

14 April 2021

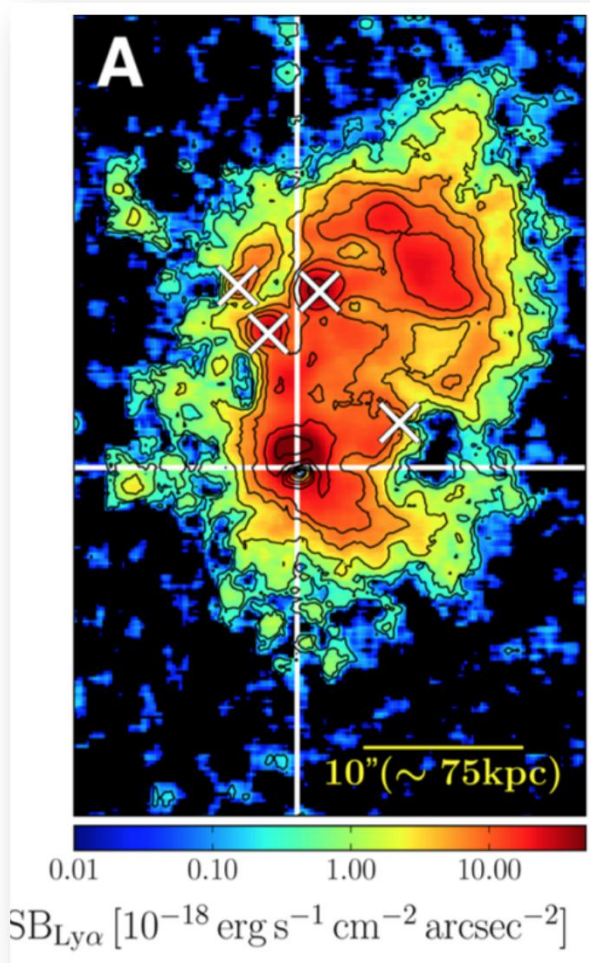
Metal enrichment in the circumgalactic medium and Ly α haloes around quasars at $z \sim 3$

Yucheng Guo

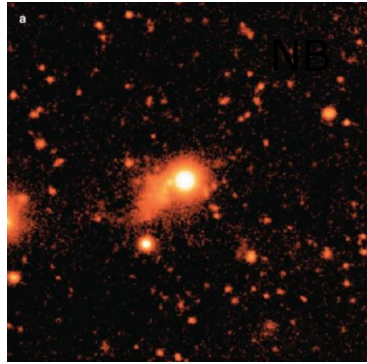
(The Kavli Institute for Astronomy and Astrophysics - Peking University)

Roberto Maiolino, Linhua Jiang, Kenta Matsuoka, Tohru Nagao, Oli Dors, Michele Ginolfi, Nick Henden, Jake Bennett, Debora Sijacki, Ewald Puchwein

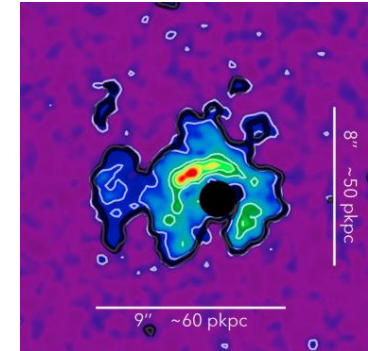
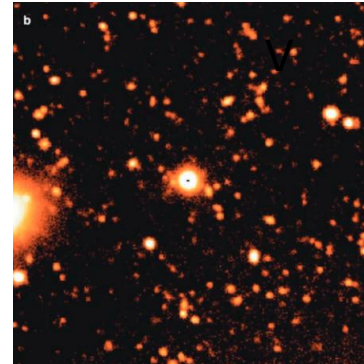
Giant Ly α nebulae



Ly α @ $z=3.3$



$z = 2.28$, Cantalupo+14

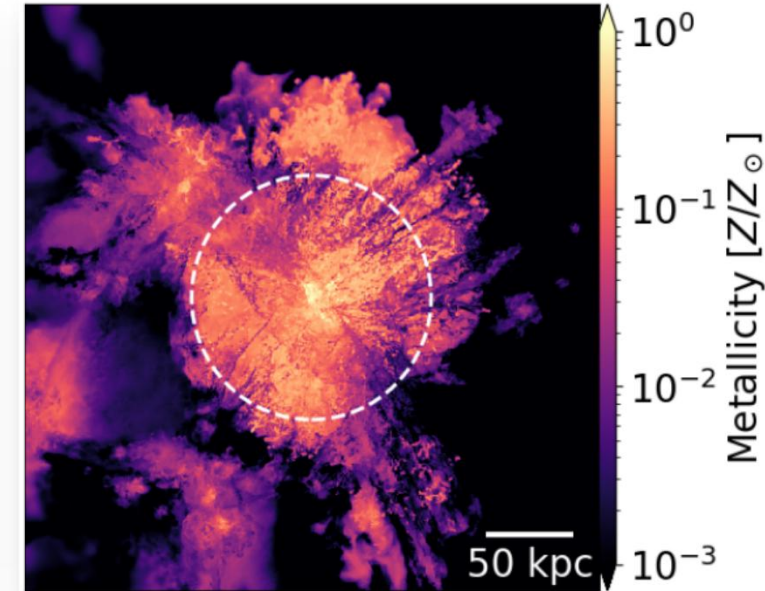
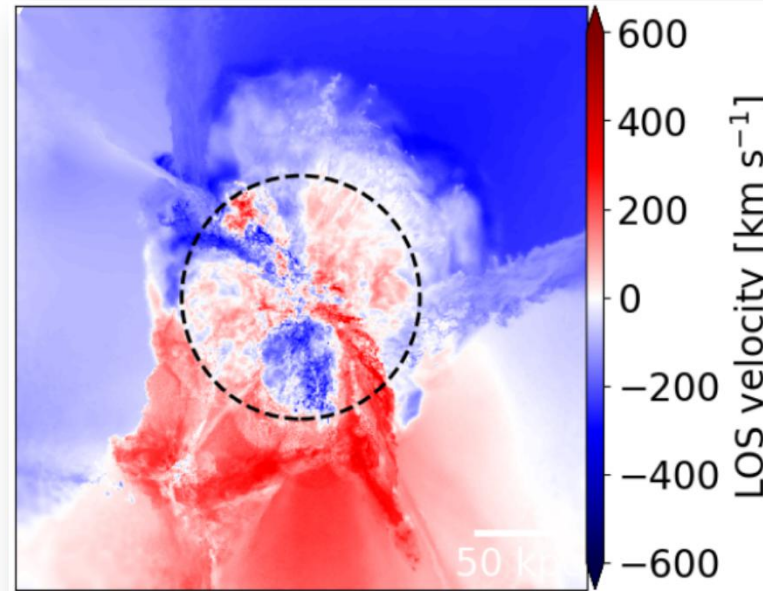
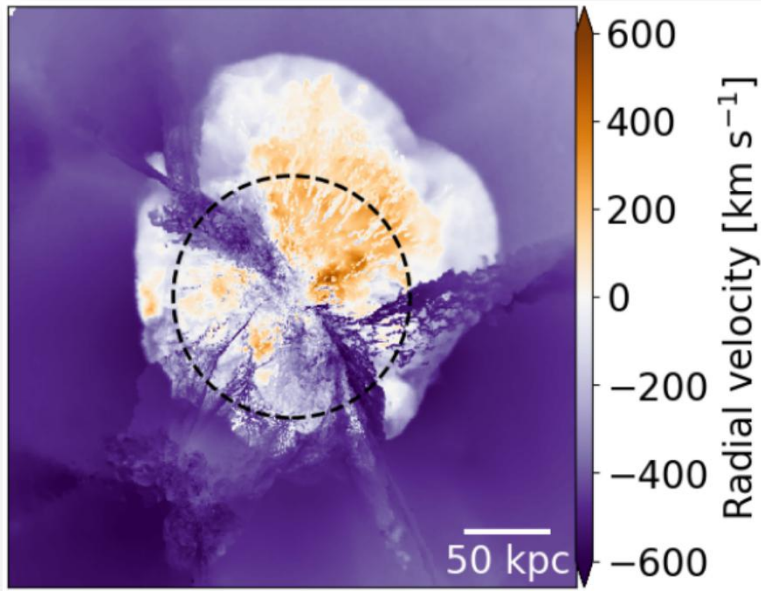


