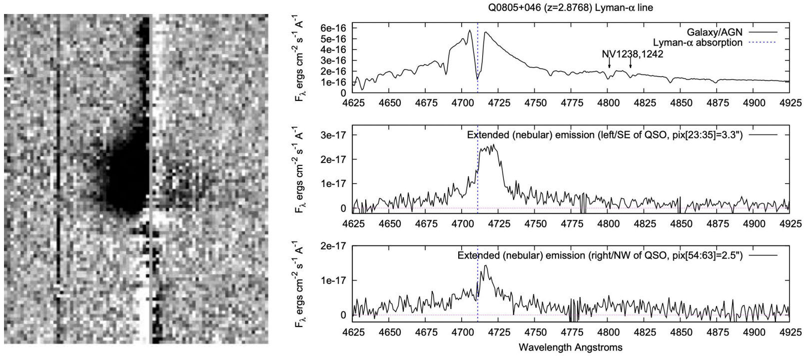
e.g. Decarli+2018, Kim&Im2019, Shao+2019)

CGM emission of intermediate/high-z quasars

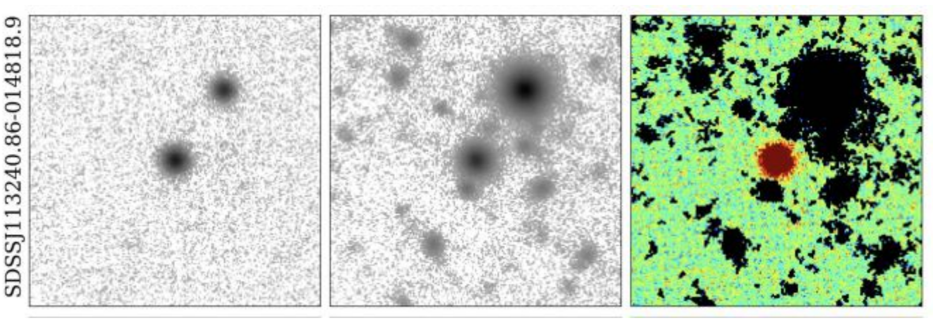


CGM emission of intermediate/high-z quasars

LS spectroscopy e.g. Roche+2012



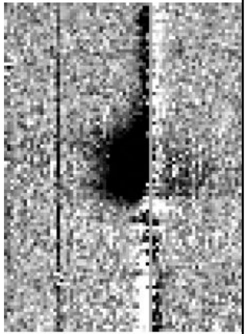
NB imaging e.g. Arrigoni Battaia+2016

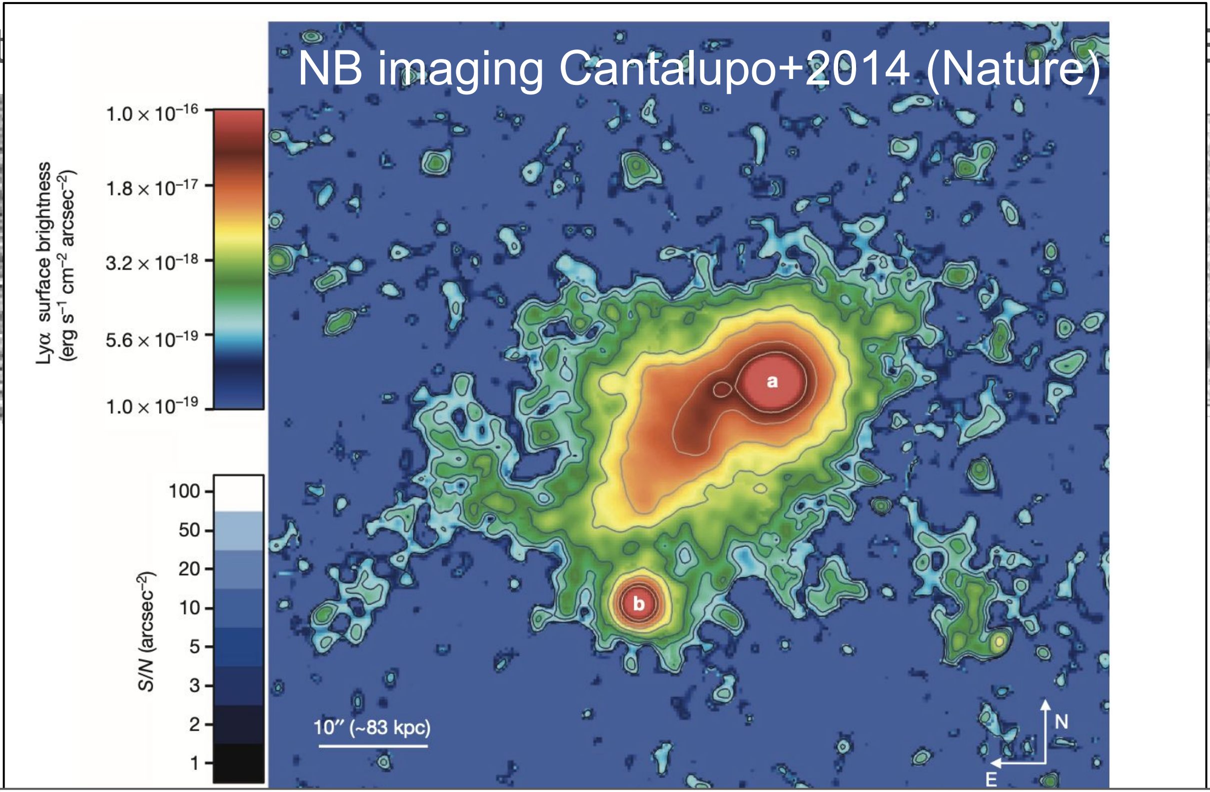


almost ubiquitous 10-50 kpc Lyα nebulae

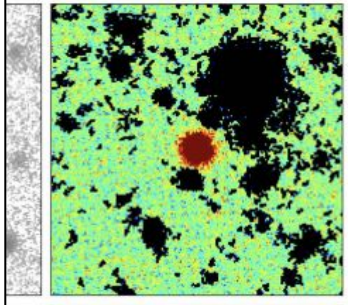
CGM emission of intermediate/high-z quasars

