

THE SPATIAL VARIATIONS OF CIRCUM-GALACTIC GAS STRUCTURES IN HIGH RESOLUTION SIMULATIONS AND IN STATE-OF-THE-ART IFU OBSERVATIONS

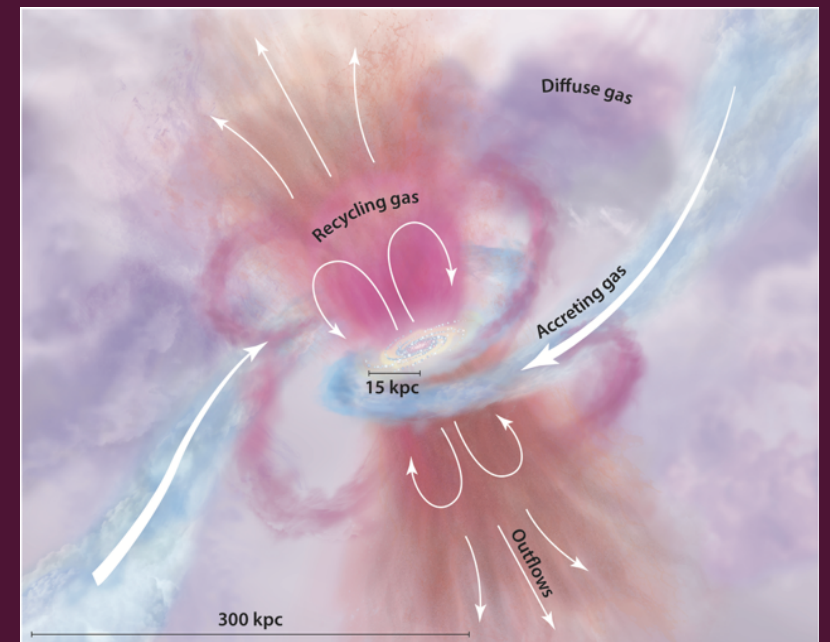
RAMONA AUGUSTIN
LEIBNIZ-INSTITUT FOR ASTROPHYSICS (AIP) POTSDAM

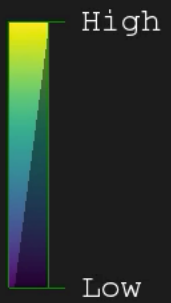
In collaboration with FOGGIE (PI: Peebles) and
SPECMAP-CGM (PI: Wisotzki)



Leibniz-Institut für
Astrophysik Potsdam

FOGGIE
Figuring Out Gas & Galaxies In Enzo



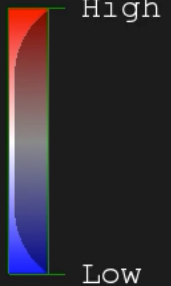


High

Low

Density

$t = 1.0 \text{ Gyr}$
 $z = 5.65$

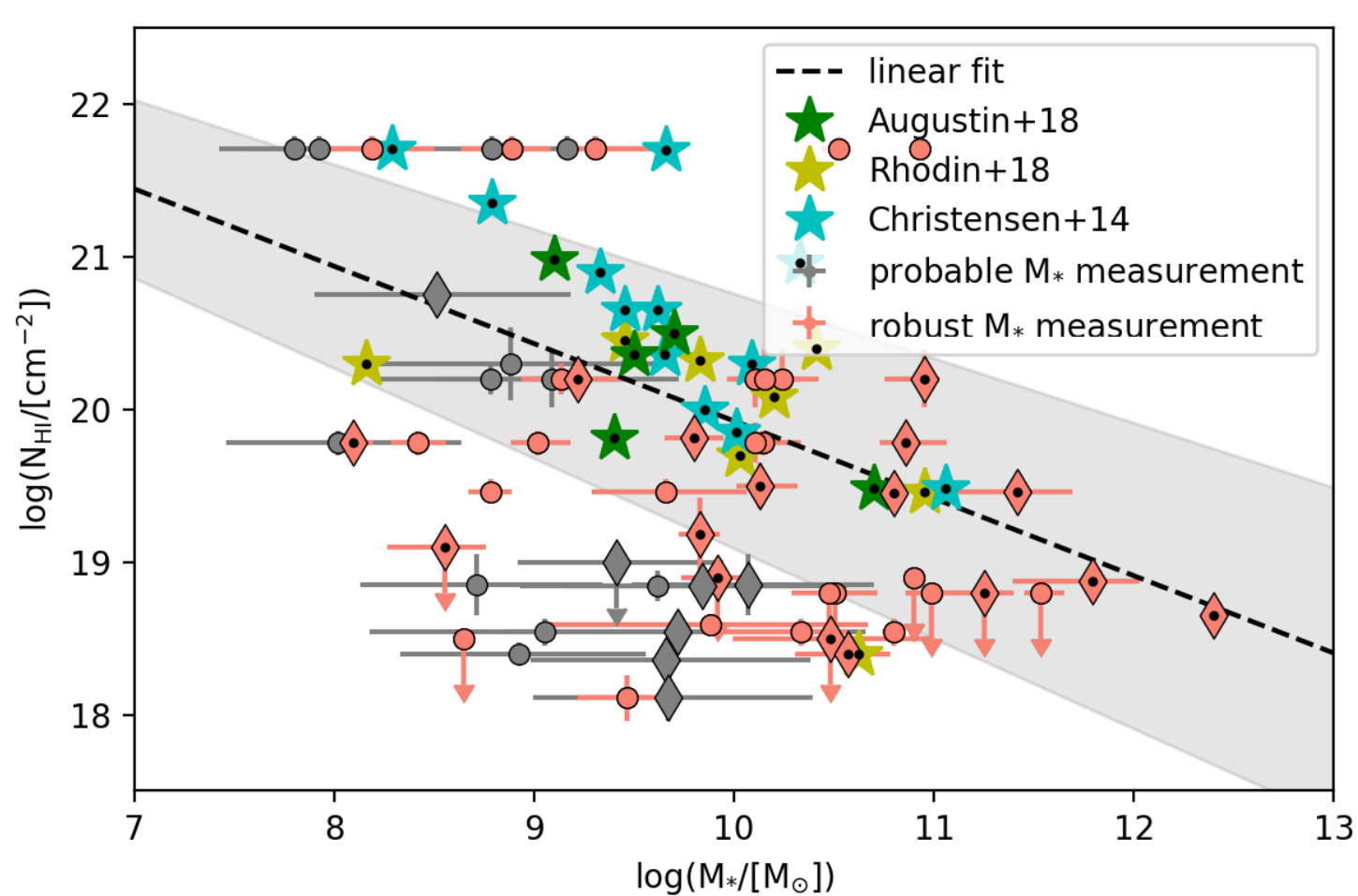


High

Low

Temperature

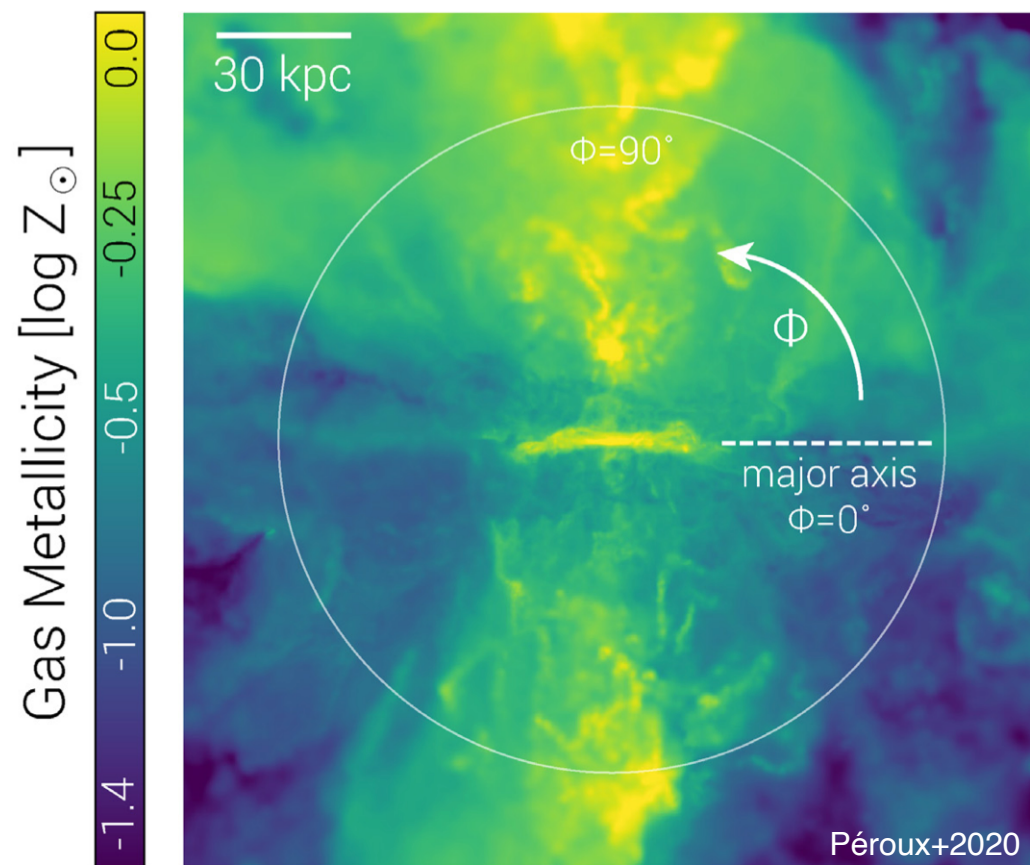
MOST ABSORBER-HOST RELATIONS RELY ON A SINGLE LOS



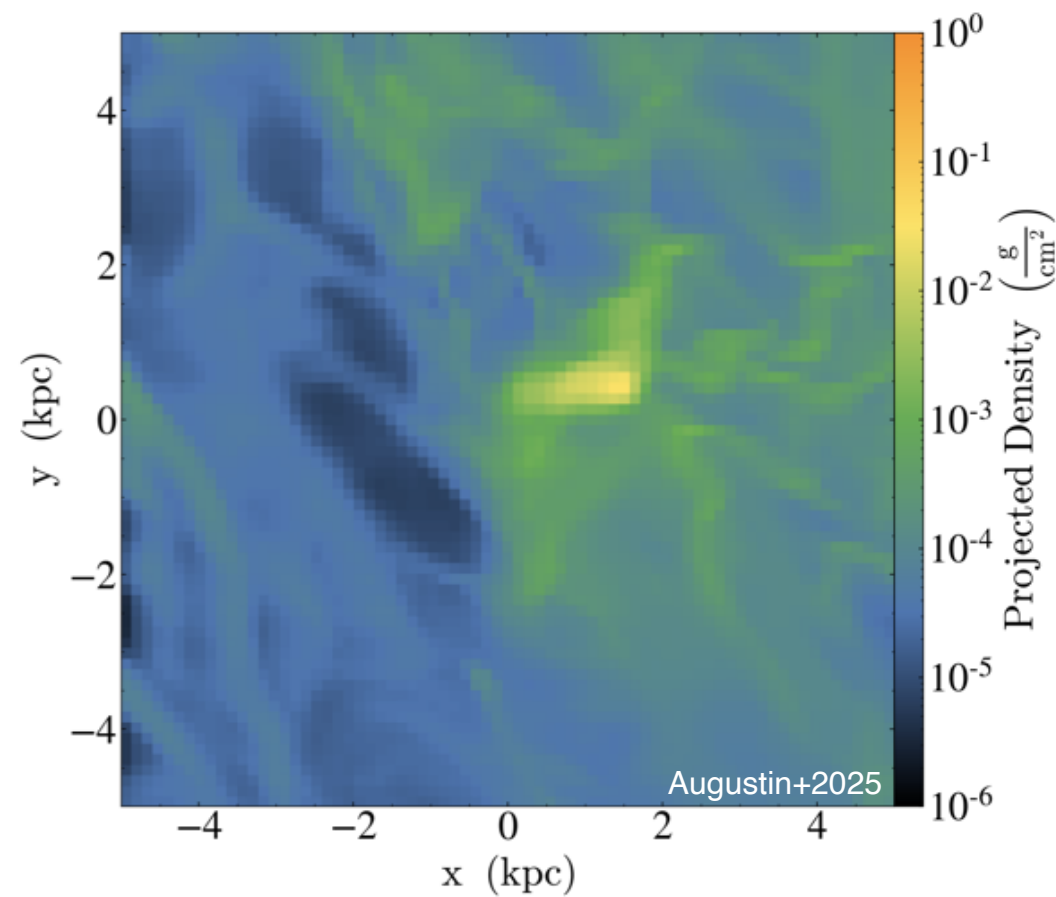
Augustin et al. (2024)