$z \sim 5$, Ginolfi+18

What is the nature of Ly α halos around high- z quasars?

Arrigoni-Battaia+18, Borisova17, Cai+18, Cantalupo+16, Fumagalli+17, Ginolfi+17, Farina+19, etc...

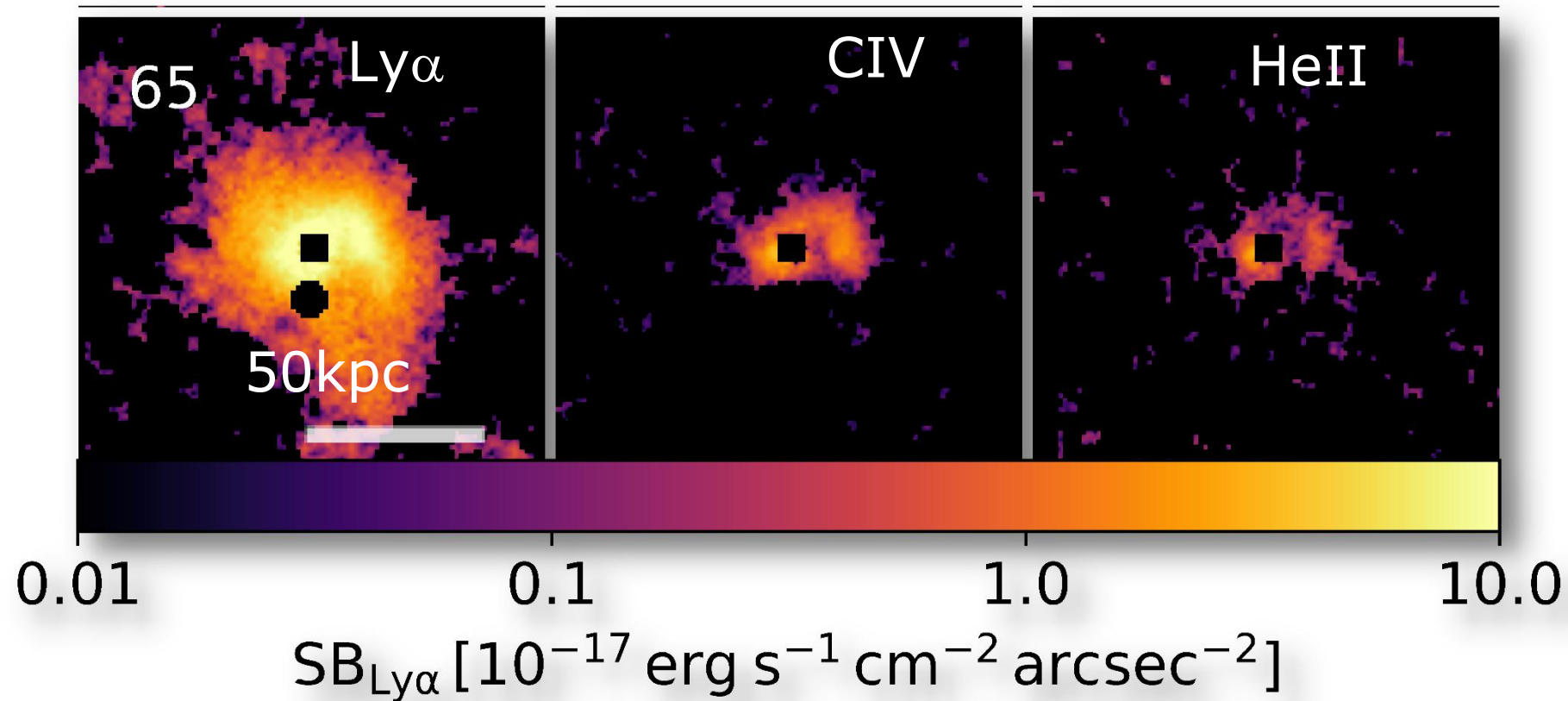
Giant Ly α nebulae - simulations



Bennett & Sijacki'20
Pallottini+16
Dubois+16
Dekel+12

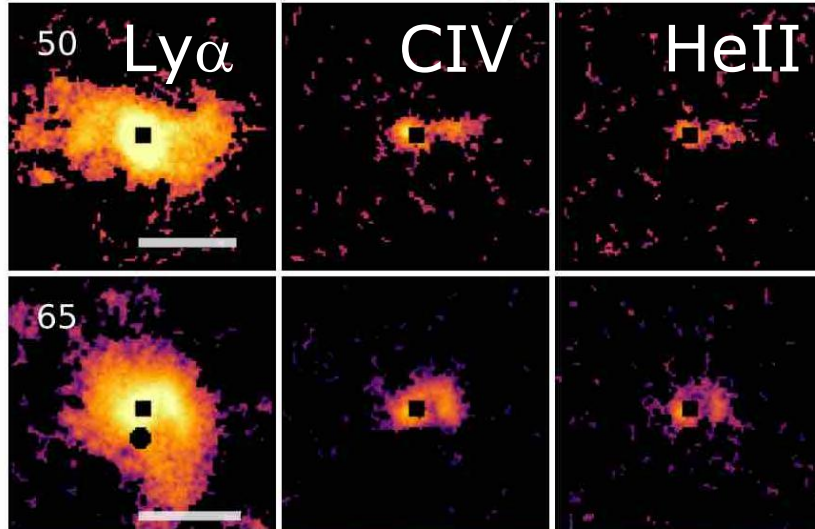
↑
Metallicity is the key

CIV, CIII] emission in the UV rest frame potentially good tracer of the CGM metallicity... but 10-100 x fainter than Ly α
-> their extended emission individually detected only in a few objects