LS spect



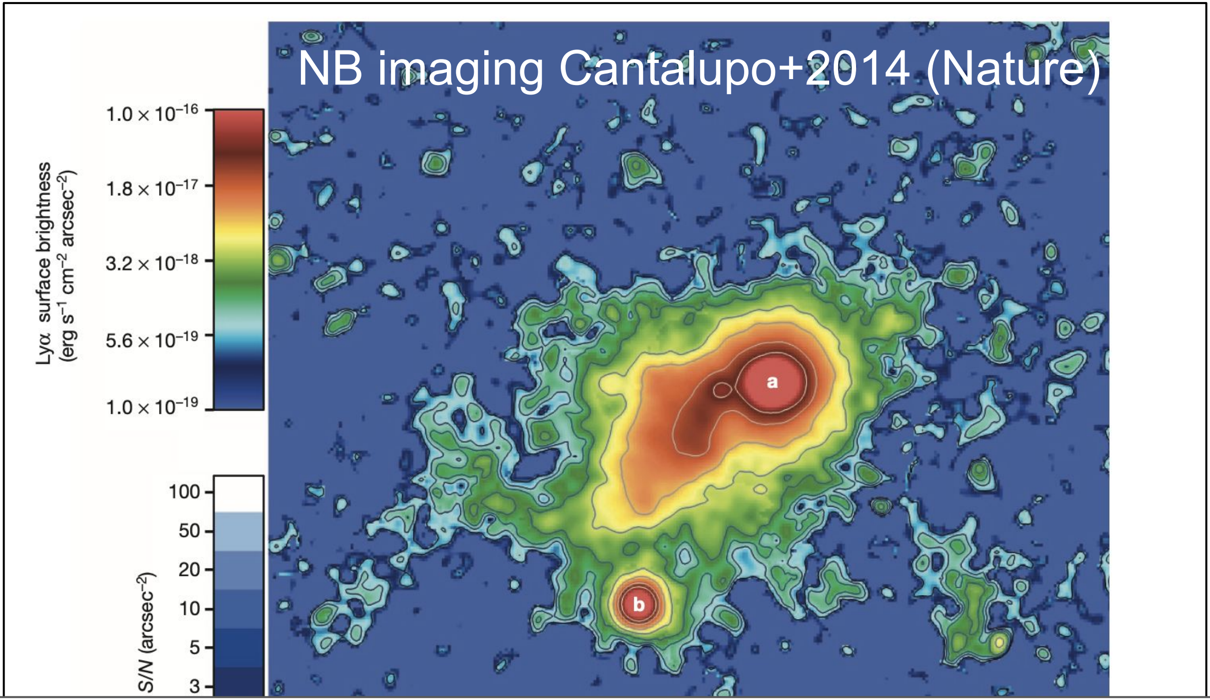


Battaia+2016



few sources surrounded by Giant Lyα nebulae (>300 kpc)

CGM emission of intermediate/high-z quasars



~460 kpc nebula around a RQ quasar
(recombination in the ionised nebula / scatter of photons from BLR)
SB up to 1.0 $\times 10^{-16}$ erg s^{-1} cm^{-2} $arcsec^{-2}$ / or better $L_{Ly\alpha} \sim 2 \times 10^{44}$ erg/s

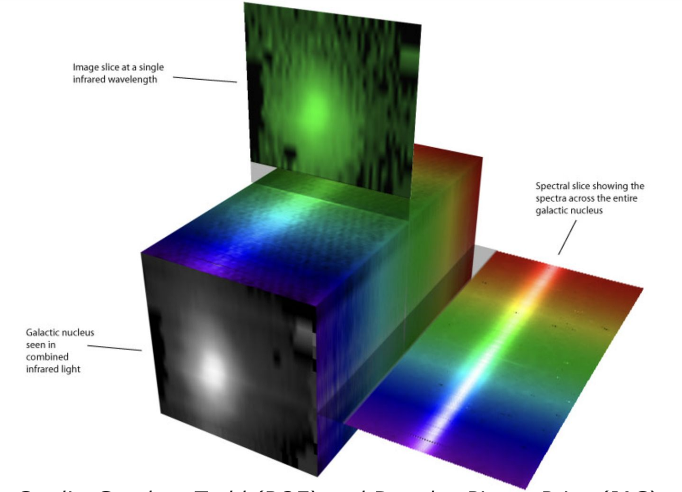
IFU detection of Lyα nebulae

Narrow Band and Long Slit LIMITATIONS

- ★ filter losses (NB) especially critical for RQ → uncertainties in phot z and in spec z from broad quasars lines / slit losses (LS) especially critical for asymmetries
- ★ quasar PSF subtraction

(General) HR IFU STRENGTHS

- ★ Large field of view
- ★ By design no filter/slit losses
- ★ Resolution for accurate PSF subtraction

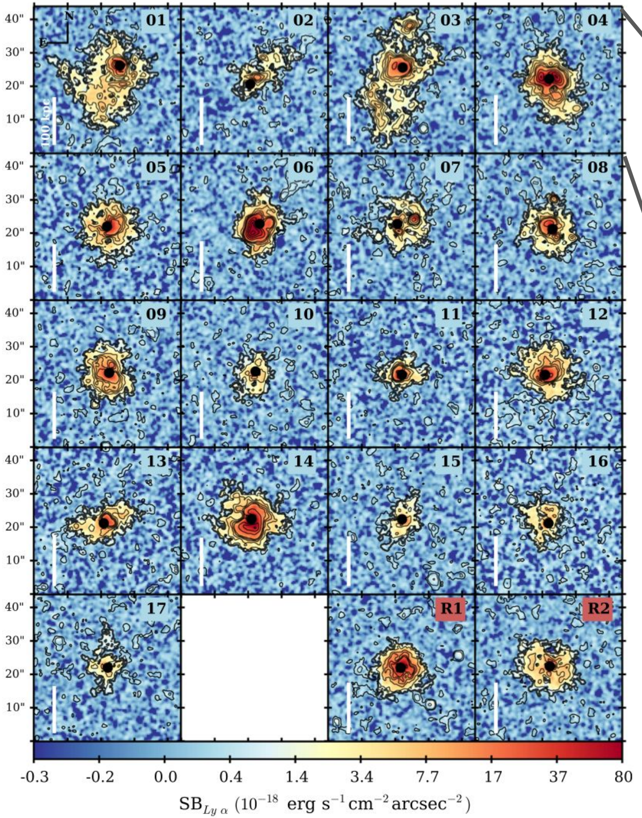


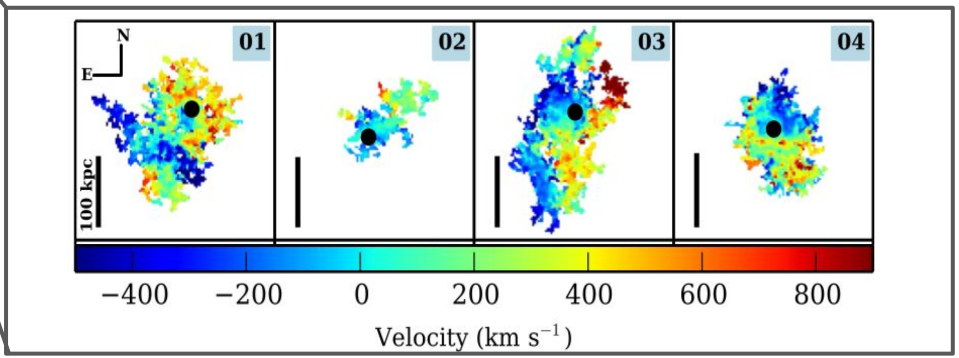
Credit: Stephen Todd (ROE) and Douglas Pierce-Price (JAC)