TWO TYPES OF SPATIAL VARIATIONS

Large scale azimuthal variations

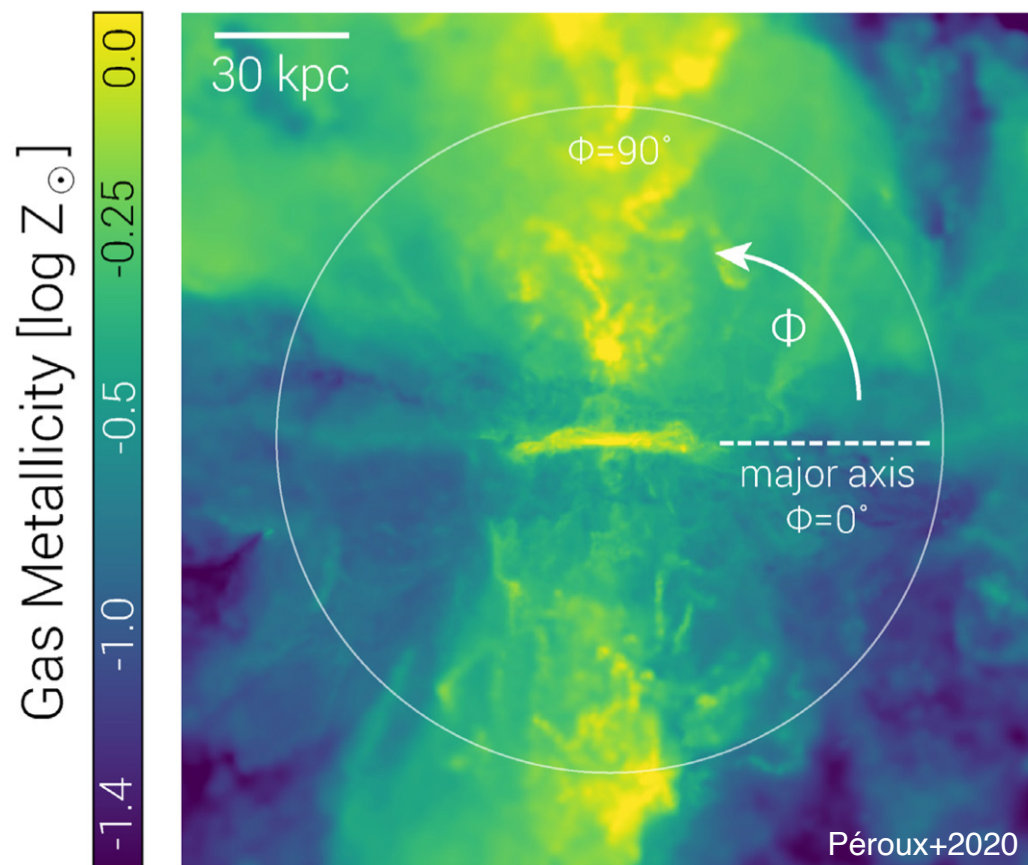


Small scale clumpy gas structure

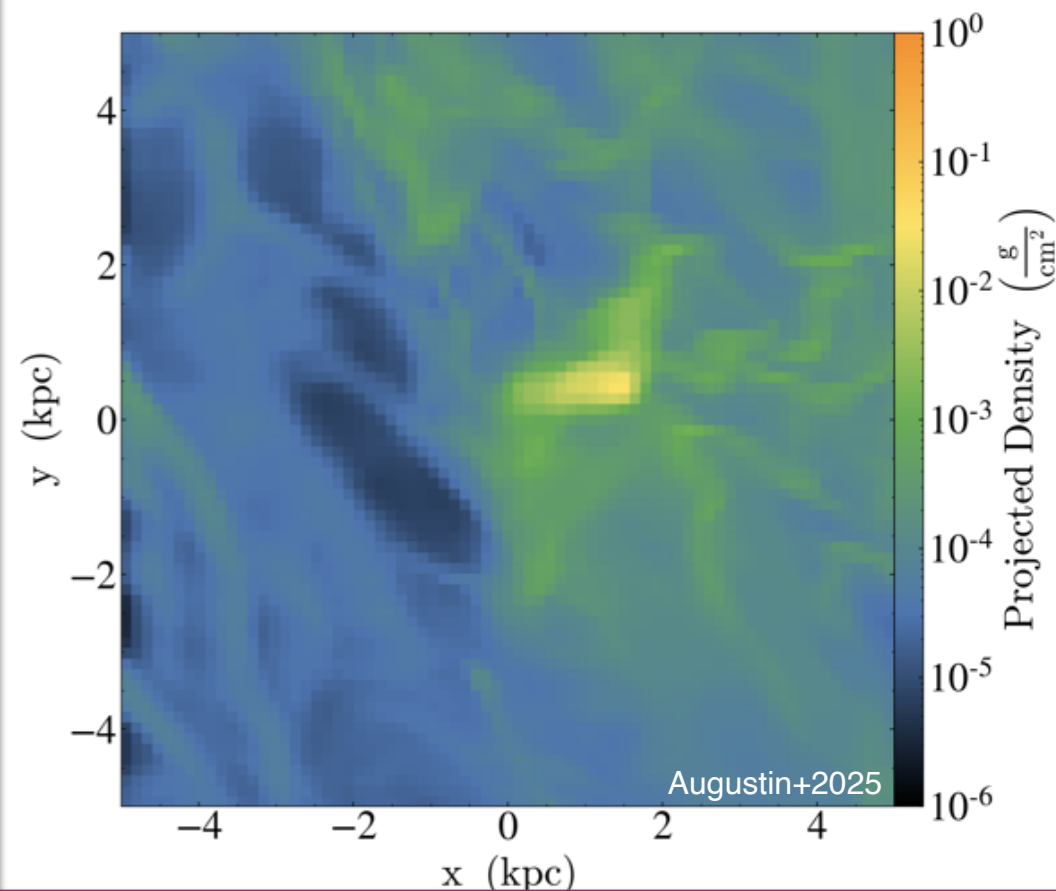


TWO TYPES OF SPATIAL VARIATIONS

Large scale azimuthal variations

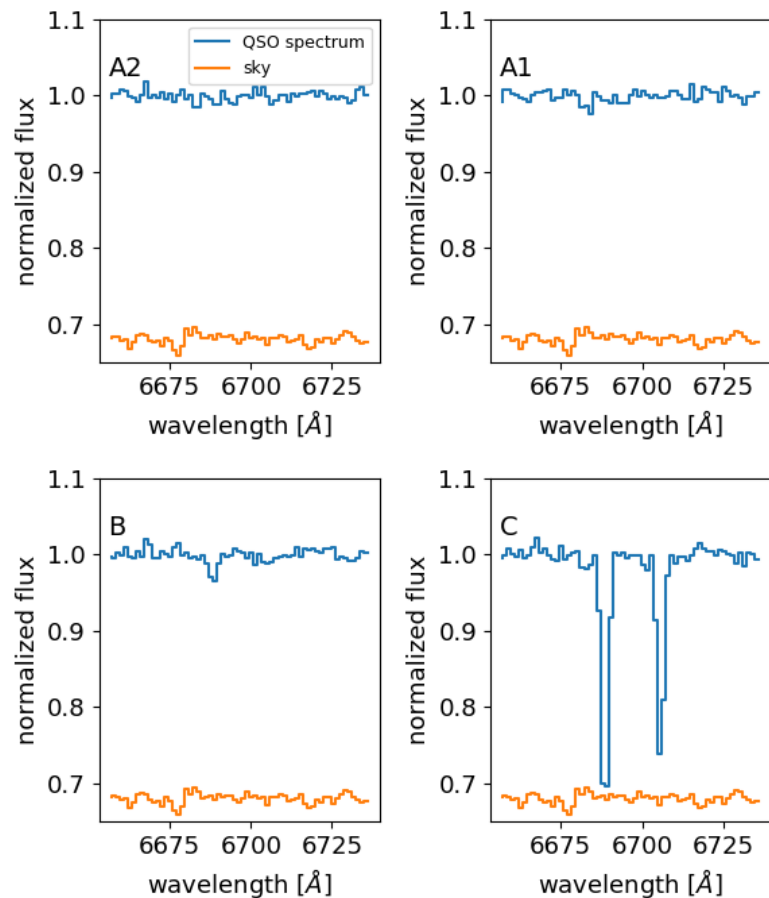


Small scale clumpy gas structure

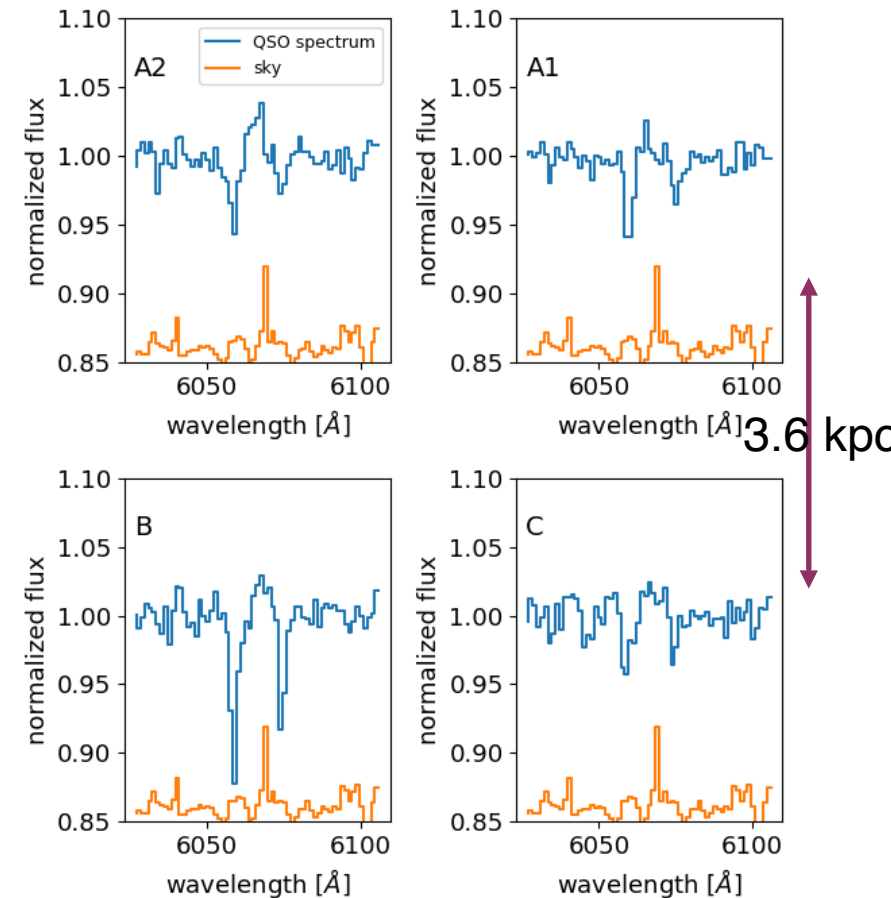
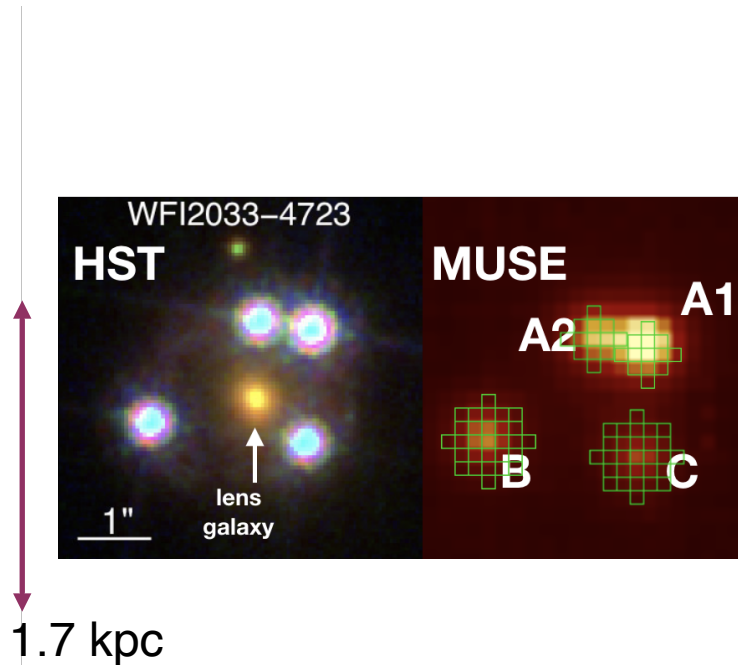


LENSED AND EXTENDED OBJECTS REVEAL ABUNDANCE VARIATION ON SMALL ($\sim$ KPC) SCALES IN THE CGM

Augustin et al. (2021)