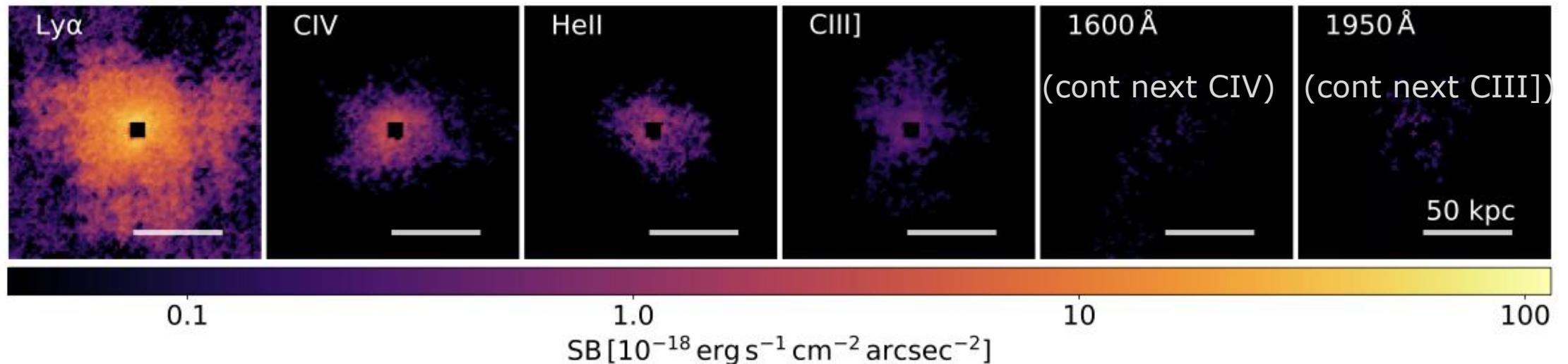


Stacking MUSE cubes of 80 quasars at $z \sim 3-4$

Total exposure time ~ 100 hr

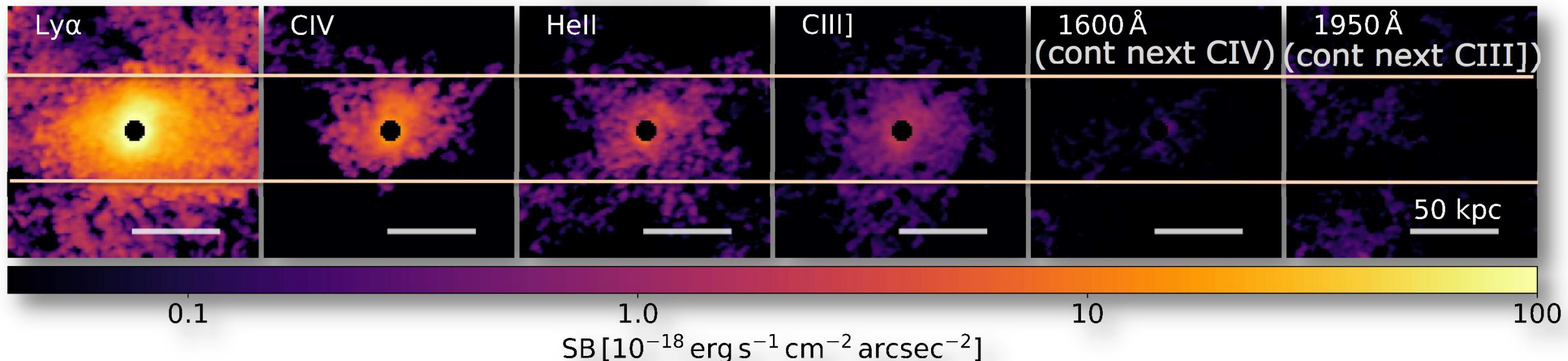
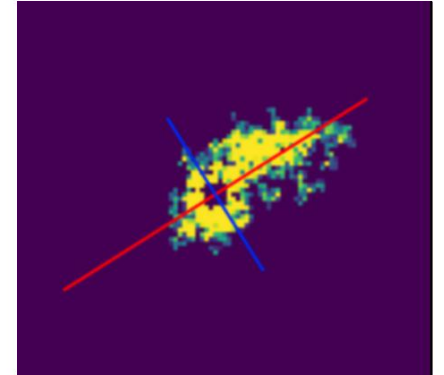
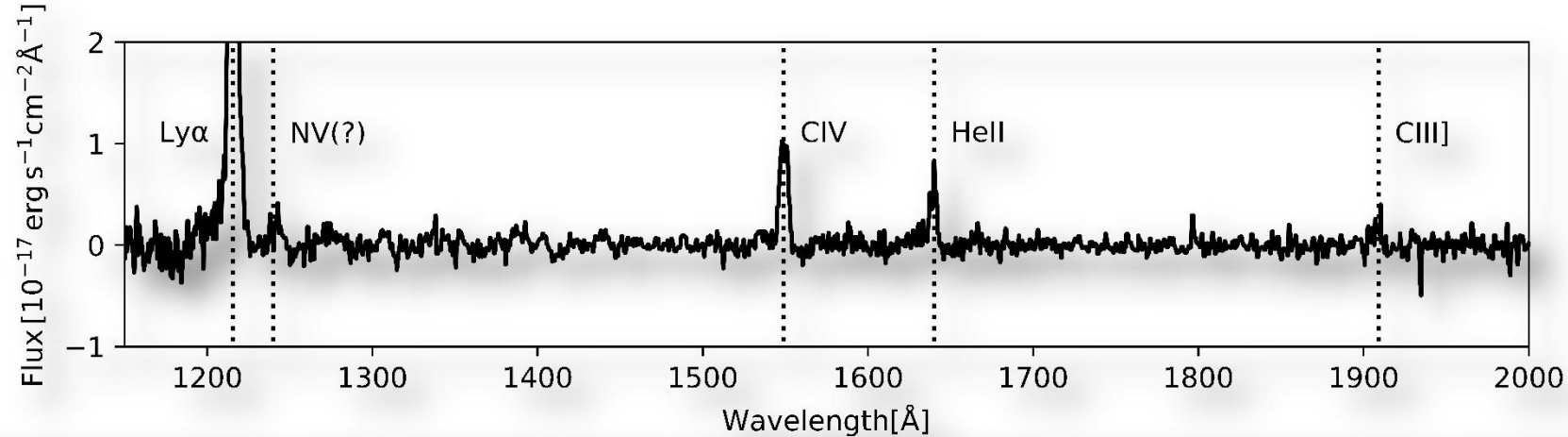


- Metal lines detected in radio loud & quiet quasars
- Diverse morphology
- Stacking (in random orientation):
 - > extended CIV, HeII and CIII] emission



