The Spatial Distribution of Metallicity in the CGM

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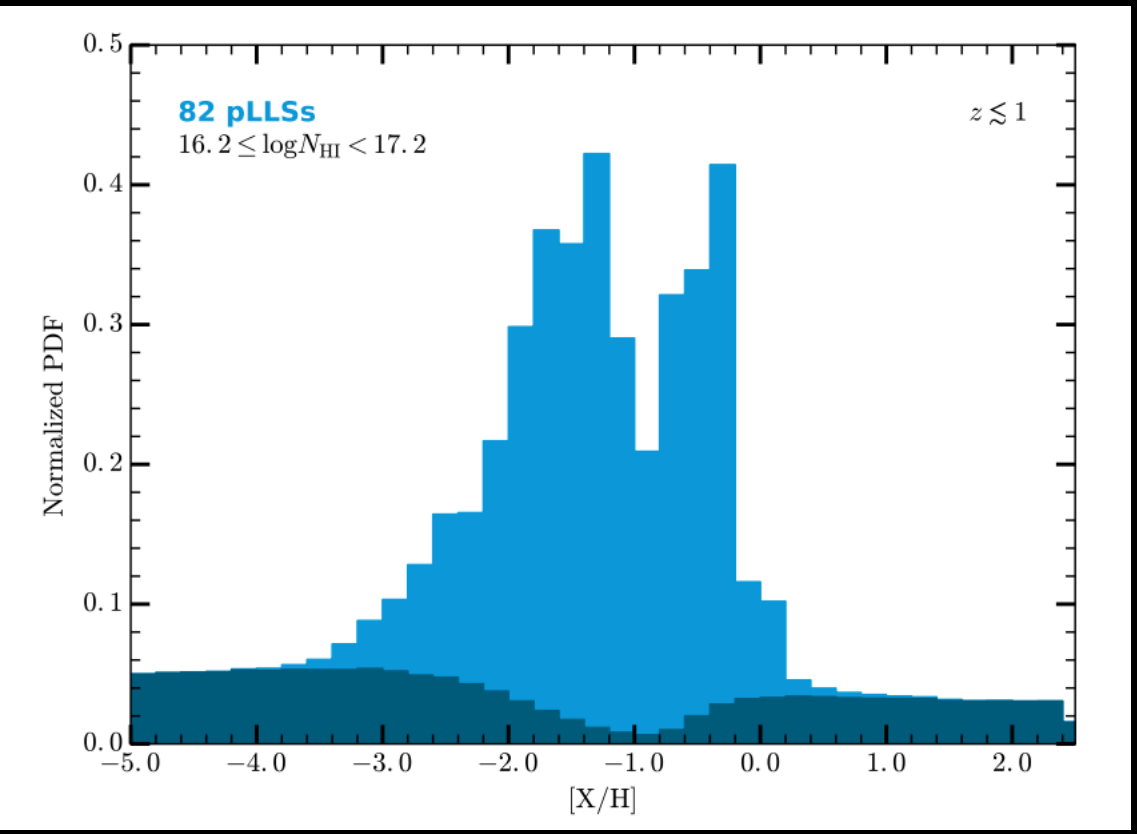
CGM Metallicities



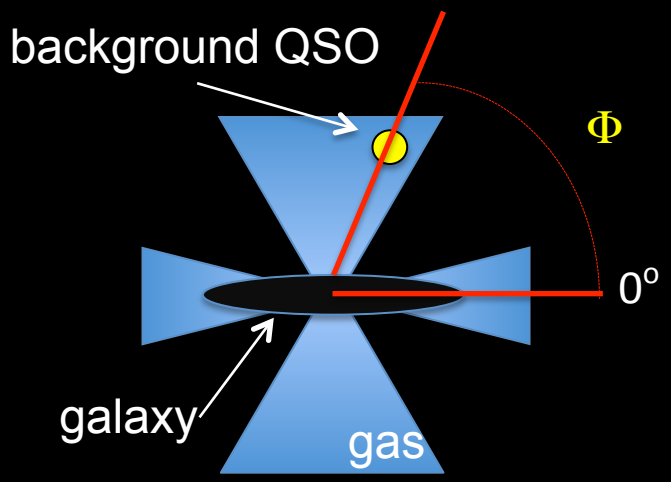
Wotta et al., 2019

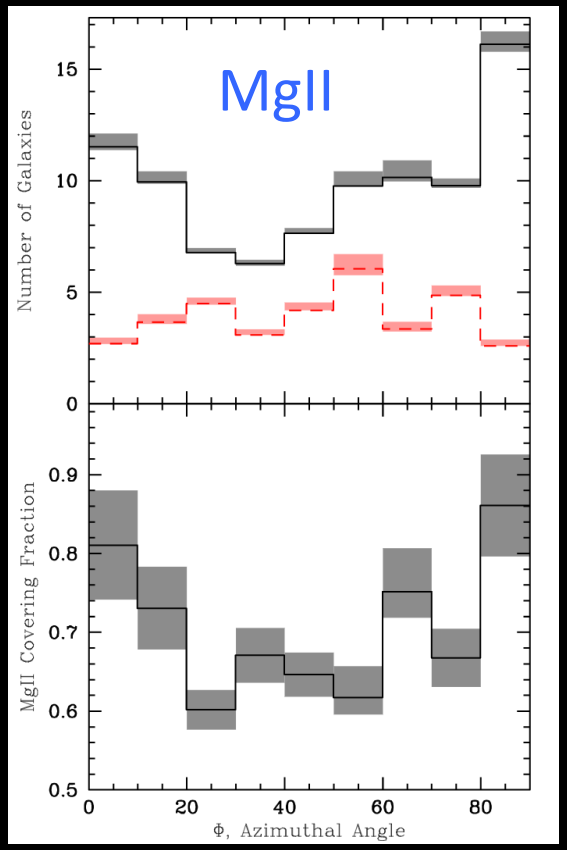
z<1 pLLS have a bimodal distribution.

It is suggested that these column density systems likely trace both outflows and accretion.

These results not replicated in simulations.