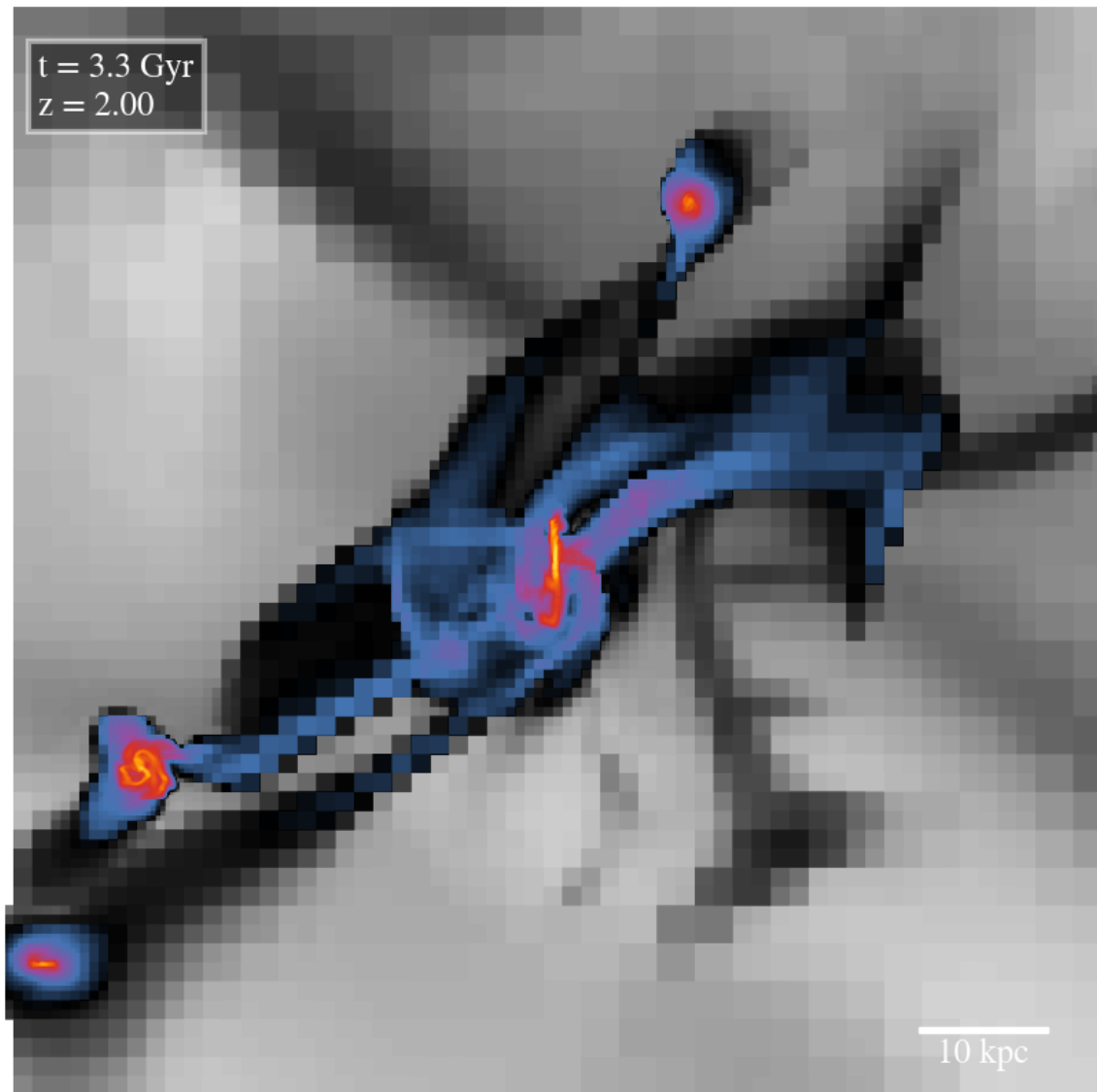


$z_{\text{abs}} = 1.393$

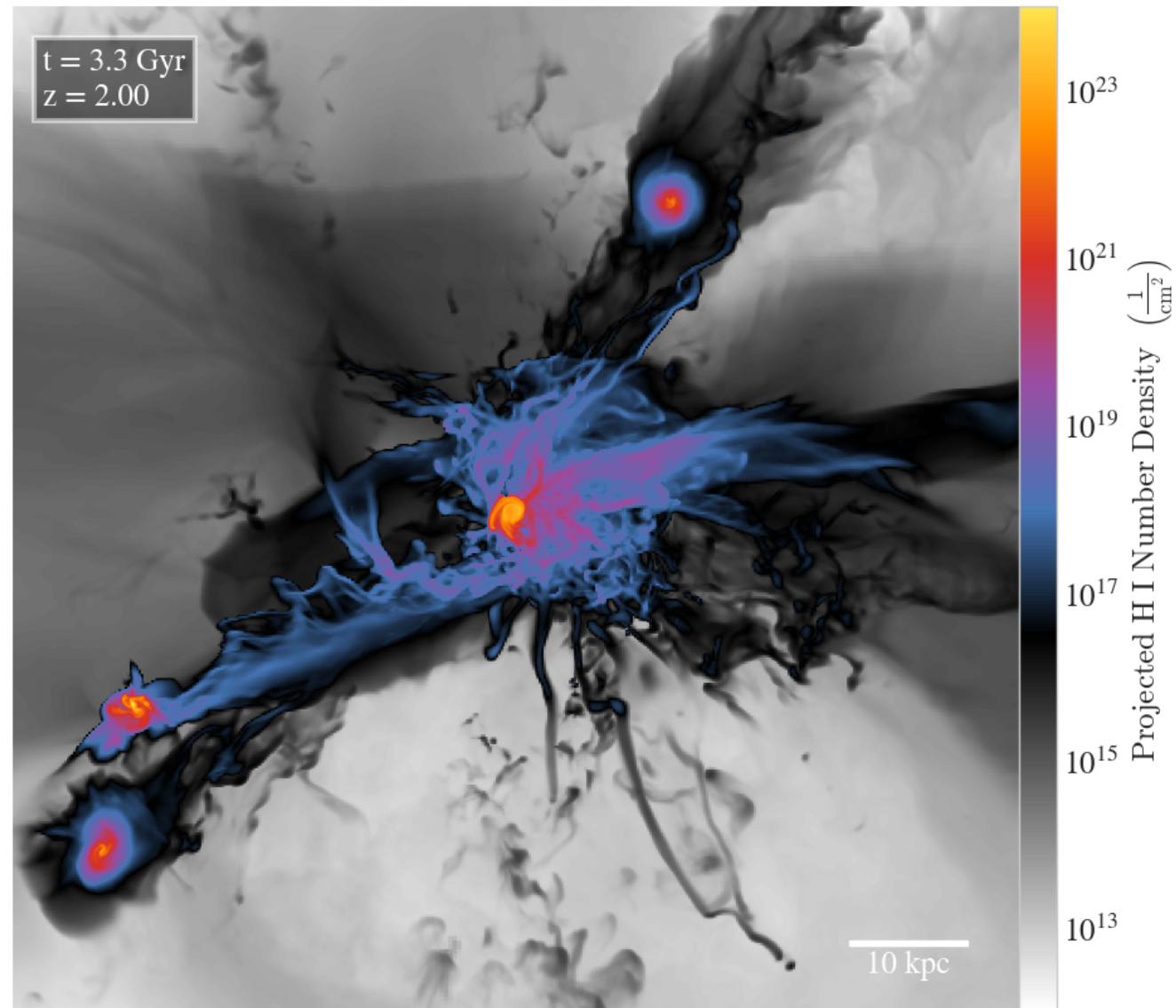


$z_{\text{abs}} = 1.168$

Normal resolution

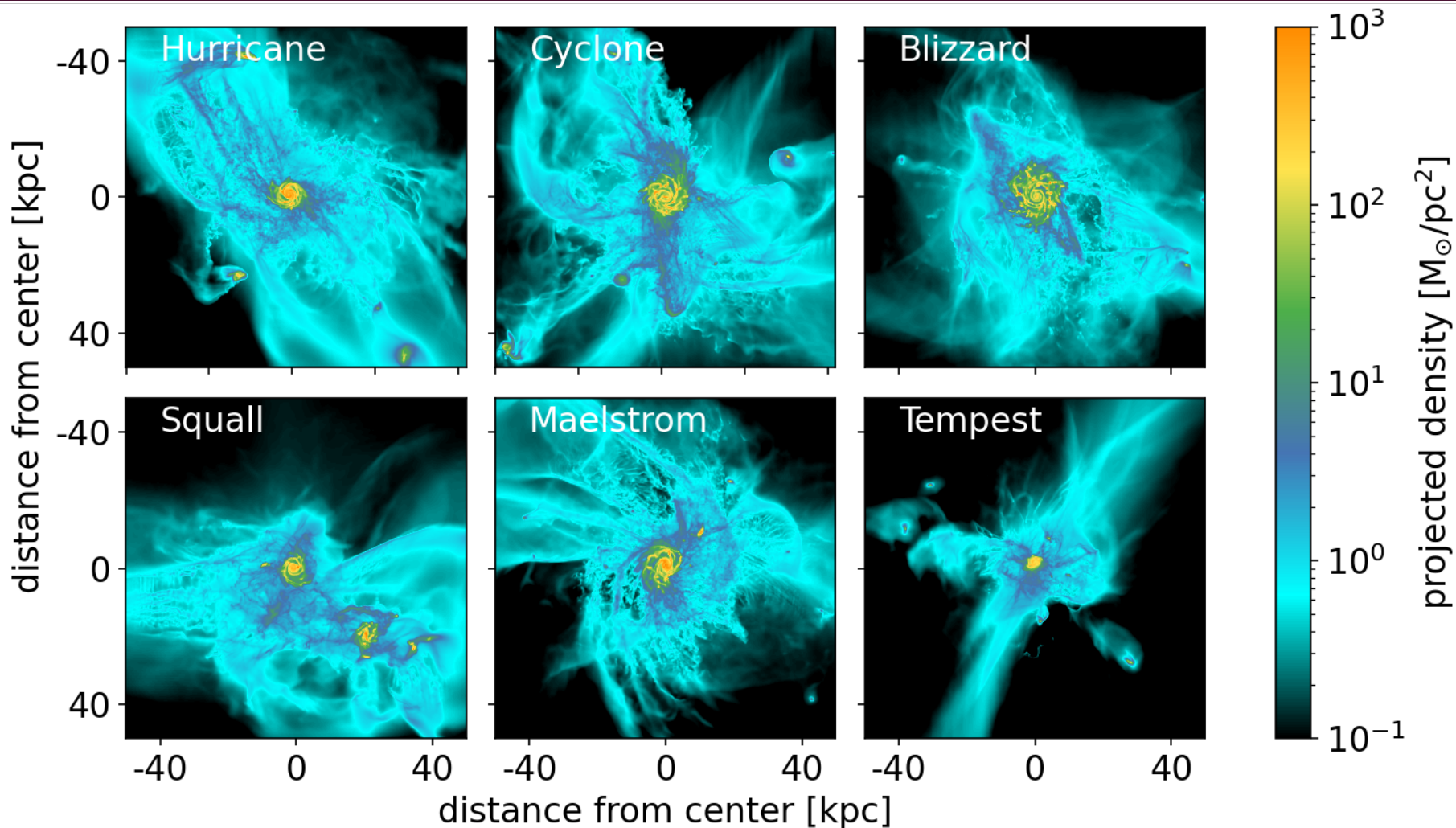


FOGGIE resolution



THE HIGH SPATIAL RESOLUTION IN FOGGIE REVEALS INDIVIDUAL KPC SCALE CLUMPS IN THE CGM

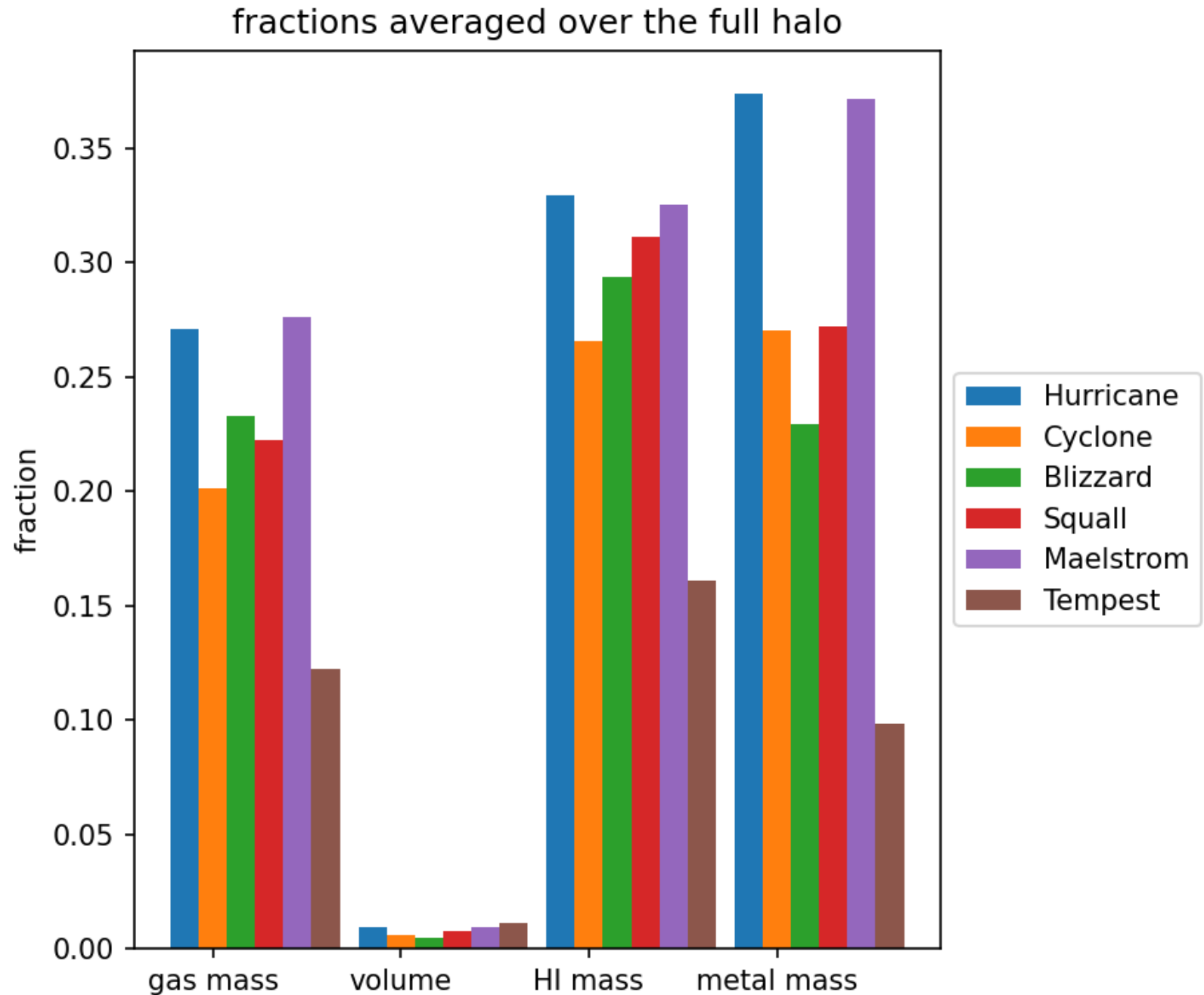
Augustin et al. (2025)



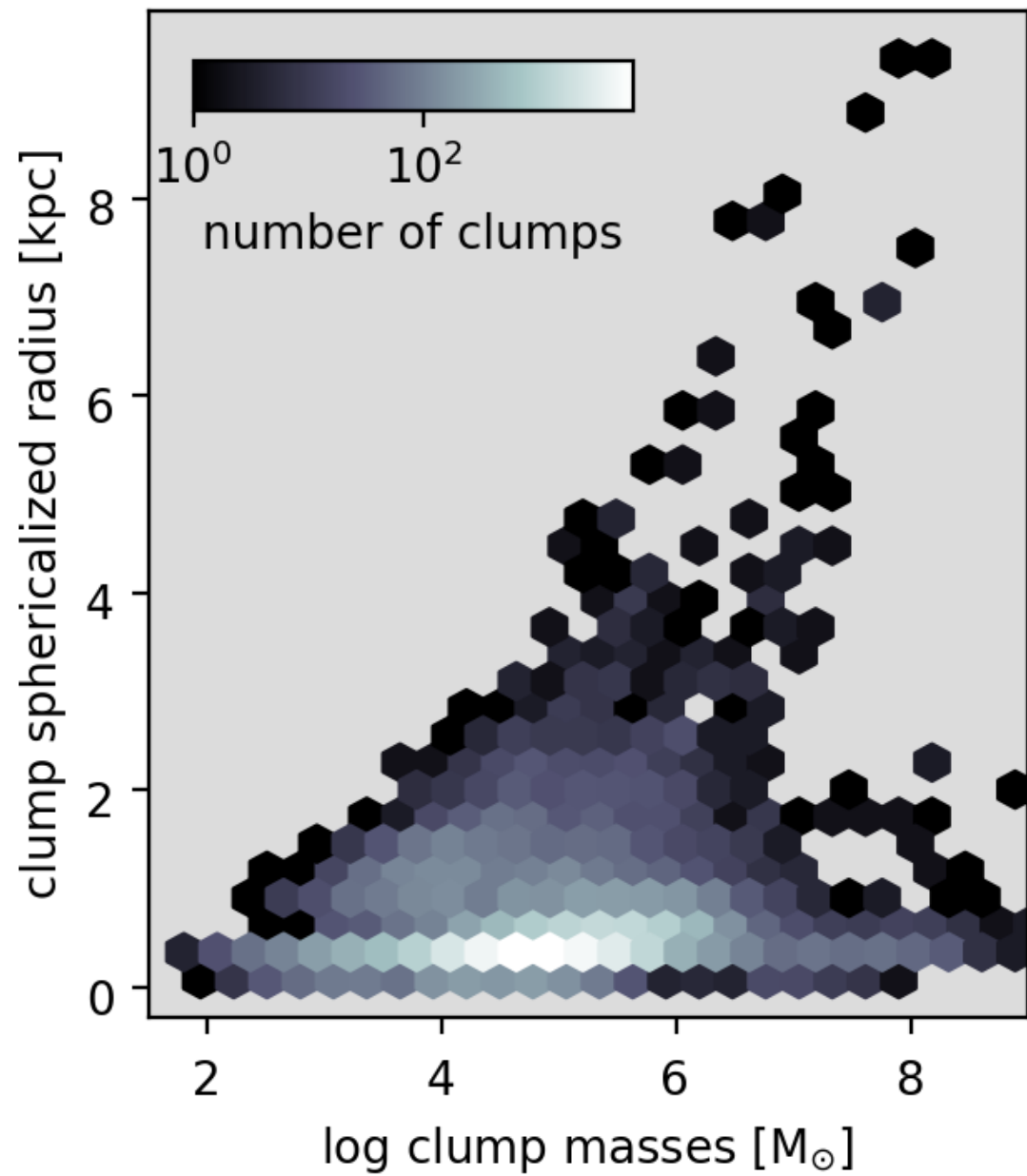
CLUMPS TAKE UP ONLY $\sim 1\%$ OF THE HALO VOLUME

But they host $\sim 1/4$ of the halo's HI mass

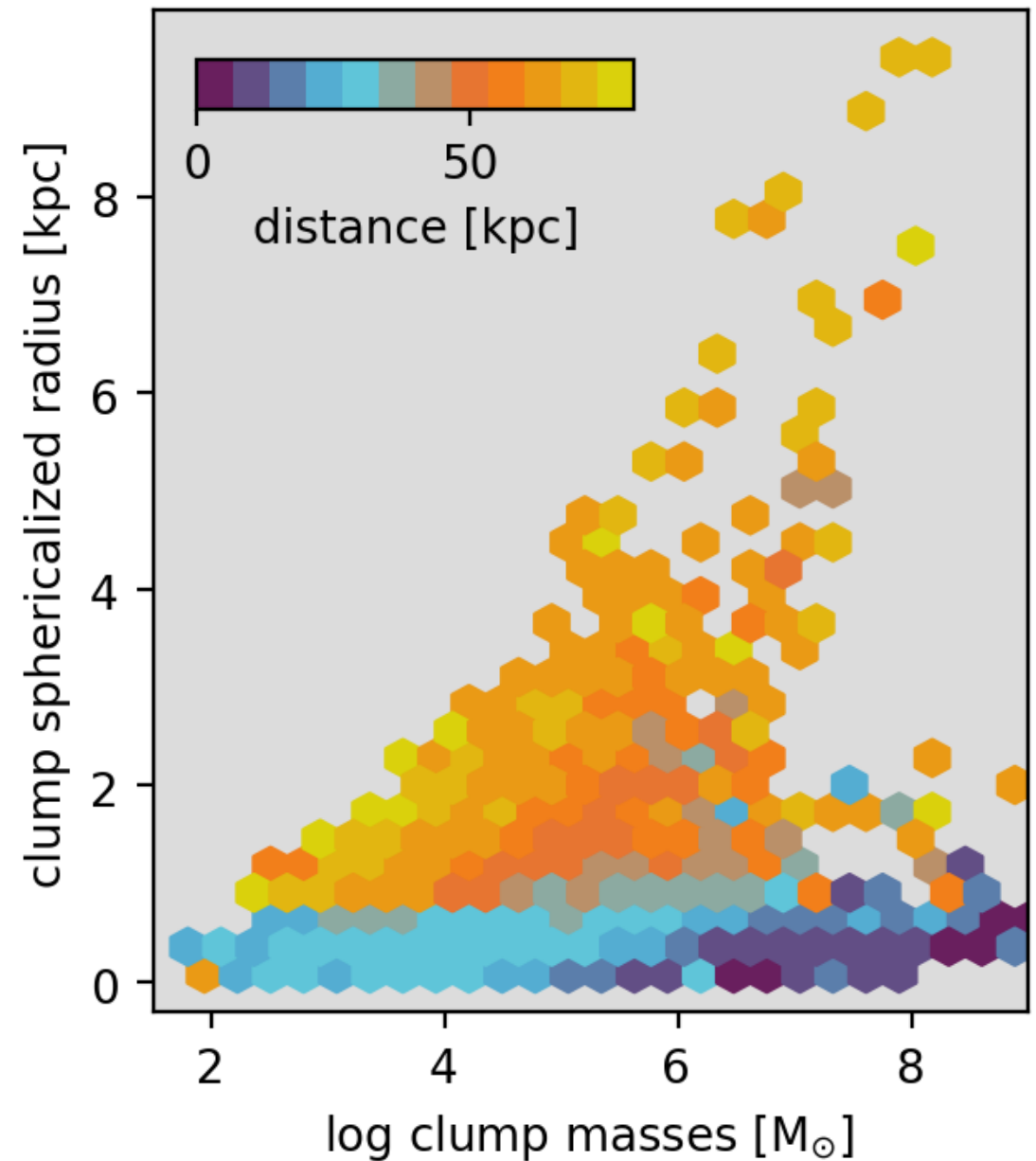
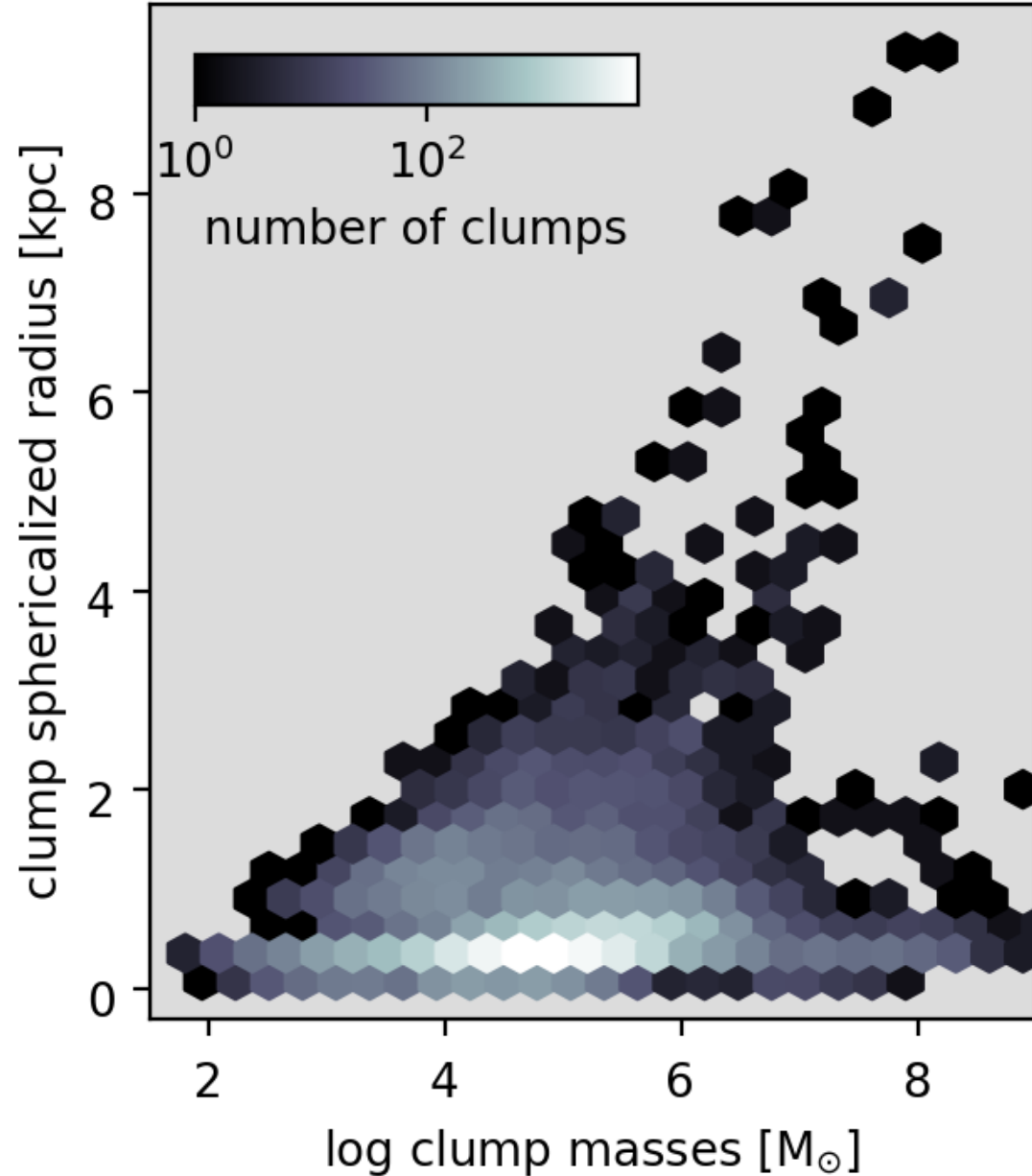
And have high covering fractions in projection