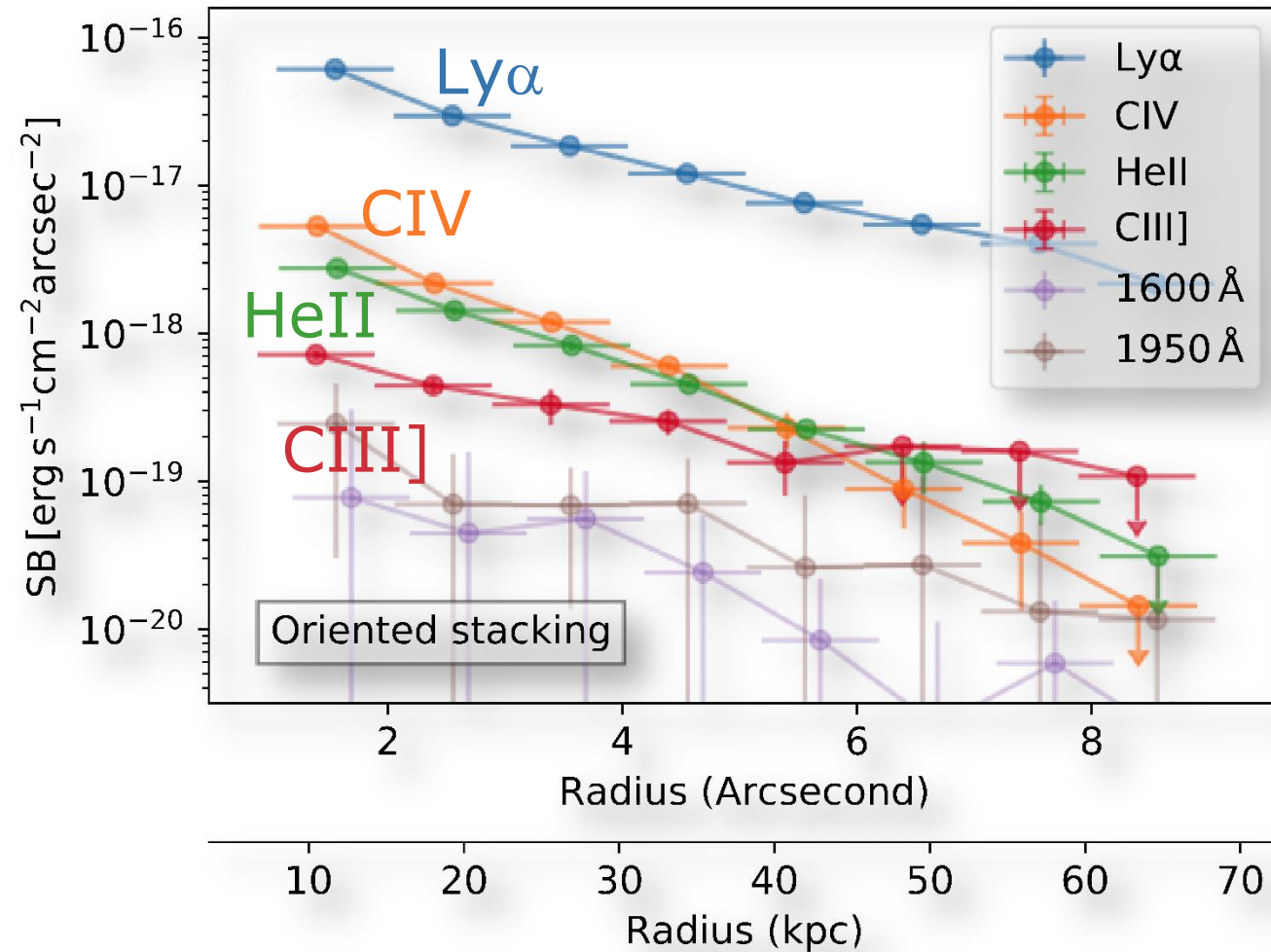
Stacking MUSE cubes of 80 quasars at $z \sim 3-4$

Oriented stacking: enhancement of S/N



(after re-orienting along the $\text{Ly}\alpha$ elongation)

Radial profile of the UV lines



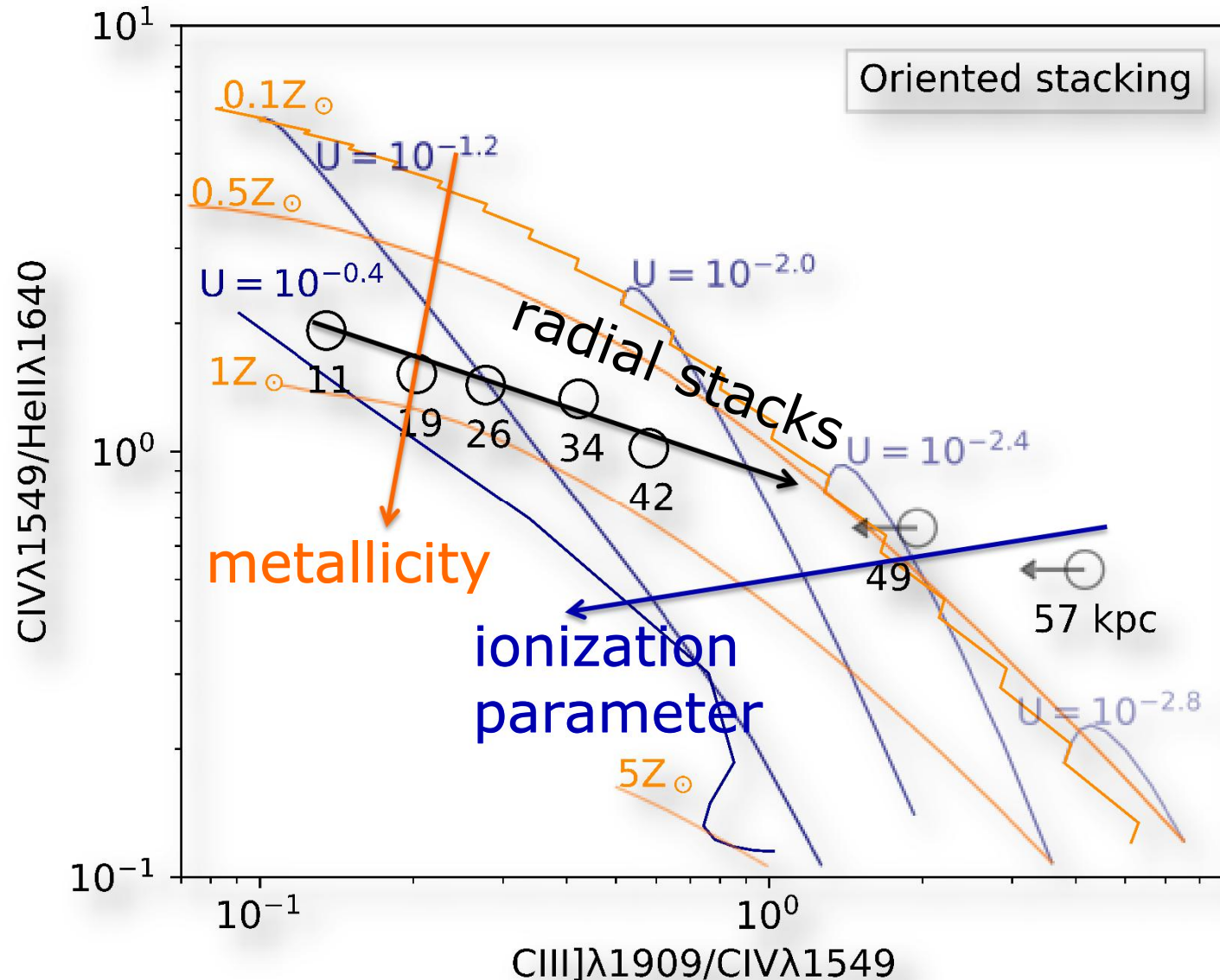
Detected out to ~ 60 kpc

CIV & HeII decline steeply
-> drop in ionization param.