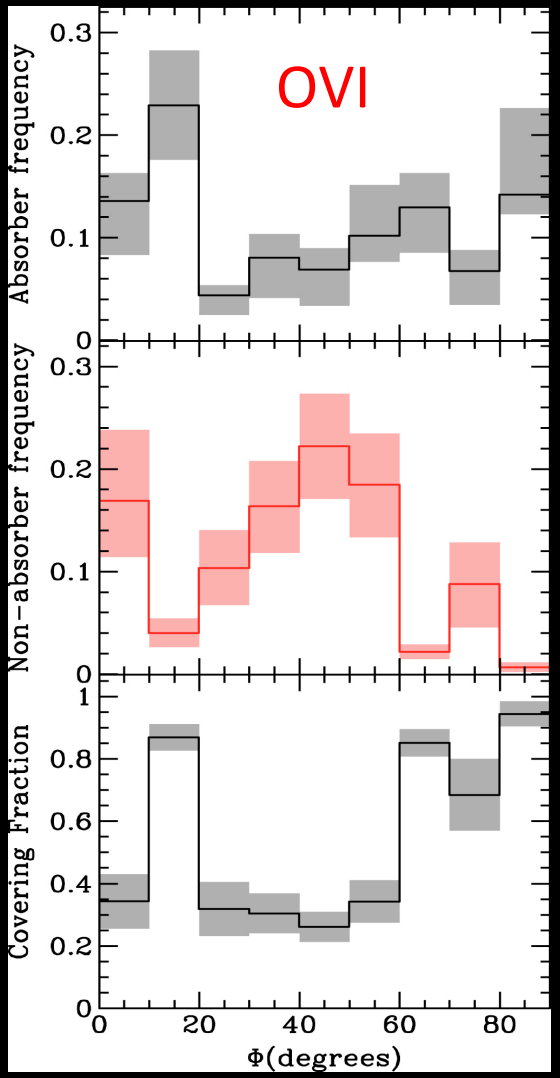
Azimuthal Distribution





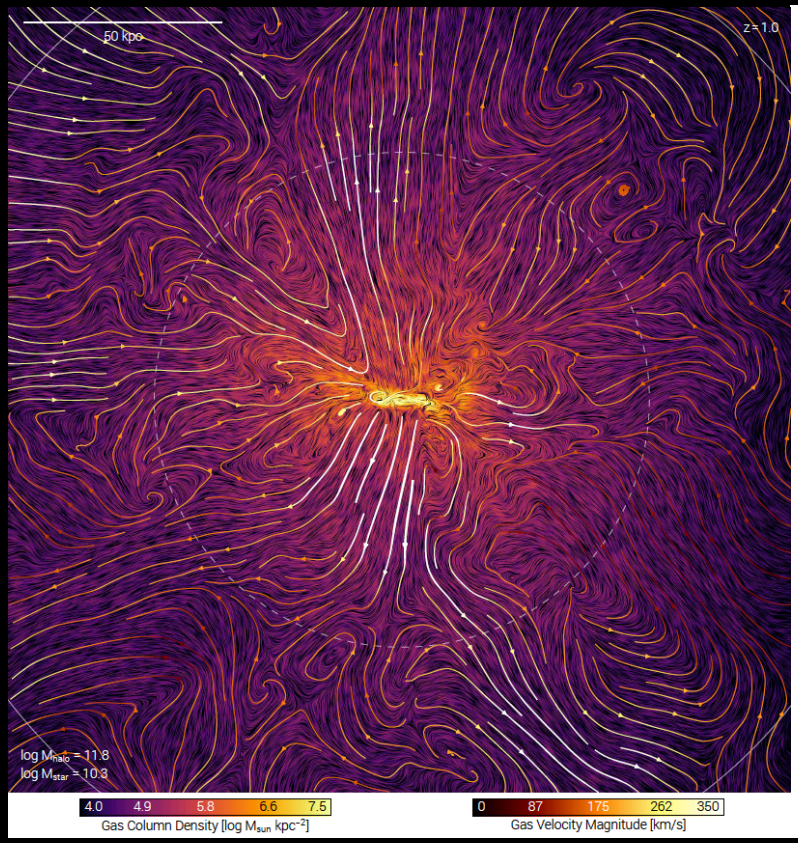
Kacprzak et al. 2012

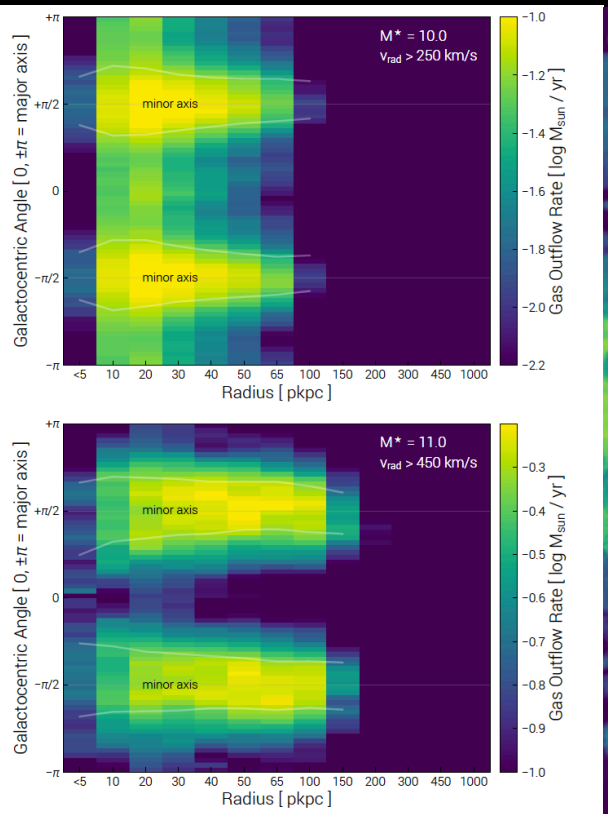
Bouche et al. 2011,
Bordoloi et al. 2011,
Lan et al. 2014, 2018,
Schroetter et al. 2019

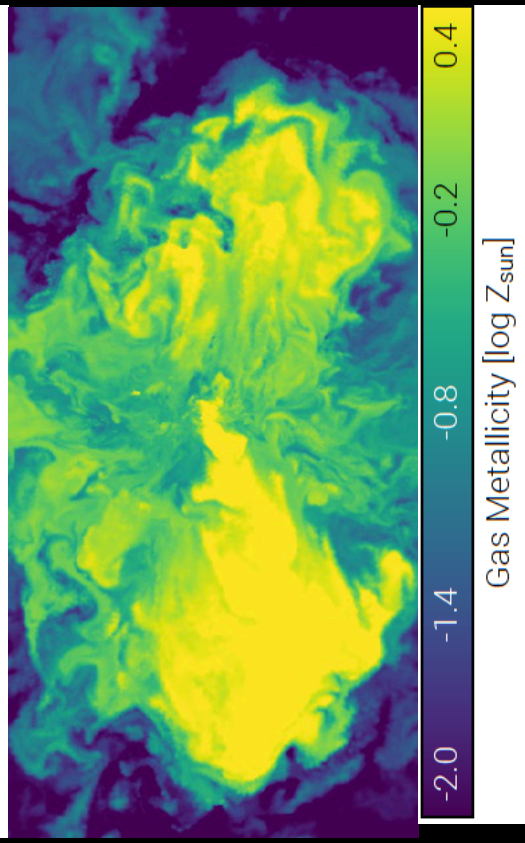


Kacprzak et al. 2015

Azimuthal Dependence in TNG50



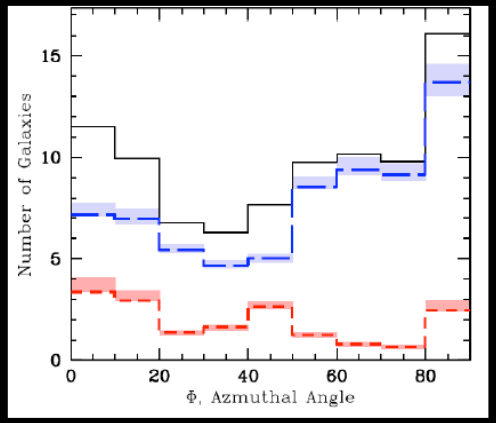




Nelson et al. 2019

Simple Model and Simple Math

Orientation bimodality



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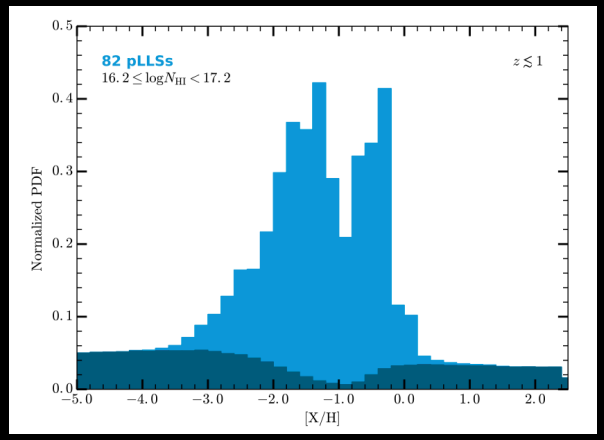
Metallicity bimodality



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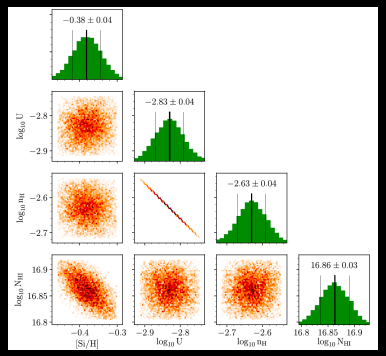
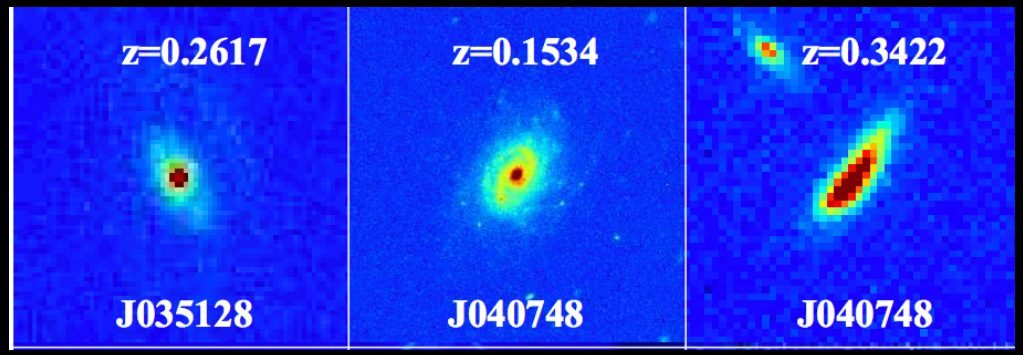
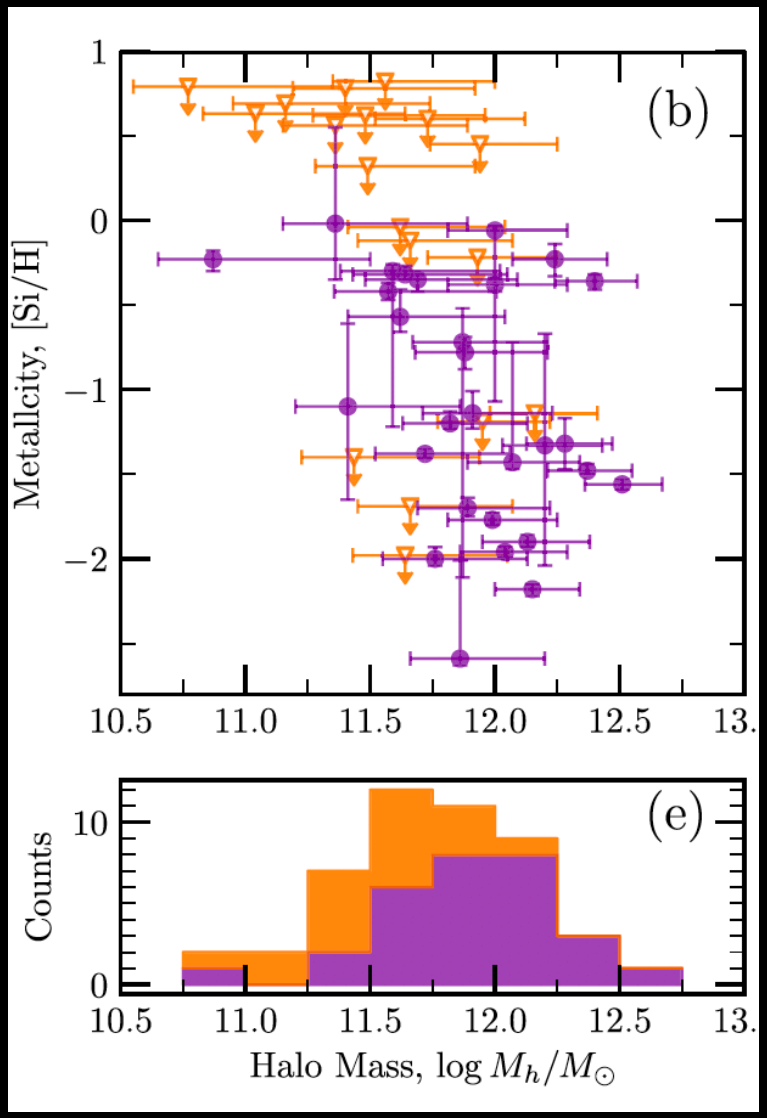
CGM Metallicities and Galaxy Orientations