IFU detection of Lyα nebulae

Borisova+2016 MUSE → giant (>100 kpc) Lyα Nebulae around all RQ quasars at z~3-4

SB > ~10^{-18} erg s^{-1} cm^{-2} $arcsec^{-2}$





resolved kinematic maps

unclear patterns → Lyα resonant line

IFU detection of Lyα nebulae

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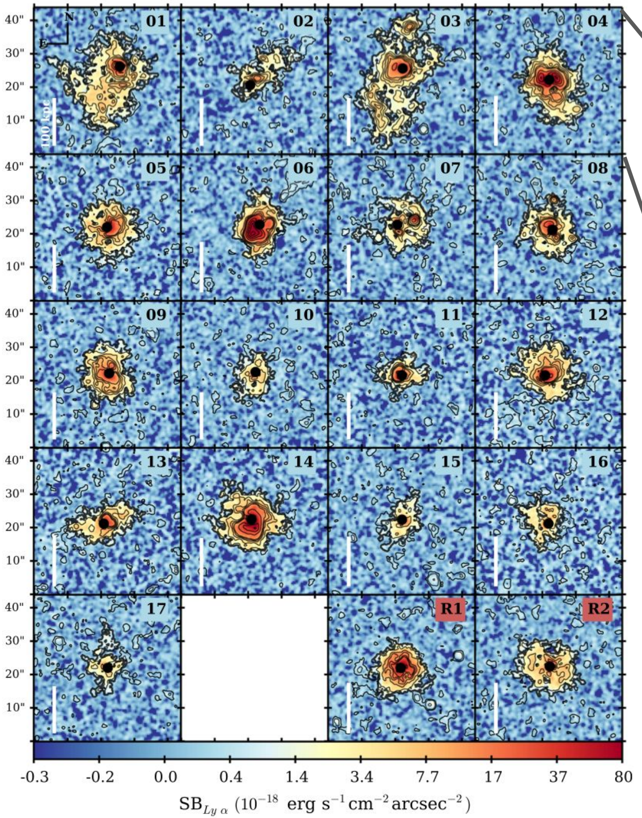
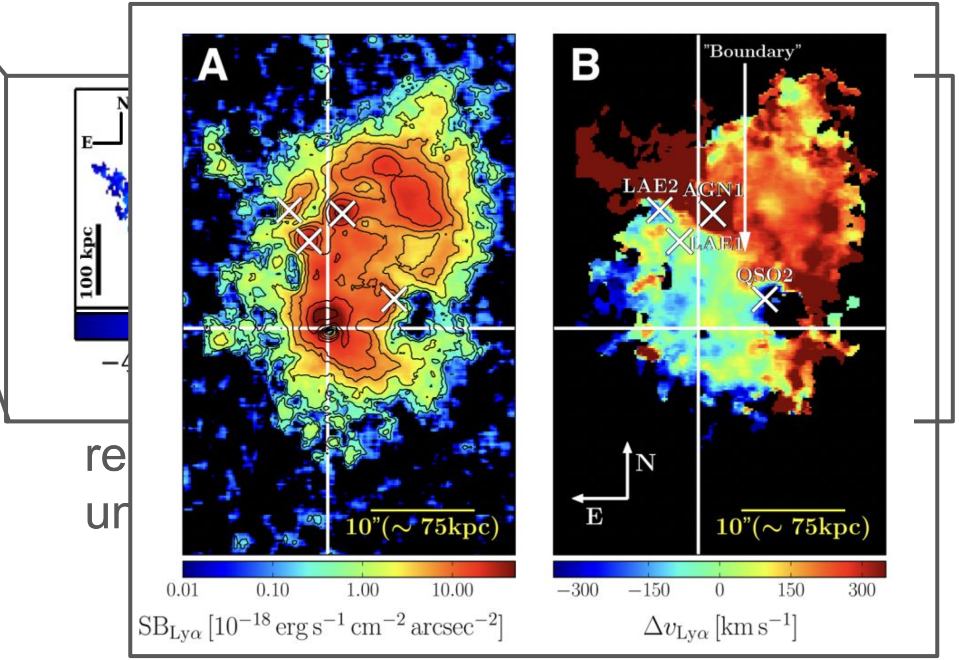
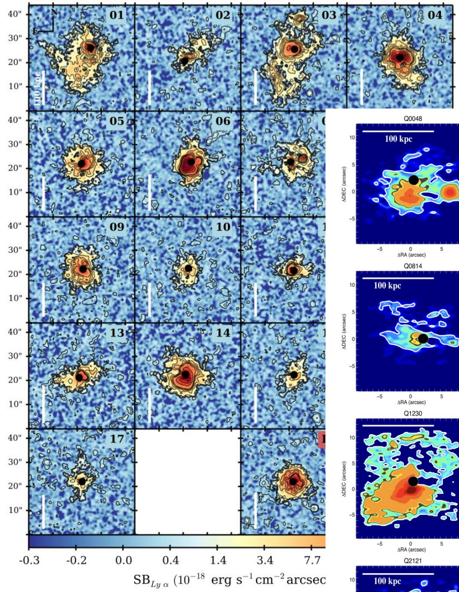