CIII] shallow radial profile
-> metal enrichment out
to > 50 kpc

$> \sim 0.5$ solar metallicity out to ~ 50 kpc

→ must be CGM pre-enriched by galactic outflows



Comparison with
absorption line studies
(e.g. Lau+16)

✓ average metallicity

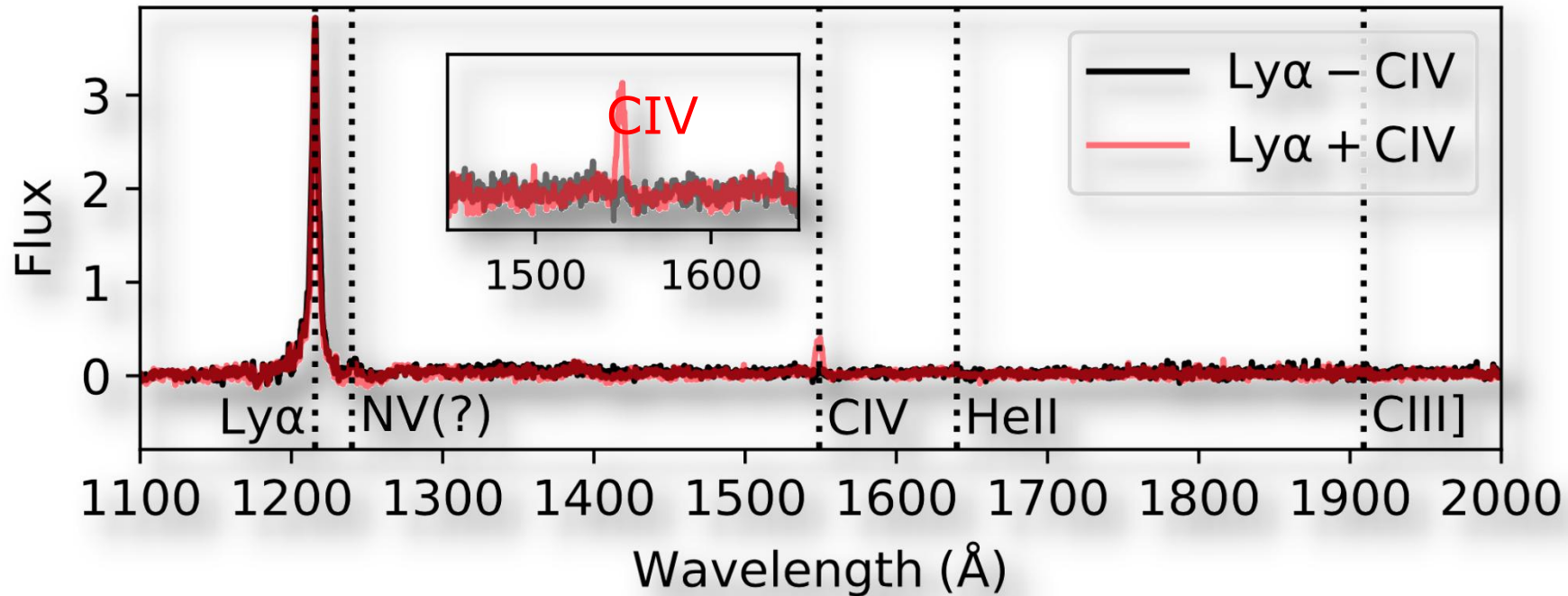
✗ ionization parameter
(increasing with radius)
→ the two methods are
sensitive to different
phases

No significant difference for
radio loud/quiet quasars

Yet, the regions without CIV detection
are truly **very** metal poor

Stack of all spaxels without CIV emission

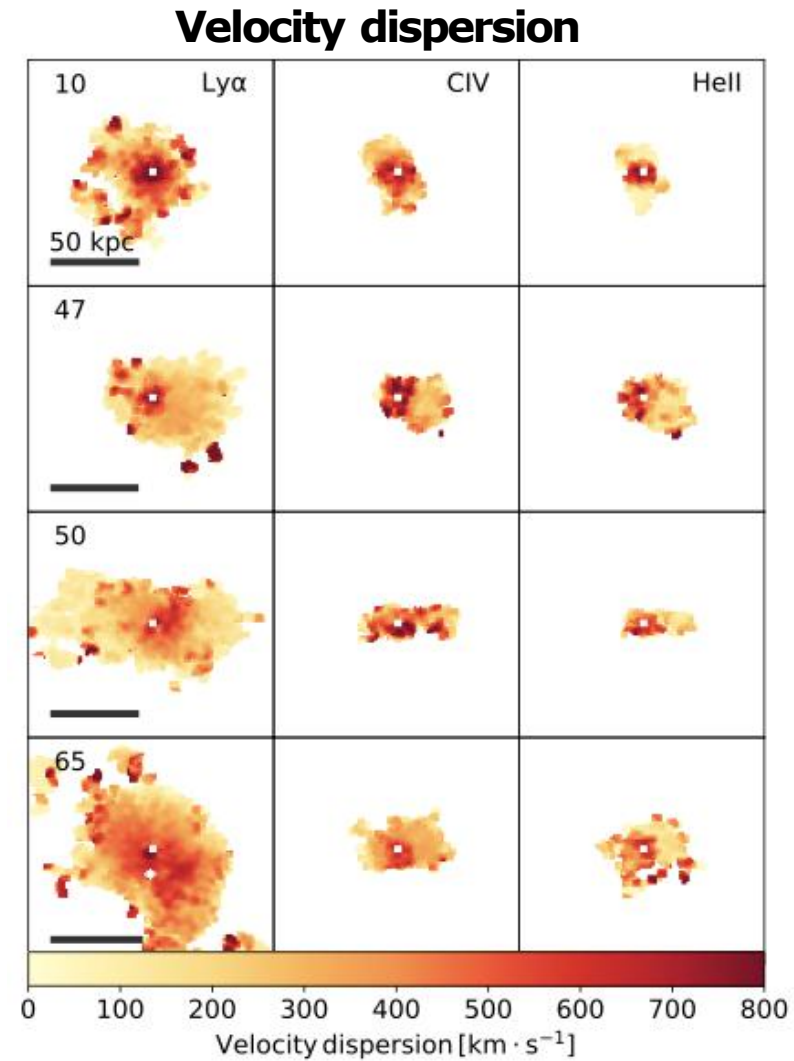
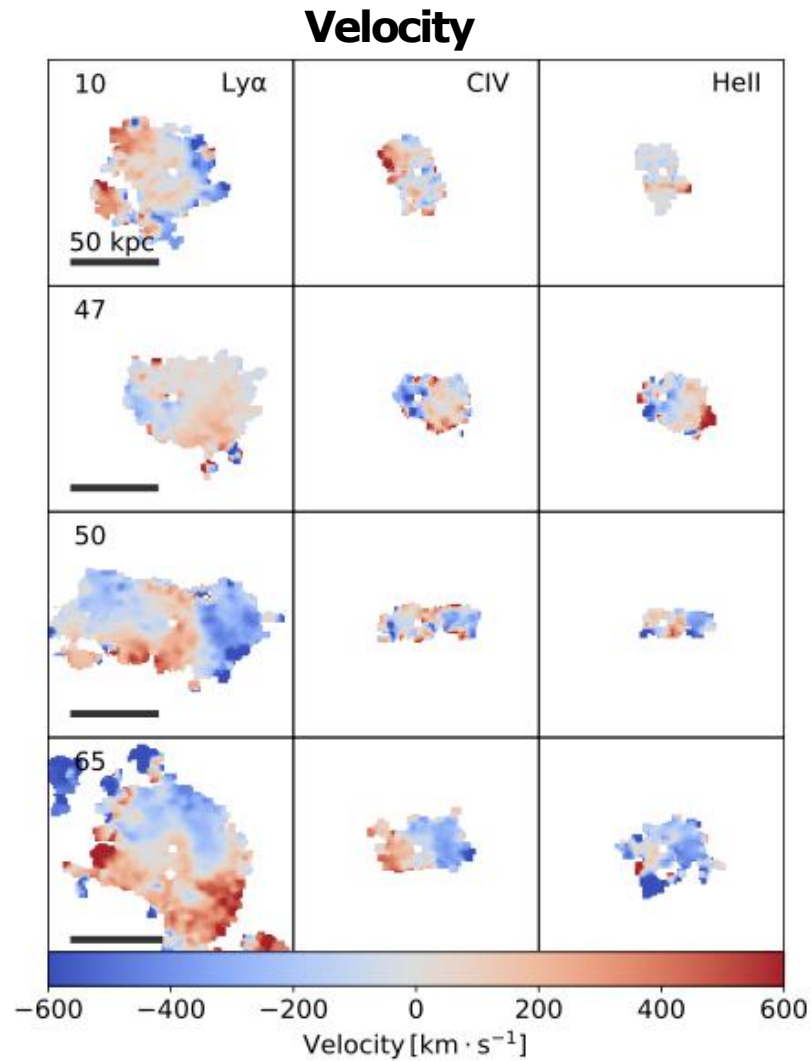
-> no CIV emission down to a very low noise level