- 47 absorber–galaxy pairs at z < 0.7, isolated galaxies
- HST/COS and HIRES or UVES spectra Covering HI, SiII, SiIII, SiIV CII, CIII, CIV, MgII, FeII, etc. 13.8 < log N(HI) < 19.9
- Infer total metallicity
  Cloudy: uniform gas layer, single phase, no dust, HM05 ionizing background + MCMC modeling (Crighton et al. 2013, 2015)
- HST images for galaxy morphology modeling





CGM Metallicity vs Halo Mass

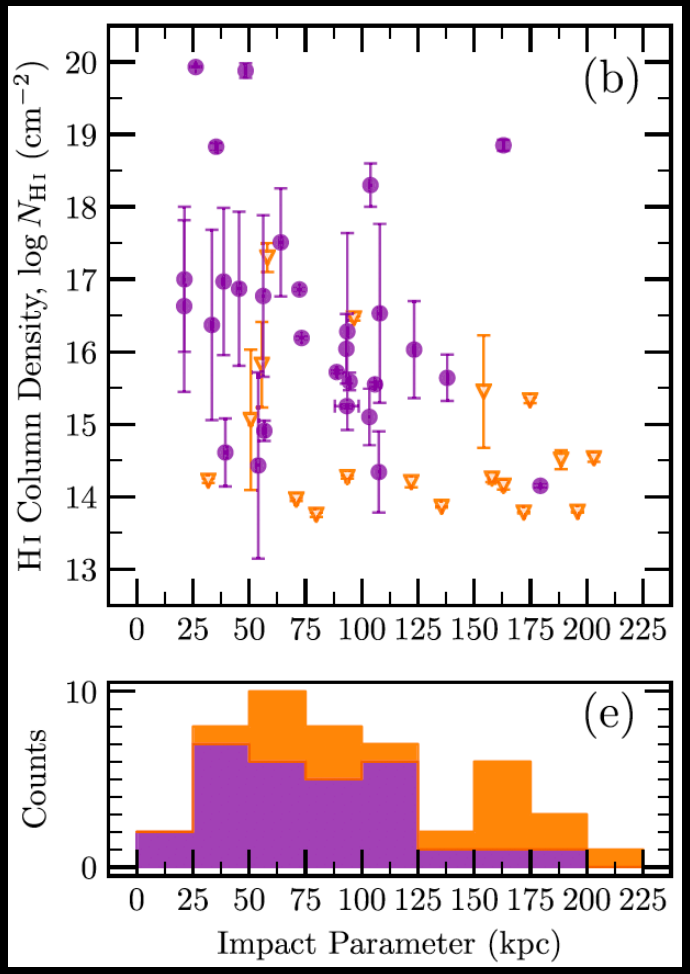


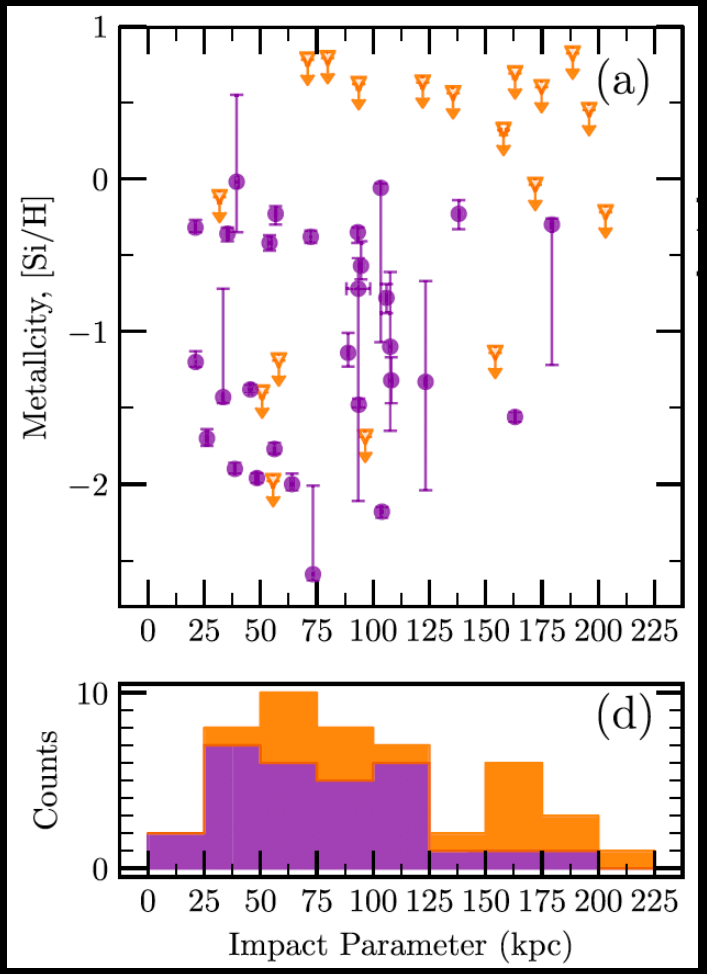
There is >2 dex scatter in CGM metallicity at fixed halo mass.

This suggests a range of gas-phase conditions and physical processes occurring within the halo.

Pointon et al. 2019 (see Prochaska et al. 2017)

Dependence on Distance



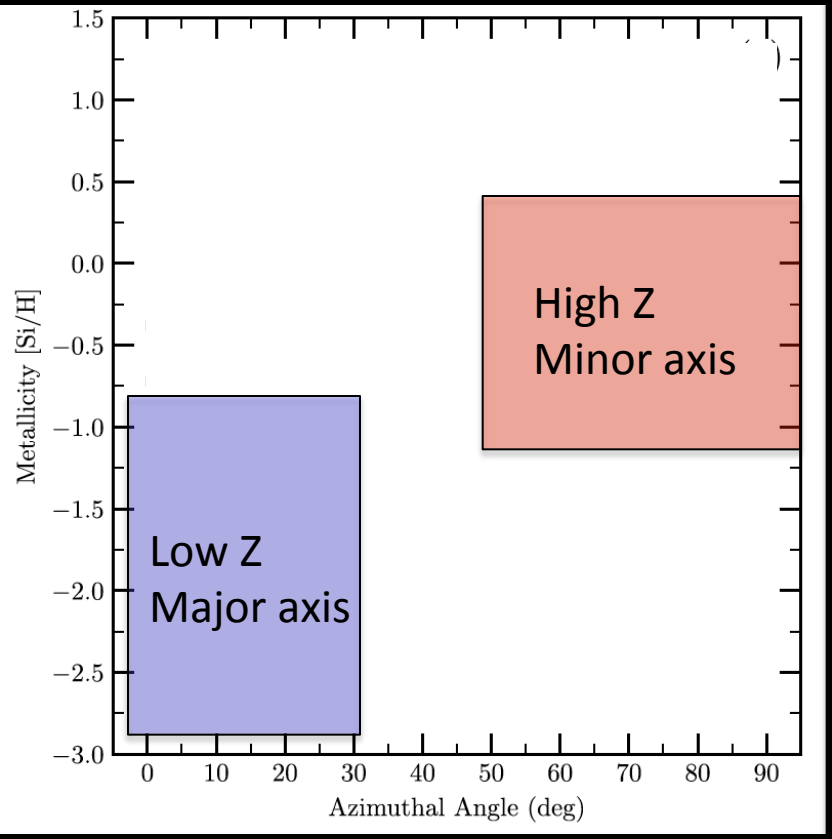


Pointon et al. 2019

HI anti-correlated with impact distance away from the galaxy.