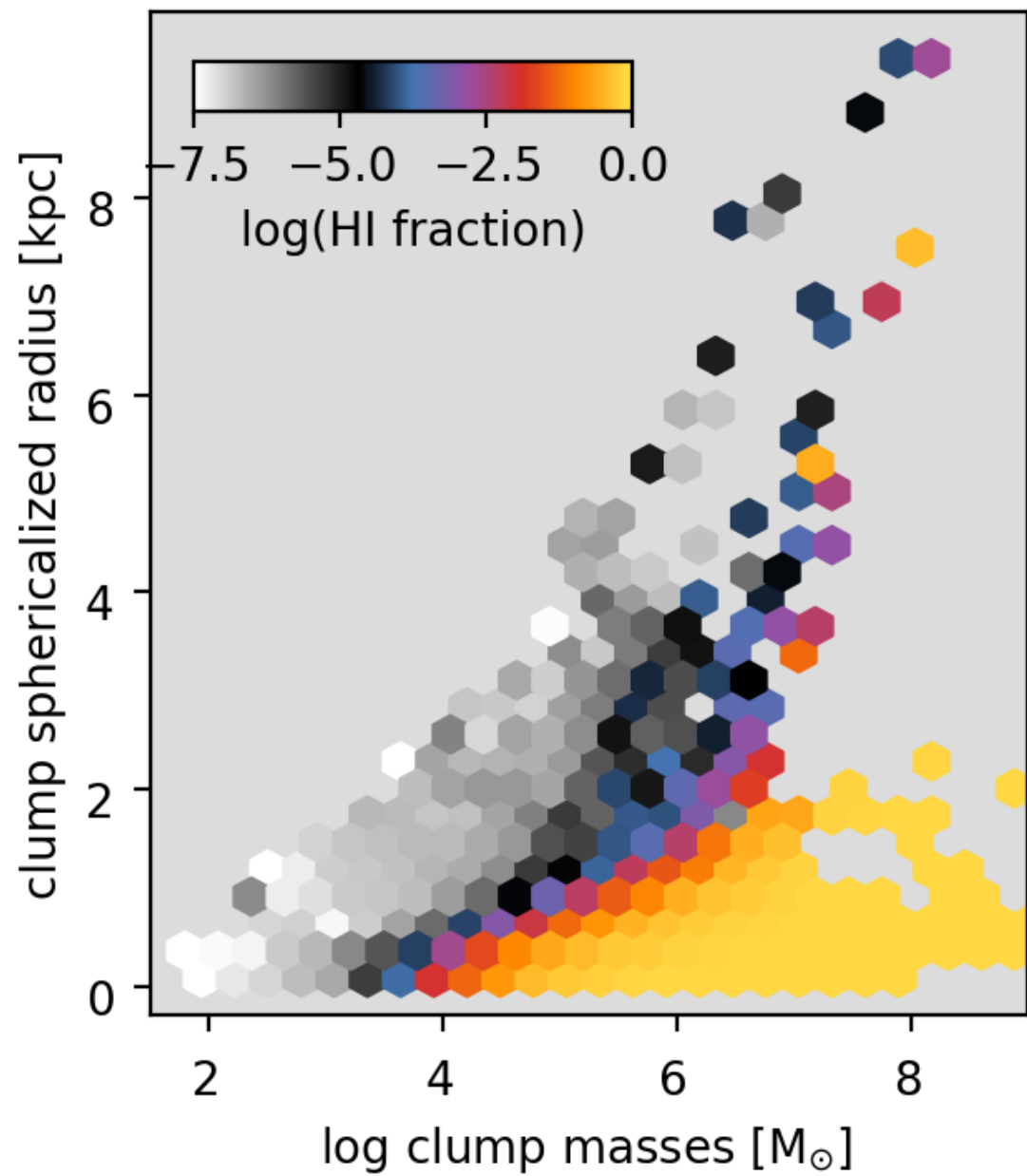
Peak mass of $\sim 10^5 M_\odot$



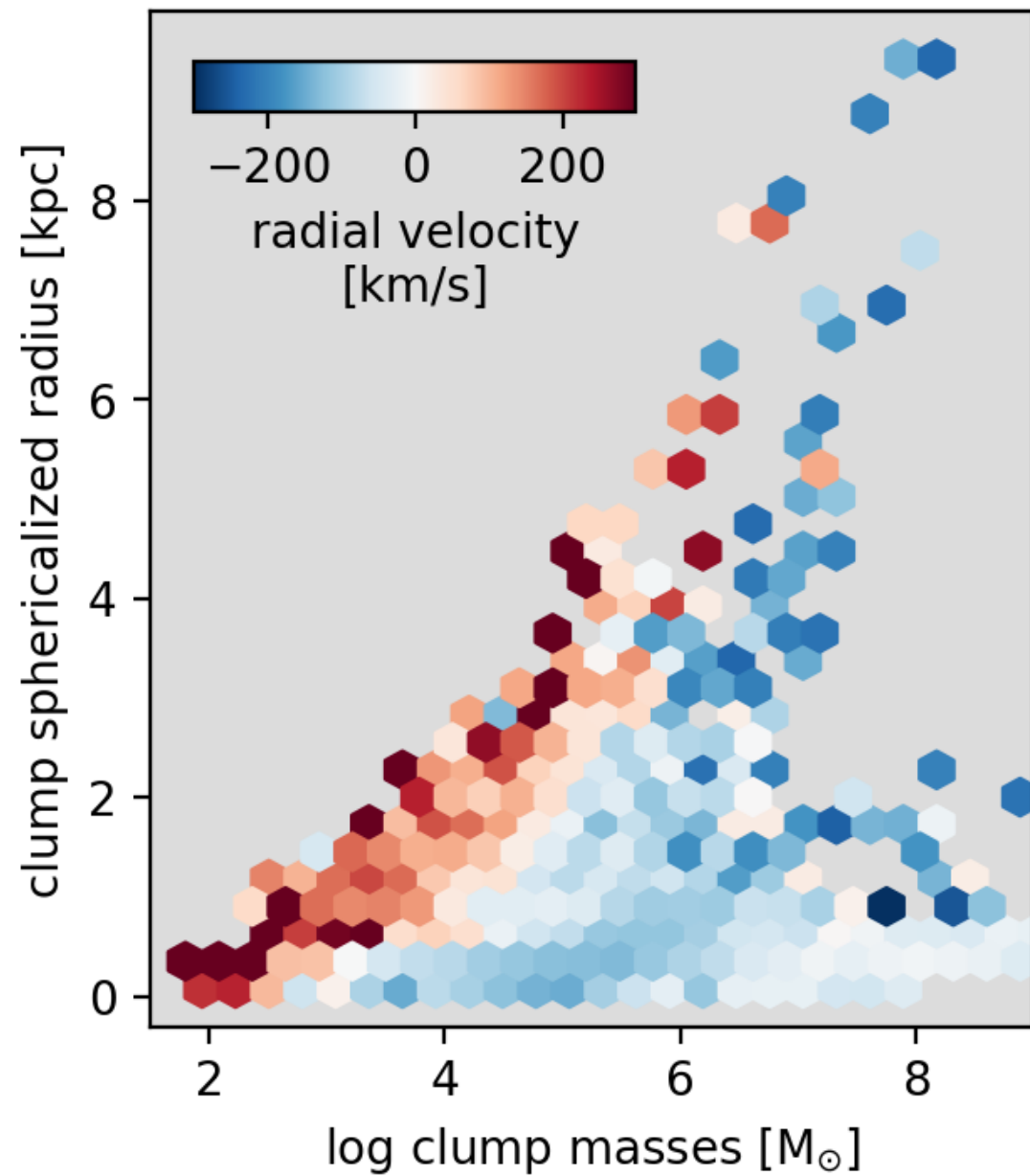
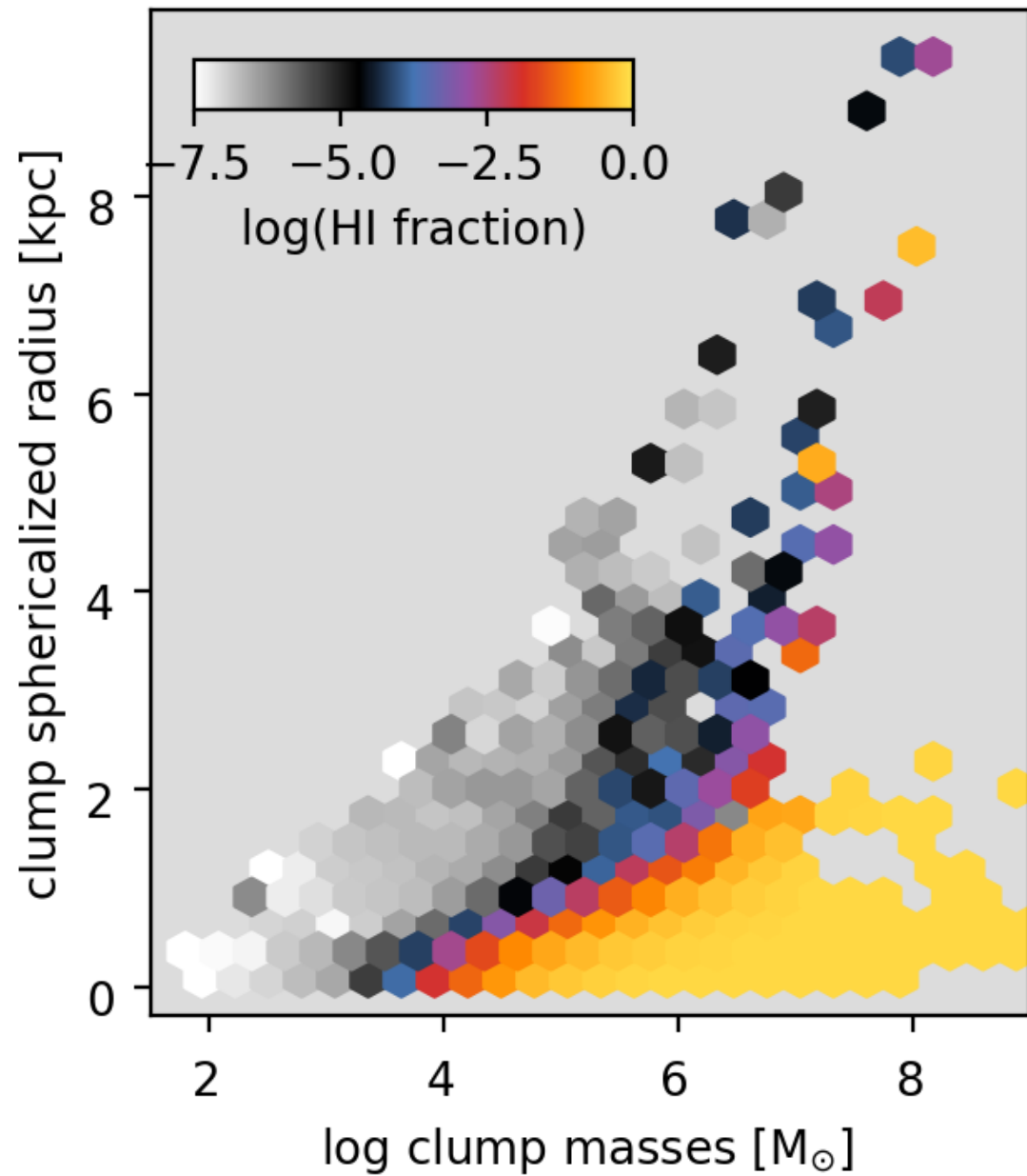
Most clumps are found close to the galactic center



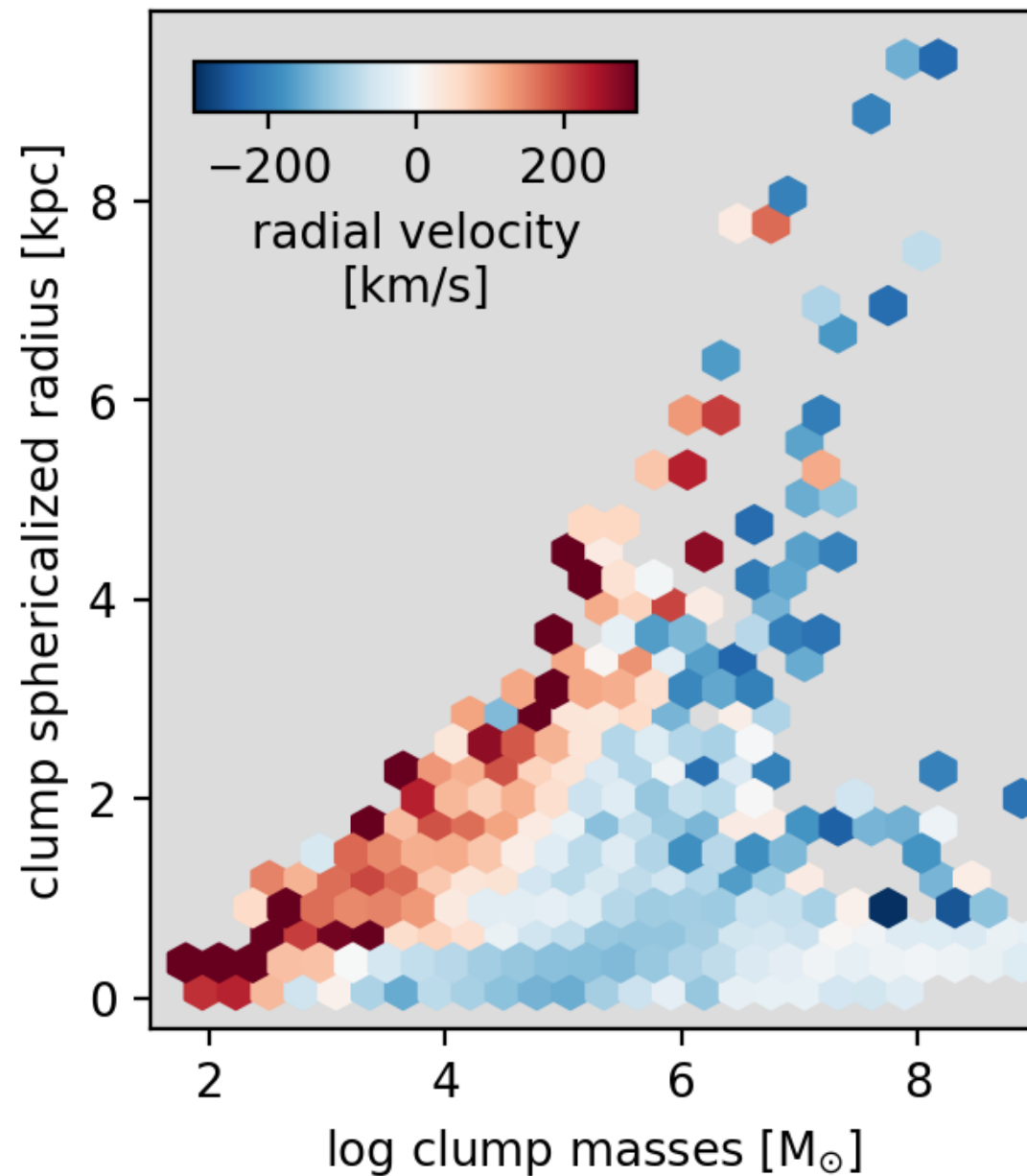
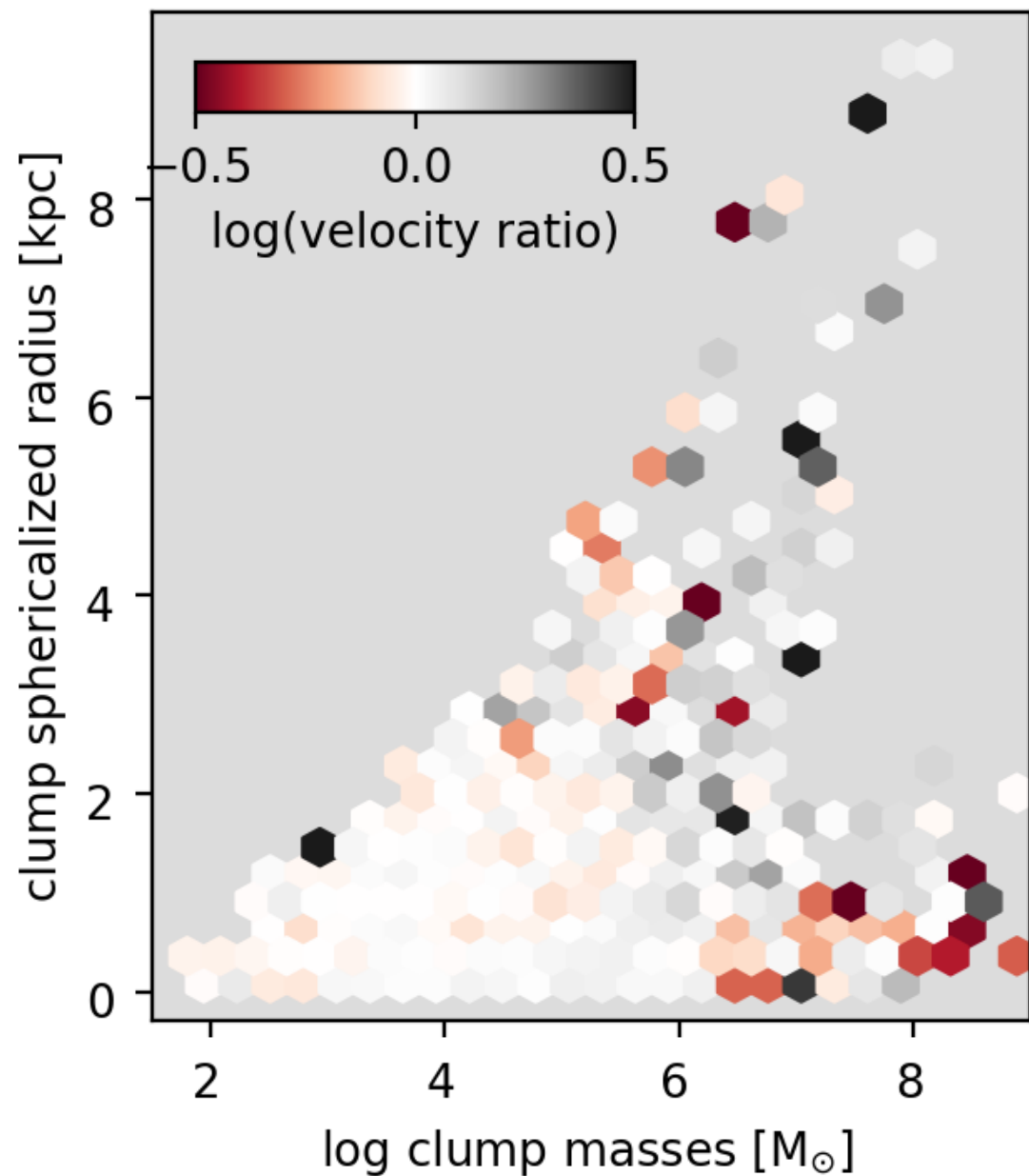
Ionisation gradient with density