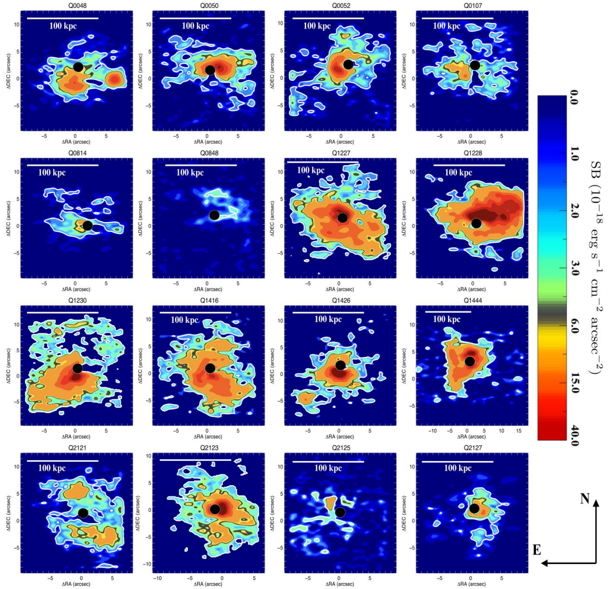
Arrigoni Battaia+2018 MUSE

Current Lyα nebulae surveys

Borisova+2016 MUSE, z=3-4

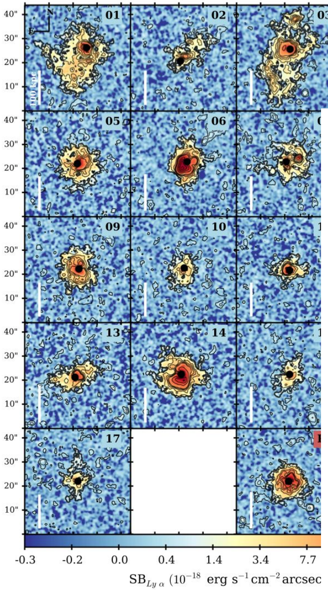


Cai+2019 KWCI survey, z~2

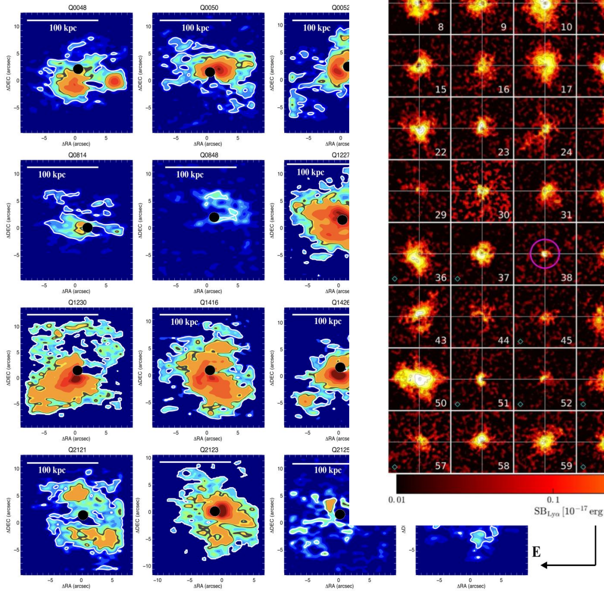


Current Lyα nebulae surveys

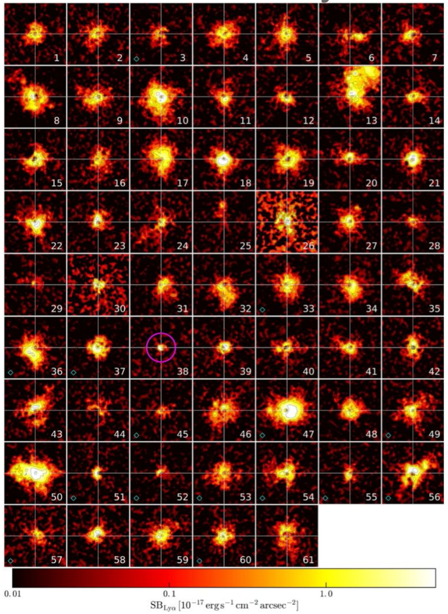
Borisova+2016 MUSE, z=3-4



Cai+2019 K

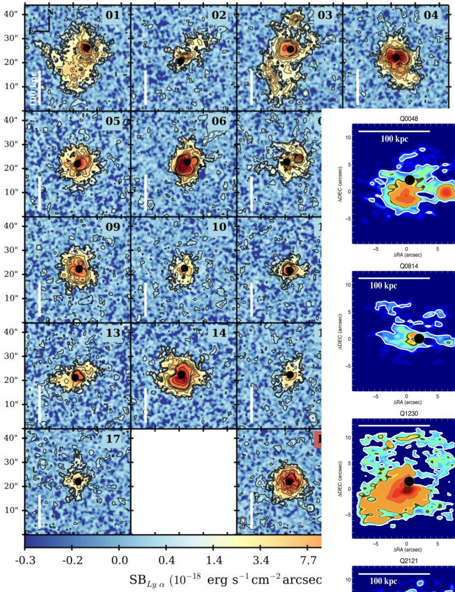


Arrigoni Battaia+2019
MUSEUM survey, z~3

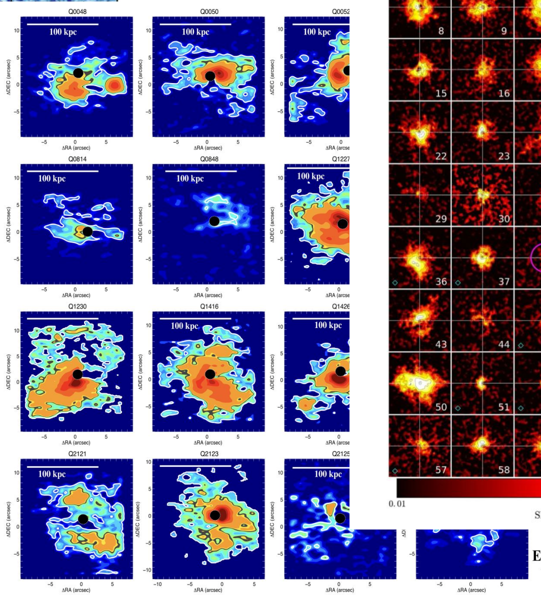


Current Lyα nebulae surveys

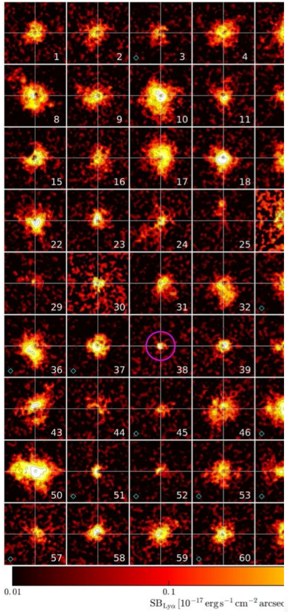
Borisova+2016 MUSE, z=3-4

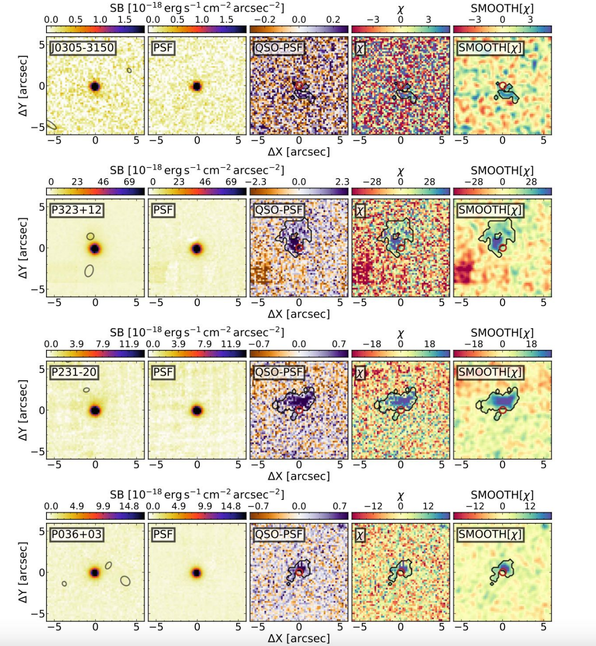


Cai+2019 K



Arrigoni Battaia+2019
MUSEUM surv

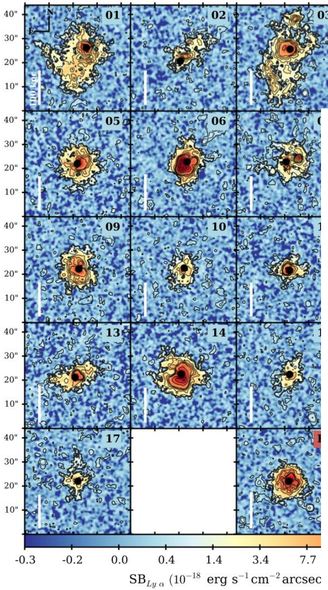




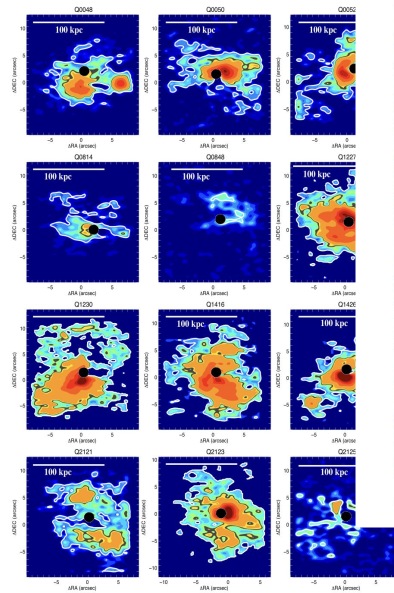
Farina+2019
REQUIEM survey, z~5.7-6.6

Current Lyα nebulae surveys

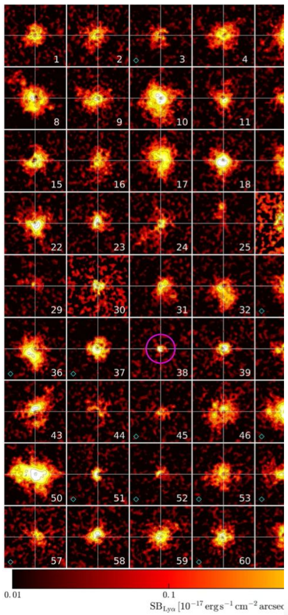
Borisova+2016 MUSE, z=3-4

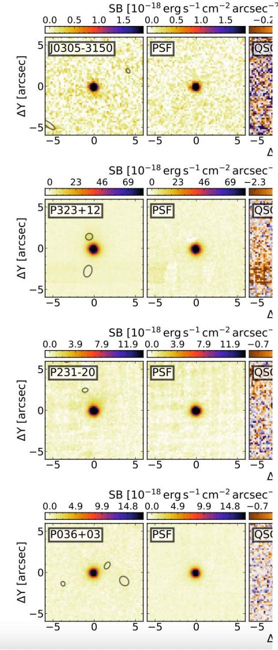


Cai+2019 KV



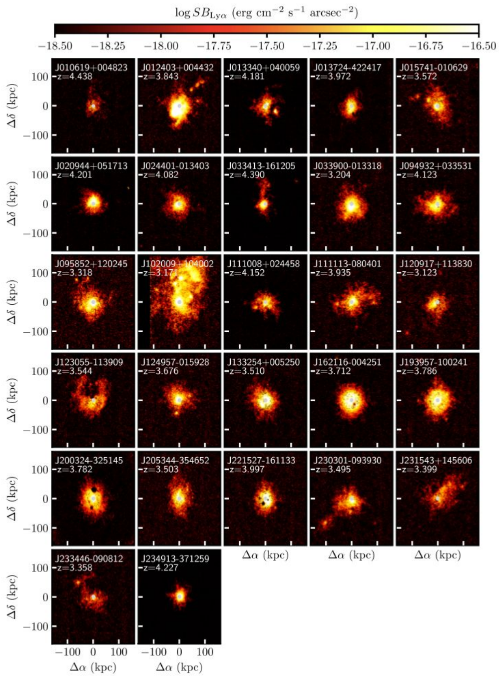
Arrigoni Battaia+2019
MUSEUM survey, z~3