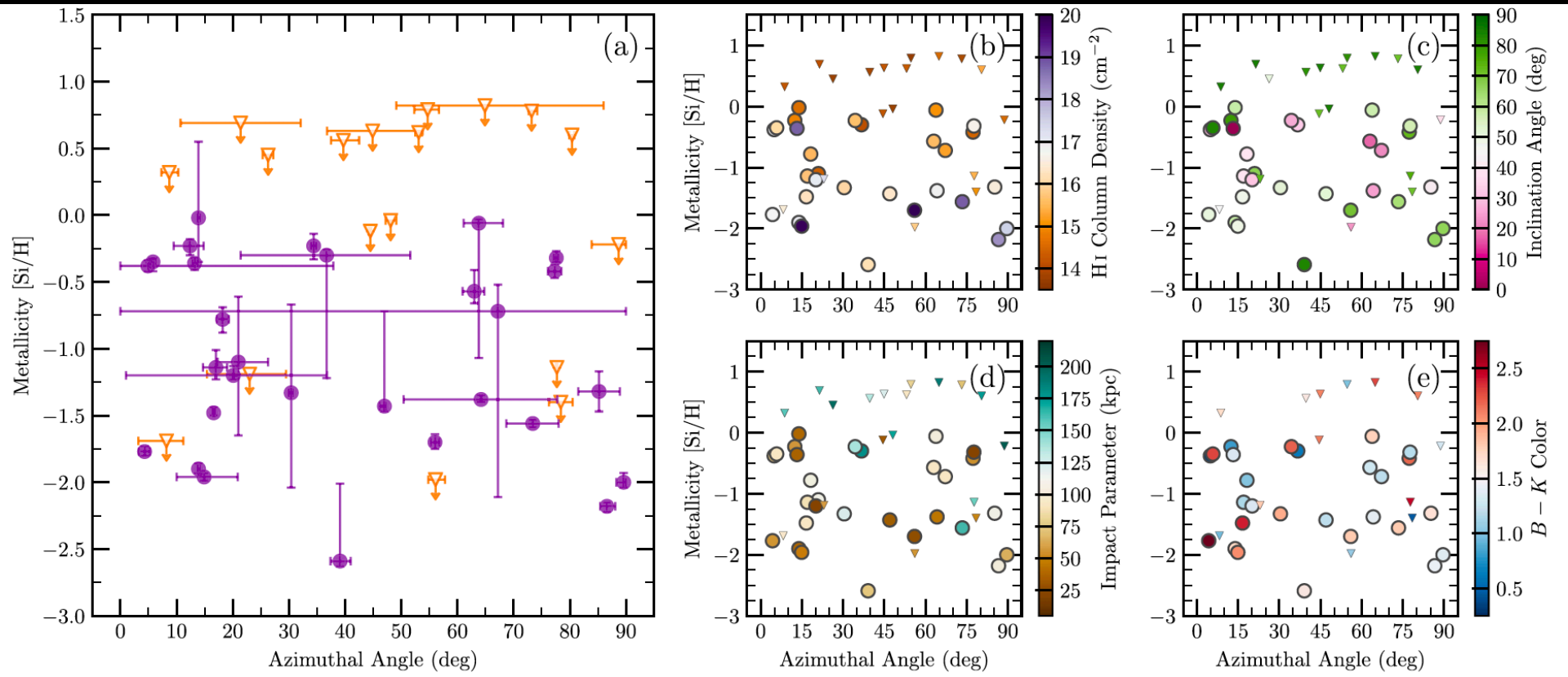
No apparent metallicity gradient

Metallicity vs Azimuthal Angle



Pointon et al. 2019

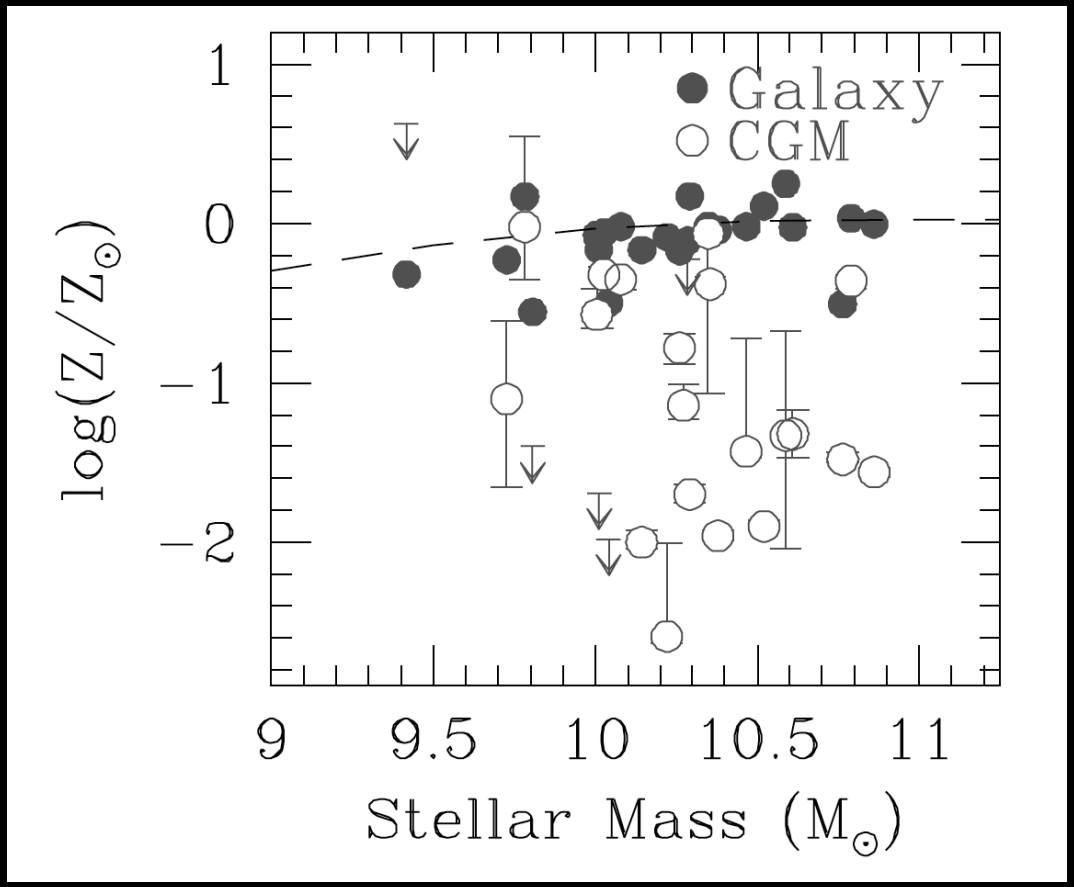
Metallicity vs Azimuthal Angle



Pointon et al. 2019

CGM and ISM Metallicities

Measure galaxy ISM metallicity from [NII] and Hα (N2 relation) for subset of ~30 galaxies from Pointon+ 2019