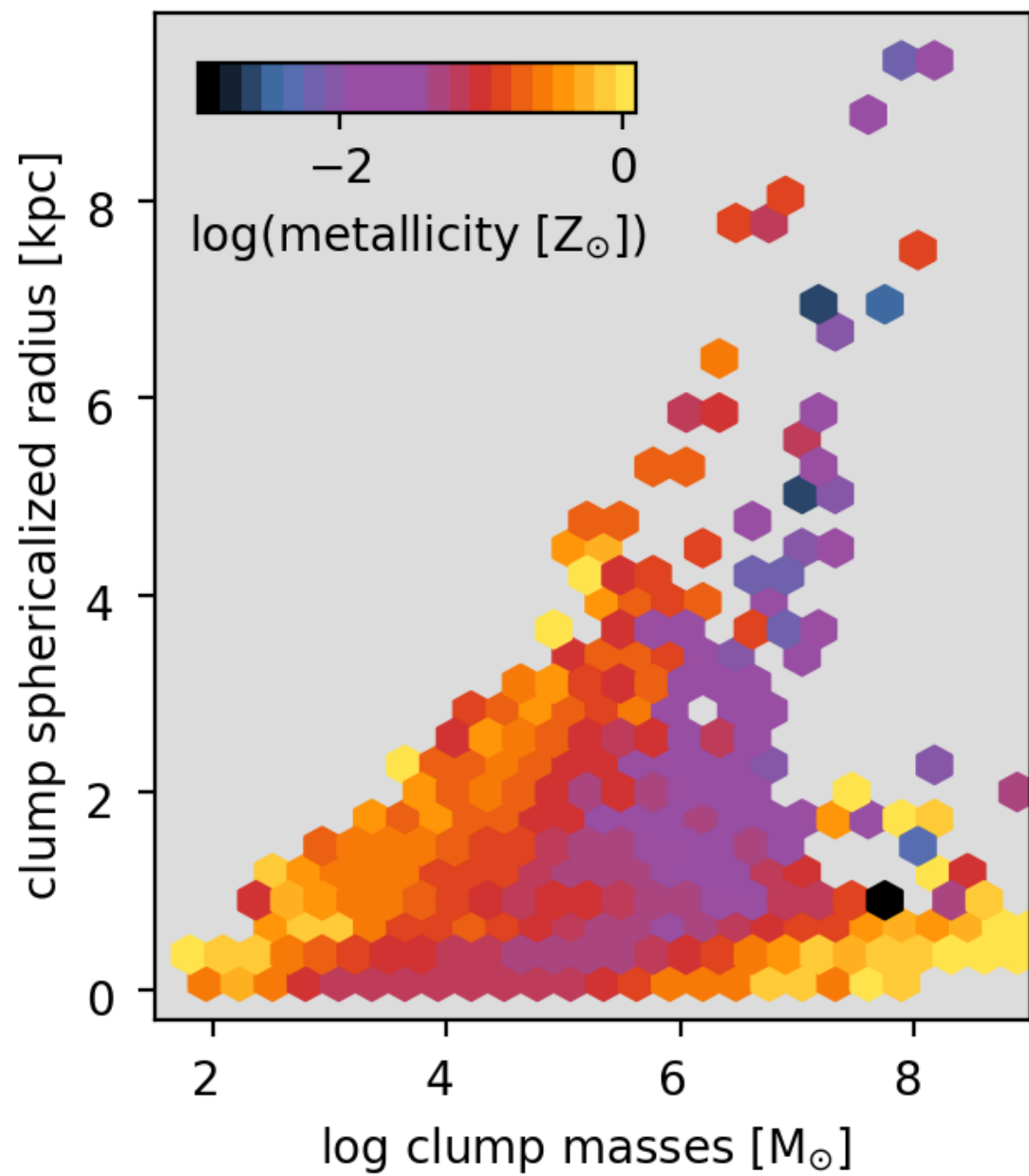
Radial velocity gradient with density



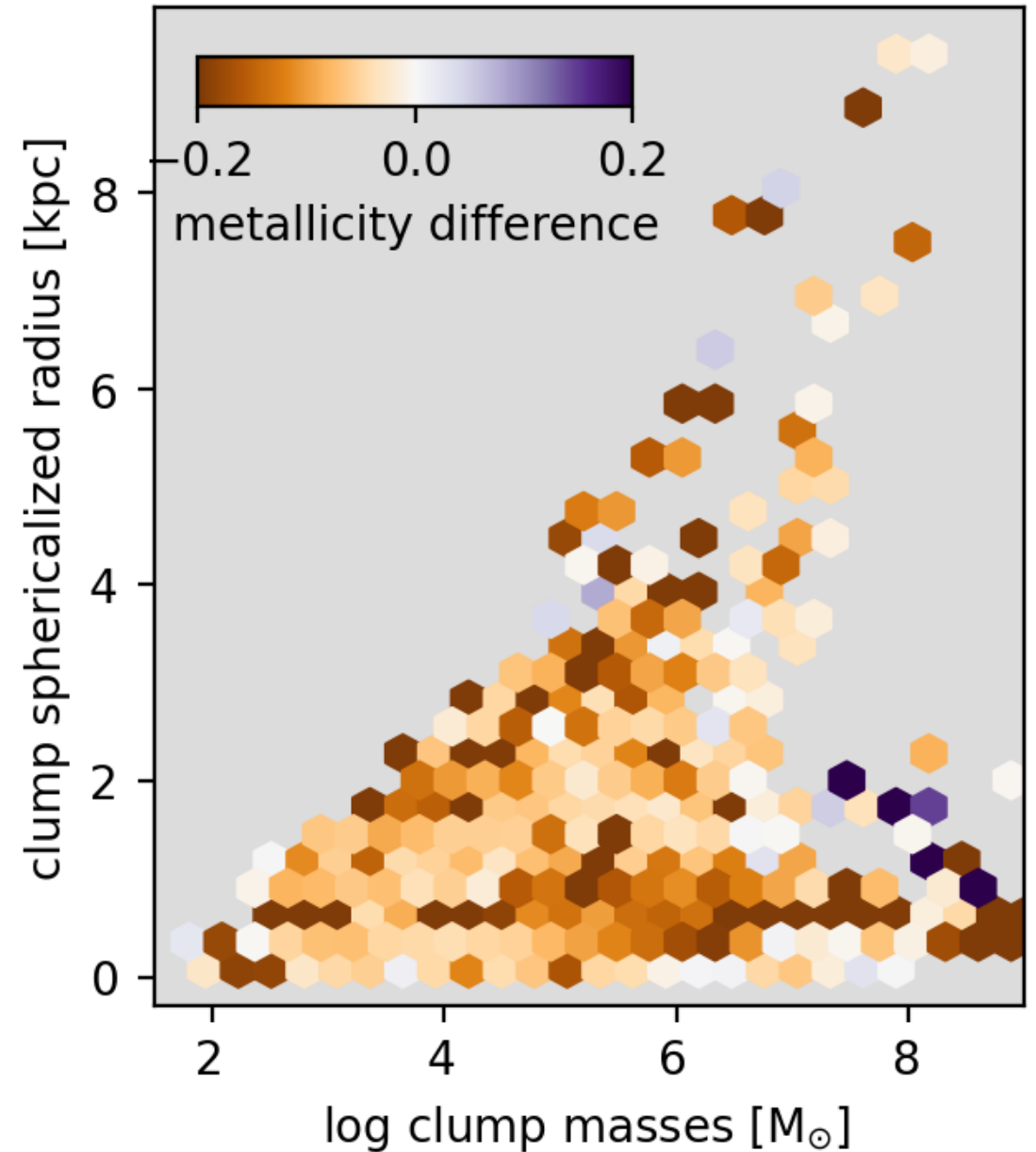
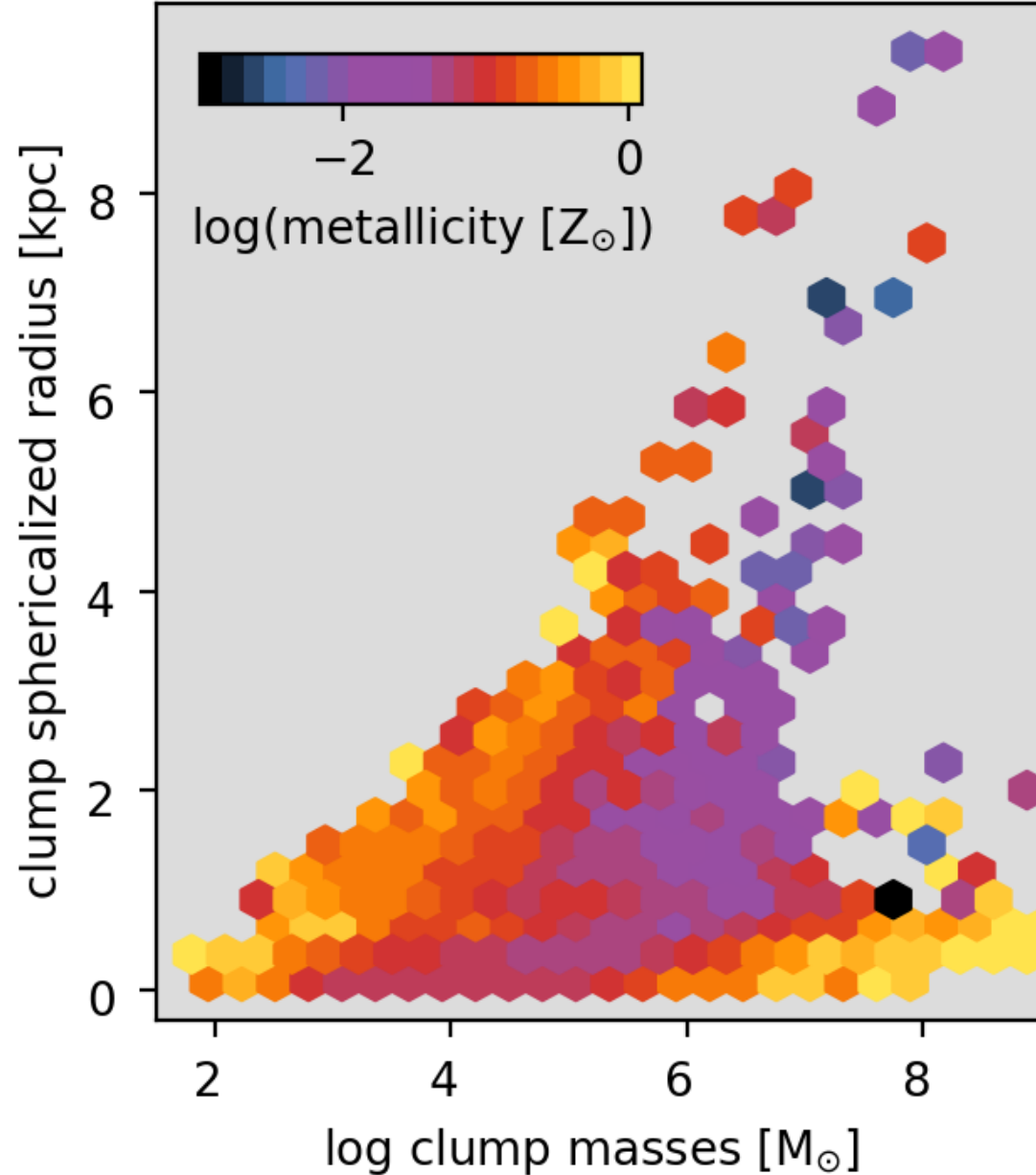
Majority of clumps well embedded into environment



Metallicity bimodality

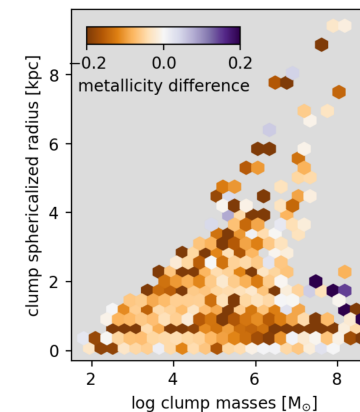
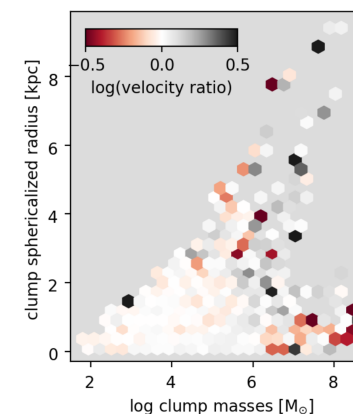
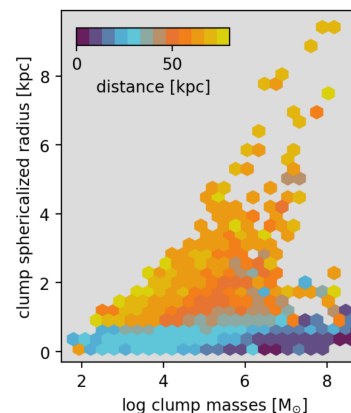


All clumps have lower metallicity than their environment

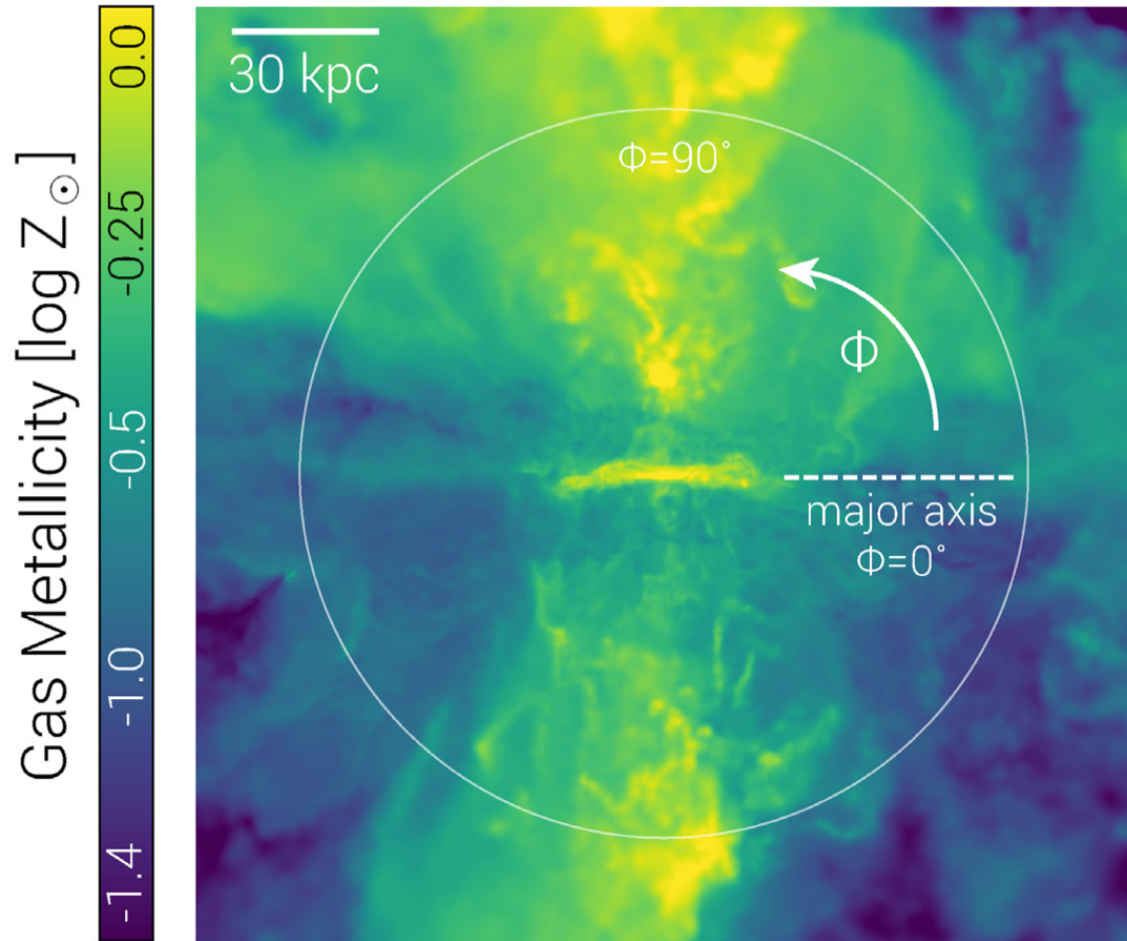


SMALL-SCALE STRUCTURES IN SIMULATIONS: TAKE-AWAYS

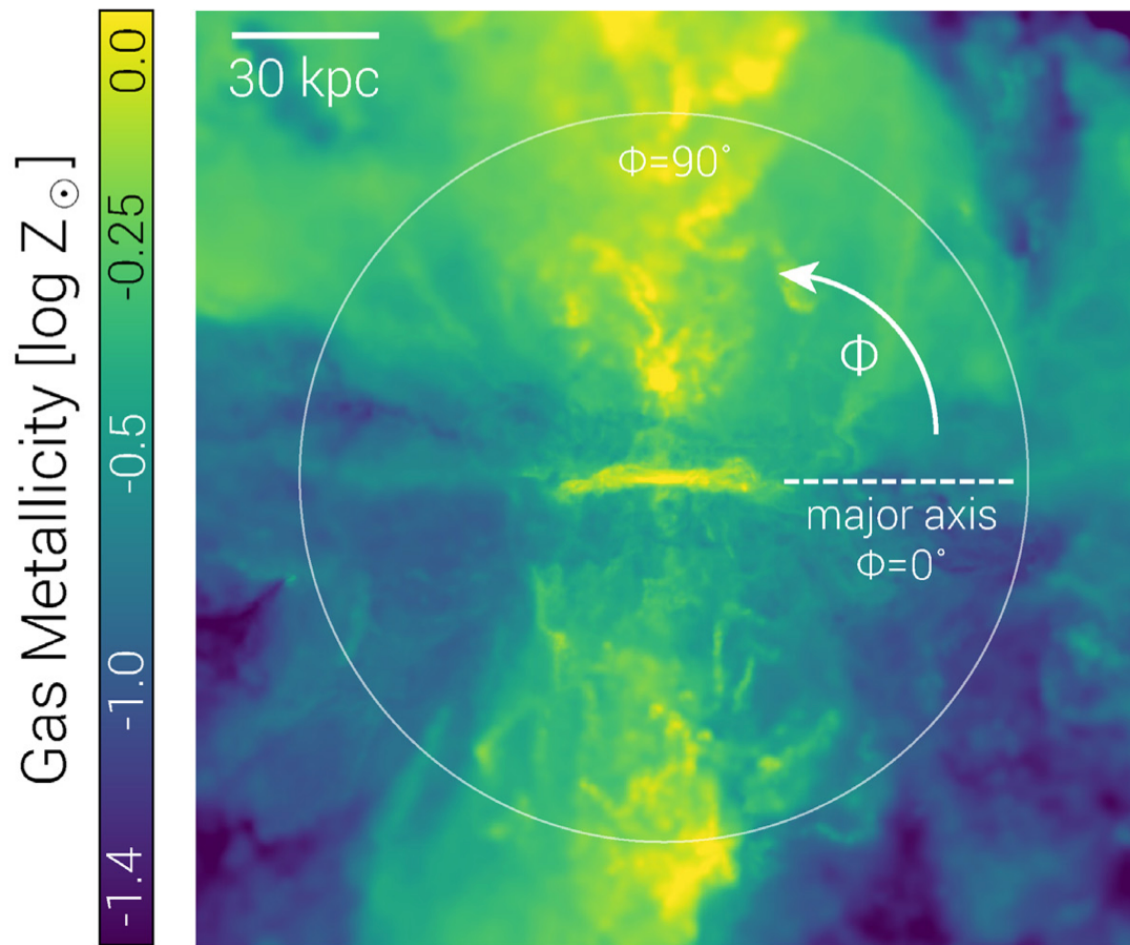
- Most clumps are found close to the galactic center
 - ➔ more absorber components in the inner CGM
- Majority of clumps well embedded into environment
 - ➔ Longevity of CGM clumps
- All clumps have lower metallicity than their environment
 - ➔ Metals carried preferentially in the diffuse gas phase?