Farina+2019
REQUIEM survey, z~5.7-6.6

Fossati+2021
MAGG survey, z~3-4.5



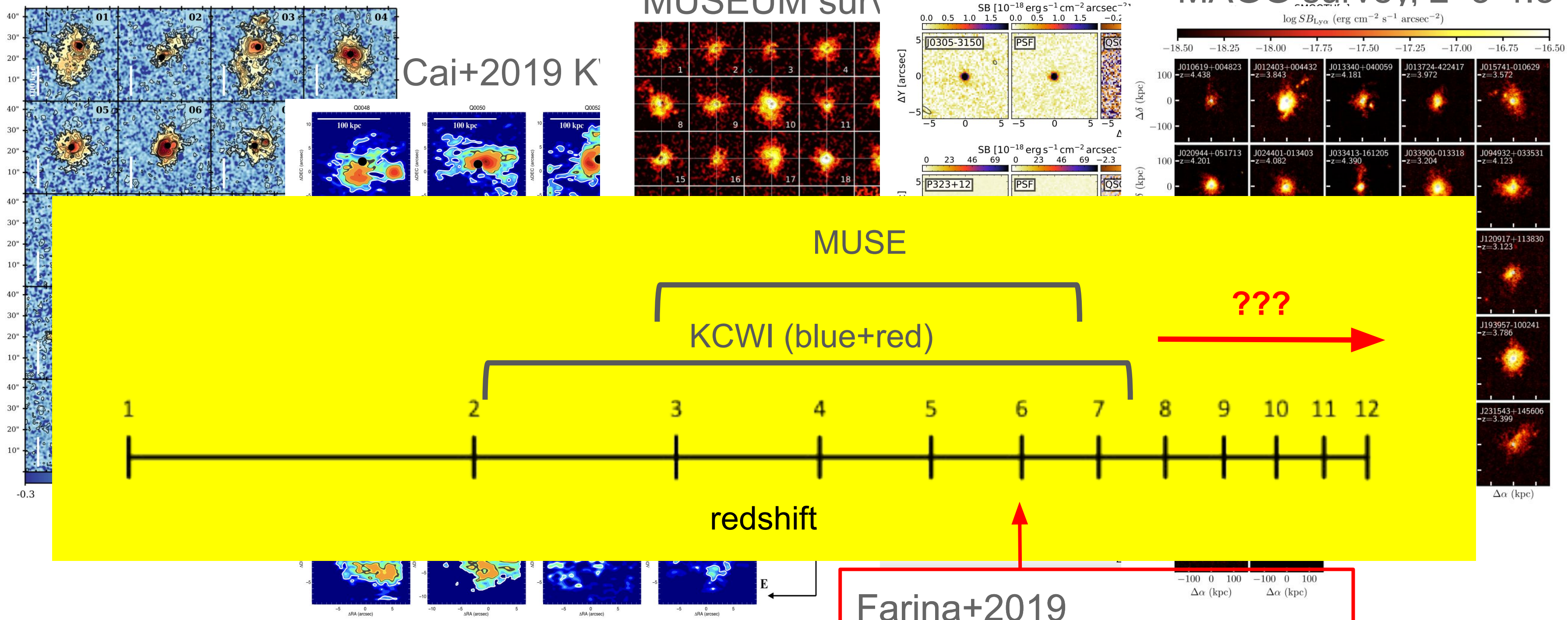
Current limitations

Borisova+2016 MUSE, z=3-4

Arrigoni Battaia+2019
MUSEUM surv

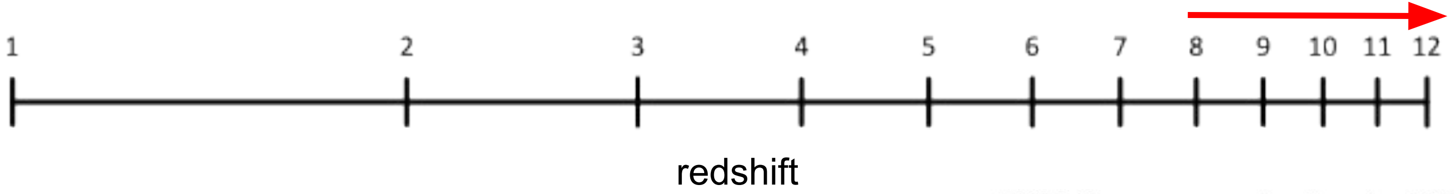
Fossati+2021
MAGG survey, z~3-4.5

Cai+2019 K



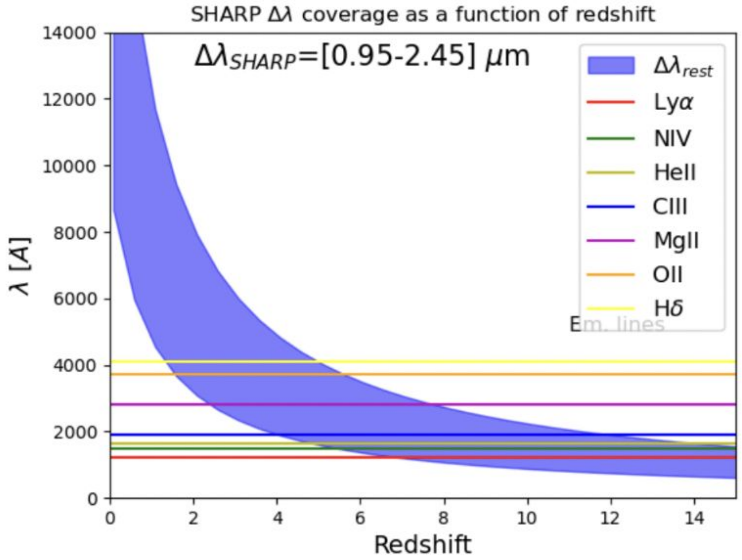
Farina+2019
REQUIEM survey, z~5.7-6.6

A new window opened by SHARP?



Bartett+2019 (Euclid Collaboration)
→ Euclid + LSST predict ~25 qso at z > 7.5
→ including ~8 qso at z > 8

Trinca+2023, Schneider+2023 estimate
→ JWST CEERS-like surveys
8 - 21 qso [10^6-10^8 $M_\odot$] at 7<z <10
JWST JADES-deep [10^4-$10^6 M_\odot$]
12-63 AGN [10^4-$10^6 M_\odot$] at 7<z <10