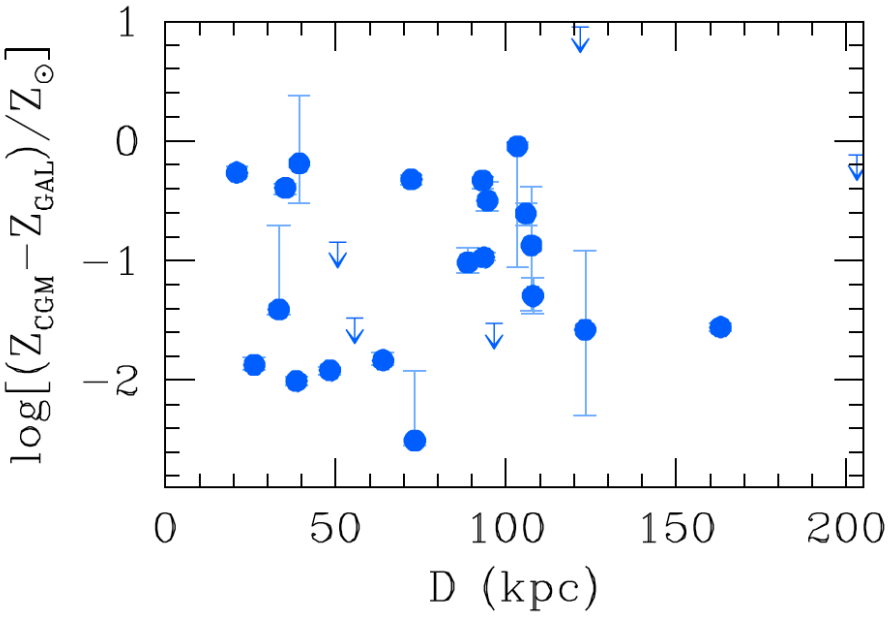
Galaxy ISM follows tight MMR

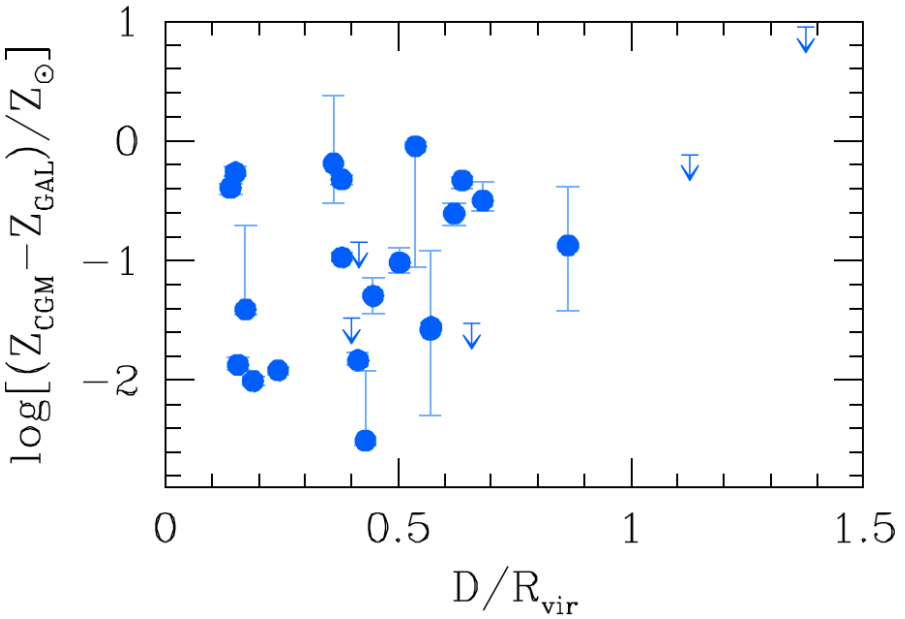
CGM-ISM= -1.2 +/- 0.1

Large scatter in relative CGM metallicities (also see Péroux et al. 2016, Prochaska et al. 2017).

Kacprzak et al. 2019, submitted

CGM-Galaxy Metallicity vs Distance

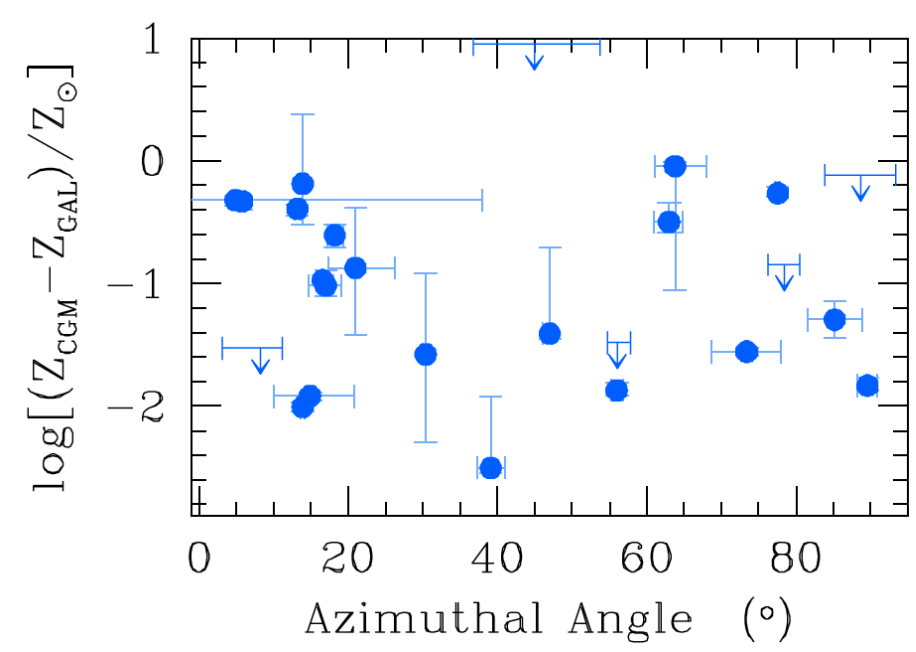


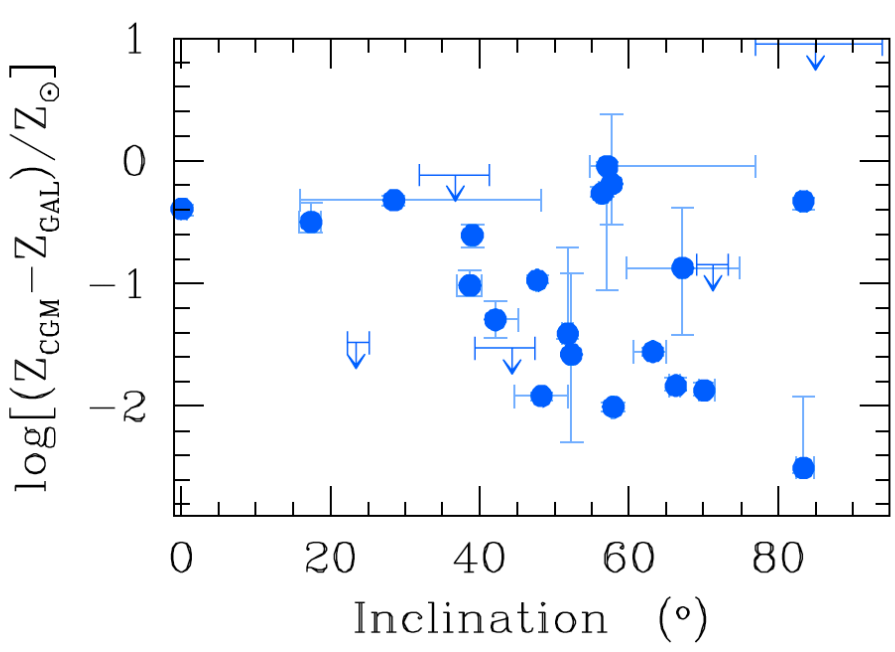


Kacprzak et al. 2019, submitted

No clear relation between the relative galaxy-CGM metallicity and D or D/Rvir

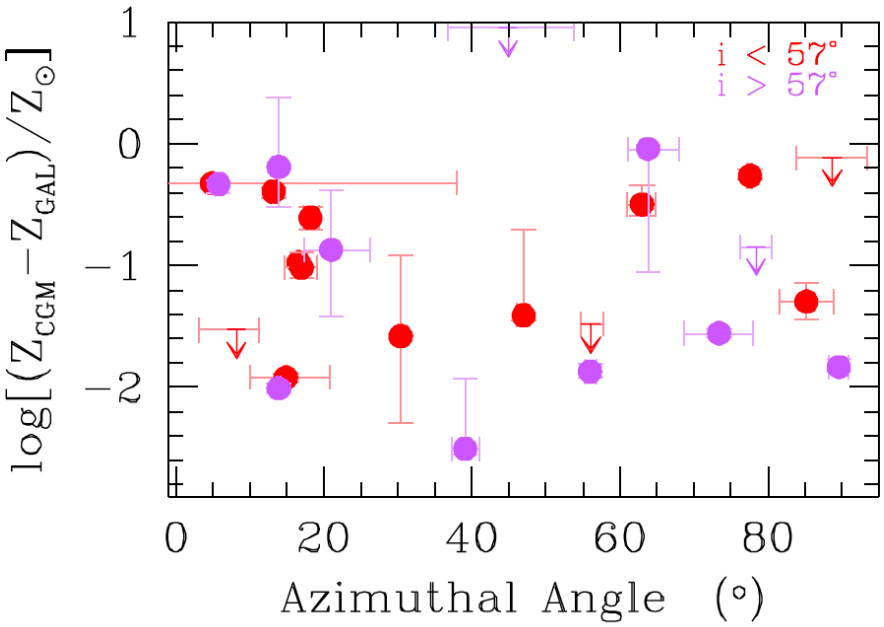
CGM-Galaxy Metallicity vs Galaxy Orientation