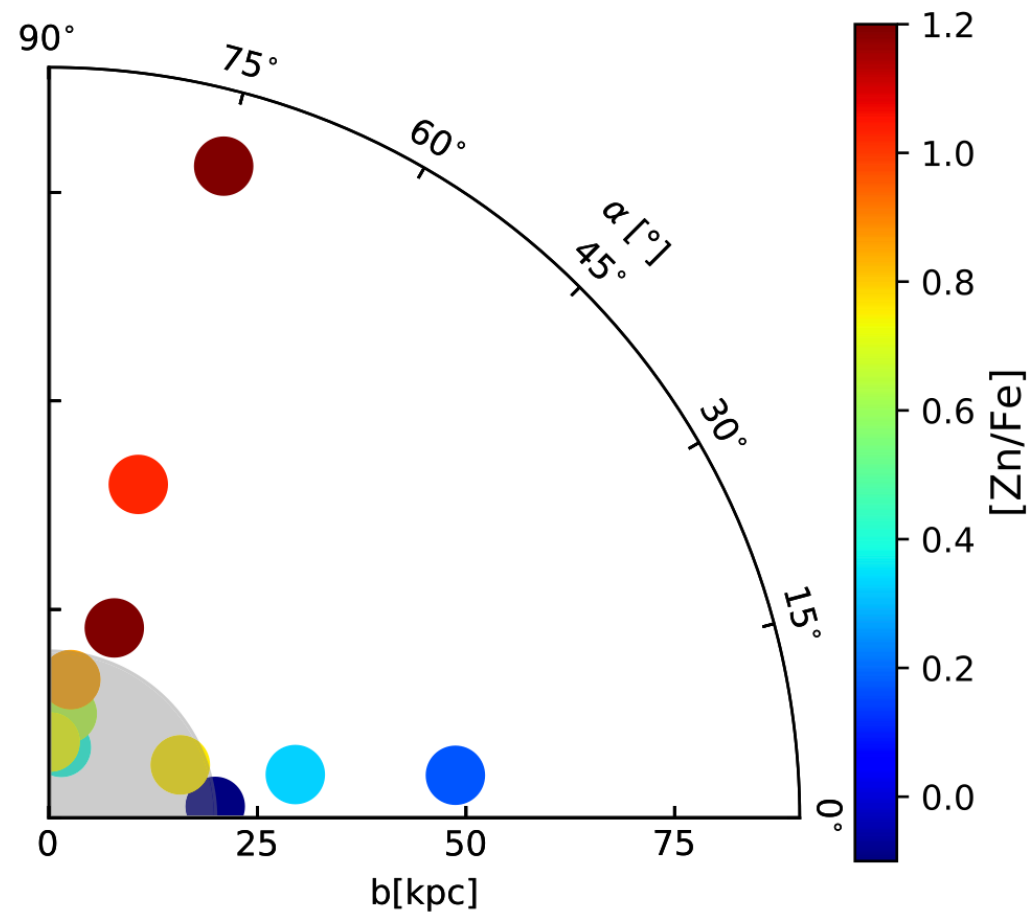
AZIMUTHAL DISTRIBUTION



AZIMUTHAL DISTRIBUTION

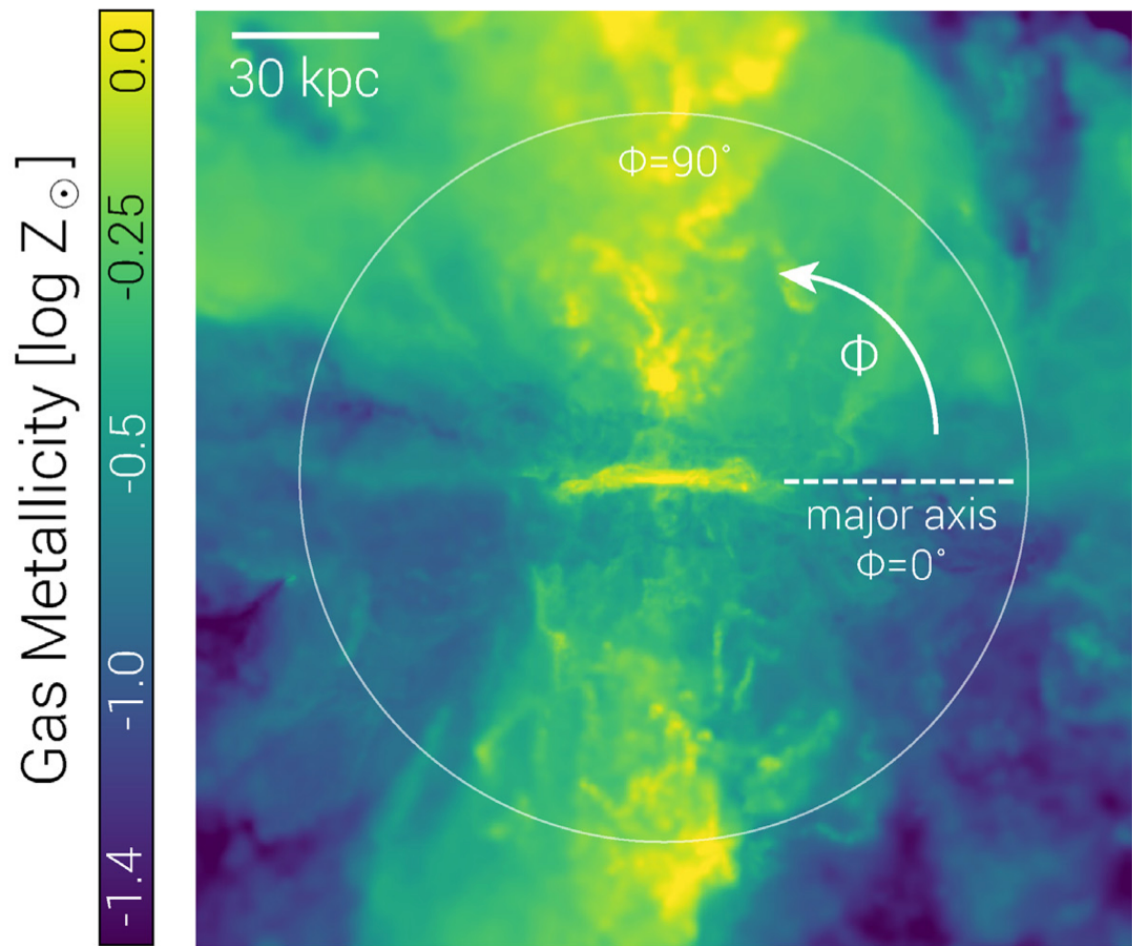


Péroux+2020

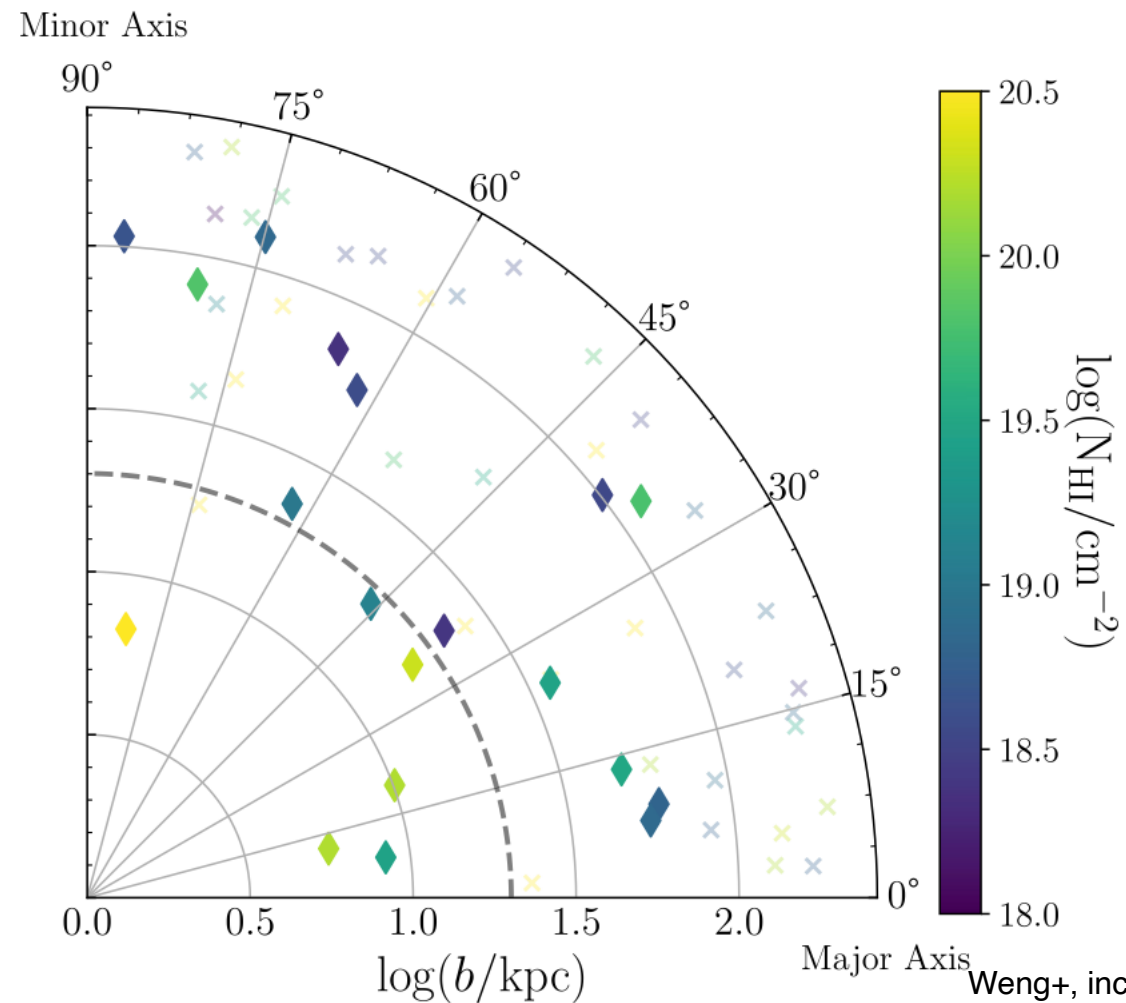


Wendt+2021

AZIMUTHAL DISTRIBUTION

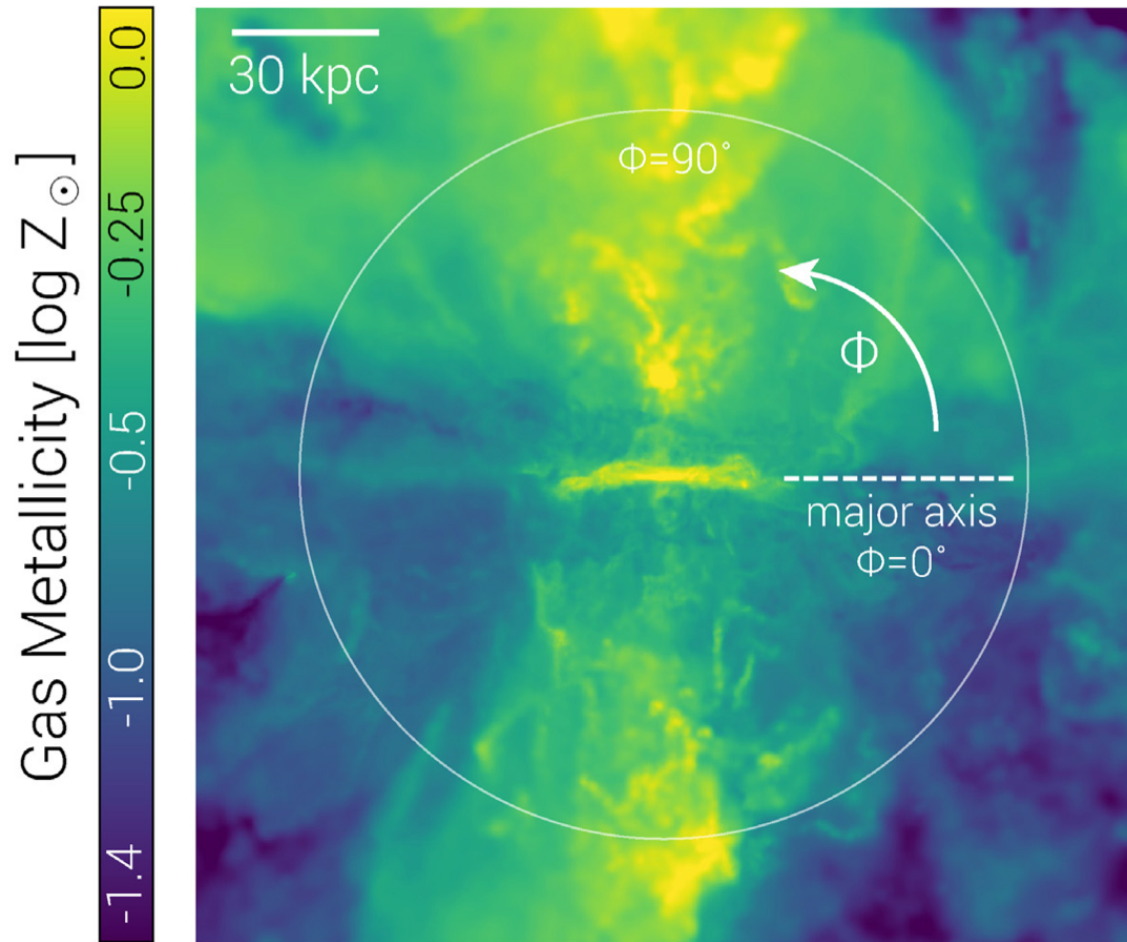


Péroux+2020

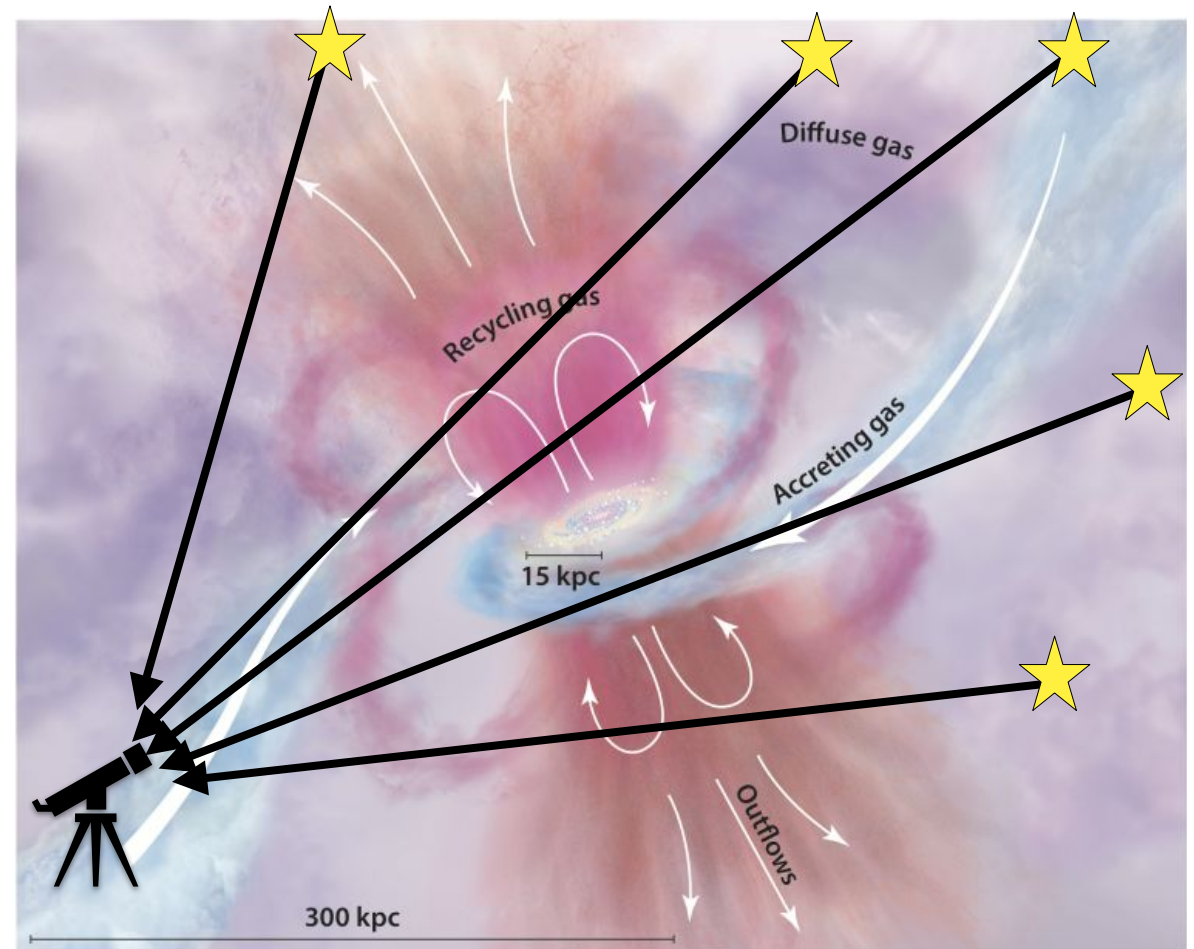


Weng+, incl RA, 2023

AZIMUTHAL DISTRIBUTION



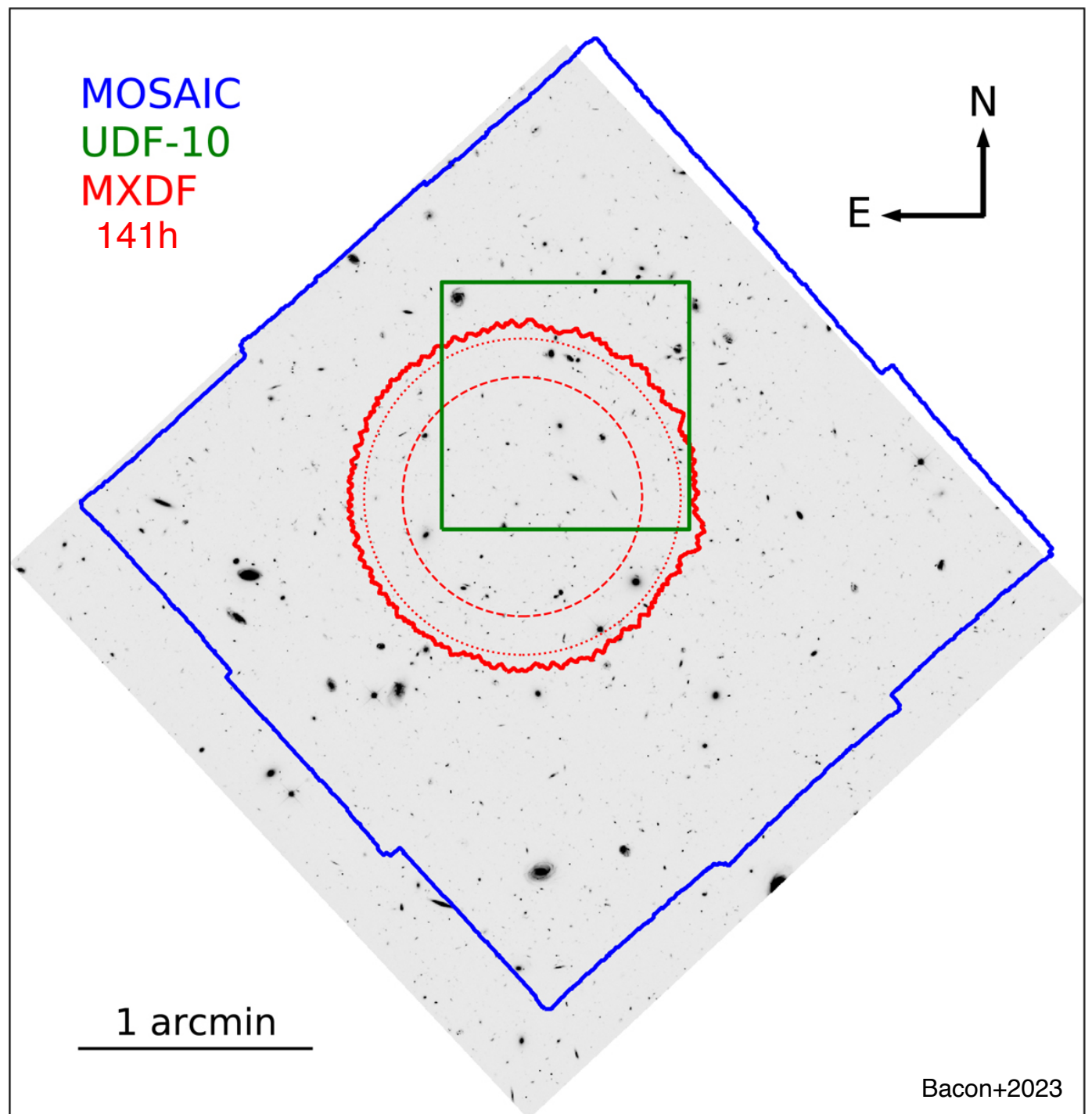
Péroux+2020



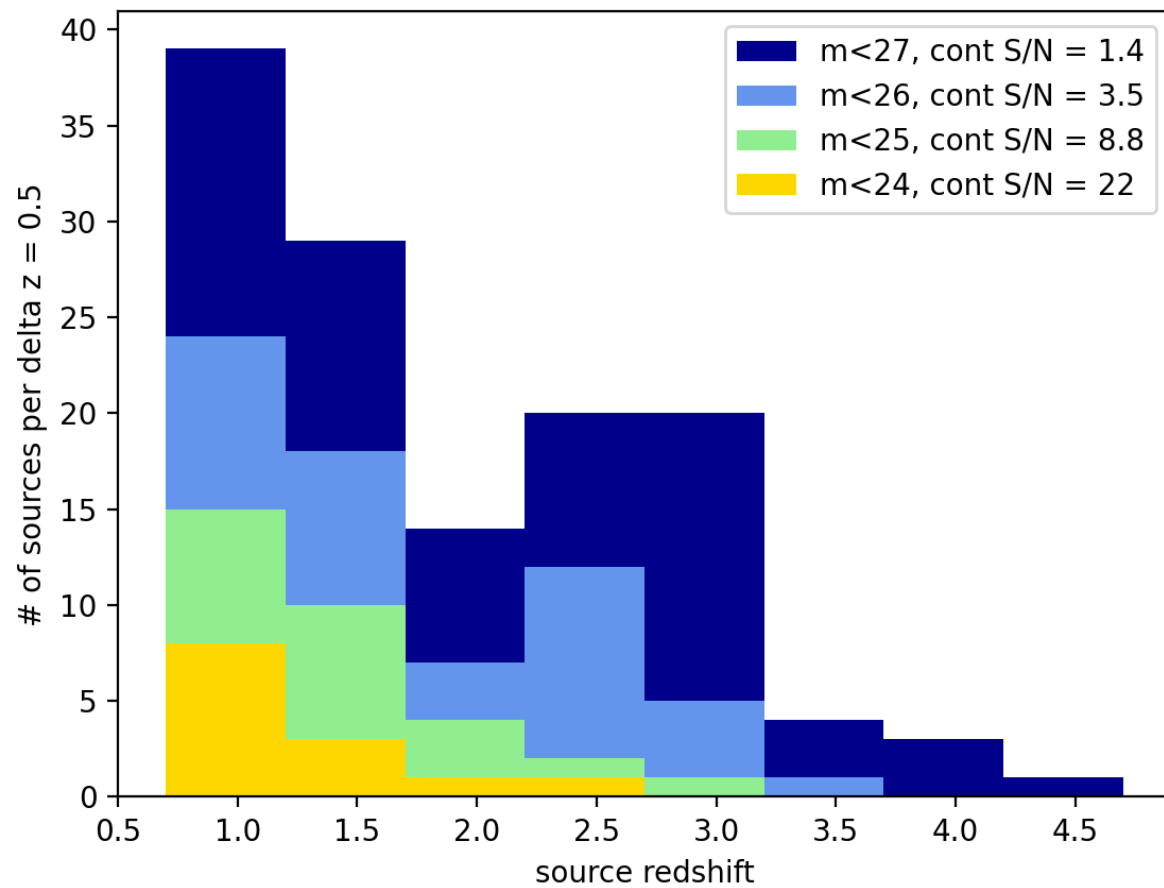