5-32 AGN [10^4-$10^6 M_\odot$] at z>=10



VESPER - 12000-24500 Å → **technically**, Lyα observable z >~ 9

Is Lyα detectable in a mostly neutral hydrogen Universe?

Epoch of Reionisation ($z>6$, e.g. Pentericci+2011, Madau+2024)

★ local damping of Lya emission in SF regions (Heinz+2023)
★ IGM increasingly neutral moving towards higher redshift (e.g. De Barros+2017)

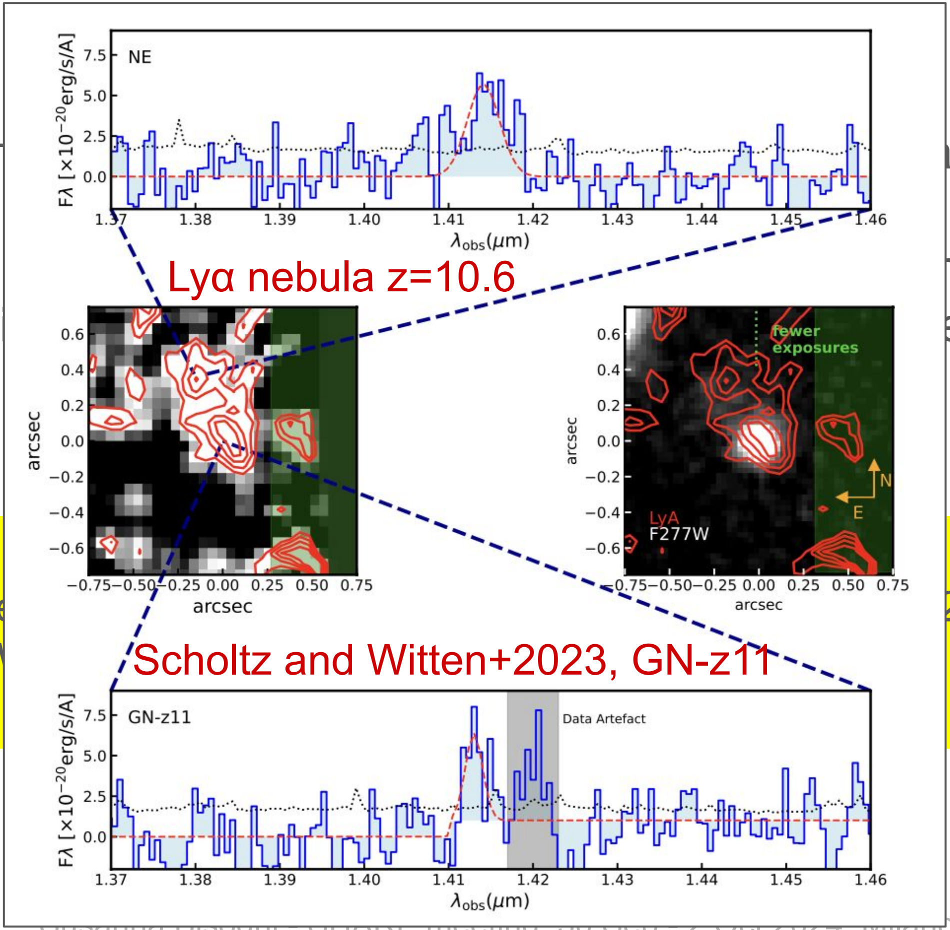
Simulations (e.g. Witten+2023) and observations (e.g. Bunker+2023, Jung+2023, Witstok+2024) confirm detectability of Lyα deep in EoR

Lyα nebulae observed with JWST @z~11

Epoch o … dau+2024)

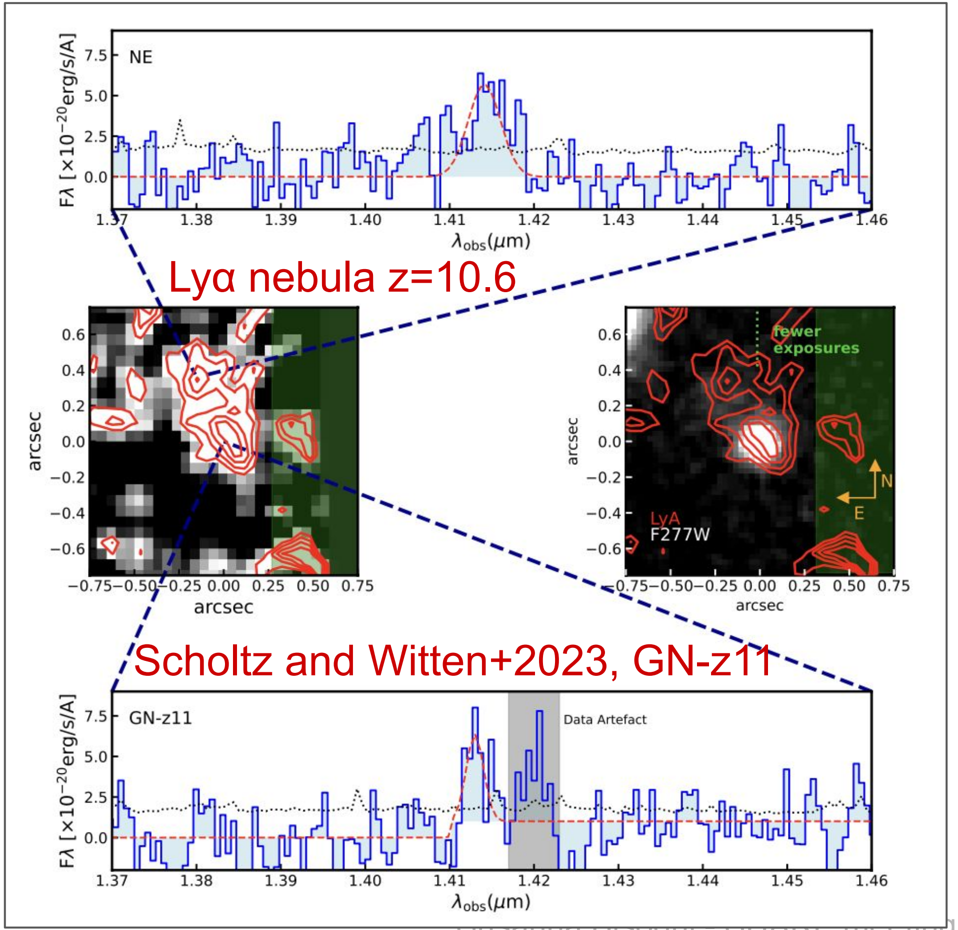
★ local … nz+2023)