Two components of $\text{Ly}\alpha$ haloes of massive primeval galaxies:

- Metal rich -> CGM pre-enriched by galactic outflows
- Metal poor -> accretion from IGM

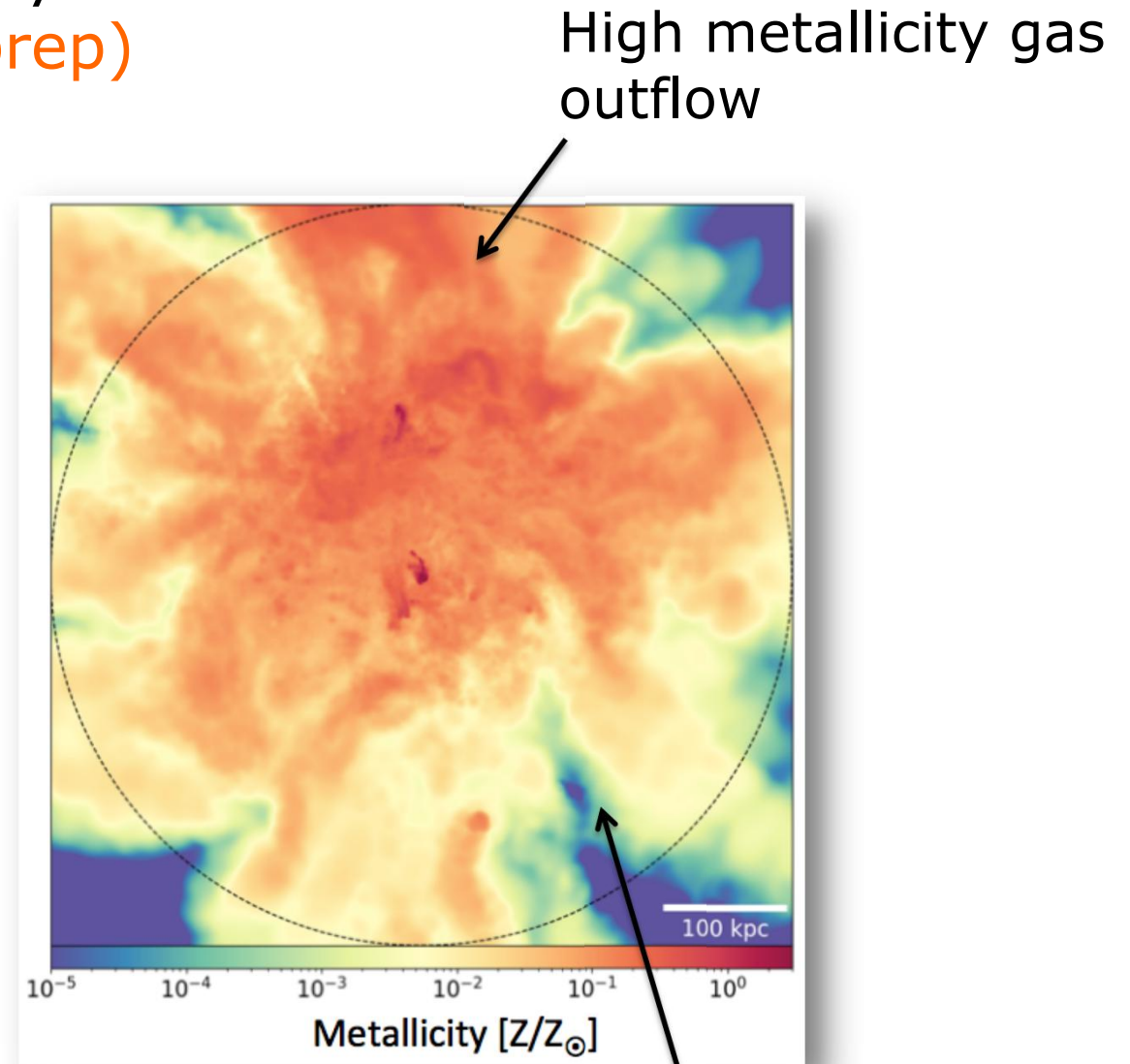
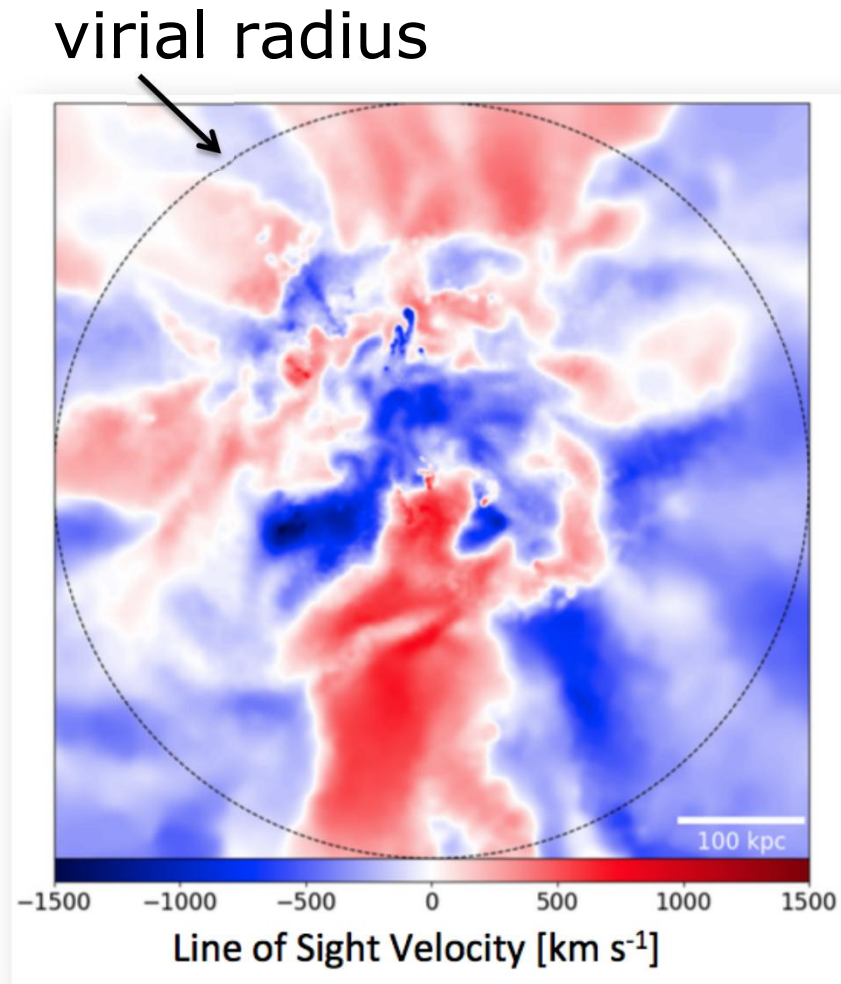
Gas kinematics in the circumgalactic medium