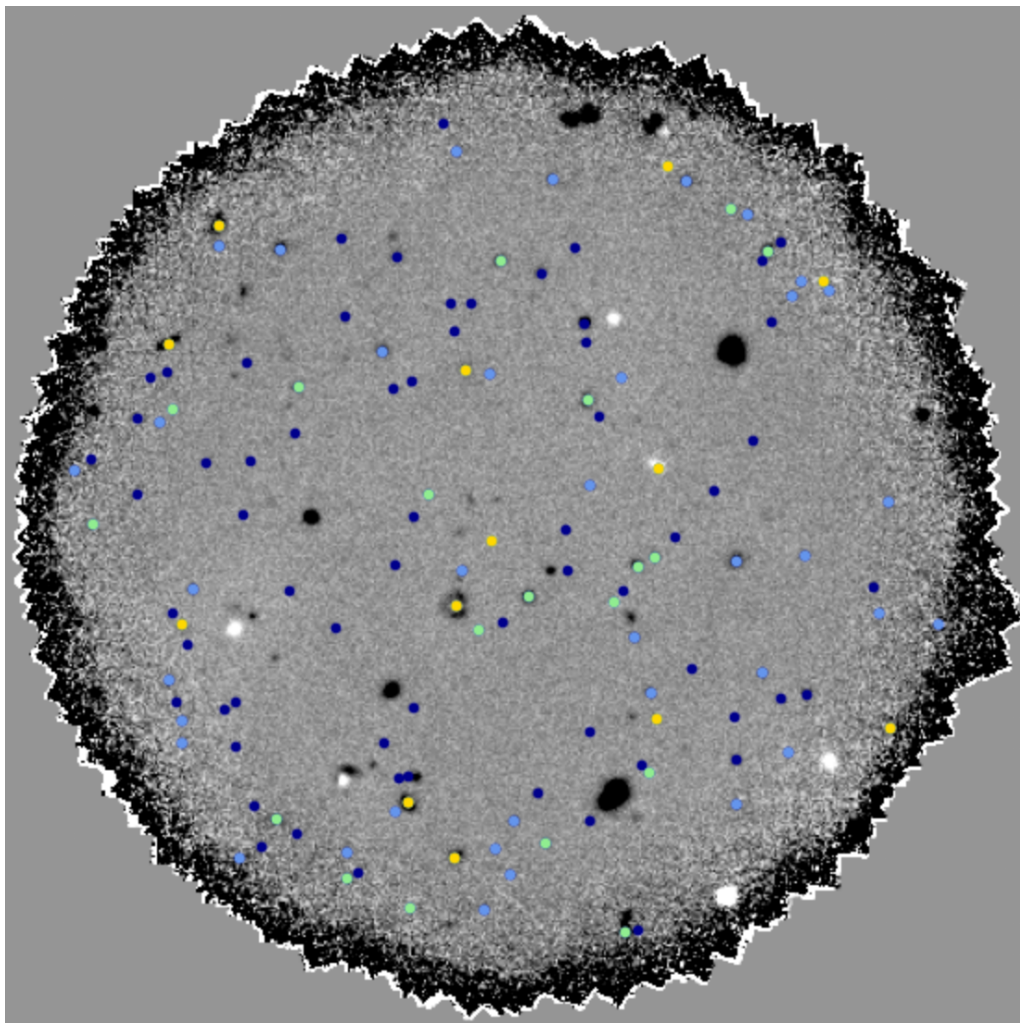
Adapted from Tumlinson, Peebles and Werk 2017

MUSE EXTREMELY DEEP FIELD (MXDF)

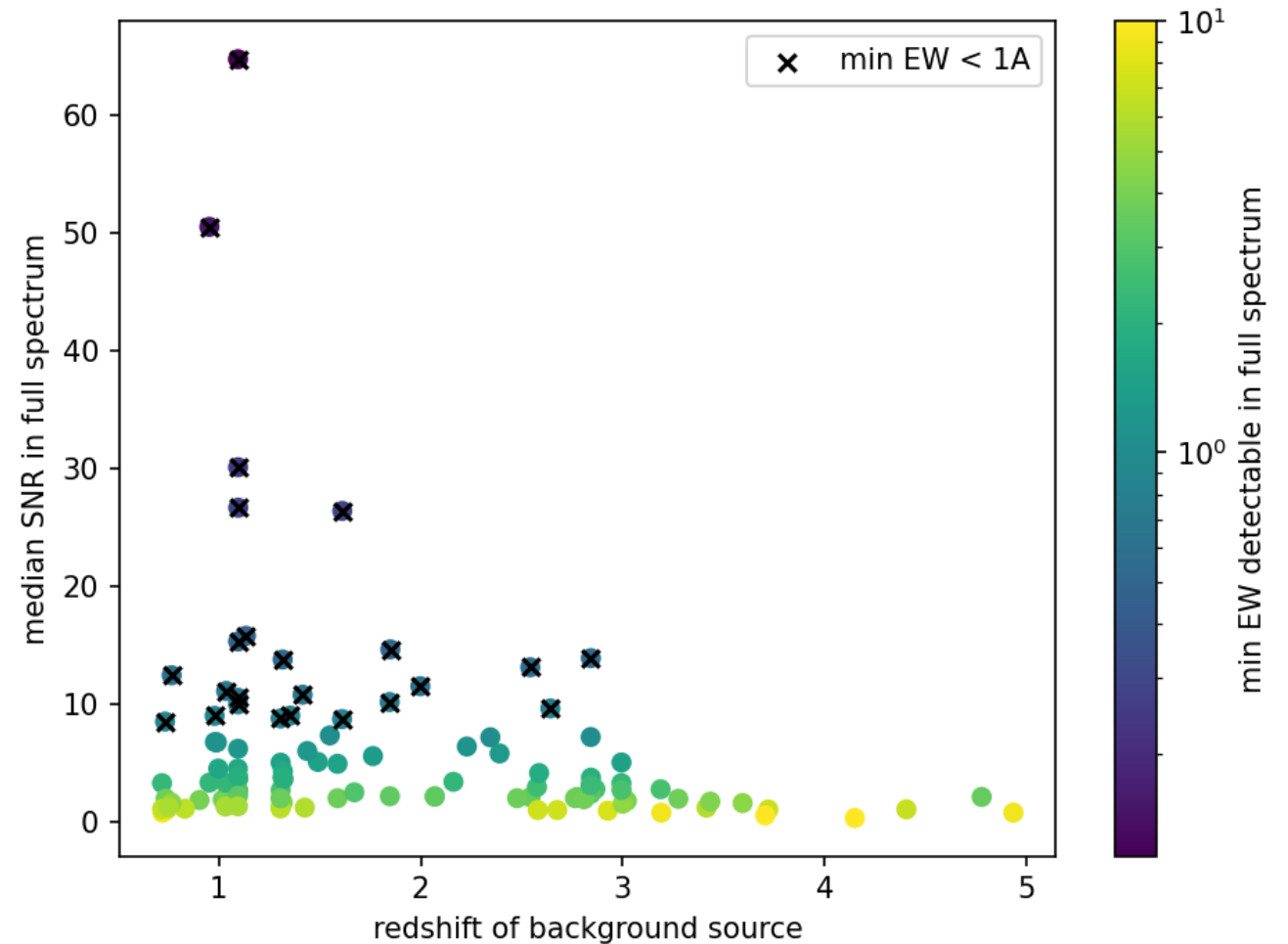
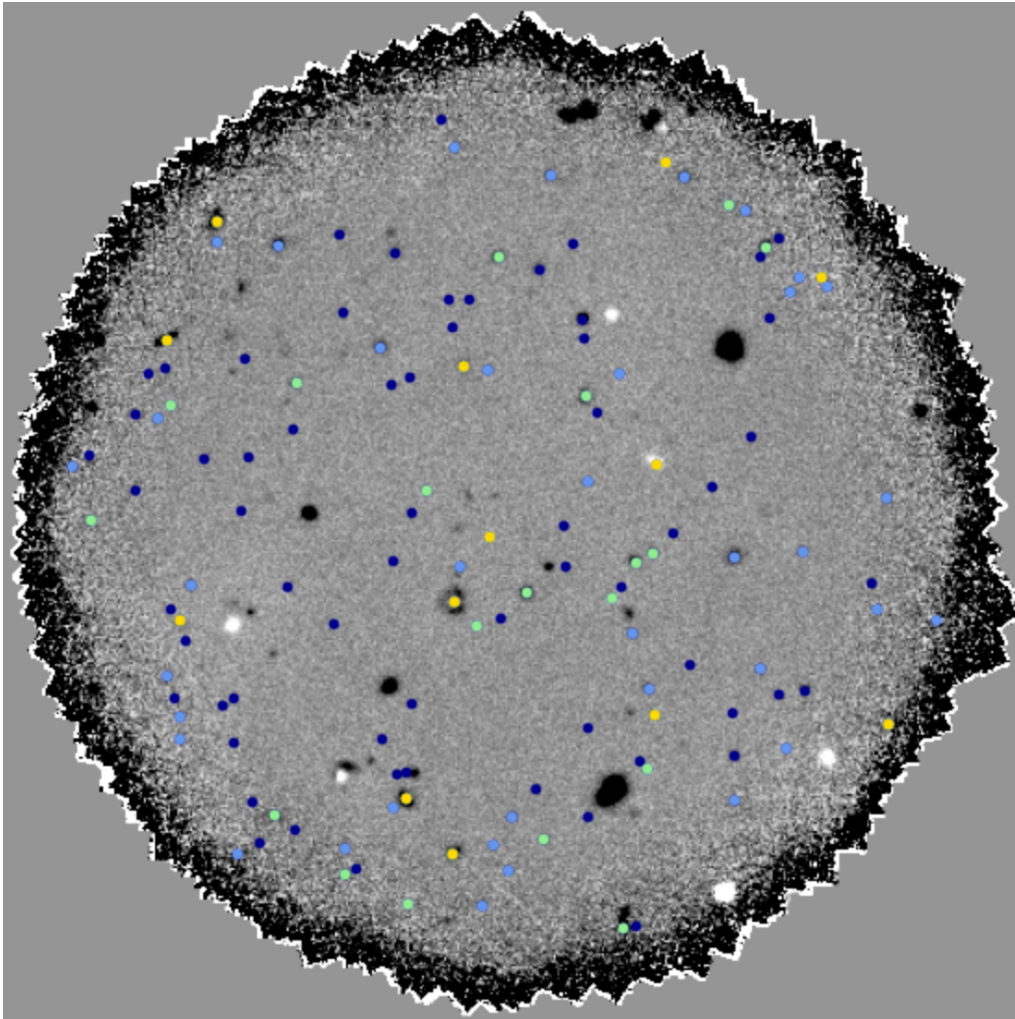
141-h adaptive-optics-
assisted MUSE
observations in the Hubble
Ultra Deep Field
1 arcmin in diameter



BACKGROUND SOURCE SELECTION

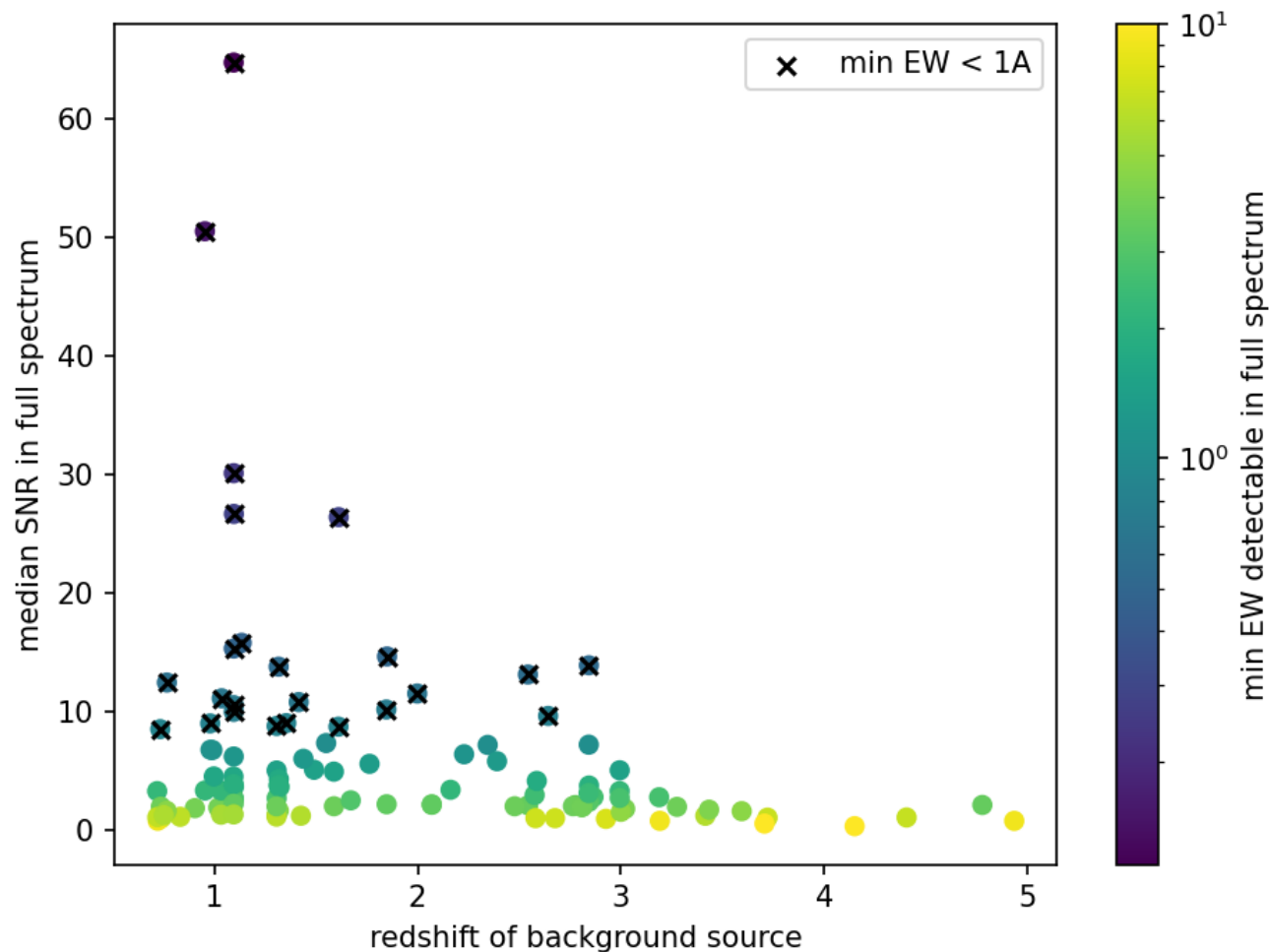
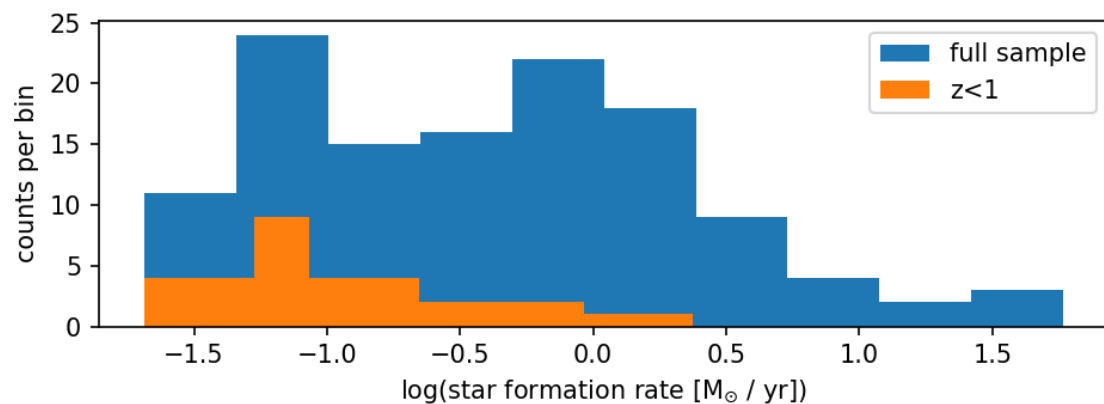
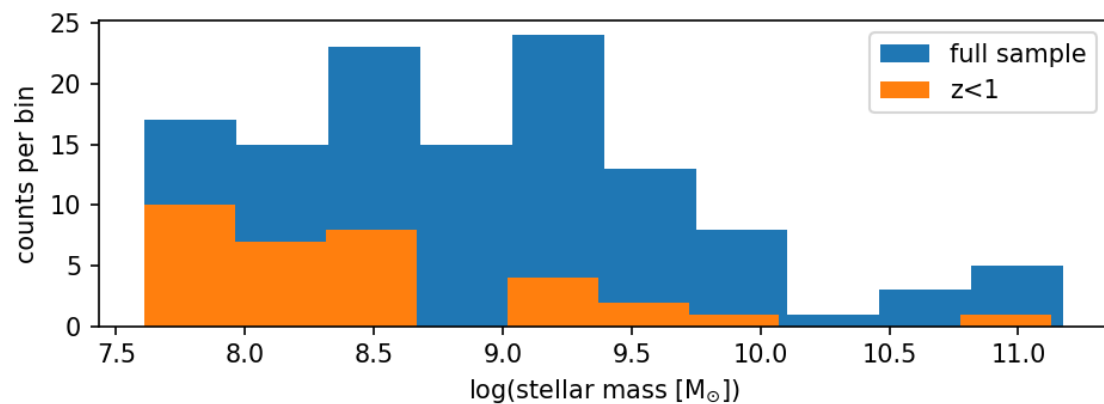