★ IGM … edshift (e.g. De B

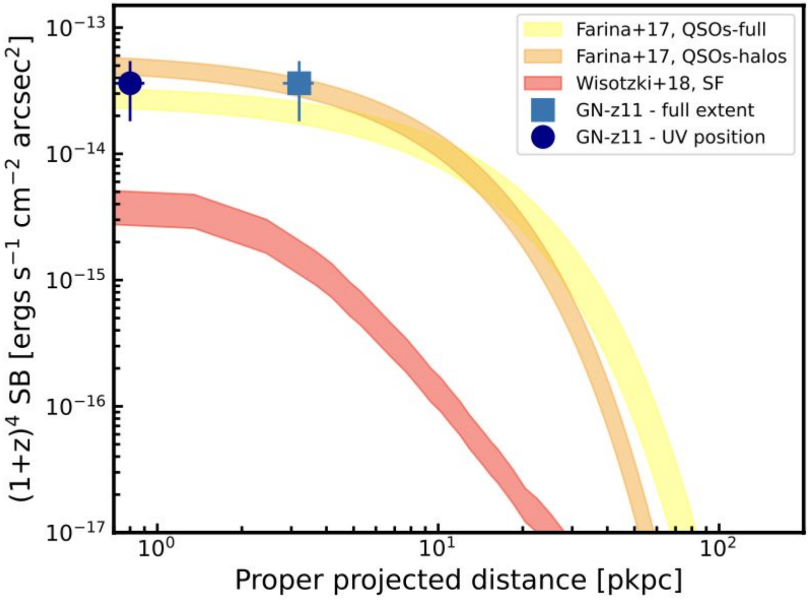


Simulations (e … 2023, Jung+2023,
V … EoR

Lyα nebulae observed with JWST @z~11

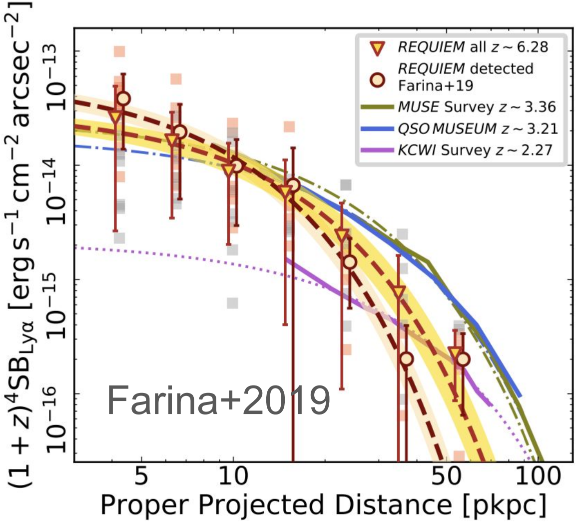


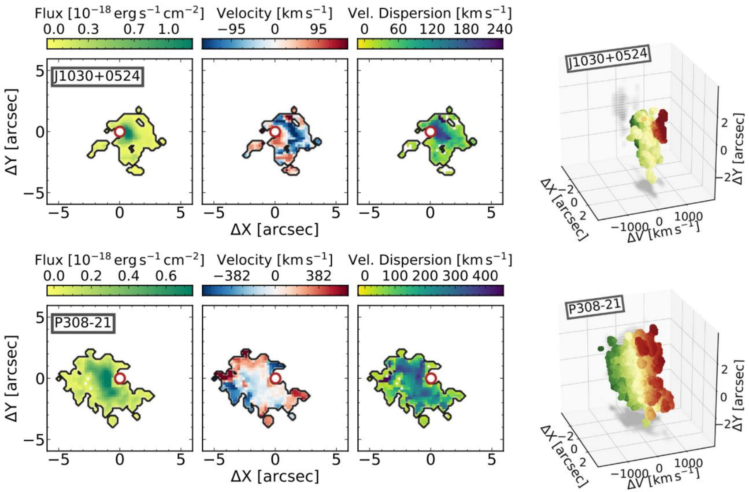
Scholtz and Witten+2023, GN-z11



SB of Lyα nebulae: MUSE vs SHARP

REQUIEM survey @z~6 → t_{exp}<~1hr (with a few exceptions)





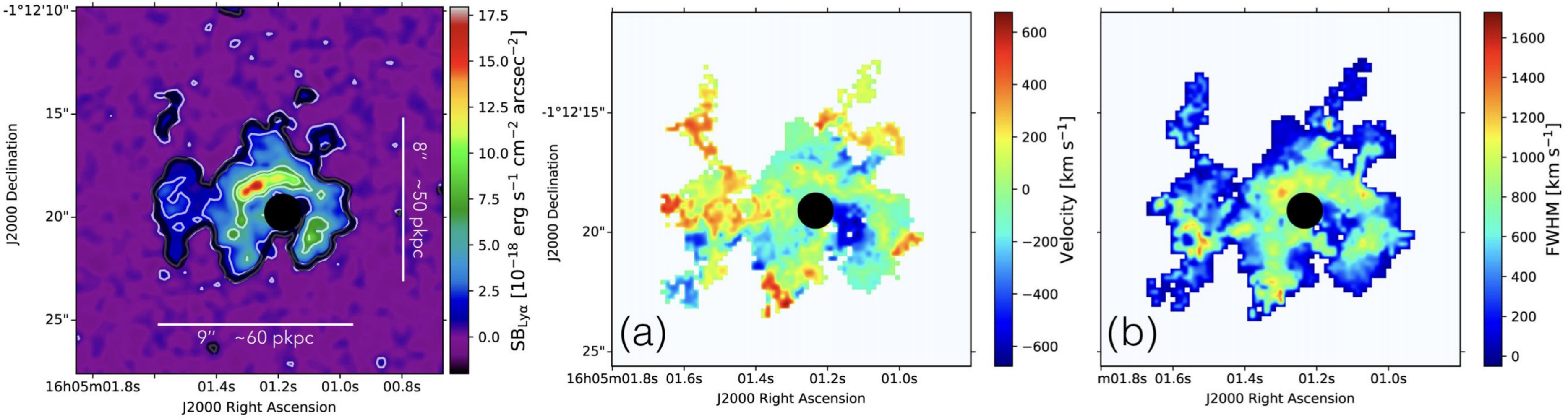
- ★ VLT vs ELT → 8m vs 40m
- ★ cosm. dimming → z~6 vs z~9
- ★ MUSE vs SHARP spaxel → 0.2” vs 0.031”