Center region: high velocity dispersion;
Outer: quiescent

Matching expectations from cosmological simulations

Example of CGM around massive galaxy at $z \sim 3$
in the FABLE simulation (Benett+ in prep)

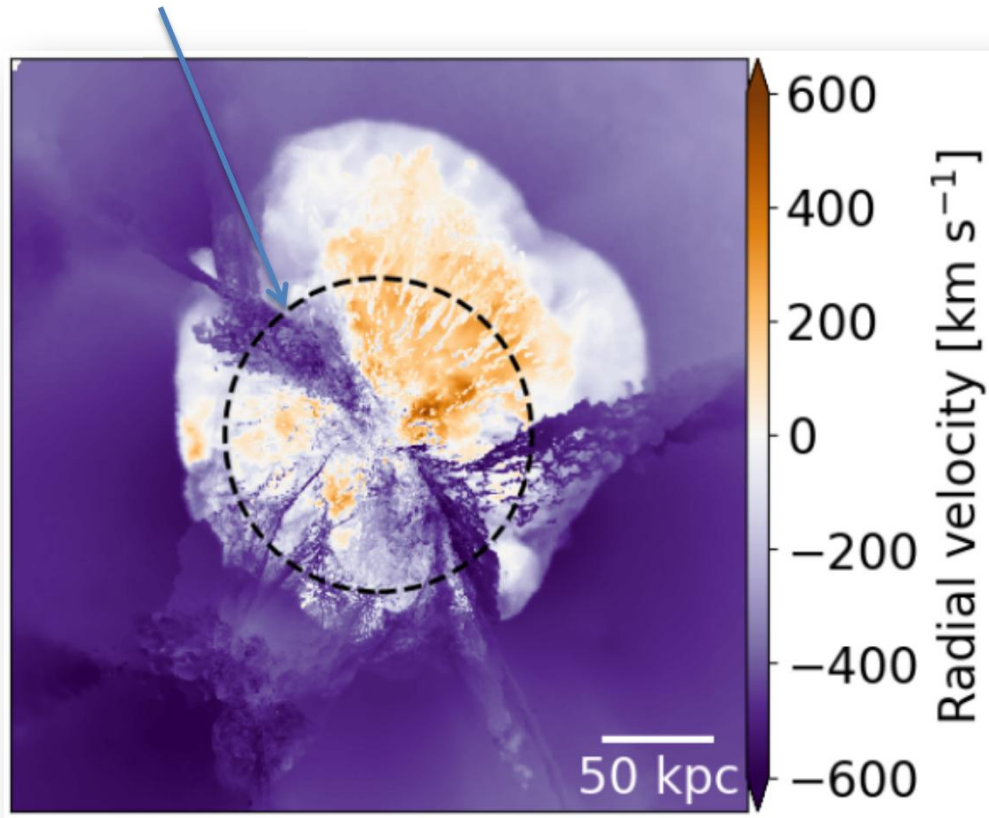


Low metallicity inflowing streams

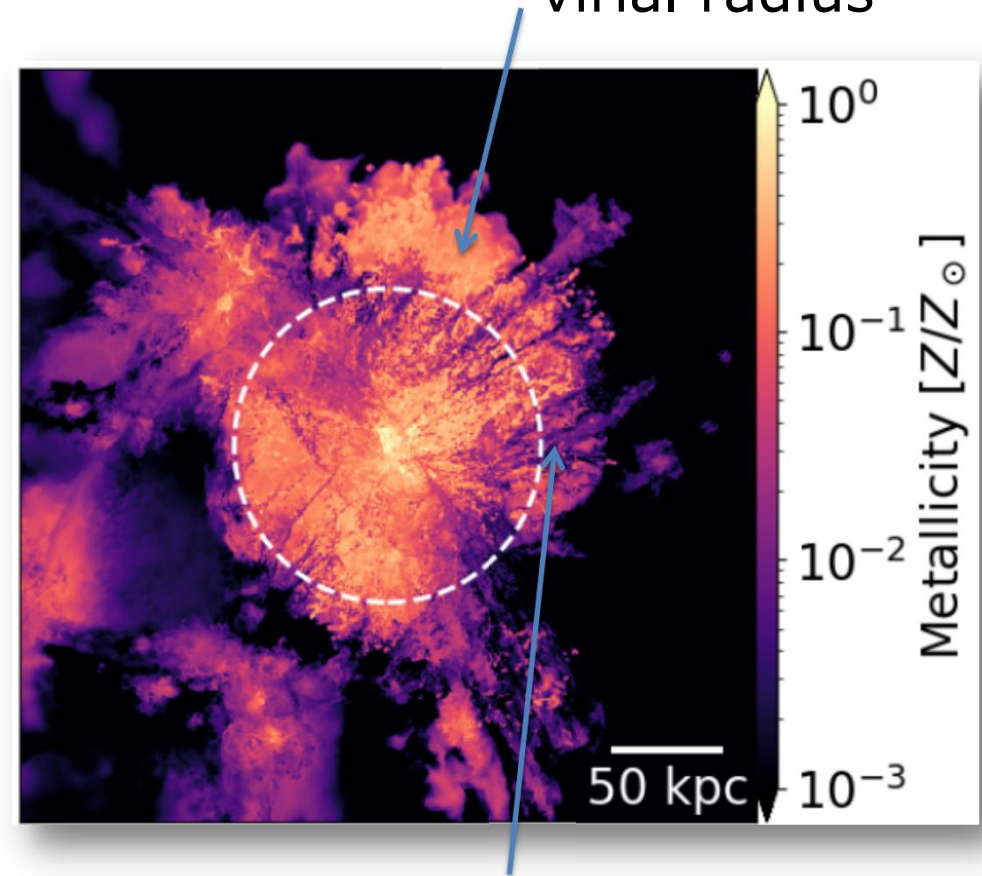
Matching expectations from cosmological simulations