BACKGROUND SOURCE SELECTION

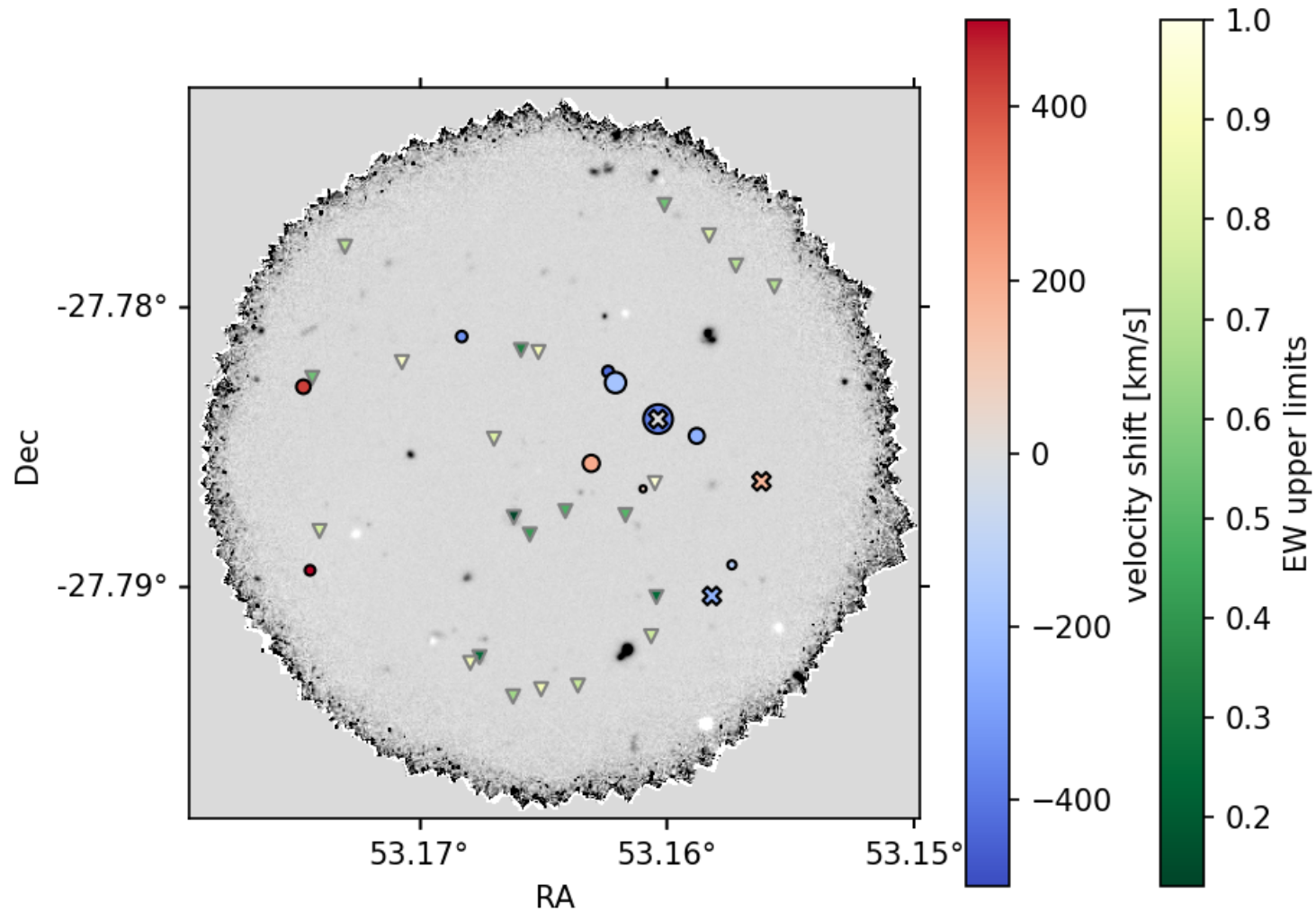


130 GALAXIES WITH MULTIPLE SIGHTLINES

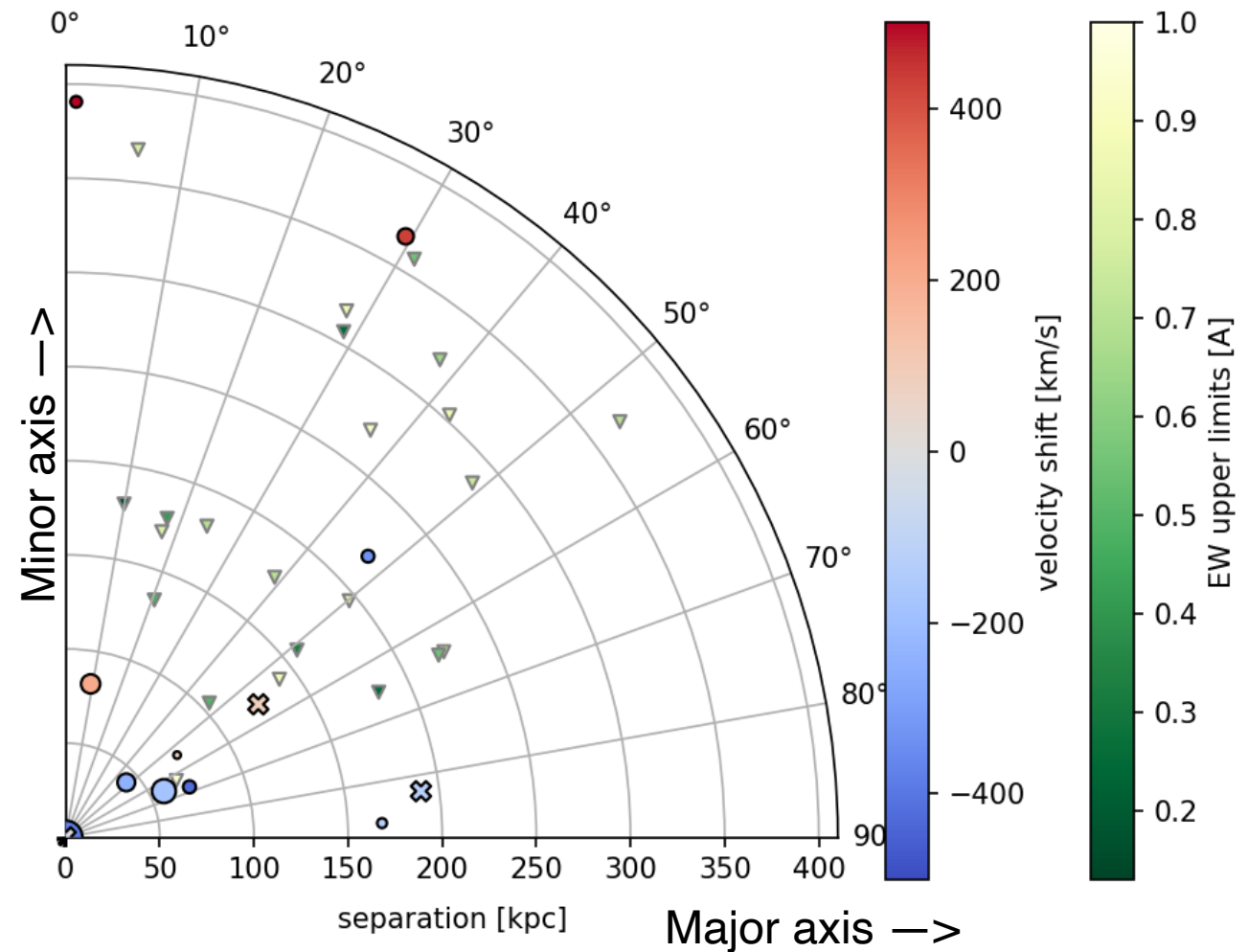
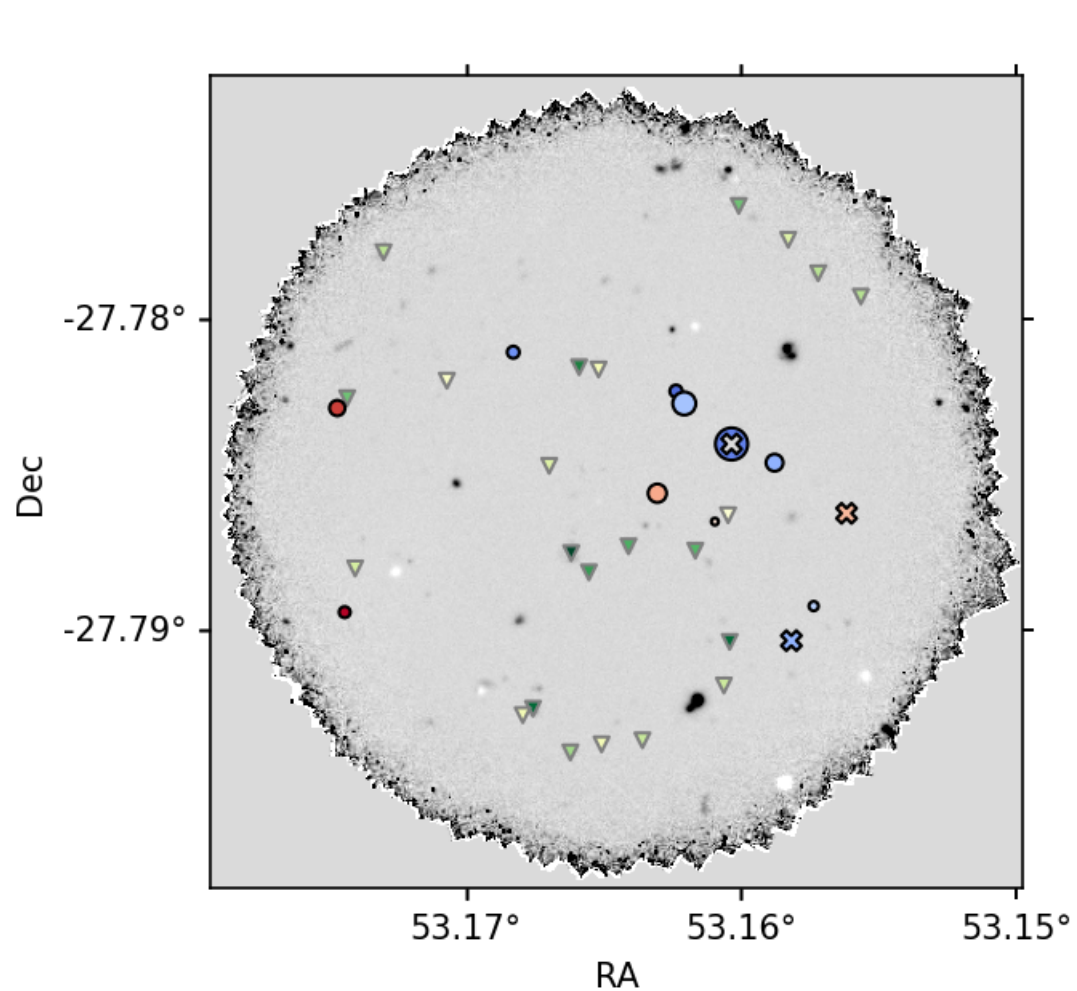
35 GALAXIES AT $Z < 1$ WITH 25+ SIGHTLINES



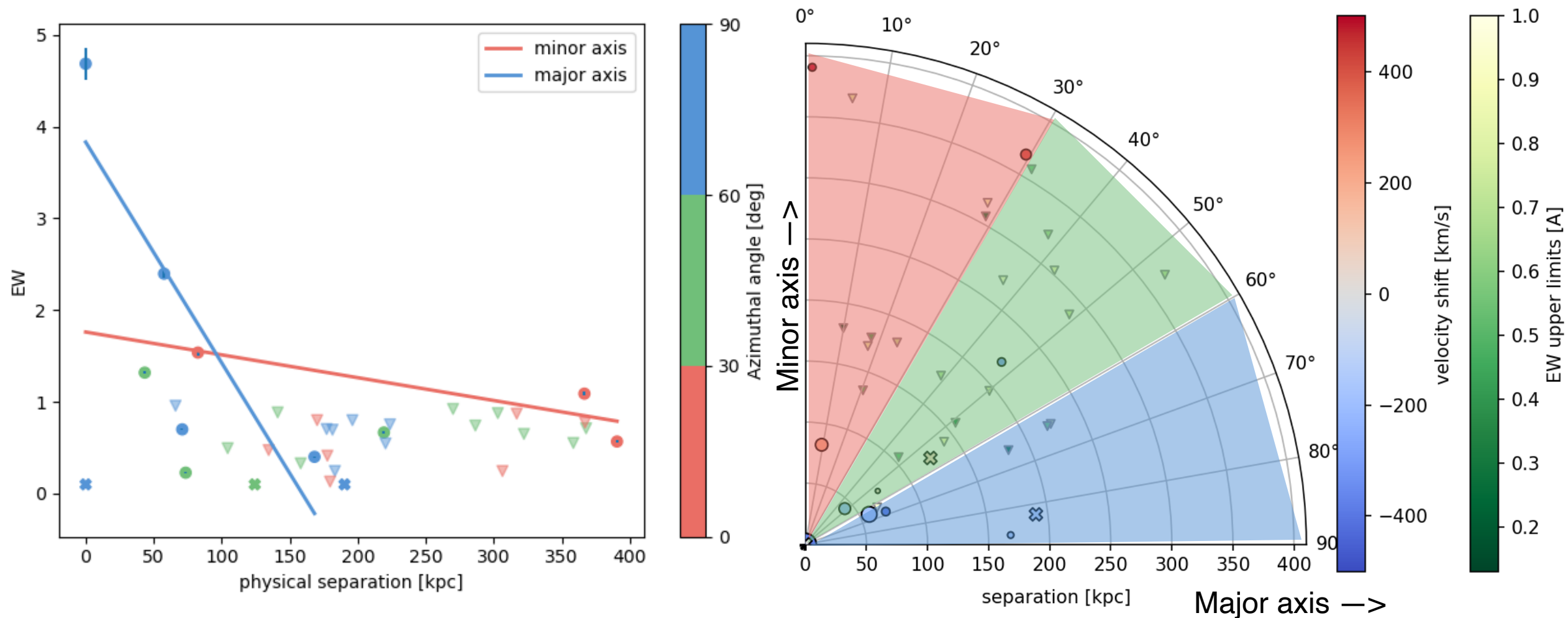
EXAMPLE FOR GALACTIC HALO AT $Z=0.95$



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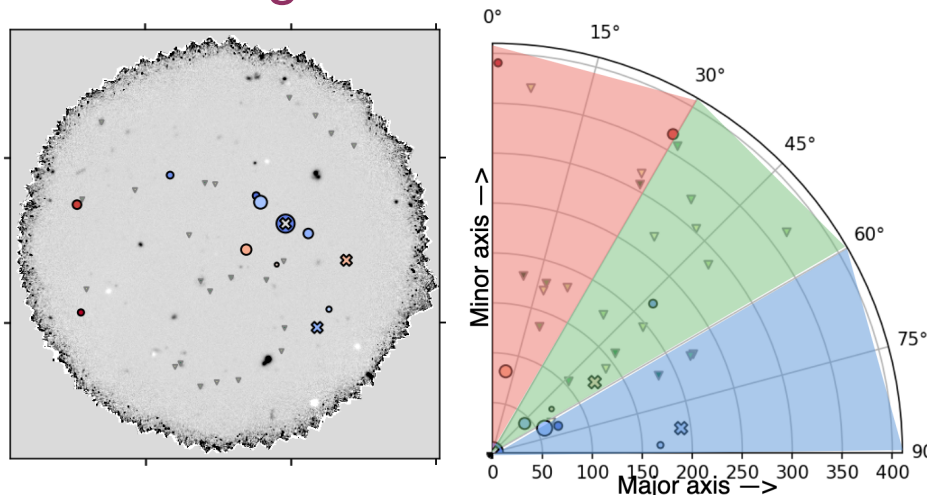


EXAMPLE FOR GALACTIC HALO AT $Z=0.95$



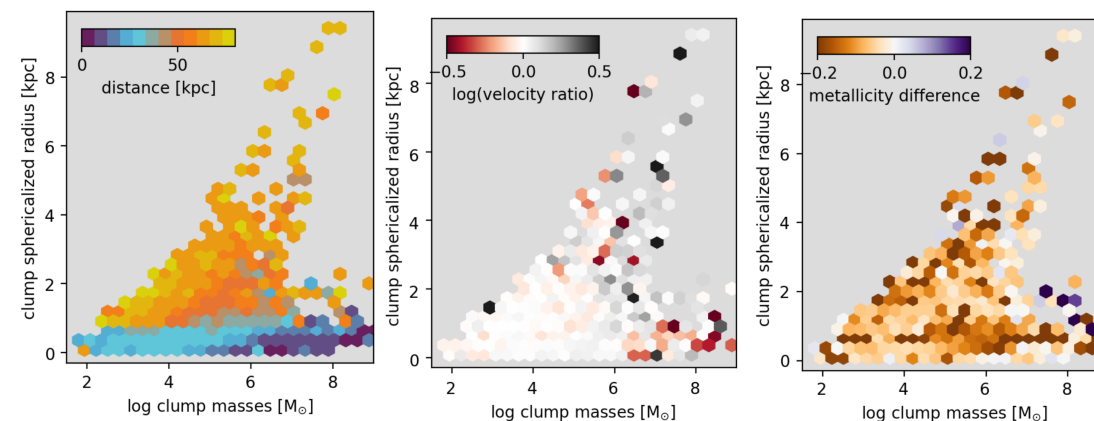
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Large scale azimuthal variations



Galaxies show azimuthal variations of metal lines - Deep MUSE observations can be used to measure this distribution in individual halos!

Small scale clumpy gas structure



Clumpy structures in simulations are clustering around the galaxy, well-embedded in their environment, and apparently metal-poor