➡ t_{exp}= 1h → t_{exp}~ 10 min

➡ t_{exp}= 1h → t_{exp}~ 7h

Resolved kinematics of Lyα nebulae and QSO outflows

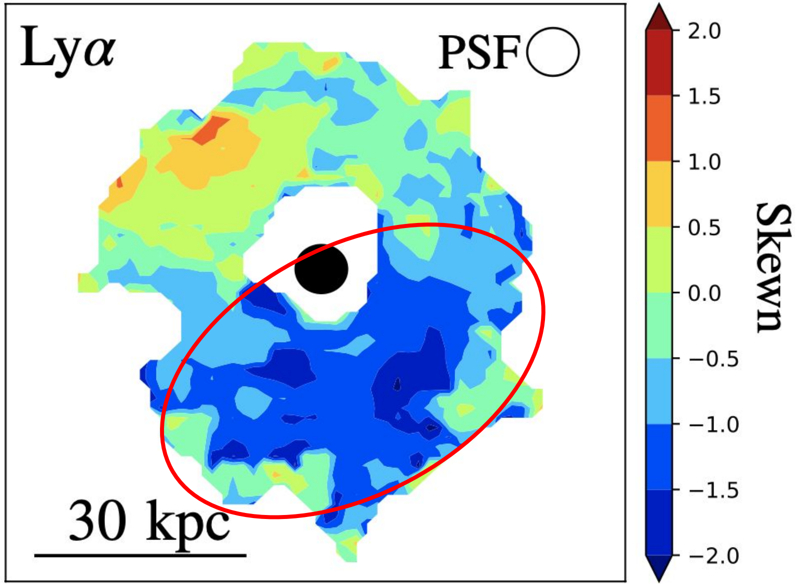
Ginolfi+2018: Broad Absorption Line QSO @z~5

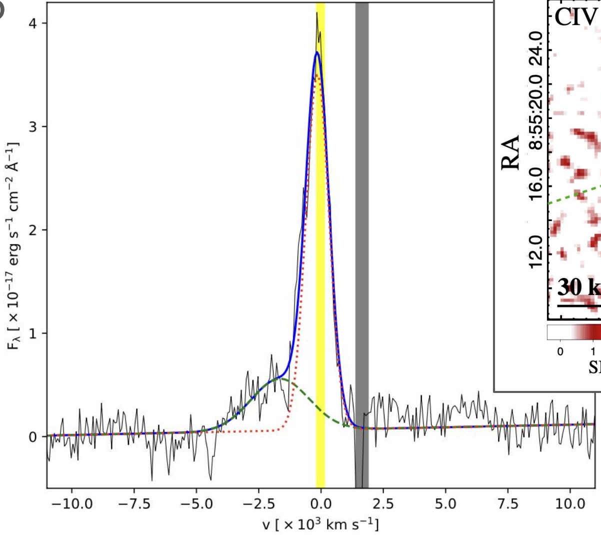


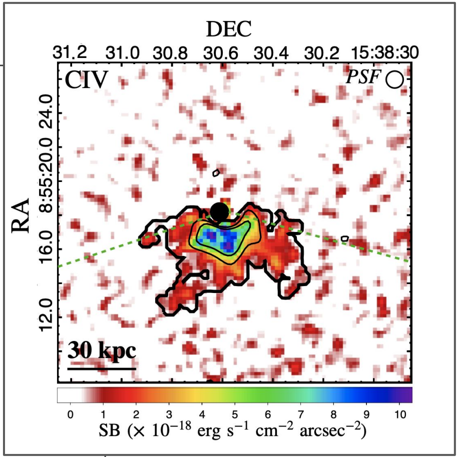
FWHM>1000 km s^{-1} in the inner 10 kpc of the CGM (twice those of Borisova+2016)
→ Is Lya probing outflows from the QSO on large scales (e.g. Bourget+2013)?
Or is the outflow introducing turbulence in the CGM causing the broadening?

Resolved kinematics of Lyα nebulae and QSO outflows

Travascio+2020: Hyper luminous QSO @z~3.6







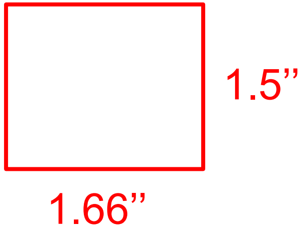
Lya spectrum of the region with sk<-0.5

→ blue comp: σ_{blue}~1200 km/s, v_{shift}~1500 km/s)

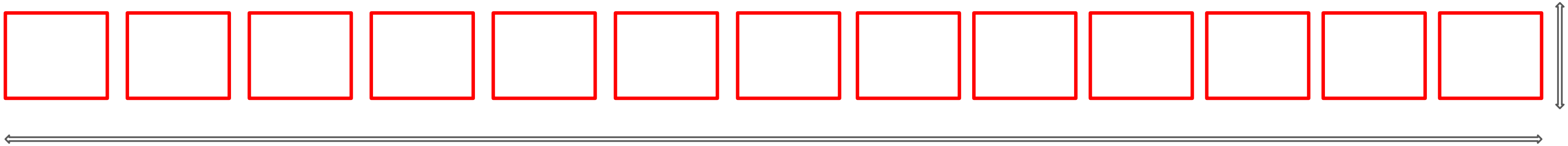
→ ionised outflow at CGM scales (>> 10 kpc)

VESPER's spatial scale (~150 pc @z=9 vs 1.5 kpc for MUSE @z=3.6) will allow us to infer the outflow physical properties and understand its role in transporting metals to the CGM

From small to large scales: VESPER's multiplexing



z=9 → 7.6 kpc x 6.8 kpc



z=9 → 24" ~ 110 kpc

VESPER will allow us to map, at the same time, the large scale of the CGM (~100 kpc) and the small scales needed to investigate quasars' outflows

Conclusions

- ★ CGM: ideal laboratory for the study of the feeding and feedback cycle and of the balance in the fuel supply between SMBH and host galaxy
- ★ A few objects at z>9 are predicted by NIR missions, but observations would be hampered by current instrumental limitations
- ★ The wavelength coverage of SHARP, coupled with the collecting area of ELT, will allow us to investigate the large scales of the Lyman alpha emission up to ~100 kpc for z>9 with highly efficient observation times
- ★ At the same time, the spatial scale of VESPER will allow us to resolve structures down to ~150 pc scale, enabling the measurements of the physical properties of quasars' outflows and their impact on the hosts