Example of CGM around massive galaxy at $z \sim 6$
in the FABLE simulation (Bennet & Sijacki 20)

virial radius

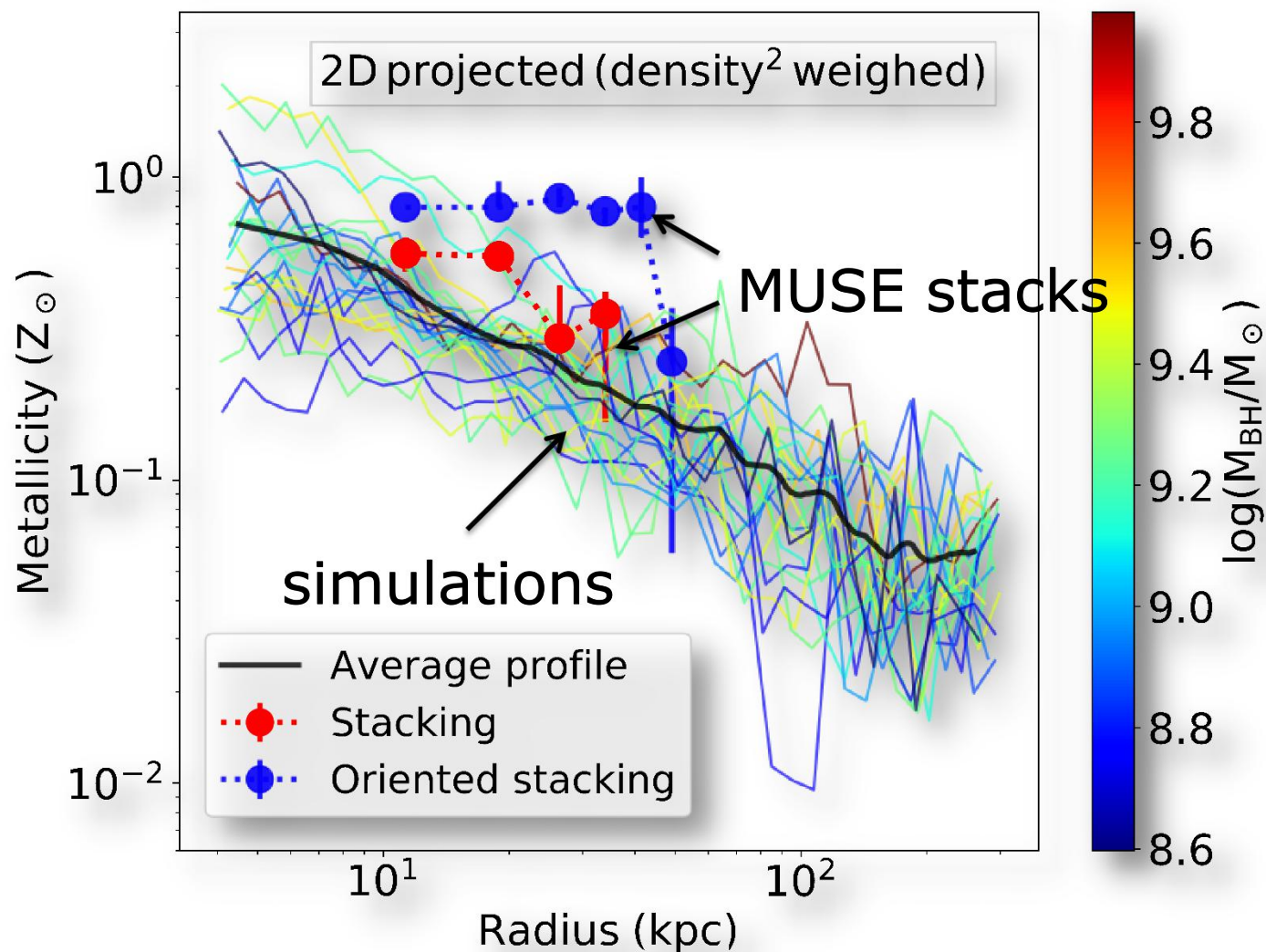


High metallicity gas
from outflow out and
beyond the
virial radius

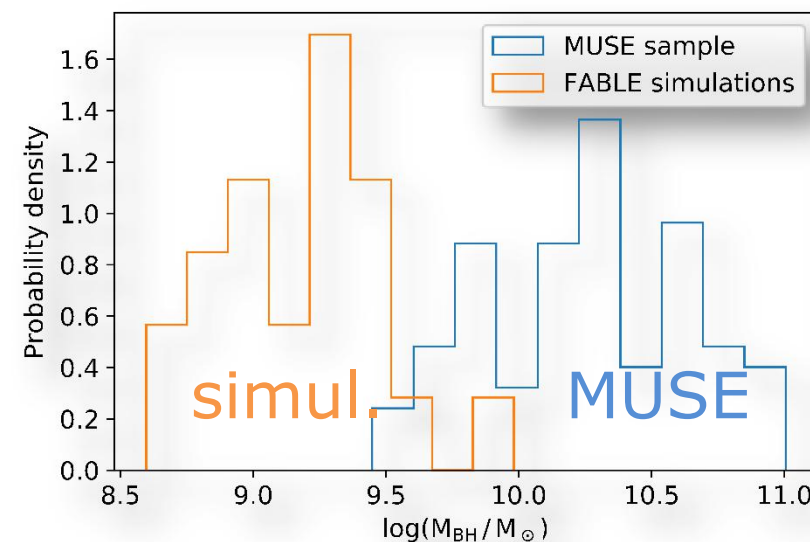


Low metallicity inflowing streams

Good match between observed metallicity radial profiles and expectations from simulations

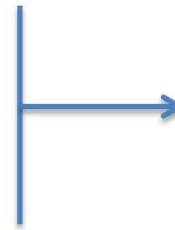


(bear in mind that the most massive BHs and galaxies in the simulation are $\sim 10\times$ less massive than in the MUSE sample)



Summary

- Stacking of MUSE data of 80 quasars at $z \sim 3-4$
- Detection of CIV, HeII and CIII] out to 50-60 kpc
- Metallicity $> \sim 0.5$ solar out to ~ 50 kpc
- Component of the CGM very metal poor
- Radial metallicity profiles consistent with expectations from cosmological simulations



Two components of the CGM of massive primeval galaxies:

- pre-enriched by outflows
- inflowing streams from IGM