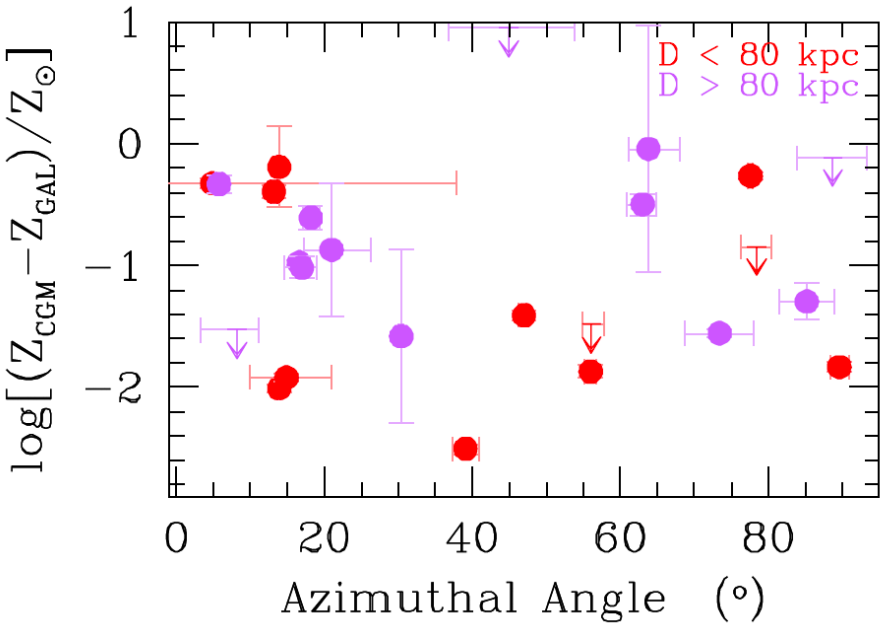


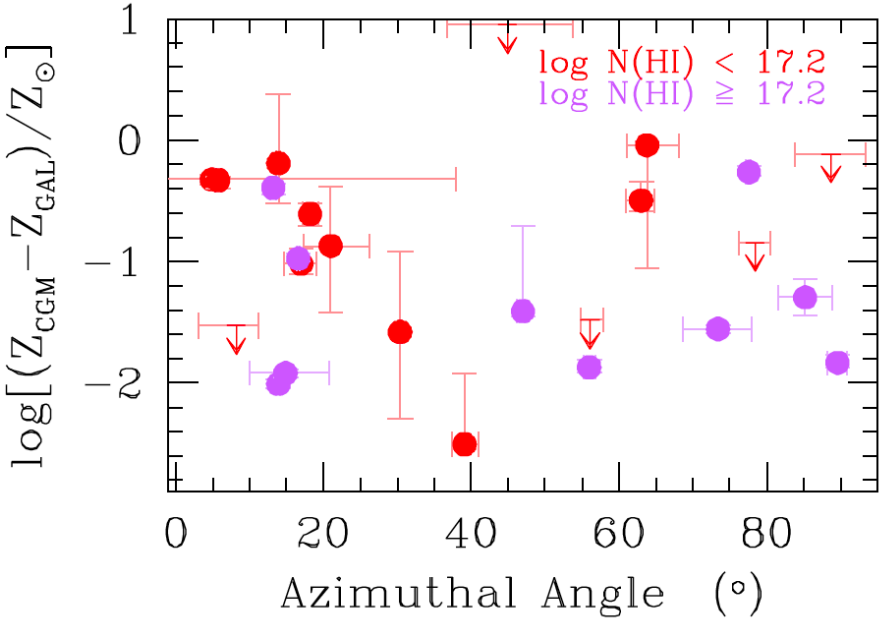


No clear relation between the relative galaxy-CGM metallicity and galaxy orientations (see Péroux et al. 2016).

Metallicity vs Azimuthal Angle



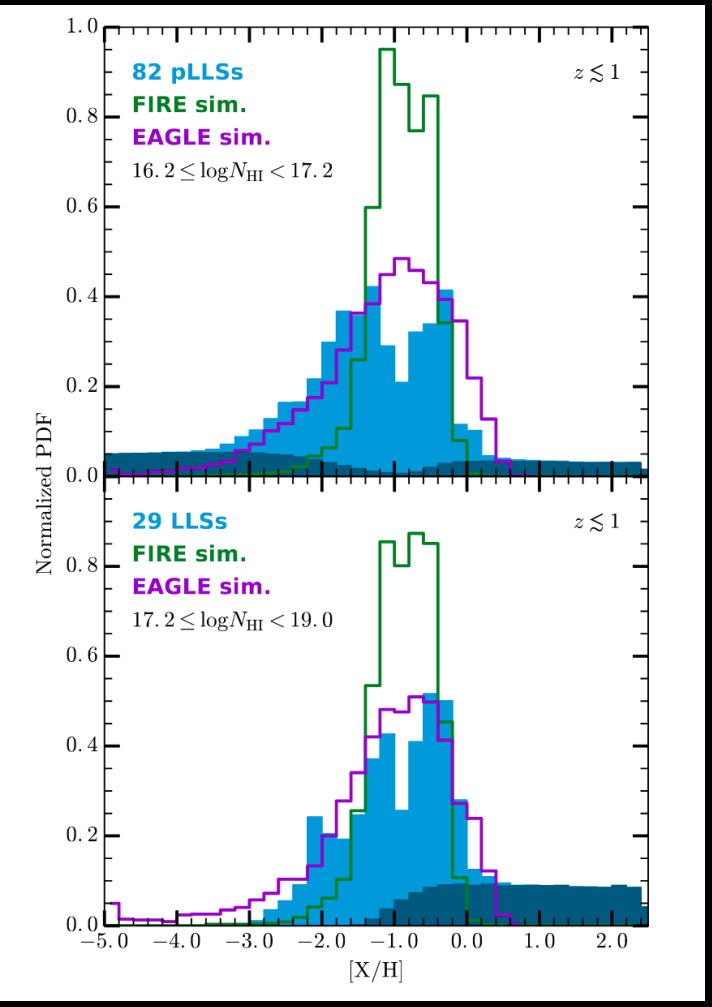




No clear relation with inclination, D, or N(HI) – need more data here to split samples.

So what is the CGM metallicity telling us?

Option #1: The CGM Metallicity Bimodality Does Not Exist?



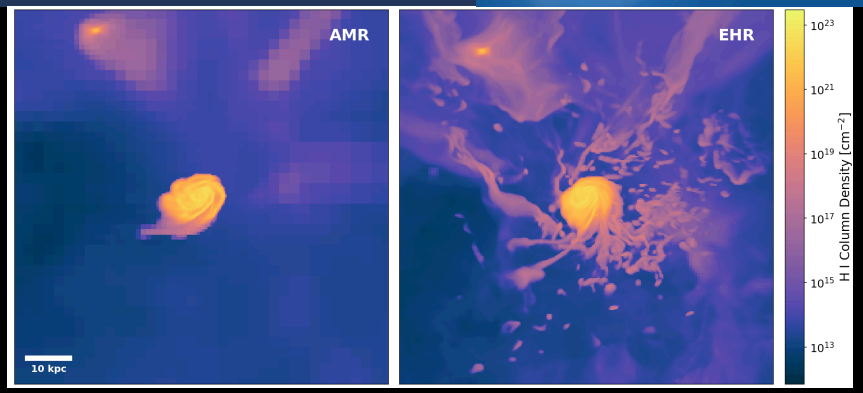
e.g., Wotta et al. 2019, Hafen et al. 2017, 2019

Simulations are unable to reproduce the metallicity bimodality yet.

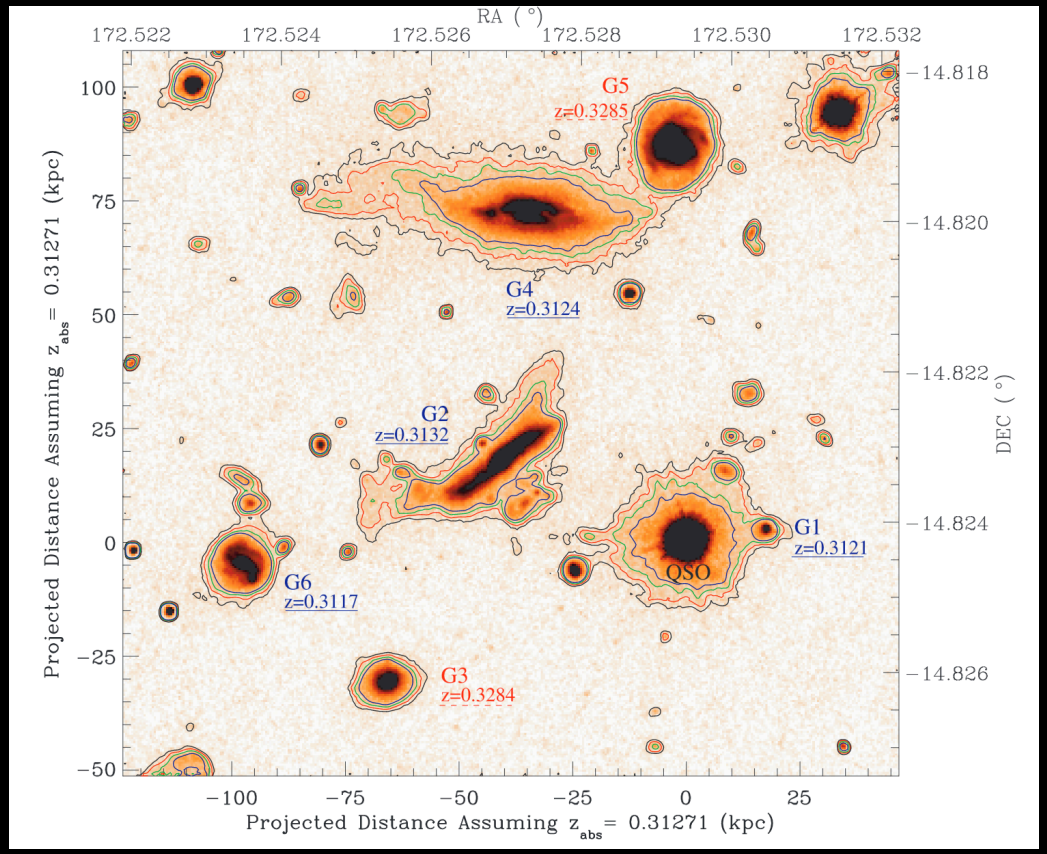
Caveat – test in high res sims:

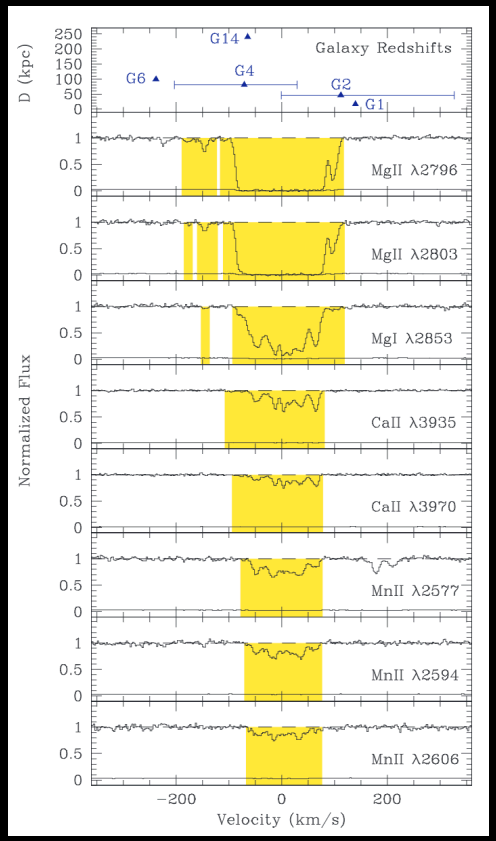
Tempest simulations

FOGGIE Figuring Out Gas & Galaxies In Enzo



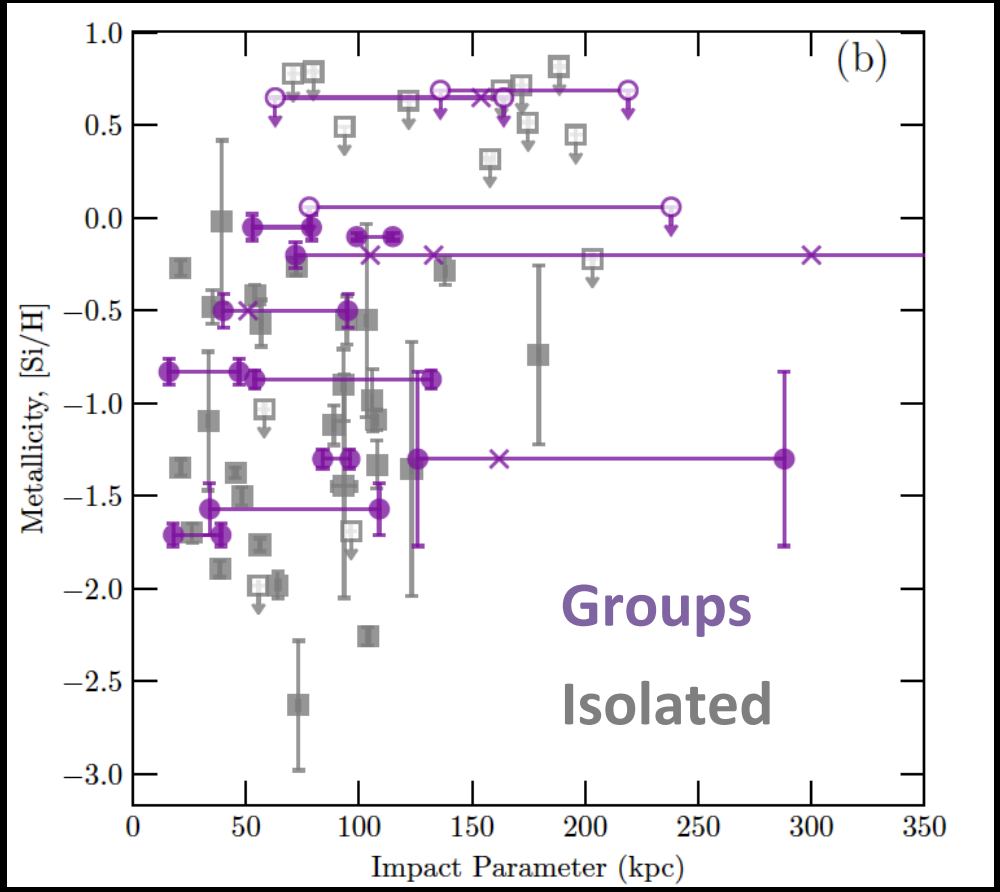
Option #2: The CGM More Complex – Galaxy Interactions/ Groups





e.g, Kacprzak et al. 2010, Nielsen et al. 2019, Peroux et al. 2017, 2019, Chen et al. 2019

Option #2: The CGM More Complex – Galaxy Interactions/ Groups

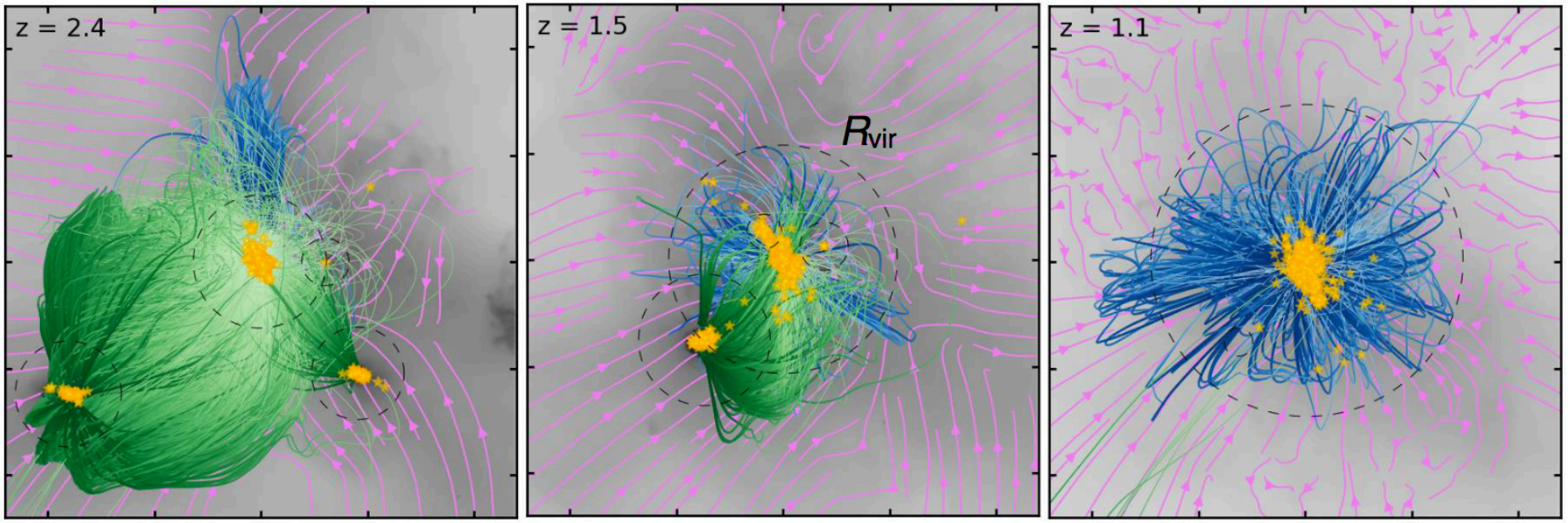


Pointon et al. 2019b, submitted

Galaxy groups and isolated galaxies have similar metallicity distributions.

Option #2: The CGM More Complex – Galaxy Interactions/ Groups

Example: $M_h(z=0)=1.4\times10^{11}$ M_{sun}



fresh accretion (streamlines)

wind recycling (future trajectories)

intergalactic transfer (future trajectories)

★★★★★ stars

Anglés-Alcázar et al. 2017

Option #2: The CGM More Complex – Galaxy Interactions/ Groups

“We find that the metallicity of CGM gas is typically a poor predictor of both its proximate and ultimate fates.

This is because there is in general little correlation between the origin of CGM gas and its fate owing to substantial mixing while in the CGM. “ – Hafen et al. 2019

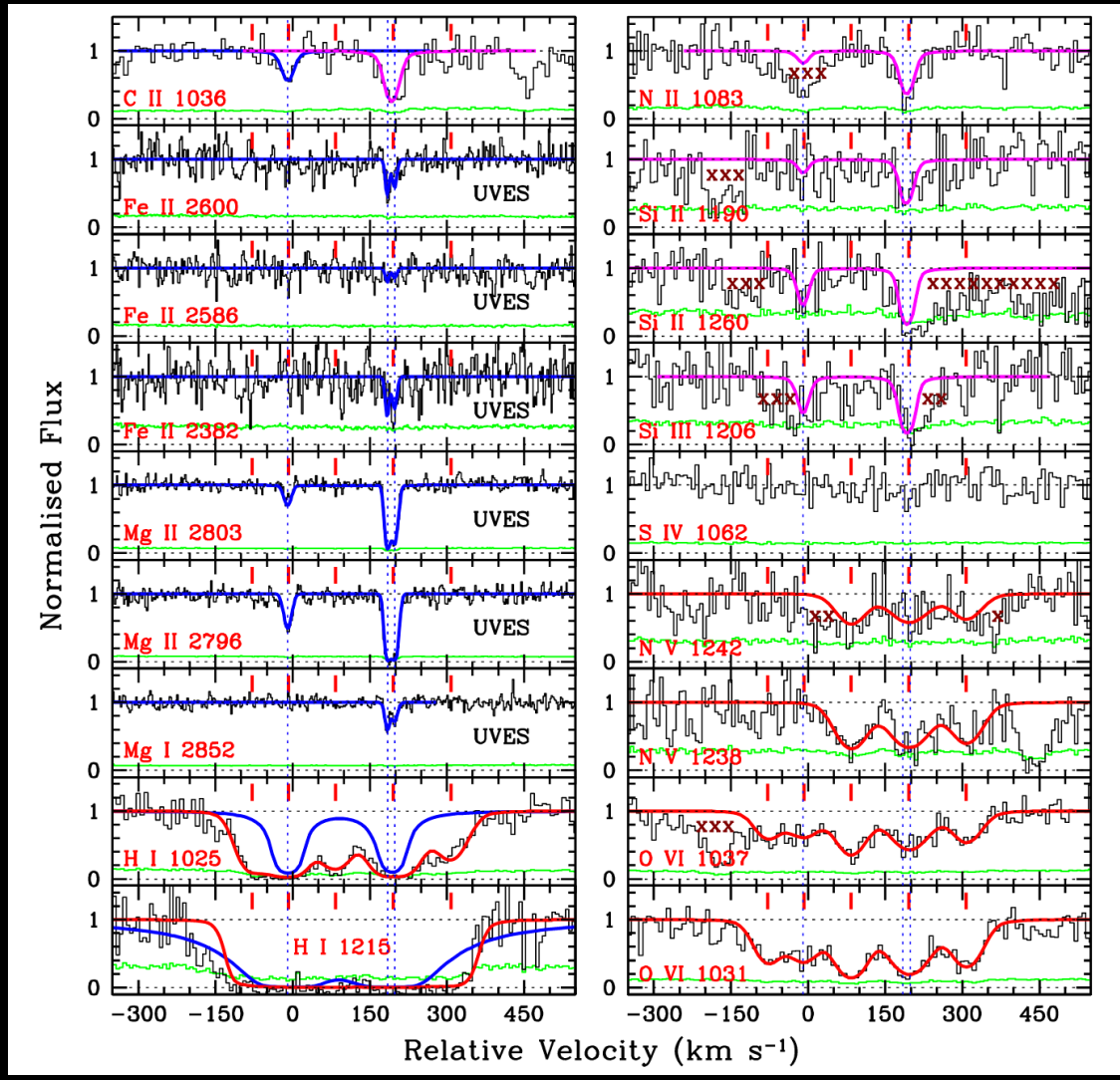
Option #3: The CGM is Not in a Single Gas Phase

Multi-phase CGM models show significant differences in metallicity:

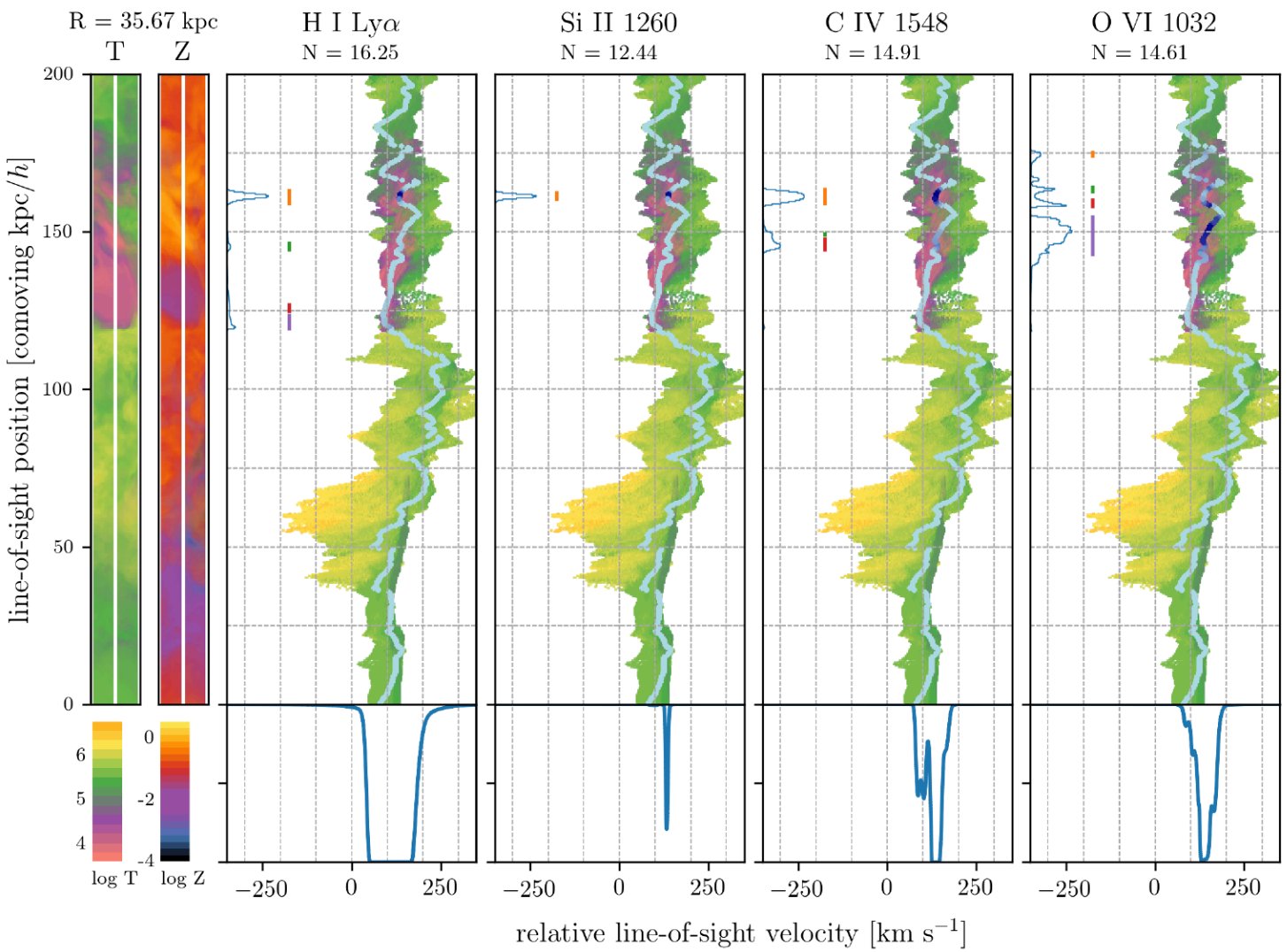
Low ionization phase: X/H ~> -1.4

High ionization phase: X/H > 0.3

e.g., Muzahid et al. 2015



Option #4: The CGM is Not Co-spatial



Peeples et al. 2018, Churchill et al. 2015

Option #5: Missed the Party – Massive Flows Occurring at High z

Concluding Remarks

Big Summary:

- Metallicity

- Kinematics, EWs, N(X)

Detailed Points:

- ~2 dex scatter in the CGM metallicity at fixed halo mass
- CGM-ISM metallicity difference -1.2+/-0.1
- No azimuthal dependence regardless of Z(ISM), D, i, N(HI) etc.
- Many reasons why one might expect to not see an azimuthal dependence